# ALMA Science:
# a review of (sub)mm band science and instruments in the ALMA era

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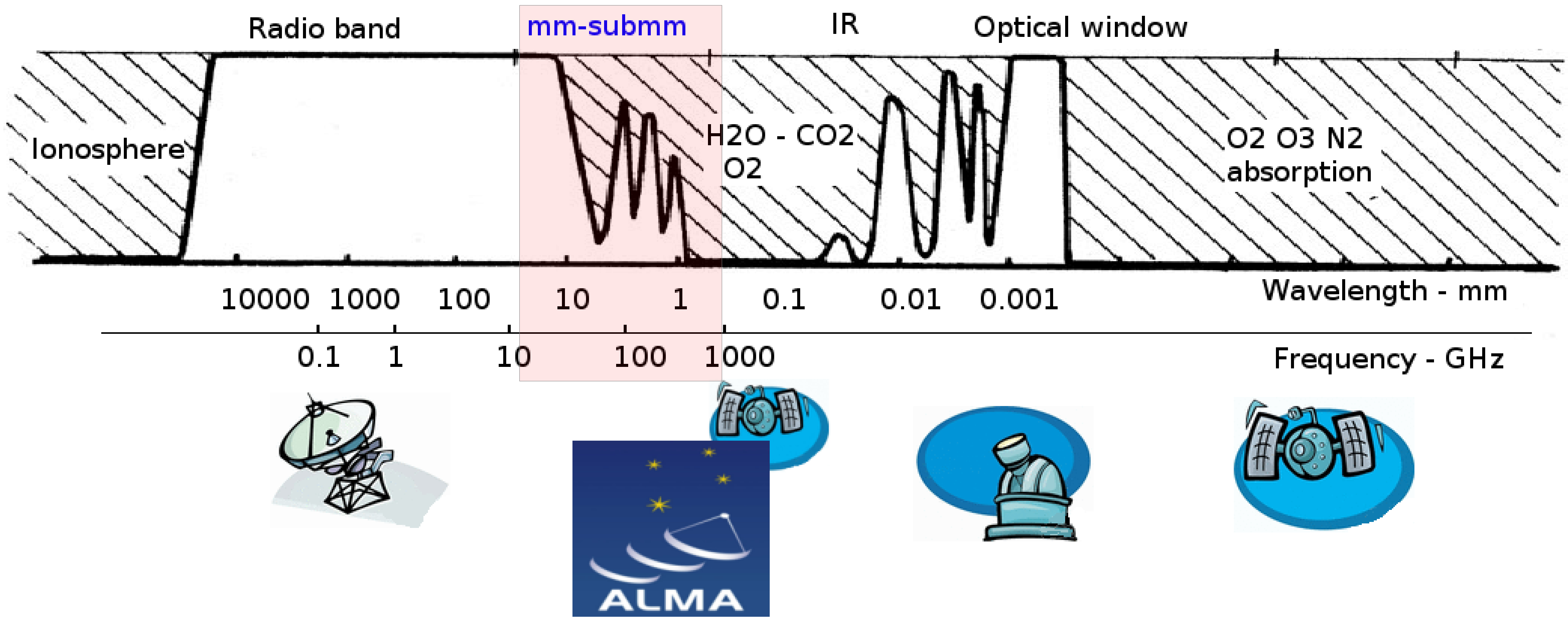
Italian node of European ALMA Regional Centre

ALMA
EUROPEAN ARC
ALMA Regional Centre || Italian

SISSA – February 2014

# Outline




| | |
|---|---|
| **Signals in (sub)mm band** | What can we get out of them? |
| **The reasons for ALMA** | Pills of interferometry<br>ALMA properties<br>Writing a proposal |
| **Galactic Science** | From planets to our Galaxy |
| **Extragalactic Science** | AGNs<br>Submm galaxies<br>Galaxy clusters |

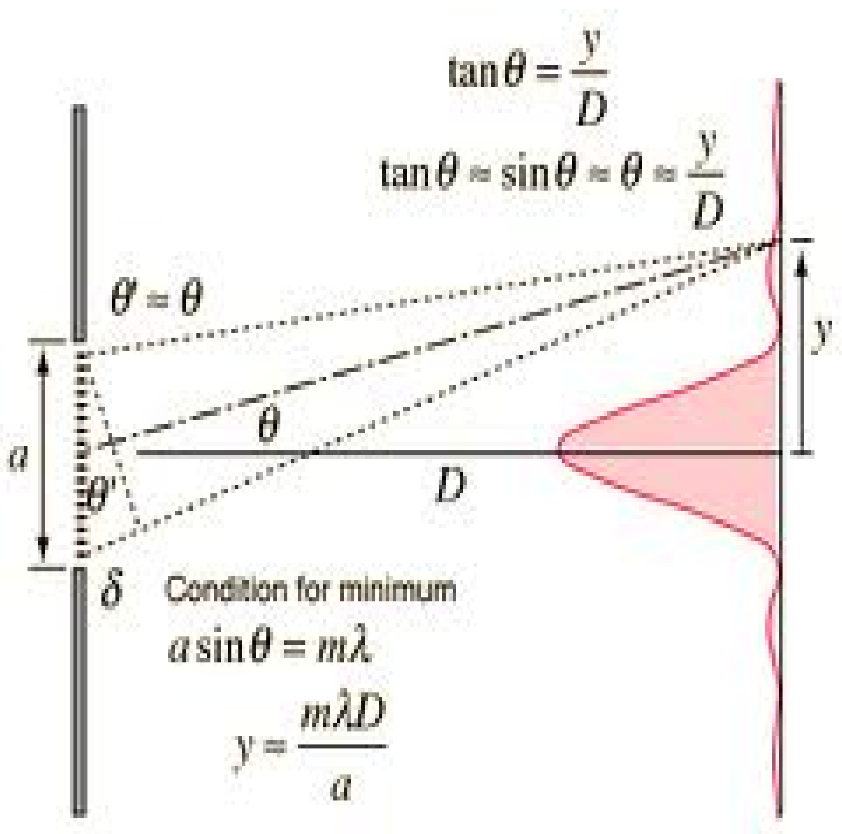
# Observing in the sub(mm)

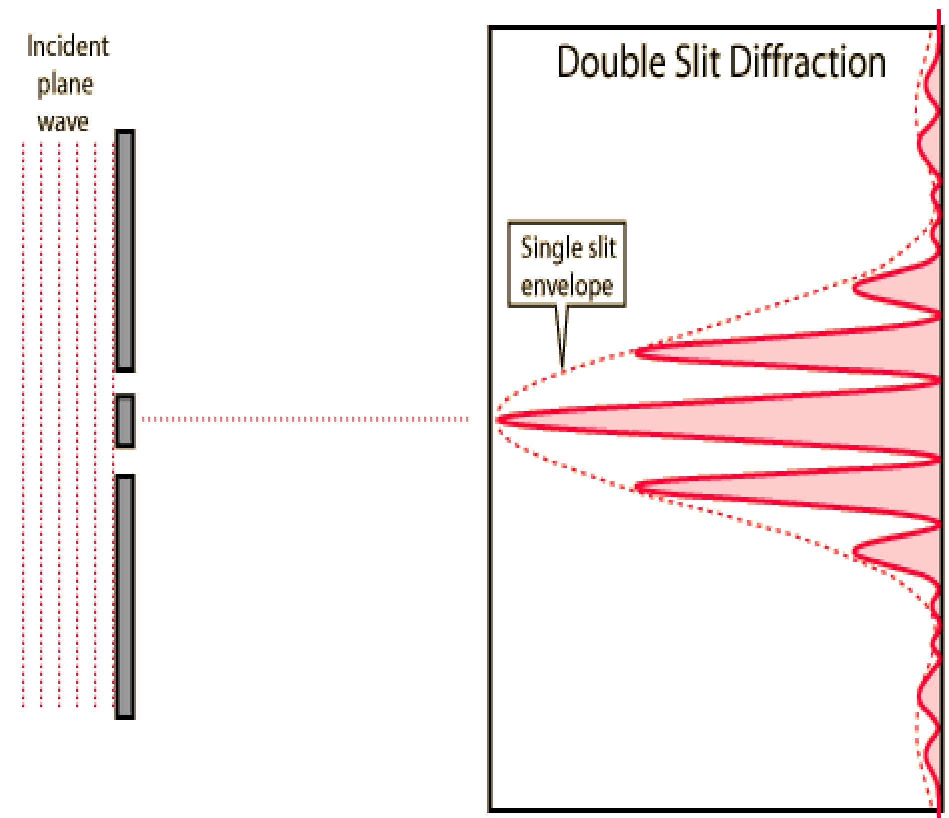
# Issues in the sub(mm)

**Resolution** for a radiotelescope of diameter D at wavelength λ and k~1

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

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



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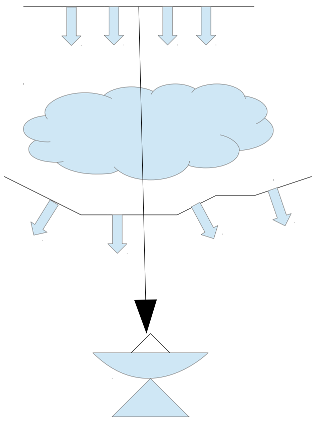

**Lower wavelengths are more sensitive to smaller obstacles.**
Atmospheric effects: scattering of signal, absorption
Instrumental effects: surface accuracy must be higher at lower wavelengths

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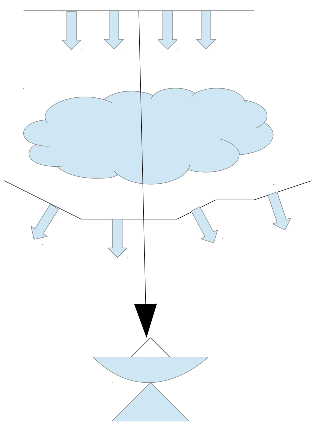


**Lower wavelengths are more sensitive to smaller obstacles.**
Atmospheric effects: scattering of signal, absorption
Instrumental effects: surface accuracy must be higher at lower wavelengths

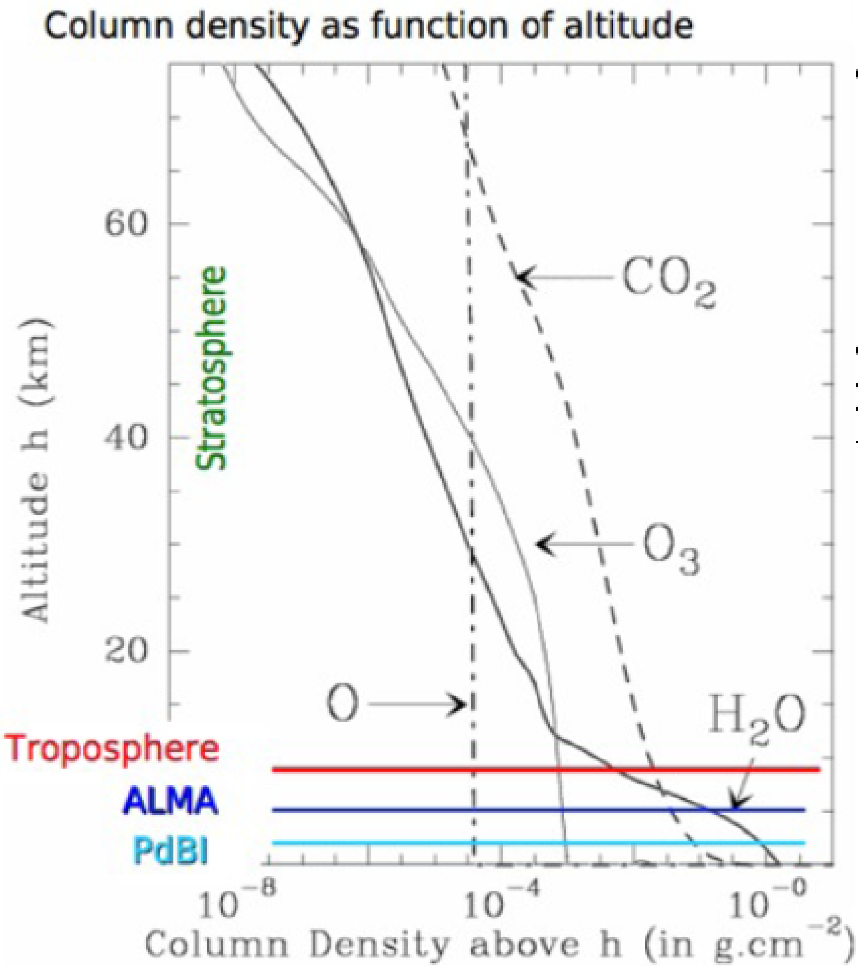
**The rms noise in the signal (sensitivity)**:
Tsys is the brightness temperature equivalent to the flux received from the antenna, including source, atmosphere, instrumental noise.

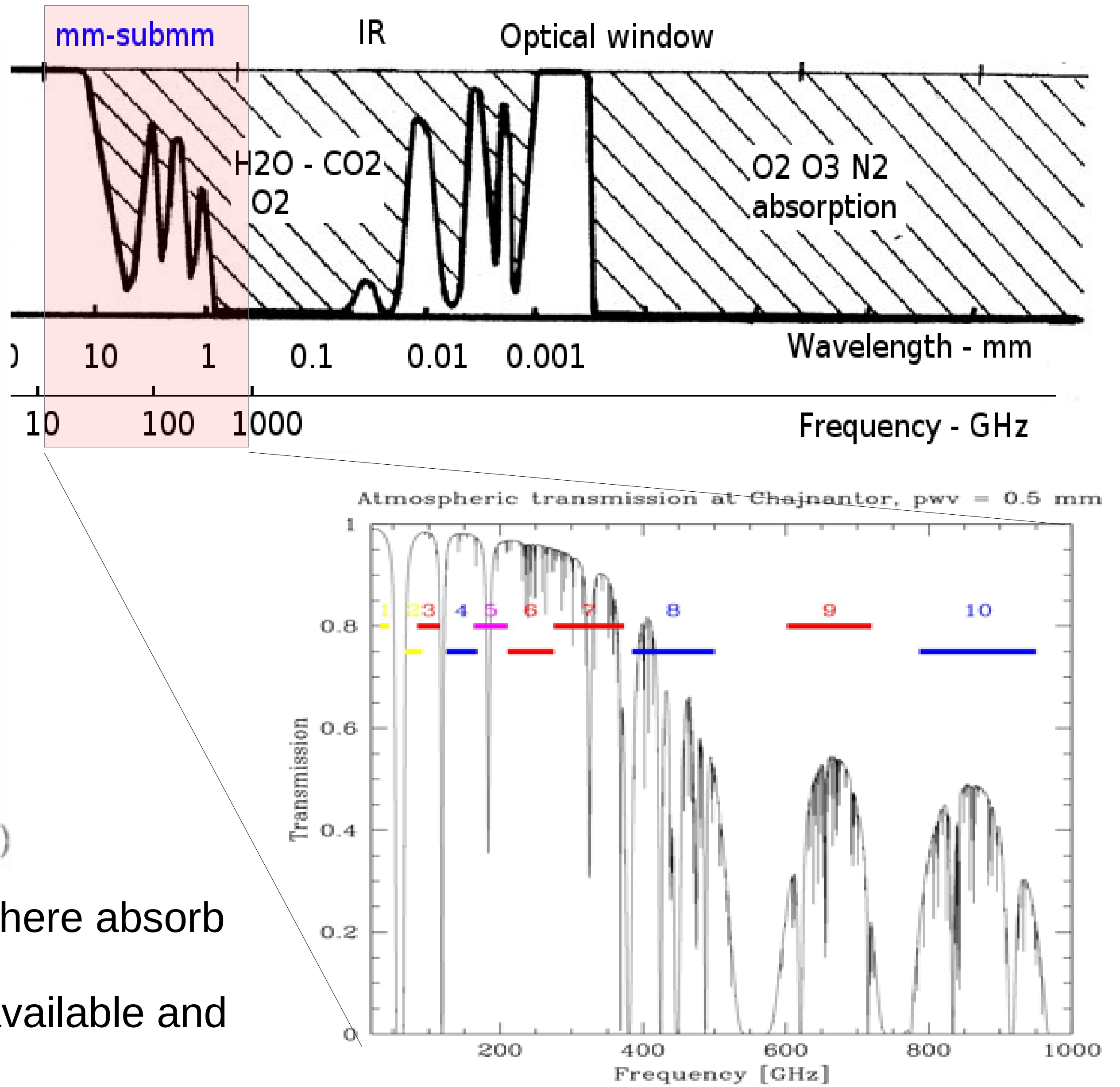
$$\Delta S_\nu = 2\,k\,\frac{T_{\rm sys}}{A_{\rm e}\sqrt{2t\,\Delta\nu}}$$

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

**Receiving system: ATMOSPHERE + ANTENNA + RECEIVER + BACKEND**

# Instruments: selecting the site




Chemical components in the atmosphere absorb the signal.
Only some transmission bands are available and only from high and dry sites.

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

# Instruments: bolometers

**An incident radiation changes the temperature of the receiver that absorb 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

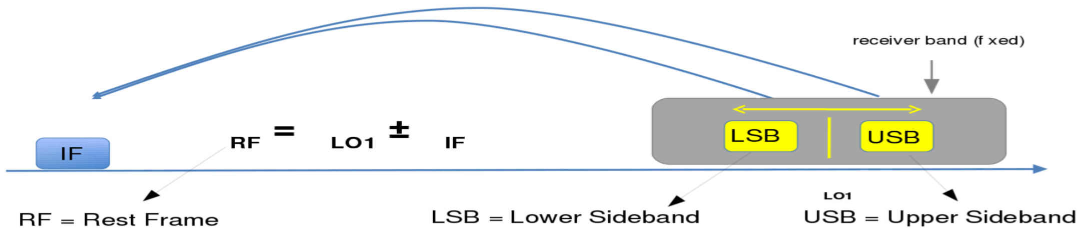
Receiving system: ATMOSPHERE + ANTENNA + RECEIVER + BACKEND

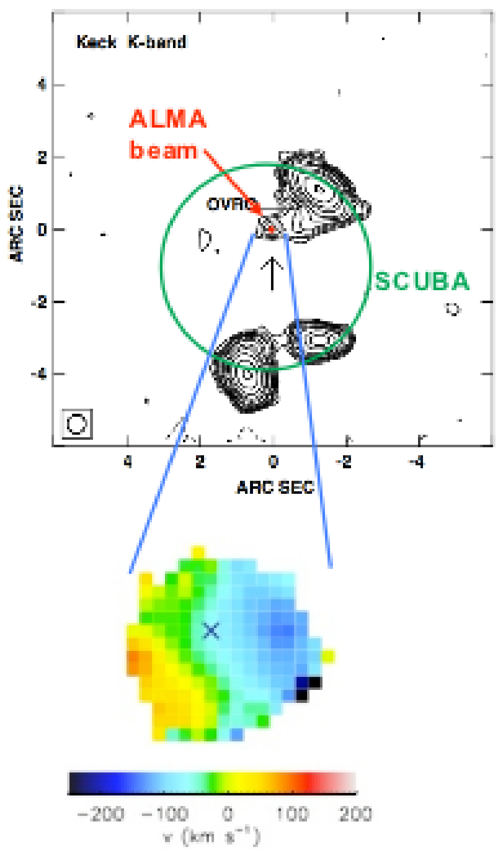
# Instruments: Coerent receivers

**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 Obscillator**.

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




| 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

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

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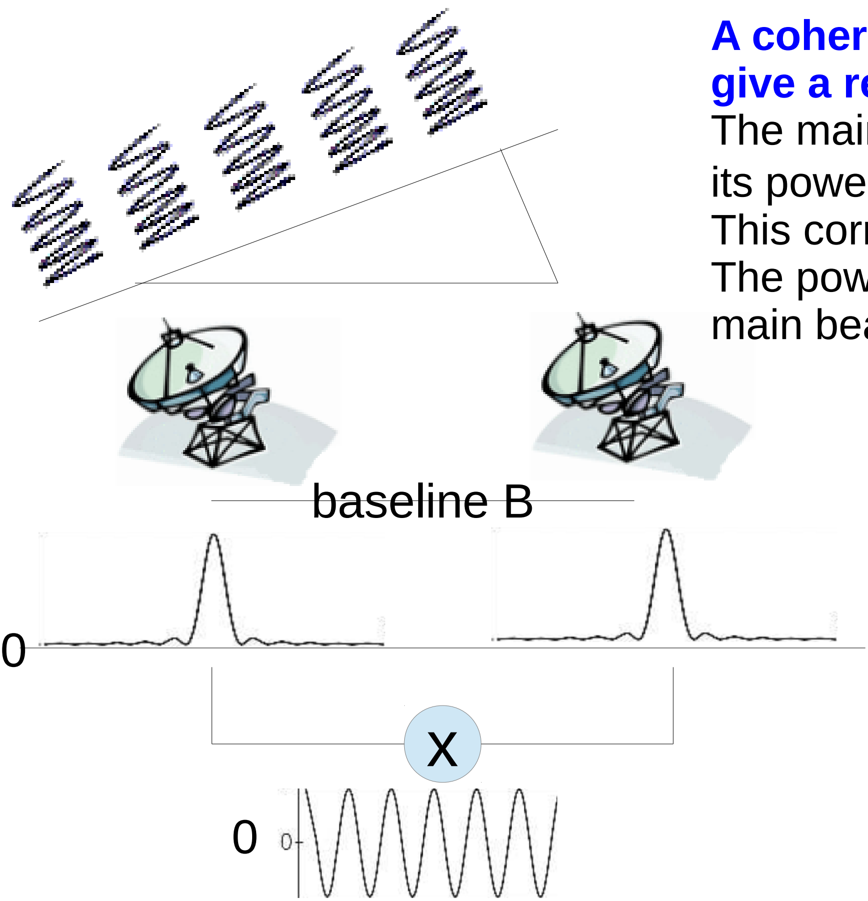


