EUROPEAN ARC
ALMA Regional Centre || Italian

ALMA

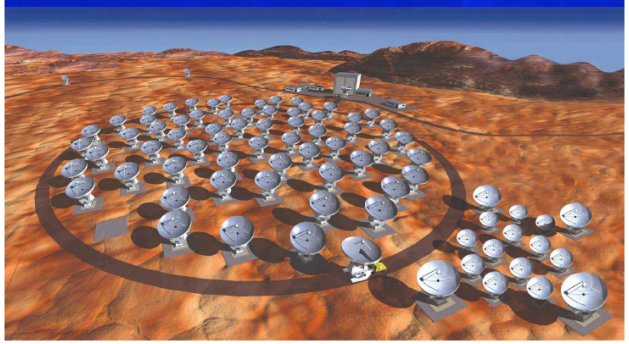
and the Italian

ALMA Regional Centre (ARC)

Jan Brand
Coordinator Italian ARC

INAF - Istituto di Radioastronomia, Bologna

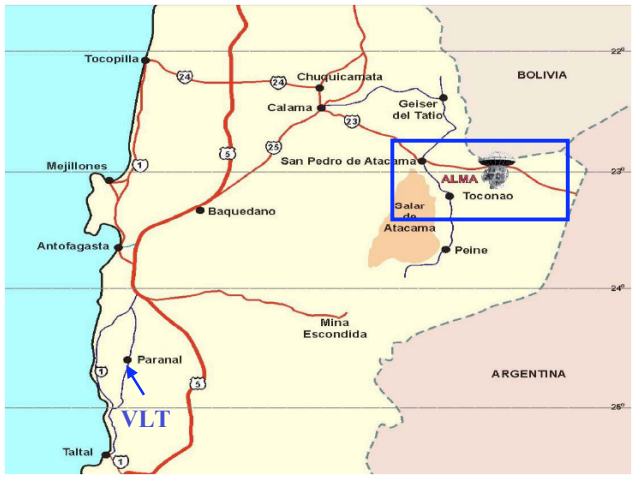
ALMA + ACA →
Atacama Large Millimeter/submillimeter Array

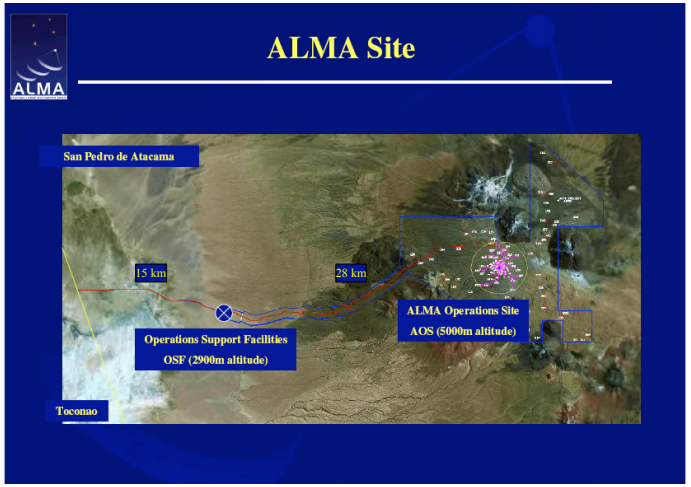


ALMA Project – Structure

- Partners:
  - **Europe** - *European Organization for Astronomical Research in the Southern Hemisphere - ESO.*
  - **North America** - *National Science Foundation (NSF) in cooperation with the National Research Council of Canada (NRC) – AUI/NRAO*
  - **Chile**
  - **Japan/Taiwan** - *National Institutes of Natural Sciences (NINS), in cooperation with the Academia Sinica in Taiwan - NAOJ*

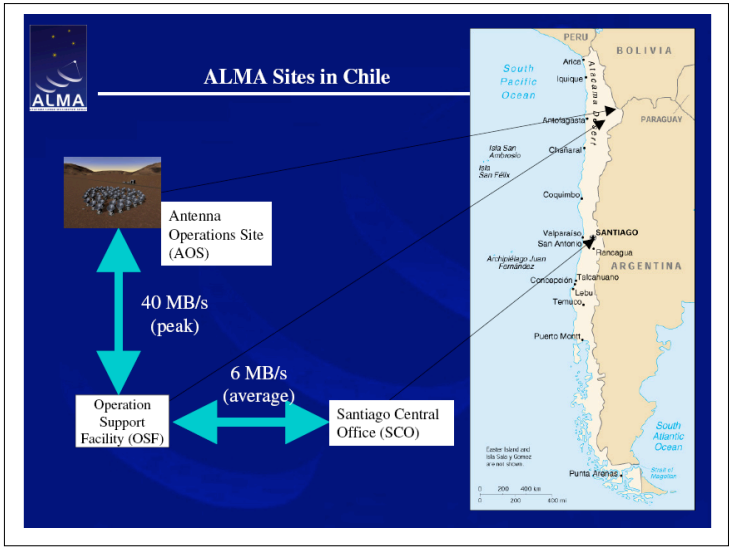
→ Joint ALMA Office: Construction project
→ Joint ALMA Observatory

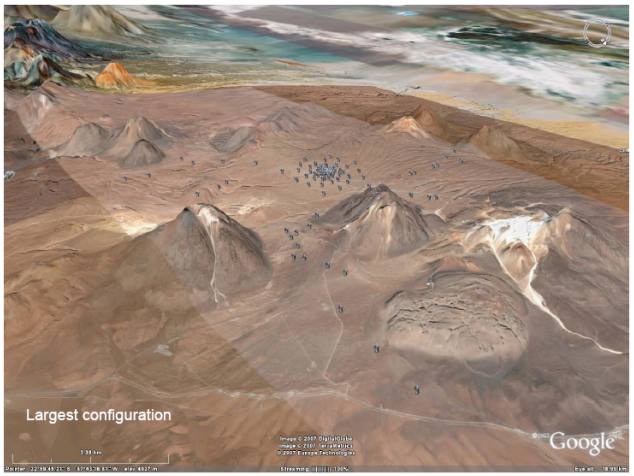

Tocopilla
Chuquicamata
BOLIVIA
Calama
Geiser del Tatio
Mejillones
San Pedro de Atacama
ALMA
Toconao
Baquedano
Salar de Atacama
Antofagasta
Peine
Mina Escondida
Paranal
ARGENTINA
VLT
Taltal

