A review of (sub)mm band science and instruments in the ALMA era

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Italian node of European ALMA Regional Centre

EUROPEAN ARC

ALMA Regional Centre || Italian

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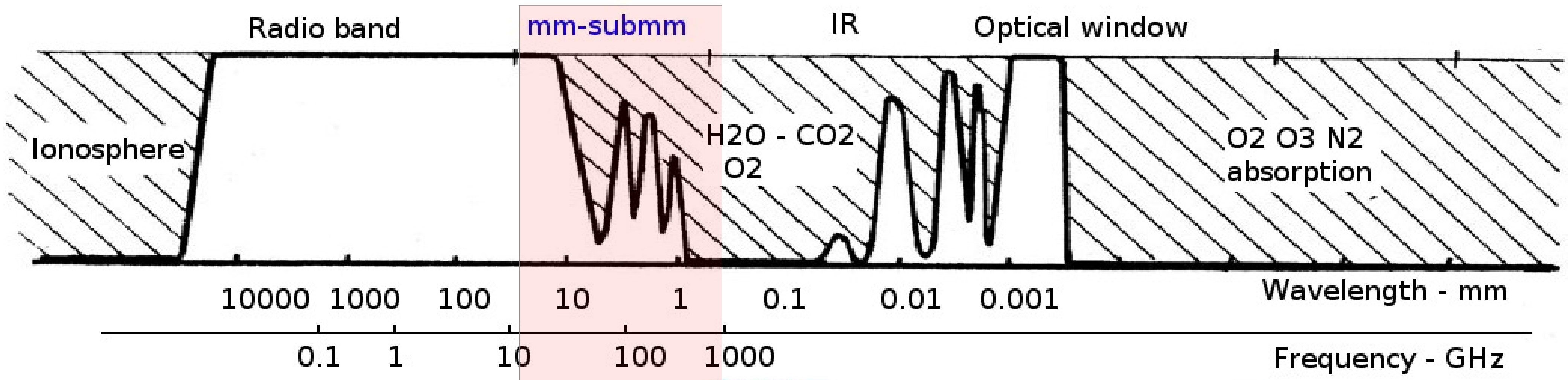
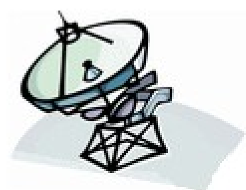
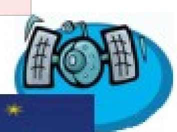
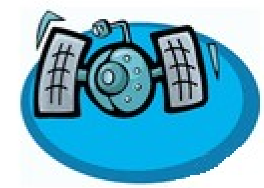
Outline





Signals: **Synchrotron**
Dust
Molecular lines

Observing instruments: **Interferometers (ALMA)**

Science cases

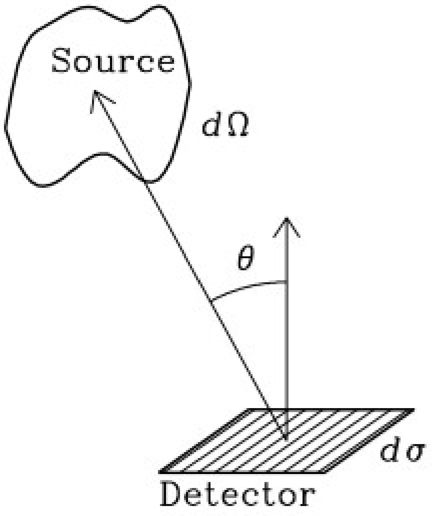
Observing processes: **Proposals and archives**

Observing instruments

Receiving system: ATMOSPHERE + ANTENNA + RECEIVER + BACKEND

Terminology: flux density

The flux density is the power of an electromagnetic wave
passing through an infinitesimal surface



$$\mathrm{d}P = I_\nu \cos\theta \,\mathrm{d}\Omega \,\mathrm{d}\sigma \,\mathrm{d}\nu$$

$$\begin{aligned}
\mathrm{d}P &= \text{power, in watts,} \\
\mathrm{d}\sigma &= \text{area of surface, m}^2, \\
\mathrm{d}\nu &= \text{bandwidth, in Hz,} \\
\theta &= \text{angle between the normal to } \mathrm{d}\sigma \text{ and the direction to } \mathrm{d}\Omega, \\
\mathrm{I}_\nu &= \text{brightness or specific intensity, in } \mathrm{W\,m^{-2}\,Hz^{-1}\,sr^{-1}}.
\end{aligned}$$

The total flux is the integral of dP over the solid angle subtended by the source

$$S_\nu = \int_{\Omega_s} I_\nu(\theta,\varphi)\cos\theta \,\mathrm{d}\Omega,$$

Flux density is measured in Jansky

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

Brightness does not depend on distance d, while flux density scales as $1/d^2$

Terminology: Sensitivity and polarization

The rms noise in the signal for a radiometer is given by:

Boltzmann k

Brightness temperature corresponding to all the signals collected including source, atmosphere and instrument

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

Bandwidth

Effective collecting Area=
#_antennas x dish_area x efficiency

Time on source

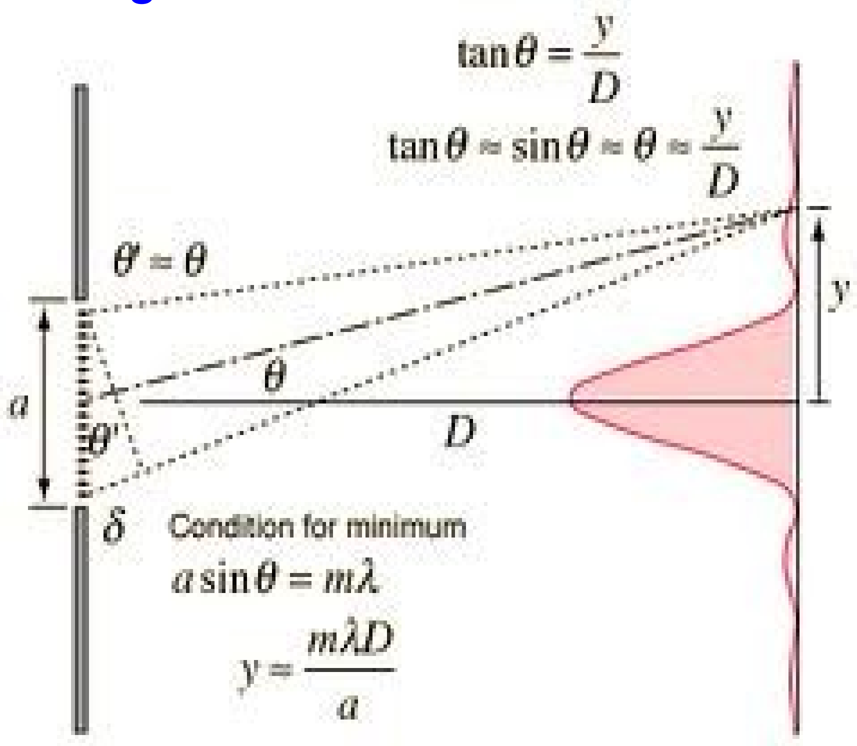
# of polarizations

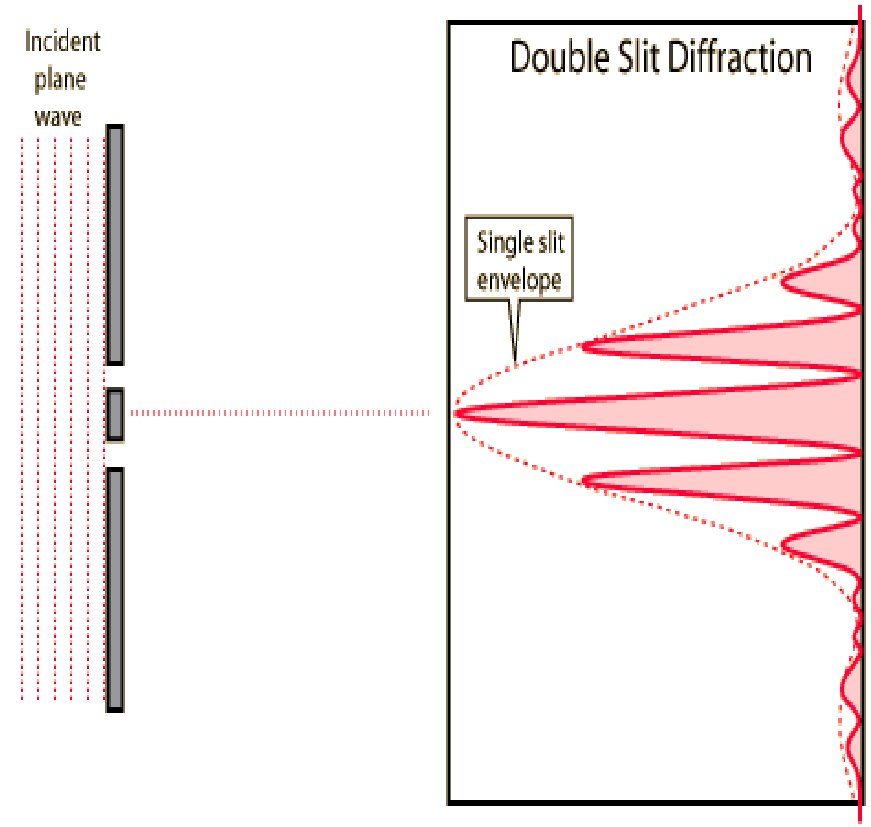
Sensitivity can be improved by
- **getting lower Tsys** (= lowering the instrumental noise or choosing sites with low water vapour levels)
- **increasing the collecting area**
- **increasing the bandwidth and/or the integration time**

Receivers are couple of dipoles, so split the signal into **2 polarizations**
By combining the independent polarizations chains it can reconstruct all the Stokes parameters.

Terminology: resolution

Antennas work as apertures of diameter a at distance B (=baseline >>a)
the Resolution for a wavelength λ is θ=λ/B.
This is defined as Synthesized Beam and is equivalent to the resolution of a single dish of diameter B.



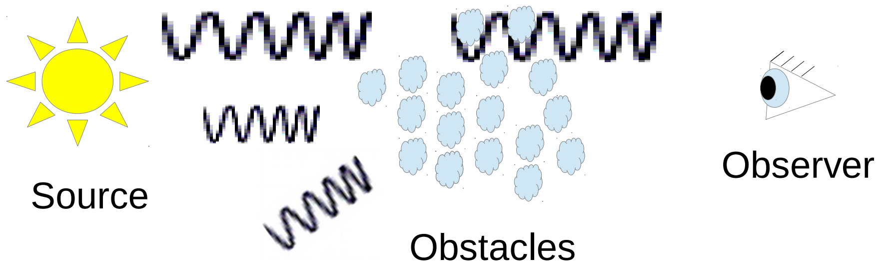


In the double slit diffraction the pattern is modulated by the single slit envelope, i.e. the response function of an interferometer is modulated in a region of size **FOV=λ/a**, with a the antenna radius, also called **Field of View or Primary Beam.**

Hence, **resolution decreases as the wavelengths decreases**.
Larger telescopes are needed to reach higher resolutions:
from space small instruments give low resolution & sensitivity
from ground larger instruments are possible.

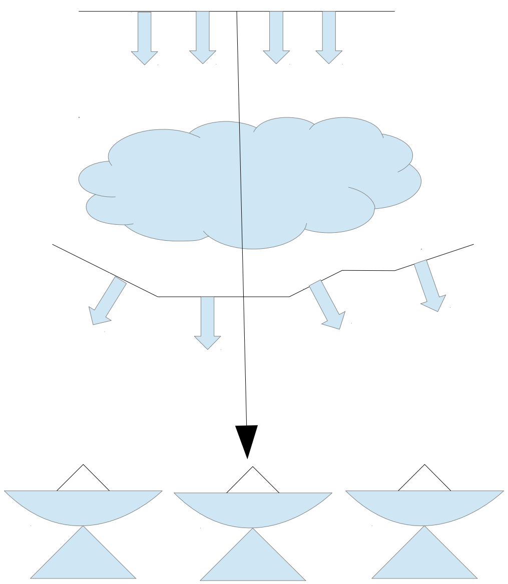
Terminology: signal “obstacles”

Obscuration & Scattering
Light **waves** path is deflected by irregularities in the propagation medium or irregularities on the reflection surface. Obstacles larger than the light wavelength obscurate (reflect) it.



Water Vapour droplets mean size ranges between 10-15 micron and up to 100 micron in clouds.

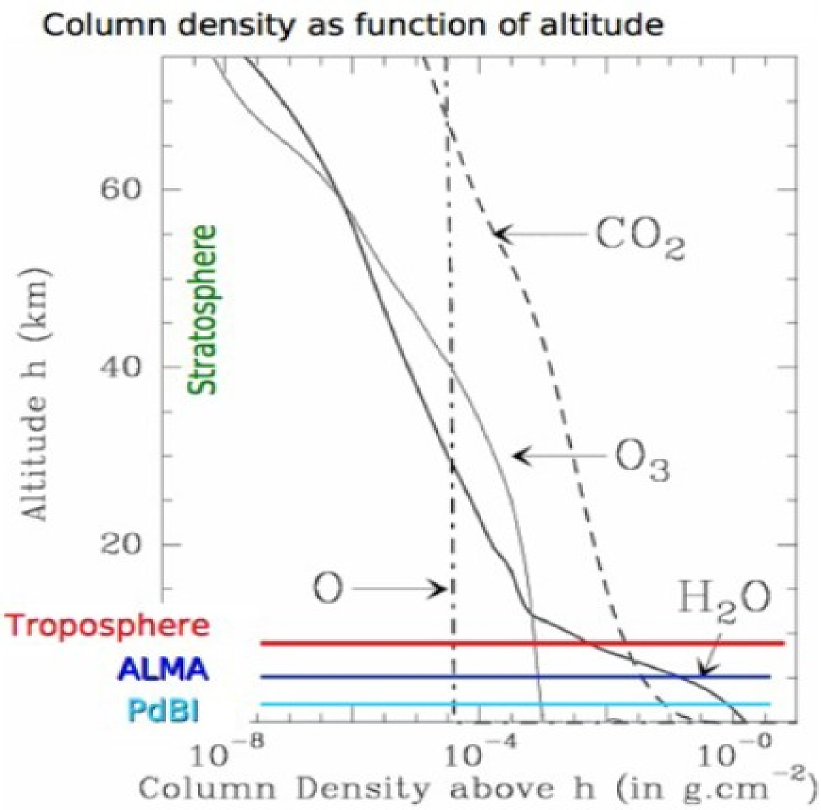
Antenna Surface irregularities should be smaller than ~1/10 of the observing wavelength (~0.03micron in submm).



Decorrelation
Scattering of light paths has the consequence that two or more receiver looking at the same wavefront receive it in different times and from different direction. If deviations are too large it is no longer possible to reconstruct the original wavefront and compare the signals

Receiving system: ATMOSPHERE + ANTENNA + RECEIVER + BACKEND

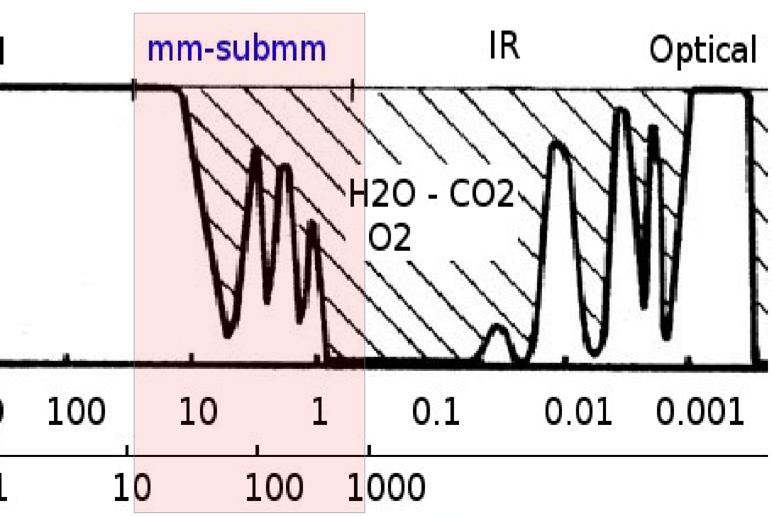
Terminology: signal "obstacles"

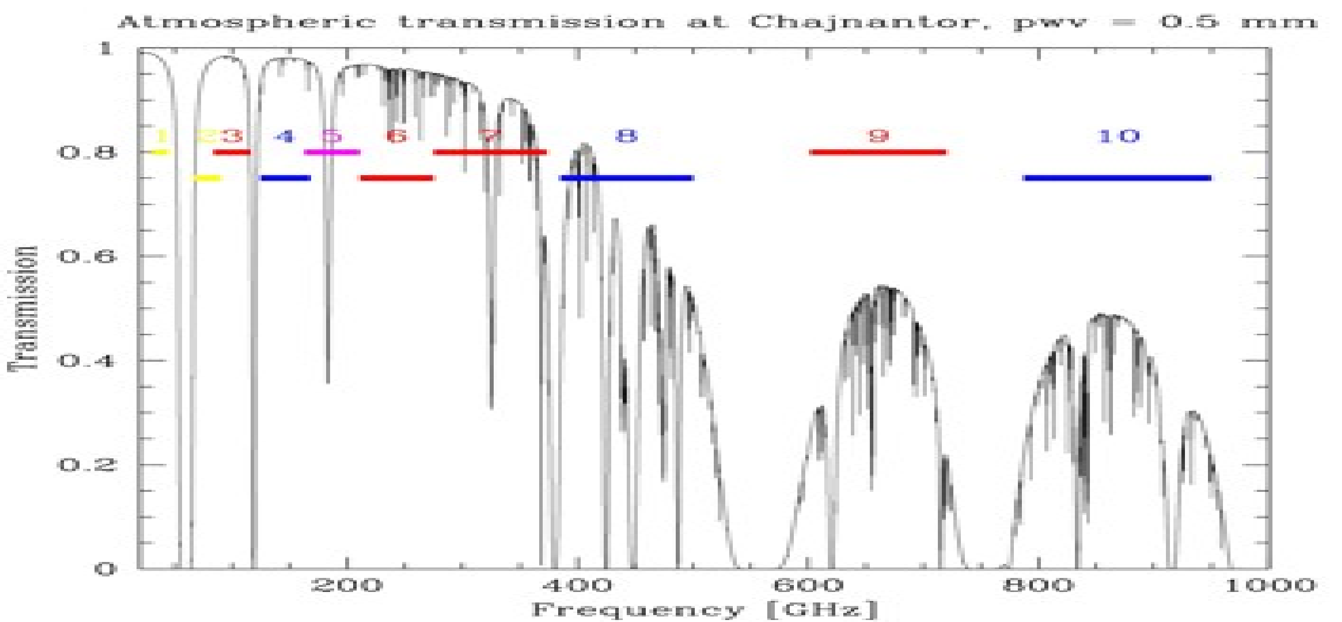


Absorption & Attenuation
Light can be absorbed by interacting with a medium and the **photon energy** is transmitted to the molecules or atoms of the medium. Light can be re-emitted attenuated or changed in energy.

Molecular transitions and some atomic transitions are excited by mm wavelength and in our atmosphere they can absorb the signals.

Transmissivity is higher the smaller are the obstacles and the less dense is the medium along the line of sight.
Only some transmission bands are available in the submm and only from high and dry sites.

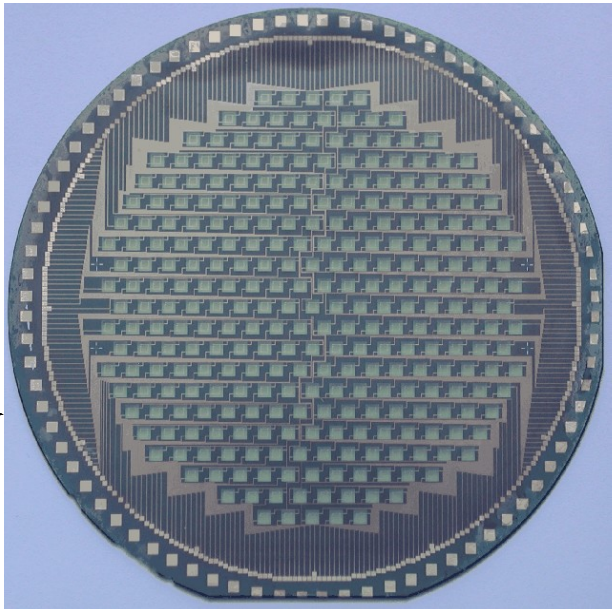




Instruments: bolometers

An incident radiation changes the temperature of the receiver that absorbs it.
The temperature variation is a measure of radiation intensity.
Bolometers are intrinsically broadband because the thermal effect is independent of frequency.
They are less sensitive to atmospheric variations.
Filters are needed for frequency determination.
They are **usually mounted on single dish**, hence limited in resolution to the antenna diameter.
To cover larger areas they are packed in arrays to increase the instantaneous Field Of View.

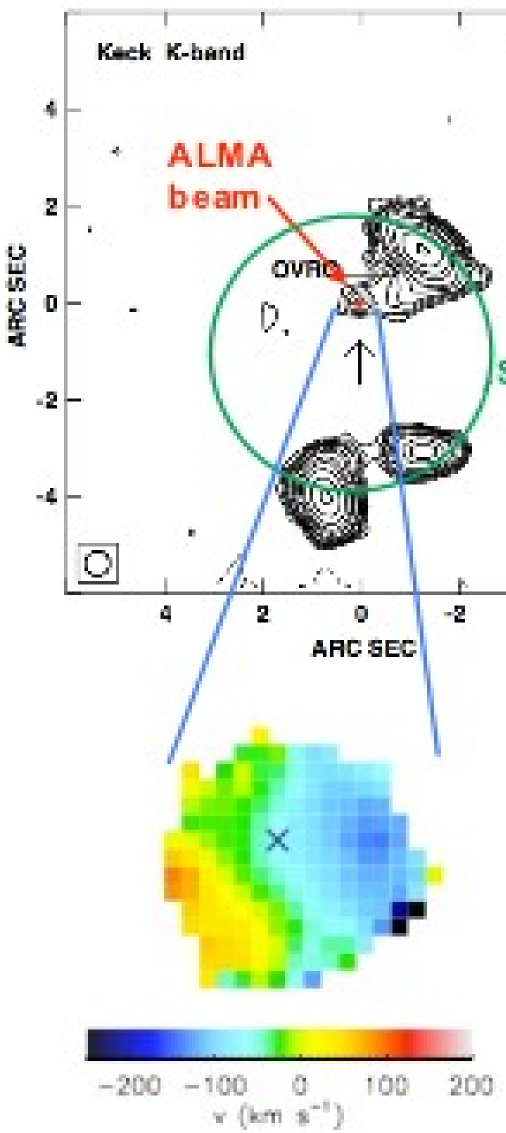
Instrument	Wavelength (microns)	F-o-V (sq-arcmins)	NEFD (mJy)	FWHM (arcsec)	Confusion (mJy)
SCUBA	450	4.2	400	7.5	0.25
	850	4.5	80	14	0.5
SCUBA-2	450	50	100	7.5	0.25
	850	50	30	14	0.5
Laboca-S	350	4	250	7	0.3
Laboca	850	11	110	18	0.8
SPIRE	250	32	29	18	2.6
	350	32	34	25	3.8
	500	32	37	35	5.4
AzTec	1100	2.4	3.5	5.5	0.06
MAMBO-2	1200	10	30	10	0.2



100 pc at z>1 appear on arcsec scales

Receiving system: ATMOSPHERE + $\boxed{\text{ANTENNA}}$ + $\boxed{\text{RECEIVER}}$ + BACKEND

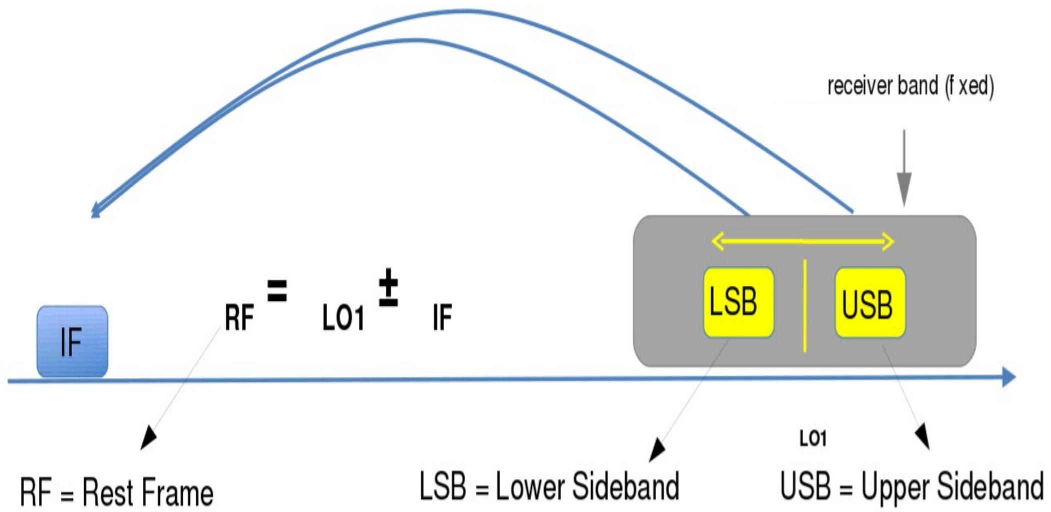
Instruments: Coerent receivers



Coherent receivers preserve the phase of the signal: can be mounted on interferometers

Furthermore, by mean of heterodyne principles the frequency is shifted to fixed lower values, without changing any other property of the signal, by combining the received signal with that of a tunable **Local Oscillator**.

This allows to have the whole electronic chain working at the same frequency.



