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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** .

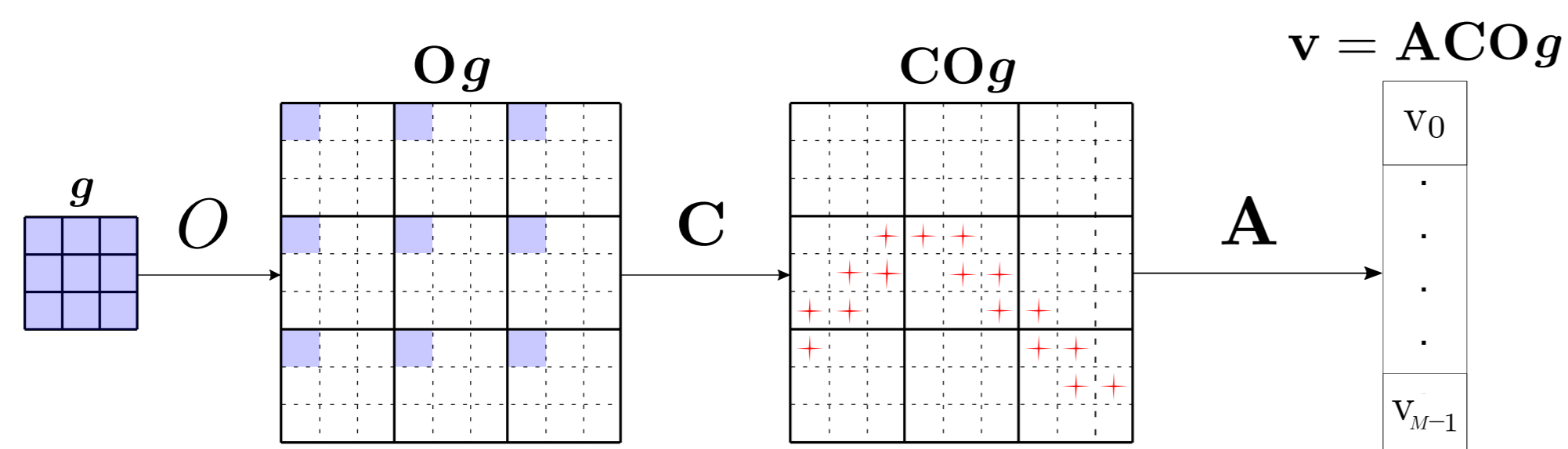


Figure: Degridding operator decomposition S .

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

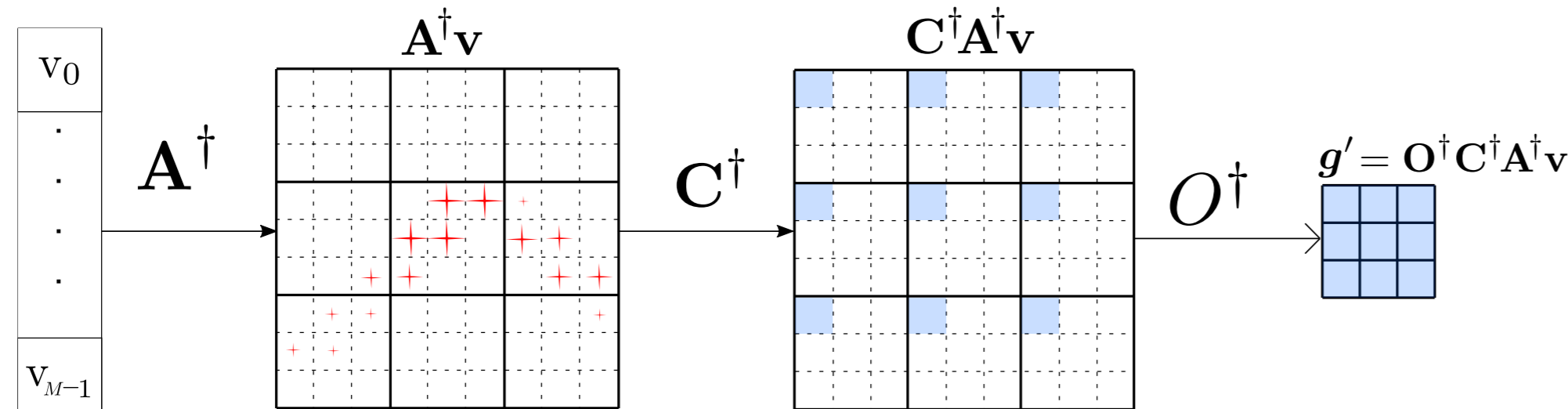


Figure: Gridding operator decomposition S^\dagger .

