Introduction to the basic concepts and terminology of radio interferometry

EUROPEAN ARC
ALMA Regional Centre || Germany

universitätbonn

Universität zu Köln

ALMA Community Days 2015, 25th March

German ARC node

Part1: Sandra Burkutean

Outline

- Part 1: by S. Burkutean
  - Introduction to aperture synthesis
  - Interferometers: spatial filters
- Part 2: by A. Sanchez-Monge
  - Interferometers: spectral set-up
  - An overview of receivers and correlators
- Part 3: by T. Badescu
  - The sensitivity of an interferometer
  - A typical observing set-up

Where is ALMA ?

Atacama desert

on the Chajnantor Plateau
at 5000 m height

control centre at 2900m

What is ALMA ?

ALMA Cycle 3

36 x 12m antennas

10 x 7m antennas (ALMA Compact Array)

2 x 12m TP antennas

Credit: ALMA (ESO/NAOJ/NRAO), O. Dessibourg

Credit: ALMA (ESO/NAOJ/NRAO)

ALMA completed

50 x 12m antennas

↓

placed apart by up to 16 km

12 x 7m antennas (ACA)

↓

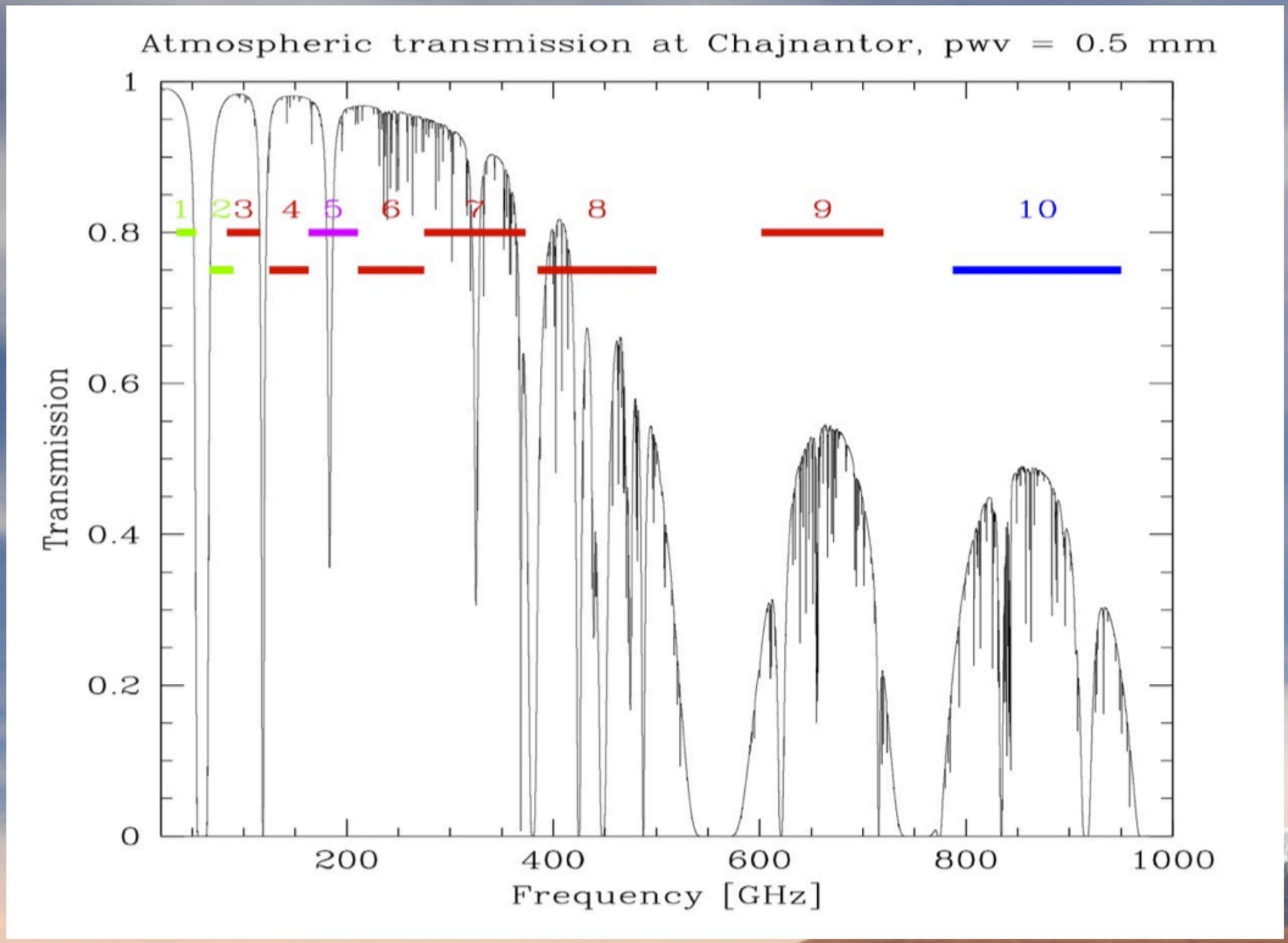
allows to see the ‘big picture’

4 x 12m TP antennas

↓

info on absolute brightness

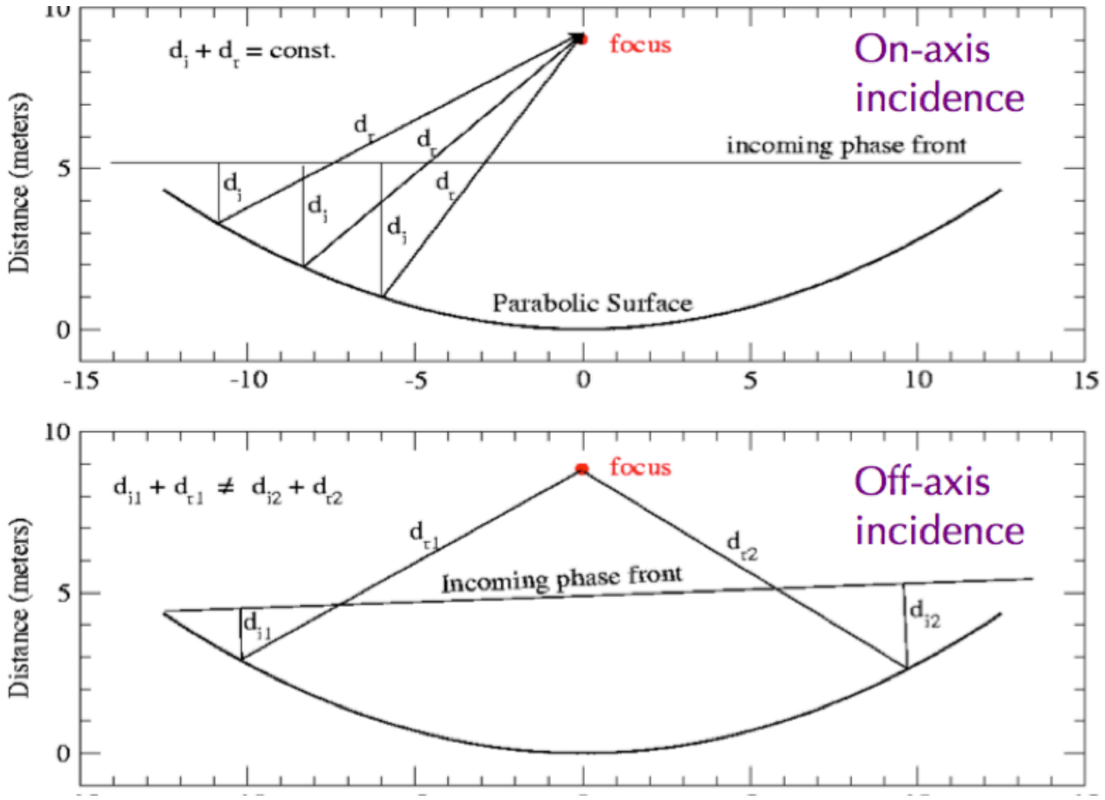
Why is ALMA on the Chajnantor plateau?



credit: ALMA Technical Handbook

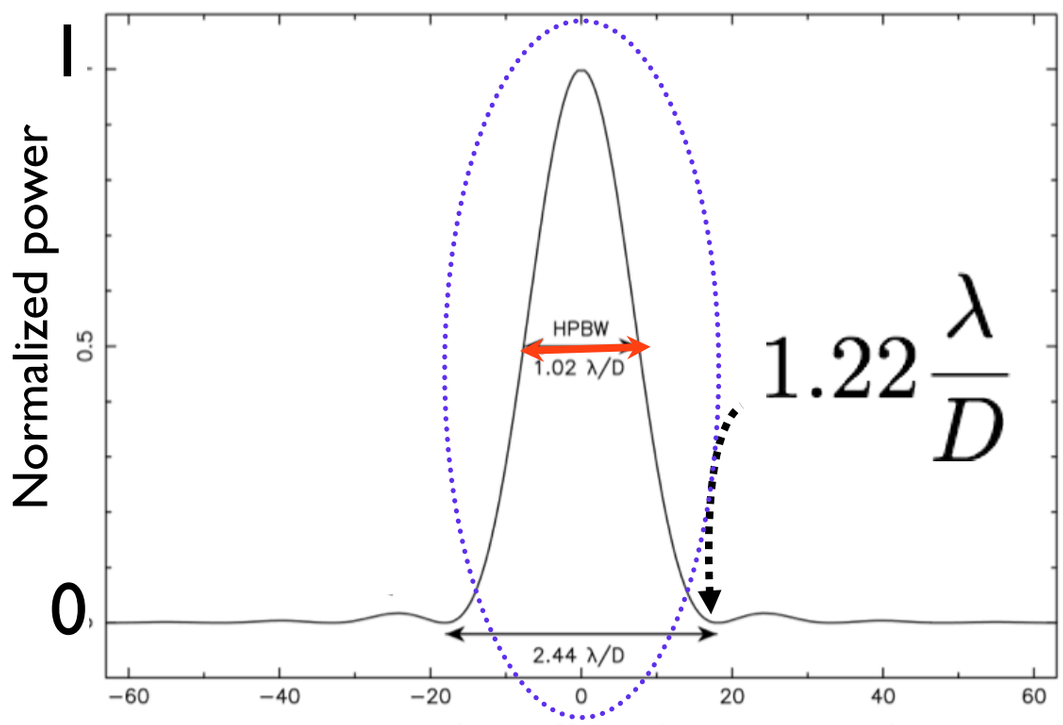
Single-dish Response

Schematic illustration



-10 antenna radius (m) +10

1D antenna power response



Credit: ALMA (ESO/NAOJ/NRAO)

credit[beam patterns, power response]: ALMA Technical Handbook

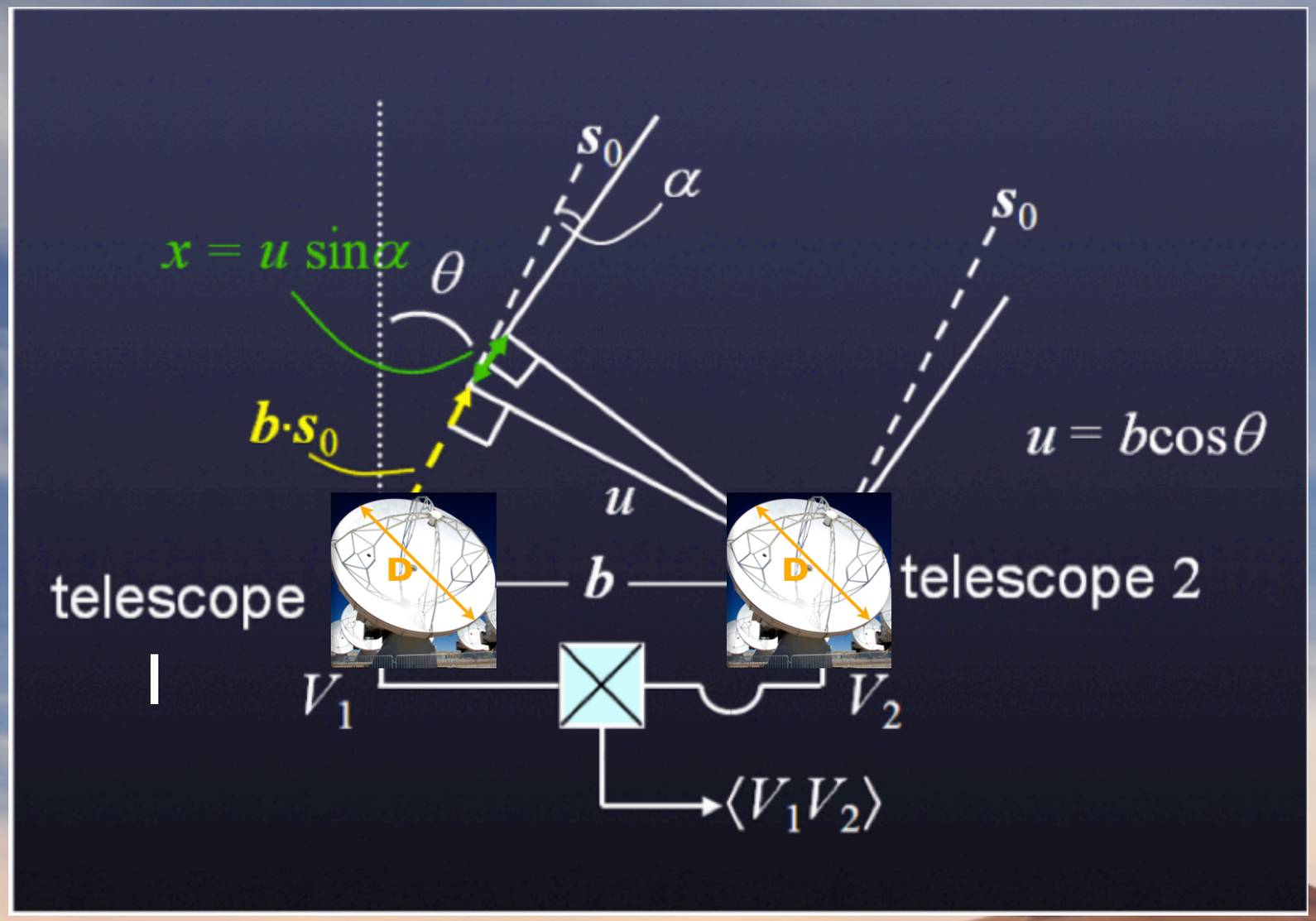
Rayleigh resolution :

$$1.22\frac{\lambda}{D}$$

primary beam half power beam width:

$$1.02\frac{\lambda}{D}$$

Aperture synthesis: baseline and projected antenna distance



credit: ALMA Technical Handbook

minimum baseline, L_min

maximum baseline L_max

$$\text{Interferometer Resolution} = \theta_{res} = k\,\lambda/L_{max},$$

$$\text{Maximum Recoverable Scale} = \theta_{MRS} \approx 0.6\lambda/L_{min},$$

k depends on the weighting

Take home message

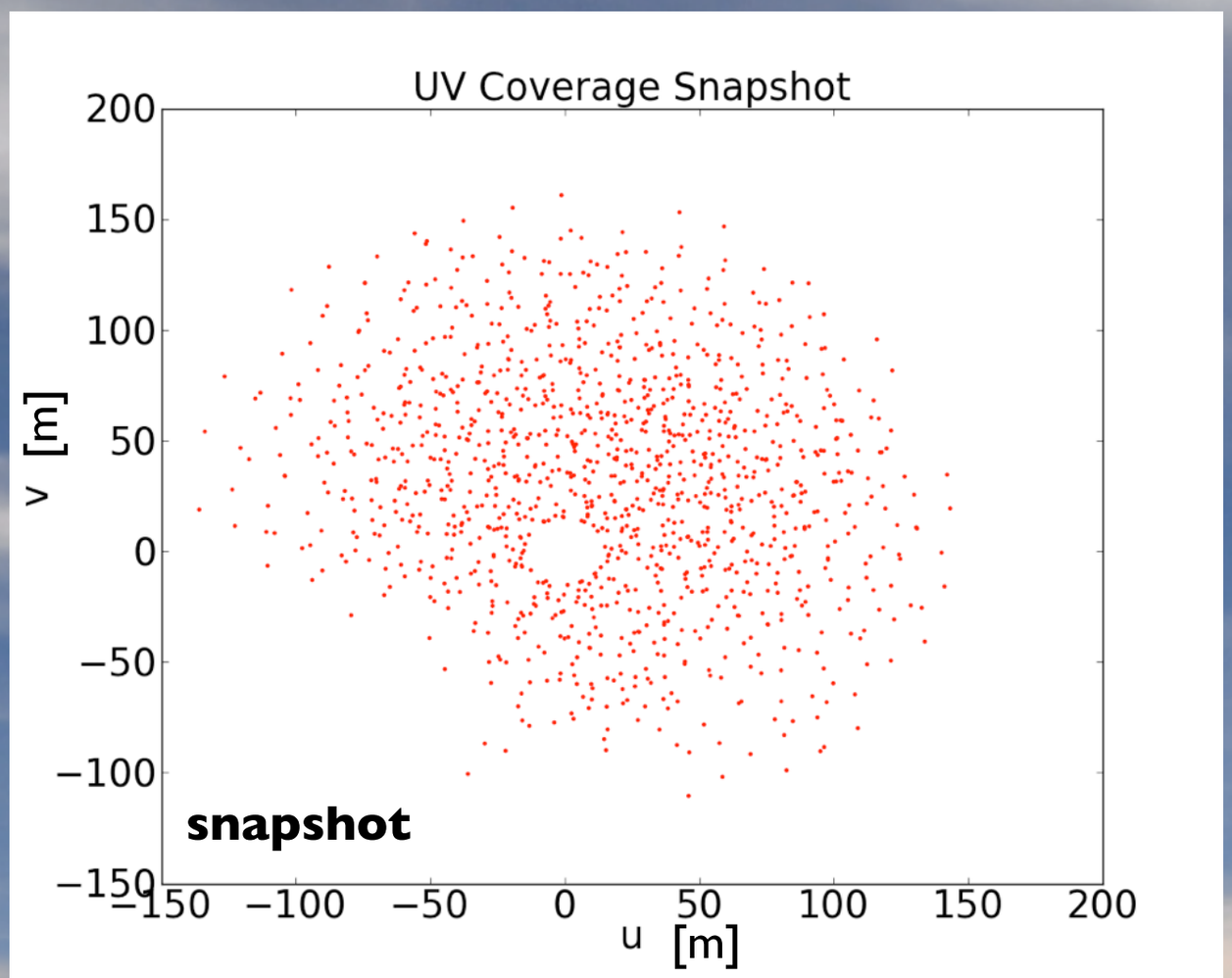
- The complex visibility is the Fourier transform of the sky brightness distribution in the image plane

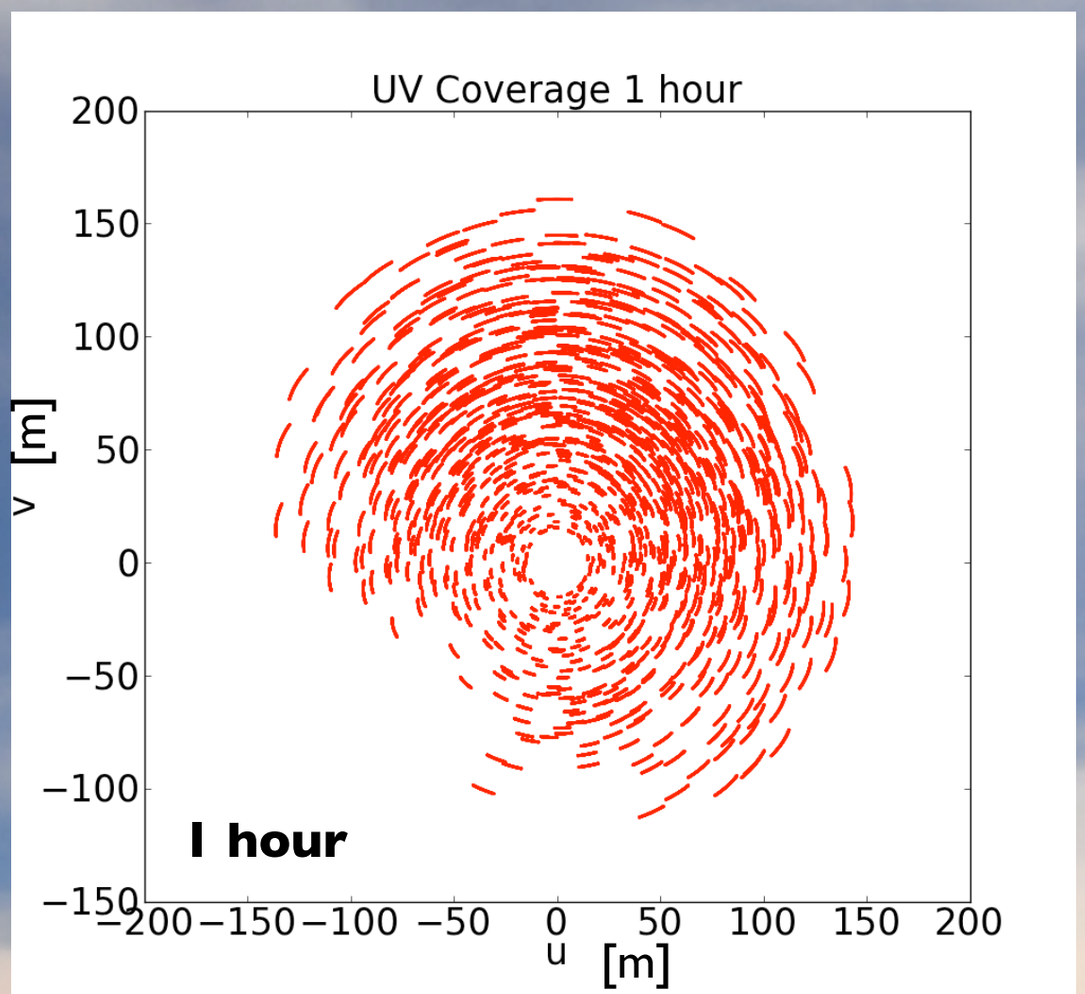
- The interferometer is a spatial sampler: we don't have full uv-coverage (there are holes in the uv-plane and thus missing information). In particular, we miss information on large angular scales.

- The dirty beam is the Fourier Transform of the uv-plane sampling distribution. (other names: synthesized beam, point spread function)

Let’s put this into practice

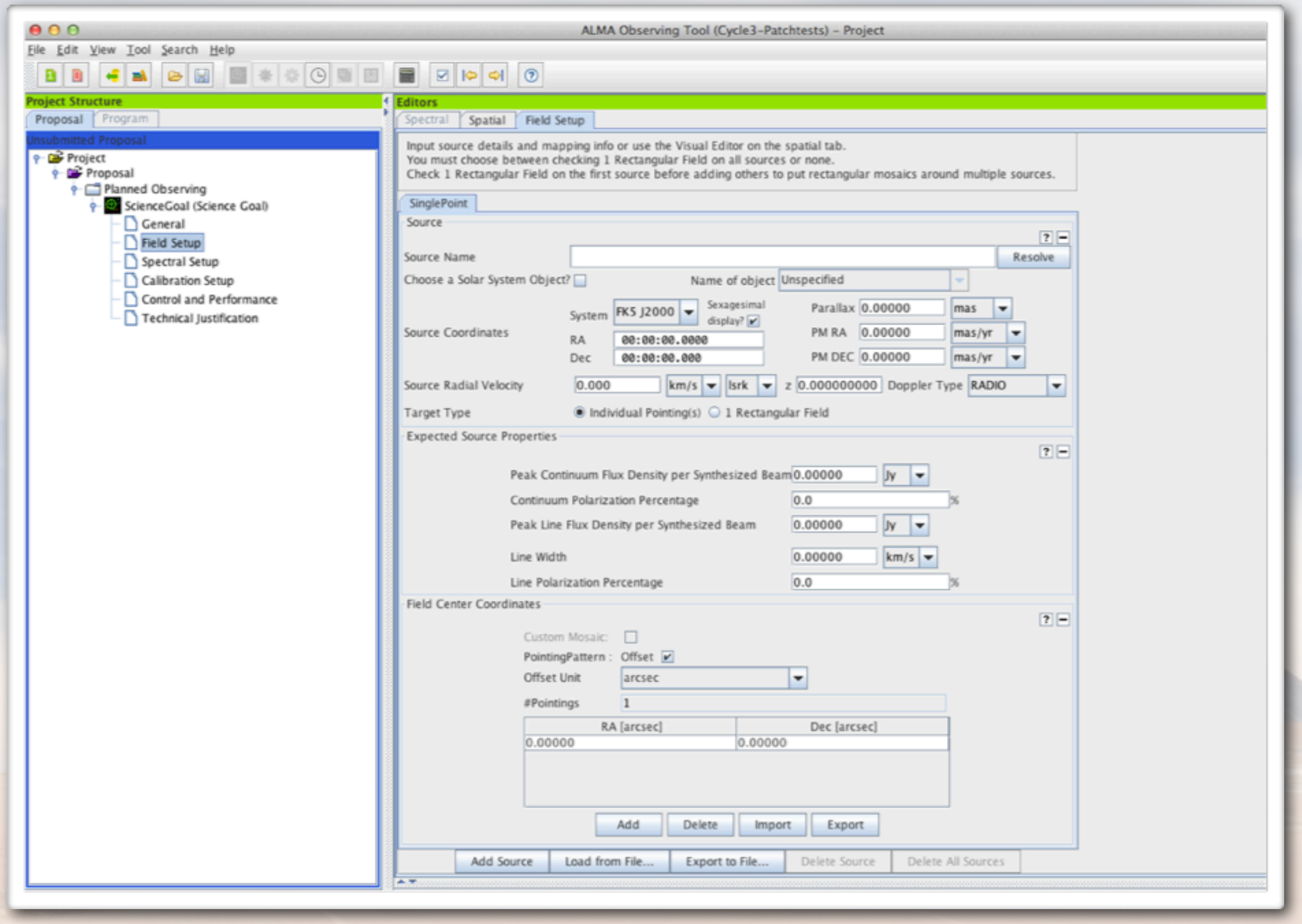
Let's put this into practice: ALMA full array





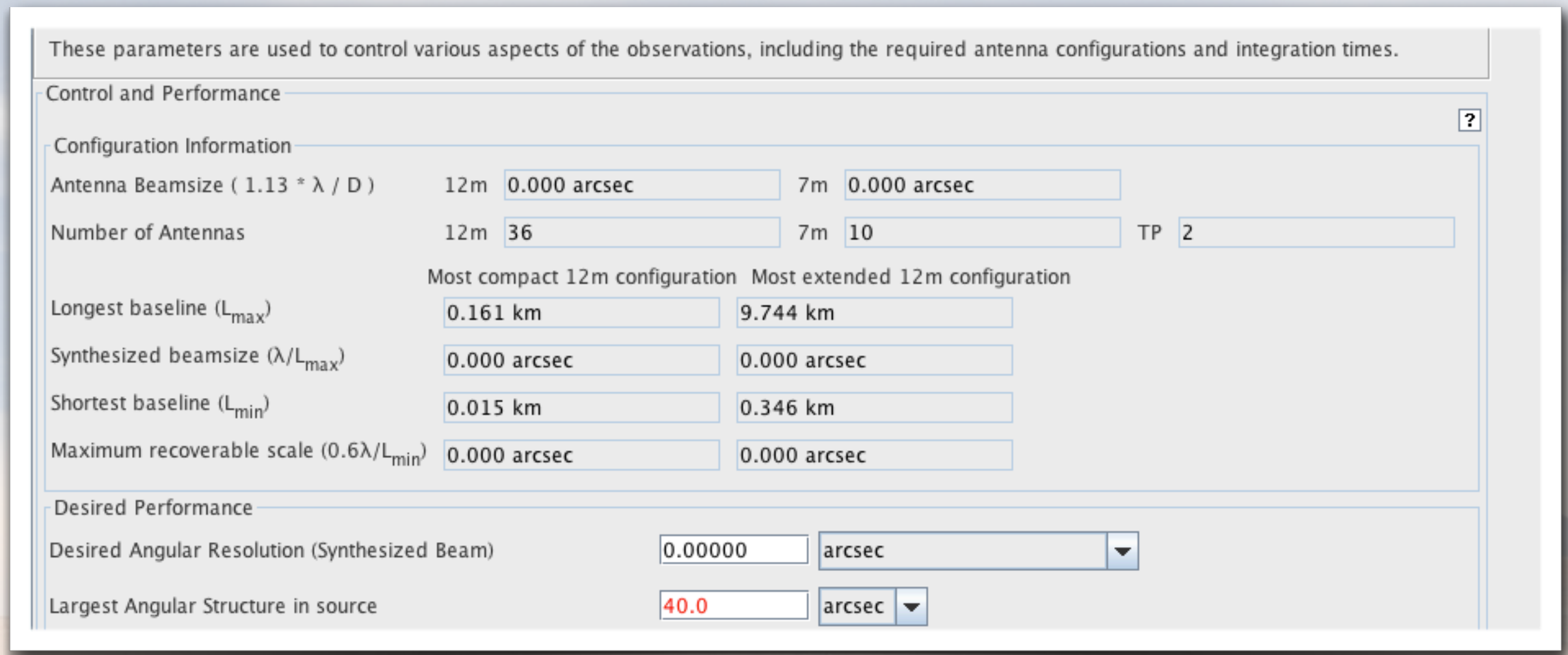
simulation for full array, tightest configuration

AIM: gain sufficient knowledge to fill in the AOT



Step 1: spatial scale parameters

Assumption: we have already selected the representative frequency (explained further in section 2)



Step 1: spatial scale parameters

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These parameters are used to control various aspects of the observations, including the required antenna configurations and integration times.