Receiving system: ATMOSPHERE + ANTENNA + RECEIVER + BACKEND

Instruments: Coerent receivers

Name	Antennas [# × Diameter]	$\Delta\lambda$ [mm]	Max ang. resol. [asec]	Total area [m^2]
IRAM-PdBI	6 × 15m	1.2–3	0.35	1060
CARMA[a]	6 × 10.4m + 10 × 6m	1.2–3	0.1	792
NMA	6 × 10m	1.2–3	1	471
SMA	8 × 6m	0.35–1.2	0.1	226
eSMA[b]	SMA + 15m + 10.4m	0.87–1.2	0.2	488
ATCA[c]	6 × 22m [d]	3–12	2.	2280[d]

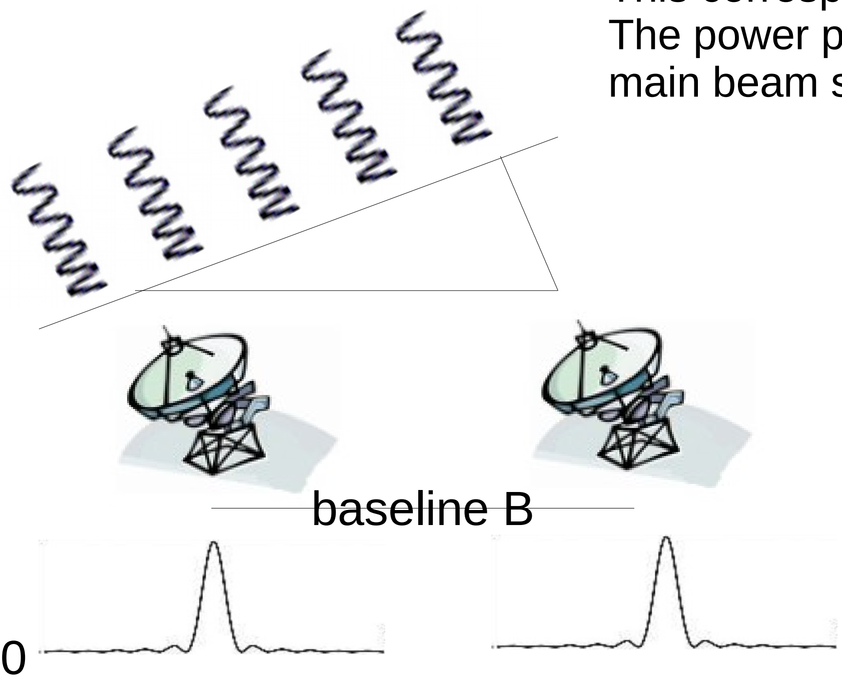
Notes:
[a] CARMA is the merging of the former OVRO (6×10.4m antennas) and BIMA (10×6m antennas) arrays.
[b] eSMA is the combination of SMA with the JCMT and CSO.
[c] ATCA can observe at much lower frequencies, down to $\lambda = 20$cm, the specifications given here only refer to the observing capabilities at mm wavelengths.
[d] At $\lambda = 3$mm only 5 of the ATCA antennas can be used, for a total collecting area of 1900 m^2.

Receiving system: ATMOSPHERE + $\boxed{\text{ANTENNA}}$ + $\boxed{\text{RECEIVER}}$ + BACKEND

Instruments: interferometers

A coherent combination of reflectors of diameter d at distance B(>>d) gives a resolution equivalent to that of a single reflector of diameter B.

The main (primary) beam (FOV) of an antenna is the solid angle where its power pattern (assuming to use it as a transmitter) is larger ($\theta=\lambda/d$).
This corresponds to the range where it is more sensitive as a receiver.
The power pattern in case of a far away point source is given by the main beam shape with amplitude equal to the source flux (total power).



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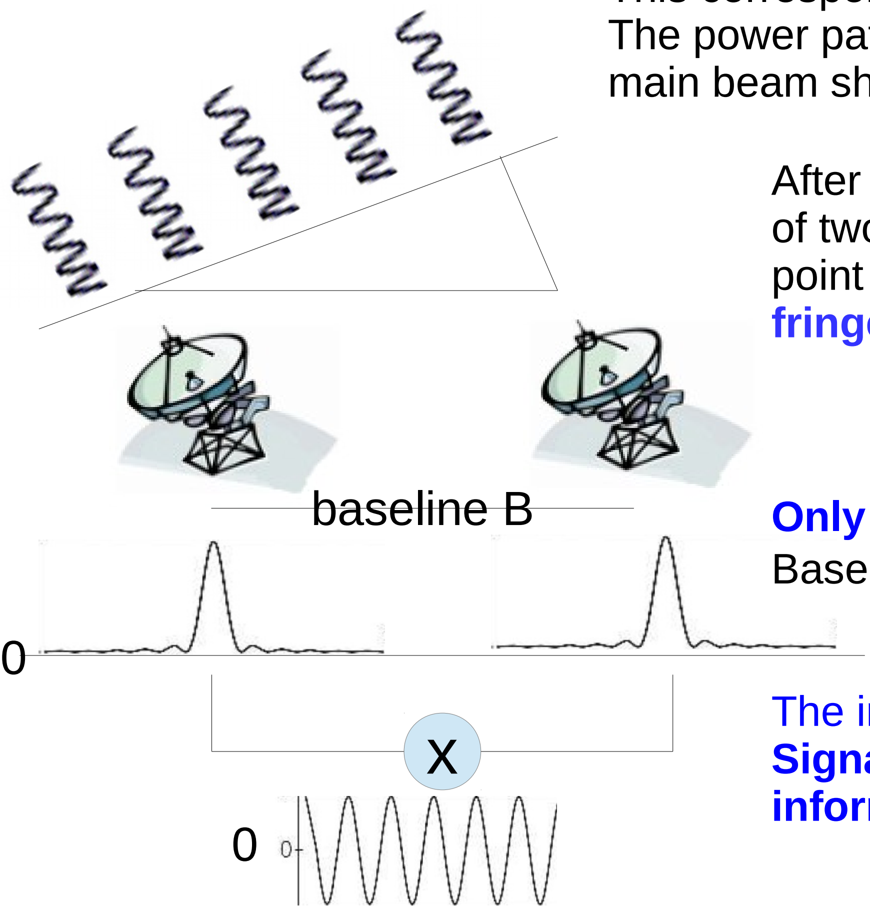


After correcting for geometrical delays, allowing the comparison of two points of the same wavefront coming from a far away point source **the output of the correlation of two signals is a fringes pattern centered around 0 (total power is lost).**

Only the spatial component corresponding to $\theta=\lambda/B$ is preserved.
Baselines equal to 2D identifies angular scales of the order of $\theta/2$.

The interferometer works as a filter in spatial scales.
Signals on multiple baselines can be combined to retrieve information on source structure (= aperture synthesis).

Receiving system: ATMOSPHERE + ANTENNA + RECEIVER + BACKEND

The visibility function

The incoming wave induces a electromagnetic voltage in the antennas (E is the wave amplitude)

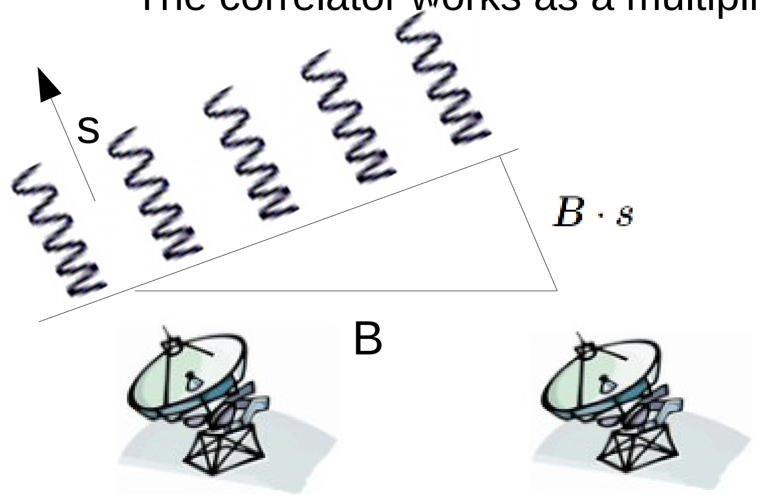
$$U_1 \propto E\,\mathrm{e}^{\,\mathrm{i}\,\omega t} \qquad U_2 \propto E\,\mathrm{e}^{\,\mathrm{i}\,\omega\,(t-\tau)}$$

The geometrical delay in the direction s=s0+ds

$$\tau = \frac{1}{c}\boldsymbol{B}\cdot\boldsymbol{s}$$

The correlator works as a multiplier and time integrator with output

$$R(\tau) \propto \frac{E^2}{T}\int^{T} \mathrm{e}^{\,\mathrm{i}\,\omega t}\,\mathrm{e}^{\,-\,\mathrm{i}\,\omega(t-\tau)}\,\mathrm{d}t$$



If t>>2π/ω

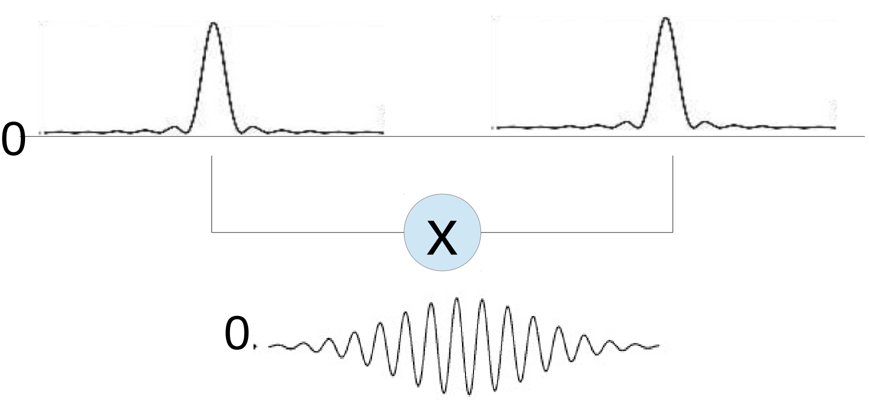
$$R(\tau) \propto \frac{\omega}{2\pi}E^2 \int_0^{2\pi/\omega} \mathrm{e}^{\,\mathrm{i}\,\omega\tau}\,\mathrm{d}t$$

that results in

$$R(\tau) \propto \tfrac{1}{2}E^2\,\mathrm{e}^{\,\mathrm{i}\,\omega\tau}$$

The power induced by the source in terms of I and effective area from in the direction s ($P \propto E^2$)

$$\begin{aligned}\mathrm{d}P &= I_\nu \cos\theta\,\mathrm{d}\Omega\,\mathrm{d}\sigma\,\mathrm{d}\nu\\ &= A(\boldsymbol{s})I_\nu(\boldsymbol{s})\,\mathrm{d}\Omega\,\mathrm{d}\nu\end{aligned}$$



The output of the correlator integrated over the source is **the visibility function**

$$r_{12} = A(\boldsymbol{s})\,I_\nu(\boldsymbol{s})\,\mathrm{e}^{\,\mathrm{i}\,\omega\tau}\,\mathrm{d}\Omega\,\mathrm{d}\nu$$

$$R(\boldsymbol{B}) = \iint_{\Omega} A(\boldsymbol{s})I_\nu(\boldsymbol{s})\exp\left[\mathrm{i}\,2\pi\nu\left(\frac{1}{c}\boldsymbol{B}\cdot\boldsymbol{s}\right)\right]\mathrm{d}\Omega\,\mathrm{d}\nu$$

Receiving system: ATMOSPHERE + $\boxed{\text{ANTENNA}}$ + $\boxed{\text{RECEIVER}}$ + BACKEND

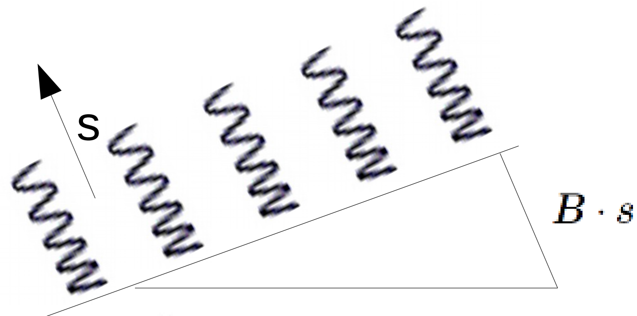
The visibility function: properties

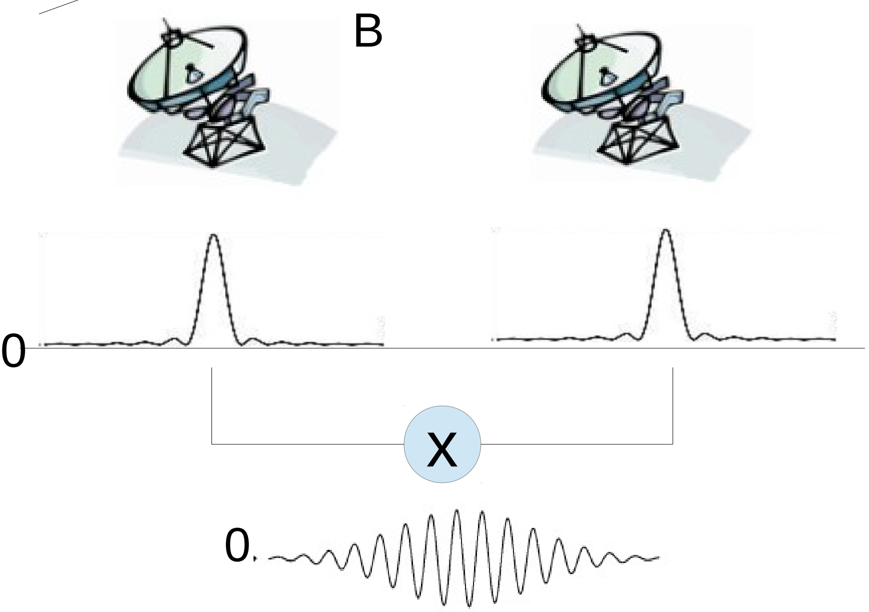
Some **visibility function** properties:

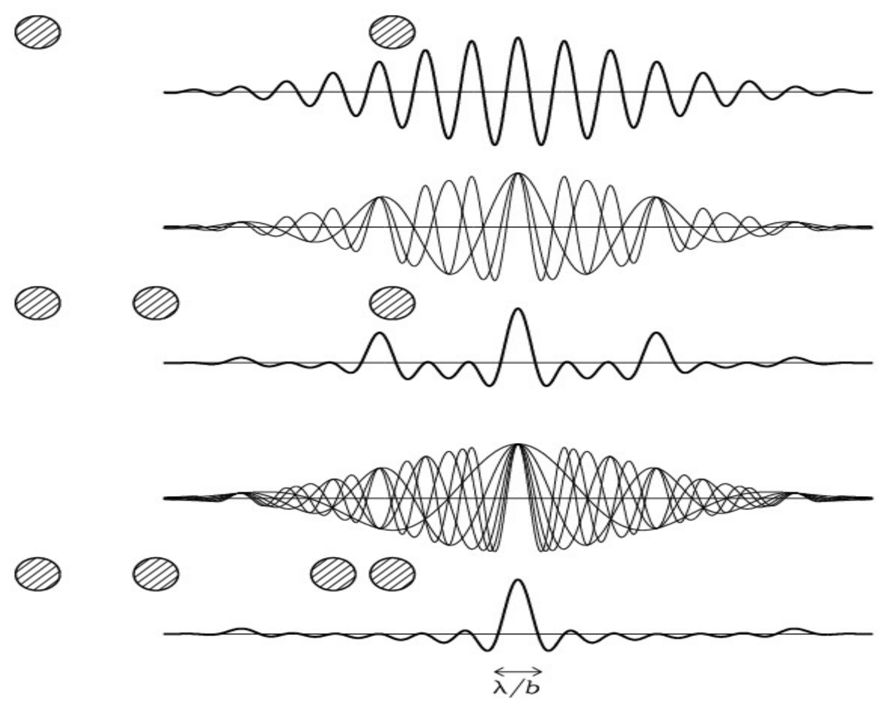
$$R(\boldsymbol{B}) = \iint_{\Omega} A(\boldsymbol{s}) I_{\nu}(\boldsymbol{s}) \exp\left[\mathrm{i}\, 2\pi\nu \left(\frac{1}{c}\boldsymbol{B}\cdot\boldsymbol{s}\right)\right] \mathrm{d}\Omega\, \mathrm{d}\nu$$

- **Amplitude is modulated by the main beam shape**
- **The phase is strictly connected with the source position**
- **Angular scales on the sky are associated with the size of the projected baseline needed to observe them and the FWHM of the response function width is the synthesized beam λ/B.**

  We can observe more angular scales either
  changing the baseline
  or averaging the signal from N Antenna couples (N(N-1)/2)







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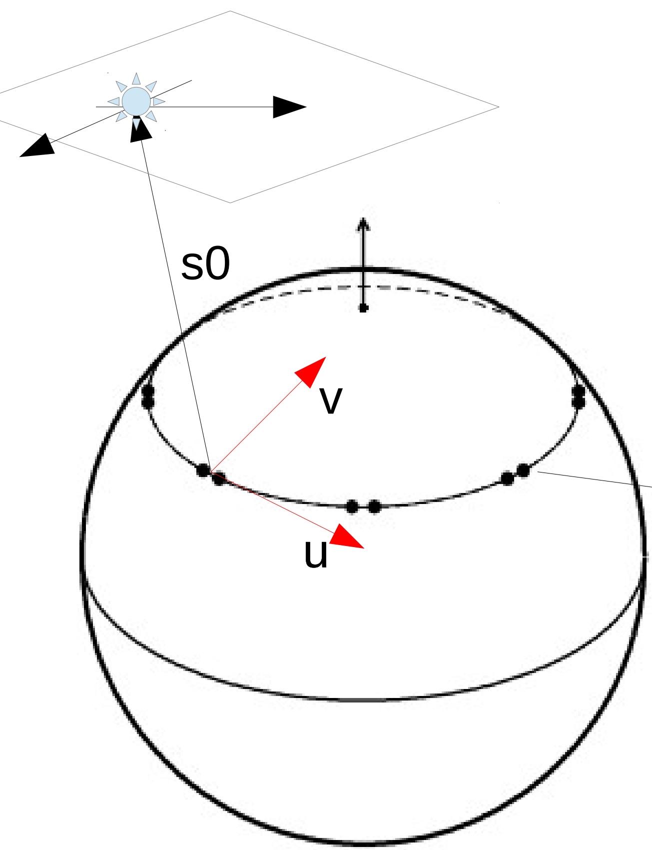
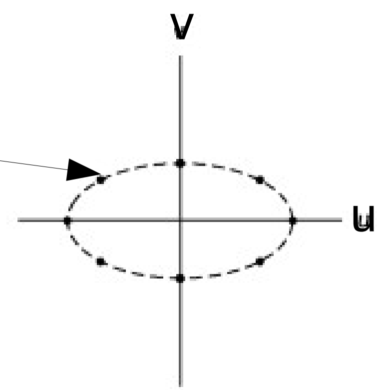
  We can observe more angular scales either
  changing the baseline
  or summing the signal from N Antenna couples (N(N-1)/2)
  or changing the angle towards the target (exploiting the Earth rotation)
  to obtain a different projection of the same baseline.





The projected baseline is described over the uv plane perpendicular to the direction to the phase center (s0) with u and v towards E and N. The earth rotation generates elliptical loci on the uv plane in 12 hr which ellipticity depends on the telescope latitude and source declination.

Receiving system: ATMOSPHERE + $\boxed{\text{ANTENNA}}$ + $\boxed{\text{RECEIVER}}$ + BACKEND

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$$R(\boldsymbol{B}) = \iint_{\Omega} A(\boldsymbol{s}) I_{\nu}(\boldsymbol{s}) \exp\left[\mathrm{i}\,2\pi\nu\left(\frac{1}{c}\boldsymbol{B}\cdot\boldsymbol{s}\right)\right] \mathrm{d}\Omega\,\mathrm{d}\nu$$

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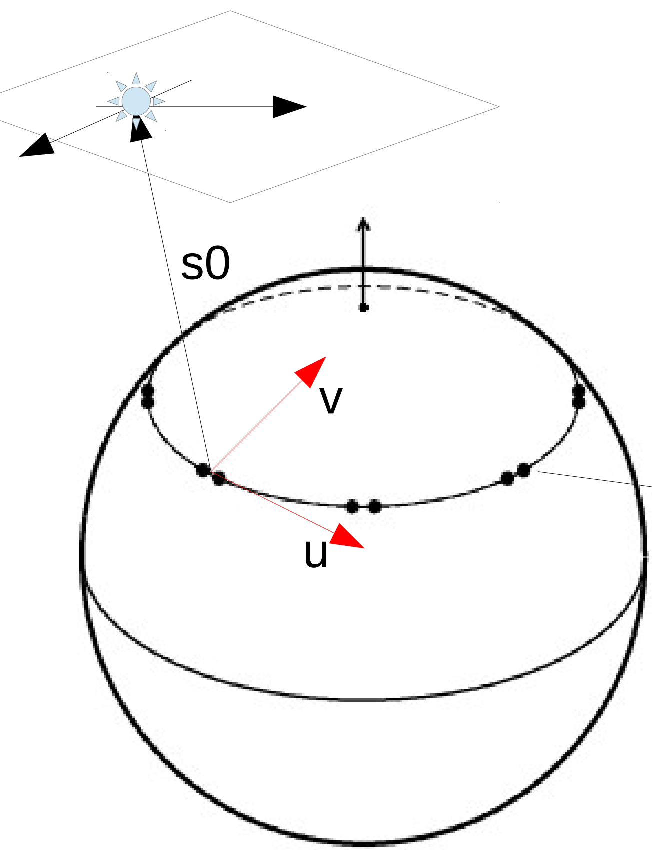

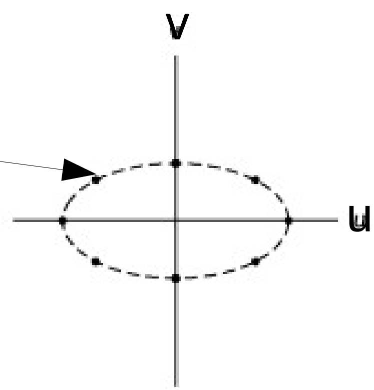

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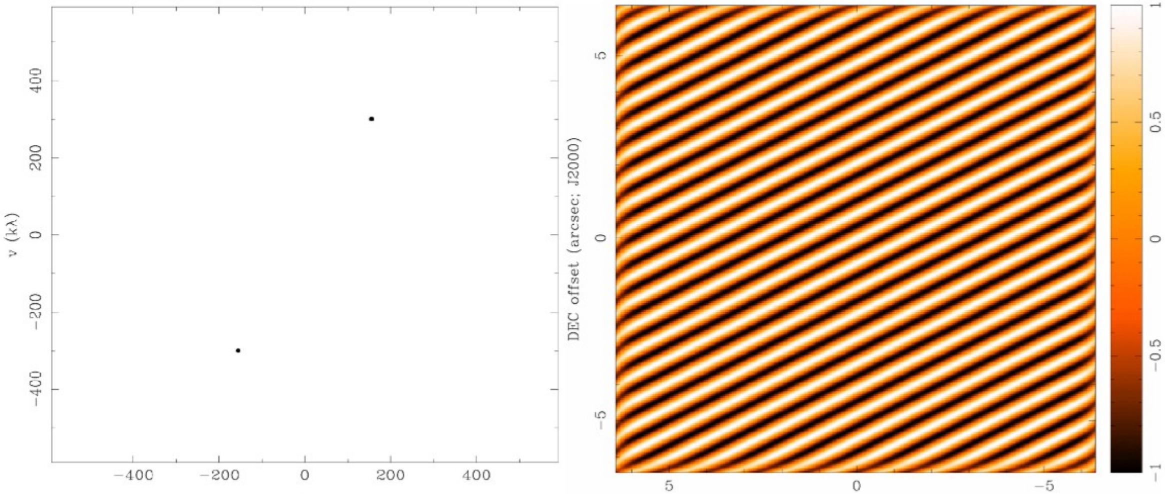
- **Van Cittert- Zernike theorem: the visibility pattern is the Fourier transform of the brightness pattern**

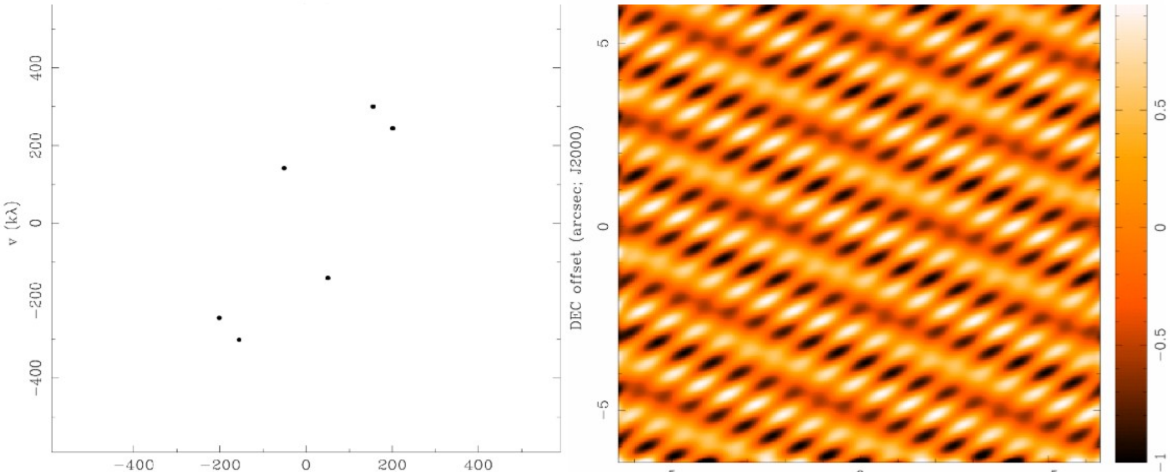
Hence the inverse transformation of the uv plane gives the image of the real plane (filtered for the observed angular scales).

