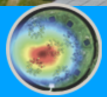
ASTRON
Netherlands Institute for Radio Astronomy

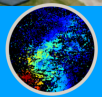
STELLAR

LOFAR

Assessing data errors

Wendy Williams (Leiden Observatory)





credits

Thanks to R. van Weeren, A. Shulevski, E. Mahony, K. Chyzy and others whose slides I have borrowed

Take home points

Problem

Solution

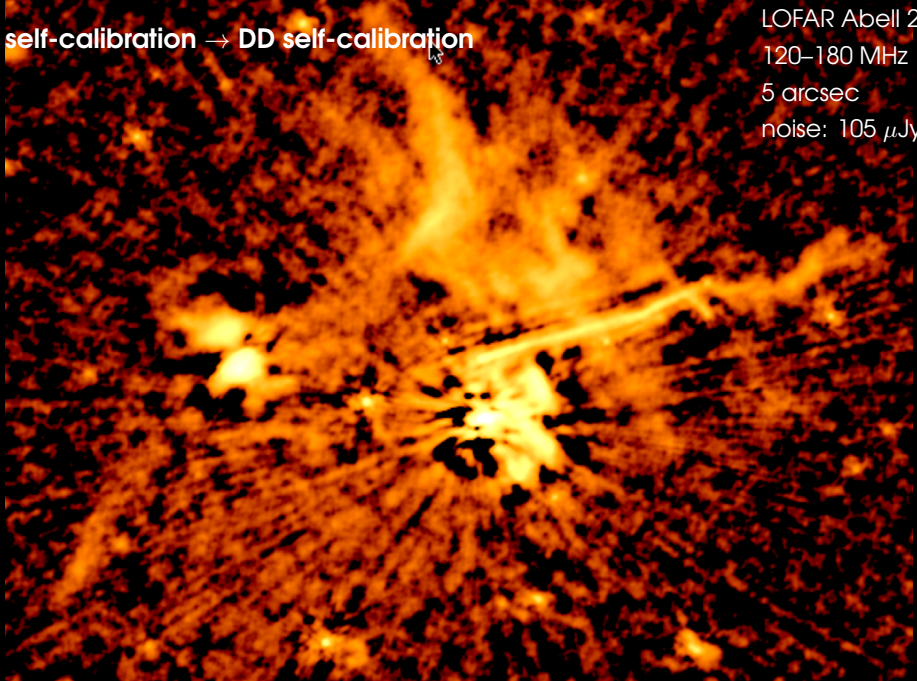
Data errors (RFI, bad stations)

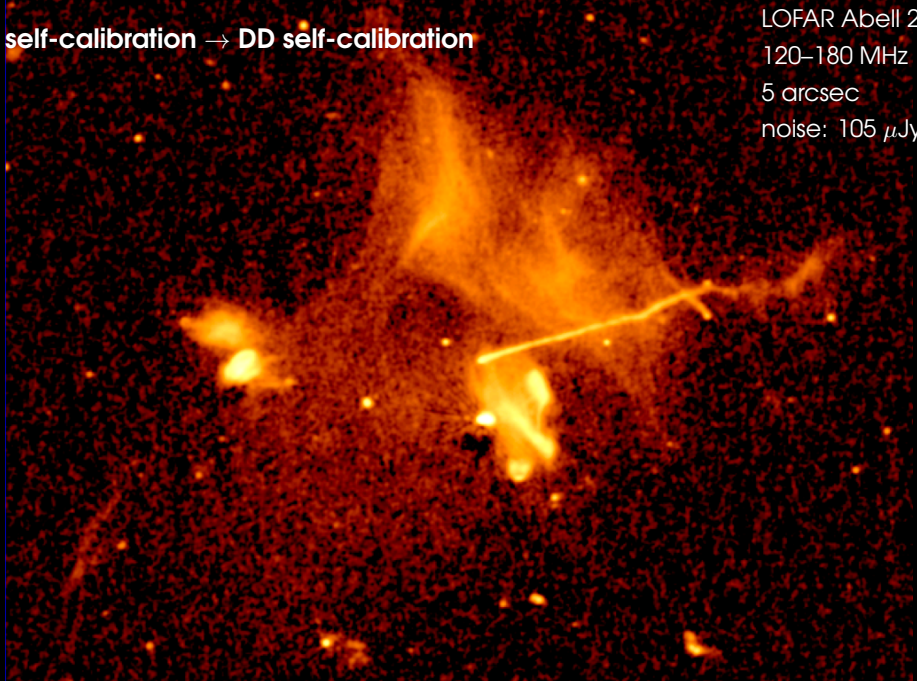
Calibration Errors (model completeness, ionosphere, the beam model, etc.)

