Short intro to interferometry

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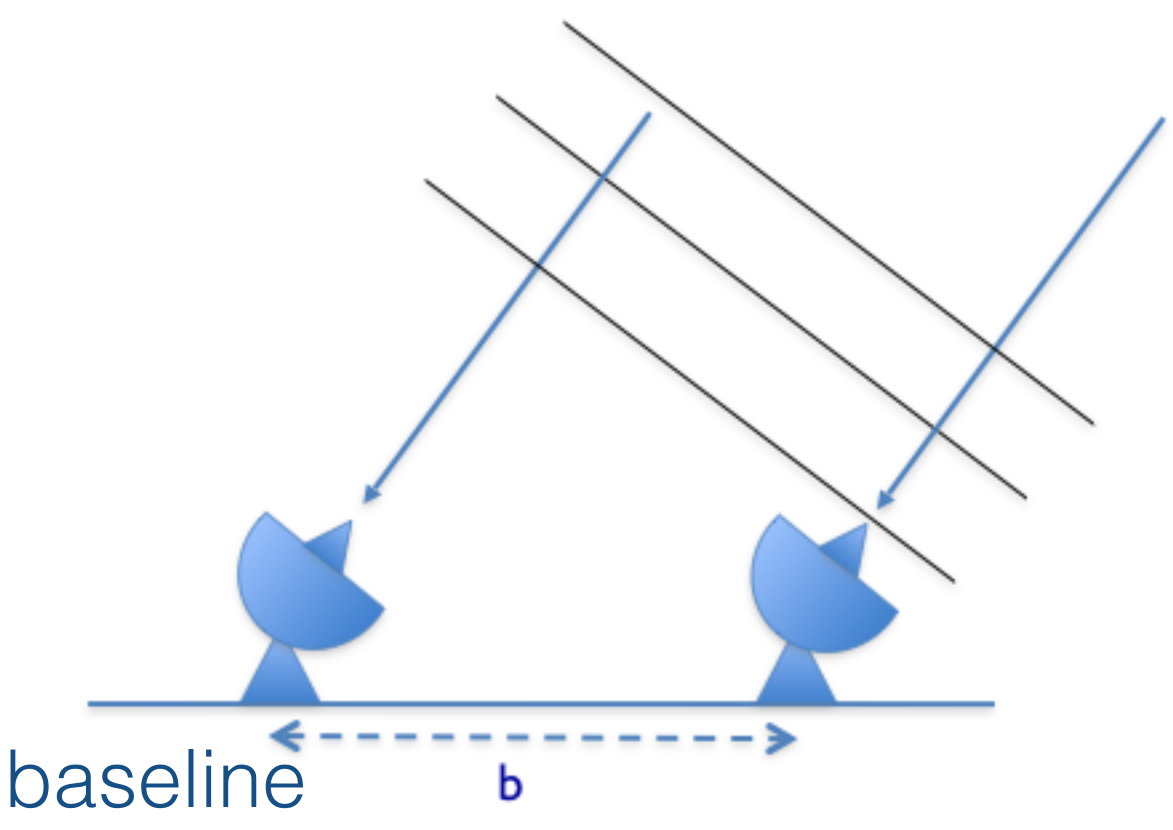
Outline

- Interferometry (the basics)
- Visibility and sky brightness
- OT quantities
    - FOV, LAS, res
    - sidebands

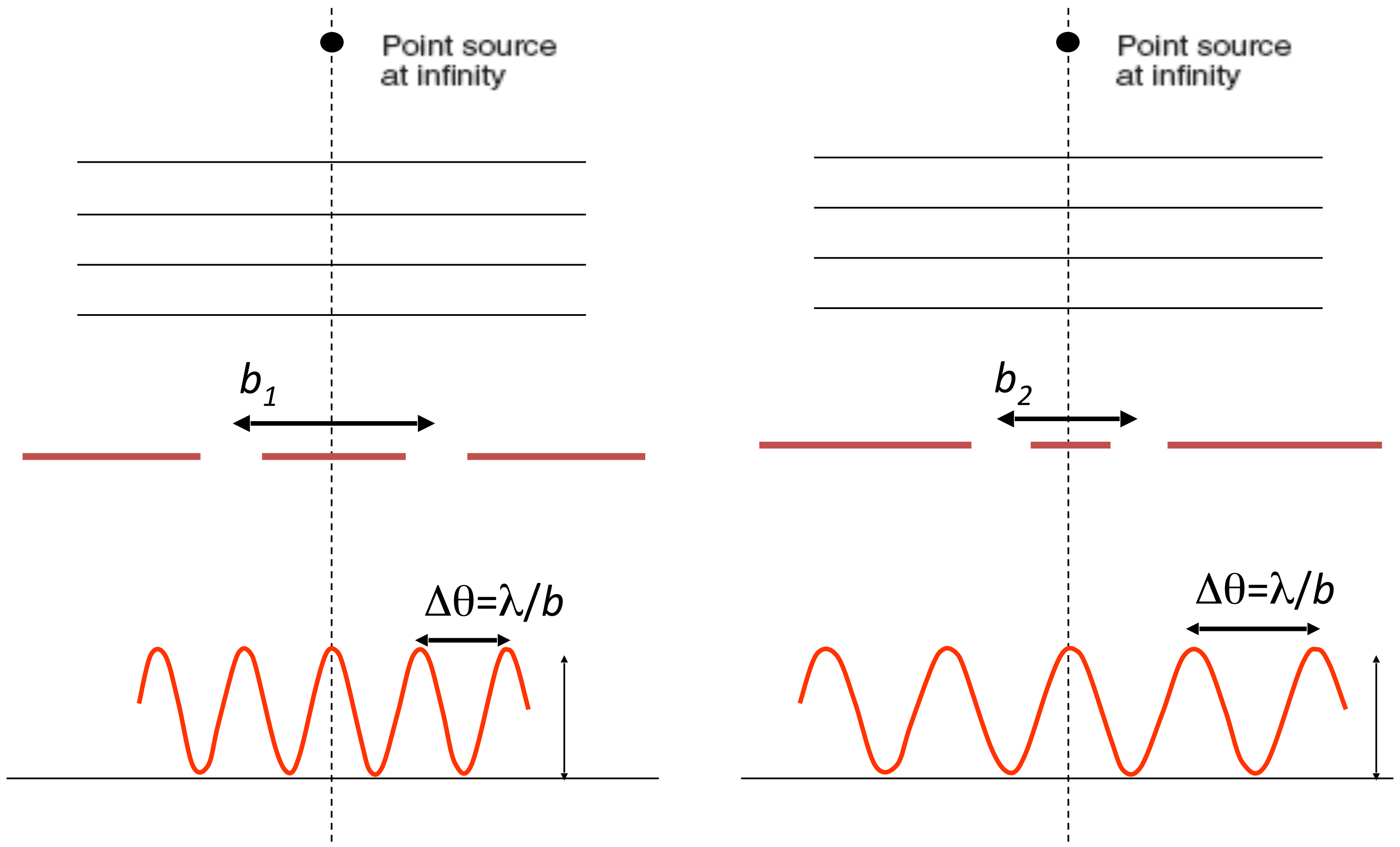
AIM: not to explain interferometry in detail, but make users less scared by using interferometry

Interferometers: the basics

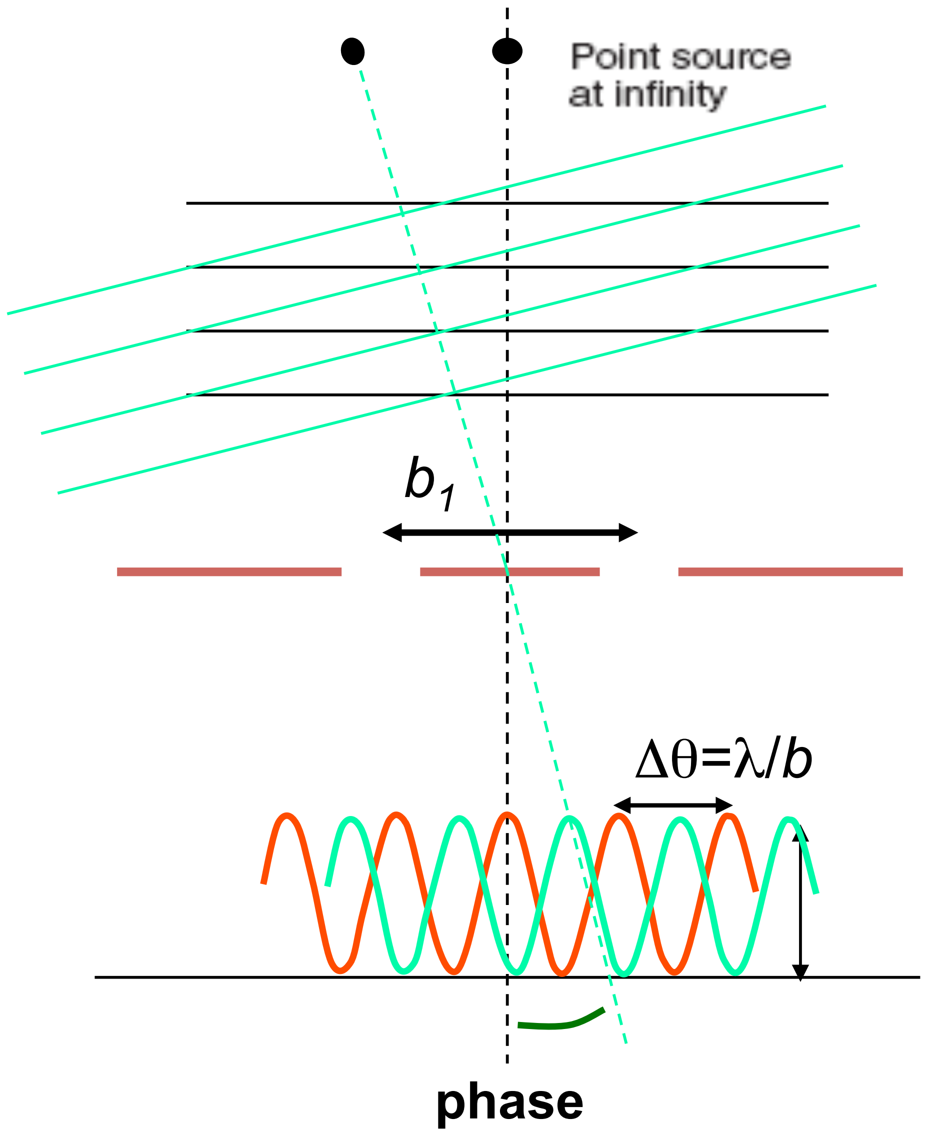
- Interferometry: a method to 'synthesize' a large aperture by combining signals collected by separated small apertures
- An Interferometer measures the interference pattern produced by two apertures, which is related to the source brightness.
- The signals from all antennas are correlated, taking into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



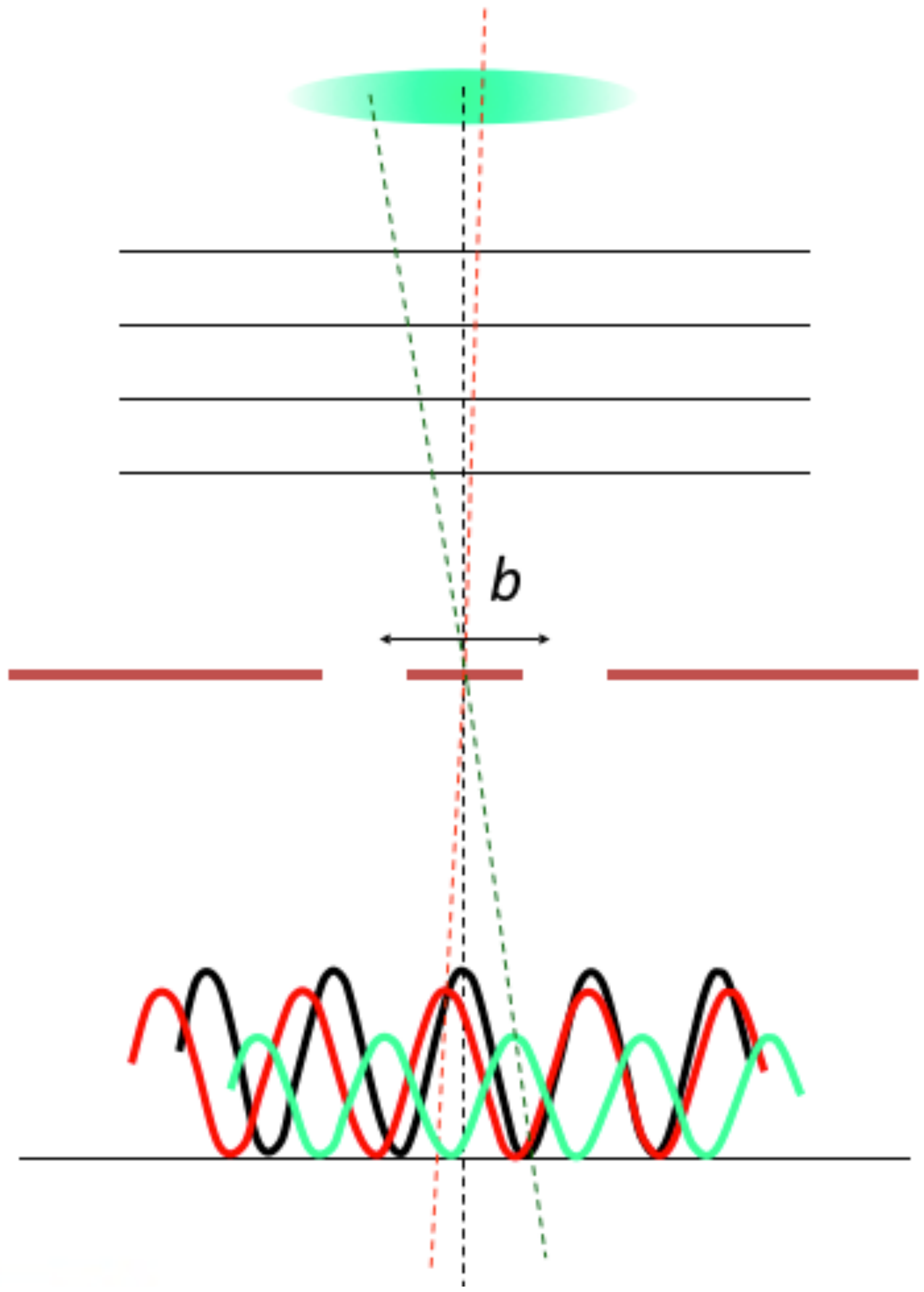
Interferometers: the basics



Interferometers: the basics



Interferometers: the basics



- Amplitude tells "how much" of a certain frequency component

- Phase tells "where" this component is located

Visibility

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

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

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

- 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

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

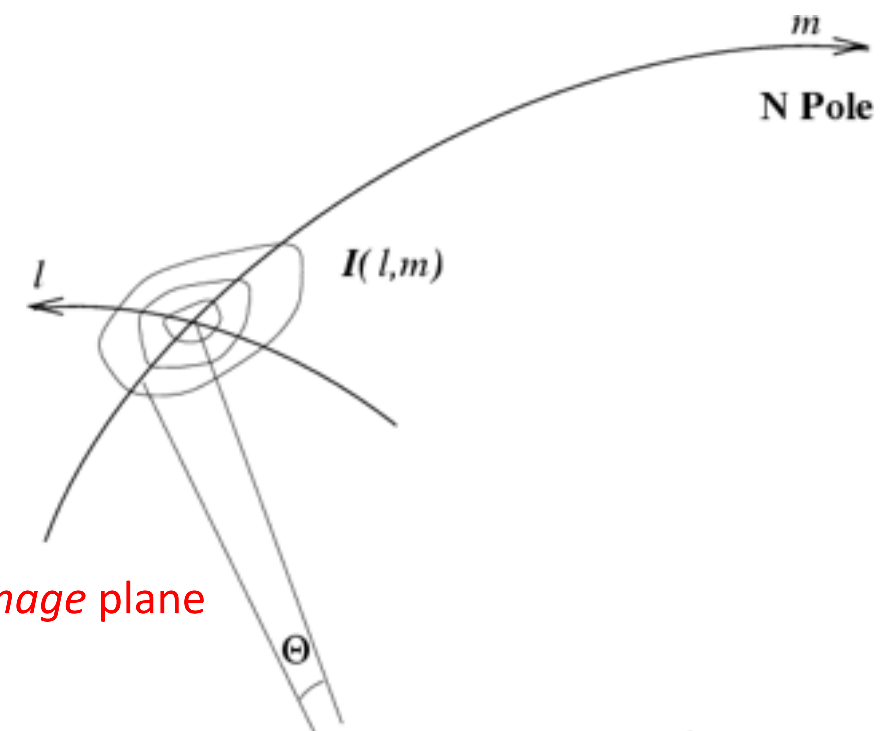
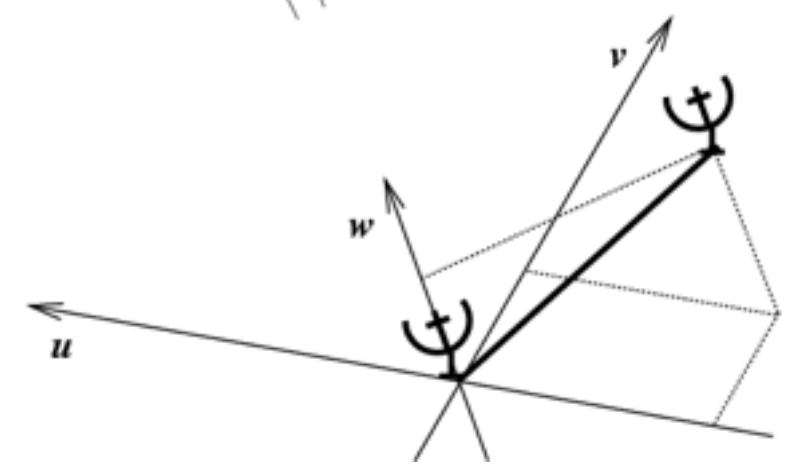


image plane

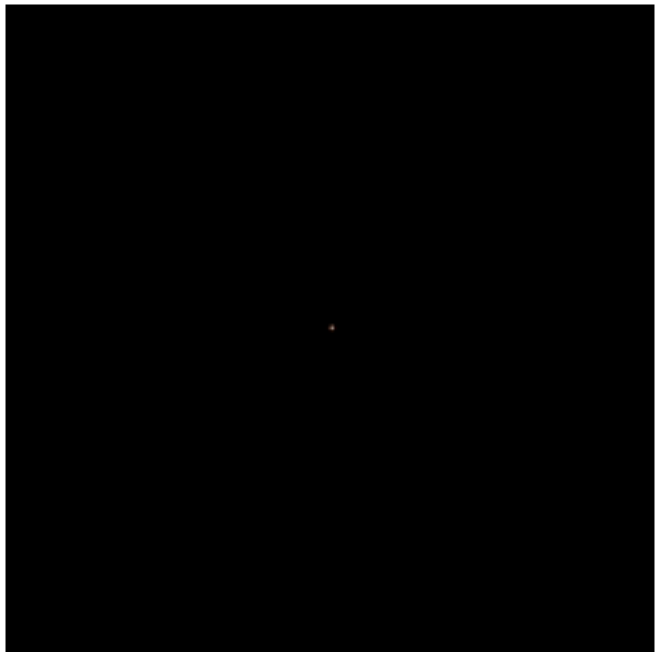


uv plane

2D Fourier Transforms

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

δ Function



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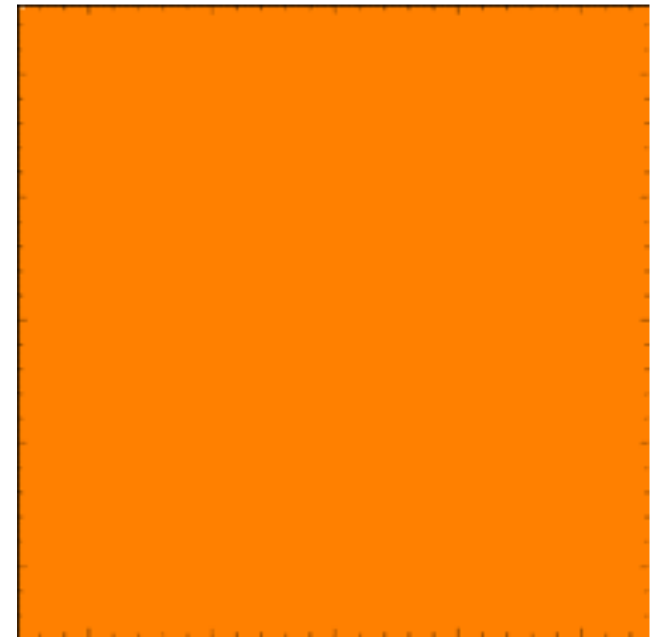
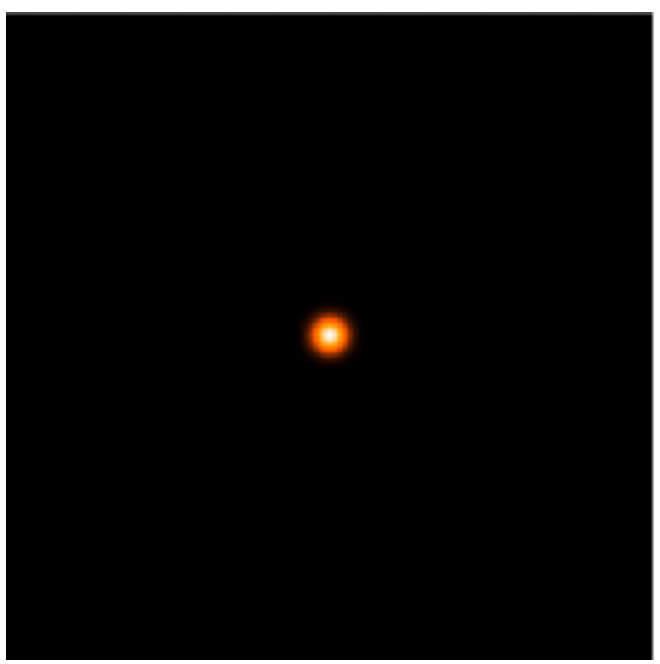


