CAASTRO
ARC CENTRE OF EXCELLENCE FOR ALL-SKY ASTROPHYSICS

THE UNIVERSITY OF SYDNEY

Error Recognition

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www.caastro.org

CASS Radio Astronomy School 2017
Based on lectures given previously by Ron Ekers and Steven Tingay

CSIRO; Swinburne

Error Recognition

Some errors are easy to recognise

Some are hard to fix

Some are easy to fix

Where do errors occur?

- Most errors and defects occur in the (*u,v)* plane
  - Measurement errors (imperfect calibration – see Calibration talk).
  - Approximations made in the (*u,v)* plane.
  - Approximations made in the transform to the image plane.
- Some are due to manipulations in the image plane.
  - Deconvolution (see Deconvolution talk).
- What we usually care about are effects in the image plane (not always e.g. spectral line).
- The relative contribution of certain errors will vary depending on the nature of the observation.

Image or *uv* plane?

- We need to work between the *uv* plane and the image plane.
  - Different types of errors may be more obvious in one plane than the other.
  - A good understanding of the relationship between both planes.
- Errors obey Fourier transform relations.
  - Narrow features transform to wide features and vice versa.
  - Symmetries important – real/imaginary, odd/even, point/line/ring.
  - The transform of a serious error may not be serious!
  - Some effects are diluted by the number of other samples.

General form of errors

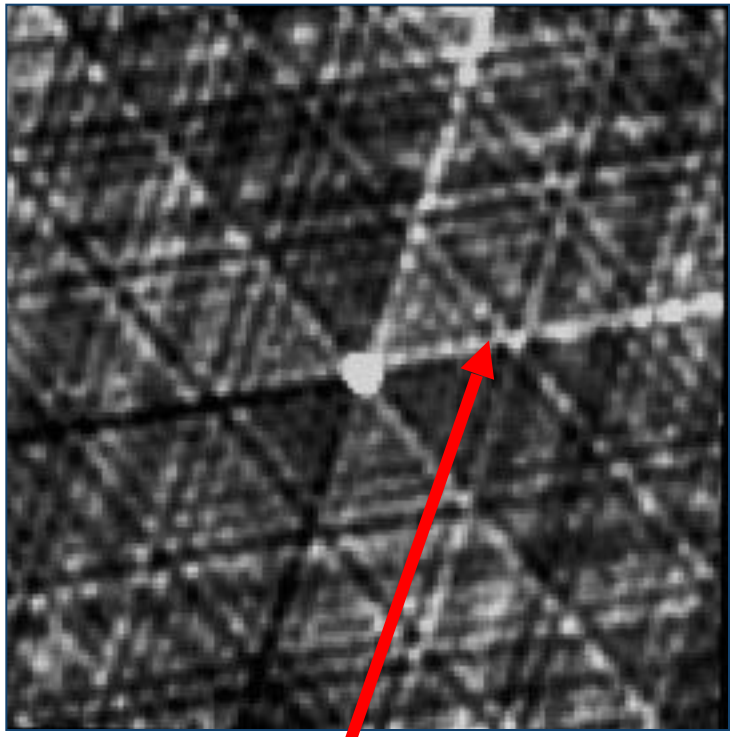
- Additive errors (out-of-field sources, RFI, cross-talk, baseline-based errors, noise)
  - $V + \varepsilon \rightarrow I + F[\varepsilon]$
- Multiplicative errors (uv-coverage effects, gain errors, atmospheric effects)
  - $V \bullet \varepsilon \rightarrow I \star F[\varepsilon]$
- Convolutional errors (primary beam effect, convolutional gridding)
  - $V \star \varepsilon \rightarrow I \bullet F[\varepsilon]$
- Other errors
  - Bandwidth and time average smearing.
  - Non-coplanar effects (see Wide Field Imaging talk by Tim Cornwell)
  - Deconvolutional errors (see Deconvolution talk by Mark Wieringa)
  - Software!!! (see everyone!)

Error Diagnosis

- If ε is pure real, then the form of the error in the (*u,v)* plane is a real and even function i.e. F[ε] will be symmetric.
  - **Such errors are often due to amplitude calibration errors.**
- If ε has an imaginary component, then the form of the error in the *uv* plane is complex and odd i.e. F[ε] will be asymmetric.
  - **Such errors are often due to phase calibration errors.**
- Short duration errors
  - Localized in (u,v) plane but distributed in image plane.
  - Narrow features in (*u,v)* are extended in orthogonal direction in image.
- Long timescale errors
  - Ridge in (*u,v)* plane causes corrugations in image plane
  - Ring in (*u,v)* plane causes concentric “Bessel” rings in image plane

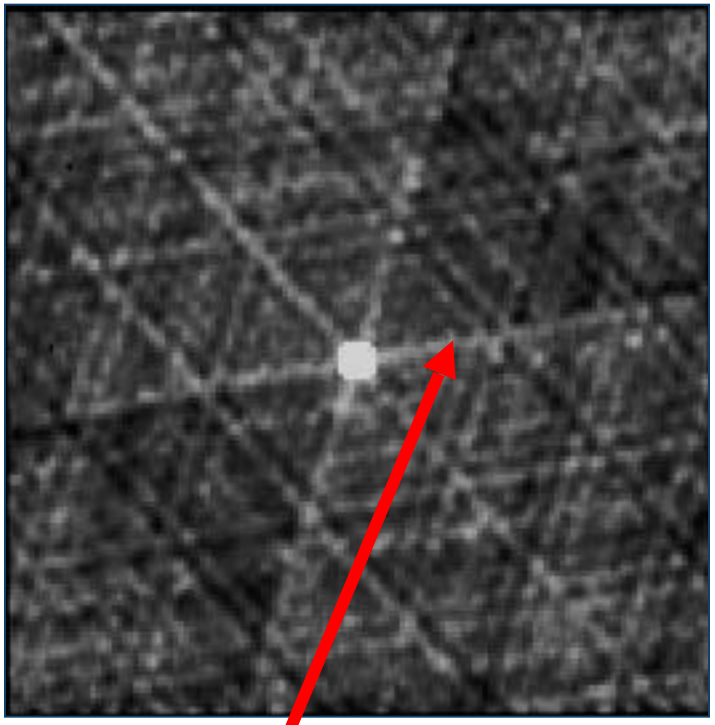
Gain Errors

10 deg phase error



anti-symmetric ridges

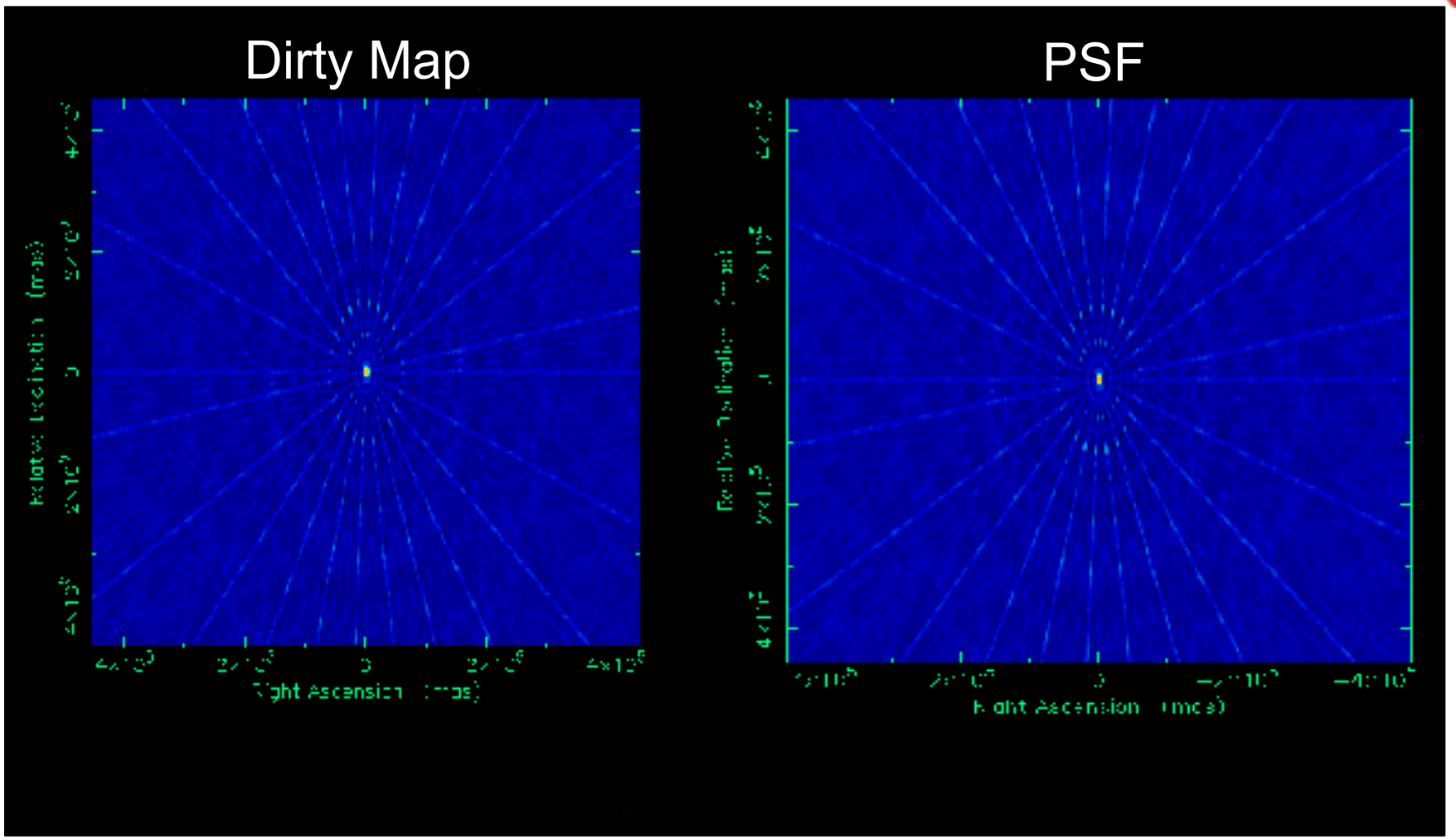
20% amp error



symmetric ridges

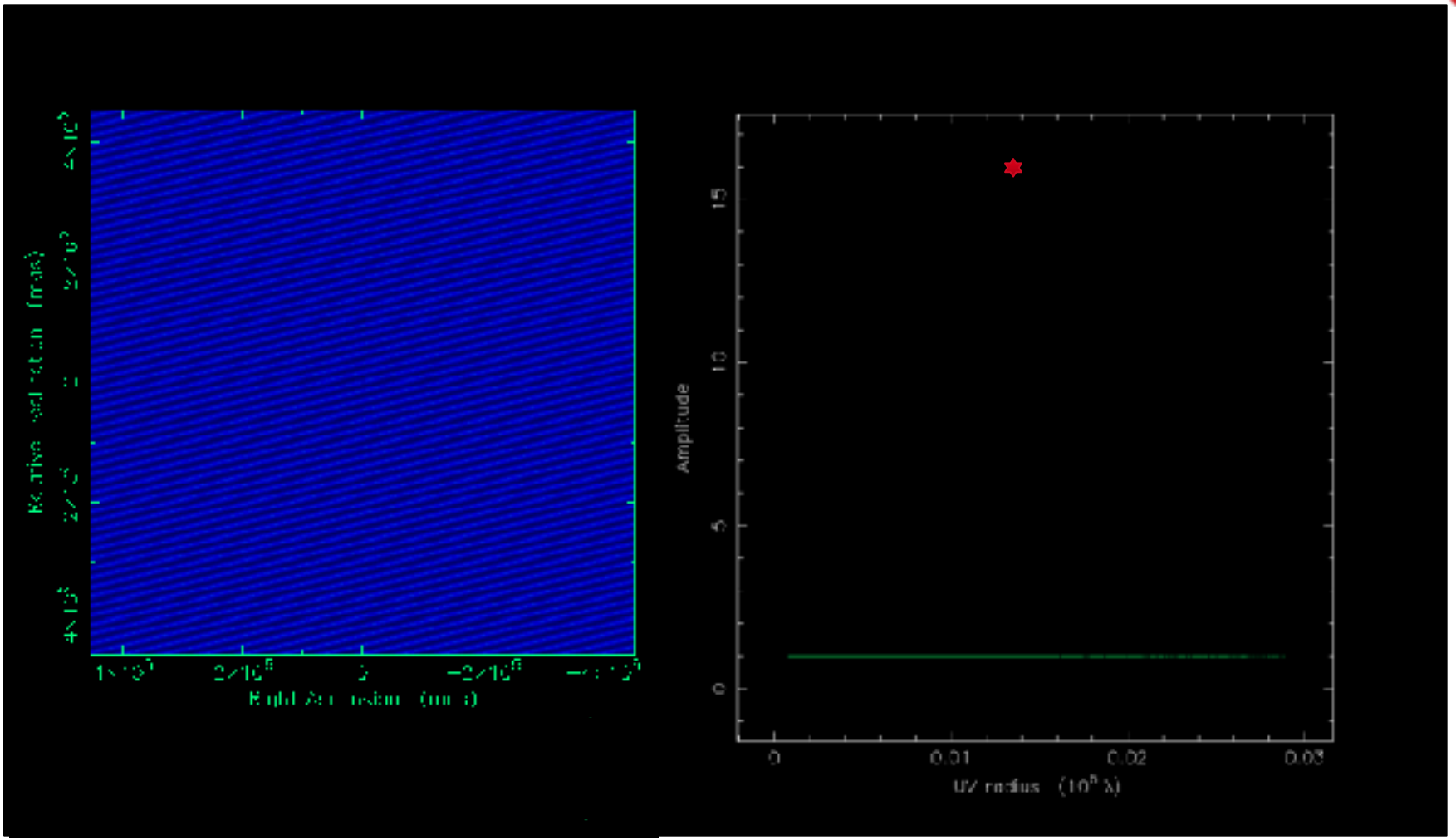
Adapted from Myers 2002 and Ekers.

Additive Errors: RFI



Observation of 1 Jy source

Finding RFI



Observation of 1 Jy source

See Mark's talk for more on removing RFI.

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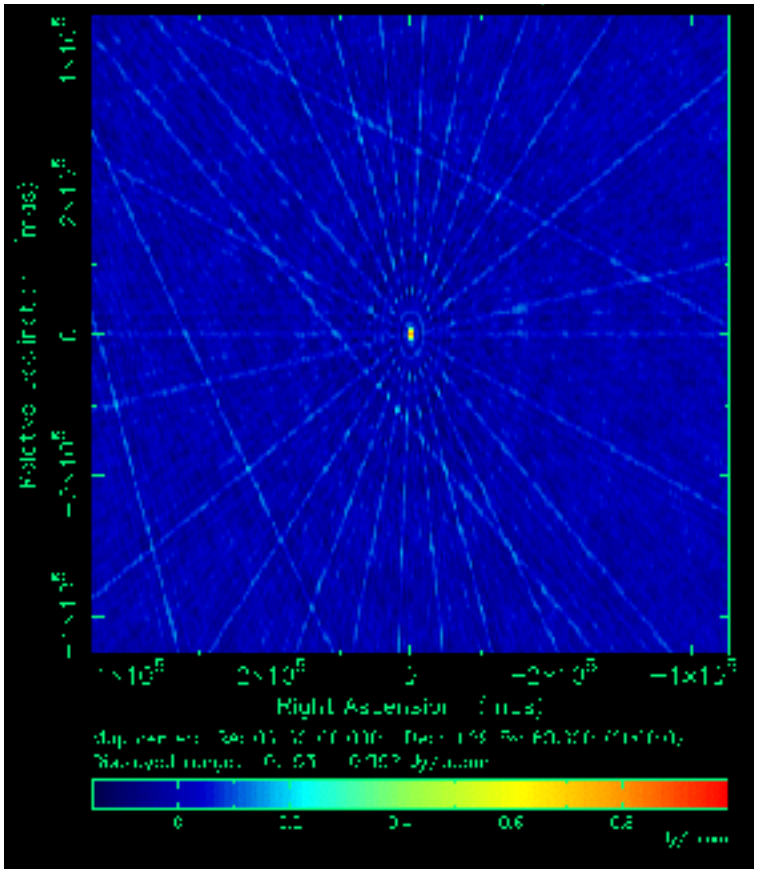
The Bigger Picture



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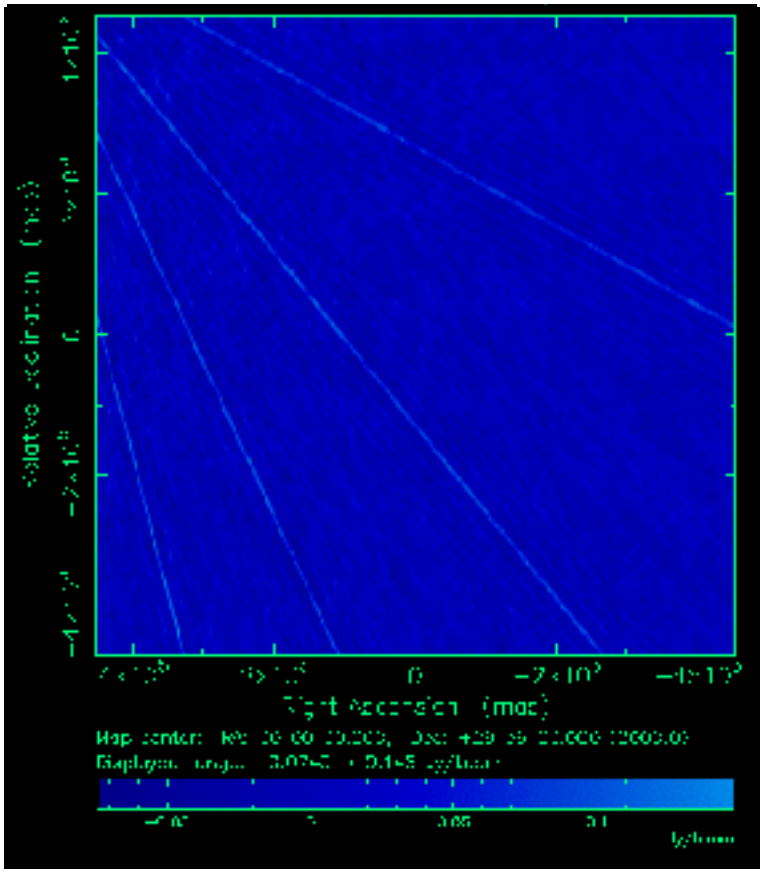

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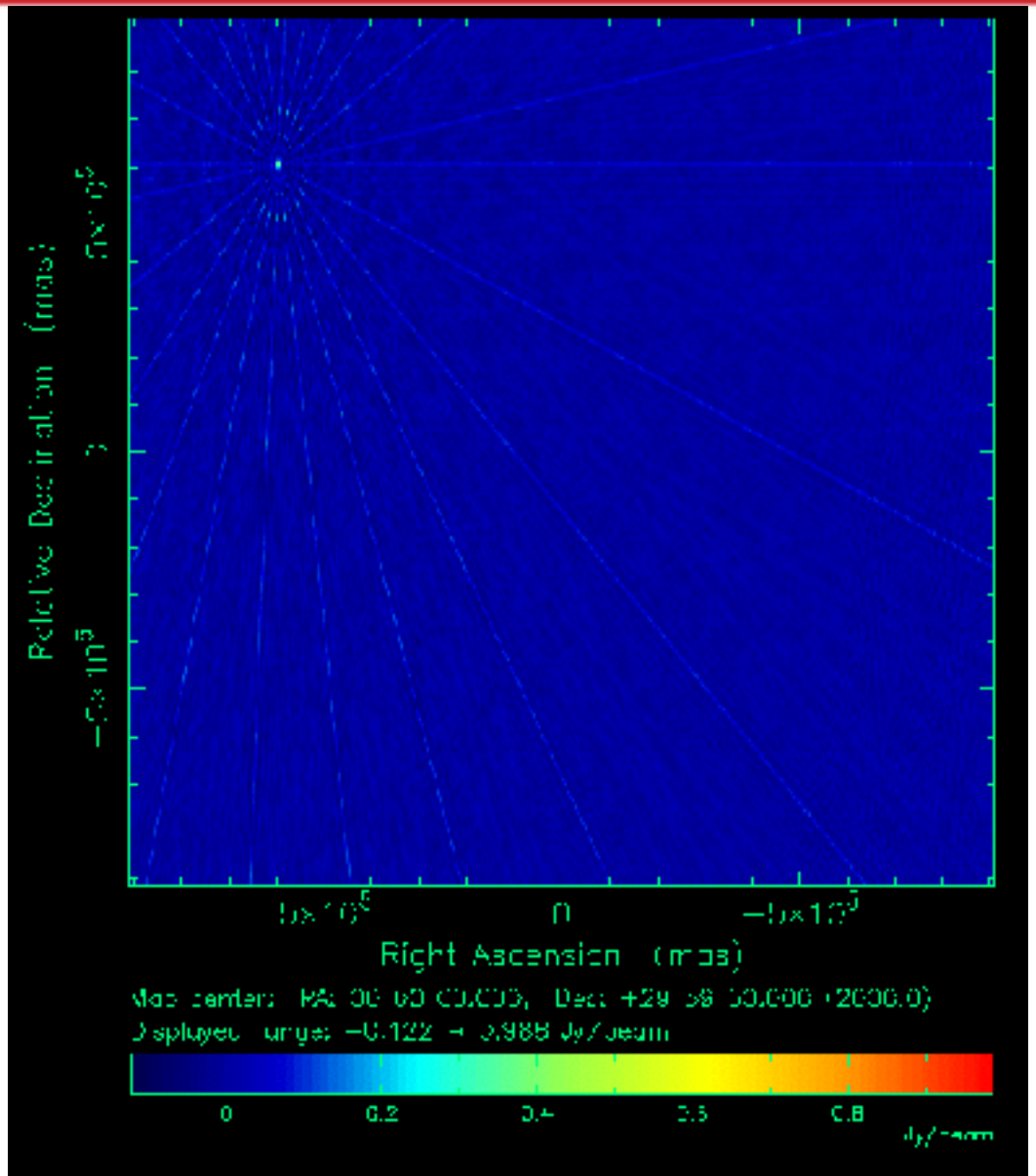

