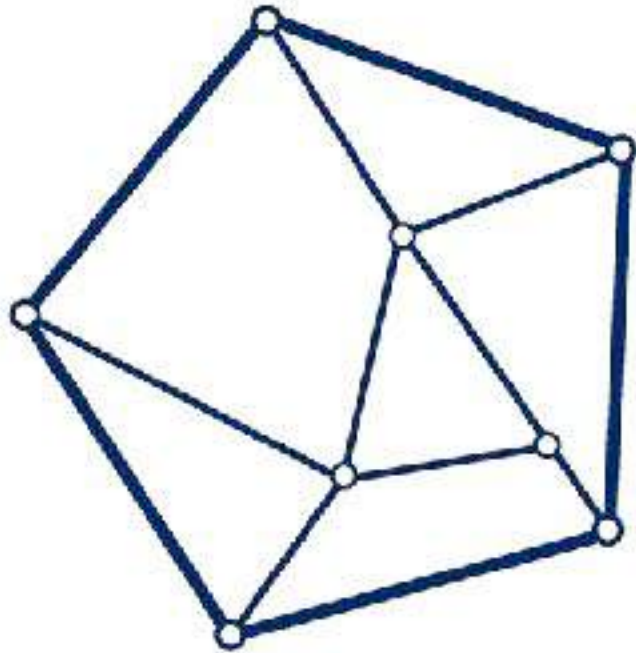




CAASTRO
ARC CENTRE OF EXCELLENCE
FOR ALL-SKY ASTROPHYSICS



THE UNIVERSITY OF
SYDNEY



Er^ror Recognitioⁿ



Emil Lenc (and Arin)

University of Sydney / CAASTRO

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

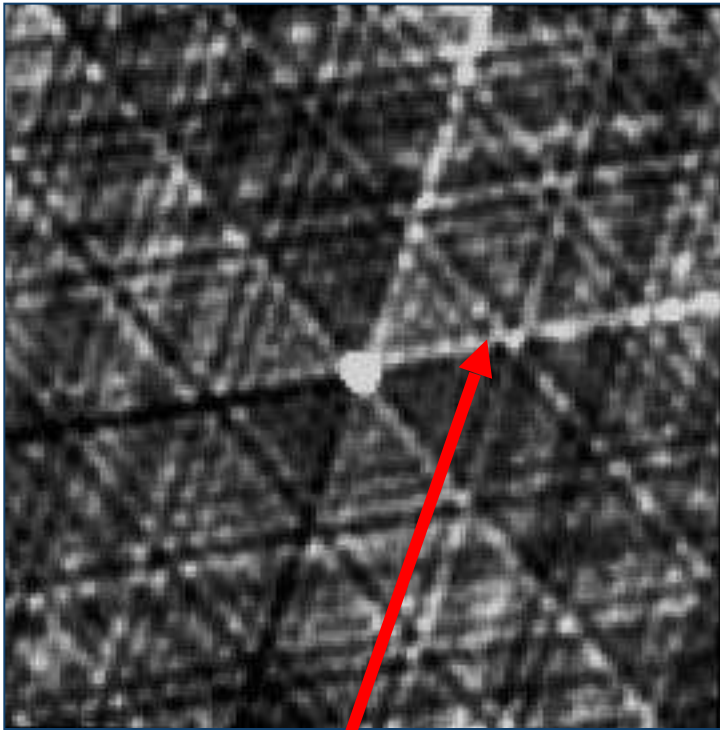
- › Additive errors (out-of-field sources, RFI, cross-talk, baseline-based errors, noise)
 - $V + \varepsilon \rightarrow I + F[\varepsilon]$
- › Multiplicative errors (uv-coverage effects, gain errors, atmospheric effects)
 - $V \bullet \varepsilon \rightarrow I \star F[\varepsilon]$
- › Convolutional 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. $F[\varepsilon]$ 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. $F[\varepsilon]$ 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

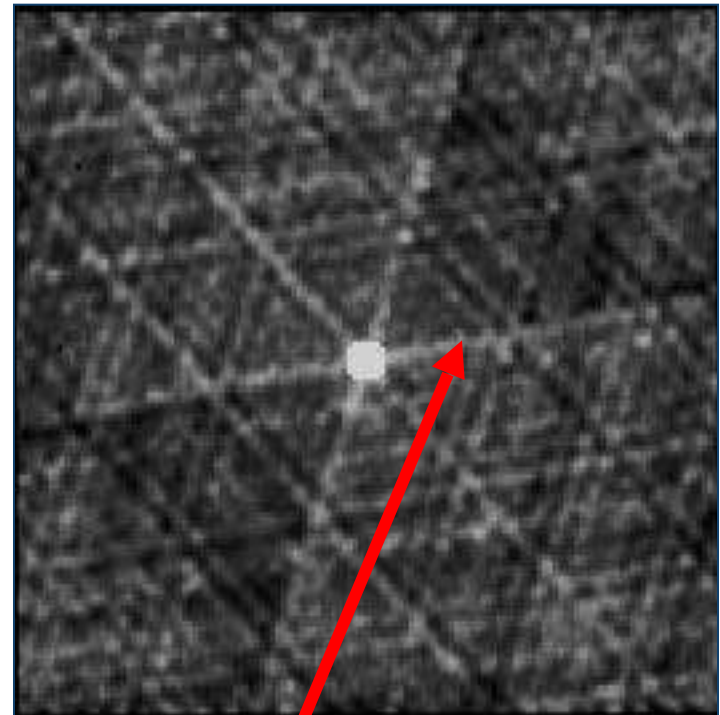
Gain Errors

10 deg phase error



anti-symmetric ridges

20% amp error



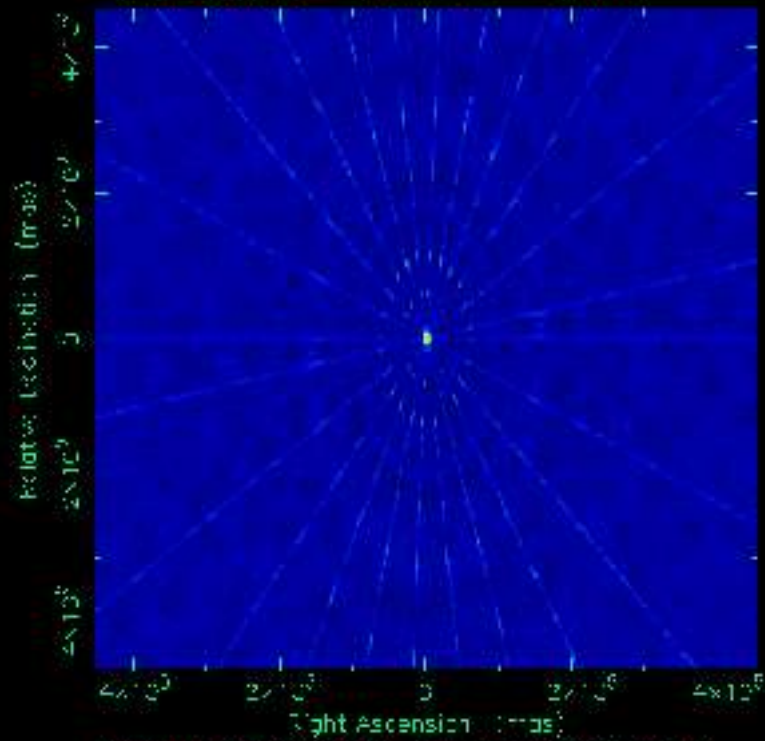
symmetric ridges

Adapted from Myers 2002 and Ekers.

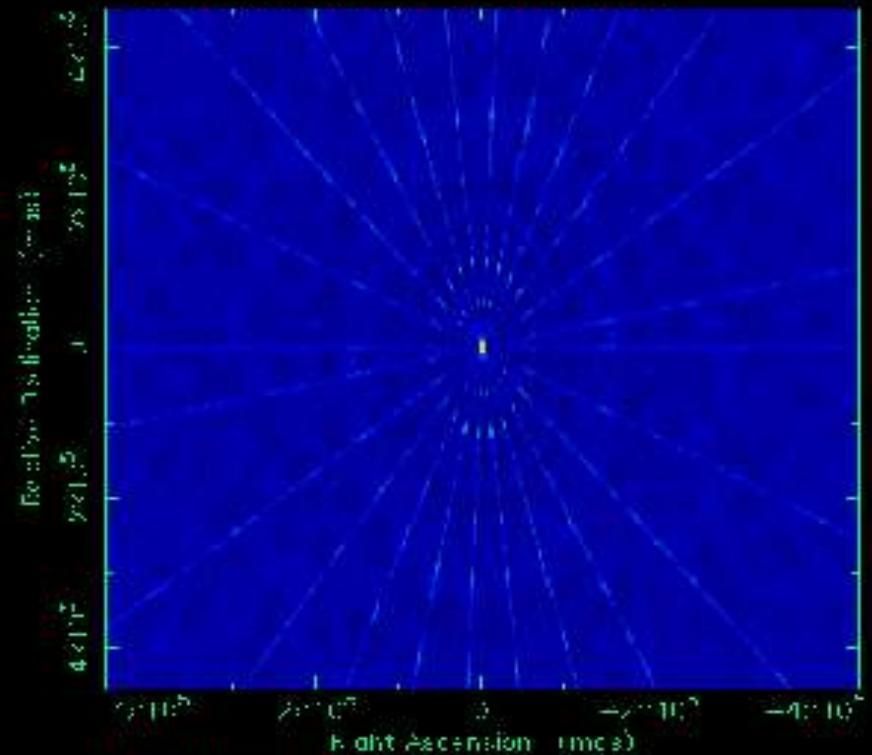


Additive Errors: RFI

Dirty Map



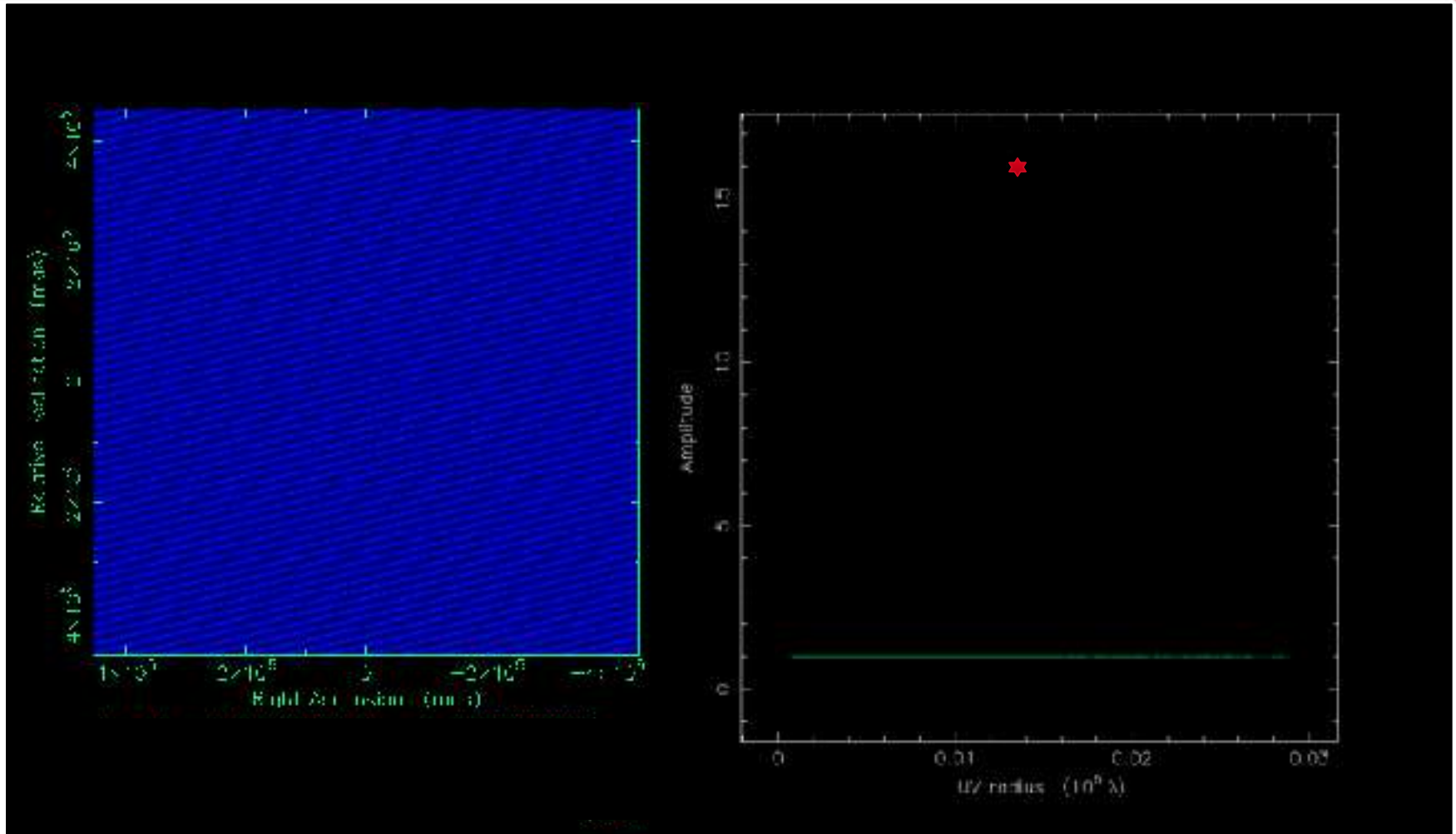
PSF



Observation of 1 Jy source



Finding RFI



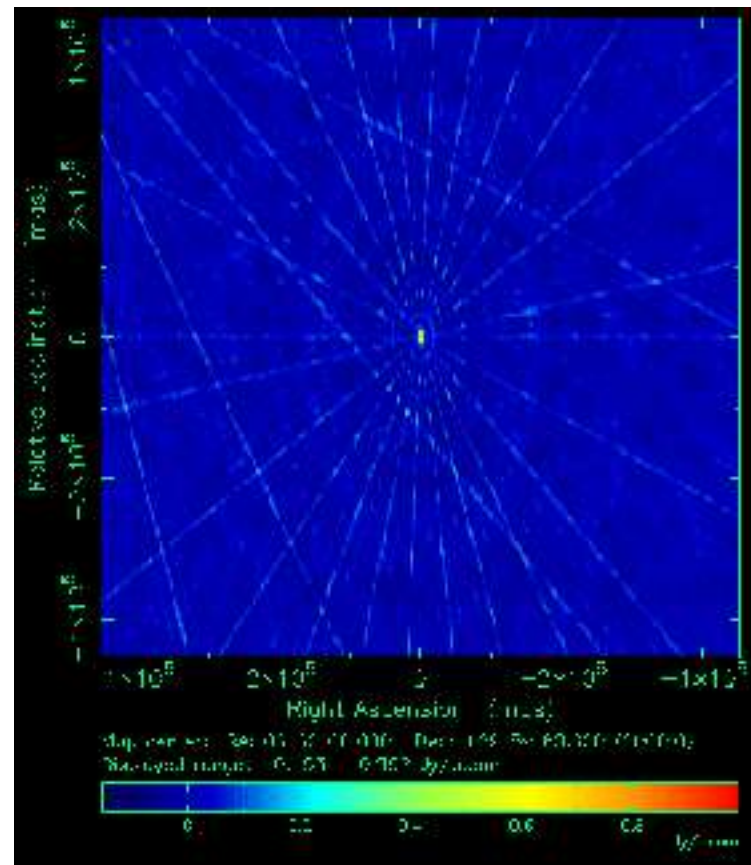
Observation of 1 Jy source

See Mark's talk for more on removing RFI.



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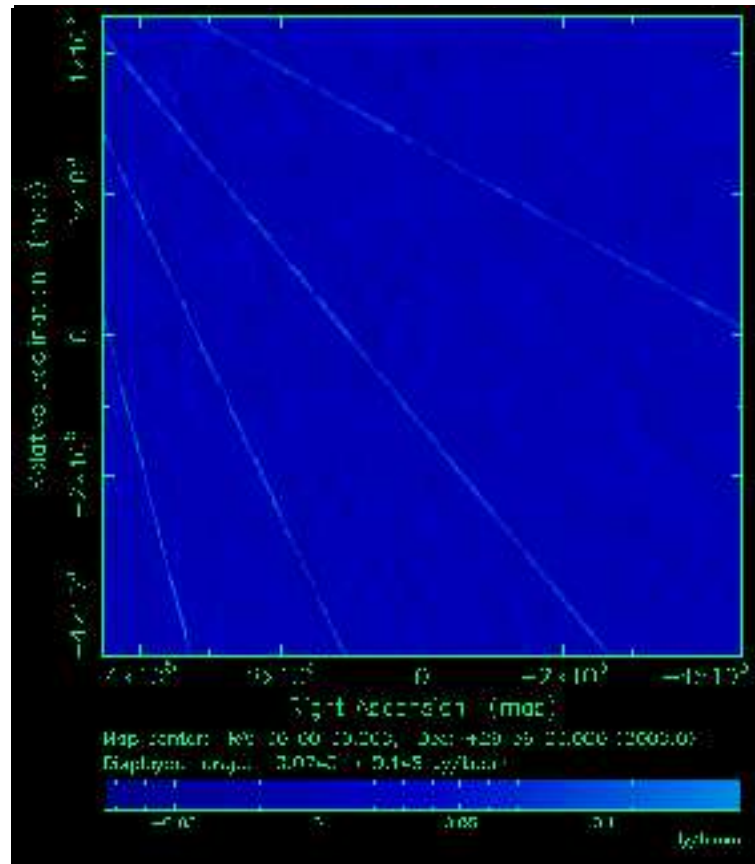
The Bigger Picture





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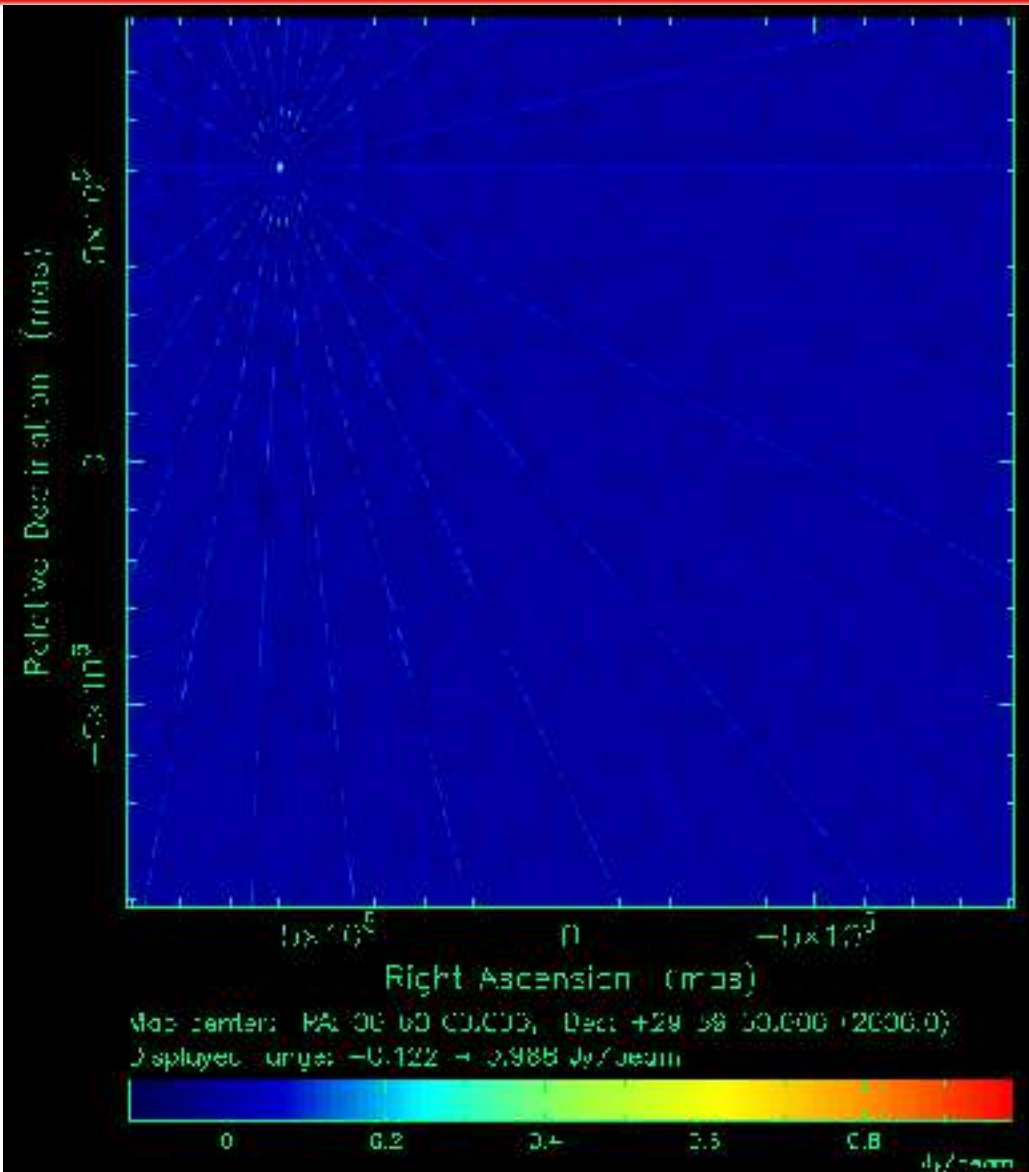
The Bigger Picture