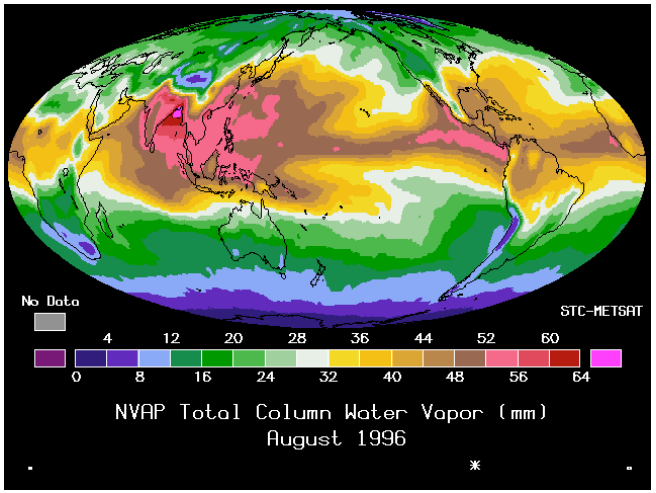

ALMA Site
ALMA
San Pedro de Atacama
15 km
28 km
ALMA Operations Site
AOS (5000m altitude)
Operations Support Facilities
OSF (2900m altitude)
Toconao

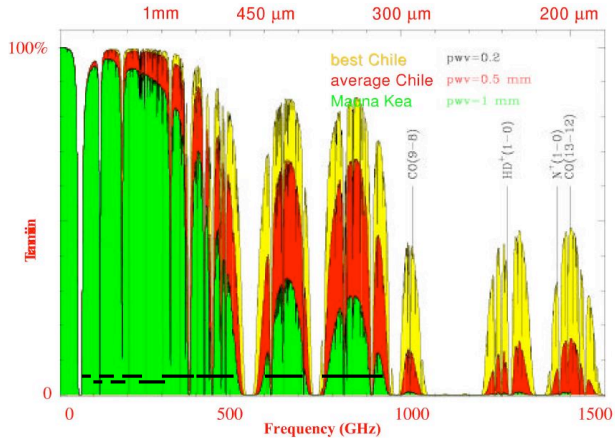

ALMA Sites
To AOS (43km)
OSF Site (15km)


ALMA Sites
ALMA
• Array Operations Site – AOS – Antennas, correlator, reconfiguration. 5 km
• Operations Support Facility – OSF – Array operation, equipment maintenance 2.9 km
• Santiago Central Offices – SCO – Administration, scientific support. sea level
• ALMA Regional Centers – ARCs + ARCIets – interfaces to astronomy community


ALMA Sites in Chile
ALMA
Antenna Operations Site (AOS)
40 MB/s (peak)
6 MB/s (average)
Operation Support Facility (OSF)
Santiago Central Office (SCO)
PERU
BOLIVIA
PARAGUAY
ARGENTINA
South Pacific Ocean
South Atlantic Ocean
Iquique
Antofagasta
Chañaral
Coquimbo
SANTIAGO
Valparaíso
San Antonio
Rancagua
Concepción
Talcahuano
Temuco
Puerto Montt
Punta Arenas


Largest configuration
Google


No Data
STC-METSAT
4 12 20 28 36 44 52 60
0 8 16 24 32 40 48 56 64
NVAP Total Column Water Vapor (mm)
August 1996


Atmospheric Transmission
1mm
450 µm
300 µm
200 µm
100%
0
Tamin
best Chile
average Chile
Mauna Kea
pwv=0.2
pwv=0.5 mm
pwv=1 mm
CO(9–8)
HD+(1–0)
N+(1–0)
CO(13–12)
0
500
1000
1500
Frequency (GHz)

ALMA Science Requirements

Three "level I" science goals:

- *Spectral line CO/C+ in z=3 MWG < 24hrs*
- *resolve PPD at 150 pc – gas/dust/fields*
- *Precise 0.1" imaging above 0.1% peak*

- High Fidelity Imaging.
- Routine sub-mJy Continuum / mK Spectral Sensitivity.
- Wideband Frequency Coverage.
- Wide Field Imaging Mosaicing.
- Submillimeter Receiver System (..& site..).
- Full Polarization Capability.
- System Flexibility (hardware/software).

⇒ ALMA Technical Specifications

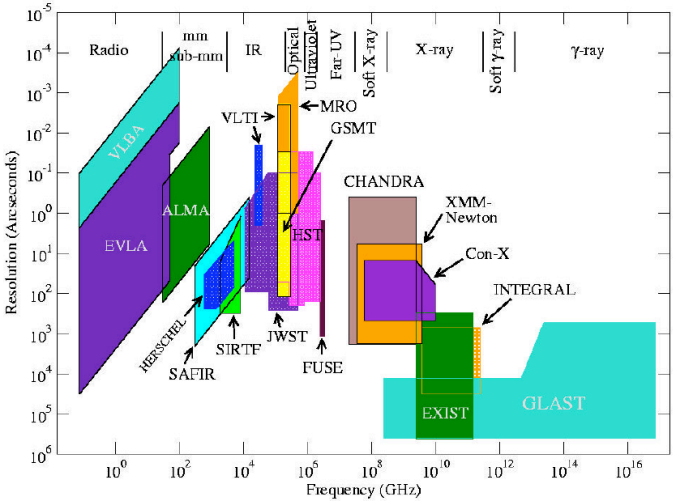
- 54 12-m antennas, 12 7-m antennas, at 5000 m altitude site, desert environment.
- Antennas: Surface accuracy ±25 μm, 0.6" reference pointing in 9m/s wind, 2" absolute pointing all-sky.
- Array configurations between 150m to ~15 -18km.
- 10 bands in 31-950 GHz + 183 GHz WVR. Initially:
  - 86-119 GHz "3" 3 mm
  - 125-169 GH "4" 2 mm
  - 211-275 GHz "6" 1.3 mm
  - 275-370 GHz "7" 0.85 mm
  - 385-500 GHz "8" 0.65 mm
  - 602-720 GHz "9" 0.45 mm
  - 787-950 GHz "10" 0.35 mm

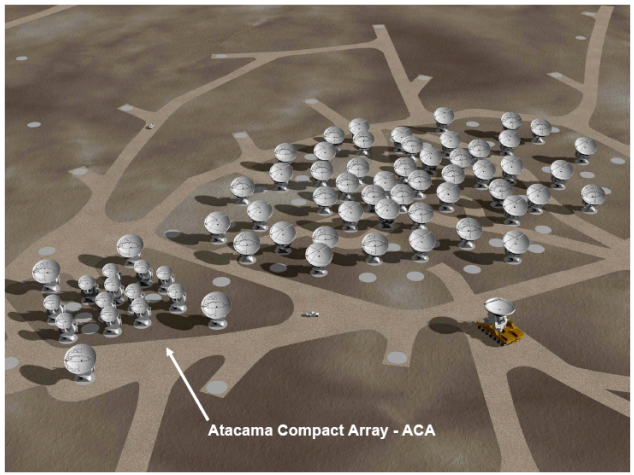
ALMA Technical Specifications

- 8 GHz BW, dual polarization.
- Flux sensitivity ~0.2 mJy in 1 min at 345 GHz
- Interferometry, mosaicing & total-power observing.
- Correlator: 4096 channels/IF (multi-IF), full Stokes.
- Data rate: 6MB/s average; peak 60-150 MB/s.
- All data archived (raw + images), pipeline processing.

