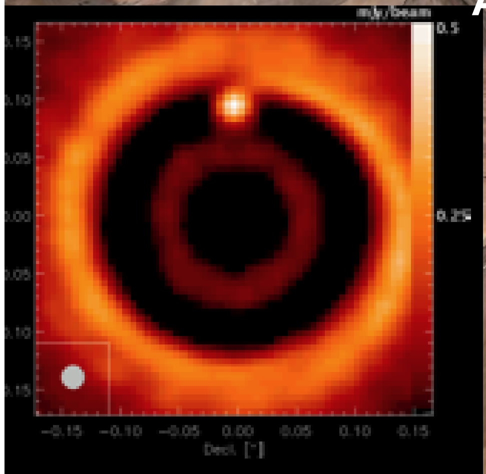
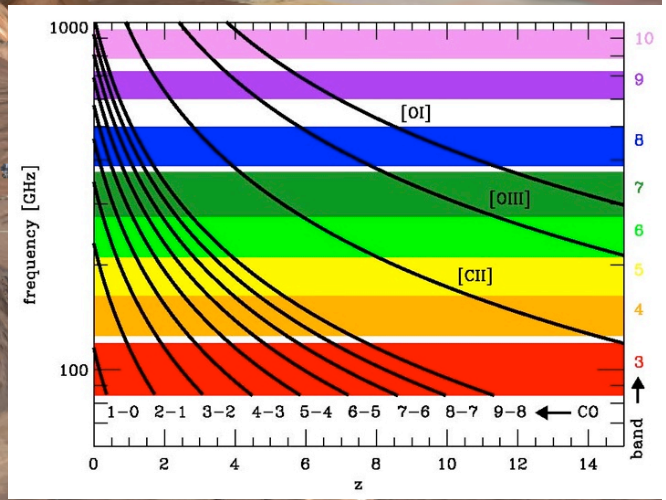
The ALMA project, future plan and first scientific results

Paola Andreani
Head of the European
ALMA Regional Centre





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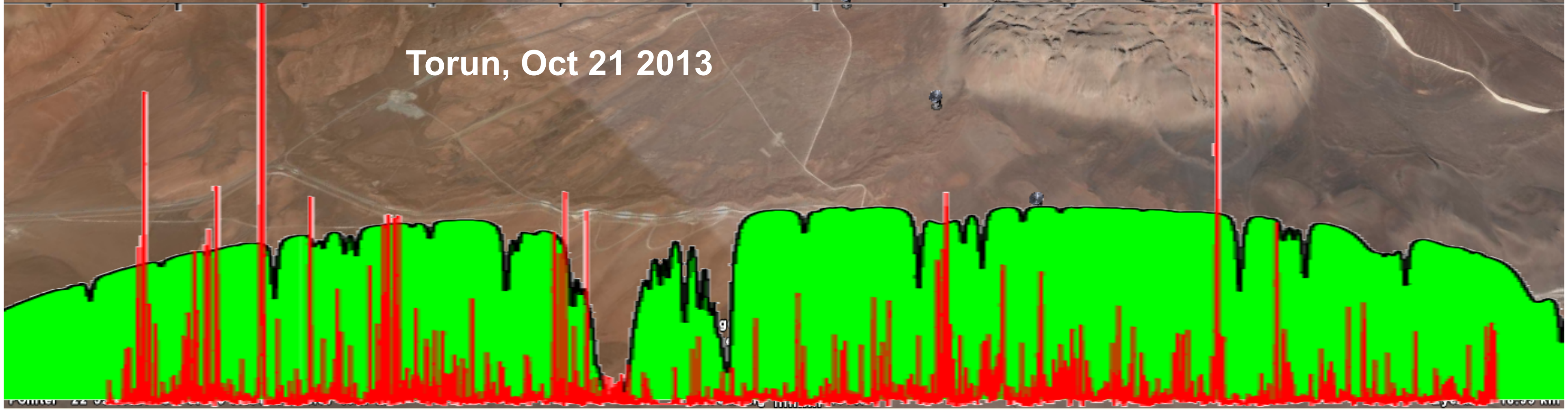
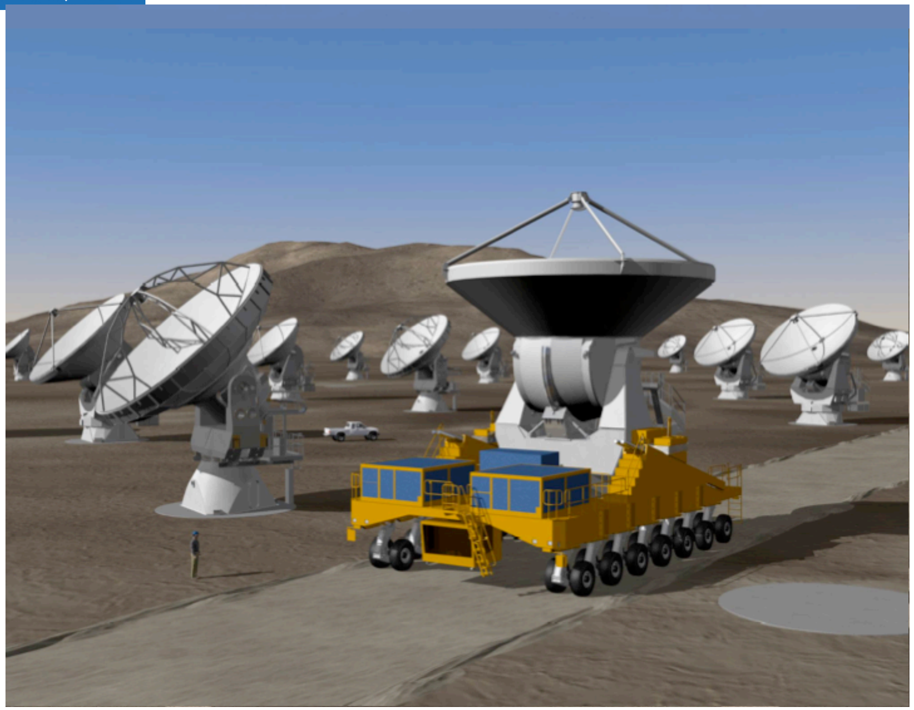


Torun, Oct 22, 2013

Paola Andreani

Atacama Large Submm/mm Array

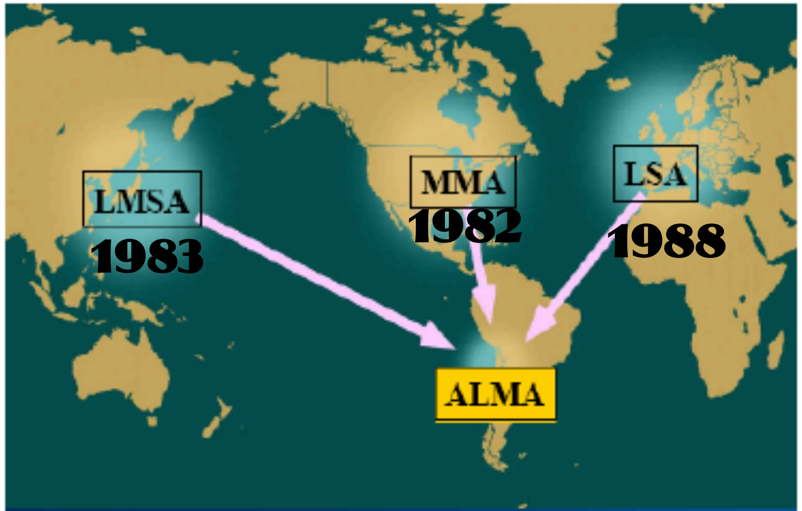


- *50x12m Antennas*
- *Frequency range 30-1000 GHz (0.3-10mm)*
- *16km max baseline (<10mas)*
- *ALMA Compact Array (4x12m and 12x7m)*

1. Detect and map CO and [C II] in a Milky Way galaxy at z=3 in less than 24 hours of observation
2. Map dust emission and gas kinematics in protoplanetary disks
3. Provide high fidelity imaging in the (sub)millimeter at 0.1 arcsec resolution