Imaging Errors (deconvolution issues, widefield, wideband, bandwidth/time smearing, station beams)

Take home points

Problem	Solution
Data errors (RFI, bad stations)	Use the observation log (report) to track big issues (ex. bad antennas). Inspect data, flag as warranted.
Calibration Errors (model completeness, ionosphere, the beam model, etc.)	DD calibration (DDF, Factor)
Imaging Errors (deconvolution issues, widefield, wideband, bandwidth/time smearing, station beams)	Multiscale clean, A/W-projection, Facets, W-stacking, IDG, Multispectral clean


self-calibration → DD self-calibration
LOFAR Abell 2256
120–180 MHz
5 arcsec
noise: 105 μJy/bm


self-calibration → DD self-calibration
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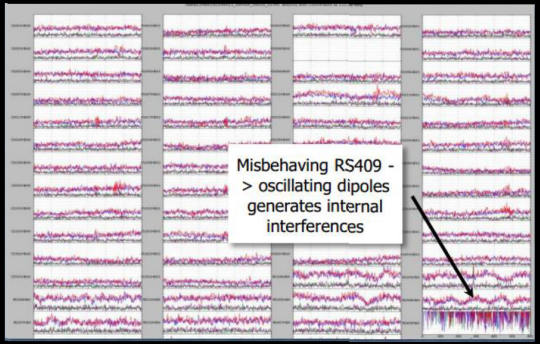
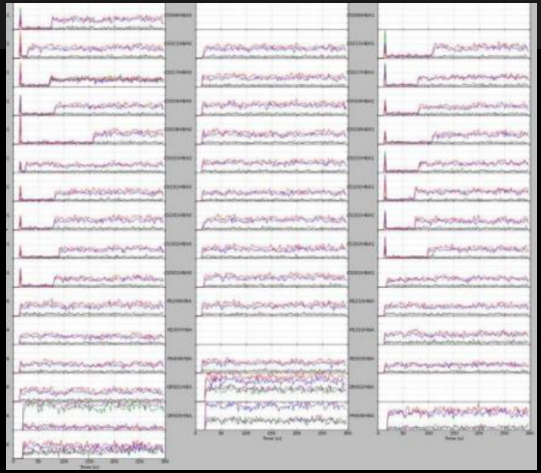
Data errors: inspection plots





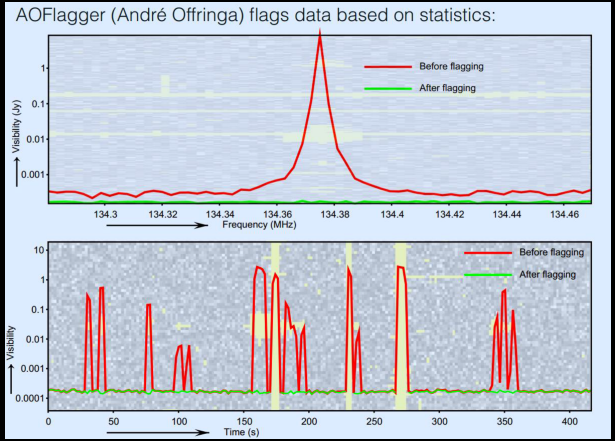
Connection problems at the start of the run

Learn more at:

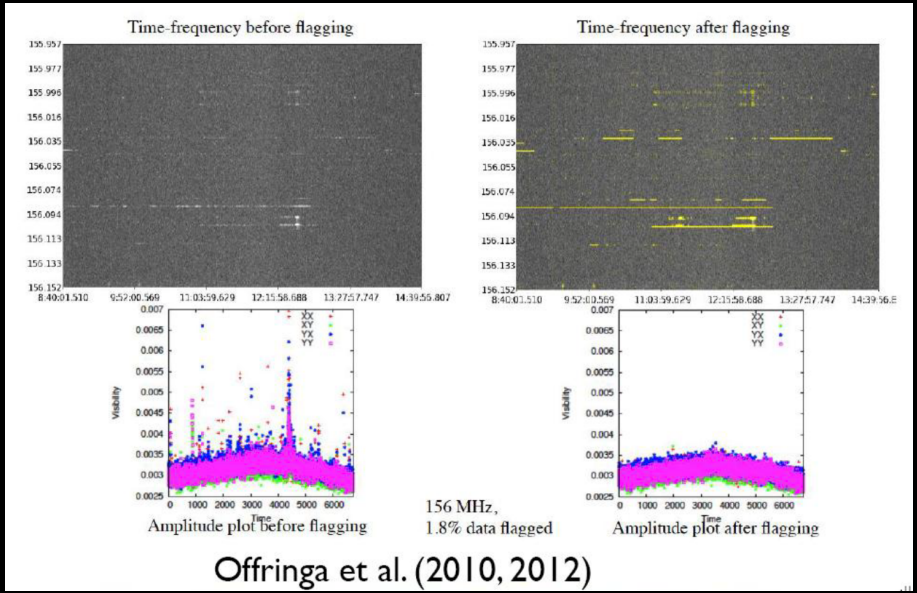
https://old.astron.nl/radio-observatory/observing-capabilities/depth-technical-information/data-quality-inspection/data-qu

