



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

Cyril Tasse

Observatoire de Paris – Rhodes University

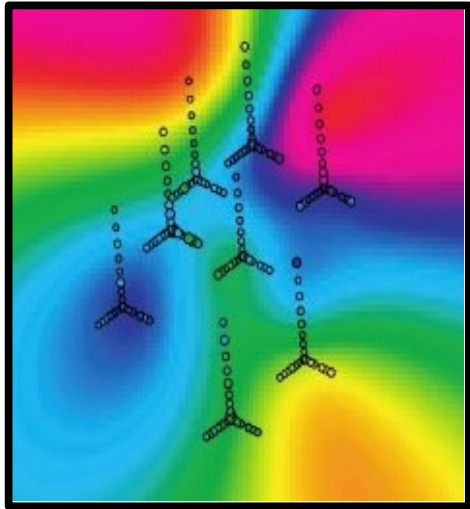
Algorithms : Oleg Smirnov, Etienne Bonnassieux, Marcellin Atemkeng, Landman Bester, Benna Hugo, Sphesihle Makhathini, Simon Perkins, ++

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

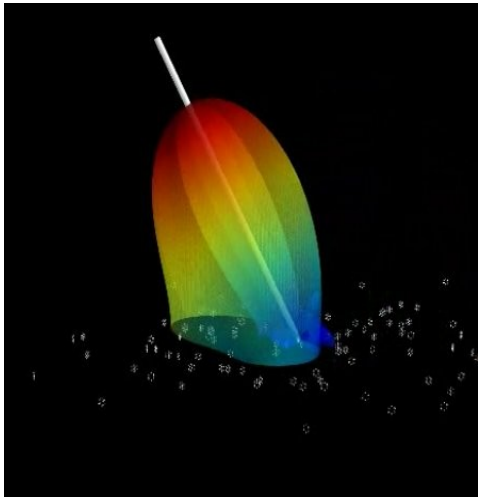
Outline

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

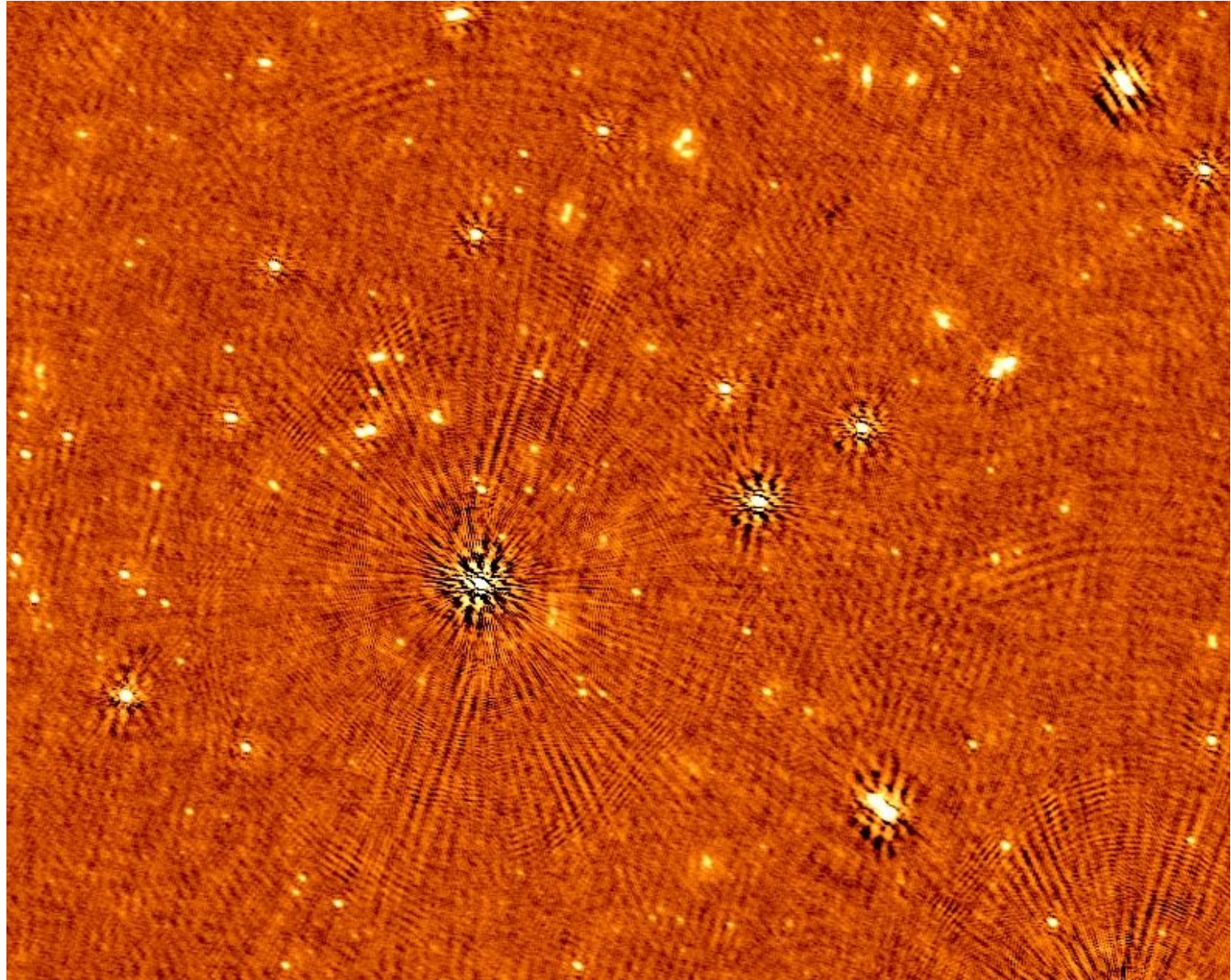
The best image you can ever get in selfcal



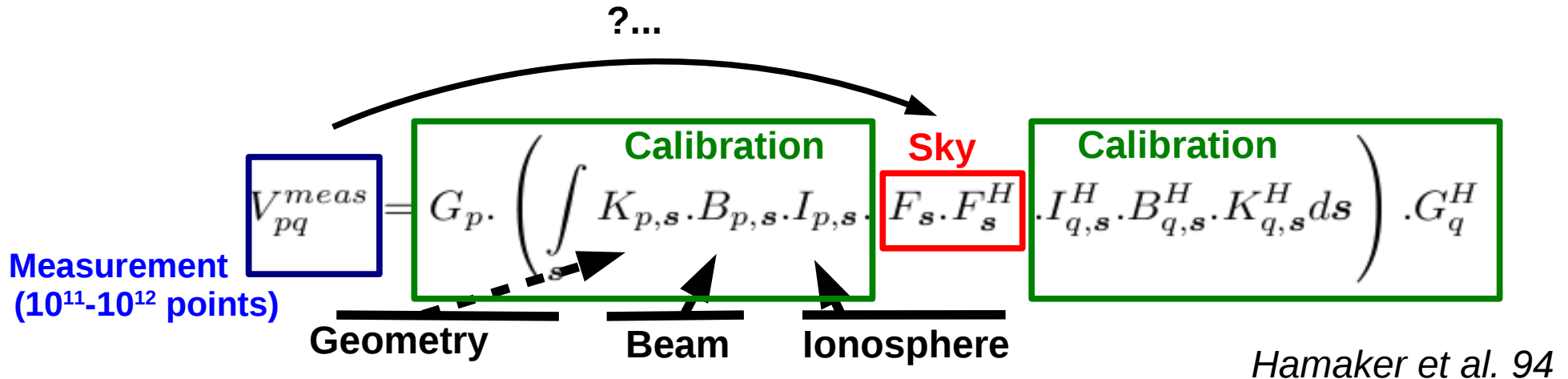
Ionospheric
disturbance + Faraday
rotation



Station lobes



«Third» generation calibration and imaging



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

(1)- Wirtinger optimisation for Direction Dependent Calibration

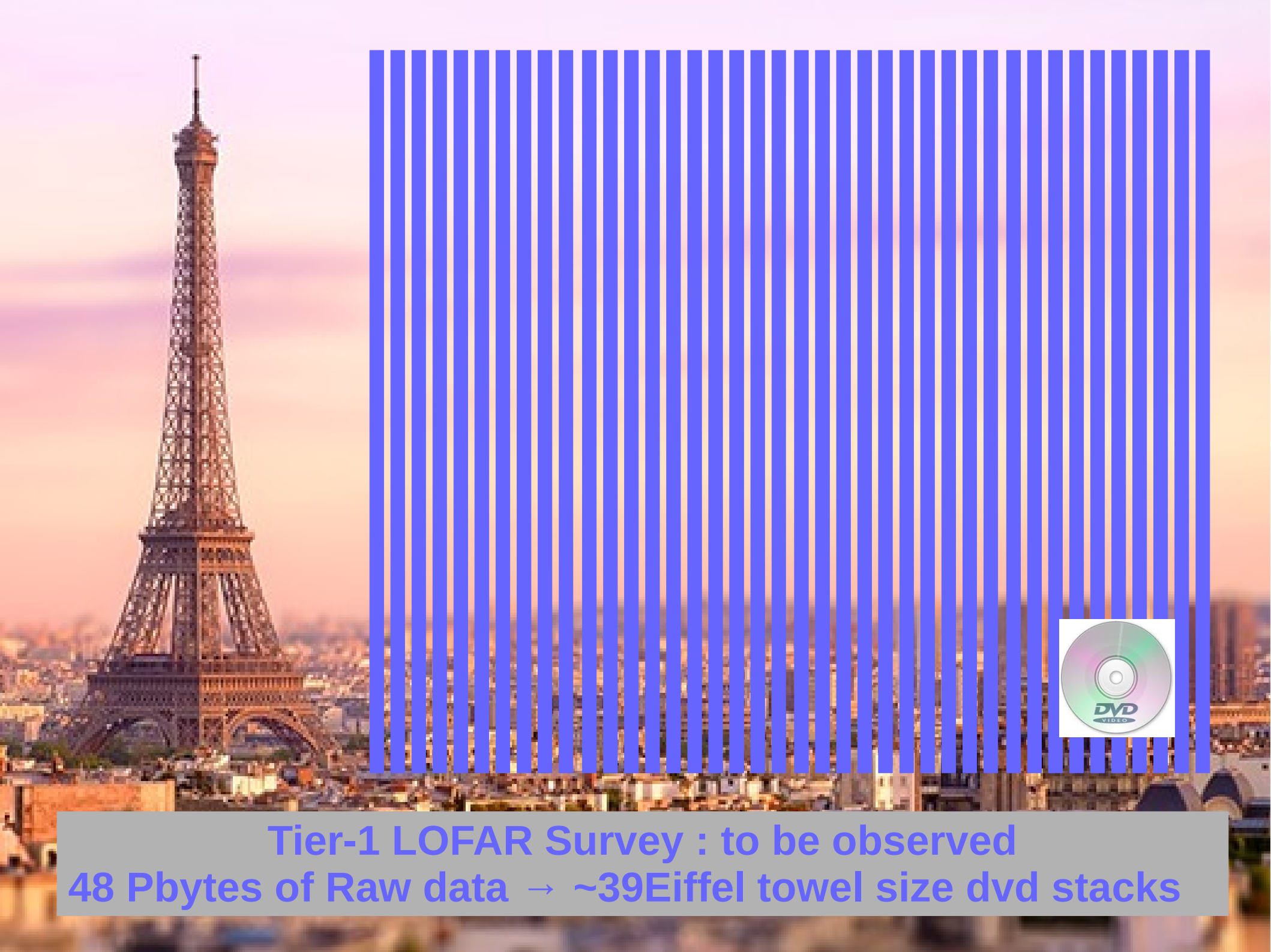
Tasse 2014

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 → ~39 Eiffel tower size dvd stacks



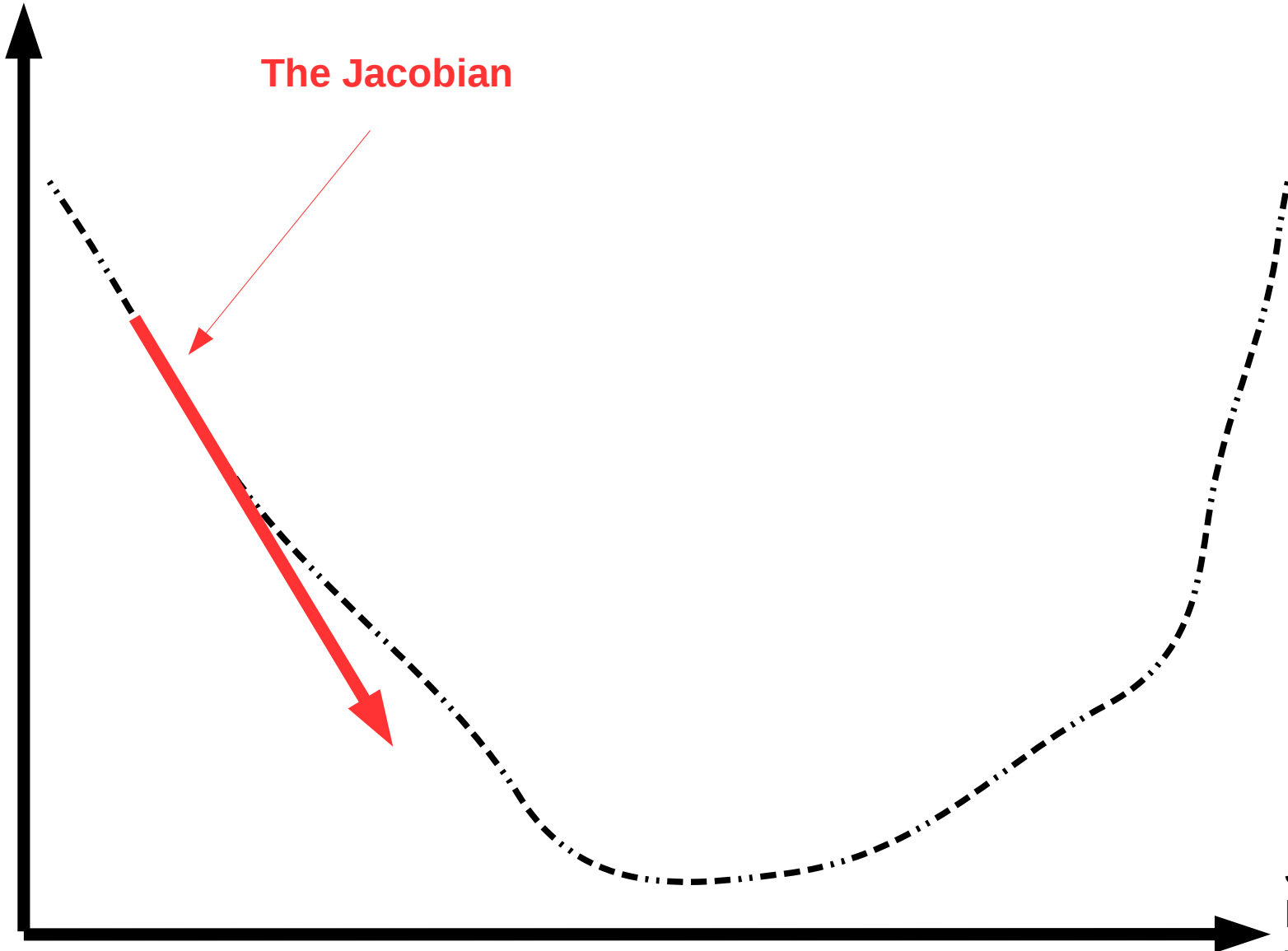
Tier-1 LOFAR Survey : observed so far
~5 Pbytes of raw data → ~4 Eiffel tower size dvd stacks

RIME Calibration

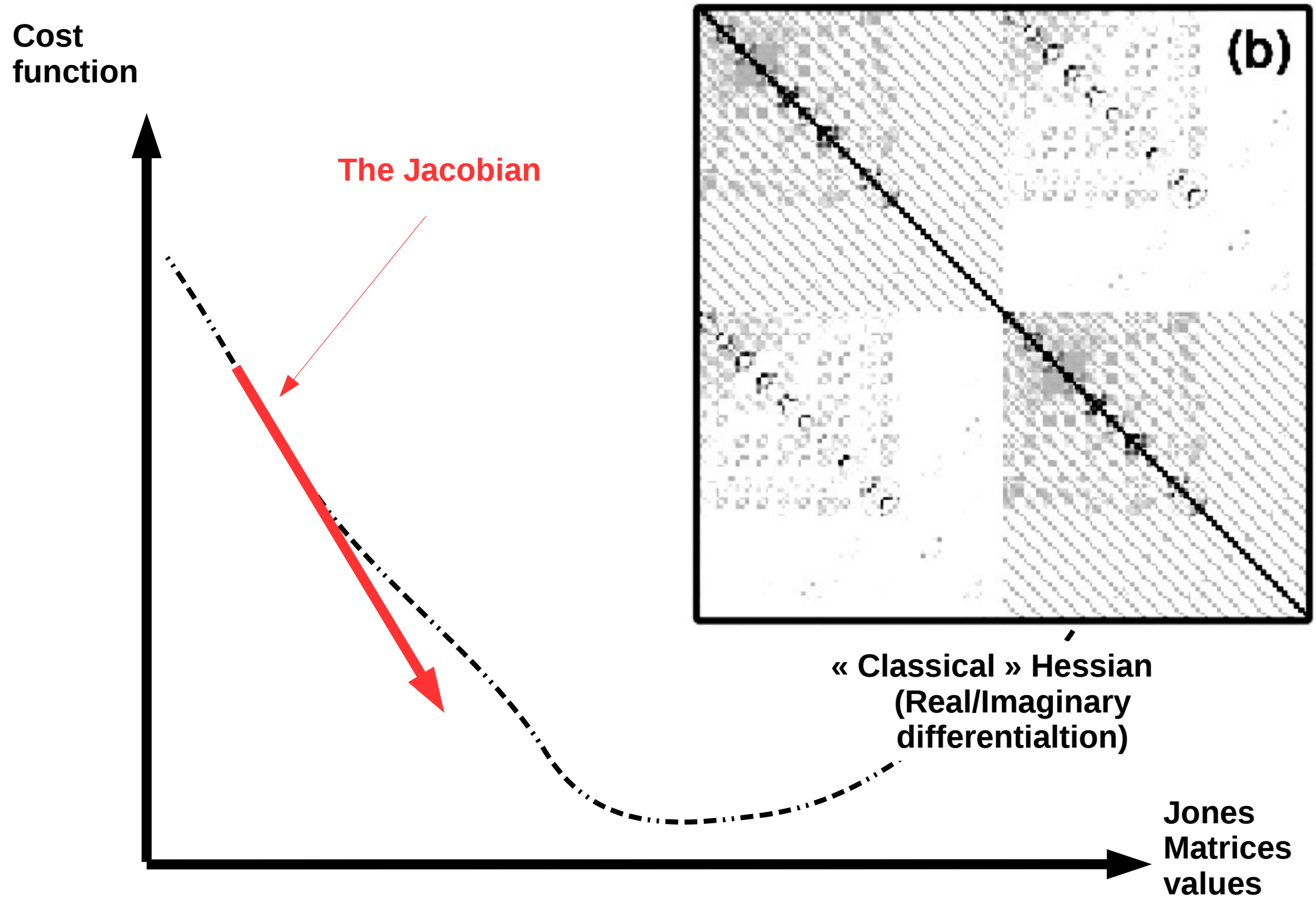
Cost
function

The Jacobian

Jones
Matrices
values



RIME Calibration

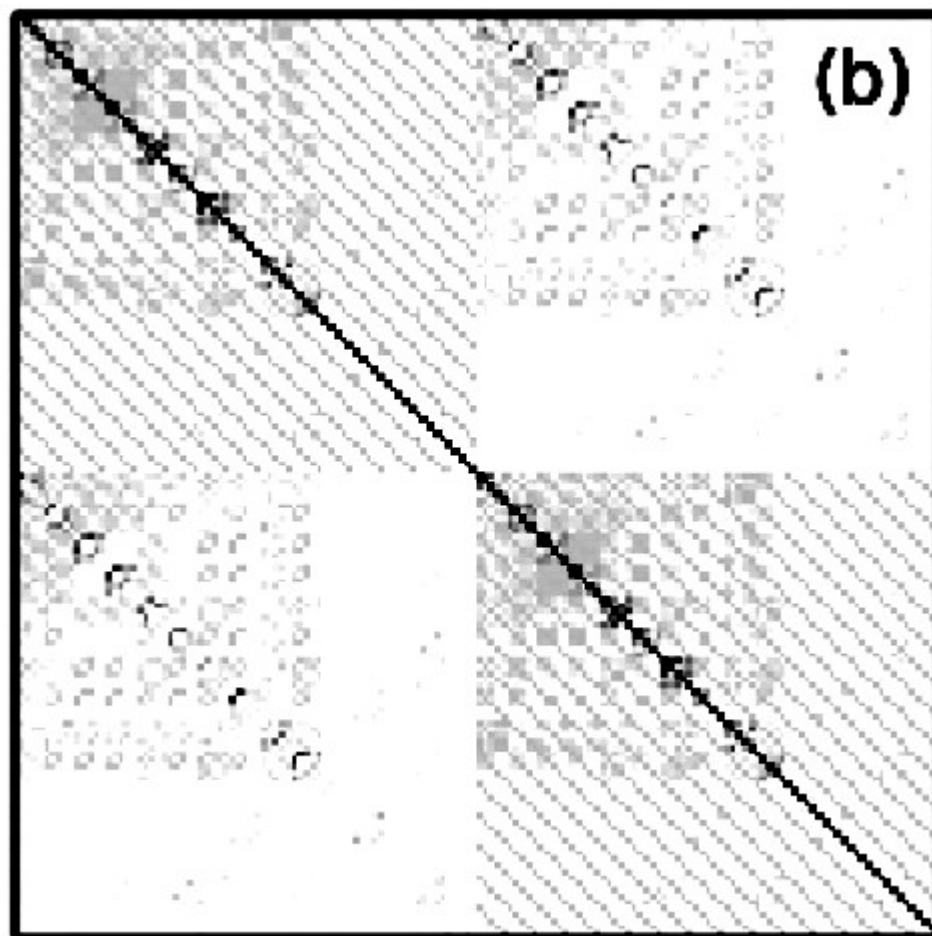


Wirtinger Optimisation: Jacobian & Hessian

(Read Tasse 2014,
Smirnov & Tasse 2015)

