Short intro to interferometry

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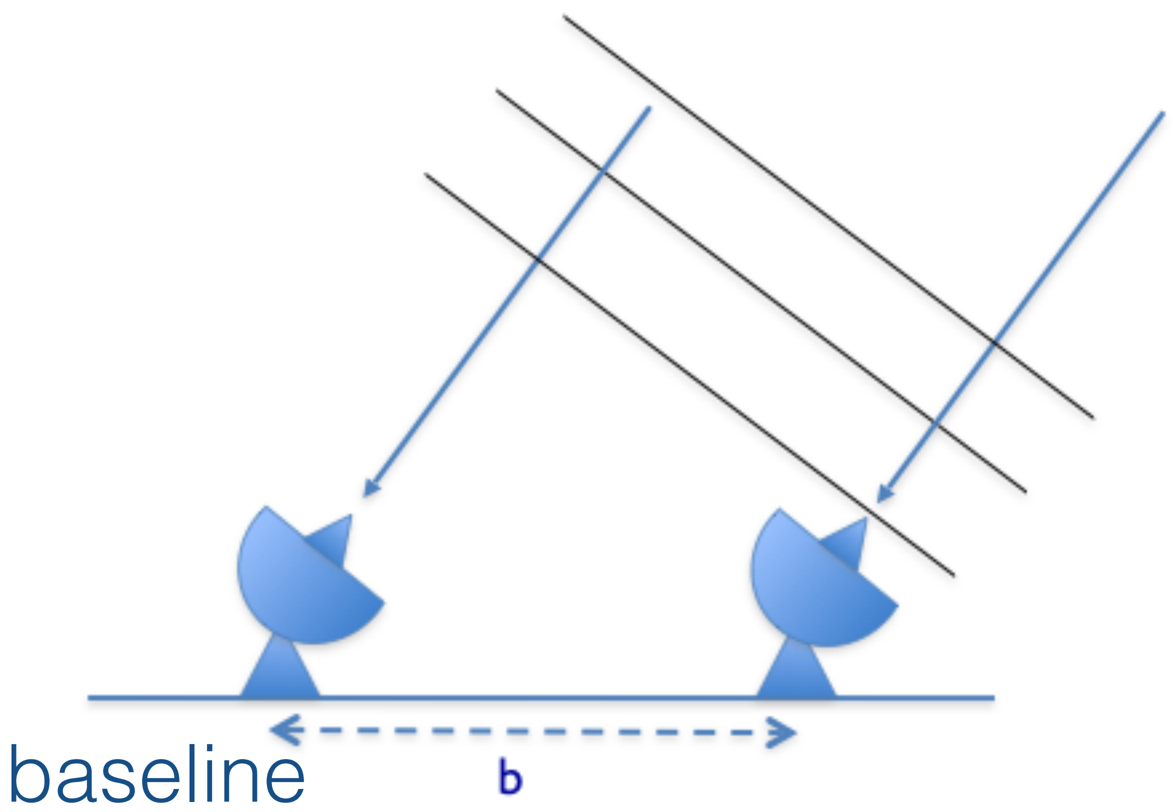
Outline

- Interferometry (the basics)
- Visibility and sky brightness
- how should I *use* ALMA archival data:
    - my scientific goal overlaps what that specific ALMA observation may offer?
- some definition (Flux, Beam, Sensitivity, data cube…)

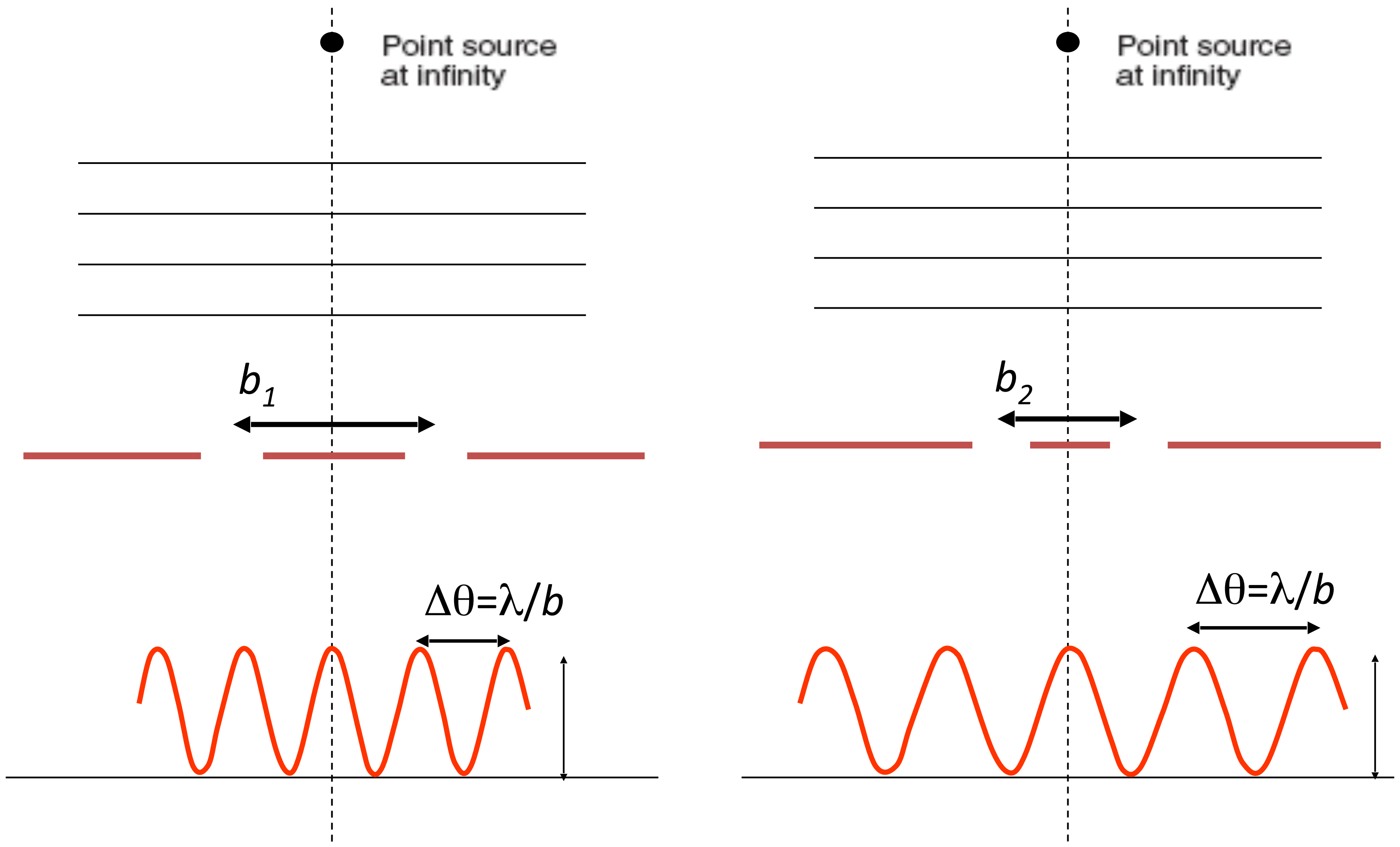
AIM: not to explain interferometry in detail, but make users more conscious when using Archive Data

Interferometers: the basics

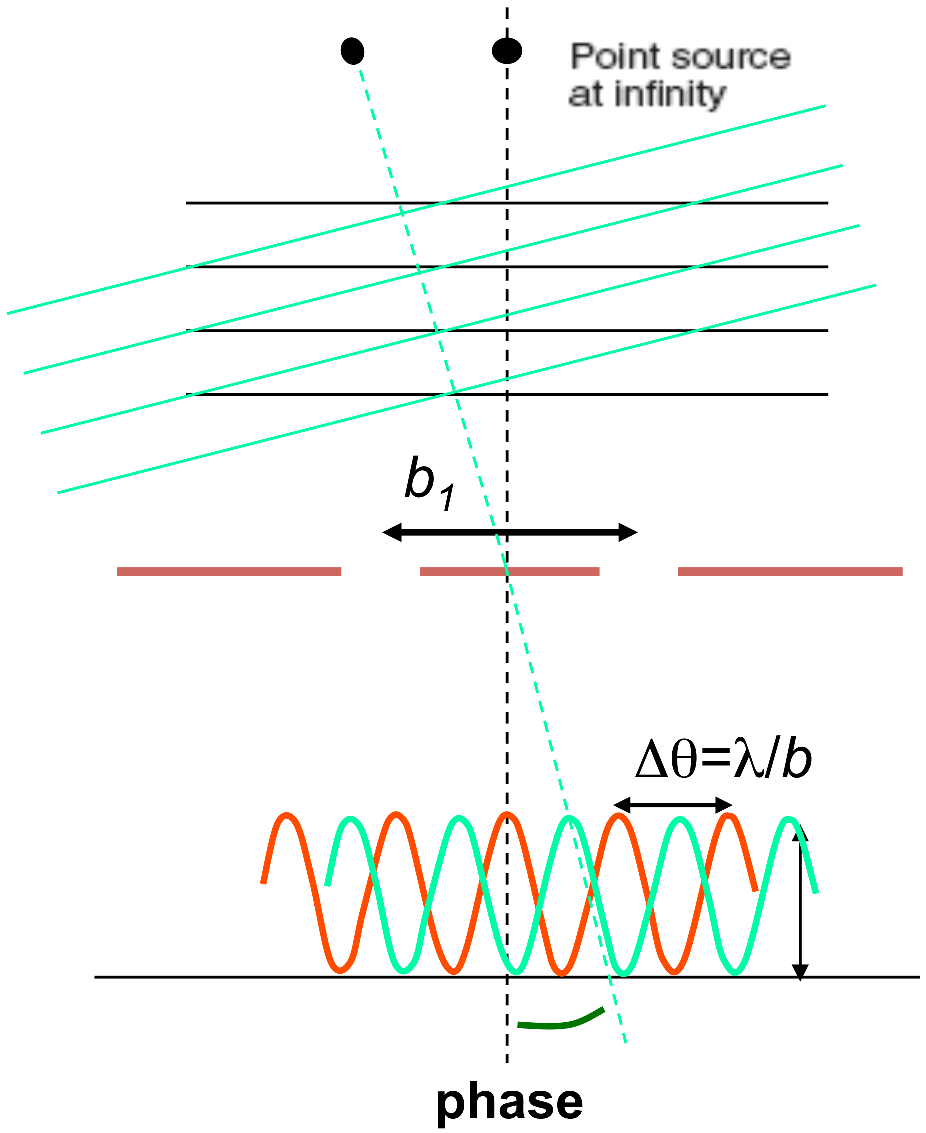
- Interferometry: a method to 'synthesize' a large aperture by combining signals collected by separated small apertures
- An Interferometer measures the interference pattern produced by two apertures, which is related to the source brightness.
- The signals from all antennas are correlated, taking into account the distance (baseline) and time delay between pairs of antennas



Interferometers: the basics



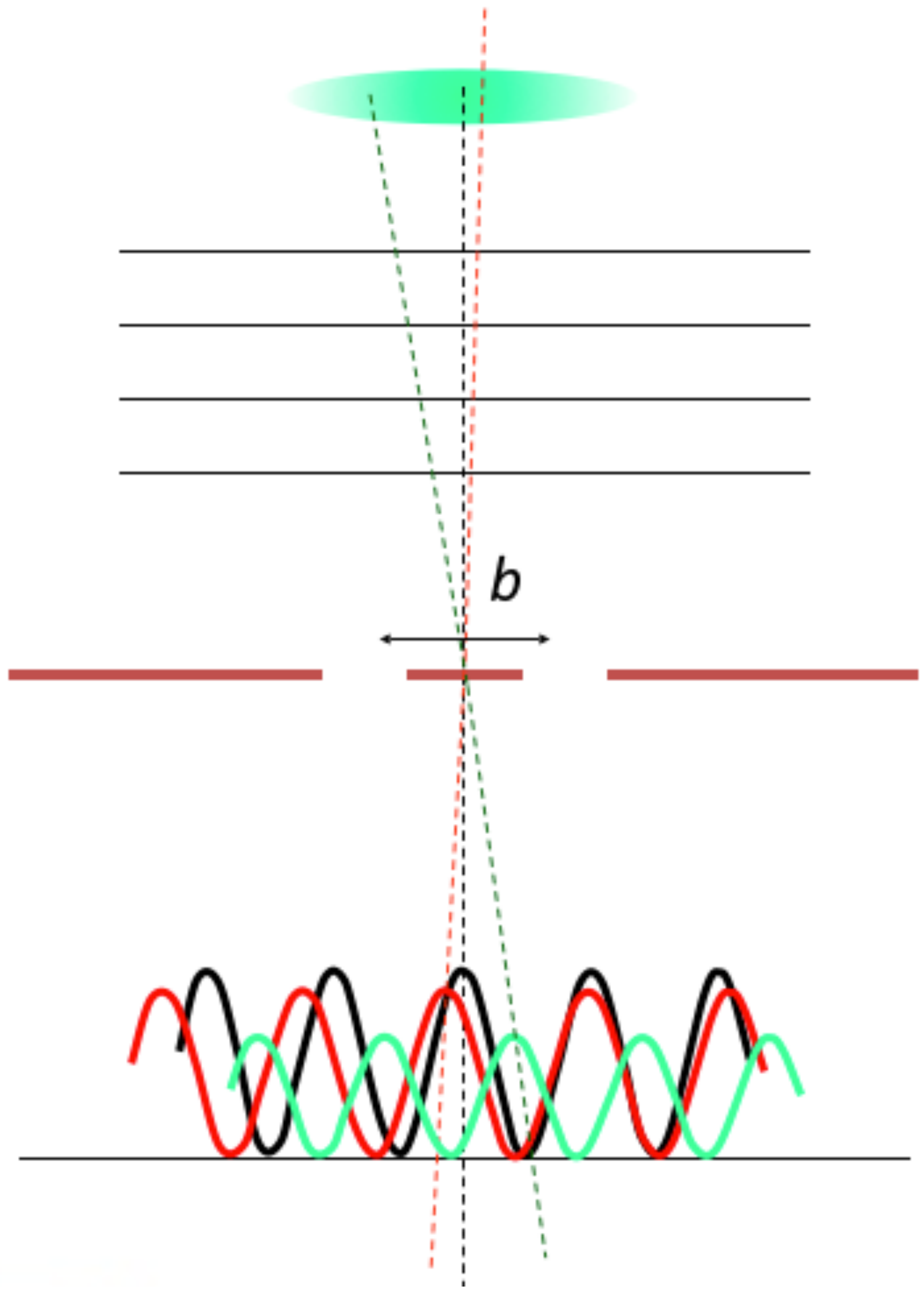
Interferometers: the basics



Spatial Frequency λ\b

if we observe at different λ, we sample different spatial frequencies

Interferometers: the basics

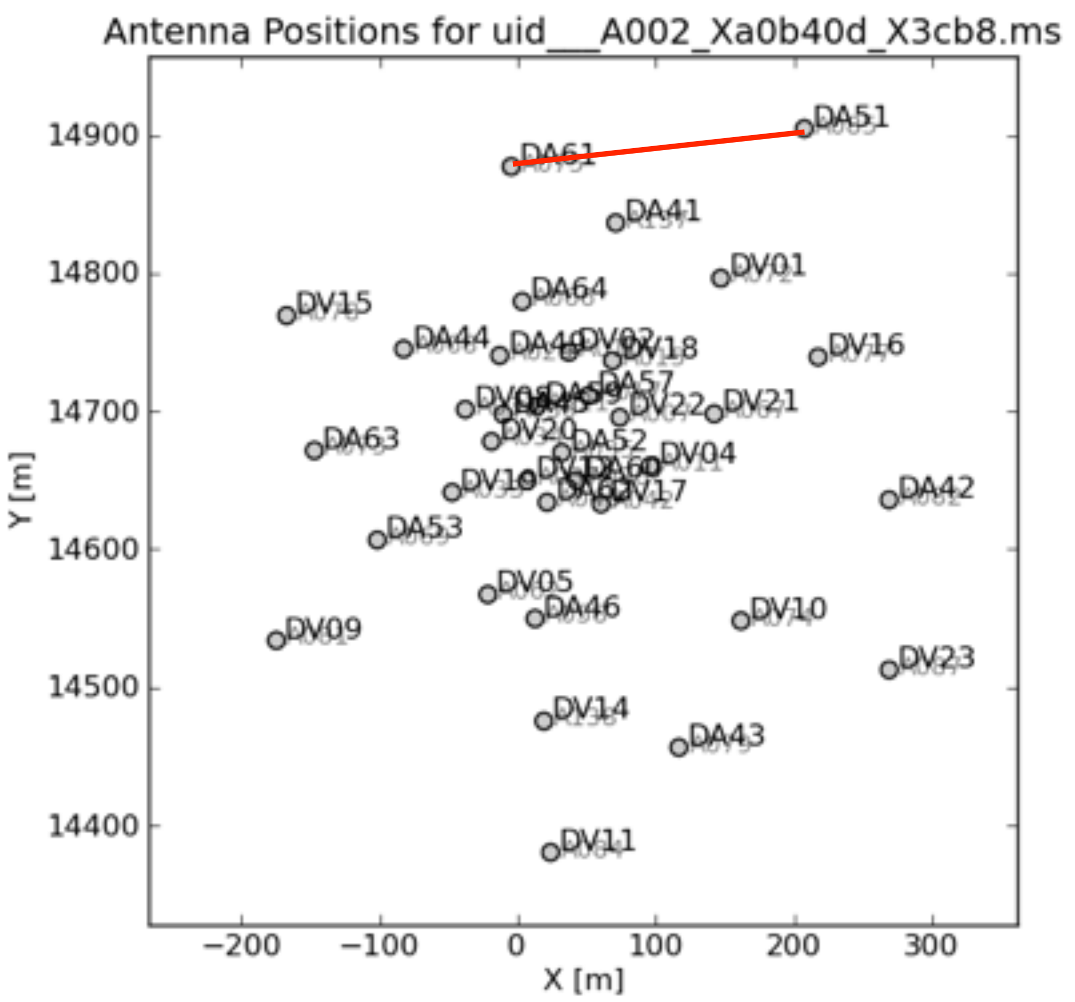


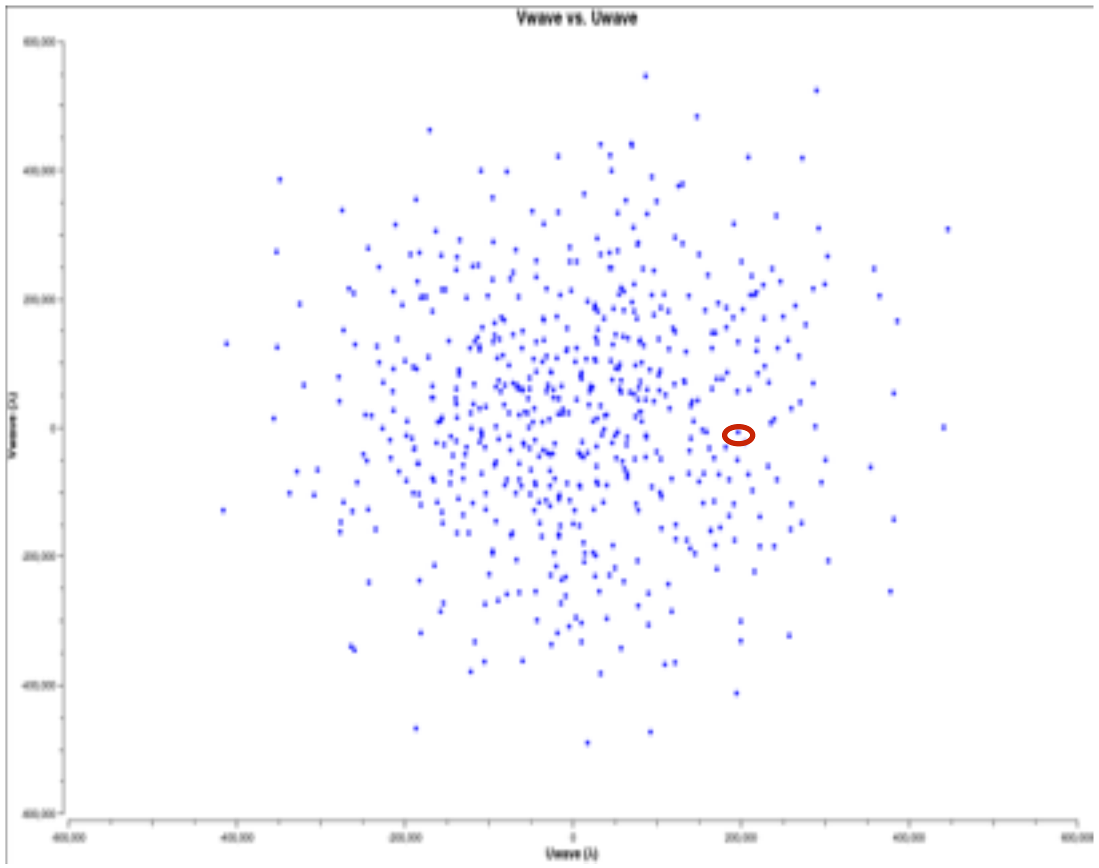
- Amplitude tells "how much" of a certain frequency component
- Phase tells "where" this component is located

Visibility

Interferometers: the baseline in the uv plane

each antenna pair —> a point in uv plane





b(u,v) in λ units

u, v components in the E-W,N-S directions

Visibility and Sky Brightness

For small fields of view: the complex visibility,V(u,v), is the 2D Fourier transform of the brightness on the sky,T(x,y)