Data errors: RFI

Flagging always the first step!
- flag at high resolution



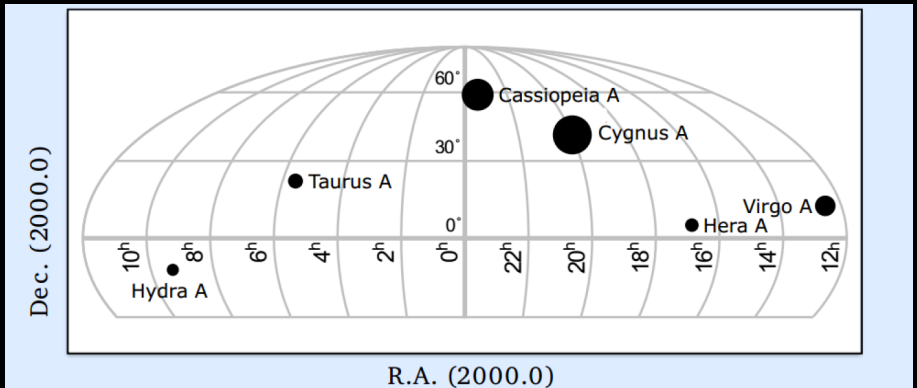
Data errors: RFI



Data (errors): Demixing

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

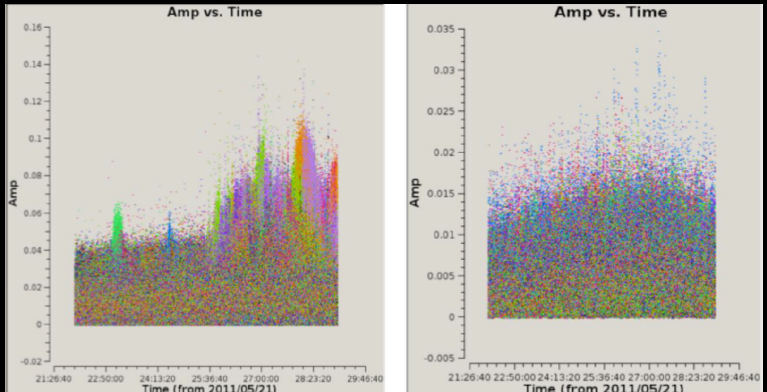
- LBA: data almost always affected by CygA, CasA at least
- HBA: data affected if phase centre within 30 deg of an A-team source or if elevation of A-team high. To make sure, simulation is needed.



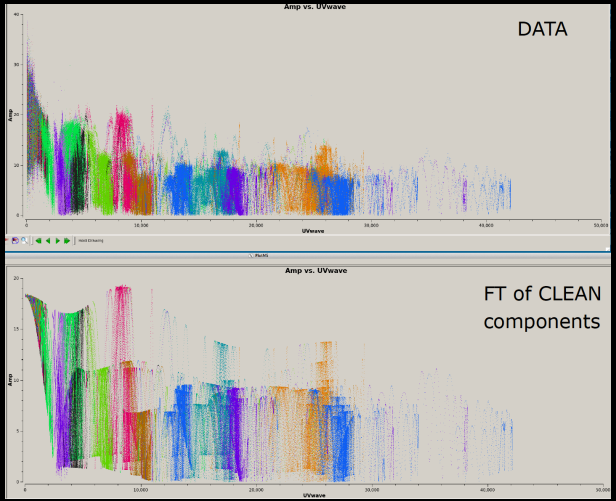
Data (errors): Demixing

A-team needs to be removed from the visibilities – "demixing"

- Use model to subtract A-team from visibilities
- Data needs to be at sufficient time+freq resolution for this to work.
- Clip of flag A-team contribution.

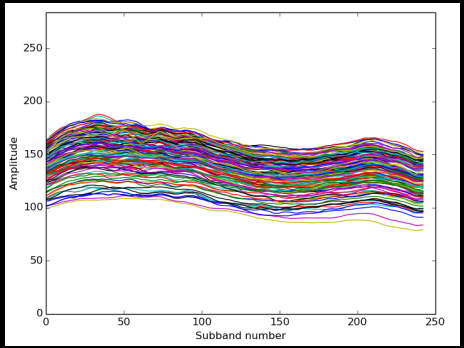


Calibration

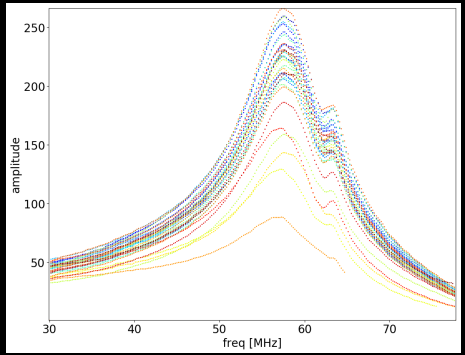


Does the model fit the data? Model errors can be absorbed in the calibration process!

