The Atacama Large Millimetre Array

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ALMA Data Handling Workshop
9-12 February 2016

ALMA

EUROPEAN ARC
ALMA Regional Centre || Italian

ALMA rationale

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, …

- 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 full array

The Atacama Large Millimeter Array is a **mm-submm reconfigurable interferometer**

Inaugurated in March 2013 on the Chajinantor plain (altitude=**5000m**, Chile)

- Antennas: **50x12m** main array + **12x7m** ACA **+ 4x12m** Total Power
- Baselines length: **15m ->150m-16km** + **9m->50m**
- Frequency range: **10 bands between 30-900 GHz** (0.3-10 mm)
- Bandwidth: **2 GHz x 4 basebands**
- Polarimetry: Full Stokes capability
- Velocity resolution: **As narrow as 0.008 × (Freq/300GHz) km/s**
  ~0.003 km/s @ 100 GHz, ~0.03 km/s @ 950 GHz

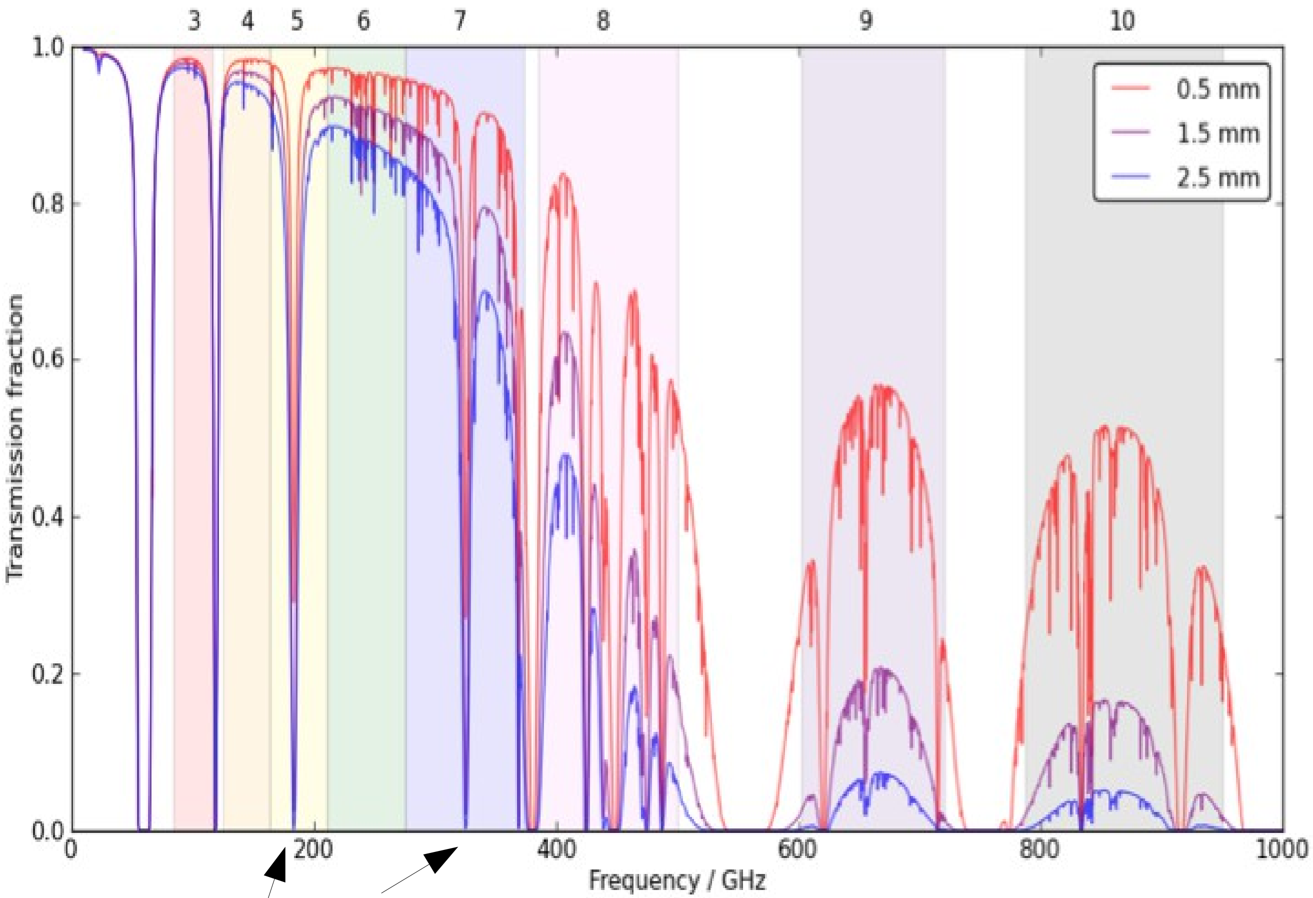
ALMA sites

- **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
  - Initial Quality Assessment

ALMA observing site & bands

Band	Frequency (GHz)	Wavelength (mm)
1	31.3-45	6.7-9.5
2	67-90	3.3-4.5
3	84-116	2.6-3.6
4	125-163	1.8-2.4
5	163-211	1.4-1.8
6	211-275	1.1-1.4
7	275-373	0.8-1.1
8	385-500	0.6-0.8
9	602-720	0.4-0.5
10	787-950	0.3-0.4

Chajinantor transmissivity chart at various PWV conditions

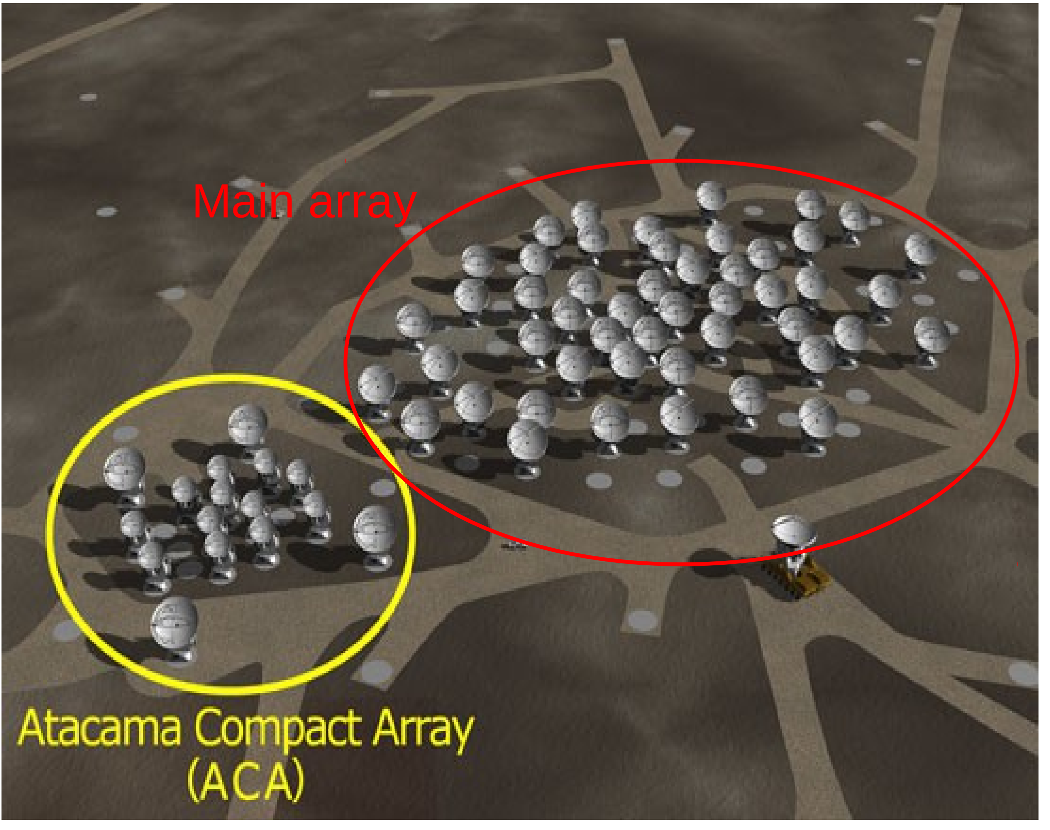


Atmospheric absorption lines.

Red=good weather
Blu=Bad weather

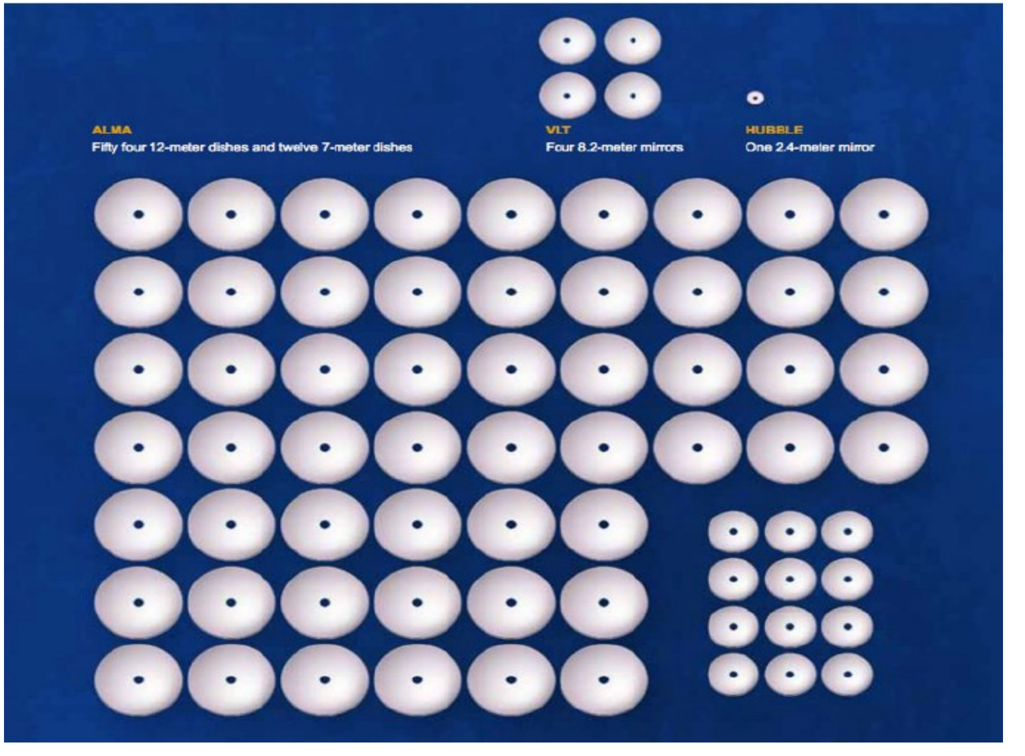
Dry site → lower Tsys and higher frequencies observable

ALMA array(s)



Main Array: 50x12m
Reconfigurable between
15m → 150m-16km

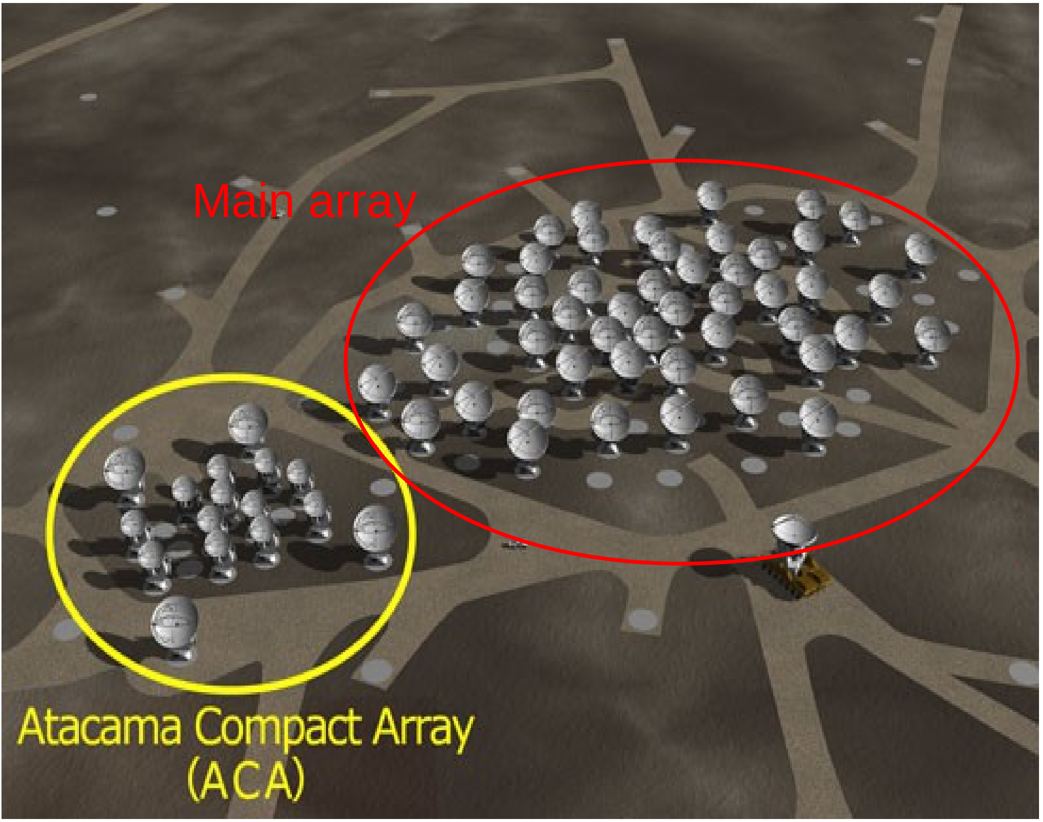
Atacama Compact Array:
12x7m between 9 → 50m
+4x12m single dish



$$\sigma_S = \frac{2\,k\,T_{sys}}{\eta_q \eta_c A_{eff} \sqrt{N(N-1)\,n_p\,\Delta\nu\,t_{int}}}$$