ALMA in a nutshell

Band	frequency range (GHz)	wavelength range (mm)	angular resolution b_{max}=200m ... 18km (arcsec)	line sensitivity (mJy)	continuum sensitivity (mJy)	primary beam (arcsec)	largest scale (arcsec)
3	84-116	2.6-3.6	3.0 .. 0.034	8.9	0.060	56	37
4	125-169	1.8-2.4	2.1 .. 0.023	9.1	0.070	48	32
5	163-211	1.4-1.8	1.6 .. 0.018	150	1.3	35	23
6	211-275	1.1-1.4	1.3 .. 0.014	13	0.14	27	18
7	275-373	0.8-1.1	1.0 .. 0.011	21	0.25	18	12
8	385-500	0.6-0.8	0.7 .. 0.008	63	0.86	12	9
9	602-720	0.4-0.5	0.5 .. 0.005	80	1.3	9	6





Role of ACA

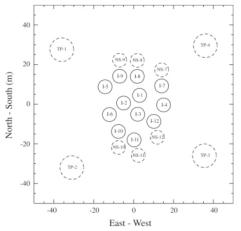
- **Supplement the 50-element array data with**
  - **Short baseline data (7-m antennas)**
  - **Total power data (12-m antennas)**

  ⇒***Enhance fidelity of ALMA images***
  (overcome "*missing-flux*" problem)

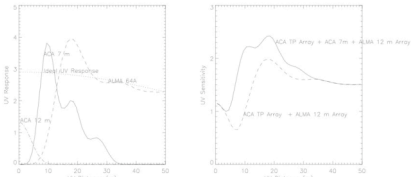
- **Stand-alone mode of operation**

  ⇒Available for ***target-of-opportunity*** observations, wide-field surveys, etc.

ACA layout



Array response



Iguchi et al., 2009 PASJ 61, 1

Fig. 2. Left: *UV* response profile of the ACA and the most compact configuration of the ALMA 64-element array with $\beta = 4$. Right: *UV* sensitivity profile. Observing parameters are same as those of Figure 1. The configuration of the ACA is a strawperson design described in Section 7.

ACA stand-alone mode

Table 6. *

Band	Frequency (GHz)	7 m Array ΔI_m (mJy beam^{-1})	7 m Array θ_{fov} (″)	7 m Array θ_{res} (″)	ACA full Array ΔI_m (mJy beam^{-1})	ACA full Array θ_{fov} (″)	ACA full Array θ_{res} (″)
Band 3	94	3.1	113	16	1.6	66	9.6
Band 4	145	4.3	73	10	2.1	43	6.2
Band 6	224	6.7	47	6.7	3.3	28	4.0
Band 7	345	16	31	4.3	8.1	18	2.6
Band 8	410	27	26	3.7	14	15	2.2
Band 9	670	190	16	2.2	102	9	1.3
Band 10	860	365	12	1.7	206	7	1.0

* Field of view (θ_{fov}), angular resolution (θ_{res}), and single point-source sensitivity (ΔI_m) for continuum observations with ACA. The 1 second on-source integration, 8 GHz bandwidth at a single polarization, and 25-percentile atmosphere at main atmospheric windows (see figure 10) are assumed.

Iguchi et al., 2009 PASJ 61, 1

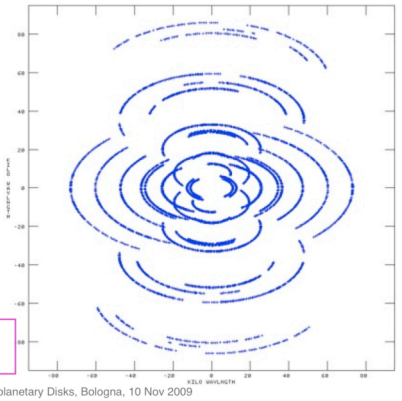
mm Interferometers (u,v) coverage

OVRO mm Array,
6 Antennas

L-configuration
single integration

L-Configuration few
hrs of observations

Final coverage: a
few hrs in both the L
and H configurations



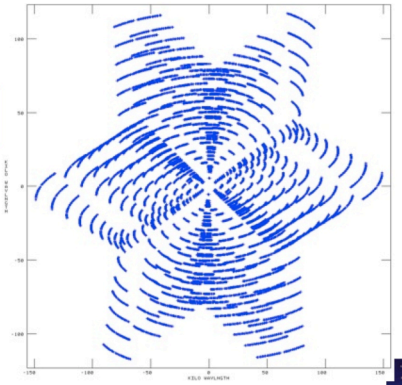
N.B. (u,v) coverage
is not uniform

mm Interferometers (u,v) coverage

Very Large Array,
27 Antennas,
1.5h of observing time!

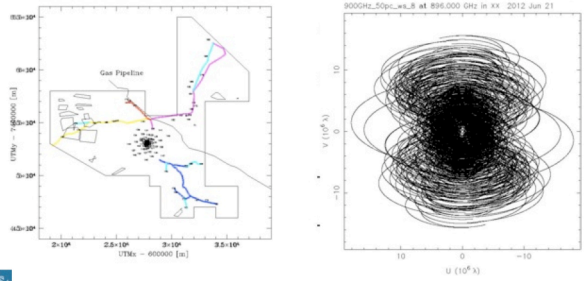
N.B. (u,v) coverage is still
not uniform.

Critical parameters:
•Long baselines
•Short baselines
•Number of (u,v) points
•(u,v) coverage distribution



mm Interferometers (u,v) coverage

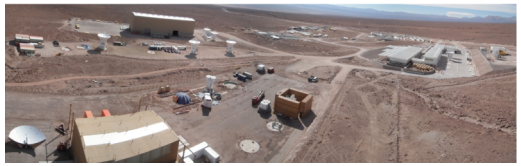
- Current mm interferometers offer typically ~10^4 visibility measurements in several hours, the VLA delivers ~10^5 visibilities per hour
- ALMA will improve by almost two orders of magnitude



