Wirtinger calibration and spectral deconvolution for the low-frequency radio surveys

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Observatoire de Paris – Rhodes University

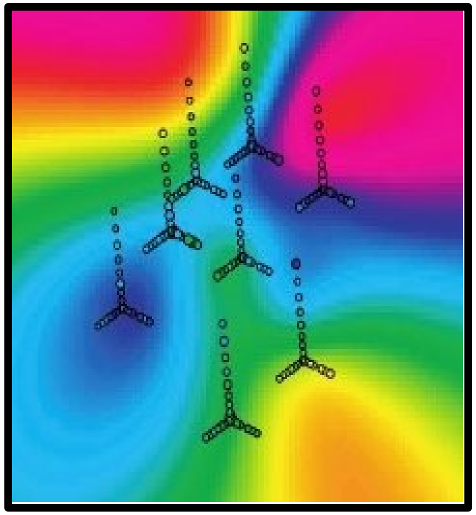
Algorithms : Oleg Smirnov, Etienne Bonnassieux, Marcellin Atemkeng, Landman Bester, Benna Hugo, Sphesihle Makhathini, Simon Perkins, ++

LOFAR science : Martin Hardcastle, Tim Shimwell, Wendy Williams, Alex Mechev, ++

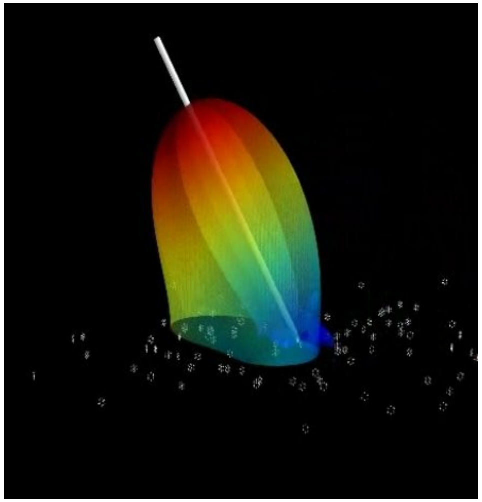
Outline

- 3rd generation « Wirtinger » Calibration
- DDFacet an imager for 3GC
- Some fancy wide-band, wide field decovolution algorithms
- Some images for LOFAR surveys KSP

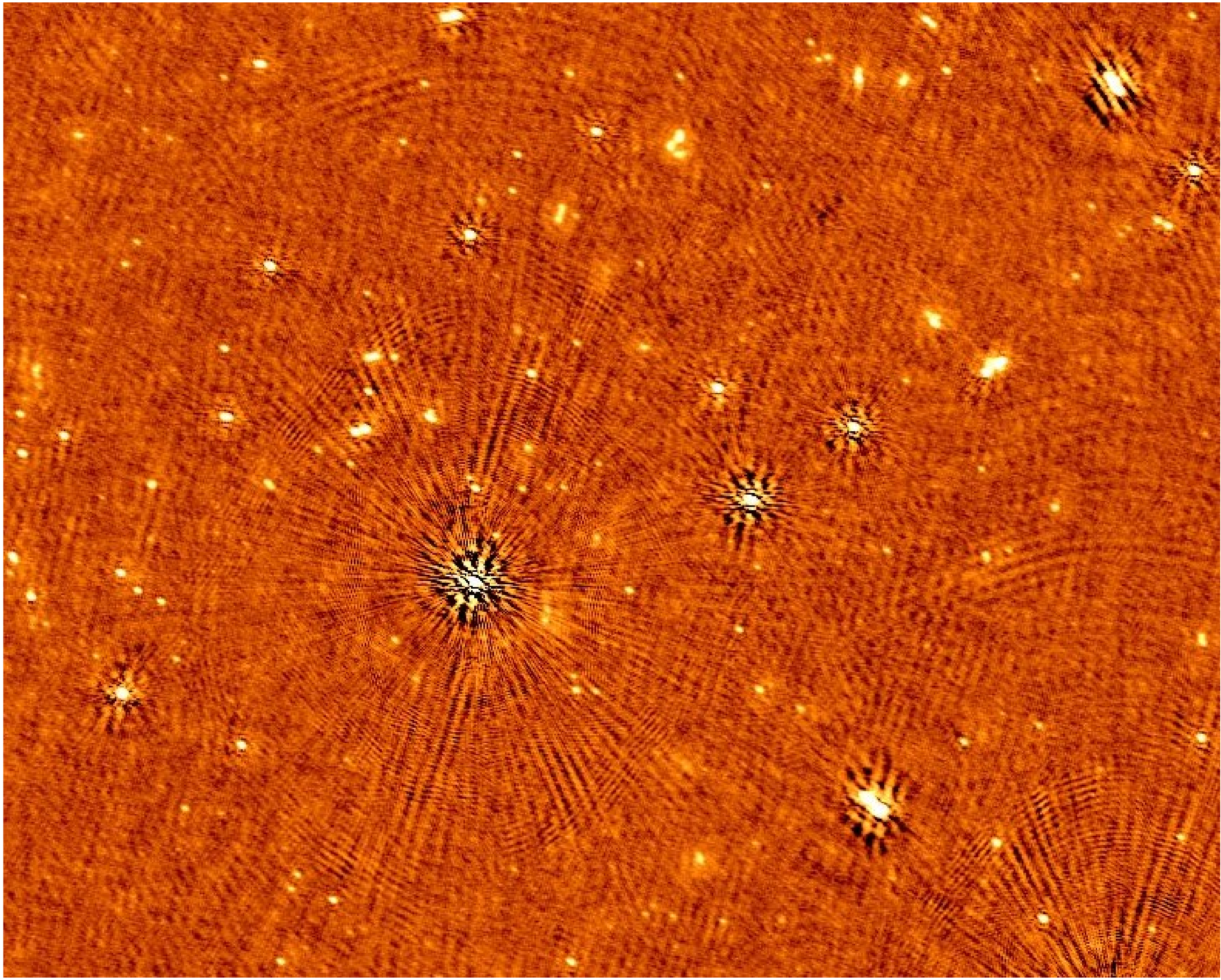
The best image you can ever get in selfcal



Ionospheric disturbance + Faraday rotation



Station lobes



«Third» generation calibration and imaging

?...

Calibration Sky Calibration

$$\boxed{V_{pq}^{meas}} = G_p . \left(\int_s K_{p,s} . B_{p,s} . I_{p,s} . \boxed{F_s . F_s^H} . I_{q,s}^H . B_{q,s}^H . K_{q,s}^H ds \right) . G_q^H$$

Measurement
(10^{11}-10^{12} points)

Geometry Beam Ionosphere

Hamaker et al. 94

…. A pretty difficult problem to invert (a post-processing adaptative optics)

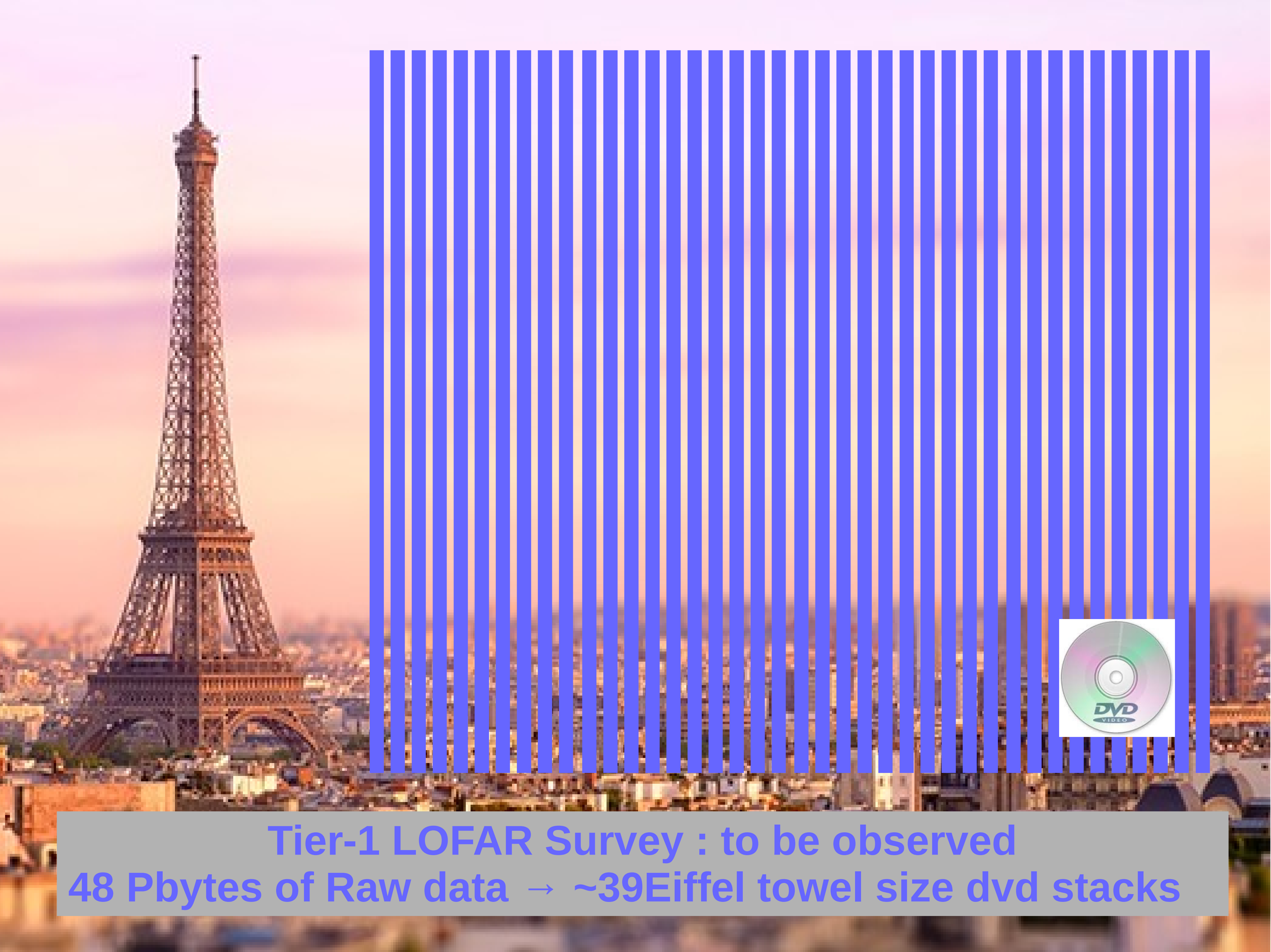
(1)- Wirtinger optimisation for Direction Dependent Calibration

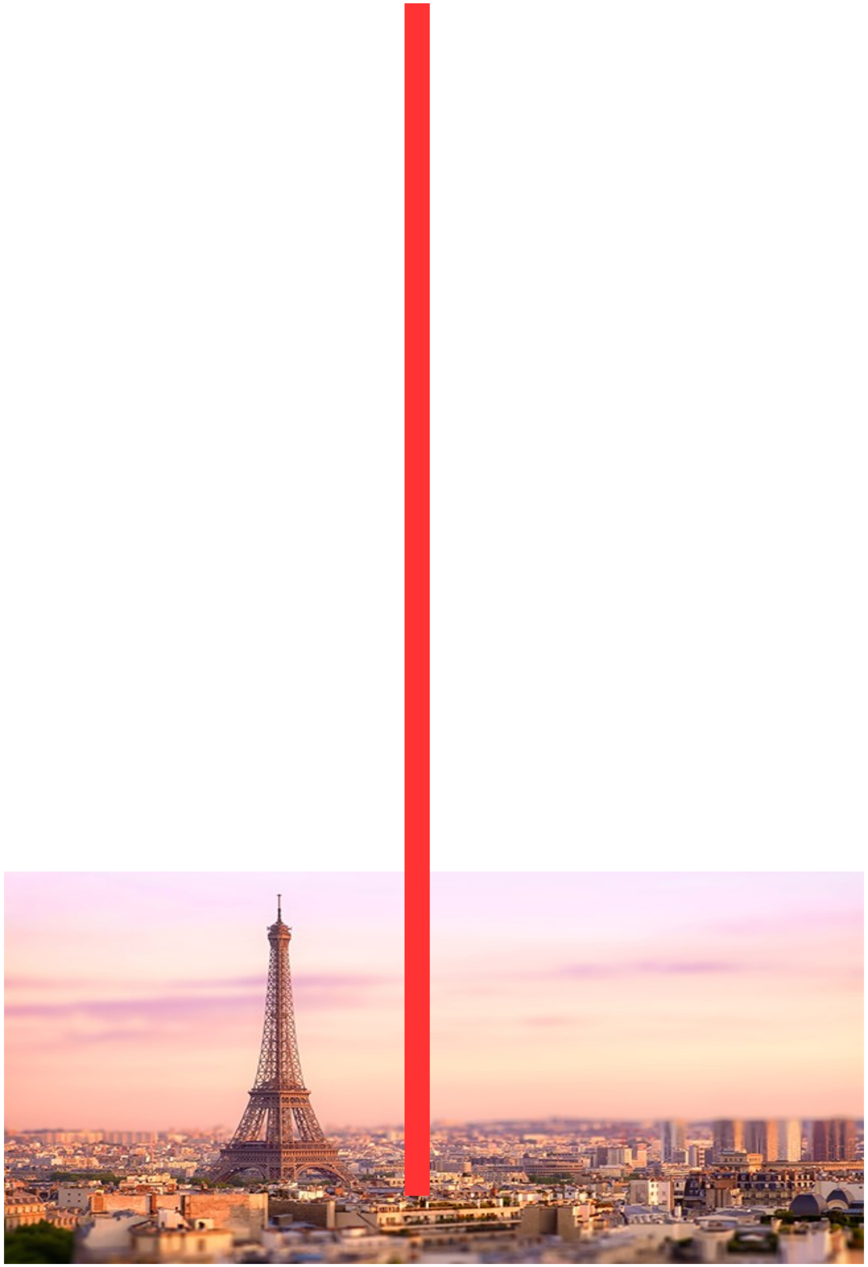
Tasse 2014
Smirnov & Tasse 2015

(2)- Imaging and deconvolution taking into account

- Direction Dependent effects (Beam, ionosphere, etc)
- Sources' spectral properties
- Variable PSF
- … and many more cool stuff

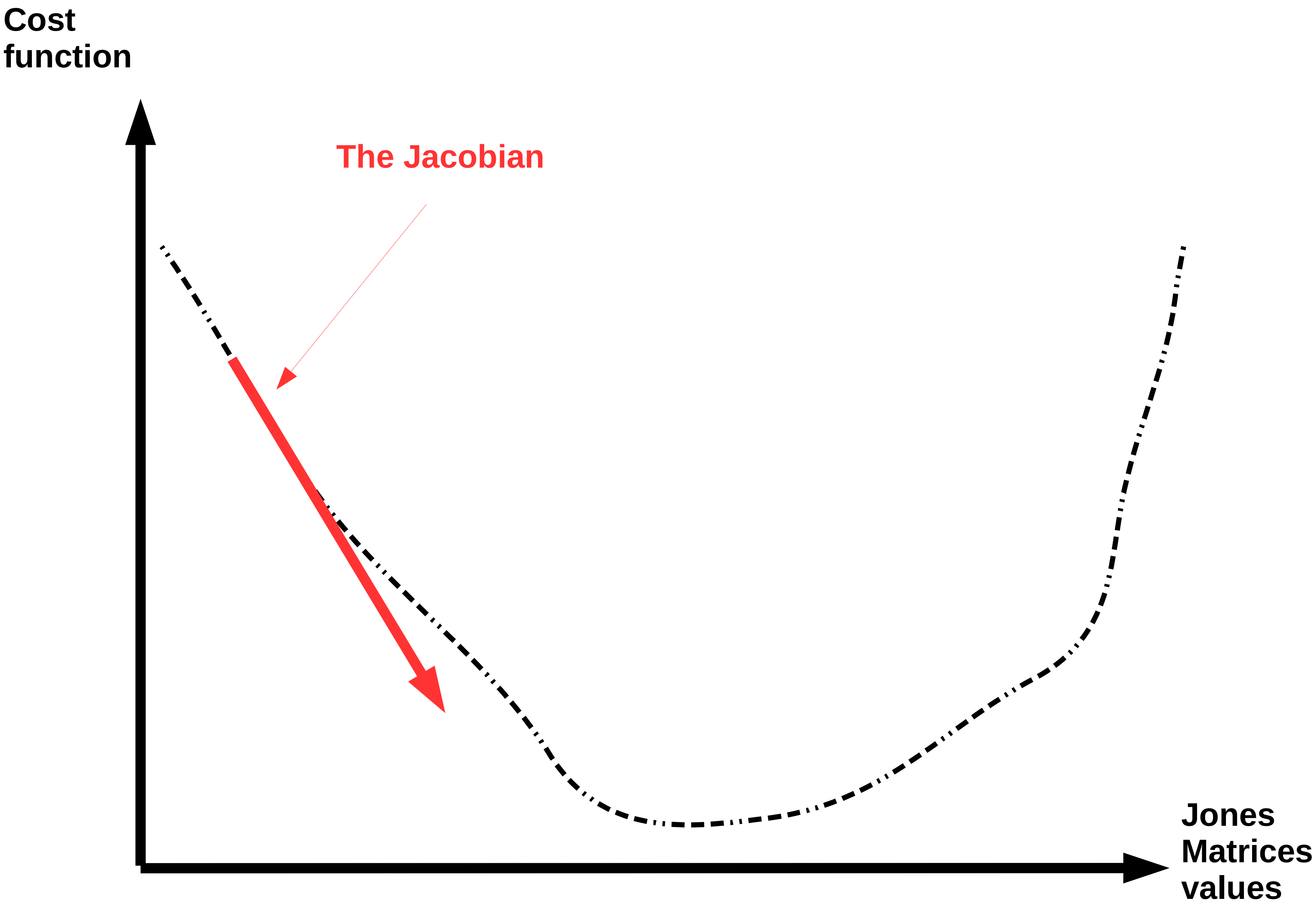
→ **DDFacet projet : a France- South Africa collaboration**


Tier-1 LOFAR Survey : to be observed
48 Pbytes of Raw data → ~39Eiffel towel size dvd stacks

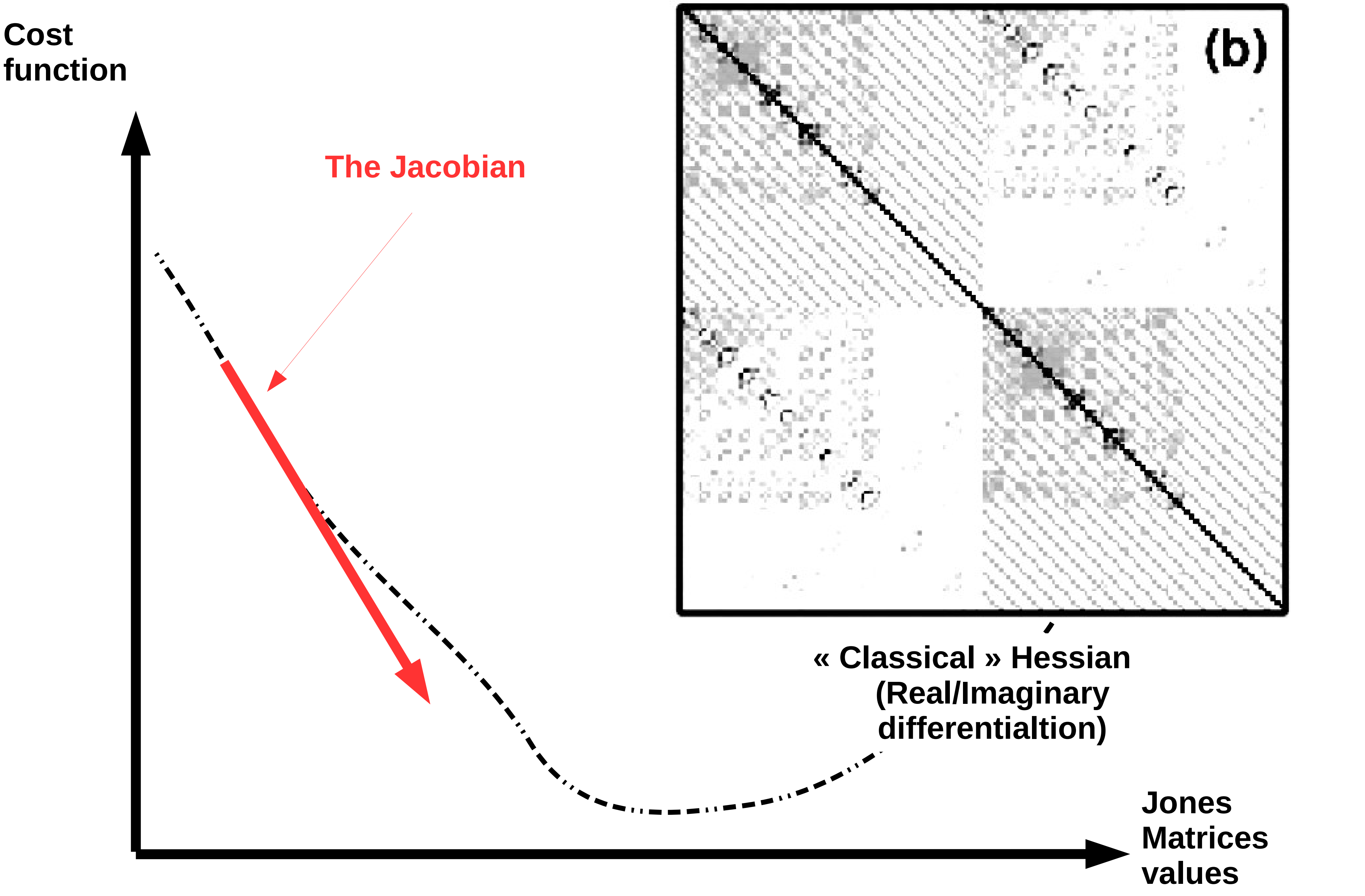


Tier-1 LOFAR Survey : observed so far
~5 Pbytes of raw data → ~4 Eiffel towel size dvd stacks