Citter-Zernike theorem

$$V(u,v) = \int\int T(x,y) e^{2\pi i(ux+vy)} dx dy$$

$$T(x,y) = \int\int V(u,v) e^{-2\pi i(ux+vy)} du dv$$

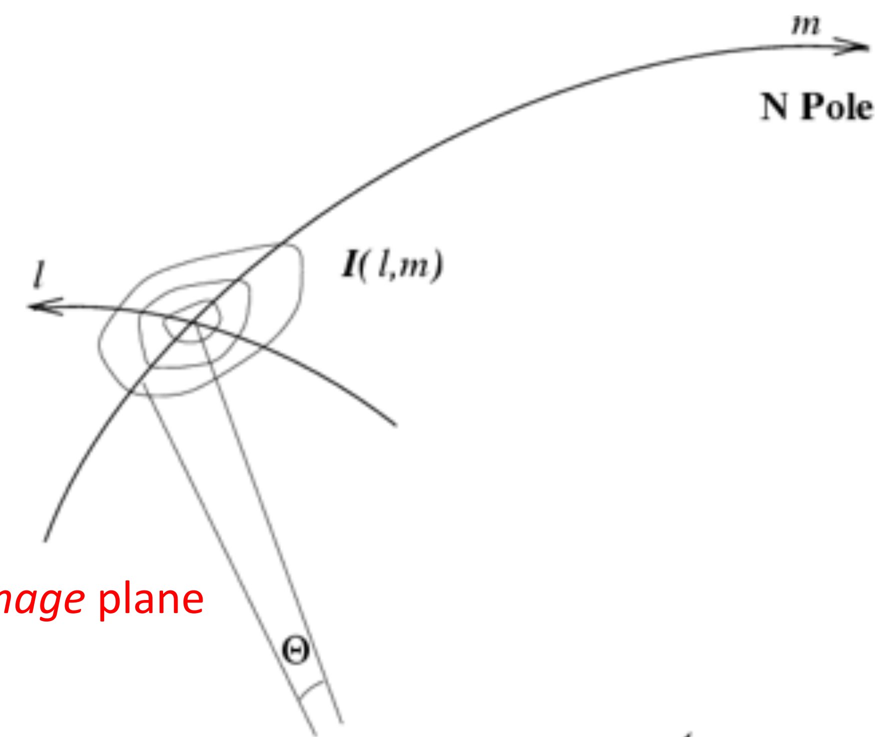
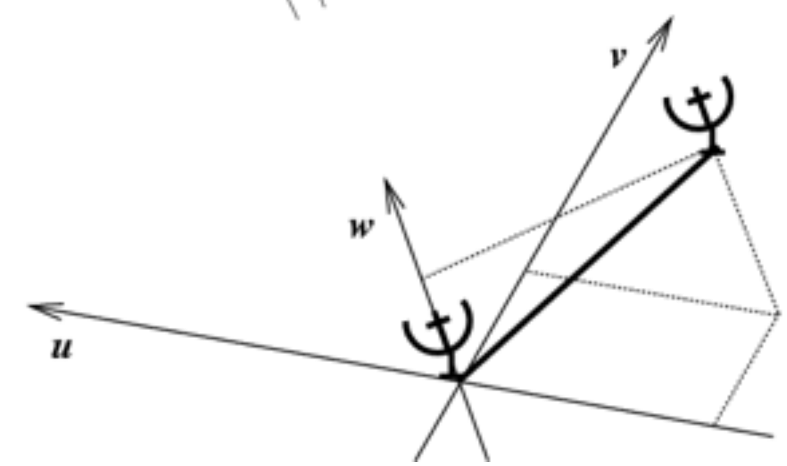


image plane

- u,v (wavelenghts) are spatial frequencies in E-W and N-S directions, i.e. the baseline lengths
- x,y (rad) are angles in tangent plane relative to a reference position in the E-W and N-S directions



$$V(u,v) \rightleftharpoons T(x,y)$$

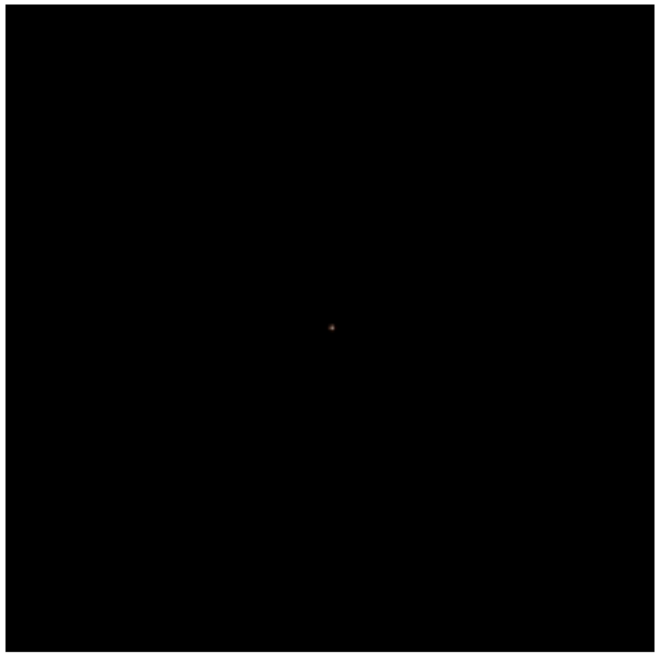
uv plane

2D Fourier Transforms

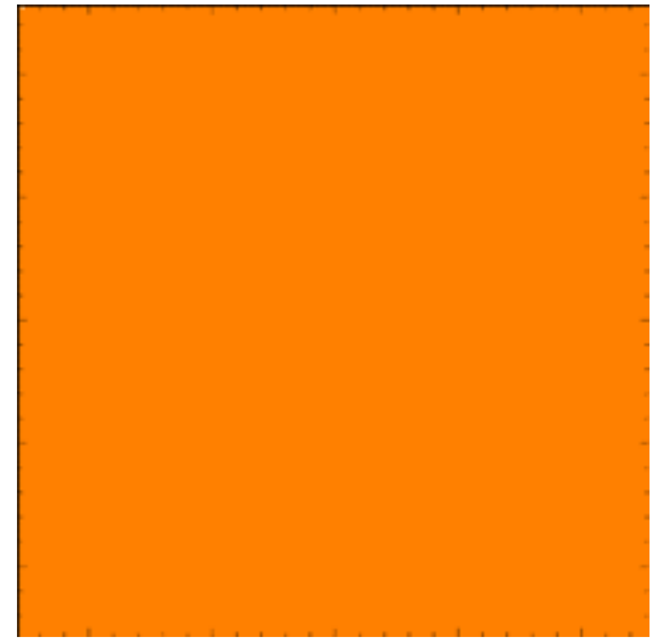
T(x,y)

Amp{V(u,v)}

δ Function

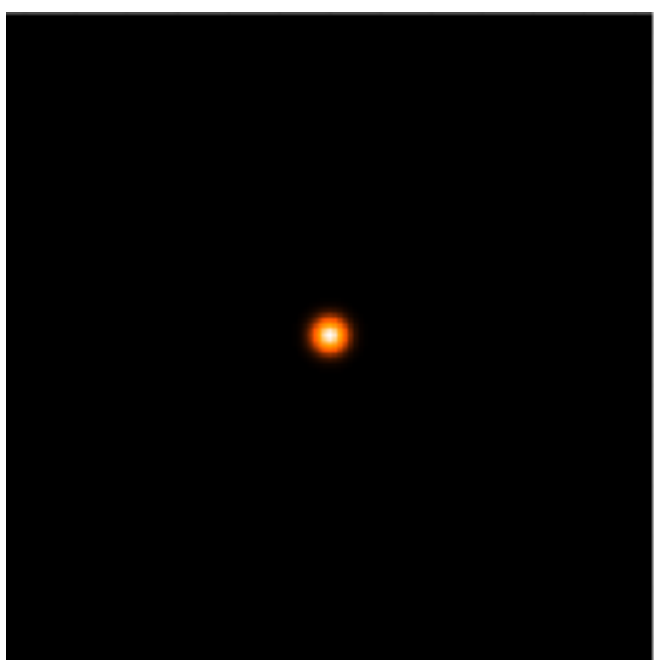


$\rightleftharpoons$



Constant

Gaussian



$\rightleftharpoons$

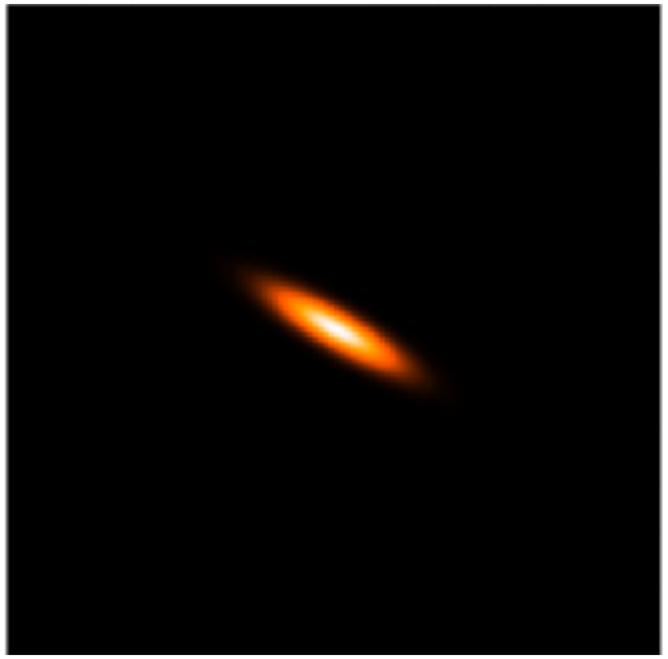
Gaussian

narrow features transform to wide features (and vice-versa)

2D Fourier Transforms

T(x,y) **Amp{V(u,v)}**

elliptical
Gaussian

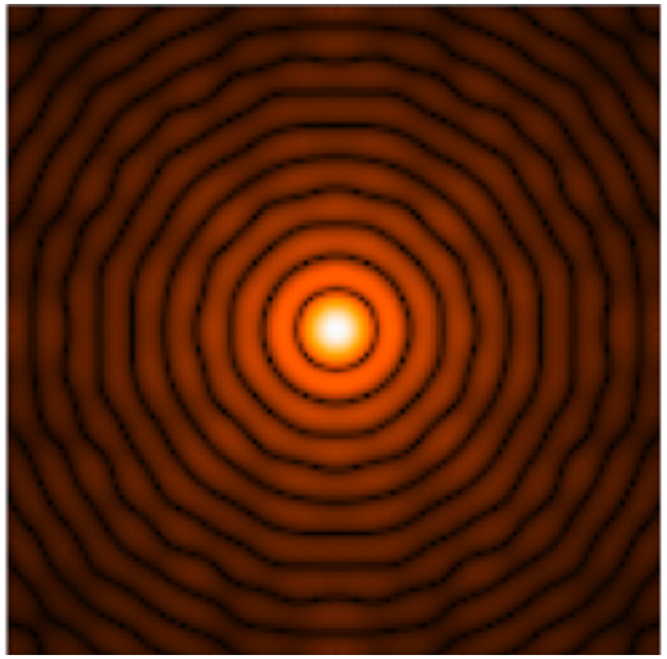


⇌

elliptical
Gaussian

Disk

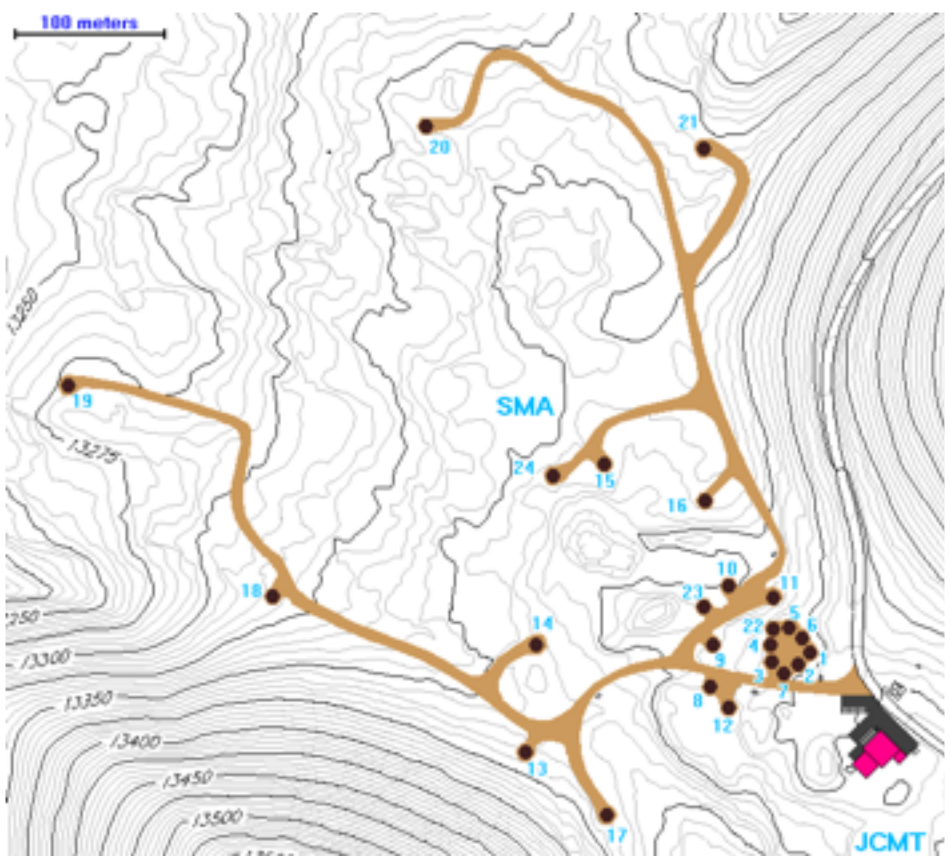
⇌

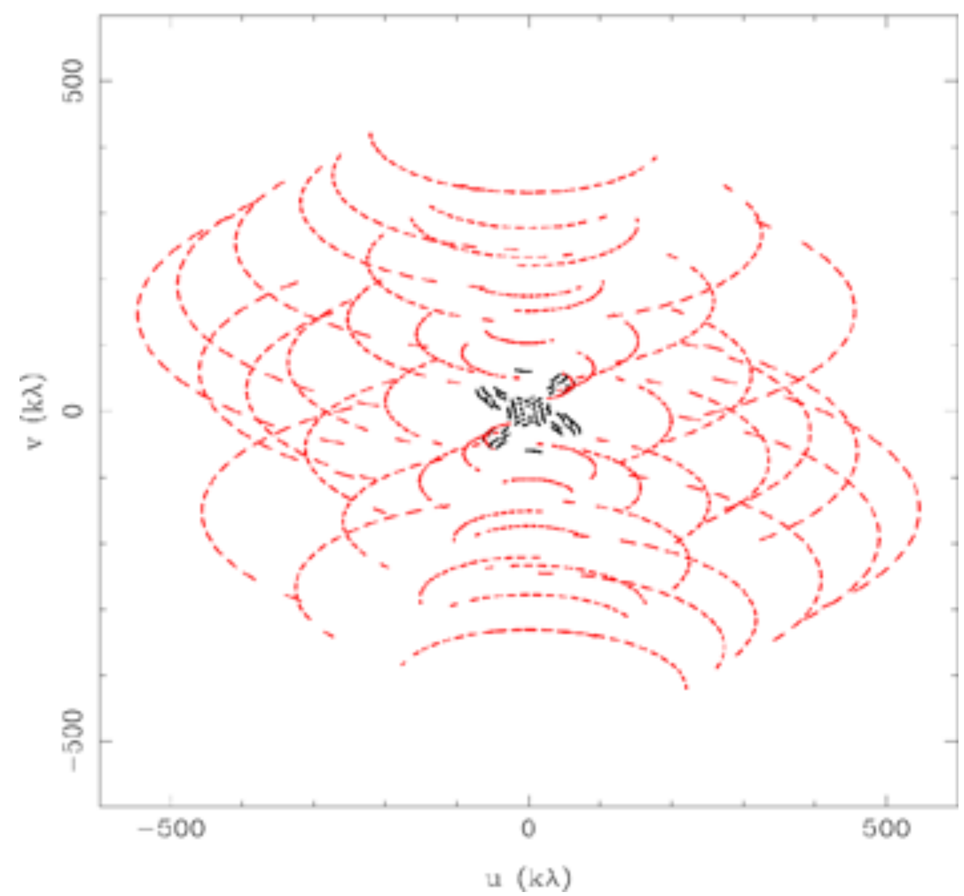


Bessel

Aperture Synthesis

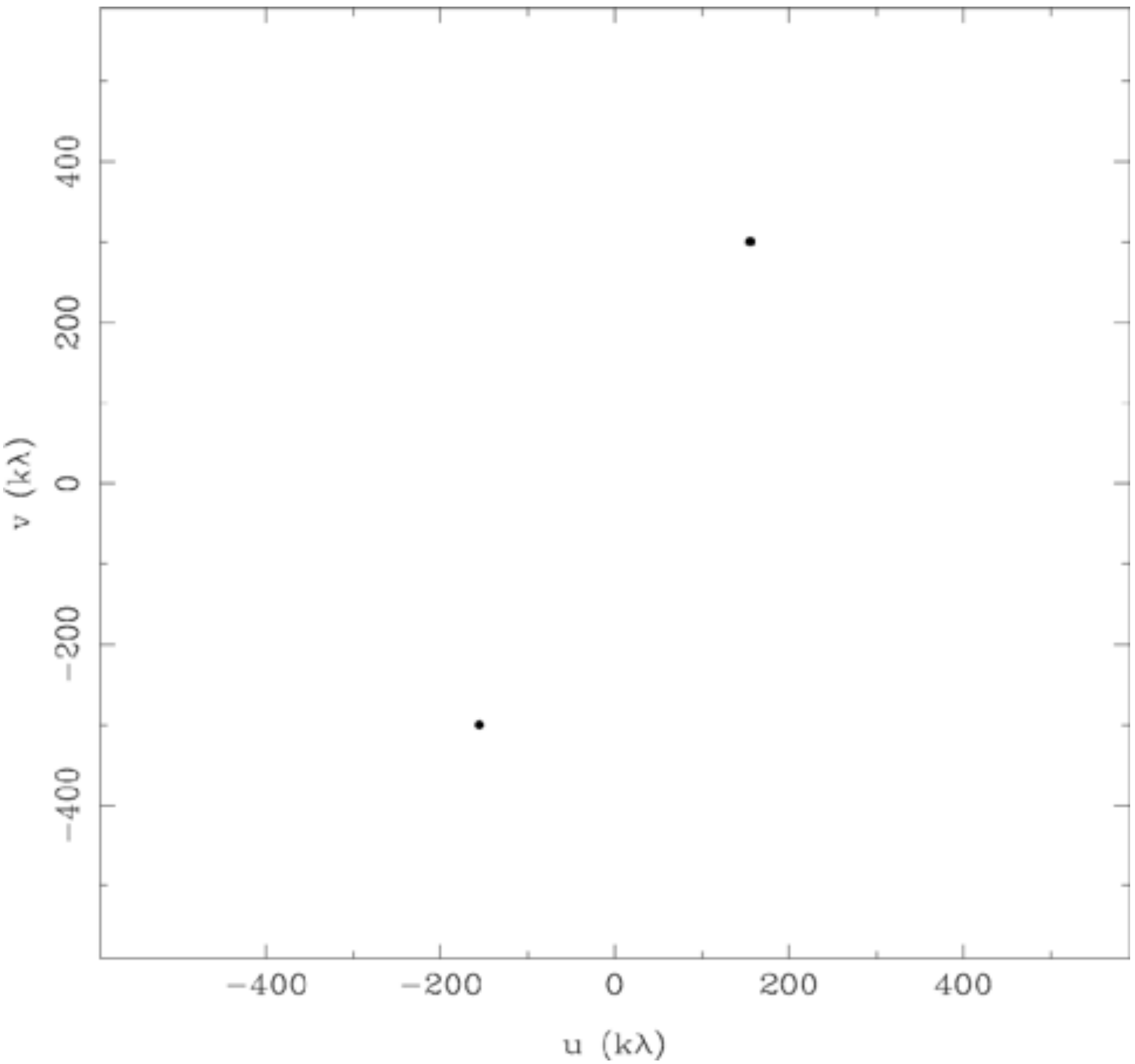
- Sample V(u,v) at enough points to synthesis the equivalent large aperture of size (u_{max}, v_{max})
  - 1 pair of telescopes → 1 (u,v) sample at a time
  - N telescopes → number of samples = N(N-1)/2
- A good image quality requires a good coverage of the uv plane
  - fill in (u,v) plane by making use of Earth rotation ("track")
  - reconfigure physical layout of N telescopes