Constant

Gaussian



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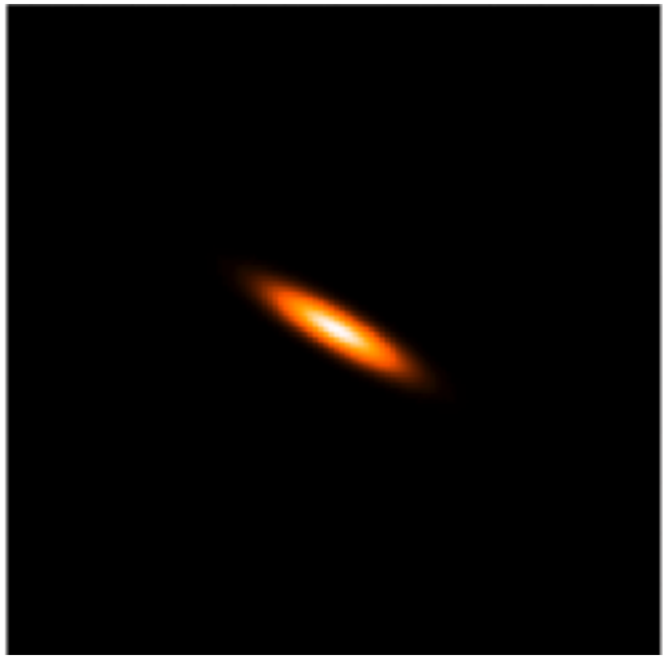
Gaussian

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

2D Fourier Transforms

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

elliptical Gaussian



⇌

elliptical Gaussian

Disk

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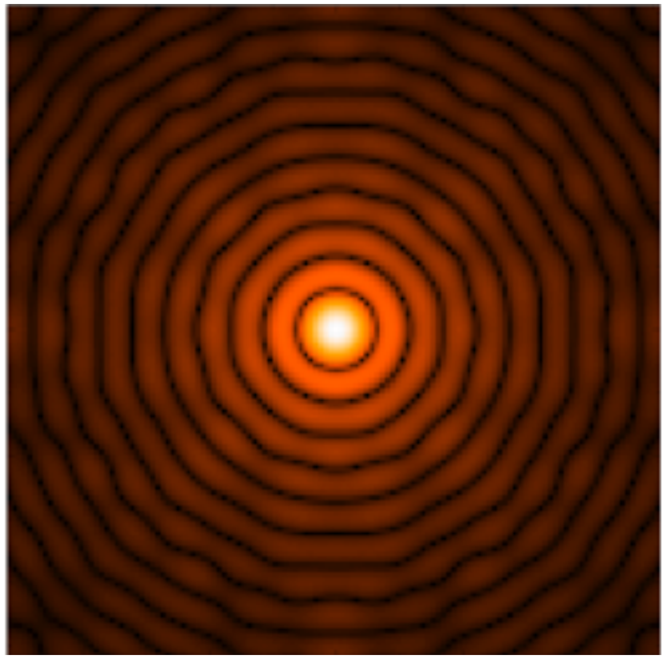
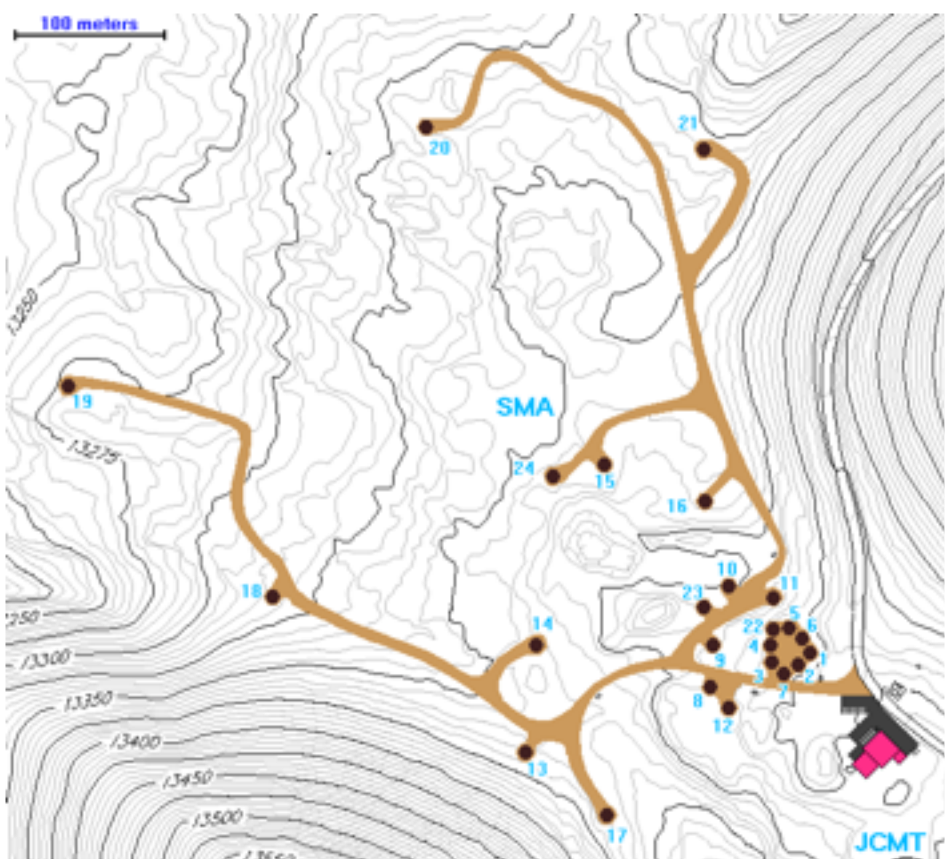


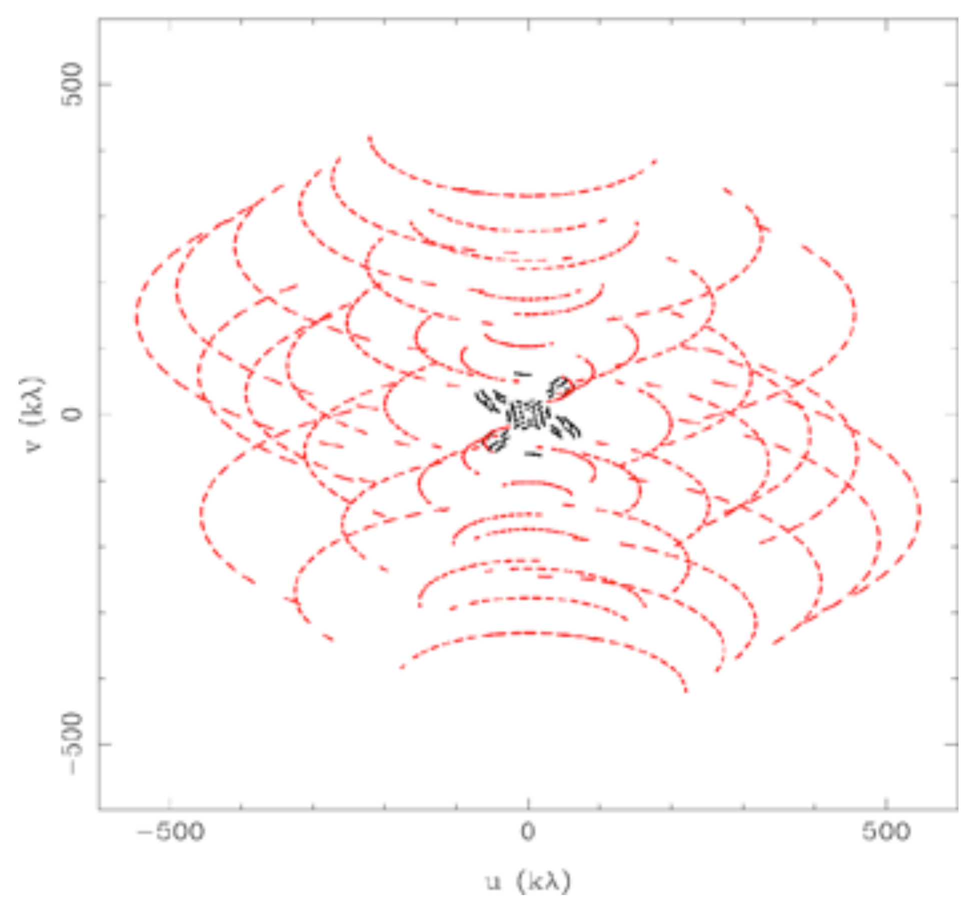
Bessel

sharp edges result in many high spatial frequencies

Aperture Synthesis

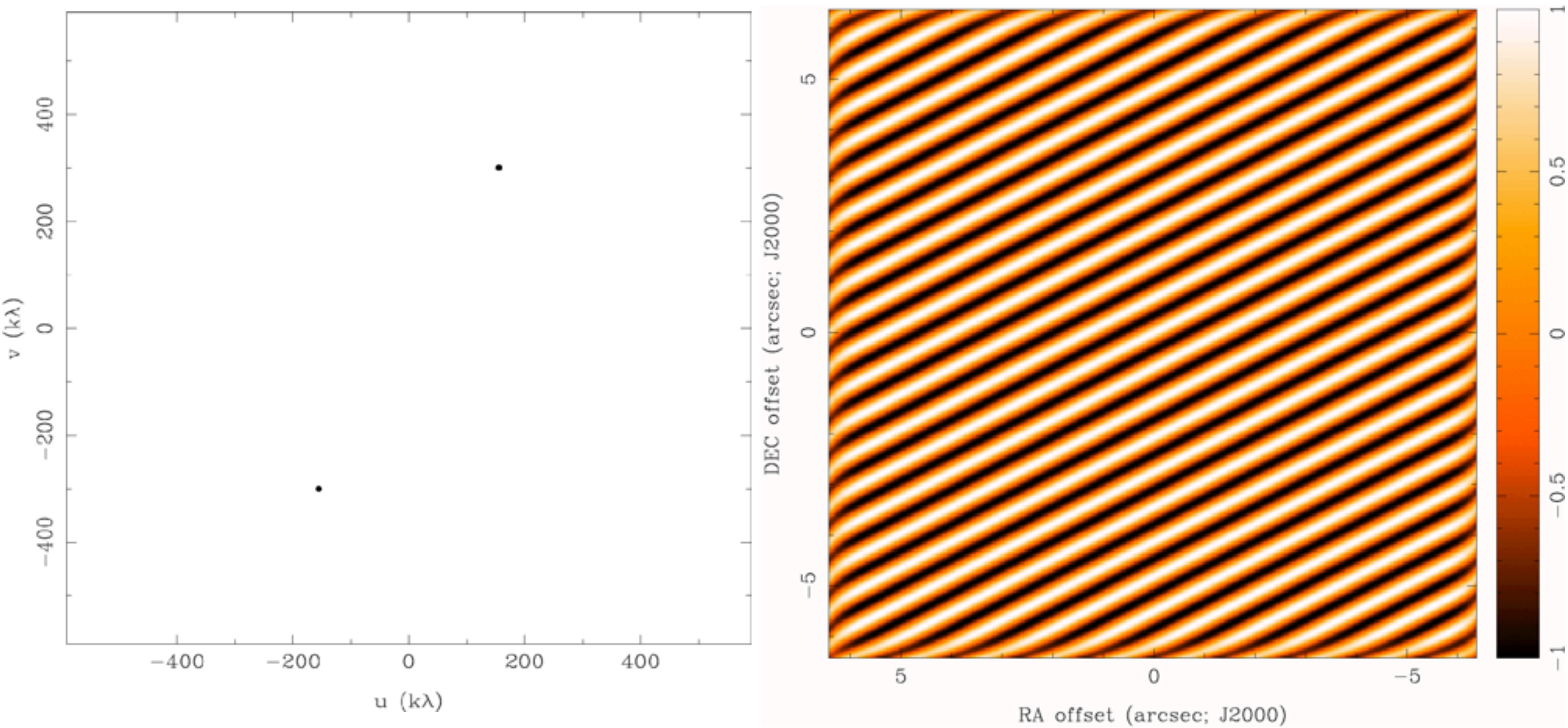
- Sample V(u,v) at enough points to synthesis the equivalent large aperture of size (u_{max},v_{max})
  - 1 pair of telescopes → 1 (u,v) sample at a time
  - N telescopes → number of samples = N(N-1)/2
- A good image quality requires a good coverage of the uv plane
  - fill in (u,v) plane by making use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





