Peering through the Lockman Hole with the LOw Frequency ARray (LOFAR)

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& many other KSP people

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LOFAR

Outline

- Low Frequency Array (LOFAR)
- LOFAR calibration: Direction Independent (Prefactor)
- Lockman Hole and previous work with LOFAR
- LOFAR calibration: Facet Calibration (FACTOR)
- Lockman Hole direction dependent calibration
- Combination of multiple night data -> Going Deep
- Summary

LOw Frequency ARray (LOFAR)

Low Band Antenna (LBA)
10 - 90 MHz

High Band Antenna (HBA)
120 - 240 MHz

LOw Frequency ARray (LOFAR)

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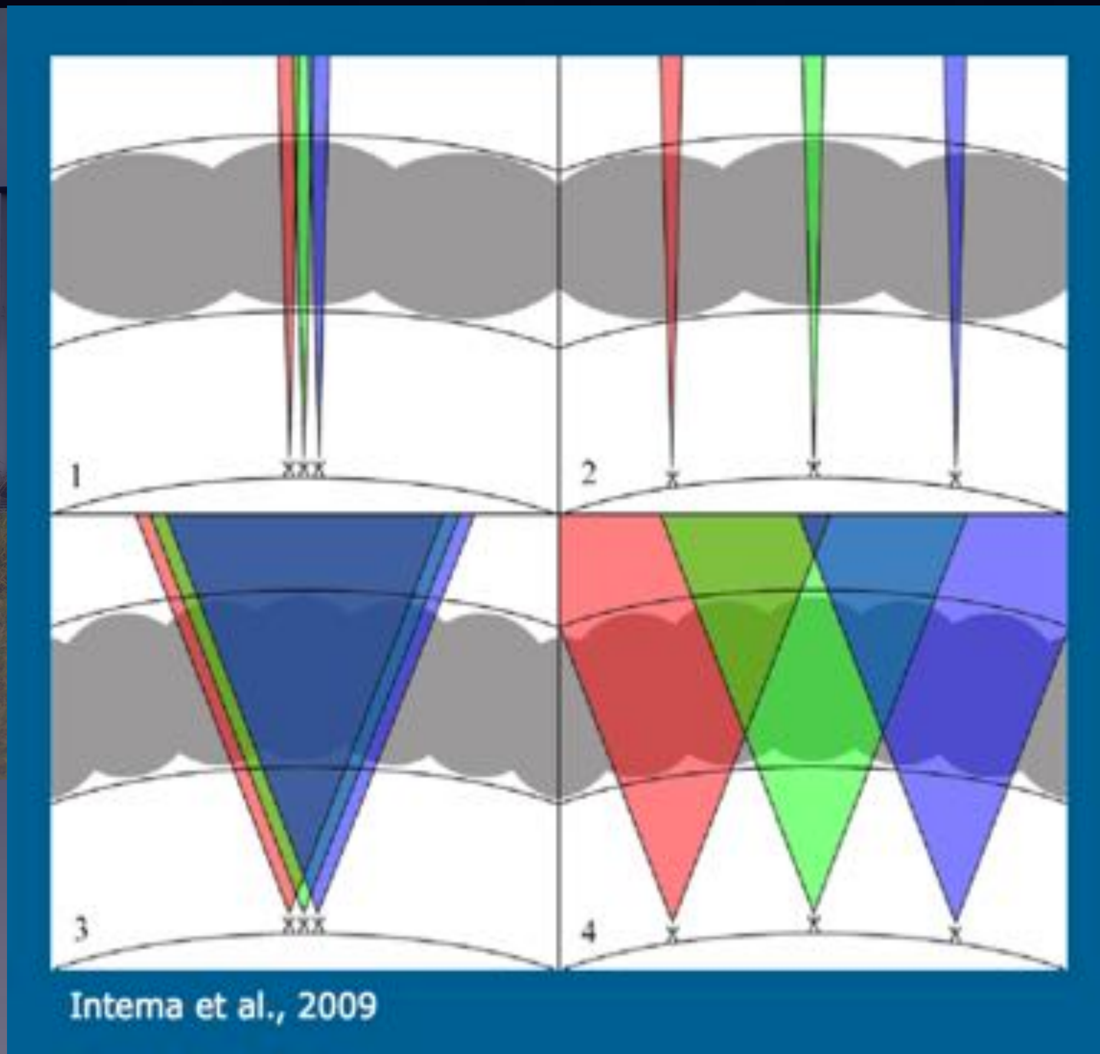
Low Band Antenna (LBA)
10 - 80 MHz

High Band Antenna (HBA)
120 - 240 MHz



Intema et al., 2009

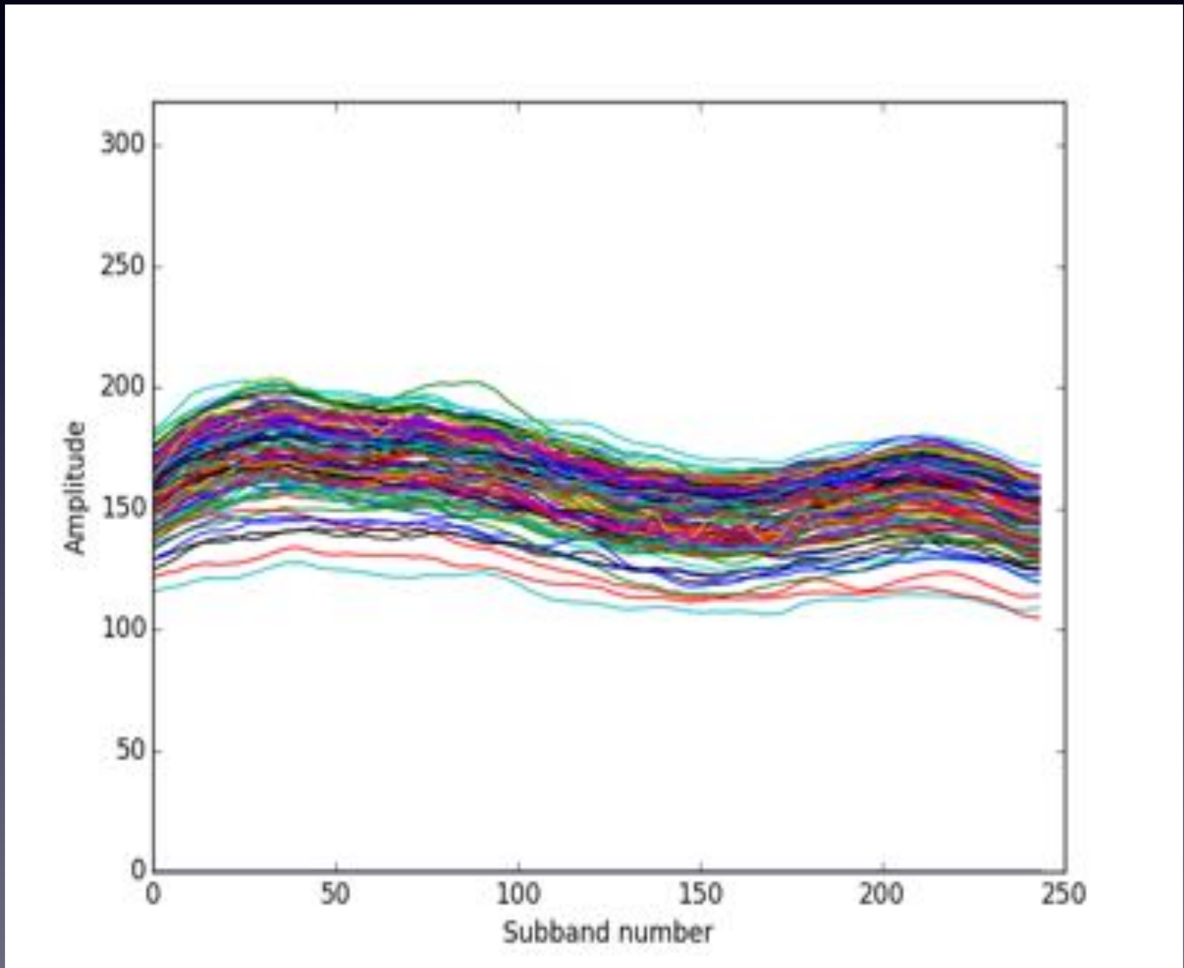
Direction Independent Calibration: Prefactor
github page: https://github.com/lofar-astron/prefactor