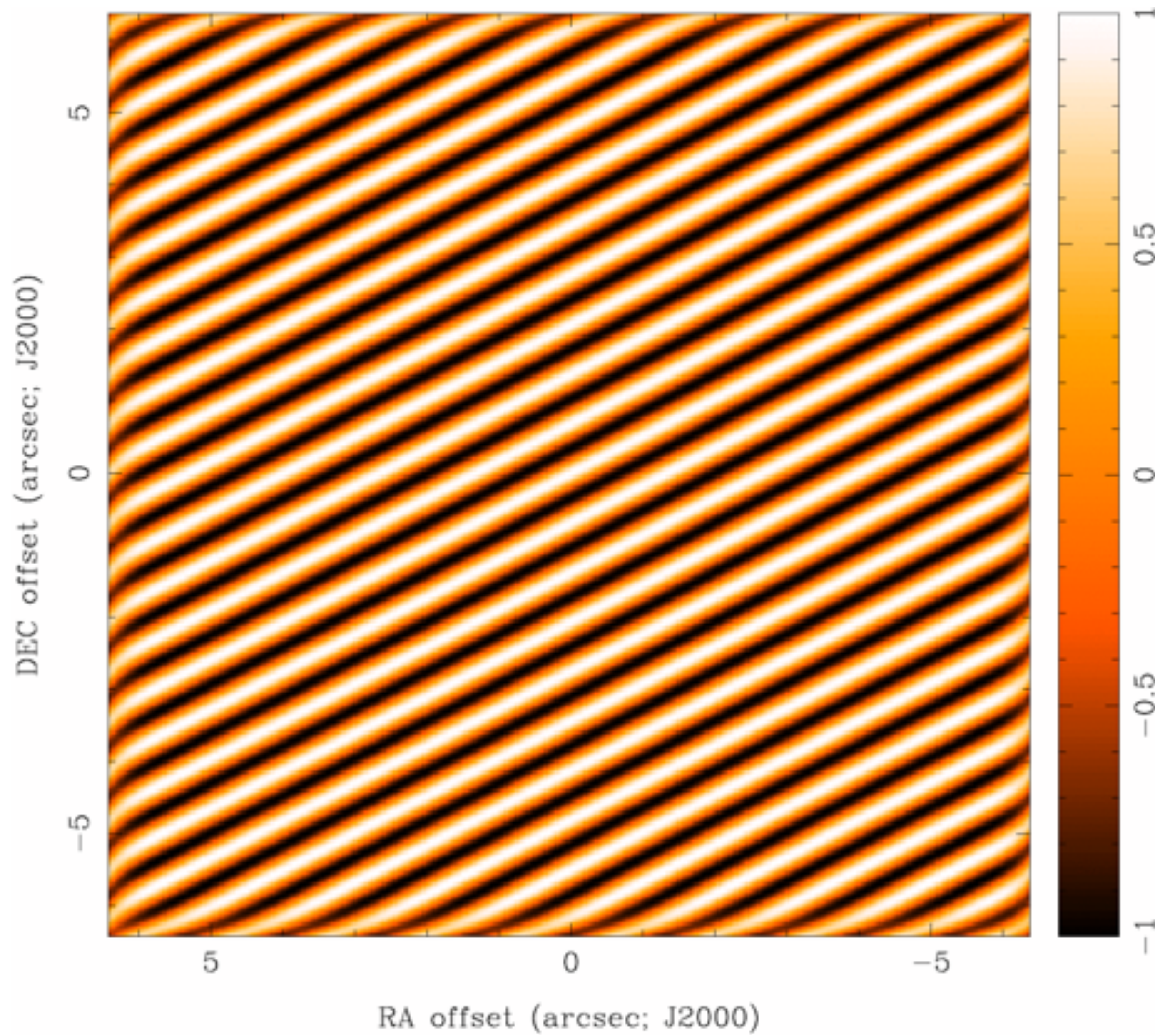




PSF shape vs. N ants

2 antennas

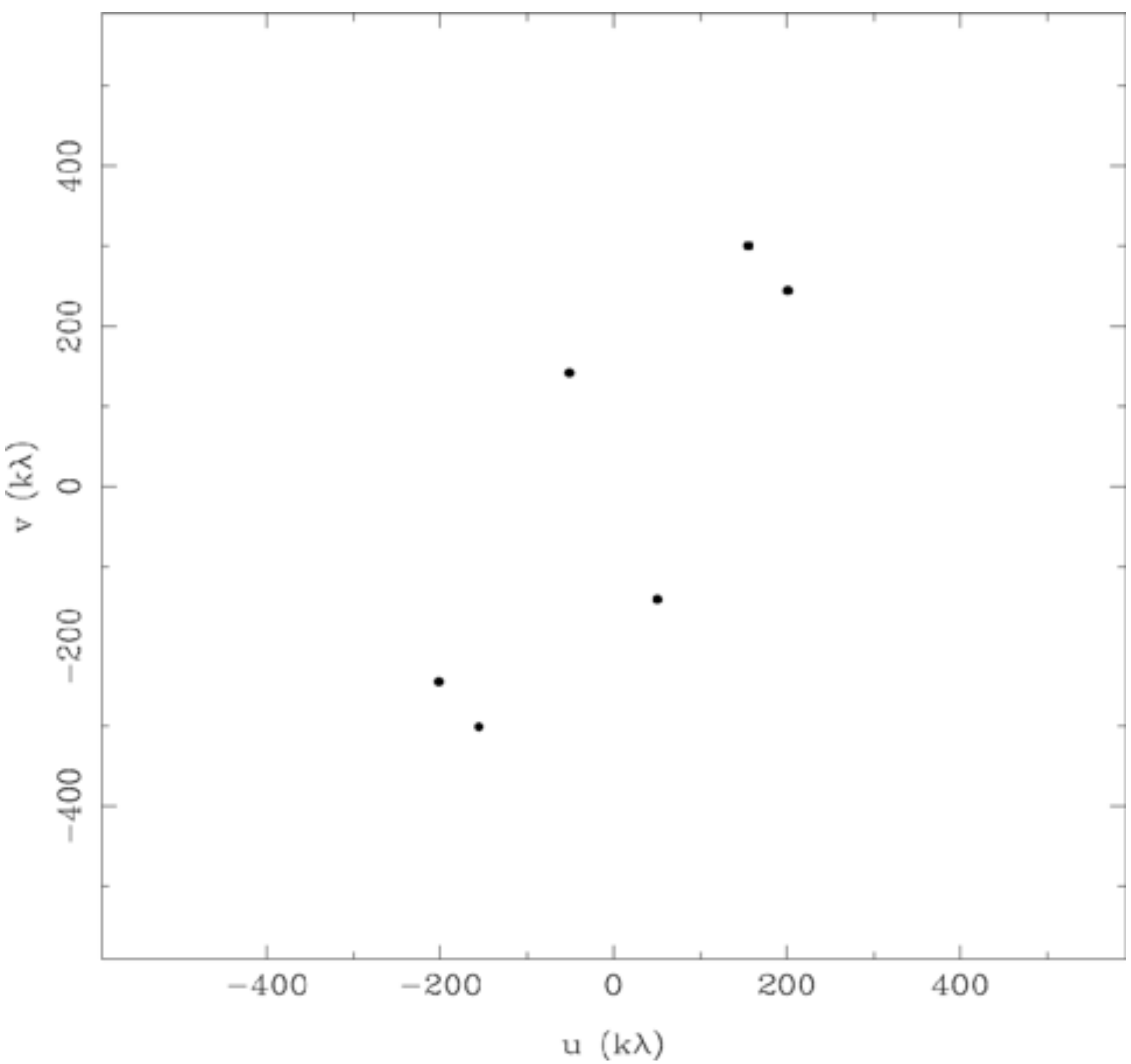


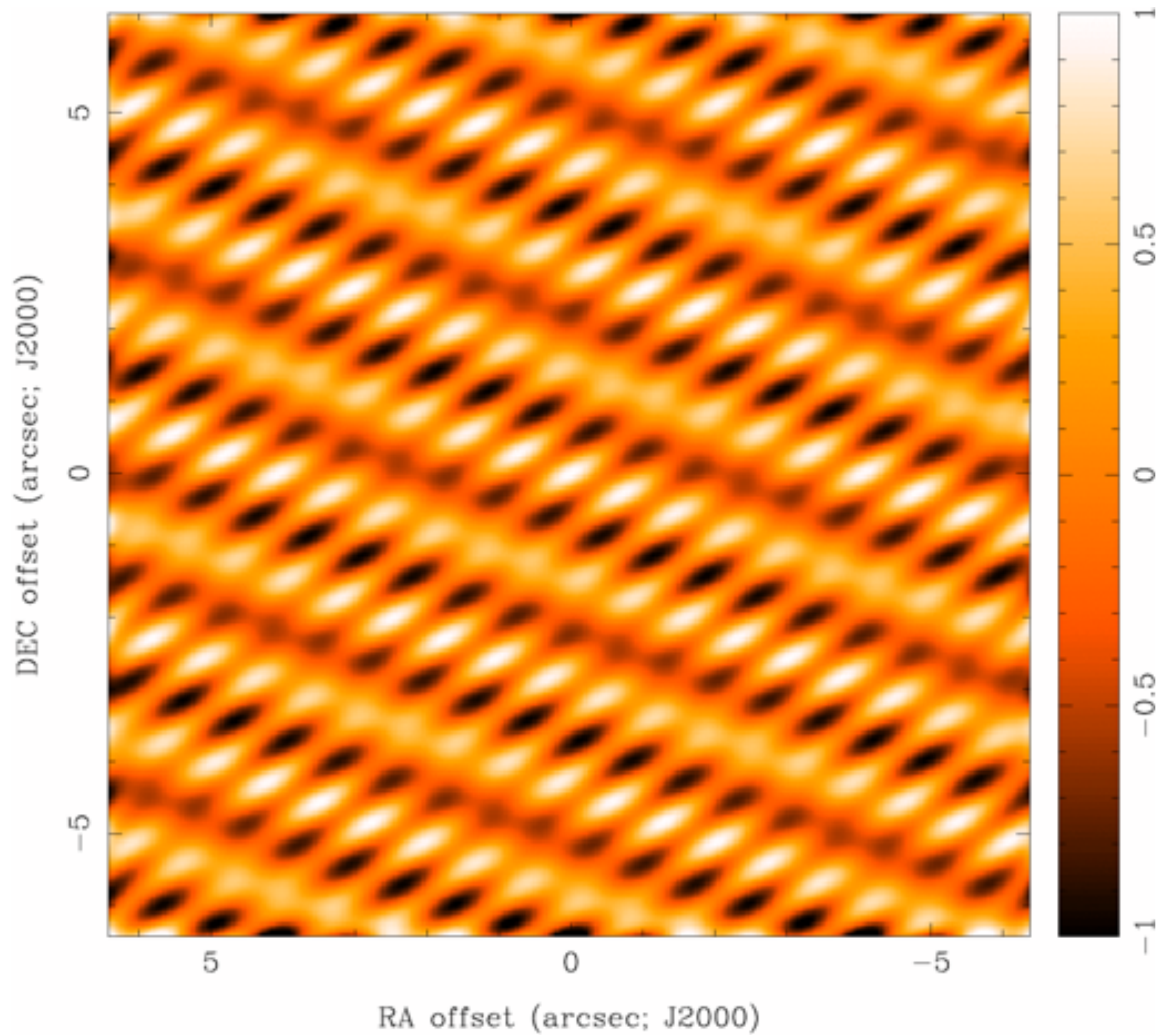


- to characterize a source, I need to sample as much as possible the uv plane.

