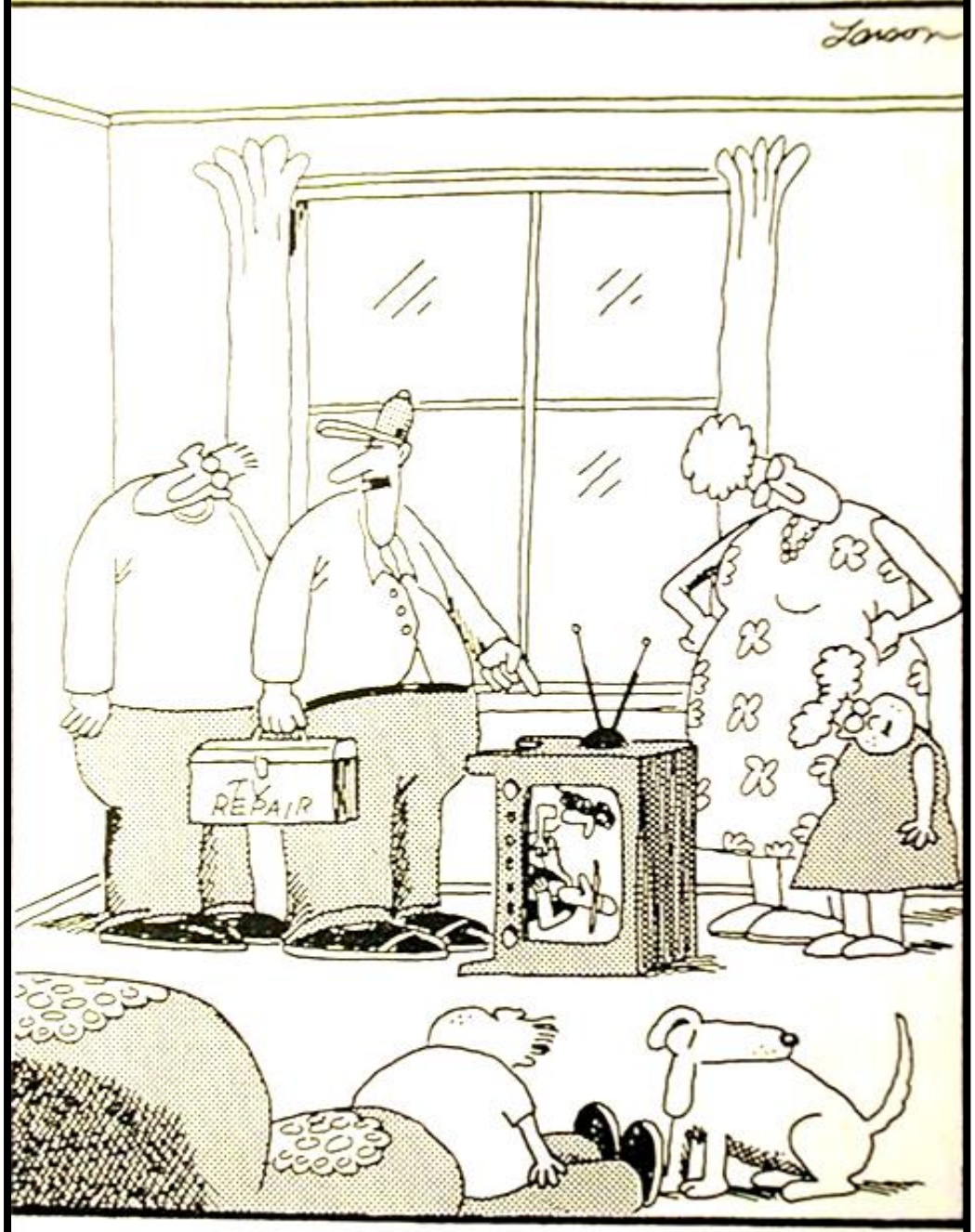
Synthesis Imaging Workshop

Error recognition

R. D. Ekers

Narrabri, 30 Sep 2015

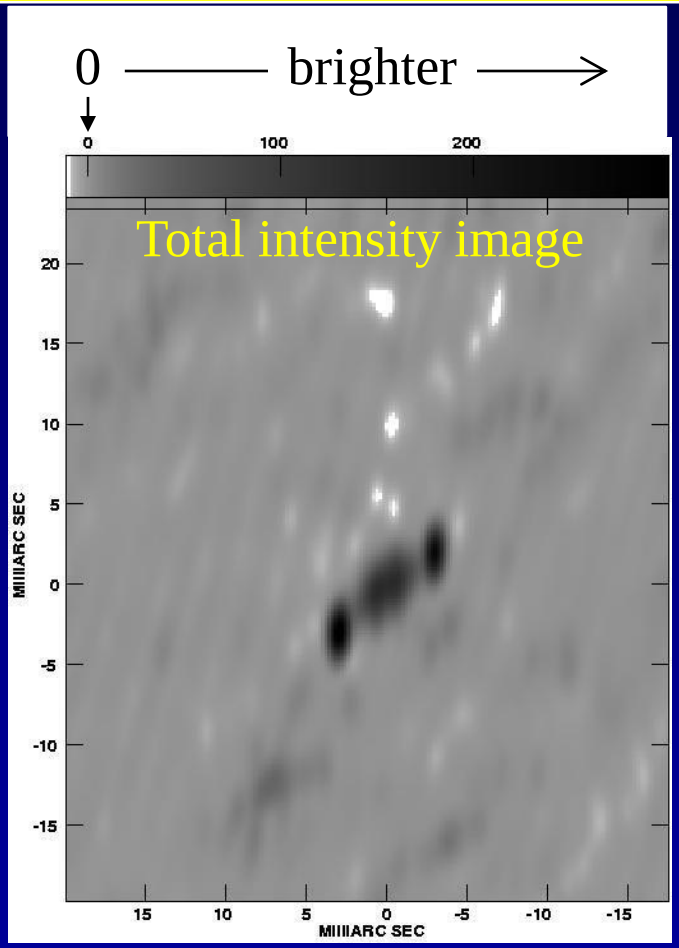


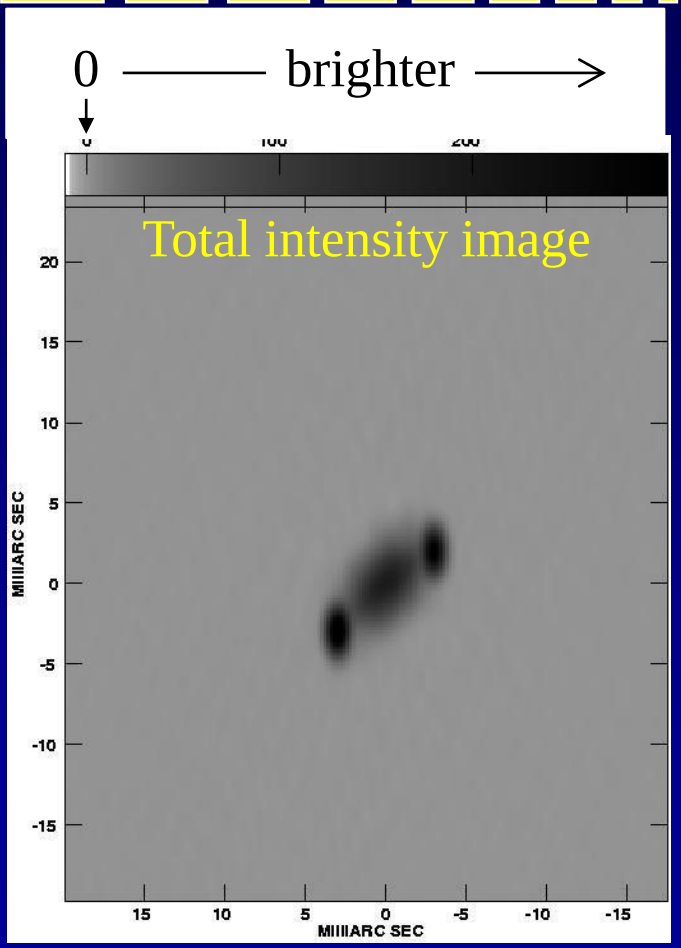
"Well, here's your problem, Mr. Schueler."

Summary

- Follows Chapter 15 “Error Recognition” in NRAO Synthesis Workshop closely
- Educational
  - Use of basic concepts and analogies
  - Fourier transform practice
- Practical information for diagnosing errors
- Diagnostic tools
- Making discoveries
- Not running into Vanessa’s next talk!

Have I got a decent radio image?





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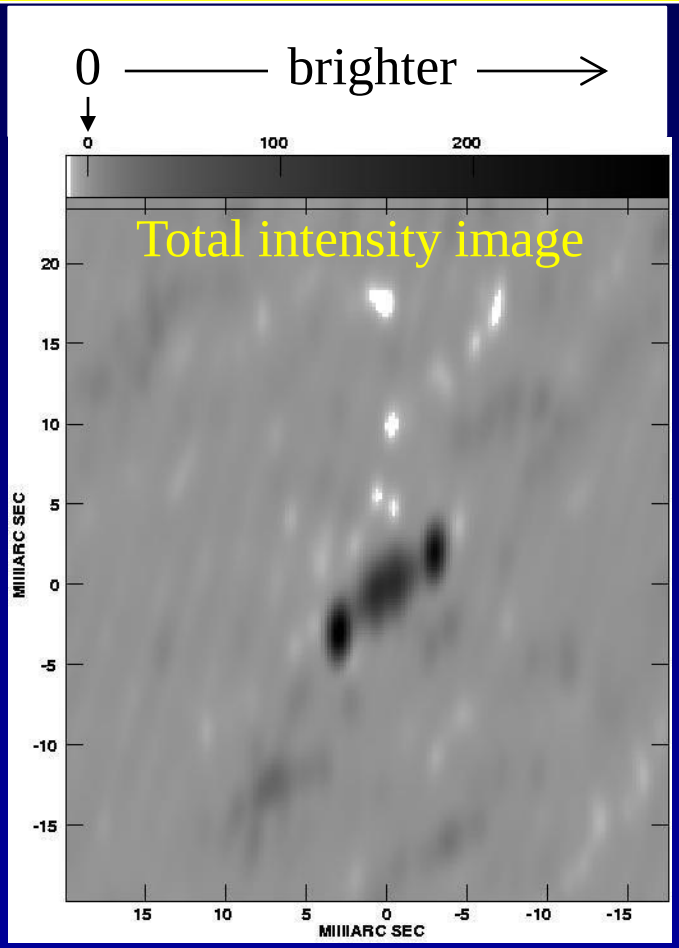
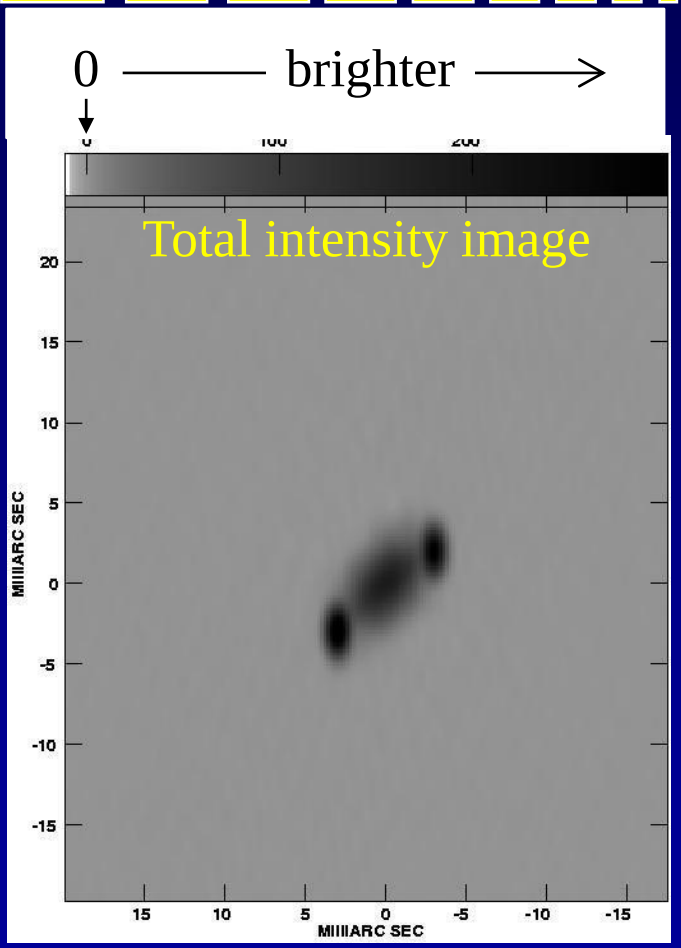


No!



Yes!

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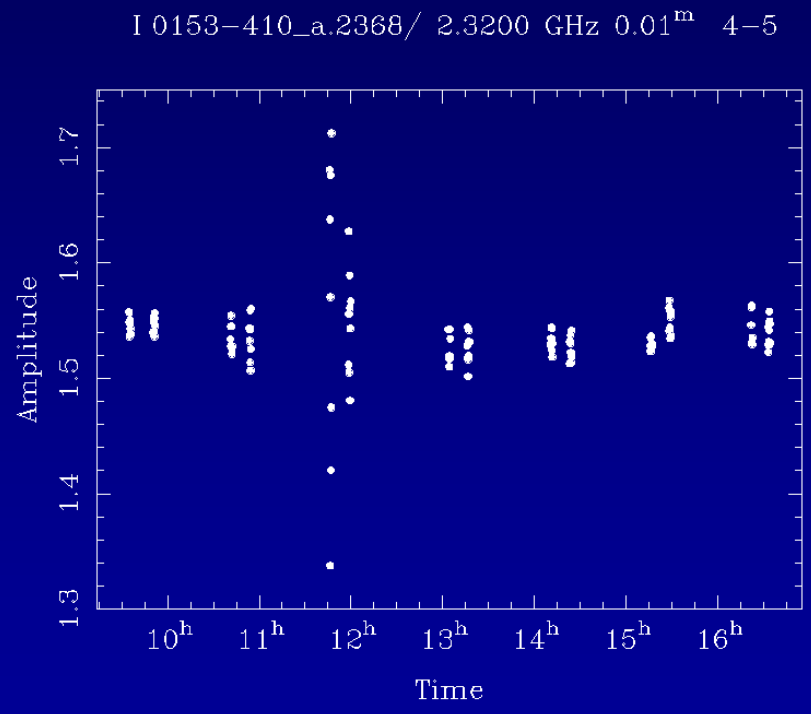
Bad Scan - Visibilities:

Unflagged:



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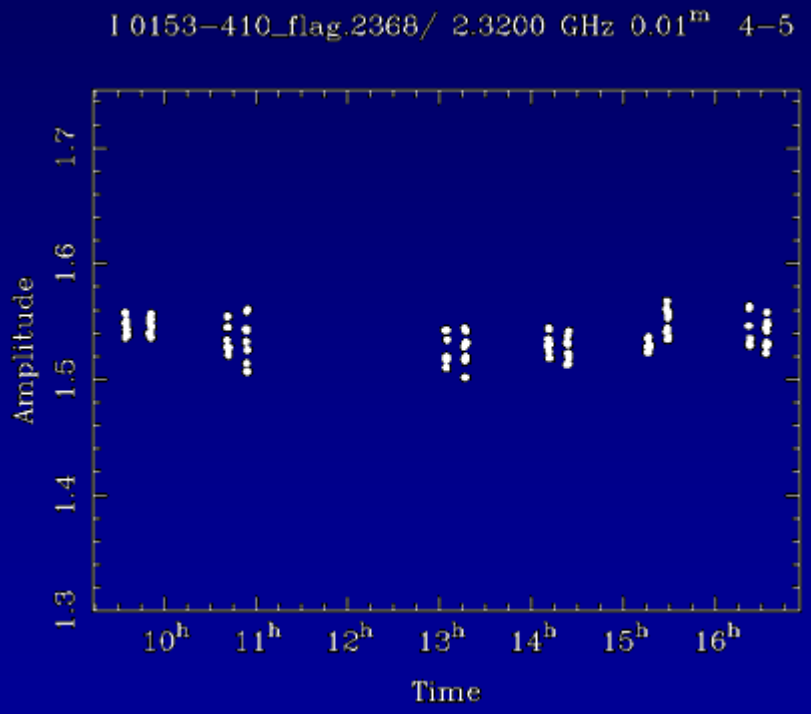

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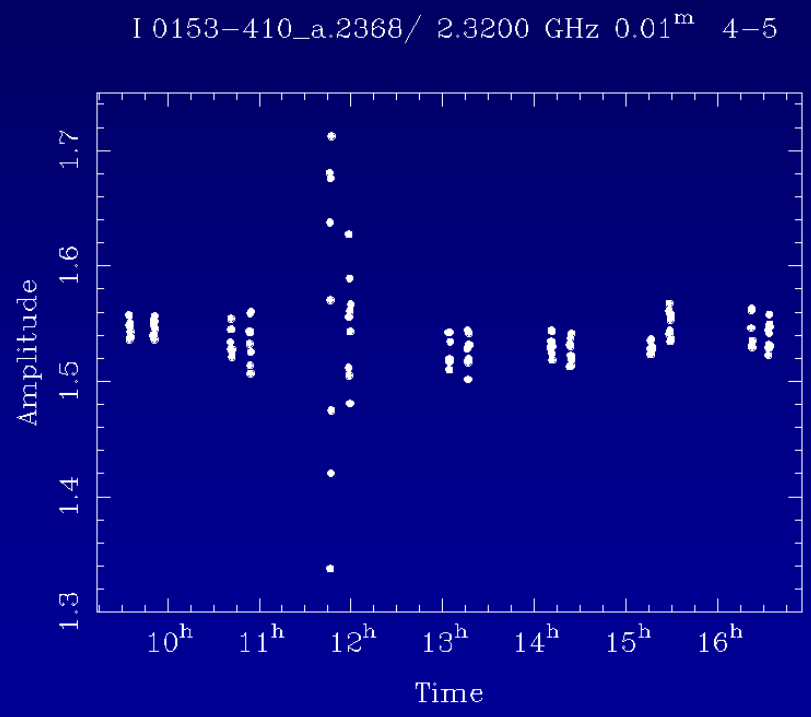