**A coherent combination of reflectors of diameter d at distance B(>>d) give a resolution equivalent to that of a single reflector of diameter B.**

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 correspond 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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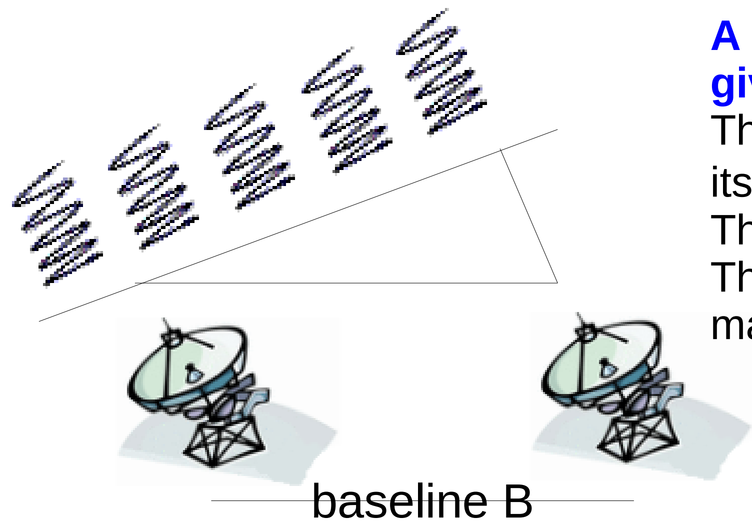


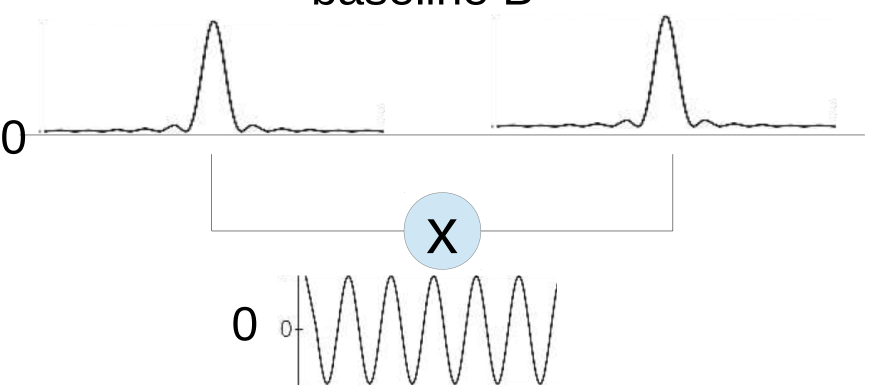


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After correcting for geometrical delays, allowing the comparison of two points of the same wavefront coming from a far away point source the output of the correlation of two signals is a fringes pattern centered around 0 (total power is lost).
**Only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

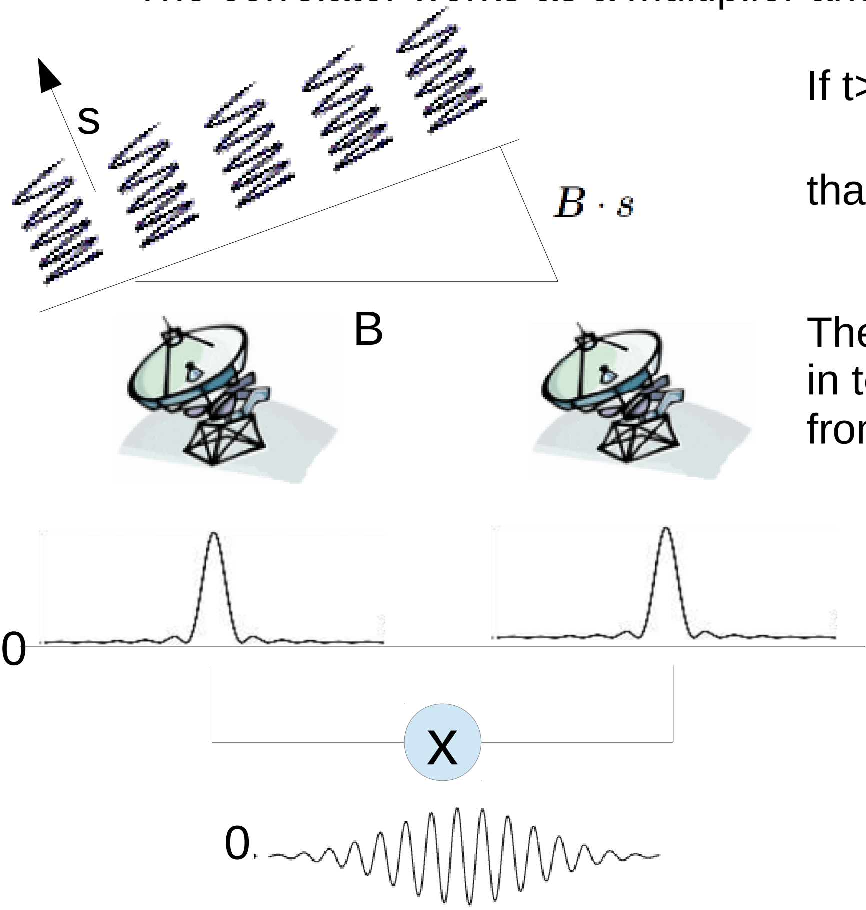
$$U_1 \propto E\,\mathrm{e}^{\,\mathrm{i}\,\omega t} \qquad U_2 \propto E\,\mathrm{e}^{\,\mathrm{i}\,\omega\,(t-\tau)}$$

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 ($P \propto E^2$)

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

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

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

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

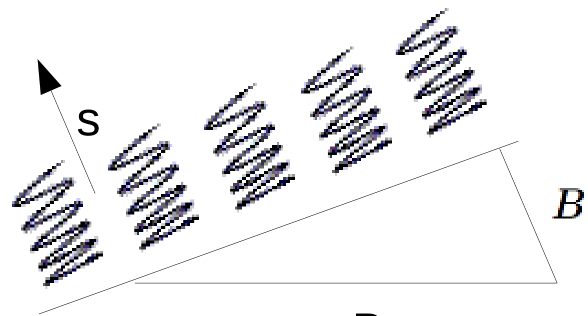
Receiving system:  ATMOSPHERE + $\boxed{\text{ANTENNA}}$ + $\boxed{\text{RECEIVER}}$ + BACKEND

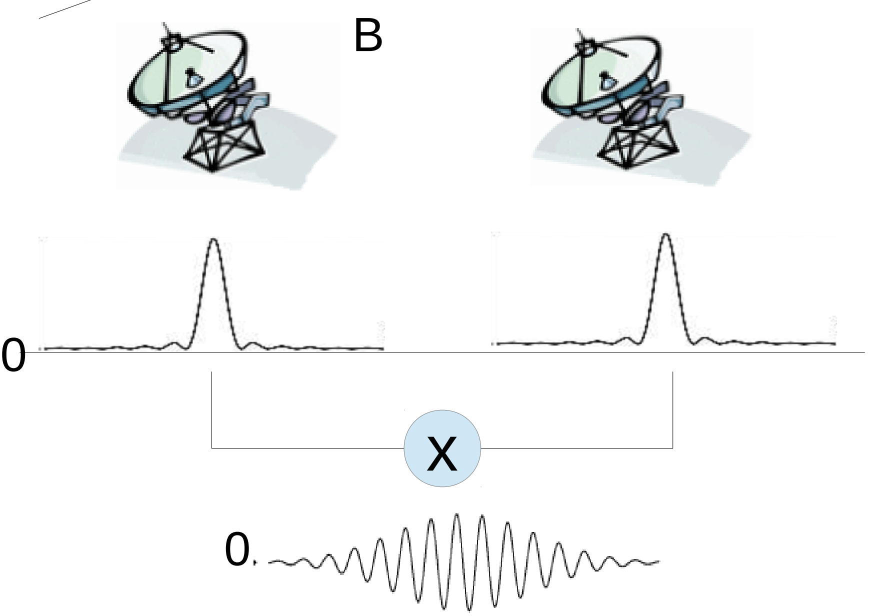
# The visibility function: properties

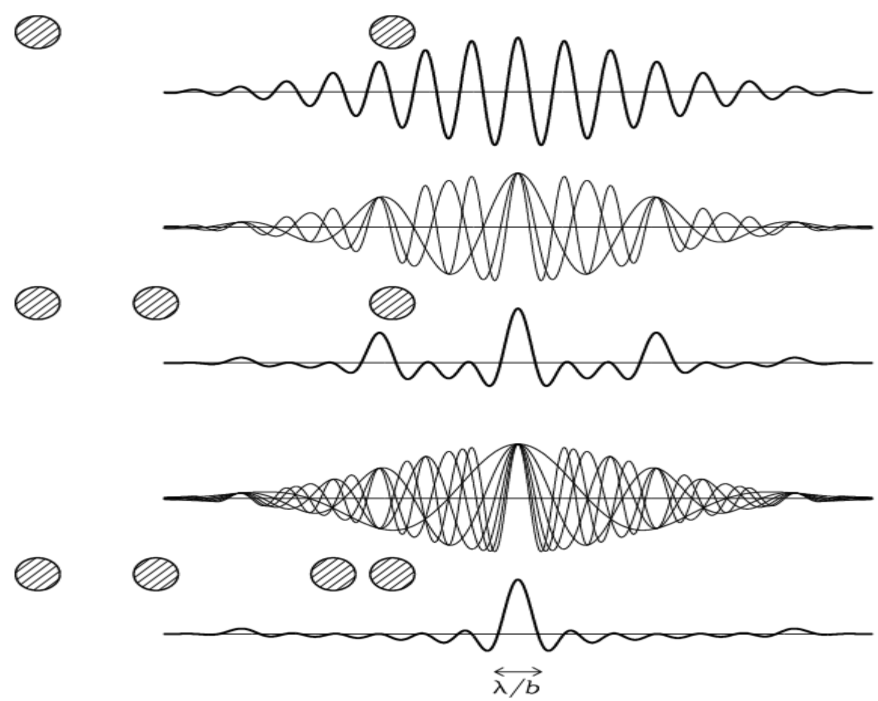
Some **visibility function** properties: $$R(\boldsymbol{B}) = \iint_{\Omega} A(\boldsymbol{s}) I_\nu(\boldsymbol{s}) \exp\left[\mathrm{i}\, 2\pi\nu \left(\frac{1}{c}\boldsymbol{B}\cdot\boldsymbol{s}\right)\right] \mathrm{d}\Omega\, \mathrm{d}\nu$$

- **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 $\lambda$/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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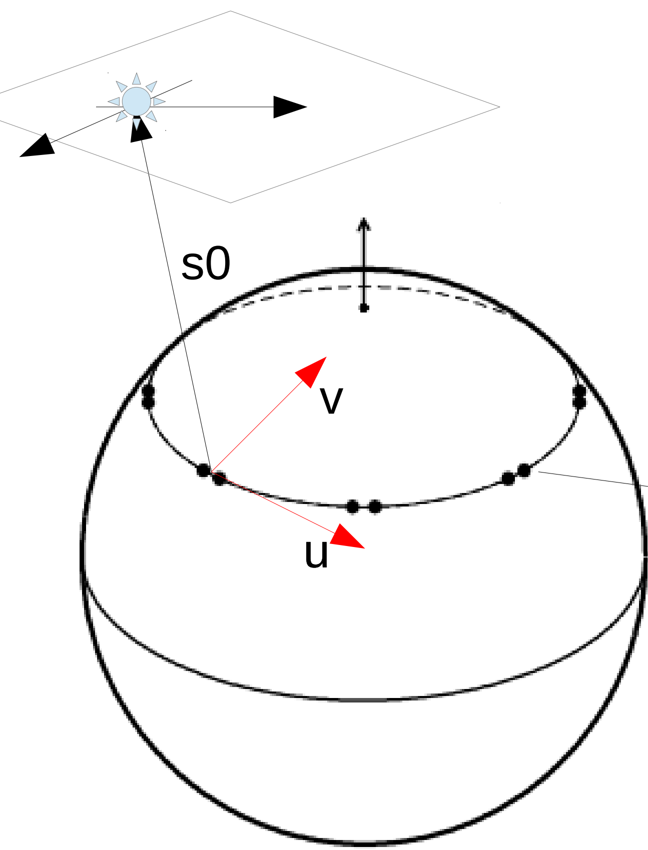
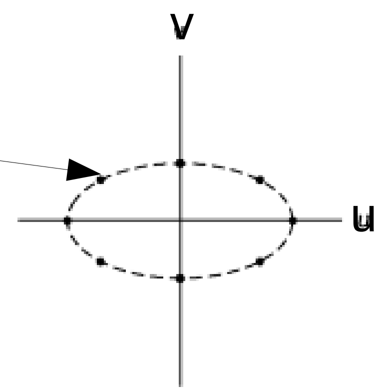
or changing the angle towards the target (exploiting the Earth rotation) to obtain a different projection of the same baseline.

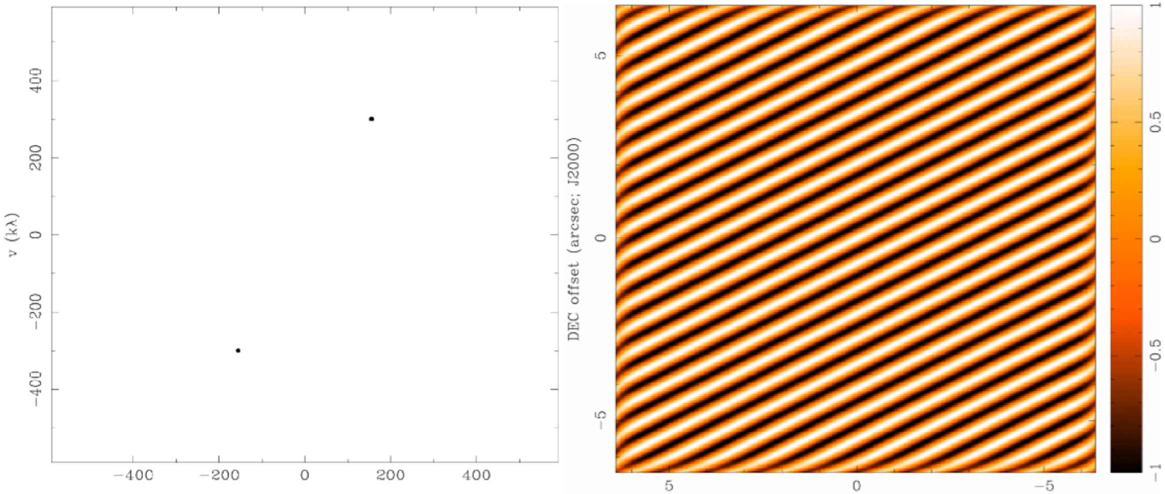


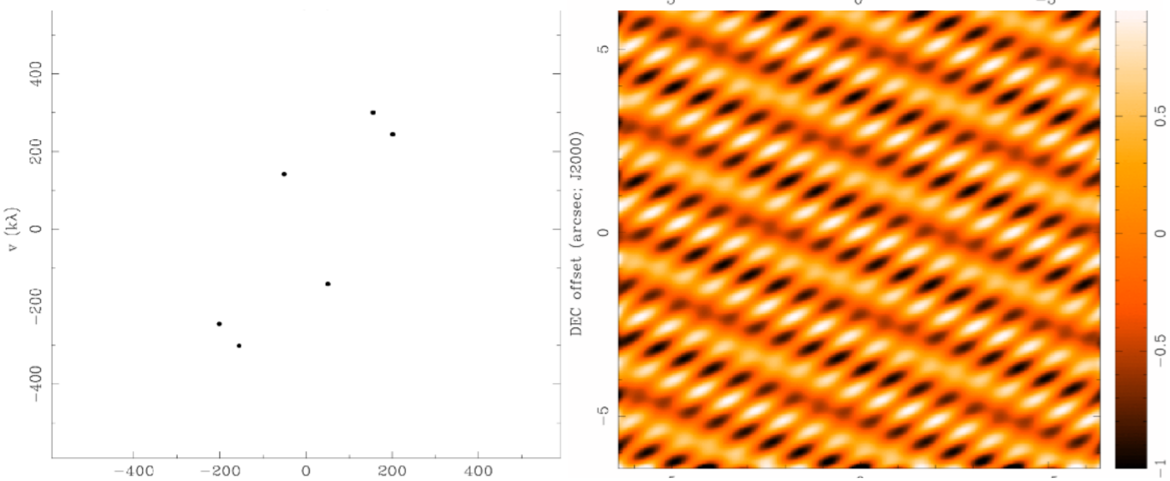

**The projected baseline is described over the uv plane perpendicular to the direction to the phase center (s0)** with u and v towards E and N. The earth rotation generates elliptical loci on the uv plane in 12 hr which ellipticity depends on the telescope latitude and source declination.

Receiving system: ATMOSPHERE + ANTENNA + RECEIVER + BACKEND

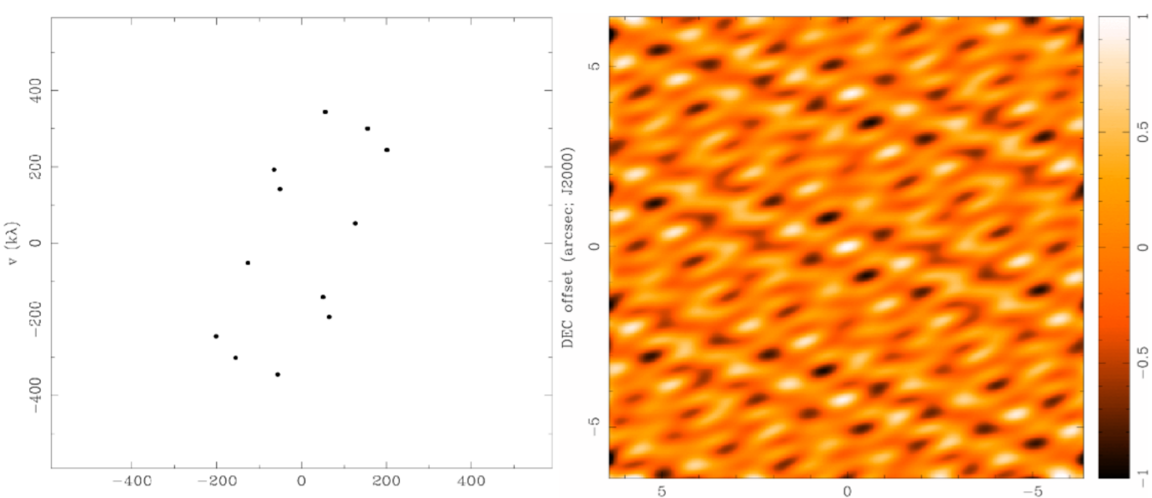
# The visibility function: the uv plane




2 antennas




3 antennas




5 antennas

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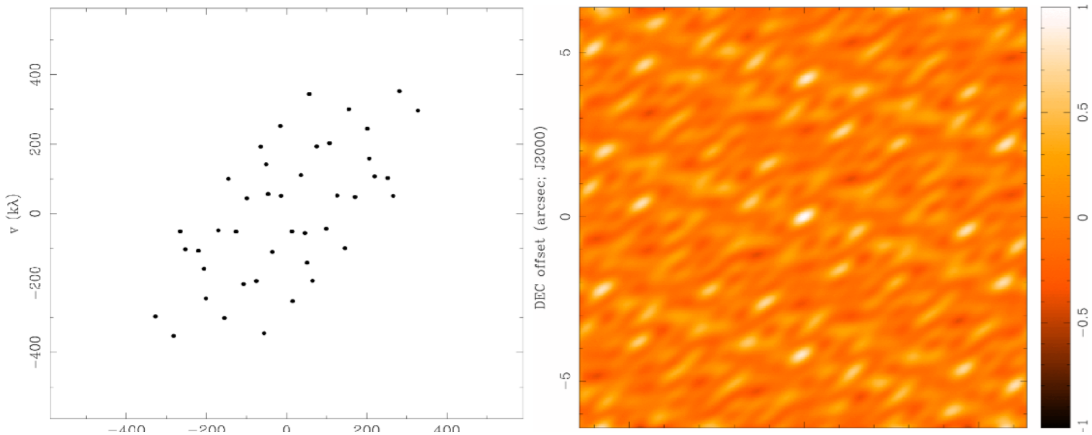
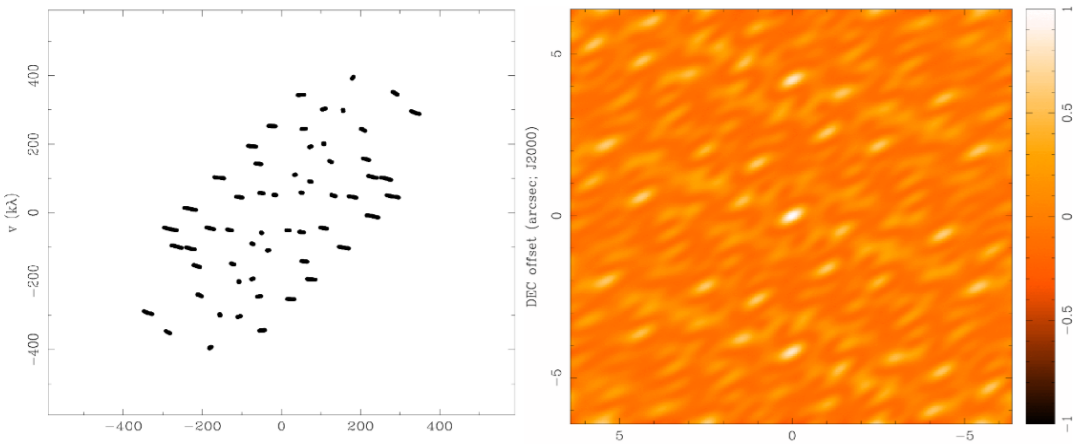
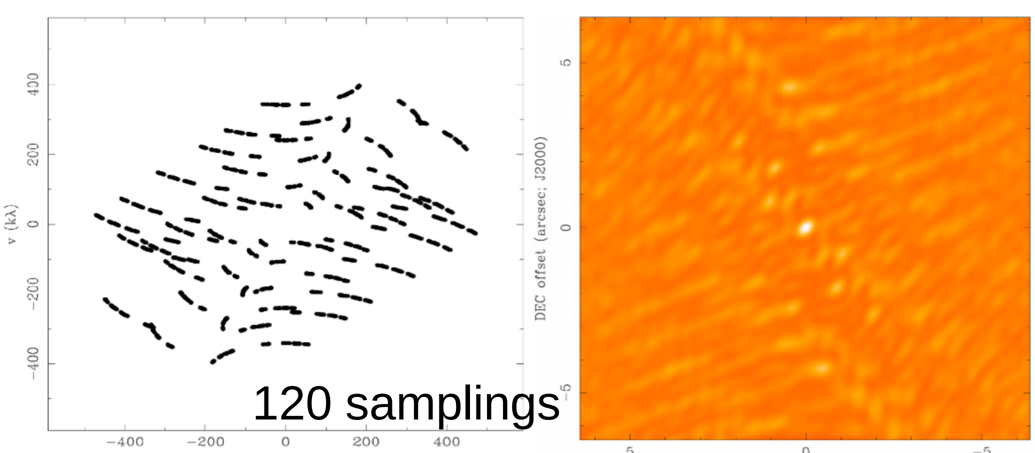