RIME Calibration



RIME Calibration

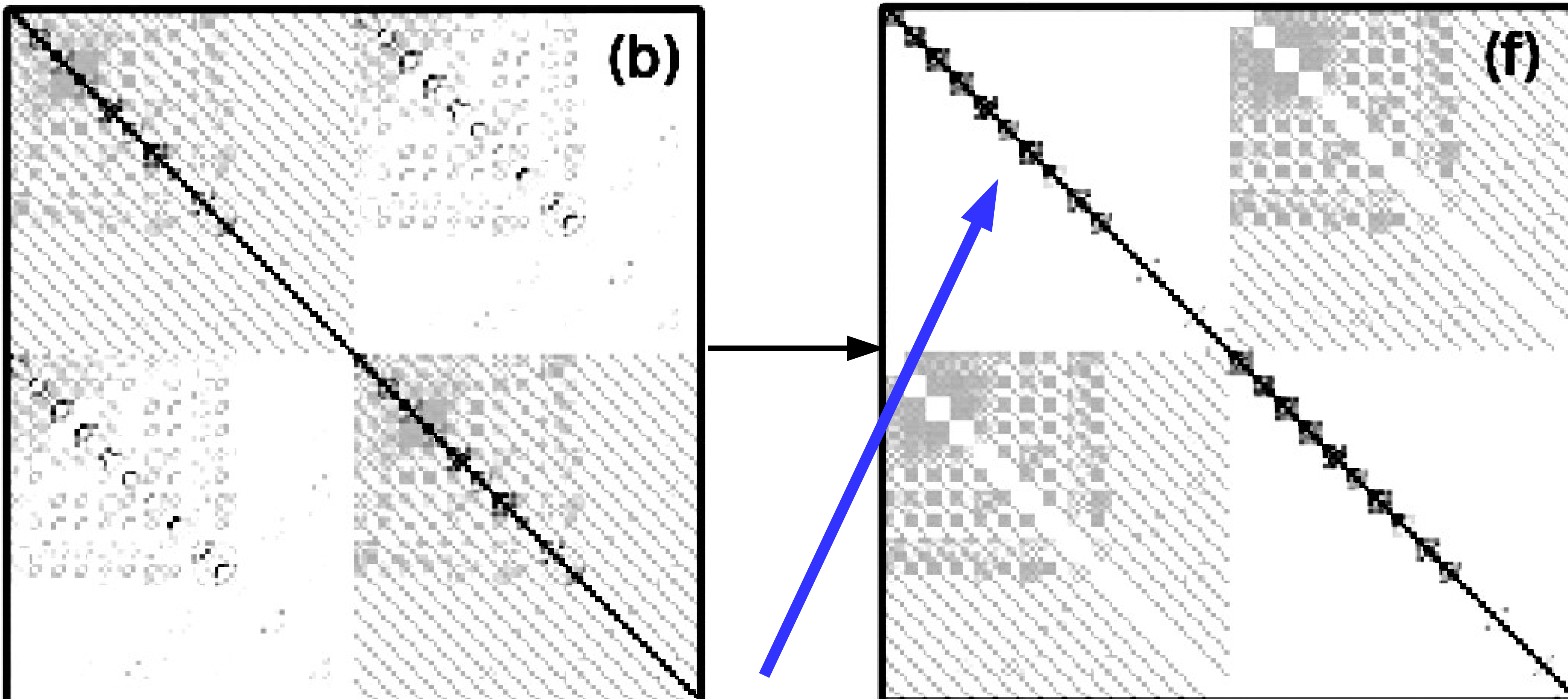


Wirtinger Optimisation: Jacobian & Hessian

(Read Tasse 2014, Smirnov & Tasse 2015)

Wirtinger derivative definition « reorganises » the process and data : the Jacobian and Hessian become sparse and compact

$$\frac{\partial \overline{z}}{\partial z} = 0 \text{ and } \frac{\partial z}{\partial \overline{z}} = 0$$



« Classical » Hessian

Those Blocks are (Nd x Nd)

Wirtinger Hessian

Wirtinger Optimisation: Jacobian & Hessian

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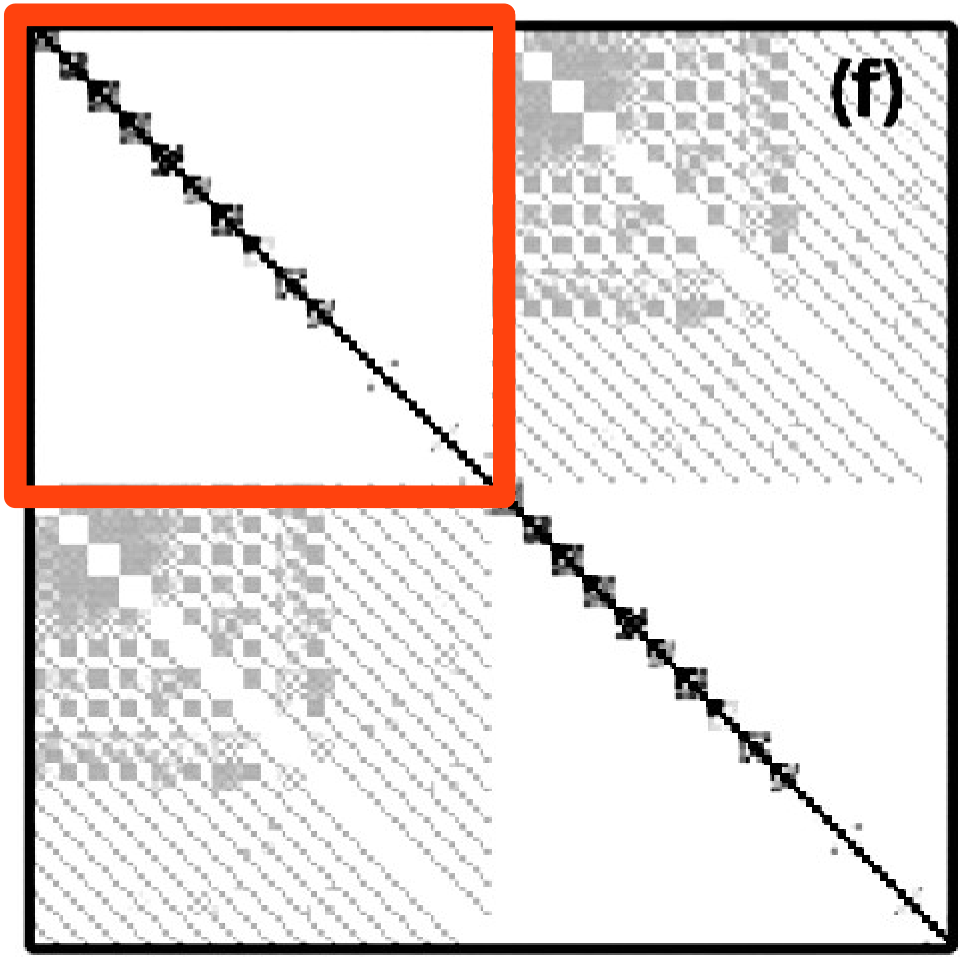
The fantastic property of Wirtinger Jacobian and Hessian for the RIME:

We can cut it in two !!!

- The result just needs to be devided by 2 !

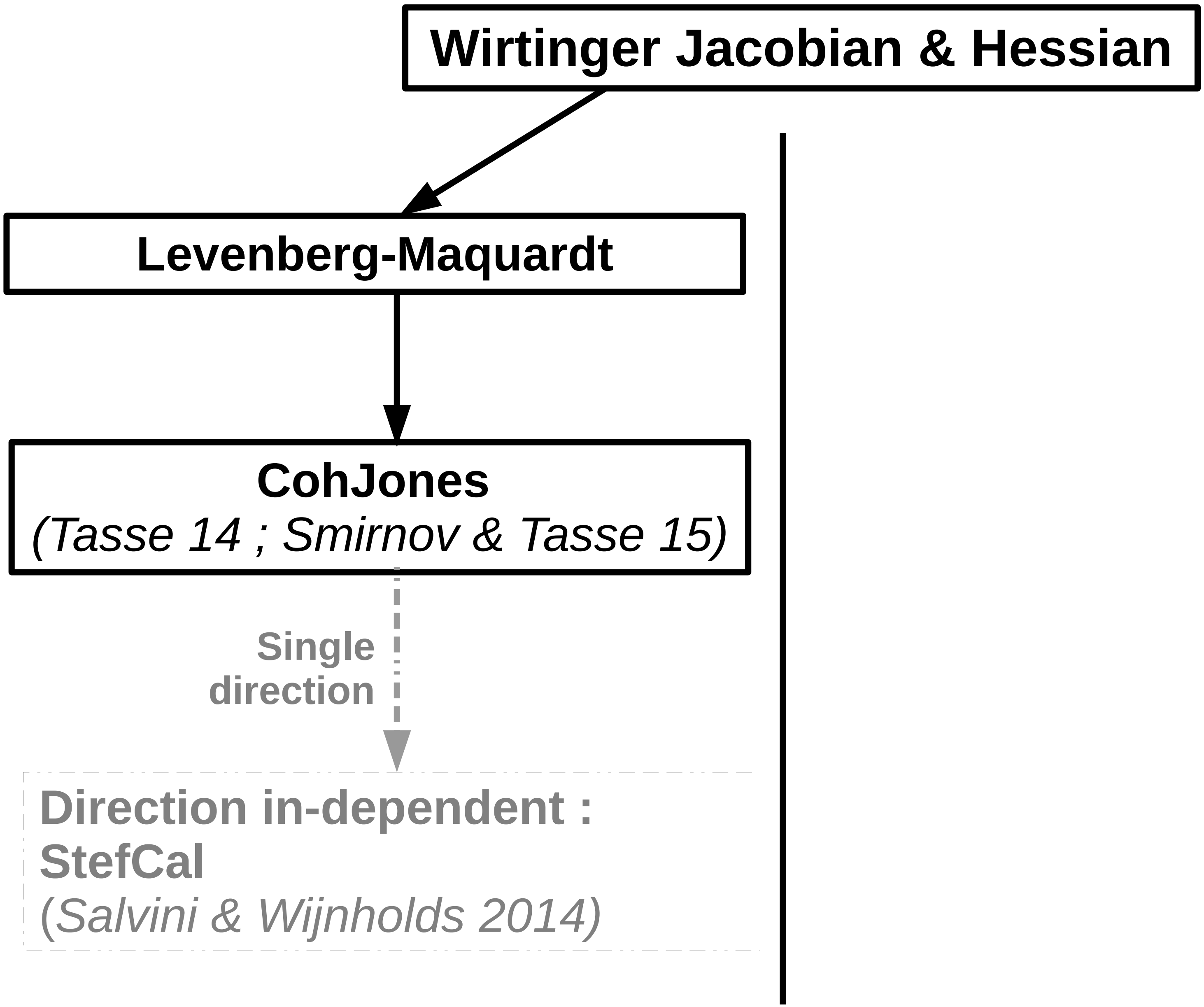
- Very non trivial to prove, but I did it just a few weeks ago

  - **Full** Wirtinger-Jacobian LM with lambda=0 is *the same as*
  - **Half** Wirtinger-Jacobian LM with lambda=1

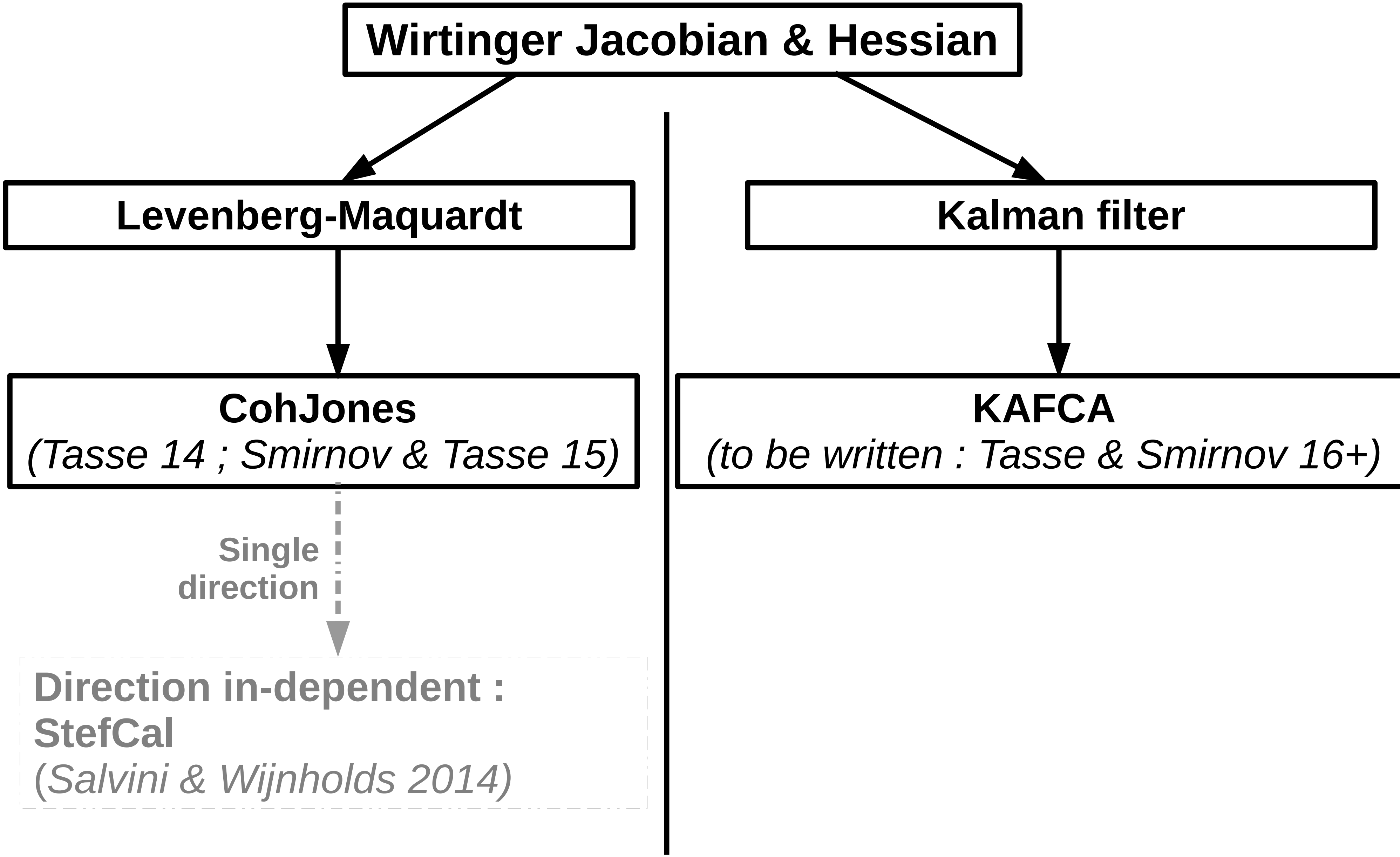


Wirtinger Hessian

Wirtinger algorithms: software



Wirtinger algorithms: software



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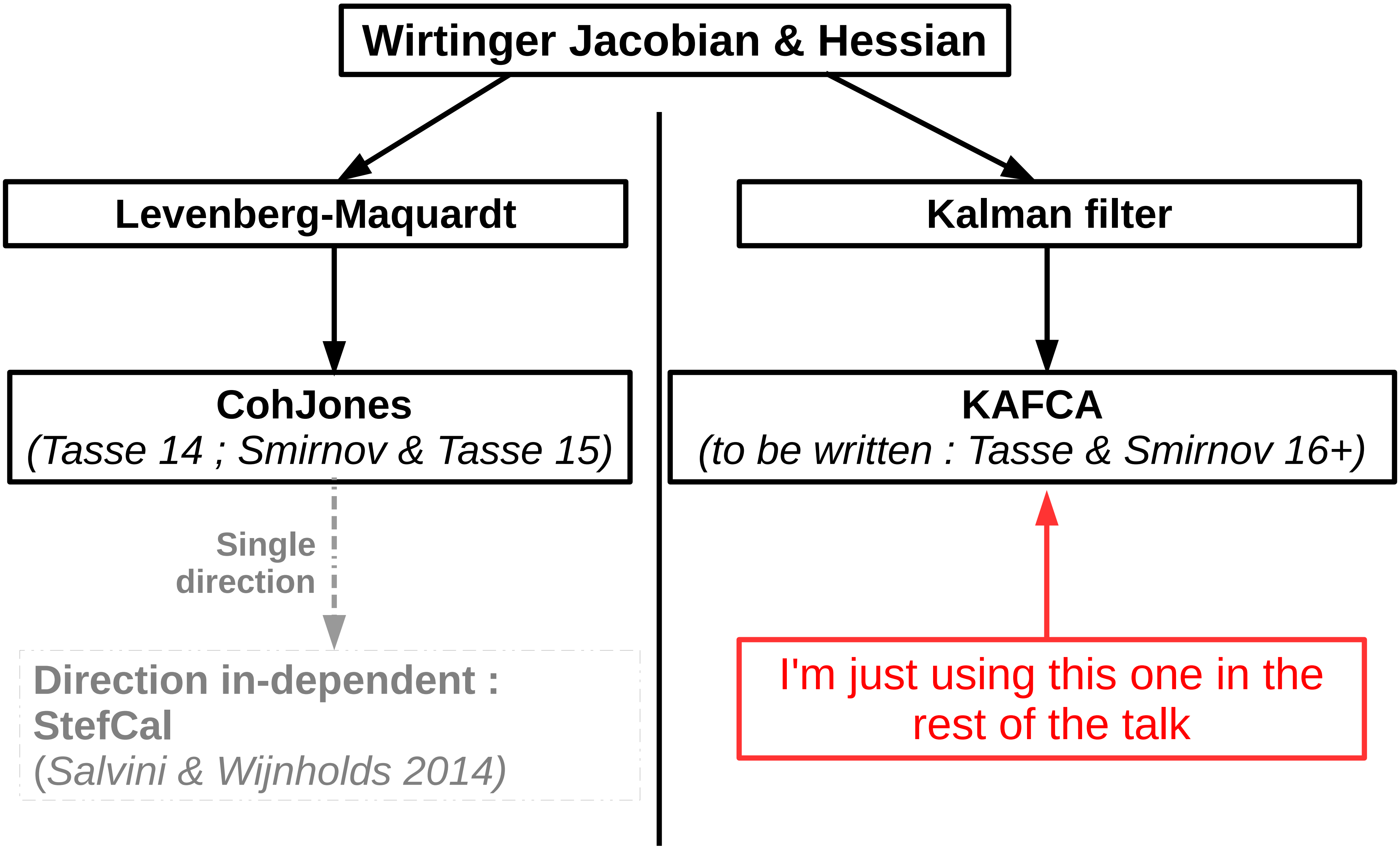
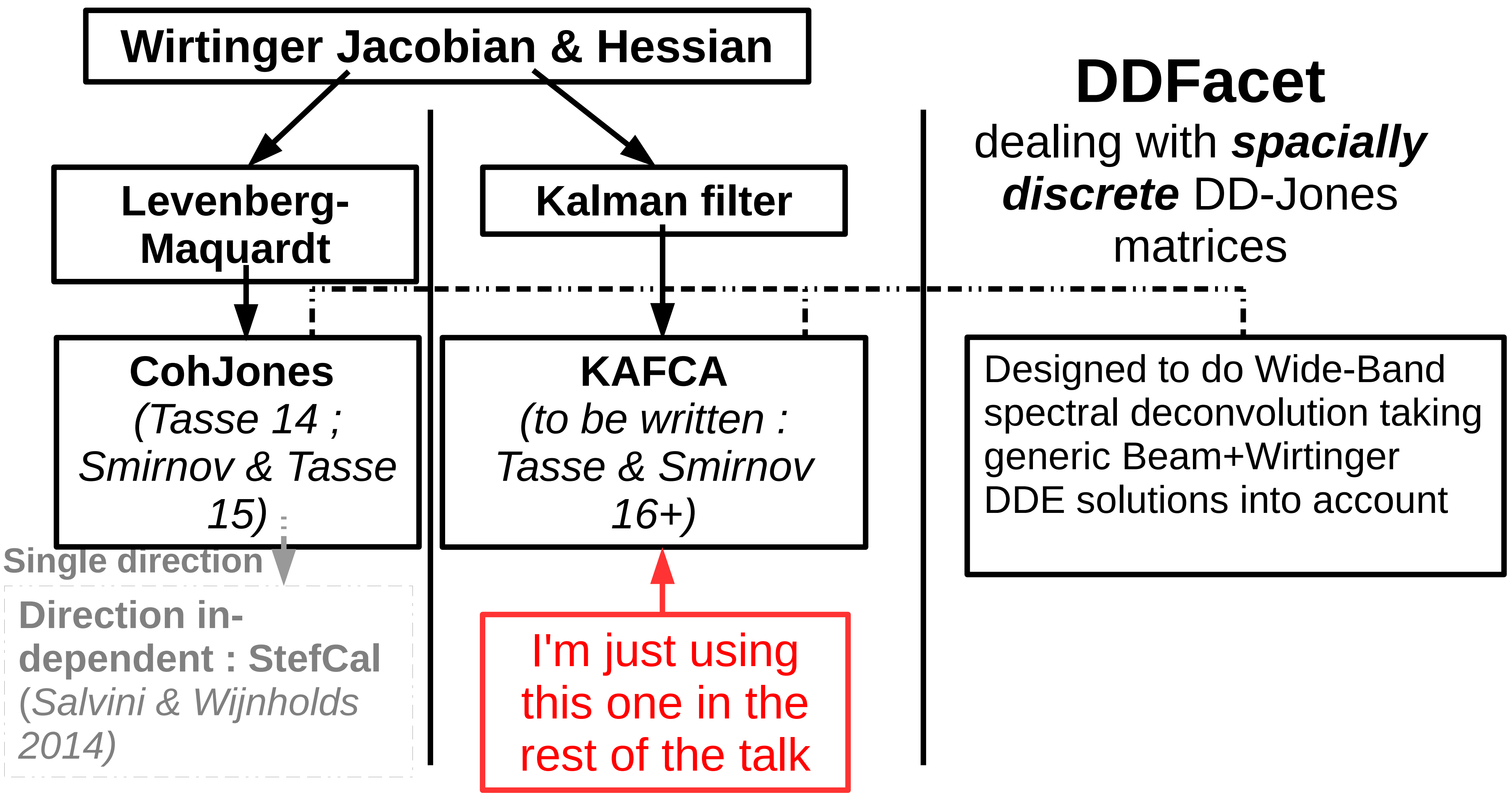


