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# The De Rham, complex Hodge and p-adic Hodge realization functor on the derived category of relative motives over a field of characteristic zero

Johann Bouali

March 21, 2022

## Abstract

We introduce the categories of geometric complex mixed Hodge modules on algebraic varieties over a subfield  $k \subset \mathbb{C}$ , and for a prime number  $p$ , the categories of p-adic mixed Hodge modules on algebraic varieties over a subfield  $k \subset \mathbb{C}_p$ . We then give a complex Hodge realization functor on the derived category of relative motives over  $k \subset \mathbb{C}$  and a p-adic Hodge realization functor on the derived category of relative motives over  $k \subset \mathbb{C}_p$ .

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# 1 Introduction

Let  $k$  be a field of characteristic zero and  $S$  be a scheme of finite type over  $k$ . Let  $DA_c(S)$  be the derived category of constructible motives over  $S$ . In a previous work ([10]) when  $k = \mathbb{C}$  is the field of complex numbers, we built a Hodge realization functor :

$$\mathcal{F}_S^{Hdg} : DA_c(S) \rightarrow D(MHM(S))$$

where  $D(MHM(S))$  is the derived category of mixed Hodge modules introduced by Morihiko Saito. This functor commute to the sixth operations formalism and define a 2-functor morphism on the category of schemes over  $\mathbb{C}$ .

In this work, we extend this realization functor to the general case of any field  $k$  of characteristic zero embedded in  $\mathbb{C}$  and we develop a  $p$ -adic analog of this realization.

The first step of the construction involves a rational version (i.e. over  $k$ ) of the category of mixed Hodge modules. The key point of the construction is the existence of the Kashiwara-Malgrange  $V$ -filtration over  $k$  for regular holonomic  $\mathcal{D}$ -modules (theorem 32) which is proved by induction on dimension

using the complex case, and Saito's theorem on the strictness and stability of the direct image for proper morphisms in the complex case. The mixed hodge modules over  $k$  are then the mixed Hodge modules whose regular holonomic sheaf is defined over  $k$ . To develop a  $p$ -adic analog, we also introduce the full subcategory of geometric mixed Hodge modules.

For simplicity, we assume  $S$  smooth and let  $(M, F^\bullet M)$  be a filtered regular holonomic  $\mathcal{D}_S$ -module. We say  $(M, F^\bullet M)$  is pur de Rham if it belong to the full abelian category generated by the successive higher direct image of the structural  $\mathcal{D}_X$ -module  $(\mathcal{O}_X, F_b)$  of the proper  $S$ -schemes  $X$  smooth over  $k$ ,  $F_b$  being the trivial filtration.

Let  $(M, F^\bullet M, W^\bullet M)$  be a bi-filtered regular holonomic  $\mathcal{D}_S$ -module ( $F^\bullet M$  is the Hodge filtration and  $W^\bullet M$  is the weight filtration). We say  $(M, F, W)$  is de Rham if the associated graded module  $Gr_W(M, F)$  is a pur de Rham module and if the weight filtration is finite and satisfy an admissibility condition with respect to the Cartier divisors of  $S$ . The de Rham modules over  $S \in \text{Var}(k)$  are introduced in definition 56.

A constructible sheaf over  $S$  is given by a constructible sheaf  $K$  over the analytic complex space  $S_{\mathbb{C}}^{an}$  such that there exist a stratification  $(S_i)$  of  $S$  over  $k$  such that  $K|_{S_{i,\mathbb{C}}^{an}}$  is a  $\mathbb{Q}$ -local system.

We denote by  $P_k(S_{\mathbb{C}}^{an}) := P(S_{\mathbb{C}}^{an}) \cap D_{c,k}(S_{\mathbb{C}}^{an})$  the full sub-category of perverse sheaves with constructible cohomology sheaves over  $S$ .

A geometric mixed Hodge module over  $S$ , assumed to be smooth for simplicity, is a triple  $((M, F, W), (K, W), \alpha)$  where  $(M, F, W)$  is a de Rham module over  $S$ ,  $(K, W) \in P_k(S_{\mathbb{C}}^{an})$  is a filtered perverse sheaf over  $S$  and  $\alpha$  is an isomorphism  $\alpha : (K, W) \otimes \mathbb{C} \simeq DR(S)((M, W)^{an})$  compatible with the de Rham comparison theorem and where  $DR(S)(M^{an})$  is the de Rham complex associated to  $M^{an}$ . The geometric mixed Hodge module over  $S \in \text{Var}(k)$  are introduced in definition 68.

Let  $D(MHM_{gm,k,\mathbb{C}}(S))$  be the derived category of the category of complexes of geometric mixed Hodge modules over  $S$ . This category can be defined for any scheme  $S$  of finite type over  $k$ . We prove the following theorem :

**Theorem 1.** *Let  $\text{Var}(k)$  be the category of schemes of finite type over a subfield  $k \subset \mathbb{C}$ . Then :*

- *The categories  $D(MHM_{gm,k,\mathbb{C}}(S))$ , for  $S \in \text{Var}(k)$ , are endowed with the formalism of the sixth operation.*
- *There exist a Hodge realization functor :*

$$\mathcal{F}_S^{Hdg} : DA_c(S) \rightarrow D(MHM_{gm,k,\mathbb{C}}(S))$$

*compatible with the sixth operations formalism.*

Let  $p$  be a prime number,  $\mathbb{C}_p$  be a completion of an algebraic closure of  $\mathbb{Q}_p$  and let  $k \subset K \subset \mathbb{C}_p$  be a subfield of a  $p$ -adic field  $K$ . Let  $S$  be a smooth scheme over  $k$ ,  $\mathbb{B}_{dR,S}$  be the sheaf of relative de Rham  $p$ -adic periods over the pro-étale site of the  $p$ -adic analytic Huber space  $S_{proet}^{an}$  (introduced by Fontaine, Faltings and Scholze) and  $C_{B_{dR}}(S)$  be the category of complexes of  $\mathbb{B}_{dR,S}$ -modules.

For any lisse  $\mathbb{Q}_p$ -sheaf  $K$  over  $S_{et}$ , the sheaf  $K \otimes \mathbb{B}_{dR,S}$  over  $S_{proet}^{an}$  has a Poincaré resolution by the de Rham complex  $\mathcal{O}_{\mathbb{B}_{dR,S}} \otimes \Omega_{S^{an}}^\bullet$ . We obtain a functor from the category of lisse  $\mathbb{Q}_p$ -sheaves over  $S_{et}$  to the category of complexes of  $\mathbb{B}_{dR,S}$ -modules. Using, a Beilinson's devissage by nearby and vanishing cycles functors, we extend this functor to perverse sheaves :

$$\mathbb{B}_{dr,S} : P_k(S_{et}) \rightarrow C_{B_{dR}}(S).$$

A geometric  $p$ -adic mixed Hodge module over  $S$ , assumed to be smooth for simplicity, is a triple  $((M, F, W), (K, W), \alpha)$  where  $(M, F, W)$  is a de Rham module over  $S$ ,  $(K, W)$  is a filtered perverse sheaf over  $S_{et}$  and

$$\alpha : \mathbb{B}_{dr,S}(K, W) \simeq F^0 DR(S)((\mathcal{O}_{\mathbb{B}_{dR,S}}, F) \otimes_{\mathcal{O}_S} (M, F, W)^{an})$$

is an isomorphism of complexes of  $W$ -filtered  $(\mathbb{B}_{dR,S}, G)$ -modules over  $S_{proet}^{an}$ , compatible with the  $p$ -adic de Rham comparison theorem (Faltings and Scholze) and where  $DR(S)$  is the de Rham complex associated an analytic  $\mathcal{D}_S$ -module and  $G := \text{Gal}(\bar{K}/K)$  is the Galois group of  $K$ . The geometric  $p$ -adic mixed

Hodge module over  $S \in \text{Var}(k)$  are introduced in definition 86.

Let  $D(MHM_{gm,k,\mathbb{C}_p}(S))$  be the derived category of the category of complexes of  $p$ -adic geometric Hodge modules over  $S$ . In fact  $D(MHM_{gm,k,\mathbb{C}_p}(S))$  can be defined for any scheme  $S$  of finite type over  $k$ . We prove the following  $p$ -adic version of theorem 1 :

**Theorem 2.** *Let  $k \hookrightarrow K \hookrightarrow \mathbb{C}_p$  be a subfield of a  $p$ -adic field. Then :*

- *The categories  $D(MHM_{gm,k,\mathbb{C}_p}(S))$ , for  $S \in \text{Var}(k)$ , are endowed with the formalism of the sixth operation.*
- *There exist a  $p$ -adic Hodge realization functor :*

$$\mathcal{F}_S^{Hdg} : DA_c(S) \rightarrow D(MHM_{gm,k,\mathbb{C}_p}(S))$$

*compatible with the sixth operations formalism*

The proof of the first part of the theorems 1 and 2 is similar to the classical complex case, the crucial point is to show in the  $p$ -adic case that the isomorphism  $\alpha$  is functorial. We are then reduced to prove that the functor  $\mathbb{B}_{dr}$  commute to direct images in the proper case (theorem 44). To do this, we use  $p$ -adic Hodge theory comparison theorems in the open case ([21]).

The proof of the second part of the theorems follows our strategy of [10] :

In the case  $k \subset \mathbb{C}$ , we first fully faithfully embed  $D(MHM_{gm,k,\mathbb{C}}(S))$  into the fiber product of the derived category of bi-filtered regular holonomic  $\mathcal{D}_S$ -modules over  $k$  and the derived category of filtered constructible  $\mathbb{Q}$ -sheaves with  $k$ -rational stratification, and construct the realization functor inside this big category (definition 116), then we check that the image is contained in  $DMHM_{gm,k,\mathbb{C}}(S)$  and commutes with the six operation (theorem 53).

In the case  $k \subset K \subset \mathbb{C}_p$ , we first fully faithfully embed  $D(MHM_{gm,k,\mathbb{C}_p}(S))$  into the fiber product of the derived category of the category of bi-filtered regular holonomic  $\mathcal{D}_S$ -modules over  $k$  and the derived category of filtered constructible  $\mathbb{Q}_p$ -etale sheaves with  $k$ -rational stratification and construct the realization functor inside this big category (definition 118), then we check that the image is contained in  $D(MHM_{gm,k,\mathbb{C}_p}(S))$  and commutes with the six operation (theorem 54).

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## 2 Preliminaries and Notations

### 2.1 Notations

- After fixing a universe, we denote by
    - Set the category of sets,
    - Top the category of topological spaces,
    - Ring the category of rings and  $\text{cRing} \subset \text{Ring}$  the full subcategory of commutative rings,
    - TRing the category of topological rings and  $\text{cTRing} \subset \text{TRing}$  the full subcategory of commutative topological rings,
    - RTop the category of ringed spaces,
      - \* whose set of objects is  $\text{RTop} := \{(X, O_X), X \in \text{Top}, O_X \in \text{PSh}(X, \text{Ring})\}$
      - \* whose set of morphism is  $\text{Hom}((T, O_T), (S, O_S)) := \{(f : T \rightarrow S), (a_f : f^*O_S \rightarrow O_T)\}$
- and by  $ts : \text{RTop} \rightarrow \text{Top}$  the forgetfull functor.

– RvTop the category of valued ringed spaces

\* whose set of objects is

$$\text{RvTop} := \{(X, O_X, (v_x, x \in X)), X \in \text{Top}, O_X \in \text{PSh}(X, \text{cTRing}), v_x \in \text{Spv}(O_{X,x})\}$$

where  $O_X$  is a sheaf of complete topological commutative ring for a non archimedean semi-norm,  $\text{Spv}(-)$  denote the set of continous valuations of a topological commutative ring for a non archimedean semi-norm

\* whose set of morphism is

$$\text{Hom}((T, O_T, (v_x, x \in T)), (S, O_S, (v_x, x \in S))) := \{((f : T \rightarrow S), (a_f : f^*O_S \rightarrow O_T)), a_f^*(v_{f(x)}) = v_x \text{ for all } x \in T\}.$$

– Cat the category of small categories which comes with the forgetful functor  $o : \text{Cat} \rightarrow \text{Fun}(\Delta^1, \text{Set})$ , where  $\text{Fun}(\Delta^1, \text{Set})$  is the category of simplicial sets,

– RCat the category of ringed topos

\* whose set of objects is  $\text{RCat} := \{(\mathcal{X}, O_{\mathcal{X}}), \mathcal{X} \in \text{Cat}, O_{\mathcal{X}} \in \text{PSh}(\mathcal{X}, \text{Ring})\}$ ,

\* whose set of morphism is  $\text{Hom}((\mathcal{T}, O_{\mathcal{T}}), (\mathcal{S}, O_{\mathcal{S}})) := \{((f : \mathcal{T} \rightarrow \mathcal{S}), (a_f : f^*O_{\mathcal{S}} \rightarrow O_{\mathcal{T}})), \}$

and by  $tc : \text{RCat} \rightarrow \text{Cat}$  the forgetfull functor,

– AbCat a category consisting of a small set of abelian categories,

– TriCat a category constisting of a small set of triangulated categories.

- Let  $F : \mathcal{C} \rightarrow \mathcal{C}'$  be a functor with  $\mathcal{C}, \mathcal{C}' \in \text{Cat}$ . For  $X \in \mathcal{C}$ , we denote by  $F(X) \in \mathcal{C}'$  the image of  $X$ , and for  $X, Y \in \mathcal{C}$ , we denote by  $F^{X,Y} : \text{Hom}(X, Y) \rightarrow \text{Hom}(F(X), F(Y))$  the corresponding map.
- For  $\mathcal{C} \in \text{Cat}$ , we denote by  $\mathcal{C}^{op} \in \text{Cat}$  the opposite category whose set of object is the one of  $\mathcal{C} : (\mathcal{C}^{op})^0 = \mathcal{C}^0$ , and whose morphisms are the morphisms of  $\mathcal{C}$  with reversed arrows.
- Let  $\mathcal{C} \in \text{Cat}$ . For  $S \in \mathcal{C}$ , we denote by  $\mathcal{C}/S$  the category

– whose set of objects  $(\mathcal{C}/S)^0 = \{X/S = (X, h)\}$  consist of the morphisms  $h : X \rightarrow S$  with  $X \in \mathcal{C}$ ,

– whose set of morphism  $\text{Hom}(X'/S, X/S)$  between  $X'/S = (X', h'), X/S = (X, h) \in \mathcal{C}/S$  consits of the morphisms  $(g : X' \rightarrow X) \in \text{Hom}(X', X)$  such that  $h \circ g = h'$ .

We have then, for  $S \in \mathcal{C}$ , the canonical forgetful functor

$$r(S) : \mathcal{C}/S \rightarrow \mathcal{C}, \quad X/S \mapsto r(S)(X/S) = X, \quad (g : X'/S \rightarrow X/S) \mapsto r(S)(g) = g$$

and we denote again  $r(S) : \mathcal{C} \rightarrow \mathcal{C}/S$  the corresponding morphism of (pre)sites.

– Let  $F : \mathcal{C} \rightarrow \mathcal{C}'$  be a functor with  $\mathcal{C}, \mathcal{C}' \in \text{Cat}$ . Then for  $S \in \mathcal{C}$ , we have the canonical functor

$$F_S : \mathcal{C}/S \rightarrow \mathcal{C}'/F(S), \quad X/S \mapsto F(X/S) = F(X)/F(S), \\ (g : X'/S \rightarrow X/S) \mapsto (F(g) : F(X')/F(S) \rightarrow F(X)/F(S))$$

– Let  $\mathcal{S} \in \text{Cat}$ . Then, for a morphism  $f : X' \rightarrow X$  with  $X, X' \in \mathcal{S}$  we have the functor

$$C(f) : \mathcal{S}/X' \rightarrow \mathcal{S}/X, \quad Y/X' = (Y, f_1) \mapsto C(f)(Y/X') := (Y, f \circ f_1) \in \mathcal{S}/X, \\ (g : Y_1/X' \rightarrow Y_2/X') \mapsto (C(f)(g) := g : Y_1/X \rightarrow Y_2/X)$$

- Let  $\mathcal{S} \in \text{Cat}$  a category which admits fiber products. Then, for a morphism  $f : X' \rightarrow X$  with  $X, X' \in \mathcal{S}$ , we have the pullback functor

$$\begin{aligned} P(f) : \mathcal{S}/X &\rightarrow \mathcal{S}/X', \quad Y/X \mapsto P(f)(Y/X) := Y \times_X X'/X' \in \mathcal{S}/X', \\ (g : Y_1/X &\rightarrow Y_2/X) \mapsto (P(f)(g) := (g \times I) : Y_1 \times_X X' \rightarrow Y_2 \times_X X') \end{aligned}$$

which is right adjoint to  $C(f) : \mathcal{S}/X' \rightarrow \mathcal{S}/X$ , and we denote again  $P(f) : \mathcal{S}/X' \rightarrow \mathcal{S}/X$  the corresponding morphism of (pre)sites.

- Let  $\mathcal{C}, \mathcal{I} \in \text{Cat}$ . Assume that  $\mathcal{C}$  admits fiber products. For  $(S_\bullet) \in \text{Fun}(\mathcal{I}^{op}, \mathcal{C})$ , we denote by  $\mathcal{C}/(S_\bullet) \in \text{Fun}(\mathcal{I}, \text{Cat})$  the diagram of category given by
  - for  $I \in \mathcal{I}$ ,  $\mathcal{C}/(S_\bullet)(I) := \mathcal{C}/S_I$ ,
  - for  $r_{IJ} : I \rightarrow J$ ,  $\mathcal{C}/(S_\bullet)(r_{IJ}) := P(r_{IJ}) : \mathcal{C}/S_I \rightarrow \mathcal{C}/S_J$ , where we denoted again  $r_{IJ} : S_J \rightarrow S_I$  the associated morphism in  $\mathcal{C}$ .
- Let  $(F, G) : \mathcal{C} \rightleftarrows \mathcal{C}'$  an adjunction between two categories.
  - For  $X \in \mathcal{C}$  and  $Y \in \mathcal{C}'$ , we consider the adjunction isomorphisms
    - \*  $I(F, G)(X, Y) : \text{Hom}(F(X), Y) \rightarrow \text{Hom}(X, G(Y))$ ,  $(u : F(X) \rightarrow Y) \mapsto (I(F, G)(X, Y)(u) : X \rightarrow G(Y))$
    - \*  $I(F, G)(X, Y) : \text{Hom}(X, G(Y)) \rightarrow \text{Hom}(F(X), Y)$ ,  $(v : X \rightarrow G(Y)) \mapsto (I(F, G)(X, Y)(v) : F(X) \rightarrow Y)$ .
  - For  $X \in \mathcal{C}$ , we denote by  $\text{ad}(F, G)(X) := I(F, G)(X, F(X))(I_{F(X)}) : X \rightarrow G \circ F(X)$ .
  - For  $Y \in \mathcal{C}'$  we denote also by  $\text{ad}(F, G)(Y) := I(F, G)(G(Y), Y)(I_{G(Y)}) : F \circ G(Y) \rightarrow Y$ .

Hence,

- for  $u : F(X) \rightarrow Y$  a morphism with  $X \in \mathcal{C}$  and  $Y \in \mathcal{C}'$ , we have  $I(F, G)(X, Y)(u) = G(u) \circ \text{ad}(F, G)(X)$ ,
- for  $v : X \rightarrow G(Y)$  a morphism with  $X \in \mathcal{C}$  and  $Y \in \mathcal{C}'$ , we have  $I(F, G)(X, Y)(v) = \text{ad}(F, G)(Y) \circ F(v)$ .

- Let  $\mathcal{C}$  a category.
  - We denote by  $(\mathcal{C}, F)$  the category of filtered objects :  $(X, F) \in (\mathcal{C}, F)$  is a sequence  $(F^\bullet X)_{\bullet \in \mathbb{Z}}$  indexed by  $\mathbb{Z}$  with value in  $\mathcal{C}$  together with monomorphisms  $a_p : F^p X \hookrightarrow F^{p-1} X \hookrightarrow X$ .
  - We denote by  $(\mathcal{C}, F, W)$  the category of bifiltered objects :  $(X, F, W) \in (\mathcal{C}, F, W)$  is a sequence  $(W^\bullet F^\bullet X)_{\bullet, \bullet \in \mathbb{Z}^2}$  indexed by  $\mathbb{Z}^2$  with value in  $\mathcal{C}$  together with monomorphisms  $W^q F^p X \hookrightarrow F^{p-1} X$ ,  $W^q F^p X \hookrightarrow W^{q-1} F^p X$ .
- Let  $\mathcal{A}$  an additive category.
  - We denote by  $C(\mathcal{A}) := \text{Fun}(\mathbb{Z}, \mathcal{A})$  the category of (unbounded) complexes with value in  $\mathcal{A}$ , where we have denoted  $\mathbb{Z}$  the category whose set of objects is  $\mathbb{Z}$ , and whose set of morphism between  $m, n \in \mathbb{Z}$  consists of one element (identity) if  $n = m$ , of one element if  $n = m + 1$  and is  $\emptyset$  in the other cases.
  - We have the full subcategories  $C^b(\mathcal{A})$ ,  $C^-(\mathcal{A})$ ,  $C^+(\mathcal{A})$  of  $C(\mathcal{A})$  consisting of bounded, resp. bounded above, resp. bounded below complexes.
  - We denote by  $K(\mathcal{A}) := \text{Ho}(C(\mathcal{A}))$  the homotopy category of  $C(\mathcal{A})$  whose morphisms are equivalent homotopic classes of morphism and by  $Ho : C(\mathcal{A}) \rightarrow K(\mathcal{A})$  the full homotopy functor. The category  $K(\mathcal{A})$  is in the standard way a triangulated category.
- Let  $\mathcal{A}$  an additive category.

- We denote by  $C_{fil}(\mathcal{A}) \subset (C(\mathcal{A}), F) = C(\mathcal{A}, F)$  the full additive subcategory of filtered complexes of  $\mathcal{A}$  such that the filtration is biregular : for  $(A^\bullet, F) \in (C(\mathcal{A}), F)$ , we say that  $F$  is biregular if  $F^\bullet A^r$  is finite for all  $r \in \mathbb{Z}$ .
- We denote by  $C_{2fil}(\mathcal{A}) \subset (C(\mathcal{A}), F, W) = C(\mathcal{A}, F, W)$  the full subcategory of bifiltered complexes of  $\mathcal{A}$  such that the filtration is biregular.
- For  $A^\bullet \in C(\mathcal{A})$ , we denote by  $(A^\bullet, F_b) \in (C(\mathcal{A}), F)$  the complex endowed with the trivial filtration (filtration bete) :  $F^p A^n = 0$  if  $p \geq n + 1$  and  $F^p A^n = A^n$  if  $p \leq n$ . Obviously, a morphism  $\phi : A^\bullet \rightarrow B^\bullet$ , with  $A^\bullet, B^\bullet \in C(\mathcal{A})$  induces a morphism  $\phi : (A^\bullet, F_b) \rightarrow (B^\bullet, F_b)$ .
- For  $(A^\bullet, F) \in C(\mathcal{A}, F)$ , we denote by  $(A^\bullet, F(r)) \in C(\mathcal{A}, F)$  the filtered complex where the filtration is given by  $F^p(A^\bullet, F(r)) := F^{p+r}(A^\bullet, F)$ .
- Let  $\mathcal{A}$  be an abelian category. Then the additive category  $(\mathcal{A}, F)$  is an exact category which admits kernel and cokernel (but is NOT an abelian category). A morphism  $\phi : (M, F) \rightarrow (N, F)$  with  $(M, F) \in (\mathcal{A}, F)$  is strict if the inclusion  $\phi(F^n M) \subset F^n N \cap \text{Im}(\phi)$  is an equality, i.e. if  $\phi(F^n M) = F^n N \cap \text{Im}(\phi)$ .
- Let  $\mathcal{A}$  be an abelian category.
  - For  $(A^\bullet, F) \in C(\mathcal{A}, F)$ , considering  $a_p : F^p A^\bullet \hookrightarrow A^\bullet$  the structural monomorphism of of the filtration, we denote by, for  $n \in \mathbb{N}$ ,

$$H^n(A^\bullet, F) \in (\mathcal{A}, F), \quad F^p H^n(A^\bullet, F) := \text{Im}(H^n(a_p) : H^n(F^p A^\bullet) \rightarrow H^n(A^\bullet)) \subset H^n(A^\bullet)$$

the filtration induced on the cohomology objects of the complex. In the case  $(A^\bullet, F) \in C_{fil}(\mathcal{A})$ , the spectral sequence  $E_r^{p,q}(A^\bullet, F)$  associated to  $(A^\bullet, F)$  converge to  $\text{Gr}_F^p H^{p+q}(A^\bullet, F)$ , that is for all  $p, q \in \mathbb{Z}$ , there exist  $r_{p+q} \in \mathbb{N}$ , such that  $E_s^{p,q}(A^\bullet, F) = \text{Gr}_F^p H^{p+q}(A^\bullet, F)$  for all  $s \leq r_{p+q}$ .

- A morphism  $m : (A^\bullet, F) \rightarrow (B^\bullet, F)$  with  $(A^\bullet, F), (B^\bullet, F) \in C(\mathcal{A}, F)$  is said to be a filtered quasi-isomorphism if for all  $n, p \in \mathbb{Z}$ ,

$$H^n \text{Gr}_F^p(m) : H^n(\text{Gr}_F^p A^\bullet) \xrightarrow{\sim} H^n(\text{Gr}_F^p B^\bullet)$$

is an isomorphism in  $\mathcal{A}$ . Consider a commutative diagram in  $C(\mathcal{A}, F)$

$$\begin{array}{ccccc} (A^\bullet, F) & \xrightarrow{m} & (B^\bullet, F) & \longrightarrow & \text{Cone}^{i_2}(m) = ((A^\bullet, F)[1] \oplus (B^\bullet, F), d, d^{p_1} m) & \longrightarrow & (A^\bullet, F)[1] \\ \phi \downarrow & & \psi \downarrow & & \downarrow (\phi[1], \psi) & & \downarrow \phi[1] \\ (A'^\bullet, F) & \xrightarrow{m'} & (B'^\bullet, F) & \longrightarrow & \text{Cone}^{i_2}(m') = ((A'^\bullet, F)[1] \oplus (B'^\bullet, F), d, d^{p_1} m') & \longrightarrow & (A'^\bullet, F)[1] \end{array}$$

If  $\phi$  and  $\psi$  are filtered quasi-isomorphisms, then  $(\phi[1], \psi)$  is an filtered quasi-isomorphism. That is, the filtered quasi-isomorphism satisfy the 2 of 3 property for canonical triangles.

- Let  $\mathcal{A}$  be an abelian category.
  - We denote by  $D(\mathcal{A})$  the localization of  $K(\mathcal{A})$  with respect to the quasi-isomorphisms and by  $D : K(\mathcal{A}) \rightarrow D(\mathcal{A})$  the localization functor. The category  $D(\mathcal{A})$  is a triangulated category in the unique way such that  $D$  a triangulated functor.
  - We denote by  $D_{fil}(\mathcal{A})$  the localization of  $K_{fil}(\mathcal{A})$  with respect to the filtered quasi-isomorphisms and by  $D : K_{fil}(\mathcal{A}) \rightarrow D_{fil}(\mathcal{A})$  the localization functor.
- Let  $\mathcal{A}$  be an abelian category. We denote by  $\text{Inj}(\mathcal{A}) \subset \mathcal{A}$  the full subcategory of injective objects, and by  $\text{Proj}(\mathcal{A}) \subset \mathcal{A}$  the full subcategory of projective objects.



- For  $\mathcal{S} \in \text{Cat}$  a small category, we denote by

- $\text{PSh}(\mathcal{S}) := \text{PSh}(\mathcal{S}, \text{Ab}) := \text{Fun}(\mathcal{S}, \text{Ab})$  the category of presheaves on  $\mathcal{S}$ , i.e. the category of presheaves of abelian groups on  $\mathcal{S}$ ,
- $K(\mathcal{S}) := K(\text{PSh}(\mathcal{S})) = \text{Ho}(C(\mathcal{S}))$  In particular, we have the full homotopy functor  $Ho : C(\mathcal{S}) \rightarrow K(\mathcal{S})$ ,
- $C_{(2)fil}(\mathcal{S}) := C_{(2)fil}(\text{PSh}(\mathcal{S})) \subset C(\text{PSh}(\mathcal{S}), F, W)$  the big abelian category of (bi)filtered complexes of presheaves on  $\mathcal{S}$  with value in abelian groups such that the filtration is biregular, and  $\text{PSh}_{(2)fil}(\mathcal{S}) = (\text{PSh}(\mathcal{S}), F, W)$ ,
- $K_{fil}(\mathcal{S}) := K_{fil}(\text{PSh}(\mathcal{S})) = \text{Ho}(C_{fil}(\mathcal{S}))$ ,
- $K_{fil,r}(\mathcal{S}) := K_{fil,r}(\text{PSh}(\mathcal{S})) = \text{Ho}_r(C_{fil}(\mathcal{S}))$ ,  $K_{fil,\infty}(\mathcal{S}) := K_{fil,\infty}(\text{PSh}(\mathcal{S})) = \text{Ho}_\infty(C_{fil}(\mathcal{S}))$ .

For  $f : \mathcal{T} \rightarrow \mathcal{S}$  a morphism a presite with  $\mathcal{T}, \mathcal{S} \in \text{Cat}$ , given by the functor  $P(f) : \mathcal{S} \rightarrow \mathcal{T}$ , we will consider the adjunctions given by the direct and inverse image functors :

- $(f^*, f_*) = (f^{-1}, f_*) : \text{PSh}(\mathcal{S}) \rightleftarrows \text{PSh}(\mathcal{T})$ , which induces  $(f^*, f_*) : C(\mathcal{S}) \rightleftarrows C(\mathcal{T})$ , we denote, for  $F \in C(\mathcal{S})$  and  $G \in C(\mathcal{T})$  by

$$\text{ad}(f^*, f_*)(F) : F \rightarrow f_* f^* F, \text{ad}(f^*, f_*)(G) : f^* f_* G \rightarrow G$$

the adjunction maps,

- $(f_*, f^\perp) : \text{PSh}(\mathcal{T}) \rightleftarrows \text{PSh}(\mathcal{S})$ , which induces  $(f_*, f^\perp) : C(\mathcal{T}) \rightleftarrows C(\mathcal{S})$ , we denote for  $F \in C(\mathcal{S})$  and  $G \in C(\mathcal{T})$  by

$$\text{ad}(f_*, f^\perp)(F) : G \rightarrow f^\perp f_* G, \text{ad}(f_*, f^\perp)(G) : f_* f^\perp F \rightarrow F$$

the adjunction maps.

- For  $(\mathcal{S}, O_S) \in \text{RCat}$  a ringed topos, we denote by

- $\text{PSh}_{O_S}(\mathcal{S})$  the category of presheaves of  $O_S$  modules on  $\mathcal{S}$ , whose objects are  $\text{PSh}_{O_S}(\mathcal{S})^0 := \{(M, m), M \in \text{PSh}(\mathcal{S}), m : M \otimes O_S \rightarrow M\}$ , together with the forgetful functor  $o : \text{PSh}(\mathcal{S}) \rightarrow \text{PSh}_{O_S}(\mathcal{S})$ ,
- $C_{O_S}(\mathcal{S}) = C(\text{PSh}_{O_S}(\mathcal{S}))$  the big abelian category of complexes of presheaves of  $O_S$  modules on  $\mathcal{S}$ ,
- $K_{O_S}(\mathcal{S}) := K(\text{PSh}_{O_S}(\mathcal{S})) = \text{Ho}(C_{O_S}(\mathcal{S}))$ , in particular, we have the full homotopy functor  $Ho : C_{O_S}(\mathcal{S}) \rightarrow K_{O_S}(\mathcal{S})$ ,
- $C_{O_S(2)fil}(\mathcal{S}) := C_{(2)fil}(\text{PSh}_{O_S}(\mathcal{S})) \subset C(\text{PSh}_{O_S}(\mathcal{S}), F, W)$ , the big abelian category of (bi)filtered complexes of presheaves of  $O_S$  modules on  $\mathcal{S}$  such that the filtration is biregular and  $\text{PSh}_{O_S(2)fil}(\mathcal{S}) = (\text{PSh}_{O_S}(\mathcal{S}), F, W)$ ,
- $K_{O_S fil}(\mathcal{S}) := K_{fil}(\text{PSh}_{O_S}(\mathcal{S})) = \text{Ho}(C_{O_S fil}(\mathcal{S}))$ ,
- $K_{O_S fil,r}(\mathcal{S}) := K_{fil,r}(\text{PSh}_{O_S}(\mathcal{S})) = \text{Ho}_r(C_{O_S fil}(\mathcal{S}))$ ,  $K_{O_S fil,\infty}(\mathcal{S}) := K_{fil,\infty}(\text{PSh}_{O_S}(\mathcal{S})) = \text{Ho}_\infty(C_{O_S fil}(\mathcal{S}))$ .

- For  $\mathcal{S} \in \text{Cat}$  a small category and  $n \in \mathbb{N}$ ,  $\text{PSh}_{\mathbb{Z}/n\mathbb{Z}}(\mathcal{S}) \subset \text{PSh}(\mathcal{S})$  is the full subcategory of  $n$ -torsion presheaves. The functor

$$(-) \otimes \mathbb{Z}/n\mathbb{Z} : \text{PSh}(\mathcal{S}) \rightarrow \text{PSh}_{\mathbb{Z}/n\mathbb{Z}}(\mathcal{S}), F \mapsto F \otimes \mathbb{Z}/n\mathbb{Z}$$

is right exact and its restriction the full subcategory  $\text{PSh}(\mathcal{S})_L \subset \text{PSh}(\mathcal{S})$  of torsion free presheaves is exact. For  $\mathcal{S} \in \text{Cat}$  a ringed topos and  $p \in \mathbb{N}$  a prime number,  $\text{PSh}_{\mathbb{Z}_p}(\mathcal{S}) \in \text{Fun}(\mathbb{N}, \text{AbCat})$  is category whose objects are  $(F_l)_{l \in \mathbb{N}}$  with  $F_l \in \text{PSh}_{\mathbb{Z}/p^l\mathbb{Z}}(\mathcal{S})$  such that  $F_l \rightarrow F_{l+1}/p^l F_{l+1}$  is an isomorphism. We then have  $C_{\mathbb{Z}_p}(\mathcal{S}) := C(\text{PSh}_{\mathbb{Z}_p}(\mathcal{S})) \in \text{Fun}(\mathbb{N}, \text{AbCat})$ . We get the functor

$$(-) \otimes \mathbb{Z}_p : C(\mathcal{S}) \rightarrow C_{\mathbb{Z}_p}(\mathcal{S}), F \mapsto (F \otimes \mathbb{Z}/p^l\mathbb{Z})_{l \in \mathbb{N}}$$

which is right exact.

- For  $\mathcal{S}_\bullet \in \text{Fun}(\mathcal{I}, \text{Cat})$  a diagram of (pre)sites, with  $\mathcal{I} \in \text{Cat}$  a small category, we denote by  $\mathcal{S}_\bullet := \Gamma\mathcal{S}_\bullet \in \text{Cat}$  the associated diagram category
  - whose objects are  $\Gamma\mathcal{S}_\bullet^0 := \{(X_I, u_{IJ})_{I \in \mathcal{I}}\}$ , with  $X_I \in \mathcal{S}_I$ , and for  $r_{IJ} : I \rightarrow J$  with  $I, J \in \mathcal{I}$ ,  $u_{IJ} : X_J \rightarrow r_{IJ}(X_I)$  are morphism in  $\mathcal{S}_J$  noting again  $r_{IJ} : \mathcal{S}_I \rightarrow \mathcal{S}_J$  the associated functor,
  - whose morphism are  $m = (m_I) : (X_I, u_{IJ}) \rightarrow (X'_I, v_{IJ})$  satisfying  $v_{IJ} \circ m_I = r_{IJ}(m_J) \circ u_{IJ}$  in  $\mathcal{S}_J$ ,

We have then  $\text{PSh}(\mathcal{S}_\bullet) = \text{PSh}(\Gamma\mathcal{S}_\bullet)$  the category of presheaves on  $\mathcal{S}_\bullet$ ,

- whose objects are  $\text{PSh}(\mathcal{S}_\bullet)^0 := \{(F_I, u_{IJ})_{I \in \mathcal{I}}\}$ , with  $F_I \in \text{PSh}(\mathcal{S}_I)$ , and for  $r_{IJ} : I \rightarrow J$  with  $I, J \in \mathcal{I}$ ,  $u_{IJ} : F_I \rightarrow r_{IJ*}F_J$  are morphism in  $\text{PSh}(\mathcal{S}_I)$ , noting again  $r_{IJ} : \mathcal{S}_J \rightarrow \mathcal{S}_I$  the associated morphism of presite,
- whose morphism are  $m = (m_I) : (F_I, u_{IJ}) \rightarrow (G_I, v_{IJ})$  satisfying  $v_{IJ} \circ m_I = r_{IJ*}m_J \circ u_{IJ}$  in  $\text{PSh}(\mathcal{S}_I)$ ,

Let  $\mathcal{I}, \mathcal{I}' \in \text{Cat}$  be small categories. Let  $(f_\bullet, s) : \mathcal{T}_\bullet \rightarrow \mathcal{S}_\bullet$  a morphism a diagrams of (pre)site with  $\mathcal{T}_\bullet \in \text{Fun}(\mathcal{I}, \text{Cat}), \mathcal{S}_\bullet \in \text{Fun}(\mathcal{I}', \text{Cat})$ , which is by definition given by a functor  $s : \mathcal{I} \rightarrow \mathcal{I}'$  and morphism of functor  $P(f_\bullet) : \mathcal{S}_{s(\bullet)} := \mathcal{S}_\bullet \circ s \rightarrow \mathcal{T}_\bullet$ . Here, we denote for short,  $\mathcal{S}_{s(\bullet)} := \mathcal{S}_\bullet \circ s \in \text{Fun}(\mathcal{I}, \text{Cat})$ . We have then, for  $r_{IJ} : I \rightarrow J$  a morphism, with  $I, J \in \mathcal{I}$ , a commutative diagram in  $\text{Cat}$

$$D_{fIJ} := \begin{array}{ccc} \mathcal{S}_{s(J)} & \xrightarrow{r_{IJ}^s} & \mathcal{S}_{s(I)} \\ f_J \uparrow & & \uparrow f_I \\ \mathcal{T}_J & \xrightarrow{r_{IJ}^t} & \mathcal{T}_I \end{array} .$$

In particular we get the adjonction given by the direct and inverse image functors :

$$\begin{aligned} ((f_\bullet, s)^*, (f_\bullet, s)_*) &= ((f_\bullet, s)^{-1}, (f_\bullet, s)_*) : \text{PSh}(\mathcal{S}_{s(\bullet)}) \rightleftarrows \text{PSh}(\mathcal{T}_\bullet), \\ F = (F_I, u_{IJ}) &\mapsto (f_\bullet, s)^* F := (f_I^* F_I, T(D_{fIJ})(F_J) \circ f_I^* u_{IJ}), \\ G = (G_I, v_{IJ}) &\mapsto (f_\bullet, s)_* G := (f_{I*} G_I, f_{I*} v_{IJ}). \end{aligned}$$

- Let  $\mathcal{I} \in \text{Cat}$  a small category. For  $(\mathcal{S}_\bullet, \mathcal{O}_{\mathcal{S}_\bullet}) \in \text{Fun}(\mathcal{I}, \text{RCat})$  a diagram of ringed topos, we denote by

$$(\mathcal{S}_\bullet, \mathcal{O}_{\mathcal{S}_\bullet}) := (\Gamma\mathcal{S}_\bullet, \mathcal{O}_{\Gamma\mathcal{S}_\bullet}) \in \text{RCat} .$$

We have then  $\text{PSh}_{\mathcal{O}_{\mathcal{S}_\bullet}}(\mathcal{S}_\bullet) = \text{PSh}_{\mathcal{O}_{\Gamma\mathcal{S}_\bullet}}(\Gamma\mathcal{S}_\bullet)$  the category of presheaves of modules on  $(\mathcal{S}_\bullet, \mathcal{O}_{\mathcal{S}_\bullet})$ ,

- whose objects are  $\text{PSh}_{\mathcal{O}_{\mathcal{S}_\bullet}}(\mathcal{S}_\bullet)^0 := \{(F_I, u_{IJ})_{I \in \mathcal{I}}\}$ , with  $F_I \in \text{PSh}_{\mathcal{O}_{\mathcal{S}_I}}(\mathcal{S}_I)$ , and for  $r_{IJ} : I \rightarrow J$  with  $I, J \in \mathcal{I}$ ,  $u_{IJ} : F_I \rightarrow r_{IJ*}F_J$  are morphism in  $\text{PSh}_{\mathcal{O}_{\mathcal{S}_I}}(\mathcal{S}_I)$ , noting again  $r_{IJ} : \mathcal{S}_J \rightarrow \mathcal{S}_I$  the associated morphism of presite,
  - whose morphism are  $m = (m_I) : (F_I, u_{IJ}) \rightarrow (G_I, v_{IJ})$  satisfying  $v_{IJ} \circ m_I = r_{IJ*}m_J \circ u_{IJ}$  in  $\text{PSh}_{\mathcal{O}_{\mathcal{S}_I}}(\mathcal{S}_I)$ ,
- For  $A \in \text{Ring}$ ,  $\dim_K(A)$  denote the Krull dimension of  $A$ . For  $\sigma : A \rightarrow B$  a morphism with  $A, B \in \text{cRing}$ , we have the extention of scalar functor

$$\begin{aligned} \otimes_A B : (-) \otimes_A B &: \text{Mod}(A) \rightarrow \text{Mod}(B), \quad M \mapsto M \otimes_A B \\ (m : M' \rightarrow M) &\mapsto (m_B := m \otimes I : M' \otimes_A B \rightarrow M \otimes_A B). \end{aligned}$$

which is left ajoint to the restriction of scalar

$$\text{Res}_{A/B} : \text{Mod}(B) \rightarrow \text{Mod}(A), \quad M = (M, a_M) \mapsto M = (M, a_M \circ \sigma), \quad (m : M' \rightarrow M) \mapsto (m : M' \rightarrow M)$$

The adjonction maps are

- for  $M \in \text{Mod}(A)$ , the canonical map in  $\text{Mod}(A)$

$$n_{A/B}(M) : M \rightarrow M \otimes_A B, \quad n_{A/B}(M)(m) := m \otimes 1,$$

- for  $M \in \text{Mod}(B)$ ,

$$I \times \Delta_B : M \otimes_A B = M \otimes_B B \otimes_A B$$

in  $\text{Mod}(B)$ , where  $\Delta_B : B \otimes_A B \rightarrow B$  is given by for  $x, y \in B$ ,  $\Delta_B(x, y) = x - y$ .

Let  $\sigma : A \rightarrow B$  a morphism with  $A, B \in \text{cRing}$ . A module  $M \in \text{Mod}(B)$  is said to be defined over  $A$  if there exist a module  $M_0 \in \text{Mod}(A)$  and an isomorphism  $M \simeq M_0 \otimes_A B$  in  $\text{Mod}(B)$ . A module  $M \in \text{Mod}(B)$  is defined over  $A$  if and only if there exist a presentation of  $M$ , that is an exact sequence in  $\text{Mod}(B)$ ,  $B^{\oplus J} \xrightarrow{\phi} B^{\oplus I} \rightarrow M \rightarrow 0$ , such that  $\phi \circ \sigma(A^{\oplus J}) \subset A^{\oplus I}$ .

- For  $f = (f, a_f) : (\mathcal{T}, O_{\mathcal{T}}) \rightarrow (\mathcal{S}, O_{\mathcal{S}})$  a morphism of ringed topos with  $(\mathcal{S}, O_{\mathcal{S}}), (\mathcal{T}, O_{\mathcal{T}}) \in \text{RCat}$ ,  $a_f : f^*O_{\mathcal{S}} \rightarrow O_{\mathcal{T}}$ , we have the pull-back of presheaves of modules

$$\begin{aligned} f^{*mod} : \text{PSh}_{O_{\mathcal{S}}}(\mathcal{S}) &\rightarrow \text{PSh}_{O_{\mathcal{T}}}(\mathcal{T}), \quad M \mapsto f^{*mod}M := f^*M \otimes_{f^*O_{\mathcal{S}}} O_{\mathcal{T}} \\ (m : M' \rightarrow M) &\mapsto (f^{*mod}M := f^*m \otimes I : f^{*mod}M' \rightarrow f^{*mod}M). \end{aligned}$$

which is left adjoint to

$$\begin{aligned} f_* : \text{PSh}_{O_{\mathcal{T}}}(\mathcal{T}) &\rightarrow \text{PSh}_{O_{\mathcal{S}}}(\mathcal{S}), \quad M = (M, a_M) \mapsto f_*M = (f_*M, a_M \circ a_f), \\ (m : M' \rightarrow M) &\mapsto (f_*m : f_*M' \rightarrow f_*M) \end{aligned}$$

The adjunction maps are

- for  $M \in \text{PSh}_{O_{\mathcal{S}}}(\mathcal{S})$ , the canonical map in  $\text{PSh}_{O_{\mathcal{S}}}(\mathcal{S})$

$$\begin{aligned} \text{ad}(f^{*mod}, f_*)(M) &:= n_{f^*O_{\mathcal{S}}/O_{\mathcal{T}}}(M) : M \rightarrow f_*f^{*mod}M = f_*f^*M \otimes_{f_*f^*O_{\mathcal{S}}} f_*O_{\mathcal{T}}, \\ n_{f^*O_{\mathcal{S}}/O_{\mathcal{T}}}(M)(m) &:= \text{ad}(f_*, f^*)(M)(m) \otimes 1, \end{aligned}$$

- for  $M \in \text{PSh}_{O_{\mathcal{T}}}(\mathcal{T})$ , the canonical map

$$\text{ad}(f^{*mod}, f_*)(M) := I \times \Delta_{O_{\mathcal{T}}} : f^{*mod}f_*M = f^*f_*M \otimes_{O_{\mathcal{T}}} O_{\mathcal{T}} \otimes_{f^*O_{\mathcal{S}}} O_{\mathcal{T}} \rightarrow M,$$

where  $\Delta_{O_{\mathcal{T}}} : O_{\mathcal{T}} \otimes_{f^*O_{\mathcal{S}}} O_{\mathcal{T}} \rightarrow O_{\mathcal{T}}$  is given by for  $x, y \in \Gamma(T, O_{\mathcal{T}})$ ,  $T \in \mathcal{T}$ ,  $\Delta_{O_{\mathcal{T}}}(x, y) = x - y$ .

Let  $f = (f, a_f) : (\mathcal{T}, O_{\mathcal{T}}) \rightarrow (\mathcal{S}, O_{\mathcal{S}})$  a morphism of ringed topos with  $(\mathcal{S}, O_{\mathcal{S}}), (\mathcal{T}, O_{\mathcal{T}}) \in \text{RCat}$ ,  $a_f : f^*O_{\mathcal{S}} \rightarrow O_{\mathcal{T}}$ . A presheaf  $M \in \text{PSh}_{O_{\mathcal{T}}}(\mathcal{T})$  is said to be defined over  $(\mathcal{S}, O_{\mathcal{S}})$  if there exist a  $M_0 \in \text{PSh}_{O_{\mathcal{S}}}(\mathcal{S})$  such that  $M \simeq f^{*mod}M_0$  in  $\text{PSh}_{O_{\mathcal{T}}}(\mathcal{T})$ . For  $M \in \text{PSh}_{O_{\mathcal{T}}}(\mathcal{T})$  quasi-coherent,  $M$  is locally defined over  $(\mathcal{S}, O_{\mathcal{S}})$  if and only if there exists locally a presentation of  $M$ , that is an exact sequence in  $\text{PSh}_{O_{\mathcal{T}}}(\mathcal{T}')$ ,  $\mathcal{T}' \subset \mathcal{T}$ ,  $O_{\mathcal{T}'}^{\oplus J} \xrightarrow{\phi} O_{\mathcal{T}'}^{\oplus I} \rightarrow M \rightarrow 0$ , such that  $\phi \circ a_f(O_{\mathcal{S}}^{\oplus J}) \subset O_{\mathcal{S}}^{\oplus I}$ .

- For  $X \in \text{Top}$ , we denote by  $\dim_F(X)$  its Krull dimension and  $\dim_L(X)$  its Lebesgue dimension. Note that if  $X$  is Hausdorff  $\dim_F(X) = 0$  and if  $X$  is everywhere not Hausdorff  $\dim_L(X) = 0$ . For  $X \in \text{Top}$  and  $x \in X$ , we denote by  $\dim_{F,x}(X) := \inf_{x \in U} \dim_F(U)$  its Krull dimension at  $x$  and  $\dim_{L,x}(X) := \inf_{x \in U} \dim_L(U)$  its Lebesgue dimension at  $x$ .
- Denote by  $\text{Sch} \subset \text{RTop}$  the full subcategory of schemes. For  $X \in \text{Sch}$ ,  $\dim(X) := \dim_F(X)$ . For  $X = \text{Spec } A \in \text{Sch}$  an affine scheme,  $\dim(X) = \dim_K(A)$ . For  $X \in \text{Sch}$  and  $x \in X$ ,  $\dim_x(X) := \dim_{F,x}(X) = \dim(O_{X,x})$ . A morphism  $h : U \rightarrow S$  with  $U, S \in \text{Sch}$  is said to be smooth if it is flat with smooth fibers geometric fibers. A morphism  $r : U \rightarrow X$  with  $U, X \in \text{Sch}$  is said to be etale if it is non ramified and flat. In particular an etale morphism  $r : U \rightarrow X$  with  $U, X \in \text{Sch}$  is smooth and quasi-finite (i.e. the fibers are either the empty set or a finite subset of  $X$ ) For  $X \in \text{Sch}$ , we denote by

- $\text{Sch}^{ft}/X \subset \text{Sch}/X$  the full subcategory consisting of objects  $X'/X = (X', f) \in \text{Sch}/X$  such that  $f : X' \rightarrow X$  is an morphism of finite type
- $X^{et} \subset \text{Sch}^{ft}/X$  the full subcategory consisting of objects  $U/X = (X, h) \in \text{Sch}/X$  such that  $h : U \rightarrow X$  is an etale morphism.
- $X^{sm} \subset \text{Sch}^{ft}/X$  the full subcategory consisting of objects  $U/X = (X, h) \in \text{Sch}/X$  such that  $h : U \rightarrow X$  is a smooth morphism.

For a field  $k$ , we consider  $\text{Sch}/k := \text{Sch}/\text{Spec } k$  the category of schemes over  $\text{Spec } k$ . We then denote by

- $\text{Var}(k) = \text{Sch}^{ft}/k \subset \text{Sch}/k$  the full subcategory consisting of algebraic varieties over  $k$ , i.e. schemes of finite type over  $k$ ,
- $\text{PVar}(k) \subset \text{QPVar}(k) \subset \text{Var}(k)$  the full subcategories consisting of quasi-projective varieties and projective varieties respectively,
- $\text{PSmVar}(k) \subset \text{SmVar}(k) \subset \text{Var}(k)$  the full subcategories consisting of smooth varieties and smooth projective varieties respectively.

For a morphism of field  $\sigma : k \hookrightarrow K$ , we have the extension of scalar functor

$$\otimes_k K : \text{Sch}/k \rightarrow \text{Sch}/K, X \mapsto X_K := X_{K,\sigma} := X \otimes_k K, (f : X' \rightarrow X) \mapsto (f_K := f \otimes I : X'_K \rightarrow X_K).$$

which is left adjoint to the restriction of scalar

$$\text{Res}_{k/K} : \text{Sch}/K \rightarrow \text{Sch}/k, X = (X, a_X) \mapsto X = (X, \sigma \circ a_X), (f : X' \rightarrow X) \mapsto (f : X' \rightarrow X)$$

The adjunction maps are

- for  $X \in \text{Sch}/k$ , the projection  $\pi_{k/K}(X) : X_K \rightarrow X$  in  $\text{Sch}/k$ , for  $X = \cup_i X_i$  an affine open cover with  $X_i = \text{Spec}(A_i)$  we have by definition  $\pi_{k/K}(X_i) = n_{k/K}(A_i)$ ,
- for  $X \in \text{Sch}/K$ ,  $I \times \Delta_K : X \hookrightarrow X_K = X \times_K K \otimes_k K$  in  $\text{Sch}/K$ , where  $\Delta_K : K \otimes_k K \rightarrow K$  is the diagonal which is given by for  $x, y \in K$ ,  $\Delta_K(x, y) = x - y$ .

The extension of scalar functor restrict to a functor

$$\otimes_k K : \text{Var}(k) \rightarrow \text{Var}(K), X \mapsto X_K := X_{K,\sigma} := X \otimes_k K, (f : X' \rightarrow X) \mapsto (f_K := f \otimes I : X'_K \rightarrow X_K).$$

and for  $X \in \text{Var}(k)$  we have  $\pi_{k/K}(X) : X_K \rightarrow X$  the projection in  $\text{Sch}/k$ . An algebraic variety  $X \in \text{Var}(K)$  is said to be defined over  $k$  if there exists  $X_0 \in \text{Var}(k)$  such that  $X \simeq X_0 \otimes_k K$  in  $\text{Var}(K)$ . By definition,

- for  $X = \text{Spec}(A) \in \text{Var}(K)$  an affine variety,  $X$  is defined over  $k$  if  $A \in \text{Mod}(K)$  is defined over  $k$ , that is if  $A = K[x_1, \dots, x_N]/I$  is a presentation of  $A$ ,  $I = \langle f_1, \dots, f_r \rangle \subset K[x_1, \dots, x_N]$  with  $f_1, \dots, f_r \in k[x_1, \dots, x_N]$  is generated by elements over  $k$ .
- for  $X = \text{Proj}(B) \in \text{PVar}(K)$  an projective variety,  $X$  is defined over  $k$  if  $B \in \text{Mod}(K)$  is defined over  $k$ , that is if  $B = K[x_0, \dots, x_N]/I$  is a presentation of  $B$  with  $I$  generated by homogeneous elements,  $I = \langle f_1, \dots, f_r \rangle \subset K[x_0, \dots, x_N]$  with  $f_1, \dots, f_r \in k[x_0, \dots, x_N]$  homogeneous.

For  $X = (X, a_X) \in \text{Var}(k)$ , we have  $\text{Sch}^{ft}/X = \text{Var}(k)/X$  since for  $f : X' \rightarrow X$  a morphism of schemes of finite type,  $(X', a_X \circ f) \in \text{Var}(k)$  is the unique structure of variety over  $k$  of  $X' \in \text{Sch}$  such that  $f$  becomes a morphism of algebraic varieties over  $k$ , in particular we have

- $X^{et} \subset \text{Sch}^{ft}/X = \text{Var}(k)/X$ ,
- $X^{sm} \subset \text{Sch}^{ft}/X = \text{Var}(k)/X$ .

- Denote by  $CW \subset \text{Top}$  the full subcategory of  $CW$  complexes, by  $CS \subset CW$  the full subcategory of  $\Delta$  complexes, by  $\text{TM}(\mathbb{R}) \subset CW$  the full subcategory of topological (real) manifolds which admits a  $CW$  structure (a topological manifold admits a  $CW$  structure if it admits a differential structure) and by  $\text{Diff}(\mathbb{R}) \subset \text{RTop}$  the full subcategory of differentiable (real) manifold.
- Denote by  $\text{AnSp}(\mathbb{C}) \subset \text{RTop}$  the full subcategory of analytic spaces over  $\mathbb{C}$ , and by  $\text{AnSm}(\mathbb{C}) \subset \text{AnSp}(\mathbb{C})$  the full subcategory of smooth analytic spaces (i.e. complex analytic manifold). For  $X \in \text{AnSp}(\mathbb{C})$ , we set  $\dim(X) := 1/2 \dim_L(X)$ , and for  $x \in X$   $\dim_x(X) := 1/2 \dim_{L,x}(X)$ . For  $X \in \text{AnSp}(\mathbb{C})$  and  $x \in X$ , there exist by Weirstrass preparation theorem a finite surjective morphism  $r : X_x \rightarrow \mathbb{D}_0^n$  where  $\mathbb{D}^n = D(0,1)^n \subset \mathbb{C}^n$  is the open ball and  $\dim_x(X) := 1/2 \dim_{L,x}(X) = \dim_K(O_{X,x}) = n$ . For  $X \in \text{AnSm}(\mathbb{C})$  and  $x \in X$ , there exist an isomorphism  $r : X_x \xrightarrow{\sim} \mathbb{D}_0^n$ , hence there exist a covering by open subsets  $X = \cup_i X_i$  such that  $r_i : X_i \xrightarrow{\sim} \mathbb{D}^{n_i}$ . If  $X \in \text{AnSm}(\mathbb{C})$  is connected then  $\dim(X) := \dim_L(X) = 2n$  where  $r : X_x \xrightarrow{\sim} \mathbb{D}_0^n$  for  $x \in X$ . For  $X \in \text{AnSp}(\mathbb{C})$ ,  $\dim(X) := \dim_L(X) = \dim_L(X_{reg})$  where  $X_{reg} \subset X$  is the smooth locus of  $X$ . A morphism  $h : U \rightarrow S$  with  $U, S \in \text{AnSp}(\mathbb{C})$  is said to be smooth if it is flat with smooth fibers. A morphism  $r : U \rightarrow X$  with  $U, X \in \text{AnSp}(\mathbb{C})$  is said to be etale if it is non ramified and flat. For  $X \in \text{AnSp}(\mathbb{C})$ , we denote by
  - $X^{et} \subset \text{AnSp}(\mathbb{C})/X$  the full subcategory consisting of objects  $U/X = (X, h) \in \text{AnSp}(\mathbb{C})/X$  such that  $h : U \rightarrow X$  is an etale morphism.
  - $X^{sm} \subset \text{AnSp}(\mathbb{C})/X$  the full subcategory consisting of objects  $U/X = (X, h) \in \text{AnSp}(\mathbb{C})/X$  such that  $h : U \rightarrow X$  is a smooth morphism.

By the Weirstrass preparation theorem (or the implicit function theorem if  $U$  and  $X$  are smooth), a morphism  $r : U \rightarrow X$  with  $U, X \in \text{AnSp}(\mathbb{C})$  is etale if and only if it is an isomorphism local. Hence for  $X \in \text{AnSp}(\mathbb{C})$ , the morphism of site  $\pi_X : X^{et} \rightarrow X$  is an isomorphism of site.

- For  $V \in \text{Var}(\mathbb{C})$ , we denote by  $V^{an} \in \text{AnSp}(\mathbb{C})$  the complex analytic space associated to  $V$  with the usual topology induced by the usual topology of  $\mathbb{C}^N$ . For  $W \in \text{AnSp}(\mathbb{C})$ , we denote by  $W^{cw} \in \text{AnSp}(\mathbb{C})$  the topological space given by  $W$  which is a  $CW$  complex. For simplicity, for  $V \in \text{Var}(\mathbb{C})$ , we denote by  $V^{cw} := (V^{an})^{cw} \in CW$ . We have then
  - the analytical functor  $\text{An} : \text{Var}(\mathbb{C}) \rightarrow \text{AnSp}(\mathbb{C})$ ,  $\text{An}(V) = V^{an}$ ,
  - the forgetful functor  $\text{Cw} = tp : \text{AnSp}(\mathbb{C}) \rightarrow CW$ ,  $\text{Cw}(W) = W^{cw}$ ,
  - the composite of these two functors  $\widetilde{\text{Cw}} = \text{Cw} \circ \text{An} : \text{Var}(\mathbb{C}) \rightarrow CW$ ,  $\widetilde{\text{Cw}}(V) = V^{cw}$ .
- Let  $S \in \text{RTop}$ . Let  $S = \cup_{i \in L} S_i$  open cover and  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embedding with  $\tilde{S}_i \in \text{RTop}$ ,  $L \in \text{Set}$ . We denote by  $(\tilde{S}_I) \in \text{Fun}(\mathcal{P}(L)^{op}, \text{RTop})$  the diagram given by for  $I \in L$   $\tilde{S}_I := \prod_{i \in I} \tilde{S}_i$  and for  $I \subset J$ ,  $p_{IJ} : \tilde{S}_J \rightarrow \tilde{S}_I$  is the projection. We have then open embeddings  $j_I : S_I := \cap_{i \in I} S_i \hookrightarrow S$  and closed embeddings  $i_I : S_I \hookrightarrow \tilde{S}_I$ . We consider the functor

$$T(S/(\tilde{S}_I)) : C(S) \rightarrow C(S/(\tilde{S}_I)) \hookrightarrow C((\tilde{S}_I)), K \mapsto T(S/(\tilde{S}_I))(K) := (i_{I*} j_I^* K, I).$$

- Let  $k \subset \mathbb{C}$  a subfield. For  $S \in \text{Var}(k)$ , let  $S = \cup_i S_i$  affine open cover and  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embedding with  $\tilde{S}_i \in \text{SmVar}(k)$  connected. We denote by  $DR(S) := DR(S)^{[-1]}$  the De Rham functor

$$\begin{aligned} DR(S) &:= DR(S)^{[-1]} : C_{\mathcal{D}fil}(S/(\tilde{S}_I)) \rightarrow C(S_{\mathbb{C}}^{an}/(\tilde{S}_{I,\mathbb{C}}^{an})), \\ ((M_I, F), u_{IJ}) &\mapsto DR(S)((M_I, F), u_{IJ}) := (DR(\tilde{S}_{I,\mathbb{C}}^{an})(M_I, F)[-d_{\tilde{S}_I}], DR(u_{IJ})) \end{aligned}$$

- We denote by  $\text{AdSp} \subset \text{RvTop}$  the full subcategory of adic spaces. By definition, for  $X = (X, O_X, O_X^+) \in \text{AdSp}$  there exist an open cover  $X = \cup_i X_i$  such that

$$X_i = \text{Spa}(R_i, R_i^+) := \{v \in \text{Spv}(R_i), v(f) \leq 1 \text{ for all } f \in R_i^+\}$$

with  $R_i \in \text{cTRing}$  for a non archimedean semi-norm and  $R_i^+ \subset R_i^o \subset R_i$  a subring, where  $R_i^o = \{f \in R_i \text{ s.t. } |f_i| \leq 1\}$ . We then have

$$R_i^+ = \{f \in R_i, v(f) \leq 1 \text{ for all } v \in \text{Spa}(R_i, R_i^+)\}.$$

- For  $K \subset \mathbb{C}_p$  a p-adic field, denote by  $\text{AnSp}(K) \subset \text{RTop}$  the full subcategory of analytic spaces over  $K$ . By definition, for  $X \in \text{AnSp}(K)$  there exist an open cover  $X = \cup_i X_i$  such that  $X_i = \text{Spv}(R_i)$  where  $R_i \in \text{cTRing}$  is a Tate algebra over  $K$ . Note that we have the map  $m : X \rightarrow M(X)$  in  $\text{RTop}$  with  $m|_{X_i} : X_i = \text{Spv}(R_i) \rightarrow M(X_i) = \text{Spec}(R_i)$  which sends a valuation  $v$  to its support  $p = \{f \in R_i, v(f) = 0\}$  and where  $M(X_i)$  is endowed with the standard G-topology. By definition, we have

- the forgetfull functor  $o_K : \text{AdSp}/(K, K^+) \rightarrow \text{AnSp}(K)$ , such that  $o_K(\text{Spa}(R, R^+)) = \text{Spv}(R)$ ,
- the canonical functor  $R_K : \text{AnSp}(K) \rightarrow \text{AdSp}/(K, O_K)$  such that  $R_K(\text{Spv}(R)) = \text{Spa}(R, R^o)$ .

We denote by  $\text{AnSm}(K) \subset \text{AnSp}(K)$  the full subcategory of smooth analytic spaces. For  $X \in \text{AnSp}(K)$ , we set  $\dim(X) := \dim_L(X)$ , and for  $x \in X$   $\dim_x(X) := \dim_{L,x}(X)$ . For  $X \in \text{AnSp}(K)$  and  $x \in X$ , there exist by Weirstrass preparation theorem a finite surjective morphism  $r : X_x \rightarrow \mathbb{D}^n$  where  $\mathbb{D}^n = D(0, 1)^n \subset K^n$  is the open ball and  $\dim_x(X) := \dim_{L,x}(X) = \dim_K(O_{X,x}) = n$ . For  $X = \text{Spv}(A) \in \text{AnSp}(K)$  affinoid,  $\dim(X) := \dim_L(X) = \dim_K(A)$  where for the last equality note that for  $0 < r < 1$ ,  $D(0, r)^n = \text{Spv}(K \langle x_1, \dots, x_n \rangle_r) \subset D(0, 1)^n = \text{Spv}(K \langle x_1, \dots, x_n \rangle)$  is a rational open subset since the norm is ultrametric in contrast to the complex case. A morphism  $h : U \rightarrow S$  with  $U, S \in \text{AnSp}(K)$  is said to be smooth if it is flat with smooth geometric fibers. A morphism  $r : U \rightarrow X$  with  $U, X \in \text{AnSp}(K)$  is said to be etale if it is non ramified and flat. For  $X \in \text{AnSp}(K)$ , we denote by

- $X^{et} \subset \text{AnSp}(K)/X$  the full subcategory consisting of objects  $U/X = (X, h) \in \text{AnSp}(K)/X$  such that  $h : U \rightarrow X$  is an etale morphism.
- $X^{sm} \subset \text{AnSp}(K)/X$  the full subcategory consisting of objects  $U/X = (X, h) \in \text{AnSp}(K)/X$  such that  $h : U \rightarrow X$  is a smooth morphism.

For  $X \in \text{AnSp}(K)$ , we have the morphism of site  $\pi_X : X^{et} \rightarrow X$ .

- Let  $K \subset \mathbb{C}_p$  a p-adic field. For  $V \in \text{Var}(K)$ , we denote by  $V^{an} \in \text{AnSp}(K)$ . We have then the analytical functor  $\text{An} : \text{Var}(K) \rightarrow \text{AnSp}(K)$ ,  $\text{An}(V) = V^{an}$ ,  $\text{An}(f) = f^{an}$ . We will also consider the canonical functor  $R_K : \text{AnSp}(K) \rightarrow \text{AdSp}/(K, O_K)$ , which sends by definition  $X = \text{Spv}(R)$  affinoid with  $R$  a Tate algebra over  $K$  to  $X = \text{Spa}(R, R^o)$  with  $R^o := \{f \in R, |f|_p \leq 1\}$ .
- Denote by  $\text{Top}^2$  the category whose set of objects is

$$(\text{Top}^2)^0 := \{(X, Z), Z \subset X \text{ closed}\} \subset \text{Top} \times \text{Top}$$

and whose set of morphism between  $(X_1, Z_1), (X_2, Z_2) \in \text{Top}^2$  is

$$\text{Hom}_{\text{Top}^2}((X_1, Z_1), (X_2, Z_2)) := \{(f : X_1 \rightarrow X_2), \text{ s.t. } Z_1 \subset f^{-1}(Z_2)\} \subset \text{Hom}_{\text{Top}}(X_1, X_2)$$

For  $S \in \text{Top}$ ,  $\text{Top}^2/S := \text{Top}^2/(S, S)$  is then by definition the category whose set of objects is

$$(\text{Top}^2/S)^0 := \{((X, Z), h), h : X \rightarrow S, Z \subset X \text{ closed}\} \subset \text{Top}/S \times \text{Top}$$

and whose set of morphisms between  $(X_1, Z_1)/S = ((X_1, Z_1), h_1), (X_2, Z_2)/S = ((X_2, Z_2), h_2) \in \text{Top}^2/S$  is the subset

$$\begin{aligned} & \text{Hom}_{\text{Top}^2/S}((X_1, Z_1)/S, (X_2, Z_2)/S) := \\ & \{(f : X_1 \rightarrow X_2), \text{ s.t. } h_1 \circ f = h_2 \text{ and } Z_1 \subset f^{-1}(Z_2)\} \subset \text{Hom}_{\text{RTop}}(X_1, X_2) \end{aligned}$$

We denote by

$$\mu_S : \text{Top}^{2,pr} / S := \{((Y \times S, Z), p), p : Y \times S \rightarrow S, Z \subset Y \times S \text{ closed}\} \hookrightarrow \text{Top}^2 / S$$

the full subcategory whose objects are those with  $p : Y \times S \rightarrow S$  a projection, and again  $\mu_S : \text{Top}^2 / S \rightarrow \text{Top}^{2,pr} / S$  the corresponding morphism of sites. We denote by

$$\begin{aligned} \text{Gr}_S^{12} : \text{Top} / S &\rightarrow \text{Top}^{2,pr} / S, X/S \mapsto \text{Gr}_S^{12}(X/S) := (X \times S, \bar{X})/S, \\ (g : X/S \rightarrow X'/S) &\mapsto \text{Gr}_S^{12}(g) := (g \times I_S : (X \times S, \bar{X}) \rightarrow (X' \times S, \bar{X}')) \end{aligned}$$

the graph functor,  $X \hookrightarrow X \times S$  being the graph embedding (which is a closed embedding if  $X$  is separated), and again  $\text{Gr}_S^{12} : \text{Top}^{2,pr} / S \rightarrow \text{Top} / S$  the corresponding morphism of sites.

- Denote by  $\text{RTop}^2$  the category whose set of objects is

$$(\text{RTop}^2)^0 := \{((X, O_X), Z), Z \subset X \text{ closed}\} \subset \text{RTop} \times \text{Top}$$

and whose set of morphism between  $((X_1, O_{X_1}), Z_1), ((X_2, O_{X_2}), Z_2) \in \text{RTop}^2$  is

$$\begin{aligned} \text{Hom}_{\text{RTop}^2}(((X_1, O_{X_1}), Z_1), ((X_2, O_{X_2}), Z_2)) &:= \\ \{(f : (X_1, O_{X_1}) \rightarrow (X_2, O_{X_2})), \text{ s.t. } Z_1 \subset f^{-1}(Z_2)\} &\subset \text{Hom}_{\text{RTop}}((X_1, O_{X_1}), (X_2, O_{X_2})) \end{aligned}$$

For  $(S, O_S) \in \text{RTop}$ ,  $\text{RTop}^2 / (S, O_S) := \text{RTop}^2 / ((S, O_S), S)$  is then by definition the category whose set of objects is

$$\begin{aligned} (\text{RTop}^2 / (S, O_S))^0 &:= \\ \{(((X, O_X), Z), h), h : (X, O_X) \rightarrow (S, O_S), Z \subset X \text{ closed}\} &\subset \text{RTop} / (S, O_S) \times \text{Top} \end{aligned}$$

and whose set of morphisms between  $((X_1, O_{X_1}), Z_1, h_1), ((X_2, O_{X_2}), Z_2, h_2) \in \text{RTop}^2 / (S, O_S)$  is the subset

$$\begin{aligned} \text{Hom}_{\text{RTop}^2 / (S, O_S)}(((X_1, O_{X_1}), Z_1) / (S, O_S), ((X_2, O_{X_2}), Z_2) / (S, O_S)) &:= \\ \{(f : (X_1, O_{X_1}) \rightarrow (X_2, O_{X_2})), \text{ s.t. } h_1 \circ f = h_2 \text{ and } Z_1 \subset f^{-1}(Z_2)\} &\subset \text{Hom}_{\text{RTop}}((X_1, O_{X_1}), (X_2, O_{X_2})) \end{aligned}$$

We denote by

$$\mu_S : \text{RTop}^{2,pr} / S := \{(((Y \times S, q^*O_Y \otimes p^*O_S), Z), p), p : Y \times S \rightarrow S, Z \subset Y \times S \text{ closed}\} \hookrightarrow \text{RTop}^2 / S$$

the full subcategory whose objects are those with  $p : Y \times S \rightarrow S$  is a projection, and again  $\mu_S : \text{RTop}^2 / S \rightarrow \text{RTop}^{2,pr} / S$  the corresponding morphism of sites. We denote by

$$\begin{aligned} \text{Gr}_S^{12} : \text{RTop} / S &\rightarrow \text{RTop}^{2,pr} / S, \\ (X, O_X) / (S, O_S) &\mapsto \text{Gr}_S^{12}((X, O_X) / (S, O_S)) := ((X \times S, q^*O_X \otimes p^*O_S), \bar{X}) / (S, O_S), \\ (g : (X, O_X) / (S, O_S) \rightarrow (X', O_{X'}) / (S, O_S)) &\mapsto \\ \text{Gr}_S^{12}(g) &:= (g \times I_S : ((X \times S, q^*O_X \otimes p^*O_S), \bar{X}) \rightarrow ((X' \times S, q^*O_{X'} \otimes p^*O_S), \bar{X}')) \end{aligned}$$

the graph functor,  $X \hookrightarrow X \times S$  being the graph embedding (which is a closed embedding if  $X$  is separated),  $p : X \times S \rightarrow S$ ,  $q : X \times S \rightarrow X$  the projections, and again  $\text{Gr}_S^{12} : \text{RTop}^{2,pr} / S \rightarrow \text{RTop} / S$  the corresponding morphism of sites.

- We denote by  $\text{Sch}^2 \subset \text{RTop}^2$  the full subcategory such that the first factors are schemes. For a field  $k$ , we denote by  $\text{Sch}^2 / k := \text{Sch}^2 / (\text{Spec } k, \{\text{pt}\})$  and by

- $\text{Var}(k)^2 \subset \text{Sch}^2/k$  the full subcategory such that the first factors are algebraic varieties over  $k$ , i.e. schemes of finite type over  $k$ ,
- $\text{PVar}(k)^2 \subset \text{QPVar}(k)^2 \subset \text{Var}(k)^2$  the full subcategories such that the first factors are quasi-projective varieties and projective varieties respectively,
- $\text{PSmVar}(k)^2 \subset \text{SmVar}(k)^2 \subset \text{Var}(k)^2$  the full subcategories such that the first factors are smooth varieties and smooth projective varieties respectively.

In particular we have, for  $S \in \text{Var}(k)$ , the graph functor

$$\begin{aligned} \text{Gr}_S^{12} : \text{Var}(k)/S &\rightarrow \text{Var}(k)^{2,pr}/S, \quad X/S \mapsto \text{Gr}_S^{12}(X/S) := (X \times S, X)/S, \\ (g : X/S \rightarrow X'/S) &\mapsto \text{Gr}_S^{12}(g) := (g \times I_S : (X \times S, X) \rightarrow (X' \times S, X')) \end{aligned}$$

the graph embedding  $X \hookrightarrow X \times S$  is a closed embedding since  $X$  is separated in the subcategory of schemes  $\text{Sch} \subset \text{RTop}$ , and again  $\text{Gr}_S^{12} : \text{Var}(k)^{2,pr}/S \rightarrow \text{Var}(k)/S$  the corresponding morphism of sites.

- We denote by  $\text{CW}^2 \subset \text{Top}^2$  the full subcategory such that the first factors are  $CW$  complexes, by  $\text{TM}(\mathbb{R})^2 \subset \text{CW}^2$  the full subcategory such that the first factors are topological (real) manifolds and by  $\text{Diff}(\mathbb{R})^2 \subset \text{RTop}^2$  the full subcategory such that the first factors are differentiable (real) manifold.

## 2.2 The $p$ -adic de Rham period sheaves for adic spaces over a $p$ -adic field

Let  $p$  a prime number. For  $X = (X, O_X, O_X^+) \in \text{AdSp}/(K, K^+)$  an adic space over a  $p$ -adic field  $K \subset \mathbb{C}_p$ , we consider

- the map  $W_X : \mathbb{A}_{inf,X} := W(\hat{O}_X^{b+}) \rightarrow \hat{O}_X^+$  where  $\hat{O}_X$  denote the completion of  $O_X$  with respect to the ideal  $pO_X \subset O_X$ ,  $b$  the tilting functor and  $W$  the Witt vectors,
- the map  $W_X : \mathbb{B}_{inf,X} := W(\hat{O}_X^{b+})[p^{-1}] \rightarrow \hat{O}_X^+ := \hat{O}_X^+[p^{-1}]$
- the integral period sheaf  $\mathbb{B}_{dr,X}^+ := \varprojlim_{n \in \mathbb{N}} \mathbb{B}_{inf,X}/(\ker W_X)^n$  with the filtration  $F^k \mathbb{B}_{dr,X}^+ := (\ker W_X)^k \mathbb{B}_{dr,X}^+ \subset \mathbb{B}_{dr,X}^+$ .
- the period sheaf  $\mathbb{B}_{dr,X} := \mathbb{B}_{dr,X}^+[t^{-1}]$  where  $t$  is a generator of the ideal  $\ker W_X \subset \mathbb{B}_{dr,X}^+$  with the filtration  $F^k \mathbb{B}_{dr,X} := \sum_j t^{-j} F^{k+j} \mathbb{B}_{dr,X}^+ \subset \mathbb{B}_{dr,X}$ .
- the integral sheaf

$$O\mathbb{B}_{dr,X}^+ := \varprojlim_{n \in \mathbb{N}} (O_X^+ \hat{\otimes}_{W(O_K/pO_K)} \mathbb{A}_{inf,X}[p^{-1}]) / (\ker I \otimes W_X)^n$$

with the filtration  $F^k O\mathbb{B}_{dr,X}^+ := (\ker W_X)^k O\mathbb{B}_{dr,X}^+ \subset O\mathbb{B}_{dr,X}^+$ .

- the period sheaf  $O\mathbb{B}_{dr,X} := O\mathbb{B}_{dr,X}^+[t^{-1}]$  where  $t$  is a generator of the ideal  $\ker W_X \subset O\mathbb{B}_{dr,X}^+$  with the filtration  $F^k O\mathbb{B}_{dr,X} := \sum_j t^{-j} F^{k+j} O\mathbb{B}_{dr,X}^+ \subset O\mathbb{B}_{dr,X}$ .

## 2.3 The classical theorems for etale topology on schemes, and the comparison theorem with the analytic topologies for algebraic varieties over local fields

We first recall the smooth base change theorem



**Theorem 3.** (i) Consider a commutative diagram in  $\text{Sch}$  which is cartesian

$$\begin{array}{ccc} X_T & \xrightarrow{f'} & T \\ \downarrow g' & & \downarrow g \\ X & \xrightarrow{f} & S \end{array}$$

such that  $g$  is smooth or more generally locally acyclic. Let  $F \in C(X^{et})$  be a torsion sheaf where we recall that  $X^{et} \subset \text{Sch}^{ft}/X$  is the small etale site. Then the transformation map (see [10] section 2) in  $D(T^{et})$

$$T(f, g)(F) : g^* Rf_* F \rightarrow Rf'_* g'^* F$$

is an isomorphism.

(ii) Let  $k'/k$  an extention of field of characteristic zero. Let  $f : X \rightarrow S$  a morphism in  $\text{Var}(k)$ . Let  $F \in C(X^{et})$  be a torsion sheaf Then the transformation map (see [10] section 2) in  $D(S_{k'}^{et})$

$$T(f, \pi_{k/k'})(F) : \pi_{k/k'}^* Rf_* F \rightarrow Rf'_{k'} \pi_{k/k'}^* F$$

is an isomorphism where we recall (see section 2)  $\pi_{k/k'} = \pi_{k/k'}(X) : X_{k'} \rightarrow X$  and  $\pi_{k/k'} = \pi_{k/k'}(S) : S_{k'} \rightarrow S$  are the projections.

*Proof.* (i): Standard : see [22] for example.

(ii): Follows from (i). □

We now recall the proper base change theorem :

**Theorem 4.** Consider a commutative diagram in  $\text{Sch}$  which is cartesian

$$\begin{array}{ccc} X_T & \xrightarrow{f'} & T \\ \downarrow g' & & \downarrow g \\ X & \xrightarrow{f} & S \end{array}$$

such that  $f$  is proper. Let  $F \in C(X^{et})$  be a torsion sheaf where we recall that  $X^{et} \subset \text{Sch}^{ft}/X$  is the small etale site. Then the transformation map (see [10] section 2) in  $D(T^{et})$

$$T(f, g)(F) : g^* Rf_* F \rightarrow Rf'_* g'^* F$$

is an isomorphism.

*Proof.* Standard : see [22] for example. □

We deduce from the proper base change theorem the projection formula and the Kunneth formula for the cohomology of etale sheaves:

**Theorem 5.** (i) Let  $f : X \rightarrow S$  a proper morphism with  $S, X \in \text{Sch}$ . Let  $n \in \mathbb{N}$ . Let  $F \in C_{\mathbb{Z}/n\mathbb{Z}}(X^{et})$  and  $G \in C_{\mathbb{Z}/n\mathbb{Z}}(S^{et})$  be  $n$ -torsion sheaves. Then the transformation map (see [10] section 2) in  $D_{\mathbb{Z}/n\mathbb{Z}}(S^{et})$

$$T(f, \otimes)(F, G) : Rf_* F \otimes_{\mathbb{Z}/n\mathbb{Z}}^L G \rightarrow Rf_*(F \otimes_{\mathbb{Z}/n\mathbb{Z}}^L f^* G)$$

is an isomorphism.

(ii) Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{Sch}$ . Let  $n \in \mathbb{N}$ . Let  $F \in C_{\mathbb{Z}/n\mathbb{Z}}(X^{et})$  and  $G \in C_{\mathbb{Z}/n\mathbb{Z}}(S^{et})$  be  $n$ -torsion sheaves. Then the transformation map (see [10] section 2) in  $D_{\mathbb{Z}/n\mathbb{Z}}(S^{et})$

$$T(f, \otimes)(F, G) : Rf_! F \otimes_{\mathbb{Z}/n\mathbb{Z}}^L G \rightarrow Rf_!(F \otimes_{\mathbb{Z}/n\mathbb{Z}}^L f^* G)$$

is an isomorphism.

*Proof.* (i): Follows from theorem 4: see [22] for example.

(ii): Follows from (i) by taking a compactification  $\bar{f} : \bar{X} \rightarrow \bar{S}$  of  $f : X \rightarrow S$ .  $\square$

**Remark 1.** Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{Sch}$ . Let  $n \in \mathbb{N}$ . Let  $F \in C_{\mathbb{Z}/n\mathbb{Z}}(X^{et})$  and  $G \in C_{\mathbb{Z}/n\mathbb{Z}}(S^{et})$  be  $n$ -torsion sheaves. Then, if  $f$  is not proper,  $H^k(Rf_*F \otimes_{\mathbb{Z}/n\mathbb{Z}}^L G)$  is NOT isomorphic in  $\text{Shv}_{\mathbb{Z}/n\mathbb{Z}}(S^{et})$  to  $H^k Rf_*(F \otimes_{\mathbb{Z}/n\mathbb{Z}}^L G)$  in general.

Let  $f_1 : X_1 \rightarrow S$  and  $f_2 : X_2 \rightarrow S$  two morphisms with  $X_1, X_2, S \in \text{Sch}$ . Denote  $p_1 : X_1 \times_S X_2 \rightarrow X_1$  and  $p_2 : X_1 \times_S X_2 \rightarrow X_2$  the base change maps. We have then

$$f_1 \otimes f_2 = f_1 \circ p_1 = f_2 \circ p_2 : X_1 \times_S X_2 \rightarrow S.$$

Let  $F_1 \in C_{\mathbb{Z}/n\mathbb{Z}}(X_1^{et})$  and  $F_2 \in C_{\mathbb{Z}/n\mathbb{Z}}(X_2^{et})$  be  $n$ -torsion sheaves. Then the canonical map in  $C_{\mathbb{Z}/n\mathbb{Z}}(S^{et})$  (see [10] section 2)

$$\begin{aligned} T(f_1, f_2, \otimes)(F_1, F_2) : Rf_{1*}F_1 \otimes_{\mathbb{Z}/n\mathbb{Z}}^L Rf_{2*}F_2 &\xrightarrow{\text{ad}(p_1^*, Rp_{1*})(F_1) \otimes \text{ad}(p_2^*, Rp_{2*})(F_2)} \\ Rf_{1*}Rp_{1*}p_1^*F_1 \otimes_{\mathbb{Z}/n\mathbb{Z}}^L Rf_{2*}Rp_{2*}p_2^*F_2 &\xrightarrow{=} R(f_1 \otimes f_2)_*p_1^*F_1 \otimes_{\mathbb{Z}/n\mathbb{Z}}^L R(f_1 \otimes f_2)_*p_2^*F_2 \\ &\xrightarrow{T(\otimes, E)(-, -)} R(f_1 \times f_2)_*(p_1^*F_1 \otimes_{\mathbb{Z}/n\mathbb{Z}}^L p_2^*F_2). \end{aligned}$$

**Theorem 6.** (i) Let  $f_1 : X_1 \rightarrow S$  and  $f_2 : X_2 \rightarrow S$  two proper morphisms with  $X_1, X_2, S \in \text{Sch}$ . Denote  $p_1 : X_1 \times_S X_2 \rightarrow X_1$  and  $p_2 : X_1 \times_S X_2 \rightarrow X_2$  the base change maps. Let  $F_1 \in C_{\mathbb{Z}/n\mathbb{Z}}(X_1^{et})$  and  $F_2 \in C_{\mathbb{Z}/n\mathbb{Z}}(X_2^{et})$  be  $n$ -torsion sheaves. Then the canonical map in  $C_{\mathbb{Z}/n\mathbb{Z}}(S^{et})$  given above

$$T(f_1, f_2, \otimes)(F_1, F_2) : Rf_{1*}F_1 \otimes_{\mathbb{Z}/n\mathbb{Z}}^L Rf_{2*}F_2 \rightarrow R(f_1 \times f_2)_*(p_1^*F_1 \otimes_{\mathbb{Z}/n\mathbb{Z}}^L p_2^*F_2)$$

is an isomorphism.

(ii) Let  $f_1 : X_1 \rightarrow S$  and  $f_2 : X_2 \rightarrow S$  two morphisms with  $X_1, X_2, S \in \text{Sch}$ . Denote  $p_1 : X_1 \times_S X_2 \rightarrow X_1$  and  $p_2 : X_1 \times_S X_2 \rightarrow X_2$  the base change maps. Let  $F_1 \in C_{\mathbb{Z}/n\mathbb{Z}}(X_1^{et})$  and  $F_2 \in C_{\mathbb{Z}/n\mathbb{Z}}(X_2^{et})$  be  $n$ -torsion sheaves. Then the canonical map in  $C_{\mathbb{Z}/n\mathbb{Z}}(S^{et})$  given after taking compactification of  $f_1$  and  $f_2$  by the one of (i) for the compactifications and on the other hand by the open embedding case

$$T(f_1, f_2, \otimes)(F_1, F_2) : Rf_{1!}F_1 \otimes_{\mathbb{Z}/n\mathbb{Z}}^L Rf_{2!}F_2 \rightarrow R(f_1 \times f_2)_!(p_1^*F_1 \otimes_{\mathbb{Z}/n\mathbb{Z}}^L p_2^*F_2)$$

is an isomorphism.

*Proof.* (i): Follows from theorem 4: see [22] for example.

(ii): Follows from (i) by taking a compactification  $\bar{f}_1 : \bar{X}_1 \rightarrow \bar{S}$  of  $f_1 : X_1 \rightarrow S$  and a compactification  $\bar{f}_2 : \bar{X}_2 \rightarrow \bar{S}$  of  $f_2 : X_2 \rightarrow S$ .  $\square$

**Remark 2.** Let  $f_1 : X_1 \rightarrow S$  and  $f_2 : X_2 \rightarrow S$  two morphisms with  $S, X_1, X_2 \in \text{Sch}$ . Let  $n \in \mathbb{N}$ . Denote  $p_1 : X_1 \times_S X_2 \rightarrow X_1$  and  $p_2 : X_1 \times_S X_2 \rightarrow X_2$  the base change maps. Let  $F_1 \in C_{\mathbb{Z}/n\mathbb{Z}}(X_1^{et})$  and  $F_2 \in C_{\mathbb{Z}/n\mathbb{Z}}(X_2^{et})$  be  $n$ -torsion sheaves. Then, if  $f_1$  or  $f_2$  is not proper,  $H^k(Rf_{1*}F_1 \otimes_{\mathbb{Z}/n\mathbb{Z}}^L Rf_{2*}F_2)$  is NOT isomorphic in  $\text{Shv}_{\mathbb{Z}/n\mathbb{Z}}(S^{et})$  to  $H^k R(f_1 \times f_2)_*(p_1^*F_1 \otimes_{\mathbb{Z}/n\mathbb{Z}}^L p_2^*F_2)$  in general.

We now recall the comparison theorems :

**Theorem 7.** Let  $f : X \rightarrow S$  a morphism with  $X, S \in \text{Var}(\mathbb{C})$ . Let  $F \in C(X^{et})$  be a torsion sheaf where we recall that  $X^{et} \subset \text{Sch}^{ft}/X = \text{Var}(\mathbb{C})/X$  is the small etale site. Then the transformation map (see [10] section 2) in  $D(S^{an})$

$$T(f, an)(F) : \text{an}_S^* Rf_* F \rightarrow Rf_* \text{an}_X^* F$$

is an isomorphism.

*Proof.* Standard, see [22] for example : follows from theorem 4 (i) and the open embedding case.  $\square$

**Theorem 8.** *Let  $K \subset \mathbb{C}_p$  be a  $p$ -adic field. Let  $f : X \rightarrow S$  a morphism with  $X, S \in \text{Var}(K)$ . Let  $F \in C_{\mathbb{Z}/n\mathbb{Z}}(X^{et})$  be an  $n$ -torsion sheaf where we recall that  $X^{et} \subset \text{Sch}^{ft}/X = \text{Var}(\mathbb{C})/X$  is the small étale site. Then the transformation map (see [10] section 2) in  $D(S^{an,et})$*

$$T(f, an)(F) : \text{an}_S^* Rf_* F \rightarrow Rf_* \text{an}_X^* F$$

is an isomorphism.

*Proof.* Standard, see [19] for example : follows from theorem 4 (i) and the open embedding case.  $\square$

## 2.4 Constructible and perverse sheaves on algebraic varieties over a subfield $k \subset \mathbb{C}$

Let  $S \in \text{AnSp}(\mathbb{C})$ . We have

- the classical dual functor

$$\mathbb{D}_S^0 : C(S) \rightarrow C(S), \quad K \mapsto \mathbb{D}_S^0 K := \mathcal{H}om(LK, E_{usu}(\mathbb{Z}_S))$$

which induces in the derived category

$$\mathbb{D}_S^0 : D(S) \rightarrow D(S), \quad K \mapsto \mathbb{D}_S^0 K := \mathcal{H}om(LK, E_{usu}(\mathbb{Z}_S)) = R\mathcal{H}om(K, \mathbb{Z}_S)$$

- the Verdier dual functor

$$\mathbb{D}_S^v : D(S) \rightarrow D(S), \quad K \mapsto \mathbb{D}_S^v K := R\mathcal{H}om(K, w_S)$$

where  $w_S := a_S^! \mathbb{Z}_S$  is the dualizing complex,  $a_S : S \rightarrow \{\text{pt}\}$  being the terminal map.

For  $S \in \text{AnSm}(\mathbb{C})$  smooth connected of dimension  $\dim(S) = d_S$  we have  $\mathbb{D}_S^v = \mathbb{D}_S^0[2d_S]$ .

We recall the definition of constructible sheaves on algebraic varieties over a subfield  $k \subset \mathbb{C}$ :

**Definition 1.** *Let  $k \subset \mathbb{C}$  a subfield. Let  $S \in \text{Var}(k)$ .*

(i) *A sheaf  $K \in \text{Shv}(S_{\mathbb{C}}^{an})$  is called constructible (with respect to a Zariski stratification over  $k$ ) if there exists a stratification  $S = \sqcup_{\alpha} S_{\alpha}$  with  $l_{\alpha} : S_{\alpha} \hookrightarrow S$  locally closed subsets such that  $l_{\alpha}^* K \in \text{Shv}(S_{\alpha, \mathbb{C}}^{an})$  are (finite dimensional) local systems (for the usual topology) for all  $\alpha$ . Note that we make the hypothesis that the strata  $S_{\alpha}$  are defined over  $k$ .*

(ii) *We denote by*

$$C_{c,k}(S_{\mathbb{C}}^{an}) \subset C(S_{\mathbb{C}}^{an}) \text{ and } D_{c,k}(S_{\mathbb{C}}^{an}) \subset D(S_{\mathbb{C}}^{an})$$

*the full subcategories consisting of  $K \in C(S_{\mathbb{C}}^{an})$  such that  $a_{usu} H^n K \in \text{Shv}(S_{\mathbb{C}}^{an})$  are constructible for all  $n \in \mathbb{Z}$  (see (i)).*

(ii)' *We denote by*

$$C_{fil,c,k}(S_{\mathbb{C}}^{an}) \subset C_{fil}(S_{\mathbb{C}}^{an}) \text{ and } D_{fil,c,k}(S_{\mathbb{C}}^{an}) \subset D_{fil}(S_{\mathbb{C}}^{an})$$

*the full subcategories consisting of  $(K, W) \in C_{fil}(S_{\mathbb{C}}^{an})$  such that  $a_{usu} H^n \text{Gr}_k^W K \in \text{Shv}(S_{\mathbb{C}}^{an})$  are constructible for all  $n, k \in \mathbb{Z}$  (see (i)).*

(iii) *We denote by*

$$P_k(S_{\mathbb{C}}^{an}) := P(S_{\mathbb{C}}^{an}) \cap D_{c,k}(S_{\mathbb{C}}^{an}) \subset D_{c,k}(S_{\mathbb{C}}^{an}) \otimes \mathbb{Q} \subset D_{c,k}(S_{\mathbb{C}}^{an})$$

*the full subcategory of perverse sheaves (which are by definition torsion free) whose cohomology sheaves are constructible with respect to a Zariski stratification (defined over  $k$ ), see (ii).*

(iii)' We denote by

$$P_{fil,k}(S_{\mathbb{C}}^{an}) := P_{fil}(S_{\mathbb{C}}^{an}) \cap D_{fil,c,k}(S_{\mathbb{C}}^{an}) \subset D_{fil,c,k}(S_{\mathbb{C}}^{an}) \otimes \mathbb{Q} \subset D_{fil,c,k}(S_{\mathbb{C}}^{an})$$

the full subcategory of filtered perverse sheaves (which are by definition torsion free) whose cohomology sheaves are constructible with respect to a Zariski stratification (defined over  $k$ ), see (ii)'.

**Theorem 9.** Let  $k \subset \mathbb{C}$  a subfield.

- Let  $S \in \text{Var}(k)$ . Then for  $K \in D_{c,k}(S_{\mathbb{C}}^{an})$ ,  $\mathbb{D}_S^v K \in D_{c,k}(S_{\mathbb{C}}^{an})$ . For  $K, K' \in D_{c,k}(S_{\mathbb{C}}^{an})$ ,  $K \otimes K' \in D_{c,k}(S_{\mathbb{C}}^{an})$ .
- Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{Var}(k)$ . Then for  $K \in D_{c,k}(X_{\mathbb{C}}^{an})$ ,  $Rf_* K \in D_{c,k}(S_{\mathbb{C}}^{an})$  and  $Rf_! K := \mathbb{D}_S^v Rf_* \mathbb{D}_X^v K \in D_{c,k}(S_{\mathbb{C}}^{an})$ .
- Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{Var}(k)$ . Then for  $K \in D_{c,k}(S_{\mathbb{C}}^{an})$ ,  $f^* K \in D_{c,k}(X_{\mathbb{C}}^{an})$  and  $f^! K := \mathbb{D}_X^v f^* \mathbb{D}_S^v K \in D_{c,k}(X_{\mathbb{C}}^{an})$ .

For  $S \in \text{Var}(k)$ , we have thus the full subcategory

$$\begin{aligned} D_{c,gm}(S_{\mathbb{C}}^{an}) : &= \langle Rf_* \mathbb{Z}_X, (f : X \rightarrow S) \in \text{Var}(k) \rangle \\ &= \langle Rf_* \mathbb{Z}_X, (f : X \rightarrow S) \in \text{Var}(k) \text{ proper, } X \text{ smooth} \rangle \subset D_{c,k}(S_{\mathbb{C}}^{an}) \end{aligned}$$

where  $\langle \rangle$  means the full triangulated category generated by.

*Proof.* Standard : follows from the fact that a morphism  $f : X \rightarrow S$  with  $X, S \in \text{Var}(k)$  admits a Whitney stratification whose strata  $X = \sqcup_{\alpha,\beta} X_{\alpha,\beta}$ ,  $S = \sqcup_{\alpha} S_{\alpha}$  are Zariski locally closed subset, that is locally closed subvarieties defined over  $k$ .  $\square$

Let  $k \subset \mathbb{C}$  a subfield.

Let  $S \in \text{Var}(k)$  and  $D = V(s) \subset S$  a Cartier divisor. Denote  $i : D \hookrightarrow S$  the closed embedding and  $j : S^o := S \setminus D \hookrightarrow S$  the open embedding. Let  $\pi : \tilde{S}_{\mathbb{C}}^{o,an} \rightarrow S_{\mathbb{C}}^{o,an}$  the universal covering. We then consider,

- for  $K \in C(S_{\mathbb{C}}^{o,an})$ , the nearby cycle functor

$$\psi_D K := i^* R(j \circ \pi)_* \pi^* K[-1] \in D(D_{\mathbb{C}}^{an}),$$

we write again  $\psi_D K := i_* \psi_D K \in D(S_{\mathbb{C}}^{an})$ ,

- for  $K \in C(S_{\mathbb{C}}^{o,an})$ , the maximal extension

$$x_{S^o/S}(K) := \text{Cone}(\text{ad}(i^*, i_*)(-) \circ \text{ad}(\pi^*, \pi_*)(j_* K) : Rj_* K \rightarrow i_* R(j \circ \pi)_* \pi^* K =: \psi_D K[1]) \in D(S_{\mathbb{C}}^{an}),$$

- for  $K \in C(S_{\mathbb{C}}^{o,an})$ , the vanishing cycle functor

$$\phi_D K := \text{Cone}(\text{ad}(j \circ \pi^*, j \circ \pi_*)(K) : i^* K \rightarrow \psi_D K) \in D(D_{\mathbb{C}}^{an})$$

together with the canonical map  $c(\phi_D K) : \psi_D K \rightarrow \phi_D K$  in  $D(D_{\mathbb{C}}^{o,an})$ , we write again  $\phi_D K := i_* \phi_D K \in D(S_{\mathbb{C}}^{an})$ ,

- for  $K \in C_c(S_{\mathbb{C}}^{o,an})$ , the canonical morphisms in  $D_c(D_{\mathbb{C}}^{an})$

$$\text{can}(K) := c(\phi_D K) : \psi_D K \rightarrow \phi_D K, \text{ var}(K) := \mathbb{D}_S^v c(\phi_D \mathbb{D}_S^v K) : \phi_D K \rightarrow \psi_D K.$$

For  $K \in C_{c,k}(S_{\mathbb{C}}^{o,an})$ , we have  $\psi_D K \in C_{c,k}(D_{\mathbb{C}}^{o,an})$  since it preserve local systems hence  $\phi_D K \in C_{c,k}(D_{\mathbb{C}}^{o,an})$  and  $x_{S^o/S} K \in C_{c,k}(S_{\mathbb{C}}^{o,an})$ .

Let  $S \in \text{Var}(k)$  and  $D = V(s) \subset S$  a Cartier divisor. Denote  $i : D \hookrightarrow S$  the closed embedding and  $j : S^o := S \setminus D \hookrightarrow S$  the open embedding. Let  $\pi : \tilde{S}_{\mathbb{C}}^{o,an} \rightarrow S_{\mathbb{C}}^{o,an}$  the universal covering.

- For  $K, K' \in C(S_{\mathbb{C}}^{o,an})$ , we have by definition  $\psi_D(K \otimes K') = \psi_D(K) \otimes \psi_D(K')$ ,
- For  $K, K' \in C_c(S_{\mathbb{C}}^{o,an})$  we have by (Verdier) duality  $\phi_D(K \otimes K') = \phi_D(K) \otimes \phi_D(K')$
- For  $K, K' \in C(S_{\mathbb{C}}^{o,an})$ , we have the tranformation map in  $D(S_{\mathbb{C}}^{o,an})$

$$T(\otimes, \psi_D)(K, K') : (\psi_D K) \otimes K' \xrightarrow{I \otimes (\text{ad}(i^*, i_*)(-) \circ \text{ad}(\pi^*, \pi_*)(-))} \psi_D K \otimes \psi_D K' = \psi_D(K \otimes K').$$

If  $K, K' \in D_c(S_{\mathbb{C}}^{o,an})$ , then  $T(\otimes, \psi_D)(K, K')$  is an isomorphism (projection formula),

- For  $K, K' \in C_c(S_{\mathbb{C}}^{o,an})$  the tranformation isomorphism in  $D_c(S_{\mathbb{C}}^{o,an})$

$$\begin{aligned} T(\otimes, \phi_D)(K, K') : \phi_D(K \otimes K') &= \mathbb{D}_S^v \psi_D(\mathbb{D}_S^v K \otimes \mathbb{D}_S^v K') \\ \xrightarrow{\mathbb{D}_S^v T(\otimes, \psi_D)(\mathbb{D}_S^v K, \mathbb{D}_S^v K')} \mathbb{D}_S^v(\psi_D \mathbb{D}_S^v(K) \otimes \mathbb{D}_S^v K') &= \phi_D K \otimes K' \end{aligned}$$

by (Verdier) duality.

In the filtered case, we will consider the weight monodromy filtration for open embeddings :

**Definition 2.** Let  $k \subset \mathbb{C}$  a subfield.

(i) Let  $S \in \text{Var}(k)$  and  $j : S^o \hookrightarrow S$  an open embedding such that  $D := S \setminus S^o = V(s) \subset S$  is a Cartier divisor. Let  $P_{fil,k}(S_{\mathbb{C}}^{o,an})^{ad,D} \subset P_{fil,k}(S_{\mathbb{C}}^{o,an})$  the full subcategory such that the relative weight monodromy filtration of  $W$  with respect to  $D \subset S$  exists.

- For  $(K, W) \in P_{fil,k}(S_{\mathbb{C}}^{o,an})^{ad,D}$ , we consider as in [25]

$$j_{*w}(K, W) := (Rj_*K, W) \in P_{fil,k}(S_{\mathbb{C}}^{an}), \quad W_k Rj_*K := \langle Rj_*W_k K, W(N)_k K \rangle \subset Rj_*K$$

so that  $j^* j_{*w}(K, W) = (K, W)$ , where  $W_k Rj_*K \subset Rj_*K$  is given by  $W$  and the weight monodromy filtration  $W(N)$  of the universal cover  $\pi : S_{\mathbb{C}}^{o,an} \rightarrow S_{\mathbb{C}}^{o,an}$ . Note that a stratification of  $W_k Rj_*K$  is given by the closure of a stratification of  $W_k K$  and  $D := S \setminus S^o$ .

- For  $(K, W) \in P_{fil,k}(S_{\mathbb{C}}^{o,an})^{ad,D}$ , we consider

$$j_{!w}(K, W) := \mathbb{D}_S^v j_{*w} \mathbb{D}_S^v(K, W) \in P_{fil,k}(S_{\mathbb{C}}^{an})$$

so that  $j^* j_{!w}(K, W) = (K, W)$ .

For  $(K', W) \in P_{fil,k}(S_{\mathbb{C}}^{an})^{ad,D}$ , there is, by construction,

- a canonical map  $\text{ad}(j^*, j_{*w})(K', W) = \text{ad}(j^*, j_*)(K') : (K', W) \rightarrow j_{*w} j^*(K', W)$  in  $P_{fil,k}(S_{\mathbb{C}}^{an})$ ,
- a canonical map  $\text{ad}(j_{!w}, j^*)(K', W) = \text{ad}(j_{!w}, j^*)(K') : j_{!w} j^*(K', W) \rightarrow (K', W)$  in  $P_{fil,k}(S_{\mathbb{C}}^{an})$ .

(ii) Let  $S \in \text{Var}(k)$ . Let  $j : S^o := S \setminus Z \hookrightarrow S$  an open embedding with  $Z = V(\mathcal{I}) \subset S$  an arbitrary closed subset,  $\mathcal{I} \subset \mathcal{O}_S$  being an ideal subsheaf. Taking generators  $\mathcal{I} = (s_1, \dots, s_r)$ , we get  $Z = V(s_1, \dots, s_r) = \bigcap_{i=1}^r Z_i \subset S$  with  $Z_i = V(s_i) \subset S$ ,  $s_i \in \Gamma(S, \mathcal{L}_i)$  and  $\mathcal{L}_i$  a line bundle. Note that  $Z$  is an arbitrary closed subset,  $d_Z \geq d_X - r$  needing not be a complete intersection. Denote by  $j_I : S^{o,I} := \bigcap_{i \in I} (S \setminus Z_i) = S \setminus (\bigcup_{i \in I} Z_i) \xrightarrow{j_I^o} S^o \xrightarrow{j} S$  the open complementary embeddings, where  $I \subset \{1, \dots, r\}$ . Denote

$$\mathcal{D}(Z/S) := \{(Z_i)_{i \in [1, \dots, r]}, Z_i \subset S, \bigcap Z_i = Z\}, Z'_i \subset Z_i$$

the flag category. Let  $P_{fil,k}(S_{\mathbb{C}}^{o,an})^{ad,(Z_i)} \subset P_{fil,k}(S_{\mathbb{C}}^{o,an})$  the full subcategory such that the relative weight monodromy filtration of  $W$  with respect to the  $Z_i \subset S$  exists. For  $(K, W) \in C(P_{fil,k}(S_{\mathbb{C}}^{o,an})^{ad,(Z_i)})$ , we define by (i)

– the (bi)-filtered complex of  $D_S$ -modules

$$j_{*w}(K, W) := \varinjlim_{\mathcal{D}(Z/S)} \text{Tot}_{\text{card}I=\bullet} (j_{I*w} j_I^{o*}(K, W)) \in C(P_{fil,k}(S_{\mathbb{C}}^{an}))$$

where the horizontal differential are given by, if  $I \subset J$ ,  $d_{IJ} := \text{ad}(j_{IJ}^*, j_{IJ*w})(j_I^{o*}(K, W))$ ,  $j_{IJ} : S^{oJ} \hookrightarrow S^{oI}$  being the open embedding, and  $d_{IJ} = 0$  if  $I \notin J$ ,

– the (bi)-filtered complex of  $D_S$ -modules

$$j_{!w}(K, W) := \varinjlim_{\mathcal{D}(Z/S)} \text{Tot}_{\text{card}I=-\bullet} (j_{I!w} j_I^{o*}(K, W)) = \mathbb{D}_S^v j_{*w} \mathbb{D}_S^v(K, W) \in C(P_{fil,k}(S_{\mathbb{C}}^{an})),$$

where the horizontal differential are given by, if  $I \subset J$ ,  $d_{IJ} := \text{ad}(j_{I!w}, j_{IJ}^*)(j_I^{o*}(K, W))$ ,  $j_{IJ} : S^{oJ} \hookrightarrow S^{oI}$  being the open embedding, and  $d_{IJ} = 0$  if  $I \notin J$ .

By definition, we have for  $(K, W) \in C(P_{fil,k}(S_{\mathbb{C}}^{o,an}))^{ad, (Z_i)}$ ,  $j^* j_{*w}(K, W) = (K, W)$  and  $j^* j_{!w}(K, W) = (K, W)$ . For  $(K', W) \in C(P_{fil,k}(S_{\mathbb{C}}^{an}))^{ad, (Z_i)}$ , there is, by (i),

- a canonical map  $\text{ad}(j^*, j_{*w})(K', W) : (K', W) \rightarrow j_{*w} j^*(K', W)$  in  $C(P_{fil,k}(S_{\mathbb{C}}^{an}))$ ,
- a canonical map  $\text{ad}(j_{!w}, j^*)(K', W) : j_{!w} j^*(K', W) \rightarrow (K', W)$  in  $C(P_{fil,k}(S_{\mathbb{C}}^{an}))$ .

**Definition 3.** Let  $S \in \text{Var}(k)$ . Let  $Z \subset S$  a closed subset. Denote by  $j : S \setminus Z \hookrightarrow S$  the complementary open embedding.

(i) We define using definition 2, the filtered Hodge support section functor

$$\begin{aligned} \Gamma_Z^w : C(P_{fil,k}(S_{\mathbb{C}}^{an})^{ad, (Z_i)}) &\rightarrow C(P_{fil,k}(S_{\mathbb{C}}^{an})), \\ (K, W) \mapsto \Gamma_Z^w(K, W) &:= \text{Cone}(\text{ad}(j^*, j_{*w})(K, W) : (K, W) \rightarrow j_{*w} j^*(K, W))[-1], \end{aligned}$$

together we the canonical map  $\gamma_Z^w(K, W) : \Gamma_Z^w(K, W) \rightarrow (K, W)$ .

(i)' Since  $j_{*w} : C(P_{fil,k}(S_{\mathbb{C}}^{o,an})^{ad, (Z_i)}) \rightarrow C(P_{fil,k}(S_{\mathbb{C}}^{an}))$  is an exact functor,  $\Gamma_Z^w$  induces the functor

$$\Gamma_Z^w : D_{fil,c,k}(S_{\mathbb{C}}^{an})^{ad, (Z_i)} \rightarrow D_{fil,c,k}(S_{\mathbb{C}}^{an}), (K, W) \mapsto \Gamma_Z^w(K, W)$$

(ii) We define using definition 2, the dual filtered Hodge support section functor

$$\begin{aligned} \Gamma_Z^{\vee,w} : C(P_{fil,k}(S_{\mathbb{C}}^{an})^{ad, (Z_i)}) &\rightarrow C(P_{fil,k}(S_{\mathbb{C}}^{an})), \\ (K, W) \mapsto \Gamma_Z^{\vee,w}(K, W) &:= \text{Cone}(\text{ad}(j_{!w}, j^*)(K, W) : j_{!w} j^*(K, W) \rightarrow (K, W)), \end{aligned}$$

together we the canonical map  $\gamma_Z^{\vee,Hdg}(K, W) : (K, W) \rightarrow \Gamma_Z^{\vee,w}(K, W)$ .

(ii)' Since  $j_{!w} : C(P_{fil,k}(S_{\mathbb{C}}^{o,an})^{ad, (Z_i)}) \rightarrow C(P_{fil,k}(S_{\mathbb{C}}^{an}))$  is an exact functor,  $\Gamma_Z^{\vee,w}$  induces the functor

$$\Gamma_Z^{\vee,w} : D_{fil,c,k}(S_{\mathbb{C}}^{an})^{ad, (Z_i)} \rightarrow D_{fil,c,k}(S_{\mathbb{C}}^{an}), (K, W) \mapsto \Gamma_Z^{\vee,w}(K, W)$$

Let  $S \in \text{Var}(k)$  and  $D = V(s) \subset S$  a Cartier divisor. Denote  $i : D \hookrightarrow S$  the closed embedding and  $j : S^o := S \setminus D \hookrightarrow S$  the open embedding. Let  $\pi : \tilde{S}_{\mathbb{C}}^{o,an} \rightarrow S_{\mathbb{C}}^{o,an}$  the universal covering. We then consider, for  $(K, W) \in D_{fil,c}(S_{\mathbb{C}}^{o,an})^{ad, D} = \text{Ho}(C(P_{fil,k}(S_{\mathbb{C}}^{o,an})^{ad, D}))$ ,

- the filtered nearby cycle functor

$$\psi_D(K, W) := (\psi_D K, W) \in D_{fil,c}(D_{\mathbb{C}}^{an}), W_k(\psi_D(K, W)) := \langle W_k \psi_D K, W(N)_k \psi_D K \rangle \subset \psi_D K,$$

- the maximal extension

$$x_{S^o/S}(K) := \text{Cone}(\text{ad}(i^*, i_*)(-) \circ \text{ad}(\pi^*, \pi_*)(j_* K) : j_{*w}(K, W) \rightarrow \psi_D(K, W)[1]) \in D_{fil,c,k}(S_{\mathbb{C}}^{an}),$$

- the vanishing cycle functor

$$\phi_D(K, W) := \text{Cone}(\text{ad}(j \circ \pi^*, j \circ \pi_*)(K) : i^*(K, W) \rightarrow \psi_D(K, W)) \in D_{fil,c,k}(D_{\mathbb{C}}^{an}),$$

- the canonical morphisms in  $D_{fil,c,k}(D_{\mathbb{C}}^{an})$

$$\begin{aligned} can(K, W) &:= c(\phi_D(K, W)) : \psi_D(K, W) \rightarrow \phi_D(K, W), \\ var(K, W) &:= \mathbb{D}_S^v c(\phi_D \mathbb{D}_S^v D(K, W)) : \phi_D(K, W) \rightarrow \psi_D(K, W). \end{aligned}$$

**Definition 4.** Let  $k \subset \mathbb{C}$  a subfield.

(i) Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{Var}(k)$ . Consider the graph factorization  $f : X \xrightarrow{l} X \times S \xrightarrow{p} S$  of  $f$  where  $l$  the the graph closed embedding and  $p$  is the projection. We have, using definition 3,

- the inverse image functor

$$f^{*w} : D_{fil,c,k}(S_{\mathbb{C}}^{an})^{ad,(\Gamma_{f,i})} \rightarrow D_{fil,c,k}(X_{\mathbb{C}}^{an}), (K, W) \mapsto f^{*w}(K, W) := l^* \Gamma_X^{\vee,w} p^*(K, W)$$

- the exceptional inverse image functor

$$f^{*w} : D_{fil,c,k}(S_{\mathbb{C}}^{an})^{ad,(\Gamma_{f,i})} \rightarrow D_{fil,c,k}(X_{\mathbb{C}}^{an}), (K, W) \mapsto f^{!w}(K, W) := l^* \Gamma_X^w p^*(K, W).$$

(ii) Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{Var}(k)$ . Consider a compactification  $f : X \hookrightarrow j\bar{X} \xrightarrow{\bar{f}} S$  of  $f$  with  $\bar{X} \in \text{Var}(k)$ ,  $j$  an open embedding and  $\bar{f}$  a proper morphism. Denote  $Z = \bar{X} \setminus X$ . We have, using definition 2,

- the direct image functor

$$Rf_{*w} : D_{fil,c,k}(X_{\mathbb{C}}^{an})^{ad,(Z_i)} \rightarrow D_{fil,c,k}(S_{\mathbb{C}}^{an}), (K, W) \mapsto Rf_{*w}(K, W) := R\bar{f}_* j_{*w}(K, W)$$

- the proper direct image functor

$$Rf_{!w} : D_{fil,c,k}(X_{\mathbb{C}}^{an})^{ad,(Z_i)} \rightarrow D_{fil,c,k}(S_{\mathbb{C}}^{an}), (K, W) \mapsto Rf_{!w}(K, W) := R\bar{f}_* j_{!w}(K, W).$$

We will use a version of a result of Beilison on perverse sheaves.

**Definition 5.** Let  $k \subset \mathbb{C}$  a subfield. Let  $S \in \text{Var}(k)$  and  $D = V(s) \subset S$  a Cartier divisor. Denote  $S^\circ := S \setminus D$ . We denote by  $P_k(S_{\mathbb{C}}^{o,an}) \times_J P_k(D_{\mathbb{C}}^{an})$  the category

- whose objects are  $(K', K'', u, v)$  where  $K' \in P_k(S_{\mathbb{C}}^{o,an})$  and  $K'' \in P_k(D_{\mathbb{C}}^{an})$  are perverse sheaves and  $u : \psi_D K'^{an} \rightarrow K''^{an}$  and  $v : K''^{an} \rightarrow \psi_D K'^{an}$  are morphism in  $D_c(D_{\mathbb{C}}^{an})$  such that  $v \circ u = T - I$ ,
- whose morphisms are  $m = (m', m'') : (K'_1, K''_1, u_1, v_1) \rightarrow (K'_2, K''_2, u_2, v_2)$  such that  $u_2 \circ \psi_D m' = m'' \circ u_1$  and  $\psi_D m' \circ v_1 = v_2 \circ m''$ .

We give the following version of the well known theorem for perserse sheaves

**Theorem 10.** Let  $k \subset \mathbb{C}$  a subfield. Let  $S \in \text{Var}(k)$  and  $D = V(s) \subset S$  a Cartier divisor. Denote  $i : D \hookrightarrow S$  the closed embedding and  $j : S^\circ := S \setminus D \hookrightarrow S$  the open embedding. Then the functor

$$(j^*, \phi_D, can, var) : P_k(S_{\mathbb{C}}^{an}) \rightarrow P_k(S_{\mathbb{C}}^{o,an}) \times_J P_k(D_{\mathbb{C}}^{an})$$

is an equivalence of category whose inverse is

$$\begin{aligned} &P_k(S_{\mathbb{C}}^{o,an}) \times_J P_k(D_{\mathbb{C}}^{an}) \rightarrow P_k(S_{\mathbb{C}}^{an}), \\ (K', K'', u, v) &\mapsto H^1(\psi_D K' \xrightarrow{(c(x_{S^\circ/S}(K')), u)} x_{S^\circ/S}(K') \oplus i_* K'' \xrightarrow{(\mathbb{D}_S^v c(x_{S^\circ/S}(\mathbb{D}_S^v K')), v)} \psi_D K'). \end{aligned}$$

We denote, for  $K \in P_k(S_{\mathbb{C}}^{an})$  by

$$Is(K) := (0, (\text{ad}(j^*, j_*)(K), \text{ad}(j \circ \pi^*, j \circ \pi_*)(K)), 0) : \\ K \xrightarrow{\sim} (\psi_D K \xrightarrow{(c(x_{S^o/S}(K)), \text{can}(K))} x_{S^o/S}(K) \oplus i_* \phi_D K \xrightarrow{(\mathbb{D}_S^v c(x_{S^o/S}(\mathbb{D}_S^v K)), \text{var}(K))} \psi_D K)$$

the canonical isomorphism in  $D_{c,k}(S_{\mathbb{C}}^{an})$ .

*Proof.* Similar to the proof of [5] : follows from the fact that  $P_k(S_{\mathbb{C}}^{an})$  form an abelian category stable by the nearby and vanishing cycle functors.  $\square$

Let  $S \in \text{Var}(k)$  and  $D = V(s) \subset S$  a Cartier divisor. Denote  $i : D \hookrightarrow S$  the closed embedding and  $j : S^o := S \setminus D \hookrightarrow S$  the open embedding. In the filtered case, we get, for  $(K, W) \in P_{fil,k}(S_{\mathbb{C}}^{an})$  the map in  $D_{fil,c,k}(S_{\mathbb{C}}^{an})$

$$Is(K, W) := (0, (\text{ad}(j^*, j_*)(K), \text{ad}(j \circ \pi^*, j \circ \pi_*)(K)), 0) : \\ (K, W) \rightarrow (\psi_D(K, W) \xrightarrow{(c(x_{S^o/S}(K, W)), \text{can}(K, W))} x_{S^o/S}(K, W) \oplus i_* \phi_D(K, W) \\ \xrightarrow{(\mathbb{D}_S^v c(x_{S^o/S}(\mathbb{D}_S^v(K, W))), \text{var}(K, W))} \psi_D(K, W))$$

which is NOT an isomorphism in general (it leads to different  $W$ -filtration on perverse cohomology).

## 2.5 Constructible and perverse etale sheaves on algebraic varieties over a field $k$ of characteristic 0

Let  $k$  a field of characteristic zero. Let  $S \in \text{Var}(k)$ . We have

- the classical dual functor

$$\mathbb{D}_S^0 : C(S^{et}) \rightarrow C(S^{et}), \quad K \mapsto \mathbb{D}_S^0 K := \mathcal{H}om(LK, E_{et}(\mathbb{Z}_S))$$

which induces in the derived category

$$\mathbb{D}_S^0 : D(S^{et}) \rightarrow D(S^{et}), \quad K \mapsto \mathbb{D}_S^0 K := \mathcal{H}om(LK, E_{et}(\mathbb{Z}_S)) = R\mathcal{H}om(K, \mathbb{Z}_S)$$

- the Verdier dual functor

$$\mathbb{D}_S^v : D(S^{et}) \rightarrow D(S^{et}), \quad K \mapsto \mathbb{D}_S^v K := R\mathcal{H}om(K, w_S)$$

where  $w_S := a_S^! \mathbb{Z}_S$  is the dualizing complex,  $a_S : S \rightarrow \{\text{pt}\}$  being the terminal map.

For  $S \in \text{SmVar}(k)$  smooth connected of dimension  $\dim(S) = d_S$  we have  $\mathbb{D}_S^v = \mathbb{D}_S^0[2d_S]$ .

We recall the definition of constructible etale sheaves on algebraic varieties over a field  $k$  of characteristic zero:

**Definition 6.** Let  $k$  a field of characteristic zero. Let  $S \in \text{Var}(k)$ . Let  $l$  a prime number. Recall (see section 2.1) that  $K = (K_n)_{n \in \mathbb{N}} \in \text{Shv}_{\mathbb{Z}_l}(S^{et})$  is a projective system with  $K_n \in \text{Shv}_{\mathbb{Z}/l^n \mathbb{Z}}(S^{et})$  such that  $K_n \rightarrow K_{n+1}/l^n K_{n+1}$  is an isomorphism.

(i) A sheaf  $K \in \text{Shv}_{\mathbb{Z}_l}(S^{et})$  is called constructible if there exists a stratification  $S = \sqcup_{\alpha} S_{\alpha}$  with  $l_{\alpha} : S_{\alpha} \hookrightarrow S$  locally closed subsets such that  $l_{\alpha}^* K \in \text{Shv}(S_{\alpha}^{et})$  are (finite dimensional) local systems (for the etale topology) for all  $\alpha$ .

(ii) We denote by

$$C_{\mathbb{Z}_l, c, k}(S^{et}) \subset C_{\mathbb{Z}_l}(S^{et}) \text{ and } D_{\mathbb{Z}_l, c, k}(S^{et}) \subset D_{\mathbb{Z}_l}(S^{et})$$

the full subcategories consisting of  $K \in C_{\mathbb{Z}_l, c}(S^{et})$  such that  $a_{et} H^n K \in \text{Shv}_{\mathbb{Z}_l}(S^{et})$  are constructible for all  $n \in \mathbb{Z}$  (see (i)).



(ii)' We denote by

$$C_{\mathbb{Z}_l, \text{fil}, c, k}(S^{et}) \subset C_{\mathbb{Z}_l, \text{fil}}(S^{et}) \text{ and } D_{\mathbb{Z}_l, \text{fil}, c, k}(S^{et}) \subset D_{\mathbb{Z}_l, \text{fil}}(S^{et})$$

the full subcategories consisting of  $(K, W) \in C_{\mathbb{Z}_l, \text{fil}}(S^{et})$  such that  $a_{et} \text{Gr}_k^W H^n K \in \text{Shv}_{\mathbb{Z}_l}(S^{et})$  are constructible for all  $n, k \in \mathbb{Z}$  (see (i)).

(iii) We denote by

$$P_{\mathbb{Z}_l, k}(S^{et}) \subset D_{\mathbb{Z}_l, c, k}(S^{et}) \otimes_{\mathbb{Z}_l} \mathbb{Q}_l \subset D_{\mathbb{Z}_l, c, k}(S^{et})$$

the full subcategory of perverse sheaves (which are by definition torsion free).

(iii)' We denote by

$$P_{\mathbb{Z}_l, \text{fil}, k}(S^{et}) \subset D_{\mathbb{Z}_l, \text{fil}, c, k}(S^{et}) \otimes_{\mathbb{Z}_l} \mathbb{Q}_l \subset D_{\mathbb{Z}_l, \text{fil}, c, k}(S^{et})$$

the full subcategory of filtered perverse sheaves (which are by definition torsion free).

Let  $k/k'$  a field extention. Let  $S \in \text{Var}(k)$ . Let  $l$  a prime number.

(i) A sheaf  $K \in \text{Shv}_{\mathbb{Z}_l}(S_{k'}^{et})$  is called constructible (over  $k$ ) if there exists a stratification  $S = \sqcup_{\alpha} S_{\alpha}$  with  $l_{\alpha} : S_{\alpha} \hookrightarrow S$  locally closed subsets such that  $l_{\alpha}^* K \in \text{Shv}(S_{\alpha}^{et})$  are (finite dimensional) local systems (for the etale topology) for all  $\alpha$ .

(ii) We denote by

$$C_{\mathbb{Z}_l, c, k}(S_{k'}^{et}) \subset C_{\mathbb{Z}_l}(S_{k'}^{et}) \text{ and } D_{\mathbb{Z}_l, c, k}(S_{k'}^{et}) \subset D_{\mathbb{Z}_l}(S_{k'}^{et})$$

the full subcategories consisting of  $K \in C_{\mathbb{Z}_l}(S_{k'}^{et})$  such that  $a_{et} H^n K \in \text{Shv}_{\mathbb{Z}_l}(S_{k'}^{et})$  are constructible over  $k$  for all  $n \in \mathbb{Z}$  (see (i)).

(ii)' We denote by

$$C_{\mathbb{Z}_l, \text{fil}, c, k}(S_{k'}^{et}) \subset C_{\mathbb{Z}_l, \text{fil}}(S_{k'}^{et}) \text{ and } D_{\mathbb{Z}_l, \text{fil}, c, k}(S_{k'}^{et}) \subset D_{\mathbb{Z}_l, \text{fil}}(S_{k'}^{et})$$

the full subcategories consisting of  $(K, W) \in C_{\mathbb{Z}_l, \text{fil}}(S_{k'}^{et})$  such that  $a_{et} \text{Gr}_k^W H^n K \in \text{Shv}_{\mathbb{Z}_l}(S_{k'}^{et})$  are constructible over  $k$  for all  $n, k \in \mathbb{Z}$  (see (i)).

(iii) We denote by

$$P_{\mathbb{Z}_l, k}(S_{k'}^{et}) := P_{\mathbb{Z}_l, k'}(S_{k'}^{et}) \cap D_{\mathbb{Z}_l, c, k}(S_{k'}^{et}) \subset D_{\mathbb{Z}_l, c, k}(S_{k'}^{et})$$

the full subcategory of perverse sheaves whose stratification is defined over  $k$ .

(iii)' We denote by

$$P_{\mathbb{Z}_l, \text{fil}, k}(S_{k'}^{et}) := P_{\mathbb{Z}_l, \text{fil}, k'}(S_{k'}^{et}) \cap D_{\mathbb{Z}_l, \text{fil}, c, k}(S_{k'}^{et}) \subset D_{\mathbb{Z}_l, \text{fil}, c, k}(S_{k'}^{et})$$

the full subcategory of filtered perverse sheaves whose stratification is defined over  $k$ .

**Theorem 11.** Let  $k$  a field of characteristic zero. Let  $l$  a prime number.

- Let  $S \in \text{Var}(k)$ . Then for  $K \in D_{\mathbb{Z}_l, c, k}(S^{et})$ ,  $\mathbb{D}_S^v K \in D_{\mathbb{Z}_l, c, k}(S^{et})$ . For  $K, K' \in D_{\mathbb{Z}_l, c, k}(S^{et})$ ,  $K \otimes K' \in D_{\mathbb{Z}_l, c, k}(S^{et})$ .
- Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{Var}(k)$ . Then for  $K \in D_{\mathbb{Z}_l, c, k}(X^{et})$ ,  $Rf_* K \in D_{\mathbb{Z}_l, c, k}(S^{et})$  and  $Rf_! K := \mathbb{D}_S^v Rf_* \mathbb{D}_X^v K \in D_{\mathbb{Z}_l, c, k}(S^{et})$ .
- Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{Var}(k)$ . Then for  $K \in D_{\mathbb{Z}_l, c, k}(S^{et})$ ,  $f^* K \in D_{\mathbb{Z}_l, c, k}(X^{et})$  and  $f^! K := \mathbb{D}_X^v f^* \mathbb{D}_S^v K \in D_{\mathbb{Z}_l, c, k}(X^{et})$ .

We have then, for  $S \in \text{Var}(k)$ , the full subcategory

$$\begin{aligned} D_{\mathbb{Z}_l, c, \text{gm}}(S^{et}) : &= \langle Rf_* \mathbb{Z}_X, (f : X \rightarrow S) \in \text{Var}(k) \rangle \\ &= \langle Rf_* \mathbb{Z}_X, (f : X \rightarrow S) \in \text{Var}(k) \text{ proper, } X \text{ smooth} \rangle \subset D_{\mathbb{Z}_l, c, k}(S^{et}) \end{aligned}$$

where  $\langle \rangle$  means the full triangulated category generated by.

*Proof.* Standard : see [22] for example.  $\square$

We now give, following Ayoub, the definition of the nearby and vanishing cycle functors for constructible étale sheaves :

Let  $k$  a field of characteristic zero. Let  $l$  a prime number. Let  $S \in \text{Var}(k)$  and  $D = V(s) \subset S$  a Cartier divisor with  $s \in \Gamma(S, L)$ . Denote  $i : D \hookrightarrow S$  the closed embedding and  $j : S^\circ := S \setminus D \hookrightarrow S$  the open embedding. Let

$$\pi : \tilde{S}^\circ := \varinjlim_{n \in \mathbb{N}} \tilde{S}_n^\circ := \text{Spec}(L[t]/(t^n - s)) \rightarrow S^\circ$$

the universal covering given by taking the  $n$ -th roots of  $s$  and  $\mathcal{A}_{S^\circ} := (S^\circ \times_{S^\circ} \times_{S^\circ} S^\circ) \in \text{Fun}(\Delta^\bullet, \text{Var}(k)^{sm}/S^\circ)$  the diagram of lattices (see [4]). We then consider,

- for  $K \in C_{\mathbb{Z}_l}(S^{o,et})$ , the nearby cycle functor

$$\psi_D K := i^* R(j \circ \pi)_* \pi^* \mathcal{H}om(\mathcal{A}_{S^\circ}, K)[-1] \in D_{\mathbb{Z}_l}(D^{et}),$$

we write again  $\psi_D K := i_* \psi_D K \in D_{\mathbb{Z}_l, c}(S^{et})$ ,

- for  $K \in C_{\mathbb{Z}_l}(S^{o,et})$ , the maximal extension

$$\begin{aligned} x_{S^\circ/S}(K) &:= \text{Cone}(\text{ad}(i^*, i_*)(-) \circ \text{ad}(\pi^*, \pi_*)(-) \circ \text{ev}(K) : \\ Rj_* K &\rightarrow i_* R(j \circ \pi)_* \pi^* \mathcal{H}om(\mathcal{A}_{S^\circ}, K) =: \psi_D K[1]) \in D_{\mathbb{Z}_l}(S^{et}), \end{aligned}$$

- for  $K \in C_{\mathbb{Z}_l}(S^{o,et})$ , the vanishing cycle functor

$$\phi_D K := \text{Cone}(\text{ad}(j \circ \pi^*, j \circ \pi_*)(-) \circ \text{ev}(K) : i^* K \rightarrow \psi_D K) \in D_{\mathbb{Z}_l}(D^{et})$$

together with the canonical map  $c(\phi_D K) : \psi_D K \rightarrow \phi_D K$  in  $D_{\mathbb{Z}_l}(D^{et})$ , we write again  $\phi_D K := i_* \phi_D K \in D_{\mathbb{Z}_l}(S^{et})$ ,

- for  $K \in C_{\mathbb{Z}_l, c, k}(S^{o,et})$ , the canonical morphisms in  $D_{\mathbb{Z}_l, c, k}(D^{et})$

$$\text{can}(K) := c(\phi_D K) : \psi_D K \rightarrow \phi_D K, \quad \text{var}(K) := \mathbb{D}_S^v c(\phi_D \mathbb{D}_S^v K) : \phi_D K \rightarrow \psi_D K.$$

Let  $S \in \text{Var}(k)$  and  $D = V(s) \subset S$  a Cartier divisor with  $s \in \Gamma(S, L)$ . Denote  $i : D \hookrightarrow S$  the closed embedding and  $j : S^\circ := S \setminus D \hookrightarrow S$  the open embedding. Let

$$\pi : \tilde{S}^\circ := \varinjlim_{n \in \mathbb{N}} \tilde{S}_n^\circ := \text{Spec}(L[t]/(t^n - s)) \rightarrow S^\circ$$

the universal covering and  $\mathcal{A}_{S^\circ} := (S^\circ \times_{S^\circ} \times_{S^\circ} S^\circ) \in \text{Fun}(\Delta^\bullet, \text{Var}(k)^{sm}/S^\circ)$  the diagram of lattices (see [4]).

- For  $K, K' \in C_{\mathbb{Z}_l}(S^{o,et})$ , we have by definition  $\psi_D(K \otimes K') = \psi_D(K) \otimes \psi_D(K')$ ,
- For  $K, K' \in C_{\mathbb{Z}_l, c, k}(S^{o,et})$  we have by (Verdier) duality  $\phi_D(K \otimes K') = \phi_D(K) \otimes \phi_D(K')$
- For  $K, K' \in C_{\mathbb{Z}_l}(S^{o,et})$ , we have the transformation map in  $D_{\mathbb{Z}_l}(S^{o,et})$

$$T(\otimes, \psi_D)(K, K') : (\psi_D K) \otimes K' \xrightarrow{I \otimes (\text{ad}(i^*, i_*)(-) \circ \text{ad}(\pi^*, \pi_*)(-))} \psi_D K \otimes \psi_D K' = \psi_D(K \otimes K').$$

If  $K, K' \in D_{\mathbb{Z}_l, c, k}(S^{o,et})$ , then  $T(\otimes, \psi_D)(K, K')$  is an isomorphism (projection formula),

- For  $K, K' \in C_{\mathbb{Z}_l, c, k}(S^{o,et})$  the transformation isomorphism in  $D_{\mathbb{Z}_l, c, k}(S^{o,et})$

$$\begin{aligned} T(\otimes, \phi_D)(K, K') : \phi_D(K \otimes K') &= \mathbb{D}_S^v \psi_D(\mathbb{D}_S^v K \otimes \mathbb{D}_S^v K') \\ \xrightarrow{\mathbb{D}_S^v T(\otimes, \psi_D)(\mathbb{D}_S^v K, \mathbb{D}_S^v K')} \mathbb{D}_S^v(\psi_D \mathbb{D}_S^v(K) \otimes \mathbb{D}_S^v K') &= \phi_D K \otimes K' \end{aligned}$$

by (Verdier) duality.

We have then the following :

**Proposition 1.** *Let  $k$  a field of characteristic zero. Let  $S \in \text{Var}(k)$  and  $D \subset S$  a Cartier divisor. For  $K \in P_{\mathbb{Z}_l, k}(S^{et})$ , we have  $\psi_D K, \phi_D K \in P_{\mathbb{Z}_l, k}(S^{et})$ .*

*Proof.* Take an embedding  $k \hookrightarrow \mathbb{C}$  and consider the morphism of site

$$\text{an}_S : S_{\mathbb{C}}^{an} = S_{\mathbb{C}}^{an, et} \rightarrow S_{\mathbb{C}}^{et} \xrightarrow{\otimes_k \mathbb{C}} S^{et}$$

given by the analytical functor. By [1], we have a canonical isomorphism in  $D_{c, k}(S_{\mathbb{C}}^{an}) \otimes \mathbb{Q}$

$$T(\text{an}, \psi) : \text{an}_S^* \psi_D K \xrightarrow{\sim} \psi_D \text{an}_S^* K$$

where we recall (see section 2) that  $D_{c, k}(S_{\mathbb{C}}^{an}) \subset D(S_{\mathbb{C}}^{an})$  is the full subcategory consisting of classes of complexes of presheaves whose cohomology sheaves are constructible with respect to a Zariski stratification of  $S$  (in particular defined over  $k$ ). Since  $K = ((K_n)_{n \in \mathbb{N}}) \otimes_{\mathbb{Q}_p} \in P_{\mathbb{Z}_l, k}(S^{et})$ ,  $\text{an}_S^* K \in P_k(S_{\mathbb{C}}^{an})$ , where we recall (see section 2) that  $P_k(S_{\mathbb{C}}^{an}) \subset D_{c, k}(S_{\mathbb{C}}^{an}) \otimes \mathbb{Q}$  is the full subcategory consisting of presheaves sheaves whose cohomology sheaves are constructible with respect to a Zariski stratification of  $S$  (defined over  $k$ ). Thus by the complex case (see e.g. [23])  $\psi_D \text{an}_S^* K \in P_k(S_{\mathbb{C}}^{an})$ . Hence  $\text{an}_S^* \psi_D K \in P_k(S_{\mathbb{C}}^{an})$  and thus  $\psi_D K, \phi_D K \in P_{\mathbb{Z}_l}(S^{et})$ .  $\square$

In the filtered case, we will consider the weight monodromy filtration for open embeddings :

**Definition 7.** *Let  $k$  a field of characteristic zero. Let  $l$  a prime number.*

(i) *Let  $S \in \text{Var}(k)$  and  $j : S^o \hookrightarrow S$  an open embedding such that  $D := S \setminus S^o = V(s) \subset S$  is a Cartier divisor. Let  $P_{\mathbb{Z}_l, \text{fil}, k}(S^{o, et})^{ad, D} \subset P_{\text{fil}, k}(S^{o, et})$  the full subcategory such that the relative weight monodromy filtration of  $W$  with respect to  $D \subset S$  exists.*

– For  $(K, W) \in P_{\mathbb{Z}_l, \text{fil}, k}(S^{o, et})^{ad, D}$ , we consider as in [25]

$$j_{*w}(K, W) := (Rj_*K, W) \in P_{\mathbb{Z}_l, \text{fil}, k}(S^{et}), \quad W_k Rj_*K := \langle Rj_*W_k K, W(N)_k K \rangle \subset Rj_*K$$

so that  $j^* j_{*w}(K, W) = (K, W)$ , where  $W_k Rj_*K \subset Rj_*K$  is given by  $W$  and the weight monodromy filtration  $W(N)$  of the universal cover  $\pi : \tilde{S}^o \rightarrow S^o$ , see [4]. Note that a stratification of  $W_k Rj_*K$  is given by the closure of a stratification of  $W_k K$  and  $D := S \setminus S^o$ .

– For  $(K, W) \in P_{\mathbb{Z}_l, \text{fil}, k}(S^{o, et})^{ad, D}$ , we consider

$$j_{!w}(K, W) := \mathbb{D}_S^v j_{*w} \mathbb{D}_S^v(K, W) \in P_{\mathbb{Z}_l, \text{fil}}(S^{et})$$

so that  $j^* j_{!w}(K, W) = (K, W)$ .

For  $(K', W) \in P_{\mathbb{Z}_l, \text{fil}, k}(S^{et})^{ad, D}$ , there is, by construction,

– a canonical map  $\text{ad}(j^*, j_{*w})(K', W) = \text{ad}(j^*, j_*)(K') : (K', W) \rightarrow j_{*w} j^*(K', W)$  in  $P_{\mathbb{Z}_l, \text{fil}, k}(S^{et})$ ,

– a canonical map  $\text{ad}(j_{!w}, j^*)(K', W) = \text{ad}(j_!, j^*)(K') : j_{!w} j^*(K', W) \rightarrow (K', W)$  in  $P_{\mathbb{Z}_l, \text{fil}, k}(S^{et})$ .

(ii) *Let  $S \in \text{Var}(k)$ . Let  $j : S^o := S \setminus Z \hookrightarrow S$  an open embedding with  $Z = V(\mathcal{I}) \subset S$  an arbitrary closed subset,  $\mathcal{I} \subset \mathcal{O}_S$  being an ideal subsheaf. Taking generators  $\mathcal{I} = (s_1, \dots, s_r)$ , we get  $Z = V(s_1, \dots, s_r) = \bigcap_{i=1}^r Z_i \subset S$  with  $Z_i = V(s_i) \subset S$ ,  $s_i \in \Gamma(S, \mathcal{L}_i)$  and  $\mathcal{L}_i$  a line bundle. Note that  $Z$  is an arbitrary closed subset,  $d_Z \geq d_X - r$  needing not be a complete intersection. Denote by  $j_I : S^{o, I} := \bigcap_{i \in I} (S \setminus Z_i) = S \setminus (\bigcup_{i \in I} Z_i) \xrightarrow{j_I^o} S^o \xrightarrow{j} S$  the open complementary embeddings, where  $I \subset \{1, \dots, r\}$ . Denote*

$$\mathcal{D}(Z/S) := \{(Z_i)_{i \in [1, \dots, r]}, Z_i \subset S, \bigcap Z_i = Z\}, Z'_i \subset Z_i$$

the flag category. Let  $P_{\mathbb{Z}_l, \text{fil}, k}(S^{o, et})^{ad, (Z_i)} \subset P_{\mathbb{Z}_l, \text{fil}, k}(S^{o, et})$  the full subcategory such that the relative weight monodromy filtration of  $W$  with respect to the  $Z_i \subset S$  exists. For  $(K, W) \in C(P_{\mathbb{Z}_l, \text{fil}, k}(S^{o, et})^{ad, (Z_i)})$ , we define by (i)

– the (bi)-filtered complex of  $D_S$ -modules

$$j_{*w}(K, W) := \varinjlim_{\mathcal{D}(Z/S)} \text{Tot}_{\text{card}I=\bullet} (j_{I*w} j_I^{o*}(K, W)) \in C(P_{\mathbb{Z}_l, \text{fil}}(S^{et}))$$

where the horizontal differential are given by, if  $I \subset J$ ,  $d_{IJ} := \text{ad}(j_{IJ}^*, j_{IJ*w})(j_I^{o*}(K, W))$ ,  $j_{IJ} : S^{oJ} \hookrightarrow S^{oI}$  being the open embedding, and  $d_{IJ} = 0$  if  $I \notin J$ ,

– the (bi)-filtered complex of  $D_S$ -modules

$$j_{!w}(K, W) := \varinjlim_{\mathcal{D}(Z/S)} \text{Tot}_{\text{card}I=-\bullet} (j_{I!w} j_I^{o*}(K, W)) = \mathbb{D}_S^v j_{*w} \mathbb{D}_S^v(K, W) \in C(P_{\mathbb{Z}_l, \text{fil}}(S^{et})),$$

where the horizontal differential are given by, if  $I \subset J$ ,  $d_{IJ} := \text{ad}(j_{I!w}, j_{IJ}^*)(j_I^{o*}(K, W))$ ,  $j_{IJ} : S^{oJ} \hookrightarrow S^{oI}$  being the open embedding, and  $d_{IJ} = 0$  if  $I \notin J$ .

By definition, we have for  $(K, W) \in C(P_{\mathbb{Z}_l, \text{fil}, k}(S^{o, et})^{ad, (Z_i)})$ ,  $j^* j_{*w}(K, W) = (K, W)$  and  $j^* j_{!w}(K, W) = (K, W)$ . For  $(K', W) \in C(P_{\mathbb{Z}_l, \text{fil}}(S^{et})^{ad, (Z_i)})$ , there is, by (i),

- a canonical map  $\text{ad}(j^*, j_{*w})(K', W) : (K', W) \rightarrow j_{*w} j^*(K', W)$  in  $C(P_{\mathbb{Z}_l, \text{fil}, k}(S^{et}))$ ,
- a canonical map  $\text{ad}(j_{!w}, j^*)(K', W) : j_{!w} j^*(K', W) \rightarrow (K', W)$  in  $C(P_{\mathbb{Z}_l, \text{fil}, k}(S^{et}))$ .

(iii) Let  $S \in \text{Var}(k)$ . Let  $j : S^o := S \setminus Z \hookrightarrow S$  an open embedding with  $Z = V(\mathcal{I}) \subset S$  an arbitrary closed subset (over  $k$ ),  $\mathcal{I} \subset \mathcal{O}_S$  being an ideal subsheaf. Let  $k/k'$  a field extension. For  $(K, W) \in C(P_{\mathbb{Z}_l, \text{fil}, k}(S_{k'}^{o, et})^{ad, (Z_i)})$ , (ii) gives

– the (bi)-filtered complex of  $D_S$ -modules

$$j_{*w}(K, W) := \varinjlim_{\mathcal{D}(Z/S)} \text{Tot}_{\text{card}I=\bullet} (j_{I*w} j_I^{o*}(K, W)) \in C(P_{\mathbb{Z}_l, \text{fil}, k}(S_{k'}^{et}))$$

– the (bi)-filtered complex of  $D_S$ -modules

$$j_{!w}(K, W) := \varinjlim_{\mathcal{D}(Z/S)} \text{Tot}_{\text{card}I=-\bullet} (j_{I!w} j_I^{o*}(K, W)) = \mathbb{D}_S^v j_{*w} \mathbb{D}_S^v(K, W) \in C(P_{\mathbb{Z}_l, \text{fil}}(S_{k'}^{et})),$$

By definition, we have for  $(K, W) \in C(P_{\mathbb{Z}_l, \text{fil}, k}(S_{k'}^{o, et})^{ad, (Z_i)})$ ,  $j^* j_{*w}(K, W) = (K, W)$  and  $j^* j_{!w}(K, W) = (K, W)$ . For  $(K', W) \in C(P_{\mathbb{Z}_l, \text{fil}, k}(S_{k'}^{et})^{ad, (Z_i)})$ , we have, see (ii),

- the canonical map  $\text{ad}(j^*, j_{*w})(K', W) : (K', W) \rightarrow j_{*w} j^*(K', W)$  in  $C(P_{\mathbb{Z}_l, \text{fil}, k}(S_{k'}^{et}))$ ,
- the canonical map  $\text{ad}(j_{!w}, j^*)(K', W) : j_{!w} j^*(K', W) \rightarrow (K', W)$  in  $C(P_{\mathbb{Z}_l, \text{fil}, k}(S_{k'}^{et}))$ .

**Definition 8.** Let  $S \in \text{Var}(k)$ . Let  $Z \subset S$  a closed subset. Denote by  $j : S \setminus Z \hookrightarrow S$  the complementary open embedding. Let  $l$  a prime number.

(i) We define using definition 7, the filtered Hodge support section functor

$$\begin{aligned} \Gamma_Z^w &: C(P_{\mathbb{Z}_l, \text{fil}, k}(S^{et})^{ad, (Z_i)}) \rightarrow C(P_{\mathbb{Z}_l, \text{fil}, k}(S^{et})), \\ (K, W) &\mapsto \Gamma_Z^w(K, W) := \text{Cone}(\text{ad}(j^*, j_{*w})(K, W) : (K, W) \rightarrow j_{*w} j^*(K, W))[-1], \end{aligned}$$

together with the canonical map  $\gamma_Z^w(K, W) : \Gamma_Z^w(K, W) \rightarrow (K, W)$ . Since  $j_{*w} : C(P_{\mathbb{Z}_l, \text{fil}, k}(S^{o, et})^{ad, (Z_i)}) \rightarrow C(P_{\mathbb{Z}_l, \text{fil}, k}(S^{et}))$  is an exact functor,  $\Gamma_Z^w$  induces the functor

$$\Gamma_Z^w : D_{\mathbb{Z}_l, \text{fil}, c, k}(S^{et})^{ad, (Z_i)} \rightarrow D_{\mathbb{Z}_l, \text{fil}, c, k}(S^{et}), (K, W) \mapsto \Gamma_Z^w(K, W)$$

(ii) We define using definition 2, the dual filtered Hodge support section functor

$$\Gamma_Z^{\vee,w} : C(P_{\mathbb{Z}_l, \text{fil}}(S^{\text{et}})^{\text{ad}, (Z_i)}) \rightarrow C(P_{\mathbb{Z}_l, \text{fil}, k}(S^{\text{et}})),$$

$$(K, W) \mapsto \Gamma_Z^{\vee,w}(K, W) := \text{Cone}(\text{ad}(j_{!w}, j^*)(K, W) : j_{!w}, j^*(K, W) \rightarrow (K, W)),$$

together we the canonical map  $\gamma_Z^{\vee, \text{Hdg}}(K, W) : (K, W) \rightarrow \Gamma_Z^{\vee,w}(K, W)$ . Since  $j_{!w} : C(P_{\mathbb{Z}_l, \text{fil}, k}(S^{\text{o,et}})^{\text{ad}, (Z_i)}) \rightarrow C(P_{\mathbb{Z}_l, \text{fil}, k}(S^{\text{et}}))$  is an exact functor,  $\Gamma_Z^{\vee,w}$  induces the functor

$$\Gamma_Z^{\vee,w} : D_{\mathbb{Z}_l \text{fil}, c, k}(S^{\text{et}})^{\text{ad}, (Z_i)} \rightarrow D_{\mathbb{Z}_l \text{fil}, c, k}(S^{\text{et}}), (K, W) \mapsto \Gamma_Z^{\vee,w}(K, W)$$

Let  $k/k'$  a field extension. Let  $S \in \text{Var}(k)$ . Let  $Z \subset S$  a closed subset (over  $k$ ). Denote by  $j : S \setminus Z \hookrightarrow S$  the complementary open embedding. Let  $l$  a prime number.

(i)' Then (i) gives the filtered Hodge support section functor

$$\Gamma_Z^w : C(P_{\mathbb{Z}_l, \text{fil}, k}(S_{k'}^{\text{et}})^{\text{ad}, (Z_i)}) \rightarrow C(P_{\mathbb{Z}_l, \text{fil}, k}(S_{k'}^{\text{et}})),$$

$$(K, W) \mapsto \Gamma_Z^w(K, W) := \text{Cone}(\text{ad}(j^*, j_{*w})(K, W) : (K, W) \rightarrow j_{*w}j^*(K, W))[-1],$$

together we the canonical map  $\gamma_Z^w(K, W) : \Gamma_Z^w(K, W) \rightarrow (K, W)$ , which induces

$$\Gamma_Z^w : D_{\mathbb{Z}_l \text{fil}, c, k}(S_{k'}^{\text{et}})^{\text{ad}, (Z_i)} \rightarrow D_{\mathbb{Z}_l \text{fil}, c, k}(S_{k'}^{\text{et}}), (K, W) \mapsto \Gamma_Z^w(K, W)$$

(ii)' Then, (ii) gives the dual filtered Hodge support section functor

$$\Gamma_Z^{\vee,w} : C(P_{\mathbb{Z}_l, \text{fil}, k}(S_{k'}^{\text{et}})^{\text{ad}, (Z_i)}) \rightarrow C(P_{\mathbb{Z}_l, \text{fil}, k}(S_{k'}^{\text{et}})),$$

$$(K, W) \mapsto \Gamma_Z^{\vee,w}(K, W) := \text{Cone}(\text{ad}(j_{!w}, j^*)(K, W) : j_{!w}, j^*(K, W) \rightarrow (K, W)),$$

together we the canonical map  $\gamma_Z^{\vee, \text{Hdg}}(K, W) : (K, W) \rightarrow \Gamma_Z^{\vee,w}(K, W)$ , which induces

$$\Gamma_Z^{\vee,w} : D_{\mathbb{Z}_l \text{fil}, c, k}(S_{k'}^{\text{et}})^{\text{ad}, (Z_i)} \rightarrow D_{\mathbb{Z}_l \text{fil}, c, k}(S_{k'}^{\text{et}}), (K, W) \mapsto \Gamma_Z^{\vee,w}(K, W)$$

Let  $S \in \text{Var}(k)$  and  $D = V(s) \subset S$  a Cartier divisor. Denote  $i : D \hookrightarrow S$  the closed embedding and  $j : S^{\text{o}} := S \setminus D \hookrightarrow S$  the open embedding. Let  $\pi : \tilde{S}_{\mathbb{C}}^{\text{o,an}} \rightarrow S_{\mathbb{C}}^{\text{o,an}}$  the universal covering. Let  $l$  a prime number. We then consider, for  $(K, W) \in D_{\mathbb{Z}_l \text{fil}, c, k}(S^{\text{o,et}})^{\text{ad}, D} = \text{Ho}(C(P_{\mathbb{Z}_l \text{fil}, k}(S^{\text{o,et}})^{\text{ad}, D}))$ ,

- the filtered nearby cycle functor

$$\psi_D(K, W) := (\psi_D K, W) \in D_{\mathbb{Z}_l \text{fil}, c, k}(D^{\text{et}}), W_k(\psi_D(K, W)) := \langle W_k \psi_D K, W(N)_k \psi_D K \rangle_{\subset} \psi_D K,$$

- the maximal extension

$$x_{S^{\text{o}}/S}(K) := \text{Cone}(\text{ad}(i^*, i_*)(-) \circ \text{ad}(\pi^*, \pi_*)(-) \circ \text{ev}(K) : j_{*w}(K, W) \rightarrow \psi_D(K, W)[1]) \in D_{\mathbb{Z}_l \text{fil}, c, k}(S^{\text{et}}),$$

- the vanishing cycle functor

$$\phi_D(K, W) := \text{Cone}(\text{ad}(j \circ \pi^*, j \circ \pi_*)(K) : i^*(K, W) \rightarrow \psi_D(K, W)) \in D_{\mathbb{Z}_l \text{fil}, c}(D^{\text{et}}),$$

- the canonical morphisms in  $D_{\mathbb{Z}_l \text{fil}, c, k}(D^{\text{et}})$

$$\text{can}(K, W) := c(\phi_D(K, W)) : \psi_D(K, W) \rightarrow \phi_D(K, W),$$

$$\text{var}(K, W) := \mathbb{D}^v c(\phi_D \mathbb{D}^v D(K, W)) : \phi_D(K, W) \rightarrow \psi_D(K, W).$$

Let  $k/k'$  a field extension. For  $(K, W) \in D_{\mathbb{Z}_l \text{fil}, c, k}(S_{k'}^{\text{o,et}})^{\text{ad}, D} = \text{Ho}(C(P_{\mathbb{Z}_l \text{fil}, k}(S_{k'}^{\text{o,et}})^{\text{ad}, D}))$ , we get

- the filtered nearby cycle functor

$$\psi_D(K, W) := (\psi_D K, W) \in D_{\mathbb{Z}_l \text{fil}, c, k}(D_{k'}^{et}), \quad W_k(\psi_D(K, W)) := \langle W_k \psi_D K, W(N)_k \psi_D K \rangle \subset \psi_D K,$$

- the maximal extension

$$x_{S^\circ/S}(K) := \text{Cone}(\text{ad}(i^*, i_*)(-) \circ \text{ad}(\pi^*, \pi_*)(-) \circ \text{ev}(K) : j_{*w}(K, W) \rightarrow \psi_D(K, W)[1]) \in D_{\mathbb{Z}_l \text{fil}, c, k}(S_{k'}^{et}),$$

- the vanishing cycle functor

$$\phi_D(K, W) := \text{Cone}(\text{ad}(j \circ \pi^*, j \circ \pi_*)(-) \circ \text{ev}(K) : i^*(K, W) \rightarrow \psi_D(K, W)) \in D_{\mathbb{Z}_l \text{fil}, c, k}(D_{k'}^{et}),$$

- the canonical morphisms in  $D_{\mathbb{Z}_l \text{fil}, c, k}(D_{k'}^{et})$

$$\begin{aligned} \text{can}(K, W) &:= c(\phi_D(K, W)) : \psi_D(K, W) \rightarrow \phi_D(K, W), \\ \text{var}(K, W) &:= \mathbb{D}^v c(\phi_D \mathbb{D}^v D(K, W)) : \phi_D(K, W) \rightarrow \psi_D(K, W). \end{aligned}$$

**Definition 9.** Let  $k$  a field of characteristic zero. Let  $l$  a prime number.

(i) Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{Var}(k)$ . Consider the graph factorization  $f : X \xrightarrow{l} X \times S \xrightarrow{p} S$  of  $f$  where  $l$  the the graph closed embedding and  $p$  is the projection. We have, using definition 8,

– the inverse image functor

$$f^{*w} : D_{\mathbb{Z}_l \text{fil}, c, k}(S^{et})^{\text{ad}, (\Gamma_{f, i})} \rightarrow D_{\mathbb{Z}_l \text{fil}, c, k}(X^{et}), \quad (K, W) \mapsto f^{*w}(K, W) := l^* \Gamma_X^{\vee, w} p^*(K, W)$$

– the exceptional inverse image functor

$$f^{*w} : D_{\mathbb{Z}_l \text{fil}, c, k}(S^{et})^{\text{ad}, (\Gamma_{f, i})} \rightarrow D_{\mathbb{Z}_l \text{fil}, c, k}(X^{et}), \quad (K, W) \mapsto f^{!w}(K, W) := l^* \Gamma_X^w p^*(K, W).$$

(i)' Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{Var}(k)$ . Consider the graph factorization  $f : X \xrightarrow{l} X \times S \xrightarrow{p} S$  of  $f$  where  $l$  the the graph closed embedding and  $p$  is the projection. Let  $k/k'$  a field extension. We have, by (i),

– the inverse image functor

$$f^{*w} : D_{\mathbb{Z}_l \text{fil}, c, k}(S_{k'}^{et})^{\text{ad}, (\Gamma_{f, i})} \rightarrow D_{\mathbb{Z}_l \text{fil}, c, k}(X_{k'}^{et}), \quad (K, W) \mapsto f^{*w}(K, W) := l^* \Gamma_X^{\vee, w} p^*(K, W)$$

– the exceptional inverse image functor

$$f^{*w} : D_{\mathbb{Z}_l \text{fil}, c, k}(S_{k'}^{et})^{\text{ad}, (\Gamma_{f, i})} \rightarrow D_{\mathbb{Z}_l \text{fil}, c, k}(X_{k'}^{et}), \quad (K, W) \mapsto f^{!w}(K, W) := l^* \Gamma_X^w p^*(K, W).$$

(ii) Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{Var}(k)$ . Consider a compactification  $f : X \hookrightarrow j\bar{X} \xrightarrow{\bar{f}} S$  of  $f$  with  $\bar{X} \in \text{Var}(k)$ ,  $j$  an open embedding and  $\bar{f}$  a proper morphism. Denote  $Z := \bar{X} \setminus X$ . We have, using definition 2,

– the direct image functor

$$Rf_{*w} : D_{\mathbb{Z}_l \text{fil}, c, k}(X^{et})^{\text{ad}, (Z_i)} \rightarrow D_{\mathbb{Z}_l \text{fil}, c, k}(S^{et}), \quad (K, W) \mapsto Rf_{*w}(K, W) := R\bar{f}_* j_{*w}(K, W)$$

– the proper direct image functor

$$Rf_{!w} : D_{\mathbb{Z}_l \text{fil}, c, k}(X^{et})^{\text{ad}, (Z_i)} \rightarrow D_{\mathbb{Z}_l \text{fil}, c, k}(S^{et}), \quad (K, W) \mapsto Rf_{!w}(K, W) := R\bar{f}_* j_{!w}(K, W).$$

(ii)' Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{Var}(k)$ . Consider a compactification  $f : X \hookrightarrow j\bar{X} \xrightarrow{\bar{f}} S$  of  $f$  with  $\bar{X} \in \text{Var}(k)$ ,  $j$  an open embedding and  $\bar{f}$  a proper morphism. Let  $k/k'$  a field extension. We have, by (ii),

– the direct image functor

$$Rf_{*w} : D_{\mathbb{Z}_l \text{fil}, c, k}(X_{k'}^{et})^{ad, (Z_i)} \rightarrow D_{\mathbb{Z}_l \text{fil}, c, k}(S_{k'}^{et}), (K, W) \mapsto Rf_{*w}(K, W) := R\bar{f}_* j_{*w}(K, W)$$

– the proper direct image functor

$$Rf_{!w} : D_{\mathbb{Z}_l \text{fil}, c, k}(X_{k'}^{et})^{ad, (Z_i)} \rightarrow D_{\mathbb{Z}_l \text{fil}, c, k}(S_{k'}^{et}), (K, W) \mapsto Rf_{!w}(K, W) := R\bar{f}_* j_{!w}(K, W).$$

We will use the etale version of a result of Beilinson on perverse sheaves.

**Definition 10.** Let  $k$  a field of characteristic zero. Let  $S \in \text{Var}(k)$  and  $D = V(s) \subset S$  a Cartier divisor. Denote  $S^o := S \setminus D$ . We denote by  $P_{\mathbb{Z}_l}(S^{o, et}) \times_J P_{\mathbb{Z}_l}(D^{et})$  the category

- whose objects are  $(K', K'', u, v)$  where  $K' \in P_{\mathbb{Z}_l}(S^{o, et})$  and  $K'' \in P_{\mathbb{Z}_l}(D^{et})$  are perverse sheaves and  $u : \psi_D K'^{an} \rightarrow K''^{an}$  and  $v : K''^{an} \rightarrow \psi_D K'^{an}$  are morphism in  $D_c(D^{an, pet})$  such that  $v \circ u = T - I$ ,
- whose morphisms are  $m = (m', m'') : (K'_1, K''_1, u_1, v_1) \rightarrow (K'_2, K''_2, u_2, v_2)$  such that  $u_2 \circ \psi_D m' = m'' \circ u_1$  and  $\psi_D m' \circ v_1 = v_2 \circ m''$ .

We give the version for etale constructible sheaves of the well known theorem 10 for perverse sheaves

**Theorem 12.** Let  $k$  a field of characteristic zero. Let  $S \in \text{Var}(k)$  and  $D = V(s) \subset S$  a Cartier divisor. Denote  $i : D \hookrightarrow S$  the closed embedding and  $j : S^o := S \setminus D \hookrightarrow S$  the open embedding. Then the functor

$$(j^*, \phi_D, \text{can}, \text{var}) : P_{\mathbb{Z}_l, k}(S^{et}) \rightarrow P_{\mathbb{Z}_l, k}(S^{o, et}) \times_J P_{\mathbb{Z}_l, k}(D^{et})$$

is an equivalence of category whose inverse is

$$\begin{aligned} & P_{\mathbb{Z}_l, k}(S^{o, et}) \times_J P_{\mathbb{Z}_l, k}(D^{et}) \rightarrow P_{\mathbb{Z}_l, k}(S^{et}), \\ (K', K'', u, v) & \mapsto H^1(\psi_D K' \xrightarrow{c(x_{S^o/S}(K')), u} x_{S^o/S}(K') \oplus i_* K'' \xrightarrow{(\mathbb{D}c(x_{S^o/S}(\mathbb{D}K')), v)} \psi_D K'). \end{aligned}$$

We denote, for  $K \in P_{\mathbb{Z}_l}(S^{et})$  by

$$\begin{aligned} Is(K) & := (0, (\text{ad}(j^*, j_*)(K), \text{ad}((j \circ \pi)^*, (j \circ \pi)_*)(K)), 0) : \\ K & \xrightarrow{\sim} (\psi_D K \xrightarrow{(c(x_{S^o/S}(K)), \text{can}(K))} x_{S^o/S}(K') \oplus i_* \phi_D K \xrightarrow{(\mathbb{D}^v c(x(\mathbb{D}^v K')), \text{var}(K))} \psi_D K) \end{aligned}$$

the canonical isomorphism in  $D_{\mathbb{Z}_l, c, k}(S^{et})$ .

*Proof.* Similar to the proof of theorem 10. Follows from the fact that  $P_{\mathbb{Z}_l, k}(S^{et}) \subset D_{\mathbb{Z}_l, c, k}(S^{et})$  is a full subcategory which is stable by the functors  $\phi_D$  and  $\phi_D$  for  $D \subset S$  a Cartier divisor by proposition 1.  $\square$

Let  $S \in \text{Var}(k)$  and  $D = V(s) \subset S$  a Cartier divisor. Denote  $i : D \hookrightarrow S$  the closed embedding and  $j : S^o := S \setminus D \hookrightarrow S$  the open embedding. In the filtered case, we get, for  $(K, W) \in P_{\mathbb{Z}_l \text{fil}, k}(S^{et})$  the map in  $D_{\mathbb{Z}_l \text{fil}, c, k}(S^{et})$

$$\begin{aligned} Is(K, W) & := (0, (\text{ad}(j^*, j_*)(K), \text{ad}(j \circ \pi^*, j \circ \pi_*)(K)), 0) : \\ (K, W) & \rightarrow (\psi_D(K, W) \xrightarrow{(c(x_{S^o/S}(K, W)), \text{can}(K, W))} x_{S^o/S}(K, W) \oplus i_* \phi_D(K, W) \\ & \xrightarrow{(\mathbb{D}c(x_{S^o/S}(\mathbb{D}(K, W))), \text{var}(K, W))} \psi_D(K, W) \end{aligned}$$

which is NOT an isomorphism in general (it leads to different  $W$ -filtration on perverse cohomology).

We recall the definition of constructible pro etale sheaves on algebraic varieties over a subfield  $k \subset K$  of a  $p$  adic field:

**Definition 11.** Let  $k \subset K \subset \mathbb{C}_p$  a subfield of a  $p$  adic field. Let  $l$  a prime number. Let  $S \in \text{Var}(k)$ .

(i) A sheaf  $K \in \text{Shv}_{\mathbb{Z}_l}(S_K^{an,pet})$  is called constructible if there exists a stratification  $S = \sqcup_{\alpha} S_{\alpha}$  with  $l_{\alpha} : S_{\alpha} \hookrightarrow S$  locally closed subsets (defined over  $k$ ) such that  $l_{\alpha}^* K \in \text{Shv}(S_{\alpha}^{an,pet})$  are (finite dimensional) local systems (for the etale topology) for all  $\alpha$ .

(ii) We denote by

$$C_{\mathbb{Z}_l,c,k}(S^{an,pet}) \subset C_{\mathbb{Z}_l}(S^{an,pet}) \text{ and } D_{\mathbb{Z}_l,c,k}(S^{an,pet}) \subset D_{\mathbb{Z}_l}(S^{an,pet})$$

the full subcategories consisting of  $K \in C(S_K^{an,pet})$  such that  $a_{et} H^n K \in \text{Shv}(S_K^{an,pet})$  are constructible for all  $n \in \mathbb{Z}$ .

(ii)' We denote by

$$C_{\mathbb{Z}_l,fil,c,k}(S^{an,pet}) \subset C_{\mathbb{Z}_l,fil}(S^{an,pet}) \text{ and } D_{\mathbb{Z}_l,fil,c,k}(S^{an,pet}) \subset D_{\mathbb{Z}_l,fil}(S^{an,pet})$$

the full subcategories consisting of  $(K, W) \in C_{\mathbb{Z}_l,fil}(S_K^{an,pet})$  such that  $a_{et} H^n \text{Gr}_k^W K \in \text{Shv}_{\mathbb{Z}_l}(S_K^{an,pet})$  are constructible for all  $n, k \in \mathbb{Z}$ .

(iii) We denote by  $P_{\mathbb{Z}_l,k}(S^{an,pet}) \subset D_{\mathbb{Z}_l,c,k}(S^{an,pet})$  the full subcategory of perverse sheaves.

(iii)' We denote by  $P_{\mathbb{Z}_l,fil,k}(S^{an,pet}) \subset D_{\mathbb{Z}_l,fil,c,k}(S^{an,pet})$  the full subcategory of filtered perverse sheaves.

Let  $K \subset \mathbb{C}_p$  a  $p$  adic field. Let  $S \in \text{Var}(K)$  and  $D = V(s) \subset S$  a Cartier divisor. Denote  $i : D \hookrightarrow S$  the closed embedding and  $j : S^{\circ} := S \setminus D \hookrightarrow S$  the open embedding. Let  $\pi : \tilde{S}^{o,an} \rightarrow S^{o,an}$  the perfectoid universal covering (see [27]). We then consider,

- for  $K \in C_{\mathbb{Z}_l}(S^{o,an,pet})$ , the nearby cycle functor

$$\psi_D K := i^* R(j \circ \pi)_* \pi^* K[-1] \in D_{\mathbb{Z}_l}(D^{an,pet}),$$

we write again  $\psi_D K := i_* \psi_D K \in D_{\mathbb{Z}_l}(S^{an,pet})$ ,

- for  $K \in C_{\mathbb{Z}_l,c}(S^{o,an,pet})$ , the maximal extension

$$\begin{aligned} x_{S^{\circ}/S}(K) &:= \text{Cone}(\text{ad}(i^*, i_*)(-) \circ \text{ad}(\pi^*, \pi_*)(j_* K) : \\ Rj_* K &\rightarrow i_* R(j \circ \pi)_* \pi^* K =: \psi_D K[1]) \in D_{\mathbb{Z}_l}(S^{an,pet}), \end{aligned}$$

- for  $K \in C_{\mathbb{Z}_l}(S^{o,an,pet})$ , the vanishing cycle functor

$$\phi_D K := \text{Cone}(\text{ad}(j \circ \pi^*, j \circ \pi_*)(K) : i^* K \rightarrow \psi_D K) \in D_{\mathbb{Z}_l}(D^{an,pet})$$

together with the canonical map  $c(\phi_D K) : \psi_D K \rightarrow \phi_D K$  in  $D_{\mathbb{Z}_l}(S^{an,pet})$  we write again  $\phi_D K := i_* \phi_D K \in D_{\mathbb{Z}_l}(S^{an,pet})$ ,

- for  $K \in C_{\mathbb{Z}_l,c,k}(S^{o,an,pet})$ , the canonical morphisms in  $D_{\mathbb{Z}_l,c,k}(D^{an,pet})$

$$\text{can}(K) := c(\phi_D K) : \psi_D K \rightarrow \phi_D K, \text{ var}(K) := \mathbb{D}_S^v c(\phi_D D_S^v K) : \phi_D K \rightarrow \psi_D K$$

Let  $k \subset K \subset \mathbb{C}_p$  a subfield of a  $p$  adic field. Let  $S \in \text{Var}(k)$  and  $D = V(s) \subset S$  a Cartier divisor. Denote by  $S^{\circ} := S \setminus D$ . By definition, we have for  $K \in C_{\mathbb{Z}_l}(S^{o,et})$

$$\text{an}_S^*(\psi_D K) = \psi_D(\text{an}_S^* K) \in D_{\mathbb{Z}_l}(S_K^{an,pet}) \text{ and } \text{an}_S^*(\phi_D K) = \phi_D(\text{an}_S^* K) \in D_{\mathbb{Z}_l}(S_K^{an,pet}).$$

where  $\text{an}_S : S_K^{an,pet} \xrightarrow{\text{ans}} S_K^{et} \xrightarrow{\otimes_k K} S^{et}$  is the morphism of site induced by the analytical functor.

We then deduce from the algebraic case the following :



**Corollary 1.** *Let  $k \subset K \subset \mathbb{C}_p$  a subfield of a  $p$  adic field. Let  $S \in \text{Var}(k)$  and  $D = V(s) \subset S$  a Cartier divisor. Denote  $i : D \hookrightarrow S$  the closed embedding and  $j : S^\circ := S \setminus D \hookrightarrow S$  the open embedding.*

(i) *For  $K \in P_{\mathbb{Z}_l, k}(S^{et})$ , we have  $\psi_D \text{an}_S^* K, \phi_D \text{an}_S^* K \in P_{\mathbb{Z}_l, k}(S_K^{an, pet})$*

(ii) *We have, for  $K \in P_{\mathbb{Z}_l, k}(S^{et})$ , denoting again  $K = \text{an}_S^* K \in P_{\mathbb{Z}_l, k}(S_K^{an, pet})$ ,*

$$I_S(K) := (0, (\text{ad}(j^*, j_*)(K), \text{ad}((j \circ \pi)^*, (j \circ \pi)_*)(K)), 0) :$$

$$K \xrightarrow{\sim} (\psi_D K \xrightarrow{(c(x_{S^\circ/S}(K)), \text{can}(K))} x_{S^\circ/S}(K') \oplus i_* \phi_D K \xrightarrow{(\mathbb{D}_S^v c(x_{S^\circ/S}(\mathbb{D}_S^v K')), \text{var}(K))} \psi_D K)$$

*the canonical isomorphism in  $D_{\mathbb{Z}_l, c, k}(S_K^{an, pet})$ .*

*Proof.* (i): Follows from proposition 1.

(ii): Follows immediately from theorem 12. □

## 2.6 Presheaves on the big Zariski site or on the big etale site

Let  $k$  a field of characteristic 0. For  $S \in \text{Var}(k)$ , we denote by  $\rho_S : \text{Var}(k)^{sm}/S \hookrightarrow \text{Var}(k)/S$  be the full subcategory consisting of the objects  $U/S = (U, h) \in \text{Var}(k)/S$  such that the morphism  $h : U \rightarrow S$  is smooth. That is,  $\text{Var}(k)^{sm}/S$  is the category

- whose objects are smooth morphisms  $U/S = (U, h), h : U \rightarrow S$  with  $U \in \text{Var}(k)$ ,
- whose morphisms  $g : U/S = (U, h_1) \rightarrow V/S = (V, h_2)$  is a morphism  $g : U \rightarrow V$  of complex algebraic varieties such that  $h_2 \circ g = h_1$ .

We denote again  $\rho_S : \text{Var}(k)/S \rightarrow \text{Var}(k)^{sm}/S$  the associated morphism of site. We will consider

$$r^s(S) : \text{Var}(k) \xrightarrow{r(S)} \text{Var}(k)/S \xrightarrow{\rho_S} \text{Var}(k)^{sm}/S$$

the composite morphism of site. For  $S \in \text{Var}(k)$ , we denote by  $\mathbb{Z}_S := \mathbb{Z}(S/S) \in \text{PSh}(\text{Var}(k)^{sm}/S)$  the constant presheaf. By Yoneda lemma, we have for  $F \in C(\text{Var}(k)^{sm}/S)$ ,  $\mathcal{H}om(\mathbb{Z}_S, F) = F$ . For  $f : T \rightarrow S$  a morphism, with  $T, S \in \text{Var}(k)$ , we have the following commutative diagram of sites

$$\begin{array}{ccc} \text{Var}(k)/T & \xrightarrow{\rho_T} & \text{Var}(k)^{sm}/T \\ \downarrow P(f) & & \downarrow P(f) \\ \text{Var}(k)/S & \xrightarrow{\rho_S} & \text{Var}(k)^{sm}/S \end{array} \quad (1)$$

We denote, for  $S \in \text{Var}(k)$ , the obvious morphism of sites

$$\tilde{e}(S) : \text{Var}(k)/S \xrightarrow{\rho_S} \text{Var}(k)^{sm}/S \xrightarrow{e(S)} \text{Ouv}(S)$$

where  $\text{Ouv}(S)$  is the set of the Zariski open subsets of  $S$ , given by the inclusion functors  $\tilde{e}(S) : \text{Ouv}(S) \hookrightarrow \text{Var}(k)^{sm}/S \hookrightarrow \text{Var}(k)/S$ . By definition, for  $f : T \rightarrow S$  a morphism with  $S, T \in \text{Var}(k)$ , the commutative diagram of sites (1) extend a commutative diagram of sites :

$$\begin{array}{ccccc} \tilde{e}(T) : \text{Var}(k)/T & \xrightarrow{\rho_T} & \text{Var}(k)^{sm}/T & \xrightarrow{e(T)} & \text{Ouv}(T) \\ \downarrow P(f) & & \downarrow P(f) & & \downarrow P(f) \\ \tilde{e}(S) : \text{Var}(k)/S & \xrightarrow{\rho_S} & \text{Var}(k)^{sm}/S & \xrightarrow{e(S)} & \text{Ouv}(S) \end{array} \quad (2)$$

- As usual, we denote by

$$(f^*, f_*) := (P(f)^*, P(f)_*) : C(\text{Var}(k)^{sm}/S) \rightarrow C(\text{Var}(k)^{sm}/T)$$

the adjunction induced by  $P(f) : \text{Var}(k)^{sm}/T \rightarrow \text{Var}(k)^{sm}/S$ . Since the colimits involved in the definition of  $f^* = P(f)^*$  are filtered,  $f^*$  also preserve monomorphism. Hence, we get an adjunction

$$(f^*, f_*) : C_{fil}(\text{Var}(k)^{sm}/S) \rightleftarrows C_{fil}(\text{Var}(k)^{sm}/T), f^*(G, F) := (f^*G, f^*F)$$

- As usual, we denote by

$$(f^*, f_*) := (P(f)^*, P(f)_*) : C(\text{Var}(k)/S) \rightarrow C(\text{Var}(k)/T)$$

the adjunction induced by  $P(f) : \text{Var}(k)/T \rightarrow \text{Var}(k)/S$ . Since the colimits involved in the definition of  $f^* = P(f)^*$  are filtered,  $f^*$  also preserve monomorphism. Hence, we get an adjunction

$$(f^*, f_*) : C_{fil}(\text{Var}(k)/S) \rightleftarrows C_{fil}(\text{Var}(k)/T), f^*(G, F) := (f^*G, f^*F)$$

For  $h : U \rightarrow S$  a smooth morphism with  $U, S \in \text{Var}(k)$ , the pullback functor  $P(h) : \text{Var}(k)^{sm}/S \rightarrow \text{Var}(k)^{sm}/U$  admits a left adjoint  $C(h)(X \rightarrow U) = (X \rightarrow U \rightarrow S)$ . Hence,  $h^* : C(\text{Var}(k)^{sm}/S) \rightarrow C(\text{Var}(k)^{sm}/U)$  admits a left adjoint

$$h_{\sharp} : C(\text{Var}(k)^{sm}/U) \rightarrow C(\text{Var}(k)^{sm}/S), F \mapsto ((V, h_0) \mapsto \lim_{(V', h_0 h') \rightarrow (V, h_0)} F(V', h'))$$

Note that we have for  $V/U = (V, h')$  with  $h' : V \rightarrow U$  a smooth morphism we have  $h_{\sharp}(\mathbb{Z}(V/U)) = \mathbb{Z}(V'/S)$  with  $V'/S = (V', h \circ h')$ . Hence, since projective presheaves are the direct summands of the representable presheaves,  $h_{\sharp}$  sends projective presheaves to projective presheaves.

We have the support section functors of a closed embedding  $i : Z \hookrightarrow S$  for presheaves on the big Zariski site.

**Definition 12.** Let  $i : Z \hookrightarrow S$  be a closed embedding with  $S, Z \in \text{Var}(k)$  and  $j : S \setminus Z \hookrightarrow S$  be the open complementary subset.

(i) We define the functor

$$\Gamma_Z : C(\text{Var}(k)^{sm}/S) \rightarrow C(\text{Var}(k)^{sm}/S), G^{\bullet} \mapsto \Gamma_Z G^{\bullet} := \text{Cone}(\text{ad}(j^*, j_*)(G^{\bullet}) : G^{\bullet} \rightarrow j_* j^* G^{\bullet})[-1],$$

so that there is then a canonical map  $\gamma_Z(G^{\bullet}) : \Gamma_Z G^{\bullet} \rightarrow G^{\bullet}$ .

(ii) We have the dual functor of (i) :

$$\Gamma_Z^{\vee} : C(\text{Var}(k)^{sm}/S) \rightarrow C(\text{Var}(k)^{sm}/S), F \mapsto \Gamma_Z^{\vee}(F^{\bullet}) := \text{Cone}(\text{ad}(j_{\sharp}, j^*)(G^{\bullet}) : j_{\sharp} j^* G^{\bullet} \rightarrow G^{\bullet}),$$

together with the canonical map  $\gamma_Z^{\vee}(G) : F \rightarrow \Gamma_Z^{\vee}(G)$ .

(iii) For  $F, G \in C(\text{Var}(k)^{sm}/S)$ , we denote by

$$I(\gamma, \text{hom})(F, G) := (I, I(j_{\sharp}, j^*)(F, G)^{-1}) : \Gamma_Z \mathcal{H}om(F, G) \xrightarrow{\sim} \mathcal{H}om(\Gamma_Z^{\vee} F, G)$$

the canonical isomorphism given by adjunction.

Let  $S_{\bullet} \in \text{Fun}(\mathcal{I}, \text{Var}(k))$  with  $\mathcal{I} \in \text{Cat}$ , a diagram of algebraic varieties. It gives the diagram of sites  $\text{Var}(k)^2/S_{\bullet} \in \text{Fun}(\mathcal{I}, \text{Cat})$ .

- Then  $C_{fil}(\text{Var}(k)/S_{\bullet})$  is the category

- whose objects  $(G, F) = ((G_I, F)_{I \in \mathcal{I}}, u_{IJ})$ , with  $(G_I, F) \in C_{fil}(\text{Var}(k)/S_I)$ , and  $u_{IJ} : (G_I, F) \rightarrow r_{IJ*}(G_J, F)$  for  $r_{IJ} : I \rightarrow J$ , denoting again  $r_{IJ} : S_I \rightarrow S_J$ , are morphisms satisfying for  $I \rightarrow J \rightarrow K$ ,  $r_{IJ*}u_{JK} \circ u_{IJ} = u_{IK}$  in  $C_{fil}(\text{Var}(k)/S_I)$ ,
- the morphisms  $m : ((G, F), u_{IJ}) \rightarrow ((H, F), v_{IJ})$  being (see section 2.1) a family of morphisms of complexes,

$$m = (m_I : (G_I, F) \rightarrow (H_I, F))_{I \in \mathcal{I}}$$

such that  $v_{IJ} \circ m_I = p_{IJ*}m_J \circ u_{IJ}$  in  $C_{fil}(\text{Var}(k)/S_I)$ .

- Then  $C_{fil}(\text{Var}(k)^{sm}/S_\bullet)$  is the category

- whose objects  $(G, F) = ((G_I, F)_{I \in \mathcal{I}}, u_{IJ})$ , with  $(G_I, F) \in C_{fil}(\text{Var}(k)^{sm}/S_I)$ , and  $u_{IJ} : (G_I, F) \rightarrow r_{IJ*}(G_J, F)$  for  $r_{IJ} : I \rightarrow J$ , denoting again  $r_{IJ} : S_I \rightarrow S_J$ , are morphisms satisfying for  $I \rightarrow J \rightarrow K$ ,  $r_{IJ*}u_{JK} \circ u_{IJ} = u_{IK}$  in  $C_{fil}(\text{Var}(k)^{sm}/S_I)$ ,
- the morphisms  $m : ((G, F), u_{IJ}) \rightarrow ((H, F), v_{IJ})$  being (see section 2.1) a family of morphisms of complexes,

$$m = (m_I : (G_I, F) \rightarrow (H_I, F))_{I \in \mathcal{I}}$$

such that  $v_{IJ} \circ m_I = p_{IJ*}m_J \circ u_{IJ}$  in  $C_{fil}(\text{Var}(k)^{sm}/S_I)$ .

As usual, we denote by

$$(f_\bullet^*, f_{\bullet*}) := (P(f_\bullet)^*, P(f_\bullet)_*) : C(\text{Var}(k)^{(sm)}/S_\bullet) \rightarrow C(\text{Var}(k)^{(sm)}/T_\bullet)$$

the adjunction induced by  $P(f_\bullet) : \text{Var}(k)^{(sm)}/T_\bullet \rightarrow \text{Var}(k)^{(sm)}/S_\bullet$ . Since the colimits involved in the definition of  $f_\bullet^* = P(f_\bullet)^*$  are filtered,  $f_\bullet^*$  also preserve monomorphism. Hence, we get an adjunction

$$(f_\bullet^*, f_{\bullet*}) : C_{fil}(\text{Var}(k)^{(sm)}/S_\bullet) \rightleftarrows C_{fil}(\text{Var}(k)^{(sm)}/T_\bullet),$$

$$f_\bullet^*((G_I, F), u_{IJ}) := ((f_I^*G_I, f_I^*F), T(f_I, r_{IJ})(-) \circ f_I^*u_{IJ}).$$

Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i=1}^l S_i$  an open affine cover and denote by  $S_I = \cap_{i \in I} S_i$ . Let  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embeddings, with  $\tilde{S}_i \in \text{Var}(k)$ . For  $I \subset [1, \dots, l]$ , denote by  $\tilde{S}_I = \prod_{i \in I} \tilde{S}_i$ . We then have closed embeddings  $i_I : S_I \hookrightarrow \tilde{S}_I$  and for  $J \subset I$  the following commutative diagram

$$D_{IJ} = \begin{array}{ccc} S_I & \xrightarrow{i_I} & \tilde{S}_I \\ j_{IJ} \uparrow & & \uparrow p_{IJ} \\ S_J & \xrightarrow{i_J} & \tilde{S}_J \end{array}$$

where  $p_{IJ} : \tilde{S}_J \rightarrow \tilde{S}_I$  is the projection and  $j_{IJ} : S_J \hookrightarrow S_I$  is the open embedding so that  $j_I \circ j_{IJ} = j_J$ . This gives the diagram of algebraic varieties  $(\tilde{S}_I) \in \text{Fun}(\mathcal{P}(\mathbb{N}), \text{Var}(k))$  which the diagram of sites  $\text{Var}(k)^{sm}/(\tilde{S}_I) \in \text{Fun}(\mathcal{P}(\mathbb{N}), \text{Cat})$ . Denote by  $m : \tilde{S}_I \setminus (S_I \setminus S_J) \hookrightarrow \tilde{S}_I$  the open embedding. Then  $C_{fil}(\text{Var}(k)^{sm}/(\tilde{S}_I))$  is the category

- whose objects  $(G, F) = ((G_I, F), u_{IJ})$  with  $(G_I, F) \in C_{fil}(\text{Var}(k)^{sm}/\tilde{S}_I)$ , and  $u_{IJ} : (G_I, F) \rightarrow p_{IJ*}(G_J, F)$  are morphisms satisfying for  $I \subset J \subset K$ ,  $p_{IJ*}u_{JK} \circ u_{IJ} = u_{IK}$  in  $C_{fil}(\text{Var}(k)^{sm}/\tilde{S}_I)$ ,
- the morphisms  $m : ((G, F), u_{IJ}) \rightarrow ((H, F), v_{IJ})$  being a family of morphisms of complexes,

$$m = (m_I : (G_I, F) \rightarrow (H_I, F))_{I \in \mathcal{I}}$$

such that  $v_{IJ} \circ m_I = p_{IJ*}m_J \circ u_{IJ}$  in  $C_{fil}(\text{Var}(k)^{sm}/\tilde{S}_I)$ .

Similarly,  $C_{fil}(\text{Var}(k)^{sm}/(\tilde{S}_I)^{op})$  is the category

- whose objects  $(G, F) = ((G_I, F)_{I \subset [1, \dots, l]}, u_{IJ})$ , with  $(G_I, F) \in C_{fil}(\text{Var}(k)^{(sm)}/\tilde{S}_I)$ , and  $u_{IJ} : (G_J, F) \rightarrow p_{IJ}^*(G_I, F)$  for  $I \subset J$ , are morphisms satisfying for  $I \subset J \subset K$ ,  $p_{JK}^* u_{IJ} \circ u_{JK} = u_{IK}$  in  $C_{fil}(\text{Var}(k)^{(sm)}/\tilde{S}_K)$ ,
- the morphisms  $m : ((G, F), u_{IJ}) \rightarrow ((H, F), v_{IJ})$  being (see section 2.1) a family of morphisms of complexes,

$$m = (m_I : (G_I, F) \rightarrow (H_I, F))_{I \subset [1, \dots, l]}$$

such that  $v_{IJ} \circ m_J = p_{IJ}^* m_I \circ u_{IJ}$  in  $C_{fil}(\text{Var}(k)^{(sm)}/\tilde{S}_J)$ .

**Definition 13.** Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i=1}^l S_i$  an open cover and denote by  $S_I = \cap_{i \in I} S_i$ . Let  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embeddings, with  $\tilde{S}_i \in \text{Var}(k)$ . We will denote by  $C_{fil}(\text{Var}(k)^{(sm)}/(S/\tilde{S}_I)) \subset C_{fil}(\text{Var}(k)^{(sm)}/\tilde{S}_I)$  the full subcategory whose objects  $(G, F) = ((G_I, F)_{I \subset [1, \dots, l]}, u_{IJ})$ , with  $(G_I, F) \in C_{fil, S_I}(\text{Var}(k)^{(sm)}/\tilde{S}_I)$ , and  $u_{IJ} : m^*(G_I, F) \rightarrow m^* p_{IJ*}(G_J, F)$  for  $I \subset J$ , are  $\infty$ -filtered Zariski local equivalence,

We now give the definition of the  $\mathbb{A}^1$  local property :

Denote by

$$\begin{aligned} p_a : \text{Var}(k)^{(sm)}/S &\rightarrow \text{Var}(k)^{(sm)}/S, X/S = (X, h) \mapsto (X \times \mathbb{A}^1)/S = (X \times \mathbb{A}^1, h \circ p_X), \\ (g : X/S &\rightarrow X'/S) \mapsto ((g \times I_{\mathbb{A}^1}) : X \times \mathbb{A}^1/S \rightarrow X' \times \mathbb{A}^1/S) \end{aligned}$$

the projection functor and again by  $p_a : \text{Var}(k)^{(sm)}/S \rightarrow \text{Var}(k)^{(sm)}/S$  the corresponding morphism of site.

**Definition 14.** Let  $S \in \text{Var}(k)$ . Denote for short  $\text{Var}(k)^{(sm)}/S$  either the category  $\text{Var}(k)/S$  or the category  $\text{Var}(k)^{(sm)}/S$ .

(i0) A complex  $F \in C(\text{Var}(k)^{(sm)}/S)$  is said to be  $\mathbb{A}^1$  homotopic if  $\text{ad}(p_a^*, p_{a*})(F) : F \rightarrow p_{a*} p_a^* F$  is an homotopy equivalence.

(i) A complex  $F \in C(\text{Var}(k)^{(sm)}/S)$  is said to be  $\mathbb{A}^1$  invariant if for all  $U/S \in \text{Var}(k)^{(sm)}/S$ ,

$$F(p_U) : F(U/S) \rightarrow F(U \times \mathbb{A}^1/S)$$

is a quasi-isomorphism, where  $p_U : U \times \mathbb{A}^1 \rightarrow U$  is the projection. Obviously, if a complex  $F \in C(\text{Var}(k)^{(sm)}/S)$  is  $\mathbb{A}^1$  homotopic then it is  $\mathbb{A}^1$  invariant.

(ii) Let  $\tau$  a topology on  $\text{Var}(k)$ . A complex  $F \in C(\text{Var}(k)^{(sm)}/S)$  is said to be  $\mathbb{A}^1$  local for the topology  $\tau$ , if for a (hence every)  $\tau$  local equivalence  $k : F \rightarrow G$  with  $k$  injective and  $G \in C(\text{Var}(k)^{(sm)}/S)$   $\tau$  fibrant, e.g.  $k : F \rightarrow E_\tau(F)$ ,  $G$  is  $\mathbb{A}^1$  invariant for all  $n \in \mathbb{Z}$ .

(iii) A morphism  $m : F \rightarrow G$  with  $F, G \in C(\text{Var}(k)^{(sm)}/S)$  is said to an  $(\mathbb{A}^1, \text{et})$  local equivalence if for all  $H \in C(\text{Var}(k)^{(sm)}/S)$  which is  $\mathbb{A}^1$  local for the etale topology

$$\text{Hom}(L(m), E_{\text{et}}(H)) : \text{Hom}(L(G), E_{\text{et}}(H)) \rightarrow \text{Hom}(L(F), E_{\text{et}}(H))$$

is a quasi-isomorphism.

Denote  $\square^* := \mathbb{P}^* \setminus \{1\}$

- Let  $S \in \text{Var}(k)$ . For  $U/S = (U, h) \in \text{Var}(k)^{(sm)}/S$ , we consider

$$\square^* \times U/S = (\square^* \times U, h \circ p) \in \text{Fun}(\Delta, \text{Var}(k)^{(sm)}/S).$$

For  $F \in C^-(\text{Var}(k)^{(sm)}/S)$ , it gives the complex

$$C_* F \in C^-(\text{Var}(k)^{(sm)}/S), U/S = (U, h) \mapsto C_* F(U/S) := \text{Tot } F(\square^* \times U/S)$$

together with the canonical map  $c_F := (0, I_F) : F \rightarrow C_*F$ . For  $F \in C(\text{Var}(k)^{sm}/S)$ , we get

$$C_*F := \text{holim}_n C_*F^{\leq n} \in C(\text{Var}(k)^{sm}/S),$$

together with the canonical map  $c_F := (0, I_F) : F \rightarrow C_*F$ . For  $m : F \rightarrow G$  a morphism, with  $F, G \in C(\text{Var}(k)^{sm}/S)$ , we get by functoriality the morphism  $C_*m : C_*F \rightarrow C_*G$ .

- Let  $S \in \text{Var}(k)$ . For  $U/S = (U, h) \in \text{Var}(k)/S$ , we consider

$$\square^* \times U/S = (\mathbb{A}^* \times U, h \circ p) \in \text{Fun}(\Delta, \text{Var}(k)/S).$$

For  $F \in C^-(\text{Var}(k)/S)$ , it gives the complex

$$C_*F \in C^-(\text{Var}(k)/S), U/S = (U, h) \mapsto C_*F(U/S) := \text{Tot } F(\square^* \times U/S)$$

together with the canonical map  $c = c(F) := (0, I_F) : F \rightarrow C_*F$ . For  $F \in C(\text{Var}(k)/S)$ , we get

$$C_*F := \text{holim}_n C_*F^{\leq n} \in C(\text{Var}(k)/S),$$

together with the canonical map  $c_F := (0, I_F) : F \rightarrow C_*F$ . For  $m : F \rightarrow G$  a morphism, with  $F, G \in C(\text{Var}(k)/S)$ , we get by functoriality the morphism  $C_*m : C_*F \rightarrow C_*G$ .

**Proposition 2.** (i) Let  $S \in \text{Var}(k)$ . Then for  $F \in C(\text{Var}(k)^{sm}/S)$ ,  $C_*F$  is  $\mathbb{A}^1$  local for the etale topology and  $c(F) : F \rightarrow C_*F$  is an equivalence ( $\mathbb{A}^1, et$ ) local.

- (ii) A morphism  $m : F \rightarrow G$  with  $F, G \in C(\text{Var}(k)^{(sm)}/S)$  is an ( $\mathbb{A}^1, et$ ) local equivalence if and only if there exists

$$\{X_{1,\alpha}/S, \alpha \in \Lambda_1\}, \dots, \{X_{r,\alpha}/S, \alpha \in \Lambda_r\} \subset \text{Var}(k)^{(sm)}/S$$

such that we have in  $\text{Ho}_{et}(C(\text{Var}(k)^{(sm)}/S))$

$$\begin{aligned} \text{Cone}(m) &\xrightarrow{\sim} \text{Cone}(\bigoplus_{\alpha \in \Lambda_1} \text{Cone}(\mathbb{Z}(X_{1,\alpha} \times \mathbb{A}^1/S) \rightarrow \mathbb{Z}(X_{1,\alpha}/S)) \\ &\rightarrow \dots \rightarrow \bigoplus_{\alpha \in \Lambda_r} \text{Cone}(\mathbb{Z}(X_{r,\alpha} \times \mathbb{A}^1/S) \rightarrow \mathbb{Z}(X_{r,\alpha}/S))) \end{aligned}$$

*Proof.* Standard : see Ayoub's thesis for example. □

**Definition-Proposition 1.** Let  $S \in \text{Var}(k)$ .

- (i) With the weak equivalence the ( $\mathbb{A}^1, et$ ) local equivalence and the fibration the epimorphism with  $\mathbb{A}_S^1$  local and etale fibrant kernels gives a model structure on  $C(\text{Var}(k)^{sm}/S)$  : the left bousfield localization of the projective model structure of  $C(\text{Var}(k)^{sm}/S)$ . We call it the projective ( $\mathbb{A}^1, et$ ) model structure.
- (ii) With the weak equivalence the ( $\mathbb{A}^1, et$ ) local equivalence and the fibration the epimorphism with  $\mathbb{A}_S^1$  local and etale fibrant kernels gives a model structure on  $C(\text{Var}(k)/S)$  : the left bousfield localization of the projective model structure of  $C(\text{Var}(k)/S)$ . We call it the projective ( $\mathbb{A}^1, et$ ) model structure.

*Proof.* See [12]. □

**Proposition 3.** Let  $g : T \rightarrow S$  a morphism with  $T, S \in \text{Var}(k)$ .

- (i) The adjunction  $(g^*, g_*) : C(\text{Var}(k)^{sm}/S) \rightleftarrows C(\text{Var}(k)^{sm}/T)$  is a Quillen adjunction for the ( $\mathbb{A}^1, et$ ) projective model structure (see definition-proposition 1).
- (i)' Let  $h : U \rightarrow S$  a smooth morphism with  $U, S \in \text{Var}(k)$ . The adjunction  $(h_{\sharp}, h^*) : C(\text{Var}(k)^{sm}/U) \rightleftarrows C(\text{Var}(k)^{sm}/S)$  is a Quillen adjunction for the ( $\mathbb{A}^1, et$ ) projective model structure.

(i)" The functor  $g^* : C(\text{Var}(k)^{sm}/S) \rightarrow C(\text{Var}(k)^{sm}/T)$  sends quasi-isomorphism to quasi-isomorphism, sends equivalence Zariski local to equivalence Zariski local, and equivalence etale local to equivalence etale local, sends  $(\mathbb{A}^1, et)$  local equivalence to  $(\mathbb{A}^1, et)$  local equivalence.

(ii) The adjunction  $(g^*, g_*) : C(\text{Var}(k)/S) \rightleftarrows C(\text{Var}(k)/T)$  is a Quillen adjunction for the  $(\mathbb{A}^1, et)$  projective model structure (see definition-proposition 1).

(ii)' The adjunction  $(g_*, g^*) : C(\text{Var}(k)/T) \rightleftarrows C(\text{Var}(k)/S)$  is a Quillen adjunction for the  $(\mathbb{A}^1, et)$  projective model structure.

(ii)" The functor  $g^* : C(\text{Var}(k)/S) \rightarrow C(\text{Var}(k)/T)$  sends quasi-isomorphism to quasi-isomorphism, sends equivalence Zariski local to equivalence Zariski local, and equivalence etale local to equivalence etale local, sends  $(\mathbb{A}^1, et)$  local equivalence to  $(\mathbb{A}^1, et)$  local equivalence.

*Proof.* Standard : see [12] for example.  $\square$

**Proposition 4.** Let  $S \in \text{Var}(k)$ .

(i) The adjunction  $(\rho_S^*, \rho_{S*}) : C(\text{Var}(k)^{sm}/S) \rightleftarrows C(\text{Var}(k)/S)$  is a Quillen adjunction for the  $(\mathbb{A}^1, et)$  projective model structure.

(ii) The functor  $\rho_{S*} : C(\text{Var}(k)/S) \rightarrow C(\text{Var}(k)^{sm}/S)$  sends quasi-isomorphism to quasi-isomorphism, sends equivalence Zariski local to equivalence Zariski local, and equivalence etale local to equivalence etale local, sends  $(\mathbb{A}^1, et)$  local equivalence to  $(\mathbb{A}^1, et)$  local equivalence.

*Proof.* Standard : see [12] for example.  $\square$

Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i=1}^l S_i$  an open affine cover and denote by  $S_I = \cap_{i \in I} S_i$ . Let  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embeddings, with  $\tilde{S}_i \in \text{Var}(k)$ .

- For  $(G_I, K_{IJ}) \in C(\text{Var}(k)^{(sm)}/(\tilde{S}_I)^{op})$  and  $(H_I, T_{IJ}) \in C(\text{Var}(k)^{(sm)}/(\tilde{S}_I))$ , we denote

$$\mathcal{H}om((G_I, K_{IJ}), (H_I, T_{IJ})) := (\mathcal{H}om(G_I, H_I), u_{IJ}((G_I, K_{IJ}), (H_I, T_{IJ}))) \in C(\text{Var}(k)^{(sm)}/(\tilde{S}_I))$$

with

$$\begin{aligned} & u_{IJ}((G_I, K_{IJ}), (H_I, T_{IJ})) : \mathcal{H}om(G_I, H_I) \\ & \xrightarrow{\text{ad}(p_{IJ}^*, p_{IJ*})(-)} p_{IJ*} p_{IJ}^* \mathcal{H}om(G_I, H_I) \xrightarrow{T(p_{IJ}, \text{hom})(-, -)} p_{IJ*} \mathcal{H}om(p_{IJ}^* G_I, p_{IJ}^* H_I) \\ & \xrightarrow{\mathcal{H}om(p_{IJ}^* G_I, T_{IJ})} p_{IJ*} \mathcal{H}om(p_{IJ}^* G_I, H_I) \xrightarrow{\mathcal{H}om(K_{IJ}, H_I)} p_{IJ*} \mathcal{H}om(G_I, H_I). \end{aligned}$$

This gives in particular the functor

$$\begin{aligned} & \mathbb{D}_{(\tilde{S}_I)}^0 : C(\text{Var}(k)^{(sm)}/(\tilde{S}_I)^{op}) \rightarrow C(\text{Var}(k)^{(sm)}/(\tilde{S}_I)), \\ & (H_I, T_{IJ}) \mapsto (\mathbb{D}_{\tilde{S}_I}^0 L H_I, T_{IJ}^d) := \mathcal{H}om((L H_I, T_{IJ}), (E_{et}(\mathbb{Z}_{\tilde{S}_I}), I_{IJ})). \end{aligned}$$

- For  $(G_I, K_{IJ}) \in C(\text{Var}(k)^{(sm)}/(\tilde{S}_I))$  and  $(H_I, T_{IJ}) \in C(\text{Var}(k)^{(sm)}/(\tilde{S}_I)^{op})$ , we denote

$$\mathcal{H}om((G_I, K_{IJ}), (H_I, T_{IJ})) := (\mathcal{H}om(G_I, H_I), u_{IJ}((G_I, K_{IJ}), (H_I, T_{IJ}))) \in C(\text{Var}(k)^{(sm)}/(\tilde{S}_I)^{op})$$

with

$$\begin{aligned} & u_{IJ}((G_I, K_{IJ}), (H_I, T_{IJ})) : \mathcal{H}om(G_I, H_I) \\ & \xrightarrow{\mathcal{H}om(\text{ad}(p_{IJ}^*, p_{IJ*})(G_I), H_I)} \mathcal{H}om(p_{IJ}^* p_{IJ*} G_I, H_I) \xrightarrow{\mathcal{H}om(p_{IJ}^* K_{IJ}, H_I)} \mathcal{H}om(p_{IJ}^* G_I, H_I) \\ & \xrightarrow{\mathcal{H}om(p_{IJ}^* G_I, T_{IJ})} \mathcal{H}om(p_{IJ}^* G_I, p_{IJ}^* H_I) \xrightarrow{T(p_{IJ}, \text{hom})(-, -)^{-1}} p_{IJ}^* \mathcal{H}om(G_I, H_I). \end{aligned}$$

This gives in particular the functor

$$\begin{aligned} \mathbb{D}_{(\tilde{S}_I)}^0 &: C(\mathrm{Var}(k)^{(sm)}/(\tilde{S}_I)) \rightarrow C(\mathrm{Var}(k)^{(sm)}/(\tilde{S}_I)^{op}), \\ (H_I, T_{IJ}) &\mapsto (\mathbb{D}_{\tilde{S}_I}^0 L H_I, T_{IJ}^d) := (\mathcal{H}om((L H_I, T_{IJ}), (E_{et}(\mathbb{Z}_{\tilde{S}_I}), I_{IJ}))). \end{aligned}$$

**Definition 15.** Let  $S \in \mathrm{Var}(k)$ . Let  $S = \cup_{i=1}^l S_i$  an open affine cover and denote by  $S_I = \cap_{i \in I} S_i$ . Let  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embeddings, with  $\tilde{S}_i \in \mathrm{Var}(k)$ .

(i0) A complex  $(F_I, u_{IJ}) \in C(\mathrm{Var}(k)^{(sm)}/(\tilde{S}_I))$  is said to be  $\mathbb{A}^1$  homotopic if  $\mathrm{ad}(p_a^*, p_{a*})((F_I, u_{IJ})) : (F_I, u_{IJ}) \rightarrow p_{a*} p_a^*(F_I, u_{IJ})$  is an homotopy equivalence.

(i) A complex  $(F_I, u_{IJ}) \in C(\mathrm{Var}(k)^{(sm)}/(\tilde{S}_I))$  is said to be  $\mathbb{A}^1$  invariant if for all  $(X_I/\tilde{S}_I, s_{IJ}) \in \mathrm{Var}(k)^{(sm)}/(\tilde{S}_I)$

$$(F_I(p_{X_I})) : (F_I(X_I/\tilde{S}_I), F_J(s_{IJ}) \circ u_{IJ}(-)) \rightarrow (F_I(X_I \times \mathbb{A}^1/\tilde{S}_I), F_J(s_{IJ} \times I) \circ u_{IJ}(-))$$

is a quasi-isomorphism, where  $p_{X_I} : X_I \times \mathbb{A}^1 \rightarrow X_I$  are the projection, and  $s_{IJ} : X_I \times \tilde{S}_J \setminus I/\tilde{S}_I \rightarrow X_J/\tilde{S}_J$ . Obviously a complex  $(F_I, u_{IJ}) \in C(\mathrm{Var}(k)^{(sm)}/(\tilde{S}_I))$  is  $\mathbb{A}^1$  invariant if and only if all the  $F_I$  are  $\mathbb{A}^1$  invariant.