Receiving system: ATMOSPHERE + ANTENNA + RECEIVER + BACKEND

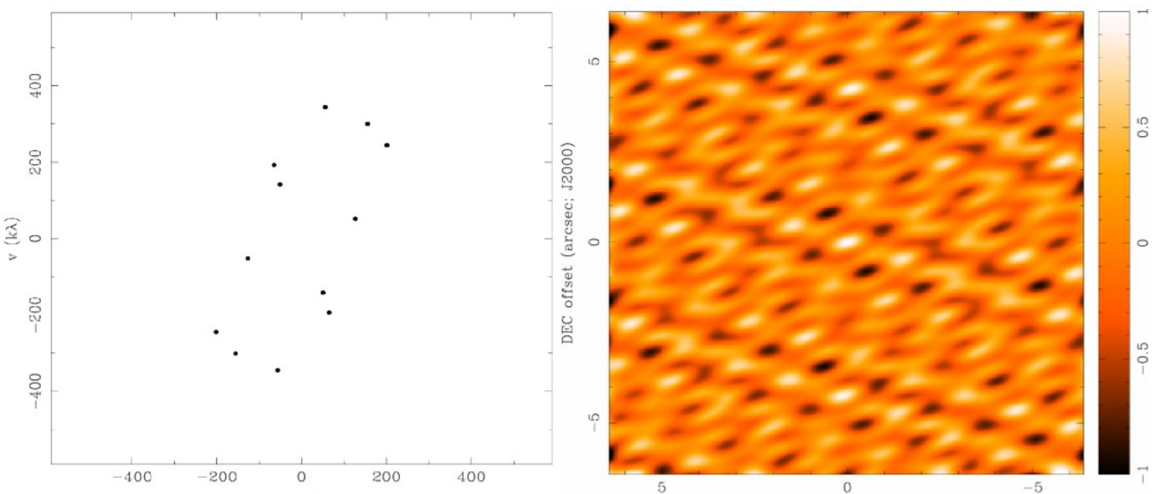
The visibility function: the uv plane



2 antennas

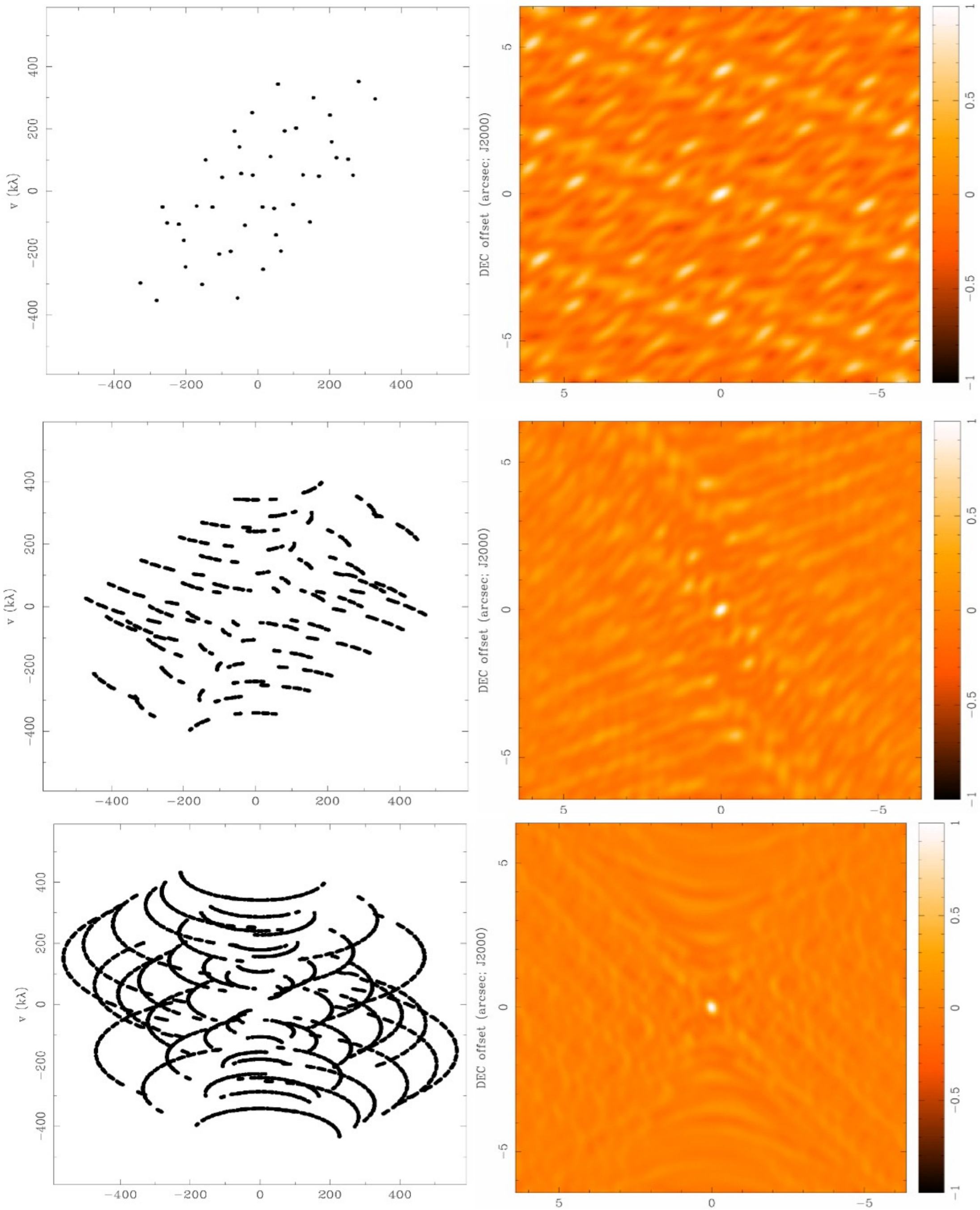


3 antennas



5 antennas

The visibility function: the uv plane



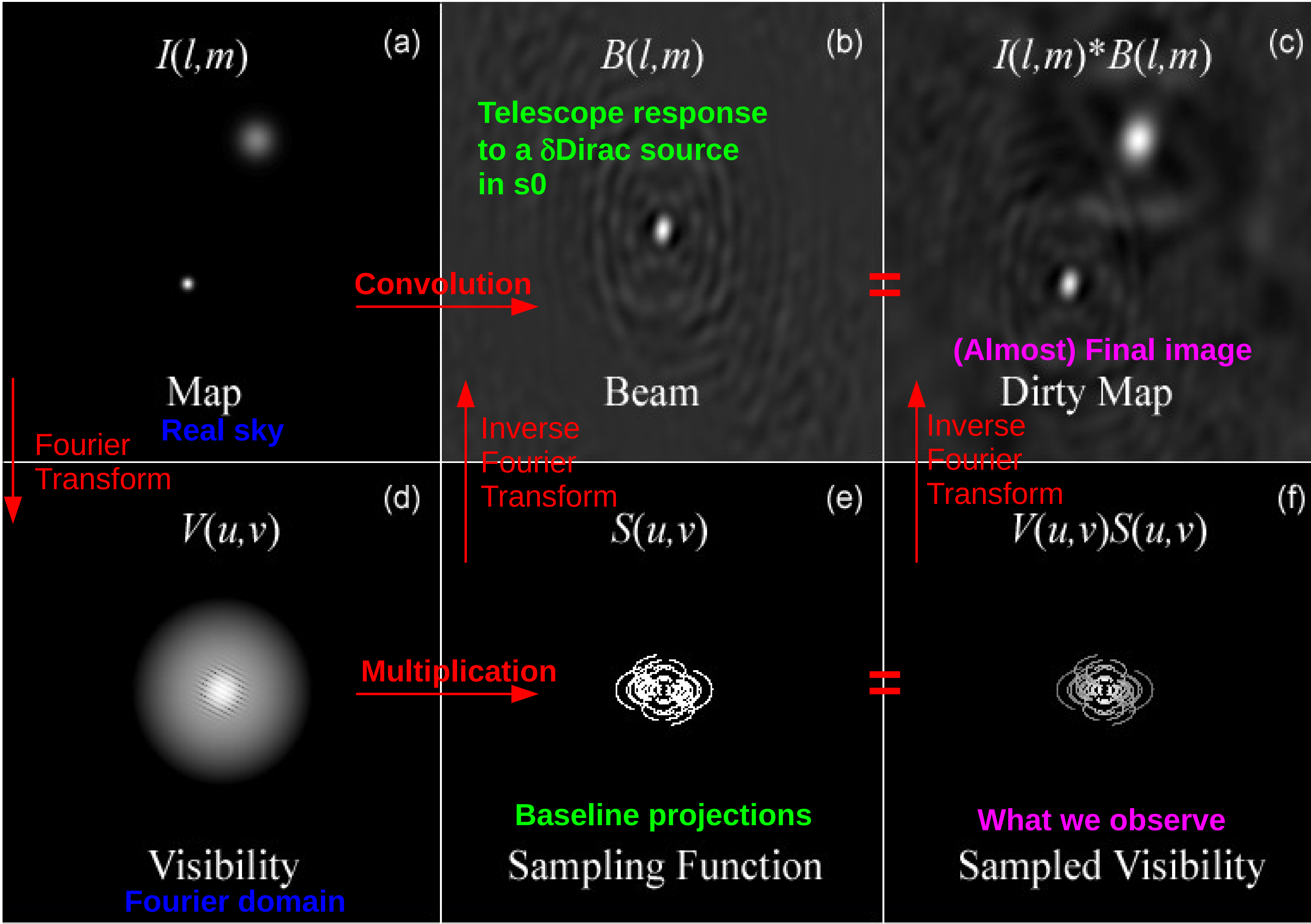
8 antennas

1 sampling

120 samplings

480 samplings

From the sky to the image



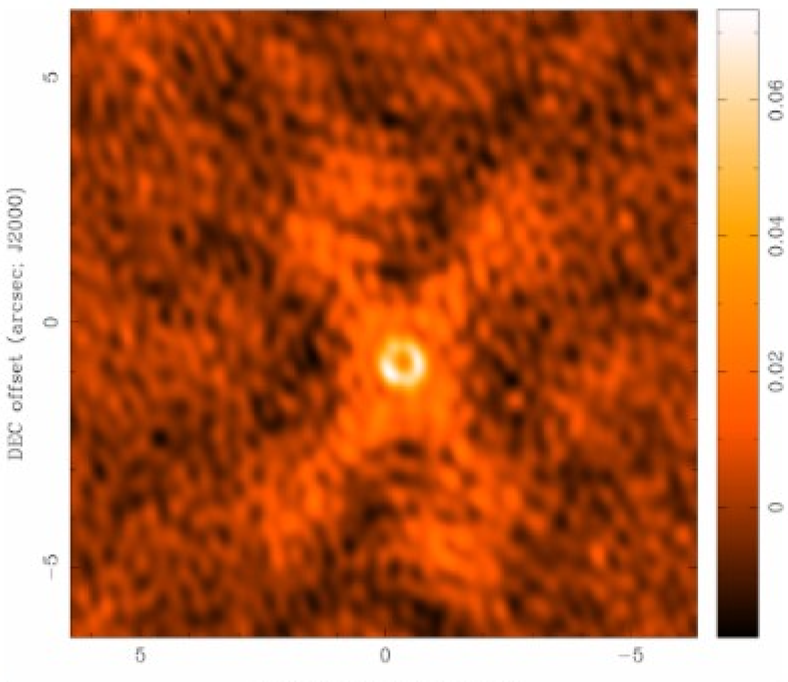
Deconvolution

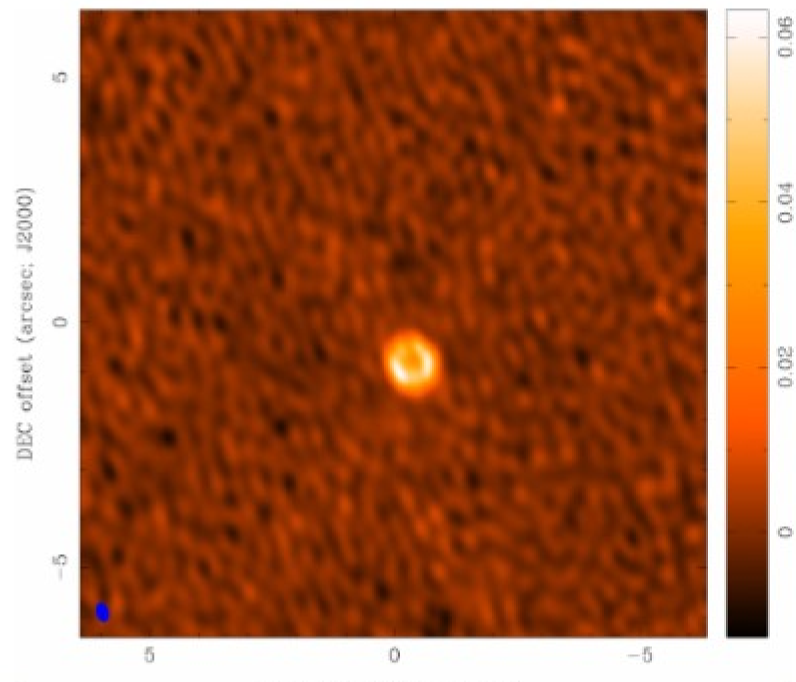
$$R(\boldsymbol{B}) = \iint_{\Omega} A(\boldsymbol{s}) I_\nu(\boldsymbol{s}) \exp\left[\mathrm{i}\,2\pi\nu\left(\frac{1}{c}\boldsymbol{B}\cdot\boldsymbol{s}\right)\right] \mathrm{d}\Omega\,\mathrm{d}\nu$$

- Aims to find a sensible model of I(s) compatible with data without sidelobes
- Uses non-linear techniques to interpolate/extrapolate samples of R(u,v) into unsampled regions of the (u,v) plane
- Requires knowledge of beam shape A(s) and a priori assumptions about I(s)

One of the most common algorithms in radio astronomy is the algorithm CLEAN (Hogbom 1974)

Dirty Image





Cleaned Image

The Atacama Large Millimeter Array

ALMA rationale

- The Atacama Large Millimeter Array is a **mm-submm reconfigurable interferometer**
- Inaugurated March 2013 on the Chajinantor plain (**5000m**, Chile)
- **The design of ALMA is driven by three key science goals:**

- The ability to detect spectral line emission from CO or [CII] in a normal galaxy like the Milky Way at a redshift of z=3, in less than 24 hours,

-> frequency bands, high sensitivity
-> study of star formation in galaxies up to high redshift, galaxy formation, Lensing, ...

- The ability to image the gas kinematics in protostars and in protoplanetary disks around young Sun-like stars in the nearest molecular clouds (150 pc),

-> high and low angular resolution, high spectral resolution
-> study of processes of star and planet formation, stellar evolution and structure, astrochemistry, ...

- The ability to provide precise high dynamic range (=|image max/image min|) images at an angular resolution of 0.1 arcsec.

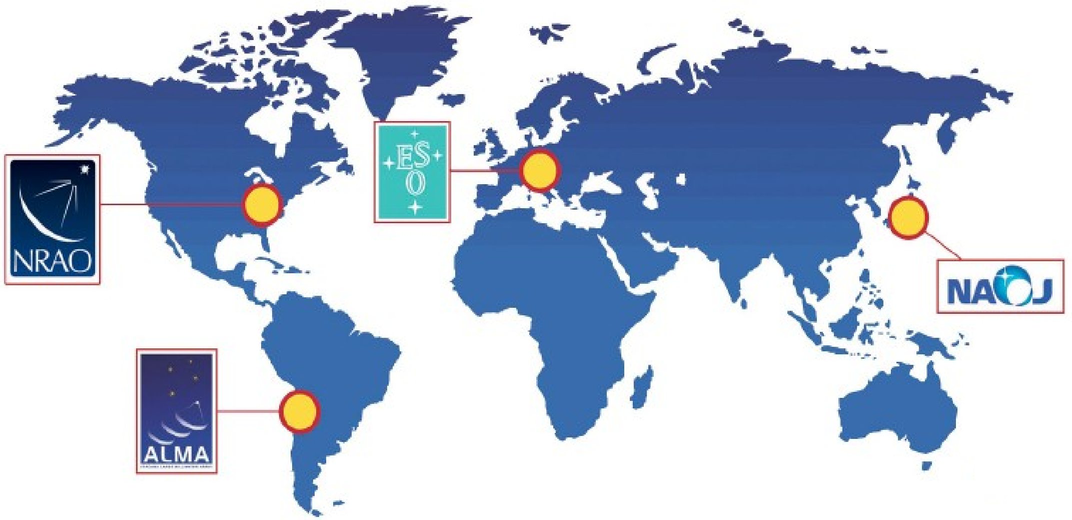
-> high angular resolution and sensitivity
-> galaxy dynamics, AGN core mechanisms, imaging of exoplanets, comets, asteroids, ...

ALMA organization

World wide collaboration

- Europe: **ESO** (14 countries)
- North America: **NRAO** (USA, Canada)
- East Asia: **NAOJ** (Japan, Taiwan)
- Chile

Contributors share the observing time



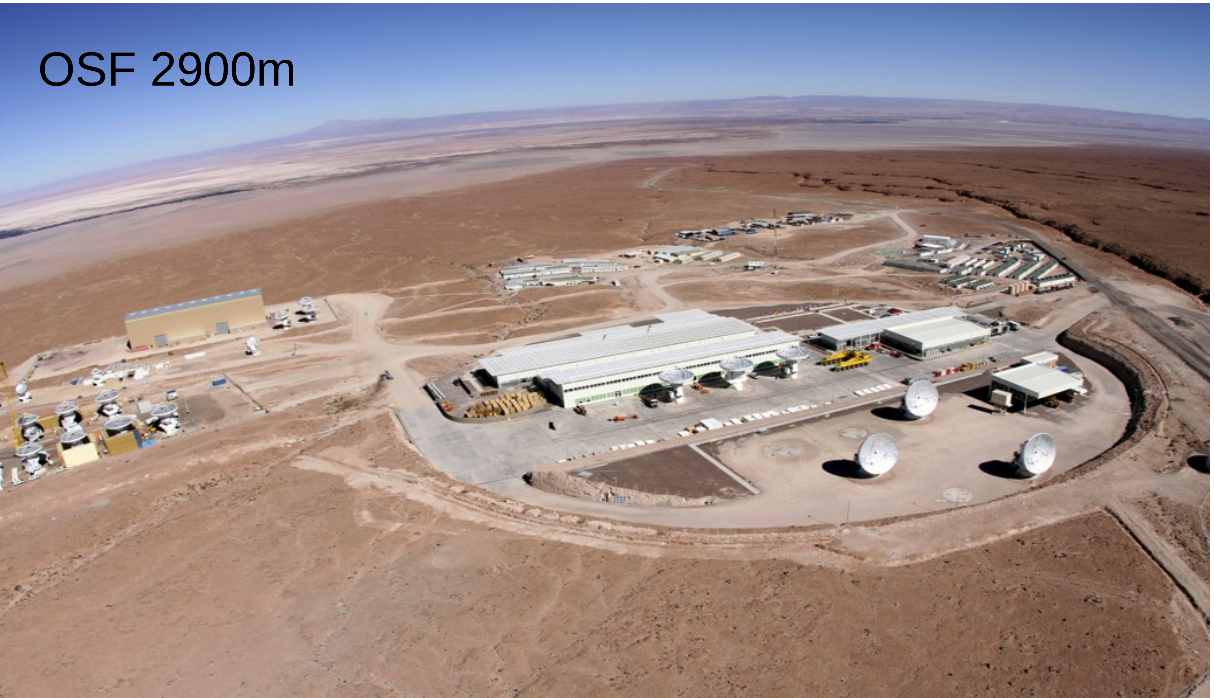
3 Sites in Chile

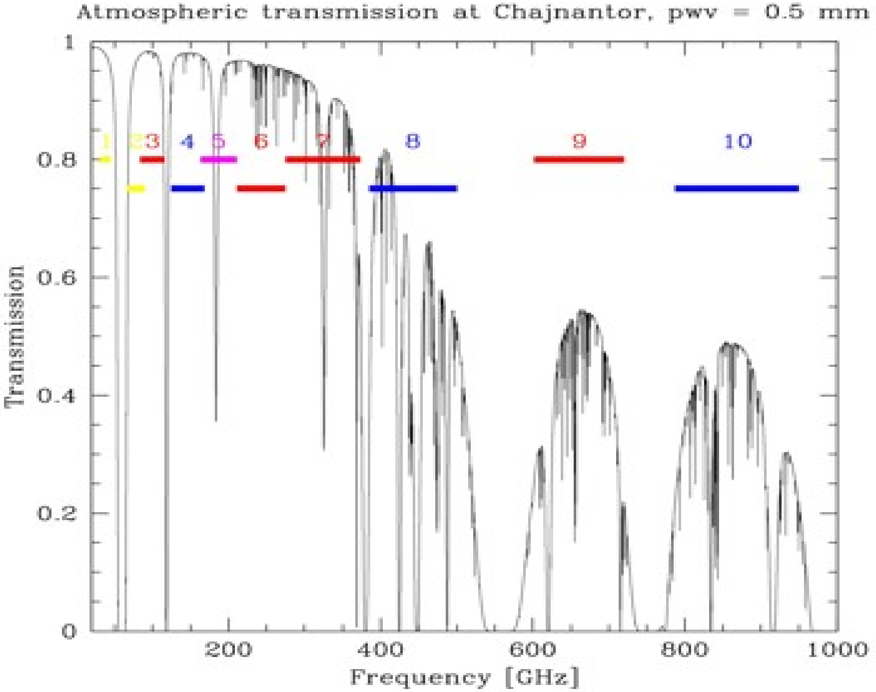
- *AOS*: ALMA Operations Site (5000m): Antennas, Correlator
- *OSF*: Operations Support Facility (3000m):
  Labs, Antenna Assembly & Maintenance Operators, Astronomers
- *SCO*: Santiago Central Office:
  - Call for Proposals
  - Running ALMA
  - Data Reduction Pipeline
  - Quality Assessment

ALMA sites

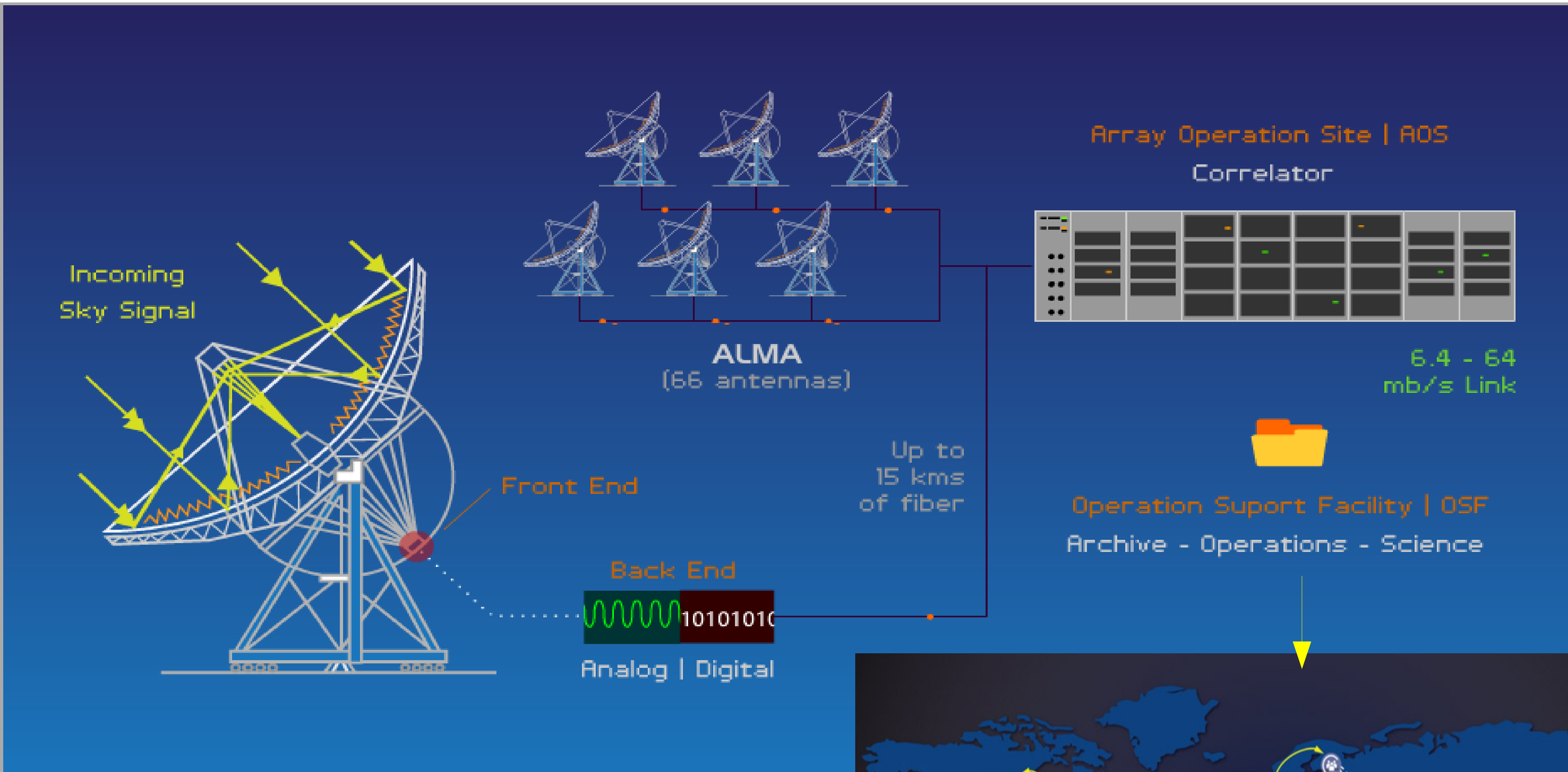

AOS 5000m


San Pedro de Atacama
15 km
28 km
ALMA Operations Site
AOS
Operations Support Facilities
OSF
Toconao


OSF 2900m


Atmospheric transmission at Chajnantor, pwv = 0.5 mm
Transmission
Frequency [GHz]
0
0.2
0.4
0.6
0.8
1
200
400
600
800
1000
1
2
3
4
5
6
7
8
9
10

ALMA data flow

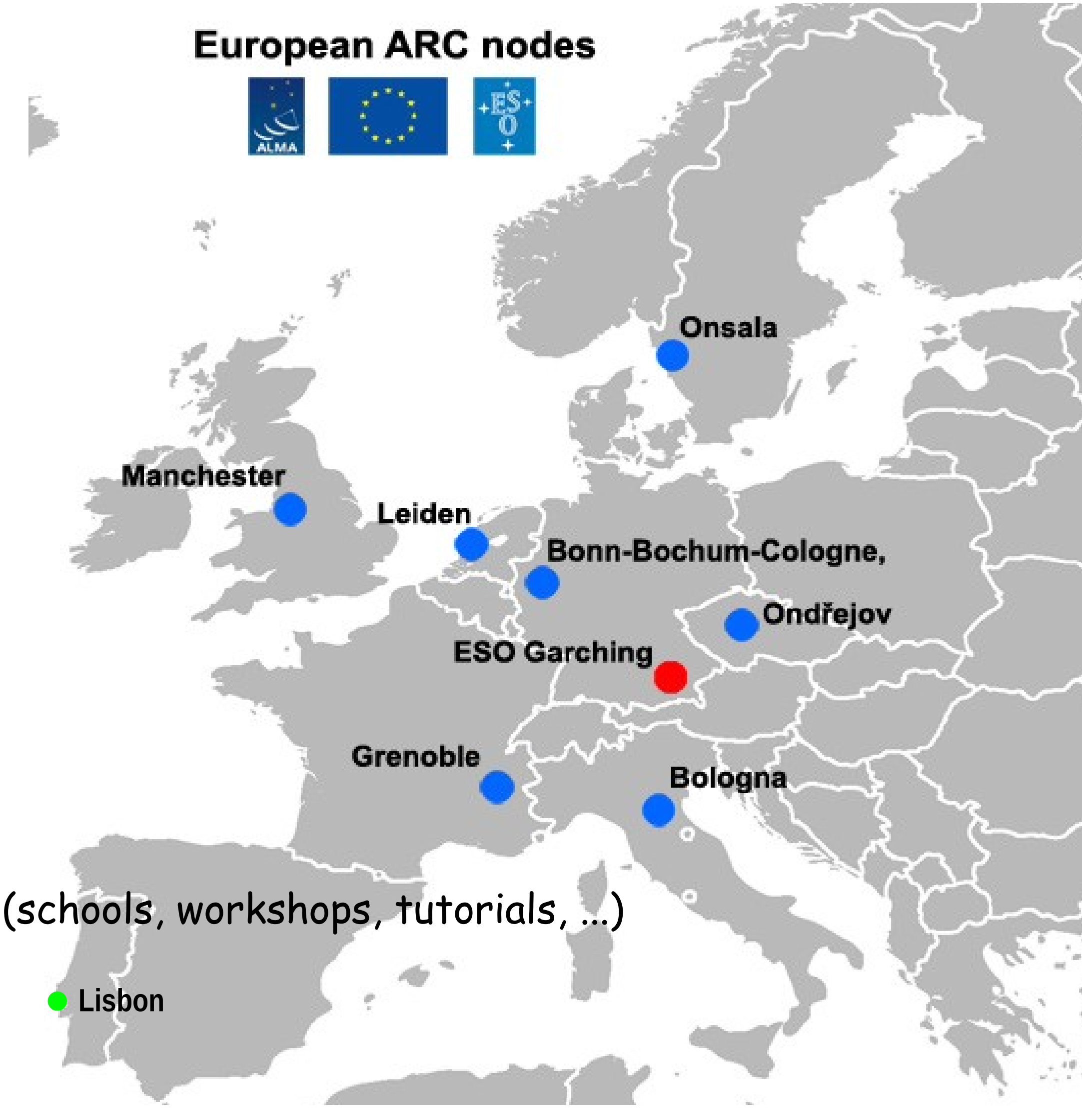


Data is collected, reduced and archived.
All the “almost” raw data is archived.