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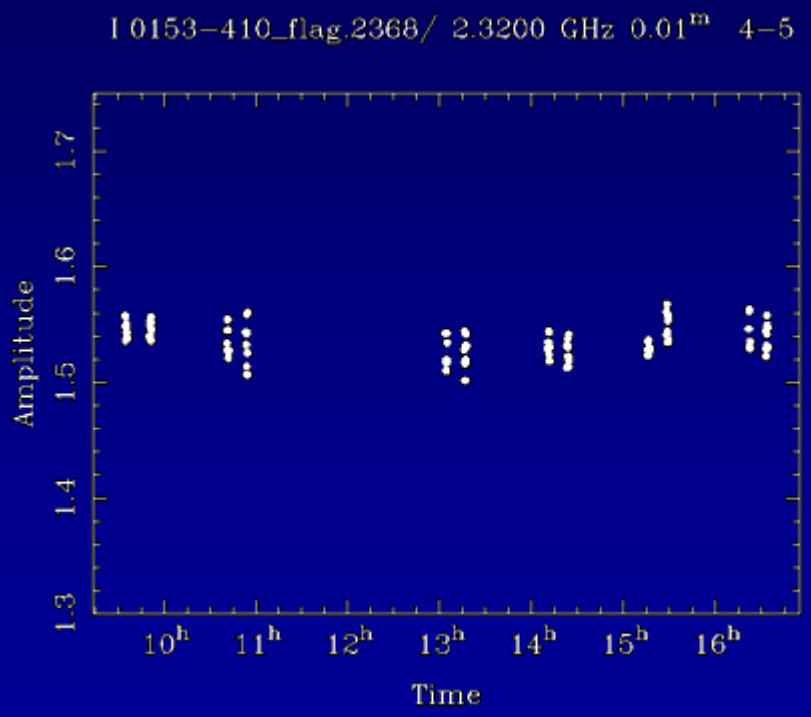
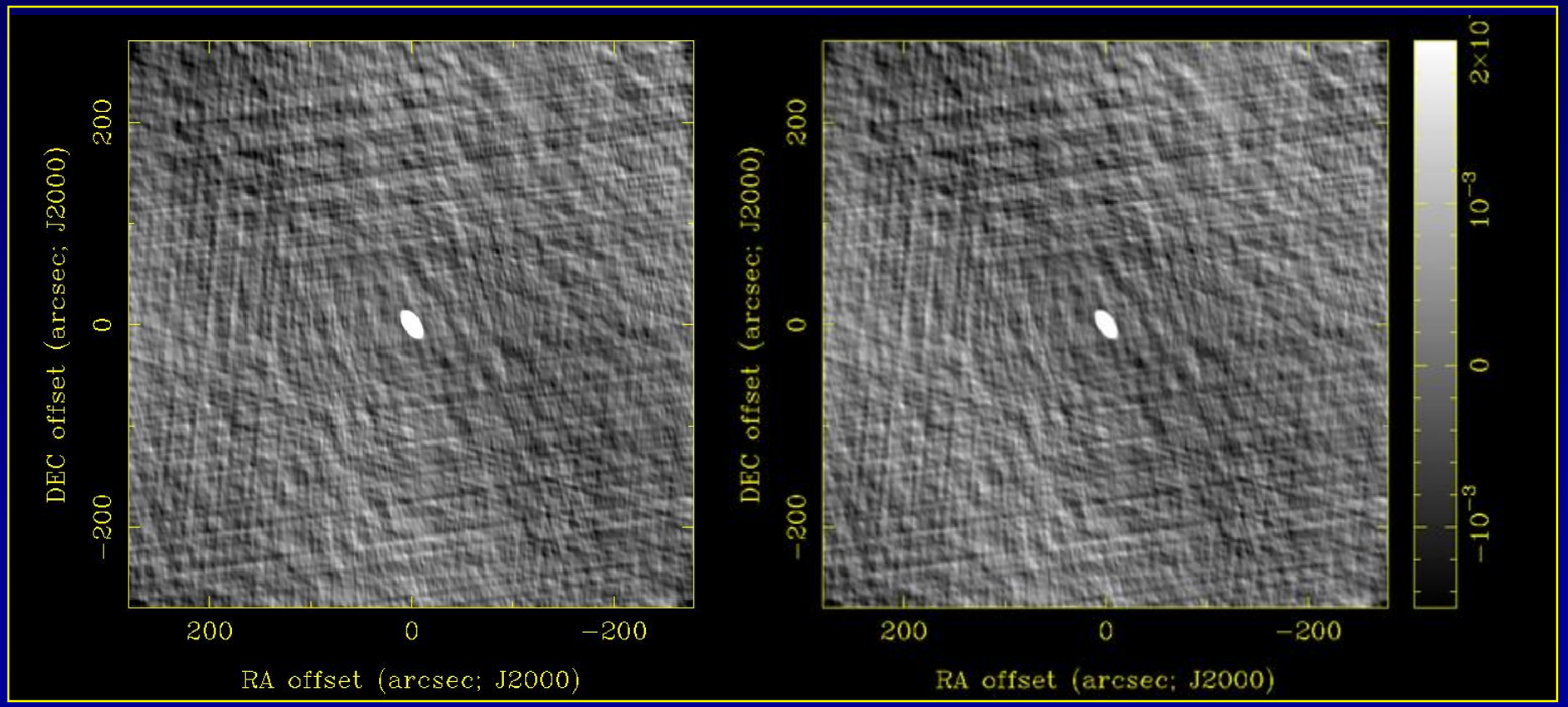


Only two scans on 1/15 baselines affected.

Bad Scan - Images:

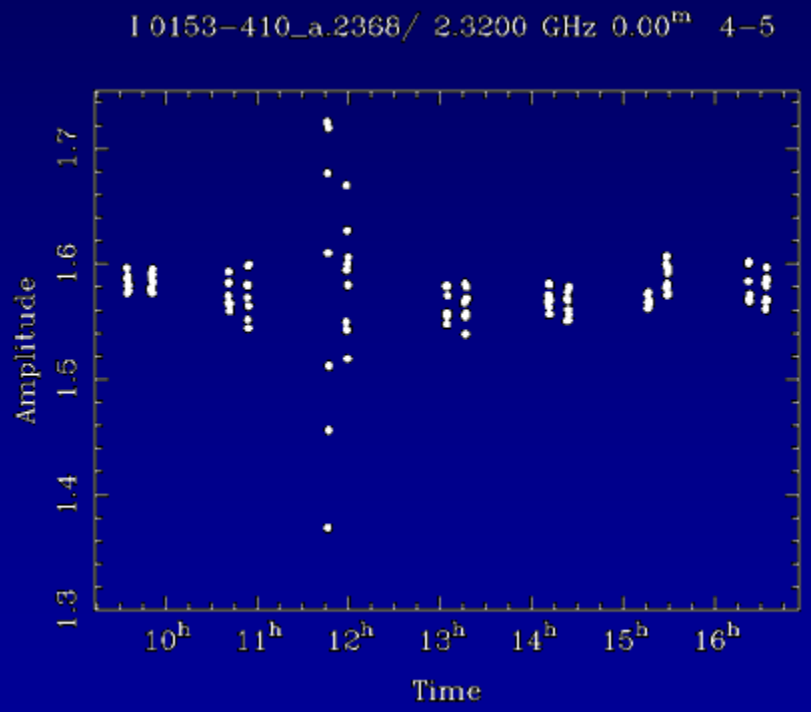
Unflagged:

Flagged:

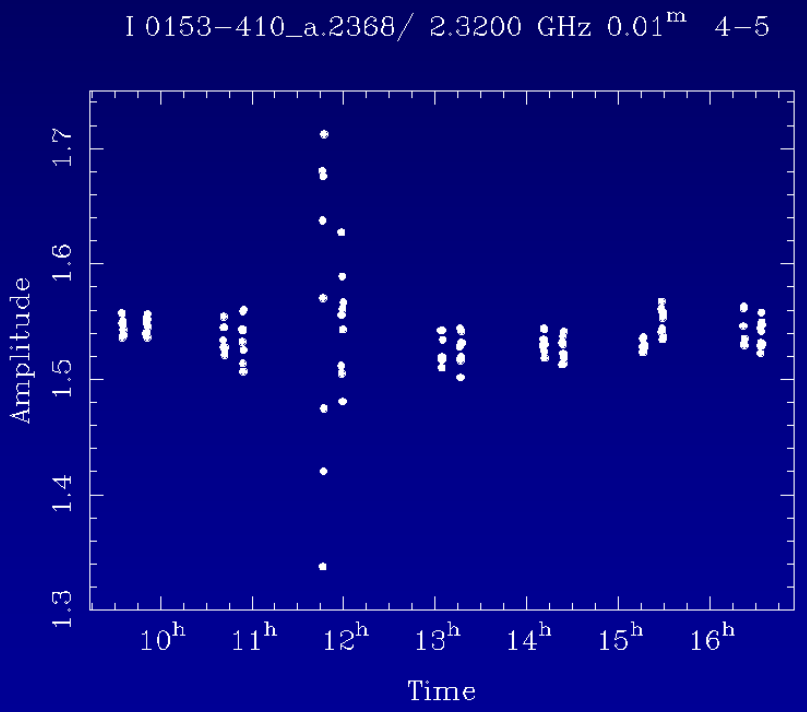


Bad Gain - Visibilities:

2.5% Gain error one ant:



Properly Calibrated:



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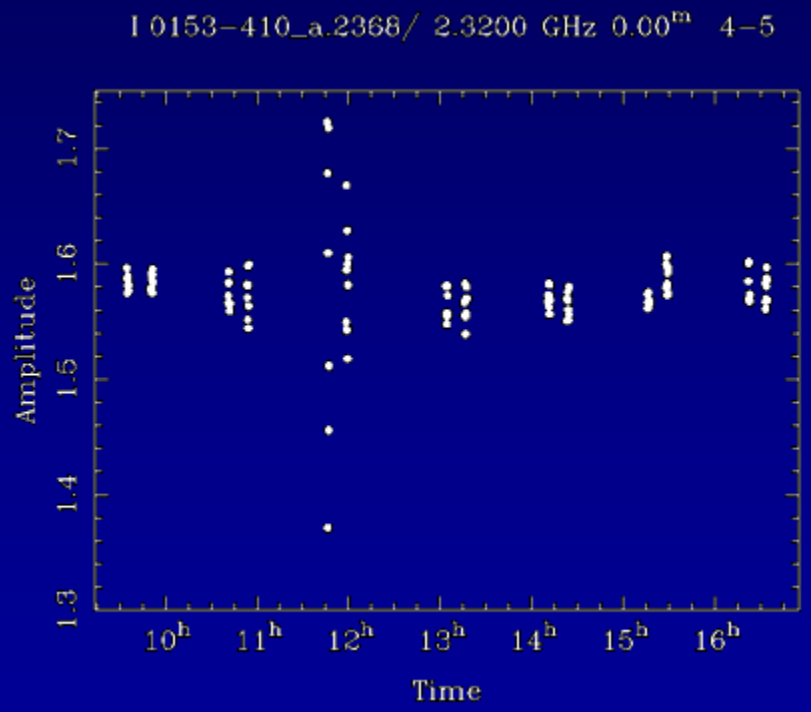

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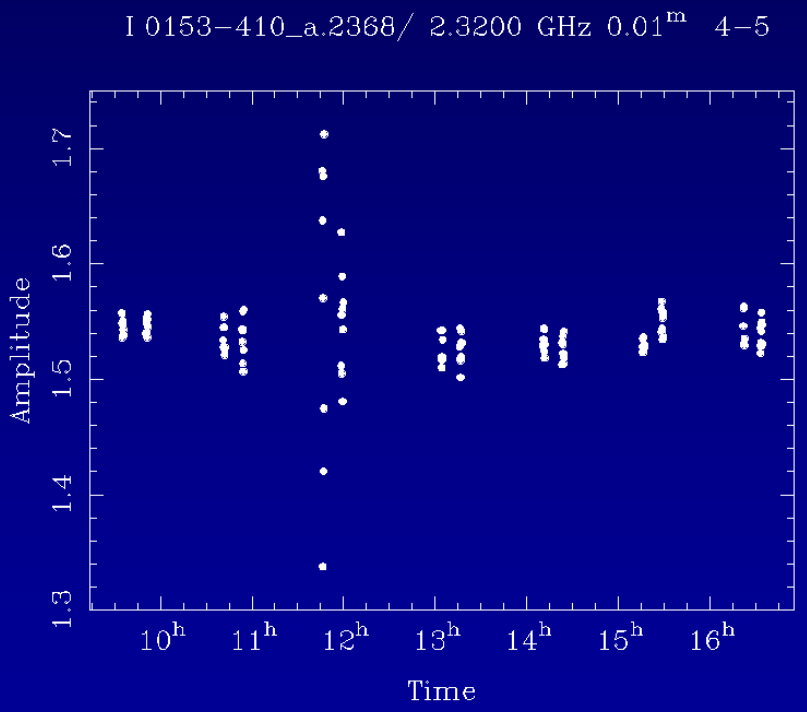

Gain error affects all visibilities on 5/15 baselines

Bad Gain - Visibilities:

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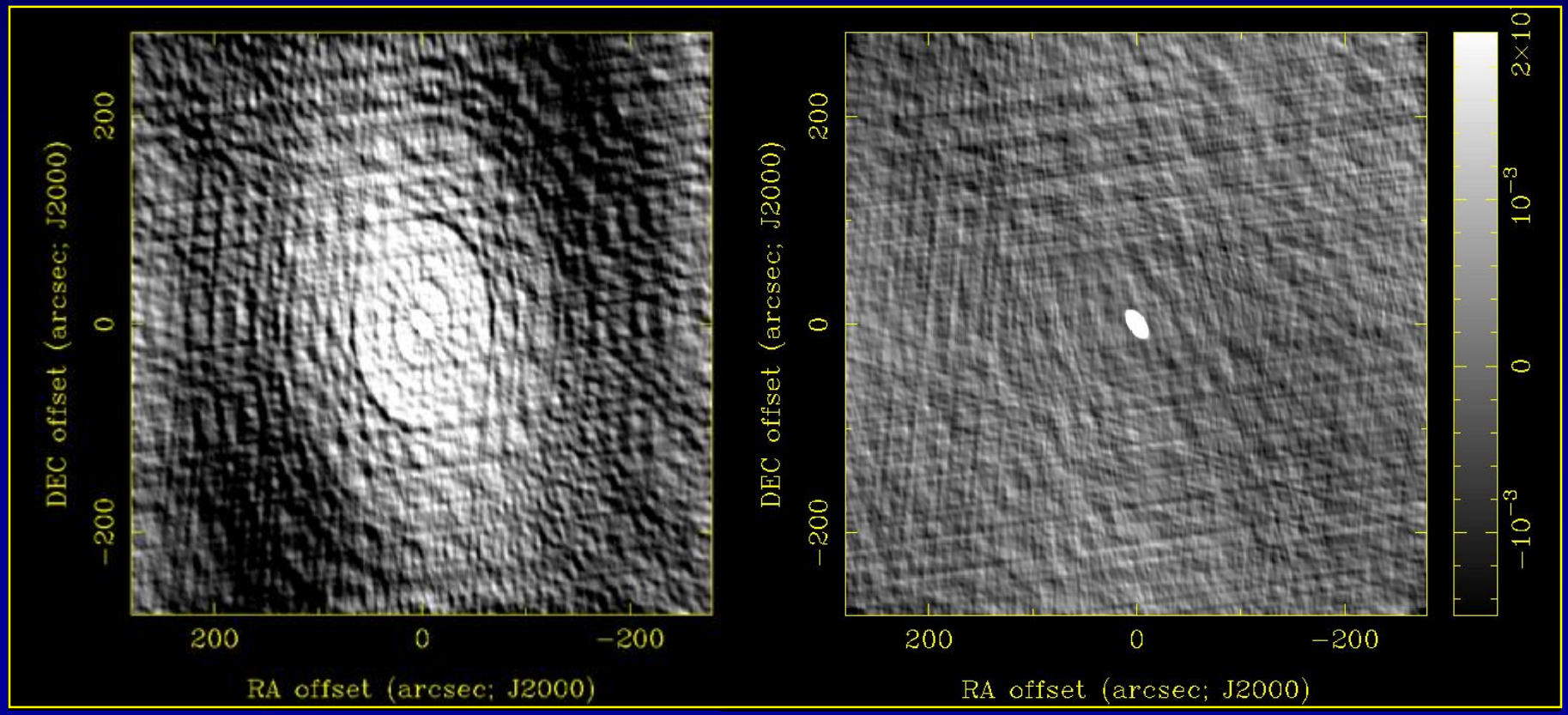

Fourier Symmetries

- symmetries determined by Fourier kernel
- real sky brightness ⇔ Hermitian uv plane
  - complex conjugate of visibility used for inverse baseline

- $\exp(i \varphi) = \cos \varphi + i \sin \varphi$
  - Real & Even ⇔ Real & Even
  - Real & Odd ⇔ Imag & Odd

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Symmetric image errors are often due to amplitude errors

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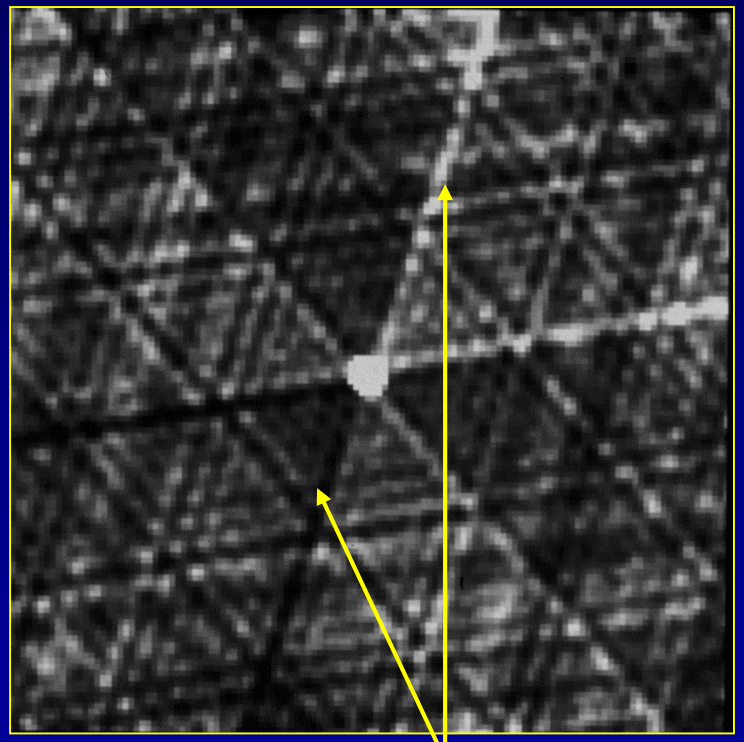
Symmetric image errors are often due to amplitude errors

image errors with odd symmetry or asymmetric often due to phase errors

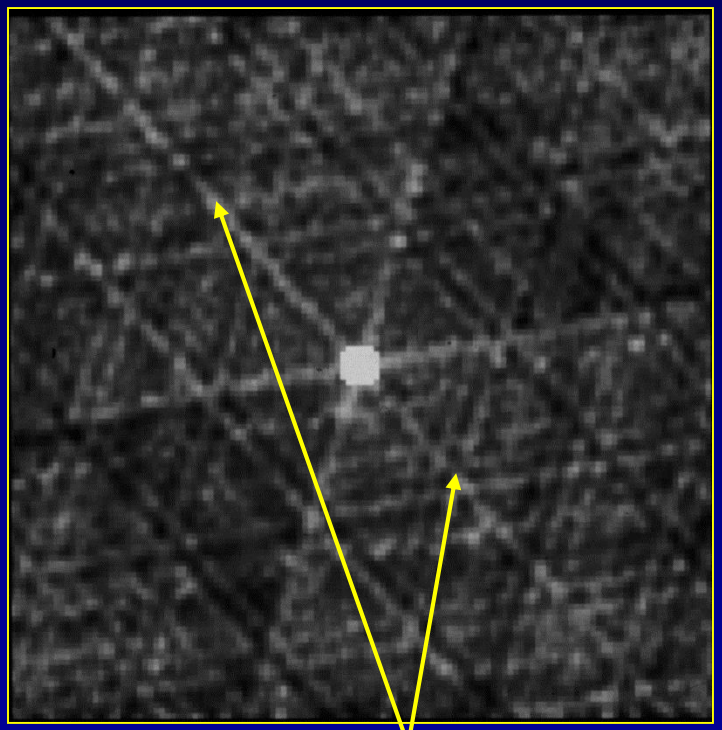
Example Gain Error - 2

10 deg phase error



anti-symmetric ridges

20% amp error



symmetric ridges

Additive or Multiplicative?