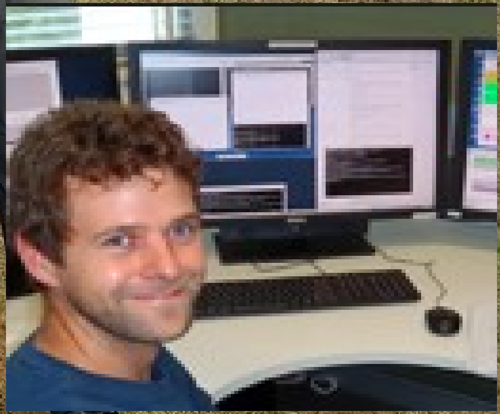
Wirtinger algorithms: software

DDF-pipeline (Tim Shimwell, Martin Hardcastle)



DDF/kMS contributors

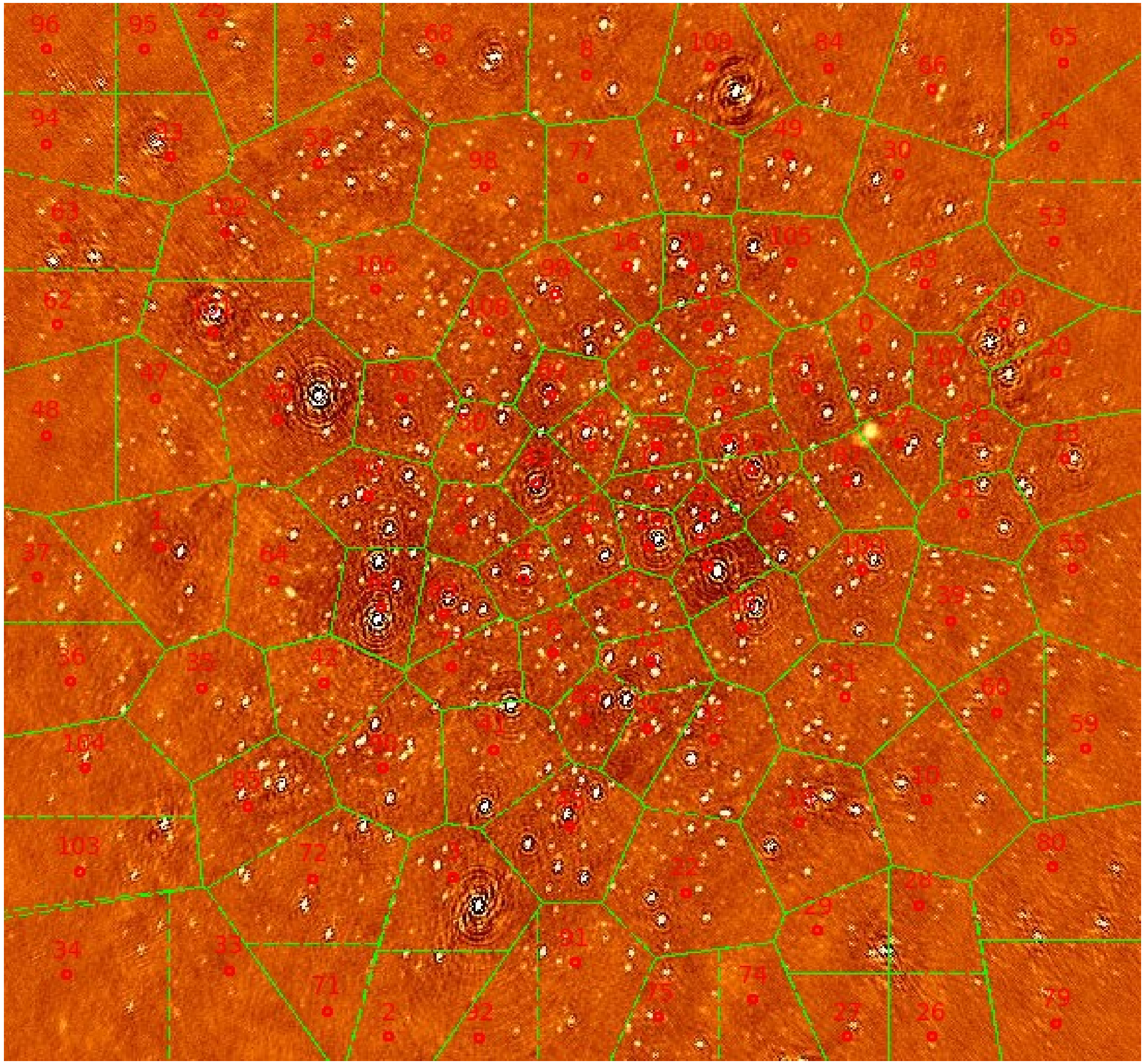
Martin Hardcastle



Tim Shimwell

DDFacet

… A facet based imager



(1) Produces a single tengential plane ! **(no « noise jumps » thanks to the kalman filter, and facetting mode)** – *largely insprired from Kogan&Greisen 2009*

(2) Does full polarisation DDE correction

(3) Baseline Dependent Averaging
90 % of the data can be compressed
(collaboration with O.Smirnov and M. Atemkeng)

(4) Does tesselated images

DDFacet

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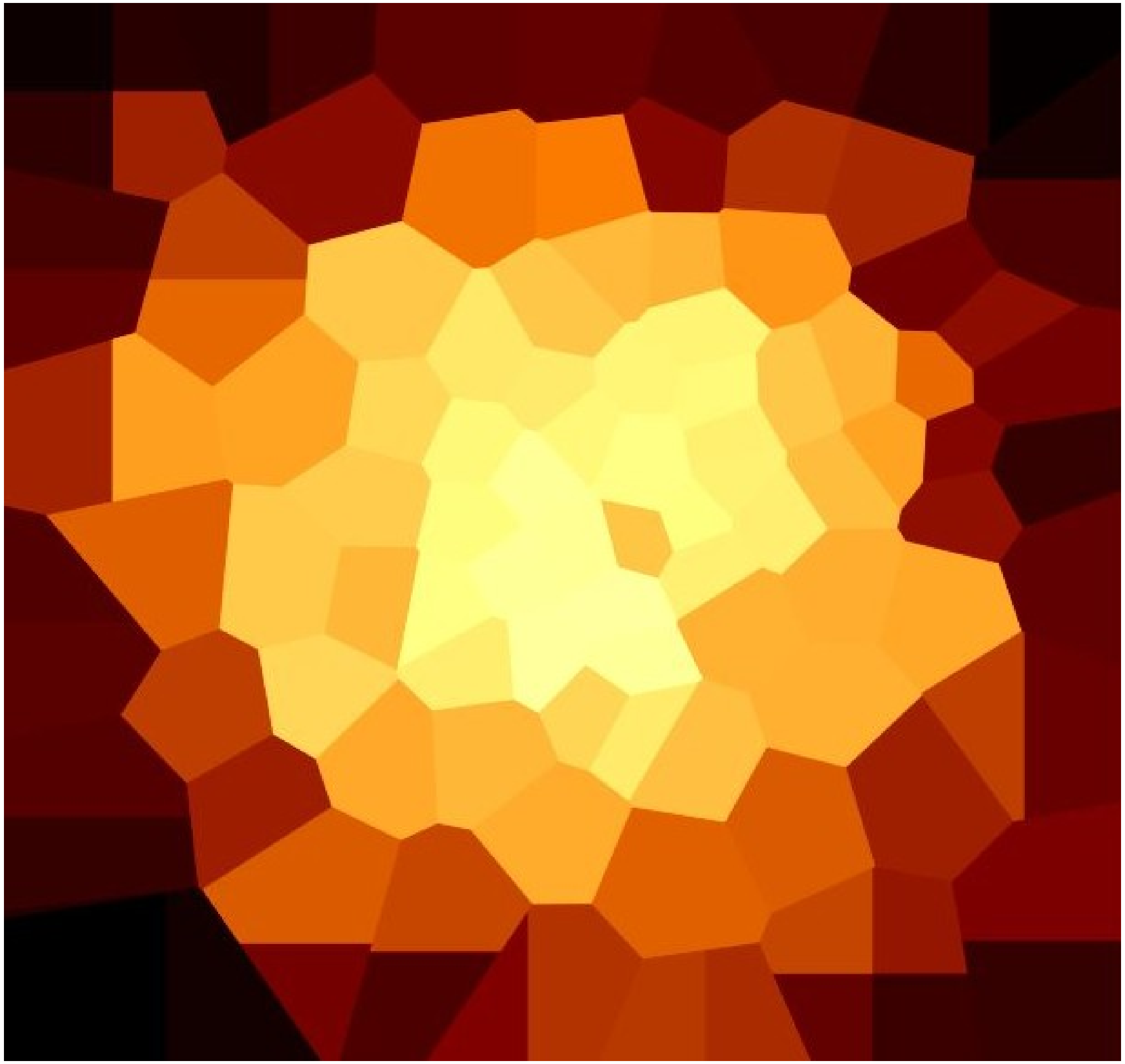

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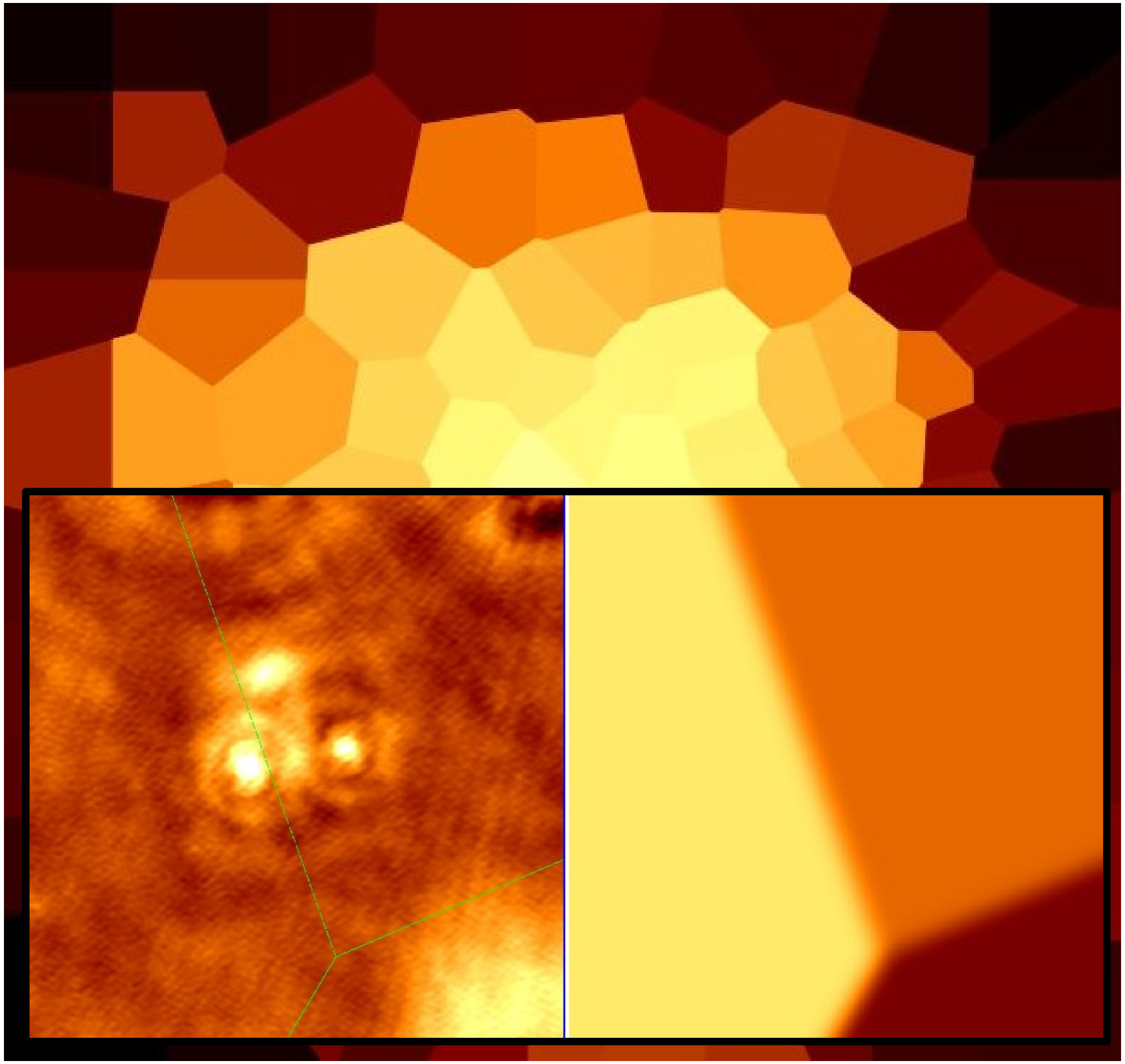

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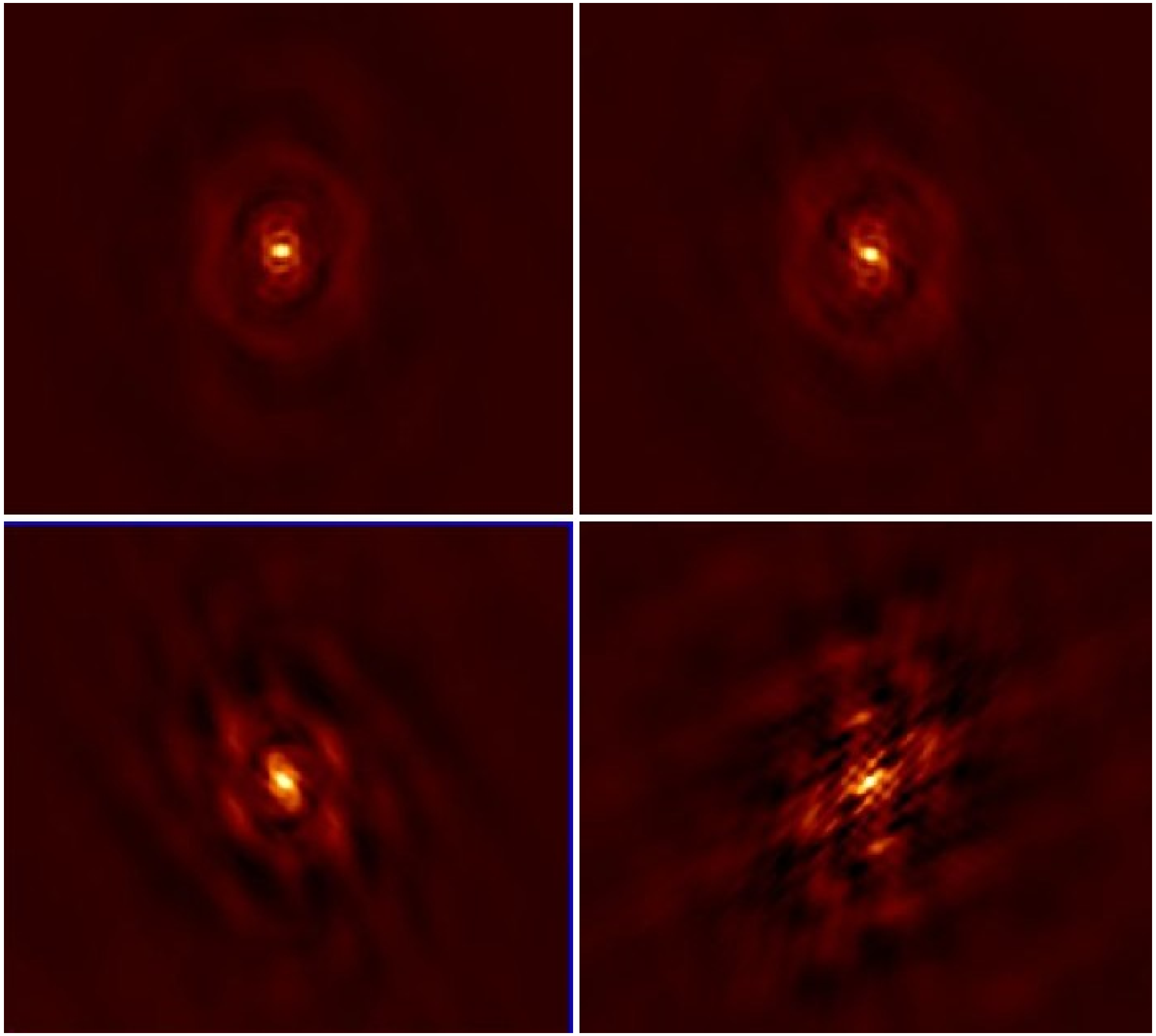

