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# Fast Sky to Sky Interpolation for Radio Interferometric Imaging

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## Introduction

- Sky image reconstruction from a large amount of radiotelescope data is computationally expensive. [1].
- The *Gridding* and *Degridding* interpolation operators are the main reasons for the computational cost of imaging algorithms.
- Our contributions:
  - ▷ Decomposition of the *Gridding* and *Degridding* operators.
  - ▷ Merge of these operators (S2S operator).
  - ▷ Reduction of the memory cost.
  - ▷ Reduction of the computational time to compute the gradient and the sky image reconstruction algorithm CLEAN.

## Radio Interferometric Imaging

- A radio interferometer is an array of antenna, and the Forward model is given by

$$v(u, v) = \iint x(l, m) e^{-2i\pi(ul+vm)} dl dm. \quad (1)$$

$$v = SFx + n \quad (2)$$

- Image estimation is an ill-posed problem. Algorithms aim to minimize the following equation

$$\hat{x} = \arg \min_x \|v - SFx\|^2 + \lambda R(x). \quad (3)$$

- Iterative algorithms need to compute the data fidelity criterion gradient  $\nabla J(x)$ , such as

$$\nabla J(x) = F^\dagger S^\dagger (v - SFx) \quad (4)$$

## Gridding and Degridding operators

- Interpolation of the data on an oversampled grid with a factor  $K$  to minimize the error.
- Convolution kernel used for the interpolation is similar to the one used for MRI imaging algorithms [2].
- Decomposition of the degridding operator  $S$  as a succession of sub-operators of **Oversampling  $O$ , Convolution  $C$ , Mapping  $A$** .

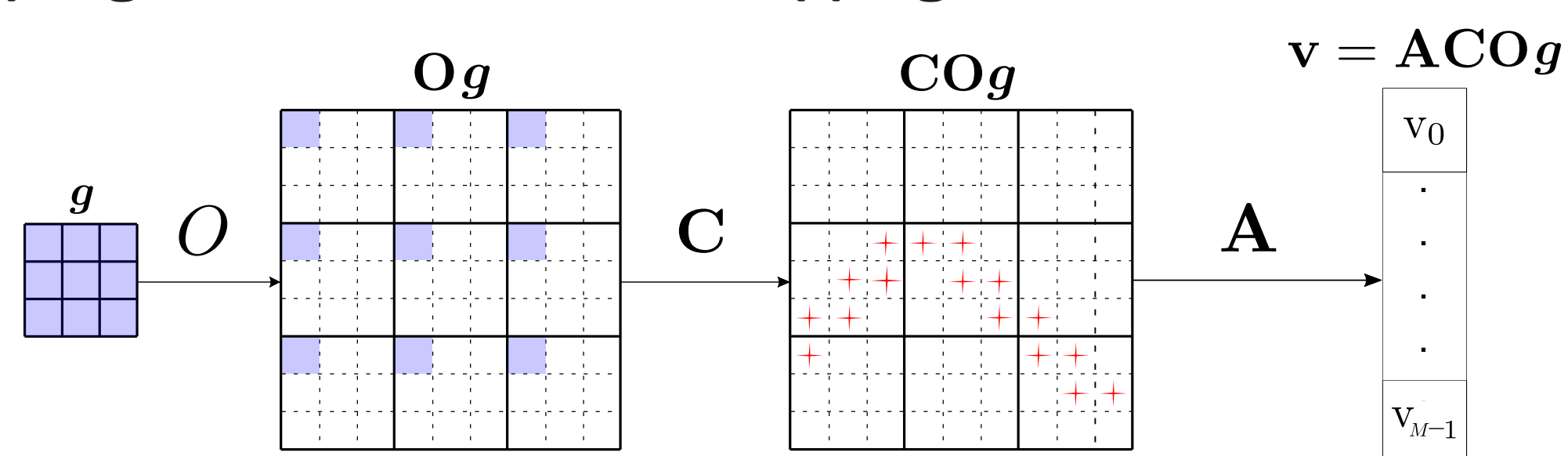


Figure: Degridding operator decomposition  $S$ .