The history of ALMA

- In the 1980's y 1990's first ideas in Europe, United States and Japan to construct the next generation of mm-wave interferometers
- 1995: first site testing in Chile
- 1999: agreement to install ALMA in Chile
- 2003: start of construction
- 2007: arrival of the first antenna in Chile
- 2011: start of Cycle 0 Early Science observations with 16 antennas
- 2013: Inauguration, end of construction



ATF (ALMA Test Facility), Socorro, NM, USA

The history of ALMA

June 1997: *Charlottesville at NRAO, ESO and NRAO sign a resolution to develop a common project*

Convergence to a common project: *expansion to submm, high altitude, reduction of antenna dish*

Feasibility?
12m dishes?
Challenges: *USA-Europa-Chile agreement*

Trilateral project
Japan joins the project in 2003
Bringing additional and unique capabilities to the observatory

RESOLUTION

Whereas the development of millimeter-wavelength astronomy has shown the potential of large millimeter interferometric arrays for revealing the origin and evolution of stars and planetary systems, of galaxies, and of the Universe itself; the communities in the United States and Europe have proposed the construction of the Millimeter Array (MMA) and the Large Southern Array (LSA), respectively; and there is an opportunity through cooperation to achieve more than either community planned; we, as the observatories responsible for these projects and with the support of our communities, resolve to organize a partnership that will explore the union of the LSA and MMA into a single, common project to be located in Chile. Specifically, this partnership will study the technical, logistical, and operational aspects of a joint project. Of particular importance, the two antenna concepts currently under consideration will be studied to identify the best antenna size and design or combination of sizes to address the scientific goals of the two research communities. In doing so we will work through our observatories, utilizing the expertise in millimeter astronomy resident in research groups and institutions in our communities. Finally, we recognize that there are similar goals for millimeter astronomy in Japan, and cooperative activities with that project will continue.

R. Giacconi
European Southern Observatory

P. Vanden Bout
National Radio Astronomy Observatory

26 June 1997

ALMA an international project

- ALMA Partners: Europe, North America, East Asia
- Chile is the host country and Chilean astronomers have 10% of the observing time
- More than 20 countries are involved in ALMA
- Construction cost: US $1600 millons

Inauguration took place on March 13th 2013

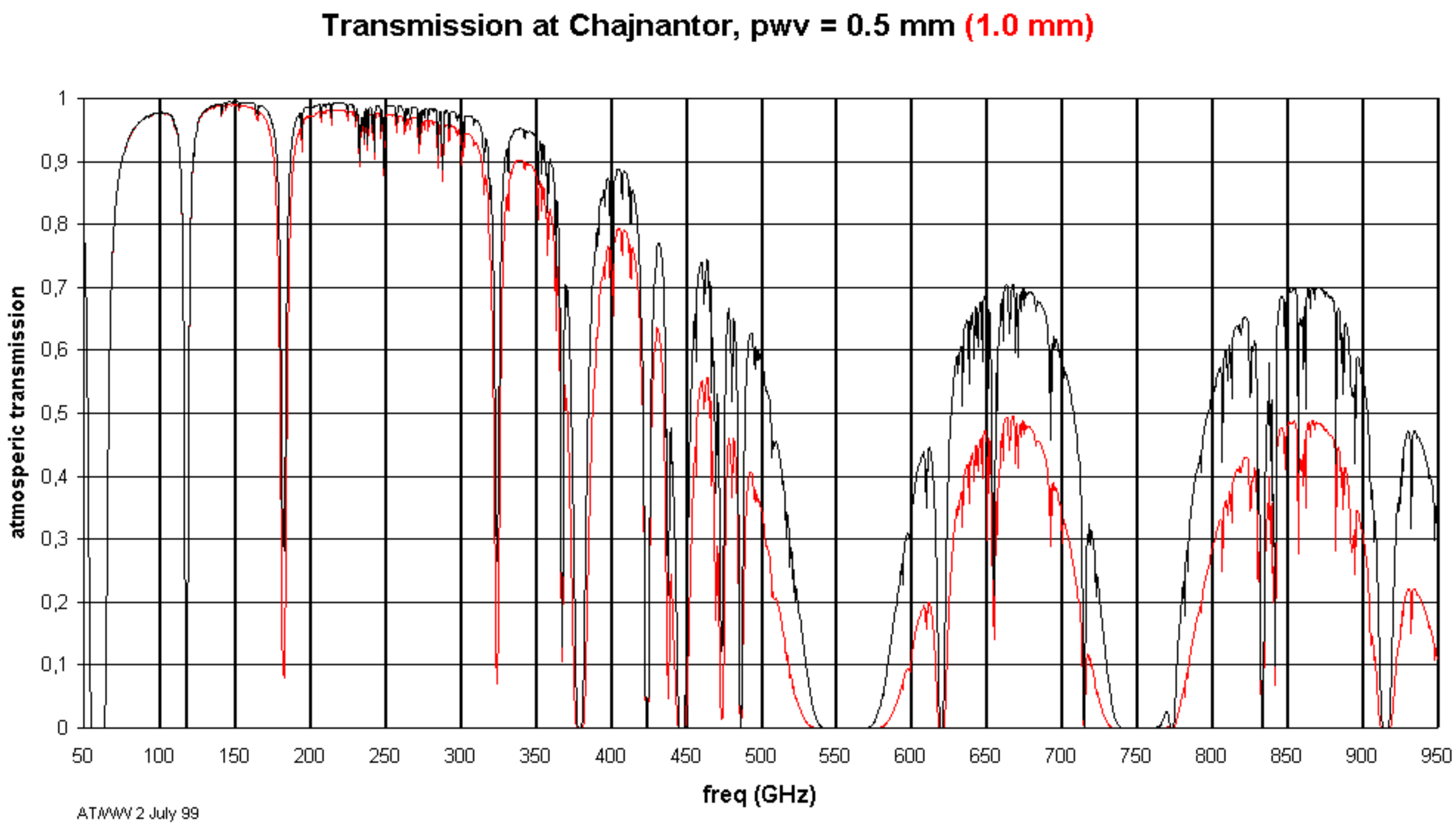
What is ALMA ?

- Aperture synthesis array with 66 radio telescopes for sub-/millimetre wavelengths
- Costruction almost complete
- Located in Northern Chile at 3000m and 5000m
- Excellent site for submm astronomy
- First science observations started on 30 Sep 2011
- ALMA uses challenging technologies

(Sub-) Millimetre Astronomy

- Wavelengths of ~0.3 to ~10 mm (1000-30 GHz)
  - Between infrared and radio regime
- Sub-/Mm astronomy studies the Cold Universe
- Sub-/Millimetre astronomy is crucial for understanding star and planet formation
- Submillimeter-wavelength (0.3 - 1.0 mm) astronomy is perhaps the last wholly unexplored wavelength frontier
  - Technically difficult
  - Earth atmosphere rather "opaque" at submm wavelengths