- some errors add to visibilities

$$V + \epsilon \quad \Leftrightarrow \quad I + \mathcal{F}\epsilon$$

- others *multiply* or *convolve* visibilities
  - multiplication ⇔ convolution in conjugate planes

$$V\epsilon \quad \Leftrightarrow \quad I * \mathcal{F}\epsilon$$

  - convolution ⇔ multiplication in conjugate planes

$$V * \epsilon \quad \Leftrightarrow \quad I\,\mathcal{F}\epsilon$$

Additive

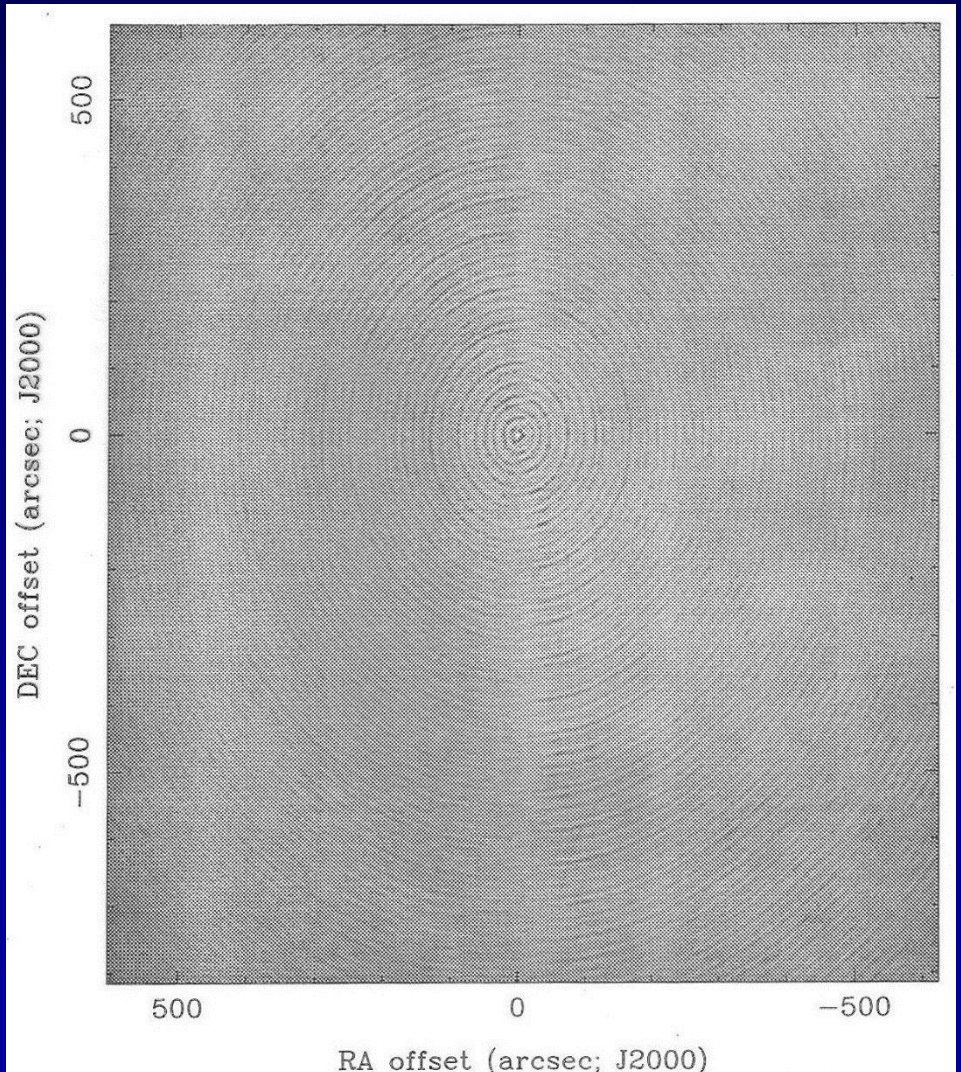
$$V + \epsilon \quad \Leftrightarrow \quad I + \mathcal{F}\epsilon$$

- adds to visibilities ⇔ adds to image
  - unconnected to real sources in the image
  - may make “fake” sources
- sources of additive errors:
  - noise
  - Interference (RFI, cross talk)
  - Sources outside beam (confusion, sun)
  - DC offsets

Noise in Images

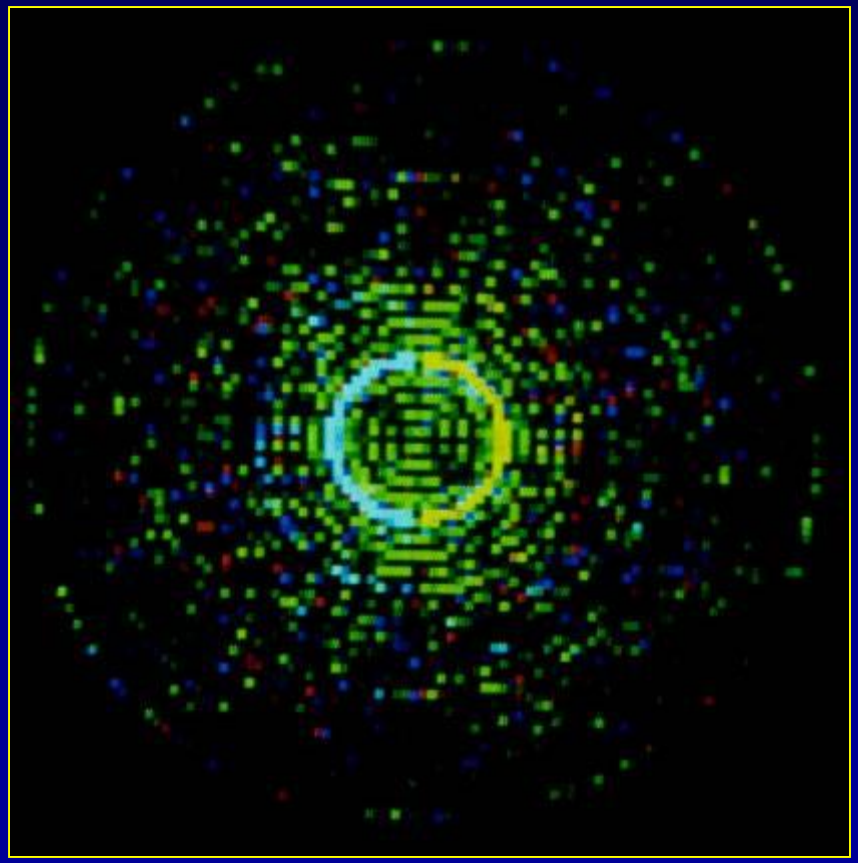
- can calculate from radiometer equation
  - you should know expected noise level
  - unexpectedly high noise levels may indicate problems
- additive where data ⇨ same *uv* distribution as data
  - will show same sidelobe pattern as real sources!

DC offset: Additive error - Image plane

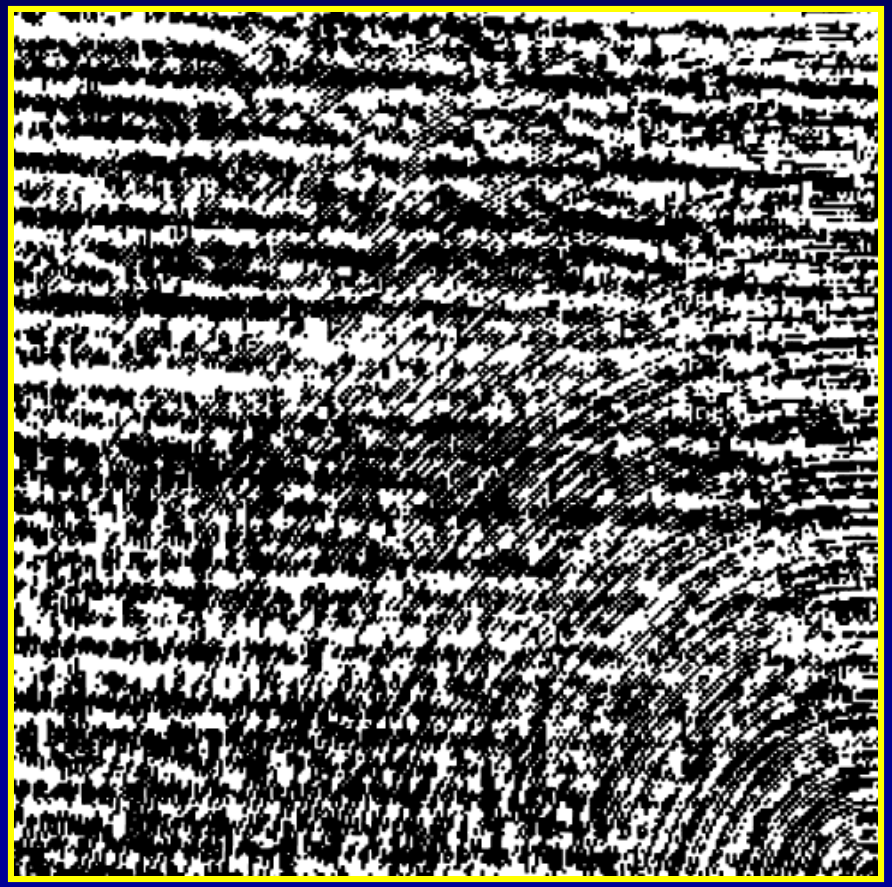


Hue/Intensity display of complex visibility

- DC offset in cos correlator
- Use of Hue/Intensity display to see phase error
  - Brightness = amplitude
  - Phase = colour
- Note conjugate effect on phase



RFI: Additive error - image plane



- Always additive
- Short or long duration
- Not moving at sidereal rate
  - Average out unless expected fringe rate is zero
  - Same as a source fixed at the celestial pole
- RFI excision techniques possible

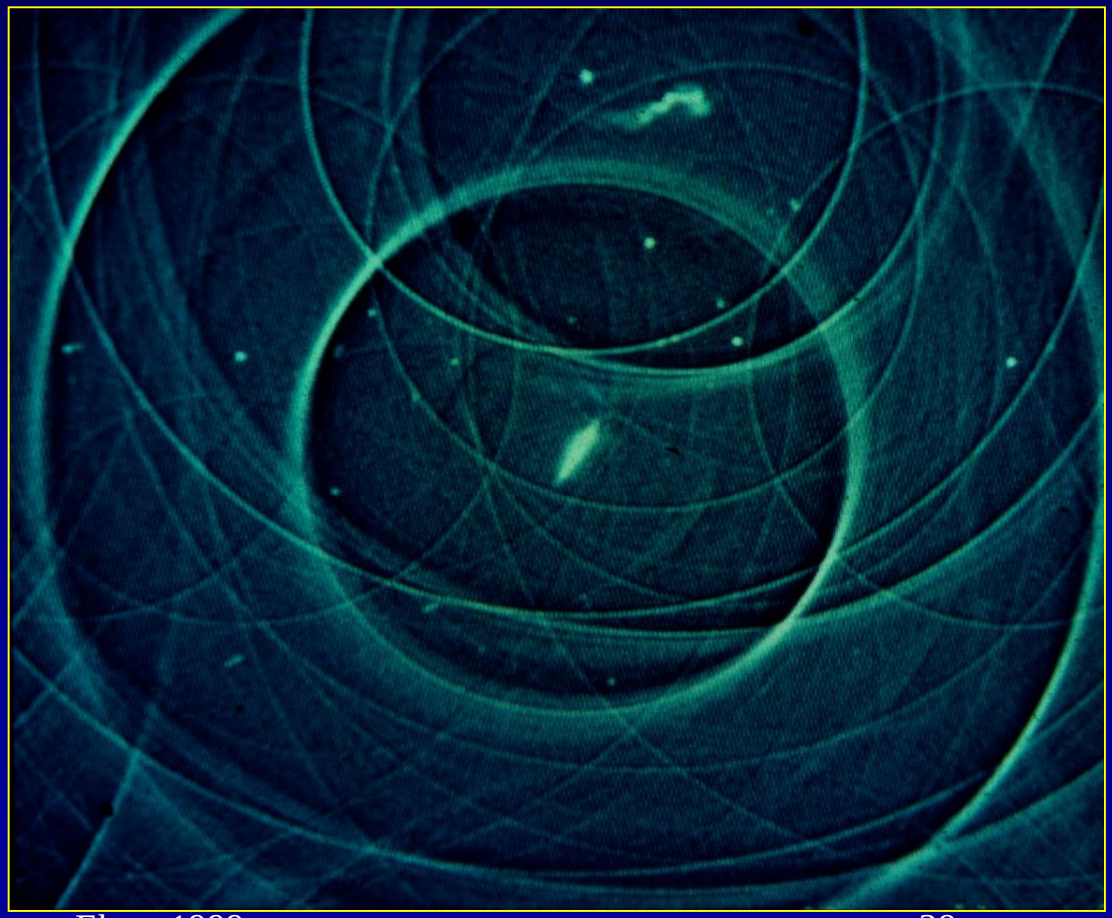
Ekers 1999

Multiplicative

$$V\epsilon \Leftrightarrow I * \mathcal{F}\epsilon \qquad V * \epsilon \Leftrightarrow I\mathcal{F}\epsilon$$

- others *multiply* or *convolve* visibilities
  - multiplication ⇔ convolution in conjugate planes
    - » examples - multiplicitive: sampling, gain errors, atmosphere, missing spacings
    - » Examples - convolution: primary beam, gridding

UV coverage
copy of PSF attached to each source



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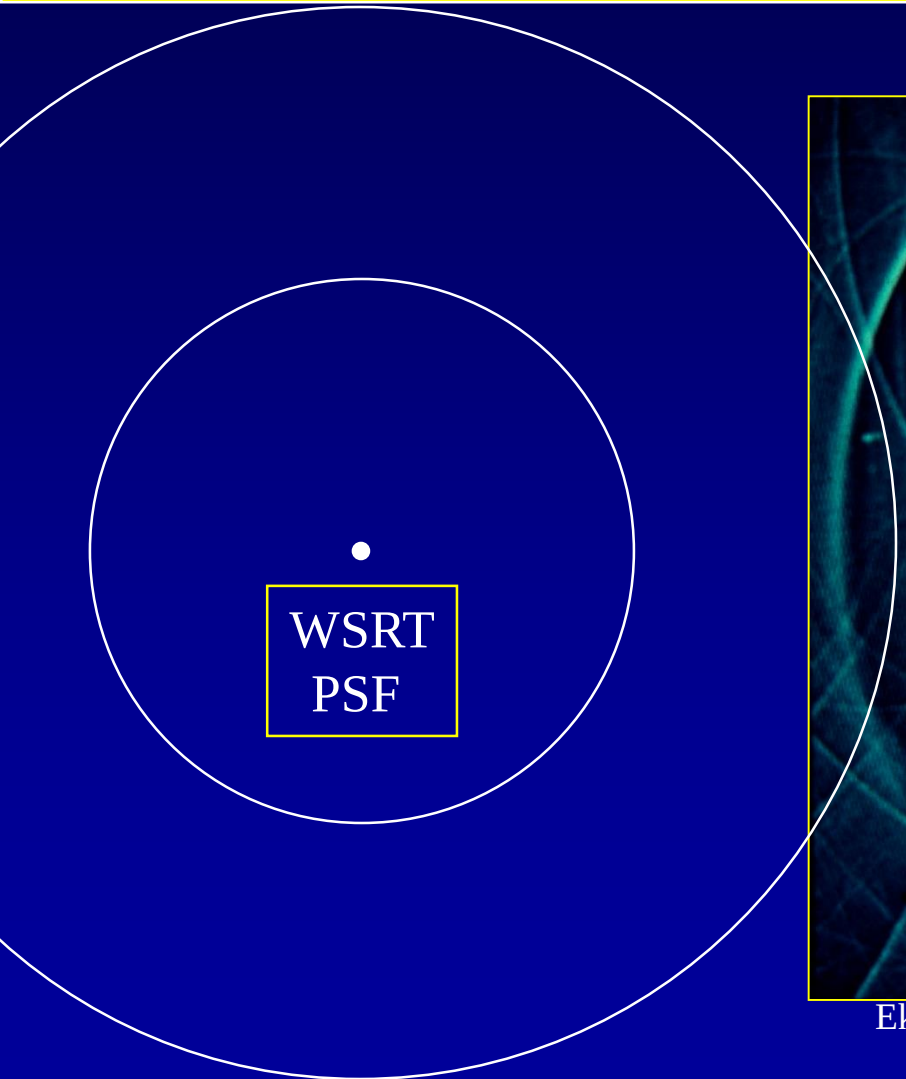