PSF shape vs. N ants

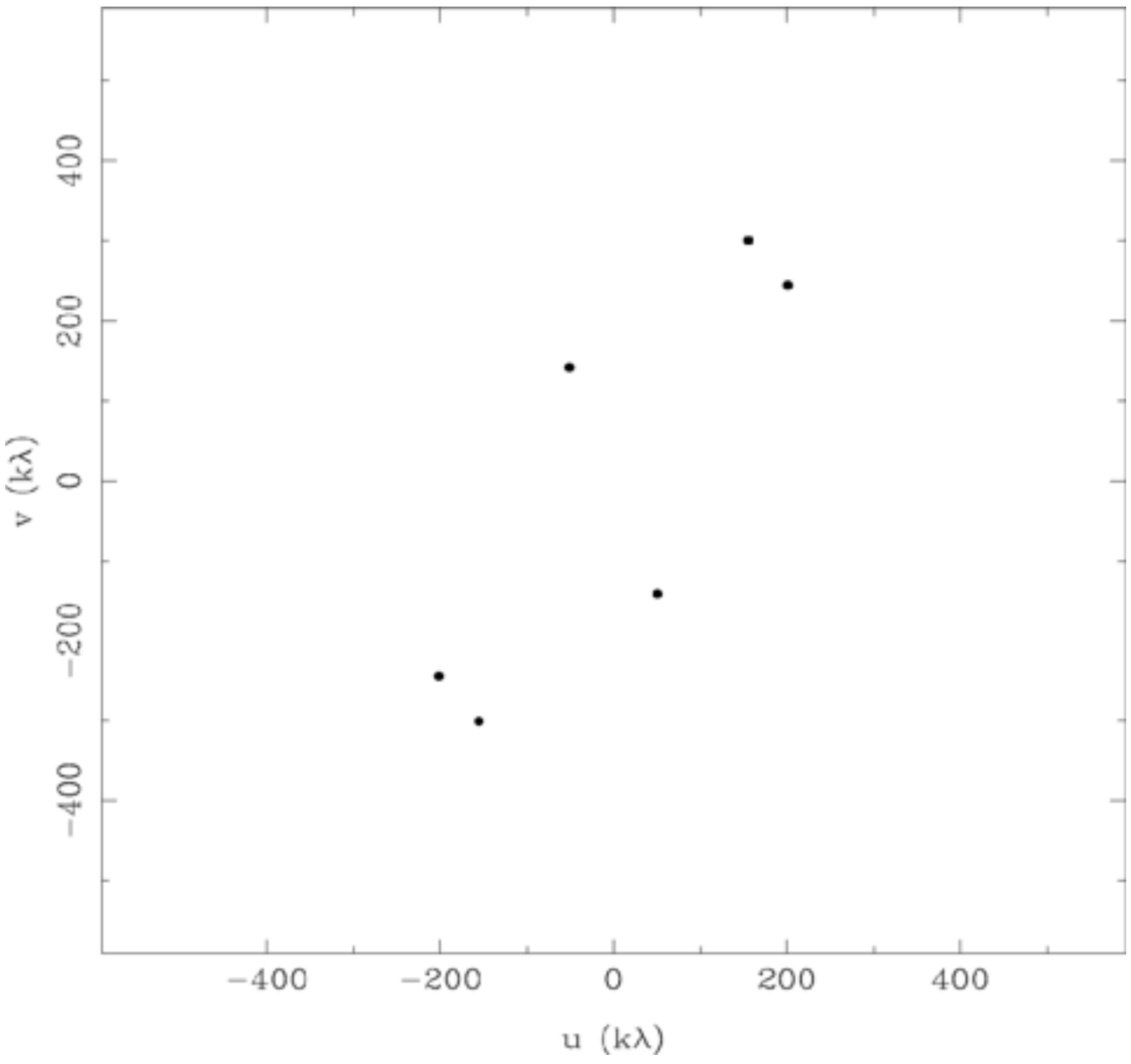
2 antennas

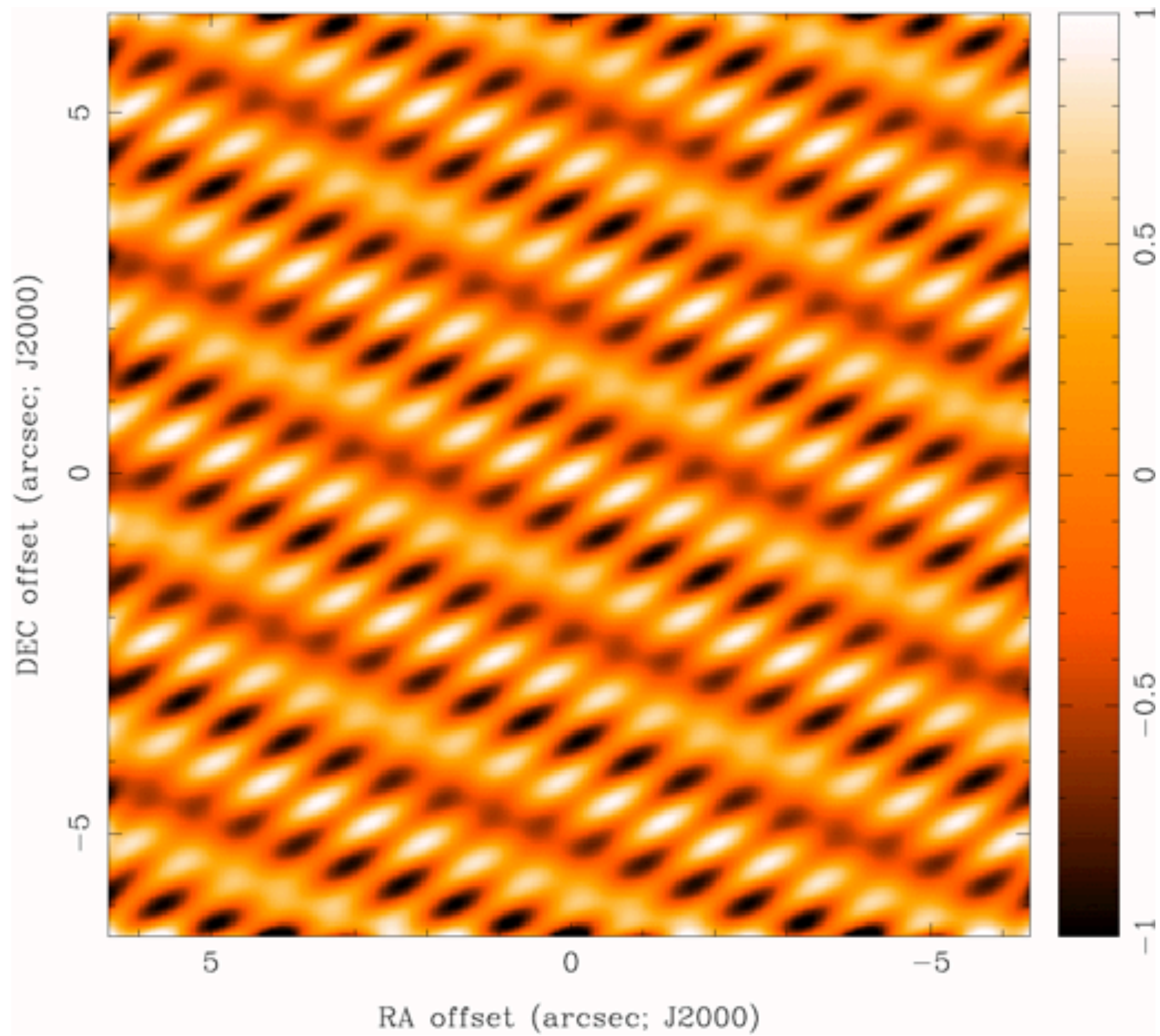


- to characterize a source, I need to sample as much as possible the uv plane.

