

Introduction to the basic concepts and terminology of radio interferometry



EUROPEAN ARC
ALMA Regional Centre || Germany



Universität zu
Köln

ALMA Community Days 2015, 25th March

German ARC node

Part I: Sandra Burkutean



Outline

• Part 1: by S. Burkutean

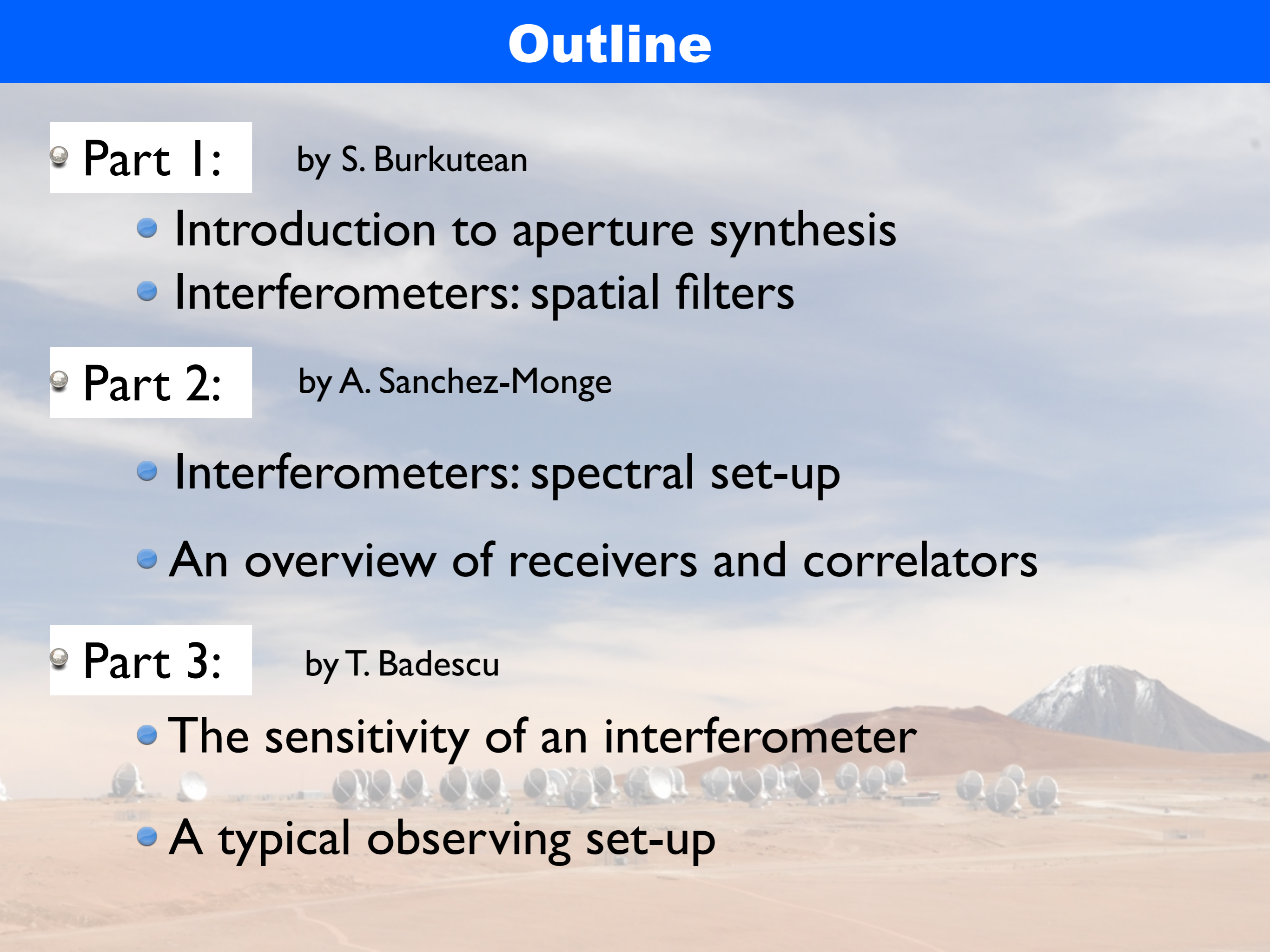
- Introduction to aperture synthesis
- Interferometers: spatial filters

• 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

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

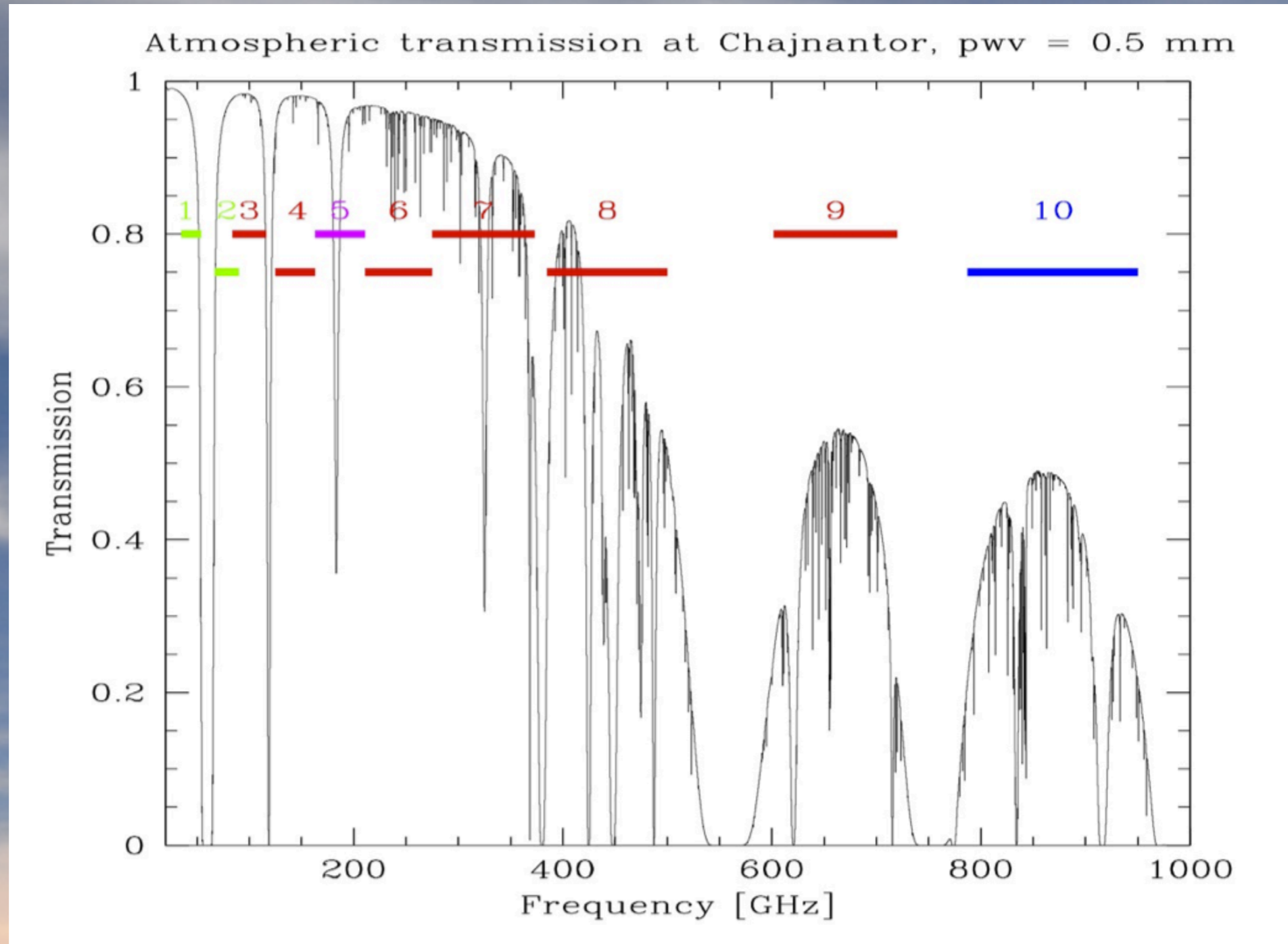


info on absolute brightness



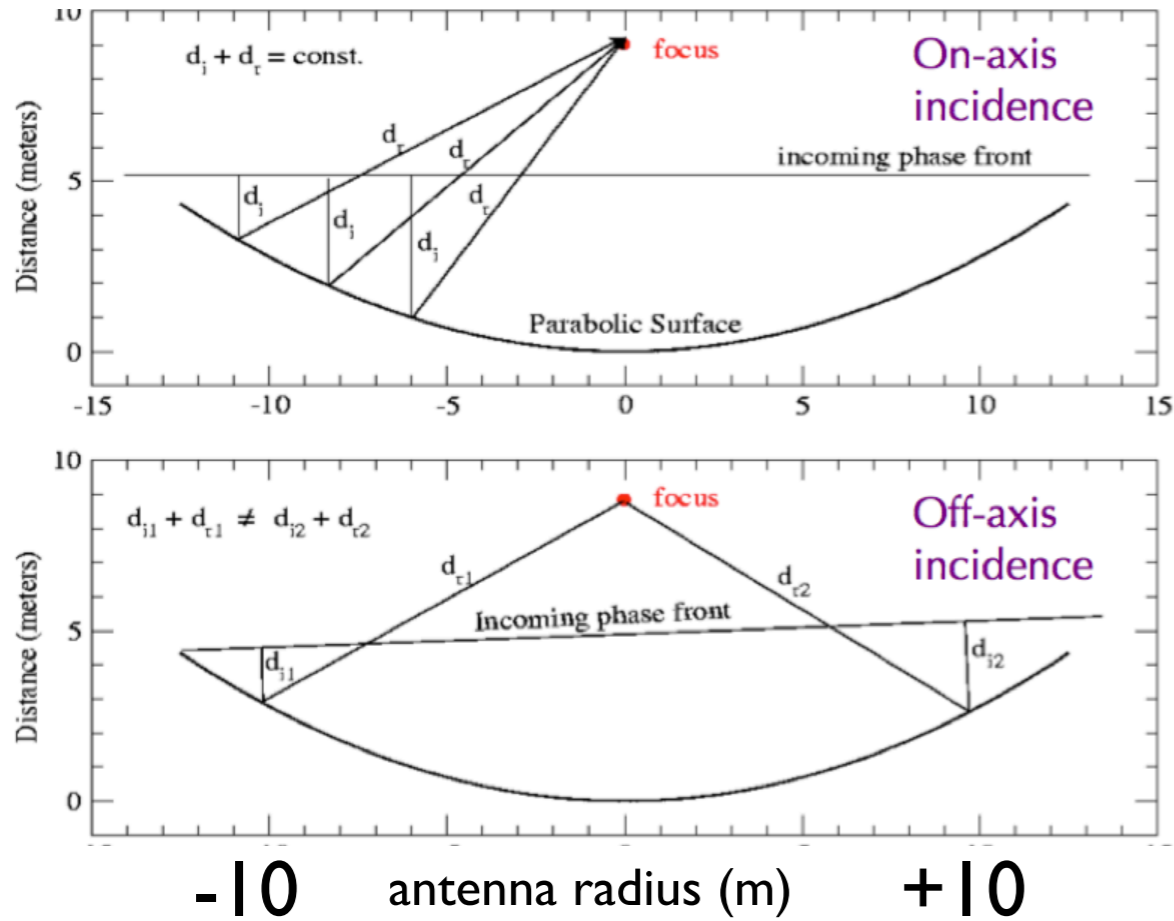
Credit: ALMA (ESO/NAOJ/NRAO)

Why is ALMA on the Chajnantor plateau?

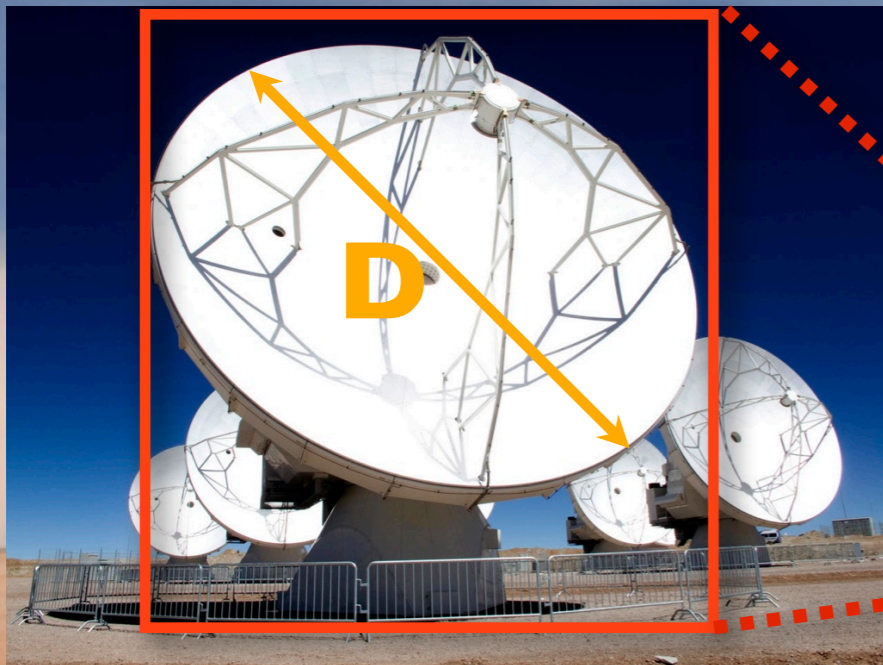
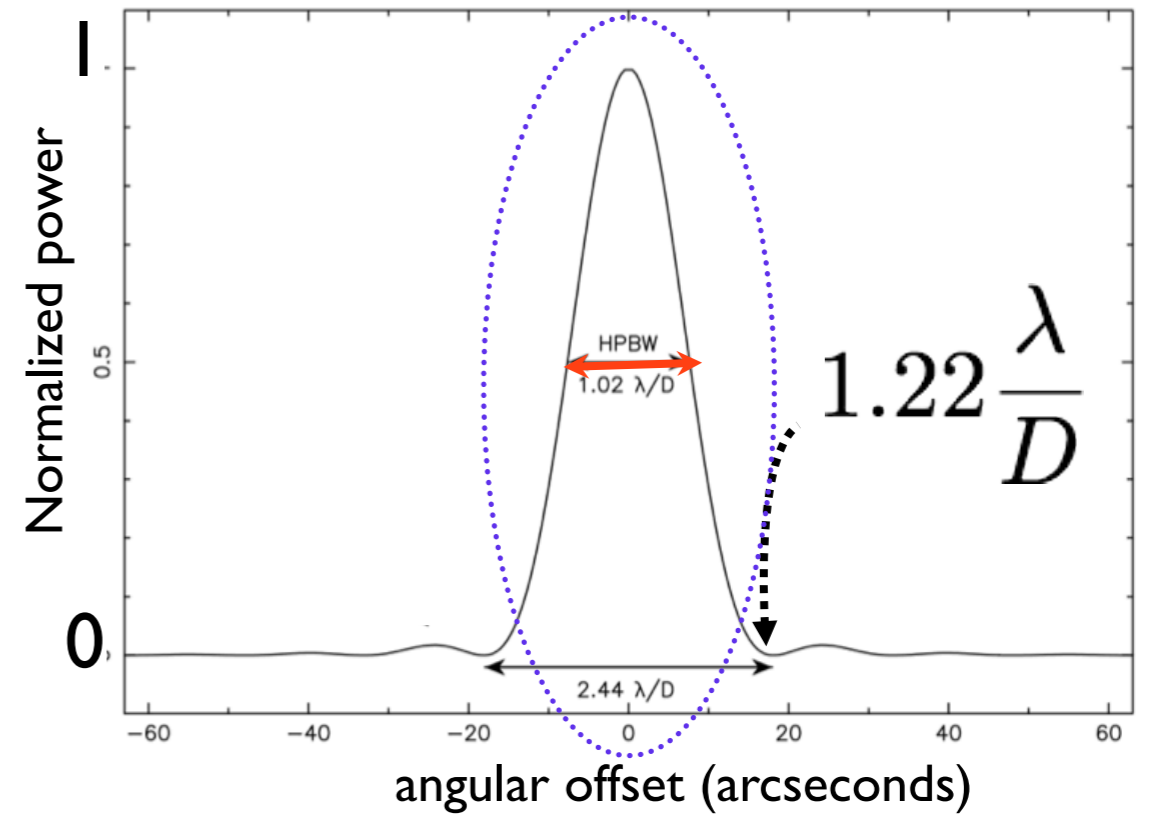


