



HAL
open science

Vanishing asymptotic Maslov index for conformally symplectic flows

Marie-Claude Arnaud, Anna Florio, Valentine Roos

► **To cite this version:**

Marie-Claude Arnaud, Anna Florio, Valentine Roos. Vanishing asymptotic Maslov index for conformally symplectic flows. 2022. hal-03714715

HAL Id: hal-03714715

<https://hal.science/hal-03714715>

Preprint submitted on 5 Jul 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

VANISHING ASYMPTOTIC MASLOV INDEX FOR CONFORMALLY SYMPLECTIC FLOWS

MARIE-CLAUDE ARNAUD^{†,‡,◦}, ANNA FLORIO^{*,◦}, VALENTINE ROOS^{+,◦}

ABSTRACT. Motivated by Mather theory of minimizing measures for symplectic twist dynamics, we study conformally symplectic flows on a cotangent bundle. These dynamics are the most general dynamics for which it makes sense to look at (asymptotic) dynamical Maslov index. Our main result is the existence of invariant measures with vanishing index without any convexity hypothesis, in the general framework of conformally symplectic flows. A degenerate twist-condition hypothesis implies the existence of *ergodic* invariant measures with zero dynamical Maslov index and thus the existence of points with zero dynamical Maslov index.

1. INTRODUCTION AND MAIN RESULTS.

This study mainly concerns conformally symplectic flows that are defined on the cotangent bundle $\mathcal{M} = T^*M$ of a closed manifold M , where \mathcal{M} is endowed with its tautological 1-form λ , its symplectic form $\omega = -d\lambda$ and we denote by $\pi : T^*M \rightarrow M$ the usual projection.

Symplectic dynamics have been intensively studied because they model conservative phenomena, but a lot of phenomena are dissipative, e.g. mechanical systems with friction. Some of these dissipative dynamics are conformally symplectic : a diffeomorphism $f : \mathcal{M} \rightarrow \mathcal{M}$ is conformally symplectic if for some constant a , we have $f^*\omega = a\omega$. When $a = 1$, the diffeomorphism is symplectic. A complete vector field X on \mathcal{M} is conformally symplectic if $L_X\omega = \alpha\omega$, where L_X is the Lie derivative, for some $\alpha \in \mathbb{R}$.

When $\dim M \geq 2$ and M is connected, we have also the following characterization of conformally symplectic dynamics of \mathcal{M} : a diffeomorphism $f : \mathcal{M} \rightarrow \mathcal{M}$ is conformally symplectic if and only if the image by Df of any Lagrangian subspace in $T\mathcal{M}$ is Lagrangian. The existence of a conformal factor at every point is a result of [LW98] and the independence of this factor from the point is a result of [Lib59].

In the symplectic setting, an inspiring example is the completely integrable Hamiltonian case. Then the manifold is foliated by invariant Lagrangian graphs.

2010 *Mathematics Subject Classification.* 37E10, 37E40, 37J10, 37J30, 37J35.

Key words and phrases. Maslov index, Conformally symplectic flows, twist condition.

[†] Université Paris Cité and Sorbonne Université, CNRS, IMJ-PRG, F-75006 Paris, France .

[‡] Member of the *Institut universitaire de France*.

[◦] ANR AAPG 2021 PRC CoSyDy: Conformally symplectic dynamics, beyond symplectic dynamics.ANR-CE40-0014.

^{*} Université Paris Dauphine - Ceremade UMR 7534 Place du M^{al} De Lattre De Tassigny 75775 PARIS Cedex 16, France.

⁺ École Normale Supérieure de Lyon, UMPA UMR 5669 46 allé d'Italie, 69364 Lyon Cedex 07, France.

This example is of course very specific.

However, several authors found some traces of integrability in many non integrable cases. Aubry-Mather theory in the case of exact symplectic twist maps and its vast extension by Mañé and Mather to the case of Tonelli Hamiltonian systems are such results.

In both settings, the method is variational and the “ghosts” of invariant submanifolds are filled by minimizing orbits. A cotangent bundle has a natural Lagrangian foliation given by its vertical fiber and a feature of the minimizing orbits is that they have vanishing Maslov index with respect to this foliation.

Here, in a more general setting, our goal is to prove the existence of a large set of points with vanishing dynamical Maslov index. We recall that the Maslov index $\text{MI}(\Gamma)$ of a piece of arc of Lagrangian subspaces $\Gamma = (\Gamma_t)_{t \in I}$ of $T\mathcal{M}$ is the algebraic number of intersection of this arc with the Maslov singular cycle of the vertical foliation, i.e. the Maslov index gives more or less the number of times when the arc is non transverse to the vertical foliation. See Subsection 2.2. The dynamical Maslov index of a Lagrangian subspace L of $T\mathcal{M}$ for some time interval I and some flow (ϕ_t) whose differential preserves Lagrangian subspaces, which is denoted by $\text{DMI}(L, (\phi_t)_{t \in I})$, is then the Maslov index $\text{MI}((D\phi_t(L))_{t \in I})$. The precise definitions are given in Section 2.

We begin with a preliminary statement, that is the key result for finding invariant measures with vanishing asymptotic Maslov index.

Theorem 1.1. *Let $\mathcal{L} \subset \mathcal{M}$ be a Lagrangian graph. Let (ϕ_t) be an isotopy of conformally symplectic diffeomorphisms of \mathcal{M} such that $\phi_0 = \text{Id}_{\mathcal{M}}$. Then there exists a smooth closed 1-form $\eta : M \rightarrow \mathcal{M}$ and a Lipschitz function $u : M \rightarrow \mathbb{R}$ that is C^1 on an open subset $U \subset M$ of full Lebesgue measure such that*

$$\forall q \in U, p := \phi_1^{-1}(\eta(q) + du(q)) \in \mathcal{L} \quad \text{and} \quad \text{DMI}\left(T_p \mathcal{L}, (\phi_s)_{s \in [0,1]}\right) = 0.$$

This theorem has important consequences concerning the so-called asymptotic Maslov index.

DEFINITION. Let (ϕ_t) be an isotopy of conformally symplectic diffeomorphisms of \mathcal{M} such that $\phi_0 = \text{Id}_{\mathcal{M}}$.

- (1) Let $L \subset T\mathcal{M}$ be a Lagrangian subspace that is transverse to the vertical foliation. Whenever the limit exists, the asymptotic Maslov index of L for (ϕ_t) is

$$\text{DMI}_{\infty}(L, (\phi_t)) := \lim_{t \rightarrow +\infty} \frac{\text{DMI}(L, (\phi_s)_{s \in [0,t]})}{t}.$$

We will prove (see Corollary 5.2) that if $L, L' \subset T_x \mathcal{M}$ then

$$\text{DMI}_{\infty}(L, (\phi_t)) = \text{DMI}_{\infty}(L', (\phi_t)).$$

This allows us to introduce the following.

- (2) Let (ϕ_t) be an isotopy of conformally symplectic diffeomorphisms of \mathcal{M} such that $\phi_0 = \text{Id}_{\mathcal{M}}$. Let $x \in \mathcal{M}$. Then the dynamical asymptotic Maslov index at x for (ϕ_t) is denoted by $\text{DMI}_{\infty}(x, (\phi_t))$ and is the asymptotic Maslov index of L for every Lagrangian subspace L of $T_x \mathcal{M}$.

The definition of (asymptotic) dynamical Maslov index first appears in the work of Ruelle [Rue85]: the author introduced the notion of *rotation number* for surface diffeomorphisms that are isotopic to identity and for 3-dimensional flows, and generalized this to symplectic dynamics. He proves that if (ϕ_t) is an isotopy such that $\phi_0 = \text{Id}_{\mathcal{M}}$ and $\phi_{t+1} = \phi_t \circ \phi_1$, then for every probability measure μ invariant by ϕ_1 with compact support, $\text{DMI}_{\infty}(x, (\phi_t))$ exists at μ -almost every point and $x \mapsto \text{DMI}_{\infty}(x, (\phi_t))$ is a measurable and bounded function. Hence he defines the asymptotic Maslov index of such a measure.

DEFINITION. Let (ϕ_t) be a conformally symplectic isotopy of \mathcal{M} such that $\phi_0 = \text{Id}_{\mathcal{M}}$ and $\phi_{t+1} = \phi_t \circ \phi_1$. Let μ be a ϕ_1 -invariant probability measure with compact support. Then, the asymptotic Maslov index of μ for (ϕ_t) is

$$\text{DMI}(\mu, (\phi_t)) := \int_{\mathcal{M}} \text{DMI}_{\infty}(x, (\phi_t)) d\mu(x).$$

If μ is a ϕ_1 -invariant *ergodic* measure with compact support, then for μ -almost every $x \in \mathcal{M}$ it holds

$$\text{DMI}_{\infty}(x, (\phi_t)) = \text{DMI}(\mu, (\phi_t)).$$

We will present in Proposition 5.2 a proof of these results that is a consequence of a result of Schwartzman, [Sch57].

Our first corollary gives the existence of invariant probability measures with vanishing asymptotic Maslov index. A priori, this doesn't implies the existence of points with vanishing dynamical Maslov index.

Corollary 1.1. *Let (ϕ_t) be a conformally symplectic isotopy of \mathcal{M} such that $\phi_0 = \text{Id}_{\mathcal{M}}$ and $\phi_{t+1} = \phi_t \circ \phi_1$. Let $\mathcal{L} \subset \mathcal{M}$ be a Lagrangian submanifold that is H -isotopic¹ to a graph and such that $\bigcup_{t \in [0, +\infty)} \phi_t(\mathcal{L})$ is relatively compact. Then there exists at*

least one ϕ_1 -invariant probability measure μ whose asymptotic Maslov index is zero and whose support is in

$$\bigcap_{T \in [0, +\infty)} \overline{\bigcup_{t \in [T, +\infty)} \phi_t(\mathcal{L})}.$$

Moreover, if (ϕ_t) is a flow, then μ can be chosen (ϕ_t) invariant.

This result applies in the autonomous conservative Tonelli case –where the Hamiltonian is a proper first integral– or in the discounted autonomous case – where there is a proper Lyapunov function defined in the complement on some compact subset–.

As \mathbb{T}^{2d} can be obtained as the quotient of $T^*\mathbb{T}^d$ by a discrete group of transformations, we obtain also a result for \mathbb{T}^{2d} . In the following statement, the leaves of the reference Lagrangian foliation are the d -dimensional Lagrangian tori $\{0\} \times \mathbb{T}^d$.

Corollary 1.2. *Let (ϕ_t) be a symplectic isotopy of \mathbb{T}^{2d} such that $\phi_0 = \text{Id}_{\mathbb{T}^{2d}}$ and $\phi_{t+1} = \phi_t \circ \phi_1$. Then, there exists at least one ϕ_1 -invariant probability measure μ whose asymptotic Maslov index is zero.*

¹A H -isotopy is a Hamiltonian isotopy.

In the latter corollaries, we cannot ensure that the measure is ergodic and then we don't know if there is at least one point with zero asymptotic Maslov index. Now we will give sufficient conditions to obtain such ergodic measures and such points.

DEFINITION. A Darboux chart $F = (F_1, F_2) : \mathcal{U} \subset \mathcal{M} \rightarrow \mathbb{R}^d \times \mathbb{R}^d$ is *vertically foliated* if

- its image is a product $I^d \times J^d$ where I and J are two intervals of \mathbb{R} ;
- $\forall x \in \mathcal{U}, F(T_{\pi(x)}^* M \cap \mathcal{U}) = F_1(x) \times J^d$.

DEFINITION. An isotopy (ϕ_t) of conformally symplectic diffeomorphisms of \mathcal{M} twists the vertical if at every point $(t_0, x_0) \in \mathbb{R} \times \mathcal{M}$, there exists

- $\varepsilon > 0$;
- a vertically foliated chart $F = (F_1, F_2) : \mathcal{U} \rightarrow \mathbb{R}^{2d}$ such that $x_0 \in \mathcal{U}$, $F(\mathcal{U}) = (-a, a)^d \times (-a, a)^d$ and $F(x_0) = 0$

that satisfy for all $t \in (t_0 - \varepsilon, t_0 + \varepsilon)$

- $\mathcal{G}_t := (\phi_t \circ \phi_{t_0}^{-1})(F^{-1}(\{0_{\mathbb{R}^d}\} \times (-\frac{a}{2}, \frac{a}{2})^d)) \subset \mathcal{U}$;
- $F(\mathcal{G}_t)$ is the graph of a function $p \mapsto q = dg_t(p)$ where
 - (1) for $t \in [t_0, t_0 + \varepsilon)$, g_t is a convex function;
 - (2) for $t \in (t_0 - \varepsilon, t_0]$, g_t is a concave function².

EXAMPLE. Assume that $a : I \rightarrow \mathbb{R}$ and $H : I \times \mathcal{M} \rightarrow \mathbb{R}$ are smooth functions and let us use the notation $H_t(x) = H(t, x)$. We assume that the Hessian of H restricted to every vertical fiber is positive definite³. We define the time-dependent vector field X_t of \mathcal{M} by

$$i_{X_t} \omega = dH_t - a(t)\lambda.$$

Then the isotopy defined by X_t is conformally symplectic and twists the vertical, see Proposition 2.5. A subclass of examples is the class of discounted Tonelli flows, see e.g. [MS17a].

REMARK. In Proposition 2.4 we will prove that, when the isotopy (ϕ_t) twists the vertical, all the dynamical Maslov indices are non positive.

Theorem 1.2. *Let $\mathcal{L} \subset \mathcal{M}$ be a Lagrangian submanifold that is H -isotopic to a graph. Let (ϕ_t) be an isotopy of conformally symplectic diffeomorphisms of \mathcal{M} that twists the vertical.*

Then there exists a constant $C \in \mathbb{N}^$ and a point $x \in \mathcal{L}$ such that*

$$\forall t \in [0, +\infty), \text{DMI}(T_x \mathcal{L}, (\phi_s)_{s \in [0, t]}) \in [-C, C].$$

In particular

$$\text{DMI}_\infty(x, (\phi_t)) = 0.$$

Moreover, we deduce the following.

²We don't assume the strict concavity or convexity.

³Observe that such a fiber is a linear space, hence the Hessian has an intrinsic meaning at every point.

Theorem 1.3. *Let $\mathcal{L} \subset \mathcal{M}$ be a Lagrangian submanifold that is H -isotopic to a graph. Let (ϕ_t) be an isotopy of conformally symplectic diffeomorphisms of \mathcal{M} that twists the vertical and such that $\phi_{1+t} = \phi_t \circ \phi_1$. Let $x \in \mathcal{L}$ be the point given by Theorem 1.2. Assume that the positive orbit of x is relatively compact. Then there exists an ergodic ϕ_1 -invariant probability measure μ with compact support such that*

$$\text{DMI}(\mu, (\phi_t)) = 0.$$

Moreover, the support of μ is contained in the ω -limit set of x .

Corollary 1.3 explains why this statement is reminiscent of Mañé and Mather theory for invariant measures of Tonelli Hamiltonians flows.

DEFINITION. A measure μ is minimizing for a Tonelli Hamiltonian flow if its dual measure ν on TM is such that

$$\int_{TM} L d\nu = \inf_{\rho} \int_{TM} L d\rho,$$

where L is the associated Lagrangian function and the infimum is taken over all measures on TM invariant by the Euler-Lagrange flow.

Corollary 1.3. *Let $\mathcal{L} \subset \mathcal{M}$ be a Lagrangian graph. Let (ϕ_t) be a Tonelli Hamiltonian flow. The invariant measure μ with compact support of zero asymptotic Maslov index given by Theorem 1.3 applied at \mathcal{L} is a Mather minimizing measure.*

QUESTION. In the symplectic Tonelli case, when \mathcal{L} is not a graph, especially when its graph selector is not semi-concave, does Theorem 1.3 always give a minimizing measure?

QUESTION. Without the Tonelli hypothesis, can we characterize the invariant measure of zero asymptotic Maslov index given by Theorem 1.3?

EXAMPLE. At the beginning of this introduction, we dealt with the completely integrable case, where \mathcal{M} is foliated by invariant graphs and where there are minimizing invariant measures in each of these graphs. But there are dissipative examples where there is only one measure with zero asymptotic Maslov index. In the case of the damped pendulum, see e.g. [MS17a], there are only two invariant measures, one supported at a sink with non-zero asymptotic index and one measure supported at a saddle hyperbolic fixed point, which has zero asymptotic Maslov index. Moreover, the only points that have zero asymptotic Maslov index are the points that belong to the stable manifold of this saddle point. In this case, the Hausdorff dimension of the set of points with vanishing asymptotic Maslov index is 1. The next statement explain why it cannot be less in this setting.

Corollary 1.4. *Let (ϕ_t) be an isotopy of conformally symplectic diffeomorphisms of \mathcal{M} that twists the vertical. Assume that there exists n closed 1-forms η_1, \dots, η_n of M such that no non-trivial linear combination of them vanishes, i.e.*

$$\forall (\lambda_1, \dots, \lambda_n) \in \mathbb{R}^n \setminus \{0_{\mathbb{R}^n}\}, \forall q \in M, \sum_{k=1}^n \lambda_k \eta_k(q) \neq 0.$$

Then

$$\dim_H \left(\{x \in \mathcal{M}; \text{DMI}(x, (\phi_t)) = 0\} \right) \geq n,$$

where $\dim_H(U)$ denotes the Hausdorff dimension of a set U .

REMARK. When M is the d dimensional torus, this statement allows to bound below by d the Hausdorff dimension of the set of points with zero asymptotic Maslov index.

We now give a by-product of the proof of Theorem 1.1. This proof relies on spectral invariants that come from the symplectic topology, in particular graph selectors that were introduced by Chaperon and Sikorav, see [Cha91], [OV94] or [PPS03]. We will see in the proof that the closed 1-form η and the Lipschitz function u in Theorem 1.1 only depend on $\phi_1(\mathcal{L})$ and not on the isotopy and will deduce, after introducing in Section 5 the angular Maslov index, the following statement, which expresses the independence of the dynamical Maslov index from the isotopy.

Proposition 1.1. *Let $(\phi_{1,t})$ and $(\phi_{2,t})$ be two isotopies of conformally symplectic diffeomorphisms of \mathcal{M} such that $\phi_{1,0} = \phi_{2,0} = \text{Id}_{\mathcal{M}}$ and $\phi_{1,1} = \phi_{2,1}$. Then for every Lagrangian subspace L of $T\mathcal{M}$ such that L and $D\phi_{1,1}(L)$ are transverse to the vertical foliation, we have*

$$\text{DMI}(L, (\phi_{1,t})_{t \in [0,1]}) = \text{DMI}(L, (\phi_{2,t})_{t \in [0,1]}).$$

REMARK. For ease of reading, we have chosen not to deal with angular Maslov index in this introduction. The statement given in Section 5 is more precise, because it deals with the angular Maslov index for every Lagrangian subspace of $T\mathcal{M}$.

Organisation of the paper. Section 2 is devoted to the definition of the Maslov index and the dynamical Maslov index. We show that the twist hypothesis forces the index to be non positive. The invariance under symplectic reduction of the Maslov index is discussed following [Vit87]. In Section 3 we prove that any Lagrangian path contained in a Lagrangian submanifold and whose endpoints project on the graph selector has zero Maslov index. This result is fundamental to prove Theorem 1.1, whose proof occupies Section 4. The angular Maslov index is introduced in Section 5, where also its relation with the Maslov index is detailed. Finally, Section 6 is devoted to the proofs of the main outcomes presented in the introduction.

Acknowledgements. The authors are grateful to Patrice Le Calvez for pointing out the link with Schwartzman's article [Sch57].

2. ON MASLOV INDEX

2.1. Some reminders on Maslov index. Let \mathcal{M} be a $2d$ -dimensional symplectic manifold that admits a Lagrangian foliation \mathcal{V} . We denote by $V(x) = V_x := T_x\mathcal{V}$ its associated Lagrangian bundle. Let $p : T\mathcal{M} \rightarrow \mathcal{M}$ be the canonical projection. Let $\Lambda(\mathcal{M})$ be the Grassmanian of Lagrangian subspaces of $T\mathcal{M}$. We recall that $\Lambda(\mathcal{M})$ is a smooth manifold with dimension $2d + \frac{d(d+1)}{2}$. The fibered singular cycle associated to \mathcal{V} is the set

$$\Sigma(\mathcal{M}) = \{L \in \Lambda(\mathcal{M}) : L \cap V_{p(L)} \neq \{0\}\}.$$

Every fiber $\Sigma_x(\mathcal{M})$ of $\Sigma(\mathcal{M})$ is a cooriented algebraic singular hypersurface of $\Lambda_x(\mathcal{M})$, see e.g. [MS17b], [RS93]. Hence $\Sigma(\mathcal{M})$ is a cooriented singular hypersurface of $\Lambda(\mathcal{M})$.

The singular locus of $\Sigma(\mathcal{M})$ is then $\{L \in \Lambda(\mathcal{M}) : \dim(L \cap V_{p(L)}) \geq 2\}$ and the regular locus is

$$(1) \quad \Sigma_1 := \{L \in \Lambda : \dim(L \cap V_{p(L)}) = 1\}.$$

Once a coorientation of $\Sigma(\mathcal{M})$ is fixed, it is classical to associate to every continuous loop $\Gamma : \mathbb{T} \rightarrow \Lambda(\mathcal{M})$ its *Maslov index* $\text{MI}(\Gamma)$, that satisfies the following properties:

- two homotopic loops have the same Maslov index;
- if Γ is a loop that avoids the singular locus and is topologically transverse to the regular one of $\Sigma(\mathcal{M})$, then $\text{MI}(\Gamma)$ is the number of signed intersections of Γ with $\Sigma(\mathcal{M})$ with respect to the chosen coorientation;
- every loop is homotopic to a smooth loop that avoid the singular locus and is transverse to the regular locus.

An arc in $\Lambda(\mathcal{M})$ is an immersion $\Gamma : [0, 1] \rightarrow \Lambda(\mathcal{M})$. In particular, $\Gamma([0, 1])$ does not have self-intersections. By smooth arc, we mean a C^∞ arc. When $\Gamma : [0, 1] \rightarrow \Lambda(\mathcal{M})$ is an arc whose endpoints are in $\Lambda(\mathcal{M}) \setminus \Sigma(\mathcal{M})$, following Duistermaat [Dui76, Page 183], we can concatenate Γ with an arc Γ_1 that connects $\Gamma(1)$ to $\Gamma(0)$ in $\Lambda(\mathcal{M}) \setminus \Sigma(\mathcal{M})$. The Maslov index of Γ is the Maslov index of this loop, which is independent from the choice of Γ_1 since Γ_1 is in $\Lambda(\mathcal{M}) \setminus \Sigma(\mathcal{M})$.

REMARK. If $\Gamma : [0, 1] \rightarrow \Lambda(\mathcal{M})$ is an arc contained in $\Lambda(\mathcal{M}) \setminus \Sigma(\mathcal{M})$, i.e. $\Gamma(t) \cap \Sigma_{p \circ \Gamma(t)} = \{0\}$ for every t , then its Maslov index $\text{MI}(\Gamma)$ is zero.