(ii) Let  $\tau$  a topology on  $\mathrm{Var}(k)$ . A complex  $F = (F_I, u_{IJ}) \in C(\mathrm{Var}(k)^{(sm)}/(\tilde{S}_I))$  is said to be  $\mathbb{A}^1$  local for the  $\tau$  topology induced on  $\mathrm{Var}(k)/(\tilde{S}_I)$ , if for an (hence every)  $\tau$  local equivalence  $k : F \rightarrow G$  with  $k$  injective and  $G = (G_I, v_{IJ}) \in C(\mathrm{Var}(k)^{(sm)}/(\tilde{S}_I))$   $\tau$  fibrant, e.g.  $k : (F_I, u_{IJ}) \rightarrow (E_\tau(F_I), E(u_{IJ}))$ ,  $G$  is  $\mathbb{A}^1$  invariant.

(iii) A morphism  $m = (m_I) : (F_I, u_{IJ}) \rightarrow (G_I, v_{IJ})$  with  $(F_I, u_{IJ}), (G_I, v_{IJ}) \in C(\mathrm{Var}(k)^{(sm)}/(\tilde{S}_I))$  is said to be an  $(\mathbb{A}^1, et)$  local equivalence if for all  $(H_I, w_{IJ}) \in C(\mathrm{Var}(k)^{(sm)}/(\tilde{S}_I))$  which is  $\mathbb{A}^1$  local for the etale topology

$$(\mathrm{Hom}(L(m_I), E_{et}(H_I))) : \mathrm{Hom}(L(G_I, v_{IJ}), E_{et}(H_I, w_{IJ})) \rightarrow \mathrm{Hom}(L(F_I, u_{IJ}), E_{et}(H_I, w_{IJ}))$$

is a quasi-isomorphism (of complexes of abelian groups). Obviously, if a morphism  $m = (m_I) : (F_I, u_{IJ}) \rightarrow (G_I, v_{IJ})$  with  $(F_I, u_{IJ}), (G_I, v_{IJ}) \in C(\mathrm{Var}(k)^{(sm)}/(\tilde{S}_I))$  is an  $(\mathbb{A}^1, et)$  local equivalence, then all the  $m_I : F_I \rightarrow G_I$  are  $(\mathbb{A}^1, et)$  local equivalence.

(iv) A morphism  $m = (m_I) : (F_I, u_{IJ}) \rightarrow (G_I, v_{IJ})$  with  $(F_I, u_{IJ}), (G_I, v_{IJ}) \in C(\mathrm{Var}(k)^{(sm)}/(\tilde{S}_I)^{op})$  is said to be an  $(\mathbb{A}^1, et)$  local equivalence if for all  $(H_I, w_{IJ}) \in C(\mathrm{Var}(k)^{(sm)}/(\tilde{S}_I)^{op})$  which is  $\mathbb{A}^1$  local for the etale topology

$$(\mathrm{Hom}(L(m_I), E_{et}(H_I))) : \mathrm{Hom}(L(G_I, v_{IJ}), E_{et}(H_I, w_{IJ})) \rightarrow \mathrm{Hom}(L(F_I, u_{IJ}), E_{et}(H_I, w_{IJ}))$$

is a quasi-isomorphism (of complexes of abelian groups). Obviously, if a morphism  $m = (m_I) : (F_I, u_{IJ}) \rightarrow (G_I, v_{IJ})$  with  $(F_I, u_{IJ}), (G_I, v_{IJ}) \in C(\mathrm{Var}(k)^{(sm)}/(\tilde{S}_I)^{op})$  is an  $(\mathbb{A}^1, et)$  local equivalence, then all the  $m_I : F_I \rightarrow G_I$  are  $(\mathbb{A}^1, et)$  local equivalence and for all  $(H_I, w_{IJ}) \in C(\mathrm{Var}(k)^{(sm)}/(\tilde{S}_I))$ ,

$$(\mathrm{Hom}(L(m_I), E_{et}(H_I))) : \mathrm{Hom}(L(G_I, v_{IJ}), E_{et}(H_I, w_{IJ})) \rightarrow \mathrm{Hom}(L(F_I, u_{IJ}), E_{et}(H_I, w_{IJ}))$$

is a quasi-isomorphism (of diagrams of complexes of abelian groups).

**Proposition 5.** Let  $S \in \mathrm{Var}(k)$ . Let  $S = \cup_{i=1}^l S_i$  an open affine cover and denote by  $S_I = \cap_{i \in I} S_i$ . Let  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embeddings, with  $\tilde{S}_i \in \mathrm{Var}(k)$ .

(i) A morphism  $m : F \rightarrow G$  with  $F, G \in C(\mathrm{Var}(k)^{(sm)}/(\tilde{S}_I))$  is an  $(\mathbb{A}^1, et)$  local equivalence if and only if there exists

$$\left\{ (X_{1,\alpha,I}/\tilde{S}_I, u_{IJ}^1), \alpha \in \Lambda_1 \right\}, \dots, \left\{ (X_{r,\alpha,I}/\tilde{S}_I, u_{IJ}^r), \alpha \in \Lambda_r \right\} \subset \mathrm{Var}(k)^{(sm)}/(\tilde{S}_I)$$

with  $u_{IJ}^1 : X_{l,\alpha,I} \times \tilde{S}_{J \setminus I} / \tilde{S}_J \rightarrow X_{l,\alpha,J} / \tilde{S}_J$ , such that we have in  $\text{Ho}_{et}(C(\text{Var}(k)^{(sm)})/(\tilde{S}_I))$

$$\begin{aligned} \text{Cone}(m) &\xrightarrow{\sim} \text{Cone}(\bigoplus_{\alpha \in \Lambda_1} \text{Cone}((\mathbb{Z}(X_{1,\alpha,I} \times \mathbb{A}^1 / \tilde{S}_I), \mathbb{Z}(u_{IJ}^1 \times I)) \rightarrow (\mathbb{Z}(X_{1,\alpha,I} / \tilde{S}_I), \mathbb{Z}(u_{IJ}^1))) \\ &\rightarrow \cdots \rightarrow \bigoplus_{\alpha \in \Lambda_r} \text{Cone}((\mathbb{Z}(X_{r,\alpha,I} \times \mathbb{A}^1 / \tilde{S}_I), \mathbb{Z}(u_{IJ}^r \times I)) \rightarrow (\mathbb{Z}(X_{r,\alpha,I} / \tilde{S}_I), \mathbb{Z}(u_{IJ}^r))) \end{aligned}$$

(ii) A morphism  $m : F \rightarrow G$  with  $F, G \in C(\text{Var}(k)^{(sm)})/(\tilde{S}_I)^{op}$  is an  $(\mathbb{A}^1, et)$  local equivalence if and only if there exists

$$\left\{ (X_{1,\alpha,I} / \tilde{S}_I, u_{IJ}^1), \alpha \in \Lambda_1 \right\}, \dots, \left\{ (X_{r,\alpha,I} / \tilde{S}_I, u_{IJ}^r), \alpha \in \Lambda_r \right\} \subset \text{Var}(k)^{(sm)}/(\tilde{S}_I)^{op}$$

with  $u_{IJ}^1 : X_{l,\alpha,J} / \tilde{S}_J \rightarrow X_{l,\alpha,I} \times \tilde{S}_{J \setminus I} / \tilde{S}_J$ , such that we have in  $\text{Ho}_{et}(C(\text{Var}(k)^{(sm)})/(\tilde{S}_I)^{op})$

$$\begin{aligned} \text{Cone}(m) &\xrightarrow{\sim} \text{Cone}(\bigoplus_{\alpha \in \Lambda_1} \text{Cone}((\mathbb{Z}(X_{1,\alpha,I} \times \mathbb{A}^1 / \tilde{S}_I), \mathbb{Z}(u_{IJ}^1 \times I)) \rightarrow (\mathbb{Z}(X_{1,\alpha,I} / \tilde{S}_I), \mathbb{Z}(u_{IJ}^1))) \\ &\rightarrow \cdots \rightarrow \bigoplus_{\alpha \in \Lambda_r} \text{Cone}((\mathbb{Z}(X_{r,\alpha,I} \times \mathbb{A}^1 / \tilde{S}_I), \mathbb{Z}(u_{IJ}^r \times I)) \rightarrow (\mathbb{Z}(X_{r,\alpha,I} / \tilde{S}_I), \mathbb{Z}(u_{IJ}^r))) \end{aligned}$$

*Proof.* Standard. See Ayoub's thesis for example.  $\square$

• For  $f : X \rightarrow S$  a morphism with  $X, S \in \text{Var}(k)$ , we denote as usual (see [12] for example),  $\mathbb{Z}^{tr}(X/S) \in \text{PSh}(\text{Var}(k)/S)$  the presheaf given by

- for  $X'/S \in \text{Var}(k)/S$ , with  $X'$  irreducible,  $\mathbb{Z}^{tr}(X/S)(X'/S) := \mathcal{Z}^{fs/X}(X' \times_S X) \subset \mathcal{Z}_{d_{X'}}(X' \times_S X)$  which consist of algebraic cycles  $\alpha = \sum_i n_i \alpha_i \in \mathcal{Z}_{d_{X'}}(X' \times_S X)$  such that, denoting  $\text{supp}(\alpha) = \cup_i \alpha_i \subset X' \times_S X$  its support and  $f' : X' \times_S X \rightarrow X'$  the projection,  $f'_{|\text{supp}(\alpha)} : \text{supp}(\alpha) \rightarrow X'$  is finite surjective,
- for  $g : X_2/S \rightarrow X_1/S$  a morphism, with  $X_1/S, X_2/S \in \text{Var}(k)/S$ ,

$$\mathbb{Z}^{tr}(X/S)(g) : \mathbb{Z}^{tr}(X/S)(X_1/S) \rightarrow \mathbb{Z}^{tr}(X/S)(X_2/S), \alpha \mapsto (g \times I)^{-1}(\alpha)$$

with  $g \times I : X_2 \times_S X \rightarrow X_1 \times_S X$ , noting that, by base change,  $f_2|_{\text{supp}((g \times I)^{-1}(\alpha))} : \text{supp}((g \times I)^{-1}(\alpha)) \rightarrow X_2$  is finite surjective,  $f_2 : X_2 \times_S X \rightarrow X_2$  being the projection.

• For  $f : X \rightarrow S$  a morphism with  $X, S \in \text{Var}(k)$  and  $r \in \mathbb{N}$ , we denote as usual (see [12] for example),  $\mathbb{Z}^{equiv}(X/S) \in \text{PSh}(\text{Var}(k)/S)$  the presheaf given by

- for  $X'/S \in \text{Var}(k)/S$ , with  $X'$  irreducible,  $\mathbb{Z}^{equiv}(X/S)(X'/S) := \mathcal{Z}^{equiv/X}(X' \times_S X) \subset \mathcal{Z}_{d_{X'}}(X' \times_S X)$  which consist of algebraic cycles  $\alpha = \sum_i n_i \alpha_i \in \mathcal{Z}_{d_{X'}}(X' \times_S X)$  such that, denoting  $\text{supp}(\alpha) = \cup_i \alpha_i \subset X' \times_S X$  its support and  $f' : X' \times_S X \rightarrow X'$  the projection,  $f'_{|\text{supp}(\alpha)} : \text{supp}(\alpha) \rightarrow X'$  is dominant, with fibers either empty or of dimension  $r$ ,
- for  $g : X_2/S \rightarrow X_1/S$  a morphism, with  $X_1/S, X_2/S \in \text{Var}(k)/S$ ,

$$\mathbb{Z}^{equiv}(X/S)(g) : \mathbb{Z}^{equiv}(X/S)(X_1/S) \rightarrow \mathbb{Z}^{equiv}(X/S)(X_2/S), \alpha \mapsto (g \times I)^{-1}(\alpha)$$

with  $g \times I : X_2 \times_S X \rightarrow X_1 \times_S X$ , noting that, by base change,  $f_2|_{\text{supp}((g \times I)^{-1}(\alpha))} : \text{supp}((g \times I)^{-1}(\alpha)) \rightarrow X_2$  is obviously dominant, with fibers either empty or of dimension  $r$ ,  $f_2 : X_2 \times_S X \rightarrow X_2$  being the projection.

• Let  $S \in \text{Var}(k)$ . We denote by  $\mathbb{Z}_S(d) := \mathbb{Z}^{equiv0}(S \times \mathbb{A}^d/S)[-2d]$  the Tate twist. For  $F \in C(\text{Var}(k)/S)$ , we denote by  $F(d) := F \otimes \mathbb{Z}_S(d)$ .

For  $S \in \text{Var}(k)$ , let  $\text{Cor}(\text{Var}(k)^{sm}/S)$  be the category

- whose objects are smooth morphisms  $U/S = (U, h)$ ,  $h : U \rightarrow S$  with  $U \in \text{Var}(k)$ ,



- whose morphisms  $\alpha : U/S = (U, h_1) \rightarrow V/S = (V, h_2)$  is finite correspondence that is  $\alpha \in \bigoplus_i \mathcal{Z}^{fs}(U_i \times_S V)$ , where  $U = \sqcup_i U_i$ , with  $U_i$  connected (hence irreducible by smoothness), and  $\mathcal{Z}^{fs}(U_i \times_S V)$  is the abelian group of cycle finite and surjective over  $U_i$ .

We denote by  $\text{Tr}(S) : \text{Cor}(\text{Var}(k)^{sm}/S) \rightarrow \text{Var}(k)^{sm}/S$  the morphism of site given by the inclusion functor  $\text{Tr}(S) : \text{Var}(k)^{sm}/S \hookrightarrow \text{Cor}(\text{Var}(k)^{sm}/S)$  It induces an adjonction

$$(\text{Tr}(S)^* \text{Tr}(S)_*) : C(\text{Var}(k)^{sm}/S) \rightleftarrows C(\text{Cor}(\text{Var}(k)^{sm}/S))$$

A complex of preheaves  $G \in C(\text{Var}(k)^{sm}/S)$  is said to admit transferts if it is in the image of the embedding

$$\text{Tr}(S)_* : C(\text{Cor}(\text{Var}(k)^{sm}/S)) \hookrightarrow C(\text{Var}(k)^{sm}/S),$$

that is  $G = \text{Tr}(S)_* \text{Tr}(S)^* G$ .

We will use to compute the algebraic Gauss-Manin realization functor the following

**Theorem 13.** *Let  $\phi : F^\bullet \rightarrow G^\bullet$  an etale local equivalence with  $F^\bullet, G^\bullet \in C(\text{Var}(k)^{sm}/S)$ . If  $F^\bullet$  and  $G^\bullet$  are  $\mathbb{A}^1$  local and admit transferts then  $\phi : F^\bullet \rightarrow G^\bullet$  is a Zariski local equivalence. Hence if  $F \in C(\text{Var}(k)^{sm}/S)$  is  $\mathbb{A}^1$  local and admits transfert*

$$k : E_{zar}(F) \rightarrow E_{et}(E_{zar}(F)) = E_{et}(F)$$

is a Zariski local equivalence.

*Proof.* See [12]. □

## 2.7 Presheaves on the big Zariski site or the big etale site of pairs

We recall the definition given in subsection 5.1 : For  $S \in \text{Var}(k)$ ,  $\text{Var}(k)^2/S := \text{Var}(k)^2/(S, S)$  is by definition (see subsection 2.1) the category whose set of objects is

$$(\text{Var}(k)^2/S)^0 := \{((X, Z), h), h : X \rightarrow S, Z \subset X \text{ closed}\} \subset \text{Var}(k)/S \times \text{Top}$$

and whose set of morphisms between  $(X_1, Z_1)/S = ((X_1, Z_1), h_1), (X_1, Z_1)/S = ((X_2, Z_2), h_2) \in \text{Var}(k)^2/S$  is the subset

$$\begin{aligned} & \text{Hom}_{\text{Var}(k)^2/S}((X_1, Z_1)/S, (X_2, Z_2)/S) := \\ & \{(f : X_2 \rightarrow X_1), \text{ s.t. } h_1 \circ f = h_2 \text{ and } Z_1 \subset f^{-1}(Z_2)\} \subset \text{Hom}_{\text{Var}(k)}(X_1, X_2) \end{aligned}$$

The category  $\text{Var}(k)^2$  admits fiber products :  $(X_1, Z_1) \times_{(S, Z)} (X_2, Z_2) = (X_1 \times_S X_2, Z_1 \times_Z Z_2)$ . In particular, for  $f : T \rightarrow S$  a morphism with  $S, T \in \text{Var}(k)$ , we have the pullback functor

$$P(f) : \text{Var}(k)^2/S \rightarrow \text{Var}(k)^2/T, P(f)((X, Z)/S) := (X_T, Z_T)/T, P(f)(g) := (g \times_S f)$$

and we note again  $P(f) : \text{Var}(k)^2/T \rightarrow \text{Var}(k)^2/S$  the corresponding morphism of sites.

We will consider in the construction of the filtered De Rham realization functor the full subcategory  $\text{Var}(k)^{2,sm}/S \subset \text{Var}(k)^2/S$  such that the first factor is a smooth morphism : We will also consider, in order to obtain a complex of D modules in the construction of the filtered De Rham realization functor, the restriction to the full subcategory  $\text{Var}(k)^{2,pr}/S \subset \text{Var}(k)^2/S$  such that the first factor is a projection :

**Definition 16.** (i) *Let  $S \in \text{Var}(k)$ . We denote by*

$$\rho_S : \text{Var}(k)^{2,sm}/S \hookrightarrow \text{Var}(k)^2/S$$

*the full subcategory consisting of the objects  $(U, Z)/S = ((U, Z), h) \in \text{Var}(k)^2/S$  such that the morphism  $h : U \rightarrow S$  is smooth. That is,  $\text{Var}(k)^{2,sm}/S$  is the category*

- whose objects are  $(U, Z)/S = ((U, Z), h)$ , with  $U \in \text{Var}(k)$ ,  $Z \subset U$  a closed subset, and  $h : U \rightarrow S$  a smooth morphism,
- whose morphisms  $g : (U, Z)/S = ((U, Z), h_1) \rightarrow (U', Z')/S = ((U', Z'), h_2)$  is a morphism  $g : U \rightarrow U'$  of complex algebraic varieties such that  $Z \subset g^{-1}(Z')$  and  $h_2 \circ g = h_1$ .

We denote again  $\rho_S : \text{Var}(k)^2/S \rightarrow \text{Var}(k)^{2,sm}/S$  the associated morphism of site. We have

$$r^s(S) : \text{Var}(k)^2 \xrightarrow{r(S) := r(S, S)} \text{Var}(k)^2/S \xrightarrow{\rho_S} \text{Var}(k)^{2,sm}/S$$

the composite morphism of site.

(ii) Let  $S \in \text{Var}(k)$ . We will consider the full subcategory

$$\mu_S : \text{Var}(k)^{2,pr}/S \hookrightarrow \text{Var}(k)^2/S$$

whose subset of object consist of those whose morphism is a projection to  $S$  :

$$(\text{Var}(k)^{2,pr}/S)^0 := \{((Y \times S, X), p), Y \in \text{Var}(k), p : Y \times S \rightarrow S \text{ the projection}\} \subset (\text{Var}(k)^2/S)^0.$$

(iii) We will consider the full subcategory

$$\mu_S : (\text{Var}(k)^{2,smpr}/S) \hookrightarrow \text{Var}(k)^{2,sm}/S$$

whose subset of object consist of those whose morphism is a smooth projection to  $S$  :

$$(\text{Var}(k)^{2,smpr}/S)^0 := \{((Y \times S, X), p), Y \in \text{SmVar}(k), p : Y \times S \rightarrow S \text{ the projection}\} \subset (\text{Var}(k)^2/S)^0$$

For  $f : T \rightarrow S$  a morphism with  $T, S \in \text{Var}(k)$ , we have by definition, the following commutative diagram of sites

$$\begin{array}{ccccc}
\text{Var}(k)^2/T & \xrightarrow{\mu_T} & \text{Var}(k)^{2,pr}/T & & \\
\downarrow P(f) & \searrow \rho_T & \downarrow \mu_T & \searrow \rho_T & \\
& & \text{Var}(k)^{2,sm}/T & \xrightarrow{\mu_T} & \text{Var}(k)^{2,smpr}/T \\
& & \downarrow P(f) & & \downarrow P(f) \\
\text{Var}(k)^2/S & \xrightarrow{P(f)} & \text{Var}(k)^{2,pr}/S & & \\
& \searrow \rho_S & \downarrow \mu_S & \searrow \rho_S & \\
& & \text{Var}(k)^{2,sm}/S & \xrightarrow{\mu_S} & \text{Var}(k)^{2,smpr}/S
\end{array} \tag{3}$$

Recall we have (see subsection 2.1), for  $S \in \text{Var}(k)$ , the graph functor

$$\begin{aligned}
\text{Gr}_S^{12} : \text{Var}(k)/S &\rightarrow \text{Var}(k)^{2,pr}/S, X/S \mapsto \text{Gr}_S^{12}(X/S) := (X \times S, X)/S, \\
(g : X/S &\rightarrow X'/S) \mapsto \text{Gr}_S^{12}(g) := (g \times I_S : (X \times S, X) \rightarrow (X' \times S, X'))
\end{aligned}$$

Note that  $\text{Gr}_S^{12}$  is fully faithfull. For  $f : T \rightarrow S$  a morphism with  $T, S \in \text{Var}(k)$ , we have by definition,

the following commutative diagram of sites

$$\begin{array}{ccccc}
\mathrm{Var}(k)^{2,pr}/T & \xrightarrow{\mathrm{Gr}_T^{12}} & \mathrm{Var}(k)/T & & \\
\downarrow P(f) & \searrow \rho_T & \downarrow & \searrow \rho_T & \\
& & \mathrm{Var}(k)^{2,smpr}/T & \xrightarrow{\mathrm{Gr}_T^{12}} & \mathrm{Var}(k)^{sm}/T \\
& & \downarrow & \downarrow P(f) & \downarrow P(f) \\
\mathrm{Var}(k)^{2,pr}/S & \xrightarrow{P(f)} & \mathrm{Var}(k)/S & & \\
& \searrow \rho_S & \downarrow & \searrow \rho_S & \\
& & \mathrm{Var}(k)^{2,sm}/S & \xrightarrow{\mathrm{Gr}_S^{12}} & \mathrm{Var}(k)^{sm}/S
\end{array} \quad . \quad (4)$$

where we recall that  $P(f)((X, Z)/S) := ((X_T, Z_T)/T)$ , since smooth morphisms are preserved by base change.

- As usual, we denote by

$$(f^*, f_*) := (P(f)^*, P(f)_*) : C(\mathrm{Var}(k)^{2,(sm)}/S) \rightarrow C(\mathrm{Var}(k)^{2,(sm)}/T)$$

the adjunction induced by  $P(f) : \mathrm{Var}(k)^{2,(sm)}/T \rightarrow \mathrm{Var}(k)^{2,(sm)}/S$ . Since the colimits involved in the definition of  $f^* = P(f)^*$  are filtered,  $f^*$  also preserve monomorphism. Hence, we get an adjunction

$$(f^*, f_*) : C_{fil}(\mathrm{Var}(k)^{2,(sm)}/S) \rightleftarrows C_{fil}(\mathrm{Var}(k)^{2,(sm)}/T), \quad f^*(G, F) := (f^*G, f^*F)$$

For  $S \in \mathrm{Var}(k)$ , we denote by  $\mathbb{Z}_S := \mathbb{Z}((S, S)/(S, S)) \in \mathrm{PSh}(\mathrm{Var}(k)^{2,(sm)}/S)$  the constant presheaf. By Yoneda lemma, we have for  $F \in C(\mathrm{Var}(k)^{2,(sm)}/S)$ ,  $\mathcal{H}om(\mathbb{Z}_S, F) = F$ .

- As usual, we denote by

$$(f^*, f_*) := (P(f)^*, P(f)_*) : C(\mathrm{Var}(k)^{2,(sm)pr}/S) \rightarrow C(\mathrm{Var}(k)^{2,(sm)pr}/T)$$

the adjunction induced by  $P(f) : \mathrm{Var}(k)^{2,(sm)pr}/T \rightarrow \mathrm{Var}(k)^{2,(sm)pr}/S$ . Since the colimits involved in the definition of  $f^* = P(f)^*$  are filtered,  $f^*$  also preserve monomorphism. Hence, we get an adjunction

$$(f^*, f_*) : C_{fil}(\mathrm{Var}(k)^{2,(sm)pr}/S) \rightleftarrows C_{fil}(\mathrm{Var}(k)^{2,(sm)pr}/T), \quad f^*(G, F) := (f^*G, f^*F)$$

For  $S \in \mathrm{Var}(k)$ , we denote by  $\mathbb{Z}_S := \mathbb{Z}((S, S)/(S, S)) \in \mathrm{PSh}(\mathrm{Var}(k)^{2,sm}/S)$  the constant presheaf. By Yoneda lemma, we have for  $F \in C(\mathrm{Var}(k)^{2,sm}/S)$ ,  $\mathcal{H}om(\mathbb{Z}_S, F) = F$ .

- For  $h : U \rightarrow S$  a smooth morphism with  $U, S \in \mathrm{Var}(k)$ ,  $P(h) : \mathrm{Var}(k)^{2,sm}/S \rightarrow \mathrm{Var}(k)^{2,sm}/U$  admits a left adjoint

$$C(h) : \mathrm{Var}(k)^{2,sm}/U \rightarrow \mathrm{Var}(k)^{2,sm}/S, \quad C(h)((U', Z'), h') = ((U', Z'), h \circ h').$$

Hence  $h^* : C(\mathrm{Var}(k)^{2,sm}/S) \rightarrow C(\mathrm{Var}(k)^{2,sm}/U)$  admits a left adjoint

$$\begin{aligned}
& h_{\sharp} : C(\mathrm{Var}(k)^{2,sm}/U) \rightarrow C(\mathrm{Var}(k)^{2,sm}/S), \\
F & \mapsto (h_{\sharp}F : ((U, Z), h_0) \mapsto \lim_{((U', Z'), h \circ h') \rightarrow ((U, Z), h_0)} F((U', Z')/U))
\end{aligned}$$

- For  $h : X \rightarrow S$  a morphism with  $X, S \in \text{Var}(k)$ ,  $P(h) : \text{Var}(k)^2/S \rightarrow \text{Var}(k)^2/X$  admits a left adjoint

$$C(h) : \text{Var}(k)^2/X \rightarrow \text{Var}(k)^2/S, C(h)((X', Z'), h') = ((X', Z'), h \circ h').$$

Hence  $h^* : C(\text{Var}(k)^2/S) \rightarrow C(\text{Var}(k)^2/X)$  admits a left adjoint

$$h_{\sharp} : C(\text{Var}(k)^2/X) \rightarrow C(\text{Var}(k)^{2,sm}/S), \\ F \mapsto (h_{\sharp}F : ((X, Z), h_0) \mapsto \lim_{((X', Z'), h \circ h') \rightarrow ((X, Z), h_0)} F((X', Z')/X))$$

- For  $p : Y \times S \rightarrow S$  a projection with  $Y, S \in \text{Var}(k)$  with  $Y$  smooth,  $P(p) : \text{Var}(k)^{2,smpr}/S \rightarrow \text{Var}(k)^{2,smpr}/Y \times S$  admits a left adjoint

$$C(p) : \text{Var}(k)^{2,smpr}/Y \times S \rightarrow \text{Var}(k)^{2,smpr}/S, \\ C(p)((Y' \times S, Z'), p') = ((Y' \times S, Z'), p \circ p').$$

Hence  $p^* : C(\text{Var}(k)^{2,smpr}/S) \rightarrow C(\text{Var}(k)^{2,smpr}/Y \times S)$  admits a left adjoint

$$p_{\sharp} : C(\text{Var}(k)^{2,smpr}/Y \times S) \rightarrow C(\text{Var}(k)^{2,smpr}/S), \\ F \mapsto (p_{\sharp}F : ((Y_0 \times S, Z), p_0) \mapsto \lim_{((Y' \times Y \times S, Z'), p \circ p') \rightarrow ((Y_0 \times S, Z), p_0)} F((Y' \times Y \times S, Z')/Y \times S))$$

- For  $p : Y \times S \rightarrow S$  a projection with  $Y, S \in \text{Var}(k)$ ,  $P(p) : \text{Var}(k)^{2,pr}/S \rightarrow \text{Var}(k)^{2,pr}/Y \times S$  admits a left adjoint

$$C(p) : \text{Var}(k)^{2,pr}/Y \times S \rightarrow \text{Var}(k)^{2,pr}/S, C(p)((Y' \times S, Z'), p') = ((Y' \times S, Z'), p \circ p').$$

Hence  $p^* : C(\text{Var}(k)^{2,pr}/S) \rightarrow C(\text{Var}(k)^{2,pr}/Y \times S)$  admits a left adjoint

$$p_{\sharp} : C(\text{Var}(k)^{2,pr}/Y \times S) \rightarrow C(\text{Var}(k)^{2,pr}/S), \\ F \mapsto (p_{\sharp}F : ((Y_0 \times S, Z), p_0) \mapsto \lim_{((Y' \times Y \times S, Z'), p \circ p') \rightarrow ((Y_0 \times S, Z), p_0)} F((Y' \times Y \times S, Z')/Y \times S))$$

Let  $S_{\bullet} \in \text{Fun}(\mathcal{I}, \text{Var}(k))$  with  $\mathcal{I} \in \text{Cat}$ , a diagram of algebraic varieties. It gives the diagram of sites  $\text{Var}(k)^2/S_{\bullet} \in \text{Fun}(\mathcal{I}, \text{Cat})$ .

- Then  $C_{fil}(\text{Var}(k)^{2,(sm)}/S_{\bullet})$  is the category

- whose objects  $(G, F) = ((G_I, F)_{I \in \mathcal{I}}, u_{IJ})$ , with  $(G_I, F) \in C_{fil}(\text{Var}(k)^{2,(sm)}/S_I)$ , and  $u_{IJ} : (G_I, F) \rightarrow r_{IJ*}(G_J, F)$  for  $r_{IJ} : I \rightarrow J$ , denoting again  $r_{IJ} : S_I \rightarrow S_J$ , are morphisms satisfying for  $I \rightarrow J \rightarrow K$ ,  $r_{IJ*}u_{JK} \circ u_{IJ} = u_{IK}$  in  $C_{fil}(\text{Var}(k)^{2,(sm)}/S_I)$ ,

- the morphisms  $m : ((G, F), u_{IJ}) \rightarrow ((H, F), v_{IJ})$  being (see section 2.1) a family of morphisms of complexes,

$$m = (m_I : (G_I, F) \rightarrow (H_I, F))_{I \in \mathcal{I}}$$

such that  $v_{IJ} \circ m_I = p_{IJ*}m_J \circ u_{IJ}$  in  $C_{fil}(\text{Var}(k)^{2,(sm)}/S_I)$ .

- Then  $C_{fil}(\text{Var}(k)^{2,(sm)pr}/S_{\bullet})$  is the category

- whose objects  $(G, F) = ((G_I, F)_{I \in \mathcal{I}}, u_{IJ})$ , with  $(G_I, F) \in C_{fil}(\text{Var}(k)^{2,(sm)pr}/S_I)$ , and  $u_{IJ} : (G_I, F) \rightarrow r_{IJ*}(G_J, F)$  for  $r_{IJ} : I \rightarrow J$ , denoting again  $r_{IJ} : S_I \rightarrow S_J$ , are morphisms satisfying for  $I \rightarrow J \rightarrow K$ ,  $r_{IJ*}u_{JK} \circ u_{IJ} = u_{IK}$  in  $C_{fil}(\text{Var}(k)^{2,(sm)}/S_I)$ ,

- the morphisms  $m : ((G, F), u_{IJ}) \rightarrow ((H, F), v_{IJ})$  being (see section 2.1) a family of morphisms of complexes,

$$m = (m_I : (G_I, F) \rightarrow (H_I, F))_{I \in \mathcal{I}}$$

such that  $v_{IJ} \circ m_I = p_{IJ*}m_J \circ u_{IJ}$  in  $C_{fil}(\text{Var}(k)^{2,(sm)pr}/S_I)$ .

For  $s : \mathcal{I} \rightarrow \mathcal{J}$  a functor, with  $\mathcal{I}, \mathcal{J} \in \text{Cat}$ , and  $f_\bullet : T_\bullet \rightarrow S_{s(\bullet)}$  a morphism with  $T_\bullet \in \text{Fun}(\mathcal{J}, \text{Var}(k))$  and  $S_\bullet \in \text{Fun}(\mathcal{I}, \text{Var}(k))$ , we have by definition, the following commutative diagrams of sites

$$\begin{array}{ccccc}
\text{Var}(k)^2/T_\bullet & \xrightarrow{\mu_{T_\bullet}} & \text{Var}(k)^{2,pr}/T_\bullet & & \\
\downarrow P(f_\bullet) & \searrow \rho_{T_\bullet} & \downarrow & \searrow \rho_{T_\bullet} & \\
& & \text{Var}(k)^{2,sm}/T_\bullet & \xrightarrow{\mu_{T_\bullet}(f_\bullet)} & \text{Var}(k)^{2,smpr}/T_\bullet \\
& & \downarrow & & \downarrow P(f_\bullet) \\
\text{Var}(k)^2/S_\bullet & \xrightarrow{P(f_\bullet)} & \text{Var}(k)^{2,pr}/S_\bullet & & \text{Var}(k)^{2,smpr}/S_\bullet \\
& \searrow \rho_{S_\bullet} & \downarrow & \searrow \rho_{S_\bullet} & \downarrow P(f_\bullet) \\
& & \text{Var}(k)^{2,sm}/S_\bullet & \xrightarrow{\mu_{S_\bullet}} & \text{Var}(k)^{2,smpr}/S_\bullet
\end{array} \quad (5)$$

and

$$\begin{array}{ccccc}
\text{Var}(k)^{2,pr}/T_\bullet & \xrightarrow{\text{Gr}_{T_\bullet}^{12}} & \text{Var}(k)/T & & \\
\downarrow P(f_\bullet) & \searrow \rho_{T_\bullet} & \downarrow & \searrow \rho_{T_\bullet} & \\
& & \text{Var}(k)^{2,smpr}/T_\bullet & \xrightarrow{\text{Gr}_{T_\bullet}^{12}(f_\bullet)} & \text{Var}(k)^{sm}/T_\bullet \\
& & \downarrow & & \downarrow P(f_\bullet) \\
\text{Var}(k)^{2,pr}/S_\bullet & \xrightarrow{P(f_\bullet)} & \text{Var}(k)/S_\bullet & & \text{Var}(k)^{sm}/S_\bullet \\
& \searrow \rho_{S_\bullet} & \downarrow & \searrow \rho_{S_\bullet} & \downarrow P(f_\bullet) \\
& & \text{Var}(k)^{2,sm}/S_\bullet & \xrightarrow{\text{Gr}_{S_\bullet}^{12}} & \text{Var}(k)^{sm}/S_\bullet
\end{array} \quad (6)$$

Let  $s : \mathcal{I} \rightarrow \mathcal{J}$  a functor, with  $\mathcal{I}, \mathcal{J} \in \text{Cat}$ , and  $f_\bullet : T_\bullet \rightarrow S_{s(\bullet)}$  a morphism with  $T_\bullet \in \text{Fun}(\mathcal{J}, \text{Var}(k))$  and  $S_\bullet \in \text{Fun}(\mathcal{I}, \text{Var}(k))$ .

- As usual, we denote by

$$(f_\bullet^*, f_{\bullet*}) := (P(f_\bullet)^*, P(f_\bullet)_*) : C(\text{Var}(k)^{2,(sm)}/S_\bullet) \rightarrow C(\text{Var}(k)^{2,(sm)}/T_\bullet)$$

the adjunction induced by  $P(f_\bullet) : \text{Var}(k)^{2,(sm)}/T_\bullet \rightarrow \text{Var}(k)^{2,(sm)}/S_\bullet$ . Since the colimits involved in the definition of  $f_\bullet^* = P(f_\bullet)^*$  are filtered,  $f_\bullet^*$  also preserve monomorphism. Hence, we get an adjunction

$$\begin{aligned}
(f_\bullet^*, f_{\bullet*}) : C_{fil}(\text{Var}(k)^{2,(sm)}/S_\bullet) &\rightleftarrows C_{fil}(\text{Var}(k)^{2,(sm)}/T_\bullet), \\
f_\bullet^*((G_I, F), u_{IJ}) &:= ((f_I^* G_I, f_I^* F), T(f_I, r_{IJ})(-) \circ f_I^* u_{IJ})
\end{aligned}$$

- As usual, we denote by

$$(f_\bullet^*, f_{\bullet*}) := (P(f_\bullet)^*, P(f_\bullet)_*) : C(\text{Var}(k)^{2,(sm)pr}/S_\bullet) \rightarrow C(\text{Var}(k)^{2,(sm)pr}/T_\bullet)$$

the adjunction induced by  $P(f_\bullet) : \text{Var}(k)^{2,(sm)pr}/T_\bullet \rightarrow \text{Var}(k)^{2,(sm)pr}/S_\bullet$ . Since the colimits involved in the definition of  $f_\bullet^* = P(f_\bullet)^*$  are filtered,  $f_\bullet^*$  also preserve monomorphism. Hence, we get an adjunction

$$\begin{aligned}
(f_\bullet^*, f_{\bullet*}) : C_{fil}(\text{Var}(k)^{2,(sm)pr}/S_\bullet) &\rightleftarrows C_{fil}(\text{Var}(k)^{2,(sm)pr}/T_\bullet), \\
f_\bullet^*((G_I, F), u_{IJ}) &:= ((f_I^* G_I, f_I^* F), T(f_I, r_{IJ})(-) \circ f_I^* u_{IJ})
\end{aligned}$$

Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i=1}^l S_i$  an open affine cover and denote by  $S_I = \cap_{i \in I} S_i$ . Let  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embeddings, with  $\tilde{S}_i \in \text{Var}(k)$ . For  $I \subset [1, \dots, l]$ , denote by  $\tilde{S}_I = \prod_{i \in I} \tilde{S}_i$ . We then have closed embeddings  $i_I : S_I \hookrightarrow \tilde{S}_I$  and for  $J \subset I$  the following commutative diagram

$$D_{IJ} = \begin{array}{ccc} S_I & \xrightarrow{i_I} & \tilde{S}_I \\ j_{IJ} \uparrow & & \uparrow p_{IJ} \\ S_J & \xrightarrow{i_J} & \tilde{S}_J \end{array}$$

where  $p_{IJ} : \tilde{S}_J \rightarrow \tilde{S}_I$  is the projection and  $j_{IJ} : S_J \hookrightarrow S_I$  is the open embedding so that  $j_I \circ j_{IJ} = j_J$ . This gives the diagram of algebraic varieties  $(\tilde{S}_I) \in \text{Fun}(\mathcal{P}(\mathbb{N}), \text{Var}(k))$  which gives the diagram of sites  $\text{Var}(k)^2 / (\tilde{S}_I) \in \text{Fun}(\mathcal{P}(\mathbb{N}), \text{Cat})$ . This gives also the diagram of algebraic varieties  $(\tilde{S}_I)^{op} \in \text{Fun}(\mathcal{P}(\mathbb{N})^{op}, \text{Var}(k))$  which gives the diagram of sites  $\text{Var}(k)^2 / (\tilde{S}_I)^{op} \in \text{Fun}(\mathcal{P}(\mathbb{N})^{op}, \text{Cat})$ .

- Then  $C_{fil}(\text{Var}(k)^{2,(sm)} / (\tilde{S}_I))$  is the category
  - whose objects  $(G, F) = ((G_I, F)_{I \subset [1, \dots, l]}, u_{IJ})$ , with  $(G_I, F) \in C_{fil}(\text{Var}(k)^{2,(sm)} / \tilde{S}_I)$ , and  $u_{IJ} : (G_I, F) \rightarrow p_{IJ*}(G_J, F)$  for  $I \subset J$ , are morphisms satisfying for  $I \subset J \subset K$ ,  $p_{IJ*}u_{JK} \circ u_{IJ} = u_{IK}$  in  $C_{fil}(\text{Var}(k)^{2,(sm)} / \tilde{S}_I)$ ,
  - the morphisms  $m : ((G, F), u_{IJ}) \rightarrow ((H, F), v_{IJ})$  being (see section 2.1) a family of morphisms of complexes,

$$m = (m_I : (G_I, F) \rightarrow (H_I, F))_{I \subset [1, \dots, l]}$$

such that  $v_{IJ} \circ m_I = p_{IJ*}m_J \circ u_{IJ}$  in  $C_{fil}(\text{Var}(k)^{2,(sm)} / \tilde{S}_I)$ .

- Then  $C_{fil}(\text{Var}(k)^{2,(sm)pr} / (\tilde{S}_I))$  is the category
  - whose objects  $(G, F) = ((G_I, F)_{I \subset [1, \dots, l]}, u_{IJ})$ , with  $(G_I, F) \in C_{fil}(\text{Var}(k)^{2,(sm)pr} / \tilde{S}_I)$ , and  $u_{IJ} : (G_I, F) \rightarrow p_{IJ*}(G_J, F)$  for  $I \subset J$ , are morphisms satisfying for  $I \subset J \subset K$ ,  $p_{IJ*}u_{JK} \circ u_{IJ} = u_{IK}$  in  $C_{fil}(\text{Var}(k)^{2,(sm)pr} / \tilde{S}_I)$ ,
  - the morphisms  $m : ((G, F), u_{IJ}) \rightarrow ((H, F), v_{IJ})$  being (see section 2.1) a family of morphisms of complexes,

$$m = (m_I : (G_I, F) \rightarrow (H_I, F))_{I \subset [1, \dots, l]}$$

such that  $v_{IJ} \circ m_I = p_{IJ*}m_J \circ u_{IJ}$  in  $C_{fil}(\text{Var}(k)^{2,(sm)pr} / \tilde{S}_I)$ .

- Then  $C_{fil}(\text{Var}(k)^{2,(sm)} / (\tilde{S}_I)^{op})$  is the category
  - whose objects  $(G, F) = ((G_I, F)_{I \subset [1, \dots, l]}, u_{IJ})$ , with  $(G_I, F) \in C_{fil}(\text{Var}(k)^{2,(sm)} / \tilde{S}_I)$ , and  $u_{IJ} : (G_J, F) \rightarrow p_{IJ}^*(G_I, F)$  for  $I \subset J$ , are morphisms satisfying for  $I \subset J \subset K$ ,  $p_{JK}^*u_{IJ} \circ u_{JK} = u_{IK}$  in  $C_{fil}(\text{Var}(k)^{2,(sm)} / \tilde{S}_K)$ ,
  - the morphisms  $m : ((G, F), u_{IJ}) \rightarrow ((H, F), v_{IJ})$  being (see section 2.1) a family of morphisms of complexes,

$$m = (m_I : (G_I, F) \rightarrow (H_I, F))_{I \subset [1, \dots, l]}$$

such that  $v_{IJ} \circ m_J = p_{IJ}^*m_I \circ u_{IJ}$  in  $C_{fil}(\text{Var}(k)^{2,(sm)} / \tilde{S}_J)$ .

- Then  $C_{fil}(\text{Var}(k)^{2,(sm)pr} / (\tilde{S}_I)^{op})$  is the category
  - whose objects  $(G, F) = ((G_I, F)_{I \subset [1, \dots, l]}, u_{IJ})$ , with  $(G_I, F) \in C_{fil}(\text{Var}(k)^{2,(sm)pr} / \tilde{S}_I)$ , and  $u_{IJ} : (G_J, F) \rightarrow p_{IJ}^*(G_I, F)$  for  $I \subset J$ , are morphisms satisfying for  $I \subset J \subset K$ ,  $p_{JK}^*u_{IJ} \circ u_{JK} = u_{IK}$  in  $C_{fil}(\text{Var}(k)^{2,(sm)pr} / \tilde{S}_K)$ ,

- the morphisms  $m : ((G, F), u_{IJ}) \rightarrow ((H, F), v_{IJ})$  being (see section 2.1) a family of morphisms of complexes,

$$m = (m_I : (G_I, F) \rightarrow (H_I, F))_{I \subset [1, \dots, l]}$$

such that  $v_{IJ} \circ m_J = p_{IJ}^* m_I \circ u_{IJ}$  in  $C_{fil}(\text{Var}(k)^{2, (sm)pr} / \tilde{S}_J)$ .

We now define the Zariski and the etale topology on  $\text{Var}(k)^2/S$ .

**Definition 17.** Let  $S \in \text{Var}(k)$ .

- (i) Denote by  $\tau$  a topology on  $\text{Var}(k)$ , e.g. the Zariski or the etale topology. The  $\tau$  covers in  $\text{Var}(k)^2/S$  of  $(X, Z)/S$  are the families of morphisms

$$\{(c_i : (U_i, Z \times_X U_i)/S \rightarrow (X, Z)/S)_{i \in I}, \text{ with } (c_i : U_i \rightarrow X)_{i \in I} \tau \text{ cover of } X \text{ in } \text{Var}(k)\}$$

- (ii) Denote by  $\tau$  the Zariski or the etale topology on  $\text{Var}(k)$ . The  $\tau$  covers in  $\text{Var}(k)^{2, sm}/S$  of  $(U, Z)/S$  are the families of morphisms

$$\{(c_i : (U_i, Z \times_U U_i)/S \rightarrow (U, Z)/S)_{i \in I}, \text{ with } (c_i : U_i \rightarrow U)_{i \in I} \tau \text{ cover of } U \text{ in } \text{Var}(k)\}$$

- (iii) Denote by  $\tau$  the Zariski or the etale topology on  $\text{Var}(k)$ . The  $\tau$  covers in  $\text{Var}(k)^{2, (sm)pr}/S$  of  $(Y \times S, Z)/S$  are the families of morphisms

$$\{(c_i \times I_S : (U_i \times S, Z \times_{Y \times S} U_i \times S)/S \rightarrow (Y \times S, Z)/S)_{i \in I}, \text{ with } (c_i : U_i \rightarrow Y)_{i \in I} \tau \text{ cover of } Y \text{ in } \text{Var}(k)\}$$

Will now define the  $\mathbb{A}^1$  local property on  $\text{Var}(k)^2/S$ .

Denote  $\square^* := \mathbb{P}_{\mathbb{C}}^* \setminus \{1\}$

- Let  $S \in \text{Var}(k)$ . For  $(X, Z)/S = ((X, Z), h) \in \text{Var}(k)^{2, (sm)pr}/S$ , we consider

$$(\square^* \times X, \square^* \times Z)/S = ((\square^* \times X, \square^* \times Z, h \circ p) \in \text{Fun}(\Delta, \text{Var}(k)^{2, (sm)pr}/S).$$

For  $F \in C^-(\text{Var}(k)^{2, (sm)pr}/S)$ , it gives the complex

$$C_*F \in C^-(\text{Var}(k)^{2, (sm)pr}/S), (X, Z)/S = ((X, Z), h) \mapsto C_*F((X, Z)/S) := \text{Tot } F((\square^* \times X, \square^* \times Z)/S)$$

together with the canonical map  $c_F := (0, I_F) : F \rightarrow C_*F$ . For  $F \in C(\text{Var}(k)^{2, (sm)pr}/S)$ , we get

$$C_*F := \text{holim}_n C_*F^{\leq n} \in C(\text{Var}(k)^{2, (sm)pr}/S),$$

together with the canonical map  $c_F := (0, I_F) : F \rightarrow C_*F$ . For  $m : F \rightarrow G$  a morphism, with  $F, G \in C(\text{Var}(k)^{2, (sm)pr}/S)$ , we get by functoriality the morphism  $C_*m : C_*F \rightarrow C_*G$ .

- Let  $S \in \text{Var}(k)$ . For  $(Y \times S, Z)/S = ((Y \times S, Z), h) \in \text{Var}(k)^{2, (sm)pr}/S$ , we consider

$$(\square^* \times Y \times S, \square^* \times Z)/S = (\square^* \times Y \times S, \square^* \times Z, h \circ p) \in \text{Fun}(\Delta, \text{Var}(k)^{2, (sm)pr}/S).$$

For  $F \in C^-(\text{Var}(k)^{2, (sm)pr}/S)$ , it gives the complex

$$C_*F \in C^-(\text{Var}(k)^{2, (sm)pr}/S), \\ (Y \times S, Z)/S = ((Y \times S, Z), h) \mapsto C_*F((Y \times S, Z)/S) := \text{Tot } F(\square^* \times Y \times S, \square^* \times Z)/S)$$

together with the canonical map  $c = c(F) := (0, I_F) : F \rightarrow C_*F$ . For  $F \in C(\text{Var}(k)^{2, (sm)pr}/S)$ , we get

$$C_*F := \text{holim}_n C_*F^{\leq n} \in C(\text{Var}(k)^{2, (sm)pr}/S),$$

together with the canonical map  $c = c(F) := (0, I_F) : F \rightarrow C_*F$ . For  $m : F \rightarrow G$  a morphism, with  $F, G \in C(\text{Var}(k)^{2, (sm)pr}/S)$ , we get by functoriality the morphism  $C_*m : C_*F \rightarrow C_*G$ .

- Let  $S \in \text{Var}(k)$ . Let  $S = \bigcup_{i=1}^l S_i$  an open affine cover and denote by  $S_I = \bigcap_{i \in I} S_i$ . Let  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embeddings, with  $\tilde{S}_i \in \text{Var}(k)$ . For  $F = (F_I, u_{IJ}) \in C(\text{Var}(k)^{2,(sm)}/(\tilde{S}_I))$ , it gives the complex

$$C_*F = (C_*F_I, C_*u_{IJ}) \in C(\text{Var}(k)^{2,(sm)}/(\tilde{S}_I)),$$

together with the canonical map  $c_F := (0, I_F) : F \rightarrow C_*F$ .

- Let  $S \in \text{Var}(k)$ . Let  $S = \bigcup_{i=1}^l S_i$  an open affine cover and denote by  $S_I = \bigcap_{i \in I} S_i$ . Let  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embeddings, with  $\tilde{S}_i \in \text{Var}(k)$ . For  $F = (F_I, u_{IJ}) \in C(\text{Var}(k)^{2,(sm)}/(\tilde{S}_I))$ , it gives the complex

$$C_*F = (C_*F_I, C_*u_{IJ}) \in C(\text{Var}(k)^{2,(sm)}/(\tilde{S}_I)^{op}),$$

together with the canonical map  $c_F := (0, I_F) : F \rightarrow C_*F$ .

- Let  $S \in \text{Var}(k)$ . Let  $S = \bigcup_{i=1}^l S_i$  an open affine cover and denote by  $S_I = \bigcap_{i \in I} S_i$ . Let  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embeddings, with  $\tilde{S}_i \in \text{Var}(k)$ . For  $F = (F_I, u_{IJ}) \in C(\text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I))$ , it gives the complex

$$C_*F = (C_*F_I, C_*u_{IJ}) \in C(\text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I)),$$

together with the canonical map  $c_F := (0, I_F) : F \rightarrow C_*F$ .

- Let  $S \in \text{Var}(k)$ . Let  $S = \bigcup_{i=1}^l S_i$  an open affine cover and denote by  $S_I = \bigcap_{i \in I} S_i$ . Let  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embeddings, with  $\tilde{S}_i \in \text{Var}(k)$ . For  $F = (F_I, u_{IJ}) \in C(\text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I))$ , it gives the complex

$$C_*F = (C_*F_I, C_*u_{IJ}) \in C(\text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I)^{op}),$$

together with the canonical map  $c_F := (0, I_F) : F \rightarrow C_*F$ .

Let  $S \in \text{Var}(k)$ . Denote for short  $\text{Var}(k)^{2,(sm)}/S$  either the category  $\text{Var}(k)^2/S$  or the category  $\text{Var}(k)^{2,sm}/S$ . Denote by

$$\begin{aligned} p_a &: \text{Var}(k)^{2,(sm)}/S \rightarrow \text{Var}(k)^{2,(sm)}/S, \\ (X, Z)/S &= ((X, Z), h) \mapsto (X \times \mathbb{A}^1, Z \times \mathbb{A}^1)/S = ((X \times \mathbb{A}^1, Z \times \mathbb{A}^1), h \circ p_X), \\ (g : (X, Z)/S \rightarrow (X', Z')/S) &\mapsto ((g \times I_{\mathbb{A}^1}) : (X \times \mathbb{A}^1, Z \times \mathbb{A}^1)/S \rightarrow (X' \times \mathbb{A}^1, Z' \times \mathbb{A}^1)/S) \end{aligned}$$

the projection functor and again by  $p_a : \text{Var}(k)^{2,(sm)}/S \rightarrow \text{Var}(k)^{2,(sm)}/S$  the corresponding morphism of site. Let  $S \in \text{Var}(k)$ . Denote for short  $\text{Var}(k)^{2,(sm)}/S$  either the category  $\text{Var}(k)^2/S$  or the category  $\text{Var}(k)^{2,sm}/S$ . Denote for short  $\text{Var}(k)^{2,(sm)pr}/S$  either the category  $\text{Var}(k)^{2,pr}/S$  or the category  $\text{Var}(k)^{2,smpr}/S$ . Denote by

$$\begin{aligned} p_a &: \text{Var}(k)^{2,(sm)pr}/S \rightarrow \text{Var}(k)^{2,(sm)pr}/S, \\ (Y \times S, Z)/S &= ((Y \times S, Z), p_S) \mapsto (Y \times S \times \mathbb{A}^1, Z \times \mathbb{A}^1)/S = ((Y \times S \times \mathbb{A}^1, Z \times \mathbb{A}^1), p_S \circ p_{Y \times S}), \\ (g : (Y \times S, Z)/S \rightarrow (Y' \times S, Z')/S) &\mapsto ((g \times I_{\mathbb{A}^1}) : (Y \times S \times \mathbb{A}^1, Z \times \mathbb{A}^1)/S \rightarrow (Y' \times S \times \mathbb{A}^1, Z' \times \mathbb{A}^1)/S) \end{aligned}$$

the projection functor and again by  $p_a : \text{Var}(k)^{2,(sm)pr}/S \rightarrow \text{Var}(k)^{2,(sm)pr}/S$  the corresponding morphism of site.

**Definition 18.** (i0) A complex  $F \in C(\text{Var}(k)^{2,(sm)}/S)$  is said to be  $\mathbb{A}^1$  homotopic if  $\text{ad}(p_a^*, p_{a*})(F) : F \rightarrow p_{a*}p_a^*F$  is an homotopy equivalence.

(i0)' A complex  $F \in C(\text{Var}(k)^{2,(sm)pr}/S)$  is said to be  $\mathbb{A}^1$  homotopic if  $\text{ad}(p_a^*, p_{a*})(F) : F \rightarrow p_{a*}p_a^*F$  is an homotopy equivalence.

(i) A complex  $F \in C(\text{Var}(k)^{2,(sm)}/S)$ , is said to be  $\mathbb{A}^1$  invariant if for all  $(X, Z)/S \in \text{Var}(k)^{2,(sm)}/S$

$$F(p_X) : F((X, Z)/S) \rightarrow F((X \times \mathbb{A}^1, (Z \times \mathbb{A}^1))/S)$$

is a quasi-isomorphism, where  $p_X : (X \times \mathbb{A}^1, (Z \times \mathbb{A}^1)) \rightarrow (X, Z)$  is the projection. Obviously, if a complex  $F \in C(\text{Var}(k)^{2,(sm)}/S)$  is  $\mathbb{A}^1$  homotopic, then it is  $\mathbb{A}^1$  invariant.



(i)' A complex  $G \in C(\text{Var}(k)^{2,(sm)pr}/S)$ , is said to be  $\mathbb{A}^1$  invariant if for all  $(Y \times S, Z)/S \in \text{Var}(k)^{2,(sm)pr}/S$

$$G(p_{Y \times S}) : G((Y \times S, Z)/S) \rightarrow G((Y \times \mathbb{A}^1 \times S, (Z \times \mathbb{A}^1))/S)$$

is a quasi-isomorphism of abelian group. Obviously, if a complex  $F \in C(\text{Var}(k)^{2,(sm)pr}/S)$  is  $\mathbb{A}^1$  homotopic, then it is  $\mathbb{A}^1$  invariant.

(ii) Let  $\tau$  a topology on  $\text{Var}(k)$ . A complex  $F \in C(\text{Var}(k)^{2,(sm)}/S)$  is said to be  $\mathbb{A}^1$  local for the  $\tau$  topology induced on  $\text{Var}(k)^2/S$ , if for an (hence every)  $\tau$  local equivalence  $k : F \rightarrow G$  with  $k$  injective and  $G \in C(\text{Var}(k)^{2,(sm)}/S)$   $\tau$  fibrant, e.g.  $k : F \rightarrow E_\tau(F)$ ,  $G$  is  $\mathbb{A}^1$  invariant.

(ii)' Let  $\tau$  a topology on  $\text{Var}(k)$ . A complex  $F \in C(\text{Var}(k)^{2,(sm)pr}/S)$  is said to be  $\mathbb{A}^1$  local for the  $\tau$  topology induced on  $\text{Var}(k)^{2,pr}/S$ , if for an (hence every)  $\tau$  local equivalence  $k : F \rightarrow G$  with  $k$  injective and  $G \in C(\text{Var}(k)^{2,(sm)pr}/S)$   $\tau$  fibrant, e.g.  $k : F \rightarrow E_\tau(F)$ ,  $G$  is  $\mathbb{A}^1$  invariant.

(iii) A morphism  $m : F \rightarrow G$  with  $F, G \in C(\text{Var}(k)^{2,(sm)}/S)$  is said to an  $(\mathbb{A}^1, et)$  local equivalence if for all  $H \in C(\text{Var}(k)^{2,(sm)}/S)$  which is  $\mathbb{A}^1$  local for the etale topology

$$\text{Hom}(L(m), E_{et}(H)) : \text{Hom}(L(G), E_{et}(H)) \rightarrow \text{Hom}(L(F), E_{et}(H))$$

is a quasi-isomorphism.

(iii)' A morphism  $m : F \rightarrow G$  with  $F, G \in C(\text{Var}(k)^{2,(sm)pr}/S)$  is said to an  $(\mathbb{A}^1, et)$  local equivalence if for all  $H \in C(\text{Var}(k)^{2,(sm)pr}/S)$  which is  $\mathbb{A}^1$  local for the etale topology

$$\text{Hom}(L(m), E_{et}(H)) : \text{Hom}(L(G), E_{et}(H)) \rightarrow \text{Hom}(L(F), E_{et}(H))$$

is a quasi-isomorphism.

**Proposition 6.** (i) Let  $S \in \text{Var}(k)$ . Then for  $F \in C(\text{Var}(k)^{2,(sm)}/S)$ ,  $C_*F$  is  $\mathbb{A}^1$  local for the etale topology and  $c(F) : F \rightarrow C_*F$  is an equivalence  $(\mathbb{A}^1, et)$  local.

(i)' Let  $S \in \text{Var}(k)$ . Then for  $F \in C(\text{Var}(k)^{2,(sm)pr}/S)$ ,  $C_*F$  is  $\mathbb{A}^1$  local for the etale topology and  $c(F) : F \rightarrow C_*F$  is an equivalence  $(\mathbb{A}^1, et)$  local.

(ii) A morphism  $m : F \rightarrow G$  with  $F, G \in C(\text{Var}(k)^{2,(sm)}/S)$  is an  $(\mathbb{A}^1, et)$  local equivalence if and only if  $a_{et}H^n C_* \text{Cone}(m) = 0$  for all  $n \in \mathbb{Z}$ .

(ii)' A morphism  $m : F \rightarrow G$  with  $F, G \in C(\text{Var}(k)^{2,(sm)pr}/S)$  is an  $(\mathbb{A}^1, et)$  local equivalence if and only if  $a_{et}H^n C_* \text{Cone}(m) = 0$  for all  $n \in \mathbb{Z}$ .

(iii) A morphism  $m : F \rightarrow G$  with  $F, G \in C(\text{Var}(k)^{2,(sm)}/S)$  is an  $(\mathbb{A}^1, et)$  local equivalence if and only if there exists

$$\{(X_{1,\alpha}, Z_{1,\alpha})/S, \alpha \in \Lambda_1\}, \dots, \{(X_{r,\alpha}, Z_{r,\alpha})/S, \alpha \in \Lambda_r\} \subset \text{Var}(k)^{2,(sm)}/S$$

such that we have in  $\text{Ho}_{et}(C(\text{Var}(k)^{2,(sm)}/S))$

$$\begin{aligned} \text{Cone}(m) &\xrightarrow{\sim} \text{Cone}(\bigoplus_{\alpha \in \Lambda_1} \text{Cone}(\mathbb{Z}((X_{1,\alpha} \times \mathbb{A}^1, Z_{1,\alpha} \times \mathbb{A}^1)/S) \rightarrow \mathbb{Z}((X_{1,\alpha}, Z_{1,\alpha})/S)) \\ &\rightarrow \dots \rightarrow \bigoplus_{\alpha \in \Lambda_r} \text{Cone}(\mathbb{Z}((X_{r,\alpha} \times \mathbb{A}^1, Z_{r,\alpha} \times \mathbb{A}^1)/S) \rightarrow \mathbb{Z}((X_{r,\alpha}, Z_{r,\alpha})/S)) \end{aligned}$$

(iii)' A morphism  $m : F \rightarrow G$  with  $F, G \in C(\text{Var}(k)^{2,(sm)pr}/S)$  is an  $(\mathbb{A}^1, et)$  local equivalence if and only if there exists

$$\{(Y_{1,\alpha} \times S, Z_{1,\alpha})/S, \alpha \in \Lambda_1\}, \dots, \{(Y_{r,\alpha} \times S, Z_{r,\alpha})/S, \alpha \in \Lambda_r\} \subset \text{Var}(k)^{2,(sm)pr}/S$$

such that we have in  $\text{Ho}_{et}(C(\text{Var}(k)^{2,(sm)}/S))$

$$\begin{aligned} \text{Cone}(m) &\xrightarrow{\sim} \text{Cone}(\bigoplus_{\alpha \in \Lambda_1} \text{Cone}(\mathbb{Z}((Y_{1,\alpha} \times \mathbb{A}^1 \times S, Z_{1,\alpha} \times \mathbb{A}^1)/S) \rightarrow \mathbb{Z}((Y_{1,\alpha} \times S, Z_{1,\alpha})/S)) \\ &\rightarrow \dots \rightarrow \bigoplus_{\alpha \in \Lambda_r} \text{Cone}(\mathbb{Z}((Y_{r,\alpha} \times \mathbb{A}^1 \times S, Z_{r,\alpha} \times \mathbb{A}^1)/S) \rightarrow \mathbb{Z}((Y_{r,\alpha} \times S, Z_{r,\alpha})/S)) \end{aligned}$$

*Proof.* Standard : see Ayoub's thesis section 4 for example. Indeed, for (iii), by definition, if  $\text{Cone}(m)$  is of the given form, then it is an equivalence  $(\mathbb{A}^1, \text{et})$  local, on the other hand if  $m$  is an equivalence  $(\mathbb{A}^1, \text{et})$  local, we consider the commutative diagram

$$\begin{array}{ccc} F & \xrightarrow{c(F)} & C_*F \\ \downarrow m & & \downarrow c_*m \\ G & \xrightarrow{c(G)} & C_*G \end{array}$$

to deduce that  $\text{Cone}(m)$  is of the given form.  $\square$

**Definition-Proposition 2.** Let  $S \in \text{Var}(k)$ .

- (i) With the weak equivalence the  $(\mathbb{A}^1, \text{et})$  local equivalence and the fibration the epimorphism with  $\mathbb{A}_S^1$  local and etale fibrant kernels gives a model structure on  $C(\text{Var}(k)^{2,(\text{sm})}/S)$  : the left bousfield localization of the projective model structure of  $C(\text{Var}(k)^{2,(\text{sm})}/S)$ . We call it the projective  $(\mathbb{A}^1, \text{et})$  model structure.
- (ii) With the weak equivalence the  $(\mathbb{A}^1, \text{et})$  local equivalence and the fibration the epimorphism with  $\mathbb{A}_S^1$  local and etale fibrant kernels gives a model structure on  $C(\text{Var}(k)^{2,(\text{sm})\text{pr}}/S)$  : the left bousfield localization of the projective model structure of  $C(\text{Var}(k)^{2,(\text{sm})\text{pr}}/S)$ . We call it the projective  $(\mathbb{A}^1, \text{et})$  model structure.

*Proof.* Similar to the proof of proposition 1.  $\square$

We have, similarly to the case of single varieties the following :

**Proposition 7.** Let  $g : T \rightarrow S$  a morphism with  $T, S \in \text{Var}(k)$ .

- (i) The adjunction  $(g^*, g_*) : C(\text{Var}(k)^{2,(\text{sm})}/S) \rightleftarrows C(\text{Var}(k)^{2,(\text{sm})}/T)$  is a Quillen adjunction for the projective  $(\mathbb{A}^1, \text{et})$  model structure (see definition-proposition 2)
- (i)' The functor  $g^* : C(\text{Var}(k)^{2,(\text{sm})}/S) \rightarrow C(\text{Var}(k)^{2,(\text{sm})}/T)$  sends quasi-isomorphism to quasi-isomorphism, sends equivalence Zariski local to equivalence Zariski local, and equivalence etale local to equivalence etale local, sends  $(\mathbb{A}^1, \text{et})$  local equivalence to  $(\mathbb{A}^1, \text{et})$  local equivalence.
- (ii) The adjunction  $(g^*, g_*) : C(\text{Var}(k)^{2,(\text{sm})\text{pr}}/S) \rightleftarrows C(\text{Var}(k)^{2,(\text{sm})\text{pr}}/T)$  is a Quillen adjunction for the projective  $(\mathbb{A}^1, \text{et})$  model structure (see definition-proposition 2)
- (ii)' The functor  $g^* : C(\text{Var}(k)^{2,(\text{sm})\text{pr}}/S) \rightarrow C(\text{Var}(k)^{2,(\text{sm})\text{pr}}/T)$  sends quasi-isomorphism to quasi-isomorphism, sends equivalence Zariski local to equivalence Zariski local, and equivalence etale local to equivalence etale local, sends  $(\mathbb{A}^1, \text{et})$  local equivalence to  $(\mathbb{A}^1, \text{et})$  local equivalence.

*Proof.* (i): Follows immediately from definition. (i)': Since the functor  $g^*$  preserve epimorphism and also monomorphism (the colimits involved being filtered),  $g^*$  sends quasi-isomorphism to quasi-isomorphism. Hence it preserve Zariski and etale local equivalence. The fact that it preserve  $(\mathbb{A}^1, \text{et})$  local equivalence then follows similarly to the single case by the fact that  $g_*$  preserve by definition  $\mathbb{A}^1$  equivariant presheaves. (ii) and (ii)': Similar to (i) and (i)'.  $\square$

**Proposition 8.** Let  $S \in \text{Var}(k)$ .

- (i) The adjunction  $(\rho_S^*, \rho_{S*}) : C(\text{Var}(k)^{2,\text{sm}}/S) \rightleftarrows C(\text{Var}(k)^2/S)$  is a Quillen adjunction for the  $(\mathbb{A}^1, \text{et})$  projective model structure.
- (i)' The functor  $\rho_{S*} : C(\text{Var}(k)^2/S) \rightarrow C(\text{Var}(k)^{2,\text{sm}}/S)$  sends quasi-isomorphism to quasi-isomorphism, sends equivalence Zariski local to equivalence Zariski local, and equivalence etale local to equivalence etale local, sends  $(\mathbb{A}^1, \text{et})$  local equivalence to  $(\mathbb{A}^1, \text{et})$  local equivalence.

(ii) The adjonction  $(\rho_S^*, \rho_{S*}) : C(\text{Var}(k)^{2,smpr}/S) \rightleftarrows C(\text{Var}(k)^{2,pr}/S)$  is a Quillen adjonction for the  $(\mathbb{A}^1, et)$  projective model structure.

(ii)' The functor  $\rho_{S*} : C(\text{Var}(k)^{2,pr}/S) \rightarrow C(\text{Var}(k)^{2,smpr}/S)$  sends quasi-isomorphism to quasi-isomorphism, sends equivalence Zariski local to equivalence Zariski local, and equivalence etale local to equivalence etale local, sends  $(\mathbb{A}^1, et)$  local equivalence to  $(\mathbb{A}^1, et)$  local equivalence.

*Proof.* Similar to the proof of proposition 4. □

**Proposition 9.** Let  $S \in \text{Var}(k)$ .

(i) The adjonction  $(\mu_S^*, \mu_{S*}) : C(\text{Var}(k)^{2,pr}/S) \rightleftarrows C(\text{Var}(k)^2/S)$  is a Quillen adjonction for the  $(\mathbb{A}^1, et)$  projective model structure.

(i)' The functor  $\mu_{S*} : C(\text{Var}(k)^2/S) \rightarrow C(\text{Var}(k)^{2,pr}/S)$  sends quasi-isomorphism to quasi-isomorphism, sends equivalence Zariski local to equivalence Zariski local, and equivalence etale local to equivalence etale local, sends  $(\mathbb{A}^1, et)$  local equivalence to  $(\mathbb{A}^1, et)$  local equivalence.

(ii) The adjonction  $(\mu_S^*, \mu_{S*}) : C(\text{Var}(k)^{2,smpr}/S) \rightleftarrows C(\text{Var}(k)^{2,pr}/S)$  is a Quillen adjonction for the  $(\mathbb{A}^1, et)$  projective model structure.

(ii)' The functor  $\mu_{S*} : C(\text{Var}(k)^{2,sm}/S) \rightarrow C(\text{Var}(k)^{2,smpr}/S)$  sends quasi-isomorphism to quasi-isomorphism, sends equivalence Zariski local to equivalence Zariski local, and equivalence etale local to equivalence etale local, sends  $(\mathbb{A}^1, et)$  local equivalence to  $(\mathbb{A}^1, et)$  local equivalence.

*Proof.* Similar to the proof of proposition 4. Indeed, for (i)' or (ii)', if  $m : F \rightarrow G$  with  $F, G \in C(\text{Var}(k)^{2,(sm)})$  is an equivalence  $(\mathbb{A}^1, et)$  local then (see proposition 6), there exists

$$\{(X_{1,\alpha}, Z_{1,\alpha})/S, \alpha \in \Lambda_1\}, \dots, \{(X_{r,\alpha}, Z_{r,\alpha})/S, \alpha \in \Lambda_r\} \subset \text{Var}(k)^{2,(sm)}/S$$

such that we have in  $\text{Ho}_{et}(C(\text{Var}(k)^{2,(sm)}/S))$

$$\begin{aligned} \text{Cone}(m) &\xrightarrow{\sim} \text{Cone}(\bigoplus_{\alpha \in \Lambda_1} \text{Cone}(\mathbb{Z}((X_{1,\alpha} \times \mathbb{A}^1, Z_{1,\alpha} \times \mathbb{A}^1)/S) \rightarrow \mathbb{Z}((X_{1,\alpha}, Z_{1,\alpha})/S)) \\ &\rightarrow \dots \rightarrow \bigoplus_{\alpha \in \Lambda_r} \text{Cone}(\mathbb{Z}((X_{r,\alpha} \times \mathbb{A}^1, Z_{r,\alpha} \times \mathbb{A}^1)/S) \rightarrow \mathbb{Z}((X_{r,\alpha}, Z_{r,\alpha})/S)) \\ &\xrightarrow{\sim} \text{Cone}(\text{Cone}(\bigoplus_{\alpha \in \Lambda_1} \mathbb{Z}((X_{1,\alpha}, Z_{1,\alpha})/S) \otimes \mathbb{Z}(\mathbb{A}^1, \mathbb{A}^1)/S) \rightarrow \bigoplus_{\alpha \in \Lambda_1} \mathbb{Z}((X_{1,\alpha}, Z_{1,\alpha})/S)) \\ &\rightarrow \dots \rightarrow \text{Cone}(\bigoplus_{\alpha \in \Lambda_r} \mathbb{Z}((X_{r,\alpha}, Z_{r,\alpha})/S) \otimes \mathbb{Z}(\mathbb{A}^1, \mathbb{A}^1)/S) \rightarrow \bigoplus_{\alpha \in \Lambda_r} \mathbb{Z}((X_{r,\alpha}, Z_{r,\alpha})/S)), \end{aligned}$$

this gives in  $\text{Ho}_{et}(C(\text{Var}(k)^{2,(sm)pr}/S))$

$$\begin{aligned} &\text{Cone}(\mu_{S*}m) \xrightarrow{\sim} \text{Cone}(\text{Cone}((L\mu_{S*} \bigoplus_{\alpha \in \Lambda_1} \mathbb{Z}((X_{1,\alpha}, Z_{1,\alpha})/S)) \otimes \mathbb{Z}(\mathbb{A}^1, \mathbb{A}^1)/S) \rightarrow (L\mu_{S*} \bigoplus_{\alpha \in \Lambda_1} \mathbb{Z}((X_{1,\alpha}, Z_{1,\alpha})/S))) \\ &\rightarrow \dots \rightarrow \text{Cone}((L\mu_{S*} \bigoplus_{\alpha \in \Lambda_r} \mathbb{Z}((X_{r,\alpha}, Z_{r,\alpha})/S)) \otimes \mathbb{Z}(\mathbb{A}^1, \mathbb{A}^1)/S) \rightarrow (L\mu_{S*} \bigoplus_{\alpha \in \Lambda_r} \mathbb{Z}((X_{1,\alpha}, Z_{1,\alpha})/S))) \end{aligned}$$

hence  $\mu_{S*}m : \mu_{S*}F \rightarrow \mu_{S*}G$  is an equivalence  $(\mathbb{A}^1, et)$  local. □

We also have

**Proposition 10.** Let  $S \in \text{Var}(k)$ .

(i) The adjonction  $(\text{Gr}_S^{12*}, \text{Gr}_{S*}^{12}) : C(\text{Var}(k)/S) \rightleftarrows C(\text{Var}(k)^{2,pr}/S)$  is a Quillen adjonction for the  $(\mathbb{A}^1, et)$  projective model structure.

(ii) The adjonction  $(\text{Gr}_S^{12*}, \text{Gr}_{S*}^{12}) : C(\text{Var}(k)^{sm}/S) \rightleftarrows C(\text{Var}(k)^{2,smpr}/S)$  is a Quillen adjonction for the  $(\mathbb{A}^1, et)$  projective model structure.

*Proof.* Immediate from definition. □

- For  $f : X \rightarrow S$  a morphism with  $X, S \in \text{Var}(k)$  and  $Z \subset X$  a closed subset, we denote  $\mathbb{Z}^{tr}((X, Z)/S) \in \text{PSh}(\text{Var}(k)^2/S)$  the presheaf given by
  - for  $(X', Z')/S \in \text{Var}(k)^2/S$ , with  $X'$  irreducible,
 
$$\mathbb{Z}^{tr}((X, Z)/S)((X', Z')/S) := \left\{ \alpha \in \mathcal{Z}^{fs/X}(X' \times_S X), s.t. p_X(p_{X'}^{-1}(Z')) \subset Z \right\} \subset \mathcal{Z}_{d_{X'}}(X' \times_S X)$$
  - for  $g : (X_2, Z_2)/S \rightarrow (X_1, Z_1)/S$  a morphism, with  $(X_1, Z_1)/S, (X_2, Z_2)/S \in \text{Var}(k)^2/S$ ,
 
$$\mathbb{Z}^{tr}((X, Z)/S)(g) : \mathbb{Z}^{tr}((X, Z)/S)((X_1, Z_1)/S) \rightarrow \mathbb{Z}^{tr}((X, Z)/S)((X_2, Z_2)/S), \alpha \mapsto (g \times I)^{-1}(\alpha)$$
 with  $g \times I : X_2 \times_S X \rightarrow X_1 \times_S X$ .
- For  $f : X \rightarrow S$  a morphism with  $X, S \in \text{Var}(k)$ ,  $Z \subset X$  a closed subset and  $r \in \mathbb{N}$ , we denote  $\mathbb{Z}^{equiv}((X, Z)/S) \in \text{PSh}(\text{Var}(k)^2/S)$  the presheaf given by
  - for  $(X', Z')/S \in \text{Var}(k)^2/S$ , with  $X'$  irreducible,
 
$$\mathbb{Z}^{equiv}((X, Z)/S)((X', Z')/S) := \left\{ \alpha \in \mathcal{Z}^{equiv/X}(X' \times_S X), s.t. p_X(p_{X'}^{-1}(Z')) \right\} \subset \mathcal{Z}_{d_{X'}}(X' \times_S X)$$
  - for  $g : (X_2, Z_2)/S \rightarrow (X_1, Z_1)/S$  a morphism, with  $(X_1, Z_1)/S, (X_2, Z_2)/S \in \text{Var}(k)^2/S$ ,
 
$$\mathbb{Z}^{equiv}((X, Z)/S)(g) : \mathbb{Z}^{equiv}((X, Z)/S)((X_1, Z_1)/S) \rightarrow \mathbb{Z}^{equiv}((X, Z)/S)((X_2, Z_2)/S), \alpha \mapsto (g \times I)^{-1}(\alpha)$$
 with  $g \times I : X_2 \times_S X \rightarrow X_1 \times_S X$ .
- Let  $S \in \text{Var}(k)$ . We denote by  $\mathbb{Z}_S(d) := \mathbb{Z}^{equiv0}((S \times \mathbb{A}^d, S \times \mathbb{A}^d)/S)[-2d]$  the Tate twist. For  $F \in C(\text{Var}(k)^2/S)$ , we denote by  $F(d) := F \otimes \mathbb{Z}_S(d)$ .

For  $S \in \text{Var}(k)$ , let  $\text{Cor}(\text{Var}(k)^{2,(sm)}/S)$  be the category

- whose objects are those of  $\text{Var}(k)^{2,(sm)}/S$ , i.e.  $(X, Z)/S = ((X, Z), h)$ ,  $h : X \rightarrow S$  with  $X \in \text{Var}(k)$ ,  $Z \subset X$  a closed subset,
- whose morphisms  $\alpha : (X', Z)/S = ((X', Z), h_1) \rightarrow (X, Z)/S = ((X, Z), h_2)$  is finite correspondence that is  $\alpha \in \oplus_i \mathbb{Z}^{tr}((X_i, Z)/S)((X', Z')/S)$ , where  $X' = \sqcup_i X'_i$ , with  $X'_i$  connected, the composition being defined in the same way as the morphism  $\text{Cor}(\text{Var}(k)^{(sm)}/S)$ .

We denote by  $\text{Tr}(S) : \text{Cor}(\text{Var}(k)^{2,(sm)}/S) \rightarrow \text{Var}(k)^{2,(sm)}/S$  the morphism of site given by the inclusion functor  $\text{Tr}(S) : \text{Var}(k)^{2,(sm)}/S \hookrightarrow \text{Cor}(\text{Var}(k)^{2,(sm)}/S)$  It induces an adjunction

$$(\text{Tr}(S)^* \text{Tr}(S)_*) : C(\text{Var}(k)^{2,(sm)}/S) \rightleftarrows C(\text{Cor}(\text{Var}(k)^{2,(sm)}/S))$$

A complex of preheaves  $G \in C(\text{Var}(k)^{2,(sm)}/S)$  is said to admit transferts if it is in the image of the embedding

$$\text{Tr}(S)_* : C(\text{Cor}(\text{Var}(k)^{2,(sm)}/S)) \hookrightarrow C(\text{Var}(k)^{2,(sm)}/S),$$

that is  $G = \text{Tr}(S)_* \text{Tr}(S)^* G$ . We then have the full subcategory  $\text{Cor}(\text{Var}(k)^{2,(sm)pr}/S) \subset \text{Cor}(\text{Var}(k)^{2,(sm)}/S)$  consisting of the objects of  $\text{Var}(k)^{2,(sm)pr}/S$ . We have the adjunction

$$(\text{Tr}(S)^* \text{Tr}(S)_*) : C(\text{Var}(k)^{2,(sm)pr}/S) \rightleftarrows C(\text{Cor}(\text{Var}(k)^{2,(sm)pr}/S))$$

A complex of preheaves  $G \in C(\text{Var}(k)^{2,(sm)pr}/S)$  is said to admit transferts if it is in the image of the embedding

$$\text{Tr}(S)_* : C(\text{Cor}(\text{Var}(k)^{2,(sm)pr}/S)) \hookrightarrow C(\text{Var}(k)^{2,(sm)pr}/S),$$

that is  $G = \text{Tr}(S)_* \text{Tr}(S)^* G$ .

Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i=1}^l S_i$  an open affine cover and denote by  $S_I = \cap_{i \in I} S_i$ . Let  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embeddings, with  $\tilde{S}_i \in \text{Var}(k)$ .

- For  $(G_I, K_{IJ}) \in C(\text{Var}(k)^{2,(sm)}/(\tilde{S}_I)^{op})$  and  $(H_I, T_{IJ}) \in C(\text{Var}(k)^{2,(sm)}/(\tilde{S}_I))$ , we denote  $\mathcal{H}om((G_I, K_{IJ}), (H_I, T_{IJ})) := (\mathcal{H}om(G_I, H_I), u_{IJ}((G_I, K_{IJ}), (H_I, T_{IJ}))) \in C(\text{Var}(k)^{2,(sm)}/(\tilde{S}_I))$  with

$$\begin{aligned} & u_{IJ}((G_I, K_{IJ})(H_I, T_{IJ})) : \mathcal{H}om(G_I, H_I) \\ \xrightarrow{\text{ad}(p_{IJ}^*, p_{IJ*})(-)} & p_{IJ*} p_{IJ}^* \mathcal{H}om(G_I, H_I) \xrightarrow{T(p_{IJ}, \text{hom})(-, -)} p_{IJ*} \mathcal{H}om(p_{IJ}^* G_I, p_{IJ}^* H_I) \\ \xrightarrow{\mathcal{H}om(p_{IJ}^* G_I, T_{IJ})} & p_{IJ*} \mathcal{H}om(p_{IJ}^* G_I, H_J) \xrightarrow{\mathcal{H}om(K_{IJ}, H_J)} p_{IJ*} \mathcal{H}om(G_J, H_J). \end{aligned}$$

This gives in particular the functor

$$\begin{aligned} \mathbb{D}_{(\tilde{S}_I)}^{12} : C(\text{Var}(k)^{2,(sm)}/(\tilde{S}_I)^{op}) &\rightarrow C(\text{Var}(k)^{2,(sm)}/(\tilde{S}_I)), \\ (H_I, T_{IJ}) \mapsto \mathbb{D}_{(\tilde{S}_I)}^{12} L(H_I, T_{IJ}) &:= \mathcal{H}om((LH_I, T_{IJ}^q), (E_{et} \mathbb{Z}_{\tilde{S}_I}, I_{IJ})) = (\mathbb{D}_{\tilde{S}_I}^{12} LH_I, T_{IJ}^d) \end{aligned}$$

- For  $(G_I, K_{IJ}) \in C(\text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I)^{op})$  and  $(H_I, T_{IJ}) \in C(\text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I))$ , we denote  $\mathcal{H}om((G_I, K_{IJ}), (H_I, T_{IJ})) := (\mathcal{H}om(G_I, H_I), u_{IJ}((G_I, K_{IJ}), (H_I, T_{IJ}))) \in C(\text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I))$  with

$$\begin{aligned} & u_{IJ}((G_I, K_{IJ})(H_I, T_{IJ})) : \mathcal{H}om(G_I, H_I) \\ \xrightarrow{\text{ad}(p_{IJ}^*, p_{IJ*})(-)} & p_{IJ*} p_{IJ}^* \mathcal{H}om(G_I, H_I) \xrightarrow{T(p_{IJ}, \text{hom})(-, -)} p_{IJ*} \mathcal{H}om(p_{IJ}^* G_I, p_{IJ}^* H_I) \\ \xrightarrow{\mathcal{H}om(p_{IJ}^* G_I, T_{IJ})} & p_{IJ*} \mathcal{H}om(p_{IJ}^* G_I, H_J) \xrightarrow{\mathcal{H}om(K_{IJ}, H_J)} p_{IJ*} \mathcal{H}om(G_J, H_J). \end{aligned}$$

This gives in particular the functor

$$\mathbb{D}_{(\tilde{S}_I)}^{12} : C(\text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I)^{op}) \rightarrow C(\text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I)), (H_I, T_{IJ}) \mapsto \mathbb{D}_{(\tilde{S}_I)}^{12} L(H_I, T_{IJ})$$

The functors  $p_a$  naturally extend to functors

$$\begin{aligned} p_a : \text{Var}(k)^{2,(sm)}/(\tilde{S}_I) &\rightarrow \text{Var}(k)^{2,(sm)}/(\tilde{S}_I), \\ ((X, Z)/\tilde{S}_I, u_{IJ}) &\mapsto ((X \times \mathbb{A}^1, Z \times \mathbb{A}^1)/\tilde{S}_I, u_{IJ} \times I), \\ (g : ((X, Z)/\tilde{S}_I, u_{IJ}) &\rightarrow ((X', Z')/\tilde{S}_I, u_{IJ})) \mapsto \\ ((g \times I_{\mathbb{A}^1}) : ((X \times \mathbb{A}^1, Z \times \mathbb{A}^1)/\tilde{S}_I, u_{IJ} \times I) &\rightarrow ((X' \times \mathbb{A}^1, Z' \times \mathbb{A}^1)/\tilde{S}_I, u_{IJ} \times I)) \end{aligned}$$

the projection functor and again by  $p_a : \text{Var}(k)^{2,(sm)}/(\tilde{S}_I) \rightarrow \text{Var}(k)^{2,(sm)}/(\tilde{S}_I)$  the corresponding morphism of site, and

$$\begin{aligned} p_a : \text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I) &\rightarrow \text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I), \\ ((Y \times \tilde{S}_I, Z)/\tilde{S}_I, u_{IJ}) &\mapsto ((Y \times \tilde{S}_I \times \mathbb{A}^1, Z \times \mathbb{A}^1)/\tilde{S}_I, u_{IJ} \times I), \\ (g : ((Y \times \tilde{S}_I, Z)/\tilde{S}_I, u_{IJ}) &\rightarrow ((Y' \times \tilde{S}_I, Z')/\tilde{S}_I, u_{IJ})) \mapsto \\ ((g \times I_{\mathbb{A}^1}) : ((Y \times \tilde{S}_I \times \mathbb{A}^1, Z \times \mathbb{A}^1)/\tilde{S}_I, u_{IJ} \times I), &((Y' \times \tilde{S}_I \times \mathbb{A}^1, Z' \times \mathbb{A}^1)/\tilde{S}_I, u_{IJ} \times I)), \end{aligned}$$

the projection functor and again by  $p_a : \text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I) \rightarrow \text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I)$  the corresponding morphism of site. These functors also gives the morphisms of sites  $p_a : \text{Var}(k)^{2,(sm)}/(\tilde{S}_I)^{op} \rightarrow \text{Var}(k)^{2,(sm)}/(\tilde{S}_I)^{op}$  and  $p_a : \text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I)^{op} \rightarrow \text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I)^{op}$ .

**Definition 19.** Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i=1}^l S_i$  an open affine cover and denote by  $S_I = \cap_{i \in I} S_i$ . Let  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embeddings, with  $\tilde{S}_i \in \text{Var}(k)$ .

(i0) A complex  $(F_I, u_{IJ}) \in C(\text{Var}(k)^{2,(sm)}/(\tilde{S}_I))$  is said to be  $\mathbb{A}^1$  homotopic if  $\text{ad}(p_a^*, p_{a*})((F_I, u_{IJ})) : (F_I, u_{IJ}) \rightarrow p_{a*}p_a^*(F_I, u_{IJ})$  is an homotopy equivalence.

(i0)' A complex  $(F_I, u_{IJ}) \in C(\text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I))$  is said to be  $\mathbb{A}^1$  homotopic if  $\text{ad}(p_a^*, p_{a*})((F_I, u_{IJ})) : (F_I, u_{IJ}) \rightarrow p_{a*}p_a^*(F_I, u_{IJ})$  is an homotopy equivalence.

(i) A complex  $(F_I, u_{IJ}) \in C(\text{Var}(k)^{2,(sm)}/(\tilde{S}_I))$  is said to be  $\mathbb{A}^1$  invariant if for all  $((X_I, Z_I)/\tilde{S}_I, s_{IJ}) \in \text{Var}(k)^{2,(sm)}/(\tilde{S}_I)$

$$(F_I(p_{X_I})) : (F_I((X_I, Z_I)/\tilde{S}_I), F_J(s_{IJ}) \circ u_{IJ}(-)) \rightarrow (F_I((X_I \times \mathbb{A}^1, (Z_I \times \mathbb{A}^1))/\tilde{S}_I), F_J(s_{IJ} \times I) \circ u_{IJ}(-))$$

is a quasi-isomorphism, where  $p_{X_I} : (X_I \times \mathbb{A}^1, (Z_I \times \mathbb{A}^1)) \rightarrow (X_I, Z_I)$  are the projection, and  $s_{IJ} : (X_I \times \tilde{S}_{J \setminus I}, Z_I)/\tilde{S}_I \rightarrow (X_J, Z_J)/\tilde{S}_I$ . Obviously a complex  $(F_I, u_{IJ}) \in C(\text{Var}(k)^{2,(sm)}/(\tilde{S}_I))$  is  $\mathbb{A}^1$  invariant if and only if all the  $F_I$  are  $\mathbb{A}^1$  invariant.

(i)' A complex  $(G_I, u_{IJ}) \in C(\text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I))$  is said to be  $\mathbb{A}^1$  invariant if for all  $((Y \times \tilde{S}_I, Z_I)/\tilde{S}_I, s_{IJ}) \in \text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I)$

$$(G_I(p_{Y \times \tilde{S}_I})) : (G_I((Y \times \tilde{S}_I, Z_I)/\tilde{S}_I), G_J(s_{IJ}) \circ u_{IJ}(-)) \rightarrow (G_I((Y \times \tilde{S}_I \times \mathbb{A}^1, (Z_I \times \mathbb{A}^1))/\tilde{S}_I), G_J(s_{IJ} \times I) \circ u_{IJ}(-))$$

is a quasi-isomorphism. Obviously a complex  $(G_I, u_{IJ}) \in C(\text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I))$  is  $\mathbb{A}^1$  invariant if and only if all the  $G_I$  are  $\mathbb{A}^1$  invariant.

(ii) Let  $\tau$  a topology on  $\text{Var}(k)$ . A complex  $F = (F_I, u_{IJ}) \in C(\text{Var}(k)^{2,(sm)}/(\tilde{S}_I))$  is said to be  $\mathbb{A}^1$  local for the  $\tau$  topology induced on  $\text{Var}(k)^2/(\tilde{S}_I)$ , if for an (hence every)  $\tau$  local equivalence  $k : F \rightarrow G$  with  $k$  injective and  $G = (G_I, v_{IJ}) \in C(\text{Var}(k)^{2,(sm)}/(\tilde{S}_I))$   $\tau$  fibrant, e.g.  $k : (F_I, u_{IJ}) \rightarrow (E_\tau(F_I), E(u_{IJ}))$ ,  $G$  is  $\mathbb{A}^1$  invariant.

(ii)' Let  $\tau$  a topology on  $\text{Var}(k)$ . A complex  $F = (F_I, u_{IJ}) \in C(\text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I))$  is said to be  $\mathbb{A}^1$  local for the  $\tau$  topology induced on  $\text{Var}(k)^2/(\tilde{S}_I)$ , if for an (hence every)  $\tau$  local equivalence  $k : F \rightarrow G$  with  $k$  injective and  $G = (G_I, u_{IJ}) \in C(\text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I))$   $\tau$  fibrant, e.g.  $k : (F_I, u_{IJ}) \rightarrow (E_\tau(F_I), E(u_{IJ}))$ ,  $G$  is  $\mathbb{A}^1$  invariant.

(iii) A morphism  $m = (m_I) : (F_I, u_{IJ}) \rightarrow (G_I, v_{IJ})$  with  $(F_I, u_{IJ}), (G_I, v_{IJ}) \in C(\text{Var}(k)^{2,(sm)}/(\tilde{S}_I))$  is said to be an  $(\mathbb{A}^1, \text{et})$  local equivalence if for all  $H = (H_I, w_{IJ}) \in C(\text{Var}(k)^{2,(sm)}/(\tilde{S}_I))$  which is  $\mathbb{A}^1$  local for the etale topology

$$(\text{Hom}(L(m_I), E_{\text{et}}(H_I))) : \text{Hom}(L(G_I, v_{IJ}), E_{\text{et}}(H_I, w_{IJ})) \rightarrow \text{Hom}(L(F_I, u_{IJ}), E_{\text{et}}(H_I, w_{IJ}))$$

is a quasi-isomorphism (of complexes of abelian groups). Obviously, if a morphism  $m = (m_I) : (F_I, u_{IJ}) \rightarrow (G_I, v_{IJ})$  with  $(F_I, u_{IJ}), (G_I, v_{IJ}) \in C(\text{Var}(k)^{2,(sm)}/(\tilde{S}_I))$  is an  $(\mathbb{A}^1, \text{et})$  local equivalence, then all the  $m_I : F_I \rightarrow G_I$  are  $(\mathbb{A}^1, \text{et})$  local equivalence.

(iii)' A morphism  $m = (m_I) : (F_I, u_{IJ}) \rightarrow (G_I, v_{IJ})$  with  $(F_I, u_{IJ}), (G_I, v_{IJ}) \in C(\text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I))$  is said to be an  $(\mathbb{A}^1, \text{et})$  local equivalence if for all  $(H_I, w_{IJ}) \in C(\text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I))$  which is  $\mathbb{A}^1$  local for the etale topology

$$(\text{Hom}(L(m_I), E_{\text{et}}(H_I))) : \text{Hom}(L(G_I, v_{IJ}), E_{\text{et}}(H_I, w_{IJ})) \rightarrow \text{Hom}(L(F_I, u_{IJ}), E_{\text{et}}(H_I, w_{IJ}))$$

is a quasi-isomorphism (of complexes of abelian groups). Obviously, if a morphism  $m = (m_I) : (F_I, u_{IJ}) \rightarrow (G_I, v_{IJ})$  with  $(F_I, u_{IJ}), (G_I, v_{IJ}) \in C(\text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I))$  is an  $(\mathbb{A}^1, \text{et})$  local equivalence, then all the  $m_I : F_I \rightarrow G_I$  are  $(\mathbb{A}^1, \text{et})$  local equivalence.

(iv) A morphism  $m = (m_I) : (F_I, u_{IJ}) \rightarrow (G_I, v_{IJ})$  with  $(F_I, u_{IJ}), (G_I, v_{IJ}) \in C(\text{Var}(k)^{2,(sm)})/(\tilde{S}_I)^{op}$  is said to be an  $(\mathbb{A}^1, et)$  local equivalence if for all  $H = (H_I, w_{IJ}) \in C(\text{Var}(k)^{2,(sm)})/(\tilde{S}_I)^{op}$  which is  $\mathbb{A}^1$  local for the etale topology

$$(\text{Hom}(L(m_I), E_{et}(H_I))) : \text{Hom}(L(G_I, v_{IJ}), E_{et}(H_I, w_{IJ})) \rightarrow \text{Hom}(L(F_I, u_{IJ}), E_{et}(H_I, w_{IJ}))$$

is a quasi-isomorphism (of complexes of abelian groups). Obviously, if a morphism  $m = (m_I) : (F_I, u_{IJ}) \rightarrow (G_I, v_{IJ})$  with  $(F_I, u_{IJ}), (G_I, v_{IJ}) \in C(\text{Var}(k)^{2,(sm)})/(\tilde{S}_I)^{op}$  is an  $(\mathbb{A}^1, et)$  local equivalence, then all the  $m_I : F_I \rightarrow G_I$  are  $(\mathbb{A}^1, et)$  local equivalence and for all  $H = (H_I, w_{IJ}) \in C(\text{Var}(k)^{2,(sm)})/(\tilde{S}_I)$  which is  $\mathbb{A}^1$  local for the etale topology

$$(\text{Hom}(L(m_I), E_{et}(H_I))) : \text{Hom}(L(G_I, v_{IJ}), E_{et}(H_I, w_{IJ})) \rightarrow \text{Hom}(L(F_I, u_{IJ}), E_{et}(H_I, w_{IJ}))$$

is a quasi-isomorphism (of diagrams of complexes of abelian groups)

(iv)' A morphism  $m = (m_I) : (F_I, u_{IJ}) \rightarrow (G_I, v_{IJ})$  with  $(F_I, u_{IJ}), (G_I, v_{IJ}) \in C(\text{Var}(k)^{2,(sm)pr})/(\tilde{S}_I)^{op}$  is said to be an  $(\mathbb{A}^1, et)$  local equivalence if for all  $(H_I, w_{IJ}) \in C(\text{Var}(k)^{2,(sm)pr})/(\tilde{S}_I)^{op}$  which is  $\mathbb{A}^1$  local for the etale topology

$$(\text{Hom}(L(m_I), E_{et}(H_I))) : \text{Hom}(L(G_I, v_{IJ}), E_{et}(H_I, w_{IJ})) \rightarrow \text{Hom}(L(F_I, u_{IJ}), E_{et}(H_I, w_{IJ}))$$

is a quasi-isomorphism (of complexes of abelian groups). Obviously, if a morphism  $m = (m_I) : (F_I, u_{IJ}) \rightarrow (G_I, v_{IJ})$  with  $(F_I, u_{IJ}), (G_I, v_{IJ}) \in C(\text{Var}(k)^{2,(sm)pr})/(\tilde{S}_I)^{op}$  is an  $(\mathbb{A}^1, et)$  local equivalence, then all the  $m_I : F_I \rightarrow G_I$  are  $(\mathbb{A}^1, et)$  local equivalence and for all  $(H_I, w_{IJ}) \in C(\text{Var}(k)^{2,(sm)pr})/(\tilde{S}_I)$  which is  $\mathbb{A}^1$  local for the etale topology

$$(\text{Hom}(L(m_I), E_{et}(H_I))) : \text{Hom}(L(G_I, v_{IJ}), E_{et}(H_I, w_{IJ})) \rightarrow \text{Hom}(L(F_I, u_{IJ}), E_{et}(H_I, w_{IJ}))$$

is a quasi-isomorphism (of diagrams of complexes of abelian groups).

**Proposition 11.** Let  $S \in \text{Var}(k)$ . Let  $S = \bigcup_{i=1}^l S_i$  an open affine cover and denote by  $S_I = \bigcap_{i \in I} S_i$ . Let  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embeddings, with  $\tilde{S}_i \in \text{Var}(k)$ .

- (i) Then for  $F \in C(\text{Var}(k)^{2,(sm)})/(\tilde{S}_I)^{op}$ ,  $C_*F$  is  $\mathbb{A}^1$  local for the etale topology and  $c(F) : F \rightarrow C_*F$  is an equivalence  $(\mathbb{A}^1, et)$  local.
- (i)' Then for  $F \in C(\text{Var}(k)^{2,(sm)pr})/(\tilde{S}_I)^{op}$ ,  $C_*F$  is  $\mathbb{A}^1$  local for the etale topology and  $c(F) : F \rightarrow C_*F$  is an equivalence  $(\mathbb{A}^1, et)$  local.
- (ii) A morphism  $m : F \rightarrow G$  with  $F, G \in C(\text{Var}(k)^{2,(sm)})/(\tilde{S}_I)^{op}$  is an  $(\mathbb{A}^1, et)$  local equivalence if and only if  $a_{et}H^n C_* \text{Cone}(m) = 0$  for all  $n \in \mathbb{Z}$ .
- (ii)' A morphism  $m : F \rightarrow G$  with  $F, G \in C(\text{Var}(k)^{2,(sm)pr})/(\tilde{S}_I)^{op}$  is an  $(\mathbb{A}^1, et)$  local equivalence if and only if  $a_{et}H^n C_* \text{Cone}(m) = 0$  for all  $n \in \mathbb{Z}$ .
- (iii) A morphism  $m : F \rightarrow G$  with  $F, G \in C(\text{Var}(k)^{2,(sm)})/(\tilde{S}_I)^{op}$  is an  $(\mathbb{A}^1, et)$  local equivalence if and only if there exists

$$\left\{ ((X_{1,\alpha,I}, Z_{1,\alpha,I})/\tilde{S}_I, u_{IJ}^1), \alpha \in \Lambda_1 \right\}, \dots, \left\{ ((X_{r,\alpha,I}, Z_{r,\alpha,I})/\tilde{S}_I, u_{IJ}^r), \alpha \in \Lambda_r \right\} \subset \text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I)^{op}$$

with

$$u_{IJ}^1 : (X_{1,\alpha,I}, Z_{1,\alpha,I})/\tilde{S}_I \rightarrow (X_{1,\alpha,I} \times \tilde{S}_{J \setminus I}, Z_{1,\alpha,I} \times \tilde{S}_{J \setminus I})/\tilde{S}_J$$

such that we have in  $\text{Ho}_{et}(C(\text{Var}(k)^{2,(sm)})/(\tilde{S}_I)^{op})$

$$\begin{aligned} & \text{Cone}(m) \xrightarrow{\sim} \text{Cone} \\ & \oplus_{\alpha \in \Lambda_1} \text{Cone}(\mathbb{Z}((X_{1,\alpha,I} \times \mathbb{A}^1, Z_{1,\alpha,I} \times \mathbb{A}^1)/\tilde{S}_I), \mathbb{Z}(u_{IJ}^1 \times I)) \rightarrow \mathbb{Z}((X_{1,\alpha,I}, Z_{1,\alpha,I})/\tilde{S}_I, \mathbb{Z}(u_{IJ}^1)) \\ & \rightarrow \dots \rightarrow \\ & \oplus_{\alpha \in \Lambda_r} \text{Cone}(\mathbb{Z}((X_{r,\alpha,I} \times \mathbb{A}^1, Z_{r,\alpha,I} \times \mathbb{A}^1)/\tilde{S}_I), \mathbb{Z}(u_{IJ}^r \times I)) \rightarrow \mathbb{Z}((X_{r,\alpha,I}, Z_{r,\alpha,I})/\tilde{S}_I, \mathbb{Z}(u_{IJ}^r)) \end{aligned}$$

(iii)' A morphism  $m : F \rightarrow G$  with  $F, G \in C(\text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I)^{op})$  is an  $(\mathbb{A}^1, et)$  local equivalence if and only if there exists

$$\left\{ ((Y_{1,\alpha,I} \times \tilde{S}_I, Z_{1,\alpha,I})/\tilde{S}_I, u_{IJ}^1), \alpha \in \Lambda_1 \right\}, \dots, \left\{ ((Y_{r,\alpha,I} \times \tilde{S}_I, Z_{r,\alpha,I})/\tilde{S}_I, u_{IJ}^r), \alpha \in \Lambda_r \right\} \\ \subset \text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I)$$

with

$$u_{IJ}^l : (Y_{l,\alpha,J} \times \tilde{S}_J, Z_{l,\alpha,J})/\tilde{S}_J \rightarrow (Y_{l,\alpha,I} \times \tilde{S}_J, Z_{l,\alpha,I} \times \tilde{S}_{J \setminus I})/\tilde{S}_J$$

such that we have in  $\text{Ho}_{et}(C(\text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I)^{op}))$

$$\begin{aligned} \text{Cone}(m) &\xrightarrow{\sim} \text{Cone}(\bigoplus_{\alpha \in \Lambda_1} \text{Cone}(\mathbb{Z}((Y_{1,\alpha,I} \times \mathbb{A}^1 \times \tilde{S}_I, Z_{1,\alpha,I} \times \mathbb{A}^1)/\tilde{S}_I), \mathbb{Z}(u_{IJ}^1 \times I)) \rightarrow \mathbb{Z}((Y_{1,\alpha,I} \times S, Z_{1,\alpha,I})/\tilde{S}_I), \mathbb{Z}(u_{IJ})) \\ &\rightarrow \dots \rightarrow \bigoplus_{\alpha \in \Lambda_r} \text{Cone}(\mathbb{Z}((Y_{r,\alpha,I} \times \mathbb{A}^1 \times \tilde{S}_I, Z_{r,\alpha,I} \times \mathbb{A}^1)/\tilde{S}_I), \mathbb{Z}(u_{IJ}^r \times I)) \rightarrow \mathbb{Z}((Y_{r,\alpha,I} \times \tilde{S}_I, Z_{r,\alpha,I})/\tilde{S}_I), \mathbb{Z}(u_{IJ}^r)) \end{aligned}$$

(iv) A similar statement then (iii) holds for equivalence  $(\mathbb{A}^1, et)$  local  $m : F \rightarrow G$  with  $F, G \in C(\text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I))$

(iv)' A similar statement then (iii) holds for equivalence  $(\mathbb{A}^1, et)$  local  $m : F \rightarrow G$  with  $F, G \in C(\text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I))$

*Proof.* Similar to the proof of proposition 6. See Ayoub's thesis for example.  $\square$

In the filtered case we also consider :

**Definition 20.** Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i=1}^l S_i$  an open affine cover and denote by  $S_I = \cap_{i \in I} S_i$ . Let  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embeddings, with  $\tilde{S}_i \in \text{SmVar}(k)$ .

- (i) A filtered complex  $(G, F) \in C_{fil}(\text{Var}(k)^{2,(sm)pr}/S)$  is said to be  $r$ -filtered  $\mathbb{A}^1$  homotopic if  $\text{ad}(p_a^*, p_{a*})(G, F) : (G, F) \rightarrow p_{a*}p_a^*(G, F)$  is an  $r$ -filtered homotopy equivalence.
- (i)' A filtered complex  $(G, F) \in C_{fil}(\text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I))$  is said to be  $r$ -filtered  $\mathbb{A}^1$  homotopic if  $\text{ad}(p_a^*, p_{a*})(G, F) : (G, F) \rightarrow p_{a*}p_a^*(G, F)$  is an  $r$ -filtered homotopy equivalence.
- (ii) A filtered complex  $(G, F) \in C_{fil}(\text{Var}(k)^{2,(sm)pr}/S)$  is said to be  $r$ -filtered  $\mathbb{A}^1$  homotopic if  $\text{ad}(p_a^*, p_{a*})(G, F) : (G, F) \rightarrow p_{a*}p_a^*(G, F)$  is an  $r$ -filtered homotopy equivalence.
- (ii)' A filtered complex  $(G, F) \in C_{fil}(\text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I))$  is said to be  $r$ -filtered  $\mathbb{A}^1$  homotopic if  $\text{ad}(p_a^*, p_{a*})(G, F) : (G, F) \rightarrow p_{a*}p_a^*(G, F)$  is an  $r$ -filtered homotopy equivalence.

We will use to compute the algebraic De Rahm realization functor the followings

**Theorem 14.** Let  $S \in \text{Var}(k)$ .

- (i) Let  $\phi : F^\bullet \rightarrow G^\bullet$  an etale local equivalence with  $F^\bullet, G^\bullet \in C(\text{Var}(k)^{2,sm}/S)$ . If  $F^\bullet$  and  $G^\bullet$  are  $\mathbb{A}^1$  local and admit transferts then  $\phi : F^\bullet \rightarrow G^\bullet$  is a Zariski local equivalence. Hence if  $F \in C(\text{Var}(k)^{2,sm}/S)$  is  $\mathbb{A}^1$  local and admits transfert

$$k : E_{zar}(F) \rightarrow E_{et}(E_{zar}(F)) = E_{et}(F)$$

is a Zariski local equivalence.

- (ii) Let  $\phi : F^\bullet \rightarrow G^\bullet$  an etale local equivalence with  $F^\bullet, G^\bullet \in C(\text{Var}(k)^{2,smpr}/S)$ . If  $F^\bullet$  and  $G^\bullet$  are  $\mathbb{A}^1$  local and admit transferts then  $\phi : F^\bullet \rightarrow G^\bullet$  is a Zariski local equivalence. Hence if  $F \in C(\text{Var}(k)^{2,smpr}/S)$  is  $\mathbb{A}^1$  local and admits transfert

$$k : E_{zar}(F) \rightarrow E_{et}(E_{zar}(F)) = E_{et}(F)$$

is a Zariski local equivalence.



*Proof.* Similar to the proof of theorem 13. □

**Theorem 15.** *Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i=1}^l S_i$  an open affine cover and denote by  $S_I = \cap_{i \in I} S_i$ . Let  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embeddings, with  $\tilde{S}_i \in \text{Var}(k)$ .*

- (i) *Let  $\phi : (F^\bullet, F) \rightarrow (G^\bullet, F)$  a filtered etale local equivalence with  $(F^\bullet, F), (G^\bullet, F) \in C_{fil}(\text{Var}(k)^{2,sm}/S)$ . If  $(F^\bullet, F)$  and  $(G^\bullet, F)$  are  $r$ -filtered  $\mathbb{A}^1$  homotopic and admit transferts then  $\phi : (F^\bullet, F) \rightarrow (G^\bullet, F)$  is an  $r$ -filtered Zariski local equivalence. Hence if  $(G, F) \in C(\text{Var}(k)^{2,sm}/S)$  is  $r$ -filtered  $\mathbb{A}^1$  homotopic and admits transfert*

$$k : E_{zar}(G, F) \rightarrow E_{et}(E_{zar}(G, F)) = E_{et}(G, F)$$

*is an  $r$ -filtered Zariski local equivalence.*

- (i)' *Let  $\phi : (F^\bullet, F) \rightarrow (G^\bullet, F)$  a filtered etale local equivalence with  $((F_I^\bullet, F), u_{IJ}), ((G_I^\bullet, F), v_{IJ}) \in C_{fil}(\text{Var}(k)^{2,sm}/(\tilde{S}_I))$ . If  $((F^\bullet, F), u_{IJ})$  and  $((G^\bullet, F), v_{IJ})$  are  $r$ -filtered  $\mathbb{A}^1$  homotopic and admit transferts then  $\phi : ((F^\bullet, F), u_{IJ}) \rightarrow ((G^\bullet, F), v_{IJ})$  is an  $r$ -filtered Zariski local equivalence. Hence if  $((G_I, F), u_{IJ}) \in C(\text{Var}(k)^{2,sm}/S)$  is  $r$ -filtered  $\mathbb{A}^1$  homotopic and admits transfert*

$$k : (E_{zar}(G_I, F), u_{IJ}) \rightarrow (E_{et}(E_{zar}(G_I, F)), u_{IJ}) = (E_{et}(G, F), u_{IJ})$$

*is an  $r$ -filtered Zariski local equivalence.*

- (ii) *Let  $\phi : (F^\bullet, F) \rightarrow (G^\bullet, F)$  a filtered etale local equivalence with  $(F^\bullet, F), (G^\bullet, F) \in C_{fil}(\text{Var}(k)^{2,smpr}/S)$ . If  $F^\bullet$  and  $G^\bullet$  are  $r$ -filtered  $\mathbb{A}^1$  homotopic and admit transferts then  $\phi : (F^\bullet, F) \rightarrow (G^\bullet, F)$  is an  $r$ -filtered Zariski local equivalence. Hence if  $(G, F) \in C(\text{Var}(k)^{2,smpr}/S)$  is  $r$ -filtered  $\mathbb{A}^1$  homotopic and admits transfert*

$$k : E_{zar}(F) \rightarrow E_{et}(E_{zar}(F)) = E_{et}(F)$$

*is an  $r$ -filtered Zariski local equivalence.*

- (ii)' *Let  $\phi : (F^\bullet, F) \rightarrow (G^\bullet, F)$  a filtered etale local equivalence with  $((F_I^\bullet, F), u_{IJ}), ((G_I^\bullet, F), v_{IJ}) \in C_{fil}(\text{Var}(k)^{2,smpr}/(\tilde{S}_I))$ . If  $((F^\bullet, F), u_{IJ})$  and  $((G^\bullet, F), v_{IJ})$  are  $r$ -filtered  $\mathbb{A}^1$  homotopic and admit transferts then  $\phi : ((F^\bullet, F), u_{IJ}) \rightarrow ((G^\bullet, F), v_{IJ})$  is an  $r$ -filtered Zariski local equivalence. Hence if  $((G_I, F), u_{IJ}) \in C(\text{Var}(k)^{2,smpr}/S)$  is  $r$ -filtered  $\mathbb{A}^1$  homotopic and admits transfert*

$$k : (E_{zar}(G_I, F), u_{IJ}) \rightarrow (E_{et}(E_{zar}(G_I, F)), u_{IJ}) = (E_{et}(G, F), u_{IJ})$$

*is an  $r$ -filtered Zariski local equivalence.*

*Proof.* Similar to the proof of theorem 14. □

## 2.8 The Borel-Moore Corti-Hanamura resolution functors $R^{CH}$ , $\hat{R}^{CH}$ , $R^{0CH}$ , and $\hat{R}^{0CH}$

Let  $k$  a field of characteristic zero.

**Definition 21.** (i) *Let  $X_0 \in \text{Var}(k)$  and  $Z \subset X_0$  a closed subset. A desingularization of  $(X_0, Z)$  is a pair of complex varieties  $(X, D) \in \text{Var}^2(k)$ , together with a morphism of pair of varieties  $\epsilon : (X, D) \rightarrow (X_0, \Delta)$  with  $Z \subset \Delta$  such that*

- $X \in \text{SmVar}(k)$  and  $D := \epsilon^{-1}(\Delta) = \epsilon^{-1}(Z) \cup (\cup_i E_i) \subset X$  is a normal crossing divisor
- $\epsilon : X \rightarrow X_0$  is a proper modification with discriminant  $\Delta$ , that is  $\epsilon : X \rightarrow X_0$  is proper and  $\epsilon : X \setminus D \xrightarrow{\sim} X \setminus \Delta$  is an isomorphism.

- (ii) *Let  $X_0 \in \text{Var}(k)$  and  $Z \subset X_0$  a closed subset such that  $X_0 \setminus Z$  is smooth. A strict desingularization of  $(X_0, Z)$  is a pair of complex varieties  $(X, D) \in \text{Var}^2(\mathbb{C})$ , together with a morphism of pair of varieties  $\epsilon : (X, D) \rightarrow (X_0, Z)$  such that*

- $X \in \text{SmVar}(k)$  and  $D := \epsilon^{-1}(Z) \subset X$  is a normal crossing divisor
- $\epsilon : X \rightarrow X_0$  is a proper modification with discriminant  $Z$ , that is  $\epsilon : X \rightarrow X_0$  is proper and  $\epsilon : X \setminus D \xrightarrow{\sim} X \setminus Z$  is an isomorphism.

We have the following well known resolution of singularities of complex algebraic varieties and their functorialities :

**Theorem 16.** (i) Let  $X_0 \in \text{Var}(k)$  and  $Z \subset X_0$  a closed subset. There exists a desingularization of  $(X_0, Z)$ , that is a pair of complex varieties  $(X, D) \in \text{Var}^2(k)$ , together with a morphism of pair of varieties  $\epsilon : (X, D) \rightarrow (X_0, \Delta)$  with  $Z \subset \Delta$  such that

- $X \in \text{SmVar}(k)$  and  $D := \epsilon^{-1}(\Delta) = \epsilon^{-1}(Z) \cup (\cup_i E_i) \subset X$  is a normal crossing divisor
- $\epsilon : X \rightarrow X_0$  is a proper modification with discriminant  $\Delta$ , that is  $\epsilon : X \rightarrow X_0$  is proper and  $\epsilon : X \setminus D \xrightarrow{\sim} X \setminus \Delta$  is an isomorphism.

(ii) Let  $X_0 \in \text{PVar}(k)$  and  $Z \subset X_0$  a closed subset such that  $X_0 \setminus Z$  is smooth. There exists a strict desingularization of  $(X_0, Z)$ , that is a pair of complex varieties  $(X, D) \in \text{PVar}^2(k)$ , together with a morphism of pair of varieties  $\epsilon : (X, D) \rightarrow (X_0, Z)$  such that

- $X \in \text{PSmVar}(k)$  and  $D := \epsilon^{-1}(Z) \subset X$  is a normal crossing divisor
- $\epsilon : X \rightarrow X_0$  is a proper modification with discriminant  $Z$ , that is  $\epsilon : X \rightarrow X_0$  is proper and  $\epsilon : X \setminus D \xrightarrow{\sim} X \setminus Z$  is an isomorphism.

*Proof.* (i):Standard. See [23] for example.

(ii):Follows immediately from (i). □

We use this theorem to construct a resolution of a morphism by Corti-Hanamura morphisms, we will need these resolution in the definition of the filtered De Rham realization functor :

**Definition-Proposition 3.** (i) Let  $h : V \rightarrow S$  a morphism, with  $V, S \in \text{Var}(k)$ . Let  $\bar{S} \in \text{PVar}(k)$  be a compactification of  $S$ .

- There exist a compactification  $\bar{X}_0 \in \text{PVar}(\mathbb{C})$  of  $V$  such that  $h : V \rightarrow S$  extend to a morphism  $\bar{f}_0 = \bar{h}_0 : \bar{X}_0 \rightarrow \bar{S}$ . Denote by  $\bar{Z} = \bar{X}_0 \setminus V$ . We denote by  $j : V \hookrightarrow \bar{X}_0$  the open embedding and by  $i_0 : \bar{Z} \hookrightarrow \bar{X}_0$  the complementary closed embedding. We then consider  $X_0 := \bar{f}_0^{-1}(S) \subset \bar{X}_0$  the open subset,  $f_0 := \bar{f}_0|_{X_0} : X_0 \rightarrow S$ ,  $Z = \bar{Z} \cap X_0$ , and we denote again  $j : V \hookrightarrow X_0$  the open embedding and by  $i_0 : Z \hookrightarrow X_0$  the complementary closed embedding.
- In the case  $V$  is smooth, we take, using theorem 16(ii), a strict desingularization  $\bar{\epsilon} : (\bar{X}, \bar{D}) \rightarrow (\bar{X}_0, \bar{Z})$  of the pair  $(\bar{X}_0, \bar{Z})$ , with  $\bar{X} \in \text{PSmVar}(\mathbb{C})$  and  $\bar{D} = \cup_{i=1}^s \bar{D}_i \subset \bar{X}$  a normal crossing divisor. We denote by  $i_\bullet : \bar{D}_\bullet \hookrightarrow \bar{X} = \bar{X}_{c(\bullet)}$  the morphism of simplicial varieties given by the closed embeddings  $i_I : \bar{D}_I = \cap_{i \in I} \bar{D}_i \hookrightarrow \bar{X}$ . Then the morphisms  $\bar{f} := \bar{f}_0 \circ \bar{\epsilon} : \bar{X} \rightarrow \bar{S}$  and  $\bar{f}_{D_\bullet} := \bar{f} \circ i_\bullet : \bar{D}_\bullet \rightarrow \bar{S}$  are projective since  $\bar{X}$  and  $\bar{D}_I$  are projective varieties. We then consider  $(X, D) := \bar{\epsilon}^{-1}(X_0, Z)$ ,  $\epsilon := \bar{\epsilon}|_X : (X, D) \rightarrow (X_0, Z)$  We denote again by  $i_\bullet : D_\bullet \hookrightarrow X = X_{c(\bullet)}$  the morphism of simplicial varieties given by the closed embeddings  $i_I : D_I = \cap_{i \in I} D_i \hookrightarrow X$ . Then the morphisms  $f := f_0 \circ \epsilon : X \rightarrow S$  and  $f_{D_\bullet} := f \circ i_\bullet : D_\bullet \rightarrow S$  are projective since  $\bar{f} : \bar{X}_0 \rightarrow \bar{S}$  is projective.

(ii) Let  $g : V'/S \rightarrow V/S$  a morphism, with  $V'/S = (V', h'), V/S = (V, h) \in \text{Var}(k)/S$

- Take (see (i)) a compactification  $\bar{X}_0 \in \text{PVar}(\mathbb{C})$  of  $V$  such that  $h : V \rightarrow S$  extend to a morphism  $\bar{f}_0 = \bar{h}_0 : \bar{X}_0 \rightarrow \bar{S}$ . Denote by  $\bar{Z} = \bar{X}_0 \setminus V$ . Then, there exist a compactification  $\bar{X}'_0 \in \text{PVar}(\mathbb{C})$  of  $V'$  such that  $h' : V' \rightarrow S$  extend to a morphism  $\bar{f}'_0 = \bar{h}'_0 : \bar{X}'_0 \rightarrow \bar{S}$ ,  $g : V' \rightarrow V$  extend to a

morphism  $\bar{g}_0 : \bar{X}'_0 \rightarrow \bar{X}_0$  and  $\bar{f}_0 \circ \bar{g}_0 = \bar{f}'_0$  that is  $\bar{g}_0$  is gives a morphism  $\bar{g}_0 : \bar{X}'_0/\bar{S} \rightarrow \bar{X}_0/\bar{S}$ . Denote by  $\bar{Z}' = \bar{X}'_0 \setminus V'$ . We then have the following commutative diagram

$$\begin{array}{ccccc} V & \xrightarrow{j} & \bar{X}_0 & \xleftarrow{i} & \bar{Z} \\ \bar{g} \uparrow & & \bar{g}_0 \uparrow & & \bar{g}' \uparrow \\ V' & \xrightarrow{j'} & \bar{X}'_0 & \xleftarrow{i'} & \bar{Z}' \xleftarrow{i''_{g',0} \bar{g}_0^{-1}(\bar{Z})} : i'_{g',0} \end{array}$$

It gives the following commutative diagram

$$\begin{array}{ccccc} V & \xrightarrow{j} & X_0 := \bar{f}_0^{-1}(S) & \xleftarrow{i} & Z \\ g \uparrow & & \bar{g}_0 \uparrow & & \bar{g}'_0 \uparrow \\ V' & \xrightarrow{j'} & X'_0 := \bar{f}'_0^{-1}(S) & \xleftarrow{i'} & Z' \xleftarrow{i''_{g',0} \bar{g}_0^{-1}(Z)} : i'_{g',0} \end{array}$$

- In the case  $V$  and  $V'$  are smooth, we take using theorem 16 a strict desingularization  $\bar{\epsilon} : (\bar{X}, \bar{D}) \rightarrow (\bar{X}_0, \bar{Z})$  of  $(\bar{X}_0, \bar{Z})$ . Then there exist a strict desingularization  $\bar{\epsilon}' : (\bar{X}', \bar{D}') \rightarrow (\bar{X}'_0, \bar{Z}')$  of  $(\bar{X}'_0, \bar{Z}')$  and a morphism  $\bar{g} : \bar{X}' \rightarrow \bar{X}$  such that the following diagram commutes

$$\begin{array}{ccc} \bar{X}'_0 & \xrightarrow{\bar{g}_0} & \bar{X}_0 \\ \bar{\epsilon}' \uparrow & & \bar{\epsilon} \uparrow \\ \bar{X}' & \xrightarrow{\bar{g}} & \bar{X} \end{array}$$

We then have the following commutative diagram in  $\text{Fun}(\Delta, \text{Var}(k))$

$$\begin{array}{ccccc} V = V_{c(\bullet)} & \xrightarrow{j} & \bar{X} = \bar{X}_{c(\bullet)} & \xleftarrow{i_\bullet} & \bar{D}_{s_g(\bullet)} \\ g \uparrow & & \bar{g} \uparrow & & \bar{g}'_\bullet \uparrow \\ V' = V'_{c(\bullet)} & \xrightarrow{j'} & \bar{X}' = \bar{X}'_{c(\bullet)} & \xleftarrow{i'_\bullet} & \bar{D}'_\bullet \xleftarrow{i''_{g',\bullet} \bar{g}_\bullet^{-1}(\bar{D}_{s_g(\bullet)})} : i'_{g',\bullet} \end{array}$$

where  $i_\bullet : \bar{D}_\bullet \hookrightarrow \bar{X}_\bullet$  the morphism of simplicial varieties given by the closed embeddings  $i_n : \bar{D}_n \hookrightarrow \bar{X}_n$ , and  $i'_\bullet : \bar{D}'_\bullet \hookrightarrow \bar{X}'_\bullet$  the morphism of simplicial varieties given by the closed embeddings  $i'_n : \bar{D}'_n \hookrightarrow \bar{X}'_n$ . It gives the commutative diagram in  $\text{Fun}(\Delta, \text{Var}(k))$

$$\begin{array}{ccccc} V = V_{c(\bullet)} & \xrightarrow{j} & X := \bar{\epsilon}^{-1}(X_0) = X_{c(\bullet)} & \xleftarrow{i_\bullet} & D_{s_g(\bullet)} \\ g \uparrow & & \bar{g} \uparrow & & \bar{g}'_\bullet \uparrow \\ V' = V'_{c(\bullet)} & \xrightarrow{j'} & X' := \bar{\epsilon}'^{-1}(X'_0) = X'_{c(\bullet)} & \xleftarrow{i'_\bullet} & D'_\bullet \xleftarrow{i''_{g',\bullet} \bar{g}_\bullet^{-1}(D_{s_g(\bullet)})} : i'_{g',\bullet} \end{array}$$

*Proof.* (i): Let  $\bar{X}_{00} \in \text{PVar}(\mathbb{C})$  be a compactification of  $V$ . Let  $l_0 : \bar{X}_0 = \bar{\Gamma}_h \hookrightarrow \bar{X}_{00} \times \bar{S}$  be the closure of the graph of  $h$  and  $\bar{f}_0 := p_{\bar{S}} \circ l_0 : \bar{X}_0 \hookrightarrow \bar{X}_{00} \times \bar{S} \rightarrow \bar{S}$ ,  $\epsilon_{\bar{X}_0} := p_{\bar{X}_{00}} \circ l_0 : \bar{X}_0 \hookrightarrow \bar{X}_{00} \times \bar{S} \rightarrow \bar{X}_{00}$  be the restriction to  $\bar{X}_0$  of the projections. Then,  $\bar{X} \in \text{PVar}(\mathbb{C})$ ,  $\epsilon_{\bar{X}_0} : \bar{X}_0 \rightarrow \bar{X}_{00}$  is a proper modification which does not affect the open subset  $V \subset \bar{X}_0$ , and  $\bar{f}_0 = \bar{h}_0 : \bar{X}_0 \rightarrow \bar{S}$  is a compactification of  $h$ .

(ii): There is two things to prove:

- Let  $\bar{f}_0 : \bar{X}_0 \rightarrow \bar{S}$  a compactification of  $h : V \rightarrow S$  and  $\bar{f}'_0 : \bar{X}'_0 \rightarrow \bar{S}$  a compactification of  $h' : V' \rightarrow S$  (see (i)). Let  $l_0 : \bar{X}'_0 \hookrightarrow \bar{\Gamma}_g \subset \bar{X}'_{00} \times_{\bar{S}} \bar{X}_0$  be the closure of the graph of  $g$ ,  $\bar{f}'_0 :=$

$(\bar{f}'_{00}, \bar{f}_0) \circ l_0 : \bar{X}'_0 \hookrightarrow \bar{X}'_{00} \times_S \bar{X}_0 \rightarrow \bar{S}$  and  $\bar{g}_0 := p_{\bar{X}_0} \circ l_0 : \bar{X}'_0 \hookrightarrow \bar{X}'_{00} \times_{\bar{S}} \bar{X}_0 \rightarrow \bar{X}_0$ ,  $\epsilon_{\bar{X}'_{00}} := p_{\bar{X}'_0} \circ i : \bar{X}'_0 \hookrightarrow \bar{X}'_{00} \times_{\bar{S}} \bar{X}_0 \rightarrow \bar{X}'_{00}$  be the restriction to  $X$  of the projections. Then  $\epsilon_{\bar{X}'_{00}} : \bar{X}'_0 \rightarrow \bar{X}'_{00}$  is a proper modification which does not affect the open subset  $V' \subset \bar{X}'_0$ ,  $\bar{f}'_0 : \bar{X}'_0 \rightarrow \bar{S}$  is an other compactification of  $h' : V' \rightarrow S$  and  $\bar{g}_0 : \bar{X}'_0 \rightarrow \bar{X}_0$  is a compactification of  $g$ .

- In the case  $V$  and  $V'$  are smooth, we take, using theorem 16, a strict desingularization  $\bar{\epsilon} : (\bar{X}, \bar{D}) \rightarrow (\bar{X}_0, \bar{Z})$  of the pair  $(\bar{X}_0, \bar{Z})$ . Take then, using theorem 16, a strict desingularization  $\bar{\epsilon}'_1 : (\bar{X}', \bar{D}') \rightarrow (\bar{X} \times_{\bar{X}_0} \bar{X}'_0, \bar{X} \times_{\bar{X}_0} \bar{Z}')$  of the pair  $(\bar{X} \times_{\bar{X}_0} \bar{X}'_0, \bar{X} \times_{\bar{X}_0} \bar{Z}')$ . We consider then following commutative diagram whose square is cartesian :

$$\begin{array}{ccc}
 & \bar{X}'_0 & \xrightarrow{\bar{g}_0} & X_0 \\
 & \uparrow \epsilon'_0 & & \uparrow \epsilon \\
 \bar{X}' & \xrightarrow{\bar{\epsilon}'_1} & \bar{X} \times_{\bar{X}_0} \bar{X}'_0 & \xrightarrow{\bar{g}'_0} & \bar{X} \\
 & \uparrow \epsilon' & & \uparrow \bar{g} \\
 & \bar{X}' & & & 
 \end{array}$$

and  $\bar{\epsilon}' := \bar{\epsilon}'_0 \circ \bar{\epsilon}'_1 : (\bar{X}', \bar{D}') \rightarrow (\bar{X}_0, \bar{Z}')$  is a strict desingularization of the pair  $(\bar{X} \times_{\bar{X}_0} \bar{X}'_0, \bar{X} \times_{\bar{X}_0} \bar{Z}')$ . □

Let  $S \in \text{Var}(k)$ . Recall we have the dual functor

$$\mathbb{D}_S^0 : C(\text{Var}(k)/S) \rightarrow C(\text{Var}(k)/S), F \mapsto \mathbb{D}_S^0(F) := \mathcal{H}om(F, E_{et}(\mathbb{Z}(S/S)))$$

which induces the functor

$$L\mathbb{D}_S : D_\tau(\text{Var}(k)/S) \rightarrow D_\tau(\text{Var}(k)/S), F \mapsto L\mathbb{D}_S(F) := \mathbb{D}_S^0(LF) := \mathcal{H}om(LF, E_{et}(\mathbb{Z}(S/S)))$$

with  $\tau$  a topology on  $\text{Var}(k)$ .

We will use the following resolutions of representable presheaves by Corti-Hanamura presheaves and their the functorialities.

**Definition 22.** (i) Let  $h : U \rightarrow S$  a morphism, with  $U, S \in \text{Var}(k)$  and  $U$  smooth. Take, see definition-proposition 3,  $\bar{f}_0 = \bar{h}_0 : \bar{X}_0 \rightarrow \bar{S}$  a compactification of  $h : U \rightarrow S$  and denote by  $\bar{Z} = \bar{X}_0 \setminus U$ . Take, using theorem 16(ii), a strict desingularization  $\bar{\epsilon} : (\bar{X}, \bar{D}) \rightarrow (\bar{X}_0, \bar{Z})$  of the pair  $(\bar{X}_0, \bar{Z})$ , with  $\bar{X} \in \text{PSmVar}(k)$  and  $\bar{D} := \epsilon^{-1}(\bar{Z}) = \cup_{i=1}^s \bar{D}_i \subset \bar{X}$  a normal crossing divisor. We denote by  $i_\bullet : \bar{D}_\bullet \hookrightarrow \bar{X} = \bar{X}_{c(\bullet)}$  the morphism of simplicial varieties given by the closed embeddings  $i_I : \bar{D}_I = \cap_{i \in I} \bar{D}_i \hookrightarrow \bar{X}$ . We denote by  $j : U \hookrightarrow \bar{X}$  the open embedding and by  $p_S : \bar{X} \times S \rightarrow S$  and  $p_S : U \times S \rightarrow S$  the projections. Considering the graph factorization  $\bar{f} : \bar{X} \xrightarrow{\bar{l}} \bar{X} \times \bar{S} \xrightarrow{p_S} \bar{S}$  of  $\bar{f} : \bar{X} \rightarrow \bar{S}$ , where  $\bar{l}$  is the graph embedding and  $p_S$  the projection, we get closed embeddings  $l := \bar{l} \times_{\bar{S}} S : X \hookrightarrow \bar{X} \times S$  and  $l_{D_I} := \bar{D}_I \times_{\bar{X}} l : D_I \hookrightarrow \bar{D}_I \times S$ . We then consider the following map in  $C(\text{Var}(k)^2/S)$

$$\begin{aligned}
 & r_{(\bar{X}, \bar{D})/S}(\mathbb{Z}(U/S)) : R_{(\bar{X}, \bar{D})/S}(\mathbb{Z}(U/S)) \\
 & \xrightarrow{=} p_{S*} E_{et}(\text{Cone}(\mathbb{Z}(i_\bullet \times I) : (\mathbb{Z}((\bar{D}_\bullet \times S, D_\bullet)/\bar{X} \times S), u_{IJ}) \rightarrow \mathbb{Z}((\bar{X} \times S, X)/\bar{X} \times S))) \\
 & \xrightarrow{p_{S*} E_{et}(0, k\text{oad}((j \times I)^*, (j \times I)_*)(\mathbb{Z}((\bar{X} \times S, X)/\bar{X} \times S)))} p_{S*} E_{et}(\mathbb{Z}((U \times S, U)/U \times S)) =: \mathbb{D}_S^{12}(\mathbb{Z}(U/S)).
 \end{aligned}$$

Note that  $\mathbb{Z}((\bar{D}_I \times S, D_I)/\bar{X} \times S)$  and  $\mathbb{Z}((\bar{X} \times S, X)/\bar{X} \times S)$  are obviously  $\mathbb{A}^1$  invariant. Note that  $r_{(X, D)/S}$  is NOT an equivalence ( $\mathbb{A}^1$ , et) local by proposition 8 since  $\rho_{\bar{X} \times S} \mathbb{Z}((\bar{D}_\bullet \times S, D_\bullet)/\bar{X} \times S) = 0$  and  $\rho_{\bar{X} \times S} \text{ad}((j \times I)^*, (j \times I)_*)(\mathbb{Z}((\bar{X} \times S, X)/\bar{X} \times S))$  is not an equivalence ( $\mathbb{A}^1$ , et) local.



(iv) For

$$Q^* := (\cdots \rightarrow \bigoplus_{\alpha \in \Lambda^n} \mathbb{Z}(U_\alpha^n/S) \xrightarrow{(\mathbb{Z}(g_{\alpha,\beta}^n))} \bigoplus_{\beta \in \Lambda^{n-1}} \mathbb{Z}(U_\beta^{n-1}/S) \rightarrow \cdots) \in C(\text{Var}(k)/S)$$

a complex of (maybe infinite) direct sum of representable presheaves with  $U_\alpha^*$  smooth, we get from (i), (ii) and (iii) the map in  $C(\text{Var}(k)^2/S)$

$$\begin{aligned} r_S^{CH}(Q^*) : R^{CH}(Q^*) &:= (\cdots \rightarrow \bigoplus_{\beta \in \Lambda^{n-1}} \varinjlim_{(\bar{X}_\beta^{n-1}, \bar{D}_\beta^{n-1})/S} R_{(\bar{X}_\beta^{n-1}, \bar{D}_\beta^{n-1})/S}(\mathbb{Z}(U_\beta^{n-1}/S)) \\ &\xrightarrow{(R_S^{CH}(g_{\alpha,\beta}^n))} \bigoplus_{\alpha \in \Lambda^n} \varinjlim_{(\bar{X}_\alpha^n, \bar{D}_\alpha^n)/S} R_{(\bar{X}_\alpha^n, \bar{D}_\alpha^n)/S}(\mathbb{Z}(U_\alpha^n/S)) \rightarrow \cdots) \rightarrow \mathbb{D}_S^{12}(Q^*), \end{aligned}$$

where for  $(U_\alpha^n, h_\alpha^n) \in \text{Var}(k)/S$ , the inductive limit run over all the compactifications  $\bar{f}_\alpha : \bar{X}_\alpha \rightarrow \bar{S}$  of  $h_\alpha : U_\alpha \rightarrow S$  with  $\bar{X}_\alpha \in \text{PSmVar}(k)$  and  $\bar{D}_\alpha := \bar{X}_\alpha \setminus U_\alpha$  a normal crossing divisor. For  $m = (m^*) : Q_1^* \rightarrow Q_2^*$  a morphism with

$$\begin{aligned} Q_1^* &:= (\cdots \rightarrow \bigoplus_{\alpha \in \Lambda^n} \mathbb{Z}(U_{1,\alpha}^n/S) \xrightarrow{(\mathbb{Z}(g_{\alpha,\beta}^n))} \bigoplus_{\beta \in \Lambda^{n-1}} \mathbb{Z}(U_{1,\beta}^{n-1}/S) \rightarrow \cdots), \\ Q_2^* &:= (\cdots \rightarrow \bigoplus_{\alpha \in \Lambda^n} \mathbb{Z}(U_{2,\alpha}^n/S) \xrightarrow{(\mathbb{Z}(g_{\alpha,\beta}^n))} \bigoplus_{\beta \in \Lambda^{n-1}} \mathbb{Z}(U_{2,\beta}^{n-1}/S) \rightarrow \cdots) \in C(\text{Var}(k)/S) \end{aligned}$$

complexes of (maybe infinite) direct sum of representable presheaves with  $U_{1,\alpha}^*$  and  $U_{2,\alpha}^*$  smooth, we get again from (i), (ii) and (iii) a commutative diagram in  $C(\text{Var}(k)^2/S)$

$$\begin{array}{ccc} R^{CH}(Q_2^*) & \xrightarrow{r_S^{CH}(Q_2^*)} & \mathbb{D}_S^{12}(Q_2^*) \\ R_S^{CH}(m) := (R_S^{CH}(m^*)) \downarrow & & \downarrow \mathbb{D}_S^{12}(m) := (\mathbb{D}_S^{12}(m^*)) \\ R^{CH}(Q_1^*) & \xrightarrow{r_S^{CH}(Q_1^*)} & \mathbb{D}_S^{12}(Q_1^*) \end{array} .$$

- Let  $S \in \text{Var}(k)$  For  $(h, m, m') = (h^*, m^*, m'^*) : Q_1^*[1] \rightarrow Q_2^*$  an homotopy with  $Q_1^*, Q_2^* \in C(\text{Var}(k)/S)$  complexes of (maybe infinite) direct sum of representable presheaves with  $U_{1,\alpha}^*$  and  $U_{2,\alpha}^*$  smooth,

$$(R_S^{CH}(h), R_S^{CH}(m), R_S^{CH}(m')) = (R_S^{CH}(h^*), R_S^{CH}(m^*), R_S^{CH}(m'^*)) : R^{CH}(Q_2^*)[1] \rightarrow R^{CH}(Q_1^*)$$

is an homotopy in  $C(\text{Var}(k)^2/S)$  using definition 22 (iii). In particular if  $m : Q_1^* \rightarrow Q_2^*$  with  $Q_1^*, Q_2^* \in C(\text{Var}(k)/S)$  complexes of (maybe infinite) direct sum of representable presheaves with  $U_{1,\alpha}^*$  and  $U_{2,\alpha}^*$  smooth is an homotopy equivalence, then  $R_S^{CH}(m) : R^{CH}(Q_2^*) \rightarrow R^{CH}(Q_1^*)$  is an homotopy equivalence.

- Let  $S \in \text{SmVar}(k)$ . Let  $F \in \text{PSh}(\text{Var}(k)^{sm}/S)$ . Consider

$$q : LF := (\cdots \rightarrow \bigoplus_{(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S} \mathbb{Z}(U_\alpha/S) \xrightarrow{(\mathbb{Z}(g_{\alpha,\beta}^n))} \bigoplus_{(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S} \mathbb{Z}(U_\alpha/S) \rightarrow \cdots) \rightarrow F$$

the canonical projective resolution given in subsection 2.3.3. Note that the  $U_\alpha$  are smooth since  $S$  is smooth and  $h_\alpha$  are smooth morphism. Definition 22(iv) gives in this particular case the map in  $C(\text{Var}(k)^2/S)$

$$\begin{aligned} r_S^{CH}(\rho_S^* LF) : R^{CH}(\rho_S^* LF) &:= (\cdots \rightarrow \bigoplus_{(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S} \varinjlim_{(\bar{X}_\alpha, \bar{D}_\alpha)/S} R_{(\bar{X}_\alpha, \bar{D}_\alpha)/S}(\mathbb{Z}(U_\alpha/S)) \\ &\xrightarrow{(R_S^{CH}(g_{\alpha,\beta}^n))} \bigoplus_{(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S} \varinjlim_{(\bar{X}_\alpha, \bar{D}_\alpha)/S} R_{(\bar{X}_\alpha, \bar{D}_\alpha)/S}(\mathbb{Z}(U_\alpha/S)) \rightarrow \cdots) \rightarrow \mathbb{D}_S^{12}(\rho_S^* LF), \end{aligned}$$

where for  $(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S$ , the inductive limit run over all the compactifications  $\bar{f}_\alpha : \bar{X}_\alpha \rightarrow \bar{S}$  of  $h_\alpha : U_\alpha \rightarrow S$  with  $\bar{X}_\alpha \in \text{PSmVar}(k)$  and  $\bar{D}_\alpha := \bar{X}_\alpha \setminus U_\alpha$  a normal crossing divisor. Definition 22(iv) gives then by functoriality in particular, for  $F = F^\bullet \in C(\text{Var}(k)^{sm}/S)$ , the map in  $C(\text{Var}(k)^2/S)$

$$r_S^{CH}(\rho_S^* LF) = (r_S^{CH}(\rho_S^* LF^*)) : R^{CH}(\rho_S^* LF) \rightarrow \mathbb{D}_S^{12}(\rho_S^* LF).$$

- Let  $g : T \rightarrow S$  a morphism with  $T, S \in \text{SmVar}(k)$ . Let  $h : U \rightarrow S$  a smooth morphism with  $U \in \text{Var}(k)$ . Consider the cartesian square

$$\begin{array}{ccc} U_T & \xrightarrow{h'} & T \\ \downarrow g' & & \downarrow g \\ U & \xrightarrow{h} & S \end{array}$$

Note that  $U$  is smooth since  $S$  and  $h$  are smooth, and  $U_T$  is smooth since  $T$  and  $h'$  are smooth. Take, see definition-proposition 3(ii), a compactification  $\bar{f}_0 = \bar{h} : \bar{X}_0 \rightarrow \bar{S}$  of  $h : U \rightarrow S$  and a compactification  $\bar{f}'_0 = g' \circ h' : \bar{X}'_0 \rightarrow \bar{S}$  of  $g' \circ h' : U_T \rightarrow S$  such that  $g' : U_T/S \rightarrow U/S$  extend to a morphism  $\bar{g}'_0 : \bar{X}'_0/\bar{S} \rightarrow \bar{X}_0/\bar{S}$ . Denote  $\bar{Z} = \bar{X}_0 \setminus U$  and  $\bar{Z}' = \bar{X}'_0 \setminus U_T$ . Take, see definition-proposition 3(ii), a strict desingularization  $\bar{\epsilon} : (\bar{X}, \bar{D}) \rightarrow (\bar{X}_0, \bar{Z})$  of  $(\bar{X}_0, \bar{Z})$ , a desingularization  $\bar{\epsilon}' : (\bar{X}', \bar{D}') \rightarrow (\bar{X}'_0, \bar{Z}')$  of  $(\bar{X}'_0, \bar{Z}')$  and a morphism  $\bar{g}' : \bar{X}' \rightarrow \bar{X}$  such that the following diagram commutes

$$\begin{array}{ccc} \bar{X}'_0 & \xrightarrow{\bar{g}'_0} & \bar{X}_0 \\ \bar{\epsilon}' \uparrow & & \uparrow \bar{\epsilon} \\ \bar{X}' & \xrightarrow{\bar{g}'} & \bar{X} \end{array}$$

We then have, see definition-proposition 3(ii), the following commutative diagram in  $\text{Fun}(\Delta, \text{Var}(k))$

$$\begin{array}{ccccc} U = U_{c(\bullet)} & \xrightarrow{j} & \bar{X} = \bar{X}_{c(\bullet)} & \xleftarrow{i_\bullet} & \bar{D}_{s_{g'}(\bullet)} \\ \uparrow g' & & \uparrow \bar{g}' & & \uparrow (\bar{g}')'_\bullet \\ U_T = U_{T,c(\bullet)} & \xrightarrow{j'} & \bar{X}' = \bar{X}'_{c(\bullet)} & \xleftarrow{i'_\bullet} & \bar{D}'_\bullet \xleftarrow{i''_{g'_\bullet} \circ i'_\bullet} \bar{D}_{s_{g'}(\bullet)} : i'_{g'_\bullet} \end{array}$$

We then consider the following map in  $C(\text{Var}(k)^2/T)$ , see definition 22(ii)

$$\begin{aligned} & T(g, R^{CH})(\mathbb{Z}(U/S)) : g^* R_{(\bar{X}, \bar{D})/S}(\mathbb{Z}(U/S)) \\ & \xrightarrow{g^* R_S^{CH}(g')} g^* R_{(\bar{X}', \bar{D}')/S}(\mathbb{Z}(U_T/S)) = g^* g_* R_{(\bar{X}', \bar{D}')/T}(\mathbb{Z}(U_T/T)) \\ & \xrightarrow{\text{ad}(g^*, g_*)(R_{(\bar{X}', \bar{D}')/T}(\mathbb{Z}(U_T/T)))} R_{(\bar{X}', \bar{D}')/T}(\mathbb{Z}(U_T/T)) \end{aligned}$$

For

$$Q^* := (\cdots \rightarrow \bigoplus_{\alpha \in \Lambda^n} \mathbb{Z}(U_\alpha^n/S) \xrightarrow{(\mathbb{Z}(g_{\alpha, \beta}^n))} \bigoplus_{\beta \in \Lambda^{n-1}} \mathbb{Z}(U_\beta^{n-1}/S) \rightarrow \cdots) \in C(\text{Var}(k)/S)$$

a complex of (maybe infinite) direct sum of representable presheaves with  $h_\alpha^n : U_\alpha^n \rightarrow S$  smooth, we get the map in  $C(\text{Var}(k)^2/T)$

$$\begin{aligned} & T(g, R^{CH})(Q^*) : g^* R^{CH}(Q^*) = (\cdots \rightarrow \bigoplus_{\alpha \in \Lambda^n} \varinjlim_{(\bar{X}_\alpha^n, \bar{D}_\alpha^n)/S} g^* R_{(\bar{X}_\alpha^n, \bar{D}_\alpha^n)/S}(\mathbb{Z}(U_\alpha^n/S)) \rightarrow \cdots) \\ & \xrightarrow{(T(g, R^{CH})(\mathbb{Z}(U_\alpha^n/S)))} (\cdots \rightarrow \bigoplus_{\alpha \in \Lambda^n} \varinjlim_{(\bar{X}_\alpha^{n'}, \bar{D}_\alpha^{n'})/T} R_{(\bar{X}_\alpha^{n'}, \bar{D}_\alpha^{n'})/T}(\mathbb{Z}(U_\alpha^n/T/S)) \rightarrow \cdots) =: R^{CH}(g^* Q^*). \end{aligned}$$

Let  $F \in \text{PSh}(\text{Var}(k)^{sm}/S)$ . Consider

$$q : LF := (\cdots \rightarrow \bigoplus_{(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S} \mathbb{Z}(U_\alpha/S) \rightarrow \cdots) \rightarrow F$$

the canonical projective resolution given in subsection 2.3.3. We then get in particular the map in  $C(\text{Var}(k)^2/T)$

$$\begin{aligned} T(g, R^{CH})(\rho_S^* LF) : g^* R^{CH}(\rho_S^* LF) = \\ (\cdots \rightarrow \bigoplus_{(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S} \varinjlim_{(\bar{X}_\alpha, \bar{D}_\alpha)/S} g^* R_{(\bar{X}_\alpha, \bar{D}_\alpha)/S}(\mathbb{Z}(U_\alpha/S)) \rightarrow \cdots) \xrightarrow{(T(g, R^{CH})(\mathbb{Z}(U_\alpha/S)))} \\ (\cdots \rightarrow \bigoplus_{(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S} \varinjlim_{(\bar{X}'_\alpha, \bar{D}'_\alpha)/T} R_{(\bar{X}'_\alpha, \bar{D}'_\alpha)/T}(\mathbb{Z}(U_\alpha, T/S)) \rightarrow \cdots) =: R^{CH}(\rho_T^* g^* LF). \end{aligned}$$

By functoriality, we get in particular for  $F = F^\bullet \in C(\text{Var}(k)^{sm}/S)$ , the map in  $C(\text{Var}(k)^2/T)$

$$T(g, R^{CH})(\rho_S^* LF) : g^* R^{CH}(\rho_S^* LF) \rightarrow R^{CH}(\rho_T^* g^* LF).$$

- Let  $S_1, S_2 \in \text{SmVar}(k)$  and  $p : S_1 \times S_2 \rightarrow S_1$  the projection. Let  $h : U \rightarrow S_1$  a smooth morphism with  $U \in \text{Var}(k)$ . Consider the cartesian square

$$\begin{array}{ccc} U \times S_2 & \xrightarrow{h \times I} & S_1 \times S_2 \\ \downarrow p' & & \downarrow p \\ U & \xrightarrow{h} & S_1 \end{array}$$

Take, see definition-proposition 3(i), a compactification  $\bar{f}_0 = \bar{h} : \bar{X}_0 \rightarrow \bar{S}_1$  of  $h : U \rightarrow S_1$ . Then  $\bar{f}_0 \times I : \bar{X}_0 \times S_2 \rightarrow \bar{S}_1 \times S_2$  is a compactification of  $h \times I : U \times S_2 \rightarrow S_1 \times S_2$  and  $p' : U \times S_2 \rightarrow U$  extend to  $\bar{p}'_0 := p_{X_0} : \bar{X}_0 \times S_2 \rightarrow \bar{X}_0$ . Denote  $Z = X_0 \setminus U$ . Take see theorem 16(i), a strict desingularization  $\bar{e} : (\bar{X}, \bar{D}) \rightarrow (\bar{X}_0, \bar{Z})$  of the pair  $(\bar{X}_0, \bar{Z})$ . We then have the following commutative diagram in  $\text{Fun}(\Delta, \text{Var}(k))$  whose squares are cartesian

$$\begin{array}{ccccc} U = U_{c(\bullet)} & \xrightarrow{j} & \bar{X} & \xleftarrow{i_\bullet} & \bar{D}_\bullet \\ \uparrow g & & \uparrow \bar{p}' := p_{\bar{X}} & & \uparrow \bar{p}'_\bullet \\ U \times S_2 = (U \times S_2)_{c(\bullet)} & \xrightarrow{j \times I} & \bar{X} \times S_2 & \xleftarrow{i'_\bullet} & \bar{D}_\bullet \times S_2 \end{array} \quad (8)$$

Then the map in  $C(\text{Var}(k)^2/S_1 \times S_2)$

$$T(p, R^{CH})(\mathbb{Z}(U/S_1)) : p^* R_{(\bar{X}, \bar{D})/S_1}(\mathbb{Z}(U/S_1)) \xrightarrow{\sim} R_{(\bar{X} \times S_2, \bar{D}_\bullet \times S_2)/S_1 \times S_2}(\mathbb{Z}(U \times S_2/S_1 \times S_2))$$

is an isomorphism. Hence, for  $Q^* \in C(\text{Var}(k)/S_1)$  a complex of (maybe infinite) direct sum of representable presheaves of smooth morphism, the map in  $C(\text{Var}(k)^2/S_1 \times S_2)$

$$T(p, R^{CH})(Q^*) : p^* R^{CH}(Q^*) \xrightarrow{\sim} R^{CH}(p^* Q^*)$$

is an isomorphism. In particular, for  $F \in C(\text{Var}(k)^{sm}/S_1)$  the map in  $C(\text{Var}(k)^2/S_1 \times S_2)$

$$T(p, R^{CH})(\rho_{S_1}^* LF) : p^* R^{CH}(\rho_{S_1}^* LF) \xrightarrow{\sim} R^{CH}(\rho_{S_1 \times S_2}^* p^* LF)$$

is an isomorphism.

- Let  $h_1 : U_1 \rightarrow S$ ,  $h_2 : U_2 \rightarrow S$  two morphisms with  $U_1, U_2, S \in \text{Var}(k)$ ,  $U_1, U_2$  smooth. Denote by  $p_1 : U_1 \times_S U_2 \rightarrow U_1$  and  $p_2 : U_1 \times_S U_2 \rightarrow U_2$  the projections. Take, see definition-proposition 3(i), a compactification  $\bar{f}_{10} = \bar{h}_1 : \bar{X}_{10} \rightarrow \bar{S}$  of  $h_1 : U_1 \rightarrow S$  and a compactification  $\bar{f}_{20} = \bar{h}_2 : \bar{X}_{20} \rightarrow \bar{S}$  of  $h_2 : U_2 \rightarrow S$ . Then,



- $\bar{f}_{10} \times \bar{f}_{20} : \bar{X}_{10} \times_{\bar{S}} \bar{X}_{20} \rightarrow S$  is a compactification of  $h_1 \times h_2 : U_1 \times_S U_2 \rightarrow S$ .
- $\bar{p}_{10} := p_{X_{10}} : \bar{X}_{10} \times_{\bar{S}} \bar{X}_{20} \rightarrow \bar{X}_{10}$  is a compactification of  $p_1 : U_1 \times_S U_2 \rightarrow U_1$ .
- $\bar{p}_{20} := p_{X_{20}} : \bar{X}_{10} \times_{\bar{S}} \bar{X}_{20} \rightarrow \bar{X}_{20}$  is a compactification of  $p_2 : U_1 \times_S U_2 \rightarrow U_2$ .

Denote  $\bar{Z}_1 = \bar{X}_{10} \setminus U_1$  and  $\bar{Z}_2 = \bar{X}_{20} \setminus U_2$ . Take, see theorem 16(i), a strict desingularization  $\bar{\epsilon}_1 : (\bar{X}_1, \bar{D}) \rightarrow (\bar{X}_{10}, \bar{Z}_1)$  of the pair  $(\bar{X}_{10}, \bar{Z}_1)$  and a strict desingularization  $\bar{\epsilon}_2 : (\bar{X}_2, \bar{E}) \rightarrow (\bar{X}_{20}, \bar{Z}_2)$  of the pair  $(\bar{X}_{20}, \bar{Z}_2)$ . Take then a strict desingularization

$$\bar{\epsilon}_{12} : ((\bar{X}_1 \times_{\bar{S}} \bar{X}_2)^N, \bar{F}) \rightarrow (\bar{X}_1 \times_{\bar{S}} \bar{X}_2, (D \times_{\bar{S}} \bar{X}_2) \cup (\bar{X}_1 \times_{\bar{S}} \bar{E}))$$

of the pair  $(\bar{X}_1 \times_{\bar{S}} \bar{X}_2, (D \times_{\bar{S}} \bar{X}_2) \cup (\bar{X}_1 \times_{\bar{S}} \bar{E}))$ . We have then the following commutative diagram

$$\begin{array}{ccccc}
 & & \bar{X}_1 & \xrightarrow{\bar{f}_1} & \bar{S} \\
 & & \uparrow \bar{p}_2 & & \uparrow \bar{f}_2 \\
 & & \bar{X}_1 \times_{\bar{S}} \bar{X}_2 & \xrightarrow{\bar{p}_1} & \bar{X}_2 \\
 (\bar{p}_2)^N \nearrow & & \uparrow \bar{\epsilon}_{12} & & \uparrow \bar{\epsilon}_2 \\
 & & (\bar{X}_1 \times_{\bar{S}} \bar{X}_2)^N & \xrightarrow{(\bar{p}_1)^N} & \bar{X}_2 \\
 & & \nearrow \bar{\epsilon}_{12} & & \nearrow \bar{\epsilon}_2
 \end{array}$$

and

- $\bar{f}_1 \times \bar{f}_2 : \bar{X}_1 \times_{\bar{S}} \bar{X}_2 \rightarrow \bar{S}$  is a compactification of  $h_1 \times h_2 : U_1 \times_S U_2 \rightarrow S$ .
- $(\bar{p}_1)^N := \bar{p}_1 \circ \bar{\epsilon}_{12} : (\bar{X}_1 \times_{\bar{S}} \bar{X}_2)^N \rightarrow \bar{X}_1$  is a compactification of  $p_1 : U_1 \times_S U_2 \rightarrow U_1$ .
- $(\bar{p}_2)^N := \bar{p}_2 \circ \bar{\epsilon}_{12} : (\bar{X}_1 \times_{\bar{S}} \bar{X}_2)^N \rightarrow \bar{X}_2$  is a compactification of  $p_2 : U_1 \times_S U_2 \rightarrow U_2$ .

We have then the morphism in  $C(\text{Var}(k)^2/S)$

$$\begin{aligned}
 & T(\otimes, R_S^{CH})(\mathbb{Z}(U_1/S), \mathbb{Z}(U_2/S)) := R_S^{CH}(p_1) \otimes R_S^{CH}(p_2) : \\
 & R_{(\bar{X}_1, \bar{D})/S}(\mathbb{Z}(U_1/S)) \otimes R_{(\bar{X}_2, \bar{E})/S}(\mathbb{Z}(U_2/S)) \xrightarrow{\sim} R_{(\bar{X}_1 \times_{\bar{S}} \bar{X}_2)^N, \bar{F}}/S(\mathbb{Z}(U_1 \times_S U_2/S))
 \end{aligned}$$

For

$$\begin{aligned}
 Q_1^* & := (\cdots \rightarrow \oplus_{\alpha \in \Lambda^n} \mathbb{Z}(U_{1,\alpha}^n/S) \xrightarrow{(\mathbb{Z}(g_{\alpha,\beta}^n))} \oplus_{\beta \in \Lambda^{n-1}} \mathbb{Z}(U_{1,\beta}^{n-1}/S) \rightarrow \cdots), \\
 Q_2^* & := (\cdots \rightarrow \oplus_{\alpha \in \Lambda^n} \mathbb{Z}(U_{2,\alpha}^n/S) \xrightarrow{(\mathbb{Z}(g_{\alpha,\beta}^n))} \oplus_{\beta \in \Lambda^{n-1}} \mathbb{Z}(U_{2,\beta}^{n-1}/S) \rightarrow \cdots) \in C(\text{Var}(k)/S)
 \end{aligned}$$

complexes of (maybe infinite) direct sum of representable presheaves with  $U_\alpha^*$  smooth, we get the morphism in  $C(\text{Var}(k)^2/S)$

$$T(\otimes, R_S^{CH})(Q_1^*, Q_2^*) : R^{CH}(Q_1^*) \otimes R^{CH}(Q_2^*) \xrightarrow{(T(\otimes, R_S^{CH})(\mathbb{Z}(U_{1,\alpha}^n), \mathbb{Z}(U_{2,\beta}^n))} R^{CH}(Q_1^* \otimes Q_2^*).$$

For  $F_1, F_2 \in C(\text{Var}(k)^{sm}/S)$ , we get in particular the morphism in  $C(\text{Var}(k)^2/S)$

$$T(\otimes, R_S^{CH})(\rho_S^* LF_1, \rho_S^* LF_2) : R^{CH}(\rho_S^* LF_1) \otimes R^{CH}(\rho_S^* LF_2) \rightarrow R^{CH}(\rho_S^*(LF_1 \otimes LF_2)).$$

**Definition 23.** Let  $h : U \rightarrow S$  a morphism, with  $U, S \in \text{Var}(k)$ ,  $U$  irreducible. Take, see definition-proposition 3,  $\bar{f}_0 = \bar{h}_0 : \bar{X}_0 \rightarrow \bar{S}$  a compactification of  $h : U \rightarrow S$  and denote by  $\bar{Z} = \bar{X}_0 \setminus U$ . Take, using theorem 16, a desingularization  $\bar{\epsilon} : (\bar{X}, \bar{D}) \rightarrow (\bar{X}_0, \bar{Z})$  of the pair  $(\bar{X}_0, \bar{Z})$ ,  $\bar{Z} \subset \bar{D}$ , with  $\bar{X} \in \text{PSmVar}(k)$  and  $\bar{D} := \bar{\epsilon}^{-1}(\bar{Z}) = \cup_{i=1}^s \bar{D}_i \subset \bar{X}$  a normal crossing divisor. Denote  $d_X := \dim(\bar{X}) = \dim(U)$ .

(i) The cycle  $(\Delta_{\bar{D}_\bullet} \times S) \subset \bar{D}_\bullet \times \bar{D}_\bullet \times S$  induces by the diagonal  $\Delta_{\bar{D}_\bullet} \subset \bar{D}_\bullet \times \bar{D}_\bullet$  gives the morphism in  $C(\text{Var}(k)^2/S)$

$$\begin{aligned} [\Delta_{\bar{D}_\bullet}] \in \text{Hom}(\mathbb{Z}^{tr}((\bar{D}_\bullet \times S, D_\bullet)/S), p_{S*}E_{et}(\mathbb{Z}((\bar{D}_\bullet \times S, D_\bullet)/\bar{X} \times S)(d_X)[2d_X])) \xrightarrow{\sim} \\ \text{Hom}(\mathbb{Z}((\bar{D}_\bullet \times S \times \bar{X}, D_\bullet)/\bar{X} \times S), \\ \mathbb{Z}^{tr}((\bar{D}_\bullet \times S \times \mathbb{P}^{d_X}, D_\bullet \times \mathbb{P}^{d_X})/\bar{X} \times S)/\mathbb{Z}^{tr}((- \times \mathbb{P}^{d_X-1}, (-) \times \mathbb{P}^{d_X-1})) \\ \subset H^0(\mathcal{Z}_{d_{D_\bullet}+d_S}(\square^* \times \bar{D}_\bullet \times \bar{D}_\bullet \times S), s.t.\alpha_*(\times D_\bullet) = D_\bullet) \end{aligned}$$

(ii) The cycle  $(\Delta_{\bar{X}} \times S) \subset \bar{X} \times \bar{X} \times S$  induces by the diagonal  $\Delta_{\bar{X}} \subset \bar{X} \times \bar{X}$  gives the morphism in  $C(\text{Var}(k)^2/S)$

$$\begin{aligned} [\Delta_{\bar{X}}] \in \text{Hom}(\mathbb{Z}^{tr}((\bar{X} \times S, X)/S), p_{S*}E_{et}(\mathbb{Z}((\bar{X} \times S, X)/\bar{X} \times S)(d_X)[2d_X])) \xrightarrow{\sim} \\ \text{Hom}(\mathbb{Z}((\bar{X} \times S \times \bar{X}, X)/\bar{X} \times S), \\ \mathbb{Z}^{tr}((\bar{X} \times S \times \mathbb{P}^{d_X}, X \times \mathbb{P}^{d_X})/\bar{X} \times S)/\mathbb{Z}^{tr}((- \times \mathbb{P}^{d_X-1}, (-) \times \mathbb{P}^{d_X-1})) \\ \subset H^0(\mathcal{Z}_{d_X+d_S}(\square^* \times \bar{X} \times \bar{X} \times S), s.t.\alpha_*(\times X) = X) \end{aligned}$$

Let  $h : U \rightarrow S$  a morphism, with  $U, S \in \text{Var}(k)$ ,  $U$  smooth connected (hence irreducible by smoothness). Take, see definition-proposition 3,  $\bar{f}_0 = \bar{h}_0 : \bar{X}_0 \rightarrow \bar{S}$  a compactification of  $h : U \rightarrow S$  and denote by  $\bar{Z} = \bar{X}_0 \setminus U$ . Take, using theorem 16(ii), a strict desingularization  $\bar{\epsilon} : (\bar{X}, \bar{D}) \rightarrow (\bar{X}_0, \bar{Z})$  of the pair  $(\bar{X}_0, \bar{Z})$  with  $\bar{X} \in \text{PSmVar}(k)$  and  $\bar{D} := \bar{\epsilon}^{-1}(\bar{Z}) = \cup_{i=1}^s \bar{D}_i \subset \bar{X}$  a normal crossing divisor. Denote  $d_X := \dim(\bar{X}) = \dim(U)$ .

(iii) We get from (i) and (ii) the morphism in  $C(\text{Var}(k)^2/S)$

$$\begin{aligned} T(p_{S\sharp}, p_{S*})(\mathbb{Z}((\bar{D}_\bullet \times S, D_\bullet)/\bar{X} \times S), \mathbb{Z}((\bar{X} \times S, X)/\bar{X} \times S)) := ([\Delta_{\bar{D}_\bullet}], [\Delta_{\bar{X}}]) : \\ \text{Cone}(\mathbb{Z}(i_\bullet \times I) : (\mathbb{Z}^{tr}((\bar{D}_\bullet \times S, D_\bullet)/S), u_{IJ}) \rightarrow \mathbb{Z}^{tr}((\bar{X} \times S, X)/S)) \rightarrow \\ p_{S*}E_{et}(\text{Cone}(\mathbb{Z}(i_\bullet \times I) : (\mathbb{Z}((\bar{D}_\bullet \times S, D_\bullet)/\bar{X} \times S), u_{IJ}) \rightarrow \\ \mathbb{Z}((\bar{X} \times S, X)/\bar{X} \times S)))(d_X)[2d_X] =: R_{(\bar{X}, \bar{D})/S}(\mathbb{Z}(U/S))(d_X)[2d_X] \end{aligned}$$

(iii)' which gives the map in  $C(\text{Var}(k)^{2, \text{smpr}}/S)$

$$\begin{aligned} T^{\mu, q}(p_{S\sharp}, p_{S*})(\mathbb{Z}((\bar{D}_\bullet \times S, D_\bullet)/\bar{X} \times S), \mathbb{Z}((\bar{X} \times S, X)/\bar{X} \times S)) : \\ \text{Cone}(\mathbb{Z}(i_\bullet \times I) : (\mathbb{Z}^{tr}((\bar{D}_\bullet \times S, D_\bullet)/S), u_{IJ}) \rightarrow \mathbb{Z}^{tr}((\bar{X} \times S, X)/S)) = \\ L\rho_{S*}\mu_{S*} \text{Cone}(\mathbb{Z}(i_\bullet \times I) : (\mathbb{Z}^{tr}((\bar{D}_\bullet \times S, D_\bullet)/S), u_{IJ}) \rightarrow \mathbb{Z}^{tr}((\bar{X} \times S, X)/S)) \\ \xrightarrow{L\rho_{S*}\mu_{S*}T(p_{S\sharp}, p_{S*})(\mathbb{Z}((\bar{D}_\bullet \times S, D_\bullet)/\bar{X} \times S), \mathbb{Z}((\bar{X} \times S, X)/\bar{X} \times S))} L\rho_{S*}\mu_{S*}R_{(\bar{X}, \bar{D})/S}(\mathbb{Z}(U/S))(d_X)[2d_X] \end{aligned}$$

**Proposition 12.** Let  $h : U \rightarrow S$  a morphism, with  $U, S \in \text{Var}(k)$ ,  $U$  irreducible. Take, see definition-proposition 3,  $\bar{f}_0 = \bar{h}_0 : \bar{X}_0 \rightarrow \bar{S}$  a compactification of  $h : U \rightarrow S$  and denote by  $\bar{Z} = \bar{X}_0 \setminus U$ . Take, using theorem 16(ii), a desingularization  $\bar{\epsilon} : (\bar{X}, \bar{D}) \rightarrow (\bar{X}_0, \Delta)$  of the pair  $(\bar{X}_0, \Delta)$ ,  $\bar{Z} \subset \Delta$  with  $\bar{X} \in \text{PSmVar}(k)$  and  $\bar{D} := \bar{\epsilon}^{-1}(\Delta) = \cup_{i=1}^s \bar{D}_i \subset \bar{X}$  a normal crossing divisor. Denote  $d_X := \dim(\bar{X}) = \dim(U)$ .

(i) The morphism

$$[\Delta_{\bar{D}_\bullet}] : \mathbb{Z}^{tr}((\bar{D}_\bullet \times S, D_\bullet)/S) \rightarrow p_{S*}E_{et}(\mathbb{Z}((\bar{D}_\bullet \times S, D_\bullet)/\bar{X} \times S)(d_X)[2d_X])$$

given in definition 23(i) is an equivalence  $(\mathbb{A}^1, et)$  local.

(ii) The morphism

$$[\Delta_{\bar{X}}] : \mathbb{Z}^{tr}((\bar{X} \times S, X)/S) \rightarrow p_{S*}E_{et}(\mathbb{Z}((\bar{X} \times S, X)/\bar{X} \times S)(d_X)[2d_X])$$

given in definition 23(ii) is an equivalence  $(\mathbb{A}^1, et)$  local.

Let  $h : U \rightarrow S$  a morphism, with  $U, S \in \text{Var}(k)$ ,  $U$  smooth connected (hence irreducible by smoothness). Take, see definition-proposition 3,  $\bar{f}_0 = \bar{h}_0 : \bar{X}_0 \rightarrow \bar{S}$  a compactification of  $h : U \rightarrow S$  and denote by  $\bar{Z} = \bar{X}_0 \setminus U$ . Take, using theorem 16(ii), a strict desingularization  $\bar{\epsilon} : (\bar{X}, \bar{D}) \rightarrow (\bar{X}_0, \bar{Z})$  of the pair  $(\bar{X}_0, \bar{Z})$ , with  $\bar{X} \in \text{PSmVar}(k)$  and  $\bar{D} := \bar{\epsilon}^{-1}(\bar{Z}) = \cup_{i=1}^s \bar{D}_i \subset \bar{X}$  a normal crossing divisor.

(iii) The morphism

$$\begin{aligned} T(p_{S\sharp}, p_{S*})(\mathbb{Z}((\bar{D}_\bullet \times S, D_\bullet)/\bar{X} \times S), \mathbb{Z}((\bar{X} \times S, X)/\bar{X} \times S)) &:= ([\Delta_{\bar{D}_\bullet}], [\Delta_{\bar{X}}]) : \\ \text{Cone}(\mathbb{Z}(i_\bullet \times I) : (\mathbb{Z}^{tr}((\bar{D}_\bullet \times S, D_\bullet)/S), u_{IJ}) \rightarrow \mathbb{Z}^{tr}((\bar{X} \times S, X)/S)) &\rightarrow \\ p_{S*}E_{et}(\text{Cone}(\mathbb{Z}(i_\bullet \times I) : (\mathbb{Z}((\bar{D}_\bullet \times S, D_\bullet)/\bar{X} \times S), u_{IJ}) \rightarrow &\rightarrow \\ \mathbb{Z}((\bar{X} \times S, X)/\bar{X} \times S))(d_X)[2d_X]) &=: R_{(\bar{X}, \bar{D})/S}(\mathbb{Z}(U/S))(d_X)[2d_X] \end{aligned}$$

given in definition 23(iii)' is an equivalence  $(\mathbb{A}^1, et)$  local.

(iii)' The morphism

$$\begin{aligned} T^{\mu, q}(p_{S\sharp}, p_{S*})(\mathbb{Z}((\bar{D}_\bullet \times S, D_\bullet)/\bar{X} \times S), \mathbb{Z}((\bar{X} \times S, X)/\bar{X} \times S)) &: \\ \text{Cone}(\mathbb{Z}(i_\bullet \times I) : (\mathbb{Z}^{tr}((\bar{D}_\bullet \times S, D_\bullet)/S), u_{IJ}) \rightarrow \mathbb{Z}^{tr}((\bar{X} \times S, X)/S)) &\rightarrow \\ \rightarrow L\rho_{S*}\mu_{S*}R_{(\bar{X}, \bar{D})/S}(\mathbb{Z}(U/S))(d_X)[2d_X] & \end{aligned}$$

given in definition 23(iii)' is an equivalence  $(\mathbb{A}^1, et)$  local.

*Proof.* (i): By Yoneda lemma, it is equivalent to show that for every morphism  $g : T \rightarrow S$  with  $T \in \text{Var}(k)$  and every closed subset  $E \subset T$ , the composition morphism

$$\begin{aligned} [\Delta_{\bar{D}_\bullet}] : \text{Hom}^\bullet(\mathbb{Z}((T, E)/S), C_*\mathbb{Z}^{tr}((\bar{D}_\bullet \times S, D_\bullet)/S)) &\xrightarrow{\text{Hom}^\bullet(\mathbb{Z}((T, E)/S), C_*\Delta_{\bar{D}_\bullet})} \\ \text{Hom}^\bullet(\mathbb{Z}((T, E)/S), p_{S*}E_{et}(\mathbb{Z}((\bar{D}_\bullet \times S, D_\bullet)/\bar{X} \times S)(d_X)[2d_X])) & \end{aligned}$$

is a quasi-isomorphism of abelian groups. But this map is the composite

$$\begin{aligned} &\text{Hom}^\bullet(\mathbb{Z}((T, E)/S), \mathbb{Z}^{tr}((\bar{D}_\bullet \times S, D_\bullet)/S)) \xrightarrow{[\Delta_{\bar{D}_\bullet}]} \\ &\text{Hom}^\bullet(\mathbb{Z}((T, E)/S), p_{S*}E_{et}(\mathbb{Z}((\bar{D}_\bullet \times S, D_\bullet)/\bar{X} \times S)(d_X)[2d_X])) \xrightarrow{\sim} \\ &\text{Hom}^\bullet(\mathbb{Z}((T \times \bar{X}, E)/S \times \bar{X}), \\ &C_*\mathbb{Z}^{tr}((\bar{D}_\bullet \times S \times \mathbb{P}^{d_X}, D_\bullet \times \mathbb{P}^{d_X})/\bar{X} \times S)/\mathbb{Z}^{tr}((-) \times \mathbb{P}^{d_X-1}, (-) \times \mathbb{P}^{d_X-1})) \end{aligned}$$

which is clearly a quasi-isomorphism.

(ii): Similar to (i).

(iii): Follows from (i) and (ii).

(iii)': Follows from (iii) and the fact that  $\mu_{S*}$  preserve  $(\mathbb{A}^1, et)$  local equivalence (see proposition 9) and the fact that  $\rho_{S*}$  preserve  $(\mathbb{A}^1, et)$  local equivalence (see proposition 8).  $\square$

**Definition 24.** (i) Let  $h : U \rightarrow S$  a morphism, with  $U, S \in \text{Var}(k)$ ,  $U$  smooth. Take, see definition-proposition 3,  $\bar{f}_0 = \bar{h}_0 : \bar{X}_0 \rightarrow \bar{S}$  a compactification of  $h : U \rightarrow S$  and denote by  $\bar{Z} = \bar{X}_0 \setminus U$ . Take, using theorem 16(ii), a strict desingularization  $\bar{\epsilon} : (\bar{X}, \bar{D}) \rightarrow (\bar{X}_0, \bar{Z})$  of the pair  $(\bar{X}_0, \bar{Z})$ , with  $\bar{X} \in \text{PSmVar}(k)$  and  $\bar{D} := \bar{\epsilon}^{-1}(\bar{Z}) = \cup_{i=1}^s \bar{D}_i \subset \bar{X}$  a normal crossing divisor. We will consider the following canonical map in  $C(\text{Var}(k)^{sm}/S)$

$$\begin{aligned} T_{(\bar{X}, \bar{D})/S}(U/S) : \text{Gr}_{S*}^{12} L\rho_{S*}\mu_{S*}R_{(\bar{X}, \bar{D})/S}(\mathbb{Z}(U/S)) &\xrightarrow{q} \text{Gr}_{S*}^{12} \rho_{S*}\mu_{S*}R_{(\bar{X}, \bar{D})/S}(\mathbb{Z}(U/S)) \\ \xrightarrow{r_{(\bar{X}, \bar{D})/S}(\mathbb{Z}(U/S))} \text{Gr}_{S*}^{12} \rho_{S*}\mu_{S*}p_{S*}E_{et}(\mathbb{Z}((U \times S, U)/U \times S)) &\xrightarrow{l(U/S)} h_*E_{et}(\mathbb{Z}(U/U)) =: \mathbb{D}_S^0(\mathbb{Z}(U/S)) \end{aligned}$$

where, for  $h' : V \rightarrow S$  a smooth morphism with  $V \in \text{Var}(k)$ ,

$$l^{00}(U/S)(V/S) : \mathbb{Z}((U \times S, U)/U \times S)(V \times U \times S, V \times_S U/U \times S) \rightarrow \mathbb{Z}(U/U)(V \times_S U), \alpha \mapsto \alpha|_{V \times_S U}$$

which gives

$$l^0(U/S)(V/S) : E_{et}^0(\mathbb{Z}((U \times S, U)/U \times S))(V \times U \times S, V \times_S U/U \times S) \rightarrow E_{et}^0(\mathbb{Z}(U/U))(V \times_S U),$$

and by induction

$$\tau^{\leq i} l(U/S) : \mathrm{Gr}_{S^*}^{12} \rho_{S^*} \mu_{S^*} \rho_{S^*} E_{et}^{\leq i}(\mathbb{Z}((U \times S, U)/U \times S)) \rightarrow h_* E_{et}^{\leq i}(\mathbb{Z}(U/U))$$

where  $\tau^{\leq i}$  is the cohomological truncation.

- (ii) Let  $g : U'/S \rightarrow U/S$  a morphism, with  $U'/S = (U', h'), U/S = (U, h) \in \mathrm{Var}(k)/S$ ,  $U, U'$  smooth. Take, see definition-proposition 3(ii), a compactification  $\bar{f}_0 = \bar{h} : \bar{X}_0 \rightarrow \bar{S}$  of  $h : U \rightarrow S$  and a compactification  $\bar{f}'_0 = \bar{h}' : \bar{X}'_0 \rightarrow \bar{S}$  of  $h' : U' \rightarrow S$  such that  $g : U'/S \rightarrow U/S$  extend to a morphism  $\bar{g}_0 : \bar{X}'_0/\bar{S} \rightarrow \bar{X}_0/\bar{S}$ . Denote  $\bar{Z} = \bar{X}_0 \setminus U$  and  $\bar{Z}' = \bar{X}'_0 \setminus U'$ . Take, see definition-proposition 3(ii), a strict desingularization  $\bar{\epsilon} : (\bar{X}, \bar{D}) \rightarrow (\bar{X}_0, \bar{Z})$  of  $(\bar{X}_0, \bar{Z})$ , a strict desingularization  $\bar{\epsilon}' : (\bar{X}', \bar{D}') \rightarrow (\bar{X}'_0, \bar{Z}')$  of  $(\bar{X}'_0, \bar{Z}')$  and a morphism  $\bar{g} : \bar{X}' \rightarrow \bar{X}$  such that the following diagram commutes

$$\begin{array}{ccc} \bar{X}'_0 & \xrightarrow{\bar{g}_0} & \bar{X}_0 \\ \bar{\epsilon}' \uparrow & & \uparrow \bar{\epsilon} \\ \bar{X}' & \xrightarrow{\bar{g}} & \bar{X} \end{array}$$

Then by the diagram given in definition 22(ii), the following diagram in  $C(\mathrm{Var}(k)^{sm}/S)$  obviously commutes

$$\begin{array}{ccc} \mathrm{Gr}_{S^*}^{12} L\rho_{S^*} \mu_{S^*} R_{(\bar{X}, \bar{D})/S}(\mathbb{Z}(U/S)) & \xrightarrow{T_{(\bar{X}, \bar{D})/S}(U/S)} & h_* E_{et}(\mathbb{Z}(U/U)) := \mathbb{D}_S^0(\mathbb{Z}(U/S)) \\ \downarrow R_{S^*}^{CH}(g) & & \downarrow T_{(g, E)(-)\circ \mathrm{ad}(g^*, g^*)}(E_{et}(\mathbb{Z}(U/U))) := \mathbb{D}_S^0(g) \\ \mathrm{Gr}_{S^*}^{12} L\rho_{S^*} \mu_{S^*} R_{(\bar{X}', \bar{D}')/S}(\mathbb{Z}(U'/S)) & \xrightarrow{T_{(\bar{X}', \bar{D}')/S}(U'/S)} & h'_* E_{et}(\mathbb{Z}(U'/U')) := \mathbb{D}_S^0(\mathbb{Z}(U'/S)) \end{array}$$

where  $l(U/S)$  are  $l(U'/S)$  are the maps given in (i).

- (iii) Let  $S \in \mathrm{SmVar}(k)$ . Let  $F \in C(\mathrm{Var}(k)^{sm}/S)$ . We get from (i) and (ii) morphisms in  $C(\mathrm{Var}(k)^{sm}/S)$

$$\begin{array}{ccc} T_S^{CH}(LF) : \mathrm{Gr}_{S^*}^{12} L\rho_{S^*} \mu_{S^*} R_{(\bar{X}^*, \bar{D}^*)/S}(\rho_S^* LF) & & \\ \xrightarrow{r_{S^*}^{CH}(LF)} & \mathrm{Gr}_{S^*}^{12} L\rho_{S^*} \mu_{S^*} \mathbb{D}_S^0(\rho_S^* LF) & \xrightarrow{l(LF)} \mathbb{D}_S^0(LF) \end{array}$$

**Lemma 1.** (i) Let  $h : U \rightarrow S$  a morphism, with  $U, S \in \mathrm{Var}(k)$ ,  $U$  smooth. Take, see definition-proposition 3,  $\bar{f}_0 = \bar{h}_0 : \bar{X}_0 \rightarrow \bar{S}$  a compactification of  $h : U \rightarrow S$  and denote by  $\bar{Z} = \bar{X}_0 \setminus U$ . Take, using theorem 16(ii), a strict desingularization  $\bar{\epsilon} : (\bar{X}, \bar{D}) \rightarrow (\bar{X}_0, \bar{Z})$  of the pair  $(\bar{X}_0, \bar{Z})$ , with  $\bar{X} \in \mathrm{PSmVar}(k)$  and  $\bar{D} := \bar{\epsilon}^{-1}(\bar{Z}) = \cup_{i=1}^s \bar{D}_i \subset \bar{X}$  a normal crossing divisor. Then the map in  $C(\mathrm{Var}(k)^{2, smpr}/S)$

$$\begin{array}{ccc} \mathrm{ad}(\mathrm{Gr}_{S^*}^{12*}, \mathrm{Gr}_{S^*}^{12})(L\rho_{S^*} \mu_{S^*} R_{(\bar{X}, \bar{D})/S}(\mathbb{Z}(U/S))) \circ q : & & \\ \mathrm{Gr}_{S^*}^{12*} L \mathrm{Gr}_{S^*}^{12} L\rho_{S^*} \mu_{S^*} R_{(\bar{X}, \bar{D})/S}(\mathbb{Z}(U/S)) \rightarrow & L\rho_{S^*} \mu_{S^*} R_{(\bar{X}, \bar{D})/S}(\mathbb{Z}(U/S)) & \end{array}$$

is an equivalence  $(\mathbb{A}^1, et)$  local.

- (ii) Let  $S \in \mathrm{SmVar}(k)$ . Let  $F \in C(\mathrm{Var}(k)^{sm}/S)$ . Then the map in  $C(\mathrm{Var}(k)^{2, smpr}/S)$

$$\begin{array}{ccc} \mathrm{ad}(\mathrm{Gr}_{S^*}^{12*}, \mathrm{Gr}_{S^*}^{12})(L\rho_{S^*} \mu_{S^*} R_{(\bar{X}^*, \bar{D}^*)/S}(\rho_S^* LF)) \circ q : & & \\ \mathrm{Gr}_{S^*}^{12*} L \mathrm{Gr}_{S^*}^{12} L\rho_{S^*} \mu_{S^*} R_{(\bar{X}^*, \bar{D}^*)/S}(\rho_S^* LF) \rightarrow & L\rho_{S^*} \mu_{S^*} R_{(\bar{X}^*, \bar{D}^*)/S}(\rho_S^* LF) & \end{array}$$

is an equivalence  $(\mathbb{A}^1, et)$  local.

*Proof.* (i): Follows from proposition 12.

(ii): Follows from (i).  $\square$

**Definition 25.** (i) Let  $h : U \rightarrow S$  a morphism, with  $U, S \in \text{Var}(k)$  and  $U$  smooth. Take, see definition-proposition 3,  $f_0 = \bar{h}_0 : \bar{X}_0 \rightarrow \bar{S}$  a compactification of  $h : U \rightarrow S$  and denote by  $\bar{Z} = \bar{X}_0 \setminus U$ . Take, using theorem 16(ii), a strict desingularization  $\bar{\epsilon} : (\bar{X}, \bar{D}) \rightarrow (\bar{X}_0, \bar{Z})$  of the pair  $(\bar{X}_0, \bar{Z})$ , with  $\bar{X} \in \text{PSmVar}(k)$  and  $\bar{D} := \epsilon^{-1}(\bar{Z}) = \cup_{i=1}^s \bar{D}_i \subset \bar{X}$  a normal crossing divisor. We denote by  $i_\bullet : \bar{D}_\bullet \hookrightarrow \bar{X} = \bar{X}_{c(\bullet)}$  the morphism of simplicial varieties given by the closed embeddings  $i_I : \bar{D}_I = \cap_{i \in I} \bar{D}_i \hookrightarrow \bar{X}$ . We denote by  $j : U \hookrightarrow \bar{X}$  the open embedding and by  $p_S : \bar{X} \times S \rightarrow S$  and  $p_{\bar{S}} : U \times S \rightarrow S$  the projections. Considering the graph factorization  $\bar{f} : \bar{X} \xrightarrow{\bar{l}} \bar{X} \times \bar{S} \xrightarrow{p_{\bar{S}}} \bar{S}$  of  $f : \bar{X} \rightarrow \bar{S}$ , where  $\bar{l}$  is the graph embedding and  $p_{\bar{S}}$  the projection, we get closed embeddings  $l := \bar{l} \times_{\bar{S}} S : X \hookrightarrow \bar{X} \times S$  and  $l_{D_I} := \bar{D}_I \times_{\bar{X}} l : D_I \hookrightarrow \bar{D}_I \times S$ . We then consider the map in  $C(\text{Var}(k)^{2, \text{smpr}}/S)$

$$\begin{aligned} & T(\hat{R}^{CH}, R^{CH})(\mathbb{Z}(U/S)) : \hat{R}_{(\bar{X}, \bar{D})/S}(\mathbb{Z}(U/S)) \\ \xrightarrow{=} & \text{Cone}(\mathbb{Z}(i_\bullet \times I) : (\mathbb{Z}^{\text{tr}}((\bar{D}_\bullet \times S, D_\bullet)/S), u_{IJ}) \rightarrow \mathbb{Z}^{\text{tr}}((\bar{X} \times S, X)/S))(-d_X)[-2d_X] \\ & \xrightarrow{T^{\mu \cdot q}(p_{S\sharp}, p_{S*})(\mathbb{Z}((\bar{D}_\bullet \times S, D_\bullet)/\bar{X} \times S), \mathbb{Z}((\bar{X} \times S, X)/\bar{X} \times S))(-d_X)[-2d_X]} \\ & L\rho_{S*} \mu_{S*} R_{(\bar{X}, \bar{D})/S}(\mathbb{Z}(U/S)). \end{aligned}$$

given in definition 23(iii).

(ii) Let  $g : U'/S \rightarrow U/S$  a morphism, with  $U'/S = (U', h'), U/S = (U, h) \in \text{Var}(k)/S$ , with  $U$  and  $U'$  smooth. Take, see definition-proposition 3(ii), a compactification  $f_0 = \bar{h} : \bar{X}_0 \rightarrow \bar{S}$  of  $h : U \rightarrow S$  and a compactification  $f'_0 = \bar{h}' : \bar{X}'_0 \rightarrow \bar{S}$  of  $h' : U' \rightarrow S$  such that  $g : U'/S \rightarrow U/S$  extend to a morphism  $\bar{g}_0 : \bar{X}'_0/\bar{S} \rightarrow \bar{X}_0/\bar{S}$ . Denote  $\bar{Z} = \bar{X}_0 \setminus U$  and  $\bar{Z}' = \bar{X}'_0 \setminus U'$ . Take, see definition-proposition 3(ii), a strict desingularization  $\bar{\epsilon} : (\bar{X}, \bar{D}) \rightarrow (\bar{X}_0, \bar{Z})$  of  $(\bar{X}_0, \bar{Z})$ , a strict desingularization  $\bar{\epsilon}' : (\bar{X}', \bar{D}') \rightarrow (\bar{X}'_0, \bar{Z}')$  of  $(\bar{X}'_0, \bar{Z}')$  and a morphism  $\bar{g} : \bar{X}' \rightarrow \bar{X}$  such that the following diagram commutes

$$\begin{array}{ccc} \bar{X}'_0 & \xrightarrow{\bar{g}_0} & \bar{X}_0 \\ \bar{\epsilon}' \uparrow & & \uparrow \bar{\epsilon} \\ \bar{X}' & \xrightarrow{\bar{g}} & \bar{X} \end{array}$$

We then have, see definition-proposition 3(ii), the diagram (7) in  $\text{Fun}(\Delta, \text{Var}(k))$

$$\begin{array}{ccccc} U = U_{c(\bullet)} & \xrightarrow{j} & \bar{X} = \bar{X}_{c(\bullet)} & \xleftarrow{i_\bullet} & \bar{D}_{s_g(\bullet)} \\ \uparrow g & & \uparrow \bar{g} & & \uparrow \bar{g}' \\ U' = U'_{c(\bullet)} & \xrightarrow{j'} & \bar{X}' = \bar{X}'_{c(\bullet)} & \xleftarrow{i'_\bullet} \bar{D}' \xleftarrow{i''_\bullet} \bar{g}'^{-1}(\bar{D}_{s_g(\bullet)}) : i'_{g\bullet} \end{array}$$

Consider

$$\begin{aligned} [\Gamma_{\bar{g}}]^t & \in \text{Hom}(\mathbb{Z}^{\text{tr}}((\bar{X} \times S, X)/S)(-d_X)[-2d_X], \mathbb{Z}^{\text{tr}}((\bar{X}' \times S, X')/S)(-d_{X'})[-2d_{X'}]) \\ & \xrightarrow{\sim} \text{Hom}(\mathbb{Z}^{\text{tr}}((\bar{X} \times \mathbb{A}^{d_{X'}} \times S, X \times \mathbb{A}^{d_{X'}})/S), \\ & \mathbb{Z}_{\text{tr}}((\bar{X}' \times \mathbb{P}^{d_X} \times S, X' \times \mathbb{P}^{d_X})/S) / \mathbb{Z}_{\text{tr}}((-) \times \mathbb{P}^{d_X-1}, (-) \times \mathbb{P}^{d_X-1})) \end{aligned}$$

the morphism given by the transpose of the graph  $\Gamma_{\bar{g}} \subset X' \times_S X$  of  $\bar{g} : \bar{X}' \rightarrow \bar{X}$ . Then, since  $i_\bullet \circ \bar{g}' = \bar{g} \circ i'_{g\bullet} = \bar{g} \circ i' \circ i'_{g\bullet}$ , we have the factorization

$$\begin{aligned} & [\Gamma_{\bar{g}}]^t \circ \mathbb{Z}(i_\bullet \times I) : (\mathbb{Z}^{\text{tr}}((\bar{D}_{s_g(\bullet)} \times S, D_{s_g(\bullet)})/S), u_{IJ})(-d_X)[-2d_X] \\ & \xrightarrow{[\Gamma_{\bar{g}'}]^t} (\mathbb{Z}^{\text{tr}}((\bar{g}'^{-1}(\bar{D}_{s_g(\bullet)}) \times S, \bar{g}'^{-1}(D_{s_g(\bullet)}))/S), u_{IJ})(-d_{X'})[-2d_{X'}]) \\ & \xrightarrow{\mathbb{Z}(i'_{g\bullet} \times I)} \mathbb{Z}^{\text{tr}}((\bar{X}' \times S, X')/S)(-d_{X'})[-2d_{X'}]. \end{aligned}$$

with

$$[\Gamma_{\bar{g}_\bullet}]^t \in \text{Hom}((\mathbb{Z}^{\text{tr}}((\bar{D}_{s_g(\bullet)} \times \mathbb{A}^{d_{X'}} \times S, D_{s_g(\bullet)} \times \mathbb{A}^{d_{X'}})/S), u_{IJ}), \\ (\mathbb{Z}^{\text{tr}}((\bar{g}^{-1}(\bar{D}_{s_g(\bullet)}) \times \mathbb{P}^{d_X} \times S, \bar{g}^{-1}(D_{s_g(\bullet)}) \times \mathbb{P}^{d_X})/S), u_{IJ})/\mathbb{Z}^{\text{tr}}((-) \times \mathbb{P}^{d_X-1}, (-) \times \mathbb{P}^{d_X-1})).$$

We then consider the following map in  $C(\text{Var}(k)^{2, \text{pr}}/S)$

$$\begin{aligned} & \hat{R}_S^{\text{CH}}(g) : \hat{R}_{(\bar{X}, \bar{D})/S}(\mathbb{Z}(U/S)) \xrightarrow{=} \\ \text{Cone}(\mathbb{Z}(i_\bullet \times I) : (\mathbb{Z}^{\text{tr}}((\bar{D}_{s_g(\bullet)} \times S, D_{s_g(\bullet)})/S), u_{IJ}) \rightarrow \mathbb{Z}^{\text{tr}}((\bar{X} \times S, X)/S))(-d_X)[-2d_X] \\ & \xrightarrow{([\Gamma_{\bar{g}_\bullet}]^t, [\Gamma_{\bar{g}}]^t)} \\ & \text{Cone}(\mathbb{Z}(i'_{g_\bullet} \times I) : \\ & (\mathbb{Z}^{\text{tr}}((\bar{g}^{-1}(\bar{D}_{s_g(\bullet)}) \times S, \bar{g}^{-1}(D_{s_g(\bullet)})/S), u_{IJ}) \rightarrow \mathbb{Z}^{\text{tr}}((\bar{X}' \times S, X')/S))(-d_{X'})[-2d_{X'}] \\ & \xrightarrow{(\mathbb{Z}(i''_{g_\bullet} \times I), I)(-d_{X'})[-2d_{X'}]} \\ \text{Cone}(\mathbb{Z}(i'_\bullet \times I) : ((\mathbb{Z}^{\text{tr}}((\bar{D}'_\bullet \times S, D'_\bullet)/S), u_{IJ}) \rightarrow \mathbb{Z}^{\text{tr}}((\bar{X}' \times S, X')/S))(-d_{X'})[-2d_{X'}] \\ & \xrightarrow{=} \hat{R}_{(\bar{X}', \bar{D}')/S}(\mathbb{Z}(U'/S)) \end{aligned}$$

Then the following diagram in  $C(\text{Var}(k)^{2, \text{smp}}/S)$  commutes by definition

$$\begin{array}{ccc} \hat{R}_{(\bar{X}, \bar{D})/S}(\mathbb{Z}(U/S)) & \xrightarrow{T(\hat{R}^{\text{CH}}, R^{\text{CH}})(\mathbb{Z}(U/S))} & L\rho_{S^*} \mu_{S^*} R_{(\bar{X}, \bar{D})/S}(\mathbb{Z}(U/S)) \\ \hat{R}_S^{\text{CH}}(g) \downarrow & & \downarrow L\rho_{S^*} \mu_{S^*} R_S^{\text{CH}}(g) \\ \hat{R}_{(\bar{X}', \bar{D}')/S}(\mathbb{Z}(U'/S)) & \xrightarrow{T(\hat{R}^{\text{CH}}, R^{\text{CH}})(\mathbb{Z}(U'/S))} & L\rho_{S^*} \mu_{S^*} R_{(\bar{X}', \bar{D}')/S}(\mathbb{Z}(U'/S)) \end{array}$$

(iii) For  $g_1 : U''/S \rightarrow U'/S$ ,  $g_2 : U'/S \rightarrow U/S$  two morphisms with  $U''/S = (U', h'')$ ,  $U'/S = (U', h')$ ,  $U/S = (U, h) \in \text{Var}(k)/S$ , with  $U$ ,  $U'$  and  $U''$  smooth. We get from (i) and (ii) a compactification  $\bar{f} = \bar{h} : \bar{X} \rightarrow \bar{S}$  of  $h : U \rightarrow S$ , a compactification  $\bar{f}' = \bar{h}' : \bar{X}' \rightarrow \bar{S}$  of  $h' : U' \rightarrow S$ , and a compactification  $\bar{f}'' = \bar{h}'' : \bar{X}'' \rightarrow \bar{S}$  of  $h'' : U'' \rightarrow S$ , with  $\bar{X}$ ,  $\bar{X}'$ ,  $\bar{X}'' \in \text{PSmVar}(k)$ ,  $\bar{D} := \bar{X} \setminus U \subset \bar{X}$ ,  $\bar{D}' := \bar{X}' \setminus U' \subset \bar{X}'$ , and  $\bar{D}'' := \bar{X}'' \setminus U'' \subset \bar{X}''$  normal crossing divisors, such that  $g_1 : U''/S \rightarrow U'/S$  extend to  $\bar{g}_1 : \bar{X}''/\bar{S} \rightarrow \bar{X}'/\bar{S}$ ,  $g_2 : U'/S \rightarrow U/S$  extend to  $\bar{g}_2 : \bar{X}'/\bar{S} \rightarrow \bar{X}/\bar{S}$ , and

$$\hat{R}_S^{\text{CH}}(g_2 \circ g_1) = \hat{R}_S^{\text{CH}}(g_1) \circ \hat{R}_S^{\text{CH}}(g_2) : \hat{R}_{(\bar{X}, \bar{D})/S} \rightarrow \hat{R}_{(\bar{X}'', \bar{D}'')/S}$$

(iv) For

$$Q^* := (\cdots \rightarrow \bigoplus_{\alpha \in \Lambda^n} \mathbb{Z}(U_\alpha^n/S) \xrightarrow{(\mathbb{Z}(g_{\alpha, \beta}^n))} \bigoplus_{\beta \in \Lambda^{n-1}} \mathbb{Z}(U_\beta^{n-1}/S) \rightarrow \cdots) \in C(\text{Var}(k)/S)$$

a complex of (maybe infinite) direct sum of representable presheaves with  $U_\alpha^*$  smooth, we get from (i), (ii) and (iii) the map in  $C(\text{Var}(k)^{2, \text{smp}}/S)$

$$\begin{aligned} T(\hat{R}^{\text{CH}}, R^{\text{CH}})(Q^*) : \hat{R}^{\text{CH}}(Q^*) & := (\cdots \rightarrow \bigoplus_{\beta \in \Lambda^{n-1}} \varinjlim_{(\bar{X}_\beta^{n-1}, \bar{D}_\beta^{n-1})/S} \hat{R}_{(\bar{X}_\beta^{n-1}, \bar{D}_\beta^{n-1})/S}(\mathbb{Z}(U_\beta^{n-1}/S)) \\ & \xrightarrow{(\hat{R}_S^{\text{CH}}(g_{\alpha, \beta}^n))} \bigoplus_{\alpha \in \Lambda^n} \varinjlim_{(\bar{X}_\alpha^n, \bar{D}_\alpha^n)/S} \hat{R}_{(\bar{X}_\alpha^n, \bar{D}_\alpha^n)/S}(\mathbb{Z}(U_\alpha^n/S)) \rightarrow \cdots) \rightarrow L\rho_{S^*} \mu_{S^*} R^{\text{CH}}(Q^*), \end{aligned}$$

where for  $(U_\alpha^n, h_\alpha^n) \in \text{Var}(k)/S$ , the inductive limit run over all the compactifications  $\bar{f}_\alpha : \bar{X}_\alpha \rightarrow \bar{S}$  of  $h_\alpha : U_\alpha \rightarrow S$  with  $\bar{X}_\alpha \in \text{PSmVar}(k)$  and  $\bar{D}_\alpha := \bar{X}_\alpha \setminus U_\alpha$  a normal crossing divisor. For  $m =$

$(m^*) : Q_1^* \rightarrow Q_2^*$  a morphism with

$$Q_1^* := (\cdots \rightarrow \bigoplus_{\alpha \in \Lambda^n} \mathbb{Z}(U_{1,\alpha}^n/S) \xrightarrow{(\mathbb{Z}(g_{\alpha,\beta}^n))} \bigoplus_{\beta \in \Lambda^{n-1}} \mathbb{Z}(U_{1,\beta}^{n-1}/S) \rightarrow \cdots),$$

$$Q_2^* := (\cdots \rightarrow \bigoplus_{\alpha \in \Lambda^n} \mathbb{Z}(U_{2,\alpha}^n/S) \xrightarrow{(\mathbb{Z}(g_{\alpha,\beta}^n))} \bigoplus_{\beta \in \Lambda^{n-1}} \mathbb{Z}(U_{2,\beta}^{n-1}/S) \rightarrow \cdots) \in C(\text{Var}(k)/S)$$

complexes of (maybe infinite) direct sum of representable presheaves with  $U_{1,\alpha}^*$  and  $U_{2,\alpha}^*$  smooth, we get again from (i), (ii) and (iii) a commutative diagram in  $C(\text{Var}(k)^{2,smpr}/S)$

$$\begin{array}{ccc} \hat{R}^{CH}(Q_2^*) & \xrightarrow{T(\hat{R}_S^{CH}, R_S^{CH})(Q_2^*)} & L\rho_{S*}\mu_{S*}R^{CH}(Q_2^*) \\ \hat{R}_S^{CH}(m) := (\hat{R}_S^{CH}(m^*)) \downarrow & & \downarrow L\rho_{S*}\mu_{S*}R_S^{CH}(m) := L\rho_{S*}\mu_{S*}(R_S^{CH}(m^*)) \\ \hat{R}^{CH}(Q_1^*) & \xrightarrow{T(\hat{R}_S^{CH}, R_S^{CH})(Q_1^*)} & L\rho_{S*}\mu_{S*}R^{CH}(Q_1^*) \end{array}$$

- Let  $S \in \text{Var}(k)$  For  $(h, m, m') = (h^*, m^*, m'^*) : Q_1^*[1] \rightarrow Q_2^*$  an homotopy with  $Q_1^*, Q_2^* \in C(\text{Var}(k)/S)$  complexes of (maybe infinite) direct sum of representable presheaves with  $U_{1,\alpha}^*$  and  $U_{2,\alpha}^*$  smooth,

$$(\hat{R}_S^{CH}(h), \hat{R}_S^{CH}(m), \hat{R}_S^{CH}(m')) = (\hat{R}_S^{CH}(h^*), \hat{R}_S^{CH}(m^*), \hat{R}_S^{CH}(m'^*)) : R^{CH}(Q_2^*[1]) \rightarrow R^{CH}(Q_1^*)$$

is an homotopy in  $C(\text{Var}(k)^{2,smpr}/S)$  using definition 25 (iii). In particular if  $m : Q_1^* \rightarrow Q_2^*$  with  $Q_1^*, Q_2^* \in C(\text{Var}(k)/S)$  complexes of (maybe infinite) direct sum of representable presheaves with  $U_{1,\alpha}^*$  and  $U_{2,\alpha}^*$  smooth is an homotopy equivalence, then  $\hat{R}_S^{CH}(m) : \hat{R}^{CH}(Q_2^*) \rightarrow \hat{R}^{CH}(Q_1^*)$  is an homotopy equivalence.

