ASTRON

Netherlands Institute for Radio Astronomy

LOFAR data:

error analysis

Aleksandar Shulevski

(with thanks to E. Mahony, K. Chyzy and others who I have borrowed/stolen slides from)

Outline

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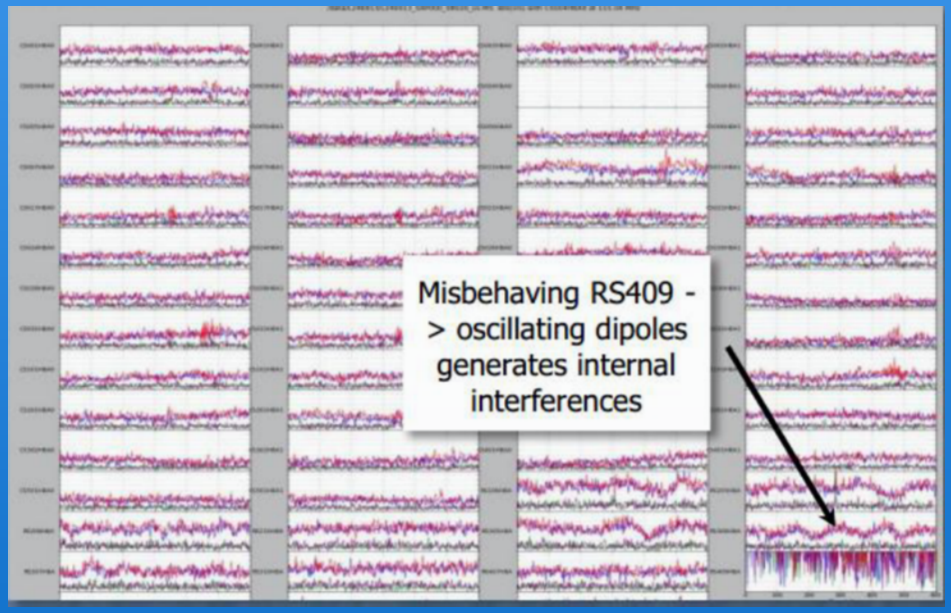
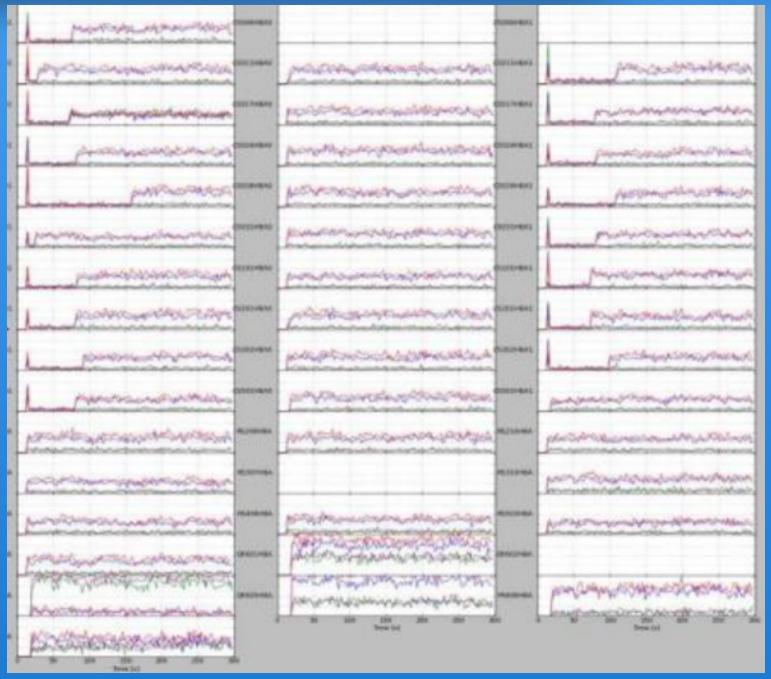
PROBLEM	SOLUTION
• Data Errors	• Use the observation log (report) to track big issues (ex. bad antennas). Inspect data, flag as warranted.
• Calibration errors	• Does the model fit the data? Ionosphere an issue?
• Image plane errors	• Deconvolution issues, residual data issues -> start at the top

Data Errors: inspection plots





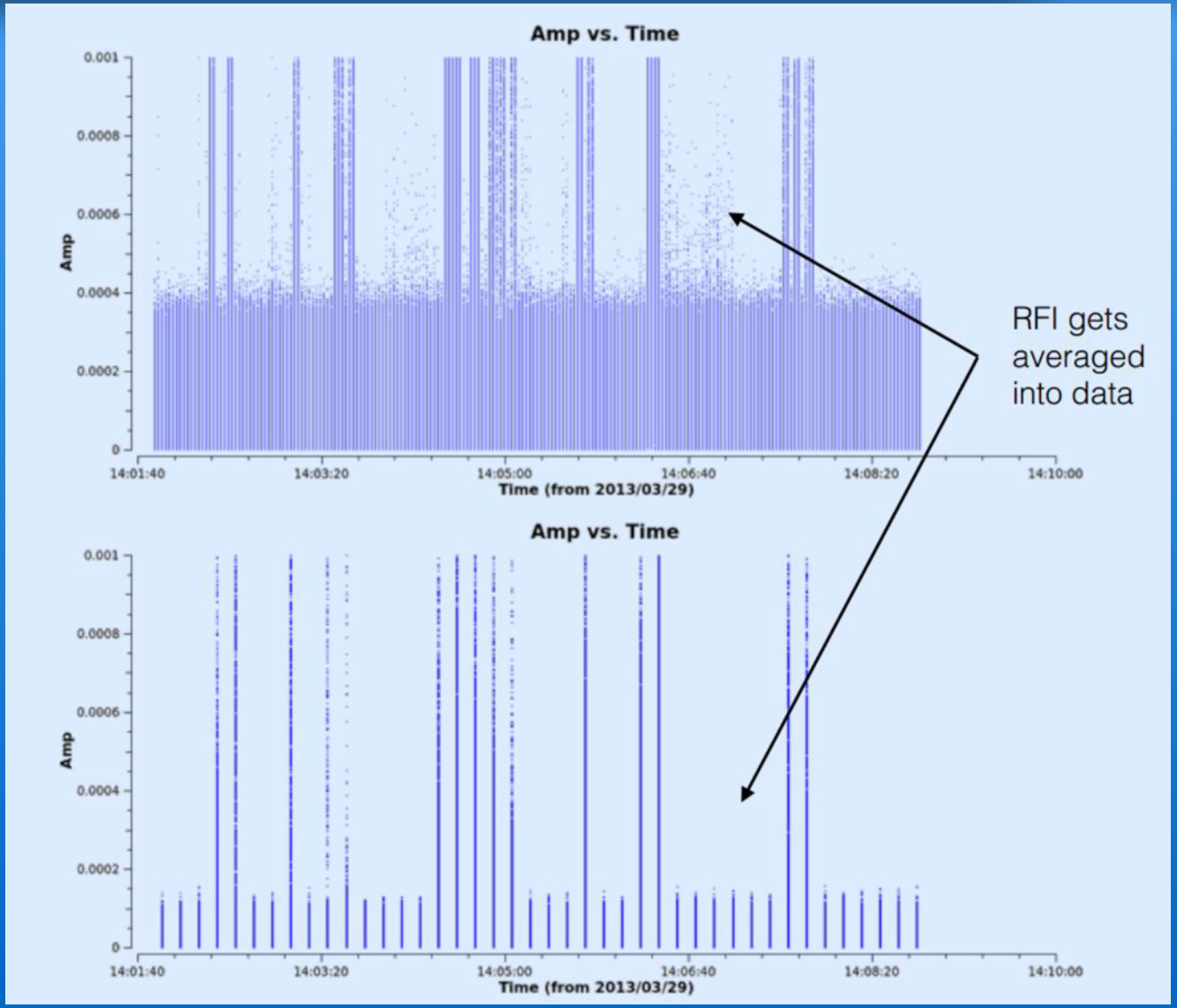
Connection problems at the start of the run

Learn more at: http://www.astron.nl/radio-observatory/observing-capabilities/depth-technical-information/data-quality-inspection/data-qu

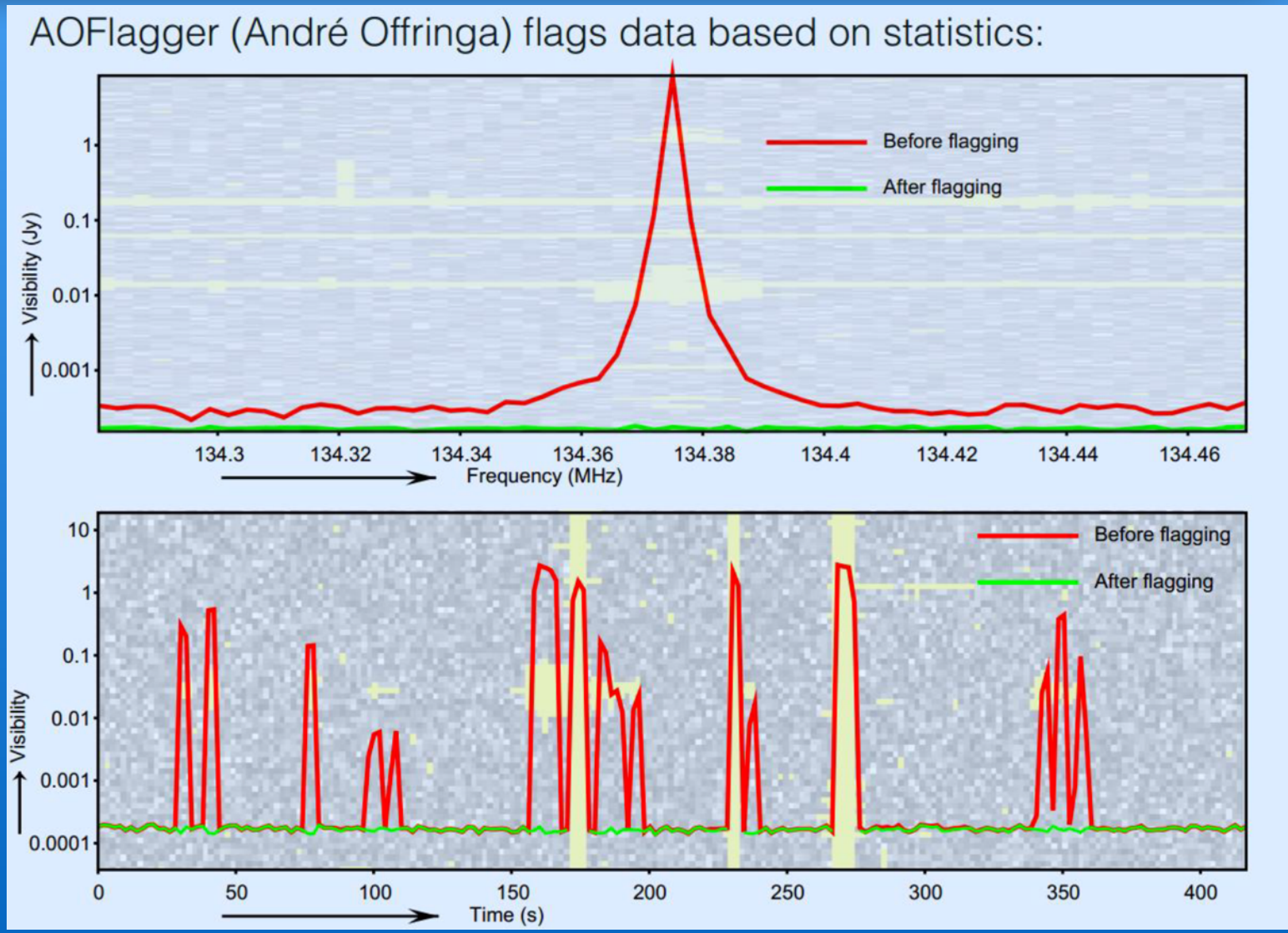
Data Errors: RFI

Flagging always the first step!