Large number of antennas → large collecting area → high sensitivity

ALMA array(s)



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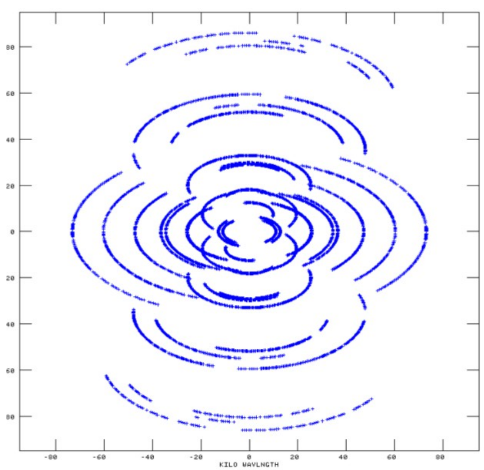
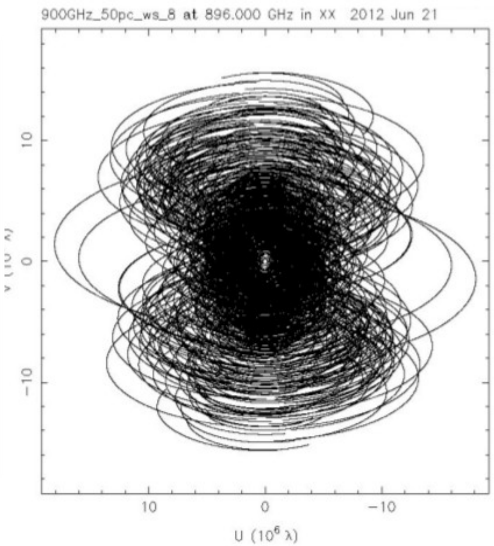


2 config OVRO

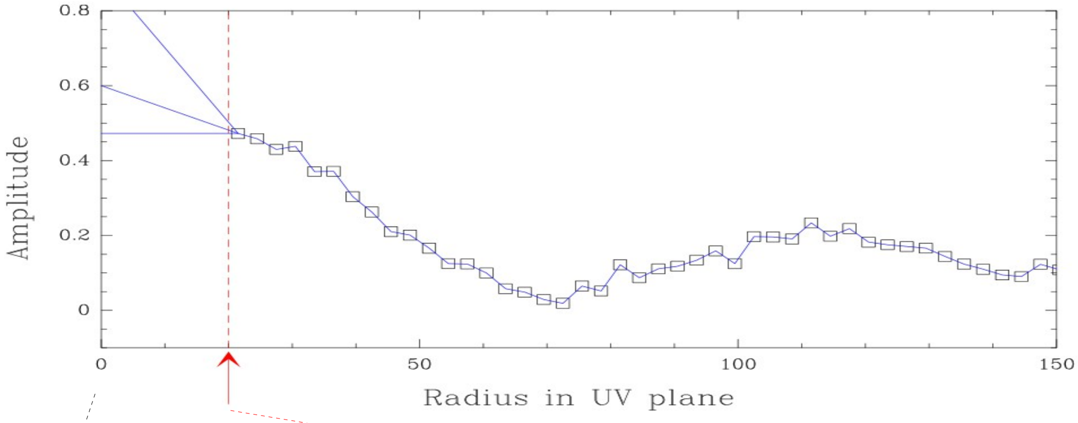


Same time 1 config ALMA

Large number of antennas → **large number of baselines**
→ **good istantaneous uv-plane coverage**
→ **good imaging in short time**

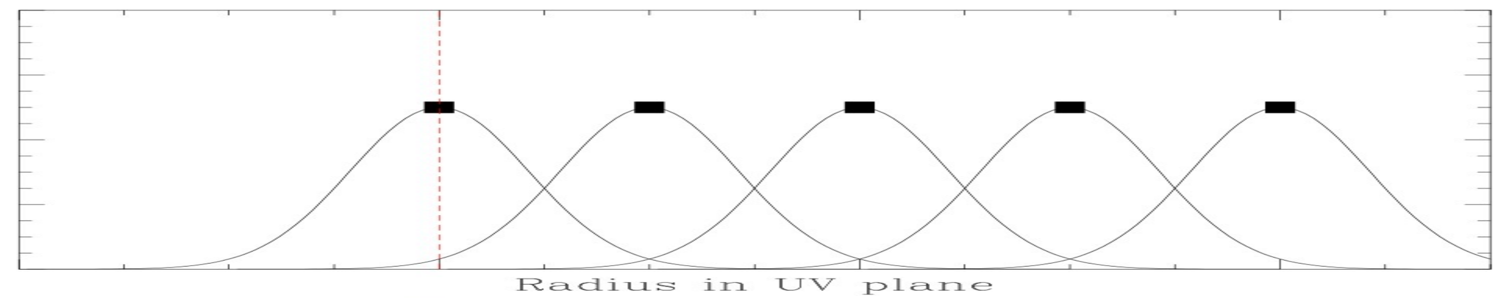
(See tutorial on UV plane)

ALMA arrays

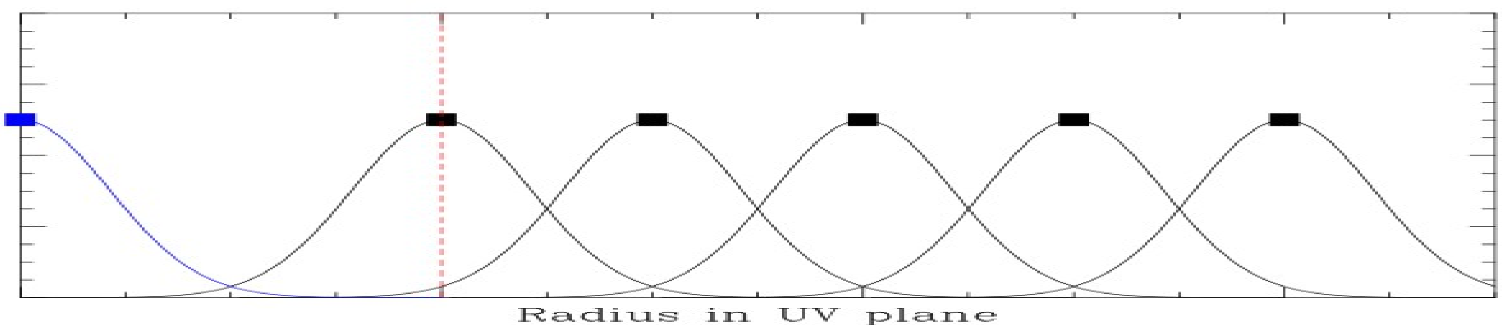


If we have an interferometer we can only "guess" what is over scales above the LAS (i.e. spacings shorter than the shortest baseline)

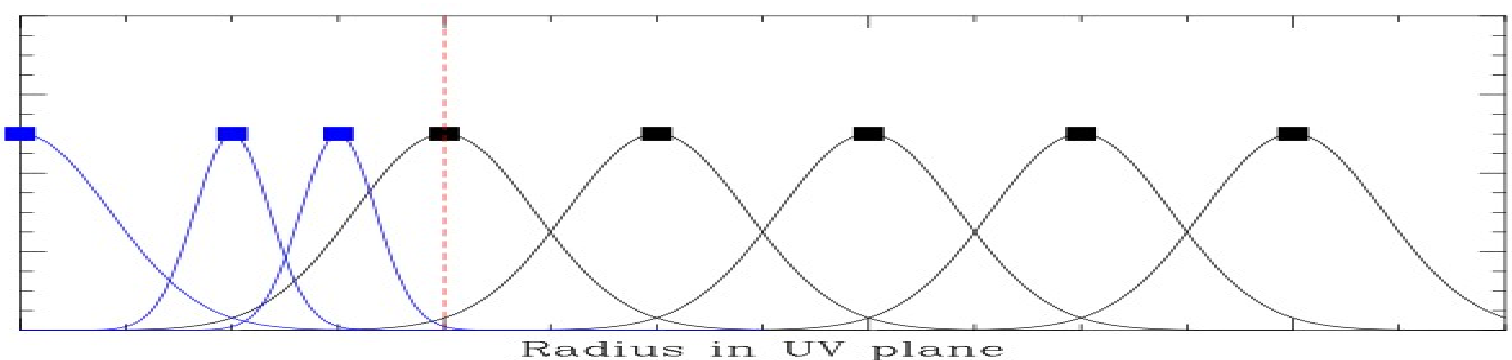
The best guess is done during imaging processes.



Extended interferometer with large antennas

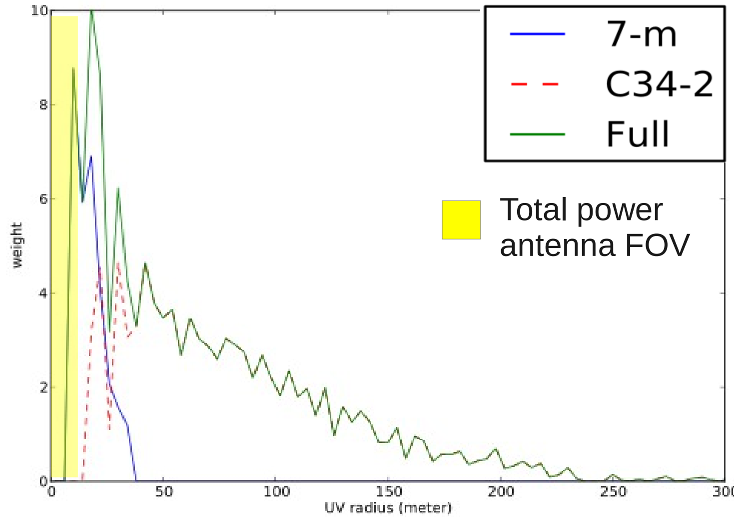


Adding single dish same size

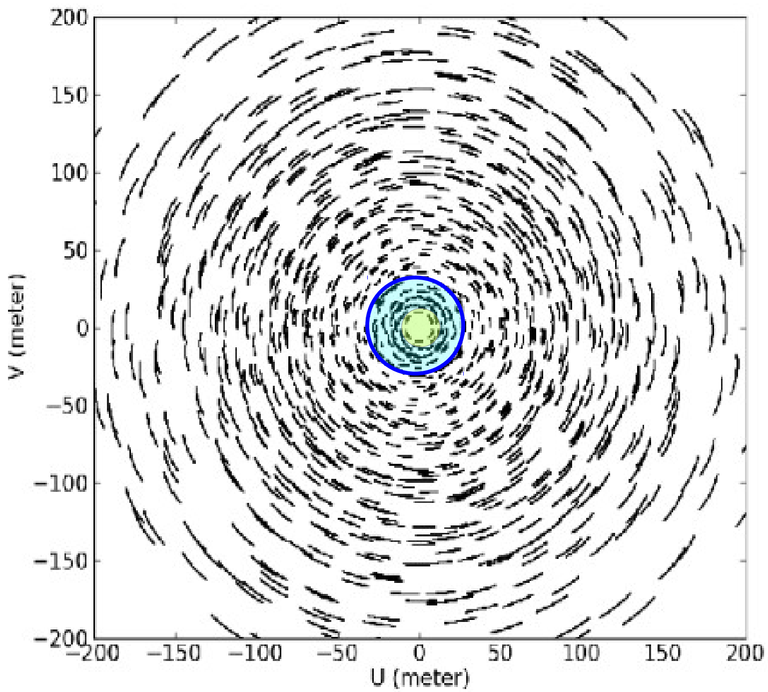


Adding compact interferometer with small antennas

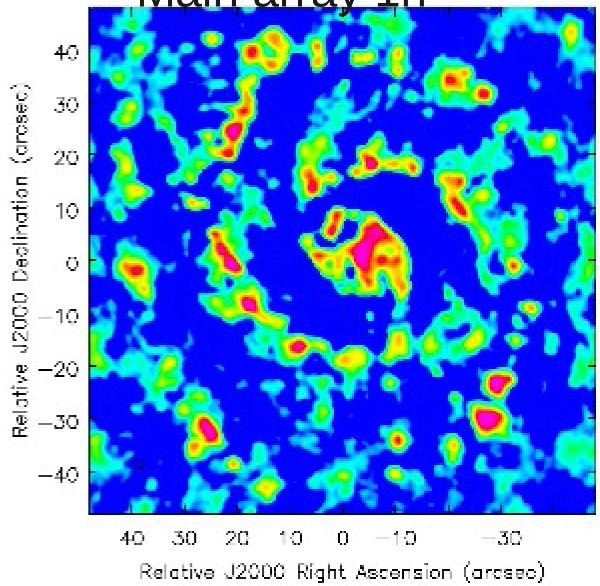
ALMA array(s)