PSF shape vs. N ants

3 antennas

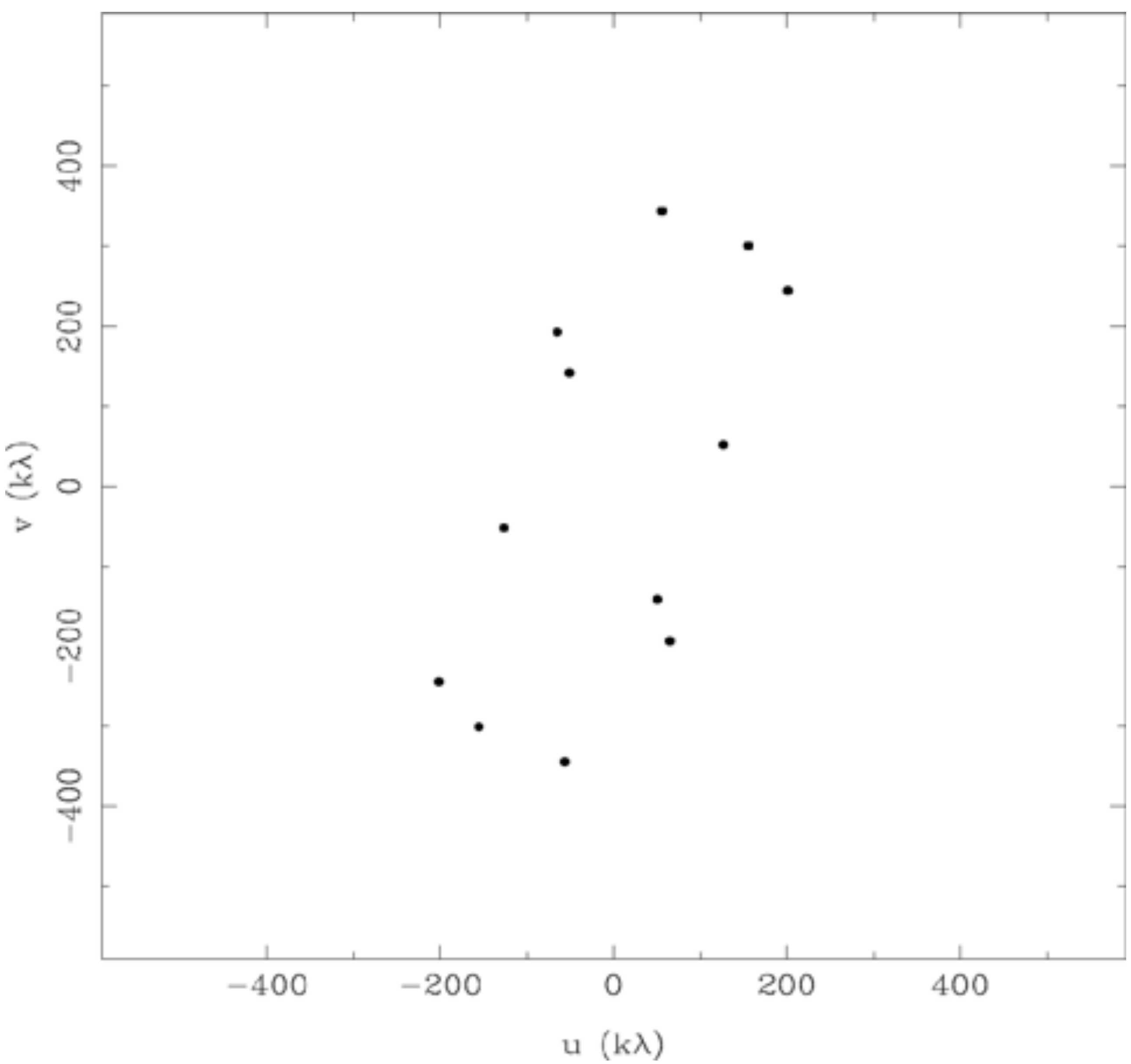


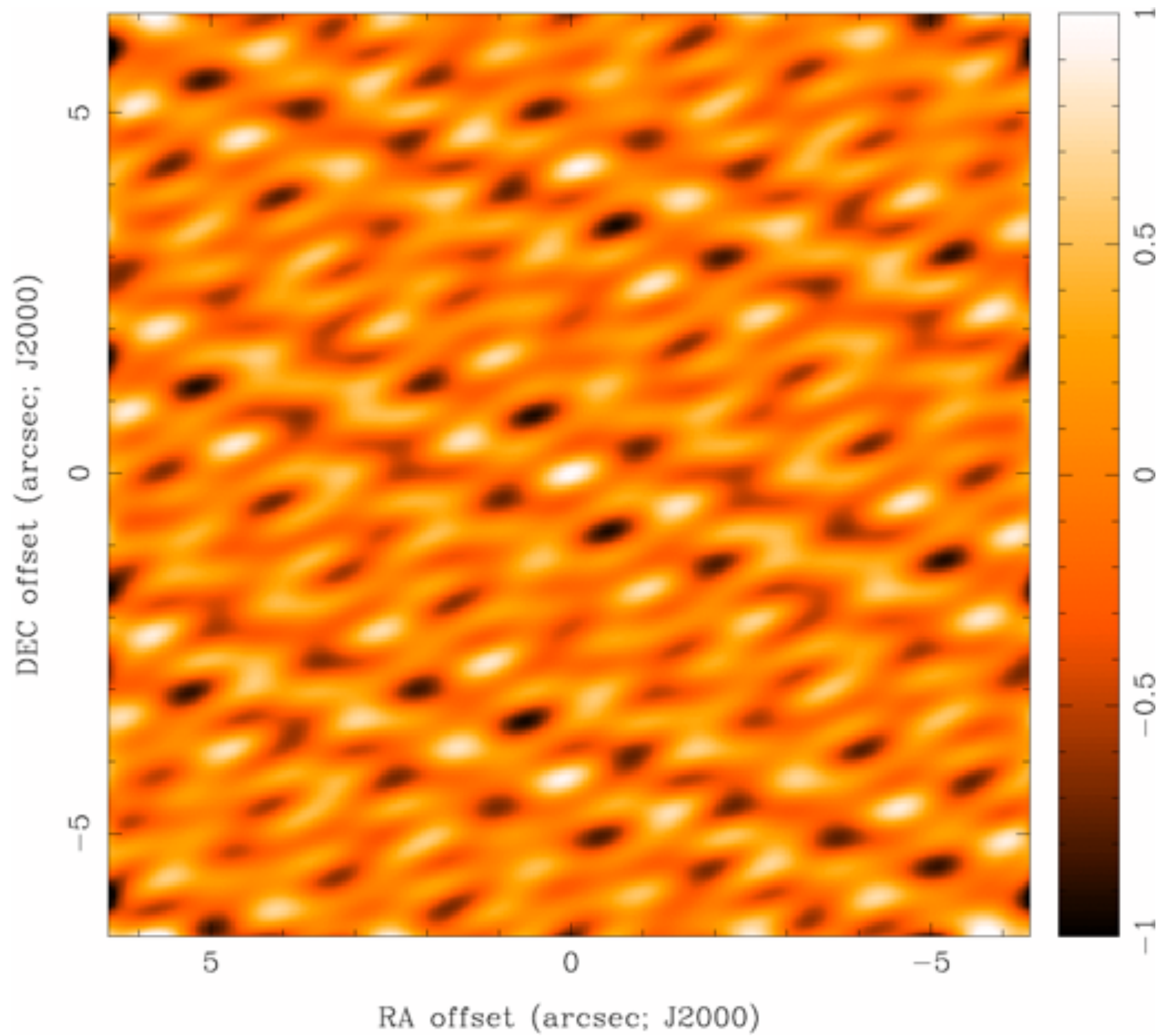


by increasing the number of antennas …

PSF shape vs. N ants

4 antennas

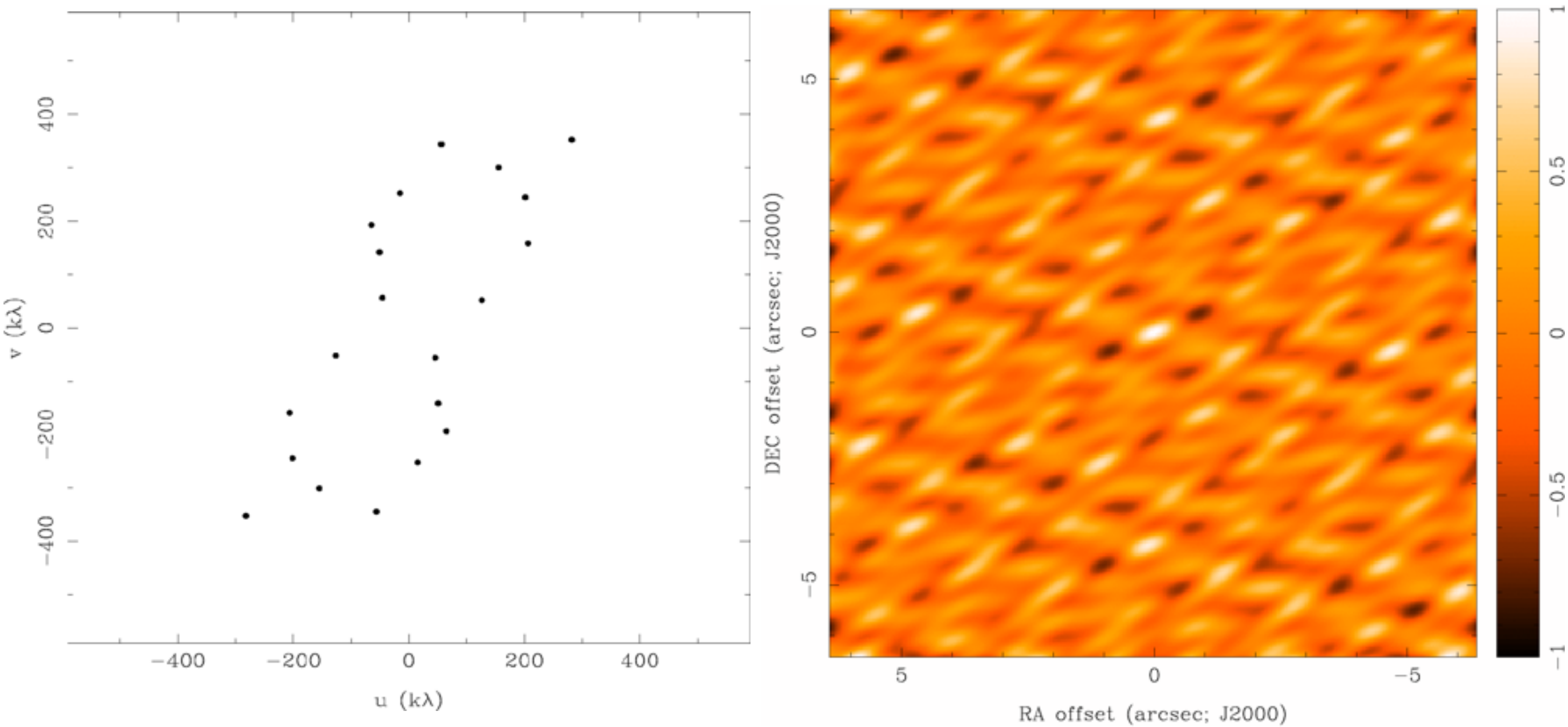




by increasing the number of antennas …

PSF shape vs. N ants

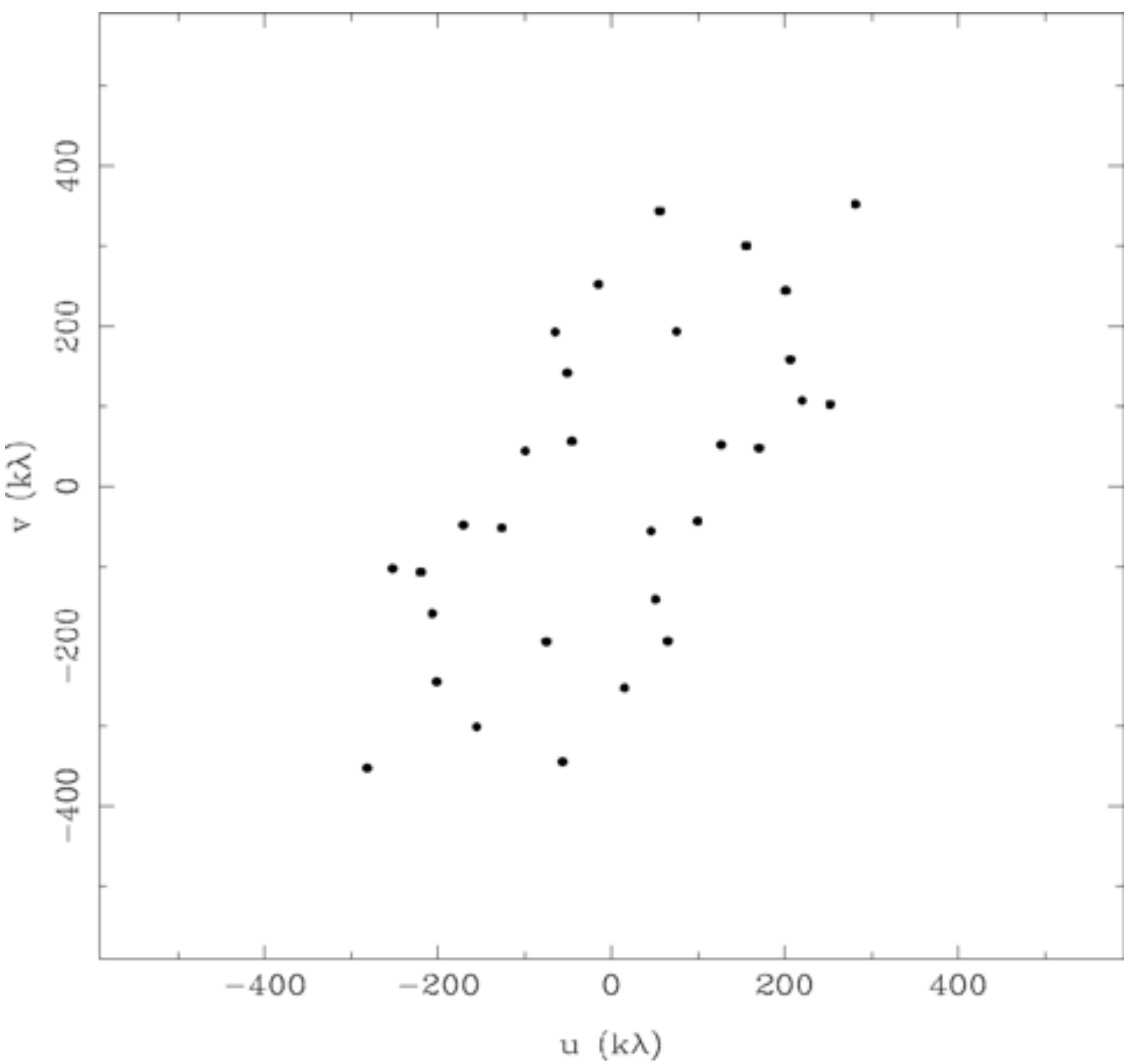
5 antennas

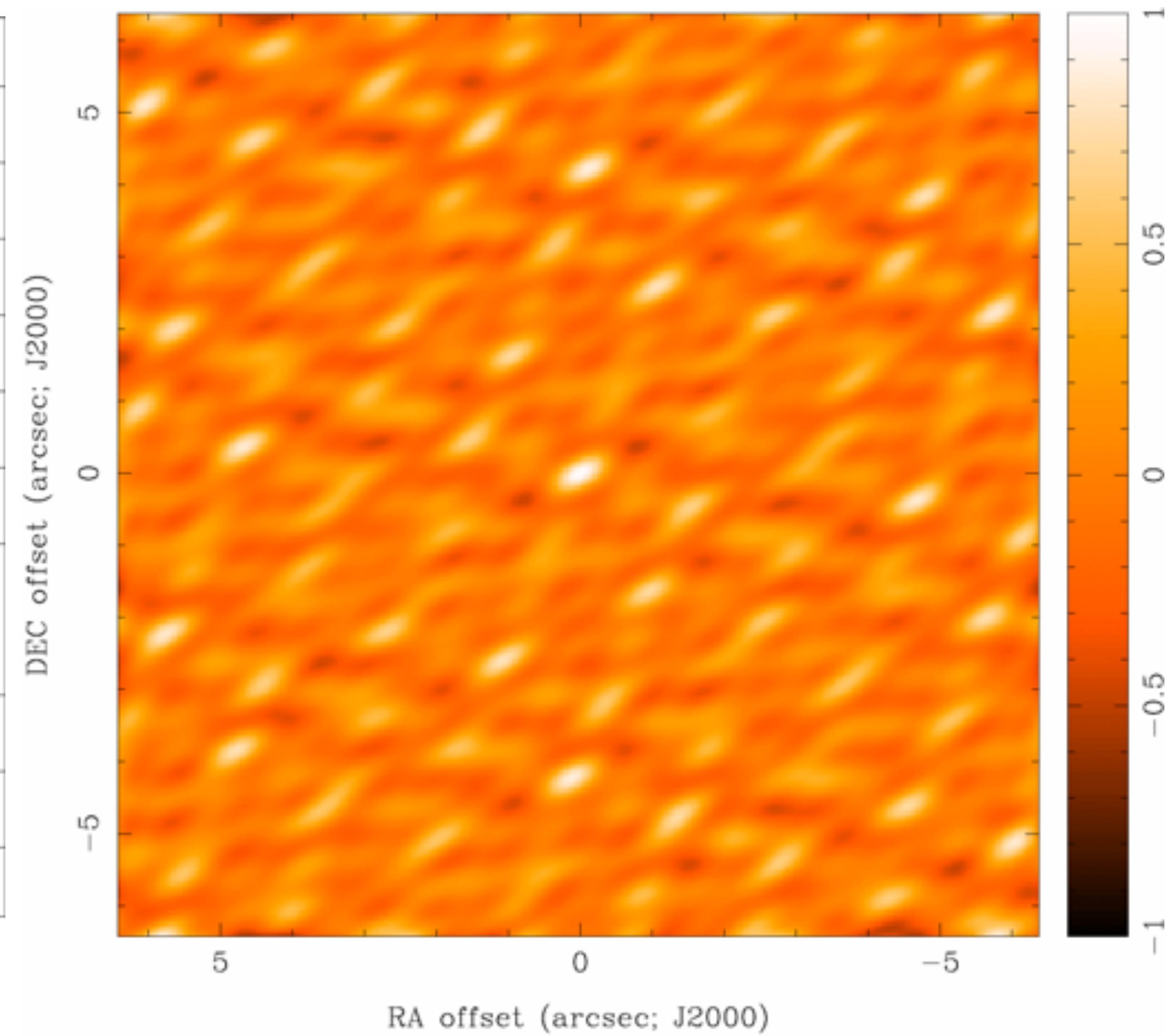


by increasing the number of antennas …

PSF shape vs. N ants

6 antennas

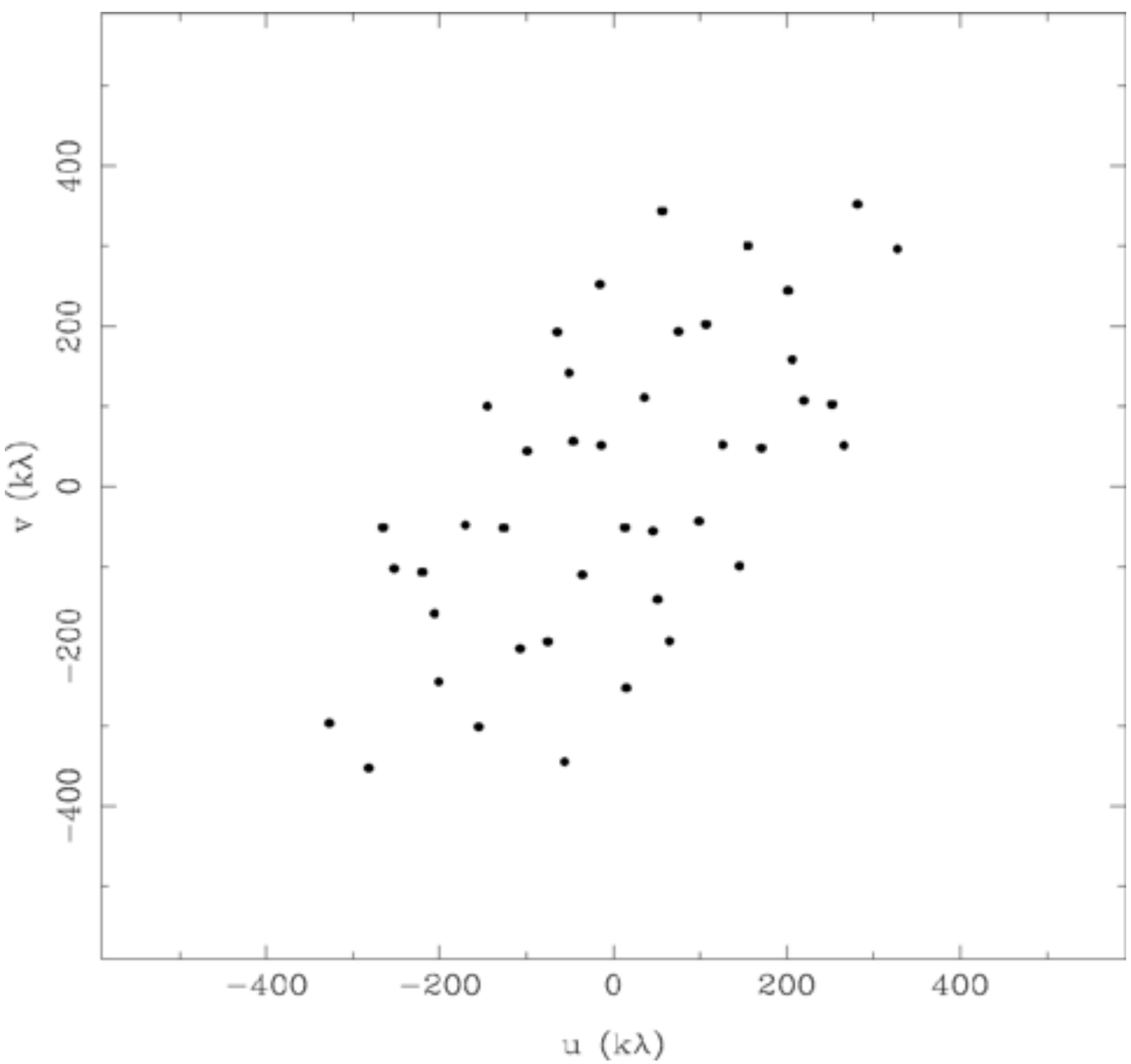


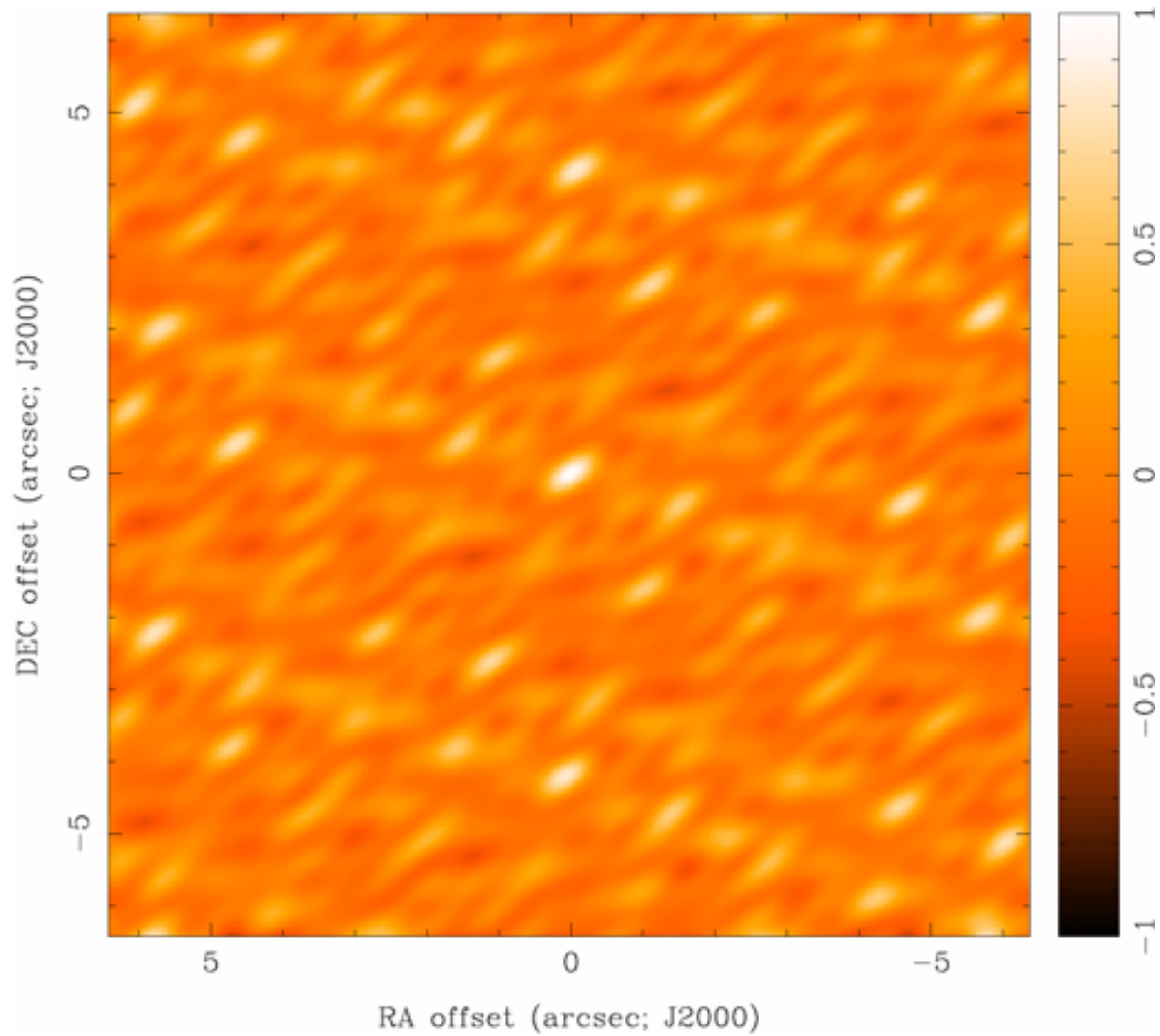


by increasing the number of antennas …

PSF shape vs. N ants

7 antennas

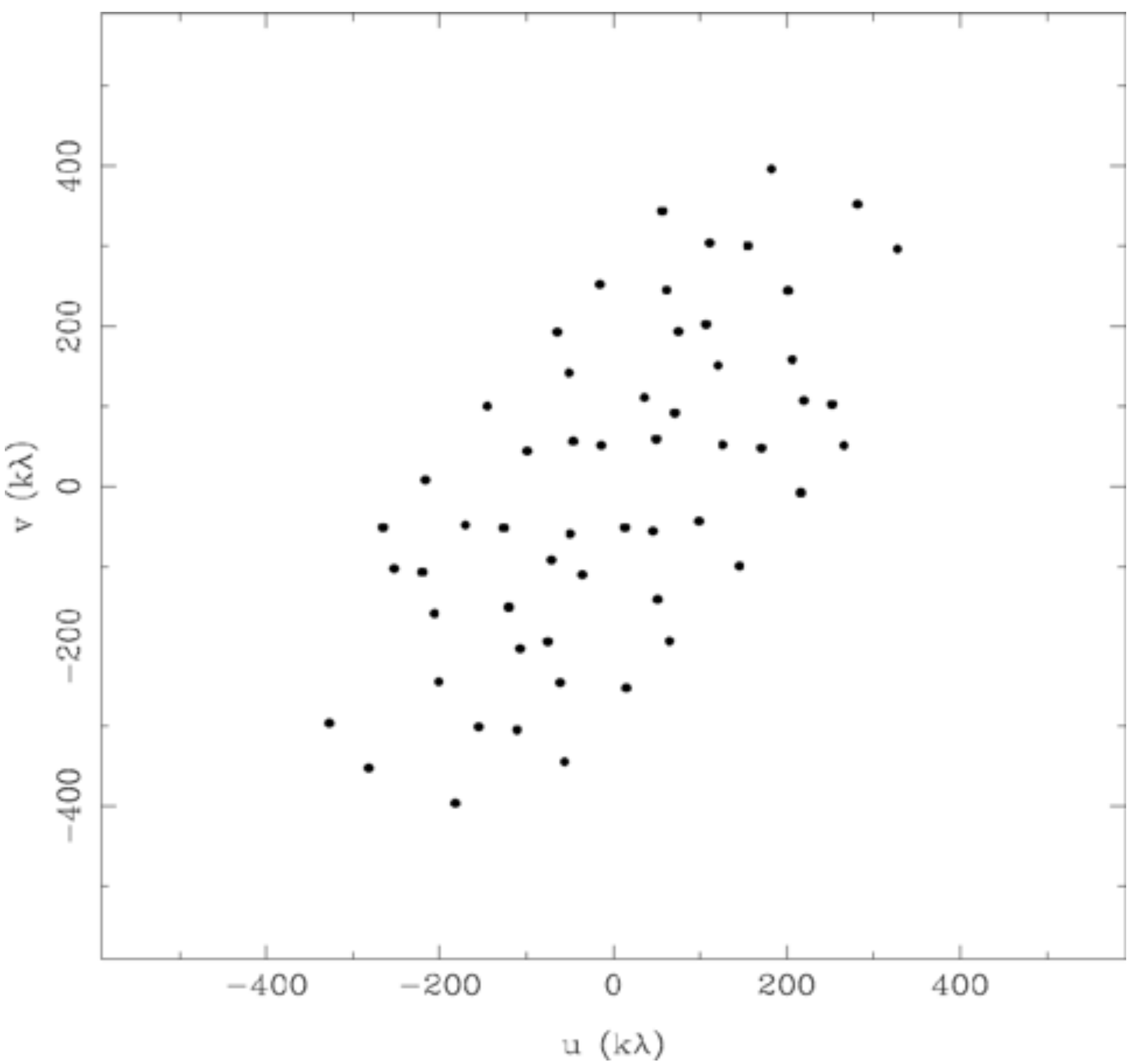


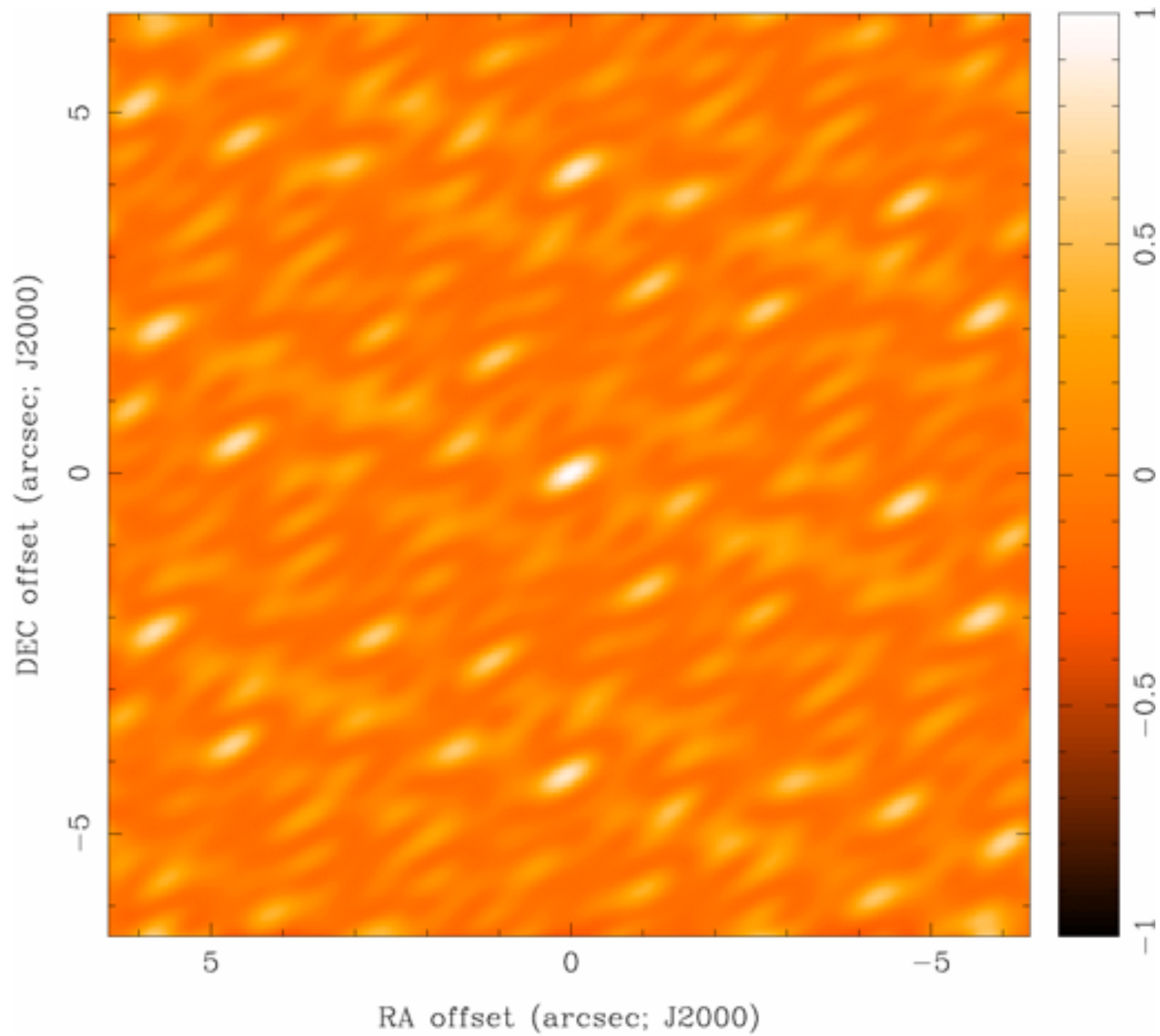


by increasing the number of antennas …

PSF shape vs. N ants

8 antennas

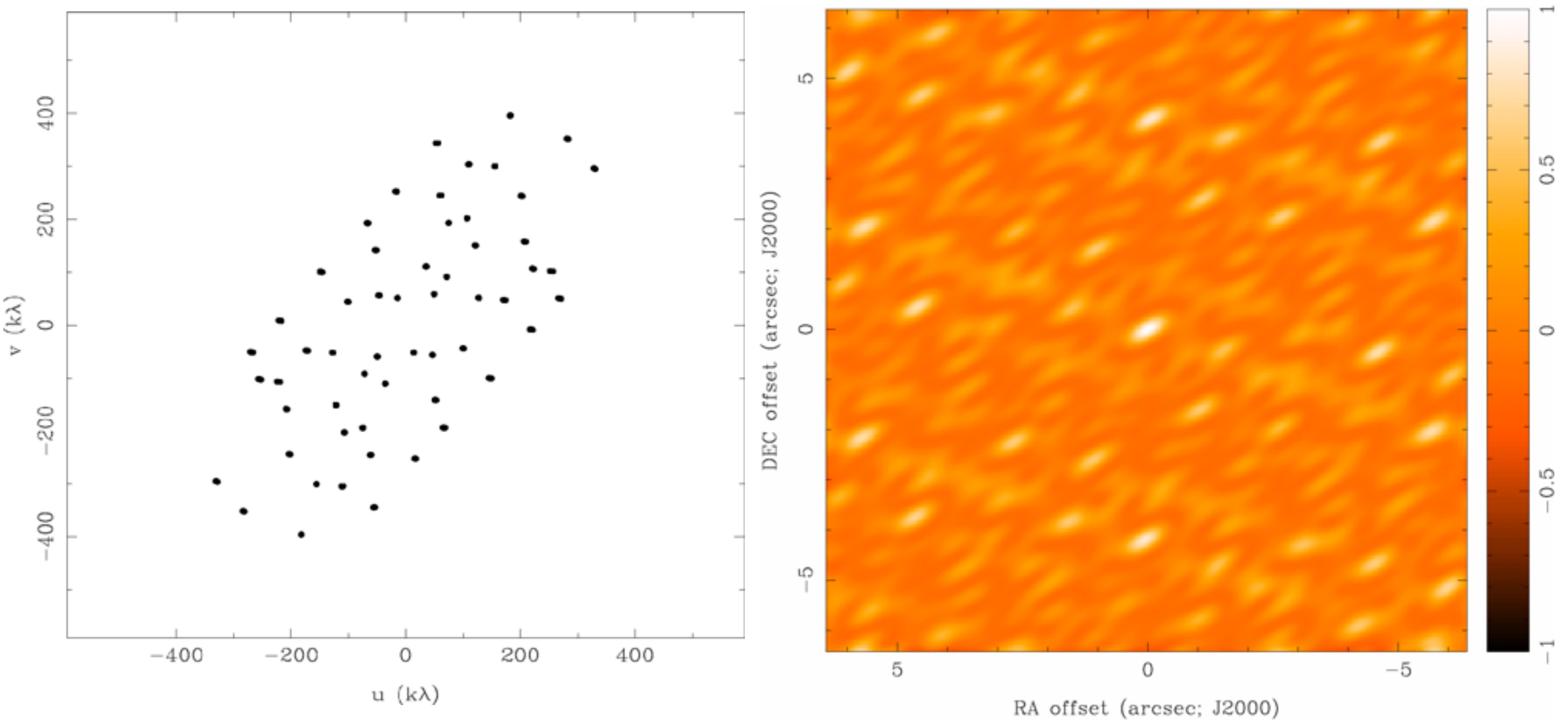




by increasing the number of antennas …