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The Bigger Picture

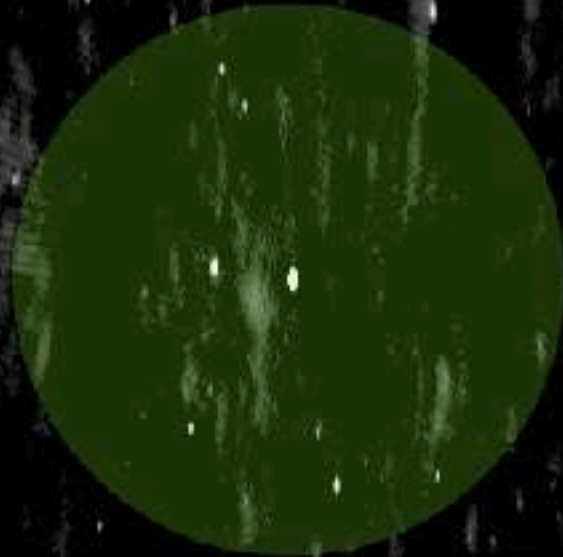




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The Bigger Picture

Long observation (25 days over several years)
of calibrator source PKS B0237-233
Dynamic range ~ 100,000:1

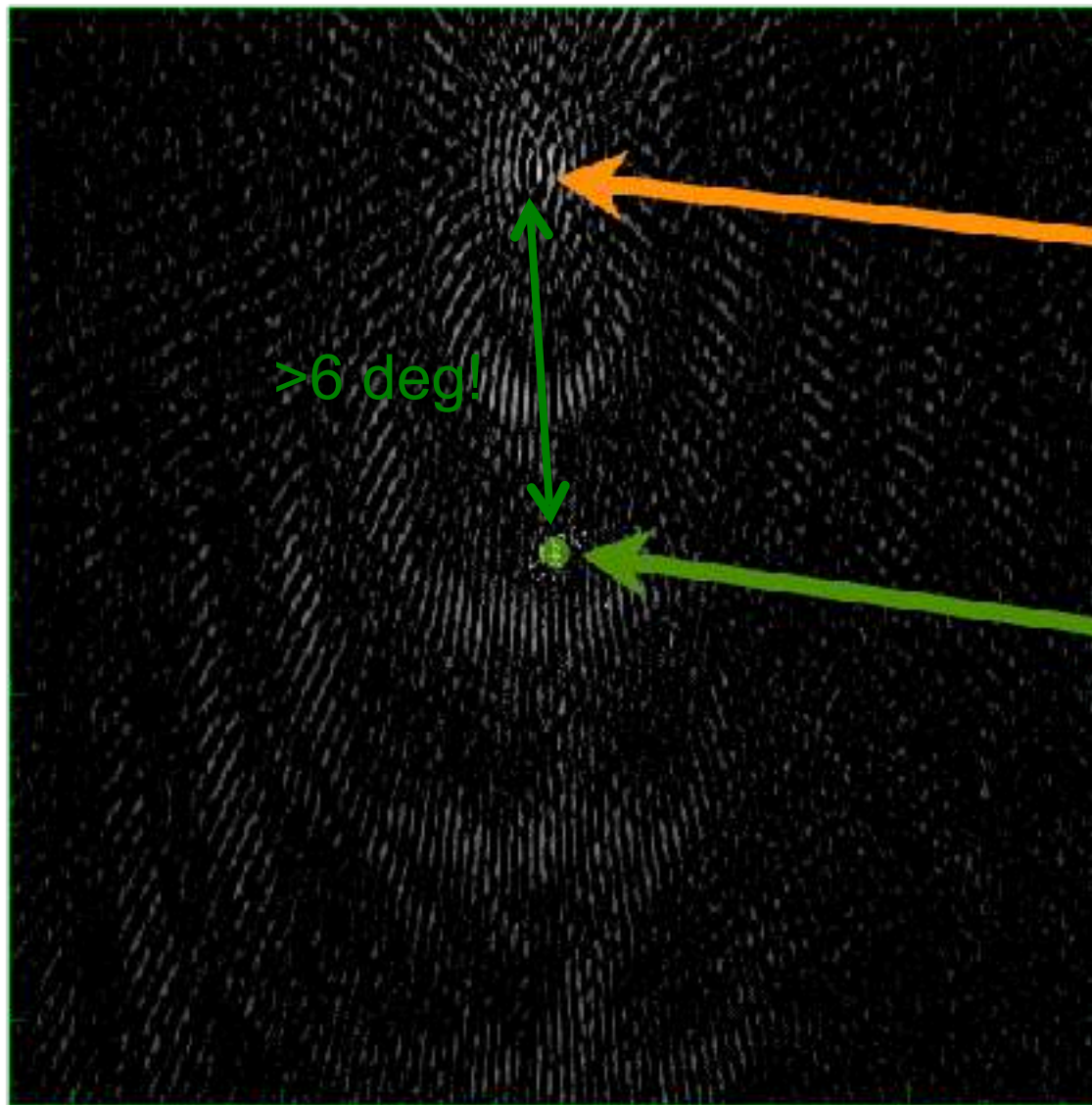


**Primary Beam
FWHM**



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The Bigger Picture



>6 deg!

**The Sun was
“near” the
calibrator during
one of the
observing days.**

**Primary Beam
FWHM**



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The Bigger Picture

Original Data
Dynamic Range 100,000:1





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The Bigger Picture

Original data with one day flagged
Dynamic range 140,000:1

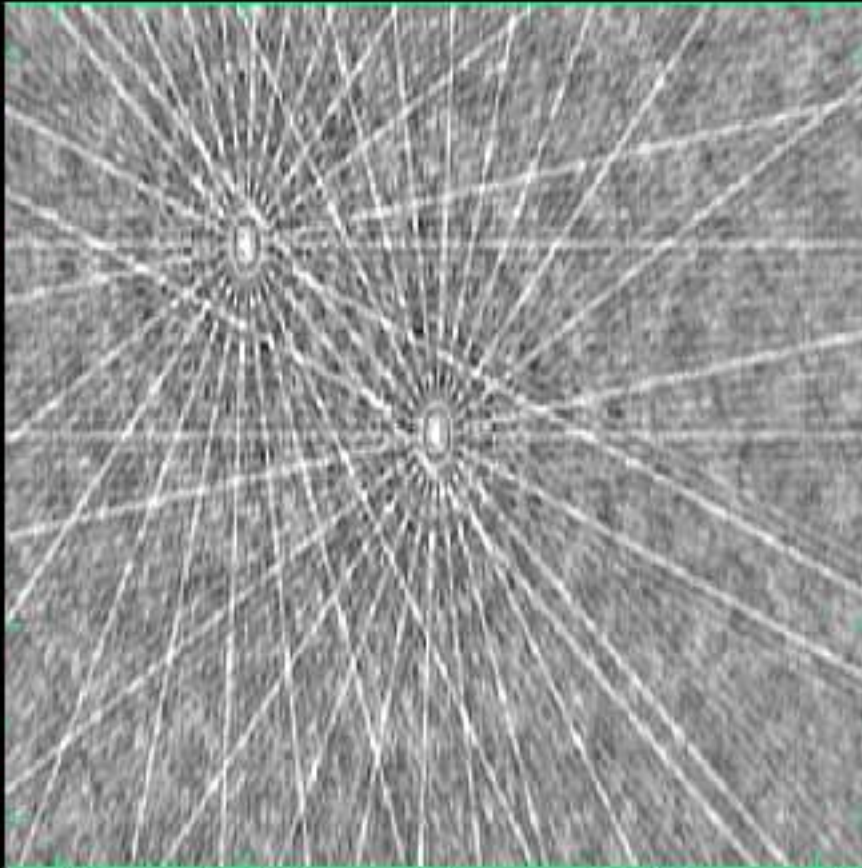




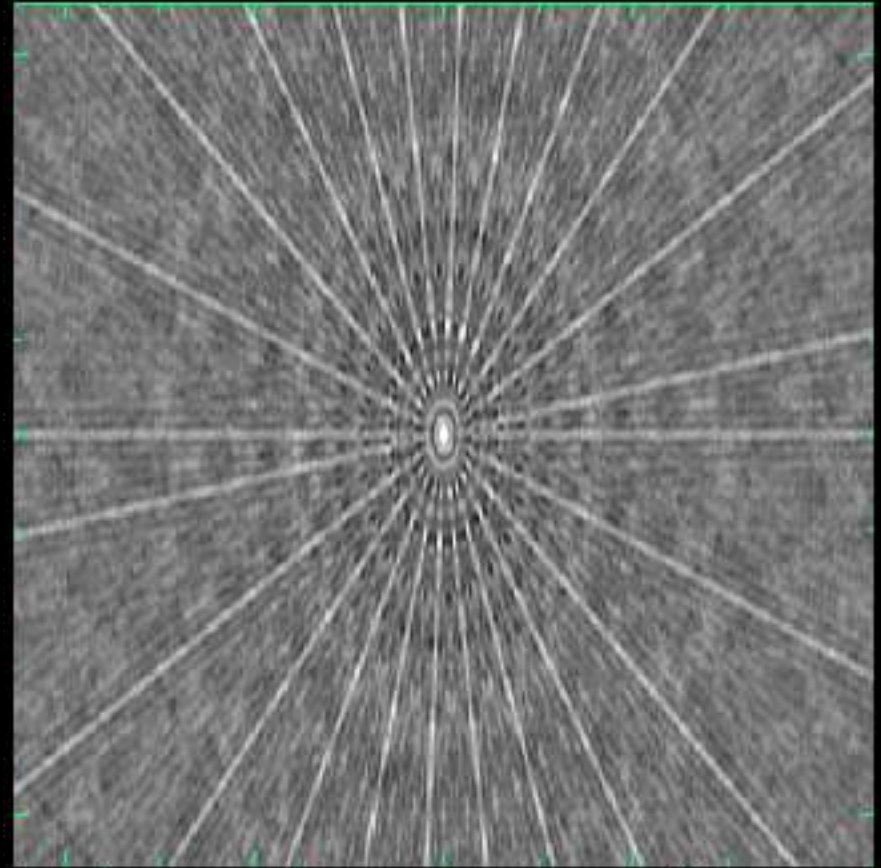
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Multiplicative Errors

Dirty Map



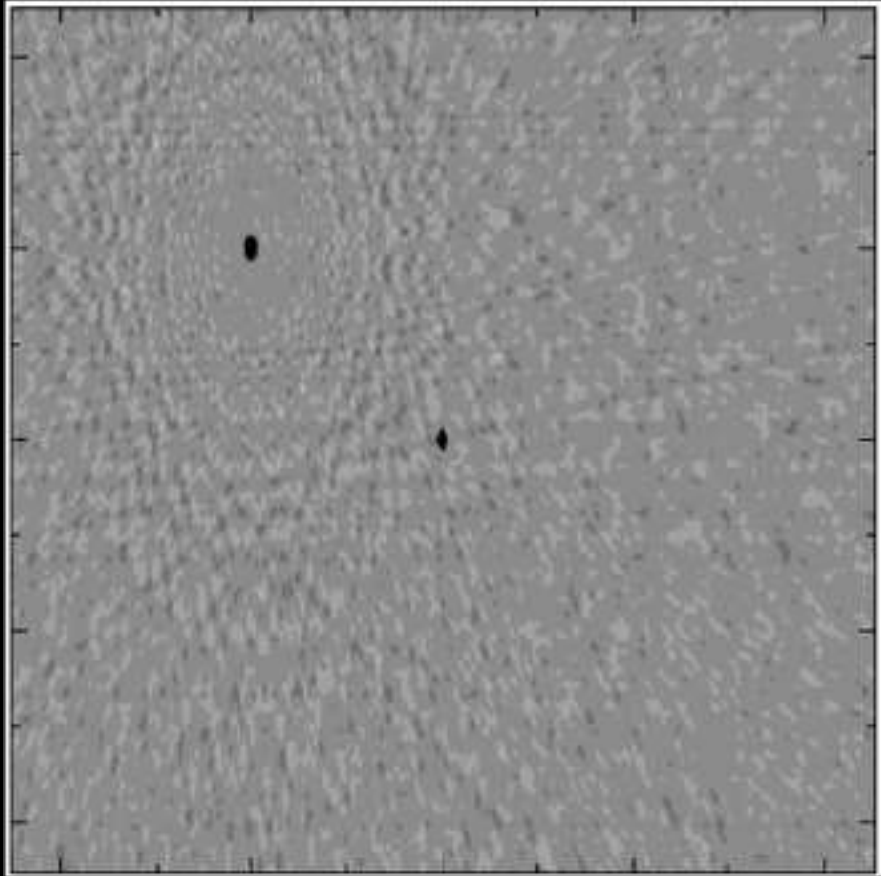
PSF



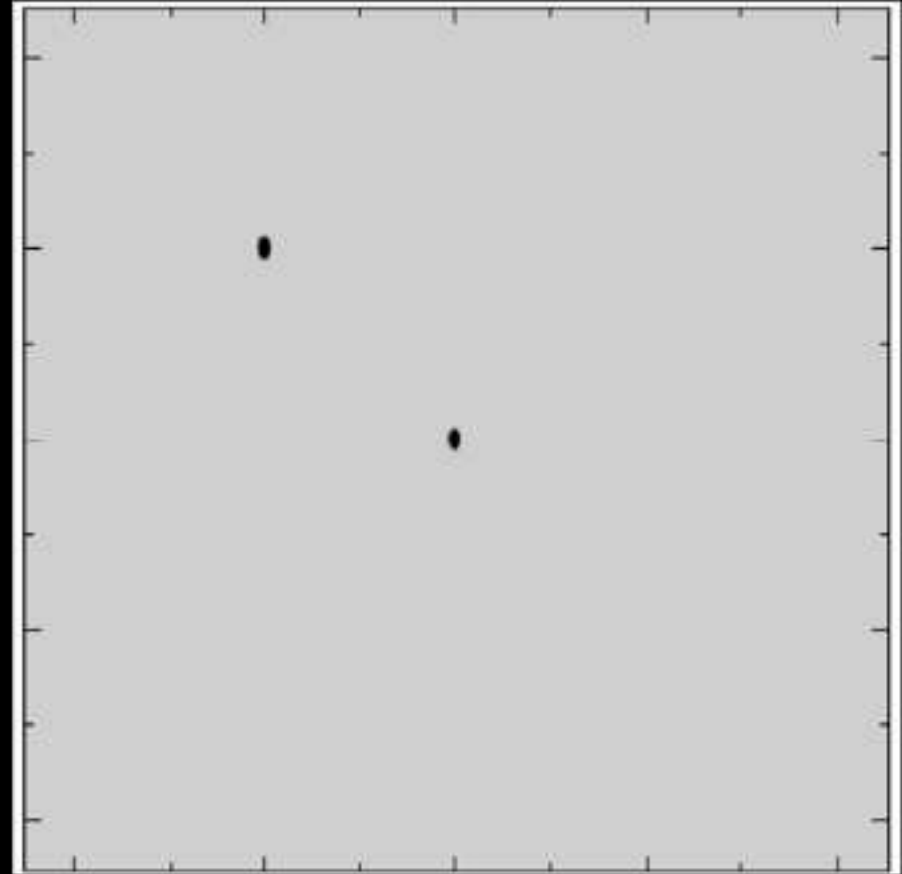
Primary Beam Error

Common in widefield imaging/instruments

Deconvolved

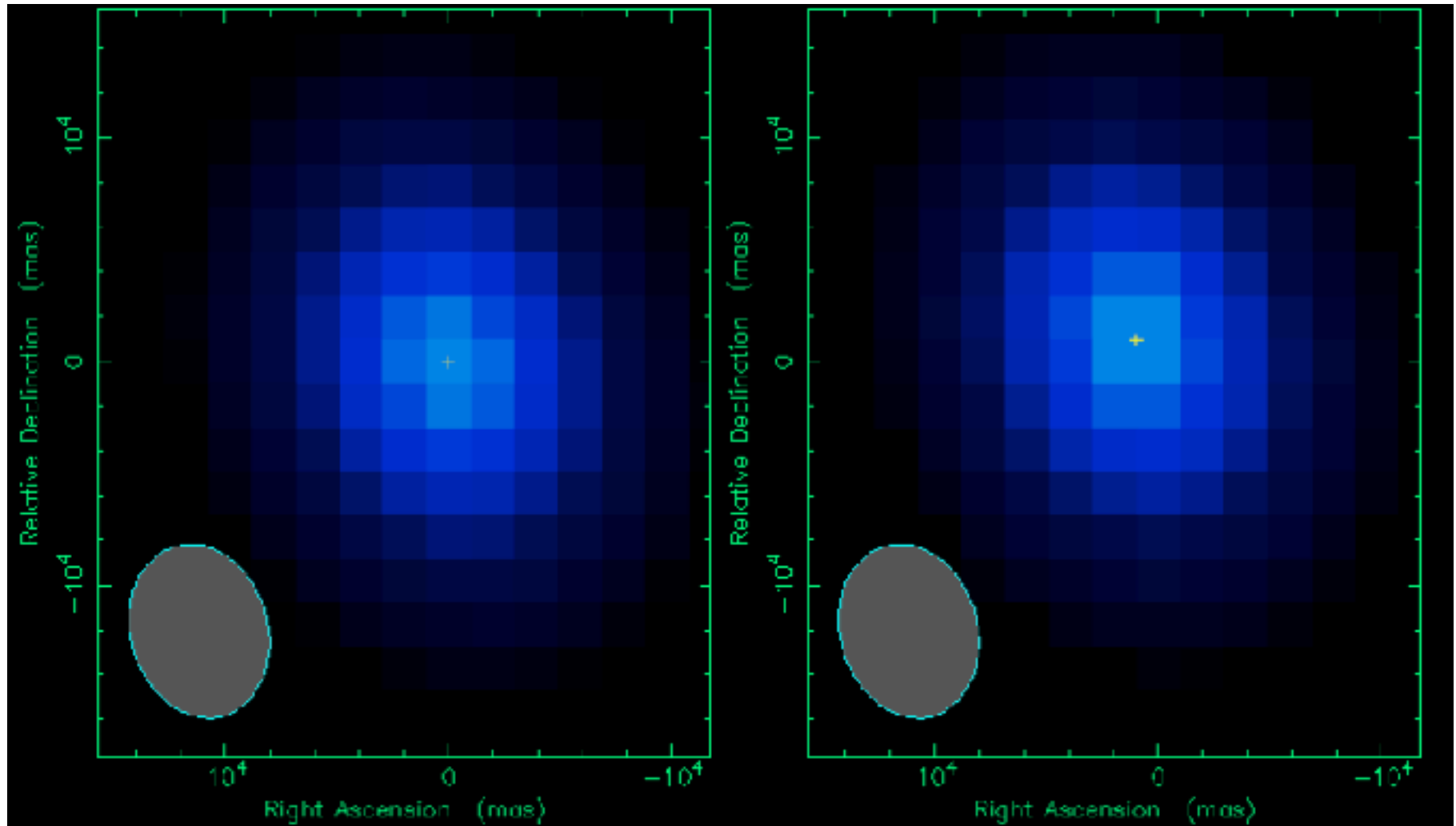


Peeled



Peeling applicable to transient and variable sources too.