PSF shape vs. N ants

3 antennas

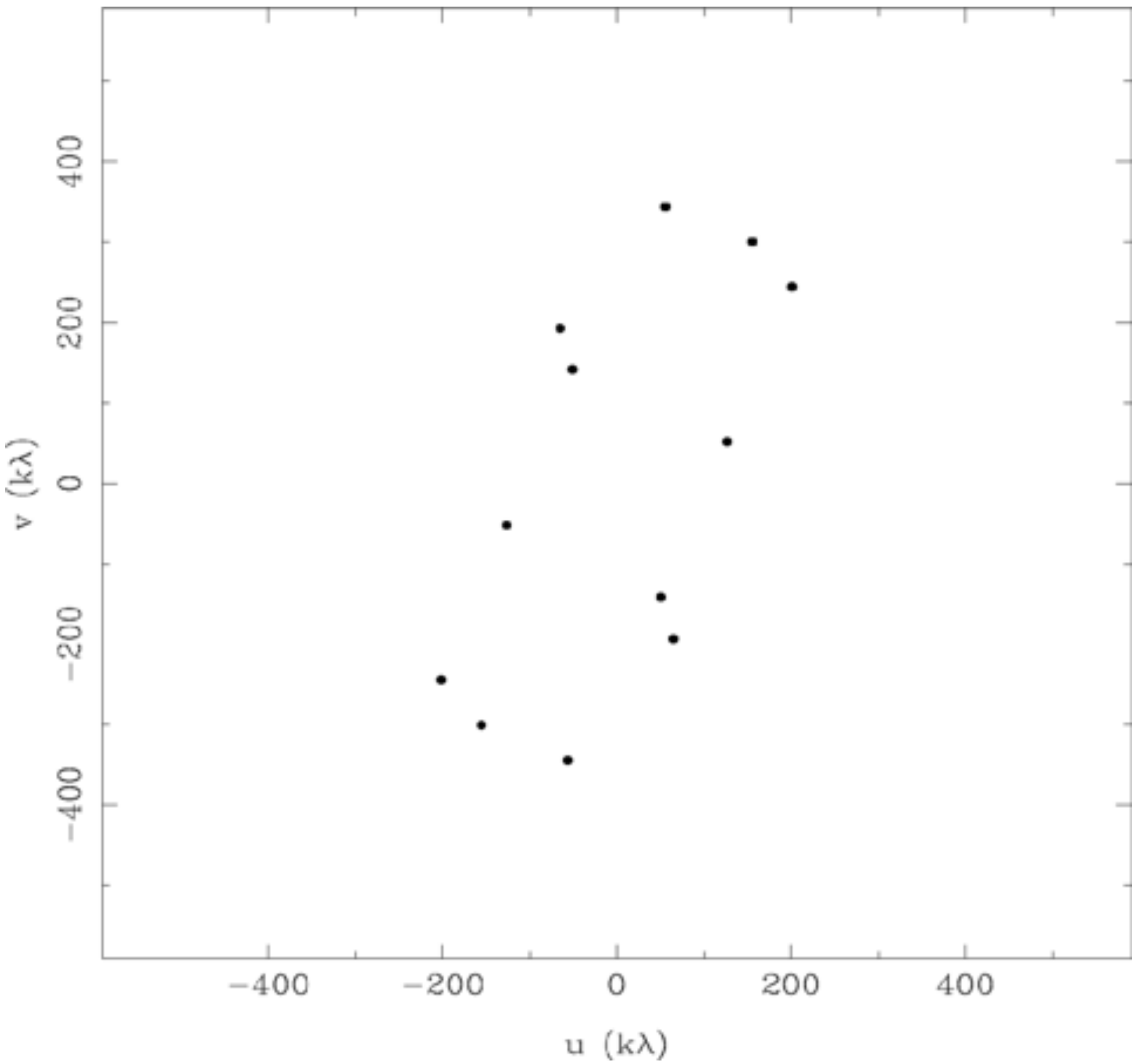


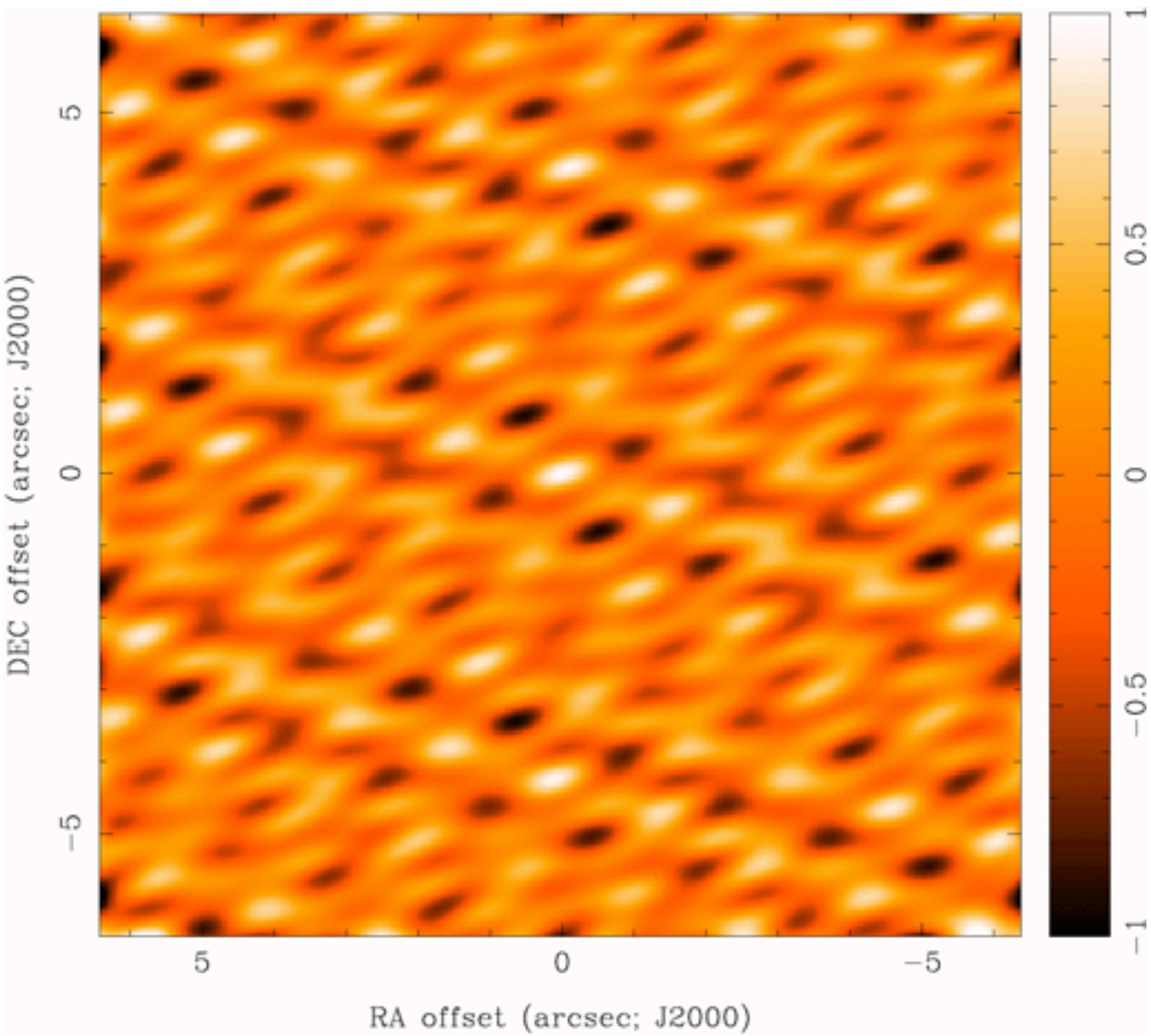


by increasing the number of antennas …

PSF shape vs. N ants

4 antennas

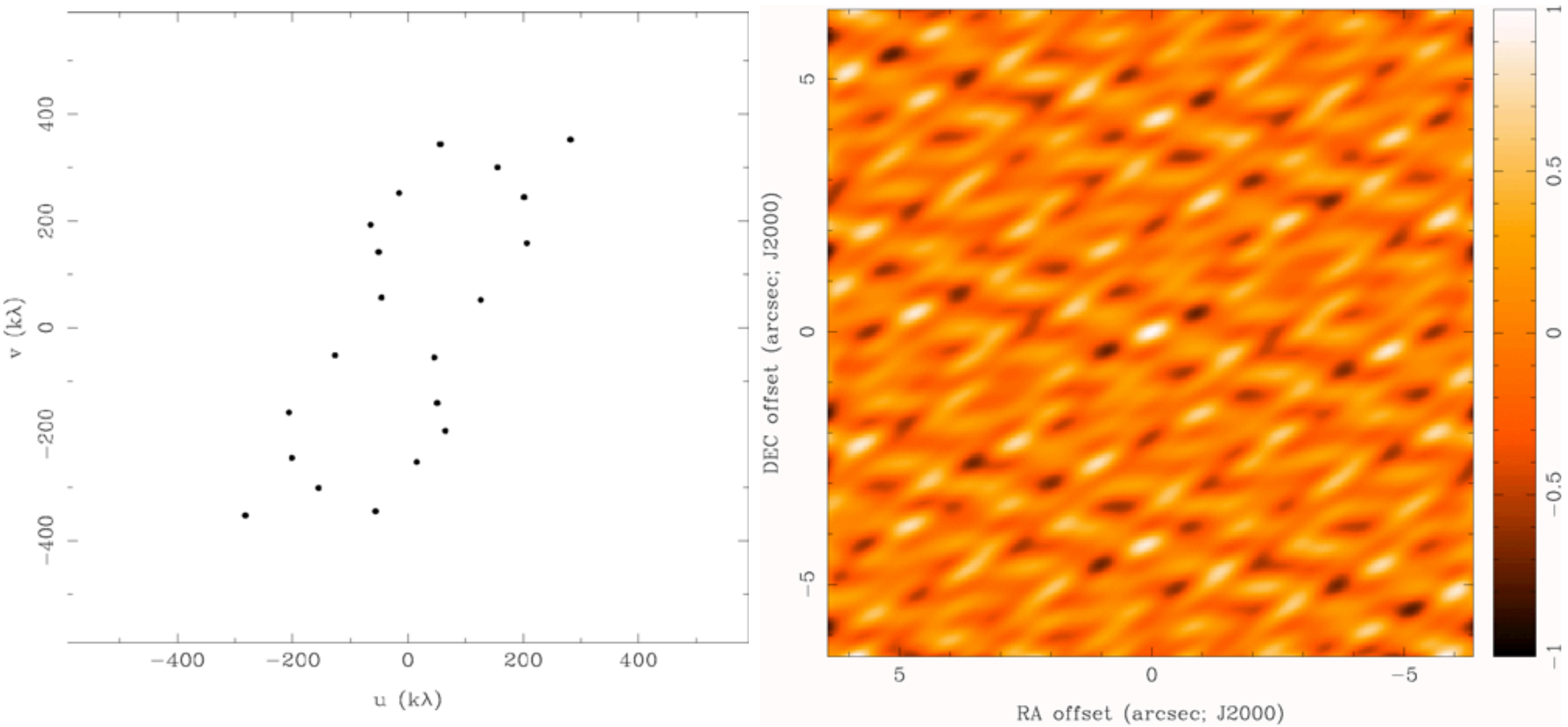




by increasing the number of antennas …

PSF shape vs. N ants

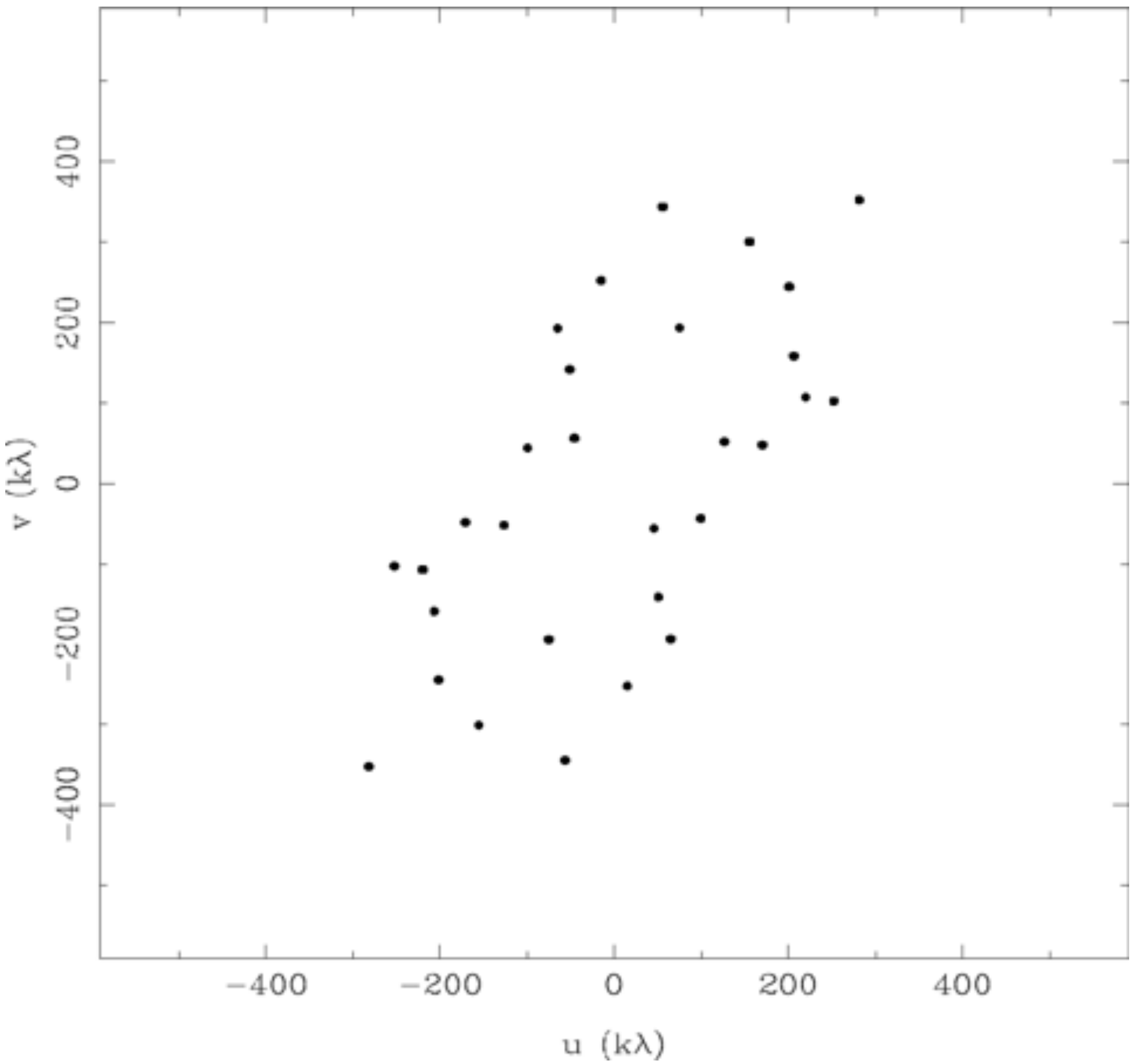
5 antennas

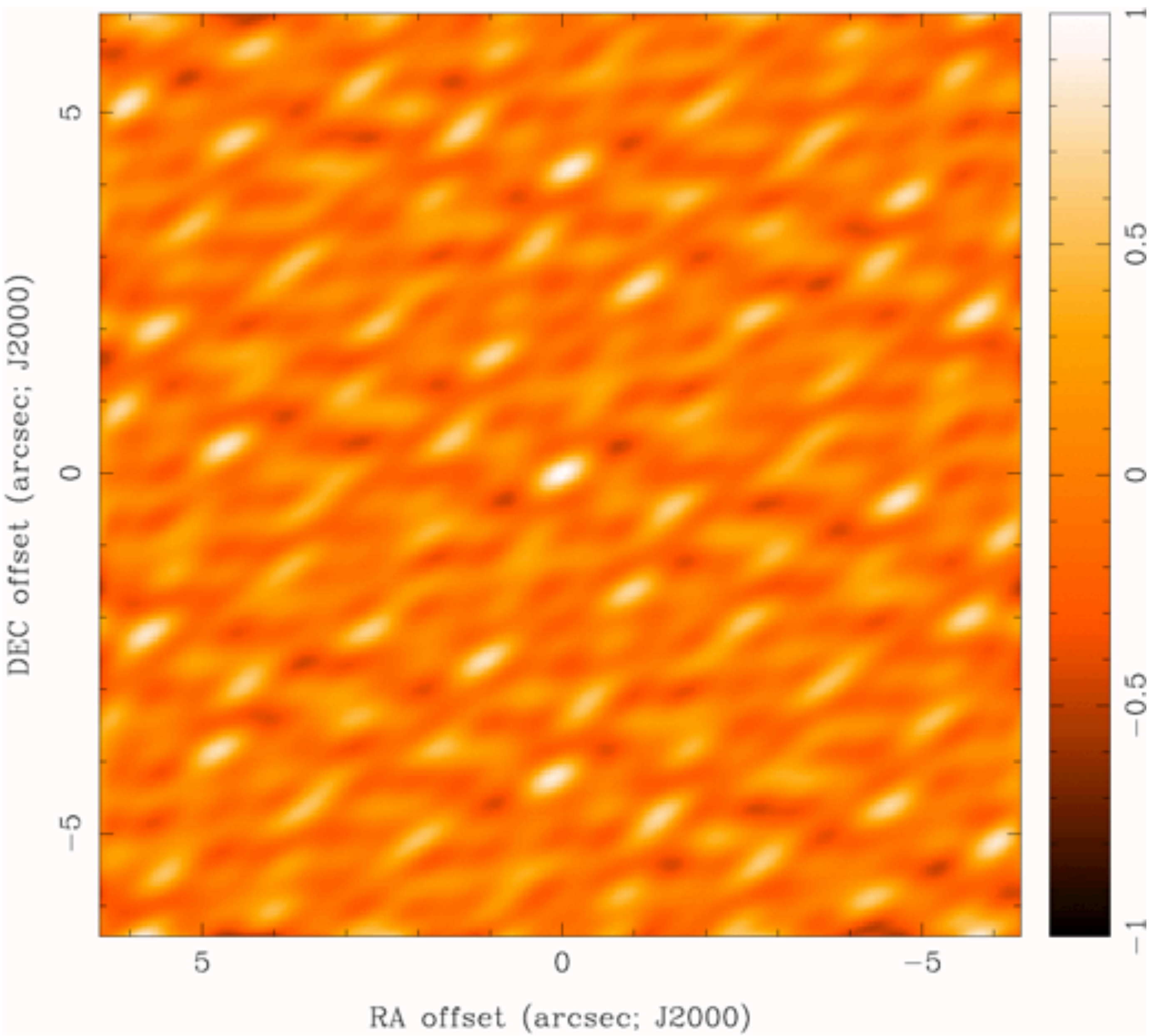


by increasing the number of antennas …

PSF shape vs. N ants

6 antennas

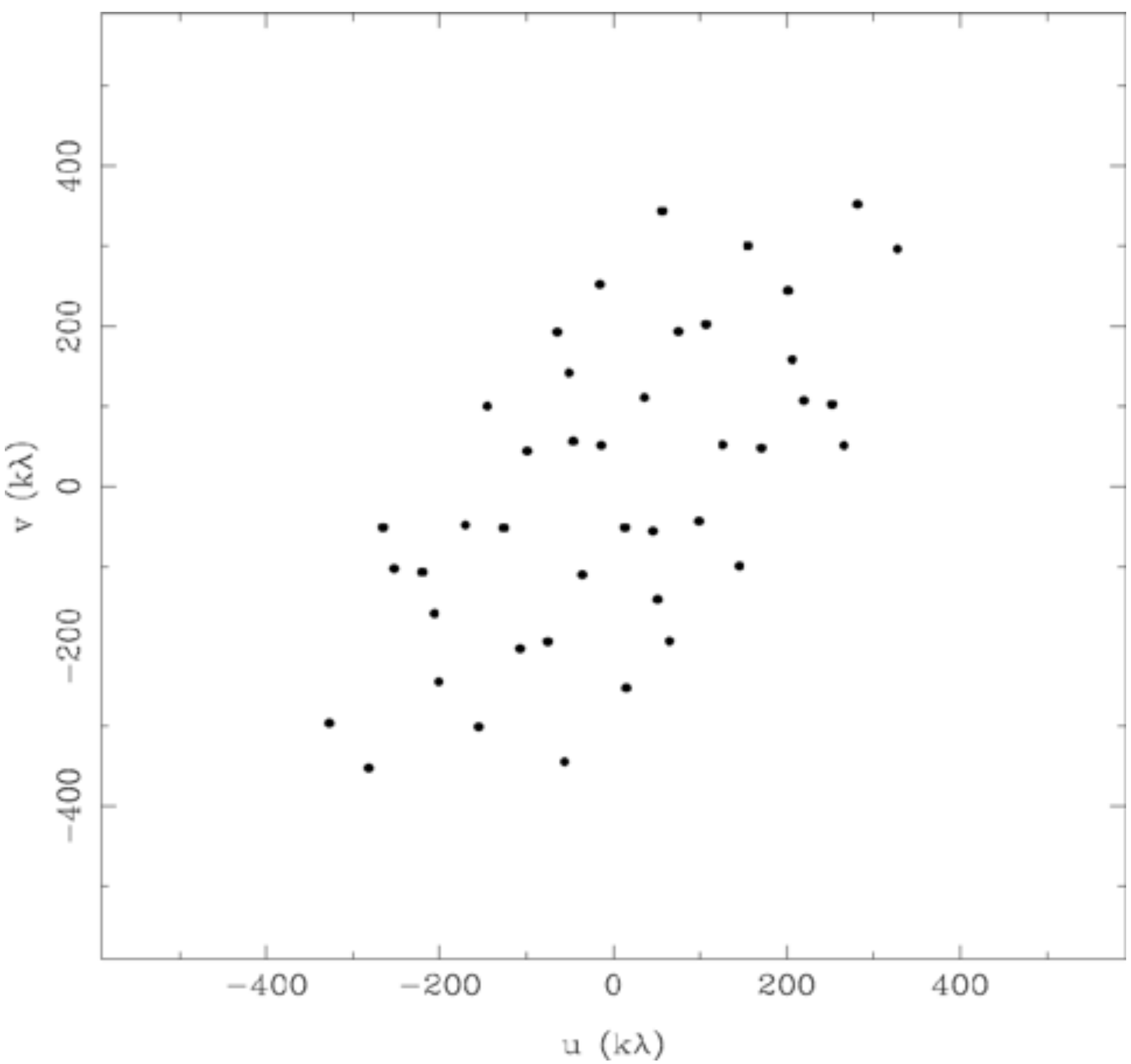


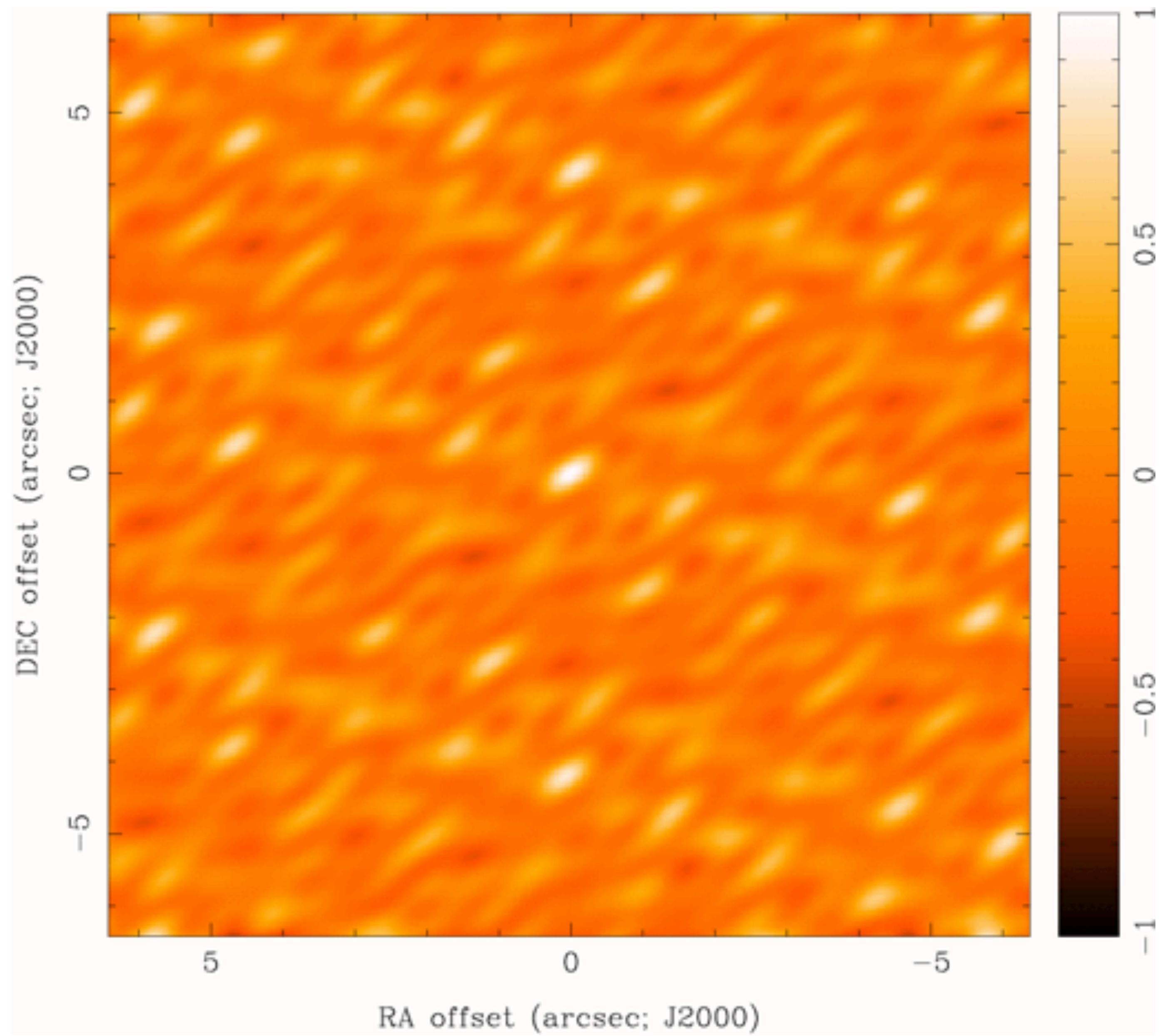


by increasing the number of antennas …

PSF shape vs. N ants

7 antennas

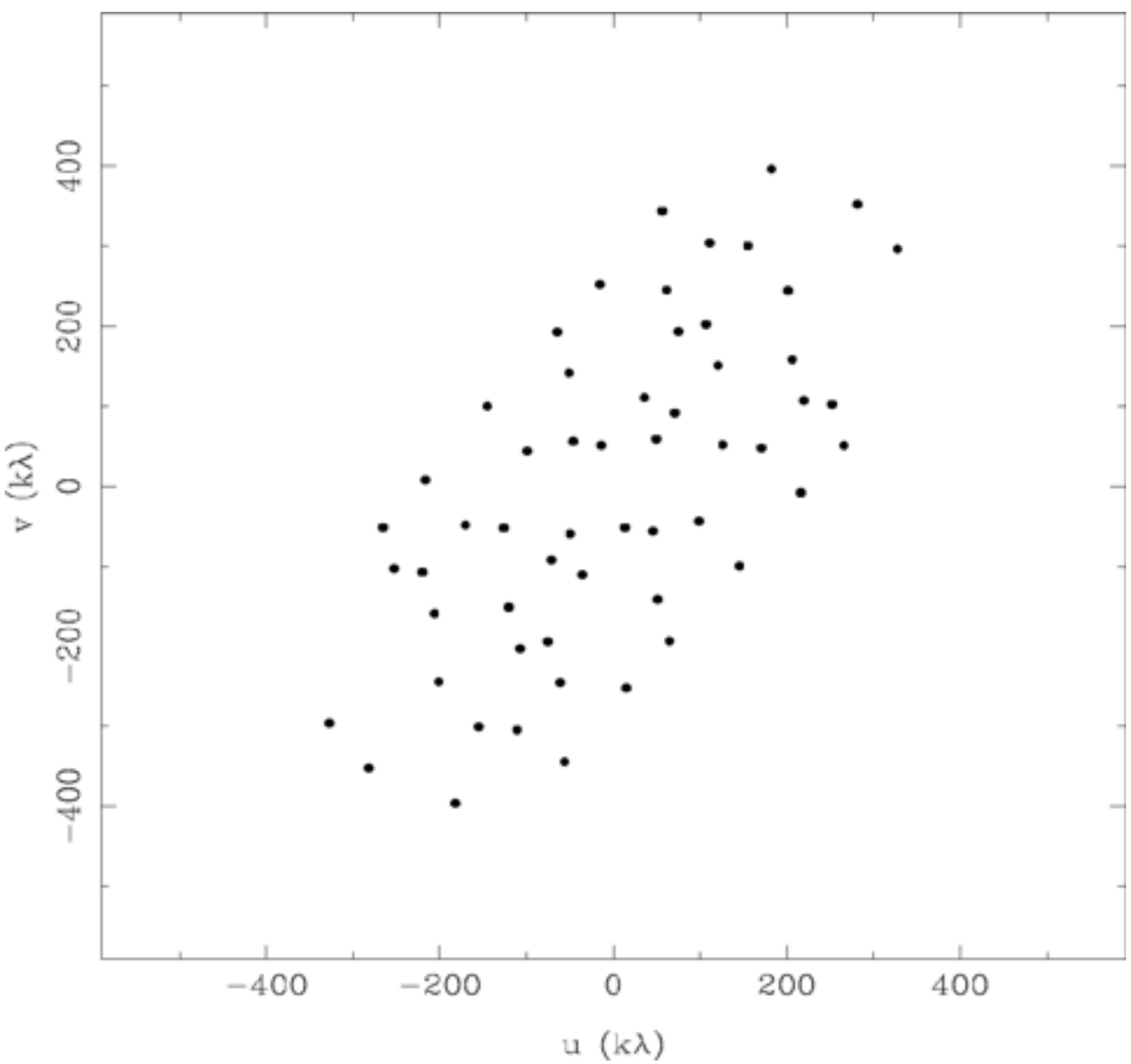


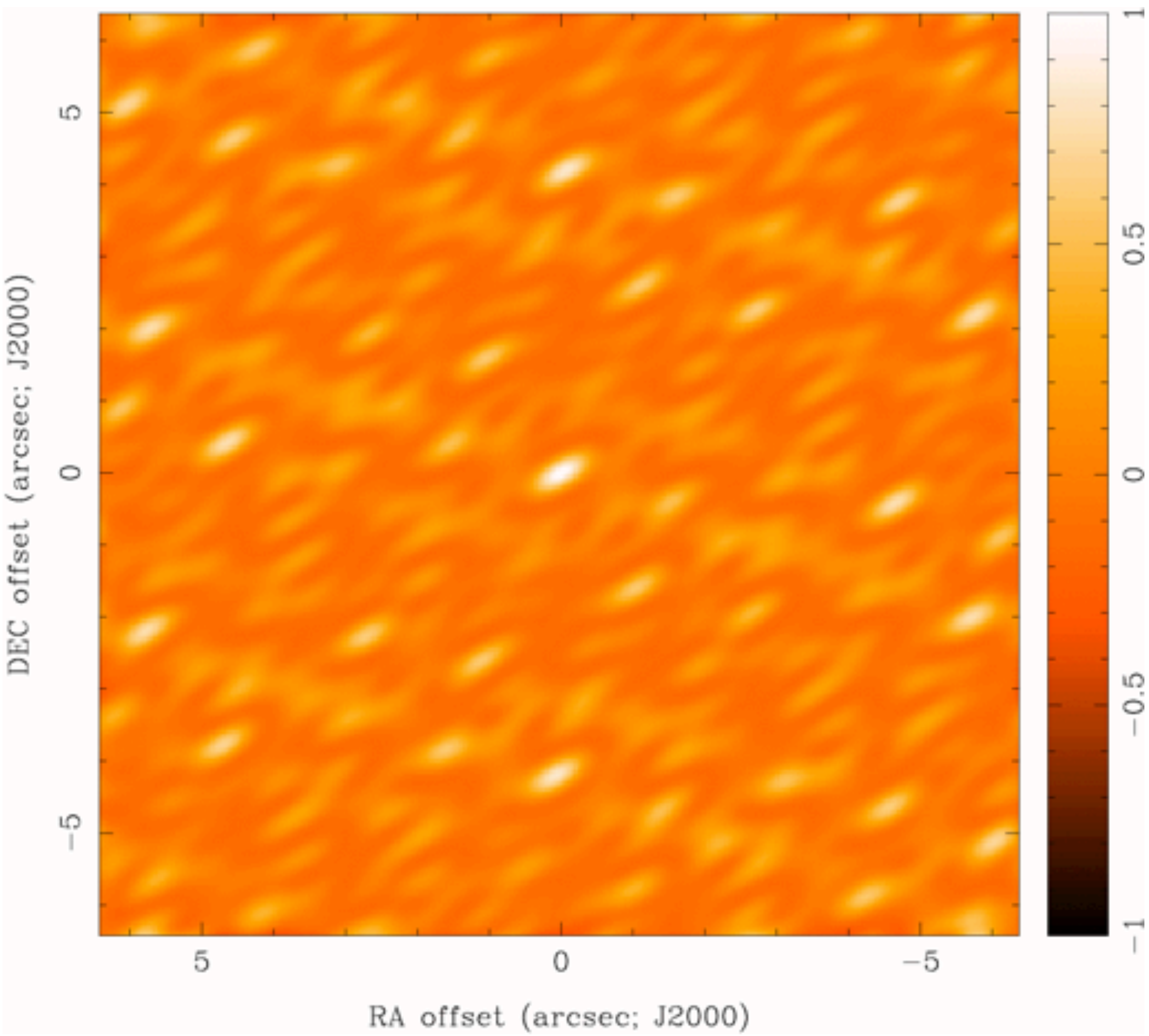


by increasing the number of antennas …

PSF shape vs. N ants

8 antennas

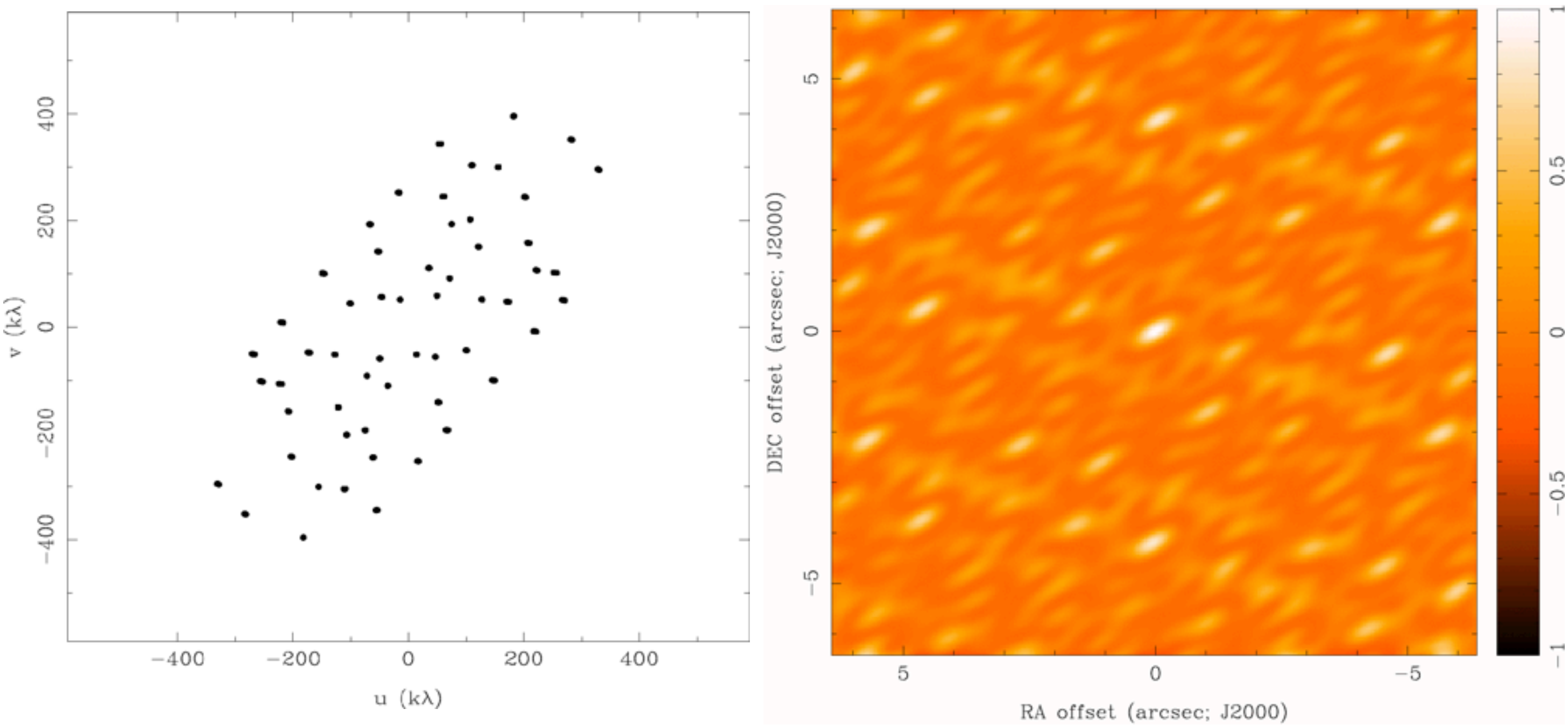