PSF shape vs. N ants

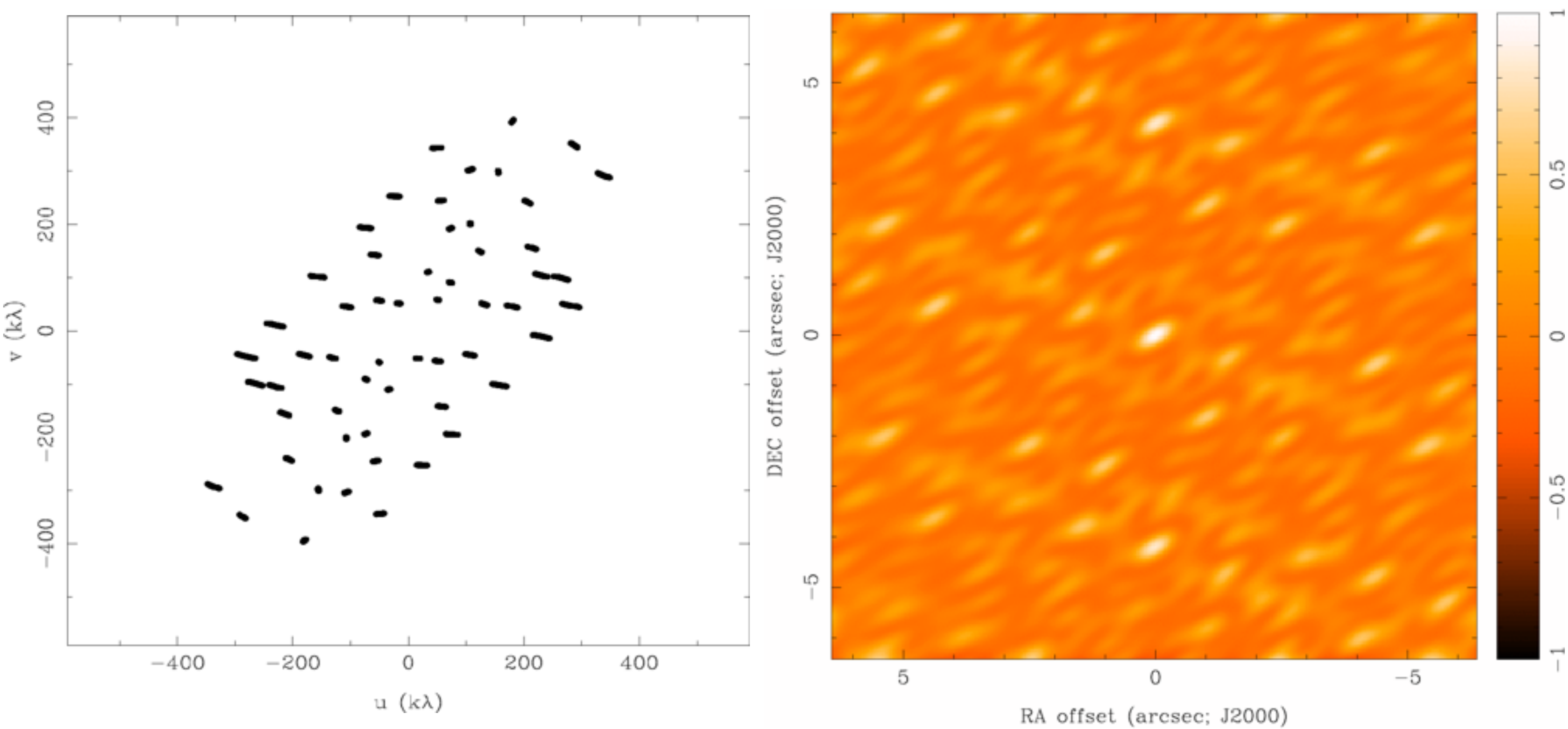
8 antennas x 6 samples



… or by increasing the integration time …

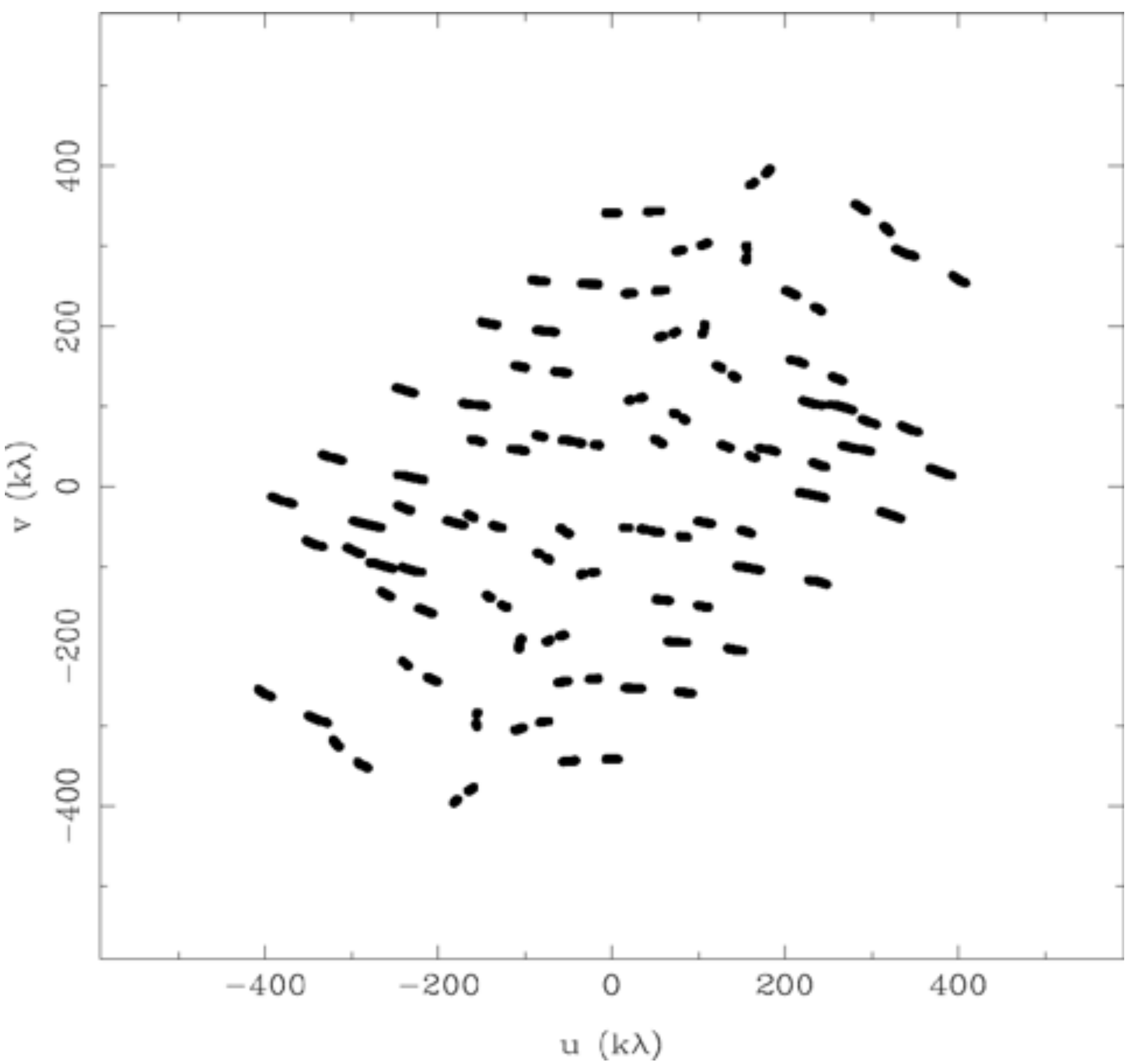
PSF shape vs. N ants

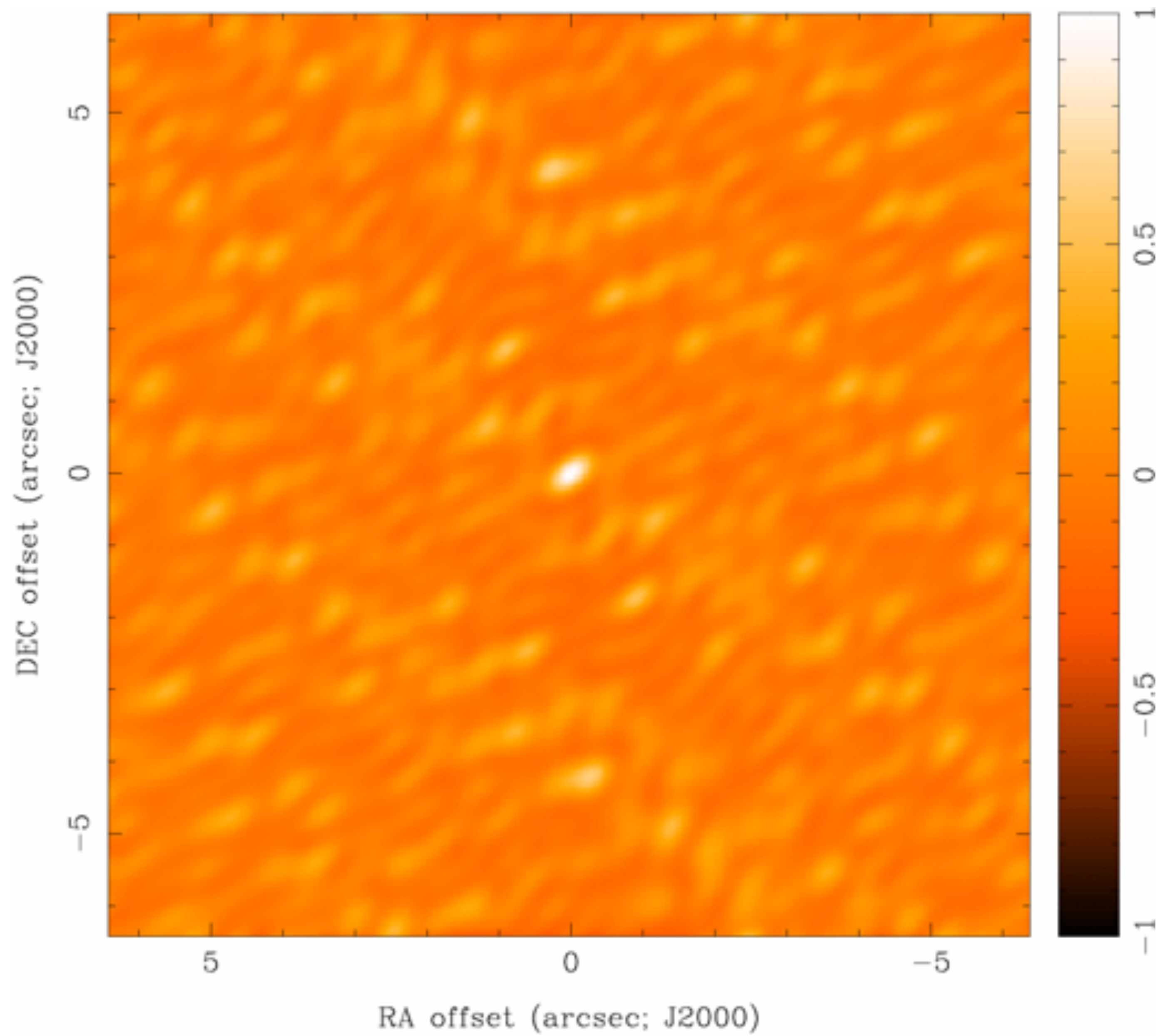
8 antennas x 30 samples



PSF shape vs. N ants

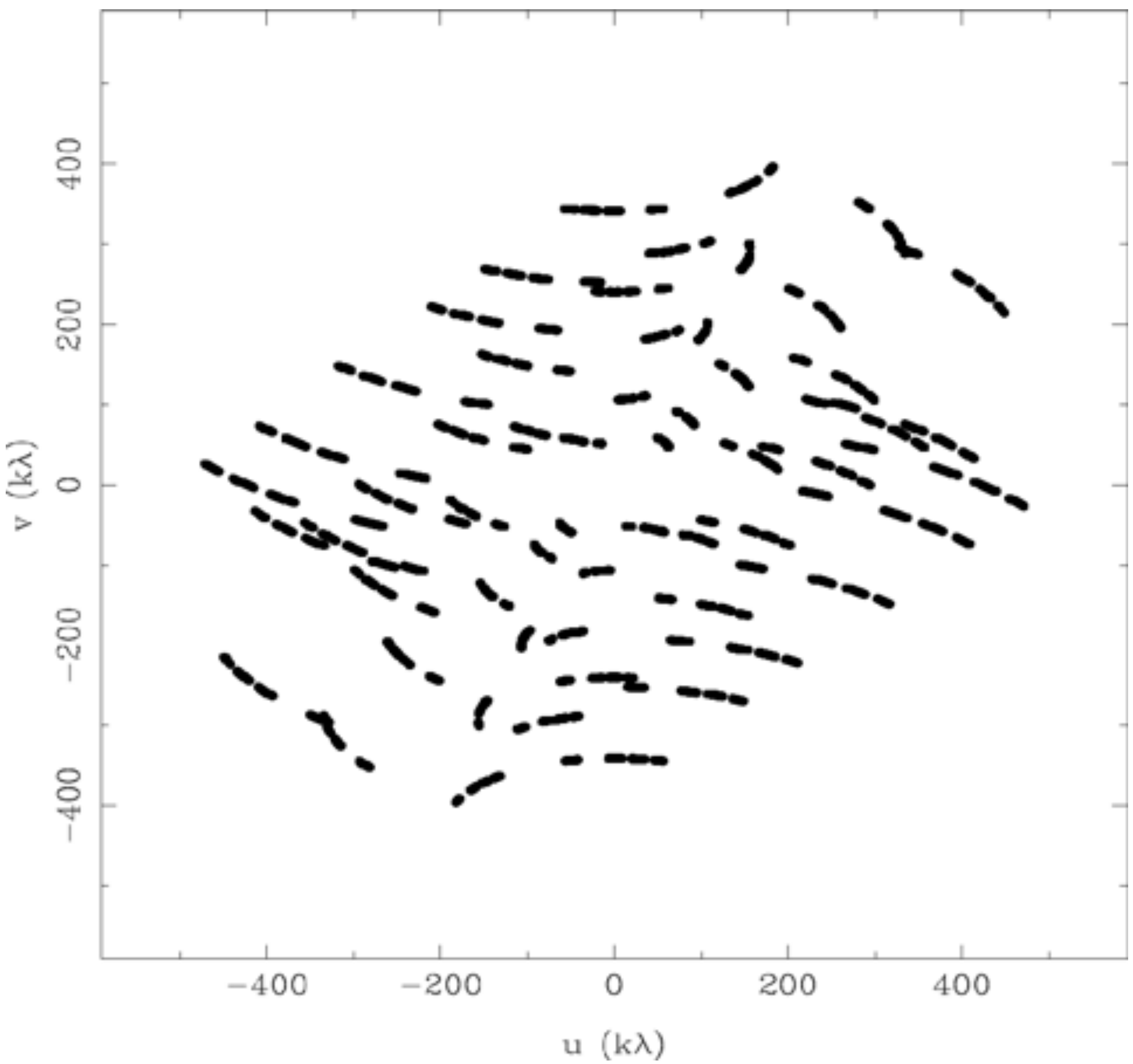
8 antennas x 60 samples

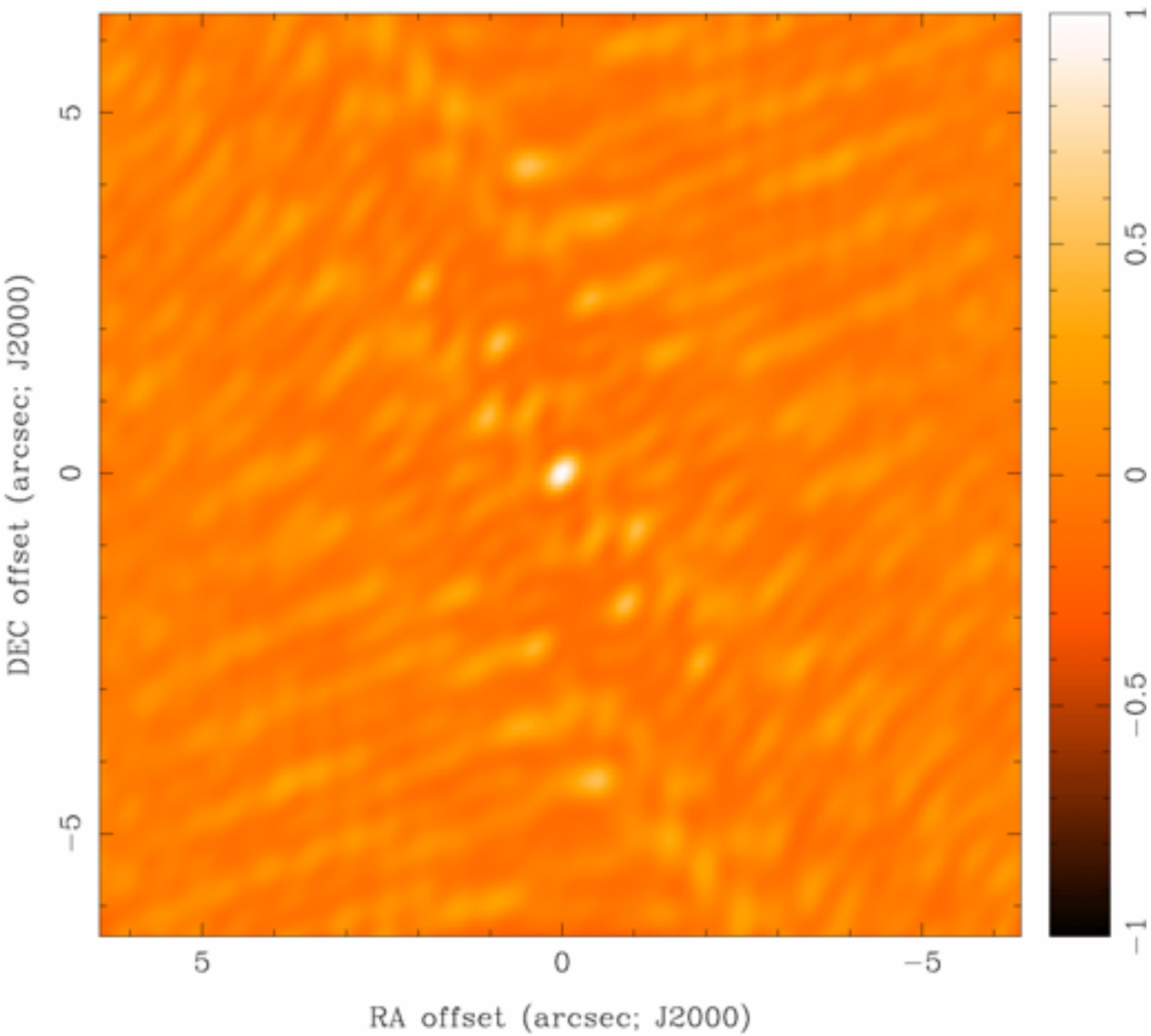




PSF shape vs. N ants

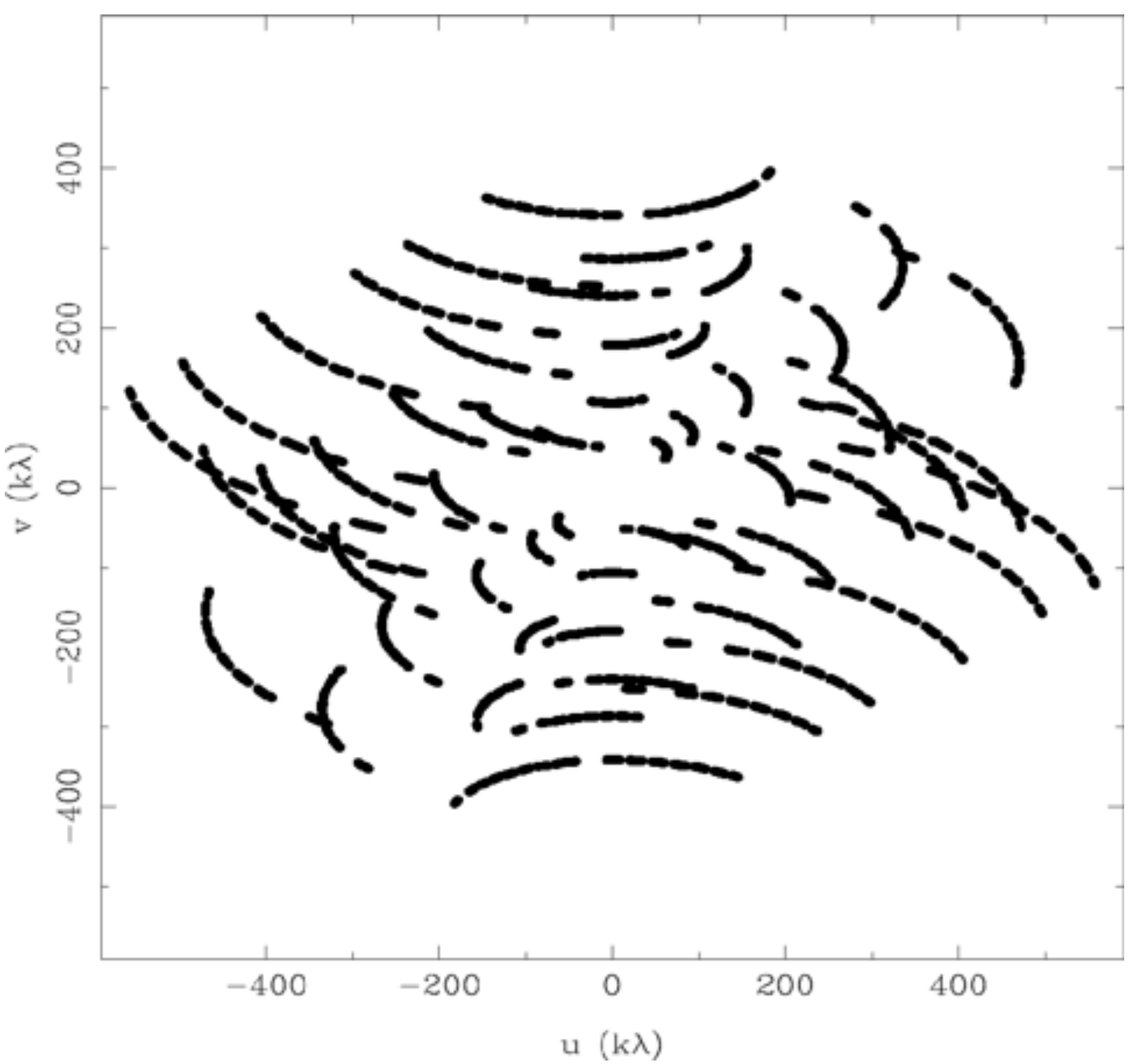
8 antennas x 120 samples

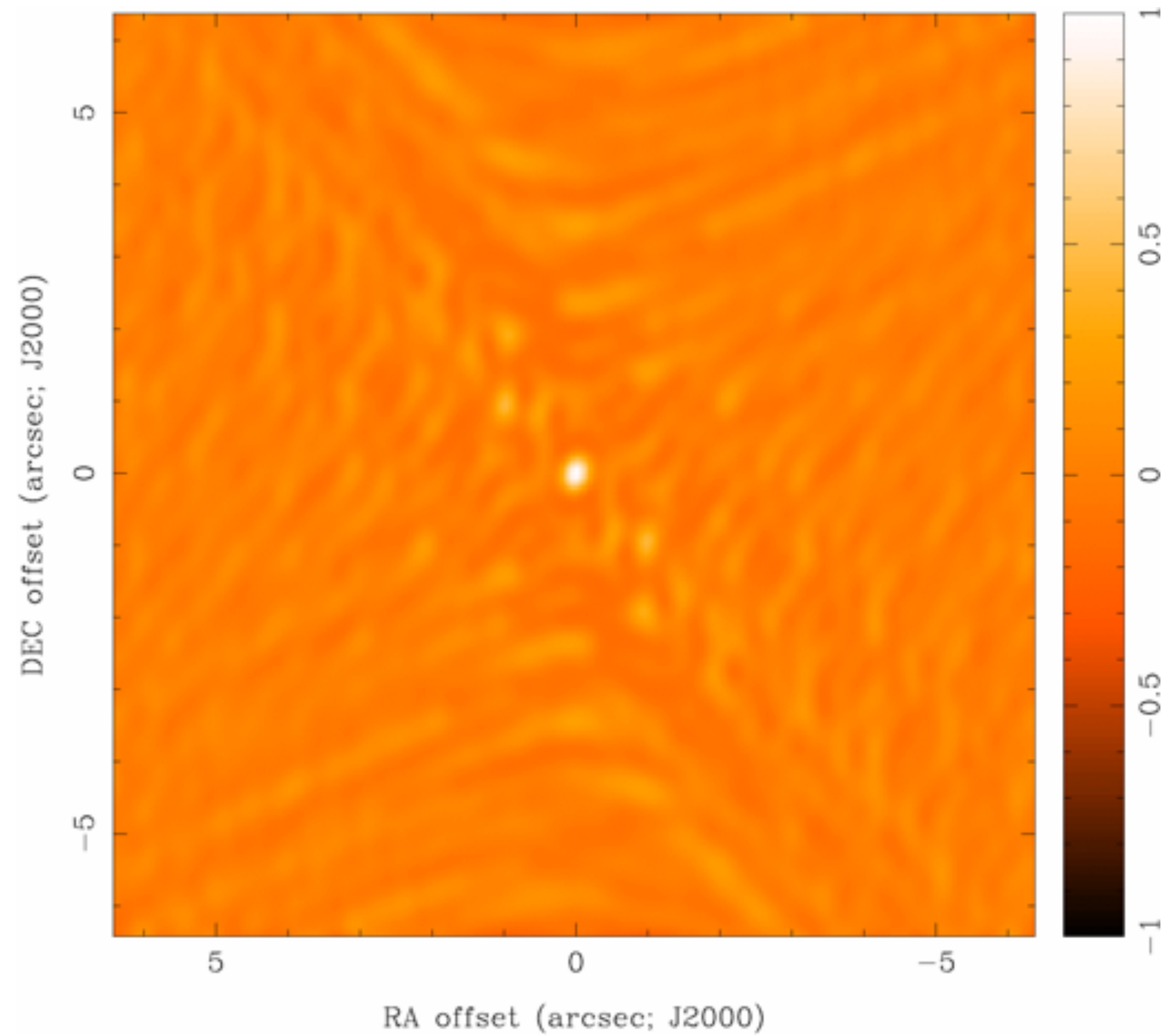




PSF shape vs. N ants

8 antennas x 240 samples





PSF shape vs. N ants

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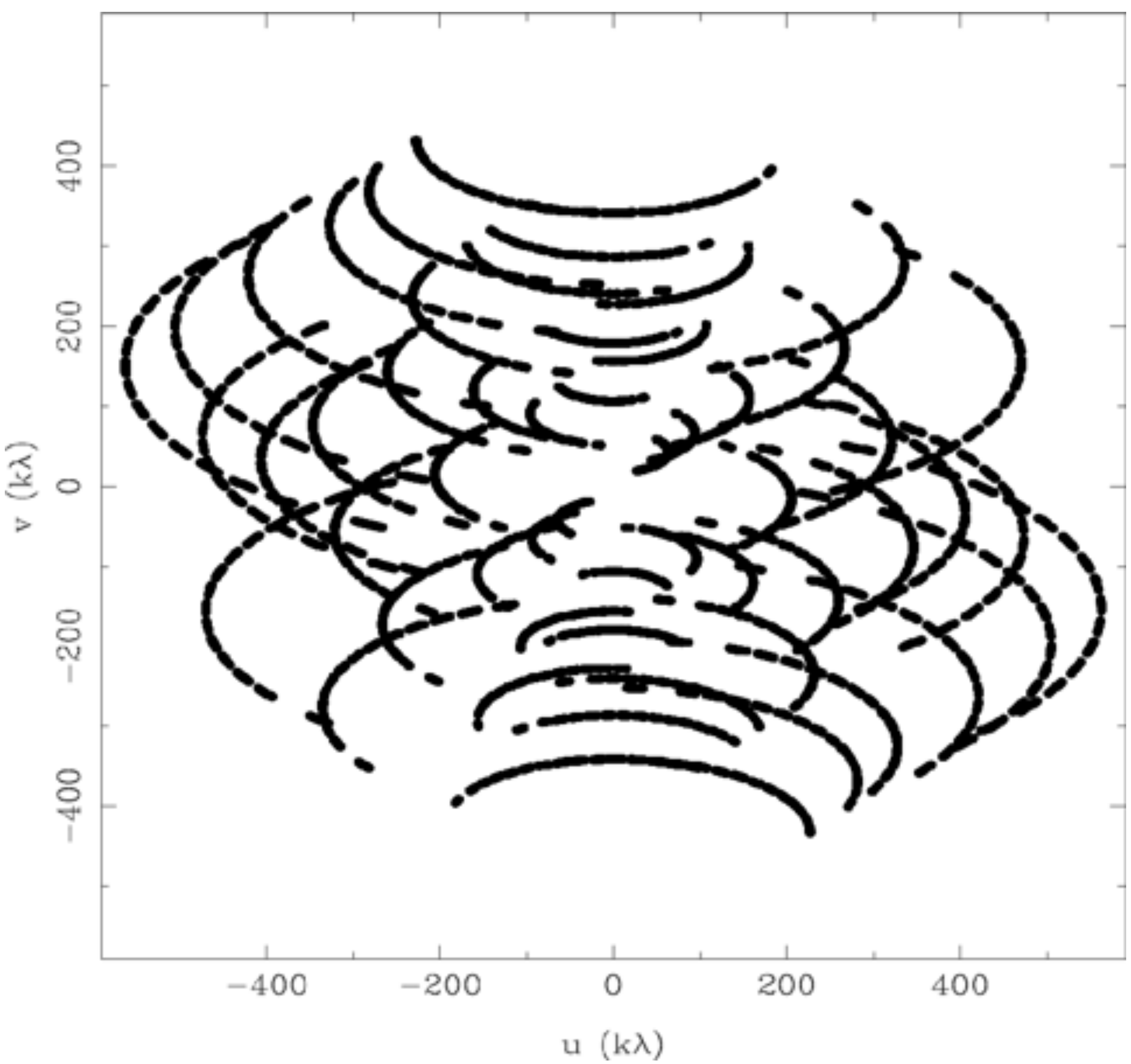

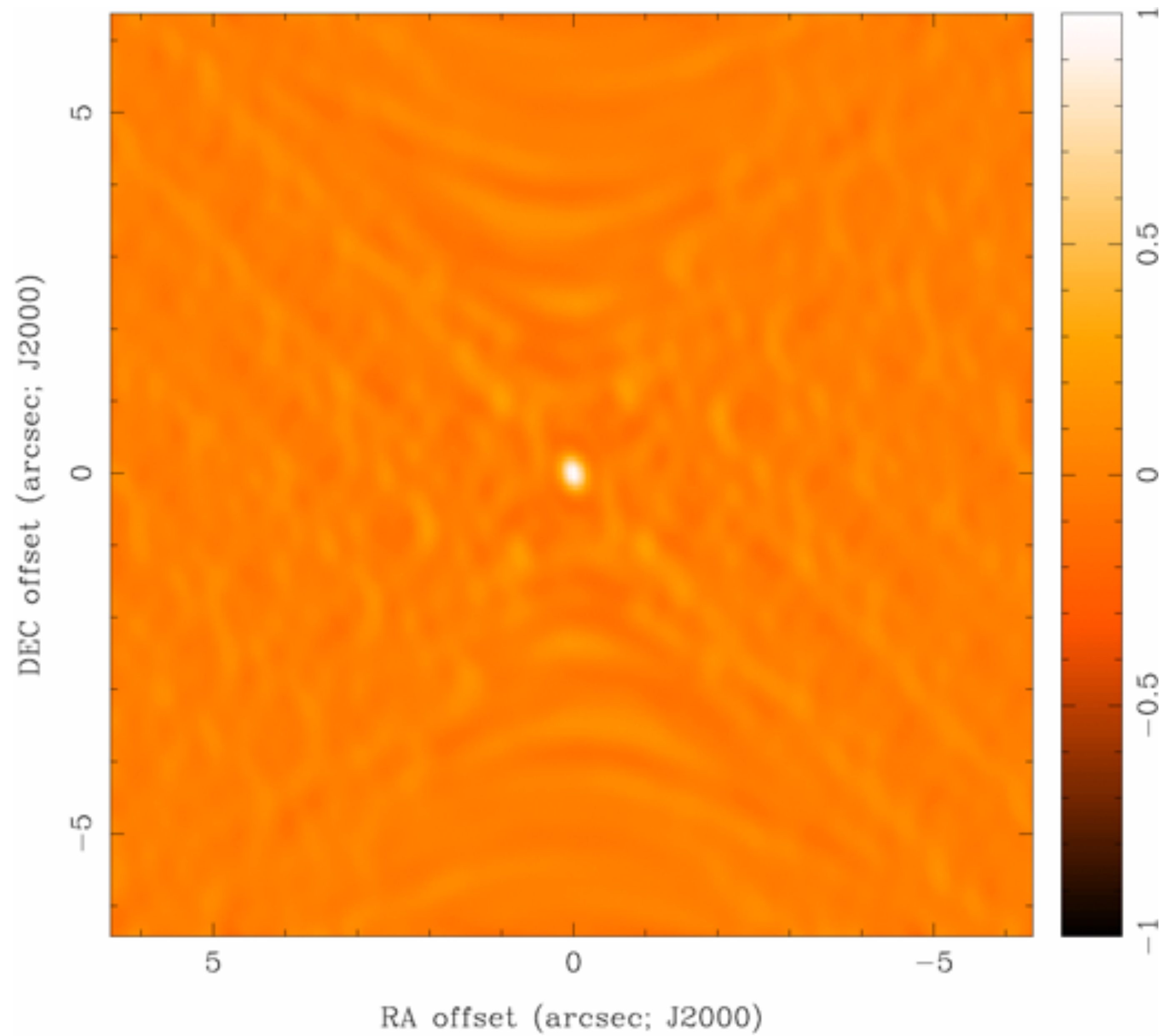

- ALMA has an *"instantaneous"* coverage uv plane…

Visibility and Sky Brightness

