Improvements of LoTSS calibration and imaging for DR2 and application to LoTSS-deep fields

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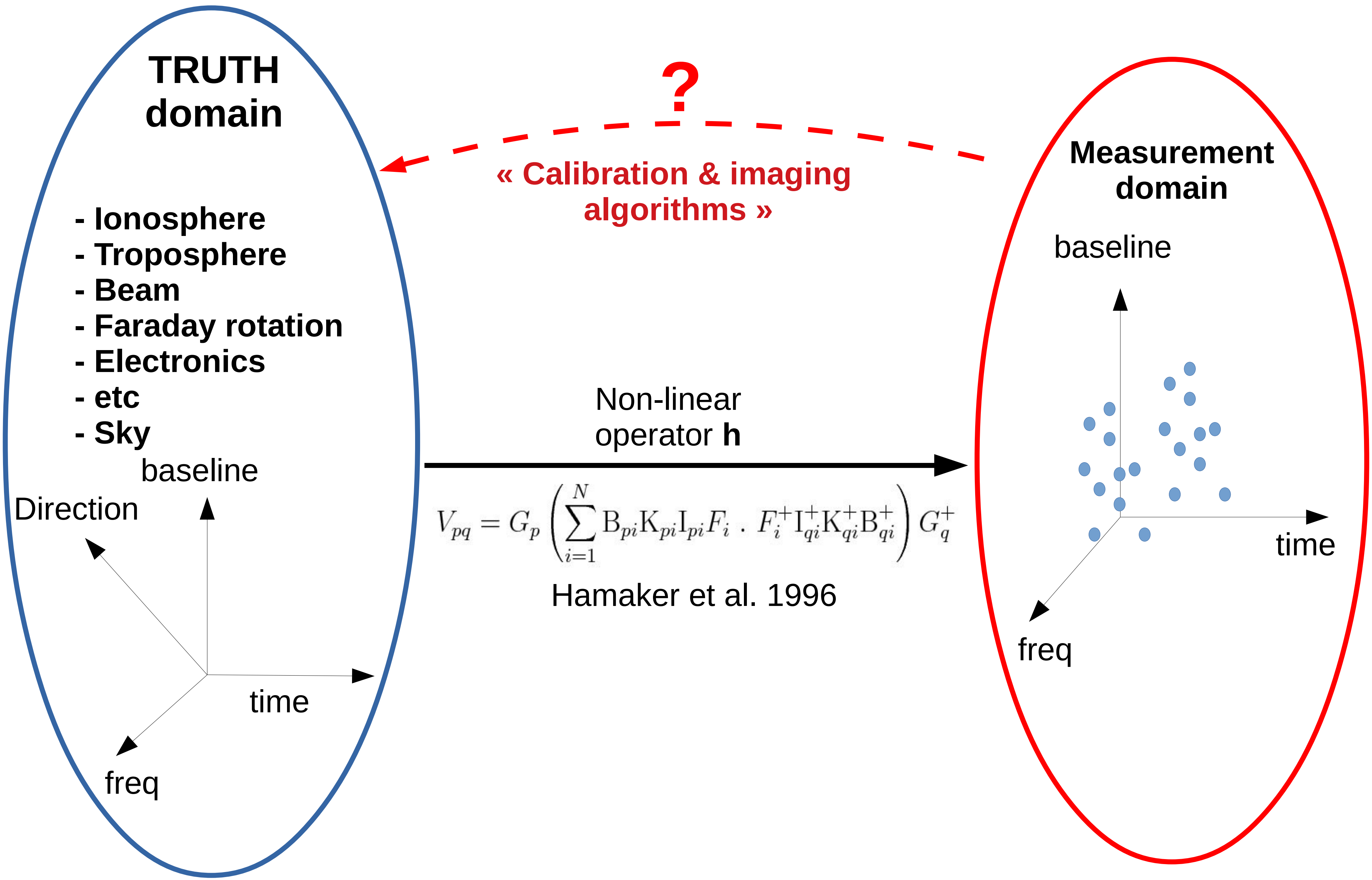
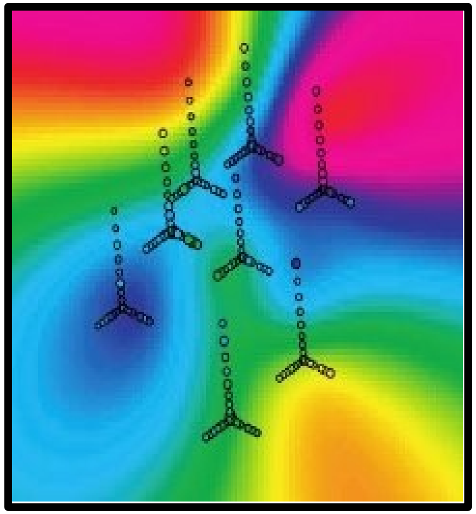
for the LOFAR Surveys KSP

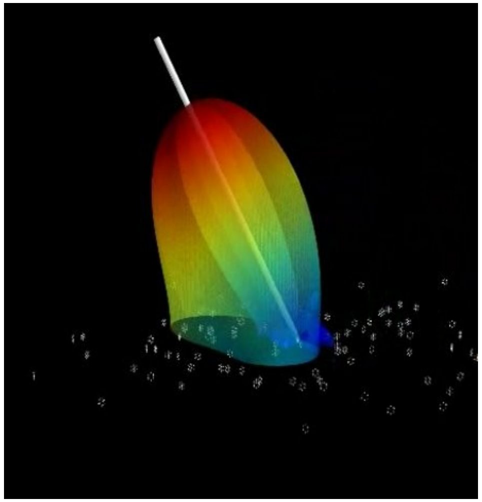
Interferometry



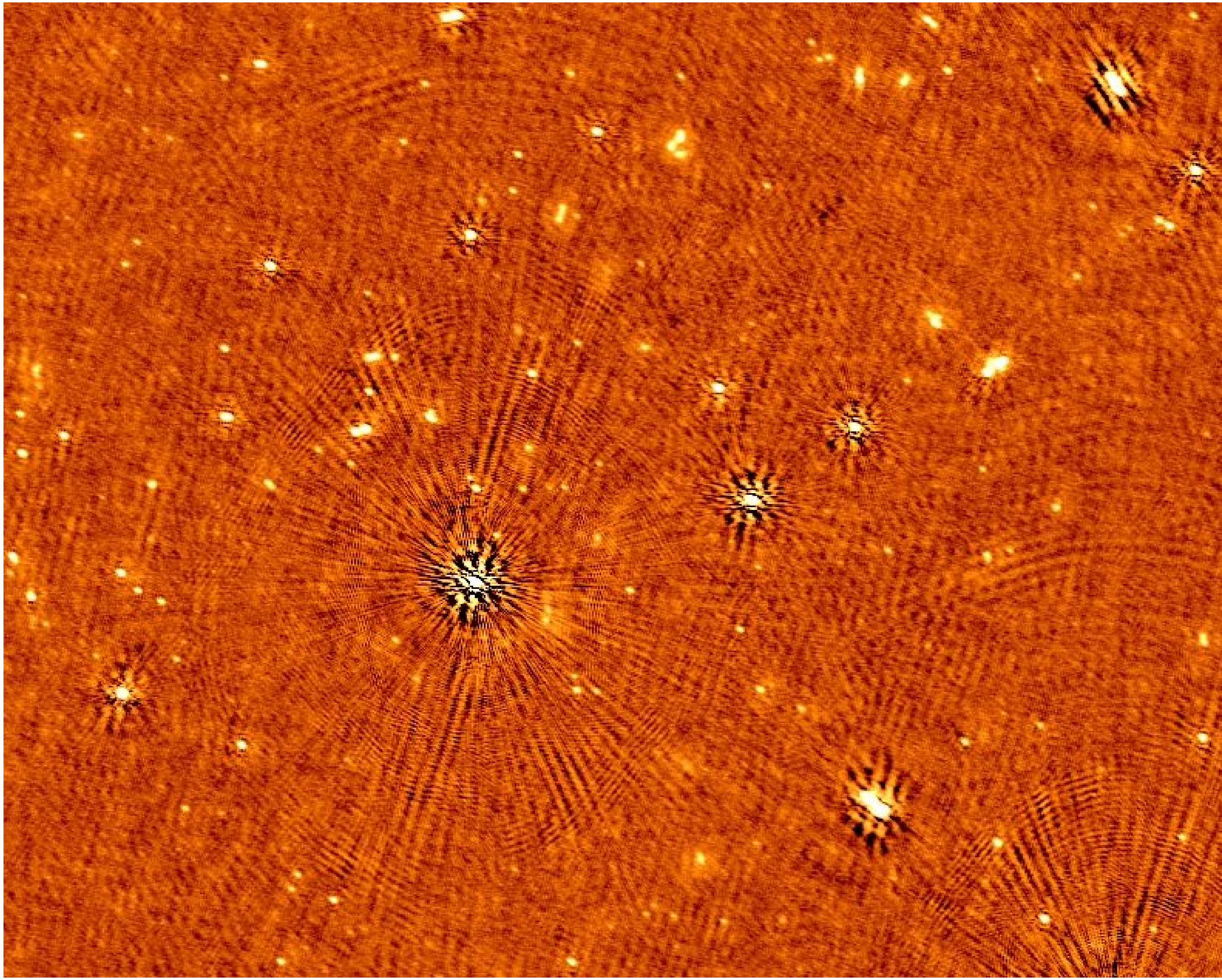
The best image you can ever get in selfcal



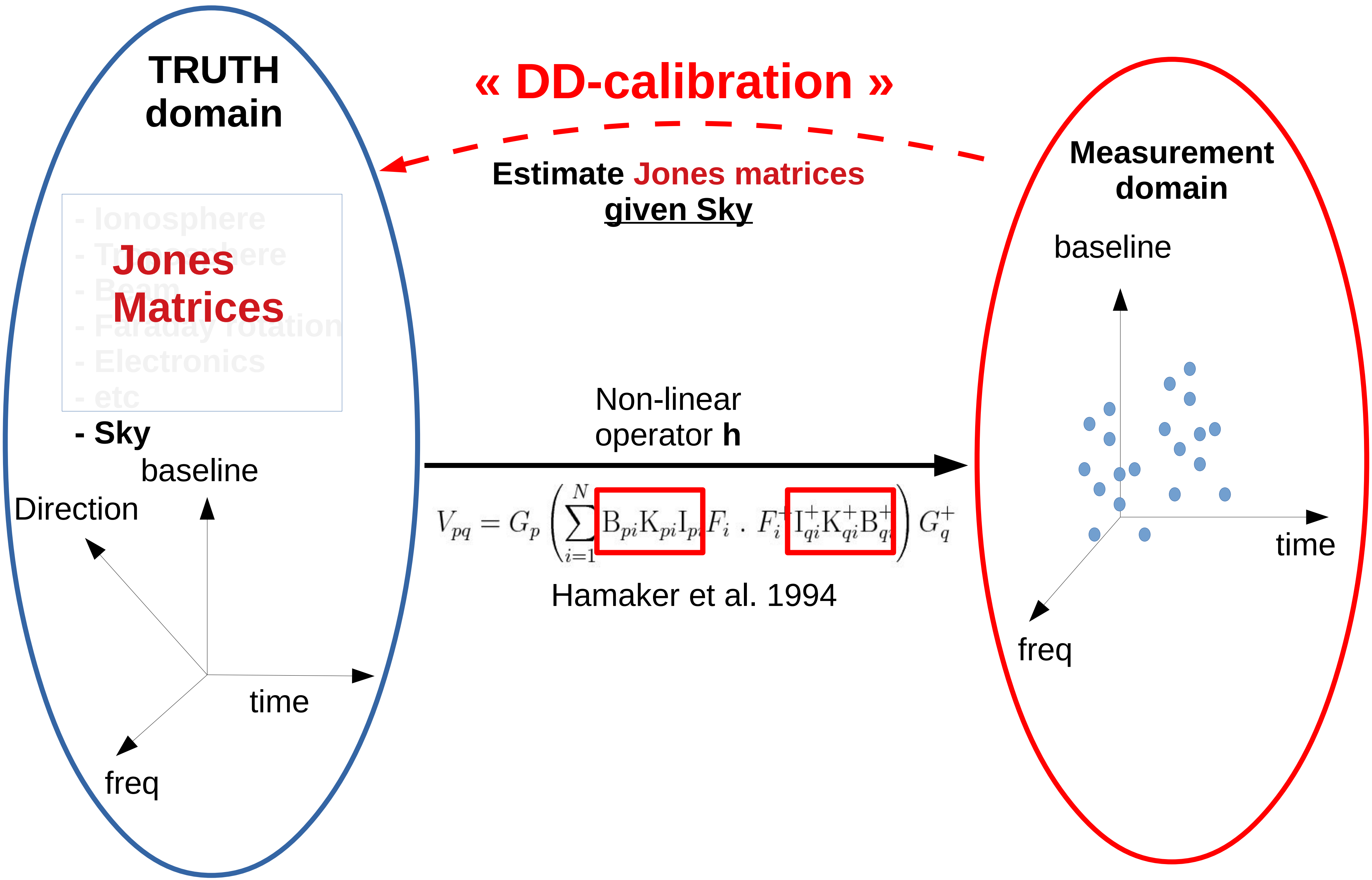
Ionospheric disturbance + Faraday rotation



