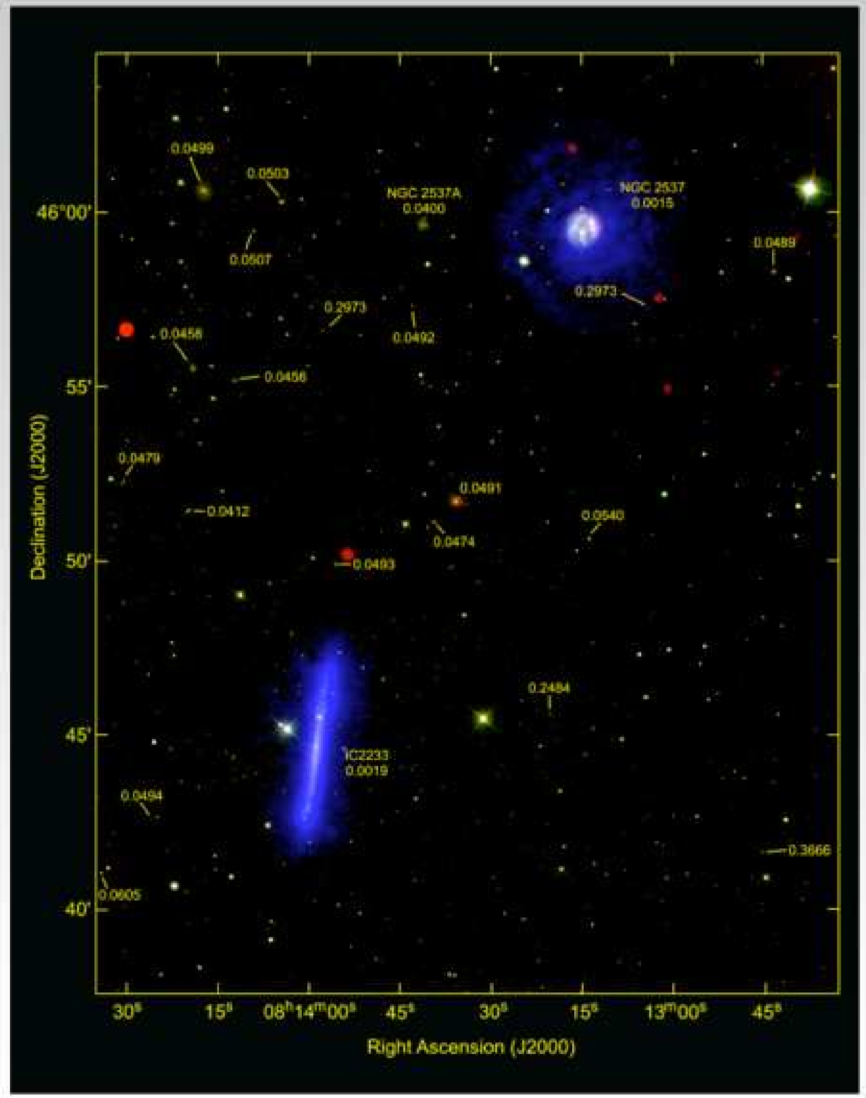
Squint, pointing, peeling and all that Jazz



Juan M. Uson (NRAO)

12/02/08

Imaging with high dynamic range

- Dynamic range is the ratio of the observed signal to the noise.

- Fidelity is the ratio of the true sky signal to the noise

- These are limited by errors
  - Random
  - Systematic
  - Absence of measurements
  - Malfunction

EVLA observations will be limited often by systematic errors

Formal Description (simple version)

- For small fields of view, the visibility function is the 2-D Fourier transform of the sky brightness:

$$V(u,v) = \int I(l,m) \cdot e^{j.2\pi.(ul+vm)} dl.dm$$

- We sample the Fourier plane at a discrete number of points:

$$S(u,v) = \sum_k w_k \cdot \delta(u-u_k) \cdot \delta(v-v_k)$$

- So the inverse transform is:

$$I^D(x,y) = F^{-1}[S(u,v) \cdot V(u,v)]$$

- Applying the Fourier convolution theorem:

$$I^D(x,y) = B(x,y) \otimes I(x,y)$$

- where B is the point spread function:

$$B(x,y) = F^{-1}[S(u,v)]$$

Real Arrays

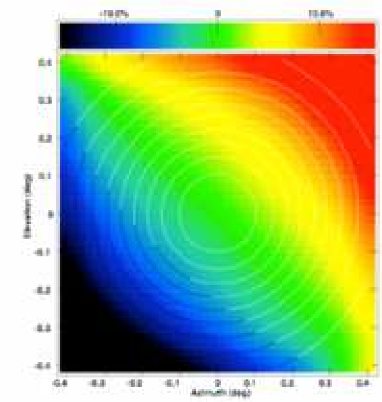


Figure 1: The VLA primary antenna pattern as measured during the NVSS survey [3] at 1.4 GHz. The instrumental Stokes V is shown in color with a scale bar at the top and contours are plotted every 10 percent in power.

- Each beam is offset from the nominal pointing center by:
  - $\Theta_S = \pm 237.56$ (arcsecond/meter) $\bullet\lambda$
- (a beam squint of 1.70′ for $\nu = 1.4$ GHz).
- This leads to a fractional value of: Squint / FWHM = 0.0549 ± 0.0005
- Also polarization coupling; these errors vary with elevation, temperature, time

Real Arrays: Measurement Equation

- Actual observations measure:

$$V_{ij}^{Obs} = M_{ij} \int M_{ij}^{Sky}(s) I(s) e^{2\pi i s \; b_{ij}} ds$$

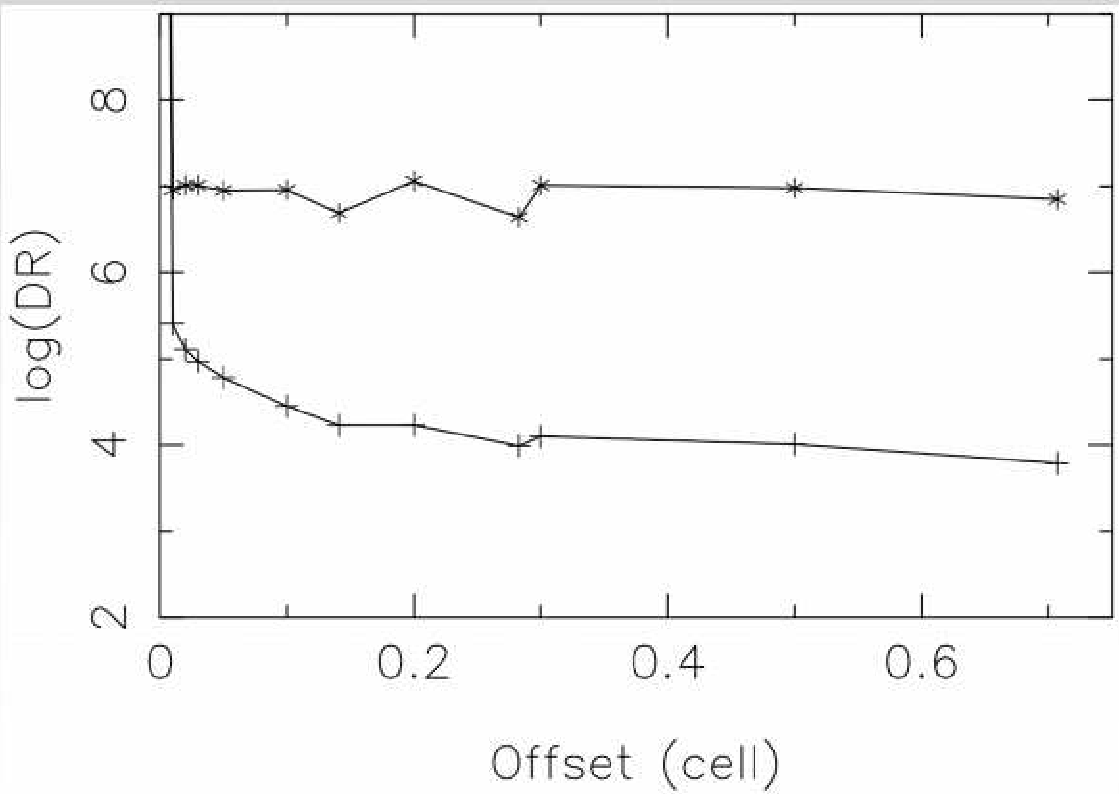
- where V_{ij}^{Obs} is the full-polarization visibility vector,
- $M_{ij}(s)$ and $M_{ij}^{Sky}(s)$ are matrices describing directionally-
- independent and directionally-dependent gains, I describes the full-polarization sky emission, s is the position vector and b_{ij} denotes the baseline.

High-accuracy imaging

- Initialize: Set of images (facets, planes if using w-projection)
  - Re-center facets, add new facets
- Deconvolve, update model image
- Compute residual visibilities accurately - corrections go here!
- Compute residual images
- Back to deconvolution step, or
- Self-calibration
- Peeling
- Back to beginning unless residuals are noise-like
- Smooth the deconvolved image, add residual image

Example: 3C84 (λ~21cm, B array)

- Even off-centering by 0.01 pixel limits dynamic range.



