

A Crash Course in Radio Astronomy and Interferometry: 3. Interferometric Imaging

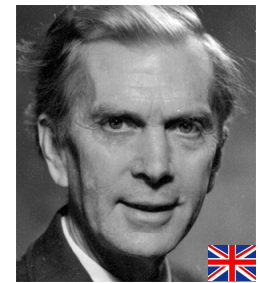
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(thanks to S. Dougherty, C. Chandler, D. Wilner & C. Brogan)

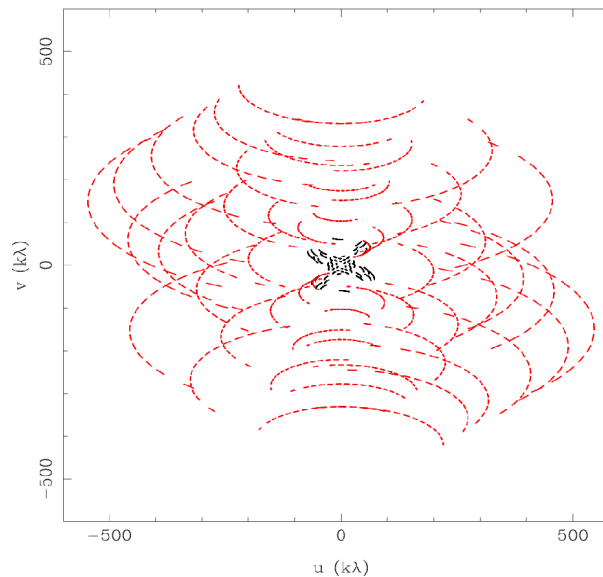
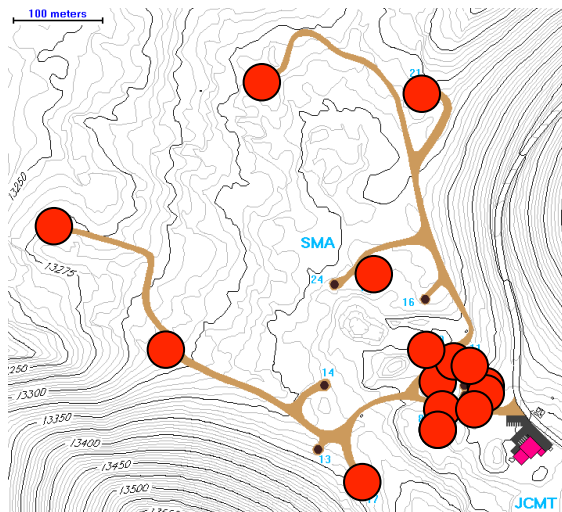


Aperture Synthesis

- sample $V(u,v)$ at enough points to synthesize the equivalent large aperture of size (u_{\max}, v_{\max})
 - 1 pair of telescopes \rightarrow 1 (u,v) sample at a time
 - N telescopes \rightarrow number of samples = $N(N-1)/2$
 - fill in (u,v) plane by making use of Earth rotation:
Martin Ryle, 1974 Nobel Prize in Physics
 - reconfigure physical layout of N telescopes for more



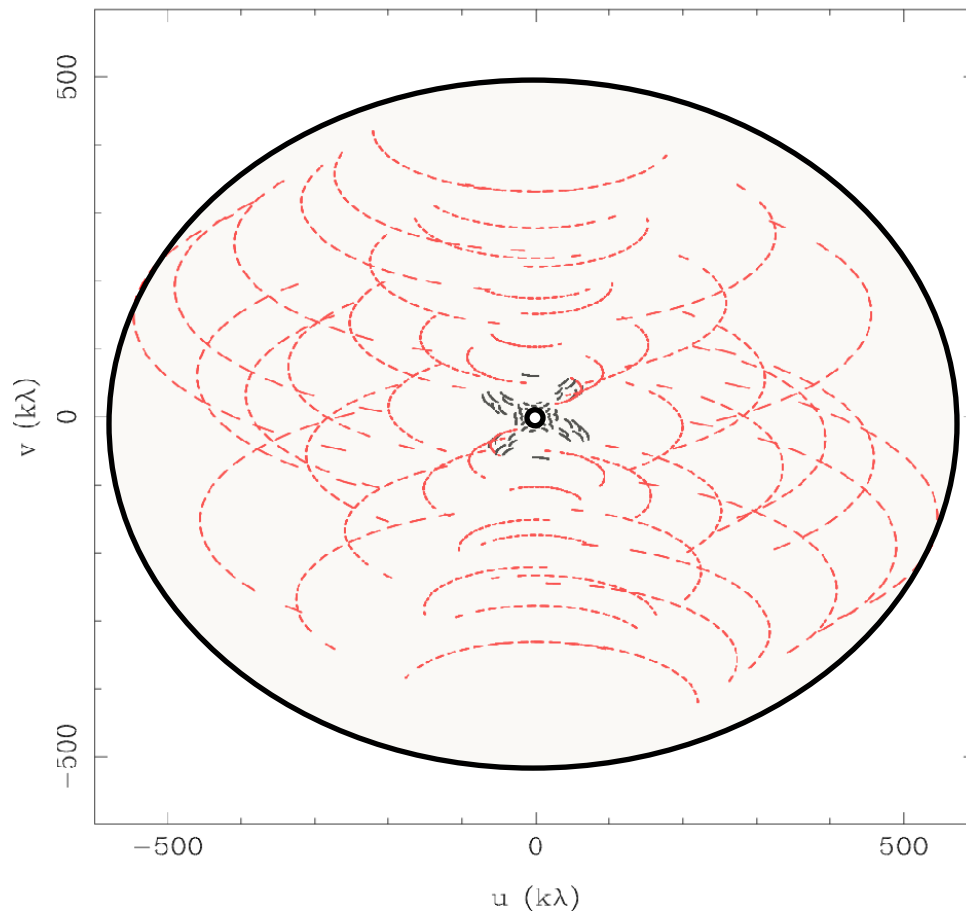
Sir Martin Ryle
1918-1984



2 configurations
of 8 SMA antennas
345 GHz
Dec = -24 deg

(u, v) Plane Sampling

- in aperture synthesis, $V(u, v)$ samples are limited by number of telescopes, and Earth-sky geometry



- *high spatial frequencies:*
 - maximum angular resolution
- *low spatial frequencies:*
 - extended structures **invisible** (aka. only a max scale can be imaged; also “zero-spacing problem” = no large scales)
- *irregular within high/low limits:*
 - sampling theorem violated
 - still more information missing

Formal Description

- sample Fourier domain at discrete points, i.e.,

$$B(u, v) = \sum \delta_{ij}(u, v)$$

- so, the inverse Fourier transform of the ensemble of visibilities is:

$$I^D(x, y) = FT^{-1}\{B(u, v) \times V(u, v)\}$$

- but the convolution theorem tells us:

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

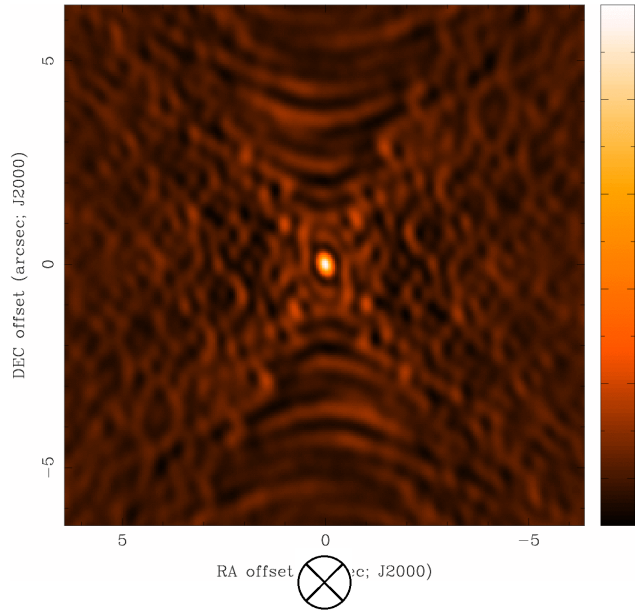
where $b(x, y) = FT^{-1}\{B(u, v)\}$ (the point spread function)

Fourier transform of sampled visibilities yields the true sky brightness convolved with the point spread function

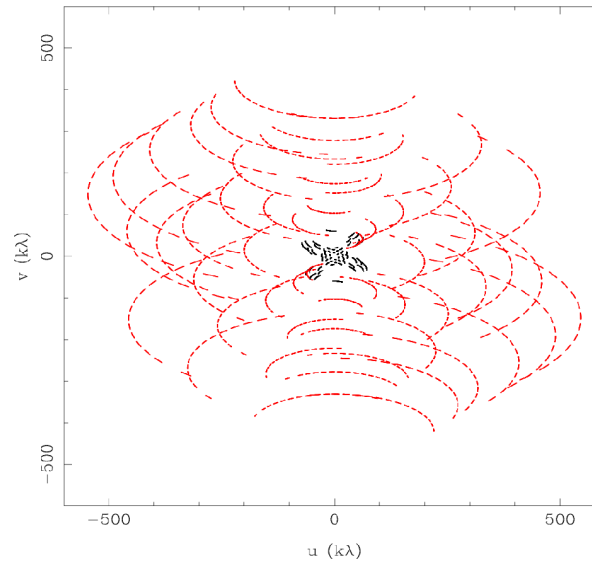
(the “dirty image” is the true image convolved with the “dirty beam”)

Dirty Beam and Dirty Image

$b(x,y)$
(dirty beam)