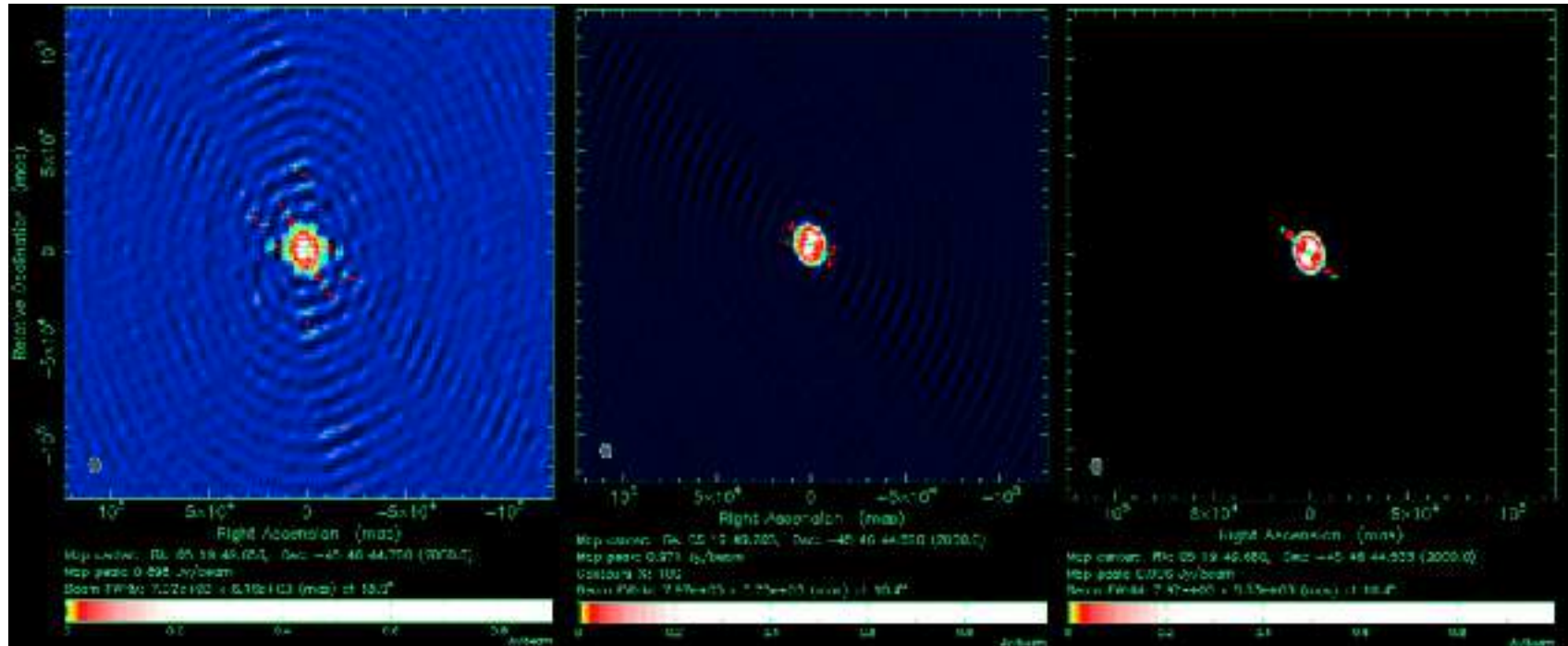
Point Deconvolution Errors



Pixel centred

Pixel not centred

Point Deconvolution Errors



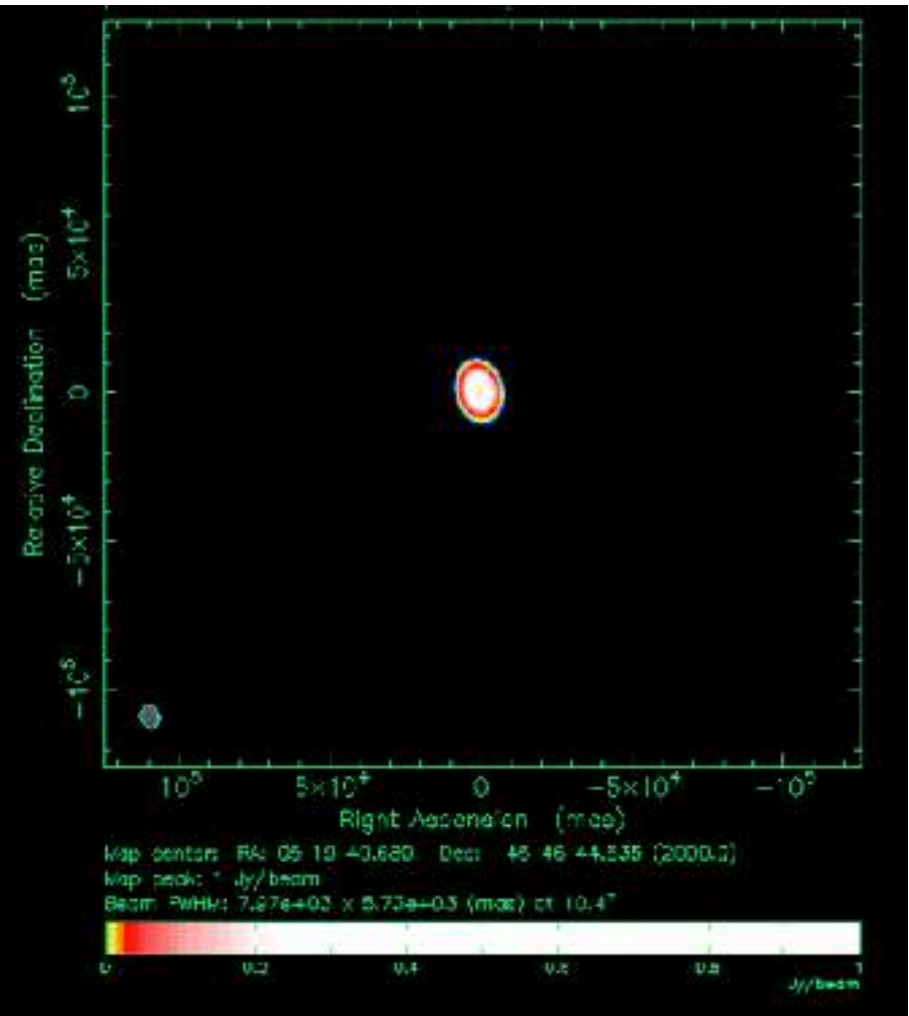
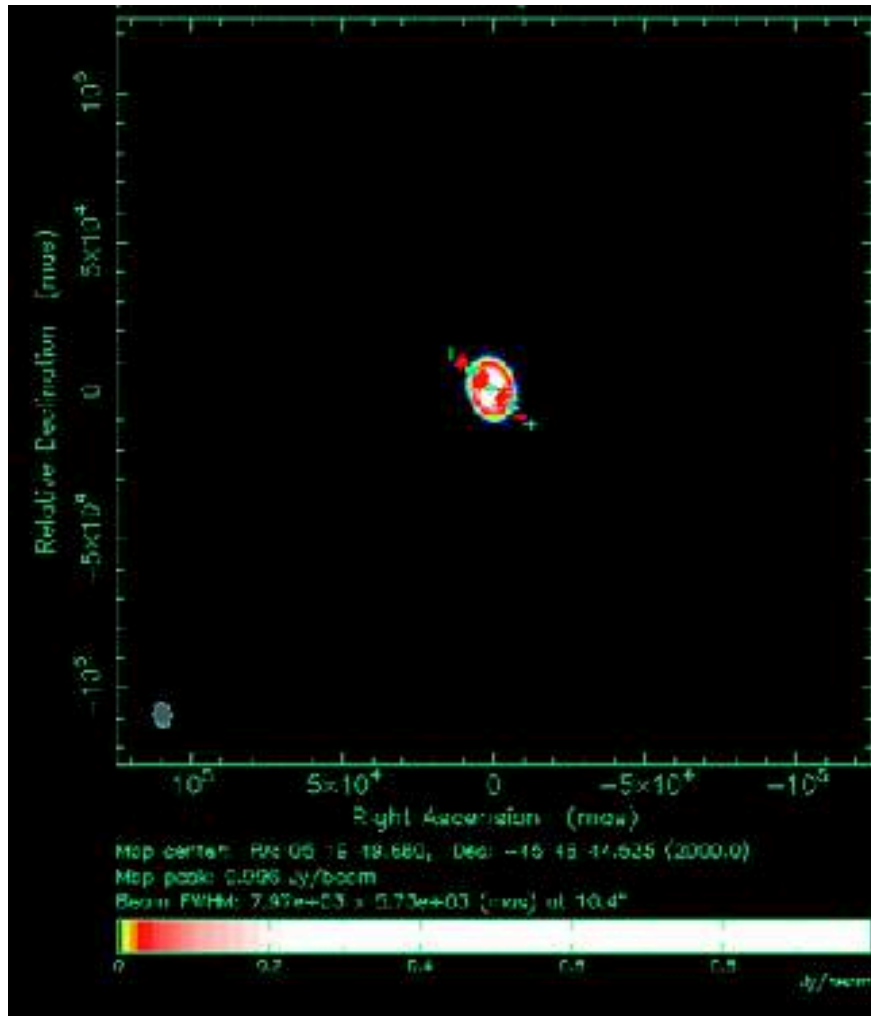
Cell size = beam/3

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.

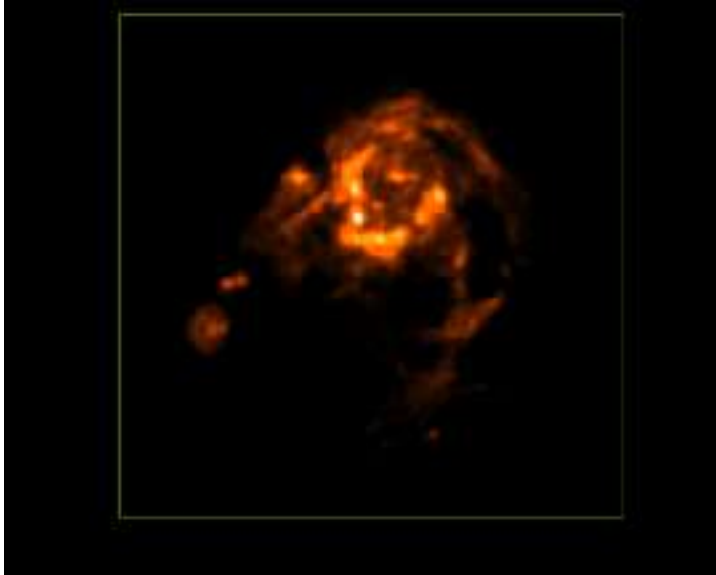
Point Deconvolution Errors



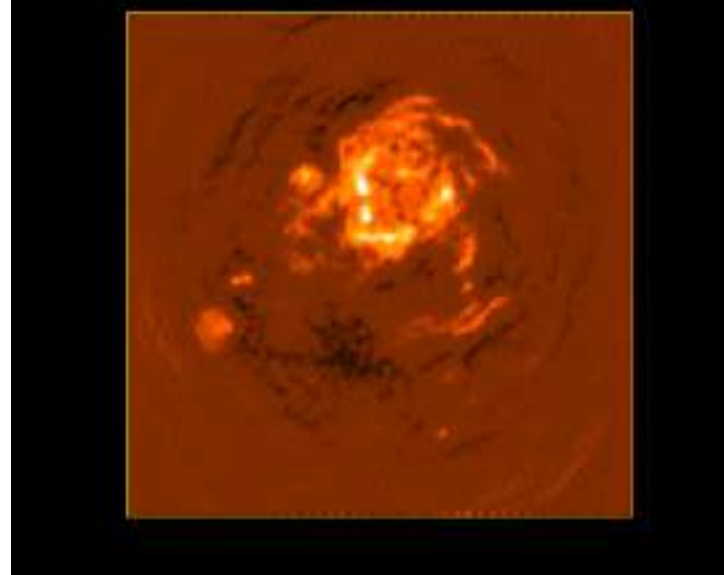
CLEAN : Cell size = beam/12

Single uv-delta model component

Deconvolution Errors (Large-scale Structure)



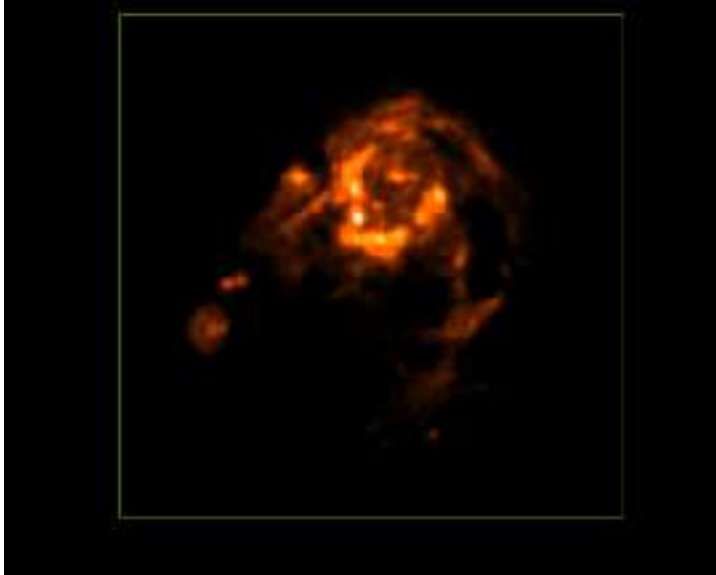
True sky



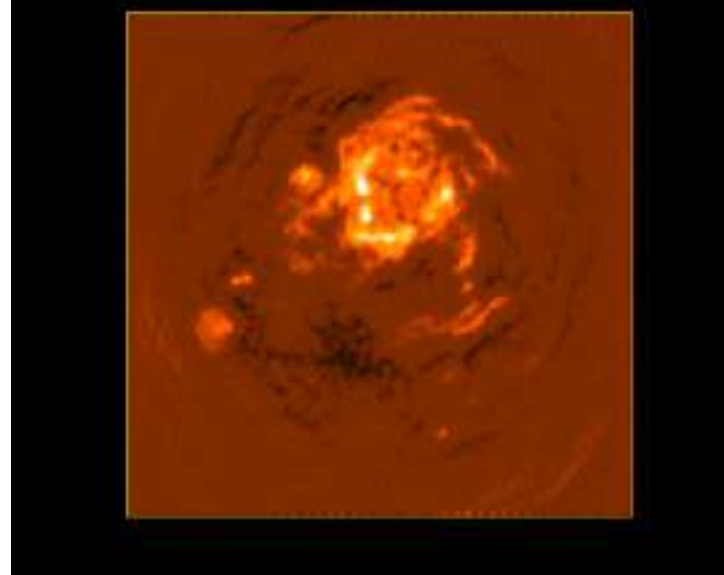
Standard CLEAN

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.

Deconvolution Errors (Large-scale Structure)



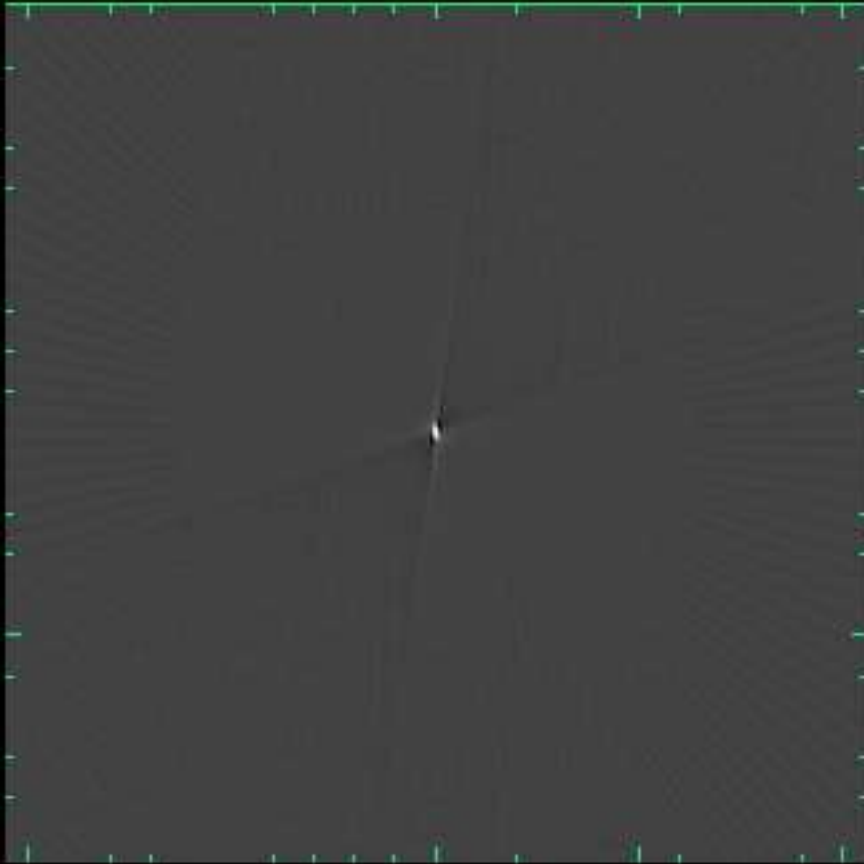
True sky



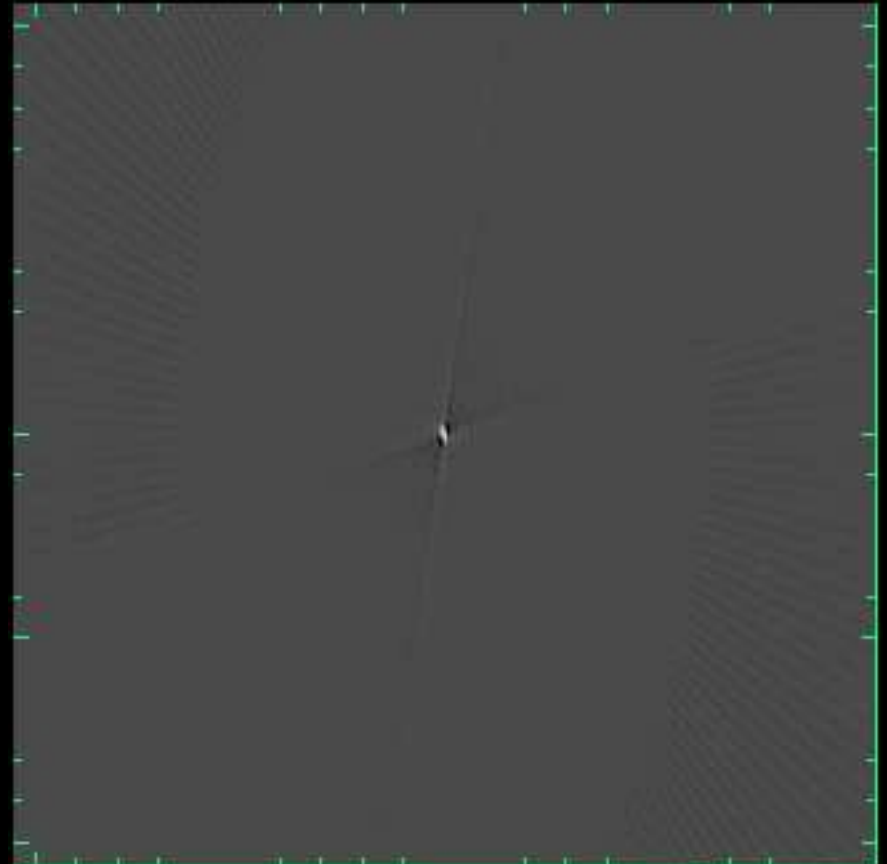
Standard CLEAN

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.