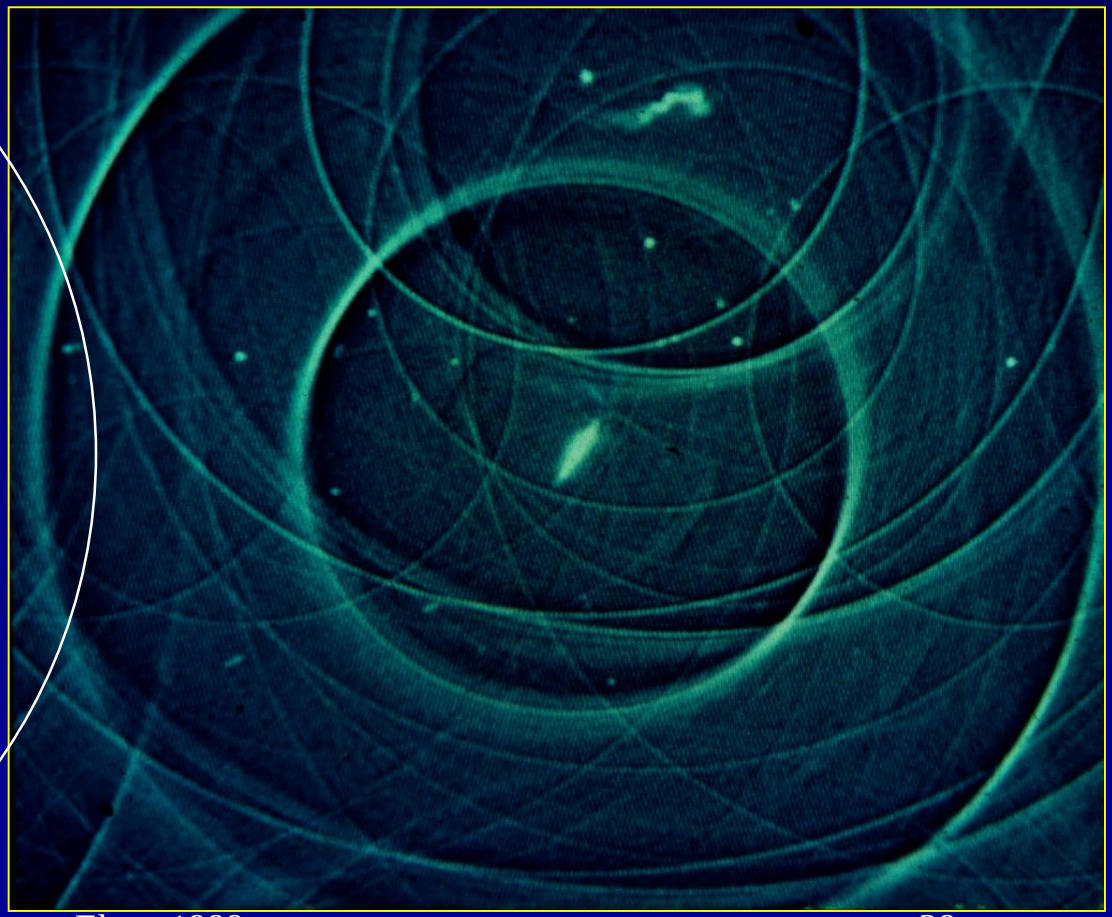

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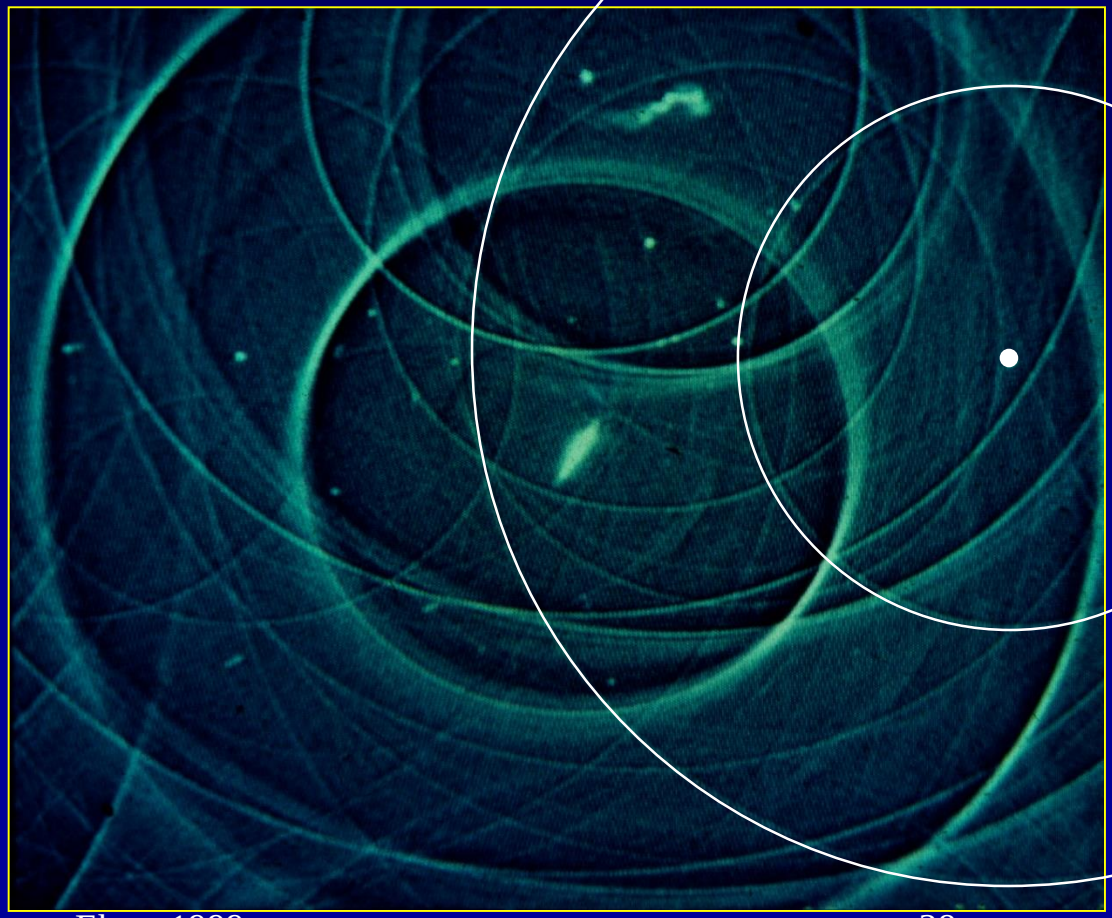
WSRT
PSF



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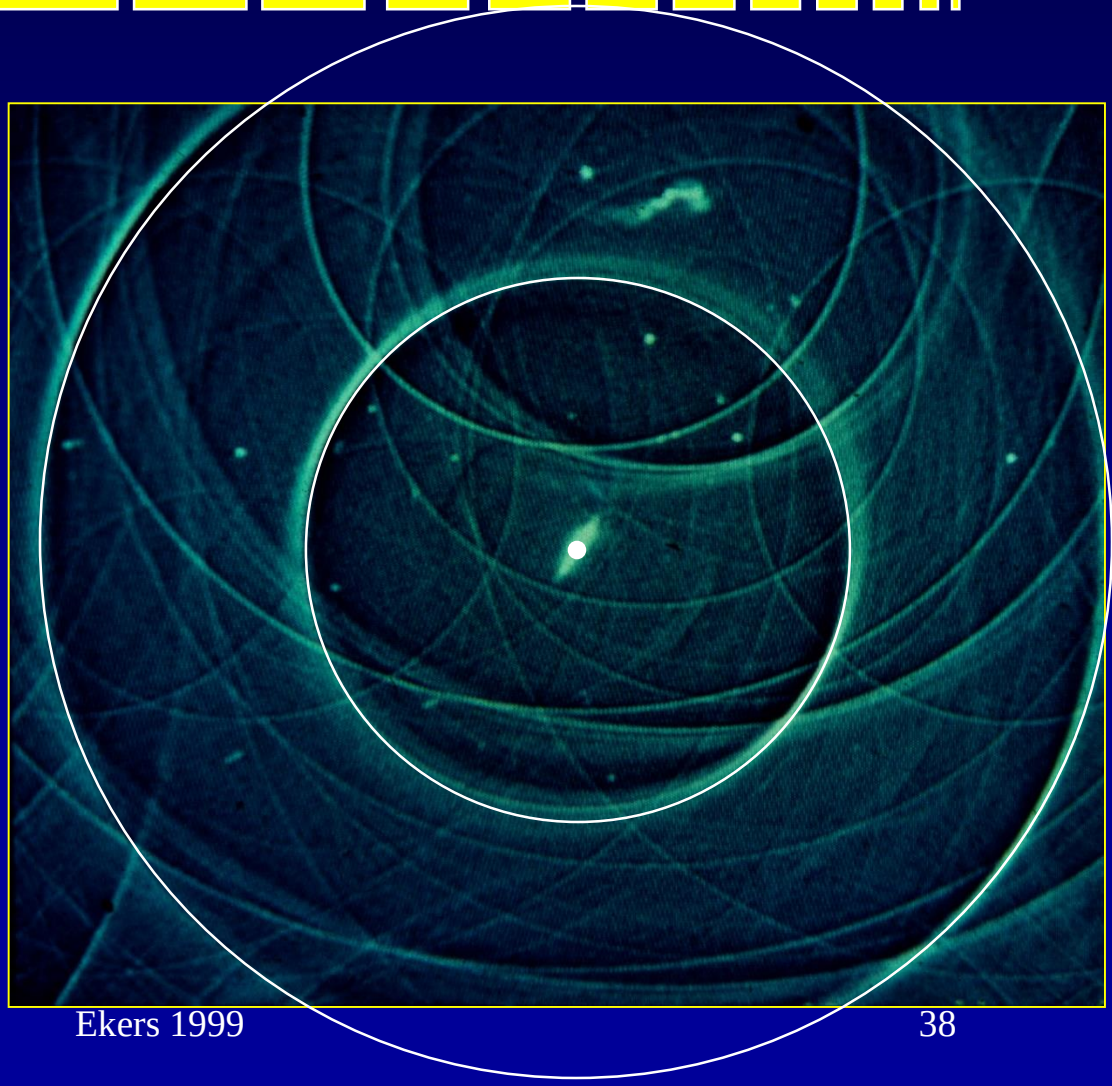
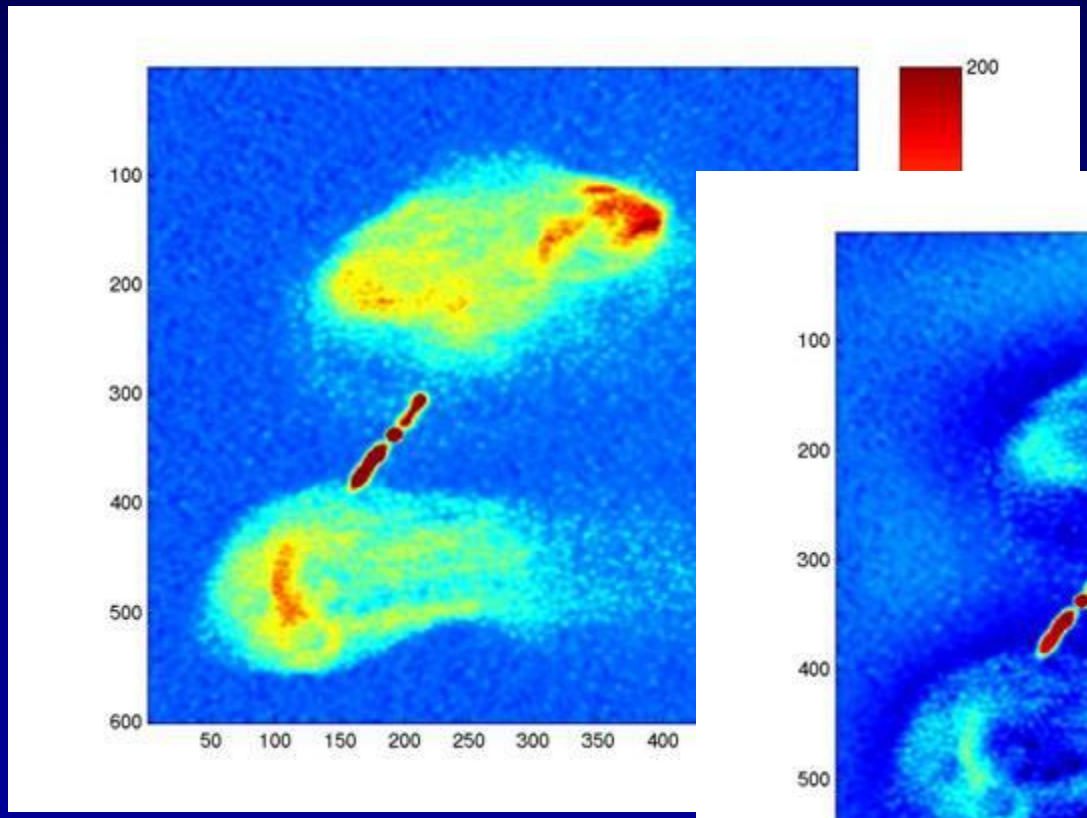


WSRT
PSF

UV coverage v Gain errors

- Both are multiplicative in UV plane
- Coverage errors multiply both the observation and coverage geometry (⇔ PSF or beam) by zero
  - ✓ They are corrected (interpolated) by the deconvolution algorithm
- Instrumental gain errors are not known a-priori so cannot be included in the beam
  - ✗ They are not removed by deconvolution
- Compare the pattern attached to the source with the beam
  - Beware resolution effects on the beam

Effect of missing short baselines



No short baselines →

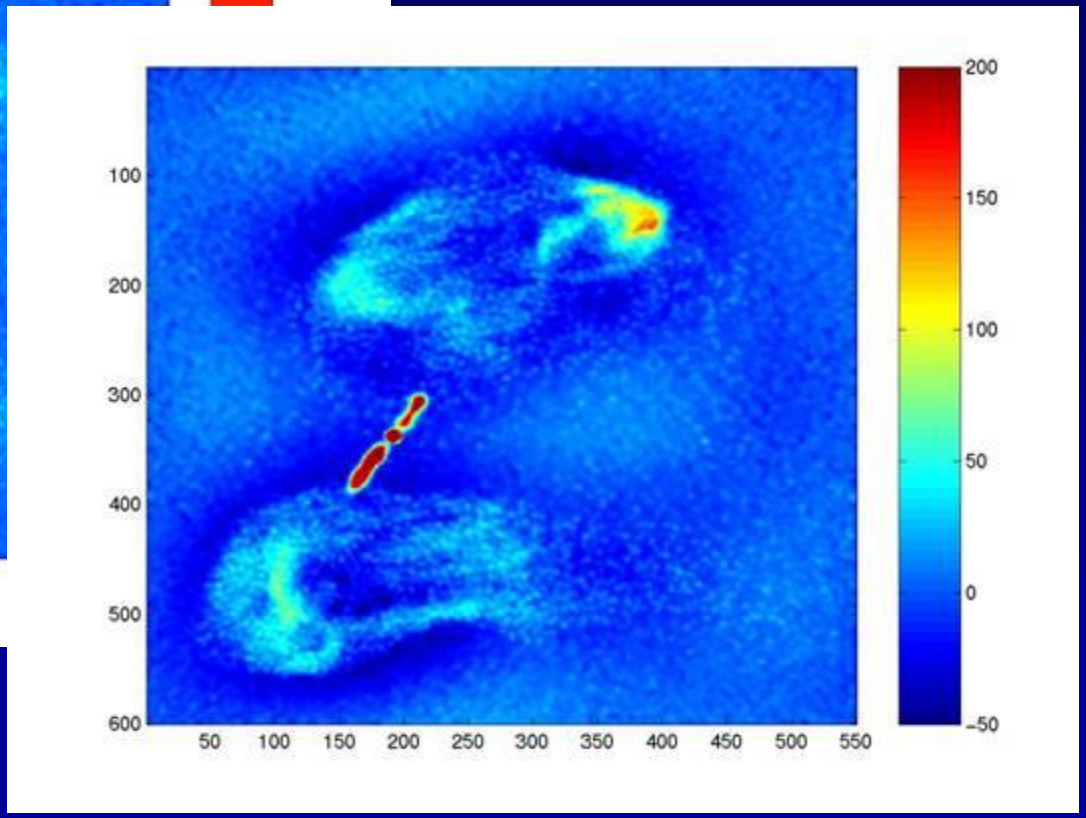
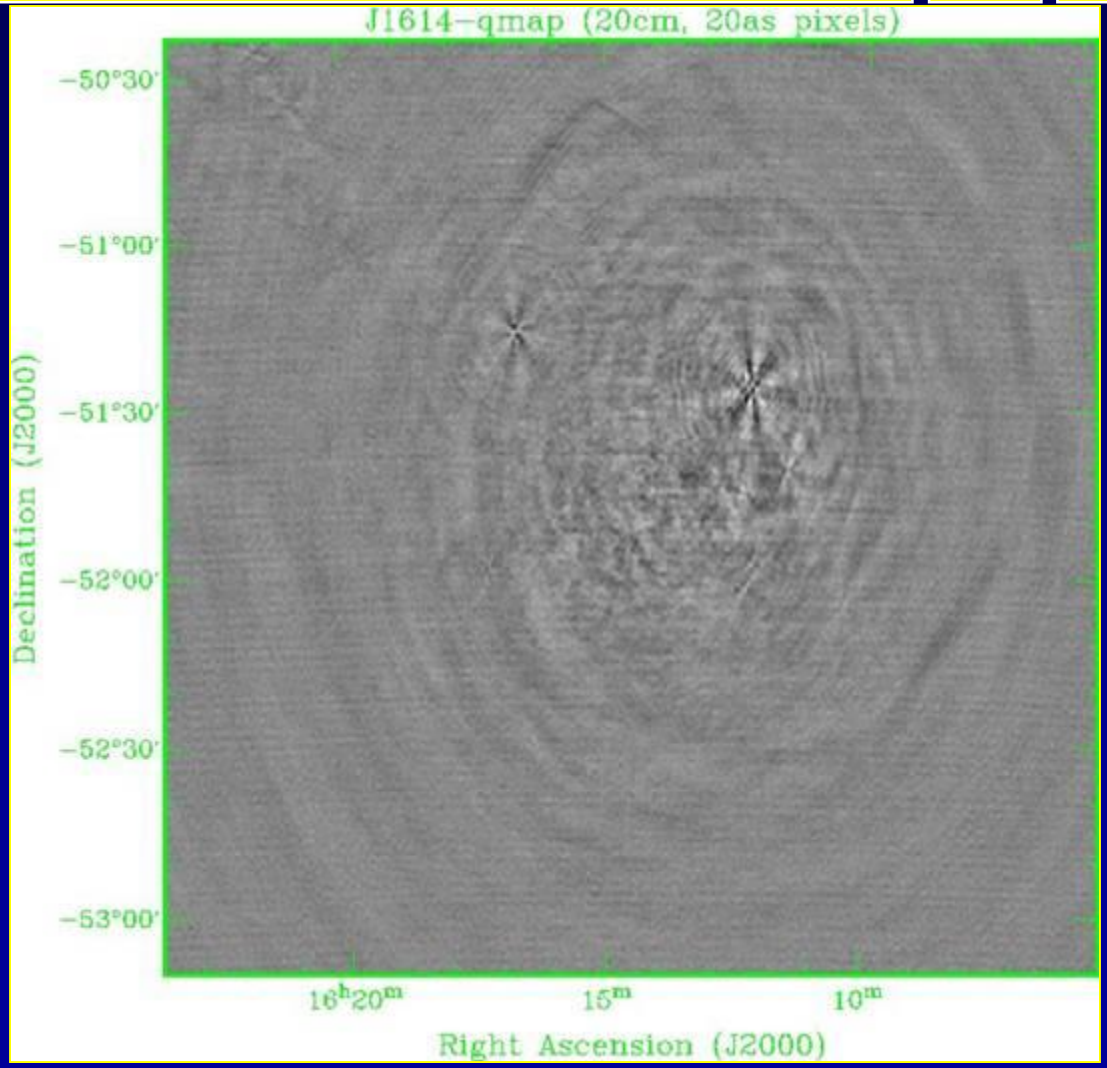