Single-dish Response

Schematic illustration



1D antenna power response



Credit: ALMA (ESO/NAOJ/NRAO)

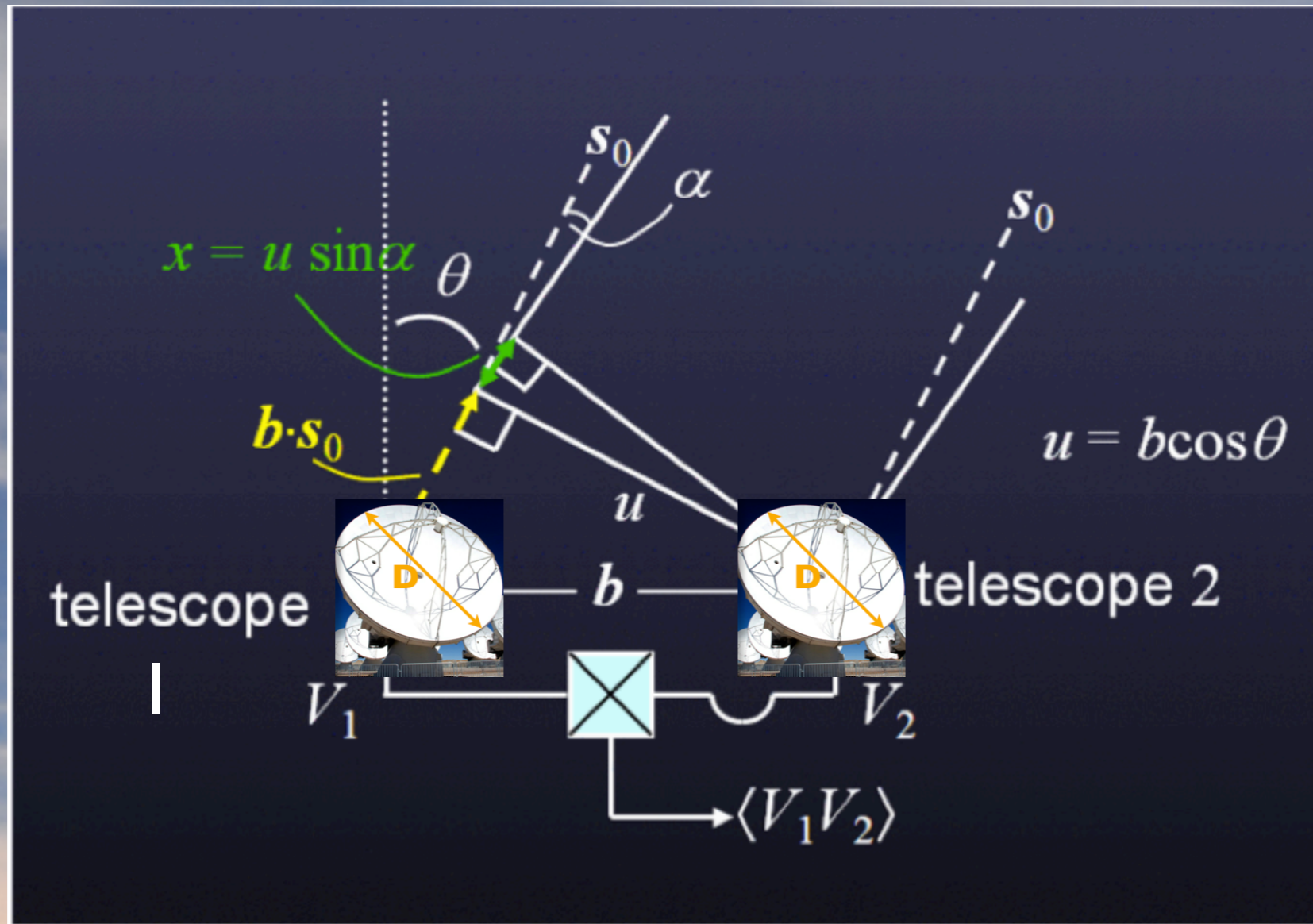
Rayleigh resolution :

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

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}

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

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

k depends on the weighting

Take home message

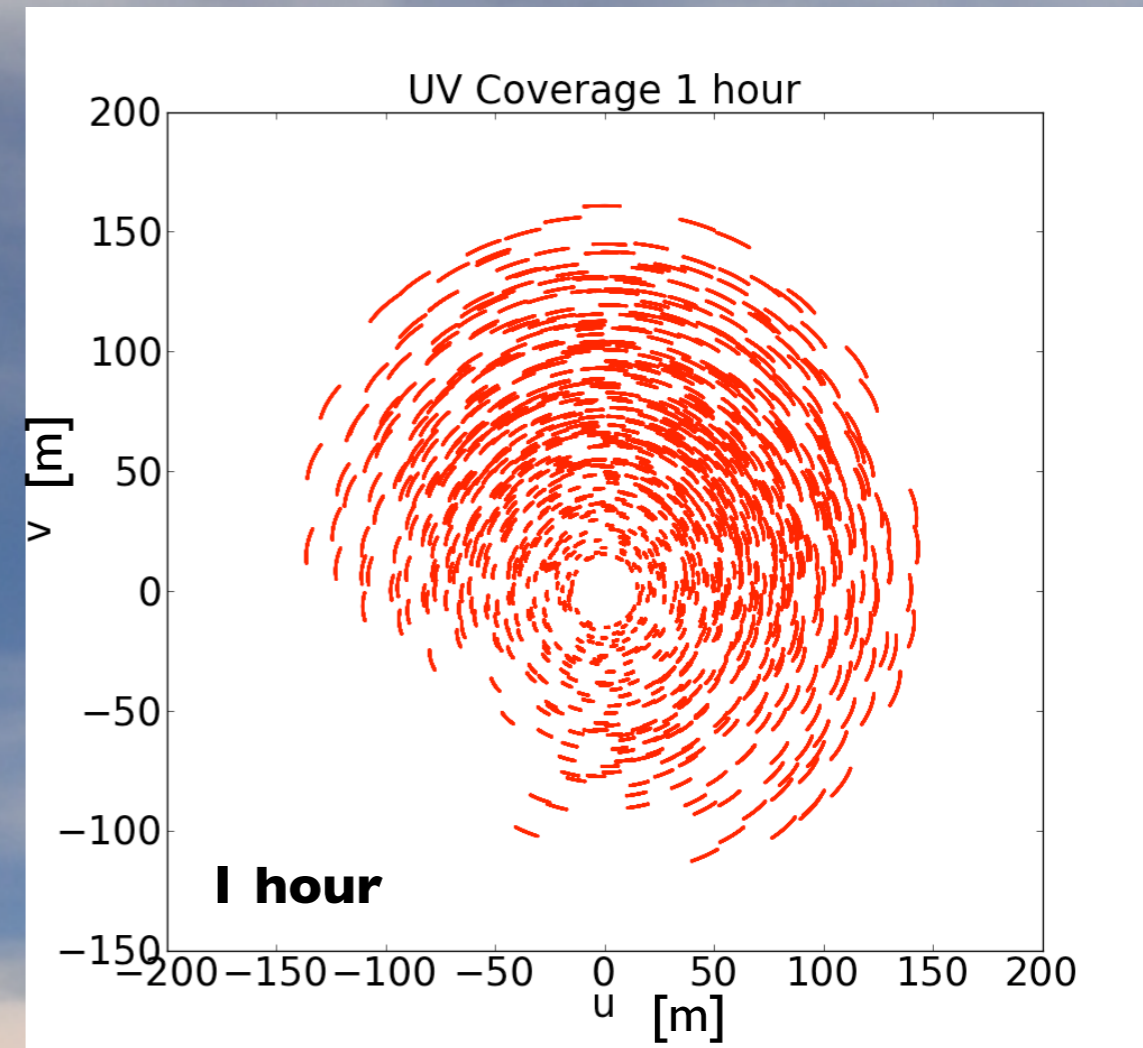
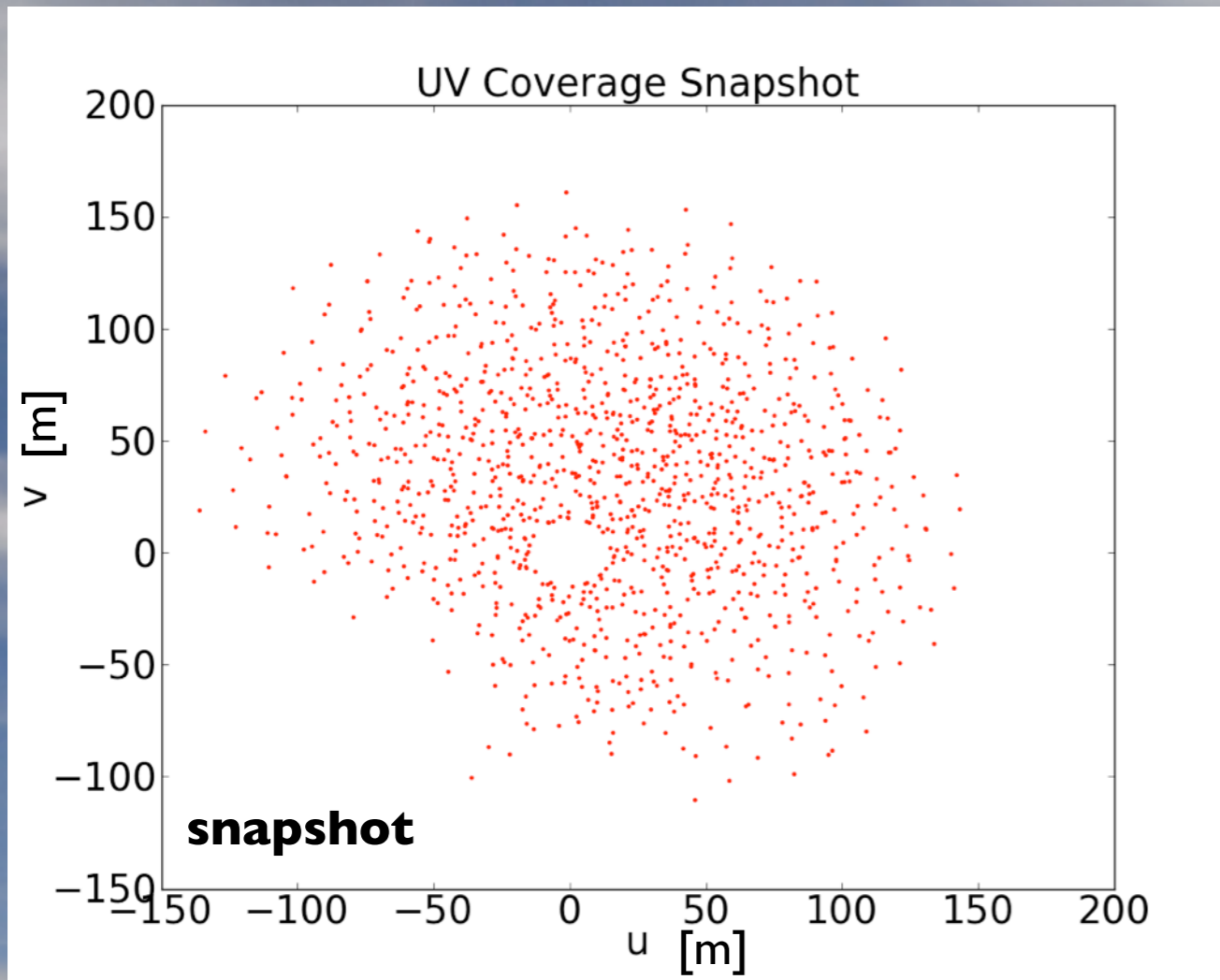
- **The complex visibility is the Fourier transform of the sky brightness distribution in the image plane**
- **The interferometer is a spatial sampler: we don't have full uv-coverage (there are holes in the uv-plane and thus missing information). In particular, we miss information on large angular scales.**
- **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

The screenshot displays the ALMA Observing Tool (Cycle3-Patchtests) - Project interface. The window title is "ALMA Observing Tool (Cycle3-Patchtests) - Project". The interface is divided into two main sections: "Project Structure" on the left and "Editors" on the right.

Project Structure: A tree view showing the project hierarchy. The "Unsubmitted Proposal" is expanded, showing "Project" > "Proposal" > "Planned Observing" > "ScienceGoal (Science Goal)". Under "ScienceGoal", several sub-items are listed: "General", "Field Setup" (highlighted), "Spectral Setup", "Calibration Setup", "Control and Performance", and "Technical Justification".

Editors: The main editing area, currently on the "Field Setup" tab. It contains the following sections:

- Source:** Fields for "Source Name" (with a "Resolve" button), "Choose a Solar System Object?" (checkbox), "Name of object" (dropdown, currently "Unspecified"), "System" (dropdown, currently "FK5 J2000"), "Sexagesimal display?" (checkbox, checked), "Parallax" (input, "0.00000", unit "mas"), "RA" (input, "00:00:00.0000", unit "mas/yr"), "Dec" (input, "00:00:00.000", unit "mas/yr"), "PM RA" (input, "0.00000", unit "mas/yr"), "PM DEC" (input, "0.00000", unit "mas/yr"), "Source Radial Velocity" (input, "0.000", unit "km/s", "lsrk" dropdown), "z" (input, "0.000000000", "Doppler Type" dropdown, currently "RADIO"), and "Target Type" (radio buttons for "Individual Pointing(s)" and "1 Rectangular Field").
- Expected Source Properties:** Fields for "Peak Continuum Flux Density per Synthesized Beam" (input, "0.00000", unit "Jy"), "Continuum Polarization Percentage" (input, "0.0", unit "%"), "Peak Line Flux Density per Synthesized Beam" (input, "0.00000", unit "Jy"), "Line Width" (input, "0.00000", unit "km/s"), and "Line Polarization Percentage" (input, "0.0", unit "%").
- Field Center Coordinates:** Fields for "Custom Mosaic" (checkbox), "PointingPattern" (dropdown, currently "Offset", checked), "Offset Unit" (dropdown, currently "arcsec"), and "#Pointings" (input, "1"). Below these is a table with columns "RA [arcsec]" and "Dec [arcsec]":

RA [arcsec]	Dec [arcsec]
0.00000	0.00000

At the bottom of the "Editors" panel, there are buttons for "Add", "Delete", "Import", and "Export". Below the entire "Editors" panel, there are buttons for "Add Source", "Load from File...", "Export to File...", "Delete Source", and "Delete All Sources".