by increasing the number of antennas …

PSF shape vs. N ants

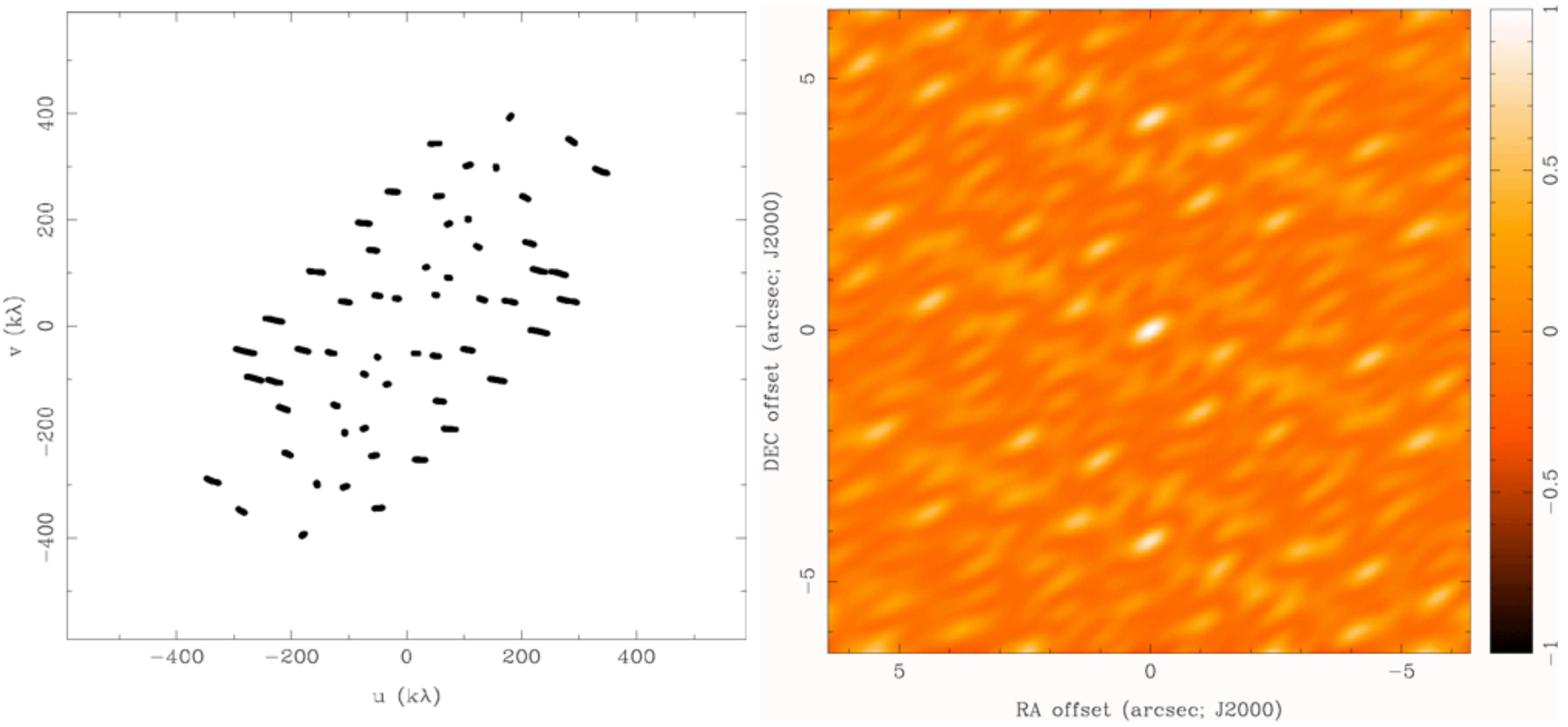
8 antennas x 6 samples



… or by increasing the integration time …

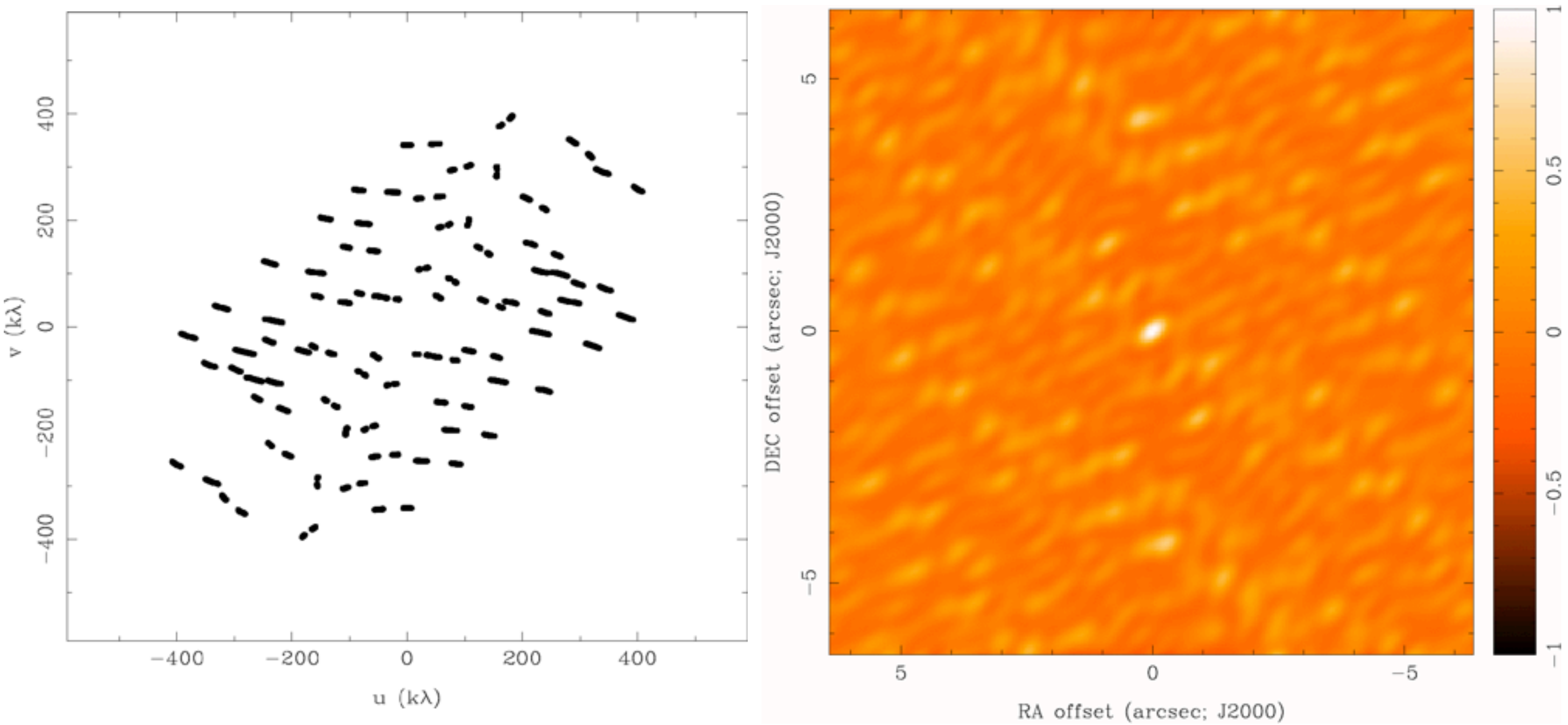
PSF shape vs. N ants

8 antennas x 30 samples



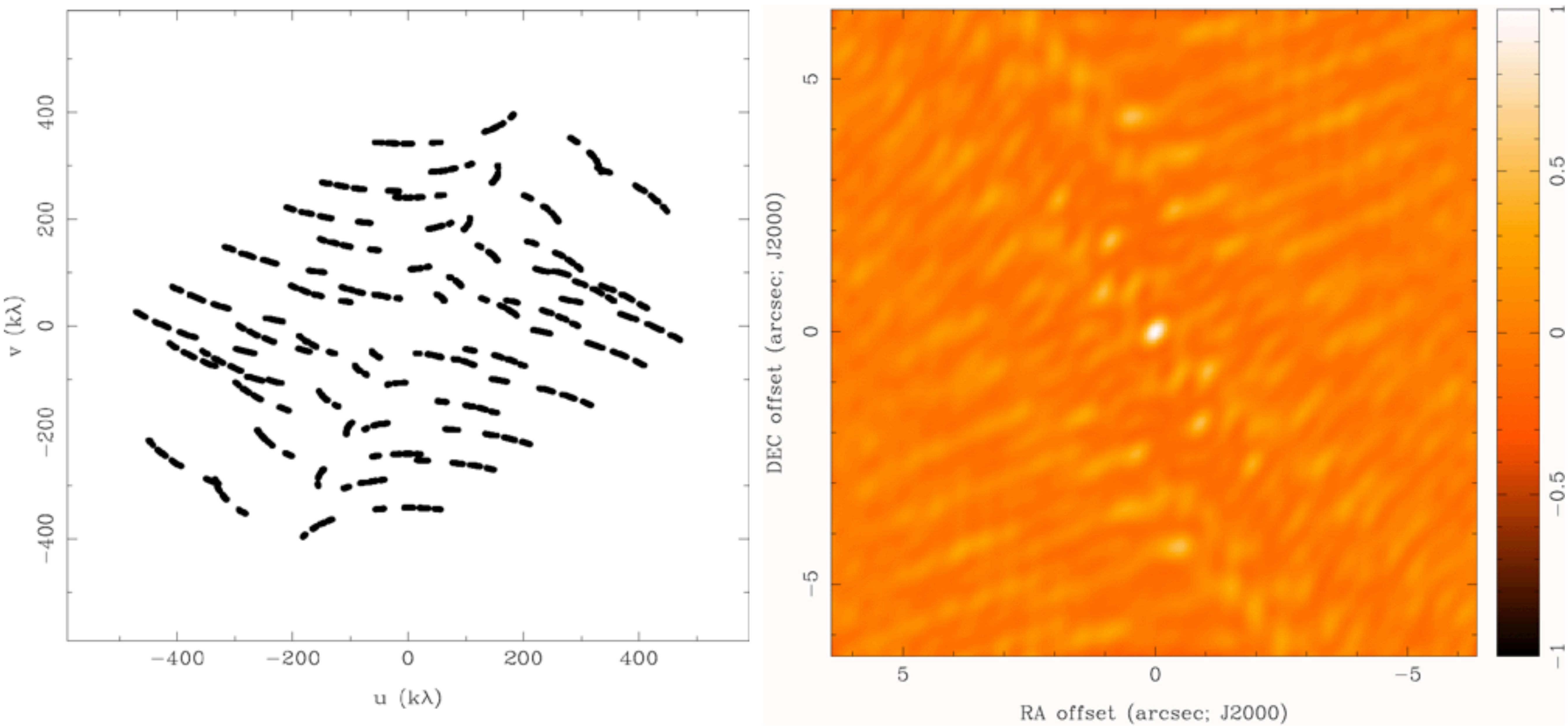
PSF shape vs. N ants

8 antennas x 60 samples



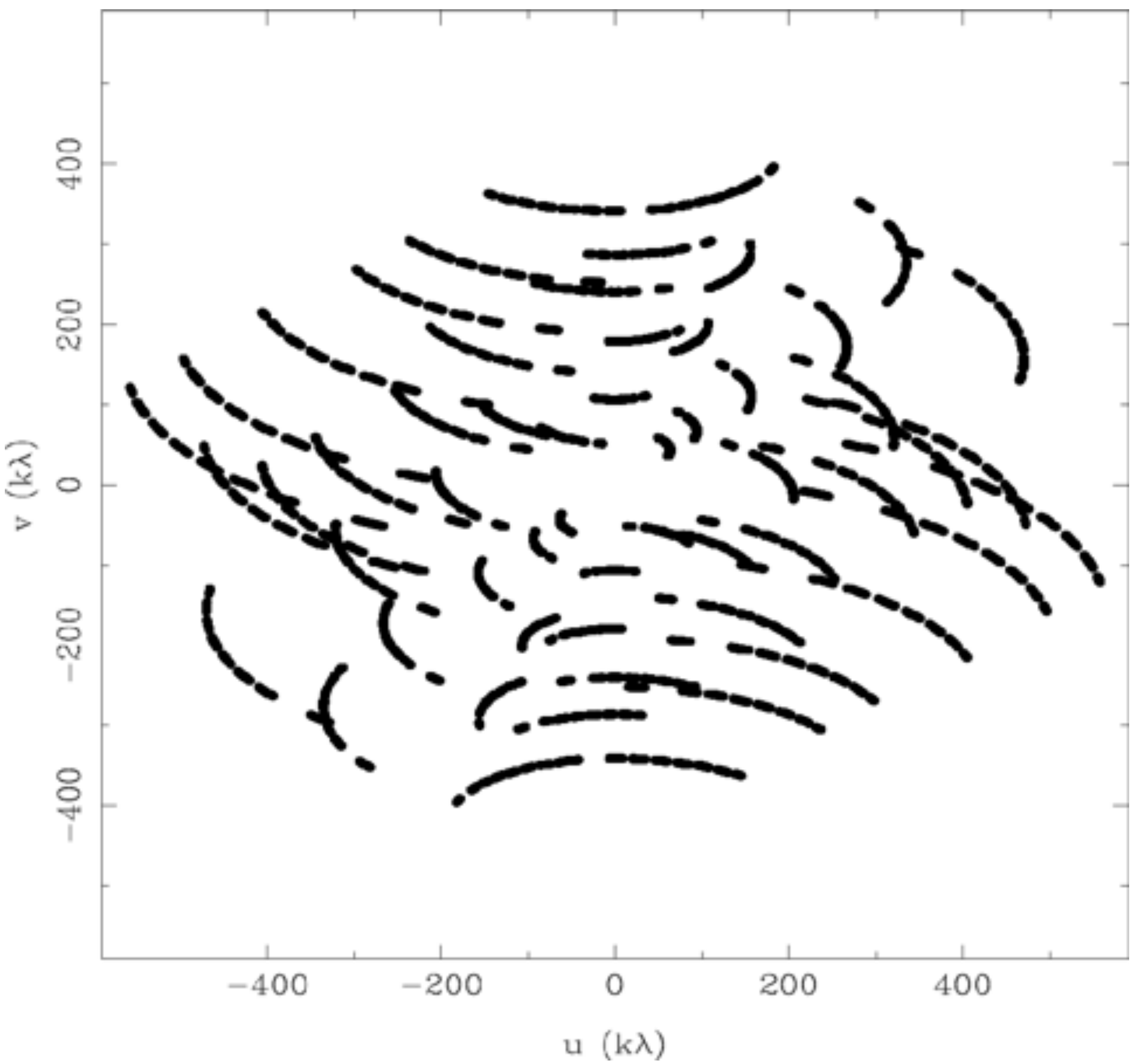
PSF shape vs. N ants

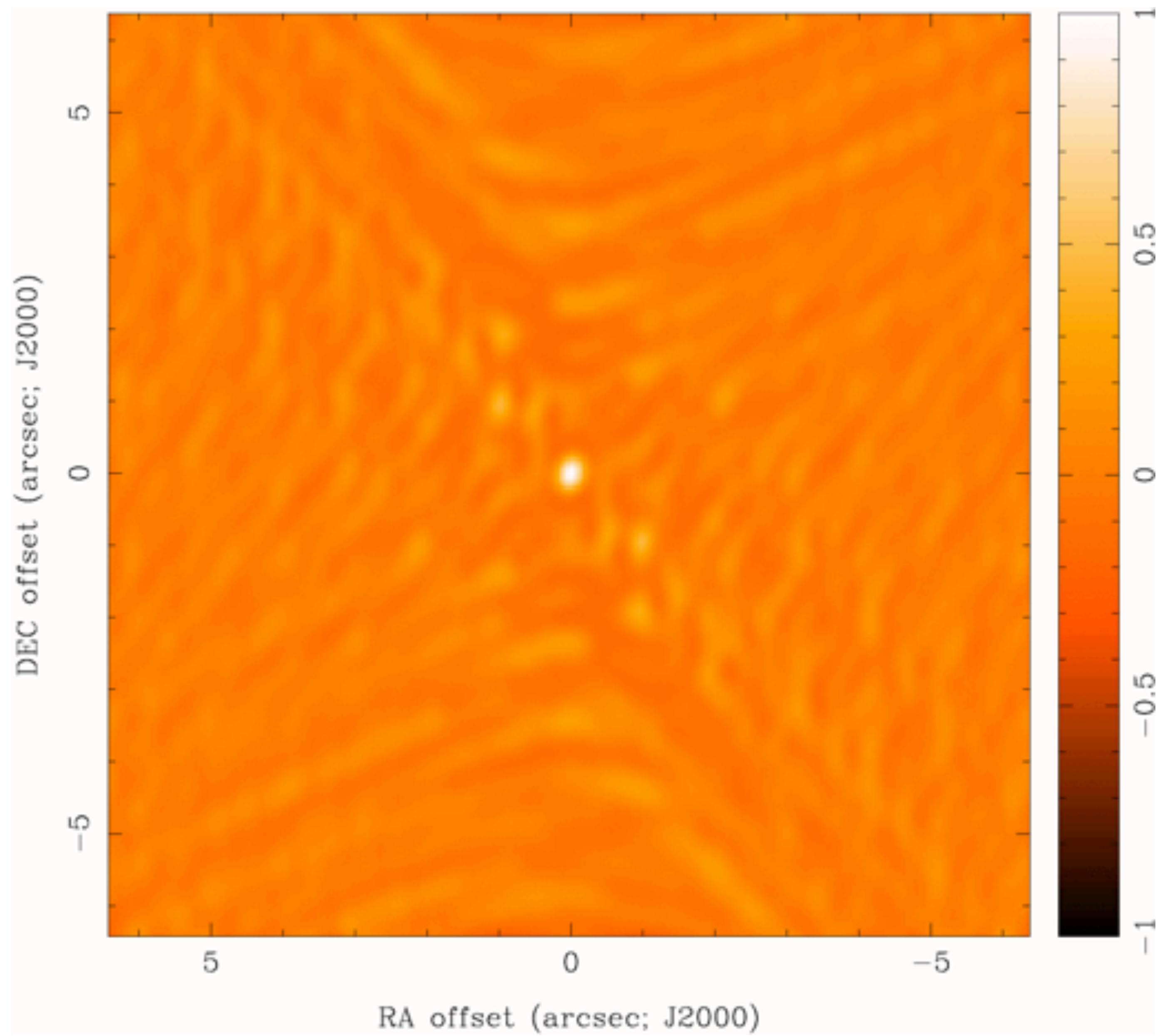
8 antennas x 120 samples



PSF shape vs. N ants

8 antennas x 240 samples





PSF shape vs. N ants

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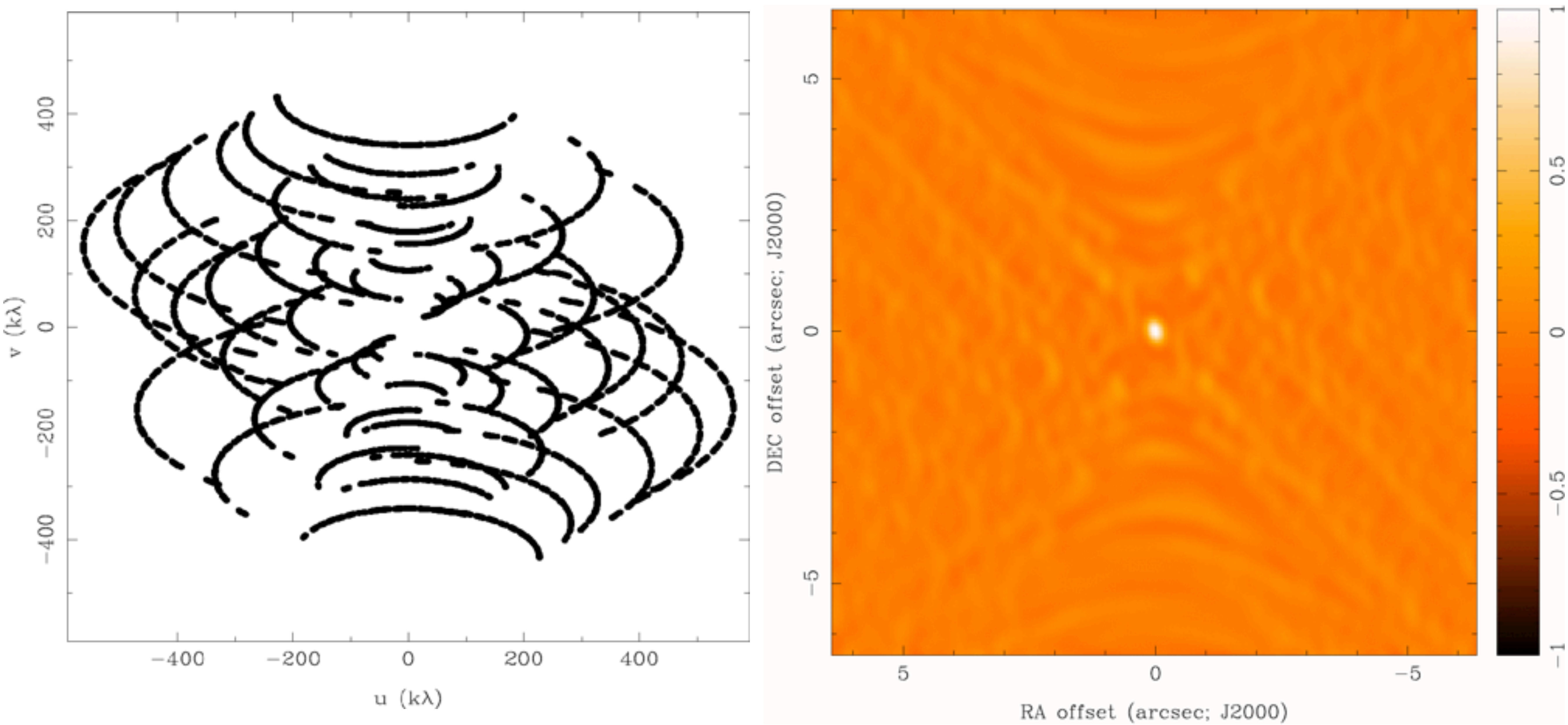
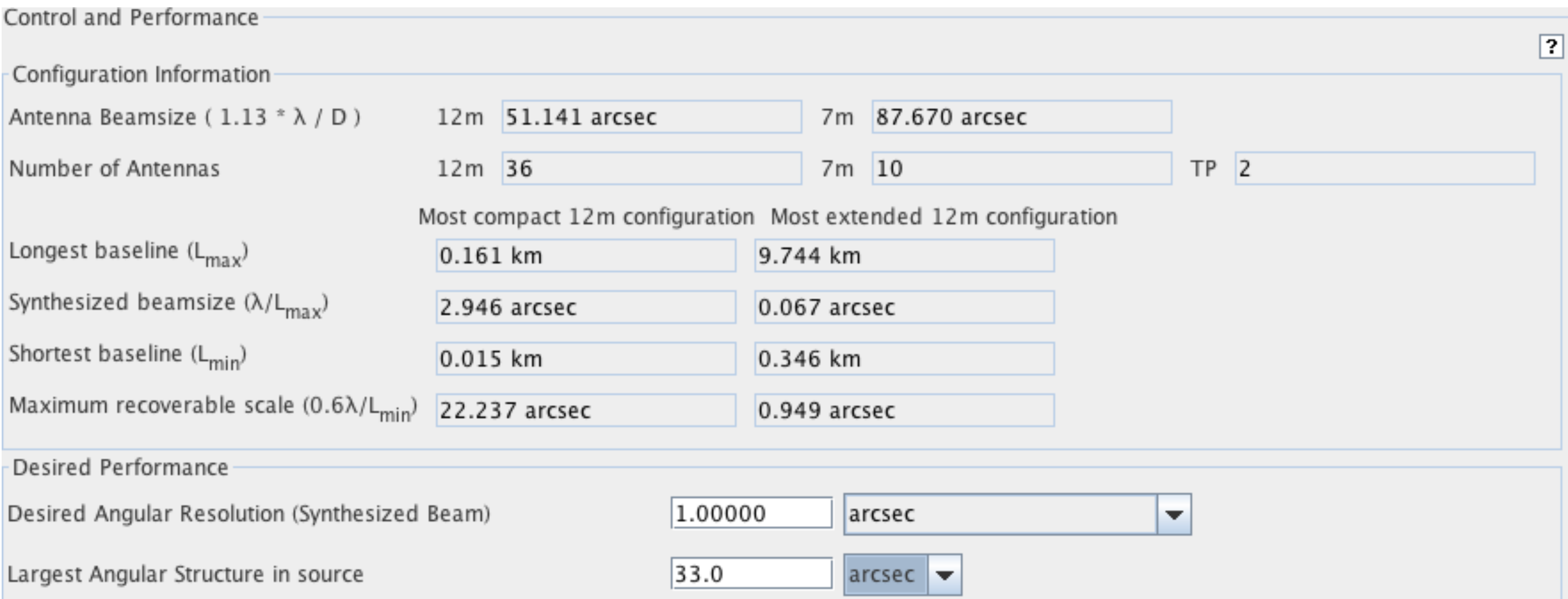


- ALMA has an *"instantaneous"* coverage uv plane…

uv coverage vs. OT input parameters

- FOV