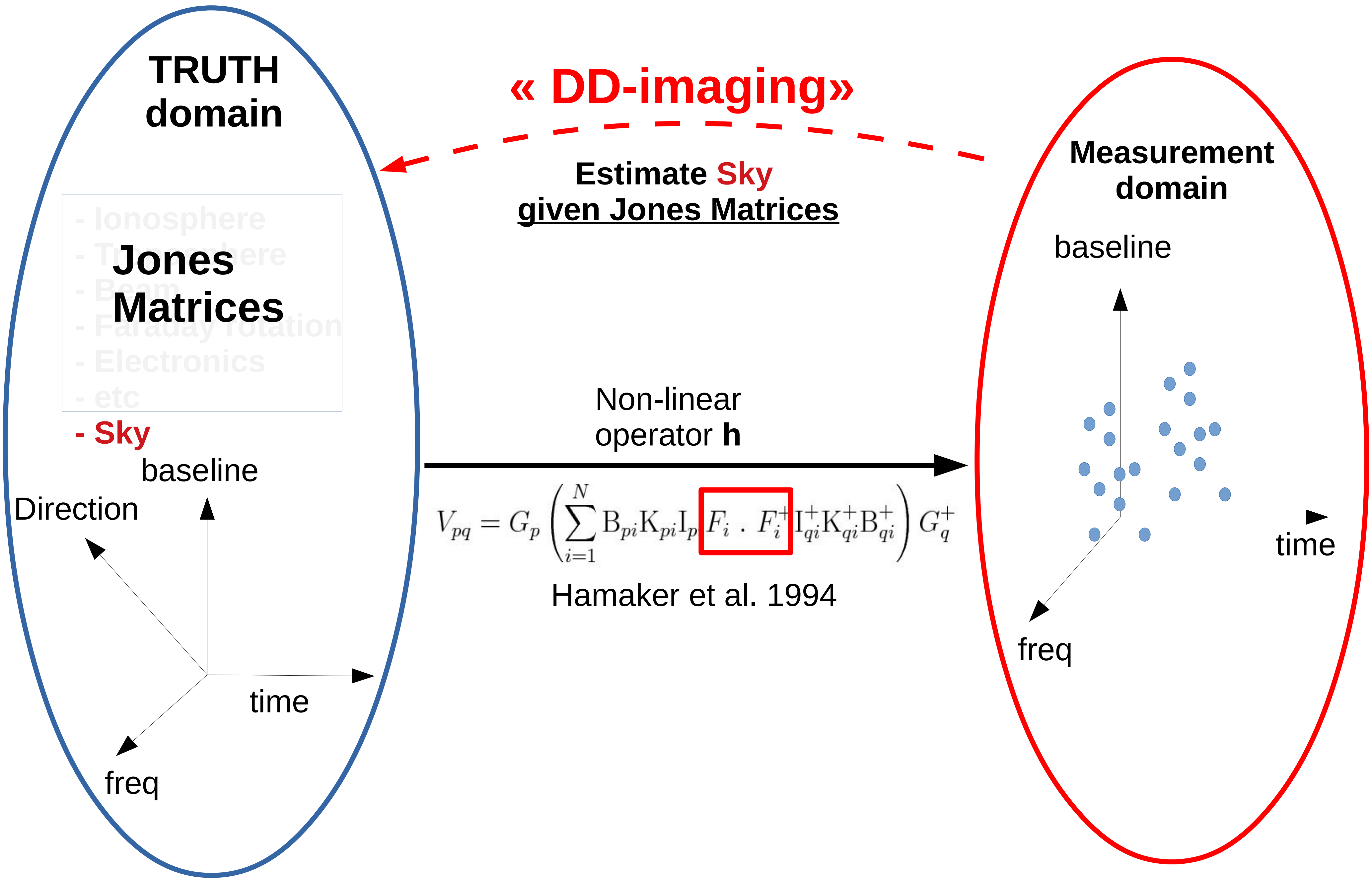
Station lobes



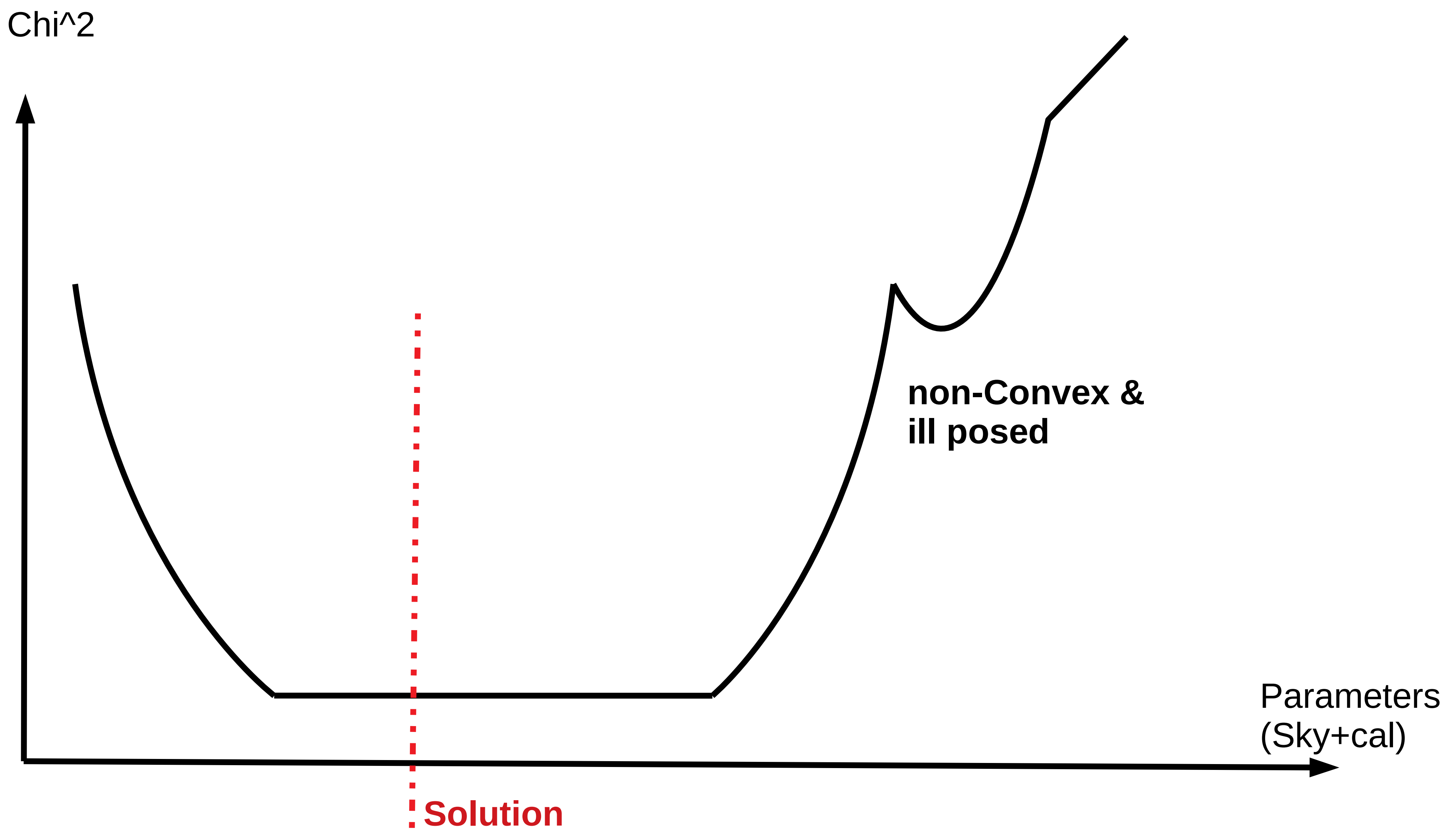
Interferometry



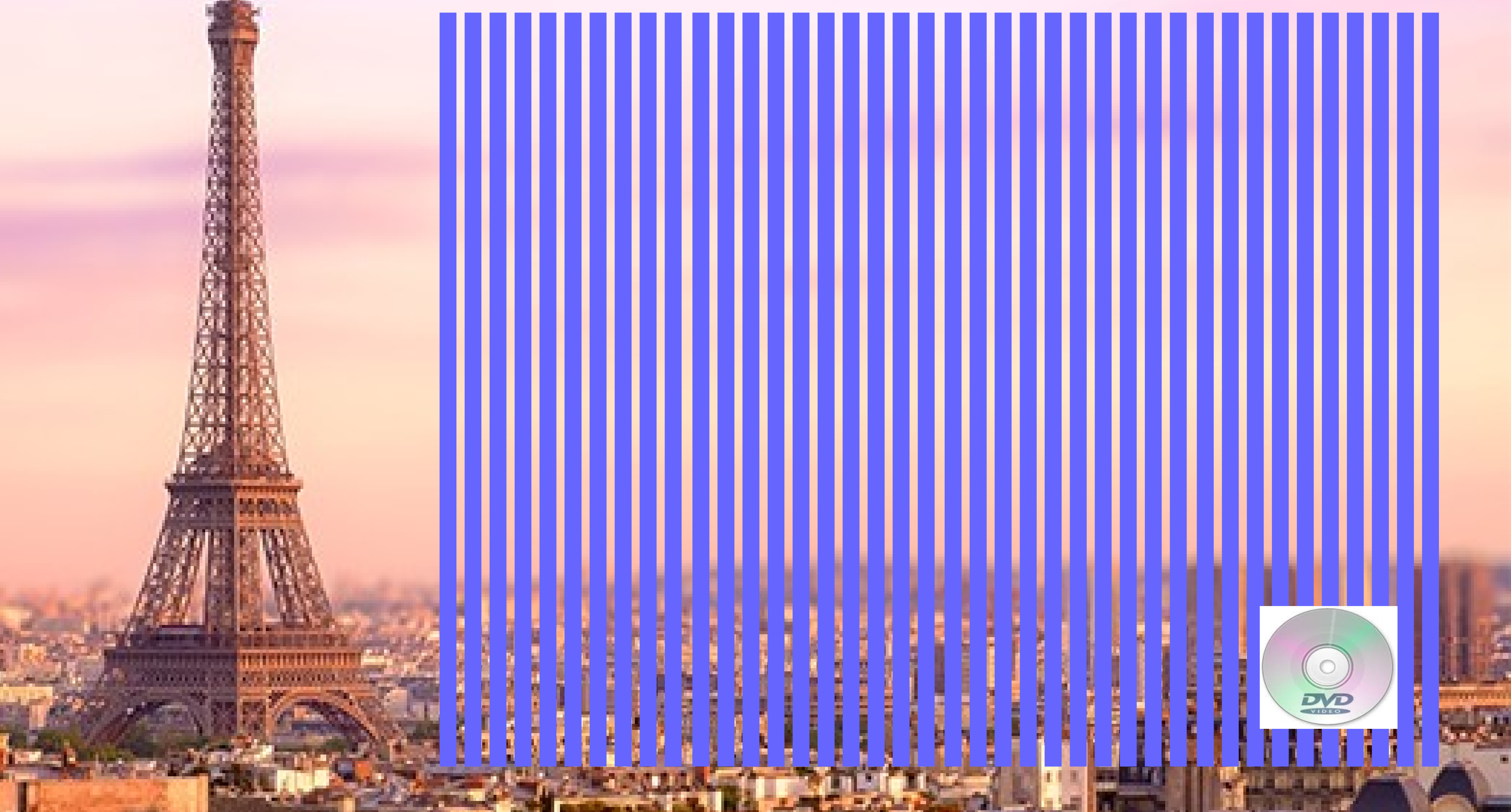
Interferometry



First issue : Convexity, Conditionning



Second issue : Data volume



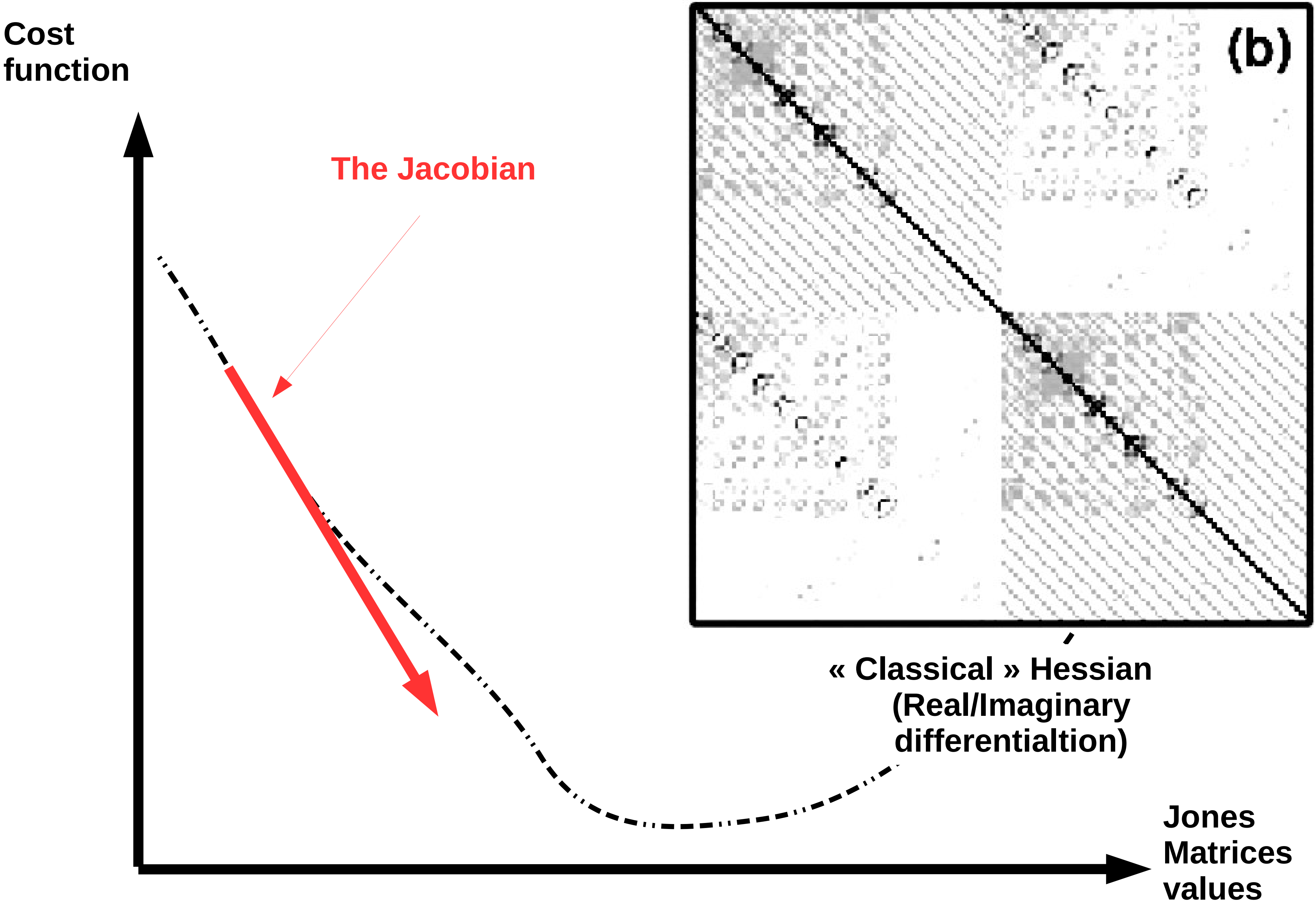
Tier-1 LOFAR Survey : to be observed
48 Pbytes of Raw data → ~39Eiffel towel size dvd stacks

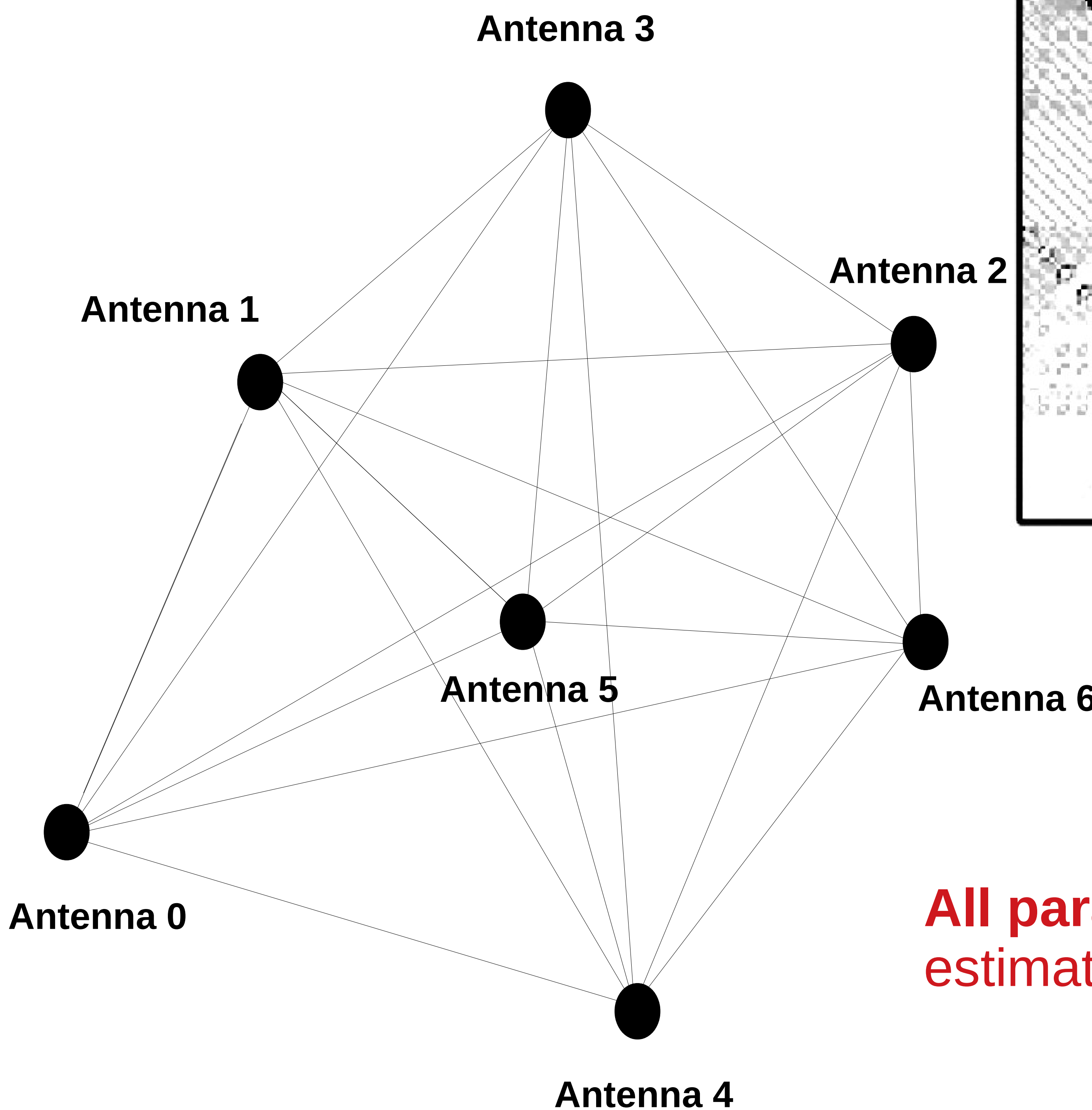
Third issue : software

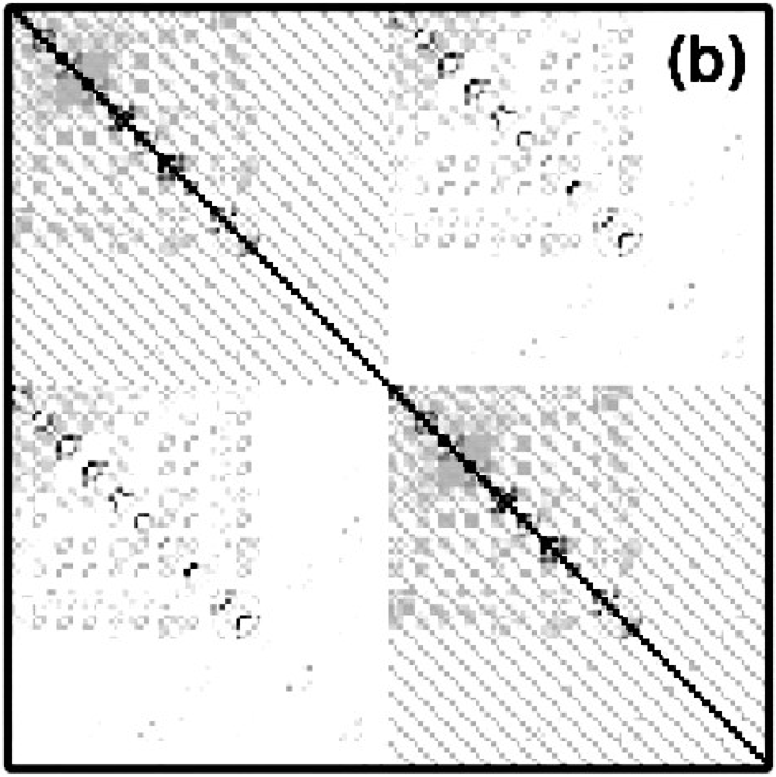
No existing software implementing

(i) generic piecewise constant,
(ii) DD-simultaneous,
(iii) full Jones,
(iv) (Cal+Im) RIME solving

RIME Calibration







« Classical » Hessian
(Real/Imaginary
differentialtion)

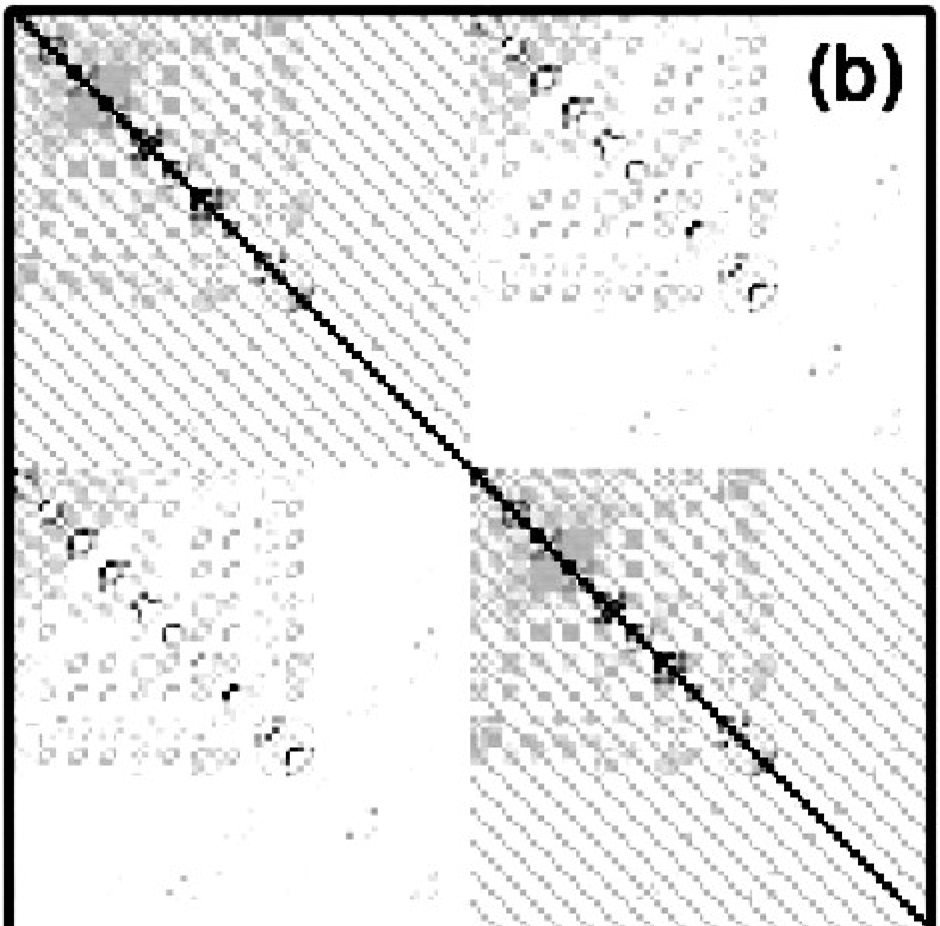
All parameters have to be estimated using **all data**

Wirtinger Optimisation: Jacobian & Hessian

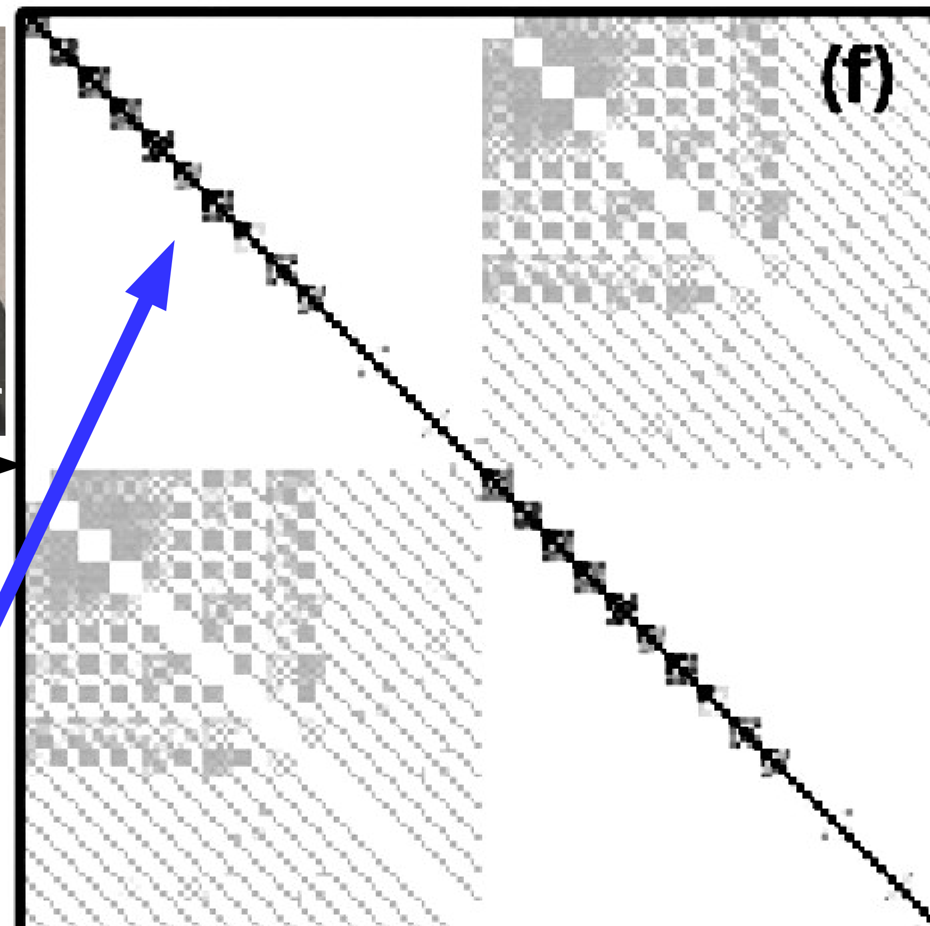
(Read Tasse 2014, Smirnov & Tasse 2015)

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

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



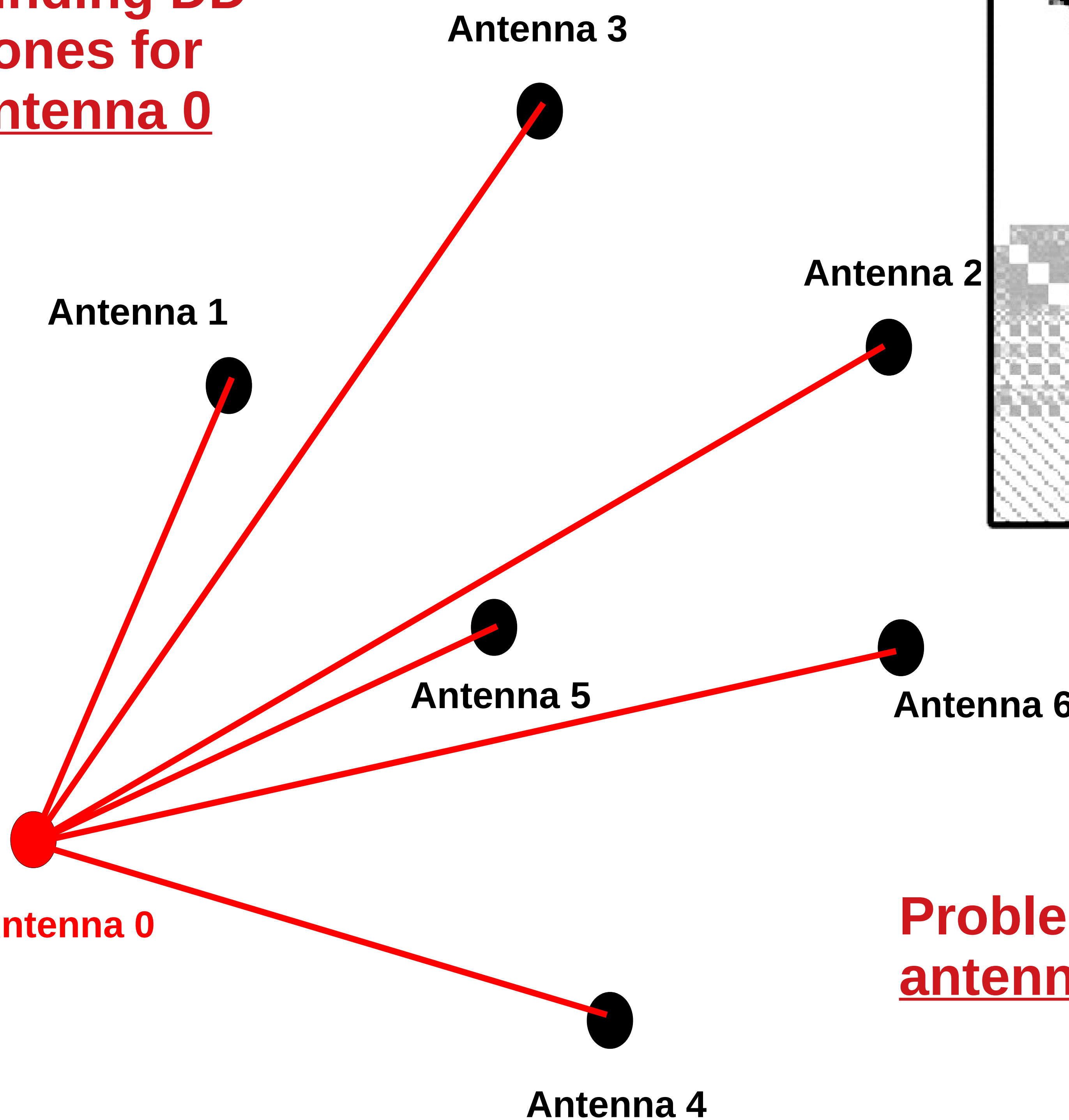
« Classical » Hessian

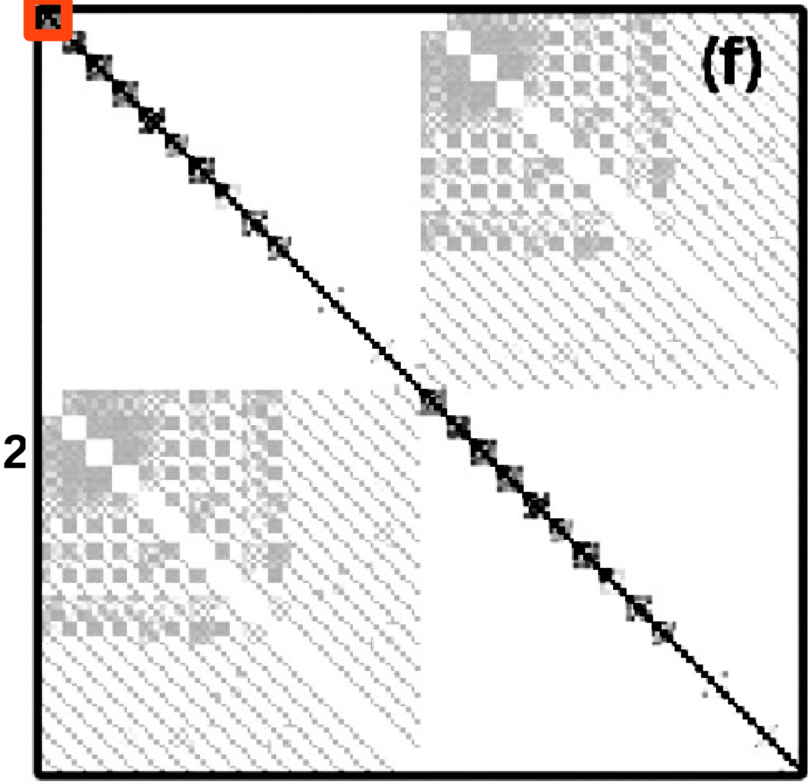


Those Blocks are (Nd x Nd)