Step 1: spatial scale parameters

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

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 ($1.13 * \lambda / D$)	12m	<input type="text" value="0.000 arcsec"/>	7m	<input type="text" value="0.000 arcsec"/>	
Number of Antennas	12m	<input type="text" value="36"/>	7m	<input type="text" value="10"/>	TP <input type="text" value="2"/>
	Most compact 12m configuration		Most extended 12m configuration		
Longest baseline (L_{max})	<input type="text" value="0.161 km"/>	<input type="text" value="9.744 km"/>			
Synthesized beamsize (λ/L_{max})	<input type="text" value="0.000 arcsec"/>	<input type="text" value="0.000 arcsec"/>			
Shortest baseline (L_{min})	<input type="text" value="0.015 km"/>	<input type="text" value="0.346 km"/>			
Maximum recoverable scale ($0.6\lambda/L_{min}$)	<input type="text" value="0.000 arcsec"/>	<input type="text" value="0.000 arcsec"/>			

Desired Performance

Desired Angular Resolution (Synthesized Beam)	<input type="text" value="0.00000"/>	<input type="text" value="arcsec"/>	▼
Largest Angular Structure in source	<input type="text" value="40.0"/>	<input type="text" value="arcsec"/>	▼

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Most compact 12m configuration Most extended 12m configuration

Longest baseline (L_{max})	<input type="text" value="0.161 km"/>	<input type="text" value="9.744 km"/>
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Maximum recoverable scale ($0.6\lambda/L_{min}$)	<input type="text" value="0.000 arcsec"/>	<input type="text" value="0.000 arcsec"/>

Desired Performance

Desired Angular Resolution (Synthesized Beam)	<input type="text" value="0.00000"/>	<input type="text" value="arcsec"/>	<input type="button" value="v"/>
Largest Angular Structure in source	<input type="text" value="40.0"/>	<input type="text" value="arcsec"/>	<input type="button" value="v"/>

smallest recoverable scale

Step 1: spatial scale parameters

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Control and Performance ?

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Number of Antennas	12m	<input type="text" value="36"/>	7m	<input type="text" value="10"/>	TP <input type="text" value="2"/>

Most compact 12m configuration Most extended 12m configuration

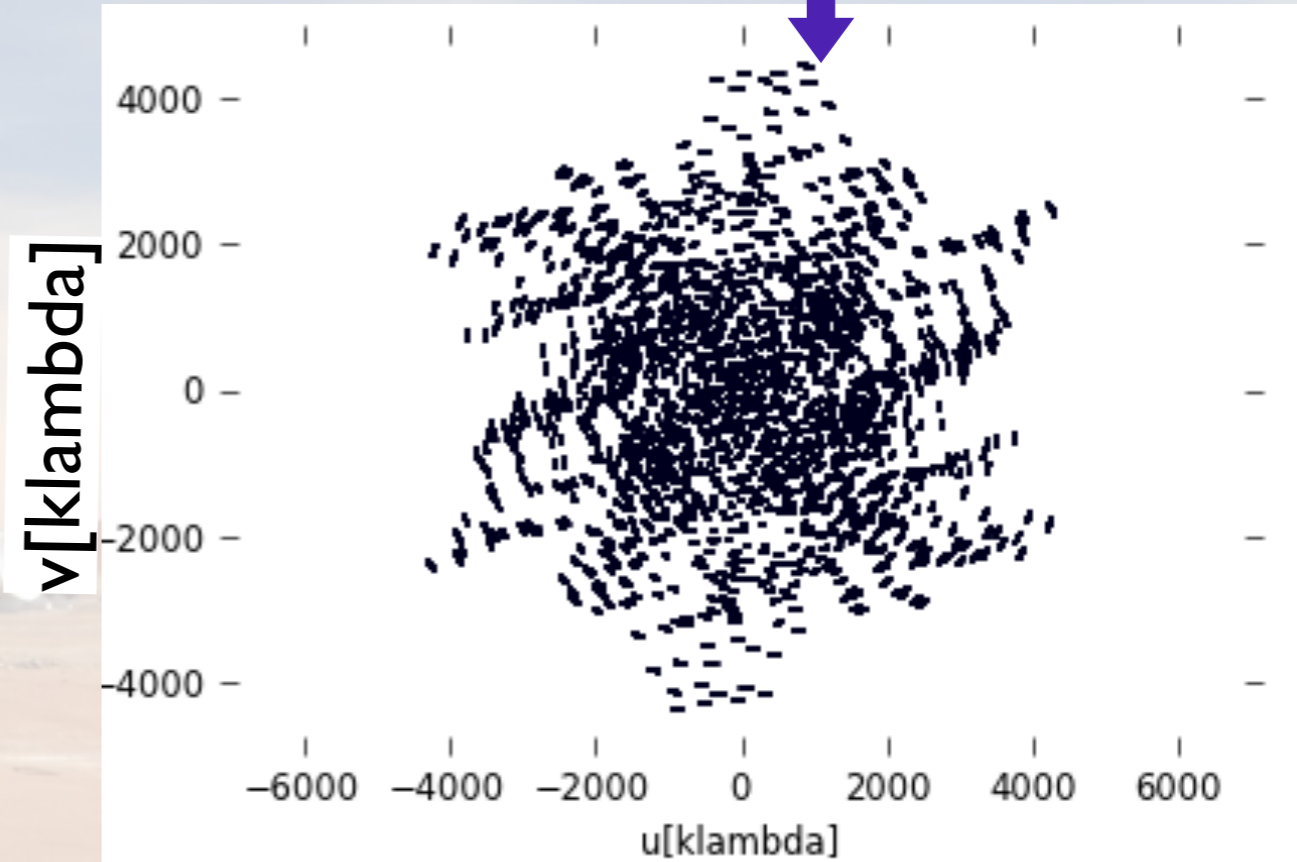
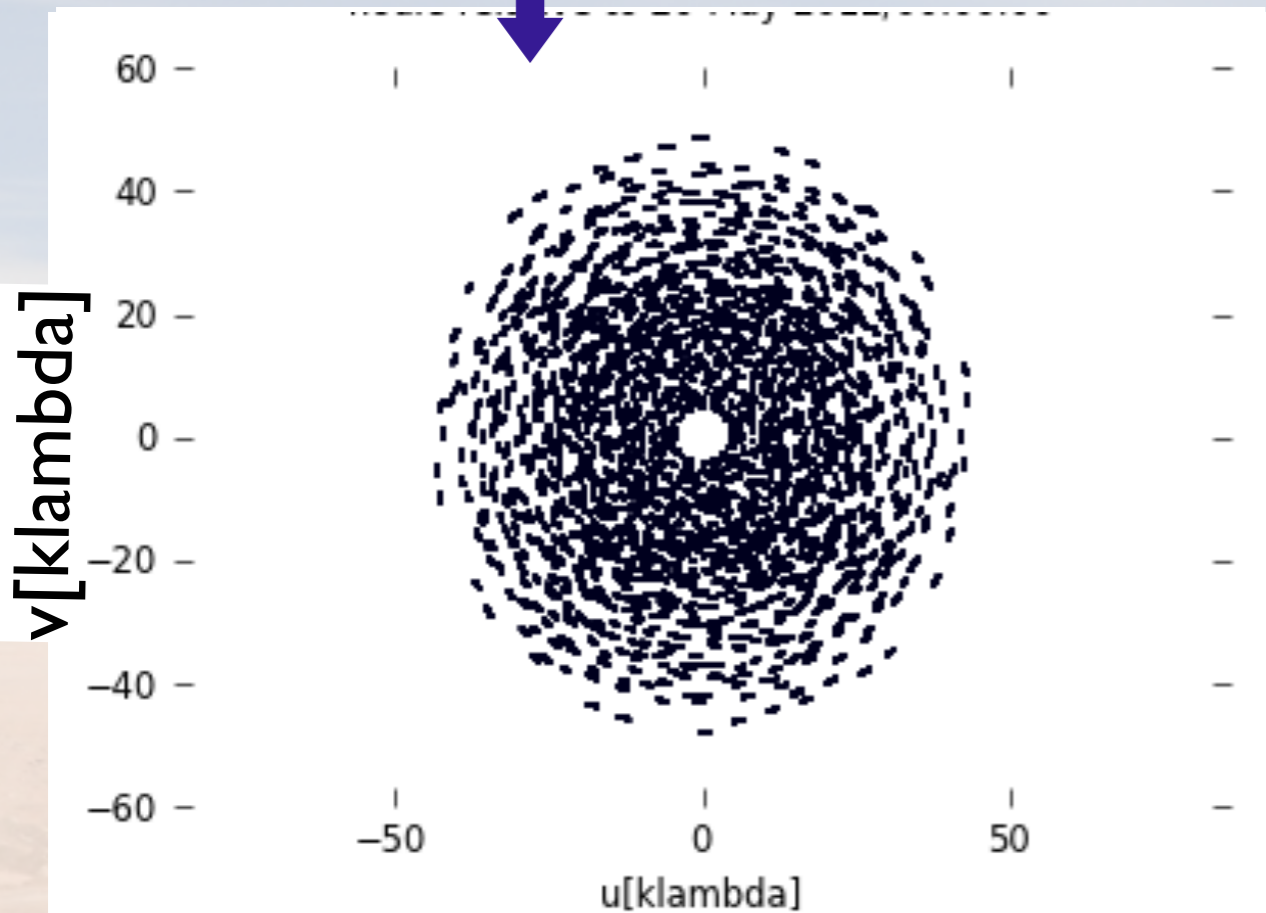
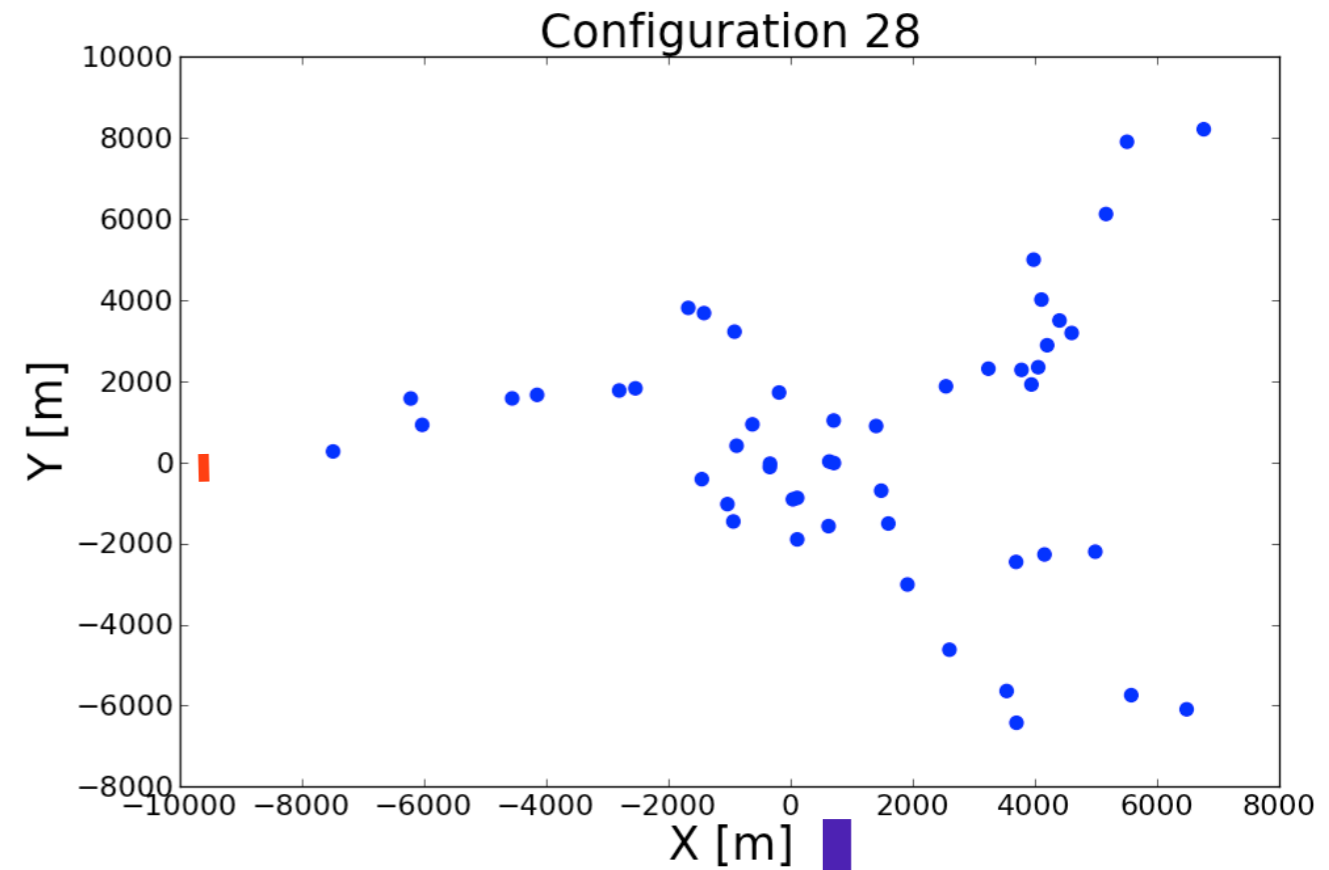
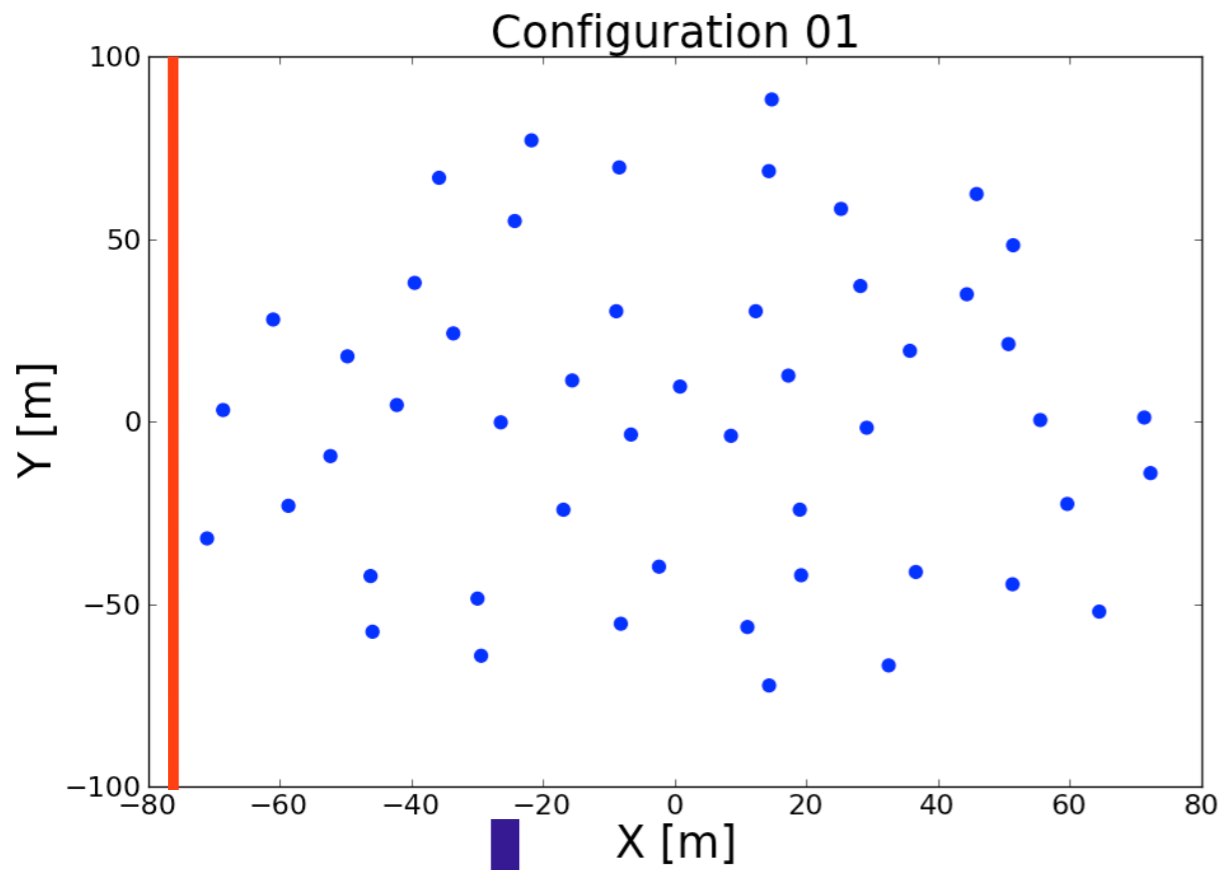
Longest baseline (L_{max})	<input type="text" value="0.161 km"/>	<input type="text" value="9.744 km"/>
Synthesized beamsize (λ/L_{max})	<input type="text" value="0.000 arcsec"/>	<input type="text" value="0.000 arcsec"/>
Shortest baseline (L_{min})	<input type="text" value="0.015 km"/>	<input type="text" value="0.346 km"/>
Maximum recoverable scale ($0.6\lambda/L_{min}$)	<input type="text" value="0.000 arcsec"/>	<input type="text" value="0.000 arcsec"/>