- synth. beamsize… i.e. angular resolution
- largest angular scale



sensitivity vs. OT input parameters

- 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}

uv coverage vs. OT input parameters

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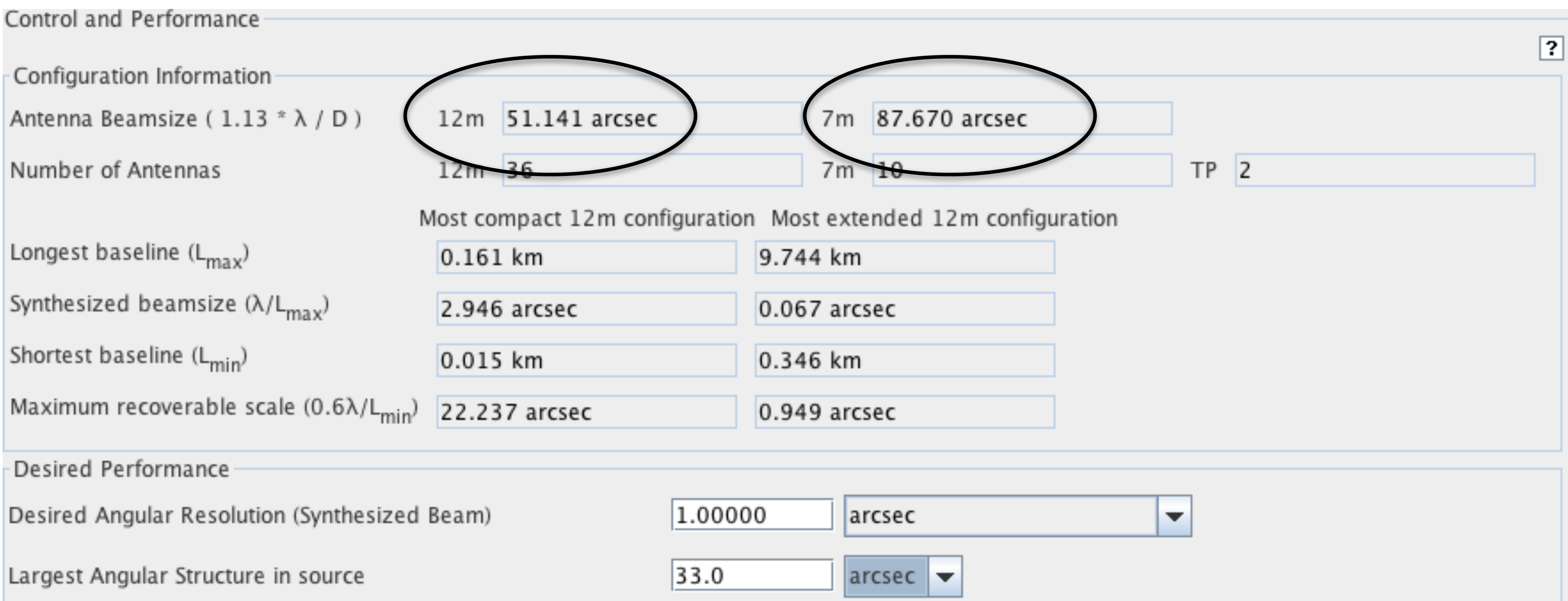
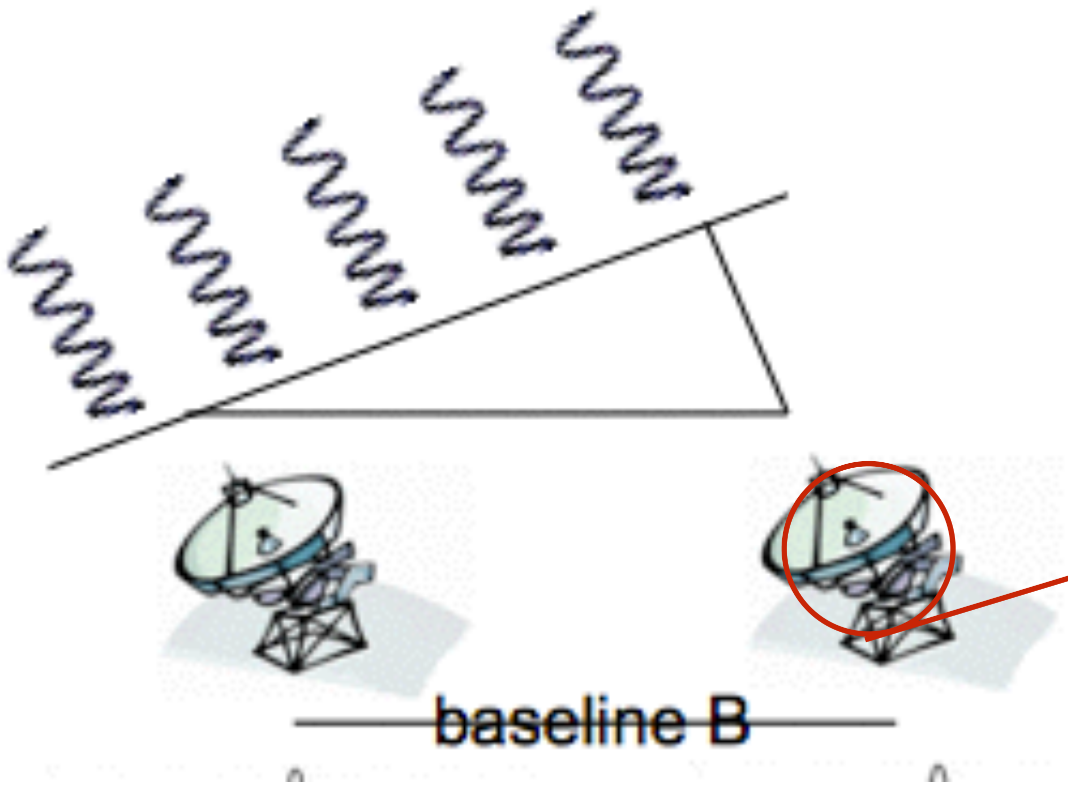


uv coverage vs. OT input parameters

- Field of View: depends on the single dish diameter



$$FOV = 1.13\lambda/D$$

smaller dish —> larger FOV

—> if observing area larger than FOV go for mosaic!!!
—> if the source is inside the FOV doesn't mean it can be observable…

uv coverage vs. OT input parameters

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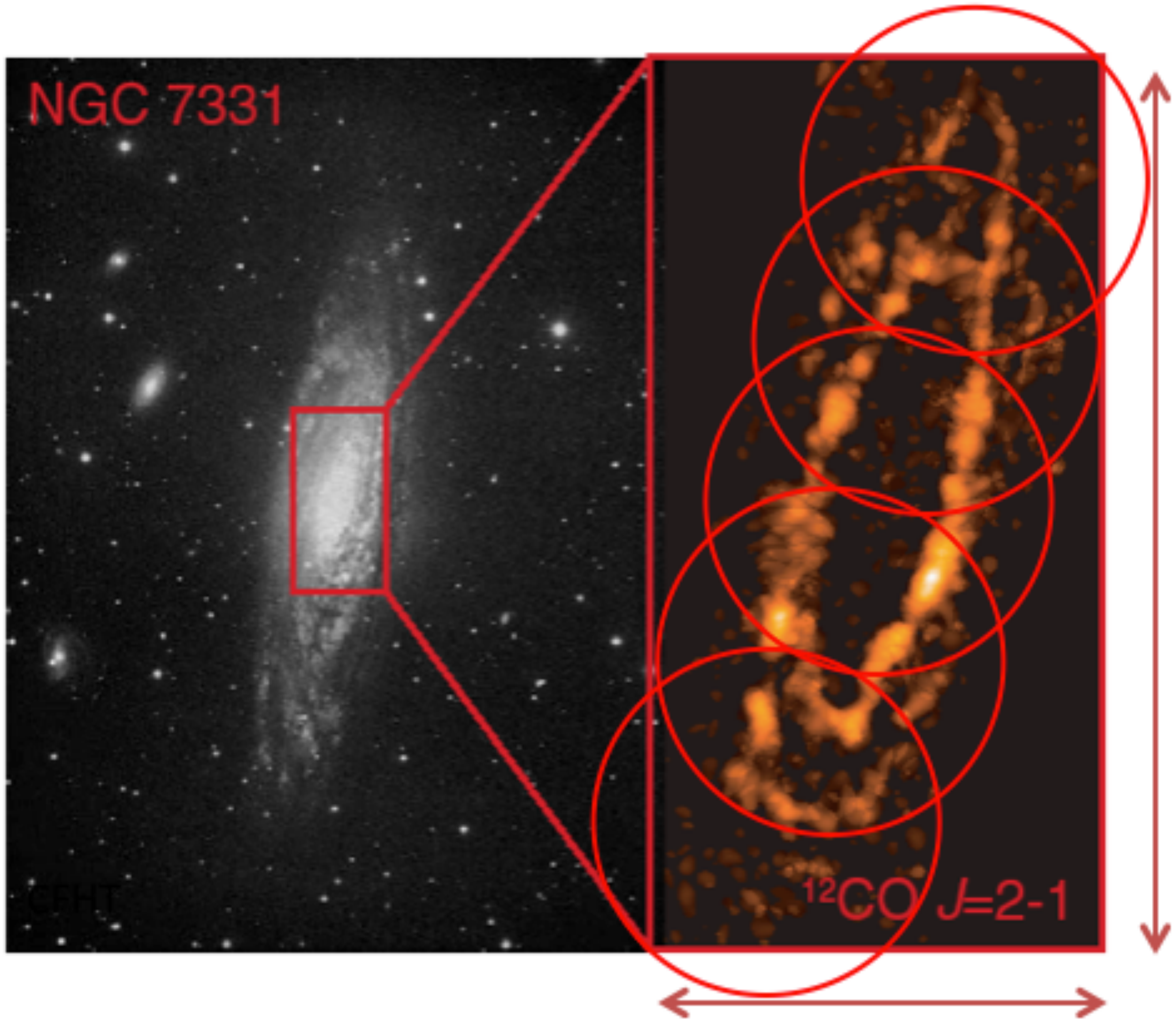

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uv coverage vs. OT input parameters