Dirty Image (2.1 GHz CABB Obs)



PSF

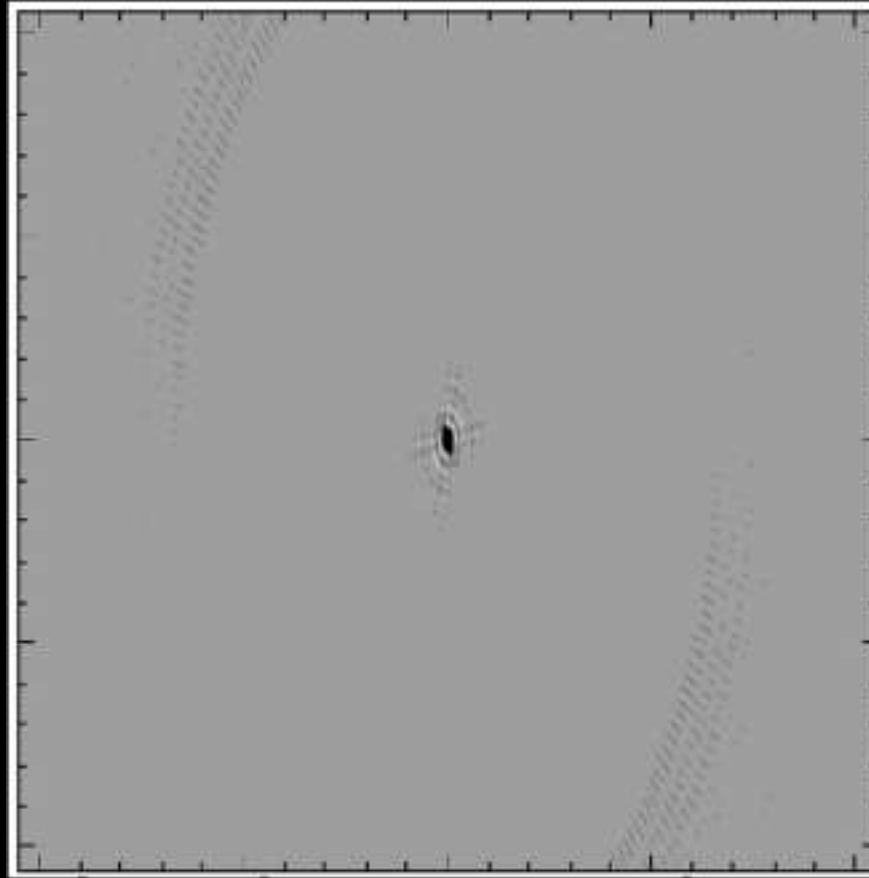




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Wideband Deconvolution Errors

Deconvolved Image

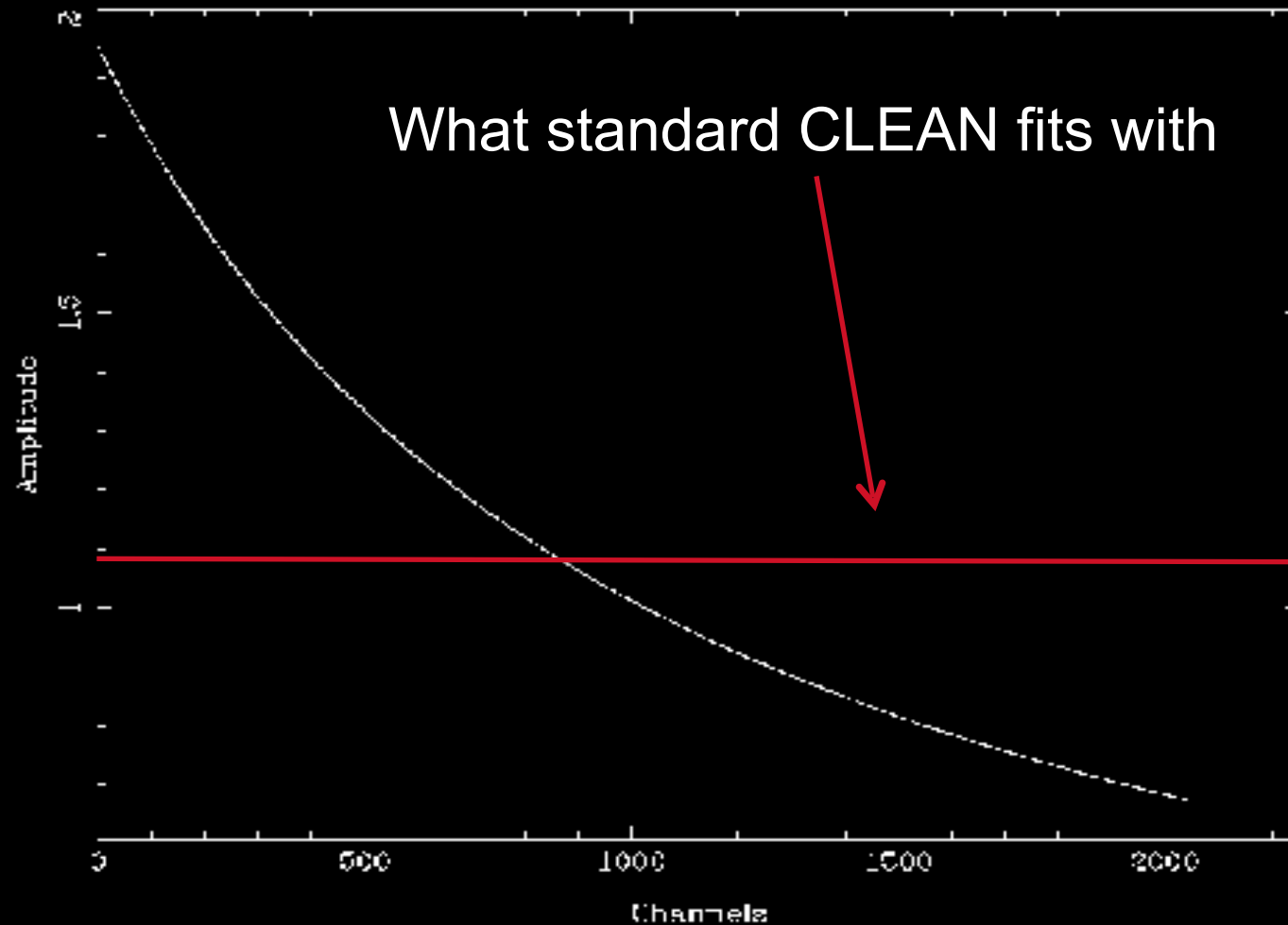


Standard CLEAN



Wideband Deconvolution Errors

Source SED

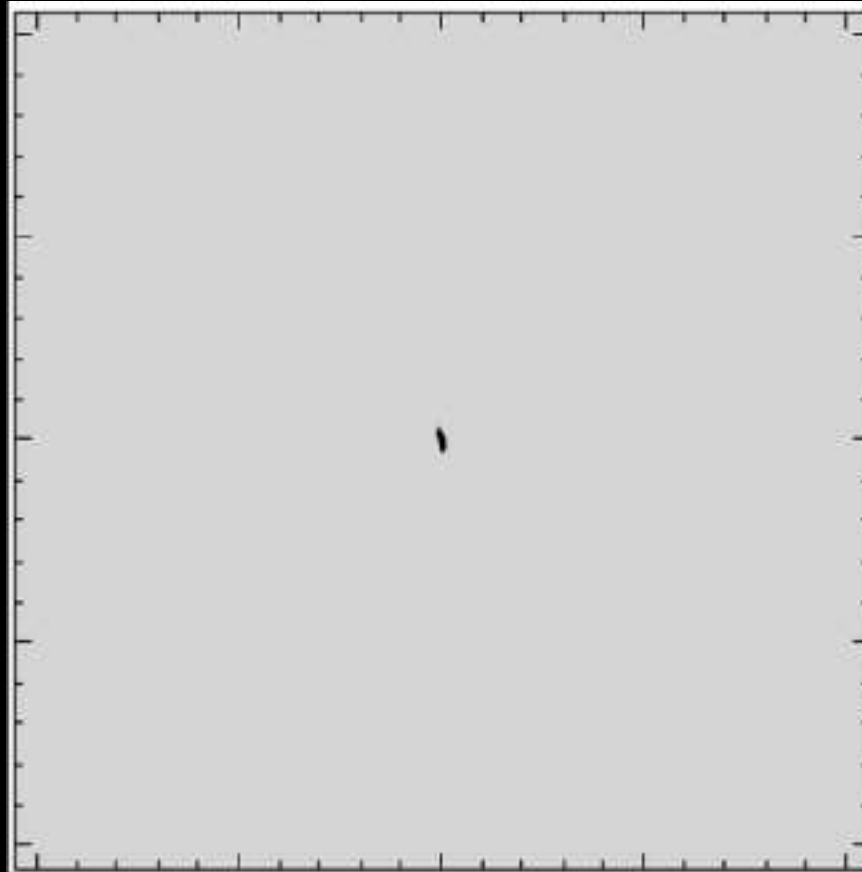




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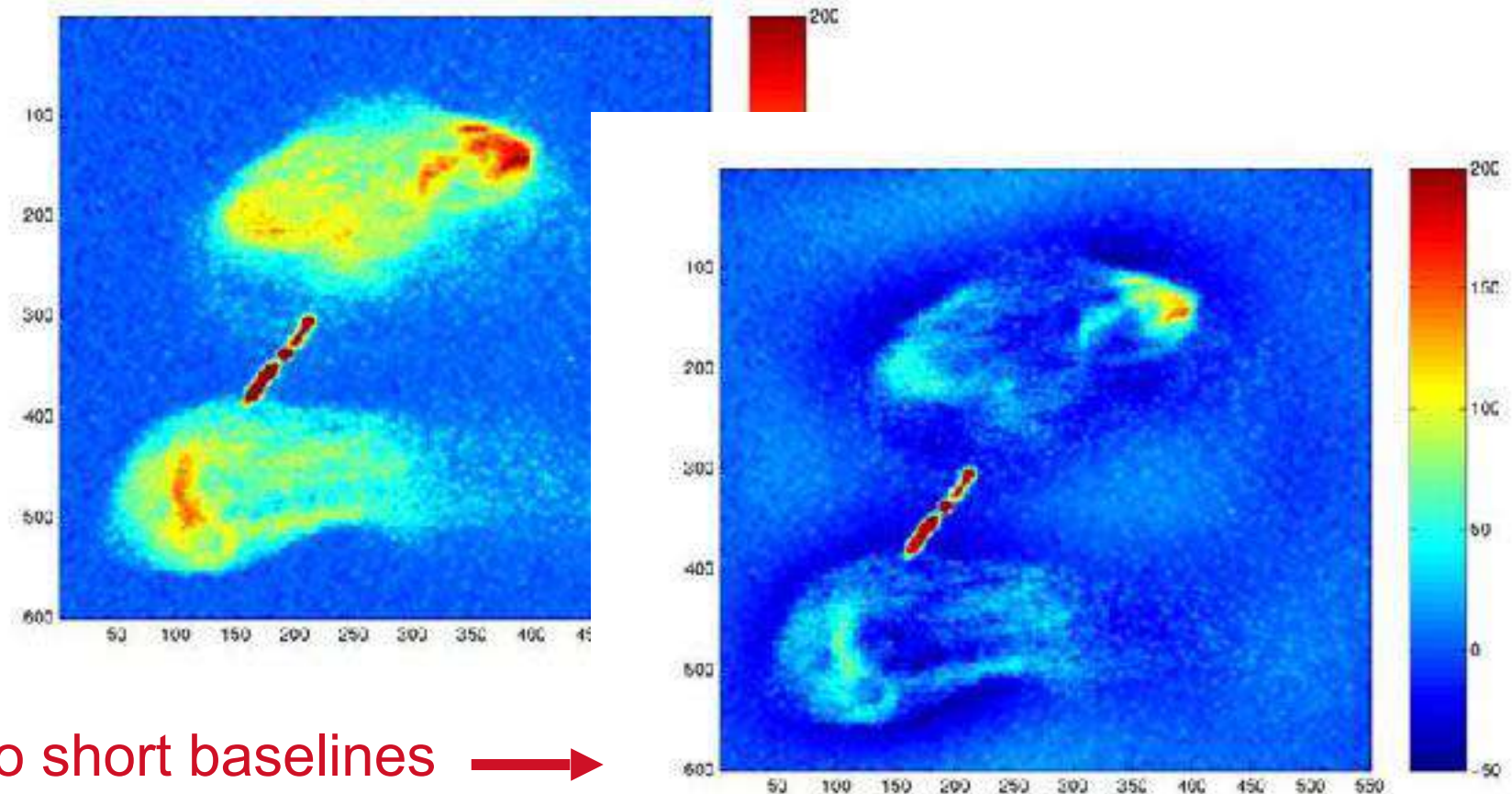
Wideband Deconvolution Errors

Deconvolved Image



Multi-frequency CLEAN

Missing short baselines

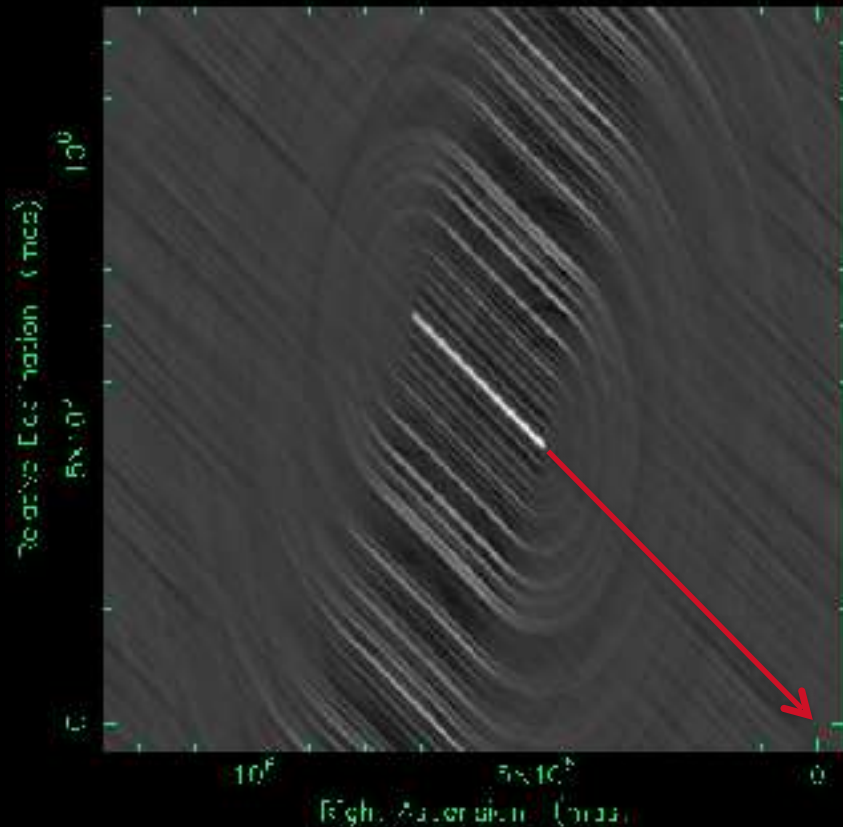


No short baselines →

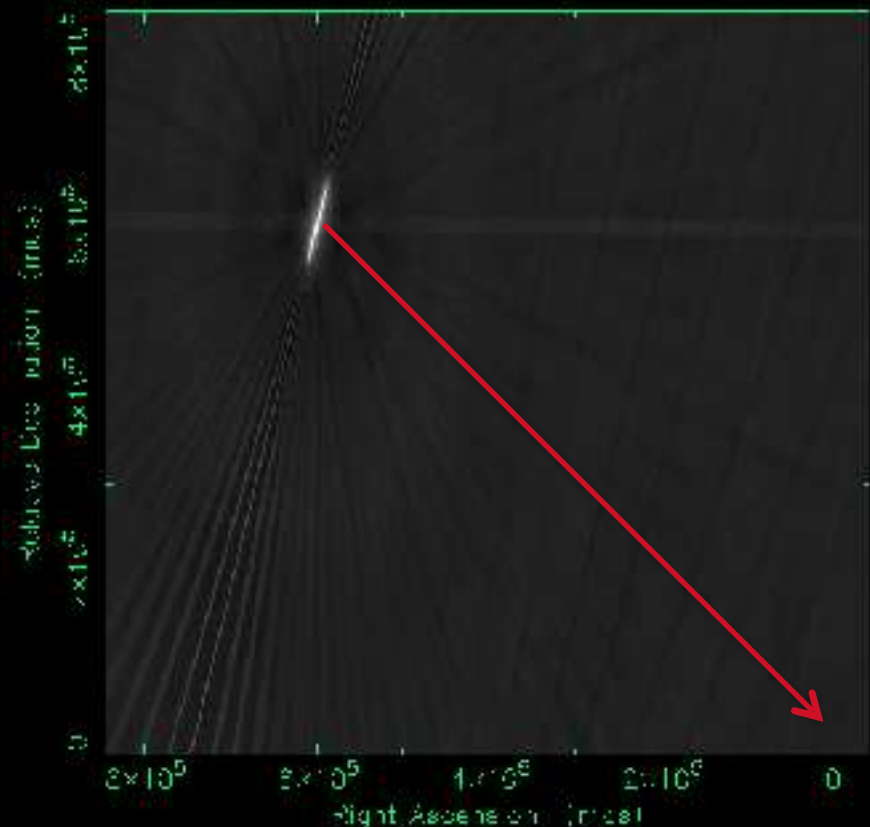
Can only be fixed with additional data.
See Shari's talk on observing strategies.

Paul Rayner 2001

Smearing Errors



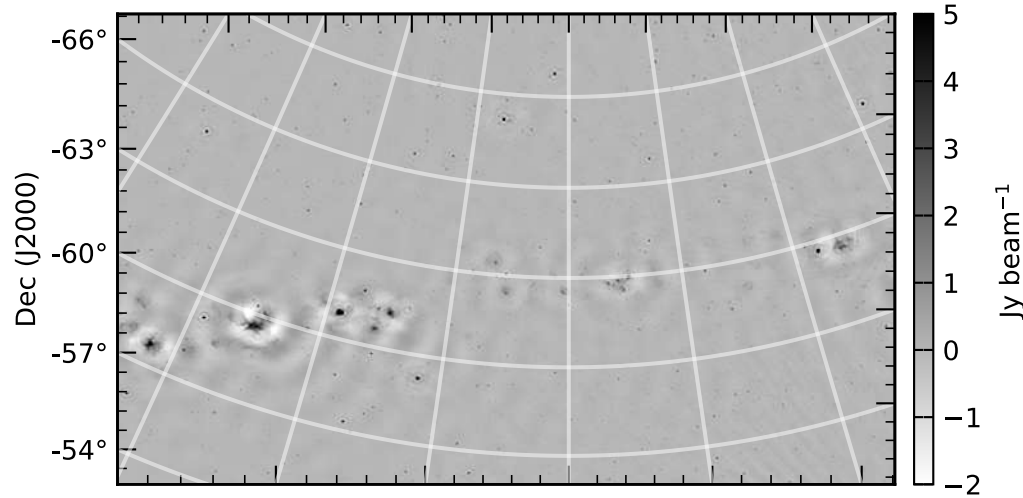
Bandwidth average
smearing
Average 512x1MHz band



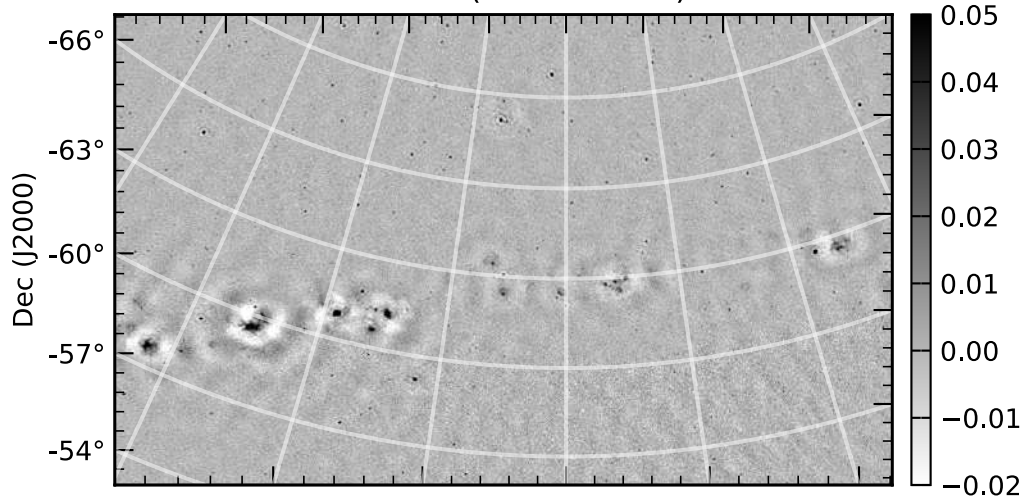
Time-average smearing
Averaging 1000s

Reality check

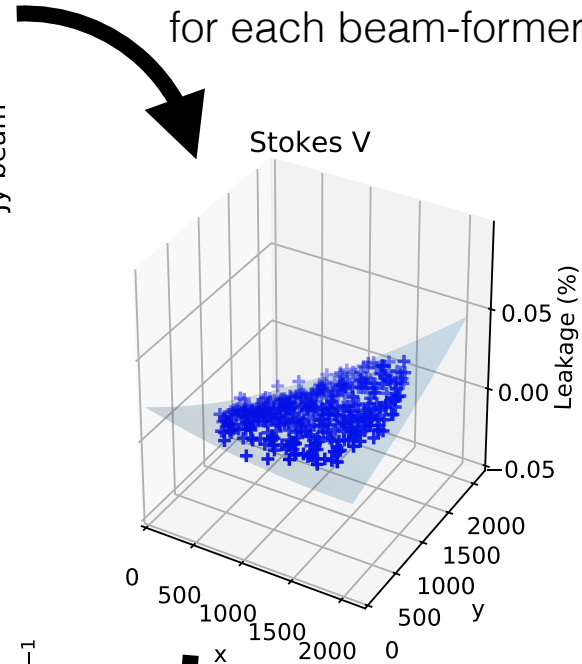
Stokes I



Stokes V (uncorrected)



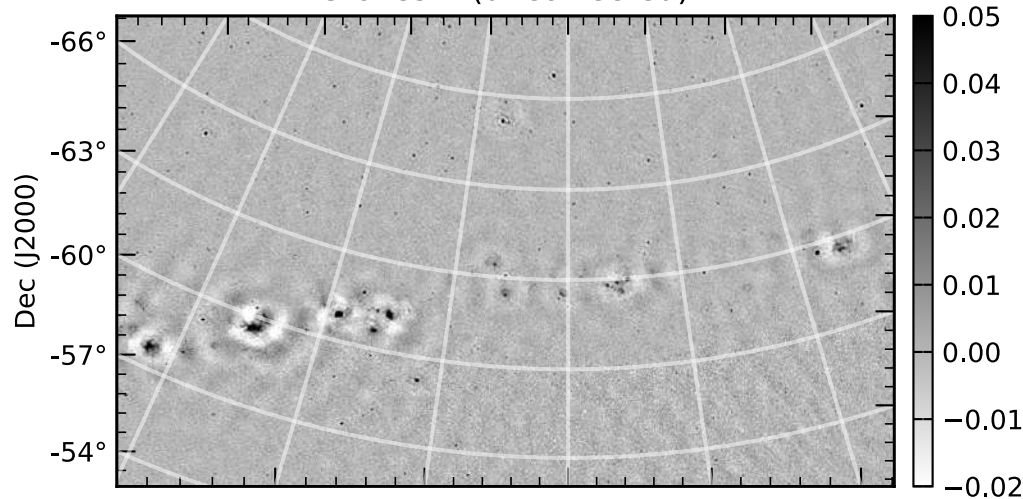
Model Stokes I to Stokes V leakage
for each beam-former setting



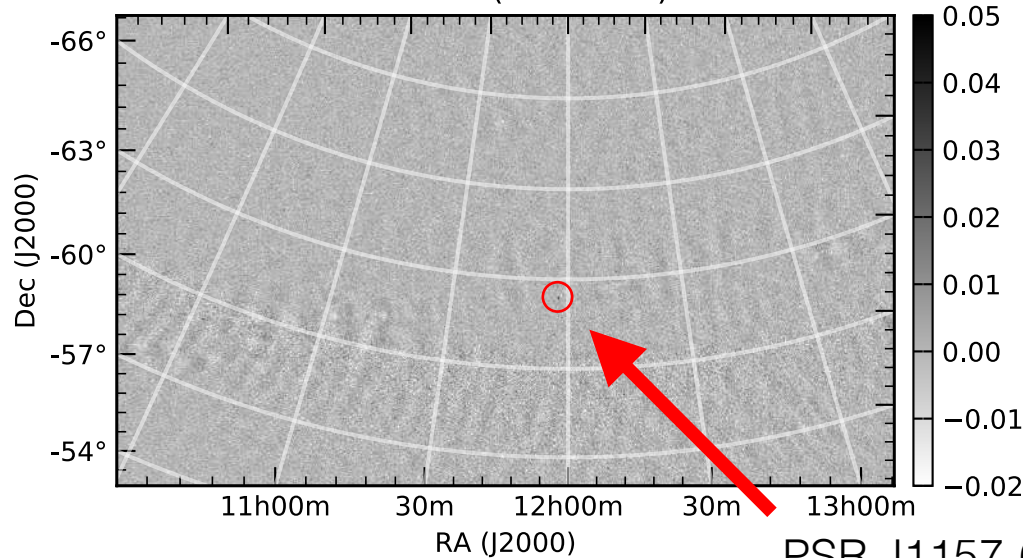
Subtract modelled component of
leakage from Stokes V.