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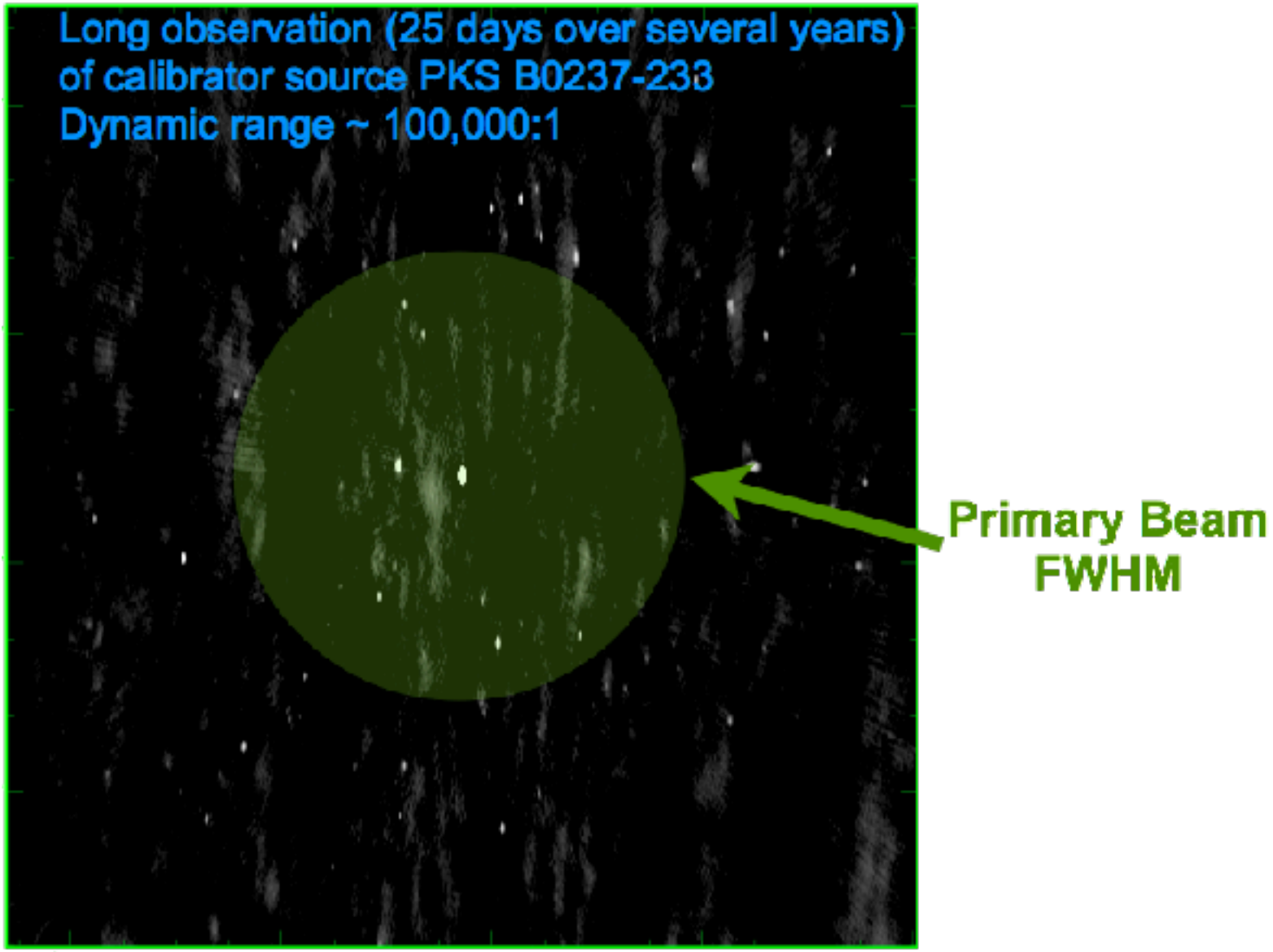

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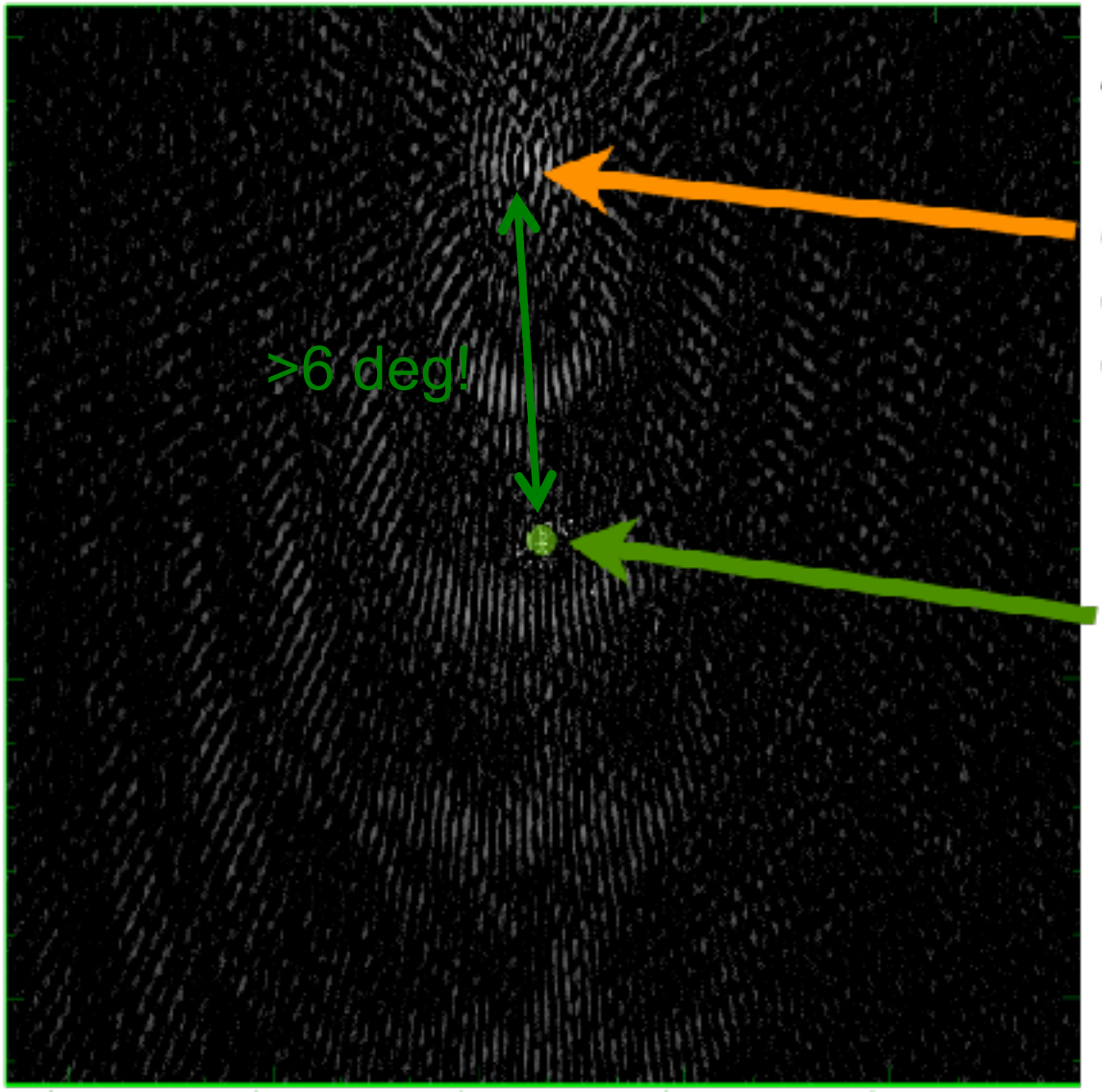

The Sun was "near" the calibrator during one of the observing days.

Primary Beam FWHM

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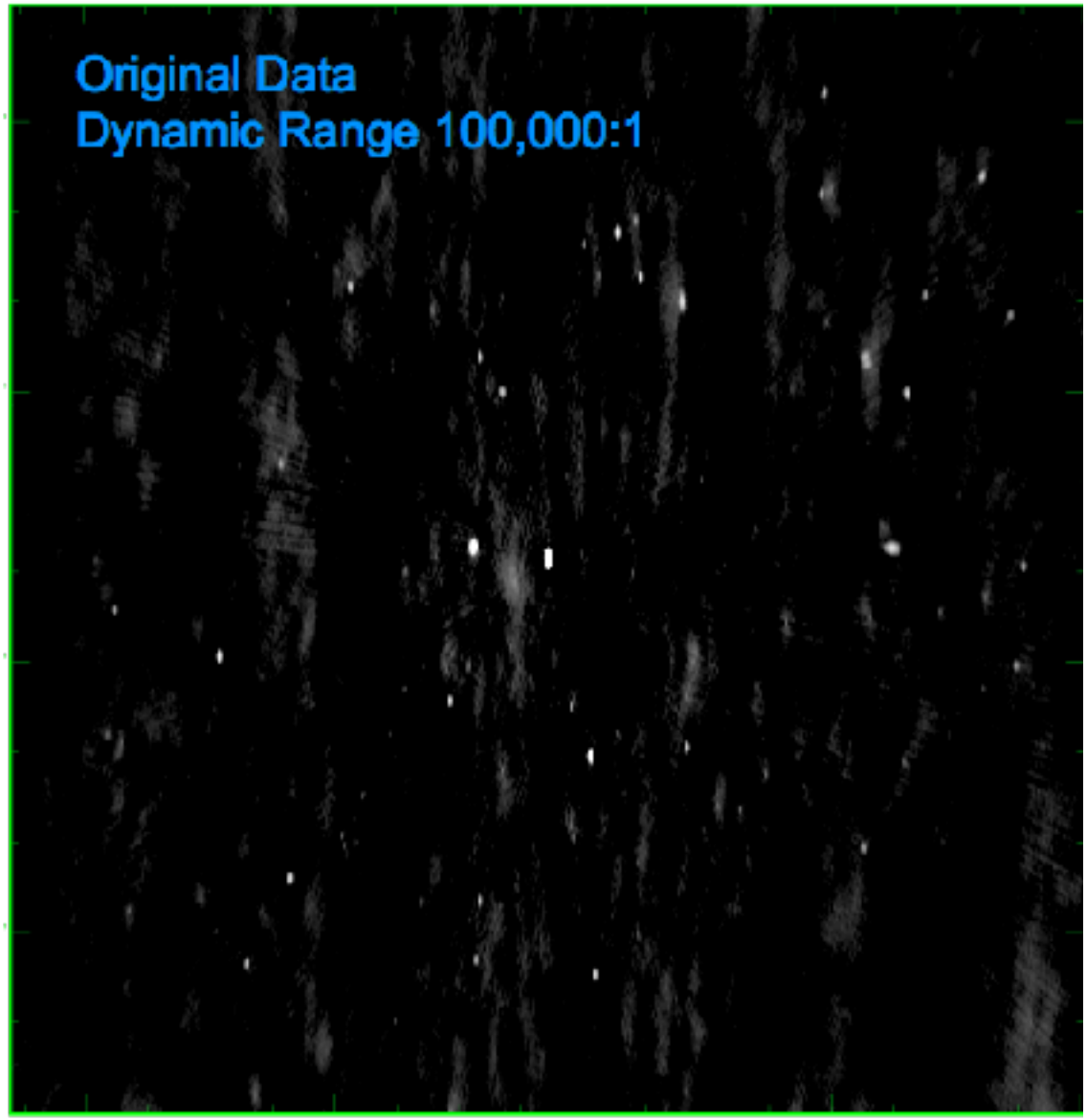
The Bigger Picture



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The Bigger Picture

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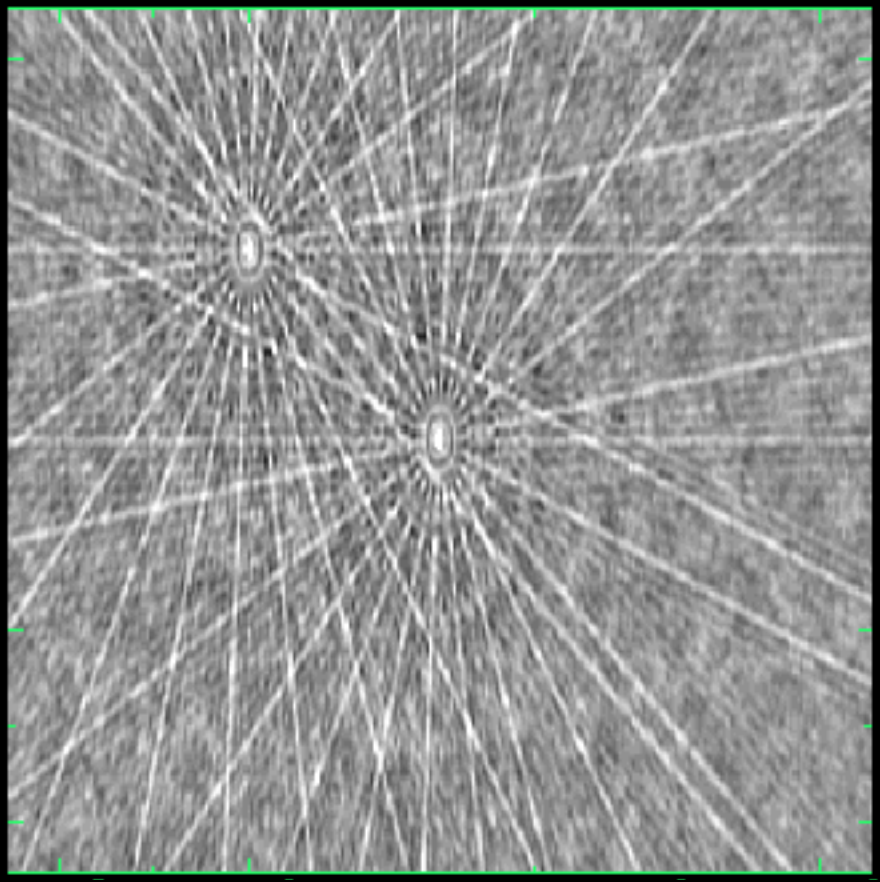
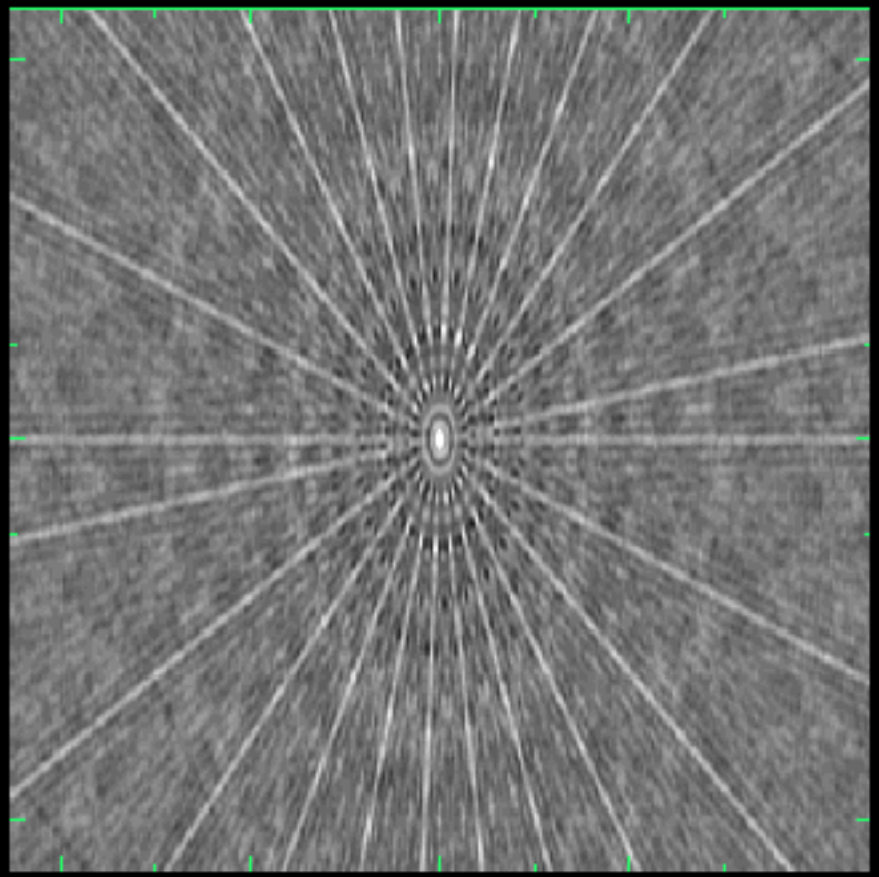
Multiplicative Errors