For small fields of view: the complex visibility,V(u,v), is the 2D Fourier transform of the brightness on the sky,T(x,y)

Cittert-Zernike theorem

$$V(u,v) = \int\int T(x,y) e^{2\pi i(ux+vy)} dxdy$$

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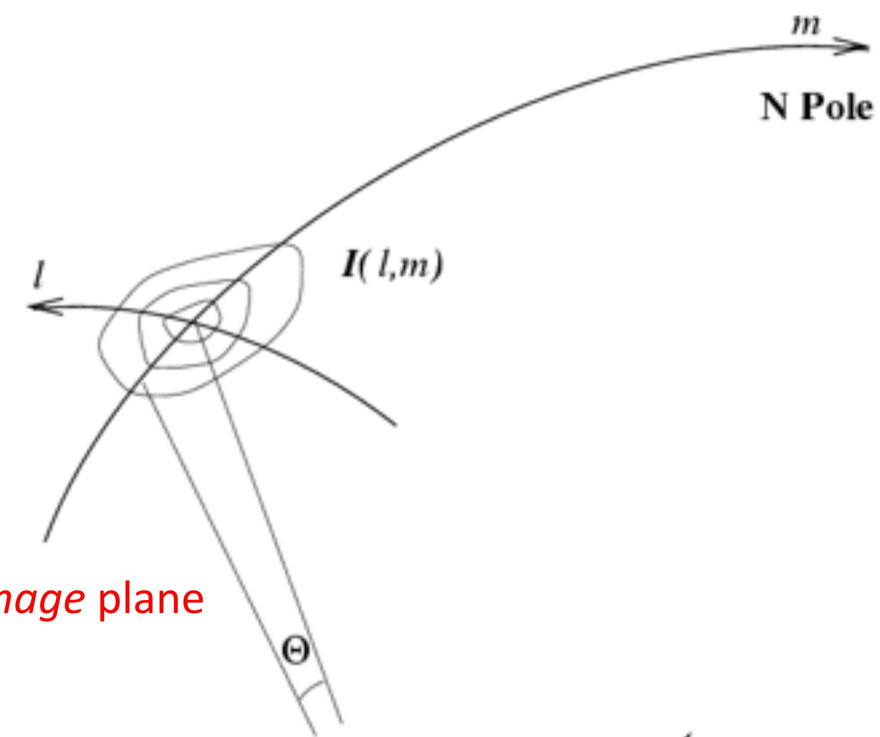
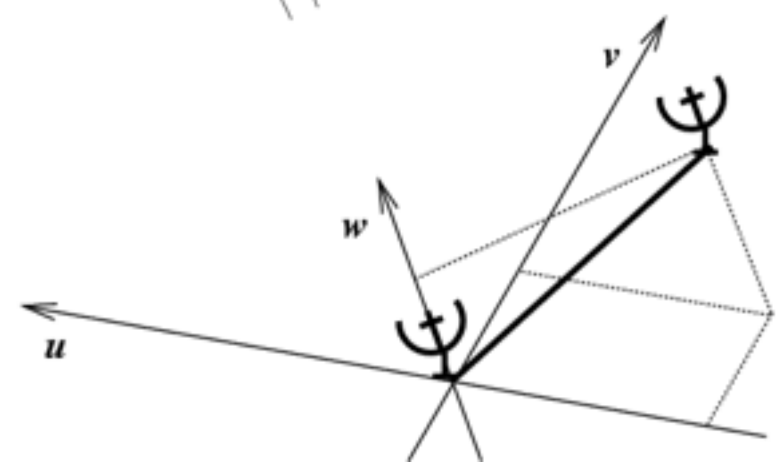


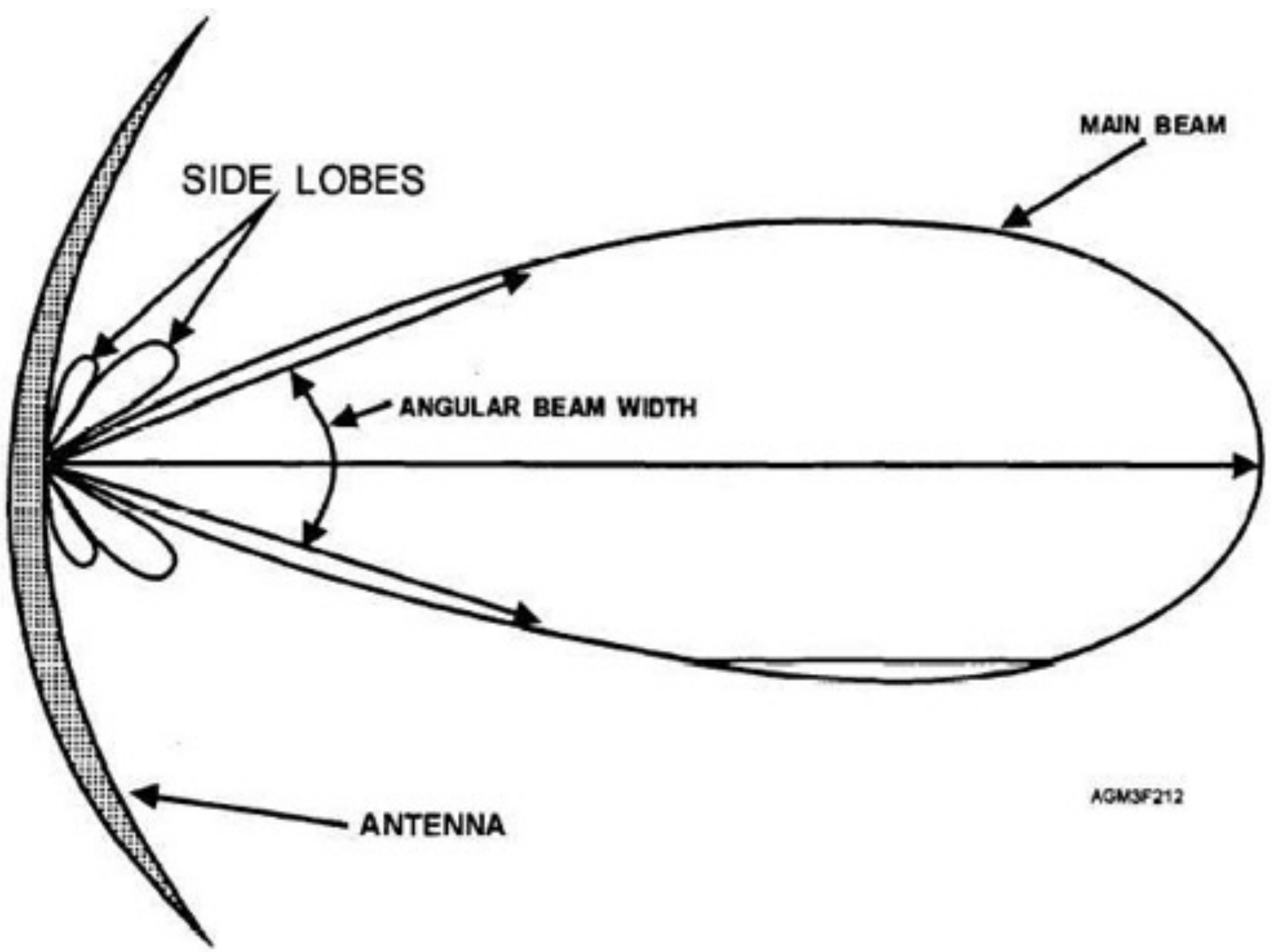
image plane



uv plane

sampling uv vs FOV (o primary beam…)

- Field of View: depends on the single dish diameter



$$\mathcal{V}(u,v) = \iint A(l,m) I(l,m) e^{-2\pi i(ul+vm)} dl dm.$$

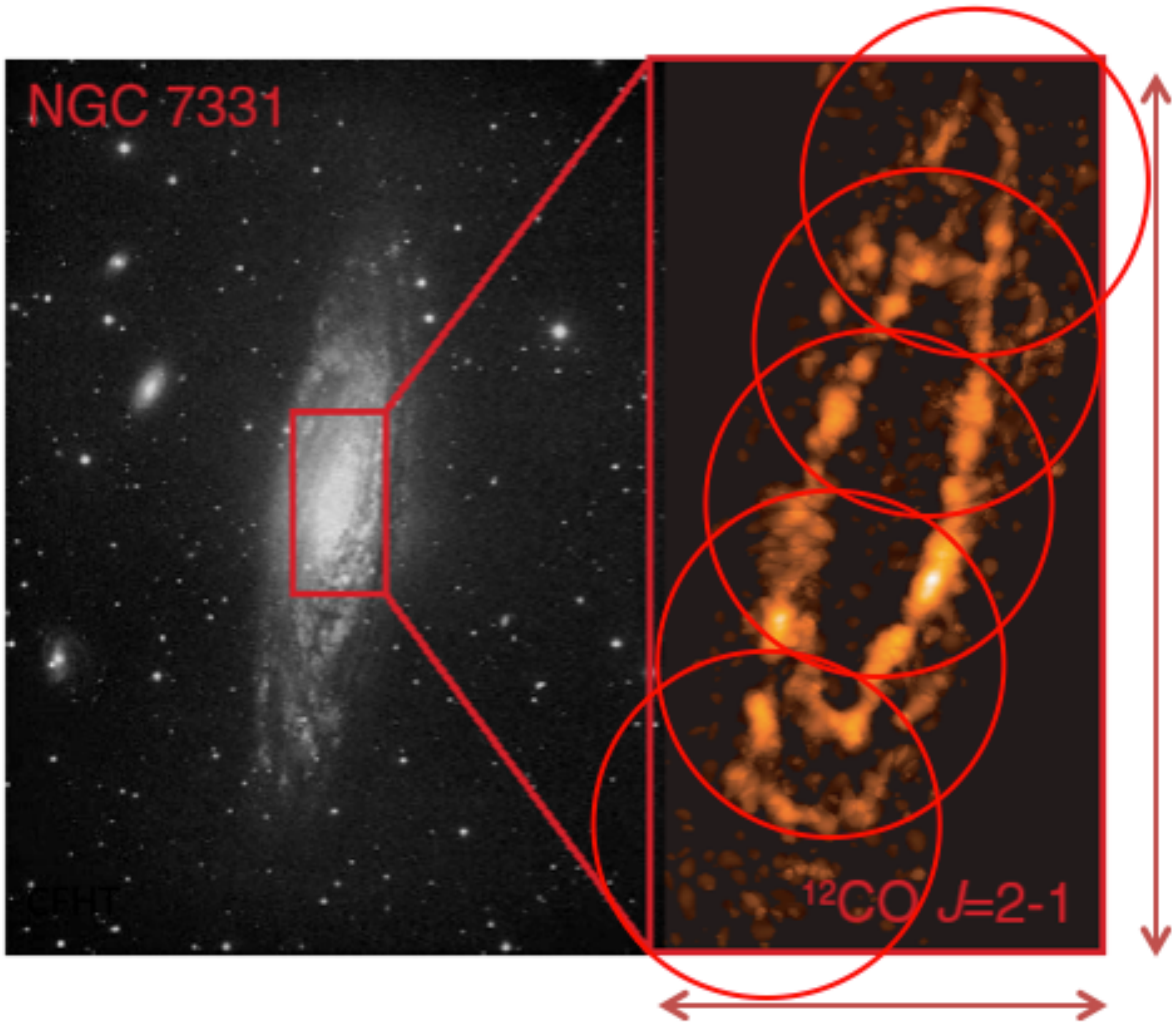
$$\text{FOV} = 1.22\lambda/D$$

smaller dish —> larger FOV

—> if object "larger" thant FOV … mosaic!

sampling uv vs FOV (o primary beam…)

- Field of View: depends on the single dish diameter



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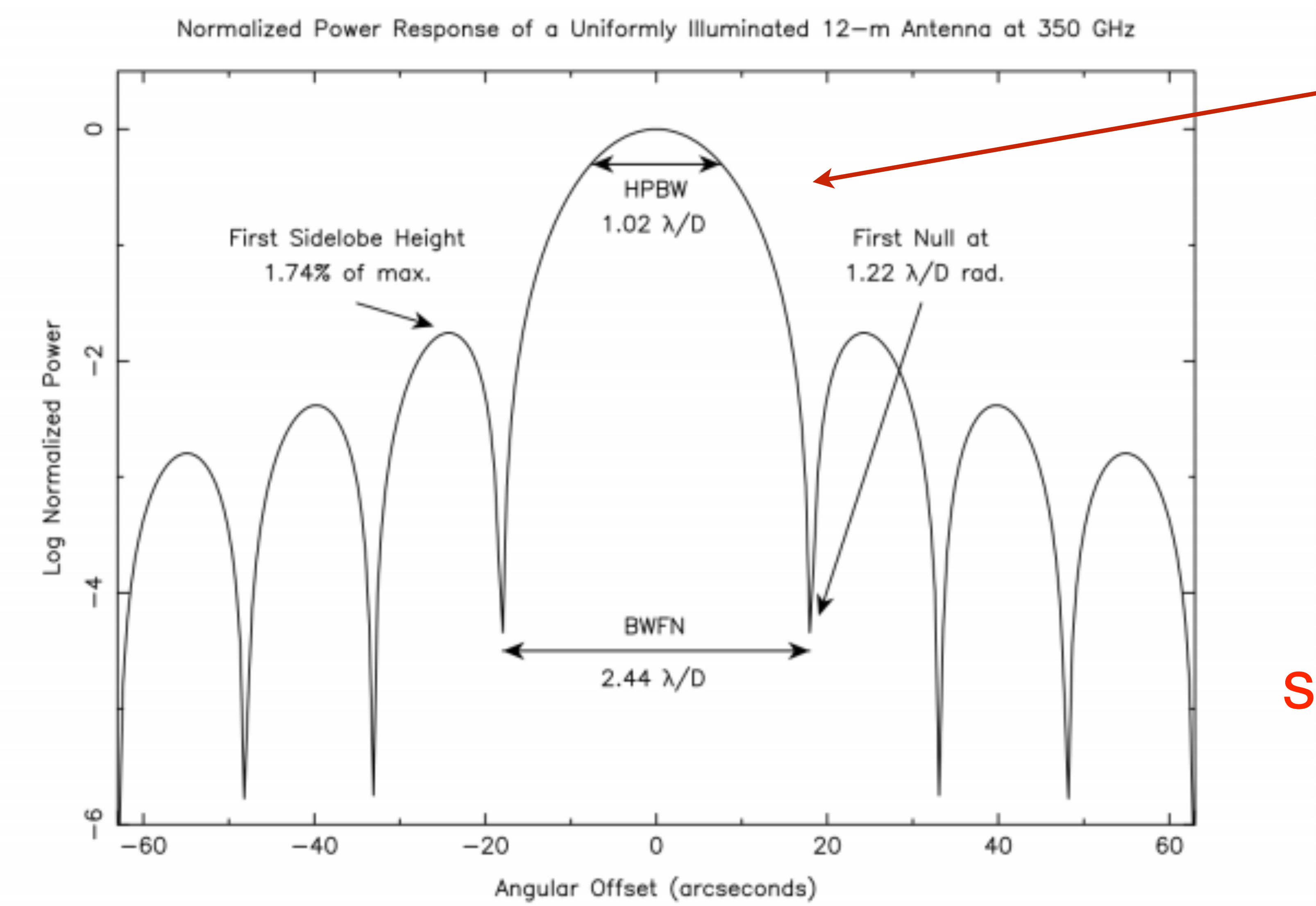