Control and Performance

Configuration Information

Antenna Beamsize (1.13 * λ / D)	12m	0.000 arcsec	7m	0.000 arcsec		
Number of Antennas	12m	36	7m	10	TP	2

	Most compact 12m configuration	Most extended 12m configuration
Longest baseline (L_{max})	0.161 km	9.744 km
Synthesized beamsize (λ/L_{max})	0.000 arcsec	0.000 arcsec
Shortest baseline (L_{min})	0.015 km	0.346 km
Maximum recoverable scale ($0.6\lambda/L_{min}$)	0.000 arcsec	0.000 arcsec

smallest recoverable scale

Desired Performance

Desired Angular Resolution (Synthesized Beam)	0.00000	arcsec
Largest Angular Structure in source	40.0	arcsec

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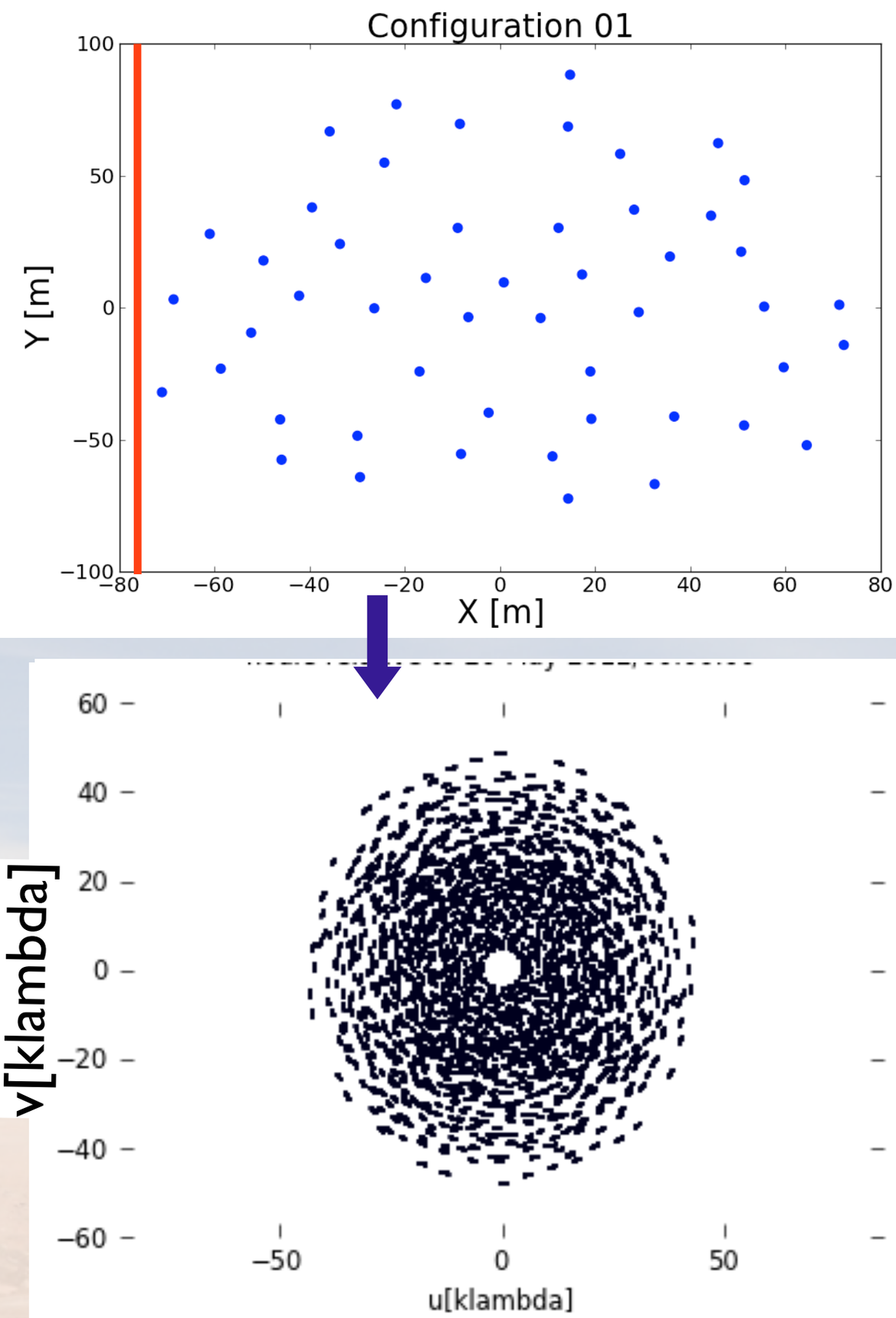
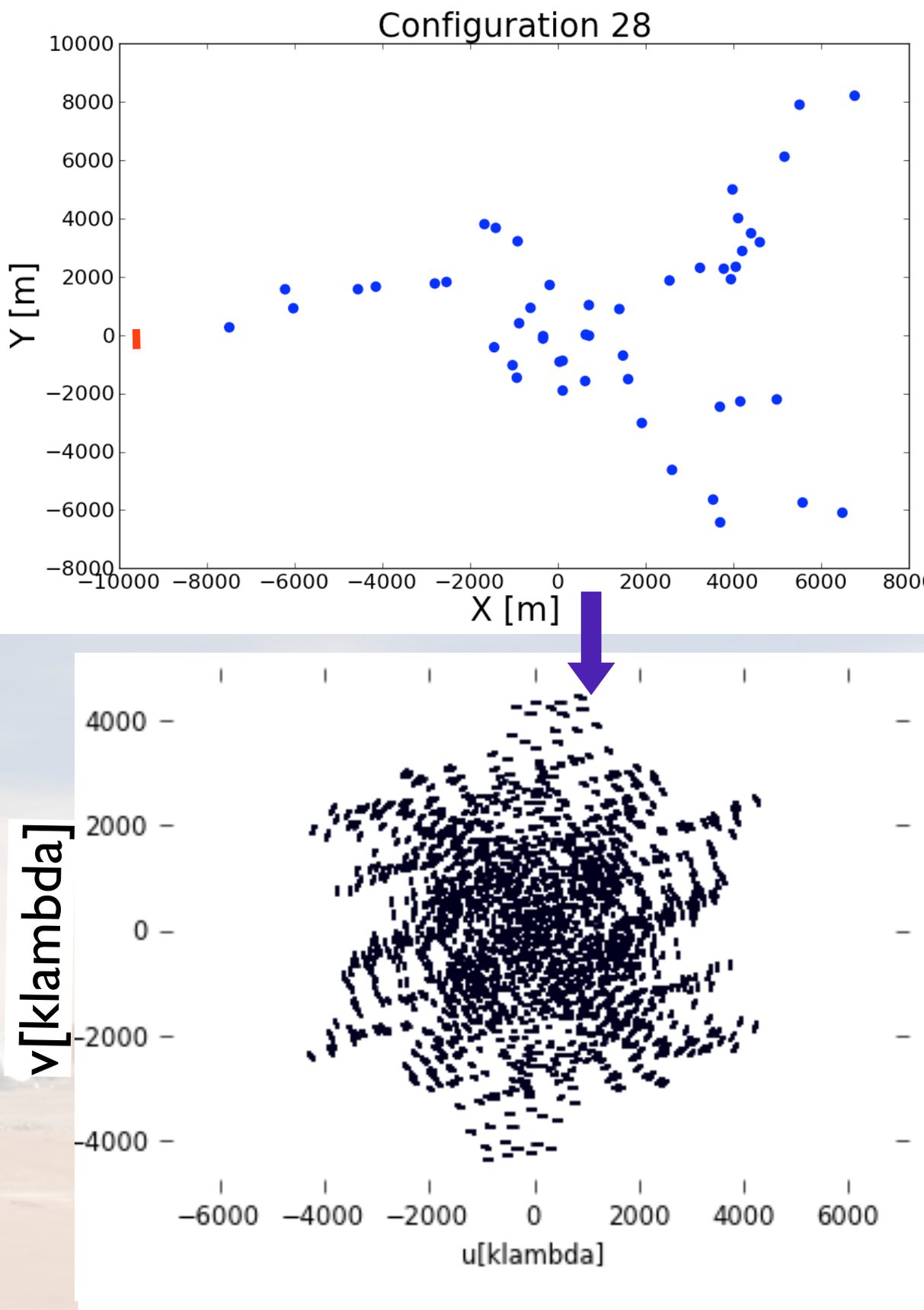
largest recoverable scale

Desired Performance

Desired Angular Resolution (Synthesized Beam)	0.00000	arcsec
Largest Angular Structure in source	40.0	arcsec

Antenna configurations and uv-coverage

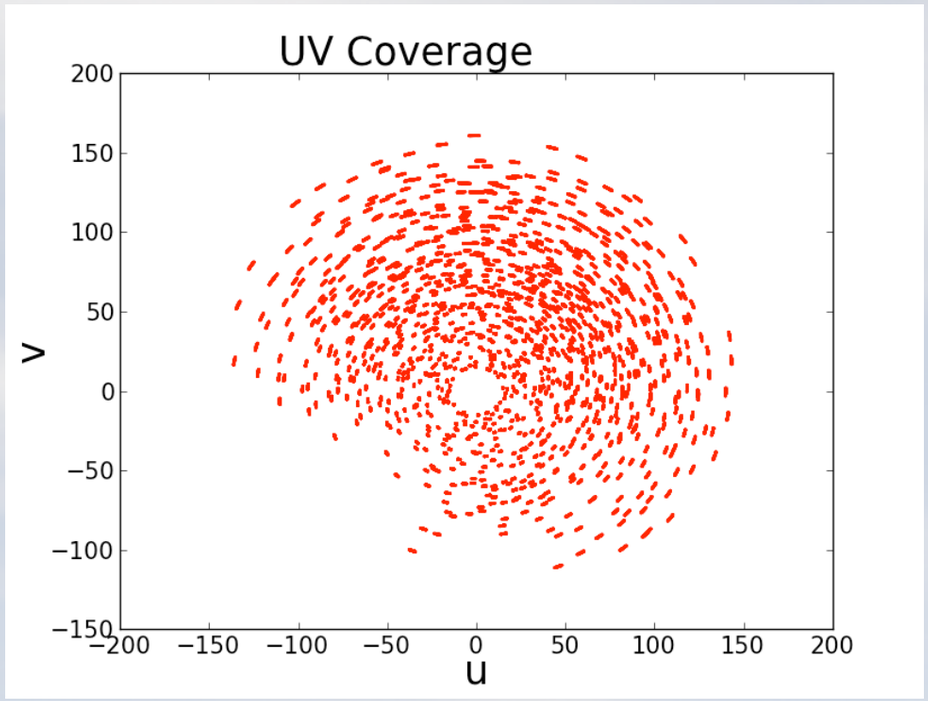




The dirty beam

Theory recap: $B(l,m) = \int\int S(u,v)e^{2\pi i(ul+vm)}dudv$

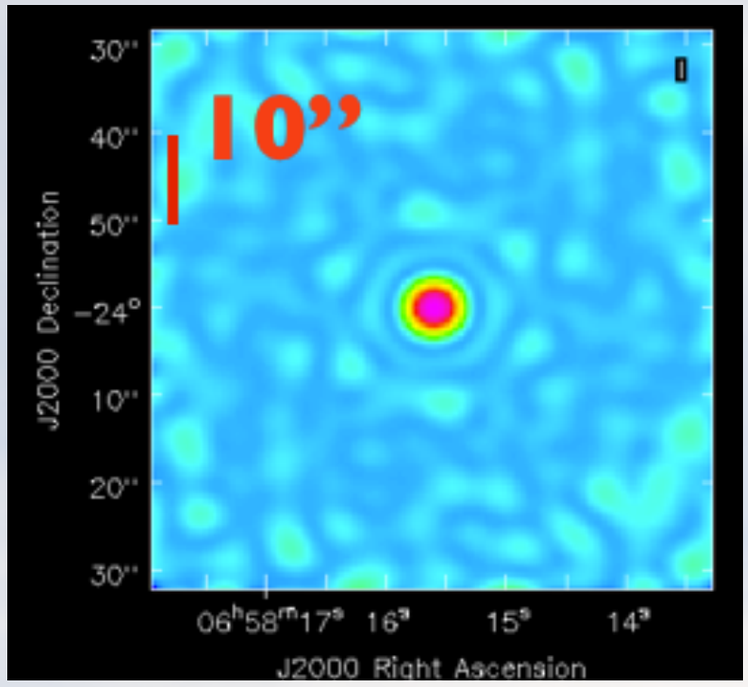
$$\text{Interferometer Resolution} = \theta_{res} = k\,\lambda/L_{max},$$

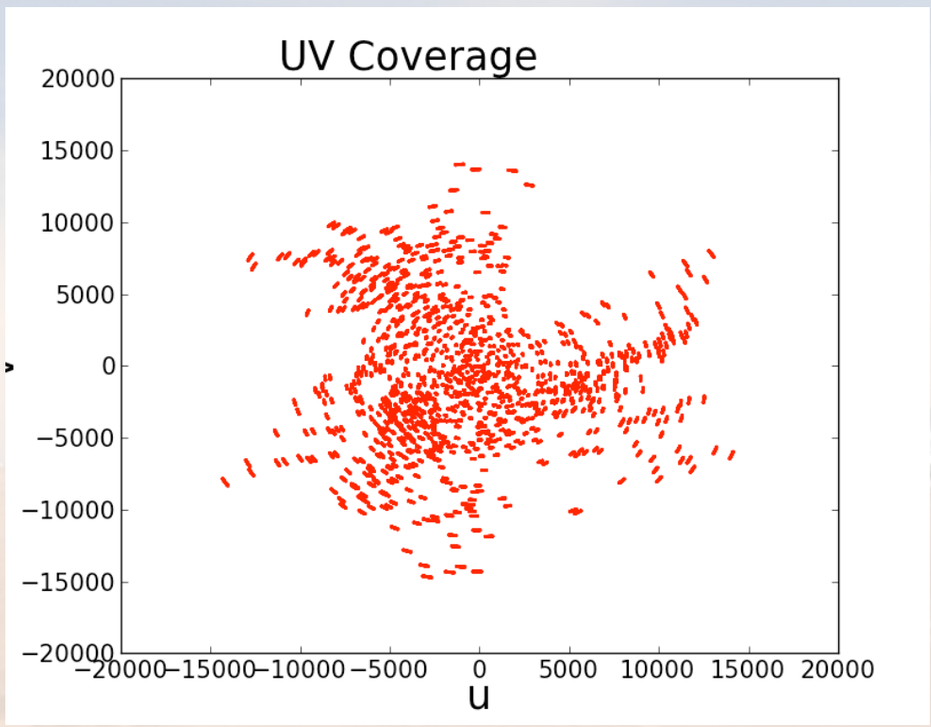


freq: 90.0 GHz

bmaj : 4.45”

bmin : 4.41”