8 antennas

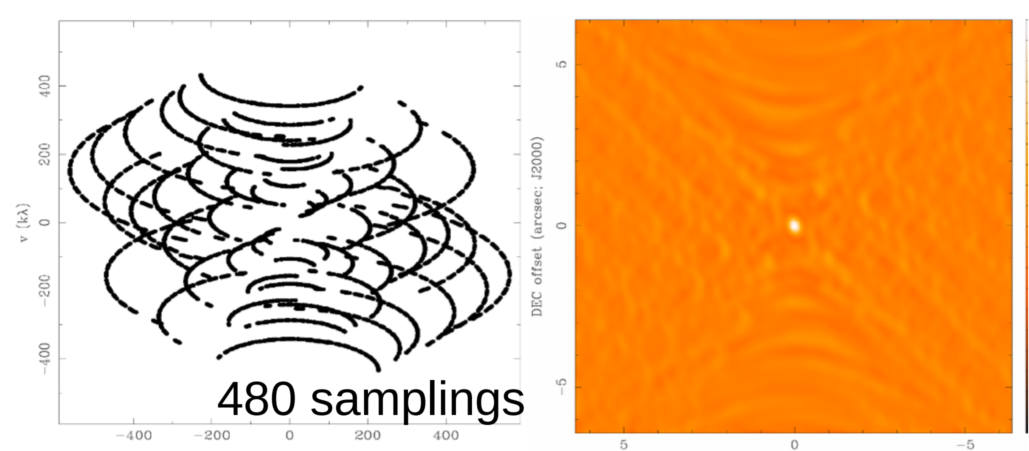
1 sampling




30 samplings




120 samplings




480 samplings

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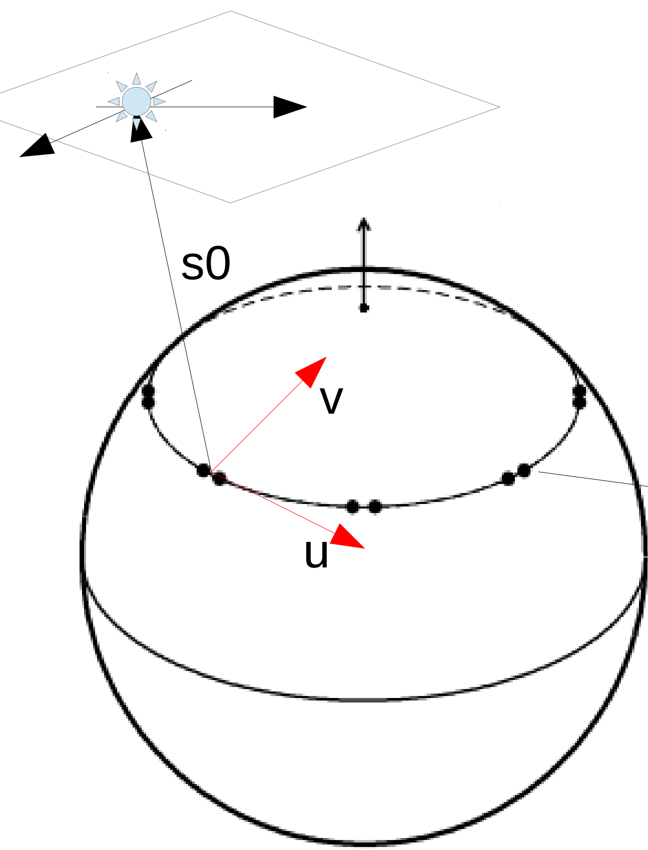


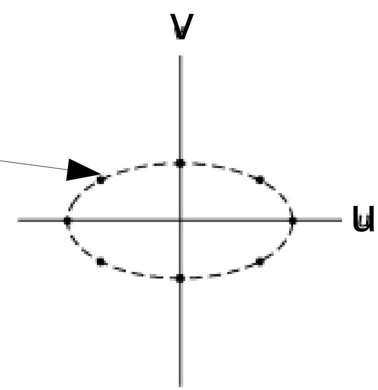


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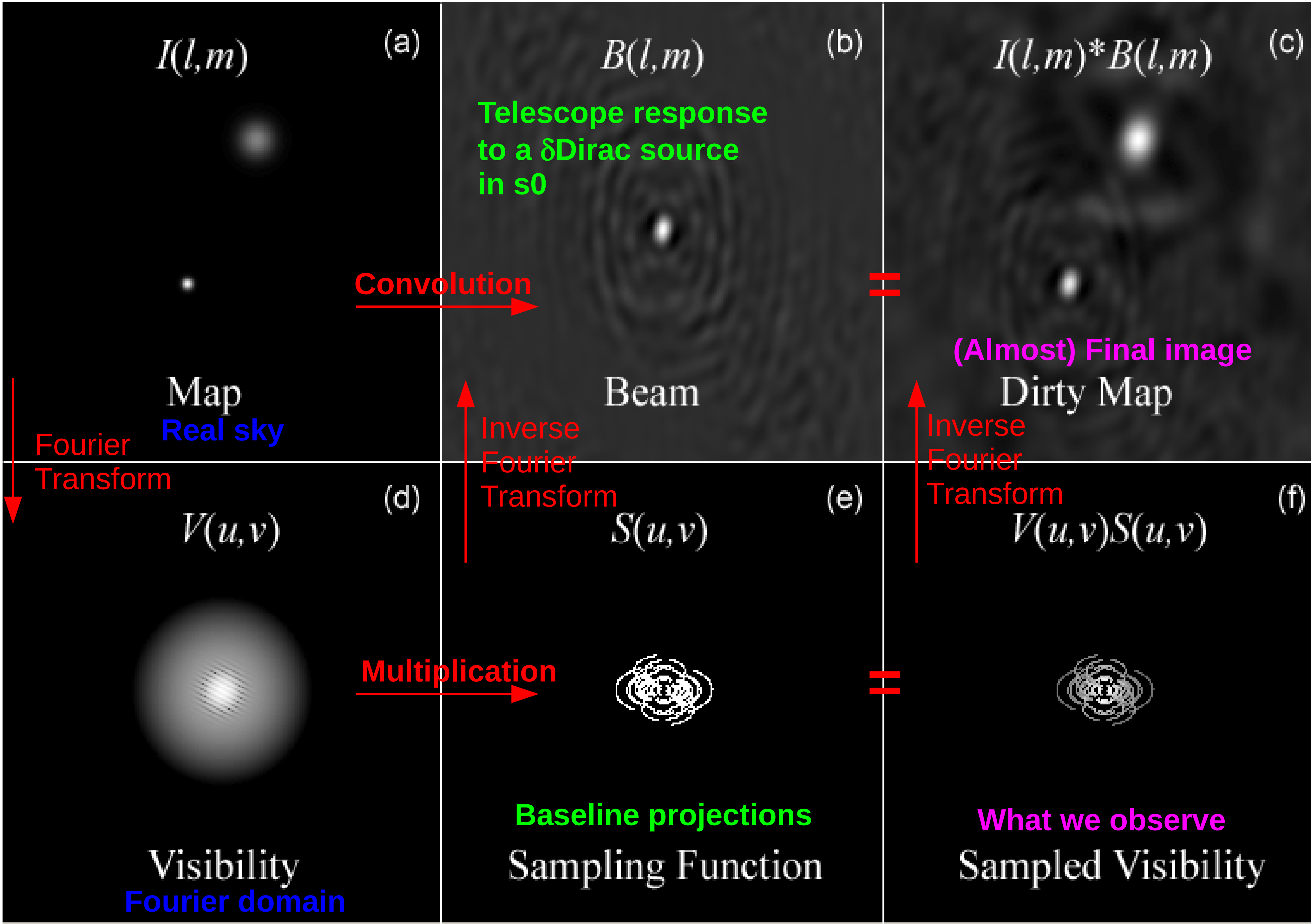
- **Van Cittert- Zernike theorem: the visibility pattern is the Fourier transform of the brightness pattern**

  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

# From the sky to the image



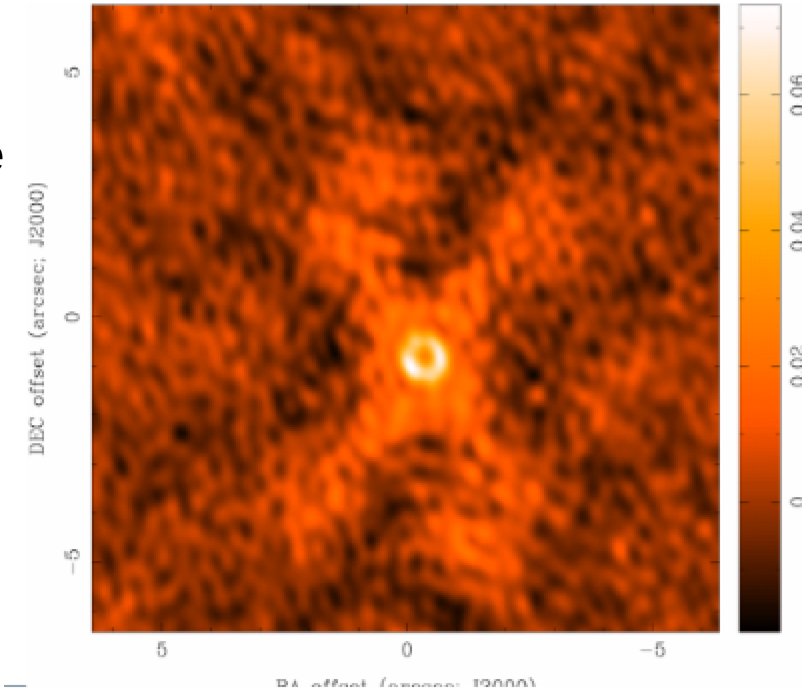
# Deconvolution

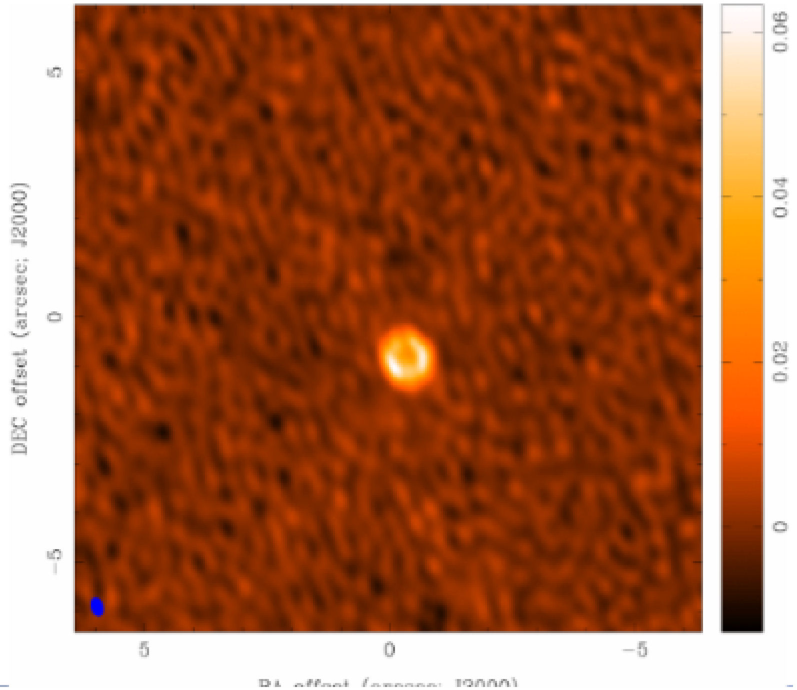
$$R(\boldsymbol{B}) = \iint_{\Omega} A(\boldsymbol{s}) I_\nu(\boldsymbol{s}) \exp\left[ \mathrm{i}\, 2\pi\nu \left( \frac{1}{c} \boldsymbol{B} \cdot \boldsymbol{s} \right) \right] \mathrm{d}\Omega\, \mathrm{d}\nu$$

·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.**

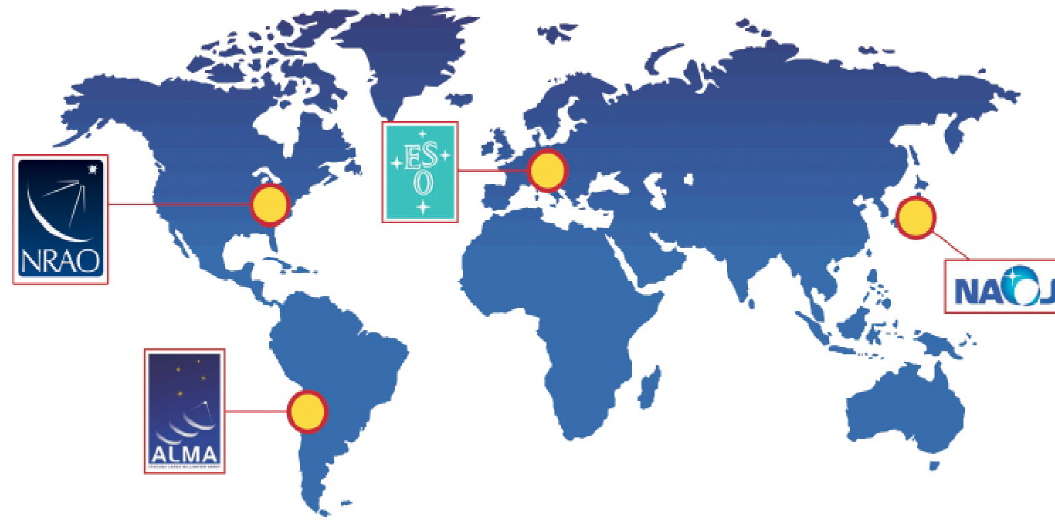
-> high angular resolution and sensitivity
-> galaxy dynamics, AGN core mechanisms,
imaging of exoplanets, comets,
asteroids, ...

# 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**

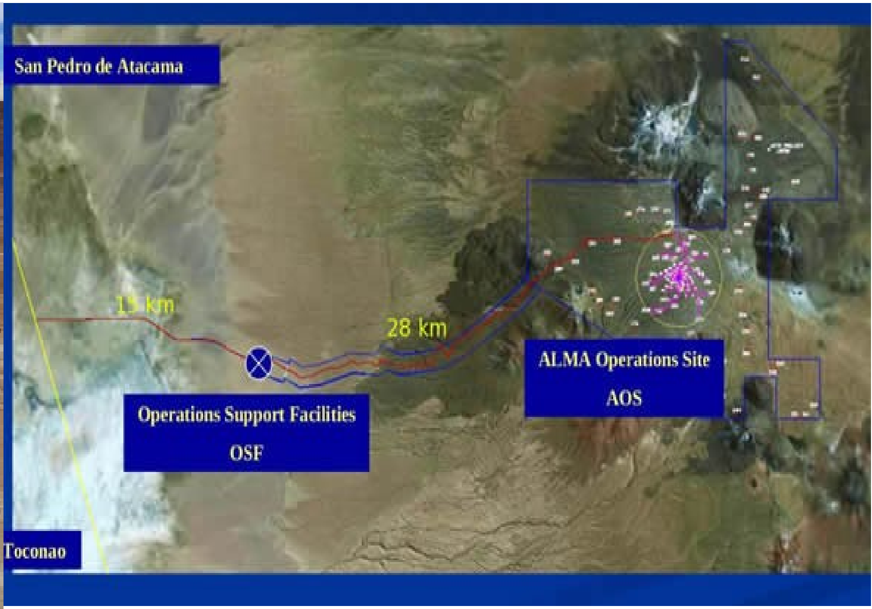



## 3 Sites in Chile

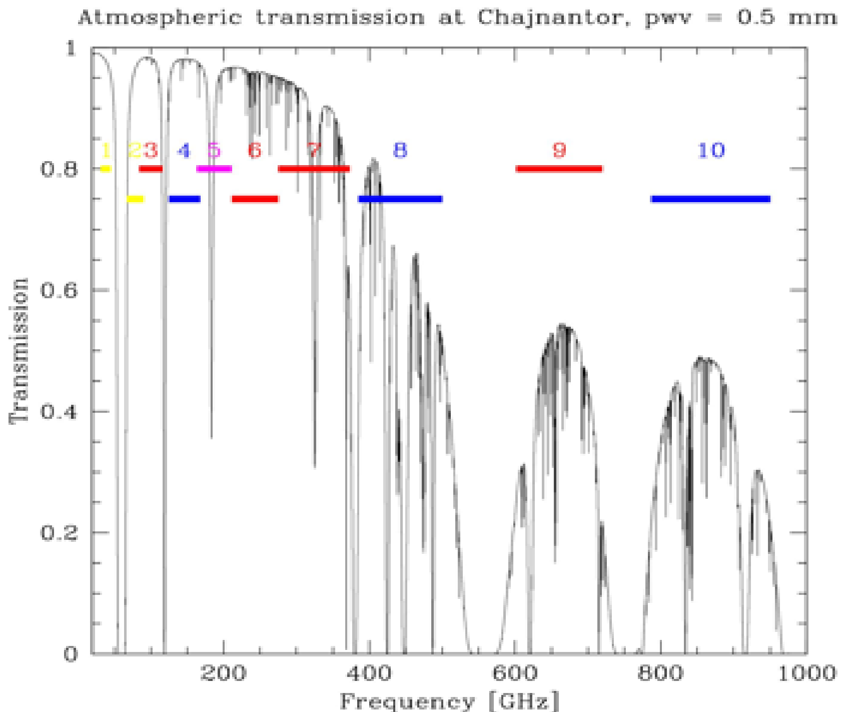
- *AOS*: ALMA Operations Site (5000m): Antennas, Correlator
- *OSF*: Operations Support Facility (3000m):
  Labs, Antenna Assembly & Maintenance Operators, Astronomers
- *SCO*: Santiago Central Office:
  - Call for Proposals
  - Running ALMA
  - Data Reduction Pipeline
  - Quality Assessment