Calibration



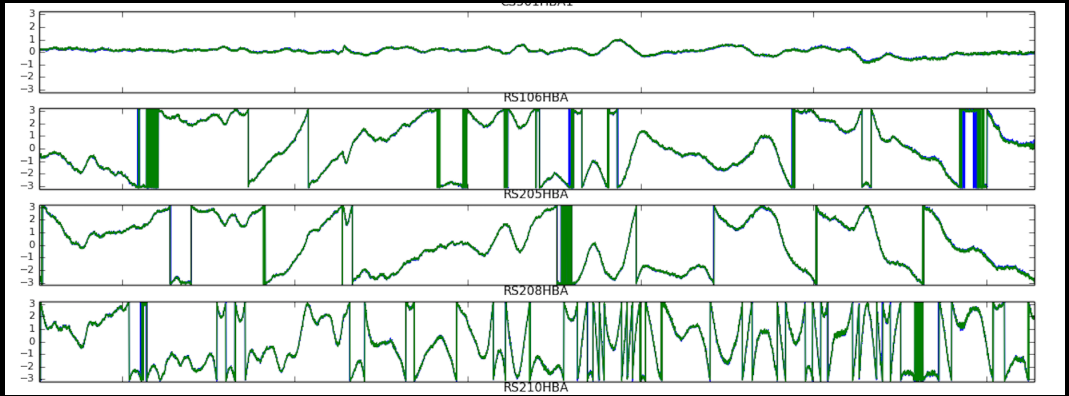
Amplitude solutions stable and at expected value?



Calibration

Phase solutions should track well

Longest baselines can lose coherence at times due to the ionosphere

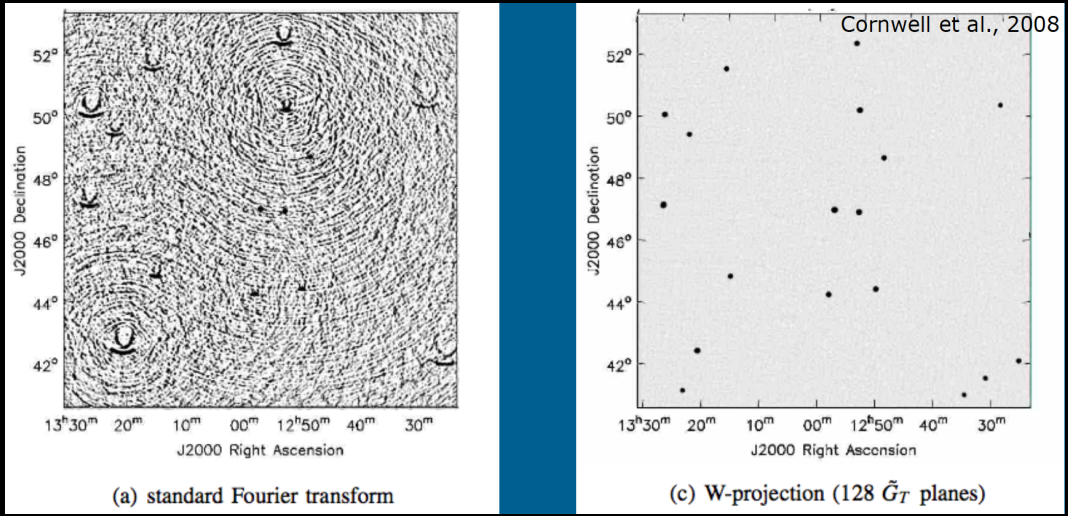


Imaging issues

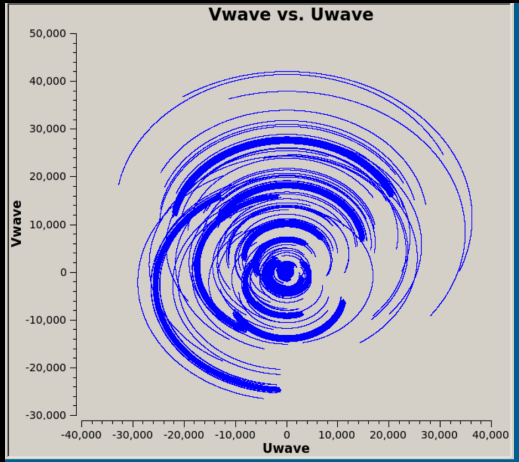
LOFAR - (very) large FoV (up to 10 deg across in LBA)

- 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
- Wide bandwidth – source flux changes across the band

