

ALMA workshop

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* Logan Francis

September 24 - 25th 2020

Part 1



University
of Victoria

Program Thursday

- **Morning lecture (9-11 AM):**
 - Introducing ALMA - Nienke
 - Basics interferometry - Nienke
 - Fundamentals interferometry - Logan
 - Calibration - Logan
 - Cleaning/imaging - Logan
 - Basic CASA inspection - Nienke
 - Continuum vs line - Nienke
 - Spectral windows - Nienke
 - Detections and non-detections - Nienke

Program Thursday

- **Hands-on session (2-4 PM)**
 - Practicing with uv coverage
 - Imaging (cleaning) tutorial TW Hya

Program Friday

- **Morning lecture (9-11 AM)**

- Using the ALMA archive (Nienke)
- Self-calibration (Logan)
- Interpretation and modeling (Nienke)
- Visibility curves disks (Nienke)
- Visibility analysis disks (Nienke)
- Frankenstein & Galario (Logan)



*Specific for
protoplanetary disks*

Program Friday

- Hands-on session (11-2.30 PM)
 - Self-calibration tutorial TW Hya
 - Galarío exercise

What we won't cover

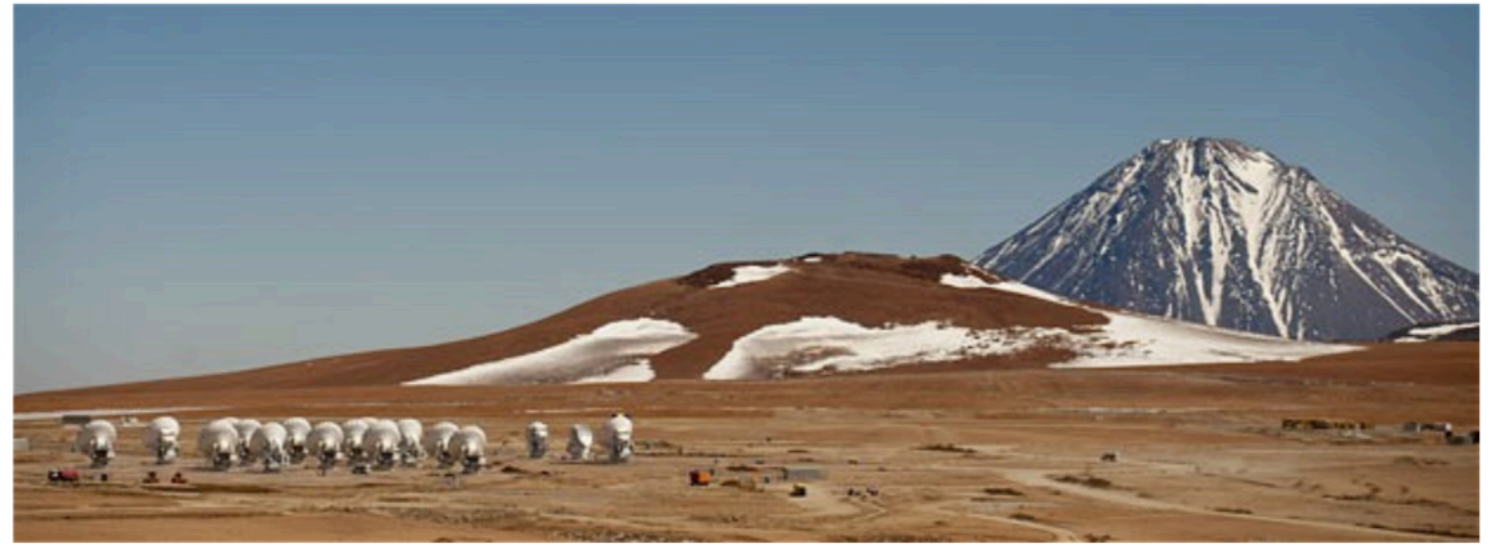
- ALMA simulator
- ALMA proposals
- Special modes (e.g. polarization, user-defined calibration, mosaicking, Solar system)
- Astrochemistry/molecular spectroscopy
- Combining multiple datasets
- Other interferometers than ALMA

ALMA

ALMA: Atacama Large Millimeter/submillimeter Array



ALMA



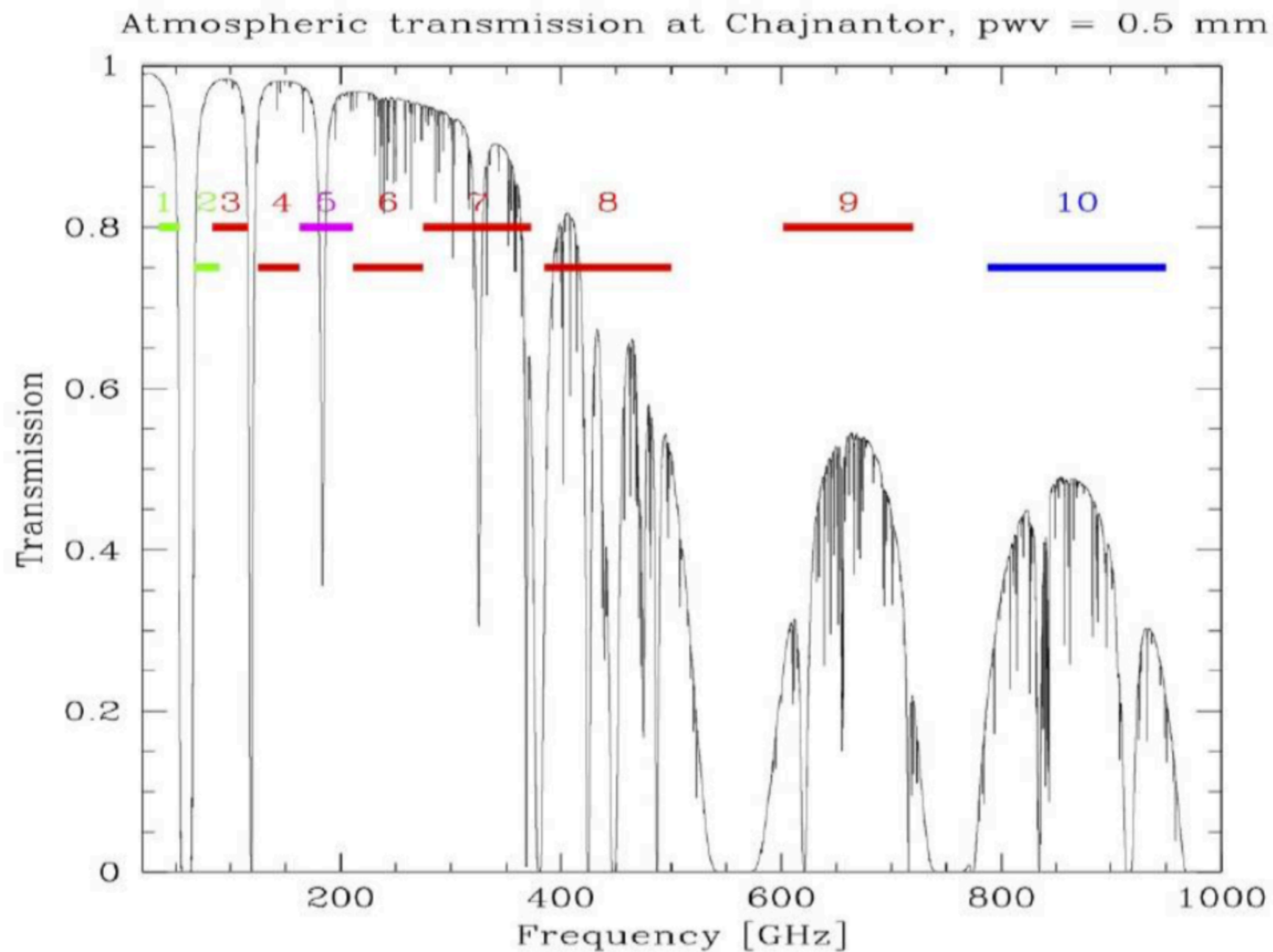
ALMA

- Array of 66 antennas in Atacama desert in Chile at 5100m elevation
- Started operations in 2011
- Global collaboration between Europe, North America, Chile and East Asia
- Budget 1.3 billion \$ for operation of 30 years
- Sensitivity 100 times higher and resolution 200 times better than previous interferometers
- Resolution down to 0.01”!
- ALMA:
 - 12m-array: 50 antennas, 10 possible configurations with baselines <16 km
 - 7m array (ACA): 12 antennas
 - Total power array: 4 antennas