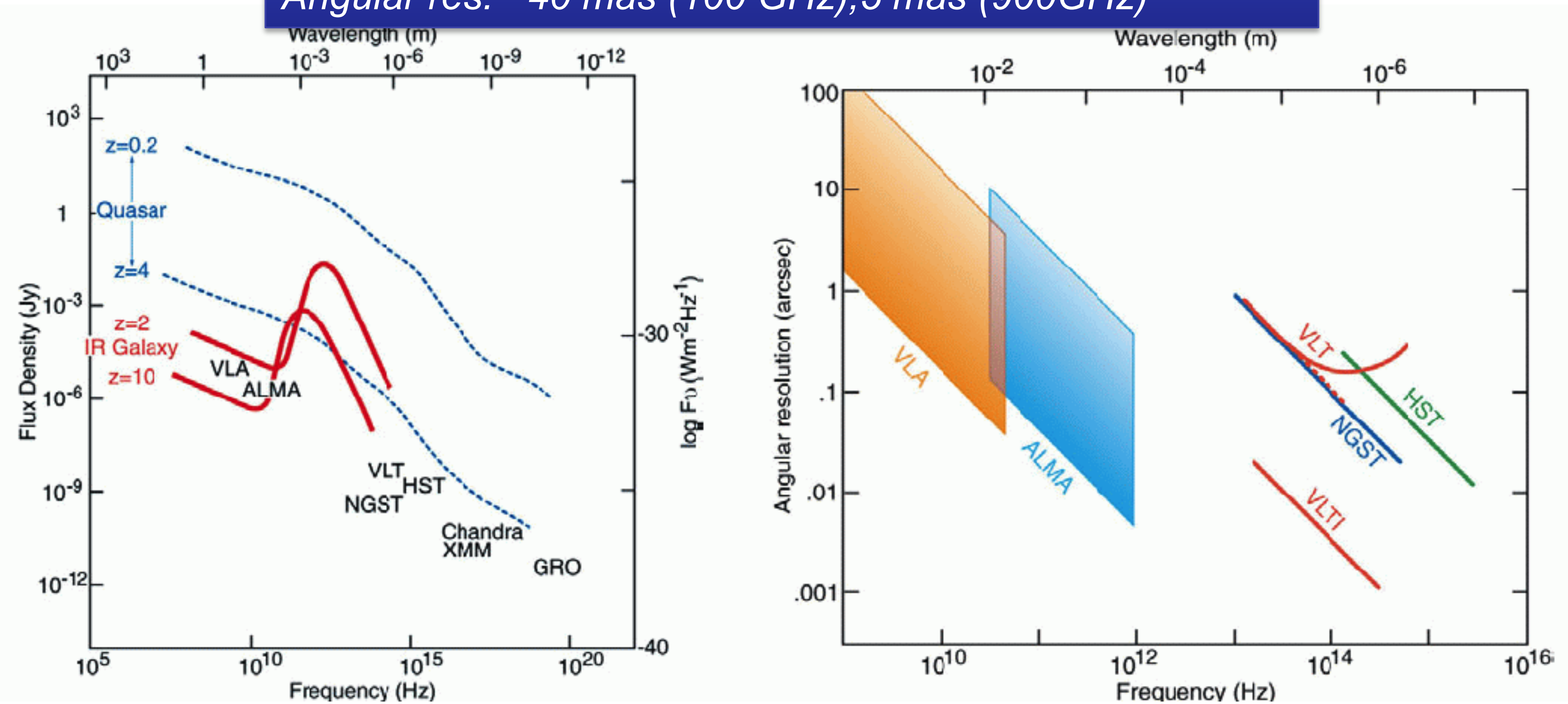
Atmospheric transmission 5000m



pwv = precipitable water vapour, i.e. the column height of condensed water vapour

Sensitivity and resolution

Sensitive, precision imaging 30 to 950 GHz
350 GHz continuum sensitivity: about 1.4mJy (1 sec)
Angular res. ~40 mas (100 GHz),5 mas (900GHz)

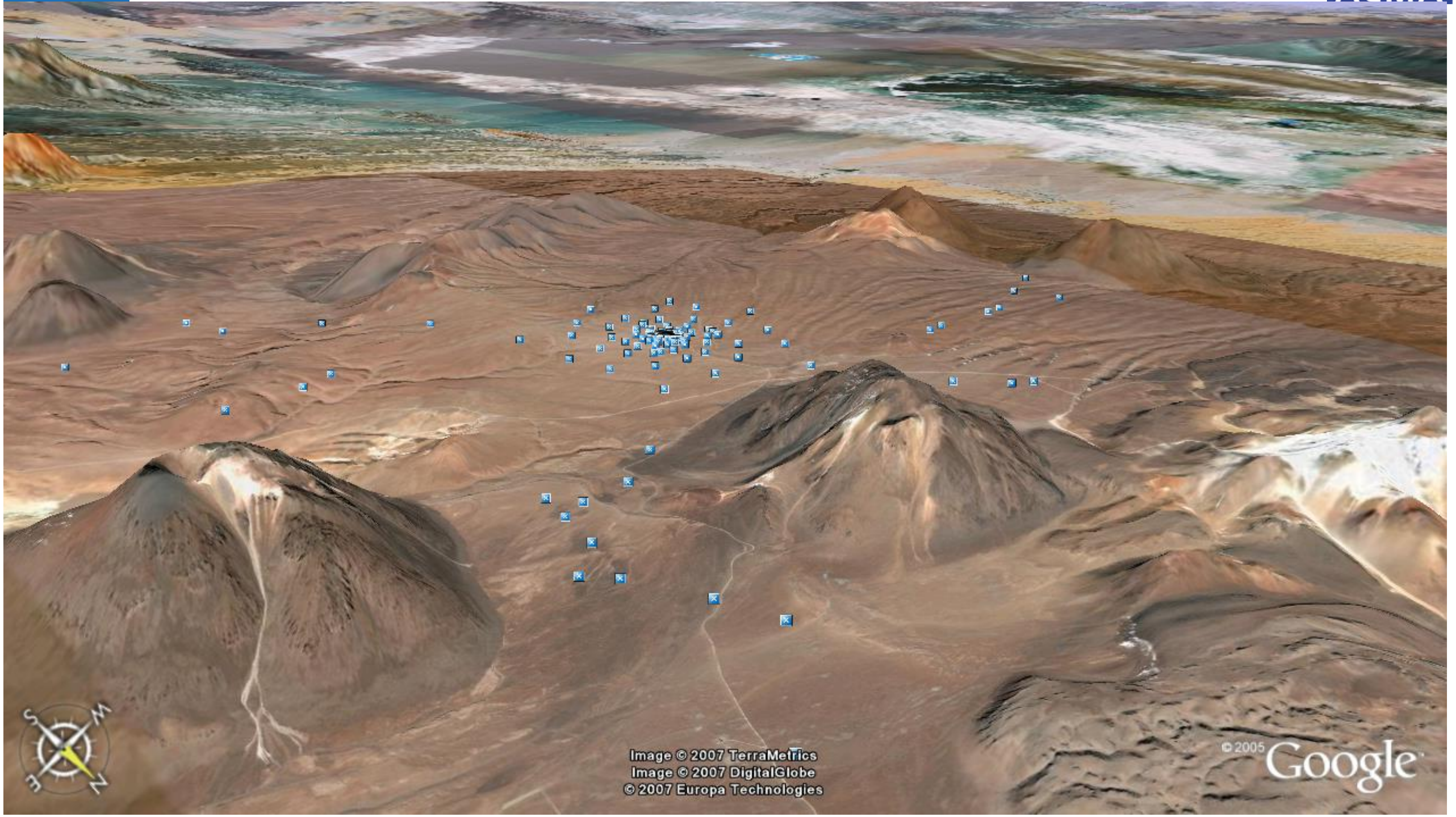


10-100 times more sensitive and better angular resolution compared to current sub-/mm arrays

ALMA Science requirements

- High fidelity imaging
- Precise Imaging at 0.1” Resolution
- Routine sub-mJy Continuum Sensitivity
- Routine mK Spectral Sensitivity
- Wideband Frequency Coverage
- Wide Field Imaging Mosaicing
- Sub-mm Receiver System
- Full Polarisation Capability
- System Flexibility