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

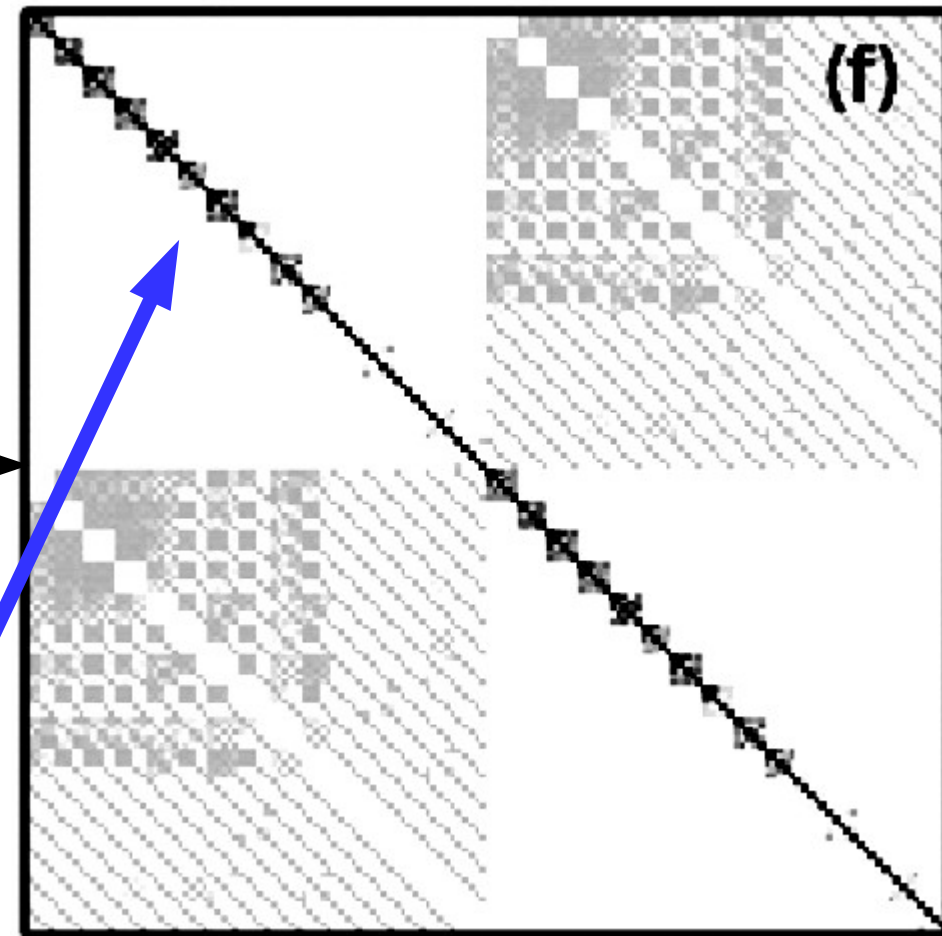
$$\frac{\partial \bar{z}}{\partial z} = 0 \text{ and } \frac{\partial z}{\partial \bar{z}} = 0$$



« Classical » Hessian



Those Blocks
are (Nd x Nd)



Wirtinger Hessian

Wirtinger Optimisation: Jacobian & Hessian

(Read Tasse 2014,
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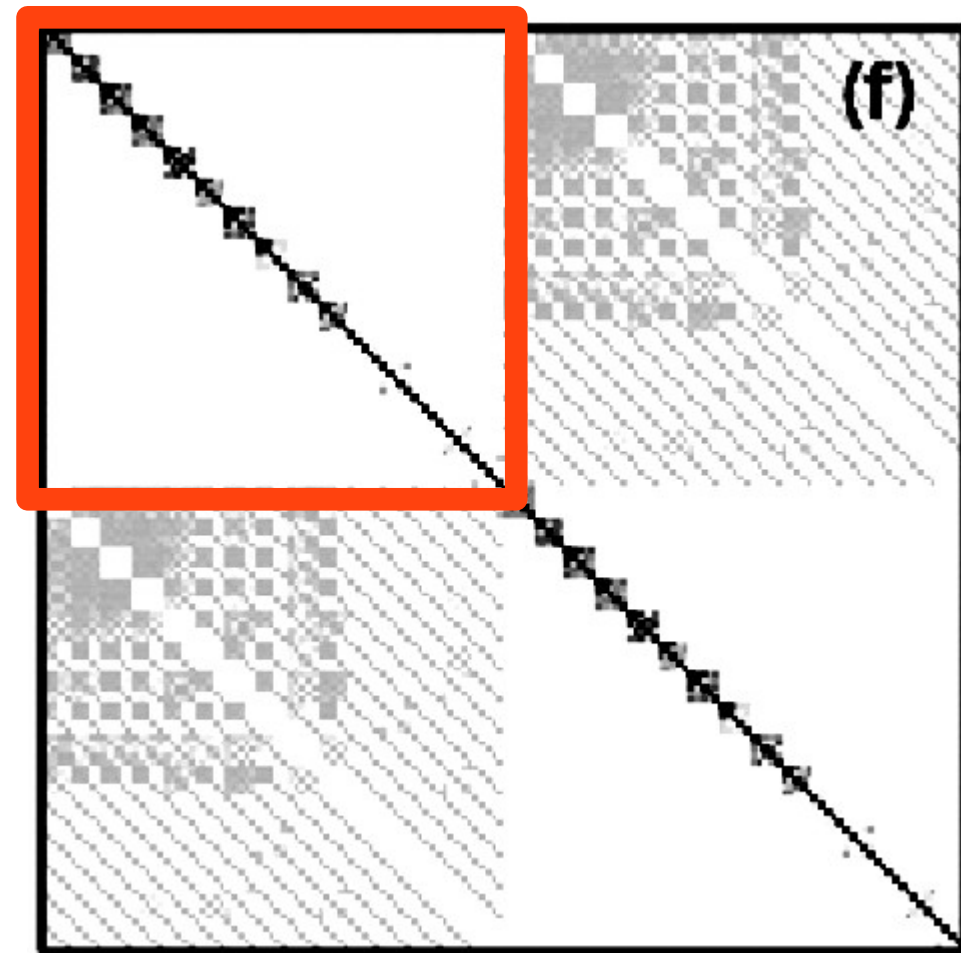
Wirtinger derivative definition « reorganises » the process and data : the Jacobian and Hessian become sparse and compact

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

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

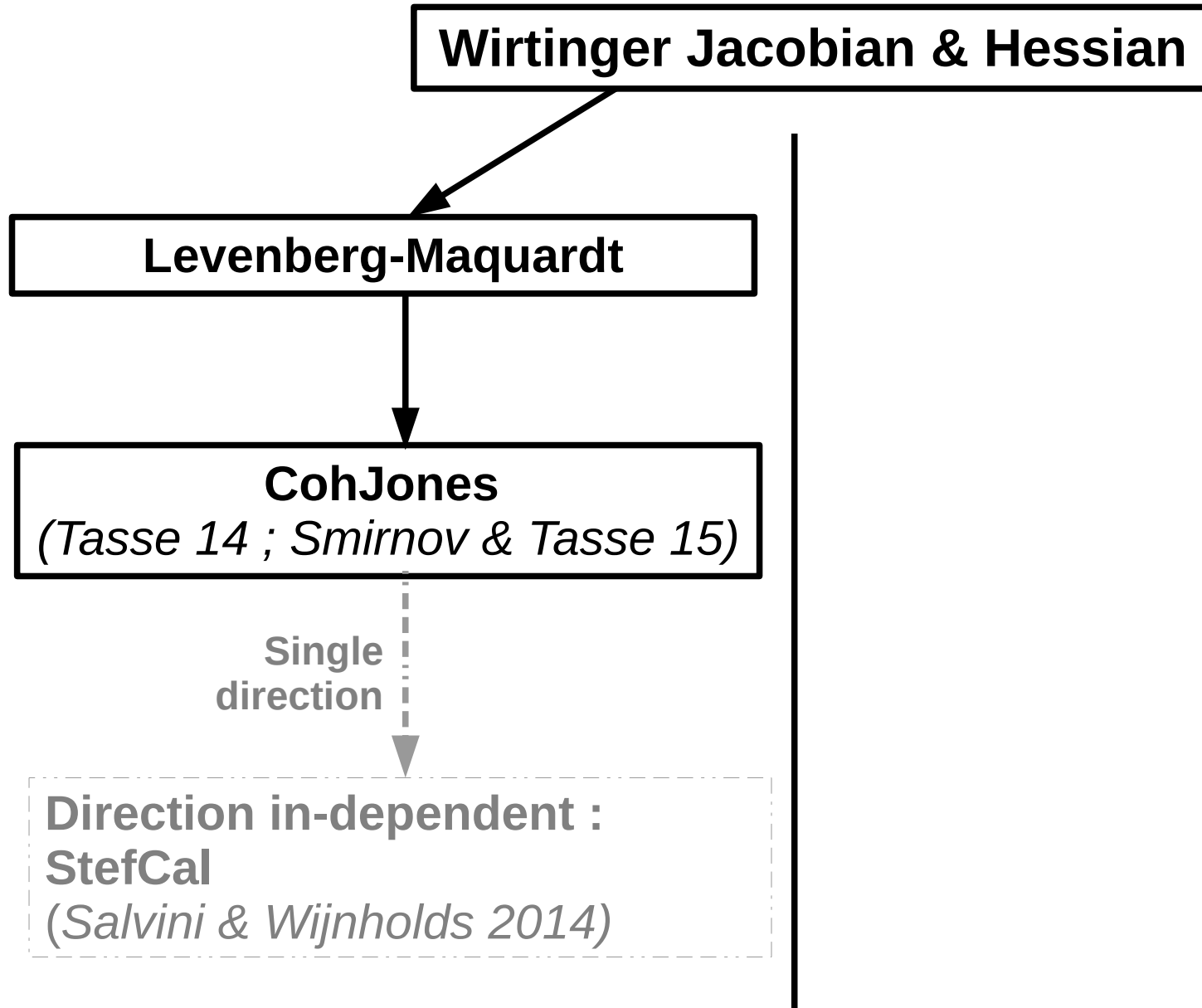
We can cut it in two !!!

- The result just needs to be divided 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 $\lambda=1$

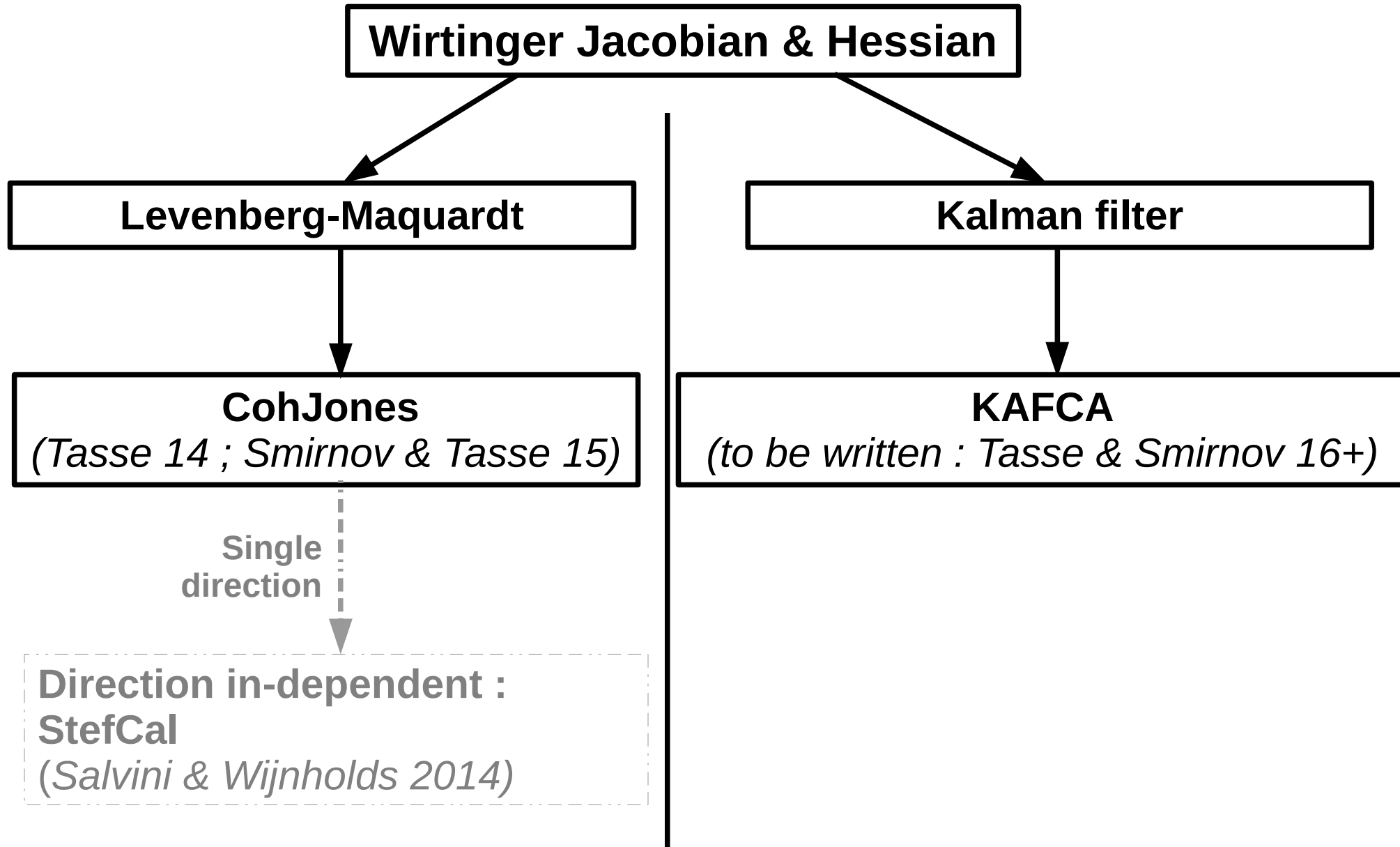


Wirtinger Hessian

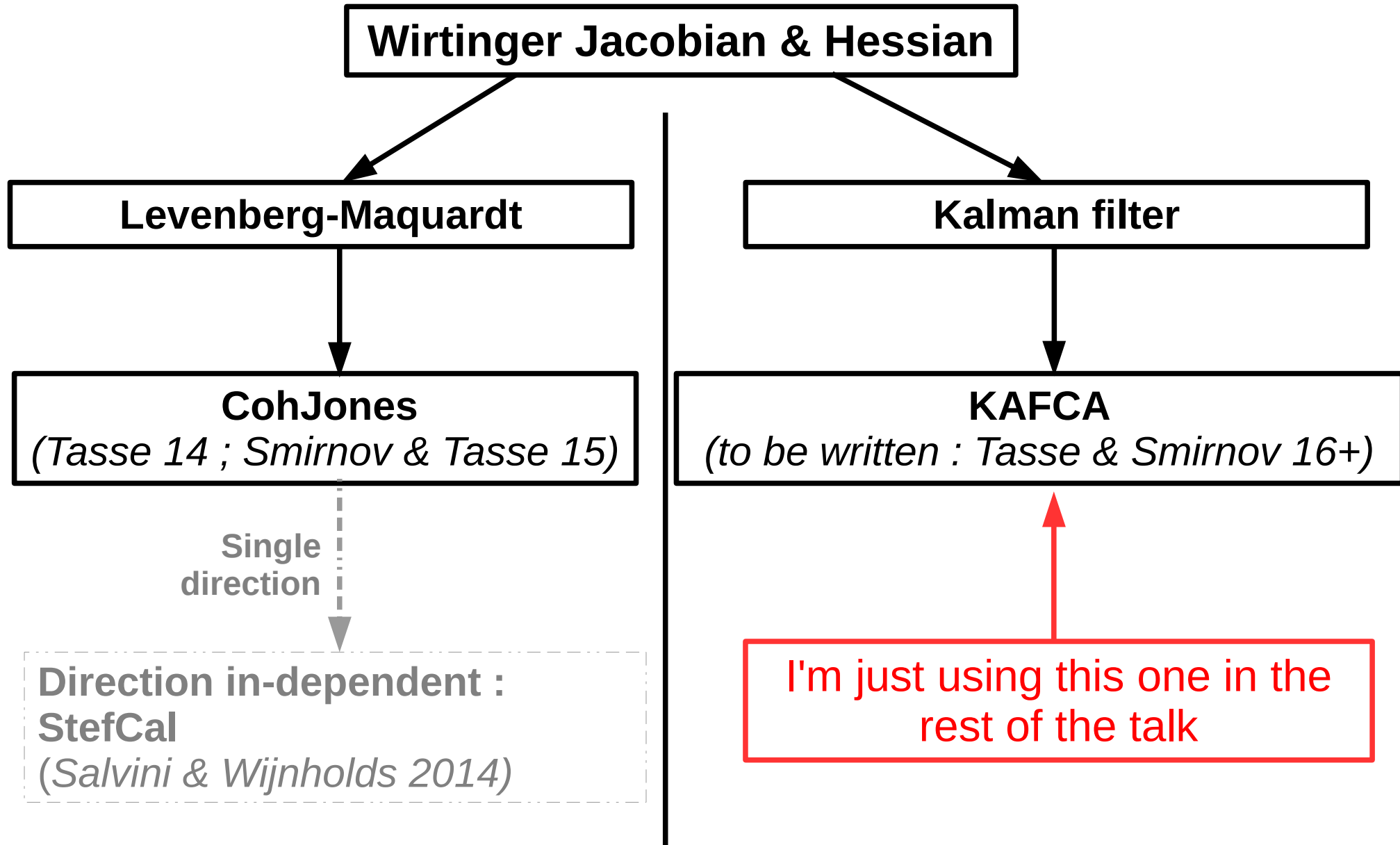
Wirtinger algorithms: software



Wirtinger algorithms: software



Wirtinger algorithms: software



Wirtinger algorithms: software

DDF-pipeline (Tim Shimwell, Martin Hardcastle)

Wirtinger Jacobian & Hessian

Levenberg-
Maquardt

Kalman filter

CohJones
(Tasse 14 ;
Smirnov & Tasse
15)

KAFCAs
(to be written :
Tasse & Smirnov
16+)

DDFacet

dealing with *spacially
discrete* DD-Jones
matrices

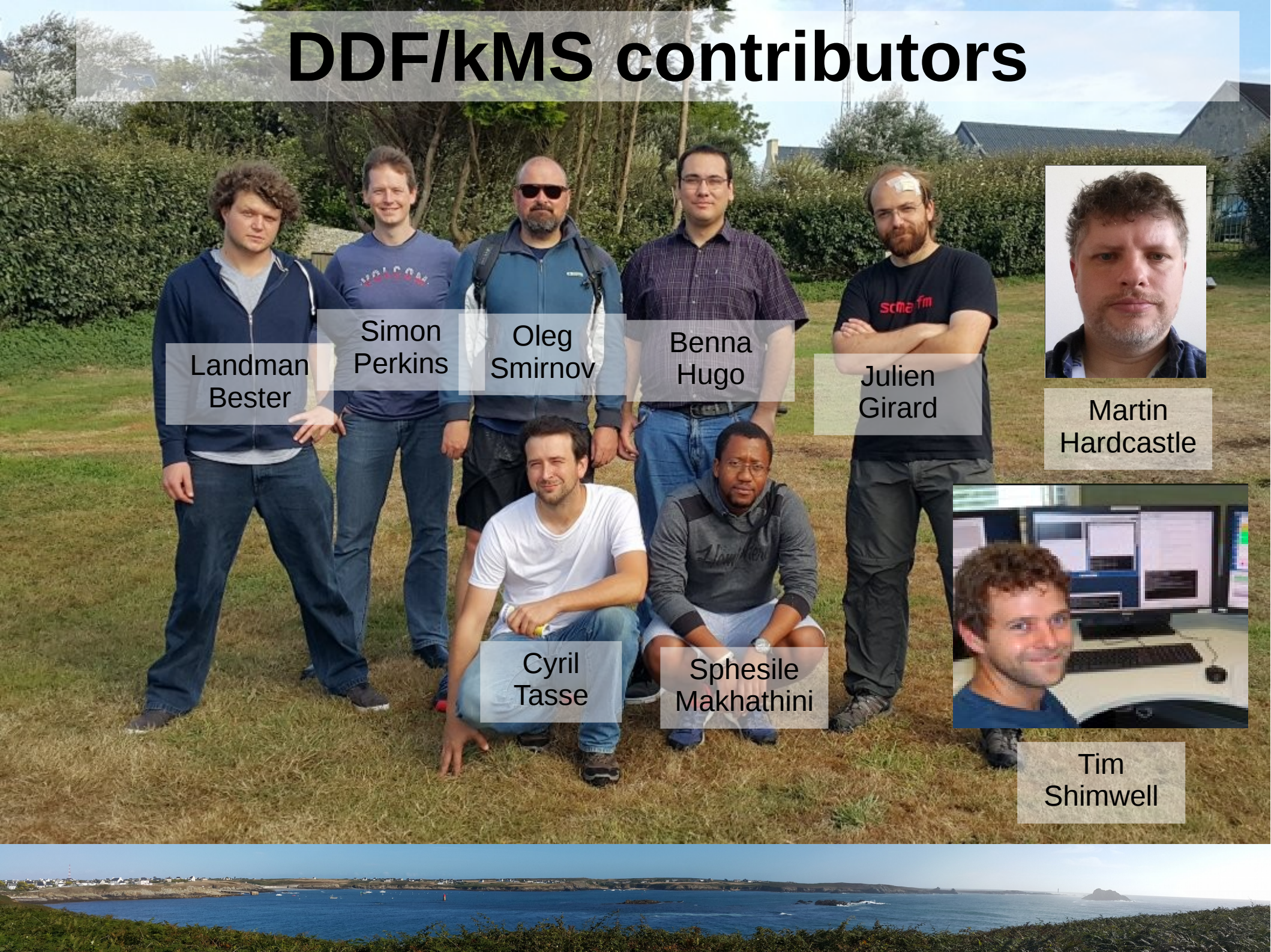
Designed to do Wide-Band
spectral deconvolution taking
generic Beam+Wirtinger
DDE solutions into account

Single direction

Direction in-
dependent : StefCal
(Salvini & Wijnholds
2014)