- Let  $S \in \text{SmVar}(k)$ . Let  $F \in \text{PSh}(\text{Var}(k)^{sm}/S)$ . Consider

$$q : LF := (\cdots \rightarrow \bigoplus_{(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S} \mathbb{Z}(U_\alpha/S) \xrightarrow{(\mathbb{Z}(g_{\alpha,\beta}^n))} \bigoplus_{(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S} \mathbb{Z}(U_\alpha/S) \rightarrow \cdots) \rightarrow F$$

the canonical projective resolution given in subsection 2.3.3. Note that the  $U_\alpha$  are smooth since  $S$  is smooth and  $h_\alpha$  are smooth morphism. Definition 25(iv) gives in this particular case the map in  $C(\text{Var}(k)^2/S)$

$$T(\hat{R}_S^{CH}, R_S^{CH})(\rho_S^* LF) : \hat{R}^{CH}(\rho_S^* LF) := (\cdots \rightarrow \bigoplus_{(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S} \varinjlim_{(\bar{X}_\alpha, \bar{D}_\alpha)/S} \hat{R}_{(\bar{X}_\alpha, \bar{D}_\alpha)/S}(\mathbb{Z}(U_\alpha/S))$$

$$\xrightarrow{(\hat{R}_S^{CH}(g_{\alpha,\beta}^n))} \bigoplus_{(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S} \varinjlim_{(\bar{X}_\alpha, \bar{D}_\alpha)/S} \hat{R}_{(\bar{X}_\alpha, \bar{D}_\alpha)/S}(\mathbb{Z}(U_\alpha/S)) \rightarrow \cdots) \rightarrow L\rho_{S*}\mu_{S*}R^{CH}(\rho_S^* LF),$$

where for  $(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S$ , the inductive limit run over all the compactifications  $\bar{f}_\alpha : \bar{X}_\alpha \rightarrow \bar{S}$  of  $h_\alpha : U_\alpha \rightarrow S$  with  $\bar{X}_\alpha \in \text{PSmVar}(k)$  and  $\bar{D}_\alpha := \bar{X}_\alpha \setminus U_\alpha$  a normal crossing divisor. Definition 25(iv) gives then by functoriality in particular, for  $F = F^\bullet \in C(\text{Var}(k)^{sm}/S)$ , the map in  $C(\text{Var}(k)^{2,smpr}/S)$

$$T(\hat{R}_S^{CH}, R_S^{CH})(\rho_S^* LF) : \hat{R}^{CH}(\rho_S^* LF) \rightarrow L\rho_{S*}\mu_{S*}R^{CH}(\rho_S^* LF).$$

- Let  $g : T \rightarrow S$  a morphism with  $T, S \in \text{SmVar}(k)$ . Let  $h : U \rightarrow S$  a smooth morphism with  $U \in \text{Var}(k)$ . Consider the cartesian square

$$\begin{array}{ccc} U_T & \xrightarrow{h'} & T \\ \downarrow g' & & \downarrow g \\ U & \xrightarrow{h} & S \end{array}$$

Note that  $U$  is smooth since  $S$  and  $h$  are smooth, and  $U_T$  is smooth since  $T$  and  $h'$  are smooth. Take, see definition-proposition 3(ii), a compactification  $\bar{f}_0 = \bar{h} : \bar{X}_0 \rightarrow \bar{S}$  of  $h : U \rightarrow S$  and a compactification  $\bar{f}'_0 = g \circ \bar{h}' : \bar{X}'_0 \rightarrow \bar{S}$  of  $g \circ h' : U' \rightarrow S$  such that  $g' : U_T/S \rightarrow U/S$  extend to a morphism  $\bar{g}'_0 : \bar{X}'_0/\bar{S} \rightarrow \bar{X}_0/\bar{S}$ . Denote  $\bar{Z} = \bar{X}_0 \setminus U$  and  $\bar{Z}' = \bar{X}'_0 \setminus U_T$ . Take, see definition-proposition 3(ii), a strict desingularization  $\bar{\epsilon} : (\bar{X}, \bar{D}) \rightarrow (\bar{X}_0, \bar{Z})$  of  $(\bar{X}_0, \bar{Z})$ , a desingularization  $\bar{\epsilon}' : (\bar{X}', \bar{D}') \rightarrow (\bar{X}'_0, \bar{Z}')$  of  $(\bar{X}'_0, \bar{Z}')$  and a morphism  $\bar{g}' : \bar{X}' \rightarrow \bar{X}$  such that the following diagram commutes

$$\begin{array}{ccc} \bar{X}'_0 & \xrightarrow{\bar{g}'_0} & \bar{X}_0 \\ \bar{\epsilon}' \uparrow & & \uparrow \bar{\epsilon} \\ \bar{X}' & \xrightarrow{\bar{g}'} & \bar{X} \end{array}$$

We then have, see definition-proposition 3(ii), the following commutative diagram in  $\text{Fun}(\Delta, \text{Var}(k))$

$$\begin{array}{ccccc} U = U_{c(\bullet)} & \xrightarrow{j} & \bar{X} = \bar{X}_{c(\bullet)} & \xleftarrow{i_\bullet} & \bar{D}_{s_{g'}(\bullet)} \\ \uparrow g' & & \uparrow \bar{g}' & & \uparrow (\bar{g}')_\bullet \\ U_T = U_{T,c(\bullet)} & \xrightarrow{j'} & \bar{X}' = \bar{X}'_{c(\bullet)} & \xleftarrow{i'_\bullet} & \bar{D}'_\bullet \xleftarrow{i''_{g'_\bullet}{}^{-1}} (\bar{D}_{s_{g'}(\bullet)}) : i'_{g_\bullet} \end{array}$$

We then consider the following map in  $C(\text{Var}(k)^{2,pr}/T)$ ,

$$\begin{aligned} & T(g, \hat{R}^{CH})(\mathbb{Z}(U/S)) : g^* \hat{R}_{(\bar{X}, \bar{D})/S}(\mathbb{Z}(U/S)) \\ \xrightarrow{=} & g^* \text{Cone}(\mathbb{Z}(i_\bullet \times I) : (\mathbb{Z}^{tr}((\bar{D}_\bullet \times S, D_\bullet)/S), u_{IJ}) \rightarrow \mathbb{Z}^{tr}((\bar{X} \times S, X)/S))(-d_X)[-2d_X] \\ & \xrightarrow{T(g,L)(-)\circ T(g,c)(-)} \\ \text{Cone}(\mathbb{Z}(i'_{g_\bullet} \times I) : (\mathbb{Z}^{tr}((\bar{D}'_\bullet \times T, \bar{g}^{-1}(D_{s_{g'}(\bullet)})/T), u_{IJ}) \rightarrow \mathbb{Z}^{tr}((\bar{X} \times T, X')/T))(-d_X)[-2d_X] \\ & \xrightarrow{([\Gamma_{\bar{g}'_\bullet}]^t, [\Gamma_{\bar{g}}]^t)} \\ & \text{Cone}(\mathbb{Z}(i'_{g_\bullet} \times I) : \\ & (\mathbb{Z}^{tr}((\bar{g}^{-1}(\bar{D}_{s_{g'}(\bullet)}) \times T, \bar{g}^{-1}(D_{s_{g'}(\bullet)})/T), u_{IJ}) \rightarrow \mathbb{Z}^{tr}((\bar{X}' \times T, X')/T))(-d_{X'})[-2d_{X'}] \\ & \xrightarrow{(\mathbb{Z}(i''_{g_\bullet} \times I), I)(-d_{X'})[-2d_{X'}]} \\ \text{Cone}(\mathbb{Z}(i'_\bullet \times I) : ((\mathbb{Z}^{tr}((\bar{D}'_\bullet \times T, D'_\bullet)/T), u_{IJ}) \rightarrow \mathbb{Z}^{tr}((\bar{X}' \times S, X')/T))(-d_{X'})[-2d_{X'}] \\ & \xrightarrow{=} \hat{R}_{(\bar{X}', \bar{D}')/T}(\mathbb{Z}(U_T/T)) \end{aligned}$$

For

$$Q^* := (\cdots \rightarrow \bigoplus_{\alpha \in \Lambda^n} \mathbb{Z}(U_\alpha^n/S) \xrightarrow{(\mathbb{Z}(g_{\alpha,\beta}^n))} \bigoplus_{\beta \in \Lambda^{n-1}} \mathbb{Z}(U_\beta^{n-1}/S) \rightarrow \cdots) \in C(\text{Var}(k)/S)$$

a complex of (maybe infinite) direct sum of representable presheaves with  $h_\alpha^n : U_\alpha^n \rightarrow S$  smooth, we get the map in  $C(\text{Var}(k)^{2,smpr}/T)$

$$\begin{aligned} & T(g, \hat{R}^{CH})(Q^*) : g^* \hat{R}^{CH}(Q^*) = (\cdots \rightarrow \bigoplus_{\alpha \in \Lambda^n} \varinjlim_{(\bar{X}_\alpha^n, \bar{D}_\alpha^n)/S} g^* \hat{R}_{(\bar{X}_\alpha^n, \bar{D}_\alpha^n)/S}(\mathbb{Z}(U_\alpha^n/S)) \rightarrow \cdots) \\ & \xrightarrow{(T(g, \hat{R}^{CH})(\mathbb{Z}(U_\alpha^n/S)))} (\cdots \rightarrow \bigoplus_{\alpha \in \Lambda^n} \varinjlim_{(\bar{X}'_\alpha^n, \bar{D}'_\alpha^n)/T} \hat{R}_{(\bar{X}'_\alpha^n, \bar{D}'_\alpha^n)/T}(\mathbb{Z}(U_{\alpha,T}^n/S)) \rightarrow \cdots) =: \hat{R}^{CH}(g^* Q^*) \end{aligned}$$



together with the commutative diagram in  $C(\text{Var}(k)^{2,smpr}/T)$

$$\begin{array}{ccc}
g^* \hat{R}^{CH}(Q^*) & \xrightarrow{T(g, \hat{R}^{CH})(Q^*)} & \hat{R}^{CH}(g^* Q^*) \\
\downarrow g^* T(\hat{R}_S^{CH}, R_S^{CH})(Q^*) & & \downarrow T(\hat{R}_T^{CH}, R_T^{CH})(g^* Q) \\
g^* L\rho_{S^*} \mu_{S^*} \hat{R}^{CH}(Q^*) & \xrightarrow{T(g, \hat{R}^{CH})(Q^*) \circ T(g, \mu)(-) \circ T(g, \rho)(-) \circ T(g, L)(-)} & L\rho_{T^*} \mu_{T^*} \hat{R}^{CH}(g^* Q^*)
\end{array}$$

Let  $F \in \text{PSh}(\text{Var}(k)^{sm}/S)$ . Consider

$$q : LF := (\cdots \rightarrow \bigoplus_{(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S} \mathbb{Z}(U_\alpha/S) \rightarrow \cdots) \rightarrow F$$

the canonical projective resolution given in subsection 2.3.3. We then get in particular the map in  $C(\text{Var}(k)^{2,smpr}/T)$

$$\begin{aligned}
& T(g, \hat{R}^{CH})(\rho_S^* LF) : g^* \hat{R}^{CH}(\rho_S^* LF) = \\
& (\cdots \rightarrow \bigoplus_{(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S} \varinjlim_{(\bar{X}_\alpha, \bar{D}_\alpha)/S} g^* \hat{R}_{(\bar{X}_\alpha, \bar{D}_\alpha)/S}(\mathbb{Z}(U_\alpha/S)) \rightarrow \cdots) \xrightarrow{(T(g, \hat{R}^{CH})(\mathbb{Z}(U_\alpha/S)))} \\
& (\cdots \rightarrow \bigoplus_{(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S} \varinjlim_{(\bar{X}'_\alpha, \bar{D}'_\alpha)/T} \hat{R}_{(\bar{X}'_\alpha, \bar{D}'_\alpha)/T}(\mathbb{Z}(U_\alpha, T/S)) \rightarrow \cdots) =: \hat{R}^{CH}(\rho_T^* g^* LF),
\end{aligned}$$

and by functoriality, we get in particular for  $F = F^\bullet \in C(\text{Var}(k)^{sm}/S)$ , the map in  $C(\text{Var}(k)^{2,smpr}/T)$

$$T(g, \hat{R}^{CH})(\rho_S^* LF) : g^* \hat{R}^{CH}(\rho_S^* LF) \rightarrow \hat{R}^{CH}(\rho_T^* g^* LF)$$

together with the commutative diagram in  $C(\text{Var}(k)^{2,smpr}/T)$

$$\begin{array}{ccc}
g^* \hat{R}^{CH}(\rho_S^* LF) & \xrightarrow{T(g, \hat{R}^{CH})(\rho_S^* LF)} & \hat{R}^{CH}(\rho_T^* g^* LF) \\
\downarrow g^* T(\hat{R}_S^{CH}, R_S^{CH})(\rho_S^* LF) & & \downarrow T(\hat{R}_T^{CH}, R_T^{CH})(\rho_T^* g^* LF) \\
g^* L\rho_{S^*} \mu_{S^*} \hat{R}^{CH}(\rho_S^* LF) & \xrightarrow{L\rho_{T^*} \mu_{T^*} T(g, \hat{R}^{CH})(\rho_S^* LF) \circ T(g, \mu)(-) \circ T(g, \rho)(-) \circ T(g, L)(-)} & L\rho_{T^*} \mu_{T^*} \hat{R}^{CH}(\rho_T^* g^* LF)
\end{array}$$

- Let  $S_1, S_2 \in \text{SmVar}(k)$  and  $p : S_1 \times S_2 \rightarrow S_1$  the projection. Let  $h : U \rightarrow S_1$  a smooth morphism with  $U \in \text{Var}(k)$ . Consider the cartesian square

$$\begin{array}{ccc}
U \times S_2 & \xrightarrow{h \times I} & S_1 \times S_2 \\
\downarrow p' & & \downarrow p \\
U & \xrightarrow{h} & S_1
\end{array}$$

Take, see definition-proposition 3(i), a compactification  $\bar{f}_0 = \bar{h} : \bar{X}_0 \rightarrow \bar{S}_1$  of  $h : U \rightarrow S_1$ . Then  $\bar{f}_0 \times I : \bar{X}_0 \times S_2 \rightarrow \bar{S}_1 \times S_2$  is a compactification of  $h \times I : U \times S_2 \rightarrow S_1 \times S_2$  and  $p' : U \times S_2 \rightarrow U$  extend to  $\bar{p}'_0 := p_{X_0} : \bar{X}_0 \times S_2 \rightarrow \bar{X}_0$ . Denote  $Z = X_0 \setminus U$ . Take see theorem 16(i), a strict desingularization  $\bar{\epsilon} : (\bar{X}, \bar{D}) \rightarrow (\bar{X}_0, \bar{Z})$  of the pair  $(\bar{X}_0, \bar{Z})$ . We then have the commutative diagram (8) in  $\text{Fun}(\Delta, \text{Var}(k))$  whose squares are cartesian

$$\begin{array}{ccccc}
U = U_{c(\bullet)} & \xrightarrow{j} & \bar{X} & \xleftarrow{i_\bullet} & \bar{D}_\bullet \\
\uparrow g & & \uparrow \bar{p}' := p_X & & \uparrow \bar{p}'_\bullet \\
U \times S_2 = (U \times S_2)_{c(\bullet)} & \xrightarrow{j \times I} & \bar{X} \times S_2 & \xleftarrow{i'_\bullet} & \bar{D}_\bullet \times S_2
\end{array}$$

Then the map in  $C(\text{Var}(k)^{2,smpr}/S_1 \times S_2)$

$$T(p, \hat{R}^{CH})(\mathbb{Z}(U/S_1)) : p^* \hat{R}_{(\bar{X}, \bar{D})/S_1}(\mathbb{Z}(U/S_1)) \xrightarrow{\sim} \hat{R}_{(\bar{X} \times_{S_2}, \bar{D}_\bullet \times_{S_2})/S_1 \times S_2}(\mathbb{Z}(U \times S_2/S_1 \times S_2))$$

is an isomorphism. Hence, for  $Q^* \in C(\text{Var}(k)/S_1)$  a complex of (maybe infinite) direct sum of representable presheaves of smooth morphism, the map in  $C(\text{Var}(k)^{2,smpr}/S_1 \times S_2)$

$$T(p, \hat{R}^{CH})(Q^*) : p^* \hat{R}^{CH}(Q^*) \xrightarrow{\sim} \hat{R}^{CH}(p^* Q^*)$$

is an isomorphism. In particular, for  $F \in C(\text{Var}(k)^{sm}/S_1)$  the map in  $C(\text{Var}(k)^{2,smpr}/S_1 \times S_2)$

$$T(p, \hat{R}^{CH})(\rho_{S_1}^* LF) : p^* \hat{R}^{CH}(\rho_{S_1}^* LF) \xrightarrow{\sim} \hat{R}^{CH}(\rho_{S_1 \times S_2}^* p^* LF)$$

is an isomorphism.

- Let  $h_1 : U_1 \rightarrow S$ ,  $h_2 : U_2 \rightarrow S$  two morphisms with  $U_1, U_2, S \in \text{Var}(k)$ ,  $U_1, U_2$  smooth. Denote by  $p_1 : U_1 \times_S U_2 \rightarrow U_1$  and  $p_2 : U_1 \times_S U_2 \rightarrow U_2$  the projections. Take, see definition-proposition 3(i)), a compactification  $\bar{f}_{10} = \bar{h}_1 : \bar{X}_{10} \rightarrow \bar{S}$  of  $h_1 : U_1 \rightarrow S$  and a compactification  $\bar{f}_{20} = \bar{h}_2 : \bar{X}_{20} \rightarrow \bar{S}$  of  $h_2 : U_2 \rightarrow S$ . Then,

- $\bar{f}_{10} \times \bar{f}_{20} : \bar{X}_{10} \times_{\bar{S}} \bar{X}_{20} \rightarrow \bar{S}$  is a compactification of  $h_1 \times h_2 : U_1 \times_S U_2 \rightarrow S$ .
- $\bar{p}_{10} := p_{X_{10}} : \bar{X}_{10} \times_{\bar{S}} \bar{X}_{20} \rightarrow \bar{X}_{10}$  is a compactification of  $p_1 : U_1 \times_S U_2 \rightarrow U_1$ .
- $\bar{p}_{20} := p_{X_{20}} : \bar{X}_{10} \times_{\bar{S}} \bar{X}_{20} \rightarrow \bar{X}_{20}$  is a compactification of  $p_2 : U_1 \times_S U_2 \rightarrow U_2$ .

Denote  $\bar{Z}_1 = \bar{X}_{10} \setminus U_1$  and  $\bar{Z}_2 = \bar{X}_{20} \setminus U_2$ . Take, see theorem 16(i), a strict desingularization  $\bar{\epsilon}_1 : (\bar{X}_1, \bar{D}) \rightarrow (\bar{X}_{10}, \bar{Z}_1)$  of the pair  $(\bar{X}_{10}, \bar{Z}_1)$  and a strict desingularization  $\bar{\epsilon}_2 : (\bar{X}_2, \bar{E}) \rightarrow (\bar{X}_{20}, \bar{Z}_2)$  of the pair  $(\bar{X}_{20}, \bar{Z}_2)$ . Take then a strict desingularization

$$\bar{\epsilon}_{12} : ((\bar{X}_1 \times_{\bar{S}} \bar{X}_2)^N, \bar{F}) \rightarrow (\bar{X}_1 \times_{\bar{S}} \bar{X}_2, (D \times_{\bar{S}} \bar{X}_2) \cup (\bar{X}_1 \times_{\bar{S}} \bar{E}))$$

of the pair  $(\bar{X}_1 \times_{\bar{S}} \bar{X}_2, (D \times_{\bar{S}} \bar{X}_2) \cup (\bar{X}_1 \times_{\bar{S}} \bar{E}))$ . We have then the following commutative diagram

$$\begin{array}{ccccc}
 & & \bar{X}_1 & \xrightarrow{\bar{f}_1} & \bar{S} \\
 & & \uparrow \bar{p}_2 & & \uparrow \bar{f}_2 \\
 & & \bar{X}_1 \times_{\bar{S}} \bar{X}_2 & \xrightarrow{\bar{p}_1} & \bar{X}_2 \\
 & \nearrow (\bar{p}_2)^N & \uparrow \bar{\epsilon}_{12} & \nearrow (\bar{p}_1)^N & \\
 & & (\bar{X}_1 \times_{\bar{S}} \bar{X}_2)^N & & 
 \end{array}$$

and

- $\bar{f}_1 \times \bar{f}_2 : \bar{X}_1 \times_{\bar{S}} \bar{X}_2 \rightarrow \bar{S}$  is a compactification of  $h_1 \times h_2 : U_1 \times_S U_2 \rightarrow S$ .
- $(\bar{p}_1)^N := \bar{p}_1 \circ \bar{\epsilon}_{12} : (\bar{X}_1 \times_{\bar{S}} \bar{X}_2)^N \rightarrow \bar{X}_1$  is a compactification of  $p_1 : U_1 \times_S U_2 \rightarrow U_1$ .
- $(\bar{p}_2)^N := \bar{p}_2 \circ \bar{\epsilon}_{12} : (\bar{X}_1 \times_{\bar{S}} \bar{X}_2)^N \rightarrow \bar{X}_2$  is a compactification of  $p_2 : U_1 \times_S U_2 \rightarrow U_2$ .

We have then the morphism in  $C(\text{Var}(k)^{2,smpr}/S)$

$$T(\otimes, \hat{R}_S^{CH})(\mathbb{Z}(U_1/S), \mathbb{Z}(U_2/S)) := \hat{R}_S^{CH}(p_1) \otimes \hat{R}_S^{CH}(p_2) : \hat{R}_{(\bar{X}_1, \bar{D})/S}(\mathbb{Z}(U_1/S)) \otimes \hat{R}_{(\bar{X}_2, \bar{E})/S}(\mathbb{Z}(U_2/S)) \xrightarrow{\sim} \hat{R}_{(\bar{X}_1 \times_{\bar{S}} \bar{X}_2)^N, \bar{F}/S}(\mathbb{Z}(U_1 \times_S U_2/S))$$

For

$$\begin{aligned}
 Q_1^* &:= (\cdots \rightarrow \bigoplus_{\alpha \in \Lambda^n} \mathbb{Z}(U_{1,\alpha}^n/S) \xrightarrow{(\mathbb{Z}(g_{\alpha,\beta}^n))} \bigoplus_{\beta \in \Lambda^{n-1}} \mathbb{Z}(U_{1,\beta}^{n-1}/S) \rightarrow \cdots), \\
 Q_2^* &:= (\cdots \rightarrow \bigoplus_{\alpha \in \Lambda^n} \mathbb{Z}(U_{2,\alpha}^n/S) \xrightarrow{(\mathbb{Z}(g_{\alpha,\beta}^n))} \bigoplus_{\beta \in \Lambda^{n-1}} \mathbb{Z}(U_{2,\beta}^{n-1}/S) \rightarrow \cdots) \in C(\text{Var}(k)/S)
 \end{aligned}$$

complexes of (maybe infinite) direct sum of representable presheaves with  $U_\alpha^*$  smooth, we get the morphism in  $C(\text{Var}(k)^{2,smpr}/S)$

$$T(\otimes, \hat{R}_S^{CH})(Q_1^*, Q_2^*) : \hat{R}^{CH}(Q_1^*) \otimes R^{CH}(Q_2^*) \xrightarrow{T(\otimes, \hat{R}_S^{CH})(\mathbb{Z}(U_{1,\alpha}^m), \mathbb{Z}(U_{2,\beta}^n))} \hat{R}^{CH}(Q_1^* \otimes Q_2^*)$$

, together with the commutative diagram in  $C(\text{Var}(k)^{2,smpr}/S)$

$$\begin{array}{ccc} \hat{R}^{CH}(Q_1^*) \otimes R^{CH}(Q_2^*) & \xrightarrow{T(\otimes, \hat{R}_S^{CH})(Q_1^*, Q_2^*)} & \hat{R}^{CH}(Q_1^* \times Q_2^*) \\ \downarrow T(\hat{R}_S^{CH}, R_S^{CH})(Q_1^*) \otimes T(\hat{R}_S^{CH}, R_S^{CH})(Q_2^*) & & \downarrow T(\hat{R}_S^{CH}, R_S^{CH})(Q_1^* \otimes Q_2^*) \\ L\rho_{S*}\mu_{S*}(R^{CH}(Q_1^*) \otimes R^{CH}(Q_2^*)) & \xrightarrow{L\rho_{S*}\mu_{S*}T(\otimes, R_S^{CH})(Q_1^*, Q_2^*)} & L\rho_{S*}\mu_{S*}R^{CH}(Q_1^* \otimes Q_2^*) \end{array}$$

For  $F_1, F_2 \in C(\text{Var}(k)^{sm}/S)$ , we get in particular the morphism in  $C(\text{Var}(k)^2/S)$

$$T(\otimes, R_S^{CH})(\rho_S^*LF_1, \rho_S^*LF_2) : R^{CH}(\rho_S^*LF_1) \otimes R^{CH}(\rho_S^*LF_2) \rightarrow R^{CH}(\rho_S^*(LF_1 \otimes LF_2))$$

together with the commutative diagram in  $C(\text{Var}(k)^{2,smpr}/S)$

$$\begin{array}{ccc} \hat{R}^{CH}(\rho_S^*LF_1) \otimes R^{CH}(\rho_S^*LF_2) & \xrightarrow{T(\otimes, \hat{R}_S^{CH})(\rho_S^*LF_1, \rho_S^*LF_2)} & \hat{R}^{CH}(\rho_S^*LF_1 \times \rho_S^*LF_2) \\ \downarrow T(\hat{R}_S^{CH}, R_S^{CH})(\rho_S^*LF_1) \otimes T(\hat{R}_S^{CH}, R_S^{CH})(\rho_S^*LF_2) & & \downarrow T(\hat{R}_S^{CH}, R_S^{CH})(\rho_S^*LF_1 \otimes \rho_S^*LF_2) \\ L\rho_{S*}\mu_{S*}(R^{CH}(\rho_S^*LF_1) \otimes R^{CH}(\rho_S^*LF_2)) & \xrightarrow{L\rho_{S*}\mu_{S*}T(\otimes, R_S^{CH})(\rho_S^*LF_1, \rho_S^*LF_2)} & L\rho_{S*}\mu_{S*}R^{CH}(\rho_S^*LF_1 \times \rho_S^*LF_2) \end{array}$$

For  $S \in \text{Var}(k)$ , we will use rather the functors  $R_S^{0CH}$  and  $\hat{R}_S^{0CH}$  since we are working in the image of the graph functor  $\text{Gr}_S^{12} : \text{Var}(k)/S \rightarrow \text{Var}(k)^2/S$ . We have the full subcategory  $\text{SmVar}(k)/S \subset \text{Var}(k)/S$  whose objects are morphisms  $f : X \rightarrow S$  with  $X \in \text{SmVar}(k)$ . Then  $\text{Gr}_S^{12}(\text{SmVar}(k)/S) \subset \text{Var}(k)^{2,smpr}/S$ . If  $S \in \text{SmVar}(k)$ , we have the factorization of morphism of site

$$\text{Gr}_S^{12} : \text{Var}(k)^{2,smpr}/S \xrightarrow{\text{Gr}_S^{12}} \text{SmVar}(k)/S \xrightarrow{\rho_S} \text{Var}(k)^{sm}/S.$$

**Definition 26.** (i) Let  $h : U \rightarrow S$  a morphism, with  $U, S \in \text{Var}(k)$  and  $U$  smooth. Take, see definition-proposition 3,  $\bar{f}_0 = \bar{h}_0 : \bar{X}_0 \rightarrow \bar{S}$  a compactification of  $h : U \rightarrow S$  and denote by  $\bar{Z} = \bar{X}_0 \setminus U$ . Take, using theorem 16(ii), a strict desingularization  $\bar{\epsilon} : (\bar{X}, \bar{D}) \rightarrow (\bar{X}_0, \bar{Z})$  of the pair  $(\bar{X}_0, \bar{Z})$ , with  $\bar{X} \in \text{PSmVar}(k)$  and  $\bar{D} := \epsilon^{-1}(\bar{Z}) = \cup_{i=1}^s \bar{D}_i \subset \bar{X}$  a normal crossing divisor. We denote by  $i_\bullet : \bar{D}_\bullet \hookrightarrow \bar{X} = \bar{X}_{c(\bullet)}$ , the morphism of simplicial varieties given by the closed embeddings  $i_I : \bar{D}_I = \cap_{i \in I} \bar{D}_i \hookrightarrow \bar{X}$ . We denote by  $j : U \hookrightarrow \bar{X}$  the open embedding. We then consider the following map in  $C(\text{Var}(k)/S)$

$$\begin{aligned} & r_{(\bar{X}, \bar{D})/S}^0(\mathbb{Z}(U/S)) : R_{(\bar{X}, \bar{D})/S}^0(\mathbb{Z}(U/S)) \\ & \xrightarrow{i_\bullet} \bar{f}_* E_{et}(\text{Cone}(\mathbb{Z}(i_\bullet) : (\mathbb{Z}((\bar{D}_\bullet)/\bar{X}), u_{I,J}) \rightarrow \mathbb{Z}((\bar{X}/\bar{X})))) \\ & \xrightarrow{\bar{f}_* E_{et}(0, \text{koad}(j^*, j_*)(\mathbb{Z}(\bar{X}/\bar{X})))} h_* E_{et}(\mathbb{Z}(U/U)) =: \mathbb{D}_S^0(\mathbb{Z}(U/S)). \end{aligned}$$

Note that  $\mathbb{Z}(\bar{D}_I/\bar{X})$  and  $\mathbb{Z}(\bar{X}/\bar{X})$  are obviously  $\mathbb{A}^1$  invariant. Note that  $r_{(X,D)/S}$  is NOT an equivalence  $(\mathbb{A}^1, et)$  local by proposition 4 since  $\rho_{\bar{X}*}\mathbb{Z}(\bar{D}_\bullet/\bar{X}) = 0$ , and  $\rho_{\bar{X}*}\text{ad}(j^*, j_*)(\mathbb{Z}(\bar{X}/\bar{X}))$  is not an equivalence  $(\mathbb{A}^1, et)$  local.

(ii) Let  $g : U'/S \rightarrow U/S$  a morphism, with  $U'/S = (U', h'), U/S = (U, h) \in \text{Var}(k)/S$ , with  $U$  and  $U'$  smooth. Take, see definition-proposition 3(ii), a compactification  $f_0 = \bar{h} : \bar{X}_0 \rightarrow \bar{S}$  of  $h : U \rightarrow S$  and a compactification  $\bar{f}'_0 = \bar{h}' : \bar{X}'_0 \rightarrow \bar{S}$  of  $h' : U' \rightarrow S$  such that  $g : U'/S \rightarrow U/S$  extend to a morphism  $\bar{g}_0 : \bar{X}'_0/\bar{S} \rightarrow \bar{X}_0/\bar{S}$ . Denote  $\bar{Z} = \bar{X}_0 \setminus U$  and  $\bar{Z}' = \bar{X}'_0 \setminus U'$ . Take, see definition-proposition 3(ii), a

strict desingularization  $\bar{\epsilon} : (\bar{X}, \bar{D}) \rightarrow (\bar{X}_0, \bar{Z})$  of  $(\bar{X}_0, \bar{Z})$ , a strict desingularization  $\bar{\epsilon}' : (\bar{X}', \bar{D}') \rightarrow (\bar{X}'_0, \bar{Z}')$  of  $(\bar{X}'_0, \bar{Z}')$  and a morphism  $\bar{g} : \bar{X}' \rightarrow \bar{X}$  such that the following diagram commutes

$$\begin{array}{ccc} \bar{X}'_0 & \xrightarrow{\bar{g}_0} & \bar{X}_0 \\ \bar{\epsilon}' \uparrow & & \uparrow \bar{\epsilon} \\ \bar{X}' & \xrightarrow{\bar{g}} & \bar{X} \end{array}$$

We then have, see definition-proposition 3(ii), the commutative diagram (7) in  $\text{Fun}(\Delta, \text{Var}(k))$

$$\begin{array}{ccccc} U = U_{c(\bullet)} & \xrightarrow{j} & \bar{X} = \bar{X}_{c(\bullet)} & \xleftarrow{i_\bullet} & \bar{D}_{s_g(\bullet)} \\ \uparrow g & & \uparrow \bar{g} & & \uparrow \bar{g}_\bullet \\ U' = U'_{c(\bullet)} & \xrightarrow{j'} & \bar{X}' = \bar{X}'_{c(\bullet)} & \xleftarrow{i'_\bullet} & \bar{D}'_\bullet \xleftarrow{i''_{g_\bullet}{}^{-1}} \bar{D}_{s_g(\bullet)} : i'_{g_\bullet} \end{array}$$

We then consider the following map in  $C(\text{Var}(k)/S)$

$$\begin{aligned} R_S^{0CH}(g) : R_{(\bar{X}, \bar{D})/S}^0(\mathbb{Z}(U/S)) &\xrightarrow{=} \\ \bar{f}_* E_{et}(\text{Cone}(\mathbb{Z}(i_\bullet) : (\mathbb{Z}((\bar{D}_{s_g(\bullet)})/\bar{X}), u_{IJ}) \rightarrow \mathbb{Z}(\bar{X}/\bar{X}))) &\xrightarrow{T(\bar{g}, E)(-) \circ p_{S*} \text{ad}(\bar{g}^*, \bar{g}_*)(-)} \\ \bar{f}'_* E_{et}(\text{Cone}(\mathbb{Z}(i'_{g_\bullet}) : (\mathbb{Z}((\bar{g}^{-1}(\bar{D}_{s_g(\bullet)})/\bar{X}'), u_{IJ}) \rightarrow \mathbb{Z}(\bar{X}'/\bar{X}')))) &\xrightarrow{\bar{f}'_* E_{et}(\mathbb{Z}(i'_{g_\bullet}), I)} \\ \bar{f}'_* E_{et}(\text{Cone}(\mathbb{Z}(i'_\bullet) : (\mathbb{Z}(\bar{D}'_\bullet/\bar{X}'), u_{IJ}) \rightarrow \mathbb{Z}(\bar{X}'/\bar{X}')))) &\xrightarrow{=} \\ &\xrightarrow{=} R_{(\bar{X}', \bar{D}')/S}^0(\mathbb{Z}(U'/S)) \end{aligned}$$

Then by the diagram (7) and adjonction, the following diagram in  $C(\text{Var}(k)/S)$  obviously commutes

$$\begin{array}{ccc} R_{(\bar{X}, \bar{D})/S}^0(\mathbb{Z}(U/S)) & \xrightarrow{r_{(\bar{X}, \bar{D})/S}(\mathbb{Z}(U/S))} & h_* E_{et}(\mathbb{Z}(U/U)) =: \mathbb{D}_S^0(\mathbb{Z}(U/S)) \\ R_S^{0CH}(g) \downarrow & & \downarrow D_S(g) := T(g, E)(-) \circ \text{ad}(g^*, g_*)(E_{et}(\mathbb{Z}(U/U))) \\ R_{(\bar{X}', \bar{D}')/S}^0(\mathbb{Z}(U'/S)) & \xrightarrow{r_{(\bar{X}', \bar{D}')/S}(\mathbb{Z}(U'/S))} & h'_* E_{et}(\mathbb{Z}(U'/U')) =: \mathbb{D}_S^0(\mathbb{Z}(U'/S)) \end{array}$$

(iii) For  $g_1 : U''/S \rightarrow U'/S$ ,  $g_2 : U'/S \rightarrow U/S$  two morphisms with  $U''/S = (U', h'')$ ,  $U'/S = (U', h')$ ,  $U/S = (U, h) \in \text{Var}(k)/S$ , with  $U$ ,  $U'$  and  $U''$  smooth. We get from (i) and (ii) a compactification  $\bar{f} = \bar{h} : \bar{X} \rightarrow \bar{S}$  of  $h : U \rightarrow S$ , a compactification  $\bar{f}' = \bar{h}' : \bar{X}' \rightarrow \bar{S}$  of  $h' : U' \rightarrow S$ , and a compactification  $\bar{f}'' = \bar{h}'' : \bar{X}'' \rightarrow \bar{S}$  of  $h'' : U'' \rightarrow S$ , with  $\bar{X}$ ,  $\bar{X}'$ ,  $\bar{X}'' \in \text{PSmVar}(k)$ ,  $\bar{D} := \bar{X} \setminus U \subset \bar{X}$ ,  $\bar{D}' := \bar{X}' \setminus U' \subset \bar{X}'$ , and  $\bar{D}'' := \bar{X}'' \setminus U'' \subset \bar{X}''$  normal crossing divisors, such that  $g_1 : U''/S \rightarrow U'/S$  extend to  $\bar{g}_1 : \bar{X}''/\bar{S} \rightarrow \bar{X}'/\bar{S}$ ,  $g_2 : U'/S \rightarrow U/S$  extend to  $\bar{g}_2 : \bar{X}'/\bar{S} \rightarrow \bar{X}/\bar{S}$ , and

$$R_S^{0CH}(g_2 \circ g_1) = R_S^{0CH}(g_1) \circ R_S^{0CH}(g_2) : R_{(\bar{X}, \bar{D})/S}^0 \rightarrow R_{(\bar{X}'', \bar{D}'')/S}^0$$

(iv) For

$$Q^* := (\dots \rightarrow \bigoplus_{\alpha \in \Lambda^n} \mathbb{Z}(U_\alpha^n/S) \xrightarrow{(\mathbb{Z}(g_{\alpha, \beta}^n))} \bigoplus_{\beta \in \Lambda^{n-1}} \mathbb{Z}(U_\beta^{n-1}/S) \rightarrow \dots) \in C(\text{Var}(k)/S)$$

a complex of (maybe infinite) direct sum of representable presheaves with  $U_\alpha^*$  smooth, we get from (i), (ii) and (iii) the map in  $C(\text{Var}(k)/S)$

$$r_S^{0CH}(Q^*) : R^{0CH}(Q^*) := (\cdots \rightarrow \bigoplus_{\beta \in \Lambda^{n-1}} \varinjlim_{(\bar{X}_\beta^{n-1}, \bar{D}_\beta^{n-1})/S} R^0_{(\bar{X}_\beta^{n-1}, \bar{D}_\beta^{n-1})/S}(\mathbb{Z}(U_\beta^{n-1}/S)) \\ \xrightarrow{(R_S^{0CH}(g_{\alpha, \beta}^n))} \bigoplus_{\alpha \in \Lambda^n} \varinjlim_{(\bar{X}_\alpha^n, \bar{D}_\alpha^n)/S} R^0_{(\bar{X}_\alpha^n, \bar{D}_\alpha^n)/S}(\mathbb{Z}(U_\alpha^n/S)) \rightarrow \cdots) \rightarrow \mathbb{D}_S(Q^*),$$

where for  $(U_\alpha^n, h_\alpha^n) \in \text{Var}(k)/S$ , the inductive limit run over all the compactifications  $\bar{f}_\alpha : \bar{X}_\alpha \rightarrow \bar{S}$  of  $h_\alpha : U_\alpha \rightarrow S$  with  $\bar{X}_\alpha \in \text{PSmVar}(k)$  and  $\bar{D}_\alpha := \bar{X}_\alpha \setminus U_\alpha$  a normal crossing divisor. For  $m = (m^*) : Q_1^* \rightarrow Q_2^*$  a morphism with

$$Q_1^* := (\cdots \rightarrow \bigoplus_{\alpha \in \Lambda^n} \mathbb{Z}(U_{1, \alpha}^n/S) \xrightarrow{(\mathbb{Z}(g_{\alpha, \beta}^n))} \bigoplus_{\beta \in \Lambda^{n-1}} \mathbb{Z}(U_{1, \beta}^{n-1}/S) \rightarrow \cdots), \\ Q_2^* := (\cdots \rightarrow \bigoplus_{\alpha \in \Lambda^n} \mathbb{Z}(U_{2, \alpha}^n/S) \xrightarrow{(\mathbb{Z}(g_{\alpha, \beta}^n))} \bigoplus_{\beta \in \Lambda^{n-1}} \mathbb{Z}(U_{2, \beta}^{n-1}/S) \rightarrow \cdots) \in C(\text{Var}(k)/S)$$

complexes of (maybe infinite) direct sum of representable presheaves with  $U_{1, \alpha}^*$  and  $U_{2, \alpha}^*$  smooth, we get again from (i), (ii) and (iii) a commutative diagram in  $C(\text{Var}(k)/S)$

$$\begin{array}{ccc} R^{0CH}(Q_2^*) & \xrightarrow{r_S^{0CH}(Q_2^*)} & \mathbb{D}_S^0(Q_2^*) \\ \downarrow R_S^{0CH}(m) := (R_S^{0CH}(m^*)) & & \downarrow \mathbb{D}_S(m) := (\mathbb{D}_S^0(m^*)) \\ R^{0CH}(Q_1^*) & \xrightarrow{r_S^{0CH}(Q_1^*)} & \mathbb{D}_S^0(Q_1^*) \end{array} .$$

(v) Let

$$Q^* := (\cdots \rightarrow \bigoplus_{\alpha \in \Lambda^n} \mathbb{Z}(U_\alpha^n/S) \xrightarrow{(\mathbb{Z}(g_{\alpha, \beta}^n))} \bigoplus_{\beta \in \Lambda^{n-1}} \mathbb{Z}(U_\beta^{n-1}/S) \rightarrow \cdots) \in C(\text{Var}(k)/S)$$

a complex of (maybe infinite) direct sum of representable presheaves with  $U_\alpha^*$  smooth, we have by definition

$$\text{Gr}_S^{12*} R^{0CH}(Q^*) = R^{CH}(Q^*) \in C(\text{Var}(k)^2/S).$$

- Let  $S \in \text{Var}(k)$  For  $(h, m, m') = (h^*, m^*, m'^*) : Q_1^*[1] \rightarrow Q_2^*$  an homotopy with  $Q_1^*, Q_2^* \in C(\text{Var}(k)/S)$  complexes of (maybe infinite) direct sum of representable presheaves with  $U_{1, \alpha}^*$  and  $U_{2, \alpha}^*$  smooth,

$$(R_S^{0CH}(h), R_S^{0CH}(m), R_S^{0CH}(m')) = (R_S^{0CH}(h^*), R_S^{0CH}(m^*), R_S^{0CH}(m'^*)) : R^{0CH}(Q_2^*)[1] \rightarrow R^{0CH}(Q_1^*)$$

is an homotopy in  $C(\text{Var}(k)/S)$  using definition 26 (iii). In particular if  $m : Q_1^* \rightarrow Q_2^*$  with  $Q_1^*, Q_2^* \in C(\text{Var}(k)/S)$  complexes of (maybe infinite) direct sum of representable presheaves with  $U_{1, \alpha}^*$  and  $U_{2, \alpha}^*$  smooth is an homotopy equivalence, then  $R_S^{0CH}(m) : R^{0CH}(Q_2^*) \rightarrow R^{0CH}(Q_1^*)$  is an homotopy equivalence.

- Let  $S \in \text{SmVar}(k)$ . Let  $F \in \text{PSh}(\text{Var}(k)^{sm}/S)$ . Consider

$$q : LF := (\cdots \rightarrow \bigoplus_{(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S} \mathbb{Z}(U_\alpha/S) \xrightarrow{(\mathbb{Z}(g_{\alpha, \beta}^n))} \bigoplus_{(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S} \mathbb{Z}(U_\alpha/S) \rightarrow \cdots) \rightarrow F$$

the canonical projective resolution given in subsection 2.3.3. Note that the  $U_\alpha$  are smooth since  $S$  is smooth and  $h_\alpha$  are smooth morphism. Definition 26(iv) gives in this particular case the map in  $C(\text{Var}(k)/S)$

$$r_S^{0CH}(\rho_S^* LF) : R^{0CH}(\rho_S^* LF) := (\cdots \rightarrow \bigoplus_{(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S} \varinjlim_{(\bar{X}_\alpha, \bar{D}_\alpha)/S} R^0_{(\bar{X}_\alpha, \bar{D}_\alpha)/S}(\mathbb{Z}(U_\alpha/S)) \\ \xrightarrow{(R_S^{0CH}(g_{\alpha, \beta}^n))} \bigoplus_{(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S} \varinjlim_{(\bar{X}_\alpha, \bar{D}_\alpha)/S} R^0_{(\bar{X}_\alpha, \bar{D}_\alpha)/S}(\mathbb{Z}(U_\alpha/S)) \rightarrow \cdots) \rightarrow \mathbb{D}_S^0(\rho_S^* LF),$$

where for  $(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S$ , the inductive limit run over all the compactifications  $\bar{f}_\alpha : \bar{X}_\alpha \rightarrow \bar{S}$  of  $h_\alpha : U_\alpha \rightarrow S$  with  $\bar{X}_\alpha \in \text{PSmVar}(\mathbb{C})$  and  $\bar{D}_\alpha := \bar{X}_\alpha \setminus U_\alpha$  a normal crossing divisor. Definition 26(iv) gives then by functoriality in particular, for  $F = F^\bullet \in C(\text{Var}(k)^{sm}/S)$ , the map in  $C(\text{Var}(k)/S)$

$$r_S^{0CH}(\rho_S^* LF) = (r_S^{0CH}(\rho_S^* LF^*)) : R^{0CH}(\rho_S^* LF) \rightarrow \mathbb{D}_S^0(\rho_S^* LF).$$

- Let  $g : T \rightarrow S$  a morphism with  $T, S \in \text{SmVar}(k)$ . Let  $h : U \rightarrow S$  a smooth morphism with  $U \in \text{Var}(k)$ . Consider the cartesian square

$$\begin{array}{ccc} U_T & \xrightarrow{h'} & T \\ \downarrow g' & & \downarrow g \\ U & \xrightarrow{h} & S \end{array}$$

Note that  $U$  is smooth since  $S$  and  $h$  are smooth, and  $U_T$  is smooth since  $T$  and  $h'$  are smooth. Take, see definition-proposition 3(ii), a compactification  $\bar{f}_0 = \bar{h} : \bar{X}_0 \rightarrow \bar{S}$  of  $h : U \rightarrow S$ . Take, see definition-proposition 3(ii), a strict desingularization  $\bar{\epsilon} : (\bar{X}, \bar{D}) \rightarrow (\bar{X}_0, \bar{Z})$  of  $(\bar{X}_0, \bar{Z})$ . Then  $\bar{f}'_0 = g \circ \bar{h}' : \bar{X}_T \rightarrow \bar{T}$  is a compactification of  $g \circ h' : U_T \rightarrow S$  such that  $g' : U_T/S \rightarrow U/S$  extend to a morphism  $\bar{g}'_0 : \bar{X}_T/\bar{S} \rightarrow \bar{X}/\bar{S}$ . Denote  $\bar{Z} = \bar{X}_0 \setminus U$  and  $\bar{Z}' = \bar{X}_T \setminus U_T$ . Take, see definition-proposition 3(ii), a strict desingularization  $\epsilon'_\bullet : (\bar{X}', \bar{D}') \rightarrow (\bar{X}_T, \bar{Z}')$  of  $(\bar{X}_T, \bar{Z}')$ . Denote  $\bar{g}' = \bar{g}'_0 \circ \epsilon'_\bullet : \bar{X}' \rightarrow \bar{X}$ . We then have, see definition-proposition 3(ii), the following commutative diagram in  $\text{Fun}(\Delta, \text{Var}(k))$

$$\begin{array}{ccccc} U = U_{c(\bullet)} & \xrightarrow{j} & \bar{X} = \bar{X}_{c(\bullet)} & \xleftarrow{i_\bullet} & \bar{D}_{s_{g'}(\bullet)} \\ \uparrow g' & & \uparrow \bar{g}'_0 & & \uparrow (\bar{g}')_\bullet \\ U_T = U_{T,c(\bullet)} & \xrightarrow{j'} & \bar{X}_T = \bar{X}_{T,c(\bullet)} & \xleftarrow{i_{g\bullet}} & \bar{g}'^{-1}(\bar{D}_{s_{g'}(\bullet)}) \\ \uparrow g' & & \uparrow \bar{g}' & & \uparrow \epsilon'_\bullet \\ U_T = U_{T,c(\bullet)} & \xrightarrow{j'} & \bar{X}' = \bar{X}'_{c(\bullet)} & \xleftarrow{i'_\bullet} & \bar{D}'_\bullet \xleftarrow{i'_{g'\bullet}} \bar{g}'^{-1}(\bar{D}_{s_{g'}(\bullet)}) : i'_{g\bullet} \end{array}$$

We then consider the following map in  $C(\text{Var}(k)/T)$ , see definition 26(ii)

$$\begin{aligned} & T(g, R^{0CH})(\mathbb{Z}(U/S)) : g^* R^0_{(\bar{X}, \bar{D})/S}(\mathbb{Z}(U/S)) \\ & \xrightarrow{g^* R_S^{0CH}(g')} g^* R^0_{(\bar{X}', \bar{D}')/S}(\mathbb{Z}(U_T/S)) = g^* g_* R^0_{(\bar{X}', \bar{D}')/T}(\mathbb{Z}(U_T/T)) \\ & \xrightarrow{\text{ad}(g^*, g_*)(R^0_{(\bar{X}', \bar{D}')/T}(\mathbb{Z}(U_T/T)))} R^0_{(\bar{X}', \bar{D}')/T}(\mathbb{Z}(U_T/T)) \end{aligned}$$

For

$$Q^* := (\cdots \rightarrow \bigoplus_{\alpha \in \Lambda^n} \mathbb{Z}(U_\alpha^n/S) \xrightarrow{(\mathbb{Z}(g_{\alpha, \beta}^n))} \bigoplus_{\beta \in \Lambda^{n-1}} \mathbb{Z}(U_\beta^{n-1}/S) \rightarrow \cdots) \in C(\text{Var}(k)/S)$$

a complex of (maybe infinite) direct sum of representable presheaves with  $h_\alpha^n : U_\alpha^n \rightarrow S$  smooth, we get the map in  $C(\text{Var}(k)/T)$

$$\begin{aligned} & T(g, R^{0CH})(Q^*) : g^* R^{0CH}(Q^*) = (\cdots \rightarrow \bigoplus_{\alpha \in \Lambda^n} \varinjlim_{(\bar{X}_\alpha^n, \bar{D}_\alpha^n)/S} g^* R^0_{(\bar{X}_\alpha^n, \bar{D}_\alpha^n)/S}(\mathbb{Z}(U_\alpha^n/S)) \rightarrow \cdots) \\ & \xrightarrow{(T(g, R^{0CH})(\mathbb{Z}(U_\alpha^n/S)))} (\cdots \rightarrow \bigoplus_{\alpha \in \Lambda^n} \varinjlim_{(\bar{X}_\alpha^{n'}, \bar{D}_\alpha^{n'})/T} R^0_{(\bar{X}_\alpha^{n'}, \bar{D}_\alpha^{n'})/T}(\mathbb{Z}(U_{\alpha, T}^n/S)) \rightarrow \cdots) =: R^{CH}(g^* Q^*). \end{aligned}$$

Let  $F \in \text{PSh}(\text{Var}(k)^{sm}/S)$ . Consider

$$q : LF := (\cdots \rightarrow \bigoplus_{(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S} \mathbb{Z}(U_\alpha/S) \rightarrow \cdots) \rightarrow F$$

the canonical projective resolution given in subsection 2.3.3. We then get in particular the map in  $C(\text{Var}(k)/T)$

$$\begin{aligned} T(g, R^{0CH})(\rho_S^* LF) : g^* R^{0CH}(\rho_S^* LF) = \\ (\cdots \rightarrow \bigoplus_{(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S} \varinjlim_{(\bar{X}_\alpha, \bar{D}_\alpha)/S} g^* R^0_{(\bar{X}_\alpha, \bar{D}_\alpha)/S}(\mathbb{Z}(U_\alpha/S)) \rightarrow \cdots) \xrightarrow{(T(g, R^{0CH})(\mathbb{Z}(U_\alpha/S)))} \\ (\cdots \rightarrow \bigoplus_{(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S} \varinjlim_{(\bar{X}'_\alpha, \bar{D}'_\alpha)/T} R^0_{(\bar{X}'_\alpha, \bar{D}'_\alpha)/T}(\mathbb{Z}(U_{\alpha,T}/S)) \rightarrow \cdots) =: R^{CH}(\rho_T^* g^* LF). \end{aligned}$$

By functoriality, we get in particular for  $F = F^\bullet \in C(\text{Var}(k)^{sm}/S)$ , the map in  $C(\text{Var}(k)/T)$

$$T(g, R^{0CH})(\rho_S^* LF) : g^* R^{0CH}(\rho_S^* LF) \rightarrow R^{0CH}(\rho_T^* g^* LF).$$

- Let  $S_1, S_2 \in \text{SmVar}(k)$  and  $p : S_1 \times S_2 \rightarrow S_1$  the projection. Let  $h : U \rightarrow S_1$  a smooth morphism with  $U \in \text{Var}(k)$ . Consider the cartesian square

$$\begin{array}{ccc} U \times S_2 & \xrightarrow{h \times I} & S_1 \times S_2 \\ \downarrow p' & & \downarrow p \\ U & \xrightarrow{h} & S_1 \end{array}$$

Take, see definition-proposition 3(i), a compactification  $\bar{f}_0 = \bar{h} : \bar{X}_0 \rightarrow \bar{S}_1$  of  $h : U \rightarrow S_1$ . Then  $\bar{f}_0 \times I : \bar{X}_0 \times S_2 \rightarrow \bar{S}_1 \times S_2$  is a compactification of  $h \times I : U \times S_2 \rightarrow S_1 \times S_2$  and  $p' : U \times S_2 \rightarrow U$  extend to  $\bar{p}'_0 := p_{X_0} : \bar{X}_0 \times S_2 \rightarrow \bar{X}_0$ . Denote  $Z = X_0 \setminus U$ . Take see theorem 16(i), a strict desingularization  $\bar{e} : (\bar{X}, \bar{D}) \rightarrow (\bar{X}_0, \bar{Z})$  of the pair  $(\bar{X}_0, \bar{Z})$ . We then have the commutative diagram (8) in  $\text{Fun}(\Delta, \text{Var}(k))$  whose squares are cartesian

$$\begin{array}{ccccc} U = U_{c(\bullet)} & \xrightarrow{j} & \bar{X} & \xleftarrow{i_\bullet} & \bar{D}_\bullet \\ \uparrow g & & \uparrow \bar{p}' := p_{\bar{X}} & & \uparrow \bar{p}'_\bullet \\ U \times S_2 = (U \times S_2)_{c(\bullet)} & \xrightarrow{j \times I} & \bar{X} \times S_2 & \xleftarrow{i'_\bullet} & \bar{D}_\bullet \times S_2 \end{array}$$

Then the map in  $C(\text{Var}(k)/S_1 \times S_2)$

$$T(p, R^{0CH})(\mathbb{Z}(U/S_1)) : p^* R^0_{(\bar{X}, \bar{D})/S_1}(\mathbb{Z}(U/S_1)) \xrightarrow{\sim} R^0_{(\bar{X} \times S_2, \bar{D}_\bullet \times S_2)/S_1 \times S_2}(\mathbb{Z}(U \times S_2/S_1 \times S_2))$$

is an isomorphism. Hence, for  $Q^* \in C(\text{Var}(k)/S_1)$  a complex of (maybe infinite) direct sum of representable presheaves of smooth morphism, the map in  $C(\text{Var}(k)/S_1 \times S_2)$

$$T(p, R^{0CH})(Q^*) : p^* R^{0CH}(Q^*) \xrightarrow{\sim} R^{0CH}(p^* Q^*)$$

is an isomorphism. In particular, for  $F \in C(\text{Var}(k)^{sm}/S_1)$  the map in  $C(\text{Var}(k)/S_1 \times S_2)$

$$T(p, R^{0CH})(\rho_{S_1}^* LF) : p^* R^{0CH}(\rho_{S_1}^* LF) \xrightarrow{\sim} R^{0CH}(\rho_{S_1 \times S_2}^* p^* LF)$$

is an isomorphism.

- Let  $h_1 : U_1 \rightarrow S$ ,  $h_2 : U_2 \rightarrow S$  two morphisms with  $U_1, U_2, S \in \text{Var}(k)$ ,  $U_1, U_2$  smooth. Denote by  $p_1 : U_1 \times_S U_2 \rightarrow U_1$  and  $p_2 : U_1 \times_S U_2 \rightarrow U_2$  the projections. Take, see definition-proposition 3(i), a compactification  $\bar{f}_{10} = \bar{h}_1 : \bar{X}_{10} \rightarrow \bar{S}$  of  $h_1 : U_1 \rightarrow S$  and a compactification  $\bar{f}_{20} = \bar{h}_2 : \bar{X}_{20} \rightarrow \bar{S}$  of  $h_2 : U_2 \rightarrow S$ . Then,

- $\bar{f}_{10} \times \bar{f}_{20} : \bar{X}_{10} \times_{\bar{S}} \bar{X}_{20} \rightarrow S$  is a compactification of  $h_1 \times h_2 : U_1 \times_S U_2 \rightarrow S$ .
- $\bar{p}_{10} := p_{X_{10}} : \bar{X}_{10} \times_{\bar{S}} \bar{X}_{20} \rightarrow \bar{X}_{10}$  is a compactification of  $p_1 : U_1 \times_S U_2 \rightarrow U_1$ .
- $\bar{p}_{20} := p_{X_{20}} : \bar{X}_{10} \times_{\bar{S}} \bar{X}_{20} \rightarrow \bar{X}_{20}$  is a compactification of  $p_2 : U_1 \times_S U_2 \rightarrow U_2$ .

Denote  $\bar{Z}_1 = \bar{X}_{10} \setminus U_1$  and  $\bar{Z}_2 = \bar{X}_{20} \setminus U_2$ . Take, see theorem 16(i), a strict desingularization  $\bar{\epsilon}_1 : (\bar{X}_1, \bar{D}) \rightarrow (\bar{X}_{10}, \bar{Z}_1)$  of the pair  $(\bar{X}_{10}, \bar{Z}_1)$  and a strict desingularization  $\bar{\epsilon}_2 : (\bar{X}_2, \bar{E}) \rightarrow (\bar{X}_{20}, \bar{Z}_2)$  of the pair  $(\bar{X}_{20}, \bar{Z}_2)$ . Take then a strict desingularization

$$\bar{\epsilon}_{12} : ((\bar{X}_1 \times_{\bar{S}} \bar{X}_2)^N, \bar{F}) \rightarrow (\bar{X}_1 \times_{\bar{S}} \bar{X}_2, (D \times_{\bar{S}} \bar{X}_2) \cup (\bar{X}_1 \times_{\bar{S}} \bar{E}))$$

of the pair  $(\bar{X}_1 \times_{\bar{S}} \bar{X}_2, (D \times_{\bar{S}} \bar{X}_2) \cup (\bar{X}_1 \times_{\bar{S}} \bar{E}))$ . We have then the following commutative diagram

$$\begin{array}{ccccc}
 & & \bar{X}_1 & \xrightarrow{\bar{f}_1} & \bar{S} \\
 & & \uparrow \bar{p}_2 & & \uparrow \bar{f}_2 \\
 & & \bar{X}_1 \times_{\bar{S}} \bar{X}_2 & \xrightarrow{\bar{p}_1} & \bar{X}_2 \\
 & \nearrow (\bar{p}_2)^N & \uparrow \bar{\epsilon}_{12} & \nearrow (\bar{p}_1)^N & \\
 (\bar{X}_1 \times_{\bar{S}} \bar{X}_2)^N & & & & 
 \end{array}$$

and

- $\bar{f}_1 \times \bar{f}_2 : \bar{X}_1 \times_{\bar{S}} \bar{X}_2 \rightarrow \bar{S}$  is a compactification of  $h_1 \times h_2 : U_1 \times_S U_2 \rightarrow S$ .
- $(\bar{p}_1)^N := \bar{p}_1 \circ \bar{\epsilon}_{12} : (\bar{X}_1 \times_{\bar{S}} \bar{X}_2)^N \rightarrow \bar{X}_1$  is a compactification of  $p_1 : U_1 \times_S U_2 \rightarrow U_1$ .
- $(\bar{p}_2)^N := \bar{p}_2 \circ \bar{\epsilon}_{12} : (\bar{X}_1 \times_{\bar{S}} \bar{X}_2)^N \rightarrow \bar{X}_2$  is a compactification of  $p_2 : U_1 \times_S U_2 \rightarrow U_2$ .

We have then the morphism in  $C(\text{Var}(k)/S)$

$$T(\otimes, R_S^{0CH})(\mathbb{Z}(U_1/S), \mathbb{Z}(U_2/S)) := R_S^{0CH}(p_1) \otimes R_S^{CH}(p_2) : R_{(\bar{X}_1, \bar{D})/S}^0(\mathbb{Z}(U_1/S)) \otimes R_{(\bar{X}_2, \bar{E})/S}^0(\mathbb{Z}(U_2/S)) \xrightarrow{\sim} R_{(\bar{X}_1 \times_{\bar{S}} \bar{X}_2)^N, \bar{F})/S}^0(\mathbb{Z}(U_1 \times_S U_2/S))$$

For

$$\begin{aligned}
 Q_1^* &:= (\cdots \rightarrow \oplus_{\alpha \in \Lambda^n} \mathbb{Z}(U_{1,\alpha}^n/S) \xrightarrow{(\mathbb{Z}(g_{\alpha,\beta}^n))} \oplus_{\beta \in \Lambda^{n-1}} \mathbb{Z}(U_{1,\beta}^{n-1}/S) \rightarrow \cdots), \\
 Q_2^* &:= (\cdots \rightarrow \oplus_{\alpha \in \Lambda^n} \mathbb{Z}(U_{2,\alpha}^n/S) \xrightarrow{(\mathbb{Z}(g_{\alpha,\beta}^n))} \oplus_{\beta \in \Lambda^{n-1}} \mathbb{Z}(U_{2,\beta}^{n-1}/S) \rightarrow \cdots) \in C(\text{Var}(k)/S)
 \end{aligned}$$

complexes of (maybe infinite) direct sum of representable presheaves with  $U_\alpha^*$  smooth, we get the morphism in  $C(\text{Var}(k)/S)$

$$T(\otimes, R_S^{0CH})(Q_1^*, Q_2^*) : R^{0CH}(Q_1^*) \otimes R^{0CH}(Q_2^*) \xrightarrow{(T(\otimes, R_S^{0CH})(\mathbb{Z}(U_{1,\alpha}^n), \mathbb{Z}(U_{2,\beta}^n))} R^{0CH}(Q_1^* \otimes Q_2^*).$$

For  $F_1, F_2 \in C(\text{Var}(k)^{sm}/S)$ , we get in particular the morphism in  $C(\text{Var}(k)/S)$

$$T(\otimes, R_S^{0CH})(\rho_S^* LF_1, \rho_S^* LF_2) : R^{0CH}(\rho_S^* LF_1) \otimes R^{0CH}(\rho_S^* LF_2) \rightarrow R^{0CH}(\rho_S^*(LF_1 \otimes LF_2)).$$

**Definition 27.** Let  $h : U \rightarrow S$  a morphism, with  $U, S \in \text{Var}(k)$ ,  $U$  irreducible. Take, see definition-proposition 3,  $\bar{f}_0 = \bar{h}_0 : \bar{X}_0 \rightarrow \bar{S}$  a compactification of  $h : U \rightarrow S$  and denote by  $\bar{Z} = \bar{X}_0 \setminus U$ . Take, using theorem 16, a desingularization  $\bar{\epsilon} : (\bar{X}, \bar{D}) \rightarrow (\bar{X}_0, \bar{Z})$  of the pair  $(\bar{X}_0, \bar{Z})$ ,  $\bar{Z} \subset \bar{D}$ , with  $\bar{X} \in \text{PSmVar}(k)$  and  $\bar{D} := \bar{\epsilon}^{-1}(\bar{Z}) = \cup_{i=1}^s \bar{D}_i \subset \bar{X}$  a normal crossing divisor. Denote  $d_X := \dim(\bar{X}) = \dim(U)$ .



(i) The diagonal  $\Delta_{\bar{D}_\bullet} \subset \bar{D}_\bullet \times \bar{D}_\bullet$  induces the morphism in  $C(\text{Var}(k)/S)$

$$\begin{aligned} [\Delta_{\bar{D}_\bullet}] &\in \text{Hom}(\mathbb{Z}^{\text{tr}}(\bar{D}_\bullet/S), \bar{f}_* E_{\text{et}}(\mathbb{Z}(\bar{D}_\bullet/\bar{X})(d_X)[2d_X])) \xrightarrow{\sim} \\ &\text{Hom}(\mathbb{Z}(\bar{D}_\bullet \times_S \bar{X}/\bar{X}), \mathbb{Z}^{\text{tr}}(\bar{D}_\bullet \times \mathbb{P}^{d_X}/\bar{X})/\mathbb{Z}^{\text{tr}}(\bar{D}_\bullet \times \mathbb{P}^{d_X-1}/\bar{X})) \\ &\subset H^0(\mathcal{Z}_{d_{D_\bullet}}(\square^* \times \bar{D}_\bullet \times_S \bar{D}_\bullet)) \end{aligned}$$

(ii) The cycle  $\Delta_{\bar{X}} \subset \bar{X} \times_S \bar{X}$  induces by the morphism in  $C(\text{Var}(k)/S)$

$$\begin{aligned} [\Delta_{\bar{X}}] &\in \text{Hom}(\mathbb{Z}^{\text{tr}}(\bar{X}/S), \bar{f}_* E_{\text{et}}(\mathbb{Z}(\bar{X}/\bar{X})(d_X)[2d_X])) \xrightarrow{\sim} \\ &\text{Hom}(\mathbb{Z}(\bar{X} \times_S \bar{X}/\bar{X}), \mathbb{Z}^{\text{tr}}(\bar{X} \times \mathbb{P}^{d_X}/\bar{X})/\mathbb{Z}^{\text{tr}}(\bar{X} \times \mathbb{P}^{d_X-1}/\bar{X})) \\ &\subset H^0(\mathcal{Z}_{d_X}(\square^* \times \bar{X} \times_S \bar{X})) \end{aligned}$$

Let  $h : U \rightarrow S$  a morphism, with  $U, S \in \text{Var}(k)$ ,  $U$  smooth connected (hence irreducible by smoothness). Take, see definition-proposition 3,  $\bar{f}_0 = \bar{h}_0 : \bar{X}_0 \rightarrow \bar{S}$  a compactification of  $h : U \rightarrow S$  and denote by  $\bar{Z} = \bar{X}_0 \setminus U$ . Take, using theorem 16(ii), a strict desingularization  $\bar{\epsilon} : (\bar{X}, \bar{D}) \rightarrow (\bar{X}_0, \bar{Z})$  of the pair  $(\bar{X}_0, \bar{Z})$  with  $\bar{X} \in \text{PSmVar}(k)$  and  $\bar{D} := \bar{\epsilon}^{-1}(\bar{Z}) = \cup_{i=1}^s \bar{D}_i \subset \bar{X}$  a normal crossing divisor. Denote  $d_X := \dim(\bar{X}) = \dim(U)$ . We get from (i) and (ii) the morphism in  $C(\text{Var}(k)/S)$

$$\begin{aligned} T(\bar{f}_\#, \bar{f}_*)(\mathbb{Z}(D_\bullet/\bar{X}), \mathbb{Z}(\bar{X}/\bar{X})) &:= ([\Delta_{\bar{D}_\bullet}], [\Delta_{\bar{X}}]) : \\ \text{Cone}(\mathbb{Z}(i_\bullet) : (\mathbb{Z}^{\text{tr}}(\bar{D}_\bullet/S), u_{IJ}) &\rightarrow \mathbb{Z}^{\text{tr}}(\bar{X}/S)) \rightarrow \\ \bar{f}_* E_{\text{et}}(\text{Cone}(\mathbb{Z}(i_\bullet) : (\mathbb{Z}(\bar{D}_\bullet/\bar{X}), u_{IJ}) &\rightarrow \mathbb{Z}(\bar{X}/\bar{X}))) (d_X)[2d_X] \\ &=: R_{(\bar{X}, \bar{D})/S}^0(\mathbb{Z}(U/S))(d_X)[2d_X]. \end{aligned}$$

**Definition 28.** (i) Let  $h : U \rightarrow S$  a morphism, with  $U, S \in \text{Var}(k)$  and  $U$  smooth. Take, see definition-proposition 3,  $\bar{f}_0 = \bar{h}_0 : \bar{X}_0 \rightarrow \bar{S}$  a compactification of  $h : U \rightarrow S$  and denote by  $\bar{Z} = \bar{X}_0 \setminus U$ . Take, using theorem 16(ii), a strict desingularization  $\bar{\epsilon} : (\bar{X}, \bar{D}) \rightarrow (\bar{X}_0, \bar{Z})$  of the pair  $(\bar{X}_0, \bar{Z})$ , with  $\bar{X} \in \text{PSmVar}(k)$  and  $\bar{D} := \bar{\epsilon}^{-1}(\bar{Z}) = \cup_{i=1}^s \bar{D}_i \subset \bar{X}$  a normal crossing divisor. We denote by  $i_\bullet : \bar{D}_\bullet \hookrightarrow \bar{X} = \bar{X}_{c(\bullet)}$  the morphism of simplicial varieties given by the closed embeddings  $i_I : \bar{D}_I = \cap_{i \in I} \bar{D}_i \hookrightarrow \bar{X}$ . We denote by  $j : U \hookrightarrow \bar{X}$  the open embedding. We then consider the map in  $C(\text{Var}(k)/S)$

$$\begin{aligned} T(\hat{R}^{0CH}, R^{0CH})(\mathbb{Z}(U/S)) &: \hat{R}_{(\bar{X}, \bar{D})/S}^0(\mathbb{Z}(U/S)) \\ \xrightarrow{=} \text{Cone}(\mathbb{Z}(i_\bullet) : (\mathbb{Z}^{\text{tr}}(D_\bullet/S), u_{IJ}) &\rightarrow \mathbb{Z}^{\text{tr}}(X/S))(-d_X)[-2d_X] \\ &\xrightarrow{T(\bar{f}_\#, \bar{f}_*)(\mathbb{Z}(\bar{D}_\bullet/\bar{X}), \mathbb{Z}(\bar{X}/\bar{X}))(-d_X)[-2d_X]} \\ &R_{(\bar{X}, \bar{D})/S}^0(\mathbb{Z}(U/S)). \end{aligned}$$

given in definition 23(iii).

(ii) Let  $g : U'/S \rightarrow U/S$  a morphism, with  $U'/S = (U', h')$ ,  $U/S = (U, h) \in \text{Var}(k)/S$ , with  $U$  and  $U'$  smooth. Take, see definition-proposition 3(ii), a compactification  $\bar{f}_0 = \bar{h} : \bar{X}_0 \rightarrow \bar{S}$  of  $h : U \rightarrow S$  and a compactification  $\bar{f}'_0 = \bar{h}' : \bar{X}'_0 \rightarrow \bar{S}$  of  $h' : U' \rightarrow S$  such that  $g : U'/S \rightarrow U/S$  extend to a morphism  $\bar{g}_0 : \bar{X}'_0/\bar{S} \rightarrow \bar{X}_0/\bar{S}$ . Denote  $\bar{Z} = \bar{X}_0 \setminus U$  and  $\bar{Z}' = \bar{X}'_0 \setminus U'$ . Take, see definition-proposition 3(ii), a strict desingularization  $\bar{\epsilon} : (\bar{X}, \bar{D}) \rightarrow (\bar{X}_0, \bar{Z})$  of  $(\bar{X}_0, \bar{Z})$ , a strict desingularization  $\bar{\epsilon}' : (\bar{X}', \bar{D}') \rightarrow (\bar{X}'_0, \bar{Z}')$  of  $(\bar{X}'_0, \bar{Z}')$  and a morphism  $\bar{g} : \bar{X}' \rightarrow \bar{X}$  such that the following diagram commutes

$$\begin{array}{ccc} \bar{X}'_0 & \xrightarrow{\bar{g}_0} & \bar{X}_0 \\ \bar{\epsilon}' \uparrow & & \uparrow \bar{\epsilon} \\ \bar{X}' & \xrightarrow{\bar{g}} & \bar{X} \end{array}$$

We then have, see definition-proposition 3(ii), the diagram (7) in  $\text{Fun}(\Delta, \text{Var}(k))$

$$\begin{array}{ccccc}
U = U_{c(\bullet)} & \xrightarrow{j} & \bar{X} = \bar{X}_{c(\bullet)} & \xleftarrow{i_\bullet} & \bar{D}_{s_g(\bullet)} \\
\uparrow g & & \uparrow \bar{g} & & \uparrow \bar{g}' \\
U' = U'_{c(\bullet)} & \xrightarrow{j'} & \bar{X}' = \bar{X}'_{c(\bullet)} & \xleftarrow{i'_\bullet} & \bar{D}'_\bullet \xleftarrow{i''_{g_\bullet}} \bar{g}^{-1}(\bar{D}_{s_g(\bullet)}) : i'_{g_\bullet}
\end{array}$$

Consider

$$\begin{aligned}
[\Gamma_{\bar{g}}]^t &\in \text{Hom}(\mathbb{Z}^{\text{tr}}(\bar{X}/S)(-d_X)[-2d_X], \mathbb{Z}^{\text{tr}}(\bar{X}'/S)(-d_{X'})[-2d_{X'}]) \\
&\simeq \text{Hom}(\mathbb{Z}^{\text{tr}}(\bar{X} \times \mathbb{P}^{d_X}/S)/\mathbb{Z}_{\text{tr}}(\bar{X} \times \mathbb{P}^{d_X-1}/S), \\
&\quad \mathbb{Z}_{\text{tr}}(\bar{X}' \times \mathbb{P}^{d_{X'}/S})/\mathbb{Z}_{\text{tr}}(\bar{X}' \times \mathbb{P}^{d_{X'}-1}/S)
\end{aligned}$$

the morphism given by the transpose of the graph  $\Gamma_g \subset X' \times_S X$  of  $\bar{g} : \bar{X}' \rightarrow \bar{X}$ . Then, since  $i_\bullet \circ \bar{g}'_\bullet = \bar{g} \circ i''_{g_\bullet} = \bar{g} \circ i'_\bullet \circ i'_{g_\bullet}$ , we have the factorization

$$\begin{aligned}
&[\Gamma_g]^t \circ \mathbb{Z}(i_\bullet) : (\mathbb{Z}^{\text{tr}}(\bar{D}_{s_g(\bullet)}/S), u_{IJ})(-d_X)[-2d_X] \\
&\xrightarrow{[\Gamma_{\bar{g}'_\bullet}]^t} (\mathbb{Z}^{\text{tr}}(\bar{g}^{-1}(\bar{D}_{s_g(\bullet)})/S), u_{IJ})(-d_{X'})[-2d_{X'}] \\
&\xrightarrow{\mathbb{Z}(i'_{g_\bullet})} \mathbb{Z}^{\text{tr}}(\bar{X}'/S)(-d_{X'})[-2d_{X'}].
\end{aligned}$$

with

$$\begin{aligned}
[\Gamma_{\bar{g}'_\bullet}]^t &\in \text{Hom}((\mathbb{Z}^{\text{tr}}(\bar{D}_{s_g(\bullet)} \times \mathbb{P}^{d_X}/S), u_{IJ})/(\mathbb{Z}^{\text{tr}}(\bar{D}_{s_g(\bullet)} \times \mathbb{P}^{d_X-1}/S), u_{IJ}), \\
&(\mathbb{Z}_{\text{tr}}(\bar{g}^{-1}(\bar{D}_{s_g(\bullet)}) \times \mathbb{P}^{d_{X'}/S}), u_{IJ})/(\mathbb{Z}_{\text{tr}}(\bar{g}^{-1}(\bar{D}_{s_g(\bullet)}) \times \mathbb{P}^{d_{X'}-1}/S), u_{IJ})).
\end{aligned}$$

We then consider the following map in  $C(\text{Var}(k)/S)$

$$\begin{aligned}
&\hat{R}_S^{0CH}(g) : \hat{R}_{(\bar{X}, \bar{D})/S}^0(\mathbb{Z}(U/S)) \xrightarrow{=} \\
&\text{Cone}(\mathbb{Z}(i_\bullet) : (\mathbb{Z}^{\text{tr}}(\bar{D}_{s_g(\bullet)}/S), u_{IJ}) \rightarrow \mathbb{Z}^{\text{tr}}(\bar{X}/S)(-d_X)[-2d_X] \\
&\quad \xrightarrow{([\Gamma_{\bar{g}'_\bullet}]^t, [\Gamma_{\bar{g}}]^t)} \\
&\text{Cone}(\mathbb{Z}(i'_{g_\bullet}) : (\mathbb{Z}^{\text{tr}}(\bar{g}^{-1}(\bar{D}_{s_g(\bullet)})/S), u_{IJ}) \rightarrow \mathbb{Z}^{\text{tr}}(\bar{X}'/S)(-d_{X'})[-2d_{X'}] \\
&\quad \xrightarrow{(\mathbb{Z}(i''_{g_\bullet}), I)(-d_{X'})[-2d_{X'}]} \\
&\text{Cone}(\mathbb{Z}(i'_\bullet) : ((\mathbb{Z}^{\text{tr}}(\bar{D}'_\bullet/S), u_{IJ}) \rightarrow \mathbb{Z}^{\text{tr}}(\bar{X}'/S)(-d_{X'})[-2d_{X'}] \\
&\quad \xrightarrow{=} \hat{R}_{(\bar{X}', \bar{D}')/S}^0(\mathbb{Z}(U'/S))
\end{aligned}$$

Then the following diagram in  $C(\text{Var}(k)/S)$  commutes by definition

$$\begin{array}{ccc}
\hat{R}_{(\bar{X}, \bar{D})/S}^0(\mathbb{Z}(U/S)) & \xrightarrow{T(\hat{R}^{0CH}, R^{0CH})(\mathbb{Z}(U/S))} & \hat{R}_{(\bar{X}, \bar{D})/S}^0(\mathbb{Z}(U/S)) \\
\hat{R}_S^{0CH}(g) \downarrow & & \downarrow R_S^{0CH}(g) \\
\hat{R}_{(\bar{X}', \bar{D}')/S}^0(\mathbb{Z}(U'/S)) & \xrightarrow{T(\hat{R}^{0CH}, R^{0CH})(\mathbb{Z}(U'/S))} & \hat{R}_{(\bar{X}', \bar{D}')/S}^0(\mathbb{Z}(U'/S))
\end{array}$$

(iii) For  $g_1 : U''/S \rightarrow U'/S$ ,  $g_2 : U'/S \rightarrow U/S$  two morphisms with  $U''/S = (U', h'')$ ,  $U'/S = (U', h')$ ,  $U/S = (U, h) \in \text{Var}(k)/S$ , with  $U$ ,  $U'$  and  $U''$  smooth. We get from (i) and (ii) a compactification  $\bar{f} = \bar{h} : \bar{X} \rightarrow \bar{S}$  of  $h : U \rightarrow S$ , a compactification  $\bar{f}' = \bar{h}' : \bar{X}' \rightarrow \bar{S}$  of  $h' : U' \rightarrow S$ , and a

compactification  $\bar{f}'' = \bar{h}'' : \bar{X}'' \rightarrow \bar{S}$  of  $h'' : U'' \rightarrow S$ , with  $\bar{X}, \bar{X}', \bar{X}'' \in \text{PSmVar}(k)$ ,  $\bar{D} := \bar{X} \setminus U \subset \bar{X}$ ,  $\bar{D}' := \bar{X}' \setminus U' \subset \bar{X}'$ , and  $\bar{D}'' := \bar{X}'' \setminus U'' \subset \bar{X}''$  normal crossing divisors, such that  $g_1 : U''/S \rightarrow U'/S$  extend to  $\bar{g}_1 : \bar{X}''/\bar{S} \rightarrow \bar{X}'/\bar{S}$ ,  $g_2 : U'/S \rightarrow U/S$  extend to  $\bar{g}_2 : \bar{X}'/\bar{S} \rightarrow \bar{X}/\bar{S}$ , and

$$\hat{R}_S^{0CH}(g_2 \circ g_1) = \hat{R}_S^{0CH}(g_1) \circ \hat{R}_S^{0CH}(g_2) : \hat{R}_{(\bar{X}, \bar{D})/S}^0 \rightarrow \hat{R}_{(\bar{X}'', \bar{D}'')/S}^0$$

(iv) For

$$Q^* := (\cdots \rightarrow \bigoplus_{\alpha \in \Lambda^n} \mathbb{Z}(U_\alpha^n/S) \xrightarrow{(\mathbb{Z}(g_{\alpha, \beta}^n))} \bigoplus_{\beta \in \Lambda^{n-1}} \mathbb{Z}(U_\beta^{n-1}/S) \rightarrow \cdots) \in C(\text{Var}(k)/S)$$

a complex of (maybe infinite) direct sum of representable presheaves with  $U_\alpha^*$  smooth, we get from (i), (ii) and (iii) the map in  $C(\text{Var}(k)/S)$

$$\begin{aligned} T(\hat{R}^{0CH}, R^{0CH})(Q^*) : \hat{R}^{0CH}(Q^*) &:= (\cdots \rightarrow \bigoplus_{\beta \in \Lambda^{n-1}} \varinjlim_{(\bar{X}_\beta^{n-1}, \bar{D}_\beta^{n-1})/S} \hat{R}_{(\bar{X}_\beta^{n-1}, \bar{D}_\beta^{n-1})/S}^0(\mathbb{Z}(U_\beta^{n-1}/S)) \\ &\xrightarrow{(\hat{R}_S^{0CH}(g_{\alpha, \beta}^n))} \bigoplus_{\alpha \in \Lambda^n} \varinjlim_{(\bar{X}_\alpha^n, \bar{D}_\alpha^n)/S} \hat{R}_{(\bar{X}_\alpha^n, \bar{D}_\alpha^n)/S}^0(\mathbb{Z}(U_\alpha^n/S)) \rightarrow \cdots) \rightarrow R^{0CH}(Q^*), \end{aligned}$$

where for  $(U_\alpha^n, h_\alpha^n) \in \text{Var}(k)/S$ , the inductive limit run over all the compactifications  $\bar{f}_\alpha : \bar{X}_\alpha \rightarrow \bar{S}$  of  $h_\alpha : U_\alpha \rightarrow S$  with  $\bar{X}_\alpha \in \text{PSmVar}(k)$  and  $\bar{D}_\alpha := \bar{X}_\alpha \setminus U_\alpha$  a normal crossing divisor. For  $m = (m^*) : Q_1^* \rightarrow Q_2^*$  a morphism with

$$\begin{aligned} Q_1^* &:= (\cdots \rightarrow \bigoplus_{\alpha \in \Lambda^n} \mathbb{Z}(U_{1, \alpha}^n/S) \xrightarrow{(\mathbb{Z}(g_{\alpha, \beta}^n))} \bigoplus_{\beta \in \Lambda^{n-1}} \mathbb{Z}(U_{1, \beta}^{n-1}/S) \rightarrow \cdots), \\ Q_2^* &:= (\cdots \rightarrow \bigoplus_{\alpha \in \Lambda^n} \mathbb{Z}(U_{2, \alpha}^n/S) \xrightarrow{(\mathbb{Z}(g_{\alpha, \beta}^n))} \bigoplus_{\beta \in \Lambda^{n-1}} \mathbb{Z}(U_{2, \beta}^{n-1}/S) \rightarrow \cdots) \in C(\text{Var}(k)/S) \end{aligned}$$

complexes of (maybe infinite) direct sum of representable presheaves with  $U_{1, \alpha}^*$  and  $U_{2, \alpha}^*$  smooth, we get again from (i), (ii) and (iii) a commutative diagram in  $C(\text{Var}(k)/S)$

$$\begin{array}{ccc} \hat{R}^{0CH}(Q_2^*) \xrightarrow{T(\hat{R}_S^{0CH}, R_S^{0CH})(Q_2^*)} \hat{R}^{0CH}(Q_2^*) & & \\ \hat{R}_S^{0CH}(m) := (\hat{R}_S^{0CH}(m^*)) \downarrow & & \downarrow (R_S^{0CH}(m^*)) \\ \hat{R}^{0CH}(Q_1^*) \xrightarrow{T(\hat{R}_S^{0CH}, R_S^{0CH})(Q_1^*)} \hat{R}^{0CH}(Q_1^*) & & \end{array}$$

(v) Let

$$Q^* := (\cdots \rightarrow \bigoplus_{\alpha \in \Lambda^n} \mathbb{Z}(U_\alpha^n/S) \xrightarrow{(\mathbb{Z}(g_{\alpha, \beta}^n))} \bigoplus_{\beta \in \Lambda^{n-1}} \mathbb{Z}(U_\beta^{n-1}/S) \rightarrow \cdots) \in C(\text{Var}(k)/S)$$

a complex of (maybe infinite) direct sum of representable presheaves with  $U_\alpha^*$  smooth, we have by definition

$$\text{Gr}_S^{12*} \hat{R}^{0CH}(Q^*) = \hat{R}^{CH}(Q^*) \in C(\text{Var}(k)^{2, \text{smpr}}/S).$$

- Let  $S \in \text{Var}(k)$  For  $(h, m, m') = (h^*, m^*, m'^*) : Q_1^*[1] \rightarrow Q_2^*$  an homotopy with  $Q_1^*, Q_2^* \in C(\text{Var}(k)/S)$  complexes of (maybe infinite) direct sum of representable presheaves with  $U_{1, \alpha}^*$  and  $U_{2, \alpha}^*$  smooth,

$$(\hat{R}_S^{0CH}(h), \hat{R}_S^{0CH}(m), \hat{R}_S^{0CH}(m')) = (\hat{R}_S^{0CH}(h^*), \hat{R}_S^{0CH}(m^*), \hat{R}_S^{0CH}(m'^*)) : R^{0CH}(Q_2^*)[1] \rightarrow R^{0CH}(Q_1^*)$$

is an homotopy in  $C(\text{Var}(k)/S)$  using definition 28 (iii). In particular if  $m : Q_1^* \rightarrow Q_2^*$  with  $Q_1^*, Q_2^* \in C(\text{Var}(k)/S)$  complexes of (maybe infinite) direct sum of representable presheaves with  $U_{1, \alpha}^*$  and  $U_{2, \alpha}^*$  smooth is an homotopy equivalence, then  $\hat{R}_S^{0CH}(m) : \hat{R}^{0CH}(Q_2^*) \rightarrow \hat{R}^{0CH}(Q_1^*)$  is an homotopy equivalence.

- Let  $S \in \text{SmVar}(k)$ . Let  $F \in \text{PSh}(\text{Var}(k)^{sm}/S)$ . Consider

$$q : LF := (\cdots \rightarrow \bigoplus_{(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S} \mathbb{Z}(U_\alpha/S) \xrightarrow{(\mathbb{Z}(g_{\alpha, \beta}^n))} \bigoplus_{(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S} \mathbb{Z}(U_\alpha/S) \rightarrow \cdots) \rightarrow F$$

the canonical projective resolution given in subsection 2.3.3. Note that the  $U_\alpha$  are smooth since  $S$  is smooth and  $h_\alpha$  are smooth morphism. Definition 28(iv) gives in this particular case the map in  $C(\text{Var}(k)/S)$

$$T(\hat{R}_S^{0CH}, R_S^{0CH})(\rho_S^* LF) : \hat{R}^{0CH}(\rho_S^* LF) := (\cdots \rightarrow \bigoplus_{(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S} \varinjlim_{(\bar{X}_\alpha, \bar{D}_\alpha)/S} \hat{R}_{(\bar{X}_\alpha, \bar{D}_\alpha)/S}^0(\mathbb{Z}(U_\alpha/S)) \\ \xrightarrow{(\hat{R}_S^{0CH}(g_{\alpha, \beta}^n))} \bigoplus_{(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S} \varinjlim_{(\bar{X}_\alpha, \bar{D}_\alpha)/S} \hat{R}_{(\bar{X}_\alpha, \bar{D}_\alpha)/S}^0(\mathbb{Z}(U_\alpha/S)) \rightarrow \cdots) \rightarrow R^{0CH}(\rho_S^* LF),$$

where for  $(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S$ , the inductive limit run over all the compactifications  $\bar{f}_\alpha : \bar{X}_\alpha \rightarrow \bar{S}$  of  $h_\alpha : U_\alpha \rightarrow S$  with  $\bar{X}_\alpha \in \text{PSmVar}(k)$  and  $\bar{D}_\alpha := \bar{X}_\alpha \setminus U_\alpha$  a normal crossing divisor. Definition 28(iv) gives then by functoriality in particular, for  $F = F^\bullet \in C(\text{Var}(k)^{sm}/S)$ , the map in  $C(\text{Var}(k)/S)$

$$T(\hat{R}_S^{0CH}, R_S^{0CH})(\rho_S^* LF) : \hat{R}^{0CH}(\rho_S^* LF) \rightarrow R^{0CH}(\rho_S^* LF).$$

- Let  $g : T \rightarrow S$  a morphism with  $T, S \in \text{SmVar}(k)$ . Let  $h : U \rightarrow S$  a smooth morphism with  $U \in \text{Var}(k)$ . Consider the cartesian square

$$\begin{array}{ccc} U_T & \xrightarrow{h'} & T \\ \downarrow g' & & \downarrow g \\ U & \xrightarrow{h} & S \end{array}$$

Note that  $U$  is smooth since  $S$  and  $h$  are smooth, and  $U_T$  is smooth since  $T$  and  $h'$  are smooth. Take, see definition-proposition 3(ii), a compactification  $\bar{f}_0 = \bar{h} : \bar{X}_0 \rightarrow \bar{S}$  of  $h : U \rightarrow S$ . Take, see definition-proposition 3(ii), a strict desingularization  $\bar{\epsilon} : (\bar{X}, \bar{D}) \rightarrow (\bar{X}_0, \bar{Z})$  of  $(\bar{X}_0, \bar{Z})$ . Then  $\bar{f}'_0 = g \circ h' : \bar{X}_T \rightarrow \bar{T}$  is a compactification of  $g \circ h' : U_T \rightarrow S$  such that  $g' : U_T/S \rightarrow U/S$  extend to a morphism  $\bar{g}'_0 : \bar{X}_T/\bar{S} \rightarrow \bar{X}/\bar{S}$ . Denote  $\bar{Z} = \bar{X}_0 \setminus U$  and  $\bar{Z}' = \bar{X}_T \setminus U_T$ . Take, see definition-proposition 3(ii), a strict desingularization  $\epsilon'_\bullet : (\bar{X}', \bar{D}') \rightarrow (\bar{X}_T, \bar{Z}')$  of  $(\bar{X}_T, \bar{Z}')$ . Denote  $\bar{g}' = \bar{g}'_0 \circ \epsilon'_\bullet : \bar{X}' \rightarrow \bar{X}$ . We then have, see definition-proposition 3(ii), the following commutative diagram in  $\text{Fun}(\Delta, \text{Var}(k))$

$$\begin{array}{ccccc} U = U_{c(\bullet)} & \xrightarrow{j} & \bar{X} = \bar{X}_{c(\bullet)} & \xleftarrow{i_\bullet} & \bar{D}_{s_{g'}(\bullet)} \\ \uparrow g' & & \uparrow \bar{g}'_0 & & \uparrow (g')'_\bullet \\ U_T = U_{T,c(\bullet)} & \xrightarrow{j'} & \bar{X}_T = X_{T,c(\bullet)} & \xleftarrow{i_{g\bullet}} & \bar{g}'^{-1}(\bar{D}_{s_{g'}(\bullet)}) \\ \uparrow g' & & \uparrow \bar{g}' & & \uparrow \epsilon'_\bullet \\ U_T = U_{T,c(\bullet)} & \xrightarrow{j'} & \bar{X}' = X'_{c(\bullet)} & \xleftarrow{i'_\bullet} & \bar{D}'_\bullet \xleftarrow{i''_{g'_\bullet}} \bar{g}'^{-1}(\bar{D}_{s_{g'}(\bullet)}) : i'_{g\bullet} \end{array}$$

We then consider the following map in  $C(\text{Var}(k)/T)$ ,

$$\begin{aligned}
& T(g, \hat{R}^{0CH})(\mathbb{Z}(U/S)) : g^* \hat{R}_{(\bar{X}, \bar{D})/S}^0(\mathbb{Z}(U/S)) \\
& \xrightarrow{\cong} g^* \text{Cone}(\mathbb{Z}(i_\bullet) : (\mathbb{Z}^{tr}(\bar{D}_\bullet/S), u_{IJ}) \rightarrow \mathbb{Z}^{tr}(\bar{X}/S))(-d_X)[-2d_X] \\
& \xrightarrow{\cong} \\
& \text{Cone}(\mathbb{Z}(i_{g\bullet}) : (\mathbb{Z}^{tr}(\bar{g}^{-1}(D_{s_{g\bullet}})/T), u_{IJ}) \rightarrow \mathbb{Z}^{tr}(\bar{X}_T/T))(-d_X)[-2d_X] \\
& \xrightarrow{(\mathbb{Z}(i'_{g\bullet}), [\Gamma_e]^\dagger)} \\
& \text{Cone}(\mathbb{Z}(i'_\bullet) : ((\mathbb{Z}^{tr}(\bar{D}'_\bullet/T), u_{IJ}) \rightarrow \mathbb{Z}^{tr}(\bar{X}'/T))(-d_{X'})[-2d_{X'}] \\
& \xrightarrow{\cong} \hat{R}_{(\bar{X}', \bar{D}')/T}^0(\mathbb{Z}(U_T/T))
\end{aligned}$$

For

$$Q^* := (\cdots \rightarrow \bigoplus_{\alpha \in \Lambda^n} \mathbb{Z}(U_\alpha^n/S) \xrightarrow{(\mathbb{Z}(g_{\alpha, \beta}^n))} \bigoplus_{\beta \in \Lambda^{n-1}} \mathbb{Z}(U_\beta^{n-1}/S) \rightarrow \cdots) \in C(\text{Var}(k)/S)$$

a complex of (maybe infinite) direct sum of representable presheaves with  $h_\alpha^n : U_\alpha^n \rightarrow S$  smooth, we get the map in  $C(\text{Var}(k)/T)$

$$\begin{aligned}
& T(g, \hat{R}^{0CH})(Q^*) : g^* \hat{R}^{0CH}(Q^*) = (\cdots \rightarrow \bigoplus_{\alpha \in \Lambda^n} \varinjlim_{(\bar{X}_\alpha^n, \bar{D}_\alpha^n)/S} g^* \hat{R}_{(\bar{X}_\alpha^n, \bar{D}_\alpha^n)/S}^0(\mathbb{Z}(U_\alpha^n/S)) \rightarrow \cdots) \\
& \xrightarrow{(T(g, \hat{R}^{0CH})(\mathbb{Z}(U_\alpha^n/S)))} (\cdots \rightarrow \bigoplus_{\alpha \in \Lambda^n} \varinjlim_{(\bar{X}'_\alpha^n, \bar{D}'_\alpha^n)/T} \hat{R}_{(\bar{X}'_\alpha^n, \bar{D}'_\alpha^n)/T}(\mathbb{Z}(U_{\alpha, T}^n/S)) \rightarrow \cdots) =: \hat{R}^{CH}(g^* Q^*)
\end{aligned}$$

together with the commutative diagram in  $C(\text{Var}(k)/T)$

$$\begin{array}{ccc}
g^* \hat{R}^{0CH}(Q^*) & \xrightarrow{T(g, \hat{R}^{0CH})(Q^*)} & \hat{R}^{0CH}(g^* Q^*) \\
\downarrow g^* T(\hat{R}_S^{0CH}, R_S^{0CH})(Q^*) & & \downarrow T(\hat{R}_T^{0CH}, R_T^{0CH})(g^* Q) \\
g^* R^{0CH}(Q^*) & \xrightarrow{T(g, R^{0CH})(Q^*)} & R^{0CH}(g^* Q^*)
\end{array}$$

Let  $F \in \text{PSh}(\text{Var}(k)^{sm}/S)$ . Consider

$$q : LF := (\cdots \rightarrow \bigoplus_{(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S} \mathbb{Z}(U_\alpha/S) \rightarrow \cdots) \rightarrow F$$

the canonical projective resolution given in subsection 2.3.3. We then get in particular the map in  $C(\text{Var}(k)/T)$

$$\begin{aligned}
& T(g, \hat{R}^{0CH})(\rho_S^* LF) : g^* \hat{R}^{0CH}(\rho_S^* LF) = \\
& (\cdots \rightarrow \bigoplus_{(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S} \varinjlim_{(\bar{X}_\alpha, \bar{D}_\alpha)/S} g^* \hat{R}_{(\bar{X}_\alpha, \bar{D}_\alpha)/S}^0(\mathbb{Z}(U_\alpha/S)) \rightarrow \cdots) \xrightarrow{(T(g, \hat{R}^{0CH})(\mathbb{Z}(U_\alpha/S)))} \\
& (\cdots \rightarrow \bigoplus_{(U_\alpha, h_\alpha) \in \text{Var}(k)^{sm}/S} \varinjlim_{(\bar{X}'_\alpha, \bar{D}'_\alpha)/T} \hat{R}_{(\bar{X}'_\alpha, \bar{D}'_\alpha)/T}(\mathbb{Z}(U_{\alpha, T}/S)) \rightarrow \cdots) =: \hat{R}^{0CH}(\rho_T^* g^* LF),
\end{aligned}$$

and by functoriality, we get in particular for  $F = F^\bullet \in C(\text{Var}(k)^{sm}/S)$ , the map in  $C(\text{Var}(k)/T)$

$$T(g, \hat{R}^{0CH})(\rho_S^* LF) : g^* \hat{R}^{0CH}(\rho_S^* LF) \rightarrow \hat{R}^{0CH}(\rho_T^* g^* LF)$$

together with the commutative diagram in  $C(\text{Var}(k)/T)$

$$\begin{array}{ccc}
g^* \hat{R}^{0CH}(\rho_S^* LF) & \xrightarrow{T(g, \hat{R}^{0CH})(\rho_S^* LF)} & \hat{R}^{0CH}(\rho_T^* g^* LF) \\
\downarrow g^* T(\hat{R}_S^{0CH}, R_S^{0CH})(\rho_S^* LF) & & \downarrow T(\hat{R}_T^{0CH}, R_T^{0CH})(\rho_T^* g^* LF) \\
g^* L\rho_{S*} \mu_{S*} R^{CH}(\rho_S^* LF) & \xrightarrow{T(g, R^{0CH})(\rho_S^* LF)} & R^{CH}(\rho_T^* g^* LF)
\end{array}$$

- Let  $S_1, S_2 \in \text{SmVar}(k)$  and  $p : S_1 \times S_2 \rightarrow S_1$  the projection. Let  $h : U \rightarrow S_1$  a smooth morphism with  $U \in \text{Var}(k)$ . Consider the cartesian square

$$\begin{array}{ccc} U \times S_2 & \xrightarrow{h \times I} & S_1 \times S_2 \\ \downarrow p' & & \downarrow p \\ U & \xrightarrow{h} & S_1 \end{array}$$

Take, see definition-proposition 3(i), a compactification  $\bar{f}_0 = \bar{h} : \bar{X}_0 \rightarrow \bar{S}_1$  of  $h : U \rightarrow S_1$ . Then  $\bar{f}_0 \times I : \bar{X}_0 \times S_2 \rightarrow \bar{S}_1 \times S_2$  is a compactification of  $h \times I : U \times S_2 \rightarrow S_1 \times S_2$  and  $p' : U \times S_2 \rightarrow U$  extend to  $\bar{p}'_0 := p_{X_0} : \bar{X}_0 \times S_2 \rightarrow \bar{X}_0$ . Denote  $Z = X_0 \setminus U$ . Take see theorem 16(i), a strict desingularization  $\bar{\epsilon} : (\bar{X}, \bar{D}) \rightarrow (\bar{X}_0, \bar{Z})$  of the pair  $(\bar{X}_0, \bar{Z})$ . We then have the commutative diagram (8) in  $\text{Fun}(\Delta, \text{Var}(k))$  whose squares are cartesian

$$\begin{array}{ccccc} U = U_{c(\bullet)} & \xrightarrow{j} & \bar{X} & \xleftarrow{i \bullet} & \bar{D} \bullet \\ \uparrow g & & \uparrow \bar{p}' := p_{\bar{X}} & & \uparrow \bar{p}' \bullet \\ U \times S_2 = (U \times S_2)_{c(\bullet)} & \xrightarrow{j \times I} & \bar{X} \times S_2 & \xleftarrow{i' \bullet} & \bar{D} \bullet \times S_2 \end{array}$$

Then the map in  $C(\text{Var}(k)/S_1 \times S_2)$

$$T(p, \hat{R}^{0CH})(\mathbb{Z}(U/S_1)) : p^* \hat{R}_{(\bar{X}, \bar{D})/S_1}^0(\mathbb{Z}(U/S_1)) \xrightarrow{\sim} \hat{R}_{(\bar{X} \times S_2, \bar{D} \bullet \times S_2)/S_1 \times S_2}^0(\mathbb{Z}(U \times S_2/S_1 \times S_2))$$

is an isomorphism. Hence, for  $Q^* \in C(\text{Var}(k)/S_1)$  a complex of (maybe infinite) direct sum of representable presheaves of smooth morphism, the map in  $C(\text{Var}(k)/S_1 \times S_2)$

$$T(p, \hat{R}^{0CH})(Q^*) : p^* \hat{R}^{0CH}(Q^*) \xrightarrow{\sim} \hat{R}^{0CH}(p^* Q^*)$$

is an isomorphism. In particular, for  $F \in C(\text{Var}(k)^{sm}/S_1)$  the map in  $C(\text{Var}(k)/S_1 \times S_2)$

$$T(p, \hat{R}^{0CH})(\rho_{S_1}^* LF) : p^* \hat{R}^{0CH}(\rho_{S_1}^* LF) \xrightarrow{\sim} \hat{R}^{0CH}(\rho_{S_1 \times S_2}^* p^* LF)$$

is an isomorphism.

- Let  $h_1 : U_1 \rightarrow S, h_2 : U_2 \rightarrow S$  two morphisms with  $U_1, U_2, S \in \text{Var}(k), U_1, U_2$  smooth. Denote by  $p_1 : U_1 \times_S U_2 \rightarrow U_1$  and  $p_2 : U_1 \times_S U_2 \rightarrow U_2$  the projections. Take, see definition-proposition 3(i), a compactification  $\bar{f}_{10} = \bar{h}_1 : \bar{X}_{10} \rightarrow \bar{S}$  of  $h_1 : U_1 \rightarrow S$  and a compactification  $\bar{f}_{20} = \bar{h}_2 : \bar{X}_{20} \rightarrow \bar{S}$  of  $h_2 : U_2 \rightarrow S$ . Then,

- $\bar{f}_{10} \times \bar{f}_{20} : \bar{X}_{10} \times_{\bar{S}} \bar{X}_{20} \rightarrow S$  is a compactification of  $h_1 \times h_2 : U_1 \times_S U_2 \rightarrow S$ .
- $\bar{p}_{10} := p_{X_{10}} : \bar{X}_{10} \times_{\bar{S}} \bar{X}_{20} \rightarrow \bar{X}_{10}$  is a compactification of  $p_1 : U_1 \times_S U_2 \rightarrow U_1$ .
- $\bar{p}_{20} := p_{X_{20}} : \bar{X}_{10} \times_{\bar{S}} \bar{X}_{20} \rightarrow \bar{X}_{20}$  is a compactification of  $p_2 : U_1 \times_S U_2 \rightarrow U_2$ .

Denote  $\bar{Z}_1 = \bar{X}_{10} \setminus U_1$  and  $\bar{Z}_2 = \bar{X}_{20} \setminus U_2$ . Take, see theorem 16(i), a strict desingularization  $\bar{\epsilon}_1 : (\bar{X}_1, \bar{D}) \rightarrow (\bar{X}_{10}, \bar{Z}_1)$  of the pair  $(\bar{X}_{10}, \bar{Z}_1)$  and a strict desingularization  $\bar{\epsilon}_2 : (\bar{X}_2, \bar{E}) \rightarrow (\bar{X}_{20}, \bar{Z}_2)$  of the pair  $(\bar{X}_{20}, \bar{Z}_2)$ . Take then a strict desingularization

$$\bar{\epsilon}_{12} : ((\bar{X}_1 \times_{\bar{S}} \bar{X}_2)^N, \bar{F}) \rightarrow (\bar{X}_1 \times_{\bar{S}} \bar{X}_2, (D \times_{\bar{S}} \bar{X}_2) \cup (\bar{X}_1 \times_{\bar{S}} \bar{E}))$$

of the pair  $(\bar{X}_1 \times_{\bar{S}} \bar{X}_2, (\bar{D} \times_{\bar{S}} \bar{X}_2) \cup (\bar{X}_1 \times_{\bar{S}} \bar{E}))$ . We have then the following commutative diagram

$$\begin{array}{ccc}
& \bar{X}_1 & \xrightarrow{\bar{f}_1} & \bar{S} \\
& \uparrow \bar{p}_2 & & \uparrow \bar{f}_2 \\
& \bar{X}_1 \times_{\bar{S}} \bar{X}_2 & \xrightarrow{\bar{p}_1} & \bar{X}_2 \\
& \uparrow \bar{\epsilon}_{12} & \nearrow (\bar{p}_1)^N & \nearrow (\bar{p}_2)^N \\
(\bar{X}_1 \times_{\bar{S}} \bar{X}_2)^N & & & 
\end{array}$$

and

- $\bar{f}_1 \times \bar{f}_2 : \bar{X}_1 \times_{\bar{S}} \bar{X}_2 \rightarrow \bar{S}$  is a compactification of  $h_1 \times h_2 : U_1 \times_S U_2 \rightarrow S$ .
- $(\bar{p}_1)^N := \bar{p}_1 \circ \bar{\epsilon}_{12} : (\bar{X}_1 \times_{\bar{S}} \bar{X}_2)^N \rightarrow \bar{X}_1$  is a compactification of  $p_1 : U_1 \times_S U_2 \rightarrow U_1$ .
- $(\bar{p}_2)^N := \bar{p}_2 \circ \bar{\epsilon}_{12} : (\bar{X}_1 \times_{\bar{S}} \bar{X}_2)^N \rightarrow \bar{X}_2$  is a compactification of  $p_2 : U_1 \times_S U_2 \rightarrow U_2$ .

We have then the morphism in  $C(\text{Var}(k)/S)$

$$T(\otimes, \hat{R}_S^{0CH})(\mathbb{Z}(U_1/S), \mathbb{Z}(U_2/S)) := \hat{R}_S^{0CH}(p_1) \otimes \hat{R}_S^{0CH}(p_2) : \\
\hat{R}_{(\bar{X}_1, \bar{D})/S}^0(\mathbb{Z}(U_1/S)) \otimes \hat{R}_{(\bar{X}_2, \bar{E})/S}^0(\mathbb{Z}(U_2/S)) \xrightarrow{\sim} \hat{R}_{(\bar{X}_1 \times_{\bar{S}} \bar{X}_2)^N, \bar{F}/S}^0(\mathbb{Z}(U_1 \times_S U_2/S))$$

For

$$Q_1^* := (\cdots \rightarrow \oplus_{\alpha \in \Lambda^n} \mathbb{Z}(U_{1,\alpha}^n/S) \xrightarrow{(\mathbb{Z}(g_{\alpha,\beta}^n))} \oplus_{\beta \in \Lambda^{n-1}} \mathbb{Z}(U_{1,\beta}^{n-1}/S) \rightarrow \cdots), \\
Q_2^* := (\cdots \rightarrow \oplus_{\alpha \in \Lambda^n} \mathbb{Z}(U_{2,\alpha}^n/S) \xrightarrow{(\mathbb{Z}(g_{\alpha,\beta}^n))} \oplus_{\beta \in \Lambda^{n-1}} \mathbb{Z}(U_{2,\beta}^{n-1}/S) \rightarrow \cdots) \in C(\text{Var}(k)/S)$$

complexes of (maybe infinite) direct sum of representable presheaves with  $U_\alpha^*$  smooth, we get the morphism in  $C(\text{Var}(k)/S)$

$$T(\otimes, \hat{R}_S^{0CH})(Q_1^*, Q_2^*) : \hat{R}_S^{0CH}(Q_1^*) \otimes R^{0CH}(Q_2^*) \xrightarrow{T(\otimes, \hat{R}_S^{0CH})(\mathbb{Z}(U_{1,\alpha}^n), \mathbb{Z}(U_{2,\beta}^n))} \hat{R}_S^{0CH}(Q_1^* \otimes Q_2^*)$$

, together with the commutative diagram in  $C(\text{Var}(k)/S)$

$$\begin{array}{ccc}
\hat{R}_S^{0CH}(Q_1^*) \otimes R^{0CH}(Q_2^*) & \xrightarrow{T(\otimes, \hat{R}_S^{0CH})(Q_1^*, Q_2^*)} & \hat{R}_S^{0CH}(Q_1^* \otimes Q_2^*) \\
\downarrow T(\hat{R}_S^{0CH}, R_S^{0CH})(Q_1^*) \otimes T(\hat{R}_S^{0CH}, R_S^{0CH})(Q_2^*) & & \downarrow T(\hat{R}_S^{0CH}, R_S^{0CH})(Q_1^* \otimes Q_2^*) \\
R^{0CH}(Q_1^*) \otimes R^{0CH}(Q_2^*) & \xrightarrow{T(\otimes, R_S^{0CH})(Q_1^*, Q_2^*)} & R^{0CH}(Q_1^* \otimes Q_2^*)
\end{array}$$

For  $F_1, F_2 \in C(\text{Var}(k)^{sm}/S)$ , we get in particular the morphism in  $C(\text{Var}(k)/S)$

$$T(\otimes, R_S^{0CH})(\rho_S^* LF_1, \rho_S^* LF_2) : R^{0CH}(\rho_S^* LF_1) \otimes R^{0CH}(\rho_S^* LF_2) \rightarrow R^{0CH}(\rho_S^*(LF_1 \otimes LF_2))$$

together with the commutative diagram in  $C(\text{Var}(k)/S)$

$$\begin{array}{ccc}
\hat{R}_S^{0CH}(\rho_S^* LF_1) \otimes R^{0CH}(\rho_S^* LF_2) & \xrightarrow{T(\otimes, \hat{R}_S^{0CH})(\rho_S^* LF_1, \rho_S^* LF_2)} & \hat{R}_S^{0CH}(\rho_S^* LF_1 \times \rho_S^* LF_2) \\
\downarrow T(\hat{R}_S^{0CH}, R_S^{0CH})(\rho_S^* LF_1) \otimes T(\hat{R}_S^{0CH}, R_S^{0CH})(\rho_S^* LF_2) & & \downarrow T(\hat{R}_S^{0CH}, R_S^{0CH})(\rho_S^* LF_1 \otimes \rho_S^* LF_2) \\
R^{0CH}(\rho_S^* LF_1) \otimes R^{0CH}(\rho_S^* LF_2) & \xrightarrow{T(\otimes, R_S^{0CH})(\rho_S^* LF_1, \rho_S^* LF_2)} & R^{0CH}(\rho_S^* LF_1 \times \rho_S^* LF_2)
\end{array}$$

### 3 Triangulated category of motives

#### 3.1 Definition and the six functor formalism

The category of motives is obtained by inverting the  $(\mathbb{A}_S^1, et)$  equivalence. Hence the  $\mathbb{A}_S^1$  local complexes of presheaves plays a key role.

**Definition 29.** *The derived category of motives of complex algebraic varieties over  $S$  is the category*

$$DA(S) := \text{Ho}_{\mathbb{A}_S^1, et}(C(\text{Var}(k)^{sm}/S)),$$

which is the localization of the category of complexes of presheaves on  $\text{Var}(k)^{sm}/S$  with respect to  $(\mathbb{A}_S^1, et)$  local equivalence and we denote by

$$D(\mathbb{A}_S^1, et) := D(\mathbb{A}_S^1) \circ D(et) : C(\text{Var}(k)^{sm}/S) \rightarrow DA(S)$$

the localization functor. We have  $DA^-(S) := D(\mathbb{A}_S^1, et)(\text{PSh}(\text{Var}(k)^{sm}/S, C^-(\mathbb{Z}))) \subset DA(S)$  the full subcategory consisting of bounded above complexes.

**Definition 30.** *The stable derived category of motives of complex algebraic varieties over  $S$  is the category*

$$DA_{st}(S) := \text{Ho}_{\mathbb{A}_S^1, et}(C_\Sigma(\text{Var}(k)^{sm}/S)),$$

which is the localization of the category of  $\mathbb{G}_{mS}$ -spectra ( $\Sigma F^\bullet = F^\bullet \otimes \mathbb{G}_{mS}$ ) of complexes of presheaves on  $\text{Var}(k)^{sm}/S$  with respect to  $(\mathbb{A}_S^1, et)$  local equivalence. The functor

$$\Sigma^\infty : C(\text{Var}(k)^{sm}/S) \hookrightarrow C_\Sigma(\text{Var}(k)^{sm}/S)$$

induces the functor  $\Sigma^\infty : DA(S) \rightarrow DA_{st}(S)$ .

We have all the six functor formalism by [12]. We give a list of the operation we will use :

- For  $f : T \rightarrow S$  a morphism with  $S, T \in \text{Var}(k)$ , the adjunction

$$(f^*, f_*) : C(\text{Var}(k)^{sm}/S) \rightleftarrows C(\text{Var}(k)^{sm}/T)$$

is a Quillen adjunction which induces in the derived categories ( $f^*$  derives trivially),  $(f^*, Rf_*) : DA(S) \rightleftarrows DA(T)$ .

- For  $h : V \rightarrow S$  a smooth morphism with  $V, S \in \text{Var}(k)$ , the adjunction

$$(h_\#, h^*) : C(\text{Var}(k)^{sm}/V) \rightleftarrows C(\text{Var}(k)^{sm}/S)$$

is a Quillen adjunction which induces in the derived categories ( $h^*$  derive trivially)  $(Lh_\#, h^*) : DA(V) \rightleftarrows DA(S)$ .

- For  $i : Z \hookrightarrow S$  a closed embedding, with  $Z, S \in \text{Var}(k)$ ,

$$(i_*, i^!) := (i_*, i^\perp) : C(\text{Var}(k)^{sm}/Z) \rightleftarrows C(\text{Var}(k)^{sm}/S)$$

is a Quillen adjunction, which induces in the derived categories ( $i_*$  derive trivially)  $(i_*, Ri^!) : DA(Z) \rightleftarrows DA(S)$ . The fact that  $i_*$  derive trivially (i.e. send  $(\mathbb{A}^1, et)$  local equivalence to  $(\mathbb{A}^1, et)$  local equivalence is proved in [4].

- For  $S \in \text{Var}(k)$ , the adjunction given by the tensor product of complexes of abelian groups and the internal hom of presheaves

$$((\cdot \otimes \cdot), \mathcal{H}om^\bullet(\cdot, \cdot)) : C(\text{Var}(k)^{sm}/S)^2 \rightarrow C(\text{Var}(k)^{sm}/S),$$

is a Quillen adjunction, which induces in the derived category

$$, ((\cdot \otimes^L \cdot), R\mathcal{H}om^\bullet(\cdot, \cdot)) : DA(S)^2 \rightarrow DA(S),$$



- Let  $M, N \in \text{DA}(S)$ ,  $Q^\bullet$  projectively cofibrant such that  $M = D(\mathbb{A}^1, \text{et})(Q^\bullet)$ , and  $G^\bullet$  be  $\mathbb{A}^1$  local for the etale topology such that  $N = D(\mathbb{A}^1, \text{et})(G^\bullet)$ . Then,

$$R\mathcal{H}om^\bullet(M, N) = \mathcal{H}om^\bullet(Q^\bullet, E(G^\bullet)) \in \text{DA}(S). \quad (9)$$

This is well defined since if  $s : Q_1 \rightarrow Q_2$  is a etale local equivalence,

$$\mathcal{H}om(s, E(G)) : \mathcal{H}om(Q_1, E(G)) \rightarrow \mathcal{H}om(Q_2, E(G))$$

is a etale local equivalence for  $1 \leq i \leq l$ .

We get from the first point 2 functors :

- The 2-functor  $C(\text{Var}(k)^{sm}/\cdot) : \text{Var}(k) \rightarrow \text{Ab Cat}$ , given by

$$S \mapsto C(\text{Var}(k)^{sm}/S), (f : T \rightarrow S) \mapsto (f^* : C(\text{Var}(k)^{sm}/S) \rightarrow C(\text{Var}(k)^{sm}/T)).$$

- The 2-functor  $\text{DA}(\cdot) : \text{Var}(k) \rightarrow \text{TriCat}$ , given by

$$S \mapsto \text{DA}(S), (f : T \rightarrow S) \mapsto (f^* : \text{DA}(S) \rightarrow \text{DA}(T)).$$

The main theorem is the following :

**Theorem 17.** [4][12] *The 2-functor  $\text{DA}(\cdot) : \text{Var}(k) \rightarrow \text{TriCat}$ , given by*

$$S \mapsto \text{DA}(S), (f : T \rightarrow S) \mapsto (f^* : \text{DA}(S) \rightarrow \text{DA}(T))$$

*is a 2-homotopic functor ([4])*

From theorem 17, we get in particular

- For  $f : T \rightarrow S$  a morphism with  $T, S \in \text{Var}(k)$ , there by theorem 17 is also a pair of adjoint functor

$$(f_!, f^!) : \text{DA}(S) \rightleftarrows \text{DA}(T)$$

- with  $f_! = Rf_*$  if  $f$  is proper,
- with  $f^! = f^*[d]$  if  $f$  is smooth of relative dimension  $d$ .

For  $h : U \rightarrow S$  a smooth morphism with  $U, S \in \text{Var}(k)$  irreducible, have, for  $M \in \text{DA}(U)$ , an isomorphism

$$Lh_{\sharp}M \rightarrow h_!M[d], \quad (10)$$

in  $\text{DA}(S)$ .

- The 2-functor  $S \in \text{Var}(k) \mapsto \text{DA}(S)$  satisfy the localization property, that is for  $i : Z \hookrightarrow X$  a closed embedding with  $Z, X \in \text{Var}(k)$ , denote by  $j : S \setminus Z \hookrightarrow S$  the open complementary subset, we have for  $M \in \text{DA}(S)$  a distinguish triangle in  $\text{DA}(S)$

$$j_{\sharp}j^*M \xrightarrow{\text{ad}(j_{\sharp}, j^*)(M)} M \xrightarrow{\text{ad}(i^*, i_*)(M)} i_*i^*M \rightarrow j_{\sharp}j^*M[1]$$

equivalently,

- the functor

$$(i^*, j^*) : \text{DA}(S) \xrightarrow{\sim} \text{DA}(Z) \times \text{DA}(S \setminus Z)$$

is conservative,

- and for  $F \in C(\text{Var}(k)^{sm}/Z)$ , the adjunction map  $\text{ad}(i^*, i_*)(F) : i^*i_*F \rightarrow F$  is an equivalence Zariski local, hence for  $M \in \text{DA}(S)$ , the induced map in the derived category

$$\text{ad}(i^*, i_*)(M) : i^*i_*M \xrightarrow{\sim} M$$

is an isomorphism.

- For  $f : X \rightarrow S$  a proper map,  $g : T \rightarrow S$  a morphism, with  $T, X, S \in \text{Var}(k)$ , and  $M \in \text{DA}(X)$ ,

$$T(f, g)(M) : g^*Rf_*M \rightarrow Rf'_*\tilde{g}'^*M$$

is an isomorphism in  $\text{DA}(T)$  if  $f$  is proper.

**Definition 31.** *The derived category of extended motives of complex algebraic varieties over  $S$  is the category*

$$\underline{\text{DA}}(S) := \text{Ho}_{\mathbb{A}_S^1, \text{et}}(C(\text{Var}(k)/S)),$$

which is the localization of the category of complexes of presheaves on  $\text{Var}(k)/S$  with respect to  $(\mathbb{A}_S^1, \text{et})$  local equivalence and we denote by

$$D(\mathbb{A}_S^1, \text{et}) := D(\mathbb{A}_S^1) \circ D(\text{et}) : C(\text{Var}(k)/S) \rightarrow \underline{\text{DA}}(S)$$

the localization functor. We have  $\underline{\text{DA}}^-(S) := D(\mathbb{A}_S^1, \text{et})(\text{PSh}(\text{Var}(k)/S, C^-(\mathbb{Z}))) \subset \underline{\text{DA}}(S)$  the full subcategory consisting of bounded above complexes.

### 3.2 Constructible motives and resolution of a motive by Corti-Hanamura motives

We now give the definition of the motives of morphisms  $f : X \rightarrow S$  which are constructible motives and the definition of the category of Corti-Hanamura motives.

**Definition 32.** *Let  $S \in \text{Var}(k)$ ,*

- *the homological motive functor is  $M(/S) : \text{Var}(k)/S \rightarrow \text{DA}(S)$ ,  $(f : X \rightarrow S) \mapsto M(X/S) := f_!f^!M(S/S)$ ,*
- *the cohomological motive functor is  $M^\vee(/S) : \text{Var}(k)/S \rightarrow \text{DA}(S)$ ,  $(f : X \rightarrow S) \mapsto M(X/S)^\vee := Rf_*M(X/X) := f_*E_{\text{et}}(\mathbb{Z}_X)$ ,*
- *the Borel-Moore motive functor is  $M^{BM}(/S) : \text{Var}(k)/S \rightarrow \text{DA}(S)$ ,  $(f : X \rightarrow S) \mapsto M^{BM}(X/S) := f_!M(X/X)$ ,*
- *the (homological) motive with compact support functor is  $M_c(/S) : \text{Var}(k)/S \rightarrow \text{DA}(S)$ ,  $(f : X \rightarrow S) \mapsto M_c(X/S) := Rf_*f^!M(S/S)$ .*

Let  $f : X \rightarrow S$  a morphism with  $X, S \in \text{Var}(k)$ . Assume that there exist a factorization  $f : X \xrightarrow{i} Y \times S \xrightarrow{p} S$ , with  $Y \in \text{SmVar}(k)$ ,  $i : X \hookrightarrow Y$  is a closed embedding and  $p$  the projection. Then,

$$Q(X/S) := p_!\Gamma_X^\vee \mathbb{Z}_{Y \times S} \in C(\text{Var}(k)^{sm}/S)$$

is projective, admits transfert, and satisfy  $D(\mathbb{A}_S^1, \text{et})(Q(X/S)) = M(X/S)$ .

**Definition 33.** (i) *Let  $S \in \text{Var}(k)$ . We define the full subcategory*

$$\begin{aligned} \text{DA}_c(S) : &= \langle Rf_*\mathbb{Z}_X, (f : X \rightarrow S) \in \text{Var}(k) \rangle \\ &= \langle Rf_*\mathbb{Z}_X, (f : X \rightarrow S) \in \text{Var}(k), \text{ proper, } X \text{ smooth} \rangle \subset \text{DA}(S) \end{aligned}$$

where  $\langle, \rangle$  denoted the full triangulated category generated by.

(ii) Let  $X, S \in \text{Var}(k)$ . If  $f : X \rightarrow S$  is proper (but not necessary smooth) and  $X$  is smooth,  $M(X/S)$  is said to be a Corti-Hanamura motive and we have by above in this case  $M(X/S) = M^{BM}(X/S)[c] = M(X/S)^\vee[c]$ , with  $c = \text{codim}(X, X \times S)$  where  $f : X \hookrightarrow X \times S \rightarrow S$ . We denote by

$$\mathcal{CH}(S) = \{M(X/S)\}_{\{X/S=(X,f),fpr,Xsm\}}^{pa} \subset DM(S)$$

the full subcategory which is the pseudo-abelian completion of the full subcategory whose objects are Corti-Hanamura motives.

(iii) We denote by

$$\mathcal{CH}^0(S) \subset \mathcal{CH}(S)$$

the full subcategory which is the pseudo-abelian completion of the full subcategory whose objects are Corti-Hanamura motives  $M(X/S)$  such that the morphism  $f : X \rightarrow S$  is projective.

For bounded above motives, we have

**Theorem 18.** Let  $S \in \text{Var}(k)$ .

(i) There exists a unique weight structure  $\omega$  on  $\text{DA}^-(S)$  such that  $\text{DA}^-(S)^{\omega=0} = \mathcal{CH}(S)$

(ii) There exist a well defined functor

$$W(S) : \text{DA}^-(S) \rightarrow K^-(\mathcal{CH}(S)), W(S)(M) = [M^{(\bullet)}]$$

where  $M^{(\bullet)} \in C^-(\mathcal{CH}(S))$  is a bounded above weight complex, such that if  $m \in \mathbb{Z}$  is the highest weight, we have a generalized distinguish triangle for all  $i \leq m$

$$T_i : M^{(i)}[i] \rightarrow M^{(i+1)}[(i+1)] \rightarrow \cdots \rightarrow M^{(m)}[m] \rightarrow M^{w \geq i} \quad (11)$$

Moreover the maps  $w(M)^{(\geq i)} : M^{\geq i} \rightarrow M$  induce an isomorphism  $w(M) : \text{holim}_i M^{\geq i} \xrightarrow{\sim} M$  in  $\text{DA}^-(S)$ .

(iii) Denote by  $\text{Chow}(S)$  the category of Chow motives, which is the pseudo-abelian completion of the category

- whose set of objects consist of the  $X/S = (X, f) \in \text{Var}(k)/S$  such that  $f$  is proper and  $X$  is smooth,
- whose set of morphisms between  $X_1/S$  and  $X_2/S$  is  $\text{CH}^{d_1}(X_1 \times_S X_2)$ , and the composition law is given in [13].

We have then a canonical functor  $\text{CH}_S : \text{Chow}(S) \hookrightarrow \text{DA}(S)$ , with  $\text{CH}_S(X/S) := M(X/S) := \text{Rf}_*\mathbb{Z}(X/X)$ , which is a full embedding whose image is the category  $\mathcal{CH}(S)$ .

*Proof.* (i): The category  $\text{DA}(S)$  is clearly weakly generated by  $\mathcal{CH}(S)$ . Moreover  $\mathcal{CH}(S) \subset \text{DA}(S)$  is negative. Hence, the result follows from [8] theorem 4.3.2 III.

(ii): Follows from (i) by standard fact of weight structure on triangulated categories. See [8] theorem 3.2.2 and theorem 4.3.2 V for example.

(iii): See [16]. □

**Theorem 19.** Let  $S \in \text{Var}(k)$ .

(i) There exists a unique weight structure  $\omega$  on  $\text{DA}^-(S)$  such that  $\text{DA}^-(S)^{\omega=0} = \mathcal{CH}^0(S)$

(ii) There exist a well defined functor

$$W(S) : \mathrm{DA}^-(S) \rightarrow K^-(\mathcal{CH}^0(S)), \quad W(S)(M) = [M^{(\bullet)}]$$

where  $M^{(\bullet)} \in C^-(\mathcal{CH}^0(S))$  is a bounded above weight complex, such that if  $m \in \mathbb{Z}$  is the highest weight, we have a generalized distinguish triangle for all  $i \leq m$

$$T_i : M^{(i)}[i] \rightarrow M^{(i+1)}[(i+1)] \rightarrow \cdots \rightarrow M^{(m)}[m] \rightarrow M^{w \geq i} \quad (12)$$

Moreover the maps  $w(M)^{(\geq i)} : M^{\geq i} \rightarrow M$  induce an isomorphism  $w(M) : \mathrm{holim}_i M^{\geq i} \xrightarrow{\sim} M$  in  $\mathrm{DA}^-(S)$ .

*Proof.* Similar to the proof of theorem 18. □

**Corollary 2.** Let  $S \in \mathrm{Var}(k)$ . Let  $M \in \mathrm{DA}(S)$ . Then there exist  $(F, W) \in C_{fil}(\mathrm{Var}(k)^{sm}/S)$  such that  $D(\mathbb{A}^1, et)(F) = M$  and  $D(\mathbb{A}^1, et)(\mathrm{Gr}_p^W F) \in \mathcal{CH}^0(S)$ .

*Proof.* By theorem 19, there exist, by induction, for  $i \in \mathbb{Z}$ , a distinguish triangle in  $\mathrm{DA}(S)$

$$T_i : M^{(i)}[i] \xrightarrow{m_i} M^{(i+1)} \xrightarrow{m_{i+1}} \cdots \xrightarrow{m_{m-1}} M^{(m)}[m] \rightarrow M^{w \geq i} \quad (13)$$

with  $M^{(j)}[j] \in \mathcal{CH}^0(S)$  and  $w(M) : \mathrm{holim}_i M^{\geq i} \xrightarrow{\sim} M$  in  $\mathrm{DA}^-(S)$ . For  $i \in \mathbb{Z}$ , take  $(F_j)_{j \geq i}, F_{w \geq i} \in C(\mathrm{Var}(k)^{sm}/S)$  such that  $D(\mathbb{A}^1, et)(F_j) = M^{(j)}[j]$ ,  $D(\mathbb{A}^1, et)(F_{w \geq i}) = M^{w \geq i}$  and such that we have in  $C(\mathrm{Var}(k)^{sm}/S)$ ,

$$F_{w \geq i} = \mathrm{Cone}(F_i \xrightarrow{m_i} F_{i+1} \xrightarrow{m_{i+1}} \cdots \xrightarrow{m_{m-1}} F_m) \quad (14)$$

where  $m_j : F_j \rightarrow F_{j+1}$  are morphisms in  $C(\mathrm{Var}(k)^{sm}/S)$  such that  $D(\mathbb{A}^1, et)(m_j) = m_j$ . Now set  $F = \mathrm{holim}_i F_{w \geq i} \in C(\mathrm{Var}(k)^{sm}/S)$  and  $W_i F := F_{w \geq i} \hookrightarrow F$ , so that  $(F, W) \in C_{fil}(\mathrm{Var}(k)^{sm}/S)$  satisfy  $D(\mathbb{A}^1, et)(\mathrm{Gr}_p^W F) = M^{(p)}[p] \in \mathcal{CH}^0(S)$ . □

## 4 The (filtered) D modules and the (filtered) De Rham functor on algebraic varieties over a field $k$ of characteristic zero

### 4.1 The D-modules on smooth algebraic varieties over a field $k$ of characteristic zero and their functorialities

Let  $k$  a field of characteristic zero.

For  $S = (S, O_S) \in \mathrm{SmVar}(k)$ , we denote by

- $D_S := D(O_S) \subset \mathcal{H}om_{\mathbb{C}_S}(O_S, O_S)$  the subsheaf consisting of differential operators. By a  $D_S$  module, we mean a left  $D_S$  module.
- we denote by
  - $\mathrm{PSh}_{\mathcal{D}}(S)$  the abelian category of Zariski presheaves on  $S$  with a structure of left  $D_S$  module, and by  $\mathrm{PSh}_{\mathcal{D},c}(S) \subset \mathrm{PSh}_{\mathcal{D}}(S)$  the full subcategory whose objects are coherent sheaves of left  $D_S$  modules,
  - $\mathrm{PSh}_{\mathcal{D}^{op}}(S)$  the abelian category of Zariski presheaves on  $S$  with a structure of right  $D_S$  module, and by  $\mathrm{PSh}_{\mathcal{D}^{op},c}(S) \subset \mathrm{PSh}_{\mathcal{D}^{op}}(S)$  the full subcategories whose objects are coherent sheaves of right  $D_S$  modules,
- we denote by
  - $C_{\mathcal{D}}(S) = C(\mathrm{PSh}_{\mathcal{D}}(S))$  the category of complexes of Zariski presheaves on  $S$  with a structure of  $D_S$  module,

–  $C_{\mathcal{D}op}(S) = C(\text{PSh}_{\mathcal{D}op}(S))$  the category of complexes of Zariski presheaves on  $S$  with a structure of right  $D_S$  module,

• in the filtered case we have

- $C_{\mathcal{D}(2)fil}(S) \subset C(\text{PSh}_{\mathcal{D}}(S), F, W) := C(\text{PSh}_{D(O_S)}(S), F, W)$  the category of (bi)filtered complexes of algebraic  $D_S$  modules such that the filtration is biregular,  $D_{\mathcal{D}(2)fil}(S) := \text{Ho}_{zar}(C_{\mathcal{D}(2)fil}(S))$  its localization with respect to filtered Zariski local equivalence, and more generally  $D_{\mathcal{D}(2)fil,r}(S) := \text{Ho}_{zar}(C_{\mathcal{D}(2)fil}(S))$  its localization with respect to  $r$ -filtered Zariski local equivalence for  $r = 1, \dots, \infty$ ,
- $C_{\mathcal{D}0fil}(S) \subset C_{\mathcal{D}fil}(S)$  the full subcategory such that the filtration is a filtration by  $D_S$  submodule (which is stronger than Griffithz transversality),  $C_{\mathcal{D}(1,0)fil}(S) \subset C_{\mathcal{D}2fil}(S)$  the full subcategory such that  $W$  is a filtration by  $D_S$  submodules,  $D_{\mathcal{D}(1,0)fil}(S) := \text{Ho}_{zar}(C_{\mathcal{D}(1,0)fil}(S))$  its localization with respect to filtered Zariski local equivalence, and more generally  $D_{\mathcal{D}(1,0)fil,r}(S) := \text{Ho}_{zar}(C_{\mathcal{D}(1,0)fil}(S))$  its localization with respect to  $r$ -filtered Zariski local equivalence for  $r = 1, \dots, \infty$ ,
- $C_{\mathcal{D}op(2)fil}(S) \subset C(\text{PSh}_{\mathcal{D}op}(S), F, W) := C(\text{PSh}_{D(O_S)op}(S), F, W)$  the category of (bi)filtered complexes of algebraic (resp. analytic) right  $D_S$  modules such that the filtration is biregular, as in the left case we consider the subcategories as above.

**Definition 34.** An  $X \in \text{SmVar}(k)$  is said to be  $D$ -affine if the following two condition hold:

- (i) The global section functor  $\Gamma(X, \cdot) : \mathcal{QCoh}_{\mathcal{D}}(X) \rightarrow \text{Mod}(\Gamma(X, D_X))$  is exact.
- (ii) If  $\Gamma(X, M) = 0$  for  $M \in \mathcal{QCoh}_{\mathcal{D}}(X)$ , then  $M = 0$ .

**Proposition 13.** If  $X \in \text{SmVar}(k)$  is  $D$ -affine, then :

- (i) Any  $M \in \mathcal{QCoh}_{\mathcal{D}}(X)$  is generated by its global sections.
- (ii) The functor  $\Gamma(X, \cdot) : \mathcal{QCoh}_{\mathcal{D}}(X) \rightarrow \text{Mod}(\Gamma(X, D_X))$  is an equivalence of category whose inverse is  $L \in \text{Mod}(\Gamma(X, D_X)) \mapsto D_X \otimes_{\Gamma(X, D_X)} L \in \mathcal{QCoh}_{\mathcal{D}}(X)$ .
- (iii) We have  $\Gamma(X, \cdot)(\text{Coh}_{\mathcal{D}}(X)) = \text{Mod}(\Gamma(X, D_X))_f$ , that is the global sections of a coherent  $D_X$  module is a finite module over the differential operators on  $X$ .

*Proof.* Similar to the complex case : see [18]. □

Let  $f : X \rightarrow S$  be a morphism with  $X, S \in \text{SmVar}(k)$ , Then, we recall from [10] section 4.1, the transfers modules

- $(D_{X \rightarrow S}, F^{ord}) := f^{*mod}(D_S, F^{ord}) := f^*(D_S, F^{ord}) \otimes_{f^*O_S} (O_X, F_b)$  which is a left  $D_X$  module and a left and right  $f^*D_S$  module
- $(D_{X \leftarrow S}, F^{ord}) := (K_X, F_b) \otimes_{O_X} (D_{X \rightarrow S}, F^{ord}) \otimes_{f^*O_S} f^*(K_S, F_b)$ . which is a right  $D_X$  module and a left and right  $f^*D_S$  module.

**Proposition 14.** Let  $i : Z \hookrightarrow S$  be a closed embedding with  $Z, S \in \text{SmVar}(k)$ . Then,  $D_{Z \rightarrow S} = i^*D_S/D_S\mathcal{I}_Z$  and it is a locally free (left)  $D_Z$  module. Similarly,  $D_{Z \leftarrow S} = i^*D_S/\mathcal{I}_Z D_S$  and it is a locally free right  $D_Z$  module.

*Proof.* Similar to the complex case : see [18]. □

• Let  $S \in \text{SmVar}(k)$ .

- For  $M \in C_{\mathcal{D}}(S)$ , we have the canonical projective resolution  $q : L_D(M) \rightarrow M$  of complexes of  $D_S$  modules.

– Let  $\tau$  a topology on  $S$ . For  $M \in C_{\mathcal{D}}(S)$ , there exist a unique structure of  $D_S$  module on the flasque presheaves  $E_{\tau}^i(M)$  such that  $E_{\tau}(M) \in C_{\mathcal{D}}(S)$  (i.e. is a complex of  $D_S$  modules) and that the map  $k : M \rightarrow E(M)$  is a morphism of complexes of  $D_S$  modules.

- Let  $S \in \text{SmVar}(k)$ . For  $M \in C_{\mathcal{D}(\text{op})}(S)$ ,  $N \in C(S)$ , we will consider the induced  $D$  module structure (right  $D_S$  module in the case one is a left  $D_S$  module and the other one is a right one) on the presheaf  $M \otimes N := M \otimes_{\mathbb{Z}_S} N$  (see section 2). We get the bifunctor

$$C(S) \times C_{\mathcal{D}}(S) \rightarrow C_{\mathcal{D}}(S), (M, N) \mapsto M \otimes N$$

- Let  $S \in \text{SmVar}(k)$ . For  $M, N \in C_{\mathcal{D}(\text{op})}(S)$ ,  $M \otimes_{O_S} N$  has a canonical structure of  $D_S$  modules (right  $D_S$  module in the case one is a left  $D_S$  module and the other one is a right one) given by (in the left case) for  $S^o \subset S$  an open subset,

$$m \otimes n \in \Gamma(S^o, M \otimes_{O_S} N), \gamma \in \Gamma(S^o, D_S), \gamma.(m \otimes n) := (\gamma.m) \otimes n - m \otimes \gamma.n$$

This gives the bifunctor

$$C_{\mathcal{D}(\text{op})}(S)^2 \rightarrow C_{\mathcal{D}(\text{op})}(S), (M, N) \mapsto M \otimes_{O_S} N$$

More generally, let  $f : X \rightarrow S$  a morphism with  $X, S \in \text{Var}(k)$ . Assume  $S$  smooth. For  $M, N \in C_{f^*\mathcal{D}(\text{op})}(X)$ ,  $M \otimes_{f^*O_S} N$  (see section 2), has a canonical structure of  $f^*D_S$  modules (right  $f^*D_S$  module in the case one is a left  $f^*D_S$  module and the other one is a right one) given by (in the left case) for  $X^o \subset X$  an open subset,

$$m \otimes n \in \Gamma(X^o, M \otimes_{f^*O_S} N), \gamma \in \Gamma(X^o, f^*D_S), \gamma.(m \otimes n) := (\gamma.m) \otimes n - m \otimes \gamma.n$$

This gives the bifunctor

$$C_{f^*\mathcal{D}(\text{op})}(X)^2 \rightarrow C_{f^*\mathcal{D}(\text{op})}(X), (M, N) \mapsto M \otimes_{f^*O_S} N$$

- Let  $S \in \text{SmVar}(k)$ . The internal hom bifunctor

$$\mathcal{H}om(\cdot, \cdot) := \mathcal{H}om_{\mathbb{Z}_S}(\cdot, \cdot) : C(S)^2 \rightarrow C(S)$$

induces a bifunctor

$$\mathcal{H}om(\cdot, \cdot) := \mathcal{H}om_{\mathbb{Z}_S}(\cdot, \cdot) : C(S) \times C_{\mathcal{D}}(S) \rightarrow C_{\mathcal{D}}(S)$$

such that, for  $F \in C(S)$  and  $G \in C_{\mathcal{D}}(S)$ , the  $D_S$  structure on  $\mathcal{H}om^{\bullet}(F, G)$  is given by

$$\gamma \in \Gamma(S^o, D_S) \mapsto (\phi \in \text{Hom}^p(F|_{S^o}^{\bullet}, G|_{S^o}) \mapsto (\gamma \cdot \phi : \alpha \in F^{\bullet}(S^o) \mapsto \gamma \cdot \phi^p(S^o)(\alpha))$$

where  $\phi^p(S^o)(\alpha) \in \Gamma(S^o, G)$ .

- Let  $S \in \text{SmVar}(k)$ . For  $M, N \in C_{\mathcal{D}}(S)$ ,  $\mathcal{H}om_{O_S}(M, N)$ , has a canonical structure of  $D_S$  modules given by for  $S^o \subset S$  an open subset and  $\phi \in \Gamma(S^o, \mathcal{H}om(M, O_S))$ ,  $\gamma \in \Gamma(S^o, D_S)$ ,  $(\gamma.\phi)(m) := \gamma.(\phi(m)) - \phi(\gamma.m)$  This gives the bifunctor

$$\text{Hom}_{O_S}^{\bullet}(-, -) : C_{\mathcal{D}}(S)^2 \rightarrow C_{\mathcal{D}}(S)^{\text{op}}, (M, N) \mapsto \text{Hom}_{O_S}^{\bullet}(M, N)$$

- Let  $S \in \text{SmVar}(k)$ . We have the bifunctors

–  $\text{Hom}_{D_S}^{\bullet}(-, -) : C_{\mathcal{D}}(S)^2 \rightarrow C(S)$ ,  $(M, N) \mapsto \mathcal{H}om_{D_S}^{\bullet}(M, N)$ , and if  $N$  is a bimodule (i.e. has a right  $D_S$  module structure whose opposite coincide with the left one),  $\mathcal{H}om_{D_S}(M, N) \in C_{\mathcal{D}^{\text{op}}}(S)$  given by for  $S^o \subset S$  an open subset and  $\phi \in \Gamma(S^o, \mathcal{H}om(M, N))$ ,  $\gamma \in \Gamma(S^o, D_S)$ ,  $(\phi.\gamma)(m) := (\phi(m)).\gamma$

- $\text{Hom}_{D_S}(-, -) : C_{\mathcal{D}^{op}}(S)^2 \rightarrow C(S)$ ,  $(M, N) \mapsto \mathcal{H}om_{D_S}(M, N)$  and if  $N$  is a bimodule,  $\mathcal{H}om_{D_S}(M, N) \in C_{\mathcal{D}}(S)$

For  $M \in C_{\mathcal{D}}(S)$ , we get in particular the dual with respect  $\mathbb{D}_S$ ,

$$\mathbb{D}_S M := \mathcal{H}om_{D_S}(M, D_S) \in C_{\mathcal{D}}(S) ; \mathbb{D}_S^K M := \mathcal{H}om_{D_S}(M, D_S) \otimes_{O_S} \mathbb{D}_S^O w(K_S)[d_S] \in C_{\mathcal{D}}(S)$$

and we have canonical map  $d : M \rightarrow \mathbb{D}_S^2 M$ . This functor induces in the derived category, for  $M \in D_{\mathcal{D}}(S)$ ,

$$L\mathbb{D}_S M := R\mathcal{H}om_{D_S}(L_D M, D_S) \otimes_{O_S} \mathbb{D}_S^O w(K_S)[d_S] = \mathbb{D}_S^K L_D M \in D_{\mathcal{D}}(S).$$

where  $\mathbb{D}_S^O w(K_S) : \mathbb{D}_S^O w(K_S) \rightarrow \mathbb{D}_S^O K_S = K_S^{-1}$  is the dual of the Kozul resolution of the canonical bundle (proposition 32), and the canonical map  $d : M \rightarrow L\mathbb{D}_S^2 M$ .

- Let  $f : X \rightarrow S$  a morphism with  $X, S \in \text{SmVar}(k)$ . For  $N \in C_{\mathcal{D}, f^* \mathcal{D}}(X)$  and  $M \in C_{\mathcal{D}}(X)$ ,  $N \otimes_{D_X} M$  has the canonical  $f^* D_S$  module structure given by, for  $X^o \subset X$  an open subset,

$$\gamma \in \Gamma(X^o, f^* D_S), m \in \Gamma(X^o, M), n \in \Gamma(X^o, N), \gamma.(n \otimes m) = (\gamma.n) \otimes m.$$

This gives the functor

$$C_{\mathcal{D}, f^* \mathcal{D}}(X) \times C_{\mathcal{D}}(X) \rightarrow C_{f^* \mathcal{D}}(X), (M, N) \mapsto M \otimes_{D_X} N$$

- Let  $f : X \rightarrow S$  be a morphism with  $X, S \in \text{SmVar}(k)$ , Then, for  $M \in C_{\mathcal{D}}(S)$ ,  $O_X \otimes_{f^* O_S} f^* M$  has a canonical  $D_X$  module structure given by given by, for  $X^o \subset X$  an open subset,

$$m \otimes n \in \Gamma(X^o, O_X \otimes_{f^* O_S} f^* M), \gamma \in \Gamma(X^o, D_X), \gamma.(m \otimes n) := (\gamma.m) \otimes n - m \otimes df(\gamma).n.$$

This gives the inverse image functor

$$f^{*mod} : \text{PSh}_{\mathcal{D}}(S) \rightarrow \text{PSh}_{\mathcal{D}}(X), M \mapsto f^{*mod} M := O_X \otimes_{f^* O_S} f^* M = D_{X \rightarrow S} \otimes_{f^* D_S} f^* M$$

which induces in the derived category the functor

$$L f^{*mod} : D_{\mathcal{D}}(S) \rightarrow D_{\mathcal{D}}(X), M \mapsto L f^{*mod} M := O_X \otimes_{f^* O_S}^L f^* M = O_X \otimes_{f^* O_S} f^* L_D M,$$

We will also consider the shifted inverse image functor

$$L f^{*mod}[-] := L f^{*mod}[d_S - d_X] : D_{\mathcal{D}}(S) \rightarrow D_{\mathcal{D}}(X).$$

- Let  $f : X \rightarrow S$  be a morphism with  $X, S \in \text{SmVar}(k)$ . For  $M \in C_{\mathcal{D}}(X)$ ,  $D_{X \leftarrow S} \otimes_{D_X} M$  has the canonical  $f^* D_S$  module structure given above. Then, the direct image functor

$$f_{*mod}^0 : \text{PSh}_{\mathcal{D}}(X) \rightarrow \text{PSh}_{\mathcal{D}}(S), M \mapsto f_{*mod} M := f_*(D_{X \leftarrow S} \otimes_{D_X} M)$$

induces in the derived category the functor

$$\int_f = R f_{*mod} : D_{\mathcal{D}}(X) \rightarrow D_{\mathcal{D}}(S), M \mapsto \int_f M = R f_*(D_{X \leftarrow S} \otimes_{D_X}^L M).$$

The functorialities given above induce :

- Let  $S \in \text{SmVar}(k)$ . For  $(M, F) \in C_{fil}(S)$  and  $(N, F) \in C_{fil}(S)$ , recall that

$$F^p((M, F) \otimes (N, F)) := \text{Im}(\oplus_q F^q M \otimes F^{p-q} N \rightarrow M \otimes N)$$

This gives the functor

$$(\cdot, \cdot) : C_{fil}(S) \times C_{fil}(S) \rightarrow C_{fil}(S), ((M, F), (N, F)) \mapsto (M, F) \otimes (N, F).$$

It induces in the derived categories by taking r-projective resolutions the bifunctors, for  $r = 1, \dots, \infty$ ,

$$(\cdot, \cdot) : D_{fil,r}(S) \times D_{fil,r}(S) \rightarrow D_{fil,r}(S), ((M, F), (N, F)) \mapsto (M, F) \otimes^L (N, F) = L_D(M, F) \otimes (N, F).$$

- Let  $S \in \text{SmVar}(k)$ . For  $(M, F) \in C_{O_S \text{fil}}(S)$  and  $(N, F) \in C_{O_S \text{fil}}(S)$ , recall that

$$F^p((M, F) \otimes_{O_S'} (N, F)) := \text{Im}(\oplus_q F^q M \otimes_{O_S'} F^{p-q} N \rightarrow M \otimes_{O_S'} N)$$

It induces in the derived categories by taking  $r$ -projective resolutions the bifunctors, for  $r = 1, \dots, \infty$ ,

$$(\cdot, \cdot) : D_{\mathcal{D}\text{fil}, r}(S)^2 \rightarrow D_{\mathcal{D}\text{fil}, r}(S), ((M, F), (N, F)) \mapsto (M, F) \otimes_{O_S}^L (N, F).$$

More generally, let  $f : X \rightarrow S$  a morphism with  $X, S \in \text{Var}(k)$ . Assume  $S$  smooth. We have the bifunctors

$$\begin{aligned} (\cdot, \cdot) : D_{f^* \mathcal{D}\text{fil}, r}(X)^2 &\rightarrow D_{f^* \mathcal{D}\text{fil}, r}(X), \\ ((M, F), (N, F)) &\mapsto (M, F) \otimes_{f^* O_S}^L (N, F) = (M, F) \otimes_{f^* O_S} L_{f^* D}(N, F). \end{aligned}$$

- Let  $S \in \text{SmVar}(k)$ . The hom functor induces the bifunctor

$$\text{Hom}(-, -) : C_{\mathcal{D}\text{fil}}(S) \times C_{\text{fil}}(S) \rightarrow C_{\mathcal{D}(1,0)\text{fil}}(S), ((M, W), (N, F)) \mapsto \mathcal{H}om((M, W), (N, F)).$$

- Let  $S \in \text{SmVar}(k)$ . The hom functor induces the bifunctor

$$\text{Hom}_{O_S}(-, -) : C_{\mathcal{D}\text{fil}}(S)^2 \rightarrow C_{\mathcal{D}2\text{fil}}(S), ((M, W), (N, F)) \mapsto \mathcal{H}om_{O_S}((M, W), (N, F)).$$

- Let  $S \in \text{SmVar}(k)$ . The hom functor induces the bifunctors

$$\begin{aligned} - \text{Hom}_{D_S}(-, -) : C_{\mathcal{D}\text{fil}}(S)^2 &\rightarrow C_{2\text{fil}}(S), ((M, W), (N, F)) \mapsto \mathcal{H}om_{D_S}((M, W), (N, F)), \\ - \text{Hom}_{D_S}(-, -) : C_{\mathcal{D}^{op}\text{fil}}(S)^2 &\rightarrow C_{2\text{fil}}(S), ((M, W), (N, F)) \mapsto \mathcal{H}om_{D_S}((M, W), (N, F)). \end{aligned}$$

We get the filtered dual

$$\mathbb{D}_S^K(\cdot) : C_{\mathcal{D}(2)\text{fil}}(S) \rightarrow C_{\mathcal{D}(2)\text{fil}}(S)^{op}, (M, F) \mapsto \mathbb{D}_S^K(M, F) := \mathcal{H}om_{D_S}((M, F), D_S) \otimes_{O_S} \mathbb{D}_S^O w(K_S)[d_S]$$

together with the canonical map  $d(M, F) : (M, F) \rightarrow \mathbb{D}_S^{2,K}(M, F)$ . Of course  $\mathbb{D}_S^K(\cdot)(C_{\mathcal{D}(1,0)\text{fil}}(S)) \subset C_{\mathcal{D}(1,0)\text{fil}}(S)$ . It induces in the derived categories  $D_{\mathcal{D}\text{fil}, r}(S)$ , for  $r = 1, \dots, \infty$ , the functors

$$L\mathbb{D}_S(\cdot) : D_{\mathcal{D}(2)\text{fil}, r}(S) \rightarrow D_{\mathcal{D}(2)\text{fil}, r}(S)^{op}, (M, F) \mapsto L\mathbb{D}_S(M, F) := \mathbb{D}_S^K L_D(M, F).$$

together with the canonical map  $d(M, F) : L_D(M, F) \rightarrow \mathbb{D}_S^{2,K} L_D(M, F)$ .

- Let  $f : X \rightarrow S$  be a morphism with  $X, S \in \text{SmVar}(k)$ . Then, the inverse image functor

$$\begin{aligned} f^{*mod} : C_{\mathcal{D}(2)\text{fil}}(S) &\rightarrow C_{\mathcal{D}(2)\text{fil}}(X), \\ (M, F) &\mapsto f^{*mod}(M, F) := (O_X, F_b) \otimes_{f^* O_S} f^*(M, F) = (D_{X \rightarrow S}, F^{ord}) \otimes_{f^* D_S} f^*(M, F), \end{aligned}$$

induces in the derived categories the functors, for  $r = 1, \dots, \infty$  (resp.  $r \in (1, \dots, \infty)^2$ ),

$$\begin{aligned} Lf^{*mod} : D_{\mathcal{D}(2)\text{fil}, r}(S) &\rightarrow D_{\mathcal{D}(2)\text{fil}, r}(X), \\ (M, F) &\mapsto Lf^{*mod} M := (O_X, F_b) \otimes_{f^* O_S}^L f^*(M, F) = (O_X, F_b) \otimes_{f^* O_S} f^* L_D(M, F). \end{aligned}$$

Of course  $f^{*mod}(C_{\mathcal{D}(1,0)\text{fil}}(S)) \subset C_{\mathcal{D}(1,0)\text{fil}}(X)$ . Note that

- If the  $M$  is a complex of locally free  $O_S$  modules, then  $Lf^{*mod}(M, F) = f^{*mod}(M, F)$  in  $D_{\mathcal{D}(2)\text{fil}, \infty}(S)$ .



- If the  $\mathrm{Gr}_F^p M$  are complexes of locally free  $O_S$  modules, then  $Lf^{*mod}(M, F) = f^{*mod}(M, F)$  in  $D_{\mathcal{D}(2)fil}(S)$ .

We will consider also the shifted inverse image functors

$$Lf^{*mod[-]} := Lf^{*mod}[d_S - d_X] : D_{\mathcal{D}(2)fil,r}(S) \rightarrow D_{\mathcal{D}(2)fil,r}(X).$$

- Let  $f : X \rightarrow S$  be a morphism with  $X, S \in \mathrm{SmVar}(k)$ . Then, the direct image functor  $f_{*mod}^{00} : (\mathrm{PSh}_{\mathcal{D}}(X), F) \rightarrow (\mathrm{PSh}_{\mathcal{D}}(S), F)$ ,  $(M, F) \mapsto f_{*mod}(M, F) := f_*((D_{S \leftarrow X}, F^{ord}) \otimes_{D_X}(M, F))$  induces in the derived categories by taking  $r$ -injective resolutions the functors, for  $r = 1, \dots, \infty$ ,

$$\int_f = Rf_{*mod} : D_{\mathcal{D}(2)fil,r}(X) \rightarrow D_{\mathcal{D}(2)fil,r}(S), (M, F) \mapsto \int_f(M, F) = Rf_*((D_{S \leftarrow X}, F^{ord}) \otimes_{D_X}^L(M, F)).$$

Let  $f_1 : X \rightarrow Y$  and  $f_2 : Y \rightarrow S$  two morphism with  $X, Y, S \in \mathrm{SmVar}(\mathbb{C})$  or with  $X, Y, S \in \mathrm{AnSm}(\mathbb{C})$ . We have, for  $(M, F) \in C_{\mathcal{D}fil}(X)$ , the canonical transformation map in  $D_{\mathcal{D}(2)fil,r}(S)$

$$\begin{aligned} & T\left(\int_{f_2} \circ \int_{f_1}, \int_{f_2 \circ f_1}\right)(M, F) : \\ & \int_{f_2} \int_{f_1} (M, F) := Rf_{2*}((D_{Y \leftarrow S}, F^{ord}) \otimes_{D_Y}^L Rf_{1*}((D_{X \leftarrow Y}, F^{ord}) \otimes_{D_X}^L(M, F))) \\ & \xrightarrow{T(f_1, \otimes)(-, -)} Rf_{2*}Rf_{1*}(f_1^*(D_{Y \leftarrow S}, F^{ord}) \otimes_{D_Y}^L((D_{X \leftarrow Y}, F^{ord}) \otimes_{D_X}^L(M, F))) \\ & \xrightarrow{\sim} Rf_{2*}Rf_{1*}((f_1^*(D_{Y \leftarrow S}, F^{ord}) \otimes_{D_Y}^L(D_{X \leftarrow Y}, F^{ord})) \otimes_{D_X}^L(M, F)) \\ & \xrightarrow{\sim} Rf_{2*}Rf_{1*}((D_{X \leftarrow S}, F^{ord}) \otimes_{D_X}^L(M, F)) := \int_{f_2 \circ f_1}(M, F) \end{aligned}$$

- Let  $f : X \rightarrow S$  be a morphism with  $X, S \in \mathrm{SmVar}(k)$ . Then the functor

$$f^{\hat{*}mod} : C_{\mathcal{D}2fil}(S) \rightarrow C_{\mathcal{D}2fil}(X), (M, F) \mapsto f^{\hat{*}mod}(M, F) := \mathbb{D}_X^K L_D f^{*mod} L_D \mathbb{D}_S^K(M, F)$$

induces in the derived categories the exceptional inverse image functors, for  $r = 1, \dots, \infty$  (resp.  $r \in (1, \dots, \infty)^2$ ),

$$\begin{aligned} & Lf^{\hat{*}mod} : D_{\mathcal{D}(2)fil,r}(S) \rightarrow D_{\mathcal{D}(2)fil,r}(X), \\ & (M, F) \mapsto Lf^{\hat{*}mod}(M, F) := L\mathbb{D}_X Lf^{*mod} L\mathbb{D}_S(M, F) := f^{\hat{*}mod} L_D(M, F). \end{aligned}$$

Of course  $f^{\hat{*}mod}(C_{\mathcal{D}(1,0)fil}(S)) \subset C_{\mathcal{D}(1,0)fil}(X)$ . We will also consider the shifted exceptional inverse image functors

$$Lf^{\hat{*}mod[-]} := Lf^{\hat{*}mod}[d_S - d_X] : D_{\mathcal{D}(2)fil,r}(S) \rightarrow D_{\mathcal{D}(2)fil,r}(X).$$

- Let  $S_1, S_2 \in \mathrm{SmVar}(k)$ . Consider  $p : S_1 \times S_2 \rightarrow S_1$  the projection. Since  $p$  is a projection, we have a canonical embedding  $p^*D_{S_1} \hookrightarrow D_{S_1 \times S_2}$ . For  $(M, F) \in C_{\mathcal{D}(2)fil}(S_1 \times S_2)$ ,  $(M, F)$  has a canonical  $p^*D_{S_1}$  module structure. Moreover, with this structure, for  $(M_1, F) \in C_{\mathcal{D}(2)fil}(S_1)$

$$\mathrm{ad}(p^{*mod}, p)(M_1, F) : (M_1, F) \rightarrow p_* p^{*mod}(M_1, F)$$

is a map of complexes of  $D_{S_1}$  modules, and for  $(M_{12}, F) \in C_{\mathcal{D}(2)fil}(S_1 \times S_2)$

$$\mathrm{ad}(p^{*mod}, p)(M_{12}, F) : p^{*mod} p_*(M_{12}, F) \rightarrow (M_{12}, F)$$

is a map of complexes of  $D_{S_1 \times S_2}$  modules.

**Proposition 15.** (i) Let  $f_1 : X \rightarrow Y$  and  $f_2 : Y \rightarrow S$  two morphism with  $X, Y, S \in \text{SmVar}(k)$ .

- Let  $(M, F) \in C_{\mathcal{D}(2)fil,r}(S)$ . Then  $(f_2 \circ f_1)^{*mod}(M, F) = f_1^{*mod} f_2^{*mod}(M, F)$ .
- Let  $(M, F) \in D_{\mathcal{D}(2)fil,r}(S)$ . Then  $L(f_2 \circ f_1)^{*mod}(M, F) = Lf_1^{*mod}(Lf_2^{*mod}(M, F))$ .

(ii) Let  $f_1 : X \rightarrow Y$  and  $f_2 : Y \rightarrow S$  two morphism with  $X, Y, S \in \text{SmVar}(k)$ . Let  $M \in D_{\mathcal{D}}(X)$ . Then,

$$T\left(\int_{f_2} \circ \int_{f_1}, \int_{f_2 \circ f_1}\right)(M) : \int_{f_2} \int_{f_1} (M) \xrightarrow{\sim} \int_{f_2 \circ f_1} (M)$$

is an isomorphism in  $D_{\mathcal{D}}(S)$  (i.e. if we forget filtration).

(iii) Let  $i_0 : Z_2 \hookrightarrow Z_1$  and  $i_1 : Z_1 \hookrightarrow S$  two closed embedding, with  $Z_2, Z_1, S \in \text{SmVar}(\mathbb{C})$ . Let  $(M, F) \in C_{\mathcal{D}(2)fil}(Z_2)$ . Then,  $(i_1 \circ i_0)^{*mod}(M, F) = i_1^{*mod}(i_0^{*mod}(M, F))$  in  $C_{\mathcal{D}(2)fil}(S)$ .

*Proof.* Similar to the complex case : see [10]. □

**Proposition 16.** For  $X \in \text{SmVar}(k)$ , we have for  $(M, F), (N, F) \in C_{O_X fil}(X)$  or  $(M, F), (N, F) \in C_{\mathcal{D}fil}(X)$ , Denote by  $\Delta_X : X \hookrightarrow X \times X$  the diagonal closed embedding and  $p_1 : X \times X \rightarrow X$ ,  $p_2 : X \times X \rightarrow X$  the projections. We have

$$(M, F) \otimes_{O_X} (N, F) = \Delta_X^{*mod}(p_1^{*mod}(M, F) \otimes_{O_{X \times X}} p_2^{*mod}(N, F))$$

*Proof.* Similar to the complex case : see [18]. □

Let  $i : Z \hookrightarrow S$  a closed embedding, with  $Z, S \in \text{SmVar}(k)$ . We have the functor

$$i^\sharp : C_{\mathcal{D}fil}(S) \rightarrow C_{\mathcal{D}fil}(Z), (M, F) \mapsto i^\sharp(M, F) := \mathcal{H}om_{i^*D_S}((D_{S \leftarrow Z}, F^{ord}), i^*(M, F))$$

where the (left)  $D_Z$  module structure on  $i^\sharp M$  comes from the right module structure on  $D_{S \leftarrow Z}$ , resp.  $O_Z$ . We denote by

- for  $(M, F) \in C_{\mathcal{D}fil}(S)$ , the canonical map in  $C_{\mathcal{D}fil}(S)$

$$\begin{aligned} \text{ad}(i_{*mod}, i^\sharp)(M, F) : i_{*mod} i^\sharp(M, F) &:= i_* (\mathcal{H}om_{i^*D_S}((D_{S \leftarrow Z}, F^{ord}), i^*(M, F)) \otimes_{D_Z} (D_{S \leftarrow Z}, F^{ord})) \\ &\rightarrow (M, F), \phi \otimes P \mapsto \phi(P) \end{aligned}$$

- for  $(N, F) \in C_{\mathcal{D}fil}(Z)$ , the canonical map in  $C_{\mathcal{D}fil}(Z)$

$$\begin{aligned} \text{ad}(i_{*mod}, i^\sharp)(N, F) : (N, F) \rightarrow i^\sharp i_{*mod}(N, F) &:= \mathcal{H}om_{i^*D_S}(D_{S \leftarrow Z}, i^* i_* ((N, F) \otimes_{D_Z} (D_{S \leftarrow Z}, F^{ord}))) \\ n &\mapsto (P \mapsto n \otimes P) \end{aligned}$$

The functor  $i^\sharp$  induces in the derived category the functor :

$$\begin{aligned} Ri^\sharp : D_{\mathcal{D}(2)fil,r}(S) \rightarrow D_{\mathcal{D}(2)fil,r}(Z), (M, F) &\mapsto \\ Ri^\sharp(M, F) &:= R\mathcal{H}om_{i^*D_S}((D_{Z \leftarrow S}, F^{ord}), i^*(M, F)) = \mathcal{H}om_{i^*D_S}((D_{Z \leftarrow S}, F^{ord}), E(i^*(M, F))). \end{aligned}$$

**Proposition 17.** Let  $i : Z \hookrightarrow S$  a closed embedding, with  $Z, S \in \text{SmVar}(k)$ . The functor  $i_{*mod} : C_{\mathcal{D}}(Z) \rightarrow C_{\mathcal{D}}(S)$  admit a right adjoint which is the functor  $i^\sharp : C_{\mathcal{D}}(S) \rightarrow C_{\mathcal{D}}(Z)$  and

$$\text{ad}(i_{*mod}, i^\sharp)(N) : N \rightarrow i^\sharp i_{*mod} N \quad \text{and} \quad \text{ad}(i_{*mod}, i^\sharp)(M) : i_{*mod} i^\sharp M \rightarrow M$$

are the adjonction maps.

*Proof.* Similar to the complex case : see [18]. □

One of the main results in D modules is Kashiwara equivalence :

**Theorem 20.** Let  $i : Z \hookrightarrow S$  a closed embedding with  $Z, S \in \text{SmVar}(k)$ .

(i) The functor  $i_{*mod} : \mathcal{QCoh}_{\mathcal{D}}(Z) \rightarrow \mathcal{QCoh}_{\mathcal{D}}(S)$  is an equivalence of category whose inverse is  $i^{\sharp} := a_{\tau}i^{\sharp} : \mathcal{QCoh}_{\mathcal{D}}(S) \rightarrow \mathcal{QCoh}_{\mathcal{D}}(Z)$ . That is, for  $M \in \mathcal{QCoh}_{\mathcal{D}}(S)$  and  $N \in \mathcal{QCoh}_{\mathcal{D}}(Z)$ , the adjunction maps

$$\text{ad}(i_{*mod}, i^{\sharp})(M) : i_{*mod}i^{\sharp}M \xrightarrow{\sim} M, \quad \text{ad}(i_{*mod}, i^{\sharp})(N) : i^{\sharp}i_{*mod}N \xrightarrow{\sim} N$$

are isomorphisms.

(ii) The functor  $\int_i = i_{*mod} : D_{\mathcal{D}}(Z) \rightarrow D_{\mathcal{D}}(S)$  is an equivalence of category whose inverse is  $Ri^{\sharp} : D_{\mathcal{D}}(S) \rightarrow D_{\mathcal{D}}(Z)$ . That is, for  $M \in D_{\mathcal{D}}(S)$  and  $N \in D_{\mathcal{D}}(Z)$ , the adjunction maps

$$\text{ad}\left(\int_i, Ri^{\sharp}\right)(M) : \int_i Ri^{\sharp}M \xrightarrow{\sim} M, \quad \text{ad}\left(\int_i, Ri^{\sharp}\right)(N) : Ri^{\sharp}\int_i N \xrightarrow{\sim} N$$

are isomorphisms.

*Proof.* Similar to the complex case : see [18] : (ii) follows from (i).  $\square$

**Lemma 2.** Let  $i : Z \hookrightarrow S$  a closed embedding with  $Z, S \in \text{Var}(k)$ . Denote by  $j : U := S \setminus Z \hookrightarrow Z$  the open complementary embedding. Then, if  $i$  is a locally complete intersection embedding (e.g. if  $Z, S$  are smooth), we have for  $M \in C_{O_U}(U)$  quasi-coherent,  $Li^{*mod}Rj_*M = 0$ .

*Proof.* Similar to the complex case : see [10].  $\square$

We deduce from theorem 20(i) and lemma 2 the localization for  $D$ -modules for a closed embedding of smooth algebraic varieties:

**Theorem 21.** Let  $i : Z \hookrightarrow S$  a closed embedding with  $Z, S \in \text{SmVar}(k)$ . Denote by  $c = \text{codim}(Z, S)$ . Then, for  $M \in C_{\mathcal{D}}(S)$ , we have by Kashiwara equivalence the following map in  $C_{\mathcal{D}}(S)$  :

$$\begin{aligned} & \mathcal{K}_{Z/S}(M) : \Gamma_Z E(M) \xrightarrow{\text{ad}(i_{*mod}, i^{\sharp})(-)^{-1}} i_{*mod}i^{\sharp}\Gamma_Z E(M) \\ & \xrightarrow{\gamma_Z(-)} i_{*mod}i^{\sharp}(E(M)) \xrightarrow{\mathcal{H}om(q_{\mathcal{K}}, E(i^*M)) \circ \mathcal{H}om(O_Z, T(i, E)(M))} i_{*mod}K_{i^*O_S}^{\vee}(O_Z) \otimes_{i^*O_S} M \end{aligned}$$

which is an equivalence Zariski local. It gives the isomorphism in  $D_{\mathcal{D}}(S)$

$$\mathcal{K}_{Z/S}(M) : R\Gamma_Z M \rightarrow i_{*mod}K_{i^*O_S}^{\vee}(O_Z) = i_{*mod}Li^{*mod}M[c]$$

*Proof.* Follows from theorem 20 and lemma 2.  $\square$

Let  $k$  a field of characteristic zero. Let  $S \in \text{SmVar}(k)$ . Let  $M \in \text{PSh}_{\mathcal{D}, c}(S)$  a coherent  $D_S$  module so that it admits a good filtration  $(M, F)$  for the filtered ring  $(D_S, F^{ord})$ . We then have the characteristic variety

$$Ch(M) := \text{supp}(cc(\text{Gr}^F M)) \subset T_S$$

which is the support of the characteristic cycle  $cc(\text{Gr}^F M) \in \mathcal{Z}(T_S)$  of the coherent sheaf  $\text{Gr}^F M \in \text{Shv}_c(T_S)$ . Since for two good filtration  $(M, F)$  and  $(M, F')$  there exist  $r, s \in \mathbb{Z}$  satisfying  $F'^i M \subset F^{i-r} M \subset F'^{i-s} M$  for all  $i$ ,  $cc(\text{Gr}^F M) \in \mathcal{Z}(T_S)$  and  $Ch(M) \in T_S$  does NOT depend on the choice of a good filtration  $F$ .

For  $k \subset k'$  a subfield of characteristic zero and  $S \in \text{SmVar}(k)$ , we have by definition

$$cc(\text{Gr}^F(\pi_{k/k'}(S)^{*mod}M)) = cc(\text{Gr}^F M) \otimes_k k' \in \mathcal{Z}(T_{S_{k'}})$$

and thus

$$Ch(\pi_{k/k'}(S)^{*mod}M) = Ch(M)_{k'} \subset T_{S_{k'}}$$

with  $S_{k'} := S \otimes_k k'$ , since if  $(M, F)$  is a good filtration then  $(\pi_{k/k'}(S)^{*mod}M, \pi_{k/k'}(S)^{*mod}F)$  is a good filtration,  $\pi_{k/k'}(S) : S_{k'} := S \otimes_k k' \rightarrow S$  being the projection (see section 2).

We have the following proposition :

**Proposition 18.** *Let  $k$  a field of characteristic zero.*

- (i) *Let  $i : Z \hookrightarrow S$  a closed embedding with  $S, Z \in \text{SmVar}(k)$ . Let  $M \in \text{PSh}_{\mathcal{D},c}(Z)$  a coherent  $D_Z$  module so that it admits a good filtration  $(M, F)$  for the filtered ring  $(D_S, F^{\text{ord}})$ . Then  $i_{*mod}(M, F)$  is a good filtration for the filtered ring  $(D_Z, F^{\text{ord}})$  and  $Ch(i_{*mod}M) = di(Ch(M)) \subset T_S$  where  $d_i : T_Z \hookrightarrow T_{S|Z} := p_S^{-1}(Z) \hookrightarrow T_S$  is the closed embedding where the first embedding is given by the differential of  $i : i^*O_S \rightarrow O_Z$ .*
- (ii) *Let  $S \in \text{SmVar}(k)$ . Let  $M \in \text{PSh}_{\mathcal{D},c}(S)$  a coherent  $D_S$  module so that it admits a good filtration  $(M, F)$  for the filtered ring  $(D_S, F^{\text{ord}})$ . Let  $Ch(M) = \cup_l C_M^l$  with  $C_M^l$  the irreducible components of  $Ch(M)$ . Then  $\dim(C_M^l) \leq \dim(S)$  for all  $l$ .*

*Proof.* (i): Similar to the proof of [18].

(ii) Let  $S = \cup_i S_i$  an open affine cover. Since by definition  $Ch(j_i^*M) = Ch(M) \cap p_S^{-1}(S_i)$ , it is enough to prove the result for a smooth affine variety. So, let  $S' \in \text{SmVar}(k)$  affine and  $i : S' \hookrightarrow \mathbb{A}_k^n$  a closed embedding. By (i)  $Ch(i_{*mod}M) = di(Ch(M))$  so the result follows from [14].  $\square$

**Definition 35.** *Let  $k$  a field of characteristic zero.*

- (i) *Let  $S \in \text{SmVar}(k)$  connected (hence irreducible since  $S$  is smooth). A coherent  $D_S$  module  $M \in \text{PSh}_{\mathcal{D},c}(S)$  is called holonomic if all the irreducible components  $C_M^l$  of  $\text{supp}(Ch(M)) = \cup_l C_M^l \in T_S$  are of dimension  $\dim(C_M^l) = \dim(S)$ .*
- (ii) *Let  $S \in \text{SmVar}(k)$ . Then  $S = \sqcup_i S_i$  with  $S_i \in \text{SmVar}(k)$  connected. A coherent  $D_S$  module  $M \in \text{PSh}_{\mathcal{D},c}(S)$  is called holonomic if  $j_i^*M \in \text{PSh}_{\mathcal{D},c}(S_i)$  is holonomic for all  $i$ .*

*Let  $k \subset k'$  a subfield. Consider the projection  $\pi := \pi_{k/k'}(S) : S_{k'} \rightarrow S$ . By definition  $M \in \text{PSh}_{\mathcal{D},c}(S)$  is holonomic if and only if  $\pi^{*mod}M \in \text{PSh}_{\mathcal{D},c}(S_{k'})$  is holonomic since  $Ch(M)_{k'} = Ch(\pi^{*mod}M) \subset T_{S_{k'}}$ . In particular considering an embedding  $\sigma : k \subset \mathbb{C}$ ,  $M \in \text{PSh}_{\mathcal{D},c}(S)$  is holonomic if and only if  $\pi_{k/\mathbb{C}}(S)^{*mod}M \in \text{PSh}_{\mathcal{D},c}(S_{\mathbb{C}})$  is holonomic.*

**Proposition 19.** *Let  $S \in \text{SmVar}(k)$ .*

- (i) *Consider an exact sequence in  $\text{PSh}_{\mathcal{D},c}(S)$*

$$0 \rightarrow M_1 \rightarrow M_2 \rightarrow M_3 \rightarrow 0.$$

*Then  $M_2 \in \text{PSh}_{\mathcal{D},h}(S)$  if and only if  $M_1, M_3 \in \text{PSh}_{\mathcal{D},h}(S)$ .*

- (ii) *An holonomic module  $M \in \text{PSh}_{\mathcal{D},h}(S)$  has finite length.*

*Proof.* Similar to the complex case : See [14] or [18].  $\square$

Let  $S \in \text{SmVar}(k)$ . A locally free  $O_S$  module with a structure of  $D_S$  module is called an integrable connexion. We denote by  $\text{Vect}_{\mathcal{D}}(S) \subset \text{PSh}_{\mathcal{D},c}(S)$  the full subcategory whose set of objects consists of integrable connexions. By definition, an integrable connexion  $M \in \text{Vect}_{\mathcal{D}}(S)$  is holonomic since  $Ch(M) = i_0(S) \subset T_S$  where  $i_0 : S \hookrightarrow T_S$ ,  $i_0(s) = (s, 0)$  is the zero section embedding. Hence  $\text{Vect}_{\mathcal{D}}(S) \subset \text{PSh}_{\mathcal{D},h}(S)$ .

**Proposition 20.** *Let  $k$  a field of characteristic zero. Let  $S \in \text{SmVar}(k)$ .*

- (i) *A coherent  $D_S$  module  $M \in \text{PSh}_{\mathcal{D},c}(S)$  which is a coherent  $O_S$  module is a locally free  $O_S$  module.*
- (ii) *An holonomic  $D_S$  module  $M \in \text{PSh}_{\mathcal{D},h}(S)$  is generically an integrable connexion, that is there exists an open subset  $j : S^\circ \subset S$  such that  $M|_{S^\circ} := j^*M \in \text{Vect}_{\mathcal{D}}(S^\circ)$ .*

*Proof.* (i): Similar to the complex case : see [18].

(ii): Similar to the complex case : follows from (i) since there exist an open subset  $S^\circ \subset S$  such that  $ch(M) \cap p^{-1}(S^\circ) = T_{S^\circ}S^\circ$  where  $T_S S \subset T_S$  is the zero section.  $\square$

Let  $k$  a field of characteristic zero. Let  $S \in \text{SmVar}(k)$

- we consider

- the full subcategories

$$C_{\mathcal{D},h}(S) \subset C_{\mathcal{D},c}(S) \subset C_{\mathcal{D}}(S) \text{ and } D_{\mathcal{D},h}(S) \subset D_{\mathcal{D},c}(S) \subset D_{\mathcal{D}}(S)$$

consisting of complexes of presheaves  $M$  such that  $a_{\tau}H^n(M)$  are coherent, resp. holonomic, sheaves of  $D_S$  modules,  $a_{\tau}$  being the sheafification functor for the Zariski topology,

- the full subcategories

$$C_{\mathcal{D}^{op},h}(S) \subset C_{\mathcal{D}^{op},c}(S) \subset C_{\mathcal{D}^{op}}(S) \text{ and } D_{\mathcal{D}^{op},h}(S) \subset D_{\mathcal{D}^{op},c}(S) \subset D_{\mathcal{D}^{op}}(S)$$

the full subcategories consisting of complexes of presheaves  $M$  such that  $a_{\tau}H^n(M)$  are coherent, resp. holonomic, sheaves of right  $D_S$  modules,

- in the filtered case we have

- the full subcategories

$$C_{\mathcal{D}(2)fil,h}(S) \subset C_{\mathcal{D}(2)fil,c}(S) \subset C_{\mathcal{D}(2)fil}(S), \text{ and } D_{\mathcal{D}(2)fil,h}(S) \subset D_{\mathcal{D}(2)fil,c}(S) \subset D_{\mathcal{D}(2)fil}(S),$$

consisting of filtered complexes of presheaves  $(M, F)$  such that  $a_{\tau}H^n(M, F)$  are filtered coherent, resp. filtered holonomic, sheaves of  $D_S$  modules, that is  $a_{\tau}H^n(M)$  are coherent, resp. holonomic sheaves of  $D_S$  modules and  $F$  induces a good filtration on  $a_{\tau}H^n(M)$  (in particular  $F^p a_{\tau}H^n(M) \subset a_{\tau}H^n(M)$  are coherent sub  $O_S$  modules), the full subcategories

$$C_{\mathcal{D}(1,0)fil,h}(S) = C_{\mathcal{D}2fil,h}(S) \cap C_{\mathcal{D}(1,0)fil}(S) \subset C_{\mathcal{D}2fil,h}(S), \text{ and} \\ D_{\mathcal{D}(1,0)fil,h}(S) = D_{\mathcal{D}2fil,h}(S) \cap D_{\mathcal{D}(1,0)fil}(S) \subset D_{\mathcal{D}2fil,h}(S),$$

consisting of filtered complexes of presheaves  $(M, F, W)$  such that  $a_{\tau}H^n(M, F)$  are filtered holonomic sheaves of  $D_S$  modules and such that  $W^p M \subset M$  are  $D_S$  submodules (recall that the  $O_S$  submodules  $F^p M \subset M$  are NOT  $D_S$  submodules but satisfy by definition  $md : F^r D_S \otimes F^p M \subset F^{p+r} M$ ),

- and similarly the full subcategories

$$C_{\mathcal{D}^{op}(2)fil,h}(S) \subset C_{\mathcal{D}^{op}(2)fil,c}(S) \subset C_{\mathcal{D}^{op}(2)fil}(S),$$

the full subcategories consisting of filtered complexes of presheaves  $(M, F)$  such that  $a_{\tau}H^n(M, F)$  are filtered coherent, resp. filtered holonomic, sheaves of right  $D_S$  modules.

Let  $S \in \text{Var}(k)$ . Let  $Z \subset S$  a closed subset. Denote by  $j : S \setminus Z \hookrightarrow S$  the open embedding. We denote by  $C_{\mathcal{D}fil,h,Z}(S) \subset C_{\mathcal{D}fil,h}(S)$  the full subcategory consisting of  $(M, F) \in C_{\mathcal{D}fil,h}(S)$  such that  $j^* \text{Gr}_F^p M \in C_{O_S}(S)$  is acyclic for all  $p \in \mathbb{Z}$ .

**Proposition 21.** *Let  $f : X \rightarrow S$  a morphism with  $X, S \in \text{SmVar}(k)$ . Then,*

- (i) *For  $(M, F) \in C_{\mathcal{D}(2)fil,h}(S)$ , we have  $L\mathbb{D}_S(M, F) \in D_{\mathcal{D}(2)fil,h}(S)$ .*
- (ii) *For  $(M, F) \in C_{\mathcal{D}(2)fil,h}(S)$ , we have  $Lf^{*mod}(M, F) \in D_{\mathcal{D}(2)fil,h}(X)$  and  $Lf^{\hat{*}mod}(M, F) \in D_{\mathcal{D}(2)fil,h}(X)$ .*
- (iii) *For  $M \in C_{\mathcal{D},h}(X)$ , we have  $\int_f M \in D_{\mathcal{D},h}(S)$  and  $\int_{f!} M := L\mathbb{D}_S \int_f L\mathbb{D}_X \in D_{\mathcal{D},h}(S)$ .*
- (iv) *If  $f$  is proper, for  $(M, F) \in C_{\mathcal{D}(2)fil,h}(X)$ , we have  $\int_f(M, F) \in D_{\mathcal{D}(2)fil,h}(S)$ .*
- (v) *For  $(M, F), (N, F) \in C_{\mathcal{D}(2)fil,h}(S)$ ,  $(M, F) \otimes_{O_S}^L (N, F) \in D_{\mathcal{D}(2)fil,h}(S)$*

*Proof.* Similar to the proof of the complex case in [18] or simply follows from the complex case since  $M \in \text{PSh}_{\mathcal{D},c}(S)$  is holonomic if and only if  $\pi_{k/\mathbb{C}}(S)^{*mod}M \in \text{PSh}_{\mathcal{D},c}(S_{\mathbb{C}})$  is holonomic. Note that (v) follows from (ii) by proposition 16.  $\square$

**Proposition 22.** *Let  $S \in \text{SmVar}(k)$ . For  $M \in C_{\mathcal{D},c}(S)$ , the canonical map  $d(M) : M \rightarrow \mathbb{D}_S^2 L_D M$  is an equivalence Zariski local*

*Proof.* Standard.  $\square$

**Proposition 23.** *Let  $f_1 : X \rightarrow Y$  and  $f_2 : Y \rightarrow S$  two morphism with  $X, Y, S \in \text{SmVar}(k)$ . Let  $M \in C_{\mathcal{D},h}(S)$ . Then, we have  $L(f_2 \circ f_1)^{*mod}M = Lf_1^{\hat{*}mod}(Lf_2^{\hat{*}mod}M)$  in  $D_{\mathcal{D},h}(X)$ .*

*Proof.* Follows from proposition 15 (i), proposition 21 and proposition 22, or directly from the complex case.  $\square$

**Theorem 22.** *Let  $k$  a field of characteristic zero. Let  $S \in \text{SmVar}(k)$ .*

(i) *Let  $M \in D_{\mathcal{D},c}(S)$ . Then  $M \in D_{\mathcal{D},h}(S)$  if and only if there exist a finite sequence*

$$S = S_0 \supset S_1 \supset \cdots \supset S_r \supset S_{r+1} = \emptyset$$

*such that for all  $l$ ,  $S_l \setminus S_{l+1}$  is smooth and  $H^k(i_l^{\hat{*}mod}M) \in \text{Vect}_{\mathcal{D}}(S_l \setminus S_{l+1})$  are integrable connexion for all  $k \in \mathbb{Z}$ ,  $i_l : S_l \setminus S_{l+1} \hookrightarrow S$  being the locally closed embedding.*

(ii) *Let  $M \in \text{PSh}_{\mathcal{D},c}(S)$ . Then  $M \in \text{PSh}_{\mathcal{D},h}(S)$  if and only if there exist a finite sequence*

$$S = S_0 \supset S_1 \supset \cdots \supset S_r \supset S_{r+1} = \emptyset$$

*such that for all  $l$ ,  $S_l \setminus S_{l+1}$  is smooth and  $i_l^{\hat{*}mod}M \in \text{Vect}_{\mathcal{D}}(S_l \setminus S_{l+1})$  is an integrable connexion,  $i_l : S_l \setminus S_{l+1} \hookrightarrow S$  being the locally closed embedding.*

*Proof.* (i): Similar to the complex case : follows from proposition 20, theorem 21 and proposition 21.

(ii):It is a particular case of (i).  $\square$

Let  $k$  a field of characteristic zero.

- Let  $C \in \text{SmVar}(k)$  connected (hence irreducible). An algebraic meromorphism connexion  $M = (M, \nabla) \in \text{Mod}(K_C, D(O_{C,s}))$  at  $s \in C$  is a  $K_C$  module  $M$  endowed with a  $k$  linear map  $\nabla : M \rightarrow \Omega_{C,s}^1 \otimes_{O_{C,s}} M$  such that  $\nabla(fm) = d_f \otimes m + f\nabla(m)$  for  $f \in K_C$  where  $K_C := \text{Frac}(O_{C,s})$  is the field of fraction of  $C$ ,
- Let  $S \in \text{SmVar}(k)$ . An algebraic meromorphism connexion  $M = (M, \nabla) \in \text{PSh}_{O_S(*D), D_S}(S)$  along a (Cartier divisor)  $D \subset S$  is a coherent  $O_S(*D)$  module which has a structure of  $D_S$  module. In particular,  $M|_{S \setminus D} \in \text{Vect}_{\mathcal{D}}(S \setminus D)$  is an integrable connexion since it is a  $D_{S \setminus D}$  module which is a coherent  $O_{S \setminus D}$  module.

**Lemma 3.** *Let  $S \in \text{SmVar}(k)$ . Let  $D \subset S$  a (Cartier) divisor. Denote by  $j : S^\circ := S \setminus D \hookrightarrow S$  the open embedding. Then, the restriction*

$$j^* : \text{PSh}_{O_S(*D), D_S}(S) \rightarrow \text{Vect}_{\mathcal{D}}(S^\circ)$$

*is an equivalence of category whose inverse is*

$$j_* : \text{Vect}_{\mathcal{D}}(S^\circ) \rightarrow \text{PSh}_{O_S(*D), D_S}(S).$$

*By proposition 21, we get a full subcategory  $\text{PSh}_{O_S(*D), D_S}(S) \subset \text{PSh}_{\mathcal{D},h}(S)$ .*

*Proof.* Standard fact on coherent  $O_S(*D) = j_*O_{S^\circ}$  module.  $\square$

We now give the definition of the regularity of integrable connexions and holonomic  $D_S$ -modules on  $S \in \text{SmVar}(k)$ : We first define it for integrable connexion and holonomic  $D_C$ -module for  $C \in \text{SmVar}(k)$  a smooth algebraic curve over  $k$ .

**Definition 36.** *Let  $k$  a field of characteristic zero.*

- (i) *Let  $C \in \text{SmVar}(k)$  connected (hence irreducible). An algebraic meromorphic connexion  $M = (M, \nabla) \in \text{Mod}(K_C, D(O_{C,s}))$  at  $s \in C$  is called regular if there exists a finitely generated  $O_{C,s}$  module  $L \subset M$  such that  $M = K_{C,s}L$  and  $x\nabla(L) \subset \Omega_{C,s}^1 \otimes_{O_{C,s}} L$  for some local parameter  $x \in O_{C,s}$ . We call such an  $L \subset M$  an integral lattice.*
- (ii) *Let  $C \in \text{SmVar}(k)$ . An integrable connexion  $M = (M, \nabla) \in \text{Vect}_{\mathcal{D}}(C)$  is called regular if for any smooth compactification  $\bar{C} \in \text{PSmVar}(k)$  of  $C$  with  $j : C \hookrightarrow \bar{C}$  denoting the open embedding the algebraic meromorphic connexion*

$$j_*M := (j_*M, j_*\nabla) \in \text{PSh}_{O_{\bar{C}}(*\bar{C} \setminus C), D_{\bar{C}}}(\bar{C})$$

*is regular at all  $s \in \bar{C}$ , that is for all  $s \in \bar{C}$  the algebraic meromorphic connexion  $(j_*M)_s = ((j_*M)_s, (j_*\nabla)_s) \in \text{Mod}(K_C, D(O_{\bar{C},s}))$  at  $s \in \bar{C}$  is regular (see (i)).*

- (iii) *Let  $C \in \text{SmVar}(k)$ . Let  $M \in \text{PSh}_{\mathcal{D},h}(C)$  an holonomic  $D_C$  module. Then by proposition 20, there exist an open subset  $l : C^\circ \subset C$  such that  $M|_{C^\circ} := l^*M \in \text{Vect}_{\mathcal{D}}(C^\circ)$  is an integrable connexion. We say that  $M$  is regular if  $l^*M \in \text{Vect}_{\mathcal{D}}(C^\circ)$  is regular (see (ii)).*

We have the following :

**Proposition 24.** *Let  $C \in \text{SmVar}(k)$  connected (hence irreducible). Consider an algebraic meromorphic connexion  $M = (M, \nabla) \in \text{Mod}(K_C, D(O_{C,s}))$  at  $s \in C$ . The following are equivalent :*

- (i)  *$M$  is regular*
- (ii) *For any  $m \in M$ , there exists a finitely generated  $O_{C,s}$  submodule  $L \subset M$  such that  $x\nabla(L) \subset L$ .*
- (iii) *For any  $m \in M$  there exist a polynomial  $F(t) = t^m + a_1t^{m-1} + \dots + a_m \in O_{C,s}[t]$  such that  $F(x\nabla)(m) = 0$ .*

*Proof.* Similar to the complex case. □

We have then the following lemma

**Lemma 4.** (i) *Let  $k : C \rightarrow C'$  a morphism with  $C, C' \in \text{SmVar}(k)$  smooth algebraic curves.*

- *Let  $M \in \text{PSh}_{\mathcal{D},h}(C)$ . Then  $M$  is regular if and only if  $H^k \int_k M \in \text{PSh}_{\mathcal{D},h}(C')$  are regular for all  $k$ .*
- *Let  $N \in \text{PSh}_{\mathcal{D},h}(C')$ . Then  $M$  is regular if and only if  $H^k Lk^{*mod} N \in \text{PSh}_{\mathcal{D},h}(C)$  are regular for all  $k$ .*

- (ii) *Let  $\sigma : k \hookrightarrow \mathbb{C}$  an embedding. Let  $C \in \text{SmVar}(k)$  and  $M \in \text{PSh}_{\mathcal{D},h}(C)$ . Then  $M$  is regular if and only if  $\pi_{k/\mathbb{C}}(C)^{*mod} M \in \text{PSh}_{\mathcal{D},h}(C_{\mathbb{C}})$  is regular*

*Proof.* (i): Similar to the complex case : see [18].

(ii): Follows from the fact that for  $l : C^\circ \hookrightarrow C$  an open subset such that  $l^*M \in \text{Vect}_{\mathcal{D}}(C^\circ)$  is an integral connexion and  $s \in \bar{C}$  with  $\bar{C} \in \text{SmVar}(k)$  a compactification of  $C$ ,  $j : C^\circ \hookrightarrow C \hookrightarrow \bar{C}$ , if  $L \subset (j_*l^*M)_s$  is an integral lattice then  $\pi_{k/\mathbb{C}}(\bar{C})^{*mod} L \subset (\pi_{k/\mathbb{C}}(\bar{C})^{*mod} j_*l^*M)_s$  is an integral lattice, and conversely if  $L' \subset (\pi_{k/\mathbb{C}}(\bar{C})^{*mod} j_*l^*M)_s$  is an integral lattice then  $L' \cap (j_*l^*M)_s \subset (j_*l^*M)_s$  is an integral lattice the canonical map

$$(j_*n_{O_{C^\circ}/O_{C_{\mathbb{C}}}}(l^*M))_s : (j_*l^*M)_s \hookrightarrow \pi_{k/\mathbb{C}}(\bar{C})^{*mod}(j_*l^*M)_s, m \mapsto m \otimes 1$$

being injective since  $l^*M$  is a locally free  $O_{C^\circ}$  module. □

For integral connexions and holonomic  $D_S$  modules on  $S \in \text{SmVar}(k)$  an algebraic variety of arbitrary dimension over  $k$ , we define it by the case of curves

**Definition 37.** *Let  $k$  a field of characteristic zero.*

- (i) *Let  $S \in \text{SmVar}(k)$ . An algebraic meromorphic connexion  $M = (M, \nabla) \in \text{PSh}_{\mathcal{O}_{\bar{S}}(*D), D_S}(S)$  along a (Cartier divisor)  $D \subset S$  is called regular, if for all morphism  $i_C : C \rightarrow S$  with  $C \in \text{SmVar}(k)$  a smooth curve and all  $s = D \cap i_C(C)$ , the meromorphic connexion  $(i_C^{\text{mod}} M, \nabla) \in \text{Mod}(K_C, D(\mathcal{O}_{C,s}))$  is regular (see definition 36).*
- (ii) *Let  $S \in \text{SmVar}(k)$ . An integrable connexion  $M = (M, \nabla) \in \text{Vect}_{\mathcal{D}}(S)$  is called regular if for any smooth compactification  $\bar{S} \in \text{PSmVar}(k)$  of  $S$  with  $D := \bar{S} \setminus S \subset \bar{S}$  a (Cartier) divisor, the algebraic meromorphic connexion  $(j_* M) = ((j_* M), (j_* \nabla)) \in \text{PSh}_{\mathcal{O}_{\bar{S}}(*D), D_{\bar{S}}}(\bar{S})$  along  $D \subset \bar{S}$  is regular, where  $j : S \hookrightarrow \bar{S}$  is the open embedding (see (i)).*
- (iii) *Let  $S \in \text{SmVar}(k)$ . An holonomic  $D_S$  module  $M \in \text{PSh}_{\mathcal{D}, h}(S)$  is called regular if for all morphism  $i_C : C \rightarrow S$  with  $C \in \text{SmVar}(k)$ ,  $i_C^{\text{mod}} M \in \text{PSh}_{\mathcal{D}, h}(C)$  is regular (see definition 36).*
- (iv) *Let  $\sigma : k \hookrightarrow \mathbb{C}$  an embedding. Let  $S \in \text{SmVar}(k)$  and  $M \in \text{PSh}_{\mathcal{D}, h}(S)$ . Consider the projection  $\pi_{k/\mathbb{C}}(S) : S \rightarrow S_{\mathbb{C}}$ . Then by lemma 4(ii), if  $\pi_{k/\mathbb{C}}(S)^{\text{mod}} M \in \text{PSh}_{\mathcal{D}, h}(S_{\mathbb{C}})$  is regular then  $M \in \text{PSh}_{\mathcal{D}, h}(S)$  is regular. So, let  $k$  a field of characteristic zero. Let  $S \in \text{SmVar}(k)$  and  $M \in \text{PSh}_{\mathcal{D}, h}(S)$ . We say that  $M$  is regular in the strong sense if*

$$\pi_{k/\mathbb{C}}(S_0)^{\text{mod}} M_0 \in \text{PSh}_{\mathcal{D}, h}(S_{0\mathbb{C}})$$

*is regular, where  $k_0 \subset k$  is a subfield of finite transcendence degree over  $\mathbb{Q}$  such that  $S$  and  $M$  are defined that is  $S = S_{0k} := S_0 \otimes_{k_0} k$  with  $S_0 \in \text{SmVar}(k_0)$  and  $M = \pi_{k_0/k}(S_0)^{\text{mod}} M_0$  with  $M_0 \in \text{PSh}_{\mathcal{D}, h}(S_0)$ , and we take an embedding  $\sigma : k_0 \hookrightarrow \mathbb{C}$ . This definition does NOT depend on the choice of the subfield  $k_0$  and the embedding  $\sigma : k_0 \hookrightarrow \mathbb{C}$ .*

For  $S \in \text{SmVar}(k)$ , we denote  $\text{PSh}_{\mathcal{D}, rh}(S) \subset \text{PSh}_{\mathcal{D}, h}(S)$  the full subcategory consisting of holonomic  $D_S$  modules  $M \in \text{PSh}_{\mathcal{D}, h}(S)$  regular in the strong sense (see (iv)).

We have then the following easy proposition :

**Proposition 25.** *Let  $S \in \text{SmVar}(k)$ . Consider an exact sequence in  $\text{PSh}_{\mathcal{D}, h}(S)$*

$$0 \rightarrow M_1 \rightarrow M_2 \rightarrow M_3 \rightarrow 0.$$

- (i) *Then,  $M_2$  is regular if and only if  $M_1$  and  $M_3$  are regular*
- (ii) *Then,  $M_2 \in \text{PSh}_{\mathcal{D}, rh}(S)$  if and only if  $M_1, M_3 \in \text{PSh}_{\mathcal{D}, rh}(S)$ .*

*Proof.* (i): Similar to the complex case : by definition we are reduced to the case of integrable connexions on curves. But for  $0 \rightarrow M_1 \rightarrow M_2 \xrightarrow{q} M_3 \rightarrow 0$  an exact sequence of integrable connexions on a curve  $C \in \text{SmVar}(k)$  with compactification  $\bar{C} \in \text{PSmVar}(k)$ ,  $M_1$  and  $M_3$  are regular at  $s \in \bar{C}$  if and only if  $M_2$  is regular at  $s$  by proposition 24 (use (iii)).

(ii): Follows by definition from the complex case which is a particular case of (i). □

Let  $k$  a field of characteristic zero. Let  $S \in \text{SmVar}(k)$

- we consider

- the full subcategories

$$C_{\mathcal{D}, rh}(S) \subset C_{\mathcal{D}, h}(S) \text{ and } D_{\mathcal{D}, rh}(S) \subset D_{\mathcal{D}, h}(S)$$

consisting of complexes of presheaves  $M$  such that  $a_{\tau} H^n(M) \in \text{PSh}_{\mathcal{D}, rh}(S)$  (see definition 37),  $a_{\tau}$  being the sheafification functor for the Zariski topology,



- the full subcategories

$$C_{\mathcal{D}^{op},rh}(S) \subset C_{\mathcal{D}^{op},h}(S) \text{ and } D_{\mathcal{D}^{op},rh}(S) \subset D_{\mathcal{D}^{op},h}(S)$$

the full subcategories consisting of complexes of presheaves  $M$  such that  $a_\tau H^n(M)^{op} \in \text{PSh}_{\mathcal{D},rh}(S)$ ,

- in the filtered case we have

- the full subcategories

$$C_{\mathcal{D}(2)fil,rh}(S) \subset C_{\mathcal{D}(2)fil,h}(S), \text{ and } D_{\mathcal{D}(2)fil,rh}(S) \subset D_{\mathcal{D}(2)fil,h}(S),$$

consisting of filtered complexes of presheaves  $(M, F)$  such that  $a_\tau H^n(M) \in \text{PSh}_{\mathcal{D},rh}(S)$  (see definition 37), the full subcategories

$$\begin{aligned} C_{\mathcal{D}(1,0)fil,rh}(S) &= C_{\mathcal{D}2fil,rh}(S) \cap C_{\mathcal{D}(1,0)fil}(S) \subset C_{\mathcal{D}2fil,rh}(S), \text{ and} \\ D_{\mathcal{D}(1,0)fil,rh}(S) &= D_{\mathcal{D}2fil,rh}(S) \cap D_{\mathcal{D}(1,0)fil}(S) \subset D_{\mathcal{D}2fil,rh}(S), \end{aligned}$$

consisting of filtered complexes of presheaves  $(M, F, W) \in C_{\mathcal{D}(1,0)fil,h}(S)$  such that  $a_\tau H^n(M) \in \text{PSh}_{\mathcal{D},rh}(S)$  (see definition 37)

- and similarly the full subcategories

$$C_{\mathcal{D}^{op}(2)fil,rh}(S) \subset C_{\mathcal{D}^{op}(2)fil,h}(S), \text{ and } D_{\mathcal{D}^{op}(2)fil,rh}(S) \subset D_{\mathcal{D}^{op}(2)fil,h}(S)$$

the full subcategories consisting of filtered complexes of presheaves  $(M, F) \in C_{\mathcal{D}^{op}(2)fil,h}(S)$  such that  $a_\tau H^n(M)^{op} \in \text{PSh}_{\mathcal{D},rh}(S)$ .

Let  $S \in \text{SmVar}(k)$ . Let  $Z \subset S$  a closed subset. Denote by  $j : S \setminus Z \hookrightarrow S$  the open embedding. We denote by  $C_{\mathcal{D}fil,Z,rh}(S) \subset C_{\mathcal{D}fil,rh}(S)$  the full subcategory consisting of  $(M, F) \in C_{\mathcal{D}fil,rh}(S)$  such that  $j^* \text{Gr}_F^p M \in C_{O_S}(S)$  is acyclic for all  $p \in \mathbb{Z}$ .

We now give an equivalent definition of regular holonomic  $D_S$  modules together with a result on stability by direct, inverse image and duality.

Let  $S \in \text{SmVar}(k)$ . For each  $M \in \text{PSh}_{\mathcal{D},h}(S)$  there exists by proposition 19(ii) a finite sequence of holonomic submodules

$$0 = M_{r+1} \subset M_r \subset \cdots \subset M_1 \subset M_0 = M$$

such that  $M_i/M_{i+1} \in \text{PSh}_{\mathcal{D},h}(S)$  is simple.

**Definition 38.** Let  $k : Z^\circ \hookrightarrow S$  a locally closed embedding with  $S, Z^\circ \in \text{SmVar}(k)$ , and assume  $k$  is affine. We define for  $M \in \text{PSh}_{\mathcal{D},h}(Z^\circ)$  the minimal extension

$$L_{Z^\circ/S}(M) := T(k_!, k_*) \left( \int_{k!} M \right) \subset \int_k M$$

where  $T(k_!, k_*)(M) : \int_{k!} M \rightarrow \int_k M$  is given by, using a factorization of  $k$  by open embeddings and proper morphisms

- the adjunction map  $T(j_!, j_*)(N) := \text{ad}(j^*, j_*)(j_! N) : j_! N \rightarrow j_* N$  for open embeddings  $j : X^\circ \hookrightarrow X$  with  $X \in \text{SmVar}(k)$ ,
- the trace map on proper morphisms.

By proposition 19(i),  $L_{Z^\circ/S}(M) \in \text{PSh}_{\mathcal{D},h}(S)$  is holonomic.

**Theorem 23.** (i) Let  $k : Z^\circ \hookrightarrow S$  a locally closed embedding with  $S, Z^\circ \in \text{SmVar}(k)$ , and assume  $k$  is affine. Let  $M \in \text{PSh}_{\mathcal{D},h}(Z^\circ)$ . If  $M$  is simple, then  $L_{Z^\circ/S}(M)$  is also simple, and is the unique simple submodule of  $\int_k M$  and the unique quotient module of  $\int_{k!} M$ .

(ii) Let  $S \in \text{SmVar}(k)$ . Let  $M \in \text{PSh}_{\mathcal{D},h}(S)$ . If  $M$  is a simple  $D_S$  module then there exist  $k : Z^\circ \hookrightarrow S$  a locally closed embedding with  $Z \in \text{SmVar}(k)$ ,  $k$  affine, such that  $M \simeq L_{Z^\circ/S}(N)$  with  $N \in \text{Vect}_{\mathcal{D}}(Z^\circ)$  a simple integral connexion.

(iii) Let  $k : Z^\circ \hookrightarrow S$ ,  $k' : Z'^\circ$  locally closed embeddings with  $S, Z^\circ, Z'^\circ \in \text{SmVar}(k)$ ,  $k, k'$  affine. Let  $N \in \text{Vect}_{\mathcal{D}}(Z^\circ)$  and  $N' \in \text{Vect}_{\mathcal{D}}(Z'^\circ)$  simple integral connexions. Then  $L_{Z^\circ/S}(N) \simeq L_{Z'^\circ/S}(N')$  in  $\text{PSh}_{\mathcal{D}}(S)$  if and only if  $\bar{Z}^\circ = \bar{Z}'^\circ$  and  $N|_U \simeq N'|_U$  for an open dense subset  $U \subset Z^\circ \cap Z'^\circ$ .

*Proof.* Similar to the complex case : see [18]. □

**Theorem 24.** Let  $S \in \text{SmVar}(k)$ . Let  $M \in \text{PSh}_{\mathcal{D},h}(S)$ . Take by proposition 19(ii) a finite sequence of holonomic submodules

$$0 = M_{r+1} \subset M_r \subset \cdots \subset M_1 \subset M_0 = M$$

such that  $M_i/M_{i+1} \in \text{PSh}_{\mathcal{D},h}(S)$  is simple. By theorem 23 there exist locally closed embeddings  $k_i : Z_i^\circ \hookrightarrow S$  with  $Z_i^\circ \in \text{SmVar}(k)$  and  $N_i \in \text{Vect}_{\mathcal{D}}(Z_i^\circ)$  simple integrable connexion such that  $M_i \simeq L_{Z_i^\circ/S}(N_i)$  in  $\text{PSh}_{\mathcal{D}}(S)$ . Then  $M$  is regular if and only if the simple integral connexions  $N_i \in \text{Vect}_{\mathcal{D}}(Z_i^\circ)$  are regular (see definition 37).

*Proof.* Similar to the proof of the complex case in [18]. □

**Theorem 25.** Let  $f : X \rightarrow S$  a morphism with  $X, S \in \text{SmVar}(k)$ . Then,

(i) For  $(M, F) \in C_{\mathcal{D}(2)fil,rh}(S)$ , we have  $L\mathbb{D}_S(M, F) \in D_{\mathcal{D}(2)fil,rh}(S)$ .

(ii) For  $(M, F) \in C_{\mathcal{D}(2)fil,rh}(S)$ , we have  $Lf^{*mod}(M, F) \in D_{\mathcal{D}(2)fil,rh}(X)$  and  $Lf^{*mod}(M, F) \in D_{\mathcal{D}(2)fil,rh}(X)$ .

(iii) For  $M \in C_{\mathcal{D},rh}(X)$ , we have  $\int_f M \in D_{\mathcal{D},rh}(S)$ . and  $\int_{f_!} M := L\mathbb{D}_S \int_f L\mathbb{D}_X \in D_{\mathcal{D},rh}(S)$ .

(iv) If  $f$  is proper, for  $(M, F) \in C_{\mathcal{D}(2)fil,rh}(X)$ , we have  $\int_f(M, F) \in D_{\mathcal{D}(2)fil,rh}(S)$ .