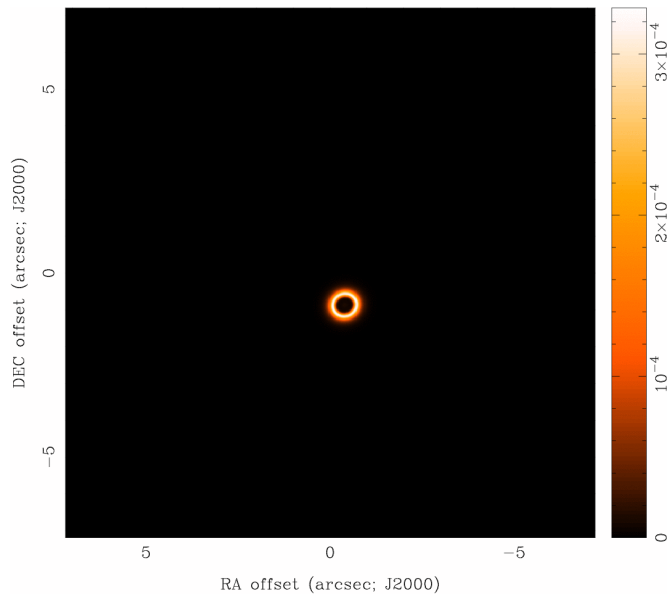


\rightleftarrows

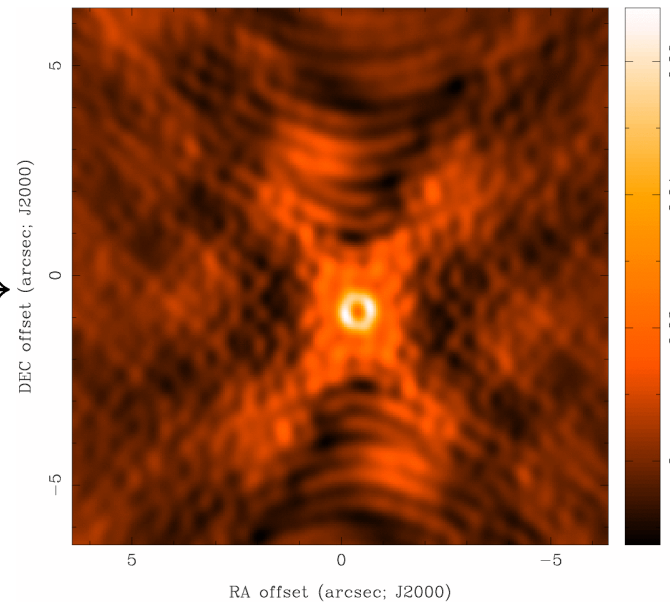


$B(u,v)$

$I(x,y)$



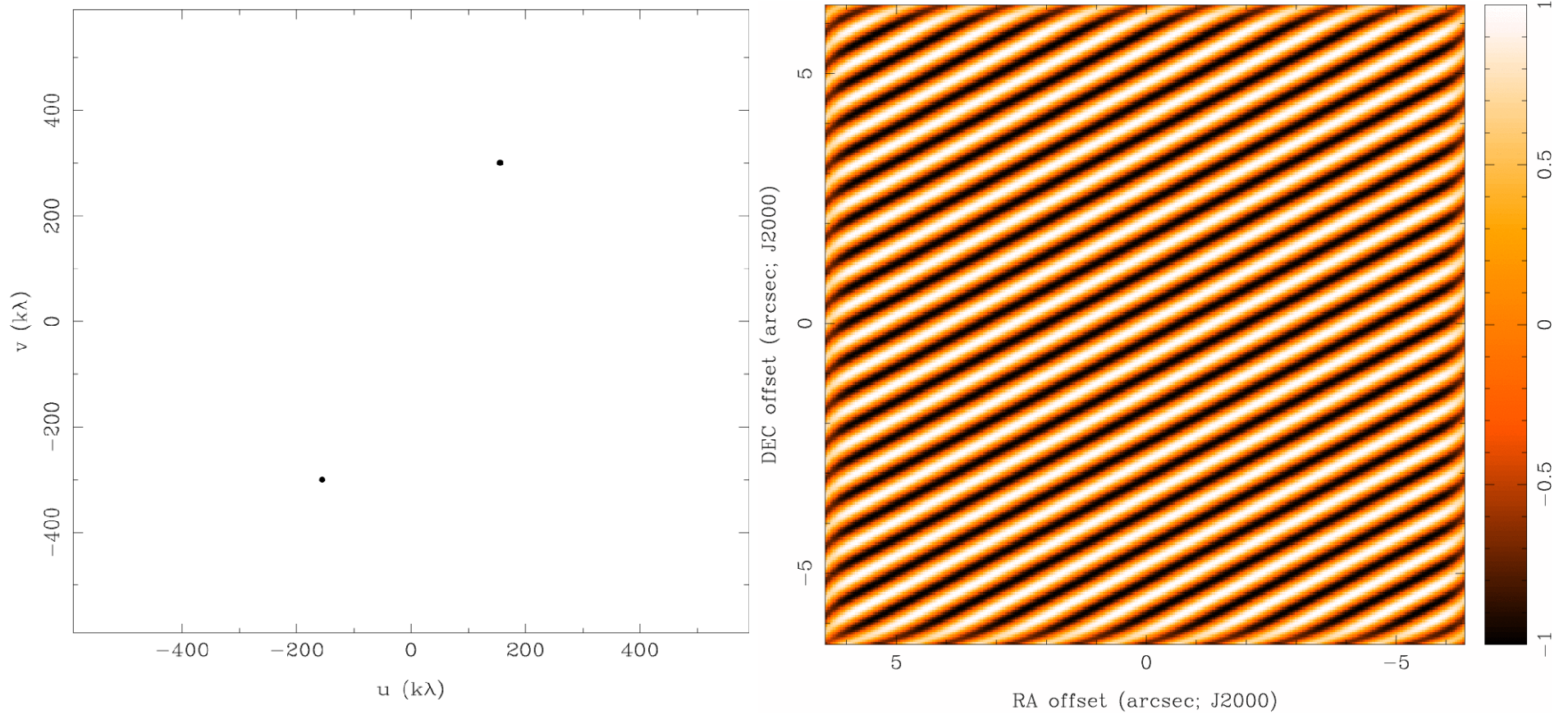
\rightarrow



$I^D(x,y)$
(dirty image)