I'm just using
this one in the
rest of the talk

DDF/kMS contributors



Landman
Bester

Simon
Perkins

Oleg
Smirnov

Benna
Hugo

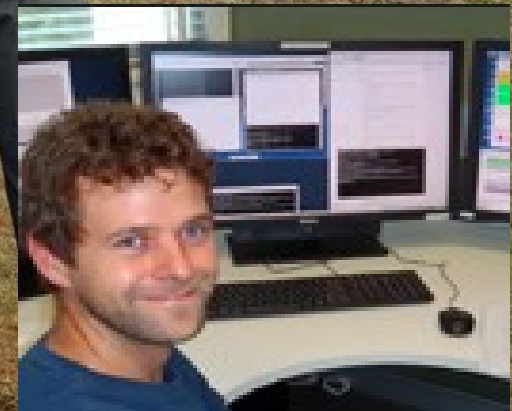
Julien
Girard



Martin
Hardcastle

Cyril
Tasse

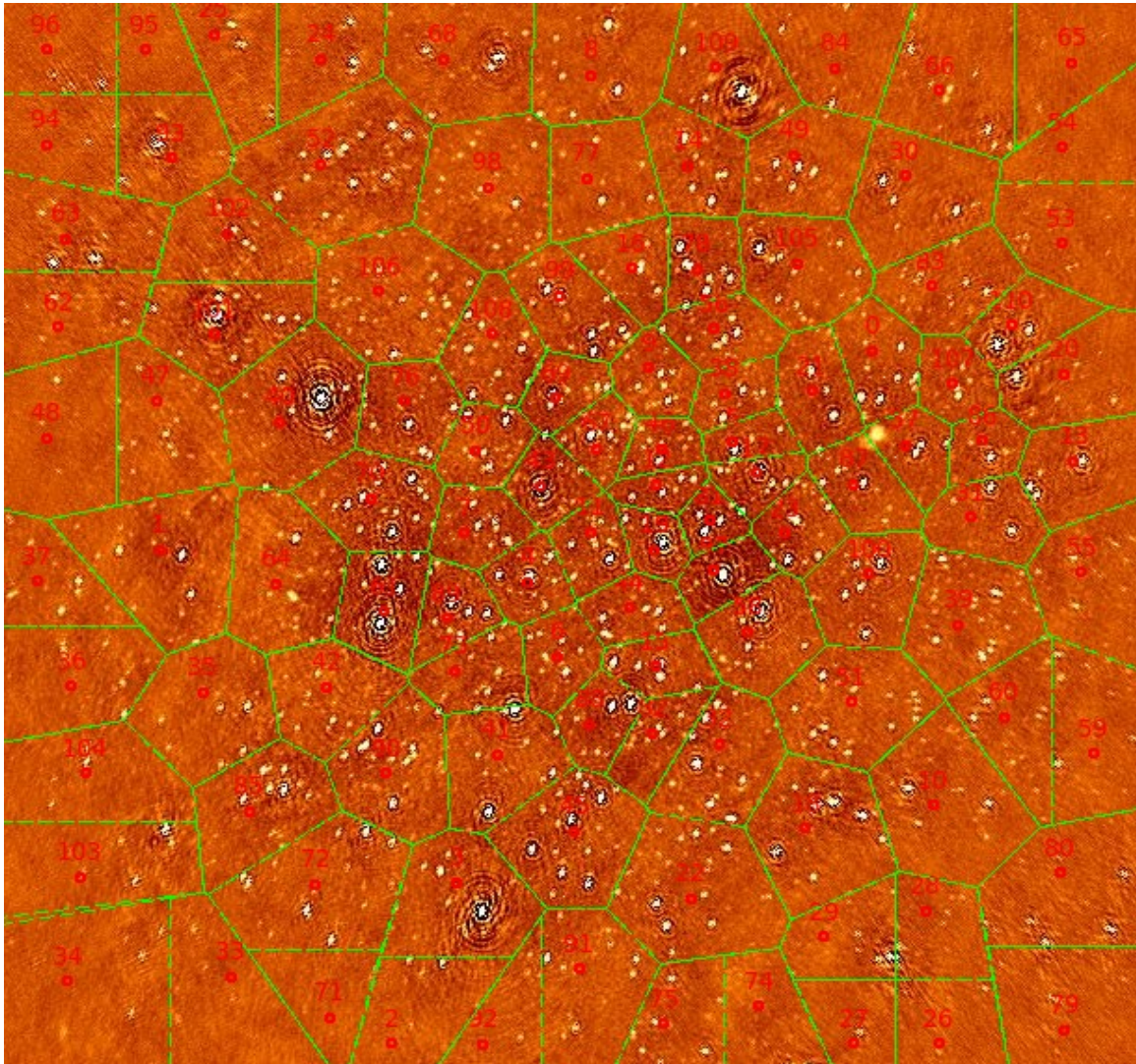
Sphestile
Makhathini



Tim
Shimwell

DDFacet

... A facet based imager



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

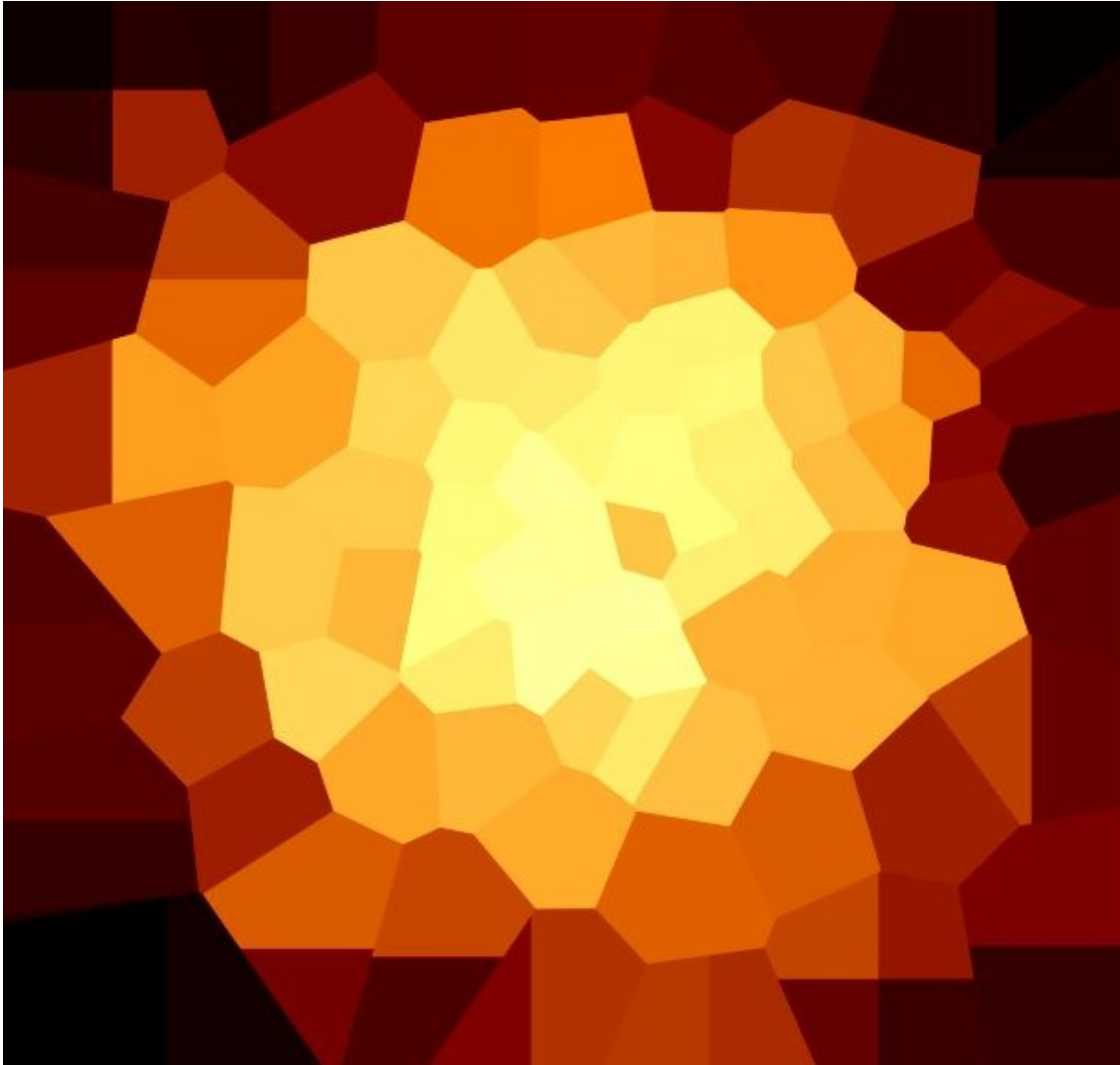
(2) Does full polarisation DDE correction

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

(4) Does tessellated images

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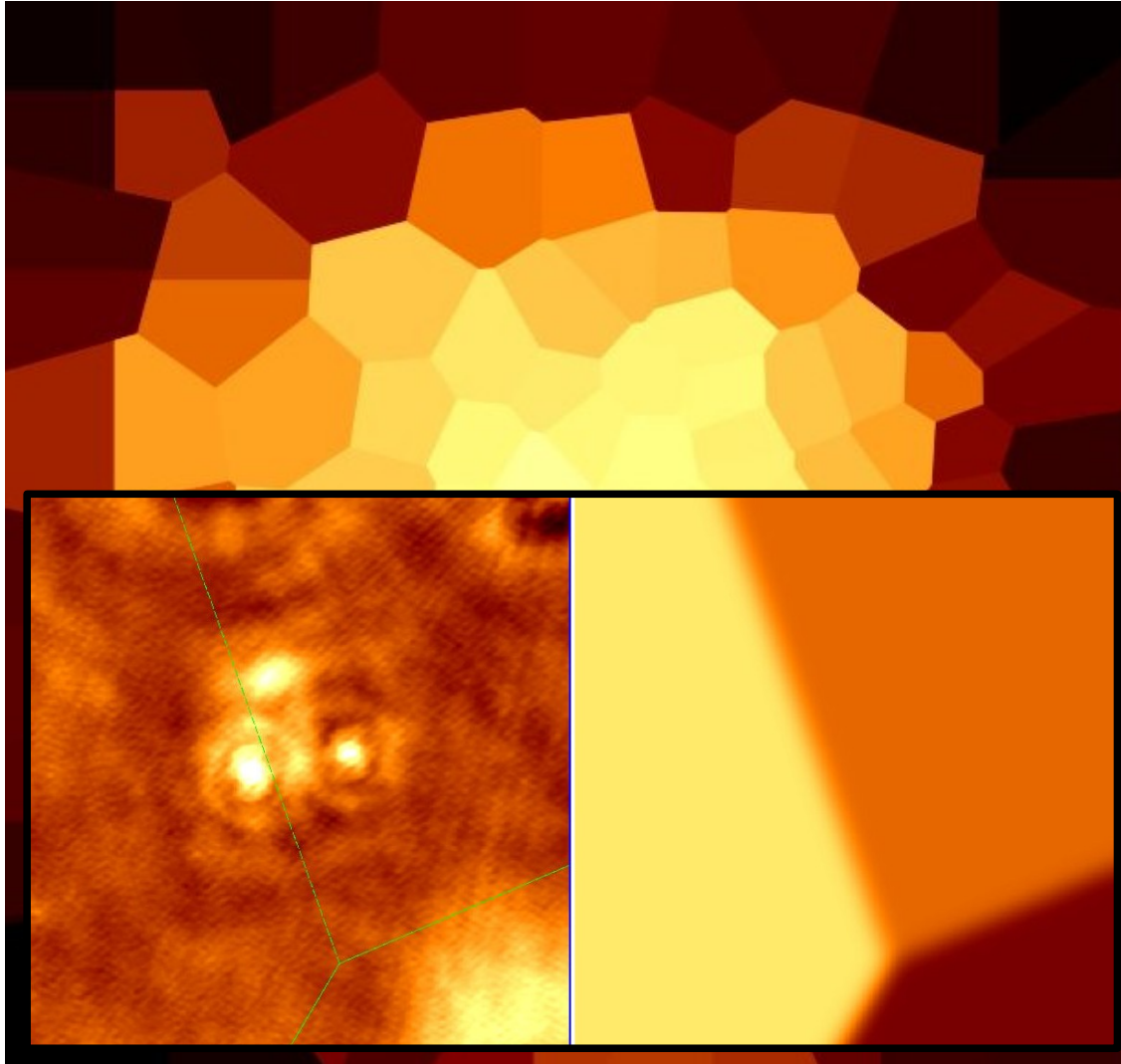
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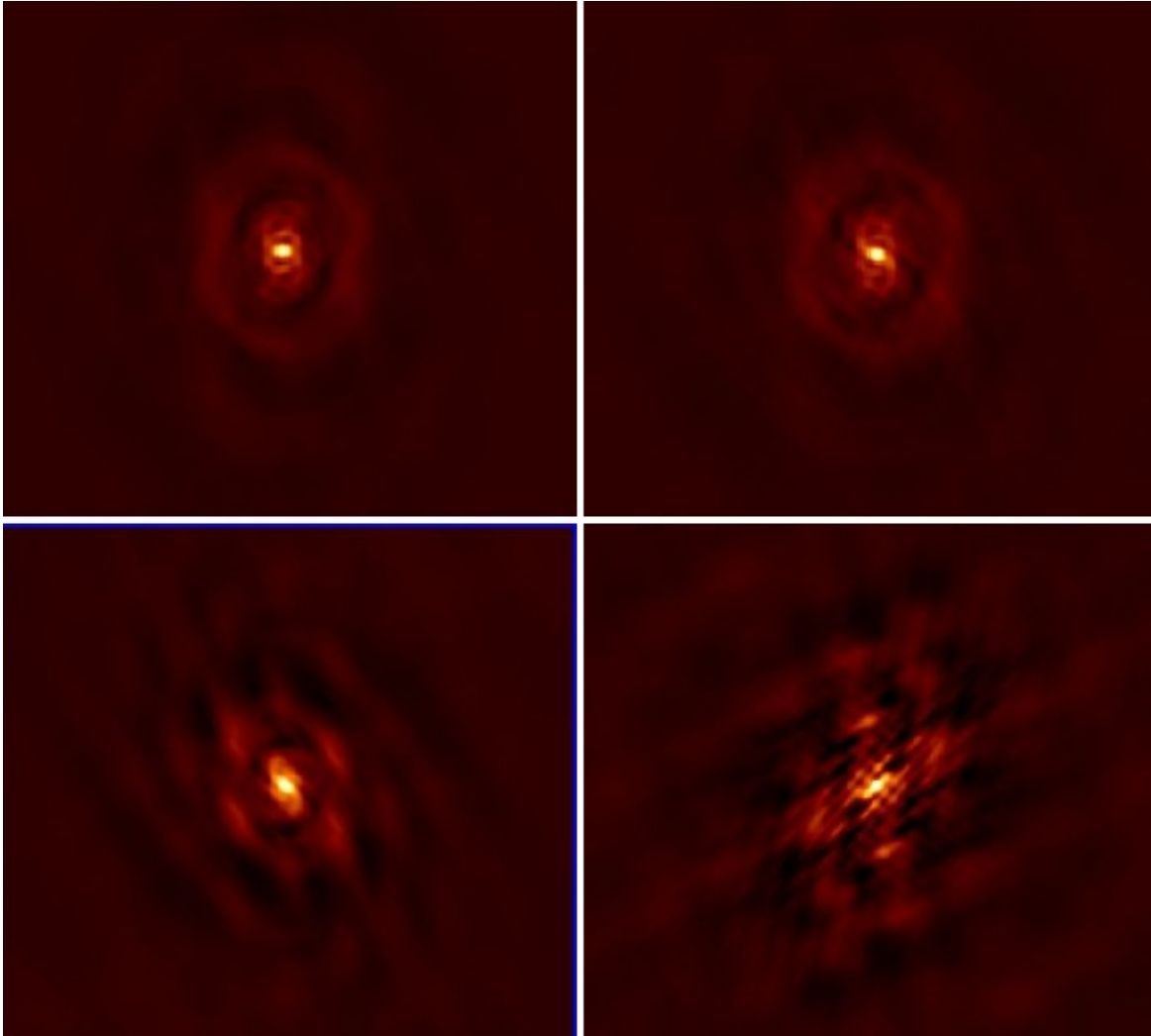
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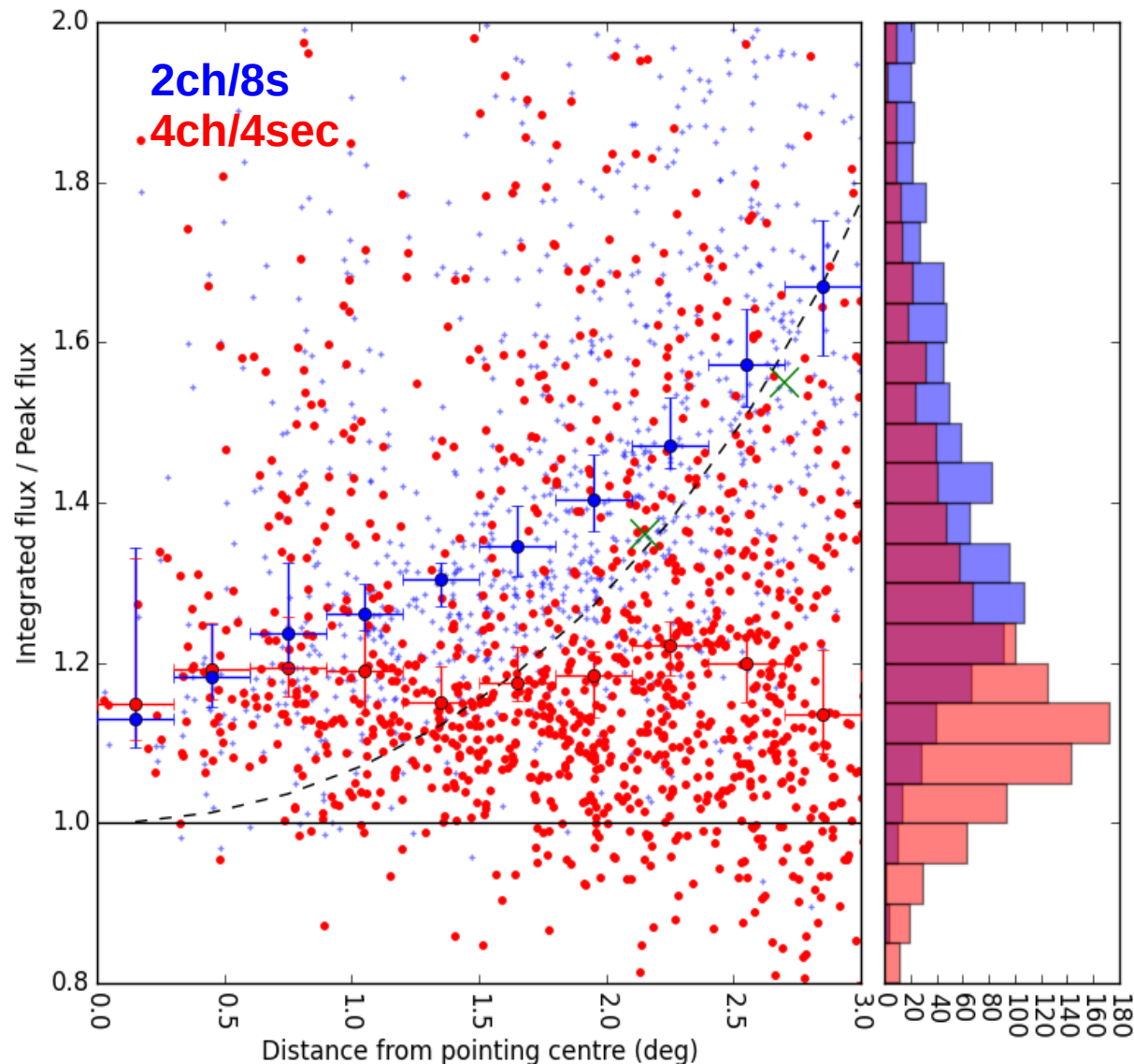
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(7) Takes variable PSF into account
(DDE, Smearing/Decorrelation)

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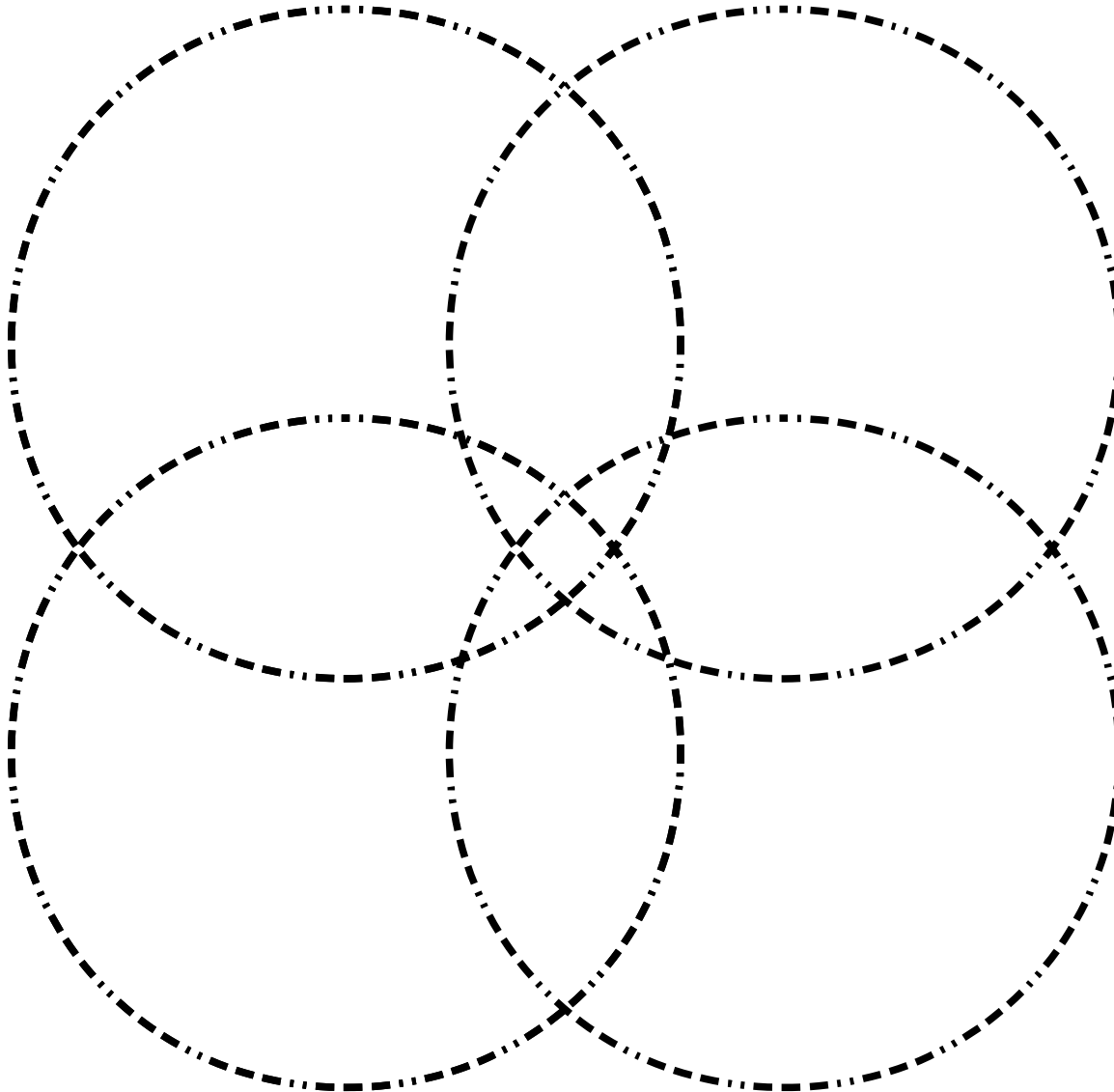
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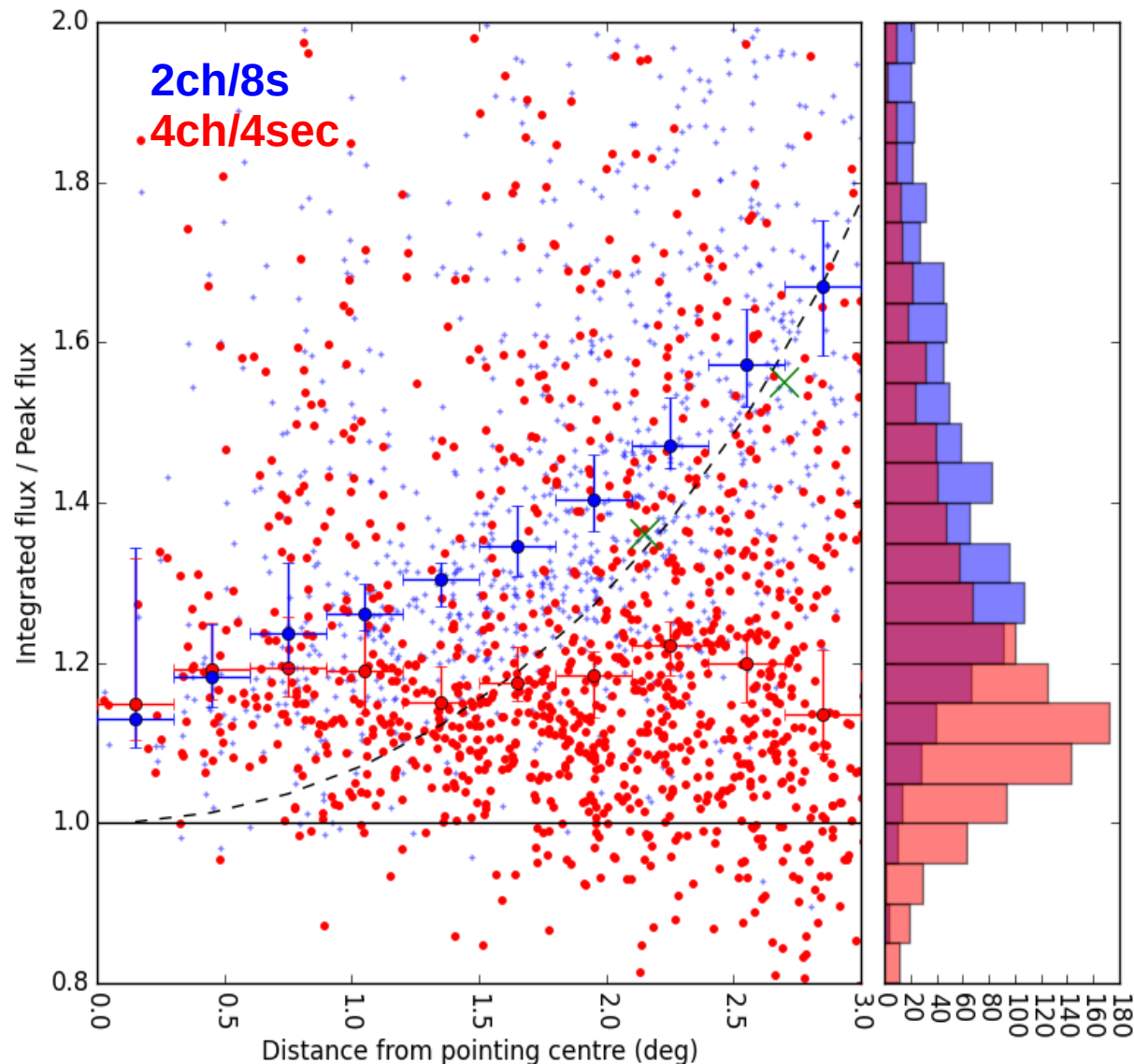
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(8) Mosaicing (!)