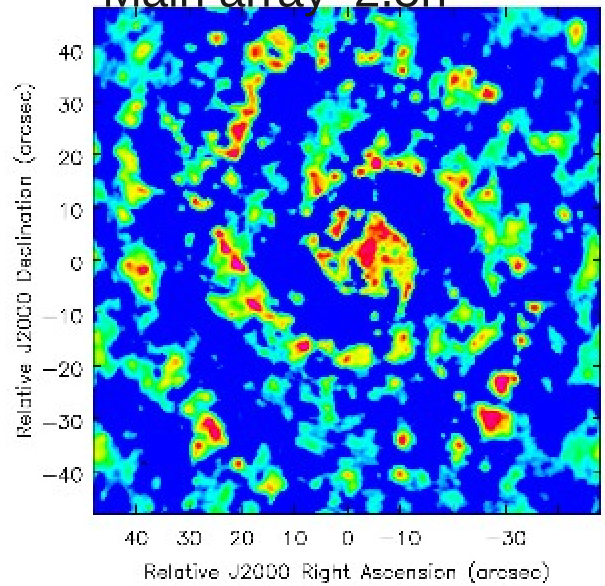
$(u^2+v^2)^{1/2}$

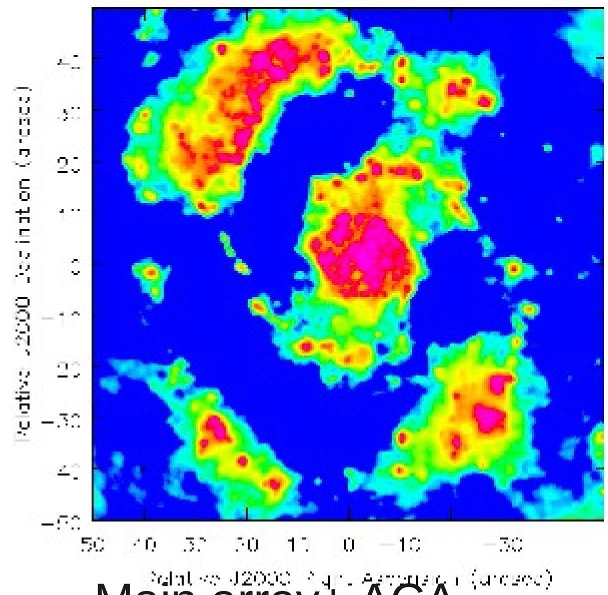


Main array 1h

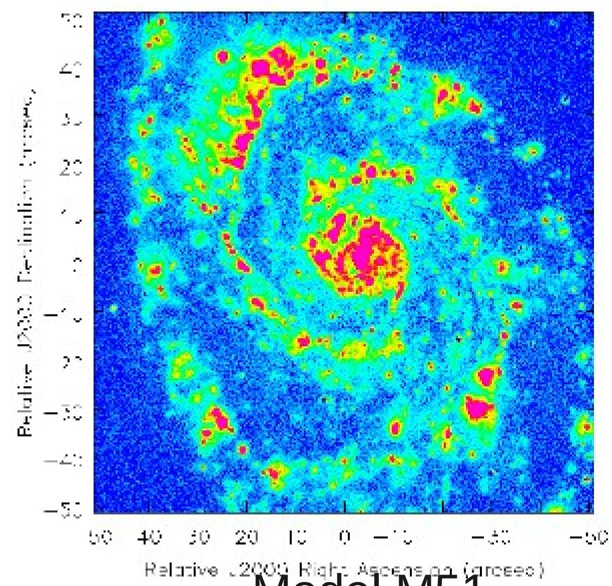


Main array 2.5h



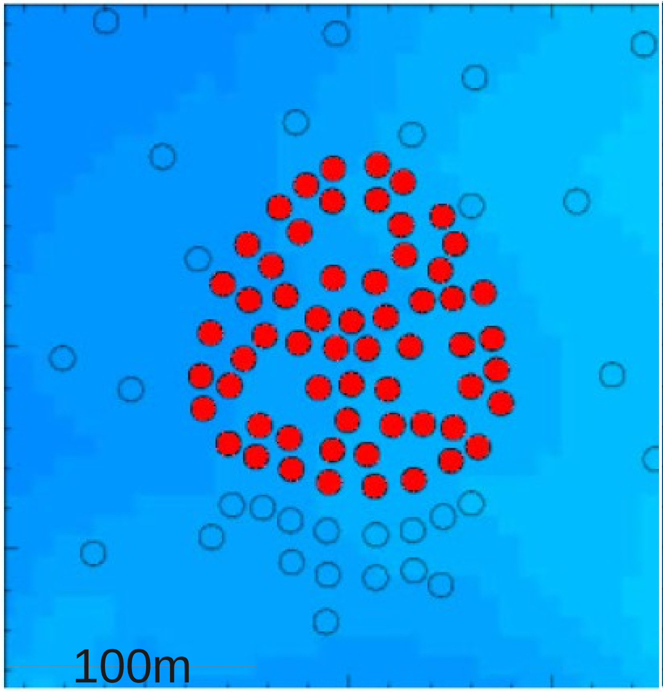


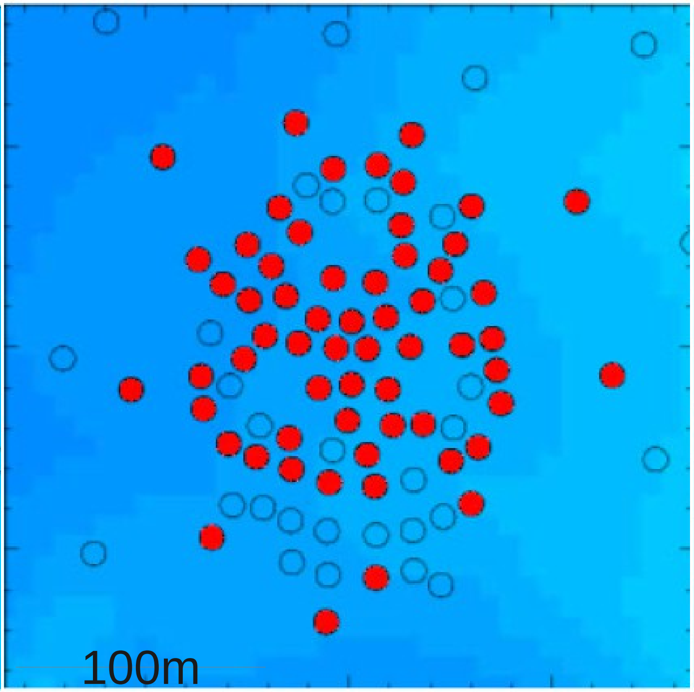
Main array+ ACA

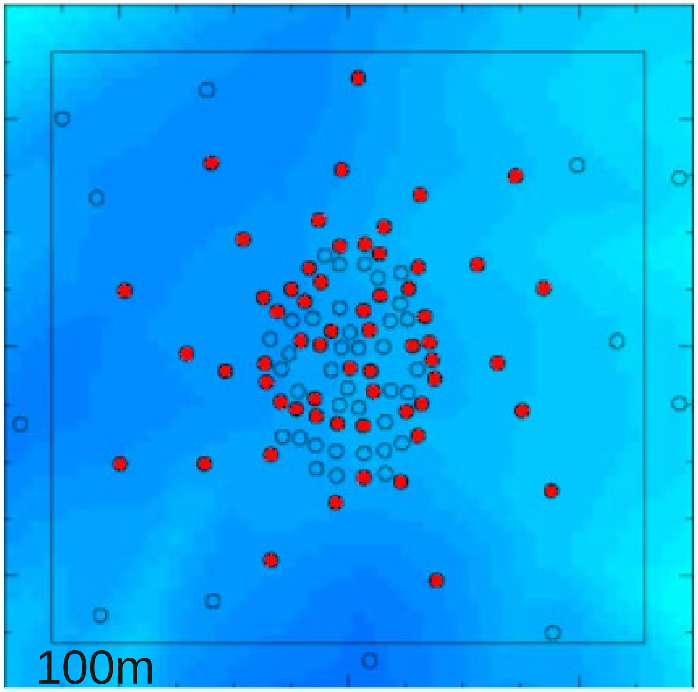


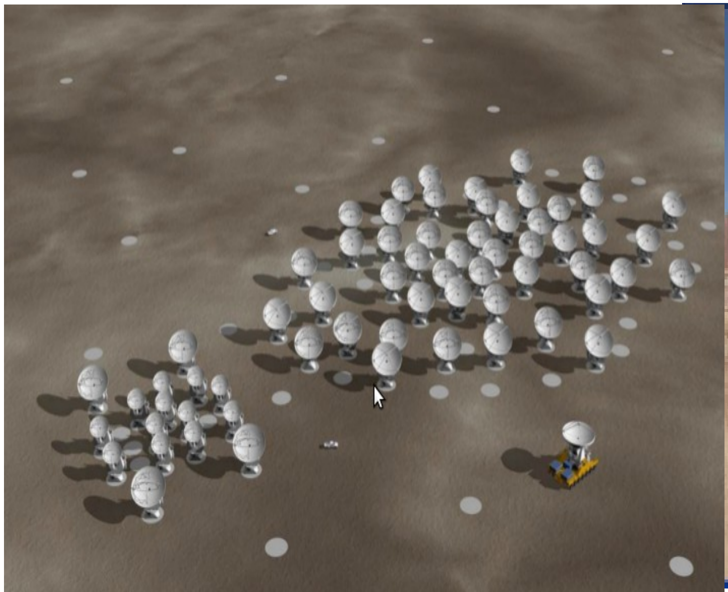
Model M51

ALMA main array reconfiguration

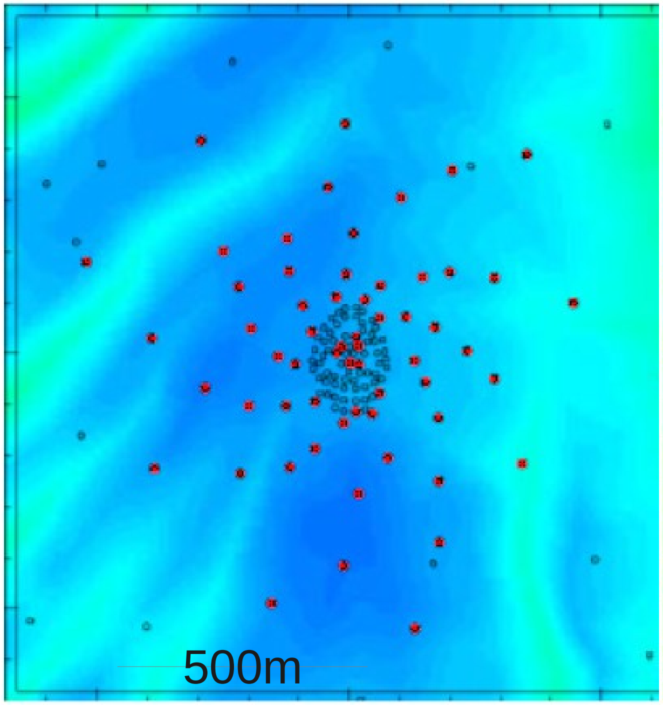


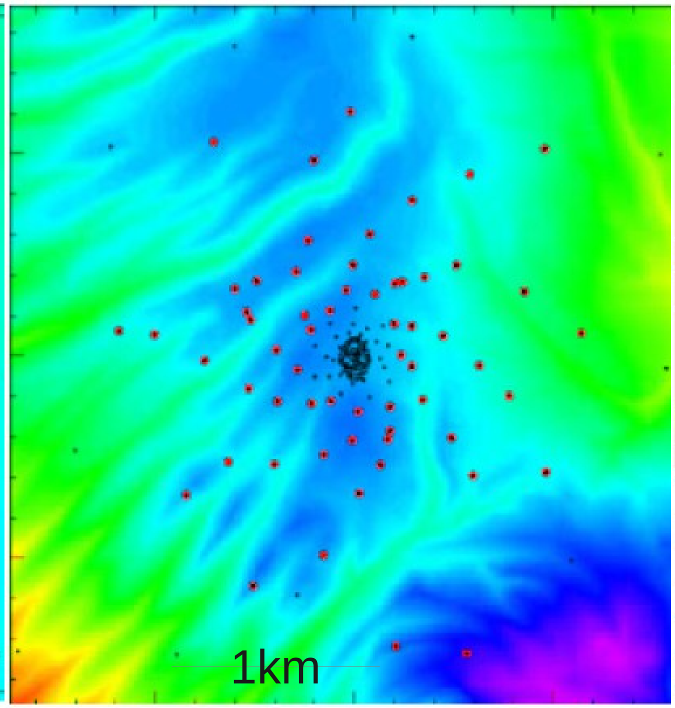


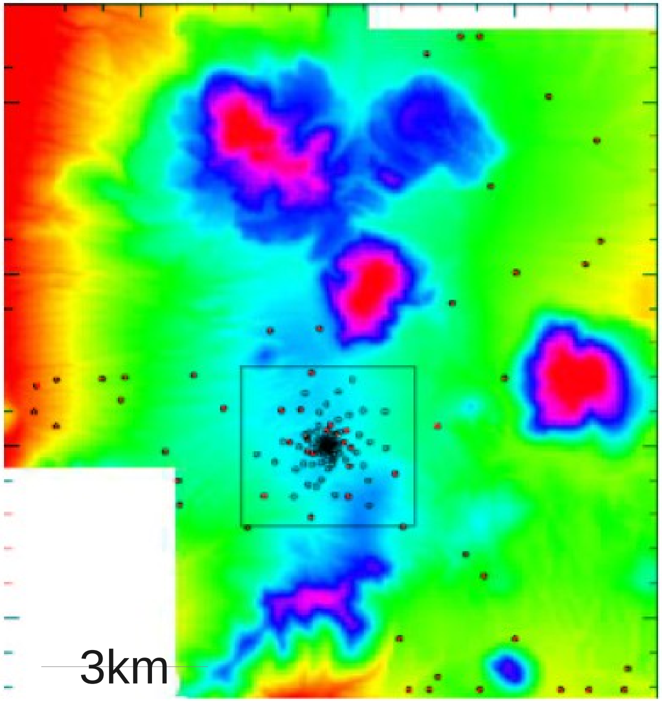


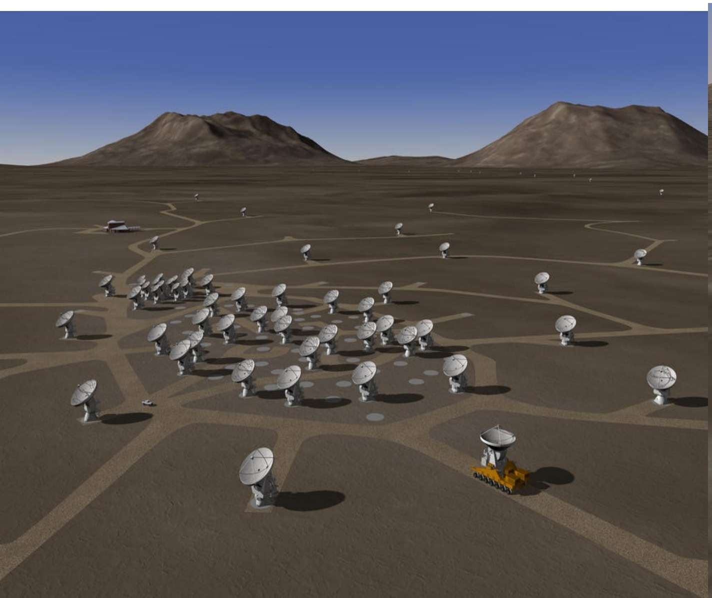


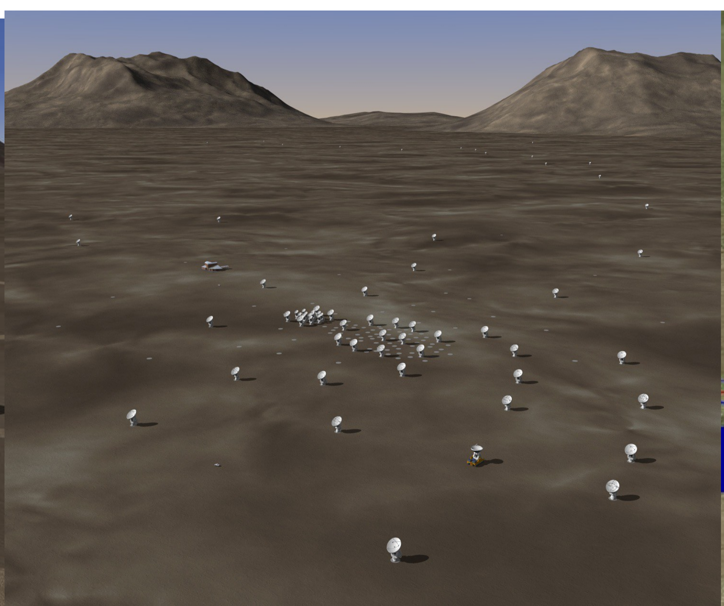
ALMA main array reconfiguration







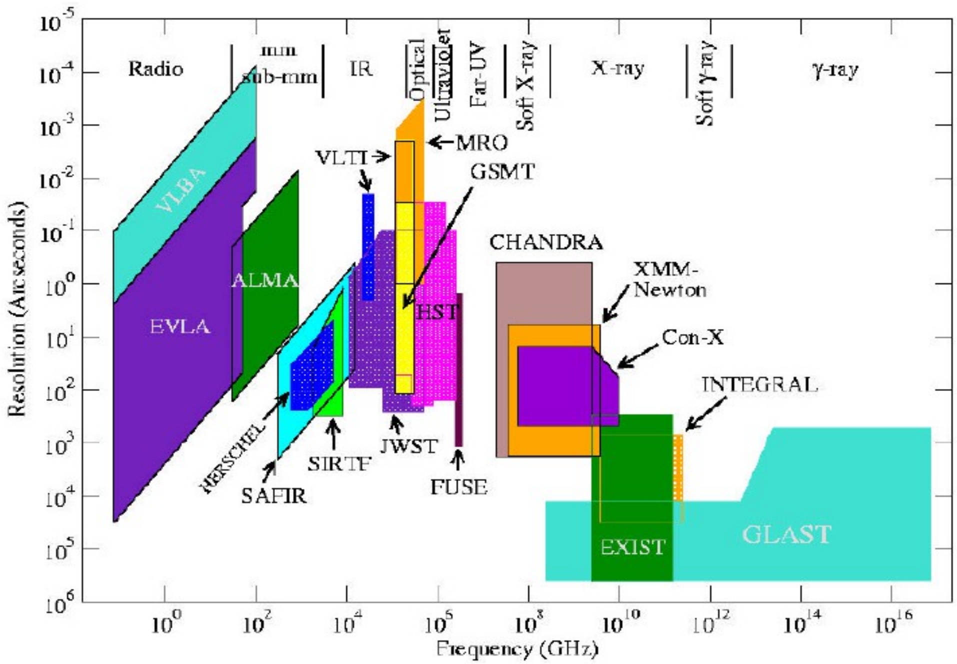




ALMA resolution & LAS

- **Baselines length: 15m → 150m-16km main array**
  9m → 50m ACA

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



- **Resolution:**
  0.2" x (300GHz / freq) x (1km / max_baseline)
- **Largest angular scale:**
  1.4" x (300GHz / freq) x (150m / min_baseline)