Steps included

- clock TEC separation with transfer of clock from the calibrator to the target
- averaging and flagging based on the solutions
- grouping of subbands by actual frequency
- speed and disk usage improvements
- applying Iononspheric RM corrections: RMextract
- diagnostic plots that allow to check the quality of the data

Diagnostic plots

Amplitude solution for the Calibrator



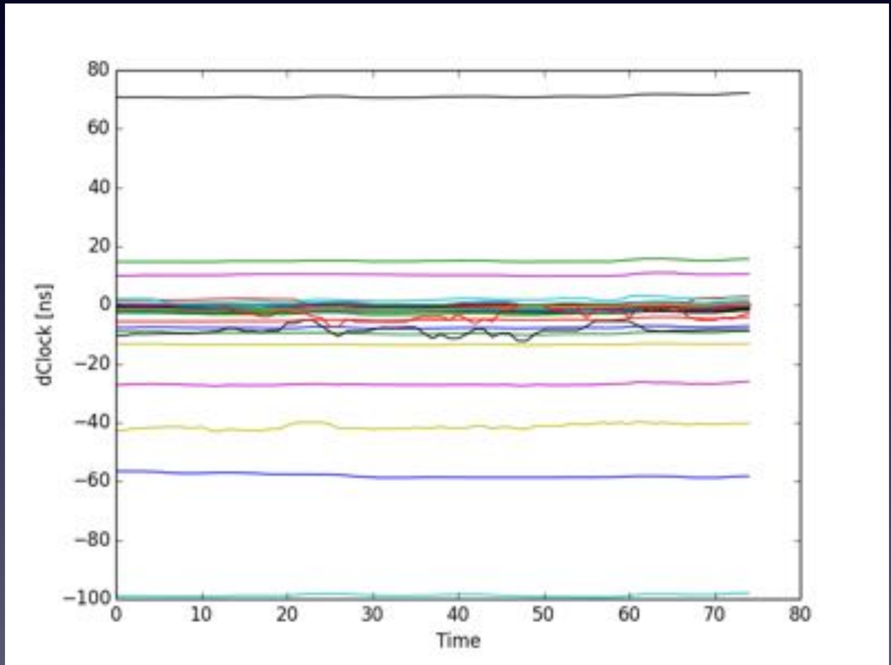
Example of good solution

No outliers / spikes

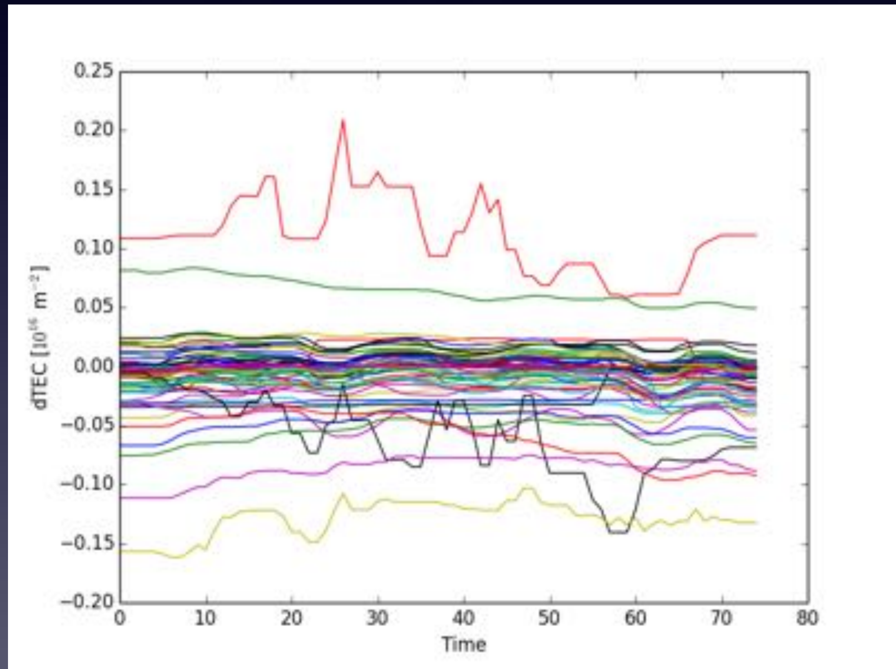
Bandpass shape is nicely visible

Diagnostic plots (contd.)

Differential Clock



Differential TEC



Lockman Hole Project (Mahony et al. 2016)

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The Lockman Hole project: LOFAR observations and spectral index properties of low-frequency radio sources

E. K. Mahony, R. Morganti, I. Prandoni, I. M. van Bemmel, T. W. Shimwell, M. Brienza, P. N. Best, M. Brüggen, G. Calistro Rivera, F. de Gasperin, M. J. Hardcastle, J. J. Harwood, G. Heald, M. J. Jarvis, S. Mandal, G. K. Miley, E. Retana-Montenegro, H. J. A. Röttgering, J. Sabater, C. Tasse, S. van Velzen, R. J. van Weeren, W. L. Williams, G. J. White

HBA Observation (110 - 170 MHz)