FOV = 1.22λ/D

smaller dish—> larger FOV

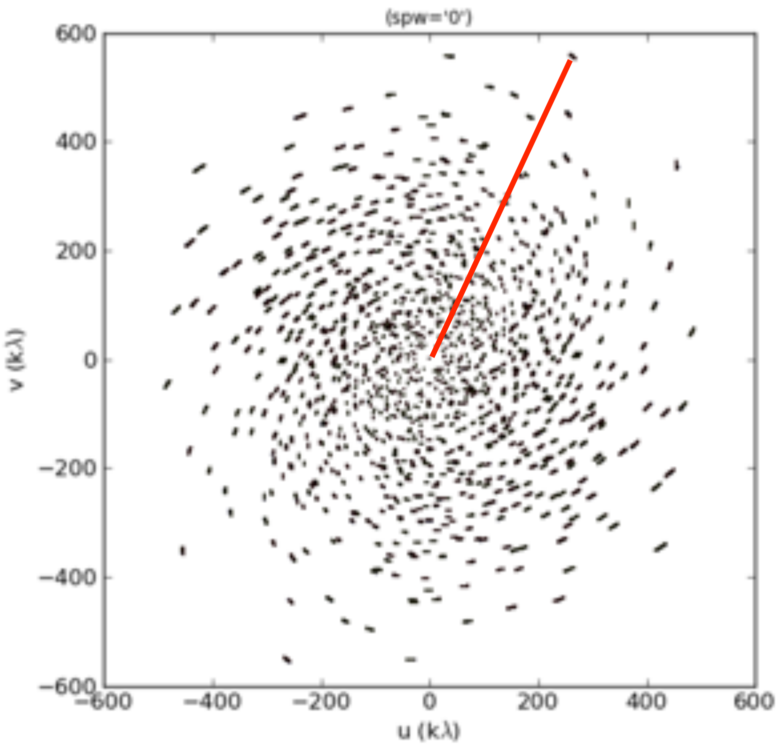
—> decreasing sensitivity with the distance from image centre

—> pbcorr images from archive (see Rosita's talk)

when you deal with mosaic images, uniform noise over an area larger than 1/3 PB

sampling uv vs PSF (o synth beam…)

- Angular resolution/Synthetized Beam:
  - Synth beam = the way the interferometer “sees” a point source
    - angular resolution= FWHM synthetized beam
  - depends on maximum distance between antennas



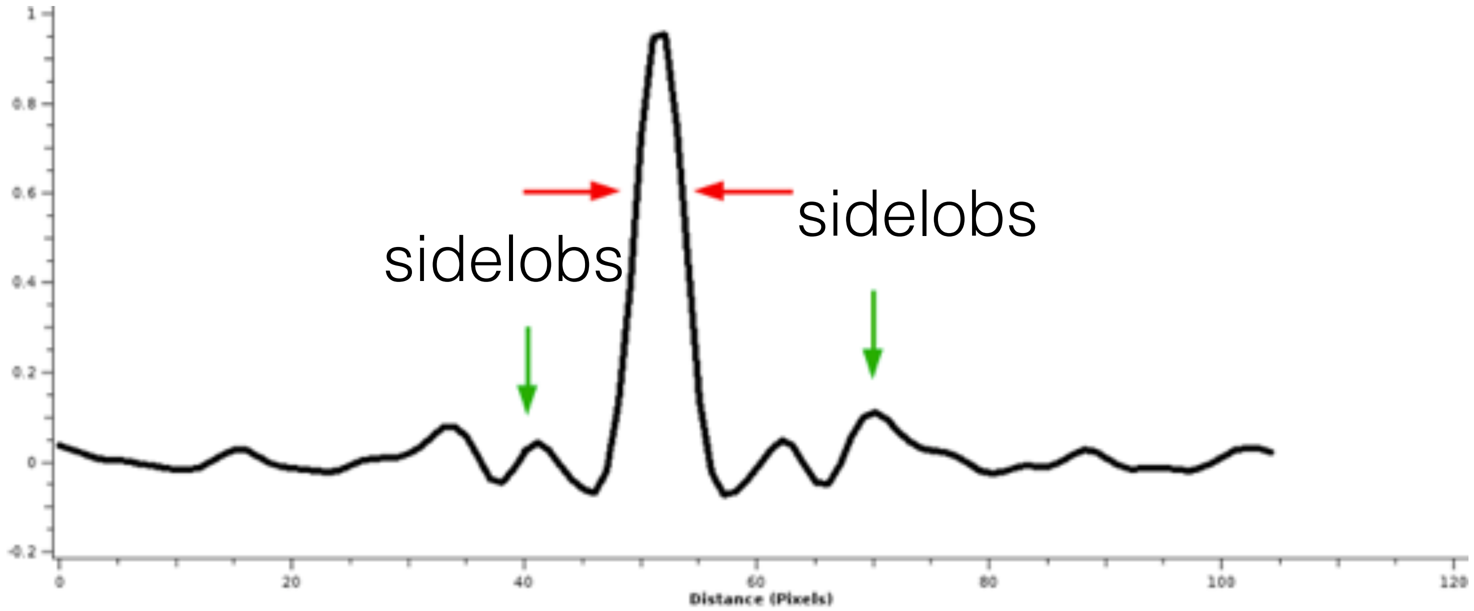
$$\theta_{max} = k\lambda/D_{max}$$

k~1”, weighting of visibilities

$$\mathcal{V}(u,v) = \iint \mathcal{A}(l,m) I(l,m) e^{-2\pi i(ul+vm)} dl dm.$$

- more distant —> more resolution (image details)
  - ok for compact objects … (increase of brightness)
  - careful with extended objects

sampling uv vs PSF (o synth beam…)



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k~1”, weighting of visibilities

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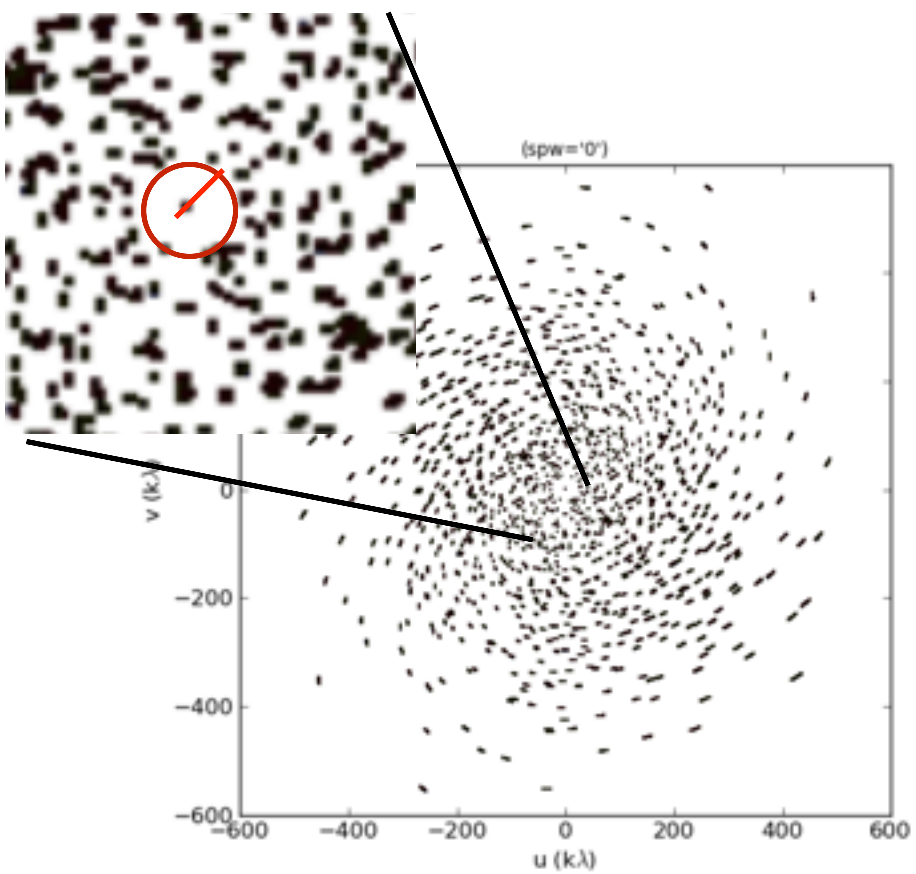
sampling uv vs. MRS

- Maximum recoverable scale: depends on minimum distance between antennas

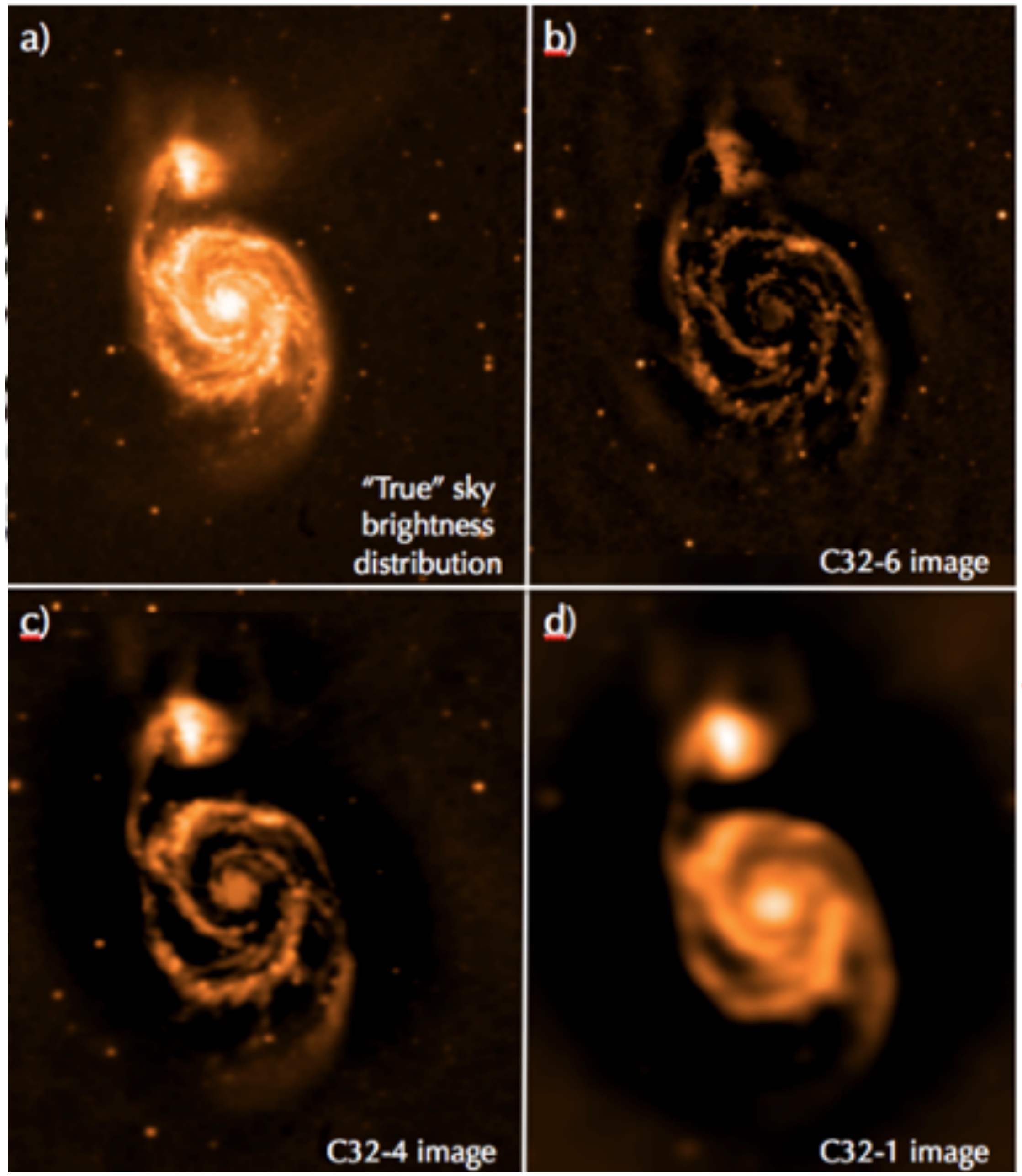


$$\theta_{MRS} \approx \frac{0.6\ \lambda}{L_{min}}\ [radians] \approx \frac{37100}{L_{min}\nu}\ [arcseconds]$$

- more compact—> sensitive to extended sources

sampling uv vs. MRS

- Maximum recoverable scale: depends on minimum distance between antennas



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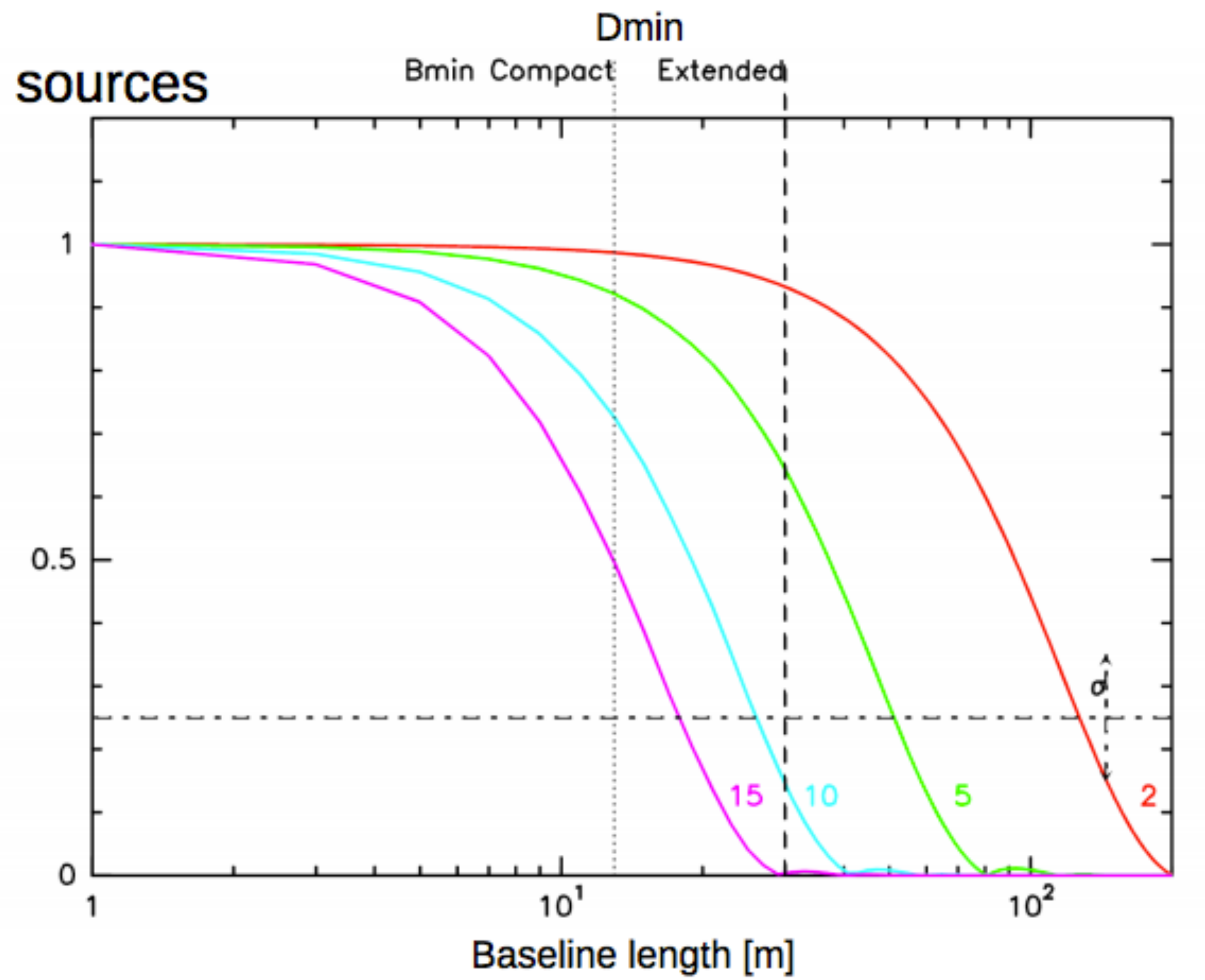
sampling uv vs. MRS the zero spacing problem

- Zero/ short spacing missing in interferometry
  - filtering of large scale emission

- Gaussian sources



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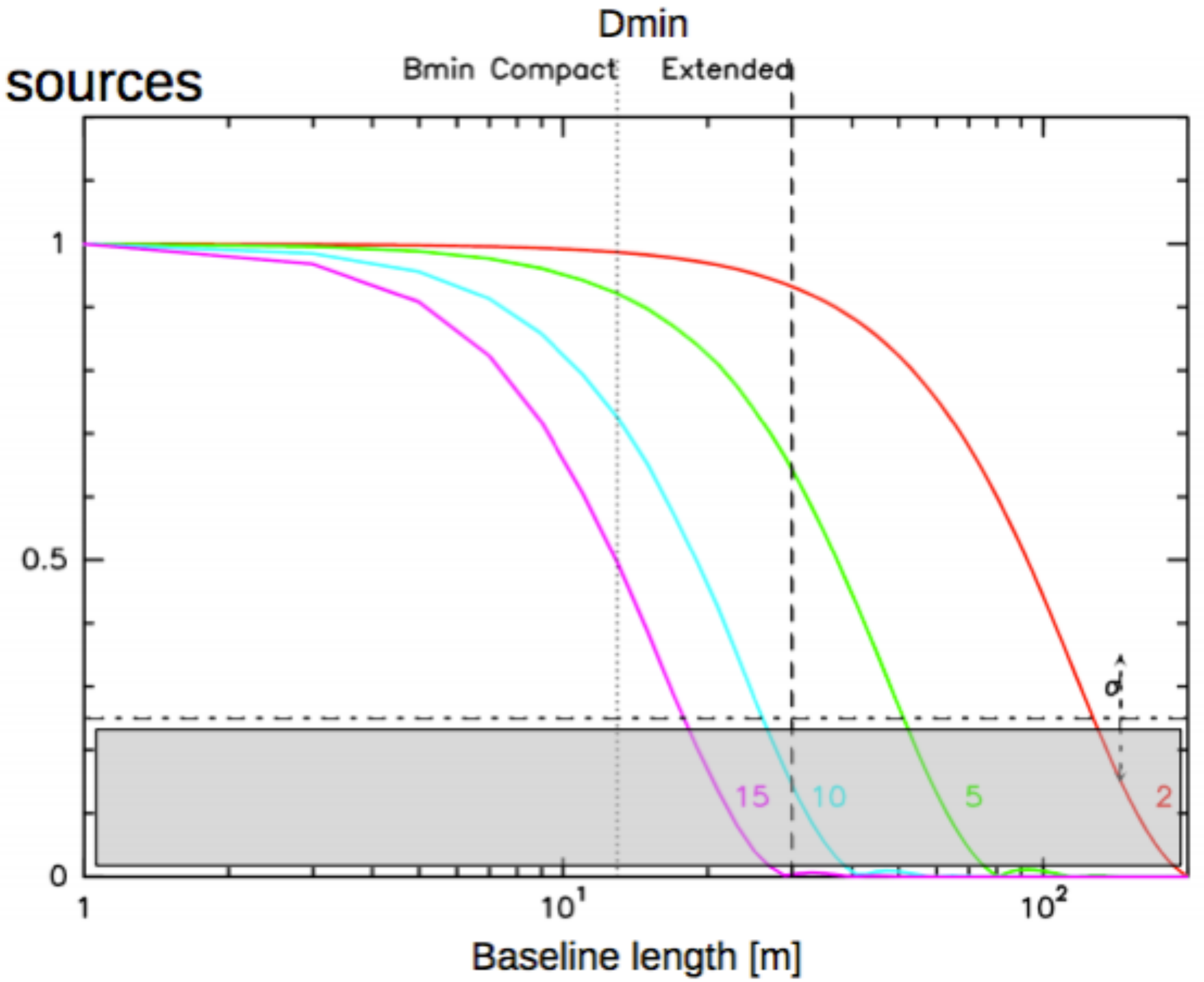

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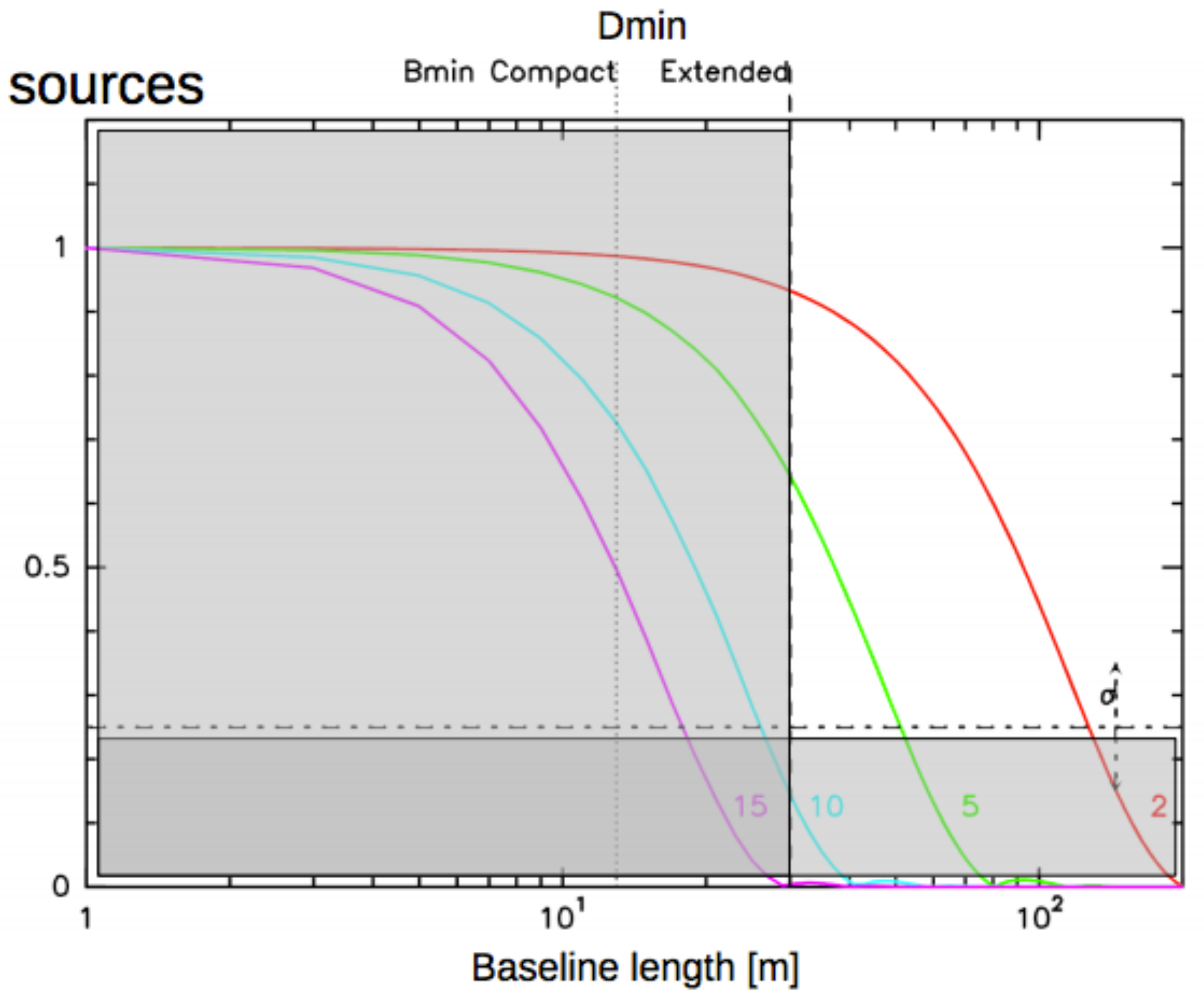