- **FOV 12m array: 17" / (300GHz / freq)**
- **FOV 7m array: 29" / (300 / freq)**

Maximum Recoverable Scale[1] and Coarsest and Finest Angular Resolutions[1] for the Cycle 3 12-m Array configurations

Frequency	Maximum Recoverable Scale without ACA[2,3]	Coarsest allowed angular resolution[2,3,4]	Finest achievable angular resolution[2,3,5]
(GHz)	(arcsec)	(arcsec)	(arcsec)
100	25.3	6.8	0.075
150	16.9	4.6	0.050
230	11.0	3.0	0.030
345	7.3	2.0	0.034
460	5.5	1.4	0.060
650	3.9	1.0	0.040
870	2.9	0.8	0.030

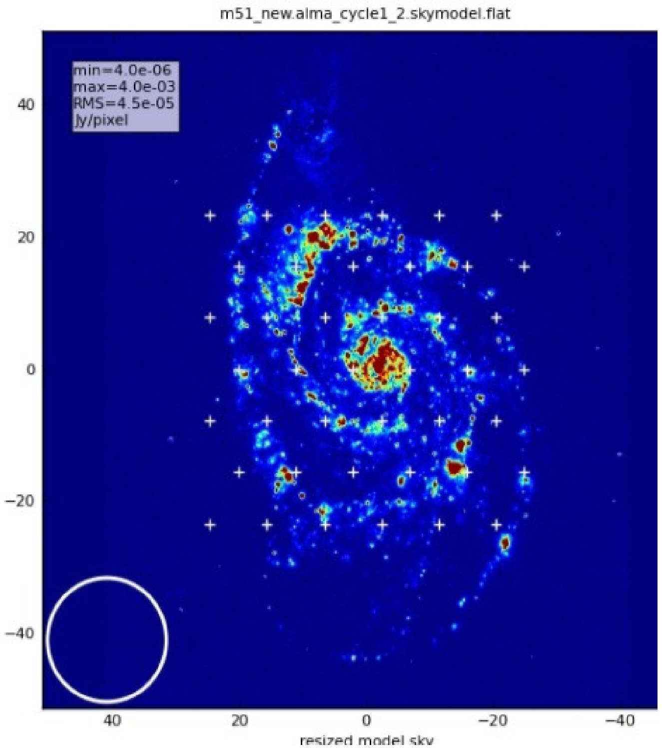
Maximum Recoverable Scales for ACA 7-m

Frequency (GHz)	Maximum Recoverable Scale[1,2] (arcsec)
100	42.8
150	28.5
230	18.6
345	12.4
460	9.3
650	6.6
870	4.9

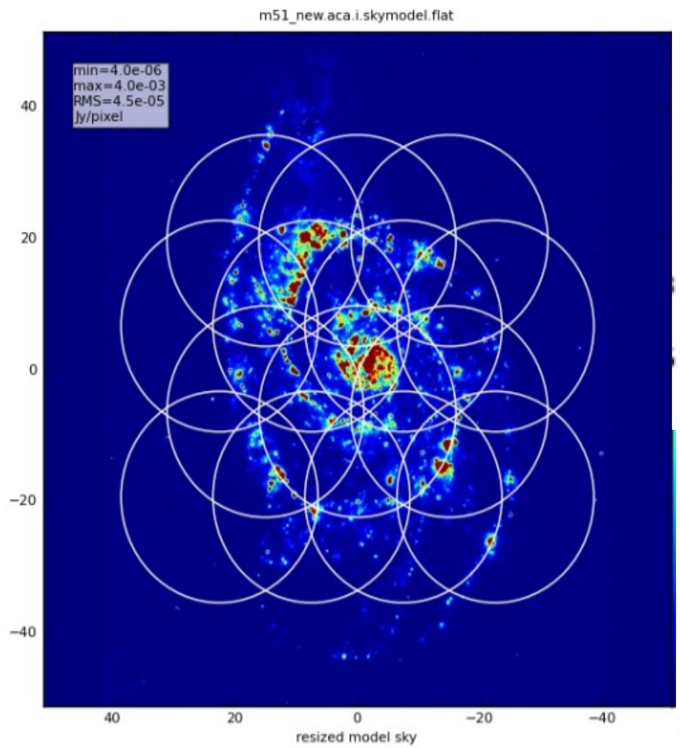
Mosaicking

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

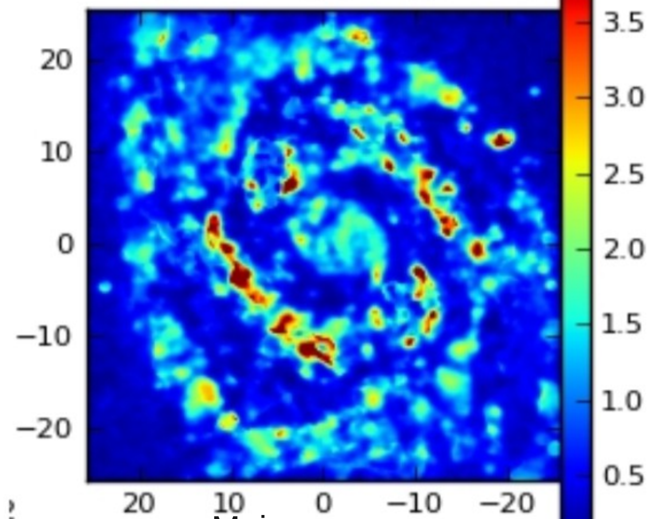
Details in the ranges available to the given baselines can be observed on larger region of the sky by mosaicking the region.