Desired Performance

Desired Angular Resolution (Synthesized Beam)	<input type="text" value="0.00000"/>	arcsec	▼
Largest Angular Structure in source	<input type="text" value="40.0"/>	arcsec	▼

largest recoverable scale

Antenna configurations and uv-coverage

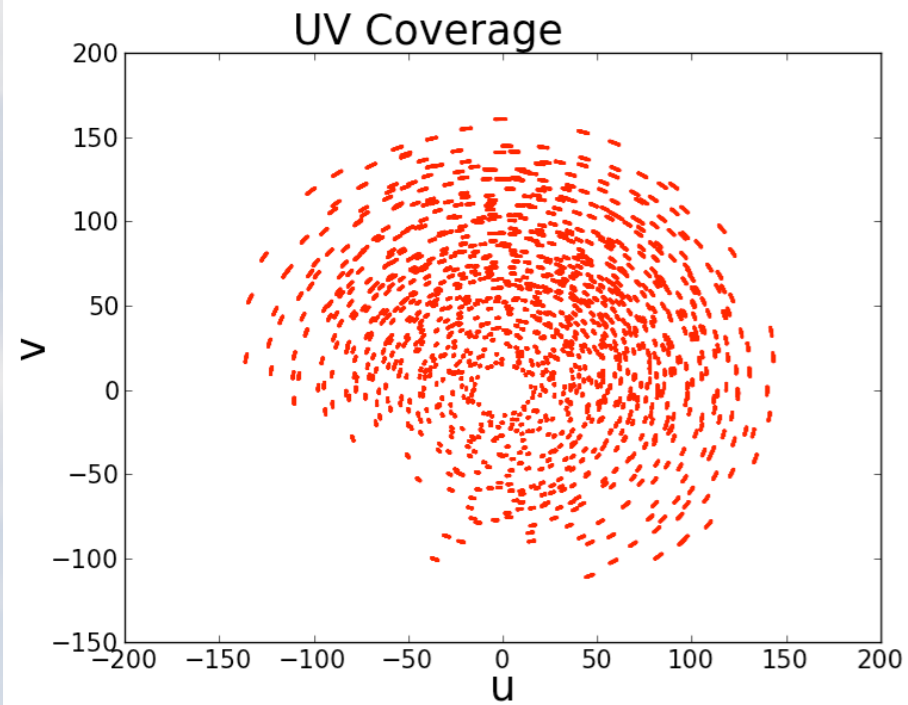


The dirty beam

Theory recap:

$$B(l, m) = \int \int S(u, v) e^{2\pi i(ul+vm)} du dv$$

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

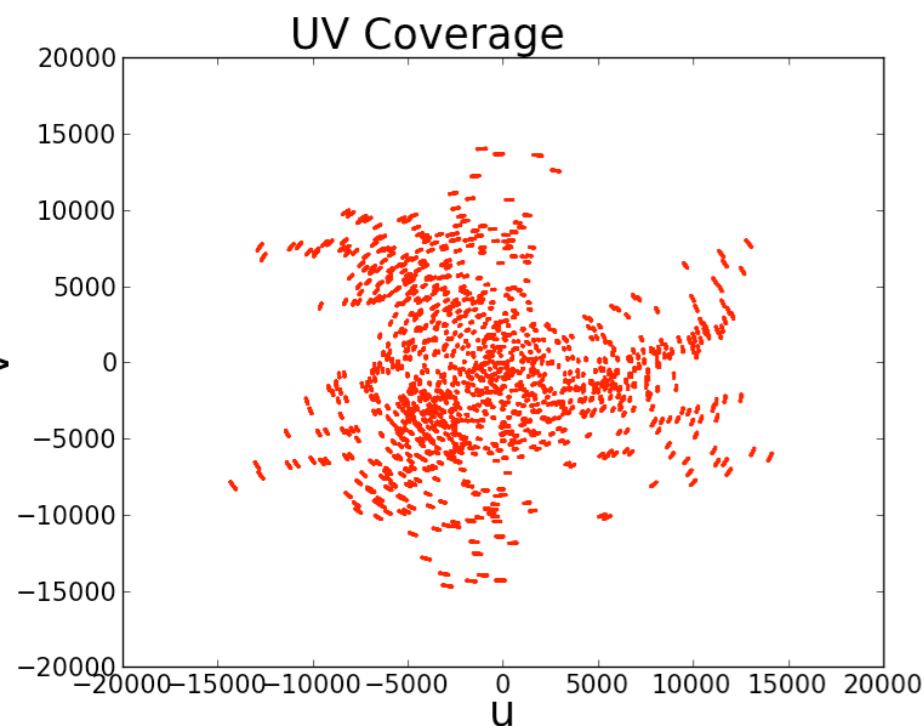
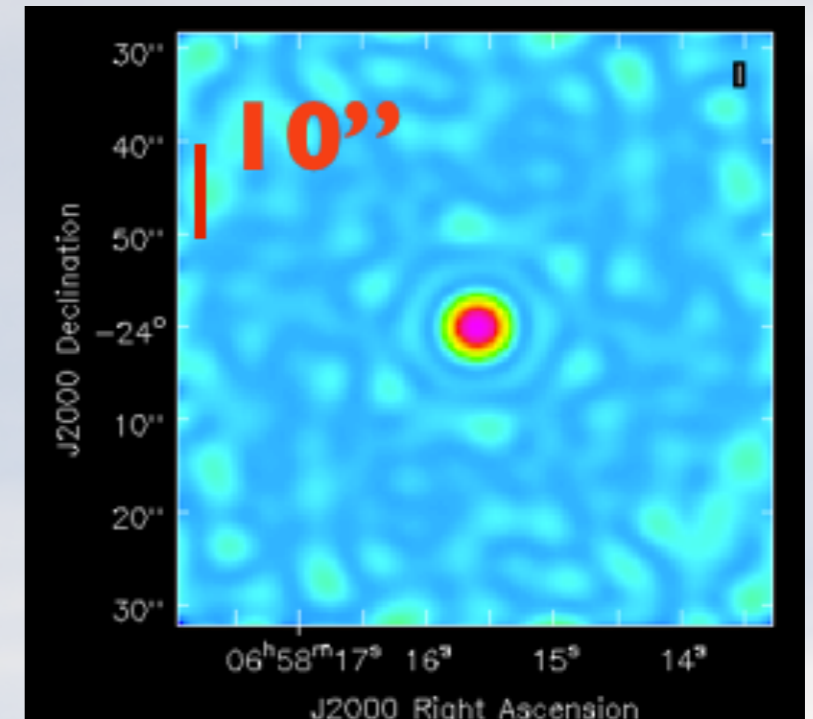


freq: 90.0 GHz



bmaj : 4.45''

bmin : 4.41''

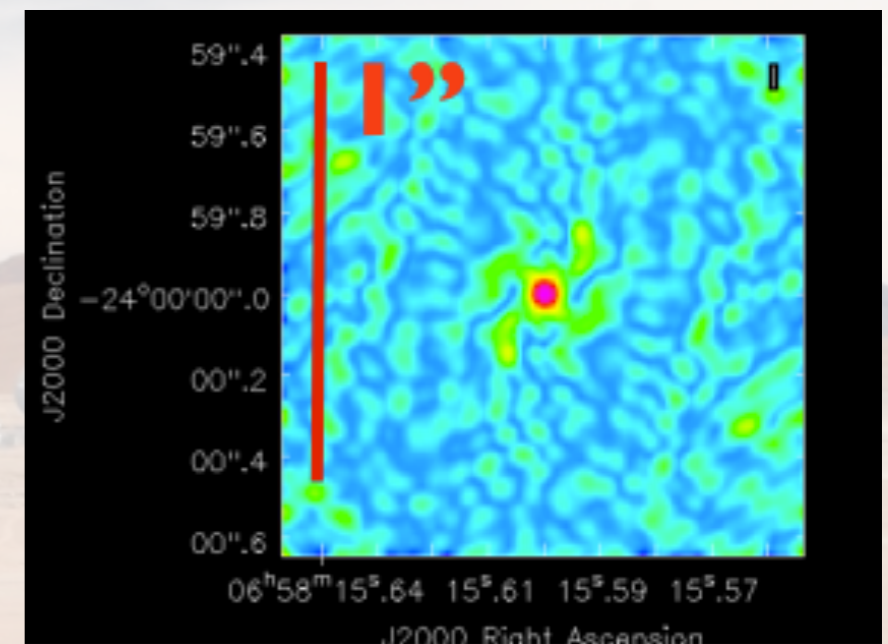


freq: 90.0 GHz



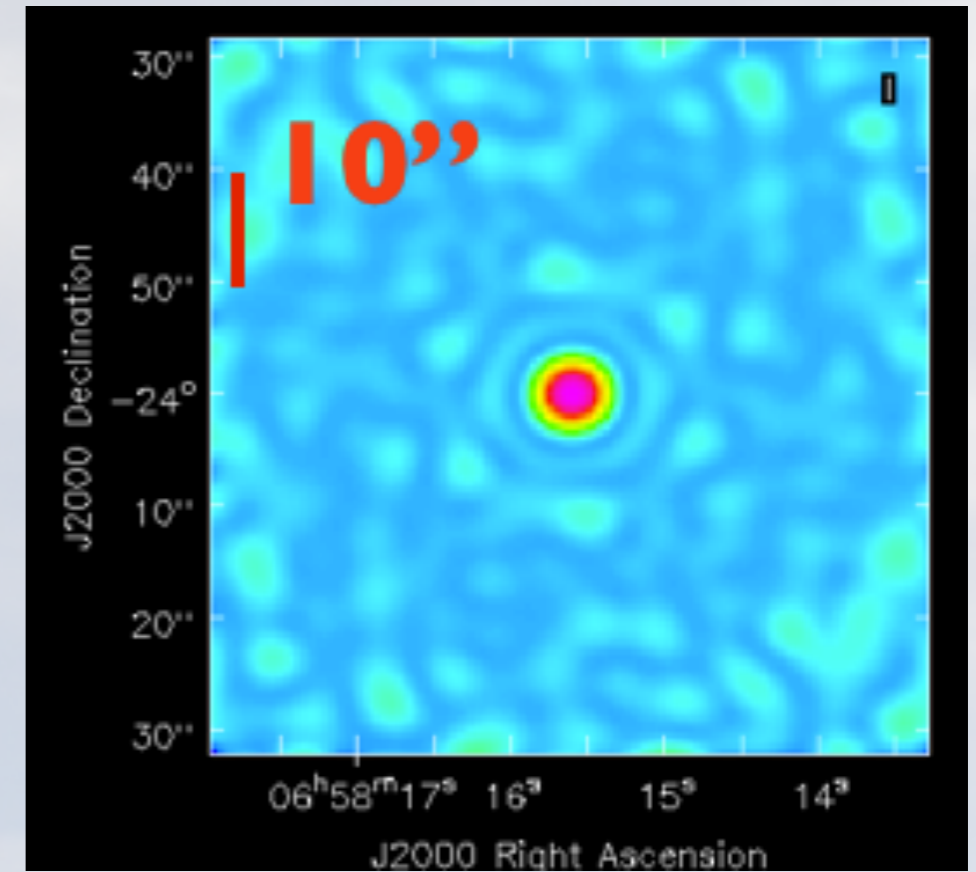
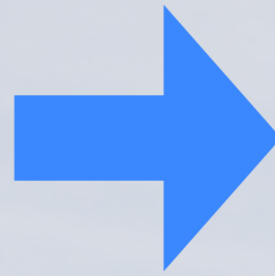
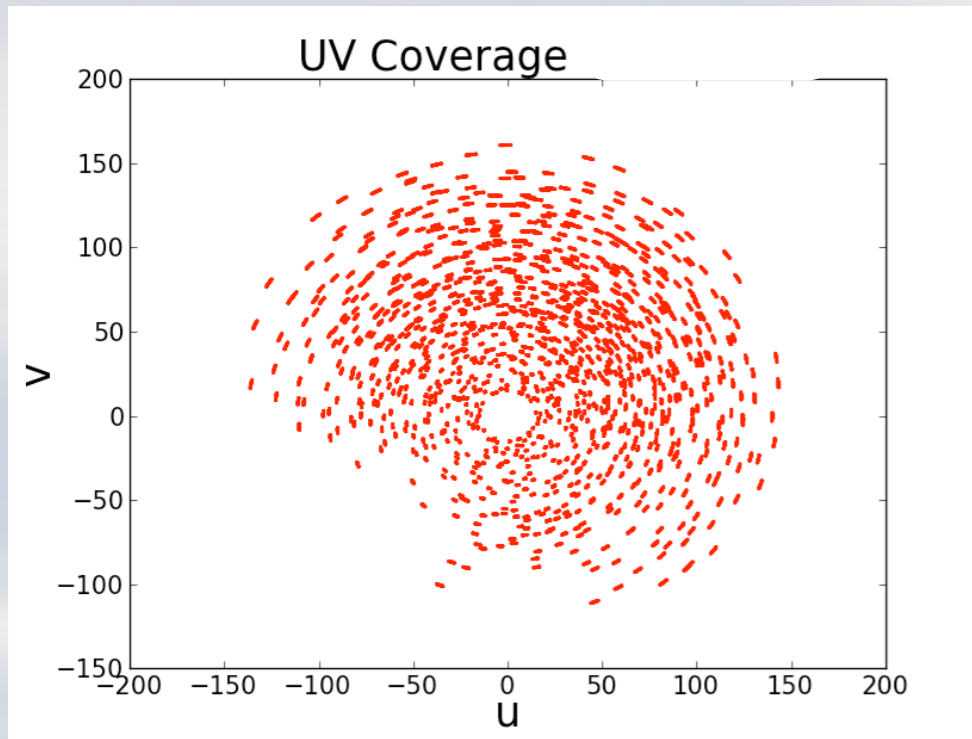
bmaj : 0.25''

bmin : 0.125''