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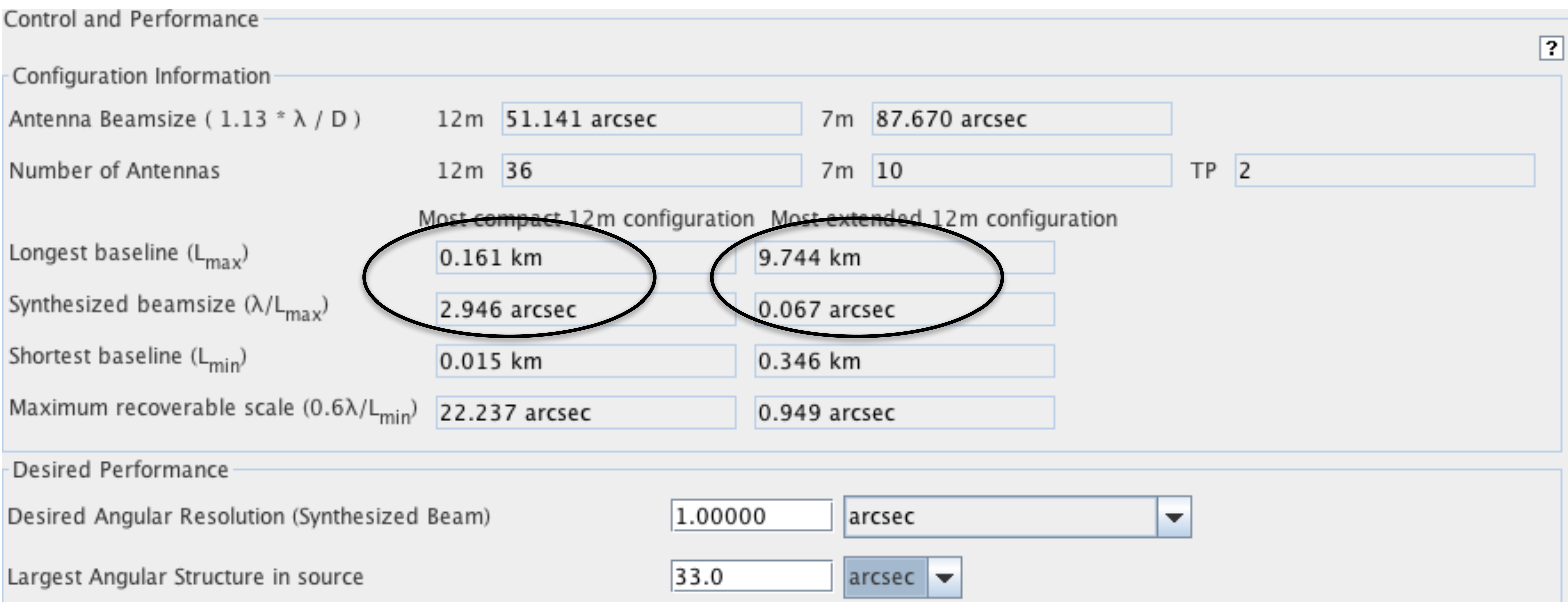
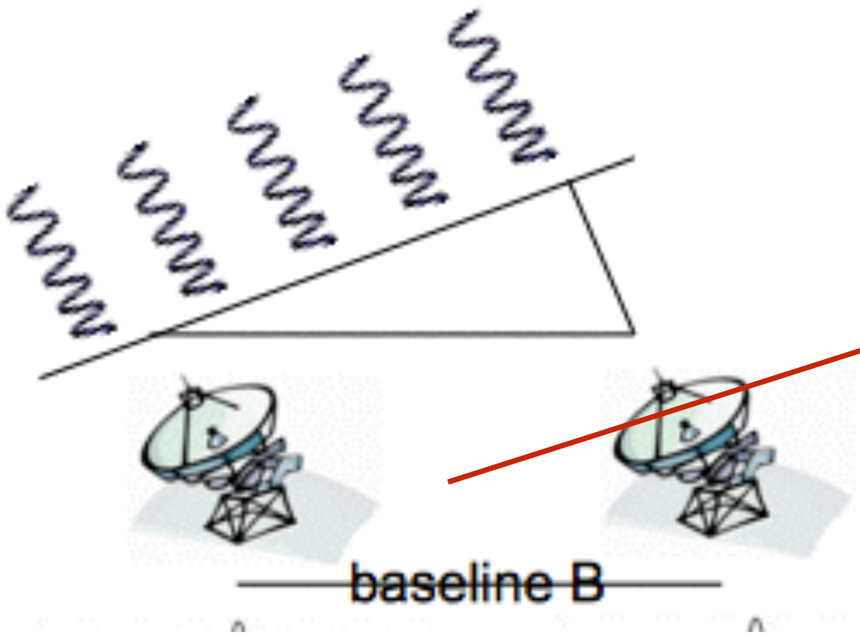
- synthetized. beamsize… i.e. angular resolution
- largest angular scale



uv coverage vs. OT input parameters

- 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



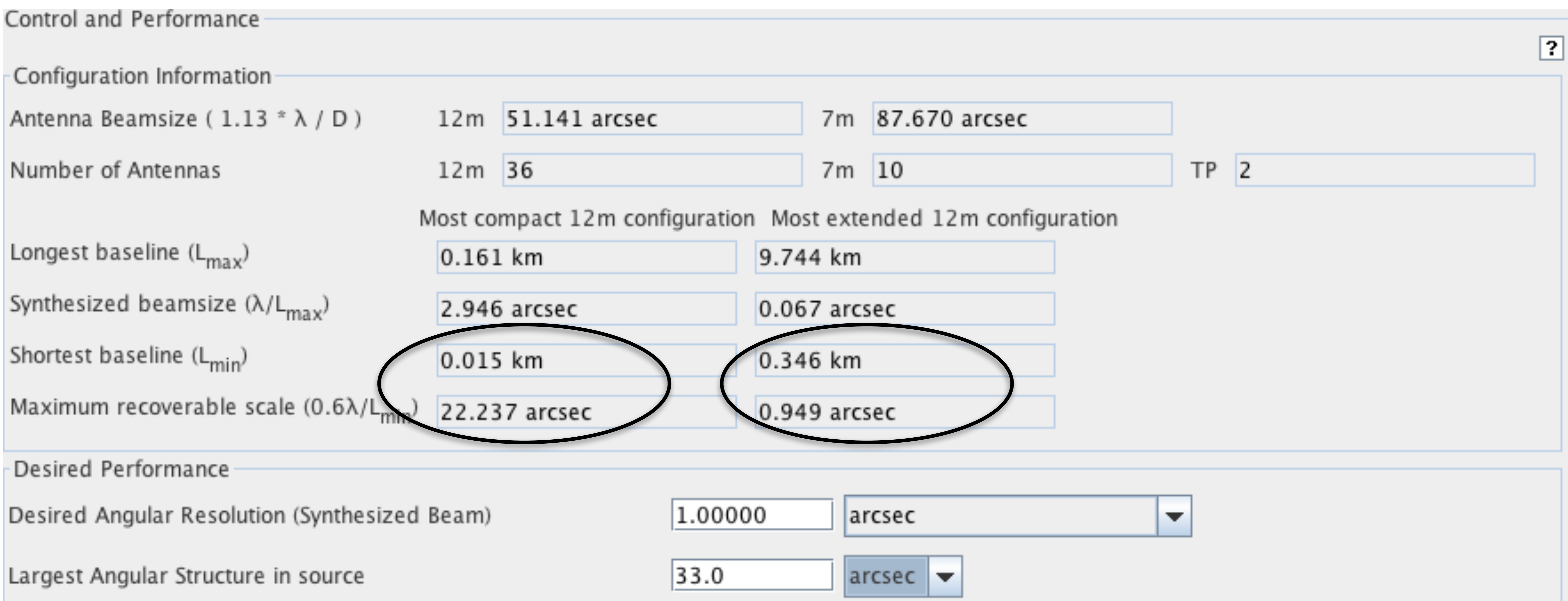
$$\theta_{max} = k\lambda/D_{max}$$

k~1", weighting of visibilities

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

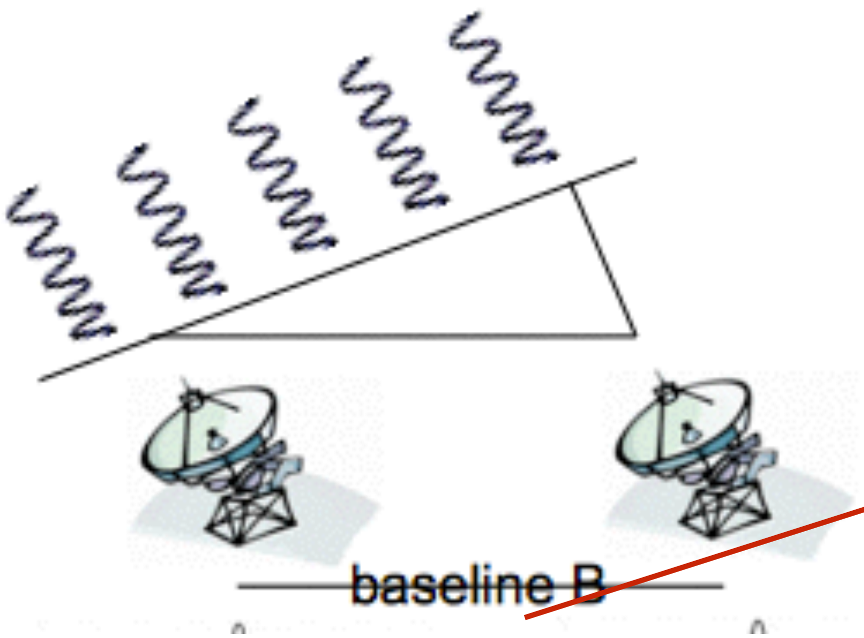
uv coverage vs. OT input parameters

- FOV
- synth. beamsize… i.e. angular resolution
- largest angular scale



uv coverage vs. OT input parameters

- Largest scale: depends on minimum distance between antennas

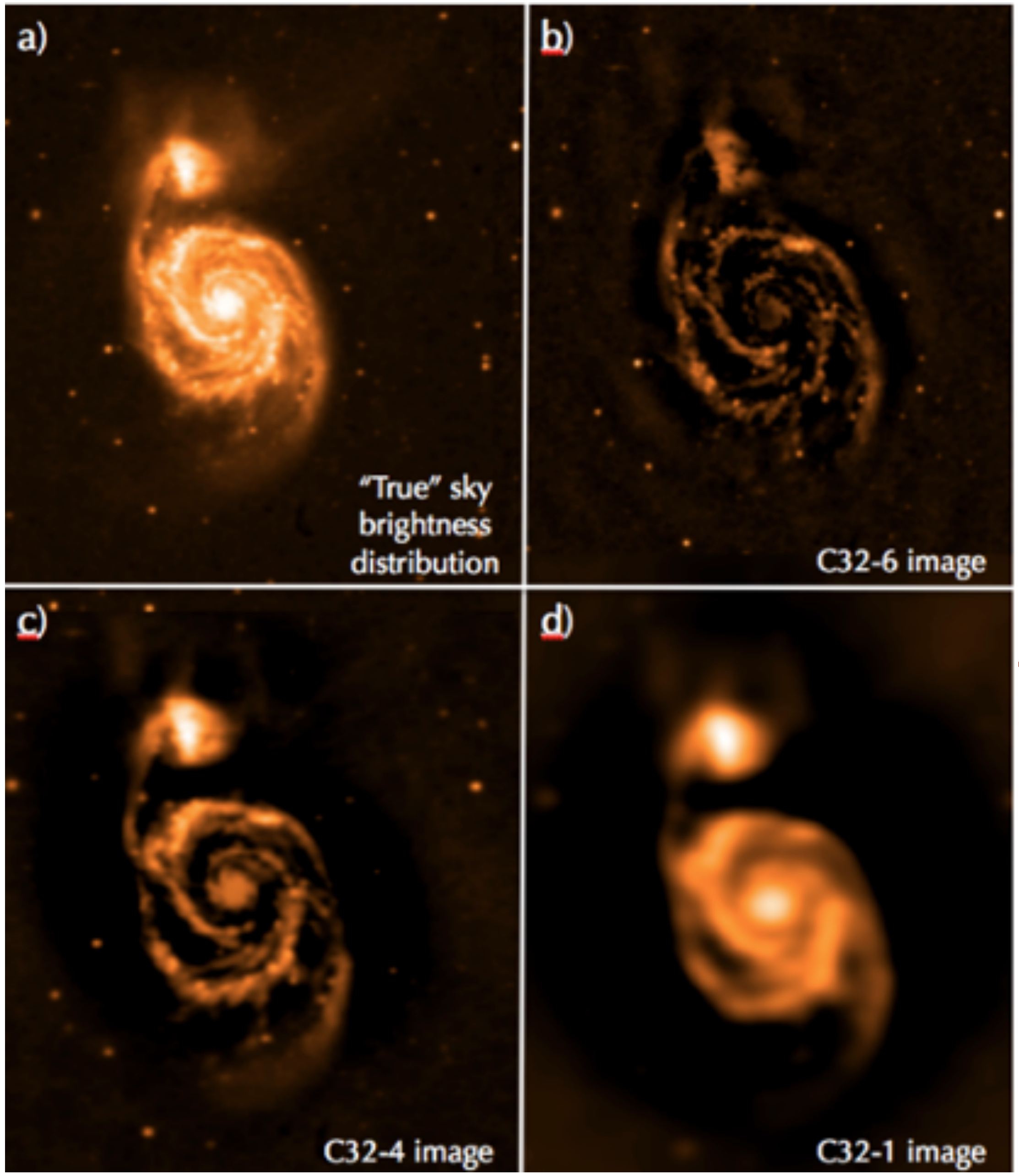


$$LAS = \lambda/D_{min}$$

- more compact —> sensitive to extended sources

uv coverage vs. OT input parameters

- Largest scale: depends on minimum distance between antennas



$$LAS = \lambda / D_{min}$$

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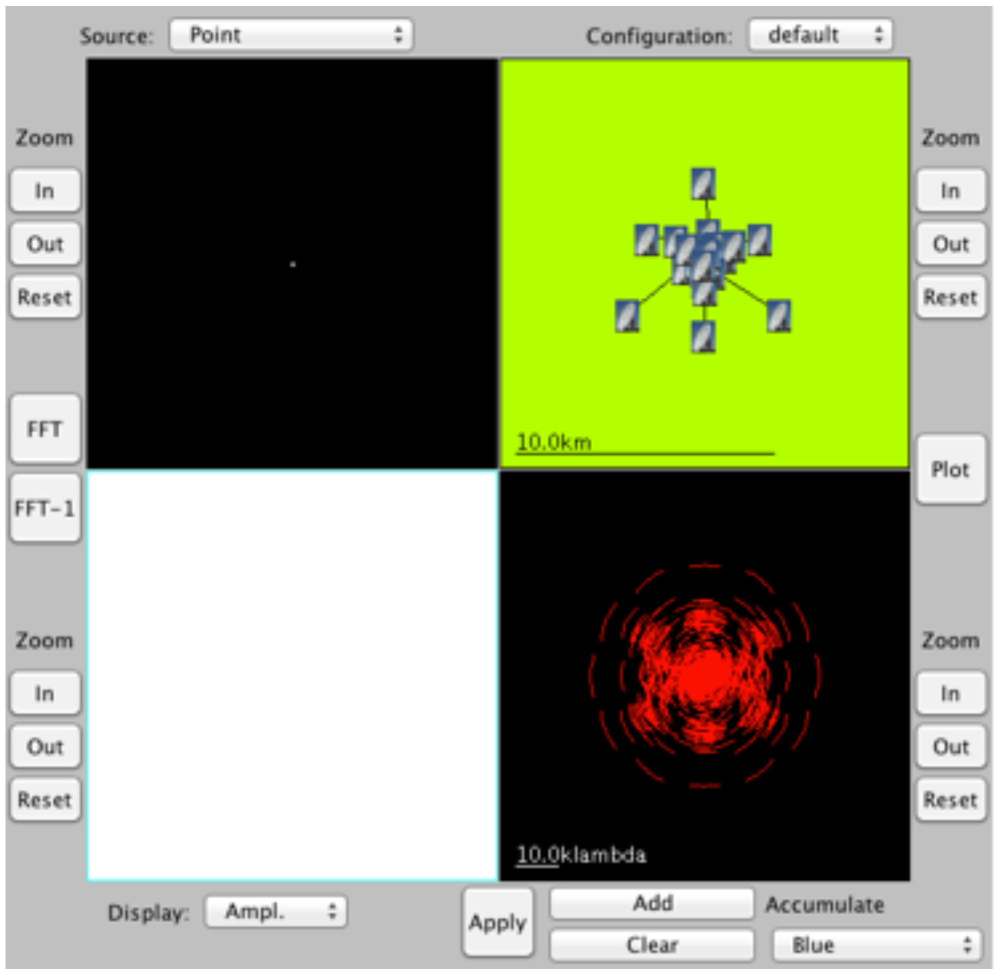
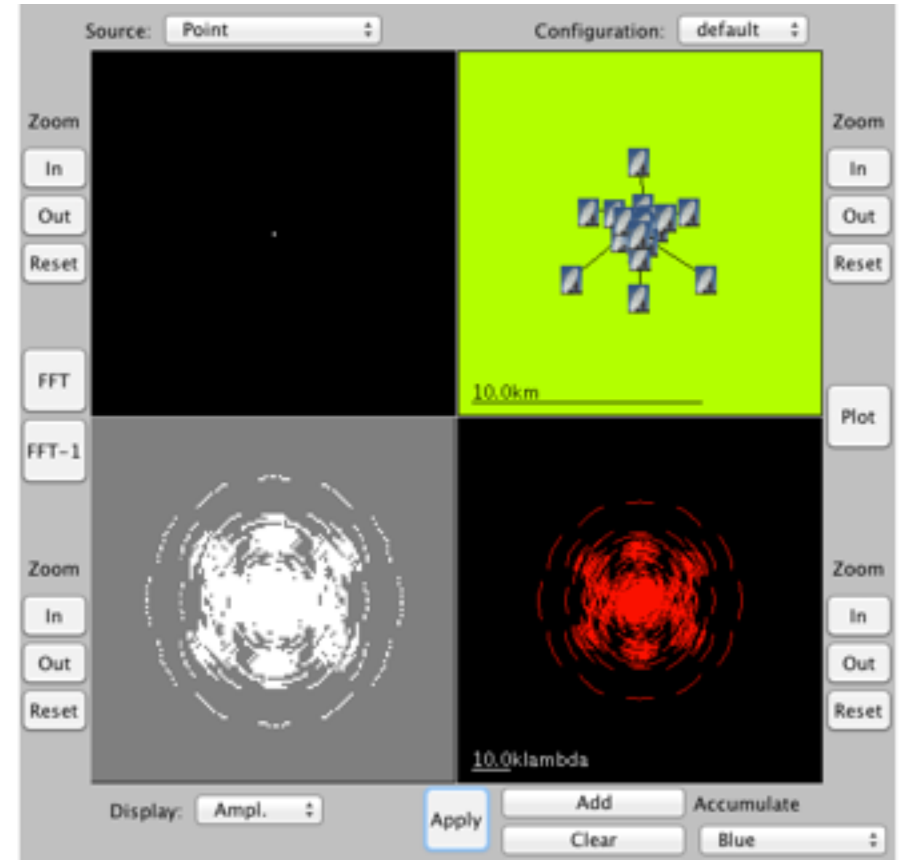
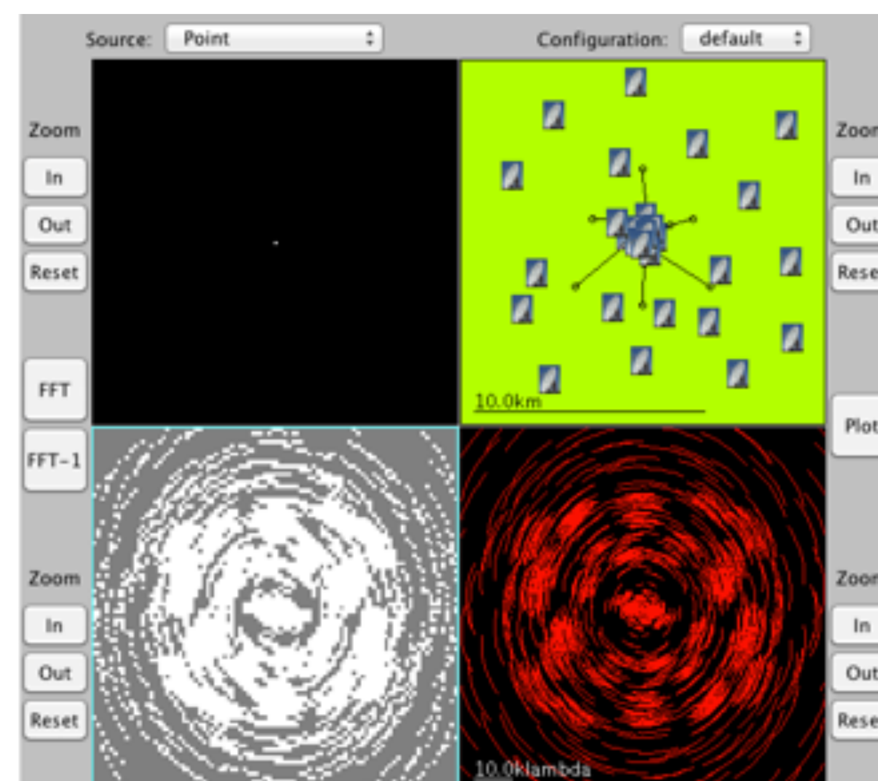
uv coverage vs. OT input parameters