(v) For  $(M, F), (N, F) \in C_{\mathcal{D}(2)fil,rh}(S)$ ,  $(M, F) \otimes_{O_S}^L (N, F) \in D_{\mathcal{D}(2)fil,rh}(S)$

*Proof.* Follows by definition from the complex case : (i),(ii) and (iii): See [18].

(iv): Follows from (iii) and stability of coherent  $O_X$ -modules by direct image of proper morphism  $f : X \rightarrow S$ .

(v): Follows from (ii) by proposition 16. □

## 4.2 The D modules on singular algebraic varieties over a field $k$ of characteristic zero

In this subsection by defining the category of complexes of filtered D-modules in the singular case and there functorialities.

### 4.2.1 Definition

In all this subsection, we fix the notations: Let  $k$  a field of characteristic zero. For  $S \in \text{Var}(k)$ , we denote by  $S = \cup_{i=1}^l S_i$  an open cover such that there exists closed embeddings  $i_i S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . We have then closed embeddings  $i_I : S_I := \cap_{i \in I} S_i \hookrightarrow \tilde{S}_I := \prod_{i \in I} \tilde{S}_i$ . Then for  $I \subset J$ , we denote by  $j_{IJ} : S_J \hookrightarrow S_I$  the open embedding and  $p_{IJ} : \tilde{S}_J \rightarrow \tilde{S}_I$  the projection, so that  $p_{IJ} \circ i_J = i_I \circ j_{IJ}$ . This gives the diagram of algebraic varieties  $(\tilde{S}_I) \in \text{Fun}(\mathcal{P}(\mathbb{N}), \text{Var}(k))$  which gives the diagram of sites  $(\tilde{S}_I) := \text{Ouv}(\tilde{S}_I) \in \text{Fun}(\mathcal{P}(\mathbb{N}), \text{Cat})$ . It also gives the diagram of sites  $(\tilde{S}_I)^{op} := \text{Ouv}(\tilde{S}_I)^{op} \in \text{Fun}(\mathcal{P}(\mathbb{N}), \text{Cat})$ . For  $I \subset J$ , we denote by  $m : \tilde{S}_I \setminus (S_I \setminus S_J) \hookrightarrow \tilde{S}_I$  the open embedding.

**Definition 39.** Let  $S \in \text{Var}(k)$  and let  $S = \cup_i S_i$  an open cover such that there exist closed embeddings  $i_i S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Then,  $\text{PSh}_{\mathcal{D}(2)fil}(S/(\tilde{S}_I)) \subset \text{PSh}_{\mathcal{D}(2)fil}((\tilde{S}_I))$  is the full subcategory

- whose objects are  $(M, F) = ((M_I, F)_{I \subset [1, \dots, l]}, s_{IJ})$ , with
  - $(M_I, F) \in \text{PSh}_{\mathcal{D}(2)\text{fil}}(\tilde{S}_I)$  such that  $\mathcal{I}_{S_I} M_I = 0$ , in particular  $(M_I, F) \in \text{PSh}_{\mathcal{D}(2)\text{fil}, S_I}(\tilde{S}_I)$
  - $s_{IJ} : m^*(M_I, F) \xrightarrow{\sim} m^* p_{IJ*}(M_J, F)[d_{\tilde{S}_I} - d_{\tilde{S}_J}]$  for  $I \subset J$ , are isomorphisms,  $p_{IJ} : \tilde{S}_J \rightarrow \tilde{S}_I$  being the projection, satisfying for  $I \subset J \subset K$ ,  $p_{IJ*} s_{JK} \circ s_{IJ} = s_{IK}$  ;
- the morphisms  $m : (M, F) \rightarrow (N, F)$  between  $(M, F) = ((M_I, F)_{I \subset [1, \dots, l]}, s_{IJ})$  and  $(N, F) = ((N_I, F)_{I \subset [1, \dots, l]}, r_{IJ})$  are by definition a family of morphisms of complexes,

$$m = (m_I : (M_I, F) \rightarrow (N_I, F))_{I \subset [1, \dots, l]}$$

such that  $r_{IJ} \circ m_J = p_{IJ*} m_J \circ s_{IJ}$  in  $C_{\mathcal{D}, S_I}(\tilde{S}_I)$ .

We denote by

$$\text{PSh}_{\mathcal{D}(2)\text{fil}, rh}(S/(\tilde{S}_I)) \subset \text{PSh}_{\mathcal{D}(2)\text{fil}, h}(S/(\tilde{S}_I)) \subset \text{PSh}_{\mathcal{D}(2)\text{fil}, c}(S/(\tilde{S}_I)) \subset \text{PSh}_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I))$$

the full subcategory consisting of  $((M_I, F), s_{IJ}) \in \text{PSh}_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I))$  such that for all  $I \subset [1, \dots, l]$ ,  $(M_I, F) \in \text{PSh}_{\mathcal{D}(2)\text{fil}, c}(\tilde{S}_I)$  resp.  $(M_I, F) \in \text{PSh}_{\mathcal{D}(2)\text{fil}, h}(\tilde{S}_I)$ , resp.  $(M_I, F) \in \text{PSh}_{\mathcal{D}(2)\text{fil}, h}(\tilde{S}_I)$  and  $M_I \in \text{PSh}_{\mathcal{D}, rh}(\tilde{S}_I)$  (see definition 37) We have the full subcategories

$$\begin{aligned} \text{PSh}_{\mathcal{D}(1,0)\text{fil}, rh}(S/(\tilde{S}_I)) \subset \text{PSh}_{\mathcal{D}2\text{fil}, rh}(S/(\tilde{S}_I)), \text{PSh}_{\mathcal{D}(1,0)\text{fil}, h}(S/(\tilde{S}_I)) \subset \text{PSh}_{\mathcal{D}2\text{fil}, h}(S/(\tilde{S}_I)), \\ \text{PSh}_{\mathcal{D}(1,0)\text{fil}, h}(S/(\tilde{S}_I)) \subset \text{PSh}_{\mathcal{D}2\text{fil}, h}(S/(\tilde{S}_I)), \end{aligned}$$

consisting of  $((M_I, F, W), s_{IJ})$  such that  $W^p M_I$  are  $D_{\tilde{S}_I}$  submodules.

We recall from [10] the following

- A morphism  $m = (m_I) : ((M_I), s_{IJ}) \rightarrow ((N_I), r_{IJ})$  in  $C(\text{PSh}_{\mathcal{D}}(S/(\tilde{S}_I)))$  is a Zariski, resp. usu, local equivalence if and only if all the  $m_I$  are Zariski local equivalences.
- A morphism  $m = (m_I) : ((M_I, F), s_{IJ}) \rightarrow ((N_I, F), r_{IJ})$  in  $C(\text{PSh}_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I)))$  is a filtered Zariski local equivalence if and only if all the  $m_I$  are filtered Zariski local equivalence.
- By definition, a morphism  $m = (m_I) : ((M_I, F), s_{IJ}) \rightarrow ((N_I, F), r_{IJ})$  in  $C(\text{PSh}_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I)))$  is an  $r$ -filtered Zariski local equivalence if there exist  $m_i : ((C_{iI}, F), s_{iIJ}) \rightarrow ((C_{(i+1)I}, F), s_{(i+1)IJ})$ ,  $0 \leq i \leq s$ , with  $((C_{iI}, F), s_{iIJ}) \in C(\text{PSh}_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I)))$ ,  $((C_{0I}, F), s_{0IJ}) = ((M_I, F), s_{IJ})$ ,  $((C_{sI}, F), s_{sIJ}) = ((N_I, F), r_{IJ})$  such that

$$m = m_s \circ \dots \circ m_i \circ \dots \circ m_0 : ((M_I, F), s_{IJ}) \rightarrow ((N_I, F), r_{IJ})$$

with  $m_i : ((C_{iI}, F), s_{iIJ}) \rightarrow ((C_{(i+1)I}, F), s_{(i+1)IJ})$  either filtered Zariski local equivalence or  $r$ -filtered homotopy equivalence.

**Definition-Proposition 4.** Let  $S \in \text{Var}(k)$  and let  $S = \cup_i S_i$  an open cover such that there exist closed embeddings  $i_i S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Then  $\text{PSh}_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I))$  does not depend on the open covering of  $S$  and the closed embeddings and we set

$$\text{PSh}_{\mathcal{D}(2)\text{fil}}(S) := \text{PSh}_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I))$$

We denote by  $C_{\mathcal{D}(2)\text{fil}}^0(S) := C(\text{PSh}_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I)))$  and by  $D_{\mathcal{D}(2)\text{fil}, r}^0(S) := K_{\mathcal{D}(2)\text{fil}, r}^0(S)[[E_1]^{-1}]$  the localization of the  $r$ -filtered homotopy category with respect to the classes of filtered Zariski local equivalences.

*Proof.* Similar to the complex case : see [10]. □

We now give the definition of our category :

**Definition 40.** Let  $S \in \text{Var}(k)$  and let  $S = \cup_i S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Then,  $C_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I)) \subset C_{\mathcal{D}(2)\text{fil}}(\tilde{S}_I)$  is the full subcategory

- whose objects are  $(M, F) = ((M_I, F)_{I \subset [1, \dots, l]}, u_{IJ})$ , with
  - $(M_I, F) \in C_{\mathcal{D}(2)\text{fil}, S_i}(\tilde{S}_I)$  that is  $(M_I, F) \in C_{\mathcal{D}(2)\text{fil}}(\tilde{S}_I)$  satisfy  $n_I^* \text{Gr}_F^p M_I \in C_O(\tilde{S}_I)$  is acyclic for all  $p \in \mathbb{Z}$ , where  $n_I : \tilde{S}_I \setminus S_I \hookrightarrow \tilde{S}_I$  is the open embedding,
  - $u_{IJ} : m^*(M_I, F) \rightarrow m^* p_{IJ*}(M_J, F)[d_{\tilde{S}_I} - d_{\tilde{S}_J}]$  for  $J \subset I$ , are morphisms,  $p_{IJ} : \tilde{S}_J \rightarrow \tilde{S}_I$  being the projection, satisfying for  $I \subset J \subset K$ ,  $p_{IJ} * u_{JK} \circ u_{IJ} = u_{IK}$  in  $C_{\mathcal{D}\text{fil}}(\tilde{S}_I)$  ;
- the morphisms  $m : ((M_I, F), u_{IJ}) \rightarrow ((N_I, F), v_{IJ})$  between  $(M, F) = ((M_I, F)_{I \subset [1, \dots, l]}, u_{IJ})$  and  $(N, F) = ((N_I, F)_{I \subset [1, \dots, l]}, v_{IJ})$  being a family of morphisms of complexes,

$$m = (m_I : (M_I, F) \rightarrow (N_I, F))_{I \subset [1, \dots, l]}$$

such that  $v_{IJ} \circ m_I = p_{IJ*} m_J \circ u_{IJ}$  in  $C_{\mathcal{D}\text{fil}}(\tilde{S}_I)$ .

We denote by  $C_{\mathcal{D}(2)\text{fil}}^\sim(S/(\tilde{S}_I)) \subset C_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I))$  the full subcategory consisting of objects  $((M_I, F), u_{IJ})$  such that the  $u_{IJ}$  are  $\infty$ -filtered Zariski local equivalences.

Let  $S \in \text{Var}(k)$  and let  $S = \cup_{i=1}^l S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Then, We denote by

$$C_{\mathcal{D}(2)\text{fil}, rh}(S/(\tilde{S}_I)) \subset C_{\mathcal{D}(2)\text{fil}, h}(S/(\tilde{S}_I)) \subset C_{\mathcal{D}(2)\text{fil}, c}(S/(\tilde{S}_I)) \subset C_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I))$$

the full subcategories consisting of those  $((M_I, F), u_{IJ}) \in C_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I))$  such that for all  $I \subset [1, \dots, l]$ ,  $(M_I, F) \in C_{\mathcal{D}(2)\text{fil}, S_i, c}(\tilde{S}_I)$ , that is such that  $a_\tau H^n(M_I, F) \in \text{PSh}_{\mathcal{D}\text{fil}, c}(\tilde{S}_I)$  are coherent endowed with a good filtration for all  $n \in \mathbb{Z}$ , resp.  $(M_I, F) \in C_{\mathcal{D}(2)\text{fil}, S_i, h}(\tilde{S}_I)$ , that is such that  $a_\tau H^n(M_I, F) \in \text{PSh}_{\mathcal{D}\text{fil}, h}(\tilde{S}_I)$  are filtered holonomic for all  $n \in \mathbb{Z}$ , resp. such that  $(M_I, F) \in C_{\mathcal{D}(2)\text{fil}, S_i, rh}(\tilde{S}_I)$ , that is such that  $a_\tau H^n(M_I, F) \in \text{PSh}_{\mathcal{D}\text{fil}, h}(\tilde{S}_I)$  are filtered holonomic for all  $n \in \mathbb{Z}$  and  $a_\tau H^n M_I \in \text{PSh}_{\mathcal{D}, rh}(\tilde{S}_I)$  (see definition 37).

We denote by

$$C_{\mathcal{D}(1,0)\text{fil}, h}(S/(\tilde{S}_I)) \subset C_{\mathcal{D}2\text{fil}, h}(S/(\tilde{S}_I)), \quad C_{\mathcal{D}(1,0)\text{fil}, rh}(S/(\tilde{S}_I)) \subset C_{\mathcal{D}2\text{fil}, rh}(S/(\tilde{S}_I)), \\ C_{\mathcal{D}(1,0)\text{fil}}(S/(\tilde{S}_I)) \subset C_{\mathcal{D}2\text{fil}}(S/(\tilde{S}_I)),$$

the full subcategories consisting of those  $((M_I, F, W), u_{IJ}) \in C_{\mathcal{D}2\text{fil}}(S/(\tilde{S}_I))$  such that  $W^p M_I$  are  $D_{\tilde{S}_I}$  submodules.

We recall from [10] the following

- A morphism  $m = (m_I) : (M_I, u_{IJ}) \rightarrow (N_I, v_{IJ})$  in  $C_{\mathcal{D}}(S/(\tilde{S}_I))$  is a Zariski local equivalence if and only if all the  $m_I$  are Zariski local equivalences.
- A morphism  $m = (m_I) : ((M_I, F), u_{IJ}) \rightarrow ((N_I, F), v_{IJ})$  in  $C_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I))$  is a filtered Zariski local equivalence if and only if all the  $m_I$  are filtered Zariski local equivalence.
- Let  $r = 1, \dots, \infty$ . By definition, a morphism  $m = (m_I) : ((M_I, F), u_{IJ}) \rightarrow ((N_I, F), v_{IJ})$  in  $C_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I))$  is an  $r$ -filtered Zariski local equivalence if there exist  $m_i : (C_{iI}, F), u_{iIJ}) \rightarrow (C_{(i+1)I}, F), u_{(i+1)IJ})$ ,  $0 \leq i \leq s$ , with  $(C_{iI}, F), u_{iIJ}) \in C_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I))$ ,  $(C_{0I}, F), u_{0IJ}) = (M_I, F), u_{IJ})$ ,  $(C_{sI}, F), u_{sIJ}) = (N_I, F), v_{IJ})$  such that

$$m = m_s \circ \dots \circ m_i \circ \dots \circ m_0 : ((M_I, F), u_{IJ}) \rightarrow ((N_I, F), v_{IJ})$$

with  $m_i : (C_{iI}, F), u_{iIJ}) \rightarrow (C_{(i+1)I}, F), u_{(i+1)IJ})$  either filtered Zariski local equivalence or  $r$ -filtered homotopy equivalence (i.e.  $r$ -filtered for the first filtration and filtered for the second filtration).

**Definition 41.** Let  $S \in \text{Var}(k)$  and let  $S = \cup_i S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ .

(i) We have the derived category

$$D_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I)) := C_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I))([E_1]^{-1})$$

the localization with respect to the classes of filtered Zariski local equivalences, together with the localization functor

$$D(\text{zar}) : C_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I)) \rightarrow K_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I)) \rightarrow D_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I)).$$

(ii) We have the full subcategories

$$D_{\mathcal{D}(1,0)\text{fil},rh}(S/(\tilde{S}_I)) \subset D_{\mathcal{D}(1,0)\text{fil},h}(S/(\tilde{S}_I)) \subset D_{\mathcal{D}2\text{fil}}(S/(\tilde{S}_I))$$

which are the image of  $C_{\mathcal{D}(1,0)\text{fil},h}(S/(\tilde{S}_I))$ , resp. of  $C_{\mathcal{D}(1,0)\text{fil},rh}(S/(\tilde{S}_I))$ , by the localization functor  $D(\text{zar}) : C_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I)) \rightarrow D_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I))$ .

(iii) We have, for  $r = 1, \dots, \infty$ , the  $r$ -filtered homotopy category

$$K_{\mathcal{D}(2)\text{fil},r}(S/(\tilde{S}_I)) := \text{Ho}_r(C_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I)))$$

whose objects are those of  $C_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I))$  and whose morphism are  $r$ -filtered homotopy classes of morphisms ( $r$ -filtered for the first filtration and filtered for the second), and

$$D_{\mathcal{D}(2)\text{fil},r}(S/(\tilde{S}_I)) := K_{\mathcal{D}(2)\text{fil},r}(S/(\tilde{S}_I))([E_1]^{-1})$$

the localization with respect to the classes of filtered Zariski local equivalences, together with the localization functor

$$D(\text{zar}) : C_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I)) \rightarrow K_{\mathcal{D}(2)\text{fil},r}(S/(\tilde{S}_I)) \rightarrow D_{\mathcal{D}(2)\text{fil},r}(S/(\tilde{S}_I)).$$

(iv) We have

$$D_{\mathcal{D}(1,0)\text{fil},\infty,h}(S/(\tilde{S}_I)) \subset D_{\mathcal{D}2\text{fil},\infty,h}(S/(\tilde{S}_I)) \subset D_{\mathcal{D}2\text{fil},\infty}(S/(\tilde{S}_I))$$

the full subcategories which are the image of  $C_{\mathcal{D}2\text{fil},h}(S/(\tilde{S}_I))$ , resp. of  $C_{\mathcal{D}(1,0)\text{fil},rh}(S/(\tilde{S}_I))$ , by the localization functor  $D(\text{zar}) : C_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I)) \rightarrow D_{\mathcal{D}(2)\text{fil},\infty}(S/(\tilde{S}_I))$ .

Let  $S \in \text{Var}(k)$  and let  $S = \cup_i S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ .

- We denote by

$$C_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I))^0 \subset C_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I)) \text{ and } D_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I))^0 \subset D_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I))$$

the full subcategories consisting of  $((M_I, F), u_{IJ}) \in C_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I))$  such that

$$H^n((M_I, F), u_{IJ}) = (H^n(M_I, F), H^n u_{IJ}) \in \text{PSh}_{\mathcal{D}(2)\text{fil}}^0(S/(\tilde{S}_I))$$

that is such that the  $H^n u_{IJ}$  are isomorphism.

- We have the full embedding functor

$$\begin{aligned} \iota_{S/(\tilde{S}_I)}^0 : C_{\mathcal{D}(2)\text{fil}}^0(S) &:= C_{\mathcal{D}(2)\text{fil}}^0(S/(\tilde{S}_I)) \hookrightarrow C_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I))^0 \hookrightarrow C_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I)), \\ &((M_I, F), s_{IJ}) \mapsto ((M_I, F), s_{IJ}) \end{aligned}$$

This full embedding induces in the derived category the functors

$$\begin{aligned} \iota_{S/(\tilde{S}_I)}^0 : D_{\mathcal{D}(2)\text{fil},r}^0(S) &:= \text{Ho}_{\text{zar}}(C_{\mathcal{D}(2)\text{fil},\infty}^0(S/(\tilde{S}_I))) \rightarrow D_{\mathcal{D}(2)\text{fil}}(S/(\tilde{S}_I))^0 \hookrightarrow D_{\mathcal{D}(2)\text{fil},r}(S/(\tilde{S}_I)), \\ &((M_I, F), s_{IJ}) \mapsto ((M_I, F), s_{IJ}). \end{aligned}$$

We can show that this functor is a full embedding.

## 4.2.2 Duality in the singular case

The definition of Saito's category comes with a dual functor :

**Definition 42.** Let  $S \in \text{Var}(k)$  and let  $S = \cup S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . We have the dual functor :

$$\mathbb{D}_S^K : C_{\mathcal{D}fil}^0(S/(\tilde{S}_I)) \rightarrow C_{\mathcal{D}fil}^0(S/(\tilde{S}_I)), ((M_I, F), s_{IJ}) \mapsto (\mathbb{D}_{\tilde{S}_I}^K(M_I, F), s_{IJ}^d),$$

with, denoting for short  $d_{IJ} := d_{\tilde{S}_J} - d_{\tilde{S}_I}$ ,

$$u_{IJ}^q : \mathbb{D}_{\tilde{S}_I}^K(M_I, F) \xrightarrow{\mathbb{D}^K(s_{IJ}^{-1})} \mathbb{D}_{\tilde{S}_I}^K p_{IJ*}(M_J, F)[d_{IJ}] \xrightarrow{T_*(p_{IJ}, D)(-)} p_{IJ*} \mathbb{D}_{\tilde{S}_J}^K(M_J, F)[d_{IJ}]$$

It induces in the derived category the functor

$$L\mathbb{D}_S^K : D_{\mathcal{D}fil}^0(S/(\tilde{S}_I)) \rightarrow D_{\mathcal{D}fil}^0(S/(\tilde{S}_I)), ((M_I, F), s_{IJ}) \mapsto \mathbb{D}_S^K Q((M_I, F), s_{IJ}),$$

with  $q : Q((M_I, F), s_{IJ}) \rightarrow ((M_I, F), s_{IJ})$  a projective resolution.

For our definition, we have

**Definition 43.** Let  $S \in \text{Var}(\mathbb{C})$  and let  $S = \cup S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(\mathbb{C})$ . We have the dual functors :

$$\mathbb{D}_S : C_{\mathcal{D}fil}(S/(\tilde{S}_I)) \rightarrow C_{\mathcal{D}fil}(S/(\tilde{S}_I)^{op}), ((M_I, F), s_{IJ}) \mapsto (\mathbb{D}_{\tilde{S}_I}(M_I, F), s_{IJ}^d),$$

with, denoting for short  $d_{IJ} := d_{\tilde{S}_J} - d_{\tilde{S}_I}$ ,

$$u_{IJ}^q : p_{IJ*} \mathbb{D}_{\tilde{S}_J}(M_J, F)[d_{IJ}]$$

and

$$\mathbb{D}_S : C_{\mathcal{D}fil}(S/(\tilde{S}_I)^{op}) \rightarrow C_{\mathcal{D}fil}(S/(\tilde{S}_I)), ((M_I, F), s_{IJ}) \mapsto (\mathbb{D}_{\tilde{S}_I}(M_I, F), s_{IJ}^d),$$

with, denoting for short  $d_{IJ} := d_{\tilde{S}_J} - d_{\tilde{S}_I}$ ,

$$u_{IJ}^q : \mathbb{D}_{\tilde{S}_I}(M_I, F)$$

It induces in the derived category the functors

$$L\mathbb{D}_S : D_{\mathcal{D}fil,r}(S/(\tilde{S}_I)) \rightarrow D_{\mathcal{D}fil,r}(S/(\tilde{S}_I)^{op}), ((M_I, F), s_{IJ}) \mapsto \mathbb{D}_S Q((M_I, F), s_{IJ}),$$

with  $q : Q((M_I, F), s_{IJ}) \rightarrow ((M_I, F), s_{IJ})$  a projective resolution, and

$$L\mathbb{D}_S : D_{\mathcal{D}fil,r}(S/(\tilde{S}_I)^{op}) \rightarrow D_{\mathcal{D}fil,r}(S/(\tilde{S}_I)), ((M_I, F), s_{IJ}) \mapsto \mathbb{D}_S Q((M_I, F), s_{IJ}),$$

with  $q : Q((M_I, F), s_{IJ}) \rightarrow ((M_I, F), s_{IJ})$  a projective resolution.

## 4.2.3 Inverse image in the singular case

We give in this subsection the inverse image functors between our categories.

Let  $n : S^\circ \hookrightarrow S$  be an open embedding with  $S \in \text{Var}(k)$  and let  $S = \cup_i S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Denote  $S_I^\circ := n^{-1}(S_I) = S_I \cap S^\circ$  and  $n_I := n|_{S_I^\circ} : S_I^\circ \hookrightarrow S^\circ$  the open embeddings. Consider open embeddings  $\tilde{n}_I : \tilde{S}_I^\circ \hookrightarrow \tilde{S}_I$  such that  $\tilde{S}_I^\circ \cap S_I = S_I^\circ$ , that is which are lift of  $n_I$ . We have the functor

$$\begin{aligned} n^* : C_{\mathcal{D}fil}(S/(\tilde{S}_I)) &\rightarrow C_{\mathcal{D}fil}(S^\circ/(\tilde{S}_I^\circ)), \\ (M, F) = ((M_I, F), u_{IJ}) &\mapsto n^*(M, F) := (\tilde{n}_I)^*(M, F) := (\tilde{n}_I^*(M_I, F), n^* u_{IJ}) \end{aligned}$$

which derive trivially.

Let  $f : X \rightarrow S$  be a morphism, with  $X, S \in \text{Var}(k)$ , such that there exist a factorization  $f; X \xrightarrow{l} Y \times S \xrightarrow{ps} S$  with  $Y \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $p_S$  the projection, and consider  $S = \cup_{i=1}^l S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$ , with  $\tilde{S}_i \in \text{SmVar}(k)$ ; The (graph) inverse image functors is

$$f^{*mod[-], \Gamma} : C_{\mathcal{D}fil}(S/(\tilde{S}_I)) \rightarrow C_{\mathcal{D}fil}(X/(Y \times \tilde{S}_I)),$$

$$(M, F) = ((M_I, F), u_{IJ}) \mapsto f^{*mod[-], \Gamma}(M, F) := (\Gamma_{X_I} E(p_{\tilde{S}_I}^{*mod[-]}(M_I, F)), \tilde{f}_J^{*mod[-]} u_{IJ})$$

with  $\tilde{f}_J^{*mod[-]} u_{IJ}$  as in [10], It induces in the derived categories the functor

$$Rf^{*mod[-], \Gamma} : D_{\mathcal{D}(2)fil, r}(S/(\tilde{S}_I)) \rightarrow D_{\mathcal{D}(2)fil, r}(X/(Y \times \tilde{S}_I)),$$

$$(M, F) = ((M_I, F), u_{IJ}) \mapsto f^{*mod[-], \Gamma}(M, F) := (\Gamma_{X_I} E(p_{\tilde{S}_I}^{*mod[-]}(M_I, F)), \tilde{f}_J^{*mod[-]} u_{IJ}).$$

It gives by duality the functor

$$Lf^{\hat{*}mod[-], \Gamma} : D_{\mathcal{D}(2)fil, r}(S/(\tilde{S}_I)) \rightarrow D_{\mathcal{D}(2)fil, r}(X/(Y \times \tilde{S}_I)),$$

$$(M, F) = ((M_I, F), u_{IJ}) \mapsto Lf^{\hat{*}mod[-], \Gamma}(M, F) := L\mathbb{D}_S Rf^{*mod[-], \Gamma} L\mathbb{D}_S(M, F).$$

The following proposition is easy :

**Proposition 26.** *Let  $f_1 : X \rightarrow Y$  and  $f_2 : Y \rightarrow S$  two morphism with  $X, Y, S \in \text{Var}(k)$ . Assume there exist factorizations  $f_1 : X \xrightarrow{l_1} Y' \times Y \xrightarrow{p_Y} Y$  and  $f_2 : Y \xrightarrow{l_2} Y'' \times S \xrightarrow{p_S} S$  with  $Y', Y'' \in \text{SmVar}(k)$ ,  $l_1, l_2$  closed embeddings and  $p_S, p_Y$  the projections. We have then the factorization*

$$f_2 \circ f_1 : X \xrightarrow{(l_2 \circ l_{Y'}) \circ l_1} Y' \times Y'' \times S \xrightarrow{p_S} S.$$

We have, for  $(M, F) \in C_{\mathcal{D}(2)fil}^{\sim}(S/(\tilde{S}_I))$ ,  $R(f_2 \circ f_1)^{*mod[-], \Gamma}(M, F) = Rf_2^{*mod[-], \Gamma} \circ Rf_1^{*mod[-], \Gamma}(M, F)$ .

*Proof.* Similar to the complex case : see [10]. □

#### 4.2.4 Direct image functor in the singular case

We define the direct image functors between our category.

Let  $f : X \rightarrow S$  be a morphism with  $X, S \in \text{Var}(k)$ , and assume there exist a factorization  $f : X \xrightarrow{l} Y \times S \xrightarrow{ps} S$  with  $Y \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $p_S$  a the projection ; Let  $S = \cup_{i=1}^l S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Then  $X = \cup_{i=1}^l X_i$  with  $X_i := f^{-1}(S_i)$ . Denote, for  $I \subset [1, \dots, l]$ ,  $S_I = \cap_{i \in I} S_i$  and  $X_I = \cap_{i \in I} X_i$ . For  $I \subset [1, \dots, l]$ , denote by  $\tilde{S}_I = \prod_{i \in I} \tilde{S}_i$ , We define the direct image functor on our category by

$$f_{*mod}^{FDR} : C_{\mathcal{D}(2)fil}(X/(Y \times \tilde{S}_I)) \rightarrow C_{\mathcal{D}(2)fil}(S/(\tilde{S}_I)),$$

$$((M_I, F), u_{IJ}) \mapsto (\tilde{f}_{I*mod}^{FDR}(M_I, F), f^k(u_{IJ})) := (p_{\tilde{S}_I} E((\Omega_{Y \times \tilde{S}_I / \tilde{S}_I}^{\bullet}, F_b) \otimes_{O_{Y \times \tilde{S}_I}} (M_I, F)[d_Y]), f^k(u_{IJ}))$$

with  $f^k(u_{IJ})$  as in [10]. It induces in the derived categories the functor

$$\int_f^{FDR} : D_{\mathcal{D}(2)fil, r}(X/(Y \times \tilde{S}_I)) \rightarrow D_{\mathcal{D}(2)fil, r}(S/(\tilde{S}_I)), ((M_I, F), u_{IJ}) \mapsto (\tilde{f}_{I*mod}^{FDR}(M_I, F), f^k(u_{IJ})).$$

In the algebraic case, we have the followings:

**Proposition 27.** Let  $f_1 : X \rightarrow Y$  and  $f_2 : Y \rightarrow S$  two morphism with  $X, Y, S \in \text{QPVar}(\mathbb{C})$  quasi-projective. Then there exist factorizations  $f_1 : X \xrightarrow{l_1} Y' \times Y \xrightarrow{p_Y} Y$  and  $f_2 : Y \xrightarrow{l_2} Y'' \times S \xrightarrow{p_S} S$  with  $Y' = \mathbb{P}^{N, o} \subset \mathbb{P}^N, Y'' = \mathbb{P}^{N', o} \subset \mathbb{P}^{N'}$  open subsets,  $l_1, l_2$  closed embeddings and  $p_S, p_Y$  the projections. We have then the factorization  $f_2 \circ f_1 : X \xrightarrow{(l_2 \circ l_{Y'}) \circ l_1} Y' \times Y'' \times S \xrightarrow{p_S} S$ . Let  $i : S \hookrightarrow \tilde{S}$  a closed embedding with  $\tilde{S} = \mathbb{P}^{n, o} \subset \mathbb{P}^n$  an open subset.

(i) Let  $M \in C_{\mathcal{D}}(X/(Y' \times Y'' \times \tilde{S}))$ . Then, we have  $\int_{f_2 \circ f_1}^{FDR}(M) = \int_{f_2}^{FDR}(\int_{f_1}^{FDR}(M))$  in  $D_{\mathcal{D}}(S/(\tilde{S}_I))$ .

(ii) Let  $M \in C_{\mathcal{D}(2)fil, h}(X/(Y' \times Y'' \times \tilde{S}))$ . Then, we have  $\int_{(f_2 \circ f_1)!}^{FDR}(M) = \int_{f_2!}^{FDR}(\int_{f_1!}^{FDR}(M))$  in  $D_{\mathcal{D}, h}(S/(\tilde{S}_I))$ .

*Proof.* Similar to the complex case : see [10]. □

#### 4.2.5 Tensor product in the singular case

Let  $S \in \text{Var}(k)$ . Let  $S = \cup S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . We have, as in the complex case, the tensor product functors

$$\begin{aligned} (-) \otimes_{\mathcal{O}_S}^{[-]} (-) : C_{\mathcal{D}fil}^2(S/(\tilde{S}_I)) &\rightarrow C_{\mathcal{D}fil}(S/(\tilde{S}_I)), ((M_I, F), u_{IJ}), ((N_I, F), v_{IJ}) \mapsto \\ &((M_I, F), u_{IJ}) \otimes_{\mathcal{O}_S}^{[-]} ((N_I, F), v_{IJ}) := ((M_I, F) \otimes_{\mathcal{O}_{\tilde{S}_I}} (N_I, F)[d_{\tilde{S}_I}], u_{IJ} \otimes v_{IJ}), \end{aligned}$$

with, denoting for short  $d_{IJ} := d_{\tilde{S}_J} - d_{\tilde{S}_I}$  and  $d_I := d_{\tilde{S}_I}$ ,

$$\begin{aligned} u_{IJ} \otimes v_{IJ} : (M_I, F) \otimes_{\mathcal{O}_{\tilde{S}_I}} (N_I, F)[d_I] &\xrightarrow{T(p_{IJ}^{*mod}, p_{IJ})(-)[d_I]} p_{IJ*} p_{IJ}^{*mod}((M_I, F) \otimes_{\mathcal{O}_{\tilde{S}_I}} (N_I, F)[d_I]) \\ &\xrightarrow{=} p_{IJ*}(p_{IJ}^{*mod}(M_I, F) \otimes_{\mathcal{O}_{\tilde{S}_I}} p_{IJ}^{*mod}(N_I, F)[d_I]) \\ &\xrightarrow{I(p_{IJ}^{*mod}, p_{IJ})(-, -)(u_{IJ}) \otimes I(p_{IJ}^{*mod}, p_{IJ})(-, -)(v_{IJ})[d_I]} p_{IJ*}((M_J, F) \otimes_{\mathcal{O}_{\tilde{S}_J}} (N_J, F)[d_J + d_{IJ}]). \end{aligned}$$

It induces in the derived category, for  $1 \leq r \leq \infty$ , the functors

$$\begin{aligned} (-) \otimes_{\mathcal{O}_S}^L (-) : D_{\mathcal{D}fil, r}^2(S/(\tilde{S}_I)) &\rightarrow D_{\mathcal{D}fil, r}(S/(\tilde{S}_I)), ((M_I, F), u_{IJ}), ((N_I, F), v_{IJ}) \mapsto \\ &((M_I, F), u_{IJ}) \otimes_{\mathcal{O}_S}^L ((N_I, F), v_{IJ}) := (L_D(M_I, F) \otimes_{\mathcal{O}_{\tilde{S}_I}} L_D(N_I, F)[d_{\tilde{S}_I}], u_{IJ}^q \otimes v_{IJ}^q). \end{aligned}$$

We have the following easy proposition :

**Proposition 28.** Let  $S \in \text{Var}(k)$ . Denote  $\Delta_S : S \hookrightarrow S \times S$  the diagonal embedding. Denote  $p_1 : S \times S \rightarrow S$  and  $p_2 : S \times S \rightarrow S$  the projections. Let  $S = \cup S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embedding with  $\tilde{S}_i \in \text{SmVar}(k)$ . We have, for  $(M_I, u_{IJ}), (N_I, v_{IJ}) \in C_{\mathcal{D}}(S/(\tilde{S}_I))$ ,

$$(M_I, u_{IJ}) \otimes_{\mathcal{O}_S}^{[-]} (N_I, v_{IJ}) = \Delta_S^{*mod, \Gamma}((p_{1I}^{*mod} M_I, p_{1I}^{*mod} u_{IJ}) \otimes_{\mathcal{O}_{S \times S}} (p_{2I}^{*mod} N_I, p_{2I}^{*mod} v_{IJ}))$$

and

$$((M_I, F), u_{IJ}) \otimes_{\mathcal{O}_S}^L ((N_I, F), v_{IJ}) = R\Delta_S^{*mod, \Gamma}((p_{1I}^{*mod} M_I, p_{1I}^{*mod} u_{IJ}) \otimes_{\mathcal{O}_{S \times S}} (p_{2I}^{*mod} N_I, p_{2I}^{*mod} v_{IJ}))$$

*Proof.* Follows from proposition 16 and theorem 21. □

#### 4.2.6 The 2 functors of D modules on the category of algebraic varieties over a field $k$ of characteristic zero and the transformation maps

**Definition 44.** Consider a commutative diagram in  $\text{Var}(k)$  which is cartesian :

$$D = \begin{array}{ccc} X_T & \xrightarrow{f'} & T \\ \downarrow g' & & \downarrow g \\ X & \xrightarrow{f} & S \end{array} .$$



Assume there exist factorizations  $f : X \xrightarrow{l_1} Y_1 \times S \xrightarrow{p_S} S$ ,  $g : T \xrightarrow{l_2} Y_2 \times S \xrightarrow{p_S} S$ , with  $Y_1, Y_2 \in \text{SmVar}(k)$ ,  $l_1, l_2$  closed embeddings and  $p_S, p_S$  the projections. Let  $S = \cup S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embedding with  $\tilde{S}_i \in \text{SmVar}(k)$ . We then have as in the complex case, for  $(M, F) = ((M_I, F), u_{IJ}) \in C_{\mathcal{D}(2)fil}(X/(Y_1 \times \tilde{S}_I))$ , the following canonical transformation map in  $D_{\mathcal{D}(2)fil,r}(T/(Y_2 \times \tilde{S}_I))$ ,

$$\begin{aligned}
& T^{\mathcal{D}mod}(f, g)(M, F) : \\
& Rg^{*mod, \Gamma} \int_f^{FDR} (M, F) := (\Gamma_{T_I} E(\tilde{g}_I^{*mod} p_{\tilde{S}_I^*} E((\Omega_{Y_1 \times \tilde{S}_I / \tilde{S}_I}^\bullet, F_b) \otimes_{O_{Y_1 \times \tilde{S}_I}} (M_I, F))), \tilde{g}_J^{*mod} f^k(u_{IJ})) \\
& \xrightarrow{(T_\omega^O(p_{\tilde{S}_I}, \tilde{g}_I)(M_I, F))} \\
& (\Gamma_{T_I} E(p_{Y_2 \times \tilde{S}_I^*} E((\Omega_{Y_1 \times Y_2 \times \tilde{S}_I / Y_2 \times \tilde{S}_I}^\bullet, F_b) \otimes_{O_{Y_1 \times Y_2 \times \tilde{S}_I}} p_{Y_1 \times \tilde{S}_I}^{*mod} (M_I, F))), f'^k(p_{Y_1 \times \tilde{S}_I}^{*mod} (u_{IJ}))) \\
& \xrightarrow{(T_\omega^O(\gamma, \otimes)(p_{Y_1 \times \tilde{S}_I}^{*mod} (M_I, F)))^{-1}} \\
& (p_{Y_2 \times \tilde{S}_I^*} E((\Omega_{Y_1 \times Y_2 \times \tilde{S}_I / Y_2 \times \tilde{S}_I}^\bullet, F_b) \otimes_{O_{Y_1 \times Y_2 \times \tilde{S}_I}} \Gamma_{Y_1 \times T_I} E(p_{Y_1 \times \tilde{S}_I}^{*mod} ((M_I, F))))), f'^k(\tilde{g}_J^{*mod} (u_{IJ}^q))) \\
& =: \int_{f'}^{FDR} Rg'^{*mod, \Gamma}(M, F).
\end{aligned}$$

**Proposition 29.** Consider a commutative diagram in  $\text{Var}(k)$

$$D = (f, g) = \begin{array}{ccc} X_T & \xrightarrow{f'} & T \\ \downarrow g' & & \downarrow g \\ X & \xrightarrow{f} & S \end{array} .$$

which is cartesian. Assume there exist factorizations  $f : X \xrightarrow{l_1} Y_1 \times S \xrightarrow{p_S} S$ ,  $g : T \xrightarrow{l_2} Y_2 \times S \xrightarrow{p_S} S$ , with  $Y_1, Y_2 \in \text{SmVar}(k)$ ,  $l_1, l_2$  closed embeddings and  $p_S, p_S$  the projections. Let  $S = \cup S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embedding with  $\tilde{S}_i \in \text{SmVar}(k)$ . For  $(M, F) = ((M_I, F), u_{IJ}) \in C_{\mathcal{D}(2)fil,c}(X/(Y \times \tilde{S}_I))$ ,

$$T^{\mathcal{D}mod}(f, g) : Rg^{*mod, \Gamma} \int_f^{FDR} (M, F) \rightarrow \int_{f'}^{FDR} Rg'^{*mod, \Gamma}(M, F)$$

is an isomorphism in  $D_{\mathcal{D}(2)fil,r}(T/(Y_2 \times \tilde{S}_I))$ .

*Proof.* Similar to the complex case. □

**Theorem 26.** Let  $f : X \rightarrow S$  a morphism with  $X, S \in \text{Var}(k)$ . Assume there exists a factorization  $f : X \xrightarrow{l} Y \times S \xrightarrow{p} S$  with  $Y \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $p$  the projection. Let  $S = \cup S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embedding with  $\tilde{S}_i \in \text{SmVar}(k)$ . Then,

- (i) For  $(M, F) \in C_{\mathcal{D}(2)fil,rh}(S/(\tilde{S}_I)^{op})$ , we have  $L\mathbb{D}_S(M, F) \in D_{\mathcal{D}(2)fil,rh}(S/(\tilde{S}_I))$ .
- (ii) For  $M \in C_{\mathcal{D},rh}(S/(\tilde{S}_I))$ ,  $Rf^{*mod, \Gamma}(M) \in D_{\mathcal{D},rh}(X/(Y \times \tilde{S}_I))$  and  $Lf^{\hat{*}mod, \Gamma} M \in D_{\mathcal{D},rh}(X/(Y \times \tilde{S}_I))$ .
- (iii) For  $M \in C_{\mathcal{D},rh}(X/(Y \times \tilde{S}_I))$ ,  $\int_f M \in D_{\mathcal{D},rh}(S/(\tilde{S}_I))$  and  $\int_{f_!} M := L\mathbb{D}_S \int_f L\mathbb{D}_X \in D_{\mathcal{D},rh}(S/(\tilde{S}_I))$ .
- (iv) If  $f$  is proper, for  $(M, F) \in C_{\mathcal{D}(2)fil,rh}(X/(Y \times \tilde{S}_I))$ , we have  $\int_f(M, F) \in D_{\mathcal{D}(2)fil,rh}(S/(\tilde{S}_I))$ .
- (v) For  $(M, F), (N, F) \in C_{\mathcal{D}(2)fil,rh}(S/(\tilde{S}_I))$ ,  $(M, F) \otimes_{O_S}^L (N, F) \in D_{\mathcal{D}(2)fil,rh}(S/(\tilde{S}_I))$

*Proof.* Follows from theorem 25. □

### 4.3 The category of complexes of quasi-coherent sheaves on an algebraic variety whose cohomology sheaves has a structure of D-modules

#### 4.3.1 Definition on a smooth algebraic variety and the functorialities

**Definition 45.** Let  $S \in \text{SmVar}(k)$ . Let  $Z \subset S$  a closed subset. Denote by  $j : S \setminus Z \hookrightarrow S$  the open complementary embedding.

- (i) We denote by  $C_{O_S, \mathcal{D}, Z}(S) \subset C_{O_S, \mathcal{D}}(S)$  the full subcategory consisting of  $M \in C_{O_S, \mathcal{D}}(S)$  such that  $j^* H^n M = 0$  for all  $n \in \mathbb{Z}$ .
- (ii) We denote by  $C_{O_S \text{fil}, \mathcal{D}, Z}(S) \subset C_{O_S \text{fil}, \mathcal{D}}(S)$  the full subcategory consisting of  $(M, F) \in C_{O_S \text{fil}, \mathcal{D}}(S)$  such that there exist  $r \in \mathbb{N}$  and an  $r$ -filtered homotopy equivalence  $m : (M, F) \rightarrow (M', F)$  with  $(M', F) \in C_{O_S \text{fil}, \mathcal{D}}(S)$  such that  $j^* H^n \text{Gr}_F^p(M', F) = 0$  for all  $n, p \in \mathbb{Z}$ .

**Definition 46.** Let  $S \in \text{SmVar}(k)$ . We have then (see section 2), for  $r = 1, \dots, \infty$ , the homotopy category  $K_{O_S \text{fil}, \mathcal{D}, r}(S) = \text{Ho}_r(C_{O_S \text{fil}, \mathcal{D}}(S))$  whose objects are those of  $C_{O_S \text{fil}, \mathcal{D}}(S)$  and whose morphisms are  $r$ -filtered homotopy classes of morphism, and its localization  $D_{O_S \text{fil}, \mathcal{D}, r}(S) = K_{O_S \text{fil}, \mathcal{D}, r}(S)[[E_1]^{-1}]$  with respect to filtered zariski, resp. usu local equivalence. Note that the classes of filtered  $\tau$  local equivalence constitute a right multiplicative system.

- Let  $S \in \text{SmVar}(k)$ . Let  $(M, F) \in C_{O_S \text{fil}, \mathcal{D}}(S)$ . Then, the canonical morphism  $q : L_O(M, F) \rightarrow (M, F)$  in  $C_{O_S \text{fil}}(S)$  being a quasi-isomorphism of  $O_S$  modules, we get in a unique way  $L_O(M, F) \in C_{O_S \text{fil}, \mathcal{D}}(S)$  such that  $q : L_O(M, F) \rightarrow (M, F)$  is a morphism in  $C_{O_S \text{fil}, \mathcal{D}}(S)$
- Let  $f : X \rightarrow S$  be a morphism with  $X, S \in \text{SmVar}(k)$ . Let  $(M, F) \in C_{O_S \text{fil}, \mathcal{D}}(S)$ . Then,  $f^{* \text{mod}} H^n(M, F) := (O_X, F_b) \otimes_{f^* O_S} f^* H^n(M, F)$  is canonical a filtered  $D_X$  module (see section 4.1 or 4.2). Consider the canonical surjective map  $q(f) : H^n f^{* \text{mod}}(M, F) \rightarrow f^{* \text{mod}} H^n(M, F)$ . Then,  $q(f)$  is an isomorphism if  $f$  is smooth. Let  $h : U \rightarrow S$  be a smooth morphism with  $U, S \in \text{SmVar}(k)$ . We get the functor

$$h^{* \text{mod}} : C_{O_S \text{fil}, \mathcal{D}}(S) \rightarrow C_{O_U \text{fil}, \mathcal{D}}(U), (M, F) \mapsto h^{* \text{mod}}(M, F),$$

- Let  $S \in \text{SmVar}(k)$ , and let  $i : Z \hookrightarrow S$  a closed embedding and denote by  $j : S \setminus Z \hookrightarrow S$  the open complementary. For  $M \in C_{O_S, \mathcal{D}}(S)$ , the cohomology presheaves of

$$\Gamma_Z M := \text{Cone}(\text{ad}(j^*, j_*)(M) : M \rightarrow j_* j^* M)[-1]$$

has a canonical  $D_S$ -module structure (as  $j^* H^n M$  is a  $j^* D_S$  module,  $H^n j_* j^* M = j_* j^* H^n M$  has an induced structure of  $D_S$  module), and  $\gamma_Z(M) : \Gamma_Z M \rightarrow M$  is a map in  $C_{O_S, \mathcal{D}}(S)$ . For  $Z_2 \subset Z$  a closed subset and  $M \in C_{O_S, \mathcal{D}}(S)$ ,  $T(Z_2/Z, \gamma)(M) : \Gamma_{Z_2} M \rightarrow \Gamma_Z M$  is a map in  $C_{O_S, \mathcal{D}}(S)$ . We get the functor

$$\begin{aligned} \Gamma_Z : C_{O_S \text{fil}, \mathcal{D}}(S) &\rightarrow C_{O_S \text{fil}, \mathcal{D}}(S), \\ (M, F) &\mapsto \Gamma_Z(M, F) := \text{Cone}(\text{ad}(j^*, j_*)((M, F)) : (M, F) \rightarrow j_* j^*(M, F))[-1], \end{aligned}$$

together we the canonical map  $\gamma_Z(M, F) : \Gamma_Z(M, F) \rightarrow (M, F)$

More generally, let  $h : Y \rightarrow S$  a morphism with  $Y, S \in \text{Var}(k)$ ,  $S$  smooth, and let  $i : X \hookrightarrow Y$  a closed embedding and denote by  $j : Y \setminus X \hookrightarrow Y$  the open complementary. For  $M \in C_{h^* O_S, h^* \mathcal{D}}(Y)$ ,

$$\Gamma_X M := \text{Cone}(\text{ad}(j^*, j_*)(M) : M \rightarrow j_* j^* M)[-1]$$

has a canonical  $h^* D_S$ -module structure, (as  $j^* H^n M$  is a  $j^* h^* D_S$  module,  $H^n j_* j^* M = j_* j^* H^n M$  has an induced structure of  $j^* h^* D_S$  module), and  $\gamma_X(M) : \Gamma_X M \rightarrow M$  is a map in  $C_{h^* O_S, h^* \mathcal{D}}(Y)$ .

For  $X_2 \subset X$  a closed subset and  $M \in C_{h^*O_S, h^*\mathcal{D}}(Y)$ ,  $T(Z_2/Z, \gamma)(M) : \Gamma_{X_2}M \rightarrow \Gamma_X M$  is a map in  $C_{h^*O_S, h^*\mathcal{D}}(Y)$ . We get the functor

$$\Gamma_X : C_{h^*O_S \text{fil}, h^*\mathcal{D}}(Y) \rightarrow C_{h^*O_S \text{fil}, h^*\mathcal{D}}(Y),$$

$$(M, F) \mapsto \Gamma_X(M, F) := \text{Cone}(\text{ad}(j^*, j_*)((M, F)) : (M, F) \rightarrow j_*j^*(M, F))[-1],$$

together with the canonical map  $\gamma_X(M, F) : \Gamma_X(M, F) \rightarrow (M, F)$

- Let  $f : X \rightarrow S$  be a morphism with  $X, S \in \text{SmVar}(k)$ . Consider the factorization  $f : X \xrightarrow{l} X \times S \xrightarrow{p} S$ , where  $l$  is the graph embedding and  $p$  the projection. We get from the two preceding points the functor

$$f^{*mod, \Gamma} : C_{O_S \text{fil}, \mathcal{D}}(S) \rightarrow C_{O_X \text{fil}, \mathcal{D}}(X \times S), (M, F) \mapsto f^{*mod, \Gamma}(M, F) := \Gamma_X p^{*mod}(M, F),$$

and

$$f^{*mod[-], \Gamma} : C_{O_S \text{fil}, \mathcal{D}}(S) \rightarrow C_{O_X \text{fil}, \mathcal{D}}(X \times S),$$

$$(M, F) \mapsto f^{*mod[-], \Gamma}(M, F) := \Gamma_X E(p^{*mod}(M, F))[-d_X],$$

which induces in the derived categories the functor

$$Rf^{*mod[-], \Gamma} : D_{O_S \text{fil}, \mathcal{D}}(S) \rightarrow D_{O_X \text{fil}, \mathcal{D}}(X \times S),$$

$$(M, F) \mapsto Rf^{*mod[-], \Gamma}(M, F) := \Gamma_X E(p^{*mod[-]}(M, F)).$$

#### 4.3.2 Definition on a singular algebraic variety and the functorialities

**Definition 47.** Let  $S \in \text{Var}(k)$  and let  $S = \cup_i S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Then,  $C_{O_{\tilde{S}_I} \text{fil}, \mathcal{D}}(S/(\tilde{S}_I))$  is the category

- whose objects are  $(M, F) = ((M_I, F)_{I \subset [1, \dots, l]}, u_{IJ})$ , with
  - $(M_I, F) \in C_{O_{\tilde{S}_I} \text{fil}, \mathcal{D}, S_I}(\tilde{S}_I)$ ,
  - $u_{IJ} : m^*(M_I, F) \rightarrow m^*p_{IJ*}(M_J, F)[d_{\tilde{S}_J} - d_{\tilde{S}_I}]$  for  $J \subset I$ , are morphisms,  $p_{IJ} : \tilde{S}_J \rightarrow \tilde{S}_I$  being the projection, satisfying for  $I \subset J \subset K$ ,  $p_{IJ*}u_{JK} \circ u_{IJ} = u_{IK}$  in  $C_{O_{\tilde{S}_I} \text{fil}, \mathcal{D}}(\tilde{S}_I)$  ;
- whose morphisms  $m : ((M_I, F), u_{IJ}) \rightarrow ((N_I, F), v_{IJ})$  between  $(M, F) = ((M_I, F)_{I \subset [1, \dots, l]}, u_{IJ})$  and  $(N, F) = ((N_I, F)_{I \subset [1, \dots, l]}, v_{IJ})$  are a family of morphisms of complexes,

$$m = (m_I : (M_I, F) \rightarrow (N_I, F))_{I \subset [1, \dots, l]}$$

such that  $v_{IJ} \circ m_I = p_{IJ*}m_J \circ u_{IJ}$  in  $C_{O_{\tilde{S}_I} \text{fil}, \mathcal{D}}(\tilde{S}_I)$ .

We denote by  $C_{O_{\tilde{S}_I} \text{fil}, \mathcal{D}}(S/(\tilde{S}_I)) \subset C_{O_{\tilde{S}_I} \text{fil}, \mathcal{D}}(S/(\tilde{S}_I))$  the full subcategory consisting of objects  $((M_I, F), u_{IJ})$  such that the  $u_{IJ}$  are  $\infty$ -filtered Zariski local equivalences.

**Definition 48.** Let  $S \in \text{Var}(k)$  and let  $S = \cup_i S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . We have then (see [10]), for  $r = 1, \dots, \infty$ , the homotopy category

$$K_{O_{\tilde{S}_I} \text{fil}, \mathcal{D}, r}(S/(\tilde{S}_I)) := \text{Ho}_r(C_{O_{\tilde{S}_I} \text{fil}, \mathcal{D}}(S/(\tilde{S}_I)))$$

whose objects are those of  $C_{O_{\tilde{S}_I} \text{fil}, \mathcal{D}}(S/(\tilde{S}_I))$  and whose morphisms are  $r$ -filtered homotopy classes of morphism, and its localization

$$D_{O_{\tilde{S}_I} \text{fil}, \mathcal{D}, r}(S/(\tilde{S}_I)) := K_{O_{\tilde{S}_I} \text{fil}, \mathcal{D}, r}(S/(\tilde{S}_I))([E_1]^{-1})$$

with respect to the classes of filtered zariski local equivalence. Note that the classes of filtered  $\tau$  local equivalence constitute a right multiplicative system.

Let  $f : X \rightarrow S$  be a morphism, with  $X, S \in \text{Var}(k)$ , such that there exist a factorization  $f; X \xrightarrow{l} Y \times S \xrightarrow{p_S} S$  with  $Y \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $p_S$  the projection, and consider  $S = \cup_{i=1}^l S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$ , with  $\tilde{S}_i \in \text{SmVar}(k)$ . Then,  $X = \cup_{i=1}^l X_i$  with  $X_i := f^{-1}(S_i)$ . We then have the filtered De Rham the inverse image functor :

$$f^{*mod[-], \Gamma} : C_{\text{Fil}, \mathcal{D}}(S/(\tilde{S}_I)) \rightarrow C_{\text{Fil}, \mathcal{D}}(X/(Y \times \tilde{S}_I)), \quad (M, F) = ((M_I, F), u_{IJ}) \mapsto \\ f^{*mod[-], \Gamma}(M, F) := (\Gamma_{X_I} E(p_{\tilde{S}_I}^{*mod[-]}(M_I, F)), \tilde{f}_J^{*mod[-]} u_{IJ})$$

with  $\tilde{f}_J^{*mod[-]} u_{IJ}$  as in the complex case It induces in the derived categories, the functor

$$Rf^{*mod[-], \Gamma} : D_{\text{Fil}, \mathcal{D}, r}(S/(\tilde{S}_I)) \rightarrow D_{\text{Fil}, \mathcal{D}, r}(X/(Y \times \tilde{S}_I)), \\ (M, F) = ((M_I, F), u_{IJ}) \mapsto \\ Rf^{*mod[-], \Gamma} := f^{*mod[-], \Gamma}(M, F) := (\Gamma_{X_I} E(p_{\tilde{S}_I}^{*mod[-]}(M_I, F)), \tilde{f}_J^{*mod[-]} u_{IJ}).$$

#### 4.4 The (filtered) De Rahm functor over a field $k$ of characteristic zero and Riemann Hilbert for holonomic D-modules on smooth algebraic varieties over a subfield $k \subset \mathbb{C}$

Let  $j : S^o \hookrightarrow S$  an open embedding with  $S = (S, O_S) \in \text{RTop}$ . Denote by  $Z := S \setminus S^o$  the closed complementary subset. Recall that we have, see [10], for  $(M, F) \in C_{\mathcal{D}\text{Fil}}(S^o)$  the canonical maps in  $C_{\text{Fil}}(S)$

$$T^w(j, \otimes)(M, F) : DR(S)(j_*(M, F)) := \Omega_S^\bullet \otimes_{O_S} j_*(M, F) \xrightarrow{\text{ad}(j^*, j_*)(\Omega_S^\bullet \otimes I)} \\ j_* j^* \Omega_S^\bullet \otimes_{O_S} j_*(M, F) \xrightarrow{\cong} j_*(\Omega_{S^o}^\bullet \otimes_{O_{S^o}} (M, F)) =: j_* DR(S^o)(M, F)$$

and

$$T^w(\gamma_Z, \otimes)(M, F) : DR(S)(\Gamma_Z(M, F)) := \Omega_S^\bullet \otimes_{O_S} \Gamma_Z(M, F) \\ \xrightarrow{(I, T^w(j, \otimes)(M, F))} \Gamma_Z(\Omega_{S^o}^\bullet \otimes_{O_{S^o}} (M, F)) =: \Gamma_Z DR(S^o)(M, F).$$

Let  $k$  a field of characteristic zero.

**Proposition 30.** *Let  $Y, S \in \text{SmVar}(k)$ . Let  $p : Y \times S \rightarrow S$  the projection. For  $(M, F) \in C_{\mathcal{D}\text{Fil}}(Y \times S)$ ,*

$$DR(Y \times S/S)(M, F) := (\Omega_{Y \times S/S}^\bullet, F_b) \otimes_{O_{Y \times S}} (M, F) \in C_{p^* O_S \text{Fil}}(Y \times S)$$

*is a naturally a complex of filtered  $p^* D_S$  modules, that is*

$$DR(Y \times S/S)(M, F) := (\Omega_{Y \times S/S}^\bullet, F_b) \otimes_{O_{Y \times S}} (M, F) \in C_{p^* \mathcal{D}\text{Fil}}(Y \times S),$$

*where the  $p^* D_S$  module structure on  $\Omega_{Y \times S/S}^p \otimes_{O_{Y \times S}} M^n$  is given by for  $(Y \times S)^o \subset Y \times S$  an open subset,*

$$(\gamma \in \Gamma((Y \times S)^o, T_{Y \times S}), \hat{\omega} \otimes m \in \Gamma((Y \times S)^o, \Omega_{Y \times S/S}^p \otimes_{O_{Y \times S}} M^n)) \mapsto \gamma.(\hat{\omega} \otimes m) := (\hat{\omega} \otimes (\gamma.m)).$$

*Moreover, if  $\phi : (M_1, F) \rightarrow (M_2, F)$  a morphism with  $(M_1, F), (M_2, F) \in C_{\mathcal{D}\text{Fil}}(Y \times S)$ ,*

$$DR(Y \times S/S)(\phi) := (I \otimes \phi) : (\Omega_{Y \times S/S}^\bullet, F_b) \otimes_{O_{Y \times S}} (M_1, F) \rightarrow (\Omega_{Y \times S/S}^\bullet, F_b) \otimes_{O_{Y \times S}} (M_2, F)$$

*is a morphism in  $C_{p^* \mathcal{D}\text{Fil}}(Y \times S)$ .*

*Proof.* Follows immediately by definition : see [10]. □

**Proposition 31.** Consider a commutative diagram in  $\text{SmVar}(k)$  :

$$D = \begin{array}{ccc} Y \times S & \xrightarrow{p} & S \\ g''=(g_0'' \times g) \uparrow & & \uparrow g \\ Y' \times T & \xrightarrow{p'} & T \end{array}$$

with  $p$  and  $p'$  the projections. For  $(M, F) \in C_{\mathcal{D}fil}(Y \times S)$  the map in  $C_{g''^*p^*O_S fil}(Y' \times T)$

$$\Omega_{(Y' \times T / Y \times S) / (T / S)}(M, F) : g''^*((\Omega_{Y \times S / S}^\bullet, F_b) \otimes_{O_{Y \times S}}(M, F)) \rightarrow (\Omega_{Y' \times T / T}^\bullet, F_b) \otimes_{O_{Y' \times T}} g''^{*mod}(M, F)$$

given in [10] section 4.1 is a map in  $C_{g''^*p^*\mathcal{D}fil}(Y' \times T)$ . Hence, for  $(M, F) \in C_{\mathcal{D}fil}(Y \times S)$ , the map in  $C_{O_T fil}(T)$  (with  $L_D$  instead of  $L_O$ )

$$T_\omega^O(D)(M) : g^{*mod}L_D(p_*E((\Omega_{Y \times S / S}^\bullet, F_b) \otimes_{O_{Y \times S}}(M, F))) \rightarrow p'_*E((\Omega_{Y' \times T / T}^\bullet, F_b) \otimes_{O_{Y' \times T}} g''^{*mod}(M, F)),$$

is a map in  $C_{\mathcal{D}fil}(T)$ .

*Proof.* Follows immediately by definition.  $\square$

**Proposition 32.** Let  $S \in \text{SmVar}(k)$ .

- We have the filtered resolutions of  $K_S$  by the following complex of locally free right  $D_S$  modules:  $\omega(S) : \omega(K_S) := (\Omega_S^\bullet, F_b)[d_S] \otimes_{O_S}(D_S, F_b) \rightarrow (K_S, F_b)$  and  $\omega(S) : \omega(K_S, F^{ord}) := (\Omega_S^\bullet, F_b)[d_S] \otimes_{O_S}(D_S, F^{ord}) \rightarrow (K_S, F^{ord})$
- Dually, we have the filtered resolution of  $O_S$  by the following complex of locally free (left)  $D_S$  modules:  $\omega^\vee(S) : \omega(O_S) := (\wedge^\bullet T_S, F_b)[d_S] \otimes_{O_S}(D_S, F_b) \rightarrow (O_S, F_b)$  and  $\omega^\vee(S) : \omega(O_S, F^{ord}) := (\wedge^\bullet T_S, F_b)[d_S] \otimes_{O_S}(D_S, F^{ord}) \rightarrow (O_S, F^{ord})$ .

Let  $S_1, S_2 \in \text{SmVar}(k)$ . Consider the projection  $p = p_1 : S_1 \times S_2 \rightarrow S_1$ .

- We have the filtered resolution of  $D_{S_1 \times S_2 \rightarrow S_1}$  by the following complexes of (left)  $(p^*D_{S_1}$  and right  $D_{S_1 \times S_2})$  modules :

$$\omega(S_1 \times S_2 / S_1) : (\Omega_{S_1 \times S_2 / S_1}^\bullet[d_{S_2}], F_b) \otimes_{O_{S_1 \times S_2}}(D_{S_1 \times S_2}, F^{ord}) \rightarrow (D_{S_1 \times S_2 \leftarrow S_1}, F^{ord}).$$

- Dually, we have the filtered resolution of  $D_{S_1 \times S_2 \rightarrow S_1}$  by the following complexes of (left)  $(p^*D_{S_1}, D_{S_1 \times S_2})$  modules :

$$\omega^\vee(S_1 \times S_2 / S_1) : (\wedge^\bullet T_{S_1 \times S_2 / S_1}[d_{S_2}], F_b) \otimes_{O_{S_1 \times S_2}}(D_{S_1 \times S_2}, F^{ord}) \rightarrow (D_{S_1 \times S_2 \rightarrow S_1}, F^{ord}),$$

*Proof.* Similar to the complex case: see [18].  $\square$

**Definition 49.** (i) Let  $i : Z \hookrightarrow S$  be a closed embedding, with  $Z, S \in \text{SmVar}(k)$ . Then, for  $(M, F) \in C_{\mathcal{D}fil}(Z)$ , we set

$$i_{*mod}(M, F) := i_{*mod}^0(M, F) := i_*((M, F) \otimes_{D_Z}(D_{Z \leftarrow S}, F^{ord})) \in C_{\mathcal{D}fil}(S)$$

(ii) Let  $S_1, S_2 \in \text{SmVar}(k)$  and  $p : S_1 \times S_2 \rightarrow S_1$  be the projection. Then, for  $(M, F) \in C_{\mathcal{D}fil}(S_1 \times S_2)$ , we set

$$- p_{*mod}^0(M, F) := p_*(DR(S_1 \times S_2 / S_1)(M, F)) := p_*((\Omega_{S_1 \times S_2 / S_1}^\bullet, F_b) \otimes_{O_{S_1 \times S_2}}(M, F))[d_{S_2}] \in C_{\mathcal{D}fil}(S_1),$$

$$- p_{*mod}(M, F) := p_*E(DR(S_1 \times S_2/S_1)(M, F)) := p_*E((\Omega_{S_1 \times S_2/S_1}^\bullet, F_b) \otimes_{\mathcal{O}_{S_1 \times S_2}} (M, F))[d_{S_2}] \in C_{\mathcal{D}fil}(S_1).$$

(iii) Let  $f : X \rightarrow S$  be a morphism, with  $X, S \in \text{SmVar}(k)$ . Consider the factorization  $f : X \xrightarrow{i} X \times S \xrightarrow{p_S} S$ , where  $i$  is the graph embedding and  $p_S : X \times S \rightarrow S$  is the projection. Then, for  $(M, F) \in C_{\mathcal{D}fil}(X)$  we set

$$\begin{aligned} - f_{*mod}^{FDR}(M, F) &:= p_{S*mod}i_{*mod}(M, F) \in C_{\mathcal{D}fil}(S), \\ - \int_f^{FDR}(M, F) &:= f_{*mod}^{FDR}(M, F) := p_{S*mod}i_{*mod}(M, F) \in D_{\mathcal{D}fil}(S). \end{aligned}$$

By proposition 33 below, we have  $\int_f^{FDR} M = \int_f M \in D_{\mathcal{D}}(X)$ .

(iii) Let  $f : X \rightarrow S$  be a morphism, with  $X, S \in \text{SmVar}(k)$ . Consider the factorization  $f : X \xrightarrow{i} X \times S \xrightarrow{p_S} S$ , where  $i$  is the graph embedding and  $p_S : X \times S \rightarrow S$  is the projection. Then, for  $(M, F) \in C_{\mathcal{D}fil}(X)$  we set

$$\begin{aligned} - f_{!mod}^{FDR}(M, F) &:= \mathbb{D}_S^K L_D f_{*mod}^{FDR} \mathbb{D}_S^K L_D(M, F) := \mathbb{D}_S^K L_D p_{S*mod}i_{*mod} \mathbb{D}_{X \times S}^K L_D(M, F) \in C_{\mathcal{D}fil}(S), \\ - \int_f^{FDR}(M, F) &:= f_{!mod}^{FDR}(M, F) := \mathbb{D}_S^K L_D p_{S*mod}i_{*mod} \mathbb{D}_{X \times S}^K L_D(M, F) \in D_{\mathcal{D}fil}(S). \end{aligned}$$

**Proposition 33.** (i) Let  $i : Z \hookrightarrow S$  a closed embedding with  $S, Z \in \text{SmVar}(k)$ . Then for  $(M, F) \in C_{\mathcal{D}fil}(Z)$ , we have

$$\int_i(M, F) := Ri_*((M, F) \otimes_{D_Z}^L (D_{Z \leftarrow S}, F^{ord})) = i_*((M, F) \otimes_{D_Z} (D_{Z \leftarrow S}, F^{ord})) = i_{*mod}(M, F).$$

(ii) Let  $S_1, S_2 \in \text{SmVar}(k)$  and  $p : S_{12} := S_1 \times S_2 \rightarrow S_1$  be the projection. Then, for  $(M, F) \in C_{\mathcal{D}fil}(S_1 \times S_2)$  we have

$$\begin{aligned} \int_p(M, F) &:= Rp_*((M, F) \otimes_{D_{S_1 \times S_2}}^L (D_{S_1 \times S_2 \leftarrow S_1}, F^{ord})) \\ &= p_*E((\Omega_{S_1 \times S_2/S_1}^\bullet, F_b) \otimes_{\mathcal{O}_{S_1 \times S_2}} (D_{S_1 \times S_2}, F^{ord}) \otimes_{D_{S_1 \times S_2}} (M, F))[d_{S_2}] \\ &= p_*E((\Omega_{S_1 \times S_2/S_1}^\bullet, F_b) \otimes_{\mathcal{O}_{S_1 \times S_2}} (M, F))[d_{S_2}] =: p_{*mod}(M, F). \end{aligned}$$

where the second equality follows from Griffithz transversality (the canonical isomorphism map respect by definition the filtration).

(iii) Let  $f : X \rightarrow S$  be a morphism with  $X, S \in \text{SmVar}(k)$ . Then for  $M \in C_{\mathcal{D}}(X)$ , we have  $\int_f^{FDR} M = \int_f M$ .

*Proof.* (i): Follows from the fact that  $D_{Z \leftarrow S}$  is a locally free  $D_Z$  module and that  $i_*$  is an exact functor. (ii): Since  $\Omega_{S_{12}/S_1}^\bullet[d_{S_2}, F_b] \otimes_{\mathcal{O}_{S_{12}}} D_{S_{12}}$  is a complex of locally free  $D_{S_1 \times S_2}$  modules, we have in  $D_{fil}(S_1 \times S_2)$ , using proposition 32,

$$(D_{S_1 \times S_2 \leftarrow S_1}, F^{ord}) \otimes_{D_{S_1 \times S_2}}^L (M, F) = (\Omega_{S_{12}/S_1}^\bullet[d_{S_2}, F_b] \otimes_{\mathcal{O}_{S_{12}}} (D_{S_{12}}, F^{ord}) \otimes_{D_{S_{12}}} (M, F).$$

(iii): Follows from (i) and (ii) by proposition 15(ii).  $\square$

Let  $k$  a field of characteristic zero. Let  $S \in \text{SmVar}(k)$  connected. We use to shift the De Rham functor in order to have compatibility with perverse sheaves in the complex or p-adic analytic case by setting for  $(M, F) \in C_{\mathcal{D}fil}(S)$ ,  $DR(S)^{[-1]}(M, F) := DR(S)(M, F)[-d_S] \in C_{fil}(S)$ .

Let  $k$  a field of characteristic zero. Let  $S \in \text{SmVar}(k)$ . Recall we denote for  $M, N \in C_{\mathcal{D}}(S)$ ,

$$m(M, N) : \mathcal{H}om_{D_S}(M, D_S) \otimes_{D_S} N \rightarrow \mathcal{H}om_{D_S}(M, N), (\phi \otimes n) \mapsto (m \mapsto \phi(m)n)$$

the multiplication map in  $C(S)$ . It induces in the derived category for  $M, N \in C_{\mathcal{D}}(S)$  the map in  $D(S)$

$$\begin{aligned} m(L_D M, N) : R\mathcal{H}om_{D_S}(M, D_S) \otimes_{D_S}^L N &= \mathcal{H}om_{D_S}(L_D M, D_S) \otimes_{D_S} N \\ &\rightarrow \mathcal{H}om_{D_S}(L_D M, N) = R\mathcal{H}om_{D_S}(M, N). \end{aligned}$$

We use for the proof of theorem 28 in the next subsection the following :

**Proposition 34.** *Let  $k$  a field of characteristic zero. Let  $S \in \text{SmVar}(k)$ .*

(i) *Let  $M, N \in C_{\mathcal{D}}(S)$ . If  $N \in C_{\mathcal{D},c}(S)$ ,*

$$\begin{aligned} m(L_D M, N) : R\mathcal{H}om_{D_S}(M, D_S) \otimes_{D_S}^L N &= \mathcal{H}om_{D_S}(L_D M, D_S) \otimes_{D_S} N \\ &\rightarrow \mathcal{H}om_{D_S}(L_D M, N) = R\mathcal{H}om_{D_S}(M, N). \end{aligned}$$

*is an isomorphism in  $D(S)$ .*

(ii) *Let  $M, N \in C_{\mathcal{D}}(S)$ . If  $N \in C_{\mathcal{D},c}(S)$ , we have using (i) a canonical isomorphism in  $D(S)$*

$$\begin{aligned} D(M, N) : R\mathcal{H}om_{D_S}(M, N) &\xrightarrow{m(L_D M, N)^{-1}} R\mathcal{H}om_{D_S}(M, D_S) \otimes_{D_S}^L N \\ \xrightarrow{=} K_S \otimes_{O_S}^L L\mathbb{D}_S M[-d_S] \otimes_{D_S}^L N &\xrightarrow{=} K_S \otimes_{D_S}^L \mathbb{D}_S M \otimes_{O_S}^L N[-d_S] =: DR(S)^{[-1]}(L\mathbb{D}_S M \otimes_{O_S}^L N) \end{aligned}$$

*Proof.* (i):Standard.

(ii):Follows from (i). □

#### 4.4.1 Some complements on the (filtered)De Rahm functor for $\mathbf{D}$ modules on smooth algebraic varieties over a subfield $k \subset \mathbb{C}$

In this section, for  $S \in \text{AnSm}(\mathbb{C})$ , we write for short  $DR(S) := DR(S)^{[-1]}$ , where we recall for  $S$  connected  $DR(S)^{[-1]} := DR(S)[-d_S]$ .

For  $S \in \text{AnSp}(\mathbb{C})$ , we denote by

$$\alpha(S) : \mathbb{C}_S \hookrightarrow DR(S)(O_S)$$

the inclusion map in  $C(S)$ . In particular, we get for  $S \in \text{Var}(\mathbb{C})$ , the inclusion map

$$\alpha(S) : \mathbb{B}_{dr,S} \hookrightarrow DR(S)(O_{S^{an}})$$

in  $C(S^{an})$ .

For  $S \in \text{AnSp}(\mathbb{C})$ , we denote by

$$\iota(S) :: DR(S)(O_S) \rightarrow K_S, h \otimes w \mapsto hw$$

the canonical map in  $C(S)$ . In particular, we get for  $S \in \text{Var}(\mathbb{C})$ , the canonical map

$$\iota(S) : DR(S)(O_{S^{an}}) \rightarrow K_S$$

in  $C(S^{an})$ .

- Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{AnSm}(\mathbb{C})$ . Recall that we have for  $(M, F) \in C_{\mathcal{D}fil}(X)$  the canonical map in  $D_{fil}(S)$

$$\begin{aligned} T_*(f, DR)(M, F) : DR(S)\left(\int_f (M, F)\right) &:= \Omega_S^\bullet \otimes_{O_S} Rf_*(D_{X \leftarrow S} \otimes_{D_X}^L (M, F)) \\ &\xrightarrow{\iota(S)} Rf_*(D_{X \leftarrow S} \otimes_{D_X}^L (M, F)) \otimes_{D_S} (D_S \otimes_{O_S} K_S) \\ \xrightarrow{T(f, \otimes)(D_{X \leftarrow S} \otimes_{D_X}^L (M, F), D_S \otimes_{O_S} K_S)} &\rightarrow Rf_*(f^*(D_S \otimes_{O_S} K_S) \otimes_{f^* D_S}^L D_{X \leftarrow S} \otimes_{D_X}^L (M, F)) \\ &\xrightarrow{=} Rf_*(K_X \otimes_{O_X} D_X \otimes_{D_X}^L (M, F)) \\ &\xrightarrow{\iota(X)} Rf_*(\Omega_X^\bullet \otimes_{O_X} (M, F)) =: Rf_* DR(X)(M, F) \end{aligned}$$

which is an isomorphism. Hence, for  $S \in \text{AnSm}(\mathbb{C})$  and  $(M, F) \in C_{\mathcal{D}fil,c}(S^o)$ ,

$$T^w(j, \otimes)(M, F) : DR(S)(j_*(M, F)) := \Omega_S^\bullet \otimes_{O_S} j_*(M, F) \rightarrow j_*(\Omega_{S^o}^\bullet \otimes_{O_{S^o}} (M, F)) =: j_*DR(S^o)(M, F)$$

is a filtered quasi-isomorphism.

- Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{AnSp}(\mathbb{C})$ . Assume there exist a factorization  $f : X \xrightarrow{l} Y \times S \xrightarrow{p} S$  with  $Y \in \text{AnSm}(\mathbb{C})$ ,  $l$  a closed embedding and  $p$  the projection. Let  $S = \cup_i S_i$  an open cover such that there exists closed embedding  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{AnSm}(\mathbb{C})$ . We have for  $((M_I, F), u_{IJ}) \in C_{\mathcal{D}fil}(X/(Y \times \tilde{S}_I))$  the canonical map in  $D_{fil}(S/(\tilde{S}_I))$

$$\begin{aligned} T_*(f, DR)((M_I, F), u_{IJ}) : \\ DR(S) \left( \int_f ((M_I, F), u_{IJ}) \right) &:= (\Omega_{\tilde{S}_I}^\bullet \otimes_{O_{\tilde{S}_I}} p_{\tilde{S}_I*} E(\Omega_{Y \times \tilde{S}_I / \tilde{S}_I}^\bullet \otimes_{O_{Y \times \tilde{S}_I}} (M_I, F)), DR(fu_{IJ})) \\ \xrightarrow{=} (\Omega_{\tilde{S}_I}^\bullet \otimes_{O_{\tilde{S}_I}} D_{\tilde{S}_I} \otimes_{D_{\tilde{S}_I}} p_{\tilde{S}_I*} E(\Omega_{Y \times \tilde{S}_I / \tilde{S}_I}^\bullet \otimes_{O_{Y \times \tilde{S}_I}} D_{Y \times \tilde{S}_I} \otimes_{D_{Y \times \tilde{S}_I}} (M_I, F)), DR(fu_{IJ})) \\ &\xrightarrow{w(Y \times \tilde{S}_I) \circ T(p_{\tilde{S}_I}, \otimes)(-, -)} \\ & p_{\tilde{S}_I*} E(\Omega_{Y \times \tilde{S}_I}^\bullet \otimes_{O_{Y \times \tilde{S}_I}} D_{Y \times \tilde{S}_I} \otimes_{D_{Y \times \tilde{S}_I}} (M_I, F)), DR(fu_{IJ})) \\ &\xrightarrow{=} p_{\tilde{S}_I*} E(\Omega_{Y \times \tilde{S}_I}^\bullet \otimes_{O_{Y \times \tilde{S}_I}} (M_I, F)), DR(fu_{IJ})) =: Rf_*DR(X)((M_I, F), u_{IJ}) \end{aligned}$$

where  $w(Y \times \tilde{S}_I)$  is the wedge product.

- Let  $S \in \text{AnSm}(\mathbb{C})$ . Recall that we have for  $(M, F) \in C_{\mathcal{D}fil}(S)$  the canonical map in  $D_{fil}(S)$

$$T(D, DR)(M, F) : DR(S)(L\mathbb{D}_S(M, F)) \rightarrow \mathbb{D}_S^v(DR(S)(M, F))$$

- Let  $S \in \text{AnSp}(\mathbb{C})$ . Let  $S = \cup_i S_i$  an open cover such that there exists closed embedding  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{AnSm}(\mathbb{C})$ . Recall that we have for  $((M_I, F), u_{IJ}) \in C_{\mathcal{D}fil}(S/(\tilde{S}_I))$  the canonical map in  $D_{fil}(S/(\tilde{S}_I))$

$$T(D, DR)((M_I, F), u_{IJ}) : DR(S)(L\mathbb{D}_S((M_I, F), u_{IJ})) \rightarrow \mathbb{D}_S^v(DR(S)((M_I, F), u_{IJ}))$$

- Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{AnSm}(\mathbb{C})$ . Recall that we have for  $(N, F) \in C_{\mathcal{D}fil}(S)$  the canonical map in  $D_{fil}(X)$

$$\begin{aligned} T^*(f, DR)(M, F) : f^*DR(S)(N, F) &\xrightarrow{t_S} f^*\mathcal{H}om_{D_S}(O_S, L_D(N, F)) \\ &\xrightarrow{T(f, \text{hom})(-, -)} \mathcal{H}om_{f^*D_S}(f^*O_S, f^*L_D(N, F)) \\ \xrightarrow{Tr(-, -)} \mathcal{H}om_{D_X}(f^{*mod}O_S, f^{*mod}L_D(N, F)) &= \mathcal{H}om_{D_X}(O_X, f^{*mod}L_D(N, F)) \\ \xrightarrow{(\iota(X) \otimes I)^{-1}} \Omega_X^\bullet \otimes_{O_X} f^{*mod}L_D(N, F) &=: DR(X)(Lf^{*mod}(N, F)) \end{aligned}$$

Let  $k \subset \mathbb{C}$  a subfield.

- Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{Var}(k)$ . Assume there exist a factorization  $f : X \xrightarrow{l} Y \times S \xrightarrow{p} S$  with  $Y \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $p$  the projection. Let  $S = \cup_i S_i$  an affine open cover so that there exists closed embedding  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . We have for  $((M_I, F), u_{IJ}) \in C_{\mathcal{D}fil}(S/(\tilde{S}_I))$  the canonical map in  $D_{fil}(X_{\mathbb{C}}^{\text{an}}/(Y \times \tilde{S}_I)_{\mathbb{C}}^{\text{an}})$

$$\begin{aligned} f^!DR(S)((M_I, F), u_{IJ}) &= \Gamma_X \mathbb{D}^v p^! \mathbb{D}DR(S)((M_I, F), u_{IJ})^{\text{an}} \\ &\xrightarrow{\mathbb{D}T^*(p, DR)(-)} \Gamma_X DR(Y \times S)((p_{\tilde{S}_I}^{*mod}((M_I, F), u_{IJ}))^{\text{an}}) \\ \xrightarrow{T^w(j, \otimes)(-)^{-1}} DR(Y \times S)(\Gamma_X(p_{\tilde{S}_I}^{*mod}(M_I, F), u_{IJ})^{\text{an}}) &\xrightarrow{DR(Y \times S)(T(\gamma, \text{an})(-) := (I, T(j, \text{an})(-)))} \\ DR(Y \times S)((\Gamma_X p_{\tilde{S}_I}^{*mod}((M_I, F), u_{IJ}))^{\text{an}}) &=: DR(X)(f^{*mod, \Gamma}((M_I, F), u_{IJ})). \end{aligned}$$



- Let  $S \in \text{Var}(k)$ . Denote by  $\Delta_S : S \hookrightarrow S \times S$  the graph embedding and  $p_1 : S \times S \rightarrow S$  and  $p_2 : S \times S \rightarrow S$  the projections. Let  $S = \cup_i S_i$  an affine open cover so that there exists closed embedding  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . We have for  $((M_I, F), u_{IJ}), ((N_I, F), u_{IJ}) \in C_{\mathcal{D}fil}(S/(\tilde{S}_I))$  the canonical map in  $D_{fil}(S_{\mathbb{C}}^{an}/(\tilde{S}_{I,\mathbb{C}}^{an}))$

$$\begin{aligned}
T(\otimes, DR)((M, F)(M_I, F), u_{IJ}), ((N_I, F), u_{IJ}) &: DR(S)((M, F)^{an}) \otimes_{\mathbb{C}_S} DR(S)((N_I, F), u_{IJ})^{an} \\
&\xrightarrow{=} R\Delta_S^1((p_1^* DR(S)((M_I, F), u_{IJ})^{an}) \otimes_{\mathbb{C}_S} p_2^* DR(S)((N_I, F), u_{IJ})^{an}) \\
&\xrightarrow{=} R\Delta_S^1((p_1^! DR(S)((M_I, F), u_{IJ})^{an}) \otimes_{\mathbb{C}_S} p_2^! DR(S)((N_I, F), u_{IJ})^{an})[2d_S] \\
&\xrightarrow{T^1(p_1, DR)(-) \otimes T^1(p_2, DR)(-)} \Delta_S^1 DR(S \times S)((p_1^{*mod}(M_I, F), u_{IJ}) \otimes_{O_{S \times S}} p_2^{*mod}((N_I, F), u_{IJ}))^{an} \\
&\xrightarrow{T^1(\Delta_S, DR)(-)} DR(S)((L\Delta_S^{*mod}((p_1^{*mod}(M_I, F), u_{IJ}) \otimes_{O_{S \times S}} p_2^{*mod}((N_I, F), u_{IJ})))^{an}) \\
&\xrightarrow{=} DR(S)((M_I, F), u_{IJ}) \otimes_{O_S}^L ((N_I, F), u_{IJ})^{an}.
\end{aligned}$$

**Theorem 27.** Let  $k \subset \mathbb{C}$  a subfield.

- (i) Let  $j : S^o \hookrightarrow S$  an open embedding with  $S \in \text{SmVar}(k)$ . Then, for  $M \in C_{\mathcal{D},rh}(S^o)$ , the map in  $C(S_{\mathbb{C}}^{an})$

$$DR(S)(T(j, an)(M)) : DR(S)((j_* M)^{an}) \rightarrow DR(S)(j_*(M^{an}))$$

is a quasi-isomorphism.

- (ii) Let  $S \in \text{Var}(k)$ . Let  $S = \cup_i S_i$  an affine open cover so that there exists closed embedding  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . For  $((M_I, F), u_{IJ}) \in C_{\mathcal{D}fil}(S/(\tilde{S}_I))$  the canonical map in  $D_{fil}(S_{\mathbb{C}}^{an}/(\tilde{S}_{I,\mathbb{C}}^{an}))$

$$T(D, DR)((M_I, F), u_{IJ}) : DR(S)(L\mathbb{D}_S((M_I, F), u_{IJ})) \rightarrow \mathbb{D}_S^v(DR(S)((M_I, F), u_{IJ}))$$

is an isomorphism.

- (iii) Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{SmVar}(k)$ . Then, for  $(M, F) \in C_{\mathcal{D}fil,rh}(X)$ , the map in  $D_{fil}(S_{\mathbb{C}}^{an})$

$$\begin{aligned}
T_*(f, DR)(M, F) &: DR(S)\left(\int_f (M, F)^{an}\right) \xrightarrow{DR(S)(T(f, an)(-))} DR(S)\left(\int_f (M, F)^{an}\right) \\
&\xrightarrow{T_*(f, DR)((M, F)^{an})} Rf_* DR(X)((M, F)^{an})
\end{aligned}$$

is an isomorphism if  $f$  is proper and  $o_{fil}T(f, DR)(M, F) =: T(f, DR)(M)$  is an isomorphism in  $D(S_{\mathbb{C}}^{an})$ .

- (iii)' Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{Var}(k)$ . Assume there exist a factorization  $f : X \xrightarrow{l} Y \times S \xrightarrow{p} S$  with  $Y \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $p$  the projection. Let  $S = \cup_i S_i$  an affine open cover so that there exists closed embedding  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . For  $((M_I, F), u_{IJ}) \in C_{\mathcal{D}fil}(X/(Y \times \tilde{S}_I))$  the canonical map in  $D_{fil}(S_{\mathbb{C}}^{an}/(\tilde{S}_{I,\mathbb{C}}^{an}))$

$$\begin{aligned}
T_*(f, DR)((M_I, F), u_{IJ}) &: DR(S)\left(\int_f ((M_I, F), u_{IJ})^{an}\right) \xrightarrow{(T(p_{\tilde{S}_I}, an))} \\
DR(S)\left(\int_f (((M_I, F), u_{IJ})^{an})\right) &\xrightarrow{T_*(f, DR)((M_I, F), u_{IJ})^{an}} Rf_* DR(X)((M_I, F), u_{IJ})^{an}
\end{aligned}$$

is an isomorphism if  $f$  is proper, and  $o_{fil}T(f, DR)((M_I, F), u_{IJ}) =: T(f, DR)((M_I, u_{IJ}))$  is an isomorphism in  $D(S_{\mathbb{C}}^{an}/(\tilde{S}_{I,\mathbb{C}}^{an}))$ .

(iv) Let  $S \in \text{SmVar}(k)$ . Then, for  $M, N \in \mathcal{C}_{\mathcal{D},rh}(S)$ , the map in  $D(S_{\mathbb{C}}^{an})$

$$\begin{aligned} & T(\otimes, DR)(M, N) : DR(S)(M^{an}) \otimes_{\mathbb{C}_{S_{\mathbb{C}}^{an}}} DR(S)(N^{an}) \\ & \xrightarrow{T(\otimes, DR)(M^{an}, N^{an})} DR(S)(M^{an} \otimes_{O_S} N^{an}) = DR(S)((M \otimes_{O_S} N)^{an}) \end{aligned}$$

is an isomorphism.

*Proof.* (i): Follows from the complex case : see [18].

(ii): Follows from the complex case which is standard.

(iii): Follows from (i) and GAGA.

(iv): Follows from (i). □

**Theorem 28.** Let  $k \subset \mathbb{C}$  a subfield. Let  $S \in \text{SmVar}(k)$ .

(i) For  $M, N \in D_{\mathcal{D},rh}(S)$ , we have using proposition 34 and theorem 27(iv) and (ii) the following canonical isomorphism in  $D(\mathbb{C})$

$$\begin{aligned} & DR(M, N) : R\text{Hom}_{D_S}(M, N) \otimes_k \mathbb{C} = Ra_{S^*}R\mathcal{H}om_{D_S}(M, N) \otimes_k \mathbb{C} \\ & \xrightarrow{Ra_{S^*}D(M, N)} \int_{a_S} (L\mathbb{D}_S M \otimes_{O_S}^L N) \otimes_k \mathbb{C} = DR(pt) \int_{a_S} (L\mathbb{D}_S M \otimes_{O_S}^L N) \otimes_k \mathbb{C} \\ & \xrightarrow{(T(\otimes, DR)(-, -) \circ T_*(a_S, DR)(-))^{-1}} Ra_{S^*}(\mathbb{D}_S^v DR(S)(M^{an}) \otimes DR(S)(N^{an})) \\ & \xrightarrow{Ra_{S^*}m(DR(S)(M^{an}), DR(S)(N^{an}))} R\text{Hom}_{\mathbb{C}_{S_{\mathbb{C}}^{an}}}(DR(S)(M^{an}), DR(S)(N^{an})) \end{aligned}$$

is an isomorphism.

(i)' For  $M, N \in D_{\mathcal{D},rh}(S)$ , the canonical map in  $D(\mathbb{C})$

$$DR(S)^{L_{D^M, N}} : R\text{Hom}_{D_S}(M, N) \otimes_k \mathbb{C} \xrightarrow{\sim} R\text{Hom}_{\mathbb{C}_{S_{\mathbb{C}}^{an}}}(DR(S)(M^{an}), DR(S)(N^{an}))$$

is equal to  $DR(M, N)$ , hence is an isomorphism.

(ii1) We have  $DR(S)(D_{\mathcal{D},rh}(S)) \subset D_{\mathbb{C}_S, c}(S_{\mathbb{C}}^{an})$ , that is the image of the class of a complex of  $D_S$  module with regular holonomic cohomology sheaves is a complex of presheaves on  $S_{\mathbb{C}}^{an}$  whose cohomology sheaves are constructible for a Zariski stratification of  $S$  defined over  $k$ .

(ii2) For  $M \in \text{PSh}_{\mathcal{D},rh}(S)$ ,  $DR(S)(M) \in P(S_{\mathbb{C}}^{an})$  that is is a perverse sheaf for a Zariski stratification of  $S$  defined over  $k$ .

*Proof.* (i): Follows from proposition 34 and theorem 27(iv) and (ii).

(i)': Follows from the following commutative diagram in  $D(\mathbb{C})$

$$\begin{array}{ccc} R\text{Hom}_{D_S}(M, N) \otimes_k \mathbb{C} = Ra_{S^*}R\mathcal{H}om_{D_S}(M, N) \otimes_k \mathbb{C} & \xrightarrow{DR(S)^{L_{D^M, N}}} & R\text{Hom}_{\mathbb{C}_{S_{\mathbb{C}}^{an}}}(DR(S)(M^{an}), DR(S)(N^{an})) \\ \downarrow Ra_{S^*}D(M, N) & & \uparrow m(-, -) \\ \int_{a_S} (L\mathbb{D}_S M \otimes_{O_S}^L N) \otimes_k \mathbb{C} = DR(pt) \int_{a_S} (L\mathbb{D}_S M \otimes_{O_S}^L N) \otimes_k \mathbb{C} & \xrightarrow{(T(\otimes, DR)(-, -) \circ T_*(a_S, DR)(-))^{-1}} & Ra_{S^*}(\mathbb{D}_S^v DR(S)(M^{an}) \otimes DR(S)(N^{an})) \end{array}$$

(ii): Similar to the proof of the complex case in [18]: follows by definition from the locally free case by theorem 22. □

#### 4.4.2 On the De Rahm functor for D modules on smooth algebraic varieties over a p-adic field $K \subset \mathbb{C}_p$

For  $S \in \text{AnSp}(K)$ , we denote by

$$\alpha(S) : \mathbb{B}_{dr,S} \hookrightarrow DR(S)(O\mathbb{B}_{dr,S})$$

the inclusion map in  $C_{\mathbb{B}_{dr,S}}(S^{pet})$ . In particular, we get for  $S \in \text{Var}(K)$ , the inclusion map

$$\alpha(S) : \mathbb{B}_{dr,S} \hookrightarrow DR(S)(O\mathbb{B}_{dr,S})$$

in  $C_{\mathbb{B}_{dr,S}}(S^{an,pet})$ .

For  $S \in \text{AnSp}(K)$ , we denote by

$$\iota(S) :: DR(S)(O\mathbb{B}_{dr,S}) \rightarrow \mathbb{B}_{dr,S} \otimes K_S, h \otimes k \otimes w \mapsto k \otimes (hw)$$

the canonical map in  $C_{\mathbb{B}_{dr,S}}(S^{pet})$ . In particular, we get for  $S \in \text{Var}(K)$ , the canonical map

$$\iota(S) : DR(S)(O\mathbb{B}_{dr,S}) \rightarrow \mathbb{B}_{dr,S} \otimes K_S$$

in  $C_{\mathbb{B}_{dr,S}}(S^{an,pet})$ .

We have the following theorem

**Theorem 29.** *Let  $K \subset \mathbb{C}_p$  a p adic field.*

(i) *Let  $S \in \text{AnSm}(K)$ . The inclusion map in  $C_{\mathbb{B}_{dr,S}}(S^{an,pet})$*

$$\alpha(S) : \mathbb{B}_{dr,S} \hookrightarrow DR(S)(O\mathbb{B}_{dr,S}).$$

*is a quasi-isomorphism.*

(i)' *Let  $S \in \text{AnSm}(K)$ . the canonical map in  $C_{\mathbb{B}_{dr,S}}(S^{an,pet})$*

$$\iota(S) : DR(S)(O\mathbb{B}_{dr,S}) \rightarrow \mathbb{B}_{dr,S} \otimes K_S$$

*is a quasi-isomorphism.*

(ii) *Let  $S \in \text{Var}(K)$ . Let  $D = \cup D_i \subset S$  a normal crossing divisor and denote  $j : S^\circ := S \setminus D \hookrightarrow S$  the open embedding. The inclusion map in  $C_{\mathbb{B}_{dr,S}}(S^{an,pet})$*

$$\alpha(S) : \mathbb{B}_{dr,S}(\log D) \hookrightarrow \Omega_S^\bullet(\log D) \otimes_{O_S} O\mathbb{B}_{dr,S}(\log D) = F^0 DR(S)(j_* \text{Hdg}(O_{S^\circ}, F_b) \otimes_{O_S} (O\mathbb{B}_{dr,S}, F)).$$

*where  $j_* \text{Hdg}(O_S, F_b) = (j_* O_{S^\circ}, V_D)$  with  $V_D$  the  $V$ -filtration (see section 5) that is the filtration by order of the pole in this case, is a quasi-isomorphism.*

(iii) *Let  $S \in \text{AnSm}(K)$ . The functor*

$$\text{Vect}_{\mathcal{D}}(S) \rightarrow D_{\mathbb{B}_{dr,S}}(S^{an,pet}), (M, F) \mapsto F^0 DR(S)((M, F)^{an} \otimes_{O_S} (O\mathbb{B}_{dr,S}, F))$$

*is fully faithful whose inverse on the image is given by*

$$N \in \text{Shv}_{\mathbb{B}_{dr,S}}(S^{an,pet}) \mapsto \text{Re}_*((N, F) \otimes_{\mathbb{B}_{dr,S}} (O\mathbb{B}_{dr,S}, F)).$$

*where  $e : S^{pet} \rightarrow S^{et}$  is the morphism of site given by the inclusion functor.*

*Proof.* (i): See [27].

(i)': Follows from (i) by duality.

(i): See [21].

(ii): See [21].

□

**Definition 50.** Let  $K \subset \mathbb{C}_p$  a  $p$  adic field.

(i) Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{AnSm}(K)$ . We have for  $(M, F) \in C_{\mathcal{D}fil}(X)$  the canonical map in  $D_{\mathbb{B}_{dr,fil}}(S)$

$$\begin{aligned}
& T^{\mathbb{B}_{dr}}(f, DR)(M, F) : DR(S) \left( \int_f (M, F) \otimes_{O_S} (OB_{dr,S}, F) \right) \\
& \xrightarrow{=} (\Omega_S^\bullet, F_b) \otimes_{O_S} (OB_{dr,S}, F) \otimes_{O_S} Rf_*((D_{X \leftarrow S}, F^{ord}) \otimes_{D_X}^L (M, F)) \\
& \xrightarrow{\iota(S)} Rf_*((D_{X \leftarrow S}, F^{ord}) \otimes_{D_X}^L (M, F)) \otimes_{O_S} \mathbb{B}_{dr,S} \otimes_{D_S} K_S \\
& \xrightarrow{T^{mod}(f, \otimes)(D_{X \leftarrow S} \otimes_{D_X}^L (M, F), \mathbb{B}_{dr,S}) \otimes I} Rf_*((D_{X \leftarrow S}, F^{ord}) \otimes_{D_X}^L (M, F) \otimes_{O_X} f^{*mod} \mathbb{B}_{dr,S}) \otimes_{D_S} K_S \\
& \xrightarrow{=} Rf_*((D_{X \leftarrow S}, F^{ord}) \otimes_{D_X}^L (M, F) \otimes_{O_X} \mathbb{B}_{dr,X}) \otimes_{D_S} K_S \\
& \xrightarrow{T(f, \otimes)((D_{X \leftarrow S}, F^{ord}) \otimes_{D_X}^L (M, F) \otimes_{O_X} \mathbb{B}_{dr,X}, K_S)} Rf_*(f^* K_S \otimes_{f^* D_S}^L (D_{X \leftarrow S}, F^{ord}) \otimes_{D_X}^L (M, F) \otimes_{O_X} \mathbb{B}_{dr,X}) \\
& \xrightarrow{=} Rf_*(K_X \otimes_{O_X} \mathbb{B}_{dr,X} \otimes_{D_X}^L (M, F)) \xrightarrow{\iota(X)} Rf_*((\Omega_X^\bullet, F_b) \otimes_{O_X} (M, F) \otimes_{O_X} (OB_{dr,X}, F)) \\
& =: Rf_* DR(X)((M, F) \otimes_{O_X} (OB_{dr,X}, F))
\end{aligned}$$

which is an isomorphism.

(i)' Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{AnSp}(K)$ . Assume there exist a factorization  $f : X \xrightarrow{l} Y \times S \xrightarrow{p} S$  with  $Y \in \text{AnSm}(K)$ ,  $l$  a closed embedding and  $p$  the projection. Let  $S = \cup_i S_i$  an affine open cover so that there exists closed embedding  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{AnSm}(K)$ . We have for  $((M_I, F), u_{IJ}) \in C_{\mathcal{D}fil}(X/(Y \times \tilde{S}_I))$  the canonical map in  $D_{\mathbb{B}_{dr,fil}}(S/(\tilde{S}_I))$

$$\begin{aligned}
& T^{\mathbb{B}_{dr}}(f, DR)((M_I, F), u_{IJ}) : DR(S) \left( \int_f ((M_I, F), u_{IJ}) \otimes_{O_S} (OB_{dr,(\tilde{S}_I)}, F) \right) := \\
& (\Omega_{\tilde{S}_I}^\bullet \otimes_{O_{\tilde{S}_I}} (OB_{dr,(\tilde{S}_I)}, F) \otimes_{O_{\tilde{S}_I}} p_{\tilde{S}_I*} E(\Omega_{Y \times \tilde{S}_I / \tilde{S}_I}^\bullet \otimes_{O_{Y \times \tilde{S}_I}} (M_I, F)), DR(fu_{IJ})) \xrightarrow{=} \\
& (\Omega_{\tilde{S}_I}^\bullet \otimes_{O_{\tilde{S}_I}} (OB_{dr,(\tilde{S}_I)}, F) \otimes_{O_{\tilde{S}_I}} D_{\tilde{S}_I} \otimes_{D_{\tilde{S}_I}} p_{\tilde{S}_I*} E(\Omega_{Y \times \tilde{S}_I / \tilde{S}_I}^\bullet \otimes_{O_{Y \times \tilde{S}_I}} D_{Y \times \tilde{S}_I} \otimes_{D_{Y \times \tilde{S}_I}} (M_I, F)), DR(fu_{IJ})) \\
& \xrightarrow{w(Y \times \tilde{S}_I) \circ T^{mod}(p_{\tilde{S}_I}, \otimes)(-, -)} \\
& p_{\tilde{S}_I*} E(\Omega_{Y \times \tilde{S}_I}^\bullet \otimes_{O_{Y \times \tilde{S}_I}} (OB_{dr,(Y \times \tilde{S}_I)}, F) \otimes_{O_{Y \times \tilde{S}_I}} D_{Y \times \tilde{S}_I} \otimes_{D_{Y \times \tilde{S}_I}} (M_I, F)), DR(u_{IJ})) \\
& \xrightarrow{=} p_{\tilde{S}_I*} E(\Omega_{Y \times \tilde{S}_I}^\bullet \otimes_{O_{Y \times \tilde{S}_I}} (OB_{dr,(Y \times \tilde{S}_I)}, F) \otimes_{O_{Y \times \tilde{S}_I}} (M_I, F)), DR(u_{IJ})) \\
& =: Rf_* DR(X)((M_I, F), u_{IJ}) \otimes_{O_X} (OB_{dr,(Y \times \tilde{S}_I)}, F)
\end{aligned}$$

where  $w(Y \times \tilde{S}_I)$  is the wedge product.

(ii) Let  $S \in \text{AnSm}(K)$ . We have for  $(M, F) \in C_{\mathcal{D}fil}(S)$  the canonical map in  $D_{fil}(S)$

$$T(D, DR)(M, F) : DR(S)(\mathbb{D}_S(M, F)) \rightarrow \mathbb{D}_S^v(DR(S)(M, F))$$

(ii)' Let  $S \in \text{AnSp}(K)$ . Let  $S = \cup_i S_i$  an affine open cover so that there exists closed embedding  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{AnSm}(K)$ . We have for  $((M_I, F), u_{IJ}) \in C_{\mathcal{D}fil}(S/(\tilde{S}_I))$  the canonical map in  $D_{fil}(S/(\tilde{S}_I))$

$$T(D, DR)((M_I, F), u_{IJ}) : DR(S)(L\mathbb{D}_S((M_I, F), u_{IJ})) \rightarrow \mathbb{D}_S^v(DR(S)((M_I, F), u_{IJ}))$$

- Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{Var}(K)$ . Assume there exist a factorization  $f : X \xrightarrow{l} Y \times S \xrightarrow{p} S$  with  $Y \in \text{SmVar}(K)$ ,  $l$  a closed embedding and  $p$  the projection. Let  $S = \cup_i S_i$  an affine

open cover so that there exists closed embedding  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(K)$ . We have for  $((M_I, F), u_{IJ}) \in C_{\mathcal{D}fil}(S/(\tilde{S}_I)^{an})$  the canonical map in  $D_{fil}(X^{an}/(Y \times \tilde{S}_I)^{an})$

$$\begin{aligned} f^! DR(S)((M_I, F), u_{IJ}) &= \Gamma_X \mathbb{D}^v p^! \mathbb{D} DR(S)((M_I, F), u_{IJ})^{an} \\ &\xrightarrow{\mathbb{D}T^*(p, DR)(-)} \Gamma_X DR(Y \times S)((p_{\tilde{S}_I}^{*mod}((M_I, F), u_{IJ})^{an})) \\ &\xrightarrow{T^w(j, \otimes)(-)^{-1}} DR(Y \times S)(\Gamma_X(p_{\tilde{S}_I}^{*mod}((M_I, F), u_{IJ})^{an})) \xrightarrow{DR(Y \times S)(T(\gamma, an)(-):=(I, T(j, an)(-)))} \\ &DR(Y \times S)((\Gamma_X p_{\tilde{S}_I}^{*mod}((M_I, F), u_{IJ})^{an}) =: DR(X)(f^{*mod, \Gamma}((M_I, F), u_{IJ})). \end{aligned}$$

- Let  $S \in \text{Var}(K)$ . Denote by  $\Delta_S : S \hookrightarrow S \times S$  the graph embedding and  $p_1 : S \times S \rightarrow S$  and  $p_2 : S \times S \rightarrow S$  the projections. Let  $S = \cup_i S_i$  an affine open cover so that there exists closed embedding  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(K)$ . We have for  $((M_I, F), u_{IJ}), ((N_I, F), u_{IJ}) \in C_{\mathcal{D}fil}(S/(\tilde{S}_I)^{an})$  the canonical map in  $D_{fil}(S^{an}/(\tilde{S}_I)^{an})$

$$\begin{aligned} T(\otimes, DR)((M_I, F), u_{IJ}), ((N_I, F), u_{IJ}) &: DR(S)((M_I, F), u_{IJ})^{an} \otimes_{\mathbb{C}_S} DR(S)((N_I, F), u_{IJ})^{an} \\ &\xrightarrow{\cong} R\Delta_S^!((p_1^* DR(S)((M_I, F), u_{IJ})^{an}) \otimes_{\mathbb{C}_S} p_2^* DR(S)((N_I, F), u_{IJ})^{an})) \\ &\xrightarrow{\cong} R\Delta_S^!((p_1^! DR(S)((M_I, F), u_{IJ})^{an}) \otimes_{\mathbb{C}_S} p_2^! DR(S)((N_I, F), u_{IJ})^{an})) [2d_S] \\ &\xrightarrow{T^!(p_1, DR)(-) \otimes T^!(p_2, DR)(-)} \Delta_S^! DR(S \times S)((p_1^{*mod}((M_I, F), u_{IJ}) \otimes_{O_{S \times S}} p_2^{*mod}((N_I, F), u_{IJ}))^{an}) \\ &\xrightarrow{T^!(\Delta_S, DR)(-)} DR(S)((L\Delta_S^{*mod}((p_1^{*mod}((M_I, F), u_{IJ}) \otimes_{O_{S \times S}} p_2^{*mod}((N_I, F), u_{IJ})))^{an})) \\ &\xrightarrow{\cong} DR(S)((((M_I, F), u_{IJ}) \otimes_{O_S}^L ((N_I, F), u_{IJ}))^{an}). \end{aligned}$$

**Theorem 30.** (i) Let  $j : S^o \hookrightarrow S$  an open embedding with  $S \in \text{SmVar}(K)$ . Then, for  $M \in C_{\mathcal{D}, rh}(S^o)$ , the map in  $C(S^{an})$

$$DR(S)(T(j, an)(M)) : DR(S)((j_* M)^{an}) \rightarrow DR(S)(j_*(M^{an}))$$

is a quasi-isomorphism.

- (ii) Let  $S \in \text{Var}(K)$ . Then, for  $((M_I, F), u_{IJ}) \in C_{\mathcal{D}fil, rh}(S)$ , the map in  $D_{\mathbb{B}dr, fil}(S^{an})$

$$T(D, DR)(M, F) : DR(S)(L\mathbb{D}_S((M_I, F), u_{IJ})^{an}) \rightarrow \mathbb{D}_S^v(DR(S)((M_I, F), u_{IJ})^{an}))$$

is an isomorphism.

- (iii) Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{SmVar}(K)$ . Then, for  $(M, F) \in C_{\mathcal{D}fil, rh}(X)$ , the map in  $D_{\mathbb{B}dr, fil}(S^{an})$

$$\begin{aligned} T^{Bdr}(f, DR)(M, F) &: DR(S)((\int_f (M, F)^{an} \otimes_{O_S} (OB_{dr, S}, F)) \xrightarrow{DR(S)(T(f, an)(M, F))} \\ &DR(S)(\int_f ((M, F)^{an}) \otimes_{O_S} (OB_{dr, S}, F)) \xrightarrow{T^{Bdr}(f, DR)((M, F)^{an})} Rf_* DR(X)((M, F)^{an} \otimes_{O_X} (OB_{dr, X}, F)) \end{aligned}$$

is an isomorphism if  $f$  is proper.

- (iii)' Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{Var}(K)$ . Then, for  $((M_I, F), u_{IJ}) \in C_{\mathcal{D}fil}(X/(Y \times \tilde{S}_I)^{an})$  the map in  $D_{\mathbb{B}dr, fil}(S^{an}/(\tilde{S}_I)^{an})$

$$\begin{aligned} T^{Bdr}(f, DR)((M_I, F), u_{IJ}) &: DR(S)(\int_f ((M_I, F), u_{IJ})^{an} \otimes_{O_S} (OB_{dr, (\tilde{S}_I)}, F)) \xrightarrow{DR(S)((T(p_{\tilde{S}_I}, an)(-)))} \\ &DR(S)(\int_f (((M_I, F), u_{IJ})^{an}) \otimes_{O_S} (OB_{dr, (\tilde{S}_I)}, F)) \xrightarrow{T^{Bdr}(f, DR)((M_I, F), u_{IJ})^{an}} \\ &Rf_* DR(X)((M_I, F), u_{IJ})^{an} \otimes_{O_S} (OB_{dr, (Y \times \tilde{S}_I)}, F)) \end{aligned}$$

is an isomorphism if  $f$  is proper.

*Proof.* Similar to the proof of theorem 27. For (iii) and (iii)', we use GAGA for proper morphism of algebraic varieties over a  $p$ -adic field.  $\square$

## 5 The De Rham modules over a field $k$ of characteristic 0 : the Kashiwara Malgrange $V$ -filtration and the Hodge filtration in the geometric case

### 5.1 The Kashiwara Malgrange $V$ filtration for geometric $D$ modules on smooth algebraic varieties over a field of characteristic zero and the nearby and vanishing cycle functors.

Let  $k \subset \mathbb{C}$  a subfield. For  $S \in \text{Var}(k)$ , consider  $\pi := \pi_{k/\mathbb{C}}(S) : S_{\mathbb{C}} := S \otimes_k \mathbb{C} \rightarrow S$  the projection so that we have the injective map in  $\text{PSh}_{O_S}(S_{\mathbb{C}})$

$$n_{k/\mathbb{C}}(O_S) : \pi^* O_S \hookrightarrow O_{S_{\mathbb{C}}} := \pi^{*mod} O_S := \pi^* O_S \otimes_k \mathbb{C}, \quad h \mapsto n_{k/\mathbb{C}}(O_S)(h) := h \otimes 1.$$

For  $M \in \text{PSh}_{O_S}(S)$ , we have (see section 2) the canonical morphism in  $\text{PSh}_{O_S}(S_{\mathbb{C}})$

$$n_{O_S/O_{S_{\mathbb{C}}}}(M) : \pi^* M \rightarrow \pi^{*mod} M := \pi^* M \otimes_{\pi^* O_S} O_{S_{\mathbb{C}}}, \quad m \mapsto n_{O_S/O_{S_{\mathbb{C}}}}(M)(m) := m \otimes 1$$

For  $S \in \text{SmVar}(k)$  and  $M \in \text{PSh}_{\mathcal{D}}(S)$

$$n_{O_S/O_{S_{\mathbb{C}}}}(M) : \pi^* M \rightarrow \pi^{*mod} M = \pi^* M \otimes_{\pi^* O_S} O_{S_{\mathbb{C}}}, \quad m \mapsto n_{O_S/O_{S_{\mathbb{C}}}}(M)(m) := m \otimes 1$$

is a morphism in  $\text{PSh}_{D_S}(S_{\mathbb{C}})$ , that is is a morphism of  $\pi^* D_S$  modules.

**Definition 51.** *Let  $k$  a field of characteristic zero. Let  $S \in \text{SmVar}(k)$ .*

(i) *Let  $D = V(s) \subset S$  be a smooth (Cartier) divisor, where  $s \in \Gamma(S, L)$  is a section of the line bundle  $L = L_D$  associated to  $D$ . Let  $M \in \text{PSh}_{\mathcal{D}}(S)$ . A  $V_D$ -filtration  $(M, V_D)$  for  $M$  (see [10]) is called a Kashiwara-Malgrange  $V_D$ -filtration for  $M$  if*

- $V_{D,k}M$  are coherent  $V_{D,0}D_S$  modules for all  $k \in \mathbb{Z}$ , that is  $(M, V_D)$  is a good filtration, in particular  $M \in \text{PSh}_{\mathcal{D},c}(S)$  is coherent
- $sV_{D,k}M = V_{D,k-1}M$  for  $k \ll 0$ ,
- all eigenvalues of  $s\partial_s : \text{Gr}_{V_D,k} := V_{D,k}M/V_{D,k-1}M \rightarrow \text{Gr}_{V_D,k}M := V_{D,k}M/V_{D,k-1}M$  have real part between  $k-1$  and  $k$ .

*Almost by definition, a Kashiwara-Malgrange  $V_D$ -filtration for  $M$  if it exists is unique, so that we denote it by  $(M, V_D) \in \text{PSh}_{O_S \text{fil}}(S)$  and  $(M, V_D)$  is strict. In particular if  $m : (M_1, F) \rightarrow (M_2, F)$  a morphism with  $(M_1, F), (M_2, F) \in \text{PSh}_{\mathcal{D}(2)\text{fil}}(S)$  such that  $M_1$  and  $M_2$  admit the Kashiwara-Malgrange filtration for  $D \subset S$ , we have  $m(V_{D,q}F^p M_1) \subset V_{D,q}F^p M_2$ , that is we get  $m : (M_1, F, V_D) \rightarrow (M_2, F, V_D)$  a filtered morphism, and if  $0 \rightarrow M' \rightarrow M \rightarrow M'' \rightarrow 0$  is an exact sequence,  $0 \rightarrow (M', V_D) \rightarrow (M, V_D) \rightarrow (M'', V_D) \rightarrow 0$  is an exact sequence (strictness).*

(ii) *More generally, let  $Z = V(s_1, \dots, s_r) = D_1 \cap \dots \cap D_r \subset S$  be a smooth Zariski closed subset, where  $s_i \in \Gamma(S, L_i)$  is a section of the line bundle  $L = L_{D_i}$  associated to  $D_i$ . Let  $M \in \text{PSh}_{\mathcal{D}}(S)$ . A  $V_Z$ -filtration  $(M, V_Z)$  for  $M$  (see [10]) is called a Kashiwara-Malgrange  $V_Z$ -filtration for  $M$  if*

- $V_{Z,k}M$  are coherent  $V_{Z,0}O_S$  modules for all  $k \in \mathbb{Z}$ ,
- $\sum_{i=1}^r s_i V_{Z,k}M = V_{Z,k-1}M$  for  $k \ll 0$ ,
- all eigenvalues of  $\sum_{i=1}^r s_i \partial_{s_i} : \text{Gr}_{V_Z,k}M := V_{Z,k}M/V_{Z,k-1}M \rightarrow \text{Gr}_{V_Z,k}^V M := V_{Z,k}M/V_{Z,k-1}M$  have real part between  $k-1$  and  $k$ .

Almost by definition, a Kashiwara-Malgrange  $V_Z$ -filtration for  $M$  if it exists is unique (see [26]), so that we denote it by  $(M, V_Z) \in \text{PSh}_{\mathcal{O}_S \text{fil}}(S)$  and  $(M, V_Z)$  is strict. In particular if  $m : (M_1, F) \rightarrow (M_2, F)$  a morphism with  $(M_1, F), (M_2, F) \in \text{PSh}_{\mathcal{D}(2)\text{fil}}(S)$  such that  $M_1$  and  $M_2$  admit the Kashiwara-Malgrange filtration for  $D \subset S$ , we have  $m(V_{Z,q} F^p M_1) \subset V_{Z,q} F^p M_2$ , that is we get  $m : (M_1, F, V_Z) \rightarrow (M_2, F, V_Z)$  a filtered morphism, and if  $0 \rightarrow M' \rightarrow M \rightarrow M'' \rightarrow 0$  is an exact sequence,  $0 \rightarrow (M', V_Z) \rightarrow (M, V_Z) \rightarrow (M'', V_Z) \rightarrow 0$  is an exact sequence (strictness).

**Definition 52.** Let  $k$  a field of characteristic zero. Let  $S \in \text{SmVar}(k)$ . Let  $D = V(s) \subset S$  a (Cartier) divisor, where  $s \in \Gamma(S, L)$  is a section of the line bundle  $L = L_D$  associated to  $D$ . We then have the graph embedding  $i : S \hookrightarrow L$ ,  $i(x) := (x, s(x))$ . Let  $M \in \text{PSh}_{\mathcal{D},c}(S)$ . If the Kashiwara-Malgrange  $V_S$ -filtration exist on  $i_{*mod}M$  and the eigenvalues of  $s\partial_s$  are rational numbers, we refine the  $V_S$ -filtration to all rational numbers as follows : for  $\alpha = k - 1 + r/q \in \mathbb{Q}$ ,  $k, q, r \in \mathbb{Z}$ ,  $q \leq 0$ ,  $0 \leq r \leq q - 1$ , we set

$$V_{S,\alpha}M := q_{V,k}^{-1}(\oplus_{k-1 < \beta \leq \alpha} \text{Gr}_{k,\beta}^{V_S} M \subset V_{S,k}M$$

with  $\text{Gr}_{k,\beta}^{V_S} M := \ker(\partial_s s - \beta I) \subset \text{Gr}_k^{V_S} M$  and  $q_{V,k} : V_{S,k}M \rightarrow \text{Gr}_k^{V_S} M$  is the projection. We set similarly

$$V_{S,<\alpha}M := q_{V,k}^{-1}(\oplus_{k-1 < \beta < \alpha} \text{Gr}_{k,\beta}^{V_S} M \subset V_{S,k}M$$

The Hodge filtration induced on  $\text{Gr}_\alpha^V M$  is

$$F^p \text{Gr}_\alpha^V M := (F^p M \cap V_{S,\alpha}M) / (F^p M \cap V_{S,<\alpha}M)$$

We call it the rational Kashiwara-Malgrange  $V_S$ -filtration of  $i_{*mod}M$ . We set for  $\alpha \in \mathbb{Q}$ ,  $V_{D,\alpha}M := i^*V_{S,\alpha}i_{*mod}M$  and we call it for short the rational Kashiwara-Malgrange  $V_D$ -filtration of  $M$ .

**Definition 53.** Let  $k$  a field of characteristic zero. Let  $S \in \text{SmVar}(k)$ . Let  $D = V(s) \subset S$  a divisor with  $s \in \Gamma(S, L)$  and  $L$  a line bundle ( $S$  being smooth,  $D$  is Cartier). For  $M \in \text{PSh}_{\mathcal{D},c}(S)$  such that the rational Kashiwara-Malgrange  $V_S$ -filtration on  $i_{*mod}M$  exists, we define, denoting for  $k \in \mathbb{Q}$ ,  $V_{D,k}M := i^*V_{S,k}i_{*mod}M$

- the nearby cycle functor

$$\psi_D M := \oplus_{-1 \leq \alpha < 0} \text{Gr}_{V_S,\alpha} i_{*mod}M = \oplus_{-1 \leq \alpha < 0} \text{Gr}_{V_D,\alpha} M \in \text{PSh}_{\mathcal{D},D}(S),$$

- the vanishing cycle functor

$$\phi_D M := \oplus_{-1 < \alpha \leq 0} \text{Gr}_{V_S,\alpha} i_{*mod}M = \oplus_{-1 < \alpha \leq 0} \text{Gr}_{V_D,\alpha} M \in \text{PSh}_{\mathcal{D},D}(S),$$

- the canonical maps in  $\text{PSh}_{\mathcal{D},D}(S)$

$$\text{can}(M) := (\partial_s, I) : \psi_D M \rightarrow \phi_D M, \text{ var}(M) := (I, s) : \phi_D M \rightarrow \psi_D M.$$

By the complex case (see [20]), after considering a subfield  $k_0 \subset k$  and an embedding  $\sigma : k_0 \hookrightarrow \mathbb{C}$  we have

- for  $M \in \text{PSh}_{\mathcal{D},h}(S)$ ,  $\psi_D M, \phi_D M \in \text{PSh}_{\mathcal{D},h}(S)$ .
- for  $M \in \text{PSh}_{\mathcal{D},rh}(S)$ ,  $\psi_D M, \phi_D M \in \text{PSh}_{\mathcal{D},rh}(S)$ .

**Theorem 31.** Let  $k \subset \mathbb{C}$  a subfield. Let  $S \in \text{SmVar}(k)$ . Let  $D = V(s) \subset S$  a divisor with  $s \in \Gamma(S, L)$  and  $p : L \rightarrow S$  a line bundle ( $S$  being smooth,  $D$  is Cartier), so that we have the closed embedding  $i : S \hookrightarrow L$ ,  $i(x) = (x, s(x))$  and  $D = i^{-1}(s_0)$ ,  $s_0$  being the zero section. For  $M \in \text{PSh}_{\mathcal{D},c}(S)$ , such that the rational Kashiwara-Malgrange  $V_D$ -filtration on  $M$  exists, we have the canonical isomorphism in  $D_{c,k}(S_{\mathbb{C}}^{an})$

$$T(\psi_D, DR)(M) := B(M) \circ A(M)^{-1} : DR(S)(\psi_D M^{an}) \xrightarrow{\sim} \psi_D DR(S)(M^{an})$$

with, for  $S = \cup_{i=1}^s S_i$  an open affine cover such that  $D \cap S_i = V(f_i) \subset S_i$  is given by  $f_i \in \Gamma(S_i, \mathcal{O}_{S_i})$ , denoting  $q : L_i := p^{-1}(S_i) \rightarrow \mathbb{A}_k^1$  the projection and  $j_i : S_i \hookrightarrow S$  the open embeddings,

- the isomorphism in  $D_{c,k}(S_{\mathbb{C}}^{an})$

$$\begin{aligned} A(M) &: (\oplus_{i=1}^s \oplus_{-1 \leq \alpha < 0} \text{Cone}(\partial_s : DR(L_i/\mathbb{A}_k^1)((V_{D\alpha}M)^{an}) \otimes_{O_S} s^{\alpha+1} O_{S_{\mathbb{C}}^{an}}[\log s] \\ &\quad \rightarrow DR(L_i/\mathbb{A}_k^1)((V_{D\alpha}M)^{an}) \otimes_{O_S} s^{\alpha} O_{S_{\mathbb{C}}^{an}}[\log s]) \xrightarrow{(j_i^*)} \dots \\ &\rightarrow (\oplus_{i=1}^s DR(S_i)(\psi_D M^{an}) \xrightarrow{j_i^*} \dots) \xrightarrow{((j_i^*), 0)^{-1}} (DR(S)(\psi_D M^{an})), (\sum_j m_j \otimes (\log s)^j, m') \mapsto [m_0], \end{aligned}$$

- and the isomorphism in  $D_{c,k}(S_{\mathbb{C}}^{an})$

$$\begin{aligned} B(M) &: (\oplus_{i=1}^s \oplus_{-1 \leq \alpha < 0} \text{Cone}(\partial_s : V_{D\alpha} DR(L_i/\mathbb{A}_k^1)(M^{an}) \otimes_{O_S} s^{\alpha+1} O_{S_{\mathbb{C}}^{an}}[\log s] \\ &\quad \rightarrow V_{D\alpha} DR(L_i/\mathbb{A}_k^1)(M^{an}) \otimes_{O_S} s^{\alpha} O_{S_{\mathbb{C}}^{an}}[\log s]) \xrightarrow{(j_i^*)} \dots \\ &\quad \rightarrow (\oplus_{i=1}^s DR(p^* O_{\mathbb{A}_k^1})(i^* \pi_* \pi^* DR(L_i/\mathbb{A}_k^1)(M^{an})) \xrightarrow{(j_i^*)} \dots) \\ &\xrightarrow{=} (\oplus_{i=1}^s DR(p^* O_{\mathbb{A}_k^1})(\psi_D(DR(L_i/\mathbb{A}_k^1)(M^{an}))) \xrightarrow{(j_i^*)} \dots) \xrightarrow{((j_i^*), 0)^{-1}} \psi_D DR(S)(M^{an}), \\ &\quad (\sum_j m_j \otimes (\log s)^j, m') \mapsto \sum_j (\log s)^j m_j, \end{aligned}$$

so that  $T(\psi_D, DR)(M) \circ DR(S)(s\partial_s) = N \circ T(\psi_D, DR)(M)$  where  $N := \log T \in \text{Hom}(\psi_D DR(S)(M^{an}), \psi_D DR(S)(M^{an}))$  is induced by the monodromy automorphism  $T : \tilde{S}^o \xrightarrow{\sim} \tilde{S}^o$  of the universal covering  $\pi : \tilde{S}^o \rightarrow S^o := S \setminus D$ . As is the rest of this paper, we denote for short  $M^{an} := \text{an}_S^{*mod} M = (\pi_{k/\mathbb{C}}(S)^{*mod} M)^{an} \in \text{PSh}_{\mathcal{D},c}(S_{\mathbb{C}}^{an})$

with  $\text{an}_S : S_{\mathbb{C}}^{an} \xrightarrow{\text{an}_S} S_{\mathbb{C}} \xrightarrow{\pi_{k/\mathbb{C}}(S)} S$ .

*Proof.* See [26]. □

**Definition-Proposition 5.** Let  $k$  a field of characteristic zero. Let  $S \in \text{SmVar}(k)$ . Let  $D = V(s) \subset S$  a divisor with  $s \in \Gamma(S, L)$  and  $L$  a line bundle ( $S$  being smooth,  $D$  is Cartier), so that we have the closed embedding  $i : S \hookrightarrow L$ ,  $i(x) = (x, s(x))$  and  $D = i^{-1}(s_0)$ ,  $s_0$  being the zero section. For  $M \in \text{PSh}_{\mathcal{D},c}(S)$ , such that the rational Kashiwara-Malgrange  $V_D$ -filtration on  $M$  exists, we have the canonical morphism in  $D(S)$

$$T_{alg}(\psi_D, DR)(M) := B_{alg}(M) \circ A_{alg}(M)^{-1} : DR(S)(\psi_D M) \xrightarrow{\sim} \psi_D DR(S)(M)$$

with, for  $S = \cup_{i=1}^s S_i$  an open affine cover such that  $D \cap S_i = V(f_i) \subset S_i$  is given by  $f_i \in \Gamma(S_i, O_{S_i})$ , denoting  $q : L_i := p^{-1}(S_i) \rightarrow \mathbb{A}_k^1$  the projection and  $j_i : S_i \hookrightarrow S$  the open embeddings,

- the isomorphism in  $D_c(S)$

$$\begin{aligned} A_{alg}(M) &: (\oplus_{i=1}^s \oplus_{-1 \leq \alpha < 0} \text{Cone}(\partial_s : DR(L_i/\mathbb{A}_k^1)(V_{D\alpha}M) \otimes_{O_S} s^{\alpha+1} O_S[\log s] \\ &\quad \rightarrow DR(L_i/\mathbb{A}_k^1)(V_{D\alpha}M) \otimes_{O_S} s^{\alpha} O_S[\log s]) \xrightarrow{(j_i^*)} \dots \\ &\rightarrow (\oplus_{i=1}^s DR(S_i)(\psi_D M) \xrightarrow{j_i^*} \dots) \xrightarrow{((j_i^*), 0)^{-1}} (DR(S)(\psi_D M)), (\sum_j m_j \otimes (\log s)^j, m') \mapsto [m_0] \end{aligned}$$

- and morphism in  $D_c(S)$

$$\begin{aligned} B_{alg}(M) &: (\oplus_{i=1}^s \oplus_{-1 \leq \alpha < 0} \text{Cone}(\partial_s : V_{D\alpha} DR(L_i/\mathbb{A}_k^1)(M) \otimes_{O_S} s^{\alpha+1} O_S[\log s] \\ &\quad \rightarrow V_{D\alpha} DR(L_i/\mathbb{A}_k^1)(M) \otimes_{O_S} s^{\alpha} O_S[\log s]) \xrightarrow{(j_i^*)} \dots \\ &\quad \rightarrow (\oplus_{i=1}^s DR(p^* O_{\mathbb{A}_k^1})(i^* \pi_* \pi^{*mod} \text{Hom}(\mathcal{A}_{S^o}, DR(L_i/\mathbb{A}_k^1)(M))) \xrightarrow{(j_i^*)} \dots) \\ &\xrightarrow{=} (\oplus_{i=1}^s DR(p^* O_{\mathbb{A}_k^1})(\psi_D(DR(L_i/\mathbb{A}_k^1)(M))) \xrightarrow{(j_i^*)} \dots) \xrightarrow{((j_i^*), 0)^{-1}} \psi_D DR(S)(M), \\ &\quad (\sum_j m_j \otimes (\log s)^j, m') \mapsto \sum_j (\log s)^j m_j, \end{aligned}$$



with  $\log s \in \mathcal{H}om(\mathcal{A}_{S^\circ}, p^*O_{\mathbb{A}_k^1})$ , so that  $T_{alg}(\psi_D, DR)(M) \circ DR(S)(s\partial_s) = N \circ T_{alg}(\psi_D, DR)(M)$  where  $N := \log T \in \mathcal{H}om(\psi_D DR(S)(M), \psi_D DR(S)(M))$  is induced by the monodromy automorphism  $T : \tilde{S}^\circ \xrightarrow{\sim} \tilde{S}^\circ$  of the universal covering  $\pi : \tilde{S}^\circ := \varinjlim_{n \in \mathbb{N}} \text{Spec}(L[t]/(t^n - s)) \rightarrow S^\circ := S \setminus D$  and  $\mathcal{A}_{S^\circ} := (S^\circ \times_{S^\circ} \times_{S^\circ} S^\circ) \in \text{Fun}(\Delta^\bullet, \text{Var}(k)^{sm}/S^\circ)$  the diagram of lattices (see [4]). By definition we have for  $k \subset \mathbb{C}$  a subfield, the following commutative diagram in  $D(S_{\mathbb{C}}^{an})$

$$\begin{array}{ccc} (DR(S)(\psi_D M))^{an} & \xrightarrow{T^w(an, \otimes)(M)} & DR(S)((\psi_D M)^{an}) \\ T_{alg}(\psi_D, DR)(M) \downarrow & & \downarrow T(\psi_D, DR)(M) \\ (\psi_D DR(S)(M))^{an} & \xrightarrow{T(\psi_D, an)(M)} & \psi_D(DR(S)(M)^{an}) \end{array}$$

where  $T(\psi_D, an)(M)$  is the isomorphism given in [1].

*Proof.* The proof that  $A_{alg}(M)$  is an isomorphism is similar to the proof that  $A(M)$  is an isomorphism in theorem 31.  $\square$

**Definition 54.** Let  $k$  a field of characteristic 0. Let  $S \in \text{SmVar}(k)$  and  $D = V(s) \subset S$  a (Cartier) divisor. Denote by  $j : S^\circ := S \setminus D \hookrightarrow S$  the open embedding. Let  $M \in \text{PSh}_{\mathcal{D}, rh}(S)$  which admits the rational Kashiwara-Malgrange filtration. There exist a subfield  $k_0 \subset k$  of finite transcendence degree over  $\mathbb{Q}$ ,  $S_0 \in \text{SmVar}(k_0)$  and  $M_0 \in \text{PSh}_{\mathcal{D}, rh}(S_0)$  such that  $S = S_0 \otimes_{k_0} k$  and  $M = \pi_{k_0/k}(S_0)^{*mod} M_0$ . Denote again by  $j : S^\circ := S \setminus D \hookrightarrow S$  the open embedding. Consider then an embedding  $\sigma : k_0 \hookrightarrow \mathbb{C}$ . Denote by  $\pi : \tilde{S}_0^{an(\sigma)} \rightarrow S_0^{o, an(\sigma)} := S_0^{an(\sigma)} \setminus D^{an(\sigma)}$  the universal covering and by  $j : S_0 \hookrightarrow S_0$  the open embedding. Denote

$$\begin{aligned} A_\pi &:= \text{ad}(i^*, i_*)(-) \circ \text{ad}(\pi^*, \pi_*)(DR(S_0^\circ)(M_0^{an})) \in \text{Hom}_{D(S_{\mathbb{C}}^{an})}(j_* DR(S_0^\circ)(M_0^{an}), \psi_D DR(S_0^\circ)(M_0^{an})) \\ &= \text{Hom}_{D(S_{\mathbb{C}}^{an})}(DR(S_0)(j_* M_0^{an}), DR(S_0)(\psi_D M_0^{an})) \end{aligned}$$

where the equality follows from the isomorphisms

- $T(j, DR)(M_0) := T^w(j, \otimes)(M_0) \circ DR(S)(T(j, an)(M_0)) : DR(S_0)(j_* M_0^{an}) \xrightarrow{\sim} j_* DR(S_0^\circ)(M_0^{an})$ ,
- $T(\psi_D, DR)(M_0) : \psi_D DR(S_0)(M_0^{an}) \xrightarrow{\sim} \psi_D DR(S_0)(M_0^{an})$  of theorem 31.

We have by definition the following commutative diagram

$$\begin{array}{ccc} \text{Hom}_{D_{\mathcal{D}, rh}(S_0)}(j_* M_0, \psi_D M_0) \otimes_k \mathbb{C} & \xrightarrow{\theta_3 := DR(S)^{j_* M_0, \psi_D M_0}} & \text{Hom}_{D(S_{\mathbb{C}}^{an})}(DR(S_0)(j_* M_0^{an}), DR(S_0)(\psi_D M_0^{an})) \\ \downarrow DR(S)^{j_* M_0, \psi_D M_0} & & \uparrow \theta_2 := \mathcal{H}om(T^w(an, \otimes)(-), T^w(an, \otimes)(-)) \circ \text{an}_S^{*-1} \\ \text{Hom}_{D(S_0)}(DR(S_0)(j_* M_0), DR(S_0)(\psi_D M_0)) \otimes_k \mathbb{C} & \xrightarrow{\text{Hom}(T^w(j, \otimes)(M_0), T_{alg}(\psi_D, DR)(M_0))} & \text{Hom}_{D(S_0)}(j_* DR(S_0^\circ)(M_0), \psi_D DR(S_0^\circ)(M_0)) \otimes_k \mathbb{C} \end{array} \quad (15)$$

where  $T_{alg}(\psi_D, DR)(M_0)$  is given in definition-proposition 5. By theorem 28,  $\theta_3$  is an isomorphism, hence for  $m = \theta_2(m_k \otimes 1)$ ,  $\theta_3^{-1}(m) = m_k \otimes 1$  by the diagram (15). In particular for  $A_\pi = \theta_2(A_{\pi, k} \otimes 1)$  with

$$A_{\pi, k} := \text{ad}(i^*, i_*)(-) \circ n_{\log s}(-) \circ \text{ad}(\pi^*, \pi_*)(DR(S_0^\circ)(M_0)) \in \text{Hom}_{D(S_0)}(j_* DR(S_0^\circ)(M_0), \psi_D DR(S_0^\circ)(M_0))$$

and  $n_{\log s}(K) = K \rightarrow \mathcal{H}om(\mathcal{A}_{S^\circ}, K)$ , we get in  $\text{PSh}_{\mathcal{D}, rh}(S_0)$

$$\rho_{DR, D}(M_0) := (DR(S)^{j_* M_0, \psi_D M_0})^{-1}(A_\pi) = A_{\pi, k} : j_* M_0 \rightarrow \psi_D(M_0).$$

If  $\sigma' : k_0 \hookrightarrow \mathbb{C}$  is an other embedding, there exists  $\theta : \mathbb{C} \rightarrow \mathbb{C}$  an algebraic automorphism of  $\mathbb{C}$  such that  $\theta \circ \sigma = \sigma'$  and  $\sigma'(\rho_{DR, D}(M_0)) = \theta(\sigma(\rho_{DR, D}(M_0)))$  by the diagram (15). This map gives in particular the map in  $\text{PSh}_{\mathcal{D}, rh}(S)$

$$\rho_{DR, D}(M) := \rho_{DR, D}(M_0) \otimes_{O_{S_0}} O_S : j_*(M) \rightarrow \psi_D(M).$$

We now show, using the complex case, the existence of the rational Kashiwara-Malgrange filtration in the regular holonomic case.

**Lemma 5.** *Let  $S \in \text{SmVar}(k)$  a smooth affine variety with a closed embedding  $l : S \hookrightarrow \mathbb{A}_k^N$ . Let  $D = V(f) \subset S$  a (Cartier) Divisor which is given by a  $f \in \Gamma(S, O_S)$ . Then  $D = \tilde{D} \cap S$  with  $\tilde{D} = V(\tilde{f}) \subset \mathbb{A}_k^N$ , where the polynomial  $\tilde{f} \in \Gamma(\mathbb{A}_k^N, O_{\mathbb{A}_k^N})$  is a lift of  $f$ ; denote by  $j : S \setminus D \hookrightarrow S$  and  $\tilde{j} : \mathbb{A}_k^N \setminus \tilde{D} \hookrightarrow \mathbb{A}_k^N$  the open embeddings. We then have the graph embedding  $i : S \hookrightarrow S \times \mathbb{A}_k^1$ ,  $i(x) = (x, f(x))$  and the zero section embedding  $i_0 : S \hookrightarrow S \times \mathbb{A}_k^1$ ,  $i_0(x) = (x, 0)$ . Denote  $(x, t) \in S \times \mathbb{A}_k^1$  the coordinates and  $s = t\partial_t$ .*

(i) *Let  $M \in \text{PSh}_{\mathcal{D}}(S)$  such that the multiplication map  $m_f : M \rightarrow M$ ,  $m_f(m) = fm$ , is an isomorphism. Denote by  $\delta = 1/(f-t) \in O_S(*D)$ . Consider for  $i \in \mathbb{N}$  the polynomials  $Q_i = \pi_{j=0}^{i-1}(x+j) \in \mathbb{Z}[x]$  for  $i > 0$  and  $Q_0 = 1$ . We have then an isomorphism of  $D_S < t, t^{-1}, s >$  modules*

$$A_f(M) : M[s]f^s := i_*(M \otimes_{O_S} O_S[s]) \xrightarrow{\sim} i_{*mod}M = i_*M \otimes_k k[\partial_t] = i_*M \otimes_{O_S} i_{*mod}O_S(*D),$$

$$ms^j f^s \mapsto m \otimes (t\partial_t)^j \delta$$

whose inverse is

$$B_f(M) : i_{*mod}M \xrightarrow{\sim} M[s]f^s, m \otimes \partial_t^j \delta \mapsto m/f^j Q_j(-s)f^s$$

where the structure of  $D_S < t, t^{-1}, s >$  module on  $M[s]f^s$  is given by

- $s.(ms^j f^s) = ms^{j+1} f^s$ ,  $t.(ms^j f^s) = m(s+1)^j f^s$ ,
- $P.(ms^j f^s) = P(f)/fms^{j+1} f^s + P(m)(s+1)^j f^s$ , for  $P \in \Gamma(S, D_S)$ .

(ii) *Consider by (i) the  $D_S < t, t^{-1}, s >$  submodule*

$$N_f := D_S[s]f^s \subset O_S(*D)[s]f^s \xrightarrow{A_f(O_S(*D)) \sim} i_{*mod}O_S(*D).$$

Then  $N_f/tN_f$  an holonomic  $D_S$  module.

(iii) *The endomorphism*

$$s : N_f/tN_f \rightarrow N_f/tN_f$$

has a minimal polynomial which is equal to the Bernstein-Sato Polynomial  $b_f \in \mathbb{Q}[x]$  of  $f$ .

*Proof.* (i): See [24].

(ii): By proposition 21,  $O_S(*D) = j_*O_{S \setminus D}$  is an holonomic  $D_S$  module. Hence, since  $N_f/tN_f \subset O_S(*D)$  is a  $D_S$  submodule,  $N_f/tN_f$  is an holonomic  $D_S$  module by proposition 19.

(iii): Follows from (ii) by [14] theorem 3.3. □

For an arbitrary field of characteristic zero, we have the following key proposition :

**Proposition 35.** *Let  $k$  a field of characteristic zero.*

(i1) *Let  $S \in \text{SmVar}(k)$ . Let  $D = V(s) \subset S$  a (Cartier) divisor, where  $s \in \Gamma(S, L)$  is a section of the line bundle  $L = L_D$  associated to  $D$ . We then have the graph embedding  $i : S \hookrightarrow L$ ,  $i(x) = (x, s(x))$  and the zero section embedding  $i_0 : S \hookrightarrow L$ ,  $i_0(x) = (x, 0)$  and  $L_0 = i_0(S)$ . Denote  $j : S^\circ := S \setminus D \hookrightarrow S$  and  $\tilde{j} : L^\circ := L \setminus L_0 \hookrightarrow L$  the open complementary subsets. Then  $j_*O_{S^\circ} = O_S(*D) \in \text{PSh}_{\mathcal{D}, rh}(S)$  admits the rational Kashiwara-Malgrange  $V_D$ -filtration, that is  $j_*i_{*mod}O_{S^\circ} = i_{*mod}O_S(*D) \in \text{PSh}_{\mathcal{D}, rh}(L)$  admits the rational Kashiwara-Malgrange  $V_S$ -filtration.*

(i2) *Let  $S \in \text{SmVar}(k)$ . Let  $D \subset S$  a (Cartier) divisor. Denote  $j : S^\circ := S \setminus D \hookrightarrow S$  the open complementary subset. Then for  $E \in \text{Vect}_{\mathcal{D}}(S^\circ)$  regular in the strong sense (see definition 37),  $j_*E \in \text{PSh}_{\mathcal{D}, rh}(S)$  admits the rational Kashiwara-Malgrange  $V_E$ -filtration for all (Cartier) divisor  $E = V(s') \subset S$ .*

(ii) Let  $f : X \rightarrow S$  a proper morphism with  $X, S \in \text{SmVar}(k)$ . Let  $D \subset S$  a (Cartier) divisor. If  $M \in \text{PSh}_{\mathcal{D}, rh}(X)$  admits the (rational) Kashiwara-Malgrange  $V_{f^{-1}(D)}$  filtration, then  $H^n \int_f M$  admits the (rational) Kashiwara-Malgrange  $V_D$  filtration for all  $n \in \mathbb{Z}$ .

*Proof.* (i1): Let  $S = \cup_{i=1}^r S_i$  an open affine covering such that for each  $i$   $D \cap S_i = V(f_i) \subset S_i$  is given by one equation  $f_i \in \Gamma(S_i, \mathcal{O}_{S_i})$ . For each  $i$ , lemma 5 (iii) applied to  $S_i$  and  $D \cap S_i$ , gives the rational Kashiwara-Malgrange  $V_{S_i}$ -filtration for  $i_{*mod} \mathcal{O}_{S_i}(*D)$ . By unicity of the rational Kashiwara-Malgrange  $V$ -filtration, we get the rational Kashiwara-Malgrange  $V_S$ -filtration on  $i_{*mod} \mathcal{O}_S(*D)$  since for all  $k \in \mathbb{Q}$

$$V_{S_i, k} i_{*mod} \mathcal{O}_S(*D)|_{S_i \cap S_j} = V_{S_j, k} i_{*mod} \mathcal{O}_S(*D)|_{S_i \cap S_j}.$$

(i2): Let  $E \subset S$  a (Cartier) divisor. Consider a subfield  $k_0 \subset k$  of finite transcendence degree over  $\mathbb{Q}$  such that  $S = S_{0k} := S \otimes_{k_0} k$  with  $S_0 \in \text{SmVar}(k_0)$ ,  $D = D_{0k} := D \otimes_{k_0} k$  with  $D_0 \subset S_0$ ,  $E = E_{0k} := E \otimes_{k_0} k$  with  $E_0 \subset S_0$ ,  $E = \pi_{k_0/k}(S_0^{*mod} E_0)$  with  $E \in \text{Vect}_{\mathcal{D}}(S_0^o)$ ,  $S_0^o := S_0 \setminus D_0$ , and an embedding  $\sigma : k_0 \hookrightarrow \mathbb{C}$ . For simplicity, we denote again  $S = S_0$ ,  $E = E_0$ ,  $D = D_0$ ,  $j : S^o := S \setminus D \hookrightarrow S$  the open complementary subset and  $E = E_0 \in \text{Vect}_{\mathcal{D}}(S^o)$ , and denote for short

$$\pi := \pi_{k_0/\mathbb{C}}(S) : S_{\mathbb{C}} := S \otimes_{k_0} \mathbb{C} \rightarrow S$$

the projection. Since  $E \in \text{Vect}_{\mathcal{D}}(S^o)$  is a locally free  $\mathcal{O}_{S^o}$  module

$$n_{\mathcal{O}_S/\mathcal{O}_{S_{\mathbb{C}}}}(E) : E = \pi^* E \rightarrow \pi^{*mod} E, m \mapsto n_{\mathcal{O}_S/\mathcal{O}_{S_{\mathbb{C}}}}(E)(m) := m \otimes 1$$

is injective. Hence we get a canonical embedding

$$j_* n_{\mathcal{O}_S/\mathcal{O}_{S_{\mathbb{C}}}}(E) : j_* \pi^* E = \pi^* j_* E \hookrightarrow j_*(\pi^{*mod} E), m \mapsto m \otimes 1$$

By the complex case, see [20],  $j_*(\pi^{*mod} E) \in \text{PSh}_{\mathcal{D}, rh}(S_{\mathbb{C}})$  admits the rational Kashiwara-Malgrange  $V_E$ -filtration for all divisor  $E' \subset S_{\mathbb{C}}$ . We then set for  $k \in \mathbb{Q}$

$$V_{E, k} j_* E := \pi_*(V_{E_{\mathbb{C}}, k} j_*(\pi^{*mod} E) \cap \pi^* j_* E)$$

so that we get a strict monomorphism

$$j_* n_{\mathcal{O}_S/\mathcal{O}_{S_{\mathbb{C}}}}(E) : (j_* E, V_E) \hookrightarrow \pi_*(j_*(\pi^{*mod} E), V_{E_{\mathbb{C}}})$$

and so that this filtration satisfies the property of the Kashiwara-Malgrange  $V_E$ -filtration. Taking back the initial notations, this means that we get the  $V_{E_0}$  filtration on  $j_* E_0 \subset \text{PSh}_{\mathcal{D}, h}(S_0)$ . Then,

$$V_{E, k} j_* E := \pi_{k_0/k}(S)^{*mod} V_{E_0, k} j_* E_0 \subset \pi_{k_0/k}(S)^{*mod} j_* E_0 = j_* E$$

gives the  $V_E$  filtration on  $j_* E$ .

(ii): By definition  $H^n \int_f M = H^n f_* E(D_{X \leftarrow S} \otimes_{D_X} M)$ . We then see immediately that  $H^n f_* E(D_{X \leftarrow S} \otimes_{D_X} (M, V_{f^{-1}(D)}))$  satisfy the hypothesis of the  $V_D$  filtration : since  $f$  is proper, the  $V_{D, 0} \mathcal{O}_S$  modules

$$\begin{aligned} & V_k H^n f_* E(D_{X \leftarrow S} \otimes_{D_X} (M, V_{f^{-1}(D)})) := \\ & \text{Im}(H^n f_*(I \otimes \iota_{V_{f^{-1}(D)}}(M))) : H^n f_* E(D_{X \leftarrow S} \otimes_{D_X} V_{f^{-1}(D), k} M) \rightarrow H^n f_* E(D_{X \leftarrow S} \otimes_{D_X} M) \end{aligned}$$

are coherent. □

**Theorem 32.** Let  $k$  a field of characteristic zero. Let  $S \in \text{SmVar}(k)$ . Every  $M \in \text{PSh}_{\mathcal{D}, rh}(S)$  holonomic, regular in the strong sense (see definition 37), admits the rationnal Kashiwara-Malgrange  $V_E$  filtration for each (Cartier) divisor  $E \subset S$ .

*Proof.* We may assume without loss of generality that  $S$  is connected. We argue by induction on  $\dim \text{supp}(M)$ . If  $\dim \text{supp}(M) = 0$ , there is nothing to prove. Denote  $i : Z := \text{supp} M \hookrightarrow S$  the closed embedding. There exist by proposition 20 an open subset  $j : S^\circ \hookrightarrow S$  with  $D := S \setminus S^\circ \subset S$  a (Cartier) divisor such that  $Z^\circ := Z \cap S^\circ$  is smooth and  $i_*^{*mod} j^* M \in \text{Vect}_{\mathcal{D}}(Z^\circ)$  is an integral connexion. Then  $\dim(D \cap Z_i) = \dim(Z_i) - 1$  where  $Z_i \subset Z$  are the irreducible component of  $Z$  since an holonomic  $D_S$  module is generically an integral connexion on its support by proposition 20. Take a desingularization  $\epsilon : \tilde{Z} \rightarrow Z$  of the pair  $(Z, D \cap Z)$  and denote by  $l : Z^\circ \hookrightarrow \tilde{Z}$  the open embedding. By proposition 35 (i0) and (i2),  $l_* i_*^{*mod} j^* M \in \text{PSh}_{\mathcal{D}, rh}(\tilde{Z})$  admits the rational Kashiwara Malgrange  $V_{\epsilon^{-1}i^{-1}(E)}$  filtration, hence by proposition 35 (ii)

$$j_* j^* M = i_*^{*mod} \epsilon_*^{*mod} l_* i_*^{*mod} j^* M \in \text{PSh}_{\mathcal{D}, rh, Z}(S)$$

admits the rational Kashiwara Malgrange  $V_E$  filtration for all divisor  $E \subset S$ . We then consider

- the nearby cycle functor for  $M$

$$\psi_D(M) := \psi_D(j_* j^* M) := \bigoplus_{-1 \leq \alpha < 0} V_{D, k} j_* j^* M \in \text{PSh}_{\mathcal{D}, rh, D \cap Z}(S),$$

and we have then, by theorem 31, the canonical isomorphism

$$T(\psi_D, DR)(j_* j^* M) : DR(S)(\psi_D M) \xrightarrow{\sim} \psi_D DR(S)(M)$$

(note that  $\psi_D K = \psi_D(j_* j^* K)$  for  $K \in P(S_{\mathbb{C}}^{an})$ ),

- the vanishing cycle functor for  $M$

$$\phi_D^\rho(M) := H^0 \text{Cone}(\theta_{DR, D}(M) : \Gamma_D^{\vee, h} M \rightarrow \psi_D(M)) \in \text{PSh}_{\mathcal{D}, rh, D \cap Z}(S)$$

which is regular holonomic by proposition 25, where  $\theta_{DR, D}$  is the factorization in  $D_{\mathcal{D}, rh}(S)$

$$\rho_{DR, D}(j_* j^* M) \circ \text{ad}(j^*, j_*)(M) : M \xrightarrow{\gamma^{\vee, h}(M)} \Gamma_D^{\vee, h} M := L\mathbb{D}_S R \Gamma_D L\mathbb{D}_S M \xrightarrow{\theta_{DR, D}(M)} \psi_D(M)$$

of the map in  $\text{PSh}_{\mathcal{D}, rh}(S)$  of definition 54

$$\begin{aligned} \rho_{DR, D}(j_* j^* M) \circ \text{ad}(j^*, j_*)(M) &:= M \xrightarrow{\text{ad}(j^*, j_*)(M)} j_* j^* M \\ &\xrightarrow{\rho_{DR, D}(j_* j^* M)} \psi_D(j_* j^* M) =: \psi_D(M), \end{aligned}$$

we have then by theorem 28 the canonical isomorphism

$$(T(\gamma_D^\vee, DR)(M), T(\psi_D, DR)(j_* j^* M)) : DR(S)(\phi_D^\rho M) \xrightarrow{\sim} \phi_D DR(S)(M)$$

- the canonical map  $can^\rho(M) := H^0 c(\phi_D^\rho(M)) : \psi_D(M) \rightarrow \phi_D^\rho M$  in  $\text{PSh}_{\mathcal{D}, rh, D \cap Z}(S)$ ,
- the variation map  $var^\rho(M) := H^0 \mathbb{D}_S c(\phi_D^\rho(\mathbb{D}_S M)) : \phi_D^\rho M \rightarrow \psi_D M$  in  $\text{PSh}_{\mathcal{D}, rh, D \cap Z}(S)$ , using the isomorphisms

$$\begin{aligned} - DR(S)^{-\cdot, -1} (T_1(D, \psi, \phi)(DR(S)(M)) : \mathbb{D}_S \psi_D M &\xrightarrow{\sim} \phi_D^\rho \mathbb{D}_S M, \\ - DR(S)^{-\cdot, -1} (T_2(D, \psi, \phi)(DR(S)(M)) : \mathbb{D}_S \phi_D^\rho M &\xrightarrow{\sim} \psi_D \mathbb{D}_S M, \end{aligned}$$

Consider then the following canonical map in  $C_{\mathcal{D}, rh}(S)$

$$\begin{aligned} I_S(M) &:= (0, (\text{ad}(j^*, j_*)(M), \rho_{DR, D}(j_* j^* M) \circ \text{ad}(j^*, j_*)(M)), 0) : \\ M &\rightarrow (\psi_D M \xrightarrow{(c(x_{S^\circ/S}(M)), can^\rho(M))} x_{S^\circ/S}(M) \oplus \phi_D^\rho M \xrightarrow{(\mathbb{D}c(x_{S^\circ/S}(\mathbb{D}M)), var^\rho(M))} \psi_D M). \end{aligned}$$

with

$$x_{S^\circ/S}(M) := \text{Cone}(\rho_{DR,D}(j_*j^*M) : j_*j^*M \rightarrow \psi_D K) \in C_{\mathcal{D},rh}(S)$$

which is a quasi-isomorphism by theorem 10 and theorem 28. By induction hypothesis,  $\phi_D^\rho M \in \text{PSh}_{\mathcal{D},rh,D \cap Z}(S)$  admits the Kashiwara-Malgrange rational  $V_E$ -filtration for all divisor  $E \subset S$ . Let  $E \subset S$  a Cartier divisor. We then set for  $k \in \mathbb{Q}$

$$V_{E,k}M := Is(M)^{-1}(V_{E,k}H^1((\psi_D M, V_E) \xrightarrow{(c(x_{S^\circ/S}(M)), can^\rho(M))} \\ \text{Cone}(\rho_{DR,D}(j_*j^*M) : (j_*j^*M, V_E) \rightarrow (\psi_D K, V_E) \oplus (\phi_D^\rho M, V_E) \xrightarrow{(\mathbb{D}c(x_{S^\circ/S}(\mathbb{D}M)), var^\rho(M))} (\psi_D M, V_E))))).$$

□

**Theorem 33.** *Let  $k \subset \mathbb{C}$  a subfield. Let  $S \in \text{SmVar}(k)$ . Let  $D = V(s) \subset S$  a divisor with  $s \in \Gamma(S, L)$  and  $L$  a line bundle ( $S$  being smooth,  $D$  is Cartier). For  $M \in \text{PSh}_{\mathcal{D},rh}(S)$ , so that the rational Kashiwara-Malgrange  $V_D$ -filtration on  $M$  exists by theorem 32,*

- we have the canonical isomorphism in  $D_{c,k}(S_{\mathbb{C}}^{an})$  given in theorem 31

$$T(\psi_D, DR)(M) : DR(S)(\psi_D M^{an}) \xrightarrow{\sim} \psi_D DR(S)(M^{an})$$

so that  $T(\psi_D, DR)(M) \circ DR(S)(s\partial_s) = N \circ T(\psi_D, DR)(M)$  where  $N := \log T \in \text{Hom}(\psi_D DR(S)(M^{an}), \psi_D DR(S)(M^{an}))$  is induced by the monodromy automorphism  $T : \tilde{S}^\circ \xrightarrow{\sim} \tilde{S}^\circ$  of the universal covering  $\pi : \tilde{S}^\circ \rightarrow S^\circ := S \setminus D$ .

- we have the following canonical isomorphism in  $D_{c,k}(S_{\mathbb{C}}^{an})$

$$T(\phi_D, DR)(M) : DR(S)(\phi_D M^{an}) \xrightarrow{DR(S)((0, var(M)))} DR(S)(\phi_D^\rho M^{an}) \xrightarrow{(I, T(\psi_D, DR)(M))} \phi_D DR(S)(M^{an}).$$

where

$$\phi_D^\rho M := H^0 \text{Cone}(\theta_{DR,D}(M) : \Gamma_D^{\vee,h} M \rightarrow \psi_D M) \in \text{PSh}_{\mathcal{D},rh,D}(S)$$

with  $\theta_{DR,D}$  the factorization in  $D_{\mathcal{D},rh}(S)$

$$\rho_{DR,D}(M) \circ \text{ad}(j^*, j_*)(M) : M \xrightarrow{\gamma_D^{\vee,h}(M)} \Gamma_D^{\vee,h} M := L\mathbb{D}_S R\Gamma_D L\mathbb{D}_S M \xrightarrow{\theta_{DR,D}(M)} \psi_D(M).$$

of the map in  $\text{PSh}_{\mathcal{D},rh}(S)$  given in definition 54.

*Proof.* Follows from theorem 31. □

**Theorem 34.** *Let  $S \in \text{SmVar}(k)$ .*

- (i) *Let  $M \in \text{PSh}_{\mathcal{D},rh}(S)$ . Let  $S^\circ \subset S$  an open subset such that  $D := S \setminus S^\circ = V(s) \subset S$  is a (Cartier) divisor. Denote  $i : D \hookrightarrow S$  the closed embedding and  $j : S^\circ \hookrightarrow S$  the open embedding. Take an embedding  $\sigma : k \hookrightarrow \mathbb{C}$ . We have, using definition 54 and theorem 32, the canonical quasi-isomorphism in  $C_{\mathcal{D},rh}(S)$  :*

$$Is(M) := (0, (\text{ad}(j^*, j_*)(M), \rho_{DR,D}(M) \circ \text{ad}(j^*, j_*)(M)), 0) : \\ M \rightarrow (\psi_D M \xrightarrow{(c(x_{S^\circ/S}(M)), can(M))} x_{S^\circ/S}(M) \oplus \phi_D M \xrightarrow{(\mathbb{D}c(x_{S^\circ/S}(\mathbb{D}M)), var(M))} \psi_D M).$$

with

$$x_{S^\circ/S}(M) := \text{Cone}(\rho_{DR,D}(M) : j_*j^*M \rightarrow \psi_D K) \in C_{\mathcal{D},rh}(S)$$

(ii) Let  $D = V(s) \subset S$  a Cartier divisor. Denote  $i : D \hookrightarrow S$  the closed embedding and  $j : S^\circ := S \setminus D \hookrightarrow S$  the open embedding. Then the functor

$$(j^*, \phi_D, \text{can}, \text{var}) : \text{PSh}_{\mathcal{D}, rh}(S) \rightarrow \text{PSh}_{\mathcal{D}, rh}(S^\circ) \times_J \text{PSh}_{\mathcal{D}, rh, D}(S)$$

is an equivalence of category whose inverse is

$$\begin{aligned} & \text{PSh}_{\mathcal{D}, rh}(S^\circ) \times_J \text{PSh}_{\mathcal{D}, rh}(S) \rightarrow \text{PSh}_{\mathcal{D}, rh, D}(S), \\ (M', M'', u, v) & \mapsto H^1((\psi_D M') \xrightarrow{(c(x_{S^\circ/S}(M')), u)} x_{S^\circ/S}(M') \oplus M'' \xrightarrow{(\mathbb{D}c(x_{S^\circ/S}(\mathbb{D}M')), v)} (\psi_D M')). \end{aligned}$$

*Proof.* (i): By theorem 28, theorem 33 and definition 58 we have  $Is(M) = DR(S)^{-, -1}(Is(DR(S)(M)))$ . The result then follows from theorem 10.

(ii): Follows from (i).  $\square$

We now give the  $p$ -adic version of theorem 33 :

**Theorem 35.** Let  $k \subset K \subset \mathbb{C}_p$  a subfield with  $p$  a prime number and  $K$  a  $p$ -adic field. Let  $S \in \text{SmVar}(k)$ . Let  $D = V(s) \subset S$  a divisor with  $s \in \Gamma(S, L)$  and  $L$  a line bundle ( $S$  being smooth,  $D$  is Cartier). so that we have the closed embedding  $i : S \hookrightarrow L$ ,  $i(x) = (x, s(x))$  and  $D = i^{-1}(s_0)$ ,  $s_0$  being the zero section. For  $M \in \text{PSh}_{\mathcal{D}, rh}(S)$ , so that the rational Kashiwara-Malgrange  $V_D$ -filtration on  $M$  exists by theorem 32,

- we have the canonical isomorphism in  $D_{\mathbb{B}_{dr}}(S_K^{\text{an}, \text{pet}})$

$$\begin{aligned} T(\psi_D, DR)^{B_{dr}}(M) & := B^{B_{dr}}(M) \circ A^{B_{dr}}(M)^{-1} : \\ DR(S)(\psi_D M^{\text{an}} \otimes_{O_{S_K}} O_{\mathbb{B}_{dr, S_K}}) & \xrightarrow{\sim} \psi_D DR(S)(M^{\text{an}} \otimes_{O_{S_K}} O_{\mathbb{B}_{dr, S_K}}) \end{aligned}$$

with, for  $S = \cup_{i=1}^s S_i$  an open affine cover such that  $D \cap S_i = V(f_i) \subset S_i$  is given by  $f_i \in \Gamma(S_i, O_{S_i})$ , denoting  $q : L_i := p^{-1}(S_i) \rightarrow \mathbb{A}_k^1$  the projection and  $j_i : S_i \hookrightarrow S$  the open embeddings,

- the isomorphism in  $D_{\mathbb{B}_{dr}}(S_K^{\text{an}, \text{pet}})$

$$\begin{aligned} A^{B_{dr}}(M) : (\oplus_{i=1}^s \oplus_{-1 \leq \alpha < 0} \text{Cone}(\partial_s : DR(L_i/\mathbb{A}_k^1)((V_{D\alpha} M)^{\text{an}}) \otimes_{O_S} s^{\alpha+1} O_{\mathbb{B}_{dr, S_K}} \\ \rightarrow DR(L_i/\mathbb{A}_k^1)((V_{D\alpha} M)^{\text{an}}) \otimes_{O_S} s^\alpha O_{\mathbb{B}_{dr, S_K}}) \xrightarrow{(j_i^*)} \dots \\ \rightarrow (\oplus_{i=1}^s DR(S_i)(\psi_D M^{\text{an}} \otimes_{O_{S_K}} O_{\mathbb{B}_{dr, S_K}}) \xrightarrow{j_i^*} \dots) \\ \xrightarrow{((j_i^*), 0)^{-1}} (DR(S)(\psi_D M^{\text{an}}) \otimes_{O_{S_K}} O_{\mathbb{B}_{dr, S_K}}), \left( \sum_j m_j \otimes (\log s)^j, m' \right) \mapsto [m_0], \end{aligned}$$

- and the isomorphism in  $D_{\mathbb{B}_{dr}}(S_K^{\text{an}, \text{pet}})$

$$\begin{aligned} B^{B_{dr}}(M) : (\oplus_{i=1}^s \oplus_{-1 \leq \alpha < 0} \text{Cone}(\partial_s : V_{D\alpha} DR(L_i/\mathbb{A}_k^1)(M^{\text{an}}) \otimes_{O_S} s^{\alpha+1} \otimes_{O_{S_K}} O_{\mathbb{B}_{dr, S_K}} \\ \rightarrow V_{D\alpha} DR(L_i/\mathbb{A}_k^1)(M^{\text{an}}) \otimes_{O_S} s^\alpha \otimes_{O_{S_K}} O_{\mathbb{B}_{dr, S_K}}) \xrightarrow{(j_i^*)} \dots \\ \rightarrow (\oplus_{i=1}^s DR(p^* O_{\mathbb{A}_k^1})(i^* \pi_* \pi^{* \text{mod}} DR(L_i/\mathbb{A}_k^1)(M^{\text{an}}) \otimes_{O_{S_K}} O_{\mathbb{B}_{dr, S_K}}) \xrightarrow{(j_i^*)} \dots) \\ \xrightarrow{\cong} (\oplus_{i=1}^s DR(p^* O_{\mathbb{A}_k^1})(\psi_D(DR(L_i/\mathbb{A}_k^1)(M^{\text{an}}) \otimes_{O_{S_K}} O_{\mathbb{B}_{dr, S_K}})) \xrightarrow{(j_i^*)} \dots) \\ \xrightarrow{((j_i^*), 0)^{-1}} \psi_D DR(S)(M^{\text{an}} \otimes_{O_{S_K}} O_{\mathbb{B}_{dr, S_K}}), \left( \sum_j m_j \otimes (\log s)^j, m' \right) \mapsto \sum_j (\log s)^j m_j, \end{aligned}$$

so that  $T_{B_{dr}}(\psi_D, DR)(M) \circ DR(S)(s\partial_s) = N \circ T_{B_{dr}}(\psi_D, DR)(M)$  where

$$N := \log T \in \text{Hom}(\psi_D DR(S)(M^{\text{an}} \otimes_{O_{S_K}} O_{\mathbb{B}_{dr, S_K}}), \psi_D DR(S)(M^{\text{an}} \otimes_{O_{S_K}} O_{\mathbb{B}_{dr, S_K}}))$$

is induced by the monodromy automorphism  $T : \tilde{S}^\circ \xrightarrow{\sim} \tilde{S}^\circ$  of the perfectoid universal covering  $\pi : \tilde{S}^\circ \rightarrow S^\circ := S \setminus D$  (see [27]).

- there is a canonical isomorphism in  $D_{\mathbb{B}_{dr}}(S_K^{an,pet})$

$$T^{B_{dr}}(\phi_D, DR)(M) : DR(S)(\phi_D M^{an} \otimes_{O_{S_K}} O_{\mathbb{B}_{dr}, S_K}) \xrightarrow{DR(S)((0, var(M) \otimes I)} \\ DR(S)(\phi_D^\rho M^{an} \otimes_{O_{S_K}} O_{\mathbb{B}_{dr}, S_K}) \xrightarrow{(I, T^{B_{dr}}(\psi_D, DR)(M))} \phi_D DR(S)(M^{an} \otimes_{O_{S_K}} O_{\mathbb{B}_{dr}, S_K}).$$

where

$$\phi_D^\rho M := H^0 \text{Cone}(\theta_{DR, D}(M) : \Gamma_D^{\vee, h} M \rightarrow \psi_D M) \in \text{PSh}_{\mathcal{D}, rh, D}(S)$$

with  $\theta_{DR, D}$  the factorization in  $D_{\mathcal{D}, rh}(S)$

$$\rho_{DR, D}(M) \circ \text{ad}(j^*, j_*)(M) : M \xrightarrow{\gamma_D^{\vee, h}(M)} \Gamma_D^{\vee, h} M := L\mathbb{D}_S R \Gamma_D L\mathbb{D}_S M \xrightarrow{\theta_{DR, D}(M)} \psi_D(M).$$

of the map given in definition 54. In particular

$$\begin{aligned} & - T^{B_{dr}}(\psi_D, DR)(M) \circ DR(S)(s \otimes I) = \text{can}(DR(S)(M^{an} \otimes_{O_{S_K}} O_{\mathbb{B}_{dr}, S_K})) \circ T^{B_{dr}}(\phi_D, DR)(M) \\ & - T^{B_{dr}}(\phi_D, DR)(M) \circ DR(S)(\partial_s \otimes I) = \text{var}(DR(S)(M^{an} \otimes_{O_{S_K}} O_{\mathbb{B}_{dr}, S_K})) \circ T^{B_{dr}}(\psi_D, DR)(M). \end{aligned}$$

*Proof.* Similar to the proof of theorem 33.  $\square$

We now look at the particular case of algebraic integral connexions. The following follows from the work of Bhatwaderkar and Rao ([7]).

**Theorem 36.** *Let  $R$  a local finite type algebra over a field of characteristic zero  $k$ . Let  $f \in R$  a non zero divisor and non invertible element. If  $M \in \text{Mod}(R_f)$  is a projective  $R_f := R[1/f]$  module, then there exist a projective (hence free) module  $M' \in \text{Mod}(R)$  such that  $M'_f := M' \otimes_R R_f = M$*

*Proof.* See [7].  $\square$

**Corollary 3.** *Let  $S \in \text{SmVar}(k)$ . Let  $S^\circ \subset S$  an open subset such that  $D := S \setminus S^\circ = V(s) \subset S$  is a Cartier divisor. Denote  $j : S^\circ \hookrightarrow S$  the open embedding. Let  $E = (E, \nabla) \in \text{Vect}_{\mathcal{D}}(S^\circ)$  an integrable connexion regular along  $D$  (see definition 37).*

(i) *For all  $s \in D$ , there exist an open affine neighborhood  $W_s \subset S$  of  $s$  in  $S$  and a free  $O_{W_s}$ -submodule  $E' \subset (j_* E)|_{W_s}$  such that  $E'|_{W_s \cap S^\circ} = E|_{W_s \cap S^\circ}$ ,  $D_S E' = (j_* E)|_{W_s}$ ,  $s \nabla_s E' \subset E'$  and such that all the eigenvalue of the residue matrix  $\nabla_s : E'/sE' \rightarrow E'/sE'$  are rational numbers  $k \in \mathbb{Q}$ ,  $0 \leq k < 1$ .*

(i)' *For  $s \in D$ , such an  $E' \subset (j_* E)|_{W_s}$  is unique.*

(ii) *There exist a unique locally free  $O_S$ -submodule  $E' \subset j_* E$  such that  $E'|_{S^\circ} = E$ ,  $D_S E' = j_* E$  and  $s \nabla_s E' \subset E'$  and such that all the eigenvalue of the residue matrix  $\nabla_s : E'/sE' \rightarrow E'/sE'$  are rational numbers  $k \in \mathbb{Q}$ ,  $0 \leq k < 1$ .*

*Proof.* (i): Consider an affine neighborhood  $W'_s \subset S$  of  $s$ . Then,  $E|_{W'_s \cap S^\circ} \in \text{Vect}(W'_s \cap S^\circ)$  is projective since it is locally free and  $W'_s \cap S^\circ$  is affine. By the complex case and regularity, there exist an integral lattice  $L' \subset j_*(E \otimes_k \mathbb{C})$  such that  $D_S L' = E$ ,  $s \partial_s L' \subset L'$  and such that all the eigenvalue of the residue matrix  $\nabla_s : L'/sL' \rightarrow L'/sL'$  are rational numbers  $k \in \mathbb{Q}$ ,  $0 \leq k < 1$ . Then set  $L := L' \cap j_* E$ . we have then  $D_S L = E$ ,  $s \partial_s L \subset L$  and all the eigenvalue of the residue matrix  $\nabla_s : L/sL \rightarrow L/sL$  are rational numbers  $k \in \mathbb{Q}$ ,  $0 \leq k < 1$ . In particular  $L|_{S^\circ} = E$  and  $L$  is a coherent  $j_* O_S$  module. Denote  $R = O_{W'_s, s}$ . Then by theorem 36 the projective  $R_f$  module  $L_{s|S^\circ} \in \text{Mod}(R_f)$  extend to a free module  $\tilde{L} \in \text{Mod}(R)$ , that is  $\tilde{L} \subset j_* j^* L$  with  $\tilde{L} \otimes_R R_f = L_{s|S^\circ}$ . Then take a neighborhood  $W_s \subset W'_s$  of  $s$  in  $W'_s$  and  $E' \in \text{Vect}(W_s)$ ,  $E' \subset (j_* E)|_{W_s}$ , such that  $E'_s = \tilde{L}$ . Then,  $E'|_{W_s \cap S^\circ} = E|_{W_s \cap S^\circ}$ ,  $D_S E' = (j_* E)|_{W_s}$ ,  $s \nabla_s E' \subset E'$  and all the eigenvalue of the residue matrix  $\nabla_s : E'/sE' \rightarrow E'/sE'$  are rational numbers  $k \in \mathbb{Q}$ ,  $0 \leq k < 1$ .

(i)': Follows the unicity of the  $V_D$  filtration on  $j_* E$ .

(ii): Follows from (i) and (i)'.  $\square$

## 5.2 The De Rham modules on algebraic varieties over a field of characteristic zero

We recall the theorem of [25]

**Theorem 37.** *Let  $f : X \rightarrow S$  a projective morphism with  $X, S \in \text{Var}(\mathbb{C})$ , where projective means that there exist a factorization  $f : X \xrightarrow{l} \mathbb{P}^N \times S \xrightarrow{p_S} S$  with  $l$  a closed embedding and  $p_S$  the projection. Let  $S = \cup_{i=1}^s S_i$  an open cover such that there exists closed embeddings  $i_I : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(\mathbb{C})$ . For  $I \subset [1, \dots, s]$ , recall that we denote  $S_I := \cap_{i \in I} S_i$  and  $X_I := f^{-1}(S_I)$ . We have then the following commutative diagram*

$$\begin{array}{ccccc} X_I & \xrightarrow{i_I \circ l_I} & \mathbb{P}^N \times \tilde{S}_I & \xrightarrow{p_{\tilde{S}_I}} & \tilde{S}_I \\ j'_{I,J} \uparrow & & p'_{I,J} \uparrow & & p_{I,J} \uparrow \\ X_J & \xrightarrow{i_J \circ l_J} & \mathbb{P}^N \times \tilde{S}_J & \xrightarrow{p_{\tilde{S}_J}} & \tilde{S}_J \end{array}$$

whose right square is cartesian (see section 5).

(i) For

$$(((M_I, F), u_{I,J}), K, \alpha) \in HM(X),$$

where  $((M_I, F), u_{I,J}) \in \text{PSh}_{\mathcal{D}fil}(X_I/(\mathbb{P}^N \times \tilde{S}_I))$ ,  $K \in P(X^{an})$ , we have

$$H^n \left( \int_f^{FDR} ((M_I, F), u_{I,J}), Rf_* W, f_*(\alpha) \right) \in HM(S)$$

for all  $n \in \mathbb{Z}$ , and for all  $p \in \mathbb{Z}$ , the differentials of  $\text{Gr}_F^p \int_f^{FDR} ((M_I, F, W), u_{I,J})$  are strict for the the Hodge filtration  $F$ .

(ii) Then, for

$$(((M_I, F, W), u_{I,J}), (K, W), \alpha) \in D(MHM(X)),$$

where  $((M_I, F, W), u_{I,J}) \in C_{\mathcal{D}(1,0)fil}(X_I/(\mathbb{P}^N \times \tilde{S}_I))$ ,  $(K, W) \in C_{fil}(X^{an})$ , we have

$$H^n \left( \int_f^{FDR} ((M_I, F, W), u_{I,J}), Rf_*(K, W), f_*(\alpha) \right) \in MHM(S)$$

for all  $n \in \mathbb{Z}$ , and for all  $p \in \mathbb{Z}$ , the differentials of  $\text{Gr}_F^p \int_f^{FDR} ((M_I, F, W), u_{I,J})$  are strict for the the Hodge filtration  $F$ .

*Proof.* (i):See [26].

(ii):Follows from (i) using the spectral sequence of the filtered complex  $(\int_f^{FDR} ((M_I, F, W), u_{I,J}), Rf_*(K, W), f_*(\alpha))$  associated to the filtration  $W$ : see [25].  $\square$

**Definition 55.** *Let  $S \in \text{SmVar}(k)$ . Let  $D = V(s) \subset S$  a divisor with  $s \in \Gamma(S, L)$  and  $L$  a line bundle ( $S$  being smooth,  $D$  is Cartier). For  $(M, F, W) \in \text{PSh}_{\mathcal{D}(1,0)fil, rh}(S)$ , consider using theorem 32 the Kashiwara-Malgrange  $V_S$ -filtration on  $i_{*mod}M$  and denote  $V_{D,k}M := i^*V_{S,k}i_{*mod}M$ . We then define, using definition 53,*

- the nearby cycle functor

$$\psi_D(M, F, W) := \bigoplus_{-1 \leq \alpha < 0} (\text{Gr}_{V_D, \alpha} M, F, W) \in \text{PSh}_{\mathcal{D}(1,0)fil, D}(S)$$

where  $\text{Gr}_{V_D, \alpha} M$  is endowed with the induced filtration  $F^p \text{Gr}_{V_D, \alpha} M := F^p V_{D, \alpha} M / F^p V_{D, < \alpha} M$ ,



- the vanishing cycle functor

$$\phi_D(M, F, W) := \bigoplus_{-1 < \alpha \leq 0} (\text{Gr}_{V_D, \alpha} M, F, W) \in \text{PSh}_{\mathcal{D}(1,0)fil,D}(S)$$

where  $\text{Gr}_{V_D, \alpha} M$  is endowed with the induced filtration  $F^p \text{Gr}_{V_D, \alpha} M := F^p V_{D, \alpha} M / F^{p+1} V_{D, \alpha} M$ ,

- the canonical maps

$$\begin{aligned} \text{can}(M, F, W) &:= (\partial_s, I) : \psi_D(M, F, W) \rightarrow \phi_D(M, F, W)(-1), \\ \text{var}(M, F, W) &:= (I, s) : \phi_D(M, F, W) \rightarrow \psi_D(M, F, W). \end{aligned}$$

**Proposition 36.** Let  $S \in \text{SmVar}(k)$ . Let  $D = V(s) \subset S$  a (Cartier divisor). Consider a composition of proper morphisms  $(f : X = X_r \xrightarrow{f_r} X_{r-1} \xrightarrow{f_1} X_0 = S) \in \text{SmVar}(k)$  and

$$(M, F) = H^{n_0} \int_{f_1} \cdots H^{n_r} \int_{f_r} (O_X, F_b) \in \text{PSh}_{\mathcal{D}fil,rh}(S).$$

which admits a  $V_D$ -filtration (see theorem 32). Then,

$$\psi_D(M, F) = H^{n_0} \int_{f_1} \cdots H^{n_r} \int_{f_r} \psi_{f^{-1}(D)}(O_X, F_b) \in \text{PSh}_{\mathcal{D}fil,rh}(S)$$

and

$$\phi_D(M, F) = H^{n_0} \int_{f_1} \cdots H^{n_r} \int_{f_r} \phi_{f^{-1}(D)}(O_X, F_b) \in \text{PSh}_{\mathcal{D}fil,rh}(S).$$

*Proof.* Immediate from definition. □

**Definition 56.** (i) Let  $S \in \text{SmVar}(k)$ . We define, see theorem 25(iv), the full subcategories

$$PDRM^1(S) \subset PDRM^2(S) \subset PDRM(S) = \bigcup_{i \in \mathbb{N}} PDRM^i(S) \subset \text{PSh}_{\mathcal{D}fil,rh}(S)$$

consisting of pure De Rham modules inductively. For each  $S \in \text{SmVar}(k)$ , we define

$$PDRM^1(S) := \langle H^n \int_f (O_X, F_b), (f : X \rightarrow S) \in \text{SmVar}(k) \text{ proper}, n \in \mathbb{Z} \rangle \subset \text{PSh}_{\mathcal{D}fil,rh}(S),$$

the full abelian subcategory, where  $\langle, \rangle$  means generated by. Assume we have defined  $PDRM^{k-1}(S) \subset \text{PSh}_{\mathcal{D}fil,rh}(S)$  for all  $S \in \text{SmVar}(k)$ . For each  $S \in \text{SmVar}(k)$ , we define

$$\begin{aligned} PDRM^k(S) &:= \langle H^n \int_f (M, F), (f : X \rightarrow S) \in \text{SmVar}(k) \text{ proper}, \\ &(M, F) \in PDRM^{k-1}(X), n \in \mathbb{Z} \rangle \subset \text{PSh}_{\mathcal{D}fil,rh}(S), \end{aligned}$$

the full abelian subcategory, where  $\langle, \rangle$  means generated by. By proposition 36, for  $D = V(s) \subset S$  a (Cartier) divisor and  $(M, F) \in PDRM(S)$ , we have, using theorem 32 or proposition 35(ii), for all  $k \in \mathbb{Z}$

$$\text{Gr}_k^W \psi_D(M, F), \text{Gr}_k^W \phi_D(M, F) \in PDRM(S).$$

(i)' Let  $S \in \text{Var}(k)$  non smooth. Take an open cover  $S = \bigcup_i S_i$  such that there are closed embedding  $S_I \hookrightarrow \tilde{S}_I$  with  $S_I \in \text{SmVar}(k)$ . We define as in (i), see theorem 26(iv), the full subcategories

$$PDRM^1(S) \subset PDRM^2(S) \subset PDRM(S) = \bigcup_{i \in \mathbb{N}} PDRM^i(S) \subset \text{PSh}_{\mathcal{D}fil,rh}^0(S/(\tilde{S}_I))$$

inductively. For each  $S \in \text{Var}(k)$ , we define

$$PDRM^1(S) := \langle H^n \int_{p_S} (\Gamma_X^{\vee, Hdg}(O_{Y \times \tilde{S}_I}, F_b), x_{IJ}),$$

$$(f : X \rightarrow S) \in \text{Var}(k) \text{ proper, } X \text{ smooth, } f = p_S \circ i, n \in \mathbb{Z} \rangle \subset \text{PSh}_{\mathcal{D}fil, rh}^0(S/(\tilde{S}_I))$$

the full abelian subcategory, where  $\langle, \rangle$  means generated by,  $i : X \hookrightarrow Y \times S$  is a closed embedding with  $Y \in \text{PSmVar}(k)$ ,

- for  $j : X^o \hookrightarrow X$  an open embedding we set using proposition 35(i1)  $j_{!Hdg}(O_{X^o}, F_b) := (j_* O_{X^o}, F)$  with  $F^p j_* O_{X^o} := \bigoplus_k \partial_s^k F^{p+k} V_{X \setminus X^o, k} j_* O_{X^o}$ ,  $X \setminus X^o = V(s) \subset X$ ,
- we set

$$(\Gamma_X^{\vee, Hdg}(O_{Y \times \tilde{S}_I}, F_b), x_{IJ}) \in C_{\mathcal{D}fil, rh}(X/(Y \times \tilde{S}_I))$$

where

$$\Gamma_X^{\vee, Hdg}(O_{Y \times \tilde{S}_I}, F_b) := \text{Cone}(\text{ad}(j_{!Hdg}, j_I^*)(-) : j_{!Hdg} j_I^*(O_{Y \times \tilde{S}_I \setminus X}, F_b) \rightarrow (O_{Y \times \tilde{S}_I}, F_b)),$$

together with the maps

$$x_{IJ} : \Gamma_X^{\vee, Hdg}(O_{Y \times \tilde{S}_I}, F_b) \xrightarrow{\text{ad}(p_{IJ}^{*mod}, p_{IJ*})(-)} p_{IJ*} \Gamma_{X \times \tilde{S}_{J \setminus I}}^{\vee, Hdg}(O_{Y \times \tilde{S}_J}, F_b) \xrightarrow{\text{ad}(j_{!Hdg}, j^{IJ*})(-)} p_{IJ*} \Gamma_X^{\vee, Hdg}(O_{Y \times \tilde{S}_J}, F_b).$$

Assume we have defined  $PDRM^{k-1}(S) \subset \text{PSh}_{\mathcal{D}fil, rh}^0(S/(\tilde{S}_I))$  for all  $S \in \text{Var}(k)$ . For each  $S \in \text{Var}(k)$ , we define

$$PDRM^k(S) := \langle H^n \int_{p_S} (\Gamma_X^{Hdg}((M_I, F), u_{IJ}), (f : X \rightarrow S) \in \text{Var}(k) \text{ proper, } X \text{ smooth, } f = p_S \circ i, ((M_I, F), u_{IJ}) \in PDRM^{k-1}(X), n \in \mathbb{Z} \rangle \subset \text{PSh}_{\mathcal{D}fil}^0(S/(\tilde{S}_I))$$

the full abelian subcategory, where  $\langle, \rangle$  means generated by,  $i : X \hookrightarrow Y \times S$  is a closed embedding with  $Y \in \text{PSmVar}(k)$ ,  $((M_I, F), u_{IJ}) \in PDRM^{k-1}(X)$  and

- for  $j : X^o \hookrightarrow X'$  an open embedding with  $X' \in \text{SmVar}(k)$  and  $(M, F) \in \text{PSh}_{\mathcal{D}fil, rh}(X^o)$  we set  $j_{!Hdg}(M, F) := (j_* M, F)$  using theorem 32 or proposition 35(ii) with  $F^p j_* M := \bigoplus_k \partial_s^k F^{p+k} V_{X' \setminus X^o, k} j_*(M, F)$ ,  $X' \setminus X^o = V(s) \subset X'$ ,
- we set

$$\Gamma_X^{\vee, Hdg}((M_I, F), u_{IJ}) := (\Gamma_X^{\vee, Hdg}(M_I, F), u_{IJ}^q) \in C_{\mathcal{D}fil}(X/(Y \times \tilde{S}_I))$$

with  $\Gamma_X^{\vee, Hdg}(M_I, F) := \text{ad}(j_{!Hdg}, j_I^*)(-) : \text{Cone}(j_{!Hdg} j_I^*(M_I, F) \rightarrow (M_I, F))$ , together with the maps

$$u_{IJ}^q : \Gamma_X^{\vee, Hdg}(M_I, F) \xrightarrow{I(p_{IJ}^{*mod}, p_{IJ*})(u_{IJ}) \circ \text{ad}(p_{IJ}^{*mod}, p_{IJ*})(-)} p_{IJ*} \Gamma_{X \times \tilde{S}_{J \setminus I}}^{\vee, Hdg}(M_J, F) \xrightarrow{\text{ad}(j_{!Hdg}, j^{IJ*})(-)} p_{IJ*} \Gamma_X^{\vee, Hdg}(M_I, F).$$

Note that if  $S$  is smooth then this definition of  $PDRM(S)$  agree with the one given in (i).

For  $k \subset \mathbb{C}$  and  $S \in \text{Var}(k)$ , we have by theorem 37  $PDRM(S_{\mathbb{C}}) \subset \pi_S(HM(S_{\mathbb{C}}))$  which are by definition the De Rham factor of geometric pure Hodge modules.

(ii) Let  $S \in \text{Var}(k)$ . Take an open cover  $S = \cup_i S_i$  such that there are closed embedding  $S_I \hookrightarrow \tilde{S}_I$  with  $S_I \in \text{SmVar}(k)$ . We define using the pure case (i) and (i)' the full subcategory of weak mixed De Rham modules

$$\widetilde{DRM}(S) := \{((M_I, F, W), u_{IJ}), \text{Gr}_k^W((M_I, F, W), u_{IJ}) \in PDRM(S)\} \subset \text{PSh}_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I))$$

whose object consists of  $((M_I, F, W), u_{IJ}) \in \text{PSh}_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I))$  such that

$$\text{Gr}_k^W((M_I, F, W), u_{IJ}) := ((\text{Gr}_k^W M_I, F), \text{Gr}_W^k u_{IJ}) \in PDRM(S).$$

For  $S \in \text{SmVar}(k)$  and  $D = V(s) \subset S$  a (Cartier) divisor, we have for  $(M, F, W) \in \widetilde{DRM}(S)$ , using theorem 32,

$$\psi_D(M, F, W), \phi_D(M, F, W) \in \widetilde{DRM}(S),$$

by the pure case (c.f. (i) and proposition 36) and the strictness of the  $V$ -filtration.

(ii)' Let  $S \in \text{Var}(k)$ . Take an open cover  $S = \cup_i S_i$  such that there are closed embedding  $S_I \hookrightarrow \tilde{S}_I$  with  $S_I \in \text{SmVar}(k)$ . The category of (mixed) de Rham modules over  $S$  is the full subcategory

$$DRM(S) \subset \widetilde{DRM}(S) \subset \text{PSh}_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I))$$

whose object consists of  $((M_I, F, W), u_{IJ}) \in \widetilde{DRM}(S)$  such that for each  $I \subset [1, \dots, s]$  and every Cartier divisor  $D \subset \tilde{S}_I$ , the three filtrations  $F, W$  and  $V_D$  on  $M_I$  are compatible, the filtration  $W$  is admissible for  $D$  (that is the relative monodromy filtration  $\langle W, W(N) \rangle$  exists on  $M_I$  where  $N$  is the monodromy of  $\tilde{S}_I \setminus D$  on  $M_I$ ), and so on inductively on the graded  $\psi_D M_I$  until  $\text{supp}(\psi_{D_1} \cdots \psi_{D_r} M_I)$  has dimension zero.

For  $k \subset \mathbb{C}$  and  $S \in \text{Var}(k)$ , we have by theorem 37  $DRM(S_{\mathbb{C}}) \subset \pi_S(MHM(S_{\mathbb{C}}))$  which are by definition the De Rham factor of geometric mixed Hodge modules. In particular, for  $S \in \text{Var}(k)$ , a morphism

$$m : ((M_I, F, W), u_{IJ}) \rightarrow ((N_I, F, W), u_{IJ}), ((M_I, F, W), u_{IJ}), ((N_I, F, W), u_{IJ}) \in DRM(S)$$

is strict for the Hodge filtration  $F$ . For  $S \in \text{Var}(k)$  we get  $D(DRM(S)) := \text{Ho}_{zar}(C(DRM(S)))$  after localization with Zariski local equivalence.

**Remark 3.** (i) Let  $S \in \text{SmVar}(k)$ . By definition,

$$PDRM(S) := \langle H^{n_0} \int_{f_1} \cdots H^{n_r} \int_{f_r} (O_X, F_b), (f : X = X_r \xrightarrow{f_r} X_{r-1} \xrightarrow{f_1} X_0 = S) \in \text{SmVar}(k), \\ f_i \text{ proper}, 1 \leq i \leq r, (n_1, \dots, n_r) \in \mathbb{Z}^r \rangle \subset \text{PSh}_{\mathcal{D}fil,rh}(S).$$

(ii) Let  $S \in \text{Var}(k)$  non smooth. Take an open cover  $S = \cup_i S_i$  such that there are closed embedding  $S_I \hookrightarrow \tilde{S}_I$  with  $S_I \in \text{SmVar}(k)$ . By definition,

$$PDRM(S) := \langle H^{n_0} \int_{p_S} (\Gamma_{X_1}^{\vee, Hdg}(\cdots H^{n_r} \int_{p_{X_{r-1}}} \Gamma_X^{\vee, Hdg}(O_{Y_r \times \tilde{X}_{r-1}}, F_b)), \\ (f : X = X_r \xrightarrow{f_r} X_{r-1} \xrightarrow{f_1} X_0 = S) \in \text{Var}(k) \text{ proper}, f_i = p_{S_{i-1}} \circ i_i, 1 \leq i \leq r, (n_1, \dots, n_r) \in \mathbb{Z}^r \rangle \\ \subset \text{PSh}_{\mathcal{D}fil,rh}(S),$$

where  $i_i : X_i \hookrightarrow Y_i \times X_{i-1}$  is a closed embedding with  $Y_i \in \text{PSmVar}(k)$ . Note that if  $S$  is smooth then this definition of  $PDRM(S)$  agree with the one given in (i).

- Let  $S \in \text{SmVar}(k)$ . We consider the canonical embedding

$$\iota_S : C(\text{DRM}(S)) \hookrightarrow C_{\mathcal{D}(1,0)\text{fil}}(S)$$

which induces in the derived category the functor

$$\iota_S : D(\text{DRM}(S)) \rightarrow D_{\mathcal{D}(1,0)\text{fil}}(S) \rightarrow D_{\mathcal{D}(1,0)\text{fil},\infty}(S)$$

after localization with respect to filtered Zariski local equivalences and  $\infty$ -filtered Zariski local equivalences respectively. Note that if  $m : (M, F, W) \rightarrow (N, F, W)$  with  $(M, F, W), (N, F, W) \in C(\text{DRM}(S))$  is a Zariski local equivalence, then it is a filtered Zariski local equivalence by strictness.

- Let  $S \in \text{Var}(k)$  non smooth. Take an open cover  $S = \cup_i S_i$  such that there are closed embedding  $S_i \hookrightarrow \tilde{S}_i$  with  $S_i \in \text{SmVar}(k)$ . We consider the canonical embedding

$$\iota_S : C(\text{DRM}(S)) \hookrightarrow C_{\mathcal{D}(1,0)\text{fil}}(S/(\tilde{S}_I)),$$

which induces in the derived category the functor

$$\iota_S : D(\text{DRM}(S)) \rightarrow D_{\mathcal{D}(1,0)\text{fil}}(S/(\tilde{S}_I)) \rightarrow D_{\mathcal{D}(1,0)\text{fil},\infty}(S/(\tilde{S}_I))$$

after localization with respect to filtered Zariski local equivalences and  $\infty$ -filtered Zariski local equivalences respectively. Note that if  $m : (M, F, W) \rightarrow (N, F, W)$  with  $(M, F, W), (N, F, W) \in C(\text{DRM}(S))$  is a Zariski local equivalence, then it is a filtered Zariski local equivalence by strictness.

**Definition 57.** (i) Let  $S \in \text{SmVar}(k)$ . Let  $D = V(s) \subset S$  a divisor with  $s \in \Gamma(S, L)$  and  $L$  a line bundle ( $S$  being smooth,  $D$  is Cartier). Denote by  $j : S^\circ := S \setminus D \hookrightarrow S$  the open complementary embedding. Let  $(M, F, W) \in \text{DRM}(S^\circ)$ . By theorem 32,  $M$  admits the Kashiwara-Malgrange rational  $V_{\mathcal{D}}$ -filtration, that is  $i_{*mod}M$  admits the Kashiwara-Malgrange rational  $V_S$ -filtration and  $V_{D,k}M := i^*V_{S,k}i_{*mod}M$ . We then define,

– the canonical extension

$$j_{*Hdg}(M, F, W) := (j_*M, F, W) \in \text{DRM}(S), \quad F^p j_*M = \sum_{k \in \mathbb{N}} \partial_s^k F^{p+k} V_{D, <0} j_*M \subset j_*M,$$

$$W_k j_*M := W_k j_{*w}(M, W) := \langle j_* W_k M, W(N)_k M \rangle \subset j_*M$$

and  $(j_*M, W) := j_{*w}(M, W)$  is given by monodromy weight filtration similarly as in the complex case in [25], so that  $j^* j_{*Hdg}(M, F, W) = (M, F, W)$  and  $DR(S)(j_{*Hdg}(M, F, W)) = j_* DR(S^\circ)(M, W)$ ,

– the canonical extension

$$j_{!Hdg}(M, F, W) := \mathbb{D}_S^{Hdg} j_{*Hdg} \mathbb{D}_S^{Hdg}(M, F, W) \in \text{DRM}(S)$$

so that  $j^* j_{!Hdg}(M, F, W) = (M, F, W)$  and  $DR(S)(j_{!Hdg}(M, F, W)) = j_{!} DR(S^\circ)(M, W)$ .

Moreover for  $(M', F, W) \in \text{DRM}(S)$ ,

- there is a canonical map  $\text{ad}(j^*, j_{*Hdg})(M', F, W) : (M', F, W) \rightarrow j_{*Hdg} j^*(M', F, W)$  in  $\text{DRM}(S)$ ,
- there is a canonical map  $\text{ad}(j_{!Hdg}, j^*)(M', F, W) : j_{!Hdg} j^*(M', F, W) \rightarrow (M', F, W)$  in  $\text{DRM}(S)$ .

- (ii) Let  $S \in \text{SmVar}(k)$ . Let  $Z = V(\mathcal{I}) \subset S$  an arbitrary closed subset,  $\mathcal{I} \subset \mathcal{O}_S$  being an ideal subsheaf. Taking generators  $\mathcal{I} = (s_1, \dots, s_r)$ , we get  $Z = V(s_1, \dots, s_r) = \cap_{i=1}^r Z_i \subset S$  with  $Z_i = V(s_i) \subset S$ ,  $s_i \in \Gamma(S, \mathcal{L}_i)$  and  $\mathcal{L}_i$  a line bundle. Note that  $Z$  is an arbitrary closed subset,  $d_Z \geq d_X - r$  needing not be a complete intersection. Denote by  $j : S^\circ := S \setminus Z \hookrightarrow S$ ,  $j_I : S^{\circ,I} := \cap_{i \in I} (S \setminus Z_i) = S \setminus (\cup_{i \in I} Z_i) \xrightarrow{j_I^\circ} S^\circ \xrightarrow{j} S$  the open complementary embeddings, where  $I \subset \{1, \dots, r\}$ . Denote

$$\mathcal{D}(Z/S) := \{(Z_i)_{i \in [1, \dots, r]}, Z_i \subset S, \cap Z_i = Z\}, Z'_i \subset Z_i$$

the flag category. For  $(M, F, W) \in \text{DRM}(S^\circ)$ , we define by (i)

– the (bi)-filtered complex of  $D_S$ -modules

$$j_{*Hdg}(M, F, W) := \varinjlim_{\mathcal{D}(Z/S)} \text{Tot}_{\text{card}I=\bullet} (j_{I*}^{Hdg} j_I^{o*}(M, F, W)) \in C(\text{DRM}(S)),$$

where the horizontal differential are given by, if  $I \subset J$ ,  $d_{IJ} := \text{ad}(j_{IJ}^*, j_{IJ*}^{Hdg})(j_I^{o*}(M, F, W))$ ,  $j_{IJ} : S^{oJ} \hookrightarrow S^{oI}$  being the open embedding, and  $d_{IJ} = 0$  if  $I \notin J$ ,

– the (bi)-filtered complex of  $D_S$ -modules

$$j_{!Hdg}(M, F, W) := \varinjlim_{\mathcal{D}(Z/S)} \text{Tot}_{\text{card}I=-\bullet} (j_{I!}^{Hdg} j_I^{o*}(M, F, W)) = \mathbb{D}_S^{Hdg} j_{*Hdg} \mathbb{D}_S^{Hdg}(M, F, W) \in C(\text{DRM}(S)),$$

where the horizontal differential are given by, if  $I \subset J$ ,  $d_{IJ} := \text{ad}(j_{I!}^{Hdg}, j_{I!}^*)(j_I^{o*}(M, F, W))$ ,  $j_{I!} : S^{oJ} \hookrightarrow S^{oI}$  being the open embedding, and  $d_{IJ} = 0$  if  $I \notin J$ .

By definition, we have for  $(M, F, W) \in C(\text{DRM}(S^o))$ ,  $j^* j_{*Hdg}(M, F, W) = (M, F, W)$  and  $j^* j_{!Hdg}(M, F, W) = (M, F, W)$ . For  $(M', F, W) \in C(\text{DRM}(S))$ , there is, by construction,

- a canonical map  $\text{ad}(j^*, j_{*Hdg})(M', F, W) : (M', F, W) \rightarrow j_{*Hdg} j^*(M', F, W)$  in  $C(\text{DRM}(S))$ ,
- a canonical map  $\text{ad}(j_{!Hdg}, j^*)(M', F, W) : j_{!Hdg} j^*(M', F, W) \rightarrow (M', F, W)$  in  $C(\text{DRM}(S))$ .

Let  $j : S^o \hookrightarrow S$  an open embedding with  $S \in \text{SmVar}(k)$ . For  $(M, F, W) \in C(\text{DRM}(S^o))$ ,

- we have the canonical map in  $C_{\mathcal{D}(1,0)fil}(S)$

$$T(j_{*Hdg}, j_*)(M, F, W) := k \circ \text{ad}(j^*, j_*)(j_{*Hdg}(M, F, W)) : j_{*Hdg}(M, F, W) \rightarrow j_* E(M, F, W),$$

- we have the canonical map in  $C_{\mathcal{D}(1,0)fil}(S)$

$$T(j_!, j_{!Hdg})(M, F, W) := \mathbb{D}_S^K L_D(k \circ \text{ad}(j^*, j_*)(-)) : \\ j_!(M, F, W) := \mathbb{D}_S^K L_D j_* E(\mathbb{D}_S^K(M, F, W)) \rightarrow \mathbb{D}_S^K L_D j_{*Hdg} \mathbb{D}_S^K(M, F, W) = j_{!Hdg}(M, F, W).$$

**Remark 4.** Let  $j : S^o \hookrightarrow S$  an open embedding, with  $S \in \text{SmVar}(k)$ . Then, for  $(M, F, W) \in \text{DRM}(S^o)$ ,

- the map  $T(j_!, j_{!Hdg})(M, W) : j_{!w}(M, W) \rightarrow j_{!Hdg}(M, W)$  in  $C_{\mathcal{D}0fil}(S)$  is a filtered quasi-isomorphism (by the acyclicity of the functor  $j_*$  in the divisor case).
- the map  $T(j_{*Hdg}, j_*)(M, W) : j_{*Hdg}(M, W) \rightarrow j_{*w}(M, W)$  in  $C_{\mathcal{D}0fil}(S)$  is a filtered quasi-isomorphism (by the acyclicity of the functor  $j_*$  in the divisor case).

Hence, for  $(M, F, W) \in \text{DRM}(S^o)$ ,

- we get, for all  $p, n \in \mathbb{N}$ , monomorphisms

$$F^p H^n T(j_!, j_{!Hdg})(M, F, W) : F^p H^n j_{!w}(M, F, W) \hookrightarrow F^p H^n j_{!Hdg}(M, F, W)$$

in  $\text{PSh}_{O_S}(S)$ , but  $F^p H^n j_{!w}(M, F, W) \neq F^p H^n j_{!Hdg}(M, F, W)$  (it leads to different  $F$ -filtrations), since  $F^p H^n j_!(M, F) \subset H^n j_! M$  are sub  $D_S$  module while the  $F$ -filtration on  $H^n j_{!Hdg}(M, F)$  is given by Kashiwara-Malgrange  $V$ -filtrations, hence satisfy a non trivial Griffith transversality property, thus  $H^n j_!(M, F)$  and  $H^n j_{!Hdg}(M, F)$  are isomorphic as  $D_S$ -modules but NOT isomorphic as filtered  $D_S$ -modules.

- we get, for all  $p, n \in \mathbb{N}$ , monomorphisms

$$T(j_{*Hdg}, j_*)(M, F, W) : F^p H^n j_{*Hdg}(M, F, W) \hookrightarrow F^p H^n j_{*w}(M, F, W)$$

in  $\text{PSh}_{O_S}(S)$ , but  $F^p H^n j_{*Hdg}(M, F, W) \neq F^p H^n j_{*w}(M, F, W)$  (it leads to different  $F$ -filtrations), since  $F^p H^n j_* E(M, F) \subset H^n j_* E(M)$  are sub  $D_S$  module while the  $F$ -filtration on  $H^n j_{*Hdg}(M, F)$  is given by Kashiwara-Malgrange  $V$ -filtrations, hence satisfy a non trivial Griffith transversality property, thus  $H^n j_* E(M, F)$  and  $H^n j_{*Hdg}(M, F)$  are isomorphic as  $D_S$ -modules but NOT isomorphic as filtered  $D_S$ -modules.

**Proposition 37.** (i) Let  $S \in \text{SmVar}(k)$ . Let  $D = V(s) \subset S$  a divisor with  $s \in \Gamma(S, L)$  and  $L$  a line bundle ( $S$  being smooth,  $D$  is Cartier). Denote by  $j : S^\circ := S \setminus D \hookrightarrow S$  the open complementary embedding. Then,

- $(j^*, j_{*Hdg}) : \text{DRM}(S) \rightleftarrows \text{DRM}(S^\circ)$  is a pair of adjoint functors
- $(j_{!Hdg}, j^*) : \text{DRM}(S^\circ) \rightleftarrows \text{DRM}(S)$  is a pair of adjoint functors.

(ii) Let  $S \in \text{SmVar}(k)$ . Let  $Z = V(\mathcal{I}) \subset S$  an arbitrary closed subset,  $\mathcal{I} \subset \mathcal{O}_S$  being an ideal subsheaf. Denote by  $j : S^\circ := S \setminus Z \hookrightarrow S$ . Then,

- $(j^*, j_{*Hdg}) : D(\text{DRM}(S)) \rightleftarrows D(\text{DRM}(S^\circ))$  is a pair of adjoint functors
- $(j_{!Hdg}, j^*) : D(\text{DRM}(S^\circ)) \rightleftarrows D(\text{DRM}(S))$  is a pair of adjoint functors.