ALMA bands

- ALMA Bands: atmosphere



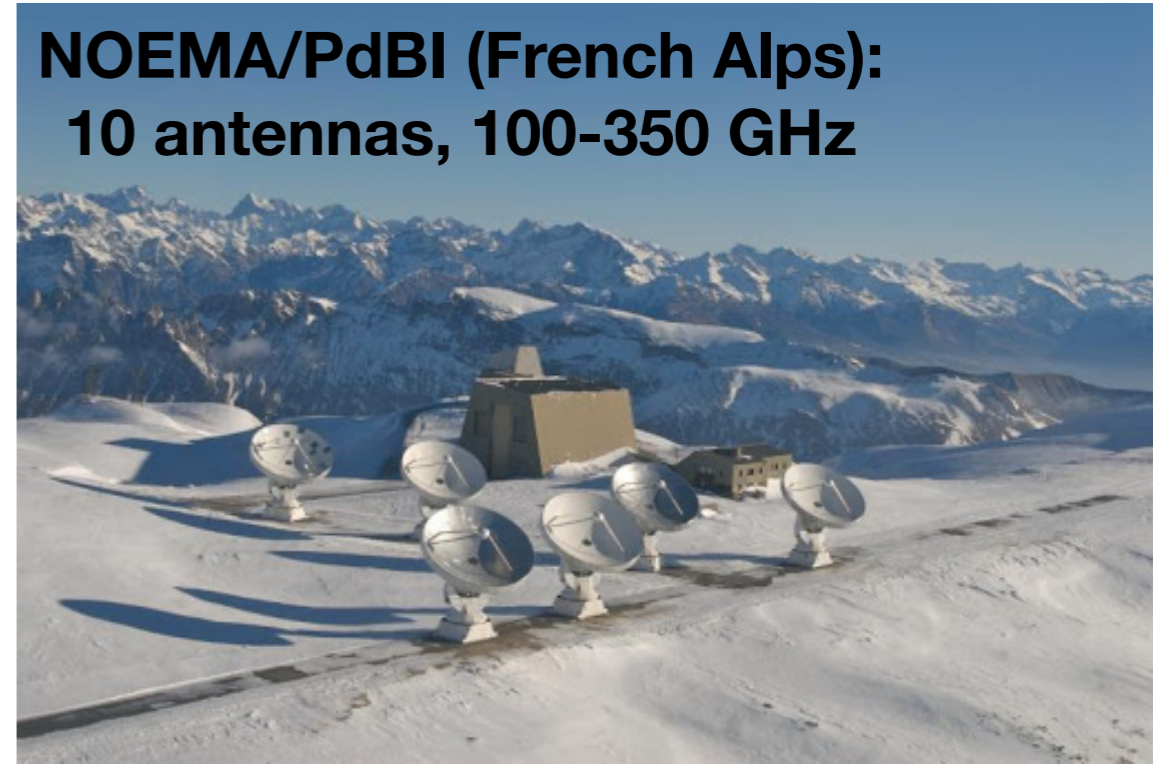
40-900 GHz

Other mm/cm arrays

**SMA (Maunakea):
8 antennas, 180-420 GHz**



**NOEMA/PdBI (French Alps):
10 antennas, 100-350 GHz**



**JVLA (New Mexico):
27 antennas, 1-50 GHz**



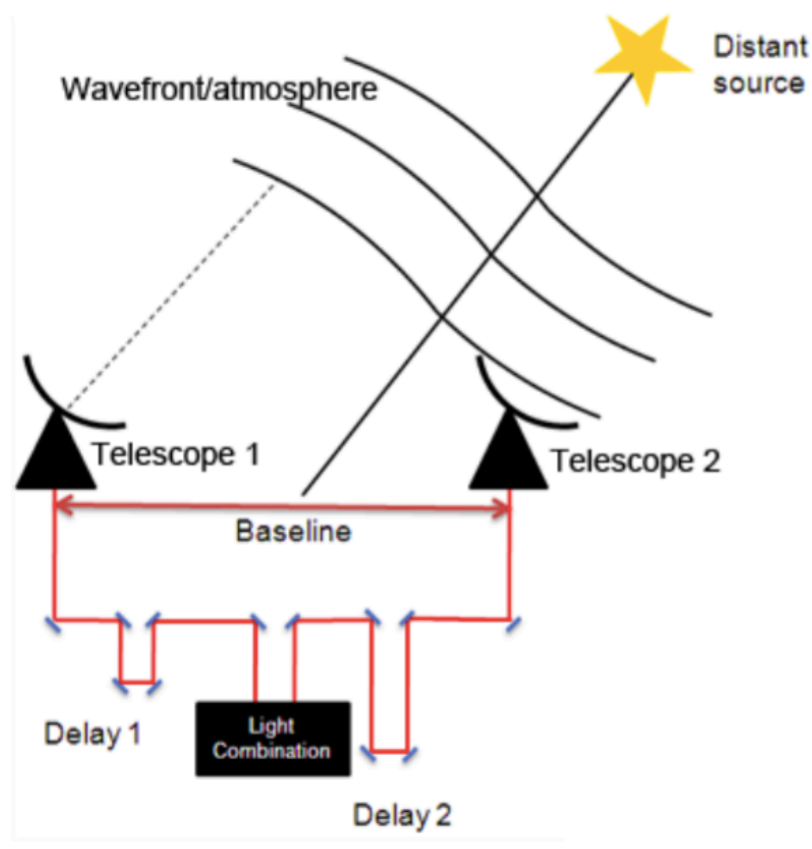
**Decommissioned: CARMA (California)
25 antennas, 100-230 GHz**