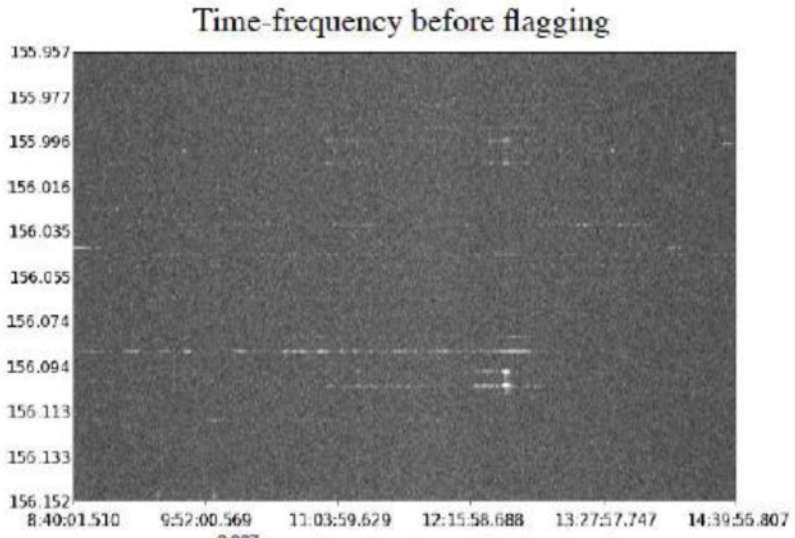
- flag at high resolution

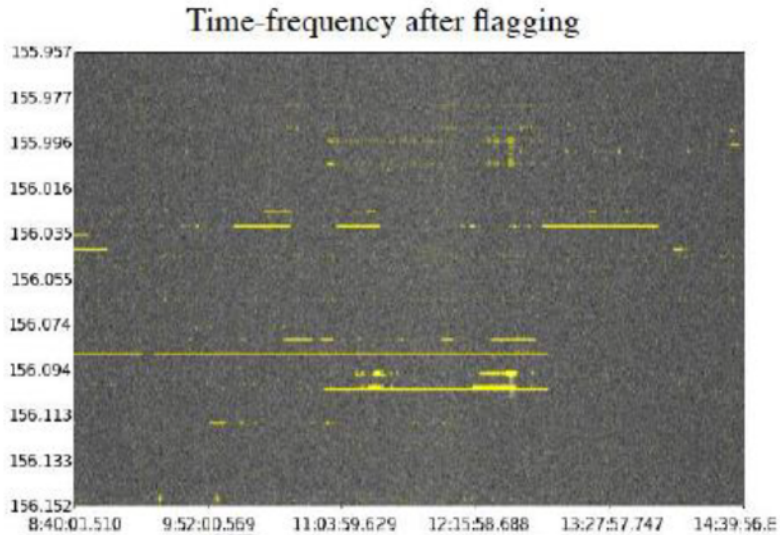


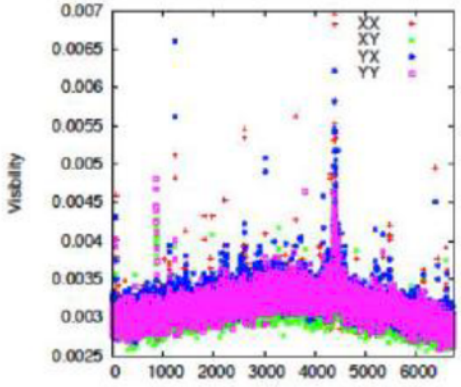
Data Errors: RFI



Data Errors: RFI

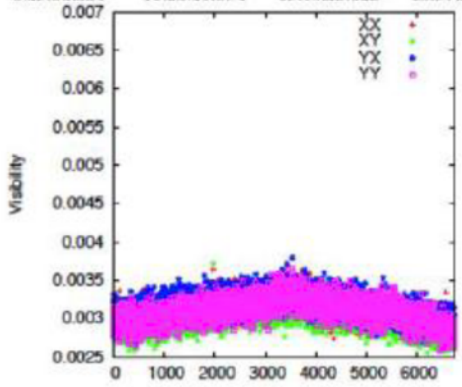






Amplitude plot before flagging

156 MHz,
1.8% data flagged



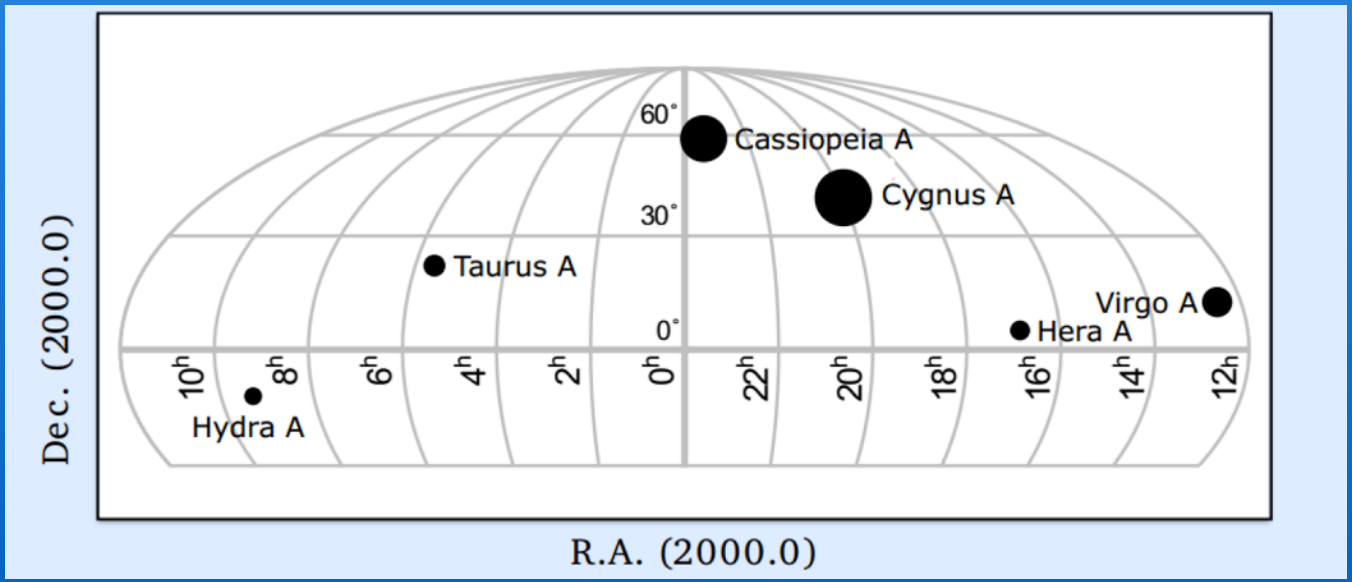
Amplitude plot after flagging

Offringa et al. (2010, 2012)

Data (Errors): Demixing

At low frequencies, visibilities are affected by the brightest radio sources on the sky - CygA, CasA, VirA, TauA, HerA, HydA - the “A-team”

- LBA: data almost always affected by CygA, CasA at least
- HBA: data affected if phase centre within 30 deg. of an A-team source or if elevation of A-team high. To make sure, simulation is needed.



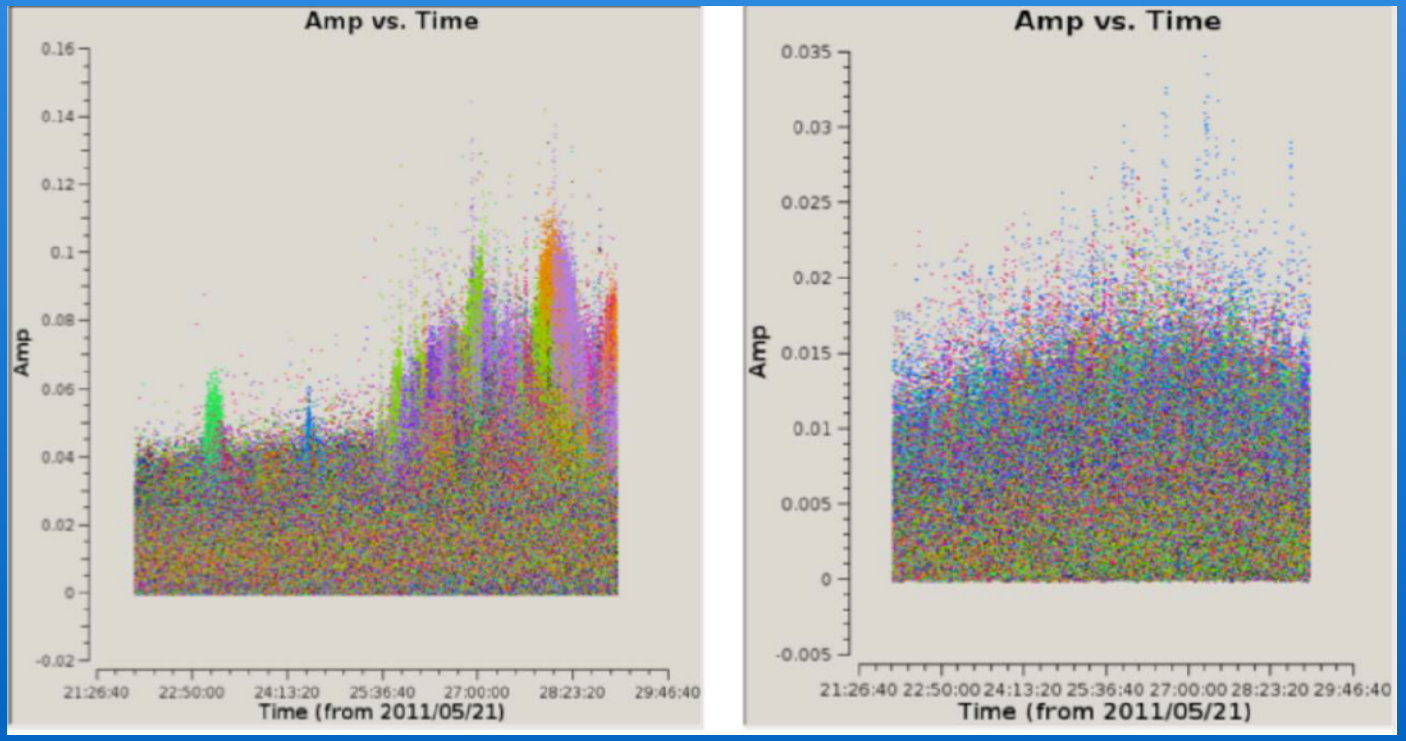
Data (Errors): Demixing

A-team needs to be removed from the visibilities - “demixing”

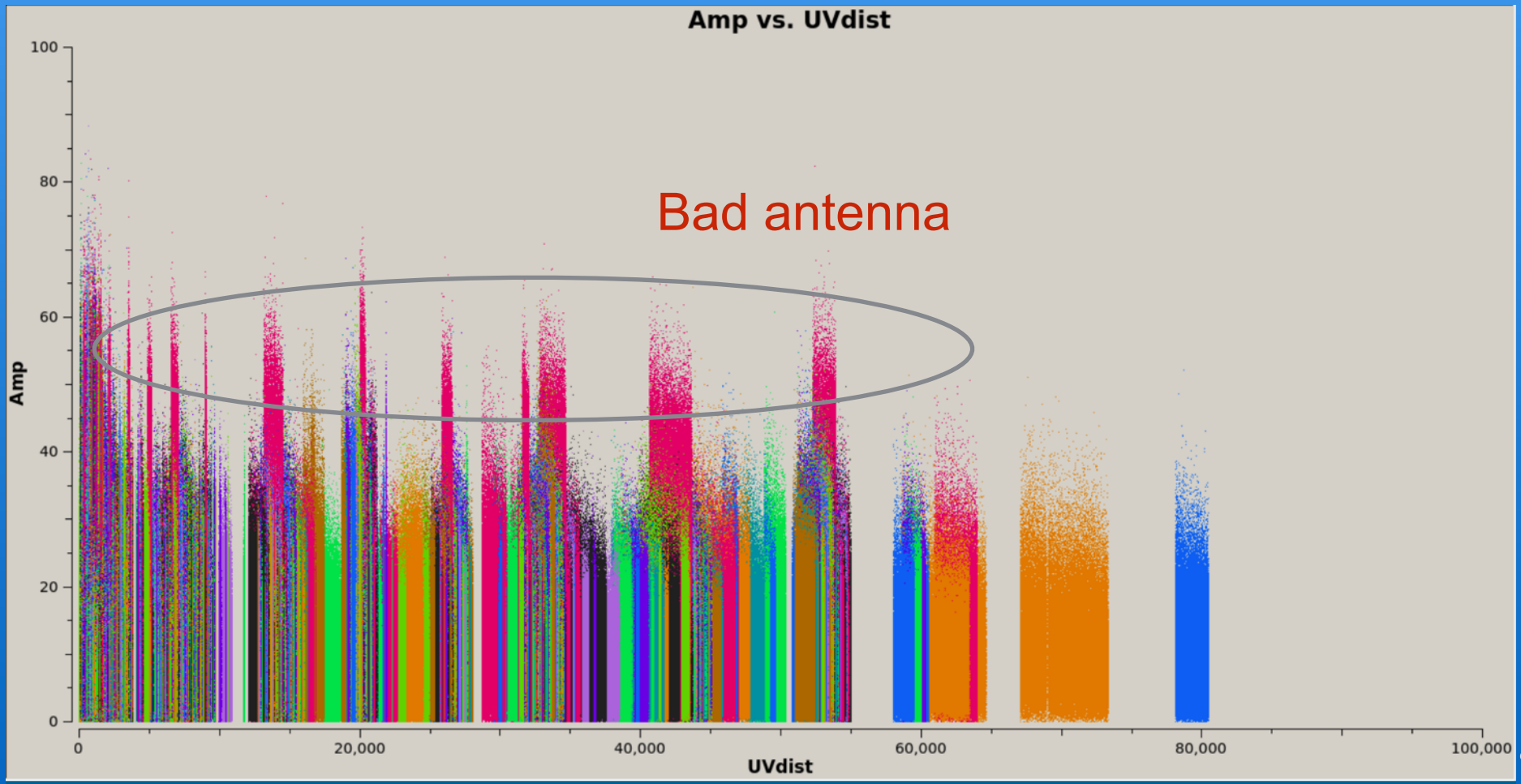
- Use model to subtract A-team from visibilities

Data needs to be at sufficient resolution for this to work.

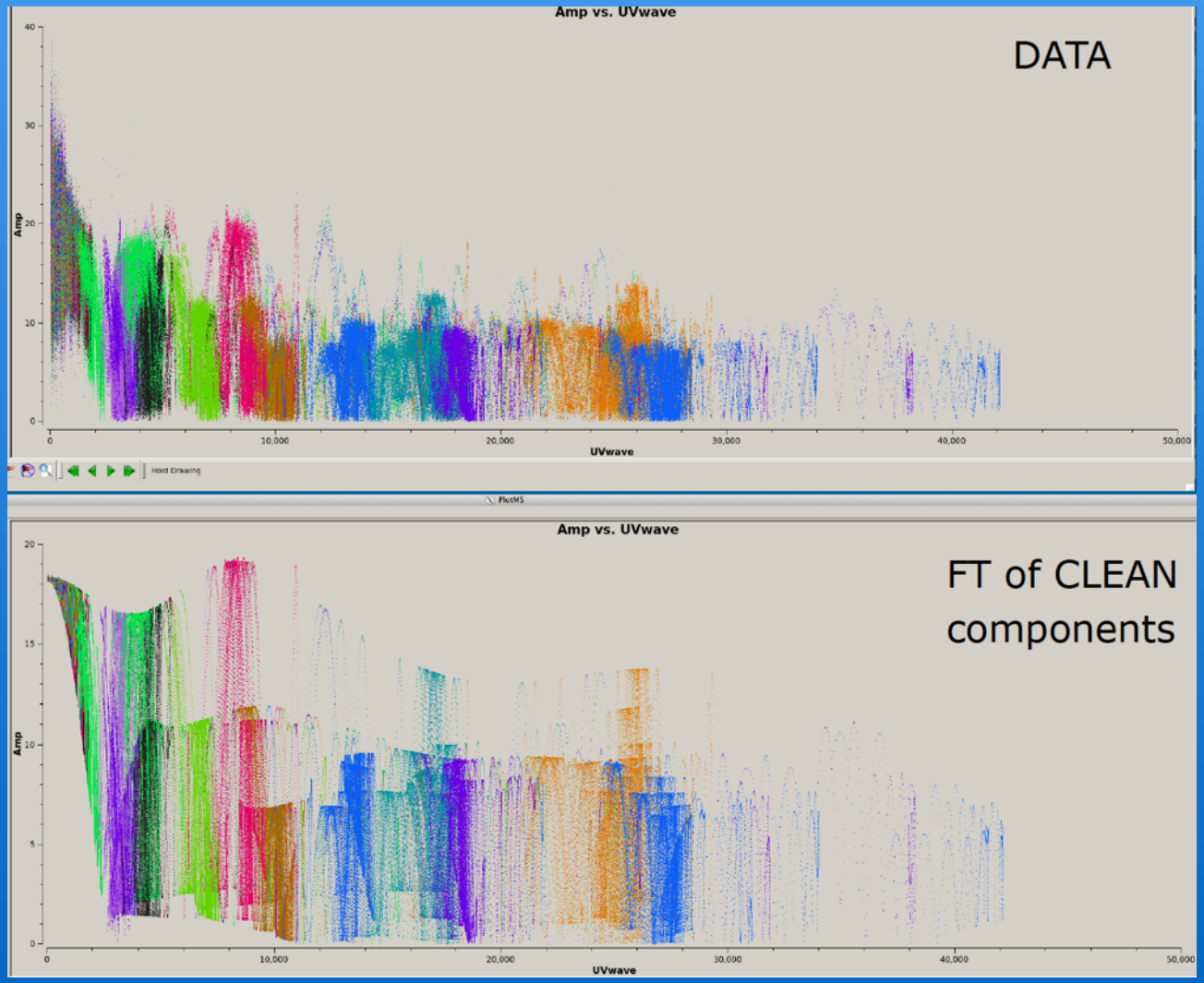
- Clip of flag A- team contribution.