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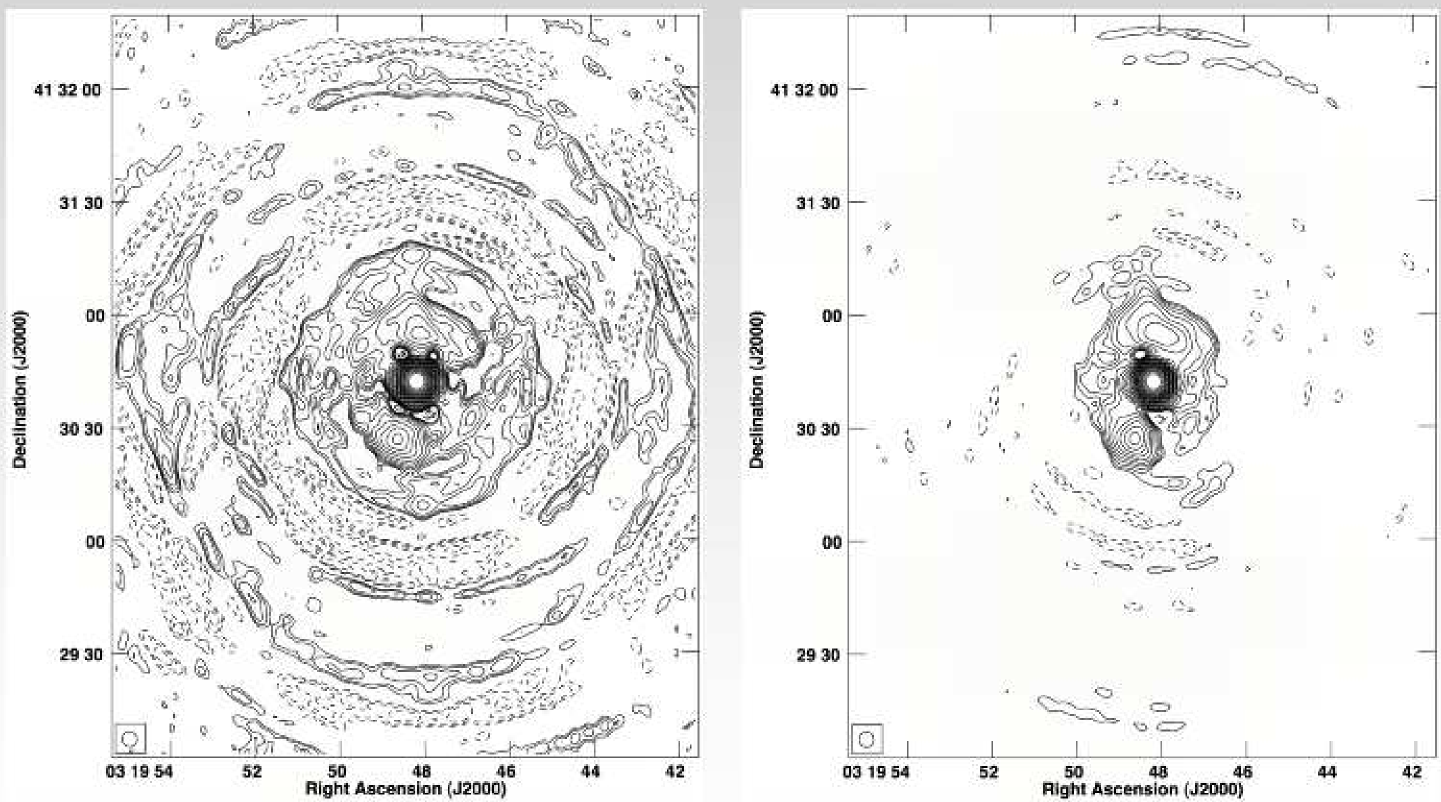

Example: 3C84 (λ~21cm, B array)

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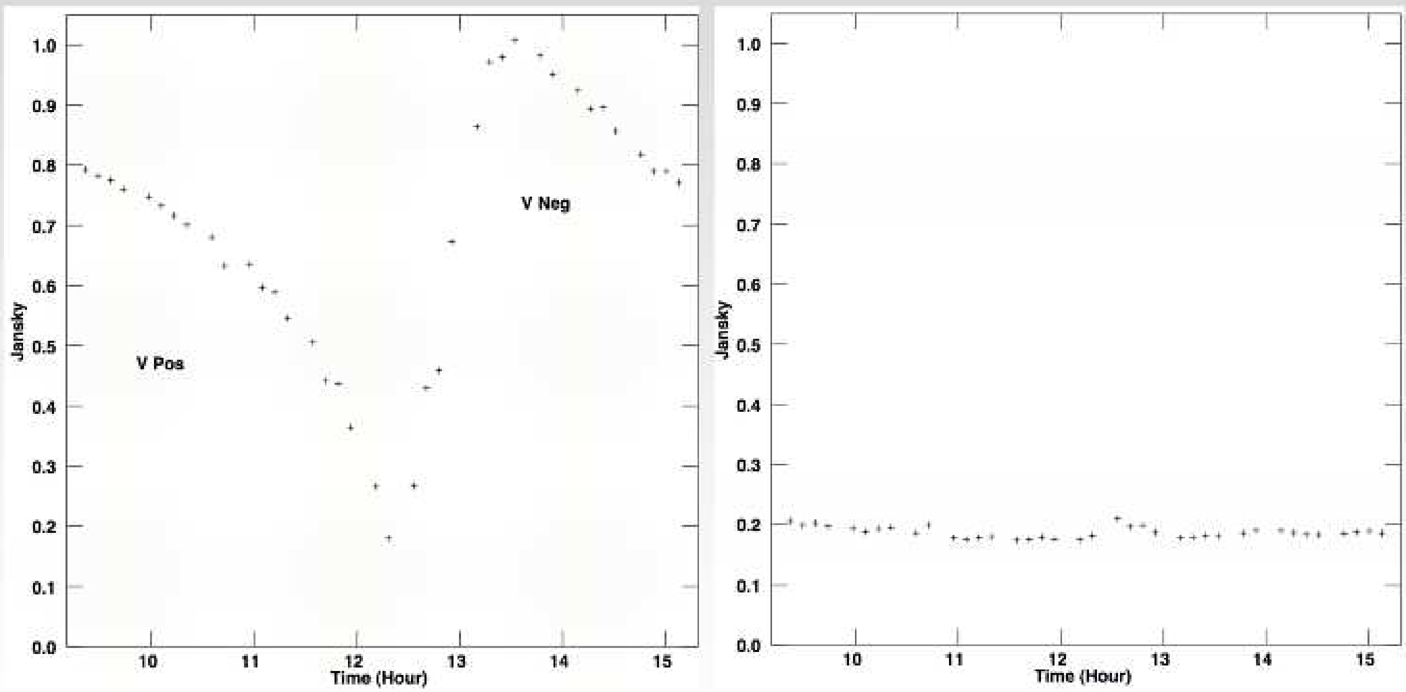

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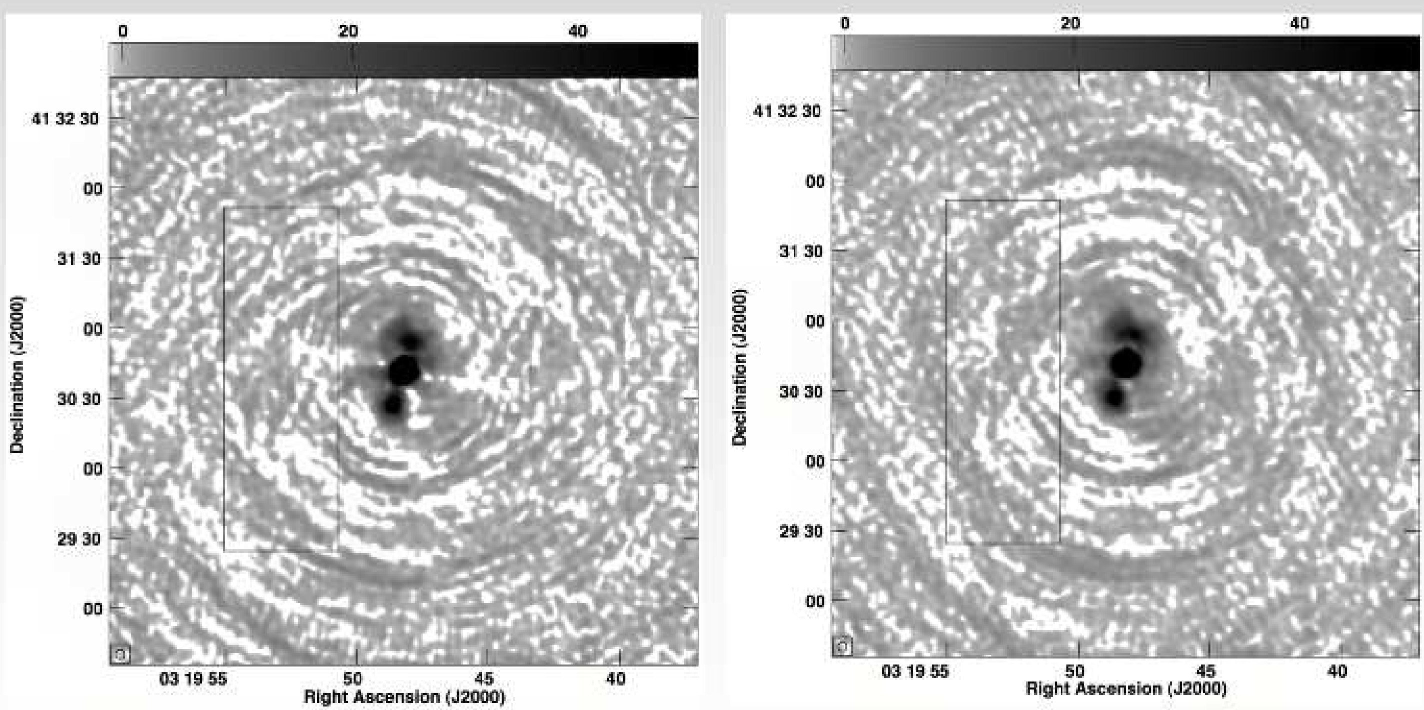