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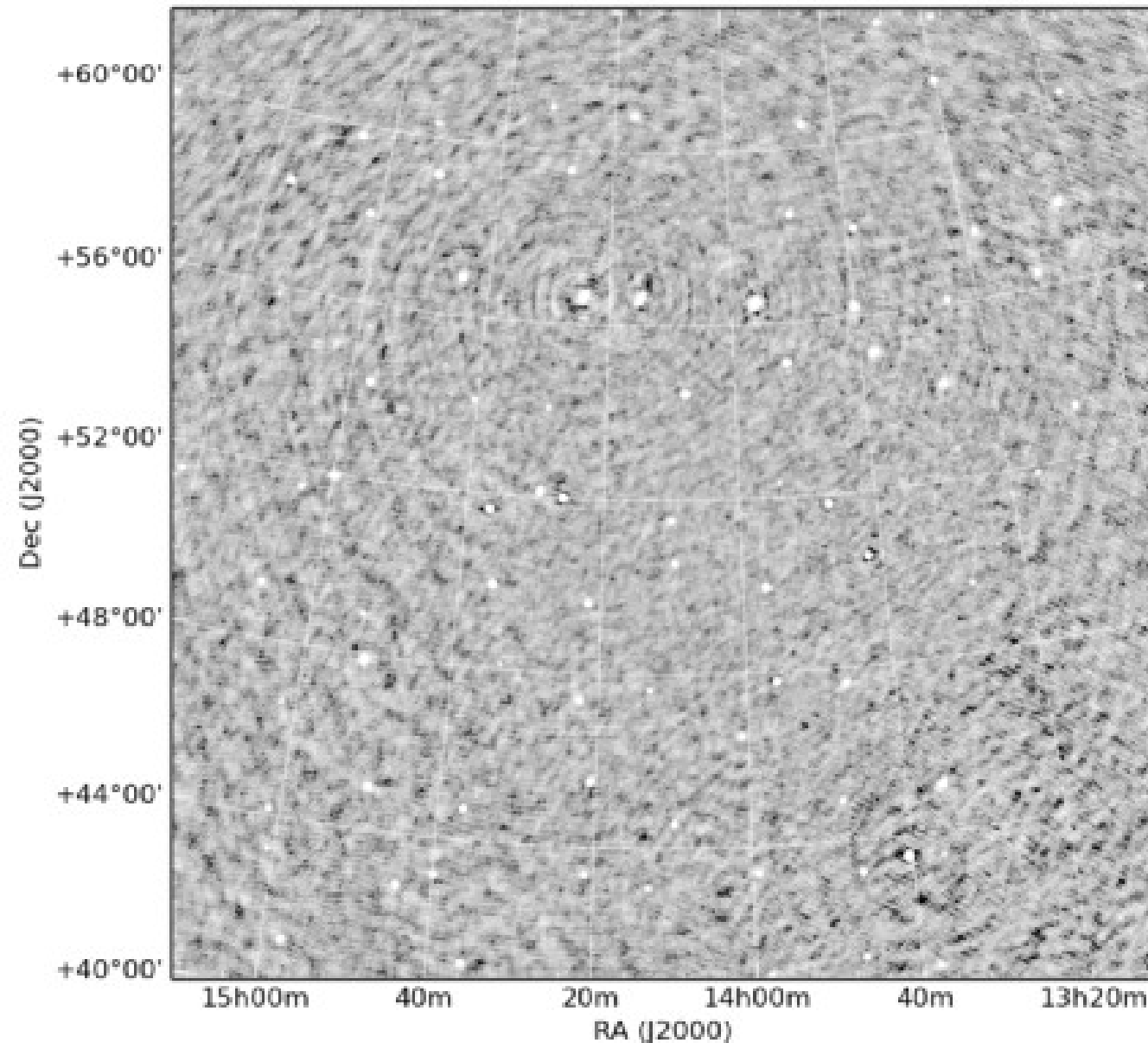
(6) Continuity between facets

(7) Takes variable PSF into account
(DDE, Smearing/Decorrelation)

(8) Mosaicing (!)

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

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



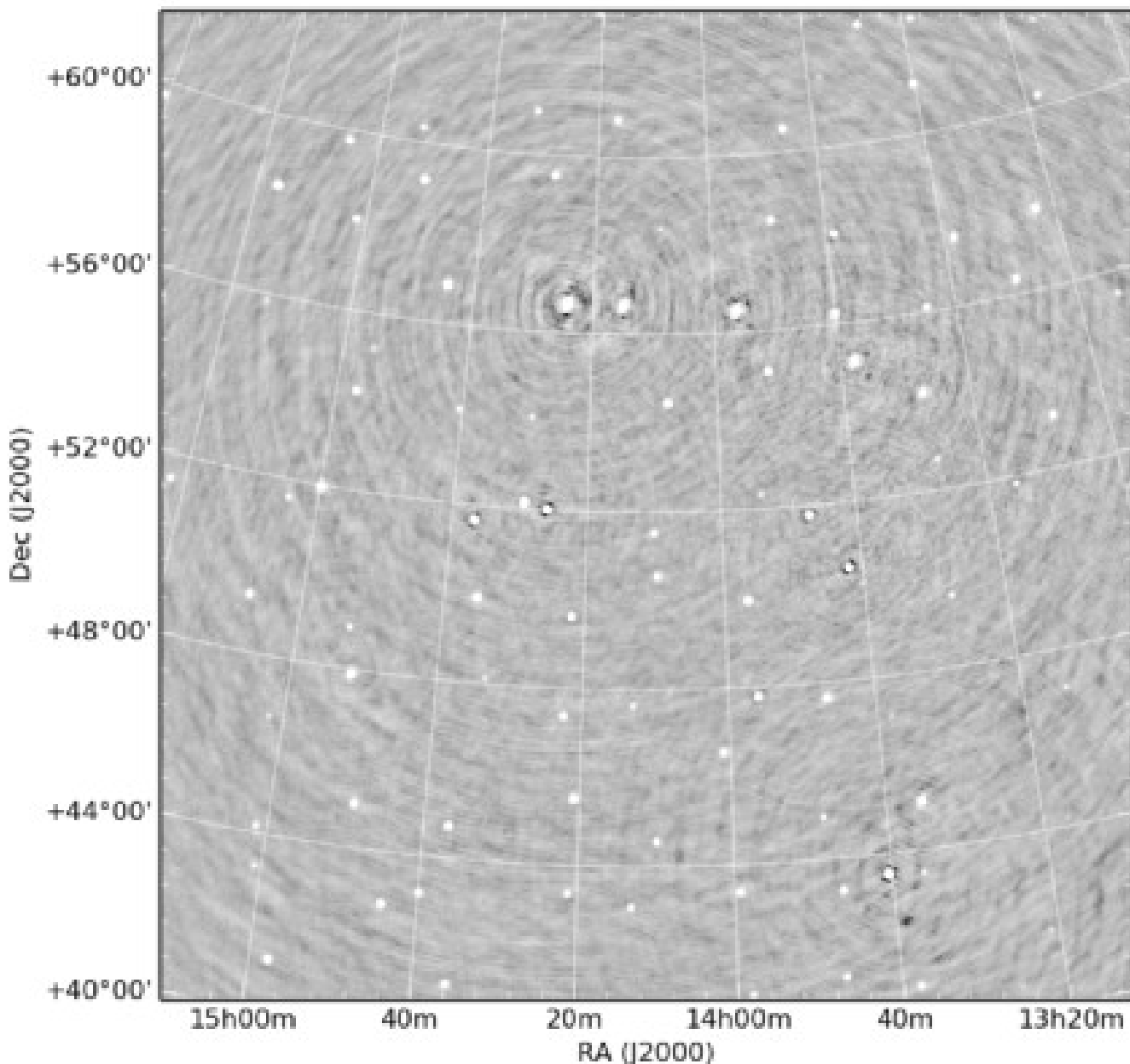
100 sources simulation

- LOFAR LBA layout
 - Fractional bandwidth of ~ 2
 - $S_{50} \sim S^{1.5}$ 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

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



100 sources simulation

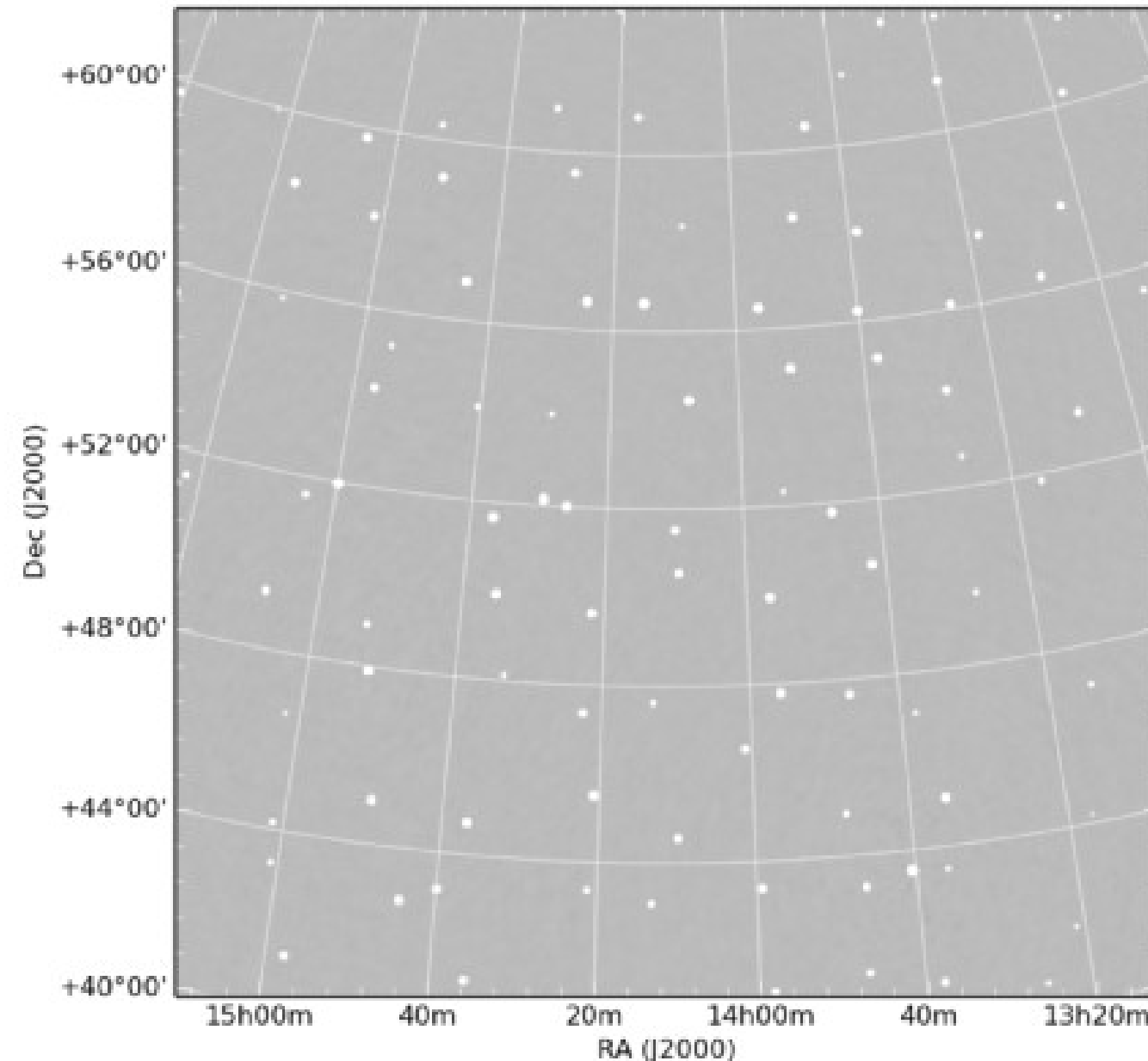
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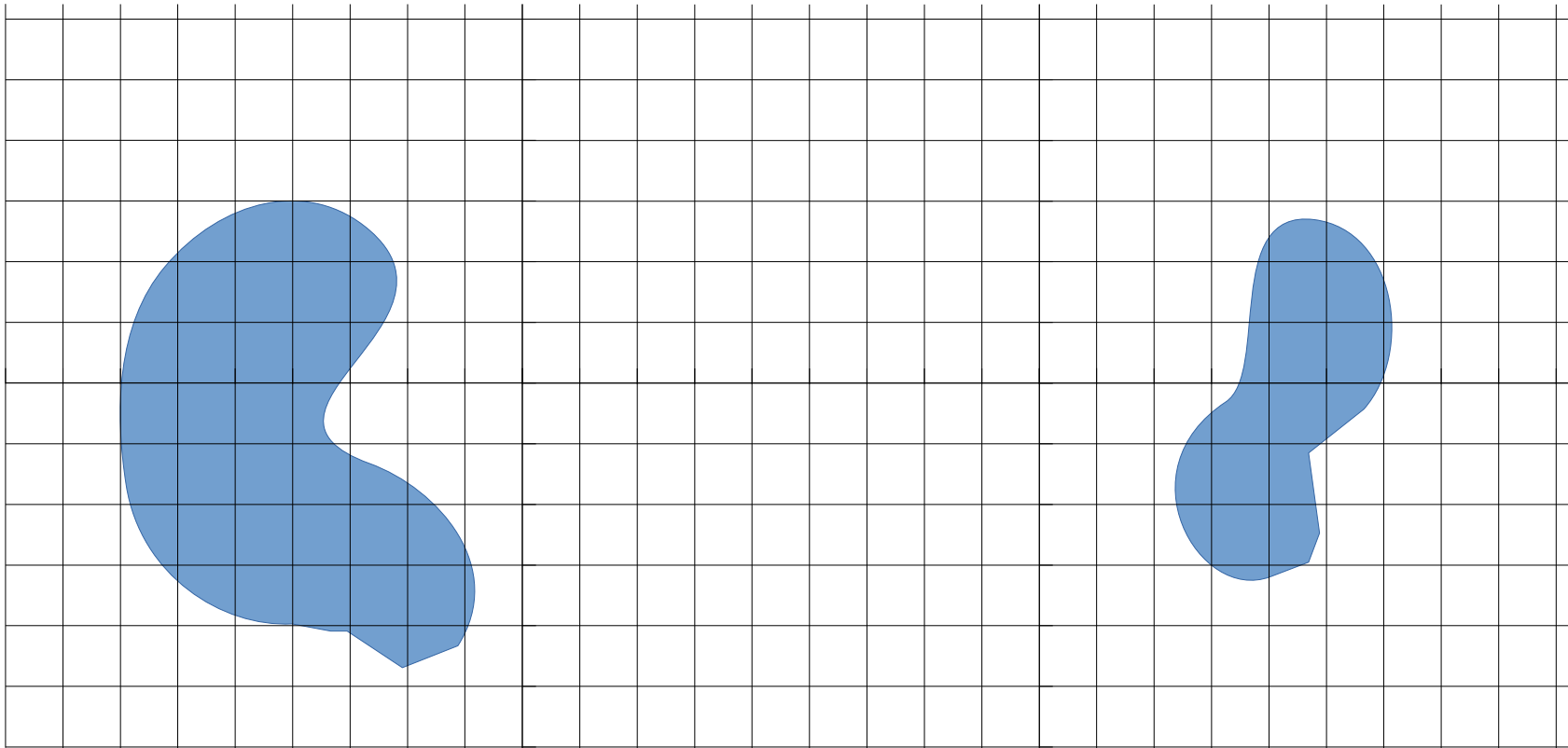
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-

- DDE deconv

- WB-spectral
deconv
(estimating α)