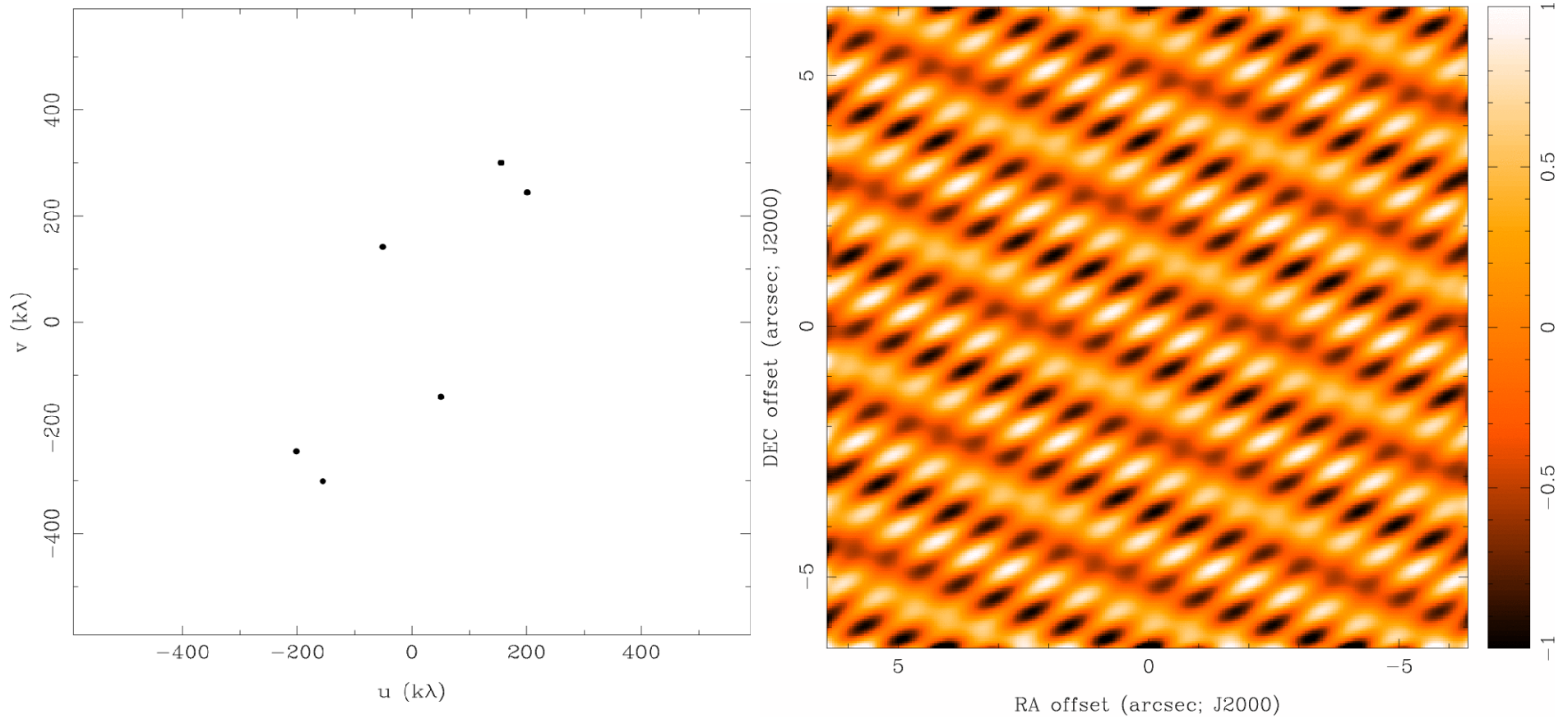
Dirty Beam Shape and N Antennas

2 Antennas



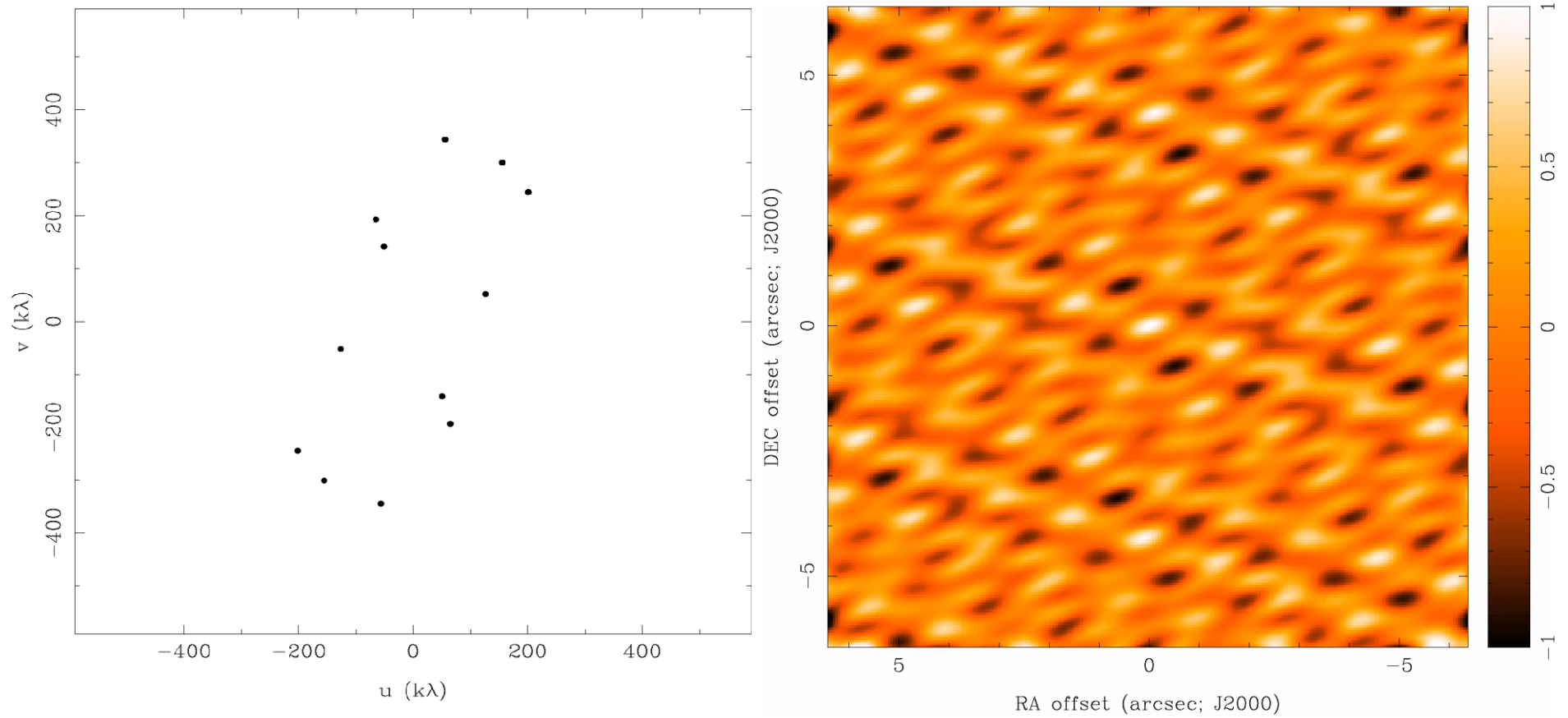
Dirty Beam Shape and N Antennas

3 Antennas



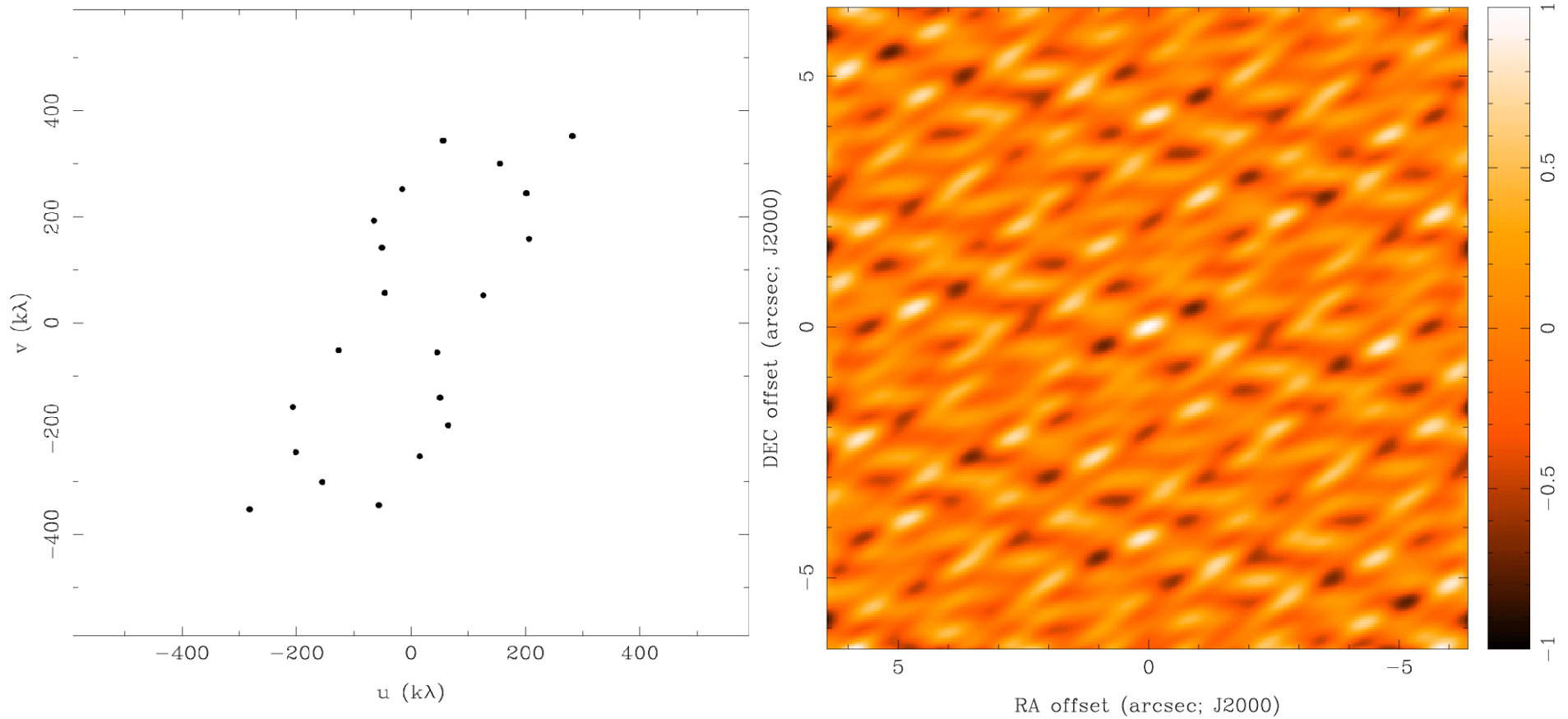
Dirty Beam Shape and N Antennas

4 Antennas