Each ARC hosts an archive mirror.

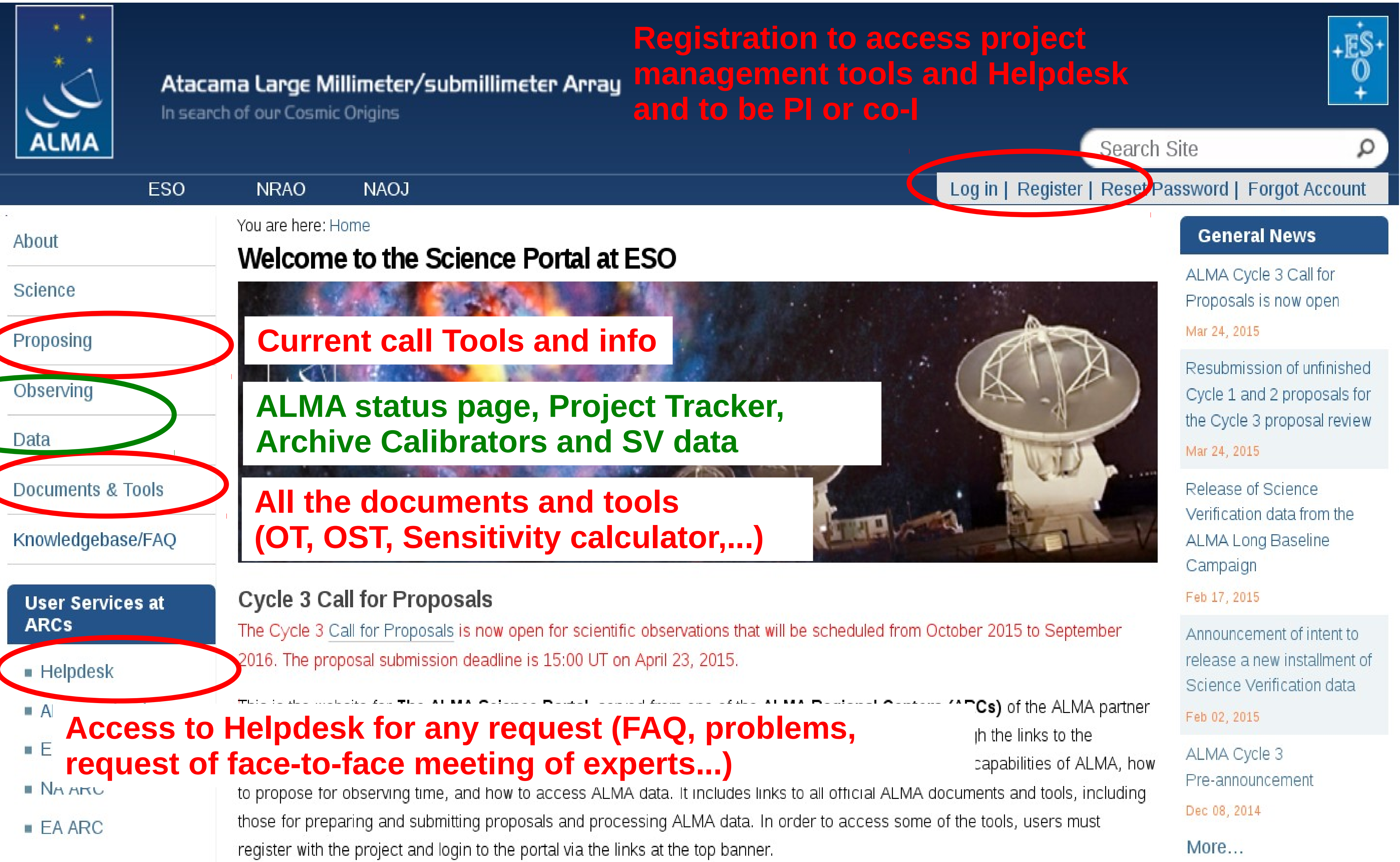
The ALMA Regional Centres (ARCs)

- **Interface between JAO and users**
- 1 ARC per Partner:
  - NRAO for North America
  - NAOJ for East Asia
  - **ESO for Europe (split in 7 nodes + 1CoE)**
- Operation support
  - Archive replication
  - Astronomer on duty
  - Software tools
- User support
  - Community formation and outreach (schools, workshops, tutorials, …)
  - Phase 1 (proposal preparation)
  - Phase 2 (scheduling block preparation)
  - Data analysis, Archive mining
  - F2F user support, Helpdesk

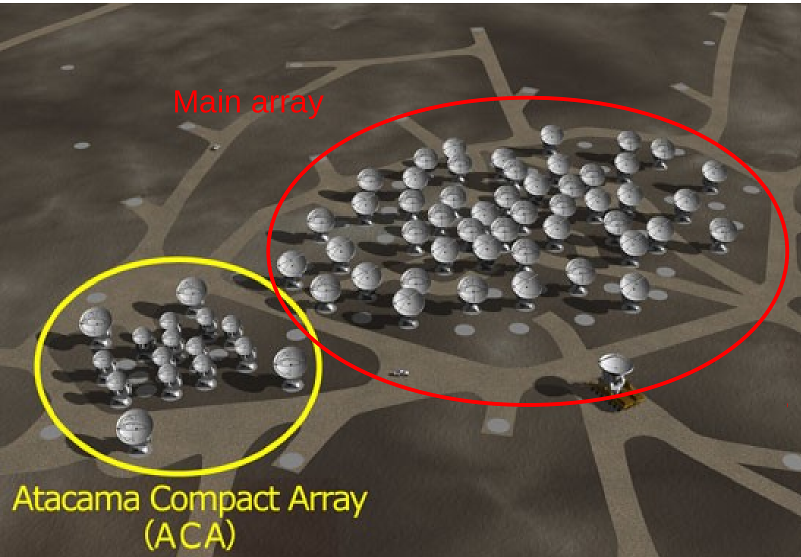


Enter the ALMA world through the ALMA Science Portal

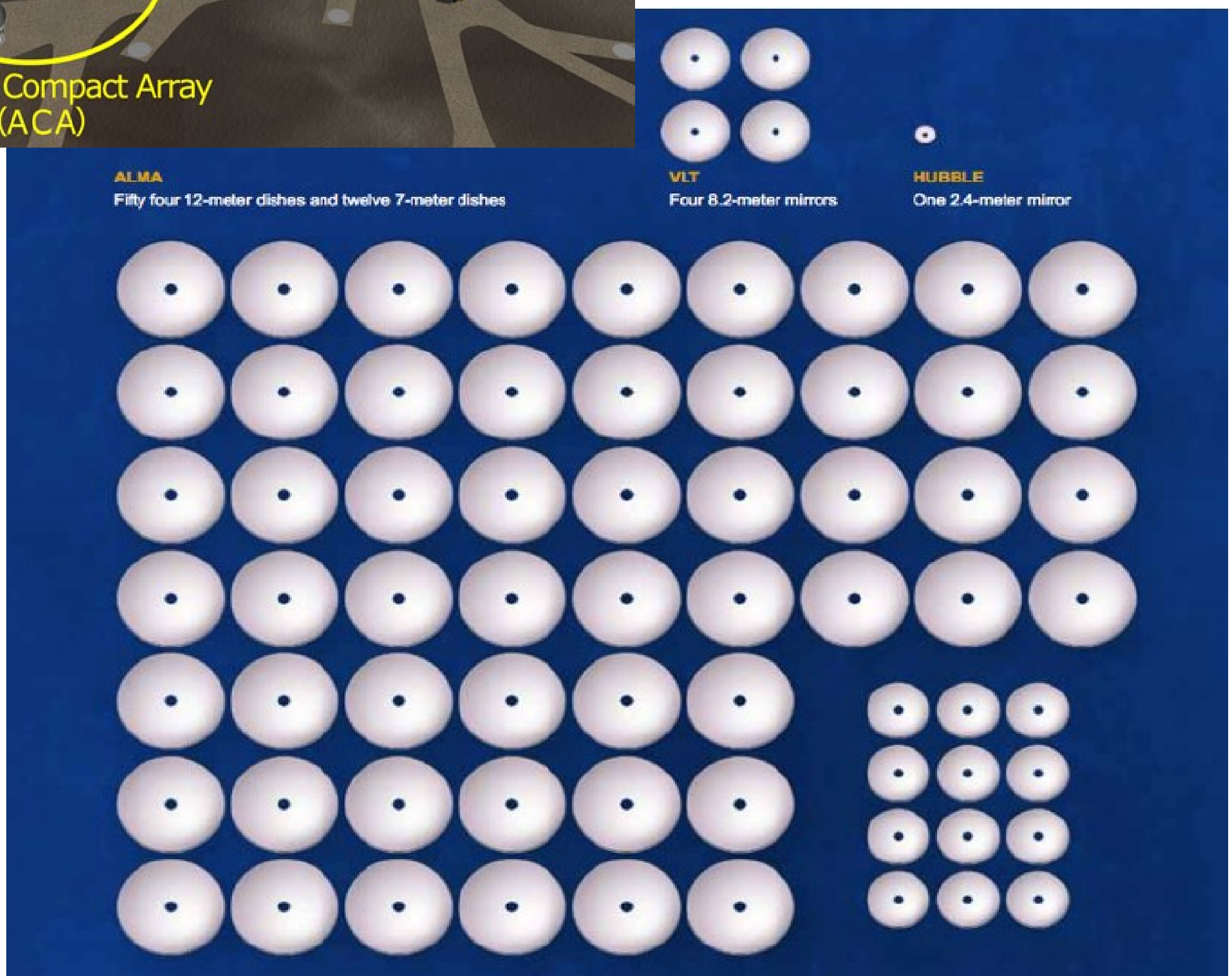
http://almascience.eso.org/



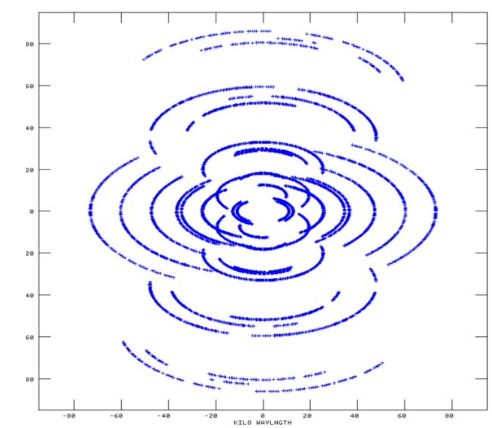
ALMA array(s)

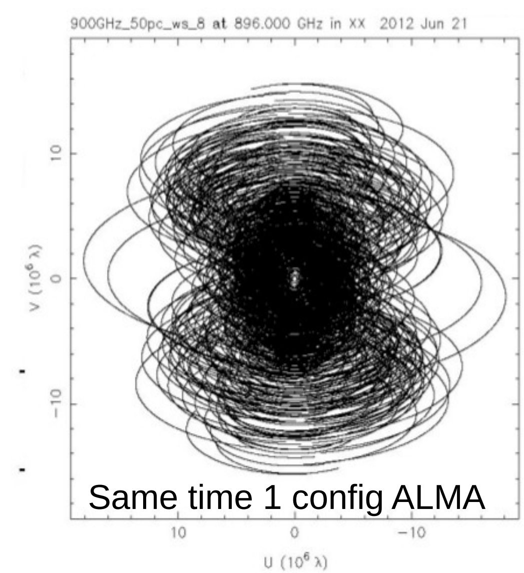


Antennas : **50x12m** main array + (**12x7m + 4x12m TP**) ACA
Baselines : **15m ->150m-16km** + **9m->50m**