Wirtinger Hessian

Finding DD-Jones for <u>antenna 0</u>



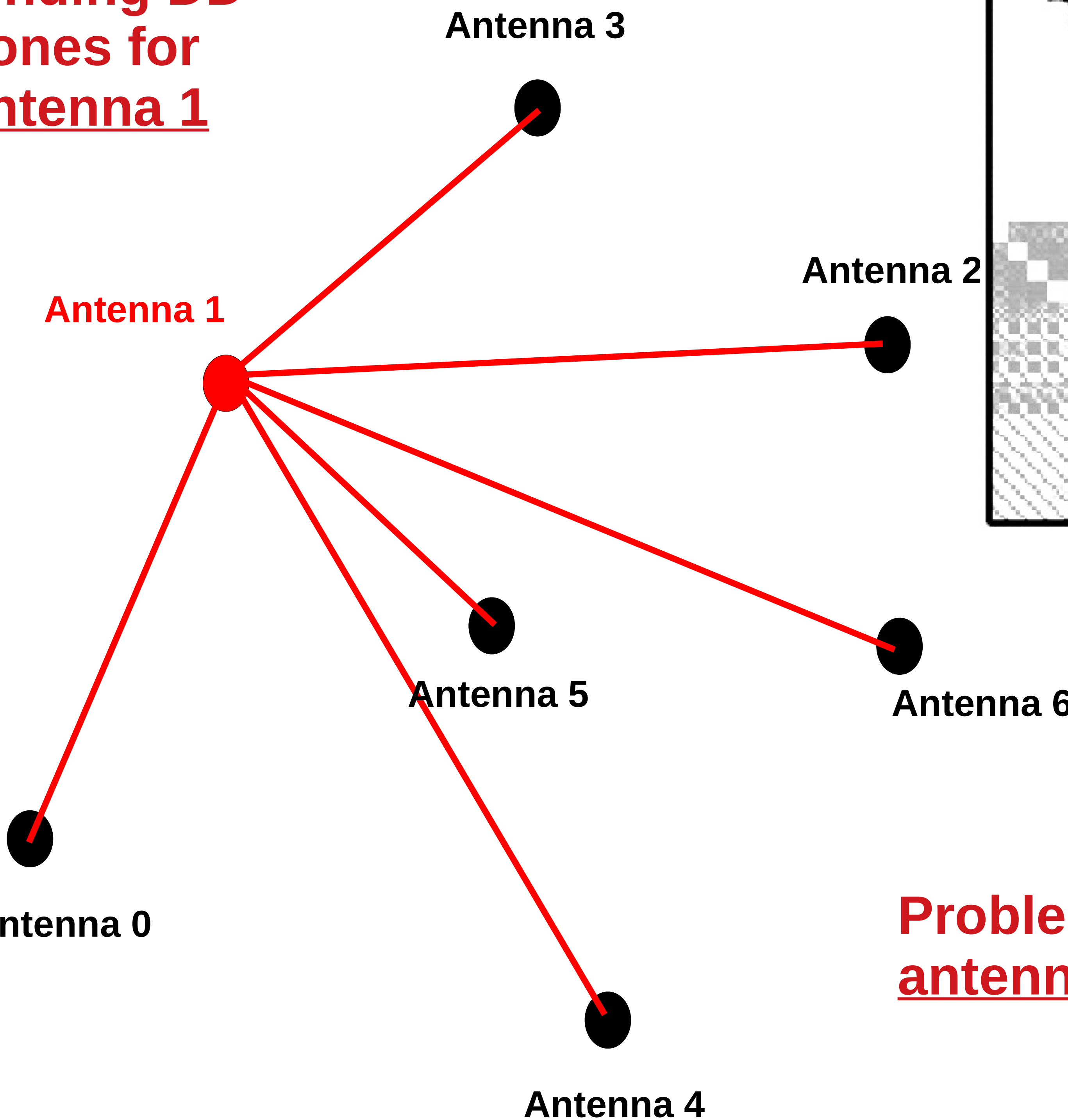


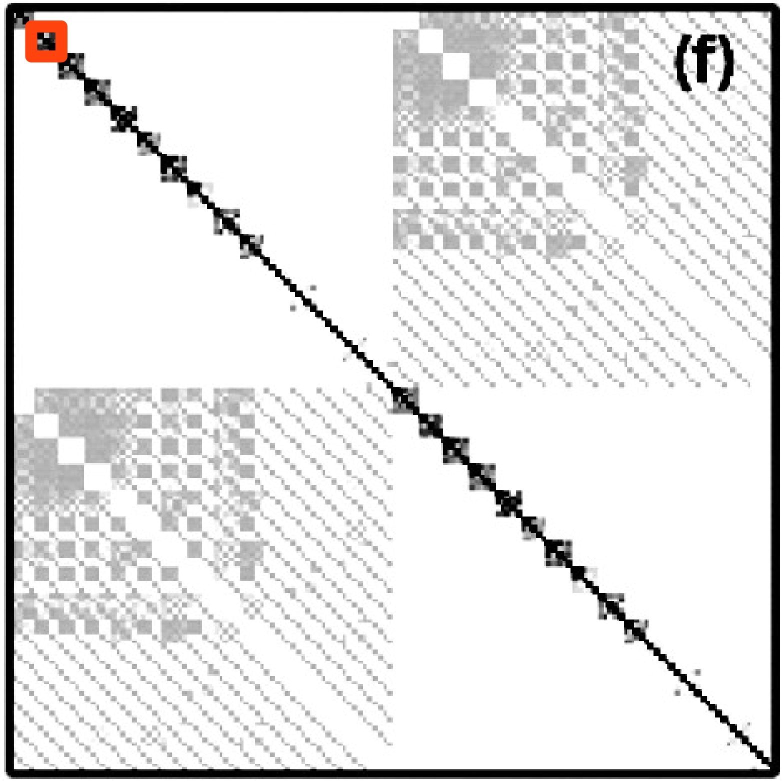
Wirtinger Hessian

(Tasse 2014, Smirnov & Tasse 2015, Repetti et al. 2017 *)*

Problem becomes <u>antenna separable</u>

Finding DD-Jones for <u>antenna 1</u>



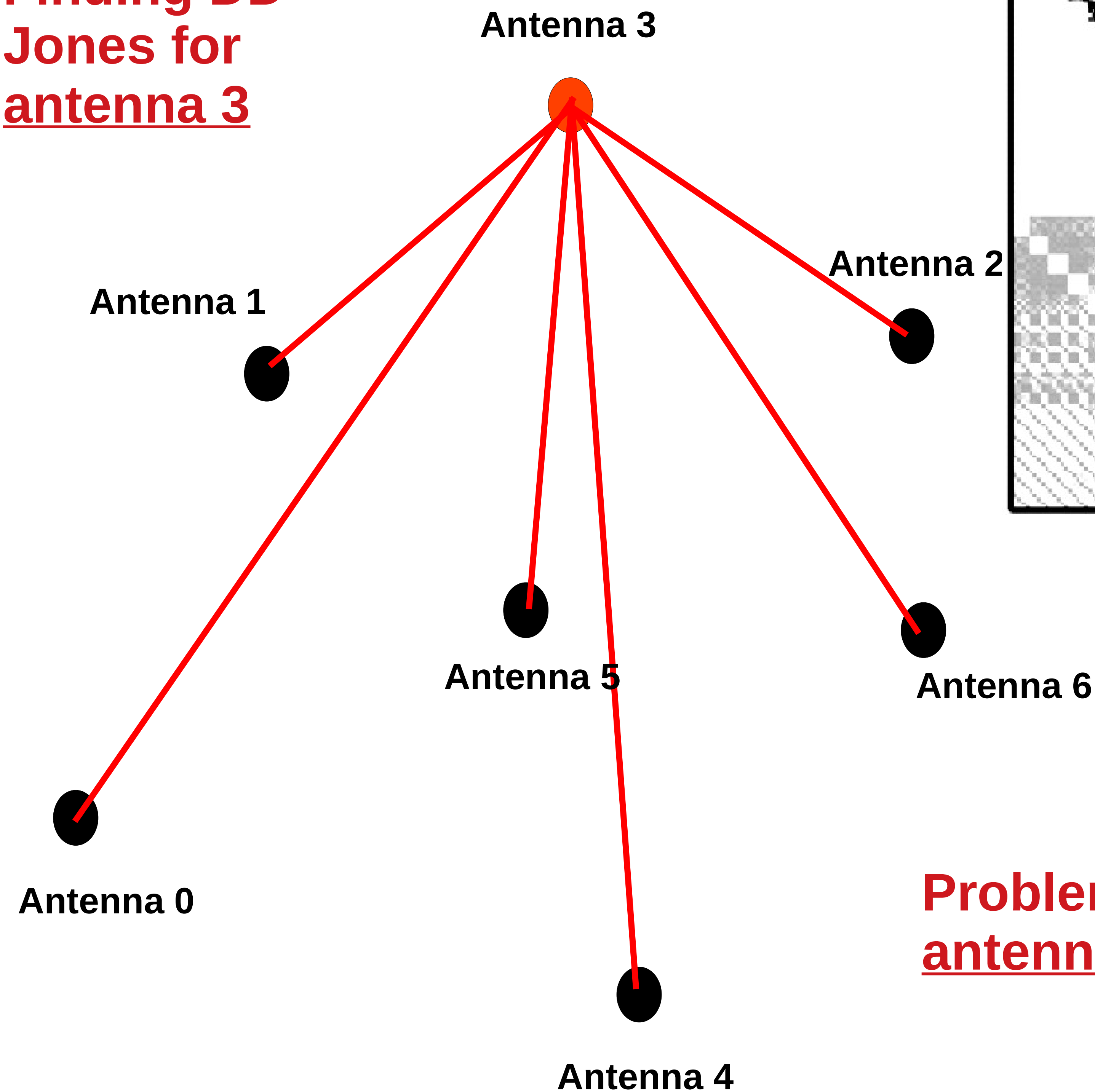


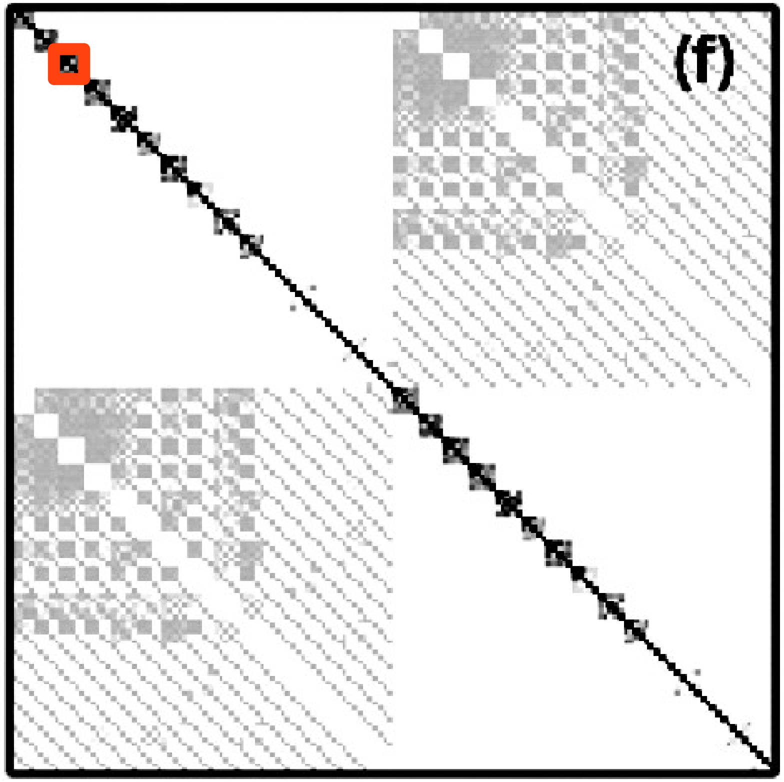
Wirtinger Hessian

(Tasse 2014, Smirnov & Tasse 2015, Repetti et al. 2017 *)*

Problem becomes <u>antenna separable</u>

Finding DD-Jones for <u>antenna 3</u>





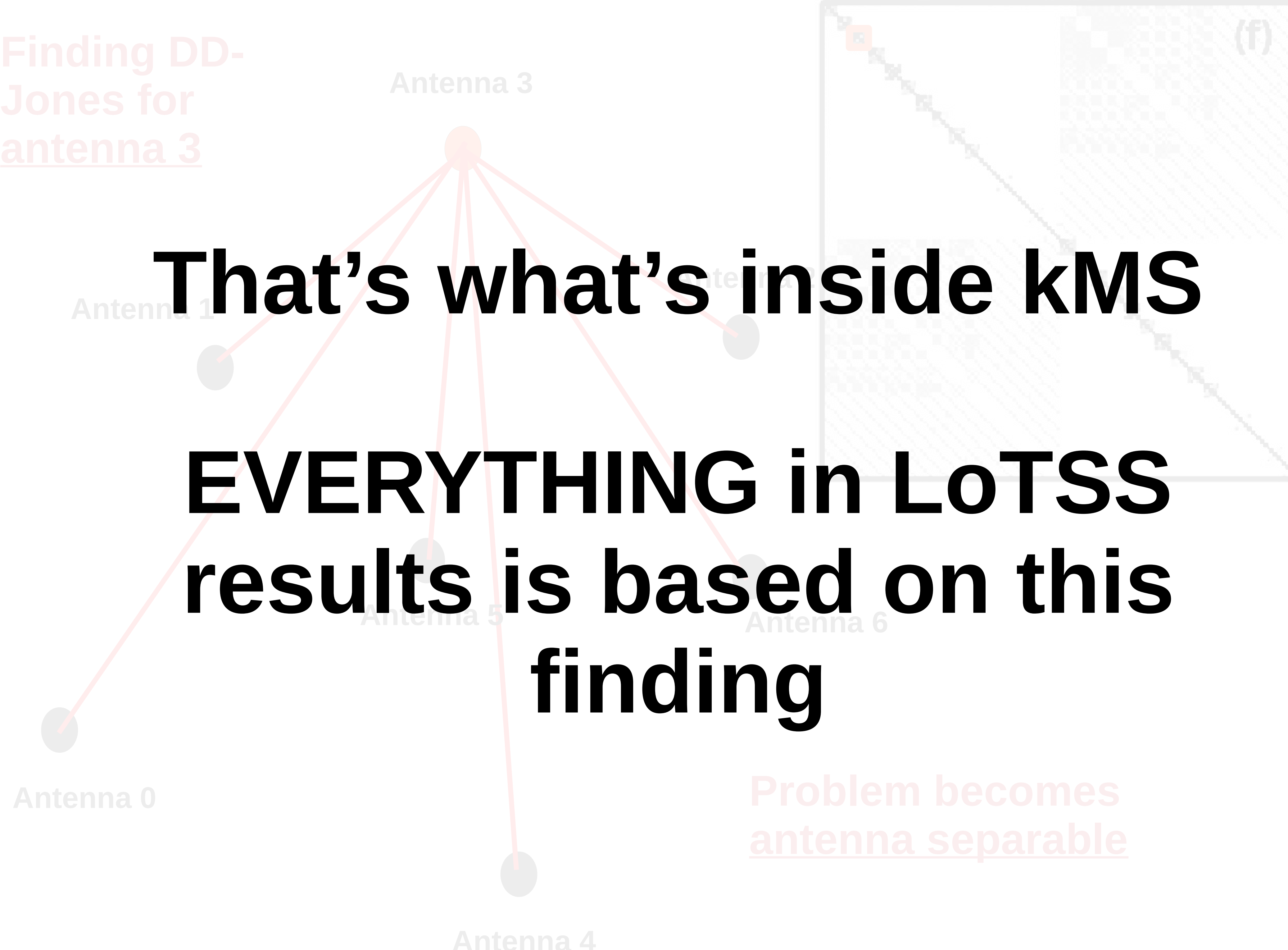
Wirtinger Hessian

(Tasse 2014, Smirnov & Tasse 2015, Repetti et al. 2017 *)*

Problem becomes <u>antenna separable</u>

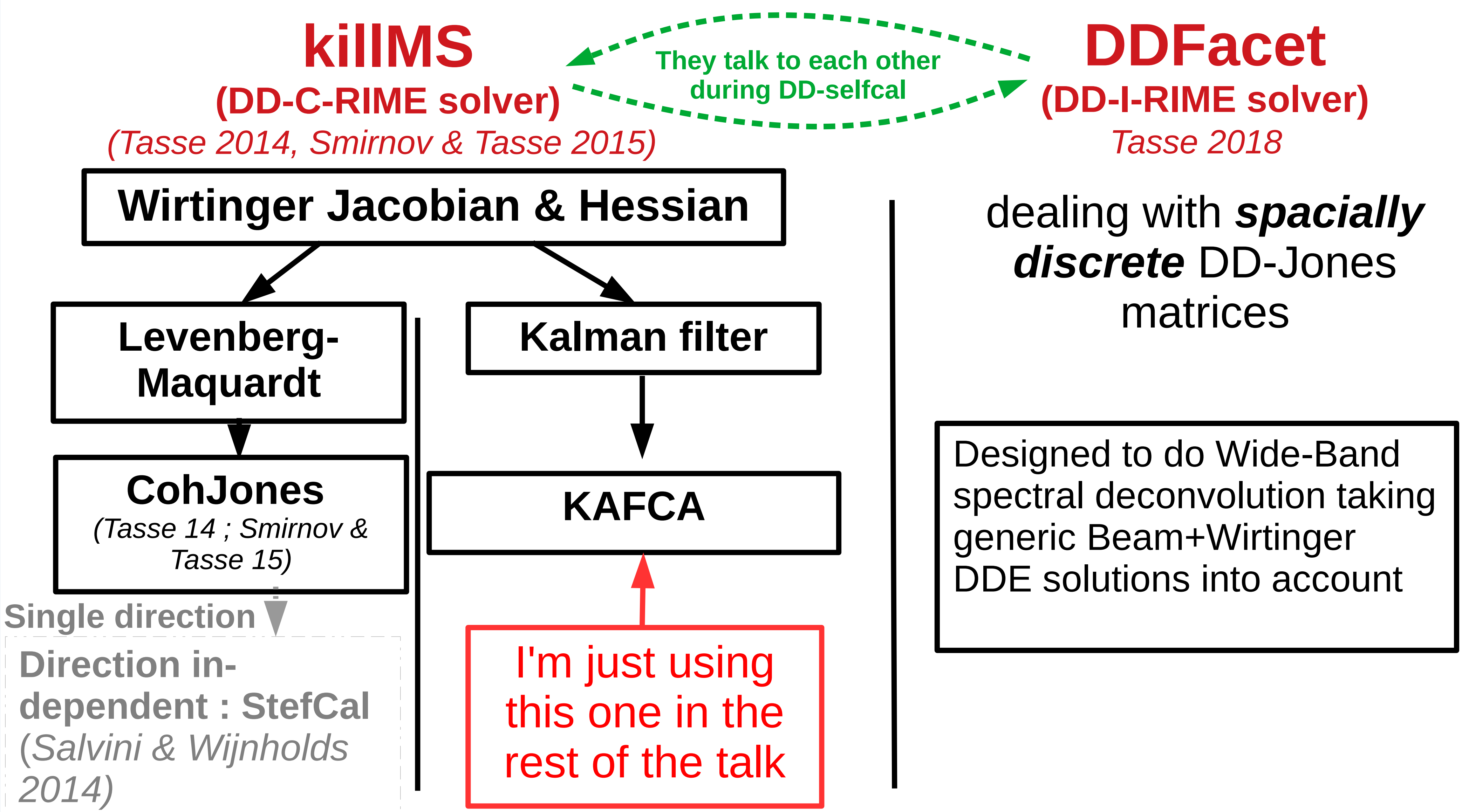
That’s what’s inside kMS

EVERYTHING in LoTSS results is based on this finding



Wirtinger algorithms: software

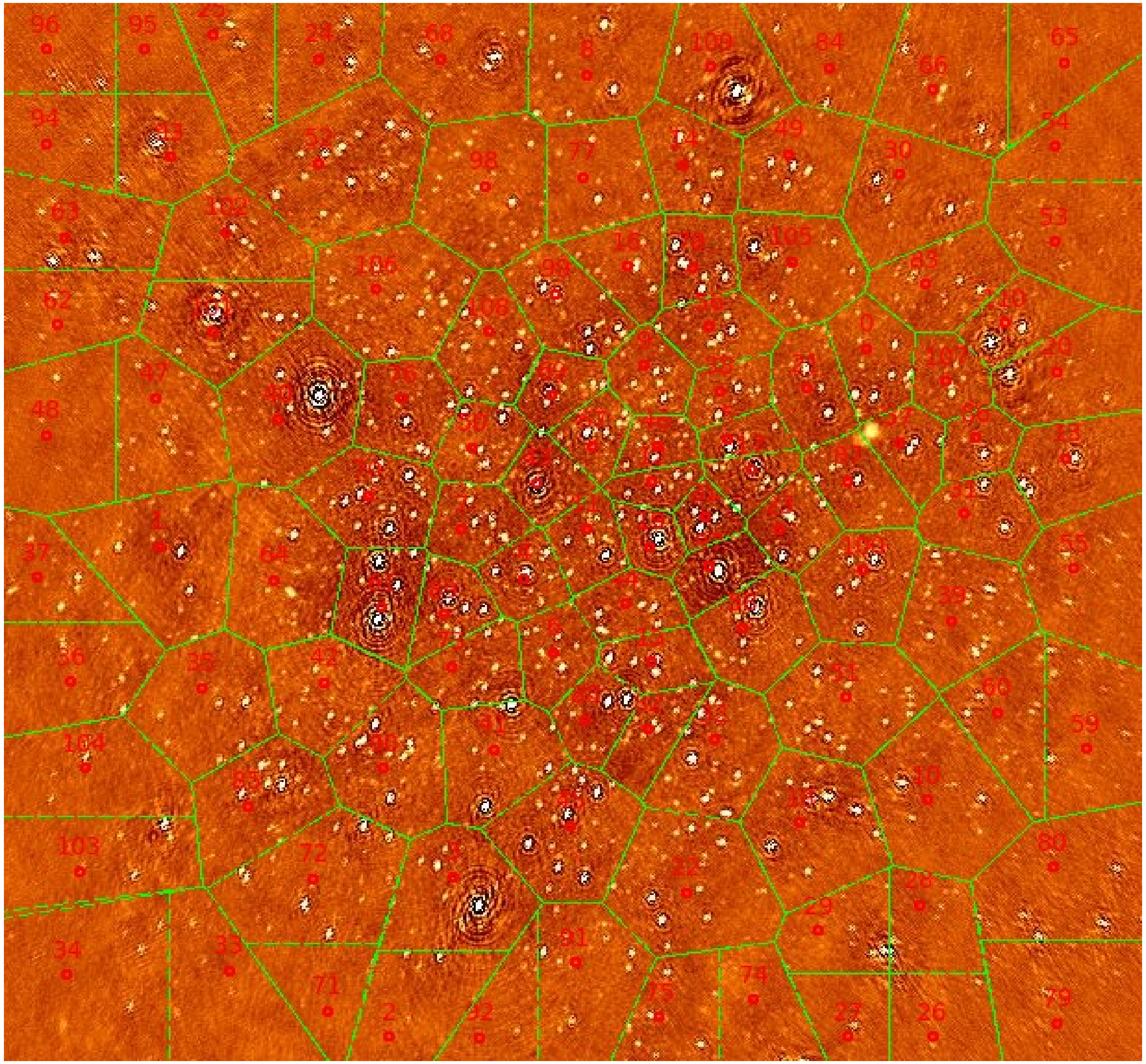
DDF-pipeline
(Martin Hardcastle, Tim Shimwell, Cyril Tasse, Wendy Williams)