- Decomposition of the gridding operator  $S^\dagger$  as a succession of sub-operators of **Accumulation  $A^\dagger$ , Convolution  $C^\dagger$ , Sub-sampling  $O^\dagger$** .

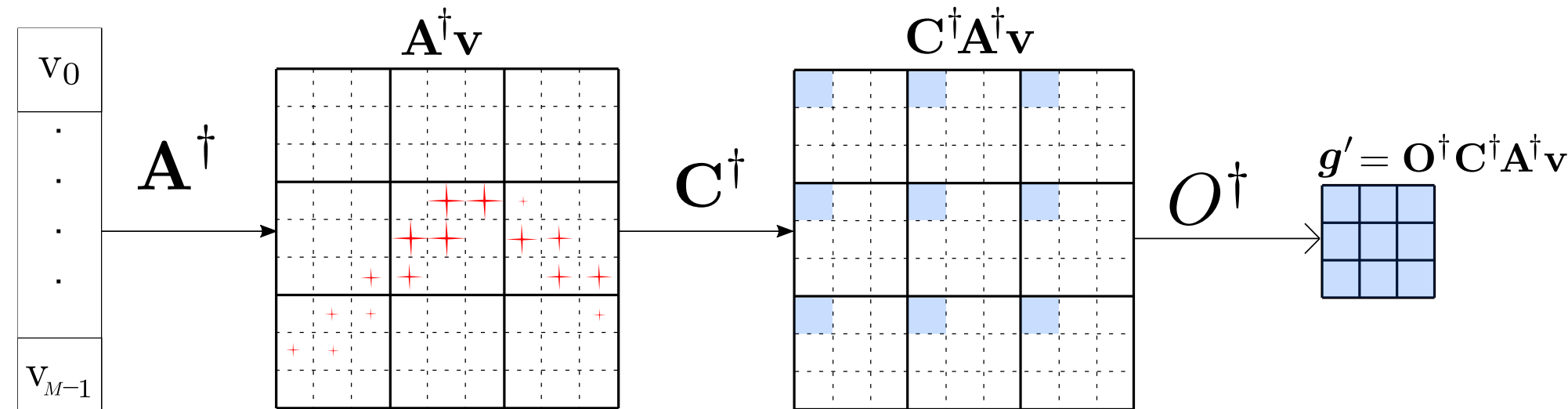


Figure: Gridding operator decomposition  $S^\dagger$ .

## Sky to Sky operator (S2S)

- Le calcul de gradient de la méthode standard (STD) peut être développé [3]

$$\begin{aligned} \nabla J(x) &= F^\dagger S^\dagger (v - SFx) \\ &= F^\dagger S^\dagger v - F^\dagger S^\dagger SFx. \end{aligned} \quad (5)$$

- Sky to Sky operator is the decomposition of  $S^\dagger S$  such as

$$\begin{aligned} S^\dagger S &= O^\dagger C^\dagger A^\dagger A C O \\ &= O^\dagger C^\dagger A^* C O. \end{aligned} \quad (6)$$