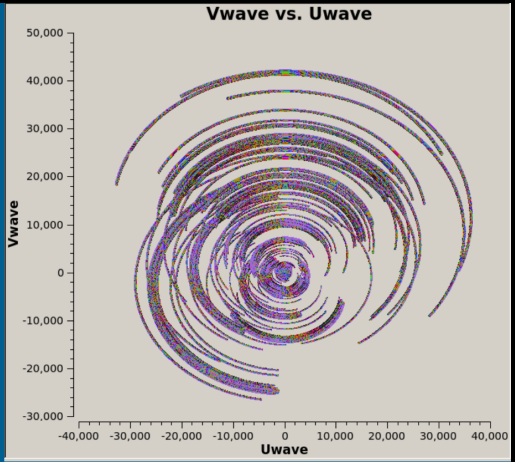
Imaging: w-projection



Imaging: BW issues

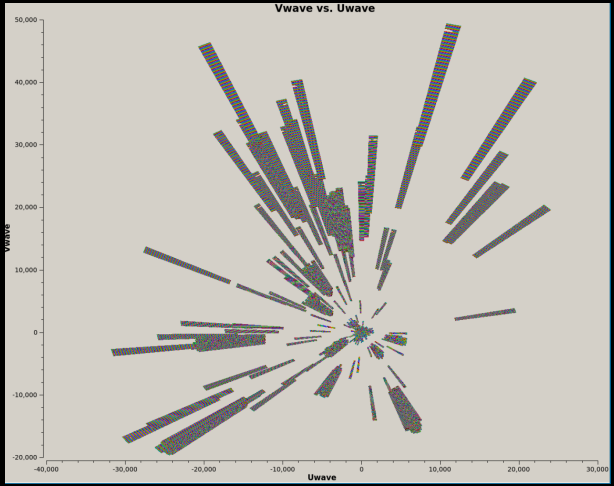


1 SB – 0.2 MHz



10 SBs – 2 MHz

Imaging: BW issues



70 MHz – 10 minutes

Imaging: BW issues

Smearing

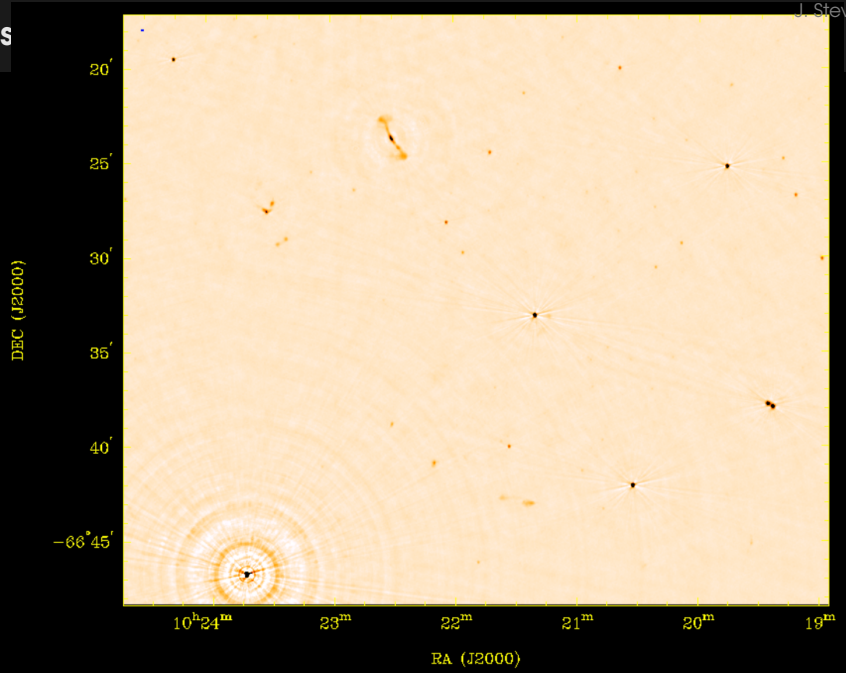
If too much averaging in time/frequency is applied, smearing results