Dirty Map

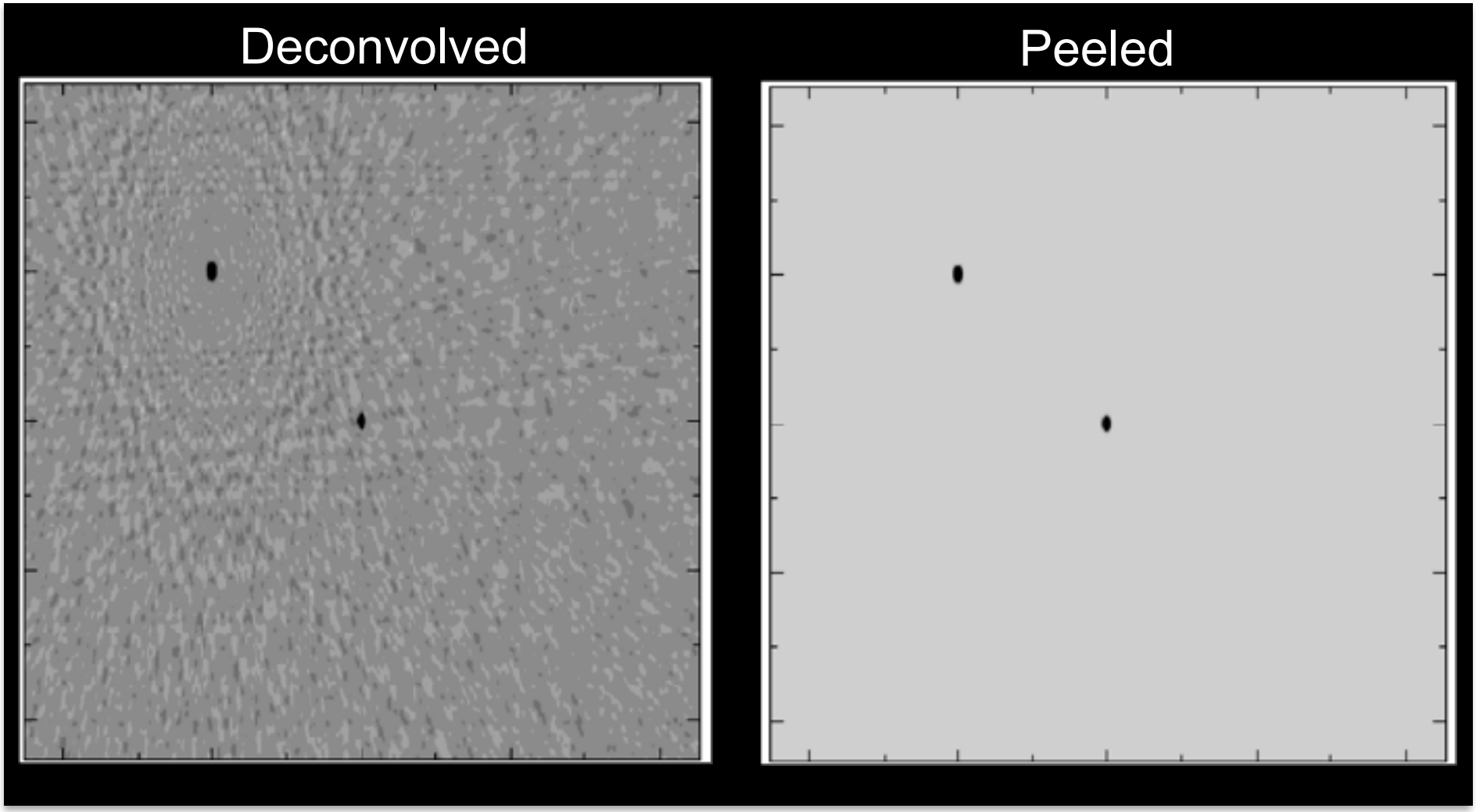


PSF



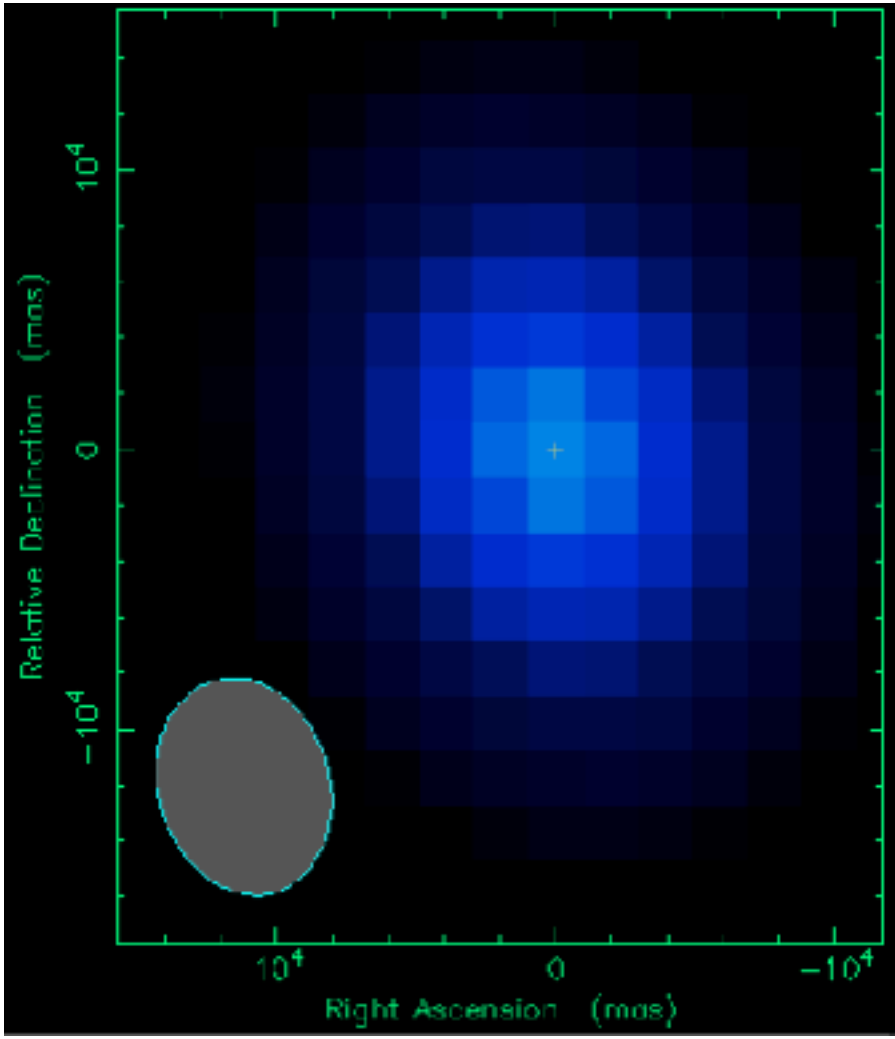
Primary Beam Error

Common in widefield imaging/instruments

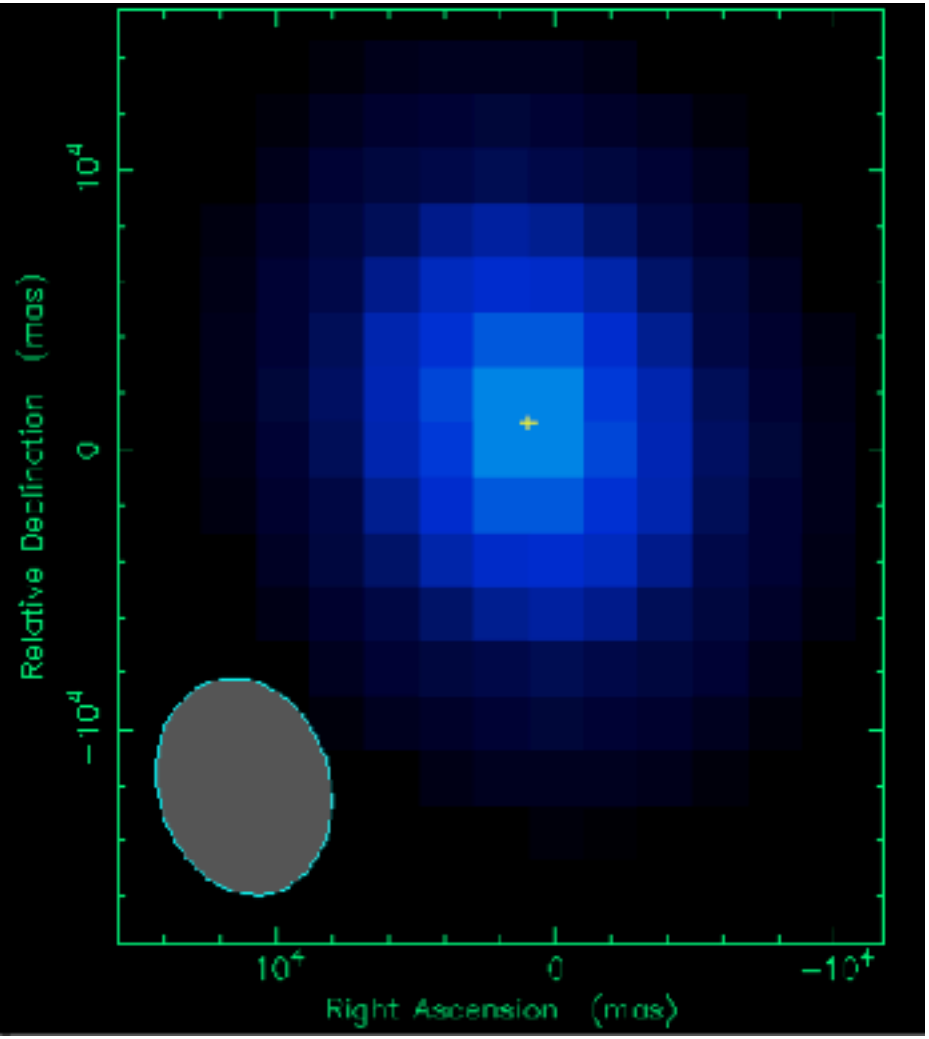


Peeling applicable to transient and variable sources too.

Point Deconvolution Errors

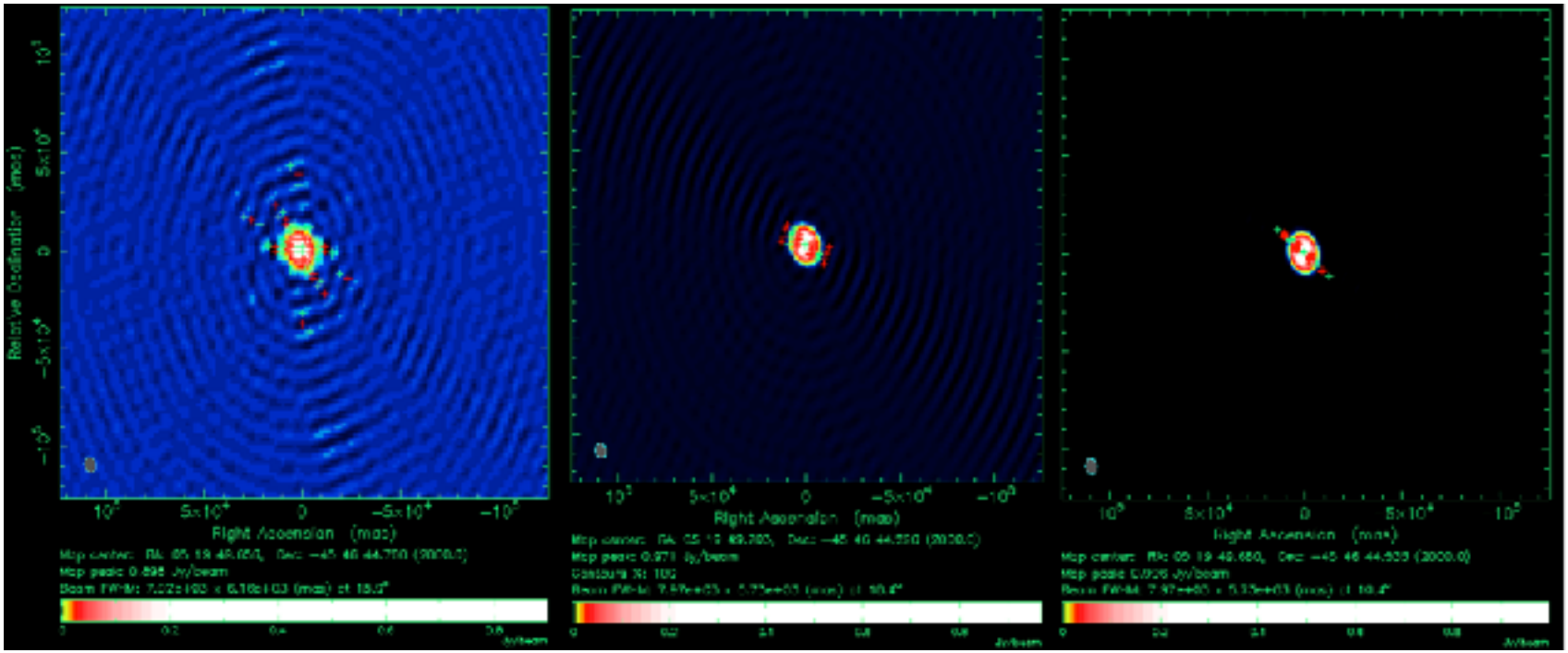


Pixel centred



Pixel not centred

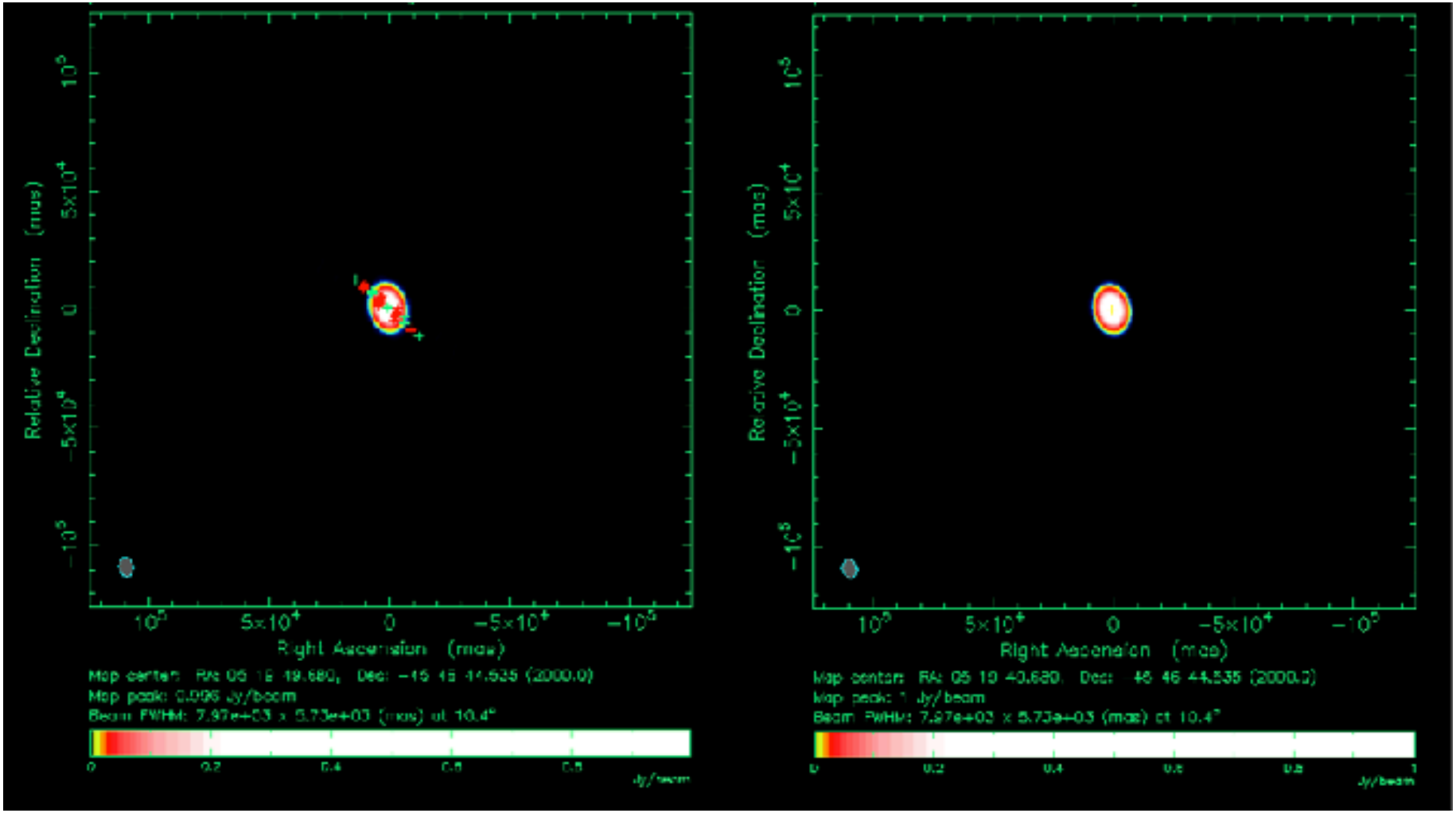
Point Deconvolution Errors



Cell size = beam/3 Cell size = beam/6 Cell size = beam/12

Effect of CLEAN performed on a single 1 Jy source that is not pixel-centred using different cell sizes.

Point Deconvolution Errors



CLEAN : Cell size = beam/12

Single uv-delta model component

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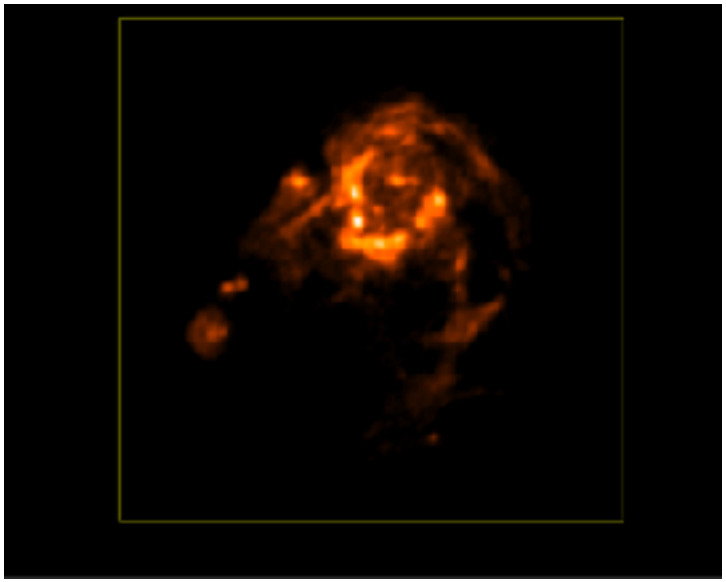
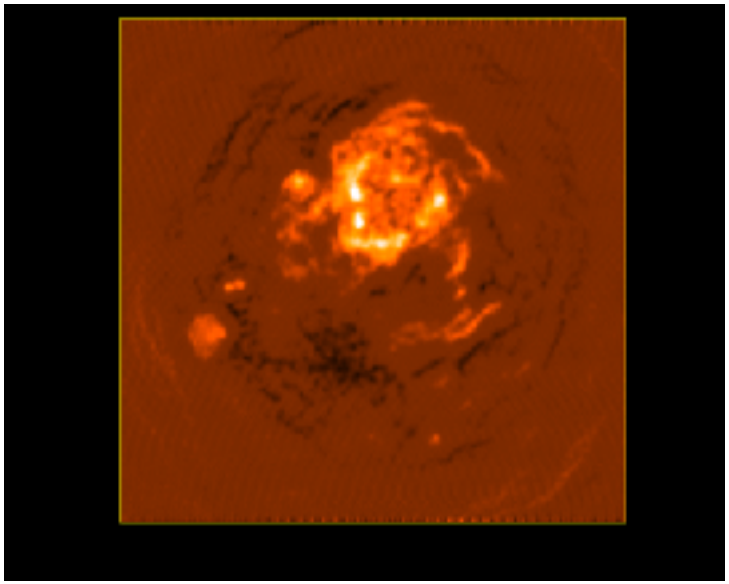
Deconvolution Errors (Large-scale Structure)



True sky



Standard CLEAN

Standard CLEAN does not handle large-scale structure well – results in negative bowls. More modern algorithms such as Multi-scale CLEAN are necessary to minimise deconvolution errors.

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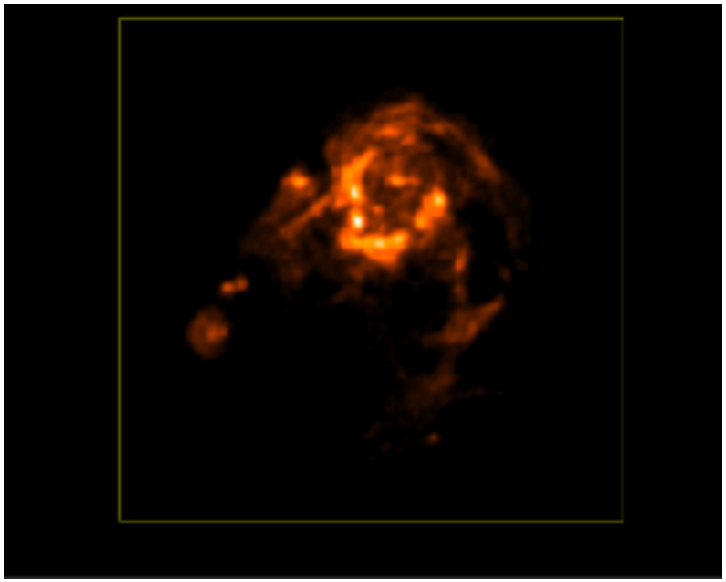

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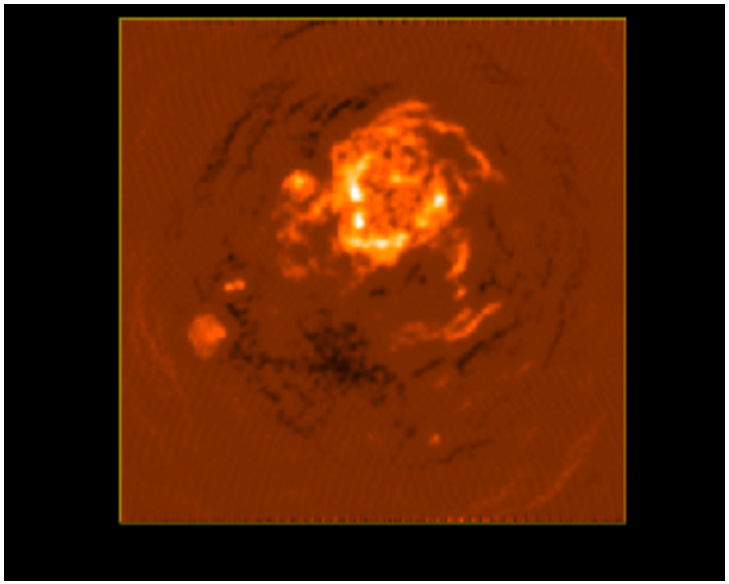

Standard CLEAN

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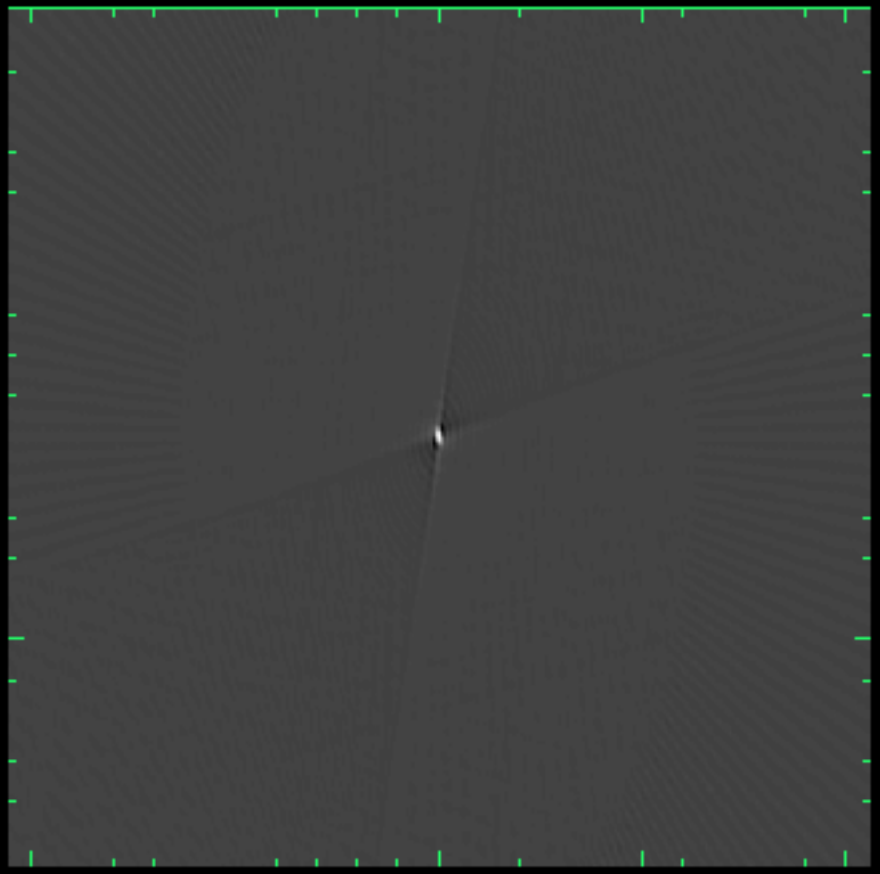
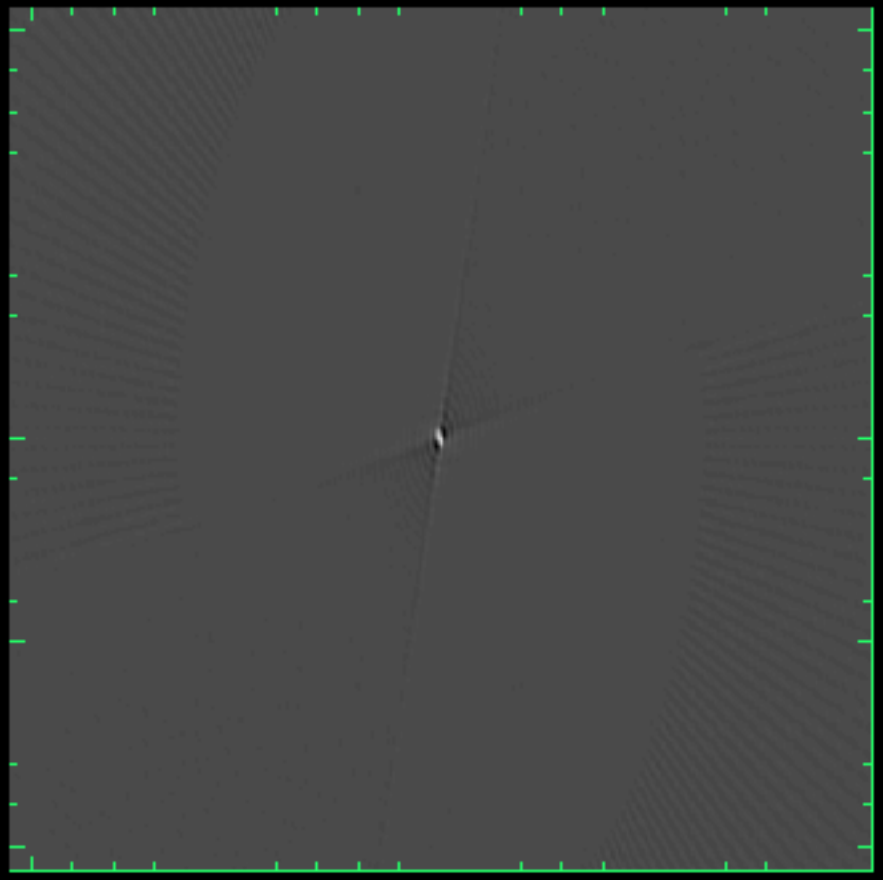
Wideband Deconvolution Errors