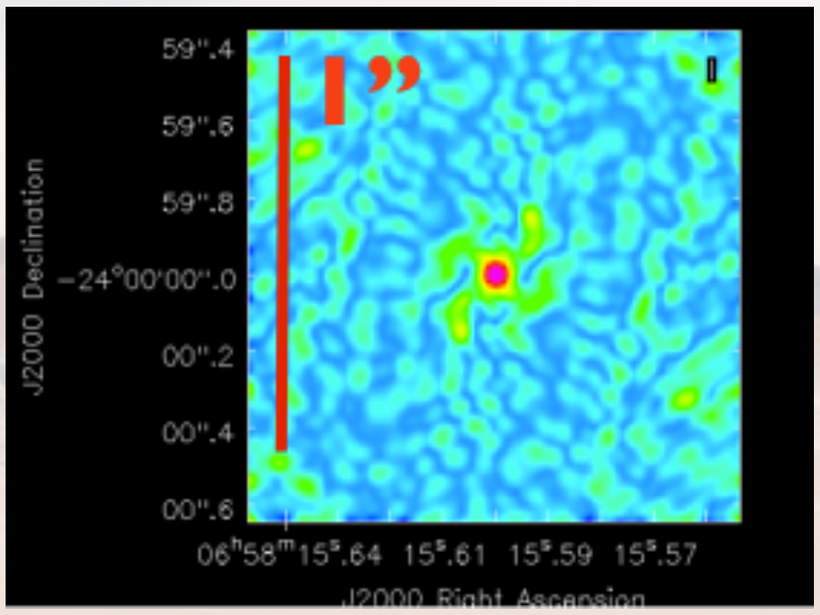




freq: 90.0 GHz

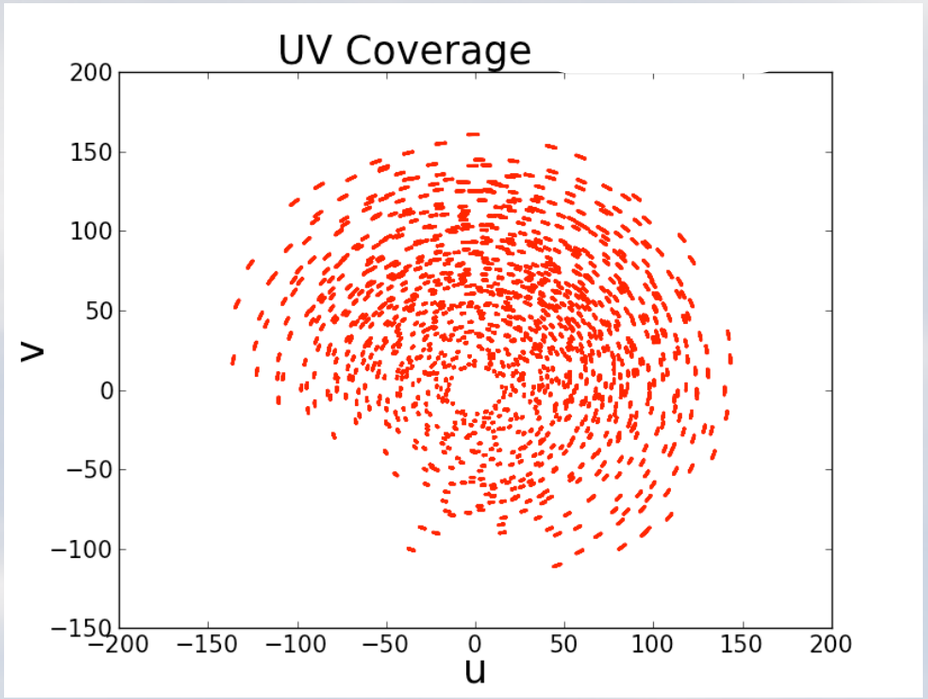
bmaj : 0.25”

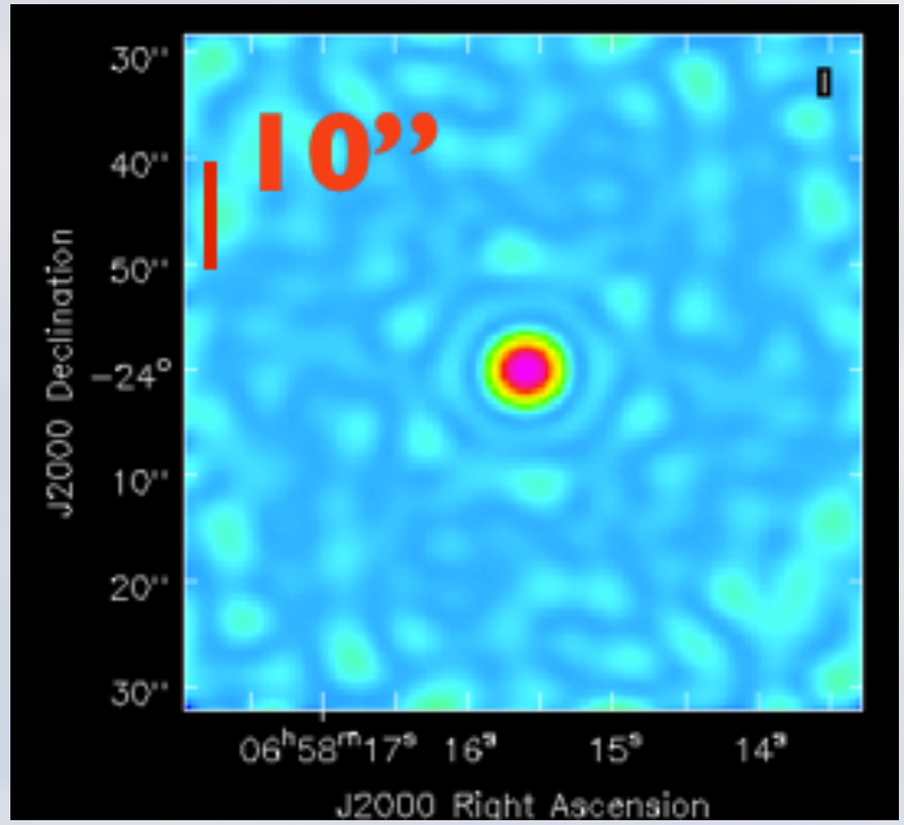
bmin : 0.125”