DDFacet

Tasse et al. 2018

… 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

(4) Does tesselated images

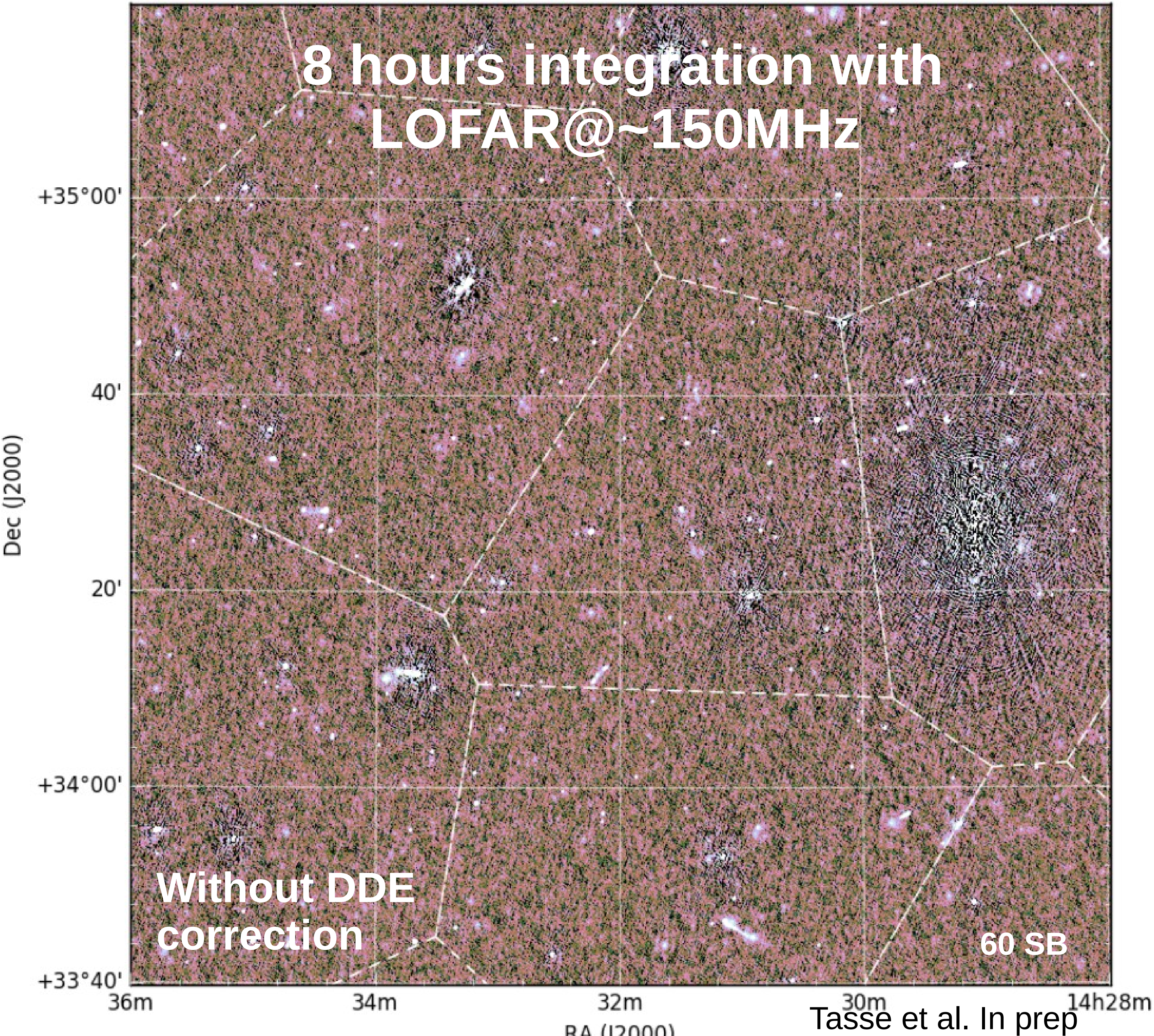
(5) Does take time-freq-baseline-direction dependent beam into account

(6) Continuity between facets

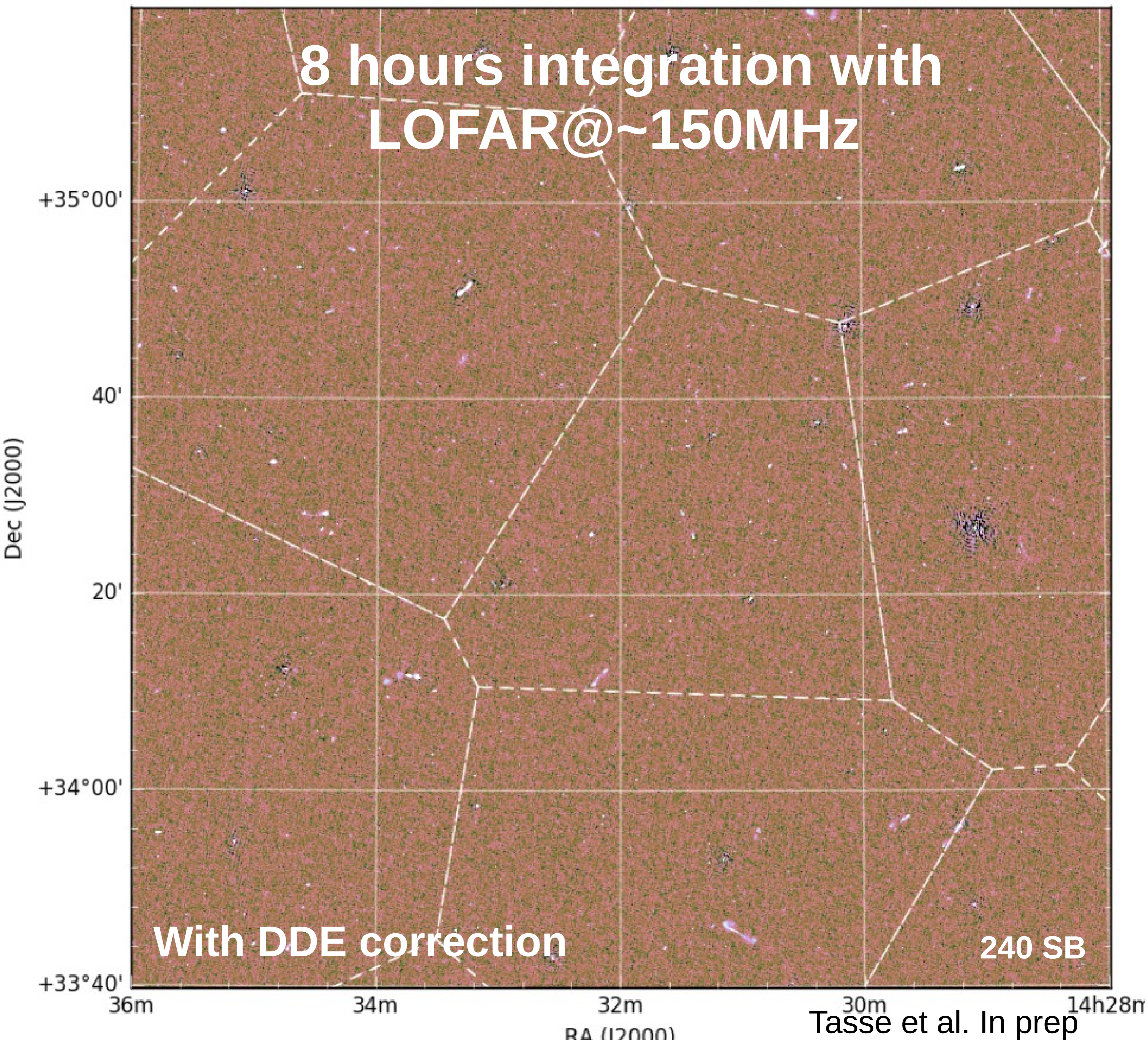
(7) Takes variable PSF into account (DDE, Smearing/Decorrelation)

(8) Mosaicing (!)

(9) Some very fancy deconvolution algorithm (SSD)

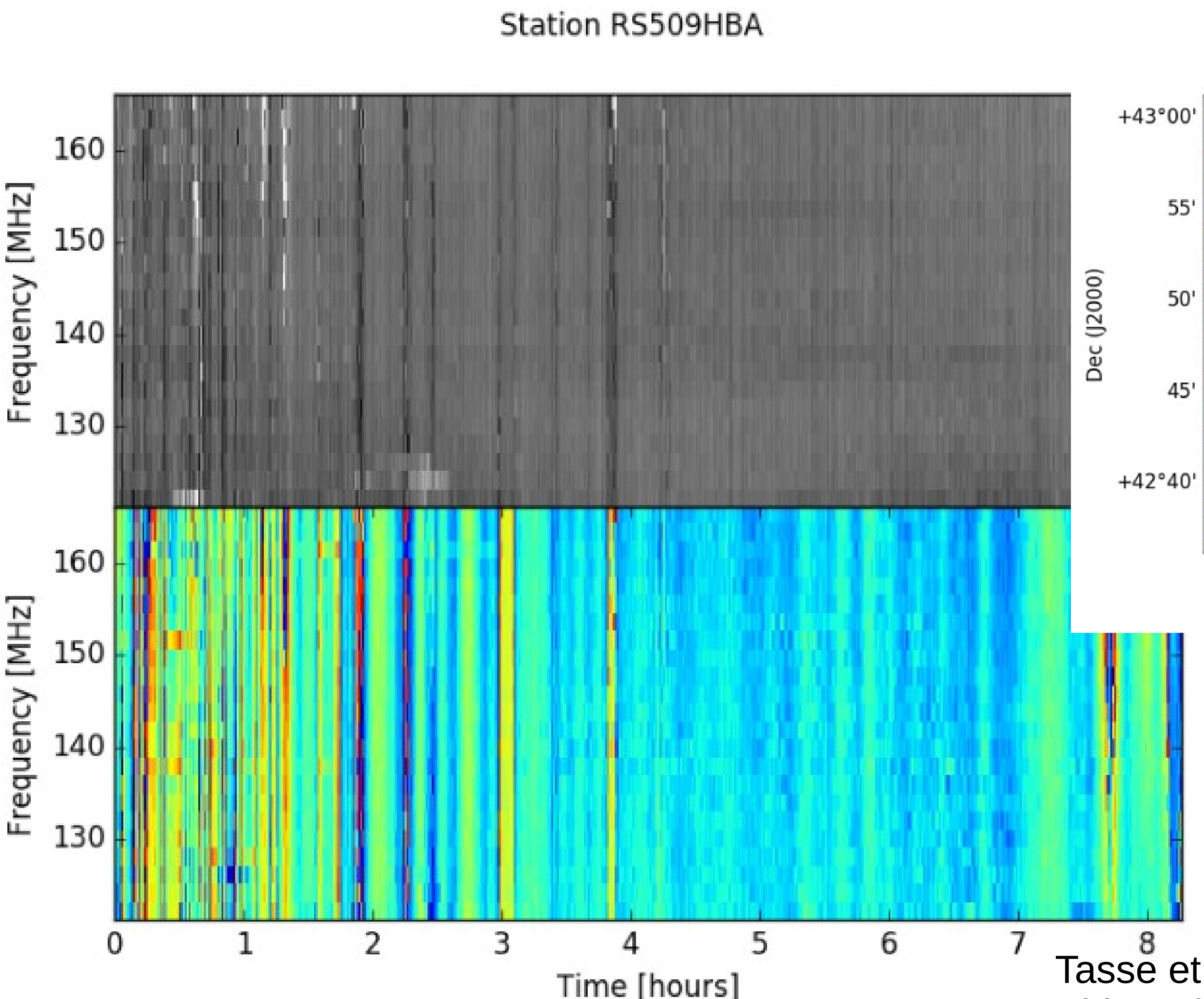


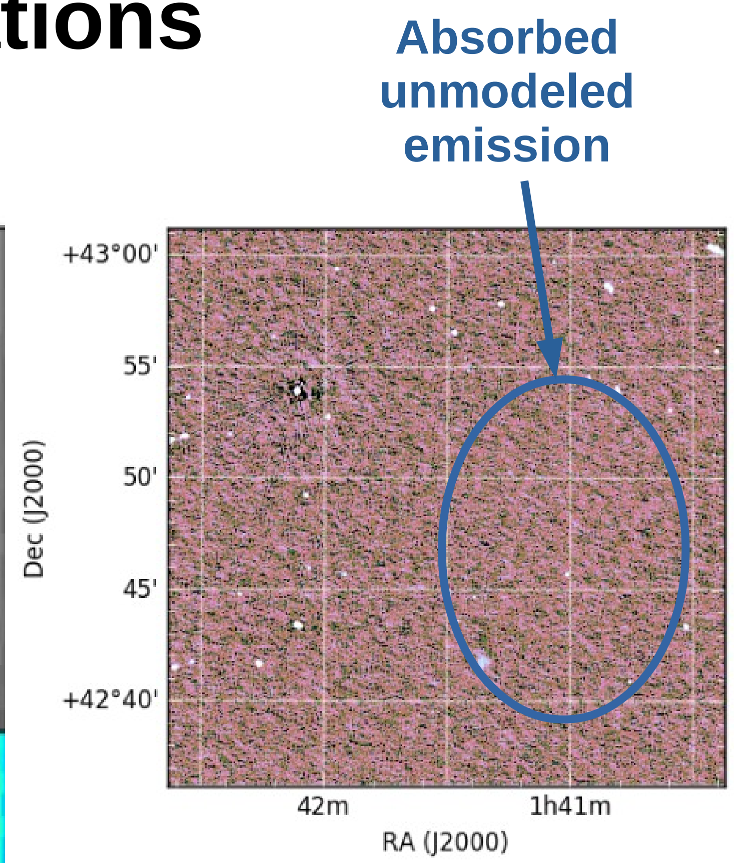
Tasse et al. In prep



Tasse et al. In prep

Ddf-pipeline & LOTSS/DR2 : Gains for different stations

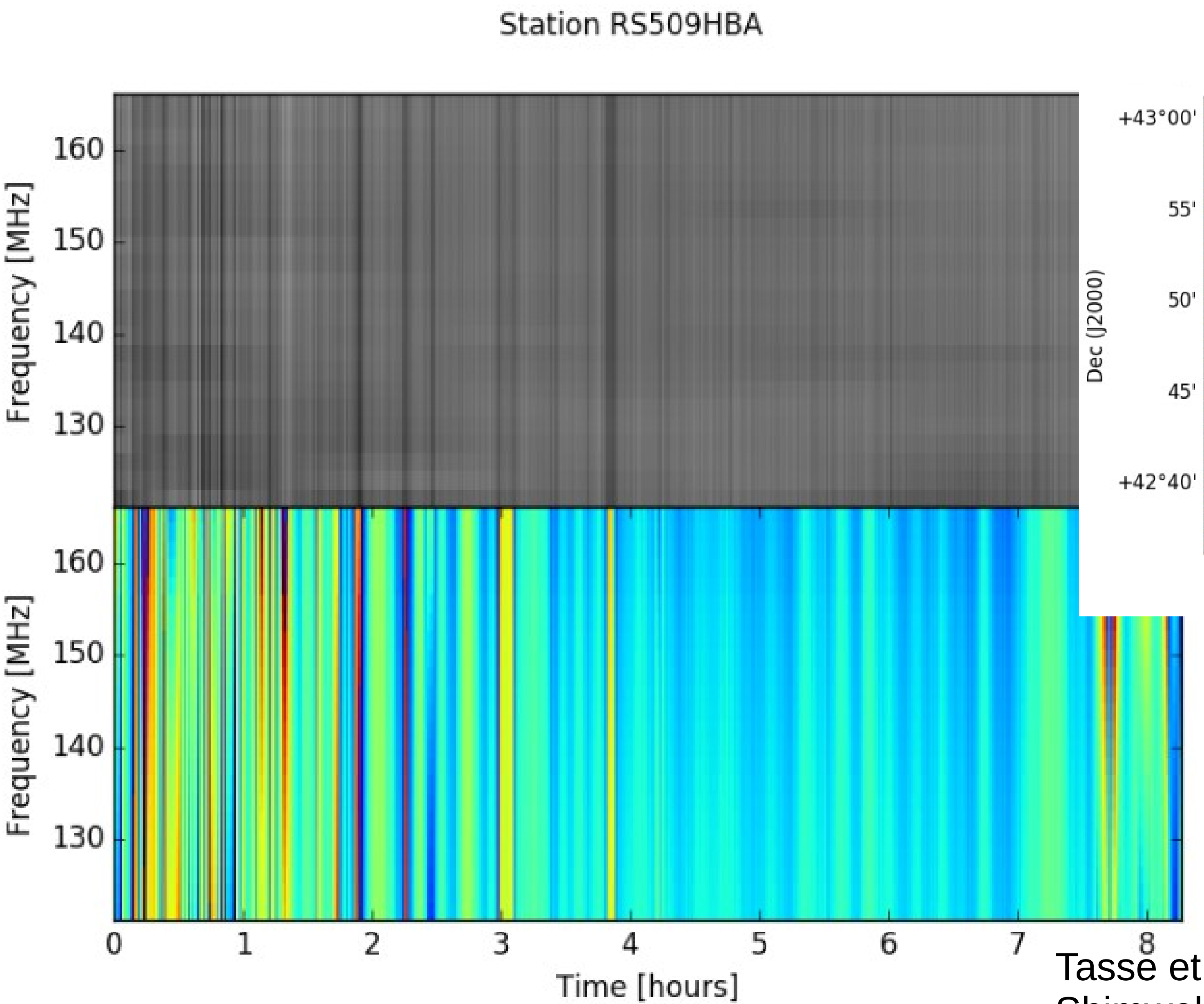




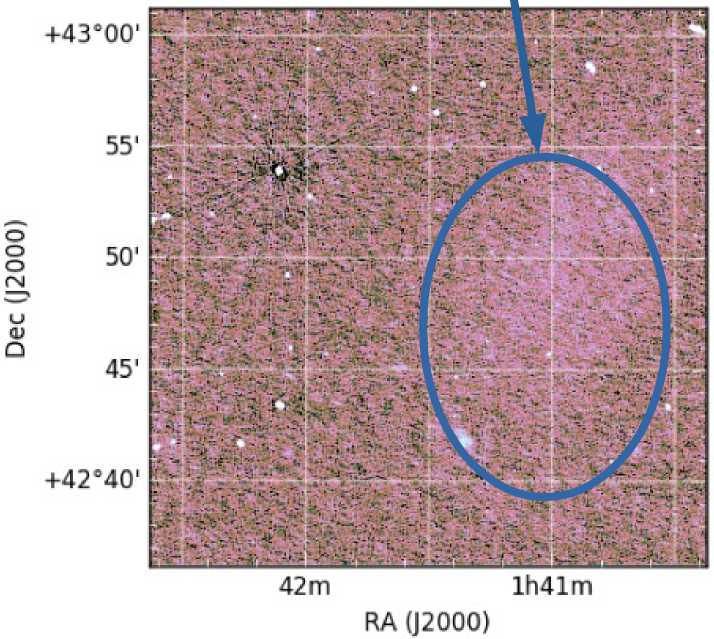
Raw DDE solutions

Tasse et al. In prep
Shimwell et al. In prep

Ddf-pipeline & LOTSS/DR2 : Gains for different stations



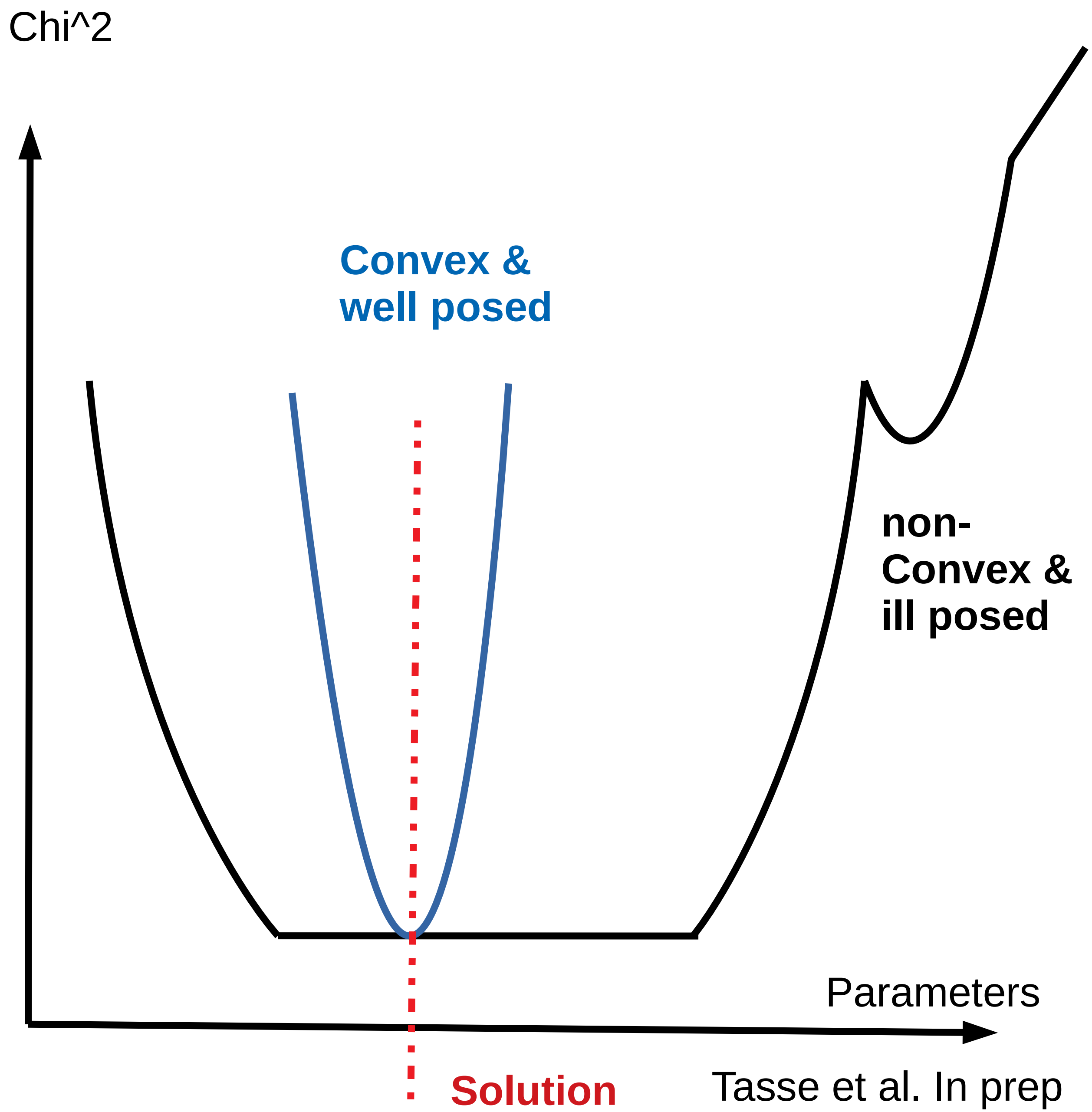
Recovered unmodeled emission



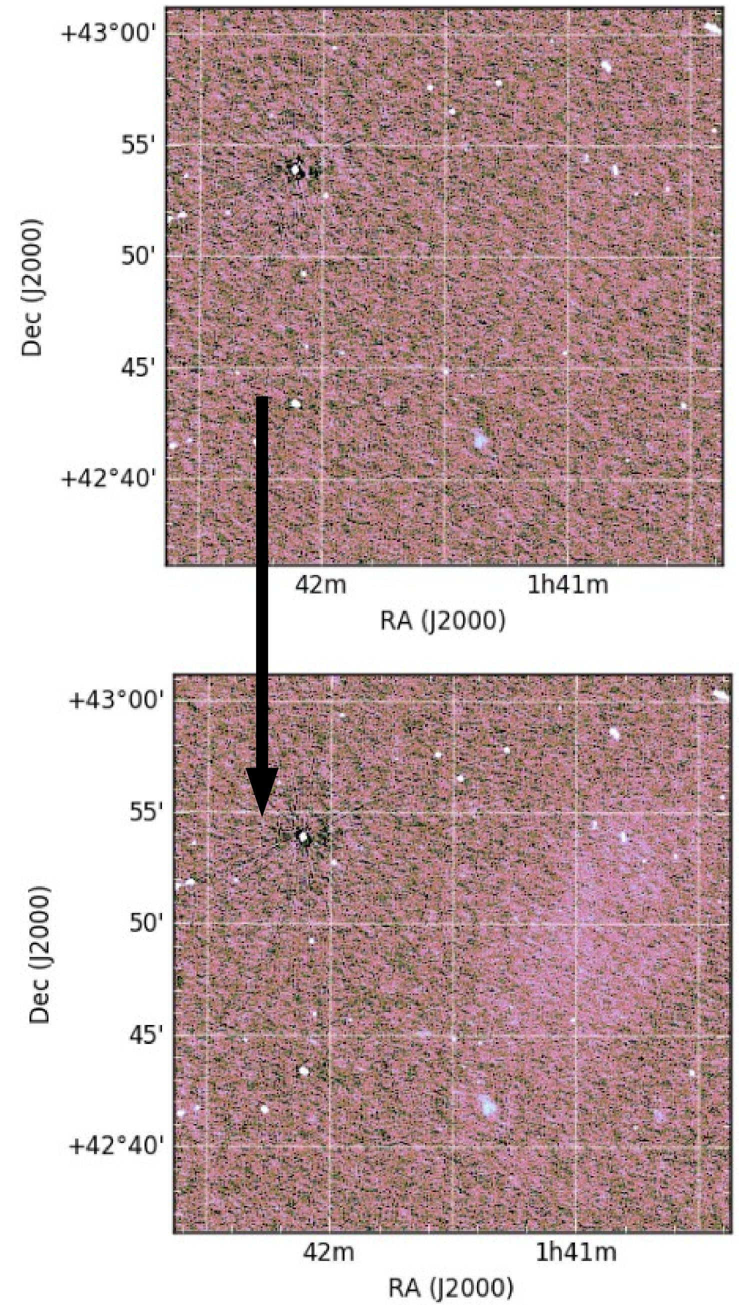
Smoothed DDE solutions

Tasse et al. In prep
Shimwell et al. In prep

Convexity, Conditionning



Tasse et al. In prep
Shimwell et al. In prep



See also
Yatawatta et al. 2017, 2018
Repetti et al. 2017

Fully automatic pipeline….