ALMA interferometry

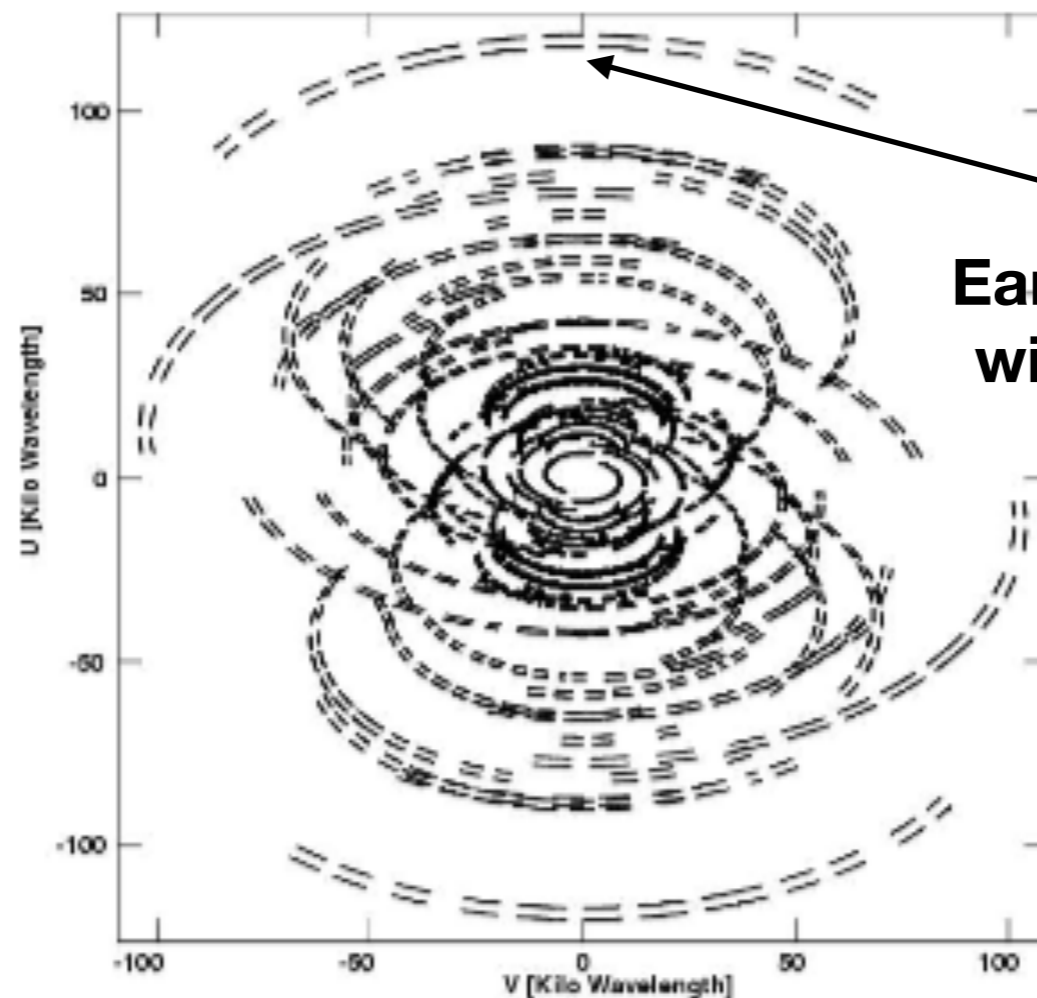


- Every antenna is connected with every antenna (baseline)
- So 3 antennas: 6 baselines, 4 antennas: 24 baselines, etc.
- Each baseline (interference pattern) provides a resolution element or spatial scale λ/B (B = baseline length), which can be described as point in the u,v -plane
- For observing, you want to ‘fill the u,v -plane’ as much as possible to cover all possible spatial scales and get a nice clean beam



ALMA interferometry

- The u,v -plane is the collection of all u,v points and can be filled up by adding more baselines and by using the Earth rotation, as the baseline orientation and position changes from the *point of view of the source* (hour angle and elevation)

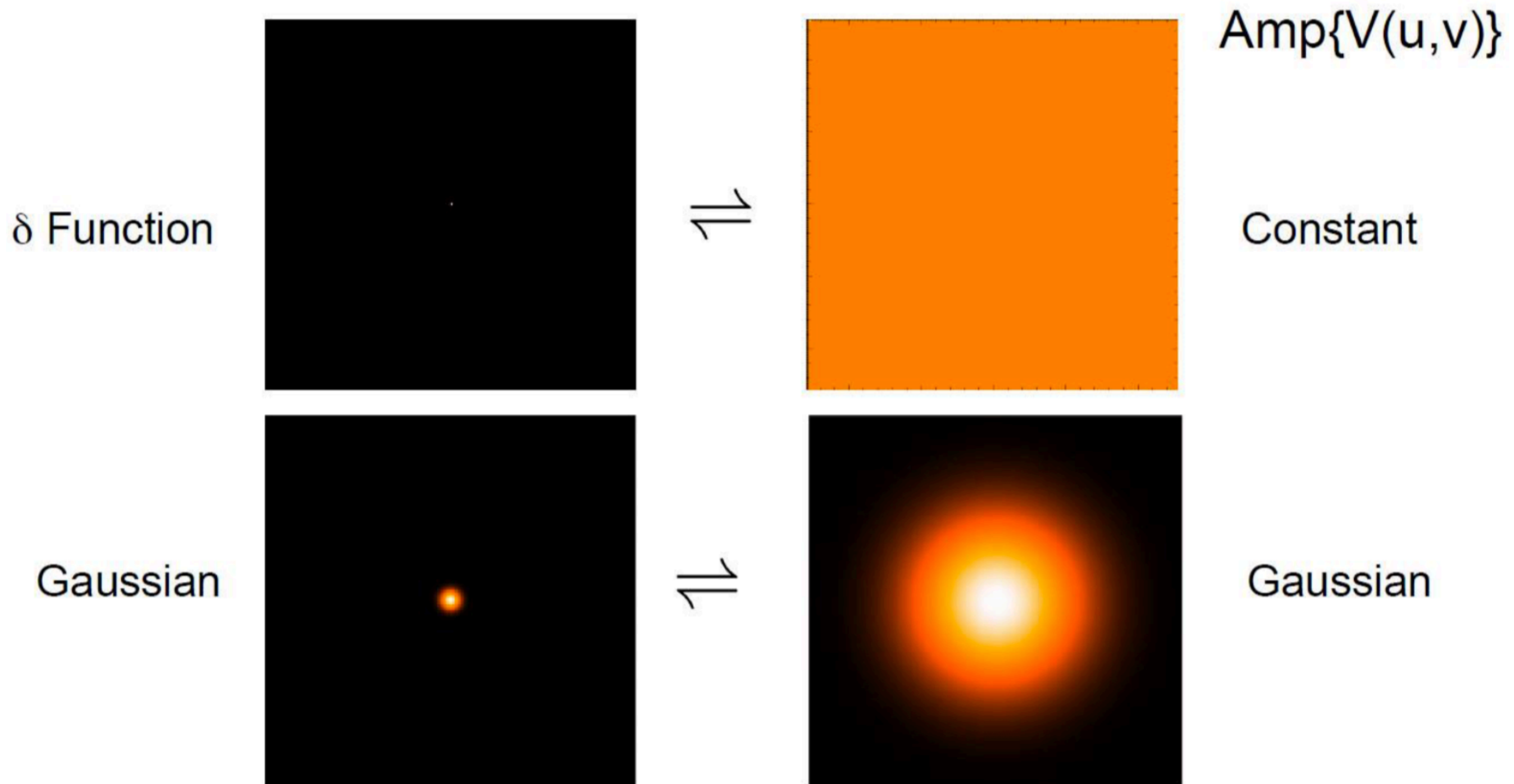


**Earth rotation and track source
with intermissions (calibrator)**

ALMA interferometry

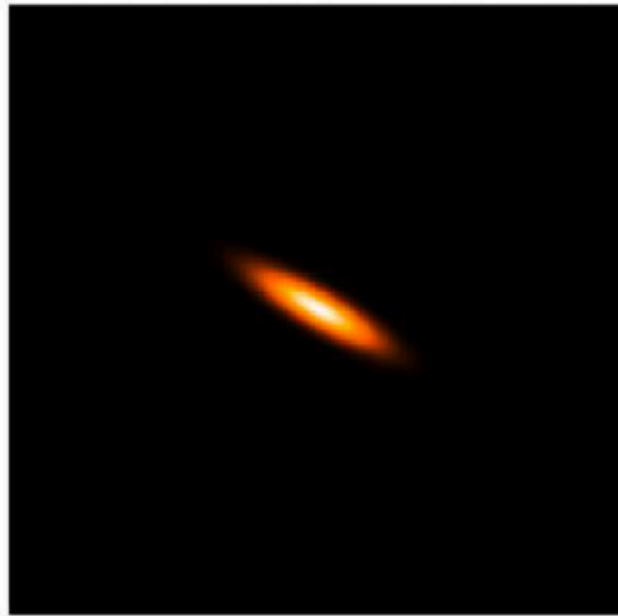
- The u,v -plane can be considered the Fourier transform of the x,y -plane: imaging interferometry data means Fourier transforming it
- The u,v -coverage :
 - The sampling of the u,v -plane: the better it is filled, the more accurate your image will be
 - The Fourier transform of the u,v -coverage gives you your beam or PSF: perfect coverage results in a perfect Gaussian beam, imperfect coverage results in a 'dirty beam' with sidelobes
 - Coverage at long baselines means you are sensitive to small spatial scales: coverage at short baselines means you are sensitive to large spatial scales => you usually cannot have both at the same time!