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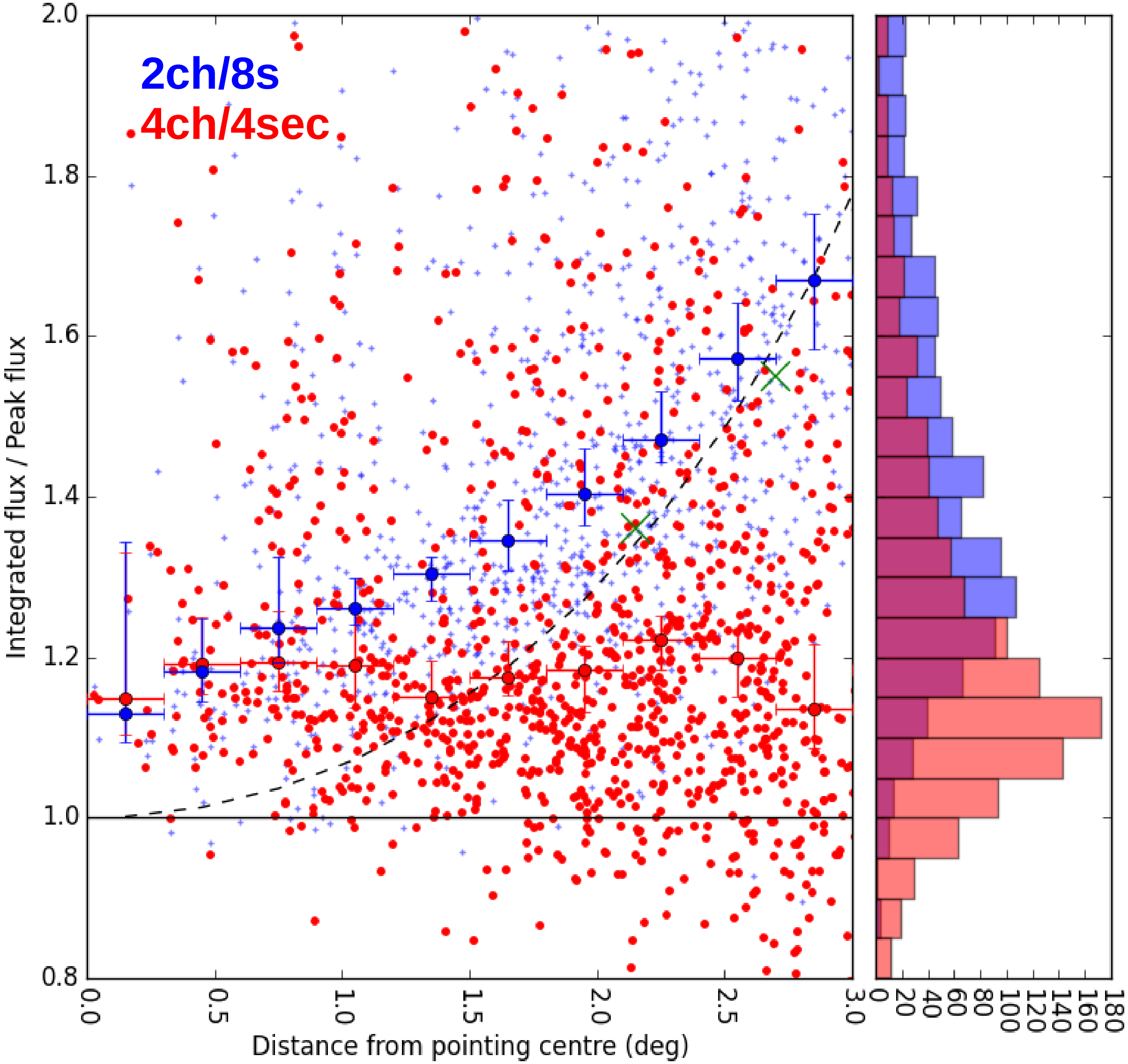

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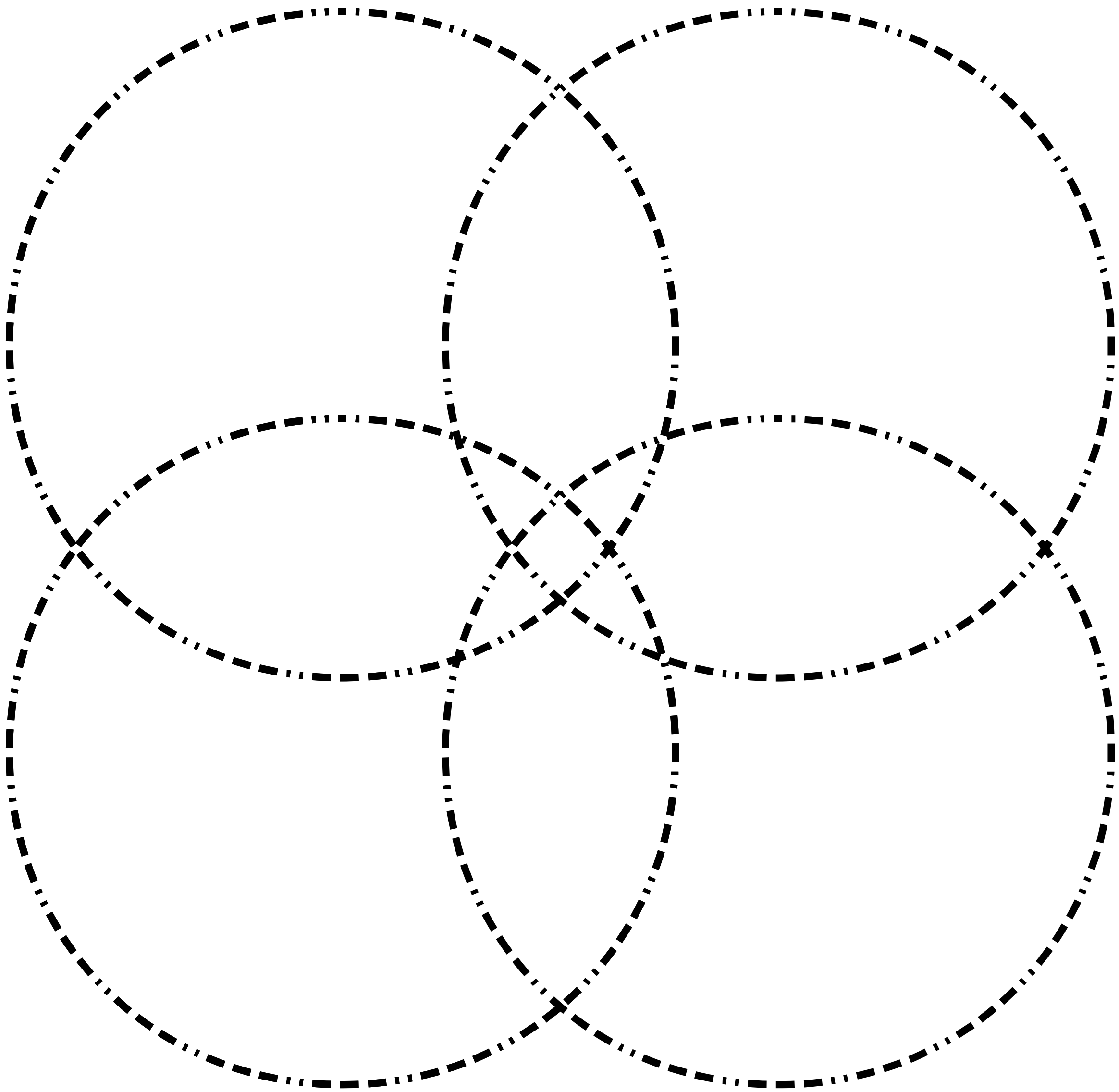

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(8) Mosaicing (!)

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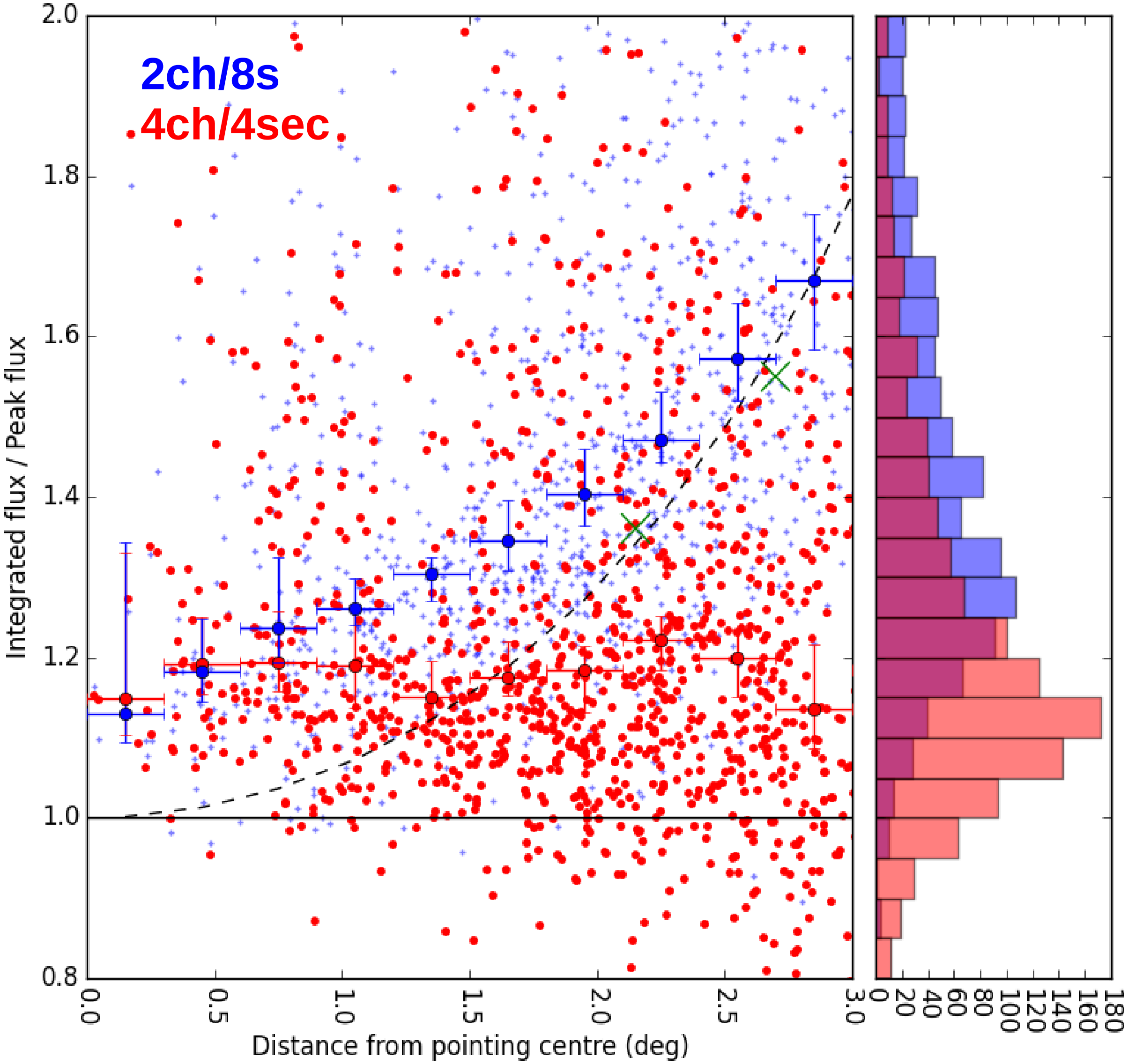

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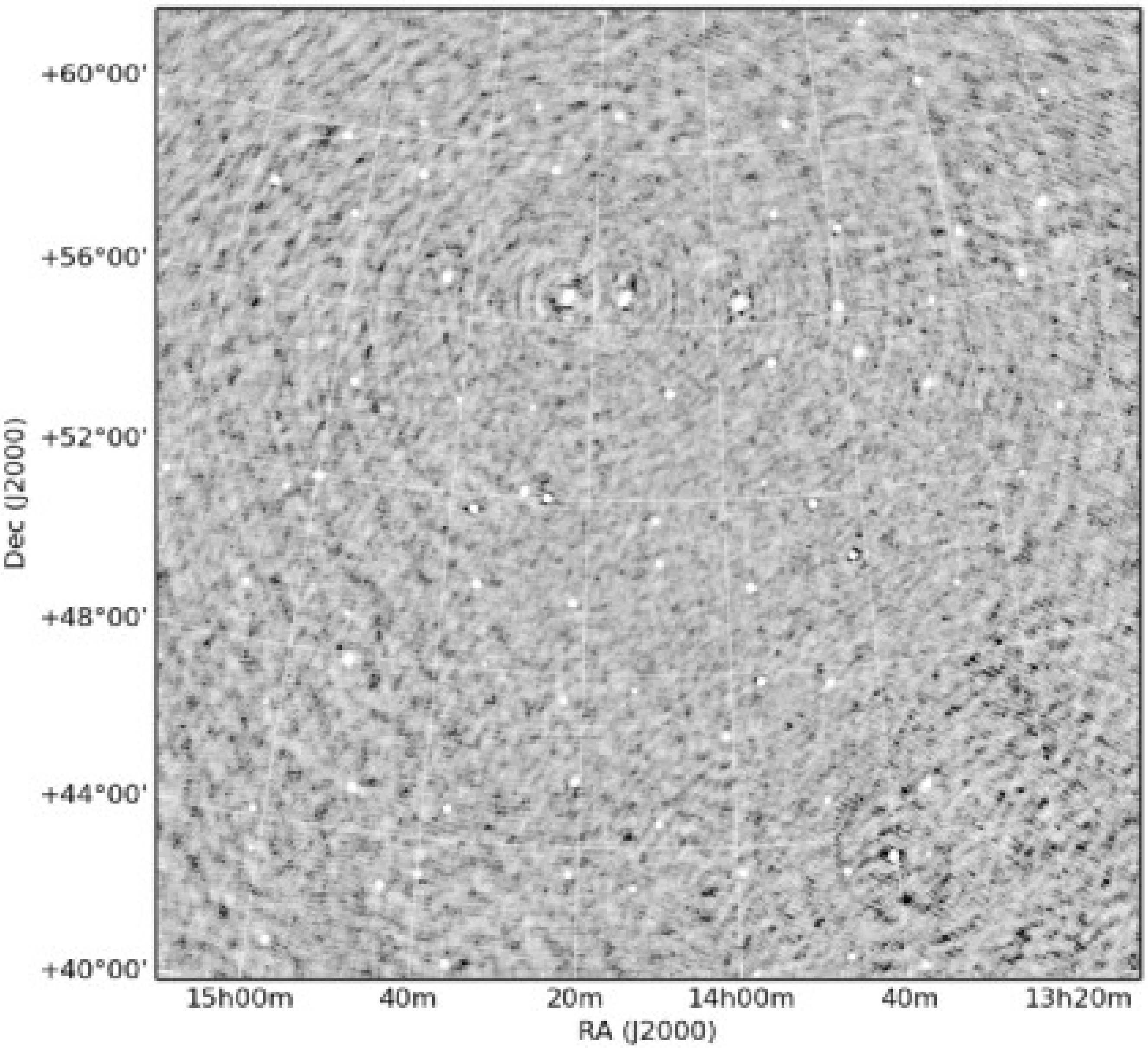
(8) Mosaicing (!)

(9) Does spectral deconvolution (Spectral indices + taking beam into account) - 8a : Hybrid Matching Poursuit
- 8b : SubSpace Deconvolution

A simulated dataset for wide-band wide-field DDE-spectral deconvolution



100 sources simulation

- LOFAR LBA layout
- Fractional bandwidth of ~2
- S_50 ~ S^{1.5} with S uniformly in 0-100
- Spectral index in [-1, 1]
- A bright 10^{4} off axis source

- No DDE deconv

- No WB-spectral deconv

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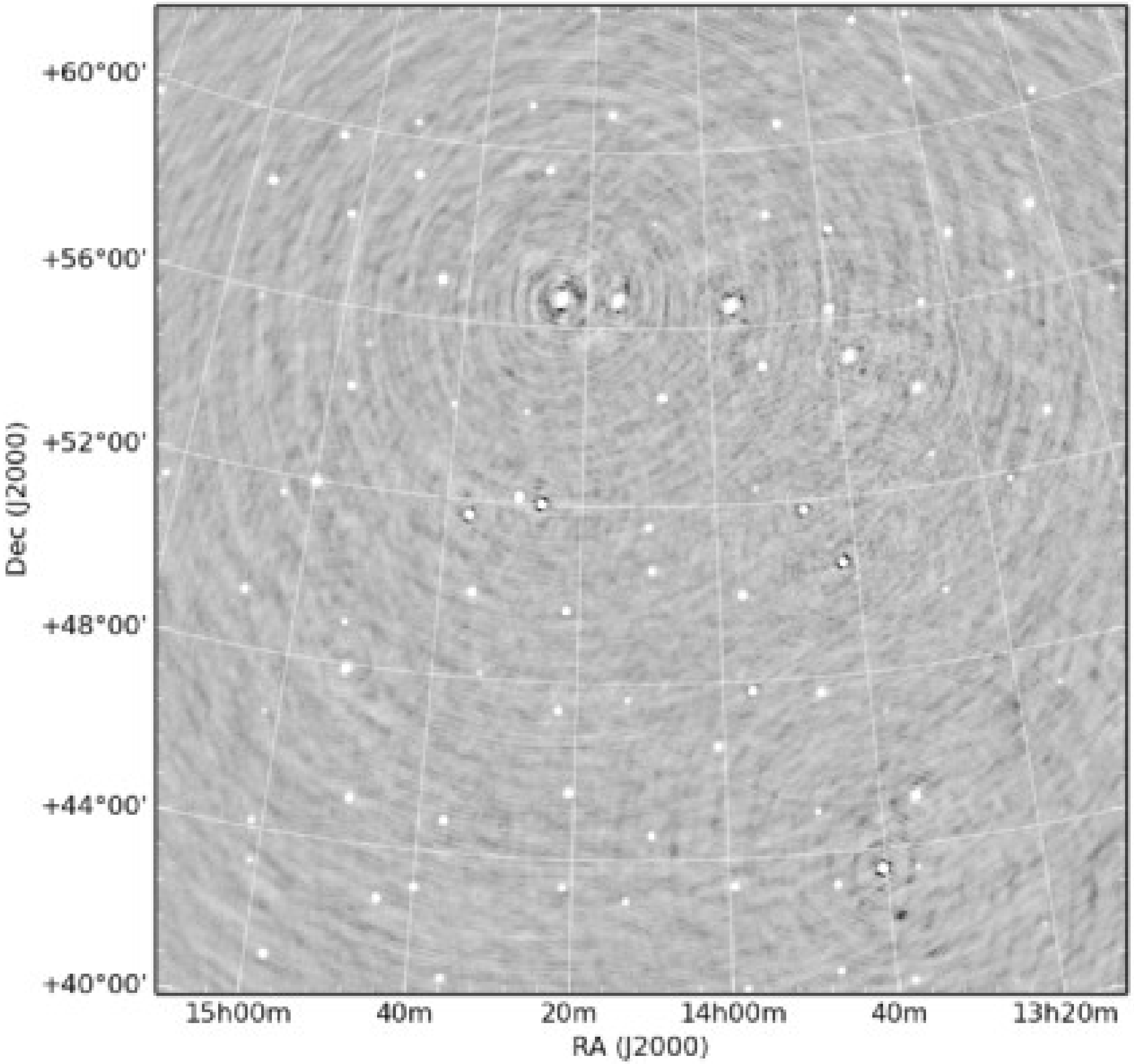

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- **DDE deconv**
- **No WB-spectral deconv**

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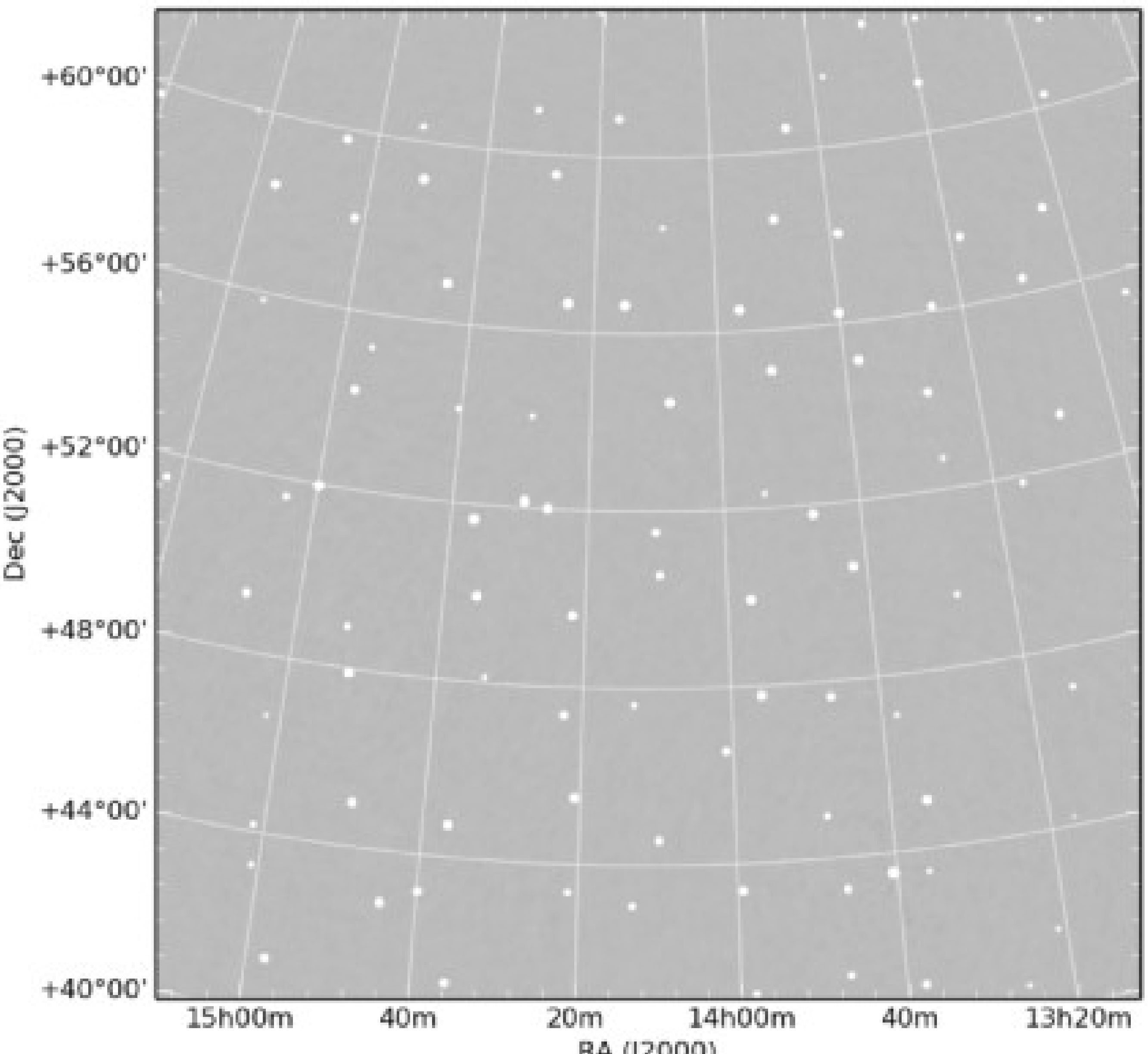