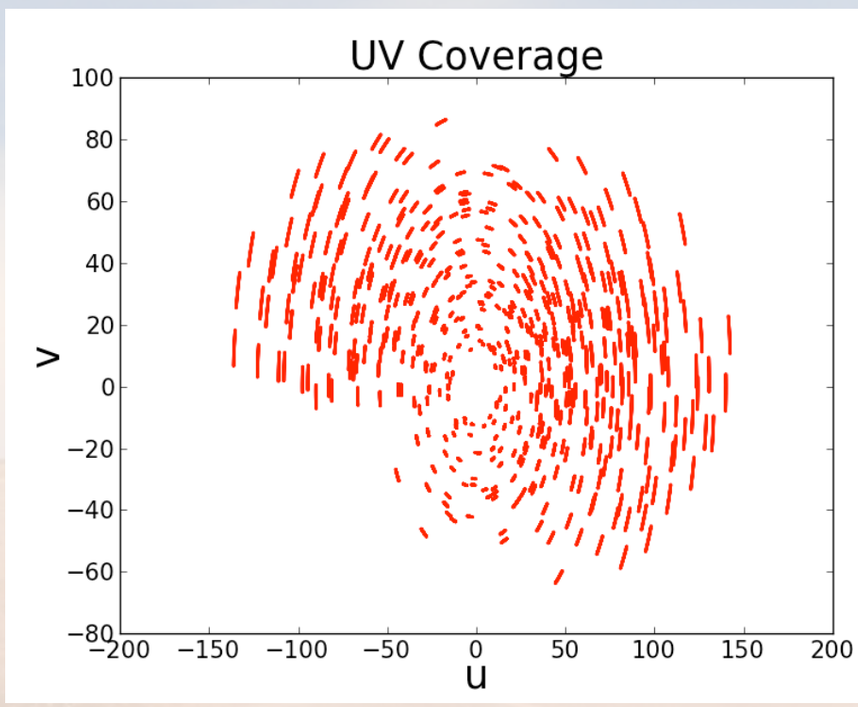
Beam shape and source declination

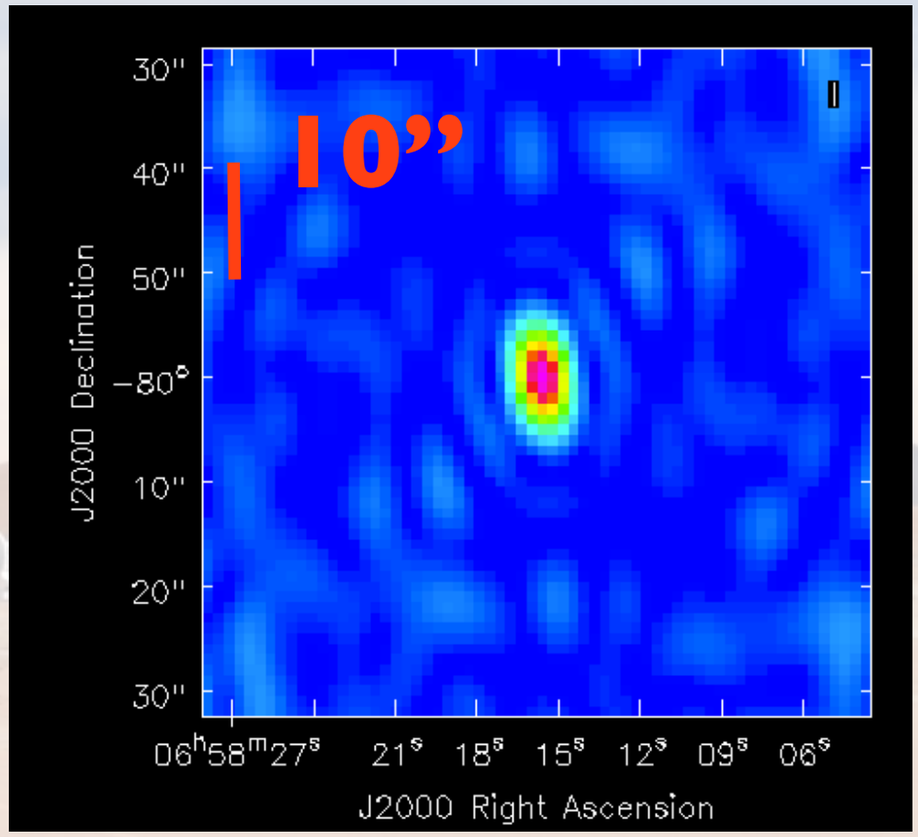
dec: -24.0d



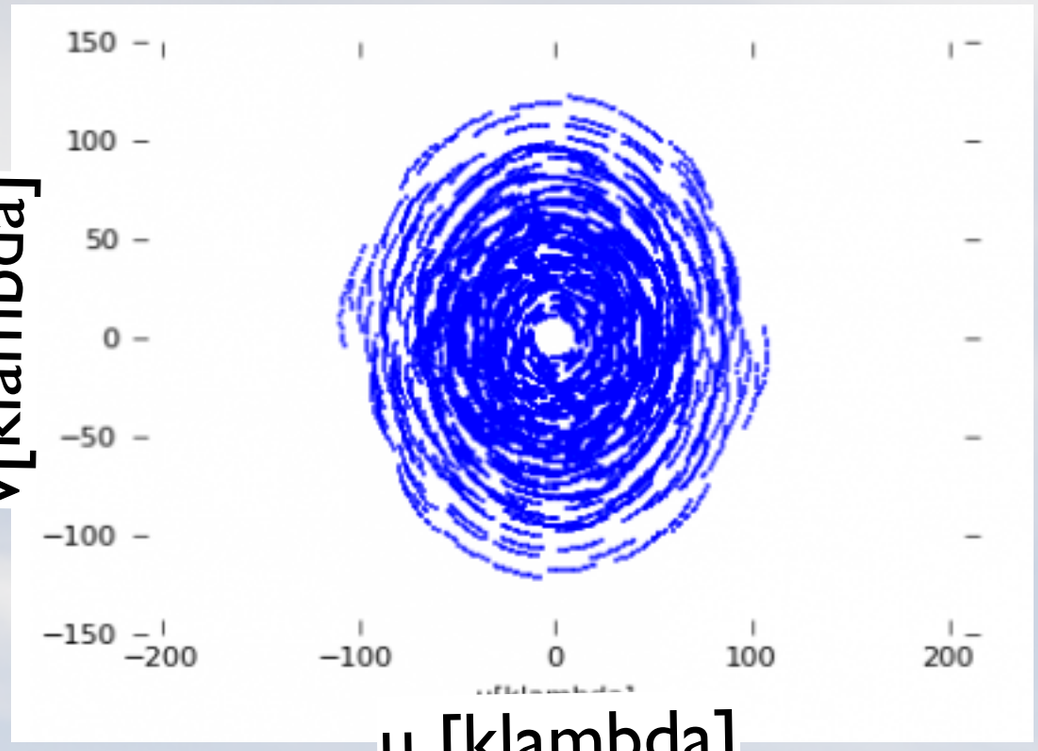


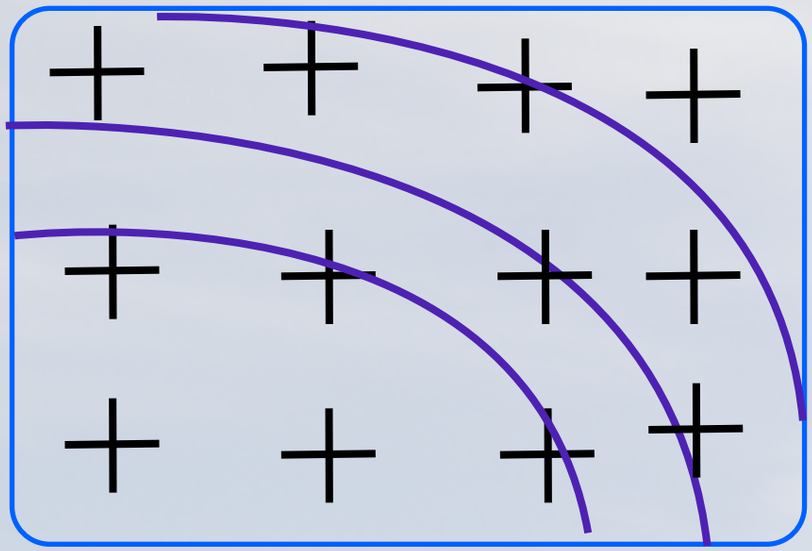
dec: -80.0d



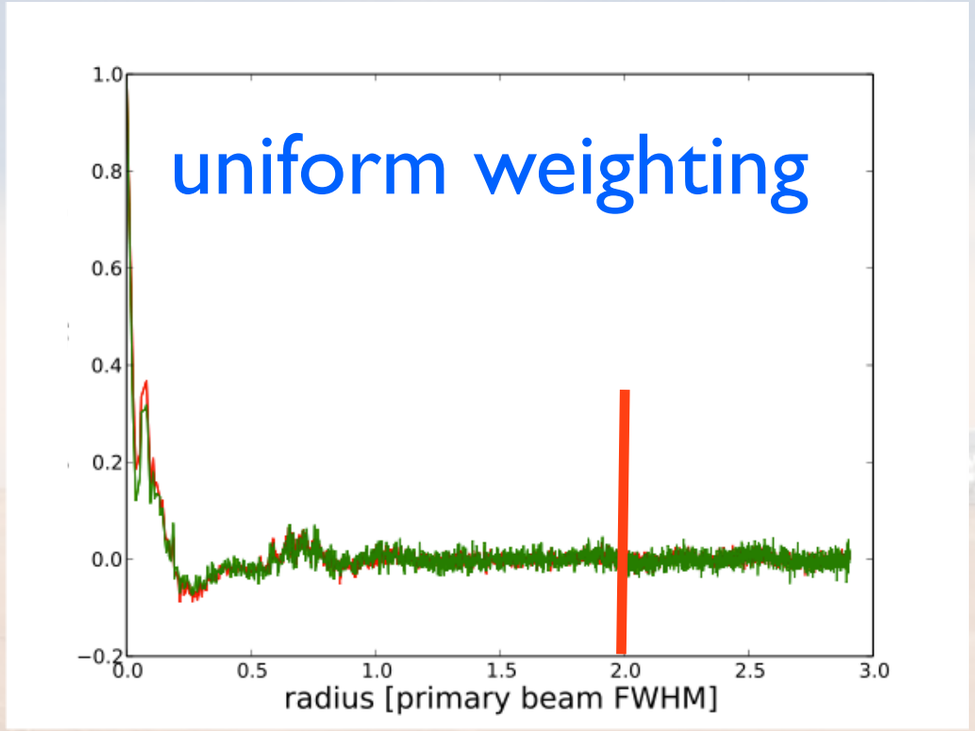


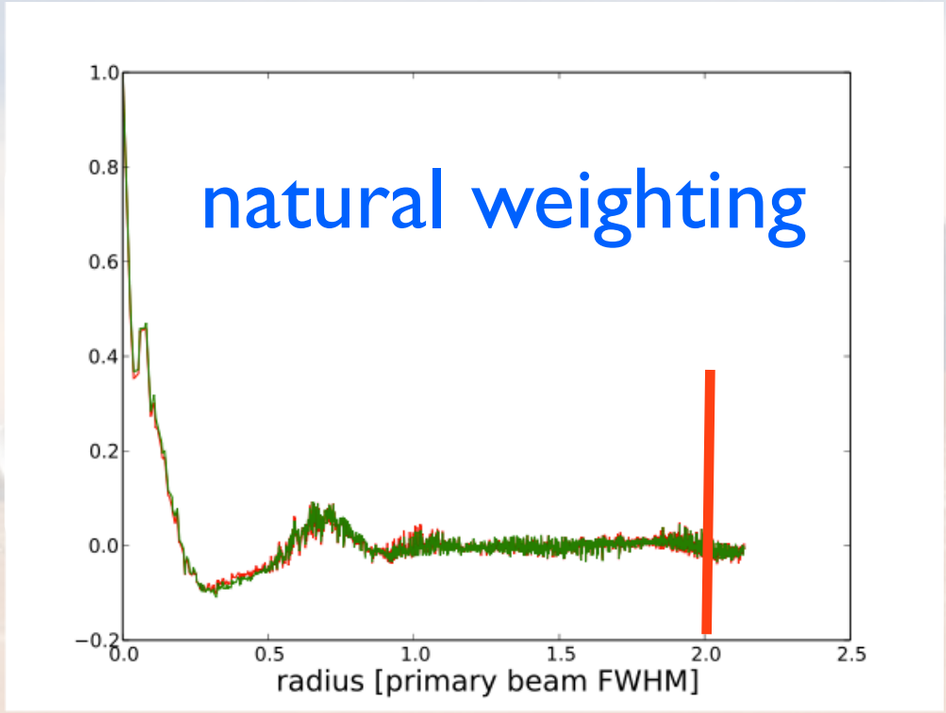
Beam shape and visibility weighting



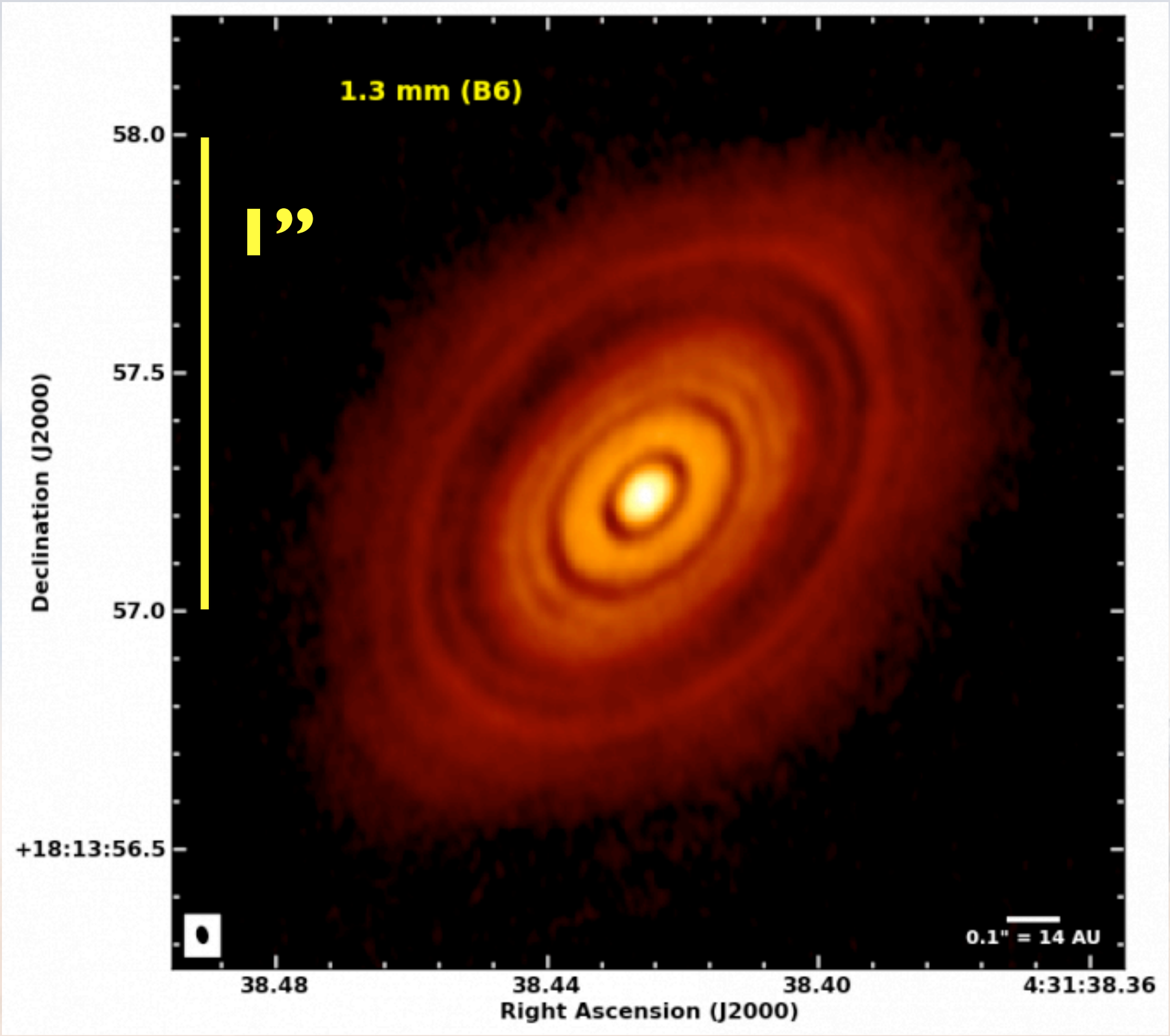


interpolate onto regular grid and weigh according to density





HL Tauri



25-30 antennas

maximum baseline = 15.24 km

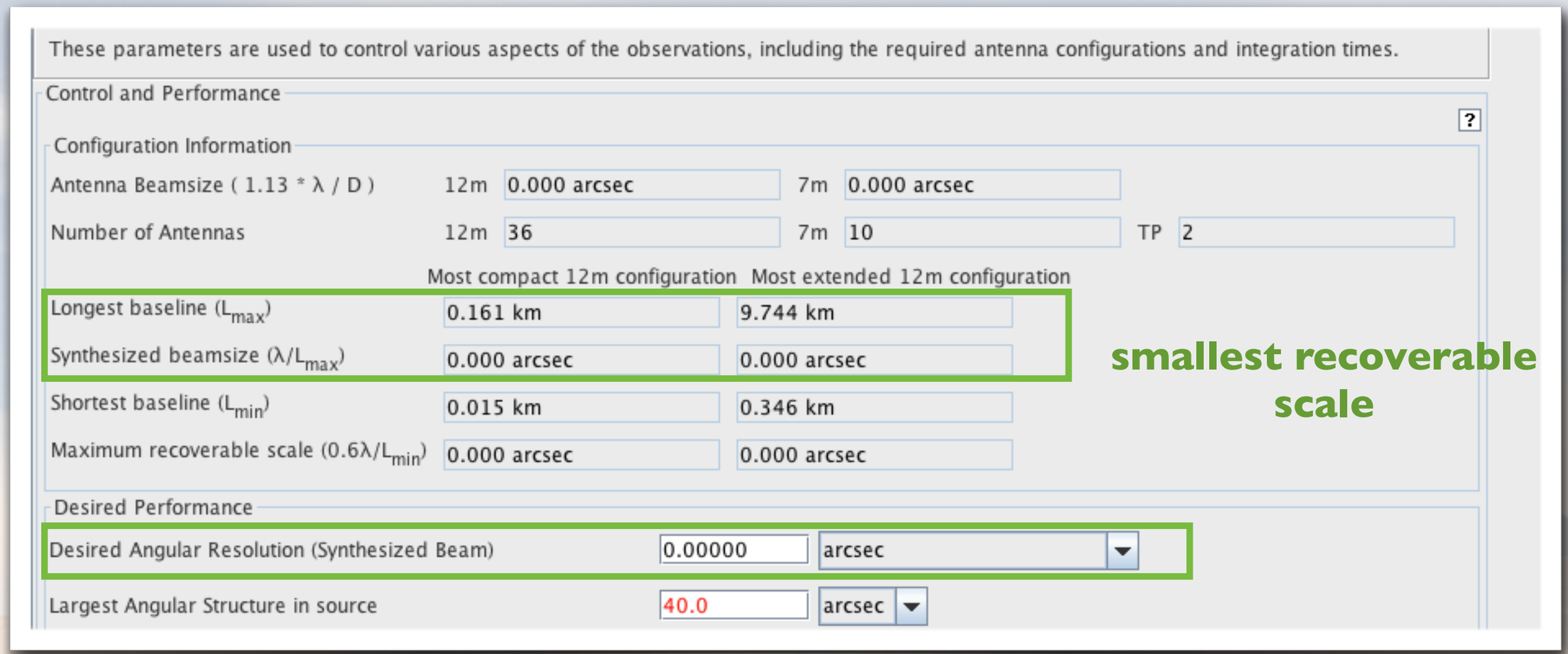
angular resolution = 35 milliarcsec

minimum baseline = 15.2 m

credit: ALMA

Spatial scale parameters

Assumption: we have already selected the representative frequency (explained further in section 2)