15 nodes running at Hertfortshire (@Hardcastle's cluster) are enough to reduce LoTSS data flow 24/7

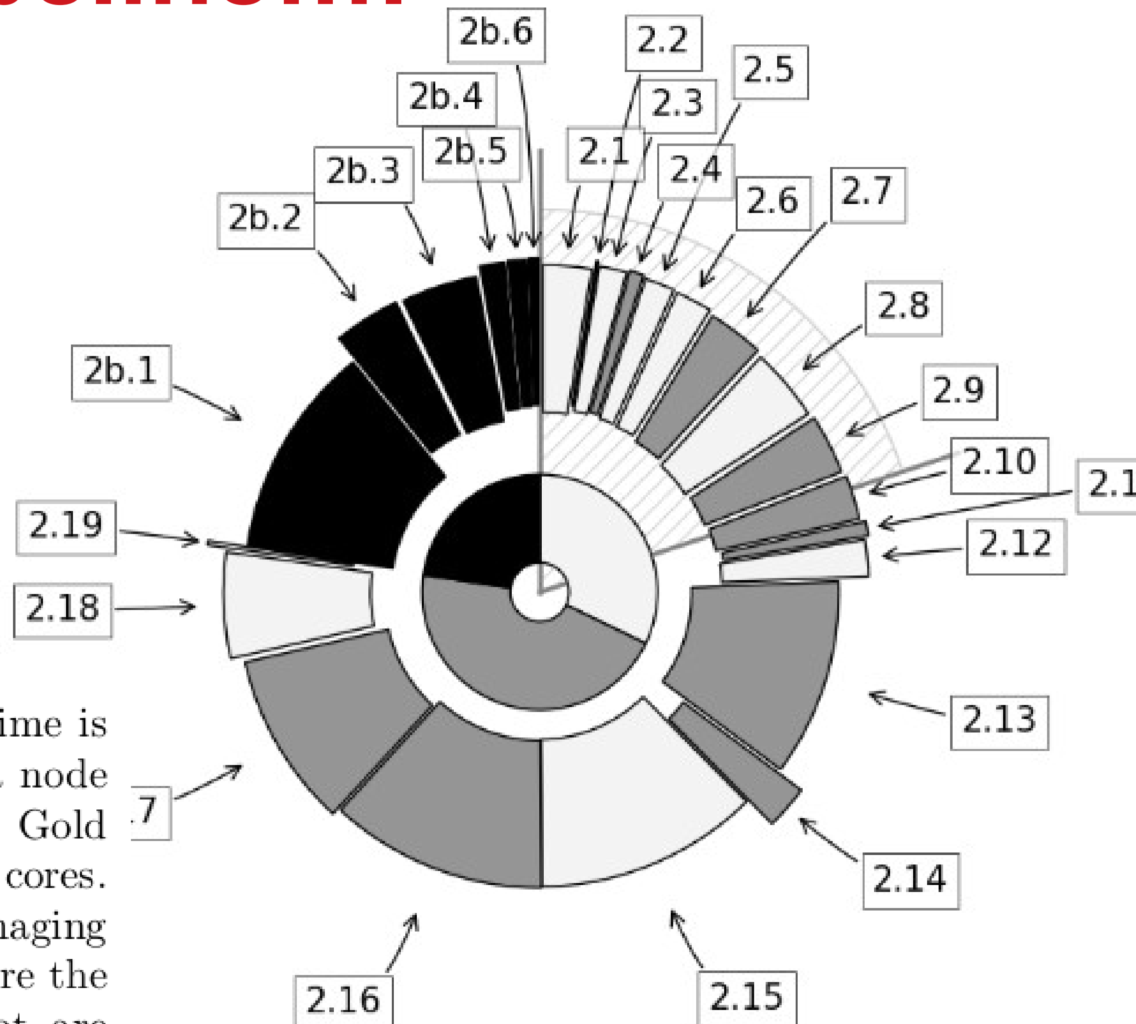
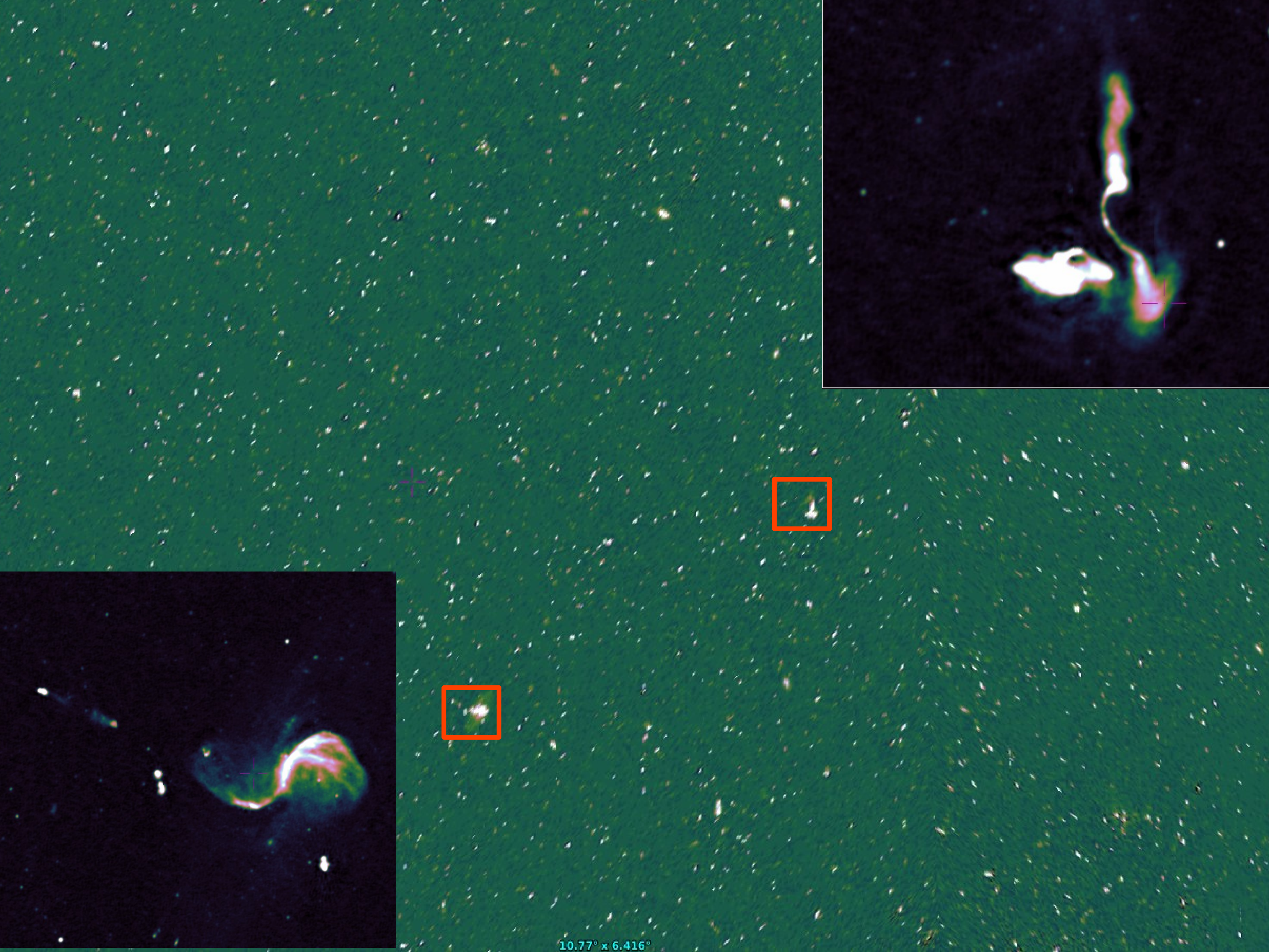


Fig. 2: This pie graph show how the computing time is distributed across the different steps of Al. 2 on a node equiped with 192 GBytes RAM and 2 Intel Xeon Gold 6130 CPU@2.10GHz, giving 32 physical compute cores. The lighter and darker grey areas represent the imaging and calibration steps respectively. The black area are the miscelaneous tasks (additional data products) that are done once the DI and DD self-calibration loops have completed. The dashed area is a quarter representing a day. The total run time is $\sim$ 5 days, so 15 such nodes are necessary to reduce the 8 hours LoTSS pointings in real-time.

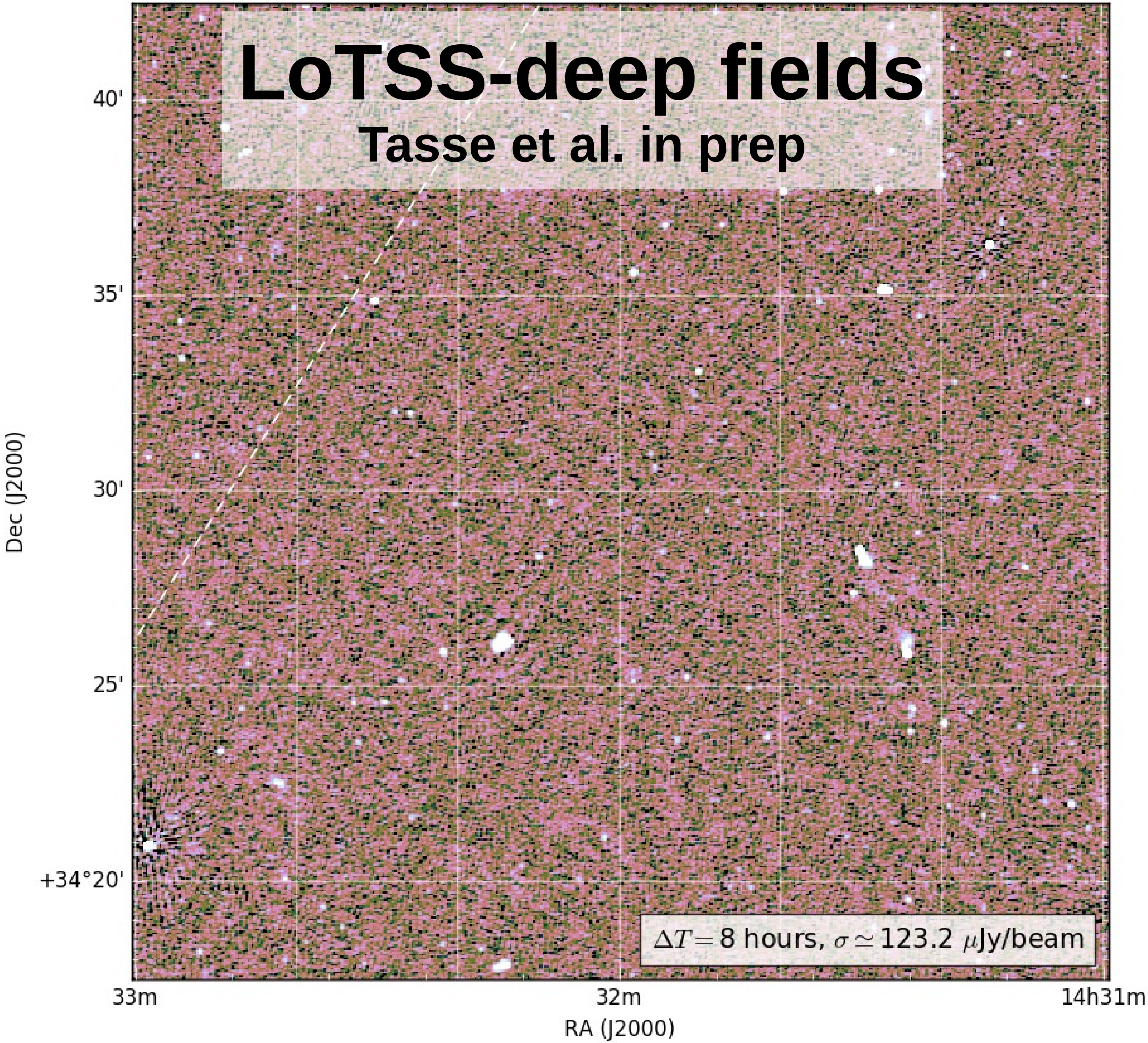
Light gray : DD-Imaging
Dark gray : DD-calibration

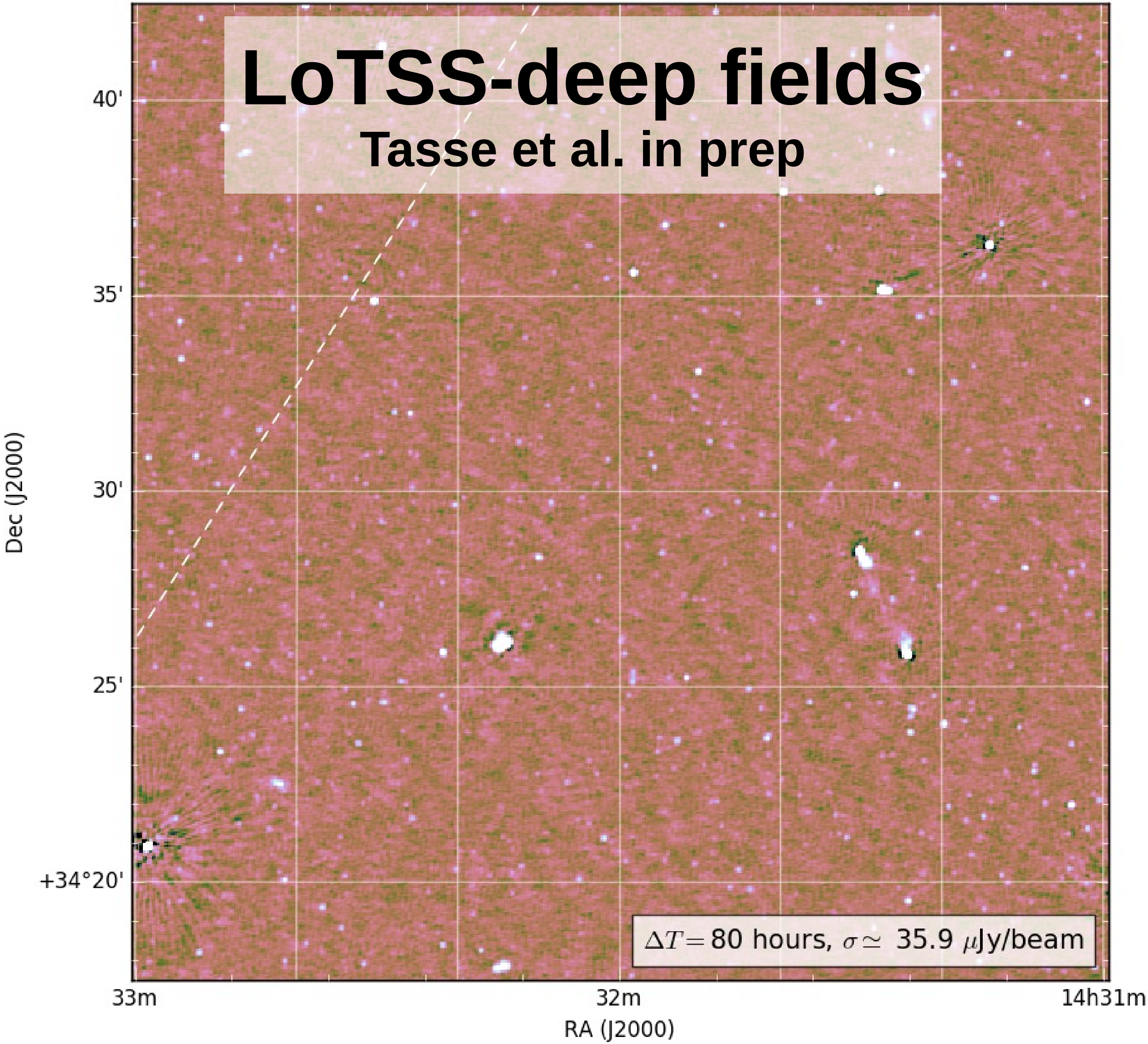
Tasse et al. In prep.