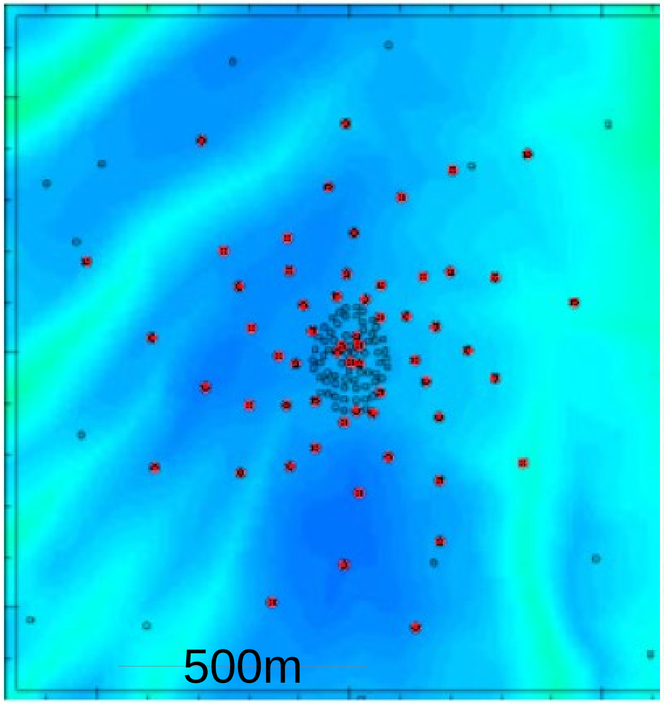


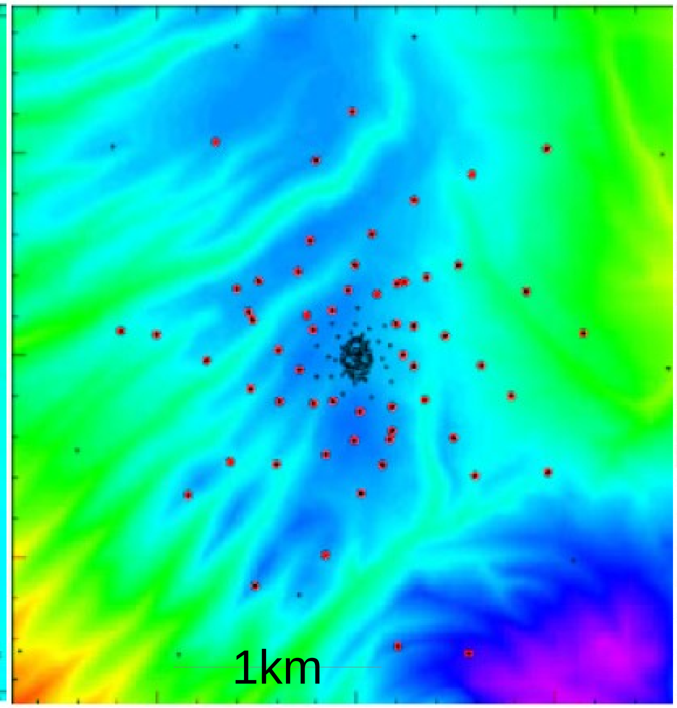
Few hr 2 config OVRO

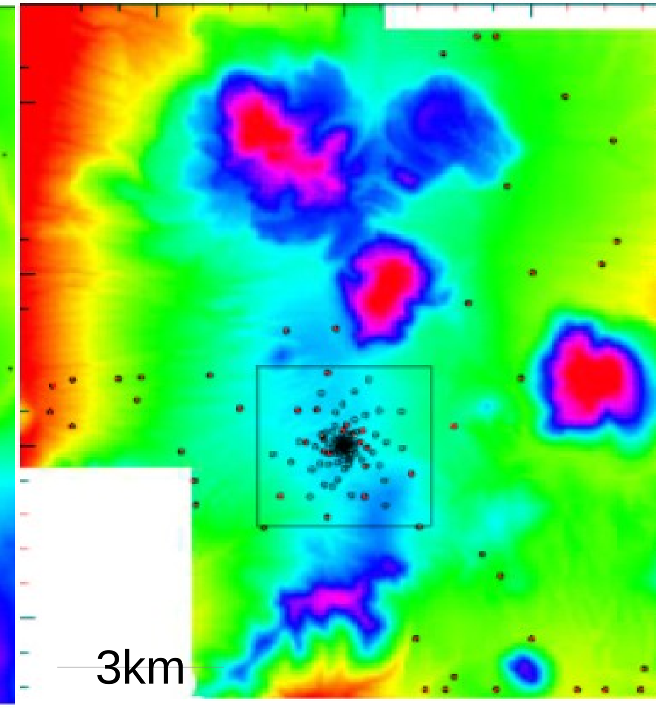


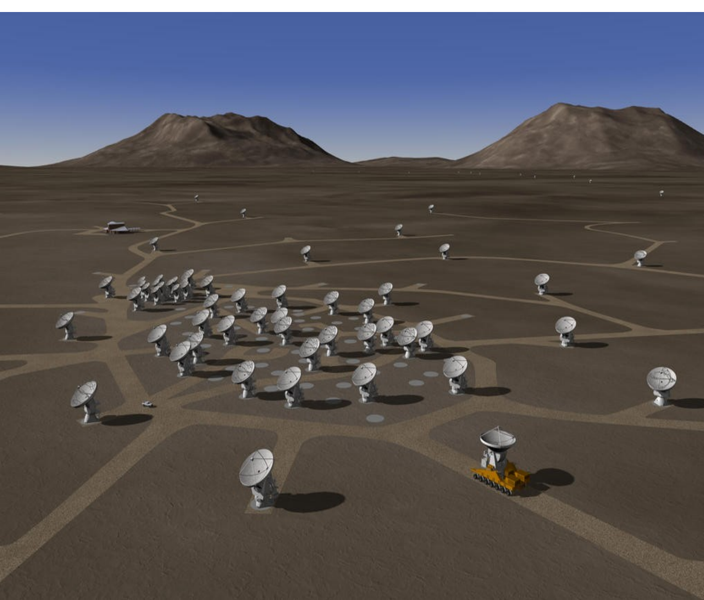


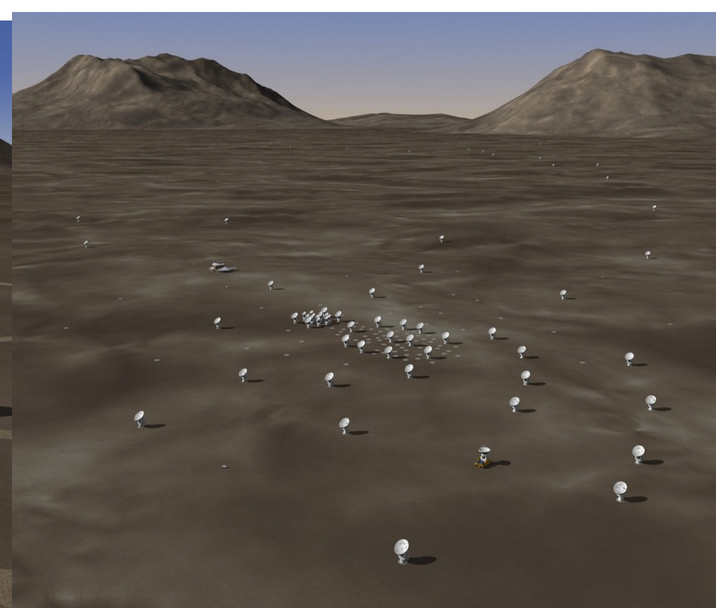
ALMA reconfiguration

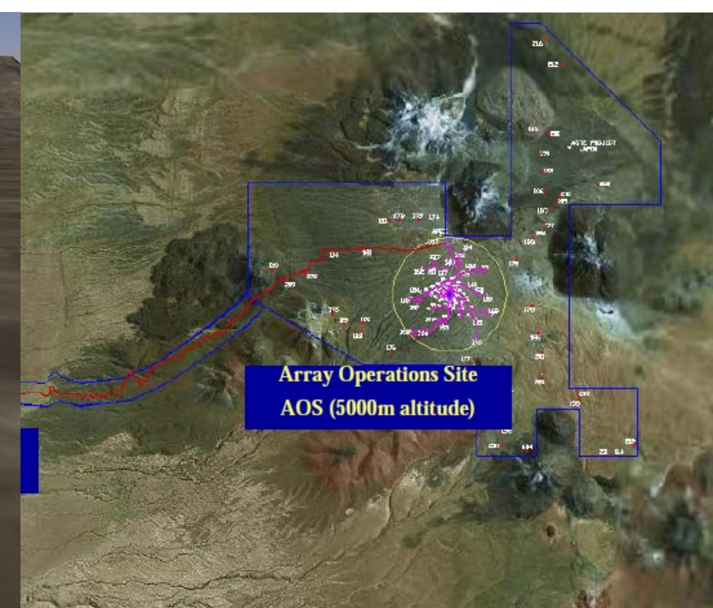




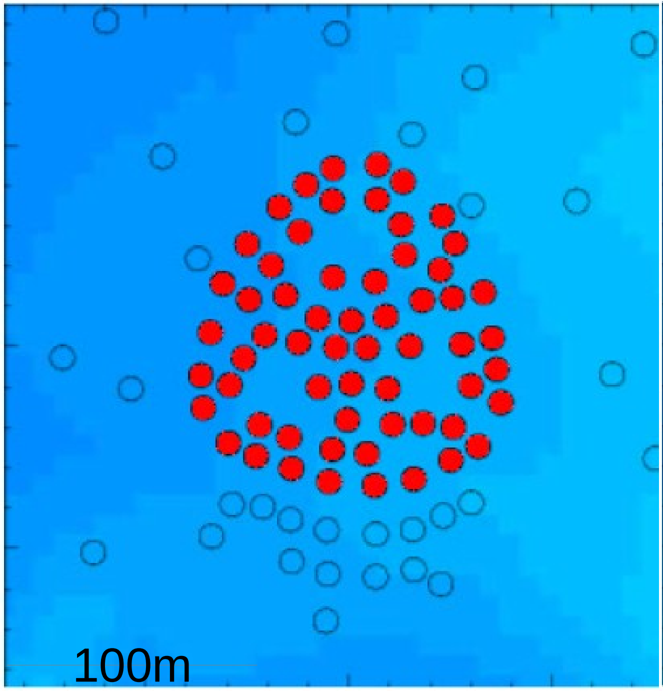


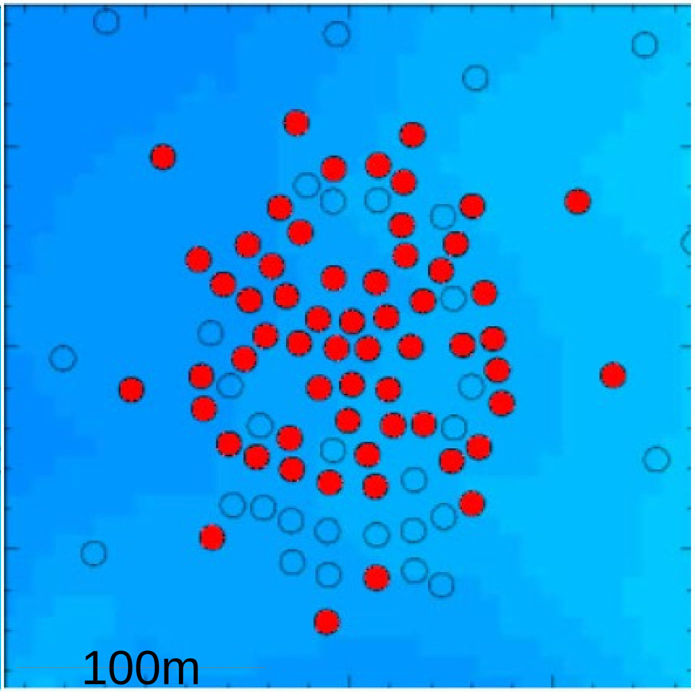


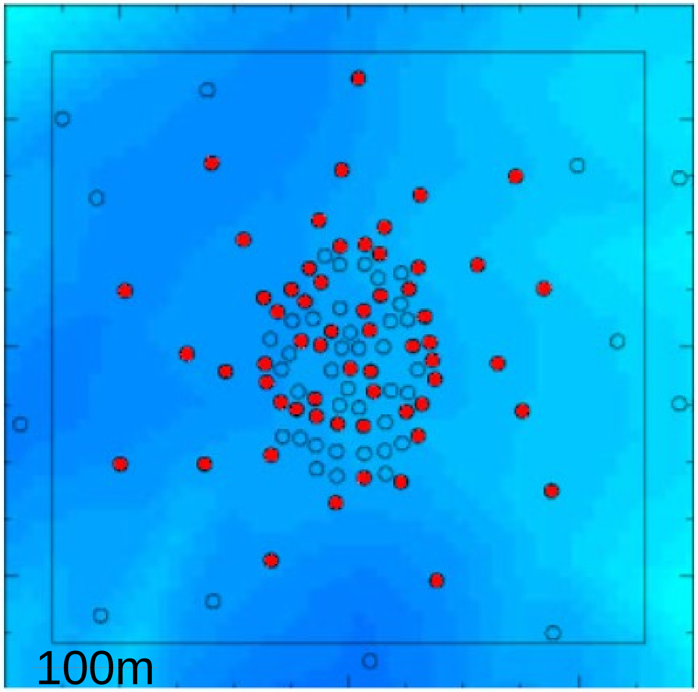


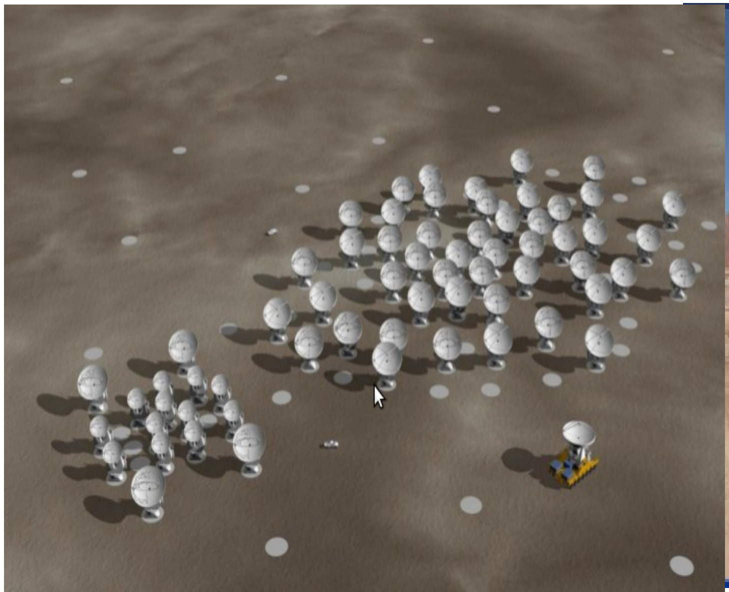


ALMA reconfiguration



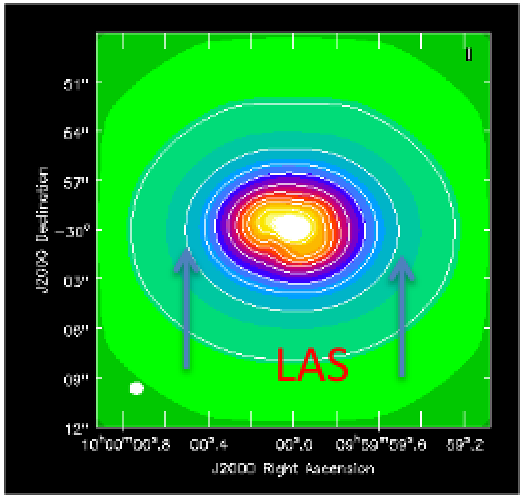




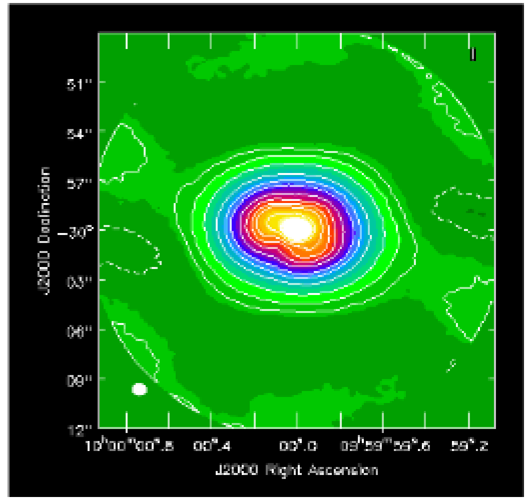


ALMA array(s)

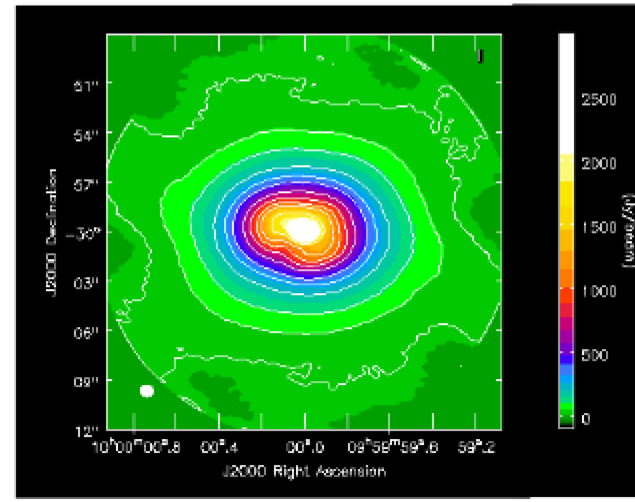
MODEL



12-m image

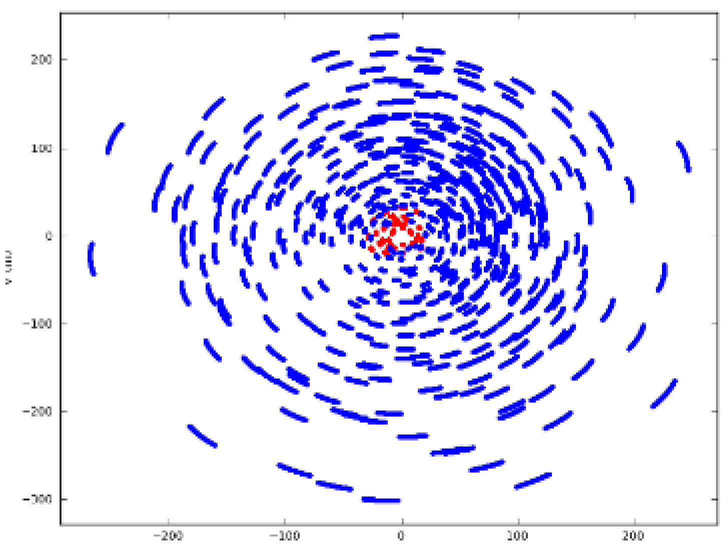


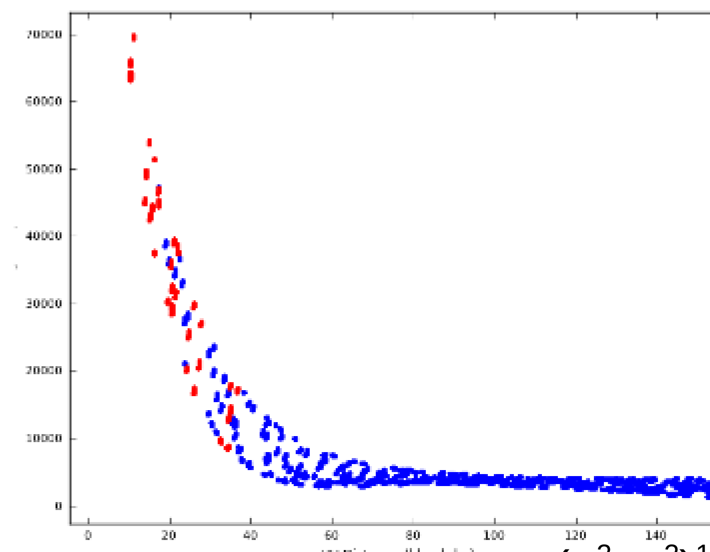
12m+7m Image



Restored flux 11000 Jy 7000 Jy 9000 Jy

Primary beam corrected: 20% cutoff: Contours: -20,20,50,100,200,300,400,600,800,1000,1200,1600,2000

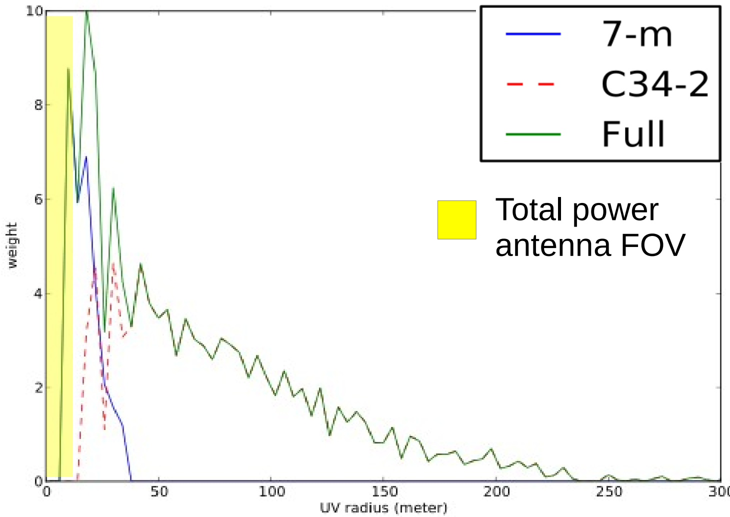




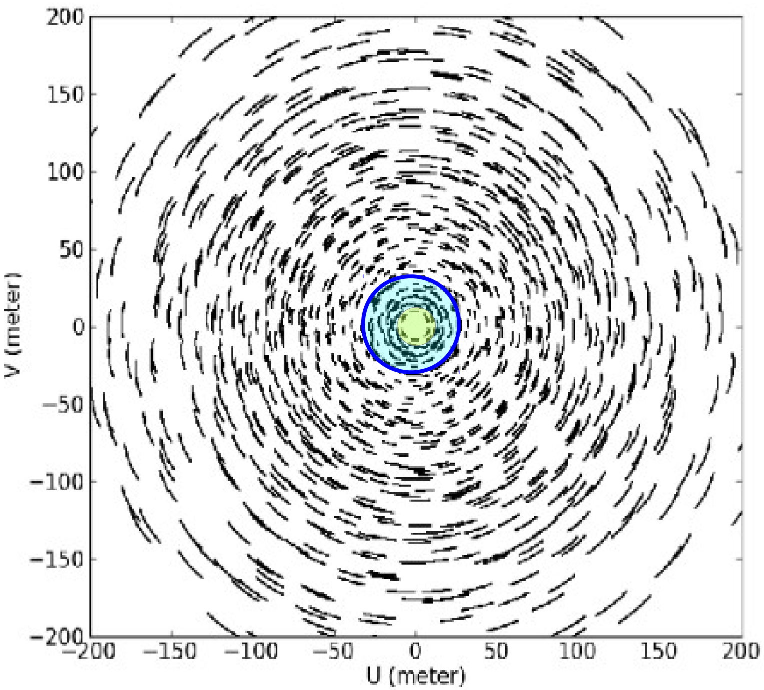
$(u^2+v^2)^{1/2}$

U-V coverage (red=ACA, blue=ALMA12m) Amplitude vs uv-distance

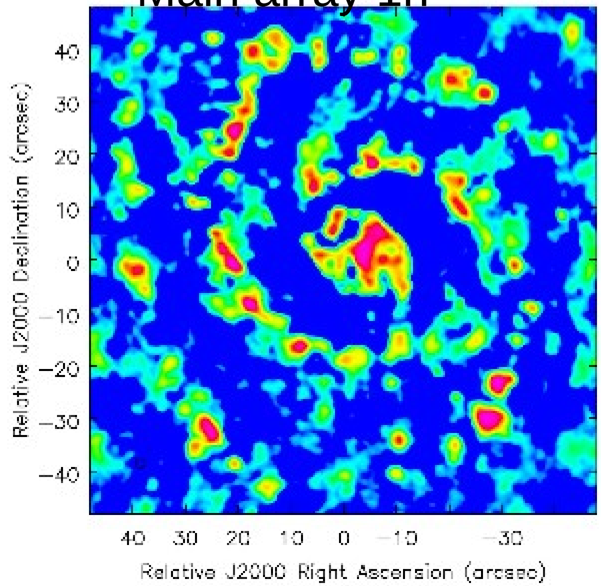
ALMA array(s)



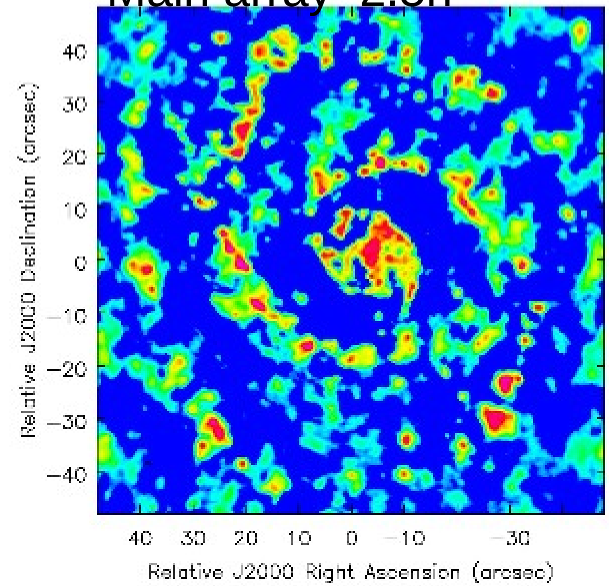
$(u^2+v^2)^{1/2}$

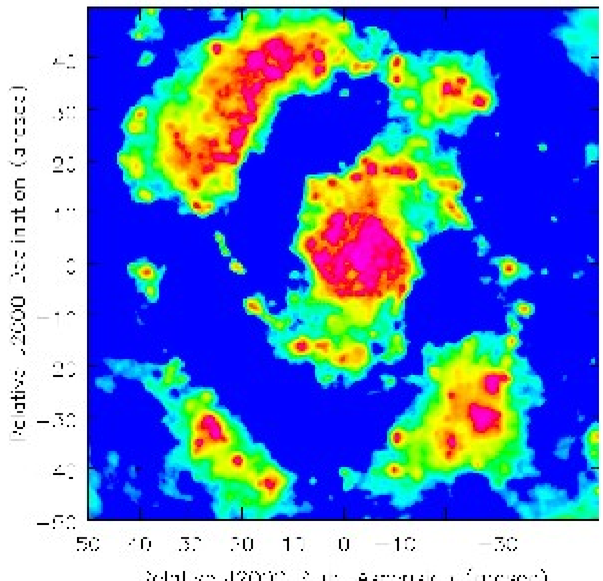


Main array 1h

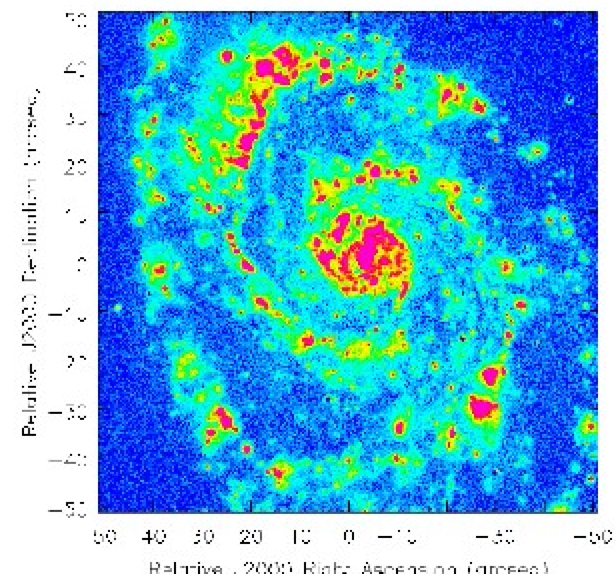


Main array 2.5h





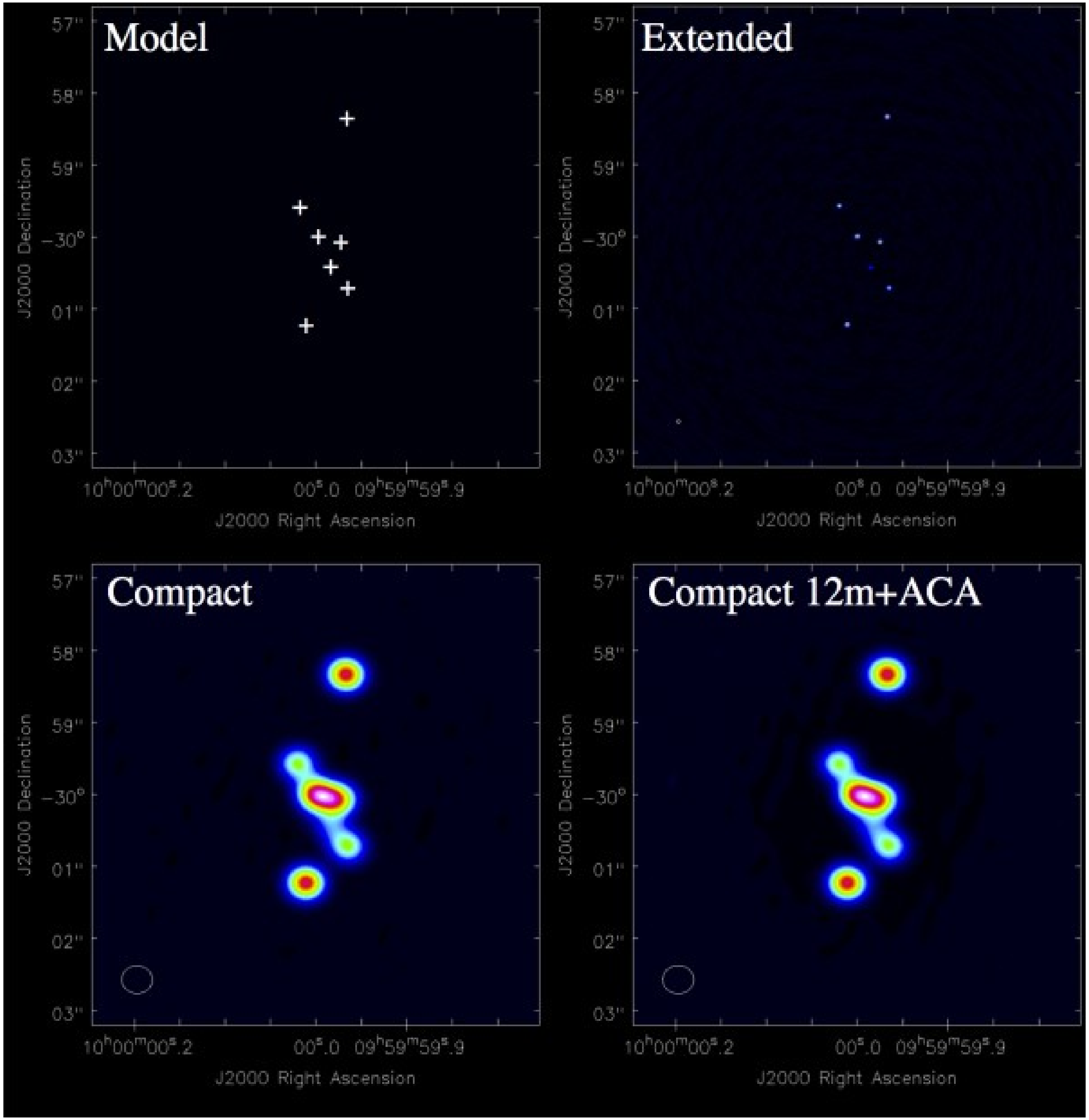
Main array+ ACA



Model M51

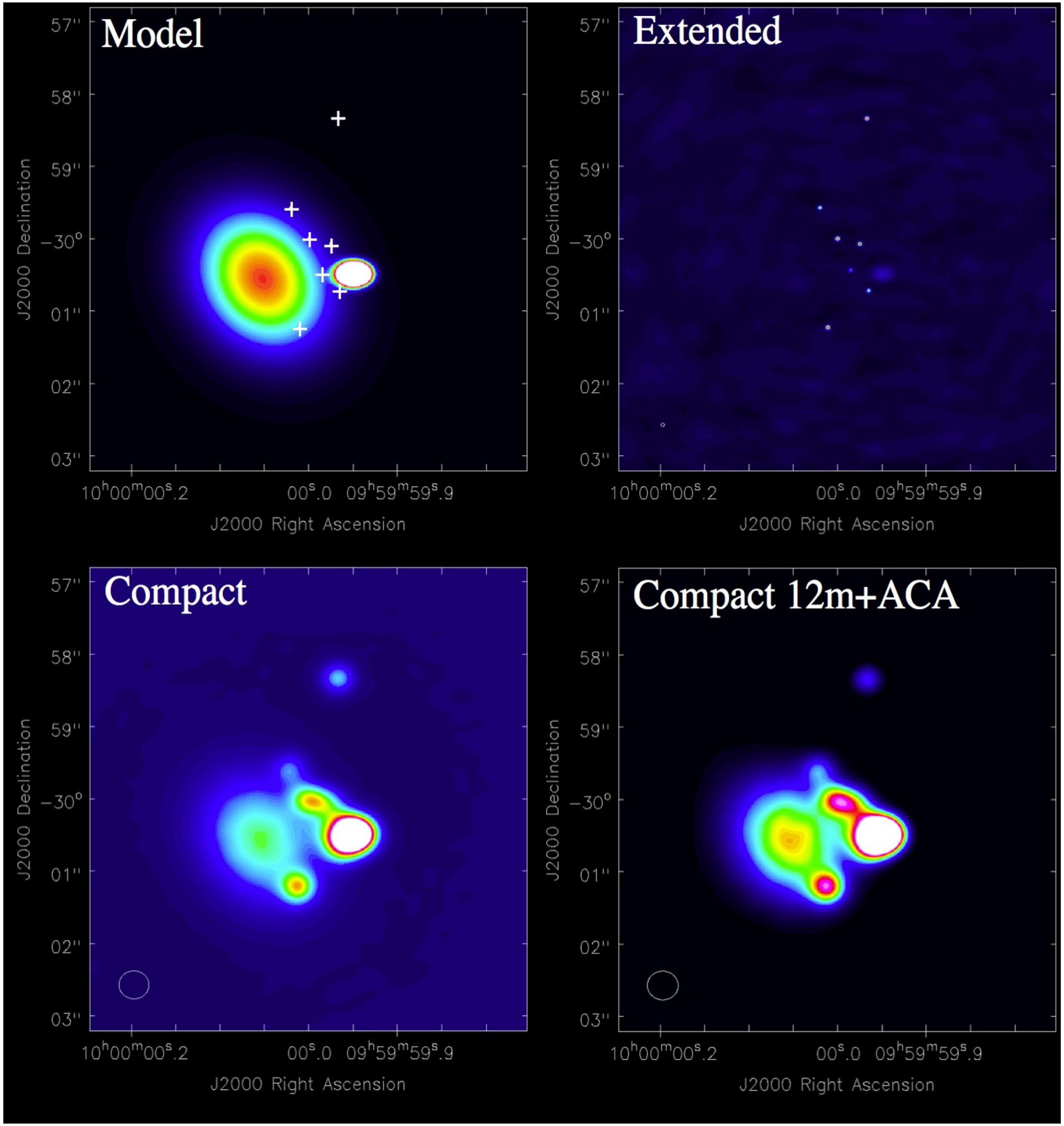
ALMA array(s)

Main array
for compact
objects



ALMA array(s)