Data Errors: visibilities



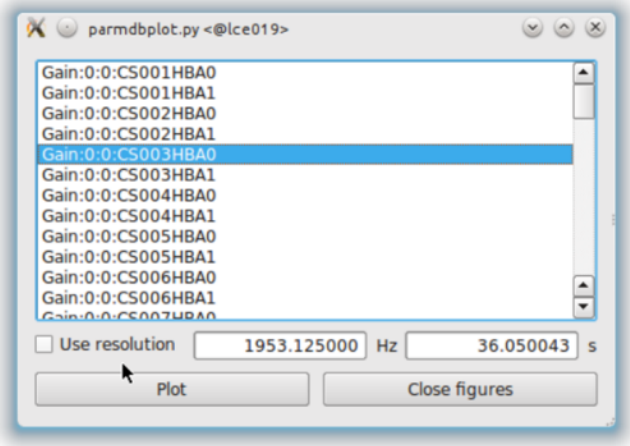
Calibration

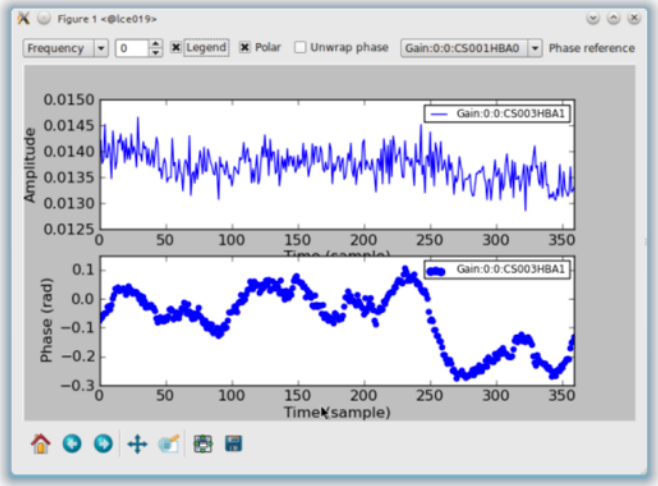


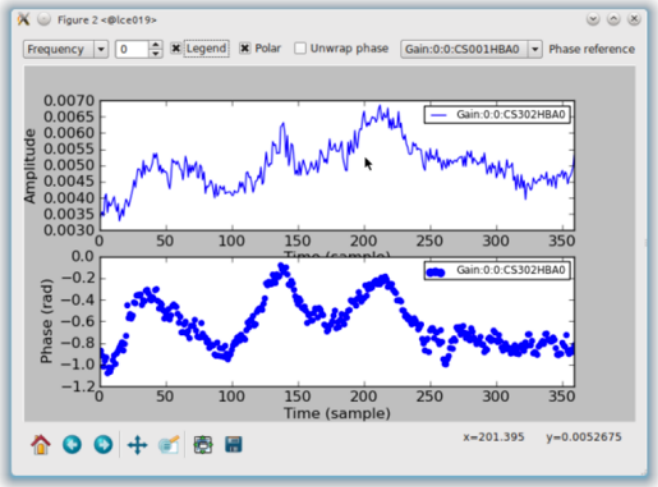
Model fits the data?

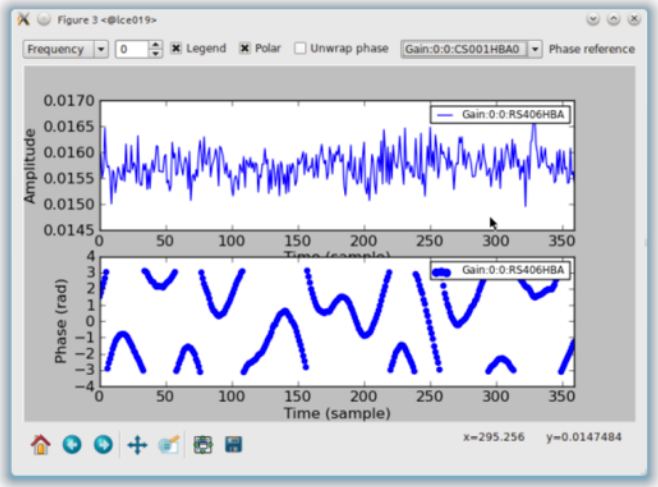
Model errors can be absorbed in the calibration process!

Calibration



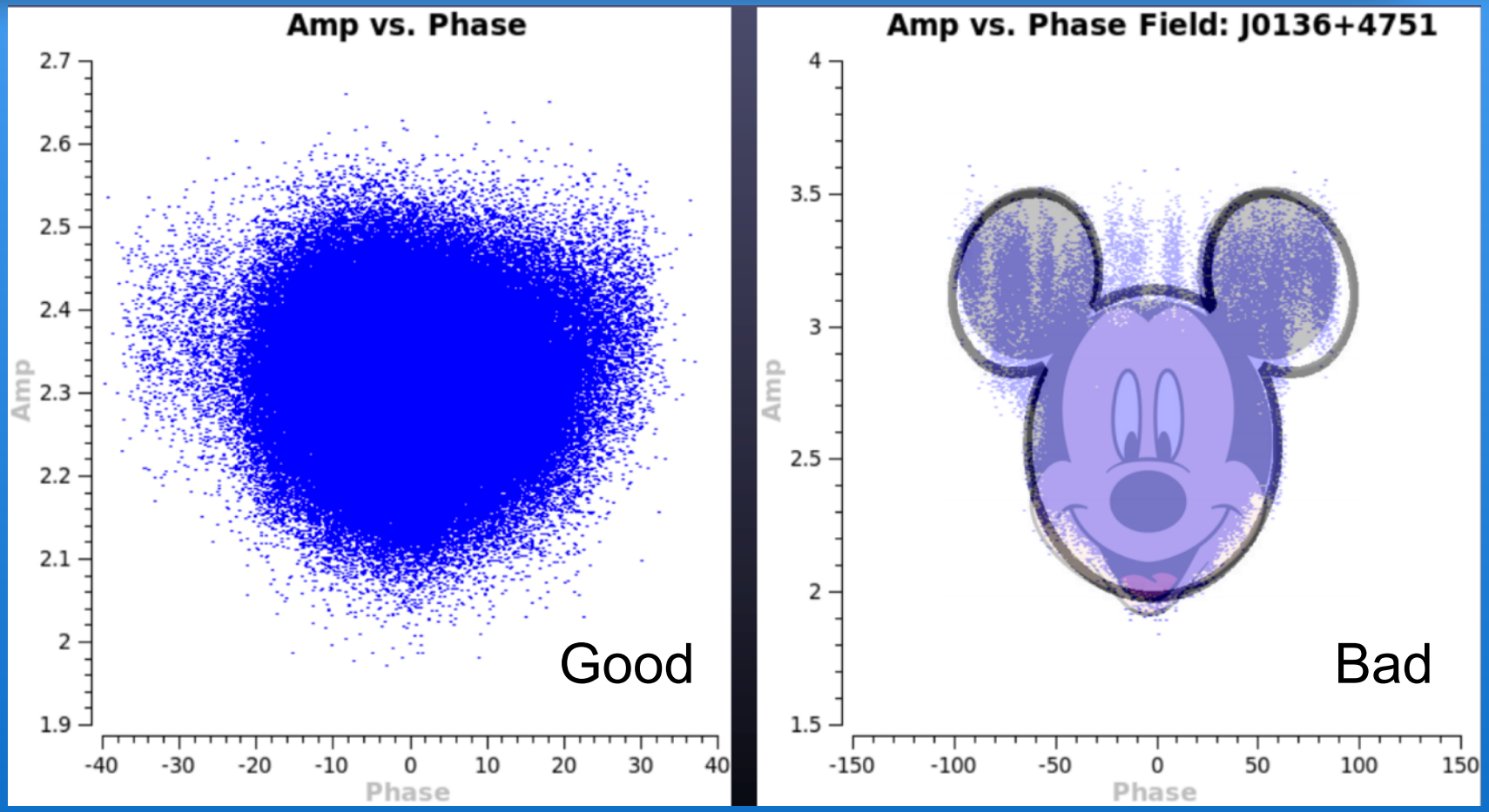






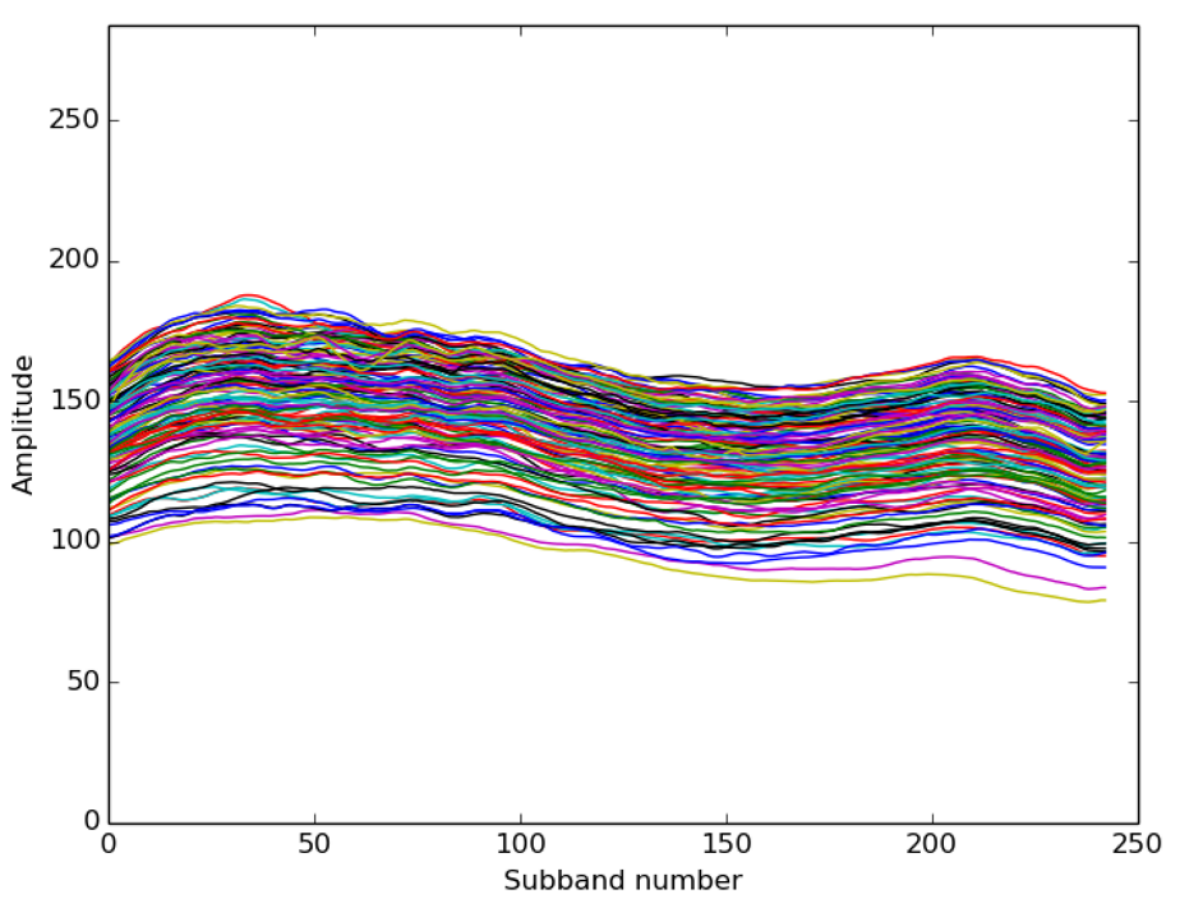
Inspect
solution behaviour

Calibration



Asymmetry in amplitude-phase plots indicates bad data

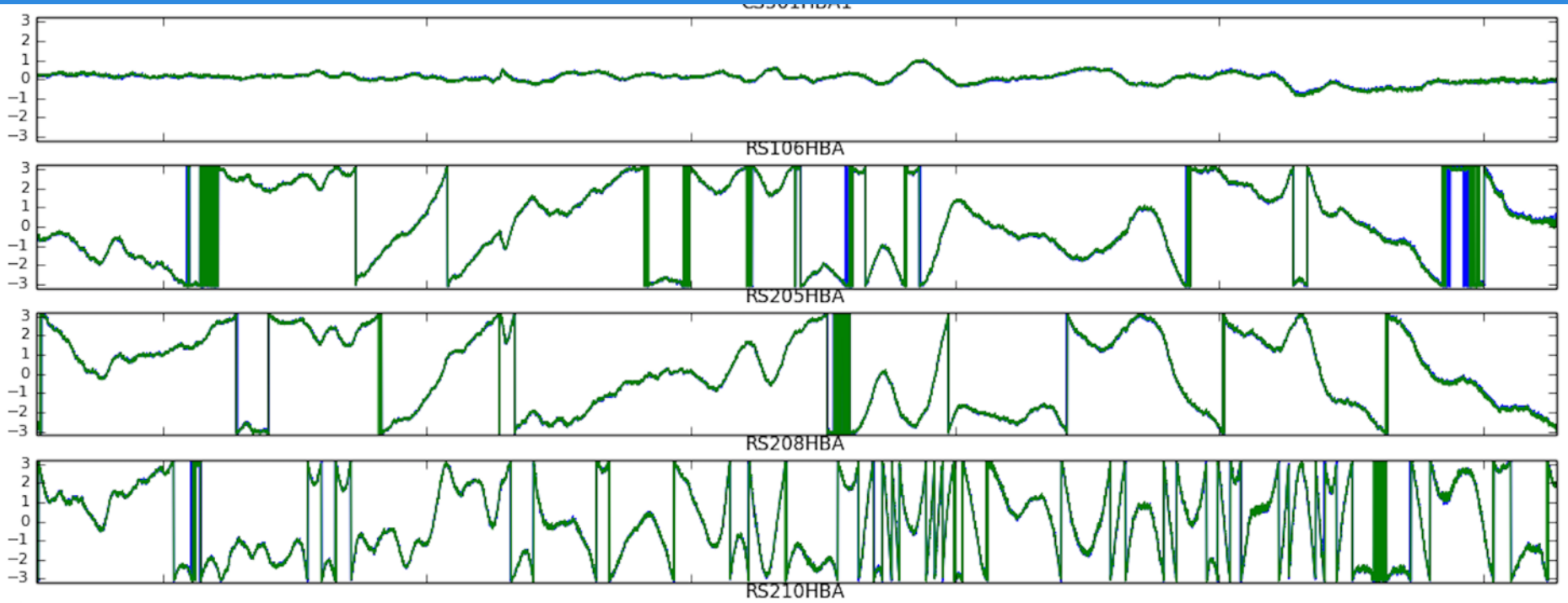
Calibration



Amplitude solutions - stable and at expected value

Calibration

Phase solutions should track well
Longest baselines can lose coherence at times due to the ionosphere