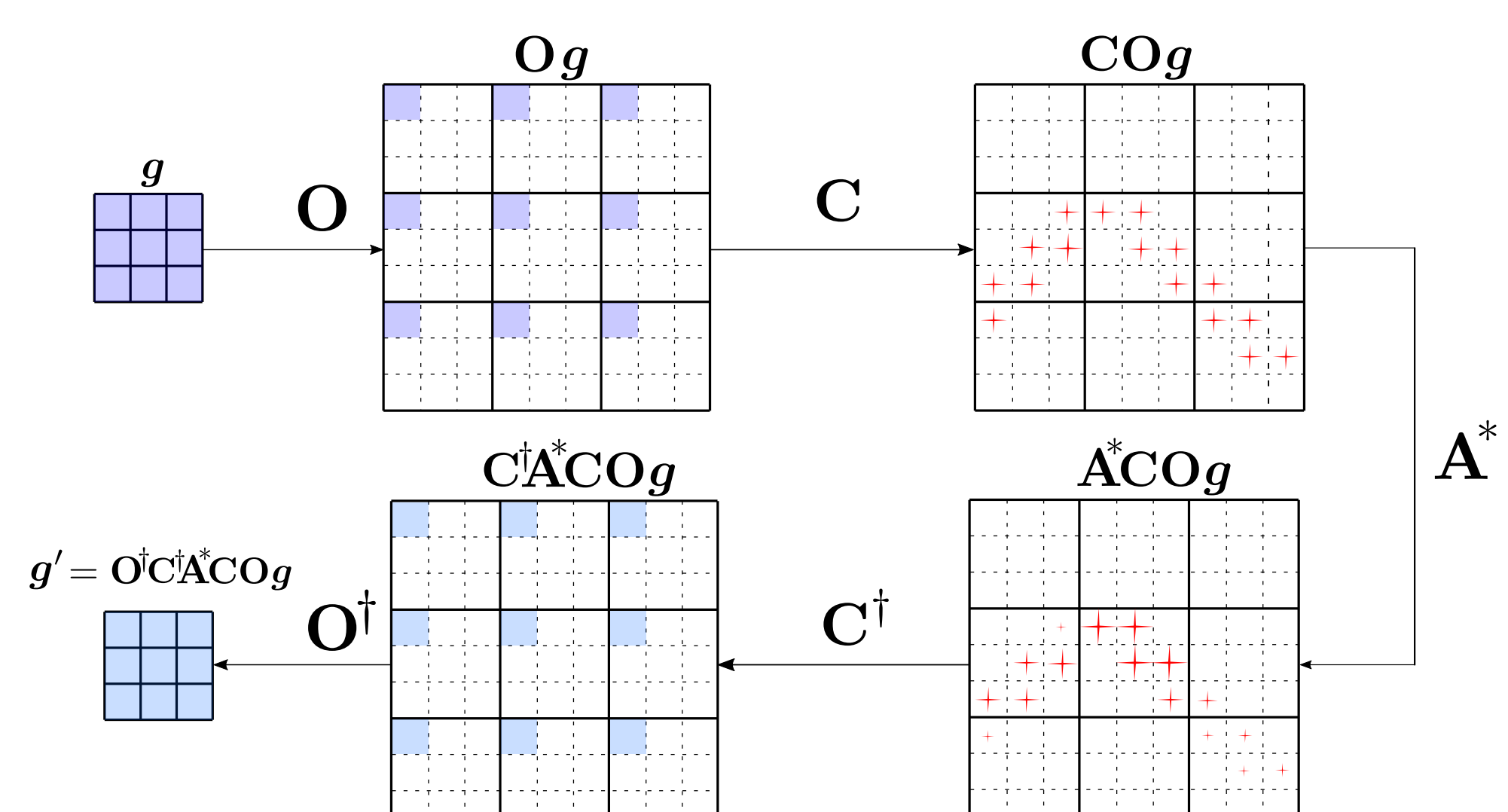


Figure: succession of Gridding and degridding operators  $S^\dagger S$  using S2S method.

## Sky to Sky operator (S2S)

- Merge of operators  $A^\dagger A = A^*$ , such as  $A^*$  is diagonal and sparse.
- If  $M'$  elements different of  $0$  in  $diag(A^*)$  et  $M$  raw data, the computing cost of S2S method is lower than STD method when

$$M' < \frac{2MC_{supp}^2 + M - P}{2C_{supp}^2 + 1}. \quad (7)$$

## Gradient Computation Results

- Raw data can be averaged to reduce the total amount of data to process.
- Oversampling error