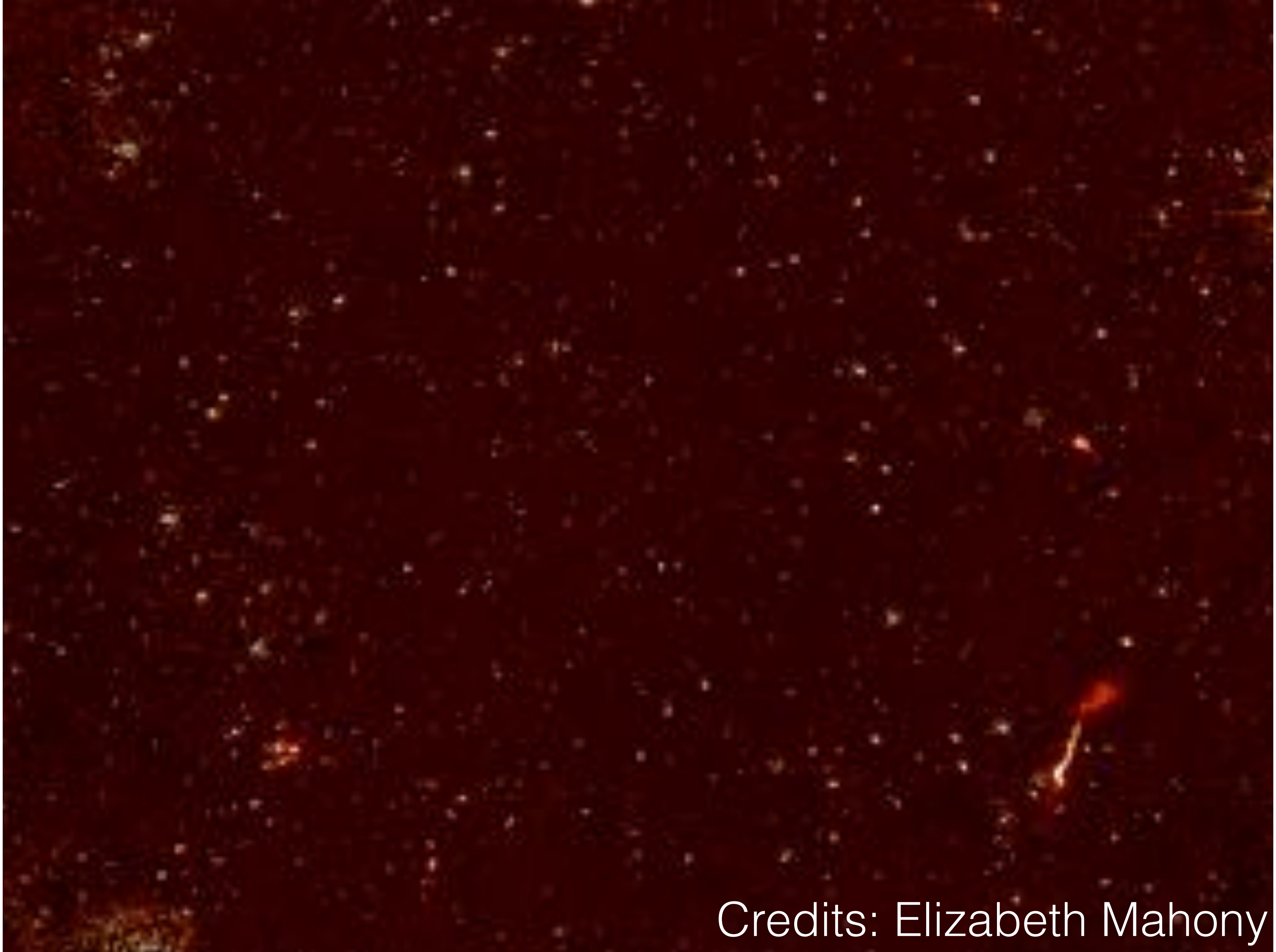
central frequency: 150 MHz

10 hrs obs time

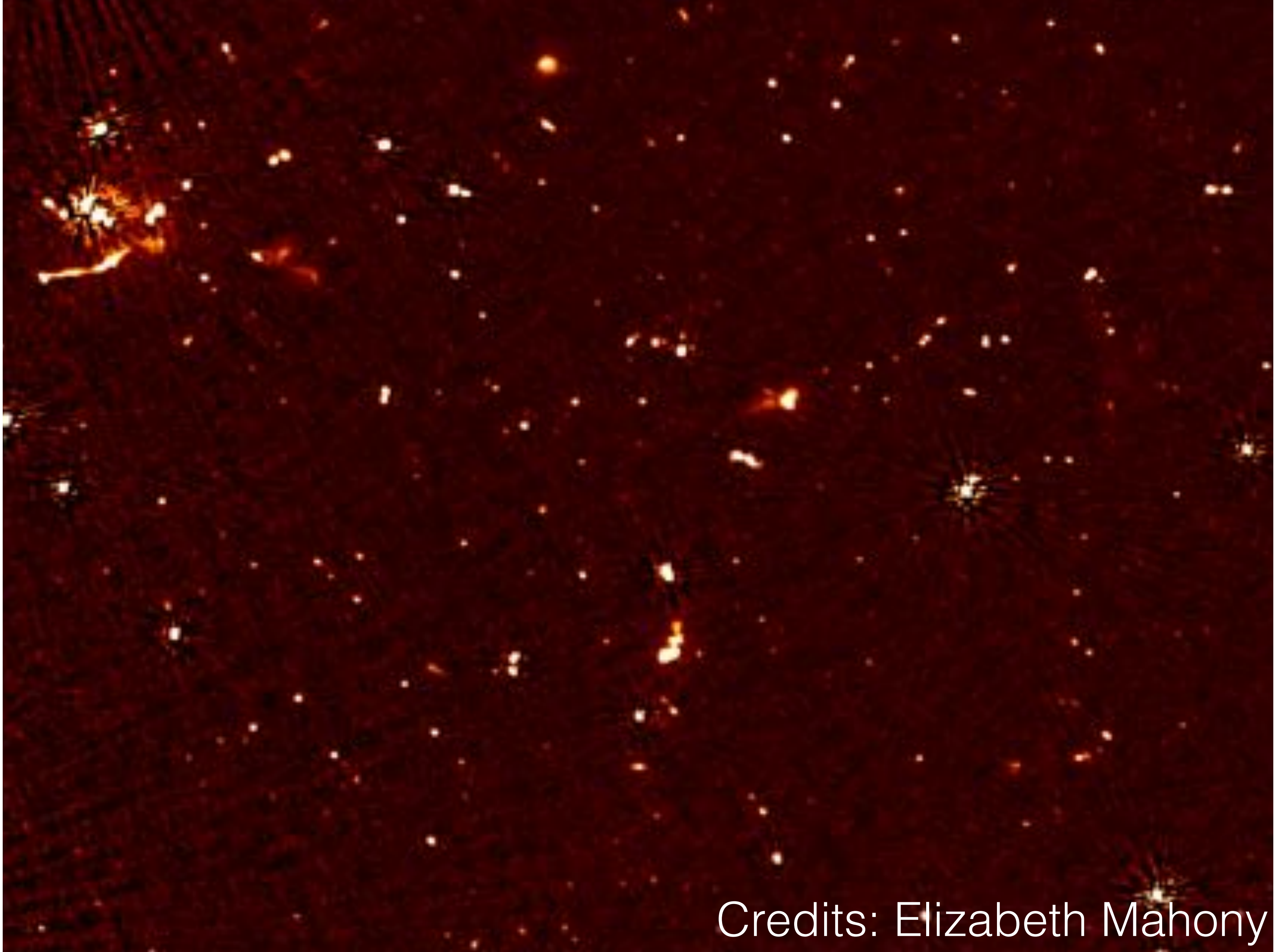
34.7 sq degrees

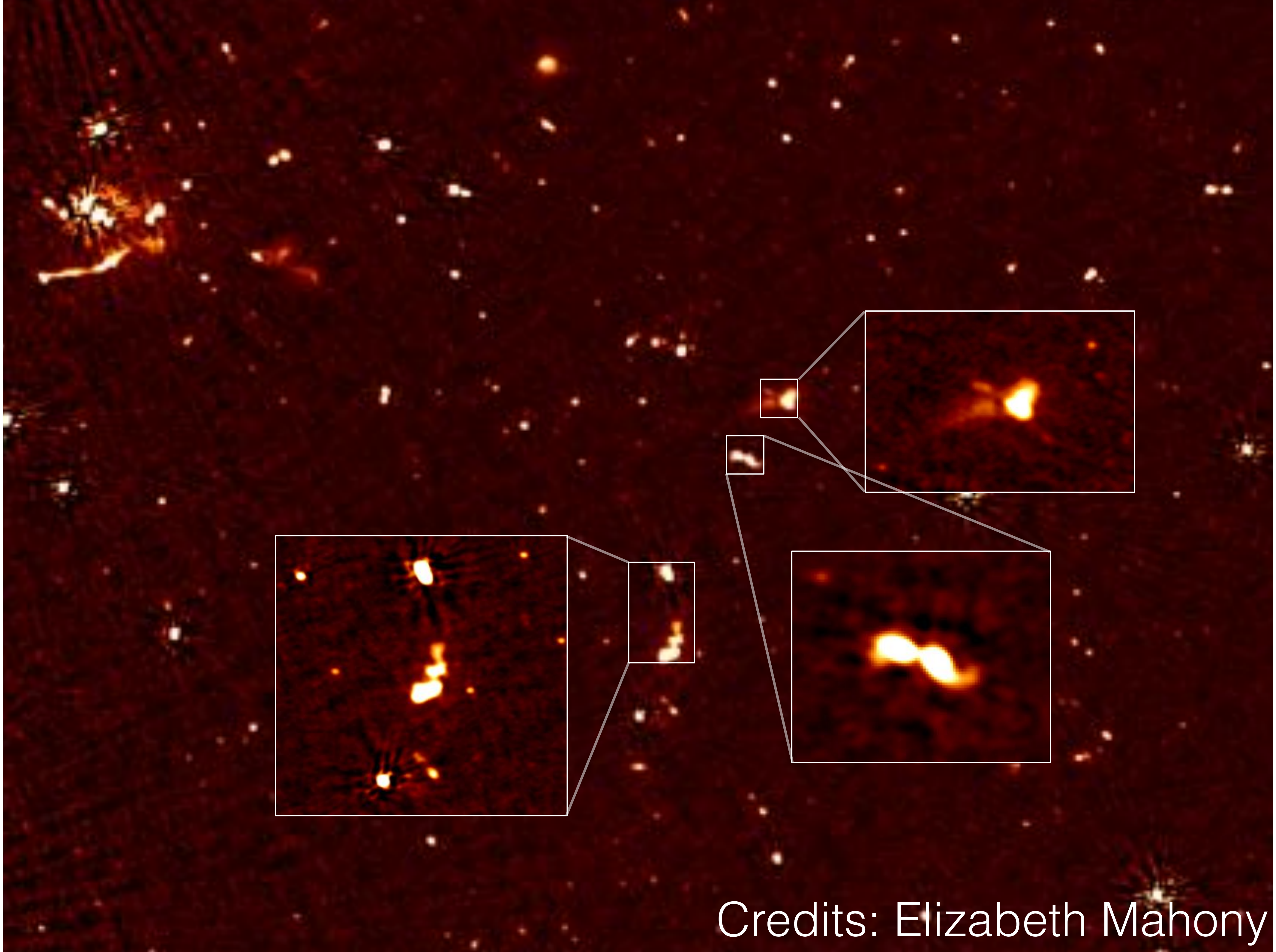
Resolution -> 18.6” x 14.7”

rms noise -> 160 uJy/beam



Credits: Elizabeth Mahony


Credits: Elizabeth Mahony


Credits: Elizabeth Mahony

Why is it important to go deeper for Lockman Hole

- One of the fields with multi-band coverage
- Very low column density of Galactic HI -> smaller amount of foreground HI makes it an ideal field for deep observations of extra galactic sources
- Deep optical/NIR data from ground based telescopes (Fotopoulou et al. 2012)
- Mid-IR/FIR/sub-mm data from the Spitzer and Herschel satellites (Mauduit et al. 2012; Oliver et al. 2012)
- Deep X-ray observation from XMM Newton and Chandra (Poletta et al. 2006; Brunner et al. 2008)

Why is it important to go deeper for Lockman Hole

Lot of Radio Data!