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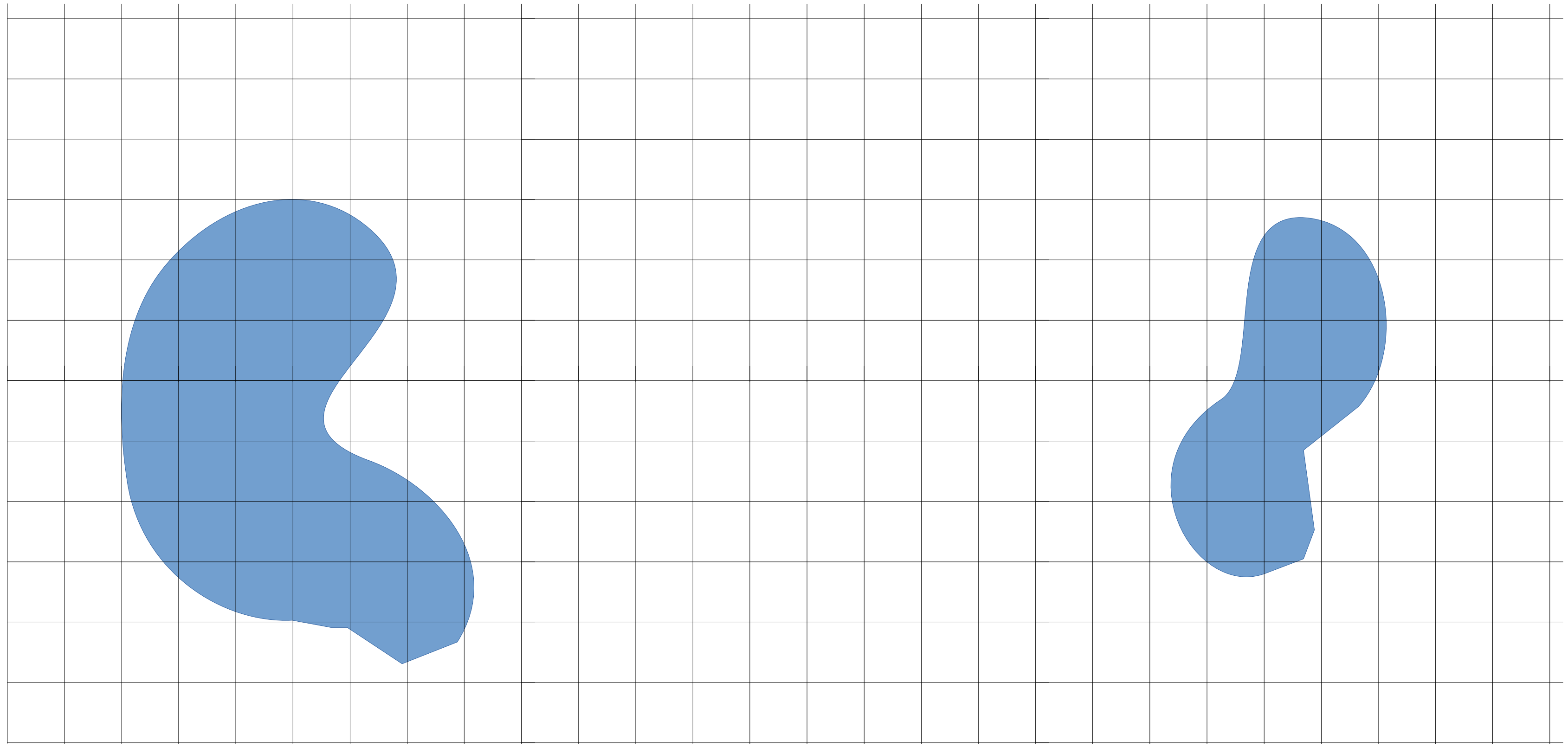
- S_50 ~ S^{1.5} with S uniformly in 0-100
- Spectral index in [-1, 1]
- A bright 10^{4} off axis source

- DDE deconv

- WB-spectral deconv ***(estimating alpha)***

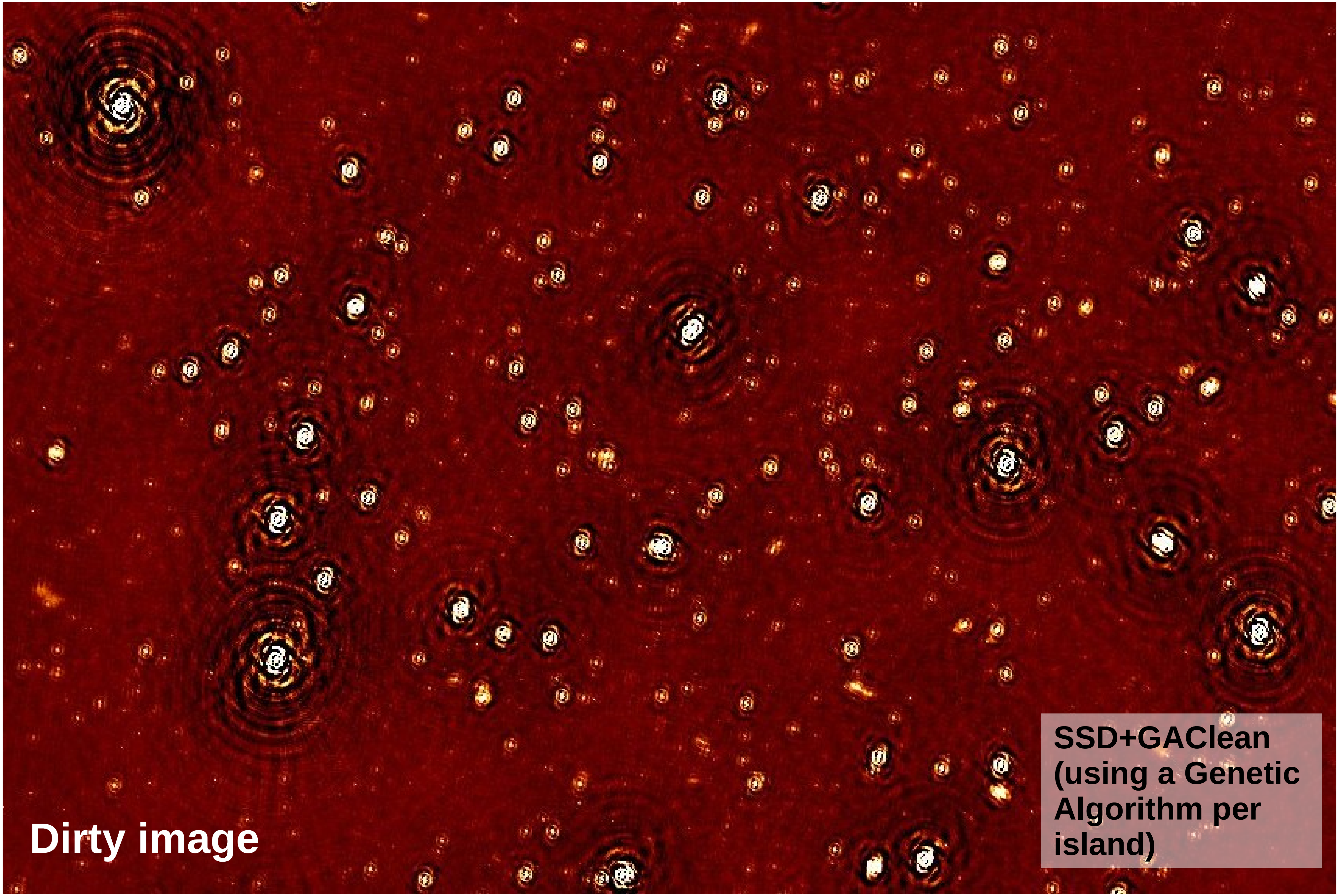
SSD



- Also starting from a spectral dirty and (facet-dependent) spectral PSF
- Pixels in SubSpaces (islands) are jointly deconvolved within each island
- Islands are deconvolved independently from each other
- Errors created by ignoring the cross contamination between islands are taken care of by a major loop

- Parallelised per island...

(… an quick intuition on what SSD is)



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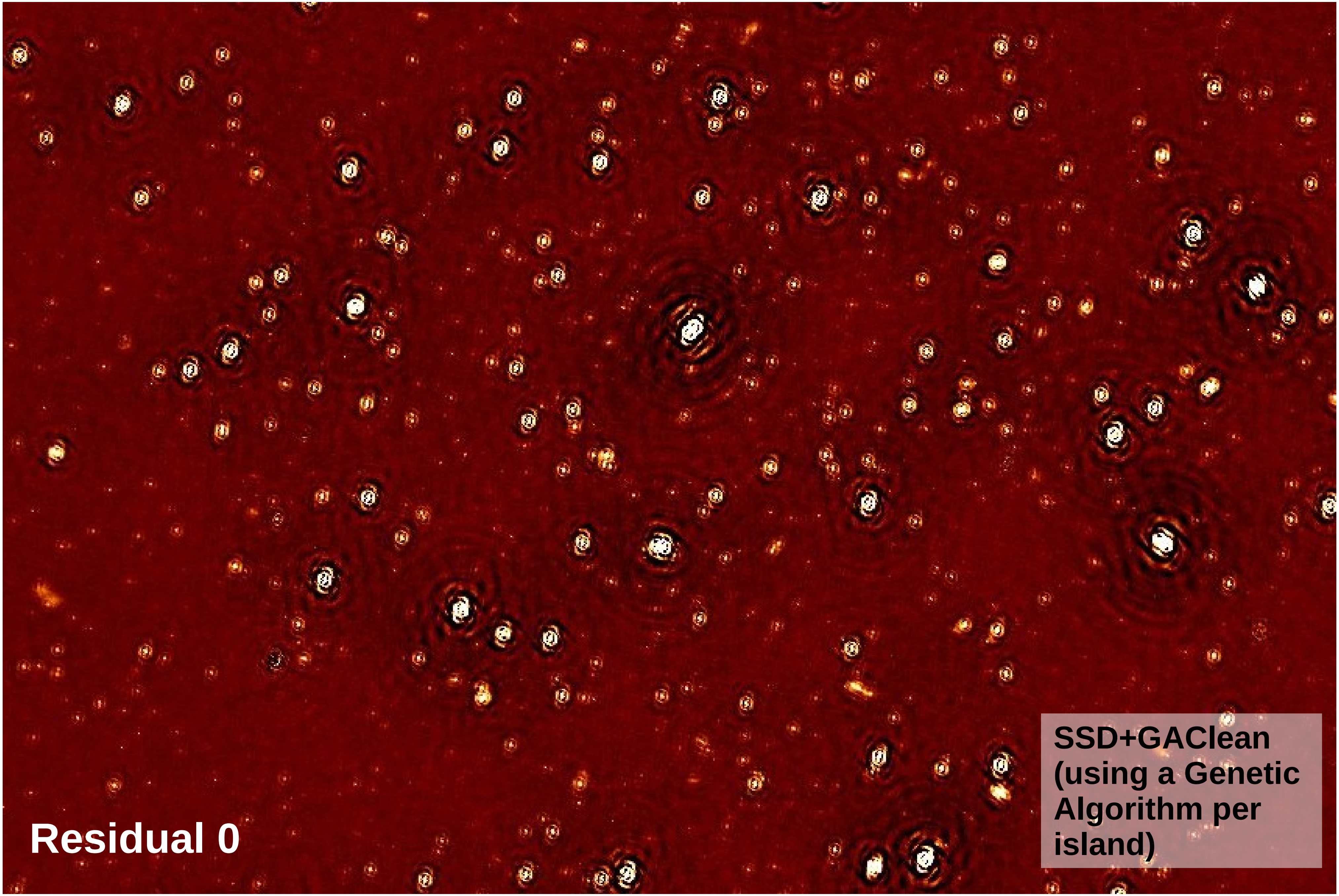

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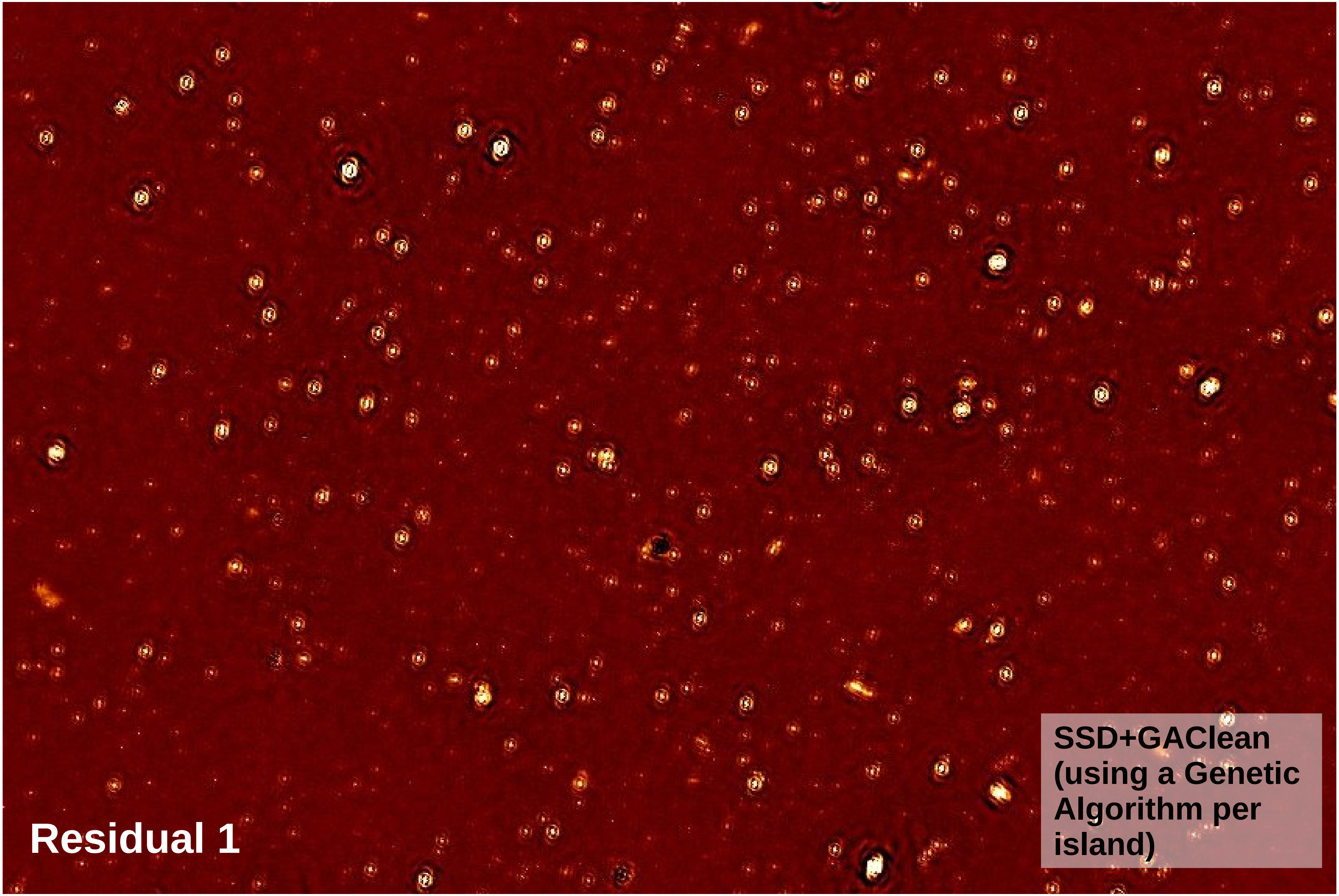

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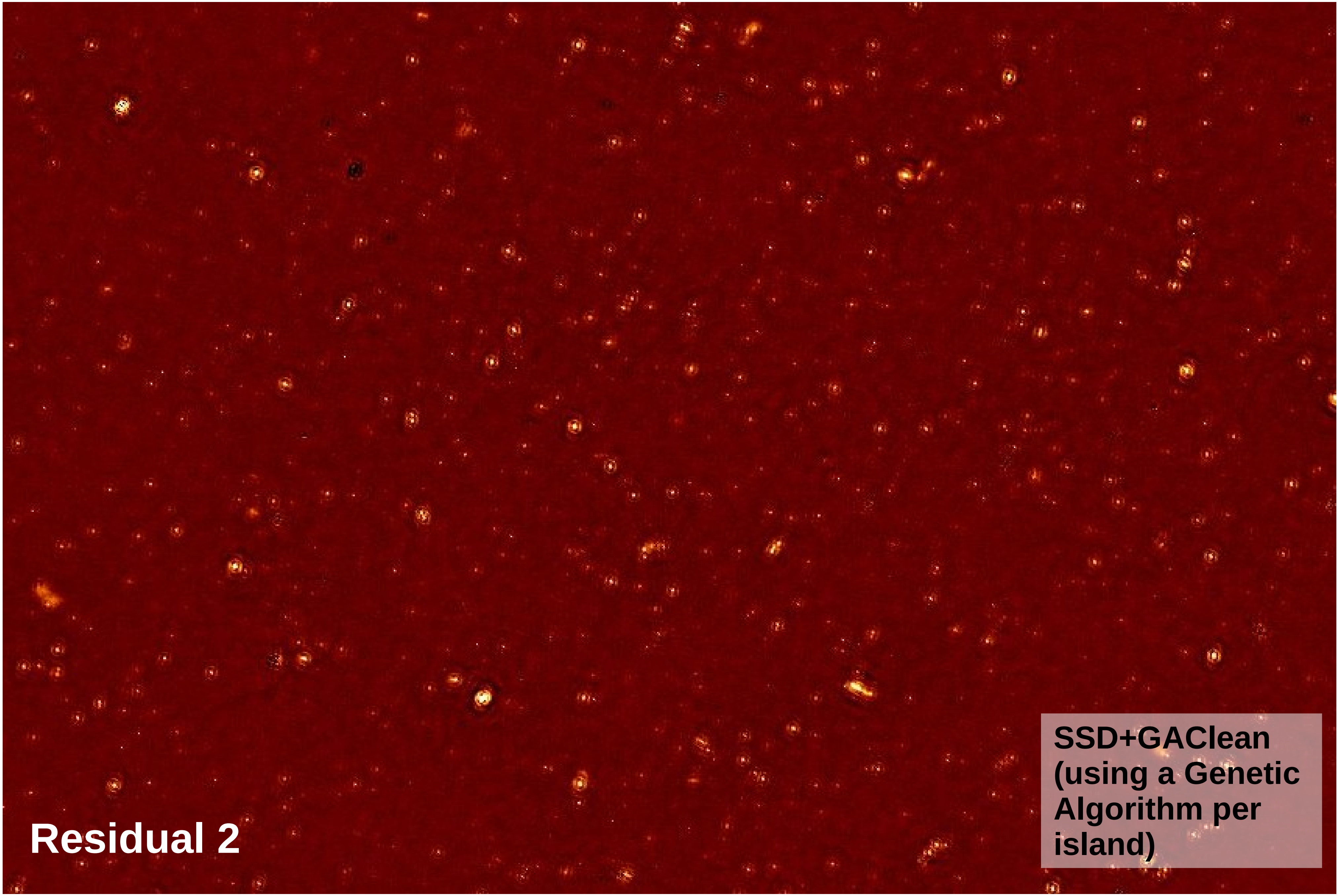