Most extended configuration – 16 km baselines



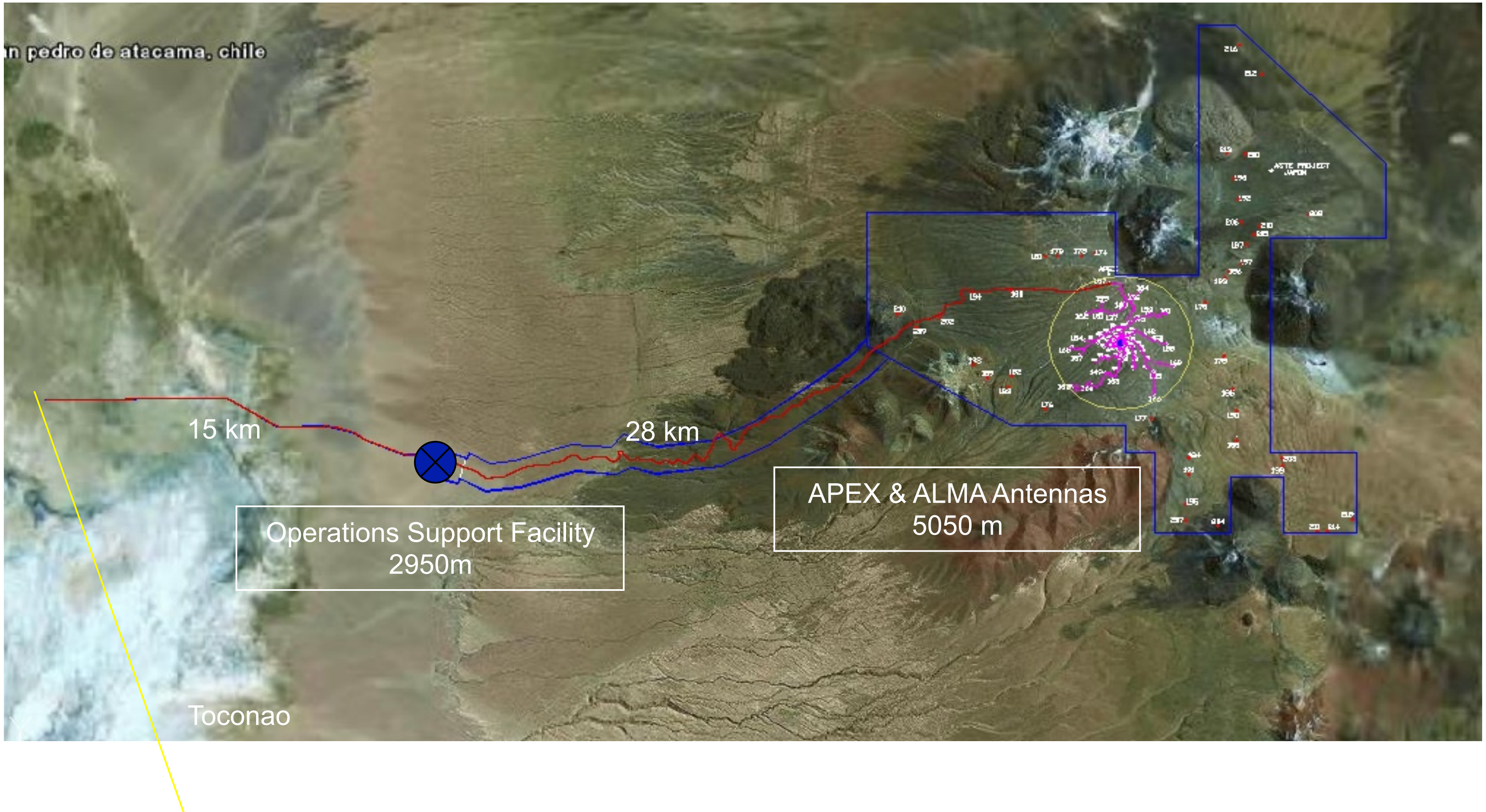
Location

Three sites in Chile

- **ALMA Operations Site (AOS)**: high, dry site, Chajnantor Plateau (5000m)
- **Operations Support Facility (OSF):** Technical base (2900m) near San Pedro de Atacama
- **Santiago** headquarters


San Pedro de Atacama (2400m)
AOS (5000m)
OSF (2900m)

ALMA: OSF and AOS



OSF – Operations Support facility (2900m)

ALMA OSF (2900m)

ALMA OSF (2900m)


Llano de Chajnantor (5050m)

AOS in March 2013

ALMA antennas

- Antennas provided by three different vendors
  - Vertex (North America)
  - AEM consortium (Europe)
  - Melco (Japan)
- Same specifications for all antennas
- Currently ~30 antennas at the 5000m site, and continuously being added more

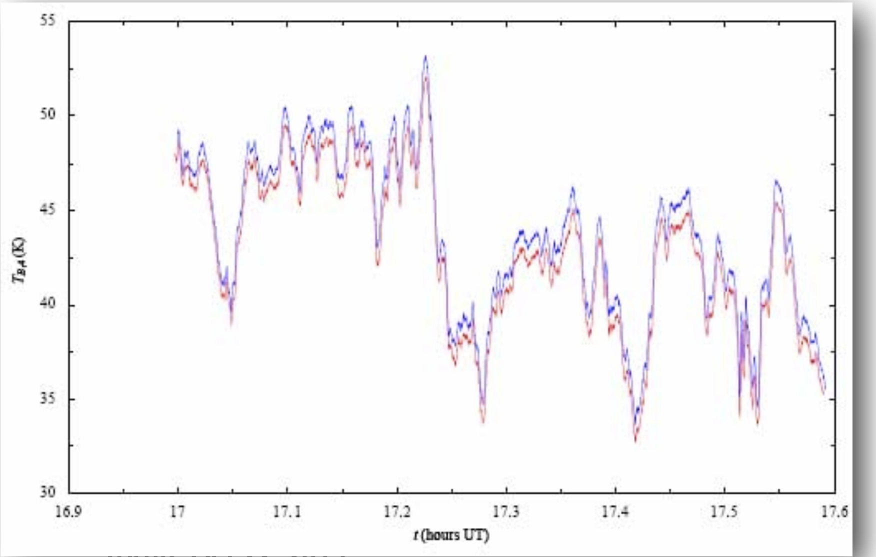


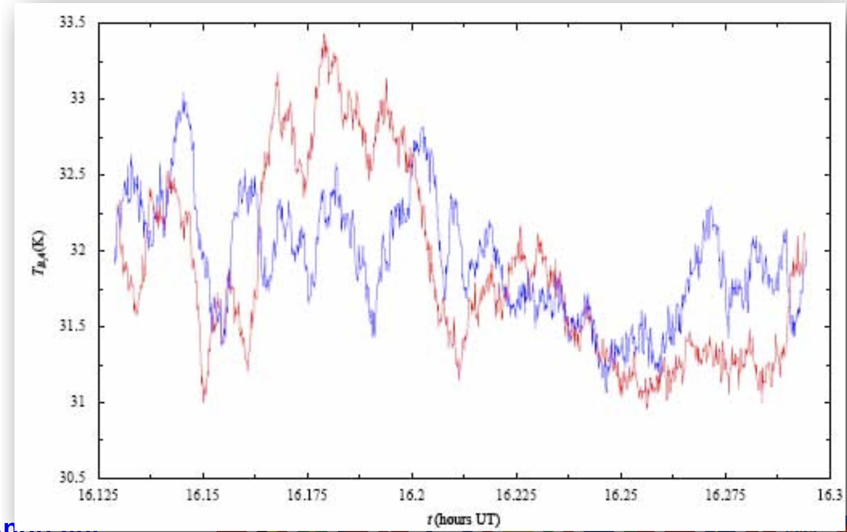

Key antenna specifications

- 12m and 7m diameter
- 25 µm rms surface accuracy under operating conditions (gravity, wind, thermal)
  - Requires ~11 µm rms surface setting
- 2 arcsec rms absolute pointing; 0.6 arcsec rms offset pointing
- Tracking speed for on-the-fly mapping 1 deg/s
- Fast switching required between target and calibrator (1.5 deg in 1.5 sec)

Water vapour Radiometers

- All antennas are equipped with water vapour radiometers observing the 183GHz atmospheric water line.
- WVR tracks phase at 1s timescale along the same path (within 3-10') as the astronomical signal. Complementary to fast switching >10s and few degs.
- Improved sensitivity and fidelity
- Allow to increase switch time