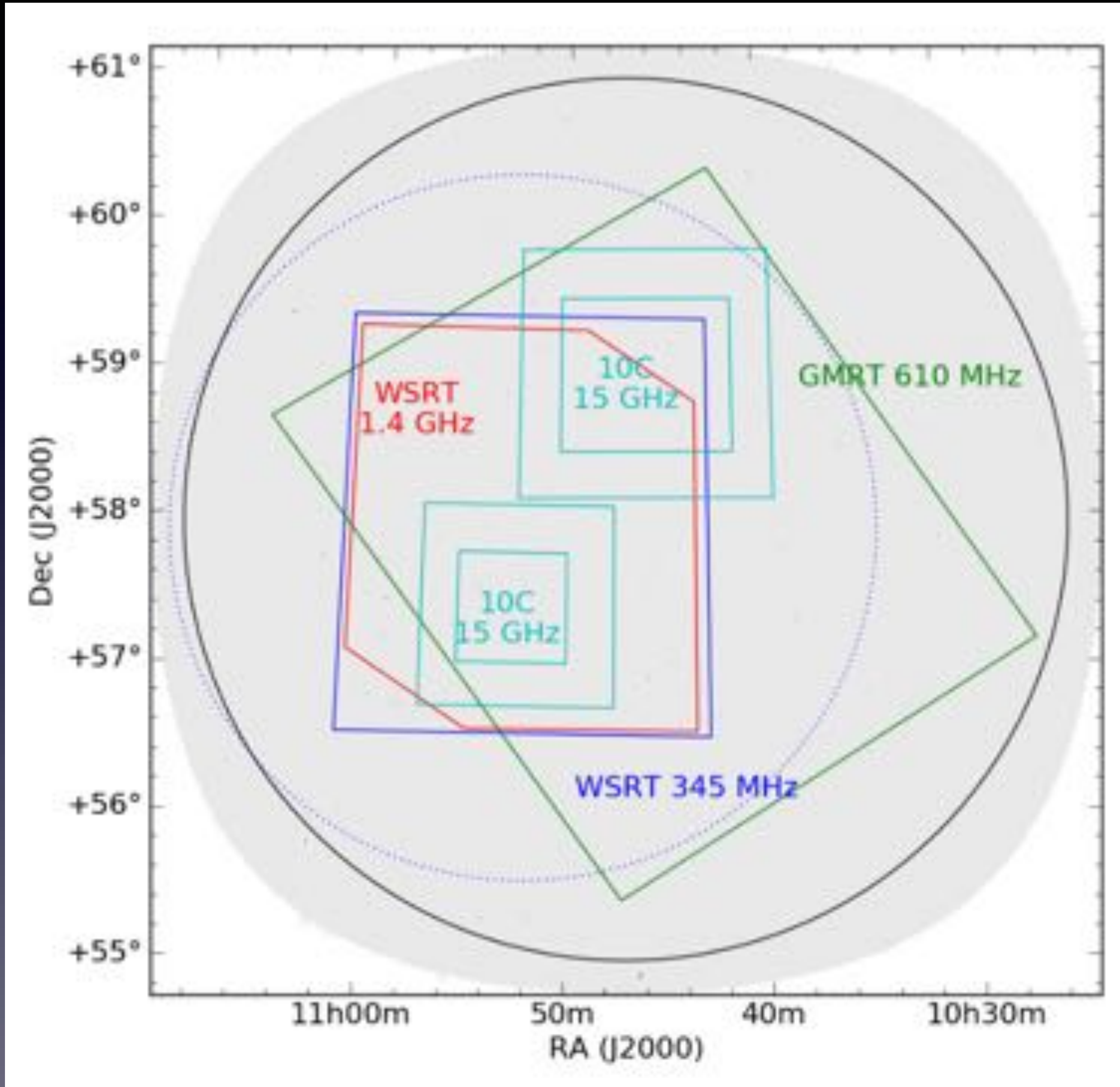


Image credits: E. Mahony

Challenges to go deep

- Huge amount of data (~4Tb per night data)
- Computational challenges
- Data combination -> UV plane / Image plane
- Software limitations
- Ionospheric condition variability
- Improper source model

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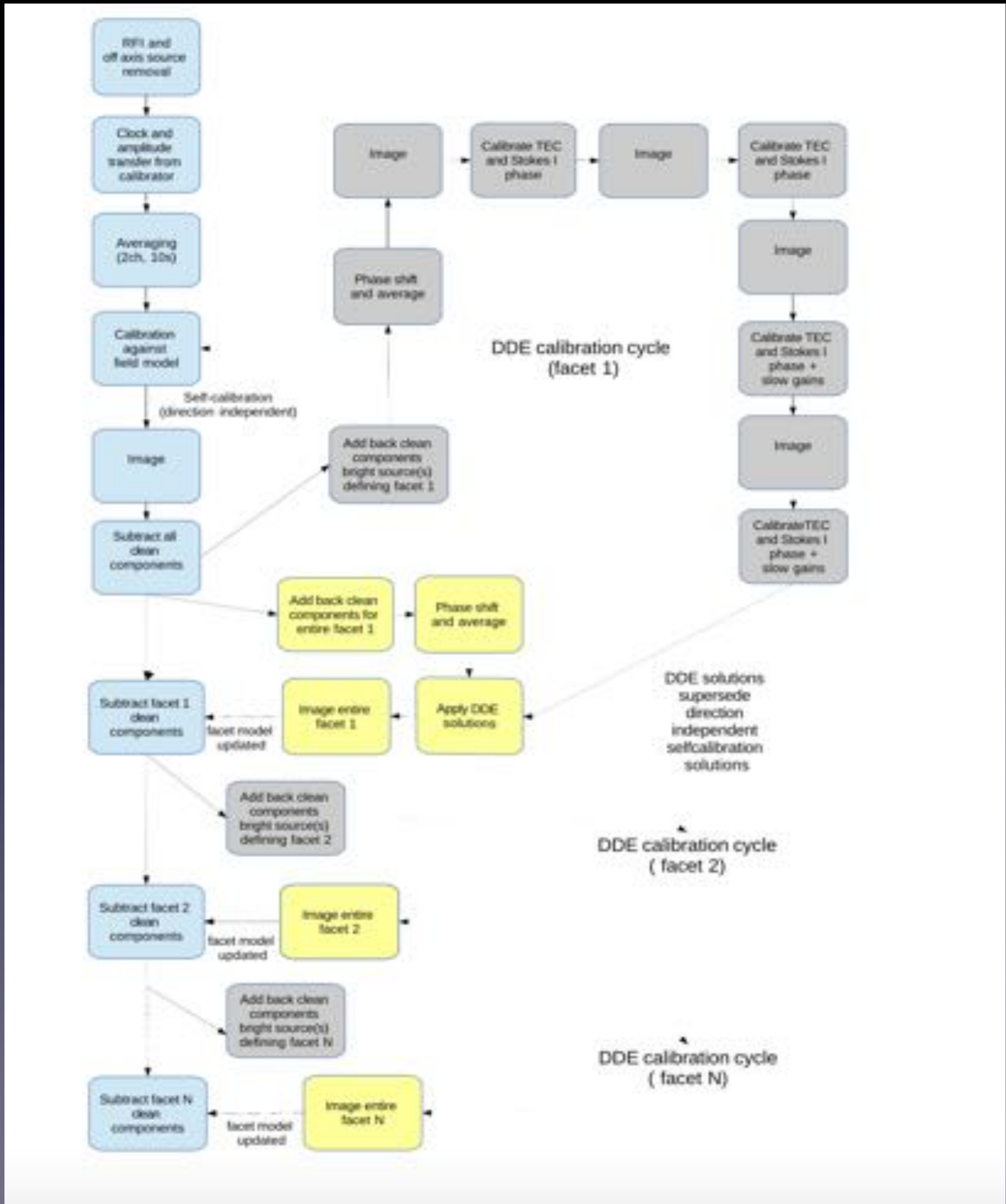
First Step: one full night data reduction with Direction Dependent Calibration