Three prototype antennas at ATF

Transport to OSF

OSF - Site Erection Facilities; Technical Facility

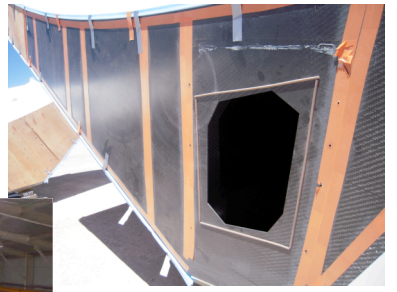


Operations Support Facility - 2900m


OSF – Feb 2008

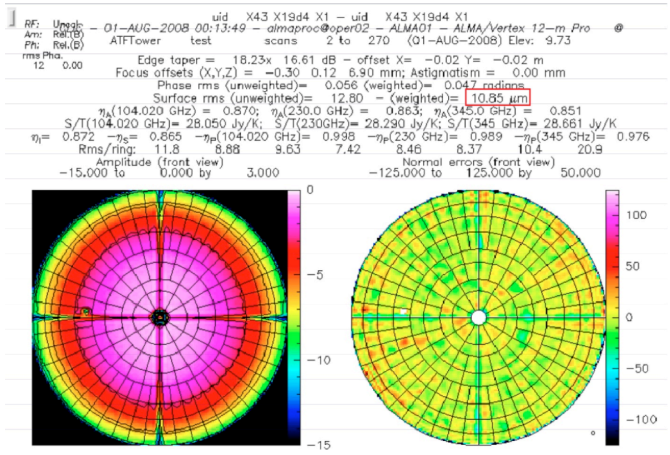

Vertex Contractor Area

CFRP BUS:
Carbon Fibre Reinforced Backup Structure



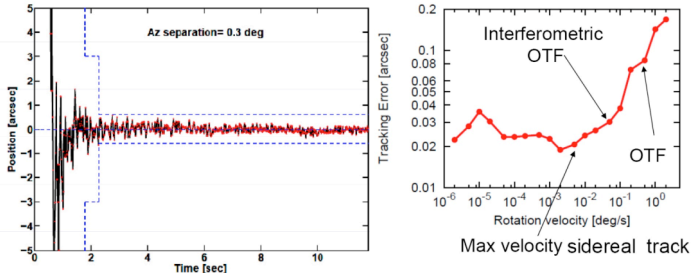
Bruno Marano

Antenna Performance



Antenna Performance

Antenna tests ➢ Excellent pointing and tracking



Front End Specifications

- Preliminary results within parentheses are referred to the vacuum window and do not include noise from optics losses

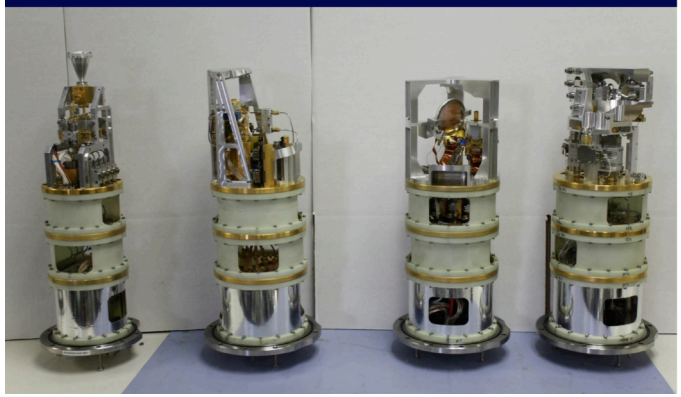
ALMA Band	Frequency Range	Receiver noise temperature		Mixing scheme	Receiver technology	Supplier
		T_{Rx} over 80% of the RF band	T_{Rx} at any RF frequency			
1	31.3 – 45 GHz	17 K	28 K	USB	HEMT	Not assigned ***
2	67 – 90 GHz	30 K	50 K	LSB	HEMT	Not assigned
3	84 – 116 GHz	37 K (40K)	62 K (50K)	2SB	SIS	HIA
4	125 – 169 GHz	51 K (45K)	85 K (~55K)	2SB	SIS	NAOJ
5	163 - 211 GHz**	65 K	108 K	2SB	SIS	OSO
6	211 – 275 GHz	83 K (40K)	138 K (60K)	2SB	SIS	NRAO
7	275 – 373 GHz*	147 K (75K)	221 K (100K)	2SB	SIS	IRAM
8	385 – 500 GHz	196 K (160K)	294 K (~270K)	2SB	SIS	NAOJ
9	602 – 720 GHz	175 K (120K)	263 K (150K)	DSB	SIS	NOVA
10	787 – 950 GHz	230 K	345 K	DSB	SIS	NAOJ ?

* - between 370 – 373 GHz T_n is less than 300 K

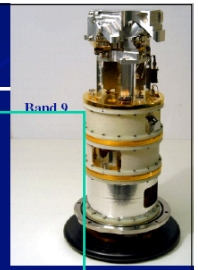
** - Limited to 6 units, funded by the EC under FP6
*** - Under consideration by U. Chile

- Dual, linear polarization channels:
  - Increased sensitivity
  - Measurement of 4 Stokes parameters
- 183 GHz water vapour radiometer:
  - Used for atmospheric path length correction

Bands 3 (84-116 GHz), 6 (211-275 GHz),
7 (275-373 GHz), and 9 (602-720 GHz) SIS "cartridges"



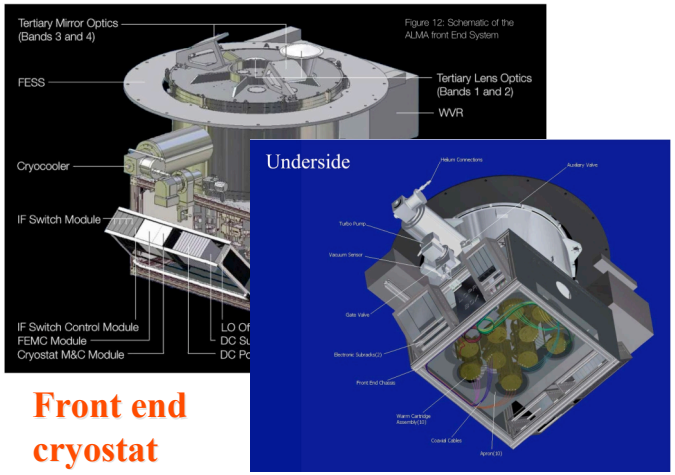
Cartridge Production



- Band 3 (HIA, Canada) 3 mm 86-119 GHz
- Band 6 (NRAO, USA) 1.3 mm 211-275 GHz
- Band 7 (IRAM, France) 0.85 mm 275-370 GHz
- Band 9 (NOVA, The Netherlands) 0.45 mm 602-720 GHz

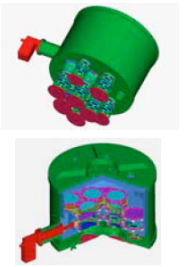
- Band 4 (NAOJ, Japan) 2 mm 125-169 GHz
- Band 8 (NAOJ, Japan) 0.65 mm 385-500 GHz
- Band 10(NAOJ, Japan) 0.35 mm 787-950 GHz