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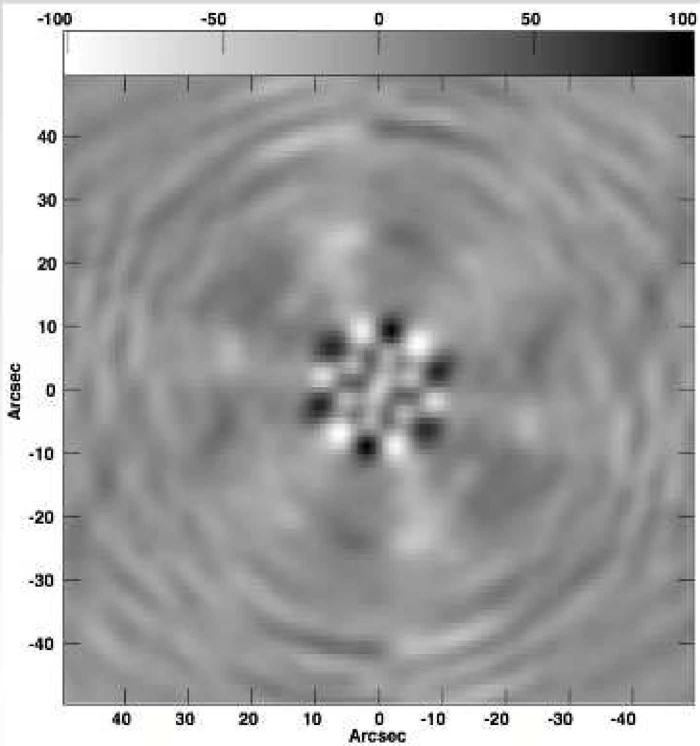
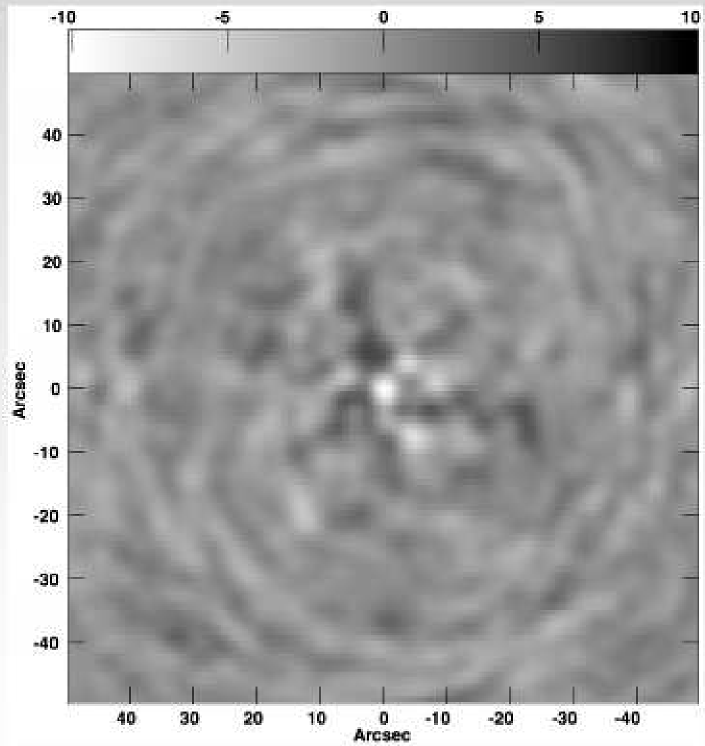
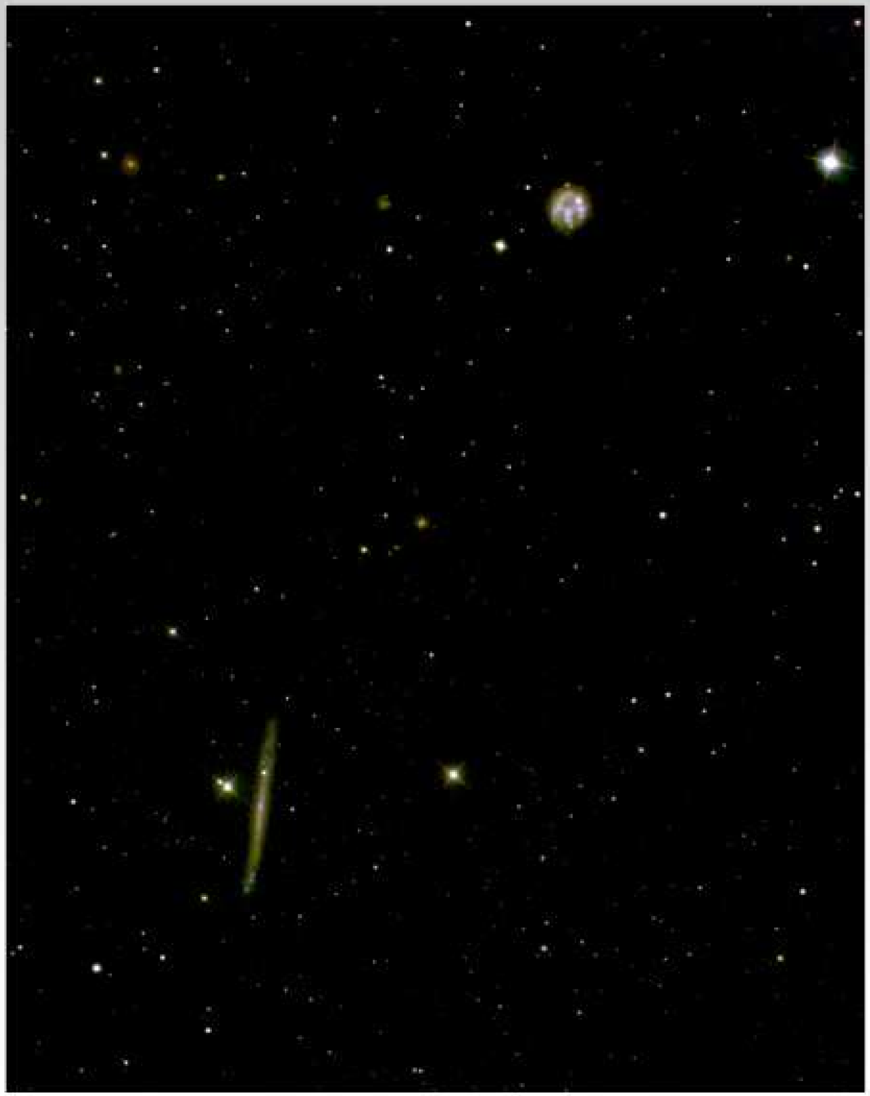




Example: 3C84 (λ~21cm, B array)

- Even off-centering by 0.01 pixel limits dynamic range.
- Observations at half-power are limited by the squint
- After full-correction, dynamic range is limited by coverage
- Dynamic range can be increased by dropping baselines
  - But Fidelity is surely lowered!

Observing with Squint: The IC 2233 / Mk 86 field

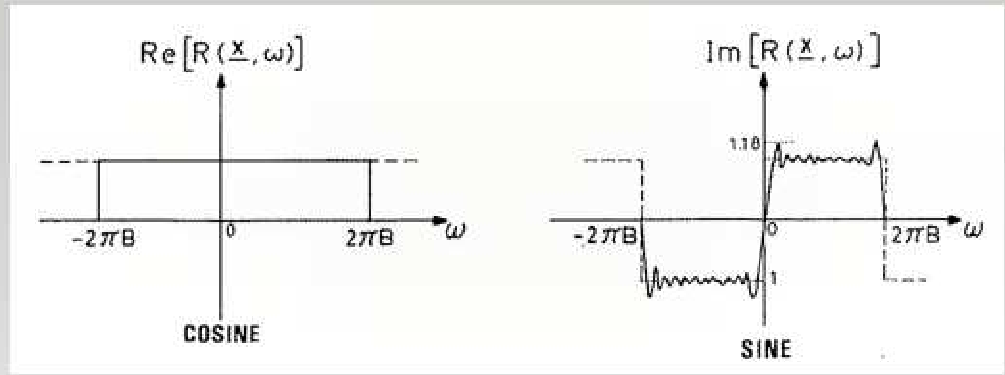


Observing with Squint: The IC 2233 / Mk 86 field

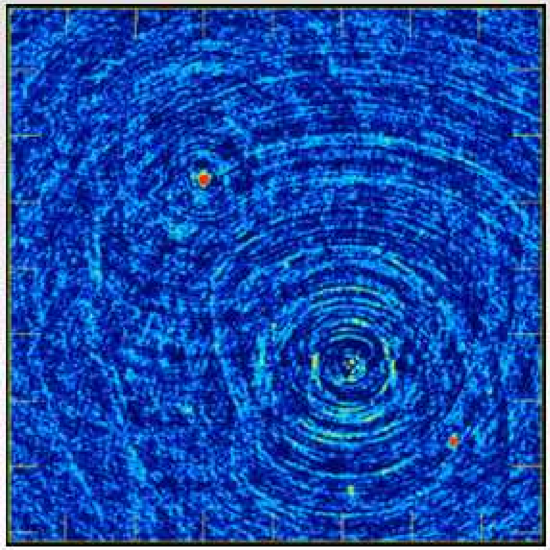
- IC 2233 is an isolated superthin galaxy (D ~ 10.5 +/- 1 Mpc)
- Mk 86 is a blue compact dwarf galaxy (D ~ 7 +/- 1 Mpc)
- They were believed to be an interacting pair

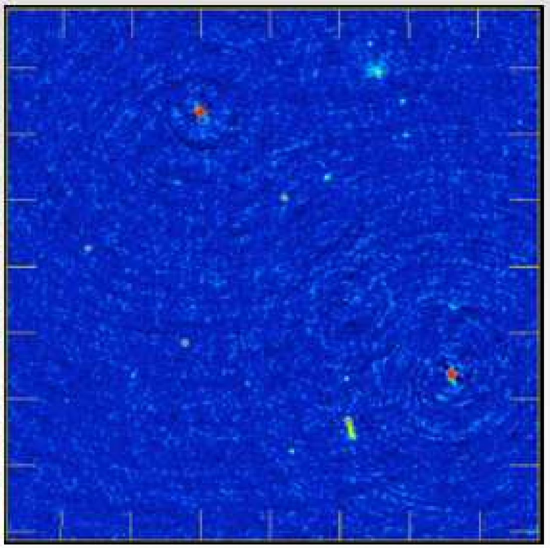
- Key experimental points:
  - The Field contains 2 "4C" sources so high dynamic range was necessary
  - The VLA suffers from Beam-Squint which leaves behind spurious signals
  - Small errors in the continuum emission can mask spectral line emission
    (errors cause ripples, chromatic aberration leads to spurious spectral features)
  - There are ghost sources at the band edges (rms higher in edge channels)

Ghosts: Spectral ripples



Channel 2
(of 86)