Reality check

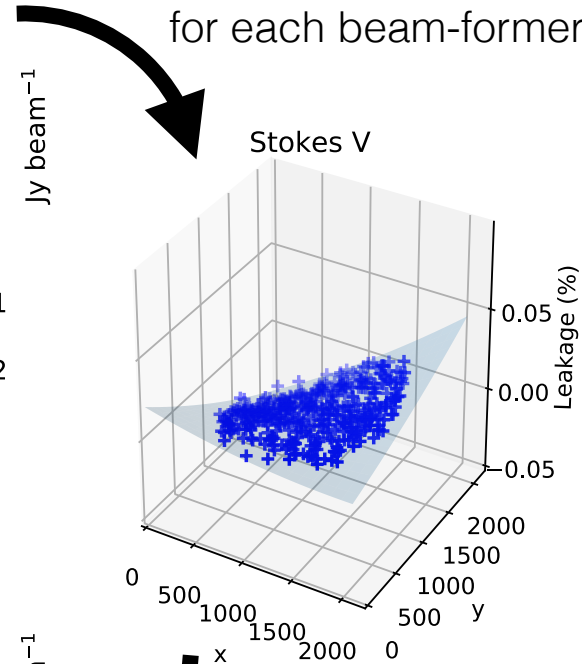
Stokes V (uncorrected)



Stokes V (corrected)



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



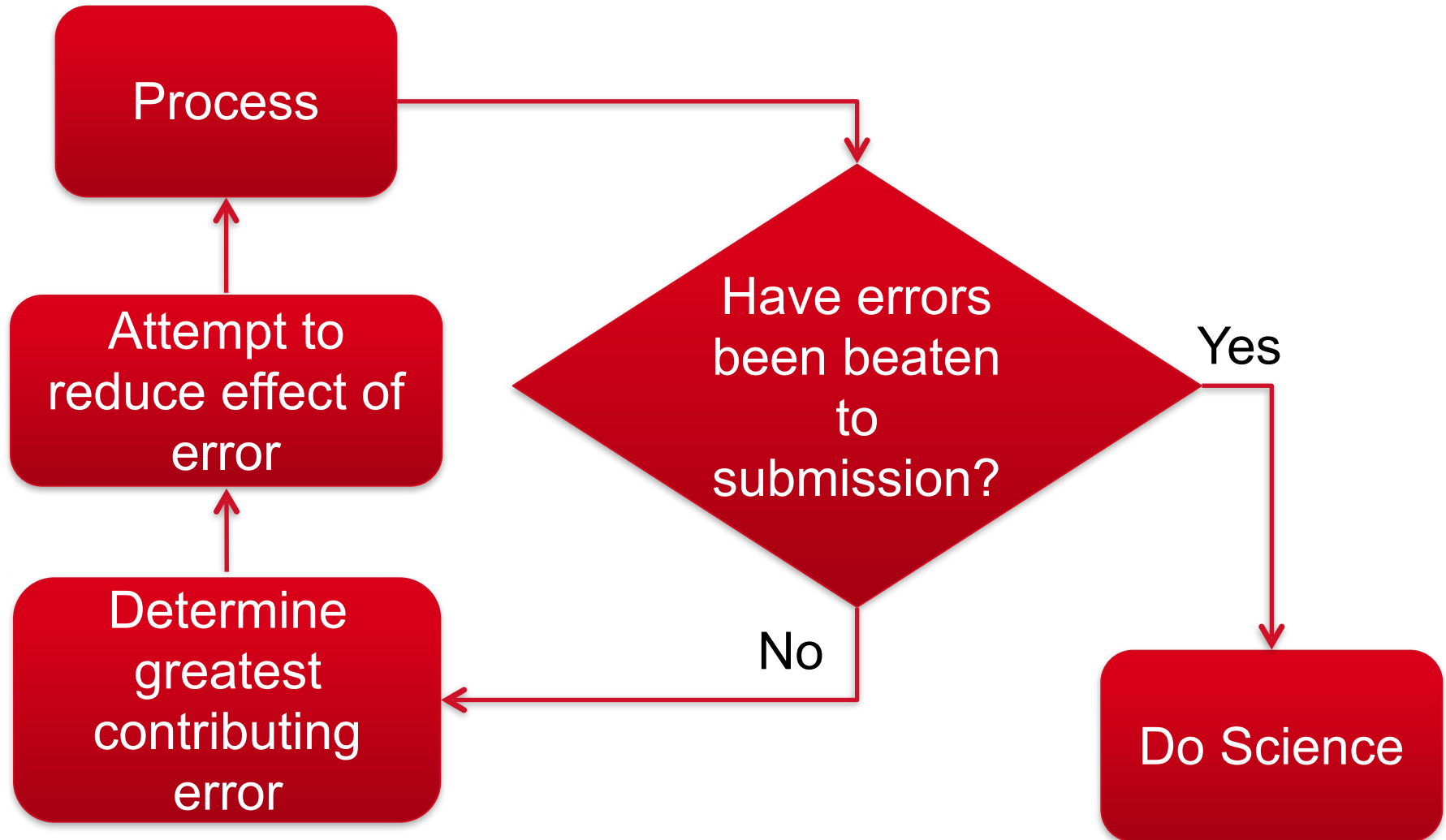
Subtract modelled component of
leakage from Stokes V.

PSR J1157-6224

- › 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.

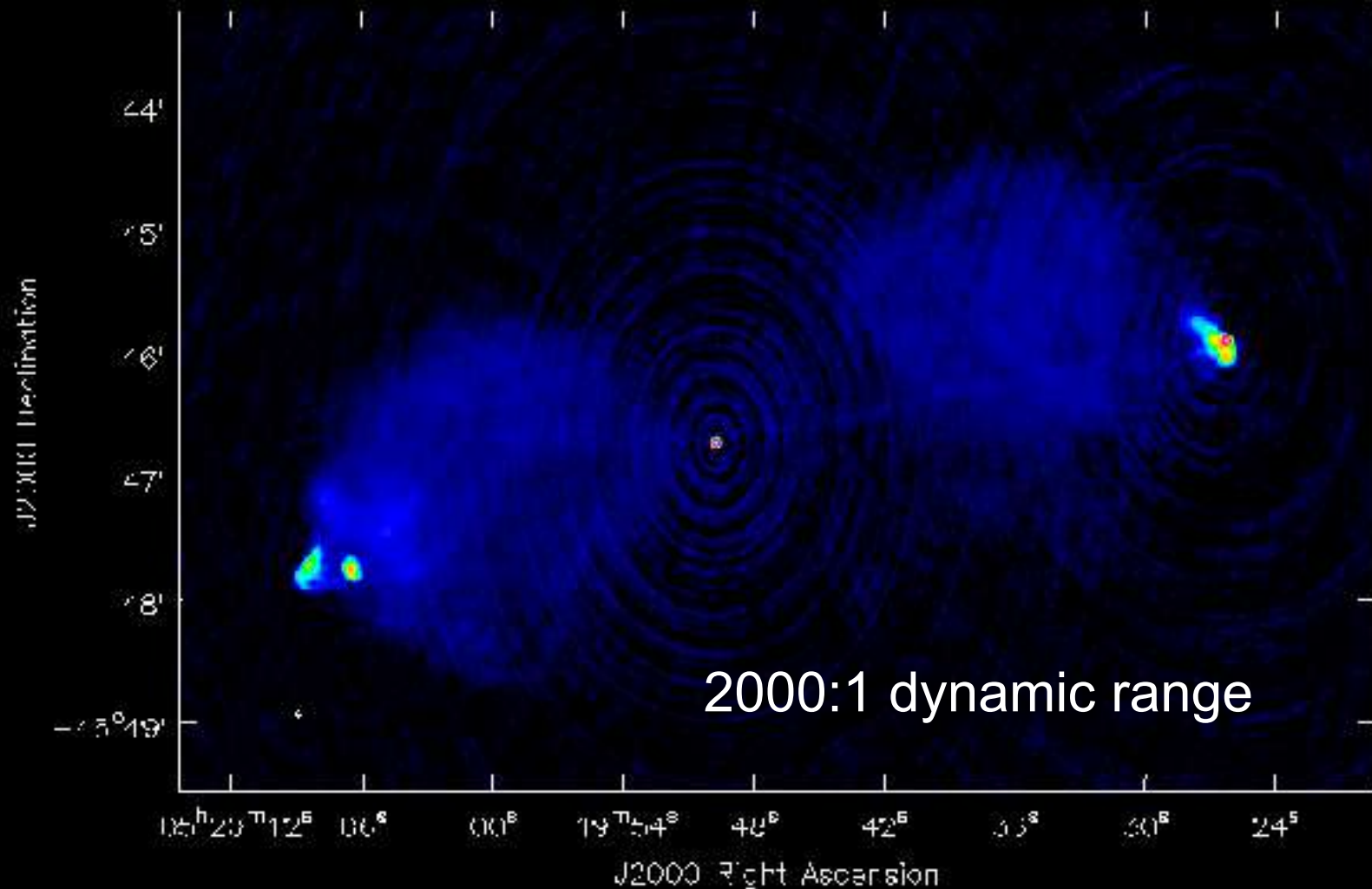


Error reduction ...



What's happening?

5.5 GHz observation, 3 configurations, 2 GHz bandwidth



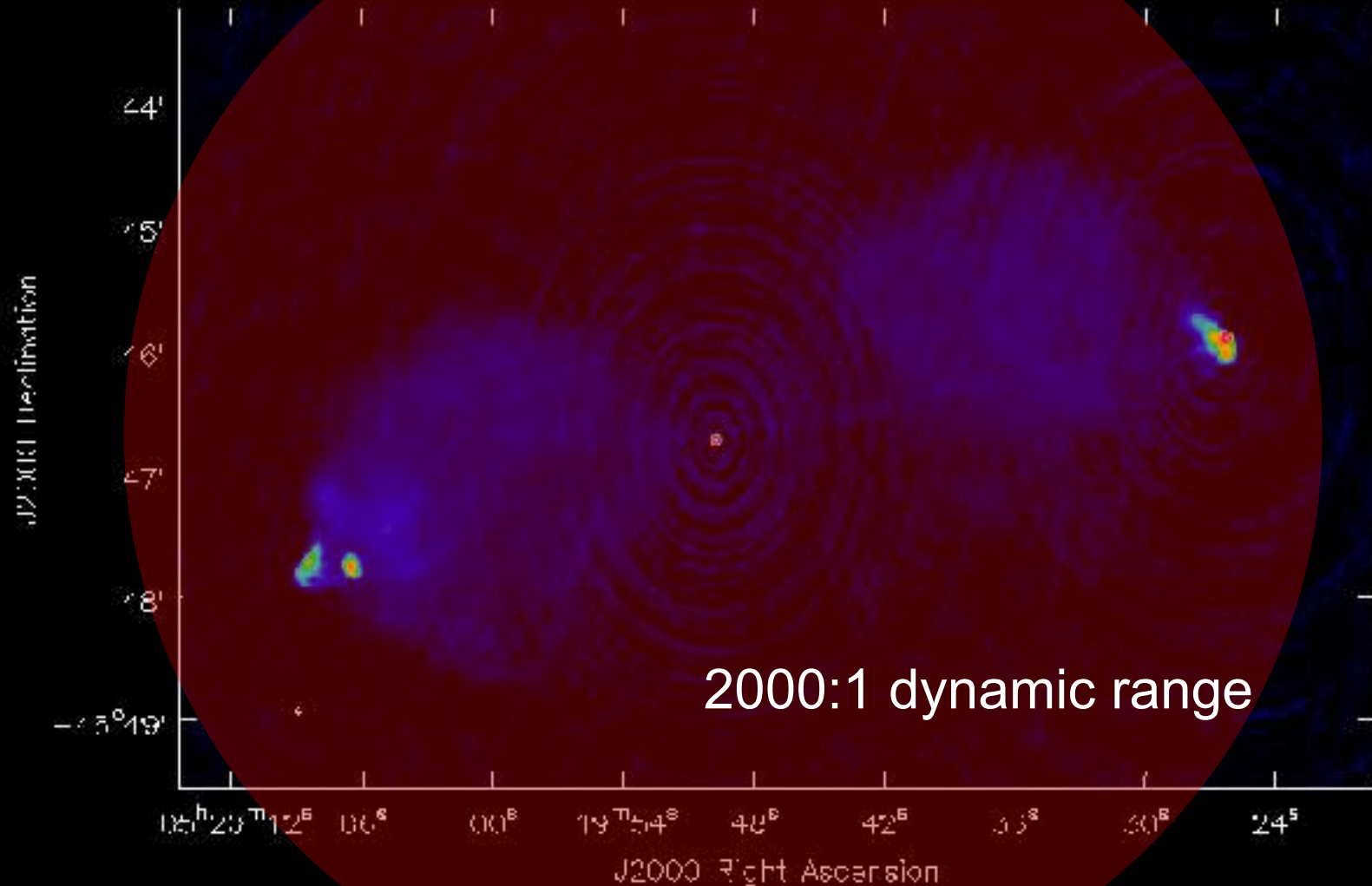


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What's happening?



5.5 GHz observation, 3 configurations, 2 GHz bandwidth



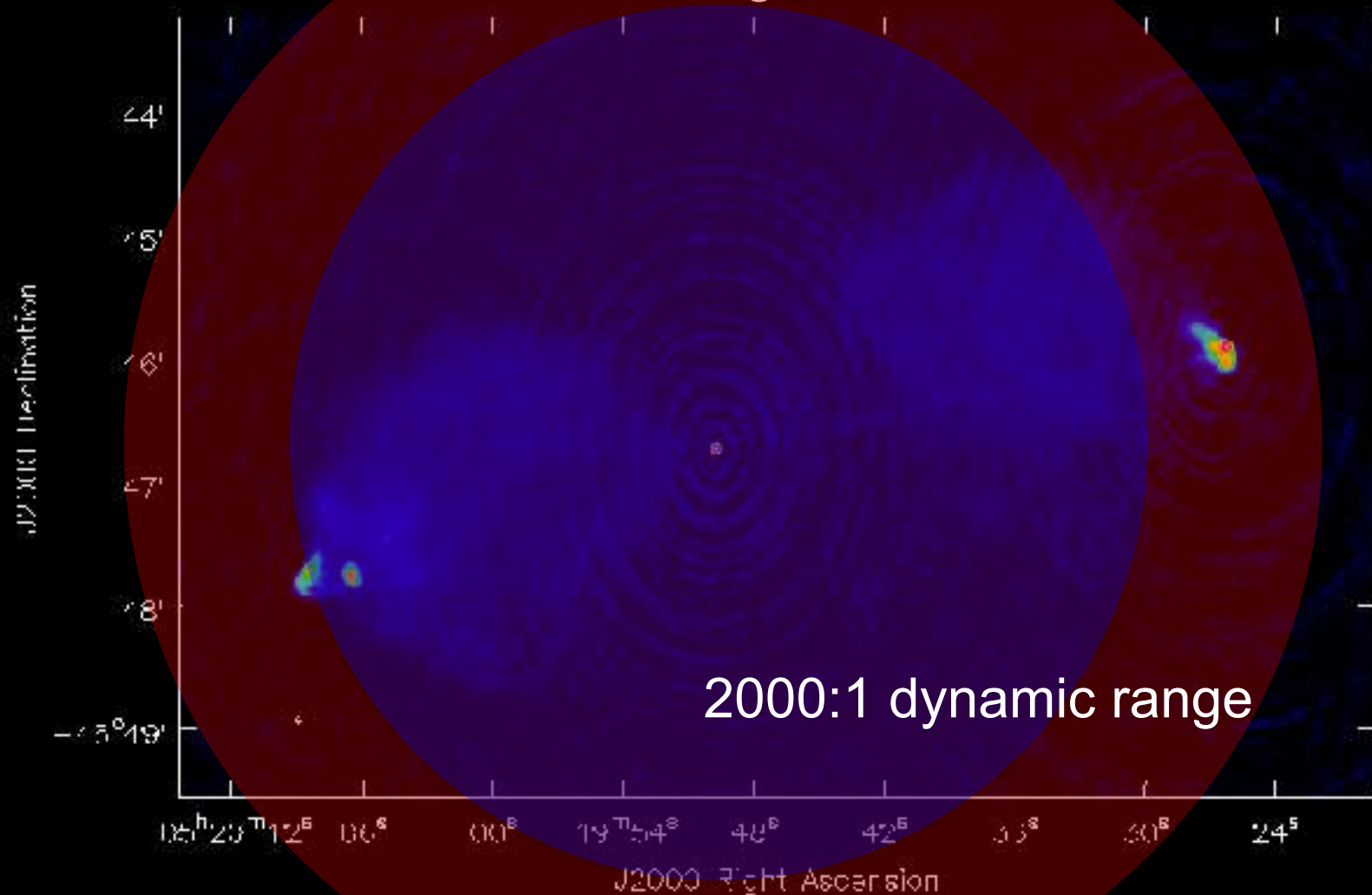


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What's happening?

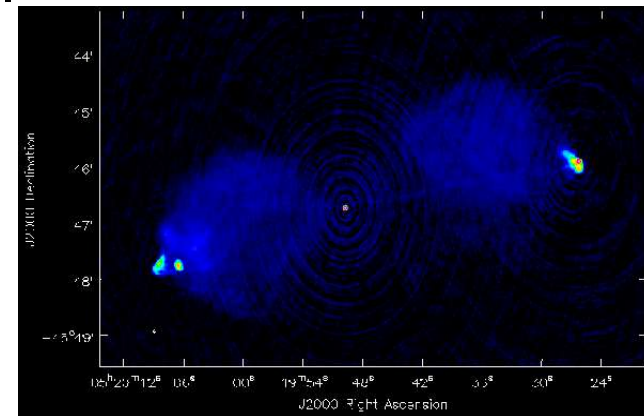


5.5 GHz observation, 3 configurations, 2 GHz bandwidth



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.