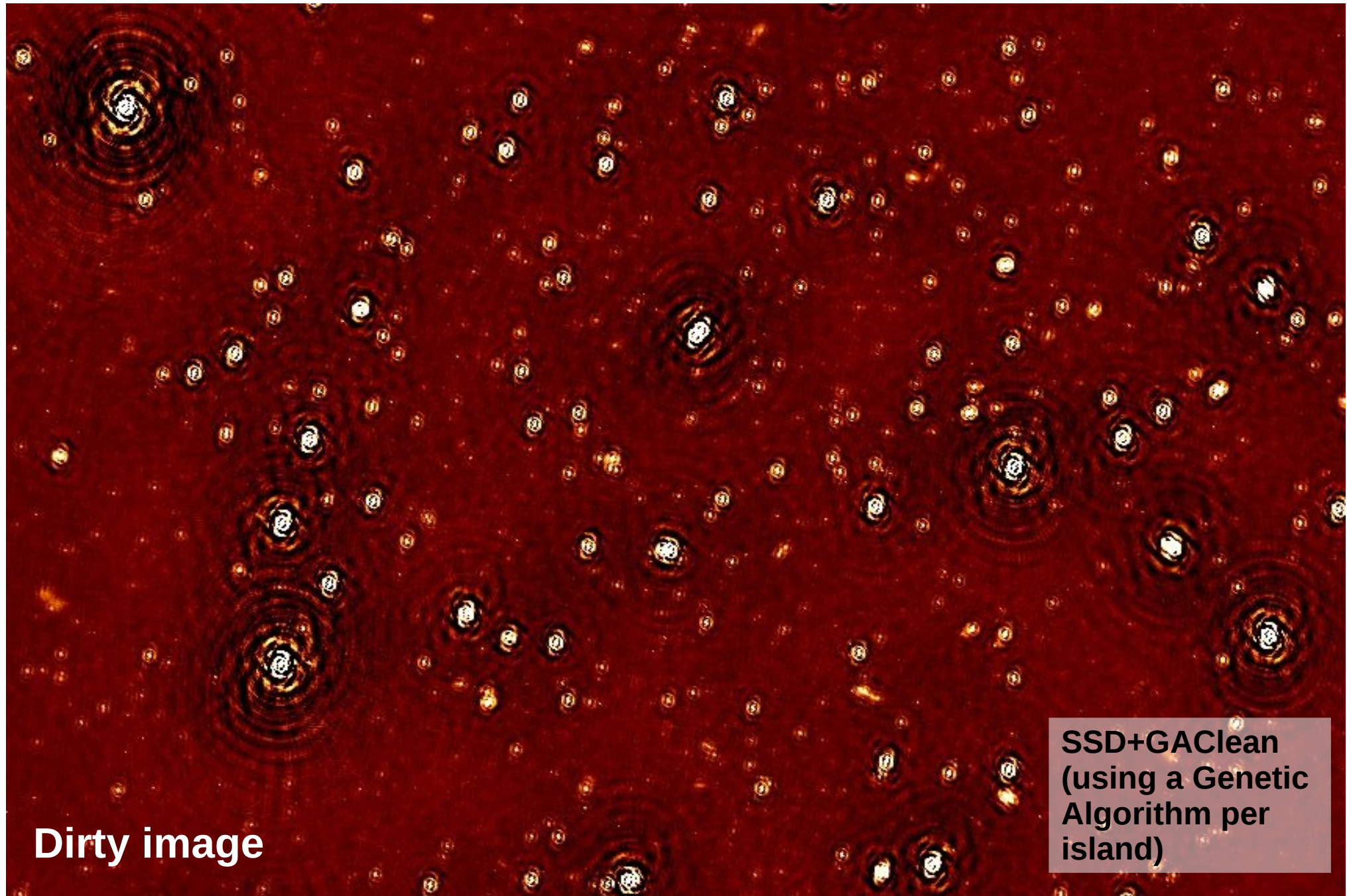


SSD

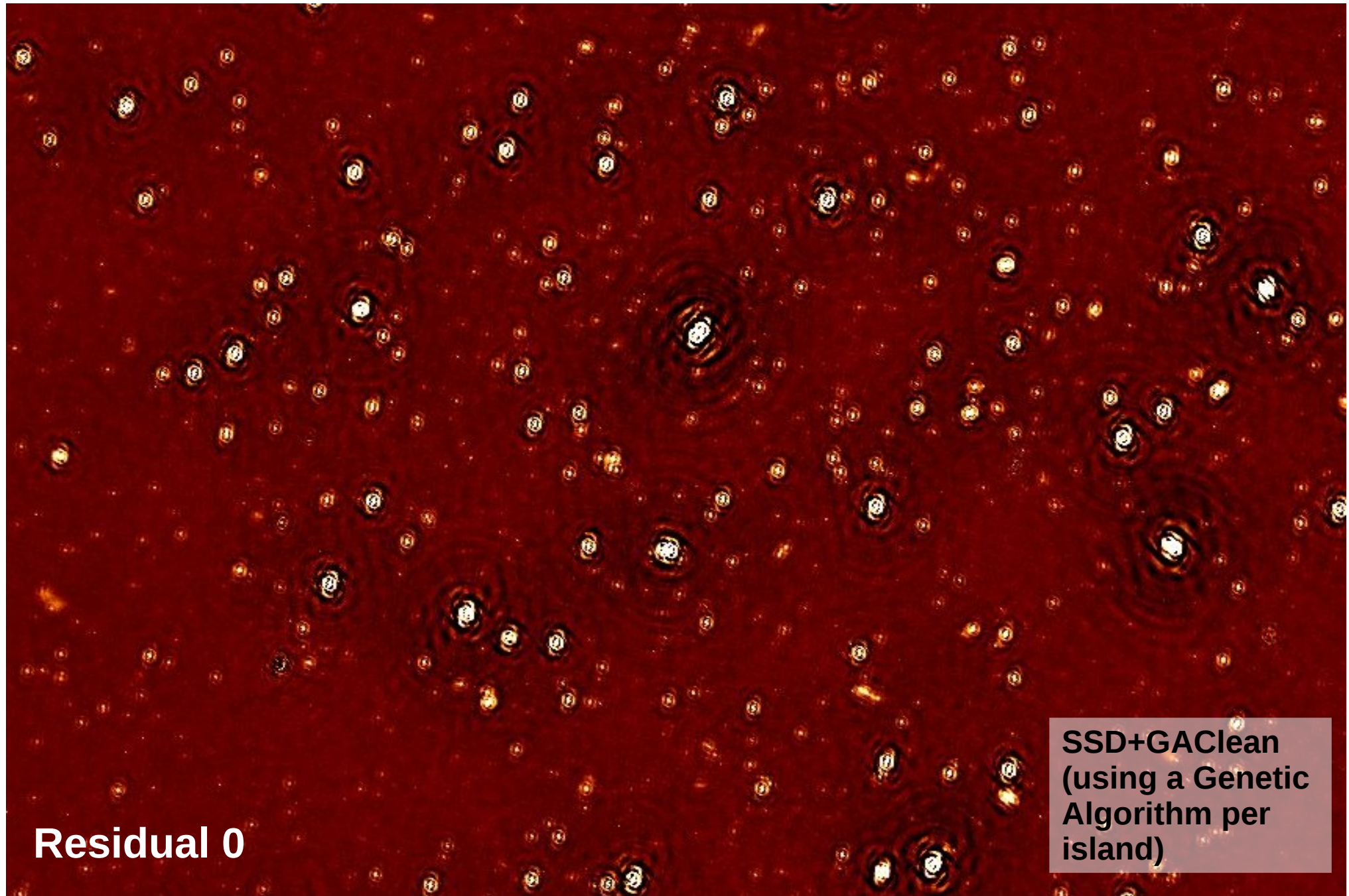


- Also starting from a spectral dirty and (facet-dependent) spectral PSF
- Pixels in SubSpaces (islands) are jointly deconvolved within each island
- Islands are deconvolved independently from each other
- Errors created by ignoring the cross contamination between islands are taken care of by a major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

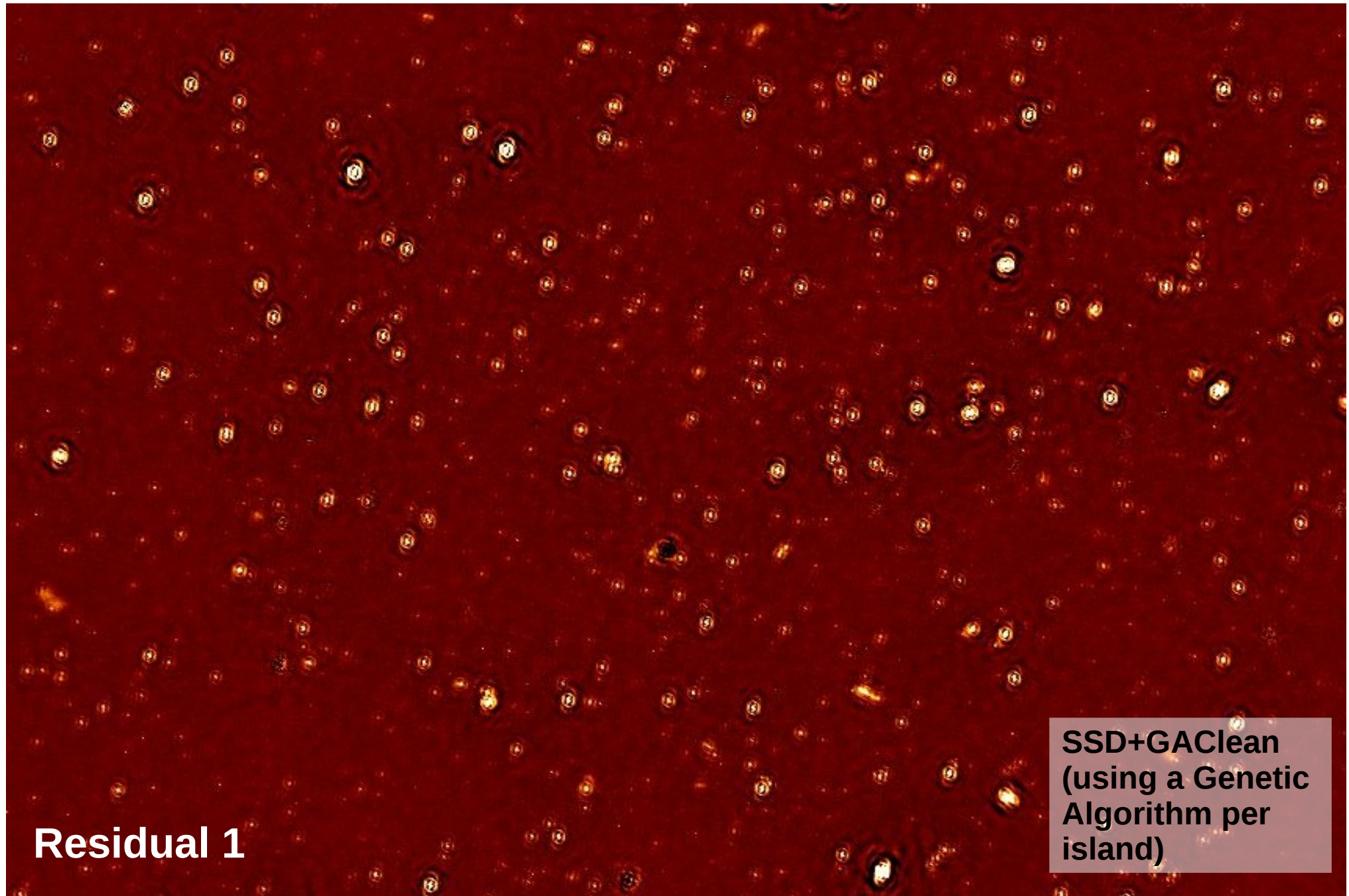
(... an quick intuition on what SSD is)



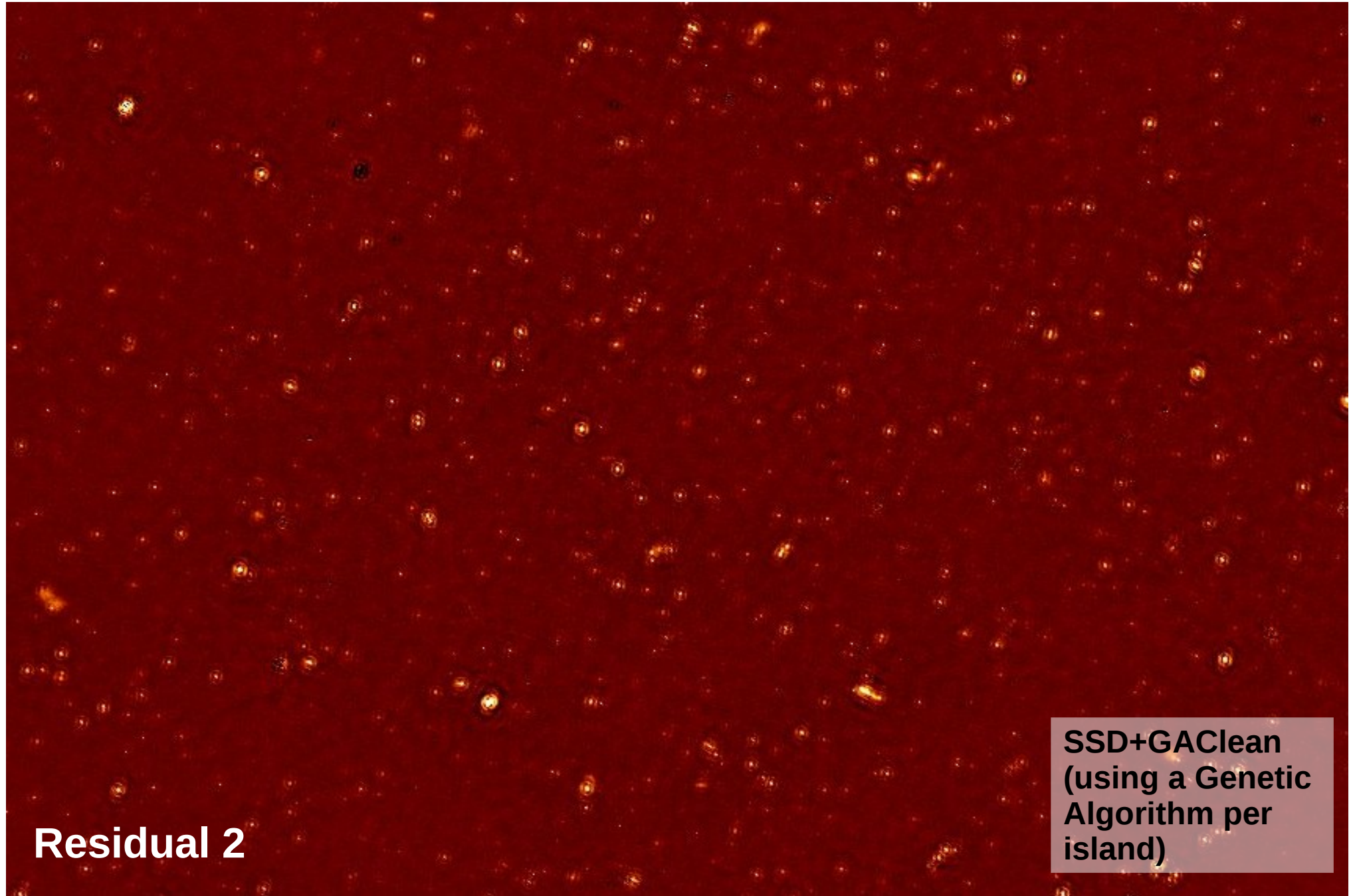
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(... an quick intuition on what SSD is)



(... an quick intuition on what SSD is)



Residual 2

**SSD+GAClean
(using a Genetic
Algorithm per
island)**

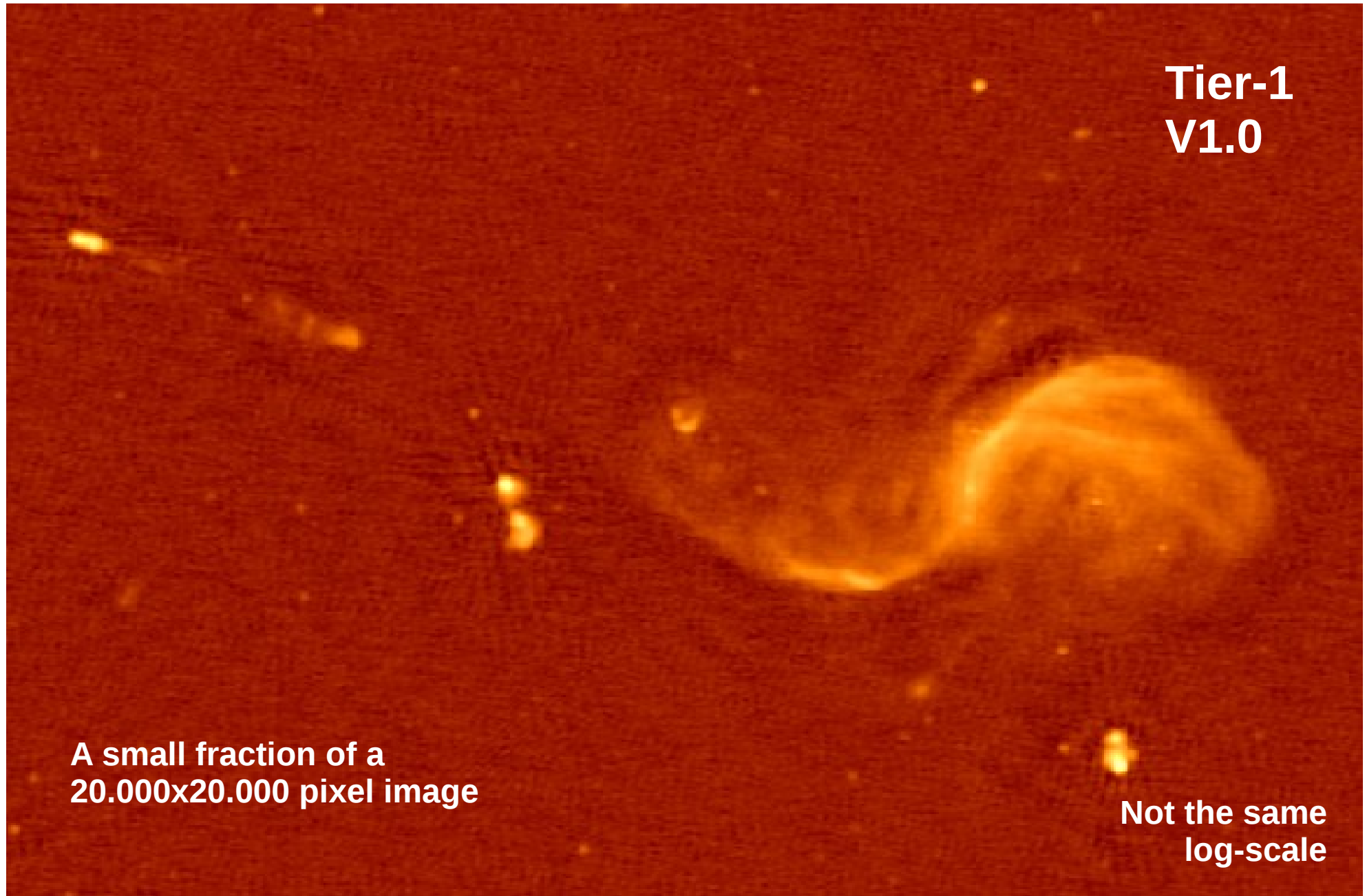
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Residual 3

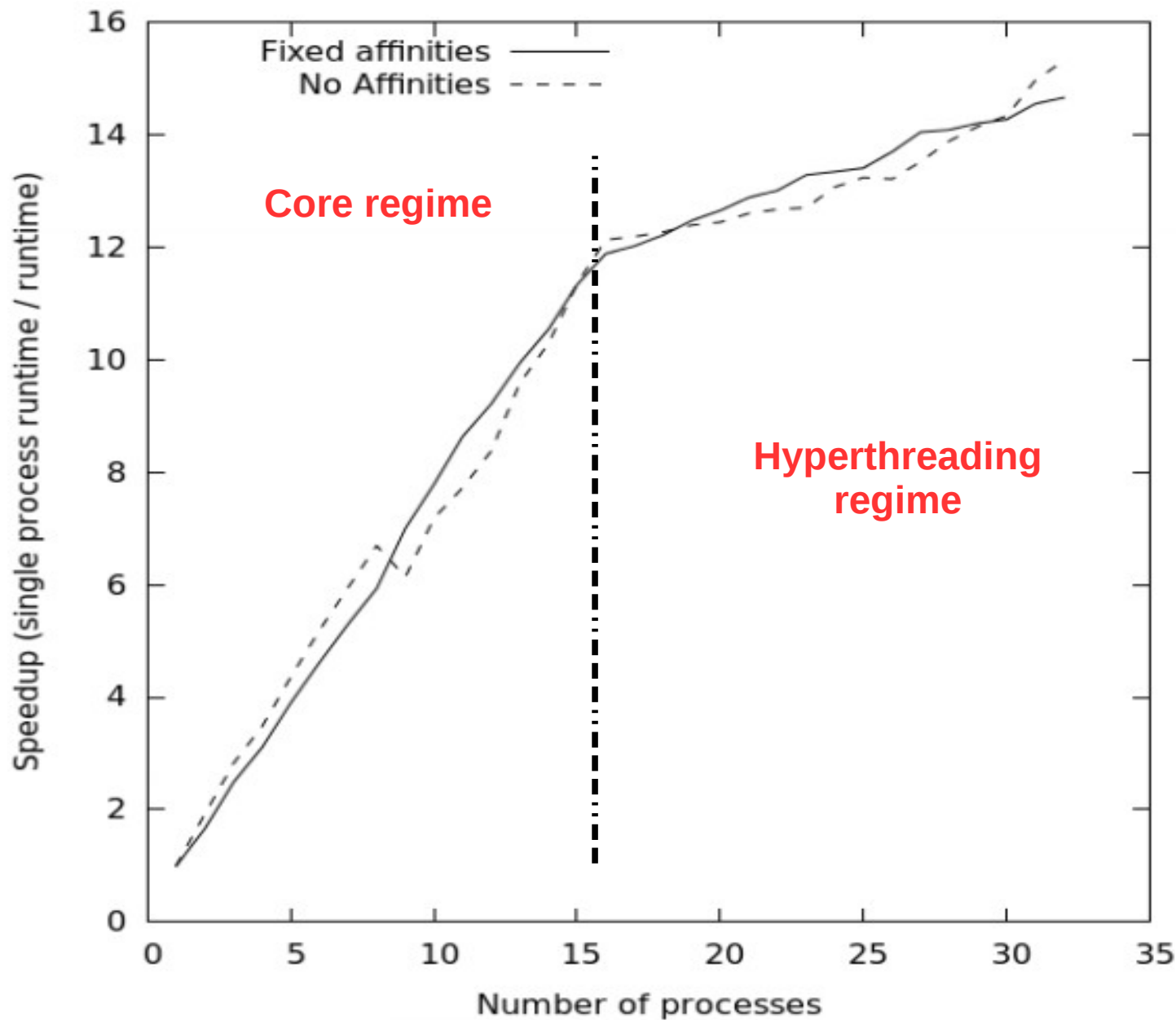
**SSD+GAClean
(using a Genetic
Algorithm per
island)**