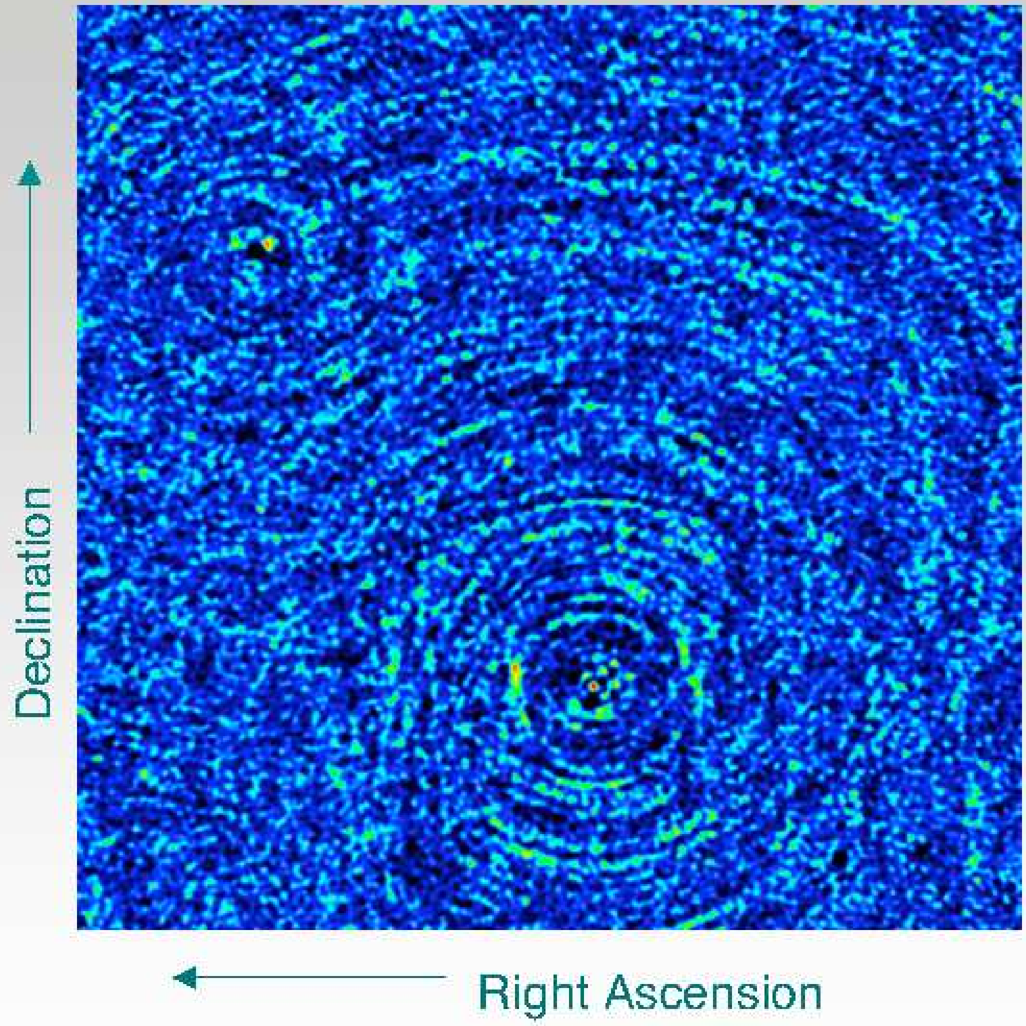




Channels 2-12
+ 67-85

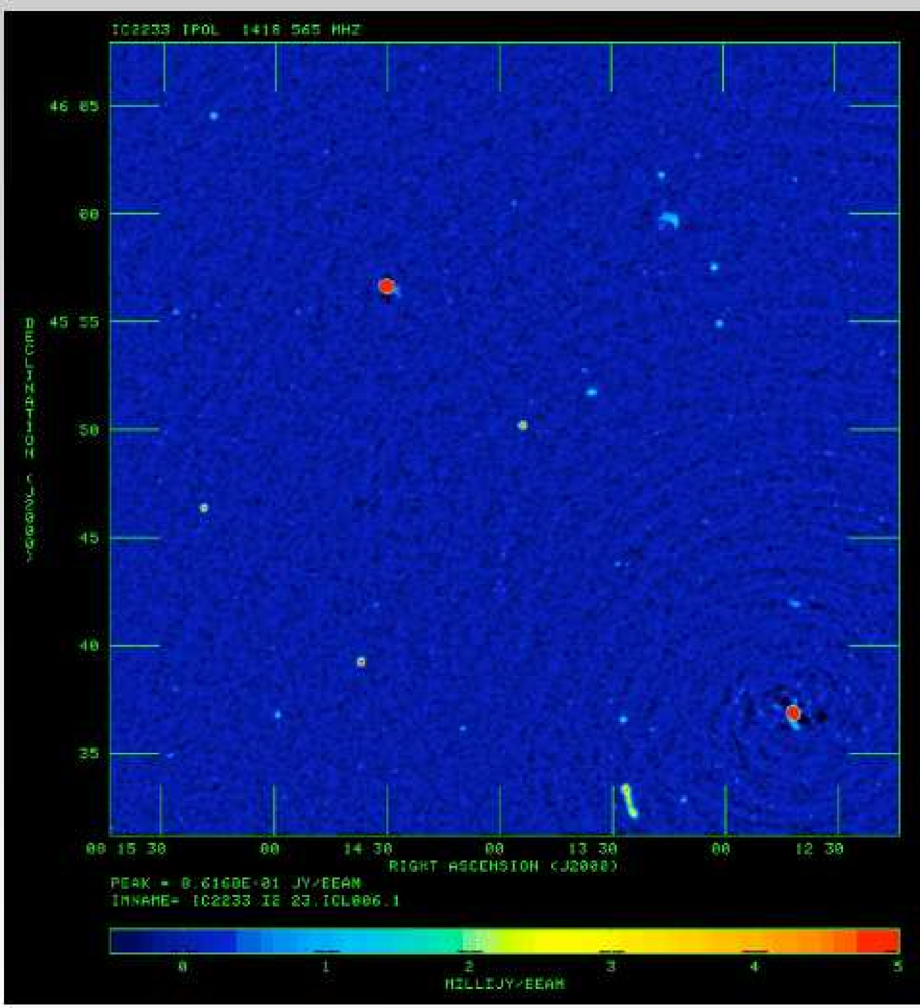
- Cannot be corrected easily as amplitude depends on the phase of the *uncalibrated* visibility. It cancels at the phase center.

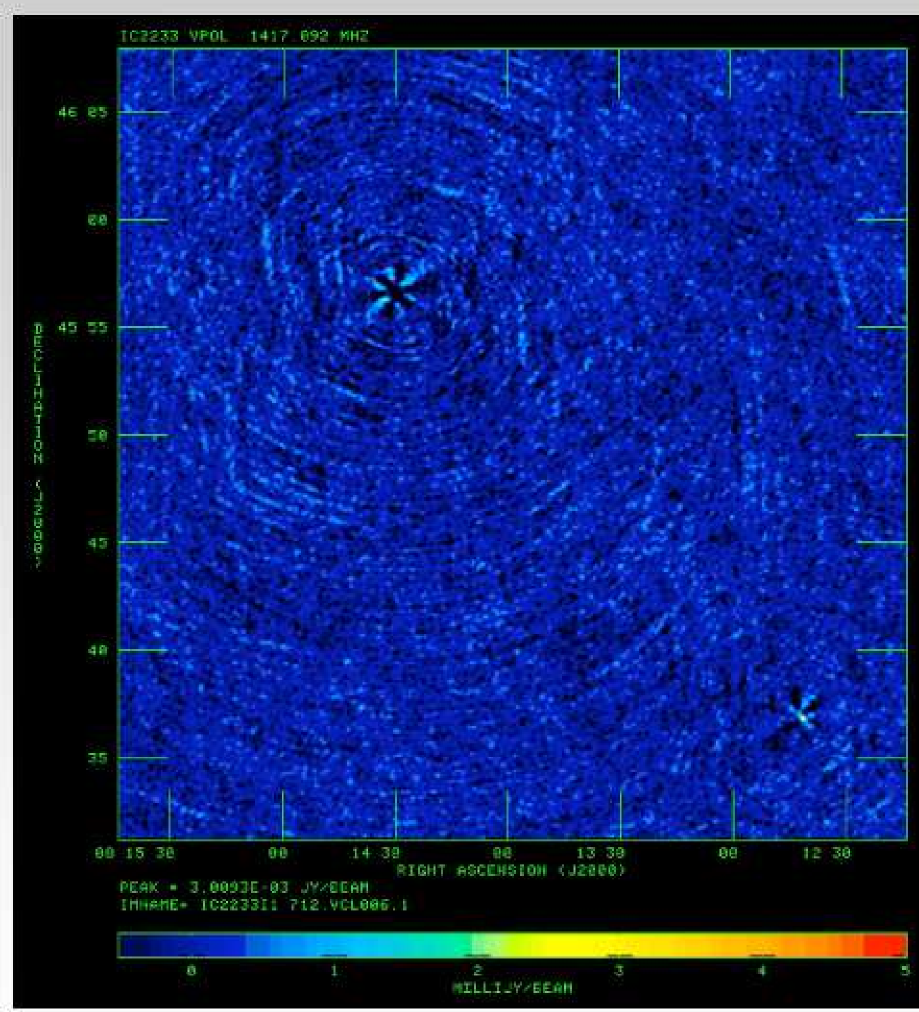
The final spectral cube



"Movie" showing a series of consecutive channel images of IC 2233 & Mk 86.
Notice the ghost images in the first and last few channels.