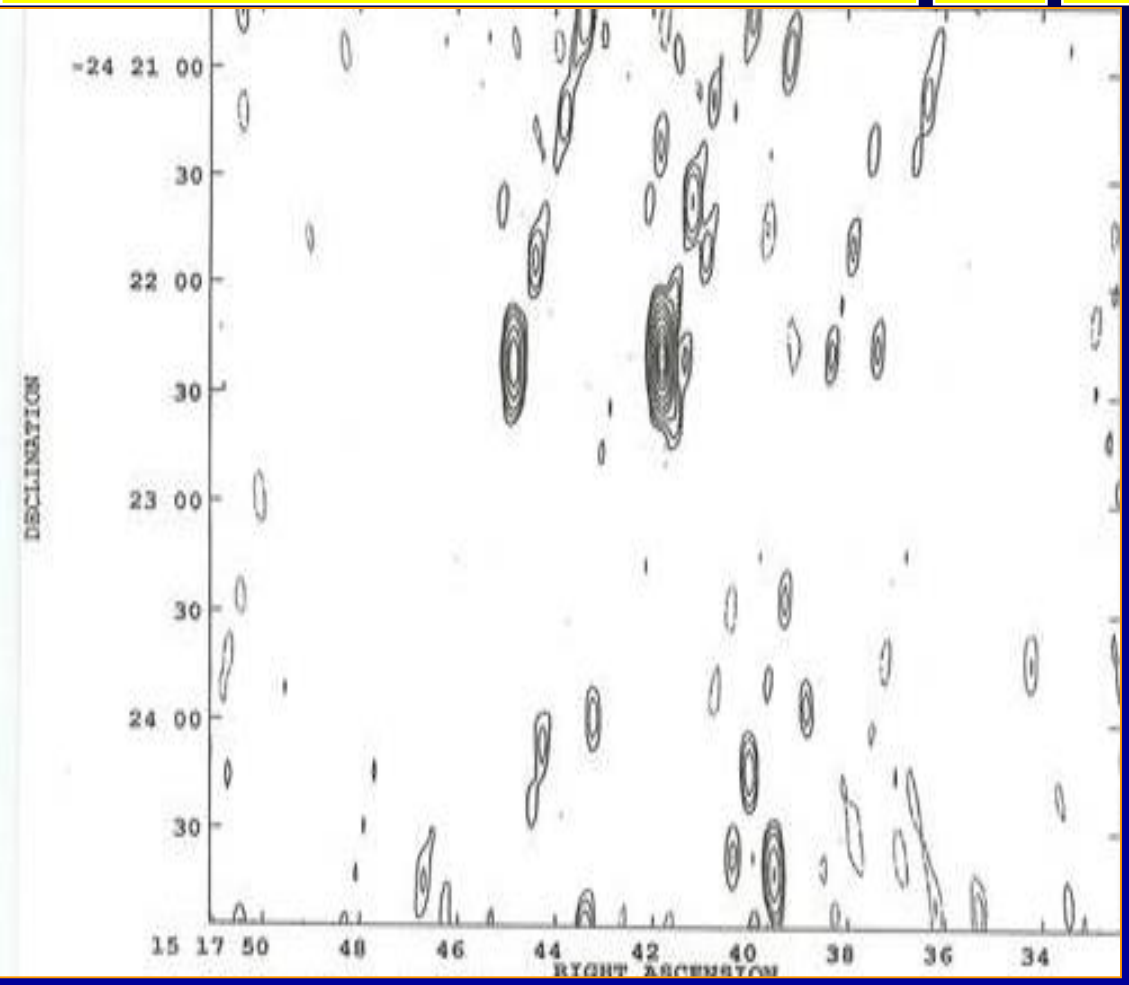
Image errors caused by rotation of the primary beam (alt-az telescope)



- Gain error in UV plane
- = Convolution in image plane
- Stokes Q image showing effect of off-axis instrumental polarization
- HII region in direction of the HESS gamma ray source

Robert Reinfrank

Non-linear processing errors - lack of constraints on image



- 2 ATCA snapshots
  - Only 30 visibilities measured

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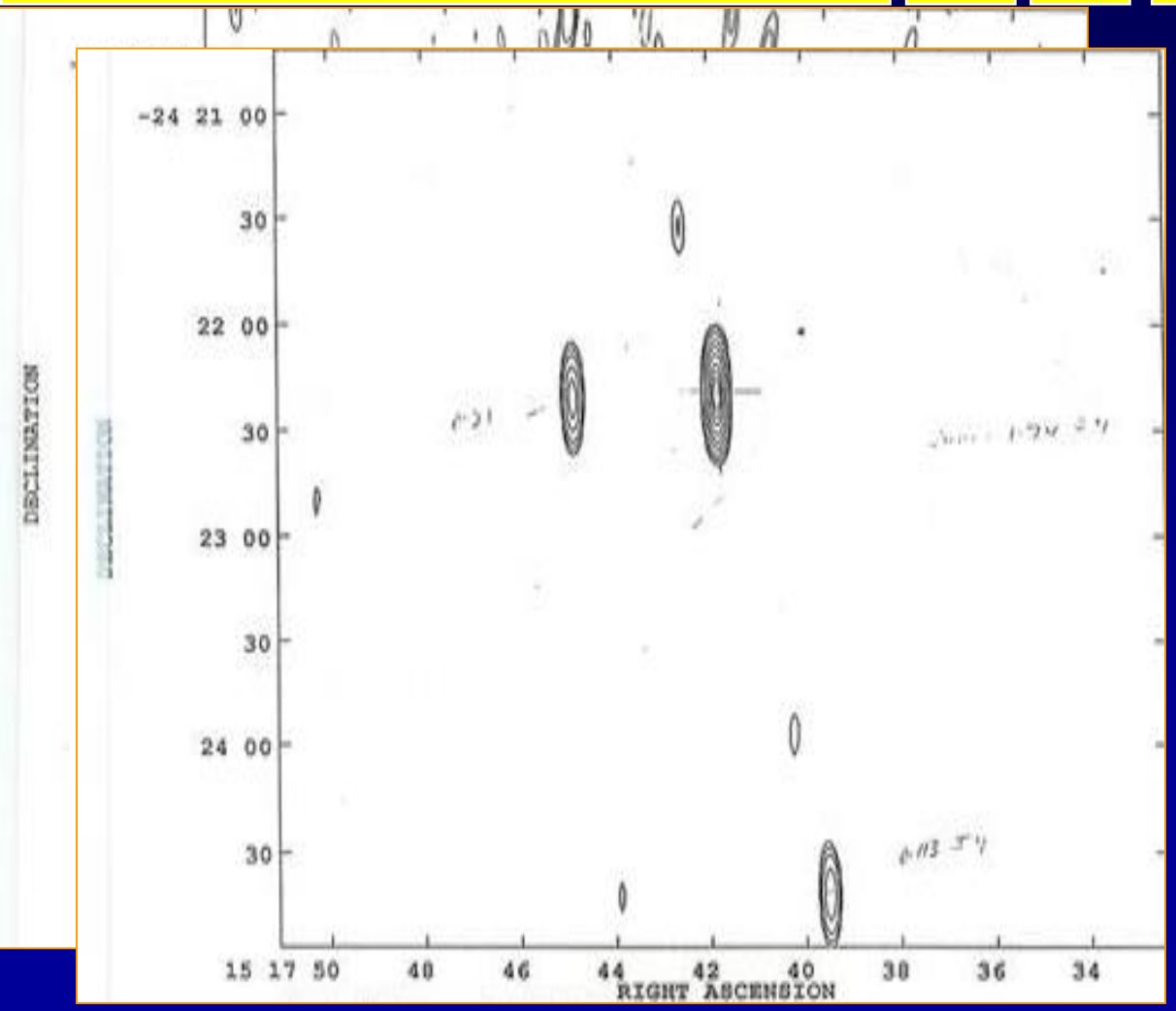

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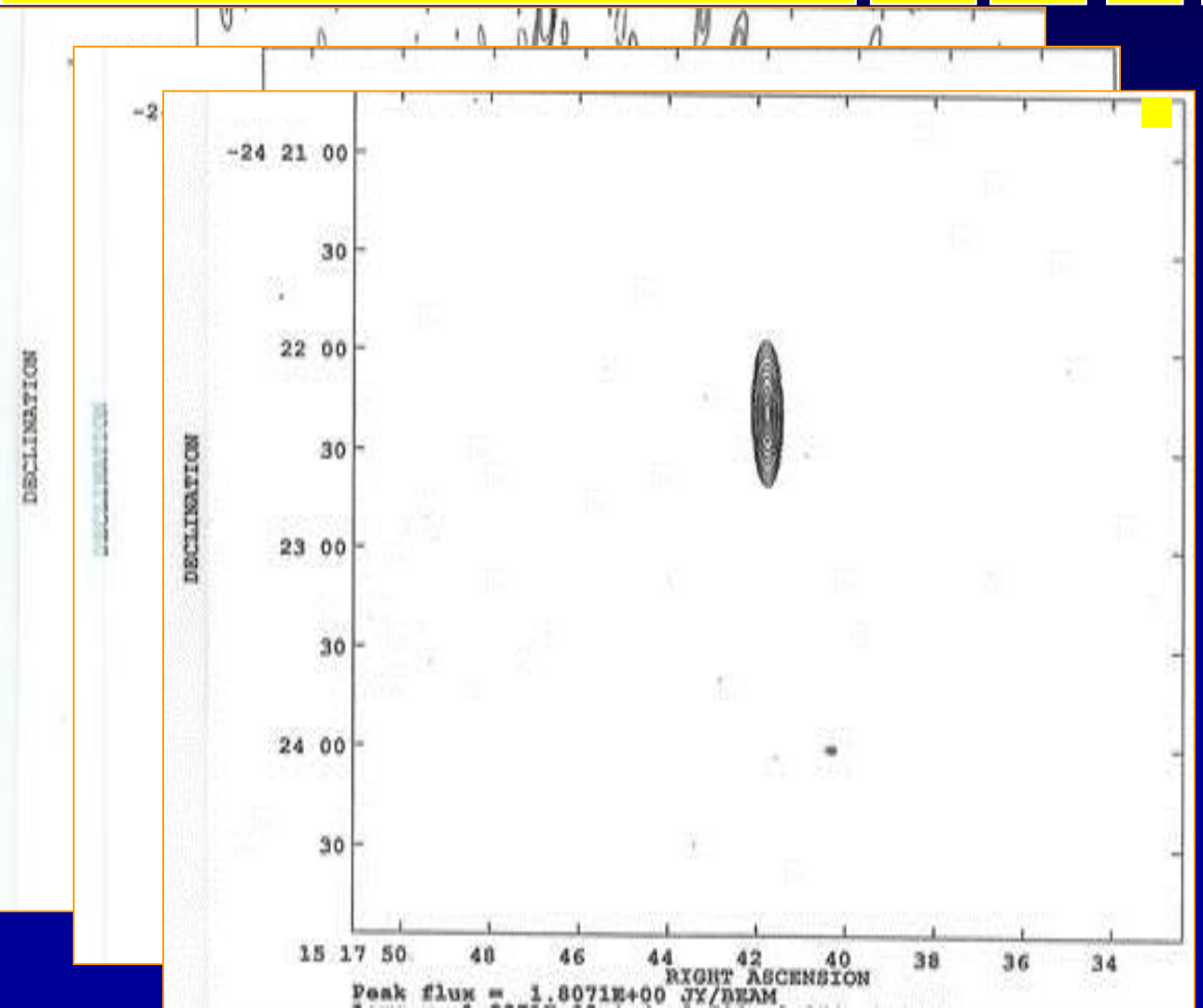


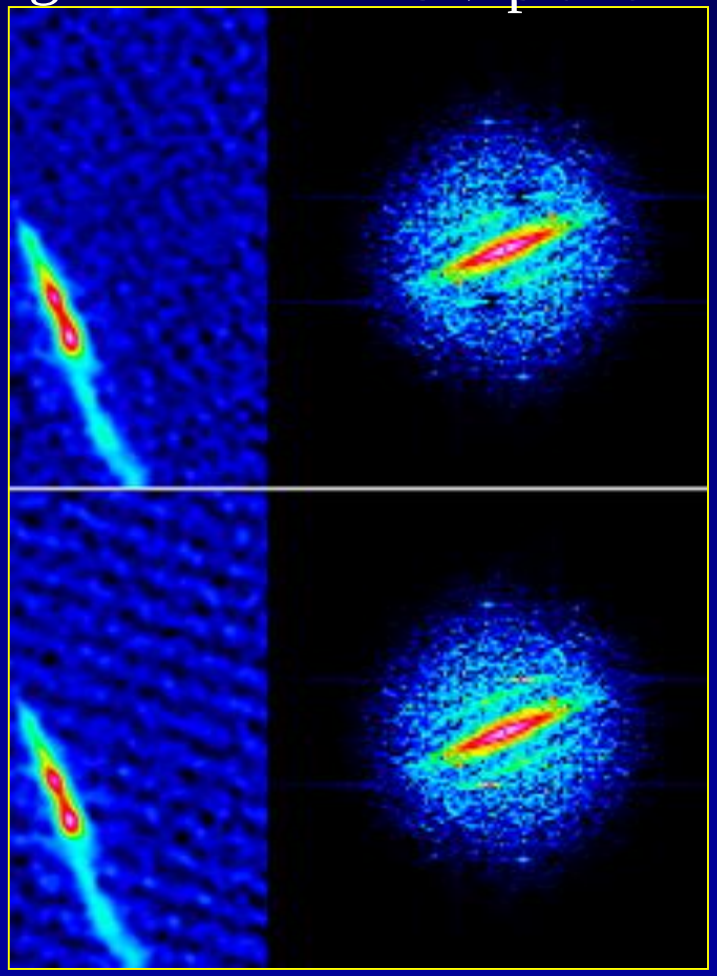
- 2 ATCA snapshots
  - Only 30 visibilities measured
  - Deconvolution interpolates 10^4 additional points
  - Selfcal adds 10 more degrees of freedom!
  - Use clean window
    - » This was just a point source!

Diagnostics

- Good image display
  - Negativity
  - Complex numbers
- Polarization
  - Make a V image
- Low resolution image of large field
- Source subtraction
- Fourier transform the image
- Statistics

IRAM-GIPSY
identify and edit a bad UV point

image UV plane



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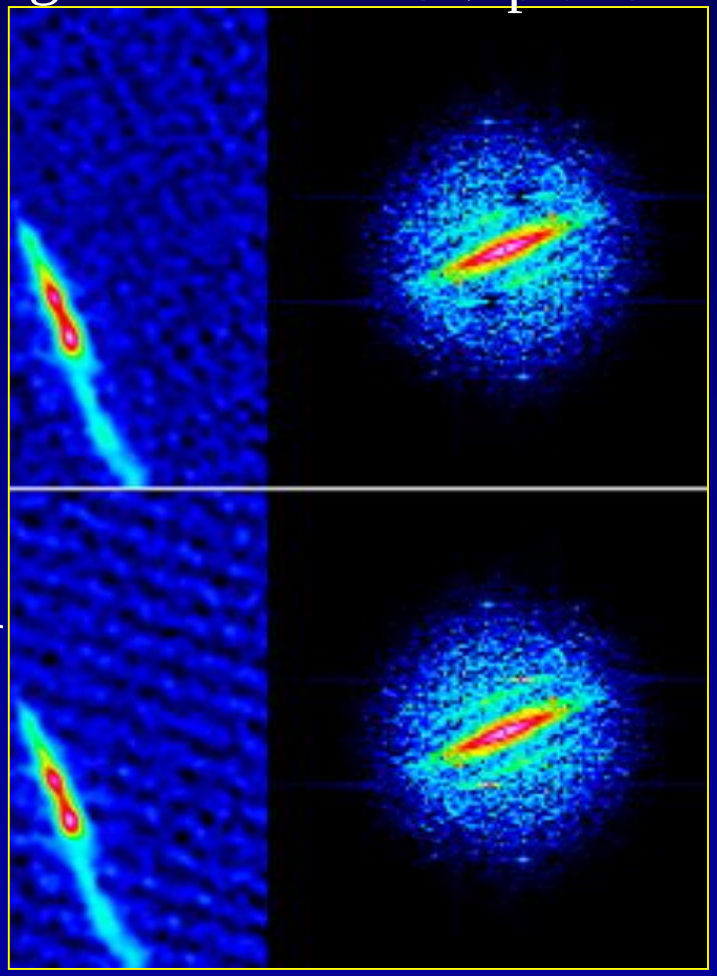

Stripes in image

IRAM-GIPSY
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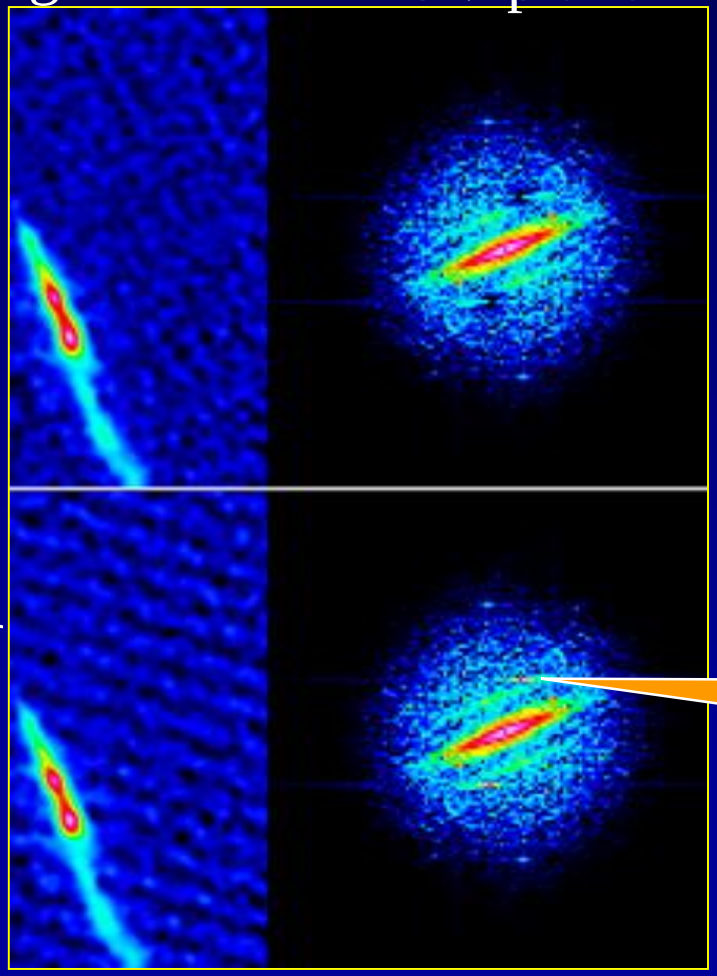

Stripes in image

Single bad point (& conjugate)

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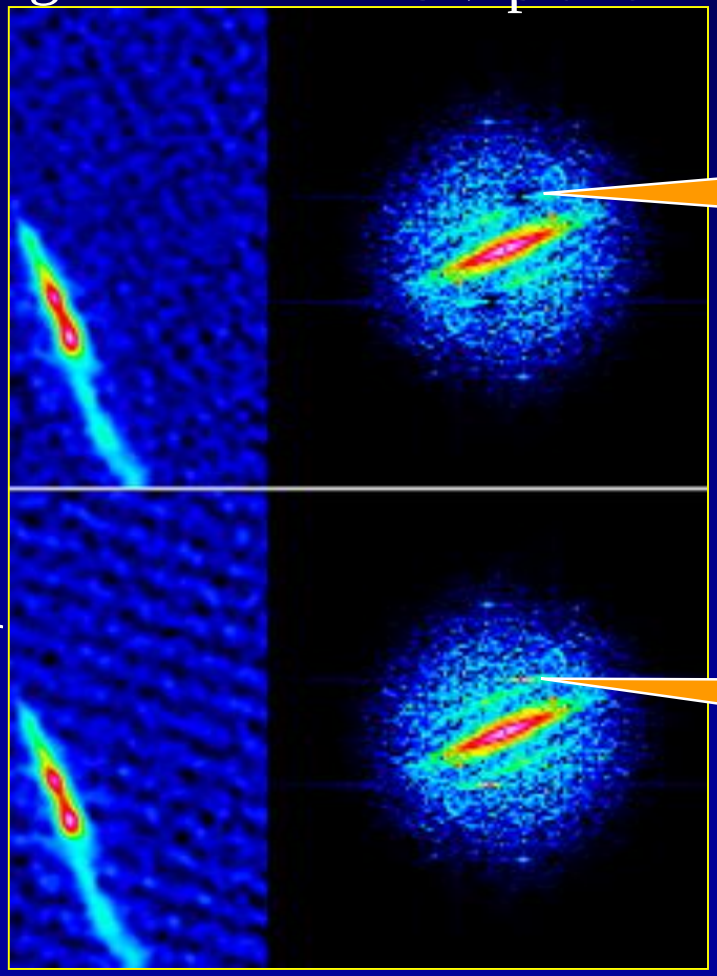
UV plane