2.2. Coorientation of Σ^1 . We now give some details concerning the singular and regular loci of $\Sigma(\mathcal{M})$ and explain our choice of coorientation of $\Sigma(\mathcal{M})$. For more details, see for example [Dui76]. For ease of reading, we denote $\Sigma(\mathcal{M})$ (resp. $\Lambda(\mathcal{M})$) by Σ (resp. Λ).

Then Σ is an algebraic subvariety of Λ that is the union of

- the regular locus that is the smooth submanifold of codimension 1 and is defined in (1),
- the boundary of Σ_1 , i.e. the singular locus $\Sigma \setminus \Sigma^1$, that is a finite union of submanifolds with codimension at least 3.

Since every loop is homotopic to a smooth loop avoiding the singular locus and intersecting transversally the regular one and since two homotopic loops have the same Maslov index, we just have to define the coorientation at points of Σ^1 . To do that, we introduce the notion of height in a symplectic vector space (E^{2d}, Ω) .

We fix a reference Lagrangian subspace V of E and denote by P^V the canonical projection on the quotient vector space E/V . If L_1, L_2 are two Lagrangian subspaces of E that are transverse to V , we define the height of L_1 above L_2 with respect to V , see [Arn08], as follows.

DEFINITION. Let $L_1, L_2 \subset E$ be two Lagrangian subspaces both transverse to V . The *height* of L_2 above L_1 with respect to V is the quadratic form

$$\mathcal{Q}_V(L_1, L_2) : E/V \rightarrow \mathbb{R}$$

defined by

$$\forall v \in E/V, \mathcal{Q}_V(L_1, L_2)(v) := \Omega((P^V|_{L_1})^{-1}(v), (P^V|_{L_2})^{-1}(v)).$$

With the hypotheses of this definition, the kernel of $\mathcal{Q}_V(L_1, L_2)$ is isomorphic to $L_1 \cap L_2$. In particular, L_1 is transverse to L_2 if and only if $\mathcal{Q}_V(L_1, L_2)$ is non degenerate.

We have

- If L_1, L_2, L_3 are Lagrangian subspaces in E , all transverse to V , it holds, see [Arn08],

$$(2) \quad \mathcal{Q}_V(L_1, L_3) = \mathcal{Q}_V(L_1, L_2) + \mathcal{Q}_V(L_2, L_3).$$

- if V, K, L are Lagrangian subspace of E such that each of them is transverse to the two others, then $\mathcal{Q}_V(K, L) \circ P^V|_L = -\mathcal{Q}_K(V, L) \circ P^K|_L$ and then $\mathcal{Q}_V(K, L)$ and $-\mathcal{Q}_K(V, L)$ have the same signature.

Let us prove that $\mathcal{Q}_V(K, L) \circ P^V|_L = -\mathcal{Q}_K(V, L) \circ P^K|_L$. For $\ell \in L$, there exists a unique pair of vectors $v \in V, k \in K$ such that $\ell = v + k$. then we have

- $\mathcal{Q}_V(K, L) \circ P^V(\ell) = \Omega(k, \ell) = \Omega(k, v);$
- $-\mathcal{Q}_K(V, L) \circ P^K(\ell) = -\Omega(v, \ell) = -\Omega(v, k) = \Omega(k, v).$
- if L and K are Lagrangian subspaces that are transverse to V and if $\phi : E \hookrightarrow$ is a symplectic isomorphism, then $\mathcal{Q}_V(K, L)$ has same signature as $\mathcal{Q}_{\phi(V)}(\phi(K), \phi(L))$.

We now describe the local coorientation of Σ_1 that we will use. Let us fix $L_0 \in \Sigma_1$ and let $x_0 := p(L_0)$. We have $\dim(L_0 \cap V_{x_0}) = 1$. We fix a Darboux chart $F = (F_1, F_2) : \mathcal{U} \rightarrow \mathbb{R}^{2d}$ at x_0 such that \mathcal{U} is a small neighborhood of x_0 in \mathcal{M} , $F(\mathcal{U}) = [a, b]^d \times [a, b]^d$ and $DF_{2|L_0}$ is injective and

$$\forall x \in \mathcal{U}, F(\mathcal{V}(x) \cap \mathcal{U}) = F_1(x) \times [a, b]^d.$$

Let us explain why such a chart exists. Using Theorem 7.1 of [Wei71], we can map locally the foliation \mathcal{V} onto the vertical foliation of \mathbb{R}^{2d} by a symplectic chart (U, Φ) . Then, composing with a symplectic isomorphism $\psi_t(x, y) = (x, y + tx)$ of $\mathbb{R}^d \times \mathbb{R}^d$, for some $t \in \mathbb{R}$, we obtain a new chart $F = (F_1, F_2)$ that maps \mathcal{V} onto the vertical foliation such that $DF(L_0)$ is transverse to $\{0\} \times \mathbb{R}^d$ and then $DF_{2|L_0}$ is injective.

We denote by \mathcal{K} the Lagrangian foliation with leaves $F^{-1}([a, b]^d \times \{y_0\})$. Then it is transverse to the vertical bundle V . Moreover, $T_{x_0}\mathcal{K}$ and L_0 are transverse, since $DF_{2|L_0}$ is injective. We denote by K the tangent bundle to \mathcal{K} . Because $\dim(L_0 \cap V) = 1$, the kernel of $\mathcal{Q}_K(V, L_0)$ is 1-dimensional. We denote by n the index⁴ of $\mathcal{Q}_K(V, L_0)$. We define

$$\mathcal{P}_1 = \{L \in \Lambda \setminus \Sigma; p(L) \in \mathcal{U}, L \pitchfork K, \text{ index } \mathcal{Q}_K(V, L) = n\}$$

and

$$\mathcal{P}_2 = \{L \in \Lambda \setminus \Sigma; p(L) \in \mathcal{U}, L \pitchfork K, \text{ index } \mathcal{Q}_K(V, L) = n + 1\}.$$

Observe that \mathcal{P}_1 and \mathcal{P}_2 are connected and that $\mathcal{P}_1 \cup \mathcal{P}_2 \cup \Sigma_1$ is a neighbourhood of L_0 in Λ . Hence \mathcal{P}_1 and \mathcal{P}_2 define locally a coorientation⁵ of Σ_1 at L_0 . To be sure that we obtain a global coorientation of Σ , we have to prove that this local coorientation is independent from the choice of our foliation \mathcal{K} . We just have to

⁴The index of a quadratic form is the maximum dimension of a subspace of E on which the quadratic form is negative definite.

⁵Let $\gamma \subset \mathcal{P}_1 \cup \mathcal{P}_1 \cup \Sigma_1$ be a path from \mathcal{P}_2 to \mathcal{P}_1 , crossing Σ_1 transversally once at $\gamma(t)$. Then $\gamma'(t) \in \mathbb{R}_+ N$, where N is a normal vector field to Σ_1 and determines a coorientation of Σ_1 at L_0 .

look at what happens in the fiber Λ_{x_0} for different choices of K_{x_0} . In other words, we will prove a result in a fixed symplectic vector space (E, Ω) .

Proposition 2.1. *Let V, L_0 be two Lagrangian subspaces of E such that $\dim(L_0 \cap V) = 1$. Let K_1, K_2 be two Lagrangian subspaces of E that are transverse to L_0 and V . We denote by n_i the index of $\mathcal{Q}_{K_i}(V, L_0)$. There exists a neighbourhood \mathcal{U} of L_0 in the Lagrangian Grassmannian of E such that*

$$\{L \in \mathcal{U}; L \pitchfork K_1, \text{ index } \mathcal{Q}_{K_1}(V, L) = n_1 + 1\} = \\ \{L \in \mathcal{U}; L \pitchfork K_2, \text{ index } \mathcal{Q}_{K_2}(V, L) = n_2 + 1\}$$

and

$$\{L \in \mathcal{U}; L \pitchfork K_1, \text{ index } \mathcal{Q}_{K_1}(V, L) = n_1\} = \{L \in \mathcal{U}; L \pitchfork K_2, \text{ index } \mathcal{Q}_{K_2}(V, L) = n_2\}.$$

Proof. Because, for $j = 1, 2$, V and K_j are transverse Lagrangian subspaces, every basis (e_1, \dots, e_d) of V can be completed in a symplectic basis $(e, f^j) = (e_1, \dots, e_d, f_1^j, \dots, f_d^j)$ of E such that $f_i^j \in K_j$. Then, every Lagrangian subspace L of E that is close enough to L_0 is the graph in this basis of a $d \times d$ symmetric matrix S_j^L that continuously depends on L and is close to $S_j^{L_0}$. We identify V with \mathbb{R}^d via the basis (e_i) .

As $\dim \ker S_j^{L_0} = 1$, we have $\mathbb{R}^d = \mathbb{R}\ell_j(L_0) + E_j(L_0)$ where $\ker S_j^{L_0} = \mathbb{R}\ell_j(L_0)$ and $E_j(L_0) = (\mathbb{R}\ell_j(L_0))^\perp$ is the orthogonal of $\ker S_j^{L_0}$ for the usual euclidean scalar product, i.e. the sum of the eigenspaces for the non-zero eigenvalues. Observe that we can choose $\ell_1(L_0) = \ell_2(L_0)$. For L in some neighbourhood \mathcal{U} of L_0 , S_j^L has a spectral gap with one eigenvalue $\lambda(S_j^L)$ close to 0 and the others far away from 0. Hence we can continuously extend $\ell_j(L)$ and $E_j(L)$ for L close to L_0 in such a way that $\ell_j(L)$ is an eigenvector for the eigenvalue that is close to 0, and $E_j(L)$ is $(\mathbb{R}\ell_j(L))^\perp$. Moreover, the signature of the restriction of S_j^L to $E_j(L)$ remains equal to its value for $L = L_0$ if \mathcal{U} is small enough.

The matrix of $\mathcal{Q}_{K_j}(V, L)$ in the basis $(P^{K_j}(e_1), \dots, P^{K_j}(e_d))$ of E/K_j is S_j^L and then to estimate the index of $\mathcal{Q}_{K_j}(V, L)$, we only need to know the sign of $\lambda(S_j^L)$.

We recall that when $L \in \mathcal{U}$ is transverse to V , we have $\mathcal{Q}_{K_j}(V, L) \circ (P^{K_j}|_L)^{-1} = -\mathcal{Q}_V(K_j, L) \circ (P^V|_L)^{-1}$. The matrix of $-\mathcal{Q}_V(K_j, L)$ in the basis $(P^V(f_1^j), \dots, P^V(f_d^j))$ is $(S_j^L)^{-1}$ and thus we are reduced to estimate the sign of the eigenvalue of $(S_j^L)^{-1}$ that has the largest absolute value. Observe that $P^V(f_i^1) = P^V(f_i^2)$. We denote by S the matrix of $\mathcal{Q}_V(K_1, K_2)$ in the same basis and we deduce from (2) that

$$(3) \quad -\left(S_1^L\right)^{-1} = -\left(S_2^L\right)^{-1} + S$$

Let us denote by $\|\cdot\|_2$ the usual Euclidean norm on \mathbb{R}^d and let us endow the set of d -dimensional matrices with the associated norm defined by

$$\|S\| = \sup_{\|v\|_2=1} \|Sv\|_2.$$

Then if \mathcal{U} is small enough, there exists $C > \|S\|$ such that for every $L \in \mathcal{U}$, $(\lambda(S_j^L))^{-1}$ is the only eigenvalue of $(S_j^L)^{-1}$ whose absolute value is larger than $3C$ and C is an upper bound of the modulus of all the other eigenvalues of $(S_j^L)^{-1}$.

Let us prove that $\lambda(S_1^L)$ and $\lambda(S_2^L)$ have the same sign. Let $v \in \mathbb{R}^d$ be an eigenvector of S_1^L for the eigenvalue $\lambda(S_1^L)$. Then there exists $v_1, v_2 \in \mathbb{R}^d$ that are

mutually orthogonal such that $v = v_1 + v_2$, $S_2^L v_1 = \lambda(S_2^L)v_1$ and v_2 is orthogonal to the eigenspace of S_2^L for $\lambda(S_2^L)$. Using (3), we obtain

$$(\lambda(S_1^L))^{-1} - (\lambda(S_2^L))^{-1} \frac{\|v_1\|_2^2}{\|v\|_2^2} = \frac{v_2^T}{\|v\|_2} (S_2^L)^{-1} \frac{v_2}{\|v\|_2} - \frac{v^T}{\|v\|_2} S \frac{v}{\|v\|_2}$$

Observe that the absolute value of the right-hand term is less than $2C$. If $\lambda(S_1^L)$ and $\lambda(S_2^L)$ have different signs, then the absolute value of the left-hand term is larger than the absolute value of $(\lambda(S_1^L))^{-1}$, then larger than $3C$, which provides a contradiction. \square

In order to define the Maslov index, we first introduce the notions of positive (resp. negative) arc. Recall that K denotes the tangent bundle to \mathcal{K} , where \mathcal{K} is the Lagrangian foliation with leaves $F^{-1}([a, b]^d \times \{y_0\})$.

DEFINITION. With the same notation, an arc $\Gamma : (-\varepsilon_0, \varepsilon_0) \rightarrow \Lambda$ such that

$$\Gamma((-\varepsilon_0, \varepsilon_0)) \cap \Sigma = \Gamma((-\varepsilon_0, \varepsilon_0)) \cap \Sigma_1 = \{\Gamma(0)\} = \{L_0\}$$

and that is topologically transverse to Σ^1 is *positive* if there exists $\varepsilon > 0$ such that

- for every $t \in (-\varepsilon, 0)$, $\text{index}(\mathcal{Q}_K(V, \Gamma(t))) = \text{index}(\mathcal{Q}_K(V, L_0)) + 1$;
- for every $t \in (0, \varepsilon)$, $\text{index}(\mathcal{Q}_K(V, \Gamma(t))) = \text{index}(\mathcal{Q}_K(V, L_0))$.

Respectively, an arc $\Gamma : (-\varepsilon_0, \varepsilon_0) \rightarrow \Lambda$ is *negative* if $\Gamma \circ (-\text{Id})$ is positive.

REMARK. This is equivalent to

- for every $t \in (-\varepsilon, 0)$, $\text{index}(\mathcal{Q}_V(K, \Gamma(t))) = d - \text{index}(\mathcal{Q}_K(V, L_0)) - 1$;
- for every $t \in (0, \varepsilon)$, $\text{index}(\mathcal{Q}_V(K, \Gamma(t))) = d - \text{index}(\mathcal{Q}_K(V, L_0))$.

DEFINITION. Let $\Gamma : [a, b] \rightarrow \Lambda$ be an arc.

- A $t \in [a, b]$ is a *crossing* for Γ if $\Gamma(t) \in \Sigma$.
- The arc Γ is in *general position* with respect to Σ if $\Gamma(a), \Gamma(b) \in \Lambda \setminus \Sigma$ and the path Γ is topologically transverse to Σ .
- The arc Γ is in *D-general position* with respect to Σ if $\Gamma(a), \Gamma(b) \in \Lambda \setminus \Sigma$ and the path Γ is transverse (in the differentiable sense) to Σ .

REMARK. If $\Gamma : [a, b] \rightarrow \Lambda$ is in general position with respect to Σ , then each crossing for Γ is isolated. Let $[a, b]$ be fixed and let $k \in \mathbb{N}^* \cup \{\infty\}$. Then, the set of C^k arcs $\Gamma : [a, b] \rightarrow \Lambda$ that are in D-general position with respect to Σ is open for the C^1 -topology.

Let $\Gamma : [a, b] \rightarrow \Lambda$ be an arc in general position with respect to Σ . A crossing t is called *positive*, respectively *negative*, if there exists $\varepsilon > 0$ such that the arc $\Gamma|_{[t-\varepsilon, t+\varepsilon]} : [t-\varepsilon, t+\varepsilon] \rightarrow \Lambda$ is positive, respectively negative.

DEFINITION. Let $\Gamma : [a, b] \rightarrow \Lambda$ be an arc in general position with respect to Σ . The Maslov index of Γ with respect to V or \mathcal{V} is

$$\text{MI}(\Gamma) :=$$

$$\text{Card}\{t : t \text{ is a positive crossing for } \Gamma\} - \text{Card}\{t : t \text{ is a negative crossing for } \Gamma\}.$$

The notion of Maslov index can be extended to Lagrangian paths that are not in general position.

DEFINITION. Let $\Gamma : [a, b] \rightarrow \Lambda$ be a path such that $\Gamma(a), \Gamma(b) \in \Lambda \setminus \Sigma$ (not necessarily in general position with respect to Σ). Let $\tilde{\Gamma} : [a, b] \rightarrow \Lambda$ be a smooth arc that is C^1 -close to Γ and is in general position with respect to Σ . Then

$$\text{MI}(\Gamma) := \text{MI}(\tilde{\Gamma}).$$

For the existence of the perturbation $\tilde{\Gamma}$ of Γ and for the independence of the previous definition from the choice of $\tilde{\Gamma}$ we refer to [MBA72] or [CLM94].

REMARK. Let ϕ be a conformally symplectic diffeomorphism on \mathcal{M} . Let $\Gamma : [a, b] \rightarrow \Lambda$ be a smooth path such that $\Gamma(a), \Gamma(b) \notin \Sigma$. Then

$$D\phi(\Gamma) : [a, b] \ni t \rightarrow D\phi(\Gamma(t)) \in \Lambda$$

is still a smooth path such that $D\phi(\Gamma)(a), D\phi(\Gamma)(b)$ do not belong to

$$\{L \in \Lambda : L \cap D\phi(V)_{p(L)} \neq \{0\}\},$$

where $D\phi(V)_x$ is the tangent bundle associated to the Lagrangian foliation $\phi(\mathcal{V})$. Then the Maslov index $\text{MI}(\Gamma)$, calculated with respect to the Lagrangian foliation \mathcal{V} , is equal to the Maslov index $\text{MI}(D\phi(\Gamma))$, calculated with respect to the Lagrangian foliation $\phi(\mathcal{V})$.

Moreover, if $\phi(\mathcal{V}) = \mathcal{V}$, then

$$\text{MI}(\Gamma) = \text{MI}(D\phi(\Gamma)).$$

In particular, for $\mathcal{M} = T^*M$, the Maslov index is invariant by *vertical translations*, that is by any diffeomorphism of the form $\phi(p) = p + \eta \circ \pi(p)$, where η is a closed 1-form in T^*M .

2.3. Dynamical Maslov index. We now give the definition of dynamical Maslov index.

DEFINITION. Let (\mathcal{M}, ω) be a symplectic manifold that admits a Lagrangian foliation \mathcal{V} . Let (ϕ_t) be an isotopy of conformally symplectic diffeomorphisms of \mathcal{M} . Let $L \in \Lambda$ and $[\alpha, \beta] \subset \mathbb{R}$ be such that $D\phi_\alpha(L), D\phi_\beta(L) \notin \Sigma$. Then

$$\text{DMI}(L, (\phi_t)_{t \in [\alpha, \beta]}) := \text{MI}(\Gamma),$$

where Γ is the Lagrangian path $[\alpha, \beta] \ni t \mapsto \Gamma(t) := D\phi_t(L) \in \Lambda$ and the Maslov index $\text{MI}(\Gamma)$ is calculated with respect to the Lagrangian foliation \mathcal{V} .

2.4. Twist and Maslov index. In this section, we work in T^*M and we denote $\mathcal{V}(x) = T_x^*M$.

In the introduction, we gave the definition of an isotopy which twists the vertical. We can enhance this in the following way (we adopt the same notations F , g_t and \mathcal{G}_t as in the definition of twist of the vertical).

DEFINITION. An isotopy (ϕ_t) of conformally symplectic diffeomorphisms of \mathcal{M} strictly twists the vertical if it twists the vertical and at every $t_0 \in \mathbb{R}$

- for all $t \in (t_0, t_0 + \epsilon)$ the image $F(\mathcal{G}_t)$ is the graph of a function $p \mapsto q = dg_t(p)$ where g_t is a strictly convex function i.e. such that d^2g_t is positive definite;

- for all $t \in (t_0 - \epsilon, t_0)$ the image $F(\mathcal{G}_t)$ is the graph of a function $p \mapsto q = dg_t(p)$ where g_t is a strictly concave function i.e. such that d^2g_t is negative definite.

Observe that the condition of convexity depends on the charts we choose (even if the property of twisting the vertical is invariant by symplectic conjugation that preserves the vertical foliation). This is a motivation to give a result of the twist property that doesn't use any chart.

Proposition 2.2. *Let (ϕ_t) be an isotopy of conformally symplectic diffeomorphisms of T^*M that twists the vertical. Let $x \in T^*M$ and let $t_0 \in \mathbb{R}$. We denote $x_t = \phi_t(x)$. Let K be a continuous Lagrangian bundle that is defined in a neighbourhood of x_{t_0} and is transverse to the vertical bundle. Then there exists $\epsilon > 0$ such that*

- $\forall t \in (t_0, t_0 + \epsilon), Q_{K(x_t)}(D\phi_t \circ (D\phi_{t_0})^{-1}V(x_{t_0}), V(x_t))$ is a negative semi-definite quadratic form;
- $\forall t \in (t_0 - \epsilon, t_0), Q_{K(x_t)}(D\phi_t \circ (D\phi_{t_0})^{-1}V(x_{t_0}), V(x_t))$ is a positive semi-definite quadratic form.

Moreover, when (ϕ_t) strictly twists the vertical, the considered quadratic forms are negative definite or positive definite.

Proof of Proposition 2.2. We fix $\epsilon > 0$ and a vertically foliated chart $F = (F_1, F_2) : \mathcal{U} \rightarrow \mathbb{R}^{2d}$ such that $x_{t_0} \in \mathcal{U}$, $F(x_{t_0}) = 0$ and for $t \in (t_0 - \epsilon, t_0 + \epsilon)$

- $\mathcal{G}_t := (\phi_t \circ \phi_{t_0}^{-1})(F^{-1}(\{0_{\mathbb{R}^d}\} \times (-\frac{\epsilon}{2}, \frac{\epsilon}{2})^d)) \subset \mathcal{U}$;
- $F(\mathcal{G}_t)$ is the graph of a function $p \mapsto q = dg_t(p)$ where
 - (1) for $t \in [t_0, t_0 + \epsilon)$, g_t is a convex function;
 - (2) for $t \in (t_0 - \epsilon, t_0]$, g_t is a concave function.

As previously, we denote by \mathcal{K} the Lagrangian foliation with leaves $F^{-1}([-a, a]^d \times \{y_0\})$ and by K its tangent bundle. For $t \in (t_0, t_0 + \epsilon)$ (resp. $(t_0 - \epsilon, t_0)$), the quadratic form

$$Q_{K(x_t)}(D(\phi_t \circ \phi_{t_0}^{-1})V(x_{t_0}), V(x_t)) = -Q_{K(x_t)}(V(x_t), D(\phi_t \circ \phi_{t_0}^{-1})V(x_{t_0}))$$

expressed in the chart F is just $-D^2g_t(F_2(x_{t_0}))$ that is a negative (resp. positive) semi-definite quadratic form because the isotopy twists the vertical.

When the isotopy strictly twists the vertical, we obtain in this case a negative (resp. positive) definite quadratic form.