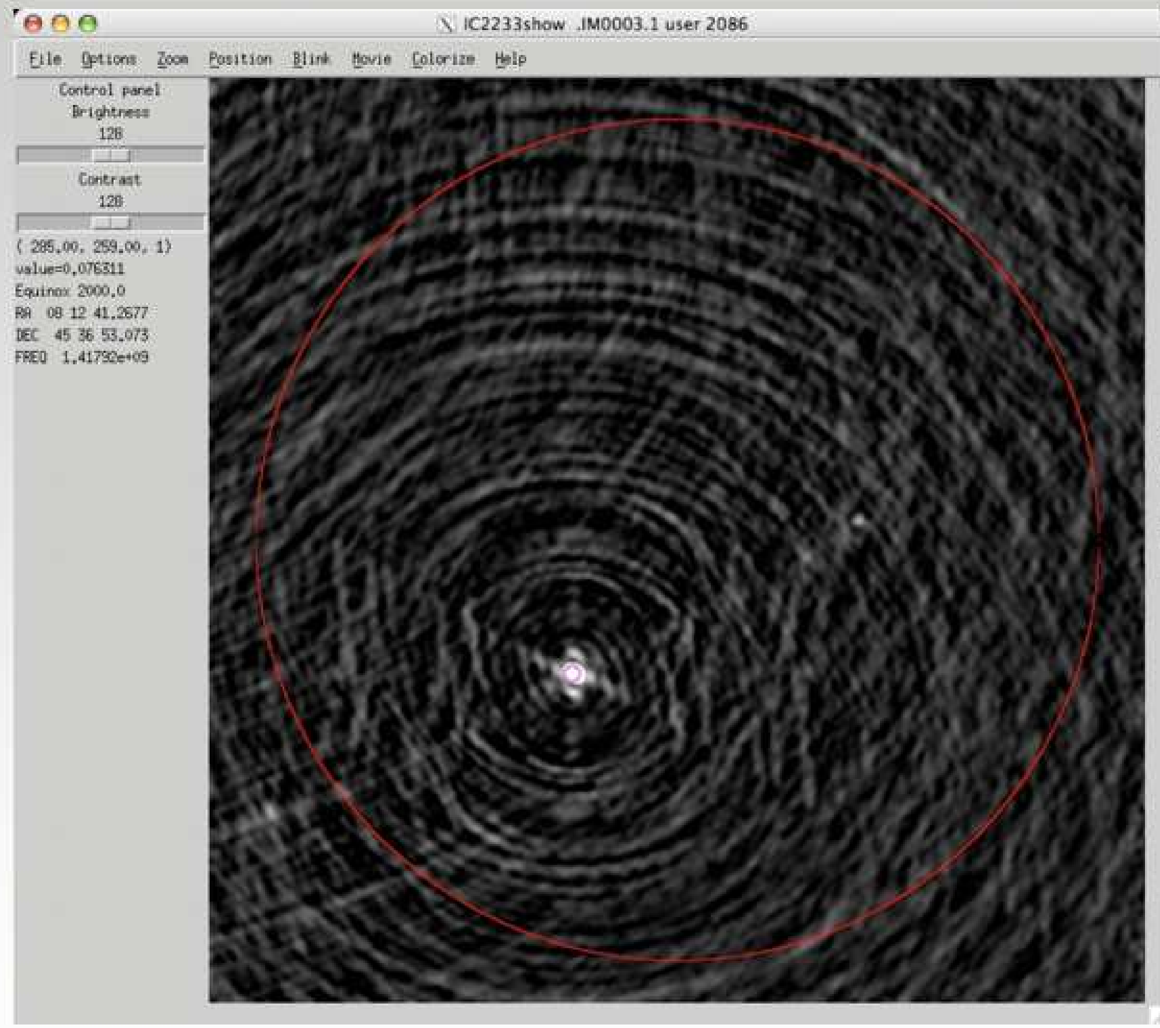
IC 2233 & Mk 86: Standard continuum

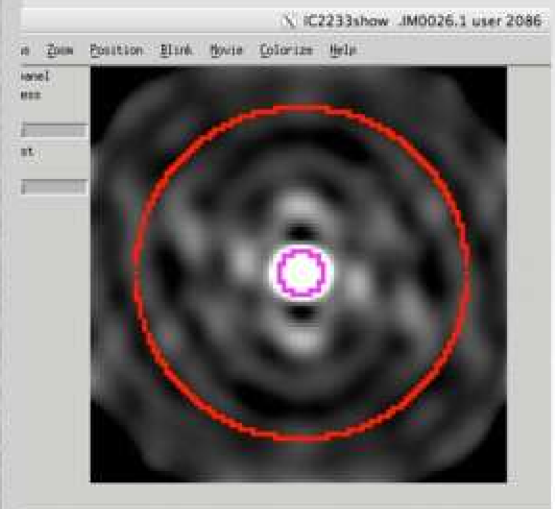




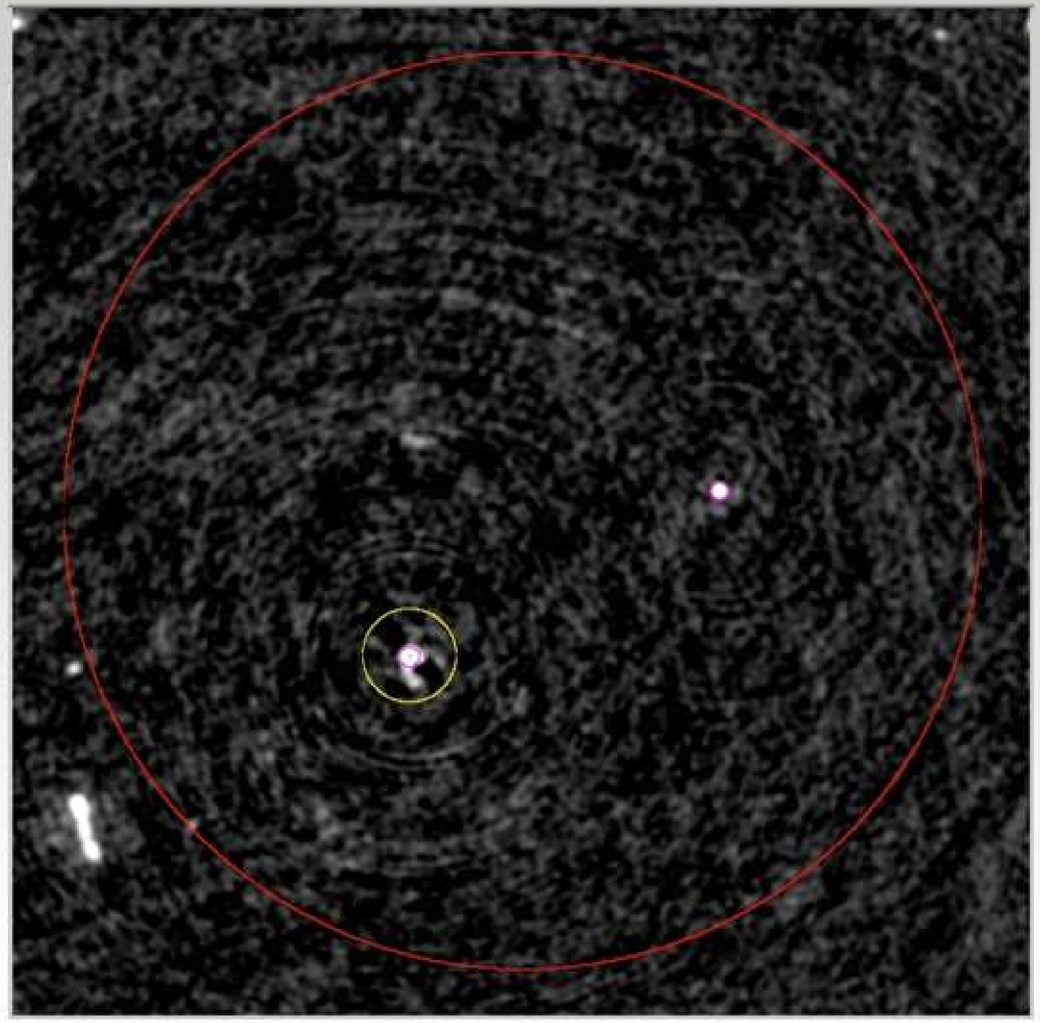
σ_I = 121 μJy/beam; σ_V = 251 μJy/beam

Obit imaging of IC 2233 & Mk 86: intermediate steps

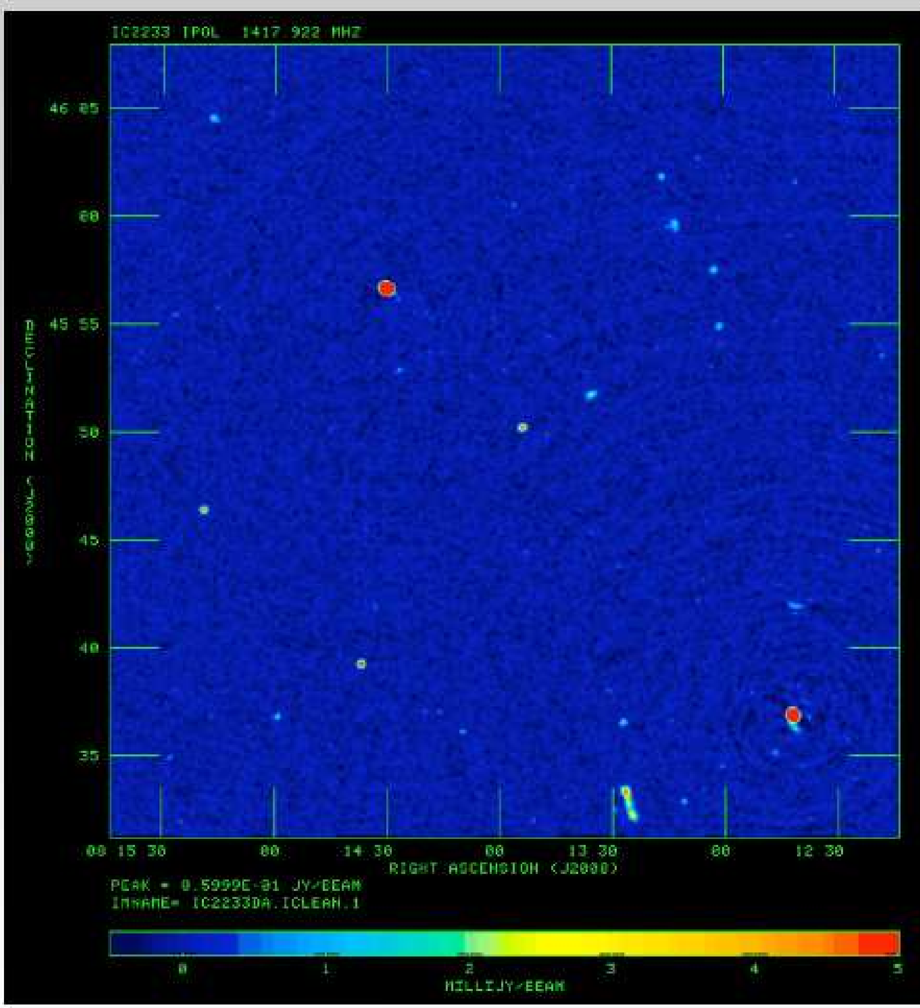


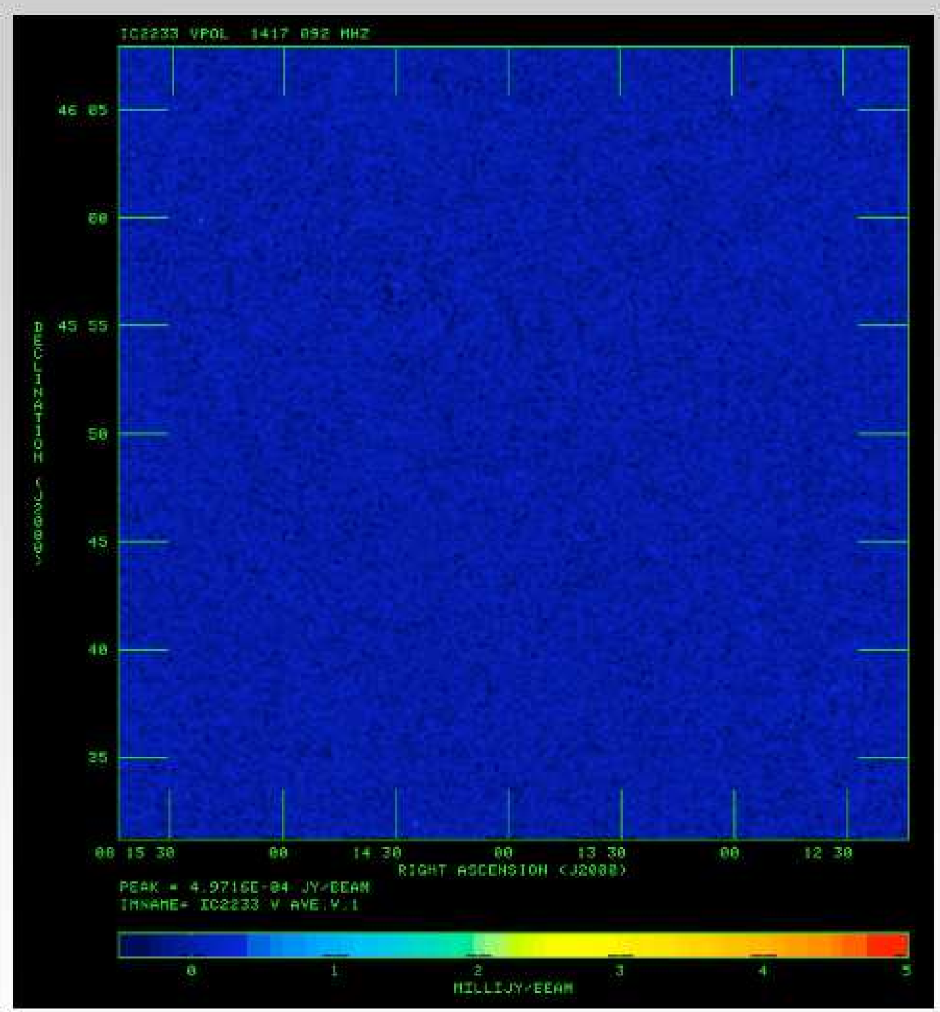


IC 2233 & Mk 86: intermediate steps



IC 2233 & Mk 86 field: Squint corrected





σ_I = 113 μJy/beam; σ_V = 104 μJy/beam

Other effects: Pointing corrections?

- It would seem possible (in principle)
  - Demonstrated on simulations (point sources, perfect calibration)
- But, the correction is not orthogonal to Amplitude selfcalibration
  - Likely always dominated by one source (as in IC2233)
  - Need correction of other effects too (extended emission)
  - SNR deprived!

- It would seem best to point the VLA better!
  - Better understanding of antennas and pointing equation
  - Might need reference pointing for high dynamic range (always?)