# ALMA sites

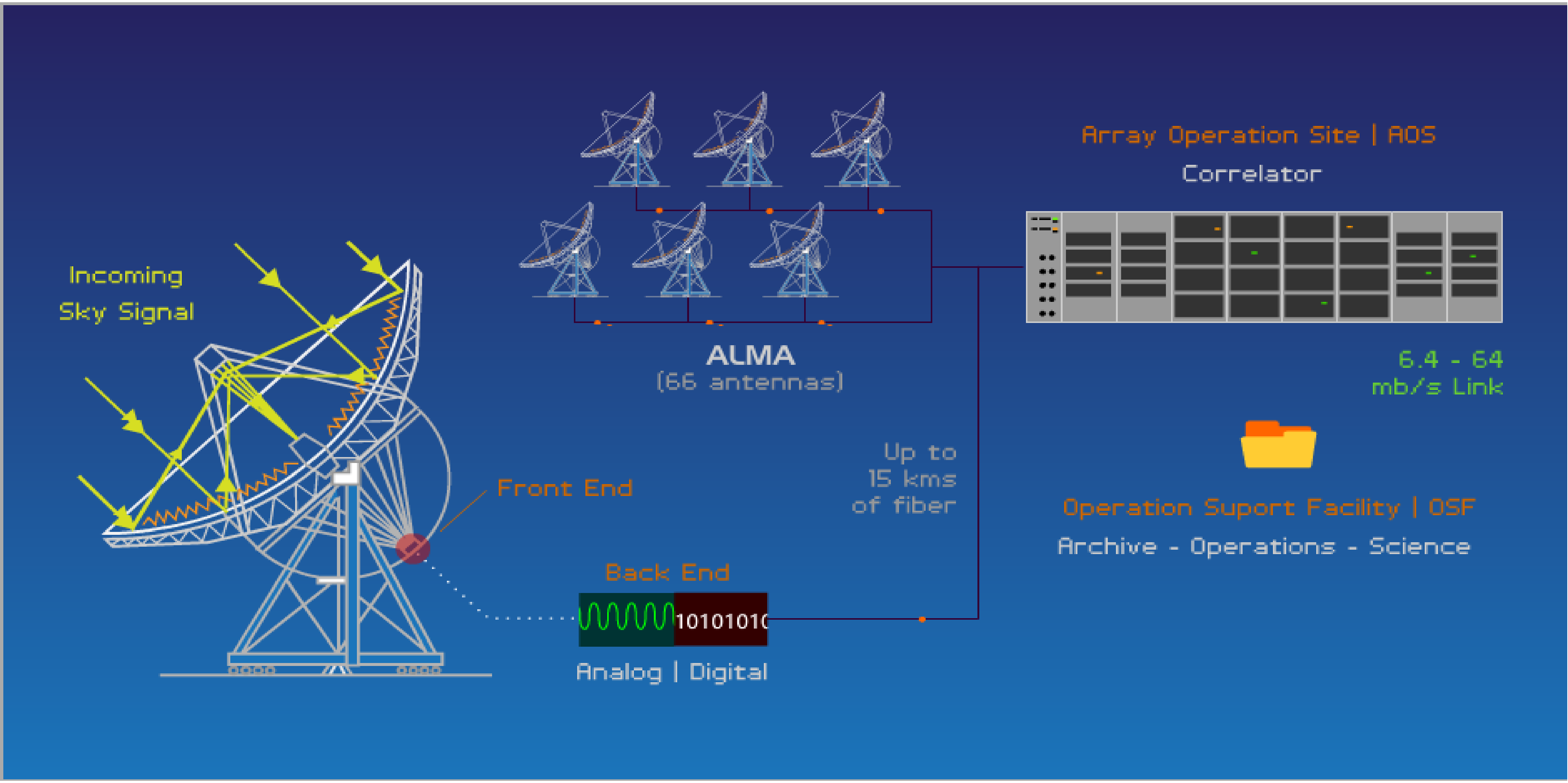

AOS 5000m


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


OSF 2900m

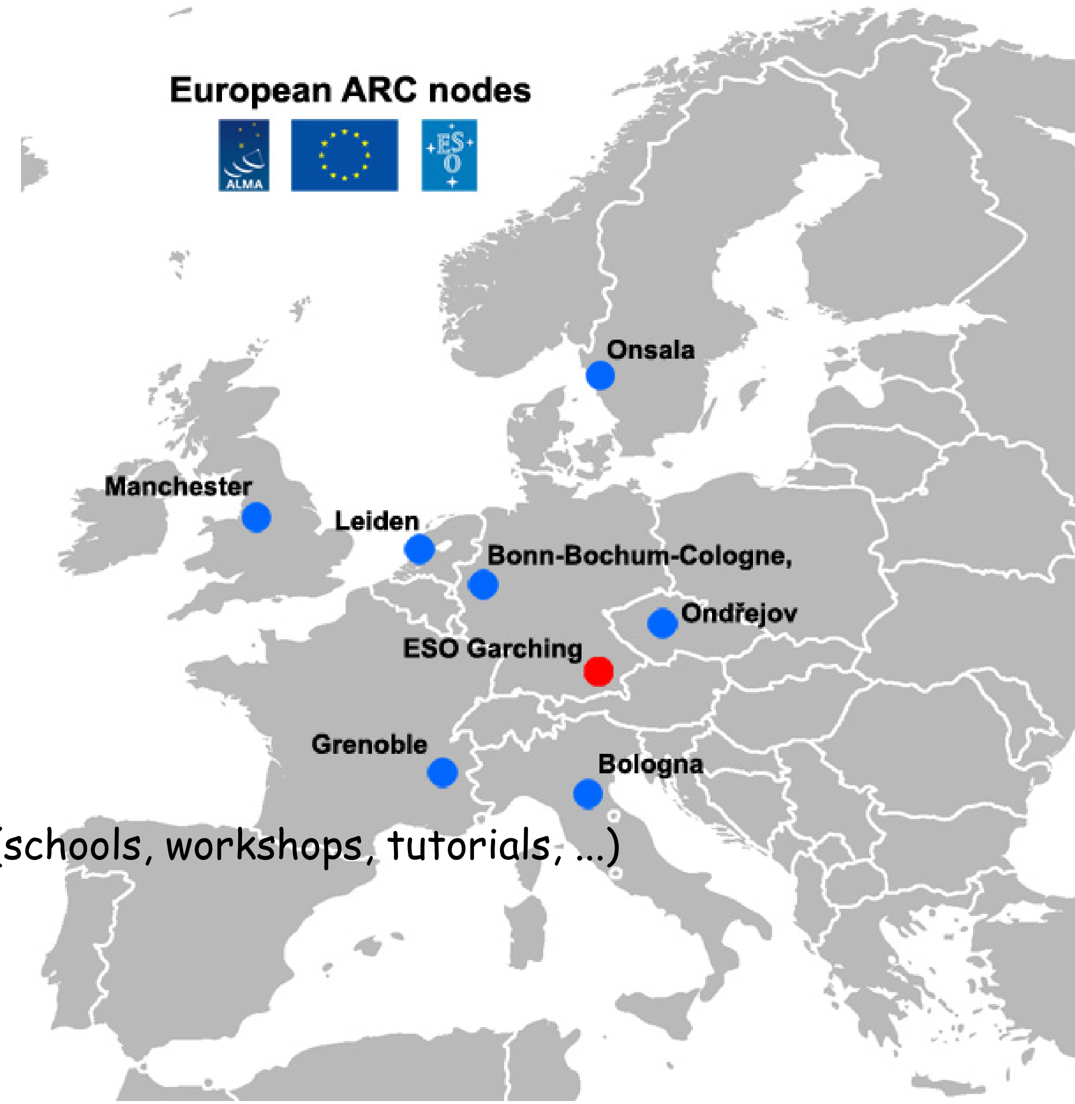

Atmospheric transmission at Chajnantor, pwv = 0.5 mm
Transmission
Frequency [GHz]
1
0.8
0.6
0.4
0.2
0
200
400
600
800
1000
1
2
3
4
5
6
7
8
9
10

# ALMA data flow



# 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)**
- 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

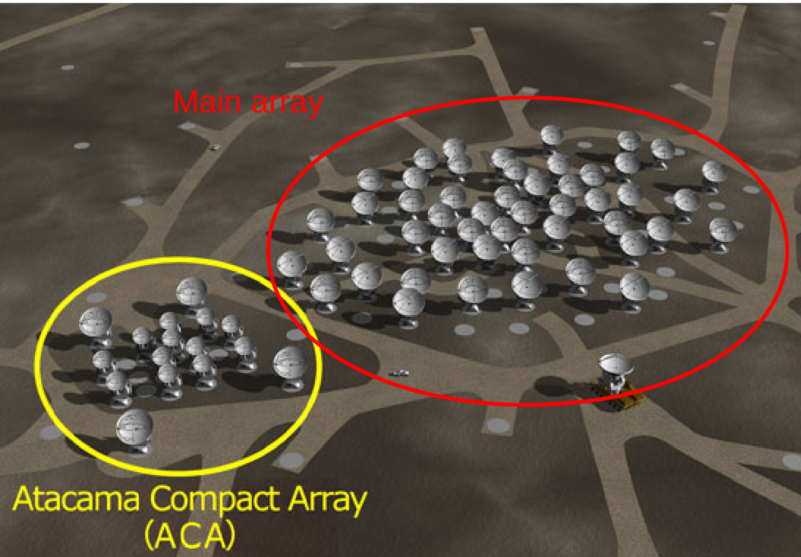


# Enter the ALMA world through the ALMA Science Portal

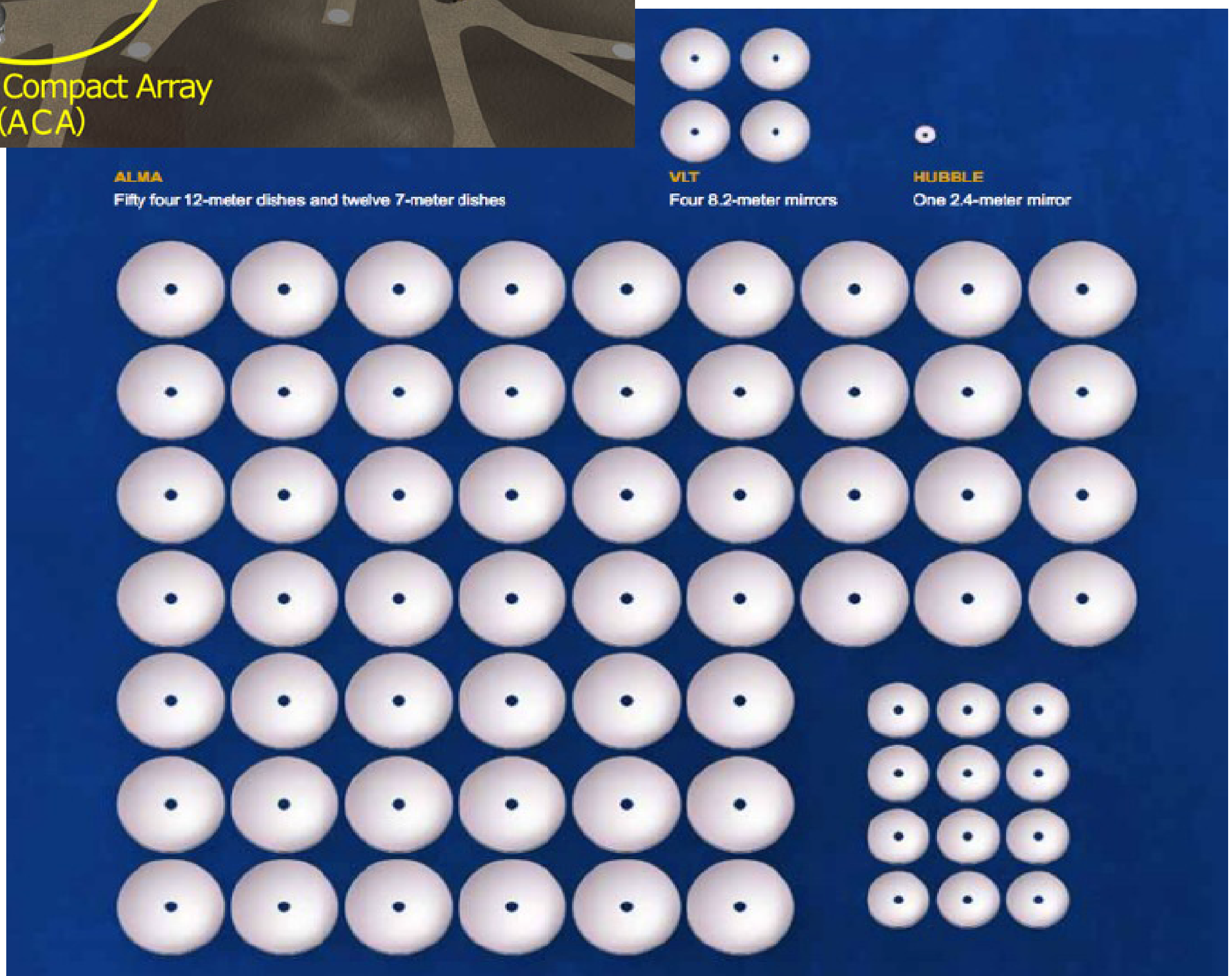
**http://almascience.eso.org/**


**Access to Helpdesk for any request (FAQ, problems, F2F...)**

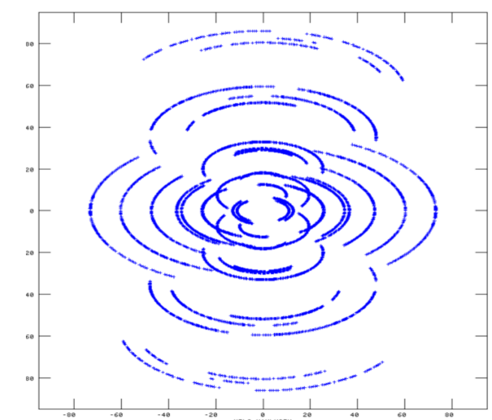
# ALMA array(s)

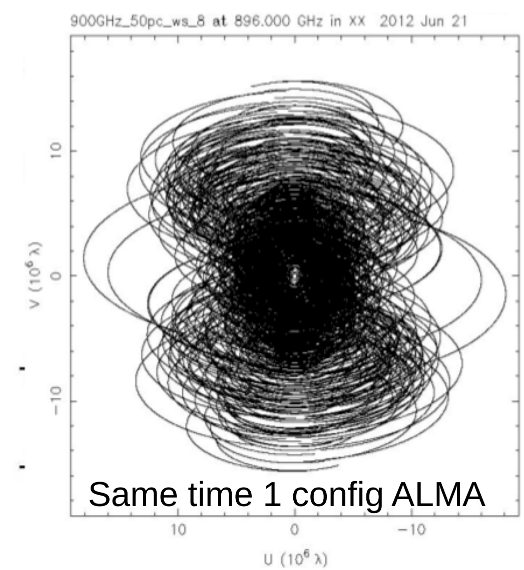



Antennas : **50x12m** main array + (**12x7m + 4x12m TP**) ACA
Baselines : **15m ->150m-16km** + **9m->50m**