Fourier transform

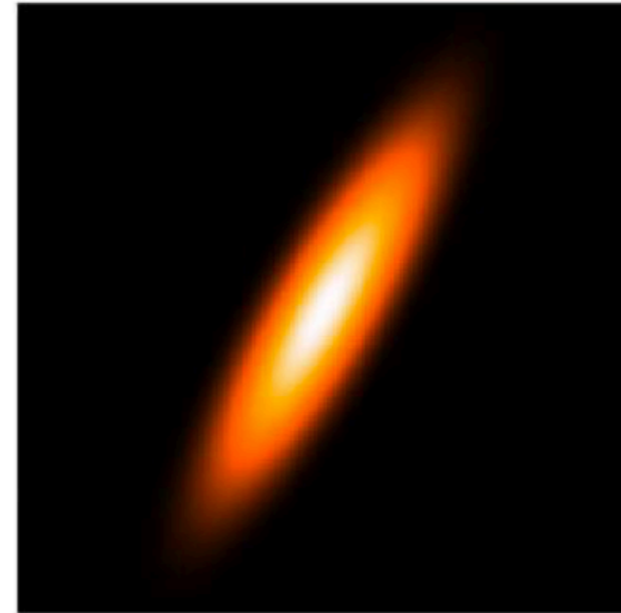


Fourier transform

elliptical
Gaussian



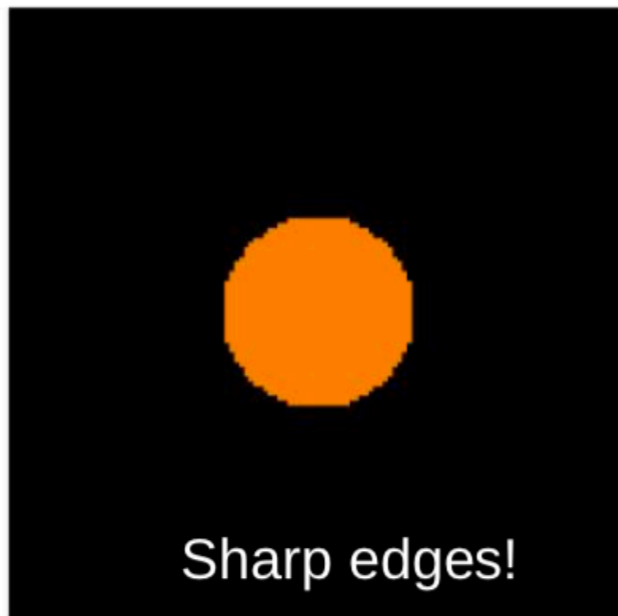
\mathcal{F}



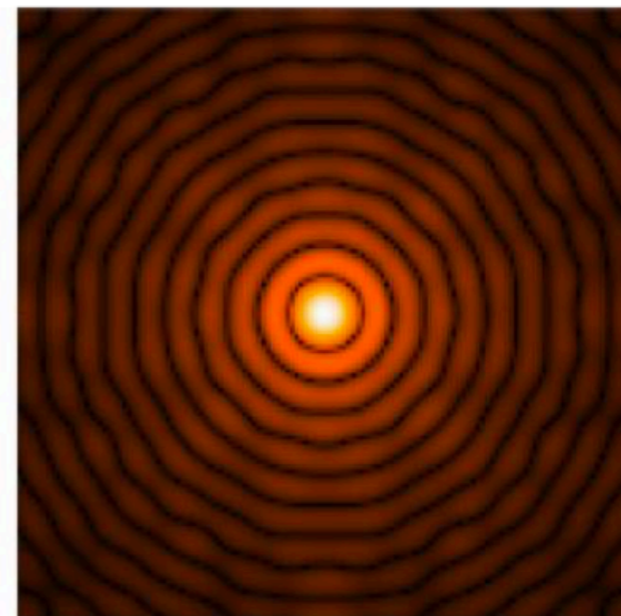
$\text{Amp}\{V(u,v)\}$