*Proof.* (i): Follows from the fact that for  $(M, F) \in \text{DRM}(S)$ , we have  $F^p V_{D, <0} M = j_* F^p j^* M \cap V_{D, <0} M$ , where  $V_{D, p} M := i^* V_{S, p} i_{* \text{mod}} M$ .

(ii): Follows from (i). □

The map given in definition 54 induces the following:

**Definition 58.** Let  $k$  a field of characteristic 0. Let  $S \in \text{SmVar}(k)$  and  $D \subset S$  a (Cartier) divisor. Let  $(M, F, W) \in \text{DRM}(S)$ . The map of definition 54 given by theorem 28 and theorem 31 in  $\text{PSh}_{\mathcal{D}, rh}(S)$

$$\rho_{DR, D}(M) := DR(S)^{-\cdot, -1}(\text{ad}(i^*, i_*)(-) \circ \text{ad}(\pi^*, \pi_*)(DR(S)(M))) : j_* M \rightarrow \psi_D(M).$$

induces, similarly to the complex case ([25]) by theorem 28, the unicity of the  $V$ -filtration, and the definition of the monodromy filtration, the following map in  $\text{PSh}_{\mathcal{D}(1,0)fil, rh}(S)$

$$\rho_{DR, D}(M, F, W) := \rho_{DR, D}(M) : j_{*Hdg}(M, F, W) \rightarrow \psi_D(M, F, W).$$

**Proposition 38.** (i) Let  $(M, F, W) \in \text{DRM}(S)$ . Let  $S^\circ \subset S$  an open subset such that  $M|_{S^\circ} \in \text{Vect}_{\mathcal{D}}(S^\circ)$ . Denote  $i : D := S \setminus D \hookrightarrow S$  the closed embedding and  $j : S^\circ \hookrightarrow S$  the open embedding. We have the canonical quasi-isomorphism in  $C_{\mathcal{D}, rh}(S)$  given in theorem 34:

$$Is(M) := (0, (\text{ad}(j^*, j_*)(M), \rho_{DR, D}(M) \circ \text{ad}(j^*, j_*)(M)), 0) : \\ M \rightarrow (\psi_D M \xrightarrow{(c(x_{S^\circ/S}(M)), \text{can}(M))} x_{S^\circ/S}(M) \oplus \phi_D M \xrightarrow{(\text{Dc}(x_{S^\circ/S}(\mathbb{D}M)), \text{var}(M))} \psi_D M).$$

gives a filtered quasi-isomorphism in  $C_{\mathcal{D}(1,0)fil, rh}(S)$

$$Is(M, F, W) := (0, (\text{ad}(j^*, j_{*Hdg})(M, F, W), \rho_{DR, D}(M, F, W) \circ \text{ad}(j^*, j_{*Hdg})(M, F, W)), 0) : \\ (M, F, W) \rightarrow (\psi_D(M, F, W) \xrightarrow{(c(x_{S^\circ/S}(M, F, W)), \text{can}(M, F, W))} x_{S^\circ/S}(M, F, W) \oplus \phi_D(M, F, W) \\ \xrightarrow{(\mathbb{D}^{Hdg} c(x_{S^\circ/S}(\mathbb{D}^{Hdg}(M, F, W))), \text{var}(M, F, W))} \psi_D(M, F, W)).$$

with, see definition 58,

$$x_{S^\circ/S}(M, F, W) := \text{Cone}(\rho_{DR, D}(M, F, W) : j_{*Hdg}(M, F, W) \rightarrow \psi_D(M, F, W)) \in C_{\mathcal{D}(1,0)fil, rh}(S)$$

(ii) Let  $S \in \text{SmVar}(k)$ . Let  $D = V(s) \subset S$  a (Cartier) divisor, where  $s \in \Gamma(S, L)$  is a section of the line bundle  $L = L_D$  associated to  $D$ . We then have the zero section embedding  $i : S \hookrightarrow L$ . We denote  $L_0 = i(S)$  and  $j : L^\circ := L \setminus L_0 \hookrightarrow L$  the open complementary subset. We denote by  $\text{DRM}(S \setminus D) \times_J \text{DRM}(D)$  the category whose set of objects consists of

$$\{(\mathcal{M}, \mathcal{N}, a, b), \mathcal{M} \in \text{DRM}(S \setminus D), \mathcal{N} \in \text{DRM}(D), a : \psi_{D_1} \mathcal{M} \rightarrow \mathcal{N}, b : \mathcal{N} \rightarrow \psi_{D_1} \mathcal{M}\}$$

The functor (see definition 55)

$$(j^*, \phi_{D1}, \text{can}, \text{var}) : \text{DRM}(S) \rightarrow \text{DRM}(S \setminus D) \times_J \text{DRM}(D),$$

$$(M, F, W) \mapsto (j^*(M, F, W), \phi_{D1}(M, F, W), \text{can}(M, F, W), \text{var}(M, F, W))$$

is an equivalence of category.

*Proof.* (i): Similar to the complex case ([25]) by theorem 28, the unicity of the  $V$ -filtration and the definition of the monodromy weight filtration.

(ii): follows from (i).  $\square$

We make the following key definition

**Definition 59.** Let  $S \in \text{SmVar}(k)$ . Let  $Z \subset S$  a closed subset. Denote by  $j : S \setminus Z \hookrightarrow S$  the complementary open embedding.

(i) We define using definition 57, the filtered Hodge support section functor

$$\Gamma_Z^{\text{Hdg}} : C(\text{DRM}(S)) \rightarrow C(\text{DRM}(S)),$$

$$(M, F, W) \mapsto \Gamma_Z^{\text{Hdg}}(M, F, W) := \text{Cone}(\text{ad}(j^*, j_{* \text{Hdg}})(M, F, W) : (M, F, W) \rightarrow j_{* \text{Hdg}} j^*(M, F, W))[-1],$$

together we the canonical map  $\gamma_Z^{\text{Hdg}}(M, F, W) : \Gamma_Z^{\text{Hdg}}(M, F, W) \rightarrow (M, F, W)$ .

(i)' Since  $j_{* \text{Hdg}} : C(\text{DRM}(S^\circ)) \rightarrow C(\text{DRM}(S))$  is an exact functor,  $\Gamma_Z^{\text{Hdg}}$  induces the functor

$$\Gamma_Z^{\text{Hdg}} : D(\text{DRM}(S)) \rightarrow D(\text{DRM}(S)), (M, F, W) \mapsto \Gamma_Z^{\text{Hdg}}(M, F, W)$$

(ii) We define using definition 57, the dual filtered Hodge support section functor

$$\Gamma_Z^{\vee, \text{Hdg}} : C(\text{DRM}(S)) \rightarrow C(\text{DRM}(S)),$$

$$(M, F, W) \mapsto \Gamma_Z^{\vee, \text{Hdg}}(M, F, W) := \text{Cone}(\text{ad}(j_{! \text{Hdg}}, j^*)(M, F, W) : j_{! \text{Hdg}}, j^*(M, F, W) \rightarrow (M, F, W)),$$

together we the canonical map  $\gamma_Z^{\vee, \text{Hdg}}(M, F, W) : (M, F, W) \rightarrow \Gamma_Z^{\vee, \text{Hdg}}(M, F, W)$ .

(ii)' Since  $j_{! \text{Hdg}} : C(\text{DRM}(S^\circ)) \rightarrow C(\text{DRM}(S))$  is an exact functor,  $\Gamma_Z^{\vee, \text{Hdg}}$  induces the functor

$$\Gamma_Z^{\vee, \text{Hdg}} : D(\text{DRM}(S)) \rightarrow D(\text{DRM}(S)), (M, F, W) \mapsto \Gamma_Z^{\vee, \text{Hdg}}(M, F, W)$$

We now give the definition of the filtered Hodge inverse image functor :

**Definition 60.** (i) Let  $i : Z \hookrightarrow S$  be a closed embedding, with  $Z, S \in \text{SmVar}(k)$ . Then, for  $(M, F, W) \in C(\text{DRM}(S))$ , we set

$$i_{\text{Hdg}}^{* \text{mod}}(M, F, W) := i^* \text{Gr}_{V_Z, 0} \Gamma_Z^{\text{Hdg}}(M, F, W) \in D(\text{DRM}(Z))$$

and

$$i_{\text{Hdg}}^{* \text{mod}}(M, F, W) := i^* \text{Gr}_{V_Z, 0} \Gamma_Z^{\vee, \text{Hdg}}(M, F, W) \in D(\text{DRM}(Z)),$$

noting that  $i_{* \text{mod}} : D(\text{DRM}(Z)) \rightarrow D(\text{DRM}_Z(S))$  is an equivalence of category whose inverse is  $i^* \text{Gr}_{V_Z, 0} : D(\text{DRM}_Z(S)) \rightarrow D(\text{DRM}(Z))$ .

(ii) Let  $f : X \rightarrow S$  be a morphism, with  $X, S \in \text{SmVar}(k)$ . Consider the factorization  $f : X \xrightarrow{i} X \times S \xrightarrow{p_S} S$ , where  $i$  is the graph embedding and  $p_S : X \times S \rightarrow S$  is the projection.

– For  $(M, F, W) \in C(\text{DRM}(S))$  we set

$$f_{\text{Hdg}}^{*\text{mod}}(M, F, W) := i_{\text{Hdg}}^{*\text{mod}} p_S^{*\text{mod}[-]}(M, F, W)(d_X)[2d_X] \in D(\text{DRM}(X)),$$

– For  $(M, F, W) \in C(\text{DRM}(S))$  we set

$$j_{\text{Hdg}}^{*\text{mod}}(M, F, W) := i_{\text{Hdg}}^{*\text{mod}} p_S^{*\text{mod}[-]}(M, F, W) \in D(\text{DRM}(X)),$$

If  $j : S^\circ \hookrightarrow S$  is a closed embedding, we have, for  $(M, F, W) \in C(\text{DRM}(S))$ ,

$$j_{\text{Hdg}}^{*\text{mod}}(M, F, W) = j_{\text{Hdg}}^{*\text{mod}}(M, F, W) = j^*(M, F, W) \in D(\text{DRM}(S^\circ))$$

(iii) Let  $f : X \rightarrow S$  be a morphism, with  $X, S \in \text{SmVar}(k)$ . Consider the factorization  $f : X \xrightarrow{i} X \times S \xrightarrow{p_S} S$ , where  $i$  is the graph embedding and  $p_S : X \times S \rightarrow S$  is the projection.

– For  $(M, F, W) \in C(\text{DRM}(S))$  we set

$$f_{\text{Hdg}}^{*\text{mod}}(M, F, W) := \Gamma_X^{\text{Hdg}} p_S^{*\text{mod}[-]}(M, F, W)(d_X)[2d_X] \in C(\text{DRM}(X \times S)),$$

– For  $(M, F, W) \in C(\text{DRM}(S))$  we set

$$j_{\text{Hdg}}^{*\text{mod}}(M, F, W) := \Gamma_X^{\vee, \text{Hdg}} p_S^{*\text{mod}[-]}(M, F, W) \in C(\text{DRM}(X \times S)),$$

**Definition-Proposition 6.** (i) Let  $g : S' \rightarrow S$  a morphism with  $S', S \in \text{SmVar}(k)$  and  $i : Z \hookrightarrow S$  a closed subset. Then, for  $(M, F, W) \in C(\text{DRM}(S))$ , there is a canonical map in  $C(\text{DRM}_{S'}(S' \times S))$

$$T^{\text{Hdg}}(g, \gamma)(M, F, W) : g_{\text{Hdg}}^{*\text{mod}, \Gamma} \Gamma_Z^{\text{Hdg}}(M, F, W) \rightarrow \Gamma_{Z \times_S S'}^{\text{Hdg}} g_{\text{Hdg}}^{*\text{mod}, \Gamma}(M, F, W)$$

unique up to homotopy such that

$$\gamma_{Z \times_S S'}^{\text{Hdg}}(g_{\text{Hdg}}^{*\text{mod}, \Gamma}(M, F, W)) \circ T^{\text{Hdg}}(g, \gamma)(M, F, W) = g_{\text{Hdg}}^{*\text{mod}, \Gamma} \gamma_Z^{\text{Hdg}}(M, F, W).$$

(i)' Let  $g : S' \rightarrow S$  a morphism with  $S', S \in \text{SmVar}(k)$  and  $i : Z \hookrightarrow S$  a closed subset. Then, for  $(M, F, W) \in C(\text{DRM}(S))$ , there is a canonical isomorphism in  $C(\text{DRM}_{S'}(S' \times S))$

$$T^{\text{Hdg}}(g, \gamma^\vee)(M, F, W) : \Gamma_{Z \times_S S'}^{\text{Hdg}} g_{\text{Hdg}}^{*\text{mod}, \Gamma}(M, F, W) \xrightarrow{\sim} g_{\text{Hdg}}^{*\text{mod}, \Gamma} \Gamma_Z^{\text{Hdg}}(M, F, W)$$

unique up to homotopy such that

$$\gamma_{Z \times_S S'}^{\vee, \text{Hdg}}(g_{\text{Hdg}}^{*\text{mod}, \Gamma}(M, F, W)) \circ g_{\text{Hdg}}^{*\text{mod}, \Gamma} \gamma_Z^{\vee, \text{Hdg}}(M, F, W) = T^{\text{Hdg}}(g, \gamma)(M, F, W).$$

(ii) Let  $S \in \text{SmVar}(k)$  and  $i_1 : Z_1 \hookrightarrow S$ ,  $i_2 : Z_2 \hookrightarrow Z_1$  be closed embeddings. Then, for  $(M, F, W) \in C(\text{DRM}(S))$ ,

– there is a canonical map  $T(Z_2/Z_1, \gamma^{\text{Hdg}})(M, F, W) : \Gamma_{Z_2}^{\text{Hdg}}(M, F, W) \rightarrow \Gamma_{Z_1}^{\text{Hdg}}(M, F, W)$  in  $C(\text{DRM}(S))$  unique up to homotopy such that

$$\gamma_{Z_1}^{\text{Hdg}}(M, F, W) \circ T(Z_2/Z_1, \gamma^{\text{Hdg}})(M, F, W) = \gamma_{Z_2}^{\text{Hdg}}(M, F, W)$$

together with a distinguish triangle in  $K(\text{DRM}(S))$

$$\begin{array}{ccc} \Gamma_{Z_2}^{\text{Hdg}}(M, F, W) & \xrightarrow{T(Z_2/Z_1, \gamma^{\text{Hdg}})(M, F, W)} & \Gamma_{Z_1}^{\text{Hdg}}(M, F, W) \\ \text{ad}(j_2^*, j_{2*}^{\text{Hdg}})(\Gamma_{Z_1}^{\text{Hdg}}(M, F, W)) & \xrightarrow{\quad} & \Gamma_{Z_1 \wedge Z_2}^{\text{Hdg}}(G, F) \rightarrow \Gamma_{Z_2}^{\text{Hdg}}(M, F, W)[1] \end{array}$$



- there is a canonical map  $T(Z_2/Z_1, \gamma^{\vee, Hdg})(M, F, W) : \Gamma_{Z_1}^{\vee, Hdg}(M, F, W) \rightarrow \Gamma_{Z_2}^{\vee, Hdg}(M, F, W)$  in  $C(DRM(S))$  unique up to homotopy such that

$$\gamma_{Z_2}^{\vee, Hdg}(M, F, W) = T(Z_2/Z_1, \gamma^{\vee, Hdg})(M, F, W) \circ \gamma_{Z_1}^{\vee, Hdg}(M, F, W).$$

together with a distinguish triangle in  $K(DRM(S))$

$$\begin{array}{ccc} \Gamma_{Z_1 \setminus Z_2}^{\vee, Hdg}(M, F, W) & \xrightarrow{\text{ad}(j_{2!}^{Hdg}, j_2^*)(M, F, W)} & \Gamma_{Z_1}^{\vee, Hdg}(M, F, W) \\ \xrightarrow{T(Z_2/Z_1, \gamma^{\vee, Hdg})(M, F, W)} & \Gamma_{Z_2}^{\vee, Hdg}(M, F, W) & \rightarrow \Gamma_{Z_2 \setminus Z_1}^{\vee, Hdg}(M, F, W)[1] \end{array}$$

*Proof.* Follows from the projection case and the closed embedding case using the adjunction maps.  $\square$

The definitions 59 and 60 immediately extends to the non smooth case :

**Definition 61.** Let  $S \in \text{Var}(k)$ . Let  $Z \subset S$  a closed subset. Let  $S = \cup_i S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Denote  $Z_I := Z \cap S_I$ . Denote by  $j : S \setminus Z \hookrightarrow S$  and  $\tilde{j}_I : \tilde{S}_I \setminus Z_I \hookrightarrow \tilde{S}_I$  the complementary open embeddings.

(i) We define using definition 57, the filtered Hodge support section functor

$$\begin{aligned} \Gamma_Z^{Hdg} : C(DRM(S)) &\rightarrow C(DRM(S)), ((M_I, F, W), u_{IJ}) \mapsto \Gamma_Z^{Hdg}((M_I, F, W), u_{IJ}) := \\ &\text{Cone}(\text{ad}(j^*, j_* Hdg)(M_I, F, W), u_{IJ}) := (\text{ad}(\tilde{j}_I^*, \tilde{j}_{I*} Hdg)(M_I, F, W)) : \\ &((M_I, F, W), u_{IJ}) \rightarrow (\tilde{j}_{I*} Hdg \tilde{j}_I^*(M_I, F, W), \tilde{j}_{J*} Hdg u_{IJ})[-1], \end{aligned}$$

together with the canonical map  $\gamma_Z^{Hdg}((M_I, F, W), u_{IJ}) : \Gamma_Z^{Hdg}((M_I, F, W), u_{IJ}) \rightarrow ((M_I, F, W), u_{IJ})$ .

(i)' Since  $\tilde{j}_{I*} Hdg : C(DRM(\tilde{S}_I \setminus S_I)) \rightarrow C(DRM(\tilde{S}_I))$  are exact functors,  $\Gamma_Z^{Hdg}$  induces the functor

$$\Gamma_Z^{Hdg} : D(DRM(S)) \rightarrow D(DRM(S)), ((M_I, F, W), u_{IJ}) \mapsto \Gamma_Z^{Hdg}((M_I, F, W), u_{IJ})$$

(ii) We define using definition 57, the dual filtered Hodge support section functor

$$\begin{aligned} \Gamma_Z^{\vee, Hdg} : C(DRM(S)) &\rightarrow C(DRM(S)), \\ ((M_I, F, W), u_{IJ}) &\mapsto \Gamma_Z^{\vee, Hdg}((M_I, F, W), u_{IJ}) := \mathbb{D}_S^{Hdg} \Gamma_Z^{Hdg} \mathbb{D}_S^{Hdg}((M_I, F, W), u_{IJ}) = \\ &\text{Cone}(\text{ad}(j_{!} Hdg, j^*)((M_I, F, W), u_{IJ}) := (\text{ad}(\tilde{j}_{I!} Hdg, \tilde{j}_I^*)((M_I, F, W)) : \\ &(\tilde{j}_{I!} Hdg \tilde{j}_I^*(M_I, F, W), (\tilde{j}_{J*} Hdg u_{IJ}^d)^d) \rightarrow ((M_I, F, W), u_{IJ}), \end{aligned}$$

together we the canonical map  $\gamma_Z^{\vee, Hdg}((M_I, F, W), u_{IJ}) : ((M_I, F, W), u_{IJ}) \rightarrow \Gamma_Z^{\vee, Hdg}((M_I, F, W), u_{IJ})$ .

(ii)' Since  $\tilde{j}_{I!} Hdg : C(DRM(\tilde{S}_I \setminus S_I)) \rightarrow C(DRM(\tilde{S}_I))$  are exact functors,  $\Gamma_Z^{\vee, Hdg}$  induces the functor

$$\Gamma_Z^{\vee, Hdg} : D(DRM(S)) \rightarrow D(DRM(S)), ((M_I, F, W), u_{IJ}) \mapsto \Gamma_Z^{\vee, Hdg}((M_I, F, W), u_{IJ})$$

**Definition 62.** Let  $f : X \rightarrow S$  a morphism with  $X, S \in \text{Var}(k)$ . Assume there exist a factorization  $f : X \xrightarrow{l} Y \times S \xrightarrow{p_S} S$  with  $Y \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $p_S$  the projection. Let  $S = \cup_{i \in I} S_i$  an open cover such that there exist closed embeddings  $i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Denote  $X_I := f^{-1}(S_I)$ . We have then  $X = \cup_{i \in I} X_i$  and the commutative diagrams

$$\begin{array}{ccccc} f : X_I & \xrightarrow{l_I} & Y \times S_I & \xrightarrow{p_{S_I}} & S_I \\ & \searrow & \downarrow i'_I := (l \times i_I) & & \downarrow i_I \\ & & Y \times \tilde{S}_I & \xrightarrow{p_{\tilde{S}_I} := \tilde{j}_I} & \tilde{S}_I \end{array}$$

(i) For  $((M_I, F, W), u_{IJ}) \in C(\text{DRM}(S))$  we set (see definition 61 for  $l$ )

$$f_{\text{Hdg}}^{*\text{mod}}((M_I, F, W), u_{IJ}) := \Gamma_X^{\text{Hdg}}(p_{\tilde{S}_I}^{*\text{mod}[-]}(M_I, F, W), u_{IJ})(d_Y)[2d_Y] \in C(\text{DRM}(X)),$$

(ii) For  $((M_I, F, W), u_{IJ}) \in C(\text{DRM}(S))$  we set (see definition 61 for  $l$ )

$$f_{\text{Hdg}}^{*\text{mod}}(M, F, W) := \Gamma_X^{\vee, \text{Hdg}}(p_{\tilde{S}_I}^{*\text{mod}[-]}(M_I, F, W), p_{\tilde{S}_I}^{*\text{mod}[-]}u_{IJ}) \in C(\text{DRM}(X)),$$

Let  $j : S^\circ \hookrightarrow S$  an open embedding with  $S \in \text{Var}(k)$ . Let  $S = \cup_{i \in I} S_i$  an open cover such that there exist closed embeddings  $i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . We have then, for  $((M_I, F, W), u_{IJ}) \in C(\text{DRM}(S))$ , quasi-isomorphisms in  $C(\text{DRM}(S))$

$$I(j^*, j_{\text{Hdg}}^{*\text{mod}})(-) : j^*((M_I, F, W), u_{IJ}) := (\tilde{j}_I^*(M_I, F, W), \tilde{j}_I^*u_{IJ}) \rightarrow j_{\text{Hdg}}^{*\text{mod}}((M_I, F, W), u_{IJ})$$

and

$$I(j^*, j_{\text{Hdg}}^{*\text{mod}})(-) : j_{\text{Hdg}}^{*\text{mod}}((M_I, F, W), u_{IJ}) \rightarrow j^*((M_I, F, W), u_{IJ}) := (\tilde{j}_I^*(M_I, F, W), \tilde{j}_I^*u_{IJ}).$$

**Definition 63.** Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i \in I} S_i$  an open cover such that there exist closed embeddings  $i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . We have the following functor

$$\begin{aligned} (-) \otimes^{\text{Hdg}} (-) &: D(\text{DRM}(S))^2 \rightarrow D(\text{DRM}(S)), \\ (((M, F, W), u_{IJ}), ((N, F, W), v_{IJ})) &\mapsto ((M, F, W), u_{IJ}) \otimes_{O_S}^{\text{Hdg}} ((N, F, W), v_{IJ}) := \\ \Delta_{S, \text{Hdg}}^{*\text{mod}}(p_{1I}^{*\text{mod}}(M_I, F, W) \otimes_{O_{\tilde{S}_I \times \tilde{S}_I}} p_{2I}^{*\text{mod}}(N_I, F, W), p_{1I}^{*\text{mod}}u_{IJ} \otimes p_{2I}^{*\text{mod}}v_{IJ}) &:= \\ \Delta_S^* \text{Gr}_{V_{\Delta_S, 0}} \Gamma_{\Delta_S}^{\vee, \text{Hdg}}(p_{1I}^{*\text{mod}}(M_I, F, W) \otimes_{O_{\tilde{S}_I \times \tilde{S}_I}} p_{2I}^{*\text{mod}}(N_I, F, W), p_{1I}^{*\text{mod}}u_{IJ} \otimes p_{2I}^{*\text{mod}}v_{IJ}) & \end{aligned}$$

using the definition 62 for the diagonal closed embedding  $\Delta_S : S \hookrightarrow S \times S$ .

**Proposition 39.** Let  $f_1 : X \rightarrow Y$  and  $f_2 : Y \rightarrow S$  two morphism with  $X, Y, S \in \text{QPVar}(k)$ .

(i) Let  $(M, F, W) \in C(\text{DRM}(S))$ . Then,

$$(f_2 \circ f_1)_{\text{Hdg}}^{*\text{mod}}(M, F, W) = f_{1\text{Hdg}}^{*\text{mod}} f_{2\text{Hdg}}^{*\text{mod}}(M, F, W) \in D(\text{DRM}(X)).$$

(ii) Let  $(M, F, W) \in C(\text{DRM}(S))$ . Then,

$$(f_2 \circ f_1)_{\text{Hdg}}^{*\text{mod}}(M, F, W) = f_{1\text{Hdg}}^{*\text{mod}} f_{2\text{Hdg}}^{*\text{mod}}(M, F, W) \in D(\text{DRM}(X))$$

*Proof.* Immediate from definition. □

**Theorem 38.** (i) Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i \in I} S_i$  an open cover such that there exists closed embedding  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Then the full embedding

$$\iota_S : \text{DRM}(S) \hookrightarrow \text{PSh}_{\mathcal{D}(1,0)\text{fil}, \text{rh}}^0(S/(\tilde{S}_I)) \hookrightarrow C_{\mathcal{D}(1,0)\text{fil}, \text{rh}}(S/(\tilde{S}_I))$$

induces a full embedding

$$\iota_S : D(\text{DRM}(S)) \hookrightarrow D_{\mathcal{D}(1,0)\text{fil}, \text{rh}}(S/(\tilde{S}_I))$$

whose image consists of  $((M_I, F, W), u_{IJ}) \in D_{\mathcal{D}(1,0)\text{fil}, \text{rh}}(S/(\tilde{S}_I))$  such that  $(H^n(M_I, F, W), H^n(u_{IJ})) \in \text{DRM}(S)$  for all  $n \in \mathbb{Z}$  and such that for all  $p \in \mathbb{Z}$ , the differentials of  $\text{Gr}_W^p(M_I, F)$  are strict for the filtrations  $F$ .

(i)' Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i \in I} S_i$  an open cover such that there exists closed embedding  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . We have then

$$\begin{aligned} D(\text{DRM}(S)) &= \langle \int_{p_S} (n \times I)!_{\text{Hdg}}(\Gamma_X^{\vee, \text{Hdg}}(O_{\mathbb{P}^N, o \times \tilde{S}_I}, F_b), x_{IJ}), (f : X \xrightarrow{l} \mathbb{P}^N, o \times S \xrightarrow{p_S} S) \in \text{QPVar}(k) \rangle \\ &= \langle \int_{p_S} (\Gamma_X^{\vee, \text{Hdg}}(O_{\mathbb{P}^N, o \times \tilde{S}_I}, F_b), x_{IJ})(f : X \xrightarrow{l} \mathbb{P}^N \times S \xrightarrow{p_S} S) \in \text{QPVar}(k), \text{ proper, } X \text{ smooth} \rangle \\ &\subset D_{\mathcal{D}(1,0)\text{fil},rh}(S/(\tilde{S}_I)) \end{aligned}$$

where  $n : \mathbb{P}^{N,o} \hookrightarrow \mathbb{P}^N$  are open embeddings,  $l$  are closed embedding and  $\langle, \rangle$  means the full triangulated category generated by.

(ii) Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i \in I} S_i$  an open cover such that there exists closed embedding  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Then the full embedding

$$\iota_S : \text{DRM}(S) \hookrightarrow \text{PSh}_{\mathcal{D}(1,0)\text{fil},rh}^0(S/(\tilde{S}_I)) \hookrightarrow C_{\mathcal{D}(1,0)\text{fil},rh}(S/(\tilde{S}_I))$$

induces a full embedding

$$\iota_S : D(\text{DRM}(S)) \hookrightarrow D_{\mathcal{D}(1,0)\text{fil},\infty,rh}(S/(\tilde{S}_I))$$

whose image consists of  $((M_I, F, W), u_{IJ}) \in D_{\mathcal{D}(1,0)\text{fil},\infty,rh}(S/(\tilde{S}_I))$  such that  $(H^n(M_I, F, W), H^n(u_{IJ})) \in \text{DRM}(S)$  for all  $n \in \mathbb{Z}$  and such that there exist  $r \in \mathbb{Z}$  and an  $r$ -filtered homotopy equivalence  $((M_I, F, W), u_{IJ}) \rightarrow ((M'_I, F, W), u_{IJ})$  such that for all  $p \in \mathbb{Z}$  the differentials of  $\text{Gr}_W^p(M'_I, F)$  are strict for the filtrations  $F$ .

*Proof.* (i): We first show that  $\iota_S$  is fully faithful, that is for all  $\mathcal{M} = ((M_I, F, W), u_{IJ}), \mathcal{M}' = ((M'_I, F, W), u_{IJ}) \in \text{DRM}(S)$  and all  $n \in \mathbb{Z}$ ,

$$\begin{aligned} \iota_S : \text{Ext}_{D(\text{DRM}(S))}^n(\mathcal{M}, \mathcal{M}') &:= \text{Hom}_{D(\text{DRM}(S))}(\mathcal{M}, \mathcal{M}'[n]) \\ \rightarrow \text{Ext}_{\mathcal{D}(S)_0}^n(\mathcal{M}, \mathcal{M}') &:= \text{Hom}_{\mathcal{D}(S)_0 := D_{\mathcal{D}(1,0)\text{fil},rh}(S/(\tilde{S}_I))}(\mathcal{M}, \mathcal{M}'[n]) \end{aligned}$$

For this it is enough to assume  $S$  smooth. We then proceed by induction on  $\max(\dim \text{supp}(M), \dim \text{supp}(M'))$ .

- For  $\text{supp}(M) = \text{supp}(M') = \{s\}$ , it is obvious. If  $\text{supp}(M) = \{s\}$  and  $\text{supp}(M') = \{s'\}$  with  $s' \neq s$ , then by the localization exact sequence

$$\text{Ext}_{D(\text{MHM}(S))}^n(\mathcal{M}, \mathcal{M}') = 0 = \text{Ext}_{\mathcal{D}(S)}^n(\mathcal{M}, \mathcal{M}')$$

- Denote  $\text{supp}(M) = Z \subset S$  and  $\text{supp}(M') = Z' \subset S$ . There exist an open subset  $S^o \subset S$  such that  $Z^o := Z \cap S^o$  and  $Z'^o := Z' \cap S^o$  are smooth, and  $\mathcal{M}|_{Z^o} := (i^* \text{Gr}_{V_{Z^o}, 0} M|_{S^o}, F, W) \in \text{DRM}(Z^o)$  and  $\mathcal{M}'|_{Z'^o} := (i'^* \text{Gr}_{V_{Z'^o}, 0} M'|_{S^o}, F, W) \in \text{DRM}(Z'^o)$  are filtered vector bundles, where  $j : S^o \hookrightarrow S$  is the open embedding, and  $i : Z^o \hookrightarrow S^o, i' : Z'^o \hookrightarrow S^o$  the closed embeddings. Considering the connected components of  $Z^o$  and  $Z'^o$ , we may assume that  $Z^o$  and  $Z'^o$  are connected. Shrinking  $S^o$  if necessary, we may assume that either  $Z^o = Z'^o$  or  $Z^o \cap Z'^o = \emptyset$ . We denote  $D = S \setminus S^o$ . Shrinking  $S^o$  if necessary, we may assume that  $D$  is a divisor and denote by  $l : S \hookrightarrow L_D$  the zero section embedding.

- If  $Z^o = Z'^o$ , denote  $i : Z^o \hookrightarrow S^o$  the closed embedding. We have then the following commutative diagram

$$\begin{array}{ccc} \text{Ext}_{D(\text{DRM}(S^o))}^n(\mathcal{M}|_{S^o}, \mathcal{M}'|_{S^o}) & \xrightarrow{\iota_{S^o}} & \text{Ext}_{\mathcal{D}(S^o)_0}^n(\mathcal{M}|_{S^o}, \mathcal{M}'|_{S^o}) \\ \uparrow i^* \text{Gr}_{V_{Z^o}, 0} \quad i_{* \text{mod}} & & \uparrow i_{* \text{mod}} \quad i^* \text{Gr}_{V_{Z^o}, 0} \\ \text{Ext}_{D(\text{DRM}(Z^o))}^n(\mathcal{M}|_{Z^o}, \mathcal{M}'|_{Z^o}) & \xrightarrow{\iota_{Z^o}} & \text{Ext}_{\mathcal{D}(Z^o)_0}^n(\mathcal{M}|_{Z^o}, \mathcal{M}'|_{Z^o}) \end{array}$$

Now we prove that  $\iota_{Z^o}$  is an isomorphism similarly to the proof the the generic case of [6]. On the other hand the left and right column are isomorphisms. Hence  $\iota_{S^o}$  is an isomorphism by the diagram.

– If  $Z^o \cap Z'^o = \emptyset$ , we consider the following commutative diagram

$$\begin{array}{ccc} \text{Ext}_{D(DRM(S^o))}^n(\mathcal{M}|_{S^o}, \mathcal{M}'|_{S^o}) & \xrightarrow{\iota_{S^o}} & \text{Ext}_{D(S^o)_0}^n(\mathcal{M}|_{S^o}, \mathcal{M}'|_{S^o}) \\ \begin{array}{c} i^* \text{Gr}_{V_{Z^o}, 0} \\ \uparrow \\ i_{*mod} \end{array} & & \begin{array}{c} i_{*mod} \\ \uparrow \\ i^* \text{Gr}_{V_{Z^o}, 0} \end{array} \\ \text{Ext}_{D(DRM(Z^o))}^n(\mathcal{M}|_{Z^o}, 0) = 0 & \xrightarrow{\iota_{Z^o}} & \text{Ext}_{D(Z^o)_0}^n(\mathcal{M}|_{Z^o}, 0) = 0 \end{array}$$

where the left and right column are isomorphism by strictness of the  $V_{Z^o}$  filtration (use a bi-filtered injective resolution with respect to  $F$  and  $V_{Z^o}$  for the right column).

- We consider now the following commutative diagram in  $C(\mathbb{Z})$  where we denote for short  $H_0 := D(DRM(S))$

$$\begin{array}{ccccccc} 0 & \longrightarrow & \text{Hom}_{H_0}^\bullet(\Gamma_D^{\vee, Hdg} \mathcal{M}, \Gamma_D^{Hdg} \text{Hom}(-, \gamma_D^{Hdg}(\mathcal{M}')) & \longrightarrow & \text{Hom}_{H_0}^\bullet(\Gamma_D^{\vee, Hdg} \mathcal{M}, \text{Hom}(-, \text{ad}(j^*, j_{*Hdg})(\mathcal{M}')) & \longrightarrow & \text{Hom}_{H_0}^\bullet(\Gamma_D^{\vee, Hdg} \mathcal{M}, j_{*Hdg} j^* \mathcal{M}') \longrightarrow \\ & & \downarrow \iota_S & & \downarrow \iota_S & & \downarrow \iota_S \\ 0 & \longrightarrow & \text{Hom}_{D(S)_0}^\bullet(\Gamma_D^{\vee, Hdg} \mathcal{M}, \Gamma_D^{Hdg} \text{Hom}(-, \gamma_D^{Hdg}(\mathcal{M}')) & \longrightarrow & \text{Hom}_{D(S)_0}^\bullet(\Gamma_D^{\vee, Hdg} \mathcal{M}, \text{Hom}(-, \text{ad}(j^*, j_{*Hdg})(\mathcal{M}')) & \longrightarrow & \text{Hom}_{D(S)_0}^\bullet(\Gamma_D^{\vee, Hdg} \mathcal{M}, j_{*Hdg} j^* \mathcal{M}') \longrightarrow \end{array}$$

whose lines are exact sequence. We have on the one hand,

$$\text{Hom}_{D(DRM(S))}^\bullet(\Gamma_D^{\vee, Hdg} \mathcal{M}, j_{*Hdg} j^* \mathcal{M}') = 0 = \text{Hom}_{D(S)}^\bullet(\Gamma_D^{\vee, Hdg} \mathcal{M}, j_{*Hdg} j^* \mathcal{M}')$$

On the other hand by induction hypothesis

$$\iota_S : \text{Hom}_{D(DRM(S))}^\bullet(\Gamma_D^{\vee, Hdg} \mathcal{M}, \Gamma_D^{Hdg} \mathcal{M}') \rightarrow \text{Hom}_{D(S)_0}^\bullet(\Gamma_D^{\vee, Hdg} \mathcal{M}, \Gamma_D^{Hdg} \mathcal{M}')$$

is a quasi-isomorphism. Hence, by the diagram

$$\iota_S : \text{Hom}_{D(DRM(S))}^\bullet(\Gamma_D^{\vee, Hdg} \mathcal{M}, \mathcal{M}') \rightarrow \text{Hom}_{D(S)_0}^\bullet(\Gamma_D^{\vee, Hdg} \mathcal{M}, \mathcal{M}')$$

is a quasi-isomorphism.

- We consider now the following commutative diagram in  $C(\mathbb{Z})$  where we denote for short  $H_0 := D(DRM(S))$

$$\begin{array}{ccccccc} 0 & \longrightarrow & \text{Hom}_{H_0}^\bullet(\Gamma_D^{\vee, Hdg} \mathcal{M}, \mathcal{M}') & \xrightarrow{\text{Hom}(\gamma_D^{\vee, Hdg}(\mathcal{M}), -)} & \text{Hom}_{H_0}^\bullet(\mathcal{M}, \mathcal{M}') & \xrightarrow{\text{Hom}(\text{ad}(j_{!Hdg}, j^*)(\mathcal{M}'), -)} & \text{Hom}_{H_0}^\bullet(j_{!Hdg} j^* \mathcal{M}, \mathcal{M}') \longrightarrow 0 \\ & & \downarrow \iota_S & & \downarrow \iota_S & & \downarrow \iota_S \\ 0 & \longrightarrow & \text{Hom}_{D(S)_0}^\bullet(\Gamma_D^{\vee, Hdg} \mathcal{M}, \mathcal{M}') & \xrightarrow{\text{Hom}(\gamma_D^{\vee, Hdg}(\mathcal{M}), -)} & \text{Hom}_{D(S)_0}^\bullet(\mathcal{M}, \mathcal{M}') & \xrightarrow{\text{Hom}(\text{ad}(j_{!Hdg}, j^*)(\mathcal{M}'), -)} & \text{Hom}_{D(S)_0}^\bullet(j_{!Hdg} j^* \mathcal{M}, \mathcal{M}') \longrightarrow 0 \end{array}$$

whose lines are exact sequence. On the one hand, the commutative diagram

$$\begin{array}{ccc} \text{Hom}_{D(DRM(S))}^\bullet(j_{!Hdg} j^* \mathcal{M}, \mathcal{M}') & \xrightarrow{j^*} & \text{Hom}_{D(DRM(S^o))}^\bullet(j^* \mathcal{M}, j^* \mathcal{M}') \\ \downarrow \iota_S & & \downarrow \iota_{S^o} \\ \text{Hom}_{D(S)_0}^\bullet(j_{!Hdg} j^* \mathcal{M}, \mathcal{M}') & \xrightarrow{j^*} & \text{Hom}_{D(S^o)_0}^\bullet(j^* \mathcal{M}, j^* \mathcal{M}') \end{array}$$

together with the fact that the horizontal arrows  $j^*$  are quasi-isomorphism by the functoriality given the uniqueness of the  $V_S$  filtration for the embedding  $l : S \hookrightarrow L_D$ , (use a bi-filtered injective resolution with respect to  $F$  and  $V_S$  for the lower arrow) and the fact that  $\iota_S$  is a quasi-isomorphism by the first two point, show that

$$\iota_S : \mathrm{Hom}_{D(DRM(S))}^\bullet(j_{!Hdg}j^*\mathcal{M}, \mathcal{M}') \rightarrow \mathrm{Hom}_{\mathcal{D}(S)_0}^\bullet(j_{!Hdg}j^*\mathcal{M}, \mathcal{M}')$$

is a quasi-isomorphism. On the other hand, by the third point

$$\iota_S : \mathrm{Hom}_{D(DRM(S))}^\bullet(\Gamma_D^{\vee, Hdg}\mathcal{M}, \mathcal{M}') \rightarrow \mathrm{Hom}_{\mathcal{D}(S)_0}^\bullet(\Gamma_D^{\vee, Hdg}\mathcal{M}, \mathcal{M}')$$

is a quasi-isomorphism. Hence, by the diagram

$$\iota_S : \mathrm{Hom}_{D(DRM(S))}^\bullet(\Gamma_D^{\vee, Hdg}\mathcal{M}, \mathcal{M}') \rightarrow \mathrm{Hom}_{\mathcal{D}(S)_0}^\bullet(\Gamma_D^{\vee, Hdg}\mathcal{M}, \mathcal{M}')$$

is a quasi-isomorphism.

This shows the fully faithfulness. We now prove the essential surjectivity : let

$$((M_I, F, W), u_{IJ}) \in C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I))$$

such that the cohomology are mixed hodge modules and such that the differential are strict. We proceed by induction on  $card\{n \in \mathbb{Z}\}$ , s.t.  $H^n(M_I, F, W) \neq 0$  by taking the cohomological troncation and using the fact that the differential are strict for the filtration  $F$  and the fully faithfulness.

(i): Follows from (i).

(ii): Follows from (i). Indeed, in the composition of functor

$$\iota_S : D(DRM(S)) \xrightarrow{\iota_S} D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \rightarrow D_{\mathcal{D}(1,0)fil,\infty,rh}(S/(\tilde{S}_I))$$

the second functor which is the localization functor is an isomorphism on the full subcategory  $D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I))^{st} \subset D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I))$  consisting of complex such that the differentials are strict for  $F$ , and the first functor  $\iota_S$  is a full embedding by (i) and  $\iota_S(D(DRM(S))) \subset D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I))^{st}$ .  $\square$

**Definition 64.** Let  $f : X \rightarrow S$  a morphism with  $X, S \in \mathrm{SmVar}(k)$ . Consider a compactification  $f : X \xrightarrow{j} \bar{X} \xrightarrow{\bar{f}} S$  of  $f$ , in particular  $j$  is an open embedding and  $\bar{f}$  is proper.

(i) For  $(M, F, W) \in C(DRM(X))$ , we define, using definition 57,

$$\int_f^{Hdg} (M, F, W) := \int_{\bar{f}}^{FDR} j_{*Hdg}(M, F, W) \in D_{\mathcal{D}(1,0)fil}(S)$$

It does not depends on the choice of the compactification as in the complex case: for two compactification  $\bar{f} : \bar{X} \rightarrow S$ ,  $\bar{f}' : \bar{X}' \rightarrow S$ , there exist a compactification  $\bar{f}'' : \bar{X}'' \rightarrow S$  together with morphisms  $e : \bar{X}'' \rightarrow \bar{X}$  and  $e' : \bar{X}'' \rightarrow \bar{X}'$  such that  $\bar{f} \circ e = \bar{f} \circ e' = \bar{f}''$ . Let  $(M, F, W) \in C(DRM(X))$ , then

– by definition  $H^i \int_{\bar{f}}^{FDR} \mathrm{Gr}_W^k j_{*Hdg}(M, F, W) \in PDRM(S)$  for all  $i, k \in \mathbb{Z}$ , hence by the spectral sequence for the filtered complex  $\int_{\bar{f}}^{FDR} j_{*Hdg}(M, W)$

$$\mathrm{Gr}_W^k(H^i \int_f^{Hdg} (M, F, W)) = \mathrm{Gr}_W^k(H^i \int_{\bar{f}}^{FDR} j_{*Hdg}(M, F, W)) \in PDRM(S)$$

since it is a sub-quotient of  $H^i \int_{\bar{f}}^{FDR} \mathrm{Gr}_W^k j_{*Hdg}(M, F, W)$ , this gives by definition  $H^i \int_f^{Hdg} (M, F, W) \in DRM(S)$  for all  $i \in \mathbb{Z}$ .

- $\int_f^{Hdg}(M, F, W)$  is the class of a complex such that the differential are strict for  $F$  by theorem 37 in the complex case

We then set using theorem 38

$$Rf_*^{Hdg}(M, F, W) := \iota_S^{-1} \int_f^{Hdg} (M, F, W) \in D(DRM(S))$$

- (ii) For  $(M, F, W) \in C(DRM(X))$ , we define, using definition 57,

$$\int_{f!}^{Hdg} (M, F, W) := \int_{\bar{f}}^{FDR} j_{!Hdg}(M, F, W) \in D_{\mathcal{D}(1,0)fil}(S)$$

It does not depends on the choice of the compactification as in the complex case: for two compactification  $\bar{f} : \bar{X} \rightarrow S$ ,  $\bar{f}' : \bar{X}' \rightarrow S$ , there exist a compactification  $\bar{f}'' : \bar{X}'' \rightarrow S$  together with morphisms  $e : \bar{X}'' \rightarrow \bar{X}$  and  $e' : \bar{X}'' \rightarrow \bar{X}'$  such that  $\bar{f} \circ e = \bar{f}'' = \bar{f}' \circ e'$ . Let  $(M, F, W) \in C(DRM(X))$ , then

- by definition  $H^i \int_{\bar{f}}^{FDR} \text{Gr}_W^k j_{!Hdg}(M, F, W) \in PDRM(S)$  for all  $i, k \in \mathbb{Z}$ , hence by the spectral sequence for the filtered complex  $\int_{\bar{f}}^{FDR} j_{!Hdg}(M, W)$

$$\text{Gr}_W^k (H^i \int_{f!}^{Hdg} (M, F, W)) == \text{Gr}_W^k (H^i \int_{\bar{f}}^{FDR} j_{!Hdg}(M, F, W)) \in PDRM(S)$$

since it is a sub-quotient of  $H^i \int_{\bar{f}}^{FDR} \text{Gr}_W^k j_{!Hdg}(M, F, W)$ , this gives by definition  $H^i \int_{f!}^{Hdg}(M, F, W) \in DRM(S)$  for all  $i \in \mathbb{Z}$ .

- $\int_{f!}^{Hdg}(M, F, W)$  is the class of a complex such that the differential are strict for  $F$  by theorem 37 in the complex case.

We then set using theorem 38

$$Rf_!^{Hdg}(M, F, W) := \iota_S^{-1} \int_{f!}^{Hdg} (M, F, W) \in D(DRM(S))$$

In the singular case, we set the following

**Definition 65.** Let  $f : X \rightarrow S$  a morphism with  $X, S \in \text{Var}(k)$ . Assume there exist a factorization  $f : X \xrightarrow{l} Y \times S \xrightarrow{p_S} S$  with  $Y \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $p_S$  the projection. Let  $\bar{Y} \in \text{PSmVar}(k)$  a compactification of  $Y$  and denote by  $n : Y \hookrightarrow \bar{Y}$  the open embedding. Denote again  $p_S : \bar{Y} \times S \rightarrow S$  the projection. Let  $S = \cup_{i \in I} S_i$  an open cover such that there exists closed embedding  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . We have then the open cover  $X = \cup_i X_i$  with  $X_i := f^{-1}(S_i)$  together with closed embeddings  $i'_i : X_i \hookrightarrow Y \times \tilde{S}_i$ .

- (i) For  $((M_I, F, W), u_{IJ}) \in C(DRM(X))$ , we define, using definition 57 for  $n \times I : Y \times S \hookrightarrow \bar{Y} \times S$ ,

$$\int_{p_S}^{Hdg} ((M_I, F, W), u_{IJ}) := \int_{p_S}^{FDR} (n \times I)_{*Hdg}((M_I, F, W), u_{IJ}) \in D_{\mathcal{D}(1,0)fil}(S/\tilde{S}_I)$$

with

$$(n \times I)_{*Hdg}((M_I, F, W), u_{IJ}) := ((n \times I)_{*Hdg}(M_I, F, W), (n \times I)_{*Hdg}u_{IJ}) \in C(\bar{X}/(\bar{Y} \times \tilde{S}_I))$$

We then set using theorem 38 and theorem 37

$$Rf_*^{Hdg}((M_I, F, W), u_{IJ}) := \iota_S^{-1} \int_{p_S}^{Hdg} ((M_I, F, W), u_{IJ}) \in D(DRM(S)).$$

(ii) For  $((M_I, F, W), u_{IJ}) \in C(DRM(X))$ , we define, using definition 57 for  $n \times I : Y \times S \hookrightarrow \bar{Y} \times S$ ,

$$\int_{ps!}^{Hdg} ((M_I, F, W), u_{IJ}) := \int_{ps}^{FDR} (n \times I)!_{Hdg} ((M_I, F, W), u_{IJ}) \in D_{\mathcal{D}(1,0)fil}(S/(\tilde{S}_I))$$

with

$$(n \times I)!_{Hdg} ((M_I, F, W), u_{IJ}) := ((n \times I)!_{Hdg}(M_I, F, W), ((n \times I)_*^{Hdg} u_{IJ}^d)^d) \in C(\bar{X}/(\bar{Y} \times \tilde{S}_I))$$

We then set using theorem 38 and theorem 37

$$Rf_!^{Hdg}((M_I, F, W), u_{IJ}) := \iota_S^{-1} \int_{ps!}^{Hdg} ((M_I, F, W), u_{IJ}) \in D(DRM(S)).$$

**Proposition 40.** Let  $f_1 : X \rightarrow Y$  and  $f_2 : Y \rightarrow S$  two morphism with  $X, Y, S \in \text{QPVar}(k)$  or with  $X, Y, S \in \text{SmVar}(k)$ .

(i) Let  $(M, F, W) \in C(DRM(X))$ . Then,

$$R(f_2 \circ f_1)_*^{Hdg}(M, F, W) = Rf_{2*}^{Hdg} Rf_{1*}^{Hdg}(M, F, W) \in D(DRM(S)).$$

(ii) Let  $(M, F, W) \in C(DRM(X))$ . Then,

$$R(f_2 \circ f_1)!^{Hdg}(M, F, W) = Rf_{2!}^{Hdg} Rf_{1!}^{Hdg}(M, F, W) \in D(DRM(S))$$

*Proof.* Immediate from definition. □

**Proposition 41.** Let  $f : X \rightarrow S$  with  $S, X \in \text{SmVar}(k)$  or with  $S, X \in \text{QPVar}(k)$ . Then

(i)  $(f_{Hdg}^{*mod}, Rf_*^{Hdg}) : D(DRM(S)) \rightarrow D(DRM(X))$  is a pair of adjoint functors. For  $(M, F, W) \in C(DRM(S))$  we denote by

$$\text{ad}(f_{Hdg}^{*mod}, Rf_*^{Hdg})(M, F, W) : (M, F, W) \rightarrow Rf_*^{Hdg} f_{Hdg}^{*mod}(M, F, W)$$

the adjonction map in  $D(DRM(S))$ . For  $(N, F, W) \in C(DRM(X))$ , we denote by

$$\text{ad}(f_{Hdg}^{*mod}, Rf_*^{Hdg})(N, F, W) : f_{Hdg}^{*mod} Rf_*^{Hdg}(N, F, W) \rightarrow (N, F, W)$$

the adjonction map in  $D(DRM(X))$ .

(ii)  $(Rf_!^{Hdg}, f_{Hdg}^{*mod}) : D(DRM(X)) \rightarrow D(DRM(S))$  is a pair of adjoint functors. For  $(M, F, W) \in C(DRM(S))$  we denote by

$$\text{ad}(Rf_!^{Hdg}, f_{Hdg}^{*mod})(M, F, W) : Rf_!^{Hdg} f_{Hdg}^{*mod}(M, F, W) \rightarrow (M, F, W)$$

the adjonction map in  $D(DRM(S))$ . For  $(N, F, W) \in C(DRM(X))$ , we denote by

$$\text{ad}(Rf_!^{Hdg}, f_{Hdg}^{*mod})(N, F, W) : (N, F, W) \rightarrow f_{Hdg}^{*mod} Rf_!^{Hdg}(N, F, W)$$

the adjonction map in  $D(DRM(X))$ .

*Proof.* Follows from proposition 37 after considering the graph factorization  $f : X \hookrightarrow \bar{X} \times S \xrightarrow{ps} S$  with  $\bar{X} \in \text{PSmVar}(k)$  a compactification of  $X$ . □

We have by proposition 39 and proposition 40 the 2 functors on  $\text{QPVar}(k)$  :

- $D(DRM(-)) : \text{QPVar}(k) \rightarrow D(DRM(-)), S \mapsto D(DRM(S)), (f : T \rightarrow S) \mapsto Rf_*^{Hdg}$ ,

- $D(\text{DRM}(-)) : \text{QPVar}(k) \rightarrow D(\text{DRM}(-)), S \mapsto D(\text{DRM}(S)), (f : T \rightarrow S) \mapsto Rf_!^{\text{Hdg}}$ ,
- $D(\text{DRM}(-)) : \text{QPVar}(k) \rightarrow D(\text{DRM}(-)), S \mapsto D(\text{DRM}(S)), (f : T \rightarrow S) \mapsto f_{\text{Hdg}}^{*\text{mod}}$ ,
- $D(\text{DRM}(-)) : \text{QPVar}(k) \rightarrow D(\text{DRM}(-)), S \mapsto D(\text{DRM}(S)), (f : T \rightarrow S) \mapsto f_{\text{Hdg}}^{\hat{*}\text{mod}}$ .

**Proposition 42.** *Let  $f : X \rightarrow S$  with  $S, X \in \text{SmVar}(k)$  or with  $S, X \in \text{QPVar}(k)$ . Then*

(i)  $(f_{\text{Hdg}}^{\hat{*}\text{mod}}, Rf_*^{\text{Hdg}}) : D(\text{DRM}(S)) \rightarrow D(\text{DRM}(X))$  is a pair of adjoint functors. For  $((M_I, F, W), u_{IJ}) \in C(\text{DRM}(S))$  we denote by

$$\text{ad}(f_{\text{Hdg}}^{\hat{*}\text{mod}}, Rf_*^{\text{Hdg}})((M_I, F, W), u_{IJ}) : ((M_I, F, W), u_{IJ}) \rightarrow Rf_*^{\text{Hdg}} f_{\text{Hdg}}^{\hat{*}\text{mod}}((M_I, F, W), u_{IJ})$$

the adjunction map in  $D(\text{DRM}(S))$ . For  $((N_I, F, W), u_{IJ}) \in C(\text{DRM}(X))$ , we denote by

$$\text{ad}(f_{\text{Hdg}}^{\hat{*}\text{mod}}, Rf_*^{\text{Hdg}})((N_I, F, W), u_{IJ}) : f_{\text{Hdg}}^{\hat{*}\text{mod}} Rf_*^{\text{Hdg}}((N_I, F, W), u_{IJ}) \rightarrow ((N_I, F, W), u_{IJ})$$

the adjunction map in  $D(\text{DRM}(X))$

(ii)  $(Rf_!^{\text{Hdg}}, f_{\text{Hdg}}^{*\text{mod}}) : D(\text{DRM}(X)) \rightarrow D(\text{DRM}(S))$  is a pair of adjoint functors. For  $((M_I, F, W), u_{IJ}) \in C(\text{DRM}(S))$  we denote by

$$\text{ad}(Rf_!^{\text{Hdg}}, f_{\text{Hdg}}^{*\text{mod}})((M_I, F, W), u_{IJ}) : Rf_!^{\text{Hdg}} f_{\text{Hdg}}^{*\text{mod}}((M_I, F, W), u_{IJ}) \rightarrow ((M_I, F, W), u_{IJ})$$

the adjunction map in  $D(\text{DRM}(S))$ . For  $((N_I, F, W), u_{IJ}) \in C(\text{DRM}(X))$ , we denote by

$$\text{ad}(Rf_!^{\text{Hdg}}, f_{\text{Hdg}}^{*\text{mod}})((N_I, F, W), u_{IJ}) : ((N_I, F, W), u_{IJ}) \rightarrow f_{\text{Hdg}}^{*\text{mod}} Rf_!^{\text{Hdg}}((N_I, F, W), u_{IJ})$$

the adjunction map in  $D(\text{DRM}(X))$ .

*Proof.* Follows from proposition 37 after considering a factorization  $f : X \hookrightarrow \bar{Y} \times S \xrightarrow{p_S} S$  with  $\bar{Y} \in \text{PSmVar}(k)$ .  $\square$

**Theorem 39.** *Let  $k$  a field of characteristic zero.*

- (i) *We have the six functor formalism on  $D(\text{DRM}(-)) : \text{SmVar}(k) \rightarrow \text{TriCat}$ .*
- (ii) *We have the six functor formalism on  $D(\text{DRM}(-)) : \text{QPVar}(k) \rightarrow \text{TriCat}$ .*

*Proof.* Follows from proposition 42.  $\square$

**Theorem 40.** *Let  $k \subset K \subset \mathbb{C}_p$  a subfield with  $p$  a prime number and  $K$  a  $p$  adic field. Let  $S \in \text{SmVar}(k)$ . Let  $D = V(s) \subset S$  a divisor with  $s \in \Gamma(S, L)$  and  $L$  a line bundle ( $S$  being smooth,  $D$  is Cartier). so that we have the closed embedding  $i : S \hookrightarrow L$ ,  $i(x) = (x, s(x))$  and  $D = i^{-1}(s_0)$ ,  $s_0$  being the zero section. For  $(M, F, W) \in \text{DRM}(S)$ ,*

- *we have the canonical isomorphism in  $D_{\mathbb{B}^{\text{dr}}}(S_K^{\text{an}, \text{pet}})$*

$$\begin{aligned} T^{\mathbb{B}^{\text{dr}}}(\psi_D, DR)(M, F, W) &:= B^{\mathbb{B}^{\text{dr}}}(M, F, W) \circ A^{\mathbb{B}^{\text{dr}}}(M, F, W)^{-1} : \\ DR(S)(\psi_D(M, F, W)^{\text{an}} \otimes_{\mathcal{O}_{S_K}} (\mathcal{O}_{\mathbb{B}^{\text{dr}}, S_K}, F)) &\xrightarrow{\sim} \psi_D DR(S)((M, F, W)^{\text{an}} \otimes_{\mathcal{O}_{S_K}} (\mathcal{O}_{\mathbb{B}^{\text{dr}}, S_K}, F)) \end{aligned}$$

with, for  $S = \cup_{i=1}^s S_i$  an open affine cover such that  $D \cap S_i = V(f_i) \subset S_i$  is given by  $f_i \in \Gamma(S_i, \mathcal{O}_{S_i})$ , denoting  $q : L_i := p^{-1}(S_i) \rightarrow \mathbb{A}_k^1$  the projection and  $j_i : S_i \hookrightarrow S$  the open embeddings,



– the isomorphism in  $D_{\mathbb{B}_{dr}2fil}(S_K^{an,pet})$

$$\begin{aligned} A^{B_{dr}}(M, F, W) &: (\oplus_{i=1}^s \oplus_{-1 \leq \alpha < 0} \text{Cone}(\partial_s : DR(L_i/\mathbb{A}_k^1)((V_{D\alpha}(M, F^*, W))^{an}) \otimes_{O_S} s^{\alpha+1} O\mathbb{B}_{dr,S_K} \\ &\rightarrow DR(L_i/\mathbb{A}_k^1)((V_{D\alpha}(M, F^{*-1}, W))^{an}) \otimes_{O_S} s^\alpha O\mathbb{B}_{dr,S_K} \xrightarrow{(j_i^*)} \cdots) \\ &\rightarrow (\oplus_{i=1}^s DR(S_i)(\psi_D(M, F, W)^{an} \otimes_{O_{S_K}} (O\mathbb{B}_{dr,S_K}, F)) \xrightarrow{j_i^*} \cdots) \\ &\xrightarrow{((j_i^*), 0)^{-1}} (DR(S)(\psi_D(M, F, W)^{an}) \otimes_{O_{S_K}} (O\mathbb{B}_{dr,S_K}, F)), (\sum_j m_j \otimes (\log s)^j, m') \mapsto [m_0], \end{aligned}$$

– and the isomorphism in  $D_{\mathbb{B}_{dr}2fil}(S_K^{an,pet})$

$$\begin{aligned} B^{B_{dr}}(M, F, W) &: (\oplus_{i=1}^s \oplus_{-1 \leq \alpha < 0} \text{Cone}(\partial_s : V_{D\alpha} DR(L_i/\mathbb{A}_k^1)((M, F^*, W)^{an}) \otimes_{O_{S_K}} s^{\alpha+1} O\mathbb{B}_{dr,S_K} \\ &\rightarrow V_{D\alpha} DR(L_i/\mathbb{A}_k^1)((M, F^{*-1}, W)^{an}) \otimes_{O_{S_K}} s^\alpha O\mathbb{B}_{dr,S_K} \xrightarrow{(j_i^*)} \cdots) \\ &\rightarrow (\oplus_{i=1}^s DR(p^* O_{\mathbb{A}_k^1})(i^* \pi_* \pi^{*mod} DR(L_i/\mathbb{A}_k^1)((M, F, W)^{an}) \otimes_{O_{S_K}} (O\mathbb{B}_{dr,S_K}, F)) \xrightarrow{(j_i^*)} \cdots) \\ &\xrightarrow{\cong} (\oplus_{i=1}^s DR(p^* O_{\mathbb{A}_k^1})(\psi_D(DR(L_i/\mathbb{A}_k^1)((M, F, W)^{an}) \otimes_{O_{S_K}} (O\mathbb{B}_{dr,S_K}, F))) \xrightarrow{(j_i^*)} \cdots) \\ &\xrightarrow{((j_i^*), 0)^{-1}} \psi_D DR(S)((M, F, W)^{an} \otimes_{O_{S_K}} (O\mathbb{B}_{dr,S_K}, F)), (\sum_j m_j \otimes (\log s)^j, m') \mapsto \sum_j (\log s)^j m_j, \end{aligned}$$

so that  $T_{B_{dr}}(\psi_D, DR)(M) \circ DR(S)(s\partial_s) = N \circ T_{B_{dr}}(\psi_D, DR)(M)$  where

$$N := \log T \in \text{Hom}(\psi_D DR(S)(M^{an} \otimes_{O_{S_K}} O\mathbb{B}_{dr,S_K}), \psi_D DR(S)(M^{an} \otimes_{O_{S_K}} O\mathbb{B}_{dr,S_K}))$$

is induced by the monodromy automorphism  $T : \tilde{S}^\circ \xrightarrow{\sim} \tilde{S}^\circ$  of the perfectoid universal covering  $\pi : \tilde{S}^\circ \rightarrow S^\circ := S \setminus D$  (see [27]).

• there is a canonical isomorphism in  $D_{\mathbb{B}_{dr}2fil}(S_K^{an,pet})$

$$\begin{aligned} T^{B_{dr}}(\phi_D, DR)(M, F, W) &: DR(S)(\phi_D(M, F, W)^{an} \otimes_{O_{S_K}} (O\mathbb{B}_{dr,S_K}, F)) \\ &\xrightarrow{DR(S)(0, (\text{var}(M, F, W) \otimes I))} DR(S)(\phi_D^\rho(M, F, W)^{an} \otimes_{O_{S_K}} (O\mathbb{B}_{dr,S_K}, F)) \\ &\xrightarrow{(I, T^{B_{dr}}(M, F, W))} \phi_D DR(S)((M, F, W)^{an} \otimes_{O_{S_K}} (O\mathbb{B}_{dr,S_K}, F)). \end{aligned}$$

where

$$\phi_D^\rho(M, F, W) := \text{Cone}(\theta_{DR,D}(M, F, W) : \Gamma_D^{\vee, Hdg}(M, F, W) \rightarrow \psi_D(M, F, W))$$

with  $\theta_{DR,D}(M, F, W)$  the factorization in  $C_{D(1,0)fil,rh}(S)$

$$\begin{aligned} &\rho_{DR,D}(M, F, W) \circ \text{ad}(j^*, j_* Hdg)(M, F, W) : \\ (M, F, W) &\xrightarrow{\gamma_D^{\vee, Hdg}(M, F, W)} \Gamma_D^{\vee, Hdg}(M, F, W) \xrightarrow{\theta_{DR,D}(M)} \psi_D(M, F, W). \end{aligned}$$

of the map given in definition 58.

*Proof.* Follows from the proof of theorem 35:  $j_i^* A^{B_{dr}}(M, F, W)$  are filtered quasi-isomorphism, hence

$$\begin{aligned} &\text{Cone}(\partial_s : V_{D\alpha} DR(L_i/\mathbb{A}_k^1)((M, F^*, W)^{an}) \otimes_{O_{S_K}} s^{\alpha+1} O\mathbb{B}_{dr,S_K} \\ &\rightarrow V_{D\alpha} DR(L_i/\mathbb{A}_k^1)((M, F^{*-1}, W)^{an}) \otimes_{O_{S_K}} s^\alpha O\mathbb{B}_{dr,S_K} \end{aligned}$$

is strict for the  $F$ -filtration (i.e. the spectral sequence for the  $F$ -filtration is  $E_1$ -degenerate, hence the fact that  $j_i^* B^{B_{dr}}(M, F, W)$  is a quasi-isomorphism implies that  $j_i^* B^{B_{dr}}(M, F, W)$  is a filtered quasi-isomorphism.  $\square$

## 6 The geometric Mixed Hodge Modules over a field $k$ of characteristic 0

### 6.1 The complex case where $k \subset \mathbb{C}$

Let  $k \subset \mathbb{C}$  a subfield. For  $S \in \text{Var}(k)$ , we denote by  $\text{an}_S : S^{\text{an}} := S_{\mathbb{C}}^{\text{an}} \xrightarrow{\text{an}_S} S_{\mathbb{C}} \xrightarrow{\pi_{k/\mathbb{C}}(S)} S$  the morphism of ringed spaces given by the analytical functor.

- For  $(M, F) \in C_{O_S \text{fil}}(S)$ , we denote by  $(M, F)^{\text{an}} := \text{an}_S^{*\text{mod}}(M, F) \in C_{O_S \text{fil}}(S_{\mathbb{C}}^{\text{an}})$ .
- For  $(M, F) \in C_{\mathcal{D} \text{fil}}(S)$ , we denote by  $(M, F)^{\text{an}} := \text{an}_S^{*\text{mod}}(M, F) \in C_{\mathcal{D} \text{fil}}(S_{\mathbb{C}}^{\text{an}})$ .

We denote for short

$$DR(S) := DR(S_{\mathbb{C}}^{\text{an}}) \circ \text{an}_S^{*\text{mod}} : C_{\mathcal{D} \text{fil}}(S) \rightarrow C_{\text{fil}}(S_{\mathbb{C}}^{\text{an}}), \quad M \mapsto DR(S)(M^{\text{an}})$$

the De Rham functor.

- Let  $S \in \text{SmVar}(k)$ . The category  $C_{\mathcal{D}(1,0) \text{fil}, rh}(S) \times_I D_{\text{fil}, c, k}(S_{\mathbb{C}}^{\text{an}})$  is the category

- whose set of objects is the set of triples  $\{((M, F, W), (K, W), \alpha)\}$  with

$$(M, F, W) \in C_{\mathcal{D}(1,0) \text{fil}, rh}(S), \quad (K, W) \in D_{\text{fil}, c, k}(S_{\mathbb{C}}^{\text{an}}), \quad \alpha : (K, W) \otimes \mathbb{C}_{S_{\mathbb{C}}^{\text{an}}} \rightarrow DR(S)^{[-1]}((M, W)^{\text{an}})$$

where  $DR(S)^{[-1]} := DR(S)^{[-1]}(S_{\mathbb{C}}^{\text{an}}) : C_{\mathcal{D}(1,0) \text{fil}, rh}(S_{\mathbb{C}}^{\text{an}}) \rightarrow C_{\text{fil}}(S_{\mathbb{C}}^{\text{an}})$  is the De Rham functor (recall for  $S' \subset S$  a connected component of  $S$  of dimension  $d$ ,  $DR(S)^{[-1]}_{|S'} := DR(S)_{|S'}[d]$ ) and  $\alpha$  is an morphism in  $D_{\text{fil}}(S_{\mathbb{C}}^{\text{an}})$ ,

- and whose set of morphisms are

$$\phi = (\phi_D, \phi_C, [\theta]) : ((M_1, F, W), (K_1, W), \alpha_1) \rightarrow ((M_2, F, W), (K_2, W), \alpha_2)$$

where  $\phi_D : (M_1, F, W) \rightarrow (M_2, F, W)$  and  $\phi_C : (K_1, W) \rightarrow (K_2, W)$  are morphisms, and

$$\theta = (\theta^\bullet, I(DR(S)(\phi_D^{\text{an}})) \circ I(\alpha_1), I(\alpha_2) \circ I(\phi_C \otimes I)) : I(K_1, W) \otimes \mathbb{C}_{S^{\text{an}}}[1] \rightarrow I(DR(S)(M_2^{\text{an}}, W))$$

is an homotopy, i.e. for all  $i \in \mathbb{Z}$ ,

$$\theta^i \circ \partial^i - \partial^{i+1} \circ \theta^i = (I(DR(S)(\phi_D)) \circ I(\alpha_1))^i - (I(\alpha_2) \circ I(\phi_C))^i,$$

$I : C_{\text{fil}}(S_{\mathbb{C}}^{\text{an}}) \rightarrow K_{\text{fil}}(S_{\mathbb{C}}^{\text{an}})$  being the injective resolution functor : for  $(K, W) \in C_{\text{fil}}(S_{\mathbb{C}}^{\text{an}})$ , we take an injective resolution  $k : (K, W) \rightarrow I(K, W)$  with  $I(K, W) \in C_{\text{fil}}(S_{\mathbb{C}}^{\text{an}})$  which is unique modulo homotopy, and the class  $[\theta]$  of  $\theta$  does NOT depend of the injective resolution ; in particular, we have

$$DR(S)^{[-1]}(\phi_D^{\text{an}}) \circ \alpha_1 = \alpha_2 \circ (\phi_C \otimes I)$$

in  $D_{\text{fil}}(S_{\mathbb{C}}^{\text{an}})$  ; and for

- \*  $\phi = (\phi_D, \phi_C, [\theta]) : ((M_1, F, W), (K_1, W), \alpha_1) \rightarrow ((M_2, F, W), (K_2, W), \alpha_2)$
- \*  $\phi' = (\phi'_D, \phi'_C, [\theta']) : ((M_2, F, W), (K_2, W), \alpha_2) \rightarrow ((M_3, F, W), (K_3, W), \alpha_3)$

the composition law is given by

$$\begin{aligned} \phi' \circ \phi &:= (\phi'_D \circ \phi_D, \phi'_C \circ \phi_C, I(DR(S)(\phi_D^{\text{an}})) \circ [\theta] + [\theta'] \circ I(\phi_C \otimes I)[1]) : \\ &((M_1, F, W), (K_1, W), \alpha_1) \rightarrow ((M_3, F, W), (K_3, W), \alpha_3), \end{aligned}$$

in particular for  $((M, F, W), (K, W), \alpha) \in C_{\mathcal{D}(1,0) \text{fil}, rh}(S) \times_I D_{\text{fil}, c, k}(S_{\mathbb{C}}^{\text{an}})$ ,

$$I_{((M, F, W), (K, W), \alpha)} = (I_M, I_K, 0).$$

We have then the full embedding

$$\mathrm{PSh}_{\mathcal{D}(1,0)fil,rh}(S) \times_I P_{fil,k}(S_{\mathbb{C}}^{an}) \hookrightarrow C_{\mathcal{D}(1,0)fil,rh}(S) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})$$

where  $\mathrm{PSh}_{\mathcal{D}(1,0)fil,rh}(S) \times_I P_{fil,k}(S_{\mathbb{C}}^{an})$  is the category

- whose set of objects is the set of triples  $\{((M, F, W), (K, W), \alpha)\}$  with

$$(M, F, W) \in \mathrm{PSh}_{\mathcal{D}(1,0)fil,rh}(S), (K, W) \in P_{fil,k}(S_{\mathbb{C}}^{an}), \alpha : (K, W) \otimes \mathbb{C}_{S_{\mathbb{C}}^{an}} \rightarrow DR(S)^{[-1]}((M, W)^{an})$$

where  $DR(S)^{[-1]}$  is the De Rahm functor and  $\alpha$  is an isomorphism in  $D_{fil}(S_{\mathbb{C}}^{an})$ ,

- and whose set of morphisms are

$$\phi = (\phi_D, \phi_C) = (\phi_D, \phi_C, 0) : ((M_1, F, W), (K_1, W), \alpha_1) \rightarrow ((M_2, F, W), (K_2, W), \alpha_2)$$

where  $\phi_D : (M_1, F, W) \rightarrow (M_2, F, W)$  and  $\phi_C : (K_1, W) \rightarrow (K_2, W)$  are morphisms (of filtered sheaves) and  $DR(S)^{[-1]}(\phi_D^{an}) \circ \alpha_1 = \alpha_2 \circ (\phi_C \otimes I)$  in  $P_{fil,k}(S_{\mathbb{C}}^{an})$ .

- Let  $S \in \mathrm{Var}(k)$ . Let  $S = \cup_{i \in I} S_i$  an open cover such that there exists closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_I \in \mathrm{SmVar}(k)$ . The category  $C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})$  is the category

- whose set of objects is the set of triples  $\{(((M_I, F, W), u_{IJ}), (K, W), \alpha)\}$  with

$$\begin{aligned} ((M_I, F, W), u_{IJ}) &\in C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)), (K, W) \in D_{fil,c,k}(S_{\mathbb{C}}^{an}), \\ \alpha &: T(S/(\tilde{S}_I))(K, W) \otimes \mathbb{C}_{S_{\mathbb{C}}^{an}} \rightarrow DR(S)^{[-1]}(((M_I, W), u_{IJ})^{an}) \end{aligned}$$

where

$$DR(S)^{[-1]} := DR(S_{\mathbb{C}}^{an})^{[-1]} : C_{\mathcal{D}(1,0)fil,rh}(S^{an}/(\tilde{S}_{I,\mathbb{C}}^{an})) \rightarrow C_{fil}(S_{\mathbb{C}}^{an}/(\tilde{S}_{I,\mathbb{C}}^{an}))$$

is the De Rahm functor and  $\alpha$  is a morphism in  $D_{fil}(S_{\mathbb{C}}^{an}/(\tilde{S}_{I,\mathbb{C}}^{an}))$ ,

- and whose set of morphisms consists of

$$\phi = (\phi_D, \phi_C, [\theta]) : (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2)$$

where  $\phi_D : ((M_{1I}, F, W), u_{IJ}) \rightarrow ((M_{2I}, F, W), u_{IJ})$  and  $\phi_C : (K_1, W) \rightarrow (K_2, W)$  are morphisms, and

$$\begin{aligned} \theta &= (\theta^\bullet, I(DR(S)(\phi_D^{an})) \circ I(\alpha_1), I(\alpha_2) \circ I(\phi_C \otimes I)) : \\ &I(T(S/(\tilde{S}_I))(K_1, W)) \otimes \mathbb{C}_{S_{\mathbb{C}}^{an}}[1] \rightarrow I(DR(S)((M_{2I}, W), u_{IJ})^{an}) \end{aligned}$$

is an homotopy,  $I : C_{fil}(S_{\mathbb{C}}^{an}/(\tilde{S}_{I,\mathbb{C}}^{an})) \rightarrow K_{fil}(S_{\mathbb{C}}^{an}/(\tilde{S}_{I,\mathbb{C}}^{an}))$  being the injective resolution functor : for  $((K_I, W), t_{IJ}) \in C_{fil}(S_{\mathbb{C}}^{an}/(\tilde{S}_{I,\mathbb{C}}^{an}))$ , we take an injective resolution

$$k : ((K_I, W), t_{IJ}) \rightarrow I((K_I, W), t_{IJ})$$

with  $I((K, W), t_{IJ}) \in C_{fil}(S_{\mathbb{C}}^{an}/(\tilde{S}_{I,\mathbb{C}}^{an}))$  which is unique modulo homotopy, and the class  $[\theta]$  of  $\theta$  does NOT depend of the injective resolution ; in particular we have

$$DR(S)^{[-1]}(\phi_D^{an}) \circ \alpha_1 = \alpha_2 \circ (\phi_C \otimes I)$$

in  $D_{fil}(S_{\mathbb{C}}^{an}/(\tilde{S}_{I,\mathbb{C}}^{an}))$  ; and for

- \*  $\phi = (\phi_D, \phi_C, [\theta]) : (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2)$
- \*  $\phi' = (\phi'_D, \phi'_C, [\theta']) : (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2) \rightarrow (((M_{3I}, F, W), u_{IJ}), (K_3, W), \alpha_3)$

the composition law is given by

$$\begin{aligned} \phi' \circ \phi &:= (\phi'_D \circ \phi_D, \phi'_C \circ \phi_C, I(DR(S)(\phi'_D)^{an}) \circ [\theta] + [\theta'] \circ I(\phi_C \otimes I)[1]) : \\ &(((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_{3I}, F, W), u_{IJ}), (K_3, W), \alpha_3) \end{aligned}$$

in particular for  $((M_I, F, W), u_{IJ}), (K, W), \alpha \in C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})$ ,

$$I_{(((M_I, F, W), u_{IJ}), (K, W), \alpha)} = ((I_{M_I}), I_K, 0).$$

We have then full embeddings

$$\begin{aligned} \text{PSh}_{\mathcal{D}(1,0)fil,rh}^0(S/(\tilde{S}_I)) \times_I P_{fil,k}(S_{\mathbb{C}}^{an}) &\hookrightarrow C_{\mathcal{D}(1,0)fil,rh}^0(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an}) \\ \xrightarrow{\iota_{S/\tilde{S}_I}^0} C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I))^0 \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an}) &\hookrightarrow C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an}) \end{aligned}$$

where  $\text{PSh}_{\mathcal{D}(1,0)fil,rh}^0(S/(\tilde{S}_I)) \times_I P_{fil,k}(S_{\mathbb{C}}^{an})$  is the category

- whose set of objects is the set of triples  $\{(((M_I, F, W), u_{IJ}), (K, W), \alpha)\}$  with

$$\begin{aligned} ((M_I, F, W), u_{IJ}) &\in \text{PSh}_{\mathcal{D}(1,0)fil,rh}^0(S/(\tilde{S}_I)), (K, W) \in P_{fil,k}(S_{\mathbb{C}}^{an}), \\ \alpha &: T(S/(\tilde{S}_I))(K, W) \otimes \mathbb{C}_{S_{\mathbb{C}}^{an}} \rightarrow DR(S)^{[-1]}(((M_I, W), u_{IJ})^{an}) \end{aligned}$$

where  $DR(S)^{[-1]}$  is the De Rahm functor and  $\alpha$  is an isomorphism in  $D_{fil}(S_{\mathbb{C}}^{an}/(\tilde{S}_{I,\mathbb{C}}^{an}))$ ,

- and whose set of morphisms are

$$\phi = (\phi_D, \phi_C) = (\phi_D, \phi_C, 0) : (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2)$$

where  $\phi_D : ((M_1, F, W), u_{IJ}) \rightarrow ((M_2, F, W), u_{IJ})$  and  $\phi_C : (K_1, W) \rightarrow (K_2, W)$  are morphisms (of filtered sheaves) such that  $\phi_D^{an} \circ \alpha_1 = \alpha_2 \circ \phi_C$  in  $P_{fil,k}(S_{\mathbb{C}}^{an})$ .

Moreover,

- For  $((M_I, F, W), u_{IJ}), (K, W), \alpha \in C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})$ , we set

$$(((M_I, F, W), u_{IJ}), (K, W), \alpha)[1] := (((M_I, F, W), u_{IJ})[1], (K, W)[1], \alpha[1]).$$

- For

$$\phi = (\phi_D, \phi_C, [\theta]) : (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2)$$

a morphism in  $C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})$ , we set (see [11] definition 3.12)

$$\text{Cone}(\phi) := (\text{Cone}(\phi_D), \text{Cone}(\phi_C), ((\alpha_1, \theta), (\alpha_2, 0))) \in D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an}),$$

$((\alpha_1, \theta), (\alpha_2, 0))$  being the matrix given by the composition law, together with the canonical maps

- $c_1(-) = (c_1(\phi_D), c_1(\phi_C), 0) : (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2) \rightarrow \text{Cone}(\phi)$
- $c_2(-) = (c_2(\phi_D), c_2(\phi_C), 0) : \text{Cone}(\phi) \rightarrow (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1)[1]$ .

**Remark 5.** By [11] theorem 3.25, if  $\phi = (\phi_D, \phi_C, [\theta]) : (((M_1, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_2, F, W), u_{IJ}), (K_2, W), \alpha_2)$  is a morphism in  $C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})$  such that  $\phi_D$  is a Zariski local equivalence and  $\phi_C$  is an isomorphism then  $\phi$  is an isomorphism.

We get from [10] the following definition :

**Definition 66.** (i) Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{SmVar}(k)$ . Let  $f : X \xrightarrow{j} \bar{X} \xrightarrow{\bar{f}} S$  a compactification of  $f$  with  $\bar{X} \in \text{SmVar}(k)$  and  $j$  the open embedding. Denote  $Z := \bar{X} \setminus X = \bigcap_i Z_i$  with  $Z_i \subset \bar{X}$  (Cartier) divisor. Let

$$\alpha : (K, W) \otimes \mathbb{C}_{X_{\mathbb{C}}^{an}} \rightarrow DR(X)((M, W)^{an})$$

a morphism in  $D_{fil}(X_{\mathbb{C}}^{an})$ , with  $(M, F, W) \in C(DRM(X))$  and  $(K, W) \in D_{fil,c,k}(X_{\mathbb{C}}^{an})^{ad,(Z_i)}$ . We then consider the maps in  $D_{fil}(S_{\mathbb{C}}^{an})$

$$\begin{aligned} f_*\alpha &: Rf_{*w}(K, W) \otimes \mathbb{C}_{S_{\mathbb{C}}^{an}} := R\bar{f}_*Rj_{*w}(K, W) \otimes \mathbb{C}_{S_{\mathbb{C}}^{an}} \\ &\xrightarrow{R\bar{f}_*j_*\alpha} R\bar{f}_*Rj_{*w}DR(X)((M, W)^{an}) \xrightarrow{T^w(j, \otimes)(-)^{-1}} R\bar{f}_*DR(\bar{X})(j_*Hdg(M, W)^{an}) \\ &\xrightarrow{T(\bar{f}, DR)(-)^{-1}} DR(S)((\int_{\bar{f}}(j_*Hdg(M, W))^{an}) = DR(S)((\int_f^{Hdg}(M, W))^{an}) \end{aligned}$$

and

$$\begin{aligned} f_!\alpha &: Rf_{!w}(K, W) \otimes \mathbb{C}_{S_{\mathbb{C}}^{an}} := R\bar{f}_*Rj_{!w}(K, W) \otimes \mathbb{C}_{S_{\mathbb{C}}^{an}} \\ &\xrightarrow{R\bar{f}_*j_!\alpha} R\bar{f}_*Rj_{!w}DR(X)((M, W)^{an}) \xrightarrow{\mathbb{D}T^w(j, \otimes)(-)} R\bar{f}_*DR(\bar{X})(j_!Hdg(M, W)^{an}) \\ &\xrightarrow{T(\bar{f}, DR)(-)^{-1}} DR(S)((\int_{\bar{f}}(j_!Hdg(M, W))^{an}) = DR(S)((\int_{f!}^{Hdg}(M, W))^{an}), \end{aligned}$$

see definition 4 and definition 64 .

(ii) Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{QPVar}(k)$ . Consider a factorization  $f : X \xrightarrow{l} Y \times S \xrightarrow{p} S$  with  $Y \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $p_S$  the projection. Let  $\bar{Y} \in \text{PSmVar}(k)$  a smooth compactification of  $Y$  with  $j : Y \hookrightarrow \bar{Y}$  the open embedding. Then  $\bar{f} : \bar{X} \xrightarrow{\bar{l}} \bar{Y} \times_S \bar{S} \xrightarrow{\bar{p}} S$  is a compactification of  $f$ , with  $\bar{X} \subset \bar{Y} \times S$  the closure of  $X$  and  $\bar{l}$  the closed embedding. Denote  $Z := \bar{X} \setminus X = \bigcap_i Z_i$  with  $Z_i \subset \bar{X}$  Cartier divisors. Let  $S = \bigcup_i S_i$  an open affine cover and  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embedding with  $\tilde{S}_i \in \text{SmVar}(k)$ . Let

$$\alpha : T(X/(Y \times \tilde{S}_I))((K, W) \otimes \mathbb{C}_{X_{\mathbb{C}}^{an}}) \rightarrow DR(X)((M_I, W)^{an}, u_{IJ}^{an})$$

a morphism in  $D_{fil}(X_{\mathbb{C}}^{an}/(Y \times \tilde{S}_I^{an}))$ , with  $((M_I, W), u_{IJ}) \in C(DRM(X)) \subset C_{\mathcal{D}0fil, rh}(X/(Y \times \tilde{S}_I))$  and  $(K, W) \in D_{fil,c,k}(X_{\mathbb{C}}^{an})^{ad,(Z_i)}$ . We then consider the maps in  $D_{fil}(S_{\mathbb{C}}^{an}/(\tilde{S}_I^{an}))$

$$\begin{aligned} f_*\alpha &= f_*(\alpha) : T(S/\tilde{S}_I)(Rf_{*w}(K, W)) \otimes \mathbb{C}_{S_{\mathbb{C}}^{an}} \\ &\xrightarrow{=} T(S/\tilde{S}_I)(R\bar{p}_*(I \times j)_{*w}(K, W)) \otimes \mathbb{C}_{S_{\mathbb{C}}^{an}} \xrightarrow{=} R\bar{p}_*(I \times j)_{*w}T(X/(Y \times \tilde{S}_I))((K, W) \otimes \mathbb{C}_{X_{\mathbb{C}}^{an}}) \\ &\xrightarrow{R\bar{p}_*\alpha} R\bar{p}_*(I \times j)_{*w}DR(X)((M_I, W), u_{IJ})^{an} \\ &\xrightarrow{(T^w(I \times j, \otimes)(-))} R\bar{p}_*DR(X)((I \times j)_{*Hdg}((M_I, W), u_{IJ})^{an}) \\ &\xrightarrow{T(\bar{f}, DR)(-)} DR(S)((\int_{\bar{f}}(I \times j)_{*Hdg}((M_I, W), u_{IJ})^{an}) = DR(S)((\int_f^{Hdg}((M_I, W), u_{IJ})^{an}) \end{aligned}$$

and

$$\begin{aligned} f_!\alpha &= f_!(\alpha) : T(S/\tilde{S}_I)(Rf_{!w}(K, W)) \otimes \mathbb{C}_{S_{\mathbb{C}}^{an}} \\ &\xrightarrow{=} T(S/\tilde{S}_I)(R\bar{p}_*(I \times j)_{!w}(K, W)) \otimes \mathbb{C}_{S_{\mathbb{C}}^{an}} \xrightarrow{=} R\bar{p}_*(I \times j)_{!w}T(X/(Y \times \tilde{S}_I))((K, W) \otimes \mathbb{C}_{X_{\mathbb{C}}^{an}}) \\ &\xrightarrow{R\bar{p}_*\mathbb{D}^v R(I \times j)_*\mathbb{D}^v \alpha} R\bar{p}_*(I \times j)_{!w}DR(X)((M_I, W), u_{IJ})^{an} \\ &\xrightarrow{T(D, DR)(-) \circ (\mathbb{D}T^w(I \times j, \otimes)(-)) \circ T(D, DR)(-)} R\bar{p}_*DR(X)((I \times j)_{!Hdg}((M_I, W), u_{IJ})^{an}) \\ &\xrightarrow{T(\bar{f}, DR)(-)} DR(S)((\int_{\bar{f}}(I \times j)_{!Hdg}((M_I, W), u_{IJ})^{an}) = DR(S)((\int_{f!}^{Hdg}((M_I, W), u_{IJ})^{an}), \end{aligned}$$

see definition 4 and definition 65 .

- (iii) Let  $l : S^\circ \hookrightarrow S$  an open embedding with  $S \in \text{Var}(k)$  and denote  $Z = S \setminus S^\circ = \bigcap_i Z_i$ . with  $Z_i \subset S$  Cartier divisors. Let  $S = \bigcup_i S_i$  an open affine cover and  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embedding with  $\tilde{S}_i \in \text{SmVar}(k)$ . Let  $l_I : \tilde{S}_I^\circ \hookrightarrow \tilde{S}_I$  open embeddings such that  $\tilde{S}_I^\circ \cap S = S^\circ \cap S_I$ . Let

$$\alpha : T(S/(\tilde{S}_I))((K, W) \otimes \mathbb{C}_{S_{\mathbb{C}}^{\text{an}}} \rightarrow DR(S)((M_I, W), u_{IJ})^{\text{an}})$$

a morphism in  $D_{\text{fil}}(S_{\mathbb{C}}^{\text{an}}/(\tilde{S}_{I, \mathbb{C}}^{\text{an}}))$ , with  $((M_I, W), u_{IJ}) \in C(\text{DRM}(S)) \subset C_{\mathcal{D}0_{\text{fil}, \text{rh}}}(S/(\tilde{S}_I))$  and  $(K, W) \in D_{\text{fil}, \text{c}, k}(S_{\mathbb{C}}^{\text{an}})$ . We then consider the maps in  $D_{\text{fil}}(S_{\mathbb{C}}^{\text{an}}/(\tilde{S}_{I, \mathbb{C}}^{\text{an}}))$

$$\begin{aligned} \Gamma_Z(\alpha) : T(S/(\tilde{S}_I))(\Gamma_Z^w(K, W) \otimes \mathbb{C}_{S_{\mathbb{C}}^{\text{an}}}) &\xrightarrow{\cong} \Gamma_Z^w T(S/(\tilde{S}_I))((K, W) \otimes \mathbb{C}_{S_{\mathbb{C}}^{\text{an}}}) \\ &\xrightarrow{R\Gamma_Z \alpha} \Gamma_Z^w DR(S)((M_I, W), u_{IJ})^{\text{an}} \\ \frac{T(\gamma_Z, DR)((M_I, W), u_{IJ})^{-1} := (I, T^w(l_I, \otimes)(M_I, W)) \circ (T^w(\text{an}, \otimes)(M_I, W))^{-1}}{\longrightarrow} &\rightarrow DR(S)((\Gamma_Z^{\text{Hdg}}((M_I, W), u_{IJ}))^{\text{an}}) \end{aligned}$$

and

$$\begin{aligned} \Gamma_Z^\vee(\alpha) : T(S/(\tilde{S}_I))(\Gamma_Z^{\vee, w}(K, W) \otimes \mathbb{C}_{S_{\mathbb{C}}^{\text{an}}}) &\xrightarrow{\cong} \Gamma_Z^\vee T(S/(\tilde{S}_I))((K, W) \otimes \mathbb{C}_{S_{\mathbb{C}}^{\text{an}}}) \\ &\xrightarrow{\Gamma_Z^\vee \alpha} \Gamma_Z^{\vee, w} DR(S)((M_I, W), u_{IJ})^{\text{an}} \\ \frac{T(\gamma_Z^\vee, DR)((M_I, W), u_{IJ}) := (\mathbb{D}(I, T^w(l_I, \otimes)(\mathbb{D}(M_I, W))) \circ (\mathbb{D}T^w(\text{an}, \otimes)(\mathbb{D}(M_I, W))))}{\longrightarrow} &\rightarrow DR(S)((\Gamma_Z^{\vee, w}((M_I, W), u_{IJ}))^{\text{an}}), \end{aligned}$$

see definition 3 and definition 59.

- (iv) Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{QPVar}(k)$ . Consider a factorization  $f : X \hookrightarrow Y \times S \xrightarrow{p} S$  with  $Y \in \text{SmVar}(k)$ . Let  $S = \bigcup_i S_i$  an open affine cover and  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embedding with  $\tilde{S}_i \in \text{SmVar}(k)$ . Let

$$\alpha : T(S/(\tilde{S}_I))((K, W) \otimes \mathbb{C}_{S_{\mathbb{C}}^{\text{an}}} \rightarrow DR(S)((M_I, W), u_{IJ})^{\text{an}})$$

a morphism in  $D_{\text{fil}}(S_{\mathbb{C}}^{\text{an}}/(\tilde{S}_{I, \mathbb{C}}^{\text{an}}))$ , with  $((M_I, W), u_{IJ}) \in C(\text{DRM}(S)) \subset C_{\mathcal{D}0_{\text{fil}, \text{rh}}}(S/(\tilde{S}_I))$  and  $(K, W) \in D_{\text{fil}, \text{c}, k}(S_{\mathbb{C}}^{\text{an}})^{\text{ad}, (\Gamma_{f, i})}$ . We then consider, see (iii), the maps in  $D_{\text{fil}}(X_{\mathbb{C}}^{\text{an}}/(Y \times \tilde{S}_I, \mathbb{C})^{\text{an}})$

$$\begin{aligned} f^! \alpha = f^!(\alpha) : T(X/(Y \times \tilde{S}_I))(f^{!w}(K, W) \otimes \mathbb{C}_{X_{\mathbb{C}}^{\text{an}}}) &\xrightarrow{\cong} T(X/(Y \times \tilde{S}_I))(\Gamma_X^w p^*(K, W) \otimes \mathbb{C}_{X_{\mathbb{C}}^{\text{an}}}) \\ &\xrightarrow{\cong} (\Gamma_X^w p_{\tilde{S}_I}^* T(S/(\tilde{S}_I))((K, W)_I \otimes \mathbb{C}_{S_{\mathbb{C}}^{\text{an}}}), \Gamma_X^w p^* T(D_{IJ})(-)) \\ &\xrightarrow{R\Gamma_X p^* \alpha} (\Gamma_X^w p_{\tilde{S}_I}^* DR(S)((M_I, W), u_{IJ})_I, \Gamma_X^w p^* DR(u_{IJ})) \\ \frac{T^!(f, DR)(-) := T(\gamma_X, DR)(-)^{-1} \circ T^!(p, DR)(-)}{\longrightarrow} &\rightarrow DR(X)(f_{\text{Hdg}}^{* \text{mod}}((M_I, W), u_{IJ})^{\text{an}}) \end{aligned}$$

and

$$\begin{aligned} f^* \alpha = f^*(\alpha) : T(X/(Y \times \tilde{S}_I))(f^{*w}(K, W) \otimes \mathbb{C}_{X_{\mathbb{C}}^{\text{an}}}) &\xrightarrow{\cong} T(X/(Y \times \tilde{S}_I))(\Gamma_X^{\vee, w} p^*(K, W) \otimes \mathbb{C}_{X_{\mathbb{C}}^{\text{an}}}) \\ &\xrightarrow{\cong} (\Gamma_X^{\vee, w} p_{\tilde{S}_I}^* T(S/(\tilde{S}_I))((K, W) \otimes \mathbb{C}_{S_{\mathbb{C}}^{\text{an}}})_I, \Gamma_X^{\vee, w} p^* T(D_{IJ})(-)) \\ &\xrightarrow{\Gamma_X^{\vee} p^* \alpha} (\Gamma_X^{\vee, w} p_{\tilde{S}_I}^* DR(S)((M_I, W), u_{IJ})_I, \Gamma_X^{\vee, w} p^* DR(u_{IJ})) \\ \frac{T^*(f, DR)(-) := T(\gamma_X^\vee, DR)(-) \circ T^*(p, DR)(-)}{\longrightarrow} &\rightarrow DR(X)(f_{\text{Hdg}}^{* \text{mod}}((M_I, W), u_{IJ})^{\text{an}}) \end{aligned}$$

- (v) Let  $S \in \text{Var}(k)$ . Let  $S = \bigcup_i S_i$  an open affine cover and  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embedding with  $\tilde{S}_i \in \text{SmVar}(k)$ . Let

$$\begin{aligned} \alpha : T(S/(\tilde{S}_I))((K, W) \otimes \mathbb{C}_{S_{\mathbb{C}}^{\text{an}}} &\rightarrow DR(S)((M_I, W), u_{IJ})^{\text{an}}, \\ \alpha' : T(S/(\tilde{S}_I))((K', W) \otimes \mathbb{C}_{S_{\mathbb{C}}^{\text{an}}} &\rightarrow DR(S)((M'_I, W), v_{IJ})^{\text{an}} \end{aligned}$$

two morphism in  $D_{fil}(S_{\mathbb{C}}^{an}/(\tilde{S}_{I,\mathbb{C}}^{an}))$ , with  $((M_I, W), u_{IJ}), ((M'_I, W), v_{IJ}) \in C(DRM(S)) \subset C_{\mathcal{D}0fil,rh}(S/(\tilde{S}_I))$  and  $(K, W), (K', W) \in D_{fil}(S_{\mathbb{C}}^{an})$ . We then consider the map

$$\begin{aligned} & \alpha \otimes \alpha' : T(S/(\tilde{S}_I))((K, W) \otimes (K', W) \otimes \mathbb{C}_{S_{\mathbb{C}}^{an}}) \\ & \xrightarrow{\cong} T(S/(\tilde{S}_I))((K, W) \otimes \mathbb{C}_{S_{\mathbb{C}}^{an}}) \otimes T(S/(\tilde{S}_I))((K', W) \otimes \mathbb{C}_{S_{\mathbb{C}}^{an}}) \\ & \xrightarrow{\alpha \otimes \alpha'} DR(S)((M_I, W), u_{IJ})^{an} \otimes DR(S)((M'_I, W), v_{IJ})^{an} \\ & \xrightarrow{T(\otimes, DR)(-, -)} DR(S)((M_I, W), u_{IJ}) \otimes_{O_S}^L ((M'_I, W), v_{IJ})^{an} \\ & \xrightarrow{\cong} DR(S)((M_I, W), u_{IJ}) \otimes_{O_S}^{Hdg} ((M'_I, W), v_{IJ})^{an} \end{aligned}$$

in  $D_{fil}(S_{\mathbb{C}}^{an}/(\tilde{S}_{I,\mathbb{C}}^{an}))$ .

**Definition 67.** Let  $S \in \text{SmVar}(k)$ . Let  $D = V(s) \subset S$  a divisor with  $s \in \Gamma(S, L)$  and  $L$  a line bundle ( $S$  being smooth,  $D$  is Cartier). For  $\mathcal{M} = ((M, F, W), (K, W), \alpha) \in \text{PSh}_{\mathcal{D}(1,0)fil,rh}(S) \times_I P_{fil,k}(S_{\mathbb{C}}^{an})$ , we then define, using definition 55 and theorem 33,

- the nearby cycle functor

$$\begin{aligned} \psi_D((M, F, W), (K, W), \alpha) & := (\psi_D(M, F, W), \psi_D(K, W), \psi_D \alpha) \in \text{PSh}_{\mathcal{D}(1,0)fil,rh}(S) \times_I P_{fil,k}(S_{\mathbb{C}}^{an}), \\ \text{with } \psi_D \alpha & := T(\psi_D, DR)(M) \circ \psi_D(\alpha). \end{aligned}$$

- the vanishing cycle functor

$$\begin{aligned} \phi_D((M, F, W), (K, W), \alpha) & := (\phi_D(M, F, W), \phi_D(K, W), \phi_D \alpha) \in \text{PSh}_{\mathcal{D}(1,0)fil,rh}(S) \times_I P_{fil,k}(S_{\mathbb{C}}^{an}), \\ \text{with } \phi_D \alpha & := T(\phi_D, DR)(M) \circ \phi_D(\alpha). \end{aligned}$$

- the canonical maps in  $\text{PSh}_{\mathcal{D}(1,0)fil,rh}(S) \times_I P_{fil,k}(S_{\mathbb{C}}^{an})$

$$\begin{aligned} \text{can}(\mathcal{M}) & := (\text{can}(M, F, W), \text{can}(K, W)) : \psi_D((M, F, W), (K, W), \alpha) \rightarrow \phi_D((M, F, W), (K, W), \alpha)(-), \\ \text{var}(\mathcal{M}) & := (\text{var}(M, F, W), \text{var}(K, W)) : \phi_D((M, F, W), (K, W), \alpha) \rightarrow \psi_D((M, F, W), (K, W), \alpha). \end{aligned}$$

**Proposition 43.** Let  $S \in \text{SmVar}(k)$ . Let  $D = V(s) \subset S$  a (Cartier divisor). Consider a composition of proper morphisms  $(f : X = X_r \xrightarrow{f_r} X_{r-1} \xrightarrow{f_1} X_0 = S) \in \text{SmVar}(k)$  and

$$\begin{aligned} (M, F) & = H^{n_0} \int_{f_1} \cdots H^{n_r} \int_{f_r} ((O_X, F_b), H^{n_0} Rf_{1*} \cdots H^{n_r} Rf_{r*} \mathbb{Z}_X, \\ & H^{n_0} f_{1*} \circ \cdots \circ H^{n_r} f_{r*} \alpha(X)) \in \text{PSh}_{\mathcal{D}fil,rh}(S) \times_I P_k(S_{\mathbb{C}}^{an}). \end{aligned}$$

Then,

$$\begin{aligned} \psi_D(M, F) & = H^{n_0} \int_{f_1} \cdots H^{n_r} \int_{f_r} (\psi_{f^{-1}(D)}(O_X, F_b), H^{n_0} Rf_{1*} \cdots H^{n_r} Rf_{r*} \psi_{f^{-1}(D)} \mathbb{Z}_X, \\ & H^{n_0} f_{1*} \circ \cdots \circ H^{n_r} f_{r*} \psi_{f^{-1}(D)} \alpha(X)) \in \text{PSh}_{\mathcal{D}fil,rh}(S) \times_I P_k(S_{\mathbb{C}}^{an}) \end{aligned}$$

and

$$\begin{aligned} \phi_D(M, F) & = H^{n_0} \int_{f_1} \cdots H^{n_r} \int_{f_r} (\psi_{f^{-1}(D)}(O_X, F_b), H^{n_0} Rf_{1*} \cdots H^{n_r} Rf_{r*} \phi_{f^{-1}(D)} \mathbb{Z}_X, \\ & H^{n_0} f_{1*} \circ \cdots \circ H^{n_r} f_{r*} \phi_{f^{-1}(D)} \alpha(X)) \in \text{PSh}_{\mathcal{D}fil,rh}(S) \times_I P_k(S_{\mathbb{C}}^{an}). \end{aligned}$$

*Proof.* Immediate from definition. □

We now come to the main definition of this section :

**Definition 68.** Let  $k \subset \mathbb{C}$  a subfield.

(i0) Let  $S \in \text{Var}(k)$ . Take an open cover  $S = \cup_i S_i$  such that there are closed embedding  $S_I \hookrightarrow \tilde{S}_I$  with  $S_I \in \text{SmVar}(k)$ . The category of mixed hodge modules over  $k$  is the full subcategory

$$MHM_{k,\mathbb{C}}(S) \subset \text{DRM}(S) \times_I P_{\text{fil},k}(S_{\mathbb{C}}^{\text{an}}) \subset \text{PSh}_{\mathcal{D}(1,0)\text{fil},rh}(S/(\tilde{S}_I)) \times_I P_{\text{fil},k}(S_{\mathbb{C}}^{\text{an}})$$

whose object consists of  $((M_I, F, W), u_{IJ}), (K, W), \alpha \in \text{DRM}(S) \times_I P_{\text{fil},k}(S_{\mathbb{C}}^{\text{an}})$  such that

$$((\pi_{k/\mathbb{C}}^{*\text{mod}}(M_I, F, W), u_{IJ}), (K, W), \alpha) \in MHM(S_{\mathbb{C}})$$

where

- $\pi_{k/\mathbb{C}} := \pi_{k/\mathbb{C}}(S) : S_{\mathbb{C}} \rightarrow S$  is the projection (see section 2),
- $\text{DRM}(S)$  is the category of de Rham modules introduced in section 5 definition 56,
- $MHM(S_{\mathbb{C}})$  is the category of mixed hodge modules on  $S_{\mathbb{C}}$  introduced by Saito ([25]).

(i) Let  $S \in \text{SmVar}(k)$ . We denote by

$$\begin{aligned} HM_{gm,k,\mathbb{C}}(S) := & \langle (R^n \int_{f_1} \cdots R^n \int_{f_r} (O_X, F_b), R^n f_{1*} \cdots R^n f_{r*} \mathbb{Z}_{X_{\mathbb{C}}^{\text{an}}}, R^n f_{1*} \cdots R^n f_{r*} \alpha(X)), \\ & (f : X = X_r \xrightarrow{f_r} X_{r-1} \rightarrow \cdots \xrightarrow{f_1} X_0 = S) \in \text{SmVar}(k), \text{ proper} \rangle \\ & \subset \text{PDRM}(S) \times_I P_{\text{fil},k}(S_{\mathbb{C}}^{\text{an}}) \subset \text{PSh}_{\mathcal{D}\text{fil},rh}(S) \times_I P_k(S_{\mathbb{C}}^{\text{an}}) \end{aligned}$$

the full abelian subcategory, where  $\langle, \rangle$  means generated by,

$$\alpha(X) : \mathbb{Z}_{X_{\mathbb{C}}^{\text{an}}} \hookrightarrow \text{DR}(X)(O_X^{\text{an}})$$

is the inclusion quasi-isomorphism in  $C(X_{\mathbb{C}}^{\text{an}})$ , and we use definition 66. We have by proposition 43 for  $((M, F), K, \alpha) \in HM_{gm,k,\mathbb{C}}(S)$ ,

$$\text{Gr}_k^W \psi_D((M, F), K, \alpha) := \text{Gr}_k^W \psi_D(M, F), \text{Gr}_k^W \psi_D K, \text{Gr}_k^W \psi_D \alpha \in HM_{gm,k,\mathbb{C}}(S).$$

and

$$\text{Gr}_k^W \psi_D((M, F), K, \alpha) := \text{Gr}_k^W \psi_D(M, F), \text{Gr}_k^W \psi_D K, \text{Gr}_k^W \psi_D \alpha \in HM_{gm,k,\mathbb{C}}(S).$$

for all  $k \in \mathbb{Z}$ . We have by theorem 37, for  $S \in \text{SmVar}(k)$ ,  $HM_{gm,k,\mathbb{C}}(S) \subset HM(S_{\mathbb{C}})$  which consists of geometric Hodge module defined over  $k$ .

(i)' Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i \in I} S_i$  an open cover such that there exists closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_I \in \text{SmVar}(k)$ . We denote by

$$\begin{aligned} HM_{gm,k,\mathbb{C}}(S) := & \langle (R^{n_1} \int_{p_1} \cdots R^{n_r} \int_{p_r} (\Gamma_{X_I}^{\vee, \text{Hdg}}(O_{Y \times \tilde{X}_{r-1,I}}, F_b), x_{IJ}), \\ & R^{n_1} p_{1*} \cdots R^{n_r} p_{r*} T(X/(Y_r \times \tilde{X}_{r-1,I}))(\mathbb{Z}_{X_{\mathbb{C}}^{\text{an}}}), R^{n_1} p_{1*} \cdots R^{n_r} p_{r*} \alpha(X)), \\ & (f : X = X_r \xrightarrow{f_r} X_{r-1} \rightarrow \cdots \xrightarrow{f_1} X_0 = S) \in \text{Var}(k) \rangle \\ & \subset \text{PDRM}(S) \times_I P_k(S_{\mathbb{C}}^{\text{an}}) \subset \text{PSh}_{\mathcal{D}\text{fil},rh}(S/(\tilde{S}_I)) \times_I P_k(S_{\mathbb{C}}^{\text{an}}) \end{aligned}$$

the full abelian subcategory, where  $\langle, \rangle$  means generated by,  $f_i : X_i \hookrightarrow Y_i \times X_{i-1} \xrightarrow{p_i} X_{i-1}$  proper,  $Y_i \in \text{PSmVar}(k)$ ,  $X_i$  smooth, with

$$\begin{aligned} \alpha(X) := & (\Gamma_{X_I}^{\vee} \alpha(Y_r \times \tilde{X}_{r-1,I})) : T(X/(Y_r \times \tilde{X}_{r-1,I}))(\mathbb{Z}_{X^{\text{an}}}) \otimes \mathbb{C}_{X^{\text{an}}} := (\Gamma_{X_I}^{\vee, w} \mathbb{Z}_{(Y \times \tilde{X}_{r-1,I})_{\mathbb{C}}^{\text{an}}}, t_{IJ}) \\ & \xrightarrow{\sim} \text{DR}(X)(o_F(\Gamma_{X_I}^{\vee, \text{Hdg}}(O_{Y \times \tilde{X}_{r-1,I}}, F_b), x_{IJ})^{\text{an}}). \end{aligned}$$



is an isomorphism in  $D(X_{\mathbb{C}}^{an}/(Y_r \times \tilde{X}_{r-1,I})_{\mathbb{C}}^{an})$ , and we use definition 66. Note that if  $S$  is smooth then this definition of  $HM_{gm,k,\mathbb{C}}(S)$  agree with the one given in (i). We have by theorem 37, for  $S \in \text{Var}(k)$ ,  $HM_{gm,k,\mathbb{C}}(S) \subset HM(S_{\mathbb{C}})$  which consists of geometric Hodge module defined over  $k$ .

(ii) Let  $S \in \text{Var}(k)$ . Take an open cover  $S = \cup_i S_i$  such that there are closed embedding  $S_I \hookrightarrow \tilde{S}_I$  with  $S_I \in \text{SmVar}(k)$ . We define using the pure case (i) and (i)' the full subcategory of mixed Hodge modules defined over  $k$

$$\begin{aligned} MHM_{gm,k,\mathbb{C}}(S) := \\ \{((M_I, F, W), u_{IJ}), (K, W), \alpha\}, \text{ s.t. } \text{Gr}_k^W(((M_I, F, W), u_{IJ}), (K, W), \alpha) \in HM_{gm,k,\mathbb{C}}(S) \} \\ \subset DRM(S) \times_I P_{fil,k}(S_{\mathbb{C}}^{an}) \subset \text{PSh}_{\mathcal{D}(1,0)_{fil,rh}}(S/(\tilde{S}_I)) \times_I P_{fil,k}(S_{\mathbb{C}}^{an}) \end{aligned}$$

whose object consists of  $((M_I, F, W), u_{IJ}), (K, W), \alpha \in DRM(S) \times_I P_{fil,k}(S_{\mathbb{C}}^{an})$  such that

$$\text{Gr}_k^W(((M_I, F, W), u_{IJ}), (K, W), \alpha) := (\text{Gr}_k^W((M_I, F), u_{IJ}), \text{Gr}_k^W K, \text{Gr}_k^W \alpha) \in HM_{gm,k,\mathbb{C}}(S).$$

We set

$$\mathbb{Z}_S^{Hdg} := ((\Gamma_{S_I}^{\vee, Hdg}(O_{\tilde{S}_I}, F_b), x_{IJ}), \mathbb{Z}_{S^{an}}^w, \alpha(S)) \in MHM_{gm,k,\mathbb{C}}(S)$$

with  $j_I^* \mathbb{Z}_{S^{an}}^w = i_I^* \Gamma_{S_I}^{\vee, w} \mathbb{Z}_{\tilde{S}_I^{an}}$  and

$$\alpha(S) := (\Gamma_{S_I}^{\vee} \alpha(\tilde{S}_I)) : T(S/(\tilde{S}_I))(\mathbb{Z}_{S^{an}}^w) = (\Gamma_{S_I}^{\vee, w}(\mathbb{C}_{\tilde{S}_I^{an}}, t_{IJ}) \xrightarrow{\sim} DR(S)(o_F(\Gamma_{S_I}^{\vee, Hdg}(O_{\tilde{S}_I}, F_b), x_{IJ})).$$

For  $S \in \text{SmVar}(k)$  and  $D = V(s) \subset S$  a (Cartier) divisor, we have for  $((M, F, W), (K, W), \alpha) \in MHM_{gm,k,\mathbb{C}}(S)$ , using theorem 32,

$$\psi_D((M, F, W), (K, W), \alpha), \phi_D((M, F, W), (K, W), \alpha) \in MHM_{gm,k,\mathbb{C}}(S),$$

by the pure case (c.f. (i) and proposition 43) and the strictness of the  $V$ -filtration.

For  $k \subset \mathbb{C}$  and  $S \in \text{Var}(k)$ , we have by theorem 37

$$MHM_{gm,k,\mathbb{C}}(S) \subset MHM_{k,\mathbb{C}}(S) \subset MHM(S_{\mathbb{C}}).$$

For  $S \in \text{Var}(k)$  we get  $D(MHM_{gm,k,\mathbb{C}}(S)) := \text{Ho}_{(zar, usu)}(C(MHM_{gm,k,\mathbb{C}}(S)))$  after localization with Zariski local equivalence and usu local equivalence.

We now look at functorialities :

**Definition 69.** Let  $k \subset \mathbb{C}$  a subfield. Let  $S \in \text{SmVar}(k)$ . Let  $j : S^{\circ} \hookrightarrow S$  an open embedding. Let  $Z := S \setminus S^{\circ} = V(\mathcal{I}) \subset S$  an the closed complementary subset,  $\mathcal{I} \subset O_S$  being an ideal subsheaf. Taking generators  $\mathcal{I} = (s_1, \dots, s_r)$ , we get  $Z = V(s_1, \dots, s_r) = \cap_{i=1}^r Z_i \subset S$  with  $Z_i = V(s_i) \subset S$ ,  $s_i \in \Gamma(S, \mathcal{L}_i)$  and  $L_i$  a line bundle. Note that  $Z$  is an arbitrary closed subset,  $d_Z \geq d_X - r$  needing not be a complete intersection. Denote by  $j_I : S^{\circ, I} := \cap_{i \in I} (S \setminus Z_i) = S \setminus (\cup_{i \in I} Z_i) \xrightarrow{j_I^{\circ}} S^{\circ} \xrightarrow{j} S$  the open embeddings. Let  $(M, F, W) \in MHM_{gm,k,\mathbb{C}}(S^{\circ})$ . We then define, using definition 57 and definition 2

- the canonical extension

$$\begin{aligned} j_* Hdg((M, F, W), (K, W), \alpha) &:= (j_* Hdg(M, F, W), j_* w(K, W), j_* \alpha) \\ &:= \text{Tot}((j_{I*} Hdg j_I^*(M, F, W), j_{I*} w j_I^*(K, W), j_{I*} \alpha)) \in MHM_{gm,k,\mathbb{C}}(S), \end{aligned}$$

so that  $j^*(j_* Hdg((M, F, W), (K, W), \alpha)) = ((M, F, W), (K, W), \alpha)$ ,

- the canonical extension

$$\begin{aligned} j_{!Hdg}((M, F, W), (K, W), \alpha) &:= (j_{!Hdg}(M, F, W), j_{!w}(K, W), j_{!}\alpha) \\ &:= \text{Tot}((j_{!Hdg}j_I^*(M, F, W), j_{!w}j_I^*(K, W), j_{!}\alpha)) \in MHM_{gm,k,\mathbb{C}}(S), \end{aligned}$$

so that  $j^*(j_{!Hdg}((M, F, W), (K, W), \alpha)) = ((M, F, W), (K, W), \alpha)$ .

Moreover for  $((M', F, W), (K', W), \alpha') \in MHM_{gm,k,\mathbb{C}}(S)$ ,

- there is a canonical map in  $MHM_{gm,k,\mathbb{C}}(S)$

$$\text{ad}(j^*, j_{*Hdg})((M', F, W), (K', W), \alpha') : ((M', F, W), (K', W), \alpha') \rightarrow j_{*Hdg}j^*((M', F, W), (K', W), \alpha'),$$

- there is a canonical map in  $MHM_{gm,k,\mathbb{C}}(S)$

$$\text{ad}(j_{!Hdg}, j^*)((M', F, W), (K', W), \alpha') : j_{!Hdg}j^*((M', F, W), (K', W), \alpha') \rightarrow ((M', F, W), (K', W), \alpha').$$

Let  $j : S^\circ \hookrightarrow S$  an open embedding with  $S \in \text{SmVar}(k)$ . For  $(M, F, W) \in C(MHM_{gm,k,\mathbb{C}}(S^\circ))$ ,

- we have the canonical map in  $C_{\mathcal{D}(1,0)fil}(S) \times_I C_{fil}(S_{\mathbb{C}}^{an})$

$$\begin{aligned} T(j_{*Hdg}, j_*)((M, F, W), (K, W), \alpha) &:= (k \circ \text{ad}(j^*, j_*)(-), k \circ \text{ad}(j^*, j_*)(0)) : \\ j_{*Hdg}((M, F, W), (K, W), \alpha) &\rightarrow (j_*E(M, F, W), j_*E(K, W), \alpha) \end{aligned}$$

- we have the canonical map in  $C_{\mathcal{D}(1,0)fil}(S) \times_I C_{fil}(S_{\mathbb{C}}^{an})$

$$\begin{aligned} T(j_{!}, j_{!Hdg})((M, F, W), (K, W), \alpha) &:= (k \circ \text{ad}(j_{!}, j^*)(-), k \circ \text{ad}(j_{!}, j^*)(-), 0) : \\ (j_{!}(M, F, W), j_{!}(K, W), j_{!}\alpha) &\rightarrow j_{!Hdg}((M, F, W), (K, W), \alpha) \end{aligned}$$

the canonical maps.

**Proposition 44.** (i) Let  $S \in \text{SmVar}(k)$ . Let  $D = V(s) \subset S$  a divisor with  $s \in \Gamma(S, L)$  and  $L$  a line bundle ( $S$  being smooth,  $D$  is Cartier). Denote by  $j : S^\circ := S \setminus D \hookrightarrow S$  the open complementary embedding. Then,

- $(j^*, j_{*Hdg}) : MHM_{gm,k,\mathbb{C}}(S) \rightleftarrows MHM_{gm,k,\mathbb{C}}(S^\circ)$  is a pair of adjoint functors
- $(j_{!Hdg}, j^*) : MHM_{gm,k,\mathbb{C}}(S^\circ) \rightleftarrows MHM_{gm,k,\mathbb{C}}(S)$  is a pair of adjoint functors.

(ii) Let  $S \in \text{SmVar}(k)$ . Let  $Z = V(\mathcal{I}) \subset S$  an arbitrary closed subset,  $\mathcal{I} \subset \mathcal{O}_S$  being an ideal subsheaf. Denote by  $j : S^\circ := S \setminus Z \hookrightarrow S$ . Then,

- $(j^*, j_{*Hdg}) : D(MHM_{gm,k,\mathbb{C}}(S)) \rightleftarrows D(MHM_{gm,k,\mathbb{C}}(S^\circ))$  is a pair of adjoint functors
- $(j_{!Hdg}, j^*) : D(MHM_{gm,k,\mathbb{C}}(S^\circ)) \rightleftarrows D(MHM_{gm,k,\mathbb{C}}(S))$  is a pair of adjoint functors.

*Proof.* (i): Follows from proposition 37.

(ii): Follows from (i) and the exactness of  $j^*$ ,  $j_{*Hdg}$  and  $j_{!Hdg}$ . □

**Definition 70.** Let  $S \in \text{SmVar}(k)$ . Let  $Z \subset S$  a closed subset. Denote by  $j : S \setminus Z \hookrightarrow S$  the complementary open embedding.

(i) We define using definition 59, definition 3 and definition 66(iii), the filtered Hodge support section functor

$$\begin{aligned} \Gamma_Z^{Hdg} : C(MHM_{gm,k,\mathbb{C}}(S)) &\rightarrow C(MHM_{gm,k,\mathbb{C}}(S)), \quad ((M, F, W), (K, W), \alpha) \mapsto \\ \Gamma_Z^{Hdg}((M, F, W), (K, W), \alpha) &:= (\Gamma_Z^{Hdg}(M, F, W), \Gamma_Z^w(K, W), \Gamma_Z(\alpha)) \\ &= \text{Cone}(\text{ad}(j^*, j_{*Hdg})(-)) : j_{*Hdg}j^*((M, F, W), (K, W), \alpha) \rightarrow ((M, F, W), (K, W), \alpha)[-1] \end{aligned}$$

see definition 69 for the last equality, together we the canonical map

$$\gamma_Z^{Hdg}((M, F, W), (K, W), \alpha) : \Gamma_Z^{Hdg}((M, F, W), (K, W), \alpha) \rightarrow ((M, F, W), (K, W), \alpha).$$

(i)' Since  $j_{*Hdg} : C(MHM_{gm,k,\mathbb{C}}(S^o)) \rightarrow C(MHM_{gm,k,\mathbb{C}}(S))$  is an exact functor,  $\Gamma_Z^{Hdg}$  induces the functor

$$\begin{aligned} \Gamma_Z^{Hdg} : D(MHM_{gm,k,\mathbb{C}}(S)) &\rightarrow D(MHM_{gm,k,\mathbb{C}}(S)), \\ ((M, F, W), (K, W), \alpha) &\mapsto \Gamma_Z^{Hdg}((M, F, W), (K, W), \alpha) \end{aligned}$$

(ii) We define using definition 59, definition 3 and definition 66(iii) the dual filtered Hodge support section functor

$$\begin{aligned} \Gamma_Z^{\vee, Hdg} : C(MHM_{gm,k,\mathbb{C}}(S)) &\rightarrow C(MHM_{gm,k,\mathbb{C}}(S)), \quad ((M, F, W), (K, W), \alpha) \mapsto \\ \Gamma_Z^{\vee, Hdg}((M, F, W), (K, W), \alpha) &:= (\Gamma_Z^{\vee, Hdg}(M, F, W), \Gamma_Z^{\vee, w}(K, W), \Gamma_Z^{\vee}(\alpha)) \\ = \text{Cone}(\text{ad}(j_{!Hdg}, j^*)(-)) : j_{!Hdg}, j^*((M, F, W), (K, W), \alpha) &\rightarrow ((M, F, W), (K, W), \alpha) \end{aligned}$$

see definition 69 for the last equality, together we the canonical map

$$\gamma_Z^{\vee, Hdg}((M, F, W), (K, W), \alpha) : ((M, F, W), (K, W), \alpha) \rightarrow \Gamma_Z^{\vee, Hdg}((M, F, W), (K, W), \alpha).$$

(ii)' Since  $j_{!Hdg} : C(MHM_{gm,k,\mathbb{C}}(S^o)) \rightarrow C(MHM_{gm,k,\mathbb{C}}(S))$  is an exact functor,  $\Gamma_Z^{Hdg, \vee}$  induces the functor

$$\begin{aligned} \Gamma_Z^{\vee, Hdg} : D(MHM_{gm,k,\mathbb{C}}(S)) &\rightarrow D(MHM_{gm,k,\mathbb{C}}(S)), \\ ((M, F, W), (K, W), \alpha) &\mapsto \Gamma_Z^{\vee, Hdg}((M, F, W), (K, W), \alpha) \end{aligned}$$

In the singular case it gives :

**Definition 71.** Let  $S \in \text{Var}(k)$ . Let  $Z \subset S$  a closed subset. Let  $S = \cup_{i=1}^s S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Denote  $Z_I := Z \cap S_I$ . Denote by  $n : S \setminus Z \hookrightarrow S$  and  $\tilde{n}_I : \tilde{S}_I \setminus Z_I \hookrightarrow \tilde{S}_I$  the complementary open embeddings.

(i) We define using definition 61, definition 3 and definition 66(iii) the filtered Hodge support section functor

$$\begin{aligned} \Gamma_Z^{Hdg} : C(MHM_{gm,k,\mathbb{C}}(S)) &\rightarrow C(MHM_{gm,k,\mathbb{C}}(S)), \\ (((M_I, F, W), u_{IJ}), (K, W), \alpha) &\mapsto \Gamma_Z^{Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha) := \\ &:= (\Gamma_Z^{Hdg}((M_I, F, W), u_{IJ}), \Gamma_Z^w(K, W), \Gamma_Z(\alpha)) \end{aligned}$$

together with the canonical map

$$\begin{aligned} \gamma_Z^{Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha) : \\ \Gamma_Z^{Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha) &\rightarrow (((M_I, F, W), u_{IJ}), (K, W), \alpha). \end{aligned}$$

(i)' By exactness of  $\Gamma_Z^{Hdg}$  and  $\Gamma_Z^w$  it induces the functor

$$\begin{aligned} \Gamma_Z^{Hdg} : D(MHM_{gm,k,\mathbb{C}}(S)) &\rightarrow D(MHM_{gm,k,\mathbb{C}}(S)), \\ (((M_I, F, W), u_{IJ}), (K, W), \alpha) &\mapsto \Gamma_Z^{Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha) \end{aligned}$$

(ii) We define using definition 61, definition 3 and definition 66(iii) the dual filtered Hodge support section functor

$$\begin{aligned} \Gamma_Z^{\vee, Hdg} : C(MHM_{gm,k,\mathbb{C}}(S)) &\rightarrow C(MHM_{gm,k,\mathbb{C}}(S)), \quad (((M_I, F, W), u_{IJ}), (K, W), \alpha) \mapsto \\ \Gamma_Z^{\vee, Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha) &:= (\Gamma_Z^{\vee, Hdg}((M_I, F, W), u_{IJ}), \Gamma_Z^{\vee, w}(K, W), \Gamma_Z^{\vee}(\alpha)), \end{aligned}$$

together we the canonical map

$$\begin{aligned} \gamma_Z^{\vee, Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha) : \\ (((M_I, F, W), u_{IJ}), (K, W), \alpha) &\rightarrow \Gamma_Z^{\vee, Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha). \end{aligned}$$

(ii)' By exactness of  $\Gamma_Z^{\vee, Hdg}$  and  $\Gamma_Z^{\vee, w}$ , it induces the functor

$$\begin{aligned} \Gamma_Z^{\vee, Hdg} : D(MHM_{gm, k, \mathbb{C}}(S)) &\rightarrow D(MHM_{gm, k, \mathbb{C}}(S)), \\ (((M_I, F, W), u_{IJ}), (K, W), \alpha) &\mapsto \Gamma_Z^{\vee, Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha) \\ &:= (\Gamma_Z^{\vee, Hdg}((M_I, F, W), u_{IJ}), \Gamma_Z^{\vee, w}(K, W), \Gamma_Z^{\vee}(\alpha)) \end{aligned}$$

This gives the inverse image functor :

**Definition 72.** Let  $f : X \rightarrow S$  a morphism with  $X, S \in \text{Var}(k)$ . Assume there exist a factorization  $f : X \xrightarrow{l} Y \times S \xrightarrow{p_S} S$  with  $Y \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $p_S$  the projection. Let  $S = \cup_{i \in I} S_i$  an open cover such that there exist closed embeddings  $i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Denote  $X_I := f^{-1}(S_I)$ . We have then  $X = \cup_{i \in I} X_i$  and the commutative diagrams

$$\begin{array}{ccccc} f : X_I & \xrightarrow{l_I} & Y \times S_I & \xrightarrow{p_{S_I}} & S_I \\ & \searrow & \downarrow i'_I := (l \times i_I) & & \downarrow i_I \\ & & Y \times \tilde{S}_I & \xrightarrow{p_{\tilde{S}_I} := \tilde{f}_I} & \tilde{S}_I \end{array}$$

(i) For  $(((M_I, F, W), u_{IJ}), (K, W), \alpha) \in C(MHM_{gm, k, \mathbb{C}}(S))$  we set (see definition 71 for  $l$ )

$$\begin{aligned} f^{*Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha) &:= \\ \Gamma_X^{Hdg}((p_{\tilde{S}_I}^{*mod[-]}(M_I, F, W), p_{\tilde{S}_I}^{*mod[-]}u_{IJ}), p_S^*(K, W), p_S^*\alpha)(d_Y)[2d_Y] &\in C(MHM_{gm, k, \mathbb{C}}(X)), \end{aligned}$$

(ii) For  $(((M_I, F, W), u_{IJ}), (K, W), \alpha) \in C(MHM_{gm, k, \mathbb{C}}(S))$  we set (see definition 71 for  $l$ )

$$\begin{aligned} f^{!Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha) &:= \\ \Gamma_X^{\vee, Hdg}((p_{\tilde{S}_I}^{*mod[-]}(M_I, F, W), p_{\tilde{S}_I}^{*mod[-]}u_{IJ}), p_S^*(K, W), p_S^*\alpha) &\in C(MHM_{gm, k, \mathbb{C}}(X)), \end{aligned}$$

Let  $j : S^o \hookrightarrow S$  an open embedding with  $S \in \text{Var}(k)$ . Let  $S = \cup_{i \in I} S_i$  an open cover such that there exist closed embeddings  $i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . We have then, for  $(((M_I, F, W), u_{IJ}), (K, W), \alpha) \in C(MHM_{gm, k, \mathbb{C}}(S))$ , quasi-isomorphisms in  $C(MHM_{gm, k, \mathbb{C}}(S))$

$$\begin{aligned} (I(j^*, j_{Hdg}^{*mod})(-), I) : j_{*Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha) &\rightarrow \\ j^*(((M_I, F, W), u_{IJ}), (K, W), \alpha) &:= (j^*((M_I, F, W), u_{IJ}), j^*(K, W), \alpha) \end{aligned}$$

and

$$\begin{aligned} (I(j^*, j_{Hdg}^{*mod})(-), I) : j^{!Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha) &\rightarrow \\ j^*(((M_I, F, W), u_{IJ}), (K, W), \alpha) &:= (j^*((M_I, F, W), u_{IJ}), j^*(K, W), \alpha) \end{aligned}$$

**Definition 73.** Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i \in I} S_i$  an open cover such that there exist closed embeddings  $i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . We have, using definition 63 the following bi-functor

$$\begin{aligned} (-) \otimes_{O_S}^{Hdg} (-) : D(MHM_{gm, k, \mathbb{C}}(S))^2 &\rightarrow D(MHM_{gm, k, \mathbb{C}}(S)), \\ (((M_I, F, W), u_{IJ}), (K, W), \alpha), (((M'_I, F, W), v_{IJ}), (K', W), \alpha') &\mapsto \\ (((M_I, F, W), u_{IJ}), (K, W), \alpha) \otimes_{O_S}^{Hdg} (((M'_I, F, W), v_{IJ}), (K', W), \alpha') &:= \\ ((M_I, F, W), u_{IJ}) \otimes_{O_S}^{Hdg} ((M'_I, F, W), v_{IJ}), (K, W) \otimes (K', W), \alpha \otimes \alpha' &\end{aligned}$$

where the map  $\alpha \otimes \alpha'$  is given in definition 66(v).

**Proposition 45.** Let  $f_1 : X \rightarrow Y$  and  $f_2 : Y \rightarrow S$  two morphism with  $X, Y, S \in \text{QPVar}(k)$ .

(i) Let  $\mathcal{M} \in C(\text{MHM}_{gm,k,\mathbb{C}}(S))$ . Then,

$$(f_2 \circ f_1)^{*Hdg}(\mathcal{M}) = f_1^{*Hdg} f_2^{*Hdg}(\mathcal{M}) \in D(\text{MHM}_{gm,k,\mathbb{C}}(X)).$$

(ii) Let  $(M, F, W) \in C(\text{MHM}_{gm,k,\mathbb{C}}(S))$ . Then,

$$(f_2 \circ f_1)^{!Hdg}(\mathcal{M}) = f_1^{!Hdg} f_2^{!Hdg}(\mathcal{M}) \in D(\text{MHM}_{gm,k,\mathbb{C}}(X))$$

*Proof.* Immediate from definition.  $\square$

**Proposition 46.** Let  $S \in \text{SmVar}(k)$ . Let  $D = V(s) \subset S$  a (Cartier) divisor, where  $s \in \Gamma(S, L)$ . Denote  $i : D := S \setminus D \hookrightarrow S$  the closed embedding and  $j : S^o \hookrightarrow S$  the open embedding.

(i) Let  $((M, F, W), (K, W), \alpha) \in \text{MHM}_{gm,k,\mathbb{C}}(S)$ . We have, using proposition 38, the canonical quasi-isomorphism in  $C(\text{MHM}_{gm,k,\mathbb{C}}(S))$  :

$$\begin{aligned} & \text{Is}(M) := (\text{Is}(M), \text{Is}(K), 0) : \\ ((M, F, W), (K, W), \alpha) & \rightarrow (\psi_D((M, F, W), (K, W), \alpha) \xrightarrow{((c(x_{S^o/S}(M)), \text{can}(M)), (c(x_{S^o/S}(K)), \text{can}(K)), 0))} \\ & x_{S^o/S}((M, F, W), (K, W), \alpha) \oplus \phi_D((M, F, W), (K, W), \alpha) \xrightarrow{=} \\ & (x_{S^o/S}(M, F, W), x_{S^o/S}(K, W), x_{S^o/S}(\alpha)) \oplus (\phi_D(M, F, W), \phi_D(K, W), \phi_D \alpha) \\ & \xrightarrow{((\mathbb{D}c(x_{S^o/S}(\mathbb{D}K M)), \text{var}(M)), (\mathbb{D}c(x_{S^o/S}(\mathbb{D}K)), \text{var}(K)), 0)} \psi_D((M, F, W), (K, W), \alpha)). \end{aligned}$$

(ii) We denote by  $\text{MHM}_{gm,k,\mathbb{C}}(S \setminus D) \times_J \text{MHM}_{gm,k,\mathbb{C}}(D)$  the category whose set of objects consists of

$$\{(\mathcal{M}, \mathcal{N}, a, b), \mathcal{M} \in \text{MHM}_{gm,k,\mathbb{C}}(S \setminus D), \mathcal{N} \in \text{MHM}_{gm,k,\mathbb{C}}(D), a : \psi_{D1} \mathcal{M} \rightarrow \mathcal{N}, b : \mathcal{N} \rightarrow \psi_{D1} \mathcal{M}\}$$

The functor (see definition 67)

$$\begin{aligned} & (j^*, \phi_{D1}, c, v) : \text{MHM}_{gm,k,\mathbb{C}}(S) \rightarrow \text{MHM}_{gm,k,\mathbb{C}}(S \setminus D) \times_J \text{MHM}_{gm,k,\mathbb{C}}(D), \\ ((M, F, W), (K, W), \alpha) & \mapsto ((j^*(M, F, W), j^*(K, W), j^* \alpha), \phi_D((M, F, W), (K, W), \alpha), \text{can}(-), \text{var}(-)) \end{aligned}$$

is an equivalence of category.

*Proof.* (i): Follows from proposition 38.

(ii): Follows from (i).  $\square$

Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i \in I} S_i$  an open cover such that there exists closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_I \in \text{SmVar}(k)$ . We have the category  $D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})$

- whose set of objects is the set of triples  $\{(((M_I, F, W), u_{IJ}), (K, W), \alpha)\}$  with

$$\begin{aligned} & ((M_I, F, W), u_{IJ}) \in D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)), (K, W) \in D_{fil,c,k}(S_{\mathbb{C}}^{an}), \\ & \alpha : T(S/(\tilde{S}_I))(K, W) \otimes \mathbb{C}S_{\mathbb{C}}^{an} \rightarrow DR(S)^{[-1]}(((M_I, W), u_{IJ})^{an}) \end{aligned}$$

where  $\alpha$  is an morphism in  $D_{fil}(S_{\mathbb{C}}^{an}/(\tilde{S}_{I,\mathbb{C}}^{an}))$ ,

- and whose set of morphisms consists of

$$\phi = (\phi_D, \phi_C, [\theta]) : (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2)$$

where  $\phi_D : ((M_1, F, W), u_{IJ}) \rightarrow ((M_2, F, W), u_{IJ})$  and  $\phi_C : (K_1, W) \rightarrow (K_2, W)$  are morphisms and

$$\theta = (\theta^\bullet, I(DR(S)(\phi_D^{an})) \circ I(\alpha_1), I(\alpha_2) \circ I(\phi_C \otimes I)) : \\ I(T(S/(\tilde{S}_I))(K_1, W)) \otimes \mathbb{C}_{S^{an}}[1] \rightarrow I(DR(S)((M_{2I}, W), u_{IJ})^{an})$$

is an homotopy,  $I : D_{fil}(S_{\mathbb{C}}^{an}/(\tilde{S}_I^{an})) \rightarrow K_{fil}(S_{\mathbb{C}}^{an}/(\tilde{S}_I^{an}))$  being the injective resolution functor, and for

- $\phi = (\phi_D, \phi_C, [\theta]) : (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2)$
- $\phi' = (\phi'_D, \phi'_C, [\theta']) : (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2) \rightarrow (((M_{3I}, F, W), u_{IJ}), (K_3, W), \alpha_3)$

the composition law is given by

$$\phi' \circ \phi := (\phi'_D \circ \phi_D, \phi'_C \circ \phi_C, I(DR(S)(\phi'_D)^{an}) \circ [\theta] + [\theta'] \circ I(\phi_C \otimes I)[1]) : \\ (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_{3I}, F, W), u_{IJ}), (K_3, W), \alpha_3),$$

in particular for  $(((M_I, F, W), u_{IJ}), (K, W), \alpha) \in D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})$ ,

$$I_{(((M_I, F, W), u_{IJ}), (K, W), \alpha)} = ((I_{M_I}, I_K, 0),$$

and also the category  $D_{\mathcal{D}(1,0)fil,rh,\infty}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})$  defined in the same way, together with the localization functor

$$(D(zar), I) : C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an}) \rightarrow D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an}) \\ \rightarrow D_{\mathcal{D}(1,0)fil,rh,\infty}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an}).$$

Note that if  $\phi = (\phi_D, \phi_C, [\theta]) : (((M_1, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_2, F, W), u_{IJ}), (K_2, W), \alpha_2)$  is a morphism in  $D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})$  such that  $\phi_D$  and  $\phi_C$  are isomorphism then  $\phi$  is an isomorphism (see remark 5). Moreover,

- For  $(((M_I, F, W), u_{IJ}), (K, W), \alpha) \in D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})$ , we set

$$(((M_I, F, W), u_{IJ}), (K, W), \alpha)[1] := (((M_I, F, W), u_{IJ})[1], (K, W)[1], \alpha[1]).$$

- For

$$\phi = (\phi_D, \phi_C, [\theta]) : (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2)$$

a morphism in  $D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})$ , we set (see [11] definition 3.12)

$$\text{Cone}(\phi) := (\text{Cone}(\phi_D), \text{Cone}(\phi_C), ((\alpha_1, \theta), (\alpha_2, 0))) \in D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an}),$$

$((\alpha_1, \theta), (\alpha_2, 0))$  being the matrix given by the composition law, together with the canonical maps

- $c_1(-) = (c_1(\phi_D), c_1(\phi_C), 0) : (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2) \rightarrow \text{Cone}(\phi)$
- $c_2(-) = (c_2(\phi_D), c_2(\phi_C), 0) : \text{Cone}(\phi) \rightarrow (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1)[1].$

We have then the following :

**Theorem 41.** (i) *Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i \in I} S_i$  an open cover such that there exists closed embedding  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Then the full embedding*

$$\iota_S : MHM_{gm,k,\mathbb{C}}(S) \hookrightarrow \text{PSh}_{\mathcal{D}(1,0)fil,rh}^0(S/(\tilde{S}_I)) \times_I P_{fil,k}(S_{\mathbb{C}}^{an}) \hookrightarrow C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})$$

induces a full embedding

$$\iota_S : D(MHM_{gm,k,\mathbb{C}}(S)) \hookrightarrow D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})$$

whose image consists of  $((M_I, F, W), u_{IJ}), (K, W), \alpha \in D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})$  such that

$$((H^n(M_I, F, W), H^n(u_{IJ})), H^n(K, W), H^n \alpha) \in MHM_{gm,k,\mathbb{C}}(S)$$

for all  $n \in \mathbb{Z}$  and such that for all  $p \in \mathbb{Z}$ , the differentials of  $\text{Gr}_W^p(M_I, F)$  are strict for the filtrations  $F$ .

(i)' Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i \in I} S_i$  an open cover such that there exists closed embedding  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Then,

$$\begin{aligned} D(MHM_{gm,k,\mathbb{C}}(S)) &= \langle \left( \int_f^{FDR} (n \times I)_{!} \text{Hdg}(\Gamma_X^{\vee, \text{Hdg}}(O_{\mathbb{P}^{N,o} \times \tilde{S}_I}, F_b), x_{IJ}), Rf_* \mathbb{Z}_X, f_* \alpha(X) \right), \\ &\quad (f : X \xrightarrow{l} \mathbb{P}^{N,o} \times S \xrightarrow{p} S) \in \text{QPVar}(k) \rangle \\ &= \langle \left( \int_f^{FDR} ((\Gamma_X^{\vee, \text{Hdg}}(O_{\mathbb{P}^{N,o} \times \tilde{S}_I}, F_b), x_{IJ}), Rf_* \mathbb{Z}_X, f_* \alpha(X) \right), \\ &\quad (f : X \xrightarrow{l} \mathbb{P}^{N,o} \times S \xrightarrow{p} S) \in \text{QPVar}(k), \text{ proper, } X \text{ smooth} \rangle \\ &\quad \subset D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an}) \end{aligned}$$

where  $n : \mathbb{P}^{N,o} \hookrightarrow \mathbb{P}^N$  are open embeddings,  $l$  are closed embedding and  $\langle, \rangle$  means the full triangulated category generated by.

(ii) Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i \in I} S_i$  an open cover such that there exists closed embedding  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Then the full embedding

$$\iota_S : MHM_{gm,k,\mathbb{C}}(S) \hookrightarrow \text{PSh}_{\mathcal{D}(1,0)fil,rh}^0(S/(\tilde{S}_I)) \times_I P_{fil,k}(S_{\mathbb{C}}^{an}) \hookrightarrow C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})$$

induces a full embedding

$$\iota_S : D(MHM_{gm,k,\mathbb{C}}(S)) \hookrightarrow D_{\mathcal{D}(1,0)fil,\infty,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})$$

whose image consists of  $((M_I, F, W), u_{IJ}), (K, W), \alpha \in D_{\mathcal{D}(1,0)fil,\infty,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})$  such that

$$((H^n(M_I, F, W), H^n(u_{IJ})), H^n(K, W), H^n \alpha) \in MHM_{gm,k,\mathbb{C}}(S)$$

for all  $n \in \mathbb{Z}$  and such that there exist  $r \in \mathbb{Z}$  and an  $r$ -filtered homotopy equivalence  $((M_I, F, W), u_{IJ}) \rightarrow ((M'_I, F, W), u_{IJ})$  such that for all  $p \in \mathbb{Z}$  the differentials of  $\text{Gr}_W^p(M'_I, F)$  are strict for the filtrations  $F$ .

*Proof.* (i): We first show that  $\iota_S$  is fully faithful, that is for all  $\mathcal{M} = (((M_I, F, W), u_{IJ}), (K, W), \alpha), \mathcal{M}' = (((M'_I, F, W), u_{IJ}), (K', W), \alpha') \in MHM_{gm,k,\mathbb{C}}(S)$  and all  $n \in \mathbb{Z}$ ,

$$\begin{aligned} \iota_S : \text{Ext}_{D(MHM_{gm,k,\mathbb{C}}(S))}^n(\mathcal{M}, \mathcal{M}') &:= \text{Hom}_{D(MHM_{gm,k,\mathbb{C}}(S))}(\mathcal{M}, \mathcal{M}'[n]) \\ \rightarrow \text{Ext}_{\mathcal{D}(S)}^n(\mathcal{M}, \mathcal{M}') &:= \text{Hom}_{\mathcal{D}(S) := D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})}(\mathcal{M}, \mathcal{M}'[n]) \end{aligned}$$

For this it is enough to assume  $S$  smooth. We then proceed by induction on  $\max(\dim \text{supp}(M), \dim \text{supp}(M'))$ .

- For  $\text{supp}(M) = \text{supp}(M') = \{s\}$ , it is the theorem for mixed hodge complexes or absolute Hodge complexes, see [11]. If  $\text{supp}(M) = \{s\}$  and  $\text{supp}(M') = \{s'\}$  and  $s' \neq s$ , then by the localization exact sequence

$$\text{Ext}_{D(MHM_{gm,k,\mathbb{C}}(S))}^n(\mathcal{M}, \mathcal{M}') = 0 = \text{Ext}_{\mathcal{D}(S)}^n(\mathcal{M}, \mathcal{M}')$$

- Denote  $\text{supp}(M) = Z \subset S$  and  $\text{supp}(M') = Z' \subset S$ . There exist an open subset  $S^\circ \subset S$  such that  $Z^\circ := Z \cap S^\circ$  and  $Z'^\circ := Z' \cap S^\circ$  are smooth, and  $\mathcal{M}|_{Z^\circ} := ((i^* \text{Gr}_{V_{Z^\circ}, 0} M|_{S^\circ}, F, W), i^* j^*(K, W), \alpha^*(i)) \in \text{MHM}_{gm, k}(Z^\circ)$  and  $\mathcal{M}'|_{Z'^\circ} := ((i'^* \text{Gr}_{V_{Z'^\circ}, 0} M'|_{S^\circ}, F, W), i'^* j^* K, \alpha^*(i')) \in \text{MHM}_{gm, k}(Z'^\circ)$  are variation of geometric mixed Hodge structure over  $k \subset \mathbb{C}$ , where  $j : S^\circ \hookrightarrow S$  is the open embedding, and  $i : Z^\circ \hookrightarrow S^\circ$ ,  $i' : Z'^\circ \hookrightarrow S^\circ$  the closed embeddings. Considering the connected components of  $Z^\circ$  and  $Z'^\circ$ , we may assume that  $Z^\circ$  and  $Z'^\circ$  are connected. Shrinking  $S^\circ$  if necessary, we may assume that either  $Z^\circ = Z'^\circ$  or  $Z^\circ \cap Z'^\circ = \emptyset$ . We denote  $D = S \setminus S^\circ$ . Shrinking  $S^\circ$  if necessary, we may assume that  $D$  is a divisor and denote by  $l : S \hookrightarrow L_D$  the zero section embedding.

- If  $Z^\circ = Z'^\circ$ , denote  $i : Z^\circ \hookrightarrow S^\circ$  the closed embedding. We have then the following commutative diagram

$$\begin{array}{ccc} \text{Ext}_{D(\text{MHM}_{gm, k, \mathbb{C}}(S^\circ))}^n(\mathcal{M}|_{S^\circ}, \mathcal{M}'|_{S^\circ}) & \xrightarrow{\iota_{S^\circ}} & \text{Ext}_{\mathcal{D}(S^\circ)}^n(\mathcal{M}|_{S^\circ}, \mathcal{M}'|_{S^\circ}) \\ (i^* \text{Gr}_{V_{Z^\circ}, 0}, i^*, \alpha^*(i)) \updownarrow (i_{*mod}, i_*, \alpha_*(i)) & & (i_{*mod}, i_*, \alpha_*(i)) \updownarrow (i^* \text{Gr}_{V_{Z^\circ}, 0}, i^*, \alpha^*(i)) \\ \text{Ext}_{D(\text{MHM}_{gm, k, \mathbb{C}}(Z^\circ))}^n(\mathcal{M}|_{Z^\circ}, \mathcal{M}'|_{Z^\circ}) & \xrightarrow{\iota_{Z^\circ}} & \text{Ext}_{\mathcal{D}(Z^\circ)}^n(\mathcal{M}|_{Z^\circ}, \mathcal{M}'|_{Z^\circ}) \end{array}$$

Now we prove that  $\iota_{Z^\circ}$  is an isomorphism similarly to the proof the the generic case of [6]. On the other hand the left and right column are isomorphisms. Hence  $\iota_{S^\circ}$  is an isomorphism by the diagram.

- If  $Z^\circ \cap Z'^\circ = \emptyset$ , we consider the following commutative diagram

$$\begin{array}{ccc} \text{Ext}_{D(\text{MHM}_{gm, k, \mathbb{C}}(S^\circ))}^n(\mathcal{M}|_{S^\circ}, \mathcal{M}'|_{S^\circ}) & \xrightarrow{\iota_{S^\circ}} & \text{Ext}_{\mathcal{D}(S^\circ)}^n(\mathcal{M}|_{S^\circ}, \mathcal{M}'|_{S^\circ}) \\ (i^* \text{Gr}_{V_{Z^\circ}, 0}, i^*, \alpha^*(i)) \updownarrow (i_{*mod}, i_*, \alpha_*(i)) & & (i_{*mod}, i_*, \alpha_*(i)) \updownarrow (i^* \text{Gr}_{V_{Z^\circ}, 0}, i^*, \alpha^*(i)) \\ \text{Ext}_{D(\text{MHM}_{gm, k, \mathbb{C}}(Z^\circ))}^n(\mathcal{M}|_{Z^\circ}, 0) = 0 & \xrightarrow{\iota_{Z^\circ}} & \text{Ext}_{\mathcal{D}(Z^\circ)}^n(\mathcal{M}|_{Z^\circ}, 0) = 0 \end{array}$$

where the left and right column are isomorphism by strictness of the  $V_{Z^\circ}$  filtration (use a bi-filtered injective resolution with respect to  $F$  and  $V_{Z^\circ}$  for the right column).

- We consider now the following commutative diagram in  $C(\mathbb{Z})$  where we denote for short  $H := D(\text{MHM}_{gm, k, \mathbb{C}}(S))$

$$\begin{array}{ccccccc} 0 \longrightarrow & \text{Hom}_{\bullet H}(\Gamma_D^{\vee, Hdg} \mathcal{M}, \Gamma_D^{Hdg} \text{Hom}(-, \gamma_D^{Hdg}(\mathcal{M}')) & \xrightarrow{\quad} & \text{Hom}_{\bullet H}(\Gamma_D^{\vee, Hdg} \mathcal{M}, \mathcal{M}') & \xrightarrow{\text{Hom}(-, \text{ad}(j^* j_{*Hdg})(\mathcal{M}'))} & \text{Hom}_{\bullet H}(\Gamma_D^{\vee, Hdg} \mathcal{M}, j_{*Hdg} j^* \mathcal{M}') & \longrightarrow 0 \\ & \downarrow \iota_S & & \downarrow \iota_S & & \downarrow \iota_S & \\ 0 \longrightarrow & \text{Hom}_{\bullet D(S)}(\Gamma_D^{\vee, Hdg} \mathcal{M}, \Gamma_D^{Hdg} \text{Hom}(-, \gamma_D^{Hdg}(\mathcal{M}')) & \xrightarrow{\quad} & \text{Hom}_{\bullet D(S)}(\Gamma_D^{\vee, Hdg} \mathcal{M}, \mathcal{M}') & \xrightarrow{\text{Hom}(-, \text{ad}(j^* j_{*Hdg})(\mathcal{M}'))} & \text{Hom}_{\bullet D(S)}(\Gamma_D^{\vee, Hdg} \mathcal{M}, j_{*Hdg} j^* \mathcal{M}') & \longrightarrow 0 \end{array}$$

whose lines are exact sequence. We have on the one hand,

$$\text{Hom}_{D(\text{MHM}_{gm, k, \mathbb{C}}(S))}^{\bullet}(\Gamma_D^{\vee, Hdg} \mathcal{M}, j_{*Hdg} j^* \mathcal{M}') = 0 = \text{Hom}_{D(S)}^{\bullet}(\Gamma_D^{\vee, Hdg} \mathcal{M}, j_{*Hdg} j^* \mathcal{M}')$$

On the other hand by induction hypothesis

$$\iota_S : \text{Hom}_{D(\text{MHM}_{gm, k, \mathbb{C}}(S))}^{\bullet}(\Gamma_D^{\vee, Hdg} \mathcal{M}, \Gamma_D^{Hdg} \mathcal{M}') \rightarrow \text{Hom}_{D(S)}^{\bullet}(\Gamma_D^{\vee, Hdg} \mathcal{M}, \Gamma_D^{Hdg} \mathcal{M}')$$

is a quasi-isomorphism. Hence, by the diagram

$$\iota_S : \text{Hom}_{D(\text{MHM}_{gm, k, \mathbb{C}}(S))}^{\bullet}(\Gamma_D^{\vee, Hdg} \mathcal{M}, \mathcal{M}') \rightarrow \text{Hom}_{D(S)}^{\bullet}(\Gamma_D^{\vee, Hdg} \mathcal{M}, \mathcal{M}')$$

is a quasi-isomorphism.



- We consider now the following commutative diagram in  $C(\mathbb{Z})$  where we denote for short  $H := D(MHM_{gm,k,c}(S))$

$$\begin{array}{ccccccc}
0 & \longrightarrow & \mathrm{Hom}_{\mathcal{H}}^{\bullet}(\Gamma_D^{\vee, Hdg} \mathcal{M}, \mathcal{M}') & \xrightarrow{\mathrm{Hom}(\gamma_D^{\vee, Hdg}(\mathcal{M}), -)} & \mathrm{Hom}_{\mathcal{H}}^{\bullet}(\mathcal{M}, \mathcal{M}') & \xrightarrow{\mathrm{Hom}(\mathrm{ad}(j_{!Hdg}, j^*)(\mathcal{M}'), -)} & \mathrm{Hom}_{\mathcal{H}}^{\bullet}(j_{!Hdg} j^* \mathcal{M}, \mathcal{M}') \longrightarrow 0 \\
& & \downarrow \iota_S & & \downarrow \iota_S & & \downarrow \iota_S \\
0 & \longrightarrow & \mathrm{Hom}_{\mathcal{D}(S)}^{\bullet}(\Gamma_D^{\vee, Hdg} \mathcal{M}, \mathcal{M}') & \xrightarrow{\mathrm{Hom}(\gamma_D^{\vee, Hdg}(\mathcal{M}), -)} & \mathrm{Hom}_{\mathcal{D}(S)}^{\bullet}(\mathcal{M}, \mathcal{M}') & \xrightarrow{\mathrm{Hom}(\mathrm{ad}(j_{!Hdg}, j^*)(\mathcal{M}'), -)} & \mathrm{Hom}_{\mathcal{D}(S)}^{\bullet}(j_{!Hdg} j^* \mathcal{M}, \mathcal{M}') \longrightarrow 0
\end{array}$$

whose lines are exact sequence. On the one hand, the commutative diagram

$$\begin{array}{ccc}
\mathrm{Hom}_{D(MHM_{gm,k,c}(S))}^{\bullet}(j_{!Hdg} j^* \mathcal{M}, \mathcal{M}') & \xrightarrow{j^*} & \mathrm{Hom}_{D(MHM_{gm,k,c}(S^{\circ}))}^{\bullet}(j^* \mathcal{M}, j^* \mathcal{M}') \\
\downarrow \iota_S & & \downarrow \iota_{S^{\circ}} \\
\mathrm{Hom}_{\mathcal{D}(S)}^{\bullet}(j_{!Hdg} j^* \mathcal{M}, \mathcal{M}') & \xrightarrow{j^*} & \mathrm{Hom}_{\mathcal{D}(S^{\circ})}^{\bullet}(j^* \mathcal{M}, j^* \mathcal{M}')
\end{array}$$

together with the fact that the horizontal arrows  $j^*$  are quasi-isomorphism by the functoriality given the uniqueness of the  $V_S$  filtration for the embedding  $l : S \hookrightarrow L_D$ , (use a bi-filtered injective resolution with respect to  $F$  and  $V_S$  for the lower arrow) and the fact that  $\iota_{S^{\circ}}$  is a quasi-isomorphism by the first two point, show that

$$\iota_S : \mathrm{Hom}_{D(MHM_{gm,k,c}(S))}^{\bullet}(j_{!Hdg} j^* \mathcal{M}, \mathcal{M}') \rightarrow \mathrm{Hom}_{\mathcal{D}(S)}^{\bullet}(j_{!Hdg} j^* \mathcal{M}, \mathcal{M}')$$

is a quasi-isomorphism. On the other hand, by the third point

$$\iota_S : \mathrm{Hom}_{D(MHM_{gm,k,c}(S))}^{\bullet}(\Gamma_D^{\vee, Hdg} \mathcal{M}, \mathcal{M}') \rightarrow \mathrm{Hom}_{\mathcal{D}(S)}^{\bullet}(\Gamma_D^{\vee, Hdg} \mathcal{M}, \mathcal{M}')$$

is a quasi-isomorphism. Hence, by the diagram

$$\iota_S : \mathrm{Hom}_{D(MHM_{gm,k,c}(S))}^{\bullet}(\Gamma_D^{\vee, Hdg} \mathcal{M}, \mathcal{M}') \rightarrow \mathrm{Hom}_{\mathcal{D}(S)}^{\bullet}(\Gamma_D^{\vee, Hdg} \mathcal{M}, \mathcal{M}')$$

is a quasi-isomorphism.

This shows the fully faithfulness. We now prove the essential surjectivity : let

$$(((M_I, F, W), u_{IJ}), (K, W), \alpha) \in C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I C_{fil}(S_{\mathbb{C}}^{an})$$

such that the cohomology are mixed hodge modules and such that the differential are strict. We proceed by induction on  $card\{n \in \mathbb{Z}\}$ , s.t.  $H^n(M_I, F, W) \neq 0$  by taking for the cohomological troncation

$$\tau^{\leq n}(((M_I, F, W), u_{IJ}), (K, W), \alpha) := ((\tau^{\leq n}(M_I, F, W), \tau^{\leq n} u_{IJ}), \tau^{\leq n}(K, W), \tau^{\leq n} \alpha)$$

and using the fact that the differential are strict for the filtration  $F$  and the fully faithfulness.

(i): Follows from (i).

(ii): Follows from (i). Indeed, in the composition of functor

$$\begin{aligned}
\iota_S : D(MHM_{gm,k,c}(S)) &\xrightarrow{\iota_S} D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil}(S_{\mathbb{C}}^{an}) \\
&\rightarrow D_{\mathcal{D}(1,0)fil,\infty,rh}(S/(\tilde{S}_I)) \times_I D_{fil}(S_{\mathbb{C}}^{an})
\end{aligned}$$

the second functor which is the localization functor is an isomorphism on the full subcategory

$$D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I))^{st} \times_I D_{fil}(S_{\mathbb{C}}^{an}) \subset D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil}(S_{\mathbb{C}}^{an})$$

consisting of complex such that the differentials are strict for  $F$ , and the first functor  $\iota_S$  is a full embedding by (i) and  $\iota_S(D(MHM_{gm,k,c}(S))) \subset D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I))^{st} \times_I D_{fil}(S_{\mathbb{C}}^{an})$ .  $\square$

**Definition 74.** Let  $f : X \rightarrow S$  a morphism with  $X, S \in \text{Var}(k)$ . Assume there exist a factorization  $f : X \xrightarrow{l} Y \times S \xrightarrow{p_S} S$  with  $Y \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $p_S$  the projection. Let  $\bar{Y} \in \text{PSmVar}(k)$  a smooth compactification of  $Y$  with  $n : Y \hookrightarrow \bar{Y}$  the open embedding. Then  $\bar{f} : \bar{X} \xrightarrow{\bar{l}} \bar{Y} \times_S \xrightarrow{\bar{p}_S} S$  is a compactification of  $f$ , with  $\bar{X} \subset \bar{Y} \times S$  the closure of  $X$  and  $\bar{l}$  the closed embedding, and we denote by  $n' : X \hookrightarrow \bar{X}$  the open embedding so that  $f = \bar{f} \circ n'$ .

(i) For  $((M_I, F, W), u_{IJ}), (K, W), \alpha \in C(MHM_{gm, k, \mathbb{C}}(X))$ , we define, using definition 65 and theorem 41

$$Rf_{*Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha) := \iota_S^{-1} \left( \int_{\bar{f}}^{FDR} (n \times I)_{*Hdg}((M_I, F, W), u_{IJ}), Rf_{*w}(K, W), f_*(\alpha) \right) \in D(MHM_{gm, k, \mathbb{C}}(S))$$

where  $f_*(\alpha)$  is given in definition 66, and since

– by definition

$$H^i \left( \int_{\bar{f}}^{FDR} \text{Gr}_W^k (I \times n)_{Hdg^*}((M_I, F, W), u_{IJ}), R\bar{f}_* \text{Gr}_W^k n'_{*w}(K, W), \bar{f}_* \text{Gr}_W^k n'_*(\alpha) \right) \in HM_{gm, k, \mathbb{C}}(S)$$

for all  $i, k \in \mathbb{Z}$ , hence by the spectral sequence for the filtered complexes  $\int_{\bar{f}}^{FDR} (I \times n)_{Hdg^*}((M_I, F, W), u_{IJ})$  and  $R\bar{f}_*((I \times n)_{*w}(K, W))$

$$\begin{aligned} & \text{Gr}_W^k H^i \left( \int_f^{Hdg} ((M_I, F, W), u_{IJ}), Rf_{*w}(K, W), f_*(\alpha) \right) := \\ & (\text{Gr}_W^k H^i \int_{\bar{f}}^{FDR} (I \times n)_{Hdg^*}((M_I, F, W), u_{IJ}), \text{Gr}_W^k H^i R\bar{f}_* n'_{*w}(K, W), \text{Gr}_W^k H^i f_*(\alpha)) \in HM_{gm, k, \mathbb{C}}(S) \end{aligned}$$

this gives by definition  $H^i(\int_f^{Hdg}((M_I, F, W), u_{IJ}), Rf_{*w}(K, W), f_*(\alpha)) \in MHM_{gm, k, \mathbb{C}}(S)$  for all  $i \in \mathbb{Z}$ .

–  $\int_f^{Hdg}((M_I, F, W), u_{IJ})$  is the class of a complex such that the differential are strict for  $F$  by theorem 37 in the complex case.

(ii) For  $((M_I, F, W), u_{IJ}), (K, W), \alpha \in C(MHM_{gm, k, \mathbb{C}}(X))$ , we define, using definition 65 and theorem 41,

$$Rf_{!Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha) := \iota_S^{-1} \left( \int_{\bar{f}}^{FDR} (n \times I)_{!Hdg}((M_I, F, W), u_{IJ}), Rf_{!w}(K, W), f_!(\alpha) \right) \in D(MHM_{gm, k, \mathbb{C}}(S))$$

where  $f_!(\alpha)$  is given in definition 66, and since

– by definition

$$H^i \left( \int_{\bar{f}}^{FDR} \text{Gr}_W^k (n \times I)_{!Hdg}((M_I, F, W), u_{IJ}), R\bar{f}_* \text{Gr}_W^k n'_{!w}(K, W), \text{Gr}_W^k f_!(\alpha) \right) \in HM_{gm, k, \mathbb{C}}(S)$$

for all  $i, k \in \mathbb{Z}$ , hence by the spectral sequence for the filtered complexes  $\int_{\bar{f}}^{FDR} (n \times I)_{!Hdg}((M_I, F, W), u_{IJ})$  and  $R\bar{f}_*((n \times I)_{!w}(K, W))$

$$\begin{aligned} & \text{Gr}_W^k H^i \left( \int_{f!}^{Hdg} ((M_I, F, W), u_{IJ}), Rf_{!w}(K, W), f_!(\alpha) \right) := \\ & (\text{Gr}_W^k H^i \int_{\bar{f}}^{FDR} (n \times I)_{!Hdg}((M_I, F, W), u_{IJ}), \text{Gr}_W^k H^i R\bar{f}_* n'_{!w}(K, W), \text{Gr}_W^k H^i f_!(\alpha)) \in HM_{gm, k, \mathbb{C}}(S) \end{aligned}$$

- this gives by definition  $H^i(\int_{f_!}^{Hdg}((M_I, F, W), u_{IJ}), Rf_{!w}(K, W), f_!(\alpha)) \in MHM_{gm,k,\mathbb{C}}(S)$  for all  $i \in \mathbb{Z}$ .
- $\int_{f_!}^{Hdg}((M_I, F, W), u_{IJ})$  is the class of a complex such that the differential are strict for  $F$  by theorem 37 in the complex case.

**Proposition 47.** *Let  $f_1 : X \rightarrow Y$  and  $f_2 : Y \rightarrow S$  two morphism with  $X, Y, S \in \text{QPVar}(k)$ .*

(i) *Let  $\mathcal{M} \in C(MHM_{gm,k,\mathbb{C}}(X))$ . Then,*

$$R(f_2 \circ f_1)_*^{Hdg} \mathcal{M} = Rf_{2*}^{Hdg} Rf_{1*}^{Hdg} \mathcal{M} \in D(MHM_{gm,k,\mathbb{C}}(S)).$$

(ii) *Let  $(M, F, W) \in C(MHM_{gm,k,\mathbb{C}}(X))$ . Then,*

$$R(f_2 \circ f_1)!^{Hdg} \mathcal{M} = Rf_{2!}^{Hdg} Rf_{1!}^{Hdg} \mathcal{M} \in D(MHM_{gm,k,\mathbb{C}}(S))$$

*Proof.* Immediate from definition. □

Let  $k \subset \mathbb{C}$  a subfield. Definition 72, definition 74 and gives by proposition 45 and proposition 47 respectively, the following 2 functors :

- We have the following 2 functor on the category of algebraic varieties over  $k \subset \mathbb{C}$

$$\begin{aligned} D(MHM_{gm,k,\mathbb{C}}(\cdot)) : \text{QPVar}(k) &\rightarrow \text{TriCat}, S \mapsto D(MHM_{gm,k,\mathbb{C}}(S)), \\ (f : T \rightarrow S) &\mapsto (f^{*Hdg} : (((M_I, F, W), u_{IJ}), (K, W), \alpha) \mapsto \\ f^{!Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha) &:= (f_{Hdg}^{*mod}(((M_I, F, W), u_{IJ})), f^{!w}(K, W), f^!\alpha)). \end{aligned}$$

see definition 62 and definition 66 for the equality.

- We have the following 2 functor on the category of quasi-projective algebraic varieties over  $k \subset \mathbb{C}$

$$\begin{aligned} D(MHM_{gm,k,\mathbb{C}}(\cdot)) : \text{QPVar}(k) &\rightarrow \text{TriCat}, S \mapsto D(MHM_{gm,k,\mathbb{C}}(S)), \\ (f : T \rightarrow S) &\mapsto (f_{*Hdg} : (((M_I, F, W), u_{IJ}), (K, W), \alpha) \mapsto Rf_{*Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha)). \end{aligned}$$

- We have the following 2 functor on the category of quasi-projective algebraic varieties over  $k \subset \mathbb{C}$

$$\begin{aligned} D(MHM_{gm,k,\mathbb{C}}(\cdot)) : \text{QPVar}(k) &\rightarrow \text{TriCat}, S \mapsto D(MHM_{gm,k,\mathbb{C}}(S)), \\ (f : T \rightarrow S) &\mapsto (f_{!Hdg} : (((M_I, F, W), u_{IJ}), (K, W), \alpha) \mapsto f_{!Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha)). \end{aligned}$$

- We have the following 2 functor on the category of algebraic varieties over  $k \subset \mathbb{C}$

$$\begin{aligned} D(MHM_{gm,k,\mathbb{C}}(\cdot)) : \text{QPVar}(k) &\rightarrow \text{TriCat}, S \mapsto D(MHM_{gm,k,\mathbb{C}}(S)), \\ (f : T \rightarrow S) &\mapsto (f^{!Hdg} : (((M_I, F, W), u_{IJ}), (K, W), \alpha) \mapsto \\ f^{*Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha) &:= (f_{Hdg}^{\hat{*}mod}(((M_I, F, W), u_{IJ})), f^{*w}(K, W), f^*\alpha)). \end{aligned}$$

see definition 62 and definition 66 for the equality.

**Proposition 48.** *Let  $f : X \rightarrow S$  with  $S, X \in \text{QPVar}(k)$ . Then*

(i)  *$(f^{*Hdg}, Rf_*^{Hdg}) : D(MHM_{gm,k,\mathbb{C}}(S)) \rightarrow D(MHM_{gm,k,\mathbb{C}}(X))$  is a pair of adjoint functors.*

– *For  $(((M_I, F, W), u_{IJ}), (K, W), \alpha) \in C(MHM_{gm,k,\mathbb{C}}(S))$ ,*

$$\begin{aligned} \text{ad}(f^{*Hdg}, Rf_*^{Hdg})(((M_I, F, W), u_{IJ}), (K, W), \alpha) &:= \\ (\text{ad}(f_{Hdg}^{\hat{*}mod}, Rf_*^{Hdg})((M_I, F, W), u_{IJ}), \text{ad}(f^{*w}, Rf_{*w})(K, W)) &: \\ (((M_I, F, W), u_{IJ}), (K, W), \alpha) &\rightarrow Rf_*^{Hdg} f^{*Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha) \end{aligned}$$

*is the adjunction map in  $D(MHM_{gm,k,\mathbb{C}}(S))$ .*

– For  $((N_I, F, W), u_{IJ}), (P, W), \beta) \in C(MHM_{gm,k,\mathbb{C}}(X))$ ,

$$\begin{aligned} & \text{ad}(f^{*Hdg}, Rf_*^{Hdg})(((N_I, F, W), u_{IJ}), (P, W), \beta) := \\ & (\text{ad}(f^{*\hat{mod}}, Rf_*^{Hdg})((N_I, F, W), u_{IJ}), \text{ad}(f^{*w}, Rf_{*w})(P, W)) : \\ & f^{*Hdg} Rf_*^{Hdg}(((N_I, F, W), u_{IJ}), (P, W), \beta) \rightarrow (((N_I, F, W), u_{IJ}), (P, W), \beta) \end{aligned}$$

is the adjunction map in  $D(MHM_{gm,k,\mathbb{C}}(X))$

(ii)  $(Rf_!^{Hdg}, f^{!Hdg}) : D(MHM_{gm,k,\mathbb{C}}(X)) \rightarrow D(MHM_{gm,k,\mathbb{C}}(S))$  is a pair of adjoint functors.

– For  $((M_I, F, W), u_{IJ}), (K, W), \alpha) \in C(MHM_{gm,k,\mathbb{C}}(S))$ ,

$$\begin{aligned} & \text{ad}(Rf_!^{Hdg}, f^{!Hdg})(((M_I, F, W), u_{IJ}), (K, W), \alpha) := \\ & (\text{ad}(f^{*\hat{mod}}, Rf_!^{Hdg})((M_I, F, W), u_{IJ}), \text{ad}(f^{!w}, Rf_{!w})(K, W)) : \\ & Rf_!^{Hdg} f^{!Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha) \rightarrow (((M_I, F, W), u_{IJ}), (K, W), \alpha) \end{aligned}$$

is the adjunction map in  $D(MHM_{gm,k,\mathbb{C}}(S))$ .

– For  $((N_I, F, W), u_{IJ}), (P, W), \beta) \in C(MHM_{gm,k,\mathbb{C}}(X))$ ,

$$\begin{aligned} & \text{ad}(Rf_!^{Hdg}, f^{!Hdg})(((N_I, F, W), u_{IJ}), (P, W), \beta) := \\ & (\text{ad}(f^{*\hat{mod}}, Rf_!^{Hdg})((N_I, F, W), u_{IJ}), \text{ad}(f^{!w}, Rf_{!w})(P, W)) : \\ & (((N_I, F, W), u_{IJ}), (P, W), \beta) \rightarrow f^{!Hdg} Rf_!^{Hdg}(((N_I, F, W), u_{IJ}), (P, W), \beta) \end{aligned}$$

is the adjunction map in  $D(MHM_{gm,k,\mathbb{C}}(X))$ .

*Proof.* Follows from proposition 44 after considering a factorization  $f : X \hookrightarrow \bar{Y} \times S \xrightarrow{ps} S$  with  $\bar{Y} \in \text{PSmVar}(k)$ .  $\square$

**Theorem 42.** Let  $k \subset \mathbb{C}$  a subfield.

(i) We have the six functor formalism on  $D(MHM_{gm,k,\mathbb{C}}(-)) : \text{SmVar}(k) \rightarrow \text{TriCat}$ .

(ii) We have the six functor formalism on  $D(MHM_{gm,k,\mathbb{C}}(-)) : \text{QPVar}(k) \rightarrow \text{TriCat}$ .

*Proof.* Follows from proposition 48.  $\square$

We recall the definition of the Deligne complex of a complex manifold and the Deligne cohomology class of an algebraic cycle of a complex algebraic variety.

**Definition 75.** (i) Let  $X \in \text{AnSm}(\mathbb{C})$ . We have for  $d \in \mathbb{Z}$  the Deligne complex

$$\mathbb{Z}_{\mathcal{D},X}(d) := (\mathbb{Z}_X(d) \hookrightarrow \tau^{\leq d} DR(X)) = (\mathbb{Z}_X(d) \hookrightarrow (O_X \rightarrow \cdots \rightarrow \Omega_X^{d-1}) \in C(X)$$

Let  $D \subset X$  a normal crossing divisor. We have for  $d \in \mathbb{Z}$  the Deligne complexes

$$\mathbb{Z}_{\mathcal{D},(X,D)}(d) := (\mathbb{Z}_X(d) \hookrightarrow (O_X \rightarrow \cdots \rightarrow \Omega_X^{d-1}(\log D))) \in C(X)$$

and

$$\mathbb{Z}_{\mathcal{D},(X,D)}(d)^\vee := (\mathbb{Z}_X(d) \hookrightarrow (O_X \rightarrow \cdots \rightarrow \Omega_X^{d-1}(D))) \in C(X).$$

Moreover we have (see [15]) canonical products

- $(-) \cdot (-) : \mathbb{Z}_{\mathcal{D},(X,D)}(d) \otimes \mathbb{Z}_{\mathcal{D},(X,D)}(d') \rightarrow \mathbb{Z}_{\mathcal{D},(X,D)}(d + d')$
- $(-) \cdot (-) : \mathbb{Z}_{\mathcal{D},(X,D)}(d)^\vee \otimes \mathbb{Z}_{\mathcal{D},(X,D)}(d')^\vee \rightarrow \mathbb{Z}_{\mathcal{D},(X,D)}(d + d')^\vee$

(ii) Let  $X \in \text{AnSm}(\mathbb{C})$ . We have for  $d \in \mathbb{Z}$  the Deligne (homology) complex

$$C_{\mathcal{D}}^{\bullet}(X, \mathbb{Z}(d)) := \text{Cone}(\mathbb{Z} \text{Hom}_{\text{Diff}(\mathbb{R})}(\Delta^{\bullet}, X) \oplus \Gamma(X, F^d \mathcal{D}_X^{\bullet}) \hookrightarrow \Gamma(X, \mathcal{D}_X^{\bullet})) \in C(\mathbb{Z})$$

Let  $D \subset X$  a normal crossing divisor. Denote  $U := X \setminus D$ . We have for  $d \in \mathbb{Z}$  the Deligne (homology) complexes

$$C_{\mathcal{D}}^{\bullet}((X, D), \mathbb{Z}(d)) := \text{Cone}(\mathbb{Z} \text{Hom}_{\text{Diff}(\mathbb{R})}(\Delta^{\bullet}, U) \oplus \Gamma(X, F^d \mathcal{D}_X^{\bullet}(\log D)) \hookrightarrow \Gamma(X, \mathcal{D}_X^{\bullet}(\log D))) \in C(\mathbb{Z})$$

and

$$C_{\mathcal{D}}^{\bullet}(X, D, \mathbb{Z}(d)) := \text{Cone}(\mathbb{Z} \text{Hom}_{\text{Diff}(\mathbb{R})}(\Delta^{\bullet}, (X, D)) \oplus \Gamma(X, F^d \mathcal{D}_X^{\bullet}(D)) \hookrightarrow \Gamma(X, \mathcal{D}_X^{\bullet}(D))) \in C(\mathbb{Z}).$$

(iii) Let  $k \subset \mathbb{C}_p$  a subfield. Let  $X \in \text{PSmVar}(k)$ . We have, for  $k \in \mathbb{Z}$  and  $d \in \mathbb{Z}$ , the Deligne cohomology

$$H_{\mathcal{D}}^k(X_{\mathbb{C}}^{an}, \mathbb{Z}(d)) := \mathbb{H}^k(X_{\mathbb{C}}^{an}, \mathbb{Z}_{X, \mathcal{D}}(d)) = H^k C_{\mathcal{D}}^{\bullet}(X_{\mathbb{C}}^{an}, D, \mathbb{Z}(d))^{\vee}$$

Let  $U \in \text{SmVar}(k)$ . Let  $X \in \text{PSmVar}(k)$  a compactification of  $U$  with  $D := X \setminus U$  a normal crossing divisor. We have, for  $k \in \mathbb{Z}$  and  $d \in \mathbb{Z}$ , the Deligne cohomology

$$H_{\mathcal{D}}^k(U_{\mathbb{C}}^{an}, \mathbb{Z}(d)) := \mathbb{H}^k(X, \mathbb{Z}_{(X_{\mathbb{C}}^{an}, D_{\mathbb{C}}^{an}), \mathcal{D}}(d)) = H^k C_{\mathcal{D}}^{\bullet}((X_{\mathbb{C}}^{an}, D_{\mathbb{C}}^{an}), \mathbb{Z}(d))^{\vee}$$

and

$$H_{\mathcal{D}}^k(X, D, \mathbb{Z}(d)) := \mathbb{H}^k(X_{\mathbb{C}}^{an}, \mathbb{Z}_{(X_{\mathbb{C}}^{an}, D_{\mathbb{C}}^{an}), \mathcal{D}}(d))^{\vee} = H^k C_{\mathcal{D}}^{\bullet}(X_{\mathbb{C}}^{an}, D_{\mathbb{C}}^{an}, \mathbb{Z}(d))^{\vee}.$$

(iv) Let  $k \subset \mathbb{C}_p$  a subfield. Let  $U \in \text{SmVar}(k)$ . Let  $X \in \text{PSmVar}(k)$  a compactification of  $U$  with  $D := X \setminus U$  a normal crossing divisor. We define the Deligne cohomology of a (higher) cycle  $Z \in \mathcal{Z}^d(U, n)^{\partial=0}$  by

$$[Z]_{\mathcal{D}} := \text{Im}(H^{2d-n}(\gamma_{\text{supp}(Z)})([Z])),$$

$$H^k(\gamma_{\text{supp}(Z)}) : \mathbb{H}_{\mathcal{D}, \text{supp}(Z)}^{2d-n}(X_{\mathbb{C}}^{an}, \mathbb{Z}_{X_{\mathbb{C}}^{an}, D_{\mathbb{C}}^{an}}(d)) \rightarrow \mathbb{H}_{\mathcal{D}}^{2d-n}(X_{\mathbb{C}}^{an}, \mathbb{Z}_{X_{\mathbb{C}}^{an}, D_{\mathbb{C}}^{an}}(d))$$

with  $\text{supp}(Z) := p_X(\text{supp}(Z)) \subset X$ , where  $\text{supp}(Z) \subset X \times \square^n$  is the support of  $Z$ .

(v) Let  $k \subset \mathbb{C}_p$  a subfield. Let  $U \in \text{SmVar}(k)$ . Let  $X \in \text{PSmVar}(k)$  a compactification of  $U$  with  $D := X \setminus U$  a normal crossing divisor. We have for  $d \in \mathbb{Z}$  the morphism of complexes

$$\mathcal{R}_U^d : \mathcal{Z}^d(U, \bullet) \rightarrow C_{\mathcal{D}}^{\bullet}(X_{\mathbb{C}}^{an}, D_{\mathbb{C}}^{an}, \mathbb{Z}(d)), \quad Z \mapsto \mathcal{R}_U^d(Z) := (T_{\bar{Z}}, \Omega_{\bar{Z}}, R_{\bar{Z}})$$

which gives for  $Z \in \mathcal{Z}^d(U, n)^{\partial=0}$ ,

$$[\mathcal{R}_U^d(Z)] = [Z]_{\mathcal{D}} \in H_{\mathcal{D}}^{2d-n}(U_{\mathbb{C}}^{an}, \mathbb{Z}(d))$$

Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{AnSm}(\mathbb{C})$ . We have for  $d \in \mathbb{Z}$  the canonical morphism of Deligne complexes

$$(\text{ad}(f^*, f_*)(\mathbb{Z}_S), \Omega_{X/S}^{\leq d}) : \mathbb{Z}_{\mathcal{D}, S}(d) \rightarrow f_* \mathbb{Z}_{\mathcal{D}, X}(d)$$

which induces after taking the resolution of the Deligne complexes by differential forms the morphism in  $C(\mathbb{Z})$

$$f^* := (f^*, f^*, \theta(f)^t) : \text{Cone}(\mathbb{Z} \text{Hom}_{\text{Diff}(\mathbb{R})}(\Delta^{\bullet}, S)^{\vee} \oplus \Gamma(S, F^d \mathcal{A}_S^{\bullet}) \hookrightarrow \Gamma(S, \mathcal{A}_S^{\bullet}))$$

$$\rightarrow \text{Cone}(\mathbb{Z} \text{Hom}_{\text{Diff}(\mathbb{R})}(\Delta^{\bullet}, X)^{\vee} \oplus \Gamma(X, F^d \mathcal{A}_X^{\bullet}) \hookrightarrow \Gamma(X, \mathcal{A}_X^{\bullet}))$$

where  $\theta(f)^t$  is the homotopy in the morphism in  $D_{fil}(k) \otimes_I D(\mathbb{Z})$

$$(f^*, f^*, \theta(f)^t) : (\Gamma(S, (\Omega_S^{\bullet}, F_b)), \mathbb{Z} \text{Hom}_{\text{Diff}(\mathbb{R})}(\Delta^{\bullet}, S)^{\vee}, a_{S*} \alpha(S))$$

$$\rightarrow (\Gamma(X, (\Omega_X^{\bullet}, F_b)), \mathbb{Z} \text{Hom}_{\text{Diff}(\mathbb{R})}(\Delta^{\bullet}, X)^{\vee}, a_{X*} \alpha(X)),$$

which induces in cohomology for  $n \in \mathbb{Z}$ , the morphisms of abelian groups

$$f_* : H_{\mathcal{D}}^n(S, \mathbb{Z}(d)) \rightarrow H_{\mathcal{D}}^n(X, \mathbb{Z}(d));$$

we get dually, after taking the resolution of the Deligne complexes by currents the morphism in  $C(\mathbb{Z})$

$$\begin{aligned} f_* := (f_*, f_*, \theta(f)) : C_{\mathcal{D}}^{\bullet}(X, \mathbb{Z}(d)) &:= \text{Cone}(\mathbb{Z} \text{Hom}_{D_{\text{diff}}(\mathbb{R})}(\Delta^{\bullet}, X) \oplus \Gamma(X, F^d \mathcal{D}_X^{\bullet}) \hookrightarrow \Gamma(X, \mathcal{D}_X^{\bullet})) \\ &\rightarrow C_{\mathcal{D}}^{\bullet}(S, \mathbb{Z}(d)) := \text{Cone}(\mathbb{Z} \text{Hom}_{D_{\text{diff}}(\mathbb{R})}(\Delta^{\bullet}, S) \oplus \Gamma(S, F^d \mathcal{D}_S^{\bullet}) \hookrightarrow \Gamma(S, \mathcal{D}_S^{\bullet})) \end{aligned}$$

where  $\theta(f)$  is the homotopy in the morphism in  $D_{\text{fil}}(k) \otimes_I D(\mathbb{Z})$

$$\begin{aligned} (f_*, f_*, \theta(f)) : (\Gamma(X, (\Omega_X^{\bullet}, F_b)), \mathbb{Z} \text{Hom}_{D_{\text{diff}}(\mathbb{R})}(\Delta^{\bullet}, X), a_{X!} \alpha(X)) \\ \rightarrow (\Gamma(S, (\Omega_S^{\bullet}, F_b)), \mathbb{Z} \text{Hom}_{D_{\text{diff}}(\mathbb{R})}(\Delta^{\bullet}, S), a_{S!} \alpha(S)), \end{aligned}$$

which induces in homology for  $n \in \mathbb{Z}$ , the morphisms of abelian groups

$$f_* : H_{n, \mathcal{D}}(X, \mathbb{Z}(d)) \rightarrow H_{n, \mathcal{D}}(S, \mathbb{Z}(d)).$$

**Theorem 43.** *Let  $k \subset \mathbb{C}$  a subfield.*

(i) *Let  $U \in \text{SmVar}(k)$ . Denote by  $a_U : U \rightarrow \text{pt}$  the terminal map. Let  $X \in \text{PSmVar}(k)$  a compactification of  $U$  with  $D := X \setminus U$  a normal crossing divisor. The embedding (see theorem 41)*

$$\iota : D(\text{MHM}_{g_m, k, \mathbb{C}}(\{\text{pt}\})) \rightarrow D_{\text{fil}}(k) \times_I D(\mathbb{Z})$$

*induces for  $k \in \mathbb{Z}$  and  $d \in \mathbb{Z}$ , canonical isomorphisms*

$$\begin{aligned} \iota(a_{U!} \mathbb{Z}_U^{\text{Hdg}}) : H^k(a_{U!} \mathbb{Z}_U^{\text{Hdg}}) &\xrightarrow{\sim} H_{\mathcal{D}}^k(X_{\mathbb{C}}^{\text{an}}, D_{\mathbb{C}}^{\text{an}}, \mathbb{Z}(d)), \text{ and} \\ \iota(a_{U^*} \mathbb{Z}_U^{\text{Hdg}}) : H^k(a_{U^*} \mathbb{Z}_U^{\text{Hdg}}) &\xrightarrow{\sim} H_{\mathcal{D}}^k(U_{\mathbb{C}}^{\text{an}}, \mathbb{Z}(d)). \end{aligned}$$

(ii) *Let  $h : U \rightarrow S$  and  $h' : U' \rightarrow S$  two morphism with  $S, U, U' \in \text{SmVar}(k)$ . Let  $X \in \text{PSmVar}(k)$  a compactification of  $U$  with  $D := X \setminus U$  a normal crossing divisor such that  $h : U \rightarrow S$  extend to  $f : X \rightarrow \bar{S}$ . Let  $X' \in \text{PSmVar}(k)$  a compactification of  $U'$  with  $D' := X' \setminus U'$  a normal crossing divisor such that  $h' : U' \rightarrow S$  extend to  $f' : X' \rightarrow \bar{S}$ . The embedding  $\iota : D(\text{MHM}_{g_m, k, \mathbb{C}}(\text{pt})) \rightarrow D_{\text{fil}}(k) \times_I D(\mathbb{Z})$  (see theorem 41) induces for  $k \in \mathbb{Z}$  and  $d \in \mathbb{Z}$  a canonical isomorphism*

$$\begin{aligned} \iota(a_{U' \times_S U!} \mathbb{Z}_{U' \times_S U}^{\text{Hdg}}) : \text{Hom}_{D(\text{MHM}_{g_m, k, \mathbb{C}}(S))}(h_{U'!} \mathbb{Z}_{U'}^{\text{Hdg}}, h_{U!} \mathbb{Z}_U^{\text{Hdg}}(d)[k]) \\ \xrightarrow{RI(-, -)} \text{Hom}_{D(\text{MHM}_{g_m, k, \mathbb{C}}(\text{pt}))}(\mathbb{Z}_{\text{pt}}^{\text{Hdg}}, a_{U' \times_S U!} \mathbb{Z}_{U' \times_S U}^{\text{Hdg}}(d)[k]) = H^k(a_{U' \times_S U!} \mathbb{Z}_{U' \times_S U}^{\text{Hdg}}(d)) \\ \xrightarrow{\sim} H_{\mathcal{D}}^k((X' \times_S X)_{\mathbb{C}}^{\text{an}}, ((X' \times_S U) \cup (U' \times_S X))_{\mathbb{C}}^{\text{an}}, \mathbb{Z}(d)). \end{aligned}$$

(iii) *Let  $U \in \text{SmVar}(k)$ . Let  $X \in \text{PSmVar}(k)$  a compactification of  $U$  with  $D := X \setminus U$  a normal crossing divisor. For  $[Z] \in \text{CH}^d(U, n)$  and  $[Z'] \in \text{CH}^{d'}(U, n')$ , we have*

$$([Z] \cdot [Z'])_{\mathcal{D}} = [Z]_{\mathcal{D}} \cdot [Z']_{\mathcal{D}} \in H^{2d+2d'-n-n'}(U_{\mathbb{C}}^{\text{an}}, \mathbb{Z}(d+d'))$$

*where the product on the left is the intersection of higher Chow cycle which is well defined modulo boundary (they intersect properly modulo boundary) while the right product of Deligne cohomology classes is induced by the product of Deligne complexes  $(-) \cdot (-) : \mathbb{Z}_{\mathcal{D}, (X, D)}(d) \otimes \mathbb{Z}_{\mathcal{D}, (X, D)}(d') \rightarrow \mathbb{Z}_{\mathcal{D}, (X, D)}(d+d')$ .*

(iv) *Let  $h : U \rightarrow S, h' : U' \rightarrow S, h'' : U'' \rightarrow S$  three morphism with  $S, U, U', U'' \in \text{SmVar}(k)$ . Let  $X \in \text{PSmVar}(k)$  a compactification of  $U$  with  $D := X \setminus U$  a normal crossing divisor such that  $h : U \rightarrow S$  extend to  $f : X \rightarrow \bar{S}$ . Let  $X' \in \text{PSmVar}(k)$  a compactification of  $U'$  with  $D' := X' \setminus U'$*

a normal crossing divisor such that  $h' : U' \rightarrow S$  extend to  $f' : X' \rightarrow \bar{S}$ . Let  $X' \in \text{PSmVar}(k)$  a compactification of  $U'$  with  $D' := X' \setminus U'$  a normal crossing divisor such that  $h' : U' \rightarrow S$  extend to  $f' : X' \rightarrow \bar{S}$ . For  $[Z] \in \text{CH}^d(U \times_S U', n)$  and  $[Z'] \in \text{CH}^{d'}(U' \times_S U'', n')$ , we have

$$([Z] \circ [Z'])_{\mathcal{D}} = [Z]_{\mathcal{D}} \circ [Z']_{\mathcal{D}} \in H^{d''-n''}((U \times_S U'')_{\mathbb{C}}^{an}, \mathbb{Z}(d'' - n''))$$

where the composition on the left is the composition of higher correspondence modulo boundary while the composition on the right is given by (ii).

*Proof.* (i):Standard.

(ii):Follows on the one hand from (i) and on the other hand the six functor formalism on the 2-functor  $D(\text{MHM}_{gm,k,\mathbb{C}}(-)) : \text{SmVar}(k) \rightarrow \text{TriCat}$  (theorem 42) gives the isomorphism  $RI(-, -)$ .

(iii):Standard.

(iv):Follows from (iii). □

## 6.2 The $p$ -adic case where $k \subset K \subset \mathbb{C}_p$

Let  $p$  a prime integer. Let  $k \subset K \subset \mathbb{C}_p$  a subfield of a  $p$  adic field  $K$ . Denote by  $\bar{k} \subset \mathbb{C}_p$  its algebraic closure. We denote by  $G := \text{Gal}(\bar{K}/K) \subset \text{Gal}(\bar{k}/k)$  the Galois group of  $K$ . Recall (see section 2) that for a prime number  $l$ , a  $\mathbb{Z}_l$  module  $K = (K_n)_{n \in \mathbb{N}}$  is a projective system with  $K_n$  a  $l^n$  torsion group such that  $K_n \rightarrow K_{n+1}/l^n K_{n+1}$  is an isomorphism. For  $S \in \text{Var}(k)$  and  $l$  a prime integer, we have (see section 2)  $P_{\mathbb{Z}_l, \text{fil}}(S^{et}) \subset D_{\mathbb{Z}_l, \text{fil}, c}(S^{et})$  and  $P_{\mathbb{Z}_l, \text{fil}, k}(S_K^{an, \text{pet}}) \subset D_{\mathbb{Z}_l, \text{fil}, c, k}(S_K^{an, \text{pet}})$  the full subcategories of filtered perverse sheaves whose cohomology sheaves are constructible with respect to a Zariski stratification of  $S$ . For  $S \in \text{Var}(k)$ , we denote by  $\text{an}_S : S^{an} := S_{\mathbb{C}_p}^{an} \rightarrow S_{\mathbb{C}_p} \rightarrow S$  the morphism of ringed spaces given by the analytical functor. For  $S \in \text{Var}(k)$ , we denote  $\mathbb{B}_{dr, S_K} := \mathbb{B}_{dr, R_K(S_K^{an})}$  and  $O\mathbb{B}_{dr, S_K} := O\mathbb{B}_{dr, R_K(S_K^{an})}$  where  $R_K : \text{AnSp}(K) \rightarrow \text{AdSp}/(K, O_K)$  the canonical functor (see section 2).

- For  $(M, F) \in C_{O_S \text{fil}}(S)$ , we denote by  $(M, F)^{an} := \text{an}_S^{*mod}(M, F) \in C_{O_S \text{fil}}(S_{\mathbb{C}_p}^{an})$ .
- For  $(M, F) \in C_{\mathcal{D} \text{fil}}(S)$ , we denote by  $(M, F)^{an} := \text{an}_S^{*mod}(M, F) \in C_{\mathcal{D} \text{fil}}(S_{\mathbb{C}_p}^{an})$ .

We denote for short

$$DR(S) := DR(S_{\mathbb{C}_p}^{an}) \circ \text{an}_S^{*mod} : C_{\mathcal{D} \text{fil}}(S) \rightarrow C_{\text{fil}}(S_{\mathbb{C}_p}^{an, \text{pet}}), M \mapsto DR(S)(M^{an})$$

the De Rham functor. For  $M, N \in D_{\mathbb{B}_{dr, S_K}}(S_K^{an, \text{pet}})$ , we denote for short  $M \otimes_{\mathbb{B}_{dr, S}} N := M \otimes_{\mathbb{B}_{dr, S_K}}^L N \in D_{\mathbb{B}_{dr, S_K}}(S_K^{an, \text{pet}})$  the derived tensor product.

### 6.2.1 The $\mathbb{B}_{dr}$ functor

Motivated by theorem 29 and theorem 12, we make the following definition:

**Definition 76.** Let  $S \in \text{SmVar}(k)$ . Let  $D = V(s) \subset S$  a (Cartier) divisor, where  $s \in \Gamma(S, L)$  is a section of the line bundle  $L = L_D$  associated to  $D$ . We denote by  $j : S^\circ := S \setminus D \hookrightarrow S$  the open complementary subset. Let  $\pi : \tilde{S}_K^{o, an} \rightarrow S_K^{o, an}$  the perfectoid universal covering.

(i) We define, using definition 57,

$$\mathbb{B}_{dr, S^\circ/S, K} := F^0 DR(S)((j_* \text{Hdg}(O_{S^\circ}, F_b))^{an} \otimes_{O_{S_K^{an}}} (O\mathbb{B}_{dr, S_K}, F)) \in C_{\mathbb{B}_{dr, S_K}}(S_K^{an, \text{pet}})$$

together with the canonical map in  $C_{\mathbb{B}_{dr, S_K}}(S_K^{an, \text{pet}})$

$$a_S(\mathbb{B}_{dr, S^\circ/S, K}) := F^0 DR(S)(\text{ad}(j^*, j_* \text{Hdg})(O_S, F_b)^{an} \otimes I) : \mathbb{B}_{dr, S_K} \rightarrow \mathbb{B}_{dr, S^\circ/S, K}$$

(ii) We define, using definition 55, the nearby cycle module

$$\mathbb{B}_{dr,\psi_D,K} := F^0 DR(S)((\psi_D(O_{S^\circ}, F_b))^{an} \otimes_{O_{S^\circ/K}} (O_{\mathbb{B}_{dr,S_K}, F})) \in C_{\mathbb{B}_{dr,S}}(S_K^{an,pet})$$

together with the canonical maps in  $C_{\mathbb{B}_{dr,S_K}}(S_K^{an,pet})$

$$\rho_{\mathbb{B}_{dr},D}(O_S) := F^0 DR(S)(\rho_{DR,D}(O_{S^\circ}, F_b)^{an} \otimes I) : \mathbb{B}_{dr,S^\circ/S,K} \rightarrow \mathbb{B}_{dr,\psi_D,K}$$

and

$$a_S(\mathbb{B}_{dr,\psi_D}) := F^0 DR(S)((\rho_{DR,D}(O_{S^\circ}, F_b) \circ \text{ad}(j^*, j_{*Hdg})(O_S, F_b))^{an} \otimes I) : \\ \mathbb{B}_{dr,S_K} \xrightarrow{a_S(\mathbb{B}_{dr,S^\circ/S,K})} \mathbb{B}_{dr,S^\circ/S,K} \xrightarrow{\rho_{\mathbb{B}_{dr},D}(O_S)} \mathbb{B}_{dr,\psi_D,K}$$

where  $\rho_{DR,D}(O_{S^\circ}, F_b) : j_{*Hdg}(O_{S^\circ}, F_b) \rightarrow \psi_D(O_{S^\circ}, F_b)$  is given in definition 58.