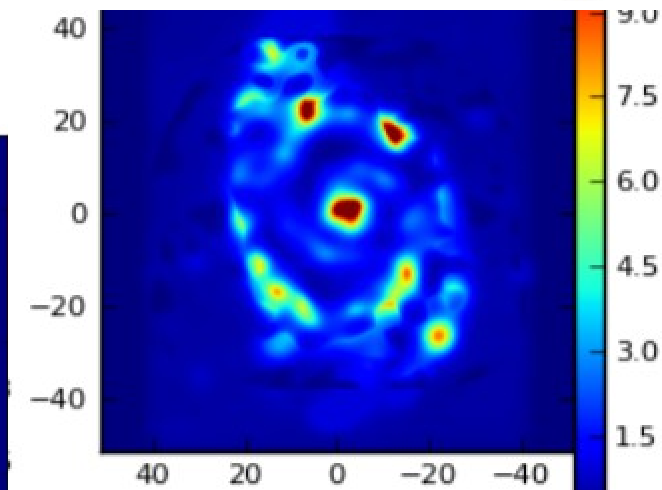
Model & 12m FOV



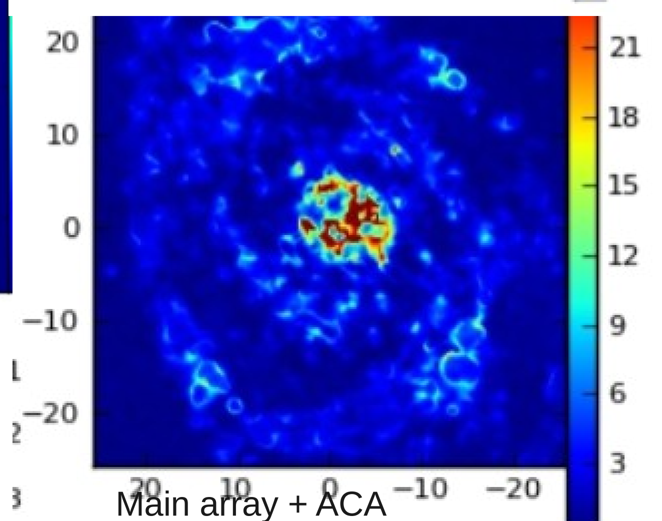
ACA Pointing map



Main array



ACA



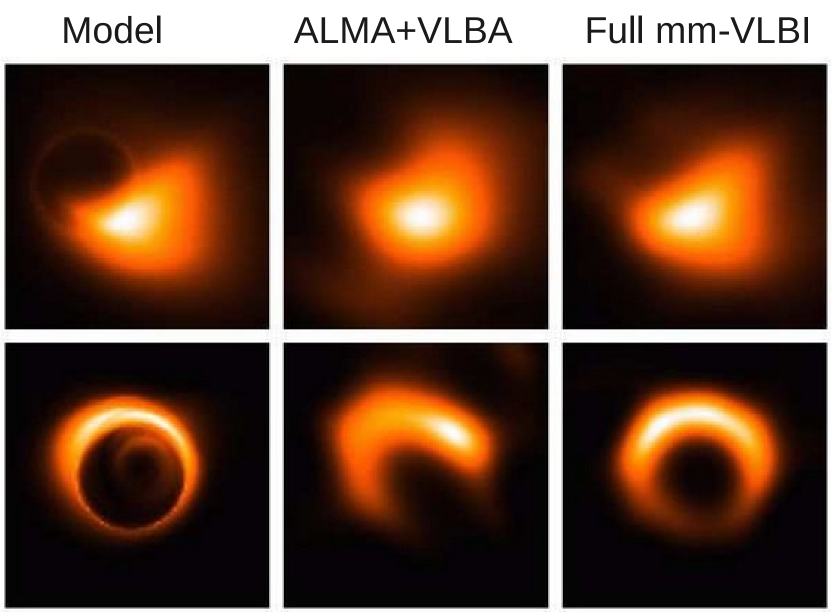
Main array + ACA

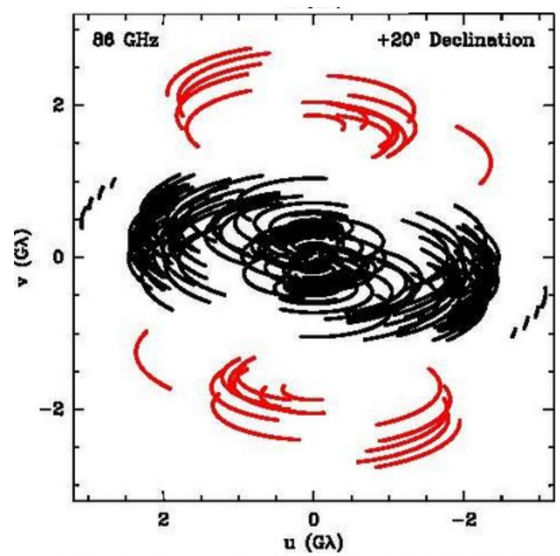
mm-VLBI with ALMA

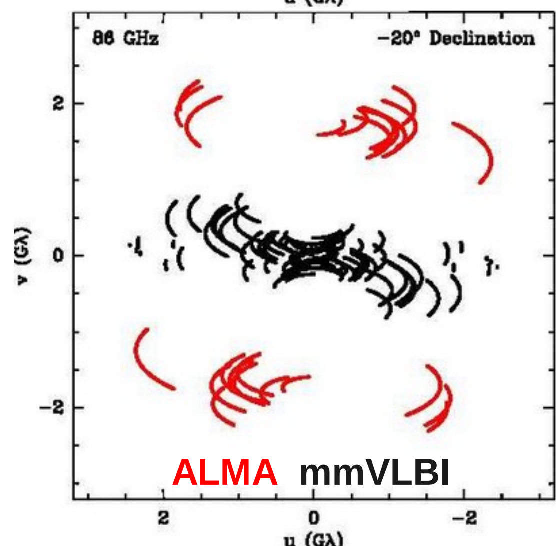
VLBI is a worldwide network of telescopes that matches simultaneous observations in different sites, exploiting the phase information to construct a world-wide interferometer.

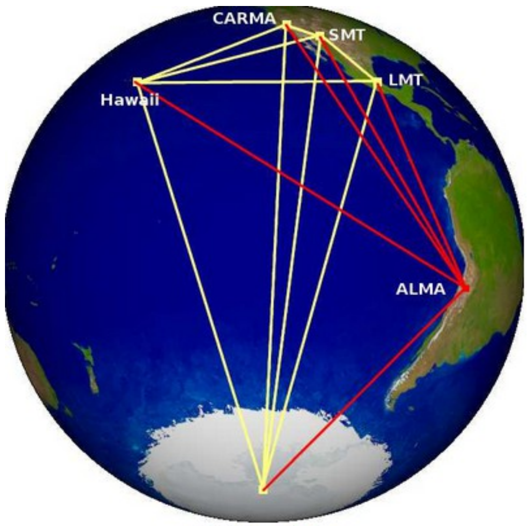
At 1 mm and a baseline of 9000 km offers resolution of about 20 microarcseconds
ALMA will increase the sensitivity by more than an order of magnitude

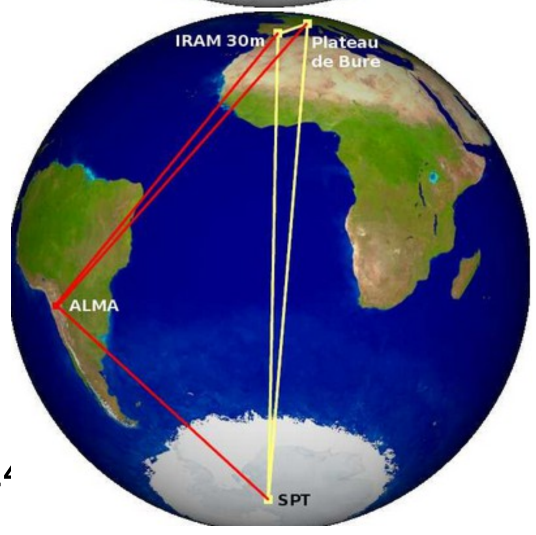
This capability will allow the shadow of the event horizon in the black hole at the Galactic Centre , the relativistic jet flows in AGN and the dusty winds near stellar surfaces to be imaged











ALMA spectral properties: receivers

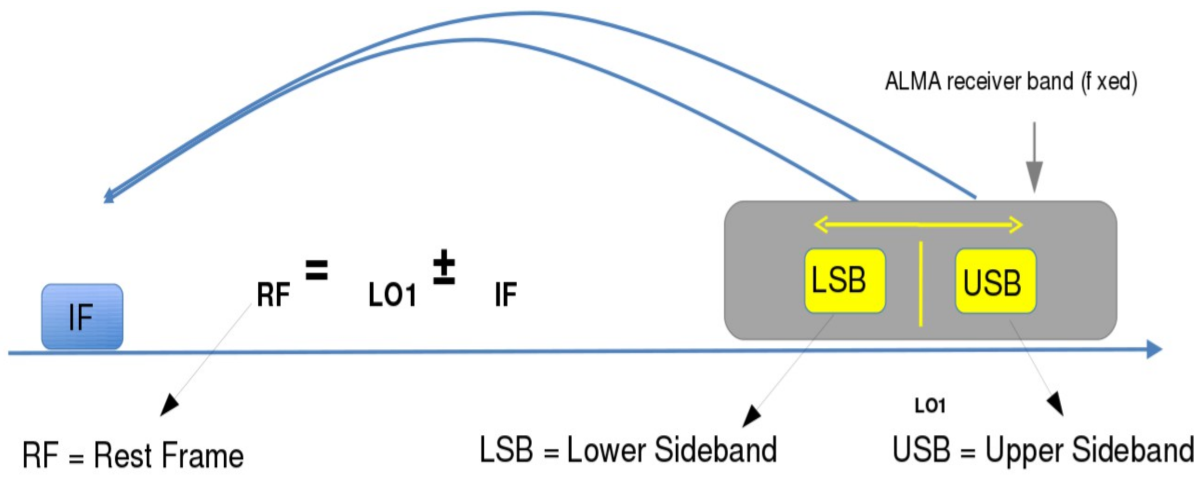


Table A-4: Properties of ALMA Cycle 3 Receiver Bands

Band	Frequency range[1] (GHz)	Wavelength range (mm)	IF range	Type
3	84 – 116	3.6 – 2.6	4 – 8	2SB
4	125 – 163	2.4 – 1.8	4 – 8	2SB
6	211 – 275	1.4 – 1.1	5 – 10	2SB
7	275 – 373	1.1 – 0.8	4 – 8	2SB
8	385 – 500	0.78 – 0.60	4 – 8	2SB
9	602 – 720	0.50 – 0.42	4 – 12	DSB
10	787 – 950	0.38 – 0.32	4-12	DSB

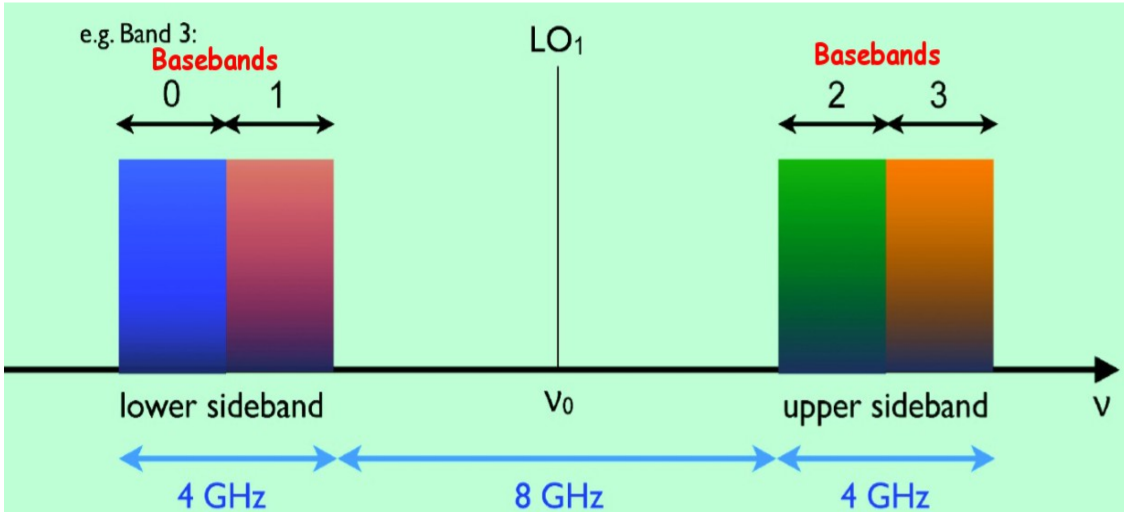
Receivers are couple of dipoles,
so split the signal into **2 polarizations**
By combining the indipendent
polarizations chains it can reconstruct
all the Stokes parameters

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

**Hence the set up is constituted by
a Lower Sideband,
a gap, and
an Upper sideband
centered at a certain rest frequency**

The gap size and the width
of the sidebands are fixed
(depends on the IF) but might
be different in different bands
The PI can chose the RF
(i.e. tune the LO)

ALMA spectral properties: receivers



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 by the PI.

Archive data reflect the PI choices

Query Form | Results Table

Submit download request

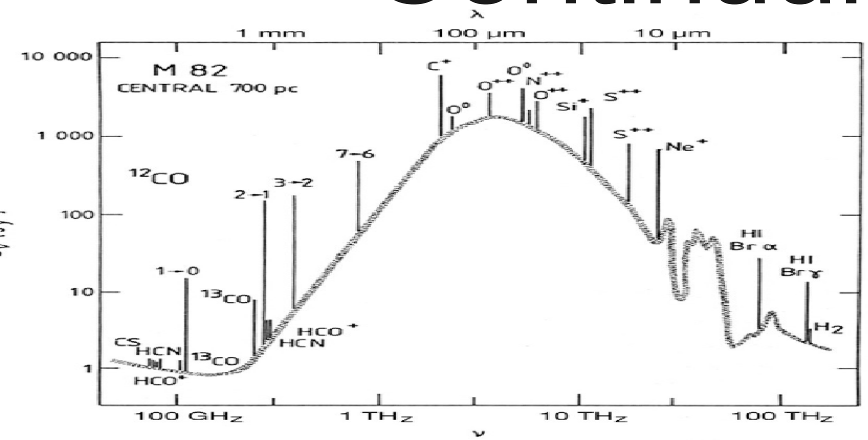
Results Bookmark   Export Table   Results Help

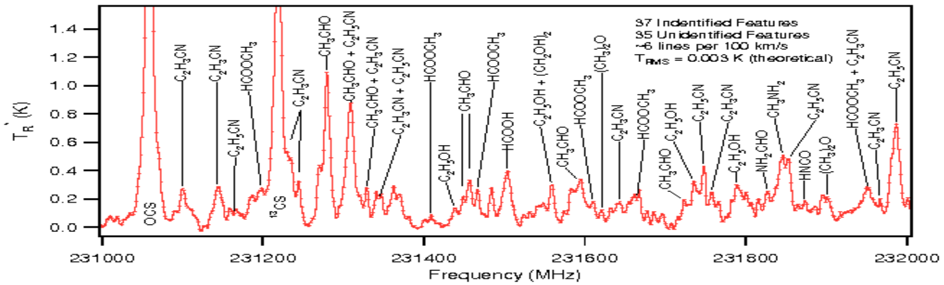
Showing 28 of 28 rows.   More columns

	Project code	Source name	RA	Dec	Band	Integration	Release date	Velocity resolution	Frequency support
Filter:								m/s	
☐	2011.0.00020.S	NGC 1614	04:34:00.03	-08:34:44.6	7	120.96	2013-01-12	834.09	344.15..357.85GHz
☐	2011.0.00020.S	NGC 1614	04:34:00.03	-08:34:44.6	7	120.96	2013-01-12	851.55	336.17..351.86GHz
☐	2011.0.00768.S	NGC1614	04:34:00.03	-08:34:44.6	7	120.96	2013-10-15	846.76	337.97..353.59GHz
☐	2011.0.00768.S	NGC1614	04:34:00.03	-08:34:44.6	7	120.96	2013-10-15	846.76	337.97..353.59GHz
☐	2011.0.00768.S	NGC1614	04:34:00.03	-08:34:44.6	7	120.96	2013-10-15	846.76	337.97..353.59GHz
☐	2011.0.00182.S	NGC 1614	04:34:00.03	-08:34:45.2	9	151.2	2013-12-21	13784.20	675.82..683.31GHz
☐	2011.0.00182.S	NGC 1614	04:34:00.03	-08:34:45.2	9	151.2	2013-12-21	13784.20	675.82..683.31GHz
☐	2013.1.01172.S	ngc_1614	04:34:00.05	-08:34:59.0	6	151.2	2015-08-08	2625.60	214.12..232.20GHz
☐	2013.1.01172.S	ngc_1614	04:34:00.05	-08:34:45.2	6	151			214.12..232.20GHz
☐	2013.1.01172.S	ngc_1614	04:34:00.05	-08:34:31.5	6	151			214.12..232.20GHz
☐	2013.1.01172.S	ngc_1614	04:34:00.05	-08:34:45.2	3	30.			98.68..114.41GHz
☐	2013.1.00991.S	NGC_1614	04:34:00.03	-08:34:44.6	3	60.			98.62..114.42GHz
☐	2013.1.00991.S	NGC_1614	04:34:00.03	-08:34:44.6	3	60.			93.75..109.42GHz
☐	2013.1.00991.S	NGC_1614	04:34:00.03	-08:34:44.6	3	120			98.66..114.48GHz
☐	2013.1.00991.S	NGC_1614	04:34:00.03	-08:34:44.6	3	120			98.66..114.48GHz