elliptical
Gaussian

Disk



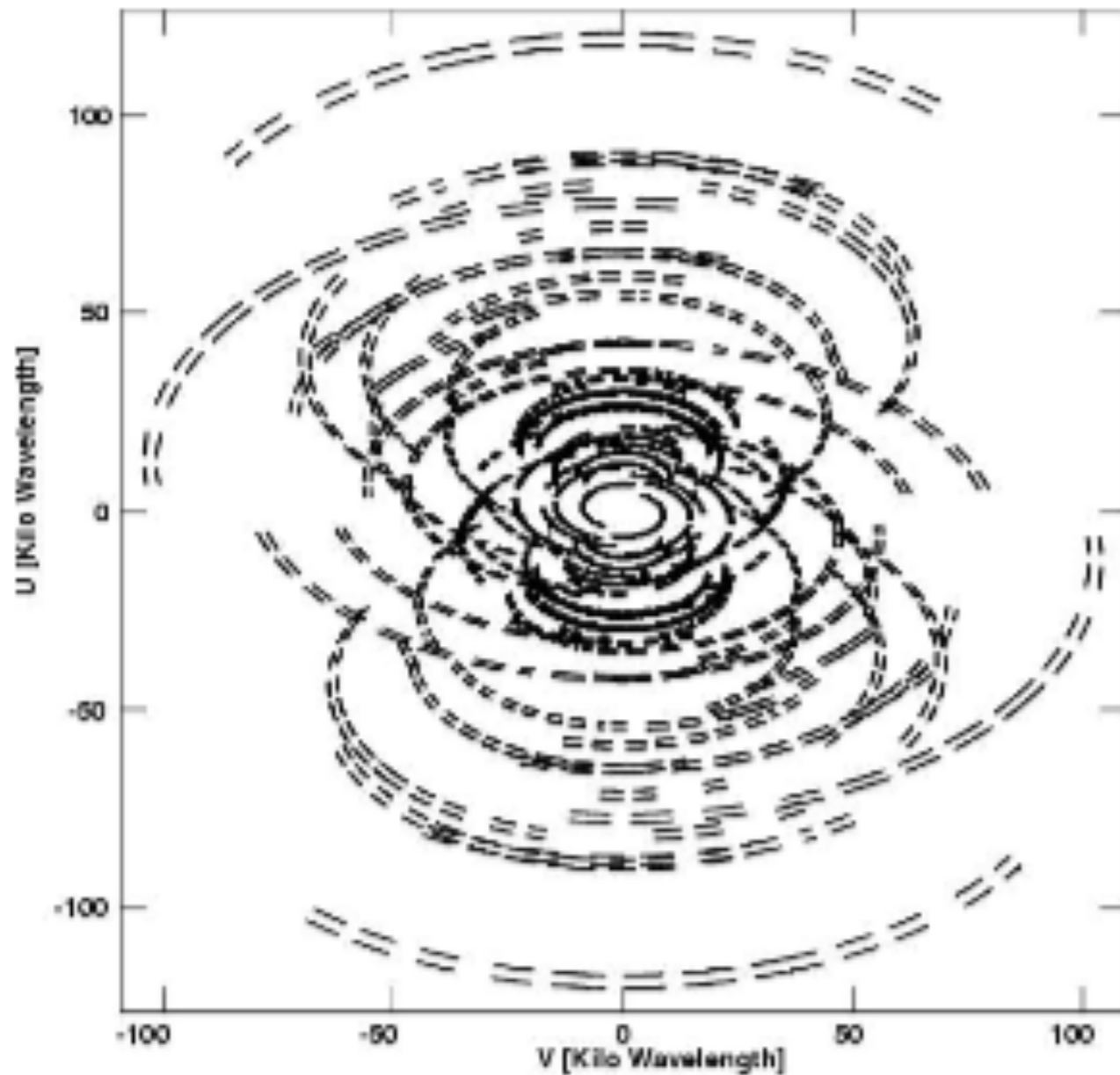
\mathcal{F}



Bessel

Sharp edges!

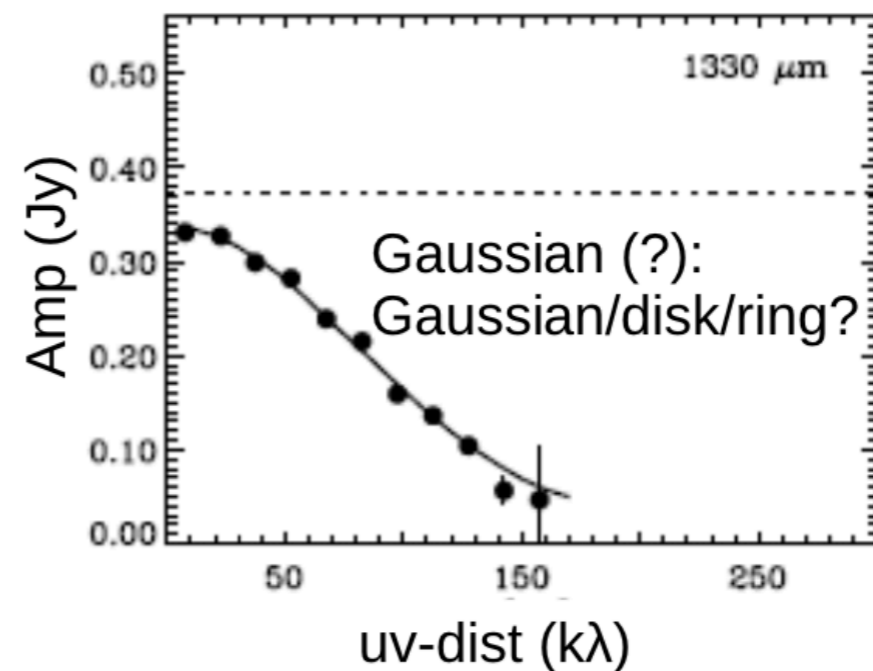
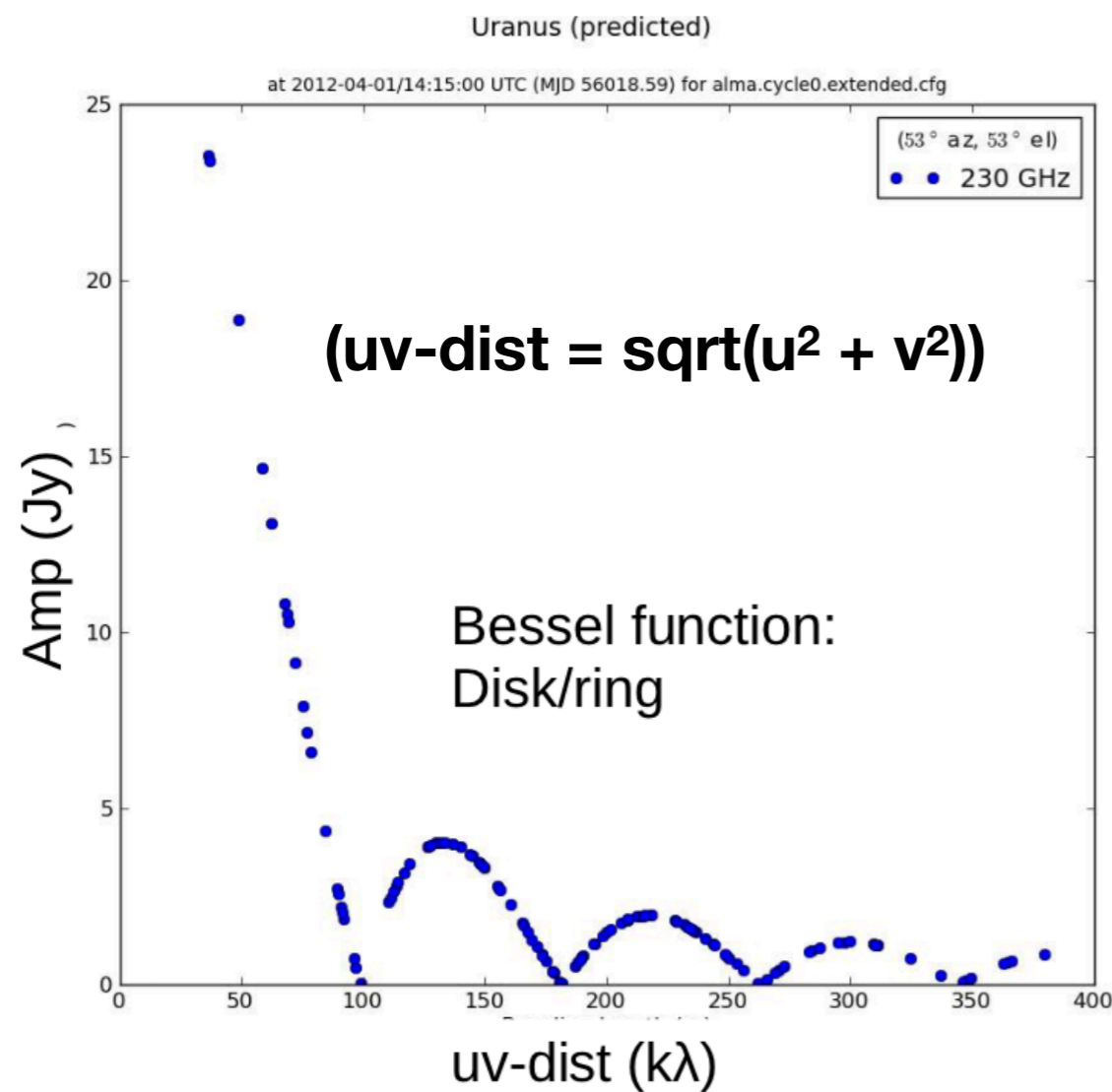
Fourier transform in practice