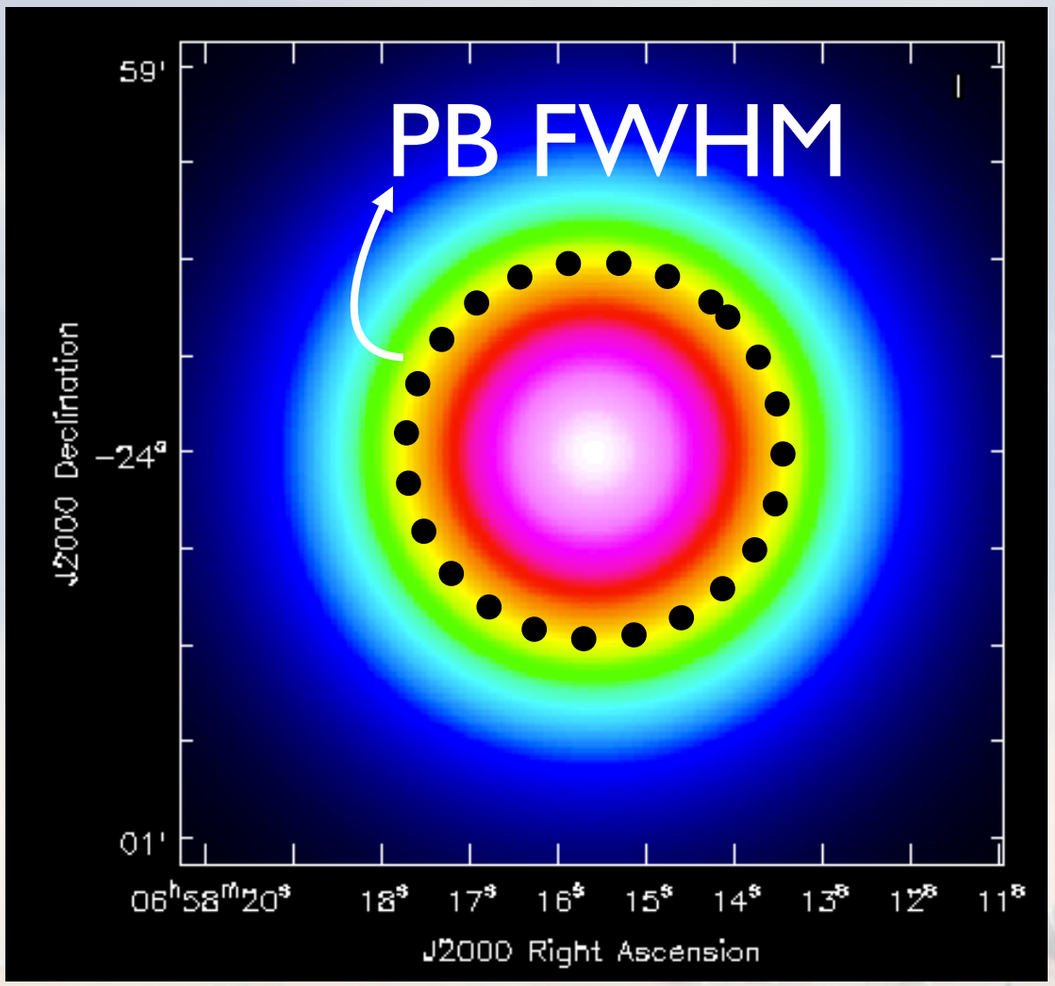
smallest recoverable scale

Largest angular scale

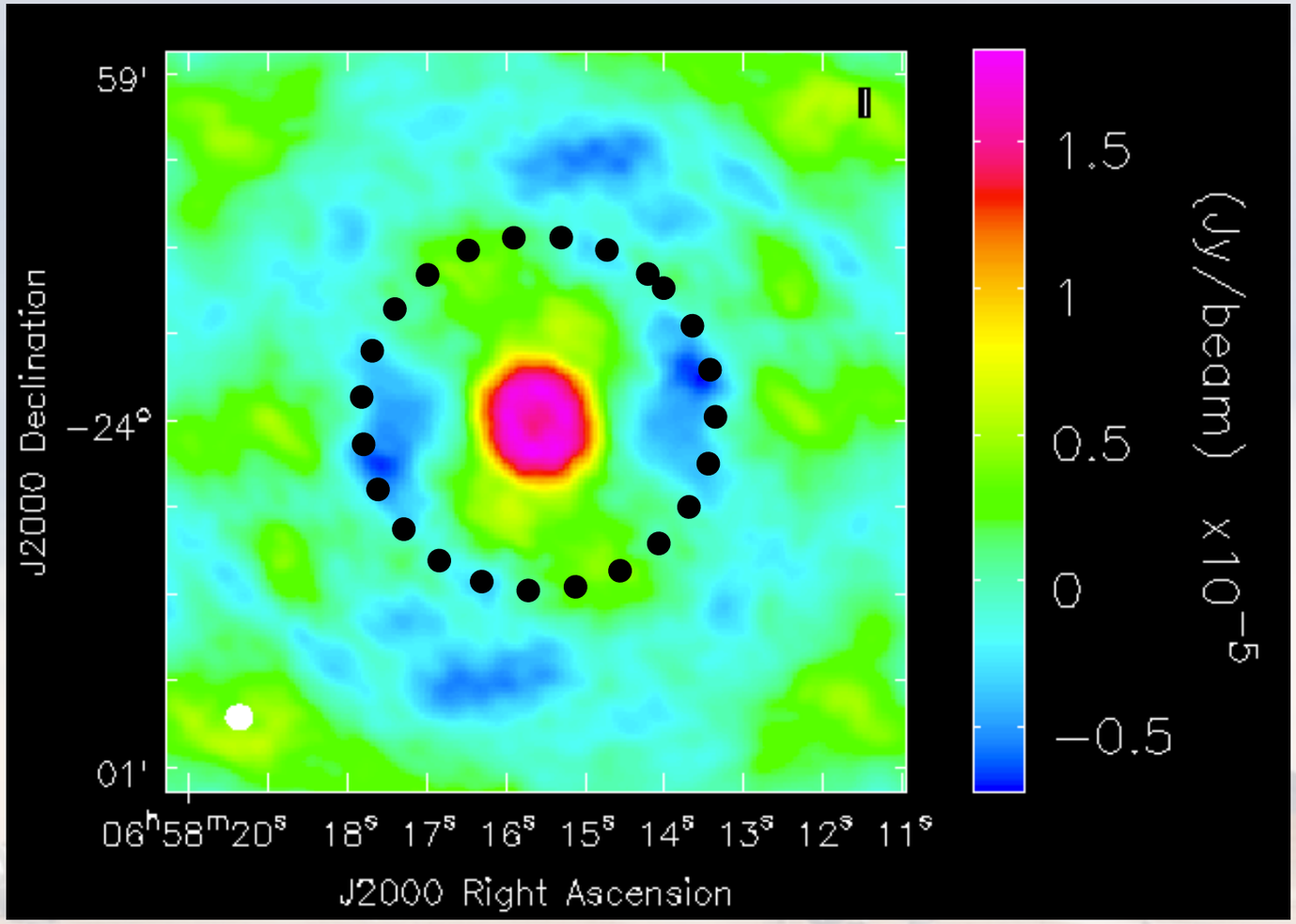
Theory recap:

$$\text{Maximum Recoverable Scale} = \theta_{MRS} \approx 0.6\lambda/L_{min},$$

input model

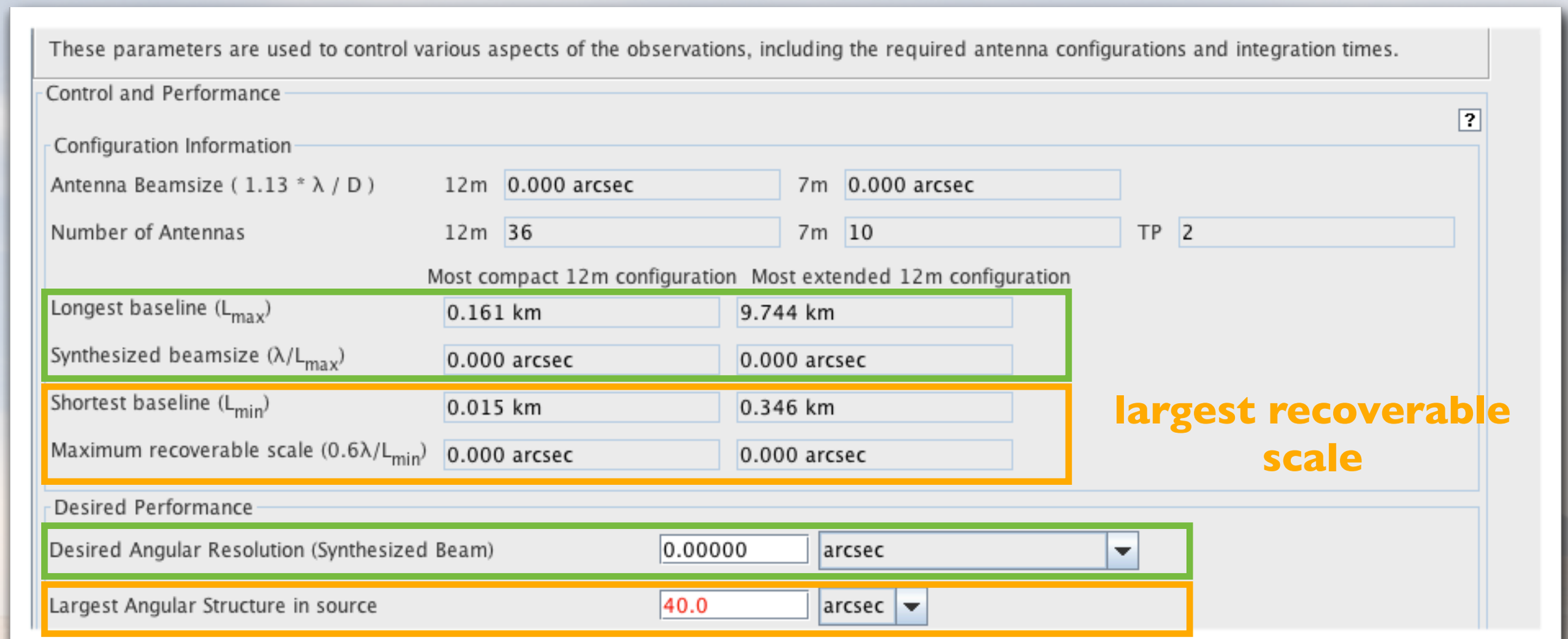


deconvolved image

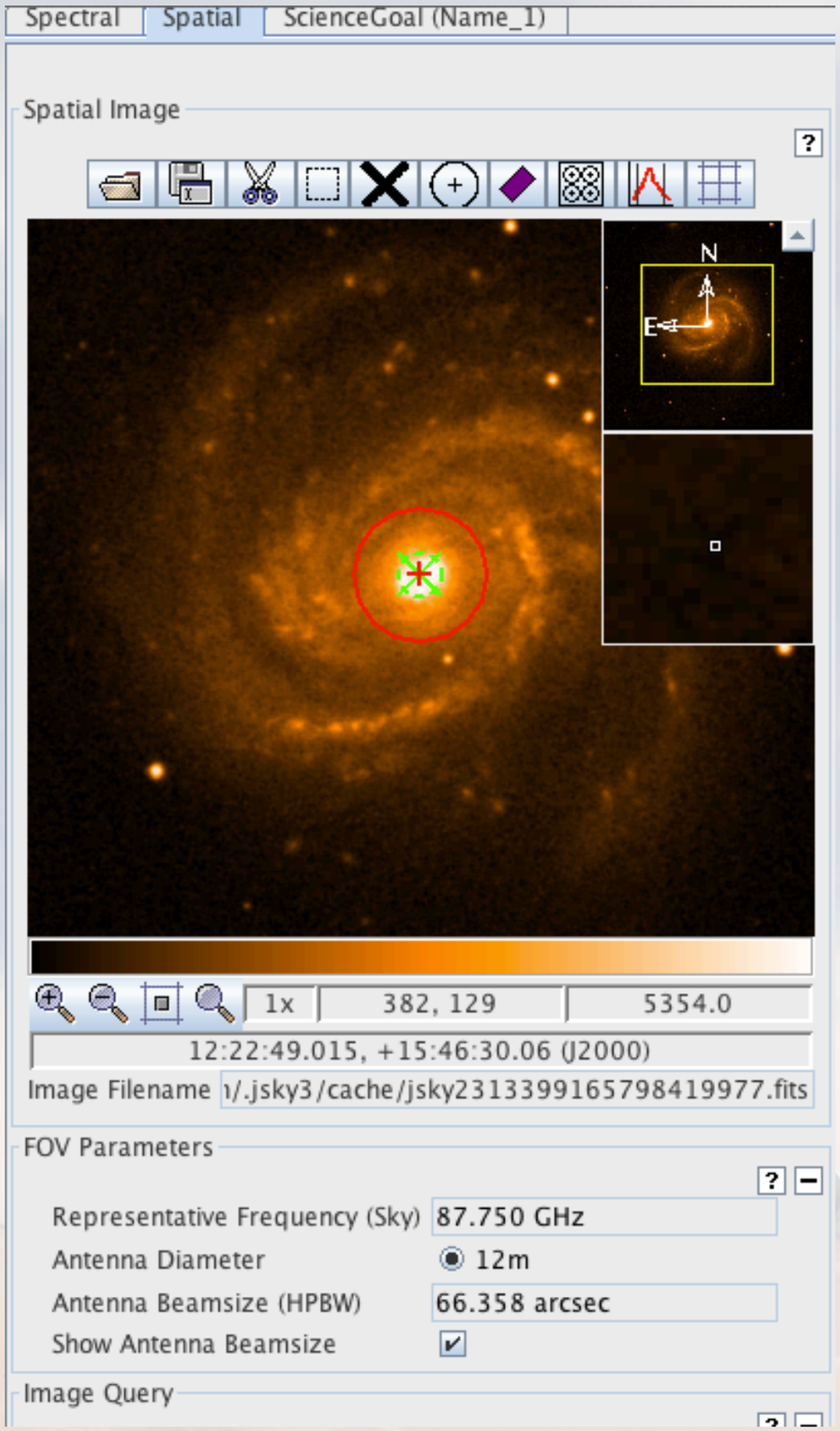


Spatial scale parameters

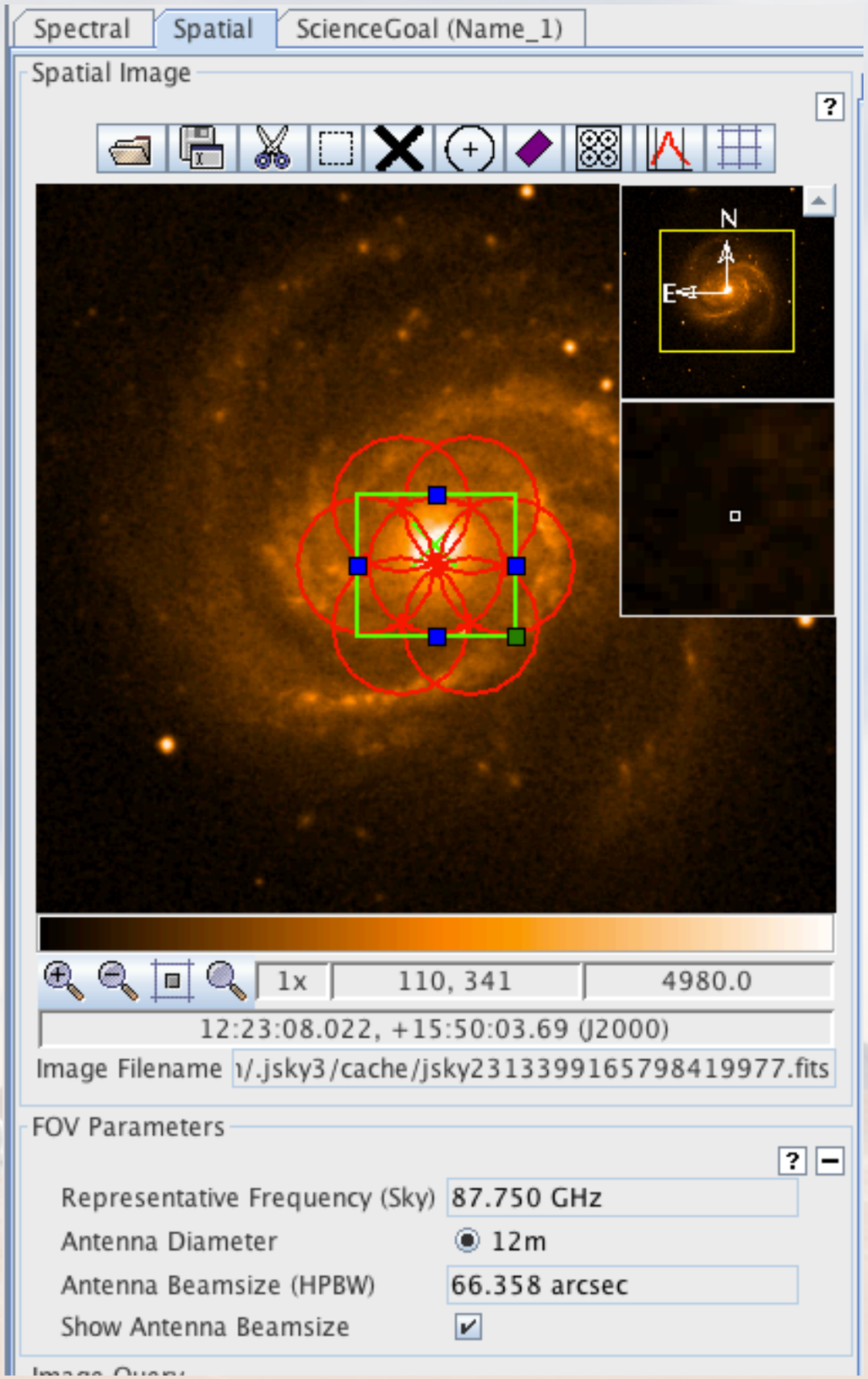
Assumption: we have already selected the representative frequency (explained further in section 2)