Bad point removed

Stripes in image

Single bad point (& conjugate)

IRAM-GIPSY
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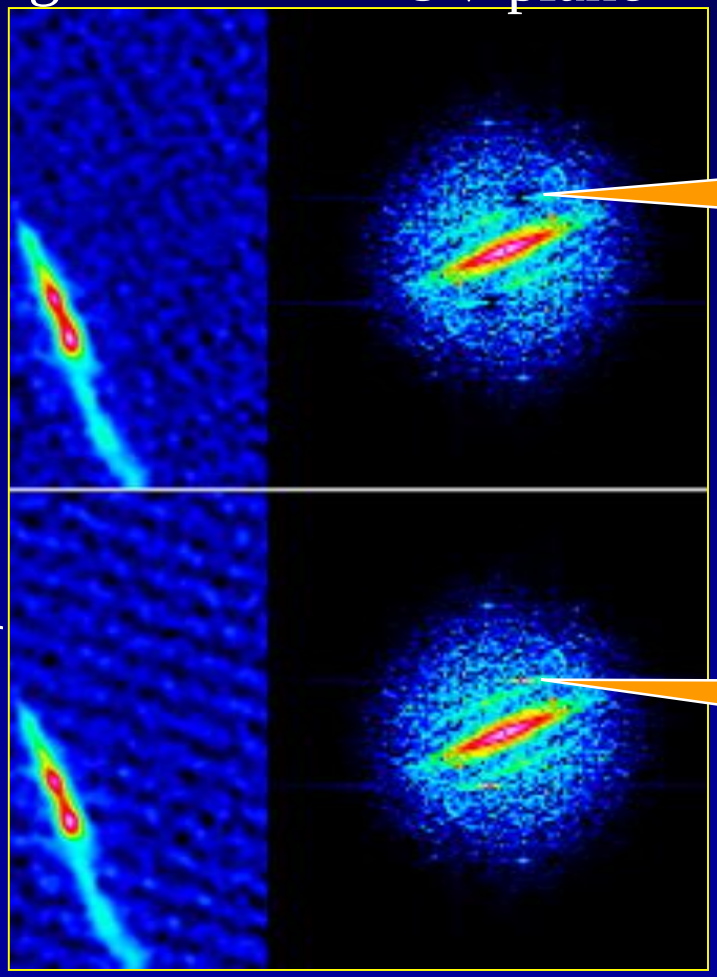
image

UV plane



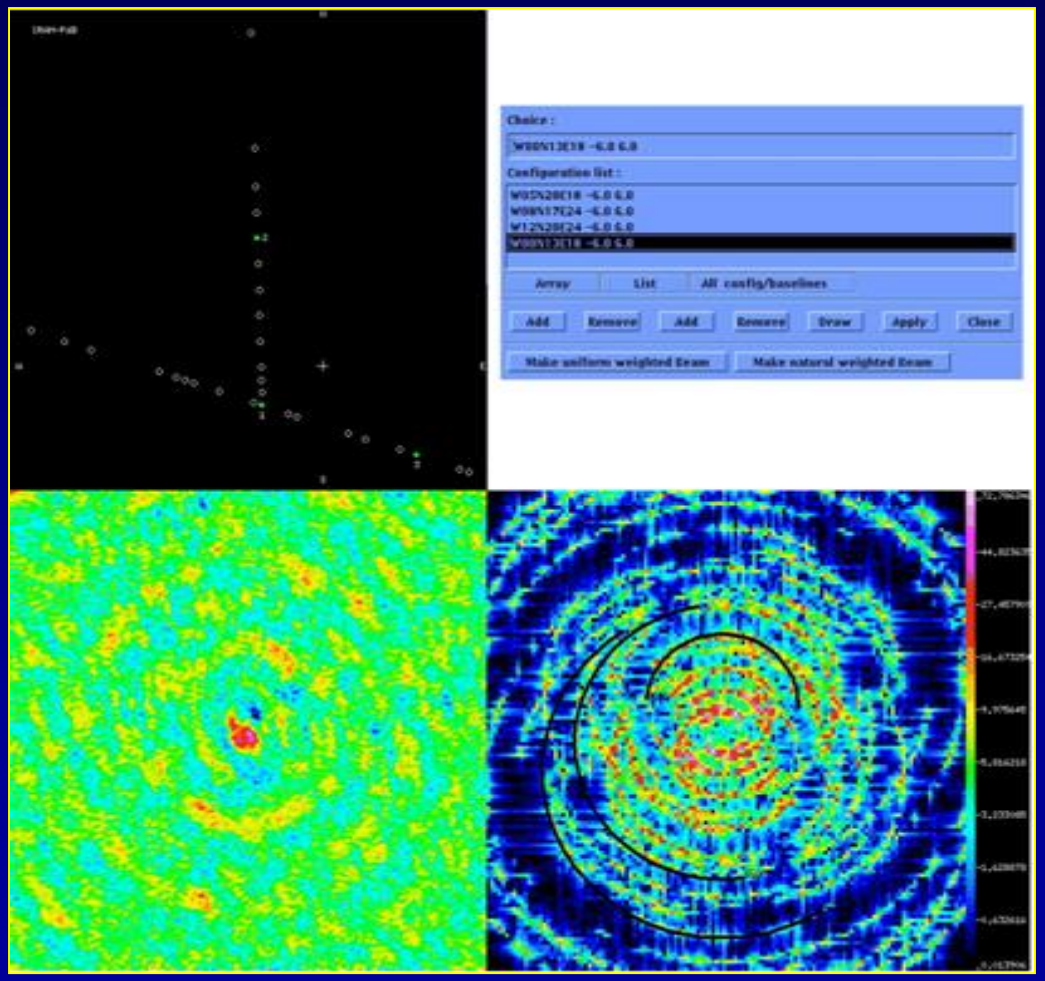
Stripes gone!

Bad point removed

Stripes in image

Single bad point (& conjugate)

IRAM-GIPSY
identify a bad antenna pair



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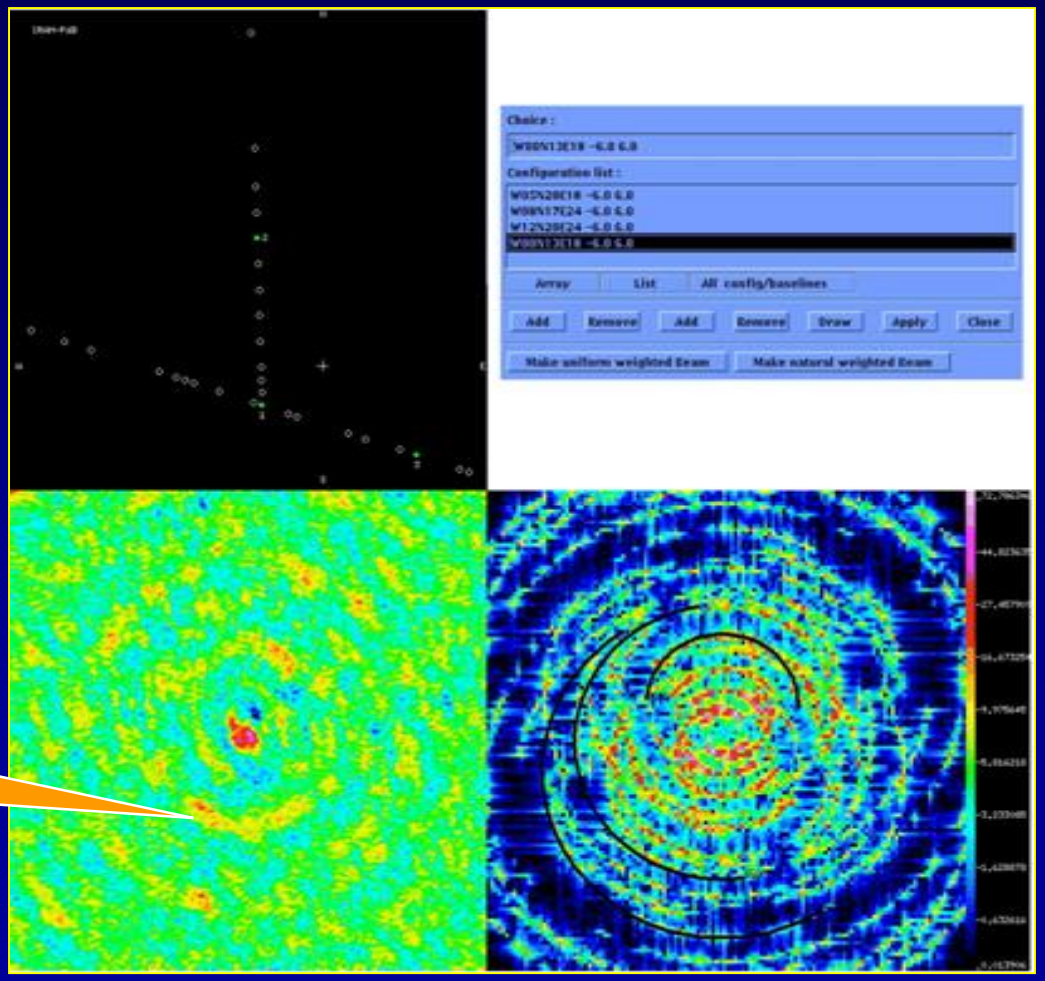

Errors in image

IRAM-GIPSY
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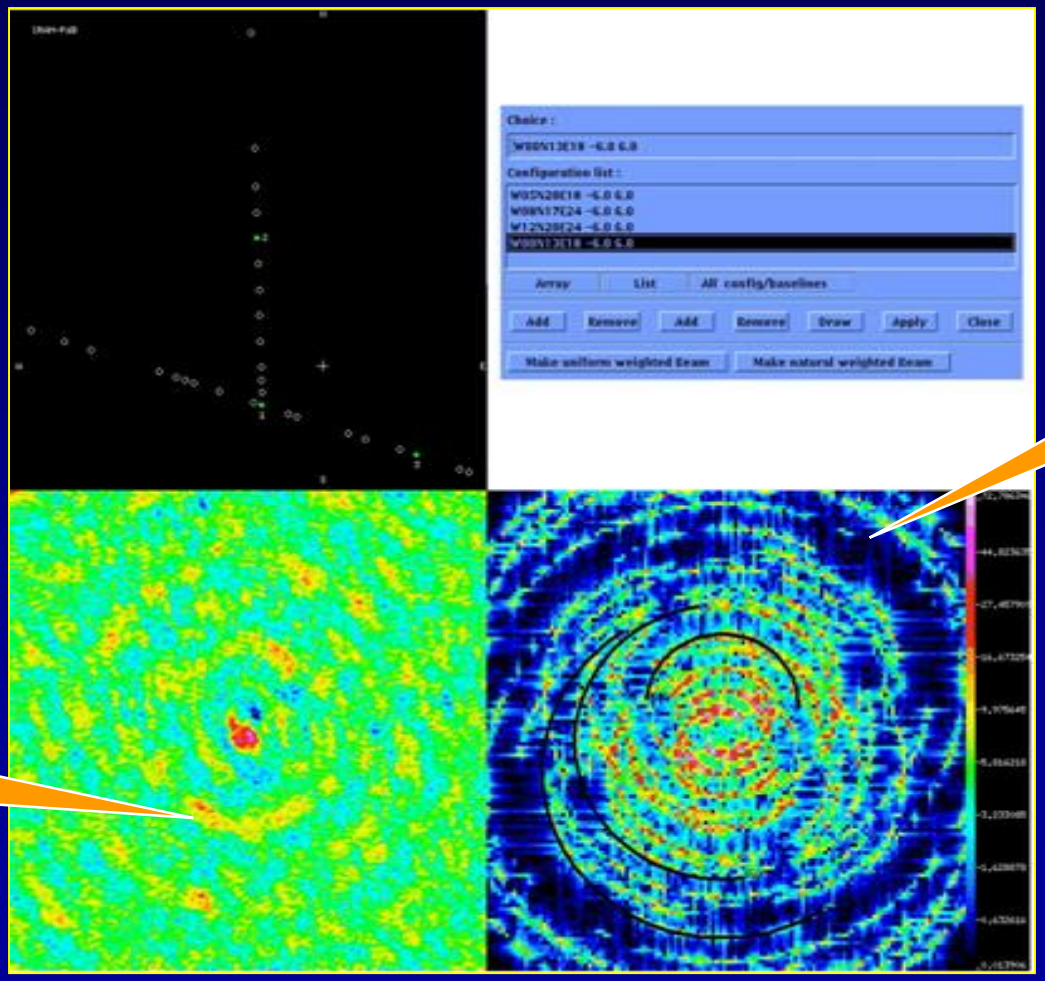
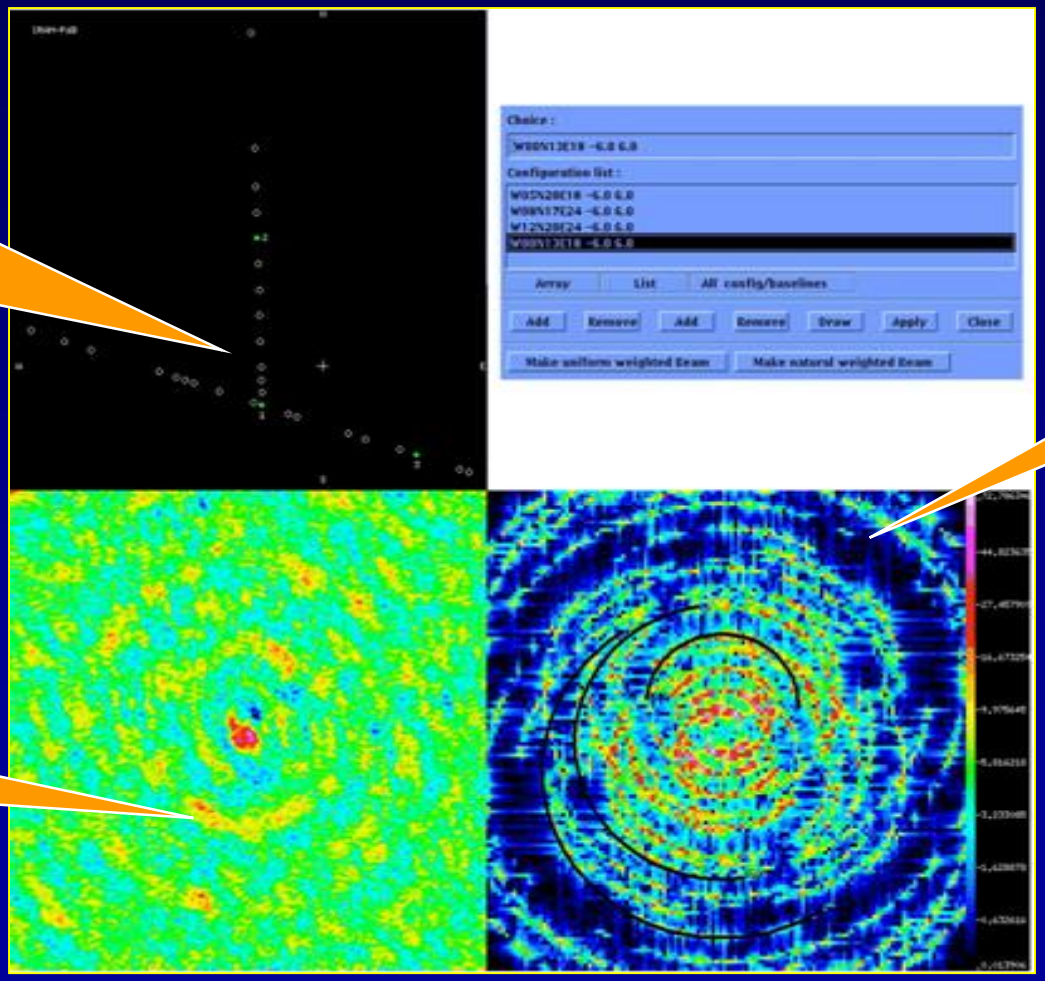


IRAM-GIPSY
identify a bad antenna pair

IRAM array with some antenna pairs selected



Fourier transform of image

Errors in image

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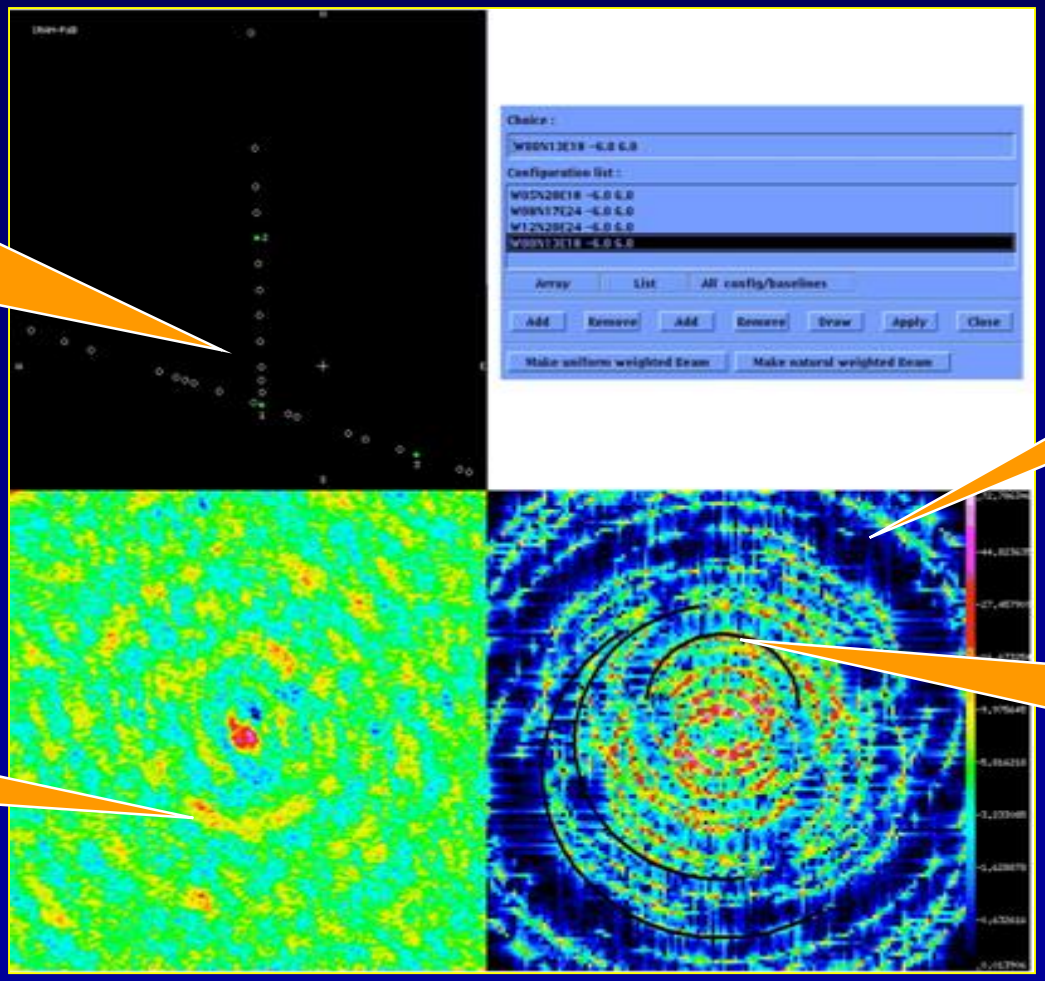