Observe that the bundle K that we use in the proof is not necessarily the same bundle as in the statement. But because the two are transverse to the vertical foliation and we consider the height between the vertical and Lagrangian subspaces that are close to the vertical (ϵ is small), the two indices are the same (we can build an isotopy between the two bundle that won't change the signature). \square

Proposition 2.3. *Let (X_t) be a conformally symplectic vector field that generates an isotopy of conformally symplectic diffeomorphisms of T^*M . We assume that at every $x \in T^*M$, there exists a vertically foliated chart $F = (F_1, F_2) : \mathcal{U} \rightarrow \mathbb{R}^{2d}$ such that if we write the vector field $X = (X_q, X_p)$ in this chart, then $\partial_p X_q$, which is always symmetric because the vector field is symplectic, is positive definite.*

*Let $x \in T^*M$ and let us denote $x_t = \phi_t(x)$. Let $t_0 \in \mathbb{R}$. Let K be a continuous Lagrangian bundle that is defined in a neighbourhood of x_{t_0} and is transverse to the vertical bundle. Then there exists $\epsilon > 0$ such that*

- $\forall t \in (t_0, t_0 + \epsilon), Q_{K(x_t)}(D\phi_t \circ (D\phi_{t_0})^{-1}V(x_{t_0}), V(x_t))$ is positive definite;

- $\forall t \in (t_0 - \varepsilon, t_0), Q_{K(x_t)}(D\phi_t \circ (D\phi_{t_0})^{-1}V(x_{t_0}), V(x_t))$ is negative definite.

Proof of Proposition 2.3. As noticed in the proof of Proposition 2.2, we only need to prove the result for the tangent space K to Lagrangian foliation \mathcal{K} with leaves $F^{-1}([-a, a]^d \times \{y_0\})$.

In the chosen chart, the Jacobian matrix of X is

$$DX(x_{t_0}) = \begin{pmatrix} \partial_q X_q(x_{t_0}) & \partial_p X_q(x_{t_0}) \\ \partial_q X_p(x_{t_0}) & \partial_p X_p(x_{t_0}) \end{pmatrix}$$

and if we denote

$$D\phi_t(x)(D\phi_{t_0})^{-1}(x_{t_0}) = \begin{pmatrix} a_t & b_t \\ c_t & d_t \end{pmatrix}$$

then we have

$$(4) \quad \begin{cases} \dot{b}_t = \partial_q X_q b_t + \partial_p X_q d_t \\ \dot{d}_t = \partial_q X_p b_t + \partial_p X_p d_t. \end{cases}$$

Hence uniformly in x it holds $d_t = \mathbf{1}_d + o(t - t_0)$ and $b_t = (t - t_0)\partial_p X_q(x_{t_0}) + o((t - t_0)^2)$, which gives $b_t(d_t)^{-1} = (t - t_0)\partial_p X_q(x_{t_0}) + o((t - t_0)^2)$. Because $b_t(d_t)^{-1}$ is the matrix of

$$Q_{K(x_t)}(D\phi_t \circ (D\phi_{t_0})^{-1}V(x_{t_0}), V(x_t))$$

in the chart, this gives the wanted result. \square

Proposition 2.4. *Let (ϕ_t) be an isotopy of conformally symplectic diffeomorphisms of T^*M that twists the vertical. Then if $L \in \Lambda$ and $[\alpha, \beta] \subset \mathbb{R}$ are such that $D\phi_\alpha(L), D\phi_\beta(L) \notin \Sigma$, then*

$$\text{DMI}(L, (\phi_t)_{t \in [\alpha, \beta]}) \leq 0.$$

Proof of Proposition 2.4. Let us first assume that (ϕ_t) is an isotopy that satisfies the conclusion of Proposition 2.2 (with definite quadratic forms) in a neighborhood of $(D\phi_t L)_{t \in [\alpha, \beta]}$. Perturbing L , we can assume that $(D\phi_t L)_{t \in [\alpha, \beta]}$ intersects Σ eventually only at the regular locus Σ_1 . We will prove that this implies that $(D\phi_t L)_{t \in [\alpha, \beta]}$ is actually topologically transverse to Σ and that the Maslov index is non-positive.

Let $t_0 \in [\alpha, \beta]$ be such that $D\phi_{t_0} L \in \Sigma_1$. We introduce $x_0 = p(L)$ and $x_t := \phi_t(x_0)$. Let K be a continuous Lagrangian bundle that is defined in a neighbourhood of x_{t_0} and is transverse to the vertical bundle. Then by hypothesis there exists $\varepsilon > 0$ such that

- $\forall t \in (t_0, t_0 + \varepsilon), Q_{K(x_t)}(D\phi_t \circ (D\phi_{t_0})^{-1}V(x_{t_0}), V(x_t))$ is positive definite;
- $\forall t \in (t_0 - \varepsilon, t_0), Q_{K(x_t)}(D\phi_t \circ (D\phi_{t_0})^{-1}V(x_{t_0}), V(x_t))$ is negative definite.

Then, for $t \in [t_0, t_0 + \varepsilon)$, if $L_t = D\phi_t L$, we have

$$\mathcal{Q}_{K(x_t)}(L_t, V(x_t)) =$$

$$\mathcal{Q}_{K(x_t)}(D(\phi_t \circ \phi_{t_0}^{-1})L_{t_0}, D(\phi_t \circ \phi_{t_0}^{-1})V(x_{t_0})) + \mathcal{Q}_{K(x_t)}(D(\phi_t \circ \phi_{t_0}^{-1})V(x_{t_0}), V(x_t)).$$

Then:

- because of the invariance by symplectic diffeomorphisms, the signature of $\mathcal{Q}_{K(x_t)}(D(\phi_t \circ \phi_{t_0}^{-1})L_{t_0}, D(\phi_t \circ \phi_{t_0}^{-1})V(x_{t_0}))$ is equal to the signature of $\mathcal{Q}_{D(\phi_{t_0} \circ \phi_t^{-1})^{-1}K(x_t)}(L_{t_0}, V(x_{t_0}))$ and if we chose ε small enough, this signature is equal to the signature of $\mathcal{Q}_{K(x_{t_0})}(L_{t_0}, V(x_{t_0}))$;

- the quadratic form

$$\mathcal{Q}_{K(x_t)}(D(\phi_t \circ \phi_{t_0}^{-1})V(x_{t_0}), V(x_t)) = -\mathcal{Q}_{K(x_t)}(V(x_t), D(\phi_t \circ \phi_{t_0}^{-1})V(x_{t_0}))$$

is negative definite because we assume that the isotopy (ϕ_t) strictly twists the vertical.

As the index of the sum of a quadratic form Q and a negative definite quadratic form is at least the sum of the index and the nullity of Q , we deduce that for $t \in (t_0, t_0 + \varepsilon)$ the index of $\mathcal{Q}_{K(x_t)}(L_t, V(x_t))$ is at least the sum of 1, which is the nullity of $\mathcal{Q}_{K(x_{t_0})}(L_{t_0}, V(x_{t_0}))$, and the index of $\mathcal{Q}_{K(x_0)}(L_{t_0}, V(x_0))$. Moreover, as the quadratic form $-\mathcal{Q}_{K(x_t)}(V(x_t), D(\phi_t \circ \phi_{t_0}^{-1})V(x_{t_0}))$ is close to 0 for ε small enough and because of the continuous dependence of the eigenvalues on the quadratic form, the index of $\mathcal{Q}_{K(x_t)}(L_t, V(x_t))$ is exactly the sum of 1 and the index of $\mathcal{Q}_{K(x_0)}(L_{t_0}, V(x_0))$. A similar argument gives that for $t \in (t_0 - \varepsilon, t_0)$, the index of $\mathcal{Q}_{K(x_t)}(L_t, V(x_t))$ is exactly the index of $\mathcal{Q}_{K(x_0)}(L_{t_0}, V(x_0))$. This proves that $(L_t)_{t \in [\alpha, \beta]}$ intersect Σ_1 topologically transversally and in the negative sense and that the Maslov index is non-positive.

Let now (ϕ_t) be an isotopy that twists the vertical (with no further assumptions). Consider the Lagrangian path $(D\phi_t L)_{t \in [\alpha, \beta]}$.

Claim 2.1. *There exists an isotopy $(\tilde{\phi}_t)$ of conformally symplectic diffeomorphisms of \mathcal{M} such that*

- $(D\tilde{\phi}_t L)_{t \in [\alpha, \beta]}$ is a smooth perturbation of $(D\phi_t L)_{t \in [\alpha, \beta]}$, and in particular, $\text{MI}((D\phi_t L)_{t \in [\alpha, \beta]}) = \text{MI}((D\tilde{\phi}_t L)_{t \in [\alpha, \beta]})$;
- $(\tilde{\phi}_t)$ is an isotopy that satisfies the conclusion of Proposition 2.2 (with definite quadratic forms) in a neighborhood of $(D\tilde{\phi}_t L)_{t \in [\alpha, \beta]}$.

The claim immediately implies that the Maslov index of $(D\phi_t L)_{t \in [\alpha, \beta]}$ is non-positive, as desired.

Let us now prove the claim. Because (ϕ_t) twists the vertical, we deduce from Proposition 2.2 that there exists $\varepsilon > 0$ such that

- $\forall t \in (t_0, t_0 + \varepsilon)$, $\mathcal{Q}_{K(x_t)}(D\phi_t \circ (D\phi_{t_0})^{-1}V(x_{t_0}), V(x_t))$ is a negative semi-definite quadratic form;
- $\forall t \in (t_0 - \varepsilon, t_0)$, $\mathcal{Q}_{K(x_t)}(D\phi_t \circ (D\phi_{t_0})^{-1}V(x_{t_0}), V(x_t))$ is a positive semi-definite quadratic form.

If the vector field associated to (ϕ_t) is written in the chart as $X = (X_q, X_p)$, we deduce from equations (4) that

$$\frac{d}{dt}(b_t(d_t)^{-1}) = \partial_q X_q b_t(d_t)^{-1} + \partial_p X_q - b_t(d_t)^{-1} \partial_q X_p b_t(d_t)^{-1} - b_t(d_t)^{-1} \partial_p X_p.$$

Because $b_t(d_t)^{-1}$ is the matrix of $\mathcal{Q}_{K(x_t)}(D\phi_t \circ (D\phi_{t_0})^{-1}V(x_{t_0}), V(x_t))$ that is zero for $t = t_0$, we deduce that

$$\frac{d}{dt}(b_t(d_t)^{-1})|_{t=t_0} = \partial_p X_q.$$

and then that $\partial_p X_q$ is a positive semi-definite quadratic form. We now add to X a small Hamiltonian vector-field Y that is associated to a Hamiltonian H that is strictly convex in the fiber direction. This implies that $\partial_p Y_q$ is positive definite and so is $\partial_p(X + Y)$. By Proposition 2.3, the isotopy that is associated to $X + Y$ is the wanted isotopy $(\tilde{\phi}_t)$. \square

Proposition 2.5. *Assume that $a : I \rightarrow \mathbb{R}$ and $H : I \times T^*M \rightarrow \mathbb{R}$ are smooth functions and let us use the notation $H_t(x) = H(t, x)$. We assume that the Hessian of H restricted to every vertical fiber is positive definite. We define the time-dependent vector field X_t of T^*M by*

$$i_{X_t}\omega = dH_t - a(t)\lambda.$$

Then the isotopy defined by X_t is conformally symplectic and strictly twists the vertical.

Proof of Proposition 2.5. For $(t_0, x_0) \in I \times T^*M$, we choose a vertically foliated Darboux chart $F = (F_1, F_2) : \mathcal{U} \rightarrow \mathbb{R}^d \times \mathbb{R}^d$ such that $F(x_0) = 0$ and $F(\mathcal{U}) = (-a, a)^d \times (-a, a)^d$.

We now work in this chart and denote by H the Hamiltonian in this chart, which has a positive definite Hessian in the p direction. We chose $\varepsilon_0 > 0$ such that for all $t \in (t_0 - \varepsilon_0, t_0 + \varepsilon_0)$, $\mathcal{G}_t := (\phi_t \circ \phi_{t_0}^{-1})(F^{-1}(\{0_{\mathbb{R}^d}\} \times (-\frac{a}{2}, \frac{a}{2})^d)) \subset \mathcal{U}$ and $F(\mathcal{G}_t)$ ⁶ is the graph of a function $p \mapsto q = dg_t(p)$. We deduce from the Hamilton equations that there exists $\varepsilon \in (0, \varepsilon_0)$ such that uniformly for $y \in (-\frac{a}{2}, \frac{a}{2})^d$ and $t \in (t_0 - \varepsilon, t_0 + \varepsilon) \setminus \{t_0\}$ if we use the notation $\phi_t(0, y) = (q_t, p_t)$ then

$$D^2g_t(p_t) = (t - t_0)\left(\frac{\partial^2 H}{\partial p^2}(t_0, 0, y) + O(t - t_0)\right).$$

This gives the (strict) twist property. \square

2.5. Maslov index and symplectic reduction. On a cotangent bundle, the Maslov index is invariant by symplectic reduction. The result is due to C. Viterbo [Vit87]. For sake of completeness, we recall here Viterbo's proof.

Let us start by showing the invariance of the Maslov index by symplectic reduction on a symplectic vector space. Let (V, ω) be a symplectic vector space of dimension $2d$. Denote by $\Lambda(V)$ the set of Lagrangian subspaces in V and, for every subspace $U \subset V$, by $\Lambda_U(V)$ the set of Lagrangian subspaces L such that $L \cap U = \{0\}$.

Fix $L_0 \in \Lambda(V)$ ⁷. Let $W \subset V$ be a coisotropic (not Lagrangian) vector subspace such that

$$W^\perp \subset L_0 \subset W,$$

where W^\perp denotes the symplectic orthogonal with respect to ω . Consider the quotient map

$$\begin{aligned} \Pi_{W^\perp} : W &\rightarrow W/W^\perp \\ v &\mapsto [v], \end{aligned}$$

where $[v] = [u]$ if and only if $v - u \in W^\perp$. Observe that Π_{W^\perp} is a surjective linear map. Then, the quotient space inherits a symplectic 2-form ω_W from ω , and $(W/W^\perp, \omega_W)$ is still a symplectic vector space. In particular, for every Lagrangian subspace L of V the image $\Pi_{W^\perp}(L \cap W)$ is still a Lagrangian space in W/W^\perp . Denote by

$$\begin{aligned} \mathcal{P}_{W^\perp} : \Lambda(V) &\leftrightarrow \Lambda(W/W^\perp) \\ L &\mapsto \Pi_{W^\perp}(L \cap W). \end{aligned}$$

The following holds.

⁶ $F(\mathcal{G}_t)$ is Lagrangian.

⁷ L_0 is the Lagrangian subspace with respect to which we calculate the Maslov index in (V, ω) .

Claim 2.2. *The map \mathcal{P}_{W^\perp} restricted to $\Lambda_{W^\perp}(V)$ is a submersion.*

Proof of the claim. Let us fix $L \in \Lambda_{W^\perp}(V)$ and let $L' \in \Lambda(V)$ be such that $W^\perp \subset L' \subset W$ and $L \cap L' = \{0\}$. The set $U = \{\tilde{L} \in \Lambda(V) : \tilde{L} \cap L' = \{0\}\}$ is an open neighbourhood of L . If $\tilde{L} \in U$, then there exists a unique linear map $B = B_{\tilde{L}} : L \rightarrow L'$ such that

$$\tilde{L} = \{v + Bv; v \in L\}$$

and B satisfies the symmetry condition

$$(5) \quad \forall \ell, \ell' \in L, \omega(\ell, B\ell') + \omega(B\ell, \ell') = 0.$$

Moreover, if $B : L \rightarrow L'$ satisfies the symmetry condition (5), then the set $\tilde{L} = \{v + Bv; v \in L\}$ is a Lagrangian subspace of V that is transverse to L' .

We denote by \mathcal{B} the set of linear maps from L to L' that satisfy the symmetry condition (5). It is a finite dimensional vector space that is the image of the chart

$$\tilde{L} \in U \mapsto B_{\tilde{L}} \in \mathcal{B}.$$

Similarly, if $\bar{L} = \mathcal{P}_{W^\perp}(L)$ and $\bar{L}' = \mathcal{P}_{W^\perp}(L')$, the set

$$V = \{\tilde{L} \in \Lambda(W/W^\perp); \tilde{L} \cap \bar{L}' = \{0\}\}$$

is an open neighbourhood of \bar{L} in $\Lambda(W/W^\perp)$. The map that associate to every $\tilde{L} \in V$ the linear map $\bar{B}_{\tilde{L}} : \bar{L} \rightarrow \bar{L}'$ such that $\tilde{L} = \{\ell + \bar{B}_{\tilde{L}}\ell; \ell \in \bar{L}\}$ is a chart whose image is the finite dimensional vector space $\bar{\mathcal{B}}$ of linear maps $\bar{B} : \bar{L} \rightarrow \bar{L}'$ such that

$$\forall \ell, \ell' \in \bar{L}, \omega_W(\ell, \bar{B}\ell') + \omega_W(\bar{B}\ell, \ell') = 0.$$

In these charts, the map \mathcal{P}_{W^\perp} is read $\Phi : \mathcal{B} \rightarrow \bar{\mathcal{B}}$ where

$$\Phi(B) = \Pi_{W^\perp} \circ B|_{L \cap W} \circ (\Pi_{W^\perp}|_{L \cap W})^{-1}.$$

Hence Φ is a linear map. This is then a submersion onto its image that is a linear subspace of $\bar{\mathcal{B}}$. If we prove that $\Phi(\mathcal{B}) = \bar{\mathcal{B}}$, we will deduce that \mathcal{P}_{W^\perp} is a submersion. Thus, let $\bar{B}_0 \in \bar{\mathcal{B}}$ and let \bar{L}_0 be the graph of \bar{B}_0 . We choose a linear subspace L'_1 of L' that is transverse to W^\perp and define $B_1 : L \cap W \rightarrow L'_1$ as

$$\forall v \in L \cap W, B_1(v) = \Pi_{W^\perp}|_{L'_1}^{-1} \circ \bar{B}_0 \circ \Pi_{W^\perp}(v).$$

When $v, w \in L \cap W$, we have

$$\begin{aligned} \omega(v, B_1 w) + \omega(B_1 v, w) &= \omega(v, \Pi_{W^\perp}|_{L'_1}^{-1} \circ \bar{B}_0[w]) + \omega(\Pi_{W^\perp}|_{L'_1}^{-1} \circ \bar{B}_0[v], w) \\ &= \omega_W([v], \bar{B}_0[w]) + \omega_W(\bar{B}_0[v], [w]) = 0. \end{aligned}$$

Hence $B_1 : L \cap W \rightarrow L'_1$ satisfies the symmetry condition and then its graph L_2 is an isotropic subspace of $(L \cap W) + L' \subset W$ such that $L_2 \cap L' = \{0\}$. We can choose a Lagrangian subspace \tilde{L} of V that contains L_2 and is transverse to L' : \tilde{L} is then the graph of a map $B_2 : L \rightarrow L'$ that satisfies the symmetry condition and contains L_2 . Then the graph of $\Phi(B_2)$ is a Lagrangian subspace of W/W^\perp that contains \bar{L}_0 , hence is equal to \bar{L}_0 and we deduce that $\Phi(B_2) = \bar{B}_0$ and Φ is surjective. \square

Denote by $i : \Lambda_{W^\perp}(V) \hookrightarrow \Lambda(V)$ the standard inclusion. This is a submersion.

Lemma 2.1. *Let $t \in [0, 1] \mapsto \gamma(t) \in \Lambda_{W^\perp}(V)$ be an arc such that $\gamma(0) \cap L_0 = \gamma(1) \cap L_0 = \{0\}$. Then*

$$\text{MI}(i \circ \gamma) = \text{MI}(\mathcal{P}_{W^\perp} \circ \gamma),$$

where

- the Maslov index $\text{MI}(i \circ \gamma)$ is calculated with respect to L_0 in $\Lambda(W)$;
- the Maslov index $\text{MI}(\mathcal{P}_{W^\perp} \circ \gamma)$ is calculated with respect to $\mathcal{P}_{W^\perp}(L_0)$ in $\Lambda(W/W^\perp)$.

Proof. Up to slightly perturb the path, we can assume that γ is in D-general position with respect to $\Sigma := \{L \in \Lambda(V); L \cap L_0 \neq \{0\}\}$. The subspace $L'_0 := \mathcal{P}_{W^\perp}(L_0)$ of W/W^\perp is Lagrangian and we denote $\bar{\Sigma} = \{L' \in \Lambda(W/W^\perp); L' \cap L'_0 \neq \{0\}\}$. Observe that $\mathcal{P}_{W^\perp}^{-1}(\bar{\Sigma}) \subset \Sigma$ because $W^\perp \subset L_0$.

Since the maps i and \mathcal{P}_{W^\perp} are submersions, we have

- the path $i \circ \gamma$ is in D-general position with respect to Σ ;
- the path $\mathcal{P}_{W^\perp} \circ \gamma$ is in D-general position with respect to $\bar{\Sigma}$.

Moreover, the choice of a coorientation of Σ determines a coorientation both on $i^{-1}(\Sigma_1)$ and on $\mathcal{P}_{W^\perp} \circ i^{-1}(\Sigma_1)$. Following [Vit87], we claim that

Claim 2.3.

$$i^{-1}(\Sigma) = \mathcal{P}_{W^\perp}^{-1}(\bar{\Sigma}) \cap \Lambda_{W^\perp}(V).$$

Proof of the claim. We first observe that on one side

$$i^{-1}(\Sigma) = \{L \in \Lambda(V) : L \cap W^\perp = \{0\} \text{ and } L \cap L_0 \neq \{0\}\}.$$

On the other side we have

$$\mathcal{P}_{W^\perp}^{-1}(\bar{\Sigma}) \cap \Lambda_{W^\perp}(V) =$$

$$\{L \in \Lambda_{W^\perp}(V); ((L \cap W + W^\perp)/W^\perp) \cap ((L_0 \cap W + W^\perp)/W^\perp) \neq \{0\}\};$$

since $W^\perp \subset L_0 \subset W$, we have $L_0 = L_0 \cap W + W^\perp$ and any $L \in \mathcal{P}_{W^\perp}^{-1}(\bar{\Sigma}) \cap \Lambda_{W^\perp}(V)$ is so that

$$((L \cap W + W^\perp)/W^\perp) \cap (L_0/W^\perp) =$$

$$(L \cap L_0 \cap W + W^\perp)/W^\perp = (L \cap L_0 + W^\perp)/W^\perp \neq \{0\}.$$

Since $L \cap W^\perp = \{0\}$

$$(L \cap L_0 + W^\perp)/W^\perp \neq \{0\} \Leftrightarrow L \cap L_0 \neq \{0\}.$$

We so conclude that

$$\begin{aligned} \mathcal{P}_{W^\perp}^{-1}(\bar{\Sigma}) \cap \Lambda_{W^\perp}(V) &= \{L \in \Lambda(V) : L \cap W^\perp = \{0\} \text{ and } L \cap L_0 \neq \{0\}\} \\ &= i^{-1}(\{L \in \Lambda(V) : L \cap L_0 \neq \{0\}\}). \end{aligned}$$

□

Since i is a submersion, the number of crossings of γ with $i^{-1}(\Sigma)$ is equal to the number of crossings of $i \circ \gamma$ with Σ . Since also \mathcal{P}_{W^\perp} is a submersion and since $\mathcal{P}_{W^\perp}(\Sigma) = \bar{\Sigma}$, we conclude that the number of crossings of γ with $i^{-1}(\Sigma)$ is equal to the number of crossings of $\mathcal{P}_{W^\perp} \circ \gamma$ with $\bar{\Sigma}$.