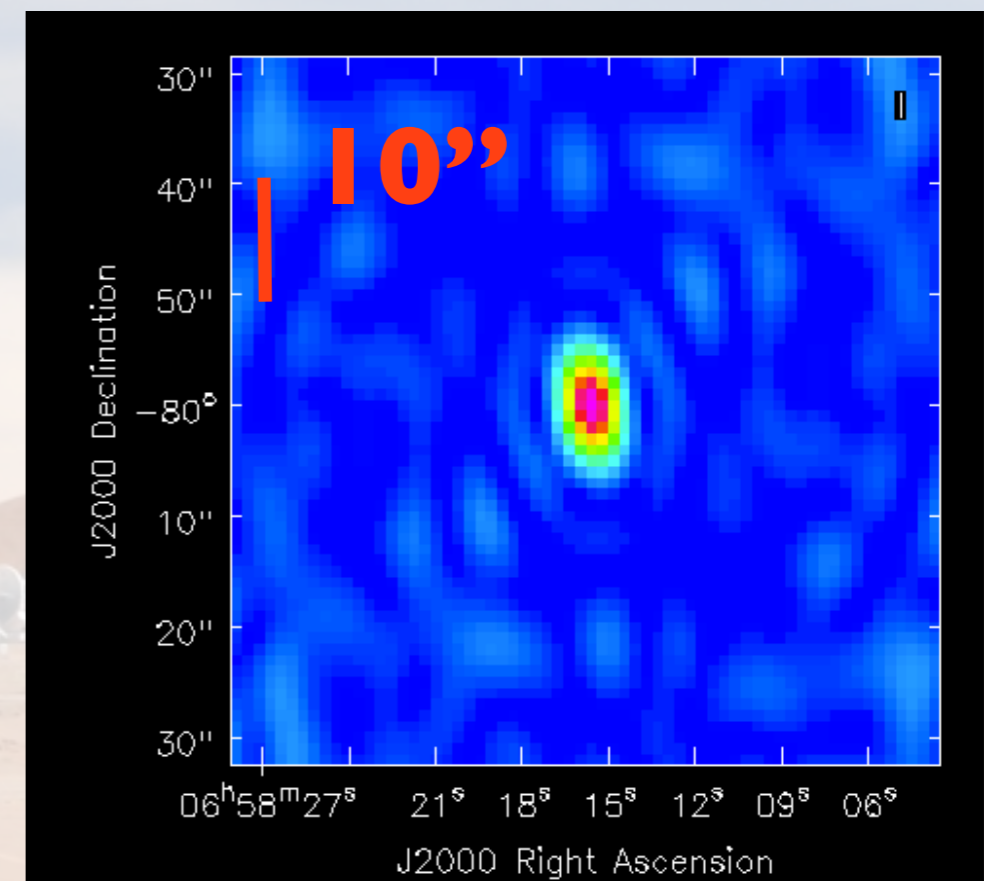
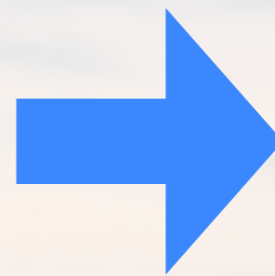
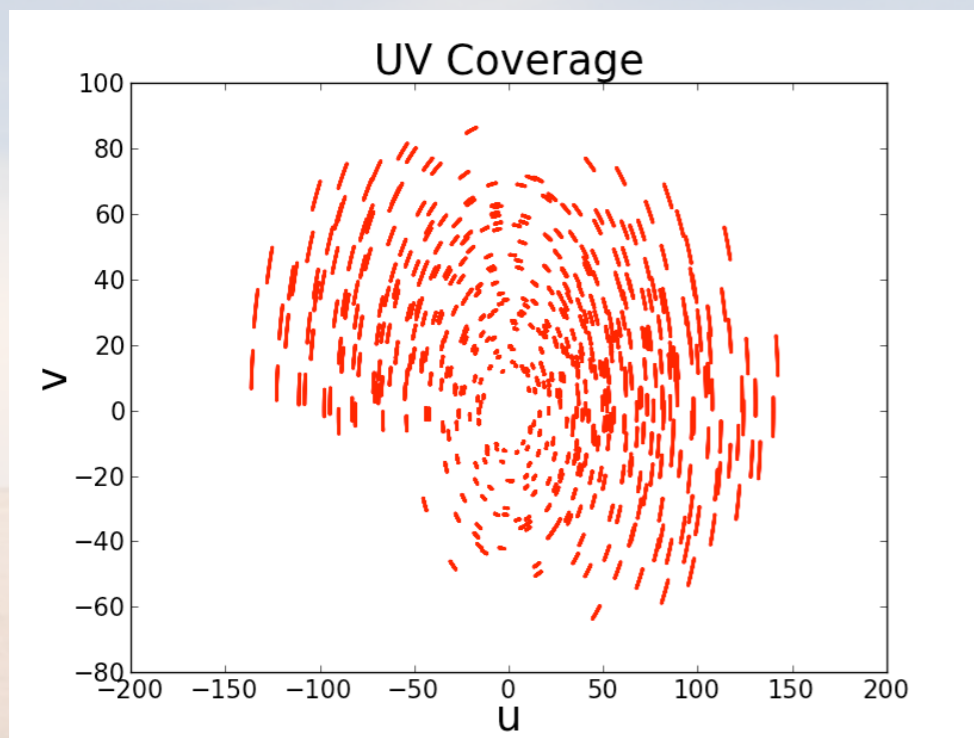


Beam shape and source declination

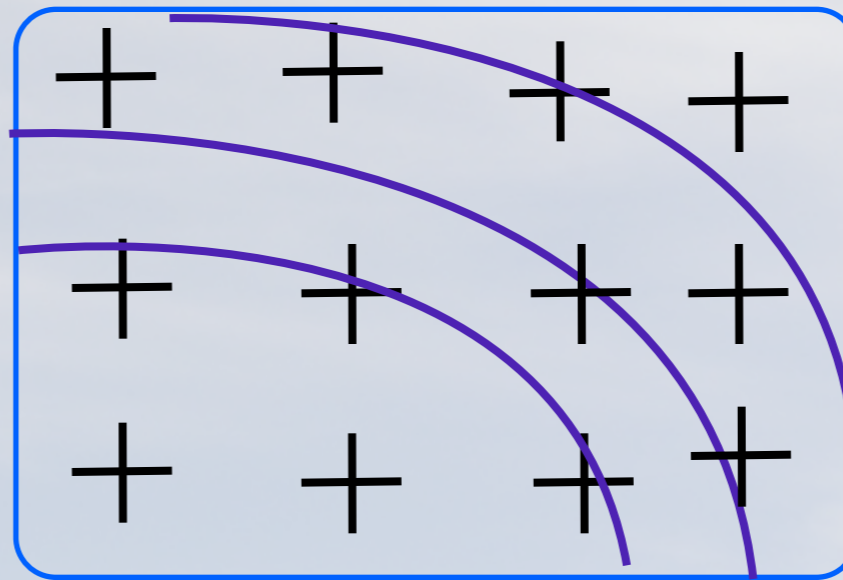
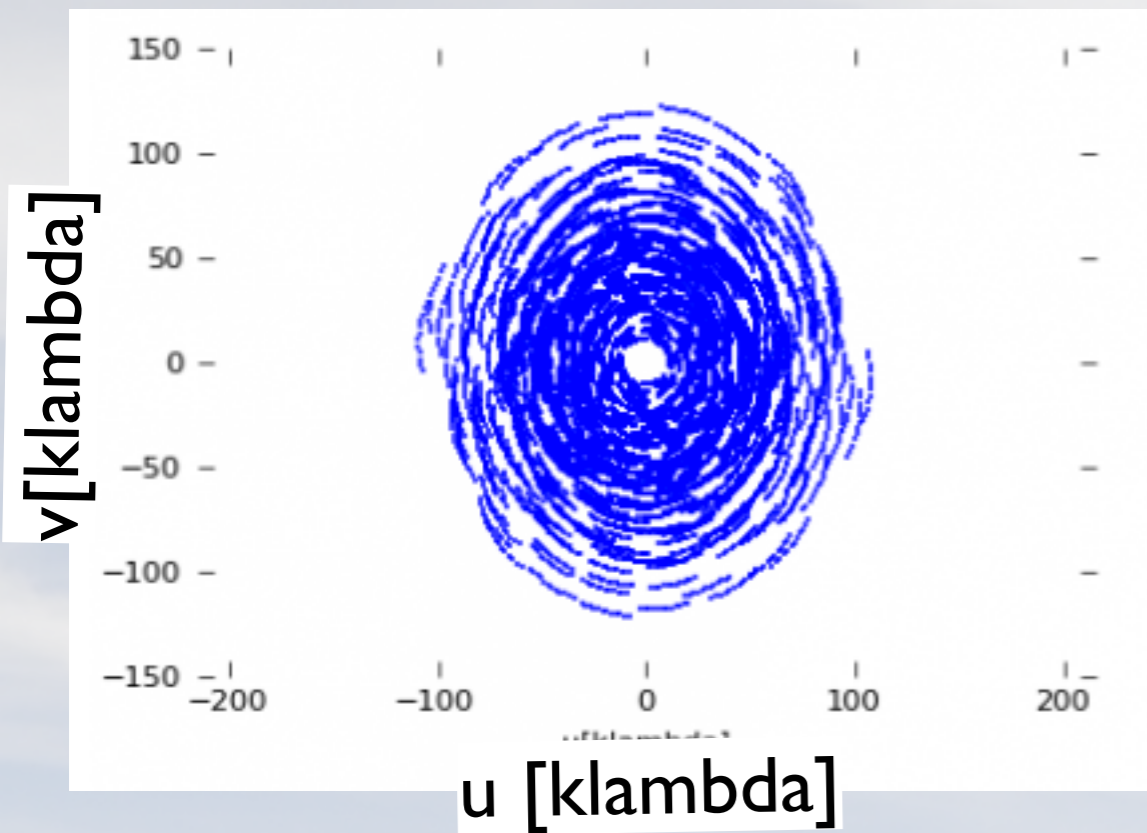
dec: -24.0d



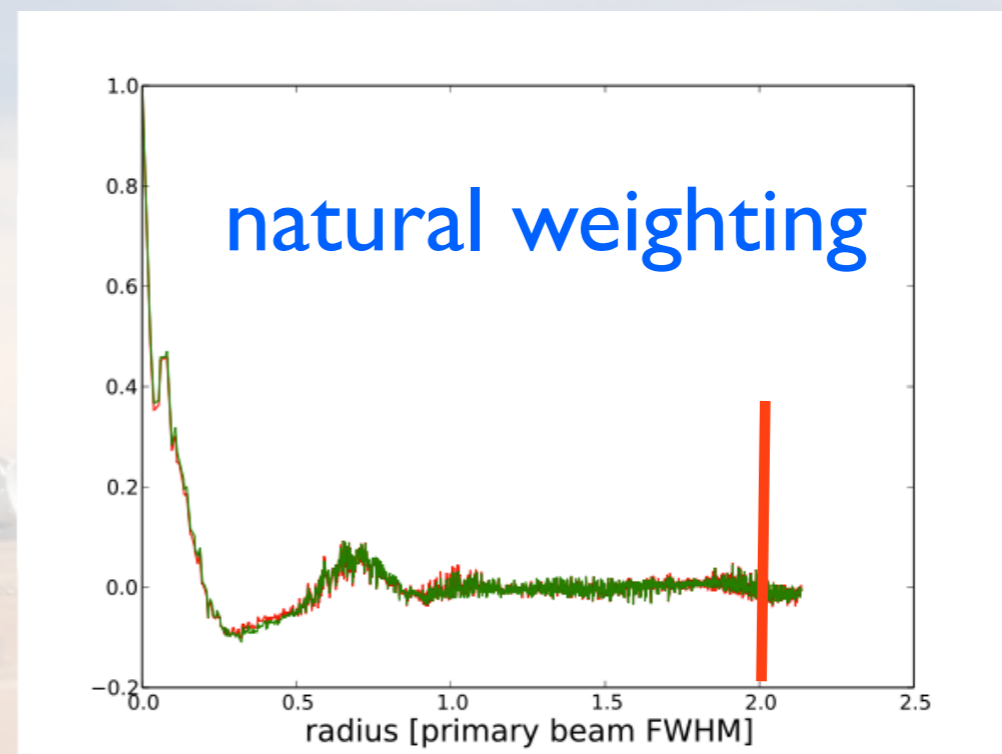
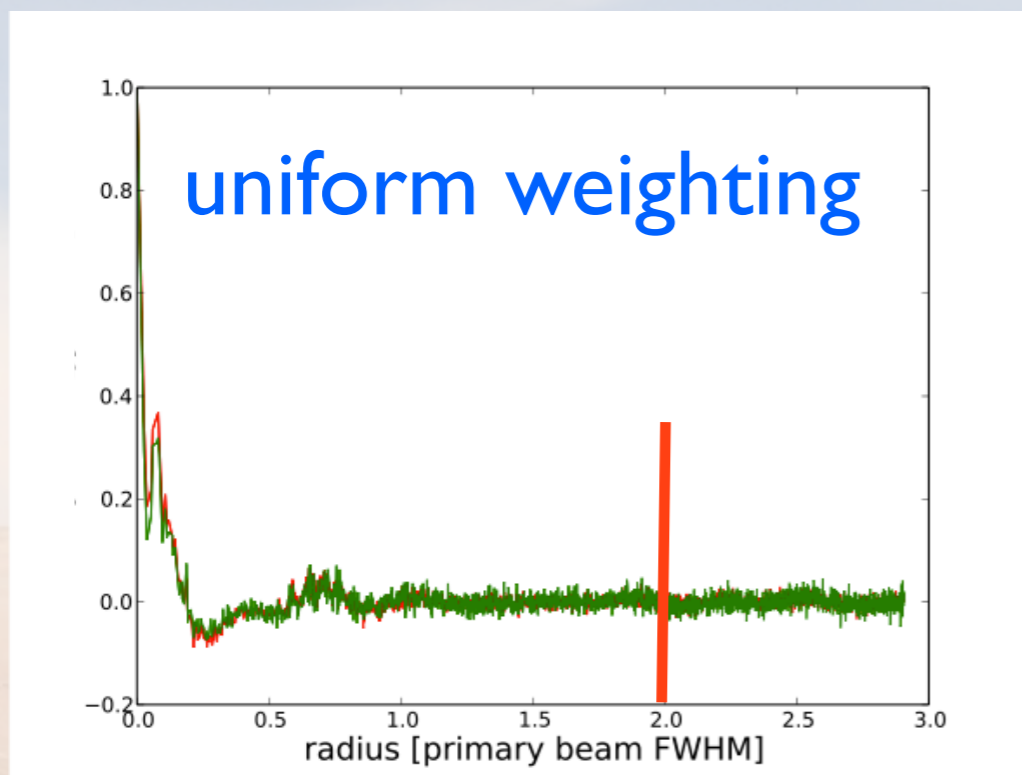
dec: -80.0d



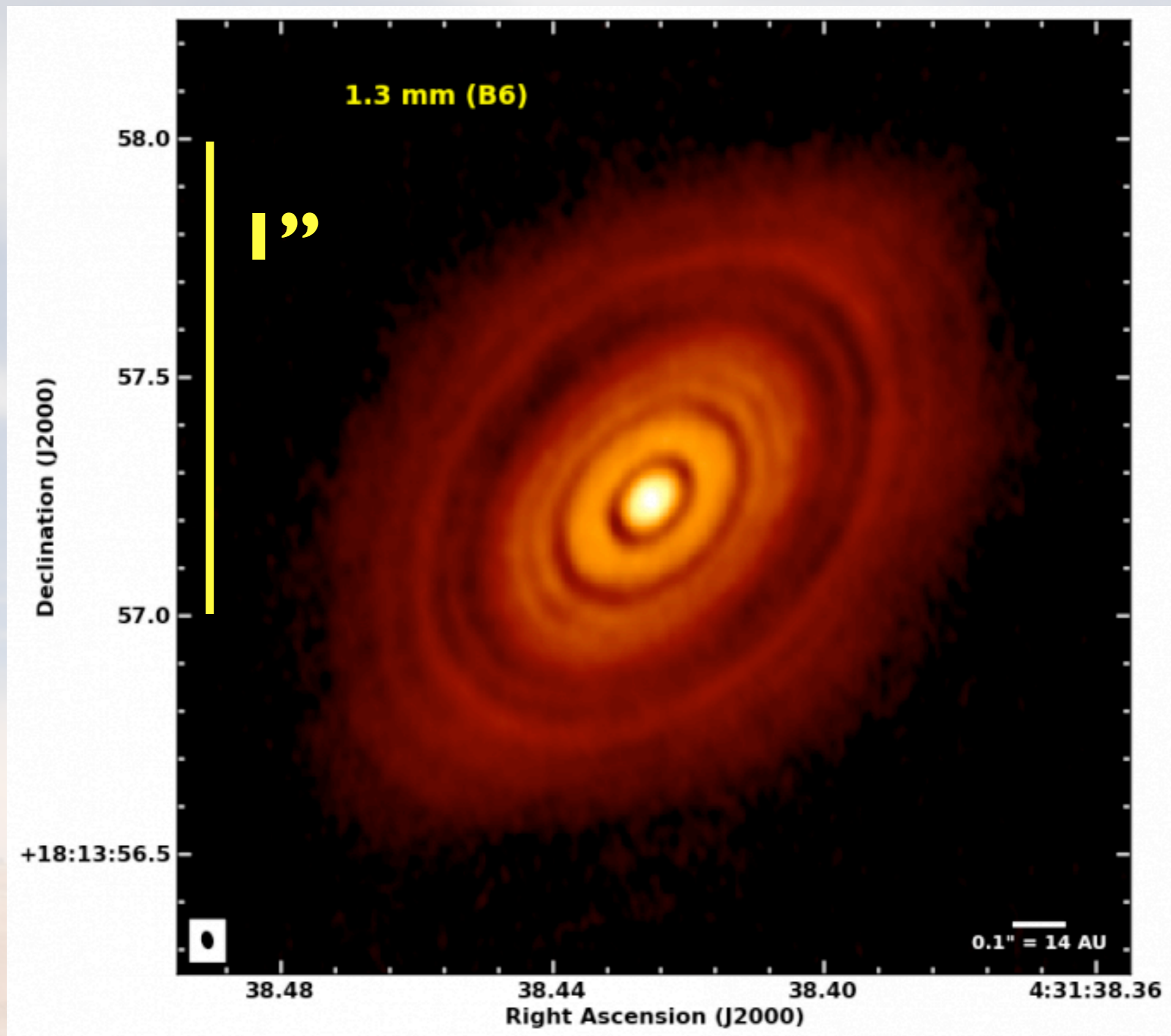
Beam shape and visibility weighting



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)

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

Control and Performance ?