SSD+GA-based spectral deconvolution

**... actually quite good at deconvolving complex
extended emission**

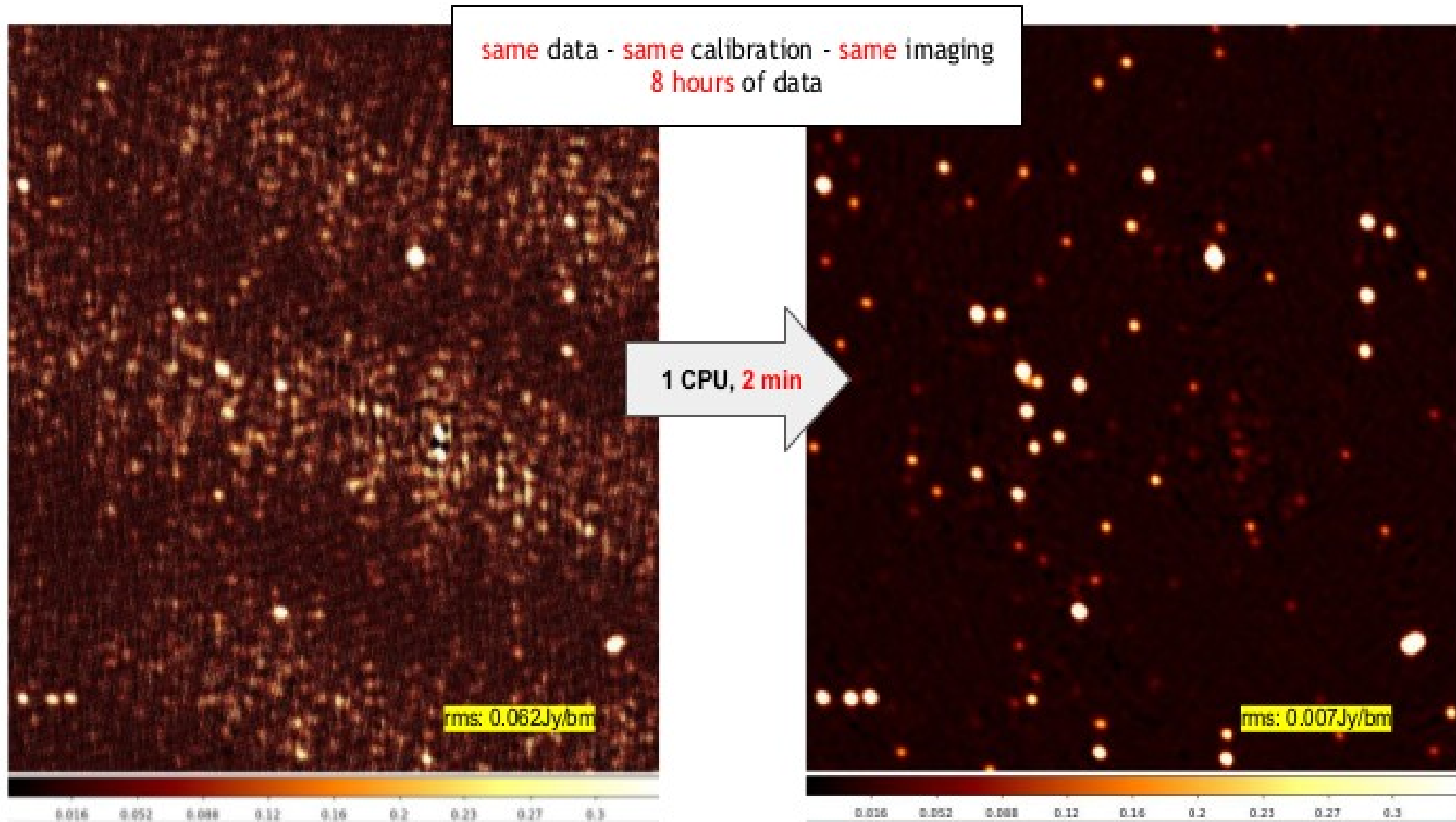


Performance for a VLA dataset



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

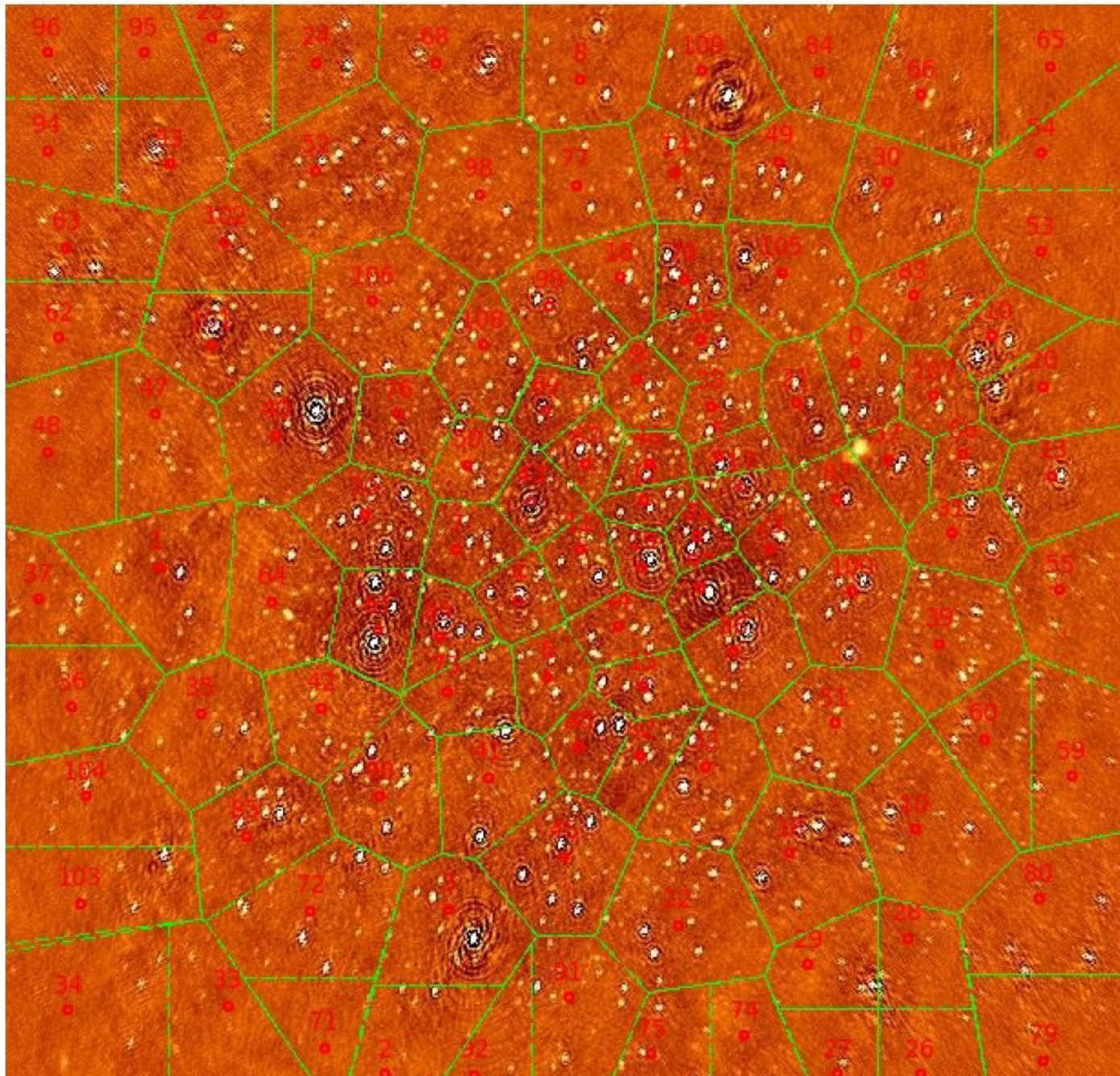
LOFAR Bootes field

48 hours integration, 55 stations, 130-170 MHz

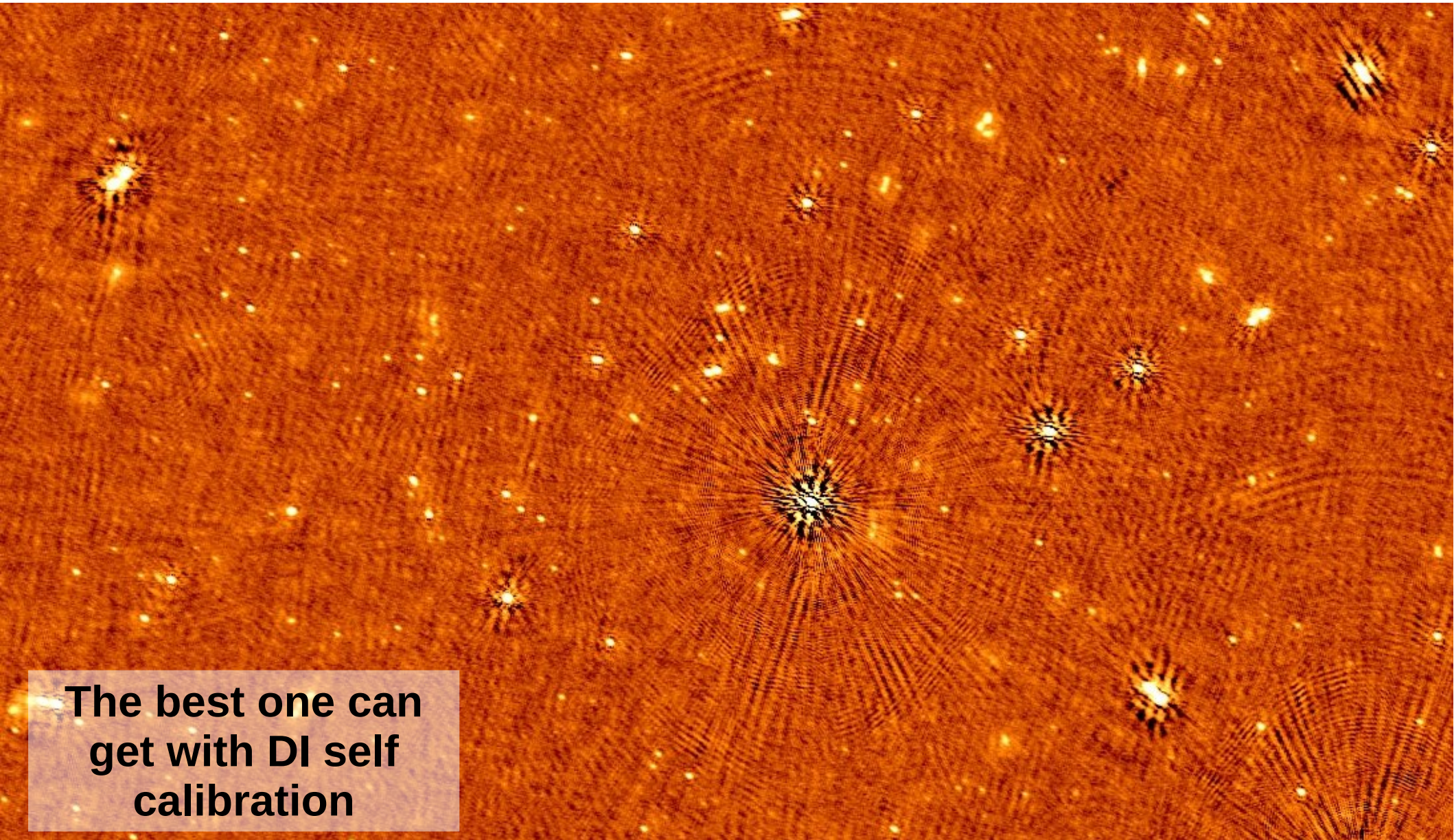
20k x 20k image
FOV : 8 degrees

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

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

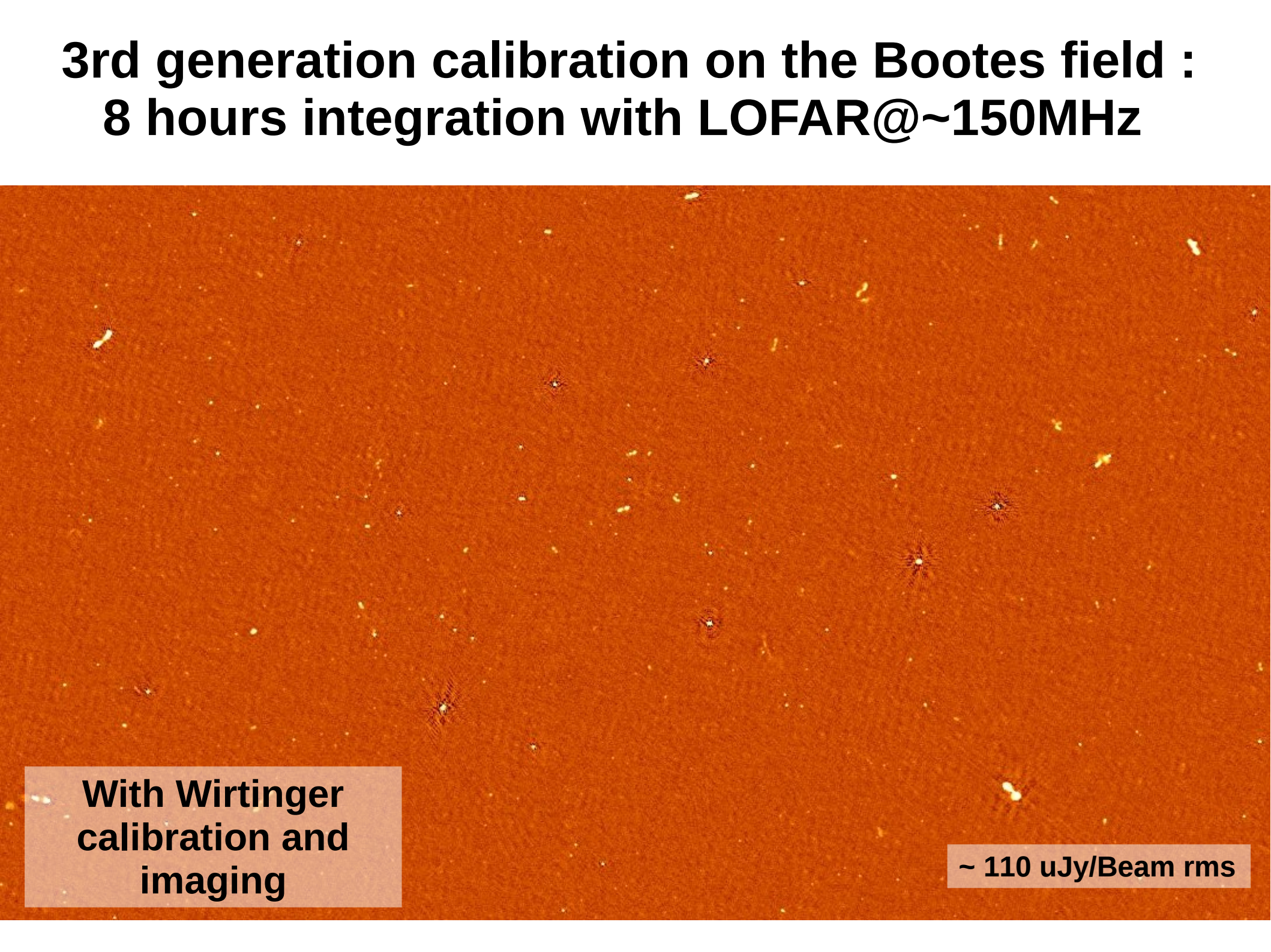


3rd generation calibration on the Bootes field : 8 hours integration with LOFAR@~150MHz



**The best one can
get with DI self
calibration**

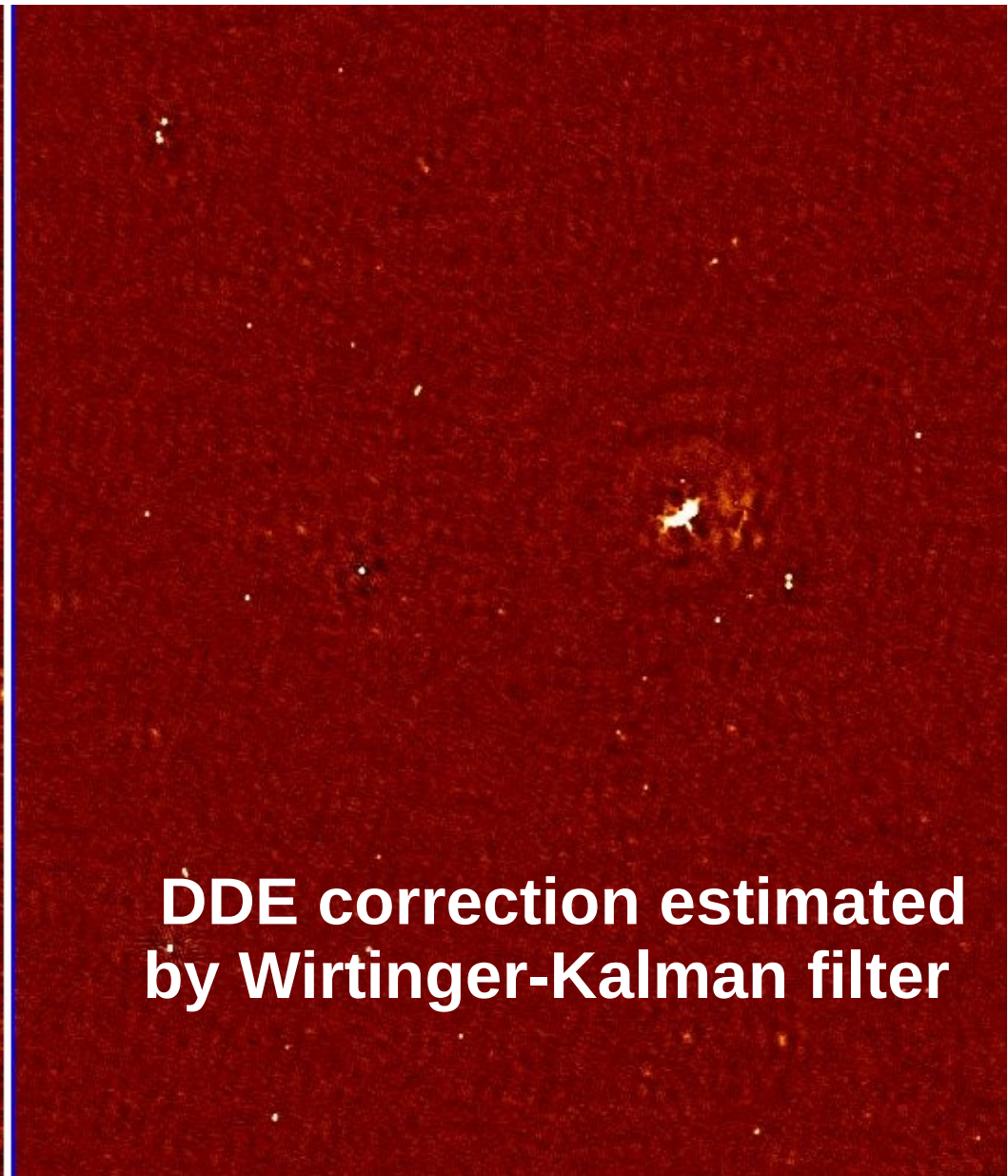
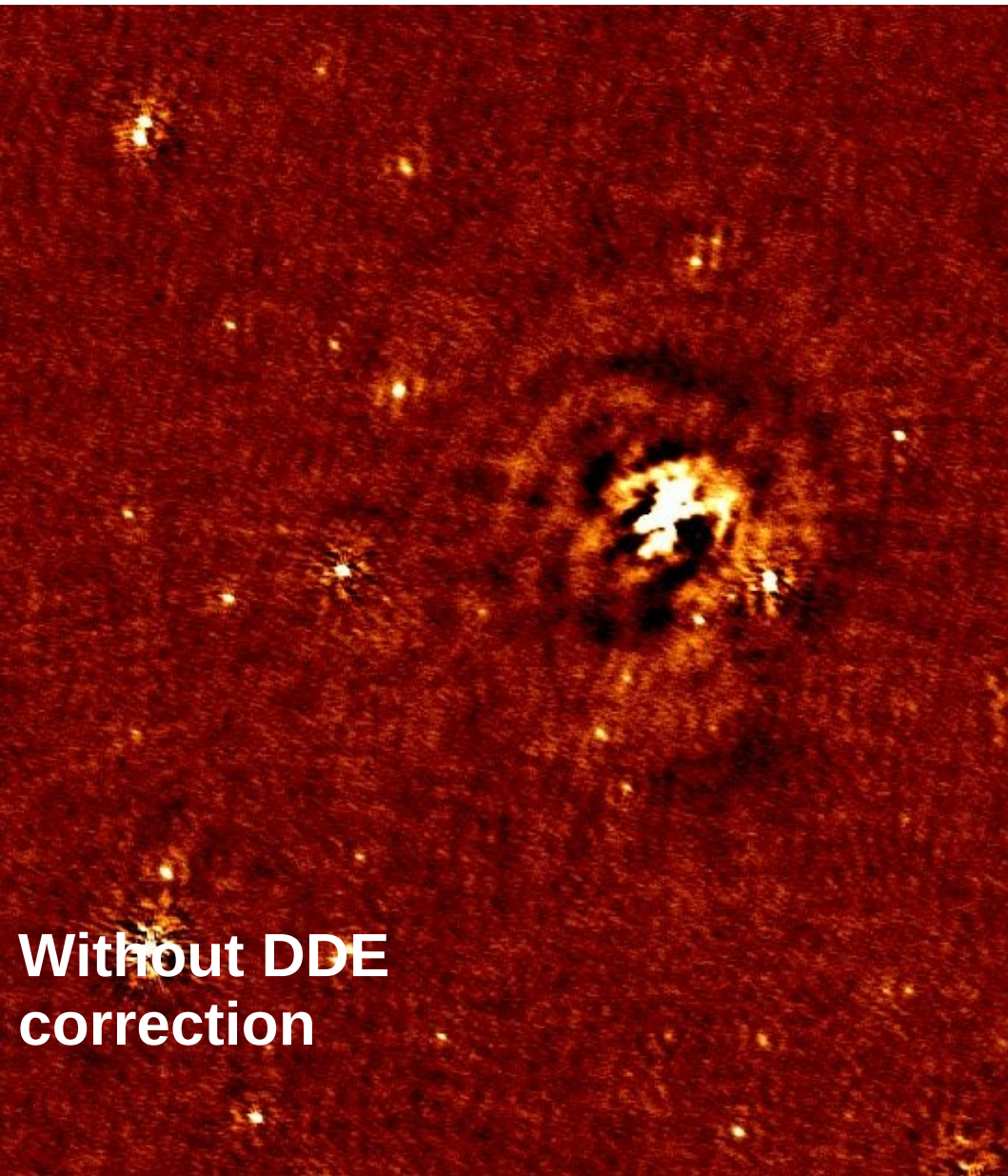
3rd generation calibration on the Bootes field : 8 hours integration with LOFAR@~150MHz

A radio map of the Bootes field at 150 MHz, showing a dense distribution of sources. The background is a noisy orange-brown color. Numerous bright, compact sources are visible, many of which exhibit a characteristic four-lobed pattern, likely due to the LOFAR interferometer's sampling. The sources vary in brightness and size, with some being very compact and others more extended.

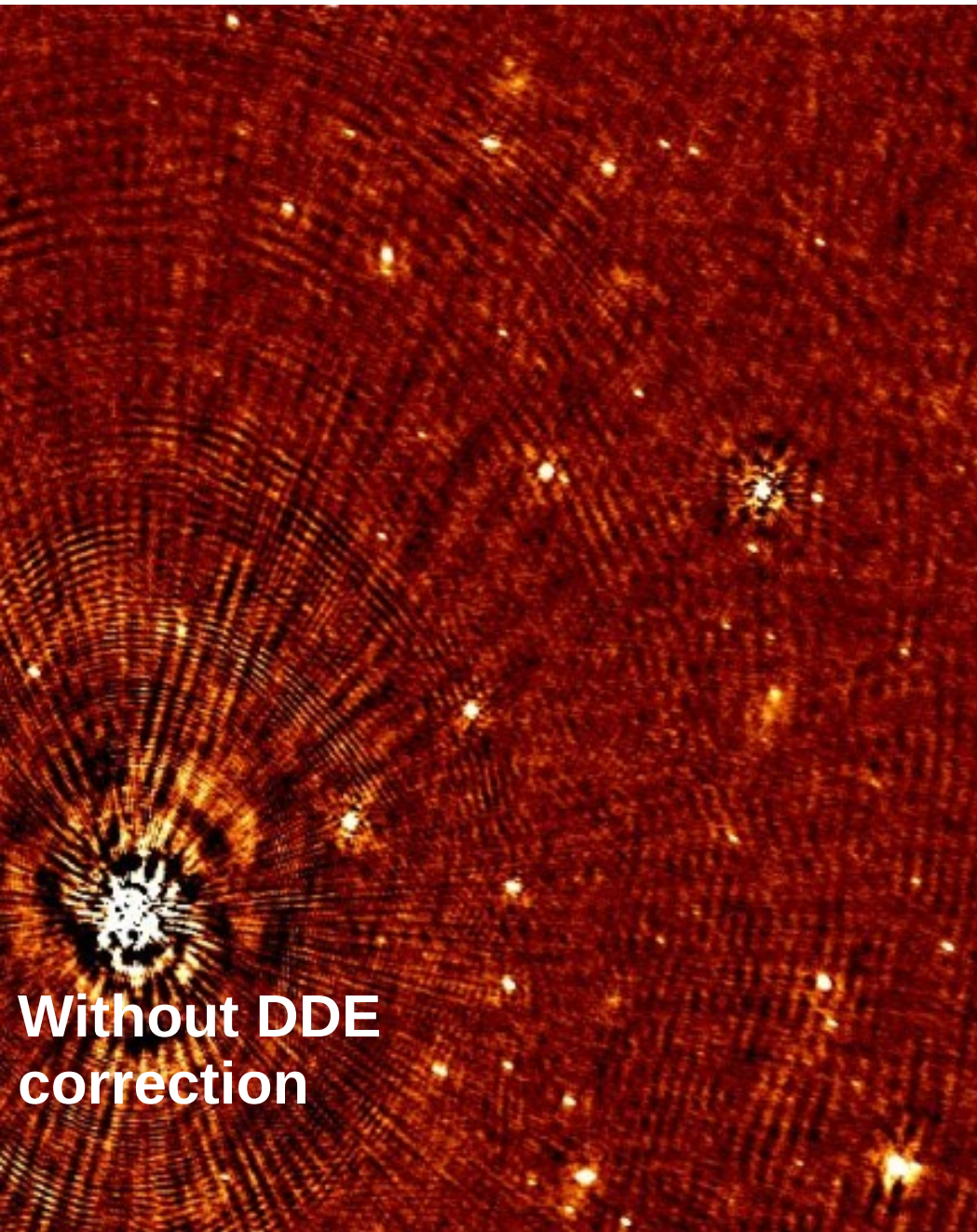
**With Wirtinger
calibration and
imaging**