10.77° x 6.416°

LoTSS-deep fields

Tasse et al. in prep

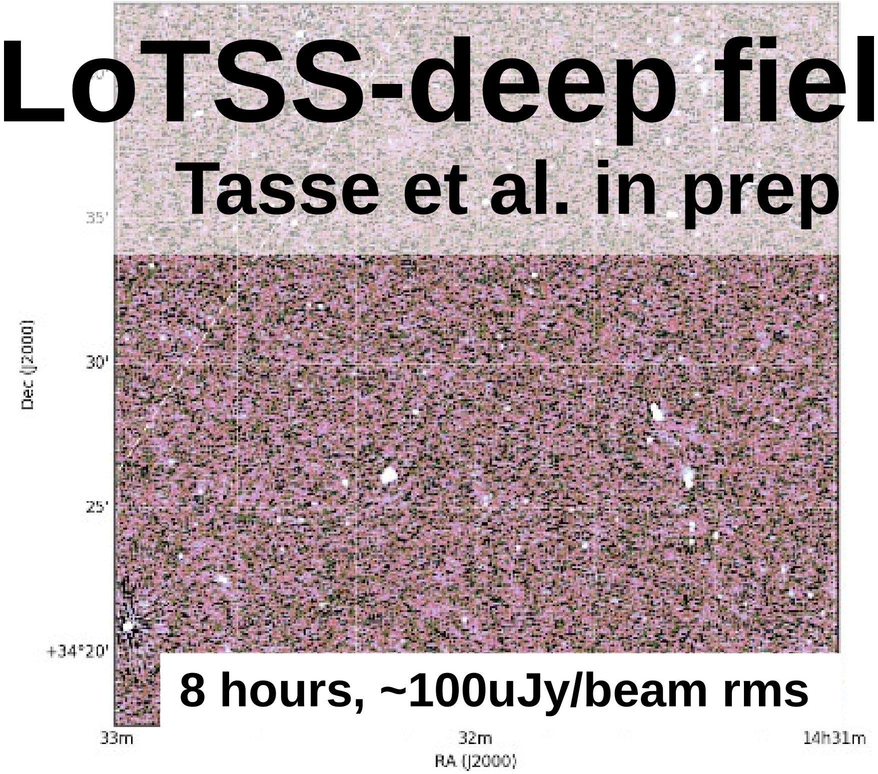


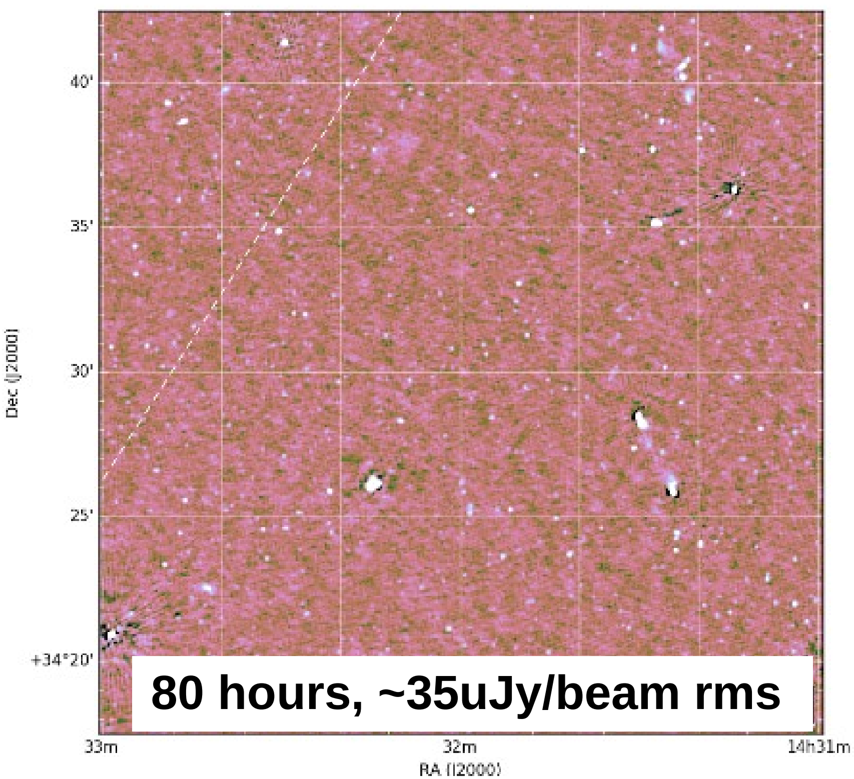


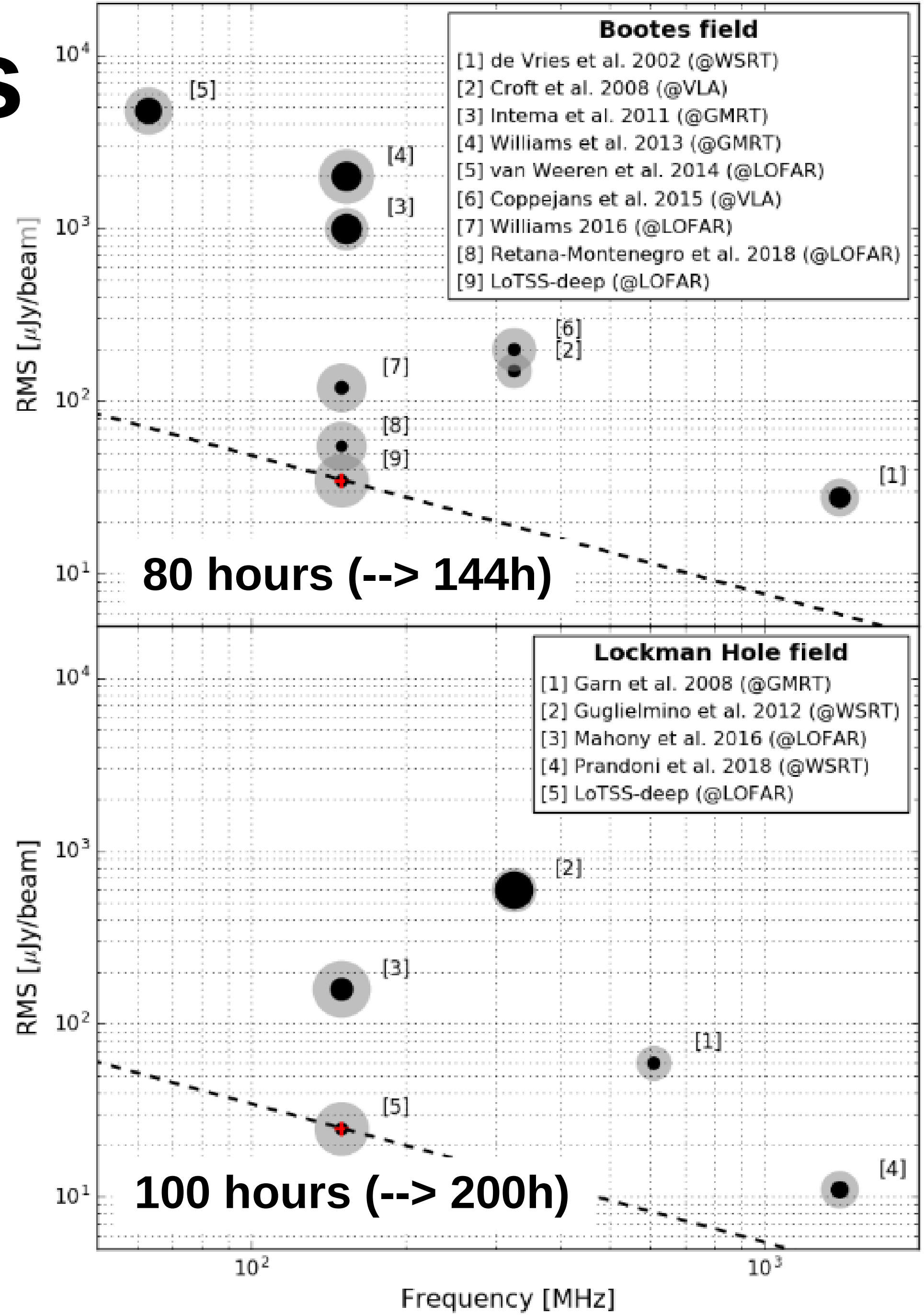
LoTSS-deep fields
Tasse et al. in prep
ΔT = 80 hours, σ ≃ 35.9 μJy/beam
40'
35'
30'
25'
+34°20'
Dec (J2000)
33m
32m
14h31m
RA (J2000)