Dirty Image (2.1 GHz CABB Obs)

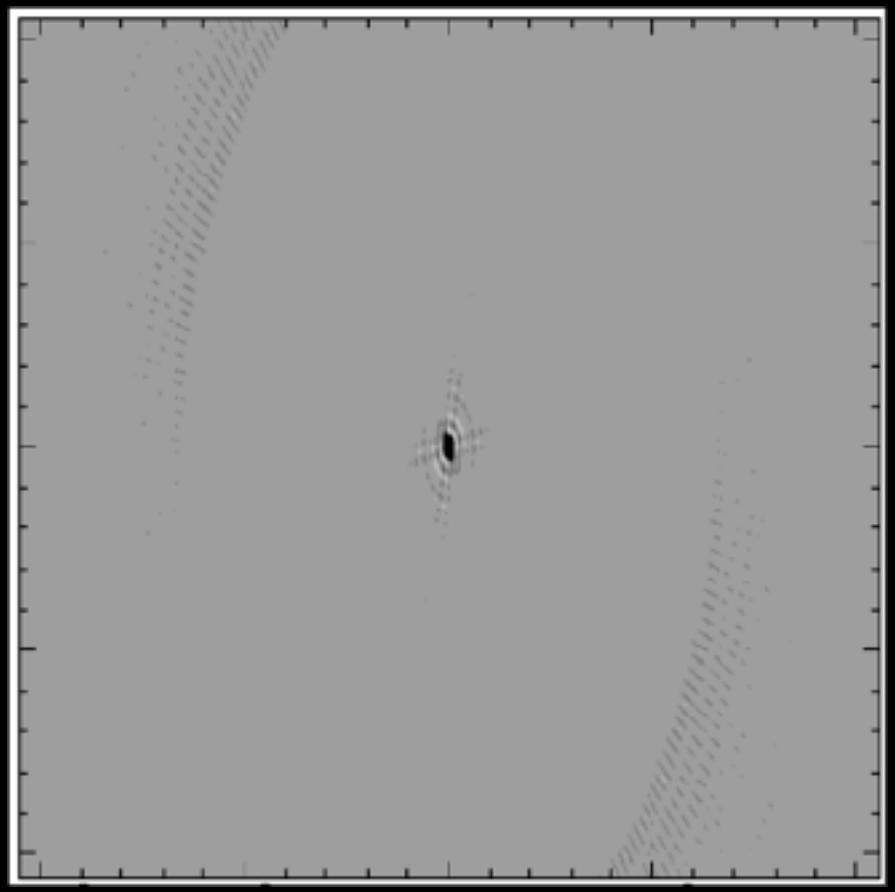


PSF



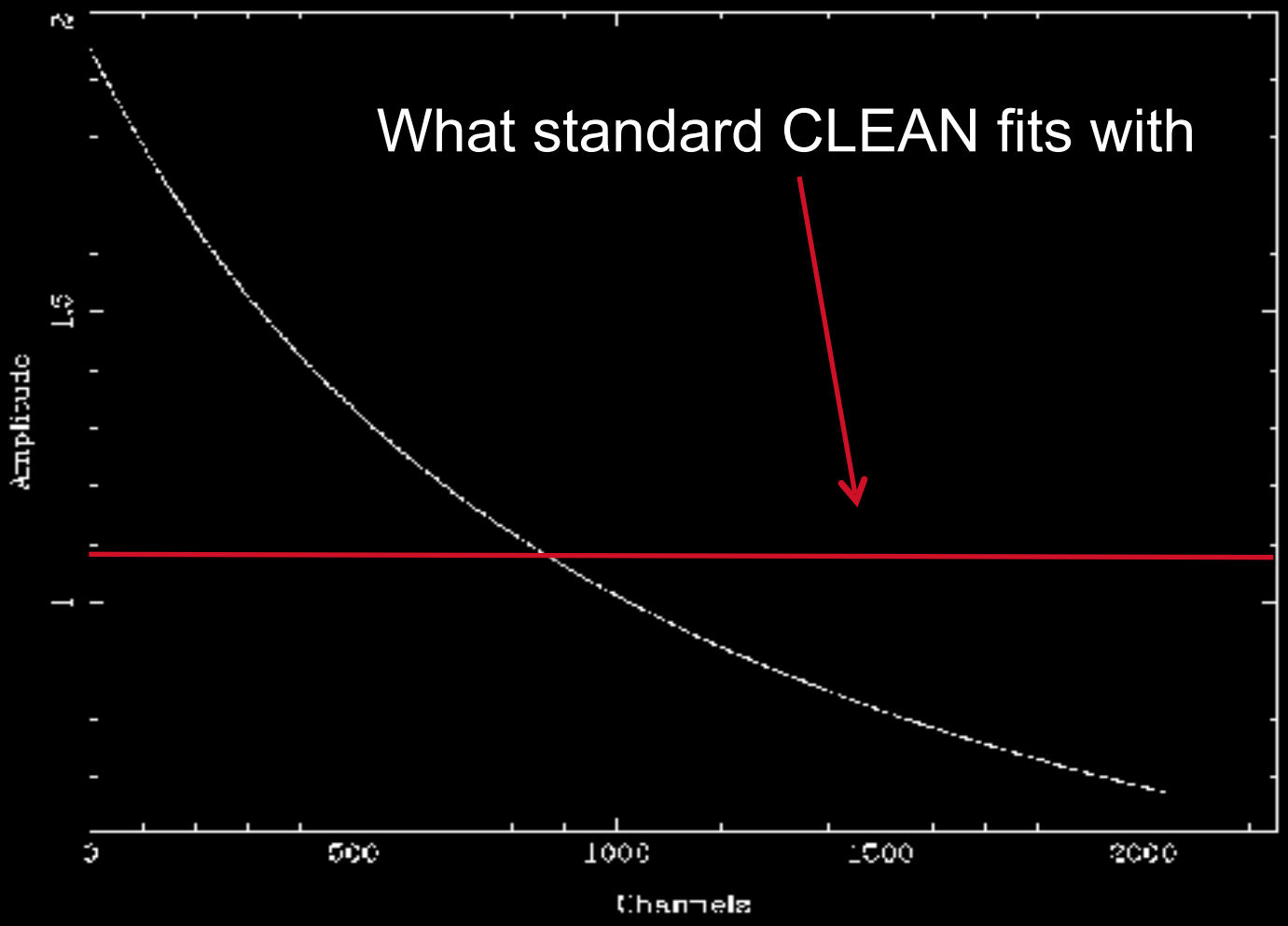
Wideband Deconvolution Errors

Deconvolved Image



Standard CLEAN

Wideband Deconvolution Errors



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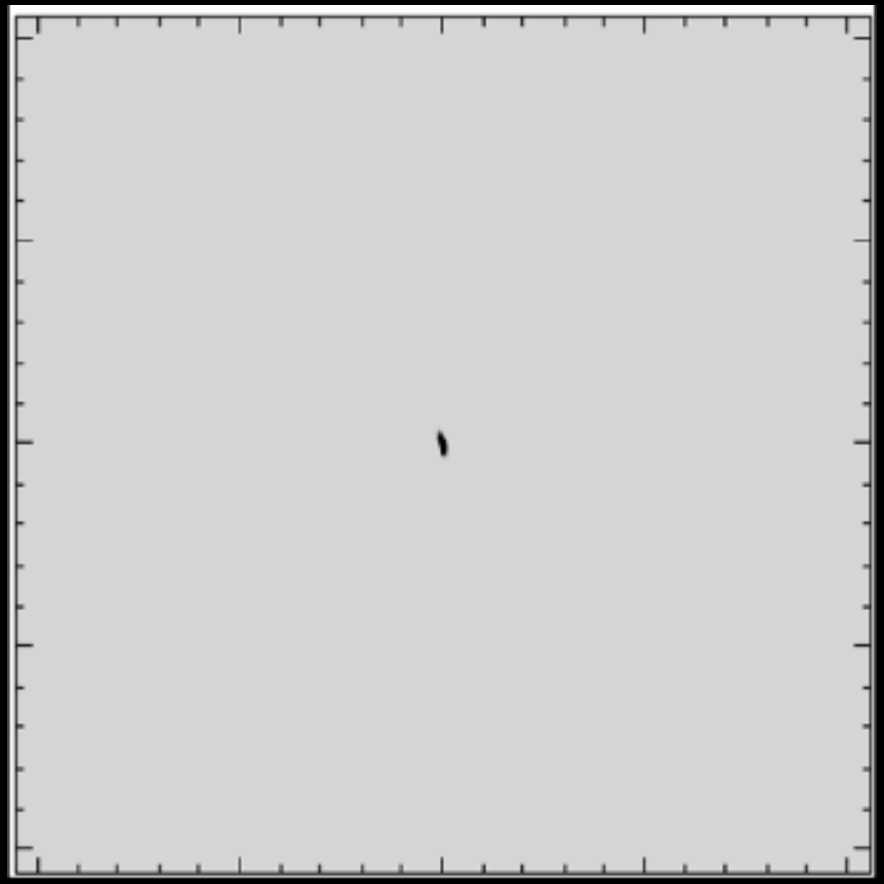
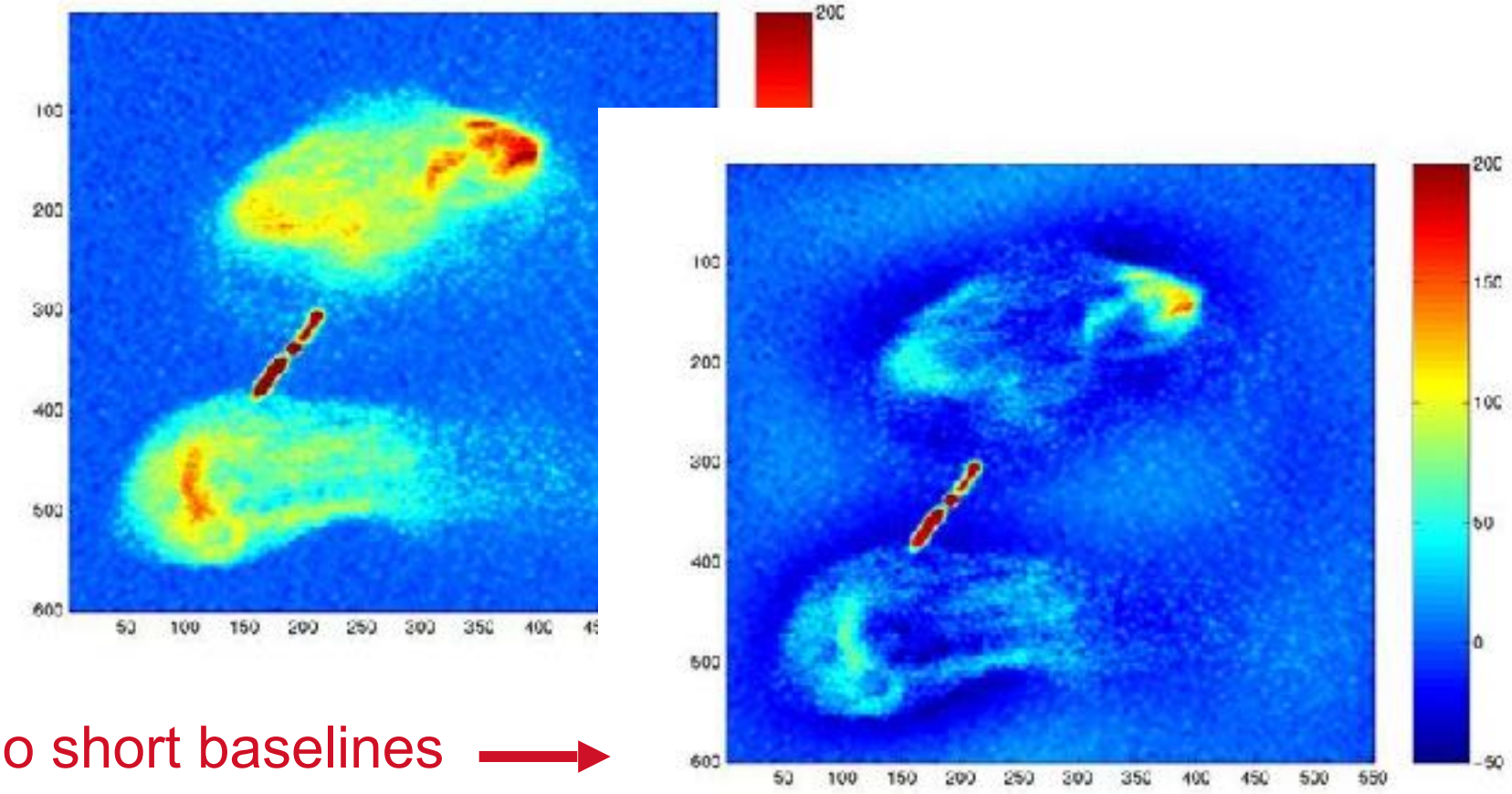
Deconvolved Image



Multi-frequency CLEAN

Missing short baselines

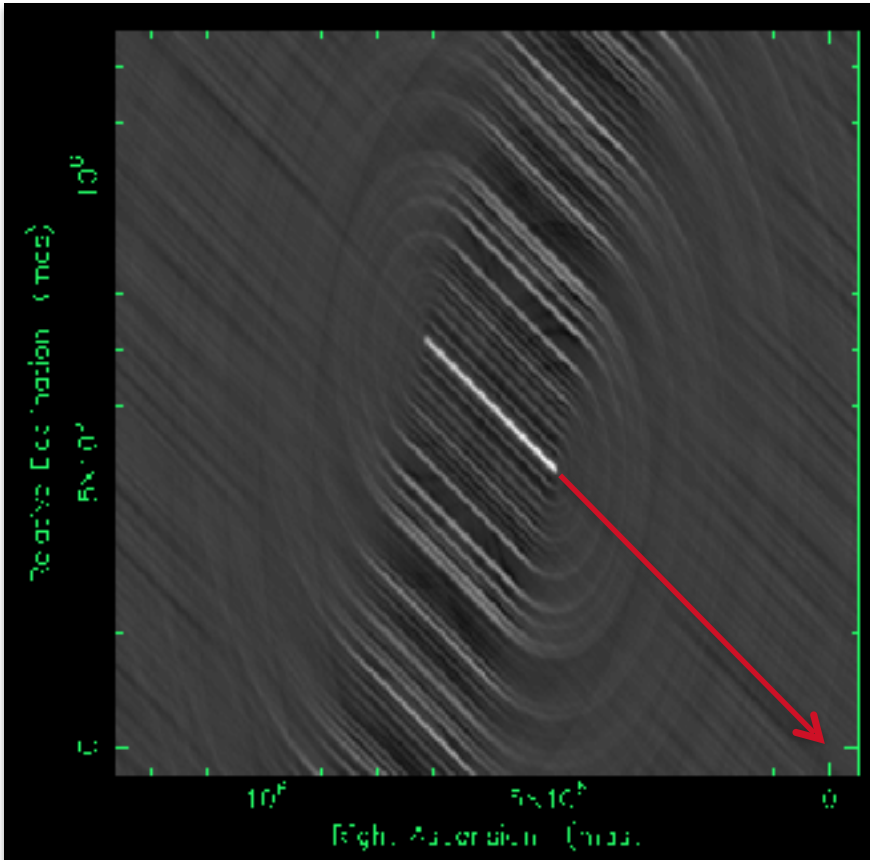


No short baselines →

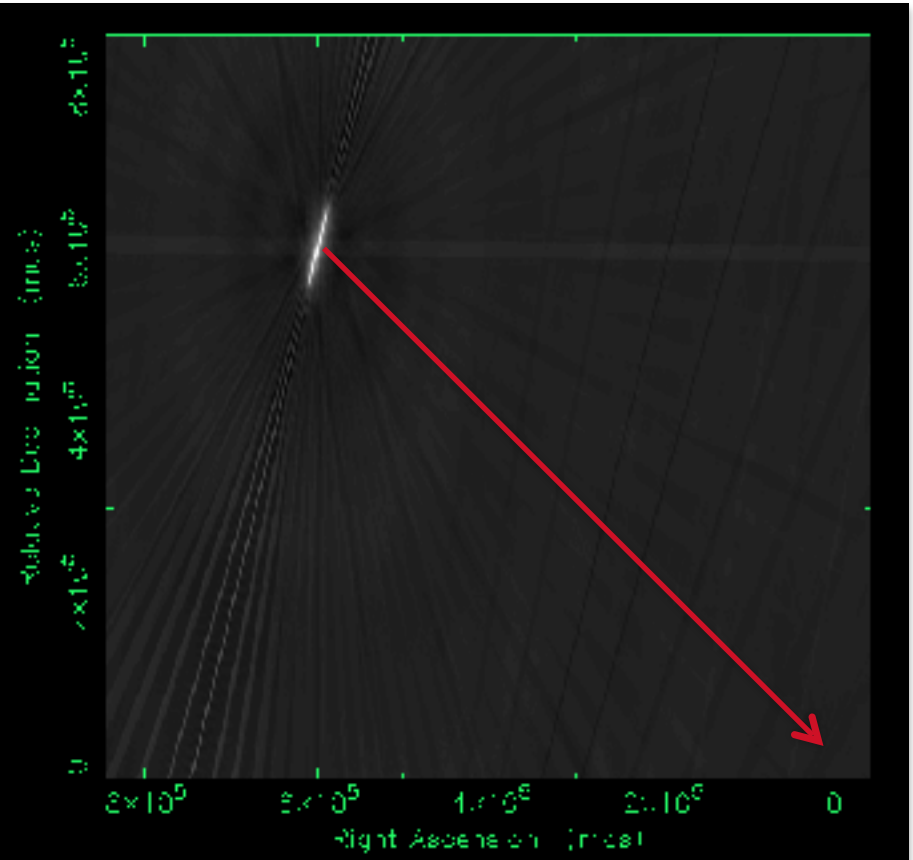
Paul Rayner 2001

Can only be fixed with additional data.
See Shari's talk on observing strategies.