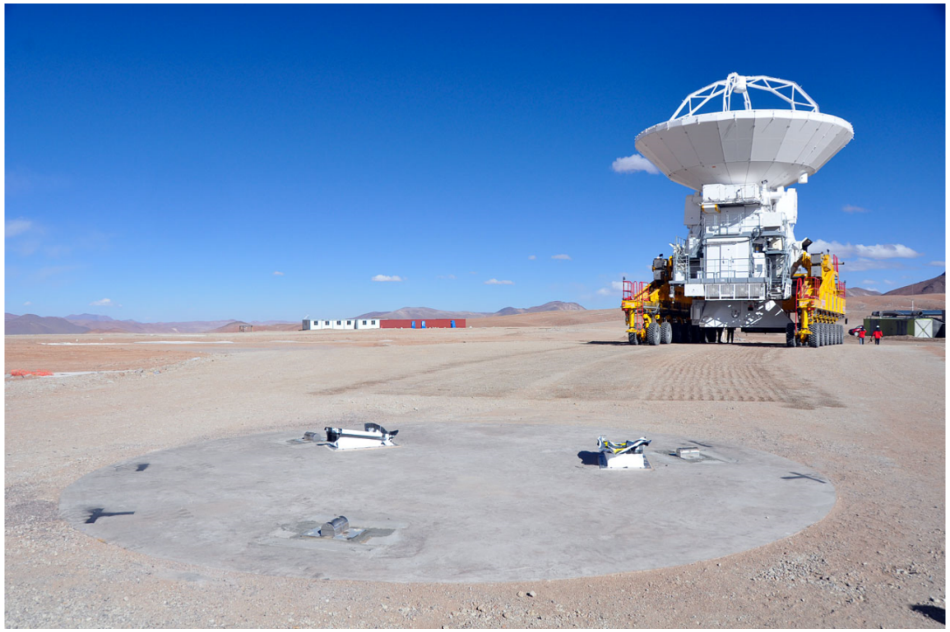




Antenna integration at OSF

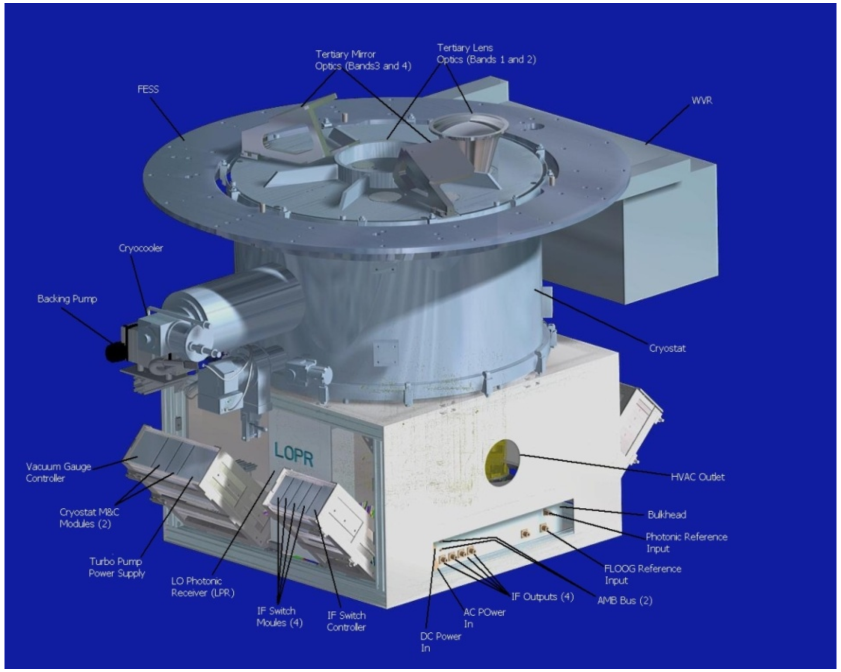
Antenna transport

- Two custom-made transporters, delivered by ESO

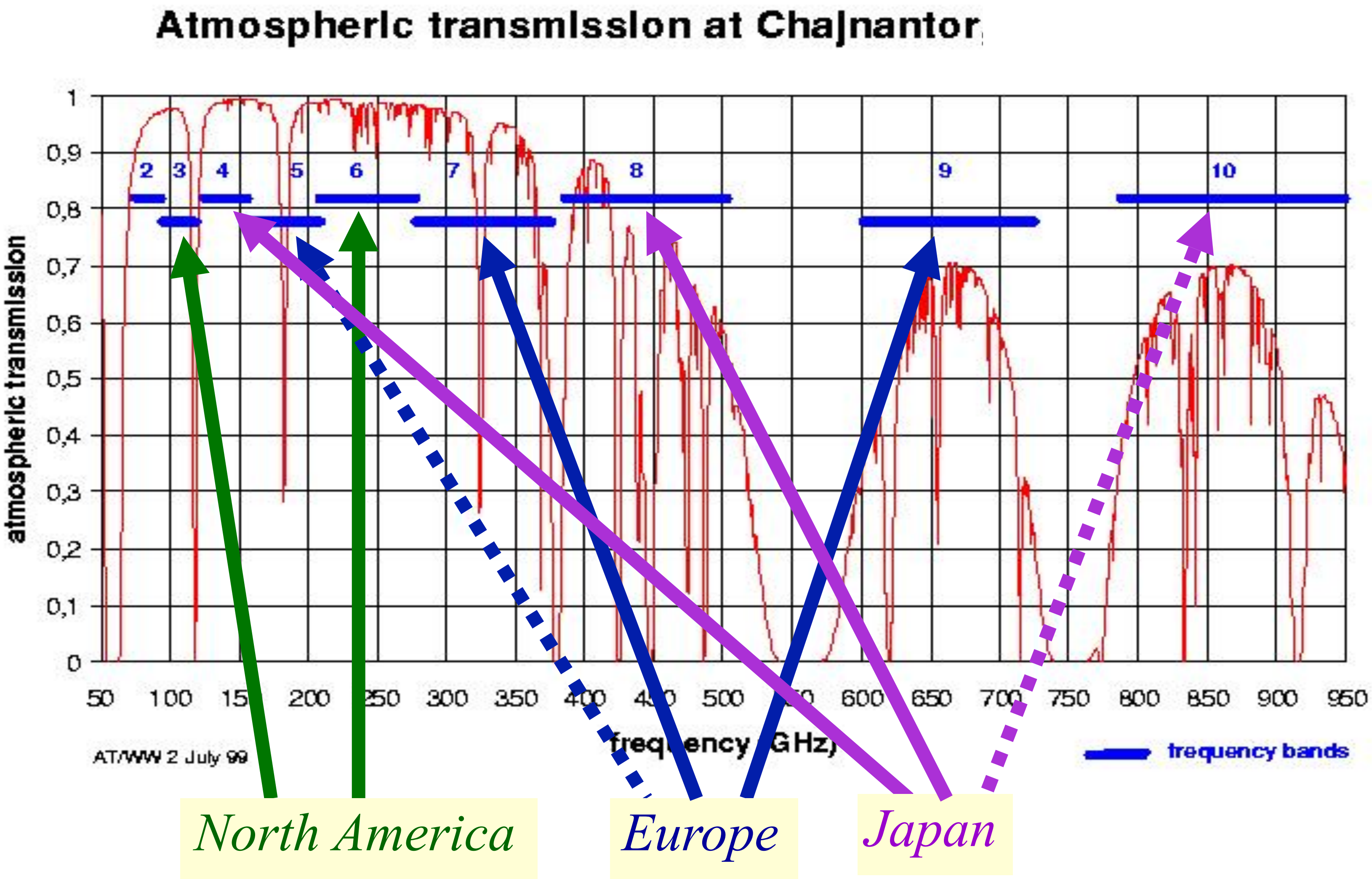


Front End Assemblies

- 10 bands from 30 GHz to 950 GHz in one cryostat
- Bands 3, 4, 6, 7, 8, and 9 in production
- Band 10 prototyping
- Band 5: 6 units, full production may start in 2012
- Band 1 under development