~ 110 μ Jy/Beam rms

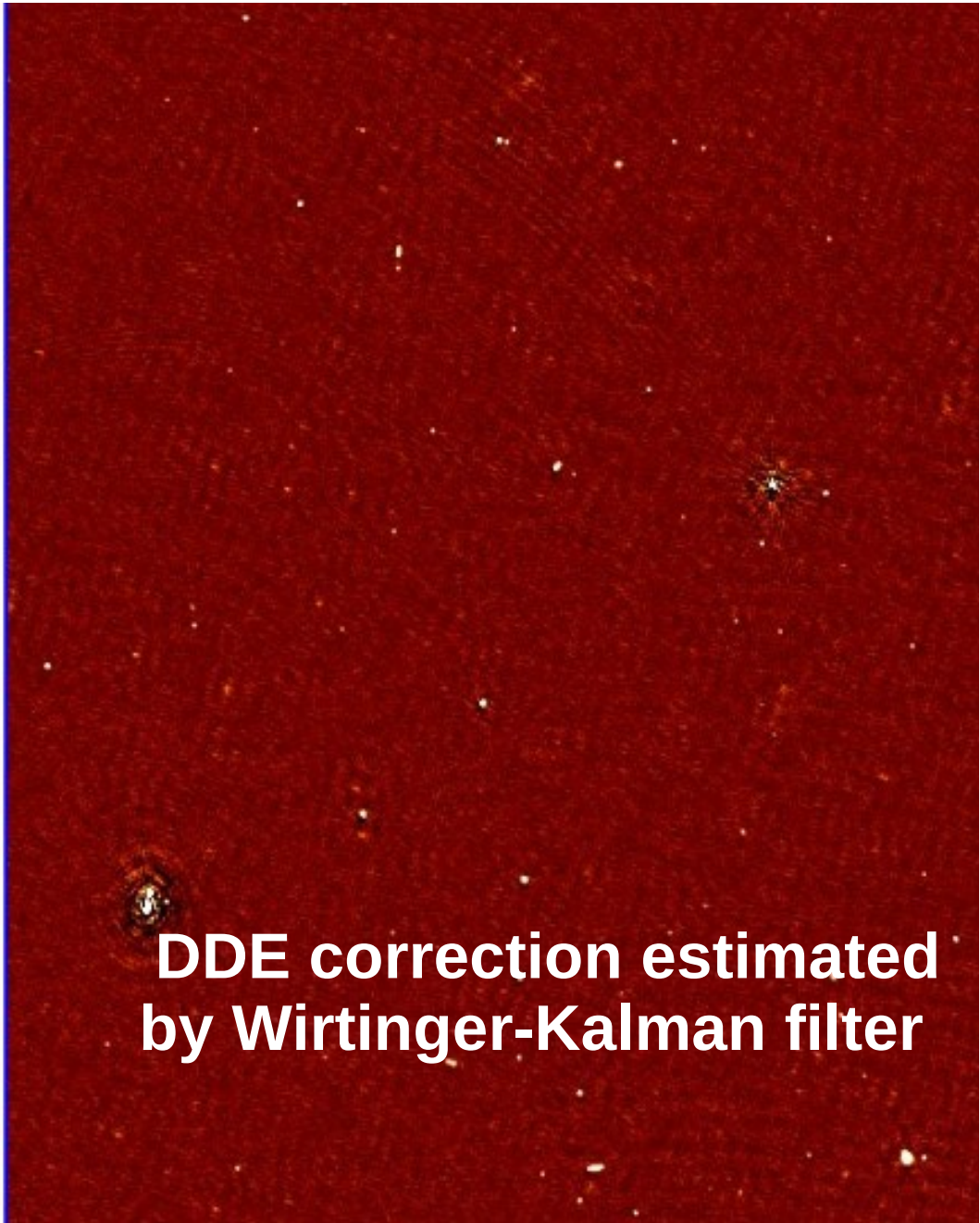
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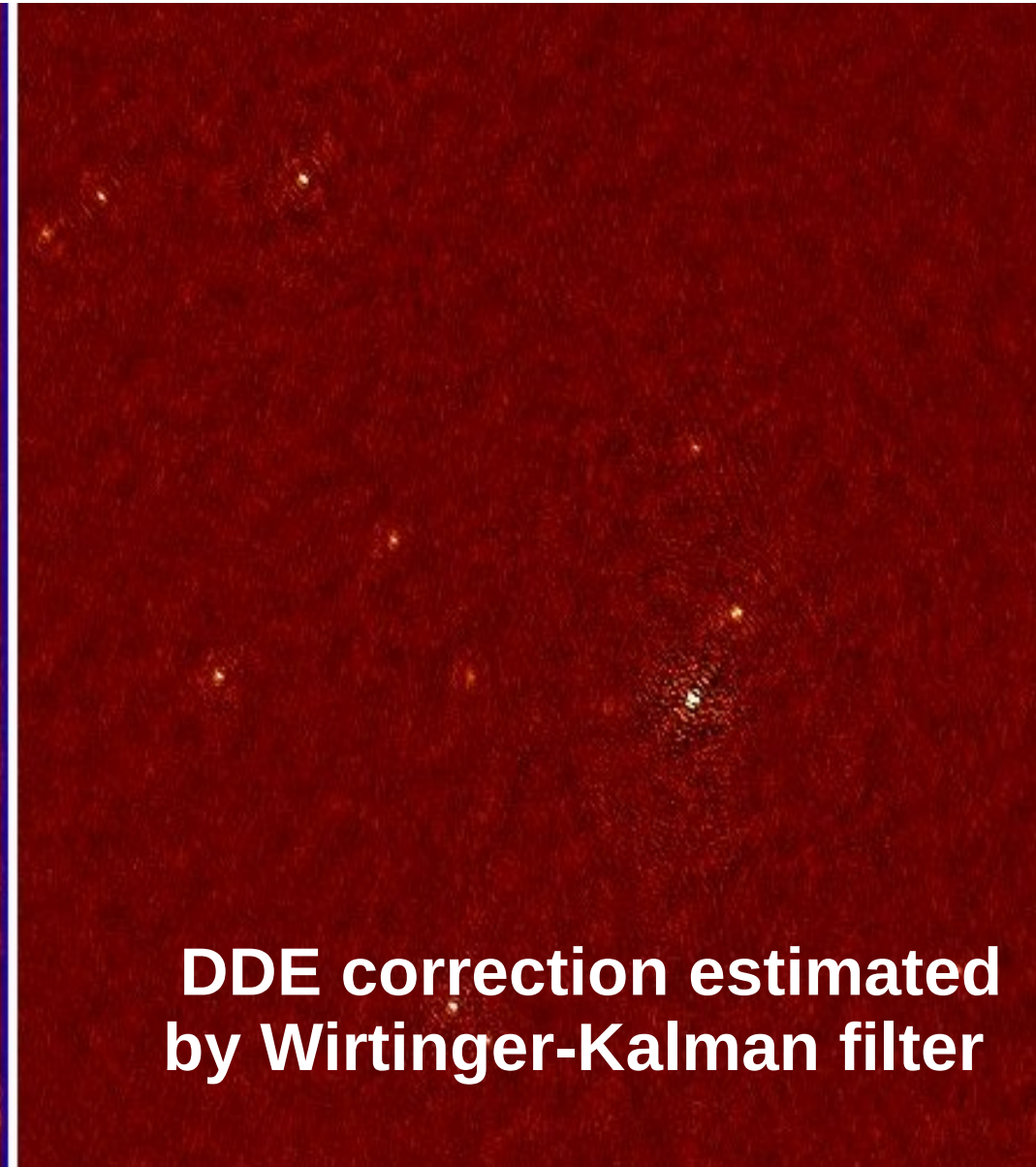
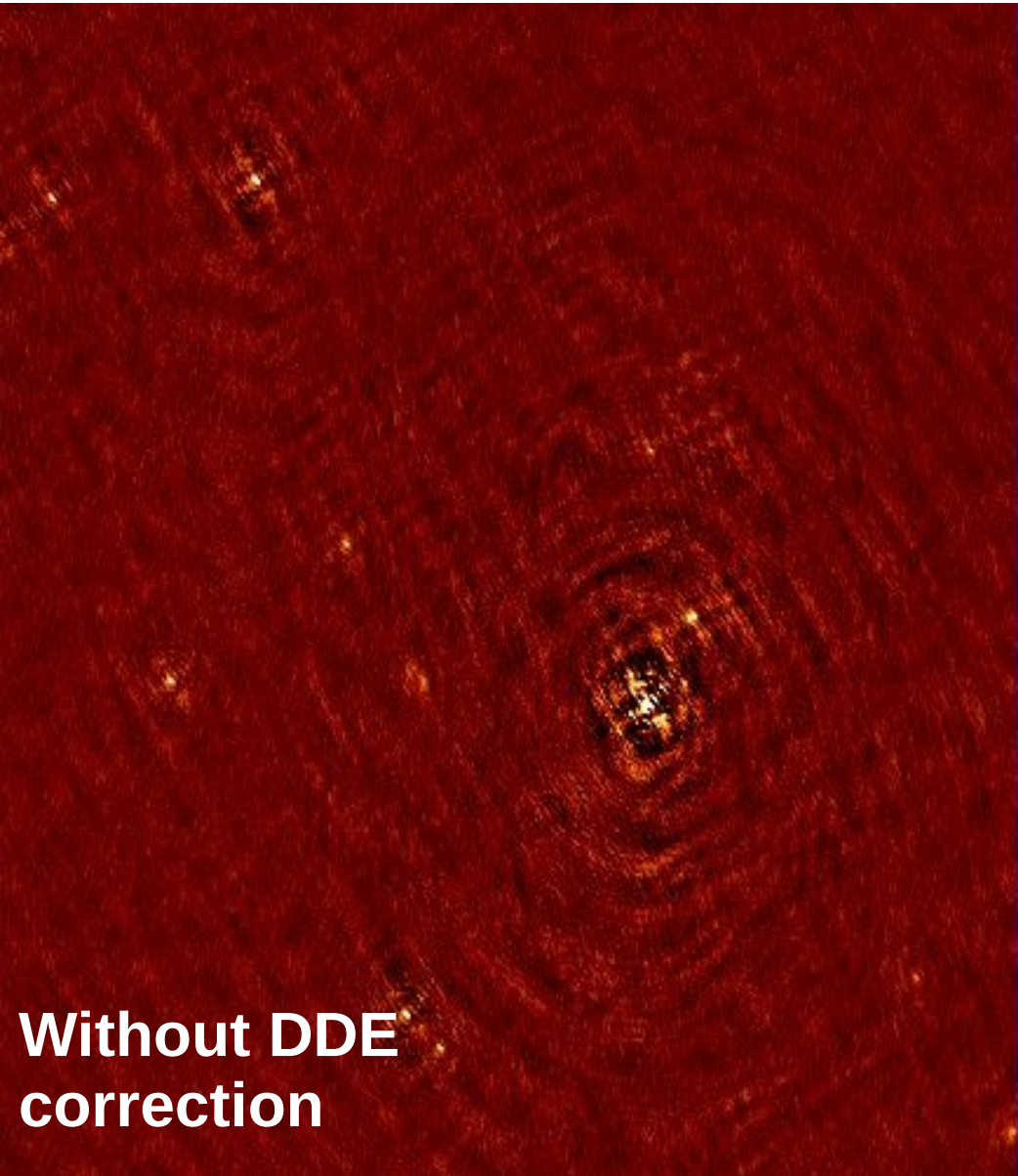


**Without DDE
correction**

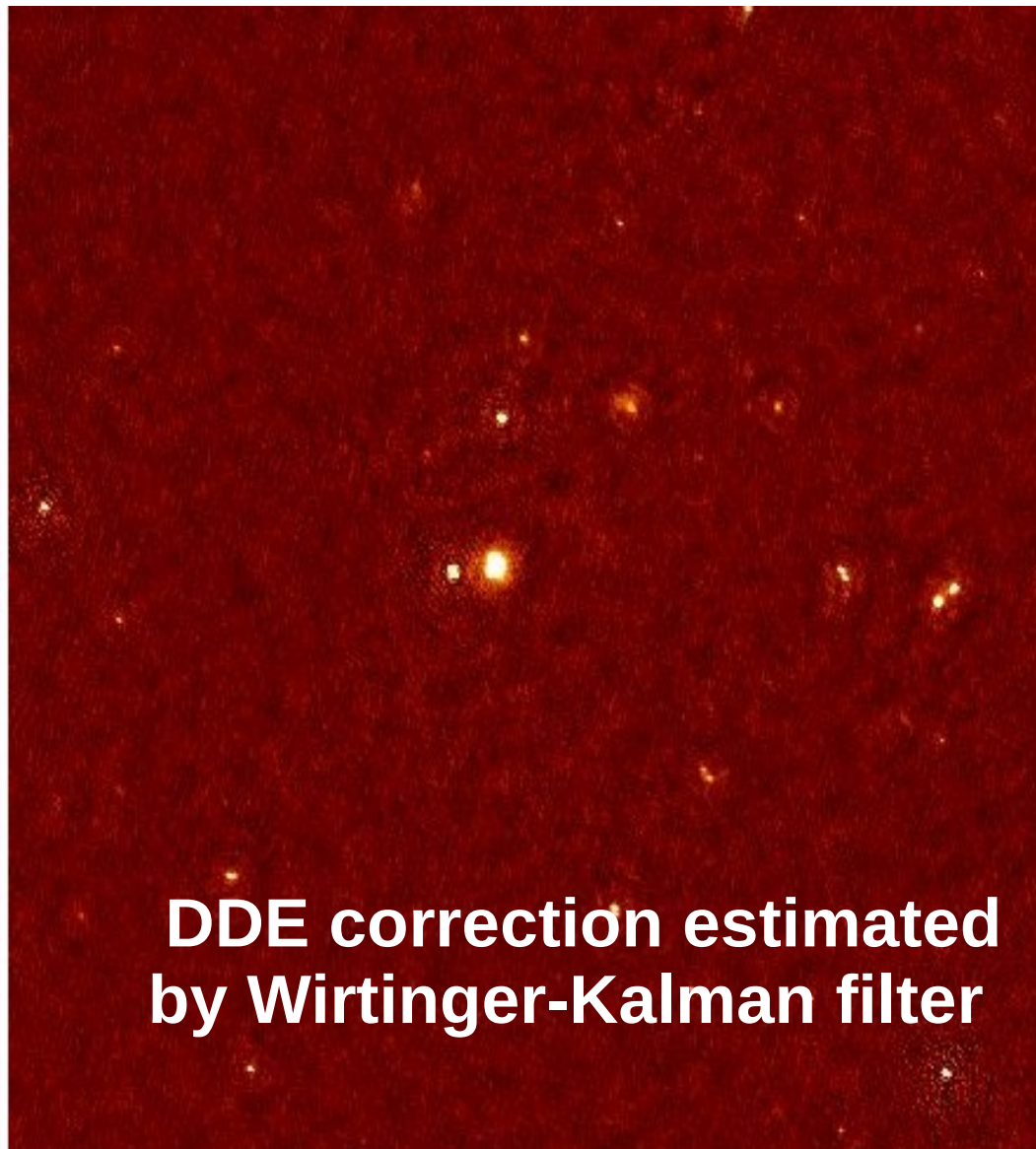
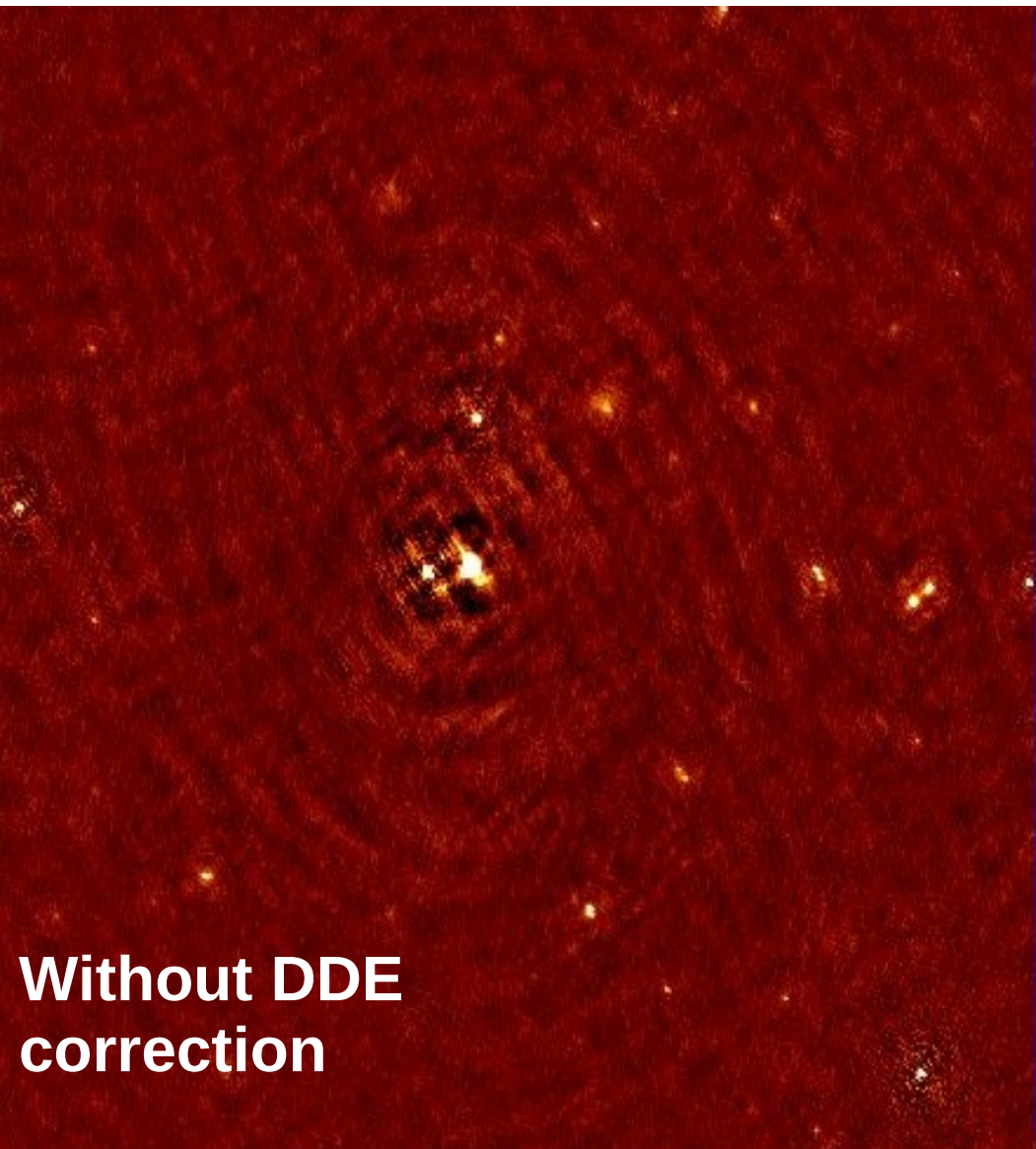