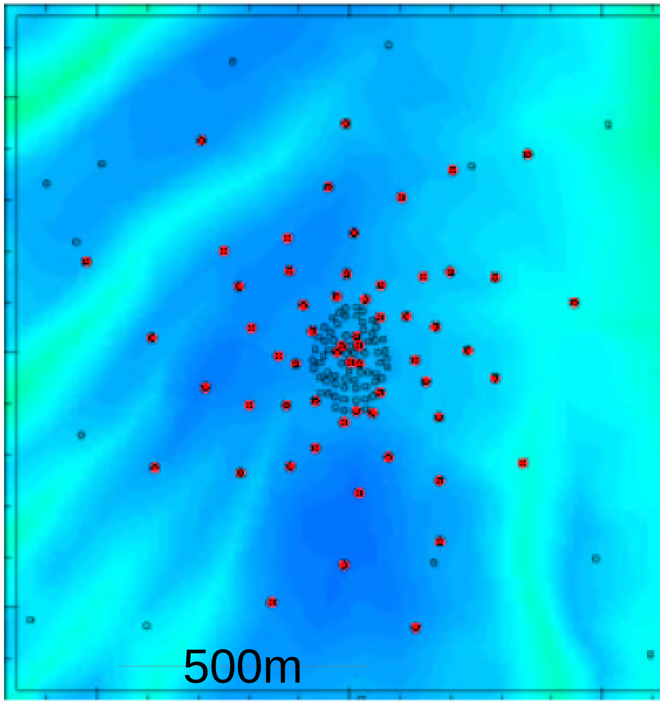

Few hr 2 config OVRO

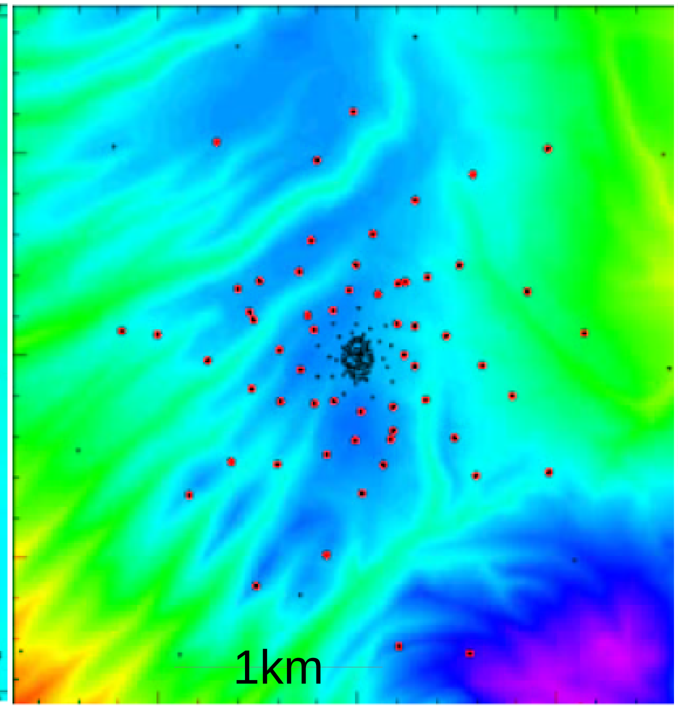


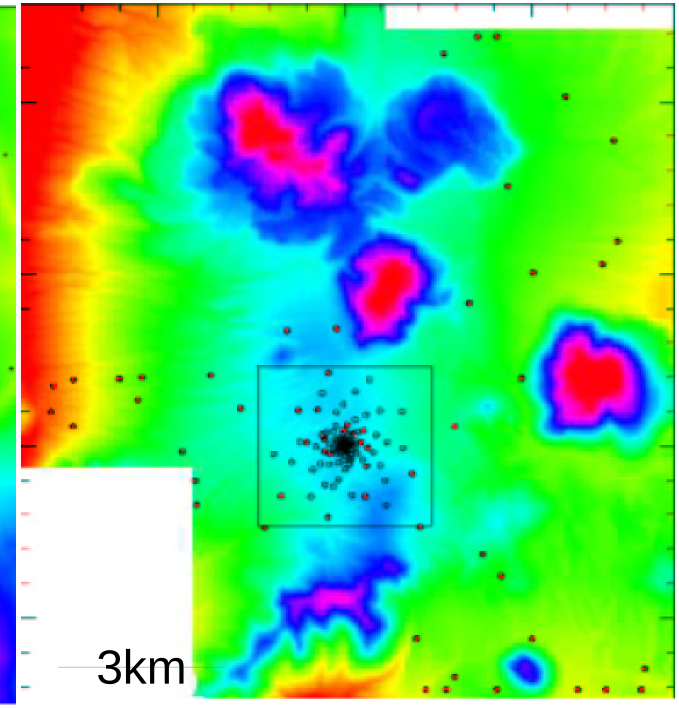


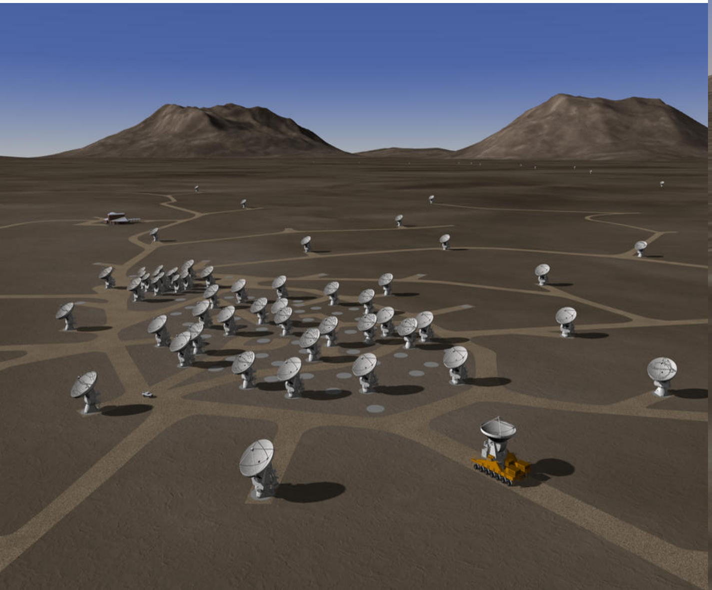

Same time 1 config ALMA

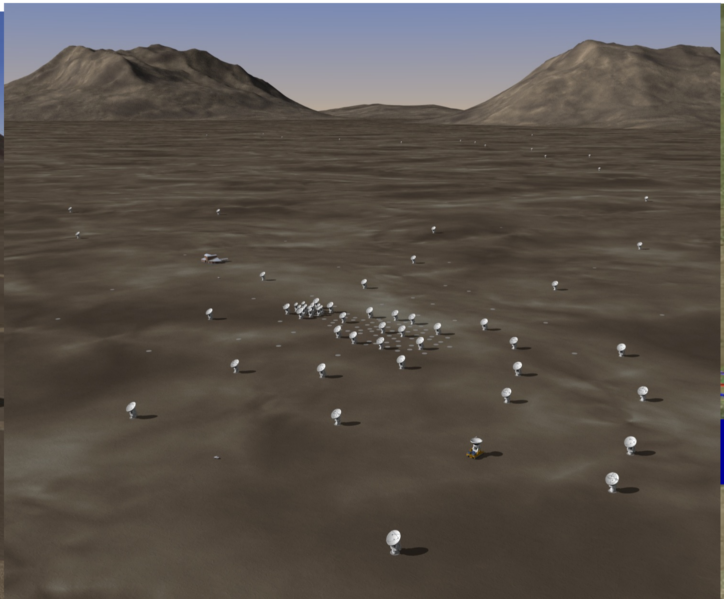
# ALMA reconfiguration

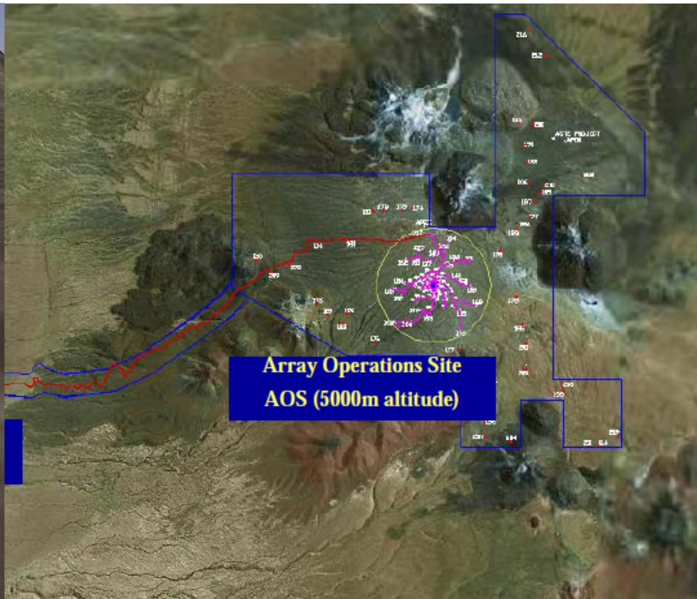


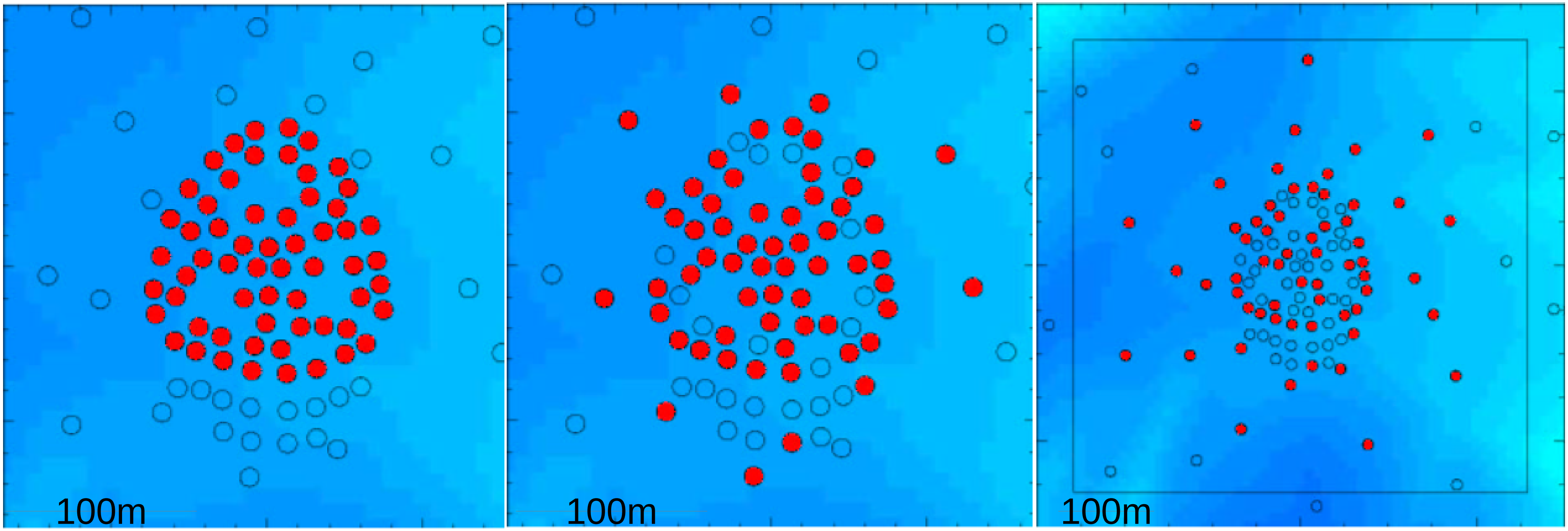



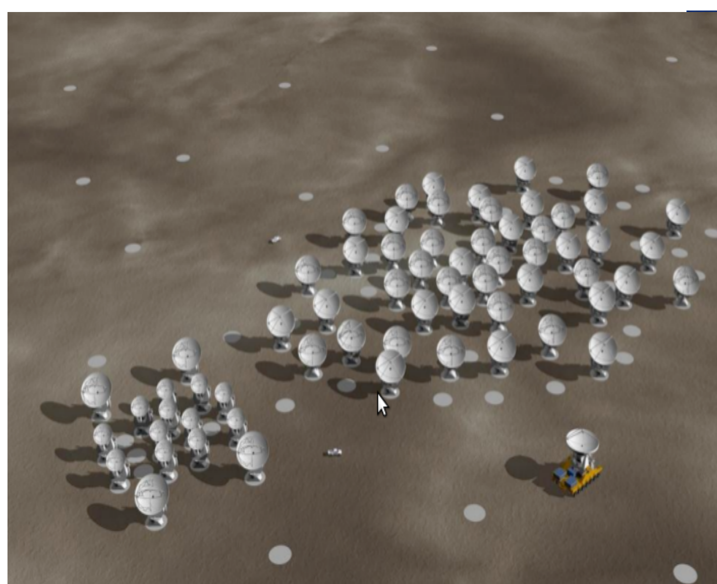




# ALMA reconfiguration

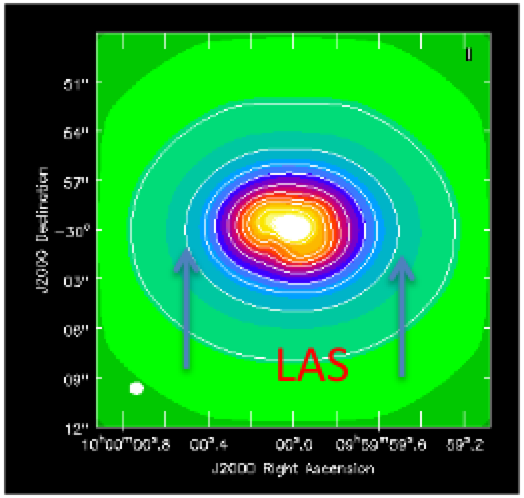


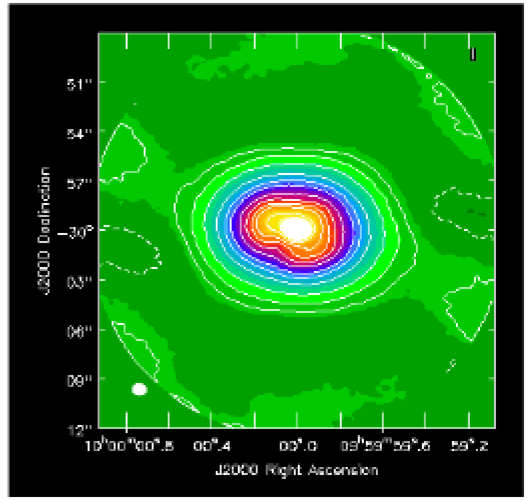


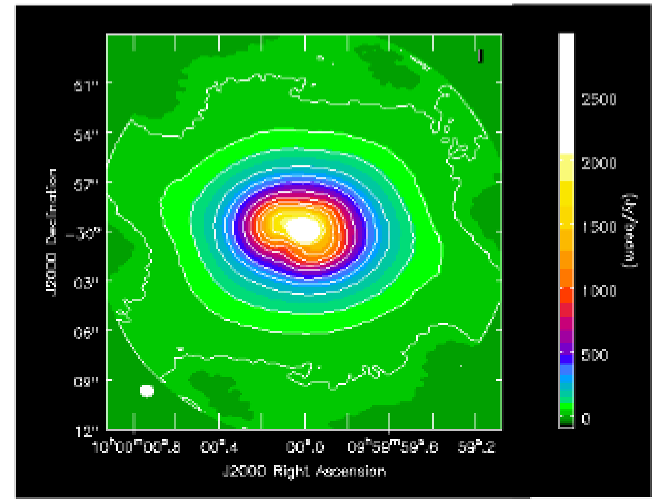


# ALMA array(s)

| MODEL | 12-m image | 12m+7m Image |
|---|---|---|

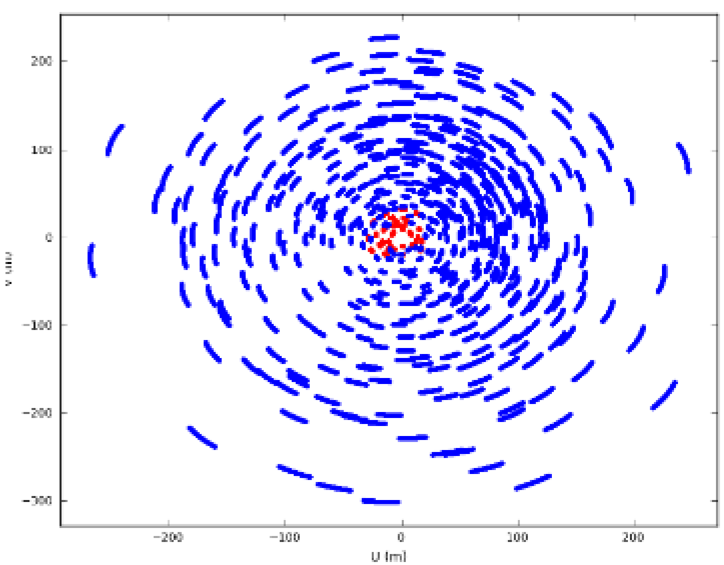


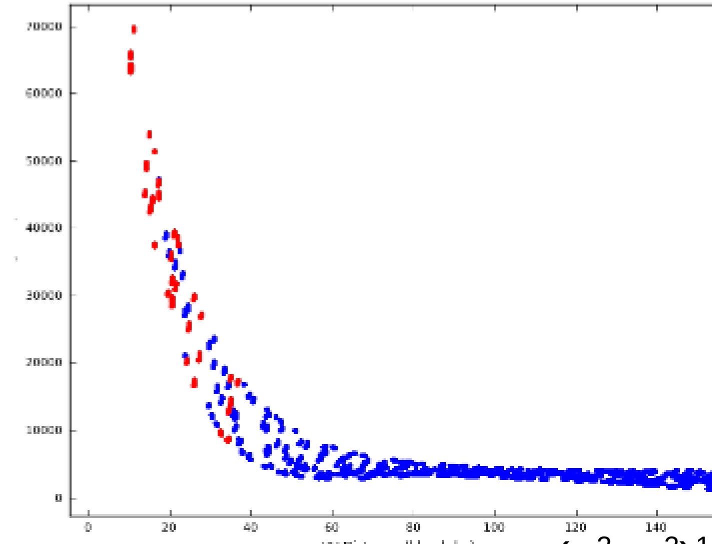




Restored flux 11000 Jy 7000 Jy 9000 Jy

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

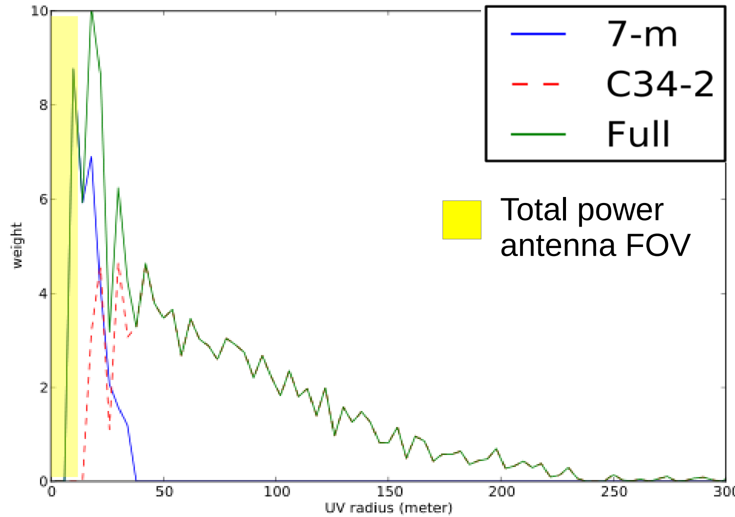


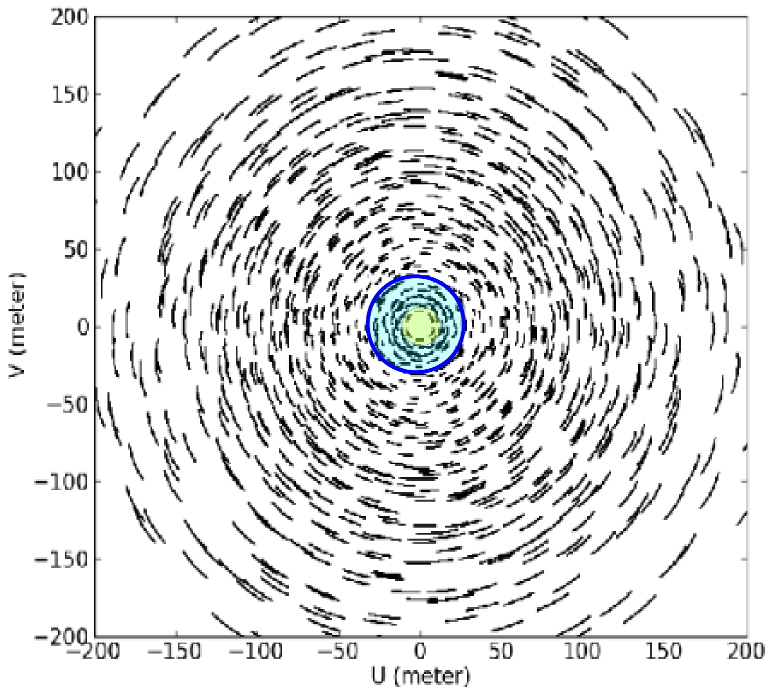

$(u^2+v^2)^{1/2}$

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

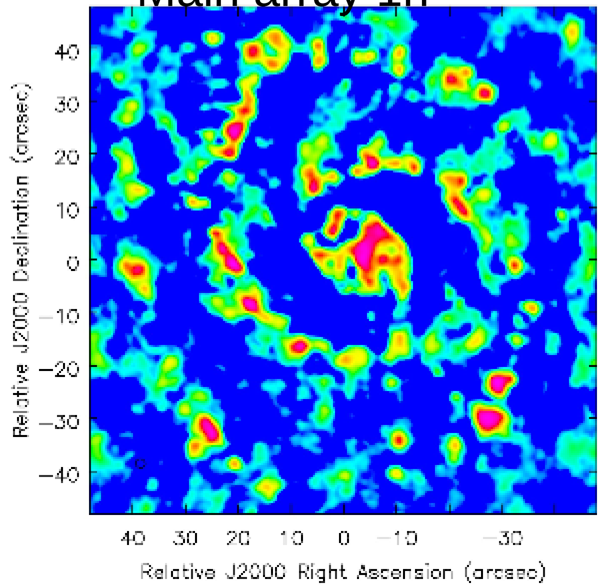
# ALMA array(s)