ALMA Frequency Bands



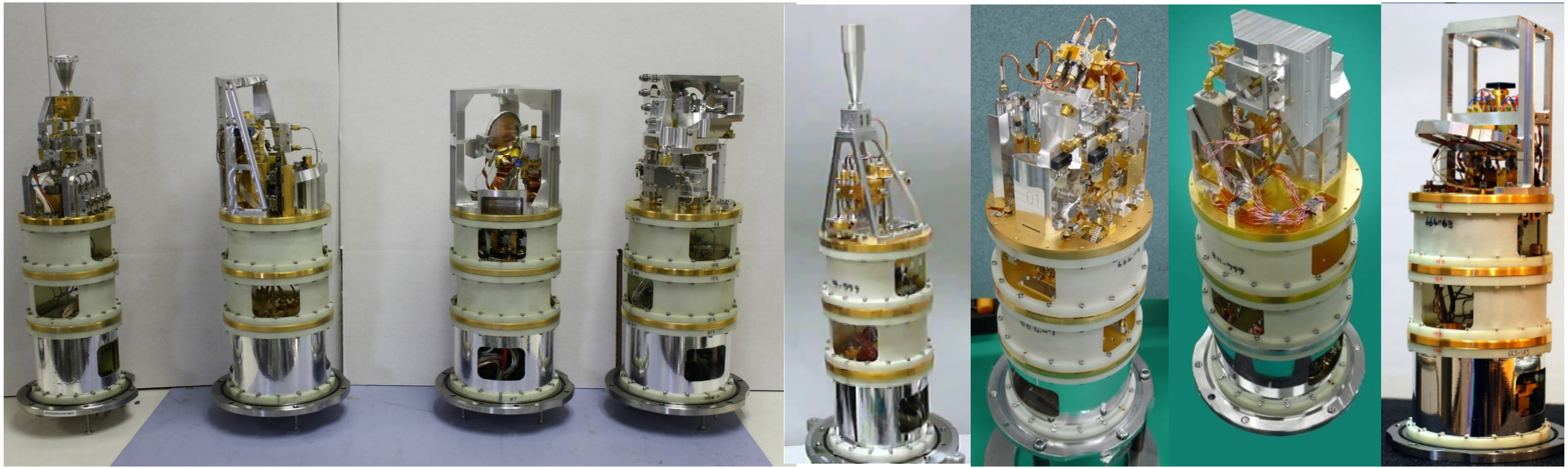
ALMA Frequency Bands

ALMA Band	Frequency Range (GHz)	Receiver Noise (K) over 80% of the RF band	Temperature (K) at any RF Frequency	To be produced by	Receiver Technology
1	31 - 45	17	26	tbd	HEMT
2	67 - 90	30	47	tbd	HEMT
3	84 - 116	37	60	HIA	SIS
4	125 - 163	51	82	NAOJ	SIS
5*	162 - 211	65	105	NOVA/OSO	SIS
6	211 - 275	83	136	NRAO	SIS
7	275 - 373	147	219	IRAM	SIS
8	385 - 500	196	292	NAOJ	SIS
9	602 - 720	175	261	NOVA	SIS
10	787 - 950	230	344	NAOJ	SIS

* Six Band 5 units produced under FP6 funding

Receiver Cartridges

The ALMA receivers are built in different institutes/countries across the ALMA partnership



Band 3	Band 6	Band 7	Band 9	Band 4	Band 8	Band 10	Band 5
HIA	NRAO	IRAM	NOVA	NAOJ	NAOJ	NAOJ	GARD+

Front End Integration

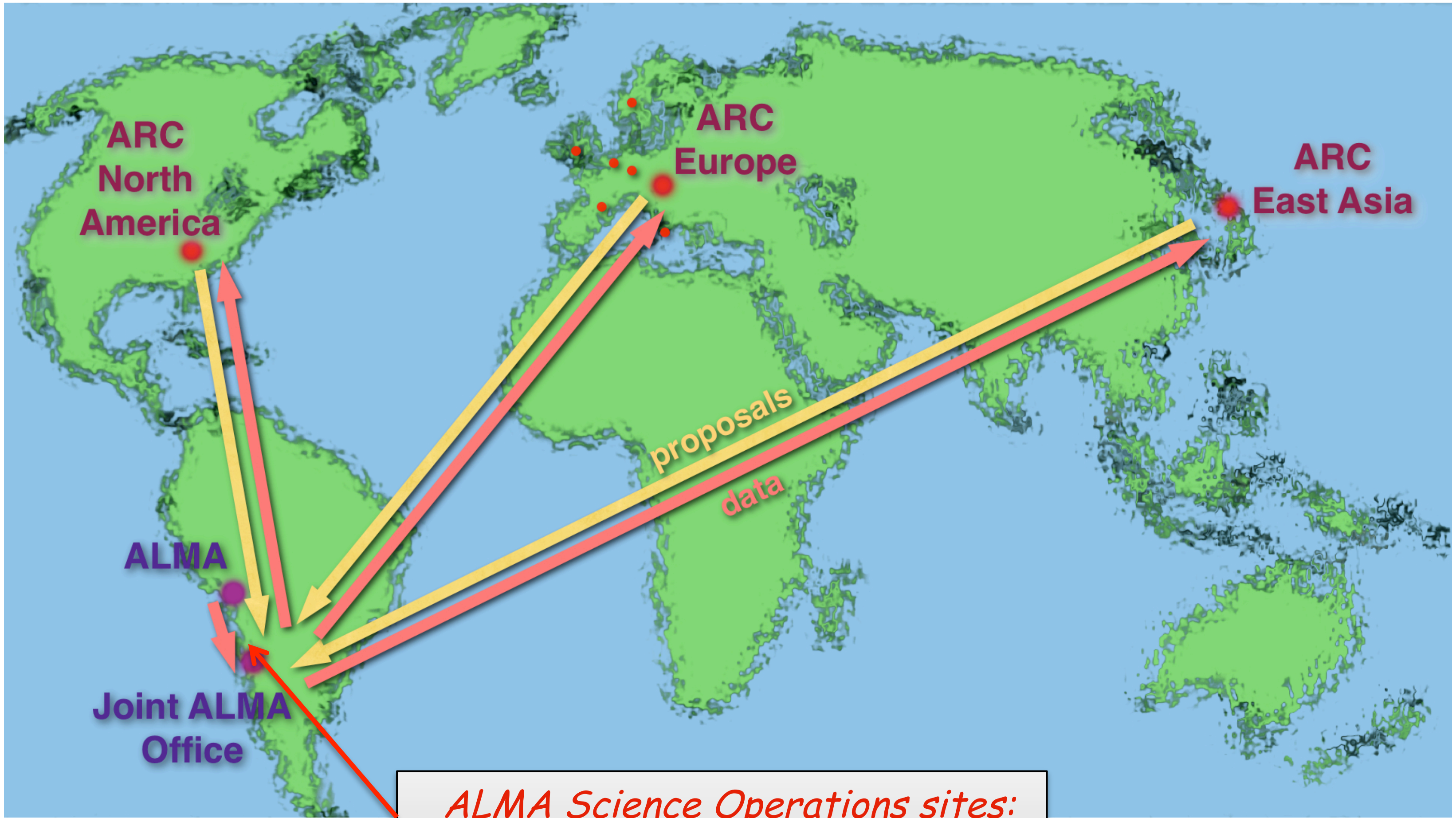
- The Front Ends are integrated and tested in three Front End Integration Centers
  - RAL (UK)
  - NRAO (USA)
  - ARL (Taiwan)
- Integration of 26 subsystems/components from all ALMA partners
- All front ends arrived in Chile

Front End Verification

Roads and Power Station

- 43 km of roads to OSF and AOS
  - 14 km from highway to OSF
  - 29 km from OSF to AOS, extra wide for antenna transport
- Power supply
  - ALMA needs ~7 MW of (peak) electrical power
  - Three multi fuel generators at OSF
  - Transmitted to AOS (29 km) via 23 kV line

ALMA in operations: the ARCs and their relation to the JAO



ALMA Science Operations sites:
Operations Support Facility (OSF)
Array Operations Site (AOS)
Santiago office

High-level concepts for Science Operations

- Observations only in service observing mode with flexible (dynamic) scheduling.
- Observations 24h/day interrupted by maintenance periods.
- All observations executed in the form of scheduling blocks (SBs).
- Default output: reliable images, calibrated according to the calibration plan.
- The Joint ALMA Observatory (JAO) is responsible for the data product quality.
- All science and calibration raw data are captured and archived.