ACA
for extended
objects

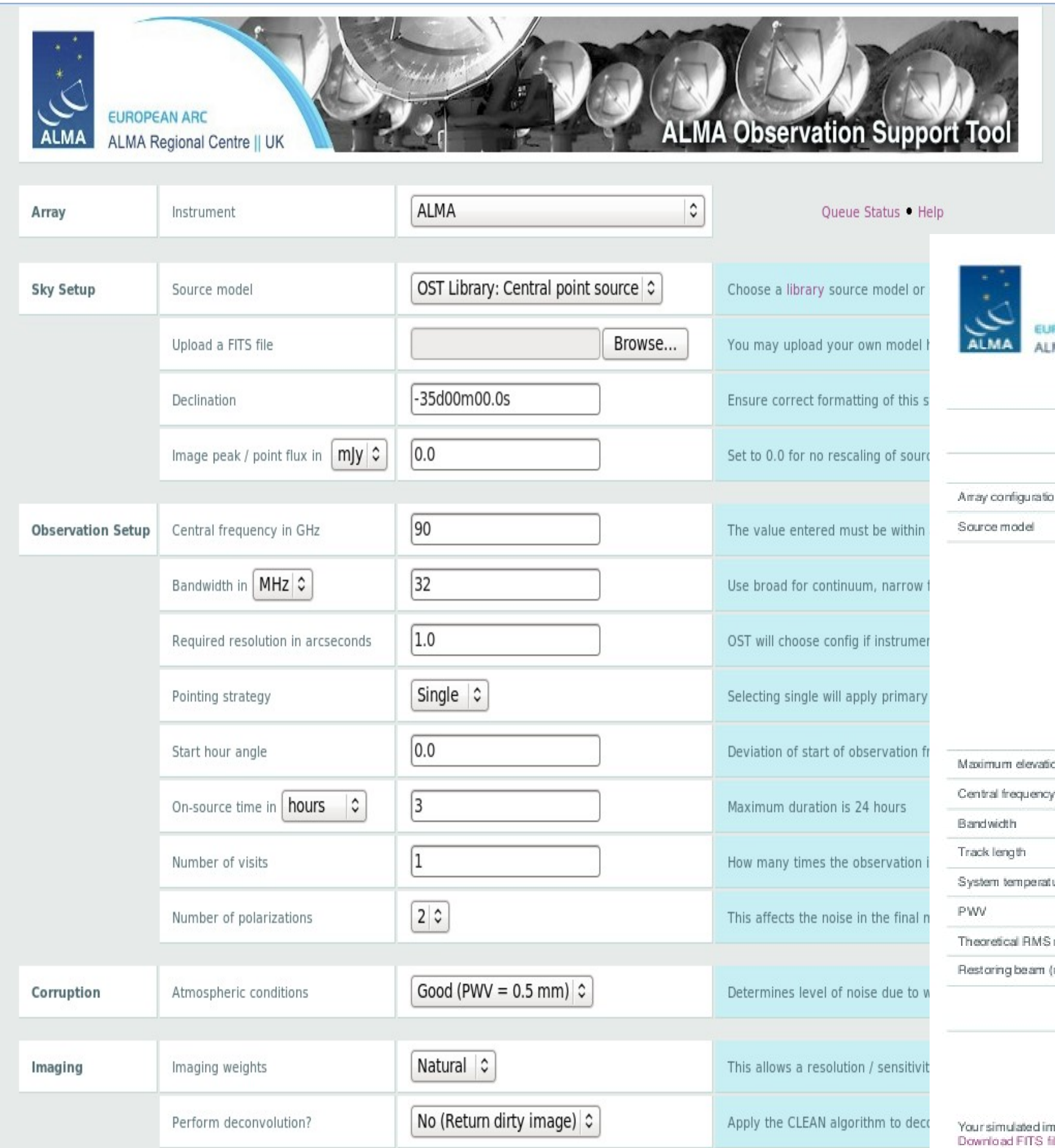


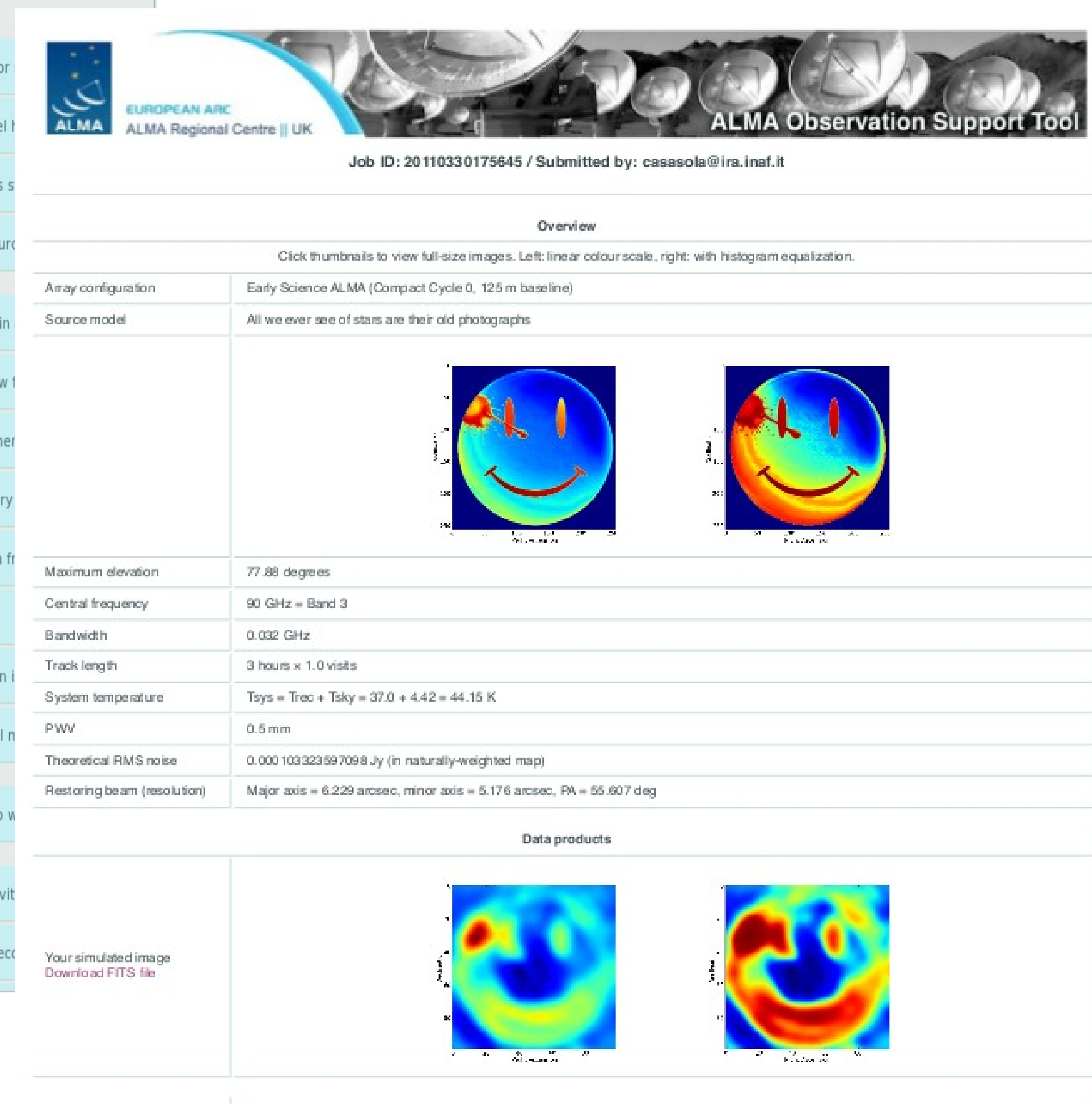
Make your ALMA simulations (Observation Support Tool)

http://almaost.jb.man.ac.uk/

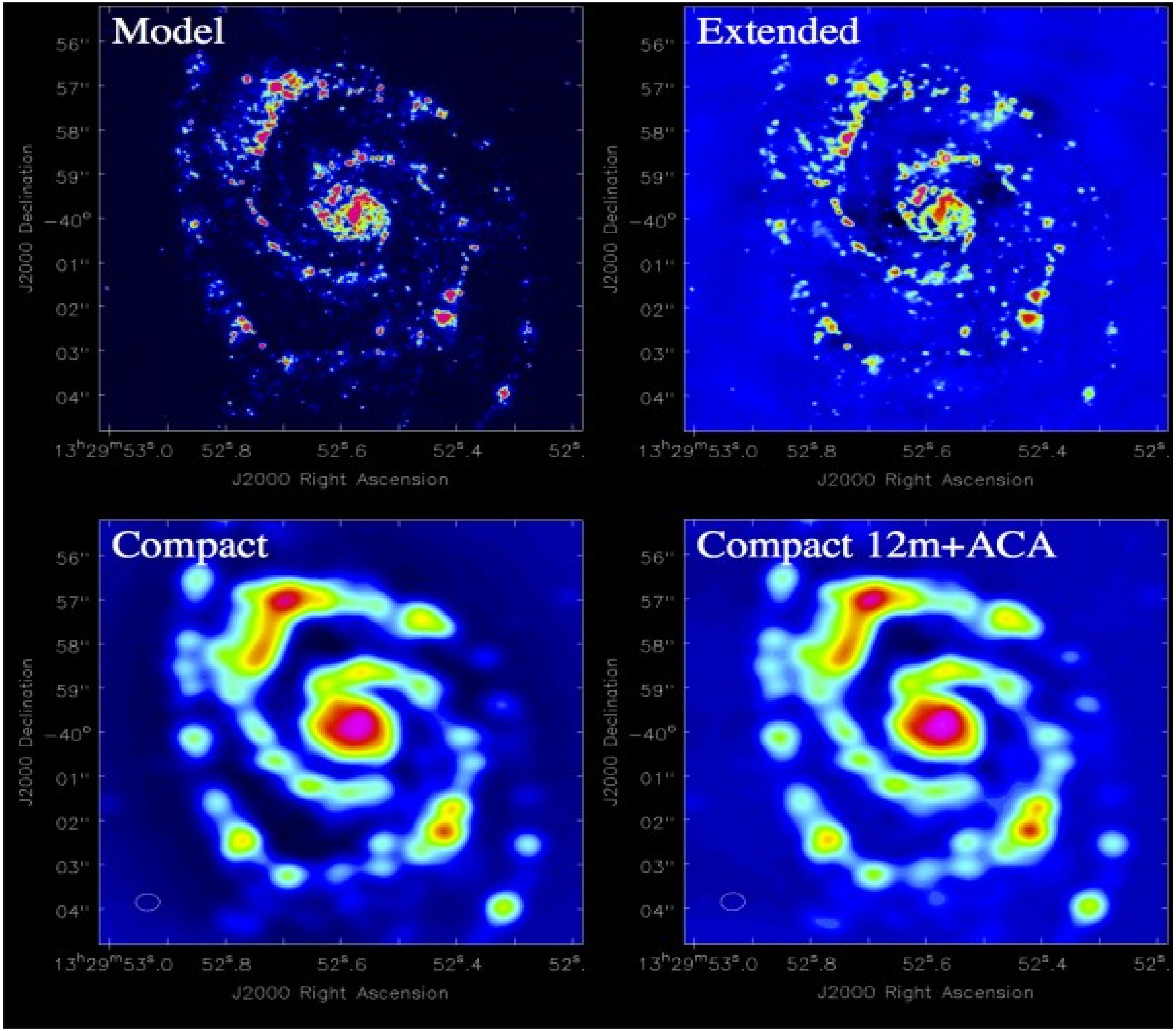
Submit a request for a full simulation of ALMA capabilities for your target

Receive the results via e-mail





Make your ALMA simulations (CASA simalma, simobserve, and simanalyze)



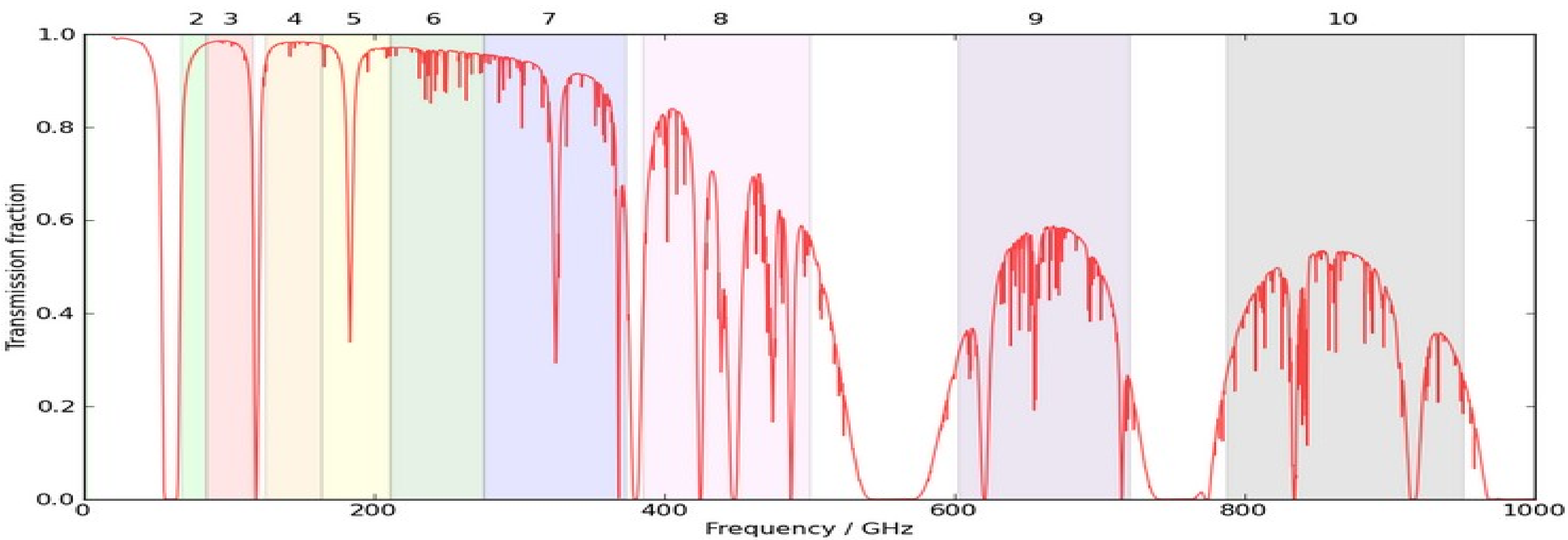
The task **simobserve** generates a data set with simulated visibilities based on an input model image.

The task **simanalyze** produces a cleaned image based on the simulated visibilities, and it generates some diagnostic images.

CASA also provides the task **simalma** that simplifies the steps needed to simulate ALMA observations that combine data from multiple arrays or multiple configurations.

ALMA bands

Full Science Capabilities					Most Compact		Most Extended	
Band	Frequency (GHz)	Wavelength (mm)	Primary Beam (FOV; ")	Continuum Sensitivity (mJy/ beam)	Angular Resolu-tion (")	Spectral Sensitivity ΔT_{line} (K)	Angular Resolution (")	Spectral Sensitivity ΔT_{line} (K)
1	31.3-45	6.7-9.5	197-137	0.04	13-9	0.006	0.12-0.08	255
2	67-90	3.3-4.5	92-69	0.06	6-4.4	0.009	0.06-0.04	413
3	84-116	2.6-3.6	73-53	0.07	4.8-3.4	0.04	0.045-0.032	430
4	125-163	1.8-2.4	49-38	0.06	3.2-2.4	0.048	0.030-0.023	330
5	163-211	1.4-1.8	38-29	0.11	2.5-1.9	0.06	0.027-0.021	641
6	211-275	1.1-1.4	29-22	0.085	1.9-1.5	0.05	0.018-0.014	490
7	275-373	0.8-1.1	22-16	0.15	1.5-1.1	0.08	0.014-0.01	814
8	385-500	0.6-0.8	16-12	0.28	1.04-0.8	0.28	0.01-0.008	1900
9	602-720	0.4-0.5	10-8.6	1.1	0.66-0.55	0.9	0.006-0.005	8900
10	787-950	0.3-0.4	7.8-6.5	1.2	0.51-0.42	1.6	0.005-0.004	—

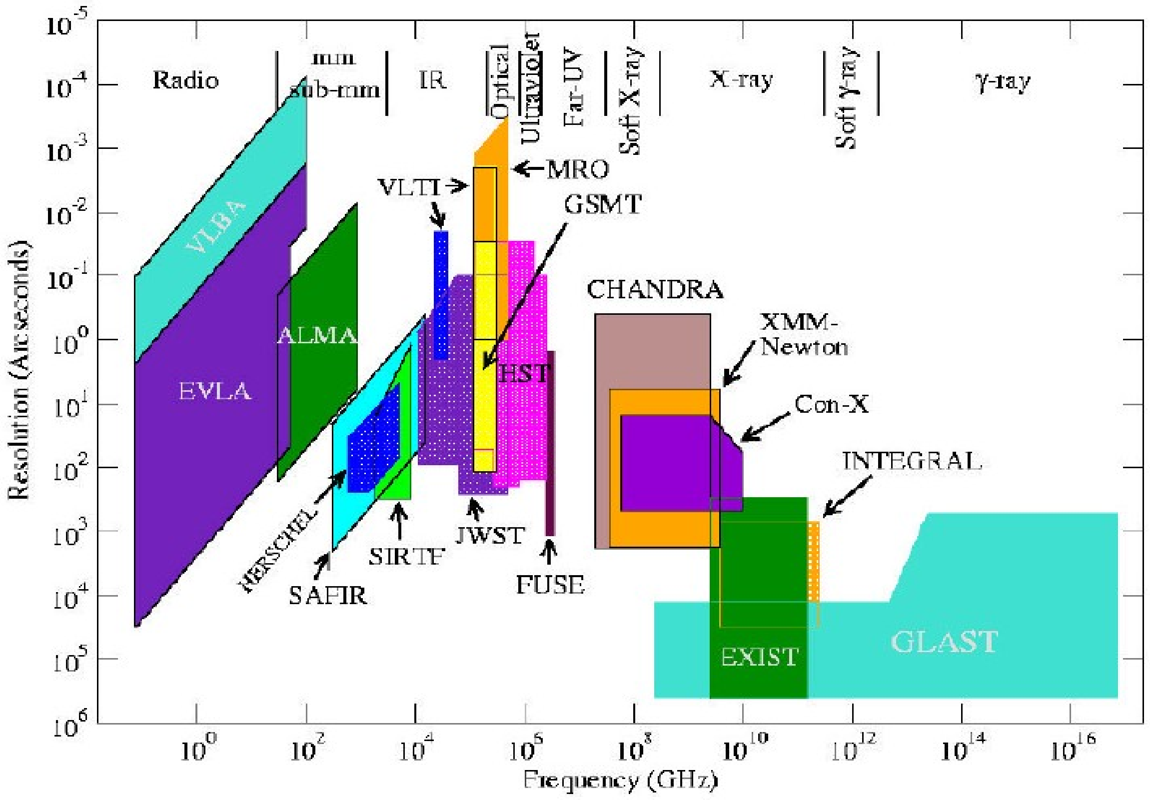


ALMA resolution

- Baselines length: **15m ->150m-16km** + **9m->50m**
- Resolution: **0.2” x (300/freq_GHz)x(1km/max_baseline)**
- FOV 12m array: **17”/(300/freq_GHz)**
- FOV 7m array: **29”/(300/freq_GHz)**

Up to 16km baselines, subarc
40 mas @ 100 GHz,
5 mas @ 900 GHz

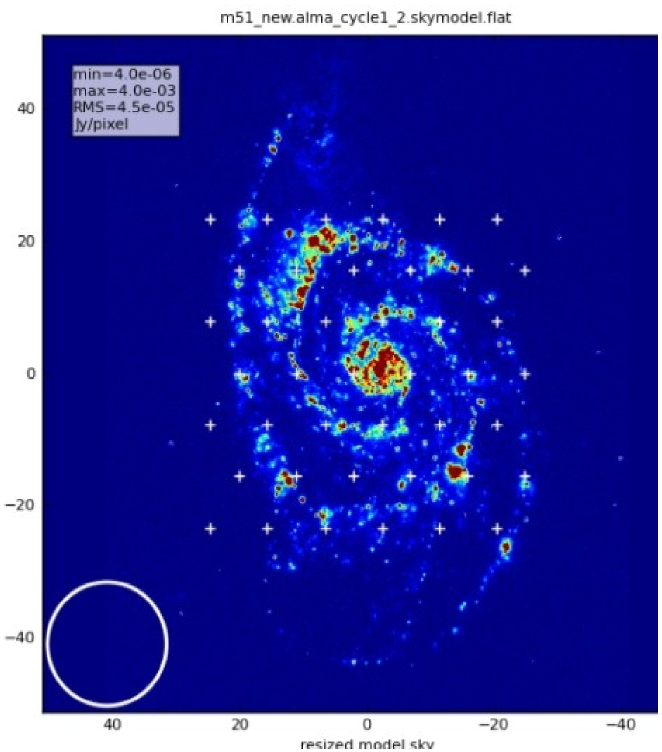
$$\theta = k\lambda/D$$



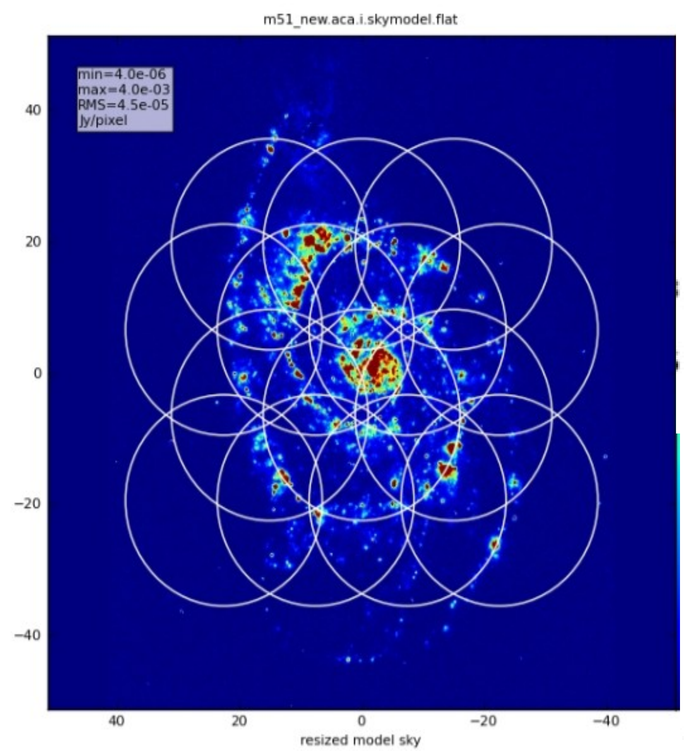
Mosaicking

Largest angular scales than that available to the shortest baseline cannot be observed.

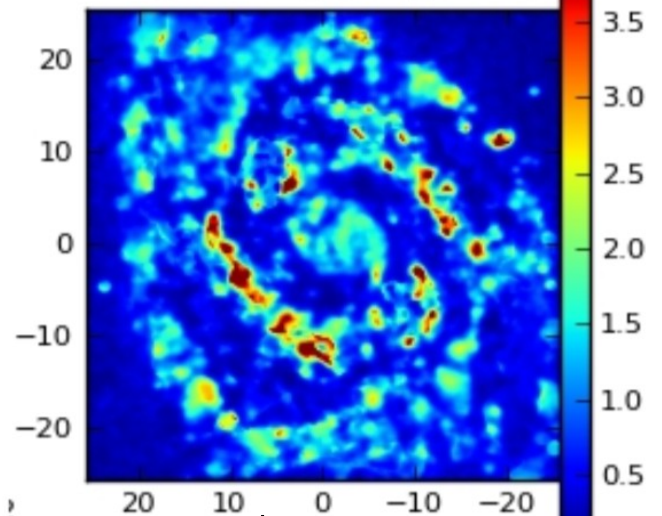
Details in the ranges available to the given baselines can be observed on larger region of the sky by mosaicking the region.