Single pointing or mosaics

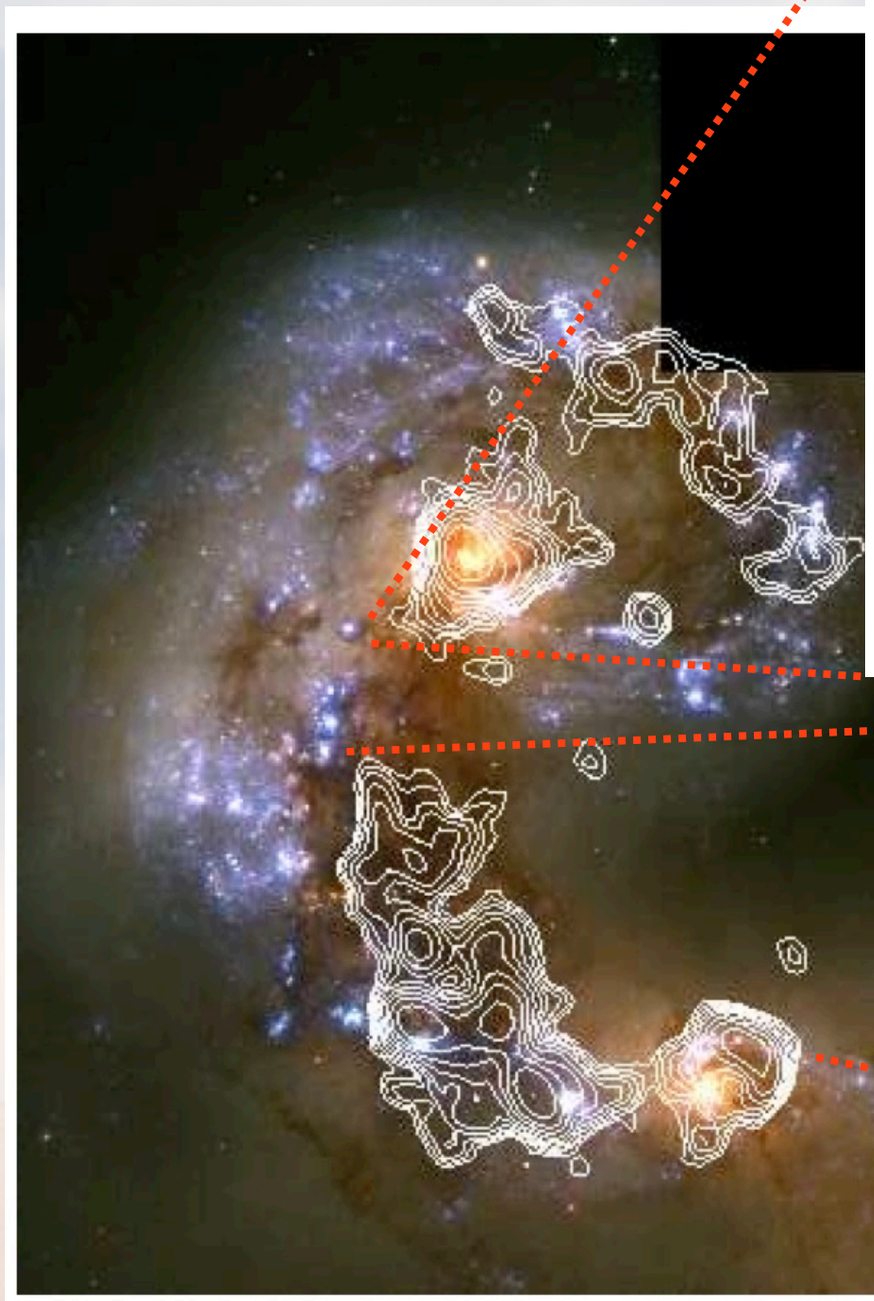


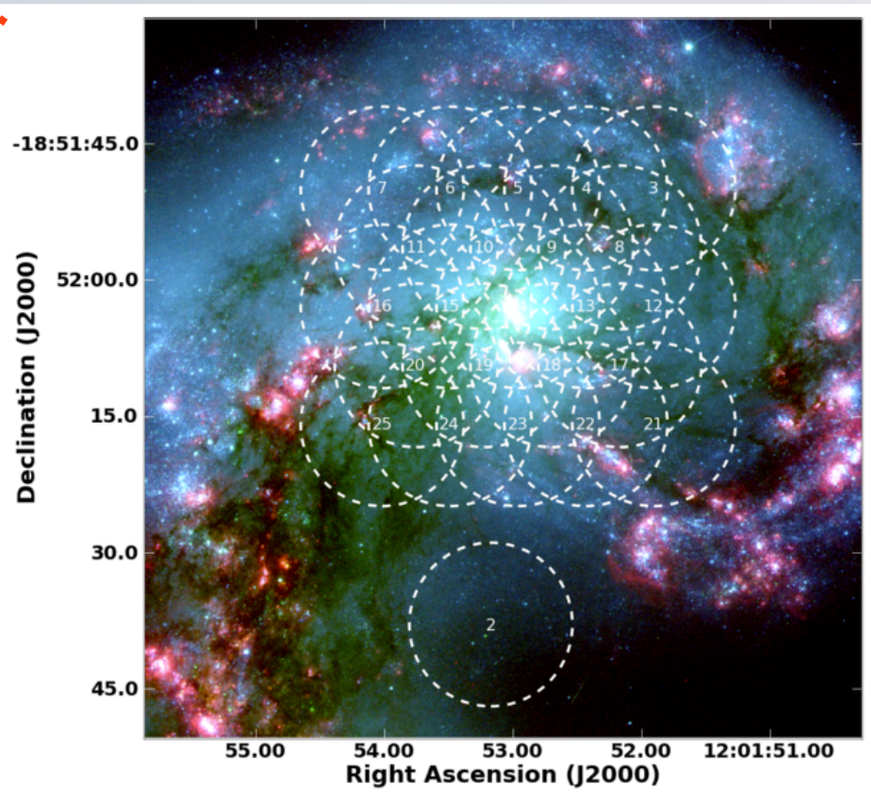
VS

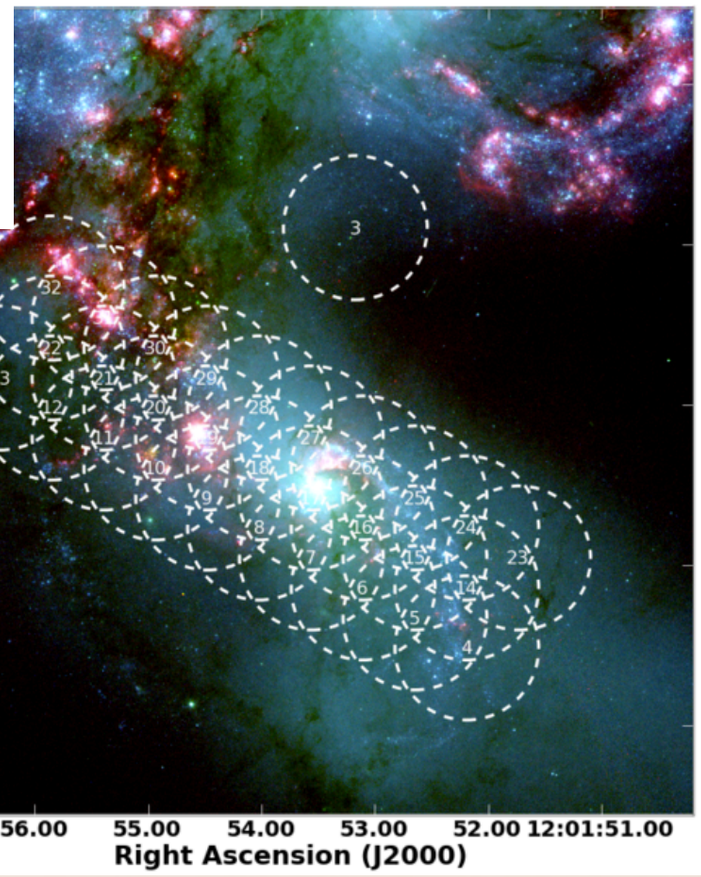


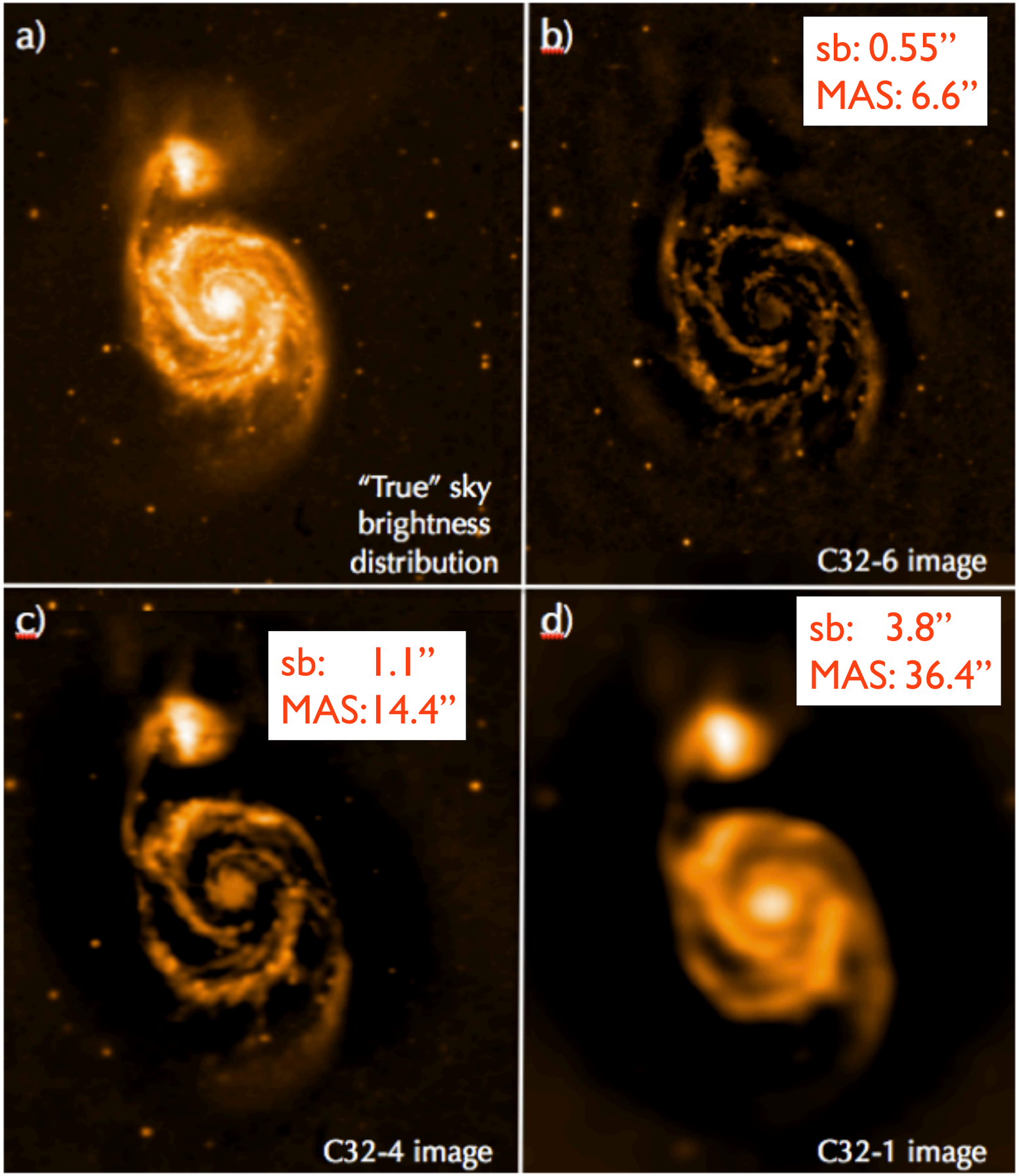
Single pointing or mosaics

example taken from: http://casaguides.nrao.edu/index.php?title=AntennaeBand7





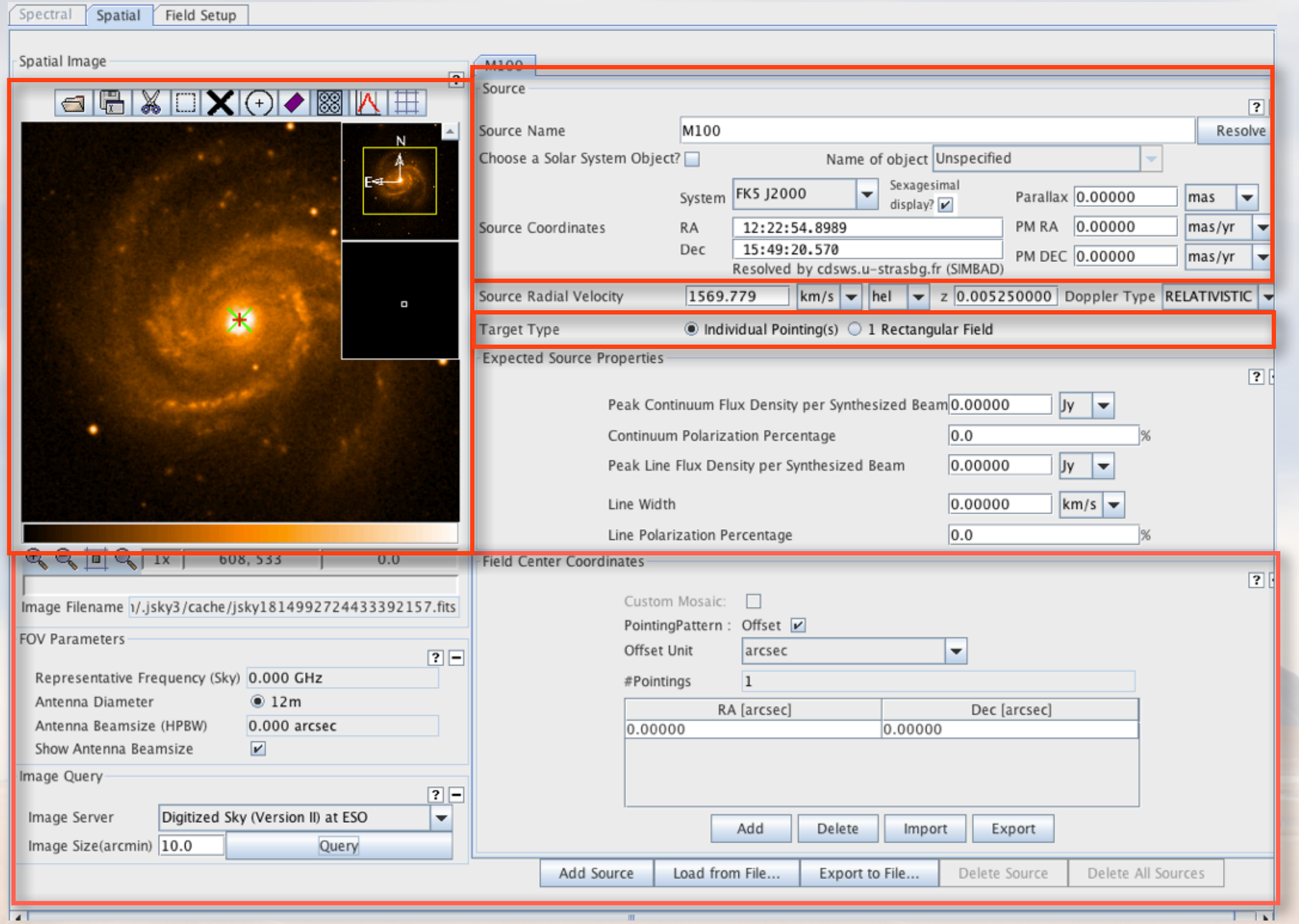




mosaic of
39 pointings

credit: ALMA Technical Handbook

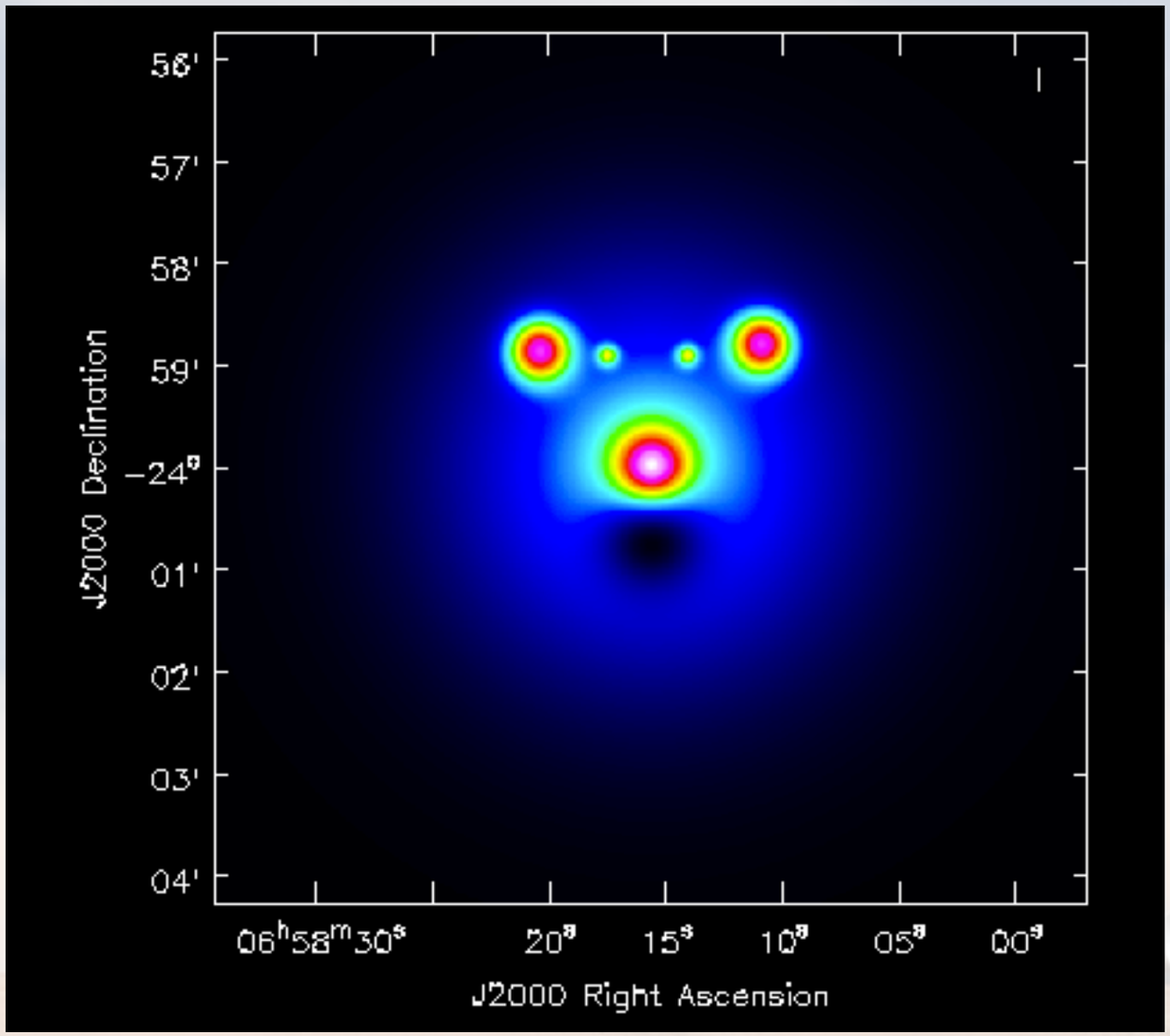
Single pointing or mosaics: the AOT



Should we include the ACA ?

simulation is without noise for demonstration purposes

input model



simulation

solely ALMA

vs

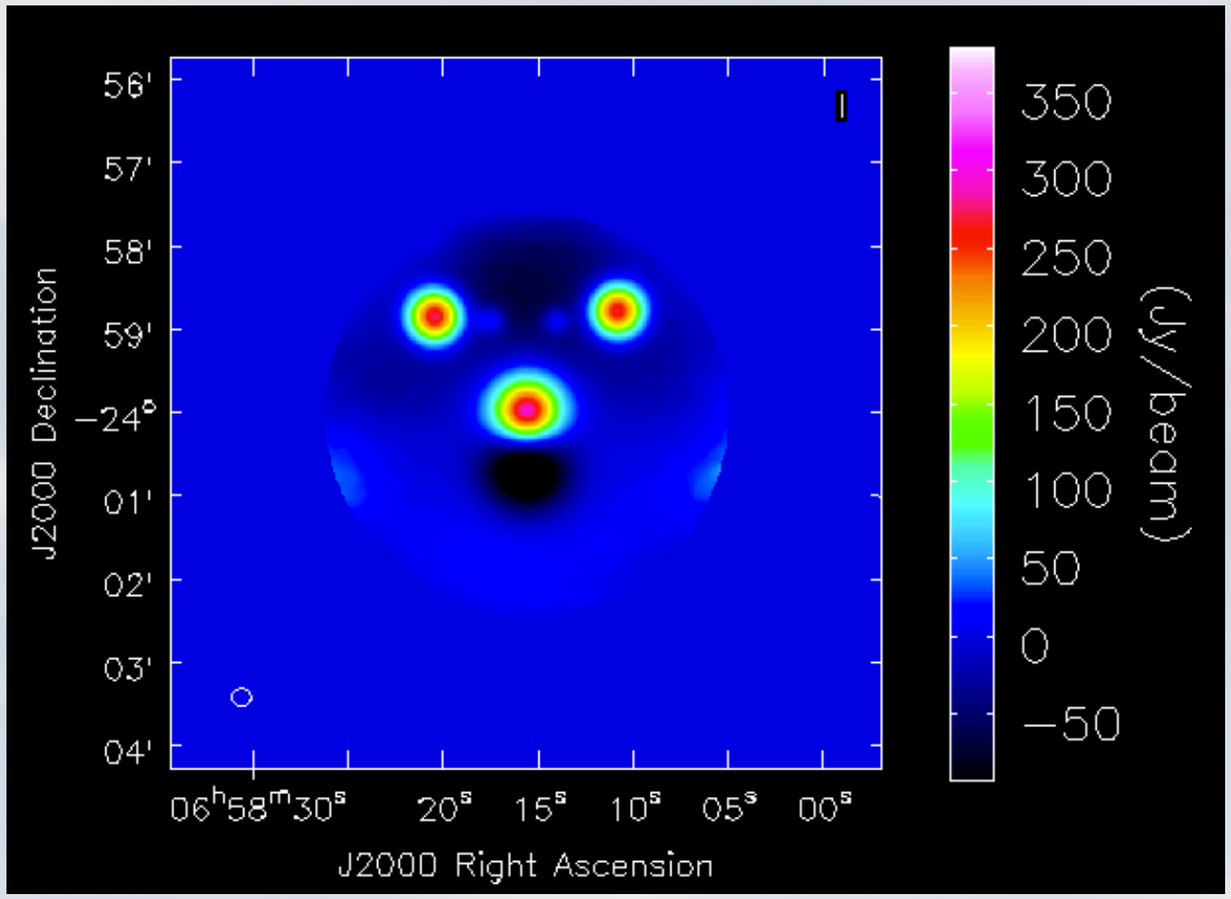
ALMA

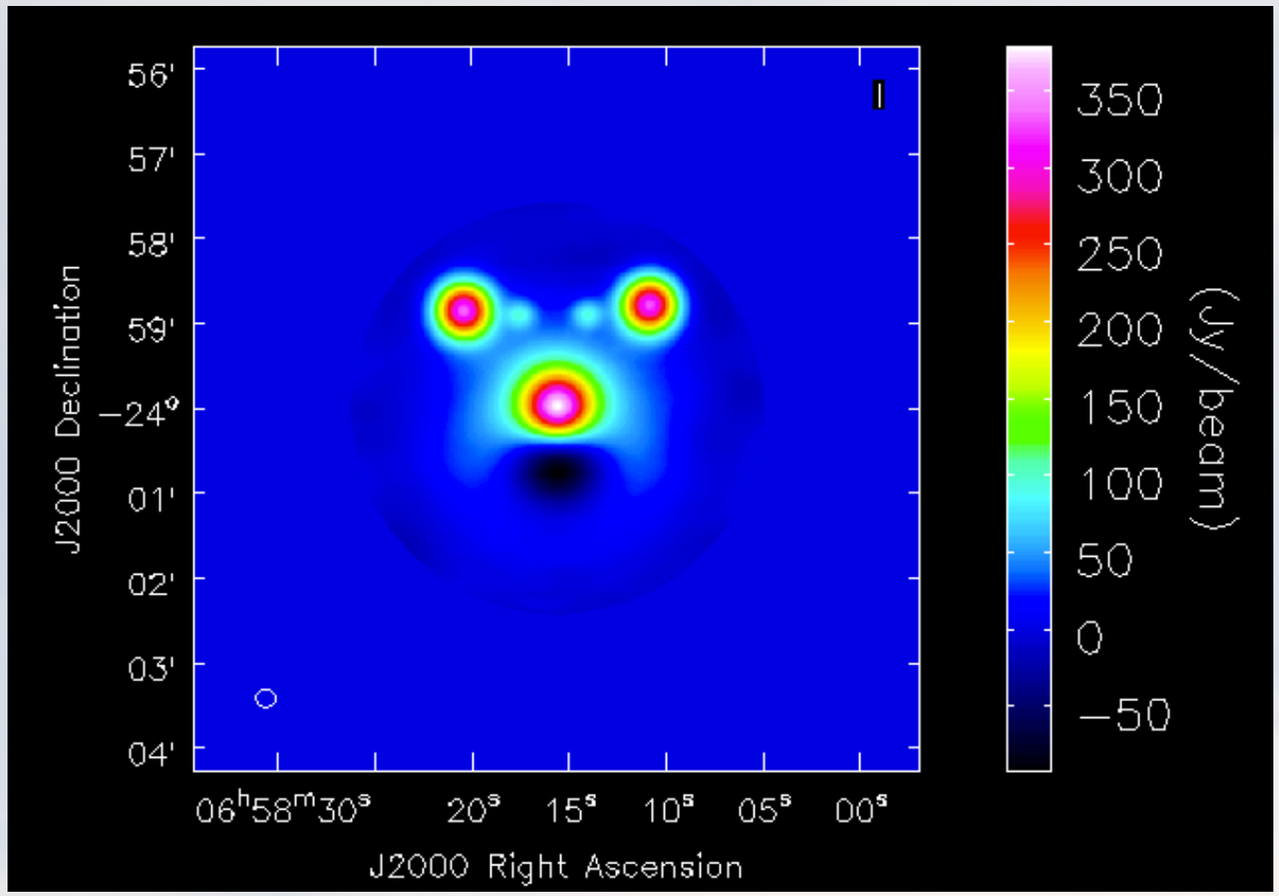
+

Credit: ALMA (ESO/NAOJ/NRAO)

The interferometer: a spatial filter

simulation is without noise for demonstration purposes





solely ALMA

ALMA + ACA

interferometers are spatial filters

adding the ACA to ALMA data helps to recover some (BUT NOT ALL) of the larger-scale signals

Should we include the ACA ? -> the AOT