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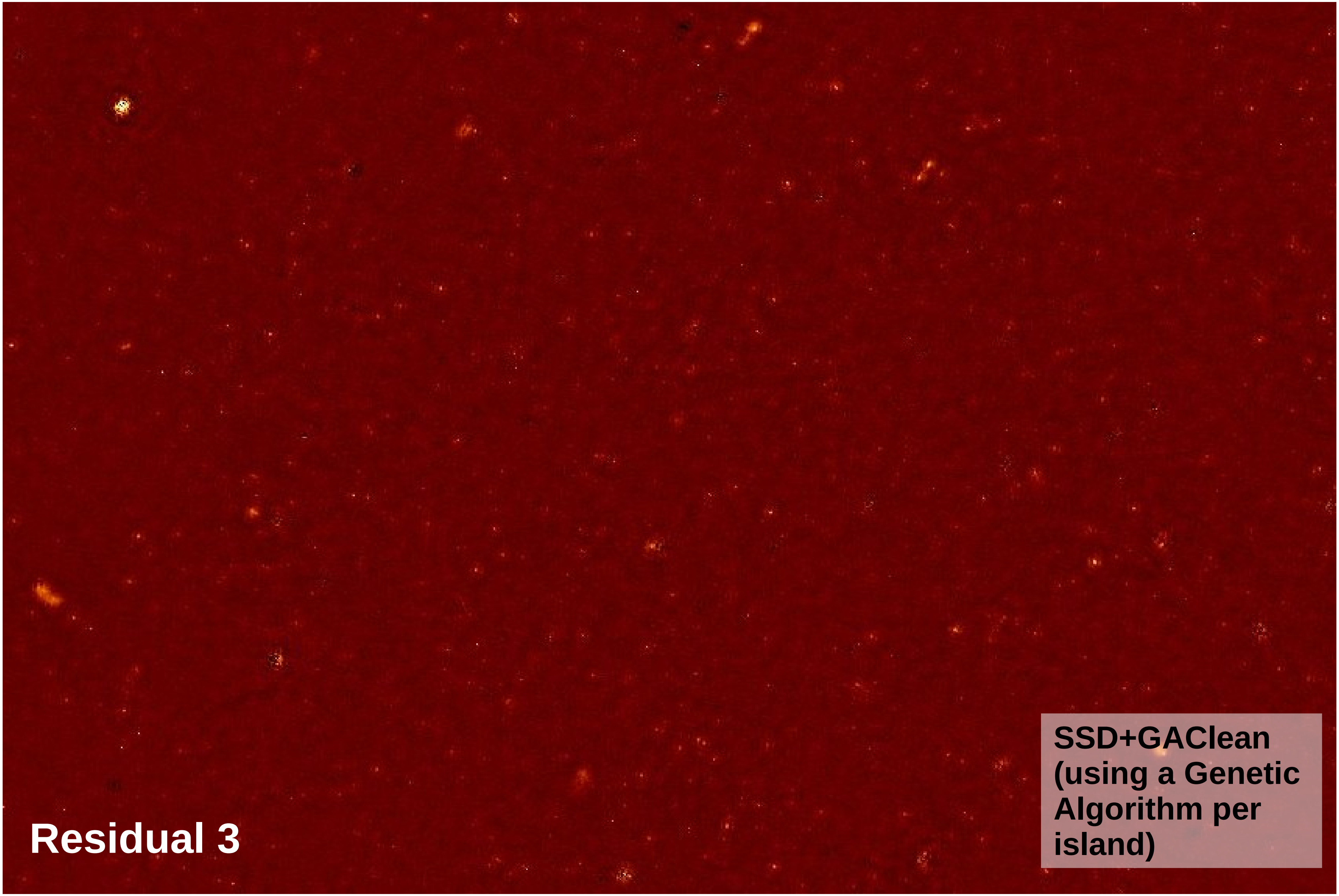
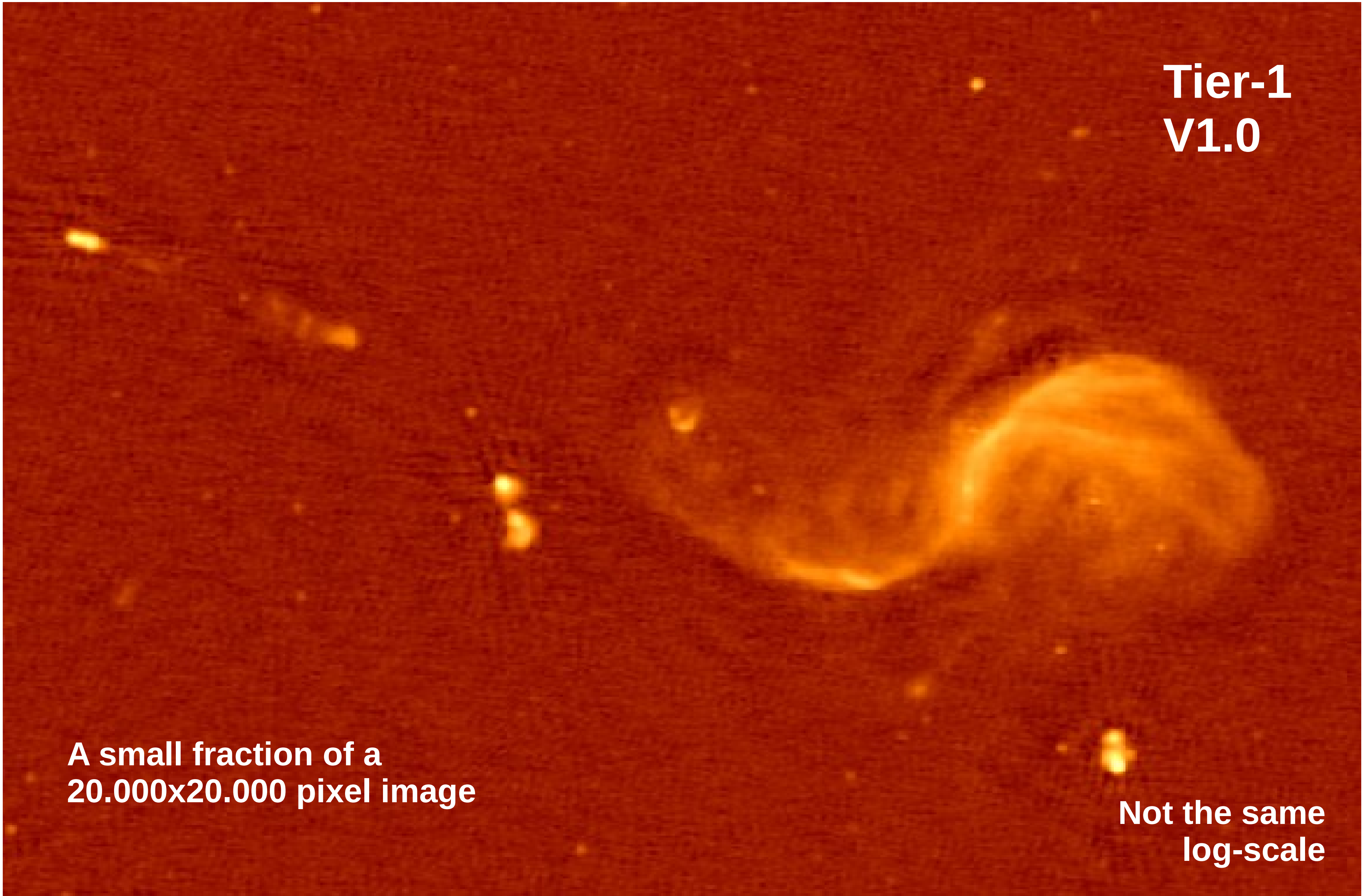
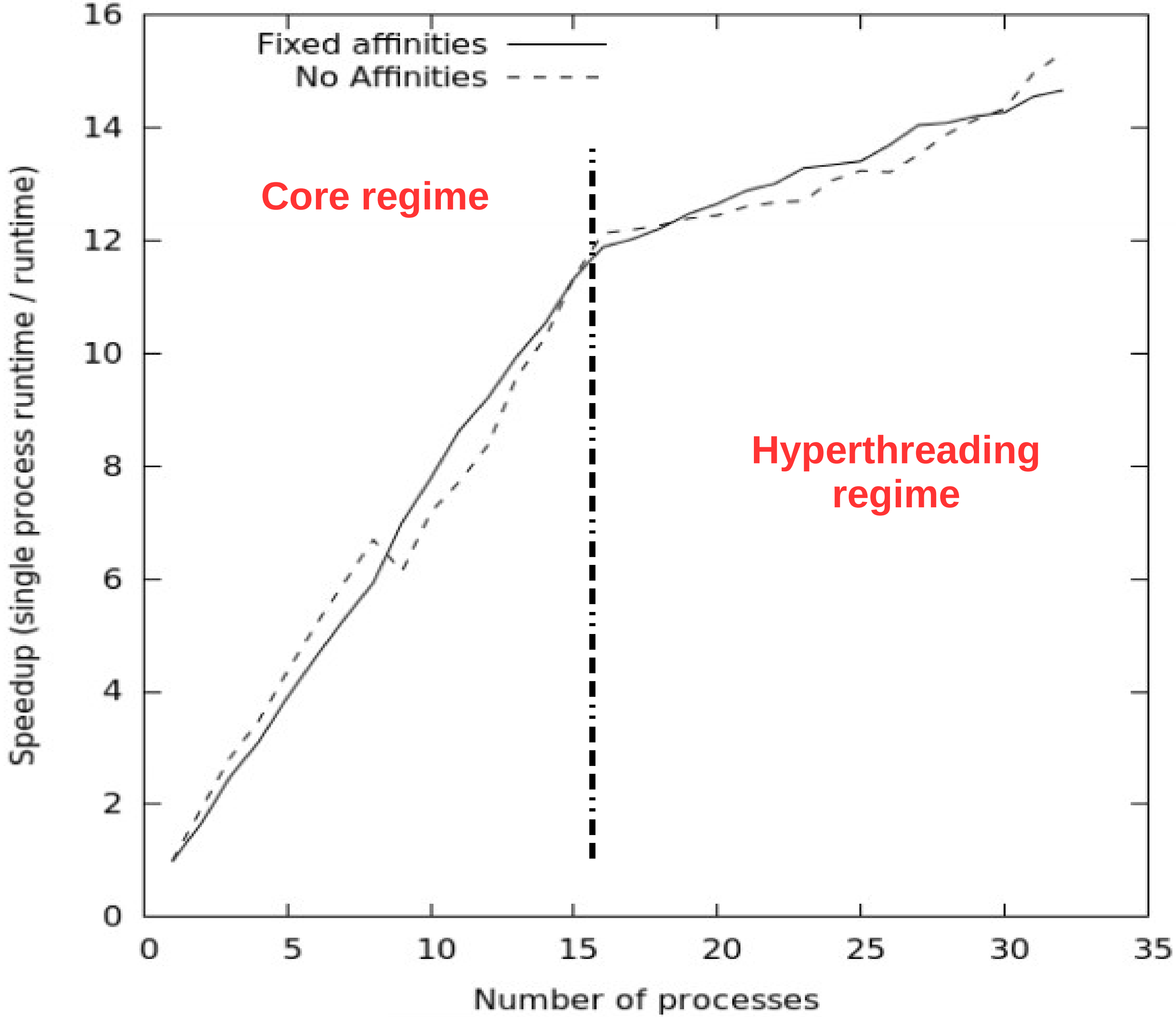


SSD+GA-based spectral deconvolution … actually quite good at deconvolving complex extended emission

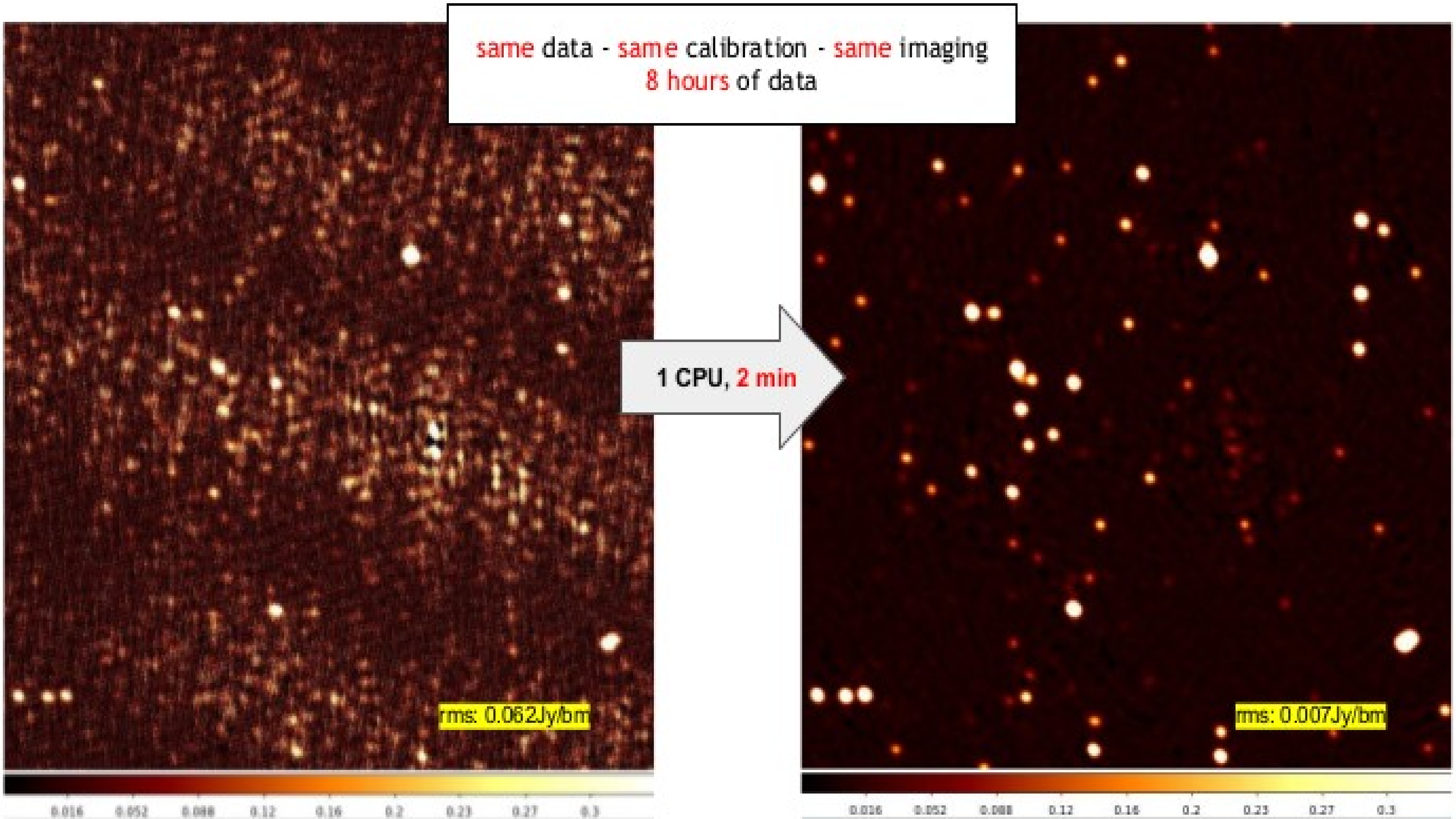


Performance for a VLA dataset



Plot from Benna Hugo

« Lucky exposure » for interferometry incorporated in kMS: work of Etienne Bonnassieux (poster)



A new weighting scheme to change the shape of the « noise psf »

The fun part of 3rd generation calibration: real life dataset

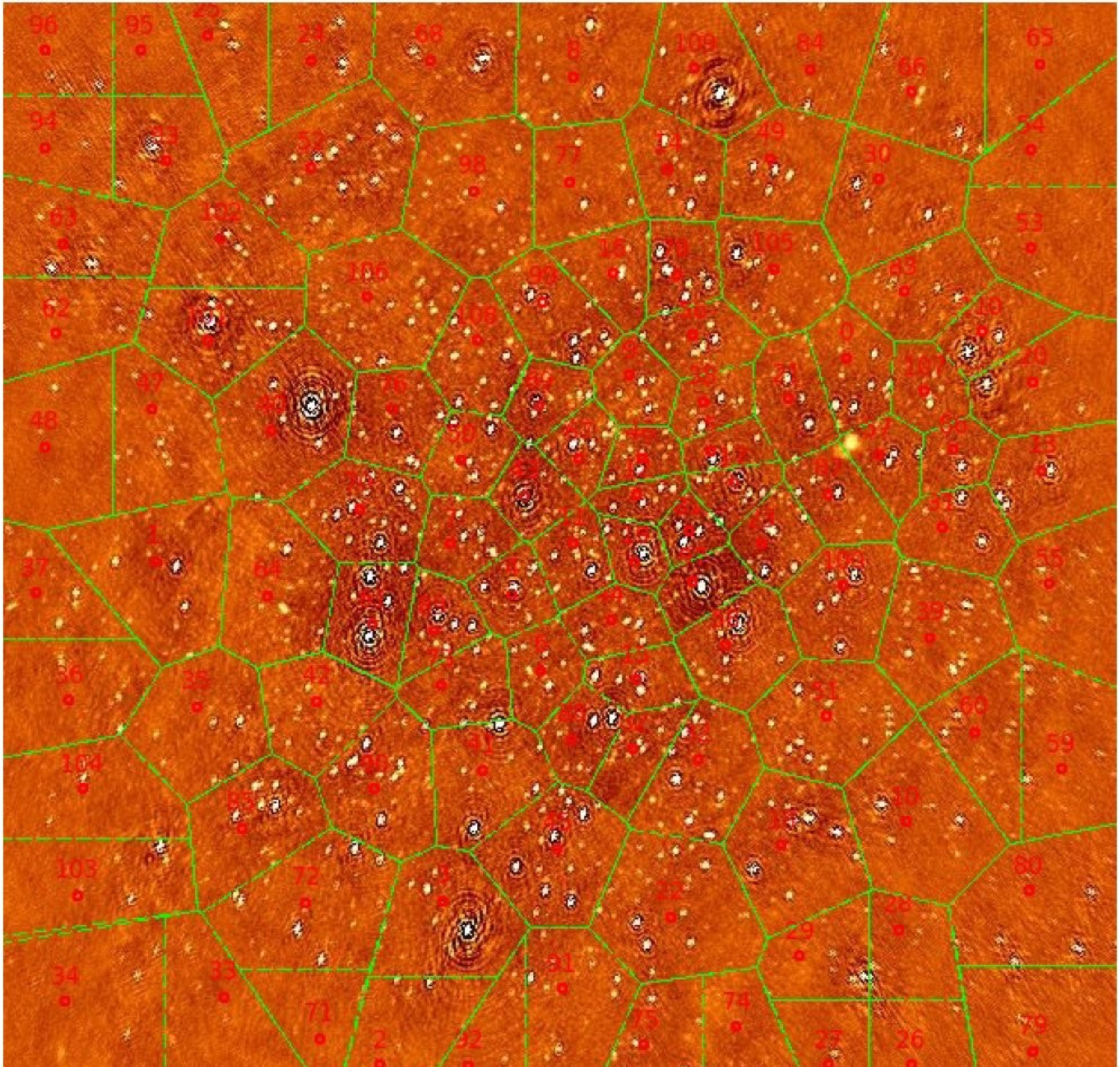
LOFAR Bootes field

48 hours integration, 55 stations, 130-170 MHz

20k x 20k image
FOV : 8 degrees

precalibrated by ***Tim Shimwell+Alex Mechev***

3rd generation calibration on the Bootes field : 8 hours integration with LOFAR@~150MHz



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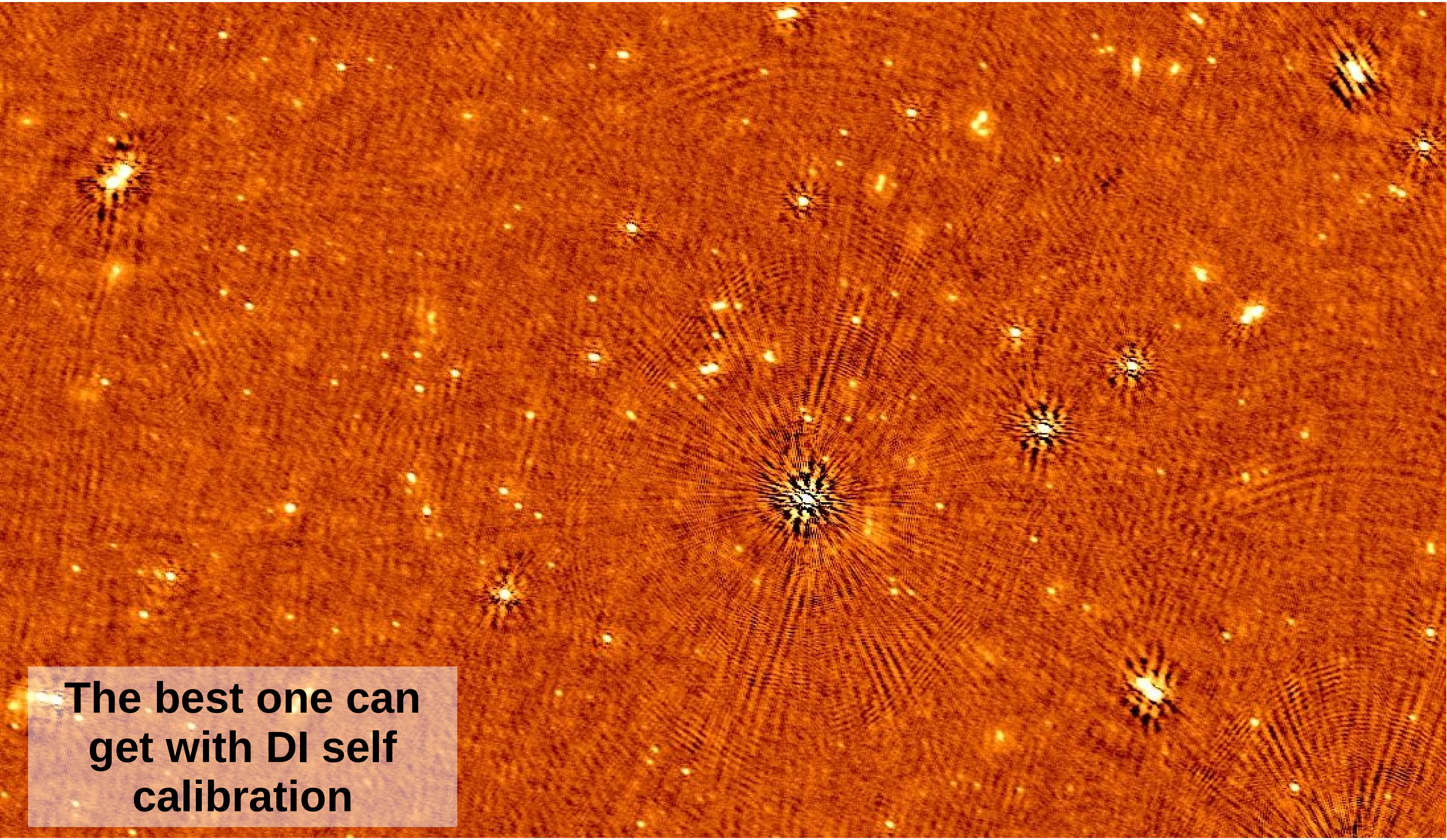