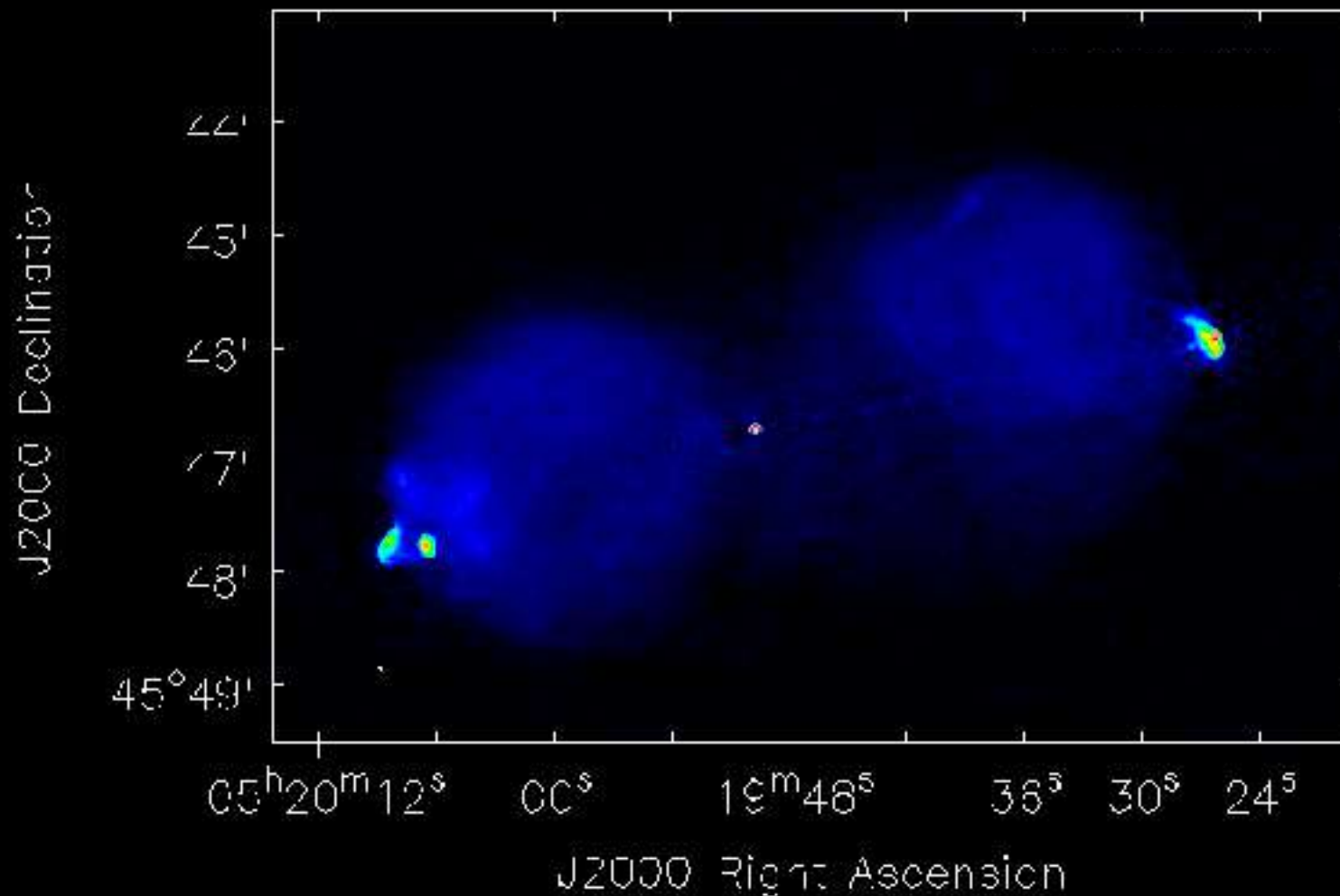


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What's happening?



38,000:1 dynamic range



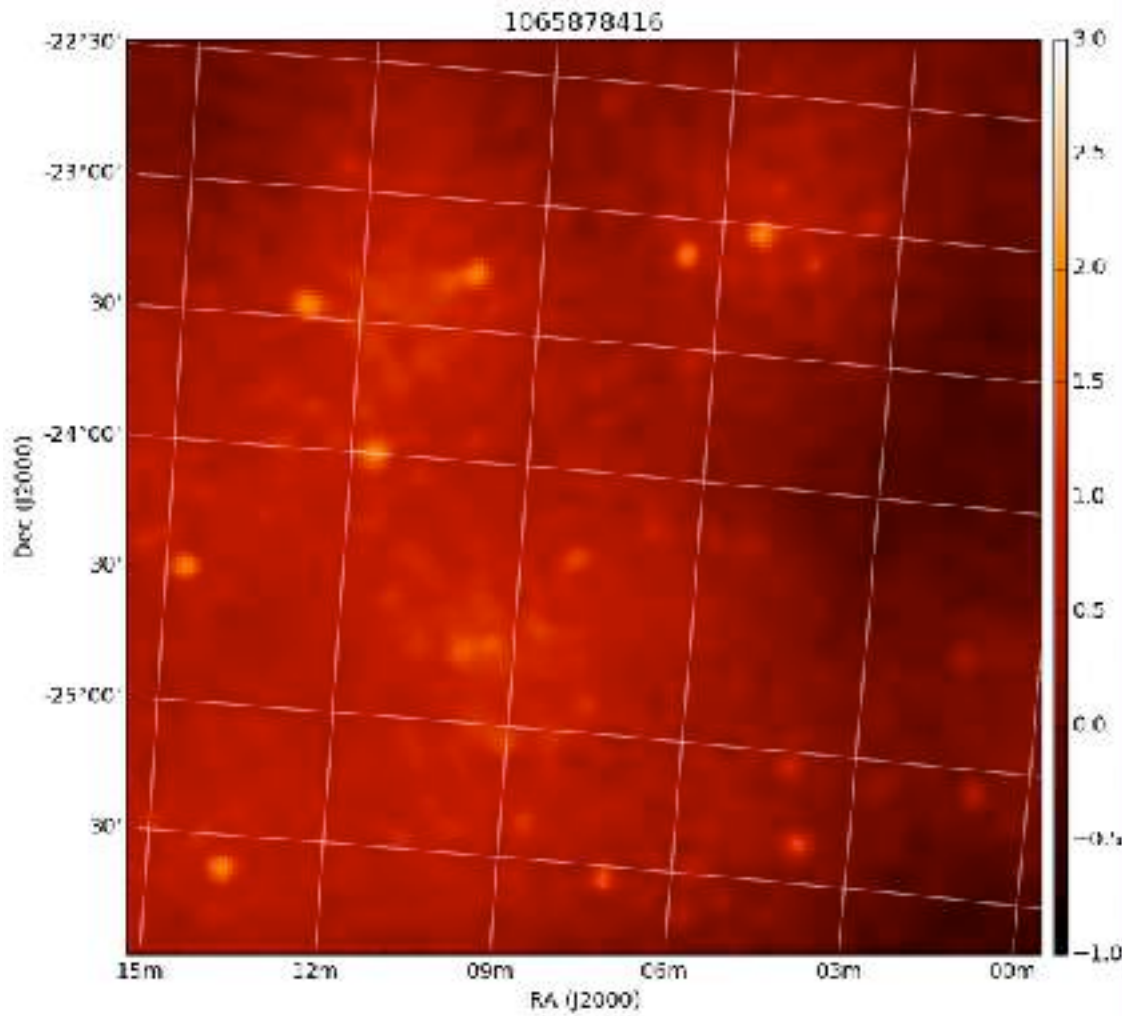


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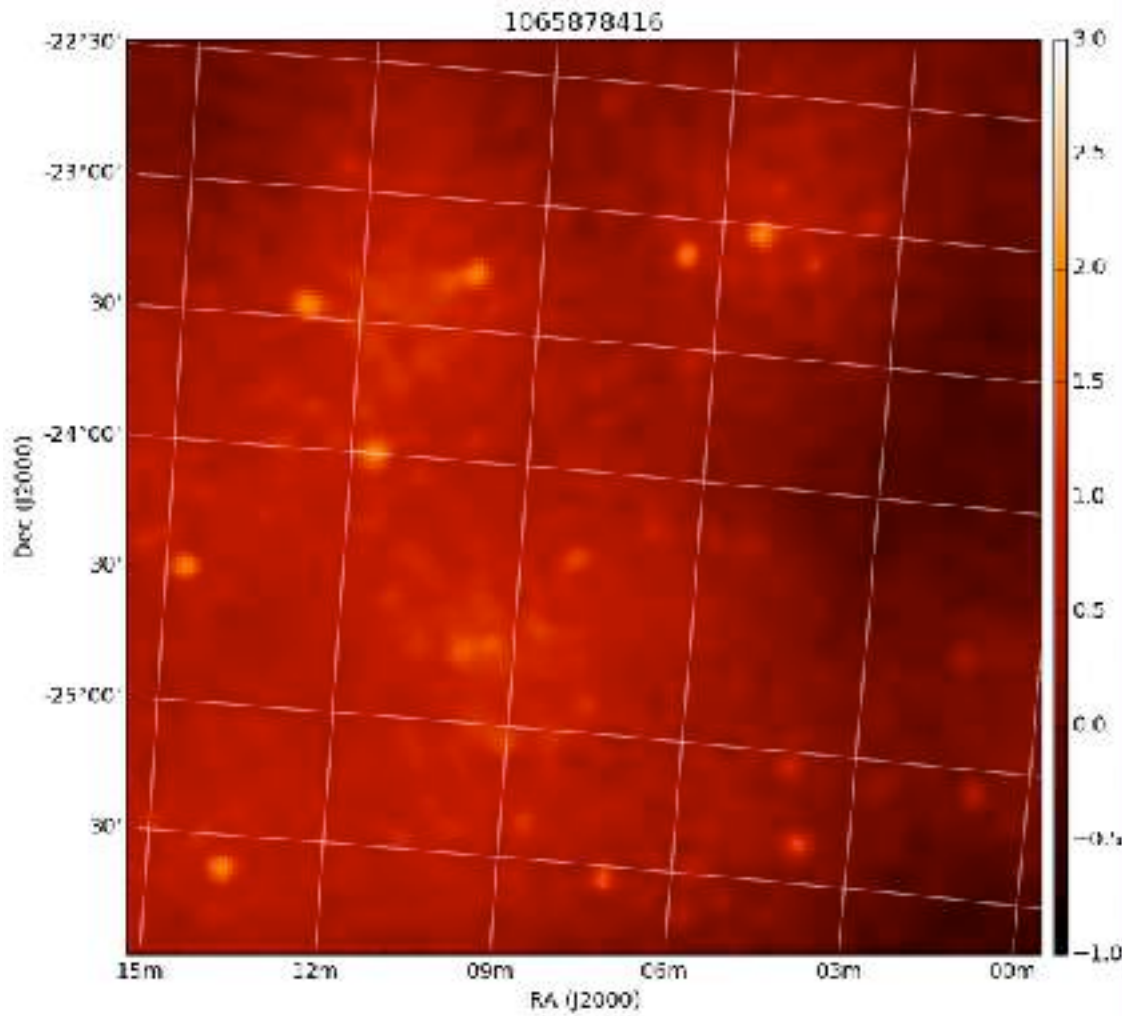
1. Can you deal with something new? What's happening?



Low frequency MWA obs.

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

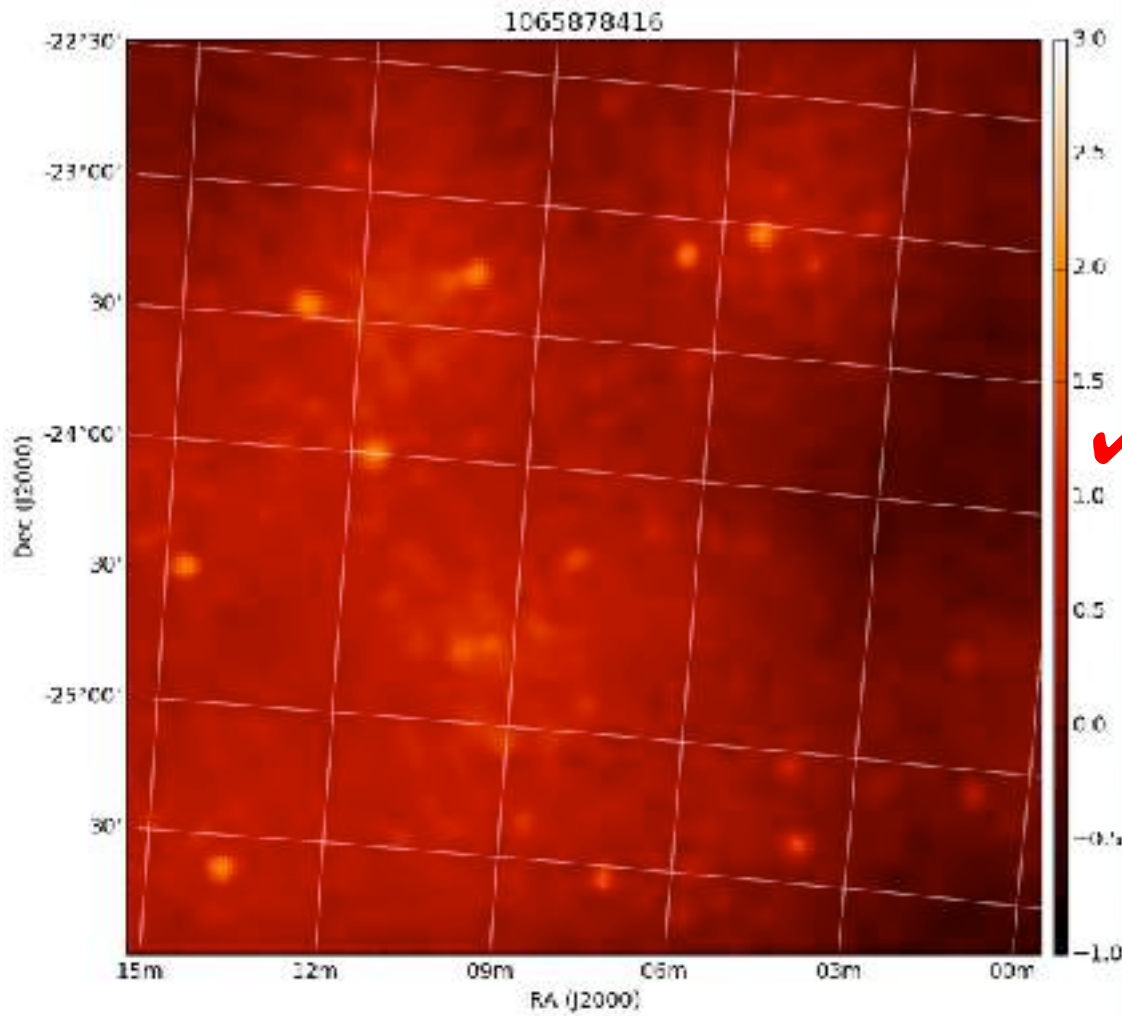
1. Can you deal with something new? What's happening?



Low frequency MWA obs.

- A. Heat haze
- B. Antenna deformation
- C. Ionosphere
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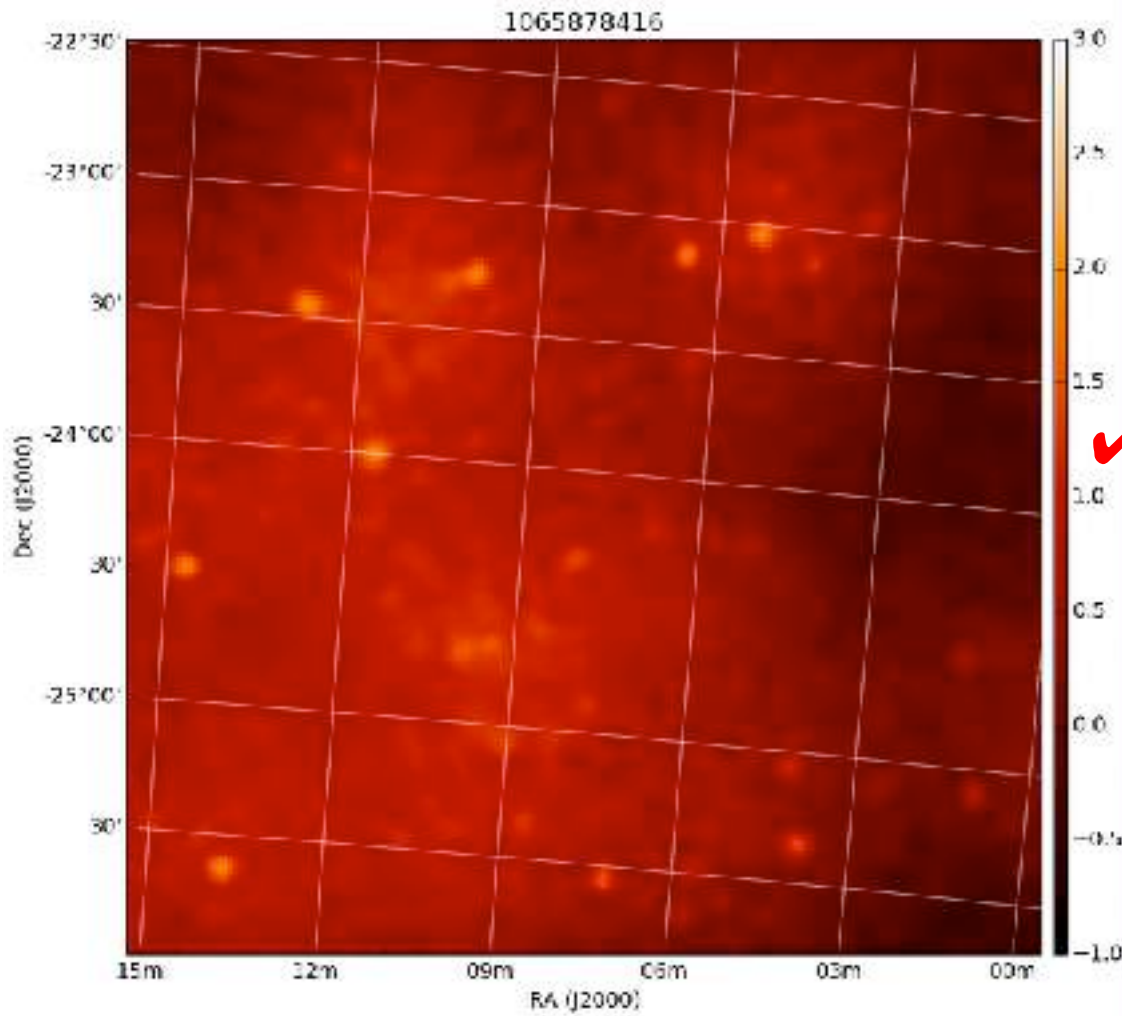
1. Can you deal with something new? What's happening?



Low frequency MWA obs.

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

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



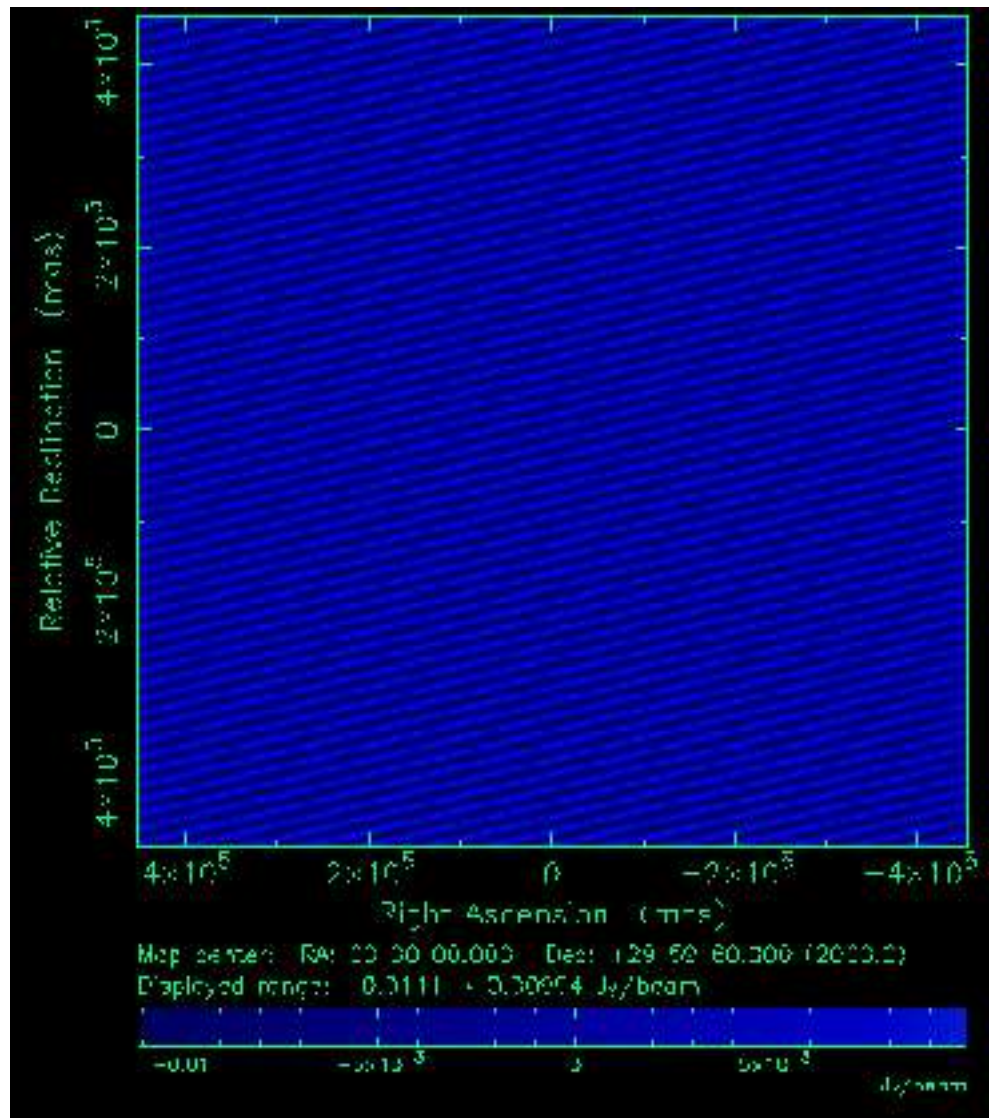
Low frequency MWA obs.