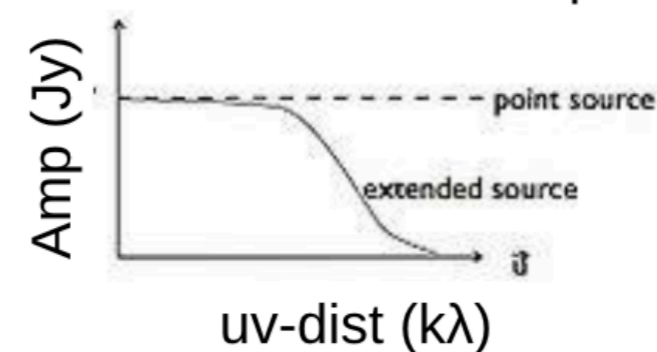
- At each u, v point you measure Real and Imaginary (as function of time and frequency)
- The “Real” represents radial variations
- The “Imag” represents azimuthal variations
- Amplitude = $\sqrt{\text{Real}^2 + \text{Imag}^2}$
- Deprojected baseline = $\sqrt{u^2 + v^2}$

Fourier transform in practice

- Visibility curve: amp vs uv-distance



Constant: unresolved point source



**Two major issues when Fourier transforming:
maximum resolvable scale and incomplete PSF**

ALMA interferometry

Table A-1: Angular Resolutions (AR) and Maximum Recoverable Scales (MRS) for the Cycle 7 Array configurations

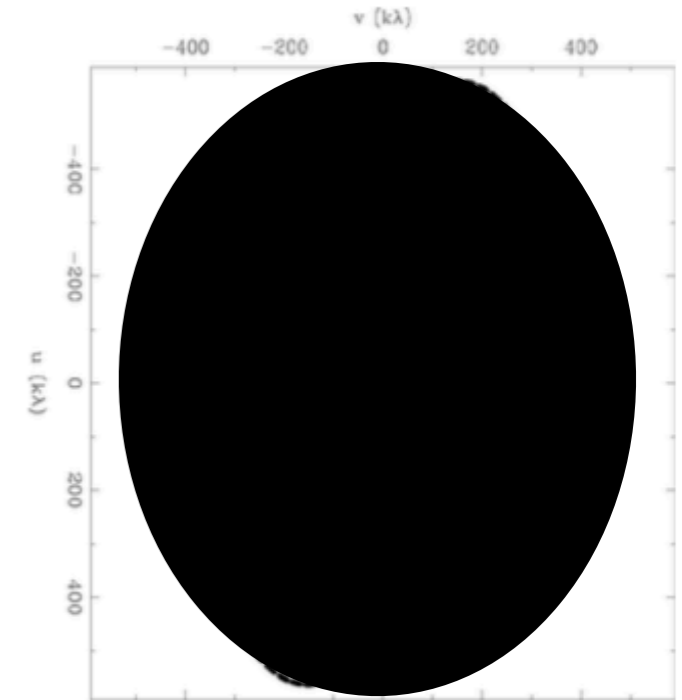
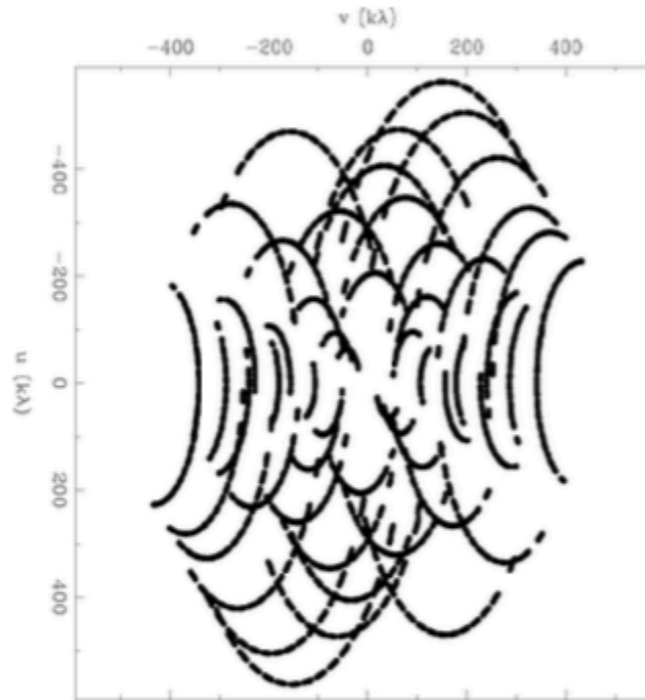
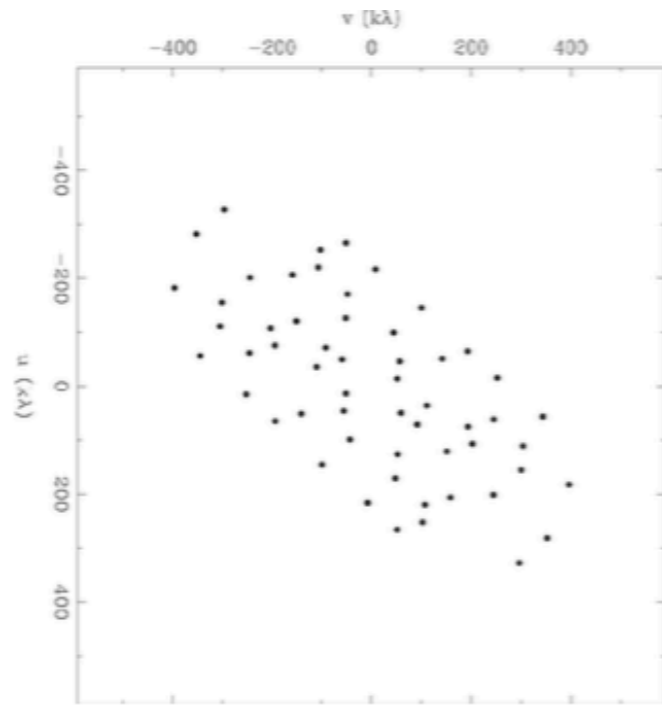
Config	Lmax		Band 3	Band 4	Band 5	Band 6	Band 7	Band 8	Band 9	Band 10
	Lmin		100 GHz	150 GHz	183 GHz	230 GHz	345 GHz	460 GHz	650 GHz	870 GHz
C43-1	161 m	AR	3.4"	2.3"	1.8"	1.5"	1.0"	0.74"	0.52"	0.39"
	15 m	MRS	28.5"	19.0"	15.4"	12.4"	8.3"	6.2"	4.4"	3.3"
C43-2	314 m	AR	2.3"	1.5"	1.2"	1.0"	0.67"	0.50"	0.35"	0.26"
	15 m	MRS	22.6"	15.0"	12.2"	9.8"	6.5"	4.9"	3.5"	2.6"
C43-3	500 m	AR	1.4"	0.94"	0.77"	0.62"	0.41"	0.31"	0.22"	0.16"
	15 m	MRS	16.2"	10.8"	8.7"	7.0"	4.7"	3.5"	2.5"	1.9"
C43-4	784 m	AR	0.92"	0.61"	0.50"	0.40"	0.27"	0.20"	0.14"	0.11"
	15 m	MRS	11.2"	7.5"	6.1"	4.9"	3.3"	2.4"	1.7"	1.3"
C43-5	1.4 km	AR	0.54"	0.36"	0.30"	0.24"	0.16"	0.12"	0.084"	0.063"
	15 m	MRS	6.7"	4.5"	3.6"	2.9"	1.9"	1.5"	1.0"	0.77"
C43-6	2.5 km	AR	0.31"	0.20"	0.16"	0.13"	0.089"	0.067"	0.047"	0.035"
	15 m	MRS	4.1"	2.7"	2.2"	1.8"	1.2"	0.89"	0.63"	0.47"

Each configuration has a limited number of baseline lengths, or a limited number of spatial scales you are sensitive to