Imaging issues

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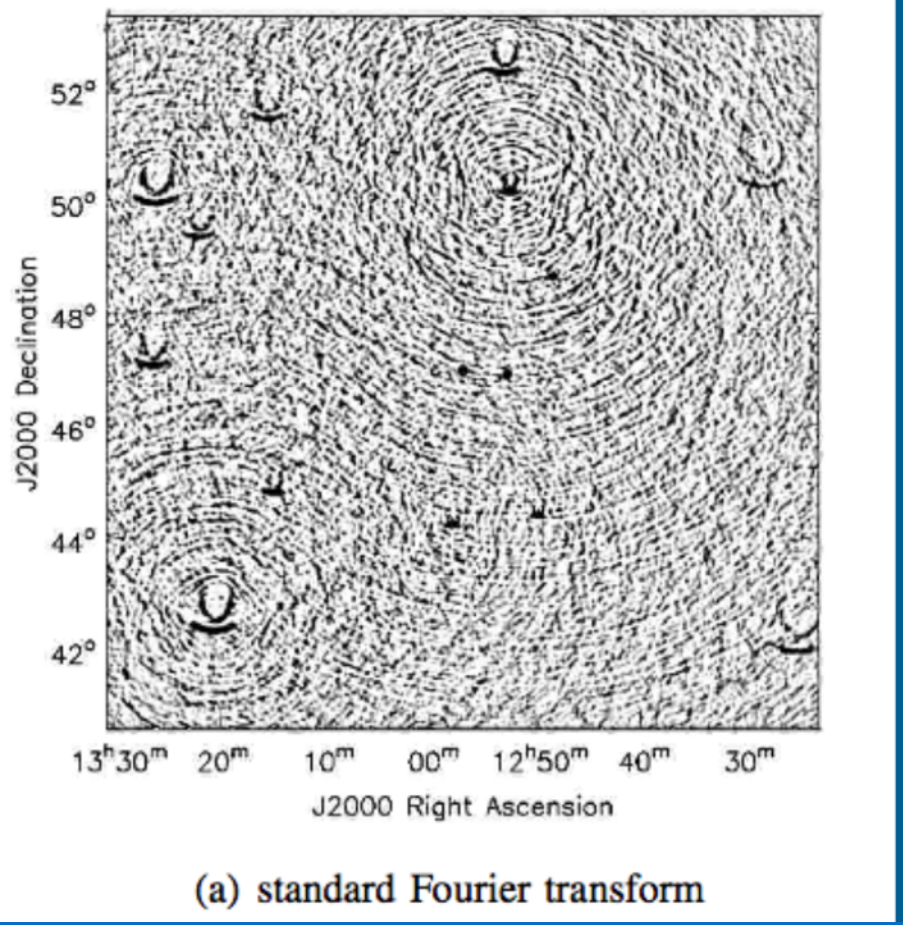
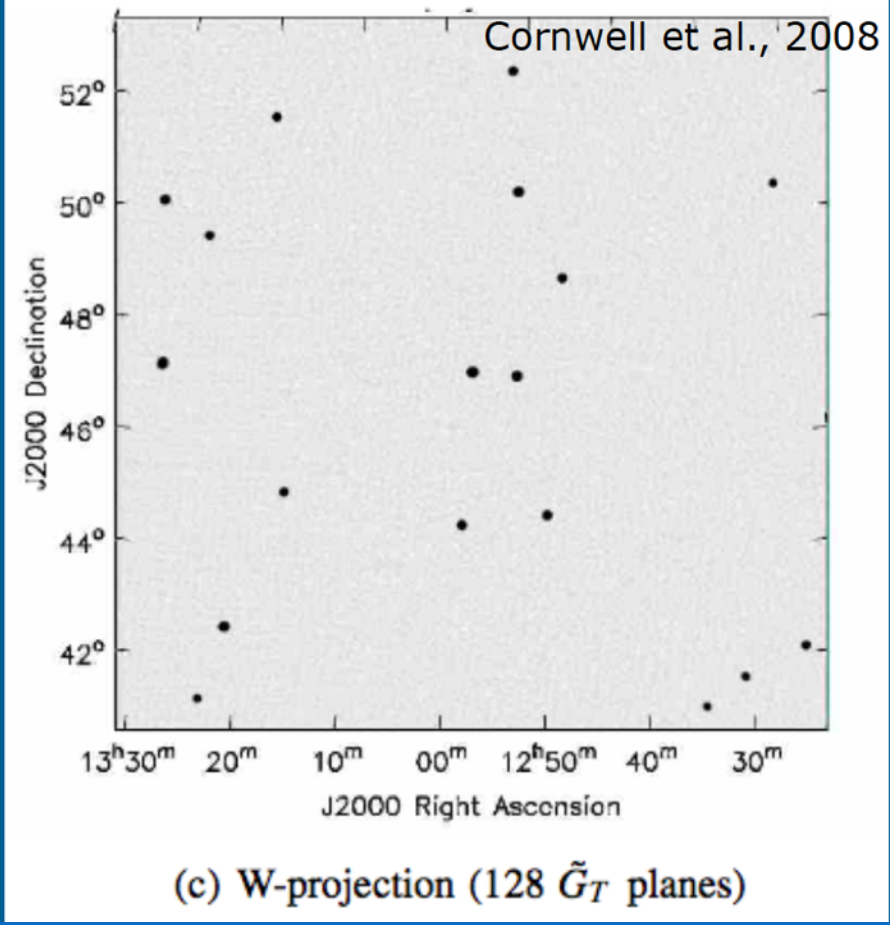
LOFAR - (very) large FoV (< 9deg across in LBA)

- 2D approximation no longer valid - W projection
- Beam constantly changes - A projection
- Wide bandwidth - BW and time averaging smearing an issue
- Ionosphere no longer iso-planatic - direction dependent effects
- Bright sources in the FoV a nuisance - peeling

Imaging: W projection



(a) standard Fourier transform



(c) W-projection (128 $\tilde{G}_T$ planes)

Imaging: BW issues

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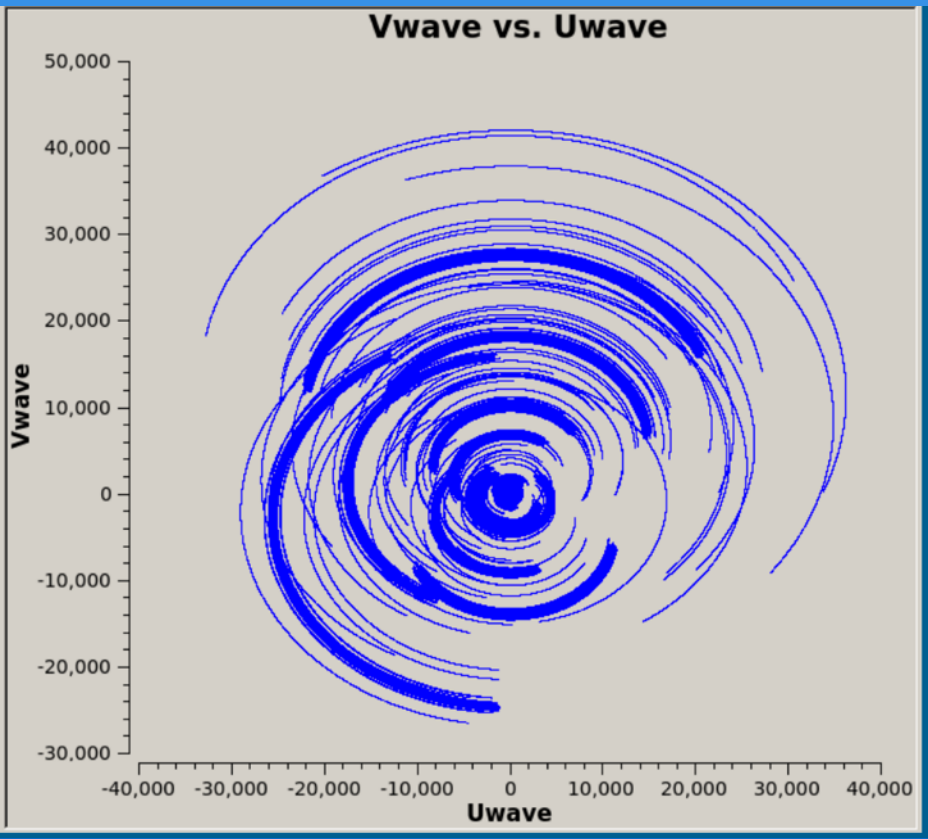
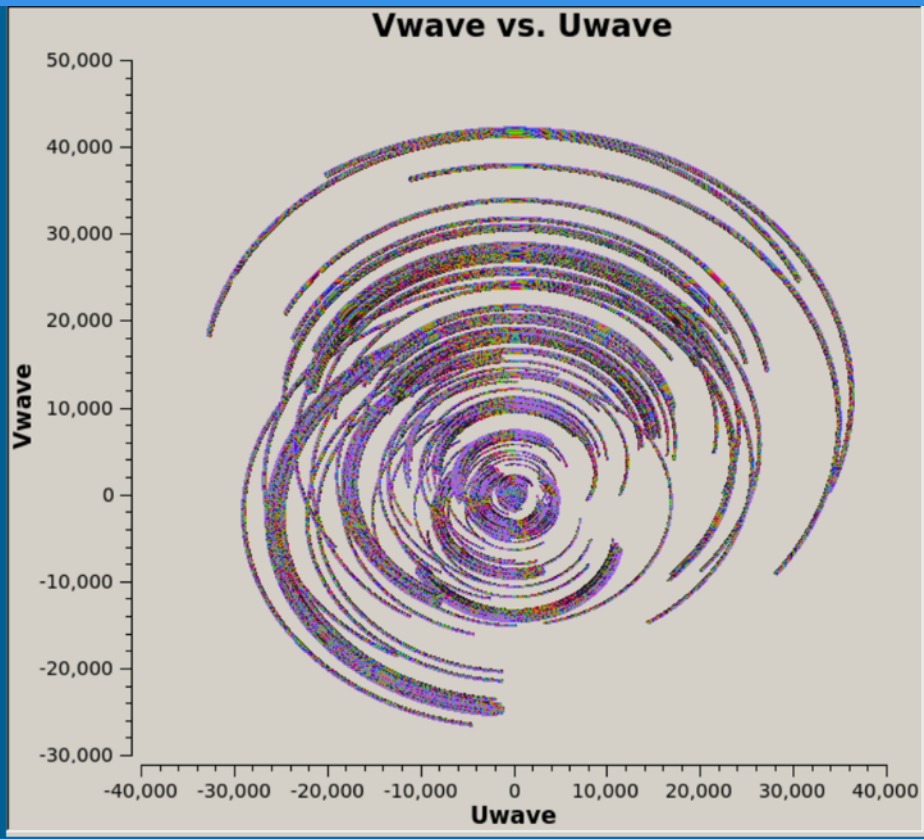
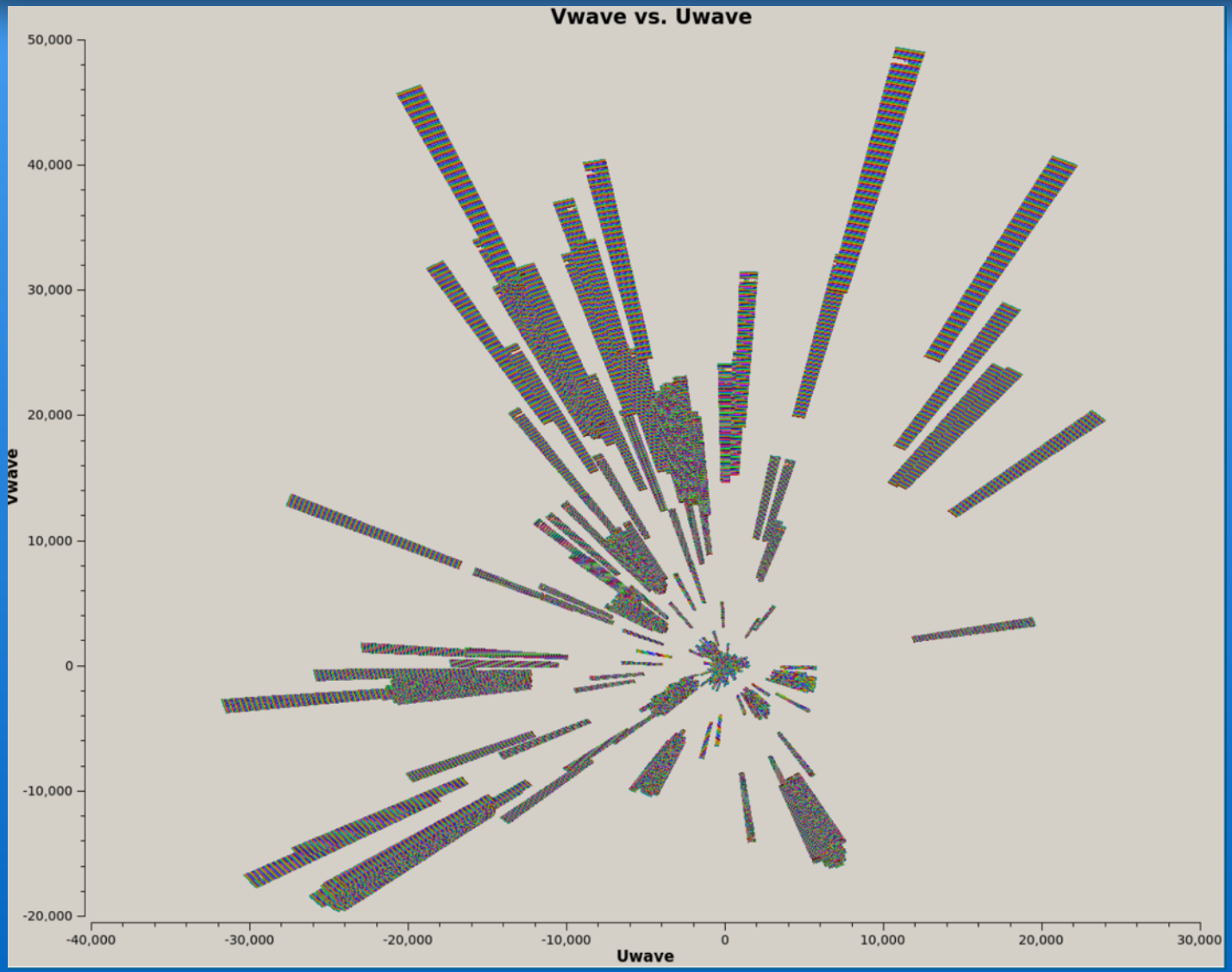
1 SB - 0.2 MHz



10 SBs - 2 MHz



Imaging: BW issues



70 MHz
10 minutes

Imaging: BW issues

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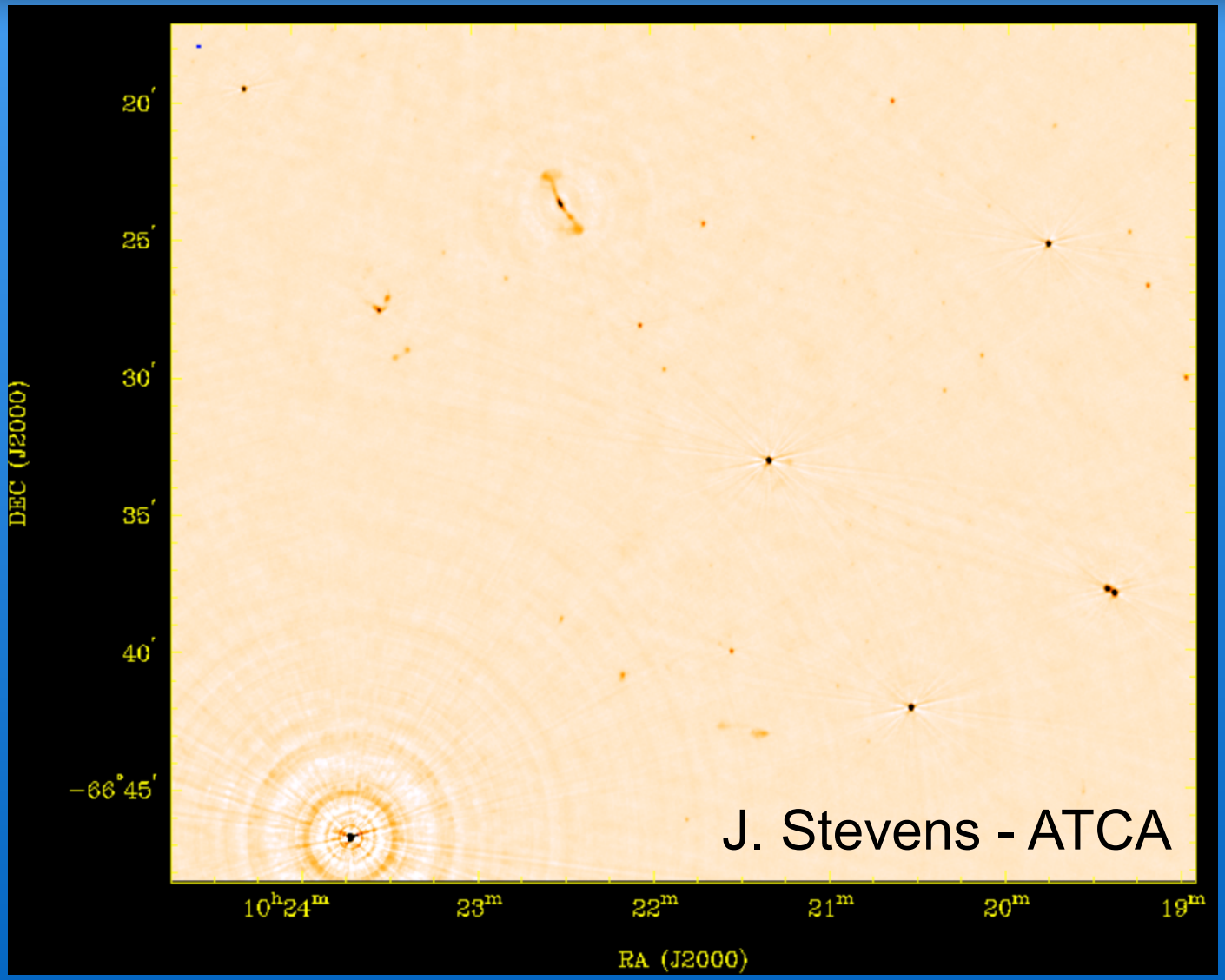
Visibilities gridded as if they were monochromatic (in case MFS imaging is not used)