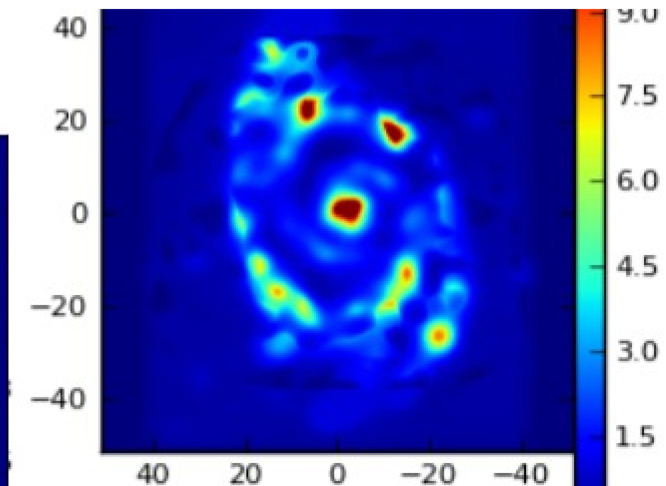
Model & 12m FOV



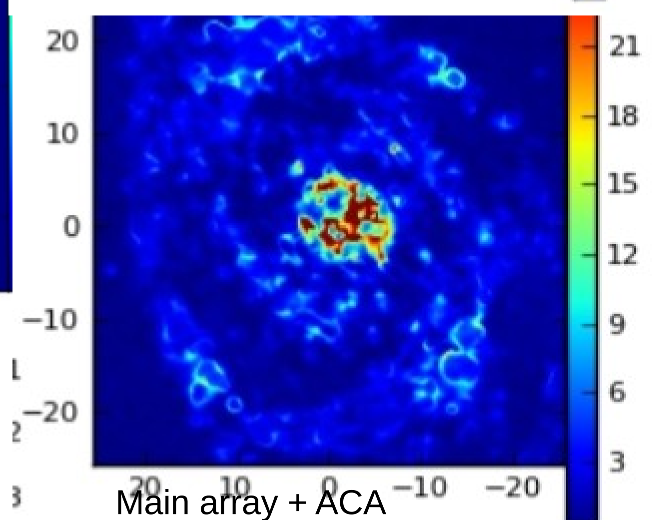
ACA Pointing map



Main array



ACA



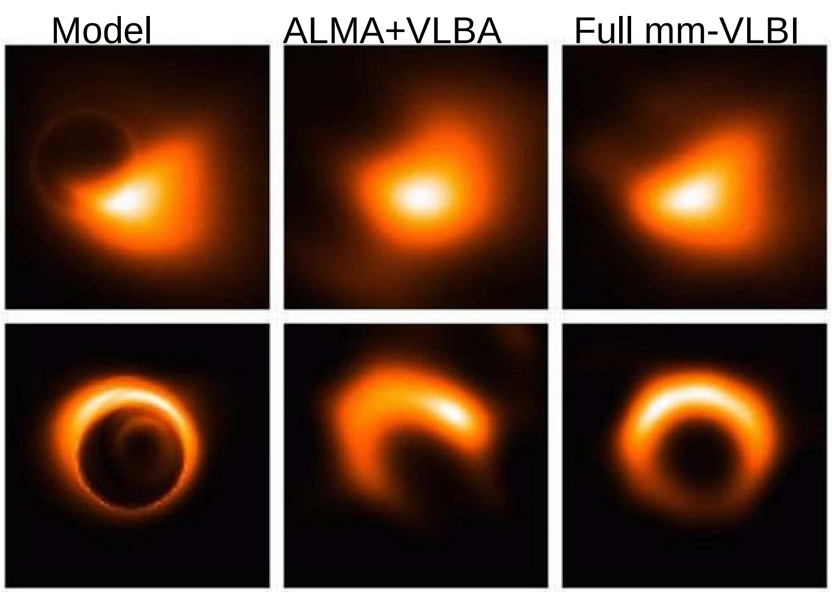
Main array + ACA

mm-VLBI with ALMA

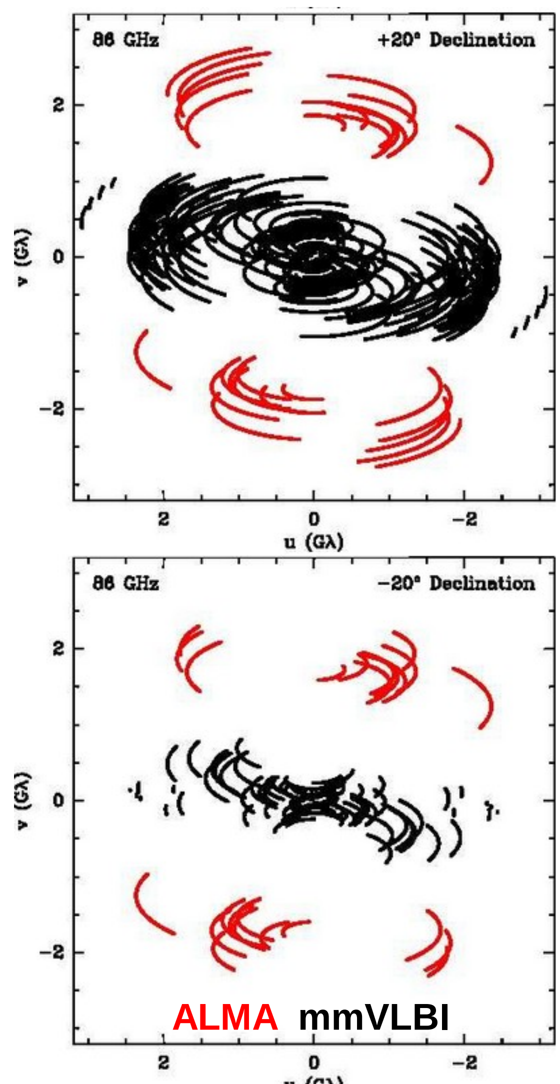
Higher and higher resolutions can be obtained with longer baselines. **VLBI is a worldwide network of telescopes that matches simultaneous observations in different sites, exploiting the phase information to construct a world-wide interferometer.**
At 1 mm and a baseline of 9000 km offers resolution of about 20 microarcseconds

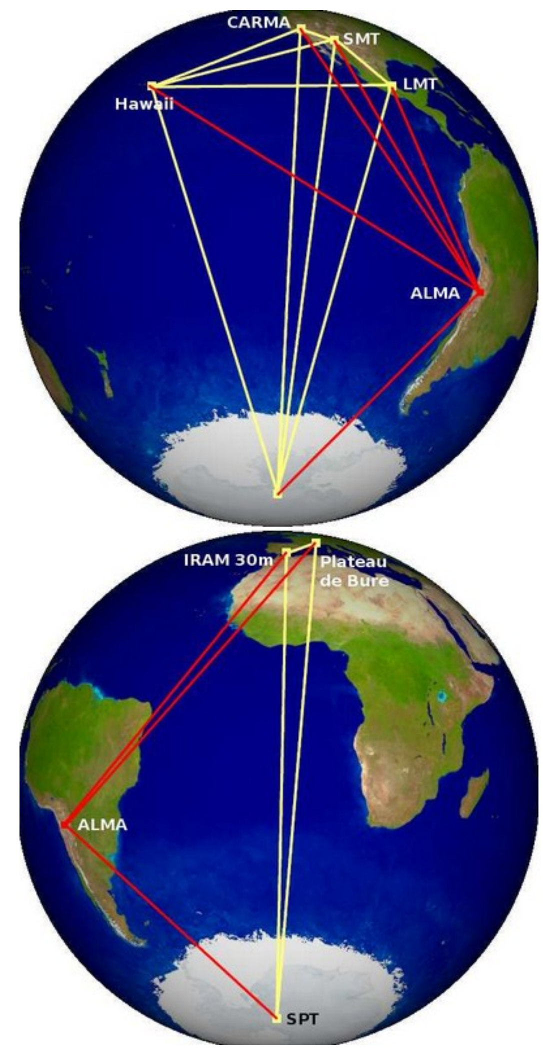
ALMA will be operating in the mm-VLBI since 2017 adding a strength in sensitivity. **Only sources with flux densities >100 mJy have been observable so far; ALMA will reduce it by more than an order of magnitude.**

This capability will allow the shadow of the event horizon in the black hole at the Galactic Centre , the relativistic jet flows in AGN and the dusty winds near stellar surfaces to be imaged



M87 models of different basis of the jet
as observed by ALMA+CARMA+SMA+ SMT
and by adding also PdBI





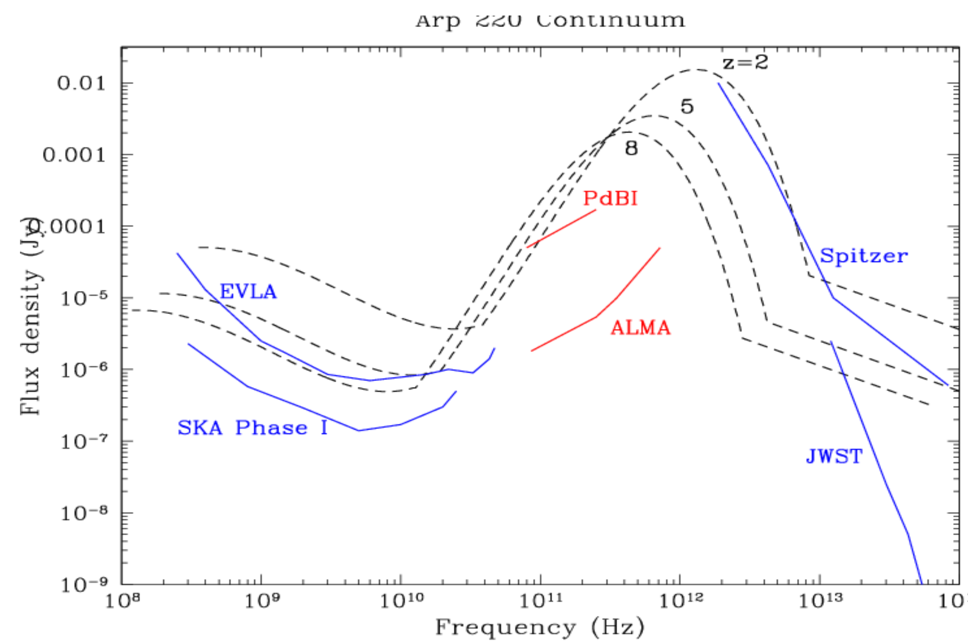
ALMA sensitivity

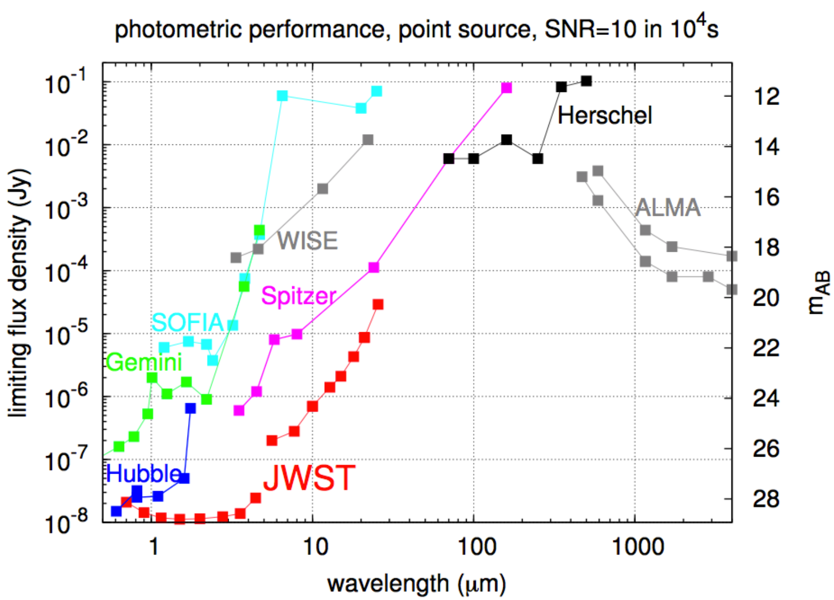
Dry site, low pwv, low Tsys, high sensitivity also at submm frequencies

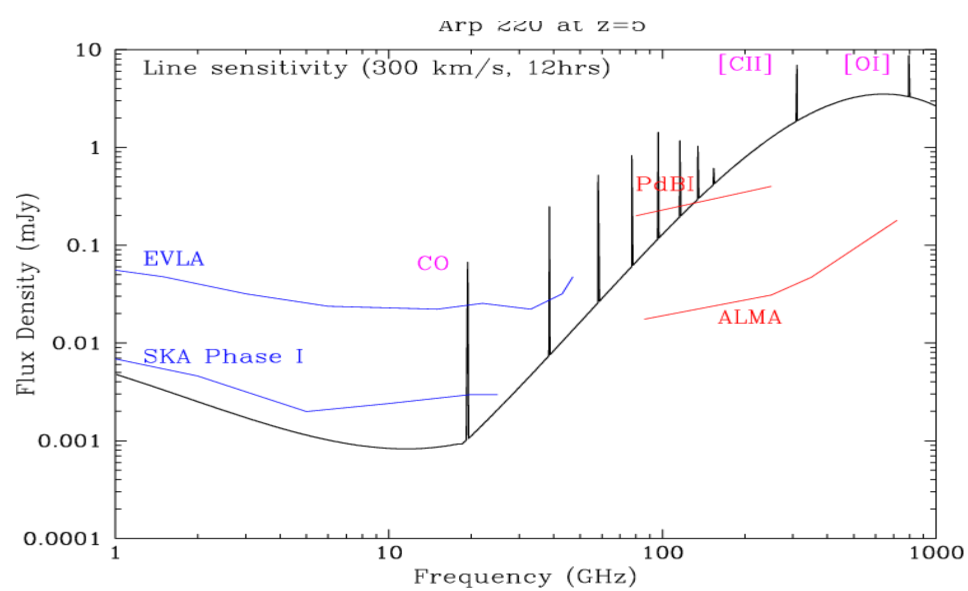
>6500sqm of effective area and 1225 baselines
for the 12m array + Short spacings with ACA
Excellent instantaneous uv coverage
& high sensitivity
<0.05mJy @100 GHz in 1 hr

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

Receivers are couple of dipoles,
so split the signal into 2 polarizations
By combining the indipendent
polarizations chains it can reconstruct
all the Stokes parameters

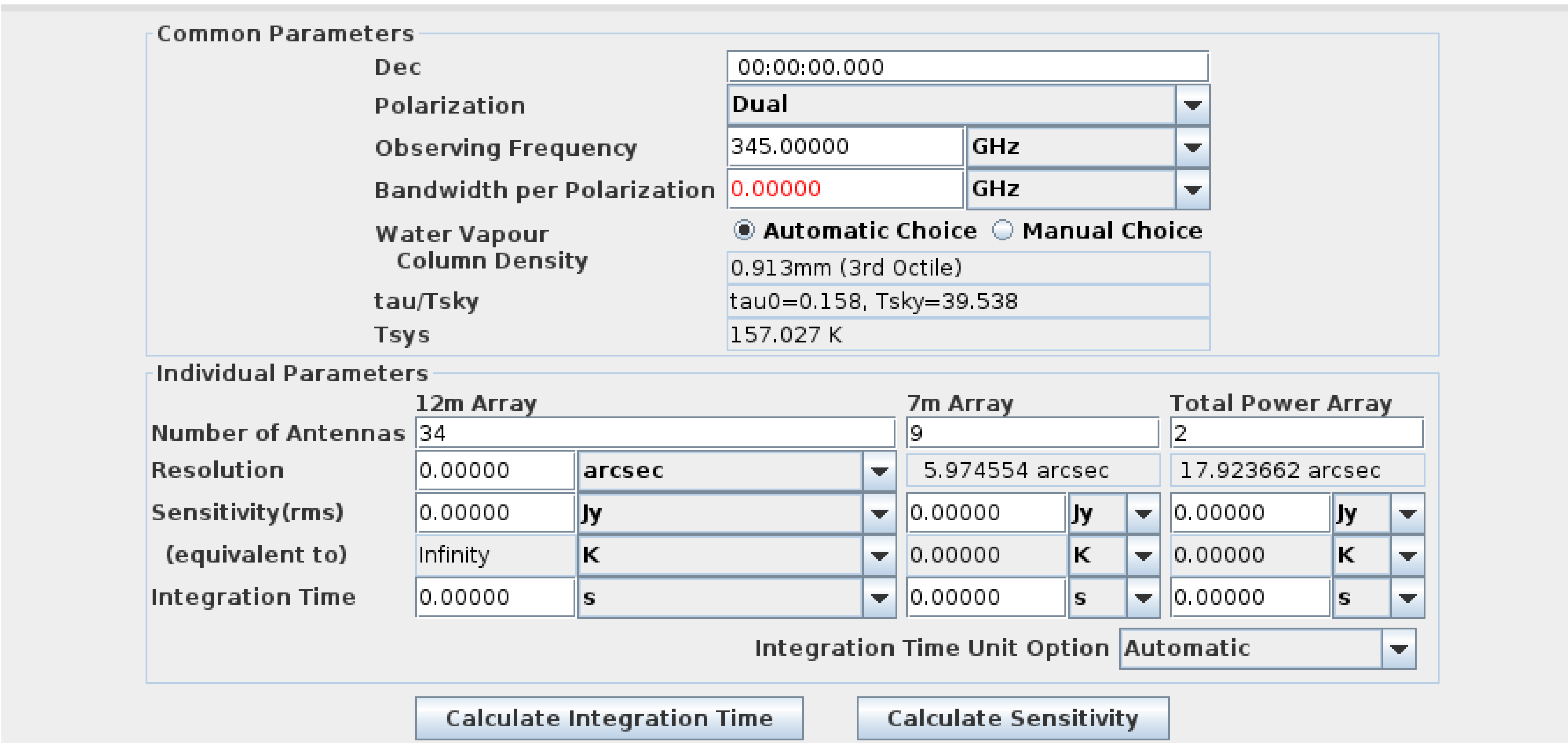




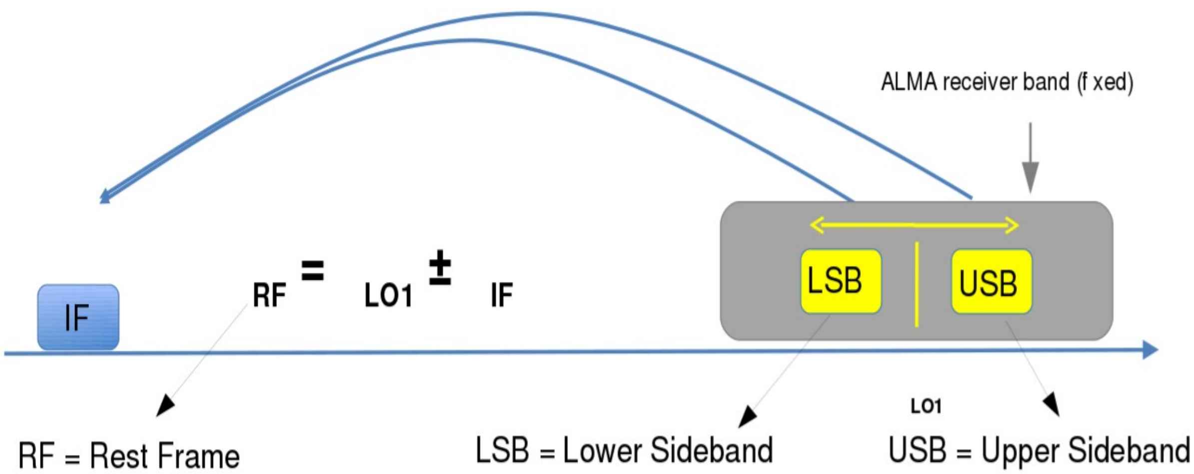


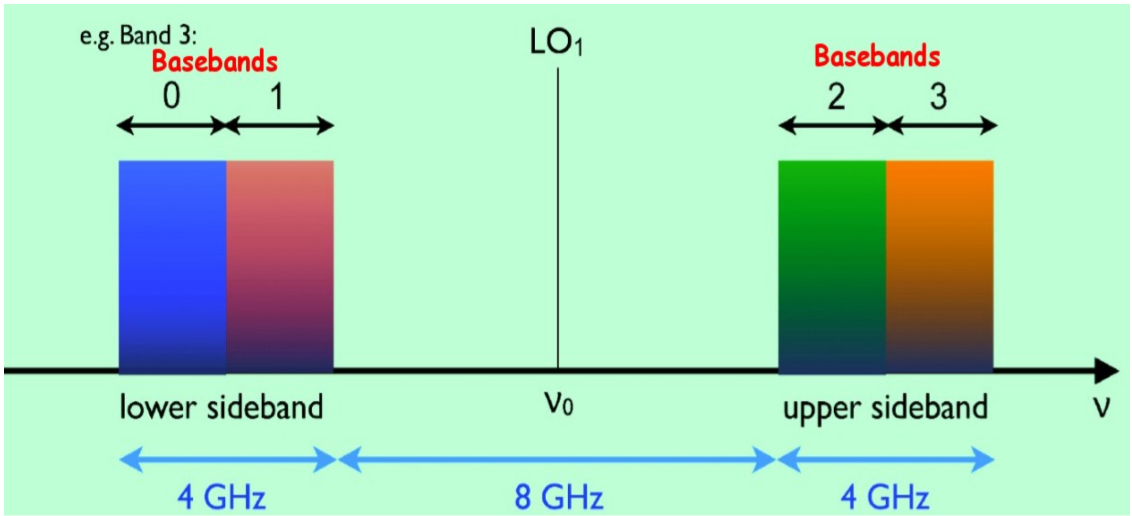
The Science Goal: Sensitivity Calculator

http://almascience.eso.org/call-for-proposals/sensitivity-calculator



ALMA spectral properties



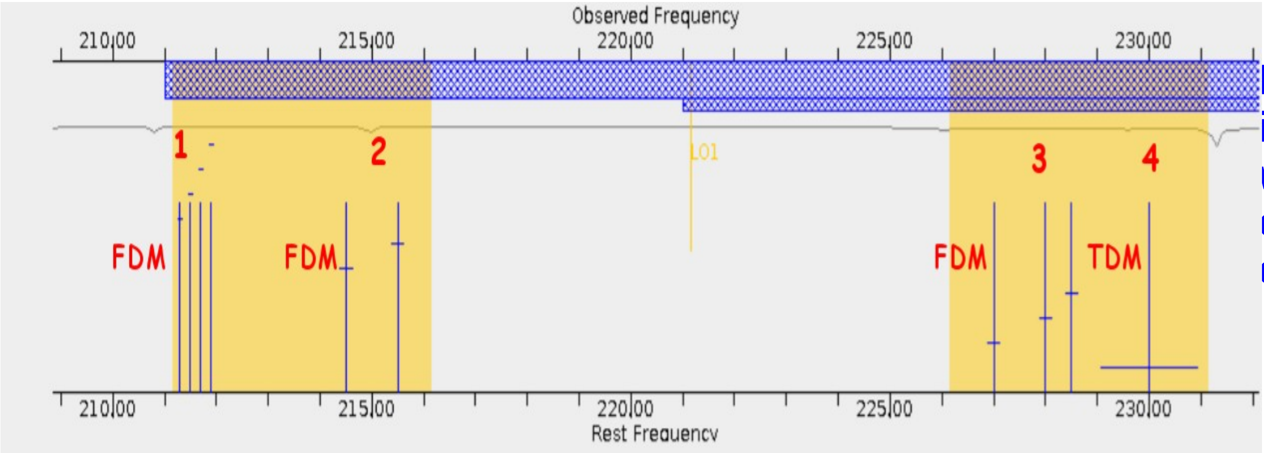


The coherent receivers map two freq regions to an Intermediate Frequency by mixing the signal with a Local Oscillator.

The receivers allows up to **4 x 2 GHz-wide Basebands** that can be placed in one sideband or distributed between the 2 Sidebands.

A maximum available 8 GHz bandwidth is achieved when the 4 basebands are chosen not to overlap.

ALMA spectral properties



Each baseband may be divided into one or more spectral windows by allocating a fraction of the correlator resources to each window.

Resolution

Typical purposes:

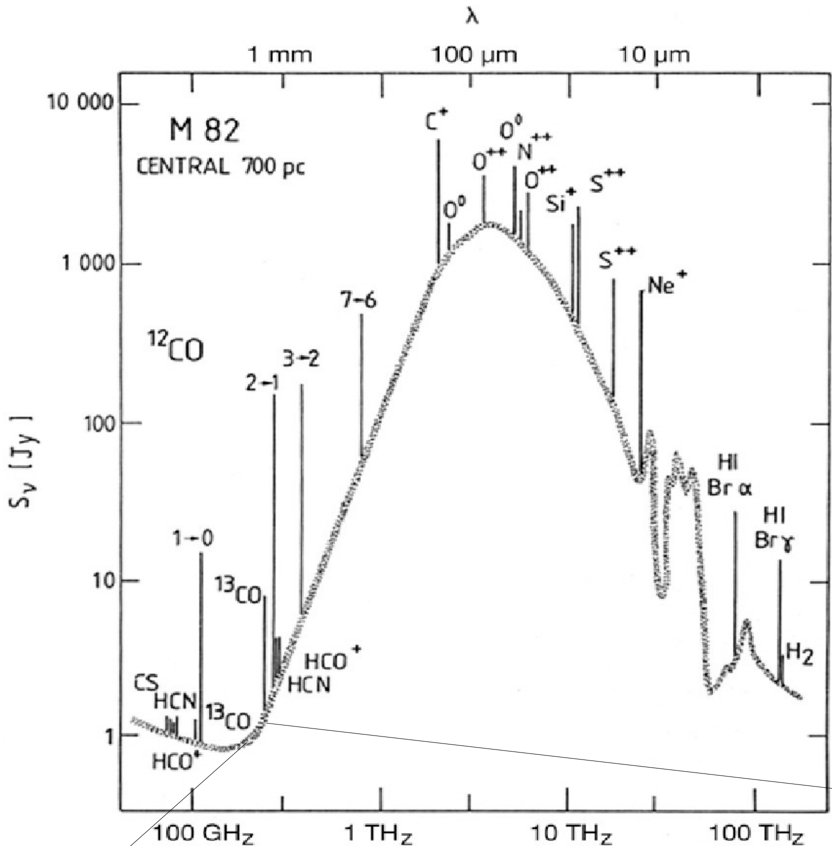
- Spectral scans (modes 7, 8)
- Targeted imaging of moderately narrow lines: cold clouds / protoplanetary disks (modes 9, 10, 11, 12, 6)
- “Continuum” or broad lines (modes 69, 71)

Mode	Polari-zation	Bandwidth per baseband (MHz)	Number of channels per baseband	Channel Spacing (MHz)	Velocity width at 300 GHz (km/s)
7	Dual	1875	3840	0.488	0.48
8	Dual	938	3840	0.244	0.24
9	Dual	469	3840	0.122	0.12
10	Dual	234	3840	0.061	0.06
11	Dual	117	3840	0.0305	0.03
12	Dual	58.6	3840	0.0153	0.015
6	Single	58.6	7680	0.00763	0.008
69	Dual	2000	128	15.625	15.6
71	Single	2000	256	7.8125	7.8

Frequency division mode: small bandwidth
High resolution
(spectral lines)

Time division mode: large bandwidth
low resolution
(continuum)

Continuum vs spectral line



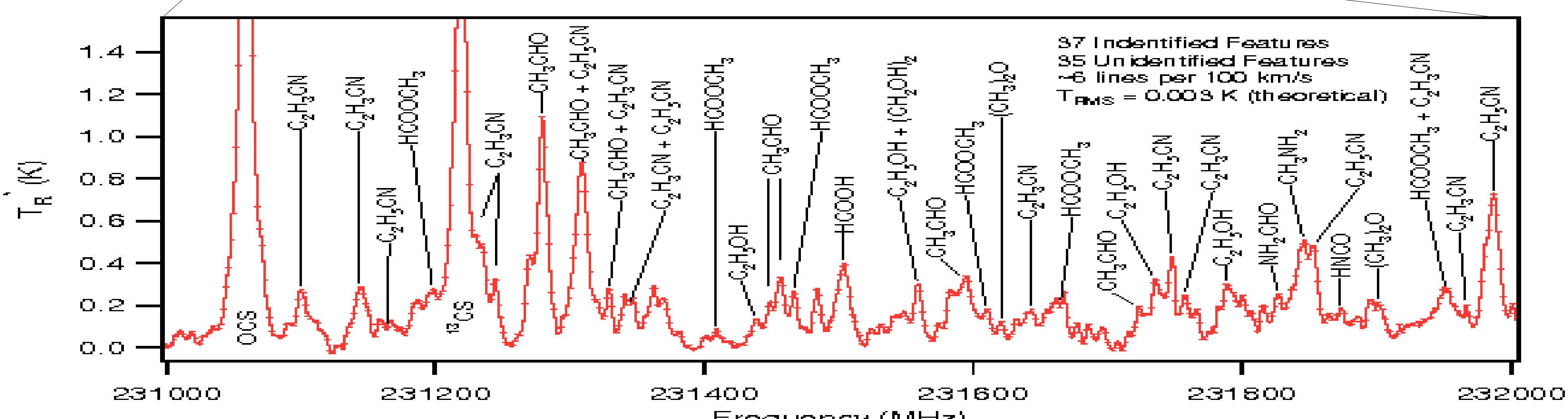
Digital correlators can be set up to different bandwidth and spectral resolution.

Sensitivity is calculated then on a frequency range.