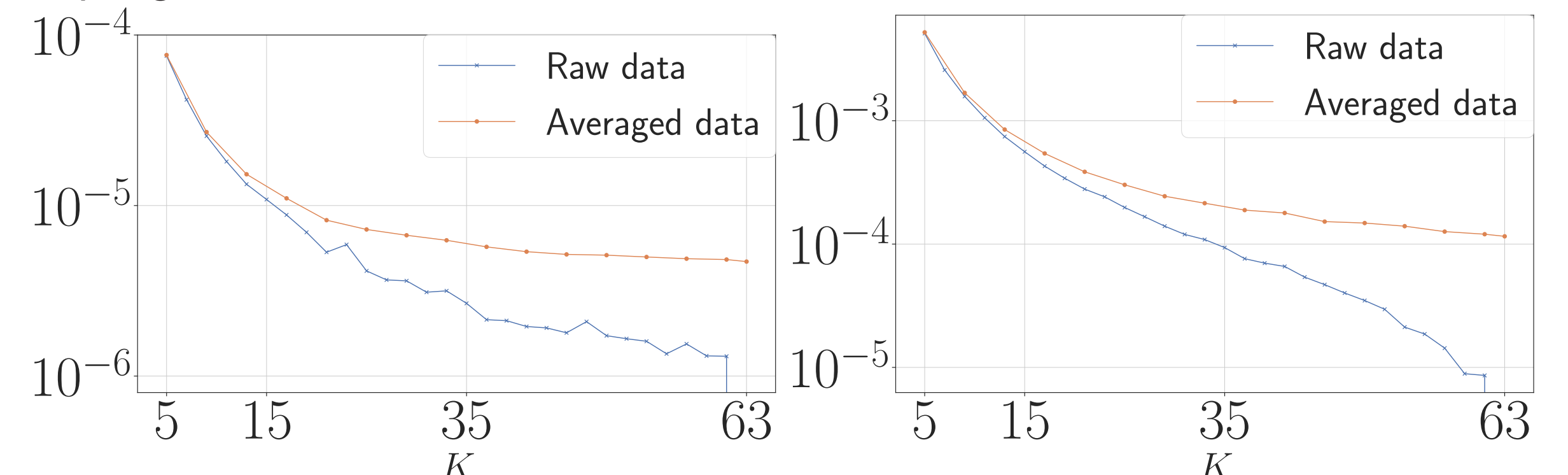


Figure: (Left) Mean Absolute Error. (Right) Maximum Absolute Error.

- Computation time cost

$K$	STD (s)	S2S (s)	STD moy.(s)	S2S moy.(s)
5	242.9	14.8 ( $\times 16.4$ )	33.7	13.9 ( $\times 2.4$ )
15	242.9	24.1 ( $\times 10.0$ )	33.7	22.1 ( $\times 1.6$ )
35	242.9	43.9 ( $\times 5.6$ )	33.7	27.0 ( $\times 1.3$ )
63	242.9	71.8 ( $\times 3.4$ )	33.7	28.5 ( $\times 1.2$ )

- Memory footprint cost

$K$	STD (GB)	S2S (GB)	STD moy.(GB)	S2S moy. (GB)
5	1.94	0.46	0.20	0.45
15	1.94	0.59	0.20	0.55
35	1.94	0.85	0.20	0.63
63	1.94	1.20	0.20	0.65