Smearing Errors

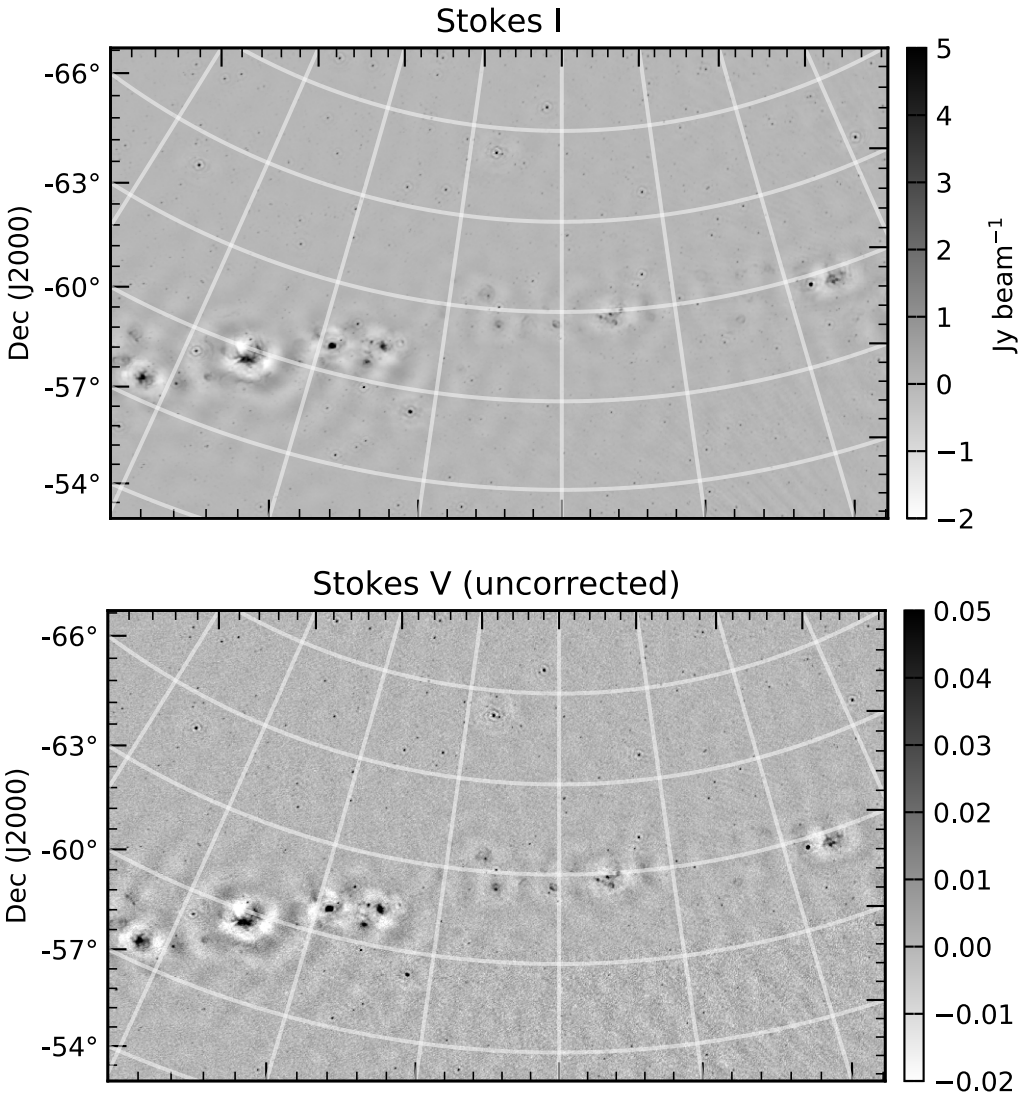


Bandwidth average smearing
Average 512x1MHz band

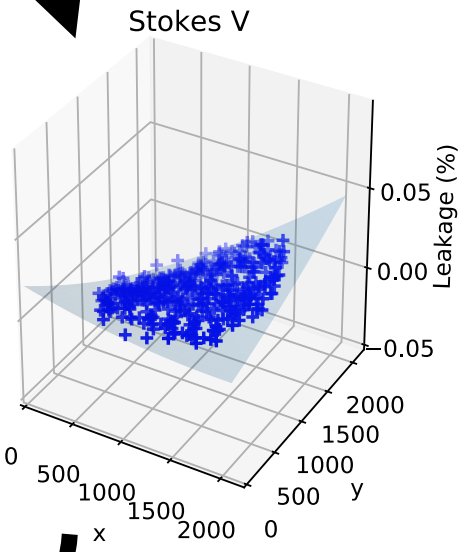


Time-average smearing
Averaging 1000s

Reality check

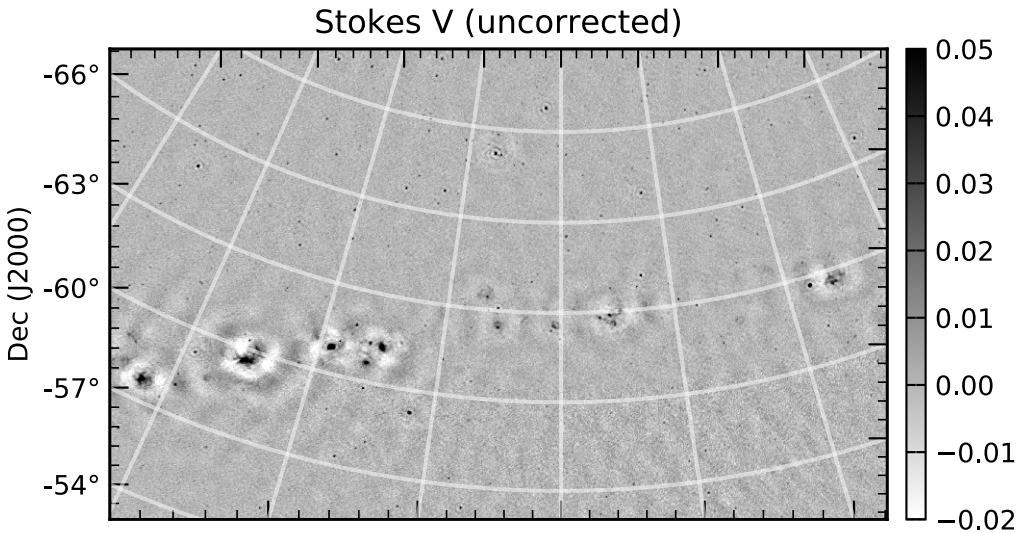


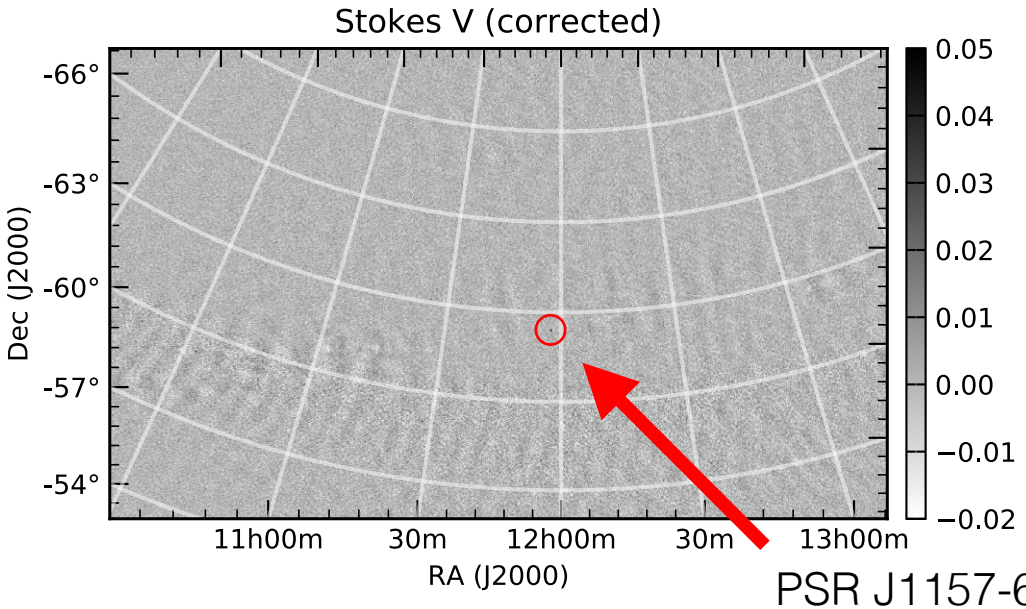
Model Stokes I to Stokes V leakage for each beam-former setting



Subtract modelled component of leakage from Stokes V.

Reality check





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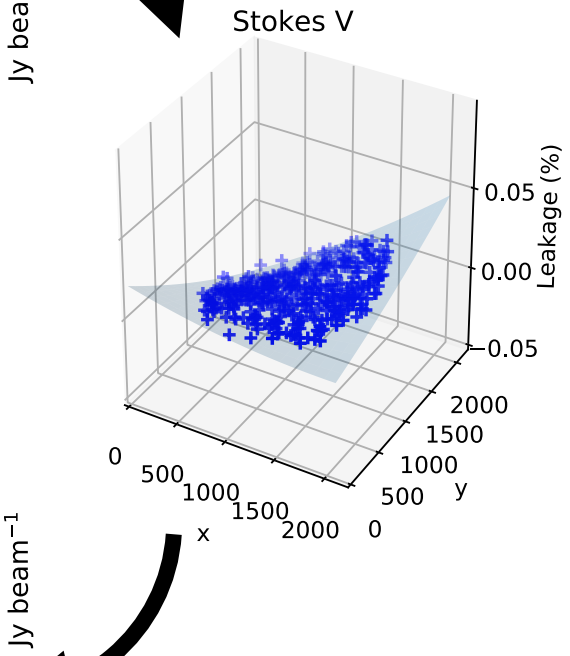


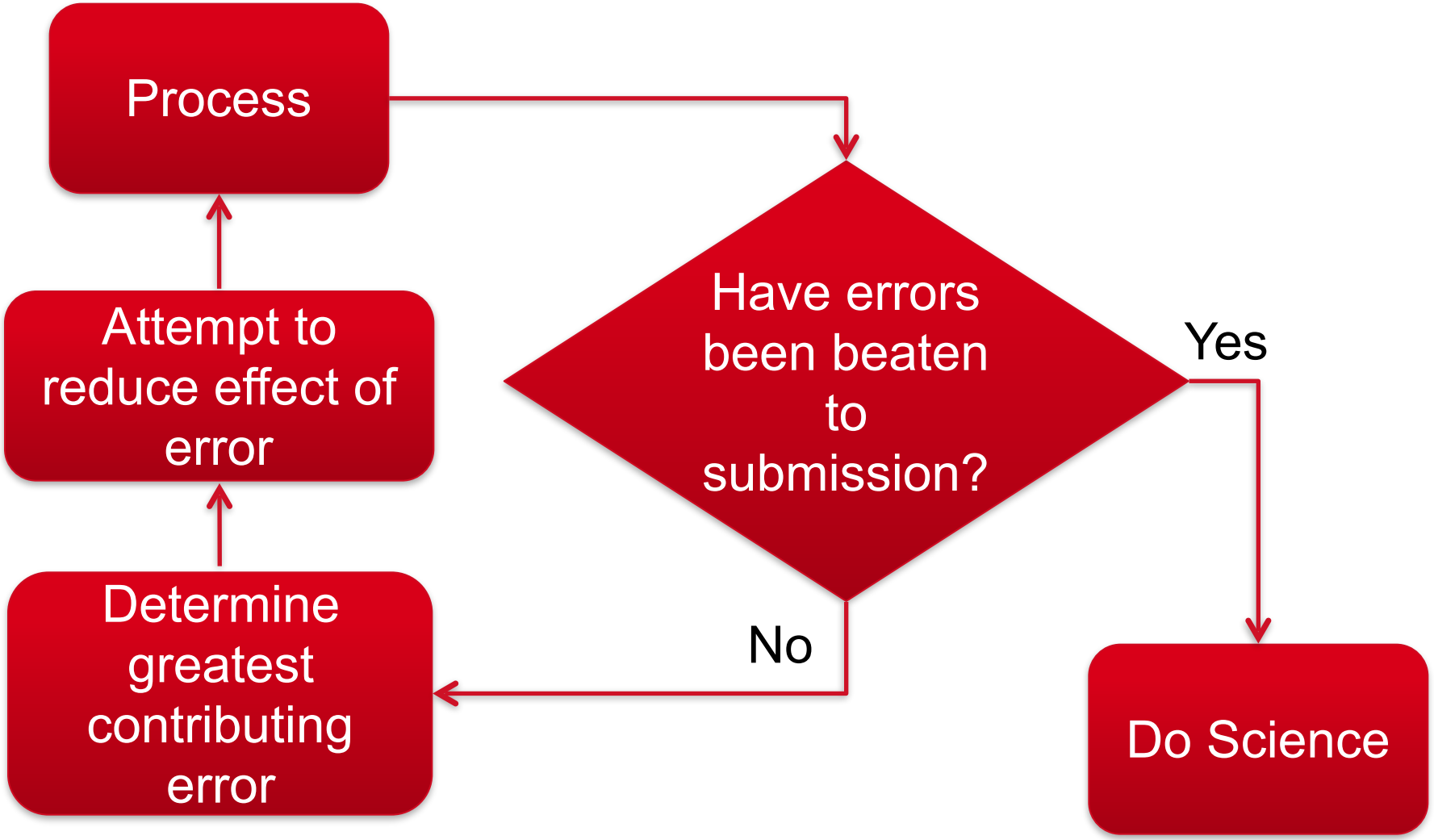
Subtract modelled component of leakage from Stokes V.

PSR J1157-6224

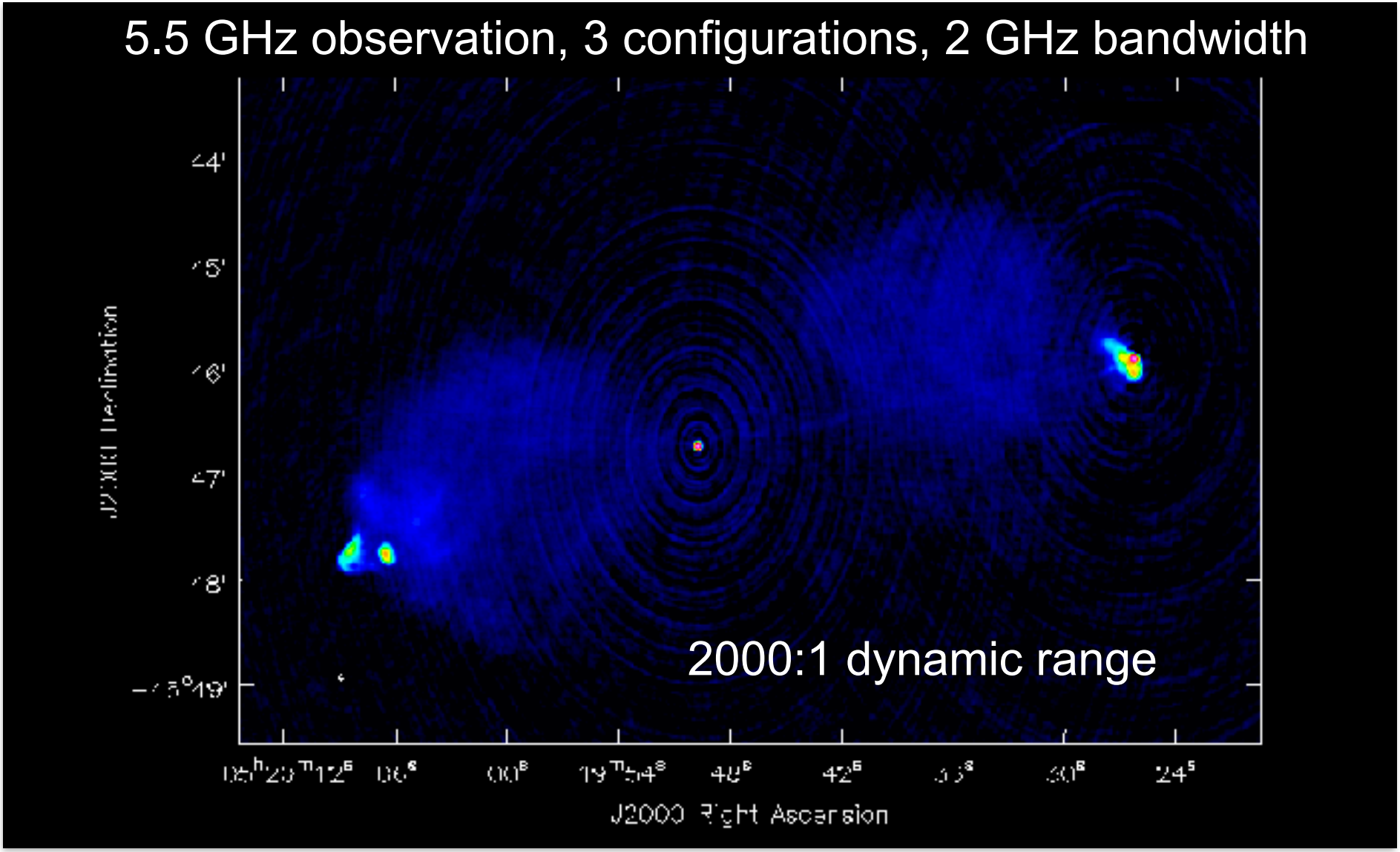
Finding the errors in your way

- Avoid sausage factory processing (at least initially)
  - Try to understand each processing step.
  - Look closely at the data after each step, check and image calibrators.
  - Does the data look plausible.
- Take a different perspective
  - Look at your data in different domains (time, (u,v), image, frequency).
  - Plot different combinations of variables in different spaces.
  - Look at residuals, FT your dirty image, FT your beam.
- Process your data in different ways
  - Try different software, algorithms.
  - Partition and process your data in different ways
  - Try split in time chunks, split up frequency band
  - Different weighting, different uv tapers.

Error reduction …



What's happening?



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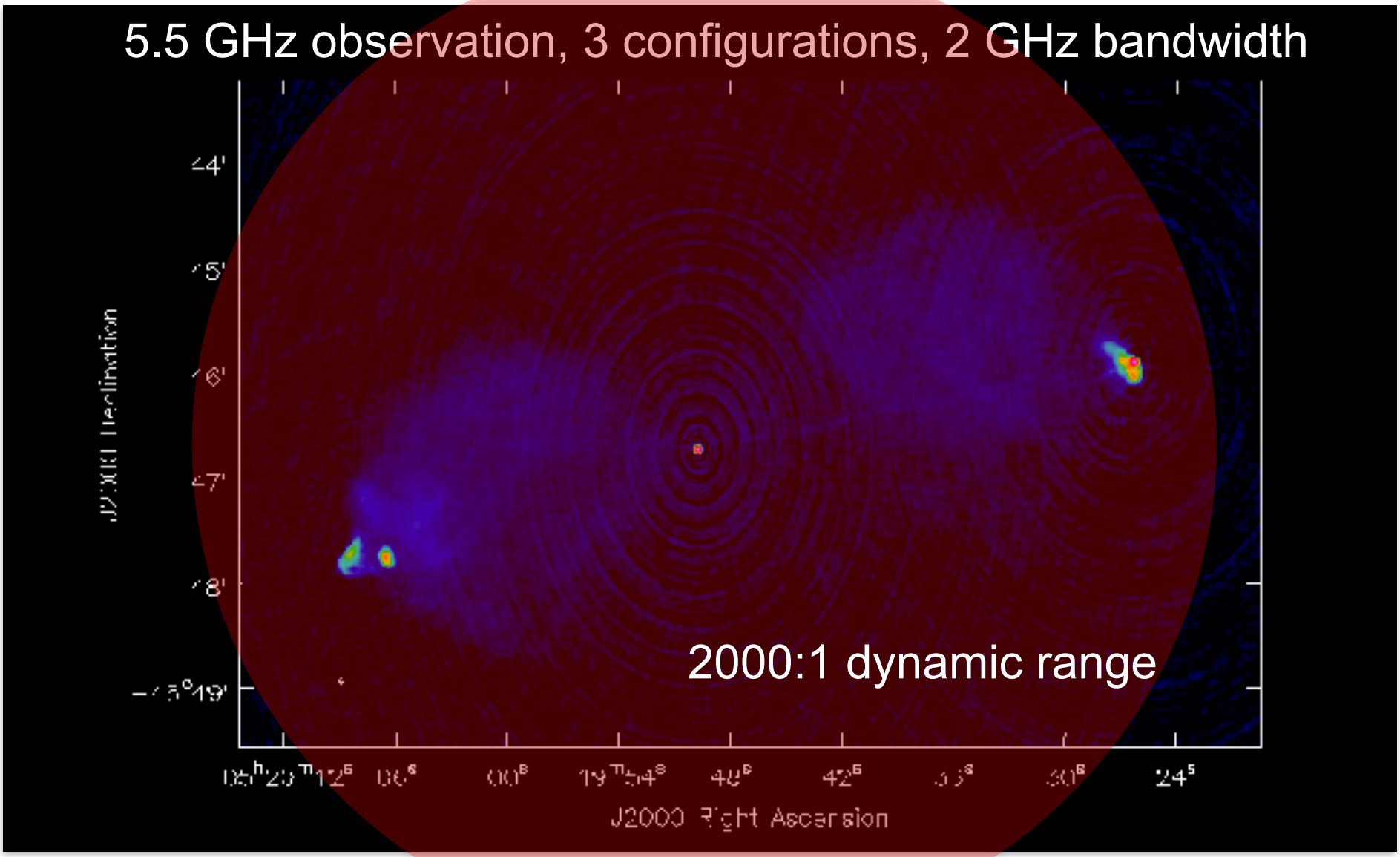

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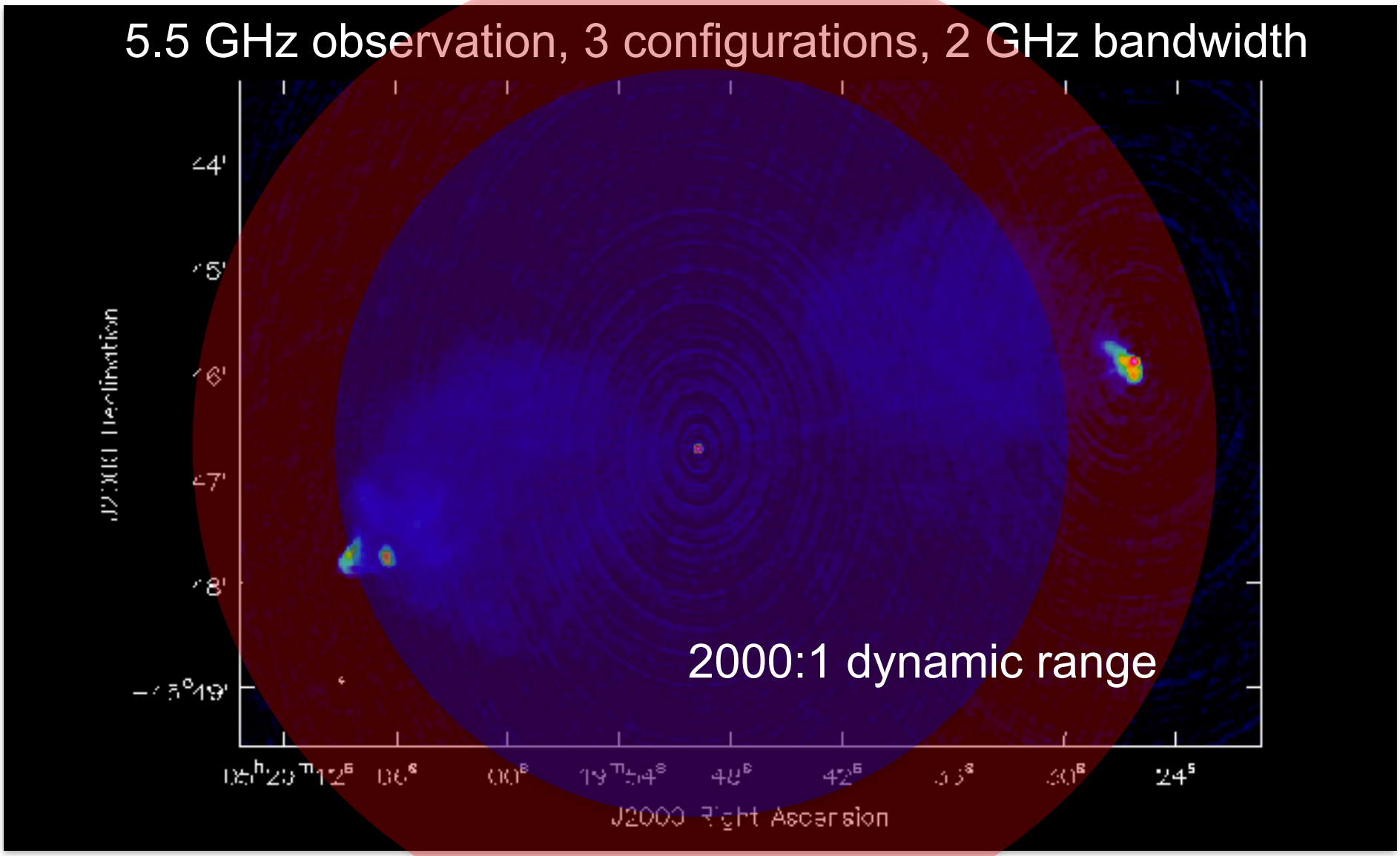
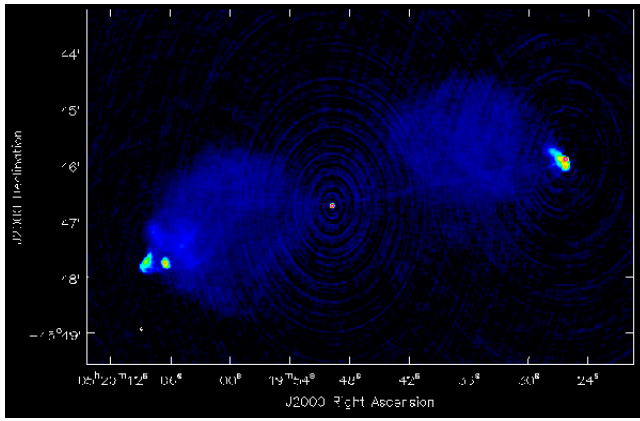