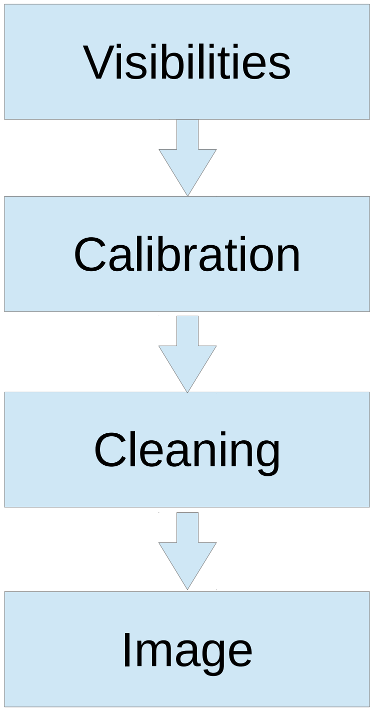
Continuum in mm-submm bands is dominated by dust and synchrotron.
Can be observed with large bandwidth
and low spectral resolution (broad frequency channels)

Detailed spectra show a very rich chemistry.
The narrower are the spectral lines the higher is the spectral resolution requested to sample it.

Hence data products are 4D cubes:
Ra, dec, frequency channels, polarization products



Interferometers



Long story made short:
Interferometers are arrays of coherent reflectors that can simulate a single dish of size equivalent to the distance between the antennas**, that collect the amplitude and phase of the electromagnetic waves emitted on selected angular scales according to the array configuration.**
Given an array, sensitivity can be improved with larger bandwidth or longer time on source.

The collected data are not an image yet!!!
Radioastronomers call the collected values from each baseline **visibilities**.

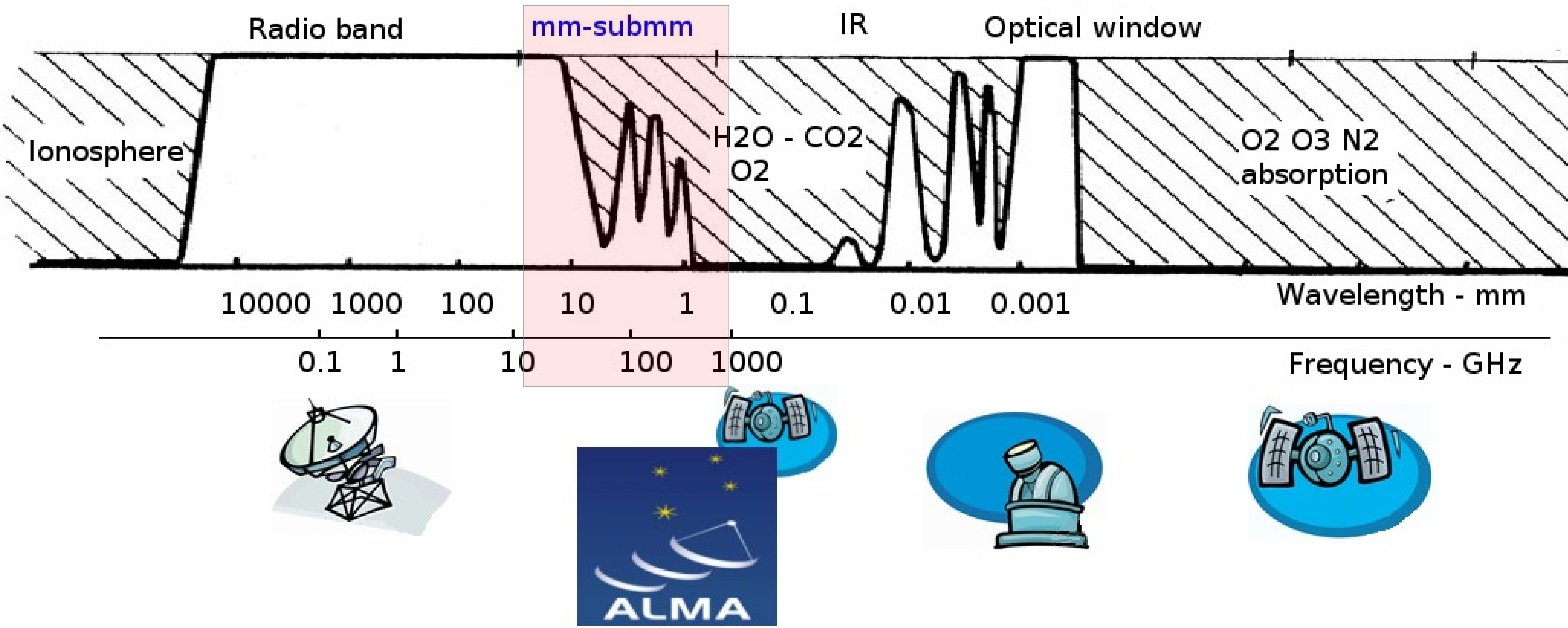
The process to generate an image includes Calibration, Inverse Fourier Transform, Deconvolutions …
too much for this talk, sorry!

For more details about interferometry and ALMA:

- **ALMA School**, Italian ARC, Bologna,9-12 February 2016 (see www.alma.inaf.it)

- Thompson, Moran, Swensson, *“Interferometry and Synthesis in Radio Astronomy”*

Outline



Signals: Synchrotron
Dust
Molecular lines

Observing instruments: Interferometers (ALMA)

Science cases

Observing processes: **Proposal and archives**

Tips to write a proposal

The proposal review process

Proposals will be reviewed by an international peer review committee.
The peer review by committee is a group of hopefully well informed peers examines your proposal, ranks it against other proposals, and then allocates resources to the highest ranked proposals.

There will at least one Review Panel for each of the **main themes**:

- Cosmology and the High Redshift Universe
- Galaxies and Galactic Nuclei
- ISM, Star Formation/protoplanetary Disks and their Astrochemistry, Exoplanets
- Stellar Evolution, the Sun and the Solar System

The ranked proposals from the different panels and sub-panels will be merged into a single ranked list in the ALMA Proposal Review Committee (APRC) and assigned a letter grade A through D:

- A the proposal will be carried over to the following cycle if it is not finished
- B the proposal should be finished during the current cycle but will not be carried over to the next cycle.
- C are 'filler' programs observed when no A or B can be scheduled
- D proposals will not be observed.

Now, this process is NOT perfect,
BUT it is NOT a lottery, or fundamentally flawed and/or fixed…..
DO NOT let that idea impact on how you write ..

Everything you can do to give your proposal a broader context, make it easier to read, more enjoyable, more clear, … all will help your chances

What should a proposal look like?

- Should have a good, readable **"Executive Summary"** that sets the research in context, sets out the big issues in a field, says what you will do, and how the results from that will address the big issues.

- Should have a **well set out background** that expands on the context and big questions in the field.

- Should clearly **explain why the observations you propose are critical** for answering those questions

- Should clearly **demonstrate the observations / research is technically feasible**, that the time / resources requested are appropriate

- Should clearly **demonstrate that your team will be able to do the work**, and/or has a track-record for having dome similar work in the past.

- Should include **"only" useful figures**

- **Must be readable and should be pleasurable to read**.

The technical justification

The Technical Justification should fully justify the technical aspects of the requested observations and should address the following aspects:

- **sensitivity**
- **resolution**
- **array configuration**
- **imaging**
- **correlator setup**
- **calibration**
- **scheduling/time constraints**
- **special constraints on standard observing mode**
- **any non-standard choices**

The technical justification must be very, very clear – say what your assumptions, required S/N, number of pointings etc are, so your reasoning can be reproduced by the technical assesors.

Try to know/understand the telescope or ask to someonw who knows it

What to never do

- Do not ignore the grading or funding criteria.
- Don’t submit proposals that are badly written – if English is not your first language, get a collaborator to proof read or rewrite it for you.
- Don’t ask for the wrong instrument, the wrong amount of time, or the wrong semester.
- Don’t rage at the panels - its not their fault they didn’t have enough money or telescope time last time
- Don’t waffle - less is more
- **Don’t use jargon & acronyms**
- **Don’t assume everyone knows this scientific area is the most compelling thing ever done.**

RS
RV
VLM
SMBH
AGN
FIR

FRII
ULIRG
ERO
SMG

CDFS
PCCS
EMU
WALLABY
POSSUM
DINGO
APEX
SCUBA
WTHDIM

Few tips

- **Tell a story**. Make your proposal and enjoyable narrative that leads the reader from point to point.
- **“Close the Loop”**
- Frame your project as an experiment (“Hypothesis and Testing”) rather than data gathering.
- Think seriously about the risks of a “new class of object” discovery project.
- Avoid the evil “Constrain”
- **The more you “quantify” the better you get the point** (i.e. avoid generic “more, much, less, few” but give numbers to give the idea that you have already dirty hands on the matter)

Ask yourself...

- **Would you want to read this proposal? Late at night? On a plane? Along with 80 others just like it?**

- **Would you be able to read and understand this proposal in under 5m per page?**

- **Can you FIND the main points in the proposal without reading the whole thing in all its gory detail?**

- **Imagine its your hard earned money, would you pay for this project?**

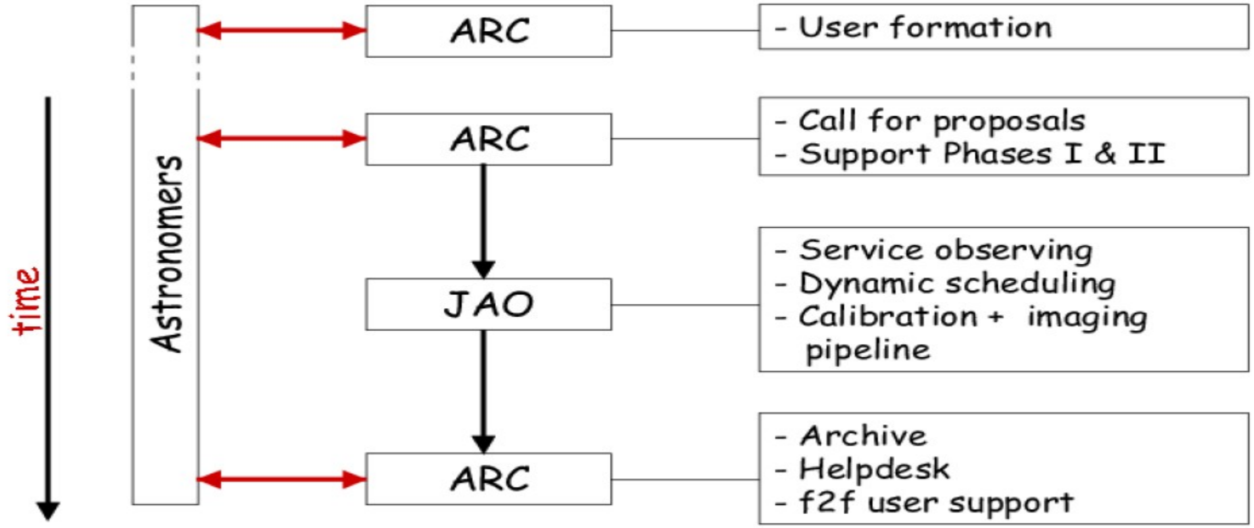
It’s not the reader’s job to understand your proposal ... its your job to make them understand it.

Readers are looking for enjoyable, understandable proposals to read that present innovative ideas for new research

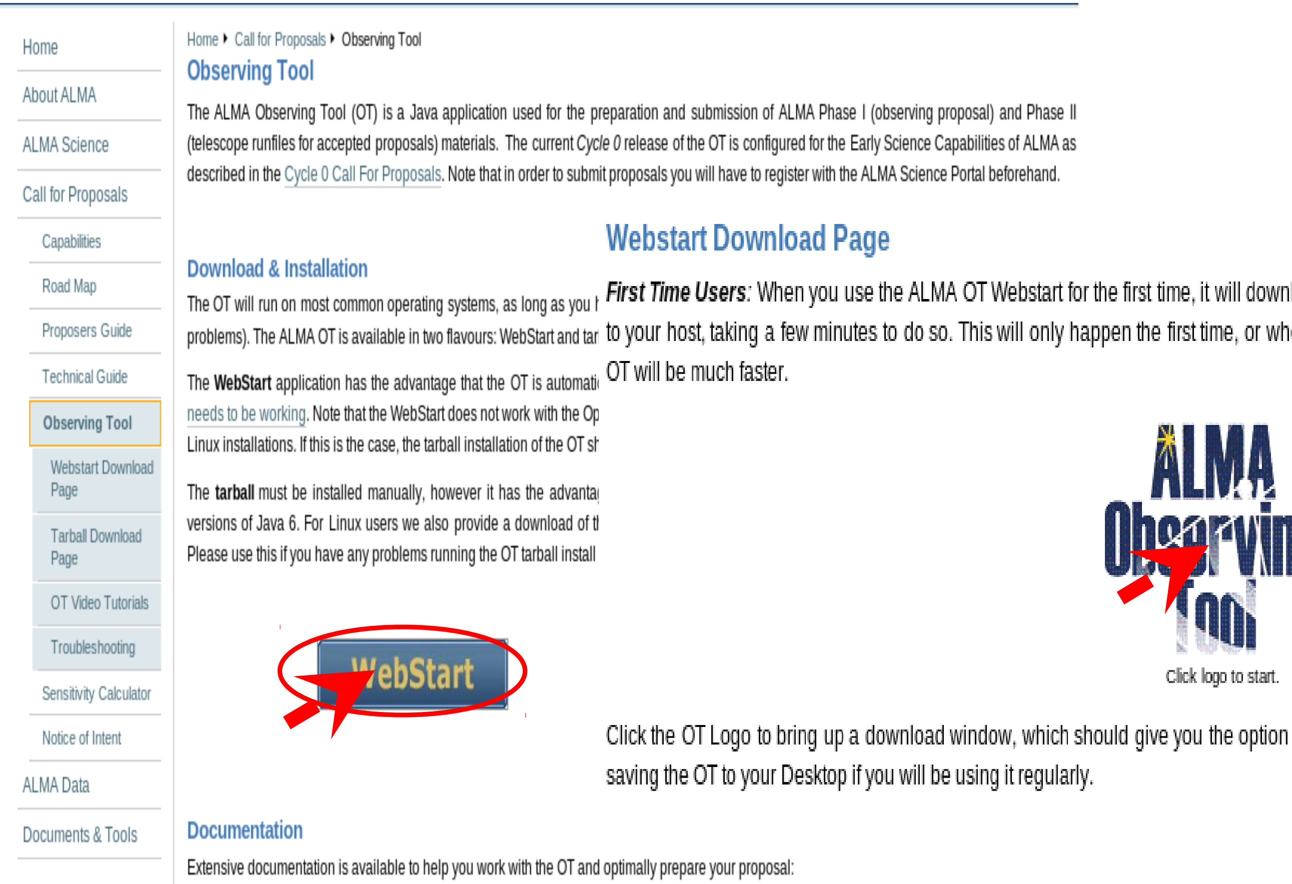
A project lifetime: phase 1 Proposal submission

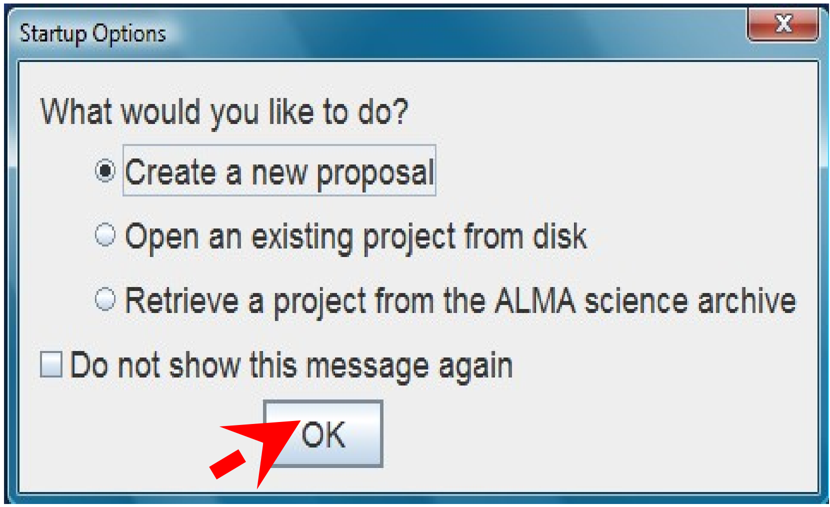
PI has a good idea!

PI estimates feasibility	Simulations are not compulsory (Sensitivity Calculator, OST, CASA)
PI splits project in Science Goals	**Minimum proposed observational unit including targets in the same sky region that roughly share the same calibration and spectral setup**
PI writes the science case in pdf and register to the Science Portal	Max 4 page, font no smaller than 12, all included (<20MB) www.almascience.org
PHASE I – Proposal submission	With the ALMA Observing Tool (OT) A copy of the project with the project ID must be saved and should be used for any resubmission within the deadline
TAC evaluation	**A**=high ranked pass to Cycle 4 if not finished **B**=high ranked but not passed over **C**=maybe filler (depends on time shares and ranking)



The ALMA Observing Tool

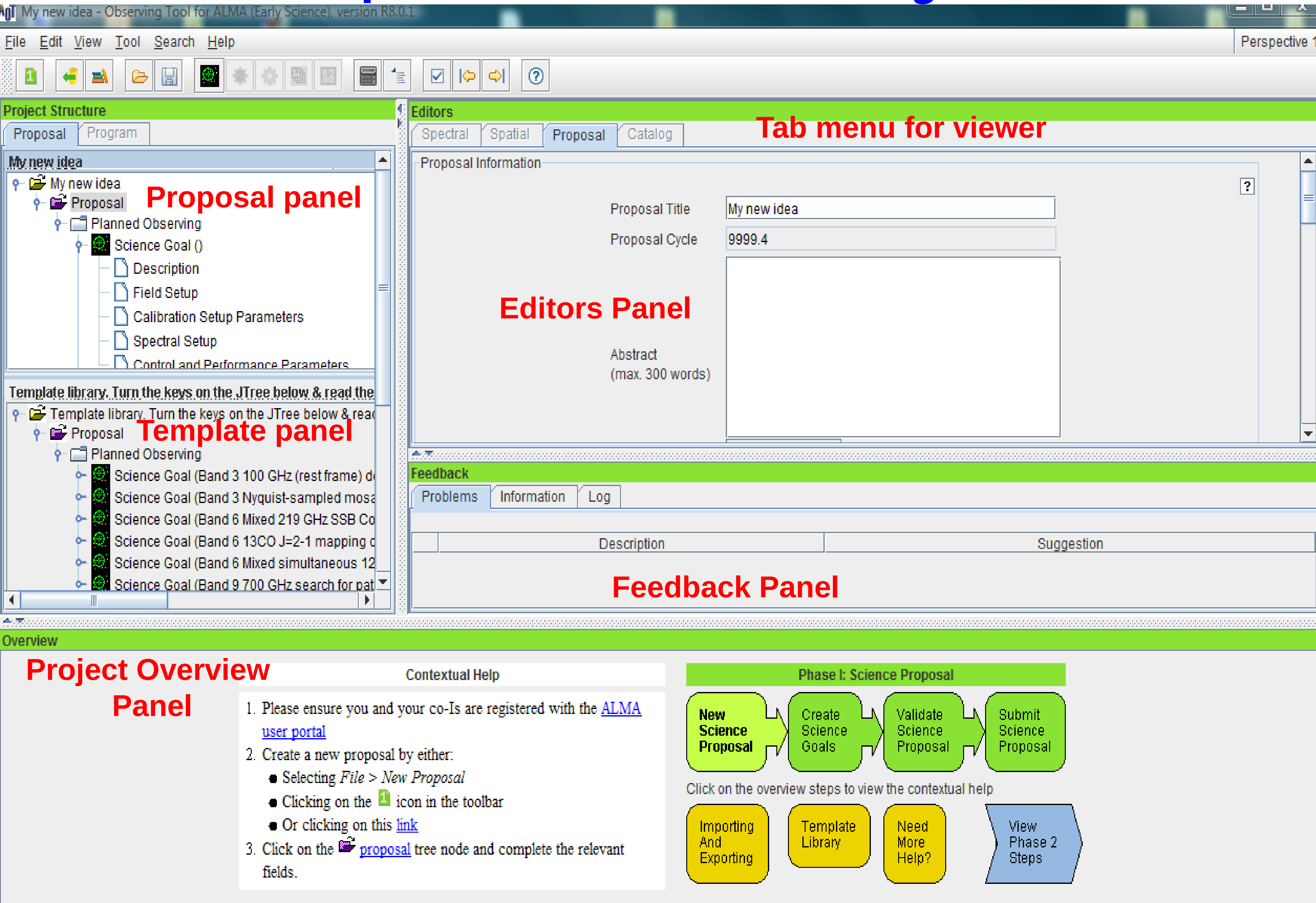




OT is a java-based client program,
runs on Linux (various distr.),
MacOS (10.5-10.6), Windows (>XP).

The graphic interface allows one to get help/feedback
and hints even with small knowledge of the system.

Proposals with the ALMA Observing Tool



(see Viviana & Rosita's talks)

Early Science Cycles

Early Science observations are conducted on a best effort basis
to allows community to observe with incomplete, but already superior array,
with priority given to the completion of the full ALMA capabilities

Past & current ALMA Early Science cycles:

	Cycle 0 Sep. 2011 - Jan. 2013	Cycle 1 Jan. 2013 - May. 2014	Cycle 2 Jun. 2014 - Oct. 2015	Cicle 3 Oct 2015 - Oct 2016
Telescope				
Hours dedicated to Science	**800**	**800**	**2000**	2100
Antennas	**> 12x12-m**	**> 32x12m +9x7m+2TP**	**> 34x12m +9x7m+2TP**	**> 36x12m +10x7m+2TP**
Receiver bands	3, 6, 7, 9	3, 6, 7, 9	**+4, 8**	**+10**
Wavelengths [mm]	3, 1.3, 0.8, 0.45	3, 1.3, 0.8 0.45	+2, 0.7	
Baselines	up to 400 m	**up to 1000 m**	**up to 1500m**	**up to 10km**
Polarisation	single-dual	single dual	**full**	**full**
Proposal outcome				
Submitted	917	1133	1381	1578
Highest priority	112	198	354	402
Filler	51	93	159	236
Success rate	12% (18%)	17% (25%)	26% (37%)	25% (40%)

Pressure factors (highest priority projects)

- Cycle 1: Europe: 9.1 (global ALMA: 5.8)
- Cycle 2: Europe: 4.9 (global ALMA: 3.9)
- Cycle 3: Europe: 6.2 (global ALMA: 3.9)

ALMA Cycle 4

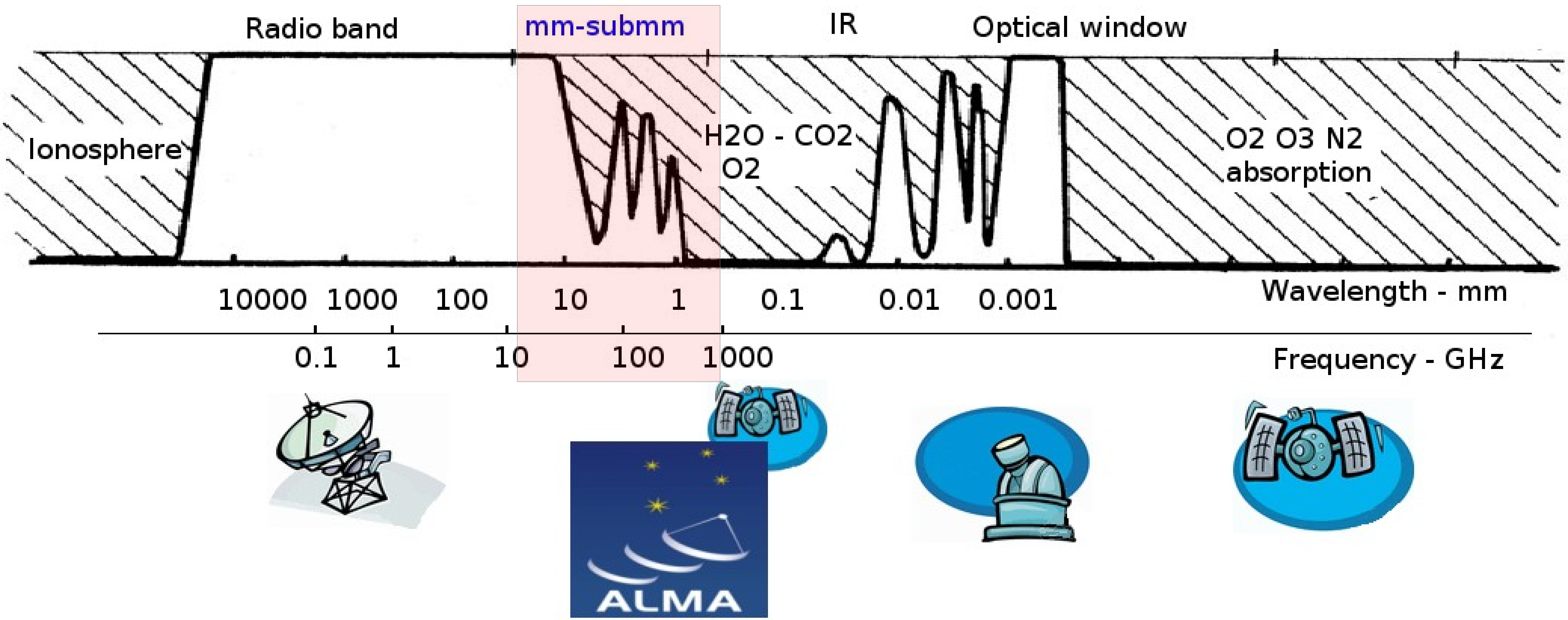
Proposal submission deadline 21 April 2016

	Oct 2016 - Oct 2017		
Telescope			
Hours dedicated to Science	2100		
Antennas	**> 40x12m +10x7m+3TP**		
Receiver bands	3,4, 6,	7,	8, 9, 10
Wavelengths [mm]	3, 2, 1.3,	0.8,	0.7, 0.45, 0.35
Baselines	**up to 12.8km,**	**5.3km,**	**2.7km**
Polarisation	**full (with some limitations)**		

News

- ACA standalone
- Large programs (>50hr of observations not splittable in smaller programs)
- mmVLBI
- Solar observations

Outline



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