Other effects: Non ideal primary beams

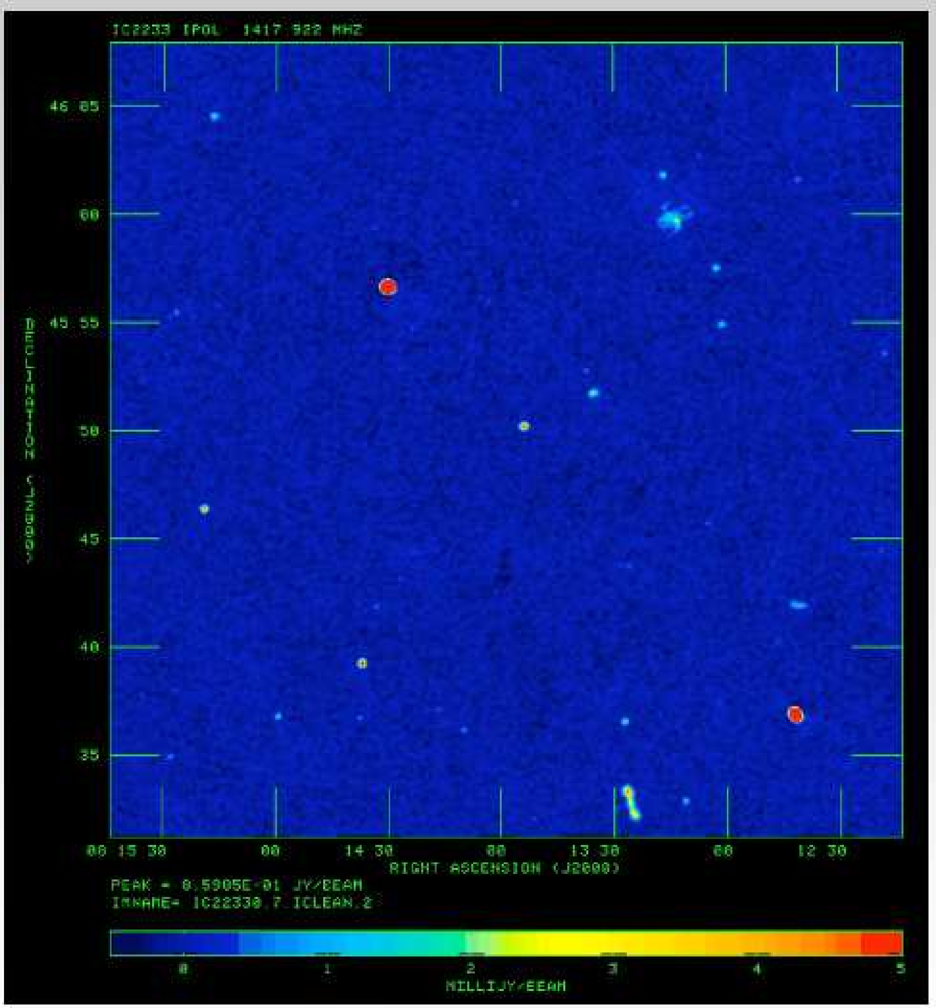
- Hard to measure the primary beam with high precision
  - Antennas deform with changes in elevation, temperature,…
- But, it is needed for high dynamic range imaging
  - Errors are likely dominated by a few sources (as in IC2233)
- Better (stiffer) antennas would help

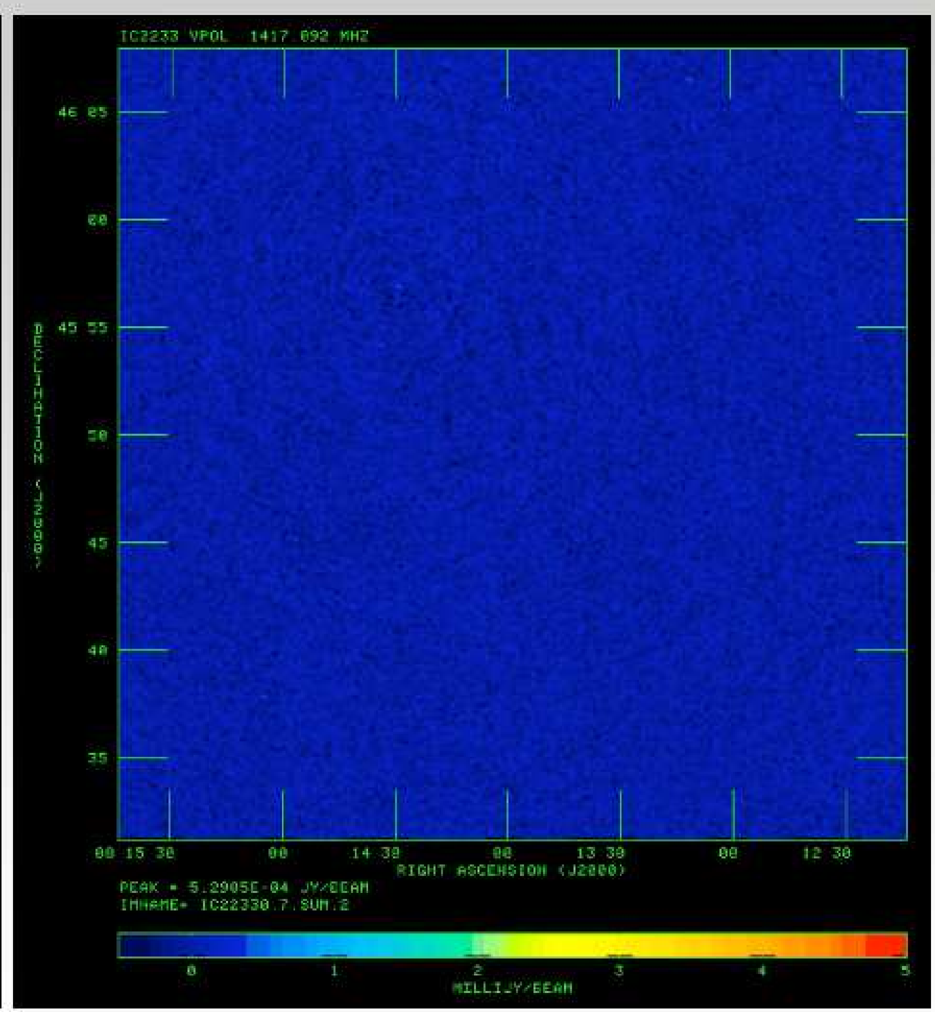
- It is possible to correct a few sources with "peeling" algorithms

Non ideal primary beams: Peeling

- Limited Peeling can help
  - Important to avoid ghosts: Must subtract non-peeling sources first
  - Undo (self)-calibration, subtract peeled source from original visibilites
- Operate on several sources in succession
- It is possible to iterate on the lot
  - Easier on strong sources but beware of the noise bias...
  - Appears to work on suitably long timescales
  - Hard to do on intermediate-strength sources
  - Hard to do on short timescales
- Limited by SNR, works only on sufficiently strong sources
  - Expensive