Since the coorientation on $i^{-1}(\Sigma)$ and on $\mathcal{P}_{W^\perp} \circ i^{-1}(\Sigma)$ is determined by the coorientation of Σ , we conclude that actually the number of positive (resp. negative) crossings of $i \circ \gamma$ corresponds to the number of positive (resp. negative) crossings of $\mathcal{P}_{W^\perp} \circ \gamma$. By the definition of Maslov index, we obtain the sought result. □

We want now to prove the invariance of the Maslov index by symplectic reduction on the cotangent bundle \mathcal{M} , endowed with the symplectic form ω . Let \mathcal{V} be the lagrangian foliation whose fibers of the associated tangent Lagrangian bundle are the vertical Lagrangian subspaces. Let $\mathcal{W} \subset \mathcal{M}$ be a coisotropic submanifold and let $i_{\mathcal{W}} : \mathcal{W} \rightarrow \mathcal{M}$ be the canonical injection; the characteristic foliation of \mathcal{W} , denoted by \mathcal{W}^\perp , admits for tangent bundle $T_x(\mathcal{W}^\perp) = \ker(i_{\mathcal{W}}^* \omega)(x) = (T_x \mathcal{W})^\perp$.

Assume that, for every $x \in \mathcal{W}$ it holds

$$(T_x \mathcal{W})^\perp \subset T_x \mathcal{V} \subset T_x \mathcal{W}.$$

We assume that the symplectic reduction of \mathcal{W} is a true symplectic manifold that we denote by $\mathcal{R} : \mathcal{W} \rightarrow \mathcal{W}/\mathcal{W}^\perp$. When $x \in \mathcal{W}$ and $L \in \Lambda_{T_x \mathcal{W}^\perp}(T_x \mathcal{M})$, we denote

$$\mathcal{P}(L) = D\mathcal{R}(x)L = (L + T_x \mathcal{W}^\perp)/T_x \mathcal{W}^\perp \in \Lambda(\mathcal{W}/\mathcal{W}^\perp).$$

Then \mathcal{P} is a submersion from $\Lambda_{\mathcal{W}^\perp}(\mathcal{M})|_{\mathcal{W}}$ to $\Lambda(\mathcal{W}/\mathcal{W}^\perp)$.

We denote $\Sigma(\mathcal{M}) := \{L \in \Lambda(\mathcal{M}); L \cap T_{p(L)} \mathcal{V} \neq \{0\}\}$ and $\Sigma(\mathcal{W}/\mathcal{W}^\perp) = \{L \in \Lambda(\mathcal{W}/\mathcal{W}^\perp); L \cap T_{p(L)} \mathcal{P}(\mathcal{V}) \neq \{0\}\}$.

Lemma 2.2. *Let $\Gamma : [a, b] \rightarrow \Lambda(\mathcal{M})$ be a smooth arc such that*

- $\Gamma(a), \Gamma(b) \notin \Sigma(\mathcal{M})$;
- Γ is in D -general position with respect to the fibered singular cycle $\Sigma(\mathcal{M})$;
- at every point the path has trivial intersection with the tangent bundle of the characteristic foliation of \mathcal{W} , i.e.

$$\Gamma(t) \cap (T_{p(\Gamma(t))} \mathcal{W})^\perp = \{0\} \quad \forall t \in [a, b].$$

Then

$$\text{MI}(\Gamma) = \text{MI}(\mathcal{P} \circ \Gamma),$$

where

- the Maslov index $\text{MI}(\Gamma)$ is calculated with respect to $T\mathcal{V}$ in $\Lambda(\mathcal{M})$;
- the Maslov index $\text{MI}(\mathcal{P} \circ \Gamma)$ is calculated with respect to $\mathcal{P}(\mathcal{V})$ in $\Lambda(\mathcal{W}/\mathcal{W}^\perp)$.

Proof. Since \mathcal{P} is a submersion and $\mathcal{P}^{-1}(\Sigma(\mathcal{W}/\mathcal{W}^\perp)) \cap \Lambda_{T\mathcal{W}^\perp}(\mathcal{M}) = \Sigma(\mathcal{M})|_{\mathcal{W}}$, also the path $\mathcal{P} \circ \Gamma$ is in D -general position with respect to $\Sigma(\mathcal{W}/\mathcal{W}^\perp)$. In order to conclude, it is then sufficient to calculate the Maslov index of a sub-path of Γ , around a (isolated) crossing t . Let $U \subset \mathcal{M}$ be a neighborhood of $p \circ \Gamma(t)$ and let

$$\Gamma|_{[t-\epsilon, t+\epsilon]} : [t-\epsilon, t+\epsilon] \rightarrow \Lambda(U),$$

be a Lagrangian path with only an isolated, transverse crossing at t . Let us trivialise $\Lambda(U)$ as $U \times \Lambda(T_{p \circ \Gamma(t)} \mathcal{M})$. Similarly, trivialise the image $\mathcal{P}(\Lambda(U))$ as $\mathcal{P}(U) \times \Lambda(T_{p \circ \Gamma(t)} \mathcal{W}/(T_{p \circ \Gamma(t)} \mathcal{W})^\perp)$. Up to restrict the neighborhood U , the Maslov index of the path $\Gamma|_{[t-\epsilon, t+\epsilon]}$ with respect to \mathcal{V} corresponds to the Maslov index of $\Gamma|_{[t-\epsilon, t+\epsilon]}$, seen as a Lagrangian path in the symplectic vector space $T_{p \circ \Gamma(t)} \mathcal{M}$ thanks to the trivialization, with respect to $T_{p \circ \Gamma(t)} \mathcal{V}$. Similarly, the Maslov index of the path $\mathcal{P}(\Gamma|_{[t-\epsilon, t+\epsilon]})$ with respect to $\mathcal{P}(\mathcal{V})$ is actually the Maslov index of the Lagrangian path $\mathcal{P}(\Gamma|_{[t-\epsilon, t+\epsilon]})$, seen in $T_{p \circ \Gamma(t)} \mathcal{W}/(T_{p \circ \Gamma(t)} \mathcal{W})^\perp$ through the trivialization, with respect to $\mathcal{P}(T_{p \circ \Gamma(t)} \mathcal{V})$. Applying then Lemma 2.1, we conclude. \square

3. MASLOV INDEX ALONG A LAGRANGIAN SUBMANIFOLD THAT ADMITS A GENERATING FUNCTION

Let $\mathcal{L} \subset T^*M$ be a Lagrangian submanifold. The goal of this Section is to prove that every arc $\Gamma : [a, b] \rightarrow T\mathcal{L}$ whose endpoints project on T^*M on the so-called graph selector of \mathcal{L} has zero Maslov index.

3.1. The relation between the Maslov index and the Morse index. Let us recall the definition of generating function for a Lagrangian submanifold \mathcal{L} of T^*M .

DEFINITION. A C^r function with $r \geq 2$ function $S : M \times \mathbb{R}^k \rightarrow \mathbb{R}$ generates a Lagrangian submanifold \mathcal{L} of T^*M if

- using the notation

$$\mathcal{C}_S = \left\{ (q, \xi) \in M \times \mathbb{R}^k : \frac{\partial S}{\partial \xi}(q, \xi) = 0 \right\},$$

at every point of \mathcal{C}_S , the map $\frac{\partial S}{\partial \xi}$ is a submersion; in this case, \mathcal{C}_S is a d -dimensional submanifold of $M \times \mathbb{R}^k$;

- the map $j_S : \mathcal{C}_S \hookrightarrow T^*M$ defined by $j_S(q, \xi) = \frac{\partial S}{\partial q}(q, \xi)$ is an embedding such that $j_S(\mathcal{C}_S) = \mathcal{L}$.

The generating function S is *quadratic at infinity* (GFQI) if there exists a compact subset $K \subset M \times \mathbb{R}^k$ and a non-degenerate quadratic form $Q : \mathbb{R}^k \rightarrow \mathbb{R}$ such that

$$\forall (q, \xi) \notin K, S(q, \xi) = Q(\xi).$$

The generating function quadratic at infinity S is of index m if the non-degenerate quadratic form Q has index m .

A result due to Sikorav [Bru91, Sik87], asserts that every H-isotopic⁸ to the zero section submanifold of T^*M admits a GFQI.

NOTATION. If we denote as before the Liouville form on T^*M by λ and the Liouville form on $T^*(\mathbb{R}^k)$ by λ_1 , the product manifold $\mathcal{N} = T^*M \times T^*(\mathbb{R}^k)$ is endowed with the symplectic form $\Omega = -p_1^*d\lambda - p_2^*d\lambda_1$ where p_i is the projection on the i -th factor.

Theorem 3.1. *Let $\mathcal{L} \subset T^*M$ be a Lagrangian submanifold that admits a generating function $S(q, \xi) : M \times \mathbb{R}^k \rightarrow \mathbb{R}$. Let $(q_i, \xi_i) \in M \times \mathbb{R}^k$, $i = 1, 2$ be such that*

- $\frac{\partial S}{\partial \xi}(q_i, \xi_i) = 0$, i.e. $(q_i, \xi_i) \in \mathcal{C}_S$;
- if we use the notation $p_i = \frac{\partial S}{\partial q}(q_i, \xi_i)$, the submanifold \mathcal{L} is transverse to the vertical fiber T_q^*M at p_i in T^*M .

Then, $\ker \frac{\partial^2 S}{\partial \xi^2}(q_i, \xi_i) = \{0\}$ and for every arc γ_0 joining $\gamma_0(0) = p_1$ to $\gamma_0(1) = p_2$ in \mathcal{L} , the Maslov index of $t \in [0, 1] \mapsto T_{\gamma_0(t)}\mathcal{L}$ with respect to the vertical is equal to the difference of the Morse indices $\text{index}\left(\frac{\partial^2 S}{\partial \xi^2}(q_2, \xi_2)\right) - \text{index}\left(\frac{\partial^2 S}{\partial \xi^2}(q_1, \xi_1)\right)$.

Proof of Theorem 3.1.

Lemma 3.1. *Let $p = \frac{\partial S}{\partial q}(q, \xi) \in \mathcal{L}$. Then \mathcal{L} is transverse to T_q^*M at p if and only if $\ker\left(\frac{\partial^2 S}{\partial \xi^2}(q, \xi)\right) = \{0\}$.*

⁸This means Hamiltonianly isotopic

Proof of Lemma 3.1. Let us fix $p \in \mathcal{L}$ and let $\delta p \in T_p(T^*M)$. We use the notation $q = \pi(p) \in M$ and $\delta q = d\pi(p)\delta p \in T_qM$.

Then δp belongs to $T_p\mathcal{L}$ if and only if there exists $\delta\xi \in \mathbb{R}^k$ such that

- $D\left(\frac{\partial S}{\partial \xi}\right)(\delta q, \delta\xi) = \frac{\partial^2 S}{\partial q \partial \xi}(q, \xi)\delta q + \frac{\partial^2 S}{\partial \xi^2}(q, \xi)\delta\xi = 0;$
- $Dj_S(\delta q, \delta\xi) = \delta p = \frac{\partial^2 S}{\partial q^2}(q, \xi)\delta q + \frac{\partial^2 S}{\partial \xi \partial q}(q, \xi)\delta\xi.$

Observe that $\pi\left(\frac{\partial S}{\partial q}(q, \xi)\right) = q$ and then

$$(6) \quad D\pi\left(\frac{\partial^2 S}{\partial q^2}(q, \xi)\delta q\right) = \delta q \quad \text{and} \quad D\pi\left(\frac{\partial^2 S}{\partial \xi \partial q}(q, \xi)\delta\xi\right) = 0.$$

We deduce

$$\begin{aligned} \delta\xi \in \ker\left(\frac{\partial^2 S}{\partial \xi^2}\right) \setminus \{0\} &\iff (0, \delta\xi) \in \ker\left(D\left(\frac{\partial S}{\partial \xi}\right)\right) \setminus \{0\} \\ &\iff Dj_S(0, \delta\xi) \in T\mathcal{L} \setminus \{0\} \iff \frac{\partial^2 S}{\partial \xi \partial q}\delta\xi \in T\mathcal{L} \setminus \{0\}. \end{aligned}$$

Using (6), we conclude that $\ker\left(\frac{\partial^2 S}{\partial \xi^2}(q, \xi)\right) \neq \{0\}$ if and only if \mathcal{L} is not transverse to T^*M at $\frac{\partial S}{\partial q}(q, \xi)$. \square

In $\mathcal{N} = T^*M \times T^*(\mathbb{R}^k)$, endowed with the symplectic form $\Omega = -p_1^*d\lambda - p_2^*d\lambda_1$, we consider the coisotropic foliation into submanifolds

$$\mathcal{W}_\chi = T^*M \times \mathbb{R}^k \times \{\chi\}$$

for $\chi \in \mathbb{R}^k$. The characteristic leaves of \mathcal{W}_χ are the submanifolds $\mathcal{W}_{(p,\chi)}^\perp = \{p\} \times \mathbb{R}^k \times \{\chi\}$ with $p \in T^*M$.

We will use also the Lagrangian foliation \mathcal{F} of \mathcal{N} with leaves $\mathcal{F}_{q,\chi} = T_q^*M \times \mathbb{R}^k \times \{\chi\}$. Then we have $\mathcal{W}_{(p,\chi)}^\perp \subset \mathcal{F}_{(\pi(p),\chi)} \subset \mathcal{W}_\chi$. We denote by $F_{(p,\xi,\chi)}$ the tangent space to the leaf $\mathcal{F}_{(\pi(p),\chi)}$ at the point (p, ξ, χ) .

The graph $\mathcal{G} = \text{graph}(dS) \subset \mathcal{N}$ of dS is a Lagrangian submanifold of \mathcal{N} that is transverse to \mathcal{W}_0 and such that $\mathcal{G} \cap \mathcal{W}_0$ is diffeomorphic to \mathcal{L} by the map

$$\mathcal{R} : (p, \xi, 0) \in \mathcal{W}_0 \mapsto p.$$

Observe that \mathcal{R} is the symplectic reduction of \mathcal{W}_0 . We denote by R the restriction of \mathcal{R} to $\mathcal{G} \cap \mathcal{W}_0$.

We use for $\gamma_0, q_i, p_i, \xi_i$ the same notations as in Theorem 3.1. Then $\Gamma_0 = R^{-1} \circ \gamma_0$ is an arc on $\mathcal{G} \cap \mathcal{W}_0$ such that $\Gamma_0(0) = (p_1, \xi_1, 0)$ and $\Gamma_0(1) = (p_2, \xi_2, 0)$. We have

Lemma 3.2. *Let $\Gamma(t) = (p(t), \xi(t), \chi(t)) \in \mathcal{G}$ be an arc in \mathcal{G} such that at $\Gamma(0)$ and $\Gamma(1)$, the quadratic form $\frac{\partial^2 S}{\partial \xi^2}$ is non-degenerate. The Maslov index of the arc of Lagrangian subspaces $t \in [0, 1] \mapsto T_{\Gamma(t)}\mathcal{G}$ with respect to the fibered singular cycle associated to \mathcal{F} is*

$$\text{index}\left(\frac{\partial^2 S}{\partial \xi^2}(q(1), \xi(1))\right) - \text{index}\left(\frac{\partial^2 S}{\partial \xi^2}(q(0), \xi(0))\right).$$

Proof of Lemma 3.2. Up to a small perturbation, there is no loss of generality in assuming that S is smooth. The proof is divided into two steps. First of all, we will perturb the Lagrangian submanifold \mathcal{L} (i.e., its generating function) and Γ on it in such a way that Γ is in D -general position with respect to the fibered singular

cycle associated to \mathcal{F} . Then we will prove the lemma.

First step. As $T_{\Gamma(0)}\mathcal{G}$ and $T_{\Gamma(1)}\mathcal{G}$ are transverse to $F_{\Gamma(0)}, F_{\Gamma(1)}$ respectively, there exists $\varepsilon > 0$ such that for all $t \in [0, \varepsilon] \cup [1 - \varepsilon, 1]$, $T_{\Gamma(t)}\mathcal{G}$ is transverse to $F_{\Gamma(t)}$. We use the notation $t \mapsto \zeta(t) := (\pi \circ p(t), \xi(t)) \in M \times \mathbb{R}^k$. We now choose a neighbourhood \mathcal{U} of $\zeta([\varepsilon, 1 - \varepsilon])$ in $M \times \mathbb{R}^k$ and a diffeomorphism $\psi : \mathcal{U} \rightarrow \mathbb{R}^d \times \mathbb{R}^k$ such that

$$\forall t \in [\varepsilon, 1 - \varepsilon], \psi(\zeta(t)) = (t, 0, \dots, 0).$$

Let $s : \psi(\mathcal{U}) \rightarrow \mathbb{R}$ defined by $s(y) = S \circ \psi^{-1}(y)$. Then in the neighborhood of $(\varepsilon, 0, \dots, 0)$ and $(1 - \varepsilon, 0, \dots, 0)$, we know that $\text{graph}(D^2s)$ and $D\psi(F)$ are transverse. We can slightly perturb the path of matrices $t \in [\varepsilon, 1 - \varepsilon] \mapsto D^2s(t, 0, \dots, 0)$ in a path $t \mapsto A(t)$ of symmetric matrices such that

- $A(t) = D^2s(t, 0, \dots, 0)$ in a neighbourhood of ε and $1 - \varepsilon$;
- the path $t \mapsto \text{graph}(A(t))$ is in D -general position

We now define for x_1 in a neighborhood of $[\varepsilon, 1 - \varepsilon]$

- $\delta(x_1) = \int_{\varepsilon}^{x_1} (A(\sigma) - D^2s(\sigma, 0, \dots, 0))(1, 0, \dots, 0) d\sigma$;
- $v(x_1) = \int_{\varepsilon}^{x_1} \delta(\sigma)(1, 0, \dots, 0) d\sigma$;
- in a neighbourhood of $[\varepsilon, 1 - \varepsilon] \times \{0_{\mathbb{R}^{d-1} \times \mathbb{R}^k}\}$,

$$\begin{aligned} u(x_1, \dots, x_{d+k}) &= s(x_1, \dots, x_{d+k}) + v(x_1) + \delta(x_1)(0, x_2, \dots, x_{d+k}) \\ &+ \frac{1}{2}(A(x_1) - D^2s(x_1, 0, \dots, 0))((0, x_2, \dots, x_{d+k}), (0, x_2, \dots, x_{d+k})). \end{aligned}$$

Then u is C^2 close to s and we have

$$\forall x_1 \in [\varepsilon, 1 - \varepsilon], D^2u(x_1, 0, \dots, 0) = A(x_1).$$

We then use a bump function η with support in a neighbourhood of $[\varepsilon, 1 - \varepsilon] \times \{0_{\mathbb{R}^{d-1} \times \mathbb{R}^k}\}$ and that is equal to 1 in a smaller neighbourhood of $[\varepsilon, 1 - \varepsilon] \times \{0_{\mathbb{R}^{d-1} \times \mathbb{R}^k}\}$. We define

$$\tilde{s}(x_1, \dots, x_{d+k}) =$$

$$(1 - \eta(x_1, \dots, x_{d+k}))s(x_1, \dots, x_{d+k}) + \eta(x_1, \dots, x_{d+k})u(x_1, \dots, x_{d+k}).$$

As \tilde{s} is equal to u in $[\varepsilon, 1 - \varepsilon] \times \{0_{\mathbb{R}^{d-1} \times \mathbb{R}^k}\}$, $D^2\tilde{s}$ is in D -general position with respect to $D\psi(F)$ along the lift of this arc in $\text{graph}Du$. In addition, as \tilde{s} is C^2 -close to s , $D^2\tilde{s}$ is transverse to $D\psi(F)$ along the lift of $([0, \varepsilon] \cup [1 - \varepsilon, 1]) \times \{0_{\mathbb{R}^{d-1} \times \mathbb{R}^k}\}$ in $\text{graph}D\tilde{s}$.

Finally, define the function \tilde{S} to be equal to S outside $\psi^{-1}(\mathcal{U})$ and to $\tilde{s} \circ \psi$ in $\psi^{-1}(\mathcal{U})$. Thus, \tilde{S} is C^2 close to S , $D\tilde{S} \circ \zeta$ is C^1 close to $DS \circ \zeta = \Gamma$ and $t \mapsto D\tilde{S} \circ \zeta(t)$ is in D -general position with respect to the fibered singular cycle associated to \mathcal{F} . As the new generating function \tilde{S} is C^2 close to S , the number $\text{index}\left(\frac{\partial^2 \tilde{S}}{\partial \xi^2}(q(1), \xi(1))\right) - \text{index}\left(\frac{\partial^2 \tilde{S}}{\partial \xi^2}(q(0), \xi(0))\right)$ does not change.

This will allow us to assume that the path $t \mapsto T_{\Gamma(t)}\mathcal{G}$ is in D -general position with respect to the fibered singular cycle associated to \mathcal{F} .

Second step. We then look at what happens at a crossing $\Gamma(\bar{t})$. We choose a chart close to $\frac{\partial S}{\partial q}(q(\bar{t}), \xi(\bar{t}))$ and we assume that we work in coordinates : $q \in U \subset \mathbb{R}^n$ and (p_1, \dots, p_n) are the dual coordinates defined by $(q, \sum p_i dq_i) \in T^*U$.

In these coordinates for $(q, p) = (q, \frac{\partial S}{\partial q}(q, \xi)) \in U \times \mathbb{R}^n$, we use the linear and symplectic change of coordinates

$$(\delta q, \delta p) \mapsto \left(\delta Q = \delta p + \left(\mathbf{1}_n - \frac{\partial^2 S}{\partial q^2}(q, \xi) \right) \delta q, \delta P = -\delta q \right).$$

In the extended space $T\mathcal{N}$ with linear coordinates $(\delta Q, \delta P, \delta \xi, \delta \chi)$, the equation of $F_{\Gamma(t)}$ is $(\delta P, \delta \chi) = (0, 0)$, i.e. $F_{\Gamma(t)}$ is the graph the zero function. The equation of $T\mathcal{G}$ is

$$(7) \quad \begin{cases} \delta P = -\delta Q + \frac{\partial^2 S}{\partial \xi \partial q} \delta \xi \\ \delta \chi = \frac{\partial^2 S}{\partial q \partial \xi} \delta Q + \left(\frac{\partial^2 S}{\partial \xi^2} - \frac{\partial^2 S}{\partial q \partial \xi} \frac{\partial^2 S}{\partial \xi \partial q} \right) \delta \xi \end{cases}$$

and this is also a graph. We compute then the change of Maslov index with respect to $F_{\Gamma(t)}$ with the help of the height of $T\mathcal{G}$ above the vertical L with respect to F , i.e. $\mathcal{Q}_F(L, T\mathcal{G})$, where L has equation $(\delta Q, \delta \xi) = (0, 0)$. Observe that, for t close to \bar{t} , F and L are transverse and the projection $p_F : TN \rightarrow TN/F$ restricted to L is an isomorphism. So we can take $(\delta P, \delta \chi)$ as coordinates in TN/F . Also, for $t \neq \bar{t}$ close to \bar{t} , F and $T\mathcal{G}$ are transverse, because crossings of a path in general position are isolated. Moreover, note that, for t close to \bar{t} , L and $T\mathcal{G}$ are transverse. If we introduce the matrix

$$(8) \quad M(t) = \begin{pmatrix} -\mathbf{1}_n & \frac{\partial^2 S}{\partial \xi \partial q} \\ \frac{\partial^2 S}{\partial q \partial \xi} & \left(\frac{\partial^2 S}{\partial \xi^2} - \frac{\partial^2 S}{\partial q \partial \xi} \frac{\partial^2 S}{\partial \xi \partial q} \right) \end{pmatrix} (q(t), \xi(t)),$$

as the equation of $T\mathcal{G}$ is (we write in coordinates)

$$\begin{pmatrix} \delta P \\ \delta \chi \end{pmatrix} = M(t) \begin{pmatrix} \delta Q \\ \delta \xi \end{pmatrix},$$

the matrix $M(t)$ is invertible for $t \neq \bar{t}$ and we have

$$\mathcal{Q}_F(L, T\mathcal{G})(\delta P, \delta \chi) = \Omega \left((0, 0, \delta P, \delta \chi), ((\delta P, \delta \chi) \cdot (M(t)^{-1})^T, \delta P, \delta \chi) \right).$$

Hence the matrix of $\mathcal{Q}_F(L, T\mathcal{G})(\delta P, \delta \chi)$ in coordinates $(\delta P, \delta \chi)$ is $M(t)^{-1}$. The change of signature of $M(t)^{-1}$ at \bar{t} is exactly the same as the change of signature of $M(t)$.