Frequency	Resolution	Polarization
98.62..100.62GHz	125000.00kHz	XX YY
100.44..102.44GHz	125000.00kHz	XX YY
110.67..112.55GHz	3906.25kHz	XX YY
112.54..114.42GHz	3906.25kHz	XX YY

Continuum vs spectral line



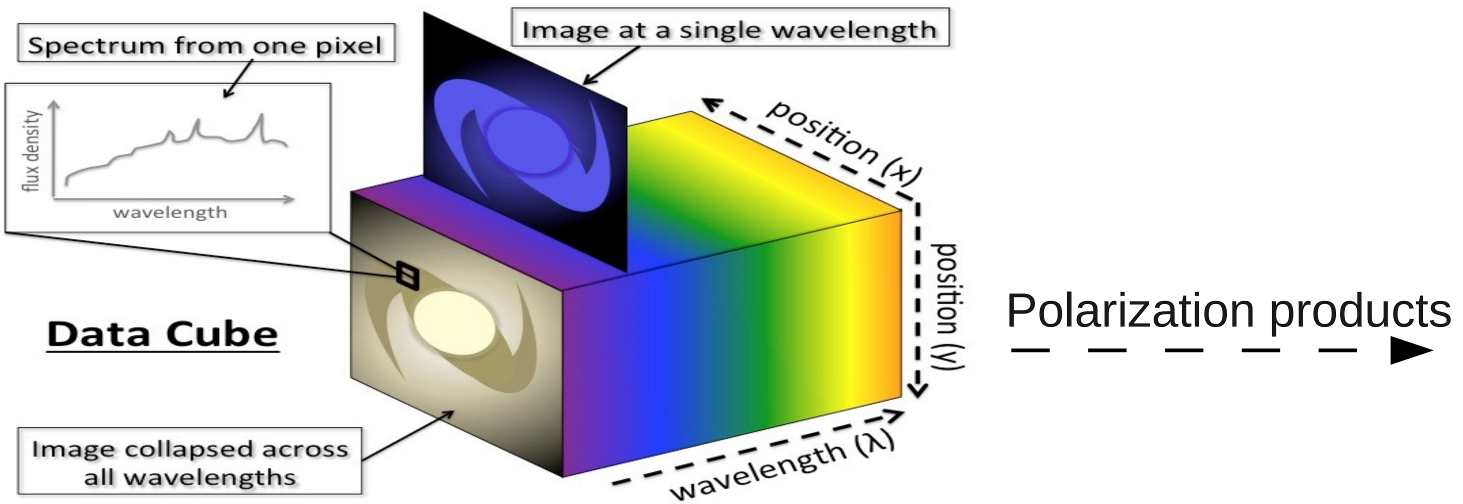


Digital correlators can be set up to different bandwidth and spectral resolution.

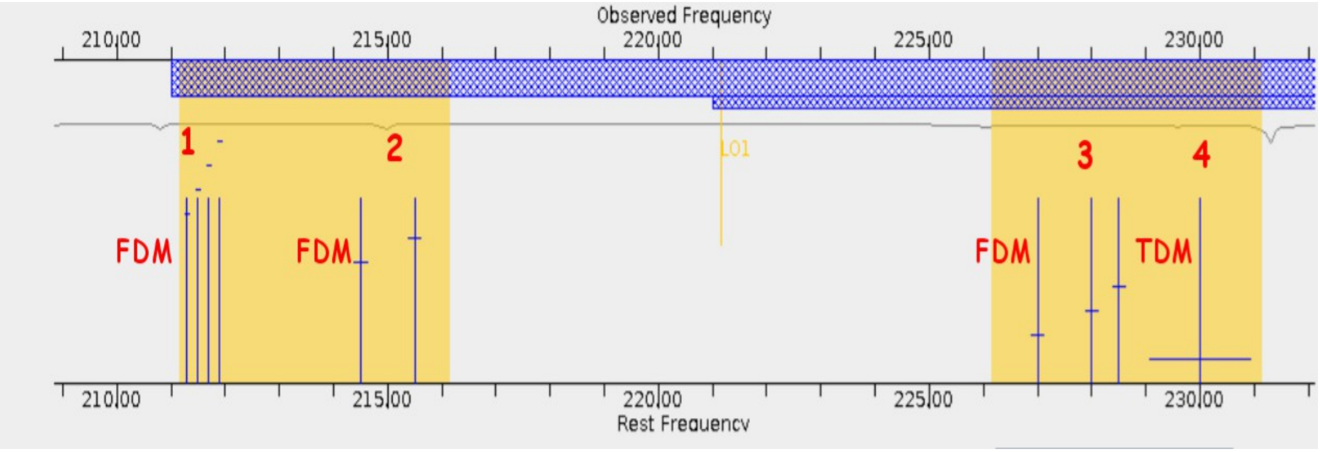
Continuum can be observed with large bandwidth and low spectral resolution (broad frequency channels)

The narrower are the spectral lines the higher is the spectral resolution requested to sample it.

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



ALMA spectral properties: correlator



Each baseband may be divided in up to 4 spectral windows by allocating a fraction of the correlator resources (up to 3840 channels in double pol) to each window.

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	Polarization	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)

The PI can request to bin the channels at the correlator stage (i.e. reduce the resolution in the data) to reduce the data rate

Large number of modes → high flexibility for different science cases

ALMA sensitivity

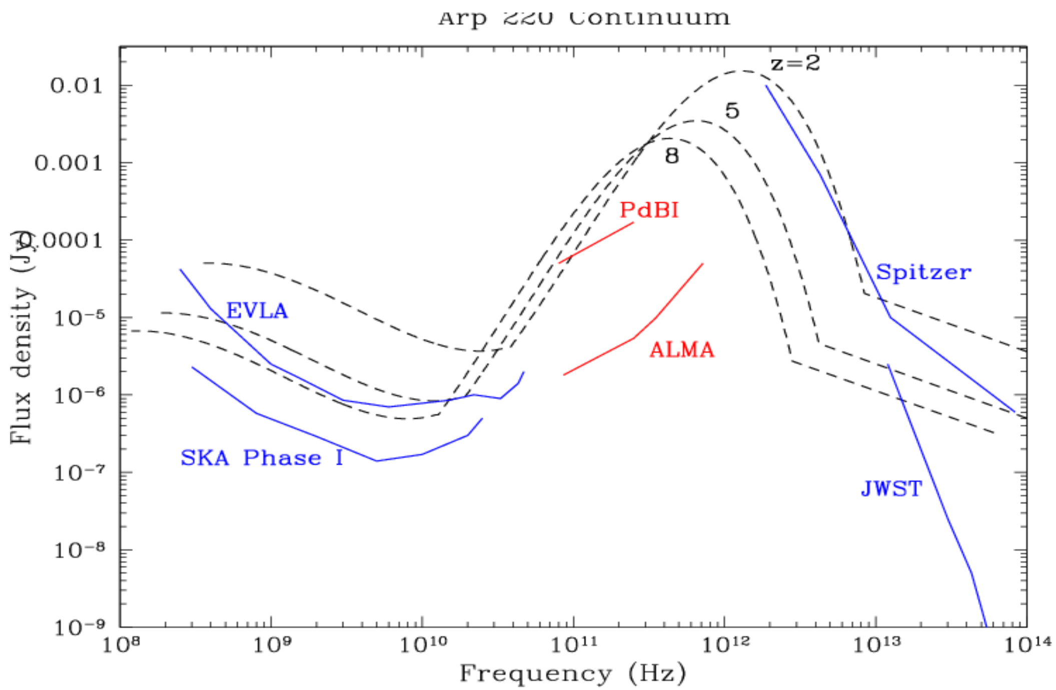
High sensitivity is the combination of

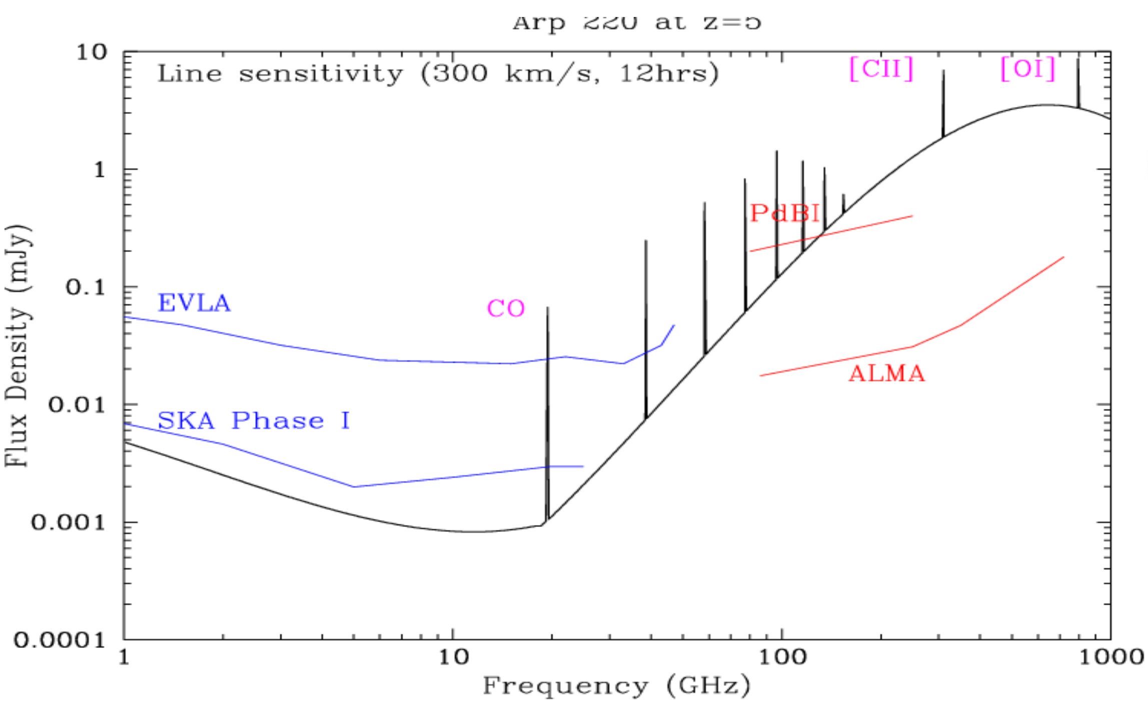
- dry site, low pwv, low Tsys,

- >6500sqm of effective area
and 1225 baselines for the 12m array
+ Short spacings and TP with ACA

- large bandwidth (for continuum)

Sensitivity is always referred to a frequency range chosen by the PI.





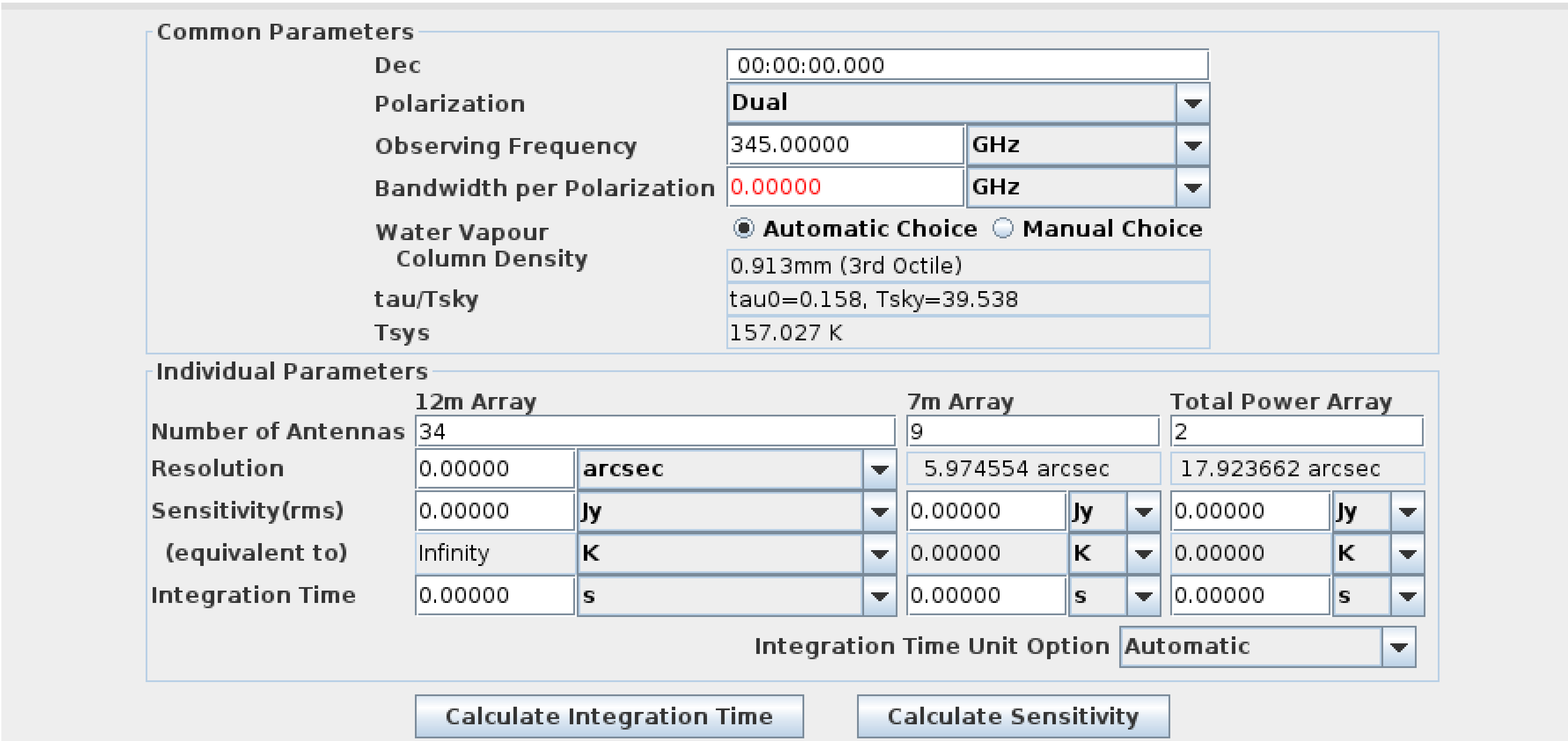
$$\sigma_S = \frac{2\,k\,T_{sys}}{\eta_q \eta_c A_{eff} \sqrt{N(N-1)\, n_p\, \Delta\nu\, t_{int}}}$$