If too much averaging in time/frequency is applied, smearing results

Effect is larger the further one goes from the phase centre - so especially important for LOFAR

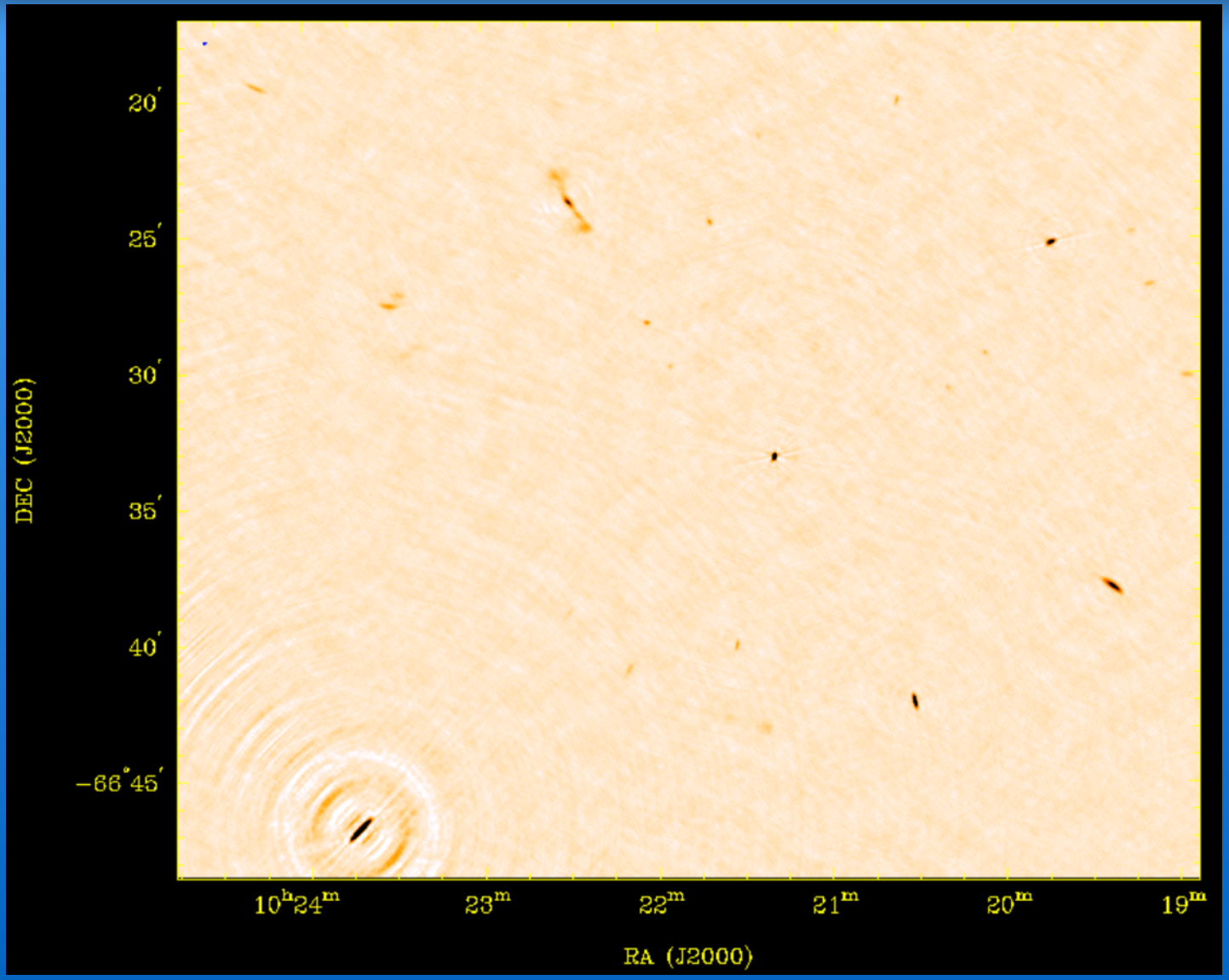
The need to mitigate these effects causes large LOFAR data sizes

Imaging: BW issues



2048ch x 1MHz
2GHz BW

Imaging: BW issues



32ch x 64MHz
2GHz BW

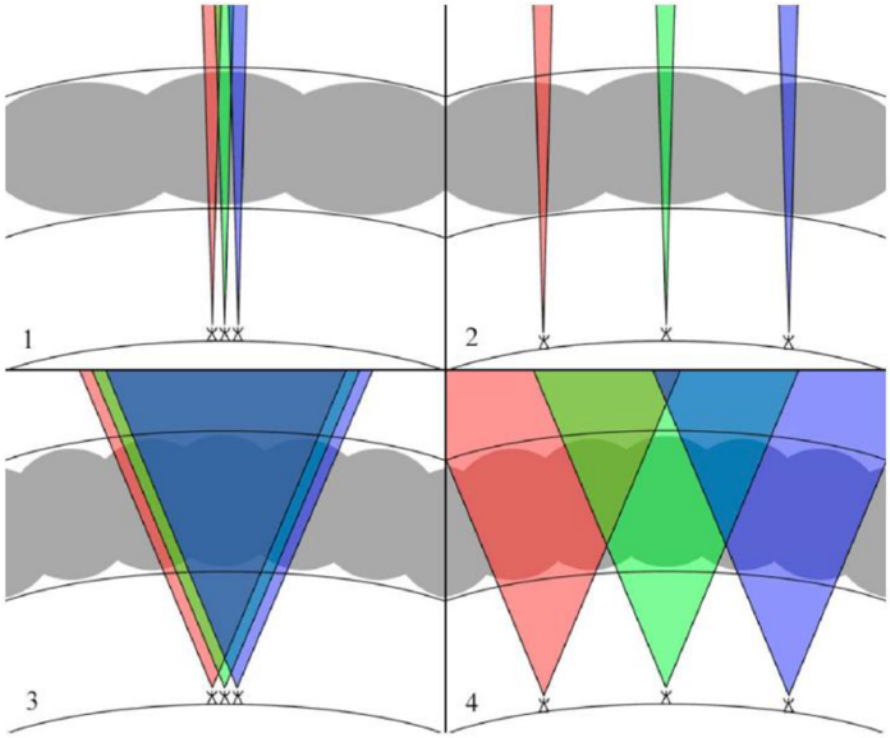
Imaging: Ionosphere

Direction independent effects – DIE

$$G_i(t)$$

Direction dependent effects - DDE

$$G_i(t, \alpha, \delta)$$

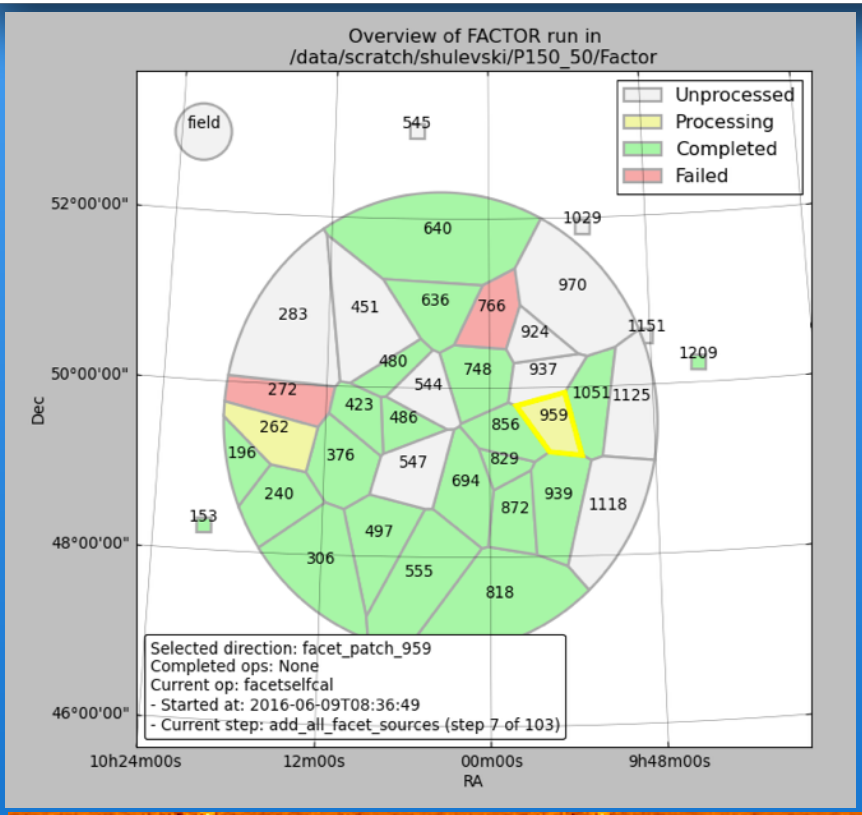


Intema et al. (2009)

1 and 2 - ionospheric phase error has no FoV dependence - self cal applicable

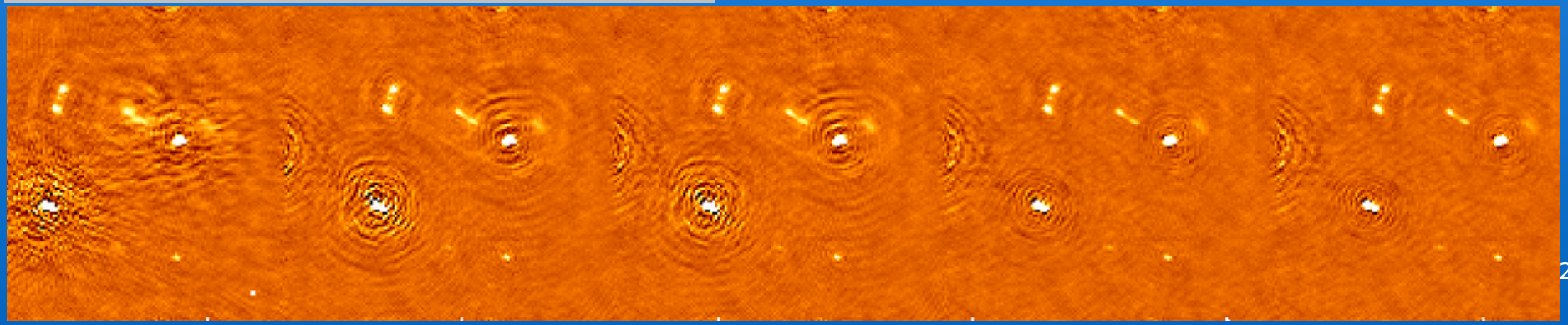
3 and 4 ionospheric phase error varies across the FoV DDE important