(iii) We define, using definition 55 and (ii), the vanishing cycle module

$$\mathbb{B}_{dr,\phi_D,K} := F^0 DR(S)((\phi_D(O_{S^\circ}, F_b))^{an} \otimes_{O_{S^\circ/K}} (O_{\mathbb{B}_{dr,S_K}, F})) \in C_{\mathbb{B}_{dr,S_K}}(S_K^{an,pet}).$$

together with the canonical maps in  $C_{\mathbb{B}_{dr,S_K}}(S_K^{an,pet})$  We have using definition 55 the following maps

$$\text{can}_{\mathbb{B}_{dr},D}(O_S) := F^0 DR(S)(\text{can}(O_{S^\circ}, F_b)^{an} \otimes I) : \mathbb{B}_{dr,\psi_D,K} \rightarrow \mathbb{B}_{dr,\phi_D,K},$$

and

$$\text{var}_{\mathbb{B}_{dr},D}(O_S) := F^0 DR(S)(\text{var}(O_{S^\circ}, F_b)^{an} \otimes I) : \mathbb{B}_{dr,\phi_D,K} \rightarrow \mathbb{B}_{dr,\psi_D,K}$$

and

$$a_S(\mathbb{B}_{dr,\phi_D,K}) := F^0 DR(S)((\text{can}(O_{S^\circ}, F_b) \circ \rho_{DR,D}(O_{S^\circ}, F_b) \circ \text{ad}(j^*, j_{*Hdg})(O_S, F_b))^{an} \otimes I) : \\ \mathbb{B}_{dr,S_K} \xrightarrow{a_S(\mathbb{B}_{dr,\psi_D,K})} \mathbb{B}_{dr,\psi_D,K} \xrightarrow{\text{can}_{\mathbb{B}_{dr},D}(O_S)} \mathbb{B}_{dr,\phi_D,K}$$

(iv) Using (ii), we set

$$\mathbb{B}_{dr,x_{S^\circ/S},K} := \text{Cone}(\rho_{\mathbb{B}_{dr},D}(O_S) : \mathbb{B}_{dr,S^\circ/S,K} \rightarrow \mathbb{B}_{dr,\psi_D,K}) \in C_{\mathbb{B}_{dr,S_K}}(S_K^{an,pet})$$

together with the canonical map in  $C_{\mathbb{B}_{dr,S_K}}(S_K^{an,pet})$

$$a_S(\mathbb{B}_{dr,x_{S^\circ/S},K}) := (a_S(\mathbb{B}_{dr,S^\circ/S,K}), a_S(\mathbb{B}_{dr,\psi_D,K})) : \mathbb{B}_{dr,S_K} \rightarrow \mathbb{B}_{dr,x_{S^\circ/S},K}.$$

We then give using definition 76 and the local system case an inverse functor to the De Rham functor for De Rham modules

**Definition 77.** (i0) Let  $S \in \text{SmVar}(k)$  irreducible. We then have the morphism of site  $\text{an}_S : S_K^{an,pet} \rightarrow S^{et}$  given by the analytical functor. Let  $K \in P_{\mathbb{Z}_p,k}(S^{et})$  a perverse sheaf, in particular there exist an open subset  $S^\circ \subset S$  with  $D := S \setminus S^\circ$  a (Cartier) divisor such that  $K|_{S^\circ} := j^*K \in C(S^\circ,et)$  is a local system for the etale topology, where we denote  $j : S_0 \hookrightarrow S$  the open embedding and  $i : D \hookrightarrow S$  the closed embedding of the Cartier divisor. Assume first that  $K|_D := i^*K$  is a local system. Then,  $\psi_D K, \phi_D K \in C_{\mathbb{Z}_p}(D^{et})$  are local systems. We denote again  $K := \text{an}_S^* K \in C(S_K^{an,pet})$  and  $K := j^*K \in C(S_K^{o,an,pet})$ . Denote by  $\pi : \tilde{S}_K^{o,an} \rightarrow S_K^{o,an}$  the perfectoid universal covering. We then have by theorem 12 a canonical isomorphism in  $D_{\mathbb{Z}_p,c}(S_K^{an,pet})$

$$Is(K) : K \xrightarrow{\sim} (\psi_D K \xrightarrow{(c(x_{S^\circ/S}(K)), \text{can}(K))} x_{S^\circ/S}(K) \oplus \phi_D K \xrightarrow{(\mathbb{D}c(\mathbb{D}K), \text{var}(K))} \psi_D K)$$



We then set using definition 76

$$\begin{aligned} \mathbb{B}_{dr,S}(x_{S^o/S}(K)) &:= x_{S^o/S}(K) \otimes_{\mathbb{Q}_p} \mathbb{B}_{dr,x_{S^o/S},K} = \\ \text{Cone}(\text{ad}(i^*, i_*)(-) \circ \text{ad}(j \circ \pi^*, j \circ \pi_*)(K)) &\otimes \rho_{\mathbb{B}_{dr,D}}(O_S) : \\ Rj_*K \otimes_{\mathbb{Q}_p} \mathbb{B}_{dr,S^o/S,K} &\rightarrow \psi_D K \otimes_{\mathbb{Q}_p} \mathbb{B}_{dr,\psi_D,K} \in D_{\mathbb{B}_{dr}}(S_K^{an,pet}) \end{aligned}$$

and

$$\begin{aligned} \mathbb{B}_{dr,S}(K) &:= (\mathbb{B}_{dr,S}(\psi_D K) := \psi_D K \otimes_{\mathbb{Q}_p} \mathbb{B}_{dr,\psi_D,K} \xrightarrow{(c(\mathbb{B}_{dr,S}(x_{S^o/S}(K))), can(K) \otimes can_{\mathbb{B}_{dr,D}}(O_S))} \\ \mathbb{B}_{dr,S}(x_{S^o/S}(K)) \oplus \mathbb{B}_{dr,S}(\phi_D K) &:= (x(K) \otimes_{\mathbb{Q}_p} \mathbb{B}_{dr,x_{S^o/S},K} \oplus \phi_D K \otimes_{\mathbb{Q}_p} \mathbb{B}_{dr,\phi_D,K} \\ \xrightarrow{(\mathbb{D}c(\mathbb{B}_{dr,S}(x_{S^o/S}(\mathbb{D}K))), var(K) \otimes var_{\mathbb{B}_{dr,D}}(O_S))} &\mathbb{B}_{dr,S}(\psi_D K) := \psi_D K \otimes_{\mathbb{Q}_p} \mathbb{B}_{dr,\psi_D,K} \in D_{\mathbb{B}_{dr}}(S_K^{an,pet}). \end{aligned}$$

(i) Let  $S \in \text{SmVar}(k)$  irreducible. We then have the morphism of site  $\text{ans} : S^{an,pet} \rightarrow S^{et}$  given by the analytical functor. We define the functor

$$\mathbb{B}_{dr,S} : D_{\mathbb{Z}_p,fil,c,k}(S^{et}) \rightarrow D_{\mathbb{B}_{dr,S,fil}}(S_K^{an,pet})$$

using the nearby and vanishing cycle functors. For  $(K, W) \in P_{pfil}(S^{et})$  a filtered perverse sheaf and  $(D_1, \dots, D_d) \in \mathcal{S}(K)$  a stratification by (Cartier) divisor  $D_i \subset S$ ,  $1 \leq i \leq d$  such that  $K_{|D(r) \setminus D(r+1)} := l_r^* K \in D_{\mathbb{Z}_p,c}(D(r) \setminus D(r+1)^{et})$  are local systems for all  $1 \leq r \leq d$ , where  $D(r) := \bigcap_{1 \leq i \leq r} D_i$  and  $l_r : D(r) \setminus D(r+1) \hookrightarrow S$  is the locally closed embedding, we have by theorem 12 a canonical isomorphism in  $D_{\mathbb{Z}_p,c}(S_K^{an,pet})$

$$Is(K) : K \xrightarrow{\sim} (\cdots \rightarrow \bigoplus_{1 < i_1 \cdots < i_d \leq d} x_{S \setminus D_{i_1}/S} \cdots x_{S \setminus D_{i_r}/S} \phi_{D_{i_{r+1}}} \cdots \phi_{D_{i_s}} \psi_{D_{i_{s+1}}} \cdots \psi_{D_{i_d}}(K) \rightarrow \cdots),$$

we then define by (i0)

$$\begin{aligned} \mathbb{B}_{dr,S}(K, W) &:= \lim_{(D_1, \dots, D_d) \in \mathcal{S}(K)} (\cdots \rightarrow \\ \bigoplus_{1 \leq i_1 < \cdots < i_d \leq d} &x_{S \setminus D_{i_1}/S} \cdots x_{S \setminus D_{i_r}/S} \phi_{D_{i_{r+1}}} \cdots \phi_{D_{i_s}} \psi_{D_{i_{s+1}}} \cdots \psi_{D_{i_d}}(K, W) \otimes_{\mathbb{Q}_p} \\ \mathbb{B}_{dr,x_{S \setminus D_{i_1}/S},K} \otimes_{\mathbb{B}_{dr,S_K}} \cdots \otimes_{\mathbb{B}_{dr,S_K}} &\mathbb{B}_{dr,x_{S \setminus D_{i_r}/S},K} \otimes_{\mathbb{B}_{dr,S_K}} \mathbb{B}_{dr,\phi_{D_{i_{r+1}}},K} \otimes_{\mathbb{B}_{dr,S_K}} \cdots \\ \otimes_{\mathbb{B}_{dr,S_K}} \mathbb{B}_{dr,\phi_{D_{i_s}},K} \otimes_{\mathbb{B}_{dr,S_K}} &\mathbb{B}_{dr,\psi_{D_{i_{s+1}}},K} \otimes_{\mathbb{B}_{dr,S_K}} \cdots \otimes_{\mathbb{B}_{dr,S_K}} \mathbb{B}_{dr,\psi_{D_{i_d}},K} \rightarrow \cdots). \end{aligned}$$

For  $m : (K_1, W) \rightarrow (K_2, W)$  a morphism with  $(K_1, W), (K_2, W) \in P_{pfil}(S^{et})$ , considering a stratification  $(D_1, \dots, D_d) \in \mathcal{S}(K_1) \cap \mathcal{S}(K_2)$  by (Cartier) divisor  $D_i \subset S$ ,  $1 \leq i \leq d$  such that  $K_{1|D(r) \setminus D(r+1)}, K_{2|D(r) \setminus D(r+1)} \in D_{\mathbb{Z}_p,c}(D(r) \setminus D(r+1)^{et})$  are local systems for all  $1 \leq r \leq d$ , we get

$$\mathbb{B}_{dr,S}(m) :$$

$$\begin{aligned} \mathbb{B}_{dr,S}(K_1, W) &:= (\cdots \rightarrow \bigoplus_{1 \leq i_1 < \cdots < i_d \leq d} x_{S \setminus D_{i_1}/S} \cdots x_{S \setminus D_{i_r}/S} \phi_{D_{i_{r+1}}} \cdots \phi_{D_{i_s}} \psi_{D_{i_{s+1}}} \cdots \psi_{D_{i_d}}(K_1, W) \otimes_{\mathbb{Q}_p} \\ &\mathbb{B}_{dr,x_{S \setminus D_{i_1}/S},K} \otimes_{\mathbb{B}_{dr,S_K}} \cdots \otimes_{\mathbb{B}_{dr,S_K}} \mathbb{B}_{dr,x_{S \setminus D_{i_r}/S},K} \otimes_{\mathbb{B}_{dr,S_K}} \\ &\mathbb{B}_{dr,\phi_{D_{i_{r+1}}},K} \otimes_{\mathbb{B}_{dr,S_K}} \cdots \otimes_{\mathbb{B}_{dr,S_K}} \mathbb{B}_{dr,\phi_{D_{i_s}},K} \\ \otimes_{\mathbb{B}_{dr,S_K}} \mathbb{B}_{dr,\psi_{D_{i_{s+1}}},K} \otimes_{\mathbb{B}_{dr,S_K}} \cdots \otimes_{\mathbb{B}_{dr,S_K}} &\mathbb{B}_{dr,\psi_{D_{i_d}},K} \rightarrow \cdots) \\ &\xrightarrow{(x_{S \setminus D_{i_1}/S} \cdots x_{S \setminus D_{i_r}/S} \phi_{D_{i_{r+1}}} \cdots \phi_{D_{i_s}} \psi_{D_{i_{s+1}}} \cdots \psi_{D_{i_d}}(m) \otimes I)} \\ \mathbb{B}_{dr,S}(K_2, W) &:= (\cdots \rightarrow \bigoplus_{1 \leq i_1 < \cdots < i_d \leq d} x_{S \setminus D_{i_1}/S} \cdots x_{S \setminus D_{i_r}/S} \phi_{D_{i_{r+1}}} \cdots \phi_{D_{i_s}} \psi_{D_{i_{s+1}}} \cdots \psi_{D_{i_d}}(K_2, W) \otimes_{\mathbb{Q}_p} \\ &\mathbb{B}_{dr,x_{S \setminus D_{i_1}/S},K} \otimes_{\mathbb{B}_{dr,S_K}} \cdots \otimes_{\mathbb{B}_{dr,S_K}} \mathbb{B}_{dr,x_{S \setminus D_{i_r}/S},K} \otimes_{\mathbb{B}_{dr,S_K}} \\ &\mathbb{B}_{dr,\phi_{D_{i_{r+1}}},K} \otimes_{\mathbb{B}_{dr,S_K}} \cdots \otimes_{\mathbb{B}_{dr,S_K}} \mathbb{B}_{dr,\phi_{D_{i_s}},K} \\ \otimes_{\mathbb{B}_{dr,S_K}} \mathbb{B}_{dr,\psi_{D_{i_{s+1}}},K} \otimes_{\mathbb{B}_{dr,S_K}} \cdots \otimes_{\mathbb{B}_{dr,S_K}} &\mathbb{B}_{dr,\psi_{D_{i_d}},K} \rightarrow \cdots). \end{aligned}$$

Note that if  $L$  is a local system on  $S$  then  $\mathbb{B}_{dr,S}(L) = L \otimes \mathbb{B}_{dr,S,K}$ , that is it does NOT depend on the choice of a stratification (see remark 6). This gives the functor

$$\mathbb{B}_{dr,S} : D_{\mathbb{Z}_p,fil,c,k}(S^{et}) = D(P_{pfil}(S^{et})) \rightarrow D_{\mathbb{B}_{dr,S,fil}}(S_K^{an,pet}).$$

(ii) Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i \in I} S_i$  an open cover such that there exists closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_I \in \text{SmVar}(k)$ . We define as in (i) the functor

$$\begin{aligned} \mathbb{B}_{dr,(\tilde{S}_I)} : D_{\mathbb{Z}_p,fil,c,k}(S^{et}) &\xrightarrow{T(S/(\tilde{S}_I))} D_{\mathbb{Z}_p,fil,c,k}(S^{et}/(\tilde{S}_I^{et})) \rightarrow D_{\mathbb{B}_{dr,fil}}(S_K^{an,pet}/(\tilde{S}_{I,K}^{an,pet})), \\ (K, W) &\mapsto \mathbb{B}_{dr,(\tilde{S}_I)}(K, W) := \mathbb{B}_{dr,(\tilde{S}_I)}(i_{I*}j_I^*(K, W), t_{IJ}) \end{aligned}$$

with for  $(K, W) \in P_{pfil}(S^{et})$ ,

$$\begin{aligned} \mathbb{B}_{dr,(\tilde{S}_I)}(K, W) &:= \lim_{(D_1, \dots, D_d) \in \mathcal{S}(K)} \\ (( \bigoplus_{1 \leq i_1 < \dots < i_d \leq d} &x_{\tilde{S}_I \setminus \tilde{D}_{i_1, I} / \tilde{S}_I} \cdots x_{\tilde{S}_I \setminus \tilde{D}_{i_r, I} / \tilde{S}_I} \phi_{\tilde{D}_{i_{r+1}, I}} \cdots \phi_{\tilde{D}_{i_s, I}} \psi_{\tilde{D}_{i_{s+1}, I}} \cdots \psi_{\tilde{D}_{i_d, I}} (i_{I*}j_I^*(K, W)) \otimes_{\mathbb{Q}_p} \\ &\mathbb{B}_{dr, x_{\tilde{S}_I \setminus \tilde{D}_{i_1, I} / \tilde{S}_I}, K} \otimes_{\mathbb{B}_{dr, \tilde{S}_I, K}} \cdots \otimes_{\mathbb{B}_{dr, \tilde{S}_I, K}} \mathbb{B}_{dr, x_{\tilde{S}_I \setminus \tilde{D}_{i_r, I} / \tilde{S}_I}, K} \otimes_{\mathbb{B}_{dr, \tilde{S}_I, K}} \\ &\mathbb{B}_{dr, \phi_{\tilde{D}_{i_{r+1}, I}, K}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I, K}} \cdots \otimes_{\mathbb{B}_{dr, \tilde{S}_I, K}} \mathbb{B}_{dr, \phi_{\tilde{D}_{i_s, I}, K}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I, K}} \\ &\mathbb{B}_{dr, \psi_{\tilde{D}_{i_{s+1}, I}, K}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I, K}} \cdots \otimes_{\mathbb{B}_{dr, \tilde{S}_I, K}} \mathbb{B}_{dr, \psi_{\tilde{D}_{i_d, I}, K}} \rightarrow \cdots), \mathbb{B}_{dr}(t_{IJ}) \end{aligned}$$

with  $(D_1, \dots, D_d) \in \mathcal{S}(K)$  stratifications by Cartier divisor  $D_i \subset S$ ,  $1 \leq i \leq d$  such that  $K|_{D(r) \setminus D(r+1)} := l_r^* K \in D_{\mathbb{Z}_p,c}(D(r) \setminus D(r+1)^{et})$  are local systems for all  $1 \leq r \leq d$ , and  $\tilde{D}_{s,I} \subset \tilde{S}_I$  are (Cartier) divisor such that  $D_s \cap S_I \subset \tilde{D}_{s,I} \cap S$  (that is  $D_s \cap S_I$  is a union of irreducible components of  $\tilde{D}_{s,I} \cap S$  which are (Cartier) divisors), having by theorem 12 the canonical isomorphism in  $D_{\mathbb{Z}_p,c,k}(S_K^{an,pet})$

$$Is(K) : K \xrightarrow{\sim} (\cdots \rightarrow \bigoplus_{1 < i_1 \cdots < i_d \leq d} x_{S \setminus D_{i_1}/S} \cdots x_{S \setminus D_{i_r}/S} \phi_{D_{i_{r+1}}} \cdots \phi_{D_{i_s}} \psi_{D_{i_{s+1}}} \cdots \psi_{D_{i_d}}(K) \rightarrow \cdots).$$

**Remark 6.** Let  $S \in \text{SmVar}(k)$ . Let  $K \in P_{\mathbb{Z}_p,k}(S^{et})$ .  $(D_1, \dots, D_d) \in \mathcal{S}(K)$  stratifications by Cartier divisor  $D_i \subset S$ ,  $1 \leq i \leq d$  such that  $K|_{D(r) \setminus D(r+1)} := l_r^* K \in D_{\mathbb{Z}_p,c}(D(r) \setminus D(r+1)^{et})$  are local systems for all  $1 \leq r \leq d$ . We then have the canonical map in  $D_{\mathbb{B}_{dr}}(S_K^{an,pet})$

$$\begin{aligned} a_S(K, \mathbb{B}_{dr}) &:= I(K) \otimes (a_S(\mathbb{B}_{dr, x_{S \setminus D_i}/S}, a_S(\mathbb{B}_{dr, \phi_{D_i}}, a_S(\mathbb{B}_{dr, \psi_{D_i}})) : K \otimes \mathbb{B}_{dr, S_K} \rightarrow \\ \mathbb{B}_{dr,S}(K) &:= \bigoplus_{1 \leq i_1 < \dots < i_d \leq d} x_{S \setminus D_{i_1}/S} \cdots x_{S \setminus D_{i_r}/S} \phi_{D_{i_{r+1}}} \cdots \phi_{D_{i_s}} \psi_{D_{i_{s+1}}} \cdots \psi_{D_{i_d}}(K) \otimes_{\mathbb{Q}_p} \\ &\mathbb{B}_{dr, x_{S \setminus D_{i_1}/S}, K} \otimes_{\mathbb{B}_{dr, S_K}} \cdots \otimes_{\mathbb{B}_{dr, S_K}} \mathbb{B}_{dr, x_{S \setminus D_{i_r}/S}, K} \otimes_{\mathbb{B}_{dr, S_K}} \\ \mathbb{B}_{dr, \phi_{D_{i_{r+1}}}} &\otimes_{\mathbb{B}_{dr, S_K}} \cdots \otimes_{\mathbb{B}_{dr, S_K}} \mathbb{B}_{dr, \phi_{D_{i_s}, K}} \otimes_{\mathbb{B}_{dr, S_K}} \mathbb{B}_{dr, \psi_{D_{i_{s+1}}}, K} \otimes_{\mathbb{B}_{dr, S_K}} \cdots \otimes_{\mathbb{B}_{dr, S_K}} \mathbb{B}_{dr, \psi_{D_{i_d}, K}} \rightarrow \cdots). \end{aligned}$$

On the other hand we have by theorem 29,

$$\alpha(S) : K \otimes \mathbb{B}_{dr, S_K} \xrightarrow{\sim} F^0 DR(S)((K \otimes O_{S_K^{an}}, F_b) \otimes_{O_{S_K^{an}}} (O_{\mathbb{B}_{dr, S_K}}, F))$$

in  $D_{\mathbb{B}_{dr}}(S_K^{an,pet})$ .

(i) If  $K \in P_p(S)$  is a local system then the map  $a_S(K, \mathbb{B}_{dr})$  is an isomorphism since by proposition 46

$$(O_S, F_b) \xrightarrow{\sim} \bigoplus_{1 \leq i_1 < \dots < i_d \leq d} x_{S \setminus D_{i_1}/S} \cdots x_{S \setminus D_{i_r}/S} \phi_{D_{i_{r+1}}} \cdots \phi_{D_{i_s}} \psi_{D_{i_{s+1}}} \cdots \psi_{D_{i_d}}(O_S, F_b)$$

in  $D(DRM(S))$ .

(ii) If  $K \in P_p(S)$  is NOT a local system then the map  $a_S(K, \mathbb{B}_{dr})$  is NOT an isomorphism is general. For example, for  $j : S^\circ \hookrightarrow S$  an open embedding with  $D := S \setminus S^\circ$  a Cartier divisor, we have in  $D_{\mathbb{B}_{dr}}(S_K^{an, pet})$ , by proposition 46,

$$\begin{aligned} T(j, \mathbb{B}_{dr})(\mathbb{Z}_{p, S^\circ}) &:= (0, c(\mathbb{B}_{dr, x_{S \setminus D/S}, K}), 0) : \mathbb{B}_{dr, S}(j_* \mathbb{Z}_{p, S^\circ}) \xrightarrow{=} \\ (\phi_D(\mathbb{Z}_{p, S_K}) \otimes \mathbb{B}_{dr, \psi_D, K} &\rightarrow (x_{S \setminus D/S}(\mathbb{Z}_{p, S_K}) \otimes \mathbb{B}_{dr, x_{S \setminus D/S}, K}) \oplus (\phi_D(\mathbb{Z}_{p, S_K}) \otimes \mathbb{B}_{dr, \phi_D, K}) \rightarrow \\ &\psi_D(\mathbb{Z}_{p, S_K}) \otimes \mathbb{B}_{dr, \psi_D, K}) \\ \xrightarrow{\sim} \mathbb{B}_{dr, S^\circ/S, K} &:= F^0 DR(S)(j_* Hdg(O_{S^\circ}, F_b)^{an} \otimes_{O_{S_K^{an}}} (O_{\mathbb{B}_{dr, S_K}, F})) \end{aligned}$$

which is, by theorem 29 (in the case of  $D$  a normal crossing divisor,  $\mathbb{B}_{dr, S^\circ/S, K} = \mathbb{B}_{dr, S_K}(\log D_K)$ ), NOT isomorphic in  $D_{\mathbb{B}_{dr}}(S_K^{an, pet})$  to

$$j_* \alpha(S^\circ) : j_* \mathbb{B}_{dr, S^\circ} = (j_* \mathbb{Z}_{p, S_K^\circ}) \otimes \mathbb{B}_{dr, S_K} \xrightarrow{\sim} F^0 DR(S)(j_*(O_S, F_b)^{an} \otimes_{O_{S_K^{an}}} (O_{\mathbb{B}_{dr, S_K}, F}))$$

Recall that the filtered De Rham functor does NOT commutes with filtered tensor product in general (it may leads to different  $F$ -filtration)

Let  $k \subset K \subset \mathbb{C}_p$  a subfield of a  $p$ -adic field. Let  $S \in \text{SmVar}(k)$  and  $D \subset S$  a Cartier divisor. Denote  $S^\circ := S \setminus D$ . We write for simplicity,  $\mathbb{B}_{dr, S} := \mathbb{B}_{dr, S_K}$ ,  $O_{\mathbb{B}_{dr, S}} := O_{\mathbb{B}_{dr, S_K}}$ ,  $\mathbb{B}_{dr, S^\circ/S} := \mathbb{B}_{dr, S^\circ/S, K}$ ,  $\mathbb{B}_{dr, x_{S^\circ/S}} := \mathbb{B}_{dr, x_{S^\circ/S}, K}$ ,  $\mathbb{B}_{dr, \psi_D} := \mathbb{B}_{dr, \psi_D, K}$  and  $\mathbb{B}_{dr, \phi_D} := \mathbb{B}_{dr, \phi_D, K}$

We now look at the functorialities with respect to the proper morphisms and with respect to the open embeddings :

Let  $f : X \rightarrow S$  a morphism with  $X, S \in \text{SmVar}(k)$ . Let  $D \subset S$  a (Cartier) divisor and denote  $S^\circ := S \setminus D$  and  $X^\circ := X \setminus f^{-1}(D)$ . Denote  $j : S^\circ \hookrightarrow S$ ,  $j' : X^\circ \hookrightarrow X$  the open embeddings.

- We have the following quasi-isomorphism in  $C_{\mathbb{B}_{dr, S}}(X_K^{an, pet})$

$$\begin{aligned} m_f(\mathbb{B}_{dr, S^\circ/S}) &: f^* \mathbb{B}_{dr, S^\circ/S} \otimes_{f^* \mathbb{B}_{dr, S}} \mathbb{B}_{dr, X} \xrightarrow{I \otimes \alpha(X_K)} \\ f^* F^0 DR(S)(j_* Hdg(O_{S^\circ}, F_b)^{an} \otimes_{O_S} (O_{\mathbb{B}_{dr, S}, F})) &\otimes_{f^* \mathbb{B}_{dr, S}} F^0 DR(X)((O_X, F_b)^{an} \otimes_{O_X} (O_{\mathbb{B}_{dr, X}, F})) \\ &\xrightarrow{=} \\ F^0 DR(f^* O_S)(f^* j_* Hdg(O_{S^\circ}, F_b)^{an} \otimes_{O_S} (O_{\mathbb{B}_{dr, S}, F})) &\otimes_{f^* \mathbb{B}_{dr, S}} F^0 DR(X)((O_X, F_b)^{an} \otimes_{O_X} (O_{\mathbb{B}_{dr, X}, F})) \\ &\xrightarrow{w_X \circ \Omega_{f^* O_S / O_X}(-)} F^0 DR(X)(f^{*mod} j_* Hdg(O_{S^\circ}, F_b)^{an} \otimes_{O_X} (O_{\mathbb{B}_{dr, X}, F})) \\ &\xrightarrow{=} F^0 DR(X)(j'^* Hdg(O_{X^\circ}, F_b)^{an} \otimes_{O_X} (O_{\mathbb{B}_{dr, X}, F})) =: \mathbb{B}_{dr, X^\circ/X}. \end{aligned}$$

- We have the following quasi-isomorphism in  $C_{\mathbb{B}_{dr, S}}(X_K^{an, pet})$

$$\begin{aligned} m_f(\mathbb{B}_{dr, \psi_D}) &: f^* \mathbb{B}_{dr, \psi_D} \otimes_{f^* \mathbb{B}_{dr, S}} \mathbb{B}_{dr, X} \xrightarrow{I \otimes \alpha(X_K)} \\ f^* F^0 DR(S)(\psi_D(O_{S^\circ}, F_b)^{an} \otimes_{O_S} (O_{\mathbb{B}_{dr, S}, F})) &\otimes_{f^* \mathbb{B}_{dr, S}} F^0 DR(X)((O_X, F_b)^{an} \otimes_{O_X} (O_{\mathbb{B}_{dr, X}, F})) \\ &\xrightarrow{=} \\ F^0 DR(f^* O_S)(f^* \psi_D(O_{S^\circ}, F_b)^{an} \otimes_{O_S} (O_{\mathbb{B}_{dr, S}, F})) &\otimes_{f^* \mathbb{B}_{dr, S}} F^0 DR(X)((O_X, F_b)^{an} \otimes_{O_X} (O_{\mathbb{B}_{dr, X}, F})) \\ &\xrightarrow{w_X \circ \Omega_{f^* O_S / O_X}(-)} F^0 DR(X)(f^{*mod} \psi_D(O_{S^\circ}, F_b)^{an} \otimes_{O_X} (O_{\mathbb{B}_{dr, X}, F})) \\ &\xrightarrow{=} F^0 DR(X)(\psi_{f^{-1}(D)}(O_{X^\circ}, F_b)^{an} \otimes_{O_X} (O_{\mathbb{B}_{dr, X}, F})) =: \mathbb{B}_{dr, \psi_{f^{-1}(D)}}. \end{aligned}$$

- We have the following quasi-isomorphism in  $C_{\mathbb{B}_{dr,S}}(X_K^{an,pet})$

$$\begin{aligned}
& m_f(\mathbb{B}_{dr,\psi_D}) : f^*\mathbb{B}_{dr,\psi_D} \otimes_{f^*\mathbb{B}_{dr,S}} \mathbb{B}_{dr,X} \xrightarrow{I \otimes \alpha(X_K)} \\
& f^*F^0DR(S)(\phi_D(O_{S^\circ}, F_b)^{an} \otimes_{O_S} (O_{\mathbb{B}_{dr,S}}, F)) \otimes_{f^*\mathbb{B}_{dr,S}} F^0DR(X)((O_X, F_b)^{an} \otimes_{O_X} (O_{\mathbb{B}_{dr,X}}, F)) \\
& \xrightarrow{=} \\
& F^0DR(f^*O_S)(f^*\phi_D(O_{S^\circ}, F_b)^{an} \otimes_{O_S} (O_{\mathbb{B}_{dr,S}}, F)) \otimes_{f^*\mathbb{B}_{dr,S}} F^0DR(X)((O_X, F_b)^{an} \otimes_{O_X} (O_{\mathbb{B}_{dr,X}}, F)) \\
& \xrightarrow{w_X \circ \Omega_{f^*O_S/O_X}(-)} F^0DR(X)(f^{*mod}\phi_D(O_{S^\circ}, F_b)^{an} \otimes_{O_X} (O_{\mathbb{B}_{dr,X}}, F)) \\
& \xrightarrow{=} F^0DR(X)(\phi_{f^{-1}(D)}(O_{X^\circ}, F_b)^{an} \otimes_{O_X} (O_{\mathbb{B}_{dr,X}}, F)) =: \mathbb{B}_{dr,\phi_{f^{-1}(D)}}.
\end{aligned}$$

- We have the following map in  $C_{\mathbb{B}_{dr,S}}(S_K^{an,pet})$

$$m_f(\mathbb{B}_{dr,x_{S^\circ/S}}) := (m_f(\mathbb{B}_{dr,S^\circ/S}), m_f(\mathbb{B}_{dr,\psi_D})) : f^*\mathbb{B}_{dr,x_{S^\circ/S}} \otimes_{f^*\mathbb{B}_{dr,S}} \mathbb{B}_{dr,X} \rightarrow \mathbb{B}_{dr,x_{X^\circ/X}}$$

**Definition 78.** (i) Let  $f : X \rightarrow S$  be a proper morphism with  $X, S \in \text{SmVar}(k)$ . Let  $(K, W) \in P_{\mathbb{Z}_p,fil,k}(X^{et})$  be a filtered perverse sheaf. We have a canonical isomorphism in  $D_{\mathbb{Z}_p,fil,c,k}(S^{et})$

$$l(K, W) : (K, W) \xrightarrow{\oplus_{k \in \mathbb{Z}}} {}^pR^k f_*(K, W).$$

Consider a stratification  $(E_1, \dots, E_d) \in \mathcal{S}(K)$  by (Cartier) divisor  $E_i \subset X$ ,  $1 \leq i \leq d$ , such that

$$K|_{E(r) \setminus E(r+1)} := l_r^* K \in D_{\mathbb{Z}_p,c}((E(r) \setminus E(r+1))^{et})$$

are local systems for all  $1 \leq r \leq d$ ,  $l_r : E(r) \hookrightarrow X$  being the locally closed embeddings. Let  $k \in \mathbb{Z}$ . Take a stratification  $(D_1, \dots, D_e) \in \mathcal{S}(K)$  by (Cartier) divisor  $D_i \subset S$ ,  $1 \leq i \leq e$ , such that

$$\begin{aligned}
& ({}^pR^k f_* x_{i_1} \cdots x_{i_r} \phi_{E_{i_{r+1}}} \cdots \phi_{E_{i_s}} \psi_{E_{i_{s+1}}} \cdots \psi_{E_{i_d}} K)|_{D(r') \setminus D(r'+1)} := \\
& m_{r'}^* {}^pR^k f_* x_{i_1} \cdots x_{i_r} \phi_{E_{i_{r+1}}} \cdots \phi_{E_{i_s}} \psi_{E_{i_{s+1}}} \in D_{\mathbb{Z}_p,c}((D(r') \setminus D(r'+1))^{et})
\end{aligned}$$

are local systems for all  $1 \leq i_1 < \cdots < i_{r+1} < \cdots < i_{s+1} < \cdots < i_d \leq d$  and all  $1 \leq r' \leq e$ ,  $m_{r'} : D(r') \hookrightarrow S$  being the locally closed embeddings. This implies that

$${}^pR^k f_* K|_{D(r') \setminus D(r'+1)} := m_{r'}^* {}^pR^k f_* K \in D_{\mathbb{Z}_p,c}((D(r') \setminus D(r'+1))^{et})$$

are local systems for all  $1 \leq r' \leq e$ . We then define the canonical maps in  $D_{\mathbb{B}_{dr,S} \text{fil}}(S_K^{\text{an}, \text{pet}})$

$$\begin{aligned}
& T^k(f, \mathbb{B}_{dr})(K, W) : \mathbb{B}_{dr,S}({}^p R^k f_*(K, W)) \xrightarrow{\mathbb{B}_{dr,S}({}^p R^k f_* \text{Is}(K, W))} \\
(\cdots \rightarrow & \bigoplus_{1 \leq i_1 \cdots < i_d \leq d} \mathbb{B}_{dr,S}({}^p R^k f_* x_{X \setminus E_{i_1}/S} \cdots x_{X \setminus E_{i_r}/S} \phi_{E_{i_{r+1}}} \cdots \phi_{E_{i_s}} \psi_{E_{i_{s+1}}} \cdots \psi_{E_{i_d}}(K, W)) \rightarrow \cdots) \\
& \xrightarrow{=} (\cdots \rightarrow \bigoplus_{1 \leq i_1 < \cdots < i_d \leq d, 1 \leq j_1 < \cdots < j_e \leq e} x_{S \setminus D_{j_1}/S} \cdots x_{S \setminus D_{i_r'}/S} \phi_{D_{j_{r'+1}}} \cdots \phi_{D_{j_s'}} \\
& \psi_{D_{j_{s'+1}}} \cdots \psi_{D_{j_e}} ({}^p R^k f_*(x_{X \setminus E_{i_1}/X} \cdots x_{X \setminus E_{i_r}/X} \phi_{E_{i_{r+1}}} \cdots \phi_{E_{i_s}} \psi_{E_{i_{s+1}}} \cdots \psi_{E_{i_d}}(K, W))) \otimes_{\mathbb{Q}_p} \\
& \mathbb{B}_{dr, x_{S \setminus D_{j_1}/S}} \otimes \cdots \otimes \mathbb{B}_{dr, x_{S \setminus D_{j_{r'}}/S}} \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr, \phi_{D_{j_{r'+1}}}} \\
& \otimes \cdots \otimes \mathbb{B}_{dr, \phi_{D_{j_s'}}} \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr, \psi_{D_{j_{s'+1}}}} \otimes \cdots \otimes \mathbb{B}_{dr, \psi_{D_{j_e}}} \rightarrow \cdots) \\
& \xrightarrow{l_k(-) \circ ((T(f, \psi)(-) \circ \cdots \circ T(f, \psi)(-) \circ T(f, \phi)(-) \circ \cdots \circ T(f, \phi)(-) \circ T(f, x)(-) \circ \cdots \circ T(f, x)(-)) \otimes I)} \\
(\cdots \rightarrow & \bigoplus_{1 \leq i_1 < \cdots < i_d \leq d, 1 \leq j_1 < \cdots < j_e \leq e} Rf_*(x_{X \setminus f^{-1}(D_{j_1})/S} x_{X \setminus E_{i_1}/S} \cdots x_{X \setminus f^{-1}(D_{j_{r'}})/X} x_{X \setminus E_{i_r}/X} \\
& \phi_{f^{-1}(D_{j_{r'+1}})} \phi_{E_{i_{r+1}}} \cdots \phi_{f^{-1}(D_{j_{s'}})} \phi_{E_{i_s}} \psi_{f^{-1}(D_{j_{s'+1}})} \psi_{E_{i_{s+1}}} \cdots \psi_{f^{-1}(D_{j_d})} \psi_{E_{i_d}}(K, W)) \otimes_{\mathbb{Q}_p} \\
& \mathbb{B}_{dr, x_{S \setminus D_{j_1}/S}} \otimes \cdots \otimes \mathbb{B}_{dr, x_{S \setminus D_{j_{r'}}/S}} \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr, \phi_{D_{j_{r'+1}}}} \otimes \cdots \otimes \mathbb{B}_{dr, \phi_{D_{j_s'}}} \\
& \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr, \psi_{D_{j_{s'+1}}}} \otimes \cdots \otimes \mathbb{B}_{dr, \psi_{D_{j_e}}} \rightarrow \cdots) \\
\frac{T(f, \otimes)(-, -)}{\rightarrow} (\cdots \rightarrow & \bigoplus_{1 \leq i_1 < \cdots < i_d \leq d, 1 \leq j_1 < \cdots < j_e \leq e} Rf_*(x_{X \setminus f^{-1}(D_{j_1})/S} x_{X \setminus E_{i_1}/S} \cdots x_{X \setminus f^{-1}(D_{j_{r'}})/X} x_{X \setminus E_{i_r}/X} \\
& \phi_{f^{-1}(D_{j_{r'+1}})} \phi_{E_{i_{r+1}}} \cdots \phi_{f^{-1}(D_{j_{s'}})} \phi_{E_{i_s}} \psi_{f^{-1}(D_{j_{s'+1}})} \psi_{E_{i_{s+1}}} \cdots \psi_{f^{-1}(D_{j_d})} \psi_{E_{i_d}}(K, W)) \otimes_{\mathbb{Q}_p} \\
& f^* \mathbb{B}_{dr, x_{S \setminus D_{j_1}/S}} \otimes \cdots \otimes f^* \mathbb{B}_{dr, x_{S \setminus D_{j_{r'}}/S}} \otimes_{f^* \mathbb{B}_{dr,S}} \mathbb{B}_{dr, \phi_{D_{j_{r'+1}}}} \otimes \cdots \otimes f^* \mathbb{B}_{dr, \phi_{D_{j_s'}}} \\
& \otimes_{f^* \mathbb{B}_{dr,S}} f^* \mathbb{B}_{dr, \psi_{D_{j_{s'+1}}}} \otimes \cdots \otimes \mathbb{B}_{dr, \psi_{D_{j_e}}} \rightarrow \cdots) \\
& \xrightarrow{Rf_*(I \otimes a_X(\mathbb{B}_{dr, x_{X \setminus E_i}/X}) \otimes a_X(\mathbb{B}_{dr, \phi_{E_i}}) \otimes a_X(\mathbb{B}_{dr, \psi_{E_i}}))} \\
(\cdots \rightarrow & \bigoplus_{1 \leq i_1 < \cdots < i_d \leq d, 1 \leq j_1 < \cdots < j_e \leq e} Rf_*(x_{X \setminus f^{-1}(D_{j_1})/S} x_{X \setminus E_{i_1}/S} \cdots x_{X \setminus f^{-1}(D_{j_{r'}})/X} x_{X \setminus E_{i_r}/X} \\
& \phi_{f^{-1}(D_{j_{r'+1}})} \phi_{E_{i_{r+1}}} \cdots \phi_{f^{-1}(D_{j_{s'}})} \phi_{E_{i_s}} \psi_{f^{-1}(D_{j_{s'+1}})} \psi_{E_{i_{s+1}}} \cdots \psi_{f^{-1}(D_{j_d})} \psi_{E_{i_d}}(K, W)) \otimes_{\mathbb{Q}_p} \\
& f^* \mathbb{B}_{dr, x_{S \setminus D_{j_1}/S}} \otimes \cdots \otimes f^* \mathbb{B}_{dr, x_{S \setminus D_{j_{r'}}/S}} \otimes_{f^* \mathbb{B}_{dr,S}} \mathbb{B}_{dr, \phi_{D_{j_{r'+1}}}} \otimes \cdots \otimes f^* \mathbb{B}_{dr, \phi_{D_{j_s'}}} \\
& \otimes_{f^* \mathbb{B}_{dr,S}} f^* \mathbb{B}_{dr, \psi_{D_{j_{s'+1}}}} \otimes \cdots \otimes \mathbb{B}_{dr, \psi_{D_{j_e}}} \otimes_{f^* \mathbb{B}_{dr,S}} \\
& \mathbb{B}_{dr, x_{X \setminus E_{i_1}/X}} \otimes_{\mathbb{B}_{dr,X}} \cdots \otimes \mathbb{B}_{dr, x_{X \setminus E_{i_r}/X}} \\
& \otimes_{\mathbb{B}_{dr,X}} \mathbb{B}_{dr, \phi_{E_{i_{r+1}}}} \otimes \cdots \otimes \mathbb{B}_{dr, \phi_{E_{i_s}}} \otimes_{\mathbb{B}_{dr,X}} \mathbb{B}_{dr, \psi_{E_{i_{s+1}}}} \otimes \cdots \otimes \mathbb{B}_{dr, \psi_{E_{i_d}}} \rightarrow \cdots) \\
& \xrightarrow{Rf_*(I \otimes m_f(\mathbb{B}_{dr, x_{S \setminus D_j}/S}) \otimes m_f(\mathbb{B}_{dr, \phi_{D_j}}) \otimes m_f(\mathbb{B}_{dr, \psi_{D_j}}))} \\
(\cdots \rightarrow & \bigoplus_{1 \leq i_1 < \cdots < i_d \leq d, 1 \leq j_1 < \cdots < j_e \leq e} Rf_*(x_{X \setminus f^{-1}(D_{j_1})/X} x_{X \setminus E_{i_1}/X} \cdots x_{X \setminus f^{-1}(D_{j_{r'}})/X} x_{X \setminus E_{i_r}/X} \\
& \phi_{f^{-1}(D_{j_{r'+1}})} \phi_{E_{i_{r+1}}} \cdots \phi_{f^{-1}(D_{j_{s'}})} \phi_{E_{i_s}} \psi_{f^{-1}(D_{j_{s'+1}})} \psi_{E_{i_{s+1}}} \cdots \psi_{f^{-1}(D_{j_d})} \psi_{E_{i_d}}(K, W)) \otimes_{\mathbb{Q}_p} \\
& \mathbb{B}_{dr, x_{X \setminus E_{i_1}/X}} \otimes_{\mathbb{B}_{dr,X}} \otimes \cdots \otimes \mathbb{B}_{dr, x_{X \setminus E_{i_r}/X}} \\
& \otimes_{\mathbb{B}_{dr,X}} \mathbb{B}_{dr, \phi_{E_{i_{r+1}}}} \otimes \cdots \otimes \mathbb{B}_{dr, \phi_{E_{i_s}}} \otimes_{\mathbb{B}_{dr,X}} \mathbb{B}_{dr, \psi_{E_{i_{s+1}}}} \otimes \cdots \otimes \mathbb{B}_{dr, \psi_{E_{i_d}}} \\
& \otimes_{\mathbb{B}_{dr,X}} \mathbb{B}_{dr, x_{X \setminus f^{-1}(D_{j_1})/X}} \otimes \cdots \otimes \mathbb{B}_{dr, x_{X \setminus f^{-1}(D_{j_{r'}})/X}} \\
& \otimes_{\mathbb{B}_{dr,X}} \mathbb{B}_{dr, \phi_{f^{-1}(D_{j_{r'+1}})}} \otimes \cdots \otimes \mathbb{B}_{dr, \phi_{f^{-1}(D_{j_{s'}})}} \otimes_{\mathbb{B}_{dr,X}} \mathbb{B}_{dr, \psi_{f^{-1}(D_{j_{s'+1}})}} \otimes \cdots \otimes \mathbb{B}_{dr, \psi_{f^{-1}(D_{j_e})}} \rightarrow \cdots) \\
& \xrightarrow{=} Rf_* \mathbb{B}_{dr,X}(K, W),
\end{aligned}$$

with  $l_k(K, W) : {}^p R^k f_*(K, W) \hookrightarrow Rf_*(K, W)$ , which gives the canonical map in  $D_{\mathbb{B}_{dr,S}}(S_K^{an,pet})$

$$T(f, \mathbb{B}_{dr})(K, W) : \mathbb{B}_{dr,S}(Rf_*(K, W)) \xrightarrow{\mathbb{B}_{dr,S}(l(K,W))} \bigoplus_{k \in \mathbb{Z}} \mathbb{B}_{dr,S}({}^p R^k f_*(K, W)) \\ \xrightarrow{(T^k(f, \mathbb{B}_{dr}))(K, W)} Rf_* \mathbb{B}_{dr,X}(K, W).$$

It gives, by functoriality, for  $(K, W) \in D_{\mathbb{Z}_p, fil, c, k}(S^{et})$ , the canonical map in  $D_{\mathbb{B}_{dr,S} fil}(S_K^{an,pet})$

$$T(f, \mathbb{B}_{dr})(K, W) : \mathbb{B}_{dr,S}(Rf_*(K, W)) \rightarrow Rf_* \mathbb{B}_{dr,X}(K, W).$$

(ii) Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{QPVar}(k)$ . Consider a factorization  $f : X \hookrightarrow Y \times S \xrightarrow{p} S$  with  $Y \in \text{SmVar}(k)$ . Let  $S = \cup_i S_i$  an open affine cover and  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embedding with  $\tilde{S}_i \in \text{SmVar}(k)$ . Denote by  $i'_I : X_I \hookrightarrow Y \times \tilde{S}_I$  the closed embeddings. For  $(K, W) \in P_{\mathbb{Z}_p, fil, k}(X^{et})$ , we have as in (i) the following map in  $D_{\mathbb{B}_{dr} fil}(S_K^{an,pet})/(\tilde{S}_{I,K})^{an,pet}$

$$T^k(f, \mathbb{B}_{dr})(K, W) : \mathbb{B}_{dr,(\tilde{S}_I)}({}^p Rf_*(K, W)) \xrightarrow{=} (H^k(\cdots \rightarrow \bigoplus_{1 \leq i_1 < \cdots < i_d \leq d, 1 \leq j_1 < \cdots < j_e \leq e} \\ x_{\tilde{S}_I \setminus D_{j_1, I} / \tilde{S}_I} \cdots x_{\tilde{S}_I \setminus \tilde{D}_{i_{r'}, I} / \tilde{S}_I} \phi_{\tilde{D}_{j_{r'+1}, I}} \cdots \phi_{\tilde{D}_{j_{s'}, I}} \psi_{\tilde{D}_{j_{s'+1}, I}} \cdots \psi_{\tilde{D}_{j_e, I}} (p_{\tilde{S}_I}^* E(x_{(Y \times \tilde{S}_I) \setminus \tilde{E}_{i_1, I} / Y \times \tilde{S}_I} \cdots \\ x_{(Y \times \tilde{S}_I) \setminus \tilde{E}_{i_r, I} / Y \times \tilde{S}_I} \phi_{\tilde{E}_{i_{r+1}}} \cdots \phi_{\tilde{E}_{i_s}} \psi_{\tilde{E}_{i_{s+1}}} \cdots \psi_{\tilde{E}_{i_d}}(K, W))) \otimes_{\mathbb{Q}_p} \\ \mathbb{B}_{dr, x_{\tilde{S}_I \setminus \tilde{D}_{j_1, I} / \tilde{S}_I}} \otimes \cdots \otimes \mathbb{B}_{dr, x_{\tilde{S}_I \setminus \tilde{D}_{j_{r'}, I} / \tilde{S}_I}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, \phi_{\tilde{D}_{j_{r'+1}, I}}} \otimes \cdots \otimes \\ \mathbb{B}_{dr, \phi_{\tilde{D}_{j_{s'}, I}}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, \psi_{\tilde{D}_{j_{s'+1}, I}}} \otimes \cdots \otimes \mathbb{B}_{dr, \psi_{\tilde{D}_{j_e, I}}} \rightarrow \cdots), \mathbb{B}_{dr}(t_{IJ})) \\ \xrightarrow{(I \otimes m_f(-) \circ (I \otimes a_-(-)) \circ T(p, \otimes)(-, -) \circ l_k(-) \circ T(p, -)(-) \circ \cdots \circ T(p, -)(-))} \\ ((\cdots \rightarrow \bigoplus_{1 \leq i_1 < \cdots < i_d \leq d, 1 \leq j_1 < \cdots < j_e \leq e} p_{\tilde{S}_I}^* E(x_{(Y \times \tilde{S}_I) \setminus p^{-1}(\tilde{D}_{j_1, I}) / Y \times \tilde{S}_I} x_{(Y \times \tilde{S}_I) \setminus \tilde{E}_{i_1, I} / Y \times \tilde{S}_I} \\ \cdots x_{(Y \times \tilde{S}_I) \setminus p^{-1}(\tilde{D}_{j_{r'}, I}) / Y \times \tilde{S}_I} x_{(Y \times \tilde{S}_I) \setminus \tilde{E}_{i_r, I} / Y \times \tilde{S}_I} \\ \phi_{p^{-1}(\tilde{D}_{j_{r'+1}, I})} \phi_{\tilde{E}_{i_{r+1}}} \cdots \phi_{p^{-1}(\tilde{D}_{j_{s'}, I})} \phi_{\tilde{E}_{i_s}} \psi_{p^{-1}(\tilde{D}_{j_{s'+1}, I})} \psi_{\tilde{E}_{i_{s+1}}} \cdots \psi_{p^{-1}(\tilde{D}_{j_d, I})} \psi_{\tilde{E}_{i_d}}(K, W) \otimes_{\mathbb{Q}_p} \\ \mathbb{B}_{dr, x_{(Y \times \tilde{S}_I) \setminus \tilde{E}_{i_1, I} / Y \times \tilde{S}_I}} \otimes_{\mathbb{B}_{dr, Y \times \tilde{S}_I}} \otimes \cdots \otimes \mathbb{B}_{dr, x_{(Y \times \tilde{S}_I) \setminus \tilde{E}_{i_r, I} / Y \times \tilde{S}_I}} \otimes_{\mathbb{B}_{dr, Y \times \tilde{S}_I}} \\ \mathbb{B}_{dr, \phi_{\tilde{E}_{i_{r+1}, I}}} \otimes \cdots \otimes \mathbb{B}_{dr, \phi_{\tilde{E}_{i_s, I}}} \otimes_{\mathbb{B}_{dr, Y \times \tilde{S}_I}} \mathbb{B}_{dr, \psi_{\tilde{E}_{i_{s+1}, I}}} \otimes \cdots \otimes \mathbb{B}_{dr, \phi_{\tilde{E}_{i_d, I}}} \\ \otimes_{\mathbb{B}_{dr, Y \times \tilde{S}_I}} \mathbb{B}_{dr, x_{(Y \times \tilde{S}_I) \setminus p^{-1}(\tilde{D}_{j_1, I}) / X}} \otimes \cdots \otimes \mathbb{B}_{dr, x_{(Y \times \tilde{S}_I) \setminus p^{-1}(\tilde{D}_{j_{r'}, I}) / X}} \\ \otimes_{\mathbb{B}_{dr, Y \times \tilde{S}_I}} \mathbb{B}_{dr, \phi_{p^{-1}(\tilde{D}_{j_{r'+1}, I})}} \otimes \cdots \otimes \mathbb{B}_{dr, \phi_{p^{-1}(\tilde{D}_{j_{s'}, I})}} \\ \otimes_{\mathbb{B}_{dr, Y \times \tilde{S}_I}} \mathbb{B}_{dr, \psi_{p^{-1}(\tilde{D}_{j_{s'+1}, I})}} \otimes \cdots \otimes \mathbb{B}_{dr, \psi_{p^{-1}(\tilde{D}_{j_e, I})}}) \rightarrow \cdots), \mathbb{B}_{dr}(t_{IJ})) \xrightarrow{=} Rp_* \mathbb{B}_{dr, (Y \times \tilde{S}_I)}(K, W)$$

where  $(E_1, \dots, E_d) \in \mathcal{S}(K)$  is a stratification by Cartier divisor  $E_i \subset X$ ,  $1 \leq i \leq d$ , such that

$$K|_{E(r) \setminus E(r+1)} := l_r^* K \in D_{\mathbb{Z}_p, c}((E(r) \setminus E(r+1))^{et})$$

are local systems for all  $1 \leq r \leq d$ ,  $l_r : E(r) \hookrightarrow X$  being the locally closed embeddings, and  $(D_1, \dots, D_e) \in \mathcal{S}(K)$  is a stratification by Cartier divisor  $D_i \subset S$ ,  $1 \leq i \leq e$ , such that

$$({}^p R^k f_* x_{i_1} \cdots x_{i_r} \phi_{E_{i_{r+1}}} \cdots \phi_{E_{i_s}} \psi_{E_{i_{s+1}}} \cdots \psi_{E_{i_d}} K)|_{D(r') \setminus D(r'+1)} := \\ m_{r'}^* {}^p R^k f_* x_{i_1} \cdots x_{i_r} \phi_{E_{i_{r+1}}} \cdots \phi_{E_{i_s}} \psi_{E_{i_{s+1}}} \in D_{\mathbb{Z}_p, c}((D(r') \setminus D(r'+1))^{et})$$

are local systems for all  $1 \leq i_1 < \cdots < i_{r+1} < \cdots < i_{s+1} < \cdots < i_d \leq d$ , all  $1 \leq r' \leq e$ ,  $k \in \mathbb{Z}$ ,  $m_{r'} : D(r') \hookrightarrow S$  being the locally closed embeddings,  $\tilde{D}_{s,I} \subset \tilde{S}_I$  (Cartier) divisor such that  $D_s \cap S_I \subset \tilde{D}_{s,I} \cap S$ , and  $\tilde{E}_{s,I} \subset Y \times \tilde{S}_I$  (Cartier) divisor such that  $E_s \cap X_I \subset \tilde{E}_{s,I} \cap X$ . It gives, by functoriality, for  $(K, W) \in D_{\mathbb{Z}_p, fil, c, k}(S^{et})$ , the canonical map in  $D_{\mathbb{B}_{dr} fil}(S_K^{an,pet})/(\tilde{S}_{I,K})^{an,pet}$

$$T(f, \mathbb{B}_{dr})(K, W) : \mathbb{B}_{dr,(\tilde{S}_I)}(Rf_*(K, W)) \rightarrow Rf_* \mathbb{B}_{dr, (Y \times \tilde{S}_I)}(K, W).$$

**Lemma 6.** *Let  $f : X \rightarrow S$  a proper morphism with  $X, S \in \text{SmVar}(k)$ . Let  $E \subset X$  a (Cartier) divisor. Denote  $j : U := X \setminus E \hookrightarrow X$  the open embedding. Let  $K \in P_{\mathbb{Z}_p, k}(X^{et})$  such that  $K|_U$  and  $K|_E$  are local systems and such that  ${}^p R^k f_* K = R^k f_* K$  are local systems for all  $k \in \mathbb{Z}$ . Then,*

(i) *The map*

$$Rf_*(I \otimes a_X(\mathbb{B}_{dr, U/X, \mathbb{C}_p})) : Rf_* Rj_* \pi_{k/\mathbb{C}_p}^* K \otimes \mathbb{B}_{dr, S_{\mathbb{C}_p}} \rightarrow Rf_*(Rj_* \pi_{k/\mathbb{C}_p}^* K \otimes \mathbb{B}_{dr, U/X, \mathbb{C}_p})$$

*is an isomorphism.*

(ii) *The map*

$$Rf_*(I \otimes a_X(\mathbb{B}_{dr, \psi_E})) : Rf_* \psi_E K \otimes \mathbb{B}_{dr, S} \rightarrow Rf_*(\psi_E K \otimes \mathbb{B}_{dr, \psi_E})$$

*is an isomorphism.*

(iii) *The map*

$$Rf_*(I \otimes a_X(\mathbb{B}_{dr, \phi_E})) : Rf_* \phi_E K \otimes \mathbb{B}_{dr, S} \rightarrow Rf_*(\phi_E K \otimes \mathbb{B}_{dr, \phi_E})$$

*is an isomorphism.*

(iv) *The map*

$$Rf_*(I \otimes a_X(\mathbb{B}_{dr, x_{U/X}})) : Rf_* x_{U/X}(\pi_{k/\mathbb{C}_p}^* K) \otimes \mathbb{B}_{dr, S_{\mathbb{C}_p}} \rightarrow Rf_*(x_{U/X}(K) \otimes \mathbb{B}_{dr, x_{U/X, \mathbb{C}_p}})$$

*is an isomorphism.*

*Proof.* (i): Take a resolution  $\epsilon : (\tilde{X}, \tilde{E}) \rightarrow (X, E)$  with  $\tilde{X} \in \text{SmVar}(\bar{k})$  and  $\tilde{E} = \cup_i \tilde{E}_i \subset \tilde{X}$  a normal crossing divisor. We then apply theorem 29.

(ii): Follows from theorem 40 and on the other hand theorem 6 and theorem 8.

(iii): Follows from theorem 40 and on the other hand theorem 6 and theorem 8.

(iv): Follows from (i), (ii). □

**Theorem 44.** (i) *Let  $X \in \text{PSmVar}(k)$ . Let  $Z \subset X$  a closed subset. Denote by  $j : U := X \setminus Z \hookrightarrow X$  the open complementary embedding. Take (Cartier) divisor  $D_1, \dots, D_r \subset X$  such that  $Z = \cap_{i=1}^r D_i$ . The map in  $D(\mathbb{B}_{dr, \mathbb{C}_p}, G)$*

$$\begin{aligned} R\Gamma(X_{\bar{k}}, I \otimes a_X(\mathbb{B}_{dr, D_i/X})) &: R\Gamma(X_{\bar{k}}, Rj_* \mathbb{Z}_{U^{et}, p}) \otimes \mathbb{B}_{dr, \mathbb{C}_p} = R\Gamma(U_{\bar{k}}, \mathbb{Z}_{p, U^{et}}) \otimes \mathbb{B}_{dr, \mathbb{C}_p} \\ &\rightarrow R\Gamma(X_{\bar{k}}, Rj_* \mathbb{Z}_{p, U^{et}} \otimes \mathbb{B}_{dr, X \setminus D_1/X} \otimes \mathbb{B}_{dr, S} \cdots \mathbb{B}_{dr, X \setminus D_r/X}) \\ &\xrightarrow{=} R\Gamma(X_{\bar{k}}, F^0 DR(X)(j_* Hdq(O_U, F_b)^{an} \otimes_{O_X} (O_{\mathbb{B}_{dr, X}, F}))) \end{aligned}$$

*is an isomorphism.*

(ii) *Let  $f : X \rightarrow S$  be a proper morphism with  $X, S \in \text{SmVar}(k)$ . For  $K \in D_{\mathbb{Z}_p, c, k}(X^{et})$ , the map in  $D_{\mathbb{B}_{dr}, G}(S_{\mathbb{C}_p}^{an, pet})$  (where the a  $G$  module structure is a continuous action of the Galois group)*

$$T(f, B_{dr})(K) : \mathbb{B}_{dr, S}(Rf_* K) \rightarrow Rf_* \mathbb{B}_{dr, X}(K)$$

*given in definition 78 is an isomorphism.*

(ii)' *Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{QPVar}(k)$ . Consider a factorization  $f : X \hookrightarrow Y \times S \xrightarrow{p} S$  with  $Y \in \text{SmVar}(k)$ . Let  $S = \cup_i S_i$  an open affine cover and  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embedding with  $\tilde{S}_i \in \text{SmVar}(k)$ . Denote by  $i'_I : X_I \hookrightarrow Y \times \tilde{S}_I$  the closed embeddings. For  $K \in D_{\mathbb{Z}_p, c, k}(X^{et})$ , the map in  $D_{\mathbb{B}_{dr}, G}(S_{\mathbb{C}_p}^{an, pet} / (\tilde{S}_I, \mathbb{C}_p)^{an, pet})$*

$$T(f, \mathbb{B}_{dr})(K) : \mathbb{B}_{dr, (\tilde{S}_I)}(Rf_* K) \rightarrow Rp_* \mathbb{B}_{dr, (Y \times \tilde{S}_I)}(K)$$

*given in definition 78 is an isomorphism.*

*Proof.* (i): We take (Cartier) divisor  $D_1, \dots, D_r \subset X$  such that  $Z = \bigcap_{i=1}^r D_i$ . Point (i) follows then from lemma 6(i) applied to each  $D_i$  by definition of  $j_{*Hdg}(O_U, F_b)$ . One can also apply theorem 29 directly using a desingularization  $\epsilon : (X', E) \rightarrow (X, Z)$  with  $X' \in \text{SmVar}(k)$  and  $E = \cup_i E_i \subset X'$  a normal crossing divisor.

(ii): Follows from lemma 6 and on the other hand theorem 5 together with theorem 8.

(ii)': Follows from lemma 6 and on the other hand theorem 5 together with theorem 8 as for (ii).  $\square$

**Remark 7.** Let  $f : X \rightarrow S$  a proper morphism with  $S, X \in \text{Var}(k)$ . Then for  $K \in C_{\mathbb{Z}_p}(X^{et})$ , the map in  $D_{\mathbb{Z}_p}(S^{an, pet})$

$$Rf_* K \otimes \mathbb{B}_{dr, S} \xrightarrow{\text{ad}(Lf^{*mod}, Rf_*)(\mathbb{B}_{dr, S})} Rf_* K \otimes Rf_* \mathbb{B}_{dr, X} \xrightarrow{T(f, f, \otimes)(K, \mathbb{B}_{dr, X})} Rf_*(K \otimes \mathbb{B}_{dr, X})$$

is an isomorphism by theorem 6 and theorem 8. In the analytic case ([27]), for  $f : X \rightarrow S$  a smooth proper morphism with  $X, S \in \text{AnSm}(K)$  and  $L \in \text{Loc}_{\mathbb{Z}_p}(X^{et})$  an analytic local system, the map in  $D_{\mathbb{Z}_p}(S^{pet})$

$$Rf_* L \otimes \mathbb{B}_{dr, S} \xrightarrow{\text{ad}(Lf^{*mod}, Rf_*)(\mathbb{B}_{dr, S})} Rf_* L \otimes Rf_* \mathbb{B}_{dr, X} \xrightarrow{T(f, f, \otimes)(L, \mathbb{B}_{dr, X})} Rf_*(L \otimes \mathbb{B}_{dr, X})$$

is an isomorphism.

**Definition 79.** (i) Let  $j : S^\circ \hookrightarrow S$  an open embedding with  $S \in \text{SmVar}(k)$  and  $D := S \setminus S^\circ$  a (Cartier) divisor. We will consider, for  $(K, W) \in P_{\mathbb{Z}_p, fil, k}(S^\circ, et)$ , the canonical isomorphism in  $D_{\mathbb{B}_{dr, S} fil}(S_K^{an, pet})$

$$\begin{aligned} T(j, \mathbb{B}_{dr})(K, W) &:= ((0, (c(x_{S^\circ/S}(-), 0)) \otimes c(\mathbb{B}_{dr, S^\circ/S}) \otimes I, 0)) : \mathbb{B}_{dr, S}(j_{*w}(K, W)) \xrightarrow{=} \\ &((\cdots \rightarrow \bigoplus_{1 \leq i_1 \cdots < i_d \leq d} \psi_D x_{S \setminus \bar{E}_{i_1}/S} \cdots x_{S \setminus \bar{E}_{i_r}/S} \phi_{\bar{E}_{i_{r+1}}} \cdots \phi_{\bar{E}_{i_s}} \psi_{\bar{E}_{i_{s+1}}} \cdots \psi_{\bar{E}_{i_d}} j_{*w}(K, W) \\ &\quad \otimes \mathbb{B}_{dr, \psi_D} \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, x_{S \setminus \bar{E}_{i_1}/S}} \otimes_{\mathbb{B}_{dr, S}} \cdots \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, x_{S \setminus \bar{E}_{i_r}/S}} \\ &\quad \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \phi_{\bar{E}_{i_{r+1}}}} \otimes \cdots \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \phi_{\bar{E}_{i_s}}} \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \psi_{\bar{E}_{i_{s+1}}}} \otimes \cdots \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \psi_{\bar{E}_{i_d}}} \rightarrow \cdots) \rightarrow \\ &(\cdots \rightarrow \bigoplus_{1 \leq i_1 \cdots < i_d \leq d} x_{S^\circ/S} x_{S \setminus \bar{E}_{i_1}/S} \cdots x_{S \setminus \bar{E}_{i_r}/S} \phi_{\bar{E}_{i_{r+1}}} \cdots \phi_{\bar{E}_{i_s}} \psi_{\bar{E}_{i_{s+1}}} \cdots \psi_{\bar{E}_{i_d}} j_{*w}(K, W) \oplus \\ &\quad \phi_D x_{S \setminus \bar{E}_{i_1}/S} \cdots x_{S \setminus \bar{E}_{i_r}/S} \phi_{\bar{E}_{i_{r+1}}} \cdots \phi_{\bar{E}_{i_s}} \psi_{\bar{E}_{i_{s+1}}} \cdots \psi_{\bar{E}_{i_d}} j_{*w}(K, W) \\ &\quad \otimes (\mathbb{B}_{dr, x_{S^\circ/S}} \oplus \mathbb{B}_{dr, \phi_D}) \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, x_{S \setminus \bar{E}_{i_1}/S}} \otimes_{\mathbb{B}_{dr, S}} \cdots \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, x_{S \setminus \bar{E}_{i_r}/S}} \\ &\quad \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \phi_{\bar{E}_{i_{r+1}}}} \otimes \cdots \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \phi_{\bar{E}_{i_s}}} \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \psi_{\bar{E}_{i_{s+1}}}} \otimes \cdots \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \psi_{\bar{E}_{i_d}}} \rightarrow \cdots) \rightarrow \\ &(\cdots \rightarrow \bigoplus_{1 \leq i_1 \cdots < i_d \leq d} \psi_D x_{S \setminus \bar{E}_{i_1}/S} \cdots x_{S \setminus \bar{E}_{i_r}/S} \phi_{\bar{E}_{i_{r+1}}} \cdots \phi_{\bar{E}_{i_s}} \psi_{\bar{E}_{i_{s+1}}} \cdots \psi_{\bar{E}_{i_d}} j_{*w}(K, W) \\ &\quad \otimes \mathbb{B}_{dr, \psi_D} \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, x_{S \setminus \bar{E}_{i_1}/S}} \otimes_{\mathbb{B}_{dr, S}} \cdots \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, x_{S \setminus \bar{E}_{i_r}/S}} \\ &\quad \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \phi_{\bar{E}_{i_{r+1}}}} \otimes \cdots \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \phi_{\bar{E}_{i_s}}} \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \psi_{\bar{E}_{i_{s+1}}}} \otimes \cdots \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \psi_{\bar{E}_{i_d}}} \rightarrow \cdots)) \\ &\quad \xrightarrow{\sim} \\ &(\cdots \rightarrow \bigoplus_{1 \leq i_1 \cdots < i_d \leq d} j_{*w} x_{S^\circ \setminus E_{i_1}/S} \cdots x_{S^\circ \setminus E_{i_r}/S} \phi_{E_{i_{r+1}}} \cdots \phi_{E_{i_s}} \psi_{E_{i_{s+1}}} \cdots \psi_{E_{i_d}}(K, W) \\ &\quad \otimes_{\mathbb{B}_{dr, S^\circ/S}} \otimes_{\mathbb{B}_{dr, S}} V_{D0} j_* (\mathbb{B}_{dr, x_{S^\circ \setminus E_{i_1}/S}} \otimes_{\mathbb{B}_{dr, S}} \cdots \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, x_{S^\circ \setminus E_{i_r}/S}} \\ &\quad \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \phi_{E_{i_{r+1}}}} \otimes \cdots \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \phi_{E_{i_s}}} \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \psi_{E_{i_{s+1}}}} \otimes \cdots \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \psi_{E_{i_d}}}) \rightarrow \cdots) \\ &\quad \xrightarrow{=} V_{D0} j_{*w} \mathbb{B}_{dr, S^\circ}(K, W) \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, S^\circ/S}. \end{aligned}$$

where  $(E_1, \dots, E_d) \in \mathcal{S}(K)$  is a stratification by (Cartier) divisor  $E_i \subset S^\circ$ ,  $1 \leq i \leq d$ , such that

$$K|_{E(r) \setminus E(r+1)} := l_r^* K \in D_{\mathbb{Z}_p, c}((E(r) \setminus E(r+1))^{et})$$

are local systems for all  $1 \leq r \leq d$ ,  $l_r : E(r) \hookrightarrow S^\circ$  being the locally closed embeddings.



(ii) Let  $l : S^\circ \hookrightarrow S$  an open embedding with  $S \in \text{Var}(k)$  such that  $D = S \setminus S^\circ \subset S$  is a Cartier divisor. Let  $\tilde{S} = \cup_i \tilde{S}_i$  an open affine cover and  $i_i : \tilde{S}_i \hookrightarrow \tilde{S}_i$  closed embedding with  $\tilde{S}_i \in \text{SmVar}(k)$ . Let  $l_I : \tilde{S}_I^\circ \hookrightarrow \tilde{S}_I$  open embeddings such that  $\tilde{S}_I^\circ \cap S = S^\circ \cap S_I$  and  $\tilde{D}_I \subset \tilde{S}_I$  a Cartier divisor such that  $D \cap S_I \subset \tilde{D}_I \cap S_I$ . We will consider, for  $(K, W) \in P_{\mathbb{Z}_p, \text{fil}, k}(S^\circ, \text{et})$ , the canonical isomorphism in  $D_{\mathbb{B}_{dr, \text{fil}}}(S_K^{\text{an}, \text{pet}} / (\tilde{S}_{I, K})^{\text{an}, \text{pet}})$

$$\begin{aligned}
& T(l, \mathbb{B}_{dr})(K, W) := ((0, (c(x_{S^\circ/S}(-), 0)) \otimes c(\mathbb{B}_{dr, S^\circ/S}) \otimes I, 0)) : \mathbb{B}_{dr, (\tilde{S}_I)}(l_{*w}(K, W)) \xrightarrow{=} \\
& (((\cdots \rightarrow \bigoplus_{1 \leq i_1 \cdots < i_d \leq d} \psi_{\tilde{D}_I} x_{\tilde{S}_I \setminus \tilde{D}_{i_1, I} / \tilde{S}_I} \cdots x_{\tilde{S}_I \setminus \tilde{D}_{i_r, I} / S} \phi_{\tilde{E}_{i_{r+1}, I}} \cdots \phi_{\tilde{E}_{i_s, I}} \psi_{\tilde{E}_{i_{s+1}, I}} \cdots \psi_{\tilde{E}_{i_d, I}} i_{I*} J_I^* l_{*w}(K, W) \\
& \quad \otimes_{\mathbb{B}_{dr, \psi_{\tilde{D}_I}}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, x_{\tilde{S}_I \setminus \tilde{E}_{i_1, I} / S}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \cdots \otimes_{\mathbb{B}_{dr, x_{\tilde{S}_I \setminus \tilde{E}_{i_r, I} / S}} \\
& \quad \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, \phi_{\tilde{E}_{i_{r+1}, I}}} \otimes \cdots \otimes_{\mathbb{B}_{dr, \phi_{\tilde{E}_{i_s, I}}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, \psi_{\tilde{E}_{i_{s+1}, I}}} \otimes \cdots \otimes_{\mathbb{B}_{dr, \psi_{\tilde{E}_{i_d, I}}} \rightarrow \cdots) \rightarrow \\
& (\cdots \rightarrow \bigoplus_{1 \leq i_1 \cdots < i_d \leq d} x_{\tilde{S}_I^\circ / \tilde{S}_I} x_{S \setminus \tilde{E}_{i_1, I} / S} \cdots x_{\tilde{S}_I \setminus \tilde{E}_{i_r, I} / S} \phi_{\tilde{E}_{i_{r+1}, I}} \cdots \phi_{\tilde{E}_{i_s, I}} \psi_{\tilde{E}_{i_{s+1}, I}} \cdots \psi_{\tilde{E}_{i_d, I}} i_{I*} J_I^* l_{*w}(K, W) \oplus \\
& \quad \phi_{\tilde{D}_I} x_{S \setminus \tilde{E}_{i_1, I} / S} \cdots x_{\tilde{S}_I \setminus \tilde{E}_{i_r, I} / S} \phi_{\tilde{E}_{i_{r+1}, I}} \cdots \phi_{\tilde{E}_{i_s, I}} \psi_{\tilde{E}_{i_{s+1}, I}} \cdots \psi_{\tilde{E}_{i_d, I}} i_{I*} J_I^* l_{*w}(K, W) \\
& \quad \otimes (\mathbb{B}_{dr, x_{\tilde{S}_I^\circ / \tilde{S}_I}} \oplus \mathbb{B}_{dr, \phi_D}) \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, x_{\tilde{S}_I \setminus \tilde{E}_{i_1, I} / S}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \cdots \otimes_{\mathbb{B}_{dr, x_{\tilde{S}_I \setminus \tilde{E}_{i_r, I} / S}} \\
& \quad \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, \phi_{\tilde{E}_{i_{r+1}, I}}} \otimes \cdots \otimes_{\mathbb{B}_{dr, \phi_{\tilde{E}_{i_s, I}}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, \psi_{\tilde{E}_{i_{s+1}, I}}} \otimes \cdots \otimes_{\mathbb{B}_{dr, \psi_{\tilde{E}_{i_d, I}}} \rightarrow \cdots) \rightarrow \\
& (\cdots \rightarrow \bigoplus_{1 \leq i_1 \cdots < i_d \leq d} \psi_{\tilde{D}_I} x_{S \setminus \tilde{E}_{i_1, I} / S} \cdots x_{S \setminus \tilde{E}_{i_r, I} / S} \phi_{\tilde{E}_{i_{r+1}, I}} \cdots \phi_{\tilde{E}_{i_s, I}} \psi_{\tilde{E}_{i_{s+1}, I}} \cdots \psi_{\tilde{E}_{i_d, I}} i_{I*} J_I^* l_{*w}(K, W) \\
& \quad \otimes_{\mathbb{B}_{dr, \psi_D}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, x_{\tilde{S}_I \setminus \tilde{E}_{i_1, I} / S}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \cdots \otimes_{\mathbb{B}_{dr, x_{\tilde{S}_I \setminus \tilde{E}_{i_r, I} / S}} \\
& \quad \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, \phi_{\tilde{E}_{i_{r+1}, I}}} \otimes \cdots \otimes_{\mathbb{B}_{dr, \phi_{\tilde{E}_{i_s, I}}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, \psi_{\tilde{E}_{i_{s+1}, I}}} \otimes \cdots \otimes_{\mathbb{B}_{dr, \psi_{\tilde{E}_{i_d, I}}} \rightarrow \cdots), \mathbb{B}_{dr}(t_{IJ})) \\
& \quad \xrightarrow{\sim} \\
& (((\cdots \rightarrow \bigoplus_{1 \leq i_1 \cdots < i_d \leq d} l_{I*} x_{\tilde{S}_I^\circ \setminus \tilde{E}_{i_1, I} / \tilde{S}_I} \cdots x_{\tilde{S}_I^\circ \setminus \tilde{E}_{i_r, I} / S} \phi_{\tilde{E}_{i_{r+1}, I}} \cdots \phi_{\tilde{E}_{i_s, I}} \psi_{\tilde{E}_{i_{s+1}, I}} \cdots \psi_{\tilde{E}_{i_d, I}} i_{I*} J_I^* l_{*w}(K, W) \\
& \quad \otimes_{\mathbb{B}_{dr, \tilde{S}_I^\circ / \tilde{S}_I}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} V_{\tilde{D}_I} 0 l_{I*} (\mathbb{B}_{dr, x_{\tilde{S}_I^\circ \setminus \tilde{E}_{i_1, I} / S}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \cdots \otimes_{\mathbb{B}_{dr, x_{\tilde{S}_I^\circ \setminus \tilde{E}_{i_r, I} / S}} \\
& \quad \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, \phi_{\tilde{E}_{i_{r+1}, I}}} \otimes \cdots \otimes_{\mathbb{B}_{dr, \phi_{\tilde{E}_{i_s, I}}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, \psi_{\tilde{E}_{i_{s+1}, I}}} \otimes \cdots \otimes_{\mathbb{B}_{dr, \psi_{\tilde{E}_{i_d, I}}} \rightarrow \cdots), \mathbb{B}_{dr}(t_{IJ})) \\
& \quad \xrightarrow{=} V_{D0} l_{*w} \mathbb{B}_{dr, (\tilde{S}_I^\circ)}(K, W) \otimes_{\mathbb{B}_{dr, S}} (\mathbb{B}_{dr, \tilde{S}_I^\circ / \tilde{S}_I}, t_{IJ}).
\end{aligned}$$

where  $(E_1, \dots, E_d) \in \mathcal{S}(K)$  is a stratification by Cartier divisor  $E_i \subset S^\circ$ ,  $1 \leq i \leq d$ , such that

$$K|_{E(r) \setminus E(r+1)} := l_r^* K \in D_{\mathbb{Z}_p, c}((E(r) \setminus E(r+1))^{\text{et}})$$

are local systems for all  $1 \leq r \leq d$ ,  $l_r : E(r) \hookrightarrow S^\circ$  being the locally closed embeddings, and  $\tilde{E}_{s, I} \subset \tilde{S}_I$ ,  $\tilde{D}_I \subset \tilde{S}_I$  are (Cartier) divisor such that  $\tilde{E}_s \cap S_I \subset \tilde{E}_{s, I} \cap S_I$  and  $D \cap S_I \subset \tilde{D}_I \cap S_I$ . It gives for  $(K, W) \in D_{\mathbb{Z}_p, \text{fil}, c, k}(S^\circ, \text{et})$ , the canonical isomorphism in  $D_{\mathbb{B}_{dr, \text{fil}}}(S_K^{\text{an}, \text{pet}} / (\tilde{S}_{I, K})^{\text{an}, \text{pet}})$

$$T(l, \mathbb{B}_{dr})(K, W) : \mathbb{B}_{dr, (\tilde{S}_I)}(l_{*w}(K, W)) \xrightarrow{\sim} V_{D0} l_{*w} \mathbb{B}_{dr, (\tilde{S}_I^\circ)}(K, W) \otimes_{\mathbb{B}_{dr, S}} (\mathbb{B}_{dr, \tilde{S}_I^\circ / \tilde{S}_I}, t_{IJ}).$$

Let  $S \in \text{SmVar}(k)$ . Let  $j : S^\circ \hookrightarrow S$  an open embedding such that  $D = S \setminus S^\circ \subset S$  is a Cartier divisor. Denote by  $\Delta_S : S \hookrightarrow S \times S$  the diagonal closed embedding and  $p_1 : S \times S \rightarrow S$  and  $p_2 : S \times S \rightarrow S$  the projections.

- We have the isomorphism in  $C_{\mathbb{B}_{dr}}(S_K^{an,pet})$

$$\begin{aligned}
& m(\mathbb{B}_{dr,S^\circ/S,K}) : \mathbb{B}_{dr,S^\circ/S,K} \otimes_{\mathbb{B}_{dr,S_K}} \mathbb{B}_{dr,S^\circ/S,K} \xrightarrow{=} \\
& F^0 DR(S)(j_*Hdg(O_{S^\circ}, F_b) \otimes_{O_S} (O\mathbb{B}_{dr,S_K}, F)) \otimes_{\mathbb{B}_{dr,S_K}} F^0 DR(S)(j_*Hdg(O_{S^\circ}, F_b) \otimes_{O_S} (O\mathbb{B}_{dr,S_K}, F)) \\
& \xrightarrow{F^0 w_S} \Delta_S^{*mod} F^0 DR(S \times S)((p_1^{*mod} j_*Hdg(O_{S^\circ}, F_b) \otimes_{O_{S \times S}} \\
& \quad p_2^{*mod} j_*Hdg(O_{S^\circ}, F_b) \otimes_{O_{S \times S}} (O\mathbb{B}_{dr,(S \times S)_K}, F))) \\
& \xrightarrow{DR(S \times S)(ad(\Delta_S^{*mod}, \Delta_{S^*mod})(-))} \\
& \Delta_S^{*mod} F^0 DR(S \times S)(\Delta_{S^*mod} \Delta_{S,Hdg}^{*mod} (p_1^{*mod} j_*Hdg(O_{S^\circ}, F_b) \otimes_{O_{S \times S}} p_2^{*mod} j_*Hdg(O_{S^\circ}, F_b)) \\
& \quad \otimes_{O_{S \times S}} (O\mathbb{B}_{dr,(S \times S)_K}, F)) \xrightarrow{T^{Bdr}(\Delta_S, DR)(-)} \\
& \Delta_S^{*mod} \Delta_{S^*} F^0 DR(S)(\Delta_{S,Hdg}^{*mod} (p_1^{*mod} j_*Hdg(O_{S^\circ}, F_b) \otimes_{O_{S \times S}} p_2^{*mod} j_*Hdg(O_{S^\circ}, F_b)) \otimes_{O_S} (O\mathbb{B}_{dr,S_K}, F)) \\
& \xrightarrow{=} F^0 DR(S)(j_*Hdg(O_{S^\circ}, F_b) \otimes_{O_S}^{Hdg} j_*Hdg(O_{S^\circ}, F_b) \otimes_{O_S} (O\mathbb{B}_{dr,S_K}, F)) \\
& \xrightarrow{F^0 DR(S)(m)} F^0 DR(S)(j_*Hdg(O_{S^\circ}, F_b) \otimes_{O_S} (O\mathbb{B}_{dr,S_K}, F)) := \mathbb{B}_{dr,S^\circ/S,K}
\end{aligned}$$

where

$$m : (j_*O_{S^\circ}, V_D) \otimes_{O_S} (j_*O_{S^\circ}, V_D) \xrightarrow{\sim} (j_*O_{S^\circ}, V_D), \quad m(b_1 \otimes b_2) = b_1 b_2$$

is the multiplication map whose inverse is

$$n : (j_*O_{S^\circ}, V_D) \xrightarrow{\sim} (j_*O_{S^\circ}, V_D) \otimes_{O_S} (j_*O_{S^\circ}, V_D), \quad n(b) = b \otimes 1.$$

- We have the isomorphism

$$\begin{aligned}
& m(\mathbb{B}_{dr,\psi_D,K}) : \mathbb{B}_{dr,\psi_D,K} \otimes_{\mathbb{B}_{dr,S_K}} \mathbb{B}_{dr,\psi_D,K} \xrightarrow{=} \\
& F^0 DR(S)(\psi_D(O_{S^\circ}, F_b) \otimes_{O_S} (O\mathbb{B}_{dr,S_K}, F)) \otimes_{\mathbb{B}_{dr,S_K}} F^0 DR(S)(\psi_D(O_{S^\circ}, F_b) \otimes_{O_S} (O\mathbb{B}_{dr,S_K}, F)) \\
& \xrightarrow{F^0 w_S} \Delta_S^{*mod} F^0 DR(S \times S)(p_1^{*mod} \psi_D(O_{S^\circ}, F_b) \otimes_{O_{S \times S}} p_2^{*mod} \psi_D(O_{S^\circ}, F_b) \otimes_{O_{S \times S}} (O\mathbb{B}_{dr,(S \times S)_K}, F)) \\
& \xrightarrow{DR(S \times S)(ad(\Delta_S^{*mod}, \Delta_{S^*mod})(-))} \\
& \Delta_S^{*mod} F^0 DR(S \times S)(\Delta_{S^*mod} \Delta_{S,Hdg}^{*mod} (p_1^{*mod} \psi_D(O_{S^\circ}, F_b) \otimes_{O_{S \times S}} p_2^{*mod} \psi_D(O_{S^\circ}, F_b)) \\
& \quad \otimes_{O_{S \times S}} (O\mathbb{B}_{dr,(S \times S)_K}, F)) \xrightarrow{T^{Bdr}(\Delta_S, DR)(-)} \\
& \Delta_S^{*mod} \Delta_{S^*} F^0 DR(S)(\Delta_{S,Hdg}^{*mod} (p_1^{*mod} \psi_D(O_{S^\circ}, F_b) \otimes_{O_{S \times S}} p_2^{*mod} \psi_D(O_{S^\circ}, F_b)) \otimes_{O_S} (O\mathbb{B}_{dr,S_K}, F)) \\
& \xrightarrow{=} F^0 DR(S)(\psi_D(O_{S^\circ}, F_b) \otimes_{O_S}^{Hdg} \psi_D(O_{S^\circ}, F_b) \otimes_{O_S} (O\mathbb{B}_{dr,S_K}, F)) \\
& \xrightarrow{F^0 DR(S)(m)} F^0 DR(S)(\psi_D(O_{S^\circ}, F_b) \otimes_{O_S} (O\mathbb{B}_{dr,S_K}, F)) := \mathbb{B}_{dr,\psi_D,K}
\end{aligned}$$

where

$$m : \psi_D(O_{S^\circ}) \otimes_{O_S} \psi_D(O_{S^\circ}) \xrightarrow{\sim} \psi_D O_{S^\circ}, \quad m(b_1 \otimes b_2) = b_1 b_2$$

is the multiplication map whose inverse is

$$n : \psi_D(O_{S^\circ}) \xrightarrow{\sim} \psi_D(O_{S^\circ}) \otimes_{O_S} \psi_D(O_{S^\circ}), \quad n(b) = b \otimes 1.$$

- We have similarly to  $\mathbb{B}_{dr,\psi_D,K}$  the isomorphism

$$m(\mathbb{B}_{dr,\phi_D,K}) : \mathbb{B}_{dr,\phi_D,K} \otimes_{\mathbb{B}_{dr,S_K}} \mathbb{B}_{dr,\phi_D,K} \xrightarrow{\sim} \mathbb{B}_{dr,\phi_D,K}$$

with

$$m : \phi_D(O_{S^\circ}) \otimes_{O_S} \phi_D(O_{S^\circ}) \xrightarrow{\sim} \phi_D O_{S^\circ}, \quad m(b_1 \otimes b_2) = b_1 b_2$$

is the multiplication map whose inverse is

$$n : \phi_D(O_{S^\circ}) \xrightarrow{\sim} \phi_D(O_{S^\circ}) \otimes_{O_S} \phi_D(O_{S^\circ}), \quad n(b) = b \otimes 1.$$

- We have similarly the isomorphism

$$m(\mathbb{B}_{dr, x_{S^\circ}/S, K}) : \mathbb{B}_{dr, x_{S^\circ}/S, K} \otimes_{\mathbb{B}_{dr, S_K}} \mathbb{B}_{dr, x_{S^\circ}/S, K} \xrightarrow{\sim} \mathbb{B}_{dr, x_{S^\circ}/S, K}$$

with

$$m := (m, 0, m) : \text{Cone}(j_* O_{S^\circ} \rightarrow \psi_D(O_{S^\circ})) \otimes_{O_S} \text{Cone}(j_* O_{S^\circ} \rightarrow \psi_D(O_{S^\circ})) \xrightarrow{\sim} \text{Cone}(j_* O_{S^\circ} \rightarrow \psi_D(O_{S^\circ})).$$

**Definition 80.** (i) Let  $S \in \text{SmVar}(k)$ . For  $(K_1, W), (K_2, W) \in P_{\mathbb{Z}_p, \text{fil}, k}(S^{et})$  filtered perverse sheaves, we have the isomorphism in  $D_{\mathbb{B}_{dr, \text{fil}}}(S_K^{an, \text{pet}})$

$$\begin{aligned} & T(\otimes, \mathbb{B}_{dr})((K_1, W), (K_2, W)) : \mathbb{B}_{dr, S}(K_1, W) \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, S}(K_2, W) \\ \xrightarrow{=} & (\cdots \rightarrow \bigoplus_{1 \leq i_1 < \cdots < i_d \leq d} x_{S \setminus D_{i_1}/S} \cdots x_{S \setminus D_{i_r}/S} \phi_{D_{i_{r+1}}} \cdots \phi_{D_{i_s}} \psi_{D_{i_{s+1}}} \cdots \psi_{D_{i_d}}(K_1, W) \otimes_{\mathbb{Q}_p} \\ & \mathbb{B}_{dr, x_{S \setminus D_{i_1}/S}} \otimes_{\mathbb{B}_{dr, S}} \cdots \otimes_{\mathbb{B}_{dr, S_K}} \mathbb{B}_{dr, x_{S \setminus D_{i_r}/S}} \otimes_{\mathbb{B}_{dr, S_K}} \mathbb{B}_{dr, \phi_{D_{i_{r+1}}}} \otimes_{\mathbb{B}_{dr, S}} \cdots \\ & \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \phi_{D_{i_s}}} \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \psi_{D_{i_{s+1}}}} \otimes_{\mathbb{B}_{dr, S}} \cdots \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \psi_{D_{i_d}}} \rightarrow \cdots) \otimes_{\mathbb{B}_{dr, S}} \\ & (\cdots \rightarrow \bigoplus_{1 \leq i_1 < \cdots < i_d \leq d} x_{S \setminus D_{i_1}/S} \cdots x_{S \setminus D_{i_r}/S} \phi_{D_{i_{r+1}}} \cdots \phi_{D_{i_s}} \psi_{D_{i_{s+1}}} \cdots \psi_{D_{i_d}}(K_2, W) \otimes_{\mathbb{Q}_p} \\ & \mathbb{B}_{dr, x_{S \setminus D_{i_1}/S}} \otimes_{\mathbb{B}_{dr, S}} \cdots \otimes_{\mathbb{B}_{dr, S_K}} \mathbb{B}_{dr, x_{S \setminus D_{i_r}/S}} \otimes_{\mathbb{B}_{dr, S_K}} \mathbb{B}_{dr, \phi_{D_{i_{r+1}}}} \otimes_{\mathbb{B}_{dr, S}} \cdots \\ & \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \phi_{D_{i_s}}} \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \psi_{D_{i_{s+1}}}} \otimes_{\mathbb{B}_{dr, S}} \cdots \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \psi_{D_{i_d}}} \rightarrow \cdots) \\ \xrightarrow{=} & (\cdots \rightarrow \bigoplus_{1 \leq i_1 < \cdots < i_d \leq d} x_{S \setminus D_{i_1}/S} \cdots x_{S \setminus D_{i_r}/S} \phi_{D_{i_{r+1}}} \cdots \phi_{D_{i_s}} \psi_{D_{i_{s+1}}} \cdots \psi_{D_{i_d}}((K_1, W) \otimes (K_2, W)) \otimes_{\mathbb{Q}_p} \\ & \mathbb{B}_{dr, x_{S \setminus D_{i_1}/S}} \otimes_{\mathbb{B}_{dr, S}} \cdots \otimes_{\mathbb{B}_{dr, S_K}} \mathbb{B}_{dr, x_{S \setminus D_{i_r}/S}} \otimes_{\mathbb{B}_{dr, S_K}} \mathbb{B}_{dr, \phi_{D_{i_{r+1}}}} \otimes_{\mathbb{B}_{dr, S}} \cdots \\ & \mathbb{B}_{dr, \phi_{D_{i_{r+1}}}} \otimes_{\mathbb{B}_{dr, S_K}} \cdots \otimes_{\mathbb{B}_{dr, S_K}} \mathbb{B}_{dr, \phi_{D_{i_s}}, K} \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \psi_{D_{i_{s+1}}}} \otimes_{\mathbb{B}_{dr, S_K}} \cdots \\ & \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \psi_{D_{i_d}}, K} \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, x_{S \setminus D_{i_1}/S}} \otimes_{\mathbb{B}_{dr, S}} \cdots \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, x_{S \setminus D_{i_r}/S}} \otimes_{\mathbb{B}_{dr, S}} \\ & \mathbb{B}_{dr, \phi_{D_{i_{r+1}}}} \otimes_{\mathbb{B}_{dr, S}} \cdots \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \phi_{D_{i_s}}} \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \psi_{D_{i_{s+1}}}} \otimes_{\mathbb{B}_{dr, S}} \cdots \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \psi_{D_{i_d}}} \rightarrow \cdots) \\ & \xrightarrow{(m(\mathbb{B}_{dr, x_{S \setminus D_{i_1}/S}), \cdots, m(\mathbb{B}_{dr, \phi_{D_{i_{r+1}}}), \cdots, m(\mathbb{B}_{dr, \psi_{D_{i_d}}, K}))} \\ & (\cdots \rightarrow \bigoplus_{1 \leq i_1 < \cdots < i_d \leq d} x_{S \setminus D_{i_1}/S} \cdots x_{S \setminus D_{i_r}/S} \phi_{D_{i_{r+1}}} \cdots \phi_{D_{i_s}} \psi_{D_{i_{s+1}}} \cdots \psi_{D_{i_d}}((K_1, W) \otimes (K_2, W)) \otimes_{\mathbb{Q}_p} \\ & \mathbb{B}_{dr, x_{S \setminus D_{i_1}/S}} \otimes_{\mathbb{B}_{dr, S}} \cdots \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, x_{S \setminus D_{i_r}/S}} \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \phi_{D_{i_{r+1}}}, K} \otimes_{\mathbb{B}_{dr, S}} \cdots \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, \phi_{D_{i_s}}} \\ & \xrightarrow{=} \mathbb{B}_{dr, S}((K_1, W) \otimes (K_2, W)) \end{aligned}$$

with  $(D_1, \dots, D_d) \in \mathcal{S}(K)$  a stratification by (Cartier) divisor  $D_i \subset S$ ,  $1 \leq i \leq d$  such that

$$K_{1|D(r) \setminus D(r+1)}, K_{2|D(r) \setminus D(r+1)} \in D_{\mathbb{Z}_p, c}(D(r) \setminus D(r+1))^{et}$$

are local systems for all  $1 \leq r \leq d$ .

(ii) Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i \in I} S_i$  an open cover such that there exists closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_I \in \text{SmVar}(k)$ . For  $(K_1, W), (K_2, W) \in P_{\mathbb{Z}_p, \text{fil}, k}(S^{et})$  filtered perverse sheaves, we have the

isomorphism in  $D_{\mathbb{B}_{dr}, \text{fil}}(S_K^{\text{an}, \text{pet}} / (\tilde{S}_{I, K}^{\text{an}, \text{pet}}))$  given as in (i)

$$\begin{aligned}
& T(\otimes, \mathbb{B}_{dr})((K_1, W), (K_2, W)) : \mathbb{B}_{dr, (\tilde{S}_I)}(K_1, W) \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, (\tilde{S}_I)}(K_2, W) \\
& \xrightarrow{=} \left( \left( \bigoplus_{1 \leq i_1 < \dots < i_d \leq d} x_{\tilde{S}_I \setminus \tilde{D}_{i_1, I} / \tilde{S}_I} \cdots x_{\tilde{S}_I \setminus \tilde{D}_{i_r, I} / \tilde{S}_I} \phi_{\tilde{D}_{i_{r+1}, I}} \cdots \phi_{\tilde{D}_{i_s, I}} \psi_{\tilde{D}_{i_{s+1}, I}} \cdots \psi_{\tilde{D}_{i_d, I}} (i_{I*} j_I^*(K_1, W)) \otimes_{\mathbb{Q}_p} \right. \right. \\
& \quad \mathbb{B}_{dr, x_{\tilde{S}_I \setminus \tilde{D}_{i_1, I} / S}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \cdots \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, x_{\tilde{S}_I \setminus D_{i_r, I} / \tilde{S}_I}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, \phi_{\tilde{D}_{i_{r+1}, I}}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \\
& \quad \cdots \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, \phi_{\tilde{D}_{i_s, I}}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, \psi_{\tilde{D}_{i_{s+1}, I}}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \cdots \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, \psi_{\tilde{D}_{i_d, I}}} \rightarrow \cdots \Big), \mathbb{B}_{dr}(t_{IJ}) \Big) \otimes_{\mathbb{B}_{dr, S}} \\
& \left( \left( \bigoplus_{1 \leq i_1 < \dots < i_d \leq d} x_{\tilde{S}_I \setminus \tilde{D}_{i_1, I} / \tilde{S}_I} \cdots x_{\tilde{S}_I \setminus \tilde{D}_{i_r, I} / \tilde{S}_I} \phi_{\tilde{D}_{i_{r+1}, I}} \cdots \phi_{\tilde{D}_{i_s, I}} \psi_{\tilde{D}_{i_{s+1}, I}} \cdots \psi_{\tilde{D}_{i_d, I}} (i_{I*} j_I^*(K_2, W)) \otimes_{\mathbb{Q}_p} \right. \right. \\
& \quad \mathbb{B}_{dr, x_{\tilde{S}_I \setminus \tilde{D}_{i_1, I} / S}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \cdots \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, x_{\tilde{S}_I \setminus D_{i_r, I} / \tilde{S}_I}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, \phi_{\tilde{D}_{i_{r+1}, I}}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \\
& \quad \cdots \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, \phi_{\tilde{D}_{i_s, I}}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, \psi_{\tilde{D}_{i_{s+1}, I}}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \cdots \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, \psi_{\tilde{D}_{i_d, I}}} \rightarrow \cdots \Big), \mathbb{B}_{dr}(t_{IJ}) \Big) \xrightarrow{=} \\
& \left( \left( \bigoplus_{1 \leq i_1 < \dots < i_d \leq d} x_{\tilde{S}_I \setminus \tilde{D}_{i_1, I} / \tilde{S}_I} \cdots x_{\tilde{S}_I \setminus \tilde{D}_{i_r, I} / \tilde{S}_I} \phi_{\tilde{D}_{i_{r+1}, I}} \cdots \phi_{\tilde{D}_{i_s, I}} \psi_{\tilde{D}_{i_{s+1}, I}} \cdots \psi_{\tilde{D}_{i_d, I}} (i_{I*} j_I^*((K_1, W) \otimes (K_2, W))) \right. \right. \\
& \quad \otimes_{\mathbb{Q}_p} \mathbb{B}_{dr, x_{\tilde{S}_I \setminus \tilde{D}_{i_1, I} / S}}^2 \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \cdots \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, x_{\tilde{S}_I \setminus D_{i_r, I} / \tilde{S}_I}}^2 \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, \phi_{\tilde{D}_{i_{r+1}, I}}}^2 \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \\
& \quad \cdots \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, \phi_{\tilde{D}_{i_s, I}}}^2 \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, \psi_{\tilde{D}_{i_{s+1}, I}}}^2 \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \cdots \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, \psi_{\tilde{D}_{i_d, I}}}^2 \rightarrow \cdots \Big), \mathbb{B}_{dr}(t_{IJ}) \Big) \\
& \quad \xrightarrow{(m(\mathbb{B}_{dr, x_{\tilde{S}_I \setminus D_{i_1, I} / S, K}), \dots, m(\mathbb{B}_{dr, \phi_{\tilde{D}_{i_{r+1}, I}}}), \dots, m(\mathbb{B}_{dr, \psi_{\tilde{D}_{i_d, I}}}))} \\
& \left( \left( \bigoplus_{1 \leq i_1 < \dots < i_d \leq d} x_{\tilde{S}_I \setminus \tilde{D}_{i_1, I} / \tilde{S}_I} \cdots x_{\tilde{S}_I \setminus \tilde{D}_{i_r, I} / \tilde{S}_I} \phi_{\tilde{D}_{i_{r+1}, I}} \cdots \phi_{\tilde{D}_{i_s, I}} \psi_{\tilde{D}_{i_{s+1}, I}} \cdots \psi_{\tilde{D}_{i_d, I}} (i_{I*} j_I^*((K_1, W) \otimes (K_2, W))) \right. \right. \\
& \quad \otimes_{\mathbb{Q}_p} \mathbb{B}_{dr, x_{\tilde{S}_I \setminus \tilde{D}_{i_1, I} / S}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \cdots \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, x_{\tilde{S}_I \setminus D_{i_r, I} / \tilde{S}_I}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, \phi_{\tilde{D}_{i_{r+1}, I}}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \cdots \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \\
& \quad \mathbb{B}_{dr, \phi_{\tilde{D}_{i_s, I}}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, \psi_{\tilde{D}_{i_{s+1}, I}}} \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \cdots \otimes_{\mathbb{B}_{dr, \tilde{S}_I}} \mathbb{B}_{dr, \psi_{\tilde{D}_{i_d, I}}} \rightarrow \cdots \Big), \mathbb{B}_{dr}(t_{IJ}) \Big) \\
& \quad \xrightarrow{=} \mathbb{B}_{dr, (\tilde{S}_I)}((K_1, W) \otimes (K_2, W))
\end{aligned}$$

with  $(D_1, \dots, D_d) \in \mathcal{S}(K)$  stratifications by Cartier divisor  $D_i \subset S$ ,  $1 \leq i \leq d$  such that

$$K_{1|D(r) \setminus D(r+1)}, K_{2|D(r) \setminus D(r+1)} \in D_{\mathbb{Z}_p, c}(D(r) \setminus D(r+1))^{\text{et}}$$

are local systems for all  $1 \leq r \leq d$ , and  $\tilde{D}_{s, I} \subset \tilde{S}_I$  (Cartier) divisor such that  $D_s \cap S_I \subset \tilde{D}_{s, I} \cap S$ . This gives, for  $(K_1, W), (K_2, W) \in D_{\mathbb{Z}_p, \text{fil}, c, k}(S^{\text{et}})$ , isomorphism in  $D_{\mathbb{B}_{dr}, \text{fil}}(S_K^{\text{an}, \text{pet}} / (\tilde{S}_{I, K}^{\text{an}, \text{pet}}))$ ,

$$\begin{aligned}
& T(\otimes, \mathbb{B}_{dr})((K_1, W), (K_2, W)) : \mathbb{B}_{dr, (\tilde{S}_I)}(K_1, W) \otimes_{\mathbb{B}_{dr, S}} \mathbb{B}_{dr, (\tilde{S}_I)}(K_2, W) \\
& \quad \xrightarrow{\sim} \mathbb{B}_{dr, (\tilde{S}_I)}((K_1, W) \otimes (K_2, W)).
\end{aligned}$$

**Definition 81.** (i) Let  $S \in \text{SmVar}(k)$ . For  $(K, W) \in D_{\mathbb{Z}_p, \text{fil}, c, k}(S^{\text{et}})$ , we have the isomorphism

$$T(D, \mathbb{B}_{dr})(K, W) : \mathbb{B}_{dr, S}(\mathbb{D}_S^v(K, W)) \xrightarrow{B((K, W), \mathbb{D}_S^v(K, W))} \mathbb{D}_S \mathbb{B}_{dr, S}(K, W)$$

given by the pairing

$$\begin{aligned}
& B((K, W), \mathbb{D}_S^v(K, W)) : \mathbb{B}_{dr, S}(\mathbb{D}_S^v(K, W)) \otimes_{\mathbb{B}_{dr, S, K}} \mathbb{B}_{dr, S}(K, W) \xrightarrow{T(\otimes, \mathbb{B}_{dr})((K, W), \mathbb{D}_S^v(K, W))} \\
& \quad \mathbb{B}_{dr, S}(\mathbb{D}_S^v(K, W) \otimes (K, W)) \xrightarrow{\mathbb{B}_{dr, S}(\text{ev}_K)} \mathbb{B}_{dr, S}(\mathbb{Z}_p, S^{\text{et}}) \xrightarrow{\alpha(S_K)^{-1}} \mathbb{B}_{dr, S, K}
\end{aligned}$$

using definition 80.

(ii) Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i \in I} S_i$  an open cover such that there exists closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_I \in \text{SmVar}(k)$ . For  $(K, W) \in D_{\mathbb{Z}_p \text{fil}, c, k}(S^{et})$ , we have the isomorphism in  $D_{\mathbb{B}_{dr}, \text{fil}}(S_K^{an, pet} / (\tilde{S}_{I, K}^{an, pet}))$

$$T(D, \mathbb{B}_{dr})(K, W) : \mathbb{B}_{dr, (\tilde{S}_I)}(\mathbb{D}_S^v(K, W)) \xrightarrow{B((K, W), \mathbb{D}_S^v(K, W))} \mathbb{D}_S \mathbb{B}_{dr, (\tilde{S}_I)}(K, W)$$

given by the pairing

$$\begin{aligned} B((K, W), \mathbb{D}_S^v(K, W)) : \mathbb{B}_{dr, (\tilde{S}_I)}(\mathbb{D}_S^v(K, W)) \otimes_{\mathbb{B}_{dr, S_K}} \mathbb{B}_{dr, (\tilde{S}_I)}(K, W) \\ \xrightarrow{T(\otimes, \mathbb{B}_{dr})((K, W), \mathbb{D}_S^v(K, W))} \mathbb{B}_{dr, (\tilde{S}_I)}(\mathbb{D}_S^v(K, W) \otimes (K, W)) \\ \xrightarrow{\mathbb{B}_{dr, (\tilde{S}_I)}(ev_K)} \mathbb{B}_{dr, (\tilde{S}_I)}(\mathbb{Z}_p, S^{et}) \xrightarrow{(\alpha(\tilde{S}_I, K))^{-1}} (\mathbb{B}_{dr, \tilde{S}_I, K}, t_{IJ}) \end{aligned}$$

using definition 80.

**Definition 82.** (i) Let  $j : S^\circ \hookrightarrow S$  an open embedding with  $S \in \text{SmVar}(k)$  and  $D := S \setminus S^\circ$  a (Cartier) divisor. We will consider, for  $(K, W) \in D_{\mathbb{Z}_p \text{fil}, c, k}(S^{\circ, et})$ , the canonical isomorphism in  $D_{\mathbb{B}_{dr}, \text{fil}}(S_K^{an, pet})$

$$\begin{aligned} T_!(j, \mathbb{B}_{dr})(K, W) : \mathbb{B}_{dr, S}(j!_w(K, W)) &:= \mathbb{B}_{dr, S}(\mathbb{D}_S^v j_{*w} \mathbb{D}_S^v(K, W)) \\ &\xrightarrow{T(D, \mathbb{B}_{dr})(j_{*w} \mathbb{D}_S^v(K, W))} \mathbb{D}_S \mathbb{B}_{dr, S}(j_{*w} \mathbb{D}_{S^\circ}^v(K, W)) \\ &\xrightarrow{\mathbb{D}_S T(j, \mathbb{B}_{dr})(\mathbb{D}_{S^\circ}^v(K, W))} \mathbb{D}_S(V_{D0} j_{*w} \mathbb{B}_{dr, S^\circ}(\mathbb{D}_{S^\circ}^v(K, W)) \otimes \mathbb{B}_{dr, S^\circ/S}) \\ &\xrightarrow{T(D, \mathbb{B}_{dr})(K, W)} \mathbb{D}_S(V_{D0} j_{*w} \mathbb{D}_{S^\circ} \mathbb{B}_{dr, S^\circ}(K, W) \otimes \mathbb{B}_{dr, S^\circ/S}) \\ &\xrightarrow{\cong} V_{D0} j!_w \mathbb{B}_{dr, S^\circ}(K, W) \otimes_{\mathbb{B}_{dr, S}} \mathbb{D}_S \mathbb{B}_{dr, S^\circ/S}, \end{aligned}$$

using definition 79 and definition 81.

(ii) Let  $l : S^\circ \hookrightarrow S$  an open embedding with  $S \in \text{Var}(k)$  such that  $D = S \setminus S^\circ$  is a Cartier divisor. Let  $S = \cup_i S_i$  an open affine cover and  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embedding with  $\tilde{S}_i \in \text{SmVar}(k)$ . Let  $l_I : \tilde{S}_I^\circ \hookrightarrow \tilde{S}_I$  open embeddings such that  $\tilde{S}_I^\circ \cap S = S^\circ \cap S_I$  and  $\tilde{D}_I \subset \tilde{S}_I$  a Cartier divisor such that  $D \cap S_I \subset \tilde{D}_I \cap S$ . We will consider, for  $(K, W) \in D_{\mathbb{Z}_p \text{fil}, c, k}(S^{\circ, et})$ , the canonical isomorphism in  $D_{\mathbb{B}_{dr}, \text{fil}}(S_K^{an, pet} / (\tilde{S}_{I, K}^{an, pet}))$

$$\begin{aligned} T_!(l, \mathbb{B}_{dr})(K, W) : \mathbb{B}_{dr, (\tilde{S}_I)}(l!_w(K, W)) &:= \mathbb{B}_{dr, (\tilde{S}_I)}(\mathbb{D}_S^v l_{*w} \mathbb{D}_S^v(K, W)) \\ &\xrightarrow{T(D, \mathbb{B}_{dr})(l_{*w} \mathbb{D}_S^v(K, W))} \mathbb{D}_S \mathbb{B}_{dr, (\tilde{S}_I)}(l_{*w} \mathbb{D}_{S^\circ}^v(K, W)) \\ &\xrightarrow{\mathbb{D}_S T(l, \mathbb{B}_{dr})(\mathbb{D}_{S^\circ}^v(K, W))} \mathbb{D}_S(V_{D0} l_{*w} \mathbb{B}_{dr, (\tilde{S}_I^\circ)}(\mathbb{D}_{S^\circ}^v(K, W)) \otimes_{\mathbb{B}_{dr, S}} (\mathbb{B}_{dr, \tilde{S}_I^\circ/\tilde{S}_I}, t_{IJ})) \\ &\xrightarrow{T(D, \mathbb{B}_{dr})(K, W)} \mathbb{D}_S(V_{D0} l_{*w} \mathbb{D}_{S^\circ} \mathbb{B}_{dr, (\tilde{S}_I^\circ)}(K, W) \otimes_{\mathbb{B}_{dr, S}} (\mathbb{B}_{dr, \tilde{S}_I^\circ/\tilde{S}_I}, t_{IJ})) \\ &\xrightarrow{\cong} V_{D0} l!_w \mathbb{B}_{dr, (\tilde{S}_I^\circ)}(K, W) \otimes_{\mathbb{B}_{dr, S}} \mathbb{D}_S(\mathbb{B}_{dr, \tilde{S}_I^\circ/\tilde{S}_I}) \end{aligned}$$

using definition 79 and definition 81.

As a consequence of this formalism we have :

**Theorem 45.** (i) Let  $S \in \text{SmVar}(k)$  irreducible. Let  $\bar{S} \in \text{PSmVar}(k)$  a compactification of  $S$ , with  $D := \bar{S} \setminus S \subset S$  a (Cartier) divisor. Denote by  $j : S^\circ \hookrightarrow S$  the open embedding. We have the canonical isomorphisms, given by, using definition 78, definition 79, definition 80 and definition

81, for  $K, K' \in D_{\mathbb{Z}_p, c, k}(S_k^{et})$ ,

$$\begin{aligned}
\mathbb{B}_{dr, S}(K_1, K_2) : R\mathrm{Hom}(K_1, K_2) \otimes \mathbb{B}_{dr, \bar{k}} &\xrightarrow{\cong} \mathbb{B}_{dr, \bar{k}}(Ra_{\bar{S}*}Rj_*\mathcal{H}om(K_1, K_2)) \\
&\xrightarrow{T(a_{\bar{S}, \mathbb{B}_{dr}}(-))} Ra_{\bar{S}*}\mathbb{B}_{dr, \bar{S}}(Rj_*\mathcal{H}om(K_1, K_2)) \\
&\xrightarrow{\mathbb{B}_{dr, \bar{S}}(T(j, \mathbb{B}_{dr})(-))} Ra_{\bar{S}*}(V_{D, 0}Rj_*\mathbb{B}_{dr, \bar{S}}(\mathcal{H}om(K_1, K_2)) \otimes_{\mathbb{B}_{dr, \bar{S}}} \mathbb{B}_{dr, \bar{S}}/\bar{S}) \\
&\xrightarrow{\mathbb{B}_{dr, \bar{S}}(m(K_1, K_2)^{-1})} Ra_{\bar{S}*}(V_{D, 0}Rj_*\mathbb{B}_{dr, \bar{S}}(\mathbb{D}_S^v K_1 \otimes K_2) \otimes_{\mathbb{B}_{dr, \bar{S}}} \mathbb{B}_{dr, \bar{S}}/\bar{S}) \\
&\xrightarrow{(T(D, \mathbb{B}_{dr})(K_1) \otimes I) \circ T(\otimes, \mathbb{B}_{dr})(\mathbb{D}_S K_1, K_2)} Ra_{\bar{S}*}(V_{D, 0}Rj_*(\mathbb{D}_S \mathbb{B}_{dr, \bar{S}}(K_1) \otimes_{\mathbb{B}_{dr, \bar{S}}} \mathbb{B}_{dr, \bar{S}}(K_2)) \otimes_{\mathbb{B}_{dr, \bar{S}}} \mathbb{B}_{dr, \bar{S}}/\bar{S}) \\
&\xrightarrow{m(\mathbb{B}_{dr, \bar{S}}(K_1), \mathbb{B}_{dr, \bar{S}}(K_2))} Ra_{\bar{S}*}(V_{D, 0}Rj_*\mathcal{H}om(\mathbb{B}_{dr, \bar{S}}(K_1), \mathbb{B}_{dr, \bar{S}}(K_2)) \otimes_{\mathbb{B}_{dr, \bar{S}}} \mathbb{B}_{dr, \bar{S}}/\bar{S}) \\
&\xrightarrow{\cong} R\mathrm{Hom}(\mathbb{B}_{dr, \bar{S}}(K_1), \mathbb{B}_{dr, \bar{S}}(K_2)).
\end{aligned}$$

(ii) Let  $S \in \mathrm{Var}(k)$ . Let  $\bar{S} \in \mathrm{PVar}(k)$  a compactification of  $S$ , with  $D := \bar{S} \setminus S \subset S$  a Cartier divisor. Denote by  $j : S^\circ \hookrightarrow S$  the open embedding. Let  $S = \cup_{i \in I} S_i$  an open cover such that there exists closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \mathrm{SmVar}(k)$ . We have the canonical isomorphisms, given by, using definition 78, definition 79, definition 80 and definition 81, for  $K, K' \in D_{\mathbb{Z}_p, c, k}(S_k^{et})$ ,

$$\begin{aligned}
\mathbb{B}_{dr, (\tilde{S}_I)}(K_1, K_2) : R\mathrm{Hom}(K_1, K_2) \otimes \mathbb{B}_{dr, \bar{k}} &\xrightarrow{\cong} \mathbb{B}_{dr, \bar{k}}(Ra_{\bar{S}*}Rj_*\mathcal{H}om(K_1, K_2)) \\
&\xrightarrow{T(a_{\bar{S}, \mathbb{B}_{dr}}(-))} Ra_{\bar{S}*}\mathbb{B}_{dr, \bar{S}}(Rj_*\mathcal{H}om(K_1, K_2)) \\
&\xrightarrow{\mathbb{B}_{dr, \bar{S}}(T(j, \mathbb{B}_{dr})(-))} Ra_{\bar{S}*}(V_{D, 0}Rj_*\mathbb{B}_{dr, \bar{S}}(\mathcal{H}om(K_1, K_2)) \otimes_{\mathbb{B}_{dr, \bar{S}}} (\mathbb{B}_{dr, \tilde{S}_I}/\tilde{S}_I, t_{IJ})) \\
&\xrightarrow{\mathbb{B}_{dr, \bar{S}}(m(K_1, K_2)^{-1})} Ra_{\bar{S}*}(V_{D, 0}Rj_*\mathbb{B}_{dr, \bar{S}}(\mathbb{D}_S^v K_1 \otimes K_2) \otimes_{\mathbb{B}_{dr, \bar{S}}} (\mathbb{B}_{dr, \tilde{S}_I}/\tilde{S}_I, t_{IJ})) \\
&\xrightarrow{(T(D, \mathbb{B}_{dr})(K_1) \otimes I) \circ T(\otimes, \mathbb{B}_{dr})(\mathbb{D}_S K_1, K_2)} \\
&\quad Ra_{\bar{S}*}(V_{D, 0}Rj_*(\mathbb{D}_S \mathbb{B}_{dr, \bar{S}}(K_1) \otimes_{\mathbb{B}_{dr, \bar{S}}} \mathbb{B}_{dr, \bar{S}}(K_2)) \otimes_{\mathbb{B}_{dr, \bar{S}}} (\mathbb{B}_{dr, \tilde{S}_I}/\tilde{S}_I, t_{IJ})) \\
&\xrightarrow{m(\mathbb{B}_{dr, \bar{S}}(K_1), \mathbb{B}_{dr, \bar{S}}(K_2))} Ra_{\bar{S}*}(V_{D, 0}Rj_*\mathcal{H}om(\mathbb{B}_{dr, \bar{S}}(K_1), \mathbb{B}_{dr, \bar{S}}(K_2)) \otimes_{\mathbb{B}_{dr, \bar{S}}} (\mathbb{B}_{dr, \tilde{S}_I}/\tilde{S}_I, t_{IJ})) \\
&\xrightarrow{\cong} R\mathrm{Hom}(\mathbb{B}_{dr, \bar{S}}(K_1), \mathbb{B}_{dr, \bar{S}}(K_2)).
\end{aligned}$$

*Proof.* Follows from theorem 44.  $\square$

Let  $S \in \mathrm{SmVar}(k)$  and  $D \subset S$  a (Cartier) divisor. We have by theorem 40 the following isomorphisms

$$\begin{aligned}
F^0 T^{B_{dr}}(O_S, F_b) : \mathbb{B}_{dr, \psi_D} &:= F^0 DR(S)(\psi_D(O_S, F_b)^{an} \otimes_{O_S} (O\mathbb{B}_{dr, S}, F)) \\
&\xrightarrow{\cong} F^0 \psi_D DR(S)(O\mathbb{B}_{dr, S}, F) \xrightarrow{\cong} \psi_D F^0 DR(S)(O\mathbb{B}_{dr, S}, F) =: \psi_D \mathbb{B}_{dr, S}
\end{aligned}$$

and

$$\begin{aligned}
F^0 T'^{B_{dr}}(O_S, F_b) : \mathbb{B}_{dr, \phi_D} &:= F^0 DR(S)(\phi_D(O_S, F_b)^{an} \otimes_{O_S} (O\mathbb{B}_{dr, S}, F)) \\
&\xrightarrow{\cong} F^0 \phi_D DR(S)(O\mathbb{B}_{dr, S}, F) \xrightarrow{\cong} \phi_D F^0 DR(S)(O\mathbb{B}_{dr, S}, F) =: \phi_D \mathbb{B}_{dr, S}.
\end{aligned}$$

**Definition 83.** (i) Let  $j : S^\circ \hookrightarrow S$  an open embedding with  $S \in \mathrm{SmVar}(k)$  and  $D := S \setminus S^\circ$  a (Cartier) divisor. We will consider, for  $(K, W) \in P_{\mathbb{Z}_p, fil, k}(S^{et})$ , the canonical isomorphism in

$D_{\mathbb{B}_{dr,S} \text{fil}}(S_K^{\text{an}, \text{pet}})$

$$\begin{aligned}
& T(\psi_D, \mathbb{B}_{dr})(K, W) : \mathbb{B}_{dr,S}(\psi_D(K, W)) \xrightarrow{=} \\
& (\cdots \rightarrow \bigoplus_{1 \leq i_1 \cdots < i_d \leq d} x_{S \setminus \bar{E}_{i_1}/S} \cdots x_{S \setminus \bar{E}_{i_r}/S} \phi_{\bar{E}_{i_{r+1}}} \cdots \phi_{\bar{E}_{i_s}} \psi_{\bar{E}_{i_{s+1}}} \cdots \psi_{\bar{E}_{i_d}} \psi_D(K, W) \\
& \quad \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr,\psi_D} \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr,x_{S \setminus \bar{E}_{i_1}/S}} \otimes_{\mathbb{B}_{dr,S}} \cdots \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr,x_{S \setminus \bar{E}_{i_r}/S}} \\
& \quad \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr,\phi_{\bar{E}_{i_{r+1}}}} \otimes \cdots \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr,\phi_{\bar{E}_{i_s}}} \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr,\psi_{\bar{E}_{i_{s+1}}}} \otimes \cdots \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr,\psi_{\bar{E}_{i_d}}} \rightarrow \cdots) \\
& \xrightarrow{I \otimes F^0 T^{\mathbb{B}_{dr}}(O_S, F_b) \otimes I} (\cdots \rightarrow \bigoplus_{1 \leq i_1 \cdots < i_d \leq d} x_{S \setminus \bar{E}_{i_1}/S} \cdots x_{S \setminus \bar{E}_{i_r}/S} \phi_{\bar{E}_{i_{r+1}}} \cdots \phi_{\bar{E}_{i_s}} \psi_{\bar{E}_{i_{s+1}}} \cdots \psi_{\bar{E}_{i_d}} \psi_D(K, W) \\
& \quad \otimes_{\psi_D} \mathbb{B}_{dr,S} \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr,x_{S \setminus \bar{E}_{i_1}/S}} \otimes_{\mathbb{B}_{dr,S}} \cdots \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr,x_{S \setminus \bar{E}_{i_r}/S}} \\
& \quad \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr,\phi_{\bar{E}_{i_{r+1}}}} \otimes \cdots \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr,\phi_{\bar{E}_{i_s}}} \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr,\psi_{\bar{E}_{i_{s+1}}}} \otimes \cdots \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr,\psi_{\bar{E}_{i_d}}} \rightarrow \cdots) \\
& \xrightarrow{I \otimes T(\psi_D, \otimes)(-, -)} (\cdots \rightarrow \bigoplus_{1 \leq i_1 \cdots < i_d \leq d} x_{S \setminus \bar{E}_{i_1}/S} \cdots x_{S \setminus \bar{E}_{i_r}/S} \phi_{\bar{E}_{i_{r+1}}} \cdots \phi_{\bar{E}_{i_s}} \psi_{\bar{E}_{i_{s+1}}} \cdots \psi_{\bar{E}_{i_d}} \psi_D(K, W) \\
& \quad \otimes_{\psi_D} (\mathbb{B}_{dr,x_{S \setminus \bar{E}_{i_1}/S}} \otimes_{\mathbb{B}_{dr,S}} \cdots \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr,x_{S \setminus \bar{E}_{i_r}/S}} \\
& \quad \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr,\phi_{\bar{E}_{i_{r+1}}}} \otimes \cdots \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr,\phi_{\bar{E}_{i_s}}} \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr,\psi_{\bar{E}_{i_{s+1}}}} \otimes \cdots \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr,\psi_{\bar{E}_{i_d}}}) \rightarrow \cdots) \\
& \xrightarrow{=} (\cdots \rightarrow \bigoplus_{1 \leq i_1 \cdots < i_d \leq d} \psi_D(x_{S \setminus \bar{E}_{i_1}/S} \cdots x_{S \setminus \bar{E}_{i_r}/S} \phi_{\bar{E}_{i_{r+1}}} \cdots \phi_{\bar{E}_{i_s}} \psi_{\bar{E}_{i_{s+1}}} \cdots \psi_{\bar{E}_{i_d}}(K, W) \\
& \quad \otimes_{\mathbb{B}_{dr,x_{S \setminus \bar{E}_{i_1}/S}} \otimes_{\mathbb{B}_{dr,S}} \cdots \otimes_{\mathbb{B}_{dr,x_{S \setminus \bar{E}_{i_r}/S}} \\
& \quad \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr,\phi_{\bar{E}_{i_{r+1}}}} \otimes \cdots \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr,\phi_{\bar{E}_{i_s}}} \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr,\psi_{\bar{E}_{i_{s+1}}}} \otimes \cdots \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr,\psi_{\bar{E}_{i_d}}}) \xrightarrow{=} \psi_D \mathbb{B}_{dr,S}((K, W))
\end{aligned}$$

We will also consider, for  $(K, W) \in D_{\mathbb{Z}_p \text{fil}, c, k}(S^{\circ, \text{et}})$ , the canonical isomorphism in  $D_{\mathbb{B}_{dr} \text{fil}}(S_K^{\text{an}, \text{pet}})$

$$\begin{aligned}
& T(\phi_D, \mathbb{B}_{dr})(K, W) : \mathbb{B}_{dr,S}(\phi_D(K, W)) = \mathbb{B}_{dr,S}(\mathbb{D}_S^v \psi_D \mathbb{D}_S^v(K, W)) \\
& \xrightarrow{T(D, \mathbb{B}_{dr})(\psi_D \mathbb{D}_S^v(K, W))} \mathbb{D}_S \mathbb{B}_{dr,S}(\psi_D \mathbb{D}_S^v(K, W)) \xrightarrow{\mathbb{D}_S T(\psi_D, \mathbb{B}_{dr})(\mathbb{D}_S^v(K, W))} \\
& \mathbb{D}_S(\psi_D \mathbb{B}_{dr,S}(\mathbb{D}_S^v(K, W))) \xrightarrow{T(D, \mathbb{B}_{dr})(K, W)} \mathbb{D}_S \psi_D \mathbb{D}_S \mathbb{B}_{dr,S}(K, W) \xrightarrow{=} \phi_D \mathbb{B}_{dr,S}(K, W),
\end{aligned}$$

using definition 81.

- (ii) Let  $l : S^\circ \hookrightarrow S$  an open embedding with  $S \in \text{Var}(k)$  such that  $D = S \setminus S^\circ \subset S$  is a Cartier divisor. Let  $S = \cup_i S_i$  an open affine cover and  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embedding with  $\tilde{S}_i \in \text{SmVar}(k)$ . Let  $l_I : \tilde{S}_I^\circ \hookrightarrow \tilde{S}_I$  open embeddings such that  $\tilde{S}_I^\circ \cap S = S^\circ \cap S_I$  and  $\tilde{D}_I \subset \tilde{S}_I$  a Cartier divisor such that  $D \cap S_I \subset \tilde{D}_I \cap S$ . We will consider, for  $(K, W) \in P_{\mathbb{Z}_p \text{fil}, k}(S^{\circ, \text{et}})$ , the canonical isomorphism in

$D_{\mathbb{B}_{dr}, \text{fil}}(S_K^{\text{an}, \text{pet}} / (\tilde{S}_{I, K})^{\text{an}, \text{pet}})$

$$\begin{aligned}
& T(\psi_D, \mathbb{B}_{dr})(K, W) : \mathbb{B}_{dr, (\tilde{S}_I)}(\psi_D(K, W)) \xrightarrow{=} \\
& ((\cdots \rightarrow \bigoplus_{1 \leq i_1 \cdots < i_d \leq d} x_{\tilde{S}_I \setminus \tilde{D}_{i_1, I} / \tilde{S}_I} \cdots x_{\tilde{S}_I \setminus \tilde{D}_{i_r, I} / S \phi_{\tilde{E}_{i_{r+1}, I}}} \cdots \phi_{\tilde{E}_{i_s, I}} \psi_{\tilde{E}_{i_{s+1}, I}} \cdots \psi_{\tilde{E}_{i_d, I}} i_{I*} j_I^* \psi_D(K, W) \\
& \quad \otimes \mathbb{B}_{dr, \psi_{\tilde{D}_I}} \otimes \mathbb{B}_{dr, \tilde{S}_I} \mathbb{B}_{dr, x_{\tilde{S}_I \setminus \tilde{E}_{i_1, I} / S}} \otimes \mathbb{B}_{dr, \tilde{S}_I} \cdots \otimes \mathbb{B}_{dr, x_{\tilde{S}_I \setminus \tilde{E}_{i_r, I} / S}} \\
& \quad \otimes \mathbb{B}_{dr, \tilde{S}_I} \mathbb{B}_{dr, \phi_{\tilde{E}_{i_{r+1}, I}}} \otimes \cdots \otimes \mathbb{B}_{dr, \phi_{\tilde{E}_{i_s, I}}} \otimes \mathbb{B}_{dr, \tilde{S}_I} \mathbb{B}_{dr, \psi_{\tilde{E}_{i_{s+1}, I}}} \otimes \cdots \otimes \mathbb{B}_{dr, \psi_{\tilde{E}_{i_d, I}}} \rightarrow \cdots), \mathbb{B}_{dr}(t_{IJ})) \\
& \quad \xrightarrow{I \otimes (F^0 B^{\mathbb{B}_{dr}}(O_{\tilde{S}_I}, F_b)) \circ (F^0 A^{\mathbb{B}_{dr}}(O_{\tilde{S}_I}, F_b))^{-1} \otimes I} \\
& ((\cdots \rightarrow \bigoplus_{1 \leq i_1 \cdots < i_d \leq d} x_{\tilde{S}_I \setminus \tilde{D}_{i_1, I} / \tilde{S}_I} \cdots x_{\tilde{S}_I \setminus \tilde{D}_{i_r, I} / S \phi_{\tilde{E}_{i_{r+1}, I}}} \cdots \phi_{\tilde{E}_{i_s, I}} \psi_{\tilde{E}_{i_{s+1}, I}} \cdots \psi_{\tilde{E}_{i_d, I}} i_{I*} j_I^* \psi_D(K, W) \\
& \quad \otimes \psi_{\tilde{D}_I} \mathbb{B}_{dr, \tilde{S}_I} \otimes \mathbb{B}_{dr, \tilde{S}_I} \mathbb{B}_{dr, x_{\tilde{S}_I \setminus \tilde{E}_{i_1, I} / S}} \otimes \mathbb{B}_{dr, \tilde{S}_I} \cdots \otimes \mathbb{B}_{dr, x_{\tilde{S}_I \setminus \tilde{E}_{i_r, I} / S}} \\
& \quad \otimes \mathbb{B}_{dr, \tilde{S}_I} \mathbb{B}_{dr, \phi_{\tilde{E}_{i_{r+1}, I}}} \otimes \cdots \otimes \mathbb{B}_{dr, \phi_{\tilde{E}_{i_s, I}}} \otimes \mathbb{B}_{dr, \tilde{S}_I} \mathbb{B}_{dr, \psi_{\tilde{E}_{i_{s+1}, I}}} \otimes \cdots \otimes \mathbb{B}_{dr, \psi_{\tilde{E}_{i_d, I}}} \rightarrow \cdots), \mathbb{B}_{dr}(t_{IJ})) \\
& \quad \xrightarrow{I \otimes (T(\psi_{\tilde{D}_I}, \otimes)(-, -))} \\
& ((\cdots \rightarrow \bigoplus_{1 \leq i_1 \cdots < i_d \leq d} x_{\tilde{S}_I \setminus \tilde{D}_{i_1, I} / \tilde{S}_I} \cdots x_{\tilde{S}_I \setminus \tilde{D}_{i_r, I} / S \phi_{\tilde{E}_{i_{r+1}, I}}} \cdots \phi_{\tilde{E}_{i_s, I}} \psi_{\tilde{E}_{i_{s+1}, I}} \cdots \psi_{\tilde{E}_{i_d, I}} i_{I*} j_I^* \psi_D(K, W) \\
& \quad \otimes \psi_{\tilde{D}_I} (\mathbb{B}_{dr, x_{\tilde{S}_I \setminus \tilde{E}_{i_1, I} / S}} \otimes \mathbb{B}_{dr, \tilde{S}_I} \cdots \otimes \mathbb{B}_{dr, x_{\tilde{S}_I \setminus \tilde{E}_{i_r, I} / S}} \\
& \quad \otimes \mathbb{B}_{dr, \tilde{S}_I} \mathbb{B}_{dr, \phi_{\tilde{E}_{i_{r+1}, I}}} \otimes \cdots \otimes \mathbb{B}_{dr, \phi_{\tilde{E}_{i_s, I}}} \otimes \mathbb{B}_{dr, \tilde{S}_I} \mathbb{B}_{dr, \psi_{\tilde{E}_{i_{s+1}, I}}} \otimes \cdots \otimes \mathbb{B}_{dr, \psi_{\tilde{E}_{i_d, I}}}) \rightarrow \cdots), \mathbb{B}_{dr}(t_{IJ})) \\
& \xrightarrow{=} ((\cdots \rightarrow \bigoplus_{1 \leq i_1 \cdots < i_d \leq d} \psi_{\tilde{D}_I} (x_{\tilde{S}_I \setminus \tilde{D}_{i_1, I} / \tilde{S}_I} \cdots x_{\tilde{S}_I \setminus \tilde{D}_{i_r, I} / S \phi_{\tilde{E}_{i_{r+1}, I}}} \cdots \phi_{\tilde{E}_{i_s, I}} \psi_{\tilde{E}_{i_{s+1}, I}} \cdots \psi_{\tilde{E}_{i_d, I}} i_{I*} j_I^* (K, W) \\
& \quad \otimes \psi_{\tilde{D}_I} (\mathbb{B}_{dr, x_{\tilde{S}_I \setminus \tilde{E}_{i_1, I} / S}} \otimes \mathbb{B}_{dr, \tilde{S}_I} \cdots \otimes \mathbb{B}_{dr, x_{\tilde{S}_I \setminus \tilde{E}_{i_r, I} / S}} \\
& \quad \otimes \mathbb{B}_{dr, \tilde{S}_I} \mathbb{B}_{dr, \phi_{\tilde{E}_{i_{r+1}, I}}} \otimes \cdots \otimes \mathbb{B}_{dr, \phi_{\tilde{E}_{i_s, I}}} \otimes \mathbb{B}_{dr, \tilde{S}_I} \mathbb{B}_{dr, \psi_{\tilde{E}_{i_{s+1}, I}}} \otimes \cdots \otimes \mathbb{B}_{dr, \psi_{\tilde{E}_{i_d, I}}}) \rightarrow \cdots), \mathbb{B}_{dr}(t_{IJ})) \\
& \quad \xrightarrow{=} \psi_D \mathbb{B}_{dr, (\tilde{S}_I)}(K, W)
\end{aligned}$$

where  $(E_1, \dots, E_d) \in \mathcal{S}(K)$  is a stratification by Cartier divisor  $E_i \subset S^\circ$ ,  $1 \leq i \leq d$ , such that

$$K_{|E(r) \setminus E(r+1)} := l_r^* K \in D_{\mathbb{Z}_p, c}((E(r) \setminus E(r+1))^{et})$$

are local systems for all  $1 \leq r \leq d$ ,  $l_r : E(r) \hookrightarrow S^\circ$  being the locally closed embeddings, and  $\tilde{E}_{s, I} \subset \tilde{S}_I$ ,  $\tilde{D}_I \subset \tilde{S}_I$  are (Cartier) divisor such that  $\tilde{E}_s \cap S_I \subset \tilde{E}_{s, I} \cap S_I$  and  $D \cap S_I \subset \tilde{D}_I \cap S_I$ . We will also consider, for  $(K, W) \in D_{\mathbb{Z}_p, \text{fil}, c, k}(S^{et})$ , the canonical isomorphism in  $D_{\mathbb{B}_{dr}, \text{fil}}(S_K^{\text{an}, \text{pet}} / (\tilde{S}_{I, K})^{\text{an}, \text{pet}})$

$$\begin{aligned}
& T(\phi_D, \mathbb{B}_{dr})(K, W) : \mathbb{B}_{dr, (\tilde{S}_I)}(\phi_D(K, W)) = \mathbb{B}_{dr, (\tilde{S}_I)}(\mathbb{D}_S^v \psi_D \mathbb{D}_S^v(K, W)) \\
& \xrightarrow{T(D, \mathbb{B}_{dr})(\psi_D \mathbb{D}_S^v(K, W))} \mathbb{D}_S \mathbb{B}_{dr, (\tilde{S}_I)}(\psi_D \mathbb{D}_S^v(K, W)) \xrightarrow{\mathbb{D}_S T(\psi_D, \mathbb{B}_{dr})(\mathbb{D}_S^v(K, W))} \\
& \mathbb{D}_S \psi_D \mathbb{B}_{dr, (\tilde{S}_I)}(\mathbb{D}_S^v(K, W)) \xrightarrow{T(D, \mathbb{B}_{dr})(K, W)} \mathbb{D}_S \psi_D \mathbb{D}_S \mathbb{B}_{dr, (\tilde{S}_I)}(K, W) \xrightarrow{=} \phi_D \mathbb{B}_{dr, (\tilde{S}_I)}(K, W),
\end{aligned}$$

using definition 81. It gives for  $(K, W) \in D_{\mathbb{Z}_p, \text{fil}, c, k}(S^{o, et})$ , the canonical isomorphisms

$$T(\psi_D, \mathbb{B}_{dr})(K, W) : \mathbb{B}_{dr, (\tilde{S}_I)}(\psi_D(K, W)) \xrightarrow{\sim} \psi_D \mathbb{B}_{dr, (\tilde{S}_I)}(K, W).$$

and

$$T(\phi_D, \mathbb{B}_{dr})(K, W) : \mathbb{B}_{dr, (\tilde{S}_I)}(\phi_D(K, W)) \xrightarrow{\sim} \phi_D \mathbb{B}_{dr, (\tilde{S}_I)}(K, W).$$

in  $D_{\mathbb{B}_{dr}, \text{fil}}(S_K^{\text{an}, \text{pet}} / (\tilde{S}_{I, K})^{\text{an}, \text{pet}})$ .



### 6.2.2 The geometric $p$ -adic Mixed Hodge Modules

Let  $p$  a prime integer. Let  $k \subset K \subset \mathbb{C}_p$  a subfield of a  $p$ -adic field. Denote by  $\bar{k} \subset \mathbb{C}_p$  its algebraic closure. Recall  $G = \text{Gal}(\bar{K}, K) \subset \text{Gal}(\bar{k}, k)$  denotes the Galois group of  $K$ .

For  $S \in \text{Var}(k)$ , we denote for short  $O_S := O_{S_{\mathbb{C}_p}^{an}}$ ,  $\mathbb{B}_{dr,S} := \mathbb{B}_{dr,S_{\mathbb{C}_p}} := \mathbb{B}_{dr,R_{\mathbb{C}_p}}(S_{\mathbb{C}_p}^{an})$  and  $O\mathbb{B}_{dr,S} := O\mathbb{B}_{dr,S_{\mathbb{C}_p}} := O\mathbb{B}_{dr,R_{\mathbb{C}_p}}(S_{\mathbb{C}_p}^{an})$ . where  $R_{\mathbb{C}_p} : \text{AnSp}(\mathbb{C}_p) \rightarrow \text{AdSp}/(\mathbb{C}_p, O_{\mathbb{C}_p})$  is the canonical functor (see section 2).

Let  $S \in \text{Var}(k)$ . Recall that  $S^{et} \subset \text{Var}(k)^{sm}/S$  denote the small etale site. We then have the morphism of site  $\text{an}_S : S^{an,pet} := S_{\mathbb{C}_p}^{an,pet} \rightarrow S^{et}$  given by the analytical functor where  $S_{\mathbb{C}_p}^{an,pet} \subset (\text{AnSp}(\mathbb{C}_p)^{sm}/S)^{pro}$  is the small pro-etale site. Then,  $\text{PSh}_{\mathbb{B}_{dr,G},fil}(S_{\mathbb{C}_p}^{an,pet})$  is the category whose objects are  $\pi_{K/\mathbb{C}_p}^{*mod}(N, F)$  with  $N \in \text{PSh}_{\mathbb{B}_{dr},fil}(S^{an,pet})$  together with a continuous action of  $G$  compatible with the  $\mathbb{B}_{dr,S}$  module structure.

- Let  $S \in \text{SmVar}(k)$ . The category  $C_{\mathcal{D}(1,0)fil,rh}(S) \times_I D_{\mathbb{Z}_p,fil,c,k}(S^{et})$  is the category
  - whose set of objects is the set of triples  $\{((M, F, W), (K, W), \alpha)\}$  with

$$(M, F, W) \in C_{\mathcal{D}(1,0)fil,rh}(S), (K, W) \in D_{\mathbb{Z}_p,fil,c,k}(S^{et}),$$

$$\alpha : \mathbb{B}_{dr,S}(K, W) \rightarrow F^0 DR(S)^{[-]}((M, F, W)^{an} \otimes_{O_S} (O\mathbb{B}_{dr,S}, F))$$

where

- \* we recall that

$$DR(S)^{[-]} = DR(S_{\mathbb{C}_p}^{an})^{[-]} : C_{\mathcal{D}(1,0)fil,rh}(S_{\mathbb{C}_p}^{an}) \rightarrow C_{\mathbb{B}_{dr}2fil}(S_{\mathbb{C}_p}^{an,pet})$$

is the De Rahm functor (for  $S' \subset S$  a connected component of dimension  $d$ ,  $DR(S)_{|S'}^{[-]} = DR(S)_{|S'}[d]$ ),

- \* the functor

$$\mathbb{B}_{dr,S} : D_{\mathbb{Z}_p,fil,c,k}(S^{et}) \rightarrow D_{\mathbb{B}_{dr},fil}(S_{\mathbb{C}_p}^{an,pet})$$

is the functor from complexes of presheaves with constructible etale cohomology to complexes of  $\mathbb{B}_{dr,S}$  modules given in definition 77 (recall that for  $L$  a local system, it is given by  $\mathbb{B}_{dr,S}(L) := \text{an}_S^* L \otimes_{\mathbb{Q}_p} \mathbb{B}_{dr,S_{\mathbb{C}_p}}$ ),

- \*  $\alpha$  is a morphism in  $D_{\mathbb{B}_{dr,G},fil}(S_{\mathbb{C}_p}^{an,pet})$ , that is a morphism in  $D_{\mathbb{B}_{dr},fil}(S_{\mathbb{C}_p}^{an,pet})$  compatible with the action of the galois group  $G = \text{Gal}(\bar{K}, K) \subset \text{Gal}(\bar{k}, k)$ ,

- and whose set of morphisms are

$$\phi = (\phi_D, \phi_C, [\theta]) : ((M_1, F, W), (K_1, W), \alpha_1) \rightarrow ((M_2, F, W), (K_2, W), \alpha_2)$$

where  $\phi_D : (M_1, F, W) \rightarrow (M_2, F, W)$  and  $\phi_C : (K_1, W) \rightarrow (K_2, W)$  are morphisms and

$$\theta = (\theta^\bullet, I(F^0 DR(S)(\phi_D^{an} \otimes I)) \circ I(\alpha_1), I(\alpha_2) \circ I(\mathbb{B}_{dr,S}(\phi_C))) :$$

$$I(\mathbb{B}_{dr,S}(K_1, W))[1] \rightarrow I(F^0 DR(S)((M, F, W)^{an} \otimes_{O_S} (O\mathbb{B}_{dr,S}, F)))$$

is an homotopy,  $I : C_{\mathbb{B}_{dr,S},G,fil}(S_{\mathbb{C}_p}^{an,pet}) \rightarrow K_{\mathbb{B}_{dr,S},G,fil}(S_{\mathbb{C}_p}^{an,pet})$  being the injective resolution functor : for  $(N, W) \in C_{\mathbb{B}_{dr,S},G,fil}(S_{\mathbb{C}_p}^{an,pet})$ ,  $k : (N, W) \rightarrow I(N, W)$  with  $I(N, W) \in C_{\mathbb{B}_{dr,S},G,fil}(S_{\mathbb{C}_p}^{an,pet})$  is an injective resolution, and the class  $[\theta]$  of  $\theta$  does NOT depend of the injective resolution ; in particular

$$F^0 DR(S)^{[-]}(\phi_D^{an} \otimes I) \circ \alpha_1 = \alpha_2 \circ \mathbb{B}_{dr,S}(\phi_C)$$

in  $D_{\mathbb{B}_{dr,S},G,fil}(S_{\mathbb{C}_p}^{an,pet})$ , and for

- \*  $\phi = (\phi_D, \phi_C, [\theta]) : ((M_1, F, W), (K_1, W), \alpha_1) \rightarrow ((M_2, F, W), (K_2, W), \alpha_2)$
- \*  $\phi' = (\phi'_D, \phi'_C, [\theta']) : ((M_2, F, W), (K_2, W), \alpha_2) \rightarrow ((M_3, F, W), (K_3, W), \alpha_3)$

the composition law is given by

$$\phi' \circ \phi := (\phi'_D \circ \phi_D, \phi'_C \circ \phi_C, I(F^0 DR(S)(\phi_C^{an} \otimes I)) \circ [\theta] + [\theta'] \circ I(\mathbb{B}_{dr,S}(\phi_C))[1]) : ((M_1, F, W), (K_1, W), \alpha_1) \rightarrow ((M_3, F, W), (K_3, W), \alpha_3),$$

in particular for  $((M, F, W), (K, W), \alpha) \in C_{\mathcal{D}(1,0)fil,rh}(S) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et})$ ,

$$I_{((M,F,W),(K,W),\alpha)} = (I_M, I_K, 0).$$

We have then the full embedding

$$\text{PSh}_{\mathcal{D}(1,0)fil,rh}(S) \times_I P_{\mathbb{Z}_p fil,k}(S^{et}) \hookrightarrow C_{\mathcal{D}(1,0)fil,rh}(S) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et})$$

where the category  $\text{PSh}_{\mathcal{D}(1,0)fil,rh}(S) \times_I P_{\mathbb{Z}_p fil,k}(S^{et})$  is the category

- whose set of objects is the set of triples  $\{((M, F, W), (K, W), \alpha)\}$  with

$$\begin{aligned} (M, F, W) &\in \text{PSh}_{\mathcal{D}(1,0)fil,rh}(S), (K, W) \in P_{\mathbb{Z}_p fil,k}(S^{et}), \\ \alpha : \mathbb{B}_{dr,S}(K, W) &\rightarrow F^0 DR(S)^{[-]}((M, F, W)^{an} \otimes_{O_S} (O_{\mathbb{B}_{dr,S}}(F))) \end{aligned}$$

where  $\alpha$  is an isomorphism,

- and whose set of morphisms are

$$\phi = (\phi_D, \phi_C) = (\phi_D, \phi_C, 0) : ((M_1, F, W), (K_1, W), \alpha_1) \rightarrow ((M_2, F, W), (K_2, W), \alpha_2)$$

where  $\phi_D : (M_1, F, W) \rightarrow (M_2, F, W)$  and  $\phi_C : (K_1, W) \rightarrow (K_2, W)$  are morphisms such that

$$F^0 DR(S)^{[-]}(\phi_D^{an} \otimes I) \circ \alpha_1 = \alpha_2 \circ \mathbb{B}_{dr,S}(\phi_C)$$

in  $P_{\mathbb{B}_{dr,S},G,fil}(S_{\mathbb{C}_p}^{an,pet})$ .

- Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i \in I} S_i$  an open cover such that there exists closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_I \in \text{SmVar}(k)$ . The category  $C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et})$  is the category

- whose set of objects is the set of triples  $\{(((M_I, F, W), u_{IJ}), (K, W), \alpha)\}$  with

$$\begin{aligned} ((M_I, F, W), u_{IJ}) &\in C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)), (K, W) \in D_{\mathbb{Z}_p fil,c,k}(S^{et}), \\ \alpha : \mathbb{B}_{dr,(\tilde{S}_I)}(K, W) &\rightarrow F^0 DR(S)^{[-]}(((M_I, F, W), u_{IJ})^{an} \otimes_{O_S} ((O_{\mathbb{B}_{dr,\tilde{S}_I}}(F), t_{IJ}))) \end{aligned}$$

where

- \* the functor

$$DR(S)^{[-]} = DR(S_{\mathbb{C}_p}^{an})^{[-]} : C_{\mathcal{D}(1,0)fil,rh}(S_{\mathbb{C}_p}^{an}/(\tilde{S}_{I,\mathbb{C}_p}^{an,pet})) \rightarrow C_{\mathbb{B}_{dr,2}fil}(S_{\mathbb{C}_p}^{an,pet}/(\tilde{S}_{I,\mathbb{C}_p}^{an,pet}))$$

is the De Rahm functor,

- \* the functor

$$\mathbb{B}_{dr,(\tilde{S}_I)} : D_{\mathbb{Z}_p fil,c,k}(S^{et}) \rightarrow D_{\mathbb{B}_{dr,fil}}(S_{\mathbb{C}_p}^{an,pet}/(\tilde{S}_{I,\mathbb{C}_p}^{an,pet}))$$

is the functor from complexes of presheaves with constructible etale cohomology to complexes of  $\mathbb{B}_{dr}$  modules given in definition 77,

- \*  $\alpha$  is a morphism in  $D_{\mathbb{B}_{dr},G,fil}(S_{\mathbb{C}_p}^{an,pet}/(\tilde{S}_{I,\mathbb{C}_p}^{an,pet}))$ , that is a morphism in  $D_{\mathbb{B}_{dr,fil}}(S_{\mathbb{C}_p}^{an,pet}/(\tilde{S}_{I,\mathbb{C}_p}^{an,pet}))$  compatible with the action of the galois group  $G = \text{Gal}(\tilde{k}, \hat{k}) \subset \text{Gal}(\bar{k}, k)$

– and whose set of morphisms are

$$\phi = (\phi_D, \phi_C, [\theta]) : (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2)$$

where  $\phi_D : ((M_{1I}, F, W), u_{IJ}) \rightarrow ((M_{2I}, F, W), u_{IJ})$  and  $\phi_C : (K_1, W) \rightarrow (K_2, W)$  are morphisms (of filtered complexes) and

$$\theta = (\theta^\bullet, I(F^0 DR(S)(\phi_D)) \circ I(\alpha_1), I(\alpha_2) \circ I(\mathbb{B}_{dr,S}(\phi_C))) : \\ I(\mathbb{B}_{dr,(\tilde{S}_I)}(K_1, W))[1] \rightarrow I(DR(S)((M_{2I}, F, W), u_{IJ})^{an} \otimes_{O_S} (O\mathbb{B}_{dr,(\tilde{S}_I)}, F), t_{IJ}))$$

is an homotopy,  $I : C_{\mathbb{B}_{dr,G,fil}}(S_{\mathbb{C}_p}^{an}/(\tilde{S}_{I,\mathbb{C}_p}^{an})) \rightarrow K_{\mathbb{B}_{dr,G,fil}}(S_{\mathbb{C}_p}^{an}/(\tilde{S}_{I,\mathbb{C}_p}^{an}))$  being the injective resolution functor : for  $((N_I, W), t_{IJ}) \in C_{\mathbb{B}_{dr,G,fil}}(S_{\mathbb{C}_p}^{an}/(\tilde{S}_{I,\mathbb{C}_p}^{an}))$ ,

$$k : ((N_I, W), t_{IJ}) \rightarrow I((N_I, W), t_{IJ})$$

with  $I((N_I, W), t_{IJ}) \in C_{\mathbb{B}_{dr,G,fil}}(S_{\mathbb{C}_p}^{an}/(\tilde{S}_{I,\mathbb{C}_p}^{an}))$  is an injective resolution, and the class  $[\theta]$  of  $\theta$  does NOT depend of the injective resolution ; in particular we have

$$F^0 DR(S)^{[-1]}(\phi_D^{an} \otimes I) \circ \alpha_1 = \alpha_2 \circ \mathbb{B}_{dr,(\tilde{S}_I)}(\phi_C)$$

in  $D_{\mathbb{B}_{dr,G,fil}}(S_{\mathbb{C}_p}/\tilde{S}_{I,\mathbb{C}_p}^{an,pet})$ , and for

$$\begin{aligned} * \phi &= (\phi_D, \phi_C, [\theta]) : (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2) \\ * \phi' &= (\phi'_D, \phi'_C, [\theta']) : (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2) \rightarrow (((M_{3I}, F, W), u_{IJ}), (K_3, W), \alpha_3) \end{aligned}$$

the composition law is given by

$$\phi' \circ \phi := (\phi'_D \circ \phi_D, \phi'_C \circ \phi_C, I(F^0 DR(S)(\phi_D^{an} \otimes I)) \circ [\theta] + [\theta'] \circ I(\mathbb{B}_{dr,(\tilde{S}_I)}(\phi_C))[1]) : \\ (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_{3I}, F, W), u_{IJ}), (K_3, W), \alpha_3).$$

in particular for  $((M_I, F, W), u_{IJ}), (K, W), \alpha \in C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p,fil,c,k}(S^{et})$ ,

$$I_{(((M_I, F, W), u_{IJ}), (K, W), \alpha)} = ((I_{M_I}), I_K, 0).$$

We have then full embeddings

$$\begin{aligned} \text{PSh}_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I P_{\mathbb{Z}_p,fil,k}(S^{et}) &\hookrightarrow C_{\mathcal{D}(1,0)fil,rh}^0(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p,fil,c,k}(S^{et}) \\ \xrightarrow{\iota_{S/\tilde{S}_I}^0} C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I))^0 \times_I D_{\mathbb{Z}_p,fil,c,k}(S^{et}) &\hookrightarrow C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p,fil,c,k}(S^{et}) \end{aligned}$$

where the category  $\text{PSh}_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I P_{\mathbb{Z}_p,fil,k}(S^{et})$  is the category

– whose set of objects is the set of triples  $\{(((M_I, F, W), u_{IJ}), (K, W), \alpha)\}$  with

$$\begin{aligned} ((M_I, F, W), u_{IJ}) &\in \text{PSh}_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)), (K, W) \in P_{\mathbb{Z}_p,fil,k}(S^{et}), \\ \alpha &: \mathbb{B}_{dr,(\tilde{S}_I)}(K, W) \rightarrow F^0 DR(S)^{[-1]}(((M_I, F, W), u_{IJ})^{an} \otimes_{O_S} (O\mathbb{B}_{dr,(\tilde{S}_I)}, F)) \end{aligned}$$

where  $\alpha$  is an isomorphism,

– and whose set of morphisms are

$$\phi = (\phi_D, \phi_C) = (\phi_D, \phi_C, 0) : (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2)$$

where  $\phi_D : ((M_{1I}, F, W), u_{IJ}) \rightarrow ((M_{2I}, F, W), u_{IJ})$  and  $\phi_C : (K_1, W) \rightarrow (K_2, W)$  are morphisms such that

$$F^0 DR(S)^{[-1]}(\phi_D^{an} \otimes I) \circ \alpha_1 = \alpha_2 \circ \mathbb{B}_{dr,(\tilde{S}_I)}(\phi_C)$$

in  $P_{\mathbb{B}_{dr,S,G,fil}}(S_{\mathbb{C}_p}^{an,pet}/(\tilde{S}_{I,\mathbb{C}_p}^{an,pet}))$ .

Moreover,

- For  $((M_I, F, W), u_{IJ}), (K, W), \alpha \in C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et})$ , we set

$$(((M_I, F, W), u_{IJ}), (K, W), \alpha)[1] := (((M_I, F, W), u_{IJ})[1], (K, W)[1], \alpha[1]).$$

- For

$$\phi = (\phi_D, \phi_C, [\theta]) : (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2)$$

a morphism in  $C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et})$ , we set (see [11] definition 3.12)

$$\text{Cone}(\phi) := (\text{Cone}(\phi_D), \text{Cone}(\phi_C), ((\alpha_1, \theta), (\alpha_2, 0))) \in D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et}),$$

$((\alpha_1, \theta), (\alpha_2, 0))$  being the matrix given by the composition law, together with the canonical maps

- $c_1(-) = (c_1(\phi_D), c_1(\phi_C), 0) : (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2) \rightarrow \text{Cone}(\phi)$
- $c_2(-) = (c_2(\phi_D), c_2(\phi_C), 0) : \text{Cone}(\phi) \rightarrow (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1)[1]$ .

**Remark 8.** By [11] theorem 3.25, if

$$\phi = (\phi_D, \phi_C, [\theta]) : (((M_1, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_2, F, W), u_{IJ}), (K_2, W), \alpha_2)$$

is a morphism in  $C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et})$  such that  $\phi_D$  is a Zariski local equivalence and  $\phi_C$  is an isomorphism then  $\phi$  is an isomorphism.

**Definition 84.** Let  $k \subset \mathbb{C}_p$  a subfield.

(i1) Let  $f : X \rightarrow S$  a proper morphism with  $S, X \in \text{SmVar}(k)$ . Let

$$\alpha : \mathbb{B}_{dr,X}(K, W) \rightarrow F^0 DR(X)((M, F, W)^{an} \otimes_{O_X} (O\mathbb{B}_{dr,X}, F))$$

a morphism in  $D_{\mathbb{B}_{dr,G,fil}}(X_{\mathbb{C}_p}^{an,pet})$ , with  $(M, F, W) \in C(DRM(X))$  and  $(K, W) \in D_{\mathbb{Z}_p fil,c,k}(X^{et})$ .

We then consider, using definition 78 and definition 50, the map in  $D_{\mathbb{B}_{dr,G,fil}}(S_{\mathbb{C}_p}^{an,pet})$

$$\begin{aligned} f_*\alpha &= f_*(\alpha) : \mathbb{B}_{dr,S}(Rf_*(K, W)) \xrightarrow{T(f, \mathbb{B}_{dr})(K, W)} Rf_*\mathbb{B}_{dr,X}(K, W) \\ &\xrightarrow{Rf_*\alpha} Rf_*F^0 DR(X)((M, F, W)^{an} \otimes_{O_X} (O\mathbb{B}_{dr,X}, F)) \\ &\xrightarrow{Rf_*\iota_{F^0}(-)} F^0 Rf_* DR(X)((M, F, W)^{an} \otimes_{O_X} (O\mathbb{B}_{dr,X}, F)) \\ &\xrightarrow{F^0 T^{\mathbb{B}_{dr}}(f, DR)(M, F, W)^{-1}} F^0 DR(S)\left(\int_f ((M, F, W)^{an}) \otimes_{O_S} (O\mathbb{B}_{dr,S}, F)\right) \\ &\xrightarrow{F^0 DR(S)(T(an, f_f)(M, F, W)^{-1})} F^0 DR(S)\left(\int_f (M, F, W)^{an} \otimes_{O_S} (O\mathbb{B}_{dr,S}, F)\right) \\ &\xrightarrow{\cong} F^0 DR(S)((Rf_* Hdq(M, F, W))^{an} \otimes_{O_S} (O\mathbb{B}_{dr,S}, F)) \end{aligned}$$

where  $\iota_{F^0}(A) = D_{fil}(\iota_{F^0}(A))$  is the image of the embedding  $\iota_{F^0}(A) : F^0 A \hookrightarrow A$  by the localization functor.

(i2) Let  $j : S^\circ \hookrightarrow S$  an open embedding with  $S \in \text{SmVar}(k)$  and  $D = S \setminus S^\circ$  a (Cartier) divisor. Let

$$\alpha : \mathbb{B}_{dr,S^\circ}(K, W) \rightarrow F^0 DR(S^\circ)((M, F, W)^{an} \otimes_{O_{S^\circ}} (O\mathbb{B}_{dr,S^\circ}, F))$$

a morphism in  $D_{\mathbb{B}_{dr},G,fil}(S_{\mathbb{C}_p}^{o,an,pet})$ , with  $(M, F, W) \in C(DRM(S^o))$  and  $(K, W) \in D_{Z_p,fil,c,k}(S^{o,et})^{ad,D}$ . We then consider, using definition 79 together with theorem 45, theorem 28 and the strictness of the  $V$ -filtration, and definition 50, the maps in  $D_{\mathbb{B}_{dr},G,fil}(S_{\mathbb{C}_p}^{an,pet})$

$$\begin{aligned}
j_*\alpha &= j_*(\alpha) : \mathbb{B}_{dr,S}(j_{*w}(K, W)) \xrightarrow{T(j, \mathbb{B}_{dr})(K, W)} V_{D_0} j_{*w} \mathbb{B}_{dr, S^o}(K, W) \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr, S^o/S} \\
&\xrightarrow{V_{D_0} j_* \alpha \otimes I} V_{D_0} j_{*w} (F^0 DR(S^o)((M, F, W)^{an} \otimes_{O_{S^o}} (O_{\mathbb{B}_{dr, S^o}}, F))) \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr, S^o/S} \\
&\xrightarrow{(T^w(j, \otimes)(M, F, W) \otimes I)^{-1}} (V_{D_0} F^0 DR(S)(j_{*w}((M, F, W)^{an}) \otimes_{O_S} (O_{\mathbb{B}_{dr, S}}, F))) \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr, S^o/S} \\
&\xrightarrow{F^0 DR(S)(V_{D_0} T(j, an)(M, F, W) \otimes I)^{-1}} \\
&(V_{D_0} F^0 DR(S)((j_{*w}(M, F, W))^{an} \otimes_{O_S} (O_{\mathbb{B}_{dr, S}}, F))) \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr, S^o/S} \\
&\xrightarrow{=} (V_{D_0} F^0 DR(S)((j_{*w}(M, F, W))^{an} \otimes_{O_S} (O_{\mathbb{B}_{dr, S}}, F))) \otimes_{\mathbb{B}_{dr,S}} \\
&\quad (F^0 DR(S)(j_{*Hdg}(O_{S^o}, F_b)^{an} \otimes_{O_S} (O_{\mathbb{B}_{dr, S}}, F))) \\
&\xrightarrow{w_S \otimes m(M)^{an}} F^0 DR(S)(j_{*Hdg}(M, F, W)^{an} \otimes_{O_S} (O_{\mathbb{B}_{dr, S}}, F))
\end{aligned}$$

where  $m(M) : O_{S^o} \otimes_{O_{S^o}} M \xrightarrow{\sim} M$ ,  $m \otimes f \mapsto fm$  is the multiplication map structure of the module  $M$  and  $w_S$  is the wedge product, and

$$\begin{aligned}
j_!\alpha &= j_!(\alpha) : \mathbb{B}_{dr,S}(j_!w(K, W)) \xrightarrow{T_!(j, \mathbb{B}_{dr})(K, W)} V_{D_0} \mathbb{D} j_* \mathbb{D} \mathbb{B}_{dr, S^o}(K, W) \otimes_{\mathbb{B}_{dr,S}} \mathbb{D}_S \mathbb{B}_{dr, S^o/S} \\
&\xrightarrow{(V_{D_0} \mathbb{D} j_* \mathbb{D} \alpha) \otimes I} V_{D_0} \mathbb{D} j_* \mathbb{D} (F^0 DR(S^o)(\mathbb{D}(M, F, W)^{an} \otimes_{O_{S^o}} (O_{\mathbb{B}_{dr, S^o}}, F))) \otimes_{\mathbb{B}_{dr,S}} \mathbb{D}_S \mathbb{B}_{dr, S^o/S} \\
&\xrightarrow{=} F^0 V_{D_0} \mathbb{D} j_* \mathbb{D} (DR(S^o)((M, F, W)^{an} \otimes_{O_S} O_{\mathbb{B}_{dr, S}})) \otimes_{\mathbb{B}_{dr,S}} \\
&\quad (F^0 DR(S)(j_!Hdg(O_{S^o}, F_b)^{an} \otimes_{O_S} (O_{\mathbb{B}_{dr, S}}, F))) \\
&\xrightarrow{(T(D, DR)(-) \circ \mathbb{D} T^w(j, \otimes)(-) \circ T(D, DR)(-)) \otimes I} \\
&\quad (V_{D_0} F^0 DR(S)((\mathbb{D} j_* \mathbb{D}(M, F, W))^{an} \otimes_{O_S} O_{\mathbb{B}_{dr, S}})) \otimes_{\mathbb{B}_{dr,S}} \\
&\quad (F^0 DR(S)(j_!Hdg(O_{S^o}, F_b)^{an} \otimes_{O_S} (O_{\mathbb{B}_{dr, S}}, F))) \\
&\xrightarrow{F^0 DR(S)(\mathbb{D} T(j, an)(-) \otimes I)} (V_{D_0} F^0 DR(S)((\mathbb{D} j_* \mathbb{D}(M, F, W))^{an} \otimes_{O_S} O_{\mathbb{B}_{dr, S}})) \otimes_{\mathbb{B}_{dr,S}} \\
&\quad (F^0 DR(S)(j_!Hdg(O_{S^o}, F_b)^{an} \otimes_{O_S} (O_{\mathbb{B}_{dr, S}}, F))) \\
&\xrightarrow{w_S \otimes m(M)^{an}} F^0 DR(S)(j_!Hdg(M, F, W)^{an} \otimes_{O_S} (O_{\mathbb{B}_{dr, S}}, F))
\end{aligned}$$

where  $m(M) : O_{S^o} \otimes_{O_{S^o}} M \xrightarrow{\sim} M$ ,  $h \otimes m \mapsto hm$  is the multiplication map and  $w_S$  is the wedge product.

(i2)' Let  $l : S^o \hookrightarrow S$  an open embedding with  $S \in \text{Var}(k)$  and  $D = S \setminus S^o$  a Cartier divisor. Let  $S = \cup_i S_i$  an open affine cover and  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embedding with  $\tilde{S}_i \in \text{SmVar}(k)$ . Let  $l_I : \tilde{S}_I^o \hookrightarrow \tilde{S}_I$  closed embeddings such that  $\tilde{S}_I^o \cap S = S^o \cap S_I$ . Let

$$\alpha : \mathbb{B}_{dr, (\tilde{S}_I^o)}(K, W) \rightarrow F^0 DR(S^o)((M_I, F, W), u_{IJ})^{an} \otimes_{O_{S^o}} ((O_{\mathbb{B}_{dr, (\tilde{S}_I^o)}}, F), t_{IJ})$$

a morphism in  $D_{\mathbb{B}_{dr},G,fil}(S_{\mathbb{C}_p}^{o,an,pet}/(\tilde{S}_{I, \mathbb{C}_p}^{o,an,pet}))$ , with  $((M_I, F, W), u_{IJ}) \in C(DRM(S^o)) \subset C_{\mathcal{D}(1,0),fil,rh}(S^o/(\tilde{S}_I^o))$

and  $(K, W) \in D_{\mathbb{Z}_p, \text{fil}, c, k}(S^{o, \text{et}})^{ad, D}$ . We then consider as in (i2) the maps in  $D_{\mathbb{B}_{dr}, G, \text{fil}}(S_{\mathbb{C}_p}^{\text{an}, \text{pet}} / (\tilde{S}_{\mathbb{C}_p}^{\text{an}, \text{pet}}))$

$$\begin{aligned}
& l_*\alpha = l_*(\alpha) : \mathbb{B}_{dr, (\tilde{S}_I)}(l_{*w}(K, W)) \\
& \xrightarrow{T(l, \mathbb{B}_{dr})(K, W)} V_{D0} l_{*w} \mathbb{B}_{dr, (\tilde{S}_I^o)}(K, W) \otimes_{\mathbb{B}_{dr, (\tilde{S}_I)}} (\mathbb{B}_{dr, \tilde{S}_I^o / \tilde{S}_I}, t_{IJ}) \\
& \xrightarrow{V_{D0} l_* \alpha \otimes I} V_{D0} l_{*w} F^0 DR(S^o) (((M_I, F, W), u_{IJ})^{an} \otimes_{O_S} ((O\mathbb{B}_{dr, \tilde{S}_I^o}, F), t_{IJ})) \otimes_{\mathbb{B}_{dr, (\tilde{S}_I)}} (\mathbb{B}_{dr, \tilde{S}_I^o / \tilde{S}_I}, t_{IJ}) \\
& \xrightarrow{(T^w(l_I, \otimes)(-)) \otimes I}^{-1} \\
& V_{D0} F^0 DR(S)(l_{*w}((M_I, F, W), u_{IJ})^{an} \otimes_{O_S} ((O\mathbb{B}_{dr, \tilde{S}_I}, F), t_{IJ})) \otimes_{\mathbb{B}_{dr, (\tilde{S}_I)}} (\mathbb{B}_{dr, \tilde{S}_I^o / \tilde{S}_I}, t_{IJ}) \\
& \xrightarrow{F^0 DR(S)(V_{D0} T(l_I, \text{an})(M_I, F, W))^{-1} \otimes I}^{-1} \\
& V_{D0} F^0 DR(S)(V_{D0} l_{*w}((M_I, F, W), u_{IJ})^{an} \otimes_{O_S} ((O\mathbb{B}_{dr, \tilde{S}_I}, F), t_{IJ})) \otimes_{\mathbb{B}_{dr, (\tilde{S}_I)}} (\mathbb{B}_{dr, \tilde{S}_I^o / \tilde{S}_I}, t_{IJ}) \\
& \stackrel{=}{\rightarrow} V_{D0}(F^0 DR(S)((l_{*w}((M_I, F, W), u_{IJ})^{an} \otimes_{O_S} ((O\mathbb{B}_{dr, \tilde{S}_I}, F), t_{IJ}))) \otimes_{\mathbb{B}_{dr, (\tilde{S}_I)}} \\
& (F^0 DR((\tilde{S}_I))((l_{I*} \text{Hdg}(O_{\tilde{S}_I^o}, F_b), x_{IJ})^{an} \otimes_{O_S} ((O\mathbb{B}_{dr, \tilde{S}_I}, F), t_{IJ}))) \\
& \xrightarrow{w_{\tilde{S}_I} \otimes m(M_I)^{an}} F^0 DR(S)((l_{*} \text{Hdg}((M_I, F, W), u_{IJ})^{an} \otimes_{O_S} ((O\mathbb{B}_{dr, \tilde{S}_I}, F), t_{IJ}))
\end{aligned}$$

and

$$\begin{aligned}
& l_! \alpha = l_!(\alpha) : \mathbb{B}_{dr, (\tilde{S}_I)}(l_{!w}(K, W)) \\
& \xrightarrow{T_!(l, \mathbb{B}_{dr})(K, W)} V_{D0} \mathbb{D} l_* \mathbb{D}(\mathbb{B}_{dr, (\tilde{S}_I^o)}(K, W)) \otimes_{\mathbb{B}_{dr, (\tilde{S}_I)}} \mathbb{D}(\mathbb{B}_{dr, \tilde{S}_I^o / \tilde{S}_I}, t_{IJ}) \xrightarrow{V_{D0} \mathbb{D} l_* \mathbb{D}(\alpha \otimes I)} \\
& V_{D0} \mathbb{D} l_{*w} \mathbb{D}(F^0 DR(S^o) (((M_I, F, W), u_{IJ})^{an} \otimes_{O_{S^o}} ((O\mathbb{B}_{dr, \tilde{S}_I^o}, F), t_{IJ}))) \otimes_{\mathbb{B}_{dr, (\tilde{S}_I)}} \mathbb{D}(\mathbb{B}_{dr, \tilde{S}_I^o / \tilde{S}_I}, t_{IJ}) \\
& \xrightarrow{(T(D, DR)(-) \circ (\mathbb{D} T^w(l_I, \otimes)(-) \circ T(D, DR)(-)) \otimes I} \\
& V_{D0}(F^0 DR(S)((\mathbb{D} l_{*w} \mathbb{D}((M_I, F, W), u_{IJ})^{an} \otimes_{O_S} ((O\mathbb{B}_{dr, \tilde{S}_I}, F), t_{IJ}))) \otimes_{\mathbb{B}_{dr, (\tilde{S}_I)}} \mathbb{D}(\mathbb{B}_{dr, \tilde{S}_I^o / \tilde{S}_I}, t_{IJ}) \\
& \xrightarrow{F^0 DR(S)(V_{D0} \mathbb{D} T(l_I, \text{an})(-)) \otimes I} \\
& V_{D0}(F^0 DR(S)((\mathbb{D} l_{*w} \mathbb{D}((M_I, F, W), u_{IJ})^{an} \otimes_{O_S} ((O\mathbb{B}_{dr, \tilde{S}_I}, F), t_{IJ}))) \otimes_{\mathbb{B}_{dr, (\tilde{S}_I)}} \\
& (F^0 DR((\tilde{S}_I))((l_{!} \text{Hdg}(O_{\tilde{S}_I^o}, F_b), x_{IJ})^{an} \otimes_{O_S} ((O\mathbb{B}_{dr, \tilde{S}_I}, F), t_{IJ}))) \\
& \xrightarrow{w_{\tilde{S}_I} \otimes m(M_I)^{an}} F^0 DR(S)(l_{!} \text{Hdg}((M_I, F, W), u_{IJ})^{an} \otimes_{O_S} ((O\mathbb{B}_{dr, \tilde{S}_I}, F), t_{IJ}))
\end{aligned}$$

(ii0) Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{SmVar}(k)$ . Take a compactification  $f : X \xrightarrow{j} \bar{X} \xrightarrow{\bar{f}} S$  of  $f$  with  $\bar{X} \in \text{SmVar}(k)$ ,  $j$  an open embedding and  $D = \bar{X} \setminus X$  a divisor (see section 2, we can take  $D$  a normal crossing divisor but it is unnecessary). Let

$$\alpha : \mathbb{B}_{dr, X}(K, W) \rightarrow F^0 DR(X)((M, F, W)^{an} \otimes_{O_X} O\mathbb{B}_{dr, X})$$

a morphism in  $D_{\mathbb{B}_{dr}, G, \text{fil}}(X_{\mathbb{C}_p}^{\text{an}, \text{pet}})$ , with  $(M, F, W) \in C(\text{DRM}(X))$  and  $(K, W) \in D_{\mathbb{Z}_p, \text{fil}, c, k}(X^{\text{et}})^{ad, D}$ . We then consider, using (i1) and (i2) the maps in  $D_{\mathbb{B}_{dr}, G, \text{fil}}(S_{\mathbb{C}_p}^{\text{an}, \text{pet}})$

$$\begin{aligned}
& f_* \alpha = f_*(\alpha) : \mathbb{B}_{dr, S}(Rf_{*w}(K, W)) = \mathbb{B}_{dr, S}(R\bar{f}_* j_{*w}(K, W)) \\
& \xrightarrow{T(\bar{f}, B_{dr})(-)} R\bar{f}_* \mathbb{B}_{dr, \bar{X}}(j_{*w}(K, W)) \xrightarrow{j_*(\alpha)} R\bar{f}_* F^0 DR(X)(j_* \text{Hdg}(M, F, W)^{an} \otimes_{O_X} (O\mathbb{B}_{dr, X}, F)) \\
& \xrightarrow{F^0 DR(S)(T(\text{an}, f_f)(-)^{-1}) \circ F^0 T^{B_{dr}}(\bar{f}, DR)(-)^{-1} \circ R\bar{f}_* \iota_{F^0}} \\
& F^0 DR(S)(R\bar{f}_* \text{Hdg} j_* \text{Hdg}(M, F, W)^{an} \otimes_{O_S} (O\mathbb{B}_{dr, S}, F)) \\
& \stackrel{=}{\rightarrow} F^0 DR(S)(Rf_* \text{Hdg}(M, F, W)^{an} \otimes_{O_S} (O\mathbb{B}_{dr, S}, F))
\end{aligned}$$

and

$$\begin{aligned}
f_! \alpha &= f_!(\alpha) : \mathbb{B}_{dr,S}(Rf_{!w}(K, W)) = \mathbb{B}_{dr,S}(R\bar{f}_* j_{!w}(K, W)) \\
&\xrightarrow{T(\bar{f}, B_{dr})(-)} R\bar{f}_* \mathbb{B}_{dr, \bar{X}}(j_{!w}(K, W)) \xrightarrow{j_!(\alpha)} R\bar{f}_* F^0 DR(X)(j_{!Hdg}(M, F, W)^{an} \otimes_{O_X} (O\mathbb{B}_{dr,X}, F)) \\
&\xrightarrow{F^0 DR(S)(T(an, f_f)(-)^{-1}) \circ F^0 T^{B_{dr}}(\bar{f}, DR)(-)^{-1} \circ R\bar{f}_* \iota_{F^0}} \\
&F^0 DR(S)(R\bar{f}_* j_{!Hdg}(M, F, W)^{an} \otimes_{O_S} (O\mathbb{B}_{dr,S}, F)) \\
&\xrightarrow{=} F^0 DR(S)(Rf_{!Hdg}(M, F, W)^{an} \otimes_{O_S} (O\mathbb{B}_{dr,S}, F)).
\end{aligned}$$

(ii) Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{Var}(k)$ . Consider a factorization  $f : X \hookrightarrow Y \times S \xrightarrow{p} S$  with  $Y \in \text{SmVar}(k)$ , and let  $f : X \xrightarrow{j} \bar{X} \hookrightarrow \bar{Y} \times S \xrightarrow{\bar{p}} S$  be a compactification of  $f$ , with  $\bar{Y} \in \text{PSmVar}(k)$  and  $D = \bar{Y} \setminus Y$  a (Cartier) divisor (e.g. a normal crossing divisor). Let  $S = \cup_i S_i$  an open affine cover and  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embedding with  $\tilde{S}_i \in \text{SmVar}(k)$ . Let

$$\alpha : \mathbb{B}_{dr, (Y \times \tilde{S}_I)}(K, W) \rightarrow F^0 DR(X)((M_I, F, W), u_{IJ})^{an} \otimes_{O_{Y \times \tilde{S}_I}} (O\mathbb{B}_{dr, Y \times \tilde{S}_I}, F))$$

a morphism in  $D_{\mathbb{B}_{dr,G}, \text{fil}}(X_{\mathbb{C}_p}^{an, \text{pet}} / (Y \times \tilde{S}_I)^{an, \text{pet}})$ , with  $((M_I, F, W), u_{IJ}) \in C(DRM(X)) \subset C_{\mathcal{D}(1,0), \text{fil}, \text{rh}}(X / (Y \times \tilde{S}_I))$  and  $(K, W) \in D_{\mathbb{Z}_p, \text{fil}, c, k}(X^{et})^{ad, D}$ . We then consider, using definitions 78 and (i2)', the maps in  $D_{\mathbb{B}_{dr,G}, \text{fil}}(S_{\mathbb{C}_p}^{an, \text{pet}} / (\tilde{S}_I)^{an, \text{pet}})$

$$\begin{aligned}
f_* \alpha &= f_*(\alpha) : \mathbb{B}_{dr, (\tilde{S}_I)}(Rf_{*w}(K, W)) = \mathbb{B}_{dr, (\tilde{S}_I)}(R\bar{f}_* j_{*w}(K, W)) \\
&\xrightarrow{T(\bar{f}, \mathbb{B}_{dr})(-)} R\bar{p}_* \mathbb{B}_{dr, (\bar{Y} \times \tilde{S}_I)}(j_{*w}(K, W)) \\
&\xrightarrow{j_* \alpha} R\bar{p}_* F^0 DR(X)((j_* Hdg((M_I, F, W), u_{IJ})^{an}) \otimes_{O_X} ((O\mathbb{B}_{dr, \bar{Y} \times \tilde{S}_I}, F), t_{IJ})) \\
&\xrightarrow{Rp_* \iota_{F^0}} F^0 R\bar{p}_* DR(X)((j_* Hdg((M_I, F, W), u_{IJ})^{an}) \otimes_{O_X} ((O\mathbb{B}_{dr, \bar{Y} \times \tilde{S}_I}, F), t_{IJ})) \\
&\xrightarrow{F^0 T^{B_{dr}}(f, DR)(j_* Hdg((M_I, F, W), u_{IJ}))} F^0 DR(S)\left(\int_{\bar{f}} (j_* Hdg((M_I, F, W), u_{IJ})^{an}) \otimes_{O_S} ((O\mathbb{B}_{dr, \tilde{S}_I}, F), t_{IJ})\right) \\
&\xrightarrow{F^0 DR(S)(T(an, f_f)(-)\otimes I)} F^0 DR(S)\left(\int_{\bar{f}} j_* Hdg((M_I, F, W), u_{IJ})^{an} \otimes_{O_S} ((O\mathbb{B}_{dr, \tilde{S}_I}, F), t_{IJ})\right) \\
&\xrightarrow{=} F^0 DR(S)((Rf_{*Hdg}((M_I, F, W), u_{IJ}))^{an} \otimes_{O_S} (O\mathbb{B}_{dr, \tilde{S}_I}, F)),
\end{aligned}$$

and

$$\begin{aligned}
f_! \alpha &= f_!(\alpha) : \mathbb{B}_{dr, (\tilde{S}_I)}(R\bar{f}_* j_{!w}(K, W)) \xrightarrow{=} \mathbb{B}_{dr, (\tilde{S}_I)}(R\bar{f}_* j_{!w}(K, W)) \\
&\xrightarrow{\mathbb{D}(T(\bar{f}, \mathbb{B}_{dr})(-))^{-1}} R\bar{p}_* \mathbb{B}_{dr, (\bar{Y} \times \tilde{S}_I)}(j_{!w}(K, W)) \\
&\xrightarrow{j_! \alpha} R\bar{p}_* F^0 DR(X)((j_! Hdg((M_I, F, W), u_{IJ})^{an}) \otimes_{O_X} ((O\mathbb{B}_{dr, \bar{Y} \times \tilde{S}_I}, F), t_{IJ})) \\
&\xrightarrow{Rp_* \iota_{F^0}} F^0 R\bar{p}_* DR(X)((j_! Hdg((M_I, F, W), u_{IJ})^{an}) \otimes_{O_X} ((O\mathbb{B}_{dr, \bar{Y} \times \tilde{S}_I}, F), t_{IJ})) \\
&\xrightarrow{F^0 T^{B_{dr}}(f, DR)(j_! Hdg((M_I, F, W), u_{IJ}))} F^0 DR(S)\left(\int_{\bar{f}} (j_! Hdg((M_I, F, W), u_{IJ})^{an}) \otimes_{O_S} ((O\mathbb{B}_{dr, \tilde{S}_I}, F), t_{IJ})\right) \\
&\xrightarrow{F^0 DR(S)(T(an, f_f)(-)\otimes I)} F^0 DR(S)\left(\int_{\bar{f}} j_! Hdg((M_I, F, W), u_{IJ})^{an} \otimes_{O_S} ((O\mathbb{B}_{dr, \tilde{S}_I}, F), t_{IJ})\right) \\
&\xrightarrow{=} F^0 DR(S)((Rf_{!Hdg}((M_I, F, W), u_{IJ}))^{an} \otimes_{O_S} ((O\mathbb{B}_{dr, (\tilde{S}_I)}, F), t_{IJ})).
\end{aligned}$$

(iii) Let  $l : S^o \hookrightarrow S$  an open embedding with  $S \in \text{Var}(k)$  and denote  $Z = S \setminus S^o$ . Let  $D_1, \dots, D_d \subset S$  Cartier divisor such that  $Z = \cap_{s=1}^d D_s$ . Denote  $l_s : D_s \hookrightarrow S$  the closed embeddings. Let  $S = \cup_i S_i$

an open affine cover and  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embedding with  $\tilde{S}_i \in \text{SmVar}(k)$ . Let  $l_{I,s} : \tilde{D}_{I,s} \hookrightarrow \tilde{S}_I$  closed embeddings such that  $\tilde{D}_{I,s} \cap S = S \cap D_{I,s}$ . Let

$$\alpha : \mathbb{B}_{dr,(\tilde{S}_I)}(K, W) \rightarrow F^0 DR(S)((M_I, F, W), u_{IJ})^{an} \otimes_{O_S} ((O\mathbb{B}_{dr,\tilde{S}_I}, F), t_{IJ})$$

a morphism in  $D_{\mathbb{B}_{dr,G},fil}(S_{\mathbb{C}_p}^{an,pet}/(\tilde{S}_{I,\mathbb{C}_p}^{an,pet}))$ , with  $((M_I, F, W), u_{IJ}) \in C(DRM(S)) \subset C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I))$  and  $(K, W) \in D_{\mathbb{Z}_p,fil,c,k}(S^{et})^{ad,(D_i)}$ . We then have by (i2), the maps in  $D_{\mathbb{B}_{dr,G},fil}(S_{\mathbb{C}_p}^{an,pet}/(\tilde{S}_{I,\mathbb{C}_p}^{an,pet}))$

$$\begin{aligned} \Gamma_Z(\alpha) : \mathbb{B}_{dr,(\tilde{S}_I)}(\Gamma_Z^w(K, W)) &\xrightarrow{\cong} \mathbb{B}_{dr,(\tilde{S}_I)}(\Gamma_{D_1}^w \cdots \Gamma_{D_s}^w(K, W)) \\ \xrightarrow{(I, (l_{1*} \cdots l_{s*}(\alpha)))} F^0 DR(S)((\Gamma_Z^{Hdg}((M_I, F, W), u_{IJ}))^{an} &\otimes_{O_S} ((O\mathbb{B}_{dr,\tilde{S}_I}, F), t_{IJ})) \end{aligned}$$

and

$$\begin{aligned} \Gamma_Z^\vee(\alpha) : \mathbb{B}_{dr,(\tilde{S}_I)}(\Gamma_Z^{\vee,w}(K, W)) &\xrightarrow{\cong} \mathbb{B}_{dr,(\tilde{S}_I)}(\Gamma_{D_1}^{\vee,w} \cdots \Gamma_{D_s}^{\vee,w}(K, W)) \\ \xrightarrow{(I, (l_{1!} \cdots l_{s!}(\alpha)))} F^0 DR(S)((\Gamma_Z^{Hdg}((M_I, F, W), u_{IJ}))^{an} &\otimes_{O_S} ((O\mathbb{B}_{dr,\tilde{S}_I}, F), t_{IJ})) \end{aligned}$$

(iv) Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{Var}(k)$ . Consider a factorization  $f : X \hookrightarrow Y \times S \xrightarrow{p} S$  with  $Y \in \text{SmVar}(k)$ . Let  $S = \cup_i S_i$  an open affine cover and  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embedding with  $\tilde{S}_i \in \text{SmVar}(k)$ . Let

$$\alpha : \mathbb{B}_{dr,(\tilde{S}_I)}(K, W) \rightarrow F^0 DR(S)((M_I, F, W), u_{IJ})^{an} \otimes_{O_{\tilde{S}_I}} ((O\mathbb{B}_{dr,\tilde{S}_I}, F), t_{IJ})$$

a morphism in  $D_{\mathbb{B}_{dr,G},fil}(S_{\mathbb{C}_p}^{an,pet}/(\tilde{S}_{I,\mathbb{C}_p}^{an,pet}))$ , with  $((M_I, F, W), u_{IJ}) \in C(DRM(S)) \subset C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I))$  and  $(K, W) \in D_{\mathbb{Z}_p,fil,c,k}(S^{et})^{ad,(\Gamma_{f,i})}$ . We then have by (iii), the maps in  $D_{\mathbb{B}_{dr,G},fil}(X_{\mathbb{C}_p}^{an,pet}/(Y \times \tilde{S}_{I,\mathbb{C}_p}^{an,pet}))$

$$\begin{aligned} f^! \alpha = f^!(\alpha) : \mathbb{B}_{dr,(Y \times \tilde{S}_I)}(f^{!w}(K, W)) &\xrightarrow{\cong} \mathbb{B}_{dr,(Y \times \tilde{S}_I)}(\Gamma_X^w p^*(K, W)) \\ \xrightarrow{\Gamma_X(p^* \alpha)} F^0 DR(X)((\Gamma_X^{Hdg} p^{*mod}((M_I, F, W), u_{IJ}))^{an} &\otimes_{O_X} ((O\mathbb{B}_{dr,Y \times \tilde{S}_I}, F), t_{IJ})) \\ \xrightarrow{\cong} DR(X)(f_{Hdg}^{*mod}((M_I, F, W), u_{IJ}))^{an} &\otimes_{O_X} ((O\mathbb{B}_{dr,Y \times \tilde{S}_I}, F), t_{IJ})) \end{aligned}$$

and

$$\begin{aligned} f^* \alpha = f^*(\alpha) : \mathbb{B}_{dr,(Y \times \tilde{S}_I)}(f^{*w}(K, W)) &\xrightarrow{\cong} \mathbb{B}_{dr,(Y \times \tilde{S}_I)}(\Gamma_X^{\vee,w} p^*(K, W)) \\ \xrightarrow{\Gamma_X^\vee(p^* \alpha)} F^0 DR(Y \times S)((\Gamma_X^{\vee,Hdg} p^{\vee*mod}((M_I, F, W), u_{IJ}))^{an} &\otimes_{O_X} ((O\mathbb{B}_{dr,Y \times \tilde{S}_I}, F), t_{IJ})) \\ \xrightarrow{\cong} F^0 DR(X)(f_{Hdg}^{\vee*mod}((M_I, F, W), u_{IJ}))^{an} &\otimes_{O_X} ((O\mathbb{B}_{dr,Y \times \tilde{S}_I}, F), t_{IJ})) \end{aligned}$$

with

$$\begin{aligned} p^* \alpha : \mathbb{B}_{dr,(Y \times \tilde{S}_I)}(p^*(K, W)) &\xrightarrow{\cong} p^{*mod} \mathbb{B}_{dr,(\tilde{S}_I)}(K, W) \\ \xrightarrow{p^{*mod} \alpha} p^{*mod} F^0 DR(S)((M_I, F, W), u_{IJ})^{an} &\otimes_{O_S} ((O\mathbb{B}_{dr,\tilde{S}_I}, F), t_{IJ})) \\ \xrightarrow{\cong} F^0 DR(Y \times S)(p^{*mod}((M_I, F, W), u_{IJ}))^{an} &\otimes_{O_{Y \times S}} ((O\mathbb{B}_{dr,Y \times \tilde{S}_I}, F), t_{IJ})) \end{aligned}$$

(v) Let  $S \in \text{Var}(k)$ . Denote by  $\Delta_S : S \hookrightarrow S \times S$  the diagonal closed embedding and  $p_1 : S \times S \rightarrow S$ ,  $p_2 : S \times S \rightarrow S$  the projections. Let  $S = \cup_i S_i$  an open affine cover and  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embedding with  $\tilde{S}_i \in \text{SmVar}(k)$ . Let

$$\begin{aligned} \alpha : \mathbb{B}_{dr,(\tilde{S}_I)}(K, W) &\rightarrow F^0 DR(S)((M_I, F, W), u_{IJ})^{an} \otimes_{O_S} ((O\mathbb{B}_{dr,\tilde{S}_I}, F), t_{IJ}), \\ \alpha' : \mathbb{B}_{dr,(\tilde{S}_I)}(K', W) &\rightarrow F^0 DR(S)((M'_I, F, W), v_{IJ})^{an} \otimes_{O_S} ((O\mathbb{B}_{dr,\tilde{S}_I}, F), t_{IJ}) \end{aligned}$$



two morphisms in  $D_{\mathbb{B}_{dr,G},fil}(S_{\mathbb{C}_p}^{an,pet}/(\tilde{S}_{IC_p}^{an,pet}))$ , with  $((M_I, F, W), u_{IJ}), ((M'_I, F, W), v_{IJ}) \in C(DRM(S)) \subset C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I))$  and  $(K, W), (K', W) \in D_{Z_p,fil,c,k}(S^{et})$ . We have then, using definition 80, the map

$$\begin{aligned} \alpha \otimes \alpha' : \mathbb{B}_{dr,(\tilde{S}_I)}((K, W) \otimes (K', W)) &\xrightarrow{T(\otimes, \mathbb{B}_{dr})((K, W), (K', W))^{-1}} \mathbb{B}_{dr,(\tilde{S}_I)}((K, W) \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr,(\tilde{S}_I)}(K', W)) \\ &\xrightarrow{\alpha \otimes \alpha'} F^0 DR(S)((M_I, F, W), u_{IJ})^{an} \otimes_{O_S} ((O_{\mathbb{B}_{dr,\tilde{S}_I}}, F), t_{IJ}) \otimes_{\mathbb{B}_{dr,S}} \\ &\quad F^0 DR(S)((M'_I, F, W), v_{IJ})^{an} \otimes_{O_S} ((O_{\mathbb{B}_{dr,\tilde{S}_I}}, F), t_{IJ}) \\ &\xrightarrow{w_S} \Delta_S^{*mod} F^0 DR(S \times S)(p_1^{*mod}((M_I, F, W), u_{IJ})^{an} \otimes_{O_{S \times S}} p_2^{*mod}((M'_I, F, W), v_{IJ})^{an} \\ &\quad \otimes_{O_{S \times S}} ((O_{\mathbb{B}_{dr,\tilde{S}_I \times \tilde{S}_I}}, F), t_{IJ})) \\ &\quad \xrightarrow{DR(S \times S)(ad(\Delta_S^{*mod}, \Delta_{S^{*mod}})(-))} \\ &\Delta_S^{*mod} F^0 DR(S \times S)(\Delta_{S^{*mod}} \Delta_{S,Hdg}^{*mod}(p_1^{*mod}((M_I, F, W), u_{IJ})^{an} \otimes_{O_{S \times S}} p_2^{*mod}((M'_I, F, W), v_{IJ})^{an} \\ &\quad \otimes_{O_{S \times S}} ((O_{\mathbb{B}_{dr,\tilde{S}_I \times \tilde{S}_I}}, F), t_{IJ})) \\ &\quad \xrightarrow{T^{B_{dr}}(\Delta_S, DR)(-)} \Delta_S^{*mod} \Delta_{S^*} F^0 DR(S)(\Delta_{S,Hdg}^{*mod}(p_1^{*mod}((M_I, F, W), u_{IJ})^{an} \\ &\quad \otimes_{O_{S \times S}} p_2^{*mod}((M'_I, F, W), v_{IJ})^{an} \otimes_{O_S} ((O_{\mathbb{B}_{dr,\tilde{S}_I}}, F), t_{IJ}))) \\ &\xrightarrow{=} F^0 DR(S)((M_I, F, W), u_{IJ})^{an} \otimes_{O_S}^{Hdg} ((M'_I, F, W), v_{IJ})^{an} \otimes_{O_S} ((O_{\mathbb{B}_{dr,\tilde{S}_I}}, F), t_{IJ}) \end{aligned}$$

in  $D_{\mathbb{B}_{dr,G},fil}(S_{\mathbb{C}_p}^{an,pet}/(\tilde{S}_{IC_p}^{an,pet}))$ .

**Lemma 7.** (i) Let  $j : S^\circ \hookrightarrow S$  an open embedding with  $S \in \text{SmVar}(k)$  such that  $D = S \setminus S^\circ = V(s) \subset S$  is a (Cartier) divisor. For  $(M, F, W) \in C(DRM(S^\circ))$ ,

$$m(M) : V_{D0} j_{*w}(M, F, W) \otimes_{O_S} j_{*Hdg}(O_{S^\circ}, F_b) \rightarrow j_{*Hdg}(M, F, W), m \otimes h \mapsto m(M)(m \otimes h) := hm$$

is an isomorphism in  $C(DRM(S))$ , whose inverse is given by

$$n(M) : j_{*Hdg}(M, F, W) \rightarrow V_{D0} j_{*w}(M, F, W) \otimes_{O_S} j_{*Hdg}(O_{S^\circ}, F_b), m \mapsto n(M)(m) := s^r m \otimes 1/s^r.$$

where  $r \in \mathbb{N}$  is such that  $s^r m \in \Gamma(W, V_{D0} j_{*w} M)$  for  $m \in \Gamma(W, M)$  and  $W \subset S$  an open subset.

(i)' Let  $l : S^\circ \hookrightarrow S$  an open embedding with  $S \in \text{Var}(k)$  such that  $D = S \setminus S^\circ = V(s) \subset S$  is a Cartier divisor. Let  $S = \cup_i S_i$  an open affine cover and  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embedding with  $\tilde{S}_i \in \text{SmVar}(k)$ . Let  $l_I : \tilde{S}_I^\circ \hookrightarrow \tilde{S}_I$  closed embeddings such that  $\tilde{S}_I^\circ \cap S = S^\circ \cap S_I$ . For  $((M_I, F, W), u_{IJ}) \in C(DRM(S^\circ))$

$$(m(M_I)) : V_{D0} l_{*w}((M_I, F, W), u_{IJ}) \otimes_{O_S} (l_{*Hdg}(O_{\tilde{S}_I^\circ}, F_b), x_{IJ}) \rightarrow (l_{*Hdg}((M_I, F, W), u_{IJ}))$$

is an isomorphism in  $C(DRM(S))$  whose inverse is given by

$$(n(M_I)) : (l_{*Hdg}((M_I, F, W), u_{IJ})) \rightarrow V_{D0} l_{*w}((M_I, F, W), u_{IJ}) \otimes_{O_S} (l_{*Hdg}(O_{\tilde{S}_I^\circ}, F_b), x_{IJ}).$$

(ii) Let  $j : S^\circ \hookrightarrow S$  an open embedding with  $S \in \text{SmVar}(k)$  such that  $D = S \setminus S^\circ = V(s) \subset S$  is a (Cartier) divisor. For  $(M, F, W) \in C(DRM(S^\circ))$ ,

$$\begin{aligned} w_S \otimes m(M)^{an} (V_{D0} F^0 DR(S)((j_{*w}(M, F, W))^{an} \otimes_{O_S} (O_{\mathbb{B}_{dr,S}}, F))) \otimes_{\mathbb{B}_{dr,S}} \\ (F^0 DR(S)(j_{*Hdg}(O_{S^\circ}, F_b)^{an} \otimes_{O_S} (O_{\mathbb{B}_{dr,S}}, F))) \\ \rightarrow F^0 DR(S)(j_{*Hdg}(M, F, W)^{an} \otimes_{O_S} (O_{\mathbb{B}_{dr,S}}, F)), (w_1 \otimes m) \otimes (w_2 \otimes h) \mapsto (w_1 \wedge w_2) \otimes (hm) \end{aligned}$$

is an isomorphism in  $C(DRM(S))$  whose inverse is

$$\begin{aligned} w_S^{-1} \otimes n(M)^{an} : F^0 DR(S)(j_{*Hdg}(M, F, W)^{an} \otimes_{O_S} (O_{\mathbb{B}_{dr,S}}, F)) \\ \rightarrow (V_{D0} F^0 DR(S)((j_{*w}(M, F, W))^{an} \otimes_{O_S} (O_{\mathbb{B}_{dr,S}}, F))) \otimes_{\mathbb{B}_{dr,S}} \\ (F^0 DR(S)(j_{*Hdg}(O_{S^\circ}, F_b)^{an} \otimes_{O_S} (O_{\mathbb{B}_{dr,S}}, F))). \end{aligned}$$

(ii)' Let  $l : S^\circ \hookrightarrow S$  an open embedding with  $S \in \text{Var}(k)$  such that  $D = S \setminus S^\circ = V(s) \subset S$  is a Cartier divisor. Let  $S = \cup_i S_i$  an open affine cover and  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embedding with  $\tilde{S}_i \in \text{SmVar}(k)$ . Let  $l_I : \tilde{S}_I^\circ \hookrightarrow \tilde{S}_I$  closed embeddings such that  $\tilde{S}_I^\circ \cap S = S^\circ \cap S_I$ . For  $((M_I, F, W), u_{IJ}) \in C(\text{DRM}(S^\circ))$

$$\begin{aligned} (w_{\tilde{S}_I} \otimes m(M_I)^{an}) : V_{D0}(F^0 DR(S)((l_{*w}((M_I, F, W), u_{IJ}))^{an} \otimes_{O_S} ((O\mathbb{B}_{dr, \tilde{S}_I}, F), t_{IJ}))) \otimes_{\mathbb{B}_{dr, (\tilde{S}_I)}} \\ (F^0 DR((\tilde{S}_I))((l_{I*Hdg}(O_{\tilde{S}_I^\circ}, F_b), x_{IJ})^{an} \otimes_{O_S} ((O\mathbb{B}_{dr, \tilde{S}_I}, F), t_{IJ}))) \\ \rightarrow F^0 DR(S)((l_{*Hdg}((M_I, F, W), u_{IJ}))^{an} \otimes_{O_S} ((O\mathbb{B}_{dr, \tilde{S}_I}, F), t_{IJ})) \end{aligned}$$

is an isomorphism in  $C(\text{DRM}(S))$  whose inverse is

$$\begin{aligned} (w_{\tilde{S}_I}^{-1} \otimes n(M_I)^{an}) : F^0 DR(S)((l_{*Hdg}((M_I, F, W), u_{IJ}))^{an} \otimes_{O_S} ((O\mathbb{B}_{dr, \tilde{S}_I}, F), t_{IJ})) \\ \rightarrow V_{D0}(F^0 DR(S)((l_{*w}((M_I, F, W), u_{IJ}))^{an} \otimes_{O_S} ((O\mathbb{B}_{dr, \tilde{S}_I}, F), t_{IJ}))) \otimes_{\mathbb{B}_{dr, (\tilde{S}_I)}} \\ (F^0 DR((\tilde{S}_I))((l_{I*Hdg}(O_{\tilde{S}_I^\circ}, F_b), x_{IJ})^{an} \otimes_{O_S} ((O\mathbb{B}_{dr, \tilde{S}_I}, F), t_{IJ}))). \end{aligned}$$

*Proof.* (i): Follows from the definition of the  $V$ -filtration and the  $F$ -filtration.

(i)': Follows from (i).

(ii): Follows from (i).

(ii)': Follows from (ii). □

**Proposition 49.** Let  $k \subset \mathbb{C}_p$  a subfield.

(i0) Let  $j : S^\circ \hookrightarrow S$  an open embedding with  $S \in \text{SmVar}(k)$  and  $D = S \setminus S^\circ$  a (Cartier) divisor. If

$$\alpha : \mathbb{B}_{dr, S^\circ}(K, W) \rightarrow F^0 DR(S^\circ)((M, F, W)^{an} \otimes_{O_{S^\circ}} (O\mathbb{B}_{dr, S^\circ}, F))$$

is an isomorphism in  $D_{\mathbb{B}_{dr, G, fil}}(S_{\mathbb{C}_p}^{0, an, pet})$ , with  $(M, F, W) \in C(\text{DRM}(S^\circ))$  and  $(K, W) \in D_{\mathbb{Z}_p, fil, c, k}(S^{o, et})$ , then the maps in  $D_{\mathbb{B}_{dr, G, fil}}(S_{\mathbb{C}_p}^{an, pet})$

$$j_* \alpha = j_*(\alpha) : \mathbb{B}_{dr, S}(j_{*w}(K, W)) \rightarrow F^0 DR(S)((j_{*Hdg}(M, F, W))^{an} \otimes_{O_S} (O\mathbb{B}_{dr, S}, F))$$

and

$$j_! \alpha = j_!(\alpha) : \mathbb{B}_{dr, S}(j_{!w}(K, W)) \rightarrow F^0 DR(S)((j_{!Hdg}(M, F, W))^{an} \otimes_{O_S} (O\mathbb{B}_{dr, S}, F))$$

given in definition 66 are isomorphisms.

(i0)' Let  $l : S^\circ \hookrightarrow S$  an open embedding with  $S \in \text{Var}(k)$  and  $D = S \setminus S^\circ$  a Cartier divisor. Let  $S = \cup_i S_i$  an open affine cover and  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embedding with  $\tilde{S}_i \in \text{SmVar}(k)$ . Let  $l_I : \tilde{S}_I^\circ \hookrightarrow \tilde{S}_I$  closed embeddings such that  $\tilde{S}_I^\circ \cap S = S^\circ \cap S_I$ . If

$$\alpha : \mathbb{B}_{dr, (\tilde{S}_I^\circ)}(K, W) \rightarrow F^0 DR(S^\circ)((M_I, F, W), u_{IJ})^{an} \otimes_{O_{\tilde{S}_I^\circ}} (O\mathbb{B}_{dr, \tilde{S}_I^\circ})$$

is an isomorphism in  $D_{\mathbb{B}_{dr, G, fil}}(S_{\mathbb{C}_p}^{an, pet} / (\tilde{S}_{I, \mathbb{C}_p}^{an, pet}))$ , with  $((M_I, F, W), u_{IJ}) \in C(\text{DRM}(S^\circ))$  and  $(K, W) \in D_{\mathbb{Z}_p, fil, c, k}(S^{et})$ . then the maps in  $D_{\mathbb{B}_{dr, G, fil}}(S_{\mathbb{C}_p}^{an, pet} / (\tilde{S}_{I, \mathbb{C}_p}^{an, pet}))$

$$l_* \alpha = l_*(\alpha) : \mathbb{B}_{dr, (\tilde{S}_I)}(l_{*w}(K, W)) \rightarrow F^0 DR(S)(l_{!Hdg}((M_I, F, W), u_{IJ}))^{an} \otimes_{O_S} (O\mathbb{B}_{dr, (\tilde{S}_I)}, F))$$

and

$$l_! \alpha = l_!(\alpha) : \mathbb{B}_{dr, (\tilde{S}_I)}(l_{!w}(K, W)) \rightarrow F^0 DR(S)(l_{!Hdg}((M_I, F, W), u_{IJ}))^{an} \otimes_{O_S} (O\mathbb{B}_{dr, (\tilde{S}_I)}, F))$$

are isomorphisms.

(i) Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{SmVar}(k)$ . If

$$\alpha : \mathbb{B}_{dr,X}(K, W) \rightarrow F^0 DR(X)((M, F, W)^{an} \otimes_{O_X} (O\mathbb{B}_{dr,X}, F))$$

an isomorphism in  $D_{\mathbb{B}_{dr,G},fil}(X_{\mathbb{C}_p}^{an,pet})$ , with  $(M, F, W) \in C(DRM(X))$  and  $(K, W) \in D_{\mathbb{Z}_p,fil,c,k}(X^{et})$ , then the morphisms given in definition 84

$$f_*\alpha = f_*(\alpha) : \mathbb{B}_{dr,S}(Rf_{*w}(K, W)) \rightarrow F^0 DR(S)((Rf_{*Hdg}(M, F, W))^{an} \otimes_{O_S} (O\mathbb{B}_{dr,S}, F))$$

and

$$f_!\alpha = f_!(\alpha) : \mathbb{B}_{dr,S}(Rf_{!w}(K, W)) \rightarrow F^0 DR(S)((Rf_{!Hdg}(M, F, W))^{an} \otimes_{O_S} (O\mathbb{B}_{dr,S}, F))$$

are isomorphisms.

(i)' Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{QPVar}(k)$ . Consider a factorization  $f : X \hookrightarrow Y \times S \xrightarrow{p} S$  with  $Y \in \text{SmVar}(k)$ . Let  $S = \cup_i S_i$  an open affine cover and  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embedding with  $\tilde{S}_i \in \text{SmVar}(k)$ . If

$$\alpha : \mathbb{B}_{dr,(Y \times \tilde{S}_I)}(K, W) \rightarrow F^0 DR(X)((M_I, F, W), u_{IJ})^{an} \otimes_{O_{Y \times \tilde{S}_I}} (O\mathbb{B}_{dr,Y \times \tilde{S}_I}, F))$$

is an isomorphism in  $D_{\mathbb{B}_{dr,G},fil}(X_{\mathbb{C}_p}^{an,pet}/(Y \times \tilde{S}_I)^{an,pet})$ , with  $((M_I, F, W), u_{IJ}) \in C(DRM(X))$  and  $(K, W) \in D_{\mathbb{Z}_p,fil,c,k}(X^{et})$ , then, the maps in  $D_{\mathbb{B}_{dr,G},fil}(S_{\mathbb{C}_p}^{an,pet}/(\tilde{S}_I)^{an,pet})$

$$f_*\alpha = f_*(\alpha) : \mathbb{B}_{dr,(\tilde{S}_I)}(Rf_{*w}(K, W)) \rightarrow F^0 DR(S)((Rf_{*Hdg}((M_I, F, W), u_{IJ}))^{an} \otimes_{O_S} (O\mathbb{B}_{dr,(\tilde{S}_I)}, F)),$$

and

$$f_!\alpha = f_!(\alpha) : \mathbb{B}_{dr,(\tilde{S}_I)}(Rf_{!w}(K, W)) \rightarrow F^0 DR(S)((Rf_{!Hdg}((M_I, F, W), u_{IJ}))^{an} \otimes_{O_S} (O\mathbb{B}_{dr,(\tilde{S}_I)}, F)),$$

are isomorphisms.

(ii) Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{QPVar}(k)$ . Consider a factorization  $f : X \hookrightarrow Y \times S \xrightarrow{p} S$  with  $Y \in \text{SmVar}(k)$ . Let  $S = \cup_i S_i$  an open affine cover and  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embedding with  $\tilde{S}_i \in \text{SmVar}(k)$ . If

$$\alpha : \mathbb{B}_{dr,(\tilde{S}_I)}(K, W) \rightarrow F^0 DR(S)((M_I, F, W), u_{IJ})^{an} \otimes_{O_{\tilde{S}_I}} (O\mathbb{B}_{dr,(\tilde{S}_I)}, F))$$

is an isomorphism in  $D_{\mathbb{B}_{dr,G},fil}(S_{\mathbb{C}_p}^{an,pet}/(\tilde{S}_I)^{an,pet})$ , with  $((M_I, F, W), u_{IJ}) \in C(DRM(S))$  and  $(K, W) \in D_{\mathbb{Z}_p,fil,c,k}(S^{et})$ , the maps in  $D_{\mathbb{B}_{dr,G},fil}(X_{\mathbb{C}_p}^{an,pet}/(Y \times \tilde{S}_I)^{an,pet})$

$$f^!\alpha = f^!(\alpha) : \mathbb{B}_{dr,(Y \times \tilde{S}_I)}(f^{!w}(K, W)) \rightarrow F^0 DR(X)(f_{Hdg}^{*mod}((M_I, F, W), u_{IJ})^{an} \otimes_{O_X} (O\mathbb{B}_{dr,(Y \times \tilde{S}_I)}, F))$$

and

$$f^*\alpha = f^*(\alpha) : \mathbb{B}_{dr,(Y \times \tilde{S}_I)}(f^!(K, W)) \rightarrow F^0 DR(X)(f_{Hdg}^{*mod}((M_I, F, W), u_{IJ})^{an} \otimes_{O_X} (O\mathbb{B}_{dr,(Y \times \tilde{S}_I)}, F))$$

given in definition 84 are isomorphisms.

*Proof.* (i0): Follows from lemma 7(ii).

(i0)': Follows from lemma 7(ii)'.

(i): Follows from (i0) and on the other hand theorem 44 and GAGA for proper morphism of algebraic varieties over a  $p$ -adic field.

(i)': Follows from (i0)' and on the other hand theorem 44 and GAGA for proper morphism of algebraic varieties over a  $p$ -adic field.