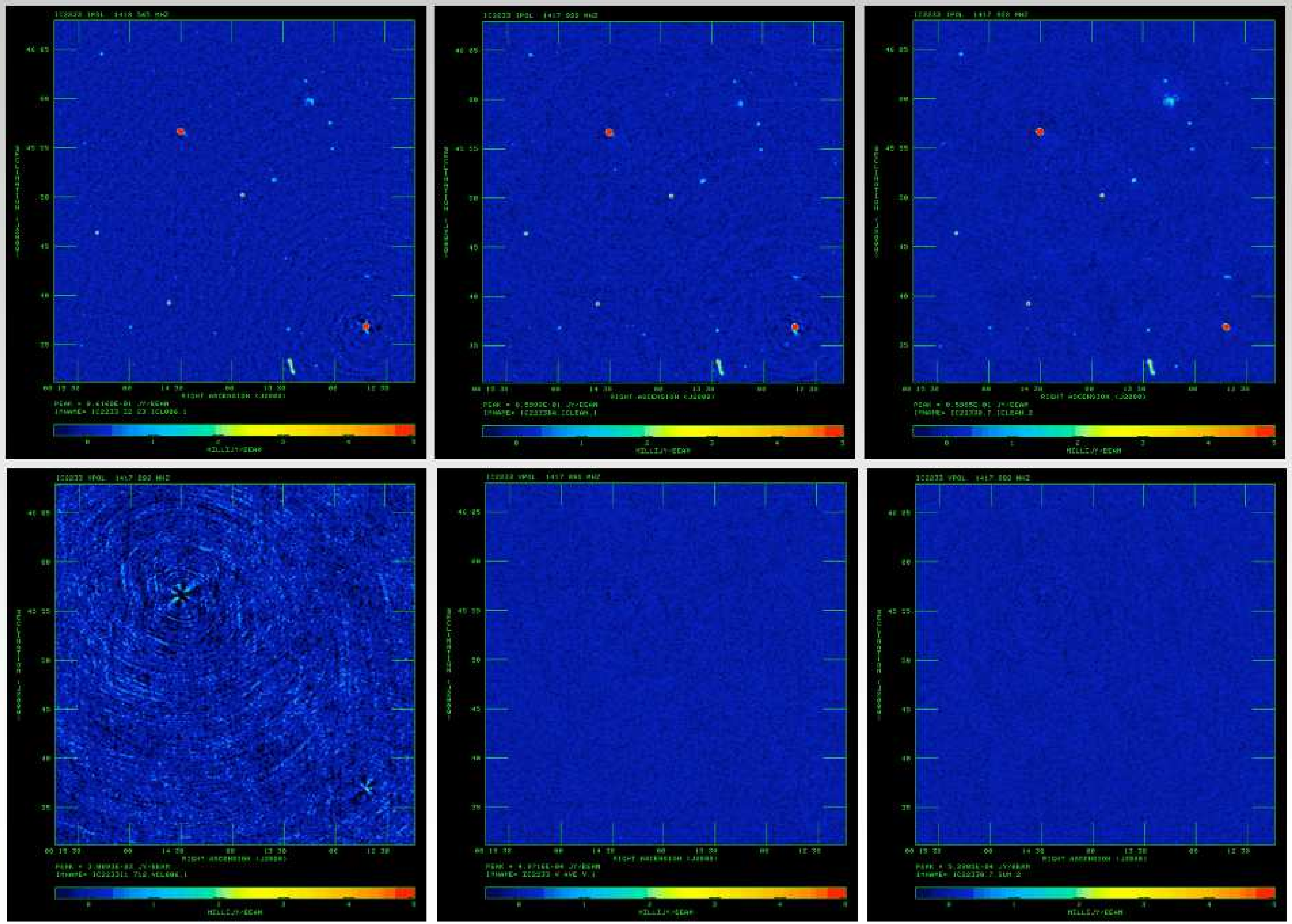
IC 2233 & Mk 86 field: Squint corrected + peeled



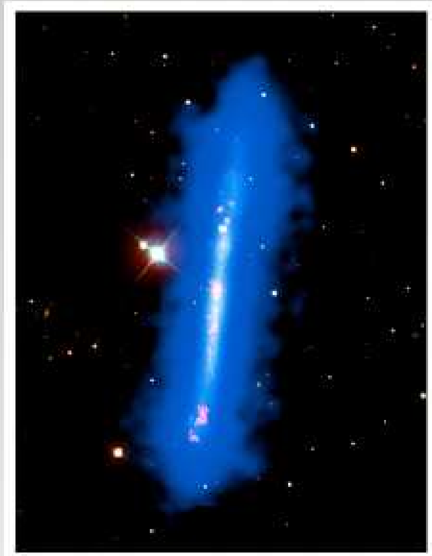


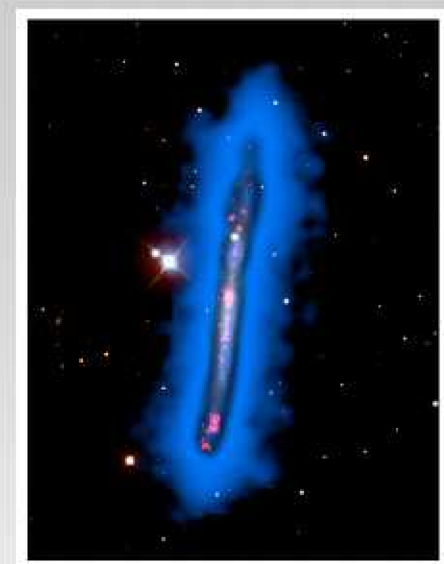
σ_I = 101 μJy/beam; σ_V = 100 μJy/beam

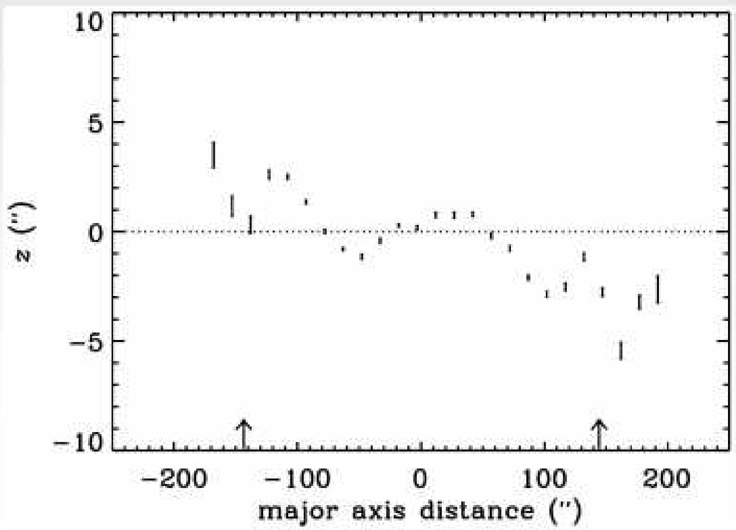
IC 2233 & Mk 86 field: A comparison

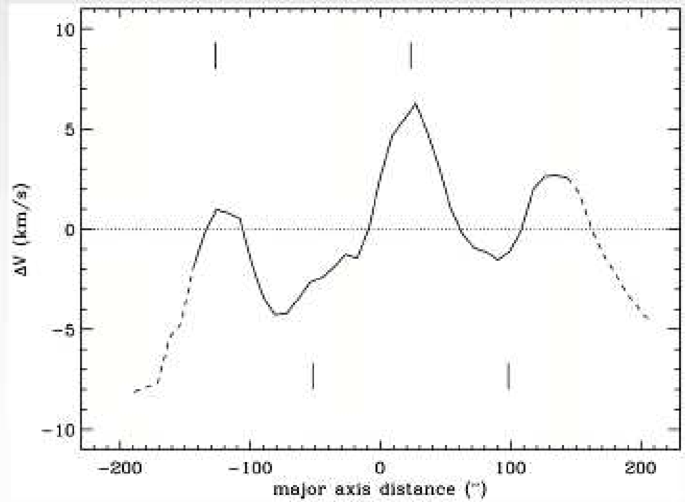


IC 2233 shows corrugations in HI !