These parameters are used to control various aspects of the observations, including the required antenna configurations and integration times.

Control and Performance

?

Configuration Information

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	Most compact 12m configuration	Most extended 12m configuration
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Desired Performance

Desired Angular Resolution (Synthesized Beam)	0.00000	arcsec			
Largest Angular Structure in source	40.0	arcsec			
Desired sensitivity per pointing	0.00000	uJy	equivalent to	Infinity	K
Bandwidth used for Sensitivity	RepresentativeWindowResolution		Frequency Width	0.000000 GHz	

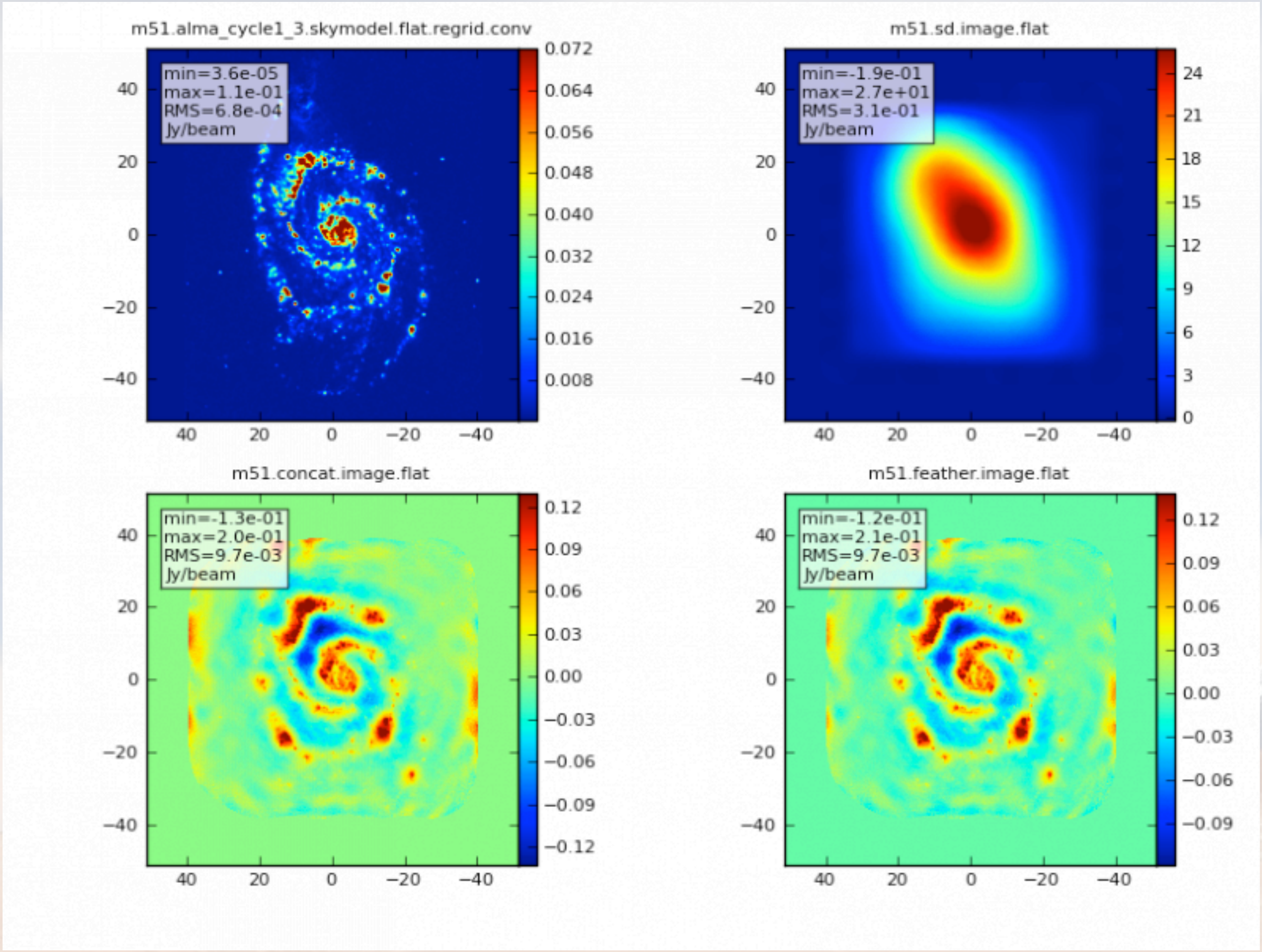
Do you request complementary ACA Observations? ○ Yes ◉ No Suggest

Science goal integration time estimate Time Estimate

Override OT's sensitivity-based time estimate (must be justified) ○ Yes ◉ No

Are the observations time-constrained? ○ Yes ◉ No

zero spacing



credit: simalma CASA example

Break #1