LoTSS-deep fields

Tasse et al. in prep

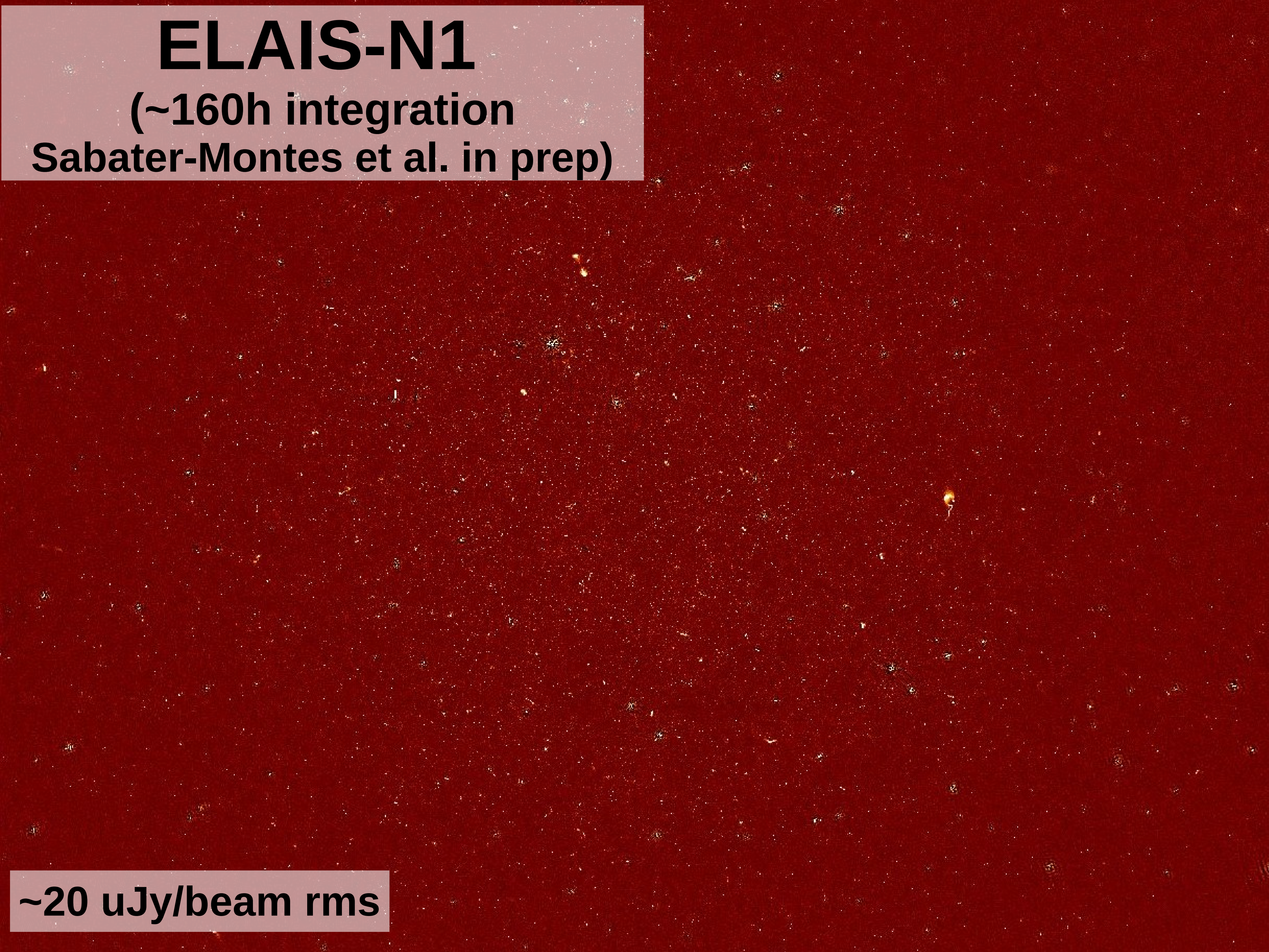


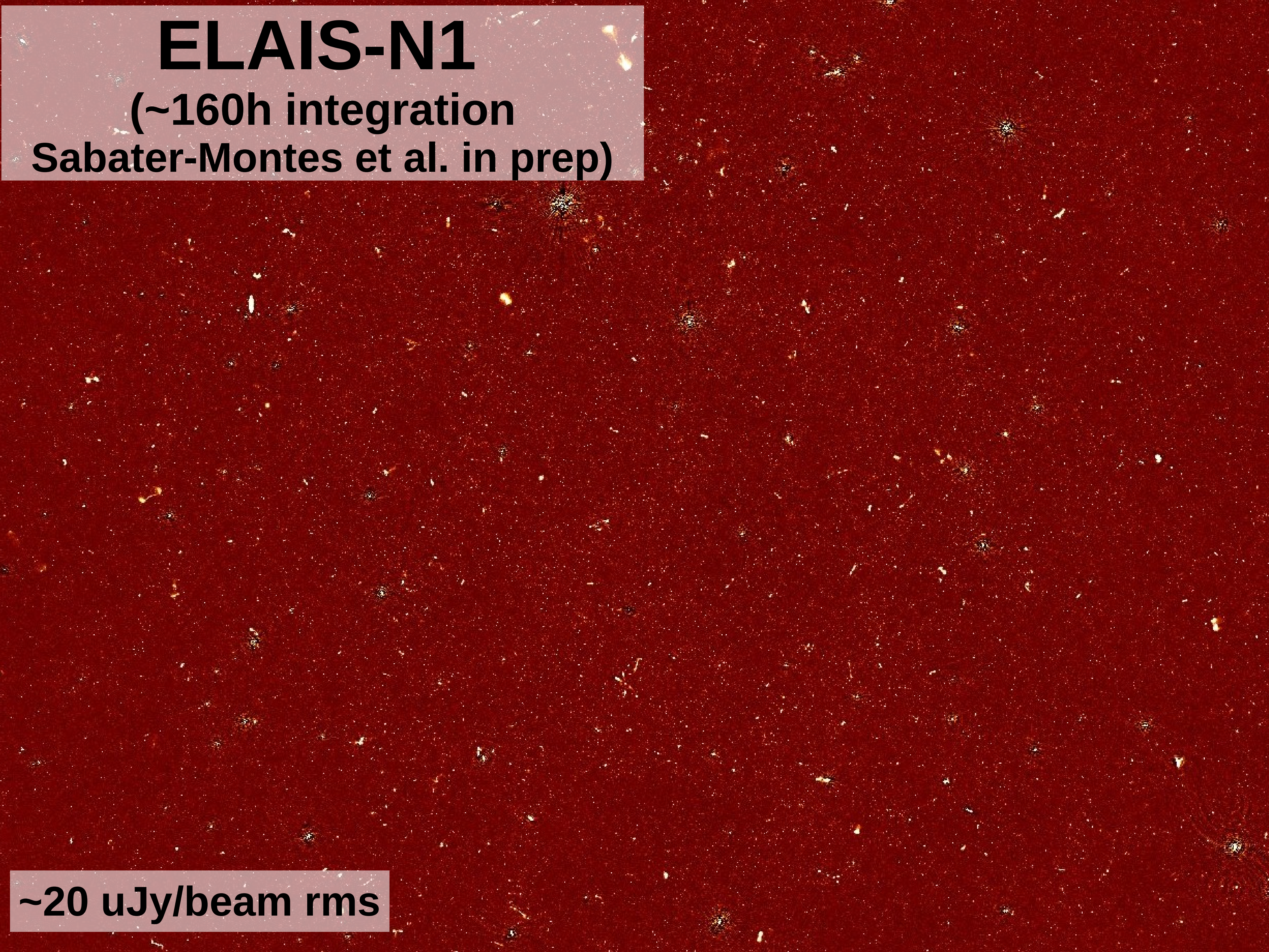


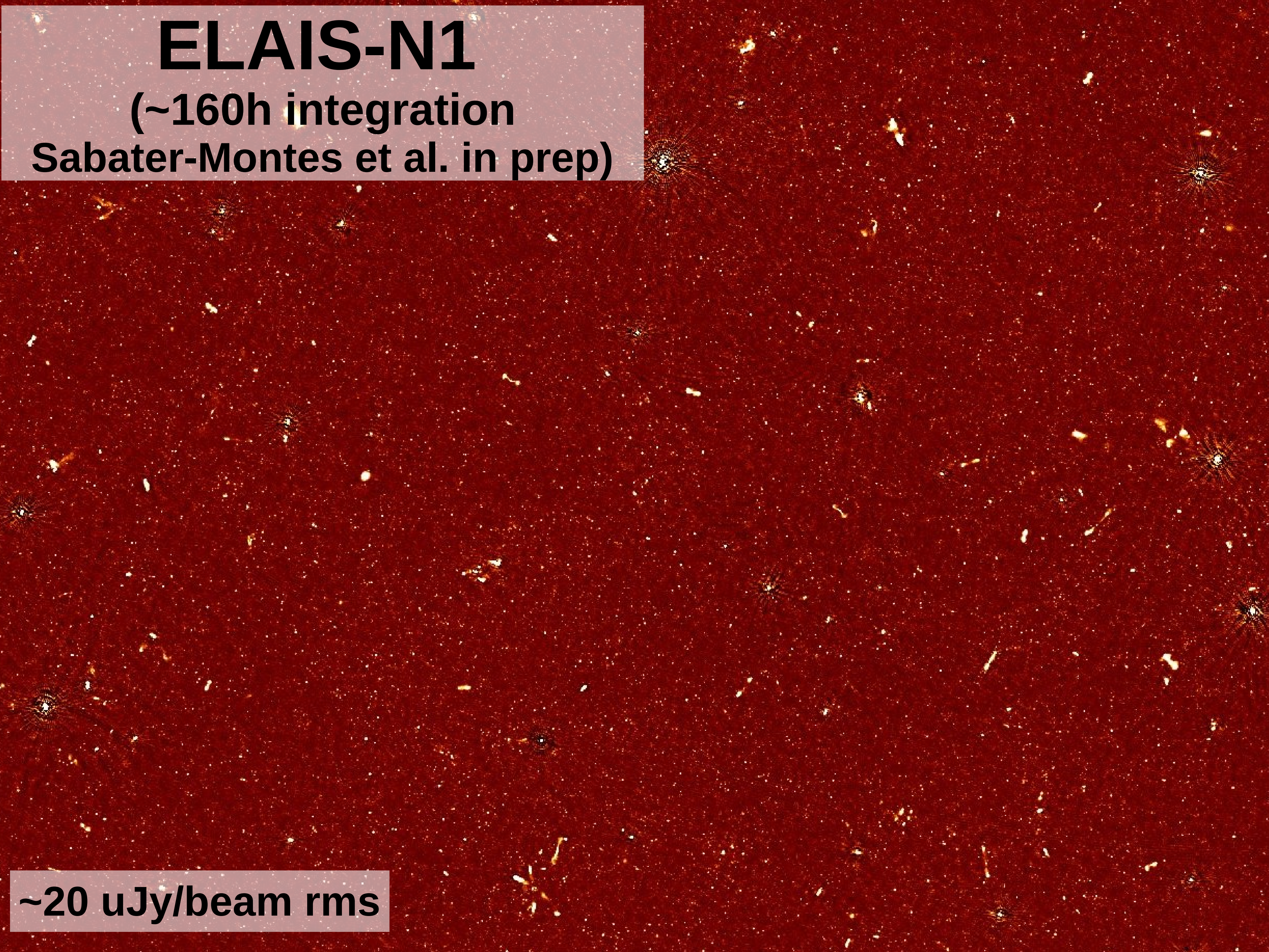


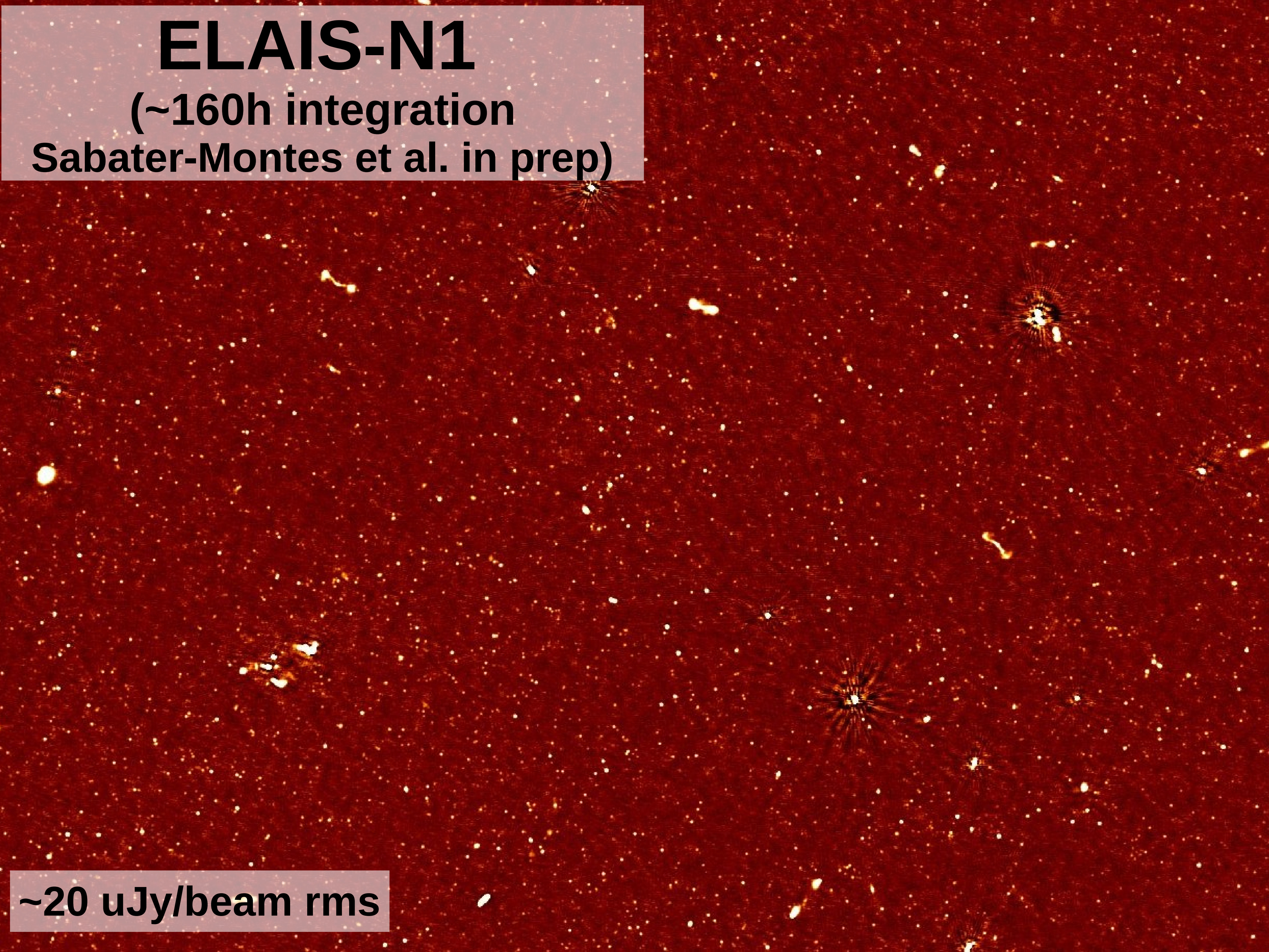
+ ELAIS-N1

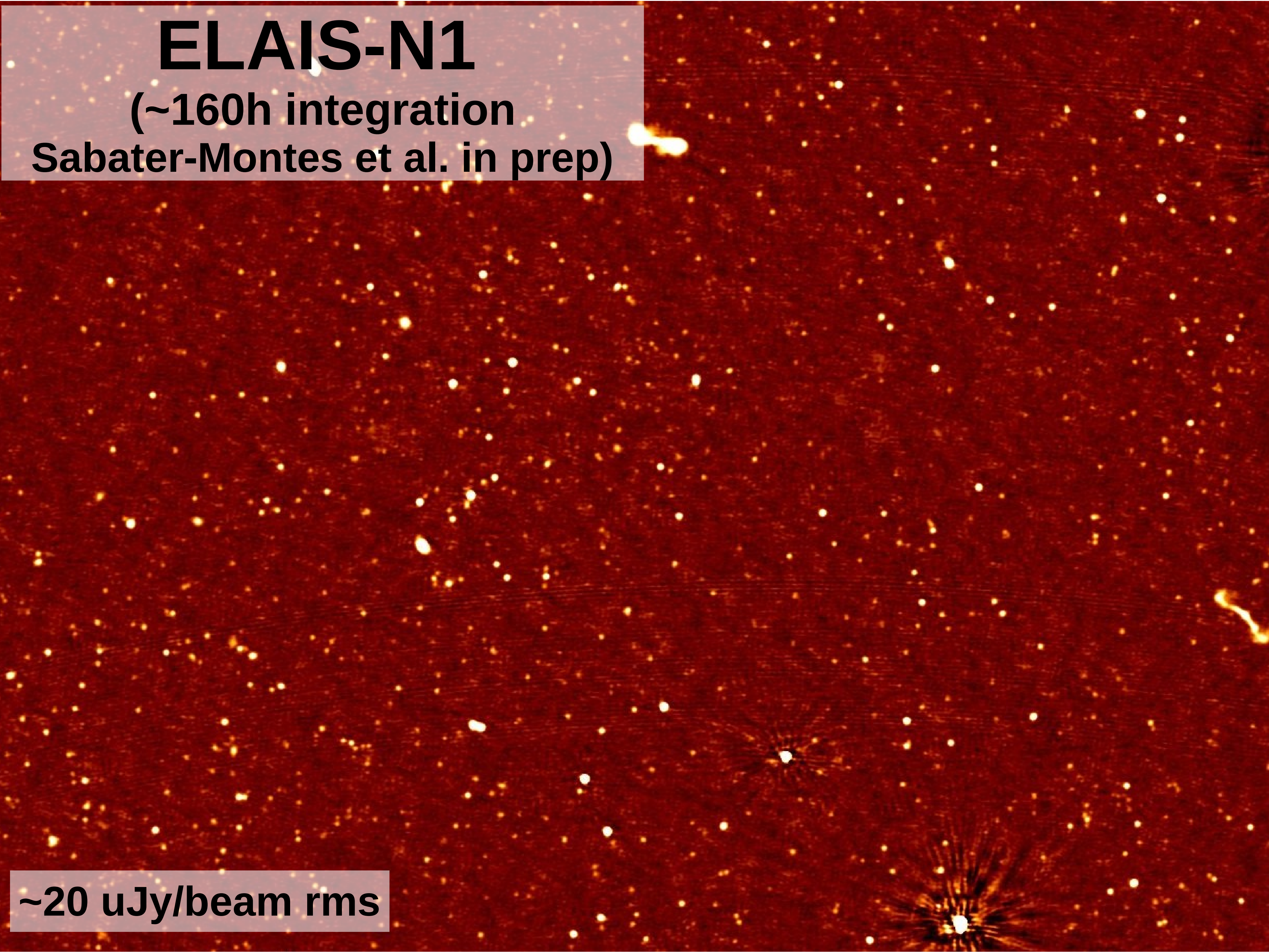
+ NCP

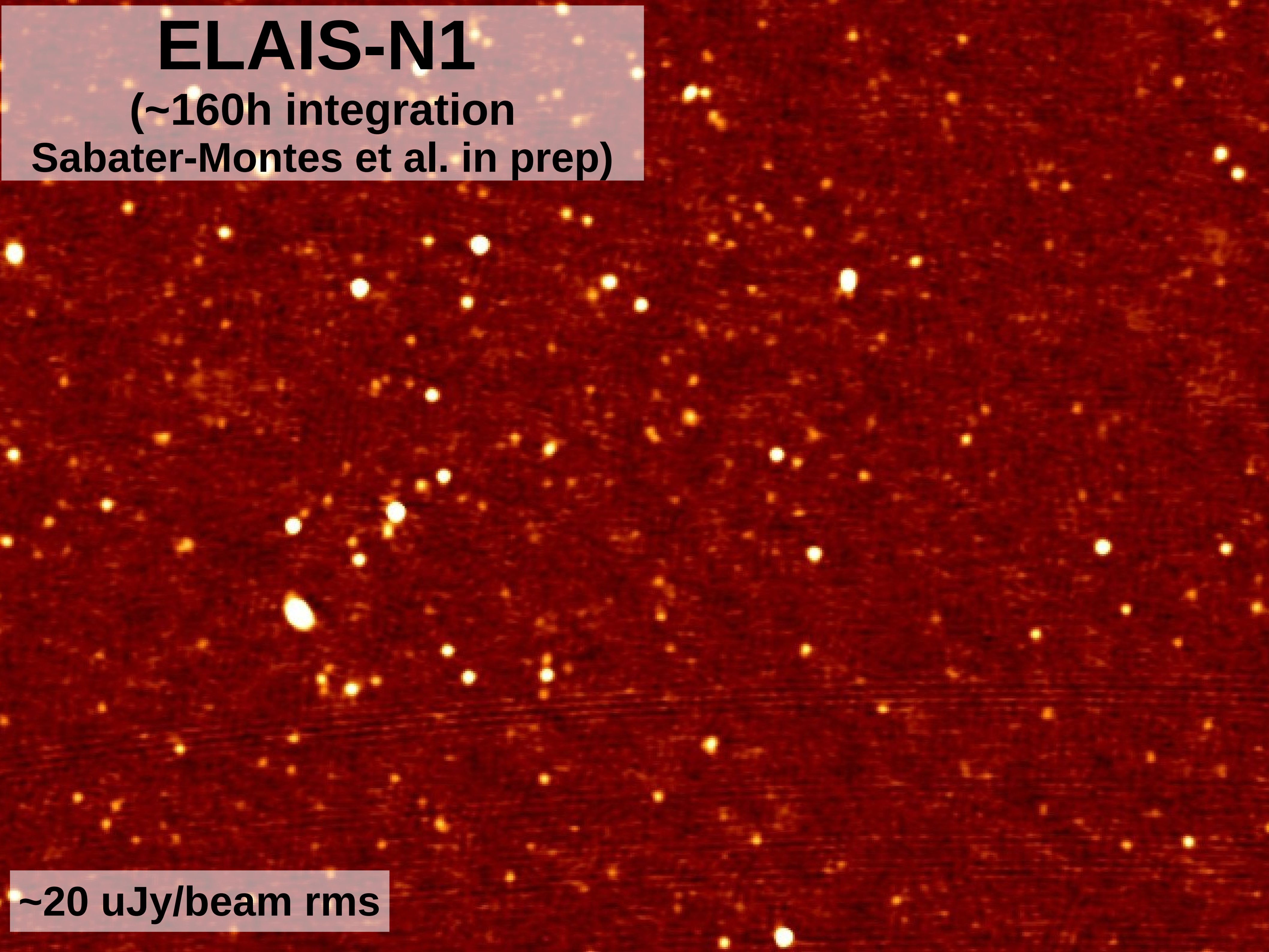

ELAIS-N1
(~160h integration
Sabater-Montes et al. in prep)
~20 uJy/beam rms


ELAIS-N1
(~160h integration
Sabater-Montes et al. in prep)
~20 uJy/beam rms


ELAIS-N1
(~160h integration
Sabater-Montes et al. in prep)
~20 uJy/beam rms

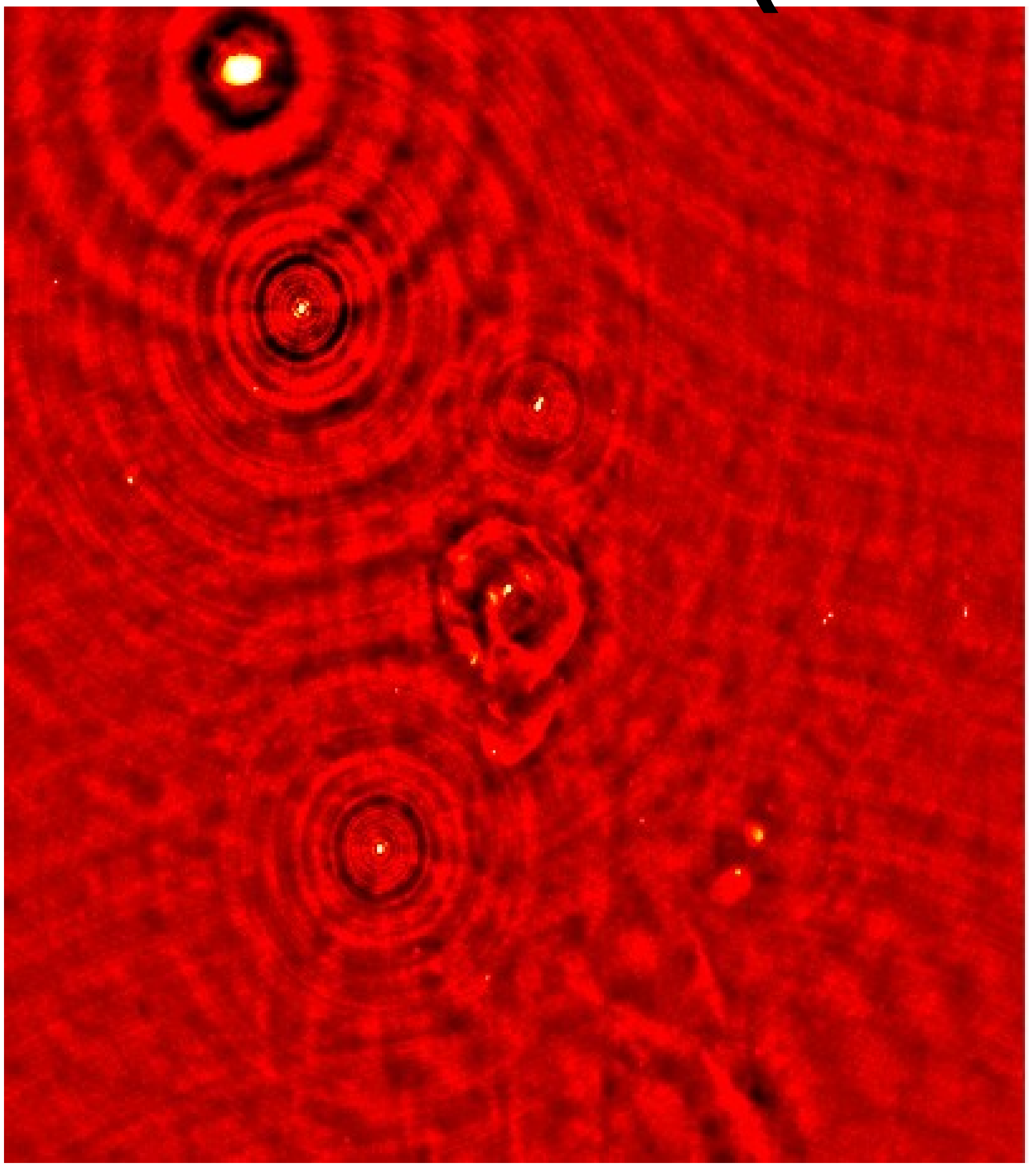

ELAIS-N1
(~160h integration
Sabater-Montes et al. in prep)
~20 uJy/beam rms


ELAIS-N1
(~160h integration
Sabater-Montes et al. in prep)
~20 uJy/beam rms

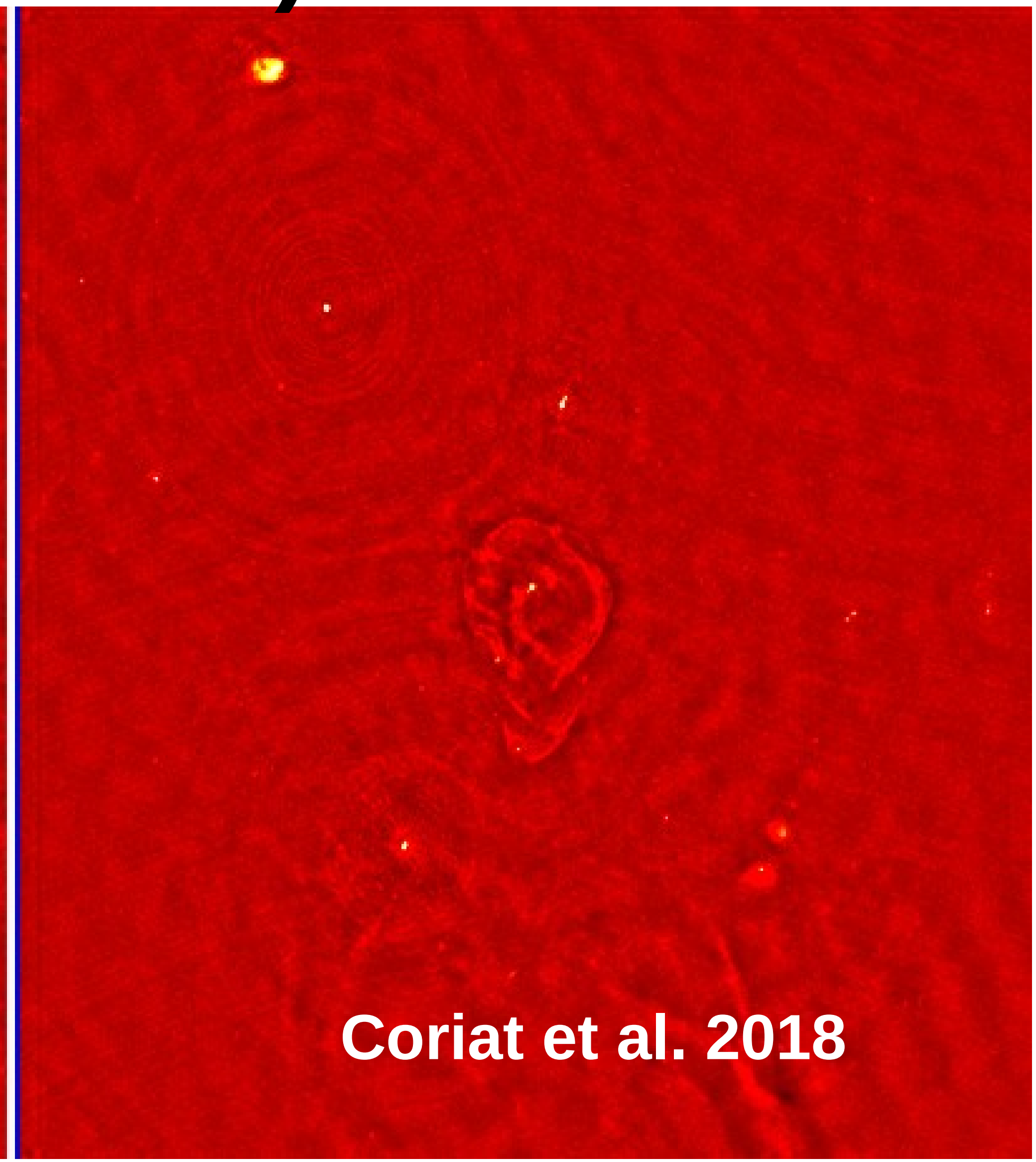

ELAIS-N1
(~160h integration
Sabater-Montes et al. in prep)
~20 uJy/beam rms


Thank you !

And it also works on ATCA data (Circinus a)