Imaging: Ionosphere

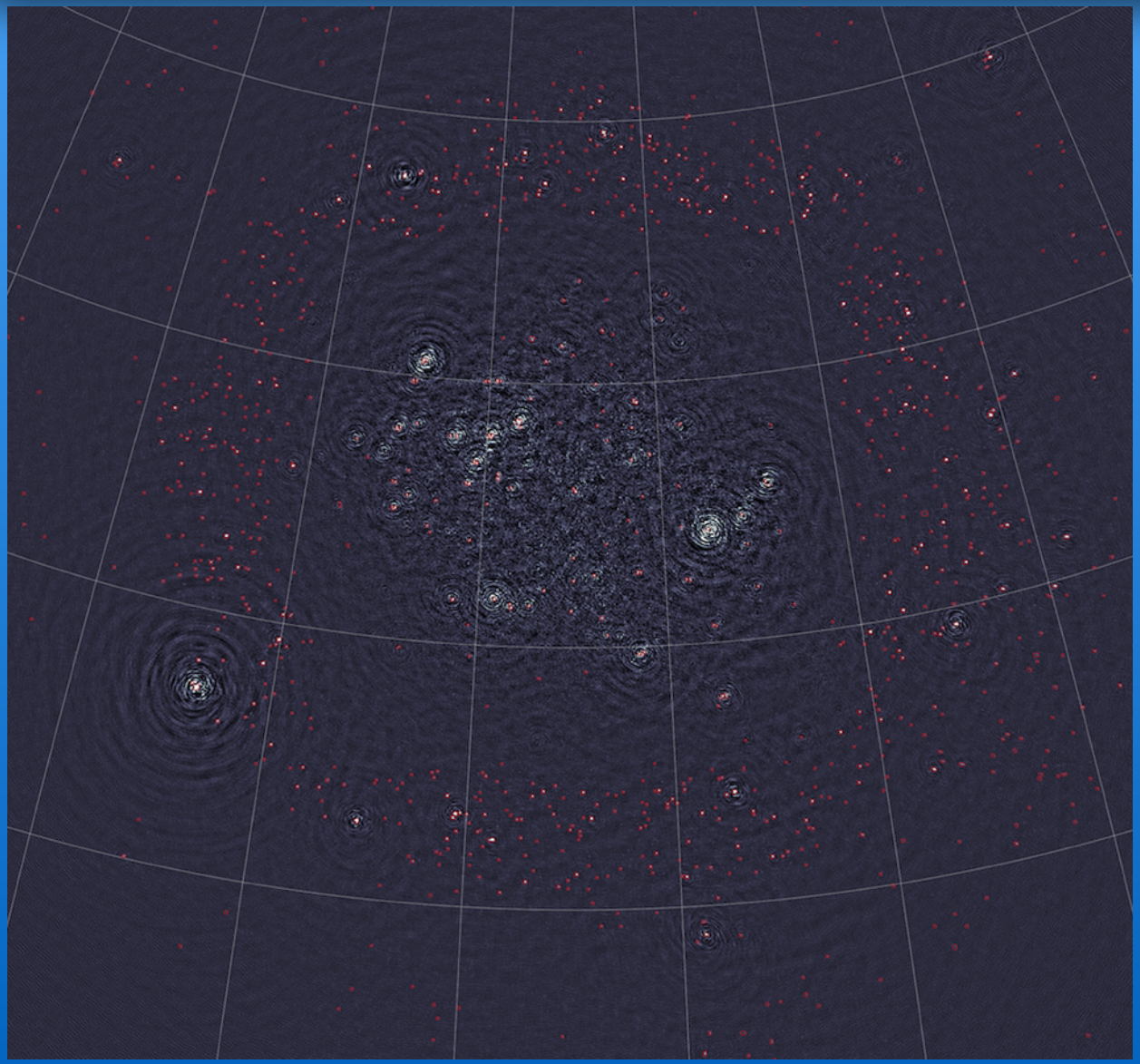


Facet calibration - FACTOR

van Weeren+ 2016, Williams+ 2016

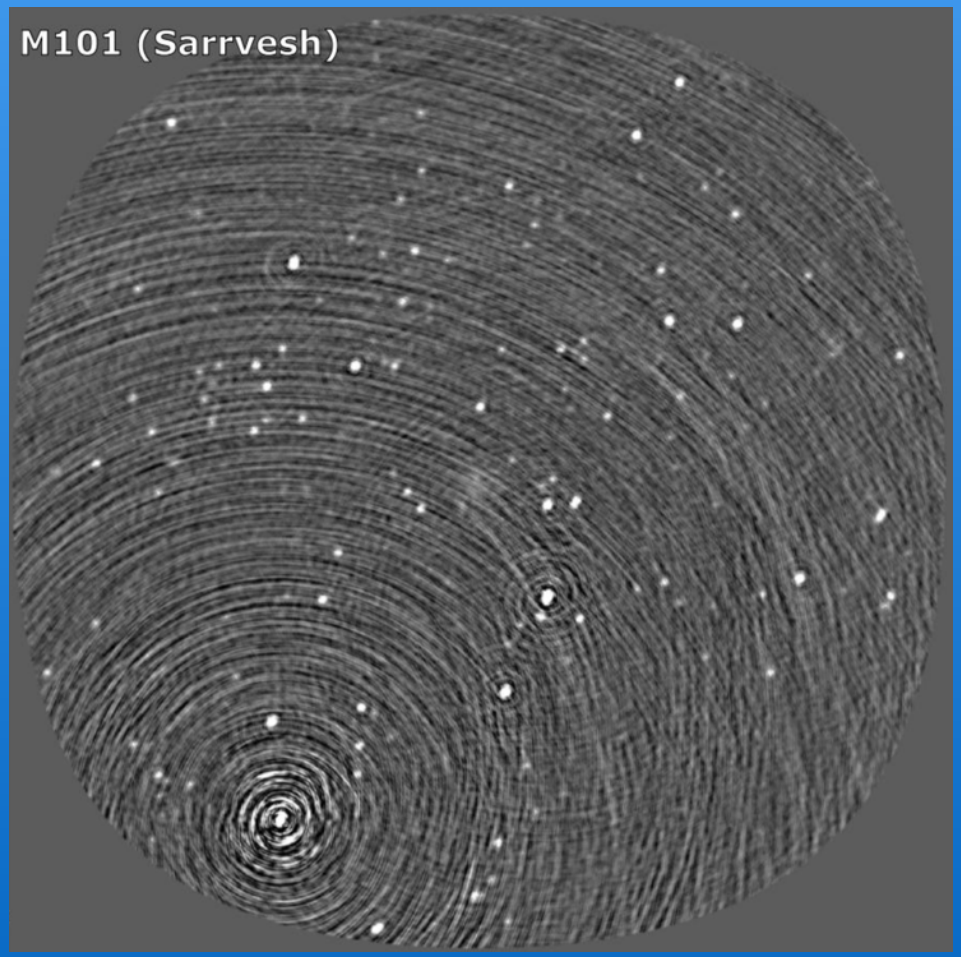


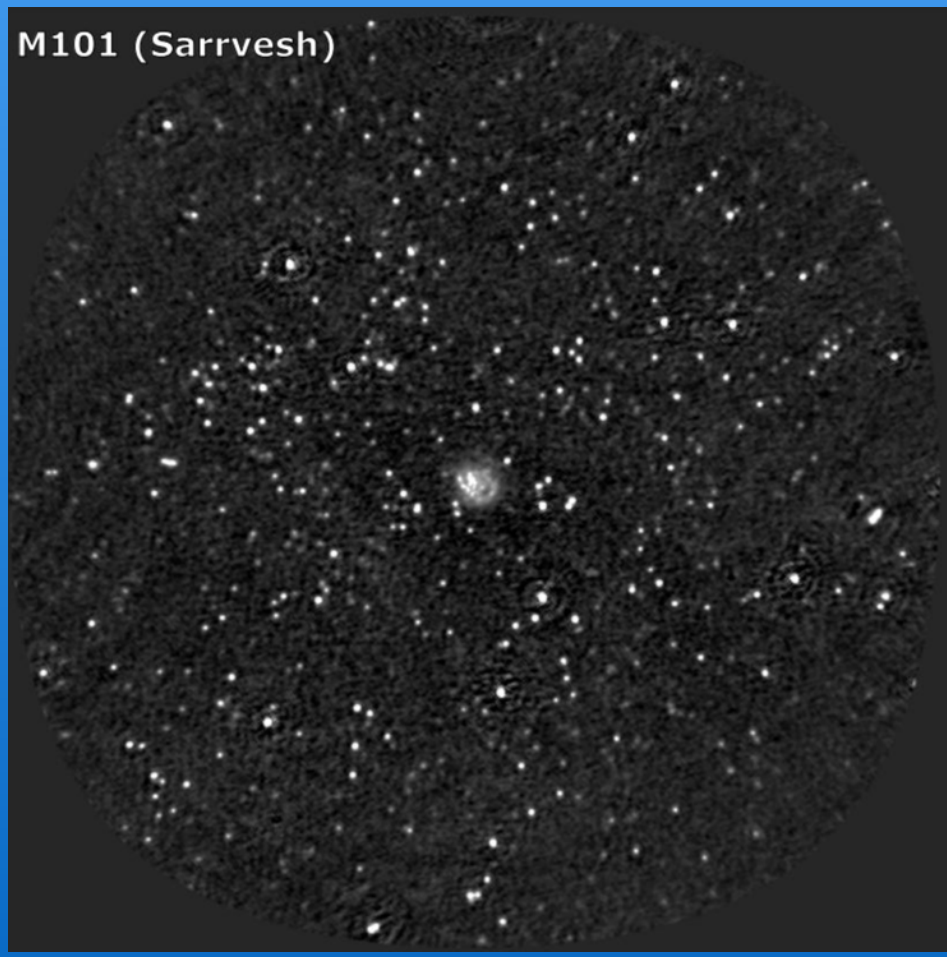
Imaging: Peeling



Imaging beyond first null of beam
lots of bright annoying sources

Imaging: Peeling





Calibration / bad data effects in image plane

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Can easily identify large errors in the u,v plane, but it's often difficult to find smaller errors

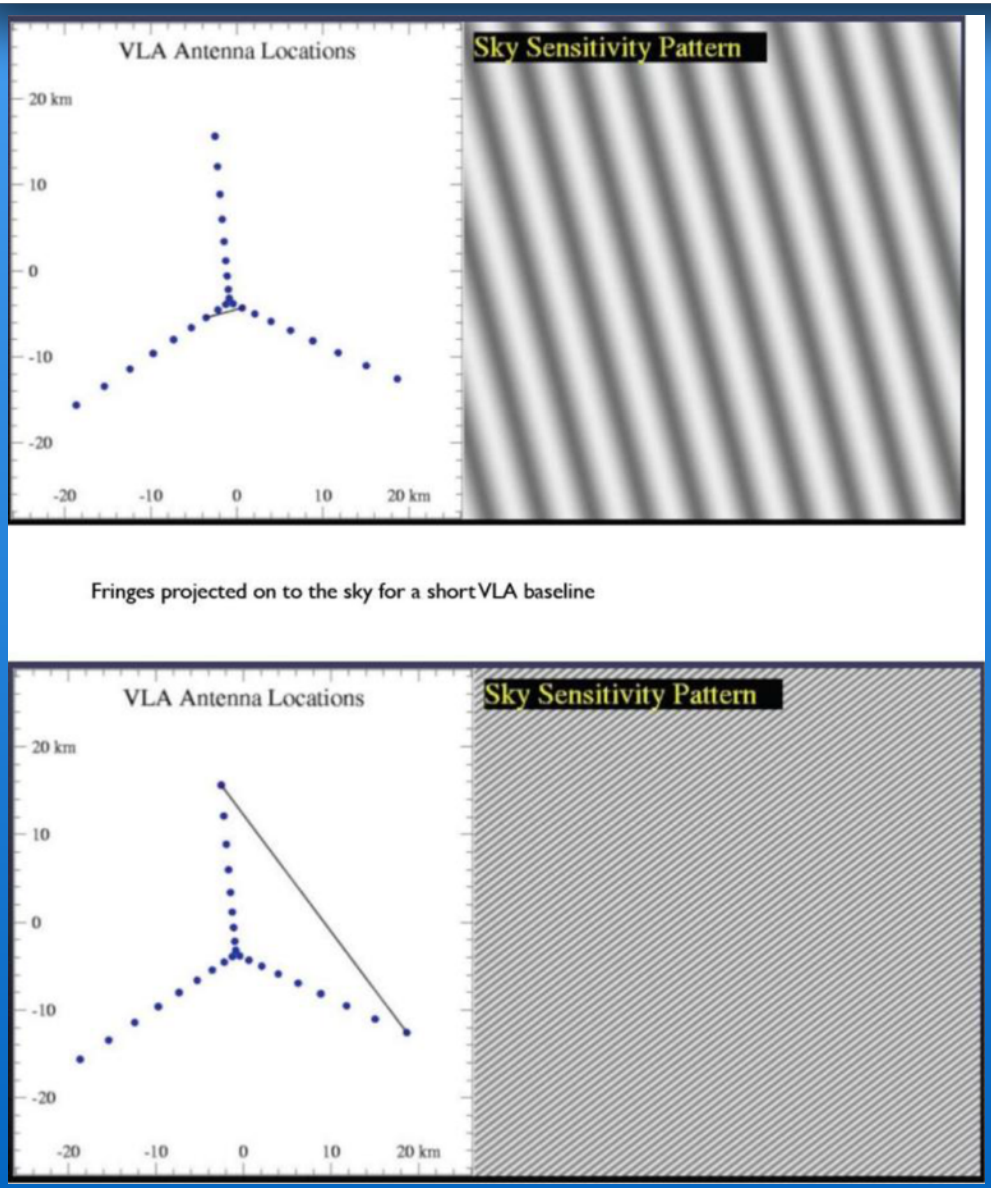
- Particularly true with LOFAR where many sources in the field of view make interpreting uvdist plots difficult!

- Remember: errors also obey the Fourier transform relation

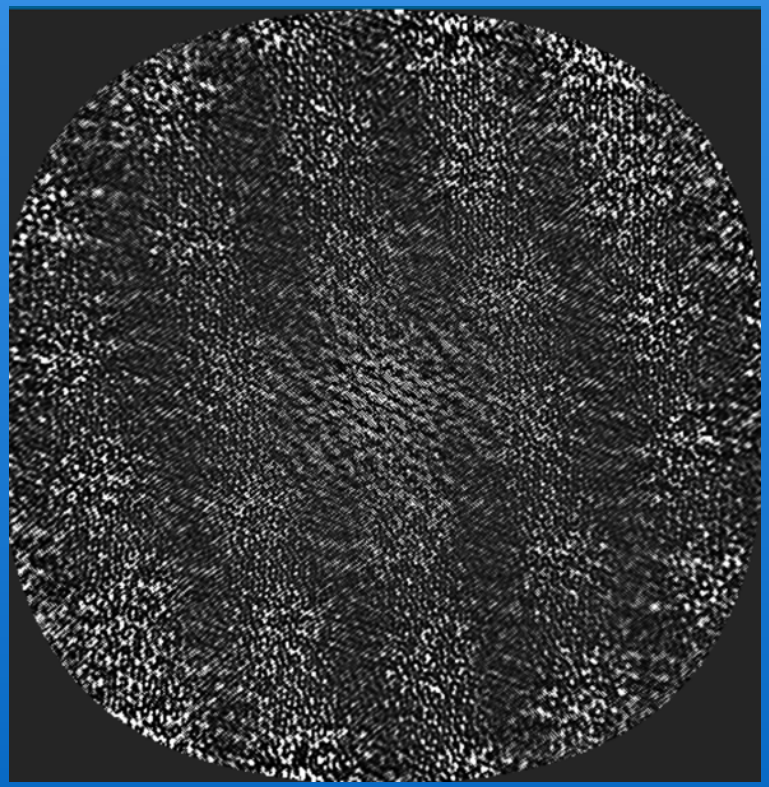
- Large errors in the u,v plane can be virtually insignificant in the image plane

- Likewise, small undetectable defects in the u,v plane can be very obvious in the image plane

Calibration / bad data effects in image plane



- Can use our knowledge of Fourier transform pairs to our advantage
- Look for patterns/symmetries



Calibration / bad data effects in image plane

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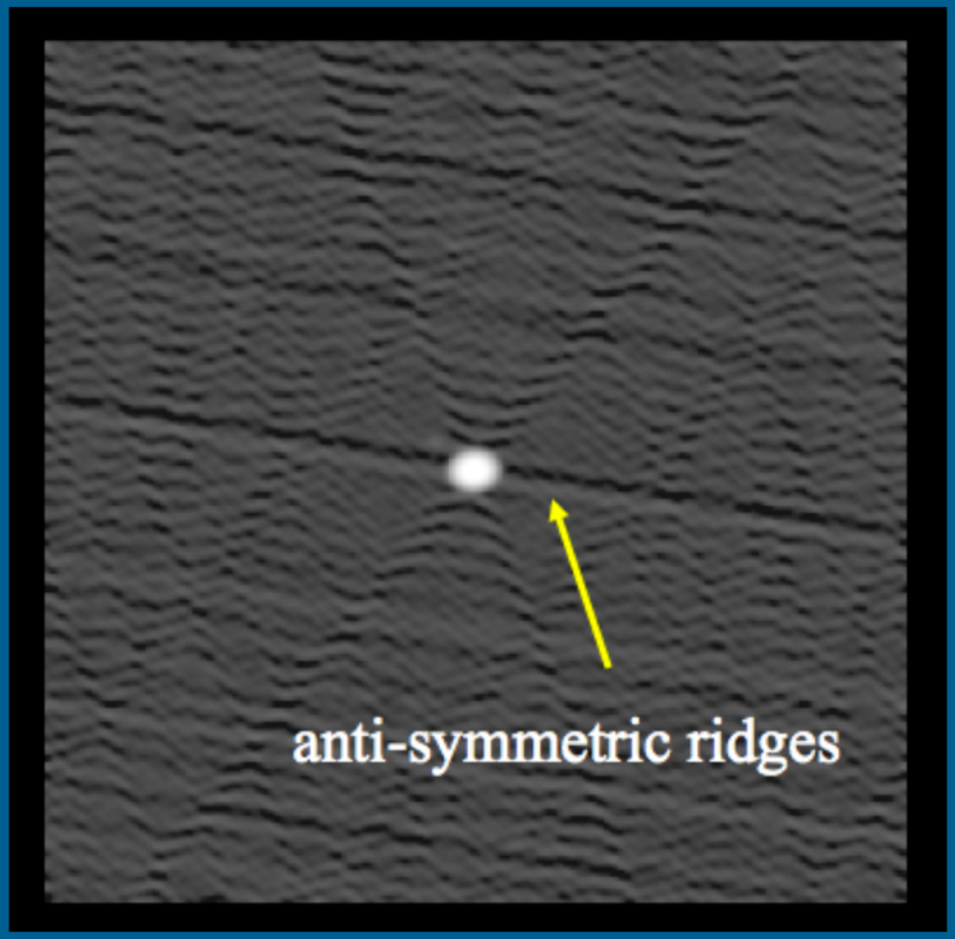
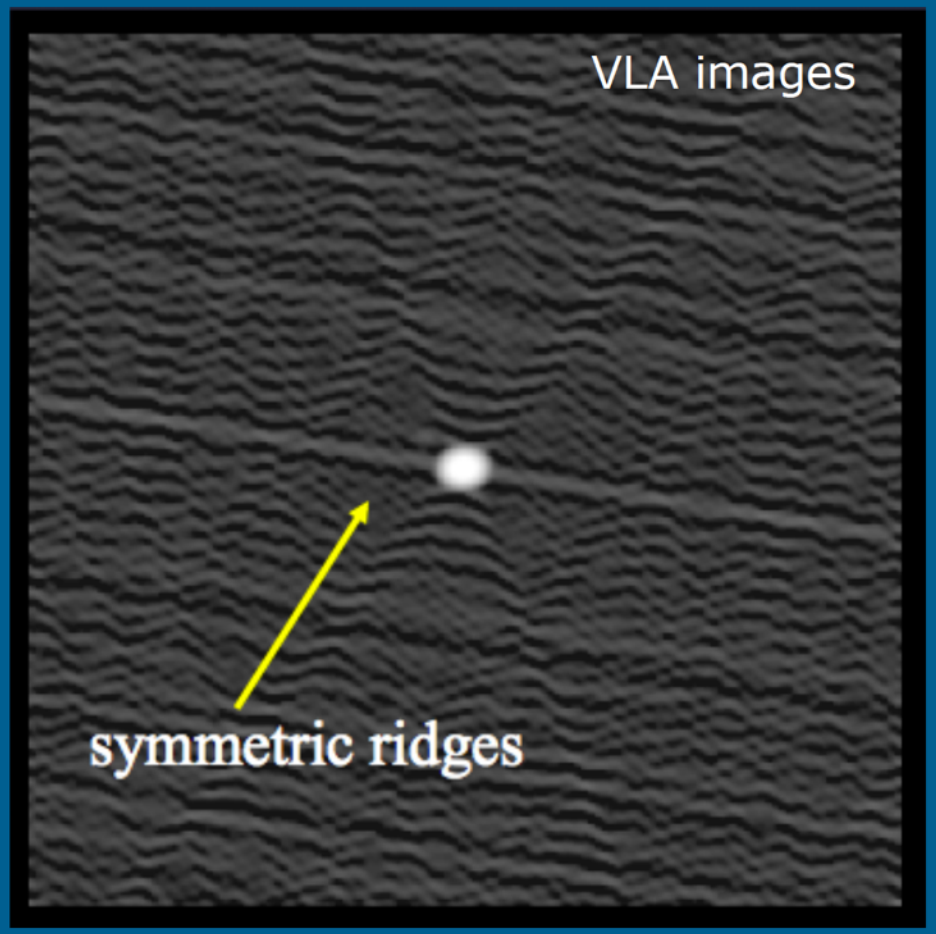
10 deg phase error for
one antenna at one time