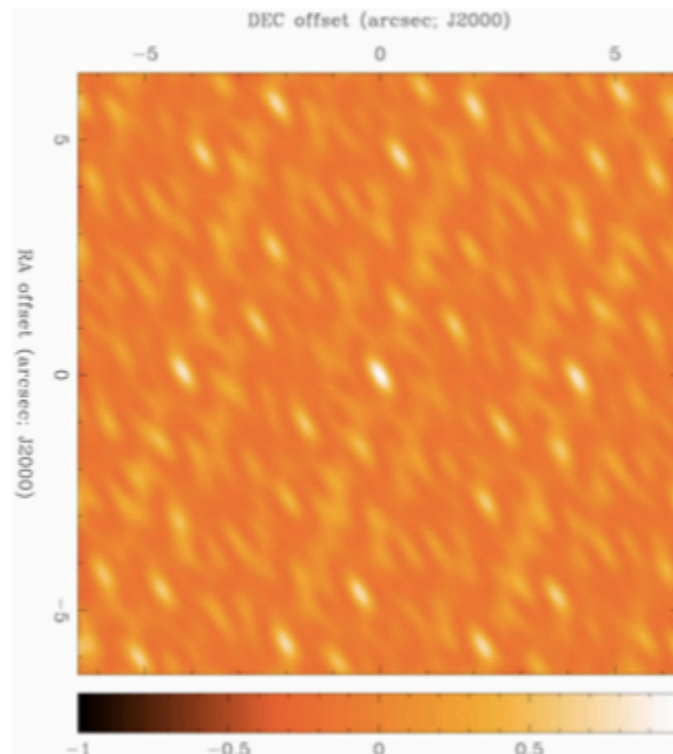
MRS: maximum recoverable scale
AR: angular resolution

Dirty beam

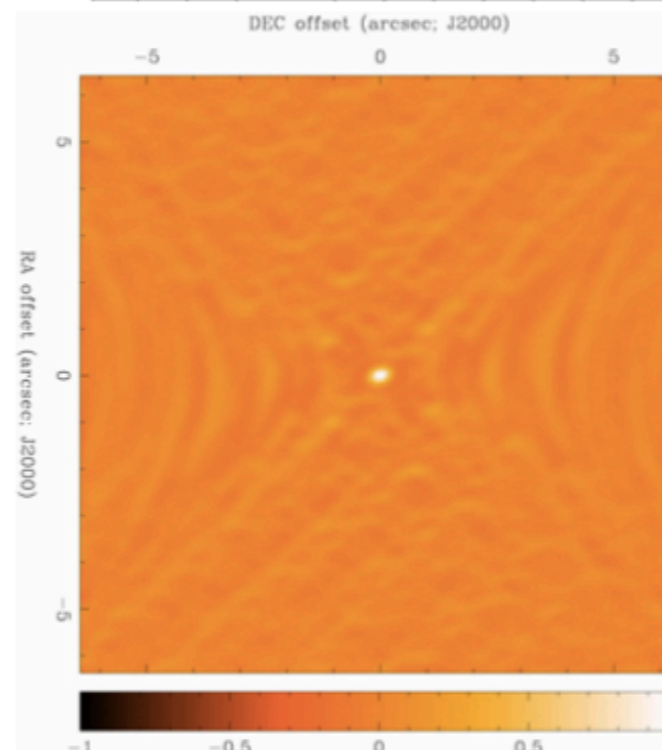
u,v-coverage
(example: SMA
with 8 antennas)