<0.05mJy @100 GHz in 1 hr

The PI requests a sensitivity in a certain setup of spectral and angular resolutions

The Science Goal: Sensitivity Calculator

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



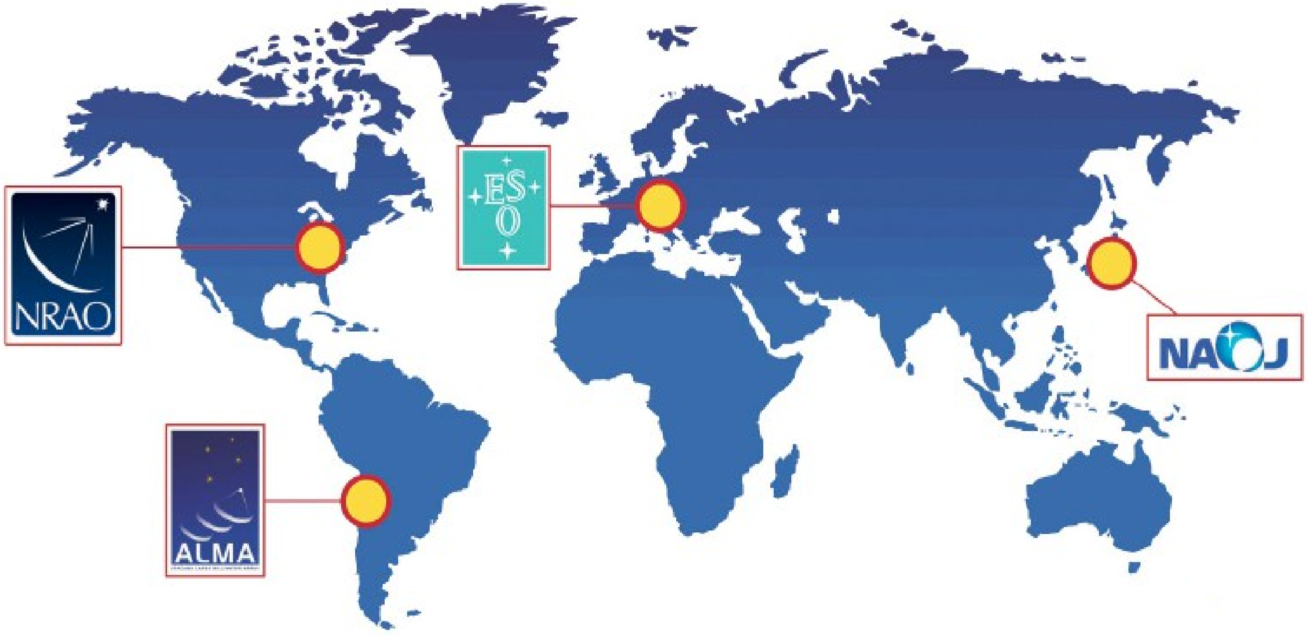
(See tutorial on Sensitivity Calculator)

ALMA organization

ALMA is a world wide collaboration

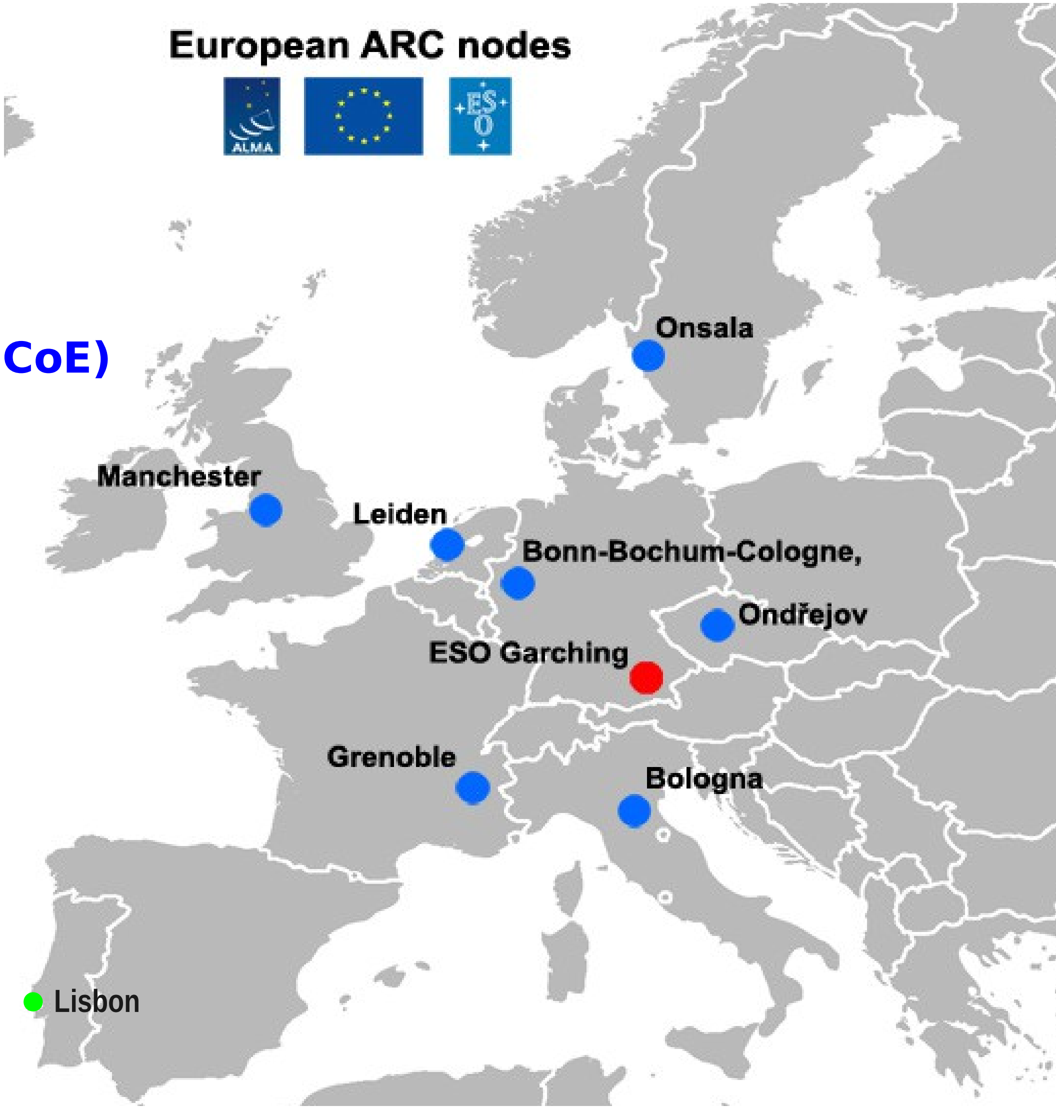
Contributors share the observing time an host a mirror of the archive

- Europe: **ESO** (14 countries) → 30%
- North America: **NRAO** (USA, Canada) → 30%
- East Asia: **NAOJ** (Japan, Taiwan) → 20%
- Chile → 10%



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/

Access the ALMA data
https://almascience.eso.org/alma-data

data cube spectroscopy

ian ARC | IRA mail | Arc-newsletter | ALMAhelpdesk | jira | Science Operations Re... | ARC TWiki | Image Archive: ALMA ... | ALMA_tel | ALMA WebShiftlog T...

ALMA

Atacama Large Millimeter/submillimeter Array

In search of our Cosmic Origins

Search Site

ESO | NRAO | NAOJ

Log in | Register | Reset Password | Forgot Account

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User Services at ARCs

- Helpdesk
- ALMA Calendars
- EU ARC
- NA ARC
- EA ARC

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ALMA Data

The ALMA Archive

The first ALMA Science data are now public. These data are accessible through the Science Portal without user registration.

Data still within its proprietary period is only accessible to PIs as authenticated users. The data proprietary period is 12 months, starting at the time when data is delivered to the PI. A single project may be divided into more than one delivery and in these cases a unique 12 month proprietary period is defined for each delivered data set.

Access is provided through the Archive link in the left side-bar.

The ALMA Archive is under development and will eventually provide access to all data obtained by the ALMA observatory. This includes: raw science data from the correlators, calibration data, processed and quality assured data, including image data cubes as well as logs and reports on project execution and quality assurance.

The ALMA Calibrator Source Catalogue

A web-based user interface to the calibrator database is provided through the Calibrator Catalogue link in the left side-bar.

The intention is to provide a more complex, public search tool for calibrator sources, which can also be accessed through the Observing Tool and included into the Scheduling Blocks. The principles of the calibrator selection during observation are described in the ALMA Cycle 2 Technical Handbook, A.8 'Calibration source selection'

The data comprise ALMA calibrator measurements of the flux density for sources drawn from seed catalogues such as ATCA, SMA and VLA, and use updated coordinates from VLBI. Stated flux density uncertainties do not in all cases fully account for uncertainties in the planetary models used for the primary amplitude calibration. Structure information, expressed as the acceptable uv range, is available for sources where relevant for past and current ranges of ALMA baseline. Polarization information will be added during Cycle 2. For further details on the Calibrator Source Catalogue, see Fomalont, E., et al., 2014, "The Calibration of ALMA using Radio Sources', The Messenger, 155, 19"

Science Verification Data

In addition to the archive, there are several datasets available as Science Verification data. These observations are performed in order to demonstrate the early capabilities of ALMA. Access to the data sets are through the link Science Verification in the left side-bar. Information about planned Science Verification observations are also presented. Publications making use of ALMA Science Verification data must include a statement in the acknowledgement that is similar to the one for regular data (see below). The Science Verification acknowledgement can be

Access the documents and tools https://almascience.eso.org/documents-and-tools

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Summary of documents and tools available for ALMA

Call for Proposals

Documentation supporting the current ALMA Call for Proposals – **Cycle 3**.

- ALMA Proposer's Guide (Contains all pertinent information regarding the ALMA Call for Proposals)
- ALMA Technical Handbook (A comprehensive description of the ALMA observatory and its components)
- ALMA Users' Policies (The long-term core policies for use of the ALMA and ALMA data by the science community.)
- Early Science Primer (Introduction to interferometry and how to use ALMA during Early Science)
- ALMA Proposal Template (LaTeX format. Recommended but not mandatory)

Observing Tool (OT)

Documents and tools supporting the current ALMA Call for Proposals – **Cycle 3**.

The ALMA Observing Tool (OT) is a Java application used for the preparation and submission of ALMA Phase 1 (observing proposal) and Phase 2 (telescope runfiles for accepted proposals) materials. The current release of the OT is configured for the Early Science Capabilities of ALMA. Note that in order to submit proposals you will have to register with the ALMA Science Portal beforehand.

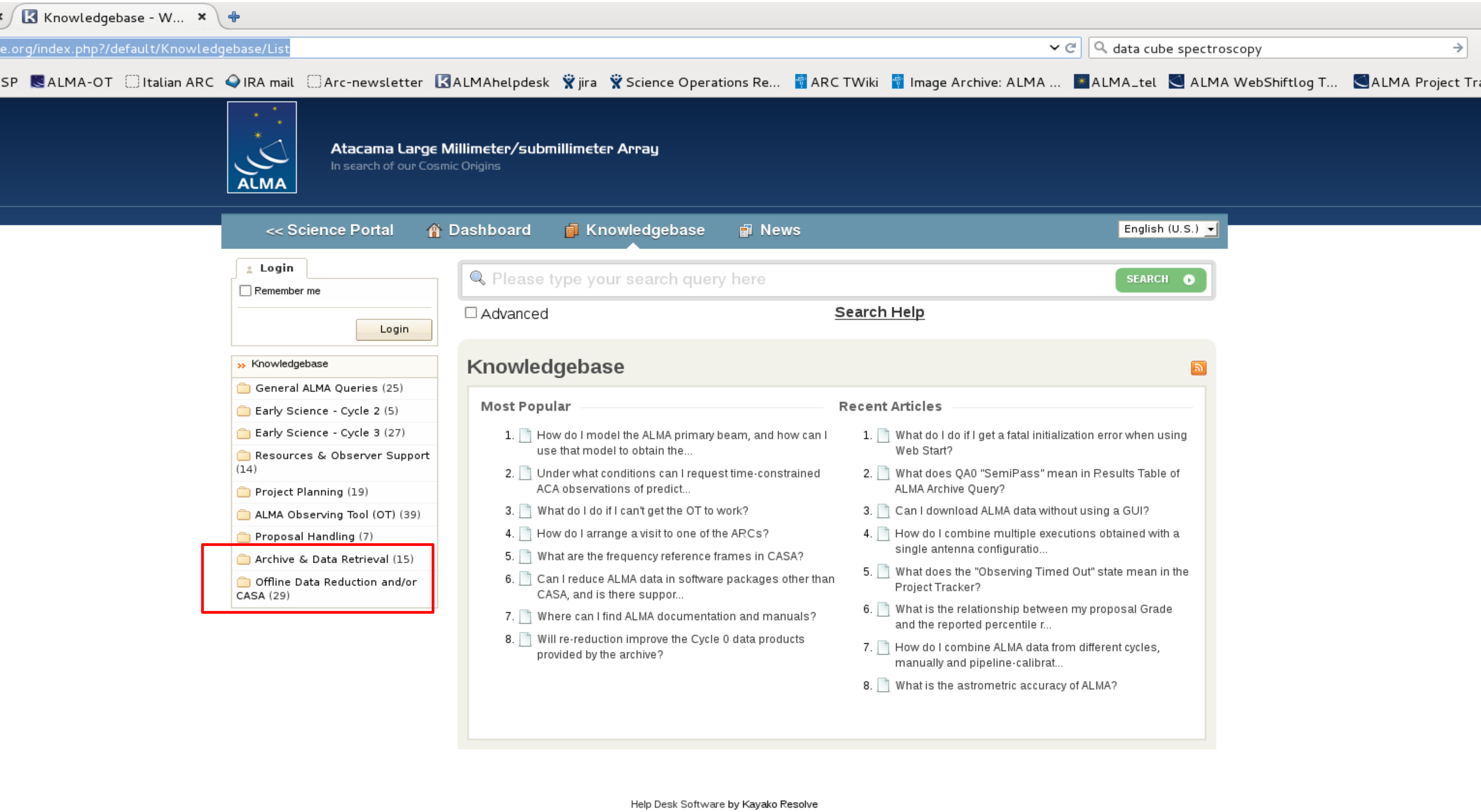
- ALMA Observing Tool (takes you to the OT page on the Science Portal)
- OT Quickstart (A Quick Start Guide for using the Observing Tool)
- OT User Manual (Describes how to use the Observing Tool for preparing ALMA proposals)
- OT Reference Manual (An in-depth description of the Observing Tool)
- Video Tutorials on how to use the Observing Tool
- Known OT issues (for those instances when OT problems are encountered)
- A User's Guide to ALMA Scheduling Blocks is a guide to understanding the structure and content of ALMA Scheduling Blocks (SBs) using the Observing Tool (OT). In particular this guide may be used by PIs when asked to verify and approve their SBs before they are placed in the queue, ready for observing.