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Maximum recoverable scale ($0.6\lambda/L_{min}$)	<input type="text" value="0.000 arcsec"/>	<input type="text" value="0.000 arcsec"/>	

Desired Performance

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Largest Angular Structure in source	<input type="text" value="40.0"/>	<input type="text" value="arcsec"/>	<input type="button" value="v"/>

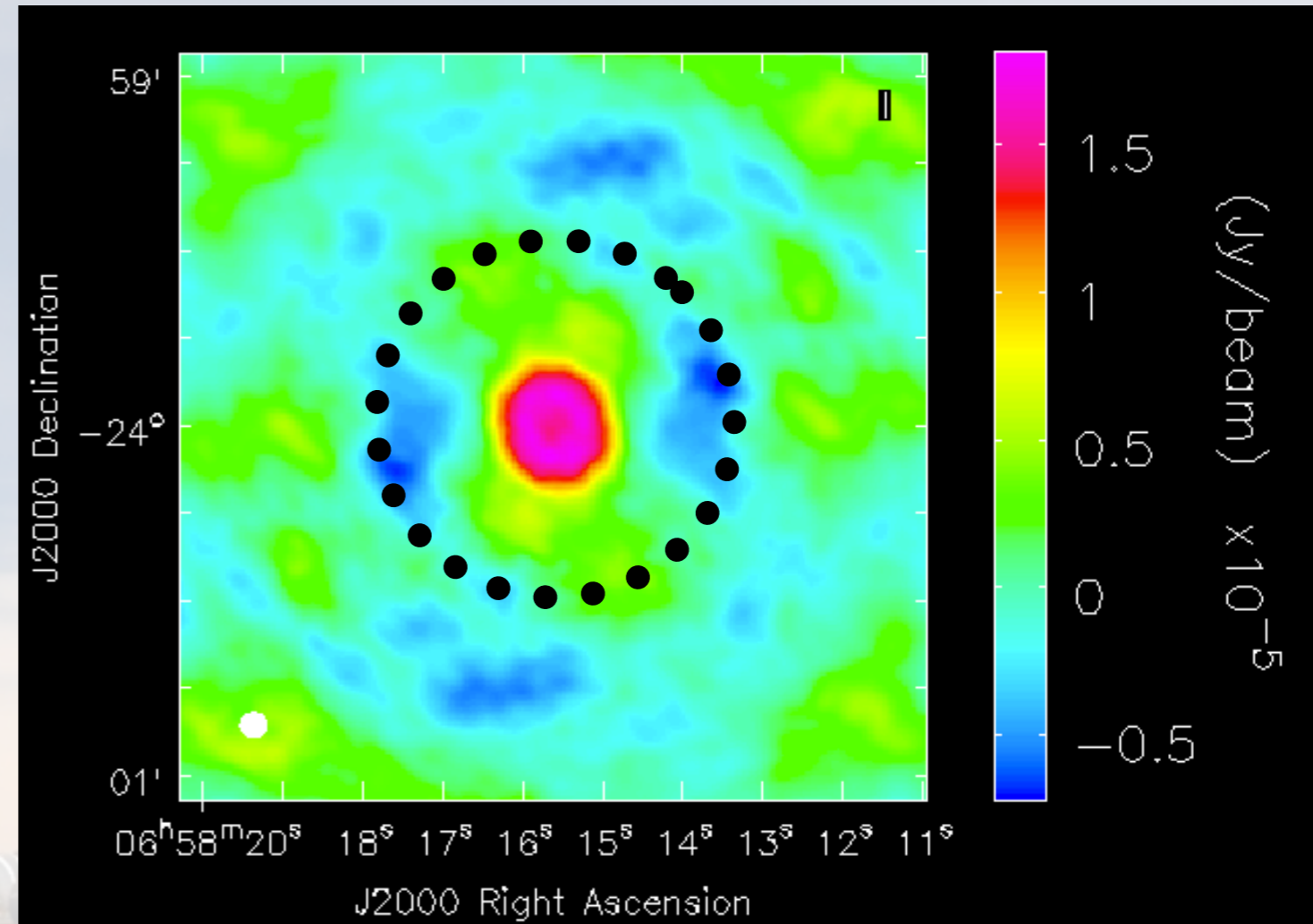
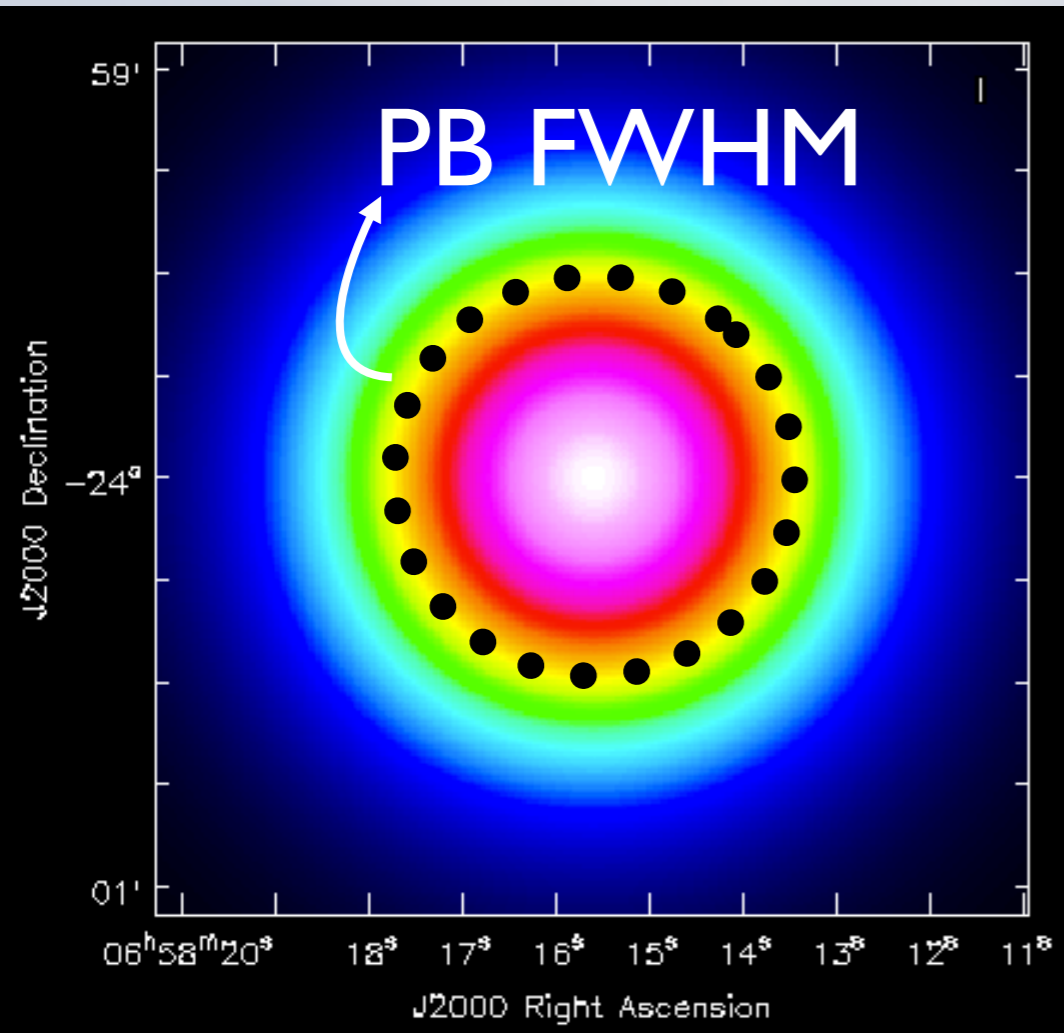
Largest angular scale

Theory recap:

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

input model

deconvolved image



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Largest Angular Structure in source	<input type="text" value="40.0"/>	arcsec <input type="button" value="v"/>

largest recoverable scale

Single pointing or mosaics

Spectral Spatial ScienceGoal (Name_1)

Spatial Image

1x 382, 129 5354.0
12:22:49.015, +15:46:30.06 (J2000)
Image Filename \/.jsky3/cache/jsky2313399165798419977.fits

FOV Parameters

Representative Frequency (Sky) 87.750 GHz
Antenna Diameter 12m
Antenna Beamsize (HPBW) 66.358 arcsec
Show Antenna Beamsize

Image Query

VS

Spectral Spatial ScienceGoal (Name_1)

Spatial Image

1x 110, 341 4980.0
12:23:08.022, +15:50:03.69 (J2000)
Image Filename \/.jsky3/cache/jsky2313399165798419977.fits