Available from start

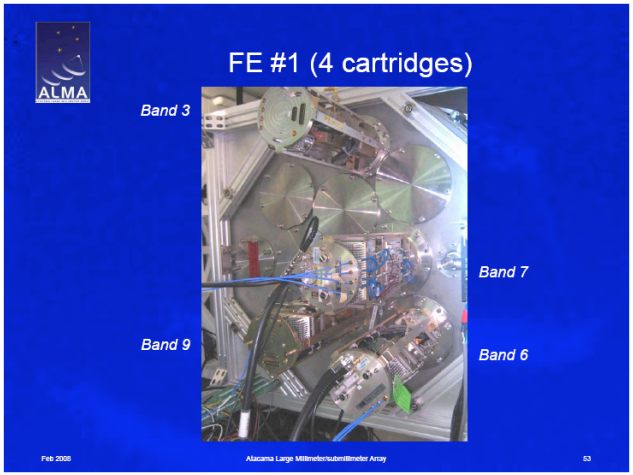


Front end cryostat

Front End Design

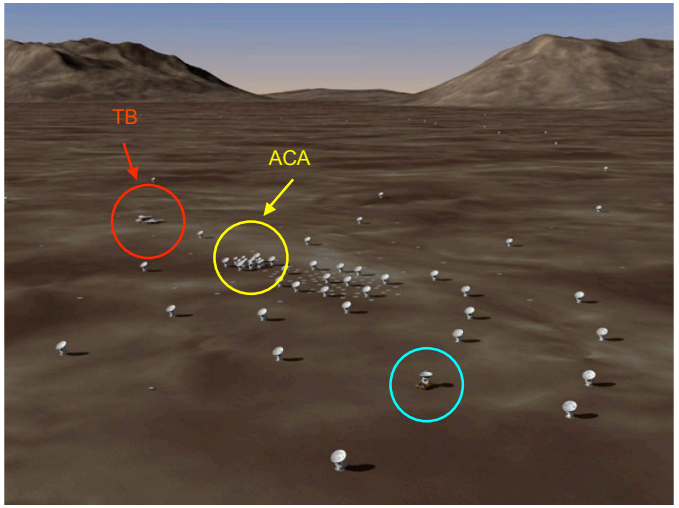


- Diameter ~ 1 m
- External optics top of dewar
- 10 Cartridges plugged from bottom
- Each cartridge contains one frequency

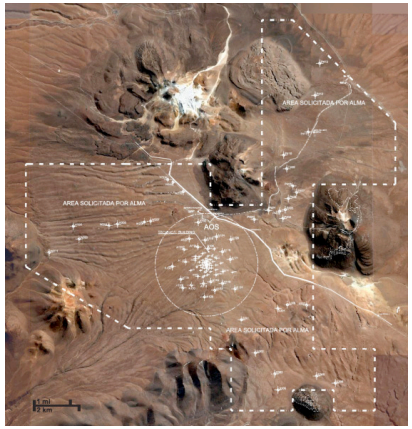


The ALMA Antenna Transporter

ESO Press Photo 45b/07 (5 October 2007)

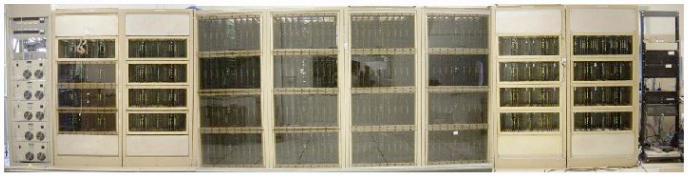


ANTENNA FOUNDATIONS LOCATIONS



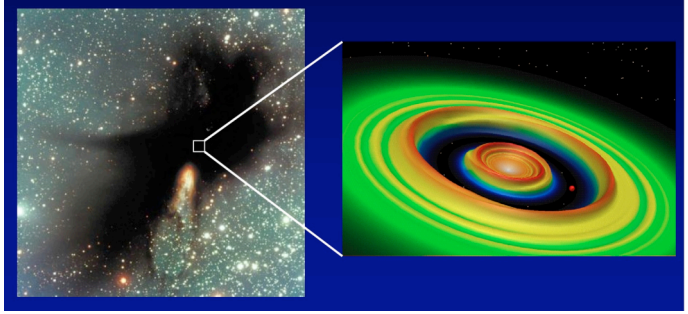
ANTENNA FOUNDATIONS (ACA)

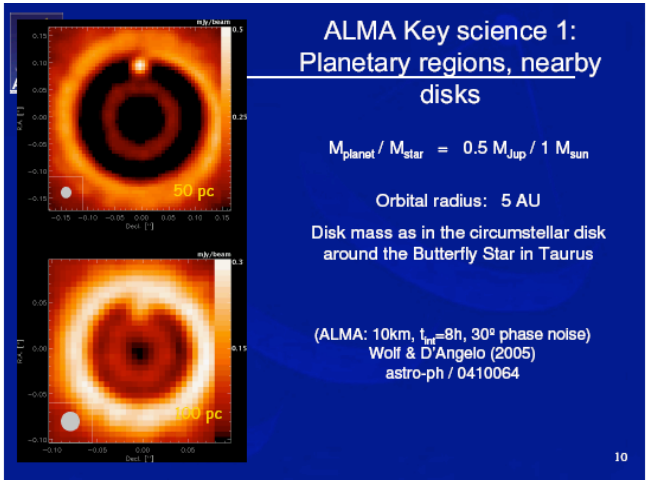
AOS - technical building, correlator Q1



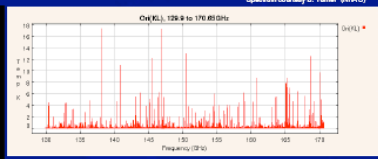
ALMA Science

Make images of new stars being formed, with planets emerging from the disks around them.





ALMA Key Science 2: Astrochemistry



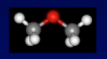
- Millimeter/submillimeter spectral components dominate the spectrum of planets, young stars, many distant galaxies.
- Most of the observed transitions of the 125 known interstellar molecules lie in the mm/submm spectral region—here some 17,000 lines are seen in a small portion of the spectrum at 2mm.

11

Some complex organic molecules

Detected

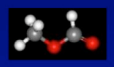

Acetic acid


Di-methyl ether


Ethanol


Sugar


Methyl cyanide

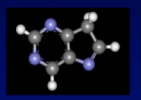

Methyl formate


Benzene


Ethyl cyanide

Not (yet) detected


Glycine


Purine

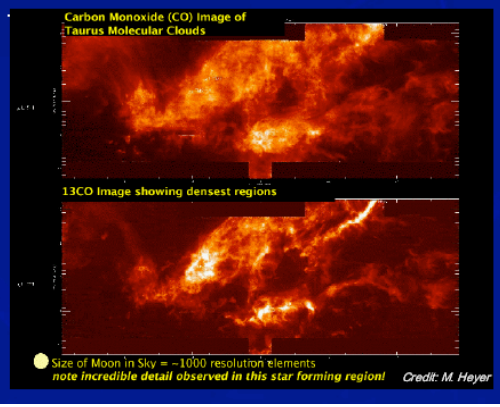

Pyrimidine


Caffeine

We do not how far this chemical complexity extends.