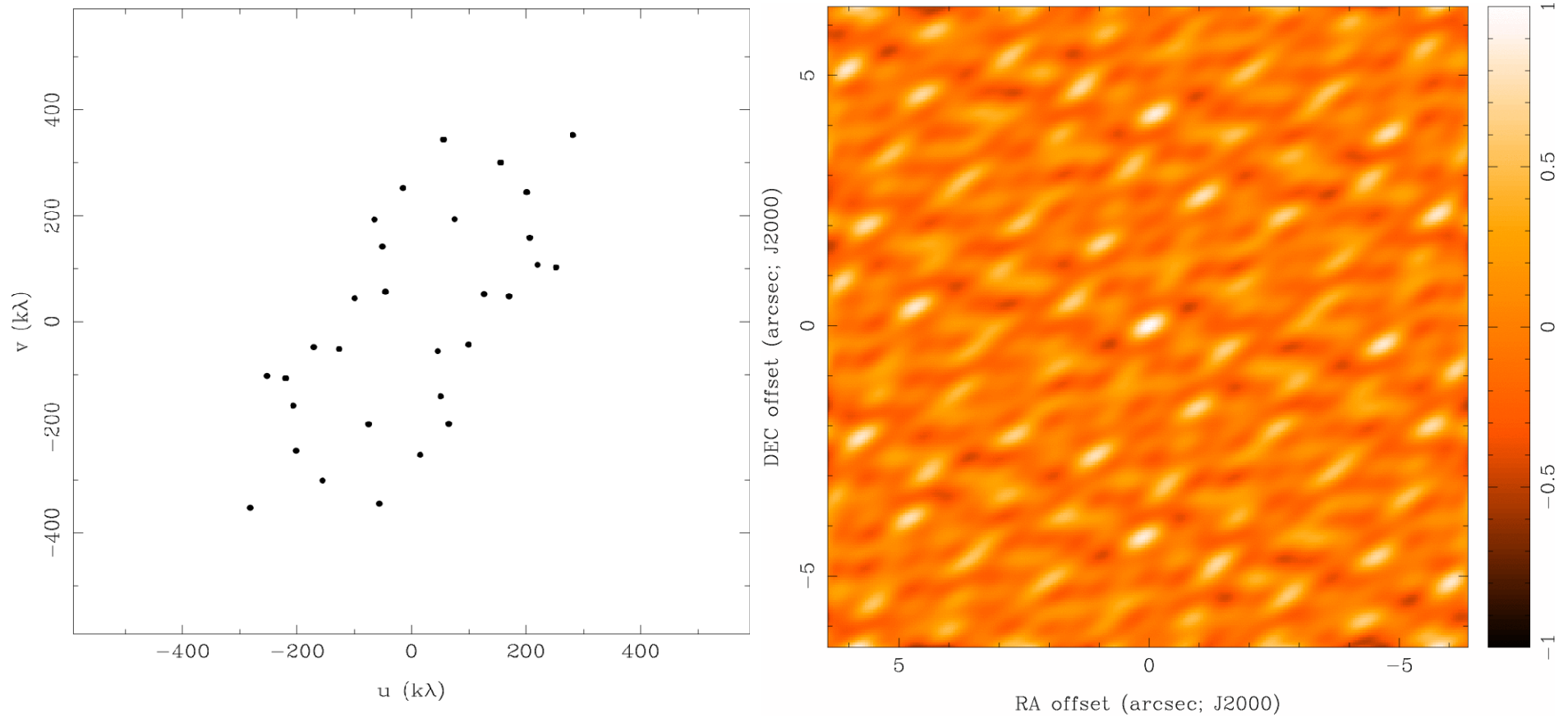
Dirty Beam Shape and N Antennas

5 Antennas



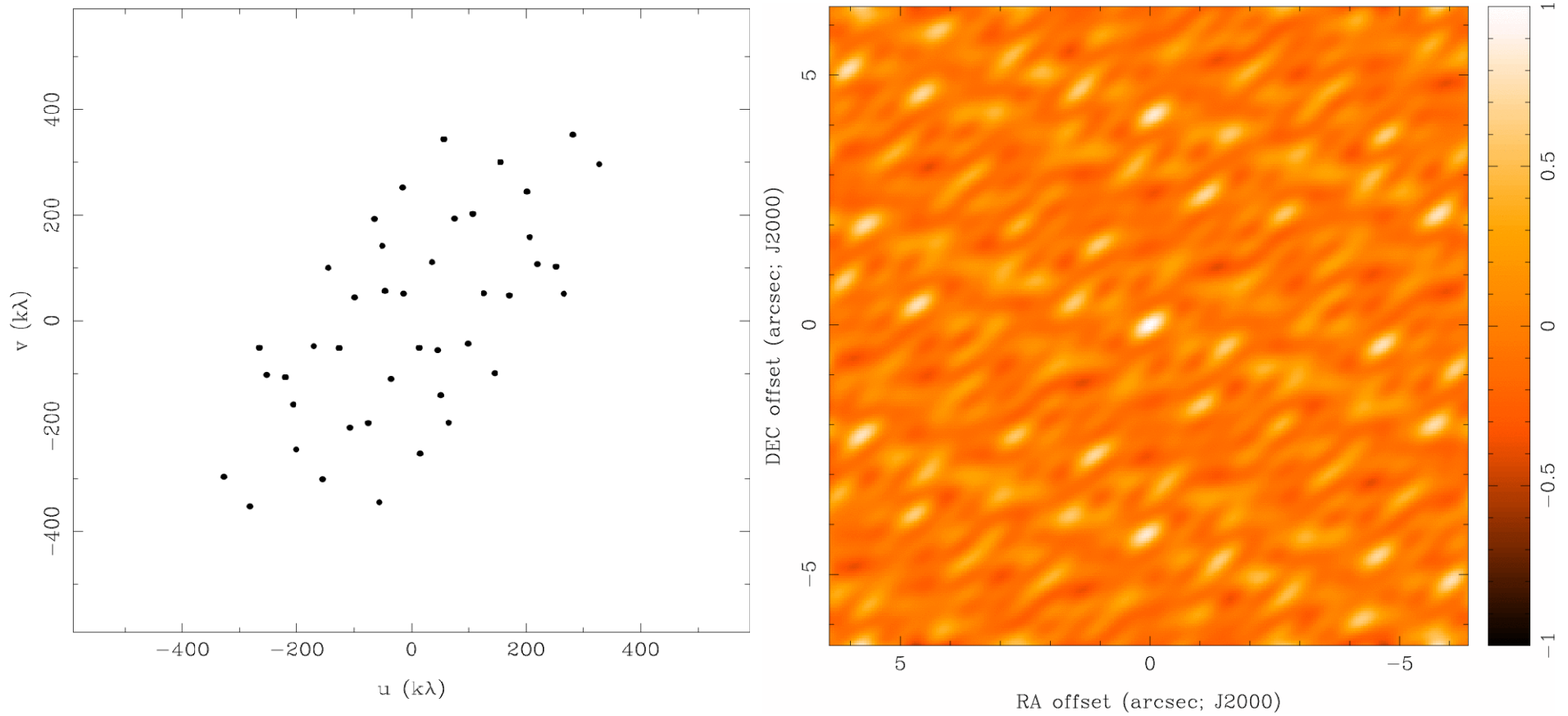
Dirty Beam Shape and N Antennas

6 Antennas



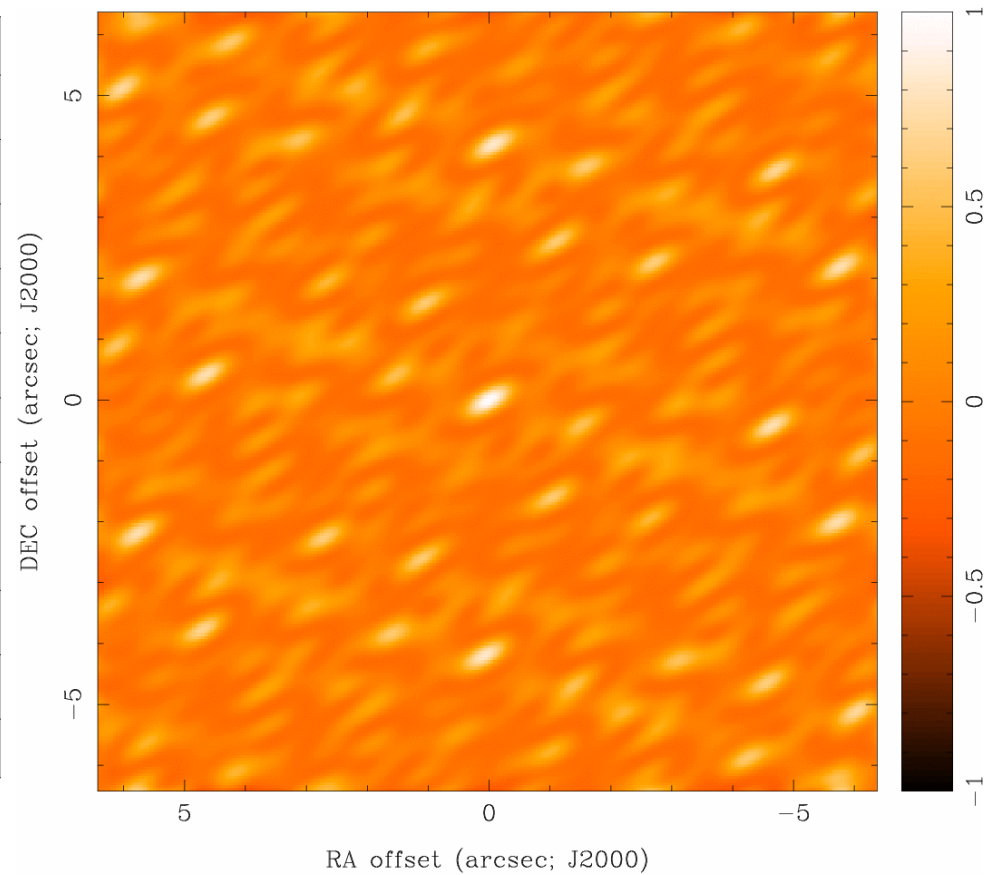
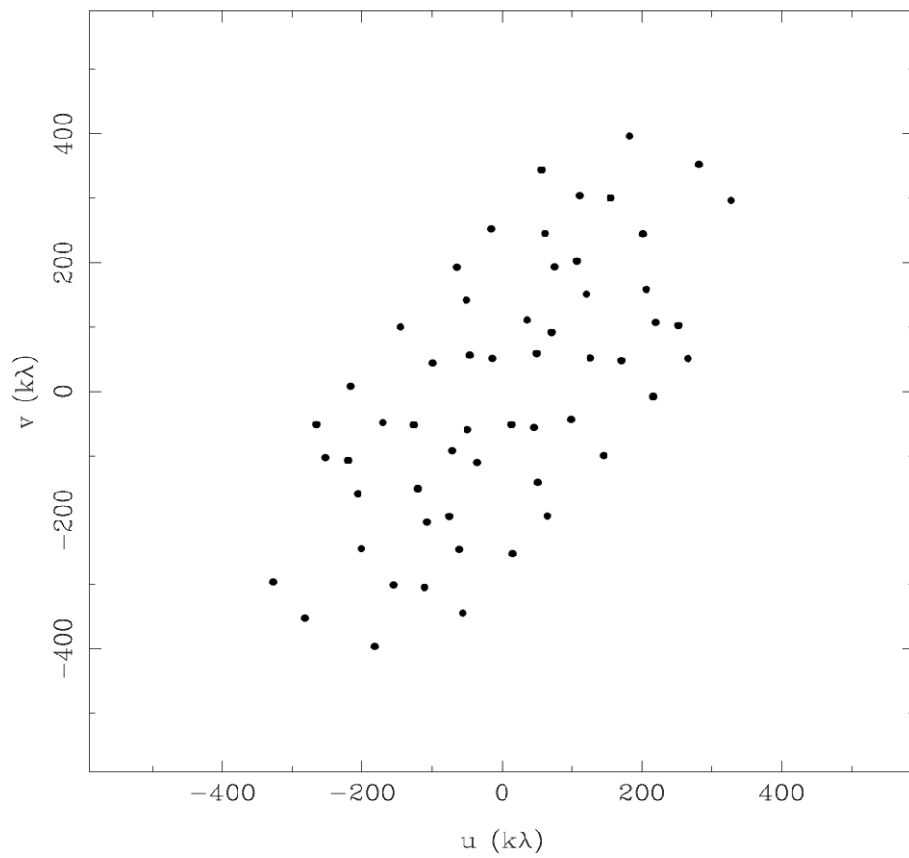
Dirty Beam Shape and N Antennas