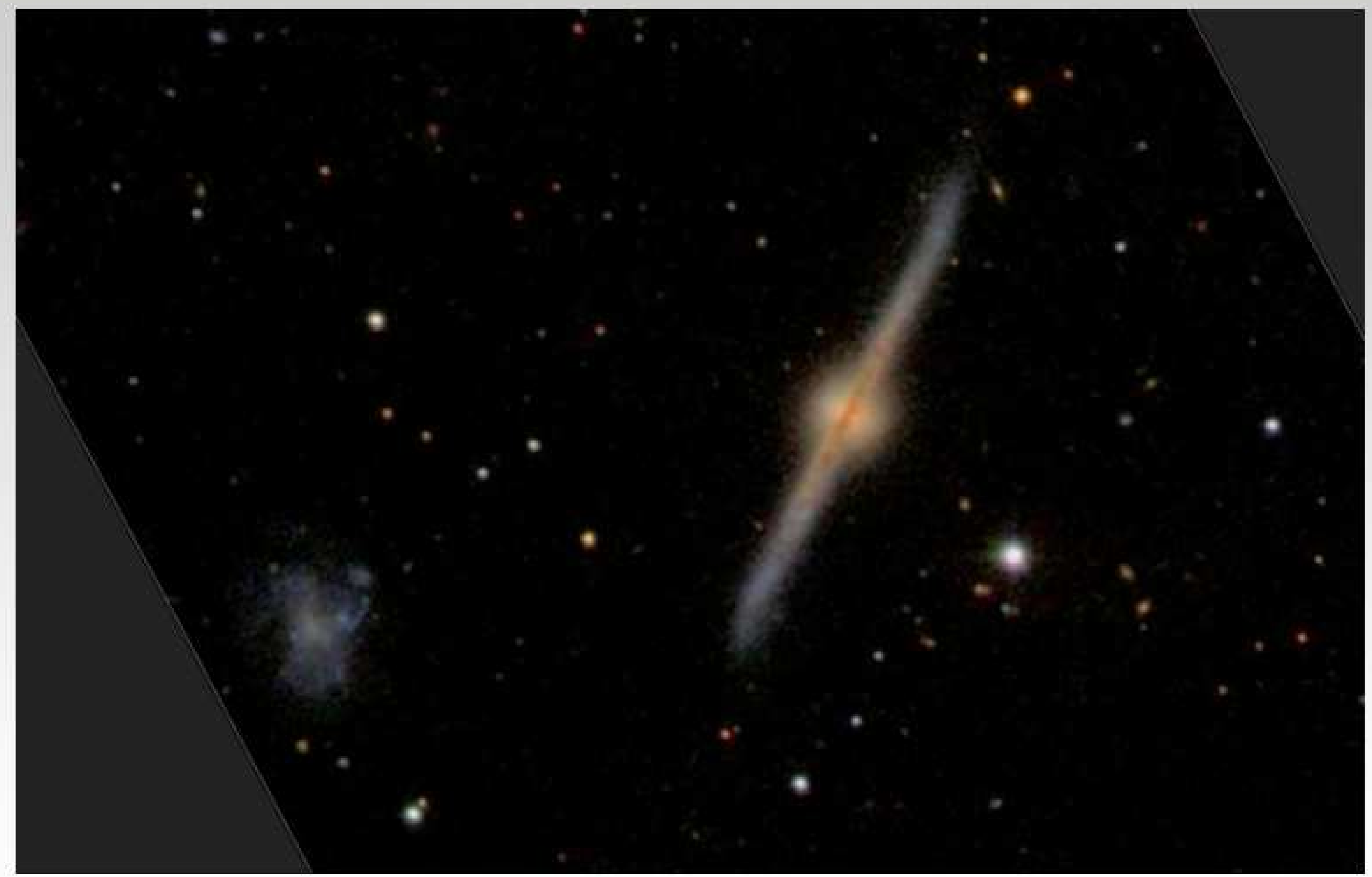






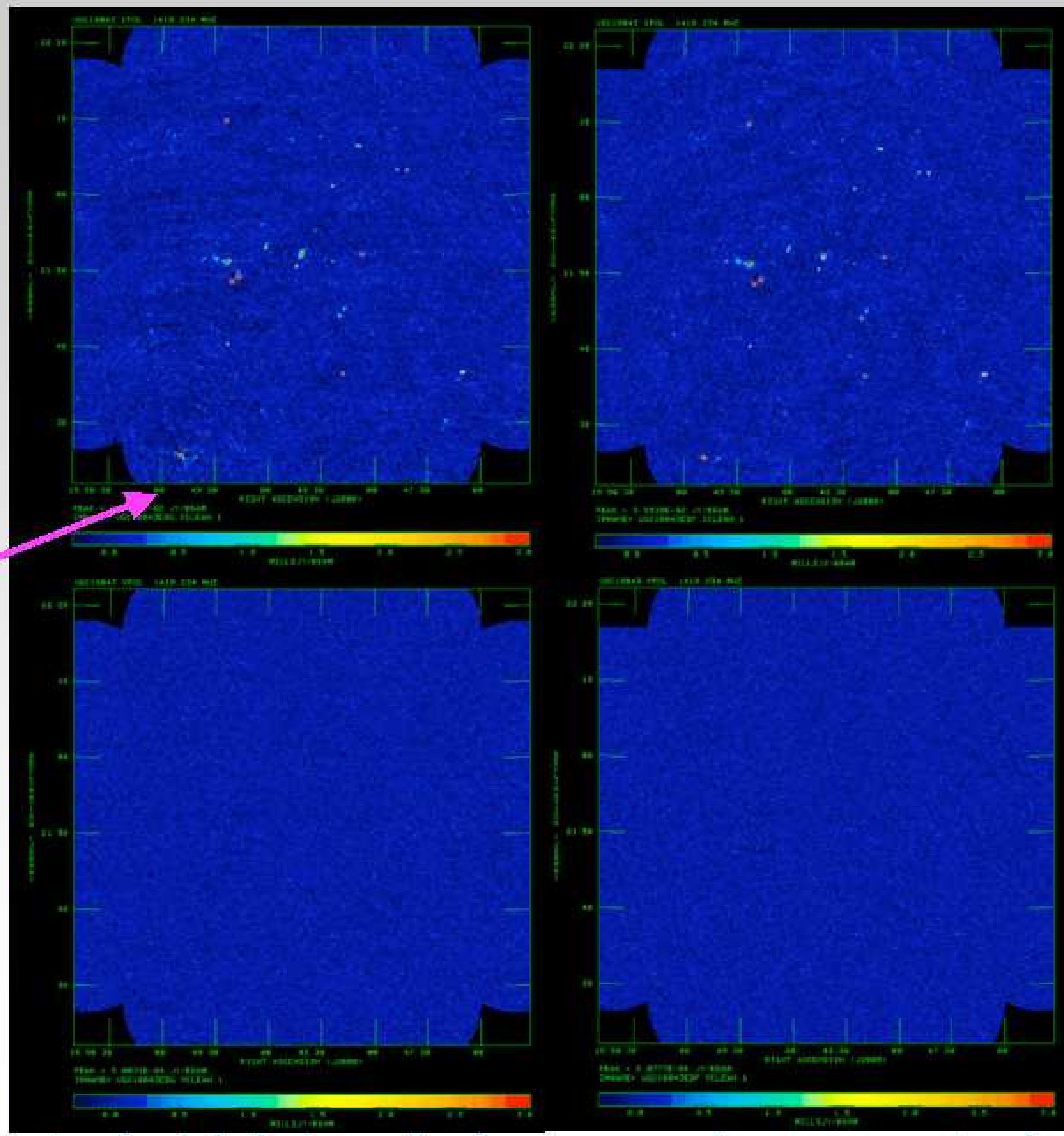
(L. D. Matthews & JMU, AJ 135, 291, 2008; ApJ 688, 237, 2008)

UGC 10043



UGC 10043 from Sloan (SDSS)

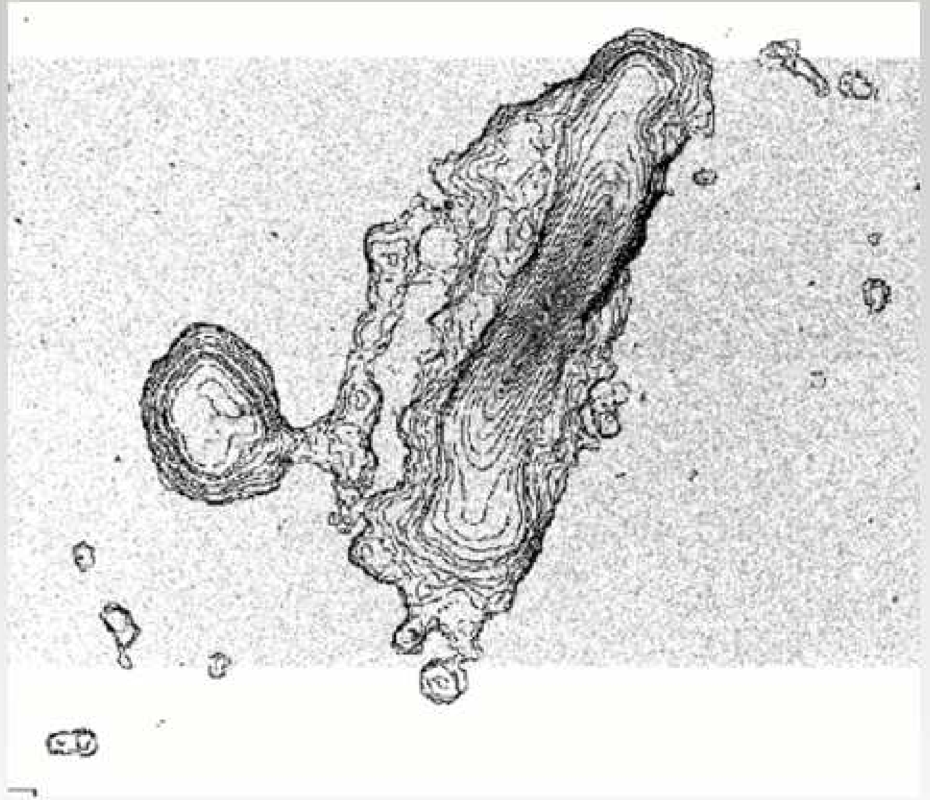
UGC 10043: A harder case?

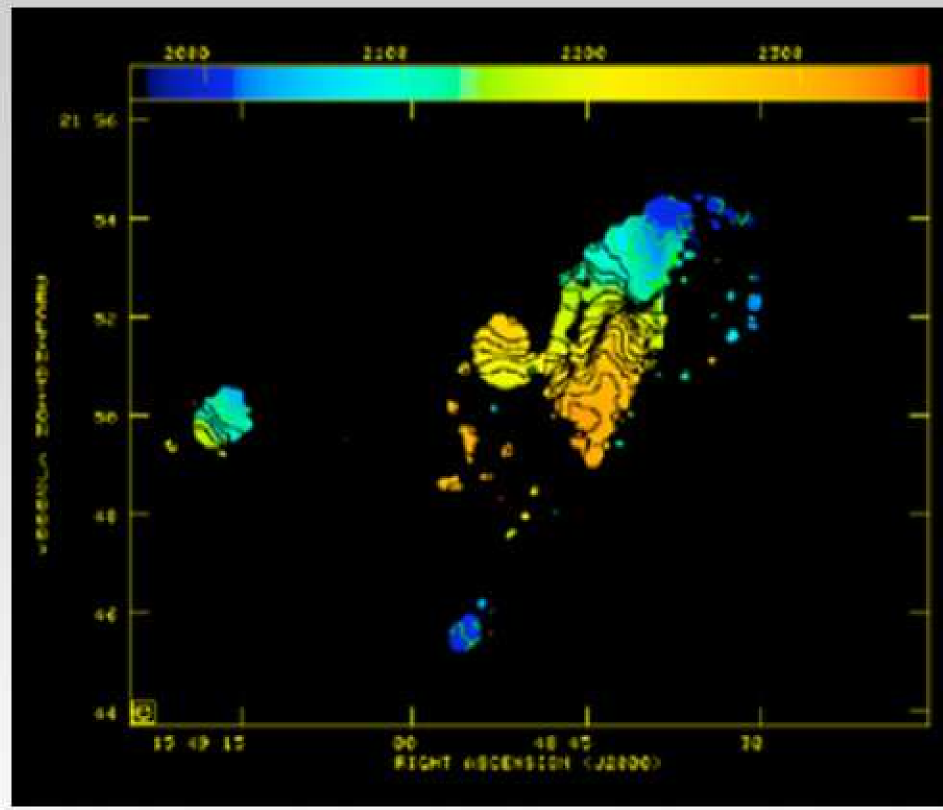


3C 324
at ~1.5%
of P. Beam

- Uncorrected sidelobes induce spurious spectral signatures

UGC 10043





UGC 10043: total HI and Moment-I

Acknowledgements

I have benefited from many conversations with Bill Cotton, Tim Cornwell, Sanjay Bhatnagar and Ed Fomalont.

VLA squint characterization and algorithmic procedures in collaboration with Bill Cotton using Obit.

Uson & Cotton, Astron. & Astrophys. 486, 647 (2008)

Cotton & Uson, Astron. & Astrophys. 490, 455 (2008)

Obit Memos (www.nrao.edu/~bcotton/Obit.html)

Research on Superthins in collaboration with Lynn Matthews

Uson & Matthews, Astron. J. 125, 2455 (2003)

Matthews & Uson, Astron. J. 135, 291 (2008)

Matthews & Uson, Astrophys. J. 688, 237 (2008)