## Sky Estimation using CLEAN algorithm

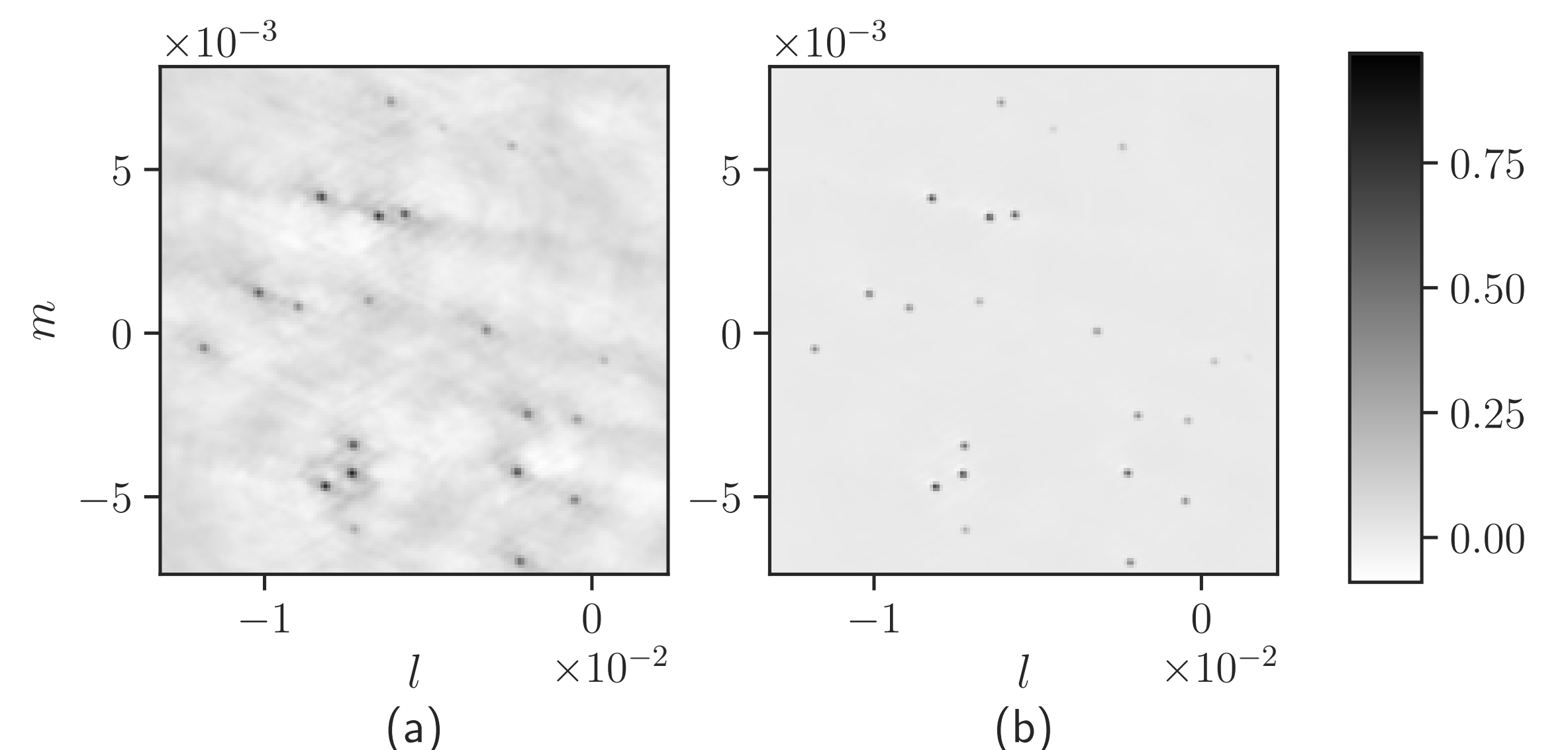


Figure: Zoom (Left): Dirty image. (Right): CLEAN Image

- Temps de calcul de l'algorithme complet :

$K$	STD (s)	S2S (s)	STD moy.(s)	S2S moy.(s)
5	641.2	186.8 ( $\times 3.4$ )	117.3	77.8 ( $\times 1.5$ )
15	641.2	201.1 ( $\times 3.2$ )	117.3	94.0 ( $\times 1.2$ )
35	641.2	240.6 ( $\times 2.7$ )	117.3	103.8 ( $\times 1.1$ )
63	641.2	296.4 ( $\times 2.1$ )	117.3	106.8 ( $\times 1.1$ )

## Conclusion and future work

- We proposed the Sky to Sky method as a merge of the Gridding and Degridding operators for radio interferometric imaging.
- This method shows a reduction of the computing time as well as the memory footprint.
- We plan to take direction-dependent effects into account and propose an implementation on hardware acceleration platform.

## References

- [1] A. R. Thompson, J. M. Moran, and G. W. Swenson, *Interferometry and synthesis in radio astronomy*, 2nd ed. Wiley, 2001.
- [2] J. A. Fessler, "On NUFFT-based gridding for non-cartesian MRI," *Journal of Magnetic Resonance*, vol. 188, no. 2, pp. 191–195, 2007.
- [3] I. Sullivan and al., "Fast holographic deconvolution: a new technique for precision radio interferometry," *The Astrophysical Journal*, vol. 759, no. 1, p. 17, 2012.