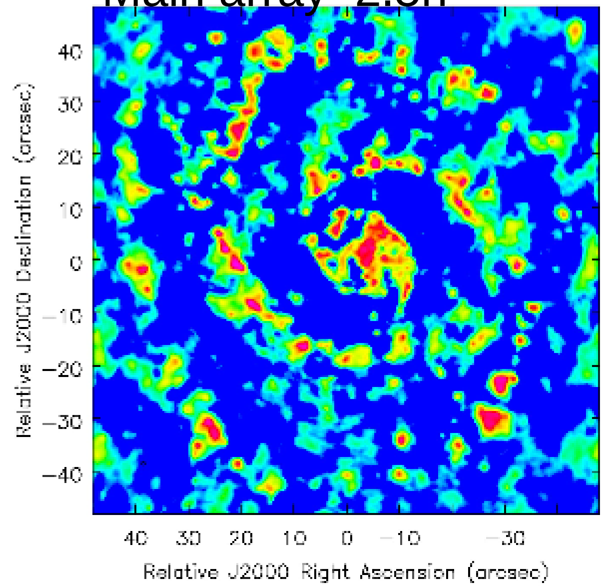

$(u^2+v^2)^{1/2}$

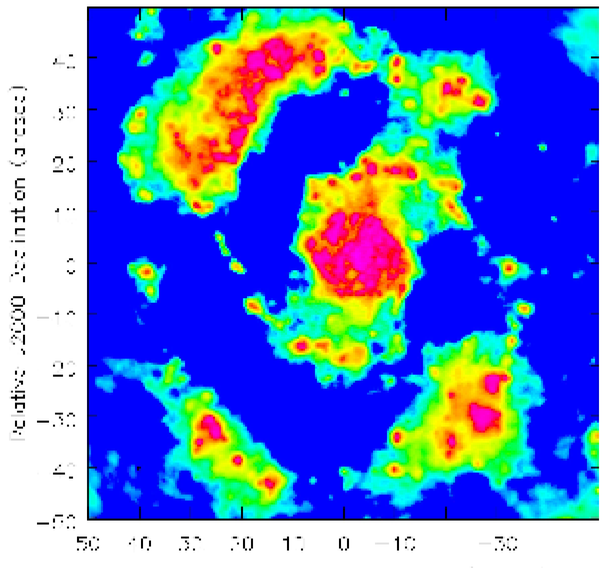



Main array 1h

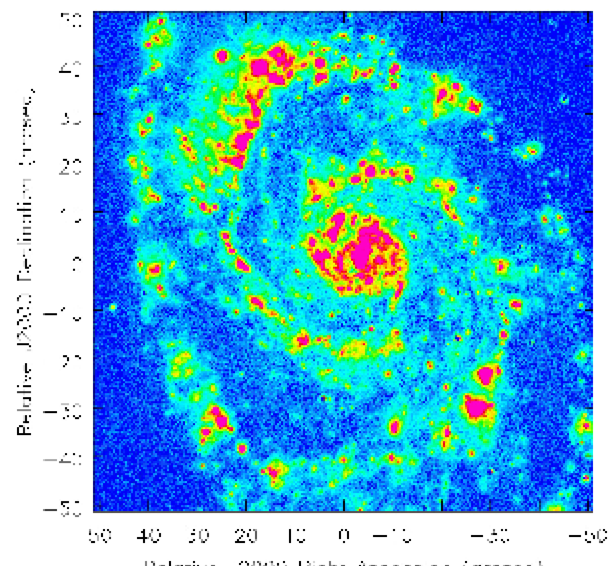



Main array 2.5h



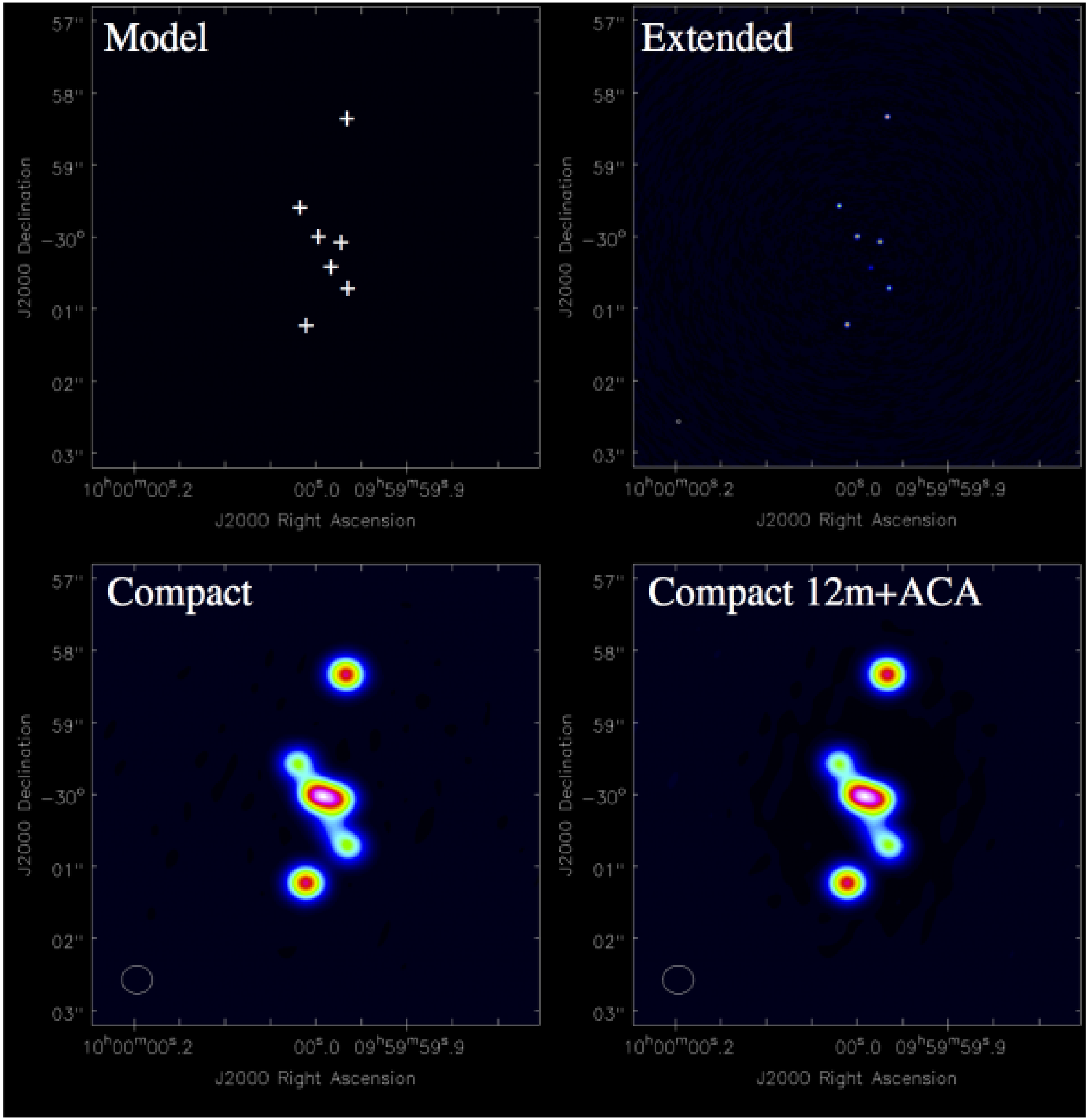
Main array+ ACA



Model M51

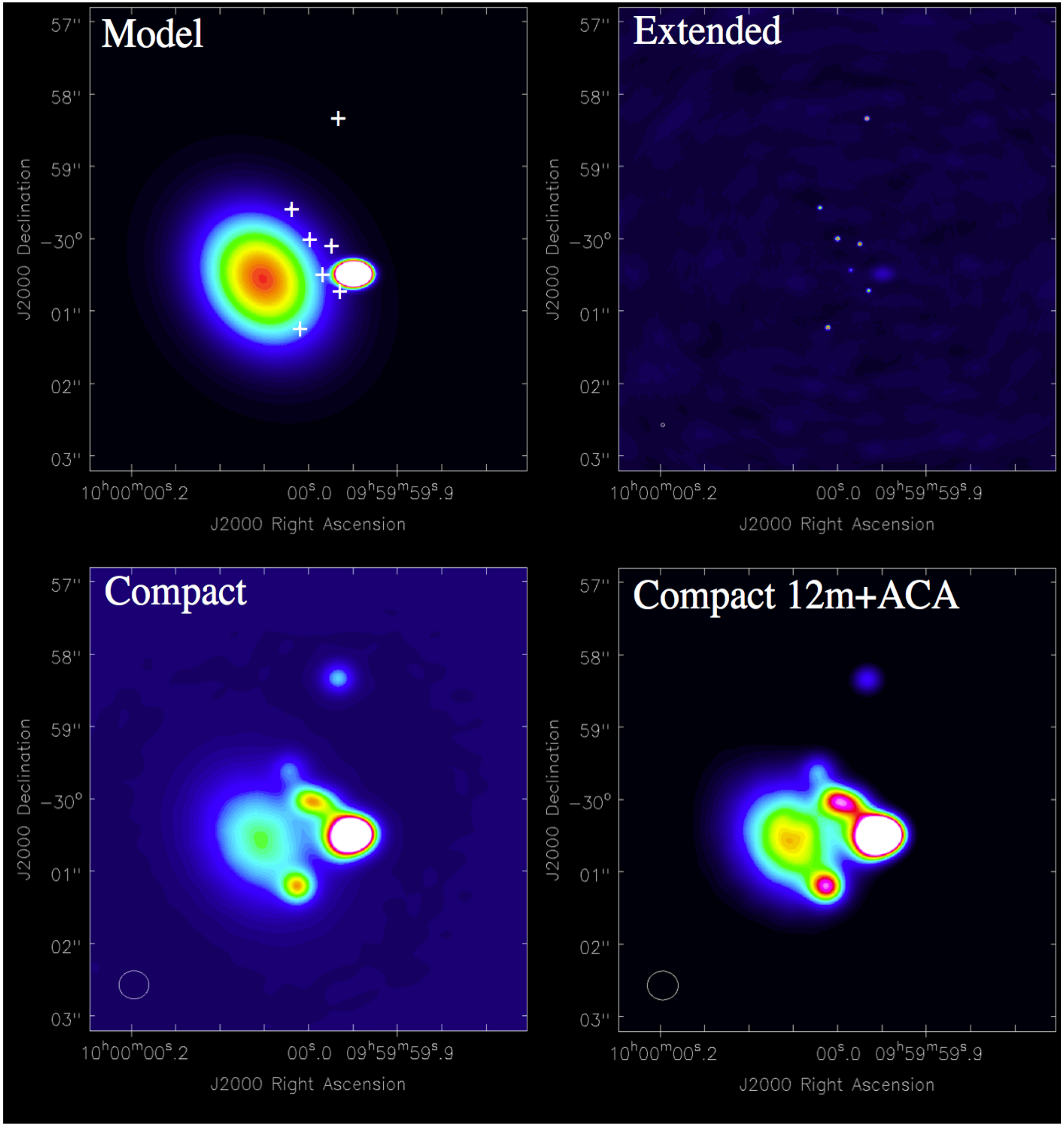
# ALMA array(s)

Main array
for compact
objects



# ALMA array(s)

ACA
for extended
objects

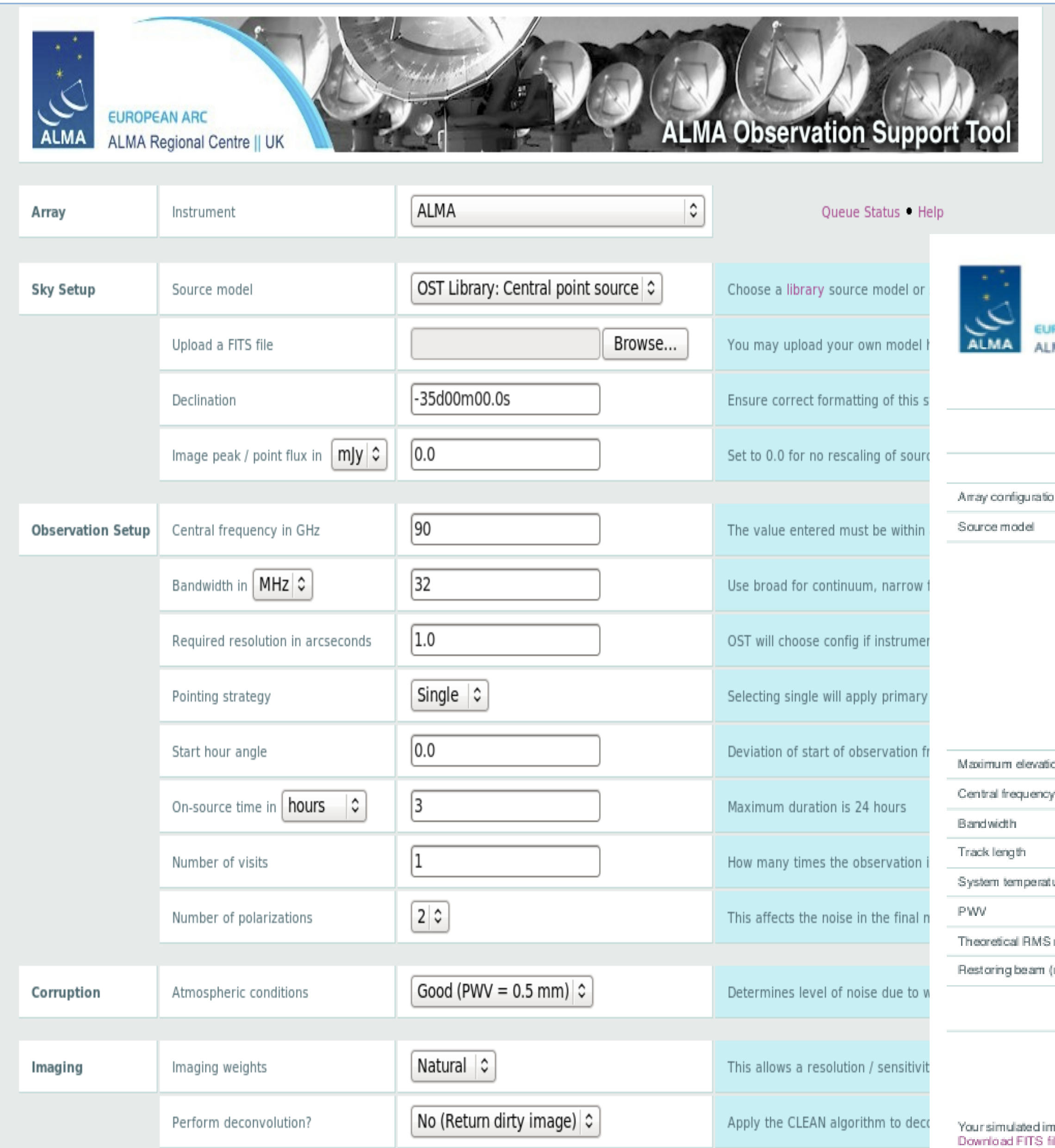


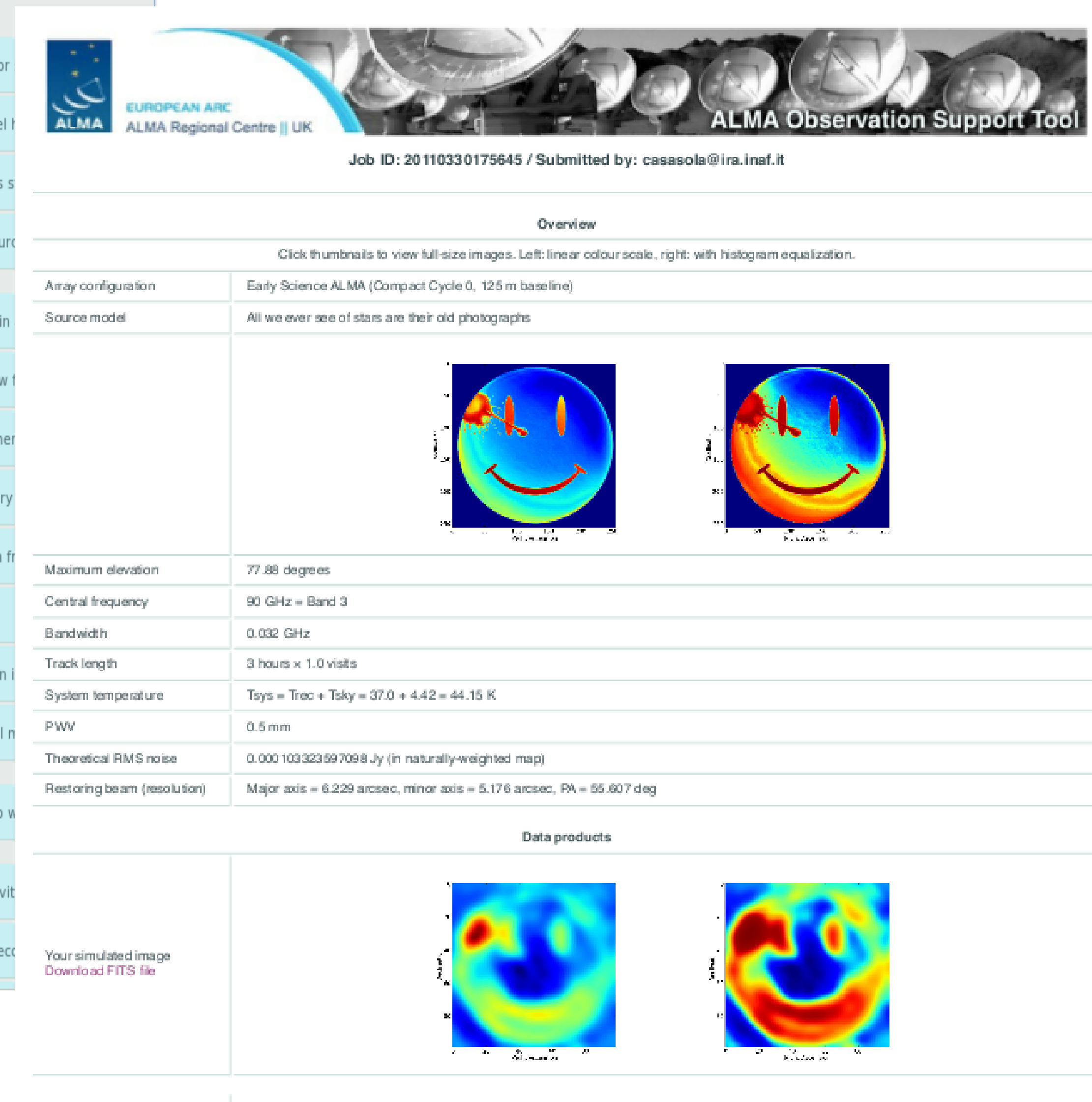
# Make your ALMA simulations (Observation Support Tool)

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

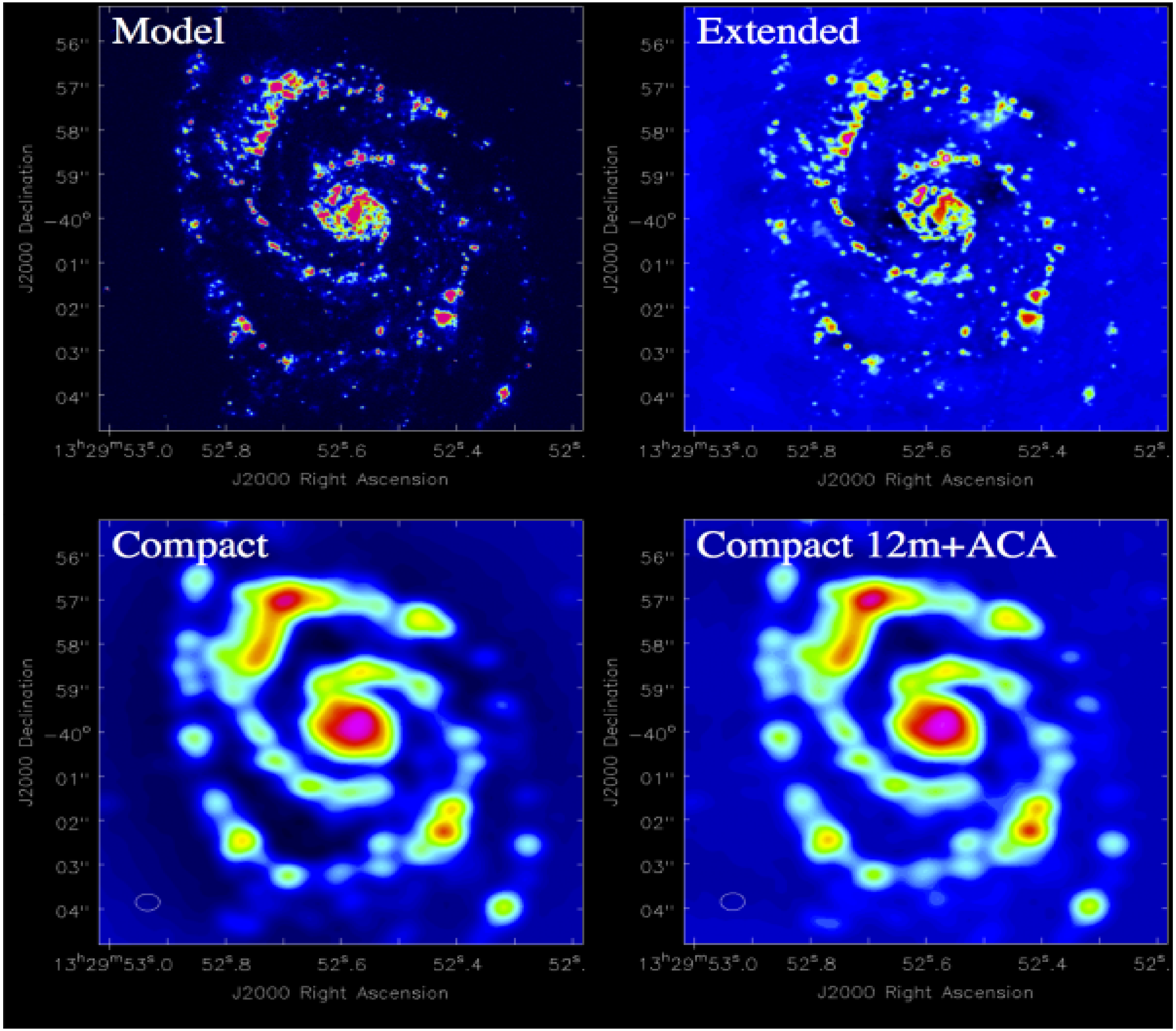
Submit a request for a full simulation of ALMA capabilities for your target

Receive the results via e-mail



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



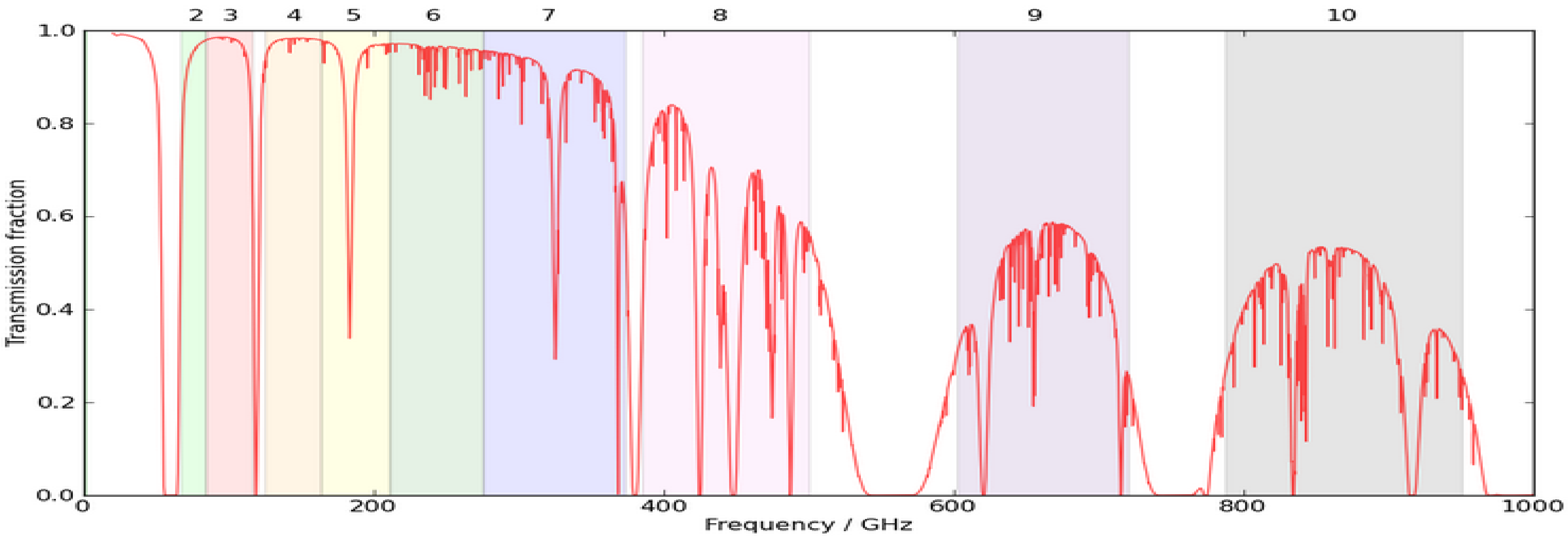

The task **simobserve** generates a data set with simulated visibilities based on an input model image.

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 Resolution (") | Spectral Sensitivity ΔTline (K) | Angular Resolution (") | Spectral Sensitivity ΔTline (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)**

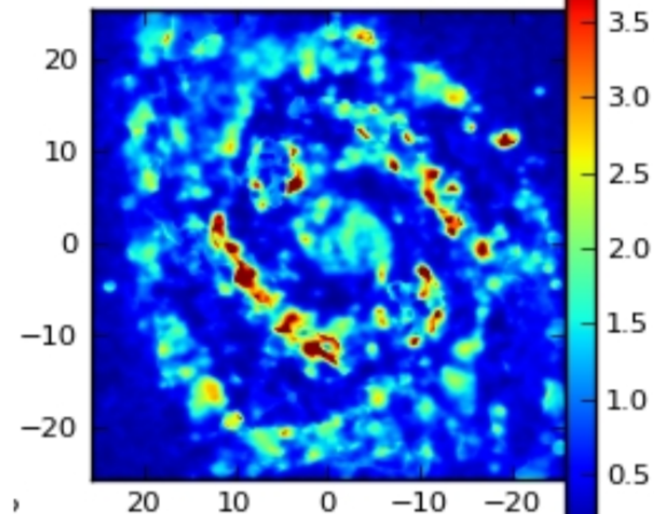
**Up to 16km baselines, subarcsec resolution**
**40 mas @ 100 GHz,**
**5 mas @ 900 GHz**

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

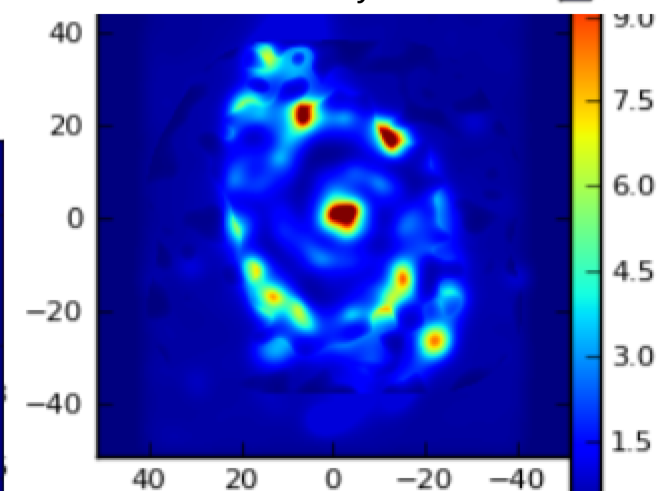
# Mosaicking

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

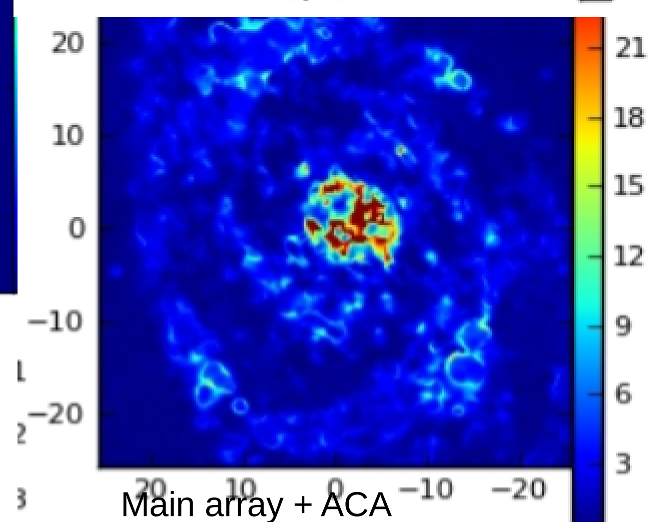
Details in the ranges available to the given baselines can be observed on larger region of the sky by mosaicking the region.