(ii): Follows from (i0). □

**Definition 85.** Let  $S \in \text{SmVar}(k)$ . Let  $D = V(s) \subset S$  a divisor with  $s \in \Gamma(S, L)$  and  $L$  a line bundle ( $S$  being smooth,  $D$  is Cartier). For  $\mathcal{M} = ((M, F, W), (K, W), \alpha) \in \text{PSh}_{\mathcal{D}(1,0)\text{fil},rh}(S) \times_I P_{\mathbb{Z}_p\text{fil},k}(S^{et})$ , we then define, using definition 55, theorem 40 and definition *TphipsiBdr*,

- the nearby cycle functor

$$\psi_D((M, F, W), (K, W), \alpha) := (\psi_D(M, F, W), \psi_D(K, W), \psi_D\alpha) \in \text{PSh}_{\mathcal{D}(1,0)\text{fil},rh}(S) \times_I P_{\mathbb{Z}_p\text{fil},k}(S^{et}),$$

with

$$\begin{aligned} \psi_D\alpha &: \mathbb{B}_{dr,S}(\psi_D(K, W)) \xrightarrow{T(\psi_D, \mathbb{B}_{dr})(K, W)} \psi_D\mathbb{B}_{dr,S}(K, W) \xrightarrow{\psi_D\alpha} \\ \psi_D DR(S)((M, F, W)^{an} \otimes_{O_S} (O\mathbb{B}_{dr,S}, F)) &\xrightarrow{T^{\mathbb{B}_{dr}}(\psi_D, DR)(M, F, W)} DR(S)(\psi_D(M, F, W)^{an} \otimes_{O_S} (O\mathbb{B}_{dr,S}, F)), \end{aligned}$$

- the vanishing cycle functor

$$\phi_D((M, F, W), (K, W), \alpha) := (\phi_D(M, F, W), \phi_D(K, W), \phi_D\alpha) \in \text{PSh}_{\mathcal{D}(1,0)\text{fil},rh}(S) \times_I P_{\mathbb{Z}_p\text{fil},k}(S^{et}),$$

with

$$\begin{aligned} \phi_D\alpha &: \mathbb{B}_{dr,S}(\phi_D(K, W)) \xrightarrow{T(\phi_D, \mathbb{B}_{dr})(K, W)} \phi_D\mathbb{B}_{dr,S}(K, W) \xrightarrow{\phi_D\alpha} \\ \phi_D DR(S)((M, F, W)^{an} \otimes_{O_S} (O\mathbb{B}_{dr,S}, F)) &\xrightarrow{T^{\mathbb{B}_{dr}}(\phi_D, DR)(M, F, W)} DR(S)(\phi_D(M, F, W)^{an} \otimes_{O_S} (O\mathbb{B}_{dr,S}, F)), \end{aligned}$$

- the canonical maps in  $\text{PSh}_{\mathcal{D}(1,0)\text{fil},rh}(S) \times_I P_{\mathbb{Z}_p\text{fil},k}(S^{et})$

$$\begin{aligned} \text{can}(\mathcal{M}) &:= (\text{can}(M, F, W), \text{can}(K, W)) : \psi_D((M, F, W), (K, W), \alpha) \rightarrow \phi_D((M, F, W), (K, W), \alpha)(-1), \\ \text{var}(\mathcal{M}) &:= (\text{var}(M, F, W), \text{var}(K, W)) : \phi_D((M, F, W), (K, W), \alpha) \rightarrow \psi_D((M, F, W), (K, W), \alpha). \end{aligned}$$

**Proposition 50.** Let  $S \in \text{SmVar}(k)$ . Let  $D = V(s) \subset S$  a (Cartier divisor). Consider a composition of proper morphisms

$$(f : X = X_r \xrightarrow{f_r} X_{r-1} \xrightarrow{f_1} X_0 = S) \in \text{SmVar}(k), \text{ proper, } 1 \leq i \leq r,$$

and

$$\begin{aligned} (M, F) &= H^{n_0} \int_{f_1} \cdots H^{n_r} \int_{f_r} ((O_X, F_b), H^{n_0} Rf_{1*} \cdots H^{n_r} Rf_{r*} \mathbb{Z}_{X_{\bar{k}}}, \\ &H^{n_0} f_{1*} \circ \cdots \circ H^{n_r} f_{r*} \alpha(X_{C_p})) \in \text{PSh}_{\mathcal{D}\text{fil},rh}(S) \times_I P_{\mathbb{Z}_p,k}(S^{et}). \end{aligned}$$

Then,

$$\begin{aligned} \psi_D(M, F) &= H^{n_0} \int_{f_1} \cdots H^{n_r} \int_{f_r} (\psi_{f^{-1}(D)}(O_X, F_b), H^{n_0} Rf_{1*} \cdots H^{n_r} Rf_{r*} \psi_{f^{-1}(D)} \mathbb{Z}_{X_{\bar{k}}}, \\ &H^{n_0} f_{1*} \circ \cdots \circ H^{n_r} f_{r*} \psi_{f^{-1}(D)} \alpha(X_{C_p})) \in \text{PSh}_{\mathcal{D}\text{fil},rh}(S) \times_I P_{\mathbb{Z}_p,k}(S^{et}), \end{aligned}$$

and

$$\begin{aligned} \phi_D(M, F) &= H^{n_0} \int_{f_1} \cdots H^{n_r} \int_{f_r} (\psi_{f^{-1}(D)}(O_X, F_b), H^{n_0} Rf_{1*} \cdots H^{n_r} Rf_{r*} \phi_{f^{-1}(D)} \mathbb{Z}_{X_{\bar{k}}}, \\ &H^{n_0} f_{1*} \circ \cdots \circ H^{n_r} f_{r*} \phi_{f^{-1}(D)} \alpha(X_{C_p})) \in \text{PSh}_{\mathcal{D}\text{fil},rh}(S) \times_I P_{\mathbb{Z}_p,k}(S^{et}), \end{aligned}$$

*Proof.* Immediate from definition. □

Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i \in I} S_i$  an open cover such that there exists closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_I \in \text{SmVar}(k)$ . We consider  $\mathbb{Z}_{p,Set}^w \in C_{\mathbb{Z}_p,fil}(S^{et})$  such that  $j_I^* \mathbb{Z}_{p,Set}^w = i_I^* \Gamma_{S_I}^{\vee,w} \mathbb{Z}_{p,\tilde{S}_I}^{et}$  and set

$$\begin{aligned}
& \alpha(S) : \mathbb{B}_{dr,(\tilde{S}_I)}(\mathbb{Z}_{p,Set}^w) \xrightarrow{:=} \\
& (\Gamma_{S_I}^{\vee} \mathbb{Z}_{p,(\tilde{S}_I)} \otimes \mathbb{B}_{dr,\phi_{\tilde{D}_{1,I}}} \otimes_{\mathbb{B}_{dr,\tilde{S}_I}} \cdots \otimes_{\mathbb{B}_{dr,\tilde{S}_I}} \mathbb{B}_{dr,\phi_{\tilde{D}_{d,I}}}, \mathbb{B}_{dr}(t_{IJ})) \\
& \xrightarrow{=} (\Gamma_{S_I}^{\vee} \mathbb{Z}_{p,\tilde{S}_I} \otimes \mathbb{B}_{dr,\tilde{S}_I} \otimes_{\mathbb{B}_{dr,\tilde{S}_I}} \mathbb{B}_{dr,\phi_{\tilde{D}_{1,I}}} \otimes_{\mathbb{B}_{dr,\tilde{S}_I}} \cdots \otimes_{\mathbb{B}_{dr,\tilde{S}_I}} \mathbb{B}_{dr,\phi_{\tilde{D}_{d,I}}}, \mathbb{B}_{dr}(x_{IJ})) \\
& \xrightarrow{\alpha((\tilde{S}_I, c_p) \otimes I)} \\
& (V_{\tilde{D}_{1,I}0} \cdots V_{\tilde{D}_{d,I}0} \Gamma_{S_I}^{\vee} (F^0 DR(\tilde{S}_I)((\mathcal{O}_{\mathbb{B}_{dr,\tilde{S}_I}}), F)) \otimes_{\mathbb{B}_{dr,\tilde{S}_I}} \mathbb{B}_{dr,\phi_{\tilde{D}_{1,I}}} \otimes_{\mathbb{B}_{dr,\tilde{S}_I}} \cdots \otimes_{\mathbb{B}_{dr,\tilde{S}_I}} \mathbb{B}_{dr,\phi_{\tilde{D}_{d,I}}}, \mathbb{B}_{dr}(t_{IJ})) \\
& \xrightarrow{(\mathbb{D}T(\gamma_{S_I}, \otimes)(-) \otimes (DR(S)(\mathbb{D}\rho_{DR,\tilde{D}_{1,I}}(\mathcal{O}_{\tilde{S}_I}, F_b)) \cdots \mathbb{D}(\rho_{DR,\tilde{D}_{d,I}}(\mathcal{O}_{\tilde{S}_I}, F_b))))} \\
& F^0 DR(S)(V_{\tilde{D}_{1,I}0} \cdots V_{\tilde{D}_{d,I}0} \Gamma_{S_I}^{\vee,h}(\mathcal{O}_{\tilde{S}_I}, F_b) \otimes_{\mathbb{B}_{dr,\tilde{S}_I}} \mathcal{O}_{\mathbb{B}_{dr,\tilde{S}_I}}(x_{IJ}) \otimes_{\mathbb{B}_{dr,(\tilde{S}_I)}} \\
& F^0 DR(S)((\Gamma_{S_I}^{\vee,Hdg}(\mathcal{O}_{\tilde{S}_I}, F_b))^{an} \otimes_{\mathcal{O}_{\tilde{S}_I}} (\mathcal{O}_{\mathbb{B}_{dr,\tilde{S}_I}}, F), x_{IJ})) \\
& \xrightarrow{T(DR, \otimes)(-, -)} F^0 DR(S)(\Gamma_{S_I}^{\vee,h}(\mathcal{O}_{\tilde{S}_I}, F_b) \otimes_{\mathcal{O}_{\tilde{S}_I}} (\Gamma_{S_I}^{\vee,Hdg}(\mathcal{O}_{\tilde{S}_I}, F_b))^{an} \otimes_{\mathcal{O}_{\tilde{S}_I}} (\mathcal{O}_{\mathbb{B}_{dr,\tilde{S}_I}}, F), x_{IJ})) \\
& \xrightarrow{F^0 DR(S)(m(\mathcal{O}_{\tilde{S}_I}))} F^0 DR(S)((\Gamma_{S_I}^{\vee,Hdg}(\mathcal{O}_{\tilde{S}_I}, F_b))^{an} \otimes_{\mathcal{O}_{\tilde{S}_I}} (\mathcal{O}_{\mathbb{B}_{dr,\tilde{S}_I}}, F), x_{IJ})) \\
& \xrightarrow{=} F^0 DR(S)((\Gamma_{S_I}^{\vee,Hdg}(\mathcal{O}_{\tilde{S}_I}, F_b), x_{IJ})^{an} \otimes_{\mathcal{O}_S} ((\mathcal{O}_{\mathbb{B}_{dr,(\tilde{S}_I)}}, F), t_{IJ}))
\end{aligned}$$

is an isomorphism in  $D_{\mathbb{B}_{dr,G}}(S_{\mathbb{C}_p}^{an,pet}/(\tilde{S}_I)_{\mathbb{C}_p}^{an,pet})$ , where  $D_1, \dots, D_d \subset S$  are Cartier divisors such that  $S = \cap_{s=1}^d D_s$ ,  $\tilde{D}_{s,I} \subset \tilde{S}_I$  are Cartier divisor such that  $D_s \cap S_I \subset \tilde{D}_{s,I} \cap S_I$ ,  $i_I : S_I \hookrightarrow \tilde{S}_I$  are the closed embeddings,  $m(O) : O \times_O O \xrightarrow{\sim} O$ ,  $h \otimes f \mapsto hf$  is the multiplication map, and we use definition 84 and proposition 49.

We now give the definition of  $p$  adic mixed Hodge modules which is the main definition of this section :

**Definition 86.** Let  $k \subset \mathbb{C}_p$  a subfield.

(i) Let  $S \in \text{SmVar}(k)$ . We denote by

$$\begin{aligned}
HM_{gm,k,\mathbb{C}_p}(S) := & \langle (R^n \int_{f_1} \cdots R^n \int_{f_r} (O_X, F_b), R^n f_{1*} \cdots R^n f_{r*} \mathbb{Z}_{p,X^{et}}, R^n f_{1*} \cdots R^n f_{r*} \alpha(X)), \\
& (f : X = X_r \xrightarrow{f_r} X_{r-1} \rightarrow \cdots \xrightarrow{f_1} X_0 = S) \in \text{SmVar}(k), \text{ proper} \rangle \\
& \subset PDRM(S) \times_I P_{\mathbb{Z}_p,k}(S^{et}) \subset \text{PSh}_{\mathcal{D}fil,rh}(S) \times_I P_{\mathbb{Z}_p,k}(S^{et})
\end{aligned}$$

the full abelian subcategory, where  $\langle, \rangle$  means generated by,

$$\alpha(X) : \mathbb{B}_{dr,X}(\mathbb{Z}_{p,X^{et}}) := \mathbb{B}_{dr,X_{\mathbb{C}_p}} \hookrightarrow DR(X)(\mathcal{O}_{\mathbb{B}_{dr,X_{\mathbb{C}_p}}})$$

is the inclusion quasi-isomorphism in  $C_{\mathbb{B}_{dr,G}}(X_{\mathbb{C}_p}^{pet})$ , and we use definition 84. We have by proposition 50 for  $((M, F), K, \alpha) \in HM_{gm,k,\mathbb{C}_p}(S)$ ,

$$\text{Gr}_k^W \psi_D((M, F), K, \alpha) := \text{Gr}_k^W \psi_D(M, F), \text{Gr}_k^W \psi_D K, \text{Gr}_k^W \psi_D \alpha \in HM_{gm,k,\mathbb{C}_p}(S).$$

and

$$\text{Gr}_k^W \psi_D((M, F), K, \alpha) := \text{Gr}_k^W \psi_D(M, F), \text{Gr}_k^W \psi_D K, \text{Gr}_k^W \psi_D \alpha \in HM_{gm,k,\mathbb{C}_p}(S).$$

for all  $k \in \mathbb{Z}$ . We set

$$\mathbb{Z}_{p,S}^{Hdg} := ((\mathcal{O}_S, F_b), \mathbb{Z}_{p,Set}, \alpha(S)) \in HM_{gm,k,\mathbb{C}_p}(S)$$

(i)' Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i \in I} S_i$  an open cover such that there exists closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_I \in \text{SmVar}(k)$ .

$$\begin{aligned} HM_{gm,k,\mathbb{C}_p}(S) := & \langle (R^{n_1} p_{1*} \text{Hdg} \cdots R^{n_r} p_{r*} \text{Hdg}(\Gamma_{X_I}^{\text{Hdg}}(O_{Y \times \tilde{X}_{r-1,I}}, F_b), x_{IJ}), \\ & R^{n_1} p_{1*} \cdots R^{n_r} p_{r*} T(X/(Y_r \times \tilde{X}_{r-1,I}))(\mathbb{Z}_{p,X^{et}}, R^{n_1} p_{1*} \cdots R^{n_r} p_{r*} \alpha(X)), \\ & (f : X = X_r \xrightarrow{f_r} X_{r-1} \rightarrow \cdots \xrightarrow{f_1} X_0 = S) \in \text{Var}(k) \rangle \\ & \subset PDRM(S) \times_I P_{\mathbb{Z}_p,k}(S^{et}) \subset \text{PSh}_{\mathcal{D}fil,rh}(S/(\tilde{S}_I)) \times_I P_{\mathbb{Z}_p,k}(S^{et}) \end{aligned}$$

the full abelian subcategory, where  $\langle, \rangle$  means generated by,  $f_i : X_i \hookrightarrow Y_i \times X_{i-1} \xrightarrow{p_i} X_{i-1}$  proper,  $Y_i \in \text{PSmVar}(k)$ ,  $X_i$  smooth, and  $\alpha(X)$  is given above. Note that if  $S$  is smooth then this definition of  $HM_{gm,k,\mathbb{C}_p}(S)$  agree with the one given in (i).

(ii) Let  $S \in \text{Var}(k)$ . Take an open cover  $S = \cup_i S_i$  such that there are closed embedding  $S_I \hookrightarrow \tilde{S}_I$  with  $S_I \in \text{SmVar}(k)$ . We define using the pure case (i) and (i)' the full subcategory of mixed Hodge modules defined over  $k$

$$\begin{aligned} MHM_{gm,k,\mathbb{C}_p}(S) := \\ \{(((M_I, F, W), u_{IJ}), (K, W), \alpha), \text{ s.t. } \text{Gr}_k^W(((M_I, F, W), u_{IJ}), (K, W), \alpha) \in HM_{gm,k,\mathbb{C}_p}(S)\} \\ \subset DRM(S) \times_I P_{\mathbb{Z}_p,fil,k}(S^{et}) \subset \text{PSh}_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I P_{\mathbb{Z}_p,fil,k}(S^{et}) \end{aligned}$$

whose object consists of  $(((M_I, F, W), u_{IJ}), (K, W), \alpha) \in DRM(S) \times_I P_{\mathbb{Z}_p,fil,k}(S^{et})$  such that

$$\text{Gr}_k^W(((M_I, F, W), u_{IJ}), (K, W), \alpha) := (\text{Gr}_k^W((M_I, F), u_{IJ}), \text{Gr}_k^W K, \text{Gr}_k^W \alpha) \in HM_{gm,k,\mathbb{C}_p}(S).$$

where  $DRM(S)$  is the category of de Rham modules introduced in section 5 definition 56. The fact that  $\alpha$  is an isomorphism implies that the Galois representation of  $G$  induced on each  $k$ -point of  $S$  is a de Rham representation. We set

$$\mathbb{Z}_{p,S}^{\text{Hdg}} := ((\Gamma_{S_I}^{\vee, \text{Hdg}}(O_{\tilde{S}_I}, F_b), x_{IJ}), \mathbb{Z}_{p,S^{et}}^w, \alpha(S)) \in MHM_{gm,k,\mathbb{C}_p}(S)$$

with  $\alpha(S)$  given above. For  $S \in \text{SmVar}(k)$  and  $D = V(s) \subset S$  a (Cartier) divisor, we have for  $((M, F, W), (K, W), \alpha) \in MHM_{gm,k,\mathbb{C}_p}(S)$ , using theorem 32,

$$\psi_D((M, F, W), (K, W), \alpha), \phi_D((M, F, W), (K, W), \alpha) \in MHM_{gm,k,\mathbb{C}_p}(S),$$

by the pure case (c.f. (i) and proposition 50) and the strictness of the  $V$ -filtration.

For  $S \in \text{Var}(k)$  we get  $D(MHM_{gm,k,\mathbb{C}_p}(S)) := \text{Ho}_{(zar,et)}(C(MHM_{gm,k,\mathbb{C}_p}(S)))$  after localization with Zariski local equivalence and etale local equivalence.

We now look at functorialities :

**Definition 87.** Let  $k \subset \mathbb{C}_p$  a subfield. Let  $S \in \text{SmVar}(k)$ . Let  $j : S^\circ \hookrightarrow S$  an open embedding. Let  $Z := S \setminus S^\circ = V(\mathcal{I}) \subset S$  an the closed complementary subset,  $\mathcal{I} \subset O_S$  being an ideal subsheaf. Taking generators  $\mathcal{I} = (s_1, \dots, s_r)$ , we get  $Z = V(s_1, \dots, s_r) = \cap_{i=1}^r Z_i \subset S$  with  $Z_i = V(s_i) \subset S$ ,  $s_i \in \Gamma(S, \mathcal{L}_i)$  and  $L_i$  a line bundle. Note that  $Z$  is an arbitrary closed subset,  $d_Z \geq d_X - r$  needing not be a complete intersection. Denote by  $j_I : S^{\circ,I} := \cap_{i \in I} (S \setminus Z_i) = S \setminus (\cup_{i \in I} Z_i) \xrightarrow{j_I^\circ} S^\circ \xrightarrow{j} S$  the open embeddings. Let  $(M, F, W) \in MHM_{gm,k,\mathbb{C}_p}(S^\circ)$ . We then define, using definition 57 and definition 7

- the canonical extension

$$\begin{aligned} j_* \text{Hdg}((M, F, W), (K, W), \alpha) & := (j_* \text{Hdg}(M, F, W), j_* w(K, W), j_* \alpha) \\ & := \in MHM_{gm,k,\mathbb{C}_p}(S), \end{aligned}$$

so that  $j^*(j_* \text{Hdg}((M, F, W), (K, W), \alpha)) = ((M, F, W), (K, W), \alpha)$ ,

- the canonical extension

$$j_{!Hdg}((M, F, W), (K, W), \alpha) := (j_{!Hdg}(M, F, W), j_{!w}(K, W), j_{!}\alpha) := \in MHM_{gm,k,C_p}(S),$$

so that  $j^*(j_{!Hdg}((M, F, W), (K, W), \alpha)) = ((M, F, W), (K, W), \alpha)$ .

Moreover for  $((M', F, W), (K', W), \alpha') \in MHM_{gm,k,C_p}(S)$ ,

- there is a canonical map in  $MHM_{gm,k,C_p}(S)$

$$\text{ad}(j^*, j_{*Hdg})((M', F, W), (K', W), \alpha') : ((M', F, W), (K', W), \alpha') \rightarrow j_{*Hdg}j^*((M', F, W), (K', W), \alpha'),$$

- there is a canonical map in  $MHM_{gm,k,C_p}(S)$

$$\text{ad}(j_{!Hdg}, j^*)((M', F, W), (K', W), \alpha') : j_{!Hdg}j^*((M', F, W), (K', W), \alpha') \rightarrow ((M', F, W), (K', W), \alpha').$$

For  $(M, F, W) \in C(MHM_{gm,k,C_p}(S^o))$ ,

- we have the canonical map in  $C_{\mathcal{D}(1,0)fil}(S) \times_I C_{fil}(S^{et})$

$$\begin{aligned} T(j_{*Hdg}, j_*)((M, F, W), (K, W), \alpha) &:= (k \circ \text{ad}(j^*, j_*)(-), k \circ \text{ad}(j^*, j_*)(-), 0) : \\ &j_{*Hdg}((M, F, W), (K, W), \alpha) \rightarrow (j_*E(M, F, W), j_*E(K, W), \alpha) \end{aligned}$$

- we have the canonical map in  $C_{\mathcal{D}(1,0)fil}(S) \times_I C_{fil}(S^{et})$

$$\begin{aligned} T(j_!, j_{!Hdg})((M, F, W), (K, W), \alpha) &:= (k \circ \text{ad}(j_!, j^*)(-), k \circ \text{ad}(j_!, j^*)(-), 0) : \\ &(j_!(M, F, W), j_!(K, W), j_!\alpha) \rightarrow j_{!Hdg}((M, F, W), (K, W), \alpha). \end{aligned}$$

**Proposition 51.** (i) Let  $S \in \text{SmVar}(k)$ . Let  $D = V(s) \subset S$  a divisor with  $s \in \Gamma(S, L)$  and  $L$  a line bundle ( $S$  being smooth,  $D$  is Cartier). Denote by  $j : S^o := S \setminus D \hookrightarrow S$  the open complementary embedding. Then,

- $(j^*, j_{*Hdg}) : MHM_{gm,k,C_p}(S) \rightleftarrows MHM_{gm,k,C_p}(S^o)$  is a pair of adjoint functors
- $(j_{!Hdg}, j^*) : MHM_{gm,k,C_p}(S^o) \rightleftarrows MHM_{gm,k,C_p}(S)$  is a pair of adjoint functors.

(ii) Let  $S \in \text{SmVar}(k)$ . Let  $Z = V(\mathcal{I}) \subset S$  an arbitrary closed subset,  $\mathcal{I} \subset \mathcal{O}_S$  being an ideal subsheaf. Denote by  $j : S^o := S \setminus Z \hookrightarrow S$ . Then,

- $(j^*, j_{*Hdg}) : D(MHM_{gm,k,C_p}(S)) \rightleftarrows D(MHM_{gm,k,C_p}(S^o))$  is a pair of adjoint functors
- $(j_{!Hdg}, j^*) : D(MHM_{gm,k,C_p}(S^o)) \rightleftarrows D(MHM_{gm,k,C_p}(S))$  is a pair of adjoint functors.

*Proof.* (i): Follows from proposition 37.

(ii): Follows from (i) and the exactness of  $j^*$ ,  $j_{*Hdg}$  and  $j_{!Hdg}$ .  $\square$

**Definition 88.** Let  $S \in \text{SmVar}(k)$ . Let  $Z \subset S$  a closed subset. Denote by  $j : S \setminus Z \hookrightarrow S$  the complementary open embedding.

(i) We define using definition 59, definition 8 and definition 84(iii), the filtered Hodge support section functor

$$\begin{aligned} \Gamma_Z^{Hdg} : C(MHM_{gm,k,C_p}(S)) &\rightarrow C(MHM_{gm,k,C_p}(S)), \quad ((M, F, W), (K, W), \alpha) \mapsto \\ &\Gamma_Z^{Hdg}((M, F, W), (K, W), \alpha) := (\Gamma_Z^{Hdg}(M, F, W), \Gamma_Z^w(K, W), \Gamma(\alpha)) \\ &= \text{Cone}(\text{ad}(j^*, j_{*Hdg})(-) : j_{*Hdg}j^*((M, F, W), (K, W), \alpha) \rightarrow ((M, F, W), (K, W), \alpha)[-1]) \end{aligned}$$

see definition 87 for the last equality, together we the canonical map

$$\gamma_Z^{Hdg}((M, F, W), (K, W), \alpha) : \Gamma_Z^{Hdg}((M, F, W), (K, W), \alpha) \rightarrow ((M, F, W), (K, W), \alpha).$$

(i)' Since  $j_{*Hdg} : C(MHM_{gm,k,\mathbb{C}_p}(S^\circ)) \rightarrow C(MHM_{gm,k,\mathbb{C}_p}(S))$  is an exact functor,  $\Gamma_Z^{Hdg}$  induces the functor

$$\begin{aligned} \Gamma_Z^{Hdg} : D(MHM_{gm,k,\mathbb{C}_p}(S)) &\rightarrow D(MHM_{gm,k,\mathbb{C}_p}(S)), \\ ((M, F, W), (K, W), \alpha) &\mapsto \Gamma_Z^{Hdg}((M, F, W), (K, W), \alpha) \end{aligned}$$

(ii) We define using definition 59, definition 8 and definition 84(iii) the dual filtered Hodge support section functor

$$\begin{aligned} \Gamma_Z^{\vee,Hdg} : C(MHM_{gm,k,\mathbb{C}_p}(S)) &\rightarrow C(MHM_{gm,k,\mathbb{C}_p}(S)), \quad ((M, F, W), (K, W), \alpha) \mapsto \\ \Gamma_Z^{\vee,Hdg}((M, F, W), (K, W), \alpha) &:= (\Gamma_Z^{\vee,Hdg}(M, F, W), \Gamma_Z^{\vee,w}(K, W), \Gamma^\vee(\alpha)) \\ = \text{Cone}(\text{ad}(j_{!Hdg}, j^*)(-)) : j_{!Hdg}, j^*((M, F, W), (K, W), \alpha) &\rightarrow ((M, F, W), (K, W), \alpha) \end{aligned}$$

see definition 87 for the last equality, together we the canonical map

$$\gamma_Z^{\vee,Hdg}((M, F, W), (K, W), \alpha) : ((M, F, W), (K, W), \alpha) \rightarrow \Gamma_Z^{\vee,Hdg}((M, F, W), (K, W), \alpha).$$

(i)' Since  $j_{!Hdg} : C(MHM_{gm,k,\mathbb{C}_p}(S^\circ)) \rightarrow C(MHM_{gm,k,\mathbb{C}_p}(S))$  is an exact functor,  $\Gamma_Z^{Hdg,\vee}$  induces the functor

$$\begin{aligned} \Gamma_Z^{Hdg,\vee} : D(MHM_{gm,k,\mathbb{C}_p}(S)) &\rightarrow D(MHM_{gm,k,\mathbb{C}_p}(S)), \\ ((M, F, W), (K, W), \alpha) &\mapsto \Gamma_Z^{Hdg,\vee}((M, F, W), (K, W), \alpha) \end{aligned}$$

In the singular case it gives :

**Definition 89.** Let  $S \in \text{Var}(k)$ . Let  $Z \subset S$  a closed subset. Let  $S = \cup_{i=1}^s S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Denote  $Z_I := Z \cap S_I$ . Denote by  $n : S \setminus Z \hookrightarrow S$  and  $\tilde{n}_I : \tilde{S}_I \setminus Z_I \hookrightarrow \tilde{S}_I$  the complementary open embeddings.

(i) We define using definition 61, definition 8 and definition 84(iii) the filtered Hodge support section functor

$$\begin{aligned} \Gamma_Z^{Hdg} : C(MHM_{gm,k,\mathbb{C}_p}(S)) &\rightarrow C(MHM_{gm,k,\mathbb{C}_p}(S)), \\ (((M_I, F, W), u_{IJ}), (K, W), \alpha) &\mapsto \Gamma_Z^{Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha) := \\ &:= (\Gamma_Z^{Hdg}((M_I, F, W), u_{IJ}), \Gamma_Z^w(K, W), \Gamma(\alpha)) \end{aligned}$$

together with the canonical map

$$\begin{aligned} \gamma_Z^{Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha) : \\ \Gamma_Z^{Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha) &\rightarrow (((M_I, F, W), u_{IJ}), (K, W), \alpha). \end{aligned}$$

(i)' By exactness of  $\Gamma_Z^{Hdg}$  and  $\Gamma_Z^w$  it induces the functor

$$\begin{aligned} \Gamma_Z^{Hdg} : D(MHM_{gm,k,\mathbb{C}_p}(S)) &\rightarrow D(MHM_{gm,k,\mathbb{C}_p}(S)), \\ (((M_I, F, W), u_{IJ}), (K, W), \alpha) &\mapsto \Gamma_Z^{Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha) \end{aligned}$$

(ii) We define using definition 61, definition 8 and definition 84(iii) the dual filtered Hodge support section functor

$$\begin{aligned} \Gamma_Z^{\vee,Hdg} : C(MHM_{gm,k,\mathbb{C}_p}(S)) &\rightarrow C(MHM_{gm,k,\mathbb{C}_p}(S)), \quad (((M_I, F, W), u_{IJ}), (K, W), \alpha) \mapsto \\ \Gamma_Z^{\vee,Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha) &:= (\Gamma_Z^{\vee,Hdg}((M_I, F, W), u_{IJ}), \Gamma_Z^{\vee,w}(K, W), \Gamma(\alpha)), \end{aligned}$$

together we the canonical map

$$\begin{aligned} \gamma_Z^{\vee,Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha) : \\ (((M_I, F, W), u_{IJ}), (K, W), \alpha) &\rightarrow \Gamma_Z^{\vee,Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha). \end{aligned}$$



(ii)' By exactness of  $\Gamma_Z^{\vee, Hdg}$  and  $\Gamma_Z^{\vee, w}$ , it induces the functor

$$\begin{aligned} \Gamma_Z^{\vee, Hdg} : D(MHM_{gm, k, \mathbb{C}_p}(S)) &\rightarrow D(MHM_{gm, k, \mathbb{C}_p}(S)), \\ (((M_I, F, W), u_{IJ}), (K, W), \alpha) &\mapsto \Gamma_Z^{\vee, Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha) \\ &:= (\Gamma_Z^{\vee, Hdg}((M_I, F, W), u_{IJ}), \Gamma_Z^{\vee, w}(K, W), \Gamma(\alpha)) \end{aligned}$$

This gives the inverse image functor :

**Definition 90.** Let  $f : X \rightarrow S$  a morphism with  $X, S \in \text{Var}(k)$ . Assume there exist a factorization  $f : X \xrightarrow{l} Y \times S \xrightarrow{ps} S$  with  $Y \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $ps$  the projection. Let  $S = \cup_{i \in I} S_i$  an open cover such that there exist closed embeddings  $i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Denote  $X_I := f^{-1}(S_I)$ . We have then  $X = \cup_{i \in I} X_i$  and the commutative diagrams

$$\begin{array}{ccccc} f : X_I & \xrightarrow{l_I} & Y \times S_I & \xrightarrow{ps_I} & S_I \\ & \searrow & \downarrow i'_I := (I \times i_I) & & \downarrow i_I \\ & & Y \times \tilde{S}_I & \xrightarrow{p_{\tilde{S}_I} := \tilde{f}_I} & \tilde{S}_I \end{array}$$

(i) For  $(((M_I, F, W), u_{IJ}), (K, W), \alpha) \in C(MHM_{gm, k, \mathbb{C}_p}(S))$  we set (see definition 89 for  $l$ )

$$\begin{aligned} f_{Hdg}^{*mod}(((M_I, F, W), u_{IJ}), (K, W), \alpha) &:= \\ \Gamma_X^{Hdg}((p_{\tilde{S}_I}^{*mod[-]}(M_I, F, W), p_{\tilde{S}_I}^{*mod[-]}u_{IJ}), p_S^*(K, W), p_S^*\alpha)(d_Y)[2d_Y] &\in C(MHM_{gm, k, \mathbb{C}_p}(X)), \end{aligned}$$

(ii) For  $(((M_I, F, W), u_{IJ}), (K, W), \alpha) \in C(MHM_{gm, k, \mathbb{C}_p}(S))$  we set (see definition 89 for  $l$ )

$$\begin{aligned} f_{Hdg}^{\hat{*}mod}(((M_I, F, W), u_{IJ}), (K, W), \alpha) &:= \\ \Gamma_X^{\vee, Hdg}((p_{\tilde{S}_I}^{*mod[-]}(M_I, F, W), p_{\tilde{S}_I}^{*mod[-]}u_{IJ}), p_S^*(K, W), p_S^*\alpha) &\in C(MHM_{gm, k, \mathbb{C}_p}(X)), \end{aligned}$$

**Definition 91.** Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i \in I} S_i$  an open cover such that there exist closed embeddings  $i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . We have the following bi-functor

$$\begin{aligned} (-) \otimes_{O_S}^{Hdg} (-) : D(MHM_{gm, k, \mathbb{C}_p}(S))^2 &\rightarrow D(MHM_{gm, k, \mathbb{C}_p}(S)), \\ (((M_I, F, W), u_{IJ}), (K, W), \alpha), (((M'_I, F, W), v_{IJ}), (K', W), \alpha') &\mapsto \\ (((M_I, F, W), u_{IJ}), (K, W), \alpha) \otimes_{O_S}^{Hdg} (((M'_I, F, W), v_{IJ}), (K', W), \alpha') &:= \\ ((M_I, F, W), u_{IJ}) \otimes_{O_S}^{Hdg} ((M'_I, F, W), v_{IJ}), (K, W) \otimes (K', W), \alpha \otimes \alpha' & \end{aligned}$$

where the map  $\alpha \otimes \alpha'$  is given in definition 84.

**Proposition 52.** Let  $f_1 : X \rightarrow Y$  and  $f_2 : Y \rightarrow S$  two morphism with  $X, Y, S \in \text{QPVar}(k)$ .

(i) Let  $\mathcal{M} \in C(MHM_{gm, k, \mathbb{C}_p}(S))$ . Then,

$$(f_2 \circ f_1)^{!Hdg}(\mathcal{M}) = f_1^{!Hdg} f_2^{!Hdg}(\mathcal{M}) \in D(MHM_{gm, k, \mathbb{C}_p}(X)).$$

(ii) Let  $(M, F, W) \in C(MHM_{gm, k, \mathbb{C}_p}(S))$ . Then,

$$(f_2 \circ f_1)^{*Hdg}(\mathcal{M}) = f_1^{*Hdg} f_2^{*Hdg}(\mathcal{M}) \in D(MHM_{gm, k, \mathbb{C}_p}(X))$$

*Proof.* Immediate from definition. □

**Proposition 53.** *Let  $S \in \text{SmVar}(k)$ . Let  $D = V(s) \subset S$  a (Cartier) divisor, where  $s \in \Gamma(S, L)$  is a section of the line bundle  $L = L_D$  associated to  $D$ .*

(i) *Let  $((M, F, W), (K, W), \alpha) \in \text{MHM}_{gm,k,\mathbb{C}_p}(S)$ . We have, using proposition 38, the canonical quasi-isomorphism in  $C(\text{MHM}_{gm,k,\mathbb{C}_p}(S))$  :*

$$\begin{aligned} & \text{Is}(M) := (\text{Is}(M), \text{Is}(K), 0) : \\ ((M, F, W), (K, W), \alpha) & \rightarrow (\psi_D((M, F, W), (K, W), \alpha) \xrightarrow{((c(x_{S^o/S}(M)), \text{can}(M)), (c(x(K)), \text{can}(K)), 0))} \\ & x_{S^o/S}((M, F, W), (K, W), \alpha) \oplus \phi_D((M, F, W), (K, W), \alpha) \xrightarrow{=} \\ & (x_{S^o/S}(M, F, W), x_{S^o/S}(K, W), x_{S^o/S}(\alpha)) \oplus (\phi_D(M, F, W), \phi_D(K, W), \phi_D \alpha) \\ & \xrightarrow{((\mathbb{D}c(x_{S^o/S}(\mathbb{D}M)), \text{var}(M)), (\mathbb{D}c(x_{S^o/S}(\mathbb{D}K)), \text{var}(K)), 0))} \psi_D((M, F, W), (K, W), \alpha)). \end{aligned}$$

(ii) *We denote by  $\text{MHM}_{gm,k,\mathbb{C}_p}(S \setminus D) \times_J \text{MHM}_{gm,k,\mathbb{C}_p}(D)$  the category whose set of objects consists of*

$$\{(\mathcal{M}, \mathcal{N}, a, b), \mathcal{M} \in \text{MHM}_{gm,k,\mathbb{C}_p}(S \setminus D), \mathcal{N} \in \text{MHM}_{gm,k,\mathbb{C}_p}(D), a : \psi_{D1} \mathcal{M} \rightarrow \mathcal{N}, b : \mathcal{N} \rightarrow \psi_{D1} \mathcal{M}\}$$

*The functor (see definition 85)*

$$\begin{aligned} (j^*, \phi_D, c, v) & : \text{MHM}_{gm,k,\mathbb{C}_p}(S) \rightarrow \text{MHM}_{gm,k,\mathbb{C}_p}(S \setminus D) \times_J \text{MHM}_{gm,k,\mathbb{C}_p}(D), \\ ((M, F, W), (K, W), \alpha) & \mapsto ((j^*(M, F, W), j^*(K, W), j^* \alpha), \phi_D((M, F, W), (K, W), \alpha), \text{can}(-), \text{var}(-)) \end{aligned}$$

*is an equivalence of category.*

*Proof.* Follows from proposition 38. □

Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i \in I} S_i$  an open cover such that there exists closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . We have the category  $D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p,fil,c,k}(S^{et})$

- whose set of objects is the set of triples  $\{(((M_I, F, W), u_{IJ}), (K, W), \alpha)\}$  with

$$\begin{aligned} & ((M_I, F, W), u_{IJ}) \in D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)), (K, W) \in D_{\mathbb{Z}_p,fil,c,k}(S^{et}), \\ \alpha & : \mathbb{B}_{dr,(\tilde{S}_I)}(K, W) \rightarrow F^0 DR(S)^{[-]}(((M_I, F, W), u_{IJ})^{an} \otimes_{O_S} ((O\mathbb{B}_{dr,\tilde{S}_I}, F), t_{IJ})) \end{aligned}$$

where  $\alpha$  is a morphism in  $D_{\mathbb{B}_{dr,G,fil}}(S_{\mathbb{C}_p}^{an,pet}/(\tilde{S}_{I,\mathbb{C}_p}^{an,pet}))$ ,

- and whose set of morphisms consists of

$$\phi = (\phi_D, \phi_C, [\theta]) : (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2)$$

where  $\phi_D : ((M_1, F, W), u_{IJ}) \rightarrow ((M_2, F, W), u_{IJ})$  and  $\phi_C : (K_1, W) \rightarrow (K_2, W)$  are morphisms and

$$\begin{aligned} \theta & = (\theta^\bullet, I(DR(S)(\phi_D^{an}) \times I) \circ I(\alpha_1), I(\alpha_2) \circ I(\mathbb{B}_{dr,(\tilde{S}_I)}(\phi_C \otimes I))) : \\ I(\mathbb{B}_{dr,(\tilde{S}_I)}(K_1, W))[1] & \rightarrow I(F^0 DR(S)((M_{2I}, F, W), u_{IJ})^{an} \otimes_{O_S} ((O\mathbb{B}_{dr,\tilde{S}_I}, F), t_{IJ})) \end{aligned}$$

is an homotopy,  $I : D_{\mathbb{B}_{dr,G,fil}}(S_{\mathbb{C}_p}^{an,pet}/(\tilde{S}_{I,\mathbb{C}_p}^{an,pet})) \rightarrow K_{\mathbb{B}_{dr,G,fil}}(S_{\mathbb{C}_p}^{an,pet}/(\tilde{S}_{I,\mathbb{C}_p}^{an,pet}))$  being the injective resolution functor, and for

- $\phi = (\phi_D, \phi_C, [\theta]) : (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2)$
- $\phi' = (\phi'_D, \phi'_C, [\theta']) : (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2) \rightarrow (((M_{3I}, F, W), u_{IJ}), (K_3, W), \alpha_3)$

the composition law is given by

$$\begin{aligned} \phi' \circ \phi := & (\phi'_D \circ \phi_D, \phi'_C \circ \phi_C, I(DR(S)(\phi'^{an}_D \otimes I)) \circ [\theta] + [\theta'] \circ I(\mathbb{B}_{dr,(\tilde{S}_I)}(\phi_C)))[1] : \\ & (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_{3I}, F, W), u_{IJ}), (K_3, W), \alpha_3), \end{aligned}$$

in particular for  $((M_I, F, W), u_{IJ}), (K, W), \alpha \in C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et})$ ,

$$I_{(((M_I, F, W), u_{IJ}), (K, W), \alpha)} = ((I_{M_I}), I_K, 0),$$

and also the category  $D_{\mathcal{D}(1,0)fil,rh,\infty}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et})$  defined in the same way, together with the localization functor

$$\begin{aligned} (D(zar), I) : C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S^{et}) & \rightarrow D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S^{et}) \\ & \rightarrow D_{\mathcal{D}(1,0)fil,rh,\infty}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S^{et}). \end{aligned}$$

Note that if  $\phi = (\phi_D, \phi_C, [\theta]) : (((M_1, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_2, F, W), u_{IJ}), (K_2, W), \alpha_2)$  is a morphism in  $D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et})$  such that  $\phi_D$  and  $\phi_C$  are isomorphism then  $\phi$  is an isomorphism (see remark 8). Moreover,

- For  $((M_I, F, W), u_{IJ}), (K, W), \alpha \in D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et})$ , we set

$$(((M_I, F, W), u_{IJ}), (K, W), \alpha)[1] := (((M_I, F, W), u_{IJ})[1], (K, W)[1], \alpha[1]).$$

- For

$$\phi = (\phi_D, \phi_C, [\theta]) : (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2)$$

a morphism in  $D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et})$ , we set (see [11] definition 3.12)

$$\text{Cone}(\phi) := (\text{Cone}(\phi_D), \text{Cone}(\phi_C), ((\alpha_1, \theta), (\alpha_2, 0))) \in D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et}),$$

$((\alpha_1, \theta), (\alpha_2, 0))$  being the matrix given by the composition law, together with the canonical maps

- $c_1(-) = (c_1(\phi_D), c_1(\phi_C), 0) : (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2) \rightarrow \text{Cone}(\phi)$
- $c_2(-) = (c_2(\phi_D), c_2(\phi_C), 0) : \text{Cone}(\phi) \rightarrow (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1)[1]$ .

We have then the following :

**Theorem 46.** (i) Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i \in I} S_i$  an open cover such that there exists closed embedding  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Then the full embedding

$$\iota_S : MHM_{gm,k,\mathbb{C}_p}(S) \hookrightarrow \text{PSh}_{\mathcal{D}(1,0)fil,rh}^0(S/(\tilde{S}_I)) \times_I P_{\mathbb{Z}_p fil,c,k}(S^{et}) \hookrightarrow C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et})$$

induces a full embedding

$$\iota_S : D(MHM_{gm,k,\mathbb{C}_p}(S)) \hookrightarrow D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et})$$

whose image consists of  $((M_I, F, W), u_{IJ}), (K, W), \alpha \in D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et})$  such that

$$((H^n(M_I, F, W), H^n(u_{IJ})), H^n(K, W), H^n \alpha) \in MHM_{gm,k,\mathbb{C}_p}(S)$$

for all  $n \in \mathbb{Z}$  and such that for all  $p \in \mathbb{Z}$ , the differentials of  $\text{Gr}_W^p(M_I, F)$  are strict for the filtrations  $F$ .

(i)' Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i \in I} S_i$  an open cover such that there exists closed embedding  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Then,

$$\begin{aligned} D(MHM_{gm,k,\mathbb{C}_p}(S)) &= \langle \left( \int_f^{FDR} (n \times I)_{!} \text{Hdg}(\Gamma_X^{\vee, \text{Hdg}}(O_{\mathbb{P}^{N,o} \times \tilde{S}_I}, F_b), x_{IJ}), Rf_* \mathbb{Z}_p, X^{et}, f_* \alpha(X) \right), \\ &\quad (f : X \xrightarrow{l} \mathbb{P}^{N,o} \times S \xrightarrow{p} S) \in \text{QPVar}(k) \rangle \\ &= \langle \left( \int_f^{FDR} ((\Gamma_X^{\vee, \text{Hdg}}(O_{\mathbb{P}^{N,o} \times \tilde{S}_I}, F_b), x_{IJ}), Rf_* \mathbb{Z}_p, X^{et}, f_* \alpha(X)), \right. \\ &\quad (f : X \xrightarrow{l} \mathbb{P}^{N,o} \times S \xrightarrow{p} S) \in \text{QPVar}(k), \text{ proper, } X \text{ smooth} \rangle \\ &\quad \subset D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et}) \end{aligned}$$

where  $n : \mathbb{P}^{N,o} \hookrightarrow \mathbb{P}^N$  are open embeddings,  $l$  are closed embedding and  $\langle, \rangle$  means the full triangulated category generated by.

(ii) Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i \in I} S_i$  an open cover such that there exists closed embedding  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Then the full embedding

$$\iota_S : MHM_{gm,k,\mathbb{C}_p}(S) \hookrightarrow \text{PSh}_{\mathcal{D}(1,0)fil,rh}^0(S/(\tilde{S}_I)) \times_I P_{\mathbb{Z}_p fil,k}(S^{et}) \hookrightarrow C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et})$$

induces a full embedding

$$\iota_S : D(MHM_{gm,k,\mathbb{C}_p}(S)) \hookrightarrow D_{\mathcal{D}(1,0)fil,\infty,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et})$$

whose image consists of  $((M_I, F, W), u_{IJ}), (K, W), \alpha) \in D_{\mathcal{D}(1,0)fil,\infty,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et})$  such that

$$((H^n(M_I, F, W), H^n(u_{IJ})), H^n(K, W), H^n \alpha) \in MHM_{gm,k,\mathbb{C}_p}(S)$$

for all  $n \in \mathbb{Z}$  and such that there exist  $r \in \mathbb{Z}$  and an  $r$ -filtered homotopy equivalence  $((M_I, F, W), u_{IJ}) \rightarrow ((M'_I, F, W), u_{IJ})$  such that for all  $p \in \mathbb{Z}$  the differentials of  $\text{Gr}_W^p(M'_I, F)$  are strict for the filtrations  $F$ .

*Proof.* (i): We first show that  $\iota_S$  is fully faithful, that is for all  $\mathcal{M} = (((M_I, F, W), u_{IJ}), (K, W), \alpha), \mathcal{M}' = (((M'_I, F, W), u_{IJ}), (K', W), \alpha') \in MHM_{gm,k,\mathbb{C}_p}(S)$  and all  $n \in \mathbb{Z}$ ,

$$\begin{aligned} \iota_S : \text{Ext}_{D(MHM_{gm,k,\mathbb{C}_p}(S))}^n(\mathcal{M}, \mathcal{M}') &:= \text{Hom}_{D(MHM_{gm,k,\mathbb{C}_p}(S))}(\mathcal{M}, \mathcal{M}'[n]) \\ \rightarrow \text{Ext}_{\mathcal{D}(S)}^n(\mathcal{M}, \mathcal{M}') &:= \text{Hom}_{\mathcal{D}(S) := D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil}(S^{et})}(\mathcal{M}, \mathcal{M}'[n]) \end{aligned}$$

For this it is enough to assume  $S$  smooth. We then proceed by induction on  $\max(\dim \text{supp}(M), \dim \text{supp}(M'))$ .

- For  $\text{supp}(M) = \text{supp}(M') = \{s\}$ , it is the theorem for mixed hodge complexes or absolute Hodge complexes, see [11]. If  $\text{supp}(M) = \{s\}$  and  $\text{supp}(M') = \{s'\}$  and  $s' \neq s$ , then by the localization exact sequence

$$\text{Ext}_{D(MHM_{gm,k,\mathbb{C}_p}(S))}^n(\mathcal{M}, \mathcal{M}') = 0 = \text{Ext}_{\mathcal{D}(S)}^n(\mathcal{M}, \mathcal{M}')$$

- Denote  $\text{supp}(M) = Z \subset S$  and  $\text{supp}(M') = Z' \subset S$ . There exist an open subset  $S^o \subset S$  such that  $Z^o := Z \cap S^o$  and  $Z'^o := Z' \cap S^o$  are smooth, and  $\mathcal{M}|_{Z^o} := ((i^* \text{Gr}_{V_{Z^o},0} M|_{S^o}, F, W), i^* j^*(K, W), \alpha^*(i)) \in MHM_{gm,k}(Z^o)$  and  $\mathcal{M}'|_{Z'^o} := ((i'^* \text{Gr}_{V_{Z'^o},0} M'|_{S^o}, F, W), i'^* j'^* K, \alpha^*(i')) \in MHM_{gm,k}(Z'^o)$  are variation of geometric mixed Hodge structure over  $k \subset \mathbb{C}$ , where  $j : S^o \hookrightarrow S$  is the open embedding, and  $i : Z^o \hookrightarrow S^o, i' : Z'^o \hookrightarrow S^o$  the closed embeddings. Considering the connected components of  $Z^o$  and  $Z'^o$ , we may assume that  $Z^o$  and  $Z'^o$  are connected. Shrinking  $S^o$  if necessary, we may assume that either  $Z^o = Z'^o$  or  $Z^o \cap Z'^o = \emptyset$ . We denote  $D = S \setminus S^o$ . Shrinking  $S^o$  if necessary, we may assume that  $D$  is a divisor and denote by  $l : S \hookrightarrow L_D$  the zero section embedding.

- If  $Z^o = Z'^o$ , denote  $i : Z^o \hookrightarrow S^o$  the closed embedding. We have then the following commutative diagram

$$\begin{array}{ccc}
\mathrm{Ext}_{D(MHM_{gm,k,C_p}(S^o))}^n(\mathcal{M}|_{S^o}, \mathcal{M}'|_{S^o}) & \xrightarrow{\iota_{S^o}} & \mathrm{Ext}_{D(S^o)}^n(\mathcal{M}|_{S^o}, \mathcal{M}'|_{S^o}) \\
(i^* \mathrm{Gr}_{V_{Z^o}, 0}, i^*, \alpha^*(i)) \updownarrow (i_{*mod}, i_*, \alpha_*(i)) & & (i_{*mod}, i_*, \alpha_*(i)) \updownarrow (i^* \mathrm{Gr}_{V_{Z^o}, 0}, i^*, \alpha^*(i)) \\
\mathrm{Ext}_{D(MHM_{gm,k,C_p}(Z^o))}^n(\mathcal{M}|_{Z^o}, \mathcal{M}'|_{Z^o}) & \xrightarrow{\iota_{Z^o}} & \mathrm{Ext}_{D(Z^o)}^n(\mathcal{M}|_{Z^o}, \mathcal{M}'|_{Z^o})
\end{array}$$

Now we prove that  $\iota_{Z^o}$  is an isomorphism similarly to the proof the the generic case of [6]. On the other hand the left and right column are isomorphisms. Hence  $\iota_{S^o}$  is an isomorphism by the diagram.

- If  $Z^o \cap Z'^o = \emptyset$ , we consider the following commutative diagram

$$\begin{array}{ccc}
\mathrm{Ext}_{D(MHM_{gm,k,C_p}(S^o))}^n(\mathcal{M}|_{S^o}, \mathcal{M}'|_{S^o}) & \xrightarrow{\iota_{S^o}} & \mathrm{Ext}_{D(S^o)}^n(\mathcal{M}|_{S^o}, \mathcal{M}'|_{S^o}) \\
(i^* \mathrm{Gr}_{V_{Z^o}, 0}, i^*, \alpha^*(i)) \updownarrow (i_{*mod}, i_*, \alpha_*(i)) & & (i_{*mod}, i_*, \alpha_*(i)) \updownarrow (i^* \mathrm{Gr}_{V_{Z^o}, 0}, i^*, \alpha^*(i)) \\
\mathrm{Ext}_{D(MHM_{gm,k,C_p}(Z^o))}^n(\mathcal{M}|_{Z^o}, 0) = 0 & \xrightarrow{\iota_{Z^o}} & \mathrm{Ext}_{D(Z^o)}^n(\mathcal{M}|_{Z^o}, 0) = 0
\end{array}$$

where the left and right column are isomorphism by strictness of the  $V_{Z^o}$  filtration (use a bi-filtered injective resolution with respect to  $F$  and  $V_{Z^o}$  for the right column).

- We consider now the following commutative diagram in  $C(\mathbb{Z})$  where we denote for short  $H := D(MHM_{gm,k,C_p}(S))$

$$\begin{array}{ccccccc}
0 & \longrightarrow & \mathrm{Hom}_{\bullet H}(\Gamma_D^{\vee, Hdg} \mathcal{M}, \Gamma_D^{Hdg} \mathrm{Hom}(-, \gamma_D^{Hdg}(\mathcal{M}')) & \xrightarrow{\quad} & \mathrm{Hom}_{\bullet H}(\Gamma_D^{\vee, Hdg} \mathcal{M}, \mathcal{M}') & \xrightarrow{\quad} & \mathrm{Hom}_{\bullet H}(\Gamma_D^{\vee, Hdg} \mathcal{M}, j_{*Hdg} j^* \mathcal{M}') \longrightarrow 0 \\
& & \downarrow \iota_S & & \downarrow \iota_S & & \downarrow \iota_S \\
0 & \longrightarrow & \mathrm{Hom}_{\bullet D(S)}(\Gamma_D^{\vee, Hdg} \mathcal{M}, \Gamma_D^{Hdg} \mathrm{Hom}(-, \gamma_D^{Hdg}(\mathcal{M}')) & \xrightarrow{\quad} & \mathrm{Hom}_{\bullet D(S)}(\Gamma_D^{\vee, Hdg} \mathcal{M}, \mathcal{M}') & \xrightarrow{\quad} & \mathrm{Hom}_{\bullet D(S)}(\Gamma_D^{\vee, Hdg} \mathcal{M}, j_{*Hdg} j^* \mathcal{M}') \longrightarrow 0
\end{array}$$

whose lines are exact sequence. We have on the one hand,

$$\mathrm{Hom}_{D(MHM_{gm,k,C_p}(S))}^{\bullet}(\Gamma_D^{\vee, Hdg} \mathcal{M}, j_{*Hdg} j^* \mathcal{M}') = 0 = \mathrm{Hom}_{D(S)}^{\bullet}(\Gamma_D^{\vee, Hdg} \mathcal{M}, j_{*Hdg} j^* \mathcal{M}')$$

On the other hand by induction hypothesis

$$\iota_S : \mathrm{Hom}_{D(MHM_{gm,k,C_p}(S))}^{\bullet}(\Gamma_D^{\vee, Hdg} \mathcal{M}, \Gamma_D^{Hdg} \mathcal{M}') \rightarrow \mathrm{Hom}_{D(S)}^{\bullet}(\Gamma_D^{\vee, Hdg} \mathcal{M}, \Gamma_D^{Hdg} \mathcal{M}')$$

is a quasi-isomorphism. Hence, by the diagram

$$\iota_S : \mathrm{Hom}_{D(MHM_{gm,k,C_p}(S))}^{\bullet}(\Gamma_D^{\vee, Hdg} \mathcal{M}, \mathcal{M}') \rightarrow \mathrm{Hom}_{D(S)}^{\bullet}(\Gamma_D^{\vee, Hdg} \mathcal{M}, \mathcal{M}')$$

is a quasi-isomorphism.

- We consider now the following commutative diagram in  $C(\mathbb{Z})$  where we denote for short  $H := D(MHM_{gm,k,C_p}(S))$

$$\begin{array}{ccccccc}
0 & \longrightarrow & \mathrm{Hom}_{\bullet H}(\Gamma_D^{\vee, Hdg} \mathcal{M}, \mathcal{M}') & \xrightarrow{\quad} & \mathrm{Hom}_{\bullet H}(\mathcal{M}, \mathcal{M}') & \xrightarrow{\quad} & \mathrm{Hom}_{\bullet H}(j_{*Hdg} j^* \mathcal{M}, \mathcal{M}') \longrightarrow 0 \\
& & \downarrow \iota_S & & \downarrow \iota_S & & \downarrow \iota_S \\
0 & \longrightarrow & \mathrm{Hom}_{\bullet D(S)}(\Gamma_D^{\vee, Hdg} \mathcal{M}, \mathcal{M}') & \xrightarrow{\quad} & \mathrm{Hom}_{\bullet D(S)}(\mathcal{M}, \mathcal{M}') & \xrightarrow{\quad} & \mathrm{Hom}_{\bullet D(S)}(j_{*Hdg} j^* \mathcal{M}, \mathcal{M}') \longrightarrow 0
\end{array}$$

whose lines are exact sequence. On the one hand, the commutative diagram

$$\begin{array}{ccc} \mathrm{Hom}_{D(MHM_{gm,k,c_p}(S))}^{\bullet}(j^!Hdgj^*\mathcal{M}, \mathcal{M}') & \xrightarrow{j^*} & \mathrm{Hom}_{D(MHM_{gm,k,c_p}(S^\circ))}^{\bullet}(j^*\mathcal{M}, j^*\mathcal{M}') \\ \downarrow \iota_S & & \downarrow \iota_{S^\circ} \\ \mathrm{Hom}_{D(S)}^{\bullet}(j^!Hdgj^*\mathcal{M}, \mathcal{M}') & \xrightarrow{j^*} & \mathrm{Hom}_{D(S^\circ)}^{\bullet}(j^*\mathcal{M}, j^*\mathcal{M}') \end{array}$$

together with the fact that the horizontal arrows  $j^*$  are quasi-isomorphism by the functoriality given the uniqueness of the  $V_S$  filtration for the embedding  $l : S \hookrightarrow L_D$ , (use a bi-filtered injective resolution with respect to  $F$  and  $V_S$  for the lower arrow) and the fact that  $\iota_{S^\circ}$  is a quasi-isomorphism by the first two point, show that

$$\iota_S : \mathrm{Hom}_{D(MHM_{gm,k,c_p}(S))}^{\bullet}(j^!Hdgj^*\mathcal{M}, \mathcal{M}') \rightarrow \mathrm{Hom}_{D(S)}^{\bullet}(j^!Hdgj^*\mathcal{M}, \mathcal{M}')$$

is a quasi-isomorphism. On the other hand, by the third point

$$\iota_S : \mathrm{Hom}_{D(MHM_{gm,k,c_p}(S))}^{\bullet}(\Gamma_D^{\vee,Hdg}\mathcal{M}, \mathcal{M}') \rightarrow \mathrm{Hom}_{D(S)}^{\bullet}(\Gamma_D^{\vee,Hdg}\mathcal{M}, \mathcal{M}')$$

is a quasi-isomorphism. Hence, by the diagram

$$\iota_S : \mathrm{Hom}_{D(MHM_{gm,k,c_p}(S))}^{\bullet}(\Gamma_D^{\vee,Hdg}\mathcal{M}, \mathcal{M}') \rightarrow \mathrm{Hom}_{D(S)}^{\bullet}(\Gamma_D^{\vee,Hdg}\mathcal{M}, \mathcal{M}')$$

is a quasi-isomorphism.

This shows the fully faithfulness. We now prove the essential surjectivity : let

$$(((M_I, F, W), u_{IJ}), (K, W), \alpha) \in C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I C_{fil}(S^{et})$$

such that the cohomology are mixed hodge modules and such that the differential are strict. We proceed by induction on  $card\{n \in \mathbb{Z}\}$ , s.t.  $H^n(M_I, F, W) \neq 0$  by taking for the cohomological troncation

$$\tau^{\leq n}(((M_I, F, W), u_{IJ}), (K, W), \alpha) := ((\tau^{\leq n}(M_I, F, W), \tau^{\leq n}u_{IJ}), \tau^{\leq n}(K, W), \tau^{\leq n}\alpha)$$

and using the fact that the differential are strict for the filtration  $F$  and the fully faithfulness.

(i): Follows from (i).

(ii): Follows from (i). Indeed, in the composition of functor

$$\begin{aligned} \iota_S : D(MHM_{gm,k,c_p}(S)) &\xrightarrow{\iota_S} D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et}) \\ &\rightarrow D_{\mathcal{D}(1,0)fil,\infty,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et}) \end{aligned}$$

the second functor which is the localization functor is an isomorphism on the full subcategory

$$D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I))^{st} \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et}) \subset D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et})$$

consisting of complex such that the differentials are strict for  $F$ , and the first functor  $\iota_S$  is a full embedding by (i) and  $\iota_S(D(MHM_{gm,k,c_p}(S))) \subset D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I))^{st} \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et})$ .  $\square$

**Definition 92.** Let  $f : X \rightarrow S$  a morphism with  $X, S \in \mathrm{Var}(k)$ . Assume there exist a factorization  $f : X \xrightarrow{l} Y \times S \xrightarrow{p_S} S$  with  $Y \in \mathrm{SmVar}(k)$ ,  $l$  a closed embedding and  $p_S$  the projection. Let  $\bar{Y} \in \mathrm{PSmVar}(k)$  a smooth compactification of  $Y$  with  $n : Y \hookrightarrow \bar{Y}$  the open embedding. Then  $\bar{f} : \bar{X} \xrightarrow{\bar{l}} \bar{Y} \times_S \xrightarrow{\bar{p}_S} S$  is a compactification of  $f$ , with  $\bar{X} \subset \bar{Y} \times S$  the closure of  $X$  and  $\bar{l}$  the closed embedding, we denote by  $n' : X \hookrightarrow \bar{X}$  the closed embedding so that  $f = \bar{f} \circ n'$ .

(i) For  $((M_I, F, W), u_{IJ}), (K, W), \alpha \in C(MHM_{gm,k,C_p}(X))$ , we define, using definition 65 and theorem 46,

$$Rf_*Hdg(((M_I, F, W), u_{IJ}), (K, W), \alpha) := \iota_S^{-1} \left( \int_f^{Hdg} ((M_I, F, W), u_{IJ}), Rf_{*w}(K, W), f_*(\alpha) \right) \in D(MHM_{gm,k,C_p}(S))$$

where  $f_*(\alpha)$  is given in definition 84, and since

– by definition

$$H^i \left( \int_{\bar{f}}^{FDR} \text{Gr}_W^k (n \times I)_{*Hdg}((M_I, F, W), u_{IJ}), R\bar{f}_* \text{Gr}_W^k n'_{*w}(K, W), \text{Gr}_W^k f_*\alpha \right) \in HM_{gm,k,C_p}(S)$$

for all  $i, k \in \mathbb{Z}$ , hence by the spectral sequence for the filtered complexes  $\int_{\bar{f}}^{FDR} (n \times I)_{*Hdg}((M_I, W), u_{IJ})$  and  $R\bar{f}_* n'_{*w}(K, W)$

$$\begin{aligned} & \text{Gr}_W^k H^i \left( \int_f^{Hdg} ((M_I, F, W), u_{IJ}), Rf_{*w}(K, W), f_*\alpha \right) := \\ & (\text{Gr}_W^k H^i \int_{\bar{f}}^{FDR} ((M_I, F, W), u_{IJ}), \text{Gr}_W^k H^i R\bar{f}_* n'_{*w}(K, W), \text{Gr}_W^k H^i f_*\alpha) \in HM_{gm,k,C_p}(S) \end{aligned}$$

this gives by definition  $H^i(\int_f^{Hdg}((M_I, F, W), u_{IJ}), Rf_{*w}(K, W), f_*(\alpha)) \in MHM_{gm,k,C_p}(S)$  for all  $i \in \mathbb{Z}$ .

–  $\int_f^{Hdg}((M_I, F, W), u_{IJ})$  is the class of a complex such that the differential are strict for  $F$  by theorem 37 in the complex case.

(ii) For  $((M_I, F, W), u_{IJ}), (K, W), \alpha \in C(MHM_{gm,k,C_p}(X))$ , we define, using definition 64 and theorem 46,

$$Rf_!Hdg(((M_I, F, W), u_{IJ}), (K, W), \alpha) := \iota_S^{-1} \left( \int_{f!}^{Hdg} ((M_I, F, W), u_{IJ}), Rf_{!w}(K, W), f_!(\alpha) \right) \in D(MHM_{gm,k,C_p}(S))$$

where  $f_!(\alpha)$  is given in definition 84, and since

– by definition

$$H^i \left( \int_{\bar{f}}^{FDR} \text{Gr}_W^k (n \times I)_{!Hdg}((M_I, F, W), u_{IJ}), R\bar{f}_* \text{Gr}_W^k n'_{!w}(K, W), \text{Gr}_W^k f_!\alpha \right) \in HM_{gm,k,C_p}(S)$$

for all  $i, k \in \mathbb{Z}$ , hence by the spectral sequence for the filtered complexes  $\int_{\bar{f}}^{FDR} (n \times I)_{!Hdg}((M_I, W), u_{IJ})$  and  $R\bar{f}_* n'_{!w}(K, W)$

$$\begin{aligned} & \text{Gr}_W^k H^i \left( \int_{f!}^{Hdg} ((M_I, F, W), u_{IJ}), Rf_{!w}K, f_!\alpha \right) := \\ & (\text{Gr}_W^k H^i \int_{\bar{f}}^{FDR} (n \times I)_{!Hdg}((M_I, F, W), u_{IJ}), \text{Gr}_W^k H^i R\bar{f}_* n'_{!w}(K, W), \text{Gr}_W^k H^i f_!\alpha) \in HM_{gm,k,C_p}(S) \end{aligned}$$

this gives by definition  $H^i(\int_{f!}^{Hdg}((M_I, F, W), u_{IJ}), Rf_{!w}(K, W), f_!(\alpha)) \in MHM_{gm,k,C_p}(S)$  for all  $i \in \mathbb{Z}$ .

–  $\int_{f_1!}^{Hdg}((M_I, F, W), u_{IJ})$  is the class of a complex such that the differential are strict for  $F$  by theorem 37 in the complex case.

**Proposition 54.** *Let  $f_1 : X \rightarrow Y$  and  $f_2 : Y \rightarrow S$  two morphism with  $X, Y, S \in \text{QPVar}(k)$ .*

(i) *Let  $\mathcal{M} \in C(\text{MHM}_{gm,k,\mathbb{C}_p}(X))$ . Then,*

$$R(f_2 \circ f_1)_*^{Hdg}(\mathcal{M}) = Rf_{2*}^{Hdg} Rf_{1*}^{Hdg}(\mathcal{M}) \in D(\text{MHM}_{gm,k,\mathbb{C}_p}(S)).$$

(ii) *Let  $\mathcal{M} \in C(\text{MHM}_{gm,k,\mathbb{C}_p}(X))$ . Then,*

$$R(f_2 \circ f_1)!^{Hdg}(\mathcal{M}) = Rf_{2!}^{Hdg} Rf_{1!}^{Hdg}(\mathcal{M}) \in D(\text{MHM}_{gm,k,\mathbb{C}_p}(S))$$

*Proof.* Immediate from definition. □

Let  $k \subset K \subset \mathbb{C}_p$  a subfield of a  $p$ -adic field  $K$ . Definition 90, definition 92 and gives by proposition 52 and proposition 54 respectively, the following 2 functors :

- We have the following 2 functor on the category of algebraic varieties over  $k \subset \mathbb{C}_p$

$$\begin{aligned} D(\text{MHM}_{gm,k,\mathbb{C}_p}(\cdot)) : \text{QPVar}(k) &\rightarrow \text{TriCat}, \quad S \mapsto D(\text{MHM}_{gm,k,\mathbb{C}_p}(S)), \\ (f : T \rightarrow S) &\mapsto (f^{*Hdg} : (((M_I, F, W), u_{IJ}), (K, W), \alpha) \mapsto \\ f^{!Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha) &:= (f_{Hdg}^{*mod}(((M_I, F, W), u_{IJ})), f^{!w}(K, W), f^! \alpha)). \end{aligned}$$

see definition 62 and definition 84 for the equality.

- We have the following 2 functor on the category of quasi-projective algebraic varieties over  $k \subset \mathbb{C}_p$

$$\begin{aligned} D(\text{MHM}_{gm,k,\mathbb{C}_p}(\cdot)) : \text{QPVar}(k) &\rightarrow \text{TriCat}, \quad S \mapsto D(\text{MHM}_{gm,k,\mathbb{C}_p}(S)), \\ (f : T \rightarrow S) &\mapsto (f_{*Hdg} : (((M_I, F, W), u_{IJ}), (K, W), \alpha) \mapsto Rf_{*Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha)). \end{aligned}$$

- We have the following 2 functor on the category of quasi-projective algebraic varieties over  $k \subset \mathbb{C}_p$

$$\begin{aligned} D(\text{MHM}_{gm,k,\mathbb{C}_p}(\cdot)) : \text{QPVar}(k) &\rightarrow \text{TriCat}, \quad S \mapsto D(\text{MHM}_{gm,k,\mathbb{C}_p}(S)), \\ (f : T \rightarrow S) &\mapsto (f_{!Hdg} : (((M_I, F, W), u_{IJ}), (K, W), \alpha) \mapsto f_{!Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha)). \end{aligned}$$

- We have the following 2 functor on the category of algebraic varieties over  $k \subset \mathbb{C}_p$

$$\begin{aligned} D(\text{MHM}_{gm,k,\mathbb{C}_p}(\cdot)) : \text{QPVar}(k) &\rightarrow \text{TriCat}, \quad S \mapsto D(\text{MHM}_{gm,k,\mathbb{C}_p}(S)), \\ (f : T \rightarrow S) &\mapsto (f^{!Hdg} : (((M_I, F, W), u_{IJ}), (K, W), \alpha) \mapsto \\ f^{*Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha) &:= (f_{Hdg}^{*mod}(((M_I, F, W), u_{IJ})), f^{*w}(K, W), f^* \alpha)). \end{aligned}$$

see definition 62 and definition 84 for the equality.

**Proposition 55.** *Let  $f : X \rightarrow S$  with  $S, X \in \text{QPVar}(k)$ . Then*

(i)  $(f^{*Hdg}, Rf_*^{Hdg}) : D(\text{MHM}_{gm,k,\mathbb{C}_p}(S)) \rightarrow D(\text{MHM}_{gm,k,\mathbb{C}_p}(X))$  is a pair of adjoint functors.

– For  $(((M_I, F, W), u_{IJ}), (K, W), \alpha) \in C(\text{MHM}_{gm,k,\mathbb{C}_p}(S))$ ,

$$\begin{aligned} \text{ad}(f^{*Hdg}, Rf_*^{Hdg})(((M_I, F, W), u_{IJ}), (K, W), \alpha) &:= \\ (\text{ad}(f_{Hdg}^{*mod}, Rf_*^{Hdg})((M_I, F, W), u_{IJ}), \text{ad}(f^{*w}, Rf_{*w})(K, W)) : \\ (((M_I, F, W), u_{IJ}), (K, W), \alpha) &\rightarrow Rf_*^{Hdg} f^{*Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha) \end{aligned}$$

is the adjunction map in  $D(\text{MHM}_{gm,k,\mathbb{C}_p}(S))$ .



– For  $((N_I, F, W), u_{IJ}), (P, W), \beta) \in C(MHM_{gm,k,\mathbb{C}_p}(X))$ ,

$$\begin{aligned} \text{ad}(f^{*Hdg}, Rf_*^{Hdg})(((N_I, F, W), u_{IJ}), (P, W), \beta) &:= \\ (\text{ad}(f_{Hdg}^{*mod}, Rf_*^{Hdg})((N_I, F, W), u_{IJ}), \text{ad}(f^{*w}, Rf_{*w})(P, W)) &: \\ f^{*Hdg} Rf_*^{Hdg}(((N_I, F, W), u_{IJ}), (P, W), \beta) &\rightarrow (((N_I, F, W), u_{IJ}), (P, W), \beta) \end{aligned}$$

is the adjunction map in  $D(MHM_{gm,k,\mathbb{C}_p}(X))$

(ii)  $(Rf_!^{Hdg}, f^{!Hdg}) : D(MHM_{gm,k,\mathbb{C}_p}(X)) \rightarrow D(MHM_{gm,k,\mathbb{C}_p}(S))$  is a pair of adjoint functors.

– For  $((M_I, F, W), u_{IJ}), (K, W), \alpha) \in C(MHM_{gm,k,\mathbb{C}_p}(S))$ ,

$$\begin{aligned} \text{ad}(Rf_!^{Hdg}, f^{!Hdg})(((M_I, F, W), u_{IJ}), (K, W), \alpha) &:= \\ (\text{ad}(f_{Hdg}^{*mod}, Rf_!^{Hdg})((M_I, F, W), u_{IJ}), \text{ad}(f^{!w}, Rf_{!w})(K, W)) &: \\ Rf_!^{Hdg} f^{!Hdg}(((M_I, F, W), u_{IJ}), (K, W), \alpha) &\rightarrow (((M_I, F, W), u_{IJ}), (K, W), \alpha) \end{aligned}$$

is the adjunction map in  $D(MHM_{gm,k,\mathbb{C}_p}(S))$ .

– For  $((N_I, F, W), u_{IJ}), (P, W), \beta) \in C(MHM_{gm,k,\mathbb{C}_p}(X))$ ,

$$\begin{aligned} \text{ad}(Rf_!^{Hdg}, f^{!Hdg})(((N_I, F, W), u_{IJ}), (P, W), \beta) &:= \\ (\text{ad}(f_{Hdg}^{*mod}, Rf_!^{Hdg})((N_I, F, W), u_{IJ}), \text{ad}(f^{!w}, Rf_{!w})(P, W)) &: \\ (((N_I, F, W), u_{IJ}), (P, W), \beta) &\rightarrow f^{!Hdg} Rf_!^{Hdg}(((N_I, F, W), u_{IJ}), (P, W), \beta) \end{aligned}$$

is the adjunction map in  $D(MHM_{gm,k,\mathbb{C}_p}(X))$ .

*Proof.* Follows from proposition 51 after considering a factorization  $f : X \hookrightarrow \bar{Y} \times S \xrightarrow{ps} S$  with  $\bar{Y} \in \text{PSmVar}(k)$ .  $\square$

**Theorem 47.** Let  $k \subset \mathbb{C}_p$  a subfield.

(i) We have the six functor formalism on  $D(MHM_{gm,k,\mathbb{C}_p}(-)) : \text{SmVar}(k) \rightarrow \text{TriCat}$ .

(ii) We have the six functor formalism on  $D(MHM_{gm,k,\mathbb{C}_p}(-)) : \text{QPVar}(k) \rightarrow \text{TriCat}$ .

*Proof.* Follows from proposition 55.  $\square$

We recall the definition of the syntomic complex of a p adic analytic space and the syntomic cohomology class of an algebraic cycle of a p adic algebraic variety.

**Definition 93.** (i) Let  $K$  a p adic field. Let  $X \in \text{AnSm}(K)$ . We have for  $d \in \mathbb{Z}$  the syntomic complex

$$\mathbb{Z}_{syn,X}(d) := (\mathbb{Z}_{p,X}(d) \hookrightarrow DR(X)(O\mathbb{B}_{dr,X}, F)/F^d) \in C(X^{et})$$

Let  $D \subset X$  a normal crossing divisor. We have for  $d \in \mathbb{Z}$  the Deligne complexes

$$\mathbb{Z}_{syn,(X,D)}(d) := (\mathbb{Z}_X(d) \hookrightarrow DR(X)(O\mathbb{B}_{dr,X}(\log D), F)/F^d) \in C(X^{et})$$

and

$$\mathbb{Z}_{syn,(X,D)}(d)^\vee := (\mathbb{Z}_X(d) \hookrightarrow DR(X)(O\mathbb{B}_{inf,X}(D), F)/F^d) \in C(X^{et}).$$

Moreover we have as for Deligne complexes canonical products

$$\begin{aligned} - (-) \cdot (-) : \mathbb{Z}_{syn,(X,D)}(d) \otimes \mathbb{Z}_{syn,(X,D)}(d') &\rightarrow \mathbb{Z}_{\mathcal{D},(X,D)}(d+d') \\ - (-) \cdot (-) : \mathbb{Z}_{syn,(X,D)}(d)^\vee \otimes \mathbb{Z}_{syn,(X,D)}(d')^\vee &\rightarrow \mathbb{Z}_{syn,(X,D)}(d+d')^\vee \end{aligned}$$

(ii) Let  $K$  a  $p$  adic field. Let  $X \in \text{AnSm}(K)$ . We have for  $d \in \mathbb{Z}$  the syntomic (cohomology) complex

$$\begin{aligned} C_{syn}^\bullet(X, \mathbb{Z}(d)) &:= \text{Cone}(\Gamma(X, E_{et}(\mathbb{Z}_{p,X})) \oplus \Gamma(X, F^d E_{et}(DR(X)(O_{\mathbb{B}_{dr,X}}), F))) \\ &\hookrightarrow \Gamma(X, E_{et}(DR(X)(O_{\mathbb{B}_{dr,X}}), F)) \in C(\mathbb{Z}_p) \end{aligned}$$

Let  $D \subset X$  a normal crossing divisor. Denote  $U := X \setminus D$ . We have for  $d \in \mathbb{Z}$  the syntomic (cohomology) complexes

$$\begin{aligned} C_{syn}^\bullet((X, D), \mathbb{Z}(d)) &:= \text{Cone}(\Gamma(X, E_{et}(\mathbb{Z}_{p,X})) \oplus \Gamma(X, F^d E_{et}(DR(X)(O_{\mathbb{B}_{dr,X}}(\log D), F))) \\ &\hookrightarrow \Gamma(X, E_{et}(DR(X)(O_{\mathbb{B}_{dr,X}}(\log D), F))) \in C(\mathbb{Z}_p) \end{aligned}$$

and

$$\begin{aligned} C_{syn}^\bullet(X, D, \mathbb{Z}(d)) &:= \text{Cone}(\Gamma(X, E_{et}(\mathbb{Z}_{p,X})) \oplus \Gamma(X, F^d E_{et}(DR(X)(O_{\mathbb{B}_{dr,X}}(D), F))) \\ &\hookrightarrow \Gamma(X, E_{et}(DR(X)(O_{\mathbb{B}_{dr,X}}(D), F))) \in C(\mathbb{Z}_p). \end{aligned}$$

(iii) Let  $k \subset K$  an embedding of a field of characteristic zero into a  $p$  adic field. Let  $X \in \text{PSmVar}(k)$ . We have, for  $k \in \mathbb{Z}$  and  $d \in \mathbb{Z}$ , the syntomic cohomology

$$H_{syn}^k(X_K^{an}, \mathbb{Z}(d)) := \mathbb{H}^k(X_K^{an}, \mathbb{Z}_{X, syn}(d)) = H^k C_{syn}^\bullet(X_K^{an}, D, \mathbb{Z}(d))$$

Let  $U \in \text{SmVar}(k)$ . Let  $X \in \text{PSmVar}(k)$  a compactification of  $U$  with  $D := X \setminus U$  a normal crossing divisor. We have, for  $k \in \mathbb{Z}$  and  $d \in \mathbb{Z}$ , the syntomic cohomology

$$H_{syn}^k(U_K^{an}, \mathbb{Z}(d)) := \mathbb{H}^k(X, \mathbb{Z}_{(X_K^{an}, D_K^{an}), syn}(d)) = H^k C_{syn}^\bullet((X_K^{an}, D_K^{an}), \mathbb{Z}(d))$$

and

$$H_{syn}^k(X, D, \mathbb{Z}(d)) := \mathbb{H}^k(X_K^{an}, \mathbb{Z}_{(X_K^{an}, D_K^{an}), syn}(d)^\vee) = H^k C_{syn}^\bullet(X_K^{an}, D_K^{an}, \mathbb{Z}(d)).$$

(iv) Let  $k \subset K \subset \mathbb{C}_p$  an embedding of a field of characteristic zero into a  $p$  adic field. Let  $U \in \text{SmVar}(k)$ . Let  $X \in \text{PSmVar}(k)$  a compactification of  $U$  with  $D := X \setminus U$  a normal crossing divisor. We define the Deligne cohomology of a (higher) cycle  $Z \in \mathcal{Z}^d(U, n)^{\partial=0}$  by

$$\begin{aligned} [Z]_{syn} &:= \text{Im}(H^{2d-n}(\gamma_{\text{supp}(Z)})([Z])), \\ H^k(\gamma_{\text{supp}(Z)}) &: \mathbb{H}_{syn, \text{supp}(Z)}^{2d-n}(X_{\mathbb{C}_p}^{an}, \mathbb{Z}_{X_{\mathbb{C}_p}^{an}, D_{\mathbb{C}_p}^{an}}(d)) \rightarrow \mathbb{H}_{syn}^{2d-n}(X_{\mathbb{C}_p}^{an}, \mathbb{Z}_{X_{\mathbb{C}_p}^{an}, D_{\mathbb{C}_p}^{an}}(d)) \end{aligned}$$

with  $\text{supp}(Z) := p_X(\text{supp}(Z)) \subset X$ , where  $\text{supp}(Z) \subset X \times \square^n$  is the support of  $Z$ .

(v) Let  $k \subset K$  an embedding of a field of characteristic zero into a  $p$  adic field. Let  $U \in \text{SmVar}(k)$ . Let  $X \in \text{PSmVar}(k)$  a compactification of  $U$  with  $D := X \setminus U$  a normal crossing divisor. We have for  $d \in \mathbb{Z}$  the morphism of complexes

$$\mathcal{R}_U^d : \mathcal{Z}^d(U, \bullet) \rightarrow C_{syn}^\bullet(X_{\mathbb{C}_p}^{an}, D_{\mathbb{C}_p}^{an}, \mathbb{Z}(d)), \quad Z \mapsto \mathcal{R}_U^d(Z) := (T_{\bar{Z}}, \Omega_{\bar{Z}}, R_{\bar{Z}})$$

which gives for  $Z \in \mathcal{Z}^d(U, n)^{\partial=0}$ ,

$$[\mathcal{R}_U^d(Z)] = [Z]_{syn} \in H_{syn}^{2d-n}(U_{\mathbb{C}_p}^{an}, \mathbb{Z}(d))$$

Let  $K$  a  $p$  adic field. Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{AnSm}(K)$ . We have for  $d \in \mathbb{Z}$  the canonical morphism of Deligne complexes

$$(\text{ad}(f^*, f_*)(\mathbb{Z}_{p,S}), \Omega_{X/S}^{\leq d}) : \mathbb{Z}_{syn,S}(d) \rightarrow f_* \mathbb{Z}_{syn,X}(d)$$

which induces after taking the canonical flasque resolution of the syntomic complexes the morphism in  $C(\mathbb{Z}_p)$

$$\begin{aligned} f^* &:= (f^*, f^*, \theta(f)^t) : C_{\text{syn}}^\bullet(S, \mathbb{Z}(d)) := \\ &\text{Cone}(\Gamma(S, E_{et}(\mathbb{Z}_p, S)) \oplus \Gamma(S, F^d E_{et}(DR(S)(O_{\mathbb{B}_{inf}, S}, F)))) \hookrightarrow \Gamma(S, E_{et}(DR(S)(O_{\mathbb{B}_{dr}, S}, F))) \\ &\rightarrow C_{\text{syn}}^\bullet(X, \mathbb{Z}(d)) := \\ &\text{Cone}(\Gamma(X, E_{et}(\mathbb{Z}_p, X)) \oplus \Gamma(X, F^d E_{et}(DR(X)(O_{\mathbb{B}_{inf}, X}, F)))) \hookrightarrow \Gamma(X, E_{et}(DR(X)(O_{\mathbb{B}_{dr}, X}, F))) \end{aligned}$$

where  $\theta(f)^t$  is the homotopy in the morphism in  $D_{fil}(k) \otimes_I D(\mathbb{Z}_p)$  (where here the comparison morphisms  $\alpha$  are in  $D_{\mathbb{B}_{dr}, G, fil}(K)$  instead of  $D_{\mathbb{B}_{dr}, G, fil}(\mathbb{C}_p)$ )

$$\begin{aligned} (f^*, f^*, \theta(f)^t) &: (\Gamma(S, E_{et}(DR(S)(O_{\mathbb{B}_{dr}, S}, F))), \Gamma(S, E_{et}(\mathbb{Z}_p, S)), \alpha(S)) \\ &\rightarrow (\Gamma(X, E_{et}(DR(X)(O_{\mathbb{B}_{dr}, X}, F))), \Gamma(X, E_{et}(\mathbb{Z}_p, X)), \alpha(X)), \end{aligned}$$

which induces in cohomology for  $n \in \mathbb{Z}$ , the morphisms of abelian groups

$$f^* : H_{\text{syn}}^n(S, \mathbb{Z}(d)) \rightarrow H_{\text{syn}}^n(X, \mathbb{Z}(d)) ;$$

we get dually,

$$\begin{aligned} f_* &:= (f_*, f_*, \theta(f)) : \\ &\text{Cone}(\Gamma(X, E_{et}(\mathbb{Z}_p, X))^\vee \oplus F^d \Gamma(X, E_{et}(DR(X)(O_{\mathbb{B}_{dr}, X}, F)))^\vee \hookrightarrow \Gamma(X, E_{et}(DR(X)(O_{\mathbb{B}_{dr}, X}, F)))^\vee \\ &\rightarrow \text{Cone}(\Gamma(S, E_{et}(\mathbb{Z}_p, S))^\vee \oplus F^d \Gamma(S, E_{et}(DR(S)(O_{\mathbb{B}_{dr}, S}, F)))^\vee \hookrightarrow \Gamma(S, E_{et}(DR(S)(O_{\mathbb{B}_{dr}, S}, F)))^\vee \end{aligned}$$

where  $\theta(f)$  is the homotopy in the morphism in  $D_{fil}(k) \otimes_I D(\mathbb{Z}_p)$  (where here the comparison morphisms  $\alpha$  are in  $D_{\mathbb{B}_{dr}, G, fil}(K)$  instead of  $D_{\mathbb{B}_{dr}, G, fil}(\mathbb{C}_p)$ )

$$\begin{aligned} (f_*, f_*, \theta(f)) &: (\Gamma(X, E_{et}(DR(X)(O_{\mathbb{B}_{dr}, X}, F)))^\vee, \Gamma(X, E_{et}(\mathbb{Z}_p, X))^\vee, \alpha(X)) \\ &\rightarrow (\Gamma(S, E_{et}(DR(S)(O_{\mathbb{B}_{dr}, S}, F)))^\vee, \Gamma(S, E_{et}(\mathbb{Z}_p, S))^\vee, \alpha(S)), \end{aligned}$$

which induces in homology for  $n \in \mathbb{Z}$ , the morphisms of abelian groups

$$f_* : H_{n, \text{syn}}(X, \mathbb{Z}(d)) \rightarrow H_{n, \text{syn}}(S, \mathbb{Z}(d)).$$

**Theorem 48.** *Let  $k \subset \mathbb{C}_p$  a subfield.*

(i) *Let  $U \in \text{SmVar}(k)$ . Denote by  $a_U : U \rightarrow \text{pt}$  the terminal map. Let  $X \in \text{PSmVar}(k)$  a compactification of  $U$  with  $D := X \setminus U$  a normal crossing divisor. The embedding (see theorem 46)*

$$\iota : D(\text{MHM}_{gm, k, \mathbb{C}_p}(\{\text{pt}\})) \rightarrow D_{fil}(k) \times_I D(\mathbb{Z}_p)$$

*induces for  $k \in \mathbb{Z}$  and  $d \in \mathbb{Z}$ , canonical isomorphisms*

$$\begin{aligned} \iota(a_U! \text{Hdg} \mathbb{Z}_U^{\text{Hdg}}) &: H^k(a_U! \text{Hdg} \mathbb{Z}_U^{\text{Hdg}}) \xrightarrow{\sim} H_{\text{syn}}^k(X_{\mathbb{C}_p}^{\text{an}}, D_{\mathbb{C}_p}^{\text{an}}, \mathbb{Z}(d)), \text{ and} \\ \iota(a_U* \text{Hdg} \mathbb{Z}_U^{\text{Hdg}}) &: H^k(a_U* \text{Hdg} \mathbb{Z}_U^{\text{Hdg}}) \xrightarrow{\sim} H_{\text{syn}}^k(U_{\mathbb{C}_p}^{\text{an}}, \mathbb{Z}(d)). \end{aligned}$$

(ii) *Let  $h : U \rightarrow S$  and  $h' : U' \rightarrow S$  two morphism with  $S, U, U' \in \text{SmVar}(k)$ . Let  $X \in \text{PSmVar}(k)$  a compactification of  $U$  with  $D := X \setminus U$  a normal crossing divisor such that  $h : U \rightarrow S$  extend to  $f : X \rightarrow \bar{S}$ . Let  $X' \in \text{PSmVar}(k)$  a compactification of  $U'$  with  $D' := X' \setminus U'$  a normal crossing divisor such that  $h' : U' \rightarrow S$  extend to  $f' : X' \rightarrow \bar{S}$ . The embedding  $\iota : D(\text{MHM}_{gm, k, \mathbb{C}_p}(\text{pt})) \rightarrow D_{fil}(k) \times_I D(\mathbb{Z}_p)$  (see theorem 46) induces for  $k \in \mathbb{Z}$  and  $d \in \mathbb{Z}$  a canonical isomorphism*

$$\begin{aligned} \iota(a_{U' \times_S U!} \text{Hdg} \mathbb{Z}_{U' \times_S U}^{\text{Hdg}}) &: \text{Hom}_{D(\text{MHM}_{gm, k, \mathbb{C}_p}(S))} (h_{U'!} \text{Hdg} \mathbb{Z}_{U'}^{\text{Hdg}}, h_{U!} \text{Hdg} \mathbb{Z}_U^{\text{Hdg}}(d)[k]) \\ \xrightarrow{RI(-, -)} &\text{Hom}_{D(\text{MHM}_{gm, k, \mathbb{C}_p}(\text{pt}))} (\mathbb{Z}_{\text{pt}}^{\text{Hdg}}, a_{U' \times_S U!} \text{Hdg} \mathbb{Z}_{U' \times_S U}^{\text{Hdg}}(d)[k]) = H^k(a_{U' \times_S U!} \text{Hdg} \mathbb{Z}_{U' \times_S U}^{\text{Hdg}}(d)) \\ &\xrightarrow{\sim} H_{\mathcal{D}}^k((X' \times_S X)_{\mathbb{C}_p}^{\text{an}}, ((X' \times_S U) \cup (U' \times_S X))_{\mathbb{C}_p}^{\text{an}}, \mathbb{Z}(d)). \end{aligned}$$

(iii) Let  $U \in \text{SmVar}(k)$ . Let  $X \in \text{PSmVar}(k)$  a compactification of  $U$  with  $D := X \setminus U$  a normal crossing divisor. For  $[Z] \in \text{CH}^d(U, n)$  and  $[Z'] \in \text{CH}^{d'}(U, n')$ , we have

$$([Z] \cdot [Z'])_{\text{syn}} = [Z]_{\text{syn}} \cdot [Z']_{\text{syn}} \in H^{2d+2d'-n-n'}(U_{\mathbb{C}_p}^{\text{an}}, \mathbb{Z}(d+d'))$$

where the product on the left is the intersection of higher Chow cycle which is well defined modulo boundary (they intersect properly modulo boundary) while the right product of Deligne cohomology classes is induced by the product of Deligne complexes  $(-) \cdot (-) : \mathbb{Z}_{\text{syn},(X,D)}(d) \otimes \mathbb{Z}_{\text{syn},(X,D)}(d') \rightarrow \mathbb{Z}_{\text{syn},(X,D)}(d+d')$ .

(iv) Let  $h : U \rightarrow S, h' : U' \rightarrow S, h'' : U'' \rightarrow S$  three morphism with  $S, U, U', U'' \in \text{SmVar}(k)$ . Let  $X \in \text{PSmVar}(k)$  a compactification of  $U$  with  $D := X \setminus U$  a normal crossing divisor such that  $h : U \rightarrow S$  extend to  $f : X \rightarrow \bar{S}$ . Let  $X' \in \text{PSmVar}(k)$  a compactification of  $U'$  with  $D' := X' \setminus U'$  a normal crossing divisor such that  $h' : U' \rightarrow S$  extend to  $f' : X' \rightarrow \bar{S}$ . Let  $X'' \in \text{PSmVar}(k)$  a compactification of  $U''$  with  $D'' := X'' \setminus U''$  a normal crossing divisor such that  $h'' : U'' \rightarrow S$  extend to  $f'' : X'' \rightarrow \bar{S}$ . For  $[Z] \in \text{CH}^d(U \times_S U', n)$  and  $[Z'] \in \text{CH}^{d'}(U' \times_S U'', n')$ , we have

$$([Z] \circ [Z'])_{\text{syn}} = [Z]_{\text{syn}} \circ [Z']_{\text{syn}} \in H^{d''-n''}((U \times_S U'')_{\mathbb{C}_p}^{\text{an}}, \mathbb{Z}(d''-n''))$$

where the composition on the left is the composition of higher correspondence modulo boundary while the composition on the right is given by (ii).

*Proof.* (i):Standard.

(ii):Follows on the one hand from (i) and on the other hand the six functor formalism on the 2-functor  $D(\text{MHM}_{\text{gm},k,\mathbb{C}_p}(-)) : \text{SmVar}(k) \rightarrow \text{TriCat}$  (theorem 42) gives the isomorphism  $RI(-, -)$ .

(iii):Standard.

(iv):Follows from (iii). □

## 7 The algebraic filtered De Rham realizations for Voevodsky relative motives over a field $k$ of characteristic 0

### 7.1 The algebraic Gauss-Manin filtered De Rham realization functor

Let  $k$  a field of characteristic zero. Consider, for  $S \in \text{Var}(k)$ , the following composition of morphism in  $\text{RCat}$  (see section 2)

$$\tilde{e}(S) : (\text{Var}(k)/S, O_{\text{Var}(k)/S}) \xrightarrow{\rho_S} (\text{Var}(k)^{\text{sm}}/S, O_{\text{Var}(k)^{\text{sm}}/S}) \xrightarrow{e(S)} (S, O_S)$$

with, for  $X/S = (X, h) \in \text{Var}(k)/S$ ,

- $O_{\text{Var}(k)/S}(X/S) := O_X(X)$ ,
- $(\tilde{e}(S)^* O_S(X/S) \rightarrow O_{\text{Var}(k)/S}(X/S)) := (h^* O_S \rightarrow O_X)$ .

and  $O_{\text{Var}(k)^{\text{sm}}/S} := \rho_{S*} O_{\text{Var}(k)/S}$ , that is, for  $U/S = (U, h) \in \text{Var}(k)^{\text{sm}}/S$ ,  $O_{\text{Var}(k)^{\text{sm}}/S}(U/S) := O_{\text{Var}(k)/S}(U/S) := O_U(U)$

**Definition 94.** (i) For  $S \in \text{Var}(k)$ , we consider the complexes of presheaves

$$\Omega_{/S}^\bullet := \text{coker}(\Omega_{O_{\text{Var}(k)/S}/\tilde{e}(S)^* O_S} : \Omega_{\tilde{e}(S)^* O_S}^\bullet \rightarrow \Omega_{O_{\text{Var}(k)/S}}^\bullet) \in C_{O_S}(\text{Var}(k)/S)$$

which is by definition given by

$$- \text{ for } X/S \text{ a morphism } \Omega_{/S}^\bullet(X/S) = \Omega_{X/S}^\bullet(X)$$

– for  $g : X'/S \rightarrow X/S$  a morphism,

$$\begin{aligned}\Omega_{/S}^\bullet(g) &:= \Omega_{(X'/X)/(S/S)}(X') : \Omega_{X/S}^\bullet(X) \rightarrow g^* \Omega_{X/S}(X') \rightarrow \Omega_{X'/S}^\bullet(X') \\ \omega &\mapsto \Omega_{(X'/X)/(S/S)}(X')(\omega) := g^*(\omega) : (\alpha \in \wedge^k T_{X'}(X') \mapsto \omega(dg(\alpha)))\end{aligned}$$

(ii) For  $S \in \text{Var}(k)$ , we consider the complexes of presheaves

$$\Omega_{/S}^\bullet := \rho_{S*} \tilde{\Omega}_{/S}^\bullet = \text{coker}(\Omega_{O_{\text{Var}(k)}^{sm}/S/e(S)^*O_S} : \Omega_{e(S)^*O_S}^\bullet \rightarrow \Omega_{O_{\text{Var}(k)}^{sm}/S}^\bullet) \in C_{O_S}(\text{Var}(k)^{sm}/S)$$

which is by definition given by

$$\text{– for } U/S \text{ a smooth morphism } \Omega_{/S}^\bullet(U/S) = \Omega_{U/S}^\bullet(U)$$

– for  $g : U'/S \rightarrow U/S$  a morphism,

$$\begin{aligned}\Omega_{/S}^\bullet(g) &:= \Omega_{(U'/U)/(S/S)}(U') : \Omega_{U/S}^\bullet(U) \rightarrow g^* \Omega_{U/S}(U') \rightarrow \Omega_{U'/S}^\bullet(U') \\ \omega &\mapsto \Omega_{(U'/U)/(S/S)}(U')(\omega) := g^*(\omega) : (\alpha \in \wedge^k T_{U'}(U') \mapsto \omega(dg(\alpha)))\end{aligned}$$

**Remark 9.** For  $S \in \text{Var}(k)$ ,  $\Omega_{/S}^\bullet \in C(\text{Var}(k)/S)$  is by definition a natural extension of  $\Omega_{/S}^\bullet \in C(\text{Var}(k)^{sm}/S)$ . However  $\Omega_{/S}^\bullet \in C(\text{Var}(k)/S)$  does NOT satisfy cdh descent.

For a smooth morphism  $h : U \rightarrow S$  with  $S, U \in \text{SmVar}(\mathbb{C})$ , the cohomology presheaves  $H^n \Omega_{U/S}^\bullet$  of the relative De Rham complex

$$DR(U/S) := \Omega_{U/S}^\bullet := \text{coker}(h^* \Omega_S \rightarrow \Omega_U) \in C_{h^*O_S}(U)$$

for all  $n \in \mathbb{Z}$ , have a canonical structure of a complex of  $h^*D_S$  modules given by the Gauss Manin connexion : for  $S^o \subset S$  an open subset,  $U^o = h^{-1}(S^o)$ ,  $\gamma \in \Gamma(S^o, T_S)$  a vector field and  $\hat{\omega} \in \Omega_{U/S}^p(U^o)^c$  a closed form, the action is given by

$$\gamma \cdot [\hat{\omega}] = [\widehat{\iota(\tilde{\gamma})\partial\omega}],$$

$\omega \in \Omega_U^p(U^o)$  being a representative of  $\hat{\omega}$  and  $\tilde{\gamma} \in \Gamma(U^o, T_U)$  a relevation of  $\gamma$  ( $h$  is a smooth morphism), so that

$$DR(U/S) := \Omega_{U/S}^\bullet := \text{coker}(h^* \Omega_S \rightarrow \Omega_U) \in C_{h^*O_S, h^*\mathcal{D}}(U)$$

with this  $h^*D_S$  structure. Hence we get  $h_* \Omega_{U/S}^\bullet \in C_{O_S, \mathcal{D}}(S)$  considering this structure. Since  $h$  is a smooth morphism,  $\Omega_{U/S}^p$  are locally free  $O_U$  modules.

The point (ii) of the definition 103 above gives the object in  $\text{DA}(S)$  which will, for  $S$  smooth, represent the algebraic Gauss-Manin De Rham realisation. It is the class of an explicit complex of presheaves on  $\text{Var}(k)^{sm}/S$ .

**Proposition 56.** Let  $S \in \text{Var}(k)$ .

(i) For  $U/S = (U, h) \in \text{Var}(k)^{sm}/S$ , we have  $e(U)_* h^* \Omega_{/S}^\bullet = \Omega_{U/S}^\bullet$ .

(ii) The complex of presheaves  $\Omega_{/S}^\bullet \in C_{O_S}(\text{Var}(k)^{sm}/S)$  is  $\mathbb{A}^1$  homotopic, in particular  $\mathbb{A}^1$  invariant. Note that however, for  $p > 0$ , the complexes of presheaves  $\Omega^{\bullet \geq p}$  are NOT  $\mathbb{A}^1$  local. On the other hand,  $(\Omega_{/S}^\bullet, F_b)$  admits transferts (recall that means  $\text{Tr}(S)_* \text{Tr}(S)^* \Omega_{/S}^p = \Omega_{/S}^p$ ).

(iii) If  $S$  is smooth, we get  $(\Omega_{/S}^\bullet, F_b) \in C_{O_S \text{ fil}, D_S}(\text{Var}(k)^{sm}/S)$  with the structure given by the Gauss Manin connexion. Note that however the  $D_S$  structure on the cohomology groups given by Gauss Main connexion does NOT comes from a structure of  $D_S$  module structure on the filtered complex of  $O_S$  module. The  $D_S$  structure on the cohomology groups satisfy a non trivial Griffithz transversality (in the non projection cases), whereas the filtration on the complex is the trivial one.

*Proof.* Similar to the proof of [10] proposition. □

We have the following canonical transformation map given by the pullback of (relative) differential forms:

Let  $g : T \rightarrow S$  a morphism with  $T, S \in \text{Var}(k)$ . Consider the following commutative diagram in RCat

:

$$\begin{array}{ccc} D(g, e) : (\text{Var}(k)^{sm}/T, \mathcal{O}_{\text{Var}(k)^{sm}/T}) & \xrightarrow{P(g)} & (\text{Var}(k)^{sm}/S, \mathcal{O}_{\text{Var}(k)^{sm}/S}) \\ \downarrow e(T) & & \downarrow e(S) \\ (T, \mathcal{O}_T) & \xrightarrow{P(g)} & (S, \mathcal{O}_S) \end{array}$$

It gives (see section 2) the canonical morphism in  $C_{g^* \mathcal{O}_S \text{fil}}(\text{Var}(k)^{sm}/T)$

$$\begin{aligned} \Omega_{/(T/S)} &:= \Omega_{(\mathcal{O}_{\text{Var}(k)^{sm}/T}/g^* \mathcal{O}_{\text{Var}(k)^{sm}/S})/(\mathcal{O}_T/g^* \mathcal{O}_S)} : \\ g^*(\Omega_{/S}^\bullet, F_b) &= \Omega_{g^* \mathcal{O}_{\text{Var}(k)^{sm}/S}/g^* e(S)^* \mathcal{O}_S}^\bullet \rightarrow (\Omega_{/T}^\bullet, F_b) = \Omega_{\mathcal{O}_{\text{Var}(k)^{sm}/T}/e(T)^* \mathcal{O}_T}^\bullet \end{aligned}$$

which is by definition given by the pullback on differential forms : for  $(V/T) = (V, h) \in \text{Var}(k)^{sm}/T$ ,

$$\begin{aligned} \Omega_{/(T/S)}(V/T) : g^*(\Omega_{/S}^\bullet)(V/T) &:= \lim_{(h' : U \rightarrow \text{SSm}, g' : V \rightarrow U, h, g)} \Omega_{U/S}^\bullet(U) \xrightarrow{\Omega_{(V/U)/(T/S)}(V/T)} \Omega_{V/T}^\bullet(V) =: \Omega_{/T}^\bullet(V/T) \\ \hat{\omega} &\mapsto \Omega_{(V/U)/(T/S)}(V/T)(\omega) := g'^* \hat{\omega}. \end{aligned}$$

If  $S$  and  $T$  are smooth,  $\Omega_{/(T/S)} : g^*(\Omega_{/S}^\bullet, F_b) \rightarrow (\Omega_{/T}^\bullet, F_b)$  is a map in  $C_{g^* \mathcal{O}_S \text{fil}, g^* D_S}(\text{Var}(k)^{sm}/T)$  It induces the canonical morphisms in  $C_{g^* \mathcal{O}_S \text{fil}, g^* D_S}(\text{Var}(k)^{sm}/T)$ :

$$E\Omega_{/(T/S)} : g^* E_{et}(\Omega_{/S}^\bullet, F_b) \xrightarrow{T(g, E_{et})(\Omega_{/S}^\bullet, F_b)} E_{et}(g^*(\Omega_{/S}^\bullet, F_b)) \xrightarrow{E_{et}(\Omega_{/(T/S)})} E_{et}(\Omega_{/T}^\bullet, F_b).$$

and

$$E\Omega_{/(T/S)} : g^* E_{zar}(\Omega_{/S}^\bullet, F_b) \xrightarrow{T(g, E_{zar})(\Omega_{/S}^\bullet, F_b)} E_{zar}(g^*(\Omega_{/S}^\bullet, F_b)) \xrightarrow{E_{zar}(\Omega_{/(T/S)})} E_{zar}(\Omega_{/T}^\bullet, F_b).$$

**Definition 95.** (i) Let  $g : T \rightarrow S$  a morphism with  $T, S \in \text{Var}(k)$ . We have, for  $F \in C(\text{Var}(k)^{sm}/S)$ , the canonical transformation in  $C_{\mathcal{O}_T \text{fil}}(T)$  :

$$\begin{aligned} T^{\mathcal{O}}(g, \Omega_{/ \cdot})(F) &: g^{*mod} L_{\mathcal{O}e(S)} \mathcal{H}om^\bullet(F, E_{et}(\Omega_{/S}^\bullet, F_b)) \\ &\xrightarrow{=} (g^* L_{\mathcal{O}e(S)} \mathcal{H}om^\bullet(F, E_{et}(\Omega_{/S}^\bullet, F_b))) \otimes_{g^* \mathcal{O}_S} \mathcal{O}_T \\ &\xrightarrow{T(e, g)(-) \circ T(g, L_{\mathcal{O}})(-)} L_{\mathcal{O}}(e(T)_* g^* \mathcal{H}om^\bullet(F, E_{et}(\Omega_{/S}^\bullet, F_b))) \otimes_{g^* \mathcal{O}_S} \mathcal{O}_T \\ &\xrightarrow{T(g, \text{hom})(F, E_{et}(\Omega_{/S}^\bullet)) \otimes I} L_{\mathcal{O}}(e(T)_* \mathcal{H}om^\bullet(g^* F, g^* E_{et}(\Omega_{/S}^\bullet, F_b))) \otimes_{g^* \mathcal{O}_S} \mathcal{O}_T \\ &\xrightarrow{ev(\text{hom}, \otimes)(-, -, -)} L_{\mathcal{O}e(T)} \mathcal{H}om^\bullet(g^* F, g^* E_{et}(\Omega_{/S}^\bullet, F_b)) \otimes_{g^* e(S)^* \mathcal{O}_S} e(T)^* \mathcal{O}_T \\ &\xrightarrow{\mathcal{H}om^\bullet(g^* F, E\Omega_{/(T/S)}) \otimes I} L_{\mathcal{O}e(T)} \mathcal{H}om^\bullet(g^* F, E_{et}(\Omega_{/T}^\bullet, F_b)) \otimes_{g^* e(S)^* \mathcal{O}_S} e(T)^* \mathcal{O}_T \\ &\xrightarrow{m} L_{\mathcal{O}e(T)} \mathcal{H}om^\bullet(g^* F, E_{et}(\Omega_{/T}^\bullet, F_b)) \end{aligned}$$

where  $m(\alpha \otimes h) := h \cdot \alpha$  is the multiplication map.

(ii) Let  $g : T \rightarrow S$  a morphism with  $T, S \in \text{Var}(k)$ ,  $S$  smooth. Assume there is a factorization  $g : T \xrightarrow{l} Y \times S \xrightarrow{p_S} S$  with  $Y \in \text{SmVar}(\mathbb{C})$ ,  $l$  a closed embedding and  $p_S$  the projection. We have, for

$F \in C(\text{Var}(k)^{sm}/S)$ , the canonical transformation in  $C_{O_T \text{fil}}(Y \times S)$  :

$$\begin{aligned} T(g, \Omega_{/\cdot})(F) &: g^{*mod, \Gamma} e(S) * \mathcal{H}om^\bullet(F, E_{et}(\Omega_{/S}^\bullet, F_b)) \\ &\xrightarrow{=} \Gamma_T E_{zar}(p_S^{*mod} e(S) * \mathcal{H}om^\bullet(F, E_{et}(\Omega_{/S}^\bullet, F_b))) \\ &\xrightarrow{T^O(p_S, \Omega_{/\cdot})(F)} \Gamma_T E_{zar}(e(T \times S) * \mathcal{H}om^\bullet(p_S^* F, E_{et}(\Omega_{/Y \times S}^\bullet, F_b))) \\ &\xrightarrow{=} e(T \times S) * \Gamma_T(\mathcal{H}om^\bullet(p_S^* F, E_{et}(\Omega_{/Y \times S}^\bullet, F_b))) \\ &\xrightarrow{I(\gamma, \text{hom})(-, -)} e(T \times S) * \mathcal{H}om^\bullet(\Gamma_T^\vee p_S^* F, E_{et}(\Omega_{/Y \times S}^\bullet, F_b)). \end{aligned}$$

For  $Q \in \text{Proj PSh}(\text{Var}(k)^{sm}/S)$ ,

$$T(g, \Omega_{/\cdot})(Q) : g^{*mod, \Gamma} e(S) * \mathcal{H}om^\bullet(Q, E_{et}(\Omega_{/S}^\bullet, F_b)) \rightarrow e(T \times S) * \mathcal{H}om^\bullet(\Gamma_T^\vee p_S^* Q, E_{et}(\Omega_{/Y \times S}^\bullet, F_b))$$

is a map in  $C_{O_T \text{fil}, \mathcal{D}}(Y \times S)$ .

Let  $S \in \text{Var}(k)$ . We have the canonical map in  $C_{O_S \text{fil}}(\text{Var}(k)^{sm}/S)$

$$w_S : (\Omega_{/S}^\bullet, F_b) \otimes_{O_S} (\Omega_{/S}^\bullet, F_b) \rightarrow (\Omega_{/S}^\bullet, F_b)$$

given by for  $h : U \rightarrow S \in \text{Var}(k)^{sm}/S$  by the wedge product

$$w_S(U/S) : (\Omega_{/U/S}^\bullet, F_b) \otimes_{h^* O_S} (\Omega_{/U/S}^\bullet, F_b)(U) \xrightarrow{w_{U/S}(U)} (\Omega_{/U/S}^\bullet, F_b)(U)$$

It gives the map

$$Ew_S : E_{et}(\Omega_{/S}^\bullet, F_b) \otimes_{O_S} E_{et}(\Omega_{/S}^\bullet, F_b) \xrightarrow{=} E_{et}((\Omega_{/S}^\bullet, F_b) \otimes_{O_S} (\Omega_{/S}^\bullet, F_b)) \xrightarrow{E_{et}(w_S)} E_{et}(\Omega_{/S}^\bullet, F_b)$$

If  $S \in \text{SmVar}(\mathbb{C})$ ,

$$w_S : (\Omega_{/S}^\bullet, F_b) \otimes_{O_S} (\Omega_{/S}^\bullet, F_b) \rightarrow (\Omega_{/S}^\bullet, F_b)$$

is a map in  $C_{O_S \text{fil}, D_S}(\text{Var}(k)^{sm}/S)$ .

**Definition 96.** Let  $S \in \text{Var}(k)$ . We have, for  $F, G \in C(\text{Var}(k)^{sm}/S)$ , the canonical transformation in  $C_{O_S \text{fil}}(S)$  :

$$\begin{aligned} T(\otimes, \Omega)(F, G) &: e(S) * \mathcal{H}om(F, E_{et}(\Omega_{/S}^\bullet, F_b)) \otimes_{O_S} e(S) * \mathcal{H}om(G, E_{et}(\Omega_{/S}^\bullet, F_b)) \\ &\xrightarrow{=} e(S) * (\mathcal{H}om(F, E_{et}(\Omega_{/S}^\bullet, F_b)) \otimes_{O_S} \mathcal{H}om(G, E_{et}(\Omega_{/S}^\bullet, F_b))) \\ &\xrightarrow{e(S) * T(\mathcal{H}om, \otimes)(-)} e(S) * \mathcal{H}om(F \otimes G, E_{et}(\Omega_{/S}^\bullet, F_b) \otimes_{O_S} E_{et}(\Omega_{/S}^\bullet, F_b)) \\ &\xrightarrow{\mathcal{H}om(F \otimes G, Ew_S)} e(S) * \mathcal{H}om(F \otimes G, E_{et}(\Omega_{/S}^\bullet, F_b)) \end{aligned}$$

If  $S \in \text{SmVar}(\mathbb{C})$ ,  $T(\otimes, \Omega)(F, G)$  is a map in  $C_{O_S \text{fil}, \mathcal{D}}(S)$ .

**Definition 97.** (i) Let  $S \in \text{SmVar}(\mathbb{C})$ . We have the functor

$$C(\text{Var}(k)^{sm}/S)^{op} \rightarrow C_{O_S \text{fil}, \mathcal{D}}(S), \quad F \mapsto e(S) * \mathcal{H}om^\bullet(L(i_{I*} j_I^* F), E_{et}(\Omega_{/S}^\bullet, F_b))[-d_S].$$

(ii) Let  $S \in \text{Var}(k)$  and  $S = \cup_{i=1}^l S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(\mathbb{C})$ . For  $I \subset [1, \dots, l]$ , denote by  $S_I := \cap_{i \in I} S_i$  and  $j_I : S_I \hookrightarrow S$  the open embedding. We then have closed embeddings  $i_I : S_I \hookrightarrow \tilde{S}_I := \prod_{i \in I} \tilde{S}_i$ . We have the functor

$$C(\text{Var}(k)^{sm}/S)^{op} \rightarrow C_{O_S \text{fil}, \mathcal{D}}(S/(\tilde{S}_I)), \quad F \mapsto (e(\tilde{S}_I) * \mathcal{H}om^\bullet(L(i_{I*} j_I^* F), E_{et}(\Omega_{/\tilde{S}_I}^\bullet, F_b)))[-d_{\tilde{S}_I}], u_{I,J}^q(F)$$

where

$$\begin{aligned}
& u_{IJ}^q(F)[d_{\tilde{S}_J}] : e(\tilde{S}_I)_* \mathcal{H}om^\bullet(L(i_{I*}j_I^*F), E_{et}(\Omega_{\tilde{S}_I}^\bullet, F_b)) \\
& \xrightarrow{\text{ad}(p_{IJ}^{*mod}, p_{IJ*})(-)} p_{IJ*} p_{IJ}^{*mod} e(\tilde{S}_I)_* \mathcal{H}om^\bullet(L(i_{I*}j_I^*F), E_{et}(\Omega_{\tilde{S}_I}^\bullet, F_b)) \\
& \xrightarrow{p_{IJ*} T(p_{IJ}, \Omega_{\tilde{S}_I})(L(i_{I*}j_I^*F))} p_{IJ*} e(\tilde{S}_J)_* \mathcal{H}om^\bullet(p_{IJ}^* L(i_{I*}j_I^*F), E_{et}(\Omega_{\tilde{S}_J}^\bullet, F_b)) \\
& \xrightarrow{p_{IJ*} e(\tilde{S}_J)_* \mathcal{H}om(S^q(D_{IJ})(F), E_{et}(\Omega_{\tilde{S}_J}^{\bullet, \Gamma}, F_b))} p_{IJ*} e(\tilde{S}_J)_* \mathcal{H}om^\bullet(L(i_{J*}j_J^*F), E_{et}(\Omega_{\tilde{S}_J}^\bullet, F_b)).
\end{aligned}$$

For  $I \subset J \subset K$ , we have obviously  $p_{IJ*} u_{JK}(F) \circ u_{IJ}(F) = u_{IK}(F)$ .

We then have the following key proposition

**Proposition 57.** (i) Let  $S \in \text{Var}(k)$ . Let  $m : Q_1 \rightarrow Q_2$  be an equivalence  $(\mathbb{A}^1, et)$  local in  $C(\text{Var}(k)^{sm}/S)$  with  $Q_1, Q_2$  complexes of projective presheaves. Then,

$$e(S)_* \mathcal{H}om(m, E_{et}(\Omega_S^\bullet, F_b)) : e(S)_* \mathcal{H}om^\bullet(Q_2, E_{et}(\Omega_S^\bullet, F_b)) \rightarrow e(S)_* \mathcal{H}om^\bullet(Q_1, E_{et}(\Omega_S^\bullet, F_b))$$

is an 2-filtered quasi-isomorphism. It is thus an isomorphism in  $D_{O_S \text{fil}, \mathcal{D}, \infty}(S)$  if  $S$  is smooth.

(ii) Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i=1}^l S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(\mathbb{C})$ . Let  $m = (m_I) : (Q_{1I}, s_{IJ}^1) \rightarrow (Q_{2I}, s_{IJ}^2)$  be an equivalence  $(\mathbb{A}^1, et)$  local in  $C(\text{Var}(k)^{sm}/(\tilde{S}_I)^{op})$  with  $Q_{1I}, Q_{2I}$  complexes of projective presheaves. Then,

$$\begin{aligned}
& (e(\tilde{S}_I)_* \mathcal{H}om(m_I, E_{et}(\Omega_{\tilde{S}_I}^\bullet, F_b))) : \\
& (e(\tilde{S}_I)_* \mathcal{H}om^\bullet(Q_{2I}, E_{et}(\Omega_{\tilde{S}_I}^\bullet, F_b)), u_{IJ}(Q_{2I}, s_{IJ}^2)) \rightarrow (e(\tilde{S}_I)_* \mathcal{H}om^\bullet(Q_{1I}, E_{et}(\Omega_{\tilde{S}_I}^\bullet, F_b)), u_{IJ}(Q_{1I}, s_{IJ}^1))
\end{aligned}$$

is an 2-filtered quasi-isomorphism. It is thus an isomorphism in  $D_{O_S \text{fil}, \mathcal{D}, \infty}((\tilde{S}_I))$ .

*Proof.* Similar to the proof of [10] proposition.  $\square$

**Definition 98.** (i) We define, using definition 97, by proposition 57, the filtered algebraic Gauss-Manin realization functor defined as

$$\mathcal{F}_S^{GM} : \text{DA}_c(S)^{op} \rightarrow D_{O_S \text{fil}, \mathcal{D}, \infty}(S), \quad M \mapsto \mathcal{F}_S^{GM}(M) := e(S)_* \mathcal{H}om^\bullet(L(F), E_{et}(\Omega_S^\bullet, F_b))[-d_S]$$

where  $F \in C(\text{Var}(k)^{sm}/S)$  is such that  $M = D(\mathbb{A}^1, et)(F)$ ,

(ii) Let  $S \in \text{Var}(k)$  and  $S = \cup_{i=1}^l S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(\mathbb{C})$ . For  $I \subset [1, \dots, l]$ , denote by  $S_I = \cap_{i \in I} S_i$  and  $j_I : S_I \hookrightarrow S$  the open embedding. We then have closed embeddings  $i_I : S_I \hookrightarrow \tilde{S}_I := \prod_{i \in I} \tilde{S}_i$ . We define, using definition 97 and proposition 57 the filtered algebraic Gauss-Manin realization functor defined as

$$\begin{aligned}
& \mathcal{F}_S^{GM} : \text{DA}_c(S)^{op} \rightarrow D_{O_S \text{fil}, \mathcal{D}, \infty}(S/(\tilde{S}_I)), \quad M \mapsto \\
& \mathcal{F}_S^{GM}(M) := ((e(\tilde{S}_I)_* \mathcal{H}om^\bullet(L(i_{I*}j_I^*F), E_{et}(\Omega_{\tilde{S}_I}^\bullet, F_b))[-d_{\tilde{S}_I}], u_{IJ}^q(F))
\end{aligned}$$

where  $F \in C(\text{Var}(k)^{sm}/S)$  is such that  $M = D(\mathbb{A}^1, et)(F)$ .

**Proposition 58.** Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{Var}(k)$ . Let  $S = \cup_{i=1}^l S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(\mathbb{C})$ . Then  $X = \cup_{i=1}^l X_i$  with  $X_i := f^{-1}(S_i)$ . Denote, for  $I \subset [1, \dots, l]$ ,  $S_I = \cap_{i \in I} S_i$  and  $X_I = \cap_{i \in I} X_i$ . Assume there exist a factorization

$$f : X \xrightarrow{l} Y \times S \xrightarrow{ps} S$$



of  $f$  with  $Y \in \text{SmVar}(\mathbb{C})$ ,  $l$  a closed embedding and  $p_S$  the projection. We then have, for  $I \subset [1, \dots, l]$ , the following commutative diagrams which are cartesian

$$\begin{array}{ccc}
f_I = f|_{X_I} : X_I \xrightarrow{l_I} Y \times S_I \xrightarrow{p_{S_I}} S_I & , & Y \times \tilde{S}_J \xrightarrow{p_{\tilde{S}_J}} \tilde{S}_J \\
\searrow & \downarrow i'_I & \downarrow i_I & p'_{I,J} \downarrow & \downarrow p_{I,J} \\
& Y \times \tilde{S}_I \xrightarrow{p_{\tilde{S}_I}} \tilde{S}_I & & Y \times \tilde{S}_I \xrightarrow{p_{\tilde{S}_I}} \tilde{S}_I
\end{array}$$

Let  $F(X/S) := p_{S,\#} \Gamma_X^\vee \mathbb{Z}(Y \times S/Y \times S)$ . The transformations maps  $(N_I(X/S) : Q(X_I/\tilde{S}_I) \rightarrow i_{I*} j_I^* F(X/S))$  and  $(k \circ I(\gamma, \text{hom})(-, -))$ , for  $I \subset [1, \dots, l]$ , induce an isomorphism in  $D_{\text{Ofil}, \mathcal{D}, \infty}(S/(\tilde{S}_I))$

$$\begin{aligned}
& I^{GM}(X/S) : \\
& \mathcal{F}_S^{GM}(M(X/S)) := (e(\tilde{S}_I)_* \mathcal{H}om(L(i_{I*} j_I^* F(X/S)), E_{et}(\Omega_{/\tilde{S}_I}^\bullet, F_b))[-d_{\tilde{S}_I}], u_{I,J}^q(F(X/S))) \\
& \xrightarrow{(e(\tilde{S}_I)_* \mathcal{H}om(LN_I(X/S), E_{et}(\Omega_{/\tilde{S}_I}^\bullet, F_b)))} (e(\tilde{S}_I)_* \mathcal{H}om(Q(X_I/\tilde{S}_I), E_{et}(\Omega_{/\tilde{S}_I}^\bullet, F_b))[-d_{\tilde{S}_I}], v_{I,J}^q(F(X/S))) \\
& \xrightarrow{(k \circ I(\gamma, \text{hom})(-, -))^{-1}} (p_{\tilde{S}_I*} \Gamma_{X_I} E_{zar}(\Omega_{Y \times \tilde{S}_I/\tilde{S}_I}^\bullet, F_b)[-d_{\tilde{S}_I}], w_{I,J}(X/S)).
\end{aligned}$$

*Proof.* Similar to the proof of [10] proposition.  $\square$

**Definition 99.** Let  $g : T \rightarrow S$  a morphism with  $T, S \in \text{SmVar}(\mathbb{C})$ . Consider the factorization  $g : T \xrightarrow{l} T \times S \xrightarrow{p_S} S$  where  $l$  is the graph embedding and  $p_S$  the projection. Let  $M \in \text{DA}_c(S)$  and  $F \in C(\text{Var}(k)^{sm}/S)$  such that  $M = D(\mathbb{A}_S^1, et)(F)$ . Then,  $D(\mathbb{A}_T^1, et)(g^* F) = g^* M$ .

(i) We have then the canonical transformation in  $D_{\text{Ofil}, \mathcal{D}, \infty}(T \times S)$  (see definition 95) :

$$\begin{aligned}
T(g, \mathcal{F}^{GM})(M) : Rg^{*mod[-], \Gamma} \mathcal{F}_S^{GM}(M) & := g^{*mod, \Gamma} e(S)_* \mathcal{H}om^\bullet(LF, E_{et}(\Omega_{/S}^\bullet, F_b))[-d_T] \\
& \xrightarrow{T(g, \Omega_{/ \cdot})(LF)} \\
e(T \times S)_* \mathcal{H}om^\bullet(\Gamma_T^\vee p_S^* LF, E_{et}(\Omega_{/T \times S}^\bullet, F_b))[-d_T] & =: \mathcal{F}_{T \times S}^{GM}(l_* g^*(M, W)).
\end{aligned}$$

(ii) We have then the canonical transformation in  $D_{\text{Ofil}, \infty}(T)$  (see definition 95) :

$$\begin{aligned}
T^O(g, \mathcal{F}^{GM})(M, W) : Lg^{*mod[-]} \mathcal{F}_S^{GM}(M) & := g^{*mod} e(S)_* \mathcal{H}om^\bullet(LF, E_{et}(\Omega_{/S}^\bullet, F_b))[-d_T] \\
& \xrightarrow{T^O(g, \Omega_{/ \cdot})(LF)} \\
e(T)_* \mathcal{H}om^\bullet(g^* LF, E_{et}(\Omega_{/T}^\bullet, F_b))[-d_T] & =: \mathcal{F}_T^{GM}(g^* M).
\end{aligned}$$

**Definition 100.** Let  $g : T \rightarrow S$  a morphism with  $T, S \in \text{Var}(k)$ . Assume we have a factorization  $g : T \xrightarrow{l} Y \times S \xrightarrow{p_S} S$  with  $Y \in \text{SmVar}(\mathbb{C})$ ,  $l$  a closed embedding and  $p_S$  the projection. Let  $S = \cup_{i=1}^l S_i$  be an open cover such that there exists closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(\mathbb{C})$ . Then,  $T = \cup_{i=1}^l T_i$  with  $T_i := g^{-1}(S_i)$  and we have closed embeddings  $i'_i := i_i \circ l : T_i \hookrightarrow Y \times \tilde{S}_i$ . Moreover  $\tilde{g}_I := p_{\tilde{S}_I} : Y \times \tilde{S}_I \rightarrow \tilde{S}_I$  is a lift of  $g_I := g|_{T_I} : T_I \rightarrow S_I$ . Denote for short  $d_{YI} := d_Y + d_{\tilde{S}_I}$ . Let  $M \in \text{DA}_c(S)$  and  $F \in C(\text{Var}(k)^{sm}/S)$  such that  $M = D(\mathbb{A}_S^1, et)(F)$ . Then,  $D(\mathbb{A}_T^1, et)(g^* F) = g^* M$ . We

have the canonical transformation in  $D_{\text{Ofil}, \mathcal{D}, \infty}(T/(Y \times \tilde{S}_I))$

$$\begin{aligned}
& T(g, \mathcal{F}^{GM})(M) : Rg^{*mod[-], \Gamma} \mathcal{F}_S^{GM}(M) := \\
& (\Gamma_{T_I} E_{zar}(\tilde{g}_I^{*mod} e(\tilde{S}_I) * \mathcal{H}om^\bullet(L(i_{I*} j_I^* F), E_{et}(\Omega_{/\tilde{S}_I}^\bullet, F_b)))[-d_Y - d_{\tilde{S}_I}], \tilde{g}_J^{*mod} u_{IJ}^q(F)) \\
& \xrightarrow{(\Gamma_{T_I} E(T(\tilde{g}_I, \Omega_{/\cdot})(L(i_{I*} j_I^*(F, W))))))} \\
& (\Gamma_{T_I} e(Y \times \tilde{S}_I) * \mathcal{H}om^\bullet(\tilde{g}_I^* L(i_{I*} j_I^* F), E_{et}(\Omega_{/Y \times \tilde{S}_I}^\bullet, F_b)))[-d_Y - d_{\tilde{S}_I}], \tilde{g}_J^* u_{IJ}^q(F)_1) \\
& \xrightarrow{(I(\gamma, \text{hom}(-, -)))} \\
& (e(Y \times \tilde{S}_I) * \mathcal{H}om^\bullet(\Gamma_{T_I}^\vee \tilde{g}_I^* L(i_{I*} j_I^* F), E_{et}(\Omega_{/Y \times \tilde{S}_I}^\bullet, F_b)))[-d_Y - d_{\tilde{S}_I}], \tilde{g}_J^* u_{IJ}^q(F)_2) \\
& \xrightarrow{(e(Y \times \tilde{S}_I) * \mathcal{H}om(T^{q, \gamma}(D_{g_I})(j_I^* F), E_{et}(\Omega_{/Y \times \tilde{S}_I}^\bullet, F_b)))^{-1}} \\
& (e(Y \times \tilde{S}_I) * \mathcal{H}om^\bullet(L(i'_{I*} j_I'^* g^* F), E_{et}(\Omega_{/Y \times \tilde{S}_I}^\bullet, F_b)))[-d_Y - d_{\tilde{S}_I}], u_{IJ}^q(g^* F)) =: \mathcal{F}_T^{GM}(g^* M).
\end{aligned}$$

**Proposition 59.** (i) Let  $g : T \rightarrow S$  a morphism with  $T, S \in \text{Var}(k)$ . Assume we have a factorization  $g : T \xrightarrow{l} Y_2 \times S \xrightarrow{p_S} S$  with  $Y_2 \in \text{SmVar}(\mathbb{C})$ ,  $l$  a closed embedding and  $p_S$  the projection. Let  $S = \cup_{i=1}^l S_i$  be an open cover such that there exists closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(\mathbb{C})$ . Then,  $T = \cup_{i=1}^l T_i$  with  $T_i := g^{-1}(S_i)$  and we have closed embeddings  $i'_i := i_i \circ l : T_i \hookrightarrow Y_2 \times \tilde{S}_i$ . Moreover  $\tilde{g}_I := p_{\tilde{S}_I} : Y \times \tilde{S}_I \rightarrow \tilde{S}_I$  is a lift of  $g_I := g|_{T_I} : T_I \rightarrow S_I$ . Let  $f : X \rightarrow S$  a morphism with  $X \in \text{Var}(k)$ . Assume that there is a factorization  $f : X \xrightarrow{l} Y_1 \times S \xrightarrow{p_S} S$ , with  $Y_1 \in \text{SmVar}(\mathbb{C})$ ,  $l$  a closed embedding and  $p_S$  the projection. We have then the following commutative diagram whose squares are cartesian

$$\begin{array}{ccccc}
f' : X_T & \longrightarrow & Y_1 \times T & \longrightarrow & T \\
\downarrow & & \downarrow & & \downarrow \\
f'' = f \times I : Y_2 \times X & \longrightarrow & Y_1 \times Y_2 \times S & \longrightarrow & Y_2 \times S \\
\downarrow & & \downarrow & & \downarrow \\
f : X & \longrightarrow & Y_1 \times S & \longrightarrow & S
\end{array}$$

Consider  $F(X/S) := p_{S, \sharp} \Gamma_X^\vee \mathbb{Z}(Y_1 \times S/Y_1 \times S)$  and the isomorphism in  $C(\text{Var}(k)^{sm}/S)$

$$\begin{aligned}
T(f, g, F(X/S)) : g^* F(X/S) & := g^* p_{S, \sharp} \Gamma_X^\vee \mathbb{Z}(Y_1 \times S/Y_1 \times S) \xrightarrow{\sim} \\
& p_{T, \sharp} \Gamma_{X_T}^\vee \mathbb{Z}(Y_1 \times T/Y_1 \times T) =: F(X_T/T).
\end{aligned}$$

which gives in  $\text{DA}(S)$  the isomorphism  $T(f, g, F(X/S)) : g^* M(X/S) \xrightarrow{\sim} M(X_T/T)$ . Then, the following diagram in  $D_{\text{Ofil}, \mathcal{D}, \infty}(T/(Y_2 \times \tilde{S}_I))$  commutes

$$\begin{array}{ccc}
Rg^{*mod, \Gamma} \mathcal{F}_S^{GM}(M(X/S)) & \xrightarrow{T(g, \mathcal{F}^{GM})(M(X/S))} & \mathcal{F}_T^{GM}(M(X_T/T)) \\
\downarrow I^{GM}(X/S) & & \downarrow I^{GM}(X_T/T) \\
g^{*mod[-], \Gamma}(p_{\tilde{S}_I} * \Gamma_{X_I} E_{zar}(\Omega_{Y_1 \times \tilde{S}_I / \tilde{S}_I}^\bullet, F_b)[-d_{\tilde{S}_I}], w_{IJ}(X/S)) & \xrightarrow{(T(\tilde{g}_I \times I, \gamma)(-) \circ T_w^O(\tilde{g}_I, p_{\tilde{S}_I}))} & (p_{Y_2 \times \tilde{S}_I} * \Gamma_{X_{T_I}} E_{zar}(\Omega_{Y_2 \times Y_1 \times \tilde{S}_I / Y_2 \times \tilde{S}_I}^\bullet, F_b)[-d_{Y_2} - d_{\tilde{S}_I}], w_{IJ}(X_T/T))
\end{array}$$

(ii) Let  $g : T \rightarrow S$  a morphism with  $T, S \in \text{SmVar}(\mathbb{C})$ . Let  $f : X \rightarrow S$  a morphism with  $X \in \text{Var}(k)$ . Assume that there is a factorization  $f : X \xrightarrow{l} Y \times S \xrightarrow{p_S} S$ , with  $Y \in \text{SmVar}(\mathbb{C})$ ,  $l$  a closed embedding and  $p_S$  the projection. Consider  $F(X/S) := p_{S, \sharp} \Gamma_X^\vee \mathbb{Z}(Y \times S/Y \times S)$  and the isomorphism

in  $C(\text{Var}(k)^{sm}/S)$

$$T(f, g, F(X/S)) : g^*F(X/S) := g^*p_{S,\sharp}\Gamma_X^\vee\mathbb{Z}(Y \times S/Y \times S) \xrightarrow{\sim} \\ p_{T,\sharp}\Gamma_{X_T}^\vee\mathbb{Z}(Y \times T/Y \times T) =: F(X_T/T).$$

which gives in  $\text{DA}(S)$  the isomorphism  $T(f, g, F(X/S)) : g^*M(X/S) \xrightarrow{\sim} M(X_T/T)$ . Then, the following diagram in  $D_{\text{Ofil},\infty}(T)$  commutes

$$\begin{array}{ccc} Lg^{*mod[-]}\mathcal{F}_S^{GM}(M(X/S)) & \xrightarrow{T^O(g,\mathcal{F}^{GM})(M(X/S))} & \mathcal{F}_T^{GM}(M(X_T/T)) \\ \downarrow I^{GM}(X/S) & & \downarrow I^{GM}(X_T/T) \\ g^{*mod}L_O(p_{S*}\Gamma_X E_{zar}(\Omega_{Y \times S/S}^\bullet, F_b)[-d_T]) & \xrightarrow{(T(g \times I, \gamma)(-) \circ T_w^O(g, ps))} & p_{Y \times T*}\Gamma_{X_T} E_{zar}(\Omega_{Y \times T/T}^\bullet, F_b)[-d_T] \\ \downarrow T_w(\otimes, \gamma)(O_{Y \times S}) & & \downarrow T_w(\otimes, \gamma)(O_{Y \times T}) \\ Lg^{*mod} \int_{p_S}^{FDR} \Gamma_X E(O_{Y \times S}, F_b)[-d_Y - d_T] & \xrightarrow{T^{\mathcal{D}^{mod}}(g, f)(\Gamma_X E(O_{Y \times S}, F_b))} & \int_{p_T}^{FDR} \Gamma_{X_T} E(O_{Y \times T}, F_b)[-d_Y - d_T]. \end{array}$$

*Proof.* Follows immediately from definition.  $\square$

We have the following theorem:

**Theorem 49.** (i) Let  $g : T \rightarrow S$  is a morphism with  $T, S \in \text{Var}(k)$ . Assume there exist a factorization  $g : T \xrightarrow{l} Y \times S \xrightarrow{ps}$  with  $Y \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $p_S$  the projection. Let  $S = \cup_{i=1}^l S_i$  be an open cover such that there exists closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(\mathbb{C})$ . Then, for  $M \in \text{DA}_c(S)$

$$T(g, \mathcal{F}^{GM})(M) : Rg^{*mod[-],\Gamma}\mathcal{F}_S^{GM}(M) \xrightarrow{\sim} \mathcal{F}_T^{GM}(g^*M)$$

is an isomorphism in  $D_{O_T \text{fil}, \mathcal{D}, \infty}(T/(Y \times \tilde{S}_I))$ .

(ii) Let  $g : T \rightarrow S$  is a morphism with  $T, S \in \text{SmVar}(\mathbb{C})$ . Then, for  $M \in \text{DA}_c(S)$

$$T^O(g, \mathcal{F}^{GM})(M) : Lg^{*mod[-]}\mathcal{F}_S^{GM}(M) \xrightarrow{\sim} \mathcal{F}_T^{GM}(g^*M)$$

is an isomorphism in  $D_{O_T}(T)$ .

(iii) A base change theorem for algebraic De Rham cohomology : Let  $g : T \rightarrow S$  is a morphism with  $T, S \in \text{SmVar}(k)$ . Let  $h : U \rightarrow S$  a smooth morphism with  $U \in \text{Var}(k)$ . Then the map (see definition [10] section 2)

$$T_w^O(g, h) : Lg^{*mod}Rh_*(\Omega_{U/S}^\bullet, F_b) \xrightarrow{\sim} Rh'_*(\Omega_{U_T/T}^\bullet, F_b)$$

is an isomorphism in  $D_{O_T}(T)$ .

*Proof.* Similar to the proof of [10] theorem.  $\square$

**Definition 101.** Let  $S \in \text{Var}(k)$  and  $S = \cup_{i=1}^l S_i$  an open affine covering and denote, for  $I \subset [1, \dots, l]$ ,  $S_I = \cap_{i \in I} S_i$  and  $j_I : S_I \hookrightarrow S$  the open embedding. Let  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embeddings, with  $\tilde{S}_i \in \text{SmVar}(\mathbb{C})$ . We have, for  $M, N \in \text{DA}(S)$  and  $F, G \in C(\text{Var}(k)^{sm}/S)$  such that  $M = D(\mathbb{A}^1, \text{et})(F)$  and

$N = D(\mathbb{A}^1, et)(G)$ , the following transformation map in  $D_{\text{Ofil}, \mathcal{D}}(S/(\tilde{S}_I))$

$$\begin{aligned}
& T(\mathcal{F}_S^{GM}, \otimes)(M, N) : \mathcal{F}_S^{GM}(M) \otimes_{O_S}^{L[-]} \mathcal{F}_S^{GM}(N) := \\
& (e(\tilde{S}_I)_* \mathcal{H}om(L(i_{I*} j_I^* F), E_{et}(\Omega_{/\tilde{S}_I}^\bullet, F_b))[-d_{\tilde{S}_I}], u_{IJ}(F)) \otimes_{O_S}^{[-]} \\
& (e(\tilde{S}_I)_* \mathcal{H}om(L(i_{I*} j_I^* G), E_{et}(\Omega_{/\tilde{S}_I}^\bullet, F_b))[-d_{\tilde{S}_I}], u_{IJ}(G)) \\
& \xrightarrow{=} ((e(\tilde{S}_I)_* \mathcal{H}om(L(i_{I*} j_I^* F), E_{et}(\Omega_{/\tilde{S}_I}^\bullet, F_b)) \otimes_{O_{\tilde{S}_I}} \\
& e(\tilde{S}_I)_* \mathcal{H}om(L(i_{I*} j_I^* G), E_{et}(\Omega_{/\tilde{S}_I}^\bullet, F_b)))[-d_{\tilde{S}_I}], u_{IJ}(F) \otimes u_{IJ}(G)) \\
& \xrightarrow{(T(\otimes, \Omega_{/\tilde{S}_I})(L(i_{I*} j_I^* F), L(i_{I*} j_I^* G)))} \\
& (e(\tilde{S}_I)_* \mathcal{H}om(L(i_{I*} j_I^* F) \otimes L(i_{I*} j_I^* G), E_{et}(\Omega_{/\tilde{S}_I}^\bullet, F_{DR}))[-d_{\tilde{S}_I}], v_{IJ}(F \otimes G)) \\
& \xrightarrow{=} (e(\tilde{S}_I)_* \mathcal{H}om(L(i_{I*} j_I^*(F \otimes G), E_{et}(\Omega_{/\tilde{S}_I}^\bullet, F_b)))[-d_{\tilde{S}_I}], u_{IJ}(F \otimes G)) =: \mathcal{F}_S^{GM}(M \otimes N)
\end{aligned}$$

**Proposition 60.** Let  $f_1 : X_1 \rightarrow S$ ,  $f_2 : X_2 \rightarrow S$  two morphism with  $X_1, X_2, S \in \text{Var}(k)$ . Assume that there exist factorizations  $f_1 : X_1 \xrightarrow{l_1} Y_1 \times S \xrightarrow{ps} S$ ,  $f_2 : X_2 \xrightarrow{l_2} Y_2 \times S \xrightarrow{ps} S$  with  $Y_1, Y_2 \in \text{SmVar}(\mathbb{C})$ ,  $l_1, l_2$  closed embeddings and  $ps$  the projections. We have then the factorization

$$f_1 \times f_2 : X_{12} := X_1 \times_S X_2 \xrightarrow{l_1 \times l_2} Y_1 \times Y_2 \times S \xrightarrow{ps} S$$

Let  $S = \cup_{i=1}^l S_i$  an open affine covering and denote, for  $I \subset [1, \dots, l]$ ,  $S_I = \cap_{i \in I} S_i$  and  $j_I : S_I \hookrightarrow S$  the open embedding. Let  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embeddings, with  $\tilde{S}_i \in \text{SmVar}(\mathbb{C})$ . We have, for  $M, N \in \text{DA}(S)$  and  $F, G \in C(\text{Var}(k)^{sm}/S)$  such that  $M = D(\mathbb{A}^1, et)(F)$  and  $N = D(\mathbb{A}^1, et)(G)$ , the following commutative diagram in  $D_{\text{Ofil}, \mathcal{D}}(S/(\tilde{S}_I))$

$$\begin{array}{ccc}
\mathcal{F}_S^{GM}(M(X_1/S)) \otimes_{O_S}^L \mathcal{F}_S^{GM}(M(X_2/S)) & \xrightarrow{T(\mathcal{F}_S^{GM}, \otimes)(M(X_1/S), M(X_2/S))} & \mathcal{F}_S^{GM}(M(X_1/S) \otimes M(X_2/S)) \\
\downarrow I^{GM}(X_1/S) \otimes I^{GM}(X_2/S) & & \downarrow I^{GM}(X_{12}/S) \\
(p_{\tilde{S}_I} \Gamma_{X_{1I}} E_{zar}(\Omega_{Y_1 \times \tilde{S}_I / \tilde{S}_I}^\bullet, F_b)[-d_{\tilde{S}_I}], w_{IJ}(X_1/S)) \otimes_{O_S} & \xrightarrow{(E_{w(Y_1 \times \tilde{S}_I, Y_2 \times \tilde{S}_I) / \tilde{S}_I})} & (p_{\tilde{S}_I} \Gamma_{X_{12I}} E_{zar}(\Omega_{Y_1 \times Y_2 \times \tilde{S}_I / \tilde{S}_I}^\bullet, F_b)[-d_{\tilde{S}_I}], \\
(p_{\tilde{S}_I} \Gamma_{X_{2I}} E_{zar}(\Omega_{Y_2 \times \tilde{S}_I / \tilde{S}_I}^\bullet, F_b)[-d_{\tilde{S}_I}], w_{IJ}(X_2/S)) & & w_{IJ}(X_{12}/S))
\end{array}$$

*Proof.* Immediate from definition. □

## 7.2 The algebraic filtered De Rham realization functor

Let  $k$  a field of characteristic zero. We recall (see section 2), for  $f : T \rightarrow S$  a morphism with  $T, S \in \text{Var}(k)$ , the commutative diagrams of sites (3) and (4)

$$\begin{array}{ccccc}
\text{Var}(k)^2/T & \xrightarrow{\mu_T} & \text{Var}(k)^{2,pr}/T & & \\
\downarrow P(f) & \searrow \rho_T & \downarrow & \searrow \rho_T & \\
& & \text{Var}(k)^{2,sm}/T & \xrightarrow{\mu_T} & \text{Var}(k)^{2,smpr}/T \\
& & \downarrow P(f) & & \downarrow P(f) \\
\text{Var}(k)^2/S & \xrightarrow{P(f)} & \text{Var}(k)^{2,pr}/S & & \\
\downarrow \rho_S & \searrow \rho_S & \downarrow & \searrow \rho_S & \\
& & \text{Var}(k)^{2,sm}/S & \xrightarrow{\mu_S} & \text{Var}(k)^{2,smpr}/S
\end{array}$$

and

$$\begin{array}{ccccc}
\text{Var}(k)^{2,pr}/T & \xrightarrow{\text{Gr}_T^{12}} & \text{Var}(k)/T & & \\
\downarrow P(f) & \searrow \rho_T & \downarrow \rho_T & & \\
& & \text{Var}(k)^{2,smpr}/T & \xrightarrow{\text{Gr}_T^{12} P(f)} & \text{Var}(k)^{sm}/T \\
& & \downarrow & & \downarrow P(f) \\
\text{Var}(k)^{2,pr}/S & \xrightarrow{P(f) \text{Gr}_S^{12}} & \text{Var}(k)/S & & \\
& \searrow \rho_S & \downarrow \rho_S & & \\
& & \text{Var}(k)^{2,sm}/S & \xrightarrow{\text{Gr}_S^{12}} & \text{Var}(k)^{sm}/S
\end{array}$$

For  $s : \mathcal{I} \rightarrow \mathcal{J}$  a functor, with  $\mathcal{I}, \mathcal{J} \in \text{Cat}$ , and  $f_\bullet : T_\bullet \rightarrow S_{s(\bullet)}$  a morphism with  $T_\bullet \in \text{Fun}(\mathcal{J}, \text{Var}(k))$  and  $S_\bullet \in \text{Fun}(\mathcal{I}, \text{Var}(k))$ , we have then the commutative diagrams of sites (5) and (6)

$$\begin{array}{ccccc}
\text{Var}(k)^2/T_\bullet & \xrightarrow{\mu_{T_\bullet}} & \text{Var}(k)^{2,pr}/T_\bullet & & \\
\downarrow P(f_\bullet) & \searrow \rho_{T_\bullet} & \downarrow \rho_{T_\bullet} & & \\
& & \text{Var}(k)^{2,sm}/T_\bullet & \xrightarrow{\mu_{T_\bullet} P(f_\bullet)} & \text{Var}(k)^{2,smpr}/T_\bullet \\
& & \downarrow & & \downarrow P(f_\bullet) \\
\text{Var}(k)^2/S_\bullet & \xrightarrow{P(f_\bullet) \mu_{S_\bullet}} & \text{Var}(k)^{2,pr}/S_\bullet & & \\
& \searrow \rho_{S_\bullet} & \downarrow \rho_{S_\bullet} & & \\
& & \text{Var}(k)^{2,sm}/S_\bullet & \xrightarrow{\mu_{S_\bullet}} & \text{Var}(k)^{2,smpr}/S_\bullet
\end{array}$$

and

$$\begin{array}{ccccc}
\text{Var}(k)^{2,pr}/T_\bullet & \xrightarrow{\text{Gr}_{T_\bullet}^{12}} & \text{Var}(k)/T & & \\
\downarrow P(f_\bullet) & \searrow \rho_{T_\bullet} & \downarrow \rho_{T_\bullet} & & \\
& & \text{Var}(k)^{2,smpr}/T_\bullet & \xrightarrow{\text{Gr}_{T_\bullet}^{12} P(f_\bullet)} & \text{Var}(k)^{sm}/T_\bullet \\
& & \downarrow & & \downarrow P(f_\bullet) \\
\text{Var}(k)^{2,pr}/S_\bullet & \xrightarrow{P(f_\bullet) \text{Gr}_{S_\bullet}^{12}} & \text{Var}(k)/S_\bullet & & \\
& \searrow \rho_{S_\bullet} & \downarrow \rho_{S_\bullet} & & \\
& & \text{Var}(k)^{2,sm}/S_\bullet & \xrightarrow{\text{Gr}_{S_\bullet}^{12}} & \text{Var}(k)^{sm}/S_\bullet
\end{array}$$

We will use the following map from the property of De Rham modules (see section 5) together with the specialization map of a filtered D module for a closed embedding (see [10] section 4.1) :

**Definition-Proposition 7.** (i) Let  $l : Z \hookrightarrow S$  a closed embedding with  $S, Z \in \text{SmVar}(k)$ . Consider an open embedding  $j : S^\circ \hookrightarrow S$ . We then have the cartesian square

$$\begin{array}{ccc}
S^\circ & \xrightarrow{j} & S \\
l' \uparrow & & \uparrow l \\
Z^\circ := Z \times_S S^{d'} & \longrightarrow & Z
\end{array}$$

where  $j'$  is the open embedding given by base change. Using proposition 35(ii) or theorem 32, the morphisms  $Q_{V_Z, V_D}^{p,0}(O_S, F_b)$  for  $D \subset S$  a closed subset of definition-proposition of [10] induces a canonical morphism in  $C_{l^*O_S \text{fil}}(Z)$

$$Q(Z, j')(O_S, F_b) : l^*Q_{V_Z, 0j!Hdg}(O_{S^\circ}, F_b) \rightarrow j'_{!Hdg}(O_{Z^\circ}, F_b),$$

where  $V_Z$  is the Kashiwara-Malgrange  $V_Z$ -filtration and  $V_D$  is the Kashiwara-Malgrange  $V_D$ -filtration, which commutes with the action of  $T_Z$ .

(ii) Let  $l : Z \hookrightarrow S$  and  $k : Z' \hookrightarrow Z$  be closed embeddings with  $S, Z, Z' \in \text{SmVar}(k)$ . Consider an open embedding  $j : S^\circ \hookrightarrow S$ . We then have the commutative diagram whose squares are cartesian.

$$\begin{array}{ccc} S^\circ & \xrightarrow{j} & S \\ l' \uparrow & & \uparrow l \\ Z^\circ := Z \times_S S^\circ & \xrightarrow{j'} & Z \\ k' \uparrow & & \uparrow k \\ Z'^\circ := Z' \times_S S^\circ & \xrightarrow{j''} & Z' \end{array}$$

where  $j'$  is the open embedding given by base change. Then,

$$\begin{aligned} Q(Z', j')(O_S, F_b) &= Q(Z', j')(O_Z, F_b) \circ (k^*Q_{V_{Z'}, 0}Q(Z, j')(O_S, F_b)) : \\ k^*Q_{V_{Z'}, 0}l^*Q_{V_Z, 0j!Hdg}(O_{S^\circ}, F_b) &\xrightarrow{k^*Q_{V_{Z'}, 0}Q(Z, j')(O_S, F_b)} k^*Q_{V_{Z'}, 0j'_{!Hdg}}(O_{Z^\circ}, F_b) \\ &\xrightarrow{Q(Z', j')(O_Z, F_b)} j''_{!Hdg}(O_{Z'^\circ}, F_b) \end{aligned}$$

in  $C_{k^*l^*O_S \text{fil}}(Z')$  which commutes with the action of  $T_{Z'}$ .

(iii) Consider a commutative diagram whose squares are cartesian

$$\begin{array}{ccccc} S^{\circ\circ} & \xrightarrow{j_2} & S^\circ & \xrightarrow{j_1} & S \\ l'' \uparrow & & \uparrow l' & & \uparrow l \\ Z^{\circ\circ} := Z \times_S S^{\circ\circ} & \xrightarrow{j'_2} & Z^\circ := Z \times_S S^\circ & \xrightarrow{j'_1} & Z \end{array}$$

where  $j_1, j_2$ , and hence  $j'_1, j'_2$  are open embeddings. We have then the following commutative diagram

$$\begin{array}{ccc} l^*Q_{V_Z, 0j_1!Hdg}(O_{S^\circ}, F_b) & \xrightarrow{\text{ad}(j_2!Hdg, j_2^*)(O_{S^\circ}, F_b)} & l^*Q_{V_Z, 0(j_1 \circ j_2)!Hdg}(O_{S^{\circ\circ}}, F_b) \\ \downarrow Q(Z, j_1)(O_S, F_b) & & \downarrow Q(Z, (j_1 \circ j_2)_!)(O_S, F_b) \\ j'_{1!Hdg}(O_{Z^\circ}, F_b) & \xrightarrow{\text{ad}(j'_2!Hdg, j'_2^*)(O_{Z^\circ}, F_b)} & (j'_1 \circ j'_2)!Hdg(O_{Z^{\circ\circ}}, F_b) \end{array}$$

in  $C_{l^*O_S \text{fil}}(Z)$  which commutes with the action of  $T_Z$ .

*Proof.* (i): By definition of  $j_{!Hdg} : \pi_{S^\circ}(MHM(S^\circ)) \rightarrow C(DRM(S))$ , we have to construct the isomorphism for each complement of a (Cartier) divisor  $j = j_D : S^\circ = S \setminus D \hookrightarrow S$ . In this case, we have the closed embedding  $i : S \hookrightarrow L$  given by the zero section of the line bundle  $L = L_D$  associated to  $D$ . We have then, using definition-proposition of [10] section 4.1, the canonical morphism in  $PSh_{l^*O_S \text{fil}}(Z)$  which commutes with the action of  $T_Z$

$$Q(Z, j_1)(O_S, F_b) : l^*Q_{V_Z, 0j_1!Hdg}(O_{S^\circ}, F_b) \xrightarrow{T_1(l, j_1)(-)^{-1}} l^*j_{!Hdg}Q_{V_Z, 0}(O_{S^\circ}, F_b) = j'_{!Hdg}(O_{Z^\circ}, F_b).$$

and  $V_Z^p T_l(l, j)(-)^{-1} = Q_{V_Z, V_S}^{p, 0}(i_{*mod}(O_S, F_b))$ . Now for  $j : S^\circ = S \setminus R \hookrightarrow S$  an arbitrary open embedding, we set

$$Q(Z, j!)(O_S, F_b) := \varprojlim_{(D_i), R \subset D_i \subset S} (Q(Z, j_{D_i}!)(j_{D_i}^*(O_S, F_b)) : l^* Q_{V_Z, 0} j! Hdg(O_{S^\circ}, F_b) \xrightarrow{\sim} j! Hdg(O_{Z^\circ}, F_b))$$

(ii): Follows from [10] section 4.1.

(iii): Follows from [10] section 4.1.  $\square$

Using definition-proposition 6 in the projection case, and the specialization map given in [10] section 4 and the isomorphism of definition-proposition 7, in the closed embedding case, we have the following canonical map :

**Definition 102.** Consider a commutative diagram in  $\text{SmVar}(k)$  whose square are cartesian

$$\begin{array}{ccccc} Z_T & \xrightarrow{i'} & T & \xleftarrow{j'} & T \setminus Z_T \\ & \searrow l' & \downarrow & \swarrow l & \downarrow l \\ & & T & \xrightarrow{I \times i} & T \times S \\ & \swarrow g' & \downarrow & \swarrow I \times j & \downarrow \\ Z & \xrightarrow{i} & S & \xleftarrow{j} & S \setminus Z \end{array}$$

*(Note: The diagram above is a simplified representation of the complex commutative diagram in the image, showing the main nodes and their relationships.)*

where  $i$  and hence  $I \times i$  and  $i'$ , are closed embeddings,  $j$ ,  $I \times j$ ,  $j'$  are the complementary open embeddings and  $g : T \xrightarrow{l} T \times S \xrightarrow{ps} S$  is the graph factorization, where  $l$  is the graph embedding and  $ps$  the projection. Then, the map in  $C_{l^* O_{T \times S} fil}(T)$

$$\begin{aligned} sp_{V_T}(\Gamma_{T \times Z}^{\vee, Hdg}(O_{T \times S}, F_b)) : l^* \Gamma_{T \times Z}^{\vee, Hdg}(O_{T \times S}, F_b) &\xrightarrow{q_{V_T, 0}} l^* Q_{V_T, 0}(\Gamma_{T \times Z}^{\vee, Hdg}(O_{T \times S}, F_b)) \\ &\xrightarrow{Q(T, (I \times j)_!(O_{T \times S}, F_b) := T_l(l, (I \times j))(-))} \Gamma_{Z_T}^{\vee, Hdg}(O_T, F_b) \end{aligned}$$

which commutes with the action of  $T_T$ , where the first map is given in [10] section 4.1 and the last map is studied definition-proposition 7, factors through

$$\begin{aligned} sp_{V_T}(\Gamma_{T \times Z}^{\vee, Hdg}(O_{T \times S}, F_b)) : l^* \Gamma_{T \times Z}^{\vee, Hdg}(O_{T \times S}, F_b) &\xrightarrow{n} l^{*mod} \Gamma_{T \times Z}^{\vee, Hdg}(O_{T \times S}, F_b) \\ &\xrightarrow{\bar{sp}_{V_T}(\Gamma_{T \times Z}^{\vee, Hdg}(O_{T \times S}, F_b))} \Gamma_{Z_T}^{\vee, Hdg}(O_T, F_b), \end{aligned}$$

with for  $U \subset T \times S$  an open subset,  $m \in \Gamma(U, O_{T \times S})$  and  $h \in \Gamma(U_T, O_T)$ ,  $n(m) := n \otimes 1$  and  $\bar{sp}_{V_T}(-)(m \otimes h) = h \cdot sp_{V_T}(m)$ ; see definition-proposition 6 and theorem 32. Then,

$$\bar{sp}_{V_T}(\Gamma_{T \times Z}^{\vee, Hdg}(O_{T \times S}, F_b)) : l^{*mod} \Gamma_{T \times Z}^{\vee, Hdg}(O_{T \times S}, F_b) \rightarrow \Gamma_{Z_T}^{\vee, Hdg}(O_T, F_b),$$

is a map in  $C_{\mathcal{D}(1,0)fil}(T)$ , i.e. is  $D_T$  linear. We then consider the canonical map in  $C_{\mathcal{D}(1,0)fil}(T)$

$$\begin{aligned} a(g, Z)(O_S, F_b) : g^{*mod} \Gamma_Z^{\vee, Hdg}(O_S, F_b) &= l^{*mod} p_S^{*mod} \Gamma_Z^{\vee, Hdg}(O_S, F_b) \xrightarrow{l^{*mod} \Gamma^{Hdg}(p, \gamma^\vee)(O_S, F_b)^{-1}} \\ &\xrightarrow{\bar{sp}_{V_T}(\Gamma_{T \times Z}^{\vee, Hdg}(O_{T \times S}, F_b))} \Gamma_{Z_T}^{\vee, Hdg}(O_T, F_b). \end{aligned}$$

**Lemma 8.** (i) For  $g : T \rightarrow S$  and  $g' : T' \rightarrow T$  two morphism with  $S, T, T' \in \text{SmVar}(k)$ , considering the commutative diagram whose squares are cartesian

$$\begin{array}{ccccc}
Z_{T'} & \xrightarrow{i''} & T' & \xleftarrow{j''} & T' \setminus Z_{T'} \\
\downarrow g' & & \downarrow g' & & \downarrow g' \\
Z_T & \xrightarrow{i'} & T & \xleftarrow{j'} & T \setminus Z_T \\
\downarrow g & & \downarrow g & & \downarrow g \\
Z & \xrightarrow{i} & S & \xleftarrow{j} & S \setminus Z
\end{array}$$

we have then

$$\begin{aligned}
a(g \circ g', Z)(O_S, F_b) &= a(g', Z_T)(O_T, F_b) \circ (g'^{*mod} a(g, Z)(O_S, F_b)) : \\
(g \circ g')^{*mod} \Gamma_Z^{\vee, Hdg}(O_S, F_b) &= g'^{*mod} g^{*mod} \Gamma_Z^{\vee, Hdg}(O_S, F_b) \xrightarrow{g'^{*mod} a(g, Z)(O_S, F_b)} g'^{*mod} \Gamma_{Z_T}^{\vee, Hdg}(O_T, F_b) \\
&\xrightarrow{a(g', Z_T)(O_T, F_b)} \Gamma_{Z_{T'}}^{\vee, Hdg}(O_{T'}, F_b).
\end{aligned}$$

(ii) For  $g : T \rightarrow S$  a morphism with  $S, T \in \text{SmVar}(k)$ , considering the commutative diagram whose squares are cartesian

$$\begin{array}{ccccc}
Z'_T & \xrightarrow{k'} & Z_T & \xrightarrow{i'} & T \\
\downarrow g & & \downarrow g & & \downarrow g \\
Z' & \xrightarrow{k} & Z & \xrightarrow{i} & S
\end{array}$$

we have then the following commutative diagram

$$\begin{array}{ccc}
g^{*mod} \Gamma_Z^{\vee, Hdg}(O_S, F_b) & \xrightarrow{g^{*mod} T(Z'/Z, \gamma^{\vee, Hdg})(O_S, F_b)} & g^{*mod} \Gamma_{Z'}^{\vee, Hdg}(O_S, F_b) \\
\downarrow a(g, Z)(O_S, F_b) & & \downarrow a(g, Z')(O_S, F_b) \\
\Gamma_{Z_T}^{\vee, Hdg}(O_T, F_b) & \xrightarrow{T(Z'_T/Z_T, \gamma^{\vee, Hdg})(O_T, F_b)} & \Gamma_{Z_T}^{\vee, Hdg}(O_T, F_b)
\end{array}$$

*Proof.* (i): Follows from definition-proposition 7 (ii)

(ii): Follows from definition-proposition 7 (iii) □

We can now define the main object :

**Definition 103.** (i) For  $S \in \text{SmVar}(k)$ , we consider the filtered complexes of presheaves

$$(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR}) \in C_{D_S fil}(\text{Var}(k)^{2, smpr} / S)$$

given by,

– for  $(Y \times S, Z)/S = ((Y \times S, Z), p) \in \text{Var}(k)^{2, smpr} / S$ ,

$$(\Omega_{/S}^{\bullet, \Gamma, pr}((Y \times S, Z)/S), F_{DR}) := ((\Omega_{Y \times S/S}^{\bullet}, F_b) \otimes_{O_{Y \times S}} \Gamma_Z^{\vee, Hdg}(O_{Y \times S}, F_b))(Y \times S)$$

with the structure of  $p^*D_S$  module given by proposition 30,



– for  $g : (Y_1 \times S, Z_1)/S = ((Y_1 \times S, Z_1), p_1) \rightarrow (Y \times S, Z)/S = ((Y \times S, Z), p)$  a morphism in  $\text{Var}(k)^{2, \text{smpr}}/S$ , denoting for short  $\hat{Z} := Z \times_{Y \times S} (Y_1 \times S)$ ,

$$\begin{aligned} \Omega_{/S}^{\bullet, \Gamma, \text{pr}}(g) &: ((\Omega_{Y \times S/S}^{\bullet, \Gamma, \text{pr}}, F_b) \otimes_{O_{Y \times S}} \Gamma_Z^{\vee, \text{Hdg}}(O_{Y \times S}, F_b))(Y \times S) \\ &\xrightarrow{i_-} g^*((\Omega_{Y_1 \times S/S}^{\bullet, \Gamma, \text{pr}}, F_b) \otimes_{O_{Y_1 \times S}} \Gamma_Z^{\vee, \text{Hdg}}(O_{Y_1 \times S}, F_b))(Y_1 \times S) \\ &\xrightarrow{\Omega_{(Y_1 \times S/Y \times S)/(S/S)}(\Gamma_Z^{\vee, \text{Hdg}}(O_{Y \times S}, F_b))(Y_1 \times S)} (\Omega_{Y_1 \times S/S}^{\bullet, \Gamma, \text{pr}}, F_b) \otimes_{O_{Y_1 \times S}} g^{*\text{mod}} \Gamma_Z^{\vee, \text{Hdg}}(O_{Y \times S}, F_b)(Y_1 \times S) \\ &\xrightarrow{DR(Y_1 \times S/S)(a(g, Z)(O_{Y \times S}, F_b))(Y_1 \times S)} (\Omega_{Y_1 \times S/S}^{\bullet, \Gamma, \text{pr}}, F_b) \otimes_{O_{Y_1 \times S}} \Gamma_{\hat{Z}}^{\vee, \text{Hdg}}(O_{Y_1 \times S}, F_b)(Y_1 \times S) \\ &\xrightarrow{DR(Y_1 \times S/S)(T(Z_1/\hat{Z}, \gamma^{\vee, \text{Hdg}})(O_{Y_1 \times S}, F_b))(Y_1 \times S)} (\Omega_{Y_1 \times S/S}^{\bullet, \Gamma, \text{pr}}, F_b) \otimes_{O_{Y_1 \times S}} \Gamma_{Z_1}^{\vee, \text{Hdg}}(O_{Y_1 \times S}, F_b)(Y_1 \times S), \end{aligned}$$

where

- \*  $i_-$  is the arrow of the inductive limit,
- \* we recall that

$$\begin{aligned} \Omega_{(Y_1 \times S/Y \times S)/(S/S)}(\Gamma_Z^{\vee, \text{Hdg}}(O_{Y \times S}, F_b)) &: g^*((\Omega_{Y \times S/S}^{\bullet, \Gamma, \text{pr}}, F_b) \otimes_{O_{Y \times S}} \Gamma_Z^{\vee, \text{Hdg}}(O_{Y \times S}, F_b)) \\ &\rightarrow (\Omega_{Y_1 \times S/S}^{\bullet, \Gamma, \text{pr}}, F_b) \otimes_{O_{Y_1 \times S}} g^{*\text{mod}} \Gamma_Z^{\vee, \text{Hdg}}(O_{Y \times S}, F_b) \end{aligned}$$

is the map given in [10] section 4.1, which is  $p_1^* D_S$  linear by proposition 31,

- \* the map

$$a(g, Z)(O_{Y \times S}, F_b) : g^{*\text{mod}} \Gamma_Z^{\vee, \text{Hdg}}(O_{Y \times S}, F_b) \rightarrow \Gamma_{\hat{Z}}^{\vee, \text{Hdg}}(O_{Y_1 \times S}, F_b)$$

is the map given in definition 102

- \* the map

$$T(Z_1/\hat{Z}, \gamma^{\vee, \text{Hdg}})(O_{Y_1 \times S}, F_b) : \Gamma_{\hat{Z}}^{\vee, \text{Hdg}}(O_{Y_1 \times S}, F_b) \rightarrow \Gamma_{Z_1}^{\vee, \text{Hdg}}(O_{Y_1 \times S}, F_b)$$

is given in definition-proposition 6.

For  $g : ((Y_1 \times S, Z_1), p_1) \rightarrow ((Y \times S, Z), p)$  and  $g' : ((Y'_1 \times S, Z'_1), p_1) \rightarrow ((Y_1 \times S, Z_1), p)$  two morphisms in  $\text{Var}(k)^{2, \text{smpr}}/S$ , we have

$$\begin{aligned} \Omega_{/S}^{\bullet, \Gamma, \text{pr}}(g \circ g') &= \Omega_{/S}^{\bullet, \Gamma, \text{pr}}(g') \circ \Omega_{/S}^{\bullet, \Gamma, \text{pr}}(g) : ((\Omega_{Y \times S/S}^{\bullet, \Gamma, \text{pr}}, F_b) \otimes_{O_{Y \times S}} \Gamma_Z^{\vee, \text{Hdg}}(O_{Y \times S}, F_b))(Y \times S) \\ &\xrightarrow{\Omega_{/S}^{\bullet, \Gamma, \text{pr}}(g)} (\Omega_{Y_1 \times S/S}^{\bullet, \Gamma, \text{pr}}, F_b) \otimes_{O_{Y_1 \times S}} \Gamma_{Z_1}^{\vee, \text{Hdg}}(O_{Y_1 \times S}, F_b)(Y_1 \times S) \\ &\xrightarrow{\Omega_{/S}^{\bullet, \Gamma, \text{pr}}(g')} (\Omega_{Y'_1 \times S/S}^{\bullet, \Gamma, \text{pr}}, F_b) \otimes_{O_{Y'_1 \times S}} \Gamma_{Z'_1}^{\vee, \text{Hdg}}(O_{Y'_1 \times S}, F_b)(Y'_1 \times S), \end{aligned}$$

since, denoting for short  $\hat{Z} := Z \times_{Y \times S} (Y_1 \times S)$  and  $\hat{Z}' := Z \times_{Y \times S} (Y'_1 \times S)$

– we have by lemma 8(i)

$$a(g \circ g', \hat{Z}')(O_{Y \times S}, F_b) = a(g', \hat{Z})(O_{Y_1 \times S}, F_b) \circ g'^{* \text{mod}} a(g, Z)(O_{Y \times S}, F_b),$$

– we have by lemma 8(ii)

$$\begin{aligned} &T(Z'_1/\hat{Z}', \gamma^{\vee, \text{Hdg}})(O_{Y'_1 \times S}, F_b) \circ a(g', \hat{Z})(O_{Y_1 \times S}, F_b) \\ &= a(g', Z_1)(O_{Y_1 \times S}, F_b) \circ g'^{* \text{mod}} T(Z_1/\hat{Z}, \gamma^{\vee, \text{Hdg}})(O_{Y_1 \times S}, F_b). \end{aligned}$$

(ii) For  $S \in \text{SmVar}(k)$ , we have the canonical map  $C_{O_S \text{fil}, D_S}(\text{Var}(k)^{\text{sm}}/S)$

$$\text{Gr}(\Omega/S) : \text{Gr}_{S^*}^{12}(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR}) \rightarrow (\Omega_{/S}, F_b)$$

given by, for  $U/S = (U, h) \in \text{Var}(k)^{\text{sm}}/S$

$$\begin{aligned} \text{Gr}(\Omega/S)(U/S) : \text{Gr}_{S^*}^{12}(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR})(U/S) &:= ((\Omega_{U \times S/S}^{\bullet, \Gamma, pr}, F_b) \otimes_{O_{U \times S}} \Gamma_U^{\vee, Hdg}(O_{U \times S}, F_b))(U \times S) \\ &\xrightarrow{\text{ad}(i_U^*, i_{U^*})(-)(U \times S)} i^*((\Omega_{U \times S/S}^{\bullet, \Gamma, pr}, F_b) \otimes_{O_{U \times S}} \Gamma_U^{\vee, Hdg}(O_{U \times S}, F_b))(U) \\ &\xrightarrow{\Omega_{(U/U \times S)/(S/S)}(-)(U)} ((\Omega_{U/S}^{\bullet, \Gamma, pr}, F_b) \otimes_{O_U} i_U^{*mod} \Gamma_U^{\vee, Hdg}(O_{U \times S}, F_b))(U) \\ &\xrightarrow{DR(U/S)(a(i_U, U))(U)} (\Omega_{U/S}^{\bullet, \Gamma, pr}, F_b)(U) =: (\Omega_{/S}^{\bullet, \Gamma, pr}, F_b)(U/S) \end{aligned}$$

where  $h : U \xrightarrow{i_U} U \times S \xrightarrow{p_S} S$  is the graph factorization with  $i_U$  the graph embedding and  $p_S$  the projection, note that  $a(i_U, U)$  is an isomorphism since for  $j_U : U \times S \setminus U \hookrightarrow U \times S$  the open complementary  $i_U^{*mod} j_U^{Hdg}(M, F, W) = 0$ .

Let  $g : T \rightarrow S$  a morphism with  $T, S \in \text{SmVar}(k)$ . We have the canonical morphism in  $C_{g^* D_S \text{fil}}(\text{Var}(k)^{2, \text{smpr}}/T)$

$$\Omega_{/(T/S)}^{\Gamma, pr} : g^*(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR}) \rightarrow (\Omega_{/T}^{\bullet, \Gamma, pr}, F_{DR})$$

induced by the pullback of differential forms : for  $((Y_1 \times T, Z_1)/T) = ((Y_1 \times T, Z_1), p) \in \text{Var}(k)^{2, \text{smpr}}/T$ ,

$$\begin{aligned} \Omega_{/(T/S)}^{\Gamma, pr}((Y_1 \times T, Z_1)/T) &:= \lim_{(h:(Y \times S, Z) \rightarrow S, g_1:(Y_1 \times T, Z_1) \rightarrow (Y \times T, Z_T), h, g)} \Omega_{/S}^{\Gamma, pr}((Y \times T, Z)/S) \\ &\xrightarrow{\Omega_{/S}^{\Gamma, pr}(g' \circ g_1)} \Omega_{/S}^{\bullet, \Gamma, pr}((Y_1 \times T, Z_1)/S) \xrightarrow{q(-)(Y_1 \times T)} \Omega_{/T}^{\bullet, \Gamma, pr}((Y_1 \times T, Z_1)/T), \end{aligned}$$

where  $g' = (I_Y \times g) : Y \times T \rightarrow Y \times S$  is the base change map and  $q(M) : \Omega_{Y_1 \times T/S} \otimes_{O_{Y_1 \times T}}(M, F) \rightarrow \Omega_{Y_1 \times T/T} \otimes_{O_{Y_1 \times T}}(M, F)$  is the quotient map. It induces the canonical morphisms in  $C_{g^* D_S \text{fil}}(\text{Var}(k)^{2, \text{smpr}}/T)$  :

$$E\Omega_{/(T/S)}^{\Gamma, pr} : g^* E_{et}(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR}) \xrightarrow{T(g, E)(-)} E_{et}(g^*(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR})) \xrightarrow{E_{et}(\Omega_{/(T/S)}^{\Gamma, pr})} E_{et}(\Omega_{/T}^{\bullet, \Gamma, pr}, F_{DR})$$

and

$$E\Omega_{/(T/S)}^{\Gamma, pr} : g^* E_{zar}(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR}) \xrightarrow{T(g, E)(-)} E_{zar}(g^*(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR})) \xrightarrow{E_{zar}(\Omega_{/(T/S)}^{\Gamma, pr})} E_{zar}(\Omega_{/T}^{\bullet, \Gamma, pr}, F_{DR}).$$

**Definition 104.** Let  $g : T \rightarrow S$  a morphism with  $T, S \in \text{SmVar}(k)$ . We have, for  $F \in C(\text{Var}(k)^{2, \text{smpr}}/S)$ , the canonical transformation in  $C_{\mathcal{D} \text{fil}}(T)$  :

$$\begin{aligned} T(g, \Omega_{/S}^{\Gamma, pr})(F) &: g^{*mod} L_{De}(S)_* \text{Gr}_{S^*}^{12} \mathcal{H}om^{\bullet}(F, E_{zar}(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR})) \\ &\xrightarrow{\cong} (g^* L_{De}(S)_* \mathcal{H}om^{\bullet}(F, E_{zar}(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR}))) \otimes_{g^* O_S} O_T \\ &\xrightarrow{T(g, \text{Gr}^{12})(-) \circ T(e, g)(-) \circ q} e(T)_* \text{Gr}_{T^*}^{12} g^* \mathcal{H}om^{\bullet}(F, E_{zar}(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR})) \otimes_{g^* O_S} O_T \\ &\xrightarrow{(T(g, \text{hom})(-, -) \otimes I)} e(T)_* \text{Gr}_{T^*}^{12} \mathcal{H}om^{\bullet}(g^* F, g^* E_{zar}(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR})) \otimes_{g^* O_S} O_T \\ &\xrightarrow{ev(\text{hom}, \otimes)(-, -, -)} e(T)_* \text{Gr}_{T^*}^{12} \mathcal{H}om^{\bullet}(g^* F, g^* E_{zar}(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR})) \otimes_{g^* e(S)^* O_S} e(T)^* O_T \\ &\xrightarrow{\mathcal{H}om^{\bullet}(g^* F, (E\Omega_{/(T/S)}^{\Gamma, pr} \otimes m))} e(T)_* \text{Gr}_{T^*}^{12} \mathcal{H}om^{\bullet}(g^* F, E_{zar}(\Omega_{/T}^{\bullet, \Gamma, pr}, F_{DR})) \end{aligned}$$

The complex of presheaves  $(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR}) \in C_{D_S fil}(\text{Var}(k)^{2, smpr}/S)$  have a monoidal structure given by the wedge product of differential forms: for  $p : (Y \times S, Z) \rightarrow S \in \text{Var}(k)^{2, smpr}/S$ , the map

$$\begin{aligned} DR(-)(\gamma_Z^{\vee, Hdg}(-)) \circ w_{Y \times S/S} : (\Omega_{Y \times S/S}^{\bullet} \otimes_{O_{Y \times S}} (O_{Y \times S}, F_b)) \otimes_{p^* O_S} (\Omega_{Y \times S/S}^{\bullet} \otimes_{O_{Y \times S}} (O_{Y \times S}, F_b)) \\ \rightarrow \Omega_{Y \times S/S}^{\bullet} \otimes_{O_{Y \times S}} \Gamma_Z^{\vee, Hdg}(O_{Y \times S}, F_b) \end{aligned}$$

factors through

$$\begin{aligned} & DR(-)(\gamma_Z^{\vee, Hdg}(-)) \circ w_{Y \times S/S} : \\ & (\Omega_{Y \times S/S}^{\bullet} \otimes_{O_{Y \times S}} (O_{Y \times S}, F_b)) \otimes_{p^* O_S} (\Omega_{Y \times S/S}^{\bullet} \otimes_{O_{Y \times S}} (O_{Y \times S}, F_b)) \\ & \xrightarrow{DR(-)(\gamma_Z^{\vee, Hdg}(-)) \otimes DR(-)(\gamma_Z^{\vee, Hdg}(-))} \\ & (\Omega_{Y \times S/S}^{\bullet} \otimes_{O_{Y \times S}} \Gamma_Z^{\vee, Hdg}(O_{Y \times S}, F_b)) \otimes_{p^* O_S} \Omega_{Y \times S/S}^{\bullet} \otimes_{O_{Y \times S}} \Gamma_Z^{\vee, Hdg}(O_{Y \times S}, F_b) \\ & \xrightarrow{(DR(-)(\gamma_Z^{\vee, Hdg}(-)) \circ w_{Y \times S/S})^\gamma} \Omega_{Y \times S/S}^{\bullet} \otimes_{O_{Y \times S}} \Gamma_Z^{\vee, Hdg}(O_{Y \times S}, F_b) \end{aligned}$$

unique up to homotopy, giving the map in  $C_{D_S fil}(\text{Var}(k)^{2, smpr}/S)$ :

$$w_S : (\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR}) \otimes_{O_S} (\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR}) \rightarrow (\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR})$$

given by for  $p : (Y \times S, Z) \rightarrow S \in \text{Var}(k)^{2, smpr}/S$ ,

$$\begin{aligned} & w_S((Y \times S, Z)/S) : \\ & (((\Omega_{Y \times S/S}^{\bullet} \otimes_{O_{Y \times S}} \Gamma_Z^{\vee, Hdg}(O_{Y \times S}, F_b)) \otimes_{p^* O_S} (\Omega_{Y \times S/S}^{\bullet} \otimes_{O_{Y \times S}} \Gamma_Z^{\vee, Hdg}(O_{Y \times S}, F_b)))(Y \times S) \\ & \xrightarrow{(DR(-)(\gamma_Z^{\vee, Hdg}(-)) \circ w_{Y \times S/S})^\gamma(Y \times S)} (\Omega_{Y \times S/S}^{\bullet} \otimes_{O_{Y \times S}} \Gamma_Z^{\vee, Hdg}(O_{Y \times S}, F_b))(Y \times S) \end{aligned}$$

which induces the map in  $C_{D_S fil}(\text{Var}(k)^{2, smpr}/S)$

$$\begin{aligned} Ew_S : E_{zar}(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR}) \otimes_{O_S} E_{zar}(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR}) \xrightarrow{=} \\ E_{zar}((\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR}) \otimes_{O_S} (\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR})) \xrightarrow{E_{zar}(w_S)} E_{et}(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR}) \end{aligned}$$

by the functoriality of the Godement resolution (see section 2).

**Definition 105.** Let  $S \in \text{SmVar}(k)$ . We have, for  $F, G \in C(\text{Var}(k)^{2, smpr}/S)$ , the canonical transformation in  $C_{\mathcal{D} fil}(S)$  :

$$\begin{aligned} & T(\otimes, \Omega)(F, G) : \\ & e(S)_* \text{Gr}_{S^*}^{12} \mathcal{H}om(F, E_{zar}(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR})) \otimes_{O_S} e(S)_* \text{Gr}_{S^*}^{12} \mathcal{H}om(G, E_{zar}(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR})) \\ & \xrightarrow{=} e(S)_* \text{Gr}_{S^*}^{12} (\mathcal{H}om(F, E_{zar}(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR})) \otimes_{O_S} \mathcal{H}om(G, E_{zar}(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR}))) \\ & \xrightarrow{T(\mathcal{H}om, \otimes)(-)} e(S)_* \text{Gr}_{S^*}^{12} \mathcal{H}om(F \otimes G, E_{zar}(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR}) \otimes_{O_S} E_{zar}(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR})) \\ & \xrightarrow{=} e(S)_* \text{Gr}_{S^*}^{12} \mathcal{H}om(F \otimes G, (E_{zar}(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR}) \otimes_{O_S} E_{zar}(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR}))) \\ & \xrightarrow{\mathcal{H}om(F \otimes G, Ew_S)} e(S)_* \text{Gr}_{S^*}^{12} \mathcal{H}om(F \otimes G, E_{zar}(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR})). \end{aligned}$$

Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i=1}^l S_i$  an open affine cover and denote by  $S_I = \cap_{i \in I} S_i$ . Let  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embeddings, with  $\tilde{S}_i \in \text{Var}(k)$ . For  $I \subset [1, \dots, l]$ , denote by  $\tilde{S}_I = \prod_{i \in I} \tilde{S}_i$ . We then have closed embeddings  $i_I : S_I \hookrightarrow \tilde{S}_I$  and for  $J \subset I$  the following commutative diagram

$$D_{IJ} = \begin{array}{ccc} S_I & \xrightarrow{i_I} & \tilde{S}_I \\ \uparrow j_{IJ} & & \uparrow p_{IJ} \\ S_J & \xrightarrow{i_J} & \tilde{S}_J \end{array}$$

where  $p_{IJ} : \tilde{S}_J \rightarrow \tilde{S}_I$  is the projection and  $j_{IJ} : S_J \hookrightarrow S_I$  is the open embedding so that  $j_I \circ j_{IJ} = j_J$ . This gives the diagram of algebraic varieties  $(\tilde{S}_I) \in \text{Fun}(\mathcal{P}(\mathbb{N}), \text{Var}(k))$  which the diagram of sites  $\text{Var}(k)^{2,smpr}/(\tilde{S}_I) \in \text{Fun}(\mathcal{P}(\mathbb{N}), \text{Cat})$ . This gives also the diagram of algebraic varieties  $(\tilde{S}_I)^{op} \in \text{Fun}(\mathcal{P}(\mathbb{N})^{op}, \text{Var}(k))$  which the diagram of sites  $\text{Var}(k)^{2,smpr}/(\tilde{S}_I)^{op} \in \text{Fun}(\mathcal{P}(\mathbb{N})^{op}, \text{Cat})$ . We then get

$$((\Omega_{/\tilde{S}_I}^{\bullet,\Gamma,pr}, F_{DR})[-d_{\tilde{S}_I}], T_{IJ}) \in C_{D_{(\tilde{S}_I)}fil}(\text{Var}(k)^{2,smpr}/(\tilde{S}_I))$$

with

$$T_{IJ} : (\Omega_{/\tilde{S}_I}^{\bullet,\Gamma,pr}, F_{DR})[-d_{\tilde{S}_I}] \xrightarrow{\text{ad}(p_{IJ}^{*mod[-]}, p_{IJ*}(-))} p_{IJ*} p_{IJ}^* (\Omega_{/\tilde{S}_I}^{\bullet,\Gamma,pr}, F_{DR}) \otimes_{p_{IJ*} O_{\tilde{S}_I}} O_{\tilde{S}_J}[-d_{\tilde{S}_J}] \\ \xrightarrow{m \circ p_{IJ*} \Omega_{/(\tilde{S}_J/\tilde{S}_I)}^{\Gamma,pr}[-d_{\tilde{S}_J}]} p_{IJ*} (\Omega_{/\tilde{S}_J}^{\bullet,\Gamma,pr}, F_{DR})[-d_{\tilde{S}_J}].$$

For  $(G_I, K_{IJ}) \in C(\text{Var}(k)^{2,smpr}/(\tilde{S}_I)^{op})$ , we denote (see section 2)

$$e'((\tilde{S}_I)_* \mathcal{H}om((G_I, K_{IJ}), (E_{zar}(\Omega_{/\tilde{S}_I}^{\bullet,\Gamma,pr}, F_{DR})[-d_{\tilde{S}_I}], T_{IJ}))) := \\ (e'(\tilde{S}_I)_* \mathcal{H}om(G_I, E_{zar}(\Omega_{/\tilde{S}_I}^{\bullet,\Gamma,pr}, F_{DR}))[-d_{\tilde{S}_I}], u_{IJ}((G_I, K_{IJ}))) \in C_{\mathcal{D}fil}((\tilde{S}_I))$$

with

$$u_{IJ}((G_I, K_{IJ})) : e'(\tilde{S}_I)_* \mathcal{H}om(G_I, E_{zar}(\Omega_{/\tilde{S}_I}^{\bullet,\Gamma,pr}, F_{DR}))[-d_{\tilde{S}_I}] \\ \xrightarrow{\text{ad}(p_{IJ}^{*mod[-]}, p_{IJ*}(-)) \circ T(p_{IJ}, e)(-)} p_{IJ*} e'(\tilde{S}_J)_* p_{IJ}^* \mathcal{H}om(G_I, E_{zar}(\Omega_{/\tilde{S}_I}^{\bullet,\Gamma,pr}, F_{DR})) \otimes_{p_{IJ*} O_{\tilde{S}_I}} O_{\tilde{S}_J}[-d_{\tilde{S}_J}] \\ \xrightarrow{T(p_{IJ}, \text{hom})(-, -)} p_{IJ*} e'(\tilde{S}_J)_* \mathcal{H}om(p_{IJ}^* G_I, p_{IJ}^* E_{zar}(\Omega_{/\tilde{S}_I}^{\bullet,\Gamma,pr}, F_{DR})) \otimes_{p_{IJ*} O_{\tilde{S}_I}} O_{\tilde{S}_J}[-d_{\tilde{S}_J}] \\ \xrightarrow{m \circ \mathcal{H}om(p_{IJ}^* G_I, T_{IJ})} p_{IJ*} e'(\tilde{S}_J)_* \mathcal{H}om(p_{IJ}^* G_I, E_{zar}(\Omega_{/\tilde{S}_J}^{\bullet,\Gamma,pr}, F_{DR}))[-d_{\tilde{S}_J}] \\ \xrightarrow{\mathcal{H}om(K_{IJ}, E_{zar}(\Omega_{/\tilde{S}_J}^{\bullet,\Gamma,pr}, F_{DR}))} p_{IJ*} e'(\tilde{S}_J)_* \mathcal{H}om(G_J, E_{zar}(\Omega_{/\tilde{S}_J}^{\bullet,\Gamma,pr}, F_{DR}))[-d_{\tilde{S}_J}].$$

This gives in particular

$$(\Omega_{/\tilde{S}_I}^{\bullet,\Gamma,pr}, F_{DR})[-d_{\tilde{S}_I}], T_{IJ}) \in C_{D_{(\tilde{S}_I)}fil}(\text{Var}(k)^{2,(sm)pr}/(\tilde{S}_I)^{op}).$$

We now define the filtered De Rahm realization functor.

**Definition 106.** (i) Let  $S \in \text{SmVar}(k)$ . We have, using definition 103 and definition 25, the functor

$$\mathcal{F}_S^{FDR} : C(\text{Var}(k)^{sm}/S) \rightarrow C_{\mathcal{D}fil}(S), F \mapsto \\ \mathcal{F}_S^{FDR}(F) := e(S)_* \text{Gr}_{S*}^{12} \mathcal{H}om^{\bullet}(\hat{R}^{CH}(\rho_S^* L(F)), E_{zar}(\Omega_{/S}^{\bullet,\Gamma,pr}, F_{DR}))[-d_S]$$

Moreover, the differentials of  $\mathcal{F}_S^{FDR}$  are strict for the filtration by theorem 37.

(ii) Let  $S \in \text{Var}(k)$  and  $S = \cup_{i=1}^l S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . For  $I \subset [1, \dots, l]$ , denote by  $S_I := \cap_{i \in I} S_i$  and  $j_I : S_I \hookrightarrow S$  the open embedding. We then have closed embeddings  $i_I : S_I \hookrightarrow \tilde{S}_I := \prod_{i \in I} \tilde{S}_i$ . Consider, for  $I \subset J$ , the following commutative diagram

$$D_{IJ} = \begin{array}{ccc} S_I & \xrightarrow{i_I} & \tilde{S}_I \\ j_{IJ} \uparrow & & \uparrow p_{IJ} \\ S_J & \xrightarrow{i_J} & \tilde{S}_J \end{array}$$

and  $j_{IJ} : S_J \hookrightarrow S_I$  is the open embedding so that  $j_I \circ j_{IJ} = j_J$ . We have, using definition 103 and definition 25, the functor

$$\begin{aligned} \mathcal{F}_S^{FDR} : C(\text{Var}(k)^{sm}/S) &\rightarrow C_{\mathcal{D}fil}(S/(\tilde{S}_I)), F \mapsto \\ \mathcal{F}_S^{FDR}(F) &:= e'((\tilde{S}_I)_* \mathcal{H}om^\bullet(\hat{R}^{CH}(\rho_{\tilde{S}_I}^* L(i_{I*} j_I^* F)), \hat{R}_{\tilde{S}_I}^{CH}(T^q(D_{IJ})(j_I^* F))), \\ &\quad (E_{zar}(\Omega_{/(\tilde{S}_I)}^{\bullet, \Gamma, pr}, F_{DR})[-d_{\tilde{S}_I}], T_{IJ})) \\ &:= (e'(\tilde{S}_I)_* \mathcal{H}om^\bullet(\hat{R}^{CH}(\rho_{\tilde{S}_I}^* L(i_{I*} j_I^* F)), E_{zar}(\Omega_{/(\tilde{S}_I)}^{\bullet, \Gamma, pr}, F_{DR})[-d_{\tilde{S}_I}], u_{IJ}^q(F))) \end{aligned}$$

where we have denoted for short  $e'(\tilde{S}_I) = e(\tilde{S}_I) \circ \text{Gr}_{\tilde{S}_I}^{12}$ , and

$$\begin{aligned} u_{IJ}^q(F)[d_{\tilde{S}_J}] &: e'(\tilde{S}_I)_* \mathcal{H}om^\bullet(\hat{R}^{CH}(\rho_{\tilde{S}_I}^* L(i_{I*} j_I^* F)), E_{zar}(\Omega_{/(\tilde{S}_I)}^{\bullet, \Gamma, pr}, F_{DR})) \\ &\xrightarrow{\text{ad}(p_{IJ}^{*mod}, p_{IJ})(-)} p_{IJ*} p_{IJ}^{*mod} e'(\tilde{S}_I)_* \mathcal{H}om^\bullet(\hat{R}^{CH}(\rho_{\tilde{S}_I}^* L(i_{I*} j_I^* F)), E_{zar}(\Omega_{/(\tilde{S}_I)}^{\bullet, \Gamma, pr}, F_{DR})) \\ &\xrightarrow{p_{IJ*} T(p_{IJ}, \Omega^{\gamma, pr})(-)} p_{IJ*} e'(\tilde{S}_J)_* \mathcal{H}om^\bullet(p_{IJ}^* \hat{R}^{CH}(\rho_{\tilde{S}_I}^* L(i_{I*} j_I^* F)), E_{zar}(\Omega_{/(\tilde{S}_J)}^{\bullet, \Gamma, pr}, F_{DR})) \\ &\quad \xrightarrow{\mathcal{H}om(T(p_{IJ}, \hat{R}^{CH})(Li_{I*} j_I^* F)^{-1}, E_{et}(\Omega_{/(\tilde{S}_J)}^{\bullet, \Gamma, pr}, F_{DR}))} \\ &\quad p_{IJ*} e'(\tilde{S}_J)_* \mathcal{H}om^\bullet(\hat{R}^{CH}(\rho_{\tilde{S}_J}^* p_{IJ}^* L(i_{I*} j_I^* F)), E_{zar}(\Omega_{/(\tilde{S}_J)}^{\bullet, \Gamma, pr}, F_{DR})) \\ &\quad \xrightarrow{\mathcal{H}om(\hat{R}_{\tilde{S}_J}^{CH}(T^q(D_{IJ})(j_I^* F)), E_{et}(\Omega_{/(\tilde{S}_J)}^{\bullet, \Gamma, pr}, F_{DR}))} \\ &\quad p_{IJ*} e'(\tilde{S}_J)_* \mathcal{H}om^\bullet(\hat{R}^{CH}(\rho_{\tilde{S}_J}^* L(i_{J*} j_J^* F)), E_{zar}(\Omega_{/(\tilde{S}_J)}^{\bullet, \Gamma, pr}, F_{DR})). \end{aligned}$$

For  $I \subset J \subset K$ , we have obviously  $p_{IJ*} u_{JK}(F) \circ u_{IJ}(F) = u_{IK}(F)$ . Moreover, the differentials of  $\mathcal{F}_S^{FDR}$  are strict for the filtration by theorem 37.

Recall, see section 2, that we have the projection morphisms of sites  $p_a : \text{Var}(k)^{2, smpr}/(\tilde{S}_I)^{op} \rightarrow \text{Var}(k)^{2, smpr}/(\tilde{S}_I)^{op}$  given by the functor

$$\begin{aligned} p_a &: \text{Var}(k)^{2, smpr}/(\tilde{S}_I)^{op} \rightarrow \text{Var}(k)^{2, smpr}/(\tilde{S}_I)^{op}, \\ p_a((Y_I \times \tilde{S}_I, Z_I)/\tilde{S}_I, s_{IJ}) &:= ((Y_I \times \mathbb{A}^1 \times \tilde{S}_I, Z_I \times \mathbb{A}^1)/\tilde{S}_I, s_{IJ} \times I), \\ p_a((g_I) : ((Y'_I \times \tilde{S}_I, Z'_I)/\tilde{S}_I, s'_{IJ}) &\rightarrow ((Y_I \times \tilde{S}_I, Z_I)/\tilde{S}_I, s_{IJ})) = \\ (g_I \times I) : ((Y'_I \times \mathbb{A}^1 \times \tilde{S}_I, Z'_I \times \mathbb{A}^1)/\tilde{S}_I, &s'_{IJ} \times I) \rightarrow ((Y_I \times \mathbb{A}^1 \times \tilde{S}_I, Z_I \times \mathbb{A}^1)/\tilde{S}_I, s_{IJ} \times I). \end{aligned}$$

We have the following key proposition :

**Proposition 61.** (i1) Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i=1}^l S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . The complex of presheaves  $(\Omega_{/(\tilde{S}_I)}^{\bullet, \Gamma, pr}, F_{DR}) \in C_{D(\tilde{S}_I)fil}(\text{Var}(k)^{2, smpr}/(\tilde{S}_I)^{op})$  is 2-filtered  $\mathbb{A}^1$  homotopic, that is

$$\text{ad}(p_a^*, p_{a*})(\Omega_{/(\tilde{S}_I)}^{\bullet, \Gamma, pr}, F_{DR}) : (\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR}) \rightarrow p_{a*} p_a^*(\Omega_{/(\tilde{S}_I)}^{\bullet, \Gamma, pr}, F_{DR})$$

is a 2-filtered homotopy.

(i2) Let  $S \in \text{SmVar}(k)$ . The complex of presheaves  $(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR}) \in C_{D_S fil}(\text{Var}(k)^{2, smpr}/S)$  admits transferts, i.e.

$$\text{Tr}(S)_* \text{Tr}(S)^*(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR}) = (\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR}).$$

(iii) Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i=1}^l S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Let  $m = (m_I) : (Q_{1I}, K_{1J}^1) \rightarrow (Q_{2I}, K_{1J}^2)$  be an equivalence  $(\mathbb{A}^1, et)$  local with

$(Q_{1I}, K_{IJ}) \rightarrow (Q_{2I}, K_{IJ}) \in C(\text{Var}(k)^{smpr}/(\tilde{S}_I)^{op})$  complexes of representable presheaves. Then, the map in  $C_{\mathcal{D}fil}(\tilde{S}_I)$

$$\begin{aligned} M &:= (e'(\tilde{S}_I)_* \mathcal{H}om^\bullet(m_I, E_{zar}(\Omega_{/\tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR})[-d_{\tilde{S}_I}])) : \\ &e'(\tilde{S}_I)_* \mathcal{H}om^\bullet((Q_{2I}, K_{IJ}^1), (E_{zar}(\Omega_{/\tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR})[-d_{\tilde{S}_I}], T_{IJ})) \\ &\rightarrow e'(\tilde{S}_I)_* \mathcal{H}om^\bullet((Q_{1I}, K_{IJ}^1), (E_{zar}(\Omega_{/\tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR})[-d_{\tilde{S}_I}], T_{IJ})) \end{aligned}$$

is a 2-filtered quasi-isomorphism. It is thus an isomorphism in  $D_{\mathcal{D}fil, \infty}(\tilde{S}_I)$ .

*Proof.* (i1): Similar to the proof of [10], proposition (ii1)

(i2): Similar to the proof of [10], proposition (ii2) : Let  $\alpha \in \text{Cor}(\text{Var}(\mathbb{C})^{2, smpr}/S)((Y_1 \times S, Z_1)/S, (Y_2 \times S, Z_2)/S)$  irreducible. Denote by  $i : \alpha \hookrightarrow Y_1 \times Y_2 \times S$  the closed embedding, and  $p_1 : Y_1 \times Y_2 \times S \rightarrow Y_1 \times S$ ,  $p_2 : Y_1 \times Y_2 \times S \rightarrow Y_2 \times S$  the projections. The morphism  $p_1 \circ i : \alpha \rightarrow Y_1 \times S$  is then finite surjective and  $(Z_1 \times Y_2) \cap \alpha \subset Y_1 \times Z_2$  (i.e.  $p_2(p_1^{-1}(Z_2) \cap \alpha) \subset Z_2$ ). Then, the transfert map is given by

$$\begin{aligned} &\Omega_{/S}^{\bullet, \Gamma, pr}(\alpha) : ((\Omega_{Y_2 \times S/S}^{\bullet, \Gamma, pr}, F_b) \otimes_{O_{Y_2 \times S}} \Gamma_{Z_2}^{\vee, Hdg}(O_{Y_2 \times S}, F_b))(Y_2 \times S) \\ &\xrightarrow{i^-} p_2^*((\Omega_{Y_2 \times S/S}^{\bullet, \Gamma, pr}, F_b) \otimes_{O_{Y_2 \times S}} \Gamma_{Z_2}^{\vee, Hdg}(O_{Y_2 \times S}, F_b))(Y_1 \times Y_2 \times S) \\ &\xrightarrow{\Omega_{(Y_1 \times Y_2 \times S/Y_2 \times S)/(S/S)}(-)(-)} ((\Omega_{Y_1 \times Y_2 \times S/S}^{\bullet, \Gamma, pr}, F_b) \otimes_{O_{Y_1 \times Y_2 \times S}} \Gamma_{Y_1 \times Z_2}^{\vee, Hdg}(O_{Y_1 \times Y_2 \times S}, F_b))(Y_1 \times Y_2 \times S) \\ &\xrightarrow{DR(-)(T((Z_1 \times Y_2) \cap \alpha/Y_1 \times Z_2, \gamma^{\vee, Hdg})(-)(-))} \\ &((\Omega_{Y_1 \times Y_2 \times S/S}^{\bullet, \Gamma, pr}, F_b) \otimes_{O_{Y_1 \times Y_2 \times S}} \Gamma_{(Z_1 \times Y_2) \cap \alpha}^{\vee, Hdg}(O_{Y_1 \times Y_2 \times S}, F_b))(Y_1 \times Y_2 \times S) \\ &\xrightarrow{i^-} i^*((\Omega_{Y_1 \times Y_2 \times S/S}^{\bullet, \Gamma, pr}, F_b) \otimes_{O_{Y_1 \times Y_2 \times S}} \Gamma_{(Z_1 \times Y_2) \cap \alpha}^{\vee, Hdg}(O_{Y_1 \times Y_2 \times S}, F_b))(\alpha) \\ &\xrightarrow{\Omega_{(\alpha/Y_1 \times Y_2 \times S)/(S/S)}(-)(-)} ((\Omega_{\alpha/S}^{\bullet, \Gamma, pr}, F_b) \otimes_{O_\alpha} i^{*mod} \Gamma_{(Z_1 \times Y_2) \cap \alpha}^{\vee, Hdg}(O_{Y_1 \times Y_2 \times S}, F_b))(\alpha) \\ &\xrightarrow{\Omega_{(\alpha/Y_1 \times S)/(S/S)}(-)(-)^{tr}} ((\Omega_{Y_1 \times S/S}^{\bullet, \Gamma, pr}, F_b) \otimes_{O_{Y_1 \times S}} \Gamma_{Z_1}^{\vee, Hdg}(O_{Y_1 \times S}, F_b))(Y_1 \times S). \end{aligned}$$

(ii): Follows from (i) and theorem 15.  $\square$

**Proposition 62.** Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i=1}^l S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ .

(i) Let  $m = (m_I) : (Q_{1I}, K_{IJ}^1) \rightarrow (Q_{2I}, K_{IJ}^2)$  be an etale local equivalence local with  $(Q_{1I}, K_{IJ}^1), (Q_{2I}, K_{IJ}^2) \in C(\text{Var}(k)^{sm}/(\tilde{S}_I))$  complexes of projective presheaves. Then,

$$\begin{aligned} &(e'(\tilde{S}_I)_* \mathcal{H}om^\bullet(\hat{R}_S^{CH}(m_I), E_{zar}(\Omega_{/\tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR})[-d_{\tilde{S}_I}])) : \\ &e'(\tilde{S}_I)_* \mathcal{H}om^\bullet((\hat{R}^{CH}(\rho_S^* Q_{1I}), \hat{R}^{CH}(K_{IJ}^1)), (E_{zar}(\Omega_{/\tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR})[-d_{\tilde{S}_I}], T_{IJ})) \\ &\rightarrow e'(\tilde{S}_I)_* \mathcal{H}om^\bullet((\hat{R}^{CH}(\rho_S^* Q_{2I}), \hat{R}^{CH}(K_{IJ}^2)), (E_{zar}(\Omega_{/\tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR})[-d_{\tilde{S}_I}], T_{IJ})) \end{aligned}$$

is a filtered quasi-isomorphism. It is thus an isomorphism in  $D_{\mathcal{D}fil}(\tilde{S}_I)$ .

(ii) Let  $m = (m_I) : (Q_{1I}, K_{IJ}^1) \rightarrow (Q_{2I}, K_{IJ}^2)$  be an equivalence  $(\mathbb{A}^1, et)$  local equivalence local with  $(Q_{1I}, K_{IJ}^1), (Q_{2I}, K_{IJ}^2) \in C(\text{Var}(k)^{sm}/(\tilde{S}_I))$  complexes of projective presheaves. Then,

$$\begin{aligned} &(e'(\tilde{S}_I)_* \mathcal{H}om^\bullet(\hat{R}_S^{CH}(m_I), E_{zar}(\Omega_{/\tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR})[-d_{\tilde{S}_I}])) : \\ &e'(\tilde{S}_I)_* \mathcal{H}om^\bullet((\hat{R}^{CH}(\rho_S^* Q_{1I}), \hat{R}^{CH}(K_{IJ}^1)), (E_{zar}(\Omega_{/\tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR})[-d_{\tilde{S}_I}], T_{IJ})) \\ &\rightarrow e'(\tilde{S}_I)_* \mathcal{H}om^\bullet((\hat{R}^{CH}(\rho_S^* Q_{2I}), \hat{R}^{CH}(K_{IJ}^2)), (E_{zar}(\Omega_{/\tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR})[-d_{\tilde{S}_I}], T_{IJ})) \end{aligned}$$

is a filtered quasi-isomorphism. It is thus an isomorphism in  $D_{\mathcal{D}fil}(\tilde{S}_I)$ .

*Proof.* Follows from proposition 61 (see the proof the complex case in [10] section 6 ) and the fact that the differential of the complexes involved are strict for the F-filtration.  $\square$

**Definition 107.** (i) Let  $S \in \text{SmVar}(k)$ . We define using definition 106(i) and proposition 62(ii) the filtered algebraic De Rahm realization functor defined as

$$\begin{aligned} \mathcal{F}_S^{FDR} : \text{DA}_c(S) &\rightarrow D_{\mathcal{D}fil}(S), M \mapsto \\ \mathcal{F}_S^{FDR}(M) &:= e(S)_* \text{Gr}_{S^*}^{12} \text{Hom}^\bullet(\hat{R}^{CH}(\rho_S^* L(F)), E_{zar}(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR}))[-d_S] \end{aligned}$$

where  $F \in C(\text{Var}(k)^{sm}/S)$  is such that  $M = D(\mathbb{A}^1, et)(F)$ .

(i)' For the Corti-Hanamura weight structure  $W$  on  $\text{DA}_c(S)^-$ , we define using definition 106(i) and proposition 62(ii)

$$\begin{aligned} \mathcal{F}_S^{FDR} : \text{DA}_c^-(S) &\rightarrow D_{\mathcal{D}(1,0)fil}^-(S), M \mapsto \\ \mathcal{F}_S^{FDR}((M, W)) &:= e(S)_* \text{Gr}_{S^*}^{12} \text{Hom}^\bullet(\hat{R}^{CH}(\rho_S^* L(F, W)), E_{zar}(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR}))[-d_S] \end{aligned}$$

where  $(F, W) \in C_{fil}(\text{Var}(k)^{sm}/S)$  is such that  $M = D(\mathbb{A}^1, et)((F, W))$  using corollary 2. Note that the filtration induced by  $W$  is a filtration by sub  $D_S$  module, which is a stronger property then Griffithz transversality. Of course, the filtration induced by  $F$  satisfy only Griffithz transversality in general.