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

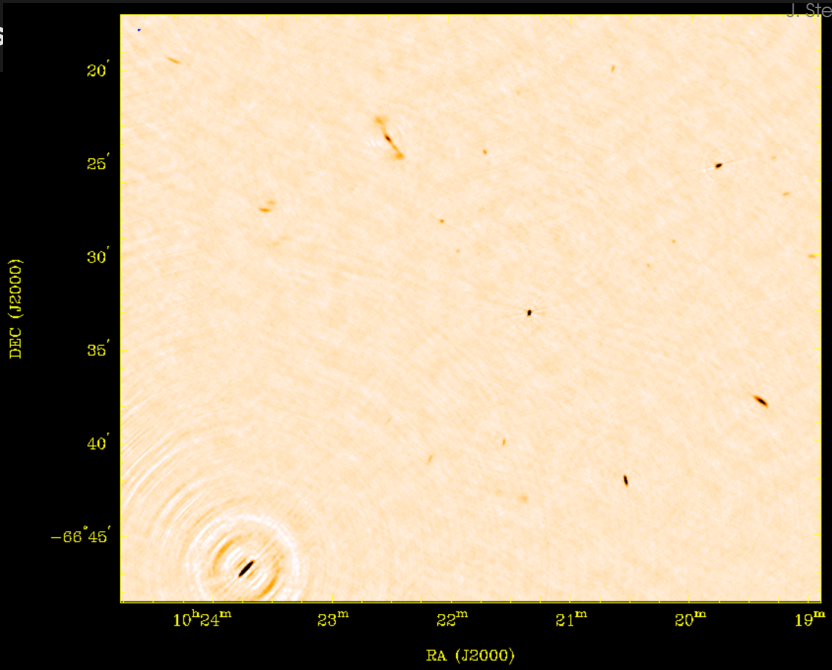
Imaging: BW iss

2048ch x 1MHz
2GHz BW



Imaging: BW iss

32ch x 64MHz
2GHz BW



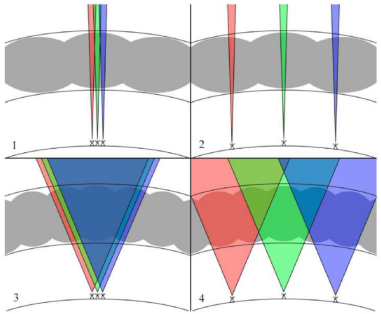
Imaging: Ionosphere

Direction independent effects – DIE

$$G_i\,(t)$$

Direction dependent effects - DDE

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

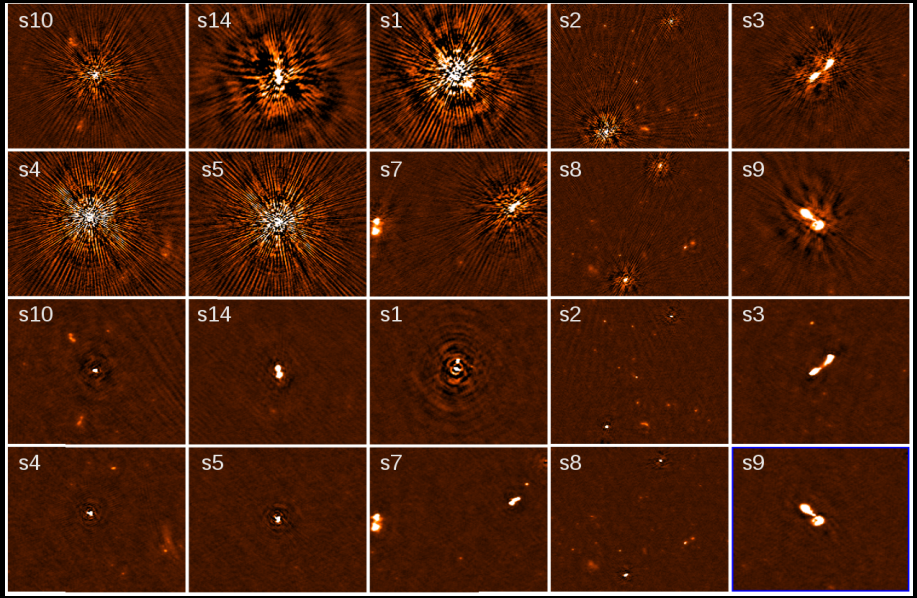


Intema et al. (2009)

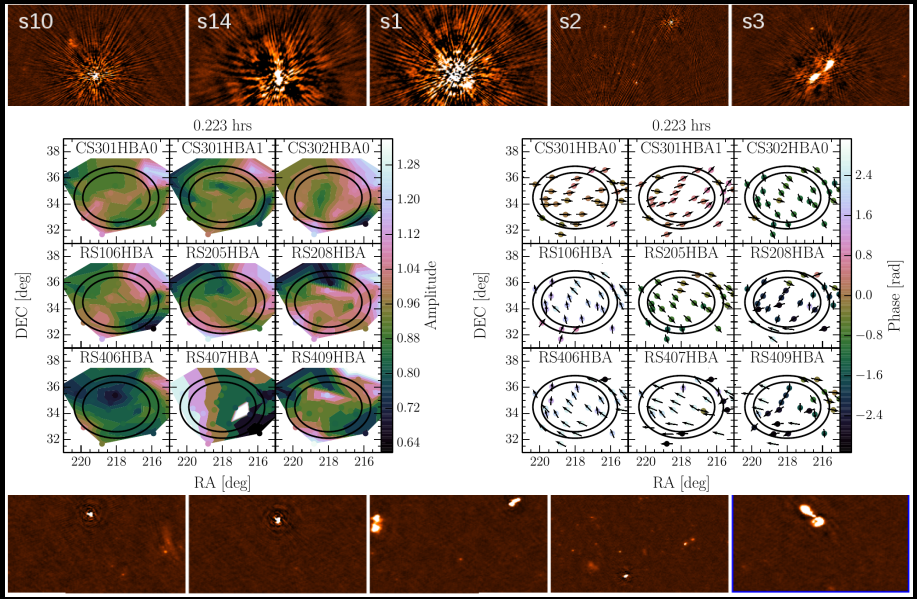
1 and 2 - ionospheric phase error has no FoV dependence - self cal applicable

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

Direction-dependent effects



Direction-dependent effects



Calibration / bad data effects in image plane

Some Questions to ask:

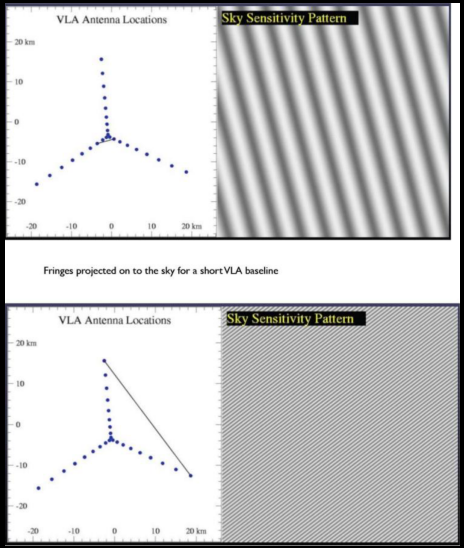
- Noise properties of image:
  - Is the rms noise about that expected from integration time?
  - Is the rms noise much larger near bright sources?
  - Are there non-random noise components (faint waves and ripples)?
- Funny looking Structure:
  - Non-physical features; stripes, rings, symmetric or anti-symmetric
  - Negative features well-below 4xrms noise
  - Does the image have characteristics that look like the dirty beam?
- Image-making parameters:
  - Is the image big enough to cover all significant emission?
  - Is cell size too large or too small? 4 points per beam okay
  - Is the resolution too high to detect most of the emission?

Calibration / bad data effects in image plane

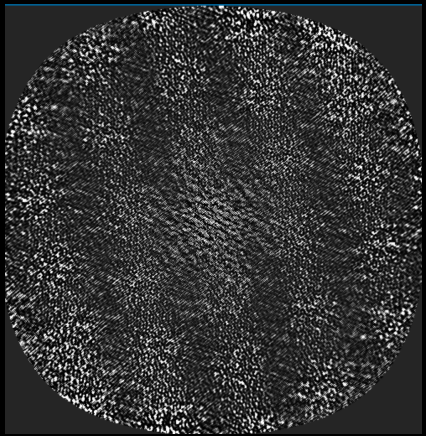
Can easily identify large errors in the u,v plane, but it's often difficult to find smaller errors

- 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

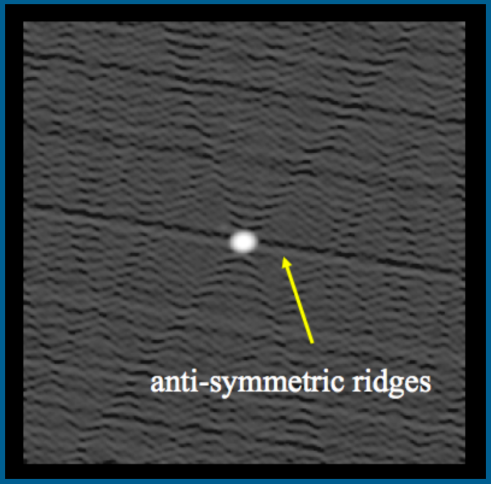


- Can use our knowledge of Fourier transform pairs to our advantage
- Look for patterns/symmetries

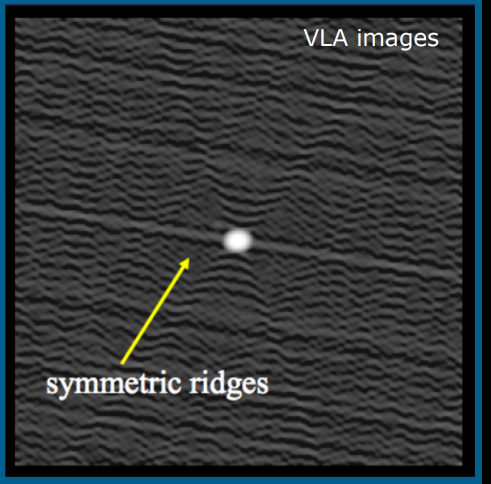


Calibration / bad data effects in image plane

10 deg phase error for
one antenna at one time

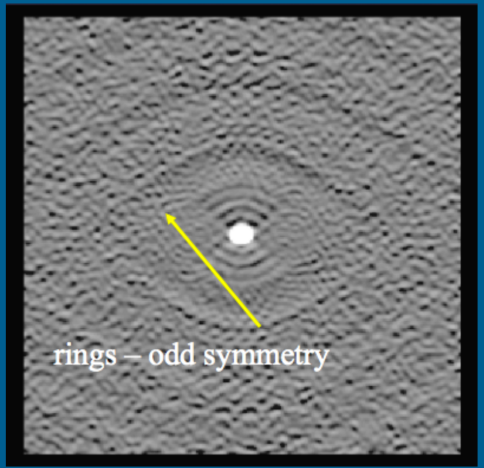


20% amplitude error for
one antenna at one time



Calibration / bad data effects in image plane

10 deg phase error for
one antenna at all times



20% amplitude error for
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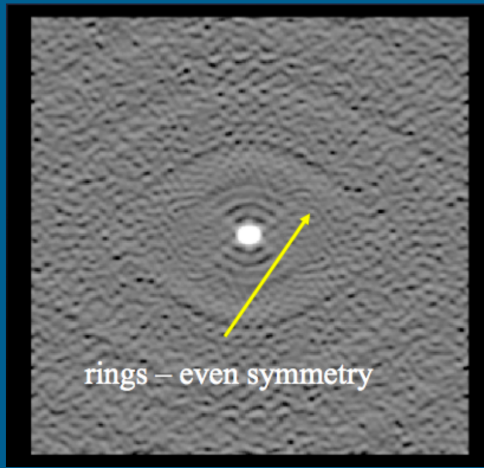