Based on Ehrenfreund 2003

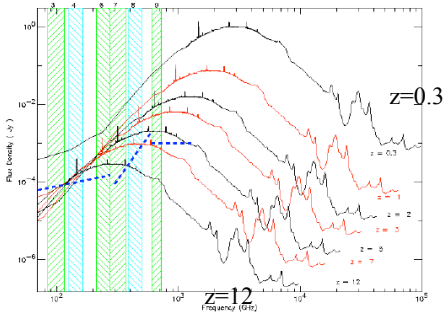
ALMA Key science 3: Interstellar Medium



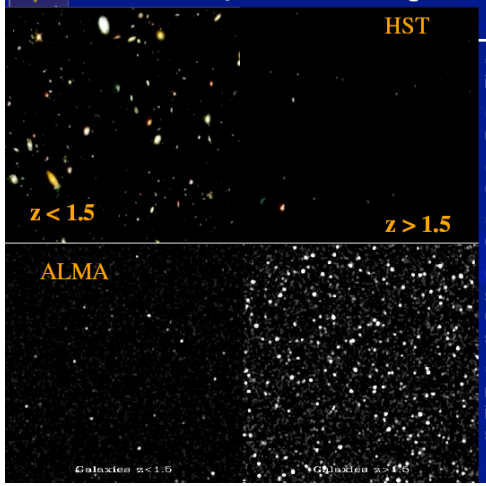
ALMA Key science 4: high redshift deep fields

M82 from ISO, Beelen and Cox

- As galaxies get redshifted into the ALMA bands, dimming due to distance is offset by the brighter part of the spectrum being redshifted in. Hence, galaxies remain at relatively similar brightness out to high distances.

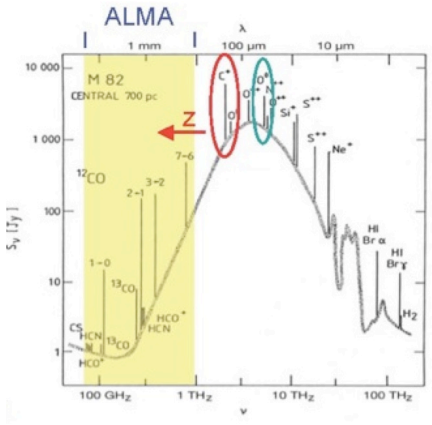


ALMA Deep field: 'normal' galaxies at high z



- Detect current submm gal in seconds!
- ALMA deep survey: 3days, **0.1 mJy (5s),** 4'
- HST: a few thousand Gals, most at z<1.5
- ALMA: a few hundred Gals, most at z>1.5
- Parallel spectroscopic surveys, 100 and 200 GHz: CO/other lines in majority of sources
- Redshifts, dust, gas masses, plus high res. images of gas dynamics, star formation

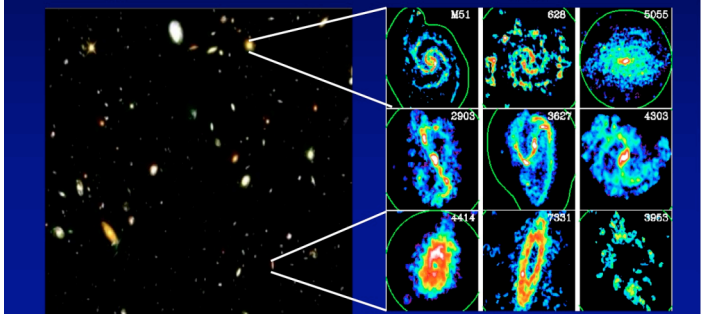
15



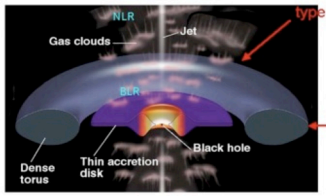
Map the most distant parts of the Universe – this means looking back in time about 12 Gyrs

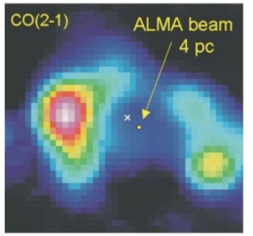
Left: Hubble image of distant galaxies

Right: Mm-wave images of nearby galaxies



The engine of nearby AGNs





Several (competing) models:

Geometry		Dynamics		Structure	
large ~100 pc	small ~1 pc	rotation	rotation and outflow	cont./diff. medium	clumpy medium
(observed)	(ALMA)	(ALMA)		(ALMA)	

ALMA OPERATIONS

- Two calls for proposals per year
- A single TAC for NA+EU+EA
- Service observing (PI not involved in observations)
- Dynamic scheduling:
  - Best project in queue determined every SB (hr-scale)
  - Depends on weather + configuration + priority

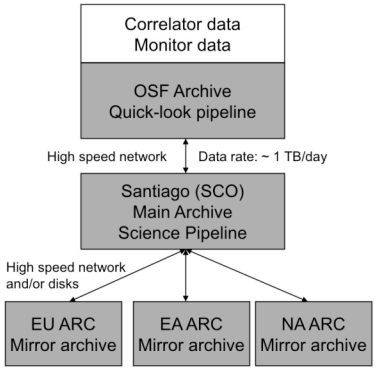
ALMA OPERATIONS

- Calibration and imaging pipeline
  - Final product: data cube
- Archive
  - Raw data + pipeline products
  - 200 TB/yr
  - public after 18 months
- User face-to-face support provided

Archive has a central role

Archive content:
- All raw and calibration data
- All monitor data
- All data products produced by the standard pipeline (images etc.)
- Observing logs
- Proposals
- SBs
- Publications and other information

Virtual Observatory compliant



Observing Time

- No guaranteed time
- Single TAC for NA+EU+EA
  EU ~ 35%, NA ~ 35%, EA ~ 20%, Chile = 10%
  - in ESO: D~21%, F~16%, E~9%
  - in ALMA: D~7.5%, F~5.5%, E~3%
- Huge competition to be expected
- Early Science Call for Proposals: end of 2010;
  ES starts 8 months later (2011)

Early Science Requirements

- At least 16 12-m antennas fully commissioned
- Receiver bands 3, 6, 7, and 9 available on all antennas, plus bands 4 and 8 on as many antennas as possible
- Sufficient antenna stations (platforms) to provide range of configurations covering the shortest spacings out to at least 1 km
- Synthesis mapping of single fields, plus pointed mosaic mode
- Basic set of spectral modes
- Linear and circular polarisation of compact sources
- Single-dish mapping of extended objects in both continuum and spectral line modes, including on-the-fly observing
- Calibration of all the above to a level comparable with existing mm-wave arrays - requires hot/ambient loads and WVRs
- Software to support users' applications, the preparation and execution of observations and off-line data reduction

Expected in 2012: observe >75% of time with >40% of antennas; 2013: formal end of construction