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



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

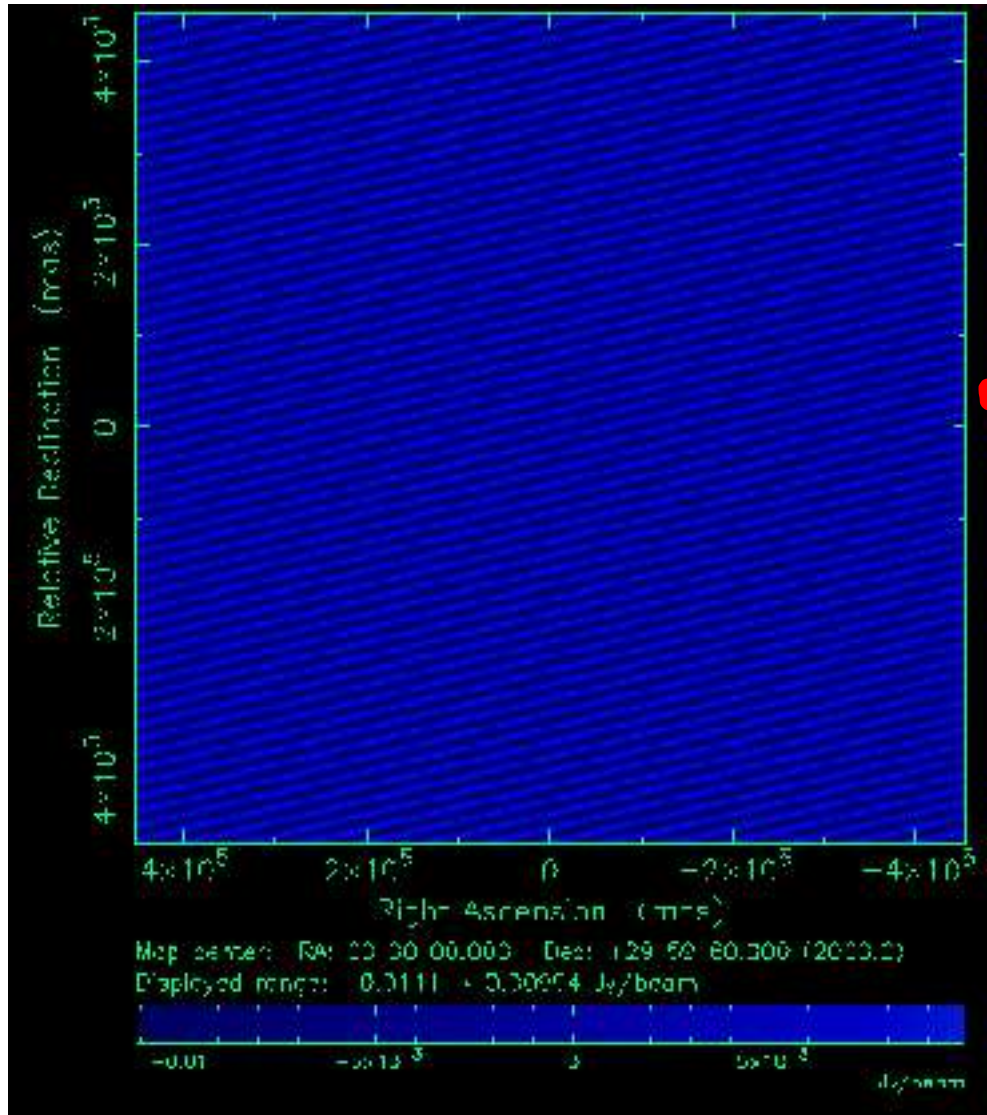


- A. Primary Beam error
- B. RFI
- C. Venetian blinds left open
- D. Deconvolution error



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

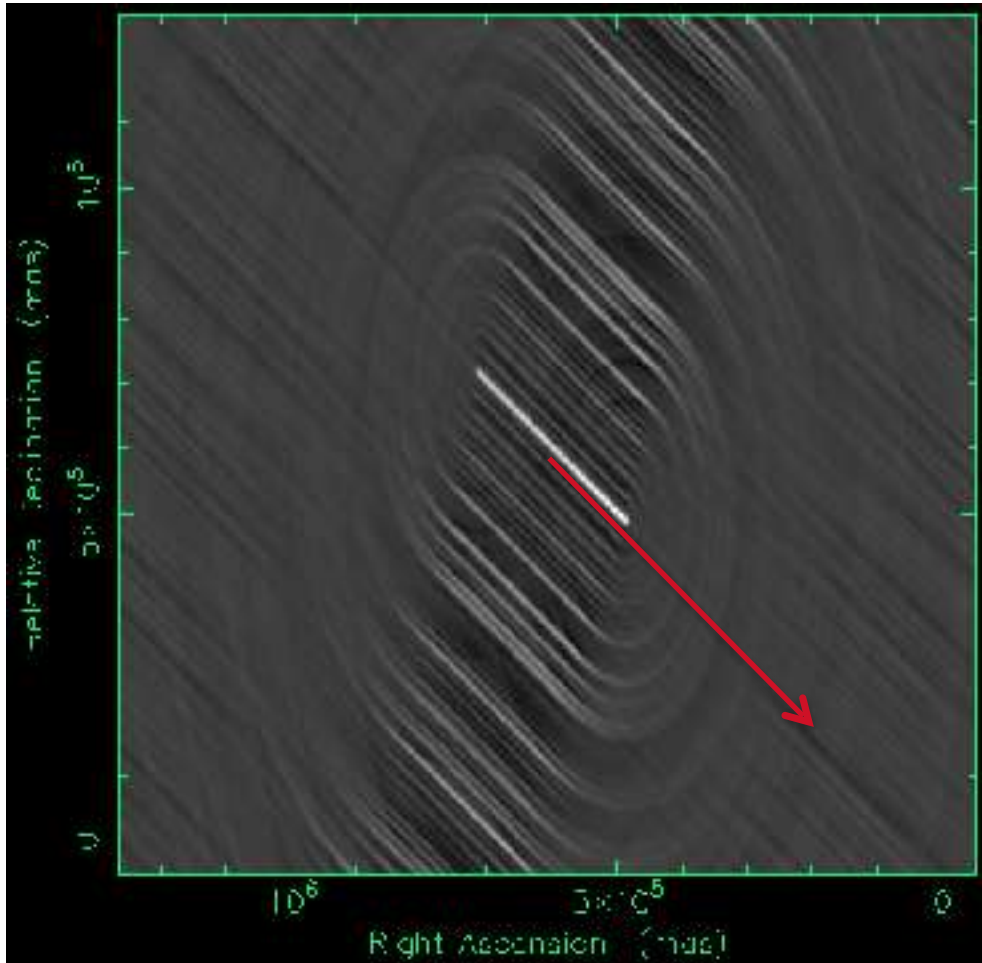


- A. Primary Beam error
- ✓ B. RFI
- C. Venetian blinds left open
- D. Deconvolution error



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

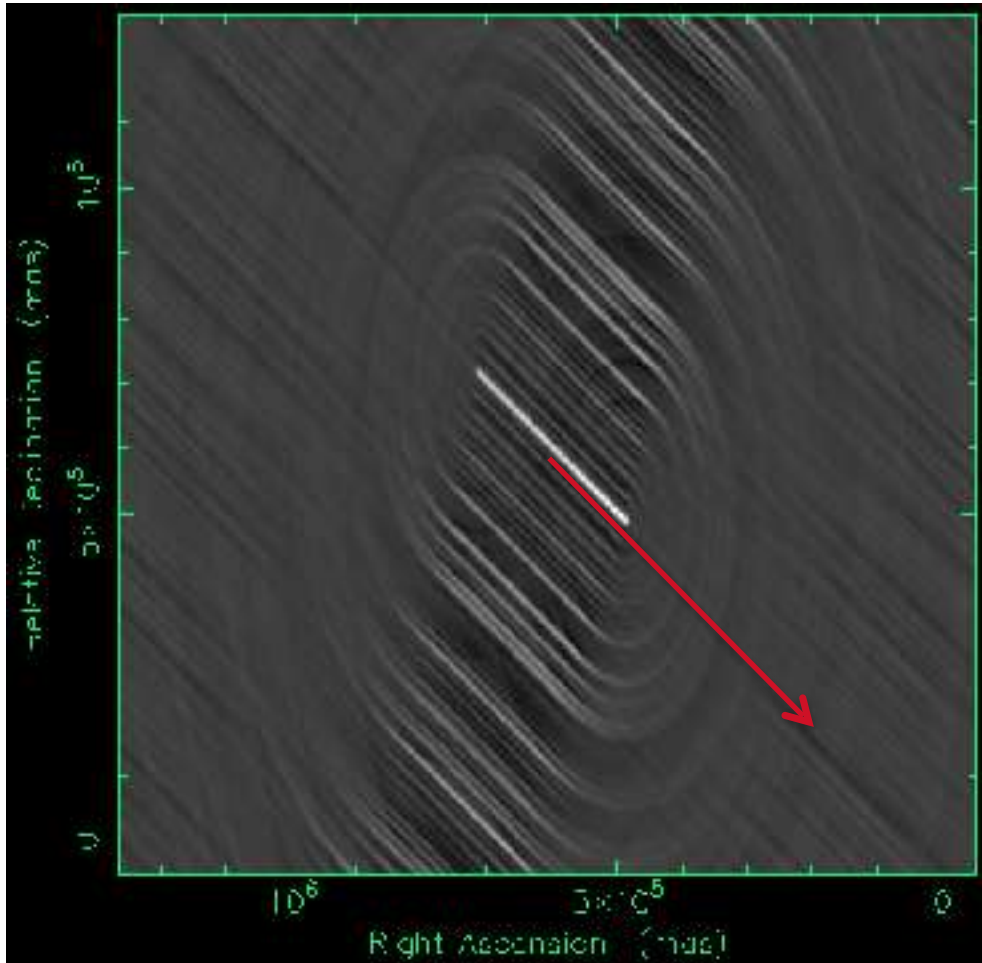


- A. Amplitude errors
- B. Cosmic ray
- C. Bandwidth smearing
- D. RFI



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

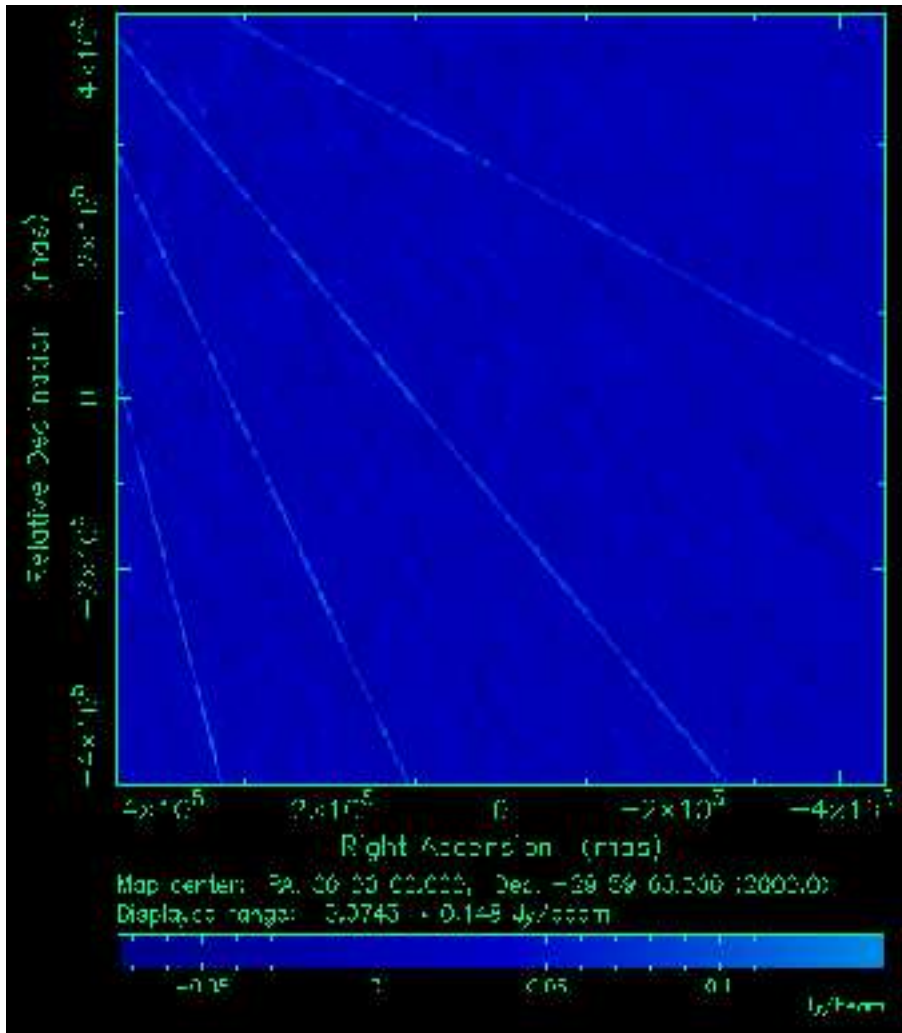


- A. Amplitude errors
- B. Cosmic ray
- ✓ C. Bandwidth smearing
- D. RFI



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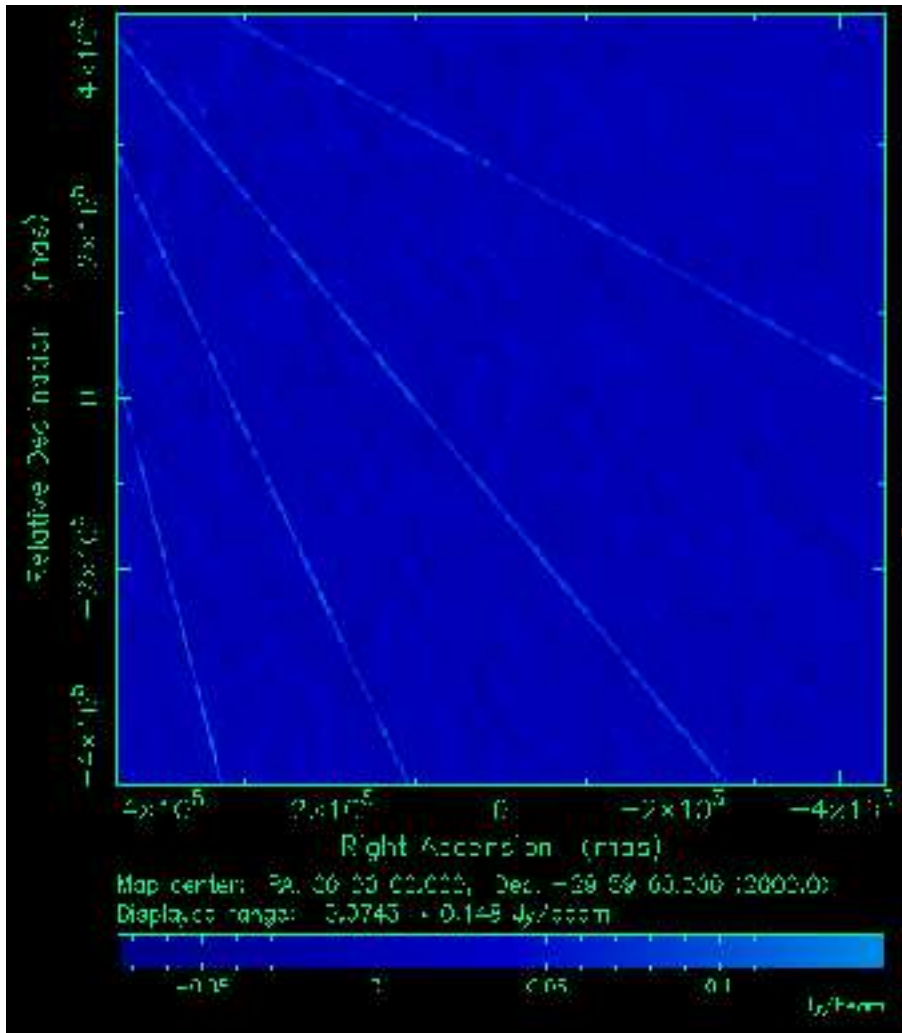
4. Dare to solve this! What's happening?



- 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?

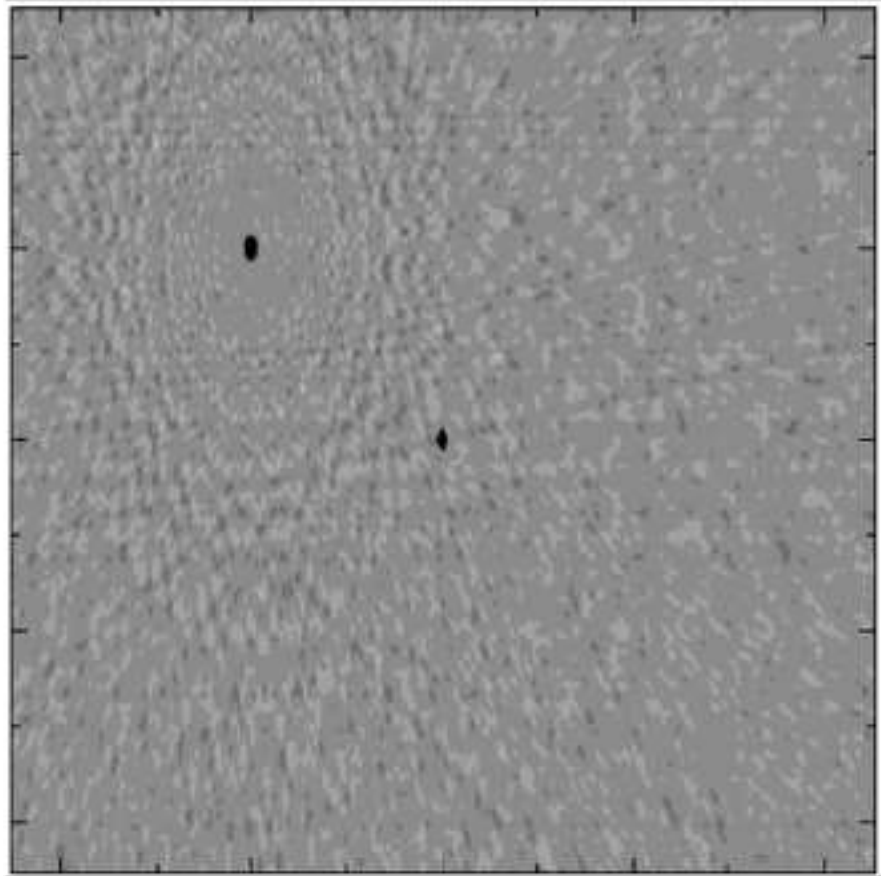


- A. Amplitude errors
- B. Phase of moon incorrect
- C. Position-dependent errors
- ✓ D. Source outside imaged field



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

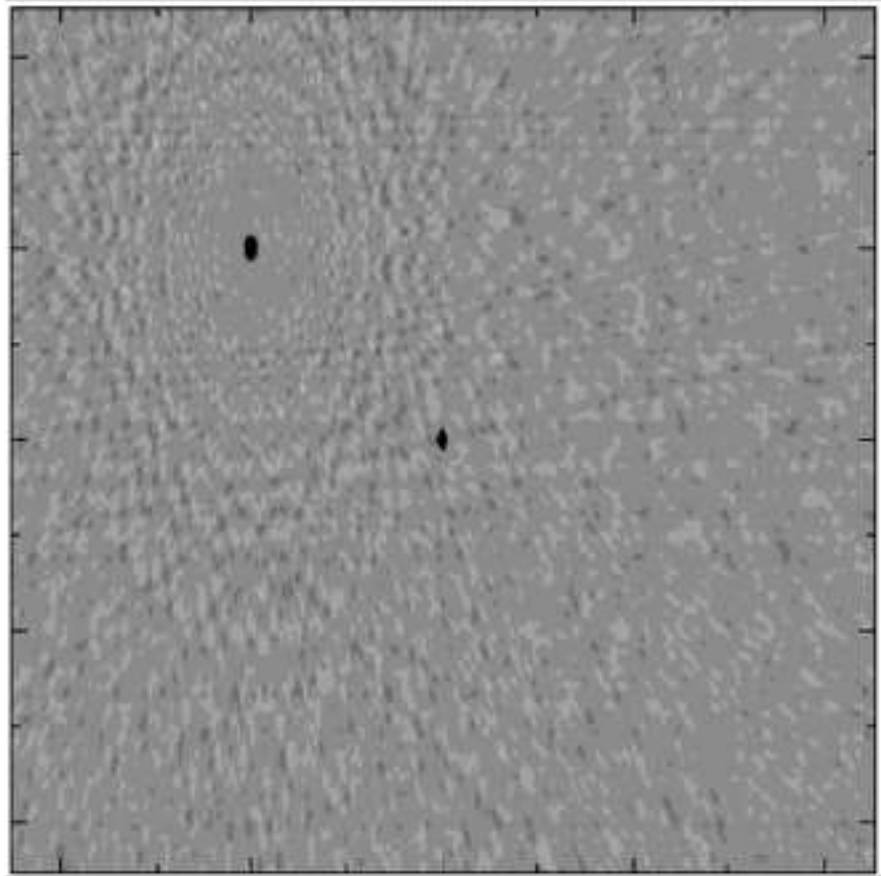


- A. RFI
- B. Bandwidth smearing
- C. Daylight savings not set
- D. Position-dependent errors