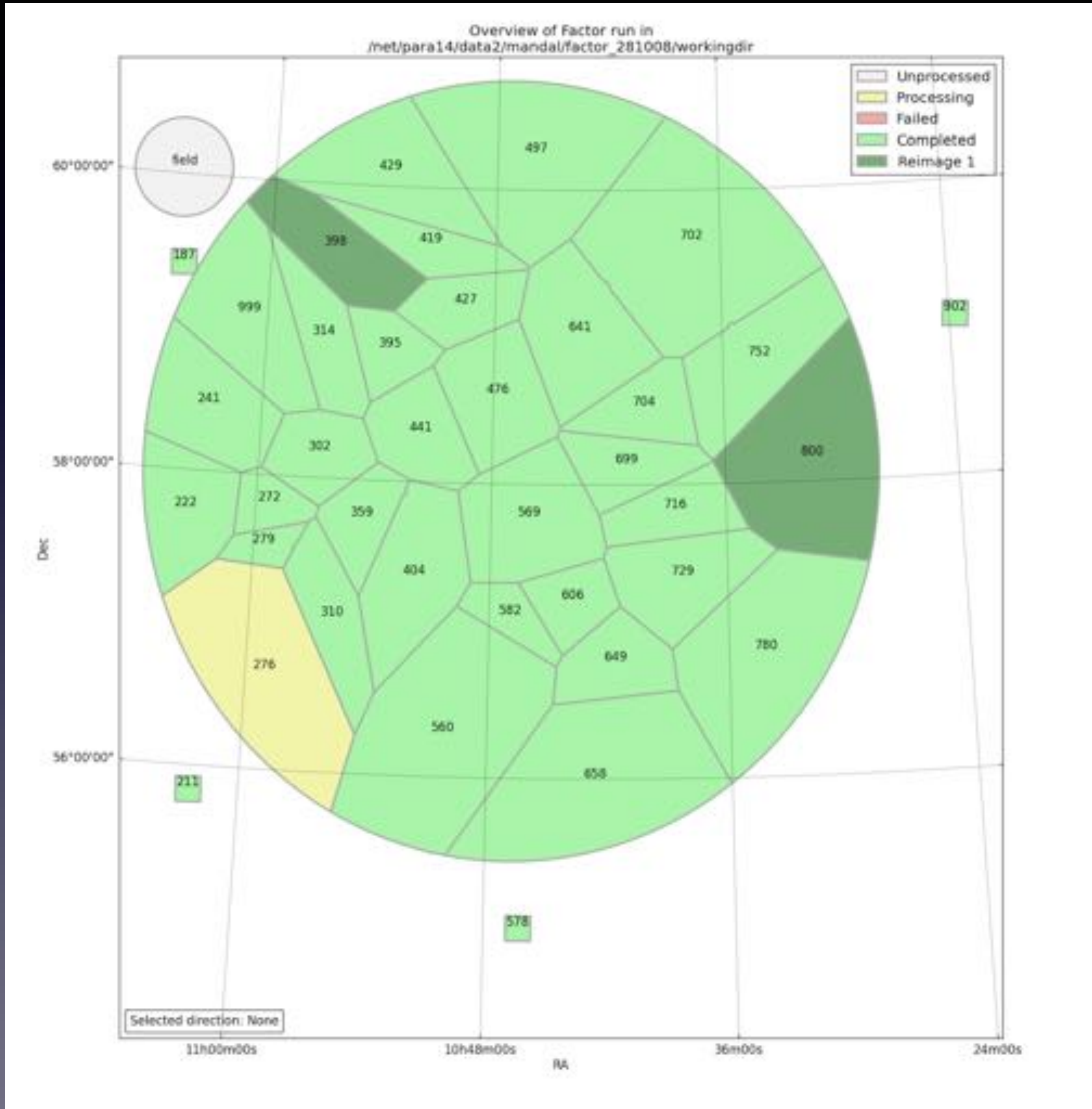
Facet Calibration (Direction Dependent Calibration)

van Weeren et al. 2016



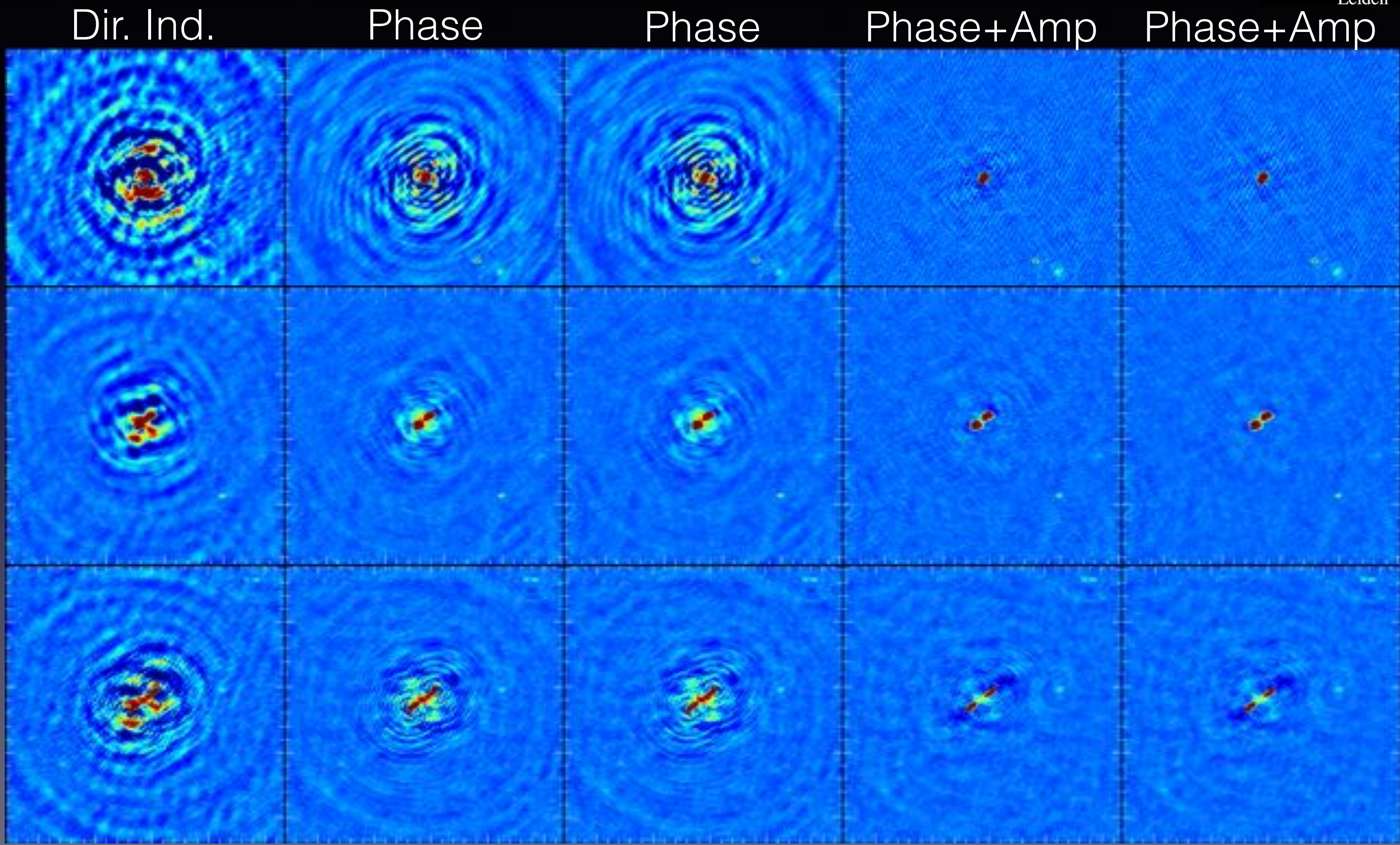
- Define calibrators
- Faceting via Voronoi tessellation.
- Subtract all sources from data and start one by one facet.
- Add back central source(s) defining facet.
- DDE self calibration cycle.
- Add back all the sources in that facet.
- Apply the solutions got from the calibrator to the entire facet.
- Image.
- Subtract updated facet model with solutions.
- Start the next Facet

FACTOR: Automated (almost) pipeline for Facet Calibration
git hub page: https://github.com/lofar-astron/factor