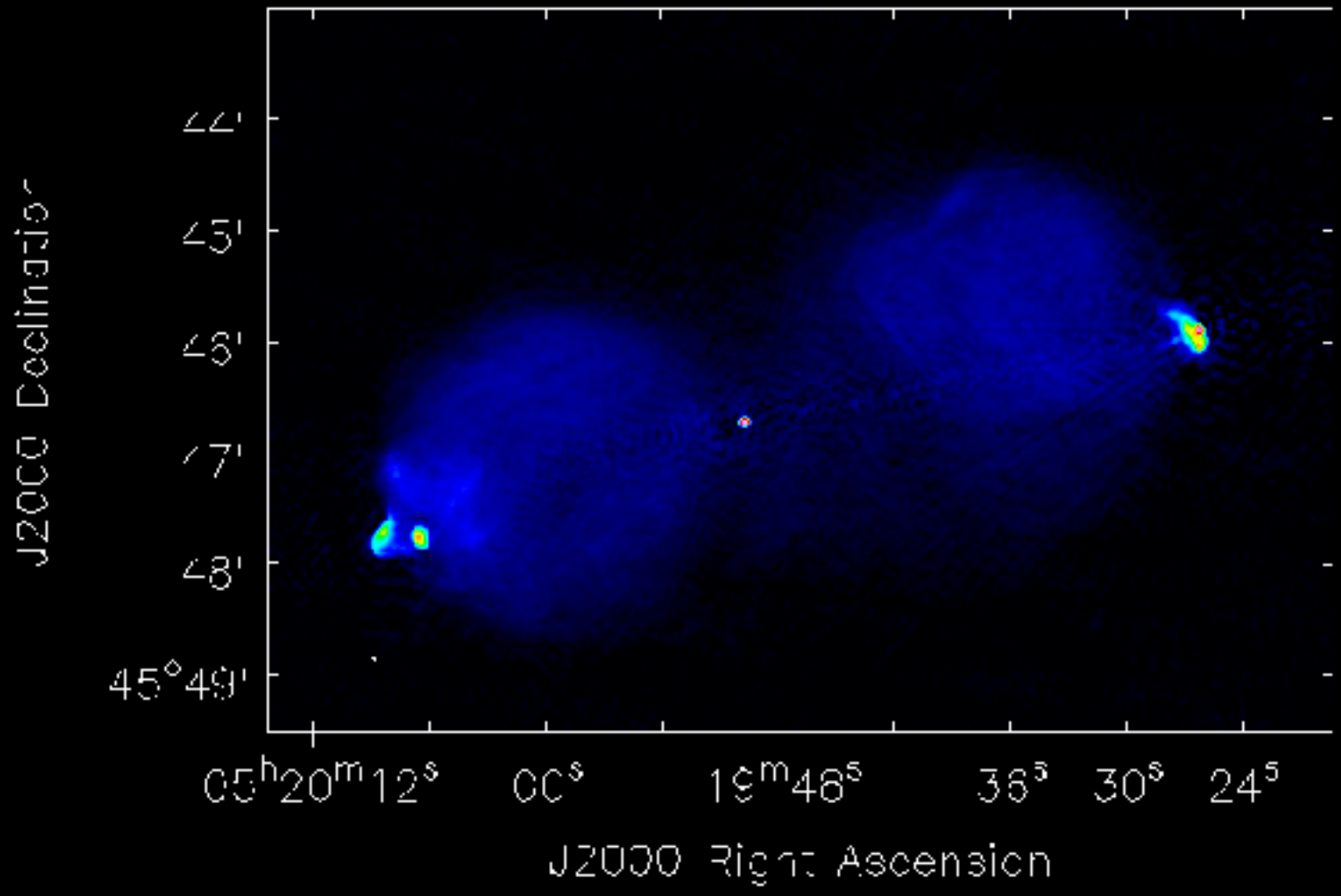
What's happening

- Amplitude calibration errors.
- Hot spot near edge of 4.5 GHz beam (outside 6.5 GHz beam)
  - Causes steepening of source spectra.
  - Causes position dependent effects.
  - Will need to consider peeling techniques.
- Spectral variation throughout the image (flat and steep)
  - Must use multi-frequency deconvolution.
- Structures on many different scales.
  - Must use appropriate deconvolution algorithms.
- North-west hot spot is bright and slightly extended.
  - Difficult to deconvolve accurately.
  - Small cell size or uv-subtract component.



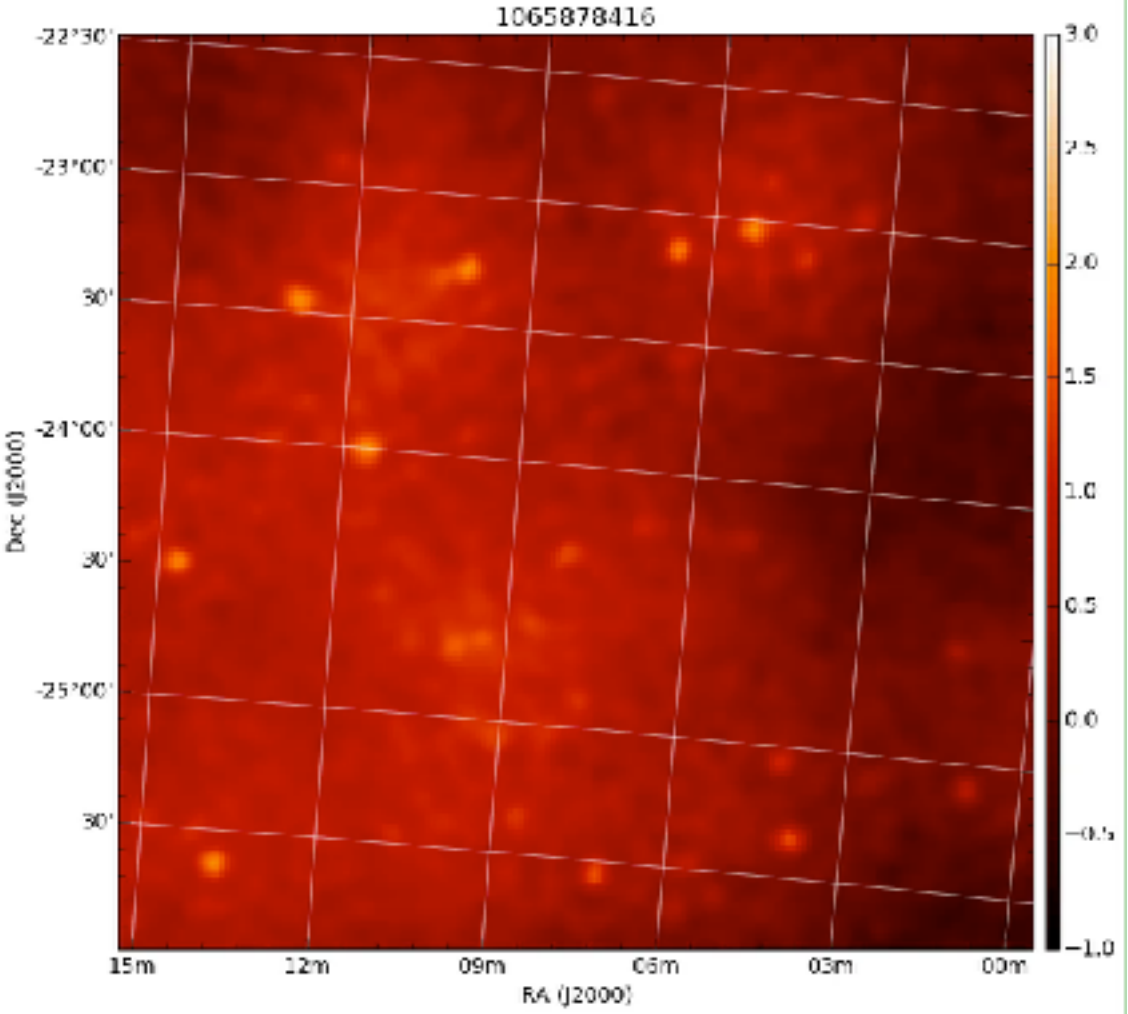
What's happening?

38,000:1 dynamic range




POP
QUIZ!

1. Can you deal with something new? What's happening?



Low frequency MWA obs.

A. Heat haze
B. Antenna deformation
C. Ionosphere
D. Compression artifacts

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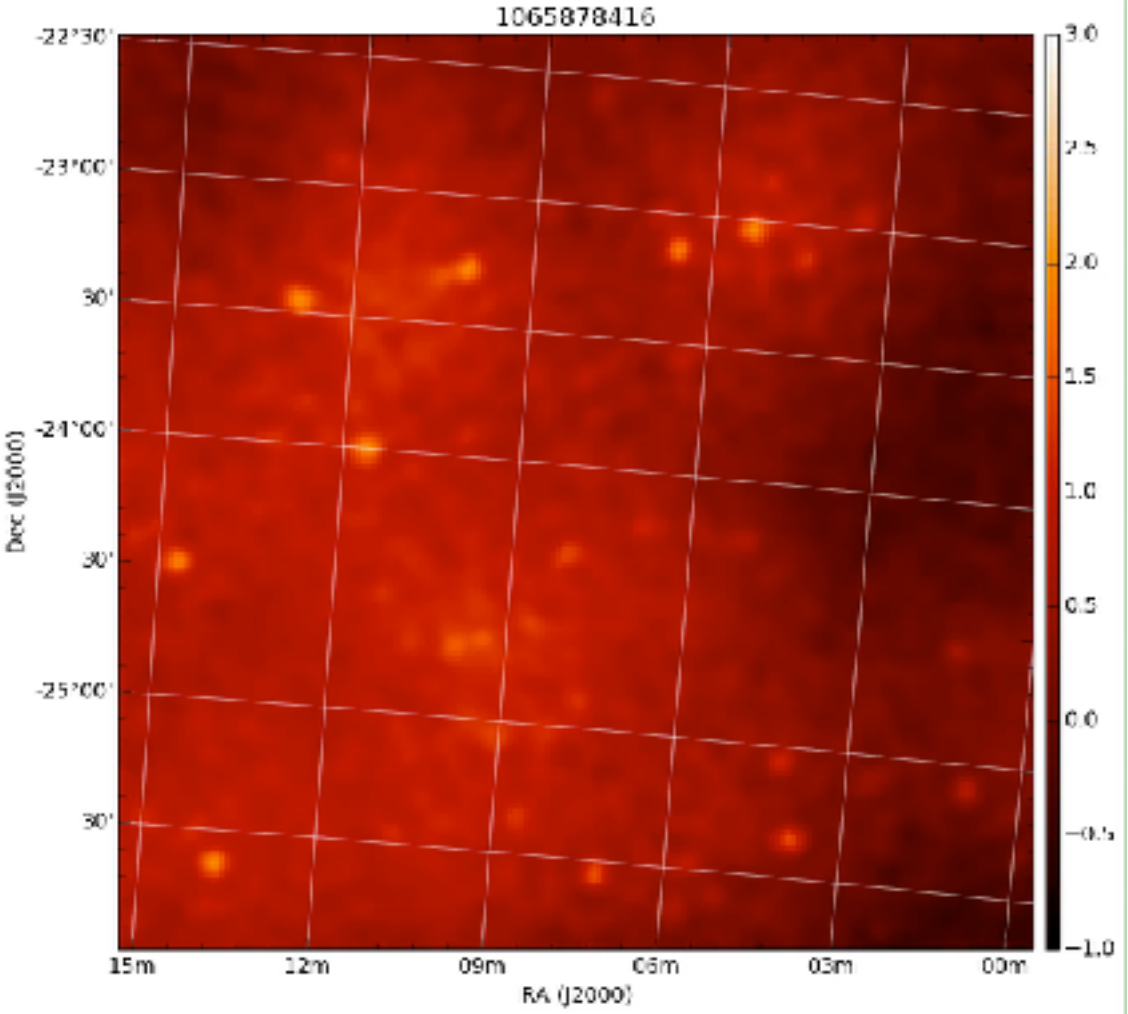

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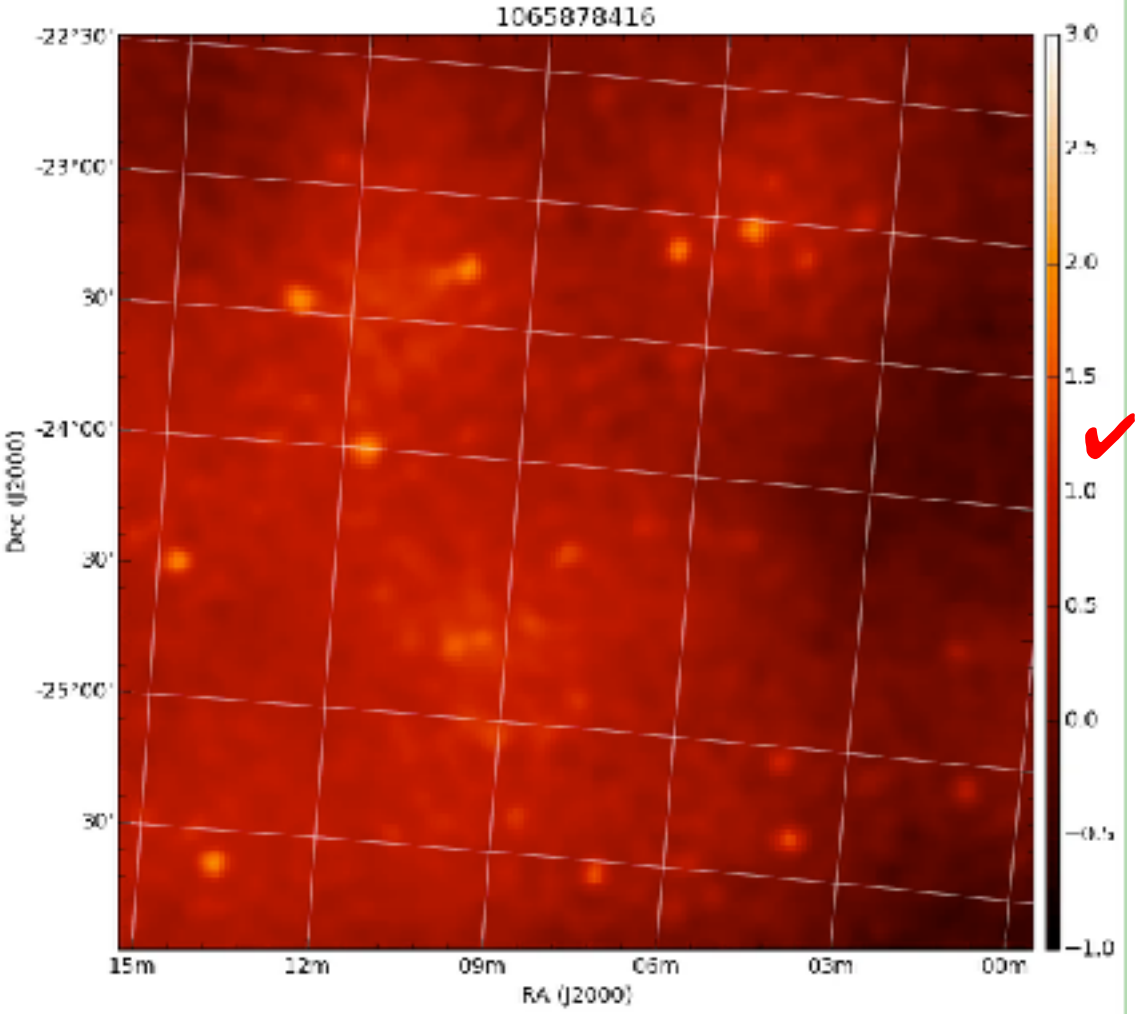

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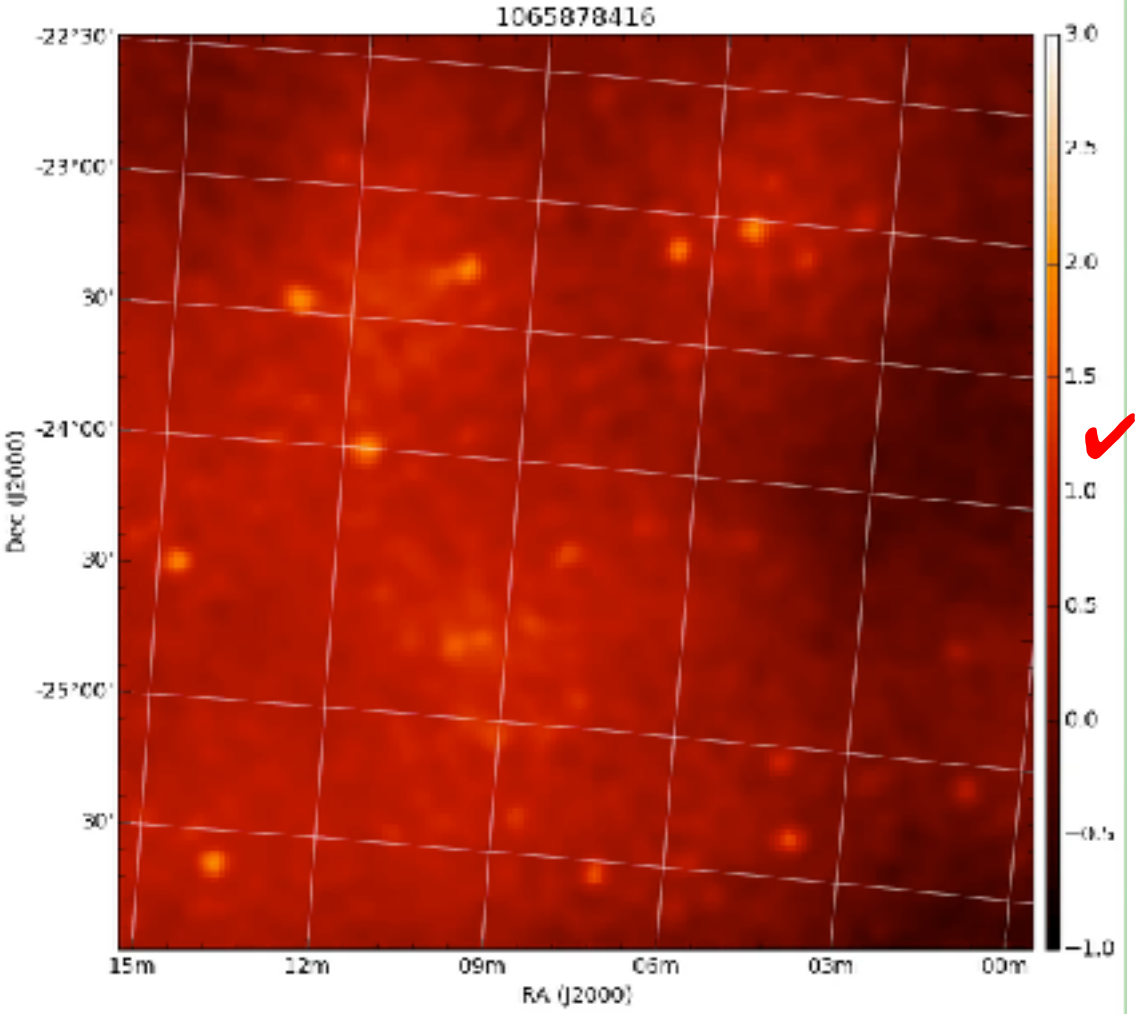