Let us introduce the matrix

$$\mathcal{P}(t) = \begin{pmatrix} \mathbf{1}_n & \frac{\partial^2 S}{\partial \xi \partial q}(q(t), \xi(t)) \\ \mathbf{0} & \mathbf{1}_k \end{pmatrix}.$$

Then we have

$$\begin{aligned} \mathcal{P}(t)^T M(t) \mathcal{P}(t) &= \begin{pmatrix} \mathbf{1}_n & \mathbf{0} \\ \frac{\partial^2 S}{\partial q \partial \xi}(q(t), \xi(t)) & \mathbf{1}_k \end{pmatrix} M(t) \begin{pmatrix} \mathbf{1}_n & \frac{\partial^2 S}{\partial \xi \partial q}(q(t), \xi(t)) \\ \mathbf{0} & \mathbf{1}_k \end{pmatrix} \\ &= \begin{pmatrix} -\mathbf{1}_n & \mathbf{0} \\ \mathbf{0} & \frac{\partial^2 S}{\partial \xi^2}(q(t), \xi(t)) \end{pmatrix}. \end{aligned}$$

Hence the change of signature of $M(t)$ at $t = \bar{t}$ along the path Γ is equal to the change of signature of $\frac{\partial^2 S}{\partial \xi^2}$. This is exactly the Maslov index of the arc of Lagrangian subspaces $t \in [\bar{t} - \varepsilon, \bar{t} + \varepsilon] \mapsto T_{\Gamma(t)}\mathcal{G}$ with respect to $F_{\Gamma(t)}$. \square

We deduce that the Maslov index of $T\mathcal{G}$ along the arc Γ_0 with respect to F is $\text{index}(\frac{\partial^2 S}{\partial \xi^2}(q_2, \xi_2)) - \text{index}(\frac{\partial^2 S}{\partial \xi^2}(q_1, \xi_1))$.

We have noticed that $\mathcal{W}_{(p,\chi)}^\perp \subset \mathcal{F}_{(\pi(p),\chi)} \subset \mathcal{W}_\chi$. Also, because \mathcal{G} is Lagrangian and transverse to \mathcal{W}_0 , at every point of intersection, the intersection of the tangent subspaces to \mathcal{G} and $\mathcal{W}_{(p,0)}^\perp$ is $\{0\}$. The path $t \mapsto \Gamma(t)$ can be put in D -general position with respect to \mathcal{F} , as done in the first step of the proof of Lemma 3.2. Thus, we can apply the results concerning the Maslov index that are given in section 2 of [Vit87], see here Lemma 2.2 and Subsection 2.5.

As the curve Γ_0 is contained in $\mathcal{G} \cap \mathcal{W}_0$, the Maslov index of $T\mathcal{G}$ along Γ_0 with respect F is equal to the Maslov index of $(T(\mathcal{G} \cap \mathcal{W}_0))/T\mathcal{W}_0^\perp$ with respect to $F/T\mathcal{W}_0^\perp$. We have $(T(\mathcal{G} \cap \mathcal{W}_0))/T\mathcal{W}_0^\perp = TR(\mathcal{G}) = T\mathcal{L}$ and $F/T\mathcal{W}_0^\perp(\Gamma(t)) = T_{\gamma_0(t)}(T_{\pi \circ \gamma_0(t)}^* M)$ is the vertical $V_{\gamma_0(t)}$. This proves the theorem. \square

3.2. Maslov index along graph selectors. Let us assume that the Lagrangian submanifold \mathcal{L} of T^*M admits a generating function quadratic at infinity. We recall the construction of a *graph selector* $u : M \rightarrow \mathbb{R}$. Such a graph selector was introduced by M. Chaperon in [Cha91] (see [PPS03] and [Sib04] too) by using the homology. Here we will use the cohomological approach (see e.g. [AV17]). We now explain this.

NOTATIONS. Let $S : M \times \mathbb{R}^k \rightarrow \mathbb{R}$ be a function that generates a Lagrangian submanifold, $q \in M$ and $a \in \mathbb{R}$ is a real number, we denote the sublevel with height a at q by

$$S_q^a = \{\xi \in \mathbb{R}^k; \quad S(q, \xi) \leq a\}$$

and we use the notation $S_q = S(q, \cdot)$.

When S is quadratic at infinity with index m , there exists $N \geq 0$ such that all the critical values of S are in $(-N, N)$. Observe that, since S is a GFQI, S_q^{-N} is the sublevel of a non-degenerate quadratic form of index m . Thus (see for example [Mil63]), the De Rham relative cohomology space $H^*(\mathbb{R}^k, S_q^{-N})$ is isomorphic to

$$H^*(\mathbb{R}^m) = \begin{cases} \mathbb{R} & \text{if } * = m, \\ 0 & \text{if } * \neq m. \end{cases}$$

We denote by α_q a closed m -form of \mathbb{R}^k such that $\alpha_q|_{S_q^{-N}} = 0$ and $0 \neq [\alpha_q] \in H^m(\mathbb{R}^k, S_q^{-N})$.

If $a \in (-N, N)$, we use the notation $i_a : (S_q^a, S_q^{-N}) \hookrightarrow (\mathbb{R}^k, S_q^{-N})$ for the inclusion and then $i_a^* : H^m(\mathbb{R}^k, S_q^{-N}) \rightarrow H^m(S_q^a, S_q^{-N})$. The *graph selector* $u : M \rightarrow \mathbb{R}$ is then defined by:

$$u(q) = \sup\{a \in \mathbb{R}; [i_a^* \alpha_q] = 0\} = \inf\{a \in \mathbb{R}; [i_a^* \alpha_q] \neq 0\}.$$

The following result is classical (see [AV17] for a proof in our setting).

Proposition 3.1. *Let $\mathcal{L} \subset T^*M$ be a Lagrangian submanifold admitting a GFQI $S : M \times \mathbb{R}^k \rightarrow \mathbb{R}$ of regularity C^r with $r \geq 2$ and let $u : M \rightarrow \mathbb{R}$ be the graph selector for S which is a Lipschitz function. Then u is C^r on the open set*

$$U := \{q \in M, \xi \mapsto S(q, \xi) \text{ is Morse excellent}^9\}$$

⁹An *excellent* function is by definition a function whose every critical value is attained at exactly one critical point.

which has full measure, and for all q in U , the following hold:

- $du(q) \in \mathcal{L}$;
- $u(q) = S \circ j_S^{-1}(du(q))$.

REMARK. Let \mathcal{L} be a Lagrangian submanifold admitting a generating function $S : M \times \mathbb{R}^k \rightarrow \mathbb{R}$. Then for all C^1 path $\gamma : [0, 1] \rightarrow \mathcal{L}$,

$$S(j_S^{-1}(\gamma(1))) - S(j_S^{-1}(\gamma(0))) = \int_{\gamma} \lambda.$$

As a consequence we may describe the open set U without mentioning the generating family:

$$U = \{q \in M, T_q^*M \pitchfork \mathcal{L} \text{ and for all path } \gamma : [0, 1] \rightarrow \mathcal{L} \\ \text{with distinct endpoints in } T_q^*M \pitchfork \mathcal{L}, \int_{\gamma} \lambda \neq 0.\}$$

Indeed, the transversality condition is equivalent to the fact that $(q, \xi) \rightarrow S(q, \xi)$ is Morse, and the condition on the path gives that the values of S above two different critical points of the generating family are necessarily distinct.

From Theorem 3.1 and the latter proposition, we deduce

Proposition 3.2. *We use the same notations as in the previous proposition. Then if $q_1, q_2 \in U$ and if $\gamma : [0, 1] \rightarrow \mathcal{L}$ is a continuous arc joining $du(q_1)$ to $du(q_2)$, the Maslov index of the arc of Lagrangian subspaces $t \mapsto T_{\gamma(t)}\mathcal{L}$ with respect to the vertical is zero.*

Proof of Proposition 3.2. We recall some well-known facts about Morse functions. Let $f : \mathbb{R}^k \rightarrow \mathbb{R}$ be a Morse function quadratic at infinity such that its critical points have different critical value. We use the notation $f^a = \{x \in \mathbb{R}^k, f(x) \leq a\}$ for the sublevels of f . Then, for every critical point c such that $D^2f(c)$ has index p , for $\varepsilon > 0$ small enough, the De Rham relative cohomology space $H^*(f^{f(c)+\varepsilon}, f^{f(c)-\varepsilon})$ is isomorphic to \mathbb{R} for $* = p$ and trivial if $* \neq p$.

Let now consider $q \in U$. As $S(q, \cdot)$ is Morse such that different critical points correspond to different critical values, there is only one $\xi_q \in \mathbb{R}^k$ that is a critical point of $S(q, \cdot)$ such that $S(q, \xi_q) = u(q)$. By definition of u , we have

- for every $\varepsilon > 0$, $0 \neq [i_{u(q)+\varepsilon}^* \alpha_q] \in H^m(S_q^{u(q)+\varepsilon}, S_q^{-N})$;
- for every $\varepsilon > 0$, $0 = [i_{u(q)-\varepsilon}^* \alpha_q] \in H^m(S_q^{u(q)-\varepsilon}, S_q^{-N})$.

We recall the notation for maps of pairs in relative cohomology. The notation $f : (M, N) \rightarrow (V, W)$ means that $f : M \rightarrow V$ with $f(N) \subset W$.

We introduce the maps associated to the inclusion $S_q^{-N} \subset S_q^{u(q)-\varepsilon} \subset S_q^{u(q)+\varepsilon}$. More precisely, we denote by $j_1 : (S_q^{u(q)+\varepsilon}, S_q^{-N}) \hookrightarrow (S_q^{u(q)+\varepsilon}, S_q^{u(q)-\varepsilon})$ and $j_2 : (S_q^{u(q)-\varepsilon}, S_q^{-N}) \hookrightarrow (S_q^{u(q)+\varepsilon}, S_q^{-N})$ the two inclusion maps. We now use the exact cohomology sequence that is induced by these maps, see [God71], that is

$$H^m(S_q^{u(q)+\varepsilon}, S_q^{u(q)-\varepsilon}) \xrightarrow{j_1^*} H^m(S_q^{u(q)+\varepsilon}, S_q^{-N}) \xrightarrow{j_2^*} H^m(S_q^{u(q)-\varepsilon}, S_q^{-N}).$$

Then $[i_{u(q)+\varepsilon}^* \alpha_q]$ is a non-zero element of $H^m(S_q^{u(q)+\varepsilon}, S_q^{-N})$ and its image by j_2^* is 0. Because the sequence is exact, $[i_{u(q)+\varepsilon}^* \alpha_q]$ is a non zero element of the image of

j_1^* . This implies that $H^m(S_q^{u(q)+\varepsilon}, S_q^{u(q)-\varepsilon}) \neq \{0\}$, and then that the index of the critical point ξ_q of $S(q, \cdot)$ is m .

Hence we have proved that for every $q \in U$, if $du(q) = \frac{\partial S}{\partial q}(q, \xi_q)$ where $\frac{\partial S}{\partial \xi}(q, \xi_q) = 0$, the index of $\frac{\partial^2 S}{\partial \xi^2}(q, \xi_q)$ is m . We deduce from Theorem 3.1 the wanted result. \square

4. DYNAMICAL MASLOV INDEX, GRAPH SELECTORS AND PROOF OF THEOREM 1.1

4.1. Graph selector techniques adapted to conformal symplectic isotopies of the zero section. Let (ϕ_t) be a C^{r+1} isotopy of conformally symplectic diffeomorphisms of T^*M with $r \geq 2$ such that $\phi_0 = \text{Id}_{T^*M}$. We want to apply the results of section 3.2 to the images $\phi_t(\mathcal{L}_0)$ of the zero-section and obtain results for the dynamical Maslov index

$$\text{DMI}(T_x \mathcal{L}, (\phi_s)_{s \in [0, t]}).$$

As every ϕ_t is conformally symplectic, there exists $a(t) \in]0, +\infty[$ such that $\phi_t^* \omega = a(t) \omega$. Then the form $\beta_t = \phi_t^* \lambda - a(t) \lambda$ is closed. The projection $\pi : T^*M = \mathcal{M} \rightarrow M$ inducing an isomorphism in cohomology, we can choose in a C^r way a closed 1-form η_t on M such that $\pi^* \eta_t - \beta_t$ is exact and $\eta_0 = 0$. If the symplectic diffeomorphism $f_t : \mathcal{M} \rightarrow \mathcal{M}$ is defined by $f_t(p) = p - \eta_t$, we have

$$f_t^* \lambda = \lambda - \pi^* \eta_t.$$

If (ψ_t) is the isotopy of conformally symplectic diffeomorphisms defined by $\psi_t = f_t \circ \phi_t$, then we have

$$\psi_t^* \lambda = \phi_t^* (\lambda - \pi^* \eta_t) = a(t) \lambda + (\beta_t - \phi_t^* \pi^* \eta_t).$$

The action of ϕ_t on cohomology is trivial because ϕ_t is homotopic to $\text{Id}_{\mathcal{M}}$. As $\pi^* \eta_t - \beta_t$ is exact, we deduce that $\psi_t^* \lambda - a(t) \lambda$ is exact. Hence the image by ψ_t of every H-isotopic to the zero-section submanifold \mathcal{L} is also H-isotopic to the zero-section, see [AF21, Corollary 3]. It admits a generating function quadratic at infinity $S_t : M \times \mathbb{R}^k \rightarrow \mathbb{R}$ and a Lipschitz continuous graph selector $u_t : M \rightarrow \mathbb{R}$.

REMARK. The generating function S_t is not unique. For every segment $[a, b]$ of \mathbb{R} , we can choose an integer $k \in \mathbb{N}$ uniformly in $t \in [a, b]$ and in a C^r way a C^r generating function $S_t : M \times \mathbb{R}^k \rightarrow \mathbb{R}$ for $\mathcal{L}_t = \psi_t(\mathcal{L})$. Then the associated graph selector¹⁰ u_t also depends in a C^r way on t .

As in Proposition 3.1, we define $U_t := \{q \in M, \xi \mapsto S_t(q, \xi) \text{ is Morse excellent}\}$, which is an open set of M with full Lebesgue measure, on which u_t is C^r and

$$(9) \quad \forall q \in U_t, \quad du_t(q) \in \psi_t(\mathcal{L}_0) \text{ i.e. } \eta_t(q) + du_t(q) \in \phi_t(\mathcal{L}_0).$$

Proposition 4.1. *The set $\mathcal{U} = \bigcup_t U_t \times \{t\}$ is an open set of $M \times \mathbb{R}$, on which the function $(q, t) \mapsto u_t(q)$ is C^r .*

¹⁰It can be proved that up to a constant, u_t is independent of the chosen generating function S_t of $\psi_t(\mathcal{L})$.

Proof. The set $\mathcal{W} = \{(q, t) \in M \times \mathbb{R}; T_q^*M \pitchfork \mathcal{L}_t\}$ is open thanks to Thom transversality theorem. Hence for every $(q_0, t_0) \in \mathcal{U}$, there exists an open subset U of \mathcal{W} that contains (q_0, t_0) , an integer $N \geq 1$ and N C^{r-1} -maps $x_i : U \rightarrow T^*M$ such that

- $\pi \circ x_i(q, t) = q$;
- $\forall i \neq j; x_i(q, t) \neq x_j(q, t)$;
- $T_q^*M \cap \mathcal{L}_t = \{x_1(q, t); \dots; x_N(q, t)\}$.

As S depends in a C^r way on (q, t) , the map $Y : \mathcal{W} \rightarrow \mathbb{R}^N$ that is defined by

$$Y(q, t) = (S_t(j_S^{-1}(x_1(q, t))), \dots, S_t(j_S^{-1}(x_N(q, t))))$$

is continuous and then

$$\mathcal{U} \cap U = \{(q, t) \in U; \forall i \neq j, S_t(j_S^{-1}(x_i(q, t))) \neq S_t(j_S^{-1}(x_j(q, t)))\}$$

is open because it is the backward image by Y of an open subset of \mathbb{R}^N . We have then proved that \mathcal{U} is open.

Let $q_0 \in U_{t_0}$ for some t_0 . By definition of the graph selector there exists ξ_0 such that $u_{t_0}(q_0) = S_{t_0}(q_0, \xi_0)$ and $\frac{\partial S_{t_0}}{\partial \xi_0}(q_0, \xi_0) = 0$. Since $S_{t_0}(q_0, \cdot)$ is Morse, we may apply the implicit function theorem to get a C^r function $(q, t) \mapsto \xi(q, t)$ solving $\frac{\partial S_t}{\partial \xi}(q, \xi(q, t)) = 0$ on an open connected neighbourhood of (q_0, t_0) in \mathcal{U} . By continuity of $(t, q) \mapsto u_t(q)$ and since we excluded the case where $S_t(q, \cdot)$ attains a critical value more than once, we also have $u_t(q) = S_t(q, \xi(q, t))$ on this neighbourhood. Thus $(t, q) \mapsto u_t(q)$ is C^r at (t_0, q_0) , hence on the whole set \mathcal{U} . \square

4.2. Proof of Theorem 1.1. Let us begin with the case where \mathcal{L} is the zero section, denoted by \mathcal{L}_0 . With the notations that we introduced in the previous paragraph, we are reduced to prove that $\text{DMI}(T_x \mathcal{L}_0, (\psi_s)_{s \in [0, t]}) = 0$ for every $x \in \psi_t^{-1}(\text{graph}(du_t|_{U_t}))$. This is a result of the two following lemmata for which we provide proofs.

Lemma 4.1. *There exists an integer n_t such that*

$$\forall x \in \psi_t^{-1}(\text{graph}(du_t|_{U_t})) \quad \text{DMI}(T_x \mathcal{L}_0, (\psi_s)_{s \in [0, t]}) = n_t.$$

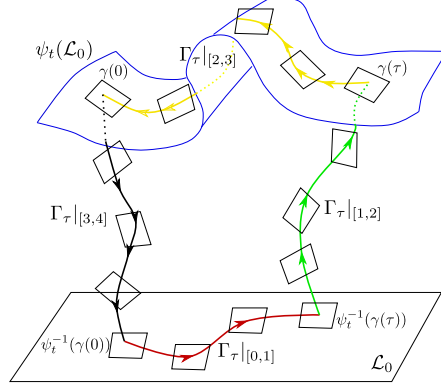
Lemma 4.2. *The map $t \mapsto n_t$ is locally constant.*

Proof of Lemma 4.1. We fix $t \in \mathbb{R}$. Let $\gamma : [0, 1] \rightarrow \psi_t(\mathcal{L}_0)$ be a path such that for $i = 0, 1$, $q_i = \pi(\gamma(i)) \in U_t$ and $\gamma(i) = du_t(q_i)$. For $\tau \in [0, 1]$, we define a loop $\Gamma = \Gamma_\tau$ by

- $\forall s \in [0, 1], \Gamma_\tau(s) = T_{\psi_t^{-1}(\gamma(s\tau))} \mathcal{L}_0$;
- $\forall s \in [1, 2], \Gamma_\tau(s) = D\psi_{(s-1)t} \left(T_{\psi_t^{-1}(\gamma(\tau))} \mathcal{L}_0 \right)$;
- $\forall s \in [2, 3], \Gamma_\tau(s) = T_{\gamma((3-s)\tau)} \psi_t(\mathcal{L}_0)$;
- $\forall s \in [3, 4], \Gamma_\tau(s) = D\psi_{(4-s)t} \left(T_{\psi_t^{-1}(\gamma(0))} \mathcal{L}_0 \right)$.

Along $\Gamma|_{[0, 1]}$, the Maslov index is zero because the path is on the zero section \mathcal{L}_0 . Along $\Gamma|_{[1, 2]}$, the Maslov index is $\text{MI} \left((D\psi_s(T_{\psi_t^{-1}(\gamma(\tau))} \mathcal{L}_0))_{s \in [0, t]} \right)$. Along $\Gamma|_{[2, 3]}$ the Maslov index is $-\text{MI} \left((T_{\gamma(s)} \psi_t(\mathcal{L}_0))_{s \in [0, \tau]} \right)$. Along $\Gamma|_{[3, 4]}$, the Maslov index is $-\text{MI} \left((D\psi_s(T_{\psi_t^{-1}(\gamma(0))} \mathcal{L}_0))_{s \in [0, t]} \right)$. Hence the total Maslov index along Γ_τ is

$$\text{MI} \left((D\psi_s(T_{\psi_t^{-1}(\gamma(\tau))} \mathcal{L}_0))_{s \in [0, t]} \right) - \text{MI} \left((T_{\gamma(s)} \psi_t(\mathcal{L}_0))_{s \in [0, \tau]} \right) - \text{MI} \left((D\psi_s(T_{\psi_t^{-1}(\gamma(0))} \mathcal{L}_0))_{s \in [0, t]} \right).$$


 FIGURE 1. The loop Γ_τ .

As $\tau \mapsto \Gamma_\tau$ is an homotopy, the total Maslov index along Γ_τ doesn't depend on τ . Observe that

- for $\tau = 0$, this index is 0;
- thanks to Proposition 3.2, we have $\text{MI}\left(\left(T_{\gamma(s)}\psi_t(\mathcal{L}_0)\right)_{s \in [0,1]}\right) = 0$. Hence the total Maslov index along Γ_1 is

$$0 = \text{MI}\left(\left(D\psi_s(T_{\psi^{-1}(\gamma(1))}\mathcal{L}_0)\right)_{s \in [0,t]}\right) - \text{MI}\left(\left(D\psi_s(T_{\psi^{-1}(\gamma(0))}\mathcal{L}_0)\right)_{s \in [0,t]}\right).$$

□

Proof of Lemma 4.2. Let us fix $(q_0, t_0) \in \mathcal{U}$. By Proposition 4.1 and continuity of (ψ_s) , there exists $\varepsilon > 0$ such that

$$\forall t \in (t_0 - \varepsilon, t_0 + \varepsilon), (\pi(\psi_t \circ \psi_{t_0}^{-1}(du_{t_0}(q_0))), t) \in \mathcal{U}.$$

We denote $\gamma(t) = \psi_t \circ \psi_{t_0}^{-1}(du_{t_0}(q_0))$ and $\mathcal{L}_t = \psi_t(\mathcal{L}_0)$. Then the arc $t \in (t_0 - \varepsilon, t_0 + \varepsilon) \mapsto T_{\gamma(t)}\mathcal{L}_t$ doesn't intersect the singular cycle. Hence $t \in (t_0 - \varepsilon, t_0 + \varepsilon) \mapsto n_t$ is constant.