Phase 1 Observing proposal

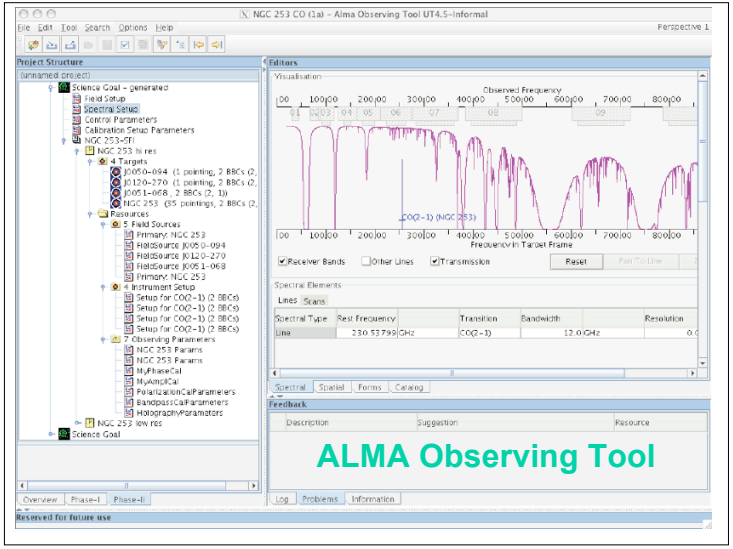
- mostly concentrated on science
- some administrative information
- minimal amount of technical information
- target list

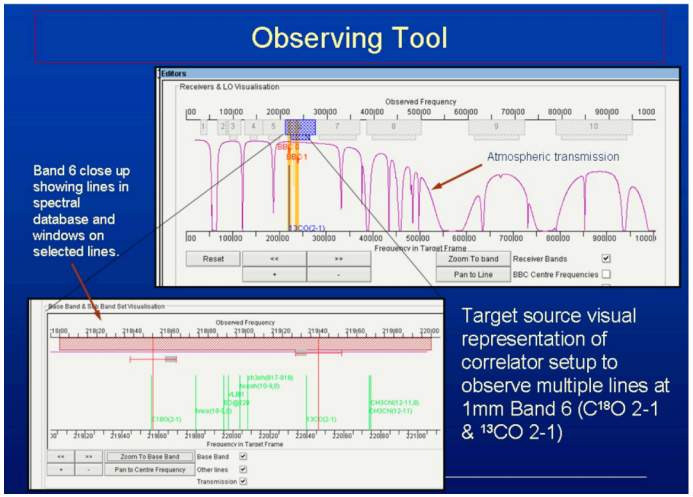
Phase 2 Observing program

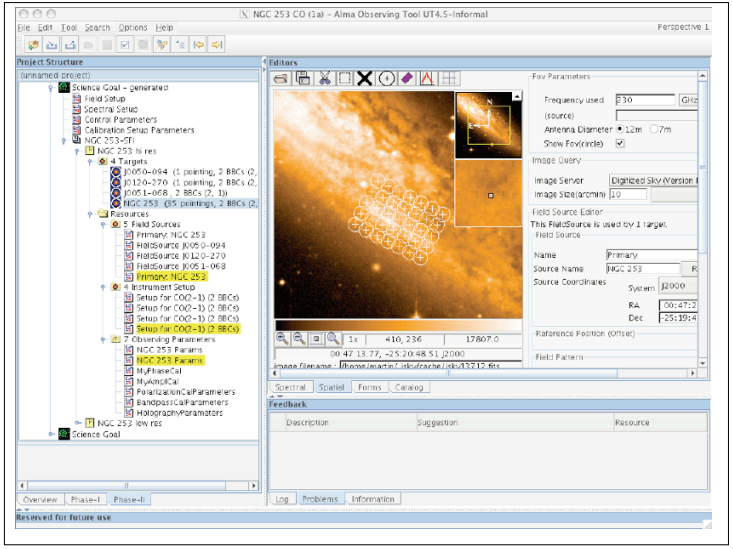
- complete set of technical details
- full specifications of how observations are to be carried out
- consistency with Phase 1

Observing program - AOT

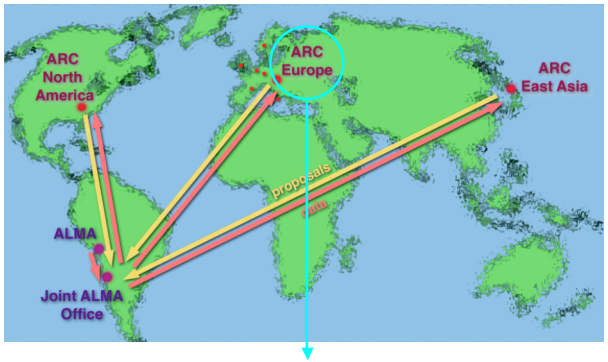
- scheduling blocks (SchedBlocks) [cf. VLT]
  - key executable self-consistent units:
    - targets, correlator set-up, receiver set-up, pointing, phase calibrators, etc.
- Observing Units Sets (ObsUnitSets)
  - structure to support recursive hierarchy of SchedBlocks







ALMA World-wide organisational structure



Central node (ESO) + Network of regional nodes

The EU ARC-network

ESO Central node
+
Independent regional nodes

- Bonn-Bochum-Cologne (D)
- IRA, Bologna (I)
- IRAM (Grenoble; F, E)
- Leiden (+; NL)
- Manchester (+; UK)
- Nordic (Onsala; DK, S, SU, NOR, IS)
- Ondrejov (CZ)

Also interested in joining: Lisbon (P); Zürich (CH); Belgium

Responsibilities & interactions detailed in "Memo of Understanding"

European ARC

Core tasks ⇒ ESO
- Basic user support (Helpdesk)
- Emit Call for Proposals, Phase I, Phase II
- ALMA archive operations
- Data product support: delivering data and software

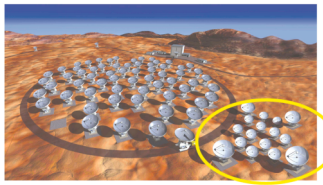
Additional tasks ⇒ ARC nodes
(see next slide)

ROLE of the ARC-nodes

- ✓ **Build a community** (e.g. ALMA/ARC-days 2007, 2008; tutorials; seminars; schools; meetings; PRINs)
- ✓ **Provide face-to-face user support (post-obs.) and archival data-mining**
- ✓ **Offer help in specific areas of expertise** (see next slide)
- ✓ **Provide user feedback**
- ✓ **Be involved with software development & testing manuals, cookbooks; share with the other ARCs/ARC-nodes**
  e.g. CASA-testing;
  ALMA Observation Preparation software-test
- ✓ **Be involved in commissioning/science verification phase**
- ✓ **Maintain website** (http://www.alma.inaf.it/)

Areas of expertise in EU ARC-nodes

1. Wide-field, high-dynamic range imaging (UK/NL/F)
2. Mosaicing (I)
3. High-frequency observing (NL)
4. Infrastructure for advances data analysis tools (D/NL/Nordic)
5. Data handling/GRID-technology (I/P)
6. Coordinating surveys/key projects (I)
7. Polarimetry (I/F/D)
8. Astrometry (Nordic/D/UK)
9. Pipeline heuristics (D)
10. Automatic data calibration (D)
11. Data pipelining (UK)
12. Multi-frequency synthesis (Nordic/UK)
13. Array combination imaging (UK)
14. Robust self-cal methods and use of WVR data (Nordic)
15. Data handling and server (P)
16. Instrumental calibration (F)
17. Atmospheric phase calibration (F)
18. ALMA imaging simulations (F)