20% amplitude error for
one antenna at one time



Calibration / bad data effects in image plane

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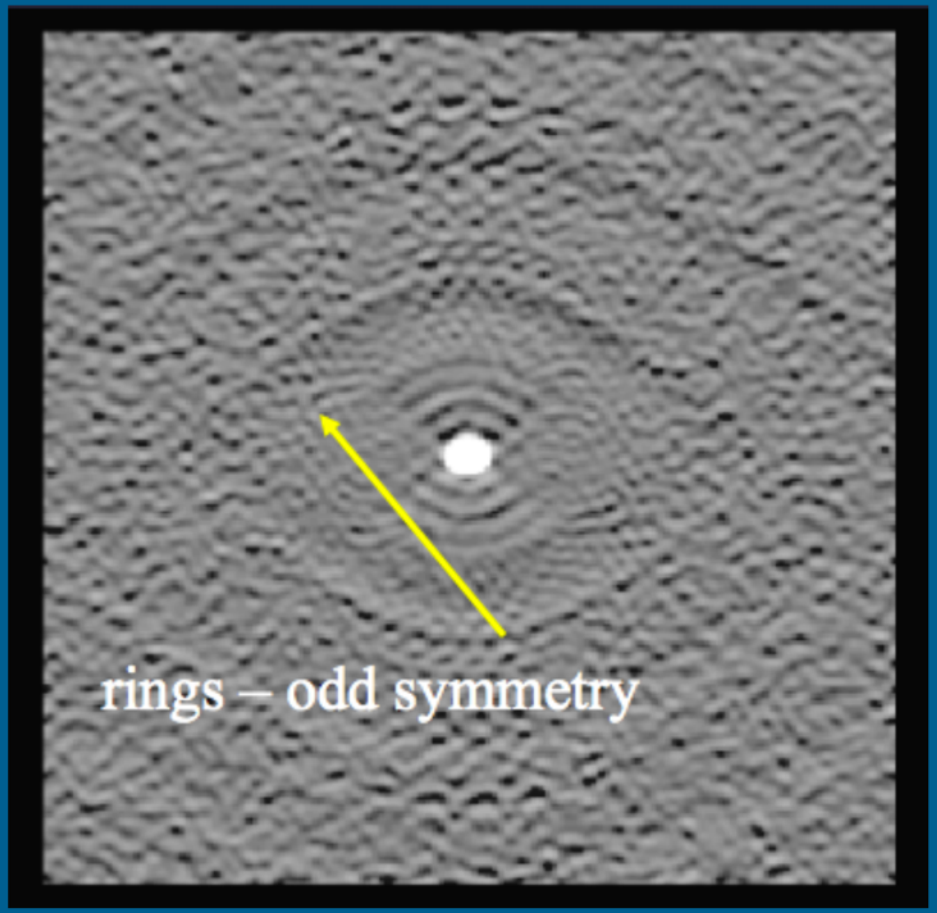
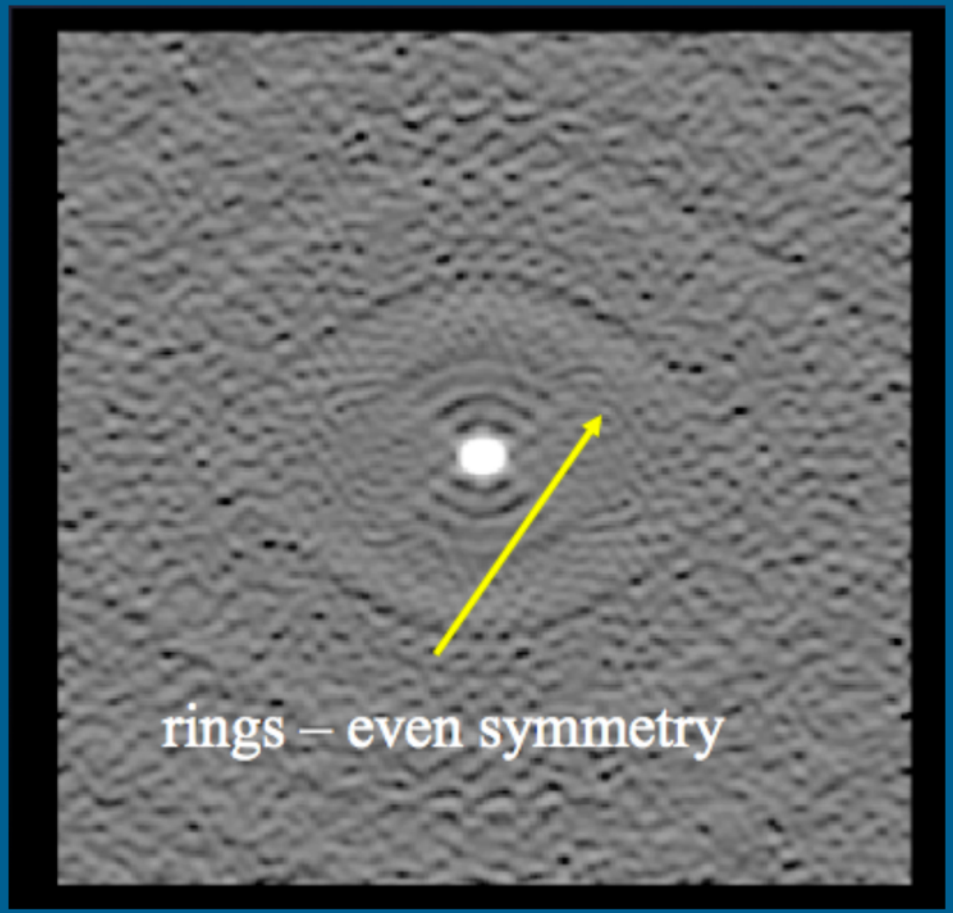
10 deg phase error for
one antenna at all times



20% amplitude error for
one antenna at all times



Calibration / bad data effects in image plane

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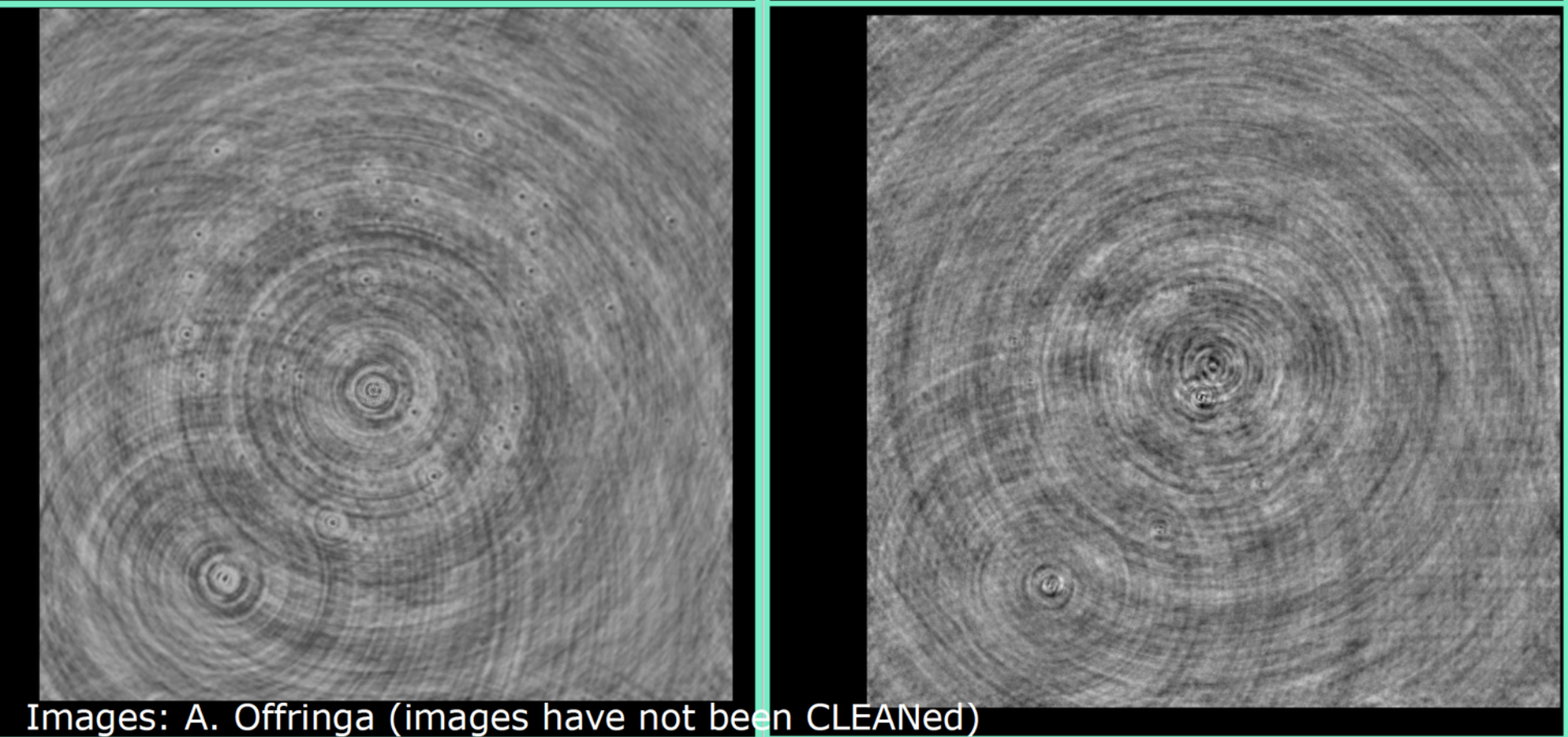
- Another example of RFI (NCP observations):