□

Observing that $n_0 = 0$, we combine the two lemmata for $t = 1$ to get that $\text{DMI}(T_x\mathcal{L}_0, (\psi_s)_{s \in [0,1]}) = 0$ for all $x \in \psi_1^{-1}(\text{graph}(du_1|_{U_1})) = \phi_1^{-1}(\text{graph}((\eta_1 + du_1)|_{U_1}))$. Since ψ is obtained by composing ϕ by a vertical translation (see paragraph 4.1), the Maslov index is the same for ϕ_t and ψ_t (see Remark at the end of section 2.2), and Theorem 1.1 is proved in the case where \mathcal{L} is the zero section, taking $u = u_1$, $\eta = \eta_1$ and $U = U_1$.

Let us now assume only that \mathcal{L} is a Lagrangian graph, i.e., the graph of a closed 1-form ν . We recall that all the diffeomorphisms $T_t : \mathcal{M} \hookrightarrow \mathcal{M}$ defined by $T_t(p) = p + t\nu$ are symplectic.

Using (T_t) and (ϕ_t) , we will define an isotopy $(F_t)_{t \in [0,1]}$ such that $F_0 = \text{Id}_{\mathcal{M}}$ and $F_1(\mathcal{L}_0) = \phi_1(\mathcal{L})$. Let $\alpha : [0,1] \rightarrow [0,1]$ be a smooth non-decreasing function such that $\alpha(0) = 0$, $\alpha(1) = 1$ and α is constant equal to $\frac{1}{2}$ when restricted to some neighbourhood of $\frac{1}{2}$. We introduce (F_t) by

- for $t \in [0, \frac{1}{2}]$, $F_t = T_{2\alpha(t)}$;

- for $t \in [\frac{1}{2}, 1]$, $F_t = \phi_{2\alpha(t)-1} \circ T_1$.

The isotopy (F_t) is an isotopy of conformally symplectic diffeomorphisms such that $F_0 = \text{Id}_{\mathcal{M}}$. Applying the first case of this proof, there exist a closed 1-form η of M and a Lipschitz map $u : M \rightarrow \mathbb{R}$ that is C^r on an open subset U of M with full Lebesgue measure such that

$$\text{graph}(\eta + du)|_U \subset F_1(\mathcal{L}_0) = \phi_1(\mathcal{L})$$

and

$$\forall x \in F_1^{-1}(\text{graph}(\eta + du)|_U), \quad \text{DMI}(T_x \mathcal{L}_0, (F_t)_{t \in [0,1]}) = 0.$$

Observe that the path $(DF_t T_x \mathcal{L}_0)_{t \in [0, \frac{1}{2}]} = (DT_{2\alpha(t)})_{t \in [0, \frac{1}{2}]}$ has zero Maslov index since all these Lagrangian subspaces are transverse to the vertical. Hence

$$\text{DMI}(T_x \mathcal{L}_0, (F_t)_{t \in [0,1]}) = \text{DMI}(T_{T_1(x)} \mathcal{L}, (F_t)_{t \in [\frac{1}{2}, 1]}).$$

The isotopy $(F_t)_{t \in [\frac{1}{2}, 1]}$ is just a reparametrization of the isotopy $(\phi_t)_{t \in [0,1]}$, hence we obtain finally

$$\forall q \in U, p := \phi_1^{-1}(\eta(q) + du(q)) \in \mathcal{L} \quad \text{and} \quad \text{DMI}(T_p \mathcal{L}, (\phi_s)_{s \in [0,1]}) = 0.$$

5. ANGULAR MASLOV INDEX

There are different approaches to Maslov index, at least three of these are contained in [BG92]. To prove some of our results, we will use the second approach that we explain now.

5.1. Definition of the angular Maslov index. In this section as in sub-section 2.1, we assume that (\mathcal{M}, ω) is a $2d$ -dimensional symplectic manifold that admits a Lagrangian foliation \mathcal{V} . We denote by $V(x) = V_x := T_x \mathcal{V}$ its associated Lagrangian bundle. We endow \mathcal{M} with an almost complex structure $J : T\mathcal{M} \hookrightarrow T\mathcal{M}$ that is compatible with ω . We briefly recall that this means that

- for every $x \in \mathcal{M}$, $J_x : T_x \mathcal{M} \hookrightarrow T_x \mathcal{M}$ is linear and $J^2 = -\text{Id}_{T\mathcal{M}}$;
 - every J_x is symplectic;
 - for every $x \in \mathcal{M}$, the symmetric bilinear form $\omega(\cdot, J_x \cdot)$ is positive definite.
- We denote $g := \omega(\cdot, J)$.

The complex structure is then defined on every $T_x \mathcal{M}$ by

$$\forall (\lambda = \lambda_1 + i\lambda_2, v) \in \mathbb{C} \times T_x \mathcal{M}, \lambda v = \lambda_1 v + \lambda_2 Jv.$$

The equality

$$\forall x \in \mathcal{M}, \forall u, v \in T_x \mathcal{M}, \Theta(u, v) = g(u, v) + i\omega(u, v)$$

define a positive definite Hermitian form on $T_x \mathcal{M}$. We denote by $\mathcal{U}(\mathcal{M})$ the fiber bundle whose fibers $\mathcal{U}_x(\mathcal{M})$ are the unitary transformations of $T_x \mathcal{M}$. Observe that a real d -dimensional linear subspace L of the complex space $T_x \mathcal{M}$ is Lagrangian if and only if the Hermitian form Θ_x restricted to L is real (and then Θ_x is a real scalar product). Hence the group $\mathcal{U}(\mathcal{M})$ acts on the Lagrangian Grassmannian Λ . It is classical (see [BW97, Lemma 3.10] or [Aud03]) that the action of $\mathcal{U}_x(\mathcal{M})$ on Λ_x is transitive.

If Stab_x is in the stabilizer of $V(x)$, then Stab_x preserves the scalar product that is the restriction of Θ_x to $V(x)$, i.e. is an orthonormal transformation of $V(x)$. Moreover, every orthogonal transformation of $V(x)$ can be extended to a unique unitary transformation of $T_x \mathcal{M}$. We denote by $\mathcal{O}(\mathcal{M})$ the fiber bundle whose fibers $\mathcal{O}_x(\mathcal{M})$

are these transformations that we call orthogonal transformations of $T_x\mathcal{M}$. There is a natural bijection between $\mathcal{U}_x(\mathcal{M})/\mathcal{O}_x(\mathcal{M})$ and Λ_x that maps Stab_x on V_x . This bijection sends each $[\phi] \in \mathcal{U}_x(\mathcal{M})/\mathcal{O}_x(\mathcal{M})$ to the Lagrangian space $\phi(V_x) \in \Lambda_x$, where $\phi \in \mathcal{U}_x(\mathcal{M})$ is a representative of $[\phi]$. We denote by $\mathcal{R}_x : \Lambda_x \rightarrow \mathcal{U}_x(\mathcal{M})/\mathcal{O}_x(\mathcal{M})$ its inverse bijection.

The map $\delta_x : \mathcal{U}_x(\mathcal{M}) \rightarrow \mathbb{C}^*$ defined by $\delta_x(\varphi) = (\det \varphi)^2$ is a morphism of groups whose kernel contains $\mathcal{O}_x(\mathcal{M})$ and whose range is the set $U(1)$ of complex numbers with modulus 1. Hence we can define $\bar{\delta}_x : \mathcal{U}_x(\mathcal{M})/\mathcal{O}_x(\mathcal{M}) \rightarrow U(1)$ and then $\Delta = \bar{\delta} \circ \mathcal{R} : \Lambda \rightarrow U(1)$.

DEFINITION. Let $\Gamma : [a, b] \rightarrow \Lambda$ be a continuous map. Let $\theta : [a, b] \rightarrow \mathbb{R}$ be any continuous lift of $\Delta \circ \Gamma$, i.e. such that

$$\forall t \in [a, b], \exp(i\theta(t)) = \Delta(\Gamma(t)).$$

Then the *angular Maslov index* of Γ is

$$(10) \quad \alpha\text{MI}(\Gamma) := \frac{\theta(b) - \theta(a)}{2\pi}.$$

DEFINITION. Let (ϕ_t) be an isotopy of conformally symplectic diffeomorphisms of \mathcal{M} . Let $L \in \Lambda(\mathcal{M})$ and $t > 0$. Define the path

$$s \in [0, t] \mapsto D\phi_s L \in \Lambda(\mathcal{M}).$$

The *dynamical angular Maslov index* of L at time t is

$$D\alpha\text{MI}(L, (\phi_s)_{s \in [0, t]}) = \alpha\text{MI}((D\phi_s L)_{s \in [0, t]}).$$

Whenever the limit exists, the *asymptotic angular Maslov index* of L , is

$$D\alpha\text{MI}_\infty(L, (\phi_s)_{s \in [0, +\infty]}) := \lim_{t \rightarrow +\infty} \frac{D\alpha\text{MI}(L, (\phi_s)_{s \in [0, t]})}{t}.$$

REMARK. In fact, the existence of a Lagrangian foliation implies that the bundle Λ is trivial, diffeomorphic to $\mathcal{M} \times U(d)/O(d)$ where $U(d)$ and $O(d)$ are the groups of $d \times d$ unitary and orthogonal matrices respectively, see e.g. [CGIP03, Section 1.2].

REMARK. Observe that the angular Maslov index is continuous with respect to the path Γ . Thus, the dynamical Maslov index at a fixed time t is continuous with respect to $L \in \Lambda(\mathcal{M})$, as long as the isotopy (ϕ_t) is at least C^1 .

The following result is classical, see [CGIP03, Lemma 2.1].

Proposition 5.1. *Let (ϕ_t) be an isotopy of conformally symplectic diffeomorphisms of \mathcal{M} . Let $x \in \mathcal{M}$ and let $L_1, L_2 \in \Lambda_x$. Then, for every $t > 0$,*

$$|D\alpha\text{MI}(L_1, (\phi_s)_{s \in [0, t]}) - D\alpha\text{MI}(L_2, (\phi_s)_{s \in [0, t]})| < 8d.$$

In particular, whenever the asymptotic angular Maslov index at x exists, it does not depend on the chosen Lagrangian subspace $L \in \Lambda_x$.

That is why we will often mention the asymptotic Maslov index at a point.

Proposition 5.2. *Let (ϕ_t) an isotopy of conformally symplectic diffeomorphisms of \mathcal{M} such that $\phi_0 = \text{Id}_{\mathcal{M}}$ and $\phi_{t+1} = \phi_t \circ \phi_1$ (resp. $(\phi_t)_t$ is a flow). If μ is a Borel probability measure with compact support that is invariant by ϕ_1 (resp. by $(\phi_t)_t$), then the asymptotic Maslov index exists at μ -almost every point $x \in \mathcal{M}$.*

Proof. The proof uses methods of [Sch57, Section 4]. We assume that μ is ergodic: if not, using ergodic decomposition theorem, see e.g. [Mn87], we deduce the result for μ from the result for ergodic measures.

Let us begin with the case when $(\phi_t)_t$ is a flow. The map $D\phi_t : \Lambda \rightarrow \Lambda$ defines a flow on Λ . Let $x \in \mathcal{M}$ be a regular point for μ , i.e. such that the family of measures $[x]_T$ defined by $[x]_T(f) = \frac{1}{T} \int_0^T f(\phi_t(x)) dt$ tends to $\int_{\mathcal{M}} f d\mu$ for every continuous $f : \mathcal{M} \rightarrow \mathbb{R}$. Recall that μ -almost every point $x \in \mathcal{M}$ is regular for μ . Let us fix $L_0 \in \Lambda_x$ and let ν be any limit point at infinity of the family of measures $[L_0]_T$ defined by

$$\forall F \in C^0(\Lambda, \mathbb{R}), [L_0]_T(F) = \frac{1}{T} \int_0^T F(D\phi_t L_0) dt.$$

Then ν is an invariant measure for $(D\phi_t)$, see [KB37], such that $p_*\nu = \mu$, where $p : T\mathcal{M} \rightarrow \mathcal{M}$ is the canonical projection. We have defined on Λ the continuous function $\Delta : \Lambda \rightarrow U(1)$. A direct result of [Sch57, Section 4], is that $\text{D}\alpha\text{MI}_\infty(L, (\phi_s)_{s \in [0, +\infty)})$ exists and is finite at ν -almost every point $(x, L) \in \Lambda$. Since the asymptotic angular Maslov index of L does not depend on the chosen Lagrangian subspace (see Proposition 5.1), we conclude that it exists at $p_*\nu = \mu$ -almost every point $x \in \mathcal{M}$.

When $\phi_{t+1} = \phi_t \circ \phi_1$, we define a flow (F_t) on $\mathbb{T} \times \Lambda$ by $F_t(s, L) = (t + s, D\phi_t L)$. Then we apply Schwartzman's result to the function $(t, L) \mapsto \Delta(L)$, this gives the wanted result. \square

5.2. The angles of a Lagrangian subspaces. Let (\mathcal{M}, ω) be a $2d$ -dimensional symplectic manifold that admits a Lagrangian foliation \mathcal{V} . Let J be an almost complex structure compatible with ω . We introduce the notion of angles of a Lagrangian subspace $L \in \Lambda$ with respect to $J\mathcal{V}$. For details, we refer to [LMS03].

NOTATION. For every $x \in \mathcal{M}$, we denote by $JV(x)$ the image by the isomorphism J_x of the Lagrangian subspace $V(x) = T_x\mathcal{V}$.

Proposition 5.3 (Section 1.4 in [LMS03]). *Let (E^{2d}, ω) be a symplectic vector space, endowed with a complex structure compatible with ω . Fix a Lagrangian subspace $H \subset E$. For every Lagrangian subspace $L \subset E$ there exists a unique unitary isomorphism of E denoted by $\Phi_{H,L}$ such that*

- $\Phi_{H,L}(H) = L$;
- $\Phi_{H,L}$ is diagonalizable relatively to a unitary basis of E whose vectors are in H , with eigenvalues of the form $e^{i\theta_j}$, $j = 1, \dots, d$, with

$$\theta_j \in \left] -\frac{\pi}{2}, \frac{\pi}{2} \right] \text{ for } j = 1, \dots, d.$$

In the sequel, we apply Proposition 5.3 to each symplectic vector space $(T_x\mathcal{M}, \omega_x)$, endowed with the almost complex structure J . The fixed Lagrangian subspace H in each $T_x\mathcal{M}$ is $JV(x)$.

DEFINITION. Let $L \in \Lambda_x$. The angles of L with respect to $JV(x)$ is the equivalence class

$$(\theta_1^{JV(x),L}, \dots, \theta_d^{JV(x),L}) / \sim,$$

where

- $(\theta_1^{JV(x),L}, \dots, \theta_d^{JV(x),L}) \in]-\frac{\pi}{2}, \frac{\pi}{2}]^d$ is the d -uplet composed by arguments of the d eigenvalues given by Proposition 5.3 applied at $T_x\mathcal{M}$ with respect to $JV(x)$ and L ;
- \sim is the equivalence relation obtained from permutations over the d -entries.

Let us denote by

$$\{e_1(x), \dots, e_d(x)\}$$

a unitary basis of $T_x\mathcal{M}$ that is contained in $JV(x)$ and given by Proposition 5.3. We have

$$\mathbb{C}e_1(x) \oplus \dots \oplus \mathbb{C}e_d(x) = T_x\mathcal{M},$$

where $T_x\mathcal{M}$ is seen as a complex vector space. In particular,

$$\{e_1(x), \dots, e_d(x), J_x e_1(x), \dots, J_x e_d(x)\}$$

is a symplectic basis of $T_x\mathcal{M}$, seen as a real vector space of dimension $2d$.

Observe that for every $x \in \mathcal{M}$ and every $v \in T_x\mathcal{M}$ it holds $J_x v = iv = e^{i\frac{\pi}{2}}v$. Referring then to notations introduced in Subsection 5.1, the image $\mathcal{R}_x(JV(x))$ is the equivalence class of $J_x \in \mathcal{U}_x(\mathcal{M})$. Thus, for $L \in \Lambda_x$ we have that $\mathcal{R}_x(L)$ is the equivalence class of the unitary transformation $\Phi_{JV(x),L} \circ J_x$. Consequently, since $\Delta_x = \bar{\delta}_x \circ \mathcal{R}_x$, it holds

$$(11) \quad \Delta_x(L) = (\det(\Phi_{JV(x),L} \circ J_x))^2 = \exp\left(2i \sum_{j=1}^d \theta_j^{JV(x),L}\right) \exp(i d\pi).$$

Let $\Gamma : [a, b] \rightarrow \Lambda$ be a continuous map.

NOTATION. To ease the notation, for every $t \in [a, b]$, we denote the angles of $\Gamma(t)$ (with respect to $JV(p \circ \Gamma(t))$) as

$$\left(\theta_1^{JV,\Gamma}(t), \dots, \theta_d^{JV,\Gamma}(t)\right) / \sim.$$

The angular Maslov index $\alpha\text{MI}(\Gamma)$ differs by an integer from the angular quantity

$$(12) \quad \frac{1}{\pi} \left(\sum_{j=1}^d \left(\theta_j^{JV,\Gamma}(b) - \theta_j^{JV,\Gamma}(a) \right) \right),$$

since the angular Maslov index is a continuous lift of the function Δ and because of Equation 11. We will see in the next paragraph that this integer is actually $\text{MI}(\Gamma)$.

REMARK. We have that $\dim(L \cap V(x)) = k$, for some $0 \leq k \leq n$, if and only if exactly k angles of L with respect to $JV(x)$ are equal to $\frac{\pi}{2}$.

5.3. Relation between Maslov index and angular Maslov index. The following proposition clarifies the relation between Maslov index and angular Maslov index.

Proposition 5.4. *Let $\Gamma : [a, b] \rightarrow \Lambda$ be a smooth path such that*

$$\Gamma(a) \cap V(p \circ \Gamma(a)) = \Gamma(b) \cap V(p \circ \Gamma(b)) = \{0\}.$$

Then

$$(13) \quad \alpha \text{MI}(\Gamma) = \frac{1}{\pi} \left(\sum_{j=1}^d (\theta_j^{JV, \Gamma}(b) - \theta_j^{JV, \Gamma}(a)) \right) + \text{MI}(\Gamma).$$

Proof. Without loss of generality, assume that the path Γ is in general position with respect to $\Sigma(\mathcal{M}) = \{L \in \Lambda(\mathcal{M}) : L \cap V(p(L)) \neq \{0\}\}$. Let $t \in]a, b[$ be a crossing. Since Γ is in general position, $\Gamma(t)$ has exactly only one angle equal to $\frac{\pi}{2}$ with respect to JV . Up to a permutation over angles, we can assume that $\theta_1^{JV, \Gamma}(t) = \frac{\pi}{2}$.

Let $\epsilon > 0$ be small enough such that

- for $s \in [t - \epsilon, t + \epsilon] \setminus \{t\}$ it holds $\Gamma(s) \cap V(p \circ \Gamma(s)) = \{0\}$;
- for $s \in [t - \epsilon, t + \epsilon]$ it holds that, for all $j > 1$,

$$|\theta_1^{JV, \Gamma}(s)| > |\theta_j^{JV, \Gamma}(s)|.$$

It will be sufficient to show that Equation 13 holds for the subpath $\Gamma|_{[t-\epsilon, t+\epsilon]}$.

Let us start by calculating the angular Maslov index of $\Gamma|_{[t-\epsilon, t+\epsilon]}$:

$$\begin{aligned} \alpha \text{MI}(\Gamma|_{[t-\epsilon, t+\epsilon]}) = \\ \frac{\theta_1^{JV, \Gamma}(t + \epsilon) - \theta_1^{JV, \Gamma}(t - \epsilon)}{\pi} + \frac{1}{\pi} \left(\sum_{j=2}^d \theta_j^{JV, \Gamma}(t + \epsilon) - \theta_j^{JV, \Gamma}(t - \epsilon) \right) + k, \end{aligned}$$

where

$$k = \begin{cases} +1 & \text{if } -\frac{\pi}{2} < \theta_1^{JV, \Gamma}(t + \epsilon) < 0 < \theta_1^{JV, \Gamma}(t - \epsilon) < \frac{\pi}{2}, \\ -1 & \text{if } -\frac{\pi}{2} < \theta_1^{JV, \Gamma}(t - \epsilon) < 0 < \theta_1^{JV, \Gamma}(t + \epsilon) < \frac{\pi}{2}. \end{cases}$$

Let us now calculate $\text{MI}(\Gamma|_{[t-\epsilon, t+\epsilon]})$. We can smoothly perturb the path $\Gamma|_{[t-\epsilon, t+\epsilon]}$ into a Lagrangian path $\tilde{\Gamma} : [t - \epsilon, t + \epsilon] \rightarrow \Lambda(\mathcal{M})$ such that

- (i) $\text{MI}(\Gamma|_{[t-\epsilon, t+\epsilon]}) = \text{MI}(\tilde{\Gamma})$;
- (ii) $\tilde{\Gamma}$ is in general position with respect to Σ , $\tilde{\Gamma}$ has a crossing at 0 with Σ and $\tilde{\Gamma}(s) \cap V(p \circ \tilde{\Gamma}(s)) = \{0\}$ for $s \in [t - \epsilon, t + \epsilon] \setminus \{t\}$;
- (iii) $\tilde{\Gamma}$ is in general position with respect to $\{L \in \Lambda(\mathcal{M}) : L \cap JV(p(L)) \neq \{0\}\}$ and $\tilde{\Gamma}(t) \cap JV(p \circ \tilde{\Gamma}(t)) = \{0\}$.

Conditions (i) and (ii) can be obtained easily, see Section 2, and they are stable under small perturbations. Moreover, since being in general position is a dense and open condition, we can assume, up to perturb Γ , that the initial path is also in general position with respect to $\{L \in \Lambda(\mathcal{M}) : L \cap JV(p(L)) \neq \{0\}\}$.

To obtain $\tilde{\Gamma}$, we need to perturb $\Gamma|_{[t-\epsilon, t+\epsilon]}$ so that the new path $\tilde{\Gamma}$ does not intersect the horizontal JV at time t .

Two cases can happen.

- (1) $\Gamma(t) \cap JV(p \circ \Gamma(t)) = \{0\}$. Then we conclude by defining $\tilde{\Gamma} = \Gamma$.