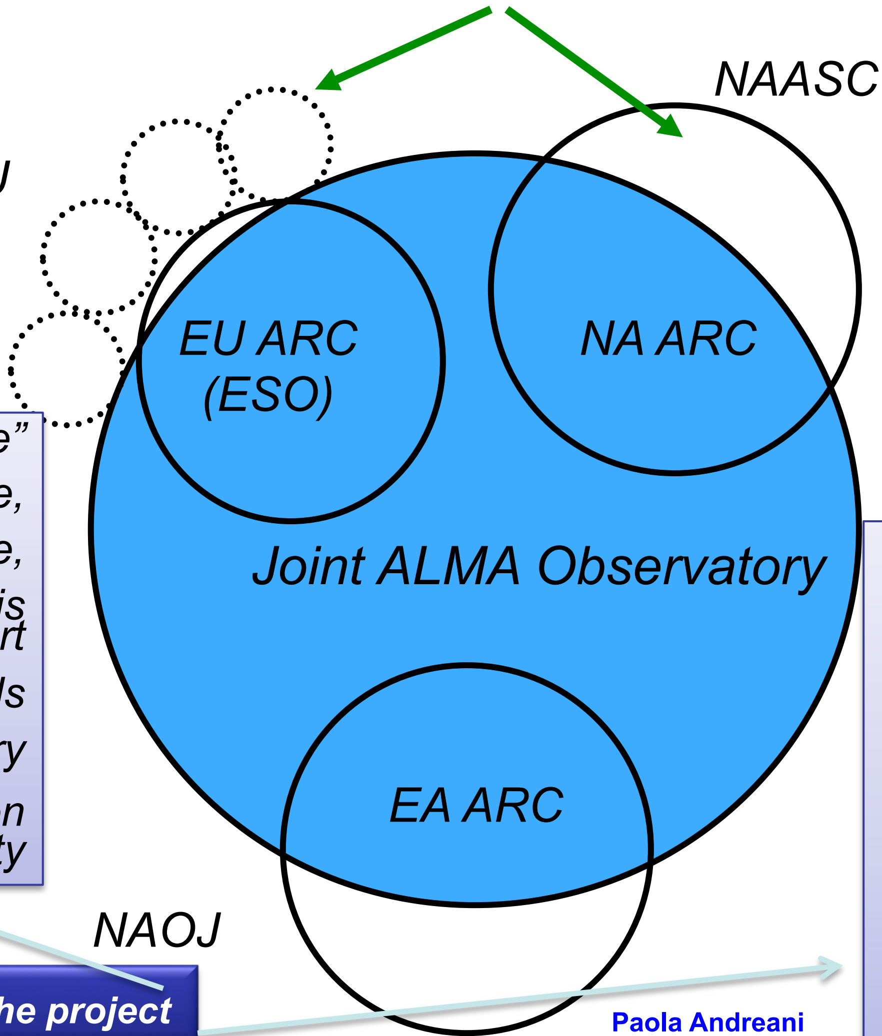
Users interface is provided by the ALMA Regional Centres (ARCs)

The Regional Centres are integrated parts of the ALMA Observatory

Funded by external agencies

Enhanced User Services

“Satellite” EU ARCs



Enhanced services essential to realise the full benefits of ALMA, provide advanced user support, algorithm development, student programs, public outreach, grants

ARCs provide”
user interface,
archive,
data analysis support
software tools
data delivery
Astronomers on duty

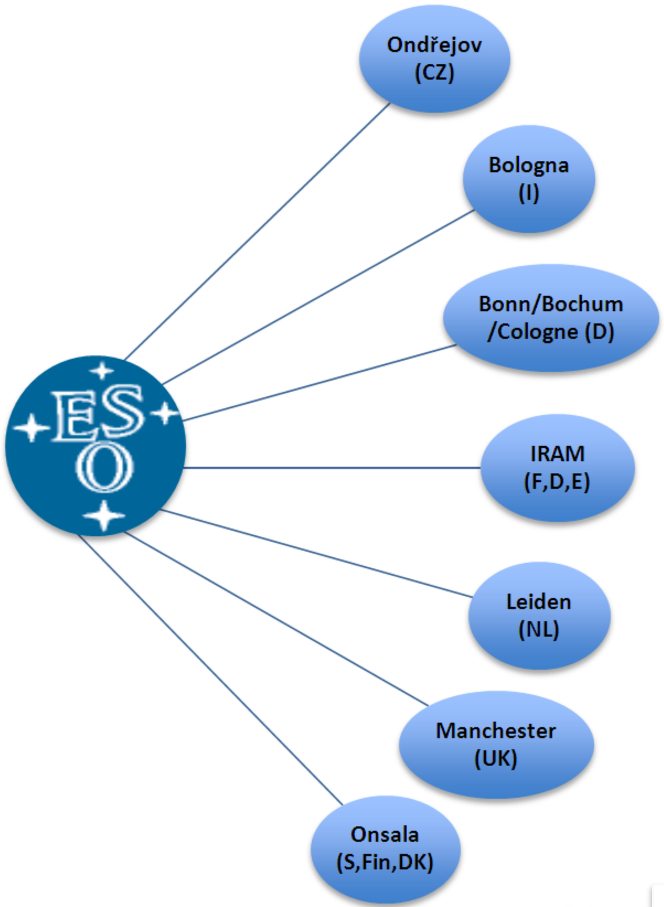
DSO provides:
- *Array operations*
- *Scheduling of projects*
- *Execution of observations*
- *Data quality assurance and trend analysis*
- *Calibration plan maintenance*
- *Delivery of data to the archives*
- *Archive operations*
- *Pipeline operations*