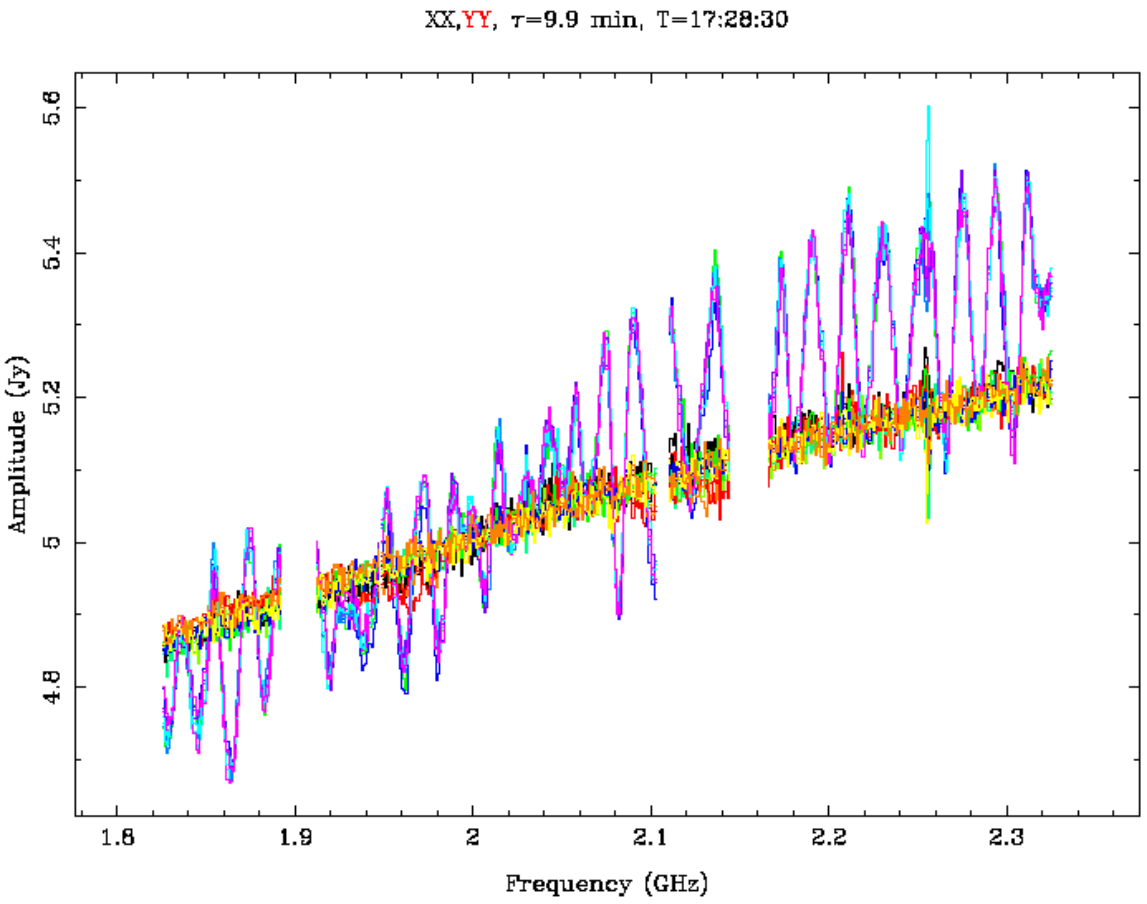
Fourier transform of image

Errors in image

Plot baselines for specific antenna pairs

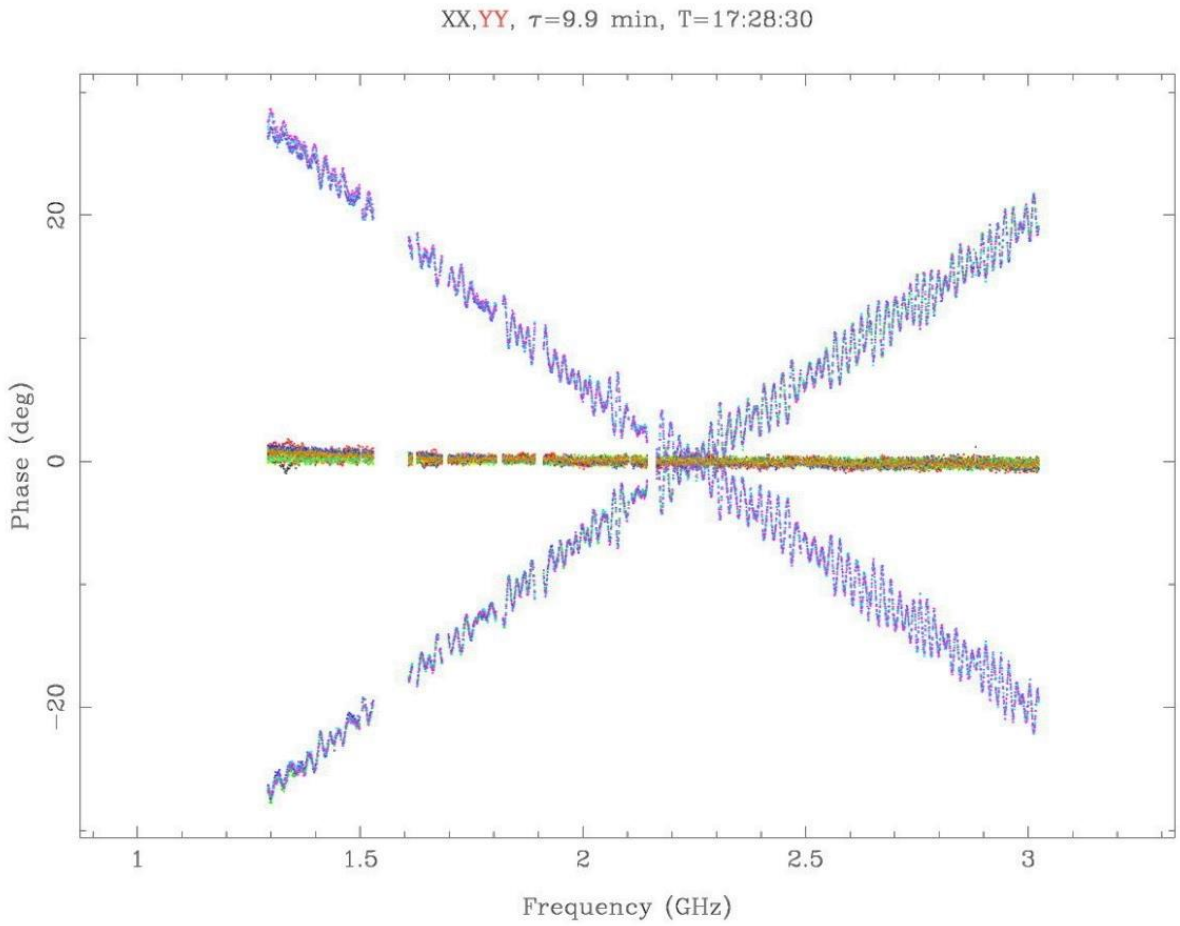
Diagnosing an Error ATCA amp v freq plot

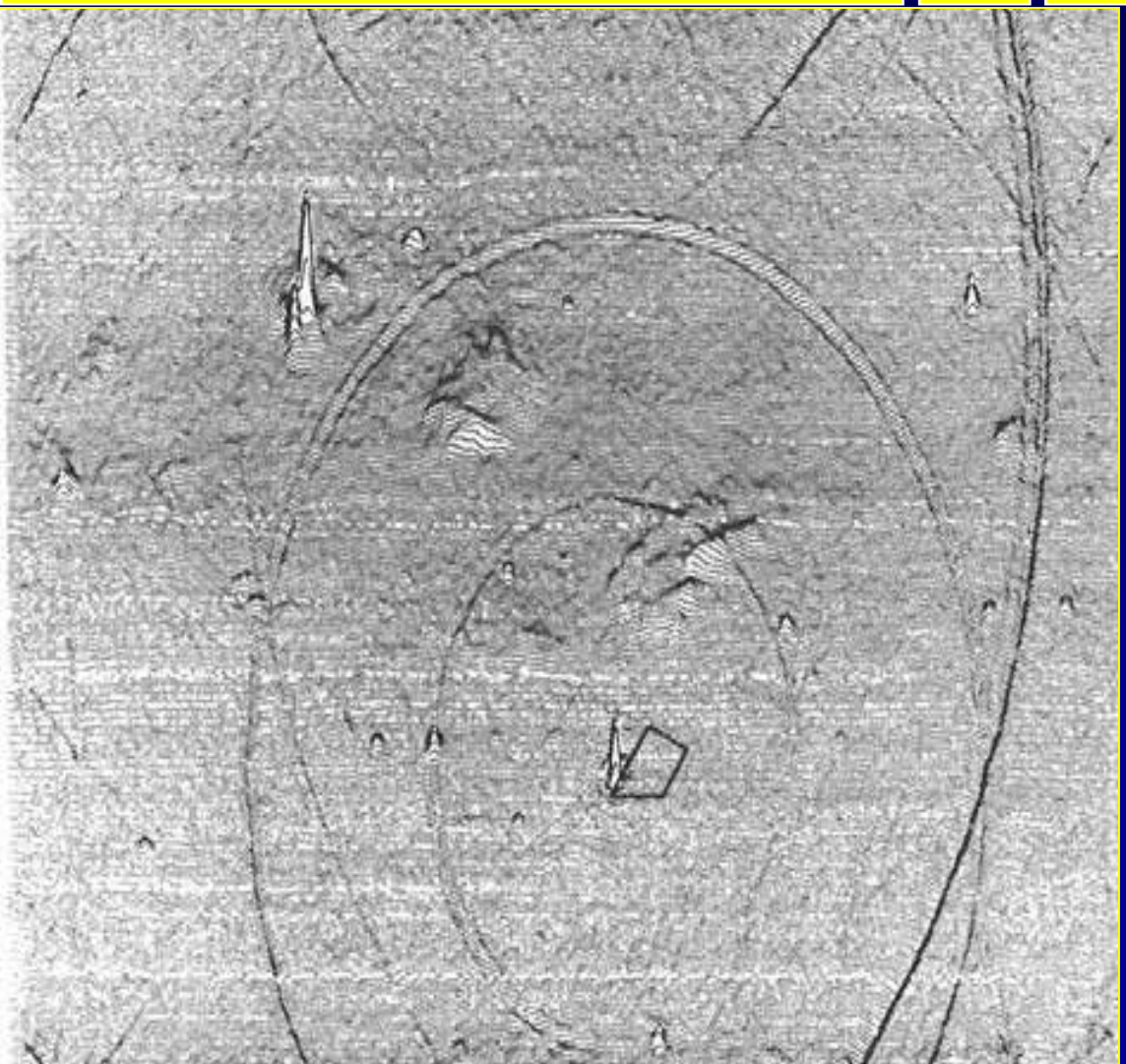
- Vanessa Moss: GPS source 1718-649
- Baselines coloured
- Error in antenna 3 only
  - So can't be confusion



Phase v Frequency

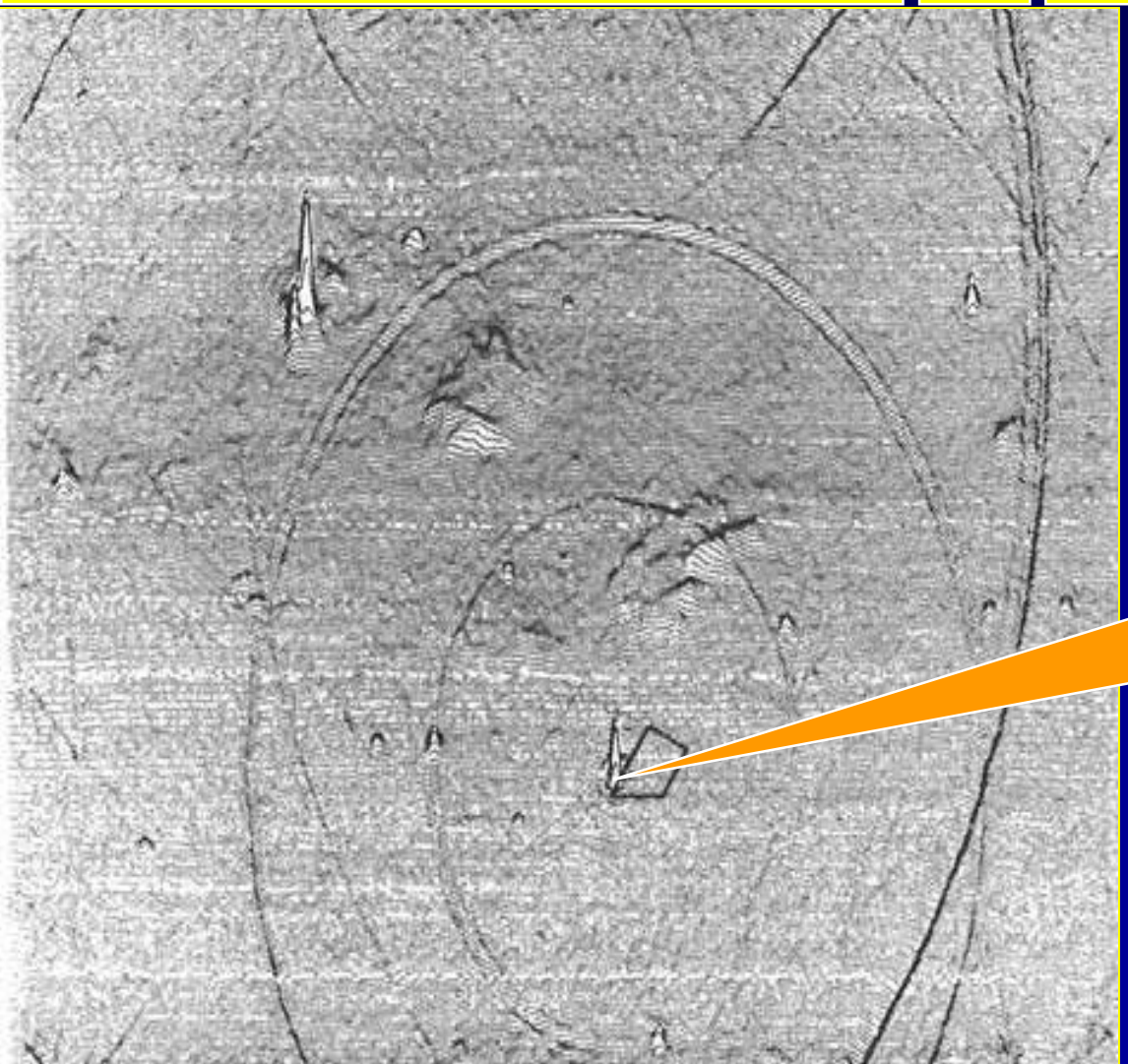
- Vanessa Moss: GPS source 1718-649
- This is a delay error
  - Dcal failed to find correct solution
- Cant always be corrected in post processing





- WSRT 21cm
- Braes and Miley (1972)

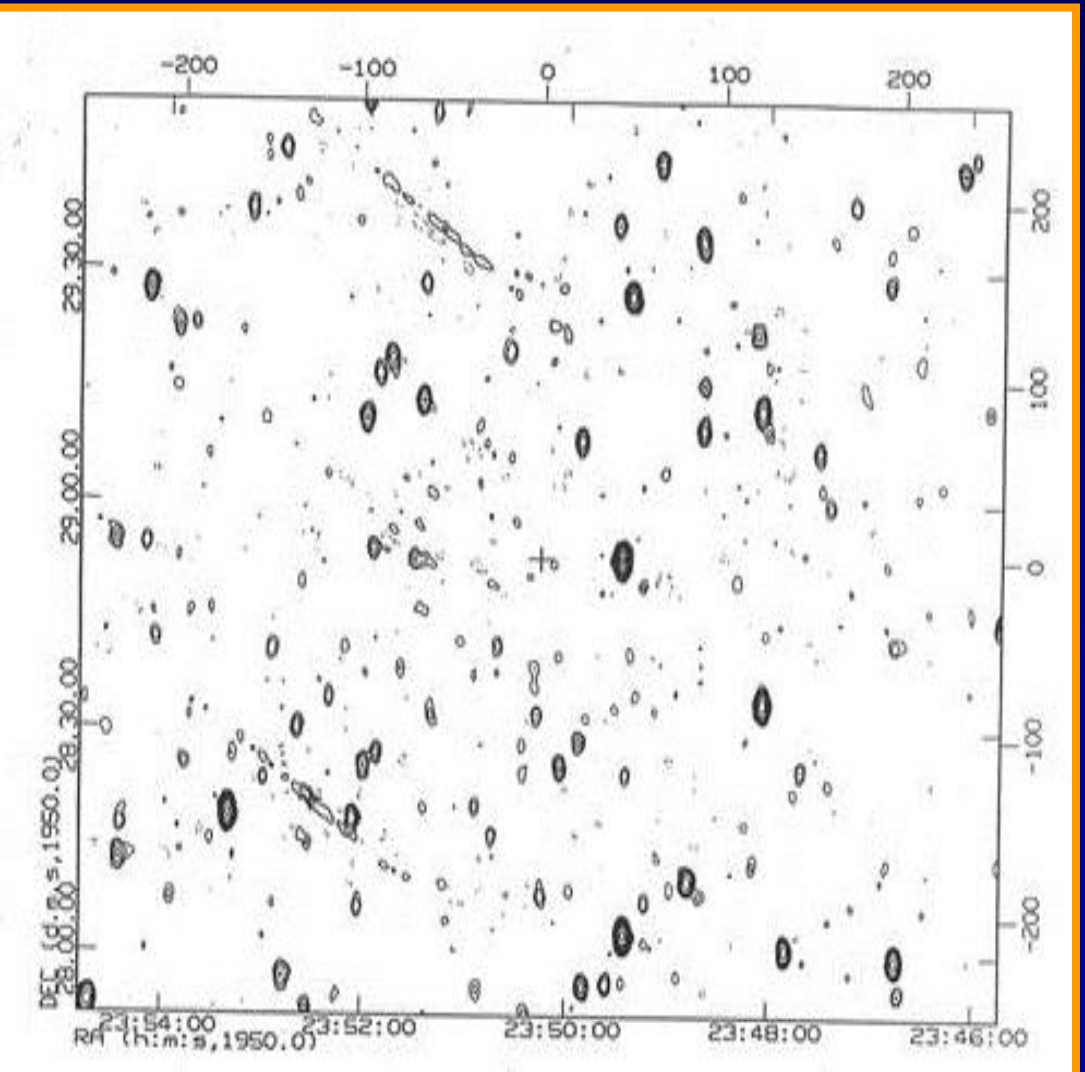
Discoveries
Radio emission from Cyg X2



- WSRT 21cm
- Braes and Miley (1972)