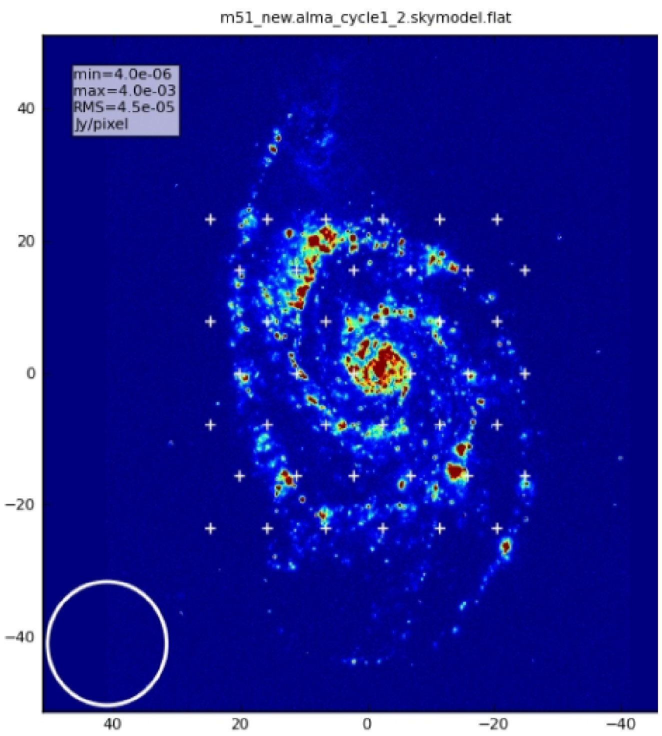
Main array



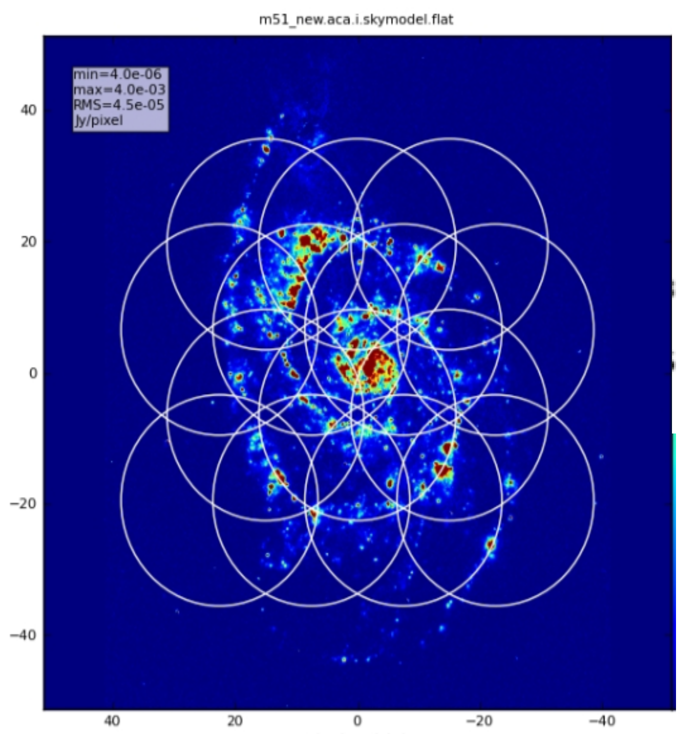
ACA



Main array + ACA




Model & 12m FOV



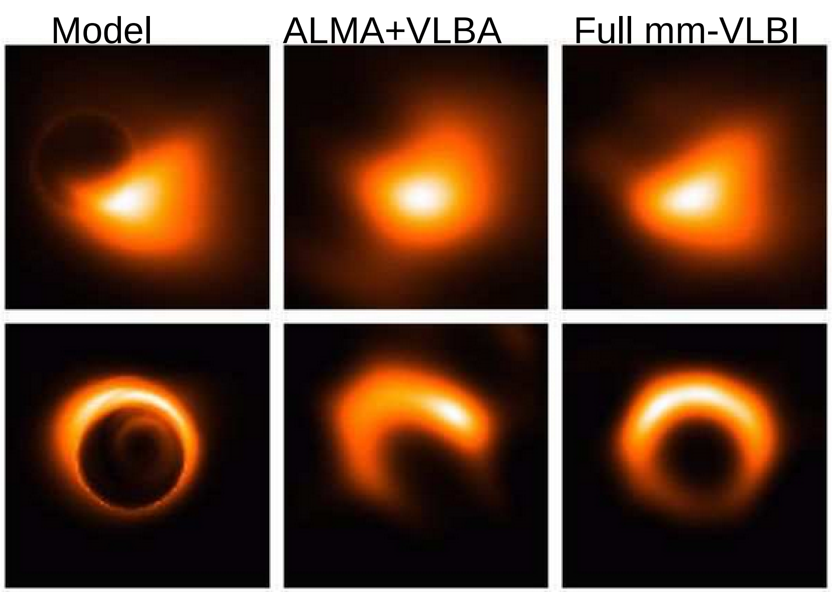

ACA Pointing map

# mm-VLBI with ALMA

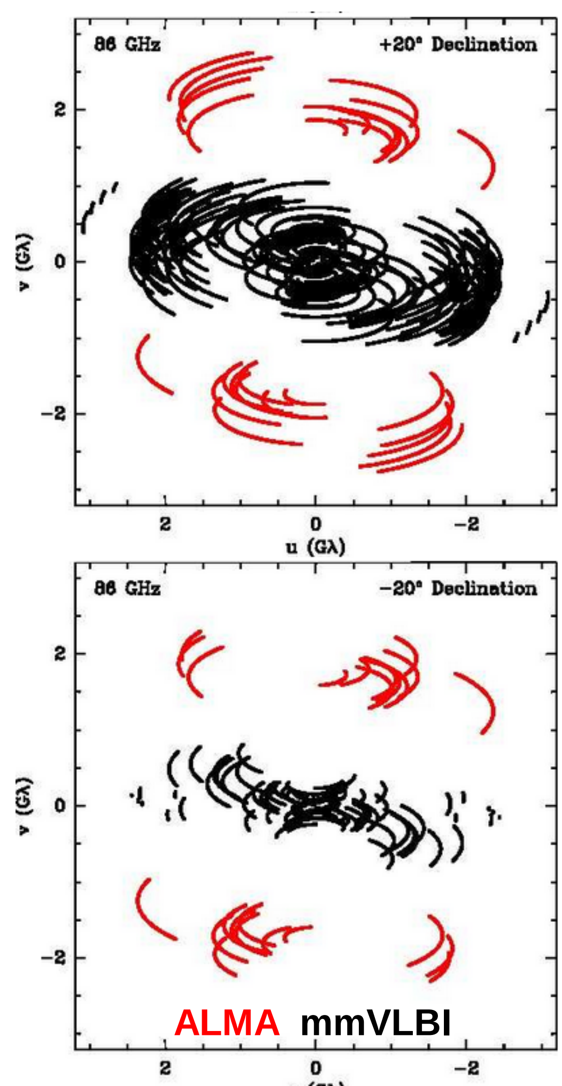
Higher and higher resolutions can be obtained with longer baselines. **VLBI is a worldwide network of telescopes that matches simultaneous observations in different sites, exploiting the phase information to construct a world-wide interferometer.**
**At 1 mm and a baseline of 9000 km offers resolution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

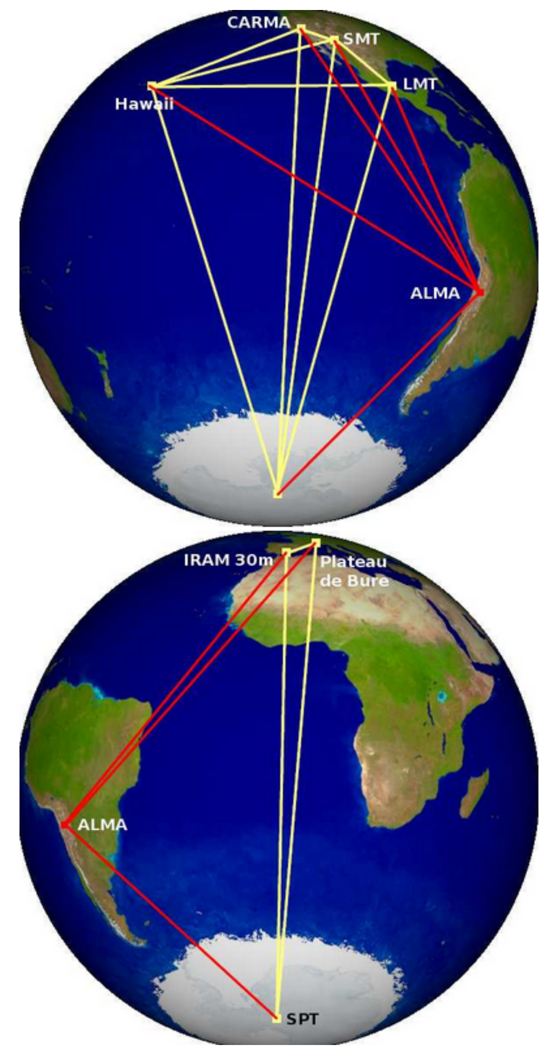
ALMA will be operating in the mm-VLBI since 2017 adding a strength in sensitivity. **Only sources with flux densities >100 mJy have been observable so far; ALMA will reduce it by more than an order of magnitude.**

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



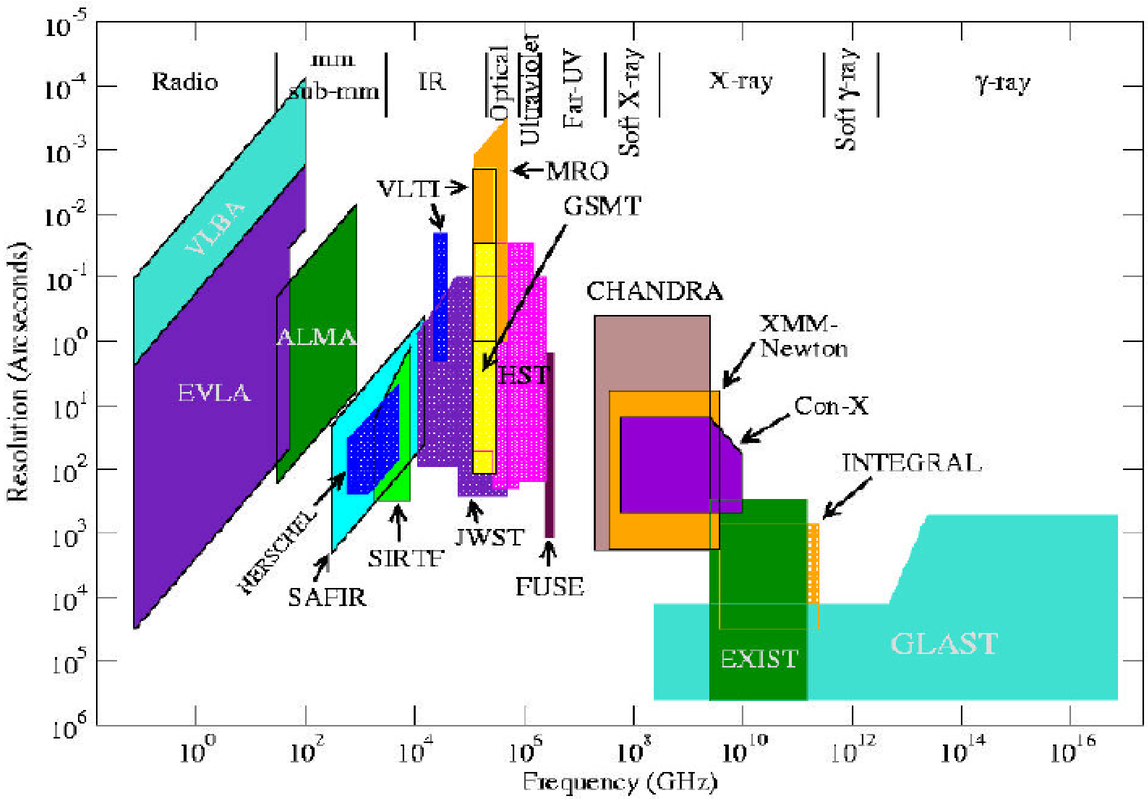
# ALMA sensitivity

**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**

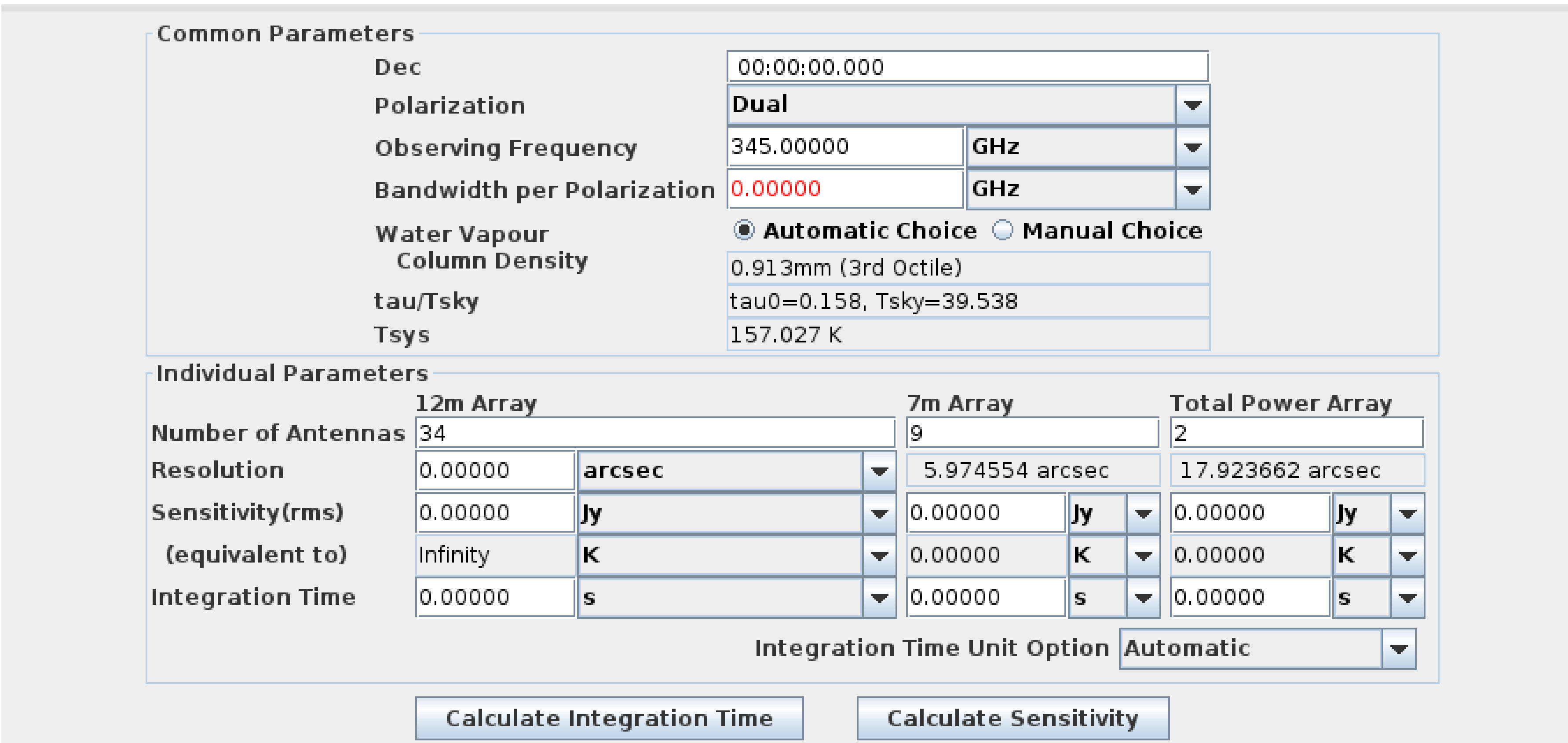
$$\Delta S_\nu = 2\,k\,\frac{T_{\rm sys}}{A_{\rm e}\sqrt{2t\,\Delta\nu}}$$

**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**

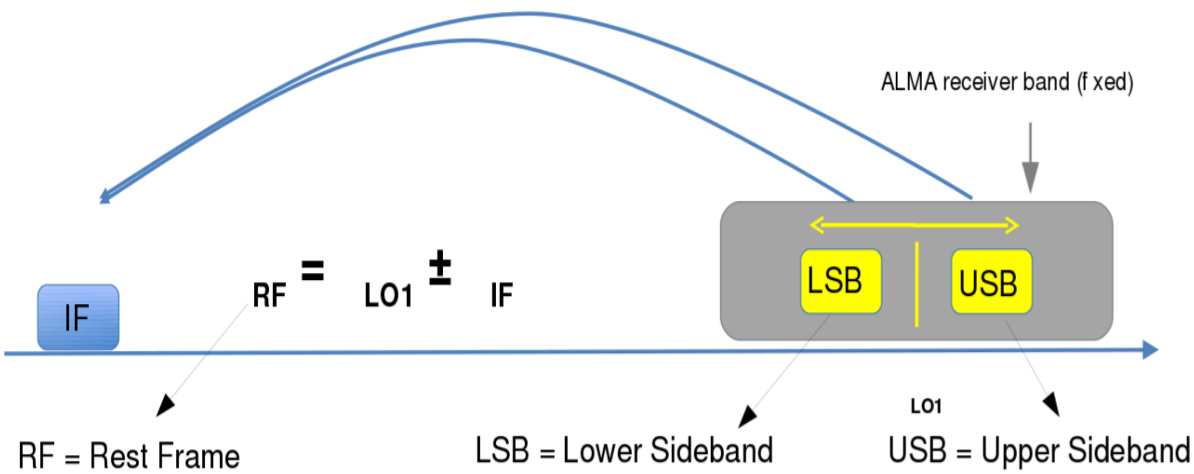


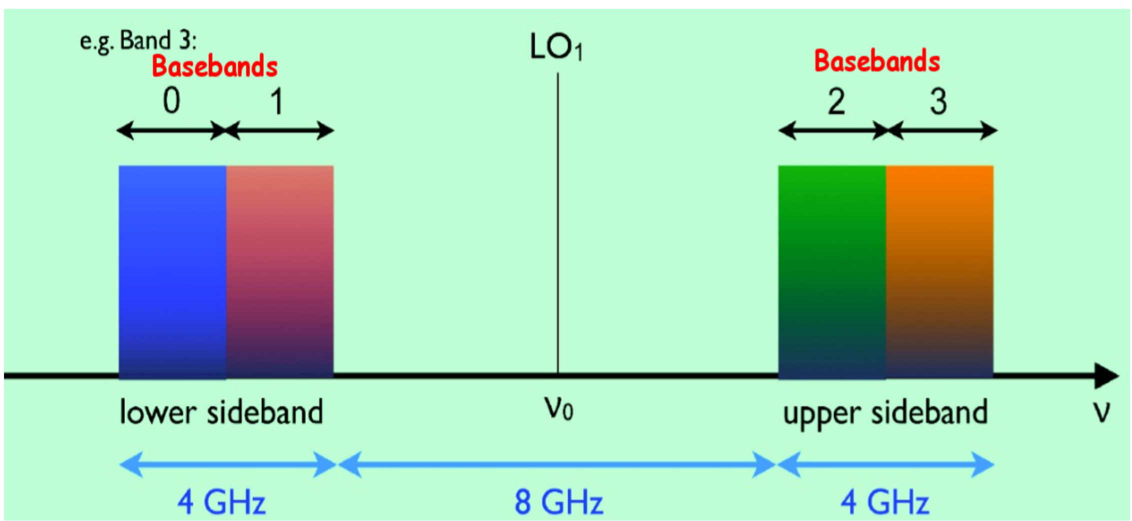
# The Science Goal: Sensitivity Calculator

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



# ALMA spectral properties



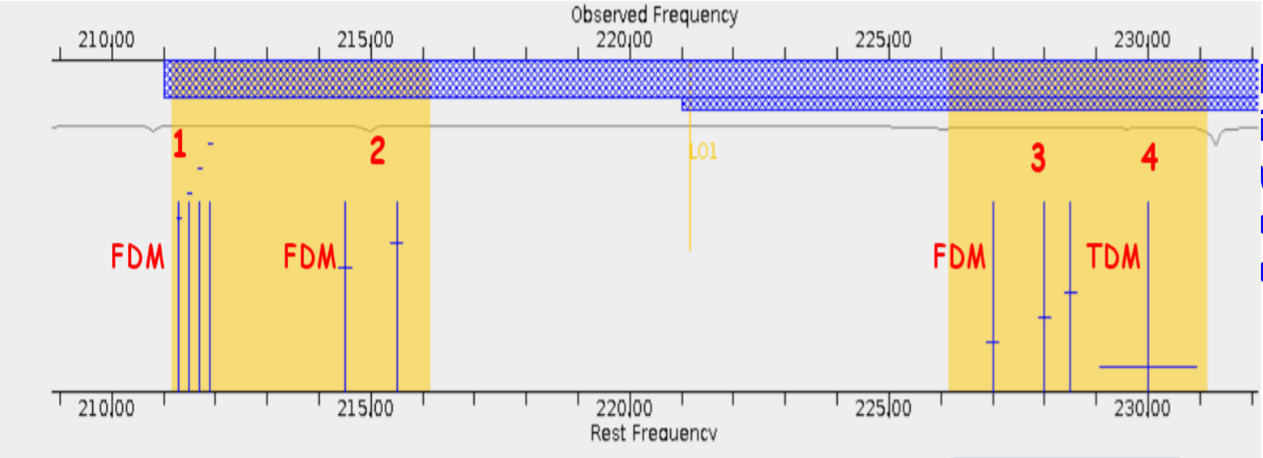




The coherent receivers map two freq regions to an Intermediate Frequency by mixing the signal with a Local Oscillator.