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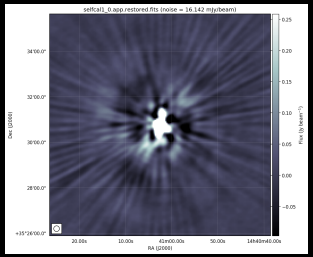
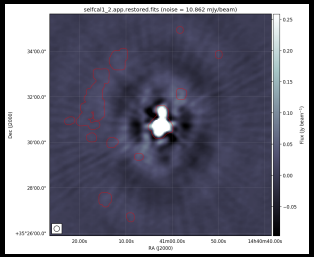
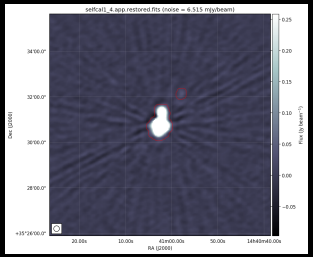
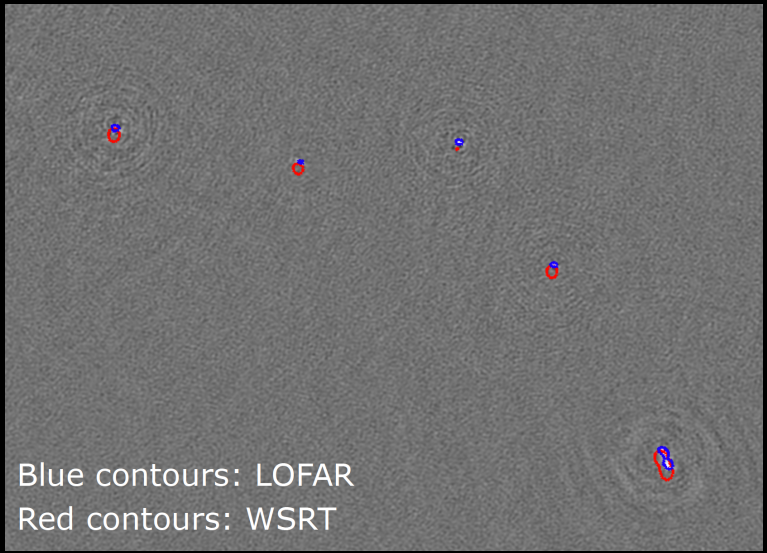






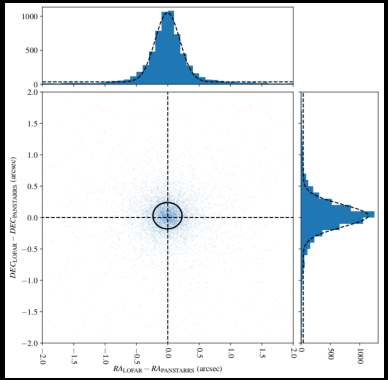
Is the imaging science worthy?

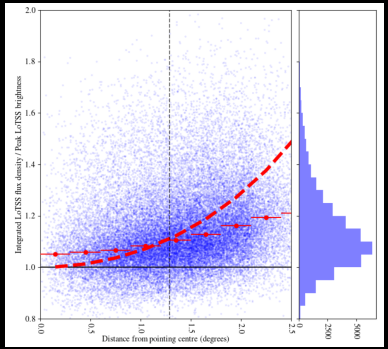


Is the imgaing science worthy?

Shimwell+ 2019, Kondapally+ 2021

- Check: Position, flux density errors
- Self-calibration does not preserve astrometry and flux-scale
- LOFAR beam model is not accurate





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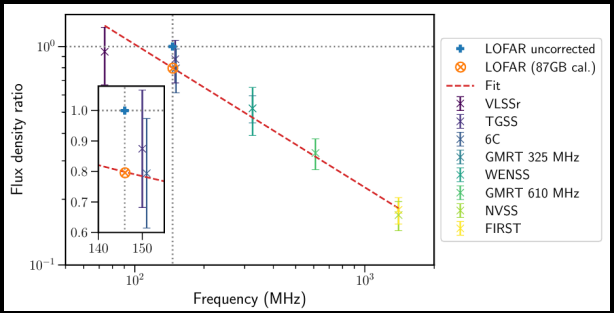

Summary

Beware of wide-field/wide-band imaging effects:

- Need to use W-projection and A-projection (e.g., WSClean)
- Be careful not to average too heavily, can lead to bandwidth- or time-average-smearing
- Direction dependent effects cannot be ignored

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)
- check of flux scale and positions (7C/VLSS/TGSS)
- check positions against PanSTARRS
- 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, 2016
  - 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, Tasse+2015,2017)