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

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

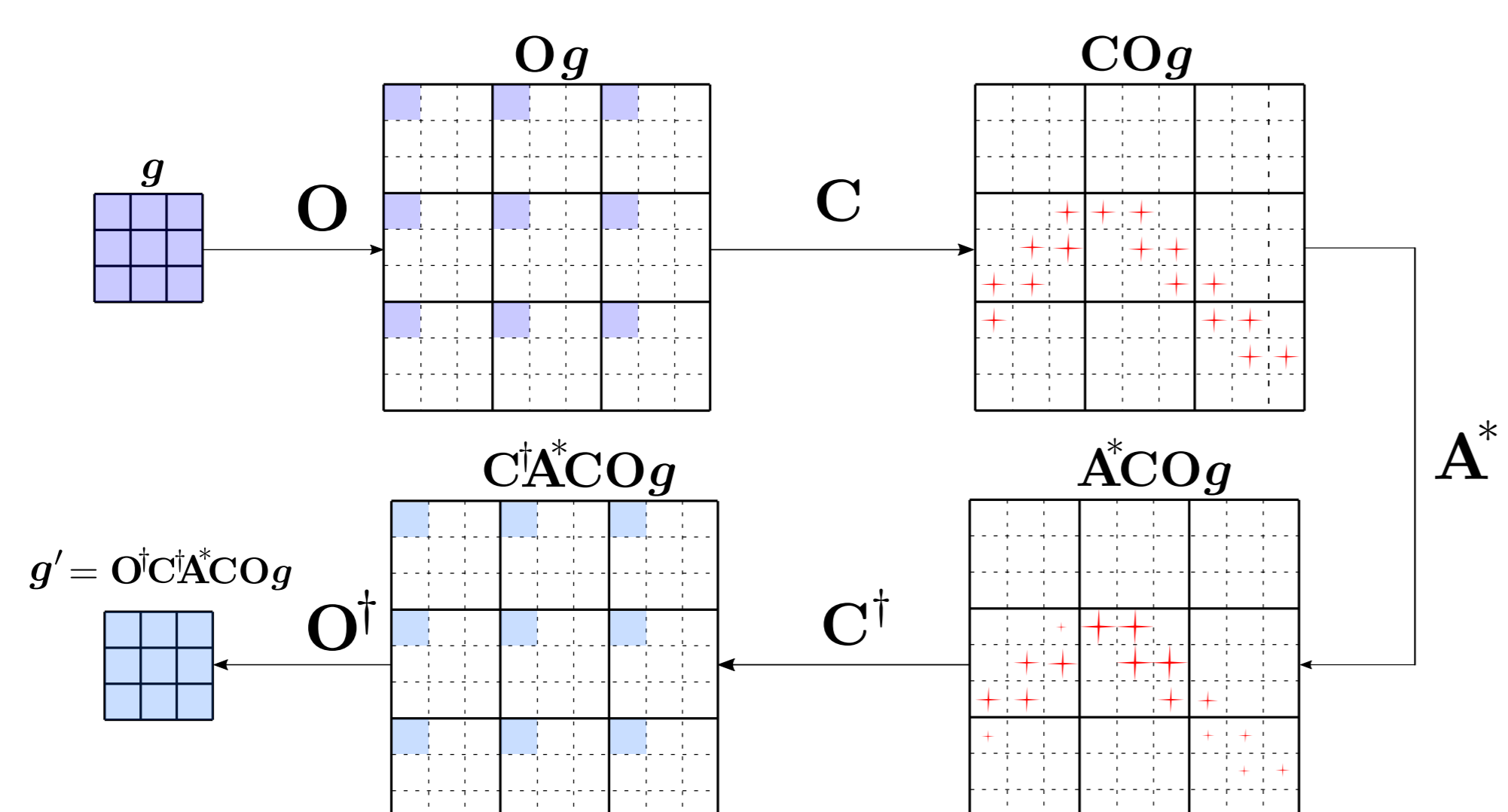


Figure: succession of Gridding and degridding operators $S^\dagger S$ using S2S method.