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)

## Quick Picker

- [x] CO $v = 0$
- [ ] $^{13}CO$ $v = 0$
- [ ] $C^{17}O$
- [ ] $C^{18}O$
- [ ] $CH_3OH$ $v_t = 0$
- [ ] $H_2CO$
- [ ] HCN $v = 0$
- [x] HNC $v = 0$
- [ ] $H^{13}CN$ $v = 0$
- [ ] $HC^{15}N$ $v = 0$
- [ ] DCN $v = 0$
- [x] $HCO^+$ $v = 0$
- [ ] CS
- [ ] $H^{13}CO^+$
- [ ] $NH_3$
- [ ] C I
- [x] C II
- [ ] O I
- [ ] O III
- [ ] N II
- [ ] $H_2O$ $v = 0$
- [ ] HDO
- [ ] SiO $v = 0$

# splatalogue

database for astronomical spectroscopy

Search:

Telescope Bands: Any / ALMA Band 3 (84-116 GHz) / ALMA Band 4 (125-163 GHz)

Redshift:

Energy Range: Min Max (•) $E_L$ ($cm^{-1}$) ( ) $E_L$ (K)

Frequency Range: Frequency Unit: GHz

Min 84 Max 750

+ Frequency - Frequency

Search

## Astronomical Filters

(Double click to unselect)

- Top 20 list
- Planetary Atmosphere
- Hot Cores
- Dark Clouds
- Diffuse Clouds
- Comets
- AGB/PPN/PN
- Extragalactic

Scan to Mobile Splat

Found 22 lines from 84 - 750 GHz, showing 1 - 22

Click on the chemical formula below for more information about that species.

| | Species | Chemical Name | Ordered Freq (GHz) (rest frame, redshifted) | Resolved QNs | CDMS/JPL Intensity | Lovas/AST Intensity | $E_L$ ($cm^{-1}$) | $E_L$ (K) | Linelist |
|---|---|---|---|---|---|---|---|---|---|
| 1 | $HCO^+$ v=0 | Formylium | 89.18853, 89.18853 | 1 - 0 | 0.00000 | 10.8 | 0.0000 | 0.0000 | SLAIM |
| 2 | HNC v=0 | Hydrogen Isocyanide | 90.66356, 90.66356 | J= 1 - 0 | 0.00000 | 1.6 | 0.0000 | 0.0000 | SLAIM |
| 3 | CO v = 0 | Carbon Monoxide | 115.27120, 115.27120 | 1- 0 | 0.00000 | 60.0 | 0.0000 | 0.0000 | SLAIM |
| 4 | $HCO^+$ v=0 | Formylium | 178.37507, 178.37507 | 2 - 1 | 0.00000 | | 2.9750 | 4.2803 | SLAIM |
| 5 | HNC v=0 | Hydrogen Isocyanide | 181.32473, 181.32473 | J= 2 - 1 | 0.00000 | | 3.0240 | 4.3508 | SLAIM |
| 6 | CO v = 0 | Carbon Monoxide | 230.53800, 230.53800 | 2- 1 | 0.00000 | 70. | 3.8450 | 5.5321 | SLAIM |
| 7 | $HCO^+$ v=0 | Formylium | 267.55763, 267.55763 | 3 - 2 | 0.00000 | 12. | 8.9250 | 12.8410 | SLAIM |
| 8 | HNC v=0 | Hydrogen Isocyanide | 271.98111, 271.98111 | J= 3 - 2 | 0.00000 | 10. | 9.0730 | 13.0539 | SLAIM |
| 9 | CO v = 0 | Carbon Monoxide | 345.79599, 345.79599 | 3- 2 | 0.00000 | 70.00 | 11.5350 | 16.5962 | SLAIM |
| 10 | $HCO^+$ v=0 | Formylium | 356.73424, 356.73424 | 4 - 3 | 0.00000 | 17.40 | 17.8500 | 25.6820 | SLAIM |
| 11 | HNC v=0 | Hydrogen Isocyanide | 362.63030, 362.63030 | J= 4 - 3 | 0.00000 | 3.0 | 18.1450 | 26.1065 | SLAIM |
| 12 | $HCO^+$ v=0 | Formylium | 445.90291, 445.90291 | 5 - 4 | 0.00000 | | 29.7490 | 42.8019 | SLAIM |
| 13 | HNC v=0 | Hydrogen Isocyanide | 453.26991, 453.26991 | J= 5 - 4 | 0.00000 | | 30.2410 | 43.5098 | SLAIM |
| 14 | CO v = 0 | Carbon Monoxide | 461.04077, 461.04077 | 4- 3 | 0.00000 | 60. | 23.0690 | 33.1910 | SLAIM |
| 15 | $HCO^+$ v=0 | Formylium | 535.06164, 535.06164 | 6 - 5 | 0.00000 | | 44.6230 | 64.2022 | SLAIM |
| 16 | HNC v=0 | Hydrogen Isocyanide | 543.89755, 543.89755 | J= 6 - 5 | 0.00000 | | 45.3600 | 65.2625 | SLAIM |
| 17 | CO v = 0 | Carbon Monoxide | 576.26793, 576.26793 | 5- 4 | 0.00000 | | 38.4480 | 55.3178 | SLAIM |
| 18 | $HCO^+$ v=0 | Formylium | 624.20846, 624.20846 | 7 - 6 | 0.00000 | 14.3 | 62.4710 | 89.8813 | SLAIM |
| 19 | HNC v=0 | Hydrogen Isocyanide | 634.51082, 634.51082 | J= 7 - 6 | 0.00000 | 14.8 | 63.5030 | 91.3661 | SLAIM |
| 20 | CO v = 0 | Carbon Monoxide | 691.47308, 691.47308 | 6- 5 | 0.00000 | 100. | 57.6700 | 82.9738 | SLAIM |
| 21 | $HCO^+$ v=0 | Formylium | 713.34137, 713.34137 | 8 - 7 | 0.00000 | 24.7 | 83.2920 | 119.8379 | SLAIM |
| 22 | HNC v=0 | Hydrogen Isocyanide | 725.10732, 725.10732 | J= 8 - 7 | 0.00000 | | 84.6680 | 121.8177 | SLAIM |

# ALMA status

## ALMA Current status:

All the antennas have completed Assembly, Integration and Verification at the OSF at 3,000m and almost all have been transported to the AOS at 5,000m

## ALMA Early Science:

allows community to observe with incomplete, but already superior array, on best effort basis:

- Cycle 0: Sep. 2011 – Jan. 2013
- Cycle 1: Jan. 2013 – May. 2014
- **Cycle 2 call for proposals: 24 October 2013, Deadline: 5 December 2013**

| | Cycle 0<br>Sep. 2011 – Jan. 2013 | Cycle 1<br>Jan. 2013 – May. 2014 | Cycle 2<br>Jun. 2014 – Oct.2015 |
|---|---|---|---|
| **Telescope** | | | |
| Hours dedicated to Science | **800** | **800** | **2000** (incl. some Cycle 1) |
| Antennas | **> 12x12-m no ACA** | **> 32x12-m+9x7m+2TP** | **> 34x12-m+9x7m+2TP** |
| Receiver bands | 3, 6, 7, 9 | 3, 6, 7, 9 | **+4, 8** |
| 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 1500** |
| Polarisation | single-dual | single dual | **+full (with limitations)** |

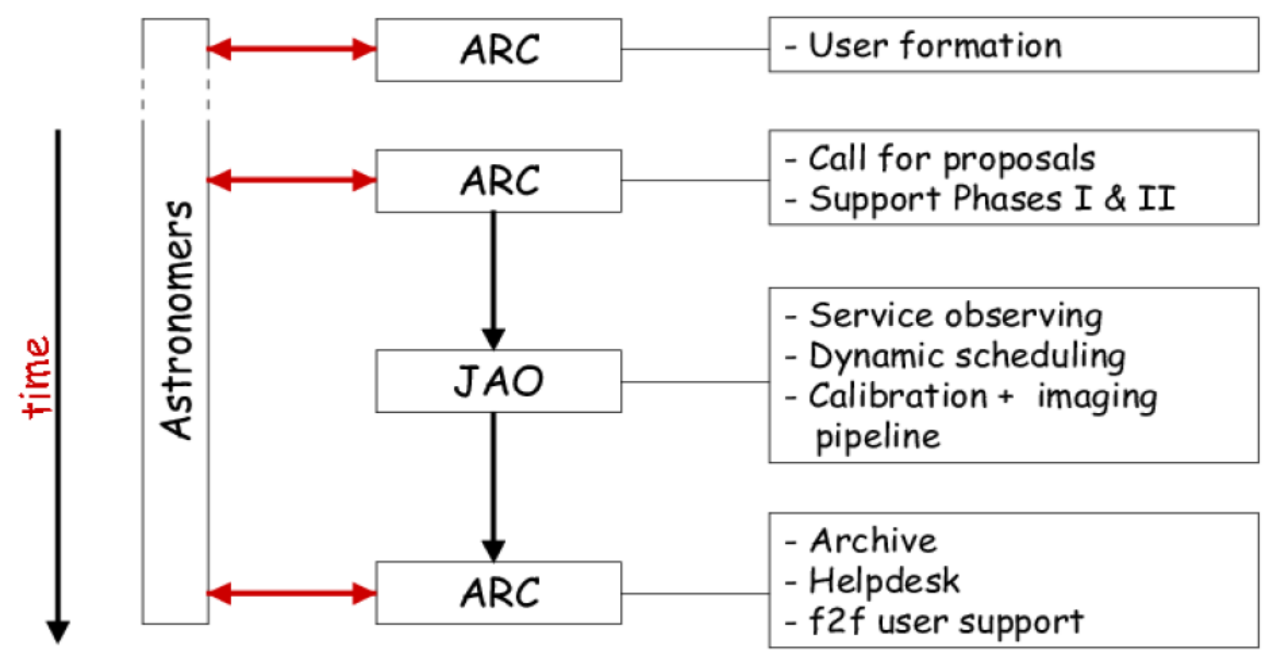
## Cycle 0:

- 111 Highest-priority + 51 filler proposals (out of 919 submissions)
- 108 (98%) Highest-priority PIs received some data

# A proposal checklist

**Have a good idea!**

| | |
|---|---|
| **Estimate required configuration** | **(CASA, Splatalogue, OST, OT)** |
| **Write the proposal idea in pdf docs** | (max 5 page) |
| | |
| **Register to the Science Portal** | **(SP)** |
| | |
| **PHASE I – Proposal submission** | **(OT, SP, Helpdesk)** |
| **TAC evaluation** | |
| **PHASE II – Observing program submission for accepted proposals** | **(OT, SP, Helpdesk)** |
| | |
| **Observations** | |
| **Data reduction and analysis** | **(CASA)** |



# Phase II and ALMA observarions

Investigators will be notified of the result of the ALMA Proposal Review process via email and successful investigators will be invited to submit a detailed observing plan.
**The ALMA Observing Tool (OT) is used to prepare individual Scheduling Blocks**

**Dynamic schedule**: the best SBs at any moment will be observed (science, weather, project...)

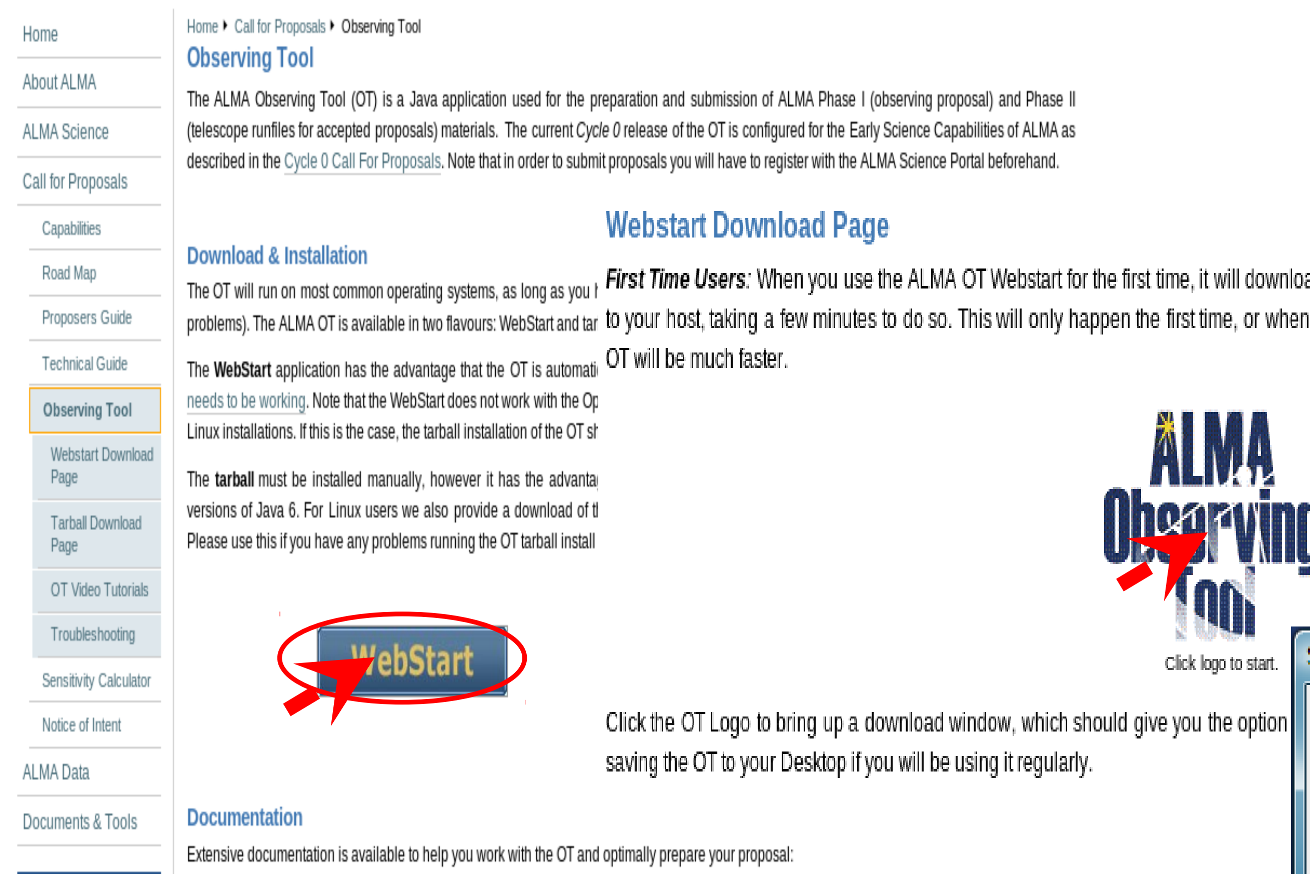
These will be used by the ALMA Scheduling Software to ensure that the observations are carried out under the required weather conditions.
The ALMA Regional Centers (ARC) will provide support to investigators in the Phase II process.

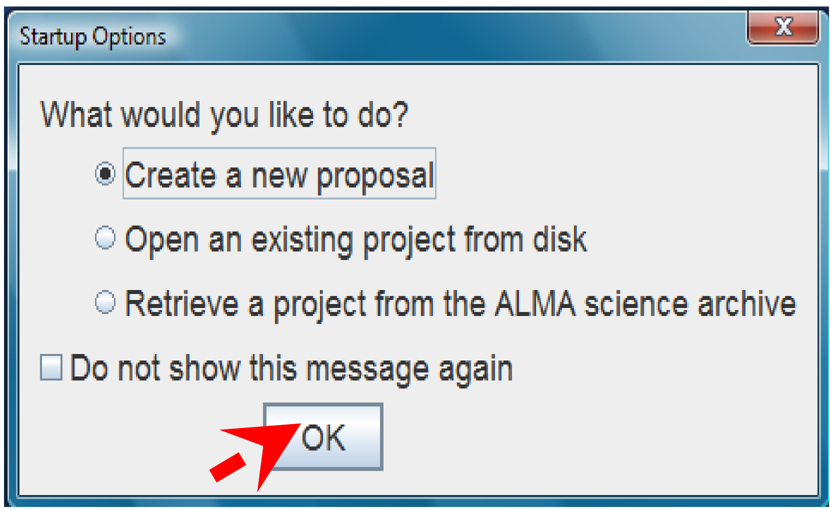
Once the Phase II preparation is finished the Scheduling Blocks will be submitted to the ALMA site and scheduled according to rank and requested observing conditions.
Investigators will be able to track the status of their project with the **ALMA Project Tracker.**

**Once observations are completed and pass the quality controls the Principal Investigator receives a link to his/her data including a minimal data reduction.**

**The CASA (Common Astronomy Software Applications) is the standard tool for ALMA data reduction.**

# The ALMA Observing Tool

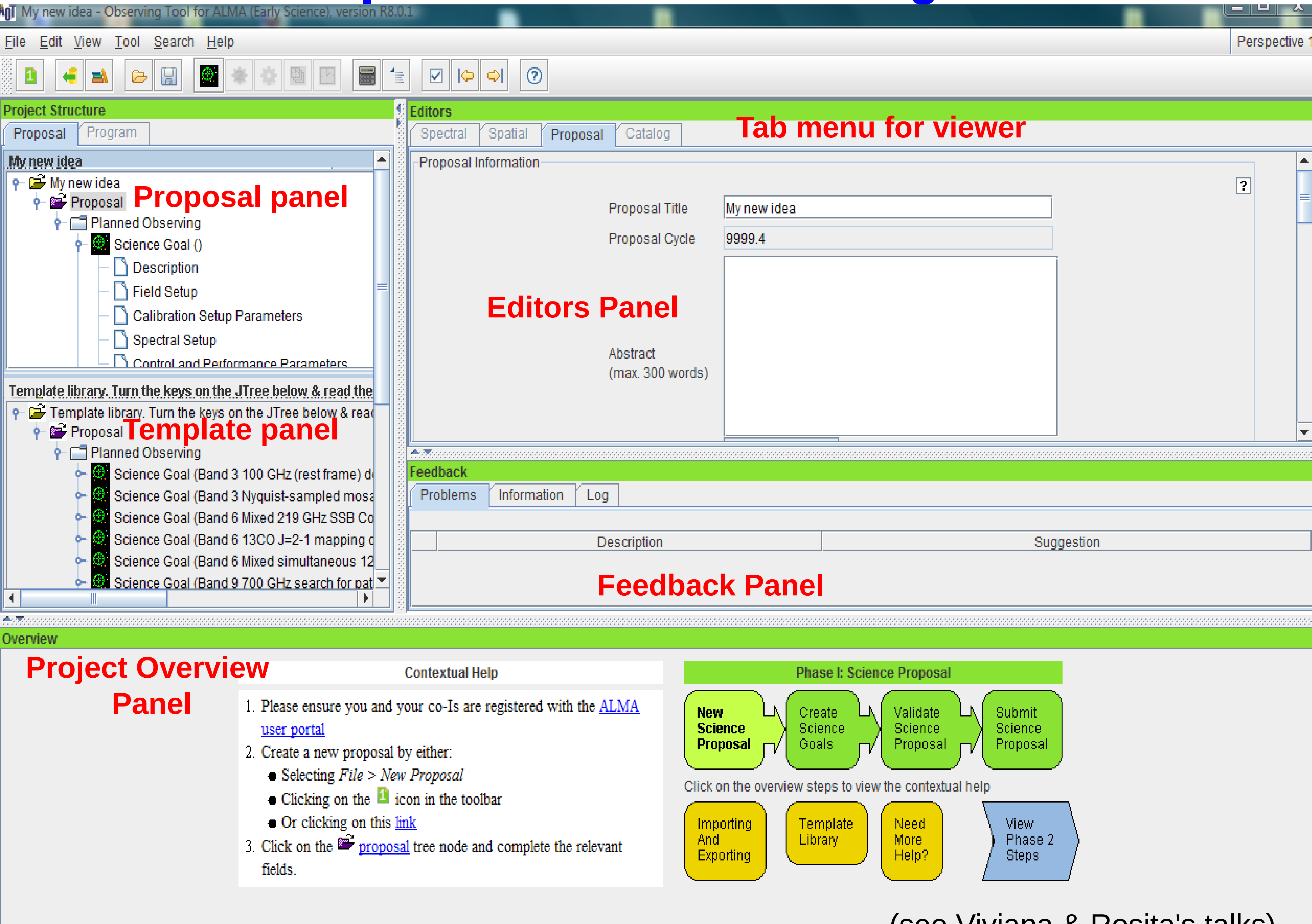



**OT is a java-based client program**,
runs on Linux (various distr.),
MacOS (10.5-10.6), Windows (>XP).

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)

# 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.**

## 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)

WAA

RS
RV
VLM
SMBH
AGN
FIR

FRII
ULIRG
ERO
SMG

CDFS
PCCS
EMU
APEX
SCUBA
WTHDIM

# 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**

# Useful hints/contact details

ALMA primer for Early science:
www.almascience.eso.org/
->proposing

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