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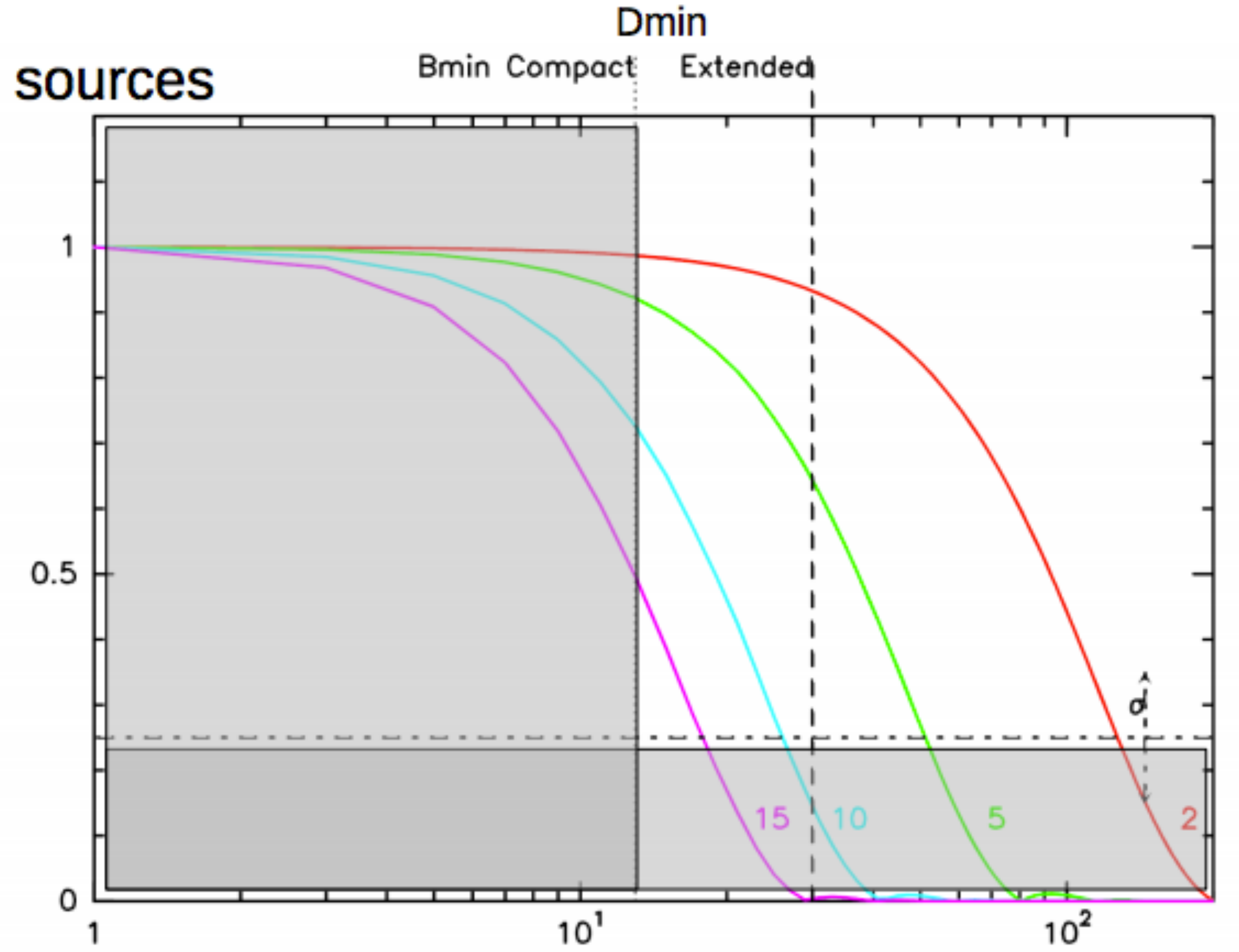

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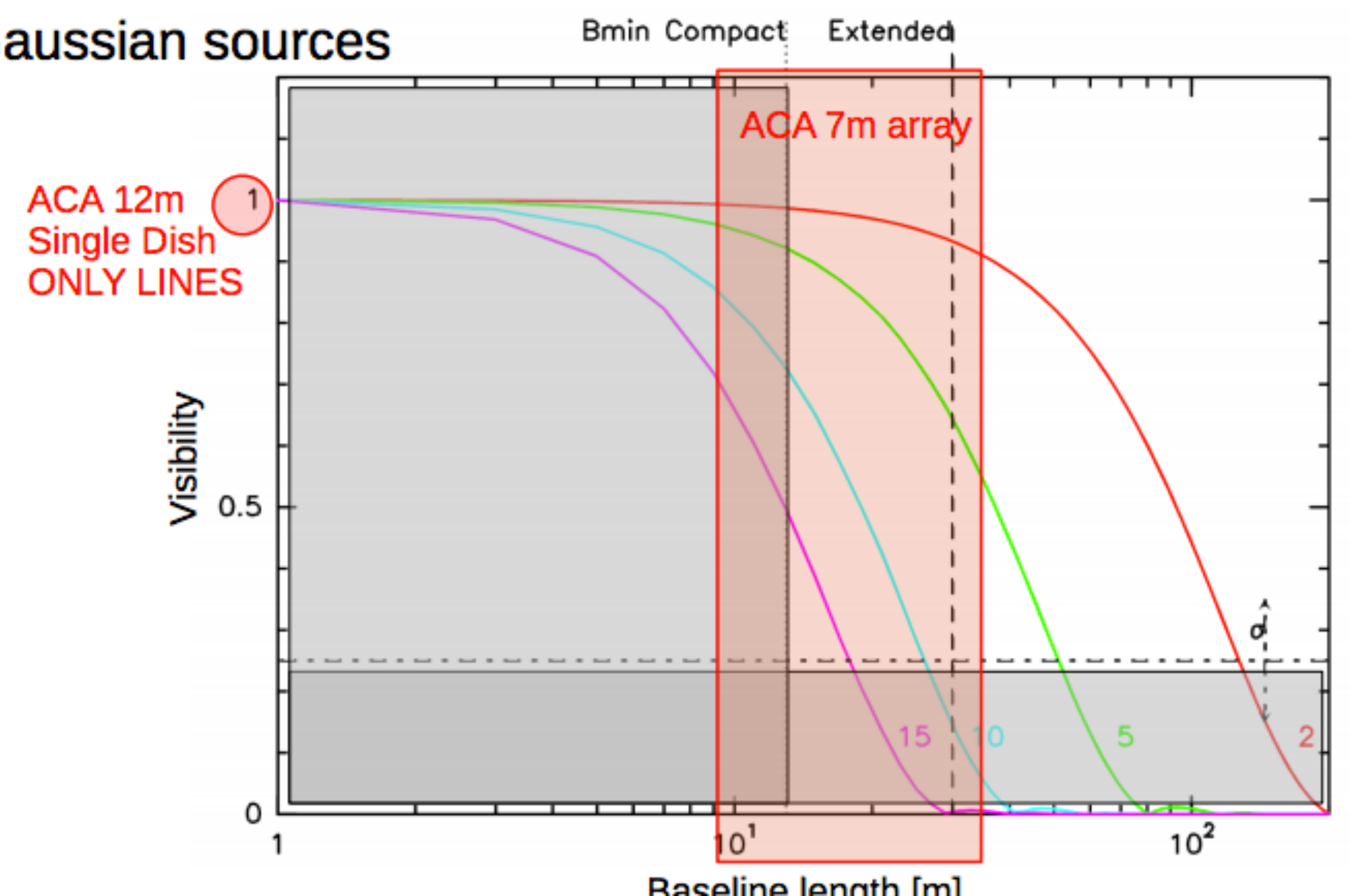
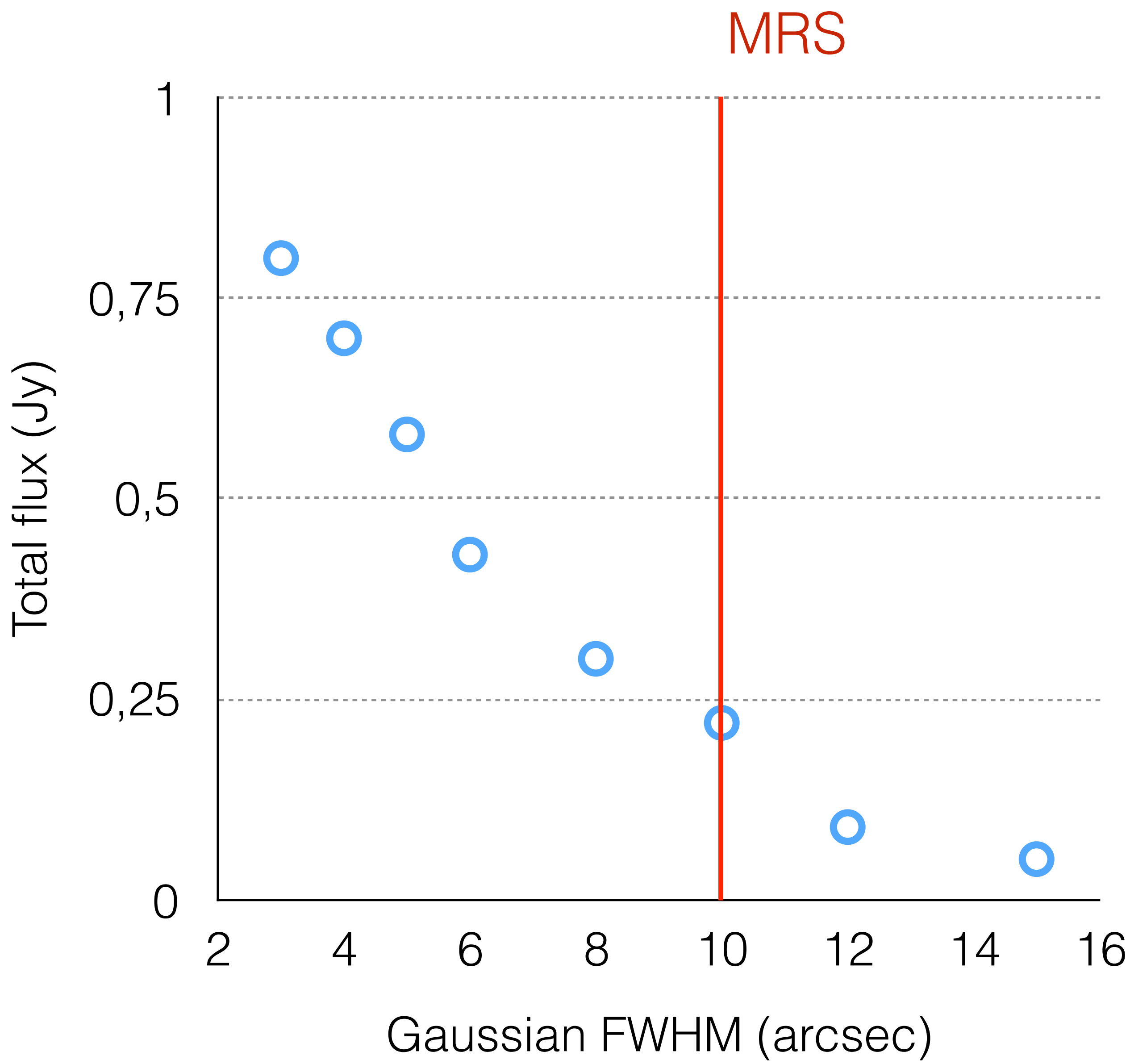
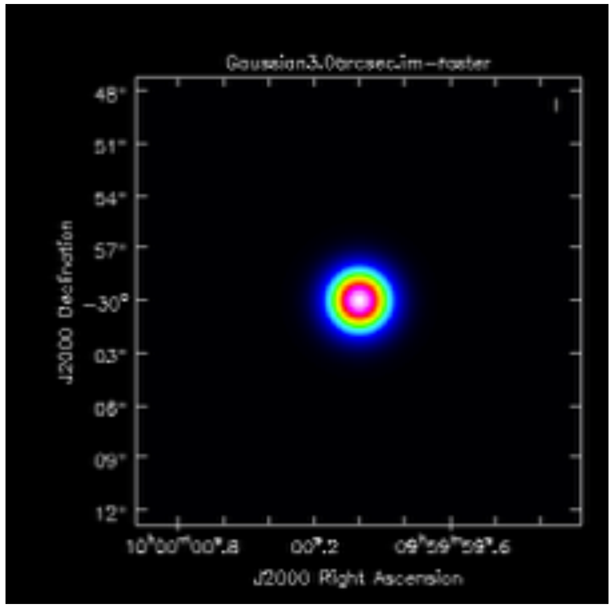


sampling uv vs. MRS the zero spacing problem

- how the interferometer “sees” different FWHM Gaussian Sources (Total Flux = 1Jy)
  - MRS ~ 10arcsec





lost a lot of flux!!
—> ACA
—> TP

Glossary: Flux vs. Brightness

- Temperature and Fluxes (Rayleigh-Jeans)
  - S = Flux density (Jy, Jy per beam)
  - T = brightness temperature (K)
  - k Boltzmann constant
  - Ω_S solid angle (steradian)
  - θ_b HPBW of a gaussian

$$I_\nu(\theta,\varphi) = \frac{2k\nu^2}{c^2} T_B(\theta,\varphi).$$

$$S_\nu = \frac{2k\nu^2}{c^2} \int T_B d\Omega.$$

$$\left(\frac{T}{1\ \mathrm{K}}\right) = \left(\frac{S_\nu}{1\ \mathrm{Jy}}\right) \left[13.6 \left(\frac{300\ \mathrm{GHz}}{\nu}\right)^2 \left(\frac{1''}{\theta_{max}}\right) \left(\frac{1''}{\theta_{min}}\right)\right].$$

1 Jy = 10^{-26} W m^{-2} Hz^{-1} = 10^{-23} erg s^{-1} cm^{-2} Hz^{-1}

Glossary: Flux vs. Brightness

- Sensitivity: depends on … a lot of things

The rms noise in the signal (sensitivity):

Tsys is the brightness temperature equivalent to the flux received from the antenna **source**, atmosphere, instrumental noise….

$$\sigma_S = \frac{2\,k\,T_{sys}}{\eta_q \eta_c A_{eff} \sqrt{N(N-1)\,n_p\,\Delta\nu\,t_{int}}}$$

Sensitivity can be improved by:

- getting **lower Tsys** (sites with low water vapour levels)
- increasing the **collecting area**
- increasing the **bandwidth** and/or the **integration time**

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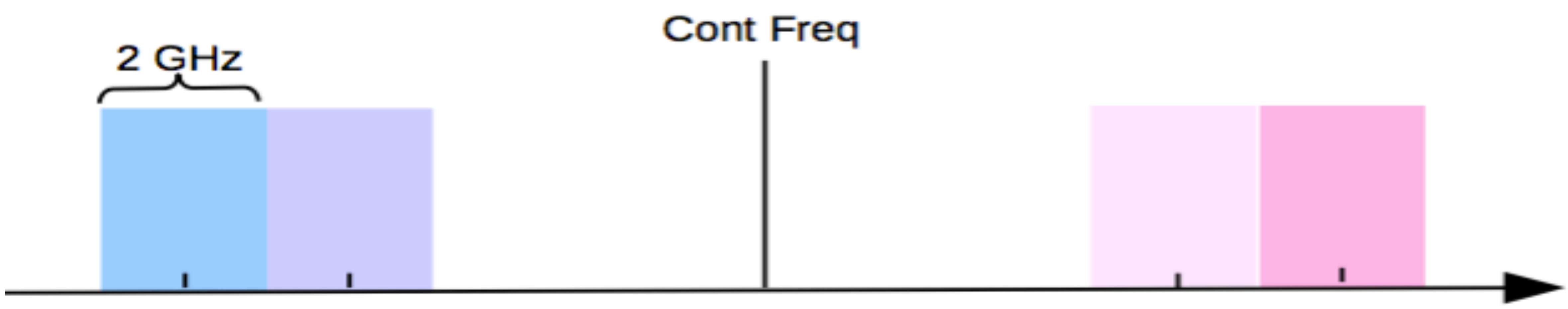
helpful for ARCHIVE data?

YES! You can average channels for lower rms

The interferometric data output

(ALMA) data format—> the cube

@mm wavelengths molecular spectroscopy
wide spectral range (~8GHz)
each spw divided into several channels



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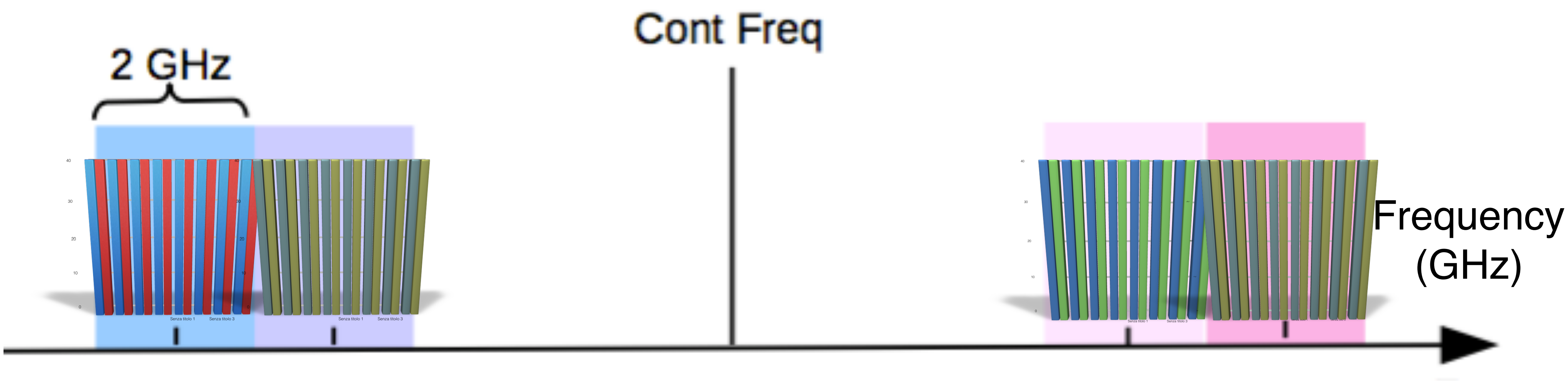

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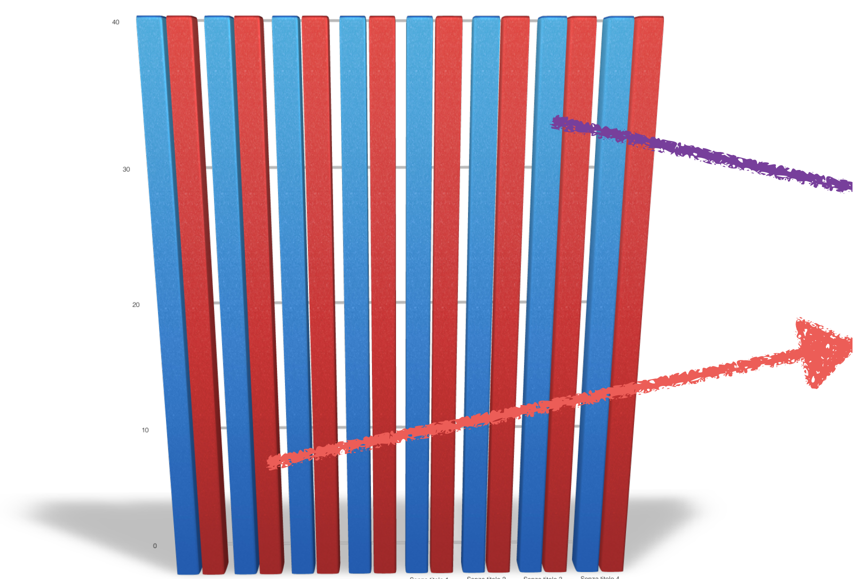
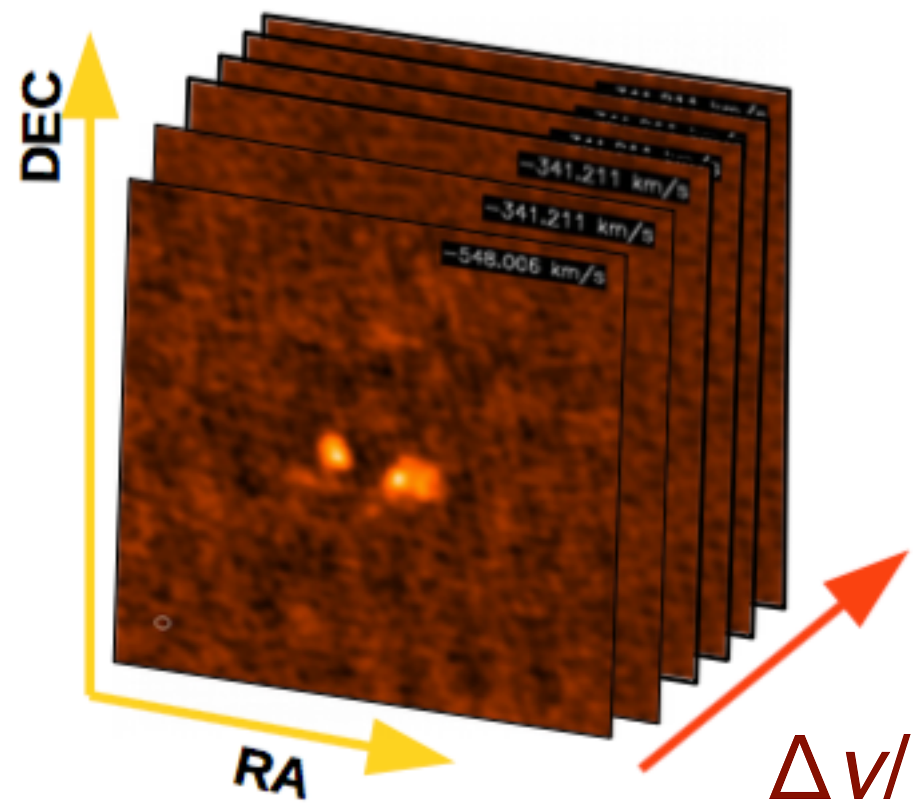
From each channel, one uv-plane/image is produced

Spectral line observations have up to 3840 channels. The highest spectral resolution achieavable is 30 kHz.





$\Delta v / v_{sky} = \Delta \nu / c$