point source (delta Dirac) —> compact source





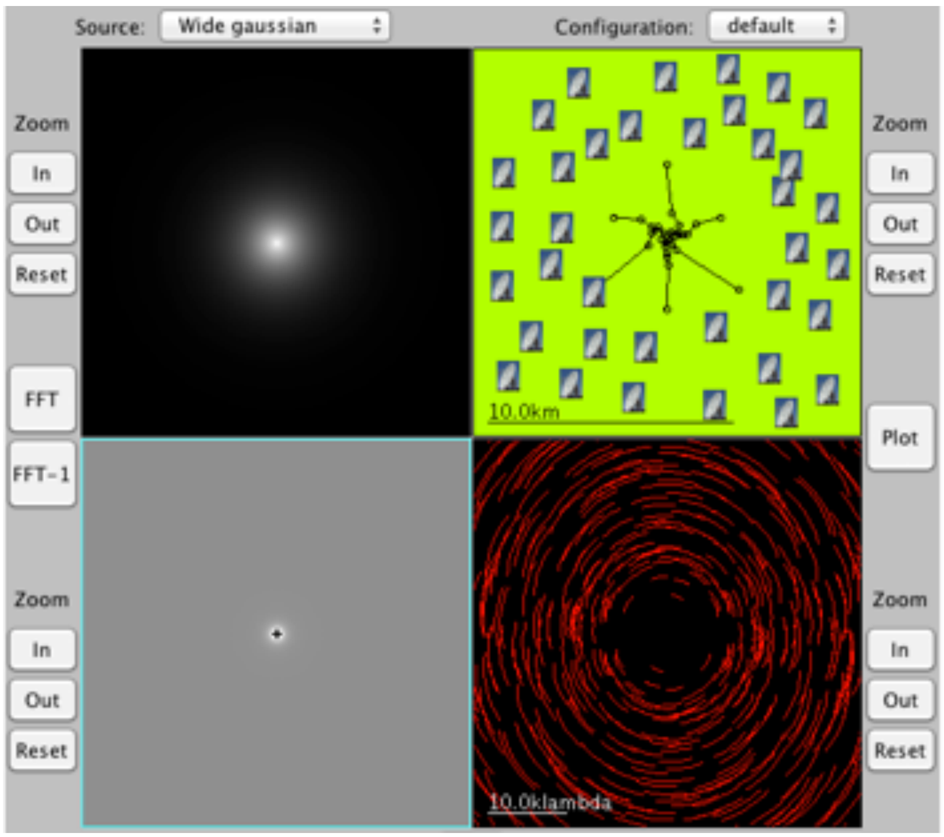


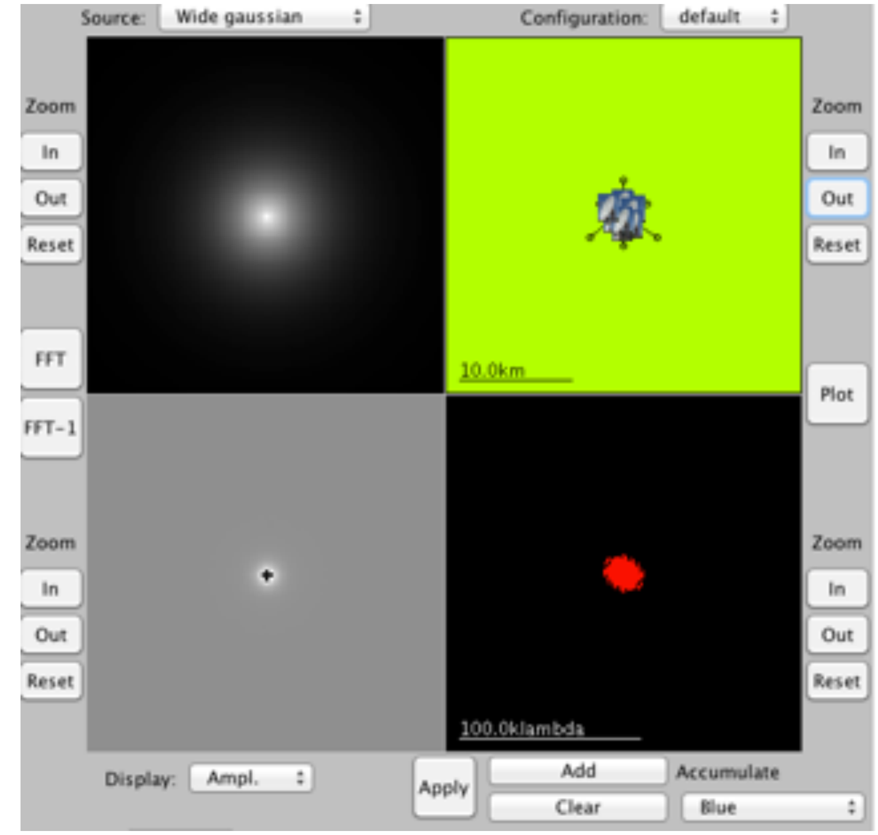
http://www.narrabri.atnf.csiro.au/astronomy/vri.html

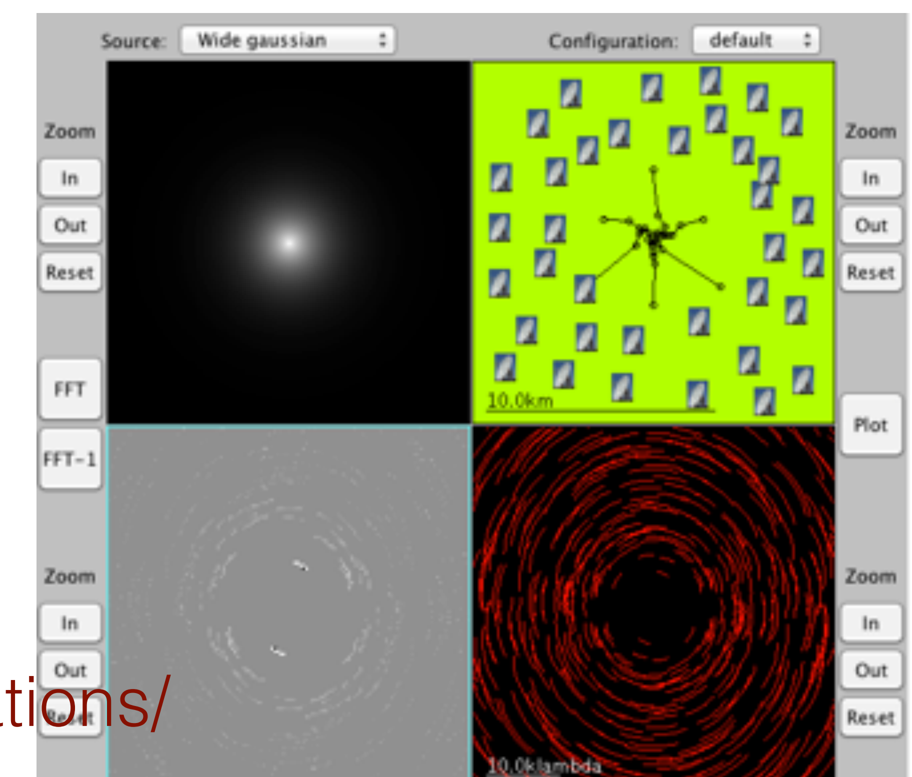
AOT: changing config, sensitivity stays constant!!!

uv coverage vs. OT input parameters

"wide" gaussian source —>extended object



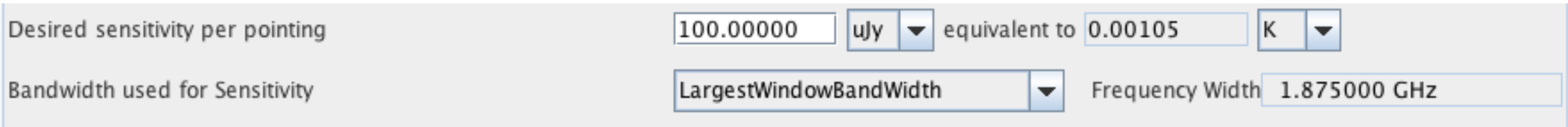




http://www.narrabri.atnf.csiro.au/astronomy/vri.html

if source size > LAS: need to use different configurations/ different arrays…

sensitivity vs. OT input parameters



- 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

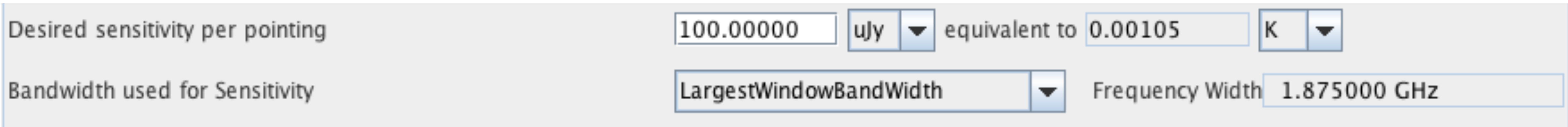
source, atmosphere, instrumental noise….

$$\Delta S_\nu = 2\,k\,\frac{T_{\rm sys}}{A_e\sqrt{2t\,\Delta\nu}}$$

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**

sensitivity vs. OT input parameters



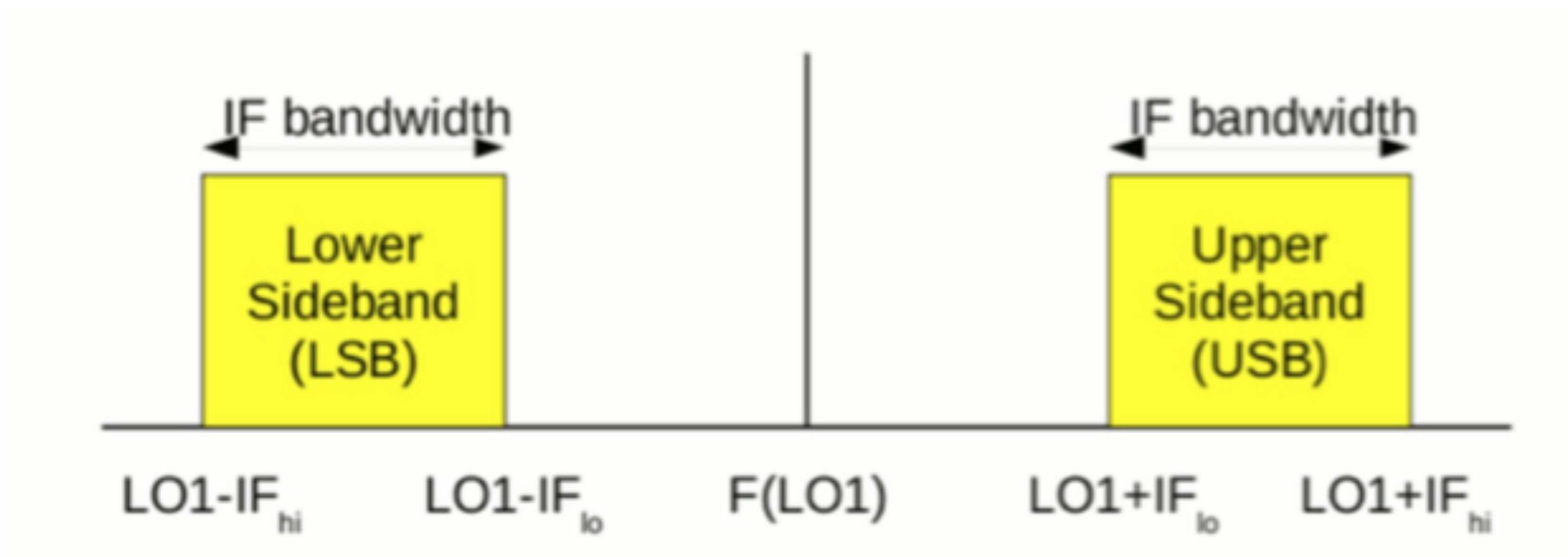
- Sensitivity:

$$\Delta S_\nu = 2\,k\,\frac{T_{\rm sys}}{A_{\rm e}\sqrt{2t\,\Delta\nu}}$$

- $\Delta\nu$ is not the channel spacing, BUT the specral resolution
  - channel spacing = channel physical width
  - velocity/frequency resolution = desired spectral resolution (resulting from the channels manipulation)
  - useful formula (from freq to vel): $\Delta v/v_{sky}=\Delta\nu/c$

spectral configuration - the sidebands

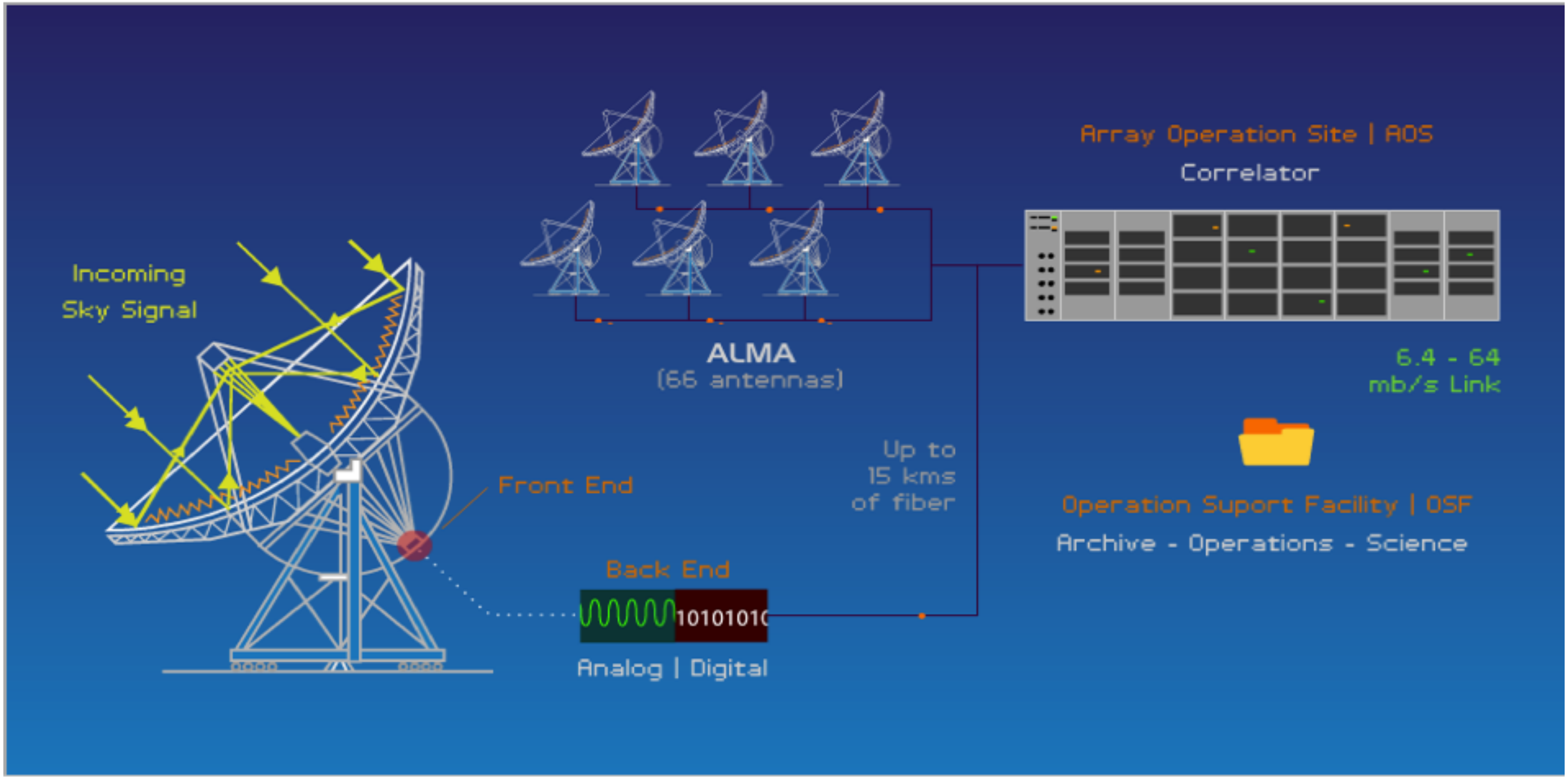
The correlation cannot work @mm sky freq —>
need to be down-converted to lower freq IF (8-12GHz)



Sky signal is combined with a LO(1) signal —> sideband
Within a sideband is possible to “create” different spw, by combining the signal with different LOs

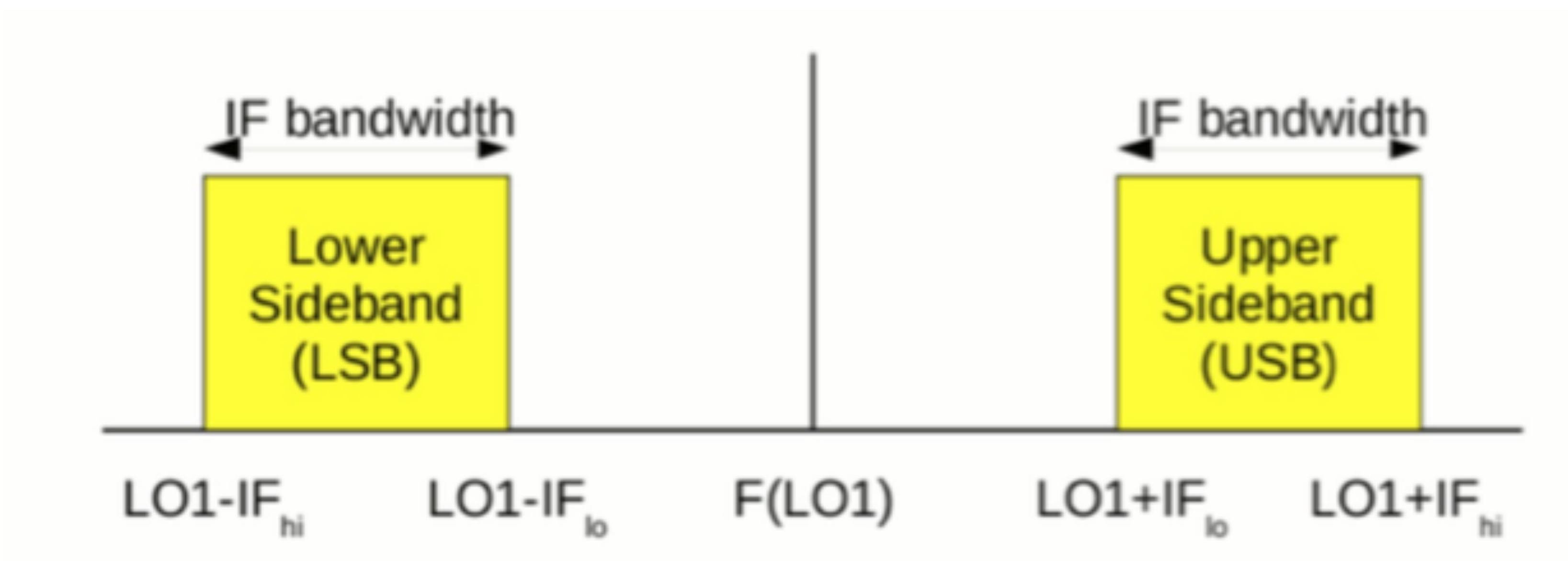
spectral configuration - the sidebands

ALMA data flow



spectral configuration - the sidebands

The correlation cannot work @mm sky freq —>
need to be down-converted to lower freq IF (4-8GHz)



Sky signal is combined with a LO(1) signal —> sideband
Within a sideband is possible to “create” different spw, by combining the signal with different LOs

more scared?