7 Antennas



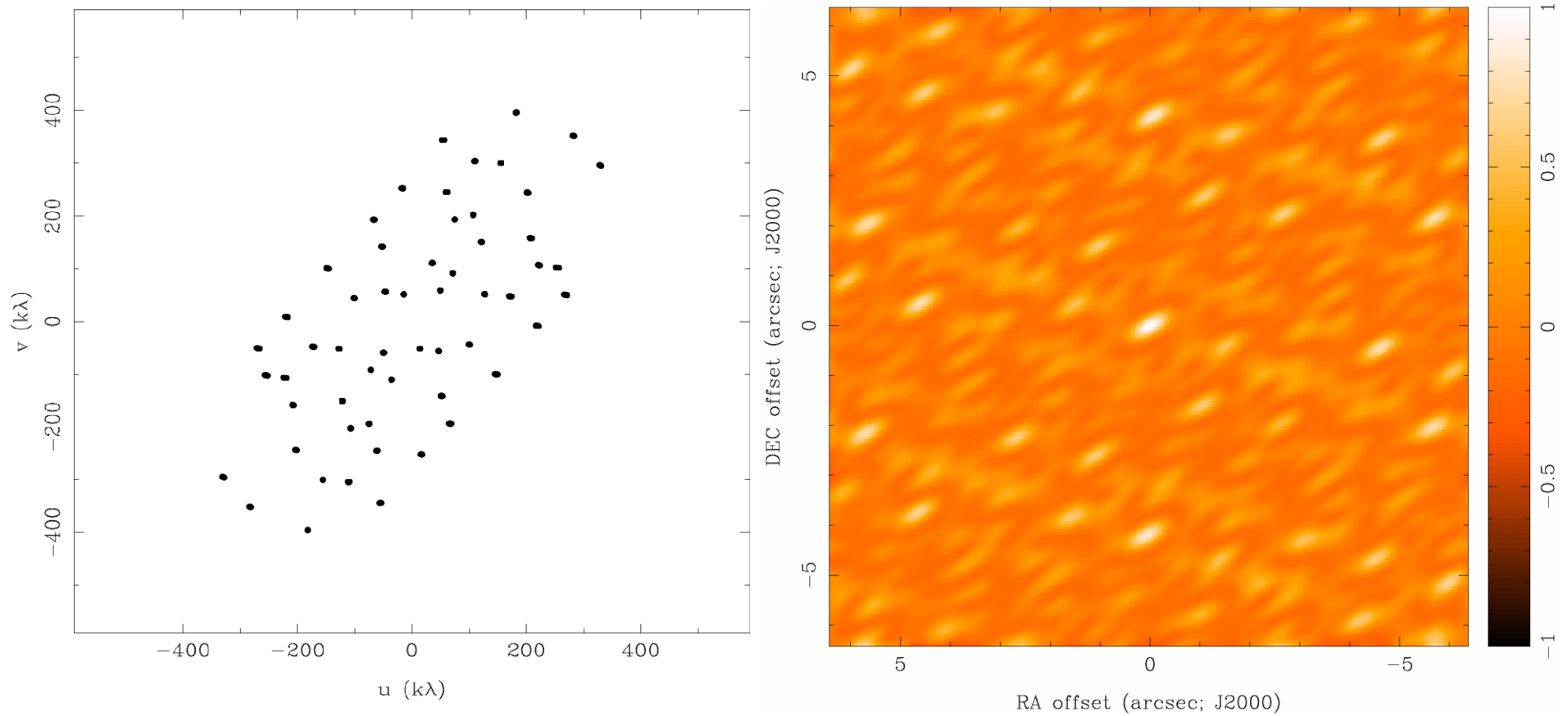
Dirty Beam Shape and N Antennas

8 Antennas



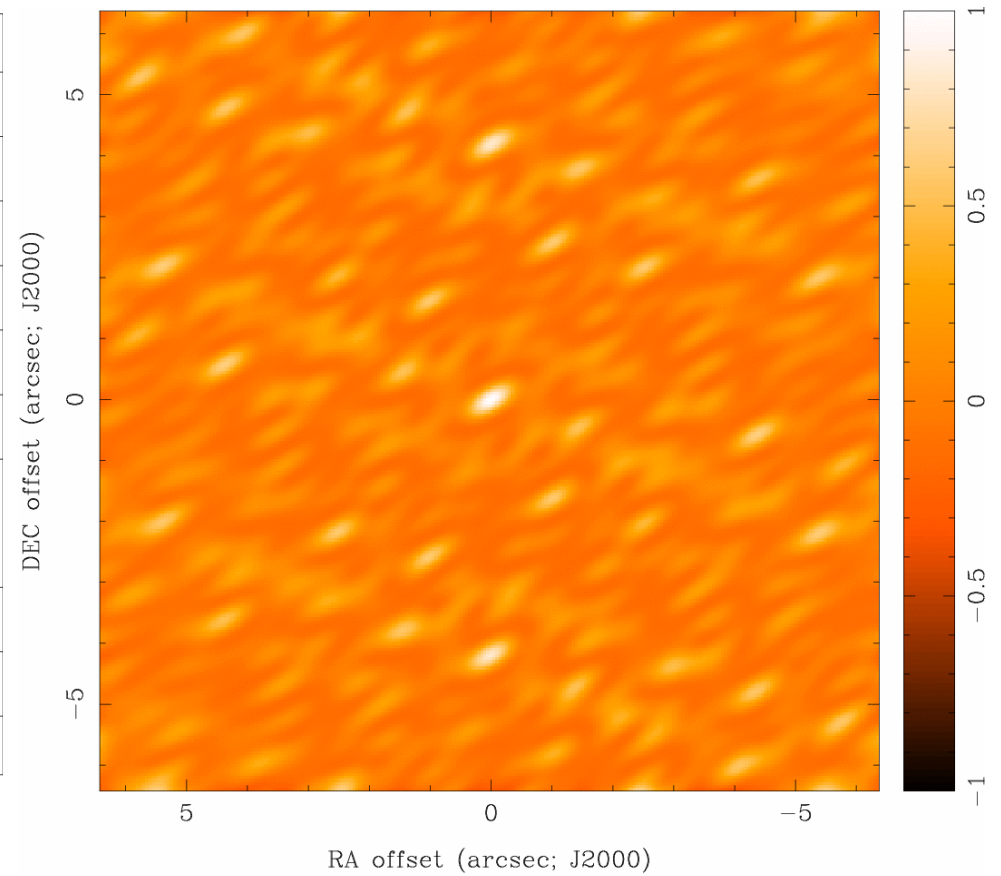
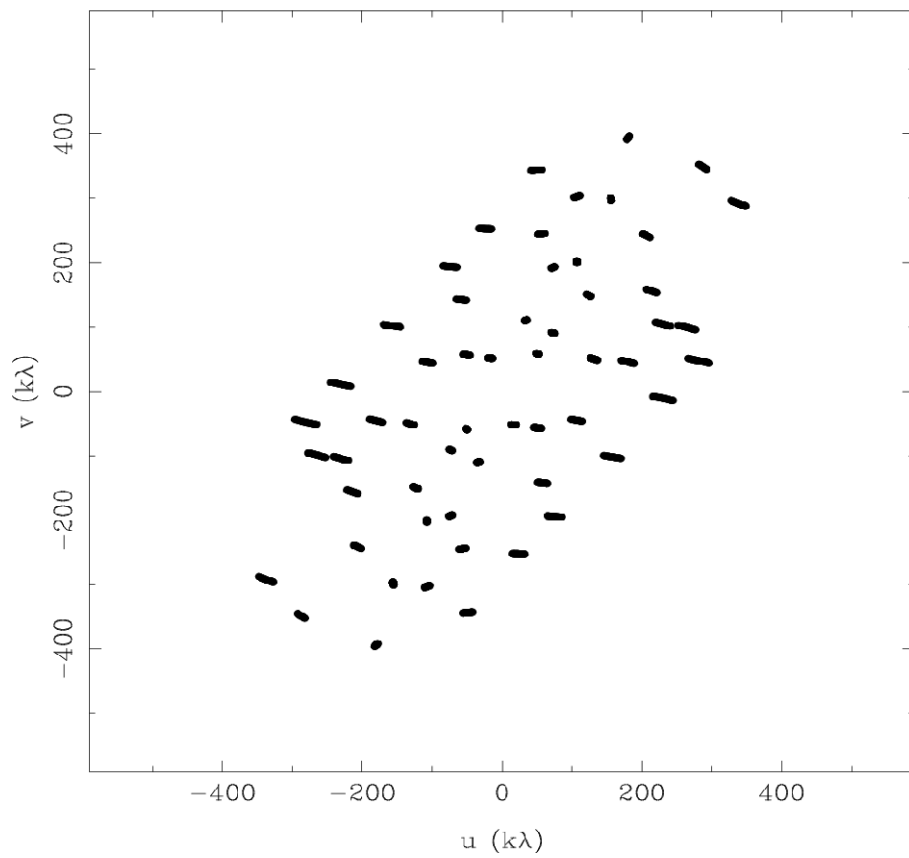
Dirty Beam Shape and N Antennas