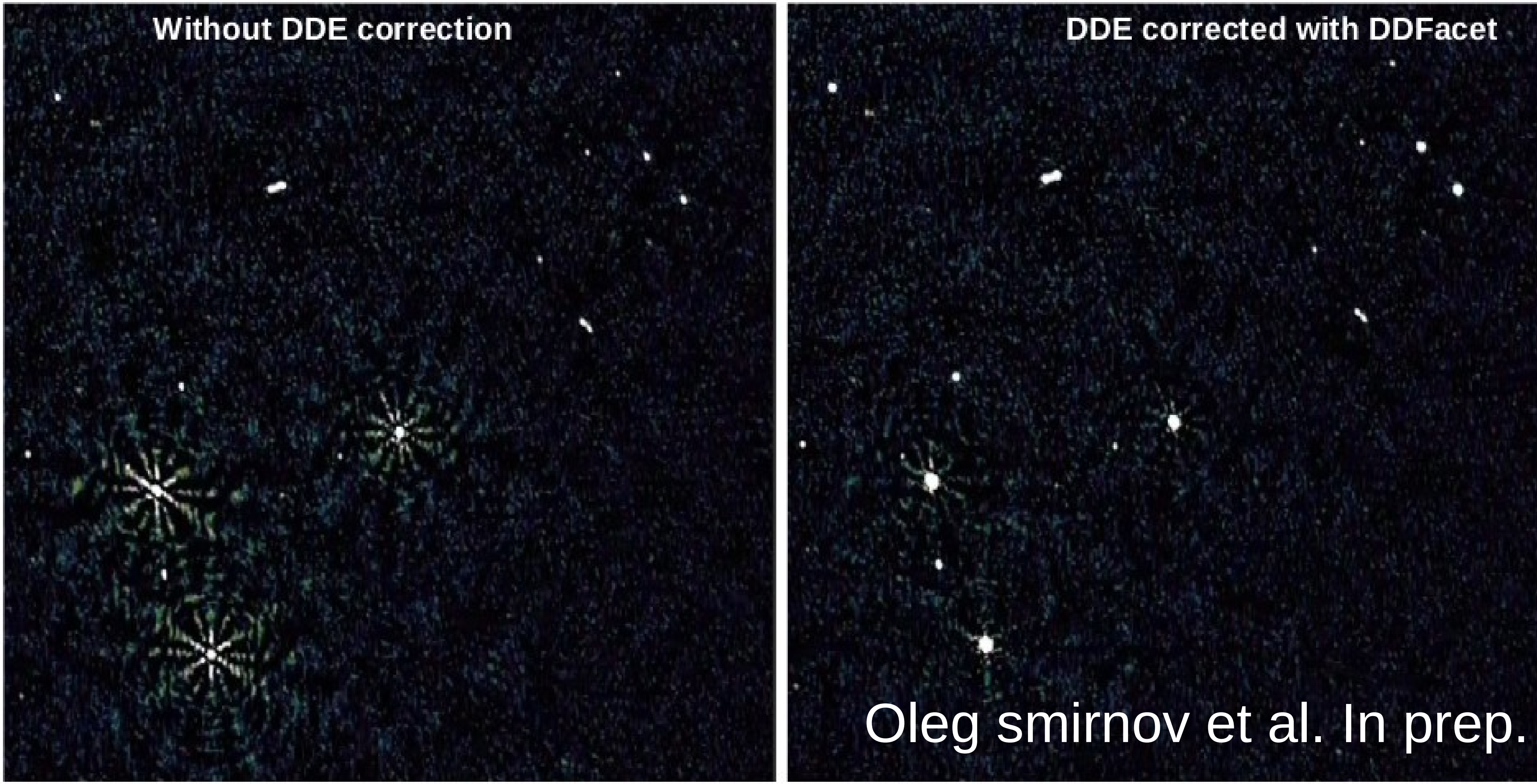


Direction independent calibration



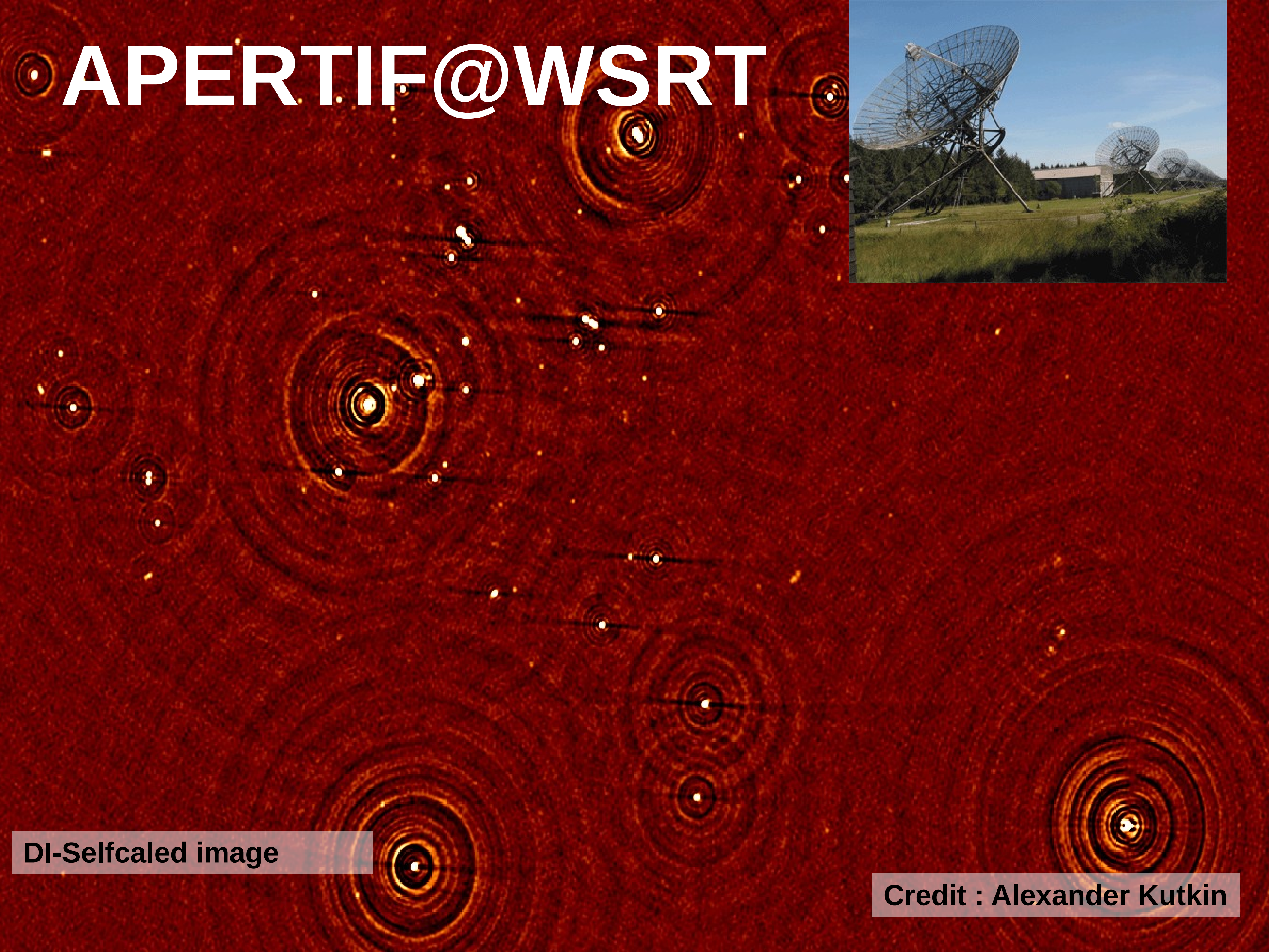
DDE with Wirtinger

And it also works on VLA data

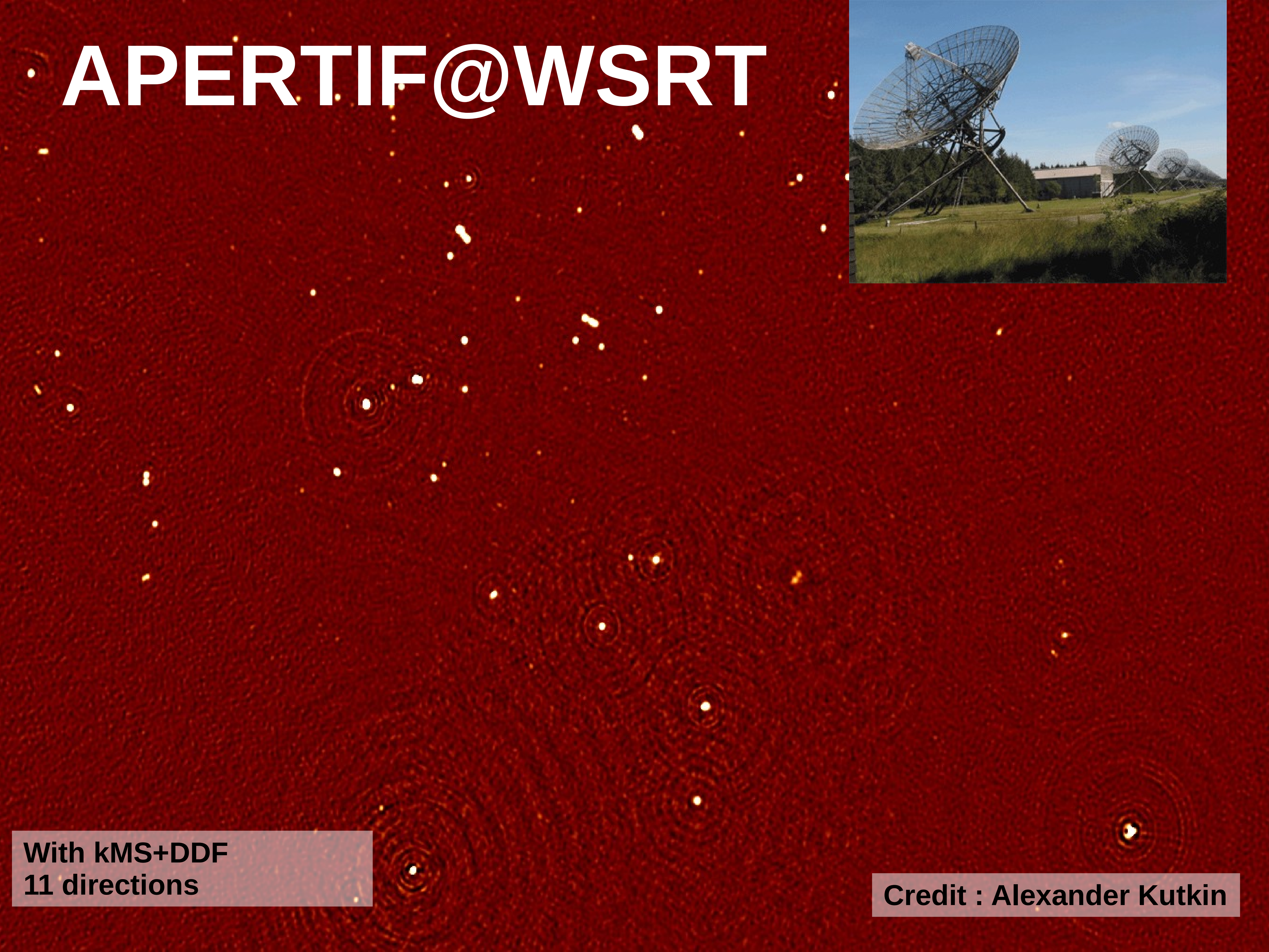


VLA beam model used to construct the Jones matrices

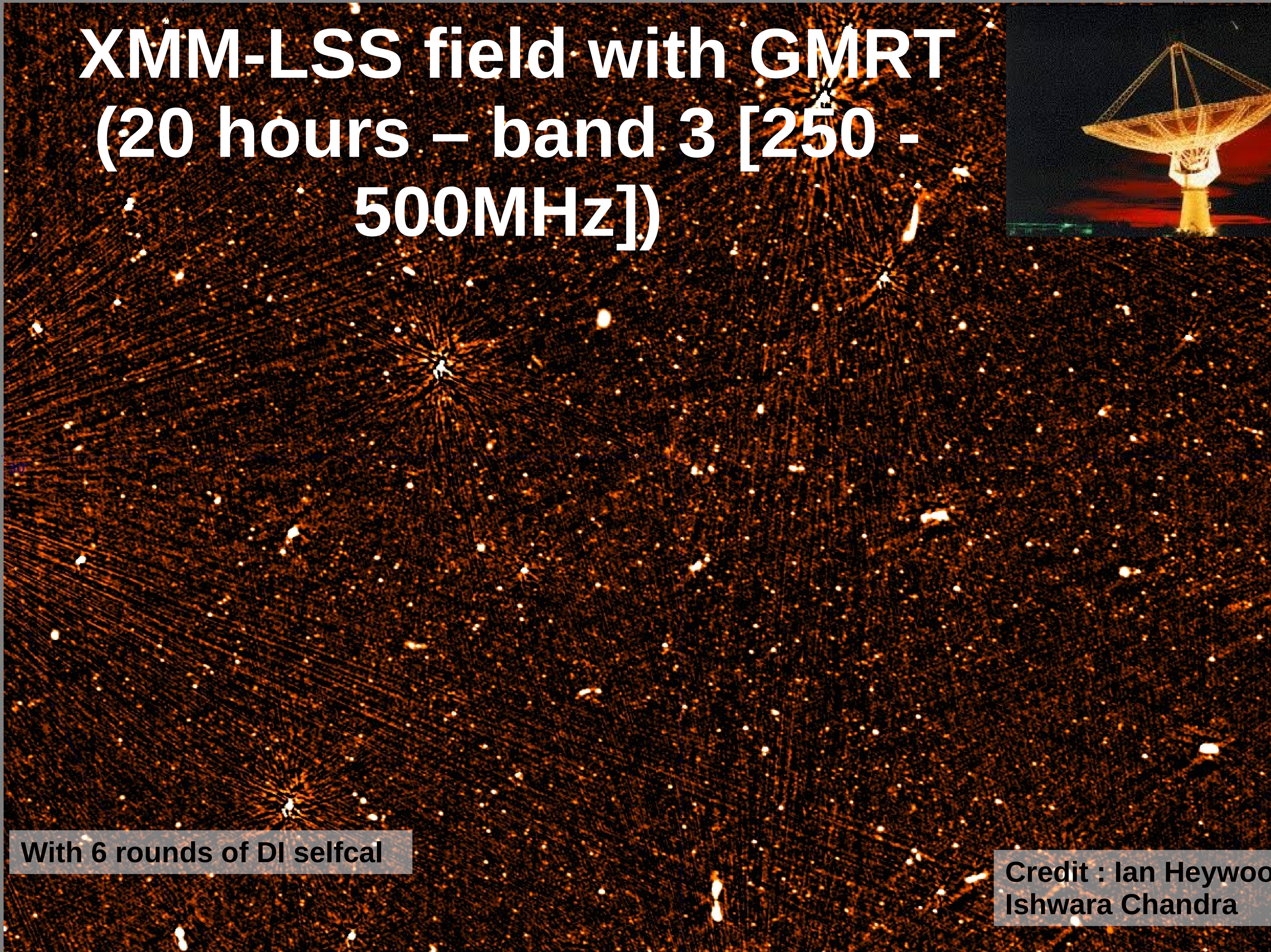
APERTIF@WSRT



APERTIF@WSRT



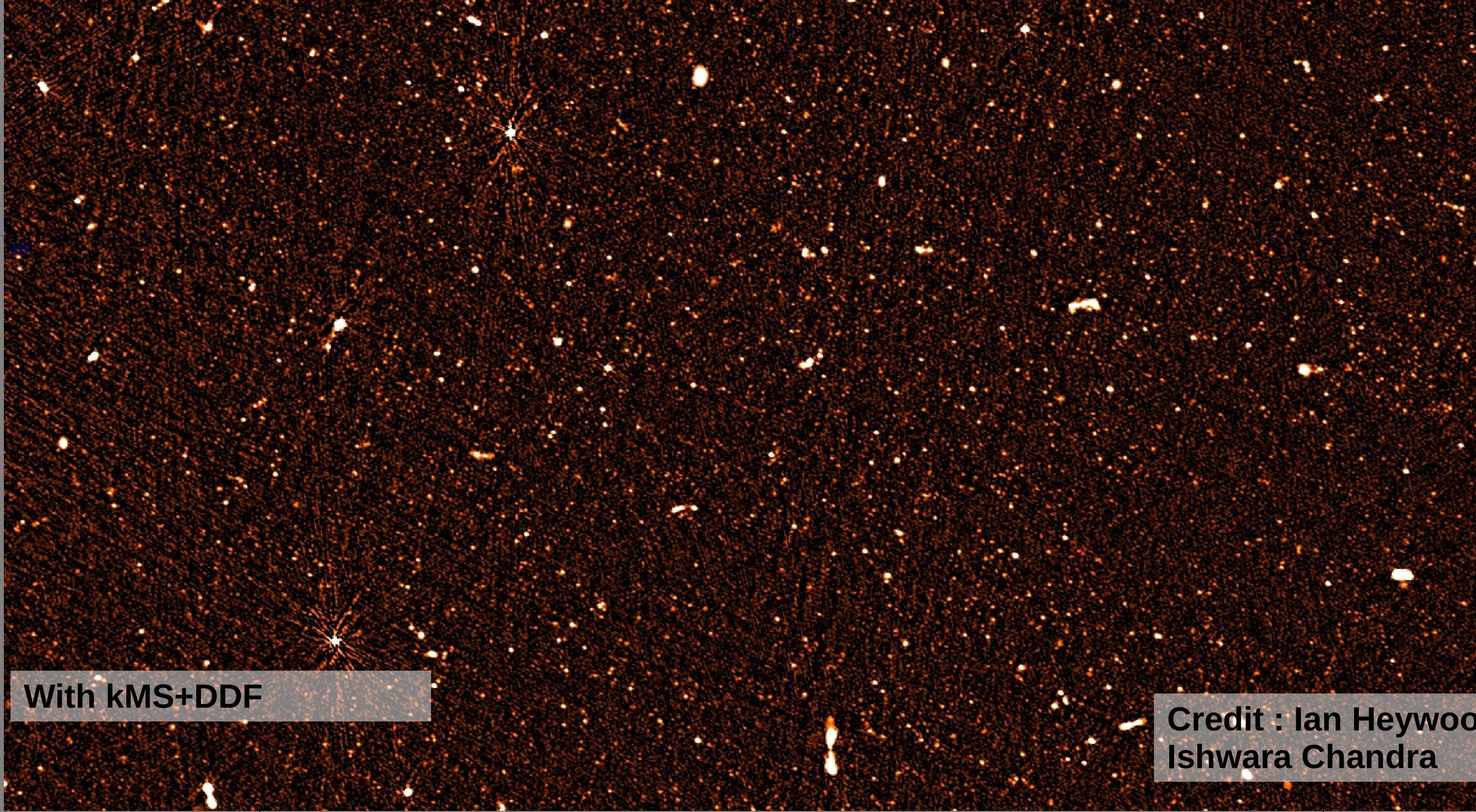
XMM-LSS field with GMRT (20 hours – band 3 [250 - 500MHz])



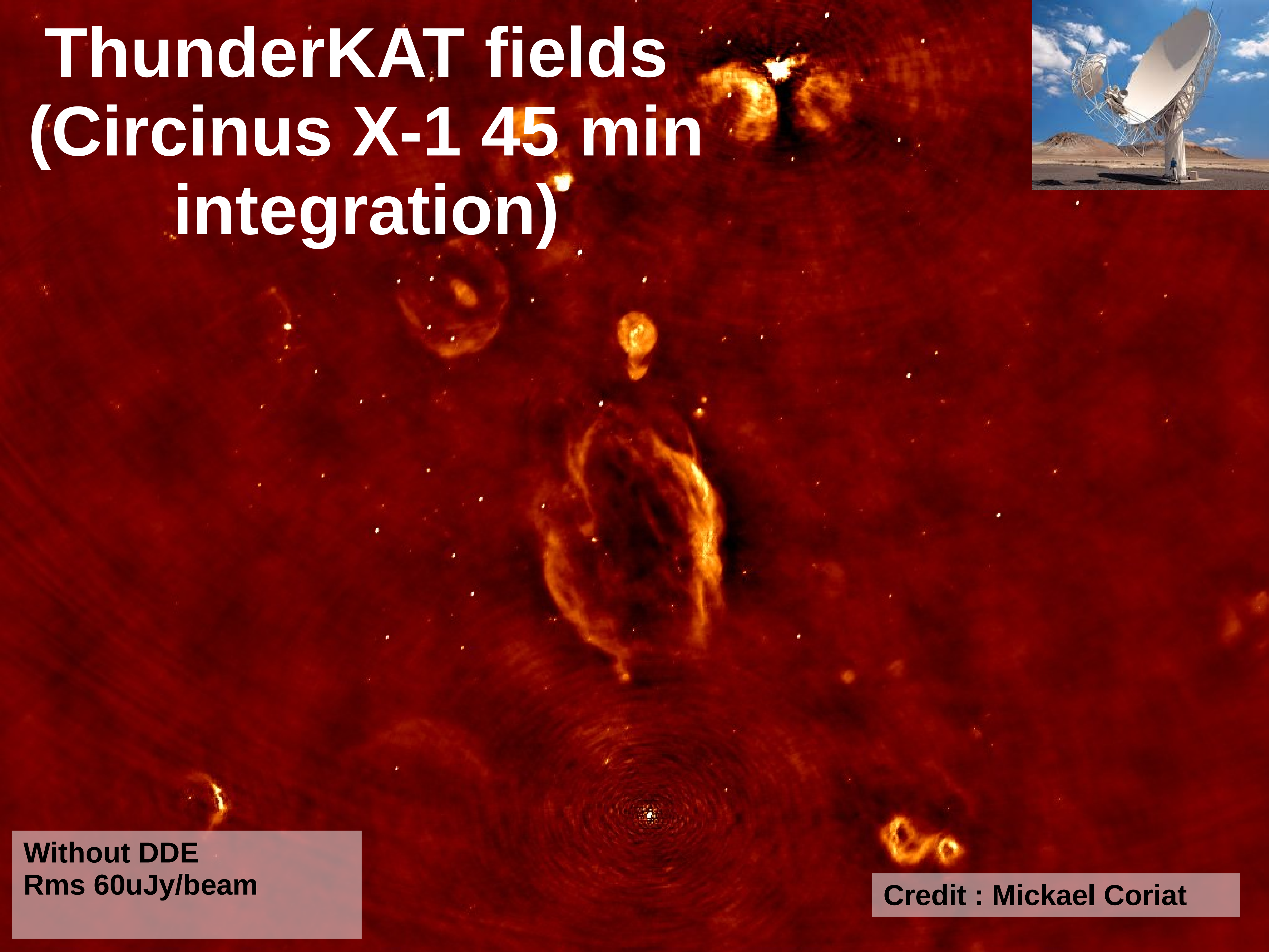
With 6 rounds of DI selfcal

Credit : Ian Heywoo
Ishwara Chandra

XMM-LSS field with GMRT (20 hours – band 3 [250 - 500MHz])



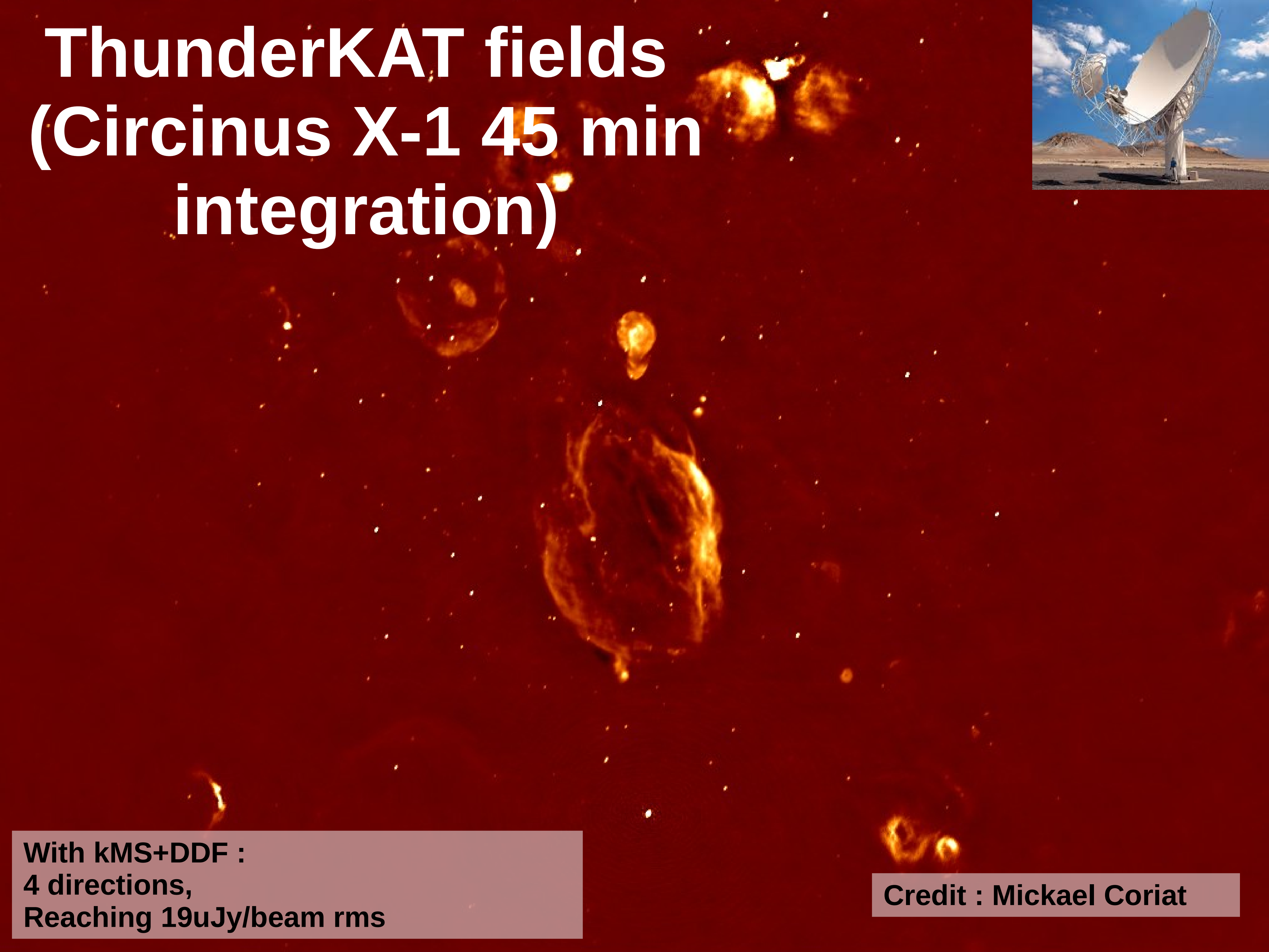
ThunderKAT fields (Circinus X-1 45 min integration)



Without DDE
Rms 60uJy/beam

Credit : Mickael Coriat

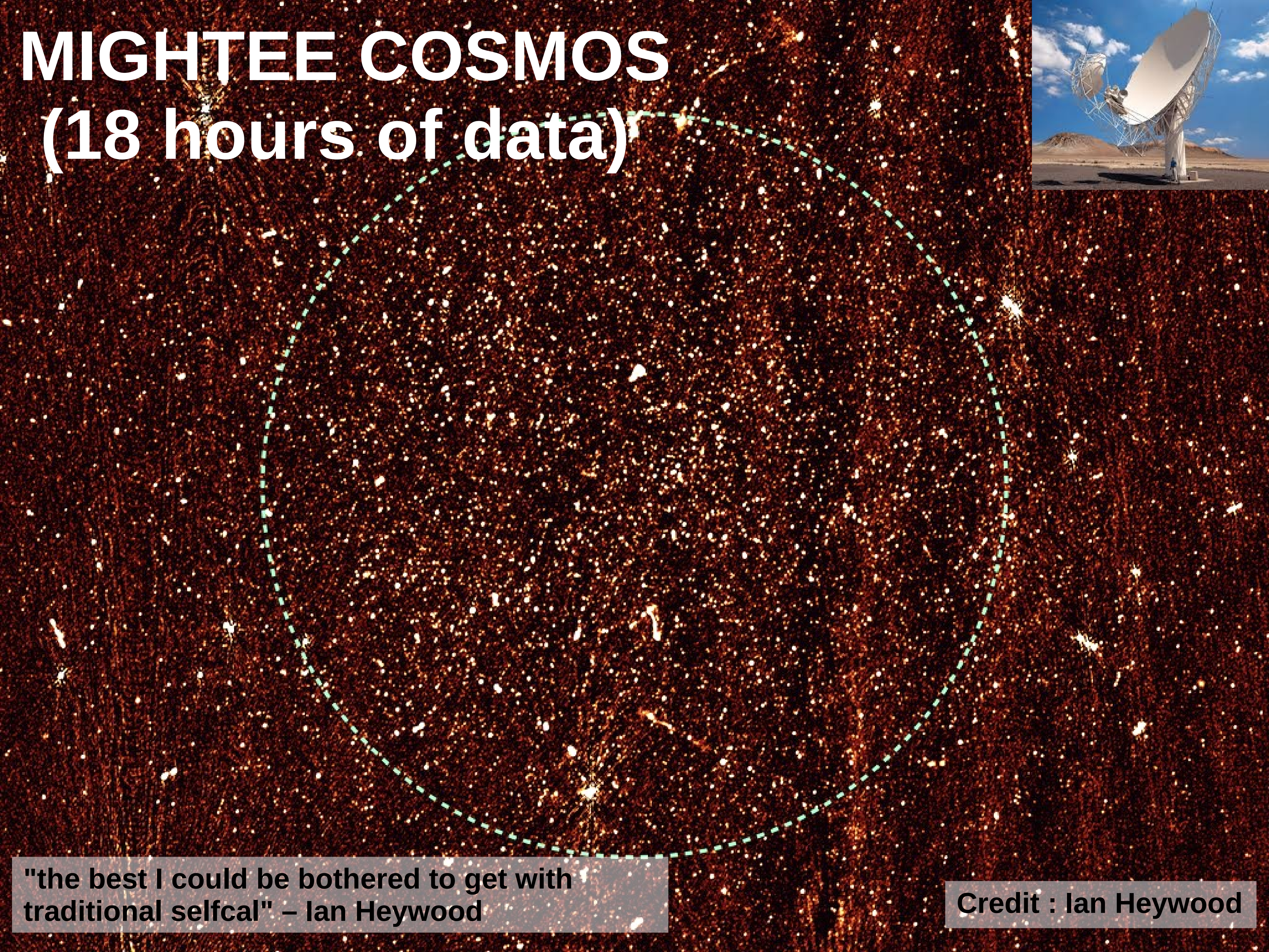
ThunderKAT fields (Circinus X-1 45 min integration)



With kMS+DDF :
4 directions,
Reaching 19uJy/beam rms

Credit : Mickael Coriat

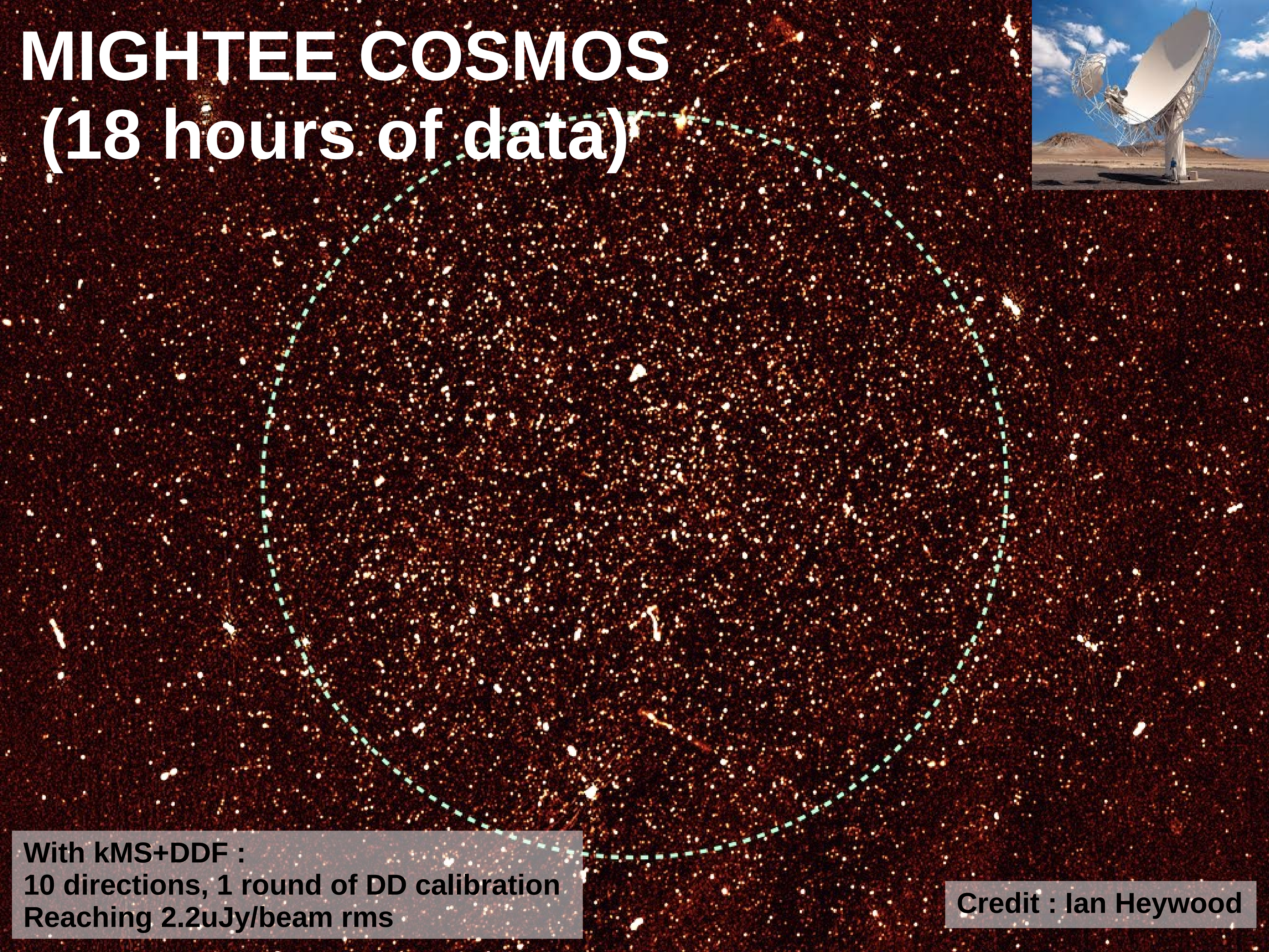
MIGHTEE COSMOS (18 hours of data)



"the best I could be bothered to get with traditional selfcal" – Ian Heywood

Credit : Ian Heywood

MIGHTEE COSMOS
(18 hours of data)



With kMS+DDF :
10 directions, 1 round of DD calibration
Reaching 2.2uJy/beam rms

Credit : Ian Heywood