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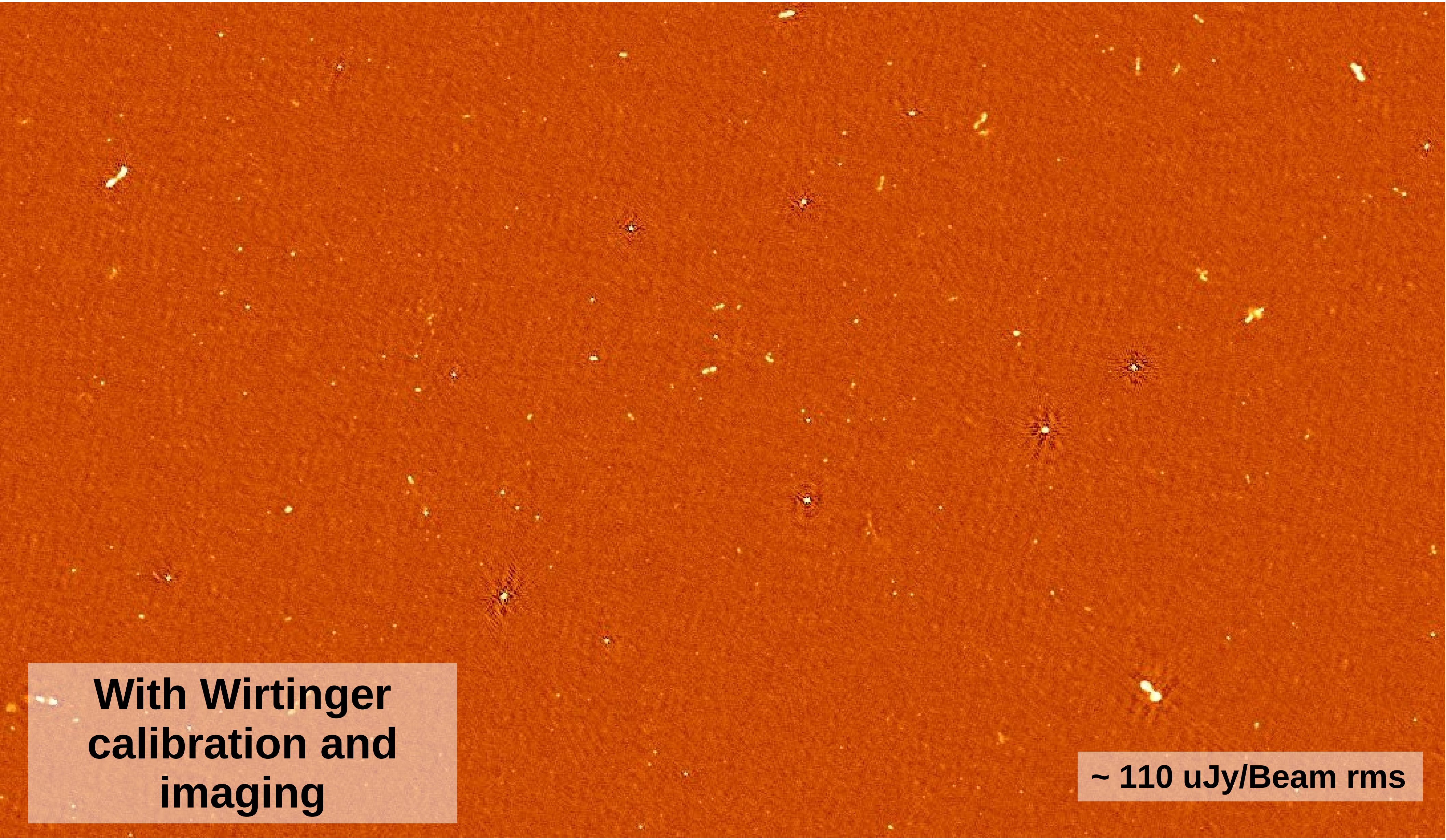

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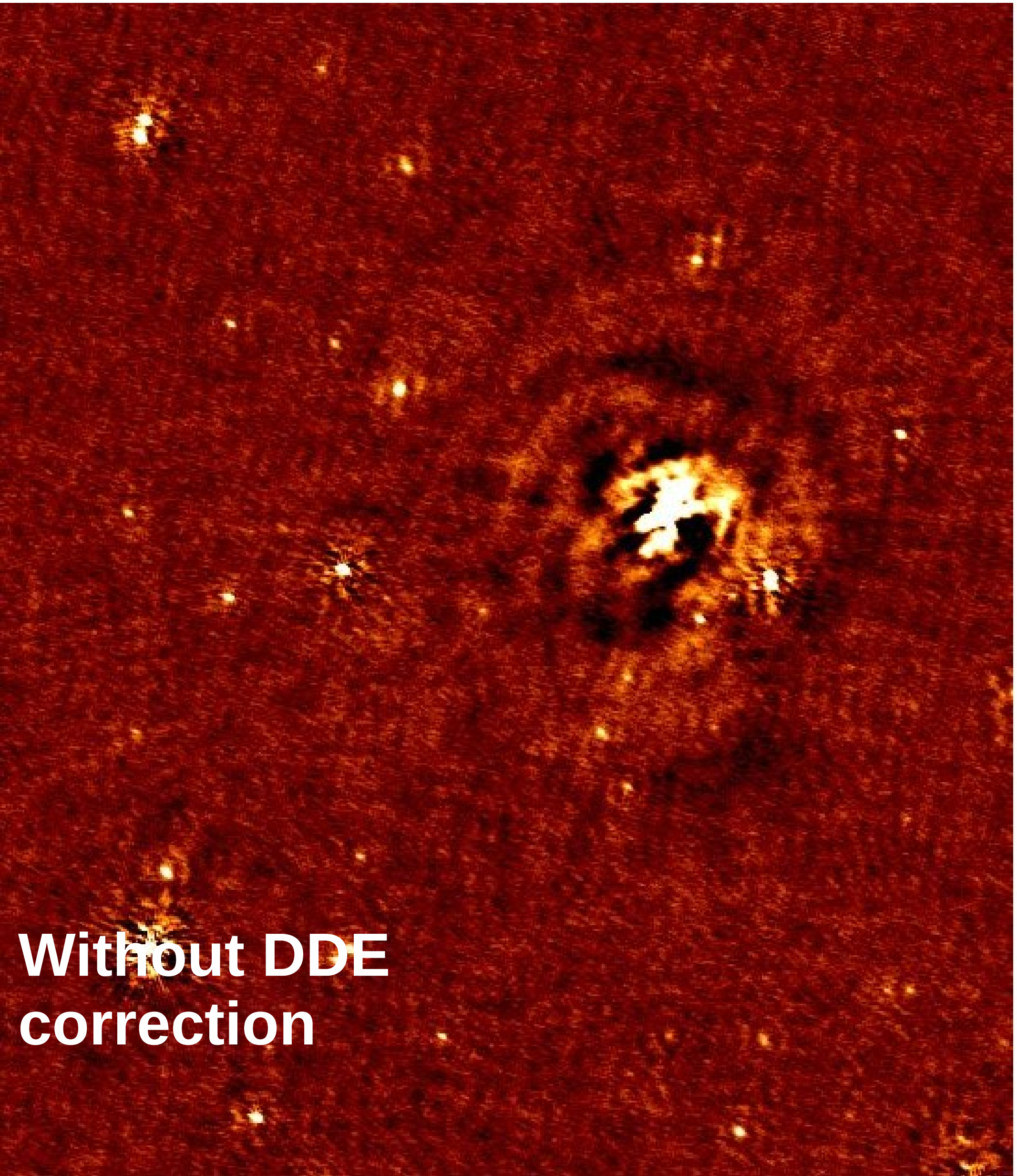

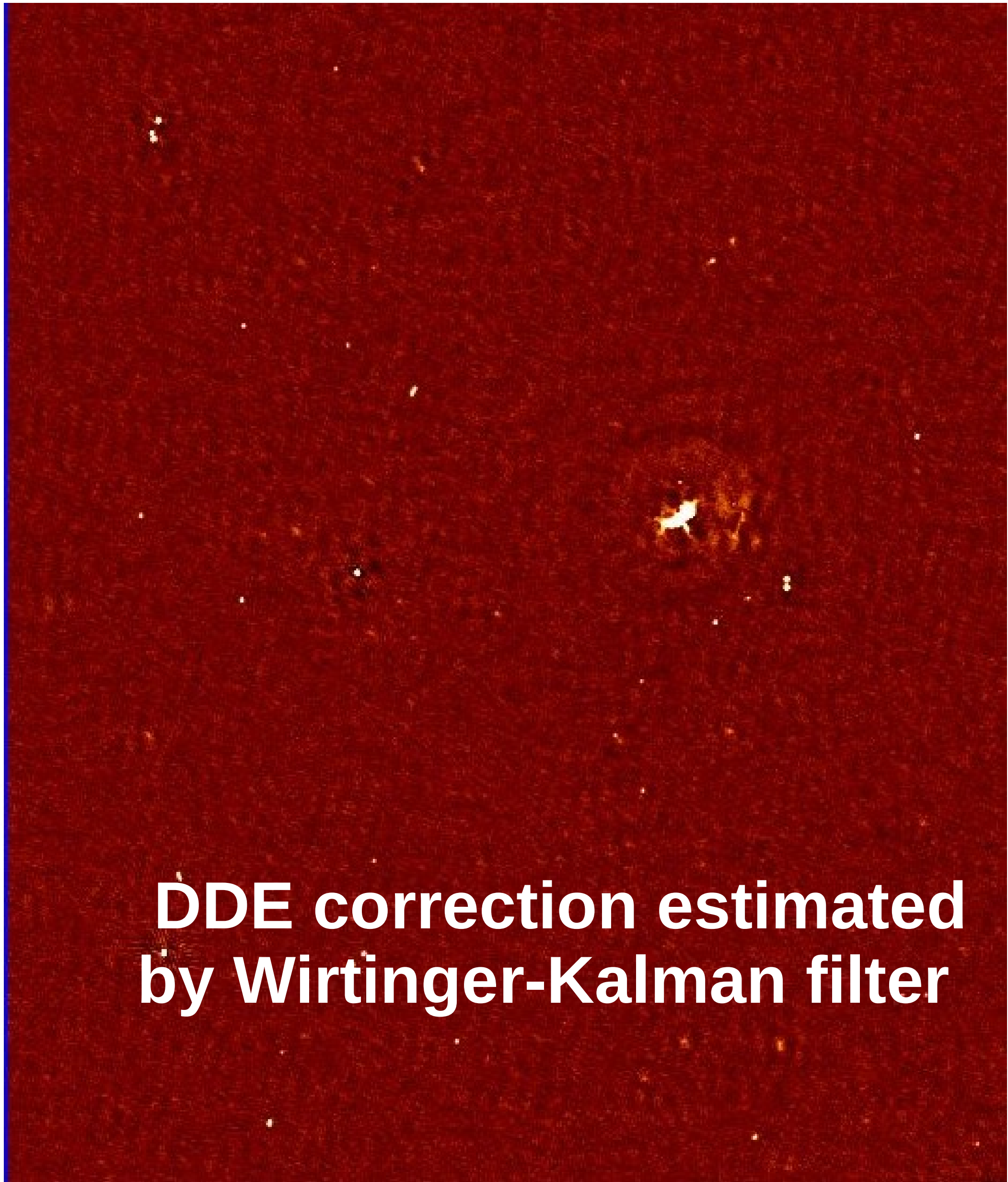

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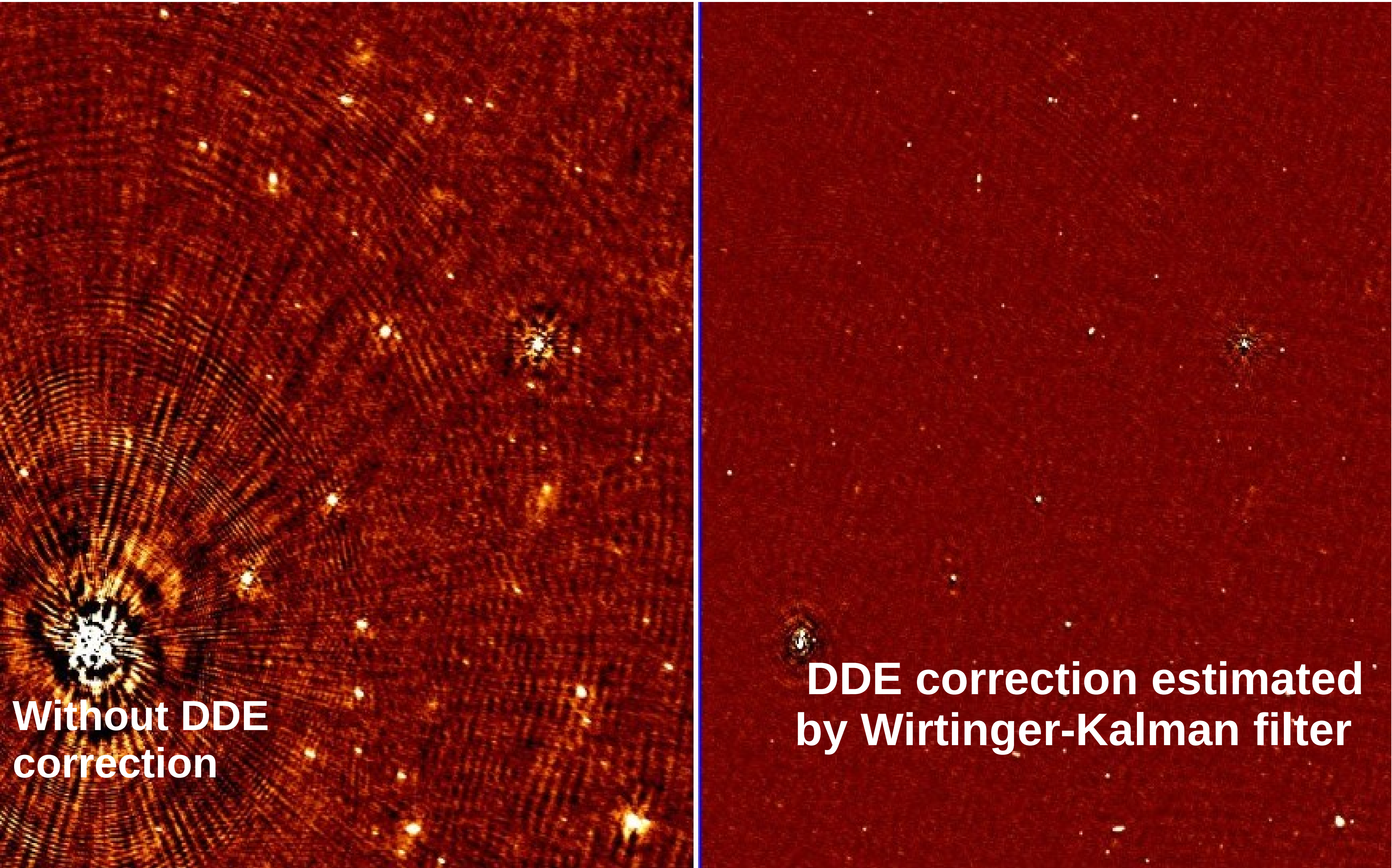
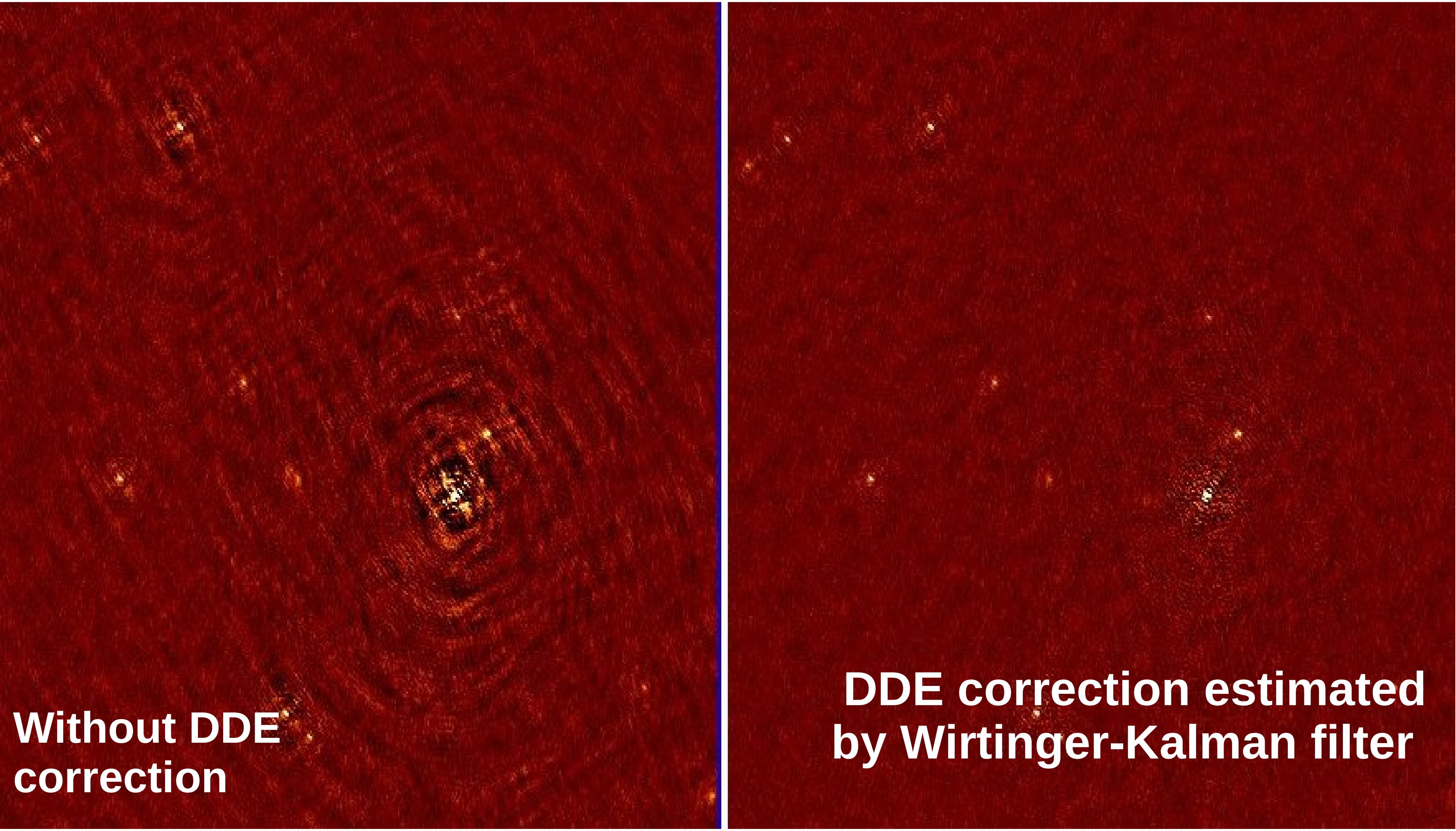


3rd generation calibration on the Bootes field : 8 hours integration with LOFAR@~150MHz