8 Antennas x 6 Samples



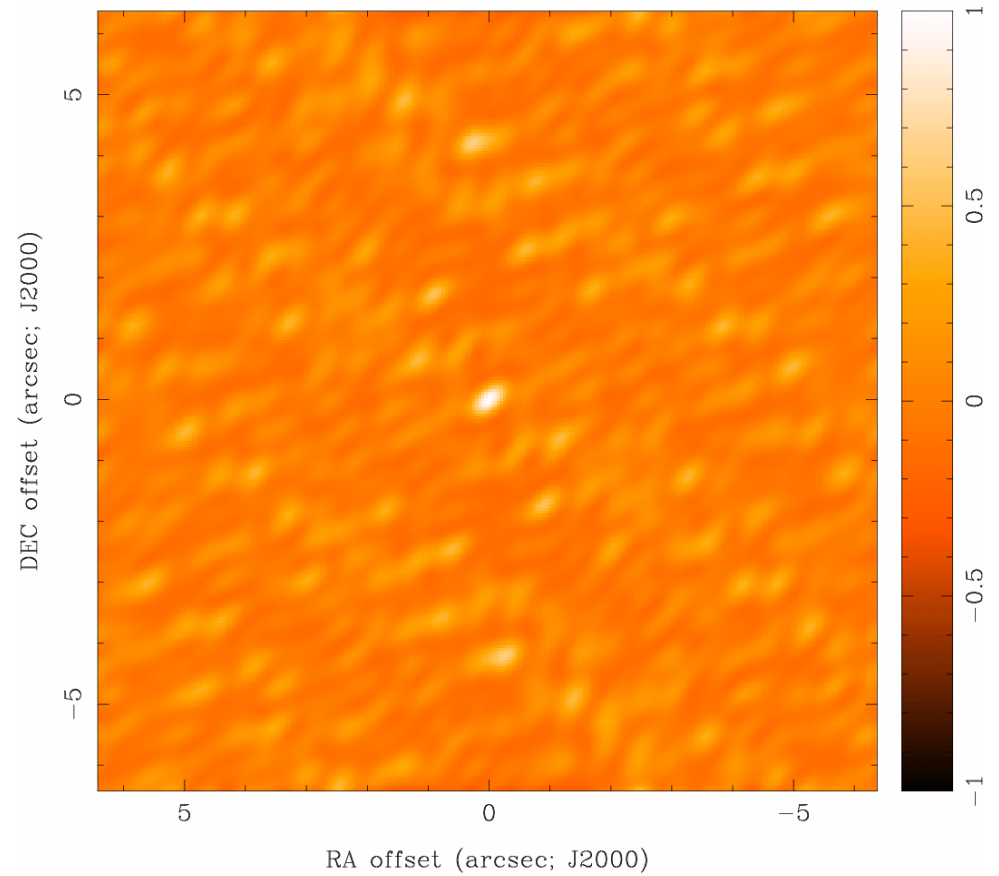
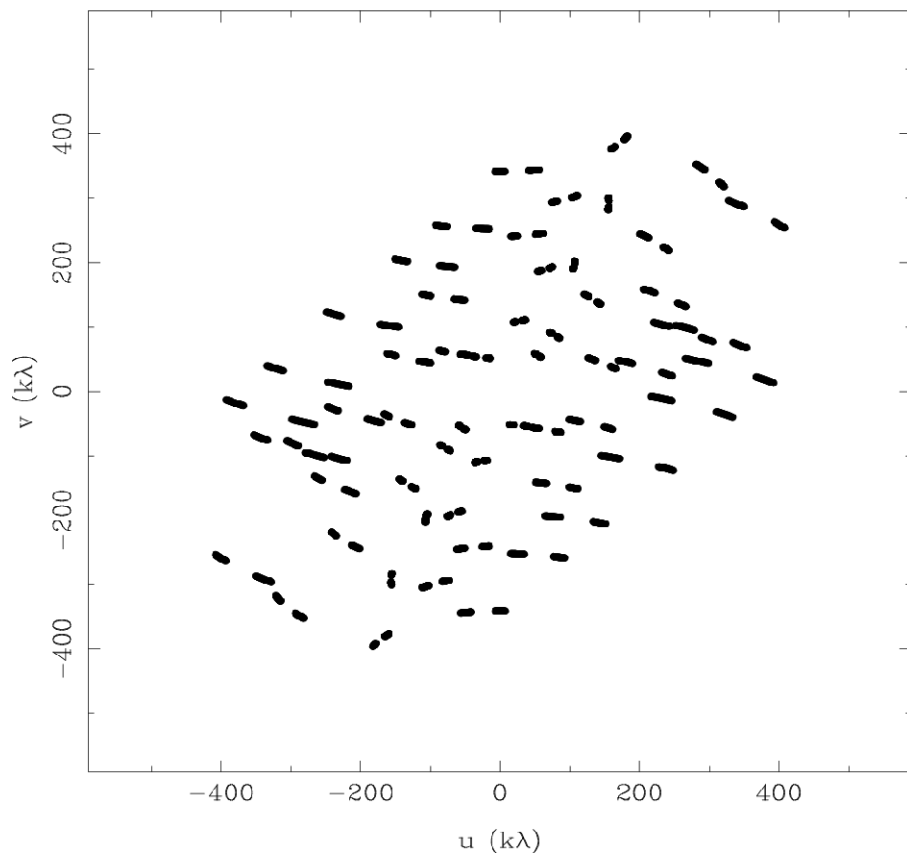
Dirty Beam Shape and N Antennas

8 Antennas x 30 Samples



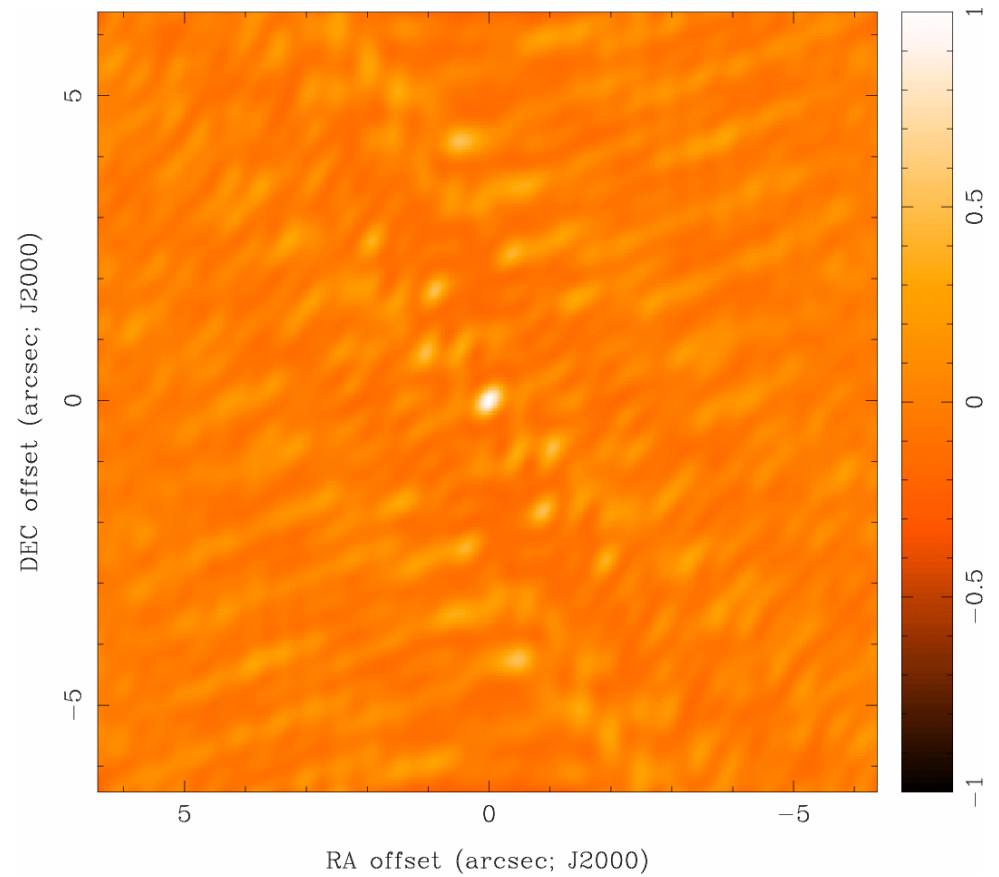
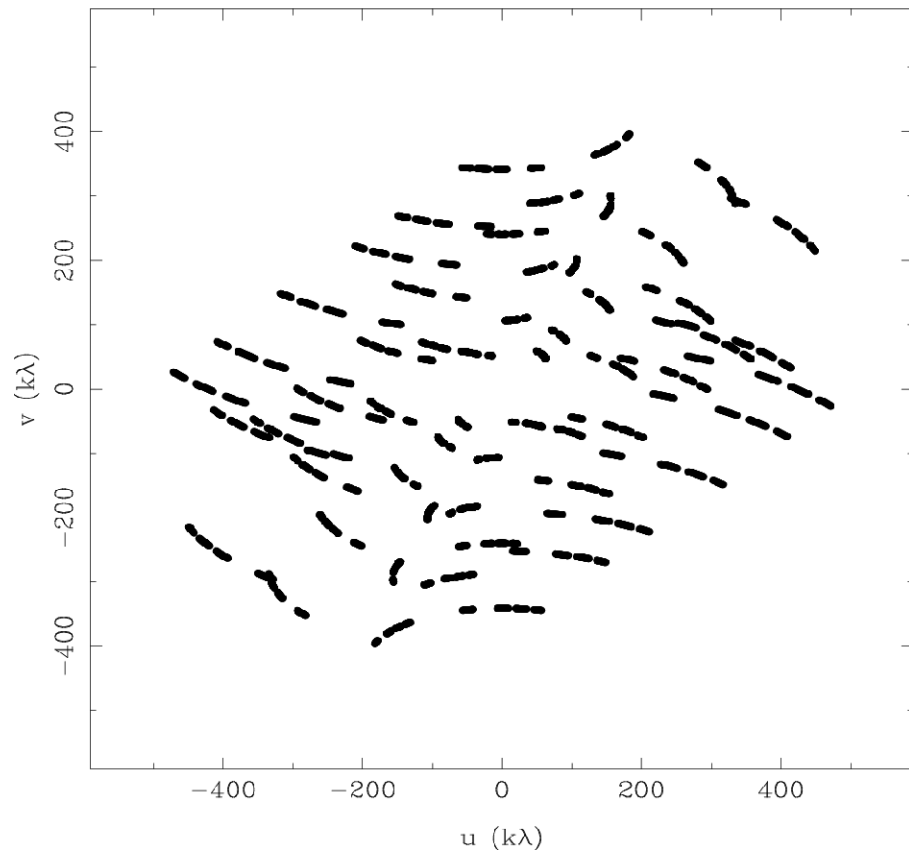
Dirty Beam Shape and N Antennas