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

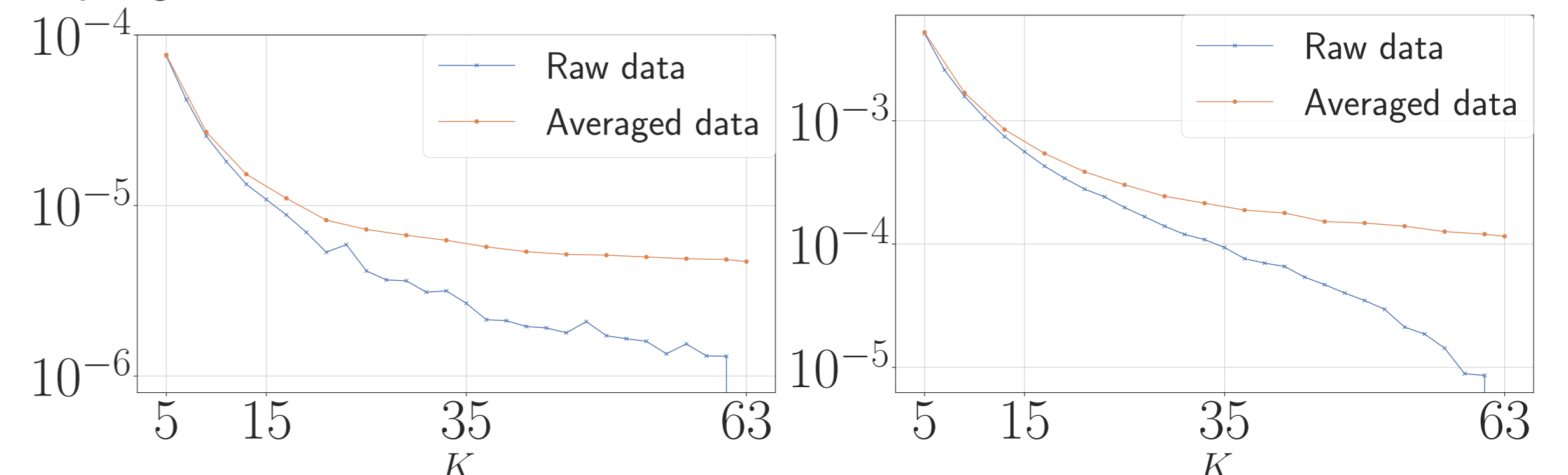


Figure: (Left) Mean Absolute Error. (Right) Maximum Absolute Error.

- 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

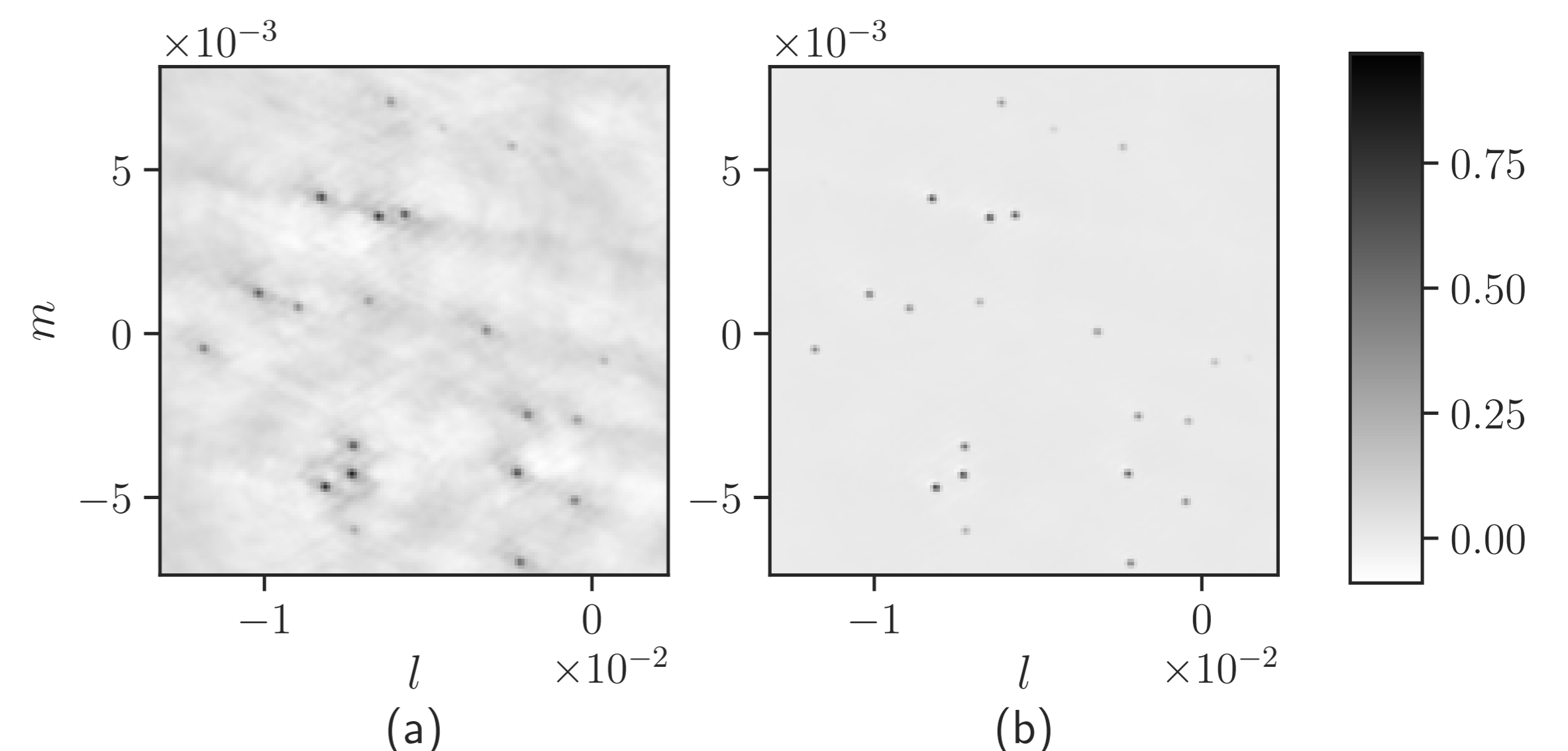


Figure: Zoom (Left): Dirty image. (Right): CLEAN Image

- 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.