Guides to the ALMA Regional Centers

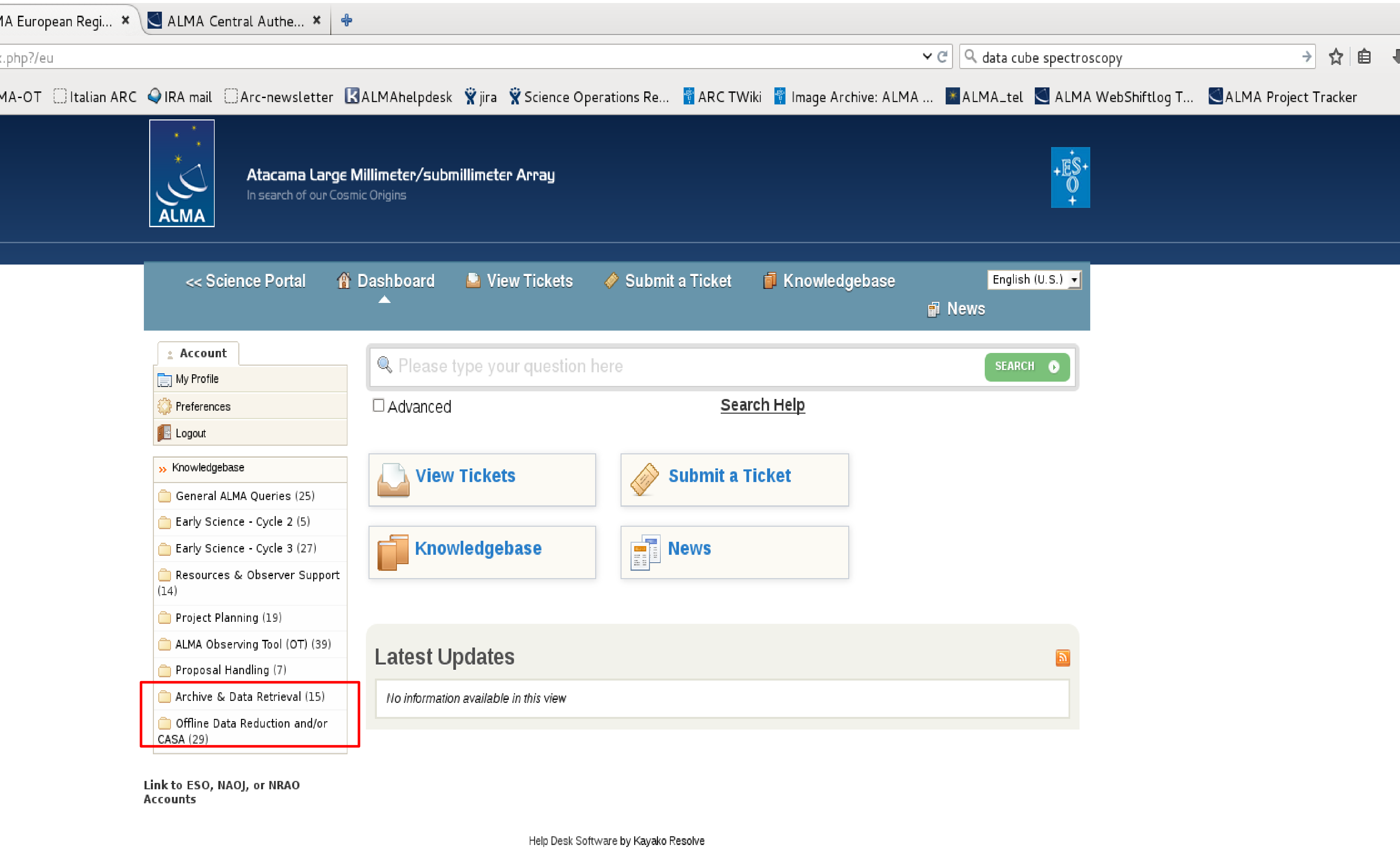
The ALMA Regional Centers provide user support and host special activities related to their respective regions. Their functions are described in the 'Guide to'.

Access the FAQ - Knowledgebase

https://help.almascience.org/index.php?/default/Knowledgebase/List



Access the Helpdesk
https://help.almascience.org/index.php?/eu
Register on the SP to access!!!



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)

Project ID (assigned at first submission):

YYYY.R.CCCCC.X

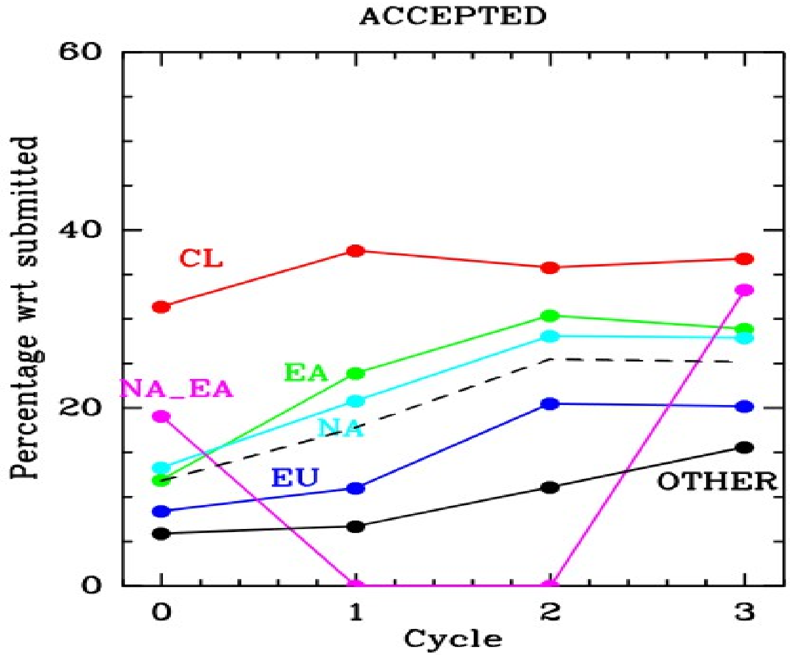
YYYY= submission year
R= number of call for the submission year
CCCCC= sequential number of submitted
X= type of proposal

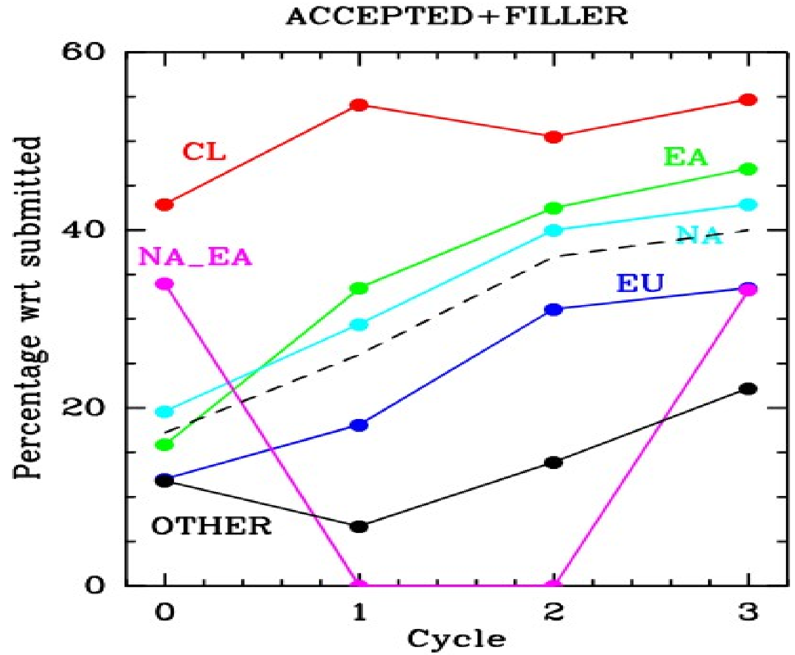
Early Science Cycles

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:

Proposal outcome	Cycle 0 Sep. 2011 – Jan. 2013	Cycle 1 Jan. 2013 - May. 2014	Cycle 2 Jun. 2014 – Oct. 2015	Cicle 3 Oct 2015 - Oct 2016
Proj_ ID	2011.*	2012.*	2013.*	2015.*
Hours dedicated to Science	800	800	2000	2100
Submitted	917	1133	1381	1578
Highest priority	112	198	354	402
Filler	51	93	159	236
Pressure factor global	8.2	5.8	3.9	3.9
Pressure factor Europe	12.3	9.1	4.9	6.2





ALMA Cycle 4 (preannounced capabilities)

Proposal submission deadline 21 April 2016

Observing epoch	**Oct 2016 - Oct 2017**		
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 (with some restrictions)
- Solar observations

Italian ALMA Proposal Preparation Day

April 11-12 2016

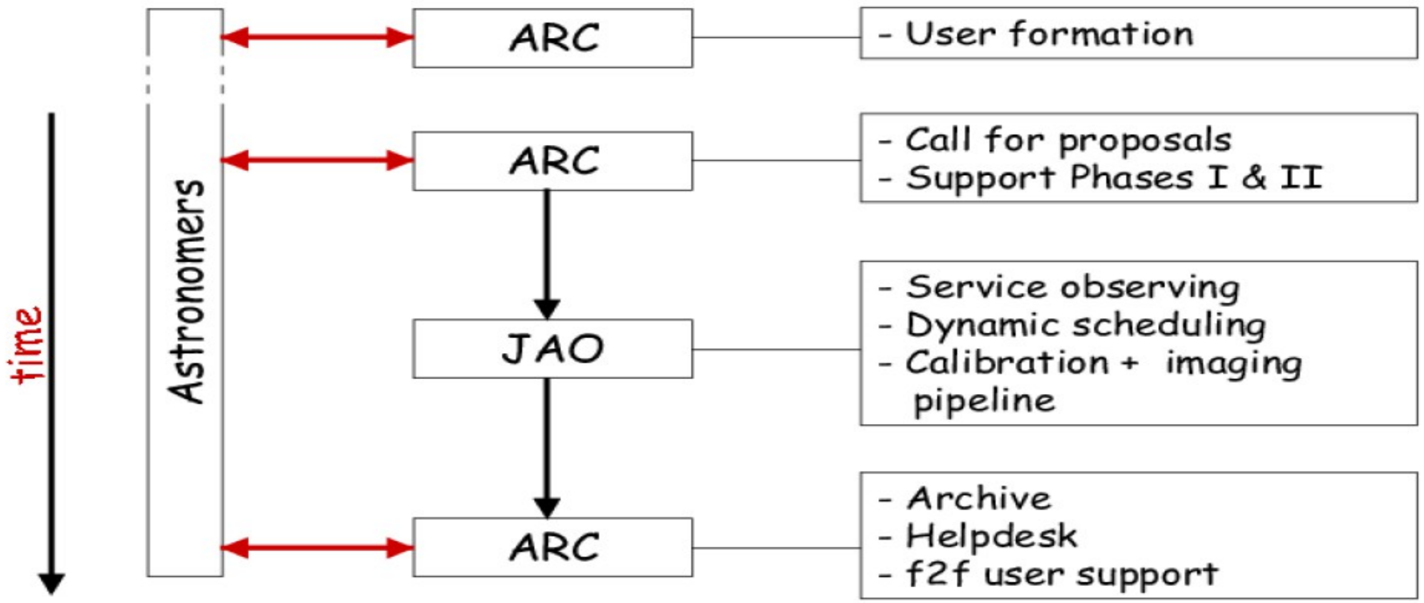
Bologna, Osservatorio di Radioastronomia (ARC)

Registrations open on alma.inaf.it

A project lifetime: phase 2 Observing process

PHASE II – Observing process

Scheduling Block	Each SG is converted into a **Scheduling Block, an observational unit including targets in the same sky region and their Calibrators to be observed with the same instrumental setup.** They are the minimum set of instructions to perform an observation.
Observations	**Projects are dynamically scheduled according to telescope configuration, weather, ranking, project status...**
Quality assessment	**QA0 and 1 = telescope conditions** **QA2 = Check for PI sensitivity requests performed by ARC staff**
Data archival and delivery	**1 yr of proprietary period before data are public through the archive**



(See talk on Archive)