8 Antennas x 60 Samples



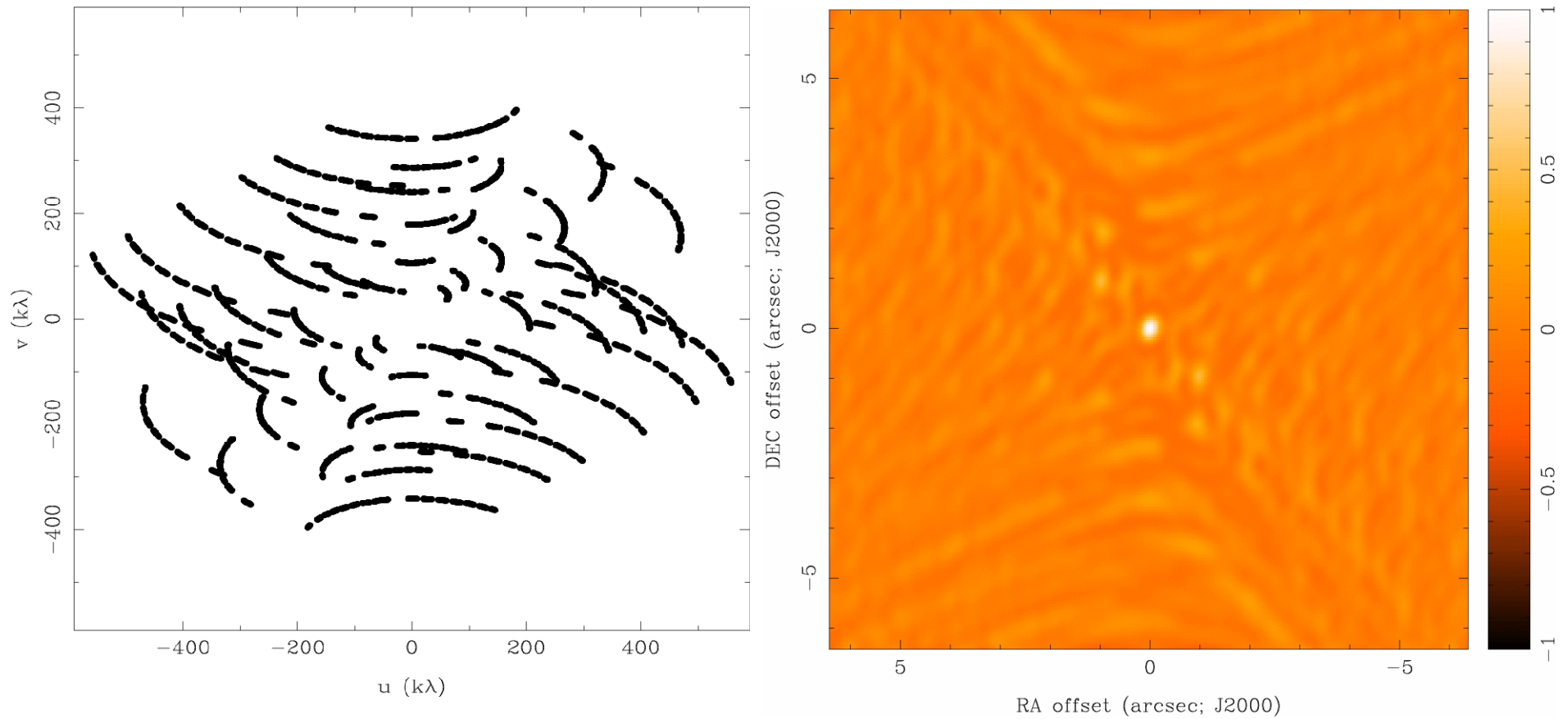
Dirty Beam Shape and N Antennas

8 Antennas x 120 Samples



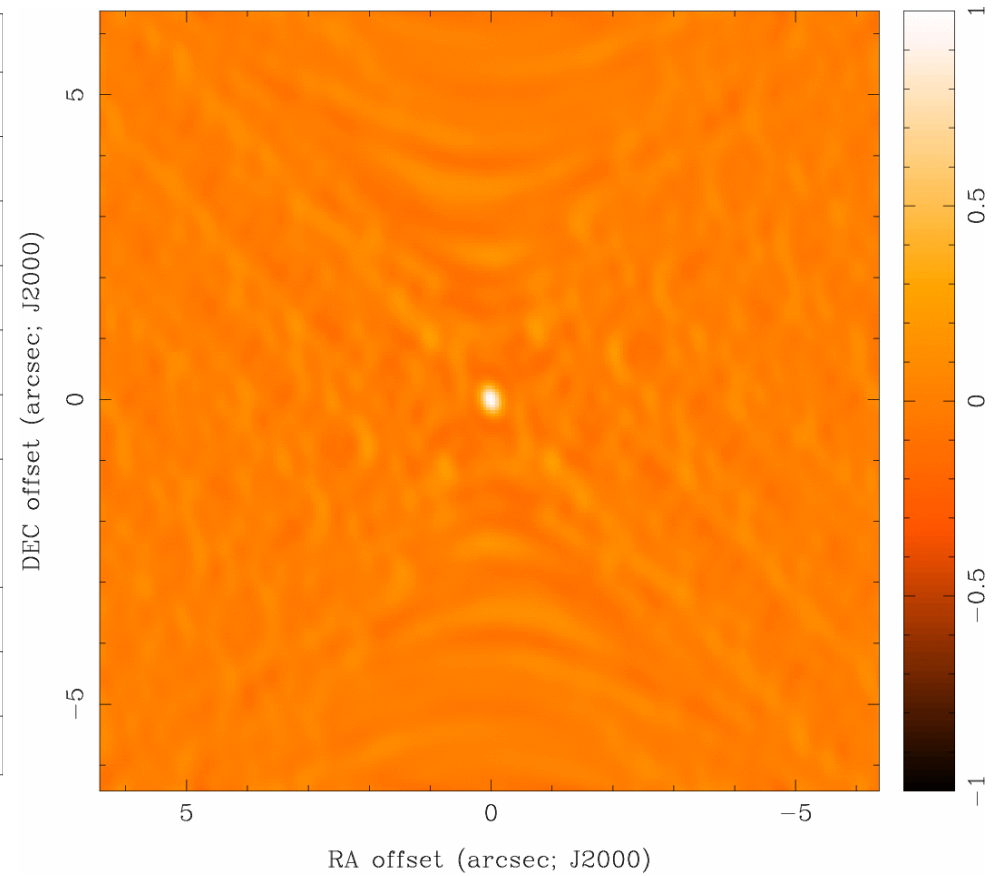
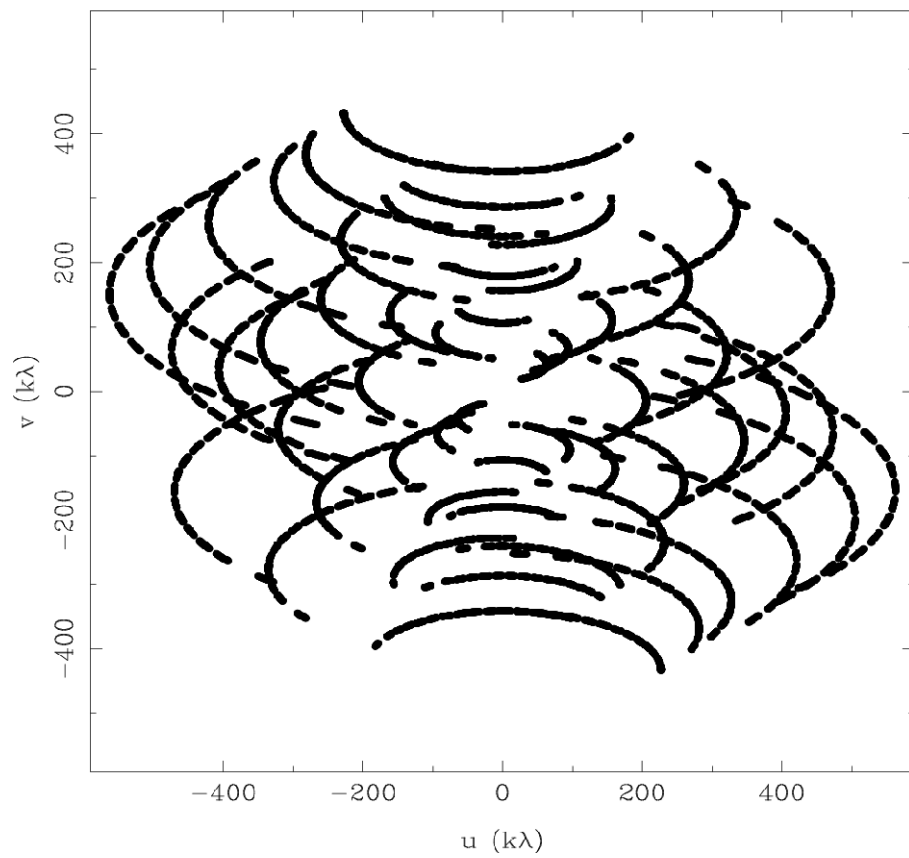
Dirty Beam Shape and N Antennas

8 Antennas x 240 Samples



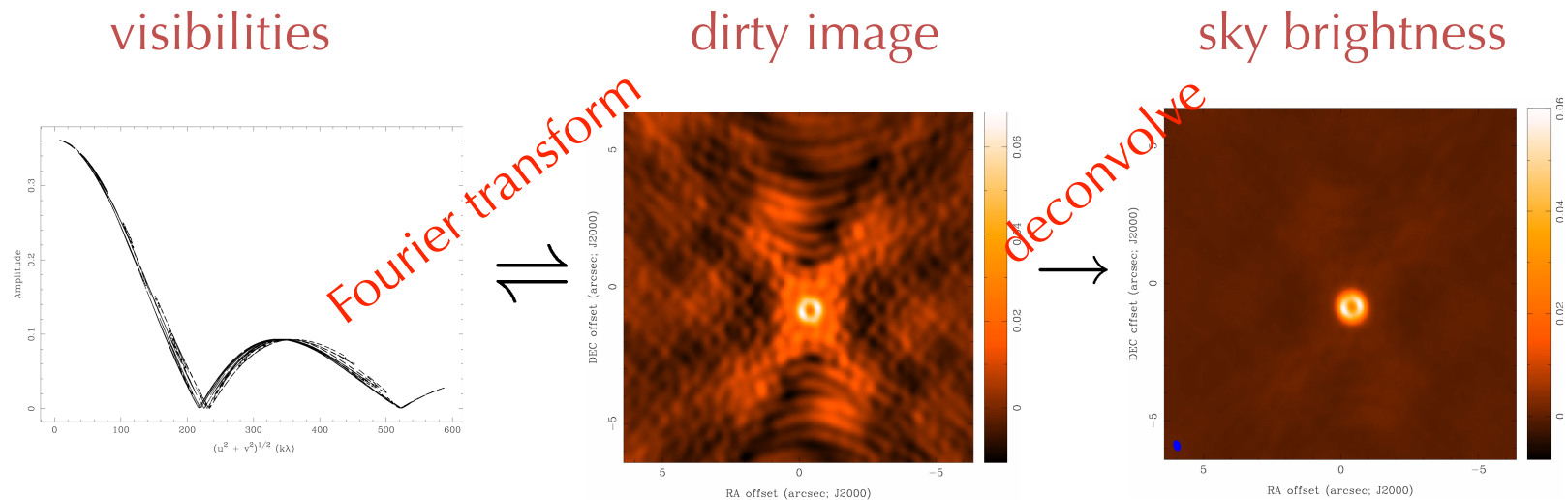
Dirty Beam Shape and N Antennas

8 Antennas x 480 Samples



How to analyze interferometer data?