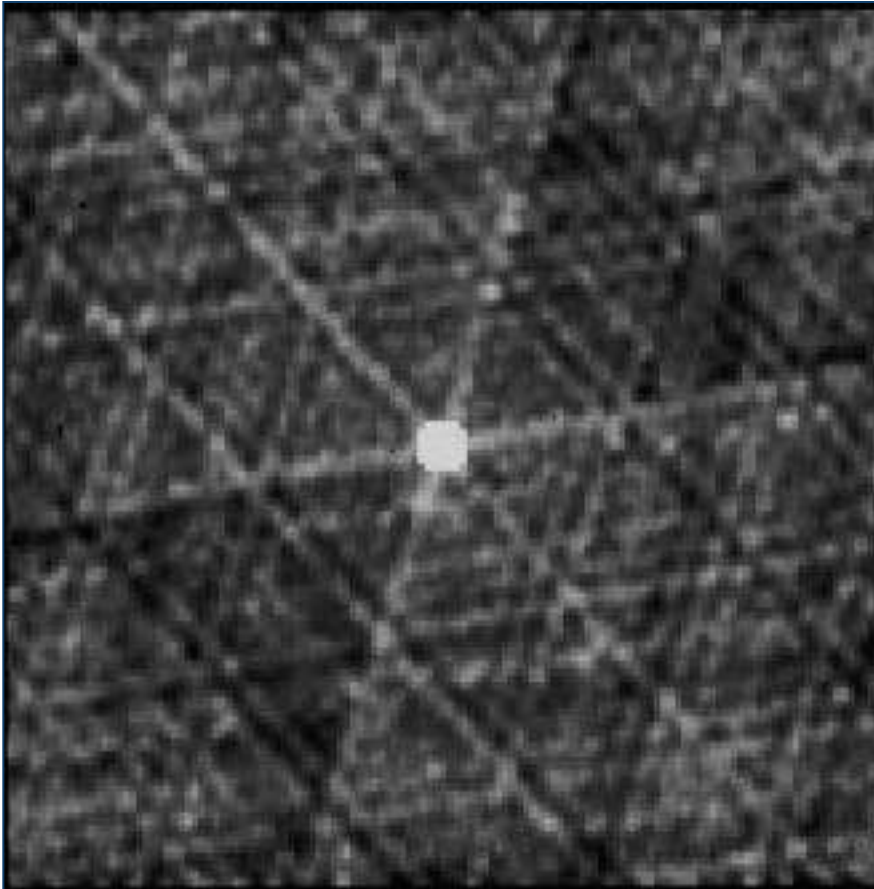
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5. Don't give up! What's happening?



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

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

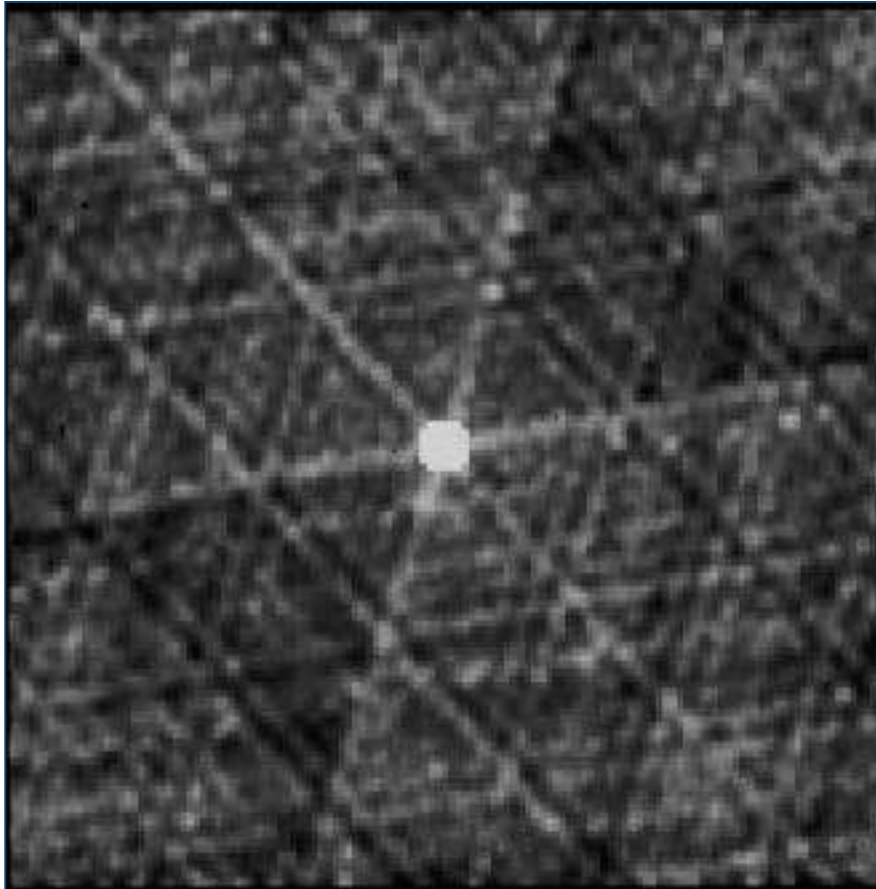


- A. Amplitude errors
- B. Tartan from wrong clan
- C. Data stored in HEX
- D. Phase errors



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

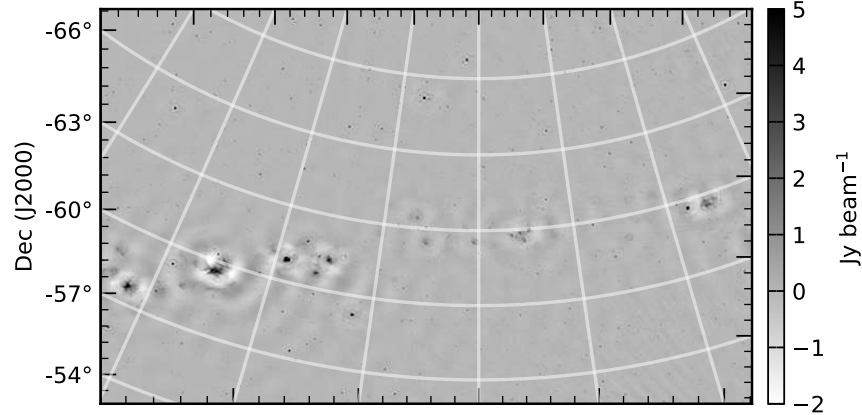


- ✓ A. Amplitude errors
- B. Tartan from wrong clan
- C. Data stored in HEX
- D. Phase errors

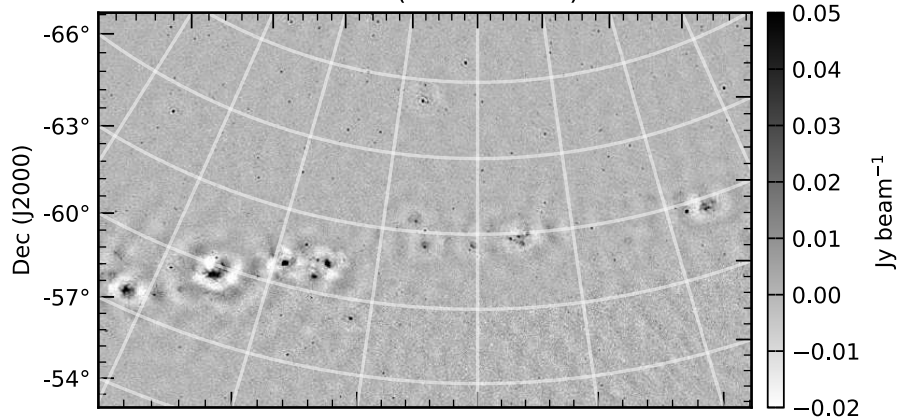


7. Can this be real? What's happening?

Stokes I



Stokes V (uncorrected)

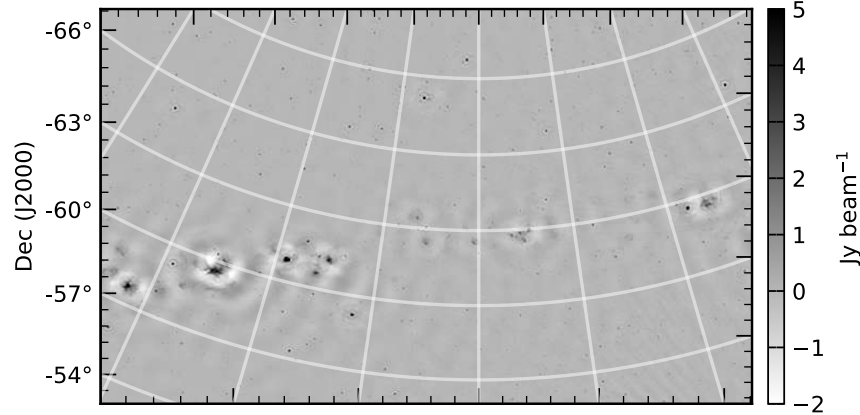


- A. Ionospheric effects
- B. Faraday rotation
- C. Polarisation leakage
- D. Galactic circular polarisation

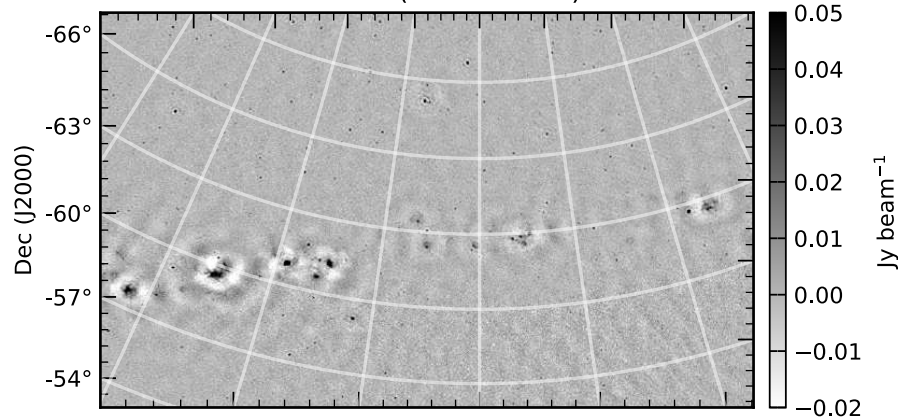


7. Can this be real? What's happening?

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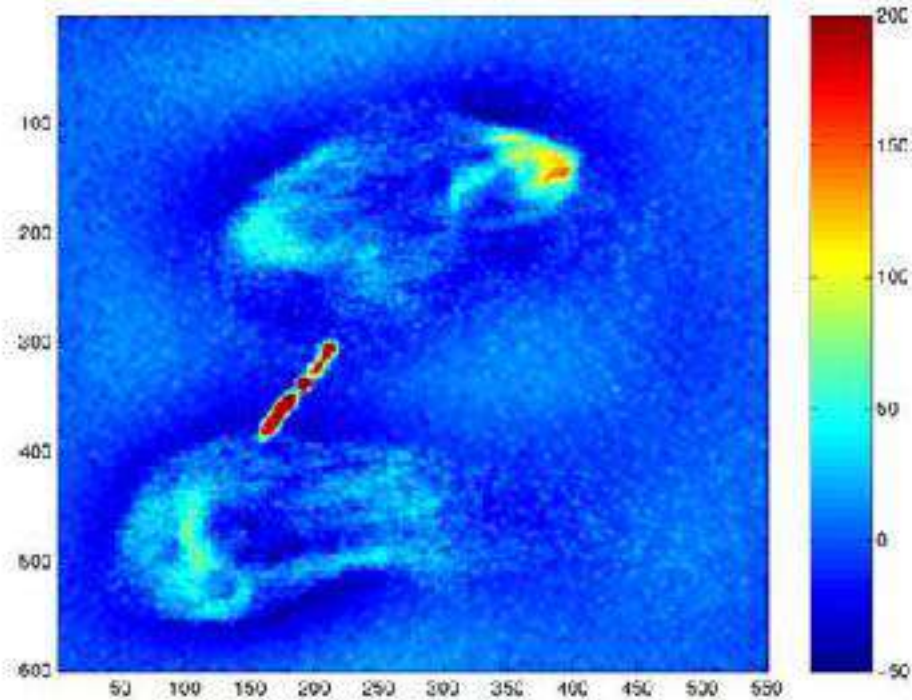
Stokes V (uncorrected)



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- ✓ C. Polarisation leakage
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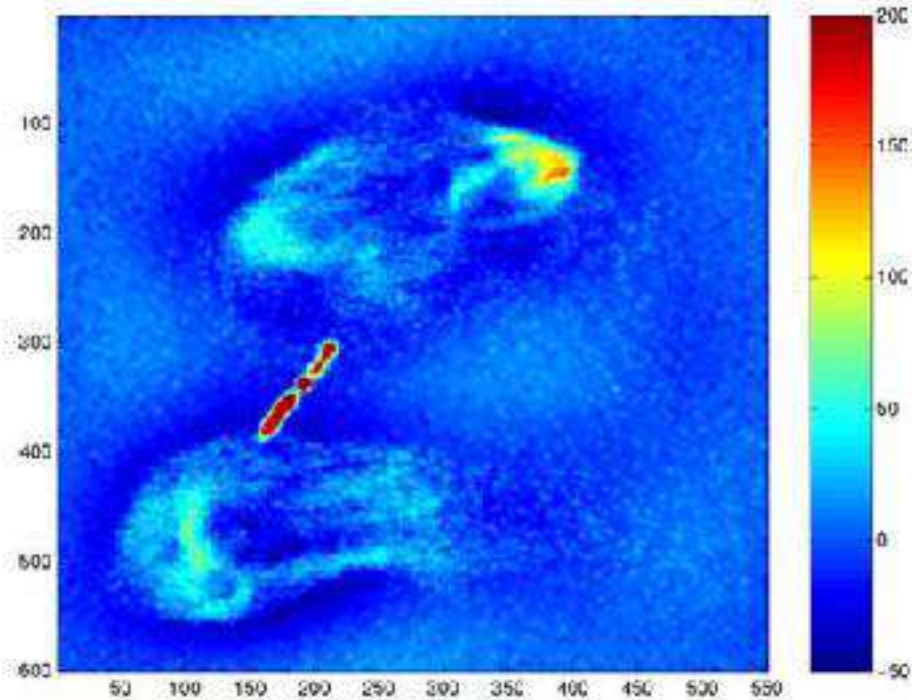
8. A tricky problem What's happening?



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

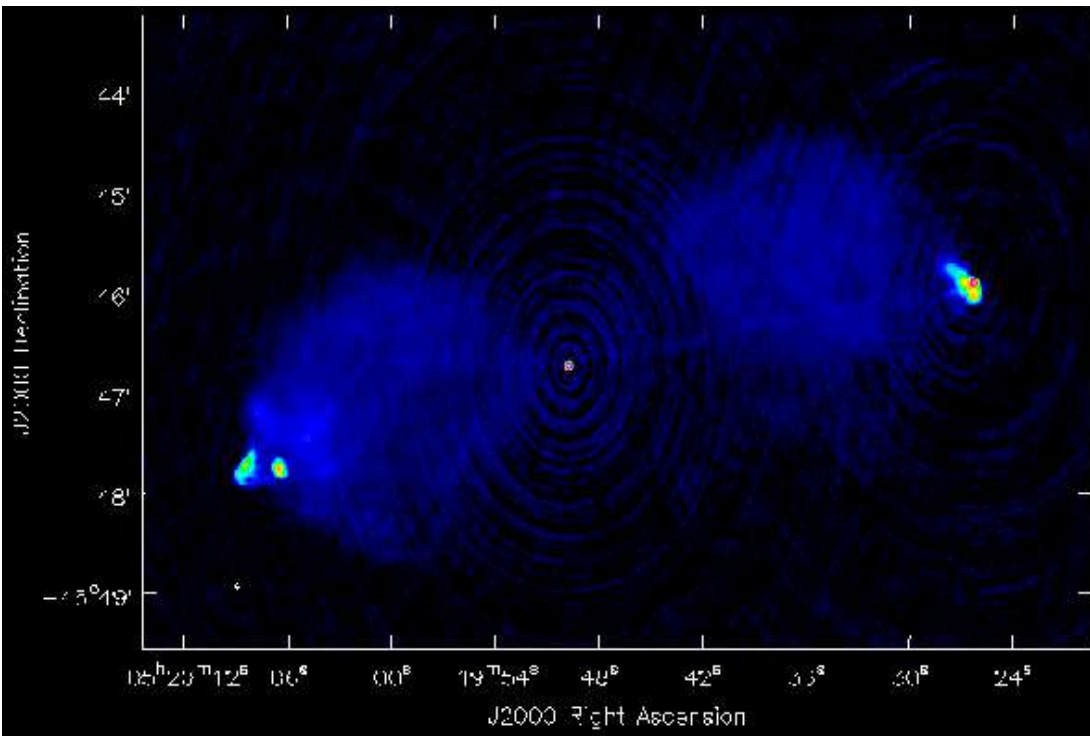


8. A tricky problem What's happening?



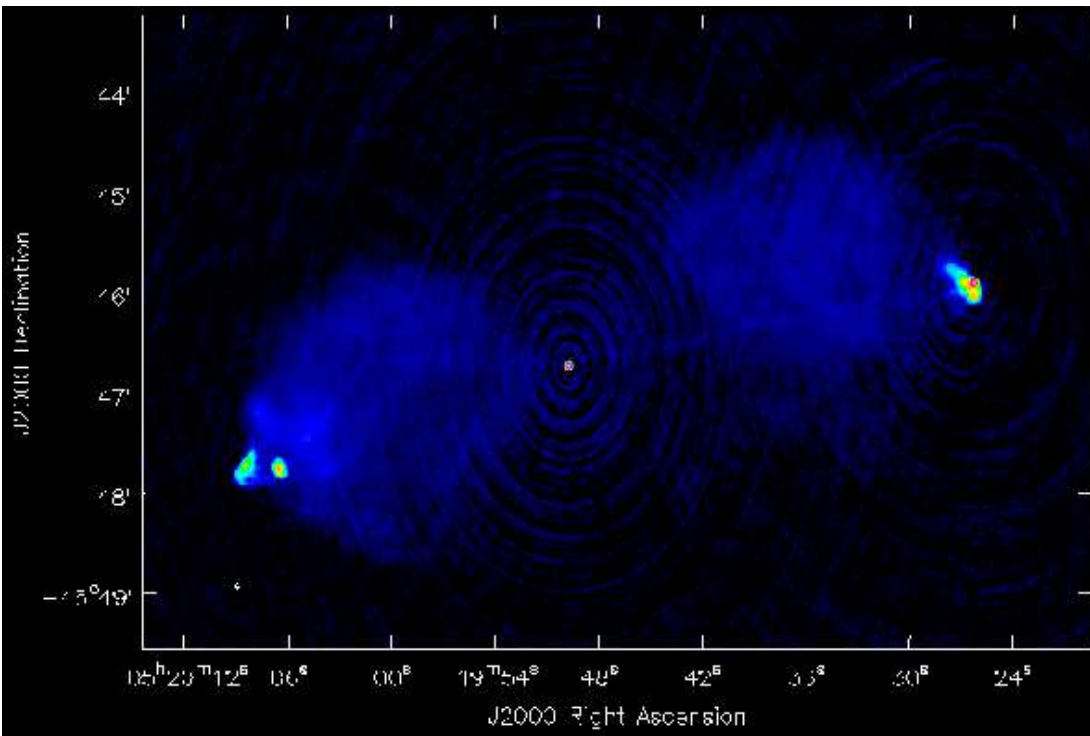
- ✓ A. Missing short baselines
- B. Missing long baselines
- C. Missing astronomer
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9. End of game question What's happening?



- 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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