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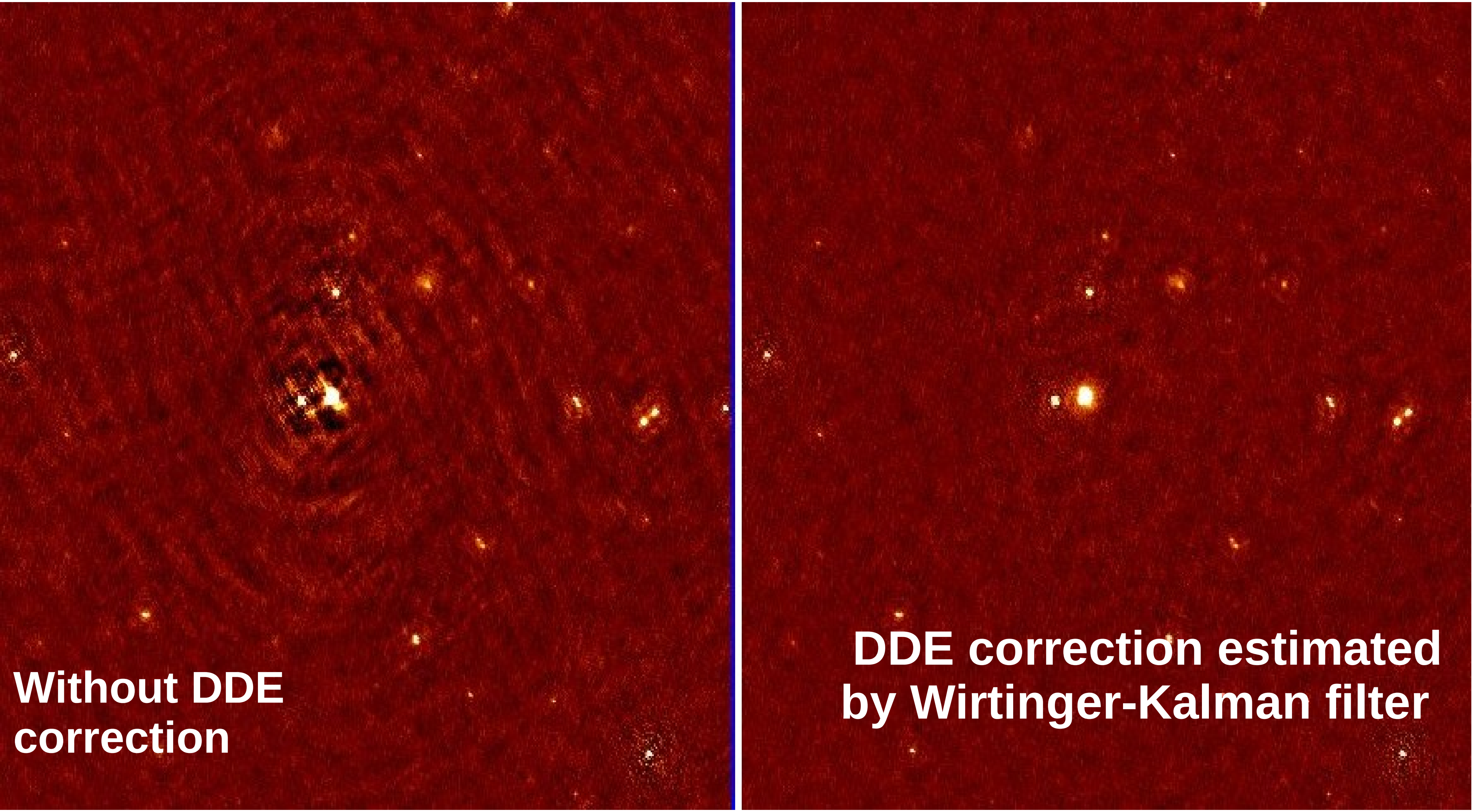

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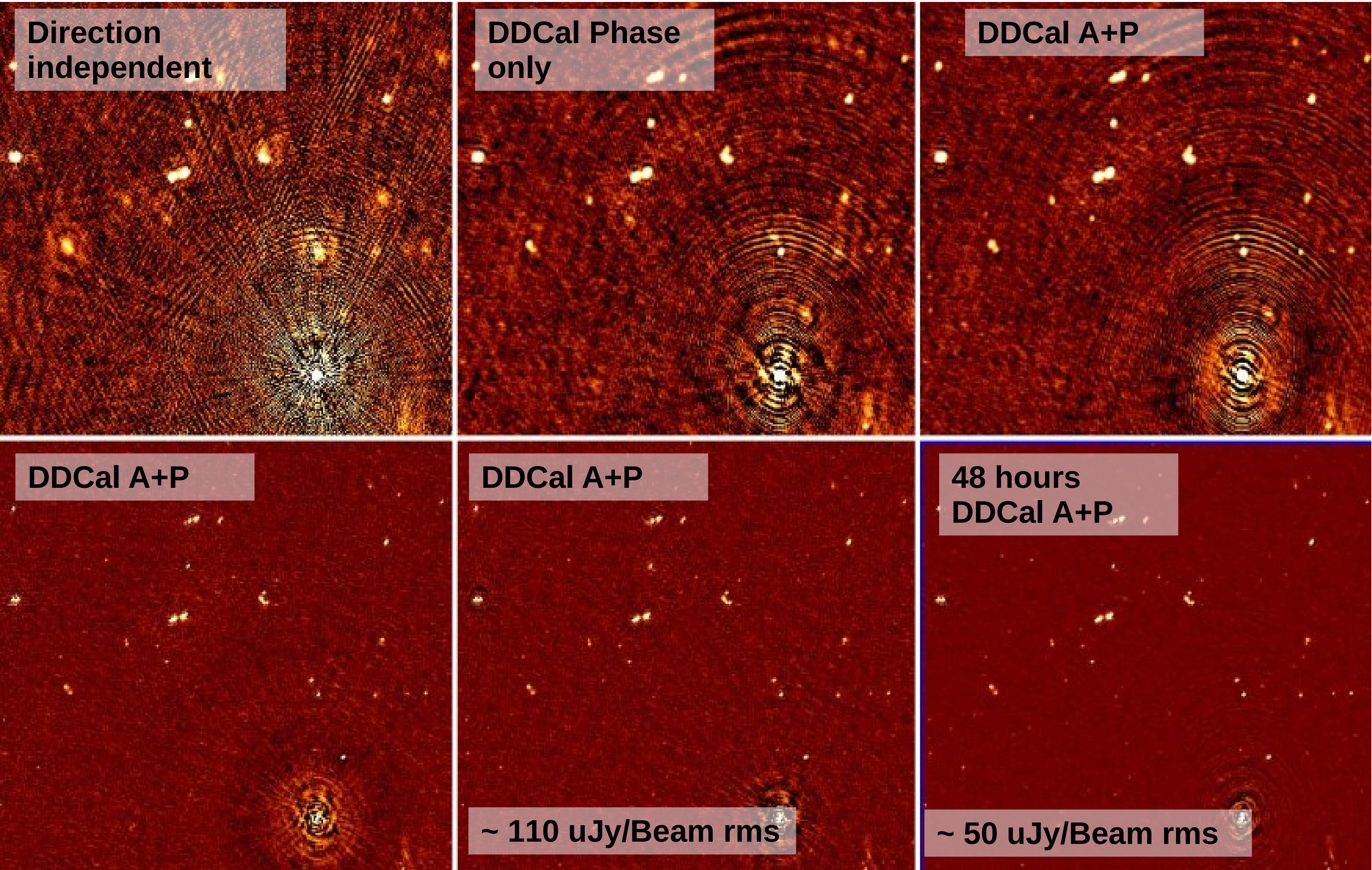
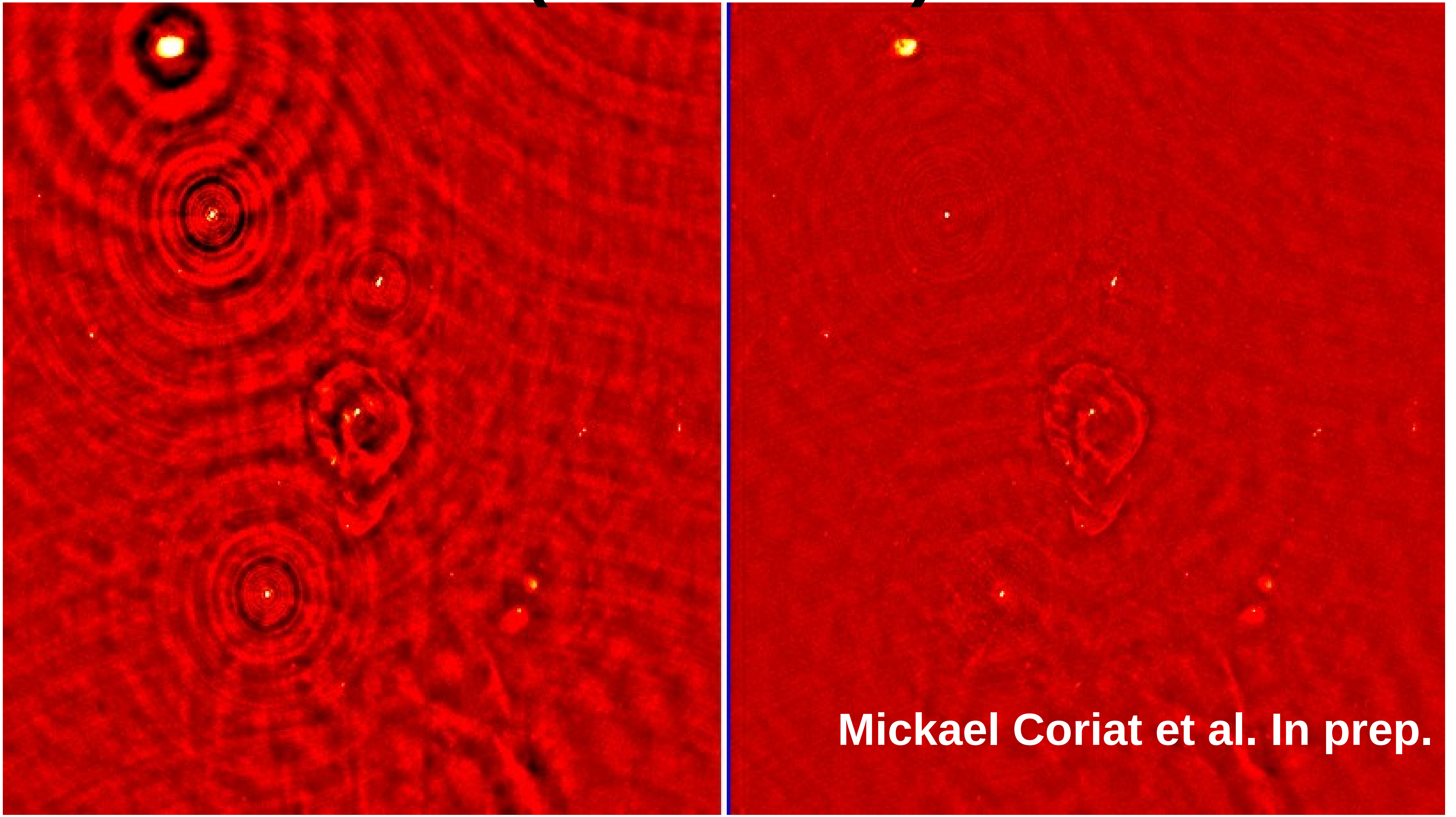


Does it work on other radio telescopes ?

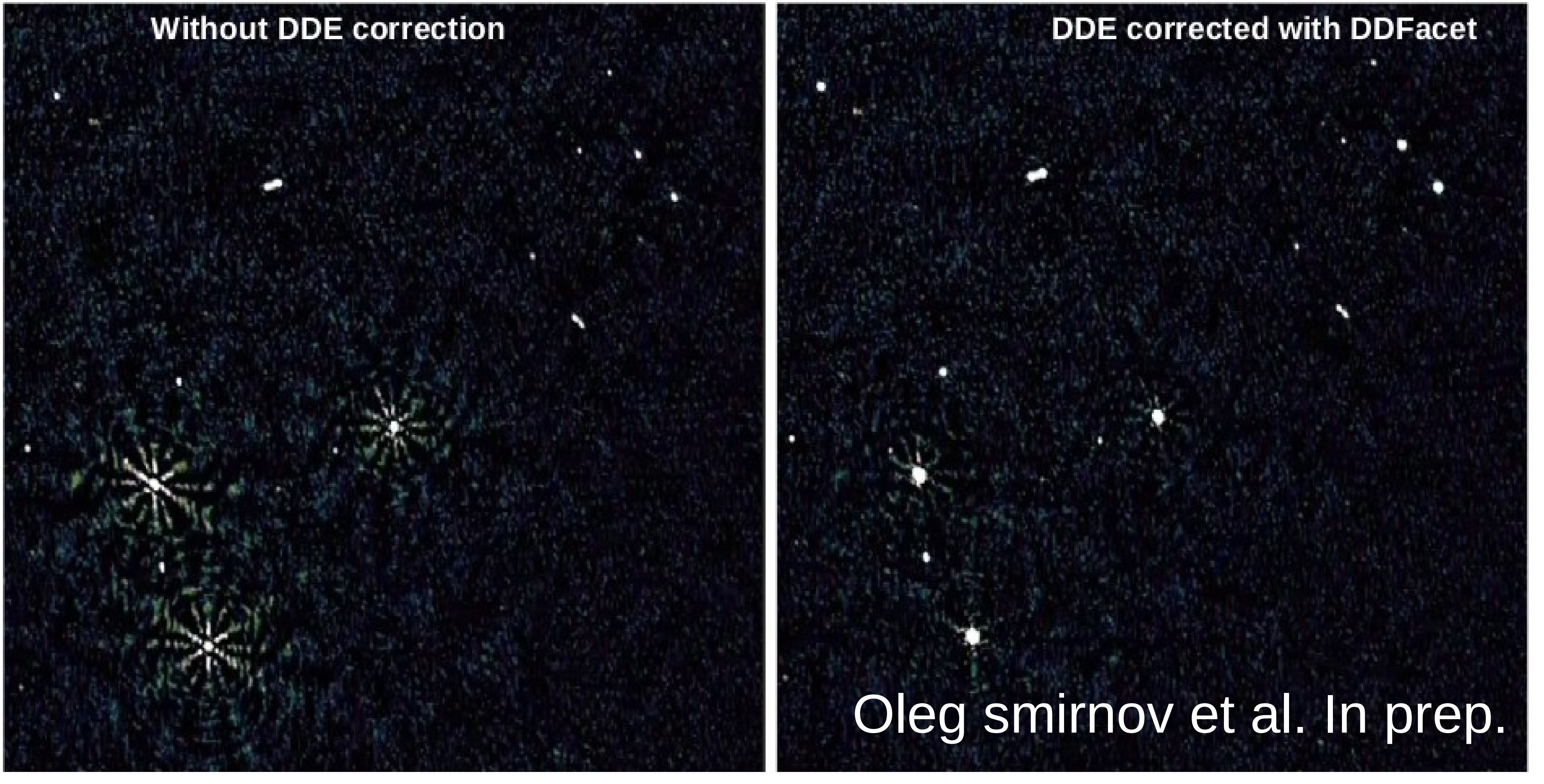
And it also works on ATCA data (Circinus a)



Direction independent calibration

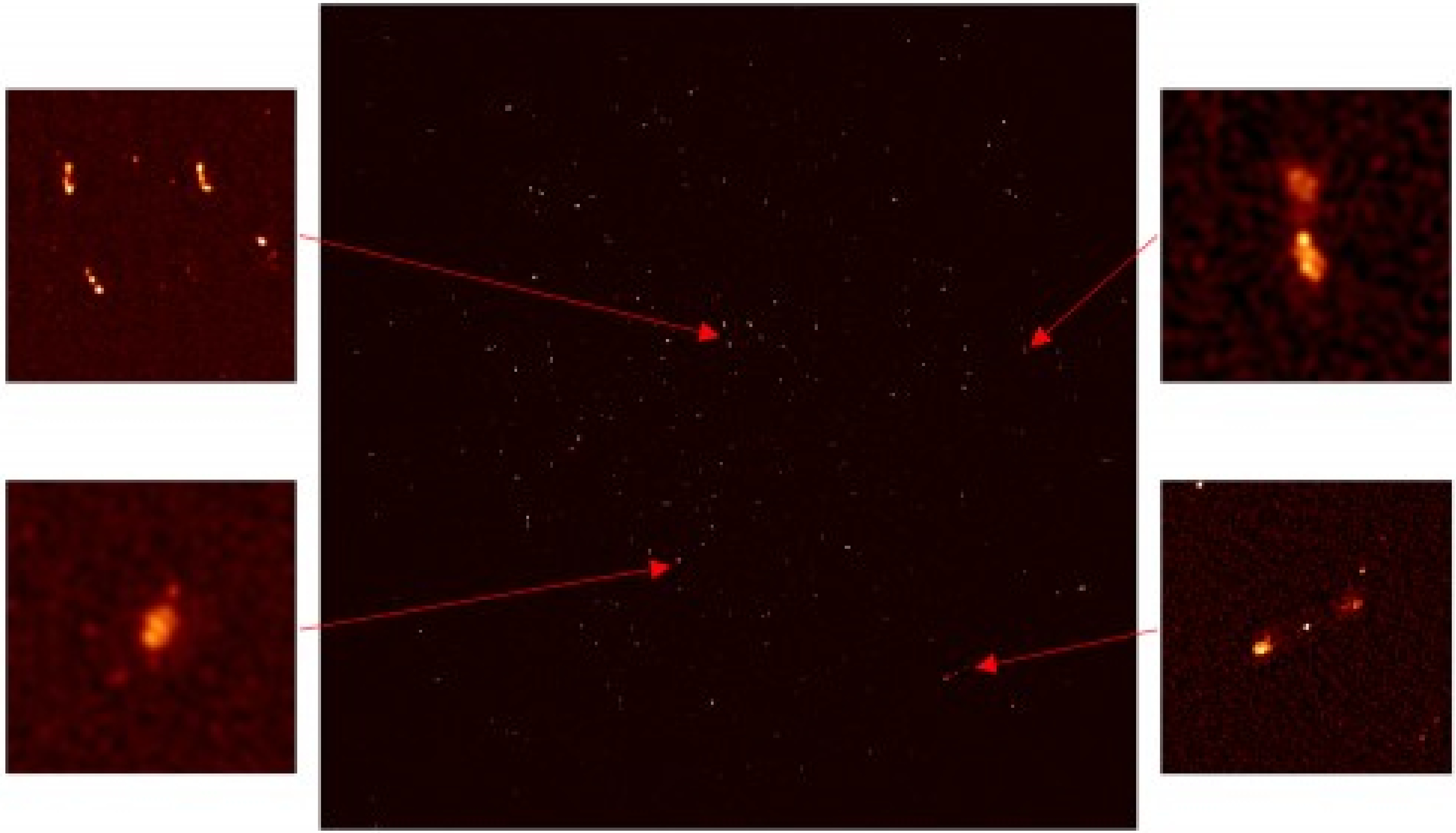
DDE with Wirtinger

And it also works on VLA data



VLA beam model used to construct the Jones matrices

Cherry on the cake :
First light MeerKAT image !



- Precalibration in South Africa (Oleg Smirnov et al.)
- Final image synthesized by myself in Nancay (killMS+DDFacet)

Final remarks

- Wirtinger calibration (DDFacet / killMS) are giving good results
  - Ingesting massive amounts of data
- The biggest problem is that it does absorb (some) faint+extended emission
  - To preserve it we need to sacrifice some dynamic range
  - Need to improve over conditionning (after the summer break)
- Imaging
  - Optimal facetting is important : still a lot to do here
  - Going very deep (Bootes field ~120 hours)
  - Easy to plug algorithms in DDFacet

DDFacet available

```
 - 21:49:23 - DDFacet                  | starting DDFacet (/media/6B5E-87D0/killMS_Pack/DDFacet/DDFacet/DDF.py testimage.parset --Output-Na
rty --Cache-Reset 1)
 - 21:49:23 - DDFacet                  | working directory is /media/tasse/data/killMS_Pack/DDFacet_Master/TestGA/TestSplitMerge
 - 21:49:23 - DDFacet                  | Successfully read parset testimage.parset, version 0.1
 - 21:49:23 - DDFacet                  |  Selected Options:
 - 21:49:23 - DDFacet                  | [Data] Visibility data options
 - 21:49:23 - DDFacet                  |  - MS ............................................ = 0000.MS
 - 21:49:23 - DDFacet                  |  - ColName ....................................... = CORRECTED_DATA_BACKUP
 - 21:49:23 - DDFacet                  |  - ChunkHours .................................... = 0.0
 - 21:49:23 - DDFacet                  |  - Sort .......................................... = True
```

- Development version
  - https://pypi.python.org/pypi/DDFacet
  - Do enable Optisation options !!!
  - Do set your max shared memory to 100 %
- Proper public release in a few weeks
- If you want to collaborate, contact us :
  - Cyril Tasse <cyril.tasse@obspm.fr>
  - Oleg Smirnov <osmirnov@gmail.com>