(2) $\Gamma(t) \cap JV(p \circ \Gamma(t)) \neq \{0\}$. In this case, because of the general position assumption, the subspace $\Gamma(t) \cap JV(p \circ \Gamma(t))$ is 1-dimensional, generated by one vector w . Let $0 < \theta \ll 1$, complete w to a unitary basis and consider the unitary transformation R that rotates by $e^{i\theta}$ the vector w and that is the identity on the other vectors of the basis. Up to select θ small enough, the Lagrangian path $\tilde{\Gamma} := R \circ \Gamma$ is a small perturbation of $\Gamma|_{[t-\epsilon, t+\epsilon]}$. Up to select a subpath of $\tilde{\Gamma}$, the defined path satisfies all the required conditions.

To calculate the Maslov index $\text{MI}(\Gamma|_{[t-\epsilon, t+\epsilon]})$, we calculate then $\text{MI}(\tilde{\Gamma})$, because of condition (i). In particular, up to select a subpath, we can assume that

$$\tilde{\Gamma} : [t - \epsilon, t + \epsilon] \rightarrow \Lambda(\mathcal{M})$$

is in general position with respect to Σ , it has a unique crossing with the vertical at $s = t$, for all $j > 1$ and all $s \in [t - \epsilon, t + \epsilon]$ it holds

$$|\theta_1^{JV, \tilde{\Gamma}}(s)| > |\theta_j^{JV, \tilde{\Gamma}}(s)|$$

and $\tilde{\Gamma}(s) \cap JV(p \circ \tilde{\Gamma}(s)) = \{0\}$ for all $s \in [t - \epsilon, t + \epsilon]$.

For every $s \in [t - \epsilon, t + \epsilon]$, by Proposition 5.3, we have a unitary basis of $T_{p(\tilde{\Gamma}(s))}\mathcal{M}$ whose vectors are in $JV(p \circ \tilde{\Gamma}(s))$

$$\{v_1(s), v_2(s), \dots, v_d(s)\}$$

made up of eigenvectors relative to the eigenvalues $e^{i\theta_j^{JV, \tilde{\Gamma}}(s)}$, $j = 1, \dots, d$ such that $(e^{i\theta_j^{JV, \tilde{\Gamma}}(s)}v_j)$, which is also a unitary basis of $T_{p(\tilde{\Gamma}(s))}\mathcal{M}$, is a basis of $\tilde{\Gamma}(s)$ over \mathbb{R} .

We want then to consider the variation of the index of the quadratic form

$$Q_{JV(p \circ \tilde{\Gamma}(s))}(V(p \circ \tilde{\Gamma}(s)), \tilde{\Gamma}(s)).$$

Up to a sign change, we can work with the quadratic form

$$Q = Q_{JV(p \circ \tilde{\Gamma}(s))}(\tilde{\Gamma}(s), V(p \circ \tilde{\Gamma}(s))).$$

In the sequel, we denote by Q both the quadratic form and the associated bilinear form. We consider the basis

$$(E_j)_{1 \leq j \leq d} = (P^{JV(p \circ \tilde{\Gamma}(s))}(e^{i\theta_j^{JV, \tilde{\Gamma}}(s)}v_j(s)))_{1 \leq j \leq d}$$

of $T_{p \circ \tilde{\Gamma}(s)}\mathcal{M}/JV(p \circ \tilde{\Gamma}(s))$. Then we have for all j, k

$$\begin{aligned} Q(E_j, E_k) &= \frac{1}{2} \left(\omega(e^{i\theta_j^{JV, \tilde{\Gamma}}(s)}v_j(s), i \sin(\theta_k^{JV, \tilde{\Gamma}}(s))v_k) + \omega(e^{i\theta_k^{JV, \tilde{\Gamma}}(s)}v_k(s), i \sin(\theta_j^{JV, \tilde{\Gamma}}(s))v_j) \right) \end{aligned}$$

We deduce that $(E_j)_{1 \leq j \leq d}$ is orthogonal for Q and that for all $j \in \{1, \dots, d\}$

$$\begin{aligned} Q(E_j, E_j) &= \omega(e^{i\theta_j^{JV, \tilde{\Gamma}}(s)}v_j(s), i \sin(\theta_j^{JV, \tilde{\Gamma}}(s))v_j) \\ &= \omega(\cos(\theta_j^{JV, \tilde{\Gamma}}(s))v_j(s) + \sin(\theta_j^{JV, \tilde{\Gamma}}(s))Jv_j(s), \sin(\theta_j^{JV, \tilde{\Gamma}}(s))Jv_j(s)) \\ &= \cos(\theta_j^{JV, \tilde{\Gamma}}(s)) \sin(\theta_j^{JV, \tilde{\Gamma}}(s)) = \frac{1}{2} \sin(2\theta_j^{JV, \tilde{\Gamma}}(s)) \end{aligned}$$

We can thus conclude that

$$\text{MI}(\Gamma|_{[t-\epsilon, t+\epsilon]}) = \text{MI}(\tilde{\Gamma}) = \begin{cases} +1 & \text{if } -\frac{\pi}{2} < \theta_1^{JV, \tilde{\Gamma}}(t+\epsilon) < 0 < \theta_1^{JV, \tilde{\Gamma}}(t-\epsilon) < \frac{\pi}{2}, \\ -1 & \text{if } -\frac{\pi}{2} < \theta_1^{JV, \tilde{\Gamma}}(t-\epsilon) < 0 < \theta_1^{JV, \tilde{\Gamma}}(t+\epsilon) < \frac{\pi}{2}. \end{cases}$$

□

From Proposition 5.4 we immediately obtain the following results.

Corollary 5.1. *Let \mathcal{M} be a 2d-dimensional symplectic manifold that admits a Lagrangian foliation. Let (ϕ_t) be an isotopy of conformally symplectic diffeomorphisms of \mathcal{M} . For every $L \in \Lambda(\mathcal{M})$ and $t > 0$ it holds*

$$(14) \quad |D\alpha\text{MI}(L, (\phi_s)_{s \in [0, t]}) - \text{DMI}(L, (\phi_s)_{s \in [0, t]})| < d.$$

In particular, whenever the asymptotic angular Maslov index exists at $x \in \mathcal{M}$, it does not depend on the chosen Lagrangian subspace and it holds

$$D\alpha\text{MI}_\infty(x, (\phi_t)) = \text{DMI}_\infty(x, (\phi_t)).$$

5.4. Independence of the asymptotic Maslov index from the isotopy. The index $D\alpha\text{MI}$ does not depend on the chosen conformally symplectic isotopy.

Proposition 5.5. *Let ϕ be a conformally symplectic diffeomorphism isotopic to the identity on \mathcal{M} . Let $(\phi_t)_{t \in [0, 1]}, (\psi_t)_{t \in [0, 1]}$ be isotopies of conformally symplectic diffeomorphisms such that $\phi_0 = \psi_0 = \text{Id}_{T^*\mathcal{M}}$ and $\phi_1 = \psi_1 = \phi$. Then for every $L \in \Lambda$*

$$D\alpha\text{MI}(L, (\phi_t)_{t \in [0, 1]}) = D\alpha\text{MI}(L, (\psi_t)_{t \in [0, 1]}).$$

Extend then each isotopy on $[0, +\infty)$ by asking that $\phi_{1+t} = \phi_t \circ \phi$ and $\psi_{1+t} = \psi_t \circ \phi$. Thus, whenever the limit exists, the asymptotic angular Maslov index does not depend on the chosen isotopy, i.e.

$$D\alpha\text{MI}_\infty(p(L), \phi) := D\alpha\text{MI}_\infty(p(L), (\phi_t)) = D\alpha\text{MI}_\infty(p(L), (\psi_t)).$$

Proof. Since $\phi_1 = \psi_1 = \phi$ and from (12), for every $L \in \Lambda$ it holds

$$D\alpha\text{MI}(L, (\phi_t)_{t \in [0, 1]}) = D\alpha\text{MI}(L, (\psi_t)_{t \in [0, 1]}) + 2k_L,$$

for some $k_L \in \mathbb{Z}$. The function

$$L \mapsto D\alpha\text{MI}(L, (\phi_t)_{t \in [0, 1]}) - D\alpha\text{MI}(L, (\psi_t)_{t \in [0, 1]})$$

is continuous. Therefore, the constant $k = k_L \in \mathbb{Z}$ does not depend on $L \in \Lambda$. To conclude, it is sufficient to find $L \in \Lambda$ such that

$$(15) \quad D\alpha\text{MI}(L, (\phi_t)_{t \in [0, 1]}) = D\alpha\text{MI}(L, (\psi_t)_{t \in [0, 1]}).$$

Consider then a Lagrangian graph $\mathcal{L} \subset \mathcal{M}$. By Theorem 1.1, with η, U and u defined as in the statement of Theorem 1.1, for every $x \in \phi^{-1}(\text{graph}((\eta + du)|_U))$ it holds

$$(16) \quad \text{DMI}(T_x \mathcal{L}, (\phi_t)_{t \in [0, 1]}) = \text{DMI}(T_x \mathcal{L}, (\psi_t)_{t \in [0, 1]}) = 0.$$

Let then \bar{x} be a point in $\phi^{-1}(\text{graph}((\eta + du)|_U)) \subset \mathcal{L}$. From Proposition 5.4 and from (16), it holds

$$D\alpha\text{MI}(T_{\bar{x}} \mathcal{L}, (\phi_t)_{t \in [0, 1]}) - D\alpha\text{MI}(T_{\bar{x}} \mathcal{L}, (\psi_t)_{t \in [0, 1]}) =$$

$$\frac{1}{\pi} \left(\sum_{j=1}^d \theta_j^{JV, D\phi_t(T_{\bar{x}}\mathcal{L})}(1) - \theta_j^{JV, D\phi_t(T_{\bar{x}}\mathcal{L})}(0) \right) - \frac{1}{\pi} \left(\sum_{j=1}^d \theta_j^{JV, D\psi_t(T_{\bar{x}}\mathcal{L})}(1) - \theta_j^{JV, D\psi_t(T_{\bar{x}}\mathcal{L})}(0) \right).$$

Since $D\phi_1(T_{\bar{x}}\mathcal{L}) = D\psi_1(T_{\bar{x}}\mathcal{L}) = D\phi(T_{\bar{x}}\mathcal{L})$, the second term of the last equality is zero, as required. \square

We may now deduce the

Proof of Proposition 1.1. Since the difference between the angular Maslov index and the Maslov index in Proposition 5.4 only depends on $\Gamma(b)$ and $\Gamma(a)$, the results of Proposition 5.5 also hold for Maslov index. \square

From Corollary 5.1 and Proposition 5.1, we deduce the following result.

Corollary 5.2. *Let (ϕ_t) be an isotopy of conformally symplectic diffeomorphisms of \mathcal{M} . For every $x \in \mathcal{M}$ the asymptotic Maslov index, whenever it exists, does not depend on the chosen Lagrangian subspace $L \in \Lambda_x$.*

Moreover, the following holds.

Corollary 5.3. *Let $(\phi_{1,t})_t, (\phi_{2,t})_t$ be two isotopies of conformally symplectic diffeomorphisms of \mathcal{M} such that $\phi_{1,0} = \phi_{2,0} = \text{Id}_{\mathcal{M}}$, $\phi_{1,1} = \phi_{2,1}$ and $\phi_{i,1+t} = \phi_{i,t} \circ \phi_{i,1}$ for $i = 1, 2$. Then for every $x \in \mathcal{M}$, whenever the limit exists,*

$$DMI_{\infty}(x, (\phi_{1,t})) = DMI_{\infty}(x, (\phi_{2,t})).$$

6. APPLICATIONS AND PROOFS OF MAIN OUTCOMES

This section is devoted to the proofs of the main consequences presented in the introduction and further interesting applications.

6.1. Proof of Corollary 1.1. Let $(\phi_t)_{t \in \mathbb{R}}$ be a conformally symplectic isotopy of \mathcal{M} such that $\phi_0 = \text{Id}_{\mathcal{M}}$ and $\phi_{t+1} = \phi_t \circ \phi_1$. Let $\mathcal{L} \subset \mathcal{M}$ be a Lagrangian submanifold that is Hamiltonianly isotopic to a graph and such that $\bigcup_{t \in [0, +\infty)} \phi_t(\mathcal{L})$ is

relatively compact.

More precisely, let $\mathcal{L}_0 \subset \mathcal{M}$ be a Lagrangian graph and let $(h_t)_{t \in [0, 1]}$ be a Hamiltonian isotopy such that $h_0 = \text{Id}_{\mathcal{M}}$ and $h_1(\mathcal{L}_0) = \mathcal{L}$. Let $\alpha : [0, 1] \rightarrow [0, 1]$ be a smooth non-decreasing function such that $\alpha(0) = 0$ and α is constant equal to 1 when restricted to some neighborhood of 1. Let $\beta : [0, 1] \rightarrow [0, 1]$ be a smooth non-decreasing function such that β is constant equal to 0 on some neighborhood of 0 and equal to the identity on some neighborhood of 1. Define then $(\psi_t)_{t \in [0, +\infty)}$ as

$$\psi_t := \begin{cases} h_{\alpha(t)} & \text{for } t \in [0, 1], \\ \phi_{\beta(t-1)} \circ h_1 & \text{for } t \in [1, 2], \\ \phi_{t-2} \circ h_1 & \text{for } t \in [2, +\infty). \end{cases}$$

Then (ψ_t) is an isotopy of conformally symplectic diffeomorphisms such that $\psi_0 = \text{Id}_{\mathcal{M}}$ and $\psi_t(\mathcal{L}_0) = \phi_{t-2}(\mathcal{L})$ for $t \geq 2$.

Applying then Theorem 1.1 to the Lagrangian graph \mathcal{L}_0 with respect to the isotopy (ψ_t) , for every $t \in [1, +\infty)$ there exists at least a point $x_t \in \mathcal{L}_0$ such that

$$(17) \quad \text{DMI}(T_{x_t} \mathcal{L}_0, (\psi_s)_{s \in [0, t]}) = 0.$$

By compactness of \mathcal{L}_0 , by the relation between DMI and $\text{D}\alpha\text{MI}$ (see Corollary 5.1) and by the continuity of the angular Maslov index, there exists a constant $C > 0$ such that for every $x \in \mathcal{L}_0$ it holds

$$(18) \quad |\text{DMI}(T_x \mathcal{L}_0, (\psi_t)_{t \in [0, 1]})| \leq C.$$

From (17) and (18), for every $t \in [0, +\infty)$ we have then a point $z_t := h_1(x_{t+1}) \in h_1(\mathcal{L}_0) = \mathcal{L}$ such that

$$(19) \quad |\text{DMI}(T_{z_t} \mathcal{L}, (\phi_s)_{s \in [0, t]})| \leq C.$$

Consider then the sequence $(z_n)_{n \in \mathbb{N}}$ in \mathcal{L} . For every $n \in \mathbb{N}$, we define the following probability measure on $\Lambda(\mathcal{M})$:

$$\mu_n := \frac{1}{n} \sum_{i=0}^{n-1} \delta_{D\phi_i(T_{z_n} \mathcal{L})},$$

where δ_* is the Dirac measure supported on $*$ $\in \Lambda(\mathcal{M})$. Since $\bigcup_{t \in [0, +\infty)} \phi_t(\mathcal{L})$ is relatively compact, we can extract a subsequence $(\mu_{n_k})_{k \in \mathbb{N}}$ that converges to a probability measure $\bar{\mu}$ on $\Lambda(\mathcal{M})$. The measure $\bar{\mu}$ is $D\phi_1$ -invariant. The projected measure $\mu := p_* \bar{\mu}$ is a ϕ_1 -invariant probability measure on \mathcal{M} .

By Corollary 5.1 it holds

$$\begin{aligned} \text{DMI}(\mu, (\phi_t)) &= \\ &= \int_{\mathcal{M}} \text{DMI}_\infty(x, (\phi_t)) d\mu(x) = \int_{\Lambda(\mathcal{M})} \text{D}\alpha\text{MI}_\infty(x, (\phi_t)) d\bar{\mu}(x). \end{aligned}$$

Since the asymptotic angular Maslov index does not depend on the chosen Lagrangian subspace, we have that

$$\int_{\mathcal{M}} \text{D}\alpha\text{MI}_\infty(x, (\phi_t)) d\mu(x) = \int_{\Lambda(\mathcal{M})} \text{D}\alpha\text{MI}_\infty(p(L), (\phi_t)) d\bar{\mu}(L).$$

Birkhoff's Ergodic Theorem, applied at the function $L \mapsto \text{D}\alpha\text{MI}(L, (\phi_t)_{t \in [0, 1]})$ and at the probability measure $\bar{\mu}$ on $\Lambda(\mathcal{M})$, assures us that

$$\int_{\Lambda(\mathcal{M})} \text{D}\alpha\text{MI}_\infty(p(L), (\phi_t)) d\bar{\mu}(L) = \int_{\Lambda(\mathcal{M})} \text{D}\alpha\text{MI}(L, (\phi_t)_{t \in [0, 1]}) d\bar{\mu}(L).$$

Since $(\mu_{n_k})_{k \in \mathbb{N}}$ converges to $\bar{\mu}$, it holds

$$\begin{aligned} \int_{\Lambda(\mathcal{M})} \text{D}\alpha\text{MI}(L, (\phi_t)_{t \in [0, 1]}) d\bar{\mu}(L) &= \lim_{k \rightarrow +\infty} \frac{1}{n_k} \sum_{i=0}^{n_k-1} \text{D}\alpha\text{MI}(D\phi_i(T_{z_{n_k}} \mathcal{L}), (\phi_t)_{t \in [0, 1]}) \\ &= \lim_{k \rightarrow +\infty} \frac{1}{n_k} \text{D}\alpha\text{MI}(T_{z_{n_k}} \mathcal{L}, (\phi_t)_{t \in [0, n_k]}). \end{aligned}$$

From (19) and from Corollary 5.1, we have that for every $k \in \mathbb{N}$

$$|\text{D}\alpha\text{MI}(T_{z_{n_k}} \mathcal{L}, (\phi_t)_{t \in [0, n_k]})| \leq C + d.$$

Thus, we conclude that

$$\text{DMI}(\mu, (\phi_t)) = \lim_{k \rightarrow +\infty} \frac{1}{n_k} \text{D}\alpha\text{MI}(T_{z_{n_k}} \mathcal{L}, (\phi_t)_{t \in [0, n_k]}) = 0,$$

as required. Observe that the support of the measure μ is contained in

$$\bigcap_{T \in [0, +\infty)} \overline{\bigcup_{t \in [T, +\infty)} \phi_t(\{z_n : n \in \mathbb{N}\})} \subset \bigcap_{T \in [0, +\infty)} \overline{\bigcup_{t \in [T, +\infty)} \phi_t(\mathcal{L})}.$$

Let now (ϕ_t) be a conformally symplectic flow on \mathcal{M} . We can then consider for every $t \in [0, +\infty)$ the measure on $\Lambda(\mathcal{M})$

$$(20) \quad \mu_t := [z_t]_t = \frac{1}{t} \int_0^t \delta_{D\phi_s(T_{z_t}\mathcal{L})} ds.$$

Observe, as before, that, from the choice of z_t , for every t it holds

$$(21) \quad |\text{D}\alpha\text{MI}(T_{z_t}\mathcal{L}, (\phi_s)_{s \in [0, t]})| \leq C + d.$$

Consider then an accumulation point $\bar{\mu}$ of $(\mu_t)_{t \in [0, +\infty)}$ in the space of measure on $\Lambda(\mathcal{M})$, which exists because $\bigcup_{t \in [0, +\infty)} \phi_t(\mathcal{L})$ is relatively compact. More precisely, let $(t_n)_{n \in \mathbb{N}}$ be a sequence such that $t_n \rightarrow +\infty$ and $\mu_{t_n} \rightarrow \bar{\mu}$ as $n \rightarrow +\infty$. The measure $\bar{\mu}$ is $(D\phi_t)$ -invariant. The projection $\mu = p_*\bar{\mu}$ is then a ϕ_t -invariant measure on \mathcal{M} .

We denote by F the derivative of the function Δ that we introduced in section 5 in the direction of the vectorfield χ , where χ is the vectorfield associated to the flow $(D\phi_s) : \Lambda(\mathcal{M}) \hookrightarrow$. Then, for every $L \in \Lambda(\mathcal{M})$ and every t it holds

$$\text{D}\alpha\text{MI}(L, (\phi_s)_{s \in [0, t]}) = \int_0^t F \circ D\phi_s(L) ds.$$

By Birkhoff Ergodic Theorem for flows (see [NS60, Page 459]), the following integral exists $\bar{\mu}$ almost everywhere

$$\bar{F}(L) := \lim_{t \rightarrow +\infty} \frac{1}{t} \int_0^t F \circ D\phi_s(L) ds = \text{D}\alpha\text{MI}_\infty(p(L), (\phi_t)),$$

and we have

$$\int_{\Lambda(\mathcal{M})} \bar{F}(L) d\bar{\mu}(L) = \int_{\Lambda(\mathcal{M})} F(L) d\bar{\mu}(L).$$

Following then the same calculus as for the previous case, it holds

$$\begin{aligned} \text{DMI}(\mu, (\phi_t)) &= \int_{\mathcal{M}} \text{DMI}_\infty(x, (\phi_t)) d\mu(x) \\ &= \int_{\mathcal{M}} \text{D}\alpha\text{MI}_\infty(x, (\phi_t)) d\mu(x) \\ &= \int_{\Lambda(\mathcal{M})} \bar{F}(L) d\bar{\mu}(L) = \int_{\Lambda(\mathcal{M})} F(L) d\bar{\mu}(L). \end{aligned}$$

Since $\bar{\mu} = \lim_{n \rightarrow \infty} \mu_{t_n}$, because of (20) and from (21), we have that

$$\begin{aligned} \int_{\Lambda(\mathcal{M})} F(L) d\bar{\mu}(L) &= \lim_{n \rightarrow +\infty} \frac{1}{t_n} \int_0^{t_n} F \circ D\phi_s(T_{z_{t_n}}\mathcal{L}) ds \\ &= \lim_{n \rightarrow +\infty} \frac{\text{D}\alpha\text{MI}(t_{z_{t_n}}\mathcal{L}, (\phi_s)_{s \in [0, t_n]})}{t_n} = 0. \end{aligned}$$

Thus, we conclude that $\text{DMI}(\mu, (\phi_t)) = 0$, as desired.

6.2. Proof of Corollary 1.2. Let (ϕ_t) be a symplectic isotopy of \mathbb{T}^{2d} such that $\phi_0 = \text{Id}_{\mathbb{T}^{2d}}$ and $\phi_{t+1} = \phi_t \circ \phi_1$. Using a covering $\Pi : T^*\mathbb{T}^d \rightarrow \mathbb{T}^{2d}$, we can lift the symplectic isotopy (ϕ_t) on \mathbb{T}^{2d} to a symplectic isotopy (Φ_t) on $T^*\mathbb{T}^d$ such that for every $t \in \mathbb{R}$

$$\Pi \circ \Phi_t = \phi_t \circ \Pi.$$

Let $\mathcal{Z}_0 \subset T^*\mathbb{T}^d$ be the zero section, which is a Lagrangian submanifold. By Theorem 1.1 for every $n \in \mathbb{N}$ there exists a point $u_n \in \mathcal{Z}_0$ such that

$$\text{DMI}(T_{u_n}\mathcal{Z}_0, (\Phi_t)_{t \in [0, n]}) = 0.$$

Since the covering Π is a submersion, for every $L \in \Lambda(T^*\mathbb{T}^d)$ we have

$$\text{DMI}(D\Pi(L), (\phi_t)_{t \in [0, 1]}) = \text{DMI}(L, (\Phi_t)_{t \in [0, 1]}),$$

where the Maslov index in $T^*\mathbb{T}^d$ is calculated with respect to the vertical Lagrangian foliation \mathcal{V} whose associated tangent bundle is $T_x T^*\mathbb{T}^d$, while the Maslov index in \mathbb{T}^{2d} is calculated with respect to the image foliation $\Pi(\mathcal{V})$. Observe that the tangent bundle associated to $\Pi(\mathcal{V})$ is $\ker(dp_1)$, where $p_1 : \mathbb{T}^{2d} \rightarrow \mathbb{T}^d$ is the projection of the first d -coordinates.