(ii) Let  $S \in \text{Var}(k)$  and  $S = \cup_{i=1}^l S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . For  $I \subset [1, \dots, l]$ , denote by  $S_I = \cap_{i \in I} S_i$  and  $j_I : S_I \hookrightarrow S$  the open embedding. We then have closed embeddings  $i_I : S_I \hookrightarrow \tilde{S}_I := \prod_{i \in I} \tilde{S}_i$ . We define, using definition 106(ii) and proposition 62(ii), the filtered algebraic De Rahm realization functor defined as

$$\begin{aligned} \mathcal{F}_S^{FDR} : \text{DA}_c(S) &\rightarrow D_{\mathcal{D}fil}(S/(\tilde{S}_I)), M \mapsto \\ \mathcal{F}_S^{FDR}(M) &:= (e'(\tilde{S}_I)_* \text{Hom}^\bullet(\hat{R}^{CH}(\rho_{\tilde{S}_I}^* L(i_{I*} j_I^* F)), E_{zar}(\Omega_{/\tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR}))[-d_{\tilde{S}_I}], u_{IJ}^q(F)) \end{aligned}$$

where  $F \in C(\text{Var}(k)^{sm}/S)$  is such that  $M = D(\mathbb{A}^1, et)(F)$ , see definition 106.

(ii)' For the Corti-Hanamura weight structure  $W$  on  $\text{DA}_c^-(S)$ , using definition 106(ii) and proposition 62(ii),

$$\begin{aligned} \mathcal{F}_S^{FDR} : \text{DA}_c^-(S) &\rightarrow D_{\mathcal{D}(1,0)fil}^-(S/(\tilde{S}_I)), M \mapsto \mathcal{F}_S^{FDR}((M, W)) := \\ &(e'(\tilde{S}_I)_* \text{Hom}^\bullet(\hat{R}^{CH}(\rho_{\tilde{S}_I}^* L(i_{I*} j_I^* (F, W))), E_{zar}(\Omega_{/\tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR}))[-d_{\tilde{S}_I}], u_{IJ}^q(F, W)) \end{aligned}$$

where  $(F, W) \in C_{fil}(\text{Var}(k)^{sm}/S)$  is such that  $(M, W) = D(\mathbb{A}^1, et)(F, W)$  using corollary 2. Note that the filtration induced by  $W$  is a filtration by sub  $D_{\tilde{S}_I}$ -modules, which is a stronger property then Griffithz transversality. Of course, the filtration induced by  $F$  satisfy only Griffithz transversality in general.

**Proposition 63.** For  $S \in \text{Var}(k)$  and  $S = \cup_{i=1}^l S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ , the functor  $\mathcal{F}_S^{FDR}$  is well defined.

*Proof.* Similar to the proof of [10] proposition : follows from proposition 62.  $\square$

**Remark 10.** (i) Let  $S \in \text{SmVar}(k)$ . We have, by proposition 61, for  $M \in \text{DA}_c(S)$  the isomorphism in  $D_{\mathcal{D}(1,0)fil, \infty}^-(S)$

$$\begin{aligned} &\text{Hom}(-, k) \circ \text{Hom}(T(\hat{R}^{CH}, R^{CH})(\rho_S^* L(F, W)), -)^{-1} : \\ \mathcal{F}_S^{FDR}((M, W)) &:= e'(S)_* \text{Hom}^\bullet(\hat{R}^{CH}(\rho_S^* L(F, W)), E_{zar}(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR}))[-d_S] \\ &\xrightarrow{\sim} e'(S)_* \text{Hom}^\bullet(L\mu_{S*} \rho_{S^*} R^{CH}(\rho_S^* L(F, W)), E_{et}(\Omega_{/S}^{\bullet, \Gamma, pr}, F_{DR}))[-d_S] \end{aligned}$$

as it was defined in [10].

(ii) Let  $S \in \text{Var}(k)$  and  $S = \cup_{i=1}^l S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . We have, by proposition 61, for  $M \in \text{DA}_c(S)$  the isomorphism in  $D_{\mathcal{D}(1,0)fil,\infty}^-(S/(\tilde{S}_I))$

$$\begin{aligned} & (\text{Hom}(-, k)) \circ (\text{Hom}(T(\hat{R}^{CH}, R^{CH})(\rho_{\tilde{S}_I}^* L(i_{I*} j_I^*(F, W))), -))^{-1} : \\ \mathcal{F}_S^{FDR}((M, W)) & := (e'(\tilde{S}_I)_* \text{Hom}^\bullet(\hat{R}^{CH}(\rho_{\tilde{S}_I}^* L(i_{I*} j_I^*(F, W))), E_{zar}(\Omega_{\tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR}))[-d_{\tilde{S}_I}], u_{I,J}^q(F, W)) \\ & \xrightarrow{\sim} (e'(\tilde{S}_I)_* \text{Hom}^\bullet(L\mu_{\tilde{S}_I*} \rho_{\tilde{S}_I*} R^{CH}(\rho_{\tilde{S}_I}^* L(i_{I*} j_I^*(F, W))), E_{et}(\Omega_{\tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR}))[-d_{\tilde{S}_I}], u_{I,J}^q(F, W)) \end{aligned}$$

as it was defined in [10].

**Proposition 64.** Let  $f : X \rightarrow S$  a morphism with  $S, X \in \text{Var}(k)$ . Assume there exist a factorization

$$f : X \xrightarrow{l} Y \times S \xrightarrow{p_S} S$$

of  $f$  with  $Y \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $p_S$  the projection. Let  $\bar{Y} \in \text{PSmVar}(k)$  a compactification of  $Y$  with  $\bar{Y} \setminus Y = D$  a normal crossing divisor, denote  $k : D \hookrightarrow \bar{Y}$  the closed embedding and  $n : Y \hookrightarrow \bar{Y}$  the open embedding. Denote  $\bar{X} \subset \bar{Y} \times S$  the closure of  $X \subset \bar{Y} \times S$ . We have then the following commutative diagram in  $\text{Var}(k)$

$$\begin{array}{ccccc} X & \xrightarrow{l} & Y \times S & & \\ \downarrow & & \downarrow & \searrow^{p_S} & \\ \bar{X} & \xrightarrow{l} & \bar{Y} \times S & \xrightarrow{\bar{p}_S} & S \\ \uparrow & \nearrow^{l_Z} & \uparrow & \nearrow^{(k \times I)} & \\ Z := \bar{X} \setminus X & \longrightarrow & D \times S & & \end{array} .$$

Let  $S = \cup_{i=1}^l S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Then  $X = \cup_{i=1}^l X_i$  with  $X_i := f^{-1}(S_i)$ . Denote, for  $I \subset [1, \dots, l]$ ,  $S_I = \cap_{i \in I} S_i$  and  $X_I = \cap_{i \in I} X_i$ . Denote  $\bar{X}_I := \bar{X} \cap (\bar{Y} \times S_I) \subset \bar{Y} \times \tilde{S}_I$  the closure of  $X_I \subset \bar{Y} \times \tilde{S}_I$ , and  $Z_I := Z \cap (\bar{Y} \times S_I) = \bar{X}_I \setminus X_I \subset \bar{Y} \times \tilde{S}_I$ . We have then for  $I \subset [1, \dots, l]$ , the following commutative diagram in  $\text{Var}(k)$

$$\begin{array}{ccccc} X_I & \xrightarrow{l_I} & Y \times \tilde{S}_I & & \\ \downarrow & & \downarrow & \searrow^{p_{\tilde{S}_I}} & \\ \bar{X}_I & \xrightarrow{l_I} & \bar{Y} \times \tilde{S}_I & \xrightarrow{\bar{p}_{\tilde{S}_I}} & \tilde{S}_I \\ \uparrow & \nearrow^{l_{Z_I}} & \uparrow & \nearrow^{(k \times I)} & \\ Z_I = \bar{X}_I \setminus X_I & \longrightarrow & D \times \tilde{S}_I & & \end{array} .$$

Let  $F(X/S) := p_{S,*} \Gamma_X^\vee Z(Y \times S/Y \times S) \in C(\text{Var}(k)^{sm}/S)$ . We have then the following isomorphism in



$D_{\mathcal{D}fil}(S/(\tilde{S}_I))$

$$\begin{aligned}
& I(X/S) : \mathcal{F}_S^{FDR}(M(X/S)) \xrightarrow{=} \\
& (e'(\tilde{S}_I)_* \mathcal{H}om(\hat{R}^{CH}(\rho_{\tilde{S}_I}^* L(i_{I*} j_I^* F(X/S))), E_{zar}(\Omega_{/\tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR}))[-d_{\tilde{S}_I}], u_{IJ}^q(F(X/S))) \\
& \xrightarrow{(\mathcal{H}om(\hat{R}_{\tilde{S}_I}^{CH}(N_I(X/S)), E_{zar}(\Omega_{/\tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR})))} \\
& (e'(\tilde{S}_I)_* \mathcal{H}om(\hat{R}^{CH}(\rho_{\tilde{S}_I}^* Q(X_I/\tilde{S}_I)), E_{zar}(\Omega_{/\tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR}))[-d_{\tilde{S}_I}], v_{IJ}^q(F(X/S))) \\
& \xrightarrow{(\mathcal{H}om(\rho_{\tilde{S}_I}^* I_{\delta}((\tilde{X}_I, Z_I)/\tilde{S}_I), -)[-d_{\tilde{S}_I}])^{-1}} \\
& (p_{\tilde{S}_I}^* E_{zar}((\Omega_{\tilde{Y} \times \tilde{S}_I/\tilde{S}_I}^{\bullet}, F_b) \otimes_{O_{\tilde{Y} \times \tilde{S}_I}} (n \times I)!^{Hdg} \Gamma_{X_I}^{\vee, Hdg}(O_{Y \times \tilde{S}_I}, F_b))(d_Y + d_{\tilde{S}_I})[2d_Y + d_{\tilde{S}_I}], w_{IJ}(X/S)) \\
& \xrightarrow{=} \iota_S Rf_!^{Hdg}(\Gamma_{X_I}^{\vee, Hdg}(O_{Y \times \tilde{S}_I}, F_b)(d_Y)[2d_Y], x_{IJ}(X/S)). \xrightarrow{=} \iota_S Rf_!^{Hdg} f_{Hdg}^{*mod} \mathbb{Z}_S^{Hdg}.
\end{aligned}$$

*Proof.* Similar to the proof of [10], proposition □

**Corollary 4.** *Let  $S \in \text{Var}(k)$  and  $S = \cup_{i=1}^l S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Then for  $M \in \text{DA}_c(S)$ ,  $\mathcal{F}_S^{FDR} \in \iota_S(D(\text{DRM}(S)))$ , where  $\iota_S : D(\text{DRM}(S)) \hookrightarrow D_{\mathcal{D}fil}(S/(\tilde{S}_I))$  is a full embedding by theorem 38.*

*Proof.* There exist by definition of constructible motives an isomorphism  $\text{DA}(S)$

$$w(M) : M \xrightarrow{\sim} \text{Cone}(M(X_1/S) \rightarrow \cdots \rightarrow M(X_r/S)).$$

Hence we have the isomorphism in  $D_{\mathcal{D}fil}(S/(\tilde{S}_I))$

$$\mathcal{F}_S^{FDR}(w(M)) : \mathcal{F}_S^{FDR}(M) \xrightarrow{\sim} \text{Cone}(\mathcal{F}_S^{FDR}(M(X_1/S)) \rightarrow \cdots \rightarrow \mathcal{F}_S^{FDR}(M(X_r/S))).$$

The result then follows from proposition 64. □

**Proposition 65.** *For  $S \in \text{Var}(k)$  not smooth, the functor (see corollary 4)*

$$\iota_S^{-1} \mathcal{F}_S^{FDR} : \text{DA}_c^-(S)^{op} \rightarrow D(\text{DRM}(S))$$

*does not depend on the choice of the open cover  $S = \cup_i S_i$  and the closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ .*

*Proof.* Similar to the proof of [10] proposition □

We have the canonical transformation map between the filtered De Rham realization functor and the Gauss-Manin realization functor :

**Definition 108.** *Let  $S \in \text{Var}(k)$  and  $S = \cup_{i=1}^l S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Let  $M \in \text{DA}_c(S)$  and  $F \in C(\text{Var}(k)^{sm}/S)$  such that  $M = D(\mathbb{A}^1, \text{et})(F)$ . We have, using definition 103(ii), definition 24, proposition 1 and proposition 61, the canonical map in  $D_{O_S fil, \mathcal{D}, \infty}(S/(\tilde{S}_I))$*

$$\begin{aligned}
& T(\mathcal{F}_S^{GM}, \mathcal{F}_S^{FDR})(M) : \\
& \mathcal{F}_S^{GM}(L\mathbb{D}_S M) = (e(\tilde{S}_I)_* \mathcal{H}om^{\bullet}(L(i_{I*} j_I^* \mathbb{D}_S L F), E_{zar}(\Omega_{/\tilde{S}_I}^{\bullet}, F_b))[-d_{\tilde{S}_I}], u_{IJ}^q(F)) \\
& \xrightarrow{\sim} (e(\tilde{S}_I)_* \mathcal{H}om^{\bullet}(L\mathbb{D}_{\tilde{S}_I}^0 L(i_{I*} j_I^* F), E_{zar}(\Omega_{/\tilde{S}_I}^{\bullet}, F_b))[-d_{\tilde{S}_I}], u_{IJ}^q(F)) \\
& \xrightarrow{\mathcal{H}om(-, \text{Gr}(\Omega_{\tilde{S}_I}))^{-1}} (e(\tilde{S}_I)_* \mathcal{H}om^{\bullet}(L\mathbb{D}_{\tilde{S}_I}^0 L(i_{I*} j_I^* F), \text{Gr}_{\tilde{S}_I}^{12} E_{zar}(\Omega_{/\tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR}))[-d_{\tilde{S}_I}], u_{IJ}^q(F)) \\
& \xrightarrow{I(\text{Gr}_{\tilde{S}_I}^{12*}, \text{Gr}_{\tilde{S}_I}^{12})(-, -)} (e(\tilde{S}_I)_* \mathcal{H}om^{\bullet}(\text{Gr}_{\tilde{S}_I}^{12*} L\mathbb{D}_{\tilde{S}_I}^0 L(i_{I*} j_I^* F), E_{zar}(\Omega_{/\tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR}))[-d_{\tilde{S}_I}], u_{IJ}^q(F)) \\
& \xrightarrow{(\mathcal{H}om^{\bullet}(r^{CH}(L(i_{I*} j_I^* F) \circ T(\hat{R}^{CH}, R^{CH})(L(i_{I*} j_I^* F))), E_{zar}(\Omega_{/\tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR}))[-d_{\tilde{S}_I}])} \\
& (e'(\tilde{S}_I)_* \mathcal{H}om^{\bullet}(\hat{R}^{CH}(\rho_{\tilde{S}_I}^* L(i_{I*} j_I^* F)), E_{zar}(\Omega_{/\tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR}))[-d_{\tilde{S}_I}], u_{IJ}^q(F)) =: \mathcal{F}_S^{FDR}(M)
\end{aligned}$$

**Proposition 66.** *Let  $S \in \text{Var}(k)$  and  $S = \cup_{i=1}^l S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ .*

(i) *For  $M \in \text{DA}_c(S)$  the map in  $D_{O_S, \mathcal{D}}(S/(\tilde{S}_I)) = D_{O_S, \mathcal{D}}(S)$*

$$o_{\text{fil}}T(\mathcal{F}_S^{GM}, \mathcal{F}_S^{FDR})(M) : o_{\text{fil}}\mathcal{F}_S^{GM}(\mathbb{L}\mathbb{D}_S M) \xrightarrow{\sim} o_{\text{fil}}\mathcal{F}_S^{FDR}(M)$$

*given in definition 108 is an isomorphism if we forgot the Hodge filtration  $F$ .*

(ii) *For  $M \in \text{DA}_c(S)$  and all  $n, p \in \mathbb{Z}$ , the map in  $\text{PSh}_{O_S, \mathcal{D}}(S/(\tilde{S}_I))$*

$$F^p H^n T(\mathcal{F}_S^{GM}, \mathcal{F}_S^{FDR})(M) : F^p H^n \mathcal{F}_S^{GM}(\mathbb{L}\mathbb{D}_S M) \hookrightarrow F^p H^n \mathcal{F}_S^{FDR}(M)$$

*given in definition 108 is a monomorphism. Note that  $F^p H^n T(\mathcal{F}_S^{GM}, \mathcal{F}_S^{FDR})(M)$  is NOT an isomorphism in general : take for example  $M(S^\circ/S)^\vee = D(\mathbb{A}^1, \text{et})(j_* E_{\text{et}}(\mathbb{Z}(S^\circ/S)))$  for an open embedding  $j : S^\circ \hookrightarrow S$ , then*

$$H^n \mathcal{F}_S^{GM}(\mathbb{L}\mathbb{D}_S M(S^\circ/S)^\vee) = \mathcal{F}_S^{GM}(\mathbb{Z}(S^\circ/S)) = j_* E(O_{S^\circ}, F_b) \notin \pi_S(\text{MHM}(S))$$

*and hence is NOT isomorphic to  $H^n \mathcal{F}_S^{FDR}(\mathbb{L}\mathbb{D}_S M(S^\circ/S)^\vee) \in \pi_S(\text{MHM}(S))$  as filtered  $D_S$ -modules (see remark 4). It is an isomorphism in the very particular cases where  $M = D(\mathbb{A}^1, \text{et})(\mathbb{Z}(X/S))$  or  $M = D(\mathbb{A}^1, \text{et})(\mathbb{Z}(X^\circ/S))$  for  $f : X \rightarrow S$  is a smooth proper morphism and  $n : X^\circ \hookrightarrow X$  is an open subset such that  $X \setminus X^\circ = \cup D_i$  is a normal crossing divisor and such that  $f|_{D_i} = f \circ i_i : D_i \rightarrow X$  are SMOOTH morphism with  $i_i : D_i \hookrightarrow X$  the closed embedding and considering  $f|_{X^\circ} = f \circ n : X^\circ \rightarrow S$  (see [10] section 6.1 in the complex case).*

*Proof.* (i): Follows from the computation for a Borel-Moore motive.

(ii): Follows from (i). □

We now define the functorialities of  $\mathcal{F}_S^{FDR}$  with respect to  $S$  which makes  $\mathcal{F}_{FDR}^-$  a morphism of 2 functor.

**Definition 109.** *Let  $S \in \text{Var}(k)$ . Let  $Z \subset S$  a closed subset. Let  $S = \cup_{i=1}^l S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Denote  $Z_I := Z \cap S_I$ . We then have closed embeddings  $Z_I \hookrightarrow S_I \hookrightarrow \tilde{S}_I$ .*

(i) *For  $F \in C(\text{Var}(k)^{\text{sm}}/S)$ , we will consider the following canonical map in  $D(\text{DRM}(S)) \subset D_{\mathcal{D}(1,0)\text{fil}}(S/(\tilde{S}_I))$*

$$\begin{aligned} & T(\Gamma_Z^{\vee, \text{Hdg}}, \Omega_{/S}^{\Gamma, \text{pr}})(F, W) : \\ & \Gamma_Z^{\vee, \text{Hdg}} \iota_S^{-1}(e'_* \mathcal{H}om^\bullet(\hat{R}^{CH}(\rho_{\tilde{S}_I}^* L(i_{I*} j_I^*(F, W))), E_{\text{zar}}(\Omega_{/\tilde{S}_I}^{\bullet, \Gamma, \text{pr}}, F_{DR}))[-d_{\tilde{S}_I}], u_{IJ}^q(F, W)) \\ & \quad \xrightarrow{\mathcal{H}om^\bullet(\hat{R}_{\tilde{S}_I}^{CH}(\gamma^{\vee, Z_I}(L(i_{I*} j_I^*(F, W))), E_{\text{zar}}(\Omega_{/\tilde{S}_I}^{\bullet, \Gamma, \text{pr}}, F_{DR}))} \\ & \Gamma_Z^{\vee, \text{Hdg}} \iota_S^{-1}(e'_* \mathcal{H}om^\bullet(\hat{R}^{CH}(\rho_{\tilde{S}_I}^* \Gamma_{Z_I}^\vee L(i_{I*} j_I^*(F, W))), E_{\text{zar}}(\Omega_{/\tilde{S}_I}^{\bullet, \Gamma, \text{pr}}, F_{DR}))[-d_{\tilde{S}_I}], u_{IJ}^q(F, W)) \\ & \quad \xrightarrow{\cong} \iota_S^{-1}(e'_* \mathcal{H}om^\bullet(\hat{R}^{CH}(\rho_{\tilde{S}_I}^* \Gamma_{Z_I}^\vee L(i_{I*} j_I^*(F, W))), E_{\text{zar}}(\Omega_{/\tilde{S}_I}^{\bullet, \Gamma, \text{pr}}, F_{DR}))[-d_{\tilde{S}_I}], u_{IJ}^q(F, W)). \end{aligned}$$

*with  $u_{IJ}^q(F)$  as in [10].*

(ii) *For  $F \in C(\text{Var}(k)^{\text{sm}}/S)$ , we have also the following canonical map in  $D(\text{DRM}(S)) \subset D_{\mathcal{D}(1,0)\text{fil}}(S/(\tilde{S}_I))$*

$$\begin{aligned} & T(\Gamma_Z^{\text{Hdg}}, \Omega_{/S}^{\Gamma, \text{pr}})(F, W) : \\ & \iota_S^{-1}(e'_* \mathcal{H}om^\bullet(\hat{R}^{CH}(\rho_{\tilde{S}_I}^* L\Gamma_{Z_I} E(i_{I*} j_I^* \mathbb{D}_S(F, W))), E_{\text{zar}}(\Omega_{/\tilde{S}_I}^{\bullet, \Gamma, \text{pr}}, F_{DR}))[-d_{\tilde{S}_I}], u_{IJ}^{q, Z, d}(F, W)) \xrightarrow{\cong} \\ & \Gamma_Z^{\text{Hdg}} \iota_S^{-1}(e'_* \mathcal{H}om^\bullet(\hat{R}^{CH}(\rho_{\tilde{S}_I}^* L\Gamma_{Z_I} E(i_{I*} j_I^* \mathbb{D}_S(F, W))), E_{\text{zar}}(\Omega_{/\tilde{S}_I}^{\bullet, \Gamma, \text{pr}}, F_{DR}))[-d_{\tilde{S}_I}], u_{IJ}^{q, Z, d}(F, W)) \\ & \quad \xrightarrow{\mathcal{H}om^\bullet(\hat{R}_{\tilde{S}_I}^{CH}(\gamma^{Z_I}(-), E_{\text{zar}}(\Omega_{/\tilde{S}_I}^{\bullet, \Gamma, \text{pr}}, F_{DR}))} \\ & \Gamma_Z^{\text{Hdg}} \iota_S^{-1}(e'_* \mathcal{H}om^\bullet(\hat{R}^{CH}(\rho_{\tilde{S}_I}^* L(i_{I*} j_I^* \mathbb{D}_S(F, W))), E_{\text{zar}}(\Omega_{/\tilde{S}_I}^{\bullet, \Gamma, \text{pr}}, F_{DR}))[-d_{\tilde{S}_I}], u_{IJ}^q(F, W)) \end{aligned}$$

with  $u_{I_J}^{q,Z}(F)$  as in [10].

**Definition 110.** Let  $g : T \rightarrow S$  a morphism with  $T, S \in \text{Var}(k)$ . Assume we have a factorization  $g : T \xrightarrow{l} Y \times S \xrightarrow{ps} S$  with  $Y \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $p_S$  the projection. Let  $S = \bigcup_{i=1}^l S_i$  be an open cover such that there exists closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Then,  $T = \bigcup_{i=1}^l T_i$  with  $T_i := g^{-1}(S_i)$  and we have closed embeddings  $i'_i := i_i \circ l : T_i \hookrightarrow Y \times \tilde{S}_i$ . Moreover  $\tilde{g}_I := p_{\tilde{S}_I} : Y \times \tilde{S}_I \rightarrow \tilde{S}_I$  is a lift of  $g_I := g|_{T_i} : T_i \rightarrow S_I$ . Let  $M \in \text{DA}_c(S)^-$  and  $(F, W) \in C_{fil}(\text{Var}(k)^{sm}/S)$  such that  $(M, W) = D(\mathbb{A}_S^1, et)(F, W)$ . Then,  $D(\mathbb{A}_T^1, et)(g^*F) = g^*M$  and there exist  $(F', W) \in C_{fil}(\text{Var}(k)^{sm}/S)$  and an equivalence  $(\mathbb{A}^1, et)$  local  $e : g^*(F, W) \rightarrow (F', W)$  such that  $D(\mathbb{A}_T^1, et)(F', W) = (g^*M, W)$ . Denote for short  $d_{YI} := -d_Y - d_{\tilde{S}_I}$ . We have, using definition 104 and definition 109(i), the canonical map in  $D(\text{DRM}(T)) \subset D_{\mathcal{D}(1,0)fil}(T/(Y \times \tilde{S}_I))$

$$\begin{aligned}
& T(g, \mathcal{F}^{FDR})(M) : g_{Hdg}^{*mod} \iota_S^{-1} \mathcal{F}_S^{FDR}(M) := \\
& \Gamma_T^{\vee, Hdg} \iota_T^{-1} (\tilde{g}_I^{*mod} (e'_* \mathcal{H}om^\bullet(\hat{R}^{CH}(\rho_{\tilde{S}_I}^*(L(i_{I^*} j_I^*(F, W))), E_{zar}(\Omega_{/\tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR}))) [d_{YI}], \tilde{g}_I^{*mod} u_{IJ}^q(F, W)) \\
& \xrightarrow{(T(\tilde{g}_I, \Omega_{/\tilde{S}_I}^{\Gamma, pr})(-))} \\
& \Gamma_T^{\vee, Hdg} \iota_T^{-1} (e'_* \mathcal{H}om^\bullet(\tilde{g}_I^* \hat{R}^{CH}(\rho_{\tilde{S}_I}^* L(i_{I^*} j_I^*(F, W))), E_{zar}(\Omega_{/Y \times \tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR})) [d_{YI}], \tilde{g}_I^* u_{IJ}^q(F, W)) \\
& \xrightarrow{\mathcal{H}om(T(\tilde{g}_I, R^{CH})(-)^{-1}, -)} \\
& \Gamma_T^{\vee, Hdg} \iota_T^{-1} (e'_* \mathcal{H}om^\bullet(\hat{R}^{CH}(\rho_{Y \times \tilde{S}_I}^* \tilde{g}_I^* L(i_{I^*} j_I^*(F, W))), E_{zar}(\Omega_{/Y \times \tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR})) [d_{YI}], \tilde{g}_I^* u_{IJ}^q(F, W)) \\
& \xrightarrow{T(\Gamma_T^{\vee, Hdg}, \Omega_{/S}^{\Gamma, pr})(F, W)} \\
& \iota_T^{-1} (e'_* \mathcal{H}om^\bullet(\hat{R}^{CH}(\rho_{Y \times \tilde{S}_I}^* \Gamma_{T_i}^\vee \tilde{g}_I^* L(i_{I^*} j_I^*(F, W))), E_{zar}(\Omega_{/Y \times \tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR})) [d_{YI}], \tilde{g}_I^* u_{IJ}^q(F, W)) \\
& \xrightarrow{(\mathcal{H}om(\hat{R}_{Y \times \tilde{S}_I}^{CH}(T^{q, \gamma}(D_{gI})(j_I^*(F, W))), E_{zar}(\Omega_{/Y \times \tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR})) [d_{YI}])} \\
& \iota_T^{-1} (e'_* \mathcal{H}om^\bullet(\hat{R}^{CH}(\rho_{Y \times \tilde{S}_I}^* L(i'_{I^*} j_I'^*(F, W))), E_{zar}(\Omega_{/Y \times \tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR})) [d_{YI}], u_{IJ}^q(g^*(F, W)) \\
& \xrightarrow{\mathcal{H}om(\hat{R}_{Y \times \tilde{S}_I}^{CH}(Li'_{I^*} j_I'^*(e)), -)} \\
& \iota_T^{-1} (e'_* \mathcal{H}om^\bullet(\hat{R}^{CH}(\rho_{Y \times \tilde{S}_I}^* L(i'_{I^*} j_I'^*(F', W))), E_{zar}(\Omega_{/Y \times \tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR})) [d_{YI}], u_{IJ}^q(F', W)) \\
& \xrightarrow{=} \mathcal{F}_T^{FDR}(g^*M)
\end{aligned}$$

**Definition 111.** • Let  $f : X \rightarrow S$  a morphism with  $X, S \in \text{Var}(k)$ . Assume there exist a factorization  $f : X \xrightarrow{l} Y \times S \xrightarrow{ps} S$  with  $Y \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $p_S$  the projection. We have, for  $M \in \text{DA}_c(X)$ , the following transformation map in  $D(\text{DRM}(S))$

$$\begin{aligned}
& T_*(f, \mathcal{F}^{FDR})(M) : \mathcal{F}_S^{FDR}(Rf_*M) \xrightarrow{\text{ad}(f_{Hdg}^{*mod}, Rf_*^{Hdg})(-)} Rf_*^{Hdg} f_{Hdg}^{*mod} \mathcal{F}_S^{FDR}(Rf_*M) \\
& \xrightarrow{T(f, \mathcal{F}^{FDR})(Rf_*M)} Rf_*^{Hdg} \mathcal{F}_X^{FDR}(f^* Rf_*M) \xrightarrow{\mathcal{F}_X^{FDR}(\text{ad}(f^*, Rf_*)(M))} Rf_*^{Hdg} \mathcal{F}_X^{FDR}(M)
\end{aligned}$$

Clearly, for  $p : Y \times S \rightarrow S$  a projection with  $Y \in \text{PSmVar}(\mathbb{C})$ , we have, for  $M \in \text{DA}_c(Y \times S)$ ,  $T_*(p, \mathcal{F}^{FDR})(M) = T_i(p, \mathcal{F}^{FDR})(M)[d_Y]$

- Let  $S \in \text{Var}(k)$ . Let  $Y \in \text{SmVar}(k)$  and  $p : Y \times S \rightarrow S$  the projection. We have then, for  $M \in \text{DA}(Y \times S)$  the following transformation map in  $D(\text{DRM}(S))$

$$\begin{aligned}
& T_i(p, \mathcal{F}^{FDR})(M) : p_!^{Hdg} \mathcal{F}_{Y \times S}^{FDR}(M) \xrightarrow{\mathcal{F}_{Y \times S}^{FDR}(\text{ad}(Lp_*, p^*)(M))} Rp_!^{Hdg} \mathcal{F}_{Y \times S}^{FDR}(p^* Lp_! M) \\
& \xrightarrow{T(p, \mathcal{F}^{FDR})(Lp_!(M, W))} Rp_!^{Hdg} p^{*mod[-]} \mathcal{F}_S^{FDR}(Lp_! M) \xrightarrow{T(p^{*mod}, p^{*mod})(-)} p_!^{Hdg} p^{*mod[-]} \\
& \mathcal{F}_S^{FDR}(Lp_! M) \xrightarrow{\text{ad}(Rp_!^{Hdg}, p^{*mod[-]})(\mathcal{F}_S^{FDR}(Lp_! M))} \mathcal{F}_S^{FDR}(Lp_! M)
\end{aligned}$$

- Let  $f : X \rightarrow S$  a morphism with  $X, S \in \text{Var}(k)$ . Assume there exist a factorization  $f : X \xrightarrow{l} Y \times S \xrightarrow{p_S} S$  with  $Y \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $p_S$  the projection. We have then, using the second point, for  $M \in \text{DA}(X)$  the following transformation map in  $D(\text{DRM}(S))$

$$\begin{aligned} T_1(f, \mathcal{F}^{FDR})(M) : R p_{!}^{Hdg} \mathcal{F}_X^{FDR}(M, W) &:= R p_{!}^{Hdg} \mathcal{F}_{Y \times S}^{FDR}(l_* M) \\ &\xrightarrow{T_1(p, \mathcal{F}^{FDR})(l_* M)} \mathcal{F}_S^{FDR}(L p_{!} l_* M) \xrightarrow{\cong} \mathcal{F}_S^{FDR}(R f_! M) \end{aligned}$$

- Let  $f : X \rightarrow S$  a morphism with  $X, S \in \text{Var}(k)$ . Assume there exist a factorization  $f : X \xrightarrow{l} Y \times S \xrightarrow{p_S} S$  with  $Y \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $p_S$  the projection. We have, using the third point, for  $M \in \text{DA}(S)$ , the following transformation map in  $D(\text{DRM}(X))$

$$\begin{aligned} T^1(f, \mathcal{F}^{FDR})(M) : \mathcal{F}_X^{FDR}(f^! M) &\xrightarrow{\text{ad}(R f_!^{Hdg}, f^{*mod}) (\mathcal{F}_X^{FDR}(f^! M))} f_{Hdg}^{*mod} R f_!^{Hdg} \mathcal{F}_X^{FDR}(f^! M) \\ &\xrightarrow{T_1(p_S, \mathcal{F}^{FDR})(\mathcal{F}^{FDR}(f^! M))} f_{Hdg}^{*mod} \mathcal{F}_S^{FDR}(R f_! f^! M) \xrightarrow{\mathcal{F}_S^{FDR}(\text{ad}(R f_!, f^!)(M))} f_{Hdg}^{*mod} \mathcal{F}_S^{FDR}(M) \end{aligned}$$

- Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i=1}^l S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . We have, using definition 105 and the preceding point, denoting  $\Delta_S : S \hookrightarrow S$  the diagonal closed embedding and  $p_1 : S \times S \rightarrow S$ ,  $p_2 : S \times S \rightarrow S$  the projections, for  $M, N \in \text{DA}(S)$  and  $(F, W), (G, W) \in C_{f!}(\text{Var}(k)^{sm}/S)$  such that  $(M, W) = D(\mathbb{A}^1, \text{et})(F, W)$  and  $(N, W) = D(\mathbb{A}^1, \text{et})(G, W)$ , the following transformation map in  $D(\text{DRM}(S))$

$$\begin{aligned} T(\mathcal{F}_S^{FDR}, \otimes)(M, N) : \mathcal{F}_S^{FDR}(M) \otimes_{O_S}^{Hdg} \mathcal{F}_S^{FDR}(N) &:= \Delta_S^{!Hdg} (p_1^{*mod} \mathcal{F}_S^{FDR}(M) \otimes_{O_{S \times S}} p_2^{*mod} \mathcal{F}_S^{FDR}(N)) \\ &\xrightarrow{T^1(p_1, \mathcal{F}_S^{FDR})(M) \otimes T^1(p_2, \mathcal{F}_S^{FDR})(N)} \Delta_S^{!Hdg} (\mathcal{F}_{S \times S}^{FDR}(p_1^! M) \otimes_{O_{S \times S}} \mathcal{F}_{S \times S}^{FDR}(p_2^! N)) \\ &\xrightarrow{(T(\otimes, \Omega)(\hat{R}^{CH}(\rho_{\tilde{S}_I \times \tilde{S}_J}^* L(i_I \times i_J)_*(j_I \times j_J)^* p_1^! F[2d_S]), \hat{R}^{CH}(\rho_{\tilde{S}_I \times \tilde{S}_J}^* L(i_I \times i_J)_*(j_I \times j_J)^* p_2^! F[2d_S])))} \\ &\Delta_S^{!Hdg} (\mathcal{F}_{S \times S}^{FDR}(p_1^! M \otimes p_2^! N)) \xrightarrow{T^1(\Delta_S, \mathcal{F}^{FDR})(p_1^! M \otimes p_2^! N)} \mathcal{F}_S^{FDR}(\Delta_S^!(p_1^! M \otimes p_2^! N)) = \mathcal{F}_S^{FDR}(M \otimes N) \end{aligned}$$

where the last equality follows from the equality in  $\text{DA}(S)$

$$\Delta_S^!(p_1^! M \otimes p_2^! N) = \Delta_S^! p_1^! M \otimes \Delta_S^! p_2^! N = M \otimes N$$

**Proposition 67.** Let  $g : T \rightarrow S$  a morphism with  $T, S \in \text{Var}(k)$ . Assume we have a factorization  $g : T \xrightarrow{l} Y_2 \times S \xrightarrow{p_S} S$  with  $Y_2 \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $p_S$  the projection. Let  $S = \cup_{i=1}^l S_i$  be an open cover such that there exists closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Then,  $T = \cup_{i=1}^l T_i$  with  $T_i := g^{-1}(S_i)$  and we have closed embeddings  $i'_i := i_i \circ l : T_i \hookrightarrow Y_2 \times \tilde{S}_i$ . Moreover  $\tilde{g}_I := p_{\tilde{S}_I} : Y \times \tilde{S}_I \rightarrow \tilde{S}_I$  is a lift of  $g_I := g|_{T_I} : T_I \rightarrow S_I$ . Let  $f : X \rightarrow S$  a morphism with  $X \in \text{Var}(k)$  such that there exists a factorization  $f : X \xrightarrow{l} Y_1 \times S \xrightarrow{p_S} S$ , with  $Y_1 \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $p_S$  the projection. We have then the following commutative diagram whose squares are cartesian

$$\begin{array}{ccccc} f' : X_T & \longrightarrow & Y_1 \times T & \longrightarrow & T \\ & \searrow & \searrow & \searrow & \searrow \\ & & Y_1 \times X & \longrightarrow & Y_1 \times Y_2 \times S \\ & \searrow & \searrow & \searrow & \searrow \\ & & Y_1 \times S & \longrightarrow & S \\ & \searrow & \searrow & \searrow & \searrow \\ f : X & \longrightarrow & Y_1 \times S & \longrightarrow & S \end{array}$$

Take a smooth compactification  $\bar{Y}_1 \in \text{PSmVar}(\mathbb{C})$  of  $Y_1$ , denote  $\bar{X}_I \subset \bar{Y}_1 \times \tilde{S}_I$  the closure of  $X_I$ , and  $Z_I := \bar{X}_I \setminus X_I$ . Consider  $F(X/S) := p_{S, \sharp} \Gamma_X^\vee \mathbb{Z}(Y_1 \times S / Y_1 \times S) \in C(\text{Var}(k)^{sm}/S)$  and the isomorphism in

$C(\text{Var}(k)^{sm}/T)$

$$T(f, g, F(X/S)) : g^*F(X/S) := g^*p_{S, \#}\Gamma_X^\vee \mathbb{Z}(Y_1 \times S/Y_1 \times S) \xrightarrow{\sim} p_{T, \#}\Gamma_{X_T}^\vee \mathbb{Z}(Y_1 \times T/Y_1 \times T) =: F(X_T/T).$$

which gives in  $\text{DA}(T)$  the isomorphism  $T(f, g, F(X/S)) : g^*M(X/S) \xrightarrow{\sim} (X_T/T)$ . Then the following diagram in  $D(\text{DRM}(T)) \subset D_{\mathcal{D}(1,0)fil}(T/(Y_2 \times \tilde{S}_I))$ , where the horizontal maps are given by proposition 64, commutes

$$\begin{array}{ccc} g_{Hdg}^{\hat{*}mod} \iota_S^{-1} \mathcal{F}_S^{FDR}(M(X/S)) & \xrightarrow{g_{Hdg}^{\hat{*}mod} I(X/S)} & g_{Hdg}^{\hat{*}mod} Rf_!^{Hdg}(\Gamma_{X_I}^{\vee, Hdg}(O_{Y_1 \times \tilde{S}_I}, F_b)(d_{Y_1})[2d_{Y_1}], x_{IJ}(X/S)) \\ \downarrow 'T(g, \mathcal{F}^{FDR})(M(X/S)) & & \downarrow T(p_{\tilde{S}_I}, \gamma^{\vee, Hdg})(-) \\ \iota_T^{-1} \mathcal{F}_T^{FDR}(M(X_T/T)) & \xrightarrow{I(X_T/T)} & Rf_!^{Hdg}(\Gamma_{X_{T_I}}^{\vee, Hdg}(O_{Y_2 \times Y_1 \times \tilde{S}_I}, F_b)(d_{Y_{12}})[2d_{Y_{12}}], x_{IJ}(X_T/T)). \end{array}$$

with  $d_{Y_{12}} = d_{Y_1} + d_{Y_2}$ .

*Proof.* Follows immediately from definition.  $\square$

**Proposition 68.** Let  $S \in \text{Var}(k)$ . Let  $Y \in \text{SmVar}(k)$  and  $p : Y \times S \rightarrow S$  the projection. Let  $S = \cup_{i=1}^l S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . For  $I \subset [1, \dots, l]$ , we denote by  $S_I = \cap_{i \in I} S_i$ ,  $j_I^\circ : S_I \hookrightarrow S$  and  $j_I : Y \times S_I \hookrightarrow Y \times S$  the open embeddings. We then have closed embeddings  $i_I : Y \times S_I \hookrightarrow Y \times \tilde{S}_I$ . and we denote by  $p_{\tilde{S}_I} : Y \times \tilde{S}_I \rightarrow \tilde{S}_I$  the projections. Let  $f' : X' \rightarrow Y \times S$  a morphism, with  $X' \in \text{Var}(k)$  such that there exists a factorization  $f' : X' \xrightarrow{l'} Y' \times Y \times S \xrightarrow{p'} Y \times S$  with  $Y' \in \text{SmVar}(k)$ ,  $l'$  a closed embedding and  $p'$  the projection. Denoting  $X'_I := f'^{-1}(Y \times S_I)$ , we have closed embeddings  $i'_I : X'_I \hookrightarrow Y' \times Y \times \tilde{S}_I$ . Consider

$$F(X'/Y \times S) := p_{Y \times S, \#}\Gamma_{X'}^\vee \mathbb{Z}(Y' \times Y \times S/Y' \times Y \times S) \in C(\text{Var}(k)^{sm}/Y \times S)$$

and  $F(X'/S) := p_{\#}F(X'/Y \times S) \in C(\text{Var}(k)^{sm}/S)$ , so that  $Lp_{\#}M(X'/Y \times S)[-2d_Y] =: M(X'/S)$ . Then, the following diagram in  $D(\text{DRM}(S)) \subset D_{\mathcal{D}(1,0)fil}(S/(Y \times \tilde{S}_I))$ , where the vertical maps are given by proposition 64, commutes

$$\begin{array}{ccc} Rp^{Hdg}! \mathcal{F}_{Y \times S}^{FDR}(M(X'/Y \times S)) & \xrightarrow{T(p, \mathcal{F}^{FDR})(M(X'/Y \times S))} & \mathcal{F}_S^{FDR}(M(X'/S)) \\ \uparrow T(p_{Hdg}^{\hat{*}mod}, p_{Hdg}^{\hat{*}mod})(-) \circ Rp^{Hdg}!(I(X'/Y \times S)) & & \uparrow I(X'/S) \\ Rp^{Hdg}! Rf_!^{Hdg} f'^{*mod} \mathbb{Z}_{Y \times S}^{Hdg} & \xrightarrow{=} & Rf_!^{Hdg} f_{Hdg}^{\hat{*}mod} \mathbb{Z}_S^{Hdg} \end{array}$$

*Proof.* Immediate from definition.  $\square$

**Proposition 69.** Let  $f_1 : X_1 \rightarrow S$ ,  $f_2 : X_2 \rightarrow S$  two morphism with  $X_1, X_2, S \in \text{Var}(k)$ . Assume that there exist factorizations  $f_1 : X_1 \xrightarrow{l_1} Y_1 \times S \xrightarrow{p_S} S$ ,  $f_2 : X_2 \xrightarrow{l_2} Y_2 \times S \xrightarrow{p_S} S$  with  $Y_1, Y_2 \in \text{SmVar}(k)$ ,  $l_1, l_2$  closed embeddings and  $p_S$  the projections. We have then the factorization

$$f_{12} := f_1 \times f_2 : X_{12} := X_1 \times_S X_2 \xrightarrow{l_1 \times l_2} Y_1 \times Y_2 \times S \xrightarrow{p_S} S$$

Let  $S = \cup_{i=1}^l S_i$  an open affine covering and denote, for  $I \subset [1, \dots, l]$ ,  $S_I = \cap_{i \in I} S_i$  and  $j_I : S_I \hookrightarrow S$  the open embedding. Let  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embeddings, with  $\tilde{S}_i \in \text{SmVar}(k)$ . We have then the

following commutative diagram in  $D(\text{DRM}(S)) \subset D_{\mathcal{D}(1,0)\text{fil}}(S/(\tilde{S}_I))$  where the vertical maps are given by proposition 64

$$\begin{array}{ccc} \mathcal{F}_S^{\text{FDR}}(M(X_1/S)) \otimes_{\mathcal{O}_S}^{\text{Hdg}} \mathcal{F}_S^{\text{FDR}}(M(X_2/S)) & \xrightarrow{I(X_1/S) \otimes I(X_2/S)} & Rf_{1!}^{\text{Hdg}}(\Gamma_{X_{1I}}^{\vee, \text{Hdg}}(O_{Y_1 \times \tilde{S}_I}, F_b)(d_2)[2d_1], x_{IJ}(X_1/S)) \otimes_{\mathcal{O}_S} \\ & & Rf_{2!}^{\text{Hdg}}(\Gamma_{X_{2I}}^{\vee, \text{Hdg}}(O_{Y_2 \times \tilde{S}_I}, F_b)(d_1)[2d_2], x_{IJ}(X_2/S)) \\ \downarrow T(\mathcal{F}_S^{\text{FDR}}, \otimes)(M(X_1/S), M(X_2/S)) & & \downarrow (Ew_{(Y_1 \times \tilde{S}_I, Y_2 \times \tilde{S}_I)/\tilde{S}_I}) \\ \mathcal{F}_S^{\text{FDR}}(M(X_1/S) \otimes M(X_2/S) = M(X_1 \times_S X_2/S)) & \xrightarrow{I(X_{12}/S)} & Rf_{12!}^{\text{Hdg}}(\Gamma_{X_{1I} \times_S X_{2I}}^{\vee, \text{Hdg}}(O_{Y_1 \times Y_2 \times \tilde{S}_I}, F_b)(d_{12})[2d_{12}], x_{IJ}(X_1/S)) \end{array}$$

with  $d_1 = d_{Y_1}$ ,  $d_2 = d_{Y_2}$  and  $d_{12} = d_{Y_1} + d_{Y_2}$ .

*Proof.* Immediate from definition.  $\square$

**Theorem 50.** (i) Let  $g : T \rightarrow S$  a morphism, with  $S, T \in \text{Var}(k)$ . Assume we have a factorization  $g : T \xrightarrow{l} Y \times S \xrightarrow{ps} S$  with  $Y \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $ps$  the projection. Let  $M \in \text{DA}_c(S)$ . Then map in  $D(\text{DRM}(T))$

$$T(g, \mathcal{F}^{\text{FDR}})(M) : g_{\text{Hdg}}^{\text{mod}} \mathcal{F}_S^{\text{FDR}}(M) \xrightarrow{\sim} \mathcal{F}_T^{\text{FDR}}(g^* M)$$

given in definition 110 is an isomorphism.

(ii) Let  $f : X \rightarrow S$  a morphism with  $X, S \in \text{Var}(k)$ . Assume there exist a factorization  $f : X \xrightarrow{l} Y \times S \xrightarrow{ps} S$  with  $Y \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $ps$  the projection. Then, for  $M \in \text{DA}_c(X)$ , the map given in definition 111

$$T_!(f, \mathcal{F}^{\text{FDR}})(M) : Rf_{!}^{\text{Hdg}} \mathcal{F}_X^{\text{FDR}}(M) \xrightarrow{\sim} \mathcal{F}_S^{\text{FDR}}(Rf_! M)$$

is an isomorphism in  $D(\text{DRM}(S))$ .

(iii) Let  $f : X \rightarrow S$  a morphism with  $X, S \in \text{Var}(k)$ ,  $S$  quasi-projective. Assume there exist a factorization  $f : X \xrightarrow{l} Y \times S \xrightarrow{ps} S$  with  $Y \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $ps$  the projection. We have, for  $M \in \text{DA}_c(X)$ , the map given in definition 111

$$T_*(f, \mathcal{F}^{\text{FDR}})(M) : \mathcal{F}_S^{\text{FDR}}(Rf_* M) \xrightarrow{\sim} Rf_*^{\text{Hdg}} \mathcal{F}_X^{\text{FDR}}(M)$$

is an isomorphism in  $D(\text{DRM}(S))$ .

(iv) Let  $f : X \rightarrow S$  a morphism with  $X, S \in \text{Var}(k)$ ,  $S$  quasi-projective. Assume there exist a factorization  $f : X \xrightarrow{l} Y \times S \xrightarrow{ps} S$  with  $Y \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $ps$  the projection. Then, for  $M \in \text{DA}_c(S)$ , the map given in definition 111

$$T^!(f, \mathcal{F}^{\text{FDR}})(M) : \mathcal{F}_X^{\text{FDR}}(f^! M) \xrightarrow{\sim} f_{\text{Hdg}}^{\text{mod}} \mathcal{F}_S^{\text{FDR}}(M)$$

is an isomorphism in  $D(\text{DRM}(X))$ .

(v) Let  $S \in \text{Var}(k)$ . Then, for  $M, N \in \text{DA}_c(S)$ , the map in  $D(\text{DRM}(S))$

$$T(\mathcal{F}_S^{\text{FDR}}, \otimes)(M, N) : \mathcal{F}_S^{\text{FDR}}(M) \otimes_{\mathcal{O}_S}^{\text{Hdg}} \mathcal{F}_S^{\text{FDR}}(N) \xrightarrow{\sim} \mathcal{F}_S^{\text{FDR}}(M \otimes N)$$

given in definition 111 is an isomorphism.

*Proof.* The proof is similar to the complex case : follows from [4] by proposition 67 and proposition 68, more precisely :

(i): follows from proposition 67 and proposition 64.

(ii): follows from proposition 68

(iii), (iv): see [10].

(v): follows from proposition 69.  $\square$

We have the following easy proposition

**Proposition 70.** *Let  $S \in \text{Var}(k)$  and  $S = \cup_{i=1}^l S_i$  an open affine covering and denote, for  $I \subset [1, \dots, l]$ ,  $S_I = \cap_{i \in I} S_i$  and  $j_I : S_I \hookrightarrow S$  the open embedding. Let  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embeddings, with  $\tilde{S}_i \in \text{SmVar}(k)$ . We have, for  $M, N \in \text{DA}(S)$  and  $F, G \in C(\text{Var}(k)^{\text{sm}}/S)$  such that  $M = D(\mathbb{A}^1, \text{et})(F)$  and  $N = D(\mathbb{A}^1, \text{et})(G)$ , the following commutative diagram in  $D_{O_S \text{fil}, \mathcal{D}, \infty}(S/\tilde{S}_I)$*

$$\begin{array}{ccc} \mathcal{F}_S^{GM}(\text{LD}_S M) \otimes_{O_S}^L \mathcal{F}_S^{GM}(\text{LD}_S N) & \xrightarrow{T(\mathcal{F}_S^{GM}, \mathcal{F}_S^{FDR})(M) \otimes T(\mathcal{F}_S^{GM}, \mathcal{F}_S^{FDR})(N)} & \mathcal{F}_S^{FDR}(M) \otimes_{O_S}^{\text{Hdg}} \mathcal{F}_S^{FDR}(N) \\ \downarrow T(\mathcal{F}_S^{GM}, \otimes)(\text{LD}_S M, \text{LD}_S N) & & \downarrow T(\mathcal{F}_S^{FDR}, \otimes)(M, N) \\ \mathcal{F}_S^{GM}(\text{LD}_S(M \otimes N)) & \xrightarrow{T(\mathcal{F}_S^{GM}, \mathcal{F}_S^{FDR})(M \otimes N)} & \mathcal{F}_S^{FDR}(M \otimes N) \end{array}$$

*Proof.* Immediate from definition.  $\square$

## 8 The Hodge realization functors for relative motives over a field $k$ of characteristic 0

### 8.1 The Hodge realization functor for relative motives over a subfield $k \subset \mathbb{C}$

Let  $k \subset \mathbb{C}$  a subfield. We have for  $f : T \rightarrow S$  a morphism with  $T, S \in \text{Var}(k)$  we have the commutative diagram of site

$$\begin{array}{ccccc} \text{AnSp}(\mathbb{C})/T_{\mathbb{C}}^{\text{an}} & \xrightarrow{\text{An}_T := \text{An}_T \circ (\otimes_k \mathbb{C})} & \text{Var}(k)/T & & \\ \downarrow P(f) & \searrow \rho_T & \downarrow \text{An}_T & \searrow \rho_T & \\ \text{AnSp}(\mathbb{C})/S_{\mathbb{C}}^{\text{an}} & \xrightarrow{\text{An}_S := \text{An}_S \circ (\otimes_k \mathbb{C})} & \text{Var}(k)/S & & \\ \downarrow P(f) & \searrow \rho_S & \downarrow \text{An}_S & \searrow \rho_S & \\ \text{AnSp}(\mathbb{C})^{\text{sm}}/T_{\mathbb{C}}^{\text{an}} & \xrightarrow{\text{An}_T} & \text{Var}(k)^{\text{sm}}/T & & \\ \downarrow P(f) & \searrow \rho_S & \downarrow \text{An}_S & \searrow \rho_S & \\ \text{AnSp}(\mathbb{C})^{\text{sm}}/S_{\mathbb{C}}^{\text{an}} & \xrightarrow{\text{An}_S} & \text{Var}(k)^{\text{sm}}/S & & \end{array}$$

This gives for  $s : \mathcal{I} \rightarrow \mathcal{J}$  a functor with  $\mathcal{I}, \mathcal{J} \in \text{Cat}$  and  $f : T_{\bullet} \rightarrow S_{s(\bullet)}$  a morphism of diagram of algebraic varieties with  $T_{\bullet} \in \text{Fun}(\mathcal{I}, \text{Var}(k))$ ,  $S_{\bullet} \in \text{Fun}(\mathcal{J}, \text{Var}(k))$  the commutative diagram of sites

$$\begin{array}{ccccc} \text{Dia}^{12}(S) := \text{AnSp}(\mathbb{C})/T_{\bullet, \mathbb{C}}^{\text{an}} & \xrightarrow{\text{An}_{T_{\bullet}} := \text{An}_{T_{\bullet}} \circ (\otimes_k \mathbb{C})} & \text{Var}(k)/T_{\bullet} & & \\ \downarrow P(f_{\bullet}) & \searrow \rho_{T_{\bullet}} & \downarrow \text{An}_{T_{\bullet}} & \searrow \rho_{T_{\bullet}} & \\ \text{AnSp}(\mathbb{C})/S_{\bullet, \mathbb{C}}^{\text{an}} & \xrightarrow{\text{An}_{S_{\bullet}} := \text{An}_{S_{\bullet}} \circ (\otimes_k \mathbb{C})} & \text{Var}(k)/S_{\bullet} & & \\ \downarrow P(f_{\bullet}) & \searrow \rho_{S_{\bullet}} & \downarrow \text{An}_{S_{\bullet}} & \searrow \rho_{S_{\bullet}} & \\ \text{AnSp}(\mathbb{C})^{\text{sm}}/T_{\bullet, \mathbb{C}}^{\text{an}} & \xrightarrow{\text{An}_{T_{\bullet}}} & \text{Var}(k)^{\text{sm}}/T_{\bullet} & & \\ \downarrow P(f_{\bullet}) & \searrow \rho_{S_{\bullet}} & \downarrow \text{An}_{S_{\bullet}} & \searrow \rho_{S_{\bullet}} & \\ \text{AnSp}(\mathbb{C})^{\text{sm}}/S_{\bullet, \mathbb{C}}^{\text{an}} & \xrightarrow{\text{An}_{S_{\bullet}}} & \text{Var}(k)^{\text{sm}}/S_{\bullet} & & \end{array}$$

### 8.1.1 The Betti realization functor

Let  $k \subset \mathbb{C}$  a subfield.

**Definition 112.** *Let  $S \in \text{Var}(k)$ .*

(i) *The Ayoub's Betti realization functor is*

$$\text{Bti}_S^* : \text{DA}(S) \rightarrow D(S_{\mathbb{C}}^{\text{an}}), \quad M \in \text{DA}(S) \mapsto \text{Bti}_S^* M = \text{Re}(S_{\mathbb{C}}^{\text{an}})_* \text{An}_S^* M = e(S_{\mathbb{C}}^{\text{an}})_* \underline{\text{sing}}_{\mathbb{D}^*} \text{An}_S^* F$$

where  $F \in C(\text{Var}(k)^{\text{sm}}/S)$  is such that  $M = D(\mathbb{A}^1, \text{et})(F)$ .

(ii) *In [9], we define the Betti realization functor as*

$$\widetilde{\text{Bti}}_S^* : \text{DA}(S) \rightarrow D(S^{\text{an}}) = D(S^{\text{cw}}), \quad M \mapsto \widetilde{\text{Bti}}_S^* M = \text{Re}(S^{\text{cw}})_* \widetilde{\text{Cw}}_S^* M = e(S^{\text{cw}})_* \underline{\text{sing}}_{\mathbb{I}^*} \widetilde{\text{Cw}}_S^* F$$

where  $F \in C(\text{Var}(k)^{\text{sm}}/S)$  is such that  $M = D(\mathbb{A}^1, \text{et})(F)$ .

(iii) *For the Corti-Hanamura weight structure on  $\text{DA}^-(S)$ , we have by functoriality of (i) the functor*

$$\text{Bti}_S^* : \text{DA}^-(S) \rightarrow D_{\text{fil}}(S_{\mathbb{C}}^{\text{an}}), \quad M \mapsto (\text{Bti}_S^* M, W) := \text{Bti}_S^*(M, W) := e(S^{\text{an}})_* \underline{\text{sing}}_{\mathbb{D}^*} \text{An}_S^*(F, W)$$

where  $(F, W) \in C_{\text{fil}}(\text{Var}(k)^{\text{sm}}/S)$  is such that  $(M, W) = D(\mathbb{A}^1, \text{et})(F, W)$ .

Note that by [9],  $\text{An}_S^*$  and  $\widetilde{\text{Cw}}_S^*$  derive trivially.

Note that, by considering the explicit  $\mathbb{D}_S^1$  local model for presheaves on  $\text{AnSp}(\mathbb{C})^{\text{sm}}/S_{\mathbb{C}}^{\text{an}}$ ,  $\text{Bti}_S^*(\text{DA}^-(S)) \subset D^-(S^{\text{an}})$ ; by considering the explicit  $\mathbb{I}_S^1$  local model for presheaves on  $\text{CW}^{\text{sm}}/S^{\text{cw}}$ ,  $\widetilde{\text{Bti}}_S^*(\text{DA}^-(S)) \subset D^-(S_{\mathbb{C}}^{\text{an}})$ .

Let  $f : T \rightarrow S$  a morphism, with  $T, S \in \text{Var}(k)$ . We have, for  $M \in \text{DA}(S)$ ,  $(F, W) \in C_{\text{fil}}(\text{Var}(k)^{\text{sm}}/S)$  such that  $(M, W) = D(\mathbb{A}^1, \text{et})(F, W)$ , and an equivalence  $(\mathbb{A}^1, \text{et})$  local  $e : f^*(F, W) \rightarrow (F', W)$  with  $(F', W) \in C_{\text{fil}}(\text{Var}(k)^{\text{sm}}/S)$  such that  $(f^*M, W) = D(\mathbb{A}^1, \text{et})(F', W)$  the following canonical transformation map in  $D_{\text{fil}}(T_{\mathbb{C}}^{\text{an}})$ :

$$\begin{aligned} T^0(f, \text{Bti})(M, W) &: f^* \text{Bti}_S^*(M, W) := f^* e(S_{\mathbb{C}}^{\text{an}})_* \underline{\text{sing}}_{\mathbb{D}^*} \text{An}_S^*(F, W) \\ &\xrightarrow{T(f, e)(-)} e(T_{\mathbb{C}}^{\text{an}})_* f^* \underline{\text{sing}}_{\mathbb{D}^*} \text{An}_S^*(F, W) \\ &\xrightarrow{e(T_{\mathbb{C}}^{\text{an}})_* T(f, c)(F, W)} e(T_{\mathbb{C}}^{\text{an}})_* \underline{\text{sing}}_{\mathbb{D}^*} f^* \text{An}_T^*(F, W) \xrightarrow{\cong} e(T_{\mathbb{C}}^{\text{an}})_* \underline{\text{sing}}_{\mathbb{D}^*} \text{An}_T^* f^*(F, W) \\ &\xrightarrow{e(T_{\mathbb{C}}^{\text{an}})_* \underline{\text{sing}}_{\mathbb{D}^*} \text{An}_T^* e} e(T_{\mathbb{C}}^{\text{an}})_* \underline{\text{sing}}_{\mathbb{D}^*} \text{An}_T^*(F', W) =: \text{Bti}_T^* f^*(M, W). \end{aligned}$$

**Definition 113.** *Let  $f : T \rightarrow S$  a morphism, with  $T, S \in \text{Var}(k)$ . Consider the graph factorization  $f : T \xrightarrow{l} T \times S \xrightarrow{p} S$  of  $f$  with  $l$  the graph closed embedding and  $p$  the projection. We have, for  $M \in \text{DA}_c(S)$ , the following canonical transformation map in  $D_{\text{fil}, c}(T_{\mathbb{C}}^{\text{an}})$ :*

$$\begin{aligned} T(f, \text{Bti})(M, W) &: f^{*w} \text{Bti}_S^*(M, W) := l^* \Gamma_T^{\vee, w} p^* \text{Bti}_S^*(F, W) \\ &\xrightarrow{T^0(p, \text{Bti})(-)} l^* \Gamma_T^{\vee, w} \text{Bti}_{T \times S}^* p^*(F, W) \xrightarrow{\gamma_T^{\vee}(p^*(F, W))} l^* \Gamma_T^{\vee, w} \text{Bti}_{T \times S}^* \Gamma_T^{\vee} p^*(F, W) \\ &\xrightarrow{\cong} l^* \text{Bti}_{T \times S}^* \Gamma_T^{\vee} p^*(F, W) \xrightarrow{T^0(l, \text{Bti})(-)} \text{Bti}_T^* l^* \Gamma_T^{\vee} p^*(F, W) = \text{Bti}_T^* f^*(M, W). \end{aligned}$$

where we use definition 4.

**Definition 114.** • *Let  $f : X \rightarrow S$  a morphism, with  $X, S \in \text{Var}(k)$ . We have, for  $M \in \text{DA}_c(X)$ , the following transformation map in  $D_{\text{fil}, c}(S_{\mathbb{C}}^{\text{an}})$*

$$\begin{aligned} T_*(f, \text{Bti})(M, W) &: \text{Bti}_S^*(Rf_*(M, W)) \xrightarrow{\text{ad}(f^*, Rf_{*w})(\text{Bti}_S^*(Rf_*(M, W)))} Rf_{*w} f^{*w} \text{Bti}_S^*(Rf_*(M, W)) \\ &\xrightarrow{T(f, \text{Bti})(Rf_*(M, W))} Rf_{*w} \text{Bti}_X^*(f^* Rf_*(M, W)) \xrightarrow{\text{Bti}_X^*(\text{ad}(f^*, Rf_*)(M, W))} Rf_{*w} \text{Bti}_X^*(M, W) \end{aligned}$$



Clearly if  $l : Z \hookrightarrow S$  is a closed embedding, then  $T_*(l, \text{Bti})(M, W)$  is an isomorphism since  $\text{ad}(l^*, l_*)(-) : l^*l_*(M, W) \rightarrow (M, W)$  is an isomorphism (see section 3).

- Let  $f : X \rightarrow S$  a morphism with  $X, S \in \text{Var}(k)$ . Assume there exist a factorization  $f : X \xrightarrow{l} Y \times S \xrightarrow{p_S} S$  with  $Y \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $p_S$  the projection. We have then, for  $M \in \text{DA}_c(X)$ , using theorem 51 for closed embeddings, the following transformation map in  $D_{\text{fil}}((Y \times S)_{\mathbb{C}}^{an})$

$$\begin{aligned} T_!(f, \text{Bti})(M) : Rf_{!w} \text{Bti}_X^*(M, W) &= Rp_{S!w} l_* \text{Bti}_X^*(M, W) \\ &\xrightarrow{T_*(l, \text{Bti})(M, W)^{-1}} Rp_{S!w} \text{Bti}(Y \times S)^*(l_*(M, W)) \\ &\xrightarrow{\text{Bti}(Y \times S)^* \text{ad}(Lp_{S\sharp}, p_S^*)(l_*(M, W))} Rp_{S!w} \text{Bti}(Y \times S)^*(p_S^* Lp_{S\sharp} l_*(M, W)) \xrightarrow{T(p_S, \text{Bti})(p_{S\sharp} l_*(M, W))} \\ &Rp_{S!w} p_S^* \text{Bti}(Y \times S)^*(Lp_{S\sharp} l_*(M, W)) = Rp_{S!w} p_S^{!w} \text{Bti}(Y \times S)^*(Rf_!(M, W)) \\ &\xrightarrow{\text{ad}(Rp_{S!w}, p_S^{!w})(-)} \text{Bti}(Y \times S)^*(Rf_!(M, W)) \end{aligned}$$

Clearly, for  $f : X \rightarrow S$  a proper morphism, with  $X, S \in \text{Var}(k)$  we have, for  $M \in \text{DA}_c(Y \times S)$ ,  $T_!(f, \text{Bti})(M, W) = T_*(f, \text{Bti})(M, W)$ .

- Let  $f : X \rightarrow S$  a morphism with  $X, S \in \text{Var}(k)$ . We have, using the second point, for  $M \in \text{DA}(S)$ , the following transformation map in  $D_{\text{fil}}(X_{\mathbb{C}}^{an})$

$$\begin{aligned} T^!(f, \text{Bti})(M, W) : \text{Bti}_X^*(f^!(M, W)) &\xrightarrow{\text{ad}(f_!, Rf^!)(\text{Bti}_X^*(f^!(M, W)))} f^{!w} Rf_{!w} \text{Bti}_X^*(f^!(M, W)) \\ &\xrightarrow{T_!(f, \text{Bti})(f^!(M, W))} f^{!w} \text{Bti}_S^*(f_! f^!(M, W)) \xrightarrow{\text{Bti}_S^*(\text{ad}(f_!, f^!)(M, W))} f^{!w} \text{Bti}_S^*(M, W) \end{aligned}$$

- Let  $S \in \text{Var}(k)$ . We have, for  $M, N \in \text{DA}(S)$  and  $F, G \in C(\text{Var}(k)^{sm}/S)$  such that  $M = D(\mathbb{A}^1, \text{et})(F)$  and  $N = D(\mathbb{A}^1, \text{et})(G)$ , the following transformation map in  $D_{\text{fil}}(S_{\mathbb{C}}^{an})$

$$\begin{aligned} \text{Bti}_S^*(M, W) \otimes \text{Bti}_S^*(N, W) &:= (e(S)_* \underline{\text{sing}}_{\mathbb{D}^*} \text{An}_S^*(F, W)) \otimes (e(S)_* \underline{\text{sing}}_{\mathbb{D}^*} \text{An}_S^*(G, F)) \\ &\xrightarrow{T(\text{sing}_{D^*}, \otimes)(\text{An}_S^*(F, W), \text{An}_S^*(G, F))} e(S)_* \underline{\text{sing}}_{\mathbb{D}^*} \text{An}_S^*((F, W) \otimes (G, W)) =: \text{Bti}_S^*((M, W) \otimes (N, W)) \end{aligned}$$

**Theorem 51.** (i) Let  $f : X \rightarrow S$  a morphism, with  $X, S \in \text{Var}(k)$ . For  $M \in \text{DA}_c(S)$ ,

$$T(f, \text{Bti})(M, W) : f^{*w} \text{Bti}_S^*(M, W) \xrightarrow{\sim} \text{Bti}_X^* f^*(M, W)$$

is an isomorphism in  $D_{\text{fil}}(X_{\mathbb{C}}^{an})$ .

(ii) Let  $f : X \rightarrow S$  a morphism, with  $X, S \in \text{Var}(k)$ . For  $M \in \text{DA}_c(X)$ ,

$$T_!(f, \text{Bti})(M, W) : Rf_{!w} \text{Bti}_X^*(M, W) \xrightarrow{\sim} \text{Bti}_S^* Rf_!(M, W)$$

is an isomorphism.

(iii) Let  $f : X \rightarrow S$  a morphism, with  $X, S \in \text{Var}(k)$ . For  $M \in \text{DA}_c(X)$ ,

$$T_*(f, \text{Bti})(M, W) : Rf_{*w} \text{Bti}_X^*(M, W) \xrightarrow{\sim} \text{Bti}_S^* Rf_*(M, W)$$

is an isomorphism.

(iv) Let  $f : X \rightarrow S$  a morphism, with  $X, S \in \text{Var}(k)$ . For  $M \in \text{DA}_c(S)$ ,

$$T^!(f, \text{Bti})(M, W) : f^{!w} \text{Bti}_S^*(M, W) \xrightarrow{\sim} \text{Bti}_X^* f^!(M, W)$$

is an isomorphism.

(v) Let  $S \in \text{Var}(k)$ . For  $M, N \in \text{DA}_c(S)$ ,

$$T(\otimes, \text{Bti})(M, W) : \text{Bti}_S^*(M, W) \otimes \text{Bti}_S^* N \xrightarrow{\sim} \text{Bti}_X^*((M, W) \otimes (N, W))$$

is an isomorphism.

*Proof.* By functoriality it reduced to the case of Corti-Hanamura motives which is then obvious.  $\square$

The main result on the Betti realization functor is the following

**Theorem 52.** (i) We have  $\text{Bti}_S^* = \widetilde{\text{Bti}}_S^*$  on  $\text{DA}^-(S)$

(ii) The canonical transformations  $T(f, \text{Bti})$ , for  $f : T \rightarrow S$  a morphism in  $\text{Var}(k)$ , define a morphism of 2 functor

$$\text{Bti}_S^* : \text{DA}(\cdot) \rightarrow D((\cdot)_{\mathbb{C}}^{an}), S \in \text{Var}(k) \mapsto \text{Bti}_S^* : \text{DA}(S) \rightarrow D(S_{\mathbb{C}}^{an})$$

which is a morphism of homotopic 2 functor.

(ii)' The canonical transformations  $T(f, \text{Bti})$ , for  $f : T \rightarrow S$  a morphism in  $\text{Var}(k)$ , define a morphism of 2 functor

$$\text{Bti}_S^* : \text{DA}_c(\cdot) \rightarrow D_{fil}((\cdot)_{\mathbb{C}}^{an}), S \in \text{Var}(k) \mapsto \text{Bti}_S^* : \text{DA}(S) \rightarrow D_{fil}(S_{\mathbb{C}}^{an})$$

which is a morphism of homotopic 2 functor.

*Proof.* (i): See [9]

(ii) and (ii)': Follows from theorem 51.  $\square$

**Remark 11.** For  $X \in \text{Var}(k)$ , the quasi-isomorphisms

$$\mathbb{Z} \text{Hom}(\bar{\mathbb{D}}_{k_{et}}^{\bullet}, X) \xrightarrow{\text{An}^*} \mathbb{Z} \text{Hom}(\bar{\mathbb{D}}_{\mathbb{C}}^n(0, 1), X_{\mathbb{C}}^{an}) \xrightarrow{\text{Hom}(i, X_{\mathbb{C}}^{cw})} \mathbb{Z} \text{Hom}([0, 1]^n, X_{\mathbb{C}}^{cw}),$$

where,

$$\bar{\mathbb{D}}_{et}^n := (e : U \rightarrow \mathbb{A}_k^n, \bar{\mathbb{D}}^n(0, 1) \subset e(U)) \in \text{Fun}(\mathcal{V}_{\mathbb{A}_k^n}^{et}(\bar{\mathbb{D}}^n(0, 1)), \text{Var}(k))$$

is the system of etale neighborhood of the closed ball  $\bar{\mathbb{D}}_k^n(0, 1) \subset \mathbb{A}_k^n$ , and  $i : [0, 1]^n \hookrightarrow \bar{\mathbb{D}}_{\mathbb{C}}^n(0, 1)$  is the closed embedding, shows that a closed singular chain  $\alpha \in \mathbb{Z} \text{Hom}^n([0, 1]^n, X_{\mathbb{C}}^{cw})$ , is homologue to a closed singular chain

$$\beta = \alpha + \partial\gamma = \tilde{\beta}|_{[0, 1]^n} \in \mathbb{Z} \text{Hom}^n(\Delta^n, X_{\mathbb{C}}^{cw})$$

which is the restriction by the closed embedding  $[0, 1]^n \hookrightarrow U_{\mathbb{C}}^{cw} \xrightarrow{e} \mathbb{A}_{\mathbb{C}}^n$ , where  $e : U \rightarrow \mathbb{A}_k^n$  an etale morphism with  $U \in \text{Var}(k)$ , of a complex algebraic morphism  $\tilde{\beta} : U_{\mathbb{C}} \rightarrow X_{\mathbb{C}}$  defined over  $k$ . Hence  $\beta([0, 1]^n) = \tilde{\beta}([0, 1]^n) \subset X$  is the restriction of a real algebraic subset of dimension  $n$  in  $\text{Res}_{\mathbb{R}}(X)$  (after restriction a scalar that is under the identification  $\mathbb{C} \simeq \mathbb{R}^2$ ) defined over  $k$ .

### 8.1.2 The complex Hodge realization functor for relative motives over a subfield $k \subset \mathbb{C}$

Let  $k \subset \mathbb{C}$  a subfield.

Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i=1}^s S_i$  an open cover such that there exists closed embedding  $i_i : S \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Recall (see section 5.2) that  $D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})$  is the category

- whose set of objects is the set of triples  $\{((M_I, F, W), u_{IJ}), (K, W), \alpha\}$  with

$$\begin{aligned} ((M_I, F, W), u_{IJ}) &\in D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)), (K, W) \in D_{fil,c,k}(S_{\mathbb{C}}^{an}), \\ \alpha &: T(S/(\tilde{S}_I))(K, W) \otimes_{S_{\mathbb{C}}^{an}} \rightarrow DR(S)^{[-1]}(((M_I, W), u_{IJ})^{an}) \end{aligned}$$

where  $\alpha$  is an morphism in  $D_{fil}(S_{\mathbb{C}}^{an}/(\tilde{S}_{I,\mathbb{C}}^{an}))$ ,

- and whose set of morphisms consists of

$$\phi = (\phi_D, \phi_C, [\theta]) : (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2)$$

where  $\phi_D : ((M_1, F, W), u_{IJ}) \rightarrow ((M_2, F, W), u_{IJ})$  and  $\phi_C : (K_1, W) \rightarrow (K_2, W)$  are morphisms and

$$\begin{aligned} \theta &= (\theta^\bullet, I(DR(S)(\phi_D^{an})) \circ I(\alpha_1), I(\alpha_2) \circ I(\phi_C \otimes I)) : \\ &I(T(S/(\tilde{S}_I))(K_1, W)) \otimes \mathbb{C}_{S^{\text{gen}}}[1] \rightarrow I(DR(S)((M_{2I}, W), u_{IJ})^{an}) \end{aligned}$$

is an homotopy,  $I : D_{fil}(S_{\mathbb{C}}^{an}/(\tilde{S}_{I,\mathbb{C}}^{an})) \rightarrow K_{fil}(S_{\mathbb{C}}^{an}/(\tilde{S}_{I,\mathbb{C}}^{an}))$  being the injective resolution functor, and for

$$\begin{aligned} - \phi &= (\phi_D, \phi_C, [\theta]) : (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2) \\ - \phi' &= (\phi'_D, \phi'_C, [\theta']) : (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2) \rightarrow (((M_{3I}, F, W), u_{IJ}), (K_3, W), \alpha_3) \end{aligned}$$

the composition law is given by

$$\begin{aligned} \phi' \circ \phi &:= (\phi'_D \circ \phi_D, \phi'_C \circ \phi_C, I(DR(S)(\phi'_D{}^{an})) \circ [\theta] + [\theta'] \circ I(\phi_C \otimes I)[1]) : \\ &(((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_{3I}, F, W), u_{IJ}), (K_3, W), \alpha_3), \end{aligned}$$

in particular for  $(((M_I, F, W), u_{IJ}), (K, W), \alpha) \in D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})$ ,

$$I_{(((M_I, F, W), u_{IJ}), (K, W), \alpha)} = (I_{M_I}, I_K, 0),$$

together with the localization functor

$$\begin{aligned} (D(zar), I) : C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an}) &\rightarrow D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an}) \\ &\rightarrow D_{\mathcal{D}(1,0)fil,rh,\infty}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an}). \end{aligned}$$

Note that if  $\phi = (\phi_D, \phi_C, [\theta]) : (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2)$  is a morphism in  $D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})$  such that  $\phi_D$  and  $\phi_C$  are isomorphisms then  $\phi$  is an isomorphism (see remark 5). Moreover,

- For  $(((M_I, F, W), u_{IJ}), (K, W), \alpha) \in D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})$ , we set

$$(((M_I, F, W), u_{IJ}), (K, W), \alpha)[1] := (((M_I, F, W), u_{IJ})[1], (K, W)[1], \alpha[1]).$$

- For

$$\phi = (\phi_D, \phi_C, [\theta]) : (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2)$$

a morphism in  $D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})$ , we set (see [11] definition 3.12)

$$\text{Cone}(\phi) := (\text{Cone}(\phi_D), \text{Cone}(\phi_C), ((\alpha_1, \theta), (\alpha_2, 0))) \in D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an}),$$

$((\alpha_1, \theta), (\alpha_2, 0))$  being the matrix given by the composition law, together with the canonical maps

$$\begin{aligned} - c_1(-) &= (c_1(\phi_D), c_1(\phi_C), 0) : (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2) \rightarrow \text{Cone}(\phi) \\ - c_2(-) &= (c_2(\phi_D), c_2(\phi_C), 0) : \text{Cone}(\phi) \rightarrow (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1)[1]. \end{aligned}$$

Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i=1}^s S_i$  an open cover such that there exists closed embedding  $i_i : S \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Consider the category

$$(D_{\mathcal{D}(1,0)fil}(\tilde{S}_I) \times_I D_{fil,c,k}(\tilde{S}_{I,\mathbb{C}}^{an})) \subset \text{Fun}(\Gamma(\tilde{S}_I), \text{TriCat})$$

- whose objects are  $((M_I, F, W), (K_I, W), \alpha_I, u_{IJ}) \in \text{Fun}(\Gamma(\tilde{S}_I), \text{TriCat})$  such that

$$((M_I, F, W), (K_I, W), \alpha_I) \in D_{\mathcal{D}(1,0)fil}(\tilde{S}_I) \times_I D_{fil,c,k}(\tilde{S}_{I,\mathbb{C}}^{an}) =: \mathcal{D}(\tilde{S}_I)$$

and for  $I \subset J$ ,

$$u_{IJ} : ((M_I, F, W), (K_I, W), \alpha_I) \rightarrow p_{IJ*}((M_J, F, W), (K_J, W), \alpha_J) := (p_{IJ*}(M_J, F, W), p_{IJ*}(K_J, W), p_{IJ*}\alpha_J)$$

are morphisms in  $\mathcal{D}(\tilde{S}_I)$ ,

- whose morphisms  $m = (m_I) : (((M_I, F, W), (K_I, W), \alpha_I), u_{IJ}) \rightarrow (((M'_I, F, W), (K'_I, W), \alpha'_I), v_{IJ})$  is a family of morphism such that  $v_{IJ} \circ m_I = p_{IJ*}m_J \circ u_{IJ}$  in  $\mathcal{D}(\tilde{S}_I)$

We have then the identity functor

$$\begin{aligned} I_S : D_{\mathcal{D}(1,0)fil}(S/(\tilde{S}_I))^0 \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an}) &\rightarrow (D_{\mathcal{D}(1,0)fil}(\tilde{S}_I) \times_I D_{fil,c,k}(\tilde{S}_{I,\mathbb{C}}^{an})), \\ (((M_I, F, W), u_{IJ}), (K, W), \alpha) &\mapsto (((M_I, F, W), i_{I*}j_I^*(K, W), j_I^*\alpha), (u_{IJ}, I, 0)), \\ m = (m_I, n) &\mapsto m = (m_I, i_{I*}j_I^*n) \end{aligned}$$

which is a full embedding since for  $((M_I, F, W), u_{IJ}) \in D_{\mathcal{D}(1,0)fil}(S/(\tilde{S}_I))^0$ ,

$$u_{IJ} : (M_I, F, W) \rightarrow p_{IJ*}(M_J, F, W)$$

are isomorphisms in  $D_{\mathcal{D}(1,0)fil}(\tilde{S}_I)$ , and hence for  $((M_I, F, W), u_{IJ}), (K, W), \alpha \in D_{\mathcal{D}(1,0)fil}(S/(\tilde{S}_I))^0 \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})$ ,

$$\begin{aligned} (u_{IJ}, I, 0) : ((M_I, F, W), i_{I*}j_I^*(K, W), j_I^*\alpha) &\rightarrow \\ p_{IJ*}((M_J, F, W), i_{J*}j_J^*(K, W), j_J^*\alpha) &= (p_{IJ*}(M_J, F, W), i_{I*}j_I^*(K, W), j_I^*\alpha) \end{aligned}$$

are isomorphisms in  $\mathcal{D}(\tilde{S}_I)$ .

**Definition 115.** For  $h : U \rightarrow S$  a smooth morphism with  $S, U \in \text{SmVar}(k)$  and  $h : U \xrightarrow{n} X \xrightarrow{f} S$  a compactification of  $h$  with  $n$  an open embedding,  $X \in \text{SmVar}(k)$  such that  $D := X \setminus U = \cup_{i=1}^s D_i \subset X$  is a normal crossing divisor, we denote by, using definition 74 and definition 103

$$\begin{aligned} I(U/S) : h_{!Hdg} h^{!Hdg} \mathbb{Z}_S^{Hdg} &\xrightarrow{:=} \\ (p_{S*} E_{zar}(\Omega_{X \times S/S}^{\bullet} \otimes_{O_{X \times S}} (n \times I)_{!Hdg} \Gamma_U^{\vee, Hdg}(O_{U \times S}, F_b)), \mathbb{D}_S h_* E_{usu} \mathbb{Q}_{U_{\mathbb{C}}^{an}}, h_! \alpha(U, \delta)) & \\ \xrightarrow{((DR(X \times S/S)(\text{ad}((n \times I)_{!Hdg}, (n \times I)^*(-)), 0), I, 0))} & \\ (\text{Cone}((\Omega_{S/S}^{\Gamma, pr}(i_{D_i} \times I))_{i \in [1, \dots, s]} : p_{S*} E_{zar}(\Omega_{X \times S/S}^{\bullet} \otimes_{O_{X \times S}} \Gamma_X^{\vee, Hdg}(O_{X \times S}, F_b)) \rightarrow & \\ (\cdots \rightarrow (p_{S*} E_{zar}(\Omega_{D_i \times S/S}^{\bullet} \otimes_{O_{D_i \times S}} \Gamma_{D_i}^{\vee, Hdg}(O_{D_i \times S}, F_b))) \rightarrow \cdots)), \mathbb{D}_S h_* E_{usu} \mathbb{Z}_{U_{\mathbb{C}}^{an}}, h_! \alpha(U, \delta)) & \\ \xrightarrow{=} (\mathcal{F}_S^{FDR}(\mathbb{Z}(U/S)), \text{Bti}_S^* \mathbb{Z}(U/S), \alpha(\mathbb{Z}(U/S))) & \end{aligned}$$

the canonical isomorphism in  $D_{\mathcal{D}fil}(S) \times_I D_{c,k}(S_{\mathbb{C}}^{an})$ , where

- we recall that (see section 6.1)

$$h^{!Hdg} \mathbb{Z}_S^{Hdg} = (\Gamma_U^{\vee, Hdg}(O_{U \times S}, F_b), \mathbb{Z}_{U_{\mathbb{C}}^{an}}, \alpha(U)) \in HM_{gm,k,\mathbb{C}}(U),$$

- $i_{D_i} : D_i \hookrightarrow X$  are the closed embeddings,

- $\alpha(\mathbb{Z}(U/S)) := h_1\alpha(U, \delta) := T^w(h, \otimes)(-) \circ h_1\alpha(U, \delta)$  (see definition 66), with

$$\alpha(U, \delta) := (DR(U)(\Omega_{(U \times U/U)/(U/pt)}(\Gamma_U^{\vee, Hdg}(O_{U \times U}))))^{-1} \circ \alpha(U) : \\ \mathbb{C}_{U_{\mathbb{C}^n}} \rightarrow DR(U)((pU_*E_{zar}(\Omega_{U \times U/U}^{\bullet} \otimes_{O_{U \times U}} \Gamma_U^{\vee, Hdg}(O_{U \times U}))))^{an},$$

by the way we note that the following diagram in  $C(U_{\mathbb{C}^n})$  commutes

$$\begin{array}{ccc} \mathbb{C}_{U_{\mathbb{C}^n}} & \xrightarrow{\alpha(U)} & \Omega_{U_{\mathbb{C}^n}}^{\bullet} =: DR(U)(O_{U_{\mathbb{C}^n}}^{an}) \\ \text{ad}(\delta_U^*, \delta_{U^*})(-) \uparrow & & \uparrow DR(U)(\Omega_{(U \times U/U)/(U/pt)}(\Gamma_U^{\vee, Hdg}(O_{U \times U}))) \\ pU_*E_{usu}\Gamma_U^{\vee}\mathbb{C}_{U \times U_{\mathbb{C}^n}} & \xrightarrow{\alpha(U \times U)} & DR(U)((pU_*E_{zar}(\Omega_{U \times U/U}^{\bullet} \otimes_{O_{U \times U}} \Gamma_U^{\vee, Hdg}(O_{U \times U}))))^{an} \end{array}$$

**Lemma 9.** Let  $S \in \text{SmVar}(k)$ . Let  $g : U'/S \rightarrow U/S$  a morphism with  $U/S := (U, h), U'/S := (U', h) \in \text{Var}(k)^{sm}/S$ . Let  $h : U \xrightarrow{n} X \xrightarrow{f} S$  a compactification of  $h$  with  $n$  an open embedding,  $X \in \text{SmVar}(k)$  such that  $D := X \setminus U = \cup_{i=1}^s D_i \subset X$  is a normal crossing divisor, Let  $h' : U \xrightarrow{n'} X' \xrightarrow{f'} S$  a compactification of  $h'$  with  $n'$  an open embedding,  $X' \in \text{SmVar}(k)$  such that  $D' := X' \setminus U = \cup_{i=1}^s D_i \subset X'$  is a normal crossing divisor and such that  $g : U' \rightarrow U$  extend to  $\bar{g} : X' \rightarrow X$ , see definition-proposition 3. Then, using definition 115, the following diagram in  $D_{\mathcal{D}fil}(S) \times_I D(S_{\mathbb{C}^n}^{an})$  commutes

$$\begin{array}{ccc} h'_{!Hdg}h'^{!Hdg}\mathbb{Z}_S^{Hdg} & \xrightarrow{I(U'/S)} & (\mathcal{F}_S^{FDR}(\mathbb{Z}(U'/S)), \text{Bti}_S^* \mathbb{Z}(U'/S), \alpha(\mathbb{Z}(U'/S))) \\ \text{ad}(g_{!Hdg}, g^{!Hdg})(h'^{!Hdg}\mathbb{Z}_S^{Hdg}) \downarrow & & \downarrow (\Omega_S^{\Gamma, pr}(R_S^{CH}(g)), \text{Bti}_S^*(g), \theta(g)) \\ h_{!Hdg}h^{!Hdg}\mathbb{Z}_S^{Hdg} & \xrightarrow{I(U/S)} & (\mathcal{F}_S^{FDR}(\mathbb{Z}(U/S)), \text{Bti}_S^* \mathbb{Z}(U/S), \alpha(\mathbb{Z}(U/S))) \end{array}$$

where

$$\theta(g) := R_{\mathcal{D}}([\Gamma_g]) : I(\text{Bti}_S^* \mathbb{Z}(U'/S) \otimes \mathbb{C})[1] \rightarrow I(DR(S)(o_F \mathcal{F}_S^{FDR}(\mathbb{Z}(U/S))^{an}))$$

is the homotopy given by the third term of the Deligne homology class of the graph  $\Gamma_g \subset U' \times_S U$  (see definition 75) and  $o_F : C_{\mathcal{D}fil}(S) \rightarrow C_{\mathcal{D}}(S)$  is the forgetful functor and we recall (see section 6.1) that  $I : C(S_{\mathbb{C}^n}^{an}/\tilde{S}_{I, \mathbb{C}}^{an}) \rightarrow K(S_{\mathbb{C}^n}^{an}/\tilde{S}_{I, \mathbb{C}}^{an})$  is the injective resolution functor.

*Proof.* Immediate from definition.  $\square$

We now define the Hodge realization functor.

**Definition 116.** Let  $k \subset \mathbb{C}$  a subfield. Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i=1}^s S_i$  an open cover such that there exists closed embedding  $i_i : S \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . We define the Hodge realization functor, using definition 106, definition 112, and lemma 9

$$\mathcal{F}_S^{Hdg} := (\mathcal{F}_S^{FDR}, \text{Bti}_S^* \otimes \mathbb{Q}) : C(\text{Var}(k)^{sm}/S) \rightarrow D_{\mathcal{D}(1,0)fil}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}^n}^{an})$$

first on objects and then on morphisms :

- for  $F \in C(\text{Var}(k)^{sm}/S)$ , taking  $(F, W) \in C_{fil}(\text{Var}(k)^{sm}/S)$  such that  $D(\mathbb{A}^1, et)(F, W)$  gives the weight structure on  $D(\mathbb{A}^1, et)(F)$ ,

$$\begin{aligned} \mathcal{F}_S^{Hdg}(F) &:= (\mathcal{F}_S^{FDR}(F, W), \text{Bti}_S^*(F, W) \otimes \mathbb{Q}, \alpha(F)) := \\ &(e(S)_* \mathcal{H}om((\hat{R}_{\tilde{S}_I}^{CH}(\rho_{\tilde{S}_I}^* Li_{I^*} J_I^*(F, W)), \hat{R}^{CH}(T^q(D_{IJ})(-))), (E_{zar}(\Omega_{\tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR}), T_{IJ})), \\ &e(S)_* \underline{\text{sing}}_{\mathbb{D}}^* \text{An}_S^* L(F, W), \alpha(F)) \in D_{\mathcal{D}(1,0)fil}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}^n}^{an}) \end{aligned}$$

where  $\alpha(F)$  is the map in  $D_{fil}(S_{\mathbb{C}}^{an}/(\tilde{S}_{I,\mathbb{C}}^{an}))$ , writing for short  $DR(S) := DR(S)^{[-1]} := (DR(\tilde{S}_I)[-d_{\tilde{S}_I}])$

$$\begin{aligned} \alpha(F) &: T(S/(\tilde{S}_I))((\text{Bti}_S^*(M, W)) \otimes \mathbb{C}_{S_{\mathbb{C}}^{an}}) := (i_{I*}j_I^*((e(S) \ast \underline{\text{sing}}_{\mathbb{D}} \ast \text{An}_S^* L(F, W)) \otimes \mathbb{C}_S), I) \\ &\xrightarrow{=} (e(\tilde{S}_I) \ast \underline{\text{sing}}_{\mathbb{D}} \ast \text{An}_{\tilde{S}_I}^* Li_{I*}j_I^*(F, W) \otimes \mathbb{C}_{S_{\mathbb{C}}^{an}}, T(p_{IJ}, \text{An})(Li_{I*}j_I^*(F, W))) \\ &\xrightarrow{=} (((\cdot \rightarrow \oplus_{(U_{I\alpha}, h_{I\alpha}) \in V_I} h_{I\alpha}! h_{I\alpha}^! \mathbb{C}_{\tilde{S}_{I,\mathbb{C}}^{an}} \xrightarrow{\text{ad}(g_{I,\alpha,\beta}^!, g_{I,\alpha,\beta}^!)(-)} \oplus_{(U_{I\alpha}, h_{I\alpha}) \in V_I} h_{I\alpha}! h_{I\alpha}^! \mathbb{C}_{\tilde{S}_{I,\mathbb{C}}^{an}} \rightarrow \cdot), u_{IJ}), W) \\ &\xrightarrow{=} (((\cdot \rightarrow \oplus_{(U_{I\alpha}, h_{I\alpha}) \in V_I} h_{I\alpha}! h_{I\alpha}^! \mathbb{C}_{\tilde{S}_{I,\mathbb{C}}^{an}} \xrightarrow{\text{ad}(g_{I,\alpha,\beta}^!, g_{I,\alpha,\beta}^!)(-)} \oplus_{(U_{I\alpha}, h_{I\alpha}) \in V_I} h_{I\alpha}! h_{I\alpha}^! \mathbb{C}_{\tilde{S}_{I,\mathbb{C}}^{an}} \rightarrow \cdot), u_{IJ}), W) \\ &\xrightarrow{=} DR(S)_{(o_F(e(S) \ast \mathcal{H}om((\hat{R}_{\tilde{S}_I}^{CH}(\rho_{\tilde{S}_I}^* Li_{I*}j_I^*(F, W)), \hat{R}^{CH}(T^q(D_{IJ})(-))), (E_{zar}(\Omega_{\tilde{S}_I}^{\bullet, pr}, F_{DR}), T_{IJ})))^{an}} \\ &\xrightarrow{=} DR(S)_{((o_F \mathcal{F}_S^{FDR}(M, W))^{an})} \end{aligned}$$

with

$$\mathcal{F}_S^{DR}(M) := o_F \mathcal{F}_S^{FDR}(M) \in D_{\mathcal{D}0fil}(S/(\tilde{S}_I)),$$

where  $o_F : D_{\mathcal{D}(1,0)fil}(S/(\tilde{S}_I)) \rightarrow D_{\mathcal{D}0fil}(S/(\tilde{S}_I))$  is the forgetful functor, using lemma 9,

$$(\alpha(\mathbb{Z}(U_{I\alpha}/S)), \theta(g_{I,\alpha,\beta}^!))$$

being the matrix given inductively by the composition law in  $D_{\mathcal{D}(1,0)fil}(\tilde{S}_I) \times_I D_{fil,c,k}(\tilde{S}_{I,\mathbb{C}}^{an})$ , that is we have the following isomorphism in  $(D_{\mathcal{D}(1,0)fil}(\tilde{S}_I) \times_I D_{fil,c,k}(\tilde{S}_{I,\mathbb{C}}^{an}))$ , denoting for short  $V_I := \text{Var}(k)^{sm}/\tilde{S}_I$

$$\begin{aligned} (I^\bullet(U_{I\alpha}/\tilde{S}_I)) &: (((\cdot \rightarrow \oplus_{(U_{I\alpha}, h_{I\alpha}) \in V_I} h_{I\alpha}! Hdg h_{I\alpha}^! \mathbb{Q}_{\tilde{S}_I}^{Hdg} \xrightarrow{\text{ad}(g_{I,\alpha,\beta}^!, g_{I,\alpha,\beta}^!)(-)} \oplus_{(U_{I\alpha}, h_{I\alpha}) \in V_I} h_{I\alpha}! Hdg h_{I\alpha}^! \mathbb{Q}_{\tilde{S}_I}^{Hdg} \rightarrow \cdot), u_{IJ}), W) \\ &\xrightarrow{\sim} I_S(\mathcal{F}_S^{Hdg}(F) := (\mathcal{F}_S^{FDR}(F, W), \text{Bti}_{\tilde{S}_I}^* Li_{I*}j_I^*(F, W) \otimes \mathbb{Q}, \alpha(F))) \end{aligned}$$

where we denote by  $g_{I,\alpha,\beta}^n : U_{I\alpha} \rightarrow U_{I\beta}$  which satisfy  $h_{I\beta} \circ g_{I,\alpha,\beta}^n = h_{I\alpha}$  the morphisms in the canonical projective resolution

$$\begin{aligned} q : Li_{I*}j_I^*(F, W) &:= ((\cdots \rightarrow \oplus_{(U_{I\alpha}, h_{I\alpha}) \in \text{Var}(k)^{sm}/\tilde{S}_I} \mathbb{Z}(U_{I\alpha}/\tilde{S}_I) \xrightarrow{(\mathbb{Z}(g_{I,\alpha,\beta}^!))} \\ &\oplus_{(U_{I\alpha}, h_{I\alpha}) \in \text{Var}(k)^{sm}/\tilde{S}_I} \mathbb{Z}(U_{I\alpha}/\tilde{S}_I) \rightarrow \cdots), W) \rightarrow i_{I*}j_I^*(F, W), \end{aligned}$$

- for  $m : F_1 \rightarrow F_2$  a morphism in  $C(\text{Var}(k)^{sm}/S)$ , taking  $(F_1, W), (F_2, W) \in C_{fil}(\text{Var}(k)^{sm}/S)$  such that  $D(\mathbb{A}^1, et)(F_2, W)$  gives the weight structure on  $D(\mathbb{A}^1, et)(F_2)$   $D(\mathbb{A}^1, et)(F_1, W)$  gives the weight structure on  $D(\mathbb{A}^1, et)(F_1)$  and such that  $m : (F_1, W) \rightarrow (F_2, W)$  is a filtered morphism, the morphism  $\mathcal{F}_S^{Hdg}(m)$  in  $D_{\mathcal{D}(1,0)fil}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})$  is given by

$$\begin{aligned} \mathcal{F}_S^{Hdg}(m) &: = I_S^{-1, -1}((I^\bullet(U_{I\alpha}/(\tilde{S}_I))) \circ (\text{ad}(l_{I\alpha,\beta}^!, l_{I\alpha,\beta}^! Hdg)(\mathbb{Q}_{U_{I\alpha}}^{Hdg})) \circ (I^\bullet(U_{I\alpha}/(\tilde{S}_I)))^{-1}) \\ &= (\mathcal{F}_S^{FDR}(m), \text{Bti}_S^*(m) \otimes \mathbb{Q}, \theta(m) := (\theta(l_{I\alpha,\beta}))) : \mathcal{F}_S^{Hdg}(F_1) \rightarrow \mathcal{F}_S^{Hdg}(F_2) \end{aligned}$$

using lemma 9, that is we have the following commutative diagram in  $(D_{\mathcal{D}(1,0)fil}(\tilde{S}_I) \times_I D_{fil,c,k}(\tilde{S}_{I,\mathbb{C}}^{an}))$ , denoting for short  $V_I := \text{Var}(k)^{sm}/\tilde{S}_I$ ,

$$\begin{array}{ccc} (((\cdot \rightarrow \oplus_{(U_{I\alpha}, h_{I\alpha}) \in V_I} h_{I\alpha}! Hdg h_{I\alpha}^! \mathbb{Q}_{\tilde{S}_I}^{Hdg} \xrightarrow{A_{g_{I,\alpha,\beta}^!}^{Hdg}} \oplus_{(U_{I\alpha}, h_{I\alpha}) \in V_I} h_{I\alpha}! Hdg h_{I\alpha}^! \mathbb{Q}_{\tilde{S}_I}^{Hdg} \rightarrow \cdot), u_{IJ}), W) \xrightarrow{(I^\bullet(U_{I\alpha}/\tilde{S}_I))^{Hdg}} \mathcal{F}_S^{Hdg}(F_1) & & \\ \text{ad}(l_{I,\alpha,\beta}^!, l_{I,\alpha,\beta}^! Hdg)(-) \downarrow & & \mathcal{F}_S^{Hdg}(m) = (\mathcal{F}_S^{FDR}(m), \text{Bti}_S^*(m), (\theta(l_{I\alpha,\beta}))) \downarrow \\ (((\cdot \rightarrow \oplus_{(U_{I\alpha}, h_{I\alpha}) \in V_I} h_{I\alpha}! Hdg h_{I\alpha}^! \mathbb{Q}_{\tilde{S}_I}^{Hdg} \xrightarrow{A_{g_{2I,\alpha,\beta}^!}^{Hdg}} \oplus_{(U_{I\alpha}, h_{I\alpha}) \in V_I} h_{I\alpha}! Hdg h_{I\alpha}^! \mathbb{Q}_{\tilde{S}_I}^{Hdg} \rightarrow \cdot), u_{IJ}), W) \xrightarrow{(I^\bullet(U_{I\alpha}/\tilde{S}_I))^{Hdg}} \mathcal{F}_S^{Hdg}(F_2) & & \end{array}$$

where

- we denoted for short  $A_{g_{1I,\alpha,\beta}^{\bullet,Hdg}} := \text{ad}(g_{1I,\alpha,\beta}^{\bullet,Hdg}, g_{1I,\alpha,\beta}^{\bullet,Hdg})(h_{I\alpha}^{\bullet,Hdg} \mathbb{Z}_{\tilde{S}_I}^{Hdg})$
- we denoted for short  $A_{g_{2I,\alpha,\beta}^{\bullet,Hdg}} := \text{ad}(g_{2I,\alpha,\beta}^{\bullet,Hdg}, g_{2I,\alpha,\beta}^{\bullet,Hdg})(h_{I\alpha}^{\bullet,Hdg} \mathbb{Z}_{\tilde{S}_I}^{Hdg})$
- we denote by  $g_{1I,\alpha,\beta}^n : U_{I\alpha} \rightarrow U_{I\beta}$ , which satisfy  $h_{I\beta} \circ g_{1I,\alpha,\beta}^n = h_{I\alpha}$ , the morphisms in the canonical projective resolution

$$q : Li_{I*}j_I^*(F_1, W) := ((\cdots \rightarrow \bigoplus_{(U_{I\alpha}, h_{I\alpha}) \in \text{Var}(k)^{sm}/\tilde{S}_I} \mathbb{Z}(U_{I\alpha}/\tilde{S}_I) \xrightarrow{(\mathbb{Z}(g_{1I,\alpha,\beta}^n))} \bigoplus_{(U_{I\alpha}, h_{I\alpha}) \in \text{Var}(k)^{sm}/\tilde{S}_I} \mathbb{Z}(U_{I\alpha}/\tilde{S}_I) \rightarrow \cdots), W) \rightarrow i_{I*}j_I^*(F_1, W)$$

- we denote by  $g_{2I,\alpha,\beta}^n : U_{I\alpha} \rightarrow U_{I\beta}$ , which satisfy  $h_{I\beta} \circ g_{2I,\alpha,\beta}^n = h_{I\alpha}$ , the morphisms in the canonical projective resolution

$$q : Li_{I*}j_I^*(F_2, W) := ((\cdots \rightarrow \bigoplus_{(U_{I\alpha}, h_{I\alpha}) \in \text{Var}(k)^{sm}/\tilde{S}_I} \mathbb{Z}(U_{I\alpha}/\tilde{S}_I) \xrightarrow{(\mathbb{Z}(g_{2I,\alpha,\beta}^n))} \bigoplus_{(U_{I\alpha}, h_{I\alpha}) \in \text{Var}(k)^{sm}/\tilde{S}_I} \mathbb{Z}(U_{I\alpha}/\tilde{S}_I) \rightarrow \cdots), W) \rightarrow i_{I*}j_I^*(F_2, W)$$

- we denote by  $l_{I\alpha,\beta}^n : U_{I\alpha} \rightarrow U_{I\beta}$  which satisfy  $h_{I\beta} \circ l_{I\alpha,\beta}^n = h_{I\alpha}$  and  $l_{I\alpha,\beta}^{n+1} \circ g_{1I\alpha,\beta}^n = g_{2I\alpha,\beta}^n \circ l_{I\alpha,\beta}^n$ , the morphisms in the morphism of canonical projective resolutions

$$Li_{I*}j_I^*(m) : Li_{I*}j_I^*(F_1, W) := ((\cdots \rightarrow \bigoplus_{(U_{I\alpha}, h_{I\alpha}) \in \text{Var}(k)^{sm}/\tilde{S}_I} \mathbb{Z}(U_{I\alpha}/\tilde{S}_I) \rightarrow \cdots), W) \xrightarrow{(\mathbb{Z}(l_{I\alpha,\beta}^n))} ((\cdots \rightarrow \bigoplus_{(U_{I\alpha}, h_{I\alpha}) \in \text{Var}(k)^{sm}/\tilde{S}_I} \mathbb{Z}(U_{I\alpha}/\tilde{S}_I) \rightarrow \cdots), W) =: Li_{I*}j_I^*(F_2, W),$$

- the maps  $I^\bullet(U_{I\alpha})$  are given by definition 115 and lemma 9.

Obviously  $\mathcal{F}_S^{Hdg}(F[1]) = \mathcal{F}_S^{Hdg}(F)[1]$  and  $\mathcal{F}_S^{Hdg}(\text{Cone}(m)) = \text{Cone}(\mathcal{F}_S^{Hdg}(m))$ . This functor induces by proposition 62 and remark 5 the functor

$$\begin{aligned} \mathcal{F}_S^{Hdg} &:= (\mathcal{F}_S^{FDR}, \text{Bti}_S^* \otimes \mathbb{Q}) : \text{DA}(S) \rightarrow D_{\mathcal{D}(1,0)\text{fil}}(S/(\tilde{S}_I)) \times_I D_{\text{fil},c,k}(S_{\mathbb{C}}^{\text{an}}), \\ M = D(\mathbb{A}^1, \text{et})(F) &\mapsto \mathcal{F}_S^{Hdg}(M) := \mathcal{F}_S^{Hdg}(F) = (\mathcal{F}_S^{FDR}(M), \text{Bti}_S^* M \otimes \mathbb{Q}, \alpha(M)), \end{aligned}$$

with  $\alpha(M) = \alpha(F)$ .

We now give the functoriality with respect to the five operation using the De Rahm realization case and the Betti realization case :

**Proposition 71.** (i) Let  $g : T \rightarrow S$  a morphism with  $T, S \in \text{Var}(k)$ . Assume there exists a factorization  $g : T \xrightarrow{l} Y \times S \xrightarrow{p} S$ , with  $Y \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $p$  the projection. Let  $S = \cup_{i \in I} S_i$  an open cover and  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embeddings with  $\tilde{S}_i \in \text{SmVar}(k)$ . Then,  $\tilde{g}_I : Y \times \tilde{S}_I \rightarrow \tilde{S}_I$  is a lift of  $g_I = g|_{T_I} : T_I \rightarrow S_I$  and we have closed embeddings  $i'_I := i_I \circ l \circ j'_I : T_I \hookrightarrow Y \times \tilde{S}_I$ . Then, for  $M \in \text{DA}_c(S)$ , the following diagram commutes :

$$\begin{array}{ccc} g^{*w} \text{Bti}_S^* M \otimes \mathbb{C} & \xrightarrow{g^*(\alpha(M))} & DR(T)^{[-1]}((g_{Hdg}^{\text{mod}} \mathcal{F}_S^{DR}(M))^{\text{an}}) \\ \downarrow T(g, \text{bti})(M) & & \downarrow DR(T)^{[-1]}((T(g, \mathcal{F}^{FDR})(M))^{\text{an}}) \\ \text{Bti}_T^* g^* M \otimes \mathbb{C} & \xrightarrow{\alpha(g^* M)} & DR(T)^{[-1]}((\mathcal{F}_T^{DR}(g^* M))^{\text{an}}) \end{array},$$

see section 5, definition 110 and definition 113

(ii) Let  $f : T \rightarrow S$  a morphism with  $T, S \in \text{QPVar}(k)$ . Then, for  $M \in \text{DA}_c(T)$ , the following diagram commutes :

$$\begin{array}{ccc} Rf_{*w} \text{Bti}_T^* M \otimes \mathbb{C} & \xrightarrow{f_*(\alpha(M))} & DR(S)^{[-1]}((Rf_*^{Hdg} \mathcal{F}_T^{DR}(M))^{an}) \\ \uparrow T_*(f, \text{bti})(M) & & \uparrow DR(S)^{[-1]}((T_*(f, \mathcal{F}^{FDR})(M))^{an}) \\ \text{Bti}_S^* Rf_* M \otimes \mathbb{C} & \xrightarrow{\alpha(Rf_* M)} & DR(S)^{[-1]}((\mathcal{F}_S^{DR}(Rf_* M))^{an}) \end{array}$$

see section 5, definition 111 and definition 114

(iii) Let  $f : T \rightarrow S$  a morphism with  $T, S \in \text{QPVar}(k)$ . Then, for  $M \in \text{DA}_c(T)$ , the following diagram commutes :

$$\begin{array}{ccc} Rf_{!w} \text{Bti}_T^* M \otimes \mathbb{C} & \xrightarrow{f_!(\alpha(M))} & DR(S)^{[-1]}((Rf_!^{Hdg} \mathcal{F}_T^{DR}(M))^{an}) \\ \downarrow T_!(f, \text{bti})(M) & & \downarrow DR(S)^{[-1]}((T_!(f, \mathcal{F}_{DR})(M))^{an}) \\ \text{Bti}_S^* Rf_! M \otimes \mathbb{C} & \xrightarrow{\alpha(Rf_! M)} & DR(S)^{[-1]}((\mathcal{F}_{DR}^S(Rf_! M))^{an}) \end{array}$$

see section 5, definition 111 and definition 114.

(iv) Let  $f : T \rightarrow S$  a morphism with  $T, S \in \text{QPVar}(k)$ . Then, for  $M \in \text{DA}_c(S)$ , the following diagram commutes :

$$\begin{array}{ccc} f^{!w} \text{Bti}_S^* M \otimes \mathbb{C} & \xrightarrow{f^!(\alpha(M))} & DR(T)^{[-1]}((f^{*mod} \mathcal{F}_S^{DR}(M))^{an}) \\ \uparrow T^!(f, \text{bti})(M) & & \uparrow DR^{[-1]}(T)((T^!(g, \mathcal{F}^{FDR})(M))^{an}) \\ \text{Bti}_T^* f^! M \otimes \mathbb{C} & \xrightarrow{\alpha(f^! M)} & DR(T)^{[-1]}((\mathcal{F}_T^{DR}(f^! M))^{an}) \end{array}$$

see section 5, definition 111 and definition 114.

(v) Let  $S \in \text{Var}(k)$ . Then, for  $M, N \in \text{DA}_c(S)$ , the following diagram commutes :

$$\begin{array}{ccc} \text{Bti}_S^* M \otimes \text{Bti}_S^* N \otimes \mathbb{C} & \xrightarrow{\alpha(M) \otimes \alpha(N)} & DR(S)((\mathcal{F}_S^{DR}(M) \otimes_{O_S} \mathcal{F}_S^{DR}(N))^{an}) \\ \downarrow T(\otimes, \text{bti})(M, N) & & \downarrow DR(S)((T(\otimes, \mathcal{F}^{DR})(M, N))^{an}) \\ \text{Bti}_S^*(M \otimes N) \otimes \mathbb{C} & \xrightarrow{(\alpha(M \otimes N))} & DR(S)((\mathcal{F}_{DR}^S(M \otimes N))^{an}) \end{array}$$

see definition 111 and definition 114.

*Proof.* (i): Follows from the following commutative diagram in  $(D_{\mathcal{D}(1,0)fil}(Y \times \tilde{S}_I) \times_I D_{fil,c,k}(Y \times \tilde{S}_{I,\mathbb{C}}^{an}))$ ,

$$\begin{array}{ccc} (((\rightarrow \oplus_{(U_{I\alpha}, h_{I\alpha}) \in V_I} \tilde{g}_I^{*Hdg} h_{I\alpha!} Hdg h_{I\alpha}^{!Hdg} \mathbb{Z}_{\tilde{S}_I}^{Hdg} \xrightarrow{g_{I,\alpha,\beta}^{A^{Hdg}}} (g_{Hdg}^{*mod} \mathcal{F}_T^{FDR}(F), \\ \oplus_{(U_{I\alpha}, h_{I\alpha}) \in V_I} h_{I\alpha!} Hdg h_{I\alpha}^{!Hdg} \mathbb{Z}_{\tilde{S}_I}^{Hdg} \rightarrow), u_{IJ}), W) & \xrightarrow{(\tilde{g}_I^{*Hdg} I^\bullet(U_{I\alpha}/\tilde{S}_I))} & g^{*w} \text{Bti}_S^*(F, W), g^*(\alpha(F))) \\ \downarrow T^{Hdg}(\tilde{g}_I, h_{I\alpha})(-) & & \downarrow (T(g, \mathcal{F}^{FDR})(M), T(g, \text{Bti})(M), 0) \\ (((\rightarrow \oplus_{(U'_{I\alpha}, h'_{I\alpha}) \in W_I} h'_{I\alpha!} Hdg h'_{I\alpha}^{!Hdg} \mathbb{Z}_{Y \times \tilde{S}_I}^{Hdg} \xrightarrow{g'_{I,\alpha,\beta}^{A^{Hdg}}} (\mathcal{F}_T^{FDR}(g^*F), \\ \oplus_{(U'_{I\alpha}, h'_{I\alpha}) \in W_I} h'_{I\alpha!} Hdg h'_{I\alpha}^{!Hdg} \mathbb{Z}_{Y \times \tilde{S}_I}^{Hdg} \rightarrow), u_{IJ}), W) & \xrightarrow{(I^\bullet(U'_\alpha/Y \times \tilde{S}_I))} & \text{Bti}_T^*(g^*F, W), \alpha(g^*F)) \end{array}$$

where, we have denoted for short  $V_I := \text{Var}(k)^{sm}/\tilde{S}_I$  and  $W_I := \text{Var}(k)^{sm}/Y \times \tilde{S}_I$ ,



- we denoted for short  $A_{g_{I,\alpha,\beta}^{\bullet,Hdg}} := \text{ad}(g_{I,\alpha,\beta}^{\bullet,Hdg}, g_{I,\alpha,\beta}^{\bullet,Hdg})(h_{I\alpha}^{\text{Hdg}} \mathbb{Z}_{\tilde{S}_I}^{\text{Hdg}})$
- we denoted for short  $A_{g'_{I,\alpha,\beta}^{\bullet,Hdg}} := \text{ad}(g'_{I,\alpha,\beta}^{\bullet,Hdg}, g'_{I,\alpha,\beta}^{\bullet,Hdg})(h_{I\alpha}^{\text{Hdg}} \mathbb{Z}_{Y \times \tilde{S}_I}^{\text{Hdg}})$
- we denote by  $g_{I,\alpha,\beta}^n : U_{I\alpha} \rightarrow U_{I\beta}$ , which satisfy  $h_{I\beta} \circ g_{I,\alpha,\beta}^n = h_{I\alpha}$ , the morphisms in the canonical projective resolution

$$q : Li_{I*} j_I^*(F, W) := (\cdots \rightarrow \bigoplus_{(U_{I\alpha}, h_{I\alpha}) \in \text{Var}(k)^{sm}/\tilde{S}_I} \mathbb{Z}(U_{I\alpha}/\tilde{S}_I) \xrightarrow{(\mathbb{Z}(g_{I,\alpha,\beta}^{\bullet}))} \bigoplus_{(U_{I\alpha}, h_{I\alpha}) \in \text{Var}(k)^{sm}/\tilde{S}_I} \mathbb{Z}(U_{I\alpha}/\tilde{S}_I) \rightarrow \cdots) \rightarrow i_{I*} j_I^*(F, W)$$

- we denote by  $g'_{I,\alpha,\beta} : U'_{I\alpha} \rightarrow U'_{I\beta}$ , which satisfy  $h'_{I\beta} \circ g'_{I,\alpha,\beta} = h'_{I\alpha}$ , the morphisms in the canonical projective resolution

$$q : Li'_{I*} j_I^*(g^*F, W) := (\cdots \rightarrow \bigoplus_{(U'_{I\alpha}, h'_{I\alpha}) \in \text{Var}(k)^{sm}/Y \times \tilde{S}_I} \mathbb{Z}(U'_{I\alpha}/Y \times \tilde{S}_I) \xrightarrow{(\mathbb{Z}(g'_{I,\alpha,\beta}^{\bullet}))} \bigoplus_{(U'_{I\alpha}, h'_{I\alpha}) \in \text{Var}(k)^{sm}/Y \times \tilde{S}_I} \mathbb{Z}(U'_{I\alpha}/Y \times \tilde{S}_I) \rightarrow \cdots) \rightarrow i'_{I*} j_I^*(g^*F, W)$$

(ii): Follows from (i) by adjonction.

(iii): The closed embedding case is given by (ii) and the smooth projection case follows from (i) by adjonction.

(iv): Follows from (iii) by adjonction.

(v): Obvious

□

We can now state the following key proposition and the main theorem:

**Proposition 72.** *Let  $k \subset \mathbb{C}$  a subfield.*

(i) *Let  $S \in \text{Var}(k)$ . Let  $S = \cup_i S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Then we have the isomorphism in  $D_{\mathcal{D}(1,0)fil}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})$*

$$\begin{aligned} \mathcal{F}_S^{\text{Hdg}}(\mathbb{Z}_S) &\xrightarrow{\cong} (\mathcal{F}_S^{\text{FDR}}(\mathbb{Z}_S, W), \text{Bti}_S^*(\mathbb{Z}_S, W) \otimes \mathbb{Q}, \alpha(\mathbb{Z}_S)) \\ &\xrightarrow{((\Omega_{\tilde{S}_I}^{\Gamma, pr}(\hat{R}^{CH}(\text{ad}(i_i^*, i_{I*}))(\Gamma_{\tilde{S}_I}^{\vee, w} \mathbb{Z}_{\tilde{S}_I}))))_{I,0}} \\ I_S^{-, -1}((e(S)_* \text{Hom}((\hat{R}^{CH}(\Gamma_{\tilde{S}_I}^{\vee, w} \mathbb{Z}_{\tilde{S}_I}), \hat{R}^{CH}(x_{IJ})), (E_{zar}(\Omega_{\tilde{S}_I}^{\Gamma, pr}, F_{DR}), T_{IJ})), T(S/(\tilde{S}_I))(\mathbb{Q}_{S_{\mathbb{C}}^{an}}^w), \Gamma_{\tilde{S}_I}^{\vee, w} \alpha(\tilde{S}_I, \delta))) & \\ &\xrightarrow{\cong} \iota_S((\Gamma_{\tilde{S}_I}^{\vee, \text{Hdg}}(O_{\tilde{S}_I}, F_b), x_{IJ}), \mathbb{Q}_{S_{\mathbb{C}}^{an}}^w, \alpha(S)) =: \iota_S(\mathbb{Q}_S^{\text{Hdg}}) \end{aligned}$$

with (see section 6.1)  $j_I^* \mathbb{Q}_{S_{\mathbb{C}}^{an}}^w = i_I^* \Gamma_{\tilde{S}_I}^{\vee, w} \mathbb{Q}_{\tilde{S}_I}$  and

$$\alpha(S) : T(S/(\tilde{S}_I))(\mathbb{Q}_{S_{\mathbb{C}}^{an}}^w) \otimes \mathbb{C}_{S_{\mathbb{C}}^{an}} \xrightarrow{\cong} (\Gamma_{\tilde{S}_I}^{\vee, w} \mathbb{C}_{\tilde{S}_I, c}^{\vee, w}, t_{IJ}) \xrightarrow{(\Gamma_{\tilde{S}_I}^{\vee} \alpha(\tilde{S}_I))} DR(S)(o_F(\Gamma_{\tilde{S}_I}^{\vee, \text{Hdg}}(O_{\tilde{S}_I}, F_b), x_{IJ}))$$

(ii) *Let  $f : X \rightarrow S$  a morphism with  $X, S \in \text{Var}(k)$ ,  $X$  quasi-projective. Consider a factorization  $f : X \xrightarrow{l} Y \times S \xrightarrow{ps} S$  with  $Y = \mathbb{P}^{N,o} \subset \mathbb{P}^N$  an open subset,  $l$  a closed embedding and  $ps$  the projection. Let  $S = \cup_i S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(\mathbb{C})$ . Recall that  $S_I := \cap_{i \in I} S_i$ ,  $X_I = f^{-1}(S_I)$ , and  $\tilde{S}_I := \prod_{i \in I} \tilde{S}_i$ . Then, using proposition 71(iii), the maps of definition 111 and definition 114 gives an isomorphism in  $D_{\mathcal{D}(1,0)fil}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})$*

$$\begin{aligned} &(T_I(f, \mathcal{F}^{\text{FDR}})(\mathbb{Z}_X, W), T_I(f, \text{Bti})(\mathbb{Z}_X, W), 0) : \\ &\mathcal{F}_S^{\text{Hdg}}(M^{BM}(X/S)) := (\mathcal{F}_S^{\text{FDR}}(Rf_I(\mathbb{Z}_X, W)), \text{Bti}_S^* Rf_I(\mathbb{Z}_X, W) \otimes \mathbb{Q}, \alpha(Rf_I \mathbb{Z}_X)) \\ &\xrightarrow{\cong} (Rf_{Hdg!}(\Gamma_{X_I}^{\vee, \text{Hdg}}(O_{Y \times \tilde{S}_I}, F_b), x_{IJ}(X/S)), Rf_{!w} \mathbb{Q}_{X_{\mathbb{C}}^{an}}^w, f_I(\alpha(X))) =: \iota_S(Rf_{!Hdg} \mathbb{Q}_X^{\text{Hdg}}). \end{aligned}$$

with

$$\mathbb{Q}_X^{Hdg} := ((\Gamma_{X_I}^{\vee, Hdg}(O_{Y \times \tilde{S}_I}, F_b), x_{IJ}(X/Y \times S)), \mathbb{Q}_{X_{\mathbb{C}}}^w, \alpha(X)) \in C(MHM_{gm,k,\mathbb{C}}(X))$$

*Proof.* (i): Follows from proposition 62.

(ii): Follows from (i) by proposition 71(iii), theorem 50(i) and theorem 51(i).  $\square$

The main theorem of this section is the following :

**Theorem 53.** *Let  $k \subset \mathbb{C}$  a subfield.*

(i) *For  $S \in \text{Var}(k)$ , we have  $\mathcal{F}_S^{Hdg}(\text{DA}_c(S)) \subset D(MHM_{gm,k,\mathbb{C}}(S))$ ,*

$$\iota_S : D(MHM_{gm,k,\mathbb{C}}(S)) \hookrightarrow D_{\mathcal{D}(1,0)fil}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S_{\mathbb{C}}^{an})$$

*being a full embedding by theorem 41.*

(ii) *The Hodge realization functor  $\mathcal{F}_{Hdg}(-)$  define a morphism of 2-functor on  $\text{Var}(k)$*

$$\mathcal{F}_-^{Hdg} : \text{Var}(k) \rightarrow (\text{DA}_c(-) \rightarrow D(MHM_{gm,k,\mathbb{C}}(-)))$$

*whose restriction to  $\text{QPVar}(k)$  is an homotopic 2-functor in sense of Ayoub. More precisely,*

(ii0) *for  $g : T \rightarrow S$  a morphism, with  $T, S \in \text{QPVar}(k)$ , and  $M \in \text{DA}_c(S)$ , the the maps of definition 110 and of definition 113 induce an isomorphism in  $D(MHM_{gm,k,\mathbb{C}}(T))$*

$$\begin{aligned} T(g, \mathcal{F}^{Hdg})(M) &:= (T(g, \mathcal{F}^{FDR})(M), T(g, bti)(M), 0) : \\ g^{\hat{*}Hdg} \mathcal{F}_S^{Hdg}(M) &:= \iota_T^{-1}(g_{Hdg}^{\hat{*}mod} \mathcal{F}_S^{FDR}(M), g^* \text{Bti}_S(M) \otimes \mathbb{Q}, g^*(\alpha(M))) \\ &\xrightarrow{\sim} \iota_T^{-1}(\mathcal{F}_T^{FDR}(g^*M), \text{Bti}_T^*(g^*M) \otimes \mathbb{Q}, \alpha(g^*M)) =: \mathcal{F}_T^{Hdg}(g^*M), \end{aligned}$$

(ii1) *for  $f : T \rightarrow S$  a morphism, with  $T, S \in \text{QPVar}(k)$ , and  $M \in \text{DA}_c(T)$ , the maps of definition 111 and of definition 114 induce an isomorphism in  $D(MHM_{gm,k,\mathbb{C}}(S))$*

$$\begin{aligned} T_*(f, \mathcal{F}^{Hdg})(M) &:= (T_*(f, \mathcal{F}^{FDR})(M), T_*(f, bti)(M), 0) : \\ Rf_{Hdg*} \mathcal{F}_T^{Hdg}(M) &:= \iota_S^{-1}(Rf_*^{Hdg} \mathcal{F}_T^{FDR}(M), Rf_* \text{Bti}_T(M) \otimes \mathbb{Q}, f_*(\alpha(M))) \\ &\xrightarrow{\sim} \iota_S^{-1}(\mathcal{F}_S^{FDR}(Rf_*M), \text{Bti}_S^*(Rf_*M) \otimes \mathbb{Q}, \alpha(Rf_*M)) =: \mathcal{F}_S^{Hdg}(Rf_*M), \end{aligned}$$

(ii2) *for  $f : T \rightarrow S$  a morphism, with  $T, S \in \text{QPVar}(k)$ , and  $M \in \text{DA}_c(T)$ , the maps of definition 111 and of definition 114 induce an isomorphism in  $D(MHM_{gm,k,\mathbb{C}}(S))$*

$$\begin{aligned} T_!(f, \mathcal{F}^{Hdg})(M) &:= (T_!(f, \mathcal{F}^{FDR})(M), T_!(f, bti)(M), 0) : \\ Rf_{!Hdg} \mathcal{F}_T^{Hdg}(M) &:= \iota_S^{-1}(Rf_{!}^{Hdg} \mathcal{F}_T^{FDR}(M), Rf_{!} \text{Bti}_T^*(M) \otimes \mathbb{Q}, f_!(\alpha(M))) \\ &\xrightarrow{\sim} \iota_S^{-1}(\mathcal{F}_S^{FDR}(Rf_{!}M), \text{Bti}_S^*(Rf_{!}M) \otimes \mathbb{Q}, \alpha(f_{!}M)) =: \mathcal{F}_S^{Hdg}(Rf_{!}M), \end{aligned}$$

(ii3) *for  $f : T \rightarrow S$  a morphism, with  $T, S \in \text{QPVar}(k)$ , and  $M \in \text{DA}_c(S)$ , the maps of definition 111 and of definition 114 induce an isomorphism in  $D(MHM_{gm,k,\mathbb{C}}(T))$*

$$\begin{aligned} T^1(f, \mathcal{F}^{Hdg})(M) &:= (T^1(f, \mathcal{F}^{FDR})(M), T^1(f, bti)(M), 0) : \\ f^{*Hdg} \mathcal{F}_S^{Hdg}(M) &:= \iota_T^{-1}(f_{Hdg}^{*mod} \mathcal{F}_S^{FDR}(M), f^! \text{Bti}_S(M) \otimes \mathbb{Q}, f^!(\alpha(M))) \\ &\xrightarrow{\sim} \iota_T^{-1}(\mathcal{F}_T^{FDR}(f^!M), \text{Bti}_T^*(f^!M) \otimes \mathbb{Q}, \alpha(f^!M)) =: \mathcal{F}_T^{Hdg}(f^!M), \end{aligned}$$

(ii4) for  $S \in \text{Var}(k)$ , and  $M, N \in \text{DA}_c(S)$ , the maps of definition 111 and of definition 114 induce an isomorphism in  $D(\text{MHM}_{gm,k,\mathbb{C}}(S))$

$$\begin{aligned} T(\otimes, \mathcal{F}^{Hdg})(M, N) &:= (T(\otimes, \mathcal{F}_S^{FDR})(M, N), T(\otimes, \text{bti})(M, N), 0) : \\ \iota_S^{-1}(\mathcal{F}_S^{FDR}(M) \otimes_{O_S}^{Hdg} \mathcal{F}_S^{FDR}(N), \text{Bti}_S(M) \otimes \text{Bti}_S(N) \otimes \mathbb{Q}, \alpha(M) \otimes \alpha(N)) \\ &\xrightarrow{\sim} \mathcal{F}_S^{Hdg}(M \otimes N) := \iota_S^{-1}(\mathcal{F}_S^{FDR}(M \otimes N), \text{Bti}_S(M \otimes N) \otimes \mathbb{Q}, \alpha(M \otimes N)). \end{aligned}$$

(iii) For  $S \in \text{Var}(k)$ , the following diagram commutes :

$$\begin{array}{ccc} \text{Var}(k)/S & \xrightarrow{\text{MH}/S} & D(\text{MHM}_{gm,k,\mathbb{C}}(S)) \\ M(S) \downarrow & & \downarrow \iota^S \\ \text{DA}(S) & \xrightarrow{\mathcal{F}_S^{Hdg}} & D_{\mathcal{D}(1,0)\text{fil}}(S/(\tilde{S}_I)) \times_I D_{\text{fil},c,k}(S_{\mathbb{C}}^{an}) \end{array}$$

*Proof.* (i): Let  $M \in \text{DA}_c(S)$ . There exist by definition of constructible motives an isomorphism in  $\text{DA}(S)$

$$w(M) : M \xrightarrow{\sim} \text{Cone}(M(X_0/S)[d_0] \xrightarrow{m_1} \dots \xrightarrow{m_m} M(X_m/S)[d_m]),$$

with  $f_n : X_n \rightarrow S$  morphisms and  $X_n \in \text{QPVar}(k)$ . This gives the isomorphism in  $D_{\mathcal{D}(1,0)\text{fil}}(S/(\tilde{S}_I)) \times_I D_{\text{fil},c,k}(S_{\mathbb{C}}^{an})$

$$\mathcal{F}_S^{Hdg}(w(M)) : \mathcal{F}_S^{Hdg}(M) \xrightarrow{\sim} \text{Cone}(\mathcal{F}_S^{Hdg}(M(X_0/S))[d_0] \xrightarrow{\mathcal{F}_S^{Hdg}(m_1)} \dots \xrightarrow{\mathcal{F}_S^{Hdg}(m_m)} \mathcal{F}_S^{Hdg}(M(X_m/S))[d_m]),$$

On the other hand, by proposition 72(i), we have

$$\mathcal{F}_S^{Hdg}(M(X_n/S)) \xrightarrow{\sim} Rf_{1Hdg} \mathbb{Q}_X^{Hdg} \in D(\text{MHM}_{gm,k,\mathbb{C}}(S)).$$

This prove (i).

(ii0): Follows from theorem 50(i), proposition 71(i) and theorem 51.

(ii1): Follows from theorem 50(iii), proposition 71(ii), and theorem 51(iii).

(ii2): Follows from theorem 50(ii), proposition 71(iii), and theorem 51(ii).

(ii3): Follows from theorem 50(iv), proposition 71(iv), and theorem 51(iv).

(ii4): Follows from theorem 50(v), proposition 71(v) and theorem 51(v).

(iii): By (ii), for  $g : X'/S \rightarrow X/S$  a morphism, with  $X', X, S \in \text{Var}(k)$  and  $X/S = (X, f)$ ,  $X'/S = (X', f')$ , we have by adjonction the following commutative diagram

$$\begin{array}{ccc} \mathcal{F}_S^{Hdg}(M(X'/S) = f'_! f'^! \mathbb{Z}_S = f_! g_! g'^! f'^! \mathbb{Z}_S) & \xrightarrow{\mathcal{F}_S^{Hdg}(M(X/S) = f_! \text{ad}(g, g^1)(f^! \mathbb{Z}_S))} & \mathcal{F}_S^{Hdg}(M(X/S) = f_! f^! \mathbb{Z}_S) \\ \downarrow T_1(f', \mathcal{F}_S^{Hdg})(f'^! M(X'/S)) \circ T^1(f', \mathcal{F}_S^{Hdg})(M(X'/S)) & & \downarrow T_1(f, \mathcal{F}_S^{Hdg})(f^! M(X/S)) \circ T^1(f, \mathcal{F}_S^{Hdg})(M(X/S)) \\ \text{MH}(X'/S) := Rf'_{!Hdg} f'^! Hdg \mathbb{Z}_S^{Hdg} = f_{!Hdg} g_! Hdg g'^! Hdg \mathbb{Z}_S^{Hdg} & \xrightarrow{f_{!Hdg} \text{ad}(g, g^1) f'^! Hdg \mathbb{Z}_S^{Hdg}} & \text{MH}(X/S) := f_{!Hdg} f^! Hdg \mathbb{Z}_S^{Hdg} \end{array}$$

where the left and right columns are isomorphisms by (ii). This proves (iii).  $\square$

The theorem 53 gives immediately the following :

**Corollary 5.** *Let  $k \subset \mathbb{C}$  a subfield. Let  $f : U \rightarrow S$ ,  $f' : U' \rightarrow S$  morphisms, with  $U, U', S \in \text{Var}(k)$  irreducible,  $U'$  smooth. Let  $\tilde{S} \in \text{PVar}(k)$  a compactification of  $S$ . Let  $\tilde{X}, \tilde{X}' \in \text{PVar}(k)$  compactification of  $U$  and  $U'$  respectively, such that  $f$  (resp.  $f'$ ) extend to a morphism  $\tilde{f} : \tilde{X} \rightarrow \tilde{S}$ , resp.  $\tilde{f}' : \tilde{X}' \rightarrow \tilde{S}$ . Denote  $\bar{D} = \tilde{X} \setminus U$  and  $\bar{D}' = \tilde{X}' \setminus U'$  and  $\bar{E} = (\bar{D} \times_{\tilde{S}} \tilde{X}') \cup (\tilde{X} \times_{\tilde{S}} \bar{D}')$ . Denote  $i : \bar{D} \hookrightarrow \tilde{X}$ ,  $i' : \bar{D}' \hookrightarrow \tilde{X}'$*

denote the closed embeddings and  $j : U \hookrightarrow \bar{X}$ ,  $j' : U' \hookrightarrow \bar{X}'$  the open embeddings. Denote  $d = \dim(U)$  and  $d' = \dim(U')$ . We have the following commutative diagram in  $D(\mathbb{Z})$

$$\begin{array}{ccc}
RHom_{\mathbf{DA}(\bar{S})}^{\bullet}(M(U'/\bar{S}), M((\bar{X}, \bar{D})/\bar{S})) & \xrightarrow{\mathcal{F}_S^{Hdg(-,-)}} & RHom_{\mathbf{DMHM}(\bar{S})}^{\bullet}(f'_{!Hdg}\mathbb{Z}_{U'}^{Hdg}, f_{*Hdg}\mathbb{Z}_U^{Hdg}) \\
\downarrow RI(-,-) & & \downarrow RI(-,-) \\
RHom^{\bullet}(M(\text{pt}), M(\bar{X}' \times_{\bar{S}} \bar{X}, \bar{E})(d')[2d']) & \xrightarrow{\mathcal{F}_{Hdg}^{pt}(-,-)} & RHom^{\bullet}(\mathbb{Z}_{\text{pt}}^{Hdg}, a_{U' \times_S U}! \mathbb{Z}_{U' \times_S U}^{Hdg}(d')[2d']) \\
\downarrow l & & \downarrow l \\
\mathcal{Z}_d(\bar{X}' \times_{\bar{S}} \bar{X}, E, \bullet) & \xrightarrow{\mathcal{R}_{\bar{X}' \times_{\bar{S}} \bar{X}}^d} & C_{2d+\bullet}^{\mathcal{D}}(\bar{X}' \times_{\bar{S}} \bar{X}, E, Z(d))
\end{array}$$

where

$$M((\bar{X}, \bar{D})/\bar{S}) := \text{Cone}(\text{ad}(i_*, i^!) : M(\bar{D}/\bar{S}) \rightarrow M(\bar{X}/\bar{S})) = \bar{f}_* j_* E_{et}(\mathbb{Z}(U/U)) \in \mathbf{DA}(\bar{S})$$

and  $l$  the isomorphisms given by canonical embedding of complexes.

*Proof.* The upper square of this diagram follows from theorem 53(ii). On the other side, the lower square follows from the absolute case.  $\square$

## 8.2 The $p$ adic Hodge realization functor for relative motives over a subfield $k \subset \mathbb{C}_p$

Let  $p$  a prime number. Let  $k \subset \mathbb{C}_p$  a subfield.

For  $S \in \text{Var}(k)$ , we have the analytical functor

$$\text{an}_S^{*mod} : C_{\mathcal{D}}(S) \rightarrow C_{D(O_{S_{\mathbb{C}_p}^{an}})}(S_{\mathbb{C}_p}^{an, pet}), M \mapsto M^{an} := \text{an}_S^{*mod} M$$

given by the morphism of ringed topological spaces  $\text{an}_S : S_{\mathbb{C}_p}^{an} \rightarrow S$ . For  $S \in \text{Var}(k)$ , we denote by for short  $O_{\mathbb{B}_{dr, S}} := O_{\mathbb{B}_{dr, S_{\mathbb{C}_p}^{an}}} := O_{\mathbb{B}_{dr, R_{\mathbb{C}_p}}(S_{\mathbb{C}_p}^{an})}$ . where  $R_{\mathbb{C}_p} : \text{AnSp}(\mathbb{C}_p) \rightarrow \text{AdSp}/(\mathbb{C}_p, O_{\mathbb{C}_p})$  is the canonical functor (see section 2). For  $\mathcal{S} \in \text{Cat}$  a site,  $p$  a prime number and  $K \in C(\mathcal{S})$ , we consider  $K \otimes \mathbb{Z}_p := (K \otimes \mathbb{Z}/p^n \mathbb{Z})_{n \in \mathbb{N}}$ .

Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i \in I} S_i$  an open cover such that there exists closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . We have the category  $D_{\mathcal{D}(1,0)fil, rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil, c, k}(S^{et})$

- whose set of objects is the set of triples  $\{((M_I, F, W), u_{IJ}), (K, W), \alpha\}$  with

$$\begin{aligned}
& ((M_I, F, W), u_{IJ}) \in D_{\mathcal{D}(1,0)fil, rh}(S/(\tilde{S}_I)), (K, W) \in D_{\mathbb{Z}_p fil, c, k}(S^{et}), \\
& \alpha : \mathbb{B}_{dr, (\tilde{S}_I)}(K, W) \rightarrow F^0 DR(S)^{[-1]}(((M_I, F, W), u_{IJ})^{an} \otimes_{O_S} ((O_{\mathbb{B}_{dr, \tilde{S}_I}}(F), t_{IJ}))
\end{aligned}$$

where  $\alpha$  is a morphism in  $D_{\mathbb{B}_{dr, G, fil}}(S_{\mathbb{C}_p}^{an, pet}/(\tilde{S}_{I, \mathbb{C}_p}^{an, pet}))$ ,

- and whose set of morphisms consists of

$$\phi = (\phi_D, \phi_C, [\theta]) : (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2)$$

where  $\phi_D : ((M_1, F, W), u_{IJ}) \rightarrow ((M_2, F, W), u_{IJ})$  and  $\phi_C : (K_1, W) \rightarrow (K_2, W)$  are morphisms and

$$\begin{aligned}
& \theta = (\theta^{\bullet}, I(DR(S)(\phi_D^{an}) \times I) \circ I(\alpha_1), I(\alpha_2) \circ I(\mathbb{B}_{dr, (\tilde{S}_I)}(\phi_C \otimes I))) : \\
& I(\mathbb{B}_{dr, (\tilde{S}_I)}(K_1, W))[1] \rightarrow I(F^0 DR(S)((M_{2I}, F, W), u_{IJ})^{an} \otimes_{O_S} ((O_{\mathbb{B}_{dr, \tilde{S}_I}}(F), t_{IJ}))
\end{aligned}$$

is an homotopy,  $I : D_{\mathbb{B}_{dr, G, fil}}(S_{\mathbb{C}_p}^{an, pet}/(\tilde{S}_{I, \mathbb{C}_p}^{an, pet})) \rightarrow K_{\mathbb{B}_{dr, G, fil}}(S_{\mathbb{C}_p}^{an, pet}/(\tilde{S}_{I, \mathbb{C}_p}^{an, pet}))$  being the injective resolution functor, and for

- $\phi = (\phi_D, \phi_C, [\theta]) : (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2)$
- $\phi' = (\phi'_D, \phi'_C, [\theta']) : (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2) \rightarrow (((M_{3I}, F, W), u_{IJ}), (K_3, W), \alpha_3)$

the composition law is given by

$$\begin{aligned} \phi' \circ \phi := & (\phi'_D \circ \phi_D, \phi'_C \circ \phi_C, I(DR(S)(\phi_D'^{an} \otimes I)) \circ [\theta] + [\theta'] \circ I(\mathbb{B}_{dr, (\tilde{S}_I)}(\phi_C)) [1]) : \\ & (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_{3I}, F, W), u_{IJ}), (K_3, W), \alpha_3), \end{aligned}$$

in particular for  $(((M_I, F, W), u_{IJ}), (K, W), \alpha) \in C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et})$ ,

$$I_{(((M_I, F, W), u_{IJ}), (K, W), \alpha)} = (I_{M_I}, I_K, 0),$$

and also the category  $D_{\mathcal{D}(1,0)fil,rh,\infty}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et})$  defined in the same way, together with the localization functor

$$\begin{aligned} (D(zar), I) : C_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et}) & \rightarrow D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et}) \\ & \rightarrow D_{\mathcal{D}(1,0)fil,rh,\infty}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et}). \end{aligned}$$

Note that if  $\phi = (\phi_D, \phi_C, [\theta]) : (((M_1, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_2, F, W), u_{IJ}), (K_2, W), \alpha_2)$  is a morphism in  $D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et})$  such that  $\phi_D$  and  $\phi_C$  are isomorphism then  $\phi$  is an isomorphism (see remark 8). Moreover,

- For  $(((M_I, F, W), u_{IJ}), (K, W), \alpha) \in D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et})$ , we set

$$(((M_I, F, W), u_{IJ}), (K, W), \alpha)[1] := (((M_I, F, W), u_{IJ})[1], (K, W)[1], \alpha[1]).$$

- For

$$\phi = (\phi_D, \phi_C, [\theta]) : (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1) \rightarrow (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2)$$

a morphism in  $D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et})$ , we set (see [11] definition 3.12)

$$\text{Cone}(\phi) := (\text{Cone}(\phi_D), \text{Cone}(\phi_C), ((\alpha_1, \theta), (\alpha_2, 0))) \in D_{\mathcal{D}(1,0)fil,rh}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et}),$$

$((\alpha_1, \theta), (\alpha_2, 0))$  being the matrix given by the composition law, together with the canonical maps

- $c_1(-) = (c_1(\phi_D), c_1(\phi_C), 0) : (((M_{2I}, F, W), u_{IJ}), (K_2, W), \alpha_2) \rightarrow \text{Cone}(\phi)$
- $c_2(-) = (c_2(\phi_D), c_2(\phi_C), 0) : \text{Cone}(\phi) \rightarrow (((M_{1I}, F, W), u_{IJ}), (K_1, W), \alpha_1)[1]$ .

Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i=1}^s S_i$  an open cover such that there exists closed embedding  $i_i : S \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Consider the category

$$(D_{\mathcal{D}(1,0)fil}(\tilde{S}_I) \times_I D_{\mathbb{Z}_p fil,c,k}(\tilde{S}_I^{et})) \subset \text{Fun}(\Gamma(\tilde{S}_I), \text{TriCat})$$

- whose objects are  $(((M_I, F, W), (K_I, W), \alpha_I), u_{IJ}) \in \text{Fun}(\Gamma(\tilde{S}_I), \text{TriCat})$  such that

$$((M_I, F, W), (K_I, W), \alpha_I) \in D_{\mathcal{D}(1,0)fil}(\tilde{S}_I) \times_I D_{\mathbb{Z}_p fil,c,k}(\tilde{S}_I^{et}) =: \mathcal{D}_p(\tilde{S}_I)$$

and for  $I \subset J$ ,

$$\begin{aligned} u_{IJ} : & ((M_I, F, W), (K_I, W), \alpha_I) \rightarrow \\ p_{IJ*} & ((M_J, F, W), (K_J, W), \alpha_J) := (p_{IJ*}(M_J, F, W), p_{IJ*}(K_J, W), p_{IJ*}\alpha_J) \end{aligned}$$

are morphisms in  $\mathcal{D}_p(\tilde{S}_I)$ ,

- whose morphisms  $m = (m_I) : (((M_I, F, W), (K_I, W), \alpha_I), u_{IJ}) \rightarrow (((M'_I, F, W), (K'_I, W), \alpha'_I), v_{IJ})$  is a family of morphism such that  $v_{IJ} \circ m_I = p_{IJ*} m_J \circ u_{IJ}$  in  $\mathcal{D}_p(\tilde{S}_I)$

We have then the identity functor

$$\begin{aligned} I_S : D_{\mathcal{D}(1,0)fil}(S/(\tilde{S}_I))^0 \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et}) &\rightarrow (D_{\mathcal{D}(1,0)fil}(\tilde{S}_I) \times_I D_{\mathbb{Z}_p fil,c,k}(\tilde{S}_I^{et})), \\ (((M_I, F, W), u_{IJ}), (K, W), \alpha) &\mapsto (((M_I, F, W), i_{I*} j_I^*(K, W), j_I^* \alpha), (u_{IJ}, I, 0)), \\ m = (m_I, n) &\mapsto m = (m_I, i_{I*} j_I^* n) \end{aligned}$$

which is a full embedding since for  $((M_I, F, W), u_{IJ}) \in D_{\mathcal{D}(1,0)fil}(S/(\tilde{S}_I))^0$ ,

$$u_{IJ} : (M_I, F, W) \rightarrow p_{IJ*}(M_J, F, W)$$

are isomorphisms in  $D_{\mathcal{D}(1,0)fil}(\tilde{S}_I)$ , and hence for  $((M_I, F, W), u_{IJ}), (K, W), \alpha \in D_{\mathcal{D}(1,0)fil}(S/(\tilde{S}_I))^0 \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et})$ ,

$$\begin{aligned} (u_{IJ}, I, 0) : ((M_I, F, W), i_{I*} j_I^*(K, W), j_I^* \alpha) &\rightarrow \\ p_{IJ*}((M_J, F, W), i_{J*} j_J^*(K, W), j_J^* \alpha) &= (p_{IJ*}(M_J, F, W), i_{I*} j_I^*(K, W), j_I^* \alpha) \end{aligned}$$

are isomorphisms in  $\mathcal{D}_p(\tilde{S}_I)$ .

**Definition 117.** For  $h : U \rightarrow S$  a smooth morphism with  $S, U \in \text{SmVar}(k)$  and  $h : U \xrightarrow{n} X \xrightarrow{f} S$  a compactification of  $h$  with  $n$  an open embedding,  $X \in \text{SmVar}(k)$  such that  $D := X \setminus U = \cup_{i=1}^s D_i \subset X$  is a normal crossing divisor, we denote by, using definition 74 and definition 103

$$\begin{aligned} I_p(U/S) : h_{!Hdg} h^{!Hdg} \mathbb{Z}_{p,S}^{Hdg} &\xrightarrow{=} \\ (p_{S*} E_{zar}(\Omega_{X \times S/S}^\bullet \otimes_{O_{X \times S}} (n \times I)_{!Hdg} \Gamma_U^{\vee, Hdg}(O_{U \times S}, F_b)), \mathbb{D}_S h_* E_{et} \mathbb{Z}_{p,U^{et}}, h_! \alpha(U, \delta)) & \\ \underbrace{((DR(X \times S/S)(\text{ad}((n \times I)_{!Hdg}, (n \times I)^*(-)), 0), I, 0))}_{\rightarrow} & \\ (\text{Cone}((\Omega_{/S}^{\Gamma, pr}(i_{D_i} \times I))_{i \in [1, \dots, s]} : p_{S*} E_{zar}(\Omega_{X \times S/S}^\bullet \otimes_{O_{X \times S}} \Gamma_X^{\vee, Hdg}(O_{X \times S}, F_b)) \rightarrow & \\ (\cdots \rightarrow (p_{S*} E_{zar}(\Omega_{D_i \times S/S}^\bullet \otimes_{O_{D_i \times S}} \Gamma_{D_i}^{\vee, Hdg}(O_{D_i \times S}, F_b))) \rightarrow \cdots)), \mathbb{D}_S h_* E_{et} \mathbb{Z}_{p,U^{et}}, h_! \alpha(U, \delta)) & \\ \xrightarrow{=} (\mathcal{F}_S^{FDR}(\mathbb{Z}(U/S)), Rh_! \mathbb{Z}_{p,U^{et}}, \alpha(\mathbb{Z}(U/S))) & \end{aligned}$$

the canonical isomorphism in  $D_{\mathcal{D}fil}(S) \times_I D_{\mathbb{Z}_p,c,k}(S^{et})$ , where

- we recall that (see section 6.2)

$$h^{!Hdg} \mathbb{Z}_{p,S}^{Hdg} = (\Gamma_U^{\vee, Hdg}(O_{U \times S}, F_b), \mathbb{Z}_{p,U^{et}}, \alpha(U)) \in HM_{gm,k,C_p}(U),$$

- $i_{D_i} : D_i \hookrightarrow X$  are the closed embeddings,
- $\alpha(\mathbb{Z}(U/S)) := h_! \alpha(U, \delta) := T^w(h, \otimes)(-) \circ h_! \alpha(U, \delta)$  (see definition 84), with

$$\begin{aligned} \alpha(U, \delta) &:= (DR(U)(\Omega_{(U \times U/U)/(U/pt)}(\Gamma_U^{\vee, Hdg}(O_{U \times U}, F_b))) \otimes I)^{-1} \circ \alpha(U) : \\ \mathbb{B}_{dr,U} &\rightarrow DR(U)((p_{U*} E_{zar}(\Omega_{U \times U/U}^\bullet \otimes_{O_{U \times U}} \Gamma_U^{\vee, Hdg}(O_{U \times U}, F_b)))^{an} \otimes_{O_U} (O_{\mathbb{B}_{dr,U}}, F)), \end{aligned}$$

by the way we note that the following diagram in  $C(U_{\mathbb{C}_p}^{an, pet})$  commutes

$$\begin{array}{ccc} \mathbb{B}_{dr,U} & \xrightarrow{\alpha(U)} & F^0((\Omega_{U_{\mathbb{C}_p}}^{\bullet, an}, F_b) \otimes_{O_U} (O_{\mathbb{B}_{dr,U}}, F)) =: F^0 DR(U)(O_{\mathbb{B}_{dr,U}}, F) \\ & & \uparrow DR(U)(\Omega_{(U \times U/U)/(U/pt)}(\Gamma_U^{\vee, Hdg}(O_{U \times U}, F_b)) \otimes I) \\ & & E_{et} F^0 DR(U)((p_{U*} E_{zar}(\Omega_{U \times U/U}^\bullet \otimes_{O_{U \times U}} \Gamma_U^{\vee, Hdg}(O_{U \times U}, F_b)))^{an} \otimes_{O_U} (O_{\mathbb{B}_{dr,U}}, F)) \\ & & \uparrow T^w(p_U, \otimes)(-)^{-1} \\ p_{U*} E_{et} \Gamma_U^{\vee} \mathbb{B}_{dr,U \times U}^{\text{ad}(\delta_U^{mod}, \delta_{U^*})(-)} & \xrightarrow{\alpha(U \times U)} & p_{U*} E_{et} F^0 DR(U \times U)((\Omega_{U \times U/U}^\bullet \otimes_{O_{U \times U}} \Gamma_U^{\vee, Hdg}(O_{U \times U}, F_b))^{an} \otimes_{O_{U \times U}} (O_{\mathbb{B}_{dr,U \times U}}, F)) \end{array}$$

**Lemma 10.** *Let  $S \in \text{SmVar}(k)$ . Let  $g : U'/S \rightarrow U/S$  o morphism with  $U/S := (U, h), U'/S := (U', h) \in \text{Var}(k)^{\text{sm}}/S$ . Let  $h : U \xrightarrow{n} X \xrightarrow{f} S$  a compactification of  $h$  with  $n$  an open embedding,  $X \in \text{SmVar}(k)$  such that  $D := X \setminus U = \cup_{i=1}^s D_i \subset X$  is a normal crossing divisor, Let  $h' : U \xrightarrow{n'} X' \xrightarrow{f'} S$  a compactification of  $h'$  with  $n'$  an open embedding,  $X' \in \text{SmVar}(k)$  such that  $D' := X' \setminus U = \cup_{i=1}^s D_i \subset X'$  is a normal crossing divisor and such that  $g : U' \rightarrow U$  extend to  $\bar{g} : X' \rightarrow X$ , see definition-proposition 3. Then, using definition 117, the following diagram in  $D_{\mathcal{D}fil}(S) \times_I D_{c,k}(S^{et})$  commutes*

$$\begin{array}{ccc} h'_{Hdg} h'^{!Hdg} \mathbb{Z}_{p,S}^{Hdg} & \xrightarrow{I_p(U'/S)} & (\mathcal{F}_S^{FDR}(\mathbb{Z}(U'/S)), e(S^{et})_* C_*(\mathbb{Z}(U'/S) \otimes \mathbb{Z}_p), \alpha(\mathbb{Z}(U'/S))) \\ \text{ad}(g^!_{Hdg}, g^!_{Hdg})(h^!_{Hdg} \mathbb{Z}_{p,S}^{Hdg}) \downarrow & & \downarrow (\Omega_{U'/S}^{\Gamma, pr}(R_S^{CH}(g)), Re(S^{et})_* \mathbb{Z}(g), \theta(g)) \\ h_{!Hdg} h^{!Hdg} \mathbb{Z}_{p,S}^{Hdg} & \xrightarrow{I_p(U/S)} & (\mathcal{F}_S^{FDR}(\mathbb{Z}(U/S)), e(S^{et})_* C_*(\mathbb{Z}(U/S) \otimes \mathbb{Z}_p), \alpha(\mathbb{Z}(U/S))) \end{array}$$

where

$$\theta(g) := R_{\mathcal{D}}([\Gamma_g]) : I(\mathbb{B}_{dr,S}(h'_! \mathbb{Z}_{p,U'^{et}})[1]) \rightarrow I(F^0 DR(S)(\mathcal{F}_S^{FDR}(\mathbb{Z}(U/S))^{an} \otimes_{O_S} (O_{\mathbb{B}_{dr,S}}(F))))$$

is the homotopy given by the third term of the syntomic homology class of the graph  $\Gamma_g \subset U' \times_S U$ , and we recall (see section 6.2) that  $I : C_{B_{dr},G}(S_{\mathbb{C}_p}^{an}/(\tilde{S}_{I,\mathbb{C}_p}^{an})) \rightarrow K_{B_{dr},G}(S_{\mathbb{C}_p}^{an}/(\tilde{S}_{I,\mathbb{C}_p}^{an}))$  is the injective resolution functor.

*Proof.* Immediate from definition. □

We can now define the p adic Hodge realization functor for motives :

**Definition 118.** *Let  $k \subset \mathbb{C}_p$  a subfield. Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i=1}^s S_i$  an open cover such that there exists closed embedding  $i_i : S \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . We define the Hodge realization functor as, using definition 106,*

$$\begin{aligned} \mathcal{F}_S^{Hdg} &:= (\mathcal{F}_S^{FDR}, e(S^{et})_* C_* L \otimes \mathbb{Z}_p) : C(\text{Var}(k)^{\text{sm}}/S) \rightarrow D_{\mathcal{D}(1,0)fil}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et}), \\ F &\mapsto \mathcal{F}_S^{Hdg}(F) := (\mathcal{F}_S^{FDR}(F, W), e(S^{et})_* C_*(L(F, W) \otimes \mathbb{Z}_p), \alpha(F)), \end{aligned}$$

first on objects and then on morphisms :

- for  $F \in C(\text{Var}(k)^{\text{sm}}/S)$ , taking  $(F, W) \in C_{fil}(\text{Var}(k)^{\text{sm}}/S)$  such that  $D(\mathbb{A}^1, et)(F, W)$  gives the weight structure on  $D(\mathbb{A}^1, et)(F)$ ,

$$\begin{aligned} \mathcal{F}_S^{Hdg}(F) &:= (\mathcal{F}_S^{FDR}(F, W), e(S^{et})_* C_*(L(F, W) \otimes \mathbb{Z}_p), \alpha(F)) := \\ &(e(S)_* \text{Hom}((\hat{R}_{\tilde{S}_I}^{CH}(\rho_{\tilde{S}_I}^* Li_I^* j_I^*(F, W)), \hat{R}^{CH}(T^q(D_{IJ})(-))), (E_{zar}(\Omega_{\tilde{S}_I}^{\bullet, \Gamma, pr}, FDR), T_{IJ})), \\ &e(S^{et})_* C_*(L(F, W) \otimes \mathbb{Z}_p), \alpha(F)) \in D_{\mathcal{D}(1,0)fil}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et}) \end{aligned}$$

where  $\alpha(F)$  is the map in  $D_{\mathbb{B}_{dr} fil}(S_{\mathbb{C}_p}^{an, pet}/(\tilde{S}_{I,\mathbb{C}_p}^{an, pet}))$  writing for short  $DR(S) := DR(S)^{[-1]} :=$

$(DR(\tilde{S}_I)[-d_{\tilde{S}_I}])$

$$\begin{aligned}
\alpha(F) : \mathbb{B}_{dr,(\tilde{S}_I)}(Re(S^{et})_*((M, W) \otimes^L \mathbb{Z}_p)) &:= \mathbb{B}_{dr,(\tilde{S}_I)}((i_{I*}j_I^*(S^{et})_*C_*(L(F, W) \otimes \mathbb{Z}_p)), I) \\
&\xrightarrow{\cong} \mathbb{B}_{dr,(\tilde{S}_I)}((e(\tilde{S}_{I,k}^{et})_*C_*(Li_{I*}j_I^*(F, W) \otimes \mathbb{Z}_p)), I) \\
&\xrightarrow{\cong} (((\cdot \rightarrow \oplus_{(U_{I\alpha}, h_{I\alpha}) \in V_I} \mathbb{B}_{dr, \tilde{S}_I}(h_{I\alpha}!h_{I\alpha}^1 \mathbb{Z}_{p, \tilde{S}_{I,k}^{et}})) \xrightarrow{\mathbb{B}_{dr, \tilde{S}_I}(\text{ad}(g_{I,\alpha,\beta}^{\bullet}, g_{I,\alpha,\beta}^{\bullet})(-))} \\
&\quad \oplus_{(U_{I\alpha}, h_{I\alpha}) \in V_I} \mathbb{B}_{dr, \tilde{S}_I}(h_{I\alpha}!h_{I\alpha}^1 \mathbb{Z}_{p, \tilde{S}_{I,k}^{et}}) \rightarrow \cdot, u_{IJ}), W) \\
&\quad \xrightarrow{(\alpha(\mathbb{Z}(U_{I\alpha}/\tilde{S}_I)), \theta(g_{I,\alpha,\beta}^{\bullet}))} \\
F^0 DR(S)((e(S)_* \mathcal{H}om((\hat{R}_{\tilde{S}_I}^{CH}(\rho_{\tilde{S}_I}^* Li_{I*}j_I^*(F, W)), \hat{R}^{CH}(T^q(D_{IJ})(-))), (E_{zar}(\Omega_{\tilde{S}_I}^{\bullet, \Gamma, pr}, F_{DR}), T_{IJ})))^{an} \\
&\quad \otimes_{O_S} ((\mathbb{O}_{dr, \tilde{S}_I}, F), t_{IJ})) \\
&\xrightarrow{\cong} F^0 DR(S)((\mathcal{F}_S^{FDR}(M, W))^{an} \otimes_{O_S} ((\mathbb{O}_{dr, \tilde{S}_I}, F), t_{IJ}))
\end{aligned}$$

using lemma 10,

$$(\alpha(\mathbb{Z}(U_{I\alpha}/S)), \theta(g_{I,\alpha,\beta}^{\bullet}))$$

being the matrix given inductively by the composition law in  $D_{\mathcal{D}(1,0)fil}(\tilde{S}_I) \times_I D_{fil}(\tilde{S}_I^{et})$ , that is we have the following isomorphism in  $(D_{\mathcal{D}(1,0)fil}(\tilde{S}_I) \times_I D_{fil}(\tilde{S}_I^{et}))$ , denoting for short  $V_I := \text{Var}(k)^{sm}/\tilde{S}_I$

$$\begin{aligned}
(I^{\bullet}(U_{I\alpha}/\tilde{S}_I)) : (((\cdot \rightarrow \oplus_{(U_{I\alpha}, h_{I\alpha}) \in V_I} h_{I\alpha}!Hdg h_{I\alpha}^1 \mathbb{Z}_{p, \tilde{S}_I}^{Hdg} \xrightarrow{\text{ad}(g_{I,\alpha,\beta}^{\bullet, Hdg}, g_{I,\alpha,\beta}^{\bullet, Hdg})(-)} \\
\oplus_{(U_{I\alpha}, h_{I\alpha}) \in V_I} h_{I\alpha}!Hdg h_{I\alpha}^1 \mathbb{Z}_{p, \tilde{S}_I}^{Hdg} \rightarrow \cdot, u_{IJ}), W) \\
\cong I_S(\mathcal{F}_S^{Hdg}(F) := (\mathcal{F}_S^{FDR}(F, W), e(\tilde{S}_I^{et})_*C_*(Li_{I*}j_I^*(F, W) \otimes \mathbb{Z}_p)), \alpha(F))
\end{aligned}$$

where we denote by  $g_{I,\alpha,\beta}^n : U_{I\alpha} \rightarrow U_{I\beta}$  which satisfy  $h_{I\beta} \circ g_{I,\alpha,\beta}^n = h_{I\alpha}$  the morphisms in the canonical projective resolution

$$\begin{aligned}
q : Li_{I*}j_I^*(F, W) &:= ((\cdots \rightarrow \oplus_{(U_{I\alpha}, h_{I\alpha}) \in \text{Var}(k)^{sm}/\tilde{S}_I} \mathbb{Z}(U_{I\alpha}/\tilde{S}_I) \xrightarrow{(\mathbb{Z}(g_{I,\alpha,\beta}^{\bullet}))} \\
&\quad \oplus_{(U_{I\alpha}, h_{I\alpha}) \in \text{Var}(k)^{sm}/\tilde{S}_I} \mathbb{Z}(U_{I\alpha}/\tilde{S}_I) \rightarrow \cdots), W) \rightarrow i_{I*}j_I^*(F, W),
\end{aligned}$$

- for  $m : F_1 \rightarrow F_2$  a morphism in  $C(\text{Var}(k)^{sm}/S)$ , taking  $(F_1, W), (F_2, W) \in C_{fil}(\text{Var}(k)^{sm}/S)$  such that  $D(\mathbb{A}^1, et)(F_2, W)$  gives the weight structure on  $D(\mathbb{A}^1, et)(F_2)$   $D(\mathbb{A}^1, et)(F_1, W)$  gives the weight structure on  $D(\mathbb{A}^1, et)(F_1)$  and such that  $m : (F_1, W) \rightarrow (F_2, W)$  is a filtered morphism, the morphism  $\mathcal{F}_S^{Hdg}(m)$  in  $D_{\mathcal{D}(1,0)fil}(S/(\tilde{S}_I)) \times_I D_{fil,c,k}(S^{et})$  is given by

$$\begin{aligned}
\mathcal{F}_S^{Hdg}(m) : &= I_S^{-,-1}((I^{\bullet}(U_{I\alpha}/(\tilde{S}_I))) \circ (\text{ad}(l_{I,\alpha,\beta}^{\bullet, Hdg}, l_{I,\alpha,\beta}^{\bullet, Hdg})(\mathbb{Z}_{p, U_{I\alpha}}^{Hdg})) \circ (I^{\bullet}(U_{I\alpha}/(\tilde{S}_I)))^{-1}) \\
&= (\mathcal{F}_S^{FDR}(m), Re(S^{et})_*\mathbb{Z}(m), \theta(m) := (\theta(l_{I,\alpha,\beta}))) : \mathcal{F}_S^{Hdg}(F_1) \rightarrow \mathcal{F}_S^{Hdg}(F_2)
\end{aligned}$$

using lemma 9, that is we have the following commutative diagram in  $(D_{\mathcal{D}(1,0)fil}(\tilde{S}_I) \times_I D_{fil,c,k}(\tilde{S}_I^{et}))$ , denoting for short  $V_I := \text{Var}(k)^{sm}/\tilde{S}_I$ ,

$$\begin{array}{ccc}
((\cdot \rightarrow \oplus_{(U_{I\alpha}, h_{I\alpha}) \in V_I} h_{I\alpha}!Hdg h_{I\alpha}^1 \mathbb{Z}_{p, \tilde{S}_I}^{Hdg} \xrightarrow{g_{I,\alpha,\beta}^{A, Hdg}} \oplus_{(U_{I\alpha}, h_{I\alpha}) \in V_I} h_{I\alpha}!Hdg h_{I\alpha}^1 \mathbb{Z}_{p, \tilde{S}_I}^{Hdg} \rightarrow \cdot, u_{IJ}), W) \xrightarrow{(I^{\bullet}(U_{I\alpha}/\tilde{S}_I))^{Hdg}} \mathcal{F}_S^{Hdg}(F_1) \\
\downarrow \text{ad}(l_{I,\alpha,\beta}^{\bullet, Hdg}, l_{I,\alpha,\beta}^{\bullet, Hdg})(-) \downarrow & & \downarrow \mathcal{F}_S^{Hdg}(m) = (\mathcal{F}_S^{FDR}(m), Re(S^{et})_*\mathbb{Z}(m), (\theta(l_{I,\alpha,\beta}))) \downarrow \\
((\cdot \rightarrow \oplus_{(U_{I\alpha}, h_{I\alpha}) \in V_I} h_{I\alpha}!Hdg h_{I\alpha}^1 \mathbb{Z}_{p, \tilde{S}_I}^{Hdg} \xrightarrow{g_{I,\alpha,\beta}^{A, Hdg}} \oplus_{(U_{I\alpha}, h_{I\alpha}) \in V_I} h_{I\alpha}!Hdg h_{I\alpha}^1 \mathbb{Z}_{p, \tilde{S}_I}^{Hdg} \rightarrow \cdot, u_{IJ}), W) \xrightarrow{(I^{\bullet}(U_{I\alpha}/\tilde{S}_I))^{Hdg}} \mathcal{F}_S^{Hdg}(F_2)
\end{array}$$

where



- we denoted for short  $A_{g_{1I,\alpha,\beta}}^{Hdg} := \text{ad}(g_{1I,\alpha,\beta}^{\bullet,!Hdg}, g_{1I,\alpha,\beta}^{\bullet,!Hdg})(h_{I\alpha}^{!Hdg} \mathbb{Z}_{\tilde{S}_I}^{Hdg})$
- we denoted for short  $A_{g_{2I,\alpha,\beta}}^{Hdg} := \text{ad}(g_{2I,\alpha,\beta}^{\bullet,!Hdg}, g_{2I,\alpha,\beta}^{\bullet,!Hdg})(h_{I\alpha}^{!Hdg} \mathbb{Z}_{\tilde{S}_I}^{Hdg})$
- we denote by  $g_{1I,\alpha,\beta}^n : U_{I\alpha} \rightarrow U_{I\beta}$ , which satisfy  $h_{I\beta} \circ g_{1I,\alpha,\beta}^n = h_{I\alpha}$ , the morphisms in the canonical projective resolution

$$q : Li_{I*}j_I^*(F_1, W) := ((\cdots \rightarrow \bigoplus_{(U_{I\alpha}, h_{I\alpha}) \in \text{Var}(k)^{sm}/\tilde{S}_I} \mathbb{Z}(U_{I\alpha}/\tilde{S}_I) \xrightarrow{(\mathbb{Z}(g_{1I,\alpha,\beta}^n))} \bigoplus_{(U_{I\alpha}, h_{I\alpha}) \in \text{Var}(k)^{sm}/\tilde{S}_I} \mathbb{Z}(U_{I\alpha}/\tilde{S}_I) \rightarrow \cdots), W) \rightarrow i_{I*}j_I^*(F_1, W)$$

- we denote by  $g_{2I,\alpha,\beta}^n : U_{I\alpha} \rightarrow U_{I\beta}$ , which satisfy  $h_{I\beta} \circ g_{2I,\alpha,\beta}^n = h_{I\alpha}$ , the morphisms in the canonical projective resolution

$$q : Li_{I*}j_I^*(F_2, W) := ((\cdots \rightarrow \bigoplus_{(U_{I\alpha}, h_{I\alpha}) \in \text{Var}(k)^{sm}/\tilde{S}_I} \mathbb{Z}(U_{I\alpha}/\tilde{S}_I) \xrightarrow{(\mathbb{Z}(g_{2I,\alpha,\beta}^n))} \bigoplus_{(U_{I\alpha}, h_{I\alpha}) \in \text{Var}(k)^{sm}/\tilde{S}_I} \mathbb{Z}(U_{I\alpha}/\tilde{S}_I) \rightarrow \cdots), W) \rightarrow i_{I*}j_I^*(F_2, W)$$

- we denote by  $l_{I\alpha,\beta}^n : U_{I\alpha} \rightarrow U_{I\beta}$  which satisfy  $h_{I\beta} \circ l_{I\alpha,\beta}^n = h_{I\alpha}$  and  $l_{I\alpha,\beta}^{n+1} \circ g_{1I,\alpha,\beta}^n = g_{2I,\alpha,\beta}^n \circ l_{I\alpha,\beta}^n$ , the morphisms in the morphism of canonical projective resolutions

$$Li_{I*}j_I^*(m) : Li_{I*}j_I^*(F_1, W) := ((\cdots \rightarrow \bigoplus_{(U_{I\alpha}, h_{I\alpha}) \in \text{Var}(k)^{sm}/\tilde{S}_I} \mathbb{Z}(U_{I\alpha}/\tilde{S}_I) \rightarrow \cdots), W) \xrightarrow{(\mathbb{Z}(l_{I\alpha,\beta}^n))} ((\cdots \rightarrow \bigoplus_{(U_{I\alpha}, h_{I\alpha}) \in \text{Var}(k)^{sm}/\tilde{S}_I} \mathbb{Z}(U_{I\alpha}/\tilde{S}_I) \rightarrow \cdots), W) =: Li_{I*}j_I^*(F_2, W),$$

- the maps  $I^\bullet(U_{I\alpha})$  are given by definition 115 and lemma 9.

Obviously  $\mathcal{F}_S^{Hdg}(F[1]) = \mathcal{F}_S^{Hdg}(F)[1]$  and  $\mathcal{F}_S^{Hdg}(\text{Cone}(m)) = \text{Cone}(\mathcal{F}_S^{Hdg}(m))$ . This functor induces by proposition 62 and remark 8 the functor

$$\begin{aligned} \mathcal{F}_S^{Hdg} &:= (\mathcal{F}_S^{FDR}, e(S^{et})_* C_*(L \otimes \mathbb{Z}_p) : \text{DA}(S) \rightarrow D_{\mathcal{D}(1,0)fil}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et}), \\ M = D(\mathbb{A}^1, et)(F) &\mapsto \mathcal{F}_S^{Hdg}(M) := \mathcal{F}_S^{Hdg}(F) = (\mathcal{F}_S^{FDR}(M), \text{Re}(S^{et})_*(M \otimes^L \mathbb{Z}_p), \alpha(M)), \end{aligned}$$

with  $\alpha(M) = \alpha(F)$ .

We now give the functoriality with respect to the five operation using the De Rahm realization case and the etale realization case :

**Proposition 73.** *Let  $p$  a prime number. Consider an embedding  $k \subset \mathbb{C}_p$ .*

- (i) *Let  $g : T \rightarrow S$  a morphism with  $T, S \in \text{Var}(k)$ . Assume there exists a factorization  $g : T \xrightarrow{l} Y \times S \xrightarrow{p} S$ , with  $Y \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $p$  the projection. Let  $S = \cup_{i \in I} S_i$  an open cover and  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embeddings with  $\tilde{S}_i \in \text{SmVar}(k)$ . Then,  $\tilde{g}_I : Y \times \tilde{S}_I \rightarrow \tilde{S}_I$  is a lift of  $g_I = g|_{T_I} : T_I \rightarrow S_I$  and we have closed embeddings  $i'_I := i_I \circ l \circ j'_I : T_I \hookrightarrow Y \times \tilde{S}_I$ . Then, for  $M = D(\mathbb{A}^1, et)(F) \in \text{DA}_c(S)$ , the following diagram commutes :*

$$\begin{array}{ccc} \mathbb{B}_{dr, (Y \times \tilde{S}_I)}(g^{*w} \text{Re}(S^{et})_*(M \otimes^L \mathbb{Z}_p)) \xrightarrow{g^{*(\alpha(M))}} F^0 DR(T)^{[-1]}((g_{Hdg}^{*mod} \mathcal{F}_S^{FDR}(M))^{an} \otimes_{O_T} ((O_{\mathbb{B}_{dr, Y \times \tilde{S}_I}}(F), t_{IJ})) & & \\ \downarrow \mathbb{B}_{dr, (Y \times \tilde{S}_I)}(T^*(g, e)(M \otimes \mathbb{Z}_p)) & & \downarrow DR(T)^{[-1]}((T(g, \mathcal{F}^{FDR})(M))^{an} \otimes I) \\ \mathbb{B}_{dr, (Y \times \tilde{S}_I)}(\text{Re}(T^{et})_* g^*(M \otimes^L \mathbb{Z}_p)) \xrightarrow{\alpha(g^*M)} F^0 DR(T)^{[-1]}((\mathcal{F}_T^{FDR}(g^*M))^{an} \otimes_{O_T} ((O_{\mathbb{B}_{dr, Y \times \tilde{S}_I}}(F), t_{IJ})), & & \end{array}$$

see definition 110 and definition 84.

(ii) Let  $f : T \rightarrow S$  a morphism with  $T, S \in \text{Var}(k)$ . Assume there exists a factorization  $f : T \xrightarrow{l} Y \times S \xrightarrow{p} S$ , with  $Y \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $p$  the projection. Let  $S = \cup_{i \in I} S_i$  an open cover and  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embeddings with  $\tilde{S}_i \in \text{SmVar}(k)$ . Then, for  $M = D(\mathbb{A}^1, et)(F) \in DA_c(T)$ , the following diagram commutes :

$$\begin{array}{ccc} \mathbb{B}_{dr,(\tilde{S}_I)}(Rf_{*w}Re(T^{et})_*(M \otimes^L \mathbb{Z}_p)) \xrightarrow{f_*(\alpha(M))} F^0 DR(S)^{[-]}((Rf_*^{Hdg} \mathcal{F}_T^{FDR}(M))^{an} \otimes_{O_S} ((O\mathbb{B}_{dr,\tilde{S}_I}, F), t_{IJ})) & & \\ \mathbb{B}_{dr,(\tilde{S}_I)}(T_*(f,e)(M \otimes^L \mathbb{Z}_p)) \uparrow & DR(S)^{[-]}((T_*(f, \mathcal{F}^{FDR})(M))^{an} \otimes I) \uparrow & \\ \mathbb{B}_{dr,(\tilde{S}_I)}(Re(S^{et})_* Rf_*(M \otimes^L \mathbb{Z}_p)) \xrightarrow{\alpha(Rf_* M)} F^0 DR(S)^{[-]}((\mathcal{F}_S^{FDR}(Rf_* M))^{an} \otimes_{O_S} ((O\mathbb{B}_{dr,\tilde{S}_I}, F), t_{IJ})) & & \end{array}$$

see definition 111 and definition 84.

(iii) Let  $f : T \rightarrow S$  a morphism with  $T, S \in \text{Var}(k)$ . Assume there exists a factorization  $f : T \xrightarrow{l} Y \times S \xrightarrow{p} S$ , with  $Y \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $p$  the projection. Let  $S = \cup_{i \in I} S_i$  an open cover and  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embeddings with  $\tilde{S}_i \in \text{SmVar}(k)$ . Then, for  $M = D(\mathbb{A}^1, et)(F) \in DA_c(T)$ , the following diagram commutes :

$$\begin{array}{ccc} \mathbb{B}_{dr,(\tilde{S}_I)}(Rf_{!w}Re(T^{et})_*(M \otimes^L \mathbb{Z}_p)) \xrightarrow{f_!(\alpha(M))} F^0 DR(S)^{[-]}((Rf_{!}^{Hdg} \mathcal{F}_{FDR}^T(M))^{an} \otimes_{O_S} ((O\mathbb{B}_{dr,\tilde{S}_I}, F), t_{IJ})) & & \\ \downarrow \mathbb{B}_{dr,(\tilde{S}_I)}(T_!(f,e)(M \otimes^L \mathbb{Z}_p)) & & \downarrow DR(S)^{[-]}((T_!(f, \mathcal{F}_{FDR})(M))^{an} \otimes I) \\ \mathbb{B}_{dr,(\tilde{S}_I)}(Re(S^{et})_* Rf_!(M \otimes^L \mathbb{Z}_p)) \xrightarrow{\alpha(Rf_! M)} F^0 DR(S)^{[-]}((\mathcal{F}_{FDR}^S(Rf_! M))^{an} \otimes_{O_S} ((O\mathbb{B}_{dr,\tilde{S}_I}, F), t_{IJ})) & & \end{array}$$

see definition 111 and definition 84.

(iv) Let  $f : T \rightarrow S$  a morphism with  $T, S \in \text{Var}(k)$ . Assume there exists a factorization  $f : T \xrightarrow{l} Y \times S \xrightarrow{p} S$ , with  $Y \in \text{SmVar}(k)$ ,  $l$  a closed embedding and  $p$  the projection. Let  $S = \cup_{i \in I} S_i$  an open cover and  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embeddings with  $\tilde{S}_i \in \text{SmVar}(k)$ . Then, for  $M = D(\mathbb{A}^1, et)(F) \in DA_c(S)$ , the following diagram commutes :

$$\begin{array}{ccc} \mathbb{B}_{dr,(Y \times \tilde{S}_I)}(f^{!w}Re(S^{et})_*(M \otimes^L \mathbb{Z}_p)) \xrightarrow{f^!(\alpha(M))} F^0 DR(T)^{[-]}((f^{*mod}_{Hdg} \mathcal{F}_S^{FDR}(M))^{an} \otimes_{O_T} ((O\mathbb{B}_{dr,Y \times \tilde{S}_I}, F), t_{IJ})) & & \\ \mathbb{B}_{dr,(Y \times \tilde{S}_I)}(T^!(f,e)(M \otimes^L \mathbb{Z}_p)) \uparrow & DR^{[-]}(T)((T^!(g, \mathcal{F}^{FDR})(M))^{an} \otimes I) \uparrow & \\ \mathbb{B}_{dr,(Y \times \tilde{S}_I)}(Re(T^{et})_* f^!(M \otimes^L \mathbb{Z}_p)) \xrightarrow{\alpha(f^! M)} F^0 DR(T)^{[-]}((\mathcal{F}_T^{FDR}(f^! M))^{an} \otimes_{O_T} ((O\mathbb{B}_{dr,Y \times \tilde{S}_I}, F), t_{IJ})) & & \end{array}$$

see definition 111 and definition 84.

(v) Let  $S \in \text{Var}(k)$ . Let  $S = \cup_{i \in I} S_i$  an open cover and  $i_i : S_i \hookrightarrow \tilde{S}_i$  closed embeddings with  $\tilde{S}_i \in \text{SmVar}(k)$ . Then, for  $M, N \in DA_c(S)$ , the following diagram commutes :

$$\begin{array}{ccc} \mathbb{B}_{dr,(\tilde{S}_I)}(Re(S^{et})_*(M \otimes^L \mathbb{Z}_p)) \otimes_{\mathbb{B}_{dr,S}} \mathbb{B}_{dr,(\tilde{S}_I)}(Re(S^{et})_*(N \otimes^L \mathbb{Z}_p)) \xrightarrow{\alpha(M) \otimes \alpha(N)} F^0 DR(S)((\mathcal{F}_S^{FDR}(M) \otimes_{O_S}^{Hdg} \mathcal{F}_S^{FDR}(N))^{an} \otimes_{O_S} (((O\mathbb{B}_{dr,\tilde{S}_I}, F), t_{IJ}))) & & \\ \downarrow T(\otimes, \mathbb{B}_{dr})(Re(S^{et})_* M \otimes^L \mathbb{Z}_p, Re(S^{et})_* N \otimes^L \mathbb{Z}_p) & & \downarrow DR(S)((T(\otimes, \mathcal{F}^{FDR})(M, N))^{an} \otimes I) \\ \mathbb{B}_{dr,(\tilde{S}_I)}(Re(S^{et})_* ((M \otimes N) \otimes^L \mathbb{Z}_p)) \xrightarrow{\alpha(M \otimes N)} F^0 DR(S)((\mathcal{F}_{FDR}^S(M \otimes N))^{an} \otimes_{O_S} ((O\mathbb{B}_{dr,\tilde{S}_I}, F), t_{IJ})) & & \end{array}$$

see definition 111 and definition 84.

*Proof.* (i): Follows from the following commutative diagram in  $(D_{\mathcal{D}(1,0)fil}(Y \times \tilde{S}_I) \times_I D_{fil}(Y \times \tilde{S}_I^{et}))$ ,

$$\begin{array}{ccc}
((\rightarrow \oplus_{(U_{I\alpha}, h_{I\alpha}) \in V_I} \tilde{g}_I^{*Hdg} h_{I\alpha} !Hdg h_{I\alpha}^!Hdg \mathbb{Z}_{p, \tilde{S}_I}^{Hdg} \xrightarrow{A_{g_{I, \alpha, \beta}^{\bullet}}^{Hdg}} & & (g_{Hdg}^{*mod} \mathcal{F}_T^{FDR}(F), \\
\oplus_{(U_{I\alpha}, h_{I\alpha}) \in V_I} h_{I\alpha} !Hdg h_{I\alpha}^!Hdg \mathbb{Z}_{p, \tilde{S}_I}^{Hdg} \rightarrow), u_{IJ}), W) & \xrightarrow{(\tilde{g}_I^{*Hdg} I^{\bullet}(U_{I\alpha}/\tilde{S}_I))} & g^{*w} e(S^{et})_* C_* L(F, W), g^*(\alpha(F))) \\
\downarrow T^{Hdg}(\tilde{g}_I, h_I)(-) & & \downarrow (T(g, \mathcal{F}^{FDR})(M), T(g, e)(M), 0) \\
((\rightarrow \oplus_{(U'_{I\alpha}, h'_{I\alpha}) \in W_I} h'_{I\alpha} !Hdg h_{I\alpha}^!Hdg \mathbb{Z}_{p, Y \times \tilde{S}_I}^{Hdg} \xrightarrow{A_{g'_{I, \alpha, \beta}^{\bullet}}^{Hdg}} & & (\mathcal{F}_T^{FDR}(g^* F), \\
\oplus_{(U'_{I\alpha}, h'_{I\alpha}) \in W_I} h'_{I\alpha} !Hdg h_{I\alpha}^!Hdg \mathbb{Z}_{p, Y \times \tilde{S}_I}^{Hdg} \rightarrow), u_{IJ}), W) & \xrightarrow{(I^{\bullet}(U'_{\alpha}/Y \times \tilde{S}_I))} & e(T^{et})_* C_* L(g^* F, W), \alpha(g^* F))
\end{array}$$

where, we have denoted for short  $V_I := \text{Var}(k)^{sm}/\tilde{S}_I$  and  $W_I := \text{Var}(k)^{sm}/Y \times \tilde{S}_I$ ,

- we denoted for short  $A_{g_{I, \alpha, \beta}^{\bullet}}^{Hdg} := \text{ad}(g_{I, \alpha, \beta}^{\bullet, !Hdg}, g_{I, \alpha, \beta}^{\bullet, !Hdg})(h_{I\alpha}^!Hdg \mathbb{Z}_{p, \tilde{S}_I}^{Hdg})$
- we denoted for short  $A_{g'_{I, \alpha, \beta}^{\bullet}}^{Hdg} := \text{ad}(g'_{I, \alpha, \beta}^{\bullet, !Hdg}, g'_{I, \alpha, \beta}^{\bullet, !Hdg})(h'_{I\alpha} !Hdg \mathbb{Z}_{p, Y \times \tilde{S}_I}^{Hdg})$
- we denote by  $g_{I, \alpha, \beta}^n : U_{I\alpha} \rightarrow U_{I\beta}$ , which satisfy  $h_{I\beta} \circ g_{I, \alpha, \beta}^n = h_{I\alpha}$ , the morphisms in the canonical projective resolution

$$q : Li_{I*} j_I^*(F, W) := (\cdots \rightarrow \oplus_{(U_{I\alpha}, h_{I\alpha}) \in \text{Var}(k)^{sm}/\tilde{S}_I} \mathbb{Z}(U_{I\alpha}/\tilde{S}_I) \xrightarrow{(\mathbb{Z}(g_{I, \alpha, \beta}^{\bullet}))} \\
\oplus_{(U_{I\alpha}, h_{I\alpha}) \in \text{Var}(k)^{sm}/\tilde{S}_I} \mathbb{Z}(U_{I\alpha}/\tilde{S}_I) \rightarrow \cdots) \rightarrow i_{I*} j_I^*(F, W)$$

- we denote by  $g'_{I, \alpha, \beta}^n : U'_{I\alpha} \rightarrow U'_{I\beta}$ , which satisfy  $h'_{I\beta} \circ g'_{I, \alpha, \beta}^n = h'_{I\alpha}$ , the morphisms in the canonical projective resolution

$$q : Li'_{I*} j_I^*(g^* F, W) := (\cdots \rightarrow \oplus_{(U'_{I\alpha}, h'_{I\alpha}) \in \text{Var}(k)^{sm}/Y \times \tilde{S}_I} \mathbb{Z}(U'_{I\alpha}/Y \times \tilde{S}_I) \xrightarrow{(\mathbb{Z}(g'_{I, \alpha, \beta}^{\bullet}))} \\
\oplus_{(U'_{I\alpha}, h'_{I\alpha}) \in \text{Var}(k)^{sm}/Y \times \tilde{S}_I} \mathbb{Z}(U'_{I\alpha}/Y \times \tilde{S}_I) \rightarrow \cdots) \rightarrow i'_{I*} j_I^*(g^* F, W)$$

(ii): Follows from (i) by adjonction.

(iii): The closed embedding case is given by (ii) and the smooth projection case follows from (i) by adjonction.

(iv): Follows from (iii) by adjonction.

(v): Obvious

□

**Proposition 74.** *Let  $p$  a prime number. Consider an embedding  $k \subset \mathbb{C}_p$ .*

(i) *Let  $S \in \text{Var}(k)$ . Let  $S = \cup_i S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Then we have the isomorphism in  $D_{\mathcal{D}(1,0)fil}(S/(\tilde{S}_I)) \times_I D_{fil}(S^{et})$*

$$\begin{aligned}
\mathcal{F}_S^{Hdg}(\mathbb{Z}_S) & \xrightarrow{\cong} (\mathcal{F}_S^{FDR}(\mathbb{Z}_S), e(S^{et})_*(\mathbb{Z}_S \otimes \mathbb{Z}_p), \alpha(\mathbb{Z}_S)) \\
& \xrightarrow{((\Omega_{\tilde{S}_I}^{\Gamma, pr}(\hat{R}^{CH}(\text{ad}(i_i^*, i_{I*})(\Gamma_{\tilde{S}_I}^{\vee, w} \mathbb{Z}_{\tilde{S}_I}))))_*, I, 0)} \\
I_S^{-, -1}((e(S)_* \mathcal{H}om((\hat{R}^{CH}(\Gamma_{\tilde{S}_I}^{\vee, w} \mathbb{Z}_{\tilde{S}_I}), \hat{R}^{CH}(x_{IJ})), (E_{zar}(\Omega_{\tilde{S}_I}^{\Gamma, pr}, F_{DR}), T_{IJ})), T(S/(\tilde{S}_I))(\mathbb{Z}_{p, S^{et}}^w), \alpha(\tilde{S}_I, \delta))) & \\
& \xrightarrow{\cong} \iota_S((\Gamma_{\tilde{S}_I}^{\vee, Hdg}(O_{\tilde{S}_I}, F_b), x_{IJ}), \mathbb{Z}_{p, S^{et}}^w, \alpha(S)) =: \iota_S(\mathbb{Z}_S^{Hdg})
\end{aligned}$$

with

$$\alpha(S) : \mathbb{B}_{dr,(\tilde{S}_I)}(\mathbb{Z}_{S^{et}} \otimes \mathbb{Z}_p) := \mathbb{B}_{dr,(\tilde{S}_I)}(\Gamma_{\tilde{S}_I}^{\vee,w} \mathbb{Z}_{p,\tilde{S}_I^{et}}, x_{IJ})$$

$$\xrightarrow{(\Gamma_{\tilde{S}_I}^{\vee} \alpha(\tilde{S}_I))} F^0 DR(S)((\Gamma_{\tilde{S}_I}^{\vee,Hdg}(O_{\tilde{S}_I}, F_b), x_{IJ}) \otimes_{O_S} (O\mathbb{B}_{dr,\tilde{S}_I}, T_{IJ}))$$

(ii) Let  $f : X \rightarrow S$  a morphism with  $X, S \in \text{Var}(k)$ ,  $X$  quasi-projective. Consider a factorization  $f : X \xrightarrow{l} Y \times S \xrightarrow{p_S} S$  with  $Y = \mathbb{P}^{N,o} \subset \mathbb{P}^N$  an open subset,  $l$  a closed embedding and  $p_S$  the projection. Let  $S = \cup_i S_i$  an open cover such that there exist closed embeddings  $i_i : S_i \hookrightarrow \tilde{S}_i$  with  $\tilde{S}_i \in \text{SmVar}(k)$ . Recall that  $S_I := \cap_{i \in I} S_i$ ,  $X_I = f^{-1}(S_I)$ , and  $\tilde{S}_I := \prod_{i \in I} \tilde{S}_i$ . Then, using proposition 73(iii), the map of definition 111 gives an isomorphism in  $D_{\mathcal{D}(1,0)fil}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et})$

$$(T_!(f, \mathcal{F}^{FDR})(\mathbb{Z}_X), T_!(e, f)(\mathbb{Z}_{p,X^{et}})) :$$

$$\mathcal{F}_S^{Hdg}(M^{BM}(X/S)) := (\mathcal{F}_S^{FDR}(Rf_! \mathbb{Z}_X), e(S^{et})_* Rf_!(\mathbb{Z}_X \otimes \mathbb{Z}_p), \alpha(Rf_! \mathbb{Z}_X))$$

$$\xrightarrow{\sim} (Rf_{Hdg!}(\Gamma_{X_I}^{\vee,Hdg}(O_{Y \times \tilde{S}_I}, F_b), x_{IJ}(X/S)), Rf_{!w} \mathbb{Z}_{p,X^{et}}^w, f_!(\alpha(X))) =: \iota_S(Rf_{!Hdg}(\mathbb{Z}_{p,X}^{Hdg})).$$

with

$$\mathbb{Z}_{p,X}^{Hdg} := ((\Gamma_{X_I}^{\vee,Hdg}(O_{Y \times \tilde{S}_I}, F_b), x_{IJ}(X/S)), \mathbb{Z}_{p,X^{et}}^w, \alpha(X)) \in C(MHM_{gm,k,\mathbb{C}_p}(X))$$

*Proof.* Follows from proposition 73(iii) and theorem 50. □

The main theorem of this section is the following :

**Theorem 54.** *Let  $p$  a prime number. Let  $k \subset \mathbb{C}_p$  a subfield.*

(i) For  $S \in \text{Var}(k)$ , we have  $\mathcal{F}_S^{Hdg}(\text{DA}_c(S)) \subset D(MHM_{gm,k,\mathbb{C}_p}(S))$ ,

$$\iota_S : D(MHM_{gm,k,\mathbb{C}_p}(S)) \hookrightarrow D_{\mathcal{D}(1,0)fil}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p fil,c,k}(S^{et})$$

being a full embedding by theorem 46.

(ii) The Hodge realization functor  $\mathcal{F}_{Hdg}(-)$  define a morphism of 2-functor on  $\text{Var}(k)$

$$\mathcal{F}_-^{Hdg} : \text{Var}(k) \rightarrow (\text{DA}_c(-) \rightarrow D(MHM_{gm,k,\mathbb{C}_p}(-)))$$

whose restriction to  $\text{QPVar}(\mathbb{C})$  is an homotopic 2-functor in sense of Ayoub. More precisely,

(ii0) for  $g : T \rightarrow S$  a morphism, with  $T, S \in \text{QPVar}(k)$ , and  $M \in \text{DA}_c(S)$ , the the map of definition 110 induces an isomorphism in  $D(MHM_{gm,k,\mathbb{C}_p}(T))$

$$T(g, \mathcal{F}^{Hdg})(M) := (T(g, \mathcal{F}^{FDR})(M), T(g, e)(M \otimes^L \mathbb{Z}_p), 0) :$$

$$g^{\star Hdg} \mathcal{F}_S^{Hdg}(M) := \iota_T^{-1}(g_{Hdg}^{\star mod} \mathcal{F}_S^{FDR}(M), g^* Re(S^{et})_*(M \otimes^L \mathbb{Z}_p), g^*(\alpha(M)))$$

$$\xrightarrow{\sim} \iota_T^{-1}(\mathcal{F}_T^{FDR}(g^* M), Re(T^{et})_* g^*(M \otimes^L \mathbb{Z}_p), \alpha(g^* M)) =: \mathcal{F}_T^{Hdg}(g^* M),$$

(ii1) for  $f : T \rightarrow S$  a morphism, with  $T, S \in \text{QPVar}(k)$ , and  $M \in \text{DA}_c(T)$ , the map of definition 111 induces an isomorphism in  $D(MHM_{gm,k,\mathbb{C}_p}(S))$

$$T_*(f, \mathcal{F}^{Hdg})(M) := (T_*(f, \mathcal{F}^{FDR})(M), I, 0) :$$

$$Rf_{Hdg*} \mathcal{F}_T^{Hdg}(M) := \iota_S^{-1}(Rf_{*}^{Hdg} \mathcal{F}_T^{FDR}(M), Rf_* Re(T^{et})_*(M \otimes^L \mathbb{Z}_p), f_*(\alpha(M)))$$

$$\xrightarrow{\sim} \iota_S^{-1}(\mathcal{F}_S^{FDR}(Rf_* M), Re(S^{et})_* Rf_*(M \otimes^L \mathbb{Z}_p), \alpha(Rf_* M)) =: \mathcal{F}_S^{Hdg}(Rf_* M),$$

(ii2) for  $f : T \rightarrow S$  a morphism, with  $T, S \in \text{QPVar}(k)$ , and  $M \in \text{DA}_c(T)$ , the map of definition 111 induces an isomorphism in  $D(\text{MHM}_{gm,k,\mathbb{C}_p}(S))$

$$\begin{aligned} T_!(f, \mathcal{F}^{Hdg})(M) &:= (T_!(f, \mathcal{F}^{FDR})(M), T_!(f, e)(M \otimes^L \mathbb{Z}_p), 0) : \\ Rf_{!Hdg} \mathcal{F}_T^{Hdg}(M) &:= \iota_S^{-1}(Rf_!^{Hdg} \mathcal{F}_T^{FDR}(M), Rf_! \text{Re}(T^{et})_*(M \otimes^L \mathbb{Z}_p), f_!(\alpha(M))) \\ &\xrightarrow{\sim} \iota_S^{-1}(\mathcal{F}_S^{FDR}(Rf_!M), \text{Re}(S^{et})_* Rf_!M \otimes \mathbb{Z}_p, \alpha(f_!M)) =: \mathcal{F}_T^{Hdg}(f_!M), \end{aligned}$$

(ii3) for  $f : T \rightarrow S$  a morphism, with  $T, S \in \text{QPVar}(k)$ , and  $M \in \text{DA}_c(S)$ , the map of definition 111 induces an isomorphism in  $D(\text{MHM}_{gm,k,\mathbb{C}_p}(T))$

$$\begin{aligned} T^!(f, \mathcal{F}^{Hdg})(M) &:= (T^!(f, \mathcal{F}^{FDR})(M), T^!(f, e)(M \otimes^L \mathbb{Z}_p), 0) : \\ f^{*Hdg} \mathcal{F}_S^{Hdg}(M) &:= \iota_T^{-1}(f^{*mod} \mathcal{F}_S^{FDR}(M), f^! \text{Re}(S^{et})_*(M \otimes^L \mathbb{Z}_p), f^!(\alpha(M))) \\ &\xrightarrow{\sim} \iota_T^{-1}(\mathcal{F}_T^{FDR}(f^!M), \text{Re}(T^{et})_* f^!(M \otimes^L \mathbb{Z}_p), \alpha(f^!M)) =: \mathcal{F}_T^{Hdg}(f^!M), \end{aligned}$$

(ii4) for  $S \in \text{Var}(k)$ , and  $M, N \in \text{DA}_c(S)$ , the map of definition 111 induces an isomorphism in  $D(\text{MHM}_{gm,k,\mathbb{C}_p}(S))$

$$\begin{aligned} T(\otimes, \mathcal{F}^{Hdg})(M, N) &:= (T(\otimes, \mathcal{F}_S^{Hdg})(M, N), I, 0) : \mathcal{F}_S^{Hdg}(M) \otimes_{O_S}^{Hdg} \mathcal{F}_S^{Hdg}(N) := \\ \iota_S^{-1}(\mathcal{F}_S^{FDR}(M) \otimes_{O_S}^{Hdg} \mathcal{F}_S^{FDR}(N), \text{Re}(S^{et})_*(M \otimes^L \mathbb{Z}_p) \otimes \text{Re}(S^{et})_*(N \otimes^L \mathbb{Z}_p), \alpha(M) \otimes \alpha(N)) \\ &\xrightarrow{\sim} \iota_S^{-1} \mathcal{F}_S^{Hdg}(M \otimes N) := \iota_S^{-1}(\mathcal{F}_S^{FDR}(M \otimes N), \text{Re}(S^{et})_*((M \otimes N) \otimes^L \mathbb{Z}_p), \alpha(M \otimes N)). \end{aligned}$$

(iii) For  $S \in \text{Var}(k)$ , the following diagram commutes :

$$\begin{array}{ccc} \text{Var}(k)/S & \xrightarrow{MH(/S)} & D(\text{MHM}_{gm,k,\mathbb{C}_p}(S)) \\ \downarrow M(/S) & & \downarrow \iota^S \\ \text{DA}(S) & \xrightarrow{\mathcal{F}_S^{Hdg}} & D_{\mathcal{D}(1,0)fil}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p,fil,c,k}(S^{et}) \end{array}$$

*Proof.* (i): Let  $M \in \text{DA}_c(S)$ . There exist by definition of constructible motives an isomorphism in  $\text{DA}(S)$

$$w(M) : M \xrightarrow{\sim} \text{Cone}(M(X_0/S)[d_0] \xrightarrow{m_1} \dots \xrightarrow{m_m} M(X_m/S)[d_m]),$$

with  $f_n : X_n \rightarrow S$  morphisms and  $X_n \in \text{QPVar}(k)$ . This gives the isomorphism in  $D_{\mathcal{D}(1,0)fil}(S/(\tilde{S}_I)) \times_I D_{\mathbb{Z}_p,fil,c,k}(S^{et})$

$$\mathcal{F}_S^{Hdg}(w(M)) : \mathcal{F}_S^{Hdg}(M) \xrightarrow{\sim} \text{Cone}(\mathcal{F}_S^{Hdg}(M(X_0/S))[d_0] \xrightarrow{\mathcal{F}_S^{Hdg}(m_1)} \dots \xrightarrow{\mathcal{F}_S^{Hdg}(m_m)} \mathcal{F}_S^{Hdg}(M(X_m/S)[d_m]),$$

On the other hand, by proposition 74(i), we have

$$\mathcal{F}_S^{Hdg}(M(X_n/S)) \xrightarrow{\sim} Rf_{!Hdg} \mathbb{Z}_{p,X}^{Hdg} \in D(\text{MHM}_{gm,k,\mathbb{C}_p}(S)).$$

This prove (i).

(ii0): Follows from theorem 50(i) and proposition 73(i).

(ii1): Follows from theorem 50(iii) and proposition 73(ii).

(ii2): Follows from theorem 50(ii) and proposition 73(iii).

(ii3): Follows from theorem 50(iv) and proposition 73(iv).

(ii4): Follows from theorem 50(v) and proposition 73(v).

(iii): By (ii), for  $g : X'/S \rightarrow X/S$  a morphism, with  $X', X, S \in \text{Var}(k)$  and  $X/S = (X, f)$ ,  $X'/S = (X', f')$ , we have by adjonction the following commutative diagram

$$\begin{array}{ccc}
\mathcal{F}_S^{Hdg}(M(X'/S) = f'_! f'^! \mathbb{Z}_S = f_! g_! g'^! \mathcal{F}_{\bar{S}}^{Hdg}(M(/S)(g)=f_! \text{ad}(g_!, g'^!)(f'^! \mathbb{Z}_S))) & \xrightarrow{\quad} & \mathcal{F}_S^{Hdg}(M(X/S) = f_! f'^! \mathbb{Z}_S) \\
\downarrow T_1(f', \mathcal{F}^{Hdg})(f'^! M(X'/S)) \circ T^1(f', \mathcal{F}^{Hdg})(M(X'/S)) & & \downarrow T_1(f, \mathcal{F}^{Hdg})(f^! M(X/S)) \circ T^1(f, \mathcal{F}^{Hdg})(M(X/S)) \\
MH(X'/S) := Rf'_!{}_{Hdg} f'^!{}_{Hdg} \mathbb{Z}_{p,S}^{Hdg} = f_!{}_{Hdg} g_!{}_{Hdg} g'^!{}_{Hdg} \mathcal{F}_{p,S}^{Hdg} \text{ad}(g_!{}_{Hdg} g'^!{}_{Hdg})(f'^!{}_{Hdg} \mathbb{Z}_{p,S}^{Hdg}) & \xrightarrow{\quad} & MH(X/S) := f_!{}_{Hdg} f'^!{}_{Hdg} \mathbb{Z}_{p,S}^{Hdg}
\end{array}$$

where the left and right columns are isomorphisms by (ii). This proves (iii).  $\square$

The theorem 54 gives immediately the following :

**Corollary 6.** *Let  $p$  a prime number. Let  $k \subset \mathbb{C}_p$  a subfield. Let  $f : U \rightarrow S$ ,  $f' : U' \rightarrow S$  morphisms, with  $U, U', S \in \text{Var}(k)$  irreducible,  $U'$  smooth. Let  $\bar{S} \in \text{PVar}(k)$  a compactification of  $S$ . Let  $\bar{X}, \bar{X}' \in \text{PVar}(k)$  compactification of  $U$  and  $U'$  respectively, such that  $f$  (resp.  $f'$ ) extend to a morphism  $\bar{f} : \bar{X} \rightarrow \bar{S}$ , resp.  $\bar{f}' : \bar{X}' \rightarrow \bar{S}$ . Denote  $\bar{D} = \bar{X} \setminus U$  and  $\bar{D}' = \bar{X}' \setminus U'$  and  $\bar{E} = (\bar{D} \times_{\bar{S}} \bar{X}') \cup (\bar{X} \times_{\bar{S}} \bar{D}')$ . Denote  $i : \bar{D} \hookrightarrow \bar{X}$ ,  $i' : \bar{D}' \hookrightarrow \bar{X}'$  denote the closed embeddings and  $j : U \hookrightarrow \bar{X}$ ,  $j' : U' \hookrightarrow \bar{X}'$  the open embeddings. Denote  $d = \dim(U)$  and  $d' = \dim(U')$ . We have the following commutative diagram in  $D(\mathbb{Z})$*

$$\begin{array}{ccc}
RHom_{\text{DA}(\bar{S})}^{\bullet}(M(U'/\bar{S}), M((\bar{X}, \bar{D})/\bar{S})) & \xrightarrow{\mathcal{F}_S^{Hdg}(-, -)} & RHom_{D(MHM_{gm,k,\mathbb{C}_p}(\bar{S}))}^{\bullet}(f'_!{}_{Hdg} \mathbb{Z}_{p,U'}^{Hdg}, f_*{}_{Hdg} \mathbb{Z}_{p,U}^{Hdg}) \\
\downarrow RI(-, -) & & \downarrow RI(-, -) \\
RHom^{\bullet}(M(\text{pt}), M(\bar{X}' \times_{\bar{S}} \bar{X}, \bar{E})(d')[2d']) & \xrightarrow{\mathcal{F}_{\text{pt}}^{Hdg}(-, -)} & RHom^{\bullet}(\mathbb{Z}_{\text{pt}}^{Hdg}, a_{U' \times_S U'} \mathbb{Z}_{p,U' \times_S U'}^{Hdg}(d')[2d']) \\
\downarrow l & & \downarrow l \\
\mathcal{Z}_d(\bar{X}' \times_{\bar{S}} \bar{X}, E, \bullet) & \xrightarrow{\mathcal{R}_{\bar{X}' \times_{\bar{S}} \bar{X}}^d} & C_{2d+\bullet}^{sym}(\bar{X}' \times_{\bar{S}} \bar{X}, E, Z(d))
\end{array}$$

where

$$M((\bar{X}, \bar{D})/\bar{S}) := \text{Cone}(\text{ad}(i_*, i^!) : M(\bar{D}/\bar{S}) \rightarrow M(\bar{X}/\bar{S})) = \bar{f}_* j_* E_{et}(\mathbb{Z}(U/U)) \in \text{DA}(\bar{S})$$

and  $l$  the isomorphisms given by canonical embedding of complexes.

*Proof.* The upper square of this diagram follows from theorem 54(ii). On the other side, the lower square follows from the absolute case.  $\square$

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