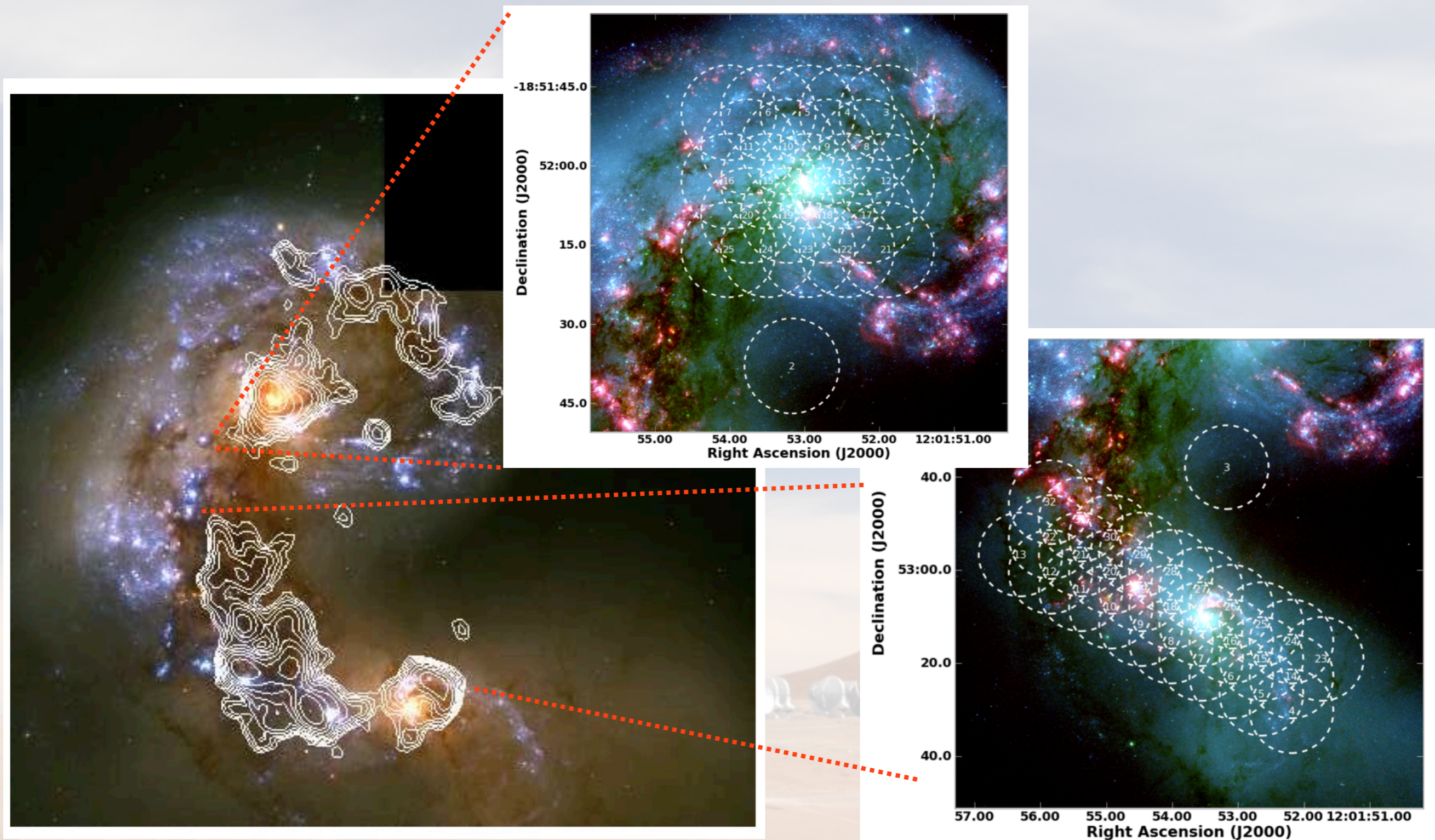
FOV Parameters

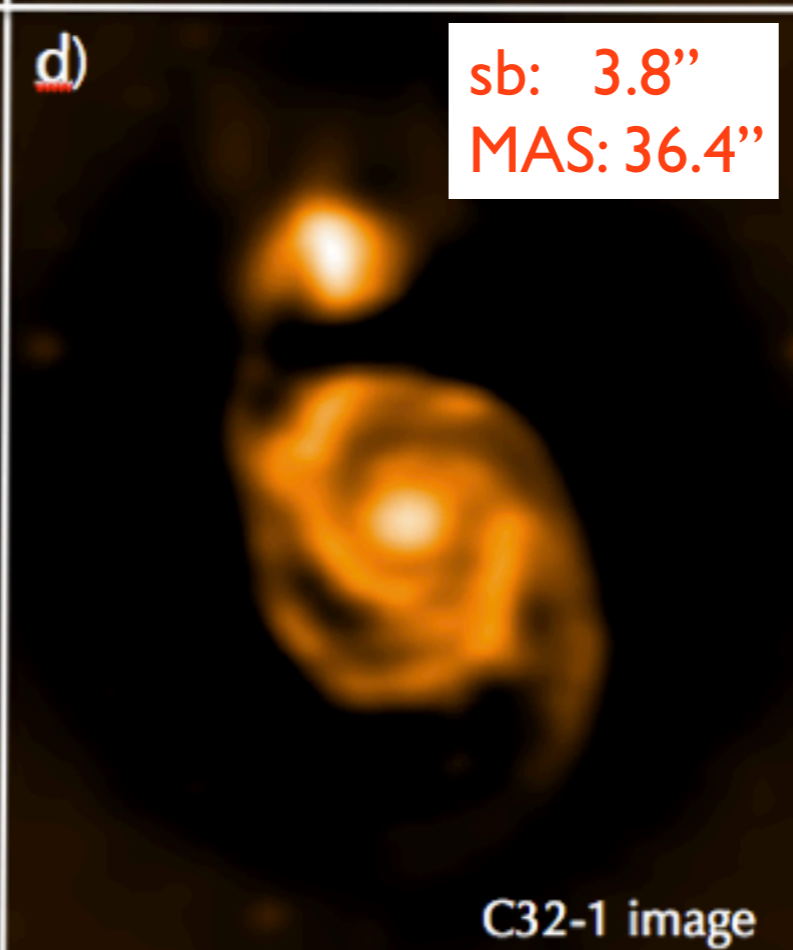
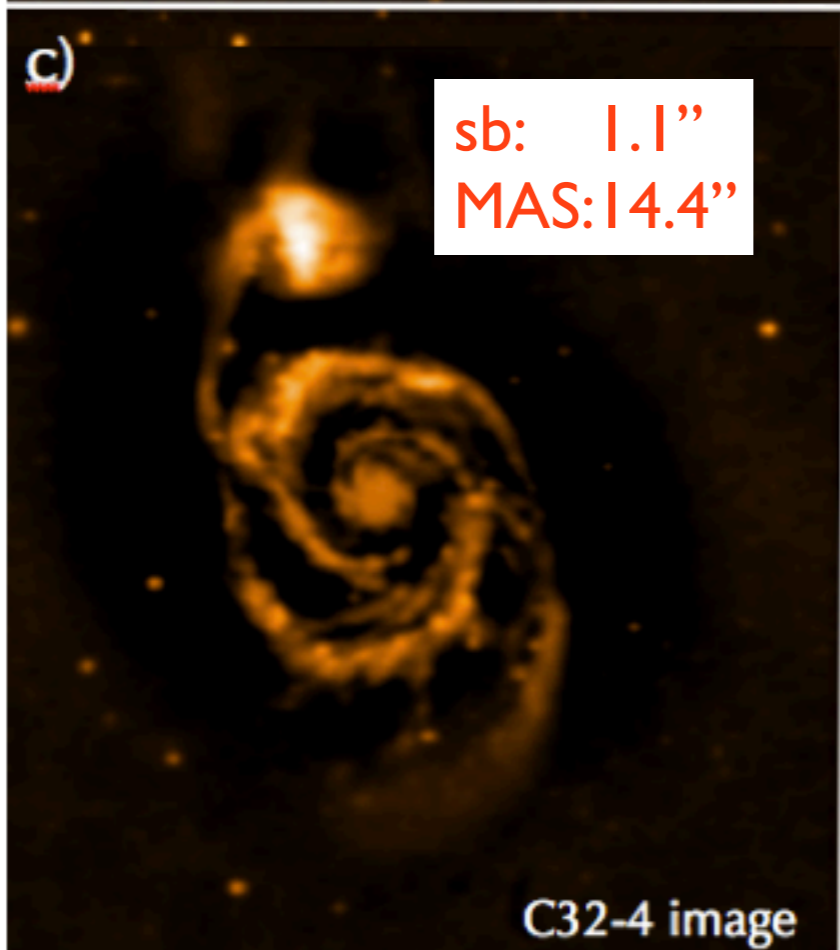
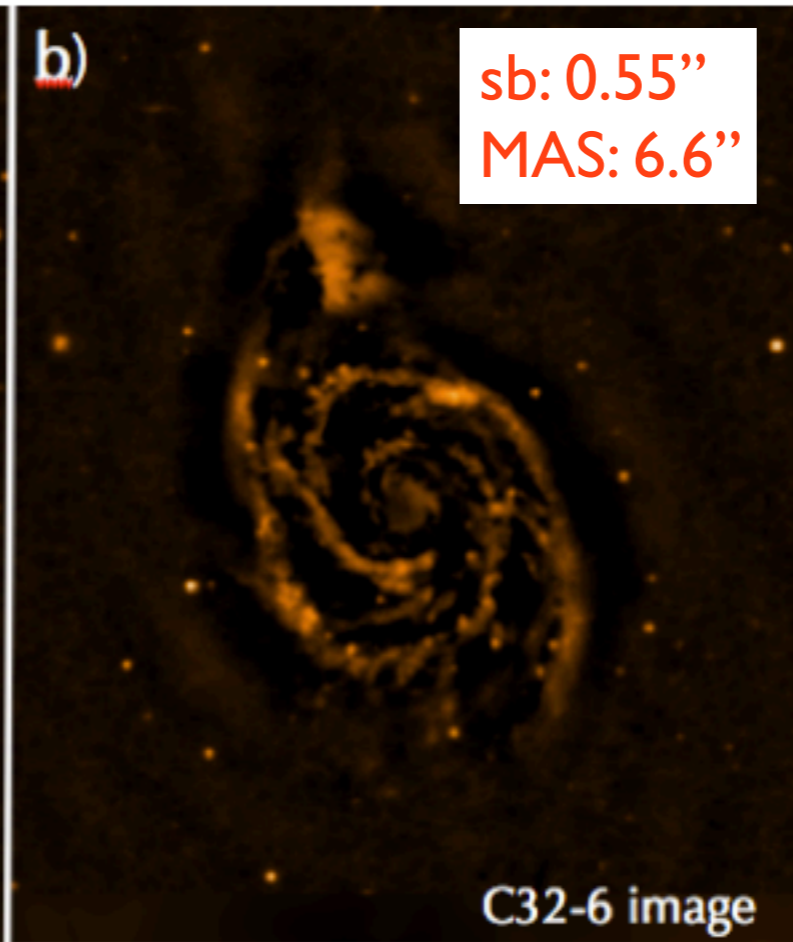
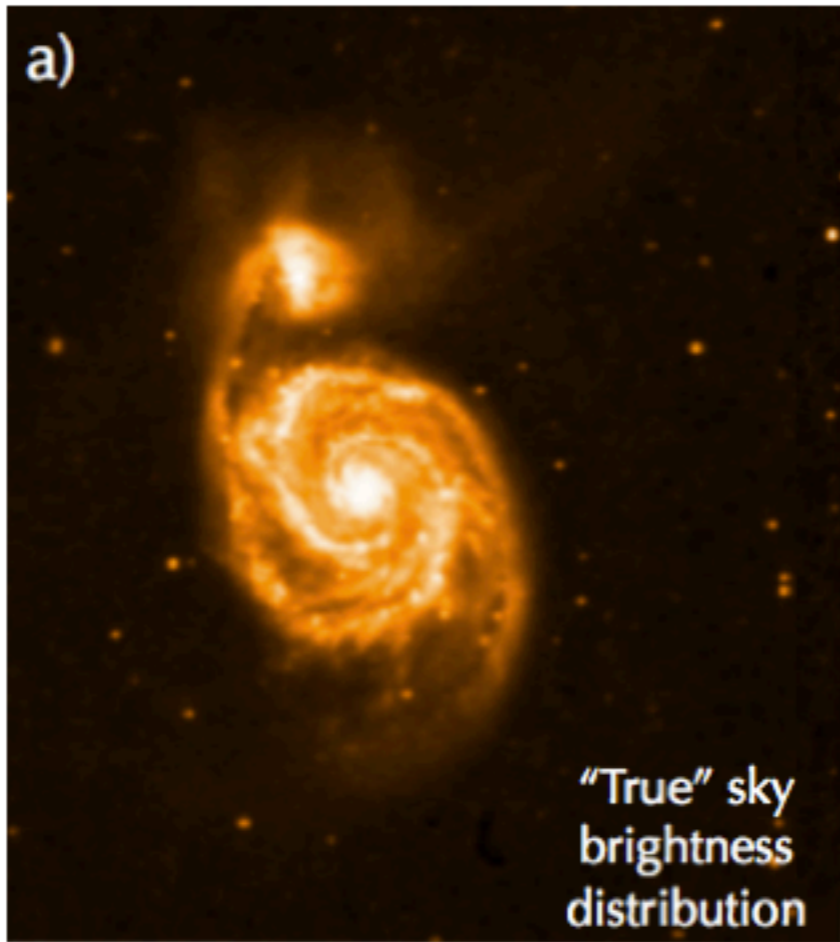
Representative Frequency (Sky) 87.750 GHz
Antenna Diameter 12m
Antenna Beamsize (HPBW) 66.358 arcsec
Show Antenna Beamsize

Image Query

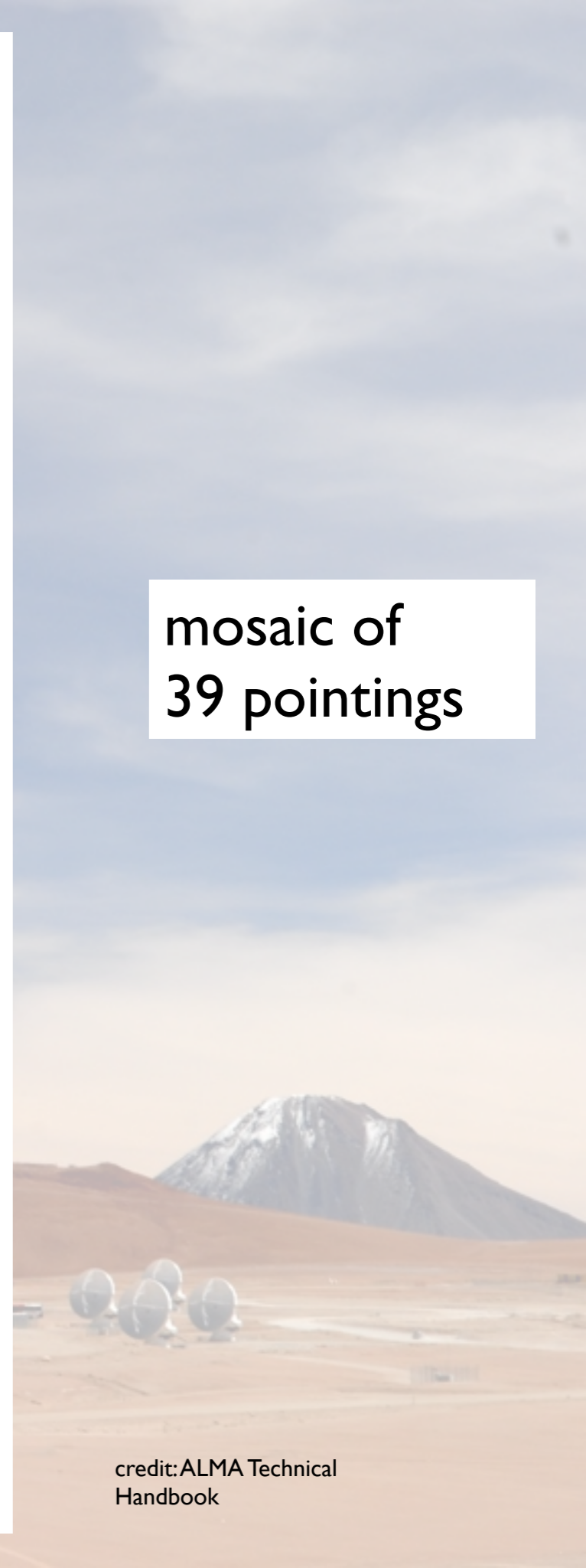
Single pointing or mosaics

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





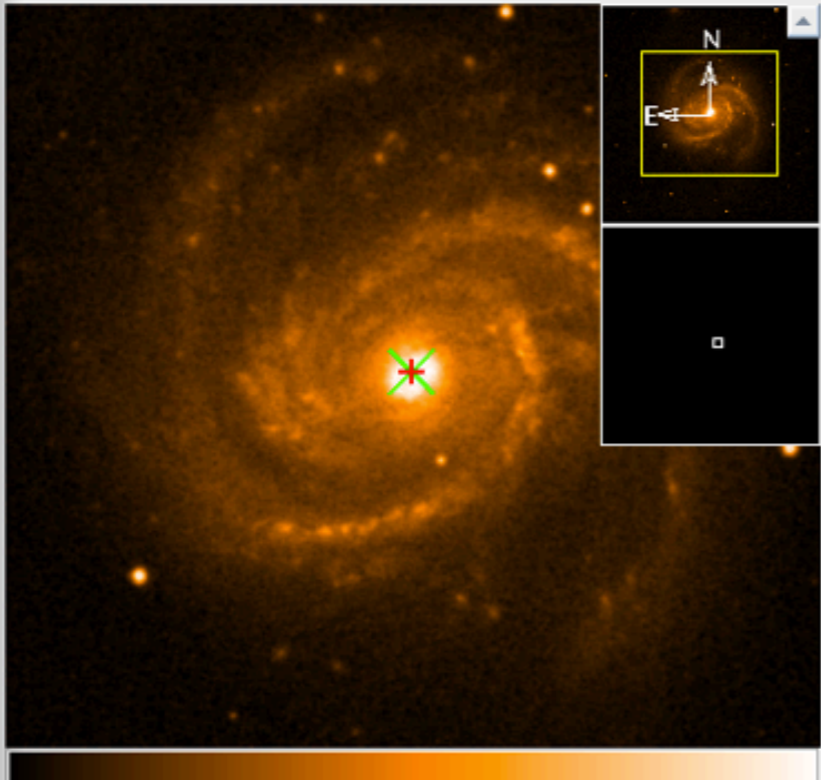
mosaic of
39 pointings



Single pointing or mosaics: the AOT

Spectral Spatial Field Setup

Spatial Image



M100

Source

Source Name: M100

Choose a Solar System Object? Name of object: Unspecified

System: FK5 J2000 Sexagesimal display?

Source Coordinates: RA: 12:22:54.8989 Dec: 15:49:20.570

Parallax: 0.00000 mas

PM RA: 0.00000 mas/yr

PM DEC: 0.00000 mas/yr

Resolved by cdsws.u-strasbg.fr (SIMBAD)

Source Radial Velocity: 1569.779 km/s hel z: 0.005250000 Doppler Type: RELATIVISTIC

Target Type: Individual Pointing(s) 1 Rectangular Field

Expected Source Properties

Peak Continuum Flux Density per Synthesized Beam: 0.00000 Jy

Continuum Polarization Percentage: 0.0 %

Peak Line Flux Density per Synthesized Beam: 0.00000 Jy

Line Width: 0.00000 km/s

Line Polarization Percentage: 0.0 %

Field Center Coordinates

Custom Mosaic:

PointingPattern: Offset

Offset Unit: arcsec

#Pointings: 1

RA [arcsec]	Dec [arcsec]
0.00000	0.00000

Add Delete Import Export

Add Source Load from File... Export to File... Delete Source Delete All Sources

Image Filename: \j.sky3/cache/jsky1814992724433392157.fits

FOV Parameters

Representative Frequency (Sky): 0.000 GHz

Antenna Diameter: 12m

Antenna Beamsize (HPBW): 0.000 arcsec

Show Antenna Beamsize:

Image Query

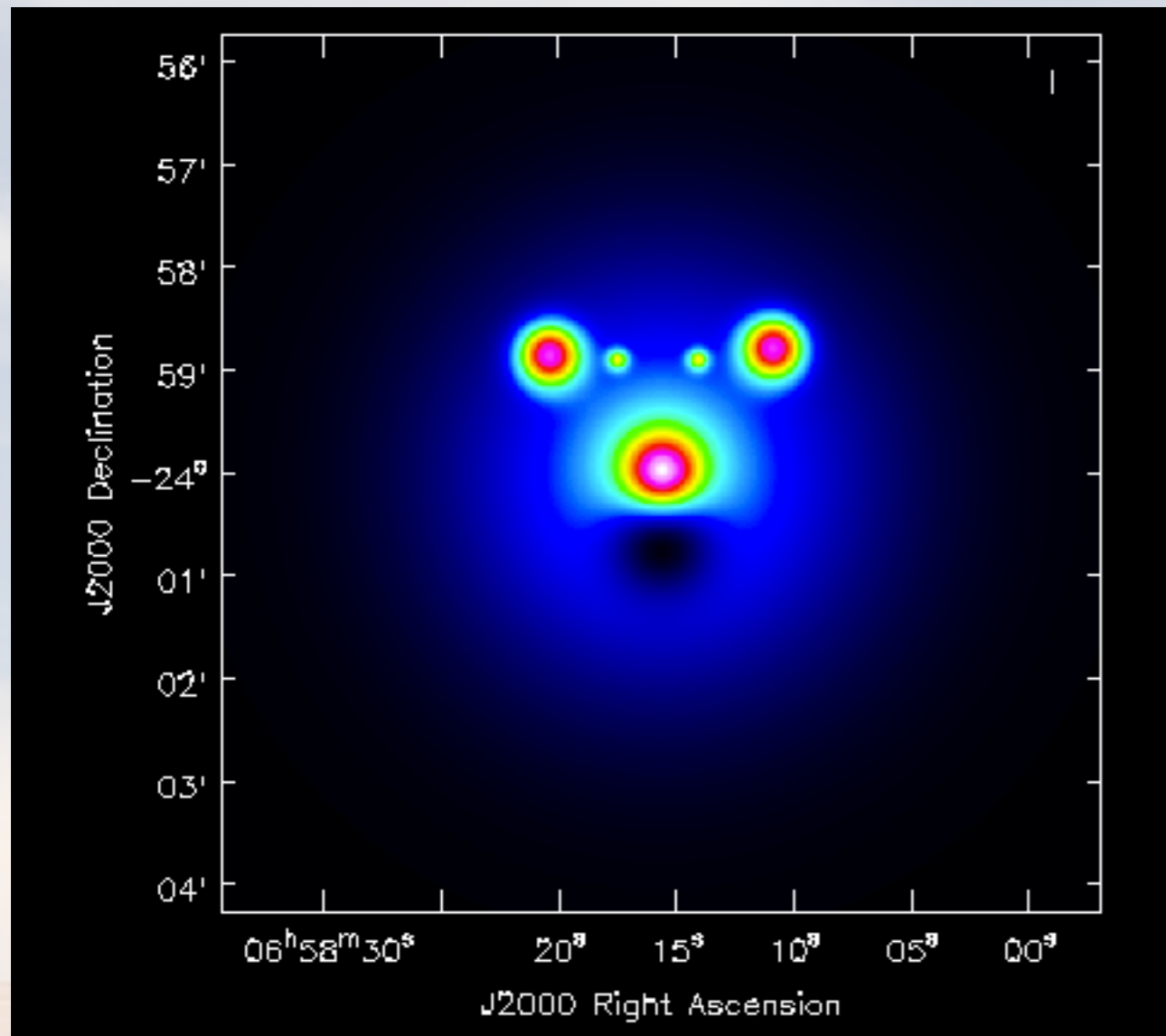
Image Server: Digitized Sky (Version II) at ESO

Image Size(arcmin): 10.0 Query

Should we include the ACA ?

simulation is without noise for demonstration purposes

input model



simulation

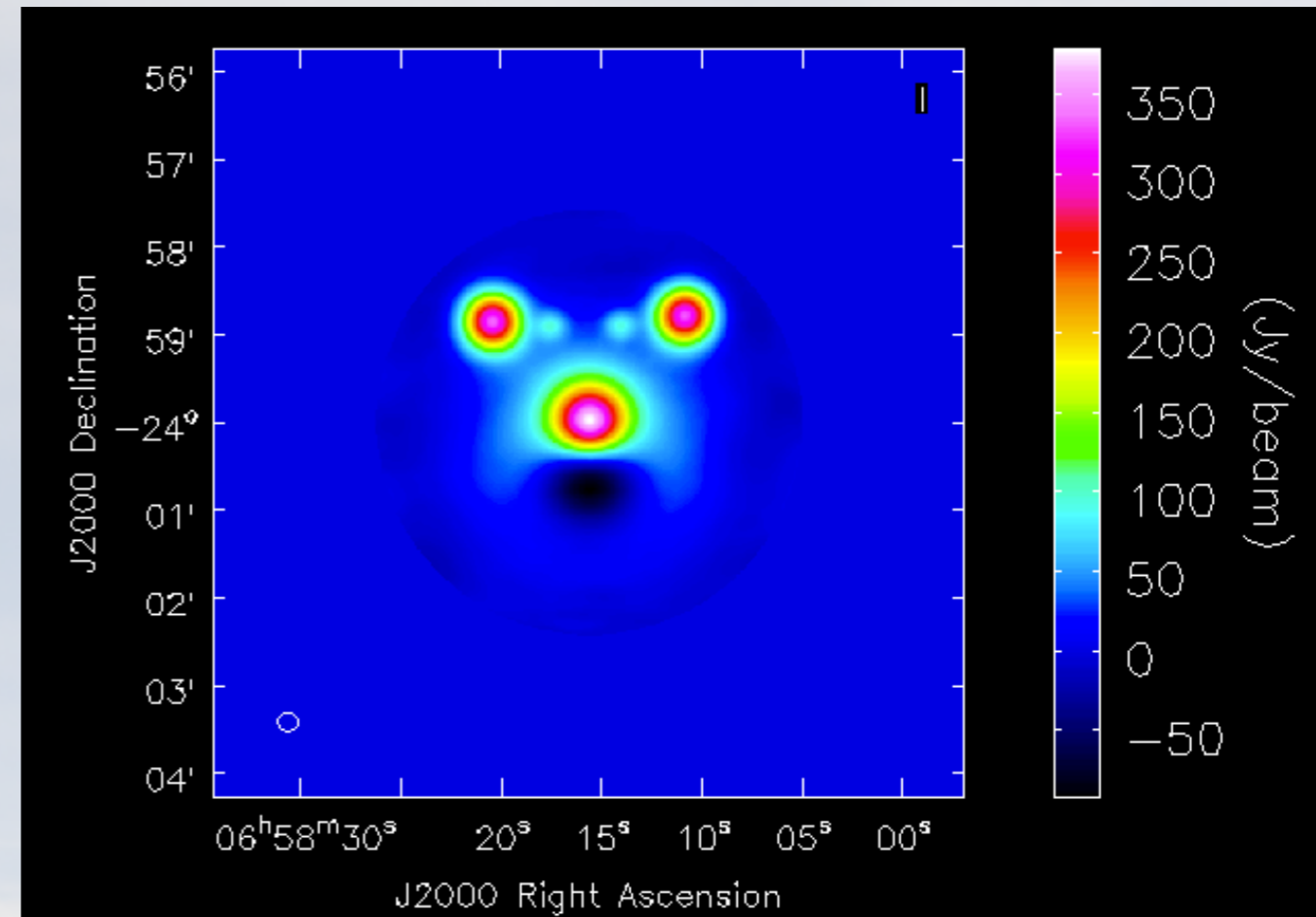
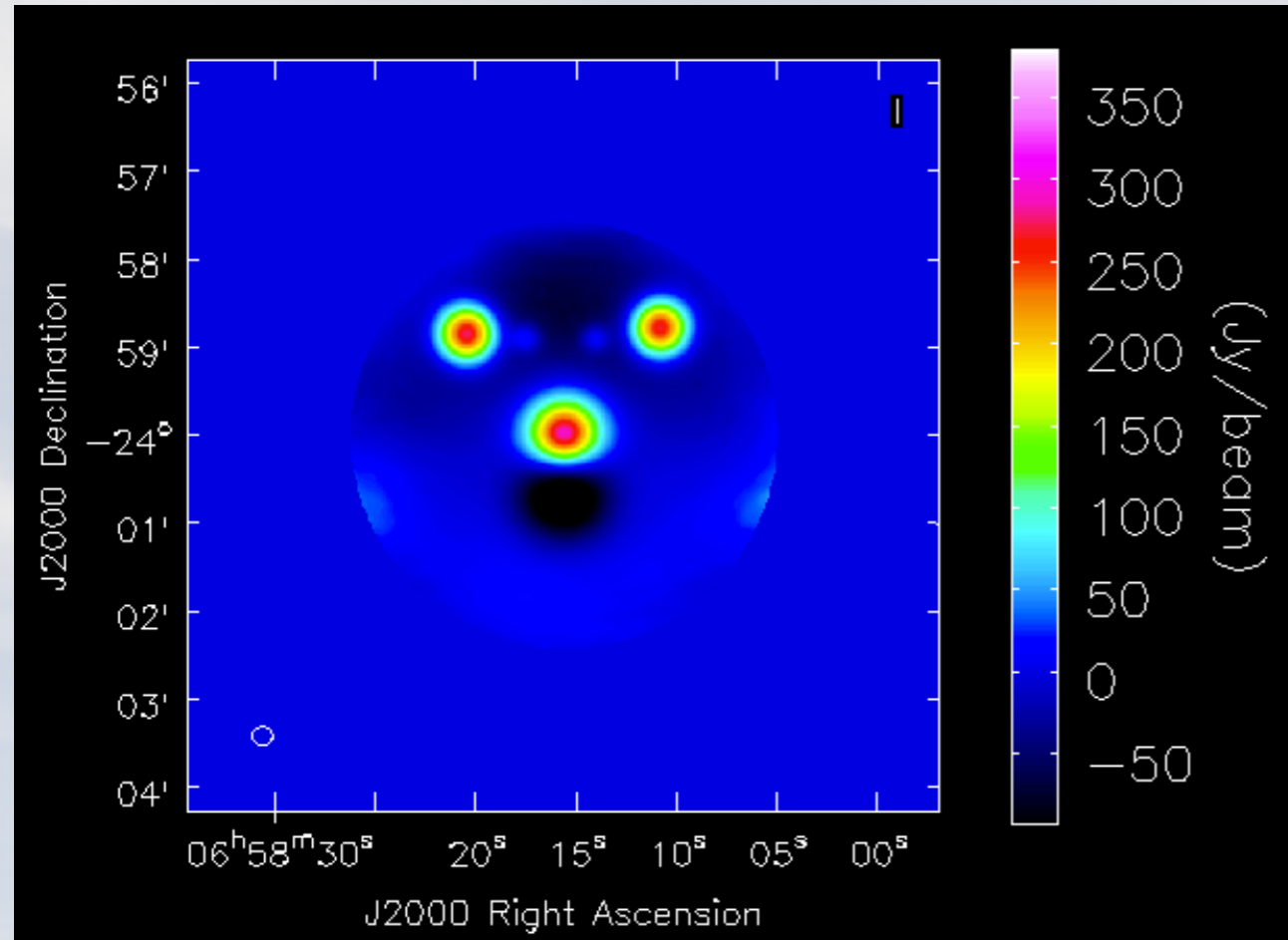
solely ALMA
VS
ALMA
+



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

Antenna Beamsize ($1.13 * \lambda / D$)	12m	<input type="text" value="0.000 arcsec"/>	7m	<input type="text" value="0.000 arcsec"/>	
Number of Antennas	12m	<input type="text" value="36"/>	7m	<input type="text" value="10"/>	TP <input type="text" value="2"/>
		Most compact 12m configuration		Most extended 12m configuration	
Longest baseline (L_{max})		<input type="text" value="0.161 km"/>		<input type="text" value="9.744 km"/>	
Synthesized beamsize (λ/L_{max})		<input type="text" value="0.000 arcsec"/>		<input type="text" value="0.000 arcsec"/>	
Shortest baseline (L_{min})		<input type="text" value="0.015 km"/>		<input type="text" value="0.346 km"/>	
Maximum recoverable scale ($0.6\lambda/L_{min}$)		<input type="text" value="0.000 arcsec"/>		<input type="text" value="0.000 arcsec"/>	

Desired Performance

Desired Angular Resolution (Synthesized Beam)	<input type="text" value="0.00000"/>	arcsec	
Largest Angular Structure in source	<input type="text" value="40.0"/>	arcsec	
Desired sensitivity per pointing	<input type="text" value="0.00000"/>	<input type="text" value="ujy"/>	equivalent to <input type="text" value="Infinity"/> <input type="text" value="K"/>
Bandwidth used for Sensitivity	<input type="text" value="RepresentativeWindowResolution"/>	Frequency Width	<input type="text" value="0.000000 GHz"/>

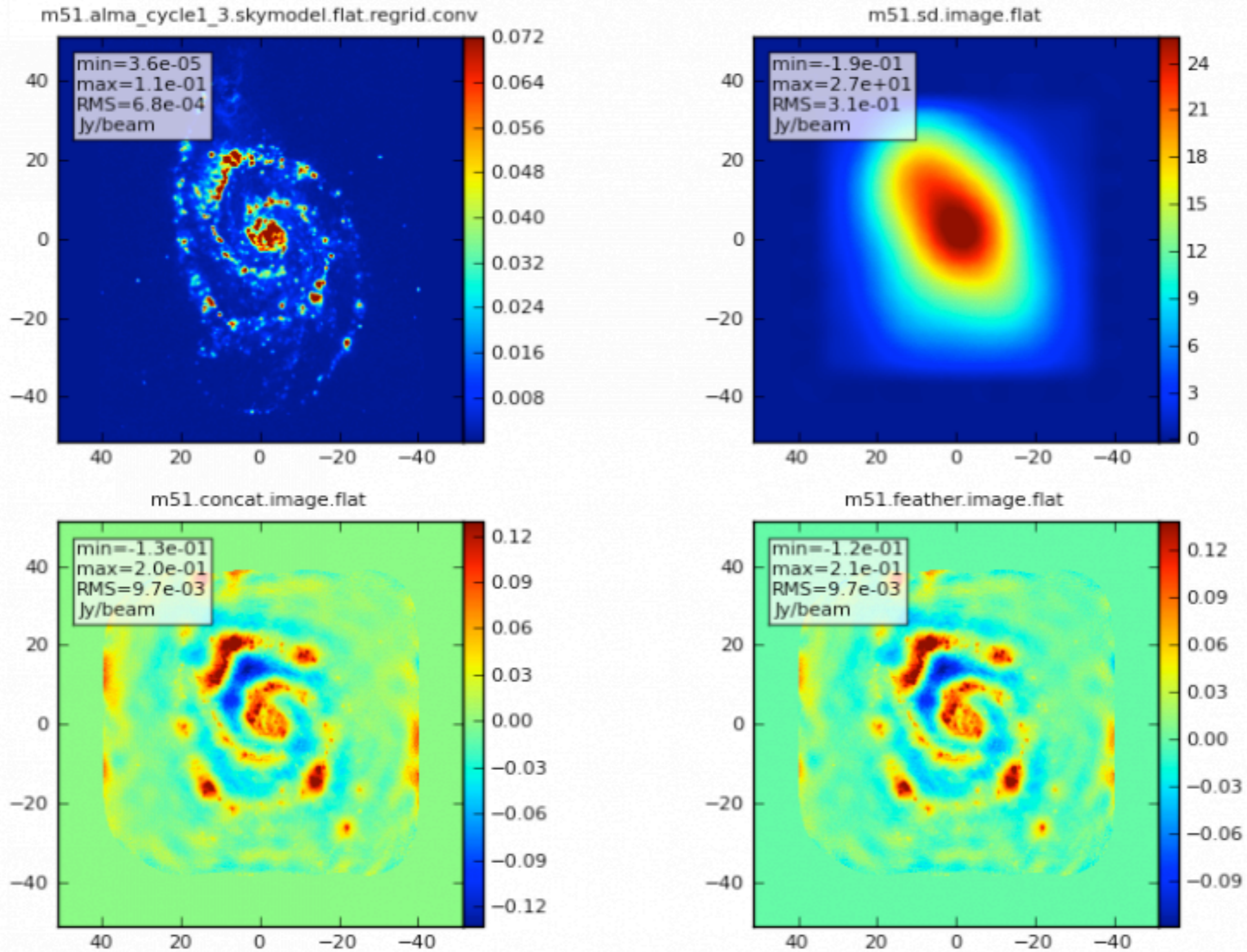
Do you request complementary ACA Observations? Yes No

Science goal integration 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