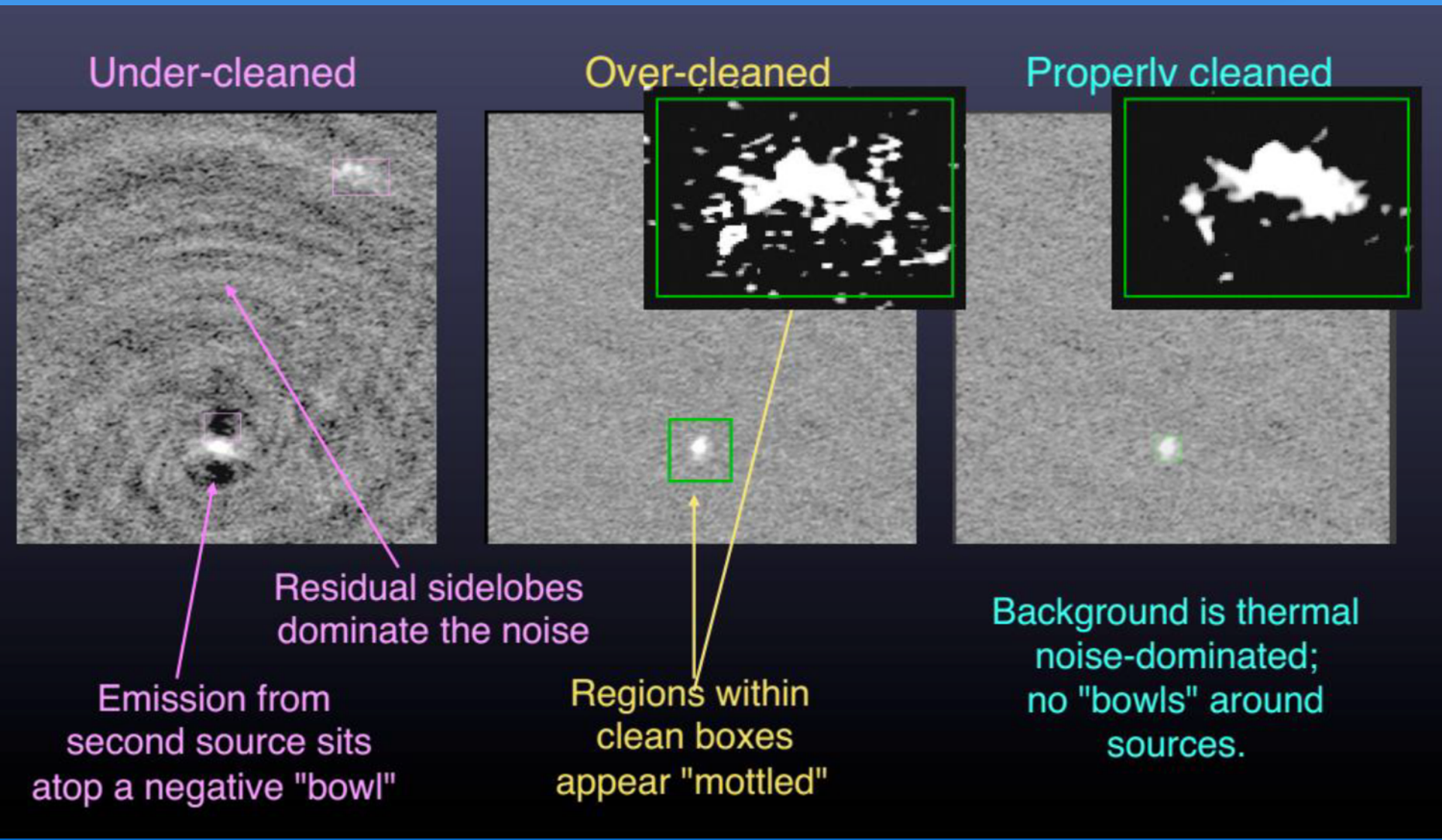
No RFI

RFI centred at the pole

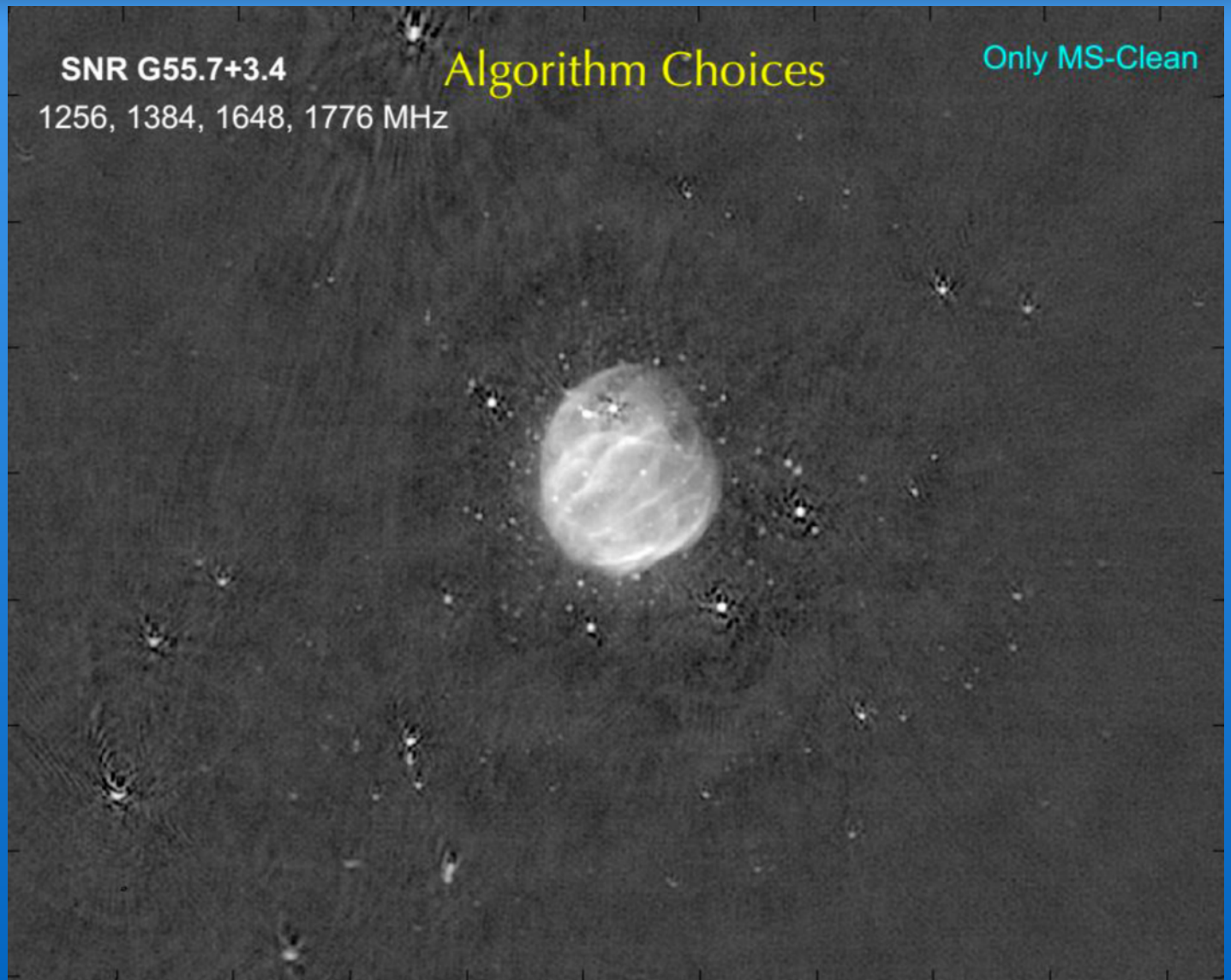


Images: A. Offringa (images have not been CLEANed)

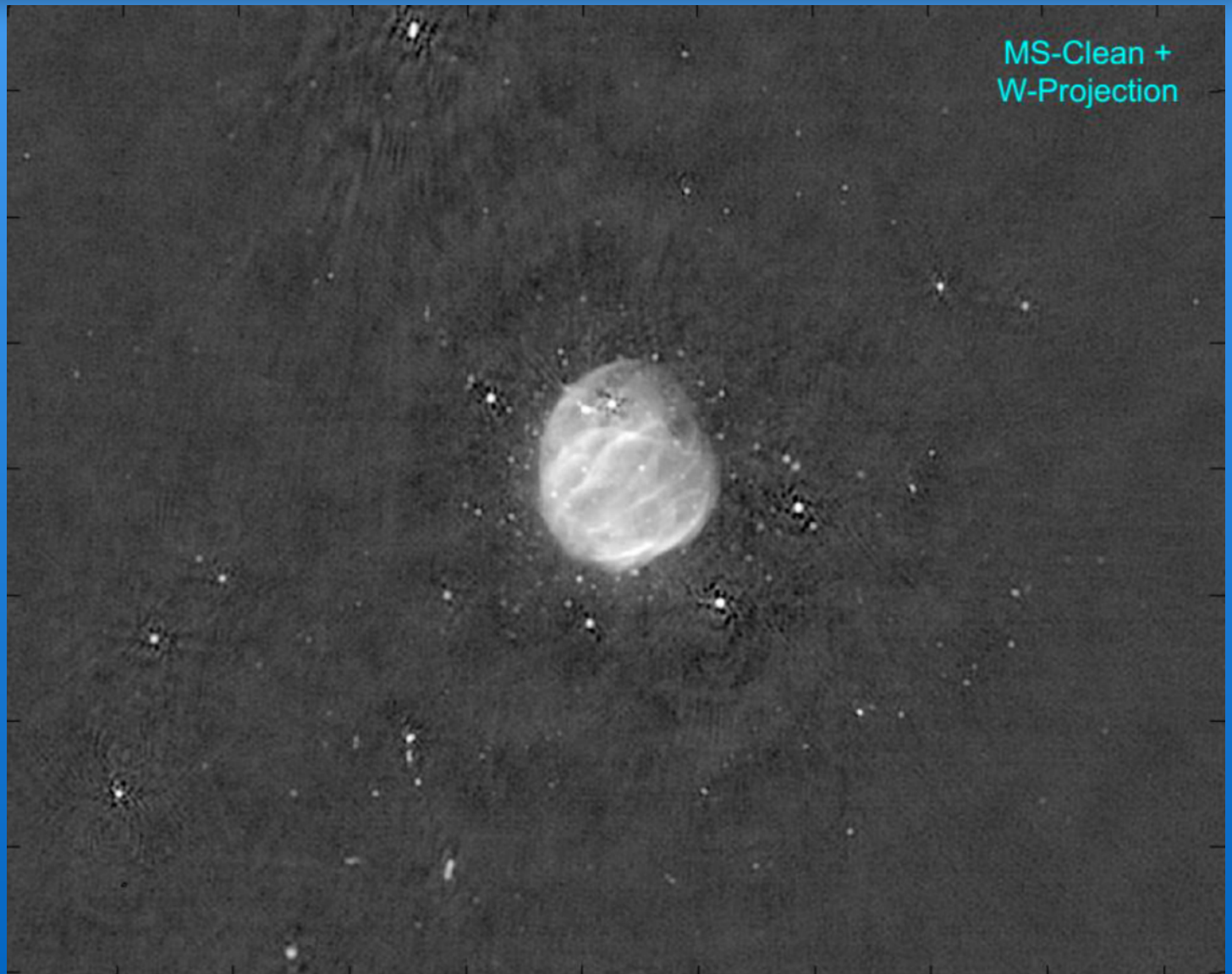
Imaging: how deep to clean?



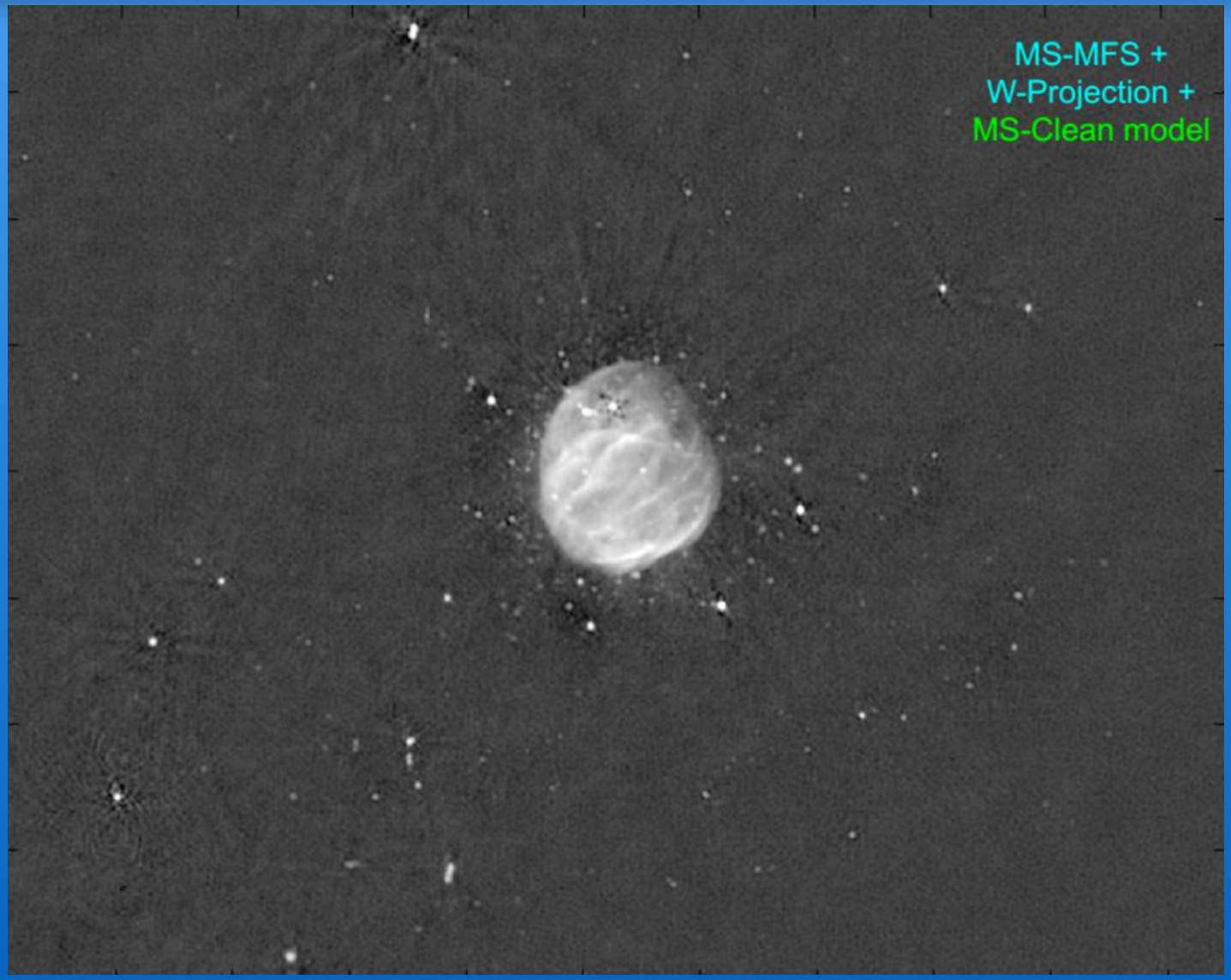
Imaging: algorithms



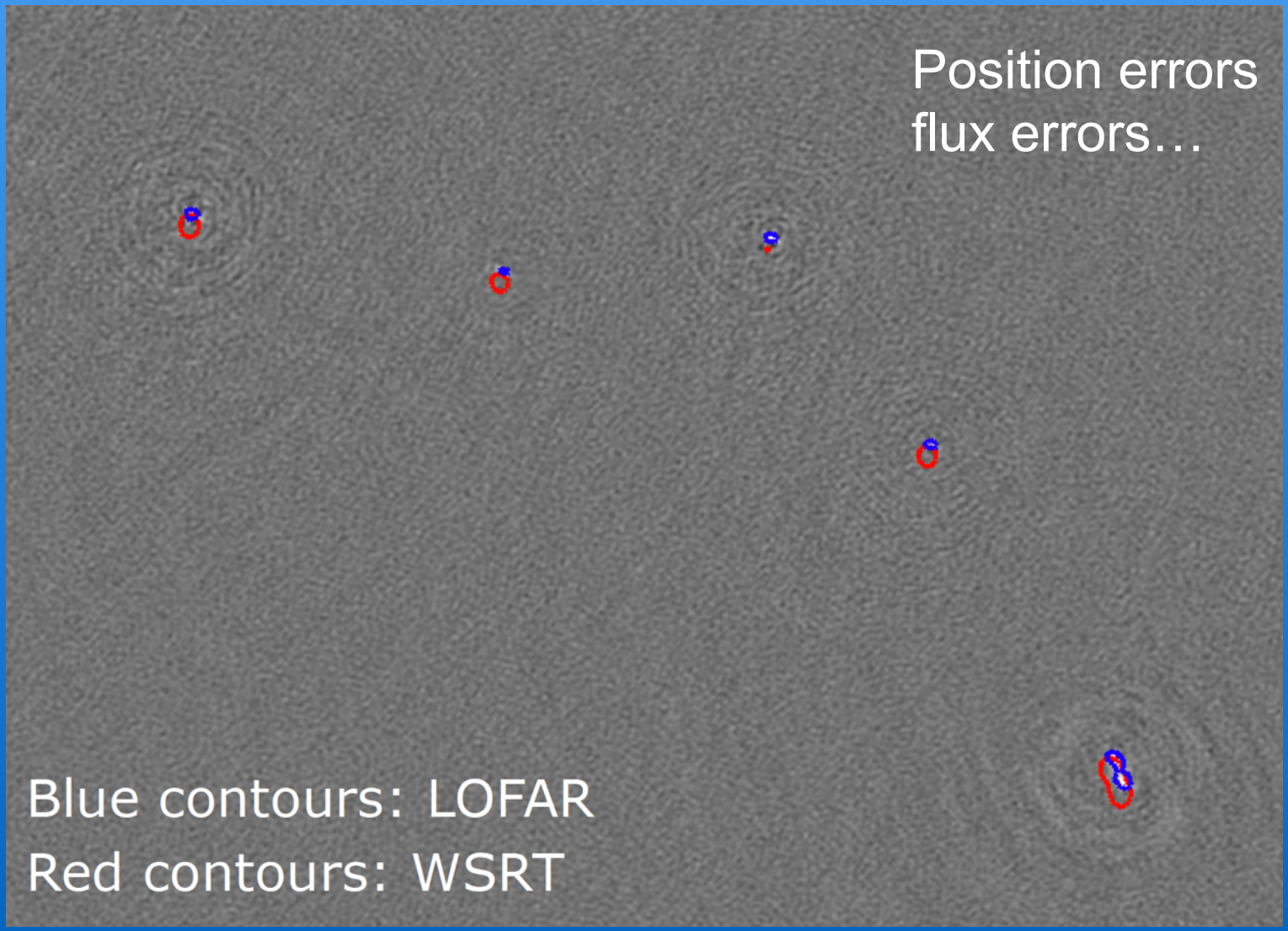
Imaging: algorithms



Imaging: algorithms



Is the imaging science-worthy?



Summary

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- Errors obey Fourier transform relation – use this to your advantage!

- Image artifacts can either come from bad u,v data which needs to be flagged, OR due to the deconvolution algorithm used -> choose wisely

- If still in doubt, try FT back into visibility space to compare -> make sure you have the best skymodel possible

Summary

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Beware of wide-field imaging effects:

- Need to use W-projection and A-projection
- Be careful not to average too heavily, can lead to bandwidth or time-smearing
- Direction dependent effects
- Are there any bright sources in the field you need to peel?

Can you do science with your image?
- Check the flux scale and source positions!

Summary

First flag obviously bad data in the u,v plane
- Make large, low resolution image first
- Identify potential issues (i.e. bright sources in the field)
- First check of flux scale (7C/VLSS/TGSS good catalogues to crossmatch with, in the future MSSS)
- Check that you have the best input skymodel possible

Start with a subset of data to reduce manually and work out the best strategy

References

VLA white book – Chapters 15, 18, 19

Lectures from previous synthesis imaging schools
- LOFAR data school 2014
- ERIS 2013 (http://www.astron.nl/eris2013/lectures.php)
- NRAO synthesis imaging workshop 2014 (https://science.nrao.edu/science/meetings/2014/14th-synthesis-imagingworkshop/lectures)
- CSIRO radio astronomy school (http://www.atnf.csiro.au/research/radio-school/2014/index.html)

Papers on w-projection and a-projection (Cornwell+ 2008; Bhatnagar+ 2008,2013; Offringa+ 2014)

Papers on direction-dependent calibration (Intema+ 2009,2014; van Weeren+ 2016; Williams+ 2016)

Thank you! Questions?

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