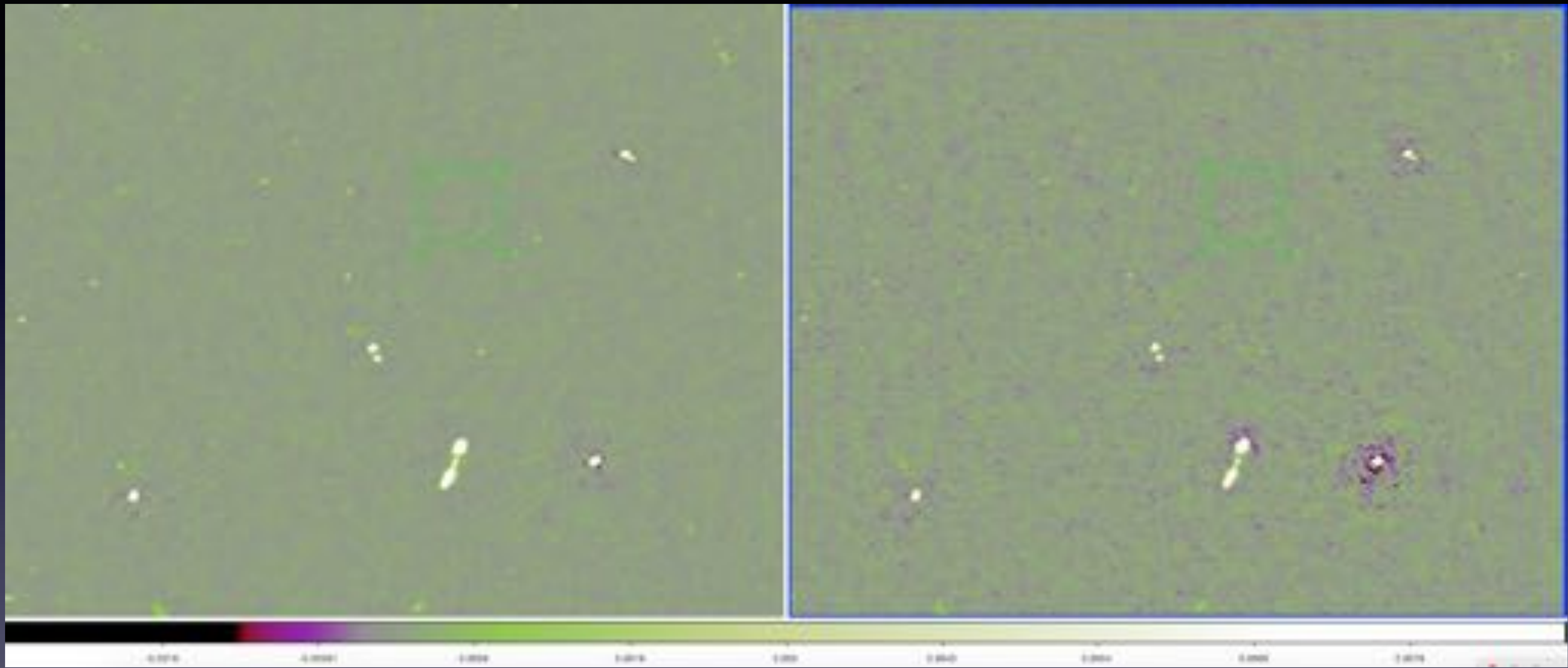


Present timescale
32 cpus
256 GB RAM
8 hours data
roughly ~ 10 days!

Calibrator different stages



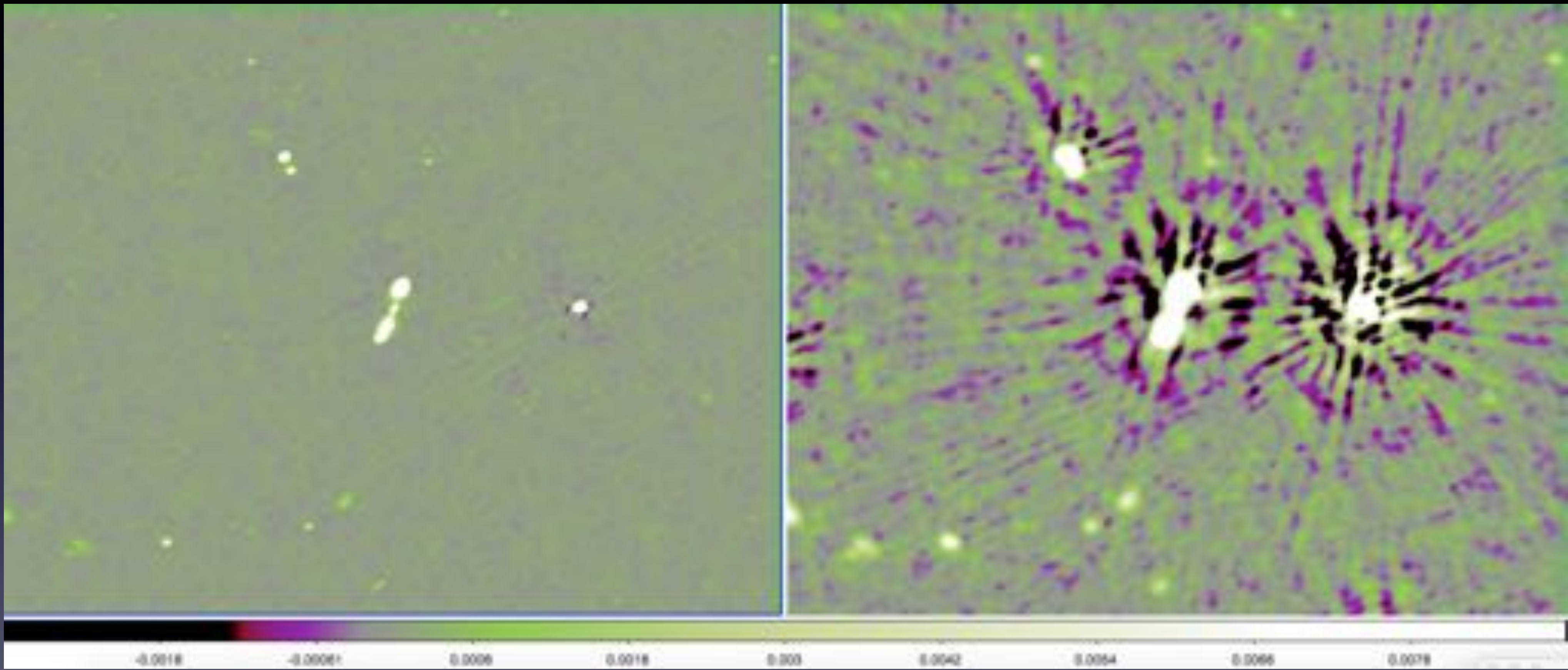
Few comparisons (240 subband reduction vs 40 subband reduction