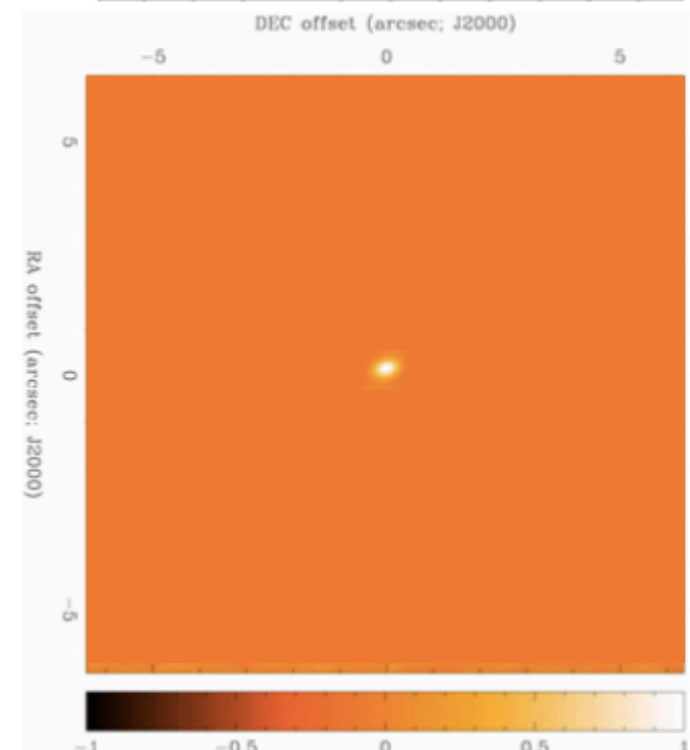
Beam or PSF



Very dirty beam



Dirty beam

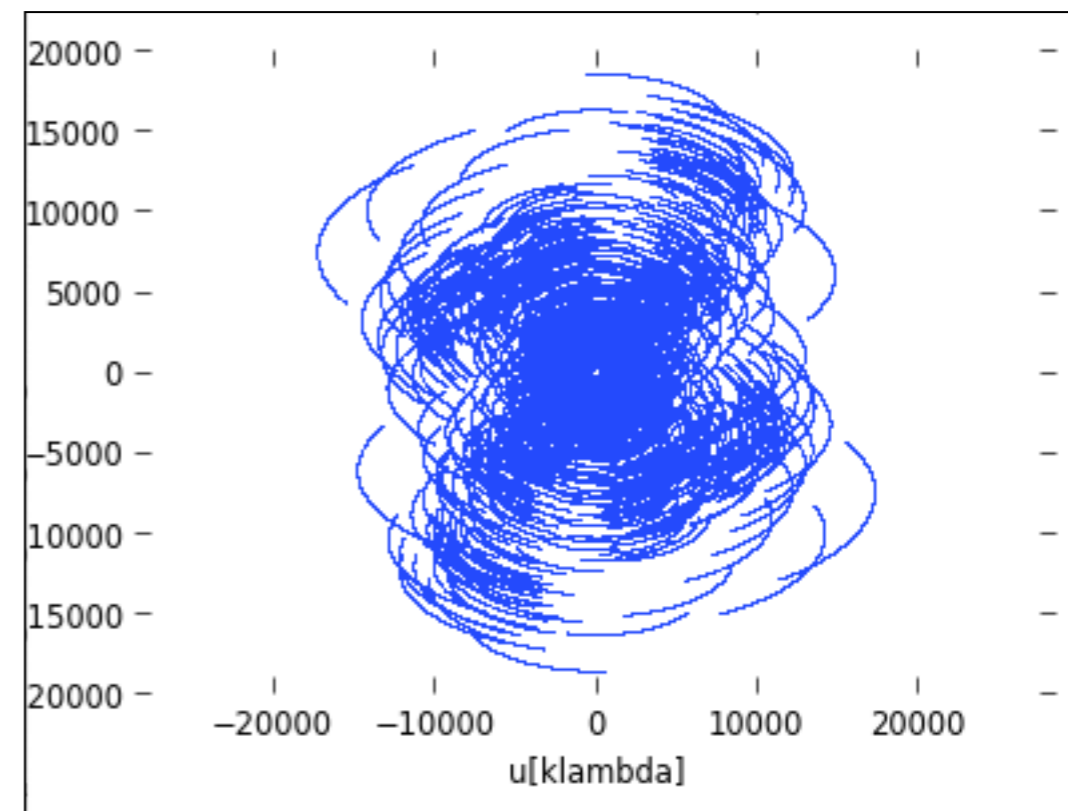


Perfect beam

Demo uv-coverage

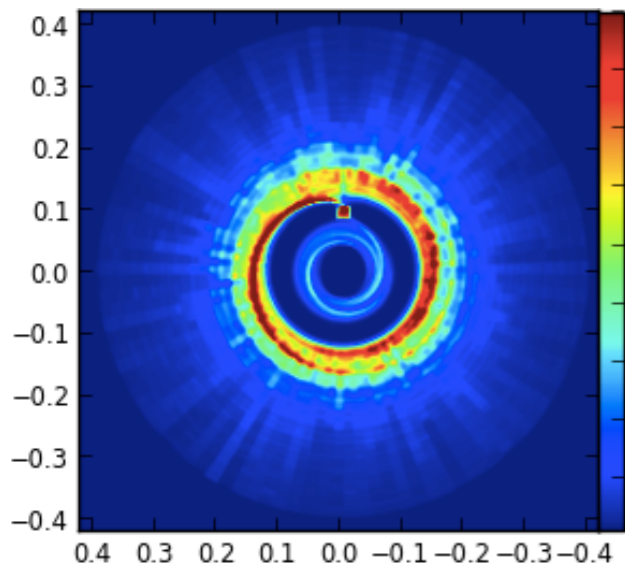
- ALMA simulation in CASA: provide an image and the details of the requested observations (configuration, integration time, declination of source, frequency) and compute how your image *would look like when observed*
- Two main differences between convolution and ALMA simulation: spatial scales + side lobes
- Difference generally gets worse in more extended configurations: less u,v-coverage at long baselines

u,v-coverage
5h ALMA observation



Demo uv-coverage

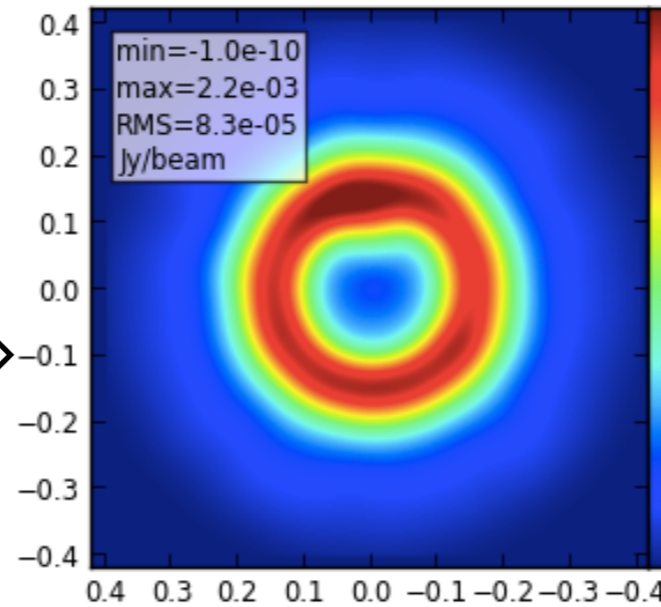
Model image
(Band9: 672 GHz)



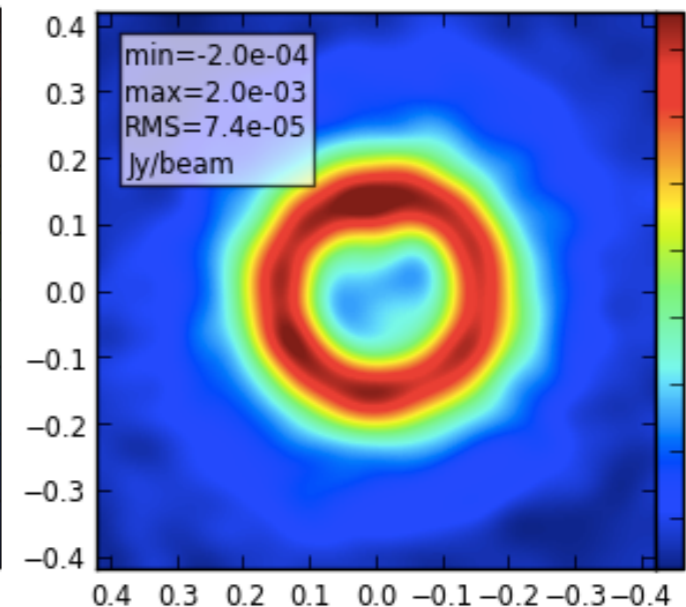
Configuration 5

AR $\sim 0.1''$
MRS $\sim 1.2''$

Convolved

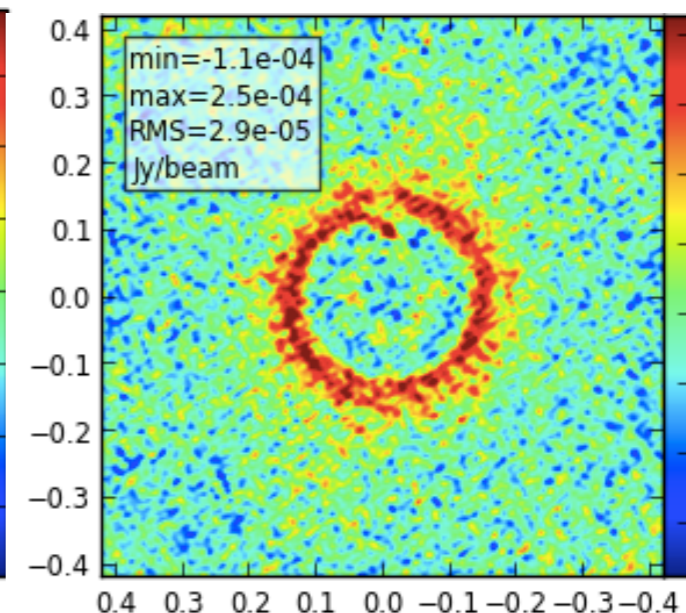
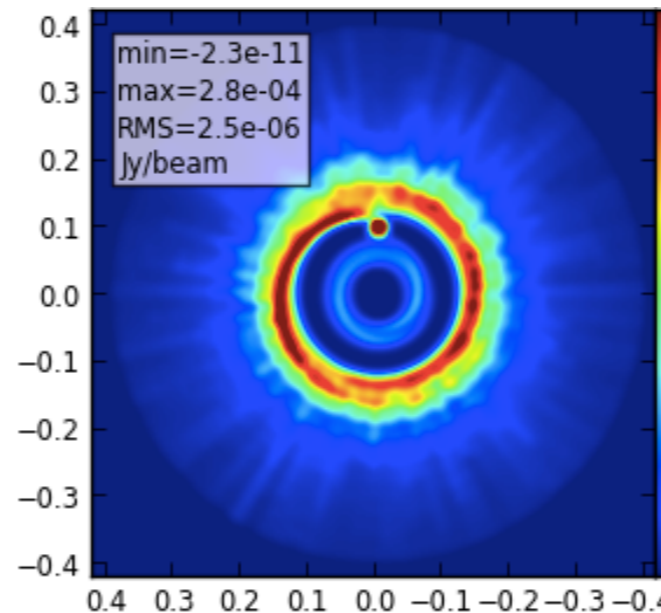


Simulated



Configuration 8

AR $\sim 0.02''$
MRS $\sim 0.2''$



Note that only 2/3 of total flux is recovered in C8