For every $n \in \mathbb{N}$ define then $U_n := D\Pi(T_{u_n}\mathcal{Z}_0) \in \Lambda(\mathbb{T}^{2d})$ and the probability measure on $\Lambda(\mathbb{T}^{2d})$

$$\mu_n := \frac{1}{n} \sum_{i=0}^{n-1} \delta_{D\phi_i(U_n)}.$$

Since $\Lambda(\mathbb{T}^{2d})$ is compact, we can extract from $(\mu_n)_{n \in \mathbb{N}}$ a subsequence converging to a $D\phi_1$ -invariant probability measure $\bar{\mu}$ on $\Lambda(\mathbb{T}^{2d})$. Using the projection $p : \Lambda(\mathbb{T}^{2d}) \rightarrow \mathbb{T}^{2d}$ and repeating the calculus done in the proof of Corollary 1.1, the ϕ_1 -invariant probability measure $\mu = p_*\bar{\mu}$ on \mathbb{T}^{2d} is then such that

$$\text{DMI}(\mu, (\phi_t)) = 0.$$

6.3. Existence of points and ergodic measures with vanishing asymptotic Maslov index for conformally symplectic isotopies that twist the vertical.

In this subsection we are mainly concerned with the proof of Theorems 1.2 and 1.3. Let us first recall that, in Proposition 2.4, we prove that, for an isotopy $(\phi_t)_{t \in \mathbb{R}}$ of conformally symplectic diffeomorphisms of \mathcal{M} that twists the vertical, for every $L \in \Lambda(\mathcal{M})$ and every $[\alpha, \beta] \subset \mathbb{R}$ such that $D\phi_\alpha(L), D\phi_\beta(L) \notin \Sigma(\mathcal{M})$ it holds

$$\text{DMI}(L, (\phi_t)_{t \in [\alpha, \beta]}) \leq 0.$$

Consequently, for every $x \in \mathcal{M}$ we have

$$\text{DMI}_\infty(x, (\phi_t)_{t \in [0, +\infty)}) \leq 0.$$

Moreover, from Corollary 5.1, we deduce that, for an isotopy $(\phi_t)_{t \in \mathbb{R}}$ of conformally symplectic diffeomorphisms on $\mathcal{M} = T^*M$ that twists the vertical, for every $L \in \Lambda$ and every $x \in \mathcal{M}$ it holds

$$D\alpha\text{MI}(L, (\phi_t)_{t \in [0, 1]}) < d \quad \text{and} \quad D\alpha\text{MI}_\infty(x, (\phi_t)_{t \in [0, +\infty)}) \leq 0,$$

where $d = \dim(M)$.

Proof of Theorem 1.2. Let $(\phi_t)_{t \in \mathbb{R}}$ be a conformally symplectic isotopy of \mathcal{M} such that $\phi_0 = \text{Id}_{\mathcal{M}}$. Let $\mathcal{L} \subset \mathcal{M}$ be a Lagrangian submanifold that is Hamiltonianly isotopic to a graph. Let $\mathcal{L}_0 \subset \mathcal{M}$ be a Lagrangian graph and let $(h_t)_{t \in [0, 1]}$ be a Hamiltonian isotopy such that $h_0 = \text{Id}_{\mathcal{M}}$ and $h_1(\mathcal{L}_0) = \mathcal{L}$. Let $\alpha : [0, 1] \rightarrow [0, 1]$

be a smooth non-decreasing function such that $\alpha(0) = 0$ and α is constant equal to 1 when restricted to some neighborhood of 1. Let $\beta : [0, 1] \rightarrow [0, 1]$ be a smooth non-decreasing function such that β is constant equal to 0 on some neighborhood of 0 and equal to the identity on some neighborhood of 1. Define then $(\psi_t)_{t \in [0, +\infty)}$ as

$$\psi_t := \begin{cases} h_{\alpha(t)} & \text{for } t \in [0, 1], \\ \phi_{\beta(t-1)} \circ h_1 & \text{for } t \in [1, 2], \\ \phi_{t-2} \circ h_1 & \text{for } t \in [2, +\infty). \end{cases}$$

Then $(\psi_t)_{t \in [0, +\infty)}$ is an isotopy of conformally symplectic diffeomorphisms such that $\psi_0 = \text{Id}_{\mathcal{M}}$.

Apply then Theorem 1.1 to the Lagrangian graph \mathcal{L}_0 with respect to the isotopy $(\psi_t)_{t \in [0, +\infty)}$. That is, for every $t \in [0, +\infty)$ there exists at least a point $z_t \in \mathcal{L}_0$ ¹¹ such that

$$(22) \quad \text{DMI}(T_{z_t} \mathcal{L}_0, (\psi_s)_{s \in [0, t]}) = 0.$$

From (22) and from the compactness of $\{h_s(\mathcal{L}_0) : s \in [0, 1]\}$, there exists an integer $\rho > 0$ such that for every $t \in [0, +\infty)$ there exists a point $x_t := \psi_1(z_{t+1}) = h_1(z_{t+1}) \in \mathcal{L}$ such that

$$\text{DMI}(T_{x_t} \mathcal{L}, (\phi_s)_{s \in [0, t]}) \in [-\rho, \rho].$$

Moreover, as (ϕ_s) twists the vertical, we have in fact

$$(23) \quad \text{DMI}(T_{x_t} \mathcal{L}, (\phi_s)_{s \in [0, t]}) \in [-\rho, 0].$$

By compactness of \mathcal{L} , we can extract from $(x_t)_{t \in [0, +\infty)}$ a subsequence $(x_n)_{n \in \mathbb{N}}$ which converges to a point $x \in \mathcal{L}$.

Fix $N \in \mathbb{N}$ and $\epsilon > 0$. By continuity of the angular Maslov index, there exists $\bar{n} \in \mathbb{N}$ such that for every $n \geq \bar{n}$ it holds

$$(24) \quad \left| \text{D}\alpha\text{MI}(T_x \mathcal{L}, (\phi_s)_{s \in [0, N]}) - \text{D}\alpha\text{MI}(T_{x_n} \mathcal{L}, (\phi_s)_{s \in [0, N]}) \right| < \epsilon.$$

Since the isotopy twists the vertical, we claim that, for every $n \geq \max(\bar{n}, N)$, it holds

$$(25) \quad \text{DMI}(T_{x_n} \mathcal{L}, (\phi_s)_{s \in [0, N]}) \in [-\rho, 0].$$

Indeed, if this does not hold, then for some $n \geq \max(\bar{n}, N)$ from Proposition 2.4 we have that

$$\text{DMI}(T_{x_n} \mathcal{L}, (\phi_s)_{s \in [0, N]}) \leq -\rho - 1.$$

From (23) and since

$$\text{DMI}(T_{x_n} \mathcal{L}, (\phi_s)_{s \in [0, n]}) = \text{DMI}(T_{x_n} \mathcal{L}, (\phi_s)_{s \in [0, N]}) + \text{DMI}(D\phi_N(T_{x_n} \mathcal{L}), (\phi_s)_{s \in [0, n-N]}),$$

we contradict Proposition 2.4 because

$$\text{DMI}(T_{\phi_N(x_n)} \phi_N(\mathcal{L}), (\phi_s)_{s \in [0, n-N]}) \geq 1.$$

¹¹Actually there exists an open set whose projection on M has full Lebesgue measure.

From (24), (25) and Corollary 5.1, we have that for every $n \geq \max(\bar{n}, N)$

$$\begin{aligned} & \left| \text{D}\alpha\text{MI}(T_x\mathcal{L}, (\phi_s)_{s \in [0, N]}) \right| \\ & \leq \left| \text{D}\alpha\text{MI}(T_x\mathcal{L}, (\phi_s)_{s \in [0, N]}) - \text{D}\alpha\text{MI}(T_{x_n}\mathcal{L}, (\phi_s)_{s \in [0, N]}) \right| + \left| \text{D}\alpha\text{MI}(T_{x_n}\mathcal{L}, (\phi_s)_{s \in [0, N]}) \right| \\ & < \epsilon + \rho + d, \end{aligned}$$

where $d = \dim(M)$. Letting $\epsilon \rightarrow 0$ and again by Corollary 5.1, for every $t \in [0, +\infty)$ we conclude that

$$\text{DMI}(T_x\mathcal{L}, (\phi_s)_{s \in [0, t]}) \in [-C, C],$$

where $C := \rho + 2d$. In particular, we deduce also that $\text{DMI}_\infty(x, (\phi_t)_{t \in [0, +\infty)}) = 0$. \square

Proof of Theorem 1.3. Let (ϕ_t) be an isotopy of conformally symplectic diffeomorphisms of \mathcal{M} such that $\phi_{1+t} = \phi_t \circ \phi_1$. Observe that, if (ϕ_t) twists the vertical, then, by Proposition 2.4, for every ϕ_1 -invariant measure with compact support μ it holds

$$(26) \quad \text{DMI}(\mu, (\phi_t)) = \int_{\mathcal{M}} \text{DMI}_\infty(x, (\phi_t)) d\mu(x) \leq 0.$$

As the function $\text{DMI}(\cdot, (\phi_t))$ is measurable and non-positive, this implies that $\text{DMI}(\cdot, (\phi_t)_{t \in [0, +\infty)}) \in L^1(\mu)$.

Let $x \in \mathcal{L}$ be the point given by Theorem 1.2. The assumption that its positive orbit is relatively compact enables us to find a ϕ_1 -invariant measure μ supported on the closure of the orbit of x with vanishing asymptotic Maslov index.

By Ergodic Decomposition Theorem (see [Mn87]), for μ almost every y , the measure

$$\mu_y = \lim_{N \rightarrow \infty} \frac{1}{N} \sum_{n=0}^N \delta_{\phi_n(y)}$$

exists and is ergodic, we have $\text{DMI}(\cdot, (\phi_t)) \in L^1(\mu_y)$ and

$$0 = \text{DMI}(\mu, (\phi_t)) = \int_{\mathcal{M}} \text{DMI}(\mu_y, (\phi_t)) d\mu(y).$$

As the function in the integral is non-positive by (26), we deduce that for μ almost every y , the measure μ_y is ergodic and has vanishing Maslov index. \square

6.4. Autonomous and 1-periodic Tonelli Hamiltonian flow case. We can consider the particular case of a Hamiltonian 1-periodic Tonelli flow on a cotangent bundle T^*M , where M is a d -dimensional compact manifold. More precisely, let $H : T^*M \times \mathbb{R}/\mathbb{Z} \rightarrow \mathbb{R}$ be a Tonelli 1-periodic Hamiltonian. Denote as $(\phi_{s,t}^H)$ the family of symplectic maps generated by the Hamiltonian vector field of H .

Using Weak KAM Theory, we can easily obtain Theorem 1.2 for a Lagrangian graph. More precisely, let $\mathcal{L} \subset T^*M$ be a Lagrangian graph, that is there exists a $C^{1,1}$ function $u : M \rightarrow \mathbb{R}$ such that $\mathcal{L} = \text{graph } du$. Then, the existence of a point $x \in \mathcal{L}$ with zero asymptotic Maslov index can be deduced from Weak KAM theory. Indeed, let $v : M \rightarrow \mathbb{R}$ be a Weak KAM solution of positive type. In particular, v is semiconvex. Consider then the function $v - u$, which is still semiconvex. Let $x_0 \in M$ be a local maximum of the function $v - u$. Then, since $v - u$ is semiconvex and x_0 is a local maximum, actually the function $v - u$ is differentiable at x_0 . We deduce that $dv(x_0) = du(x_0)$. Consequently, the Lagrangian submanifold \mathcal{L} intersects the

partial graph of dv in $du(x_0)$. Since v is a weak KAM solution of positive type, the orbit of a point lying in the partial graph of dv is minimizing on every interval $[0, t]$, for $t > 0$. In particular, the point $du(x_0)$ does not have conjugate points in the future. This implies that the Maslov index on every interval $[0, t]$ at $du(x_0)$ is zero, and so $du(x_0) \in \mathcal{L}$ has zero asymptotic Maslov index.

Recall that an autonomous Tonelli Hamiltonian flow provides an isotopy of symplectic diffeomorphisms that twists the vertical, see Proposition 2.5. By Theorem 1.3 there exists then an ergodic invariant measure of vanishing asymptotic Maslov index. In the case of an autonomous Tonelli Hamiltonian flow on T^*M , we can characterise the invariant measure of vanishing Maslov index given by Theorem 1.3. That is, the given invariant measure is actually a Mather minimizing measure, as stated in Corollary 1.3.

Proof of Corollary 1.3. Indeed it can be proved that the graph selector is unique (see e.g. [AV17]). In this case, the graph selector can be built by using the Lax-Oleinik semi-group, see [Jou91] or [Wei14]. Fathi, [Fat08], proved the convergence of the Lax-Oleinik semi-group (that is the graph selectors in our case) to a weak KAM solution. Arnaud proved in [Arn05] that the resulting pseudographs converge to the pseudograph of a weak KAM solution for the Hausdorff distance. Hence the supports of measures that are given by the last theorem are in the pseudograph of a weak KAM solution and thus minimizing, see (3.14) in [Ber08]. \square

6.5. Proof of Corollary 1.4. We endow M with a Riemannian metric.

We are assuming that

$$(27) \quad \forall (\lambda_1, \dots, \lambda_n) \in \mathbb{R}^n \setminus \{0_{\mathbb{R}^n}\}, \forall q \in M \quad \text{it holds} \quad \sum_{k=1}^n \lambda_k \eta_k(q) \neq 0.$$

This implies that the map I from $M \times \mathbb{R}^n$ to $\mathcal{M} = T^*M$ that is defined by

$$I(q, \lambda_1, \dots, \lambda_n) = \sum_{k=1}^n \lambda_k \eta_k(q)$$

is a bi-Lipschitz embedding. Indeed, it is a fibered linear monomorphism from $M \times \mathbb{R}^n$ to T^*M that continuously depends on the point $q \in M$. We denote by $\mathcal{Q} \subset \mathcal{M}$ its image $I(M \times \mathbb{R}^n)$. Then the map $j : \mathcal{Q} \rightarrow \mathbb{R}^n$ that is defined by

$$j\left(\sum_{k=1}^n \lambda_k \eta_k(q)\right) = (\lambda_1, \dots, \lambda_n)$$

is Lipschitz.

For every $(\lambda_1, \dots, \lambda_n) \in \mathbb{R}^n$ we consider the Lagrangian graph $\mathcal{L}_{(\lambda_1, \dots, \lambda_n)} := \{\sum_{k=1}^n \lambda_k \eta_k(q) : q \in M\} \subset \mathcal{M}$. As (ϕ_t) is an isotopy of conformally symplectic diffeomorphisms that twists the vertical, from Theorem 1.2, there exists at least one point $x \in \mathcal{L}_{(\lambda_1, \dots, \lambda_n)}$ with zero asymptotic Maslov index. In particular,

$$j(\{p \in \mathcal{Q} : \text{DMI}_\infty(p, (\phi_t)_{t \in [0, +\infty)}) = 0\}) = \mathbb{R}^n.$$

Because j is Lipschitz, this implies that

$$\dim_H\left(\{p \in \mathcal{M} : \text{DMI}_\infty(p, (\phi_t)_{t \in [0, +\infty)}) = 0\}\right) \geq n.$$

REFERENCES

- [AF21] M.-C. Arnaud and J. Féjoz. Invariant submanifolds of conformal symplectic dynamics. 2021. arXiv:2110.05062.
- [Arn05] M.-C. Arnaud. Convergence of the semi-group of Lax-Oleinik: a geometric point of view. *Nonlinearity*, 18(4):1835–1840, 2005.
- [Arn08] M.-C. Arnaud. Fibrés de Green et régularité des graphes C^0 -lagrangiens invariants par un flot de Tonelli. *Ann. Henri Poincaré*, 9(5):881–926, 2008.
- [Aud03] M. Audin. Lagrangian submanifolds. In *Symplectic geometry of integrable Hamiltonian systems (Barcelona, 2001)*, Adv. Courses Math. CRM Barcelona, pages 1–83. Birkhäuser, Basel, 2003.
- [AV17] M.-C. Arnaud and A. Venturelli. A multidimensional Birkhoff theorem for time-dependent Tonelli Hamiltonians. *Calc. Var. Partial Differential Equations*, 56(4):Paper No. 122, 27, 2017.
- [Ber08] Patrick Bernard. The dynamics of pseudographs in convex Hamiltonian systems. *J. Amer. Math. Soc.*, 21(3):615–669, 2008.
- [BG92] J. Barge and É. Ghys. Cocycles d’Euler et de Maslov. *Math. Ann.*, 294(2):235–265, 1992.
- [Bru91] M. Brunella. On a theorem of Sikorav. *Enseign. Math.* (2), 37(1-2):83–87, 1991.
- [BW97] S. Bates and A. Weinstein. *Lectures on the geometry of quantization*, volume 8 of *Berkeley Mathematics Lecture Notes*. American Mathematical Society, Providence, RI; Berkeley Center for Pure and Applied Mathematics, Berkeley, CA, 1997.
- [CGIP03] G. Contreras, J.-M. Gambaudo, R. Iturriaga, and G. P. Paternain. The asymptotic Maslov index and its applications. *Ergodic Theory Dynam. Systems*, 23(5):1415–1443, 2003.
- [Cha91] M. Chaperon. Lois de conservation et géométrie symplectique. *C. R. Acad. Sci. Paris Sér. I Math.*, 312(4):345–348, 1991.
- [CLM94] S. E. Cappell, R. Lee, and E. Y. Miller. On the Maslov index. *Comm. Pure Appl. Math.*, 47(2):121–186, 1994.
- [Dui76] J. J. Duistermaat. On the Morse index in variational calculus. *Advances in Math.*, 21(2):173–195, 1976.
- [Fat08] A. Fathi. Weak KAM Theorem in Lagrangian Dynamics. Preliminary Version Number 10, 2008.
- [God71] C. Godbillon. *Éléments de topologie algébrique*. Hermann, Paris, 1971.
- [Jou91] T. Joukovskaia. Singularités de Minimax et Solutions Faibles d’Équations aux Dérivées Partielles. PhD thesis, Université de Paris VII, Denis Diderot, 1991.
- [KB37] N. Kryloff and N. Bogoliouboff. La théorie générale de la mesure dans son application à l’étude des systèmes dynamiques de la mécanique non linéaire. *Ann. of Math.* (2), 38(1):65–113, 1937.
- [Lib59] P. Libermann. Sur les automorphismes infinitésimaux des structures symplectiques et des structures de contact. In *Colloque Géom. Diff. Globale (Bruxelles, 1958)*, pages 37–59. Centre Belge Rech. Math., Louvain, 1959.
- [LMS03] P. Lochak, J.-P. Marco, and D. Sauzin. On the splitting of invariant manifolds in multidimensional near-integrable Hamiltonian systems. *Mem. Amer. Math. Soc.*, 163(775):viii+145, 2003.
- [LW98] C. Liverani and M. P. Wojtkowski. Conformally symplectic dynamics and symmetry of the Lyapunov spectrum. *Comm. Math. Phys.*, 194(1):47–60, <https://www.esi.ac.at/static/esiprpr/esi427.pdf>, 1998.
- [MBA72] V. P. Maslov, V.C. Bouslaev, and V. I. Arnol’d. Théorie des perturbations et méthodes asymptotiques. 1972.
- [Mil63] J. Milnor. *Morse theory*. Annals of Mathematics Studies, No. 51. Princeton University Press, Princeton, N.J., 1963. Based on lecture notes by M. Spivak and R. Wells.
- [Mn87] R. Mañé. *Ergodic theory and differentiable dynamics*, volume 8 of *Ergebnisse der Mathematik und ihrer Grenzgebiete (3) [Results in Mathematics and Related Areas (3)]*. Springer-Verlag, Berlin, 1987. Translated from the Portuguese by Silvio Levy.
- [MS17a] S. Marò and A. Sorrentino. Aubry-Mather theory for conformally symplectic systems. *Comm. Math. Phys.*, 354(2):775–808, 2017.

- [MS17b] D. McDuff and D. Salamon. Introduction to symplectic topology. Oxford Graduate Texts in Mathematics. Oxford University Press, Oxford, third edition, 2017.
- [NS60] V. V. Nemytskii and V. V. Stepanov. Qualitative theory of differential equations. Princeton Mathematical Series, No. 22. Princeton University Press, Princeton, N.J., 1960.
- [OV94] A. Ottolenghi and C. Viterbo. Solutions généralisées pour l'équation de hamilton-jacobi dans le cas dévolution. Mémoire de DEA, available on <http://www.math.ens.fr/viterbo/>, 1994.
- [PPS03] G. P. Paternain, L. Polterovich, and K. F. Siburg. Boundary rigidity for Lagrangian submanifolds, non-removable intersections, and Aubry-Mather theory. volume 3, pages 593–619, 745. 2003. Dedicated to Vladimir I. Arnold on the occasion of his 65th birthday.
- [RS93] J. Robbin and D. Salamon. The Maslov index for paths. Topology, 32(4):827–844, 1993.
- [Rue85] D. Ruelle. Rotation numbers for diffeomorphisms and flows. Ann. Inst. H. Poincaré Phys. Théor., 42(1):109–115, 1985.
- [Sch57] S. Schwartzman. Asymptotic cycles. Ann. of Math. (2), 66:270–284, 1957.
- [Sib04] K. F. Siburg. The principle of least action in geometry and dynamics, volume 1844 of Lecture Notes in Mathematics. Springer-Verlag, Berlin, 2004.
- [Sik87] J.-C. Sikorav. Problèmes d'intersections et de points fixes en géométrie hamiltonienne. Comment. Math. Helv., 62(1):62–73, 1987.
- [Vit87] C. Viterbo. Intersection de sous-variétés lagrangiennes, fonctionnelles d'action et indice des systèmes hamiltoniens. Bull. Soc. Math. France, 115(3):361–390, 1987.
- [Wei71] Alan Weinstein. Symplectic manifolds and their Lagrangian submanifolds. Advances in Math., 6:329–346 (1971), 1971.
- [Wei14] Q. Wei. Viscosity solution of the Hamilton-Jacobi equation by a limiting minimax method. Nonlinearity, 27(1):17–41, 2014.

E-mail address: Marie-Claude.Arnaud@imj-prg.fr

E-mail address: florio@ceremade.dauphine.fr

E-mail address: valentine.roos@ens-lyon.fr