- uv plane analysis
 - best for “simple” sources, e.g., point sources, disks
- image plane analysis
 - Fourier transform $V(u,v)$ samples to image plane, get $I^D(x,y)$
 - but difficult to do science on dirty image
 - deconvolve $b(x,y)$ from $I^D(x,y)$ to determine (model of) $I(x,y)$



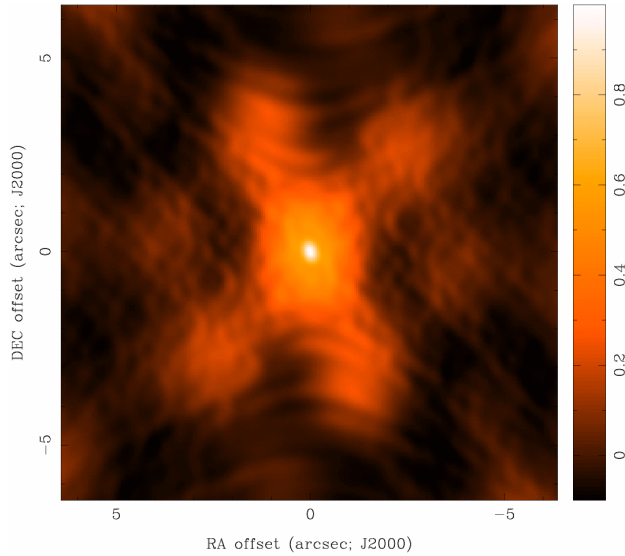
Weighting and Tapering

- Visibility Weighting in the FT:
 - Including *weighting function* W to modify dirty beam sidelobes:
$$b(x, y) = FT^{-1}\{W(u, v)B(u, v)\}$$
 - *natural weighting*: density of uv-coverage = highest compact flux sensitivity
 - *uniform weighting*: extent of uv-coverage = highest resolution
 - *robust weighting*: compromise between natural and uniform
 - *tapering*: downweights high spatial frequencies = higher extended flux sensitivity
- imaging parameters provide a lot of freedom
- appropriate choice depends on science goals
- recall that the primary beam FWHM is the “field-of-view” of a single-pointing interferometric image

Weighting and Tapering: Examples

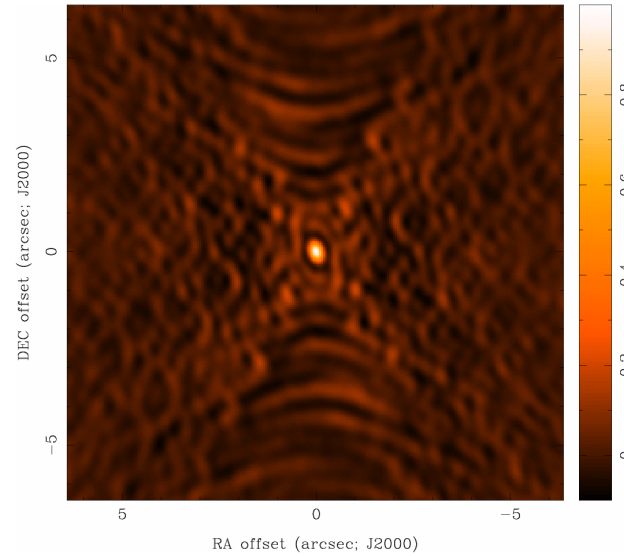
Natural
0.77x0.62

$\sigma = 1.0$



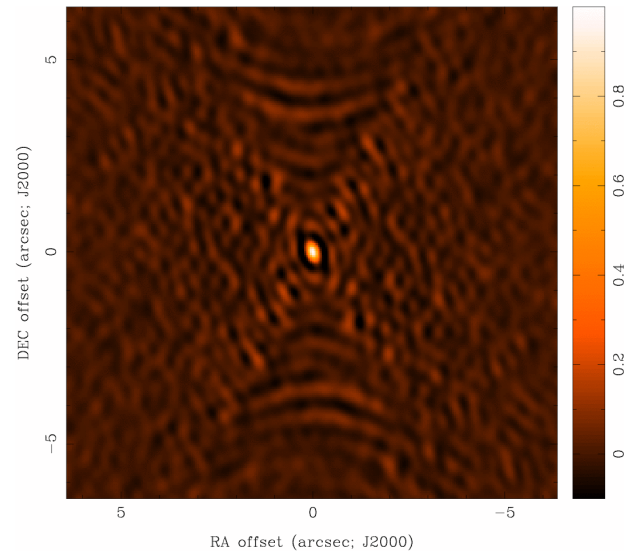
Robust 0
0.41x0.36

$\sigma = 1.6$



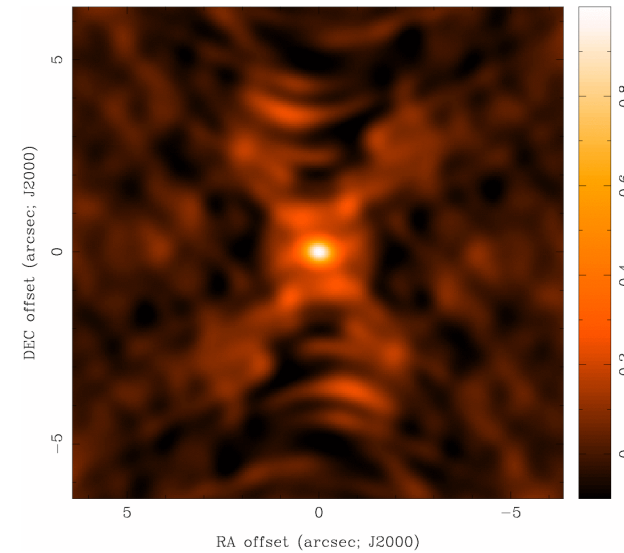
Uniform
0.39x0.31

$\sigma = 3.7$



Robust 0
+ Taper
0.77x0.62

$\sigma = 1.7$

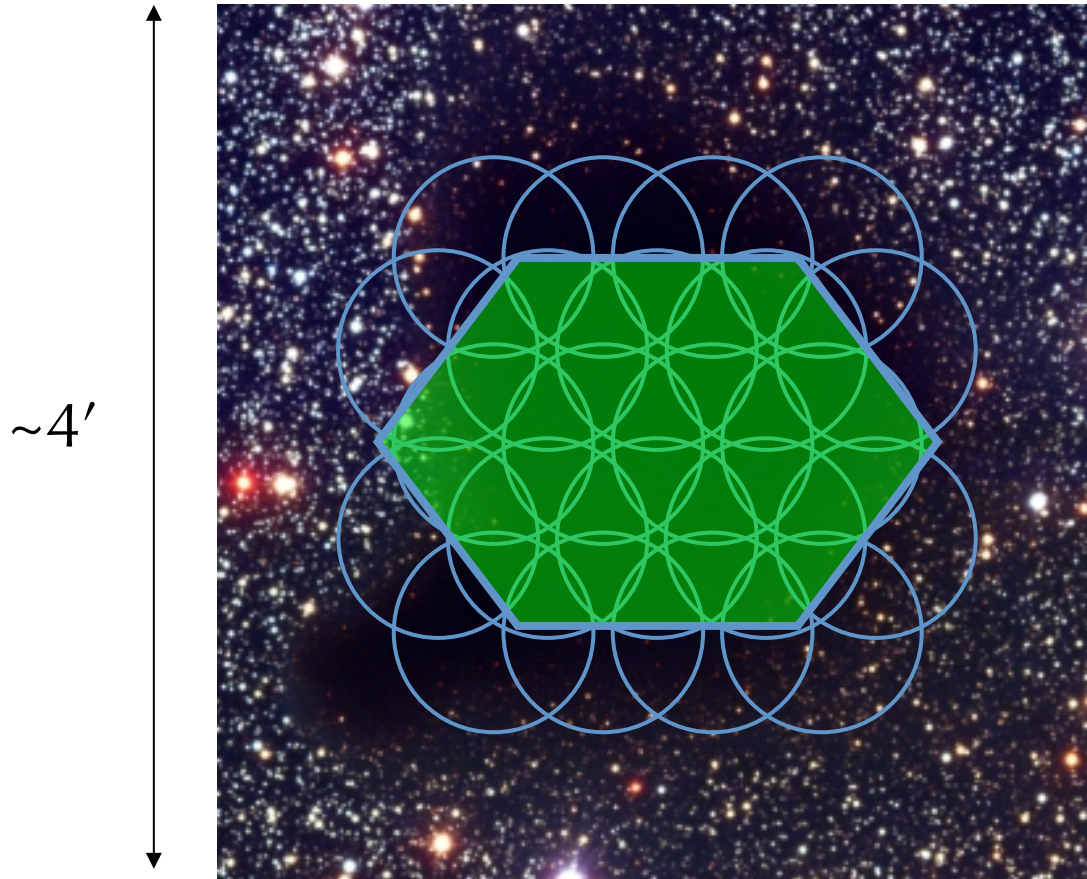


Field of View: Single Pointing



B68 ALMA single pointing

Field of View: Mosaics



B68 ALMA Band 3 mosaic

Nyquist Spacing

$$= 3^{-1/2} (\lambda/D) \text{ rad.}$$

$$= 29.75'' \times (\nu/100 \text{ GHz})^{-1}$$

= constant rms
over inner area

Mosaics of up to
50 pointings OK
for Early Science



Next: Deconvolution