**DDE correction estimated
by Wirtinger-Kalman filter**

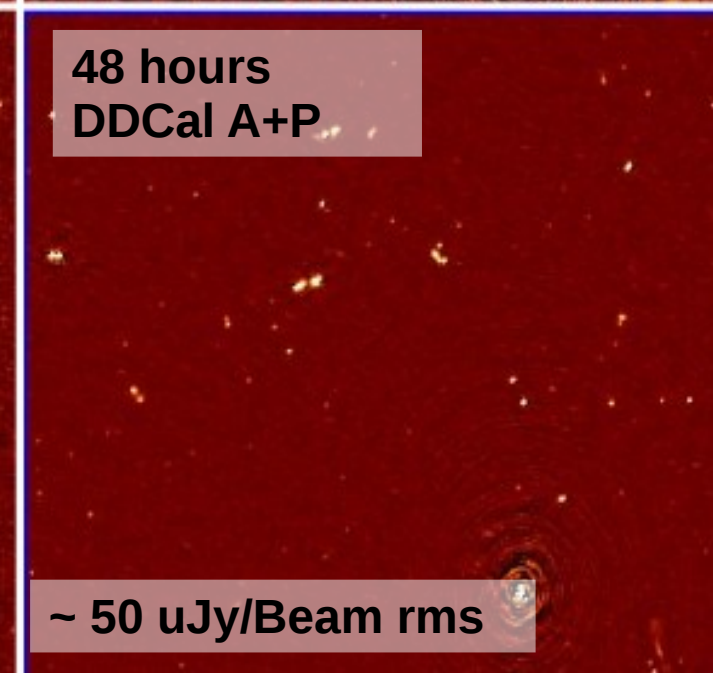
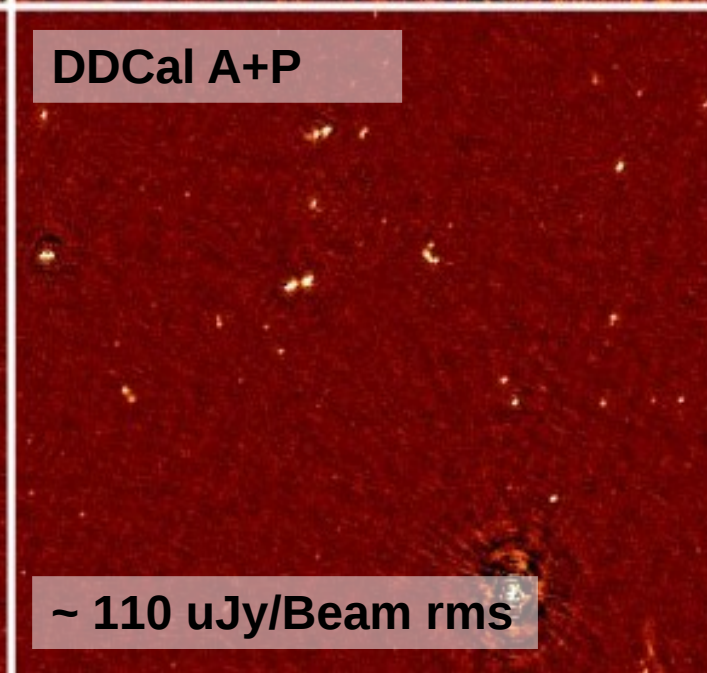
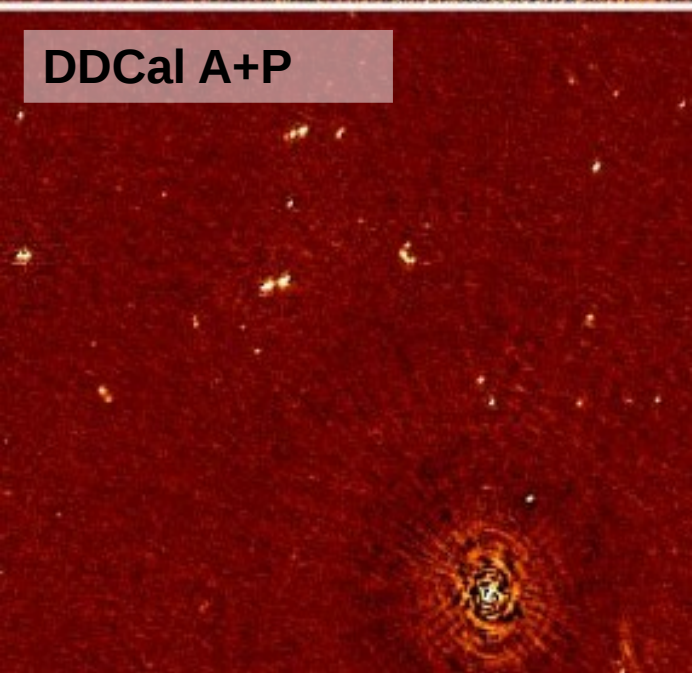
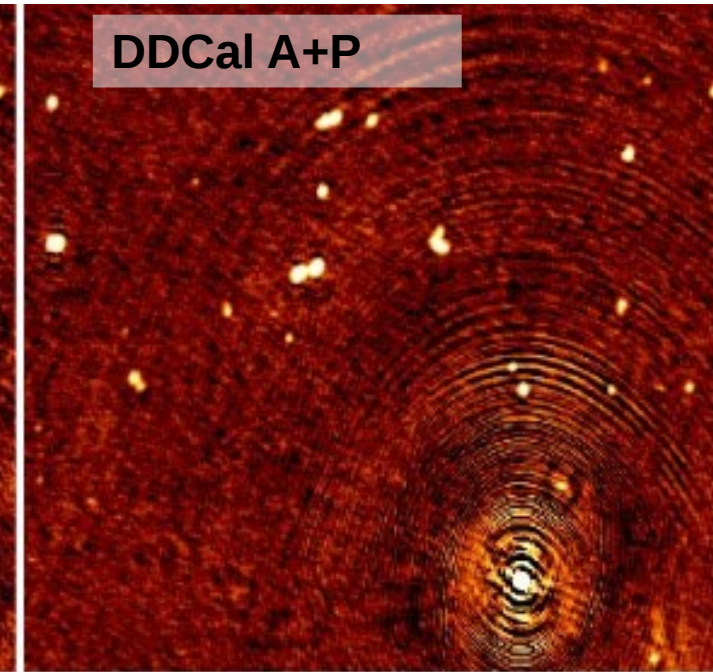
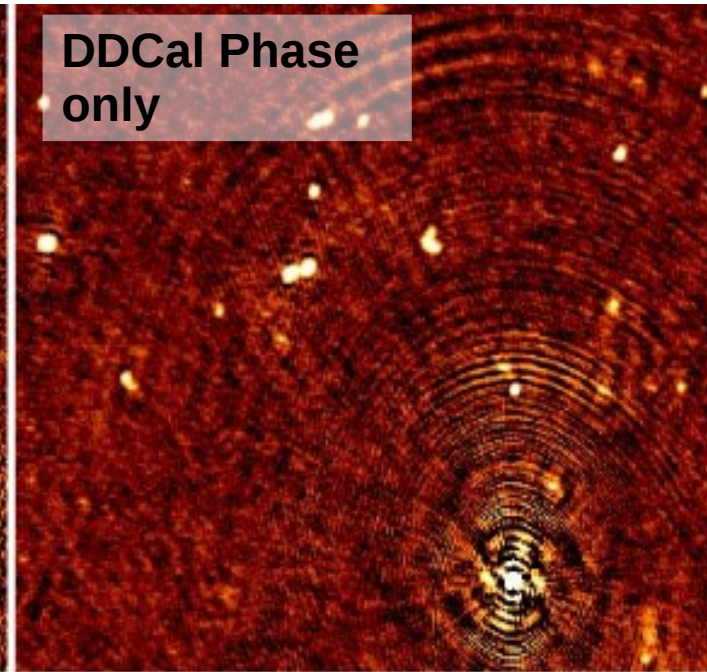
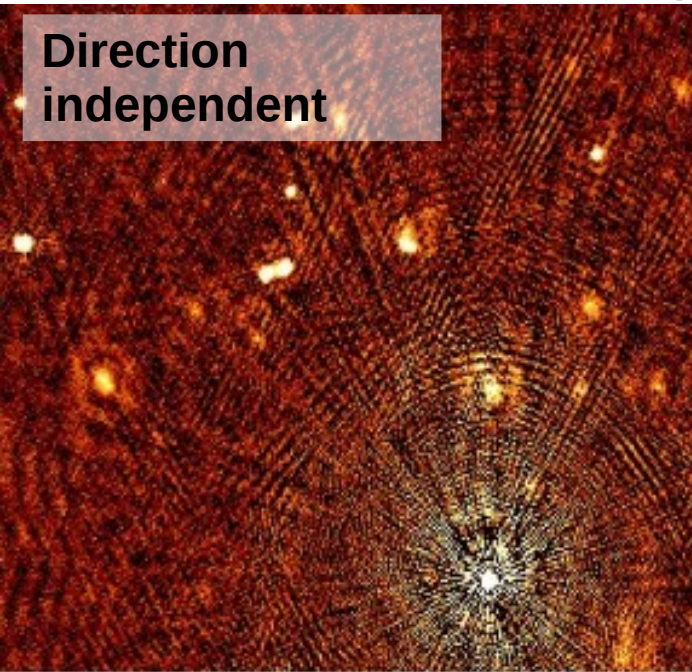
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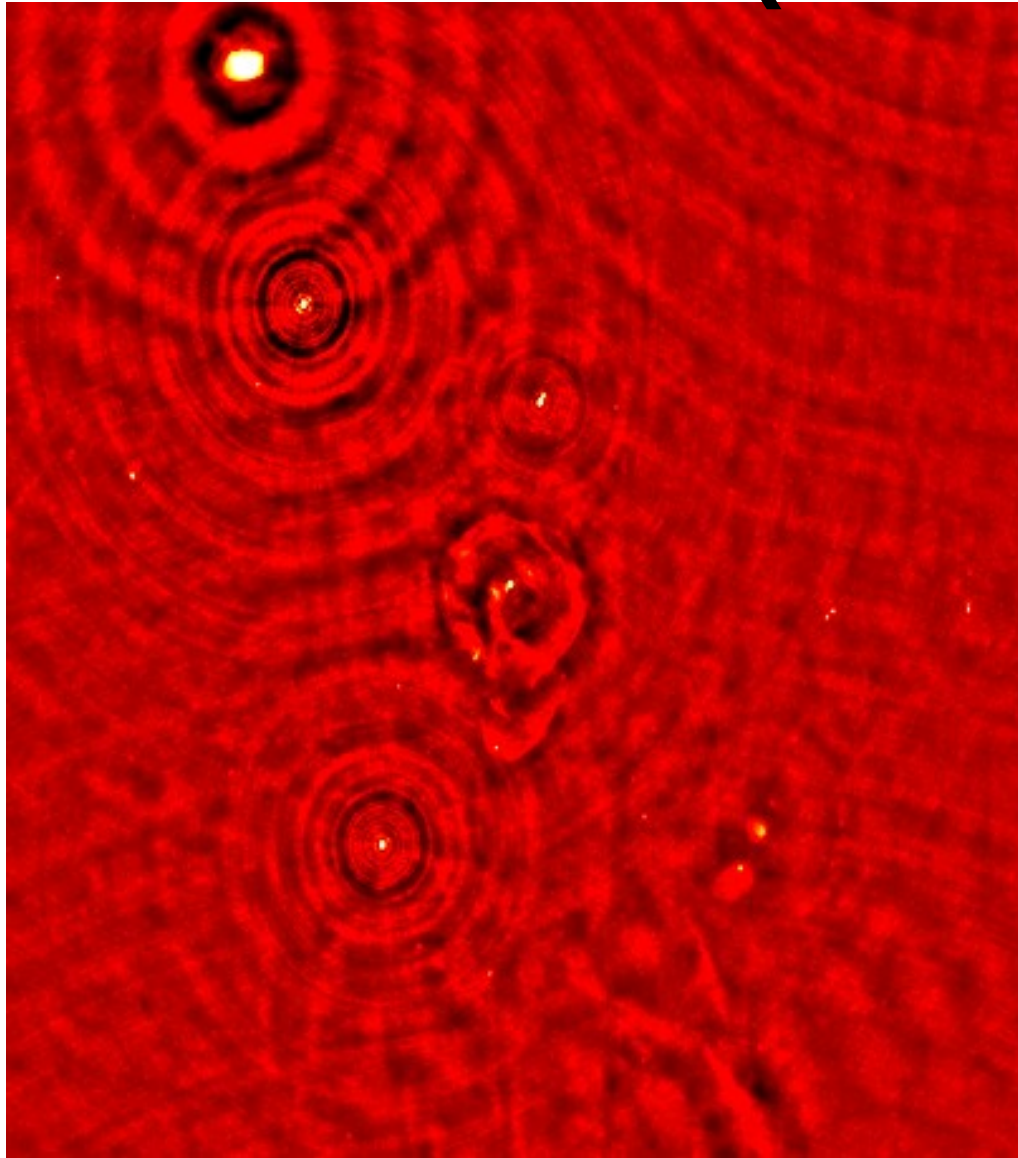


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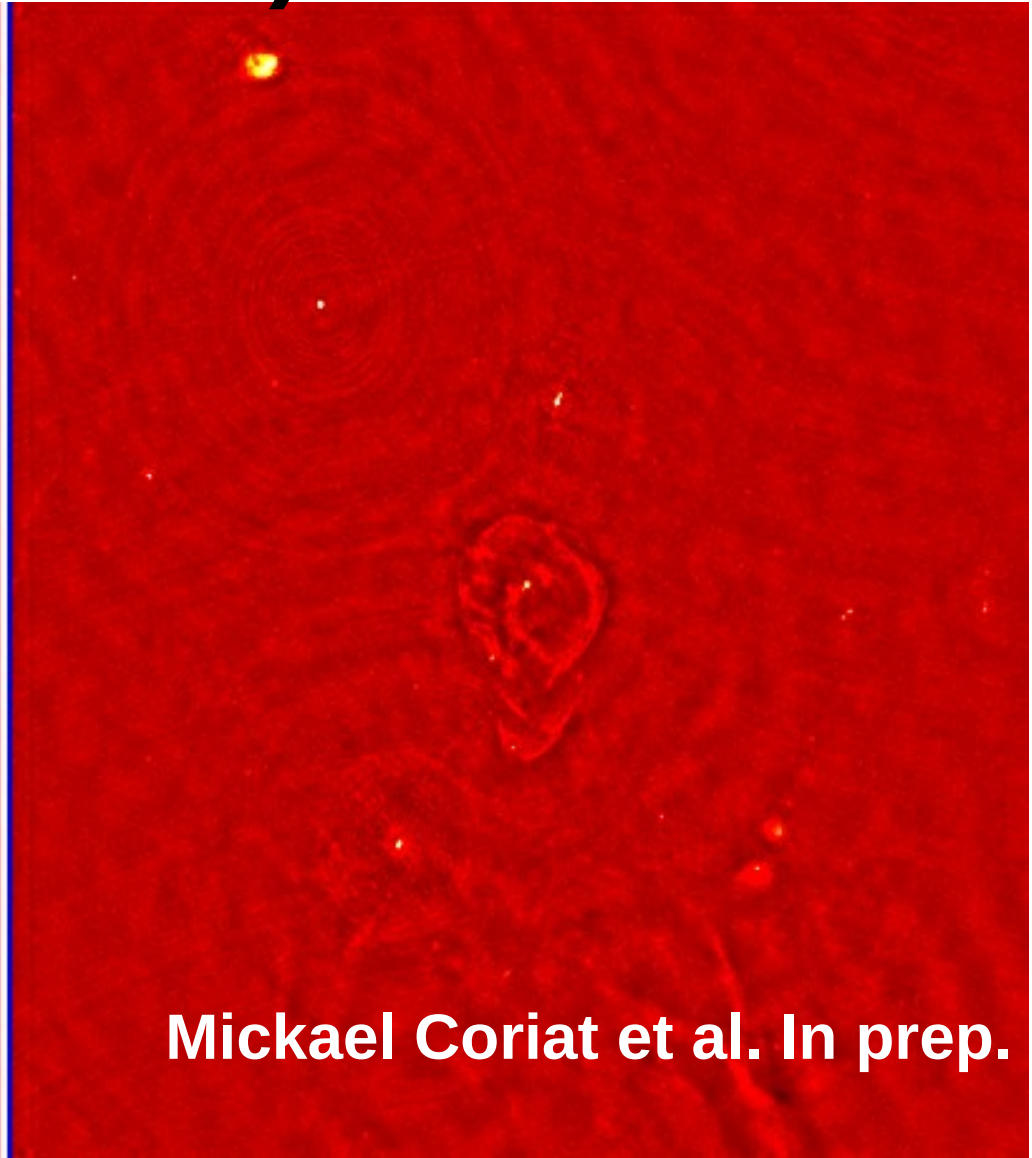


**Does it work on other
radio telescopes ?**

And it also works on ATCA data (Circinus a)



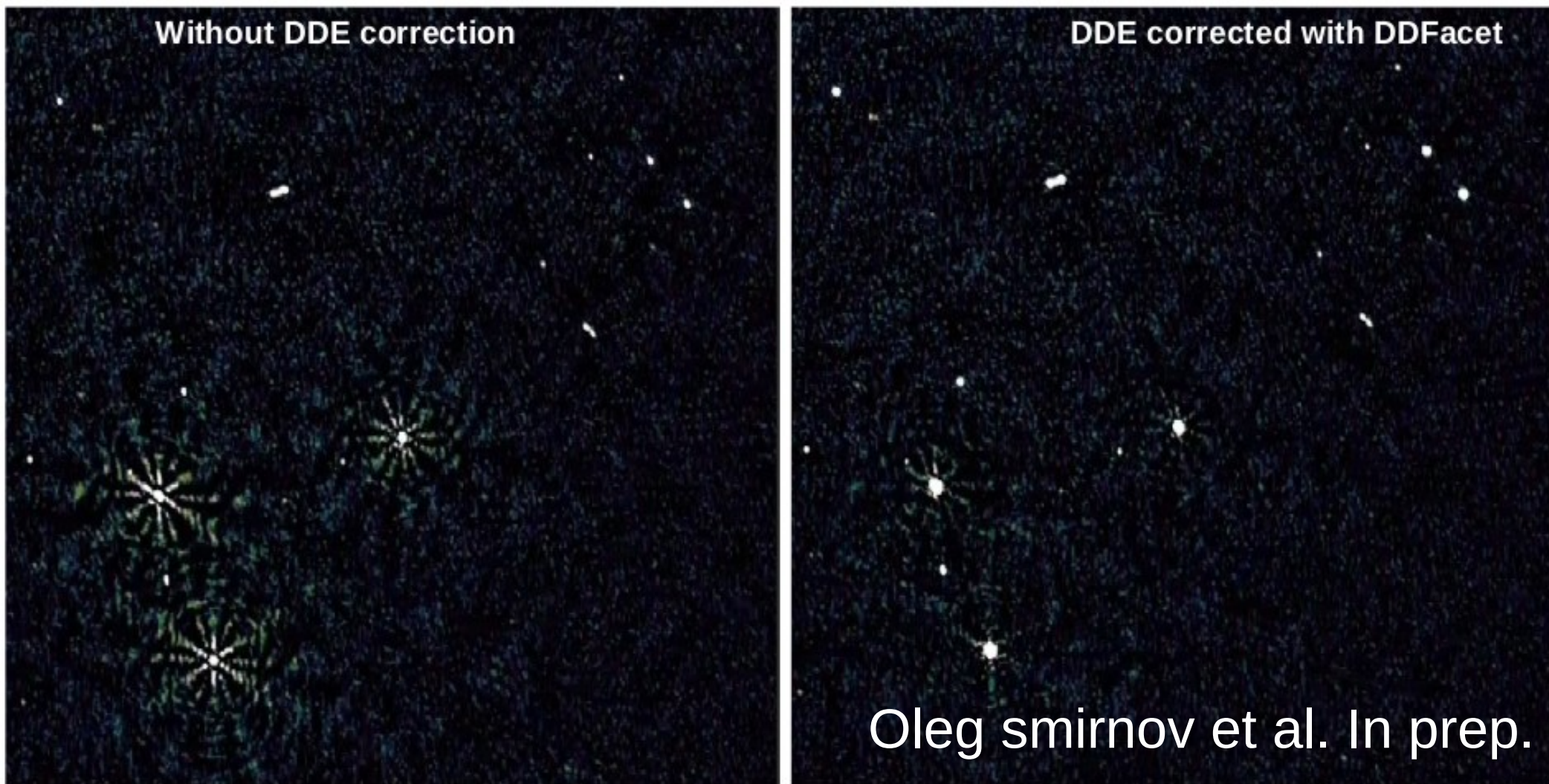
Direction independent calibration



Mickael Coriat et al. In prep.

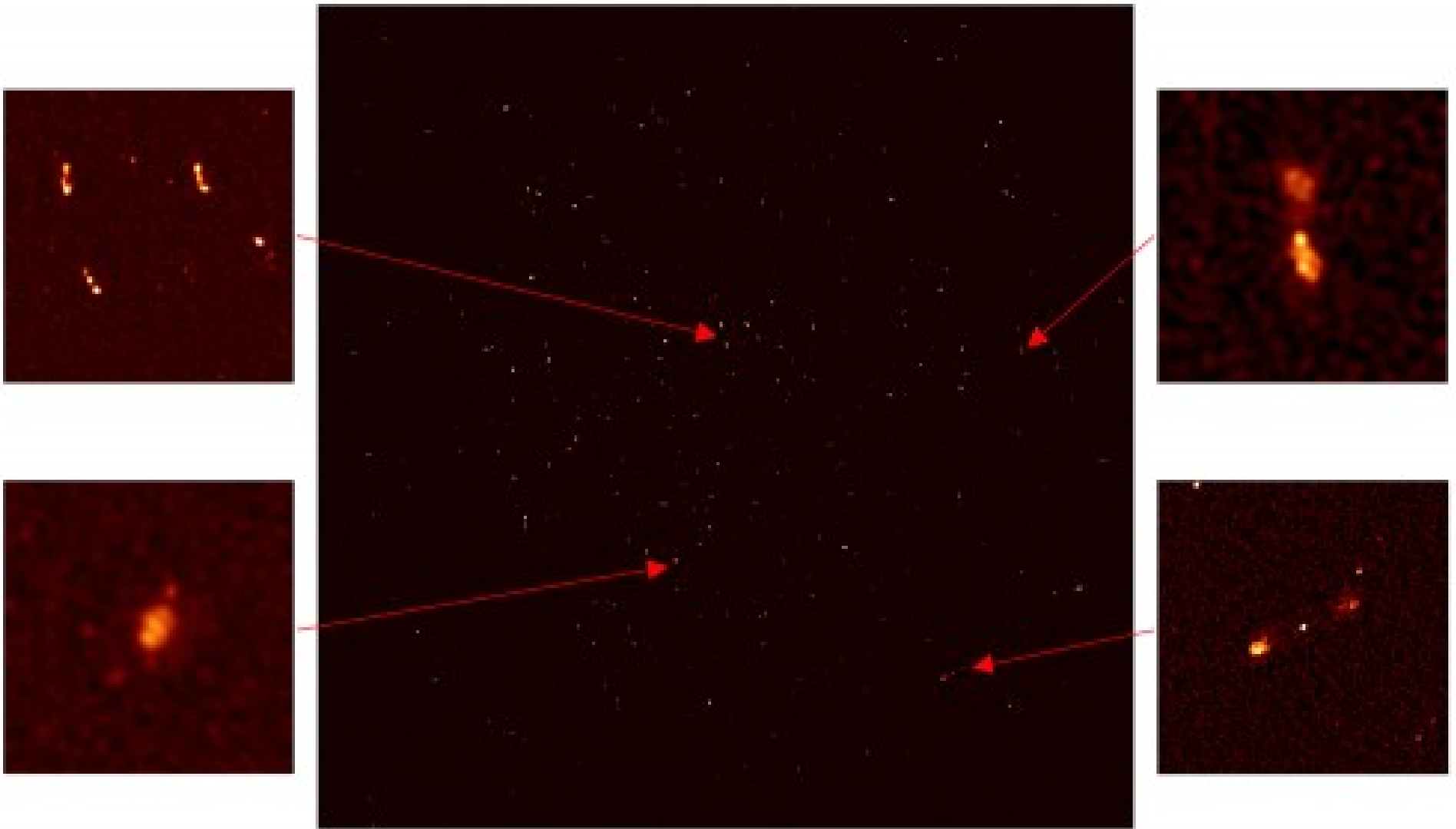
DDE with Wirtinger

And it also works on VLA data



VLA beam model used to construct the Jones matrices

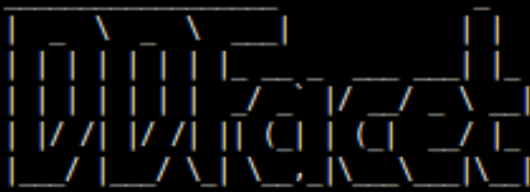
Cherry on the cake : First light MeerKAT image !



- 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 Optimisation 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>

```
- 21:49:23 - DDFacet |   [Data] Predict
- 21:49:23 - DDFacet |   - ColName ..... = None
- 21:49:23 - DDFacet |   - MaskSquare ..... = None
- 21:49:23 - DDFacet |   - FromData ..... = None
- 21:49:23 - DDFacet |   - InitDicoModel ..... = None
- 21:49:23 - DDFacet |   - ... ..... = True
- 21:49:23 - DDFacet |   [Selection] Data selection options
- 21:49:23 - DDFacet |   - Field ..... = 0
- 21:49:23 - DDFacet |   - DDID ..... = 0
- 21:49:23 - DDFacet |   - TaQL ..... = ''
- 21:49:23 - DDFacet |   - ChanStart ..... = 0
- 21:49:23 - DDFacet |   - ChanEnd ..... = -1
- 21:49:23 - DDFacet |   - ChanStep ..... = 1
- 21:49:23 - DDFacet |   - FlagAnts ..... = ''
- 21:49:23 - DDFacet |   - UVRangeKm ..... = [0, 2000]
- 21:49:23 - DDFacet |   - TimeRange ..... = ''
- 21:49:23 - DDFacet |   - DistMaxToCore ..... = ''
- 21:49:23 - DDFacet |   [Output] Options for input and output image names
- 21:49:23 - DDFacet |   - Name ..... = test_indexW
- 21:49:23 - DDFacet |   - ... ..... = None
- 21:49:23 - DDFacet |   - Restoringbeam ..... = None
- 21:49:23 - DDFacet |   - Also ..... = Noekz
- 21:49:23 - DDFacet |   - ... ..... = ''
- 21:49:23 - DDFacet |   - Images ..... = DdPAMR11kz
```