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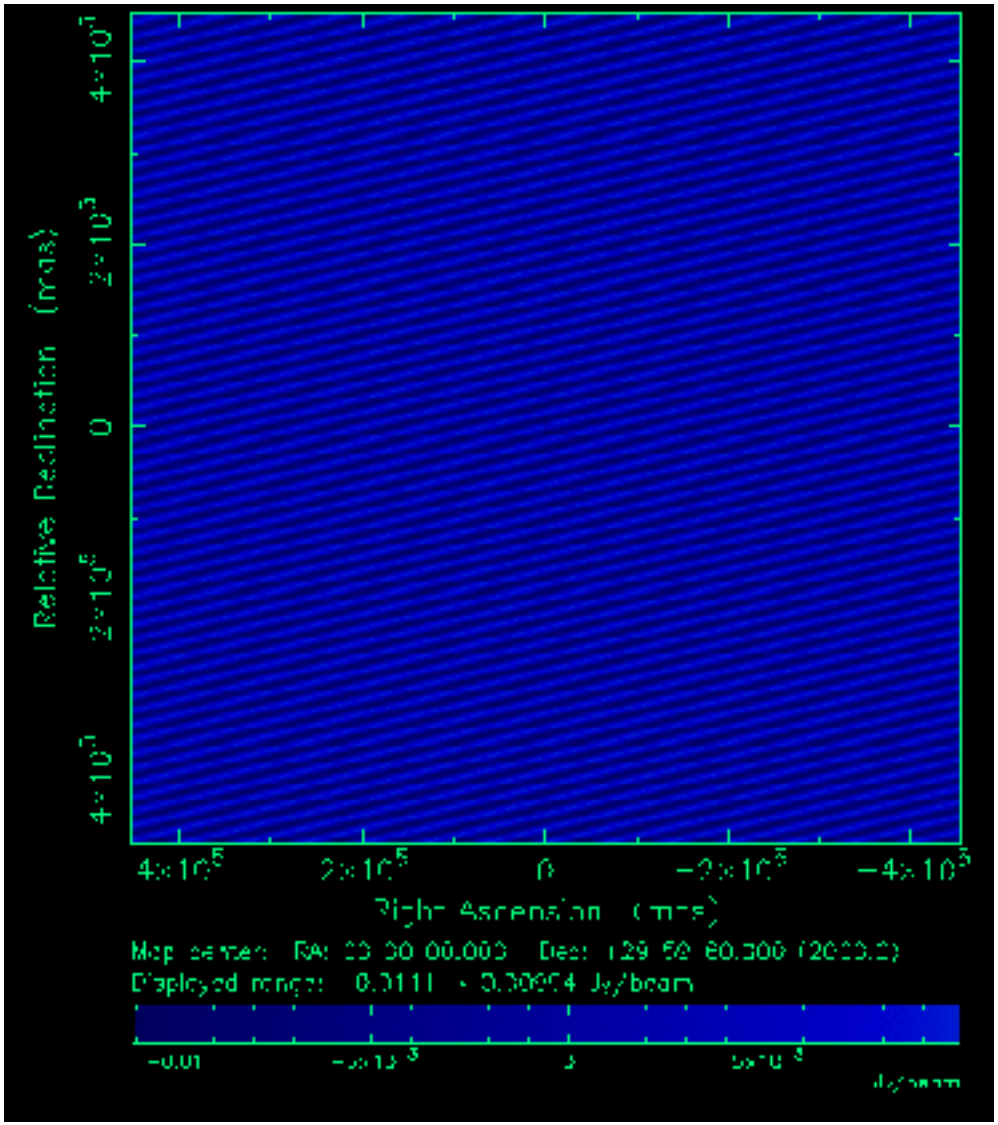
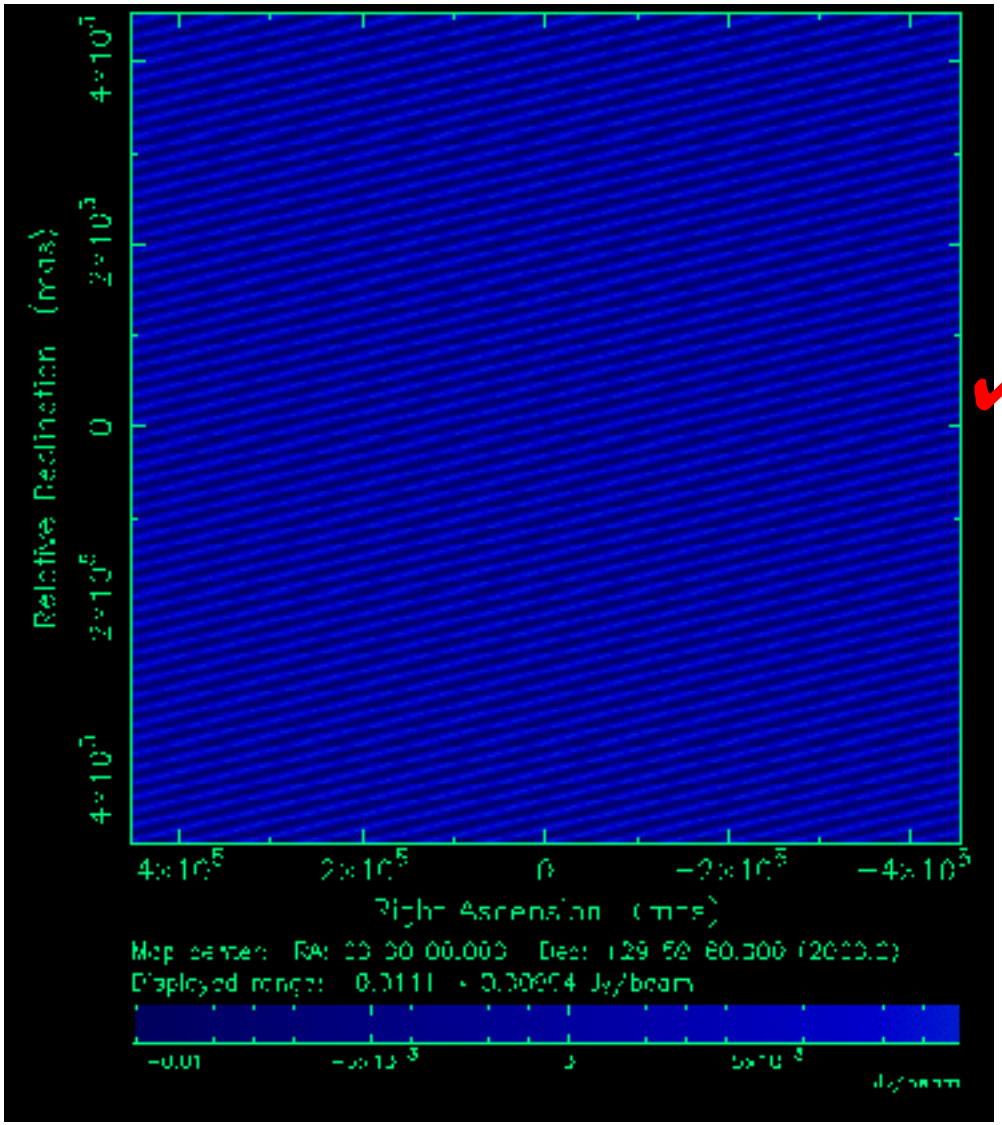
2. Be daring in your search
What's happening?



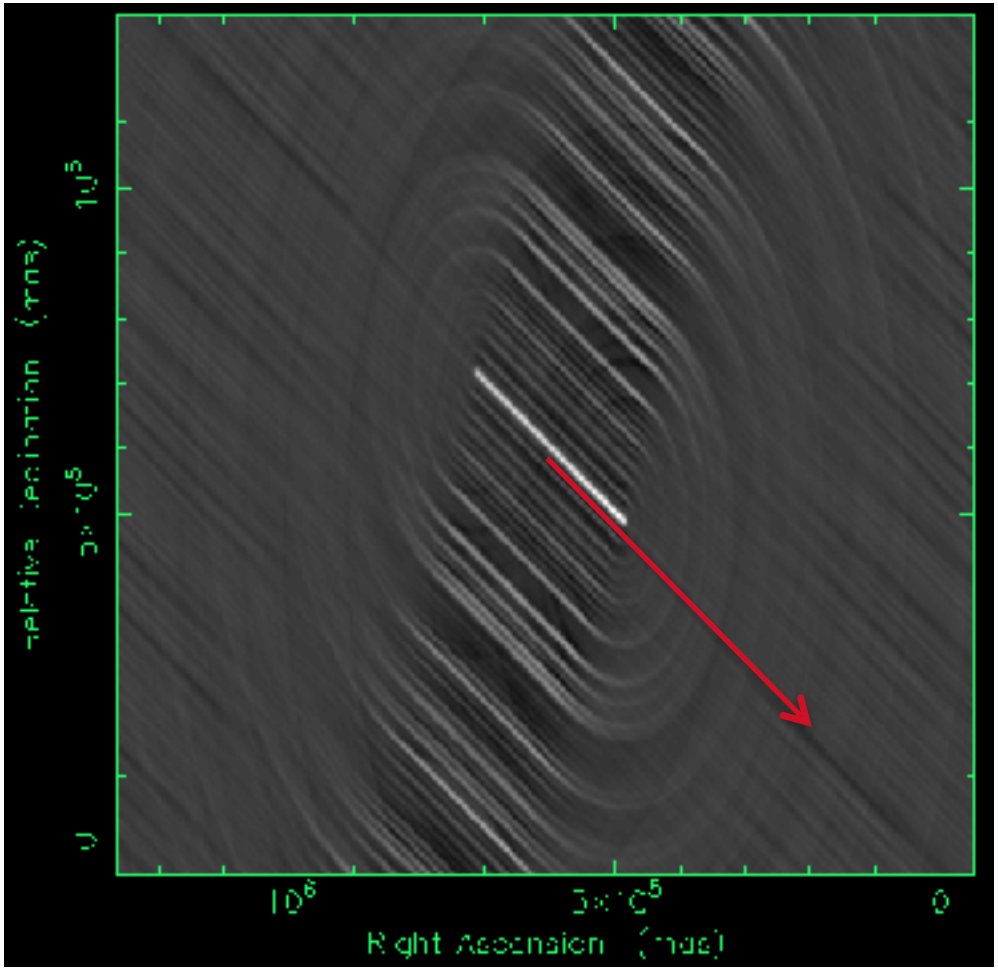
A. Primary Beam error
B. RFI
C. Venetian blinds left open
D. Deconvolution error

2. Be daring in your search
What's happening?



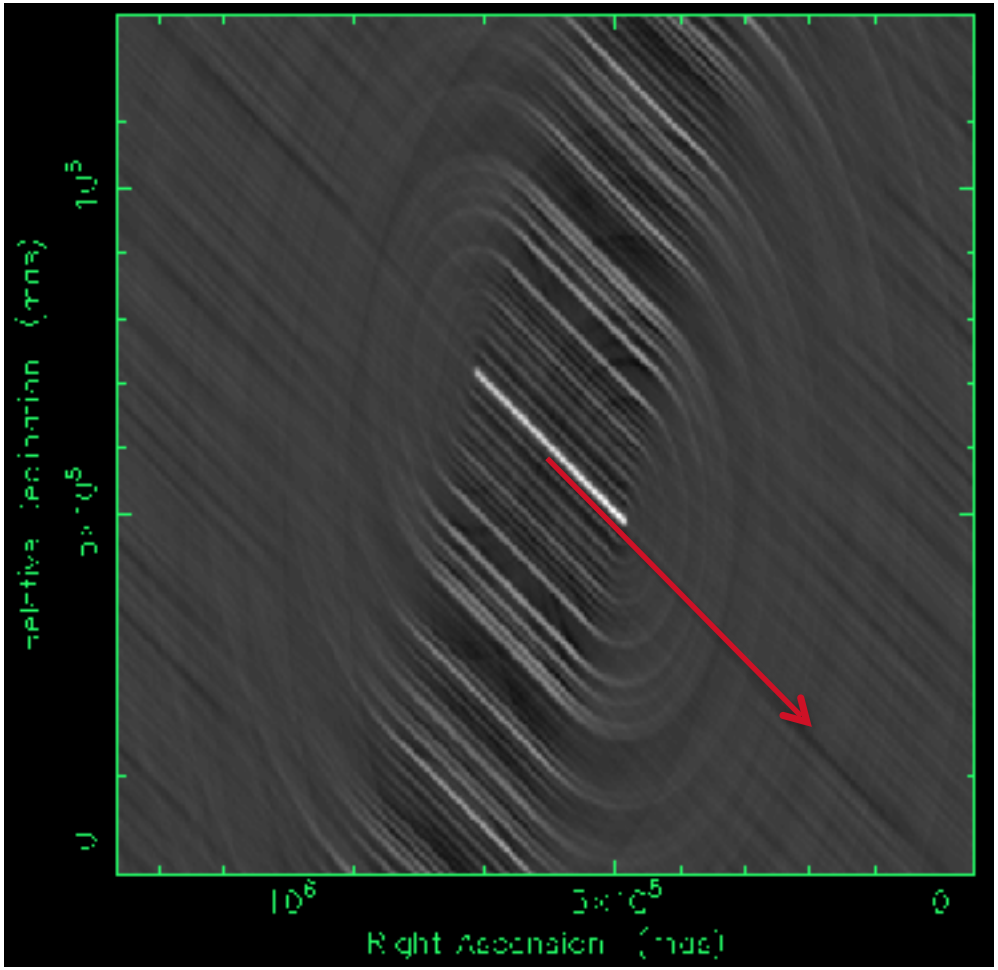
A. Primary Beam error
B. RFI ✔
C. Venetian blinds left open
D. Deconvolution error

3. Can you work this out? What's happening?



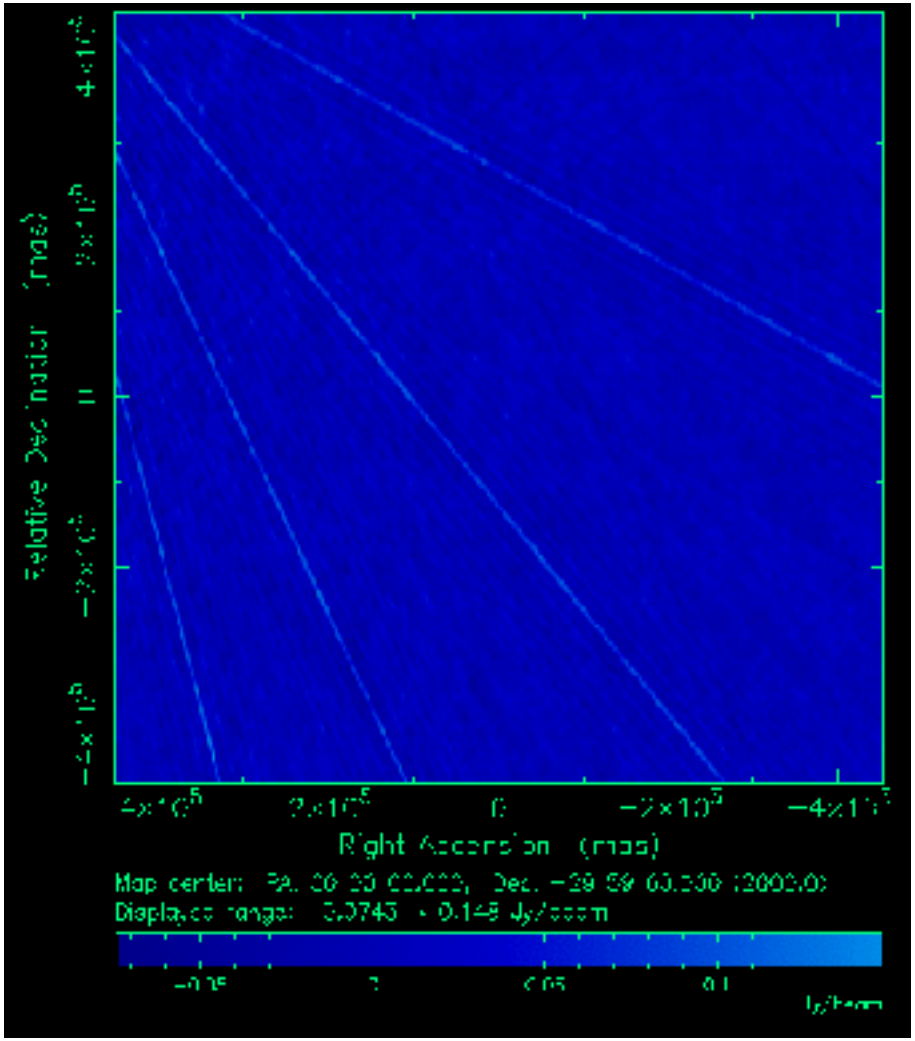
A. Amplitude errors
B. Cosmic ray
C. Bandwidth smearing
D. RFI

3. Can you work this out? What's happening?



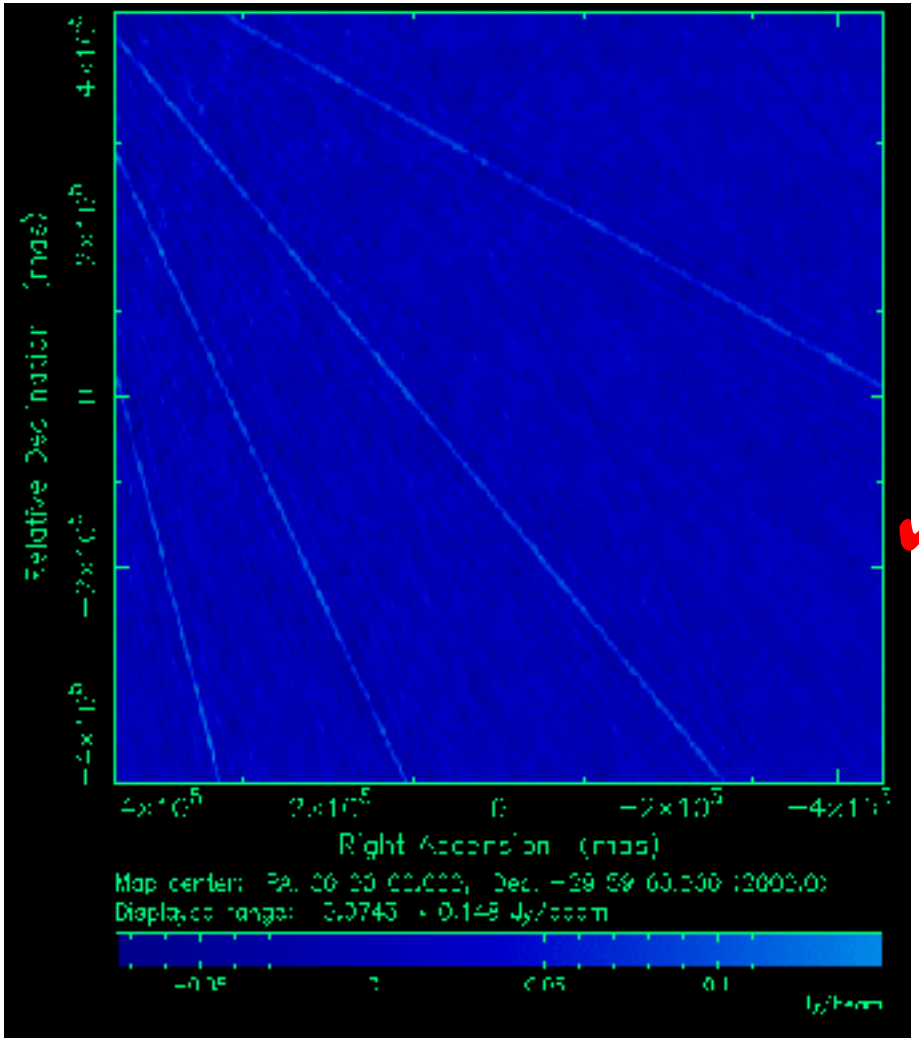
A. Amplitude errors
B. Cosmic ray
✔ C. Bandwidth smearing
D. RFI

4. Dare to solve this!
What's happening?



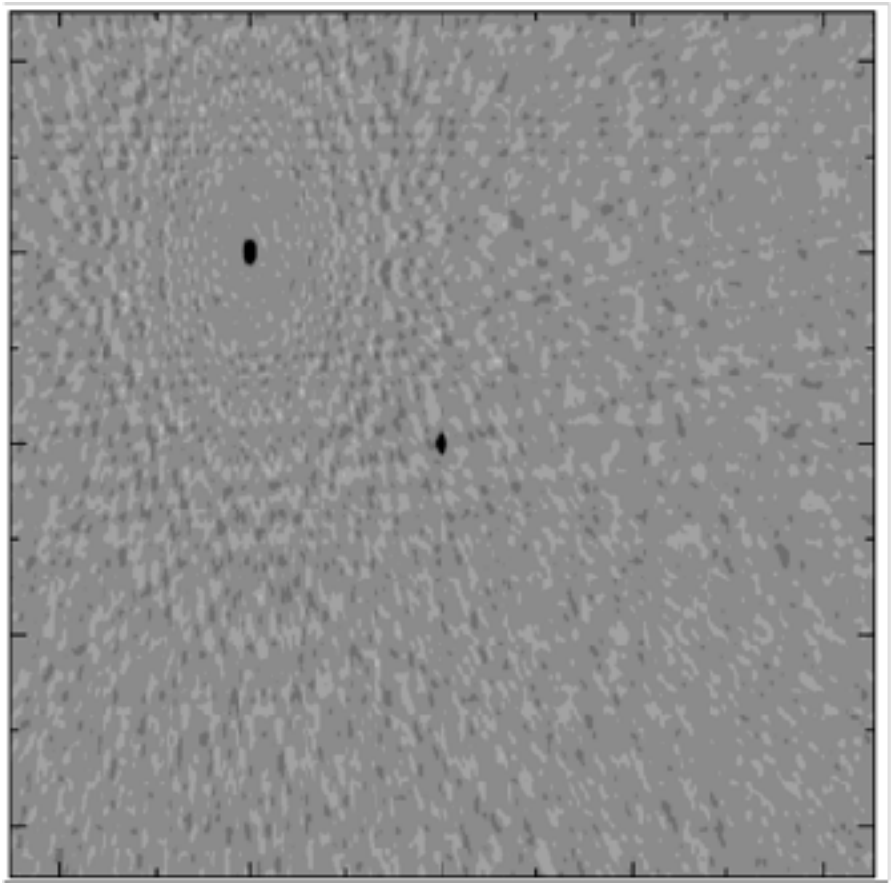
A. Amplitude errors
B. Phase of moon incorrect
C. Position-dependent errors
D. Source outside imaged field

4. Dare to solve this! What's happening?



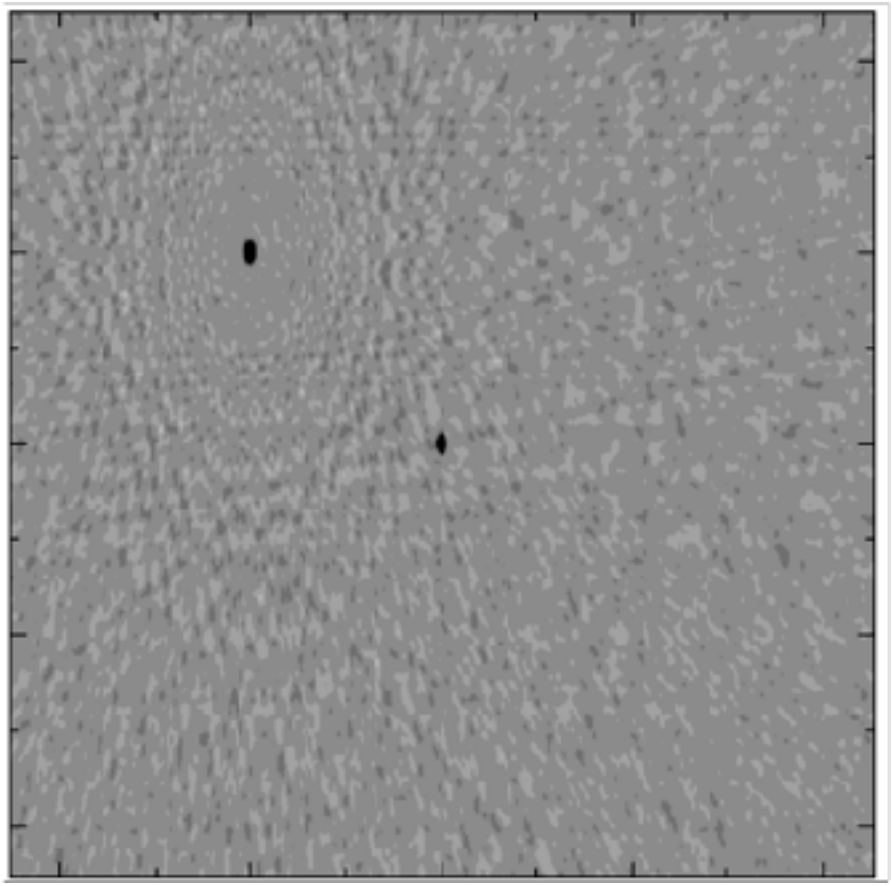
A. Amplitude errors
B. Phase of moon incorrect
C. Position-dependent errors
✔D. Source outside imaged field