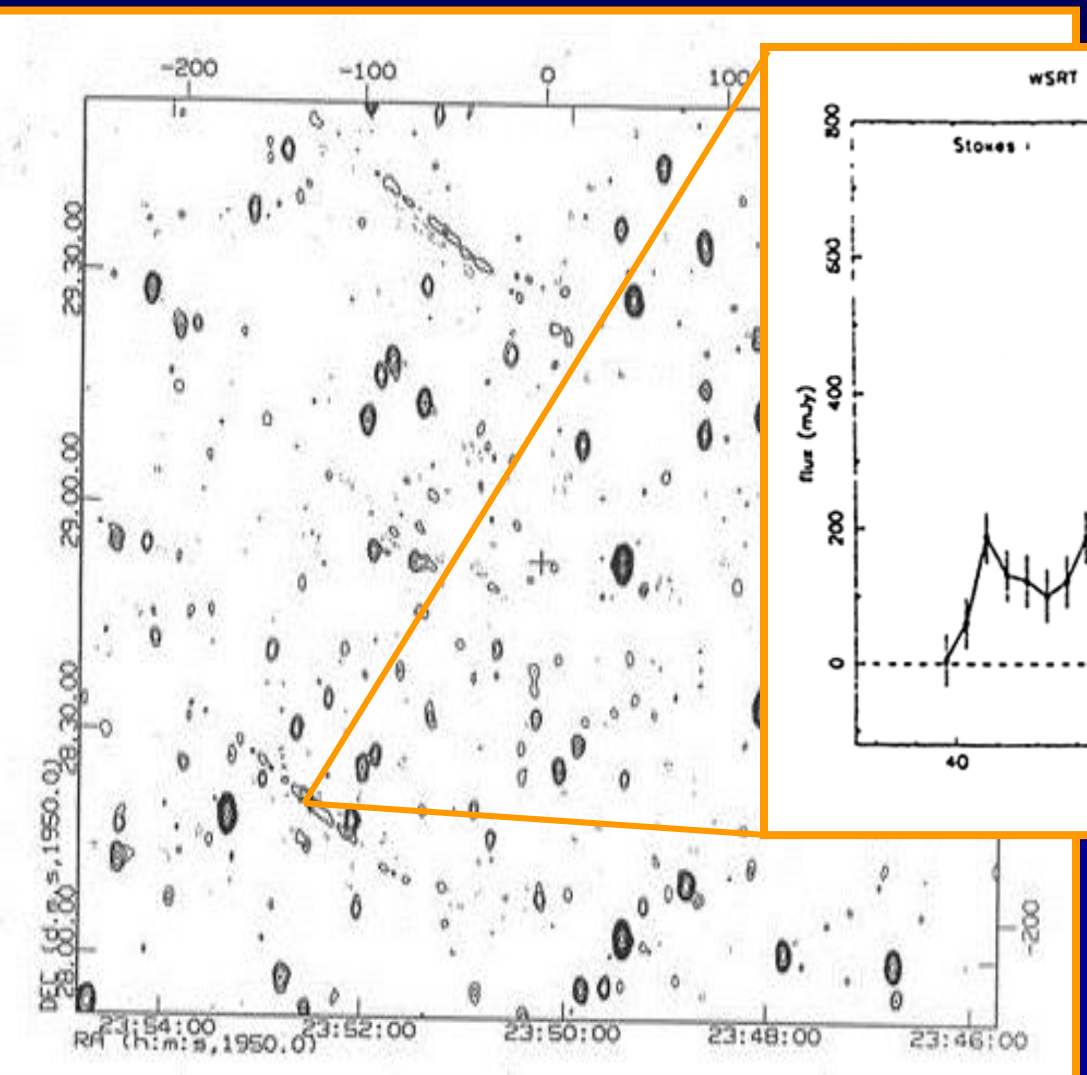
Variable source only present in 1 day of a 4 day synthesis

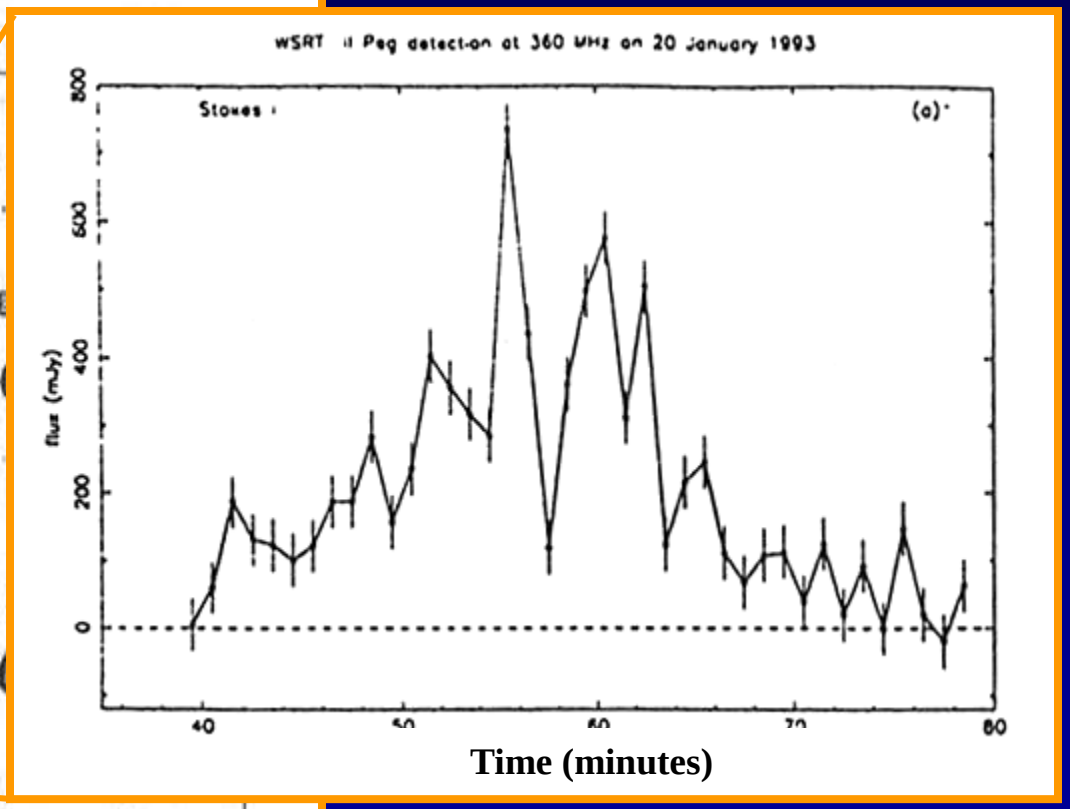
Discoveries
Flare in RS CVn system II Peg



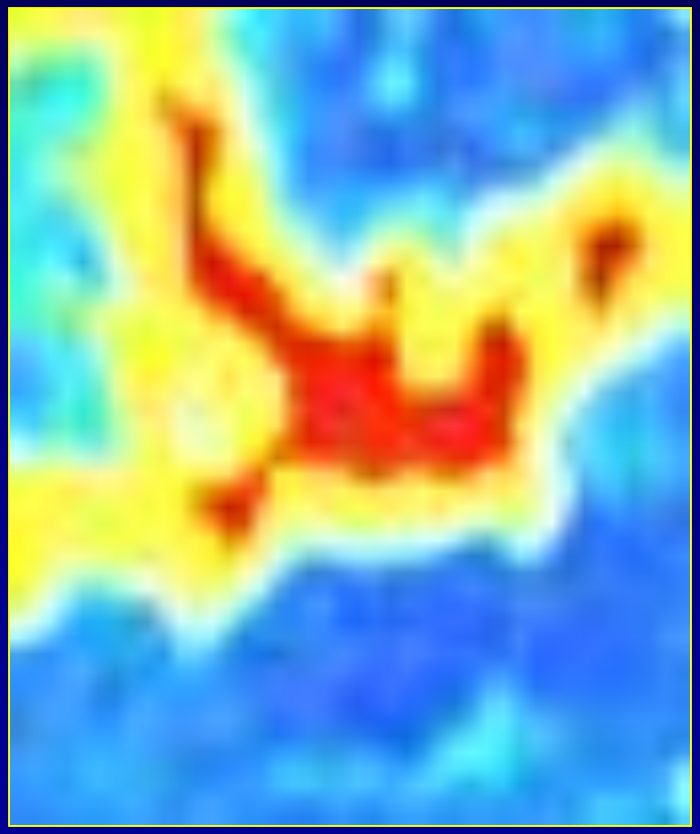
– WSRT 83cm

Discoveries
Flare in RS CVn system II Peg



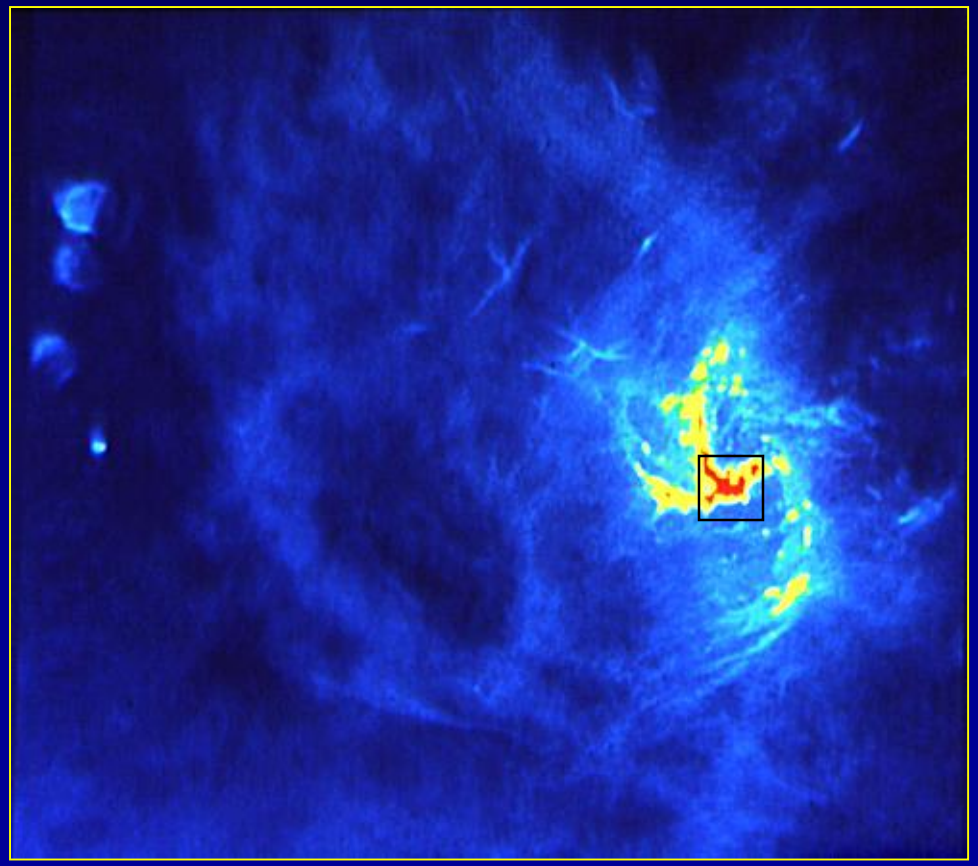


Galactic Centre



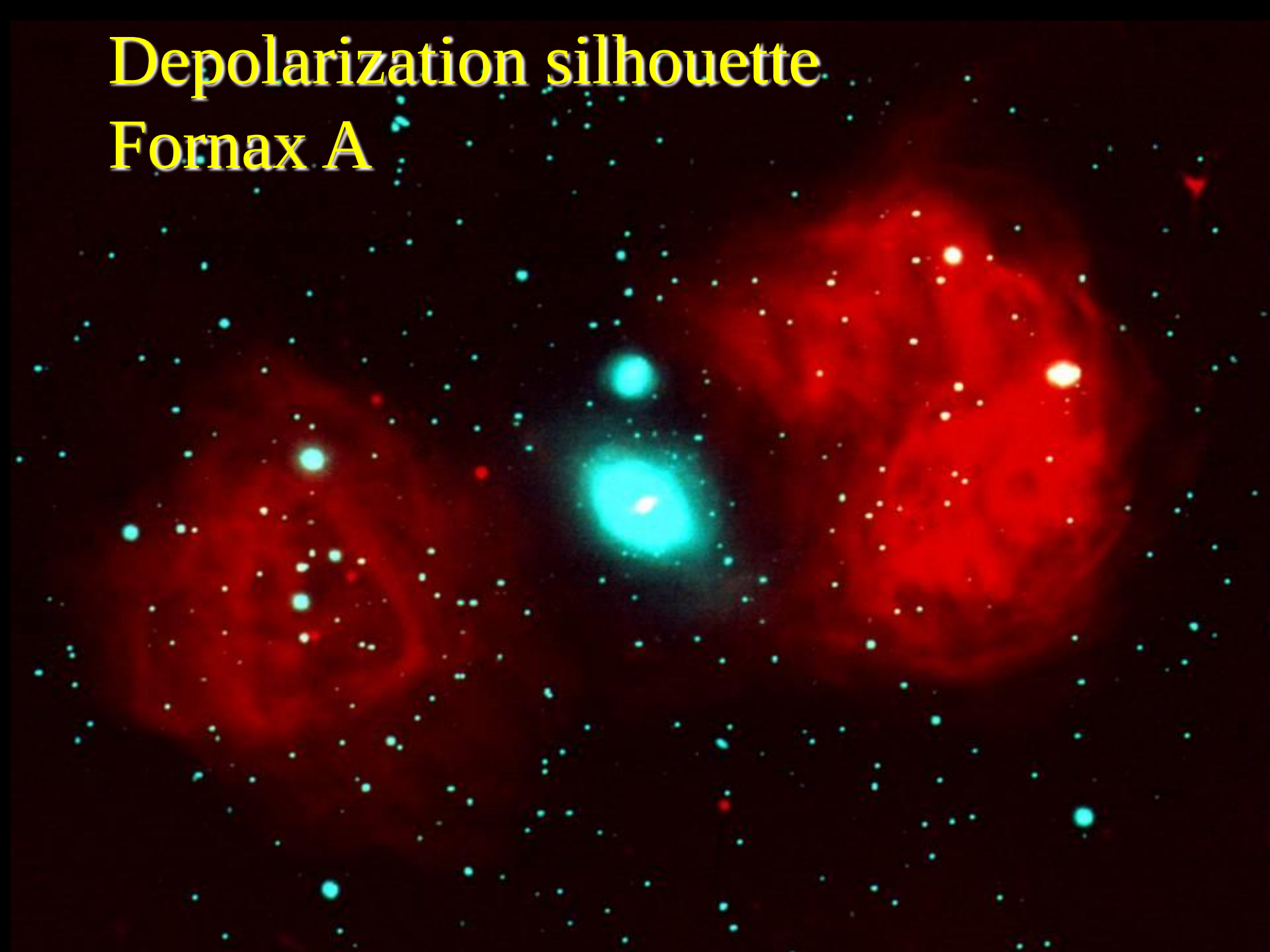
- VLA 6cm
- Big picture missed by first observers

Galactic Centre

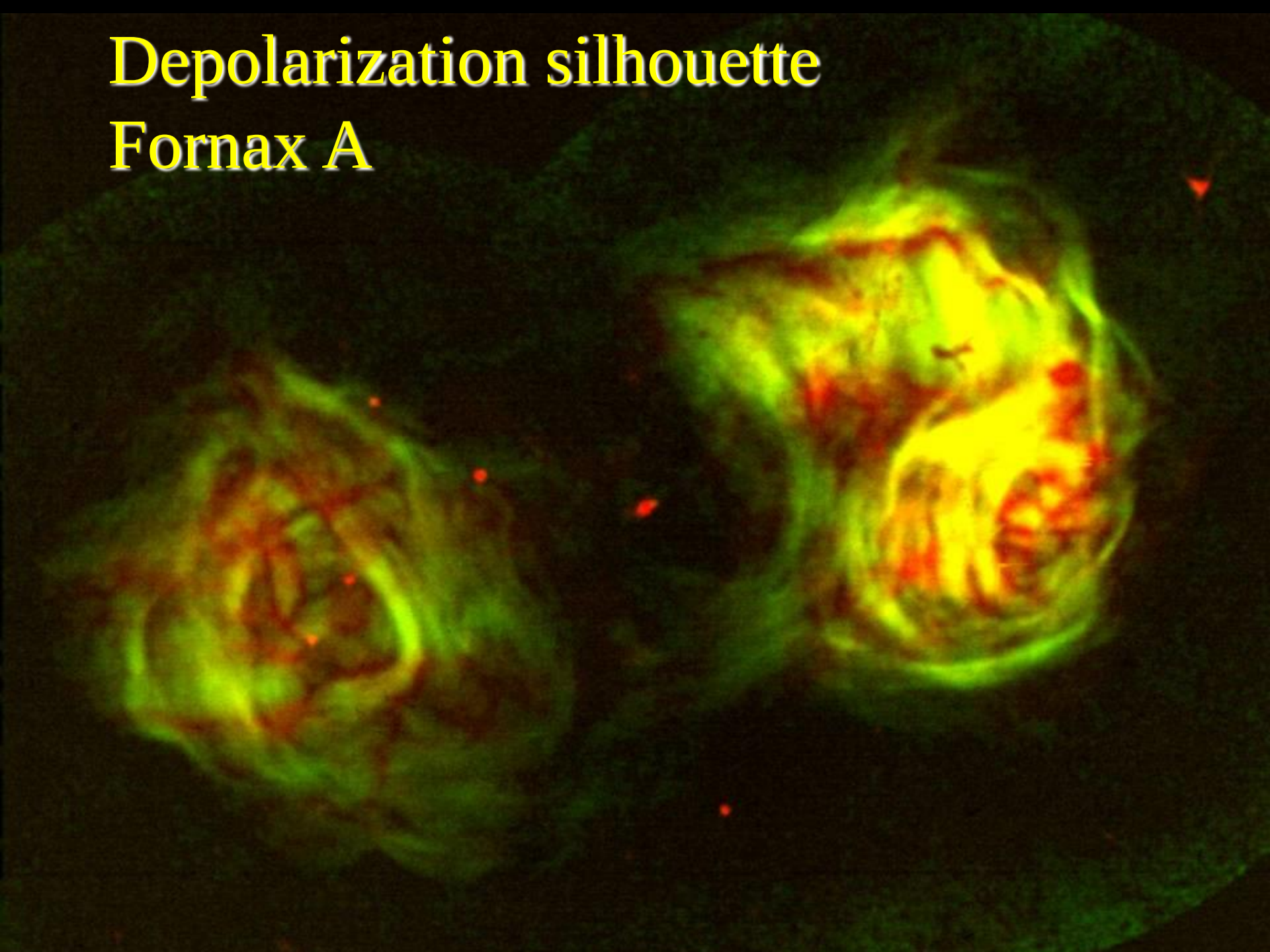


- VLA 6cm
- Big picture missed by first observers
- Too much resolution too small FOV

Depolarization silhouette
Fornax A



Depolarization silhouette
Fornax A



Summary

- effect in image depends on effect in *uv* plane or time stream
  - understand the properties of the Fourier transform
  - errors may be additive, multiplicative, radially dependent
  - move between image and *uv* plane
- effective editing
  - know expected noise levels, gauge severity in image
  - edit calibration scans carefully
  - image the full beam to look for confusing sources or RFI
  - use good visualization tools
  - know the effects of the imaging & calibration algorithms