50×12m + (4×12m + 12×7m)
0.3-3mm; resol: 0".015λ(mm)

ALMA

Key science
1: Planetary regions, nearby disks
2: Astrochemistry
3: Interstellar medium
4: High-redshift deep fields

Italy & ALMA

Strong interest in: planetary sciences, star formation, stellar evolution, galaxy formation, high-redshift universe, cosmology

Italian representatives in ALMA:
Testi – European Project Scientist
Tofani – ALMA Management Advisory Committee (AMAC)
Maiolino – European Science Advisory Committee (ESAC)
Andreani – EU ARC Manager
Tarenghi – former Director ALMA; now ESO rep. in Chile

Origin of the It. ALMA Regional Centre

In response to ESO-call, national INAF-ALMA Commission✹ was established in June 2004. This recommended:

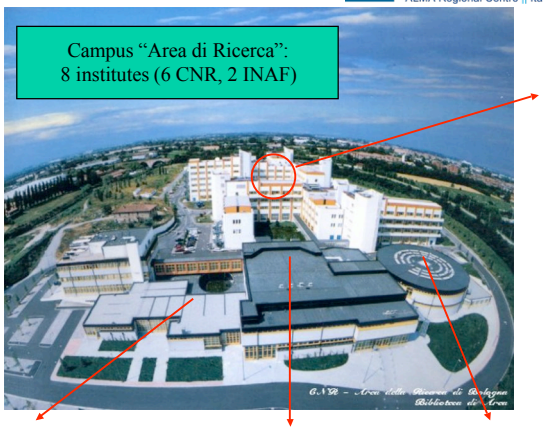
IRA to host ALMA Regional Centre

Primarily based on IRA's extensive experience with (radio) interferometrical instruments, observing techniques, software packages and development, and managing large data sets.

Expression of interest from INAF to ESO.
Italian ARC: hosted by IRA-Bologna, funded by INAF

✹ Testi, de Zotti, Mack, Natta, Pucillo

EUROPEAN ARC
ALMA Regional Centre || Italian



Present situation

EUROPEAN ARC
ALMA Regional Centre || Italian

ARC-working group consisting of:

6 staff-members Brand, Gregorini, Mack, Nanni, Prandoni, Zanichelli

3 post-docs + 1 technician:

Rossetti	(VLBI, radio, polarisation, extra-galactic)	60%
Mignano	(software development, opt/IR, extra-galactic)	50%
Casasola	(mm-interferometry, single-dish, extra-gal.)	50%
Bedosti	(computer systems, software)	100%

<7/2008: Fontani ((sub-) mm, galactic; preparation for ALMA)

Rossetti: One of 4 original EU CASA-user support specialists who train EU community in its use, and act as interface between the EU-users and developers at NRAO.

Future situation

EUROPEAN ARC
ALMA Regional Centre || Italian

Immediate Future:

1 new post-doc to be hired 2010
1 ESO-ALMA COFUND Fellow may arrive 2010
INAF: ARC astronomer (tenure) 2010
INAF: ALMA science (tenure) 2010 (Arcetri or IRA)
Hardware acquisition: ≥ 2008 (www.alma.inaf.it)

Long-term: ≥ 2011:

1 FTE provided by (4-6) IRA-staff; 1 system manager;
4 post-doc positions

+ Involve experts from other institutes

Activities: recent & future

Regular (ca. 1/month) internal ARC-meetings; ALMA days

Received first visitor!

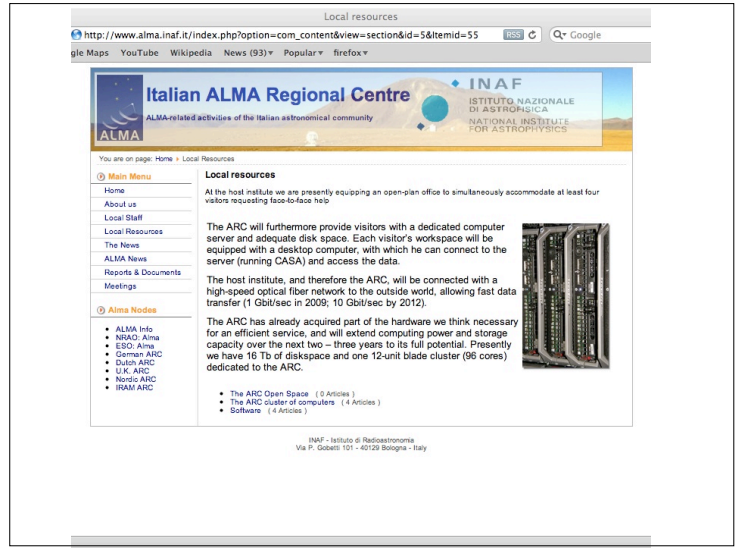
CASA-tutorial - 27-29 April 2010

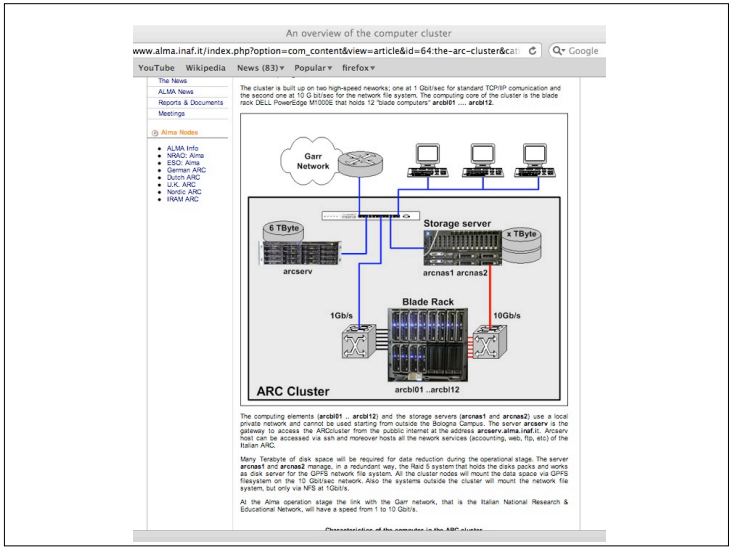
ALMA-course (Rome/Teramo) - Nov. 2009

International School on "ALMA and Astrochemistry"
(COST Action: The Chemical Cosmos: understanding chemistry in astronomical environments) - 2011

Preparation of visitors' open-plan offices (1 Gb/s link)

Web page development (Joomla!) (http://www.alma.inaf.it)





USEFUL WEB PAGES

Latest News:
http://www.almaobservatory.org/

General ALMA pages at ESO:
http://www.eso.org/sci/facilities/alma/

Possible Science Projects (DRSP):
http://www.eso.org/sci/facilities/alma/science/drsp/

ESO-ARC pages:
http://www.eso.org/sci/facilities/alma/arc/

Italian ARC-pages:
http://www.alma.inaf.it/

Check for job offers.