5. Don't give up!
What's happening?



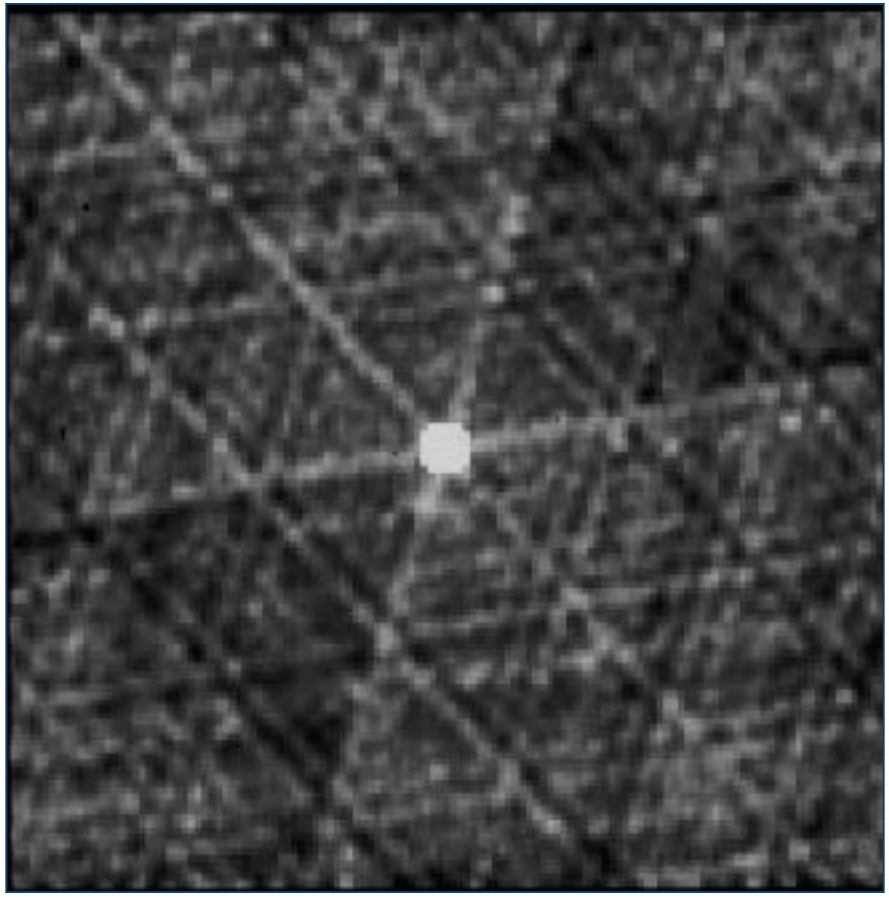
A. RFI
B. Bandwidth smearing
C. Daylight savings not set
D. Position-dependent errors

5. Don't give up!
What's happening?



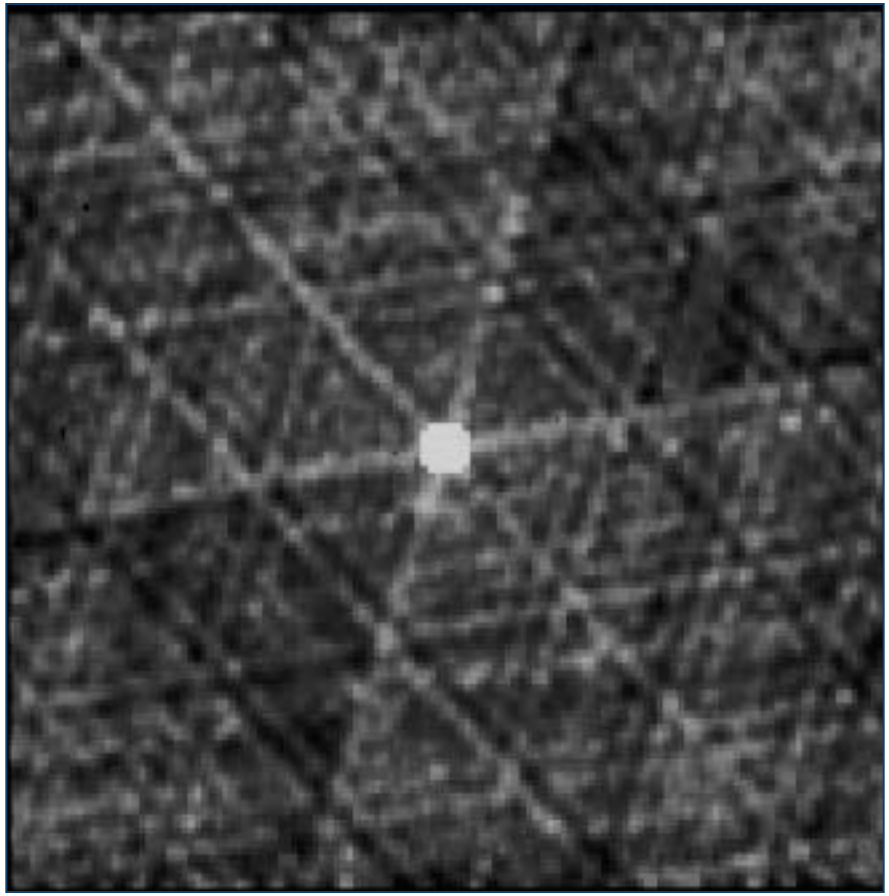
A. RFI
B. Bandwidth smearing
C. Daylight savings not set
✔D. Position-dependent errors

6. Are you able to solve this? What's happening?



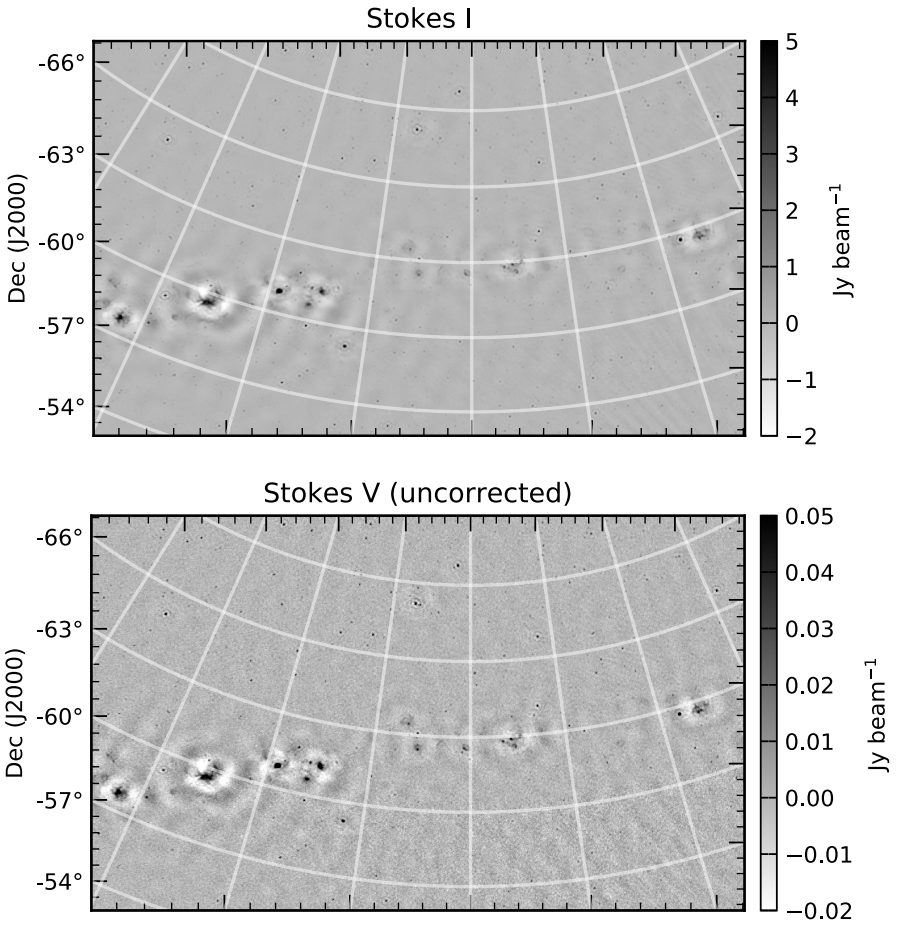
A. Amplitude errors
B. Tartan from wrong clan
C. Data stored in HEX
D. Phase errors

6. Are you able to solve this? What's happening?



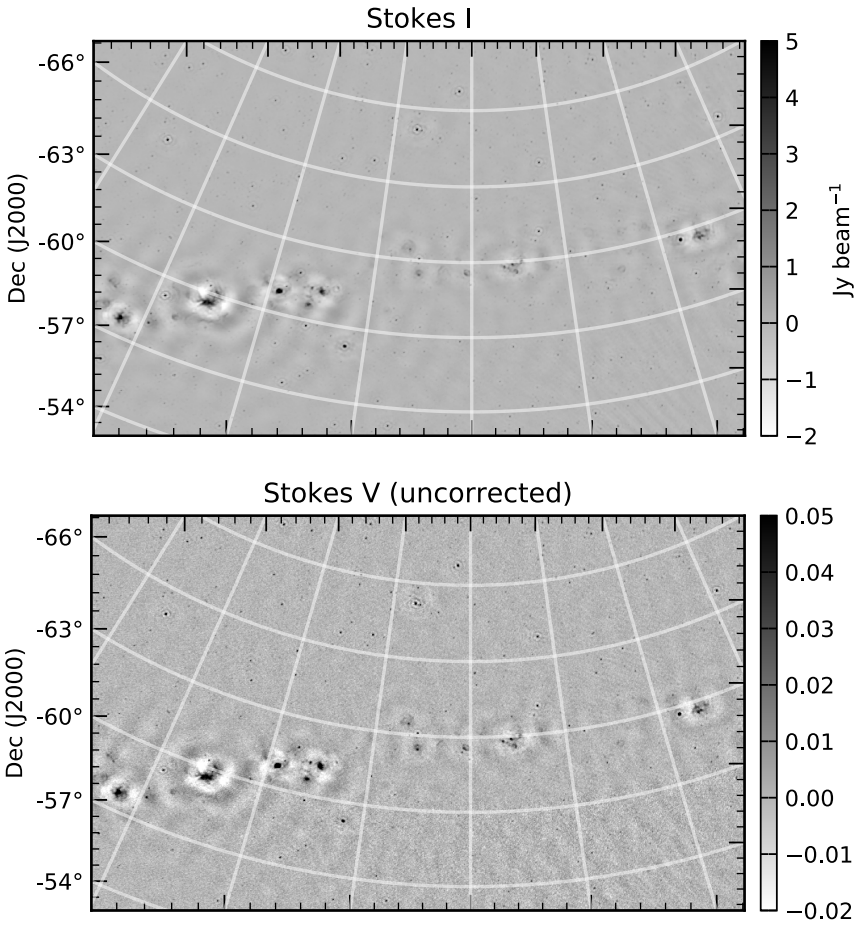
✔A. Amplitude errors
B. Tartan from wrong clan
C. Data stored in HEX
D. Phase errors

7. Can this be real? What's happening?



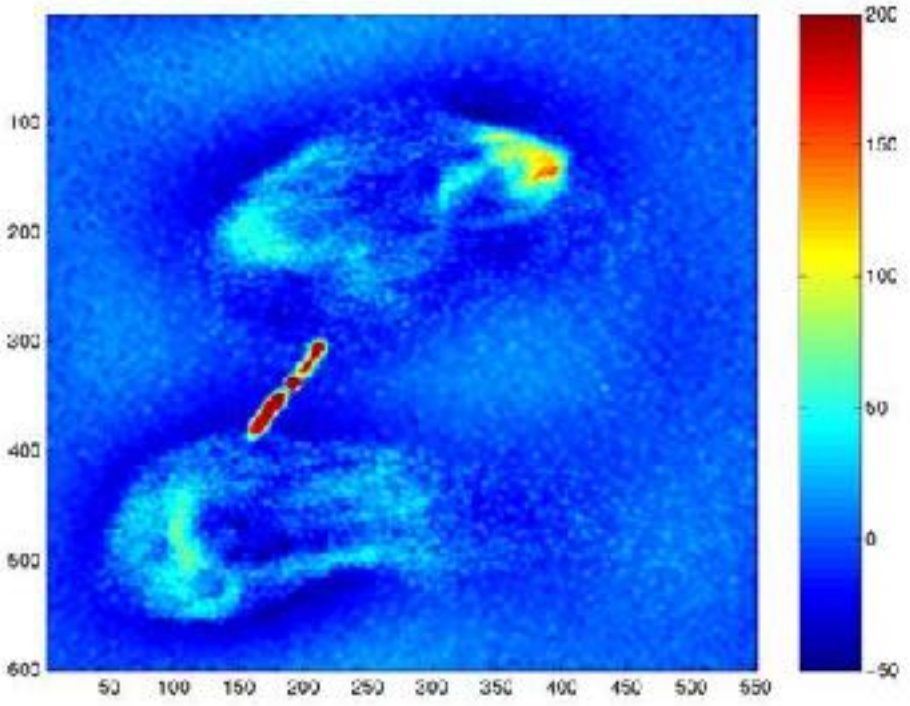
A. Ionospheric effects
B. Faraday rotation
C. Polarisation leakage
D. Galactic circular polarisation

7. Can this be real? What's happening?



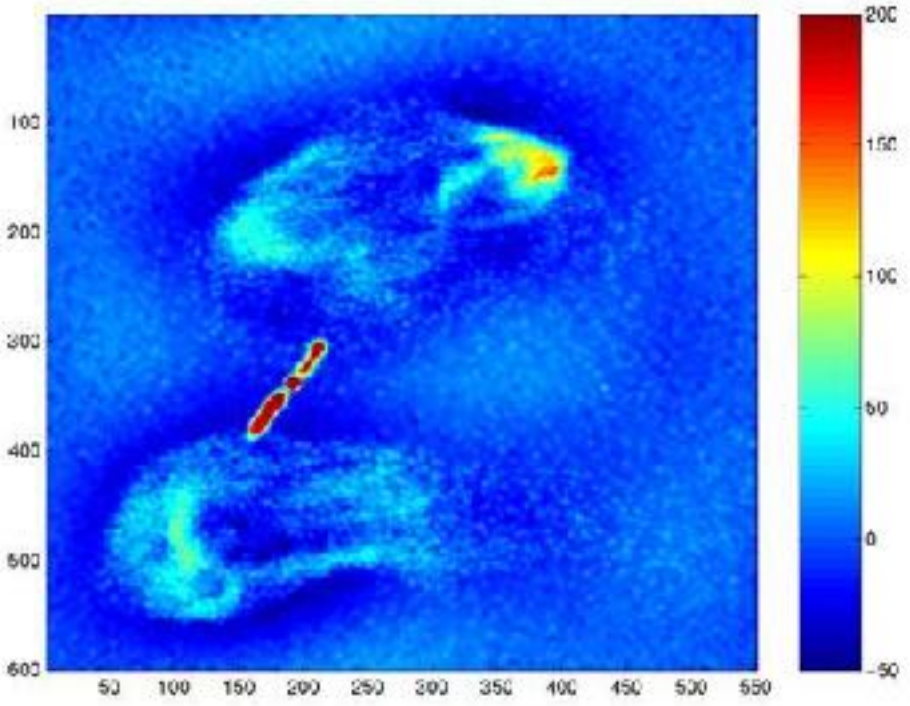
A. Ionospheric effects
B. Faraday rotation
✔C. Polarisation leakage
D. Galactic circular polarisation

8. A tricky problem
What's happening?



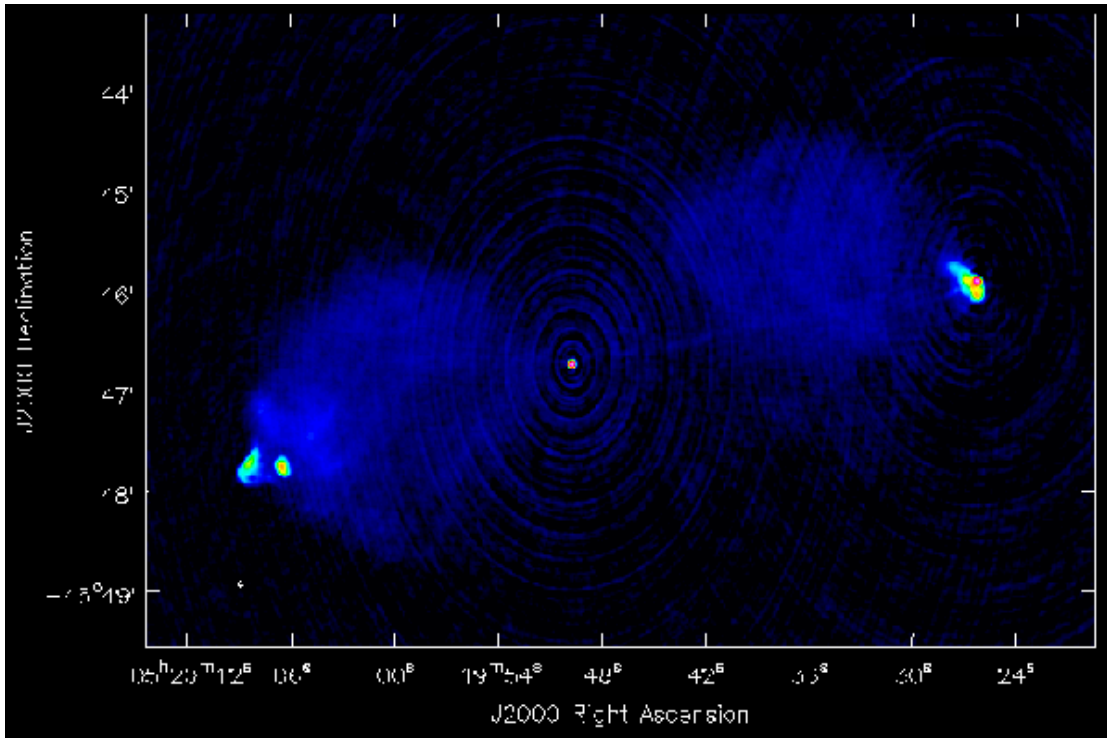
A. Missing short baselines
B. Missing long baselines
C. Missing astronomer
D. Alien Resurrection

8. A tricky problem
What's happening?



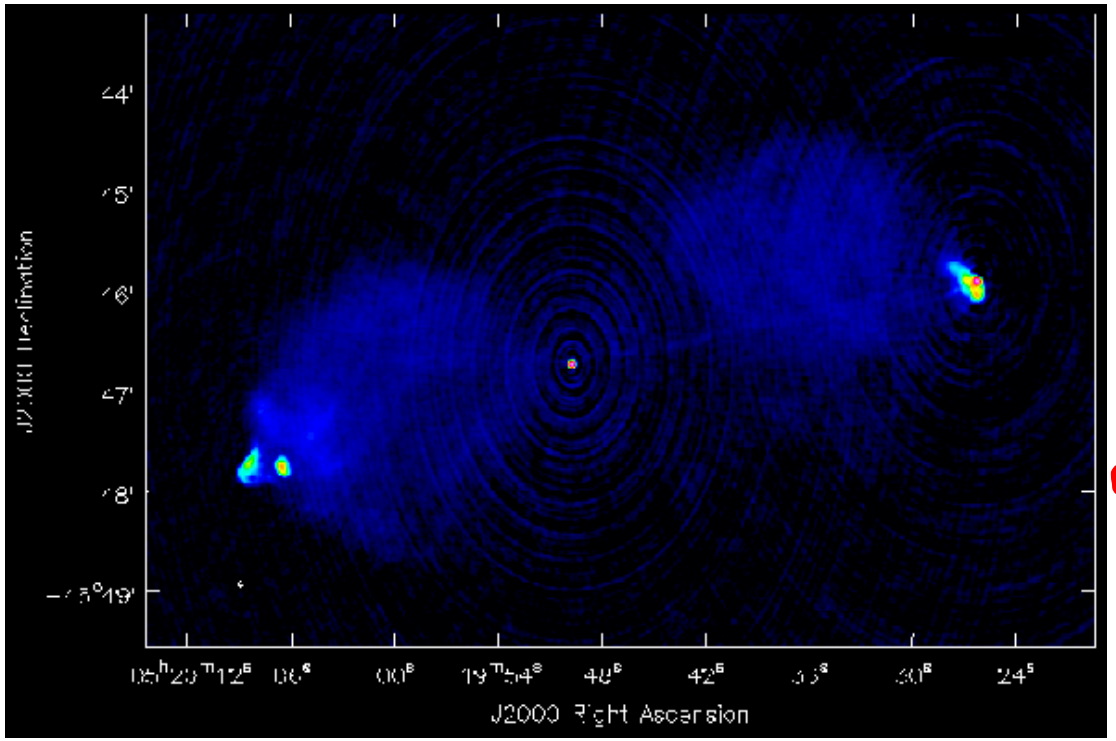
✔A. Missing short baselines
B. Missing long baselines
C. Missing astronomer
D. Alien Resurrection

9. End of game question
What's happening?



A. Amplitude errors
B. Phase errors
C. Deconvolution errors
D. Position-dep. errors
E. Almost everything

9. End of game question
What's happening?



A. Amplitude errors
B. Phase errors
C. Deconvolution errors
D. Position-dep. errors
✔ E. Almost everything

Acknowledgements

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