240 subband (48MHz BW)
facet calibrated
resolution ~ 5”
rms noise: 85 uJy/beam

40 subband (8MHz BW)
facet calibrated
resolution ~ 5”
rms noise: 143 uJy/beam

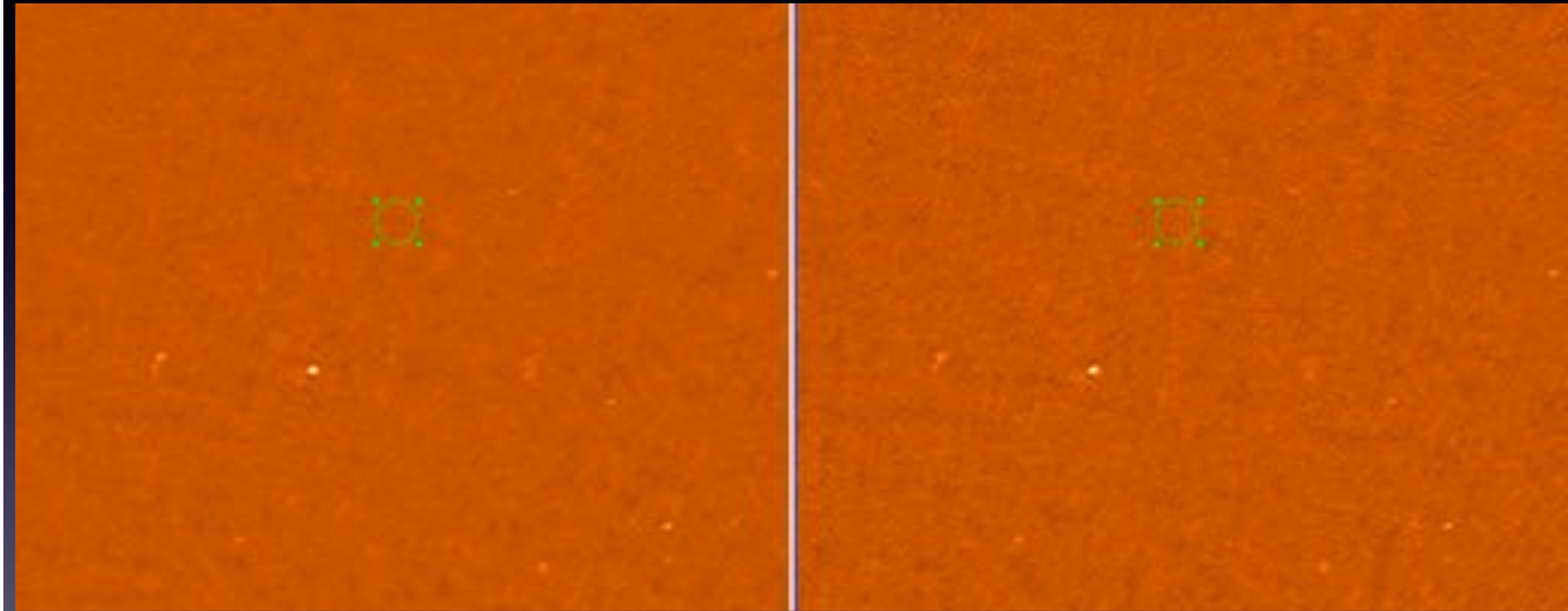
Few comparisons (Direction dependent calibration vs Direction Independent Calibration)



240 subband (48MHz BW)
facet calibrated
resolution ~ 5"
rms noise: 85 uJy/beam

300 subband (70MHz BW)
not facet calibrated
resolution ~ 18"
rms noise: 160 uJy/beam

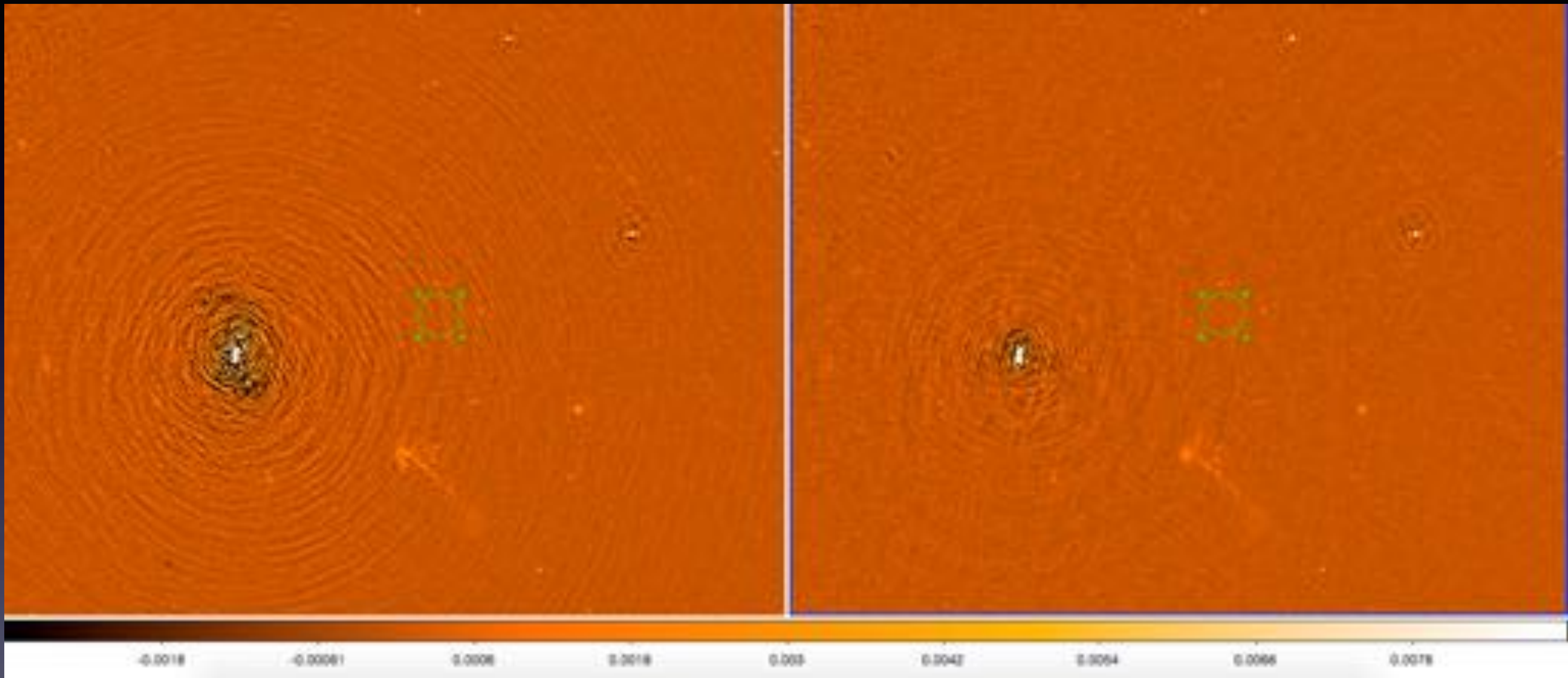
Few results: Merging (in UV plane) two different night data



Merged nights result
40 subbands = 8 MHz BW
16 hours
rms: 161 uJy/beam

Single night result
40 subbands = 8 MHz BW
8 hours
rms: 215 uJy/beam

Few results: Merging (in UV plane) two different night data



Merged nights result	Merged nights result
40 subbands = 8 MHz BW	40 subbands = 8 MHz BW
16 hours	16 hours
rms: 324 uJy/beam	rms: 284 uJy/beam

Summary

- Lockman Hole is one of the Tier-2 fields
- We aim to make one of the deepest images ever made at 150 MHz
- One full night data has been reduced
- Average noise level reached: 80-90 uJy/beam
- We have ~ 64 hours of data to be combined -> few experiments with combining datasets have been performed
- Expected noise level: 30 uJy/beam
- Using the direction dependent phase solutions for Ionospheric calibrations

Thank you