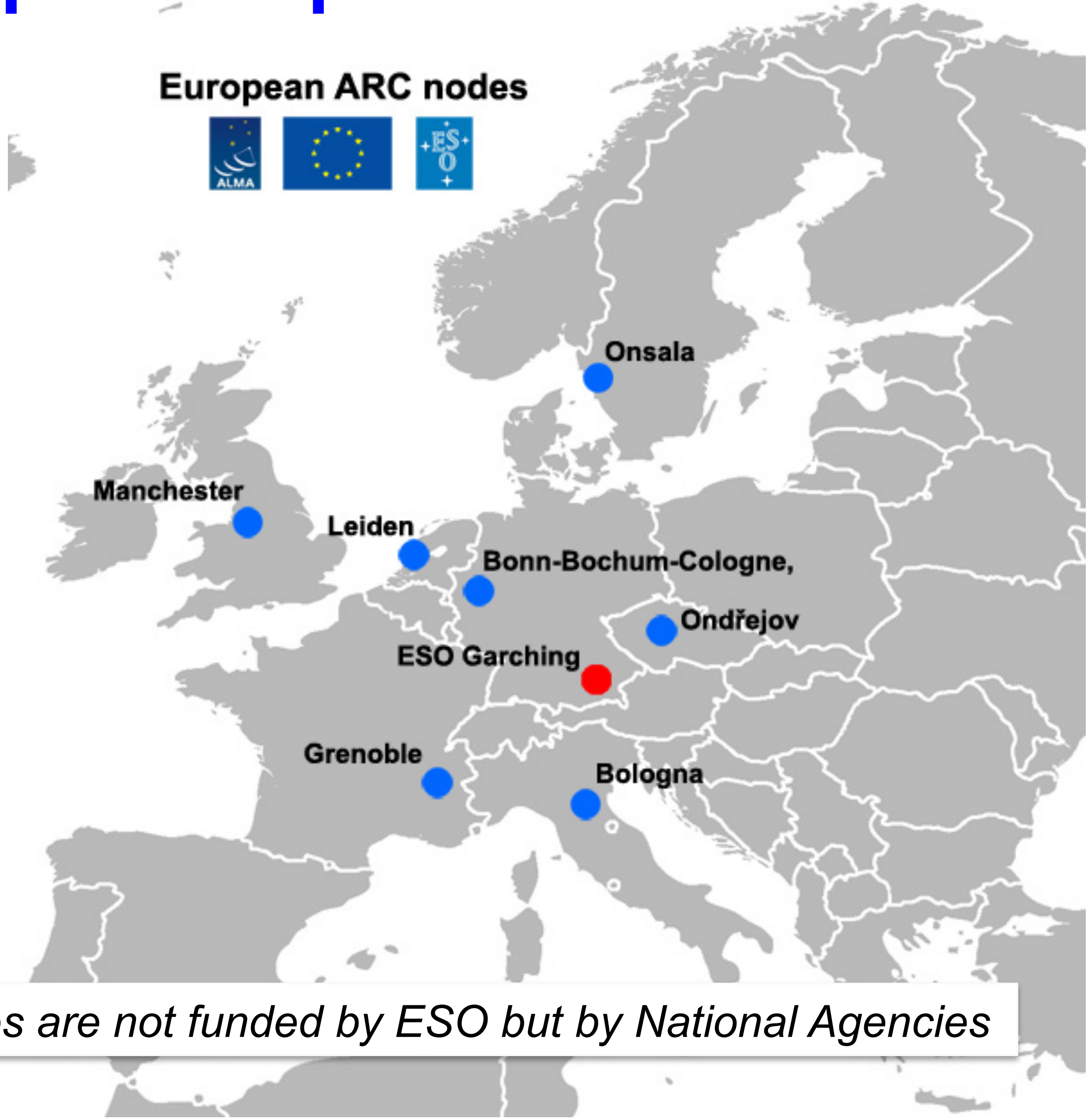
Funded by the project

The European ARC

User support is spread in EU

EU ARC = ESO + 7 Nodes



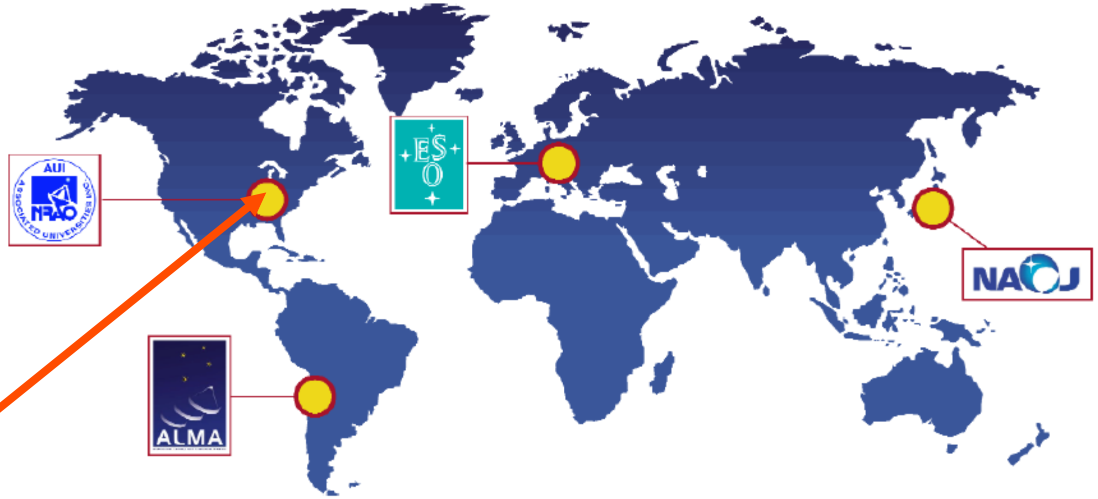


Nodes are not funded by ESO but by National Agencies

NAASC: North America ALMA Science Center (NRAO headquarters, Charlottesville, VA)

*The North American **ARC** is a partnership between the US, Canada (7.25%), and Taiwan*

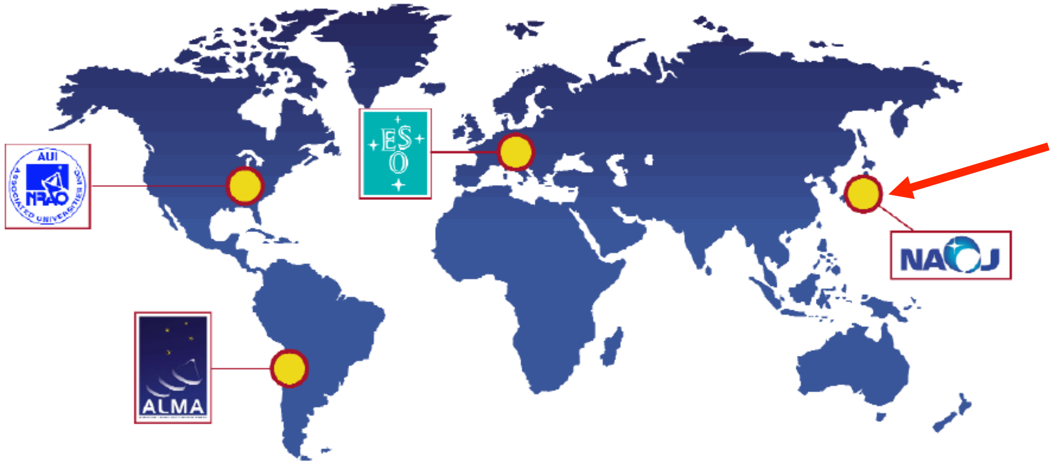
The NAASC is a combination of the NA ARC and US funded Full Science Support



One-stop shopping for NA-related astronomers

- *Proposals*
- *Observing scripts*
- *Data archive and reduction*

East Asian ARC

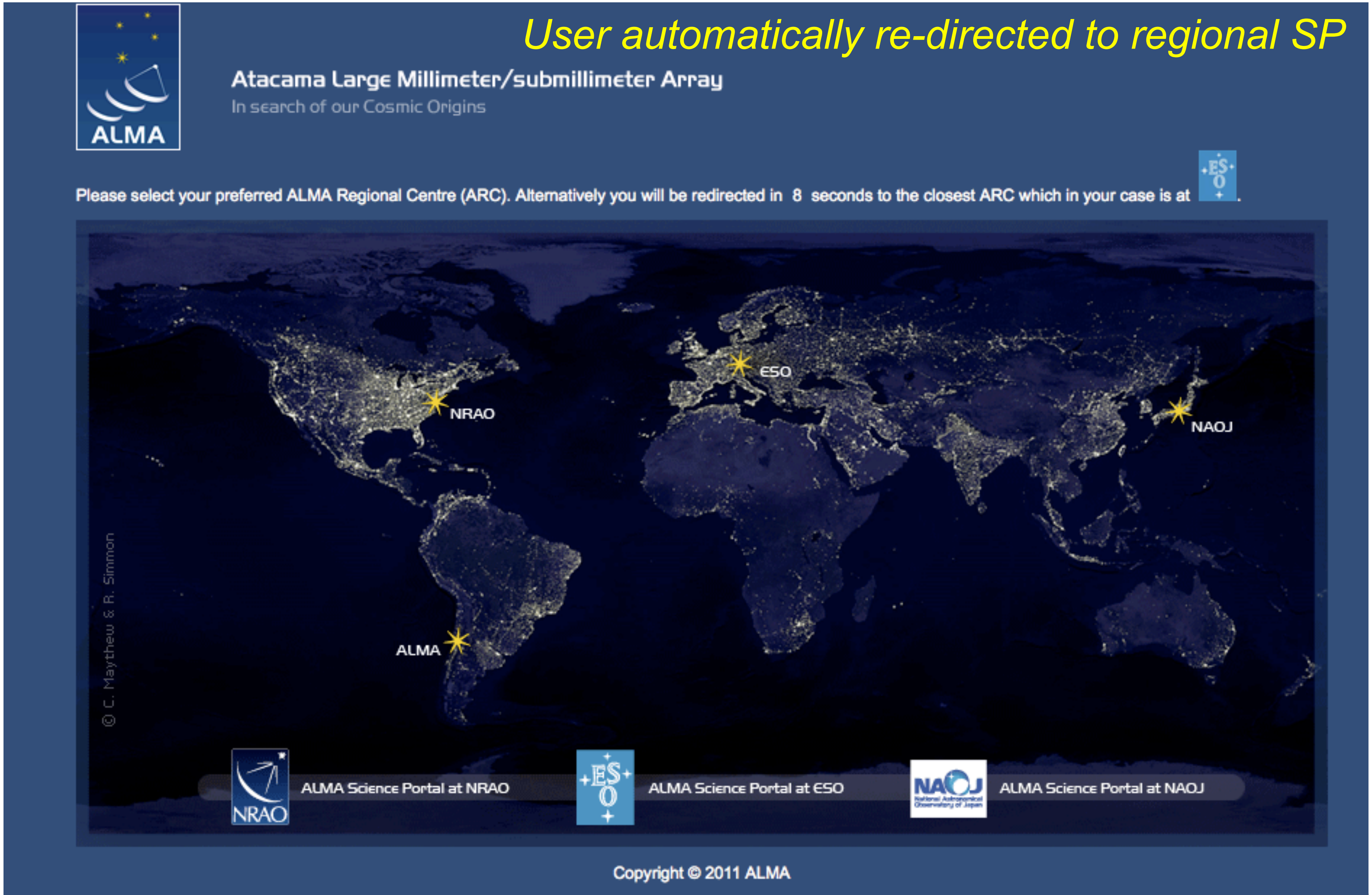


- *Located in Mitaka (at NAOJ)*
- *Partnership with Taiwan and South Korea*

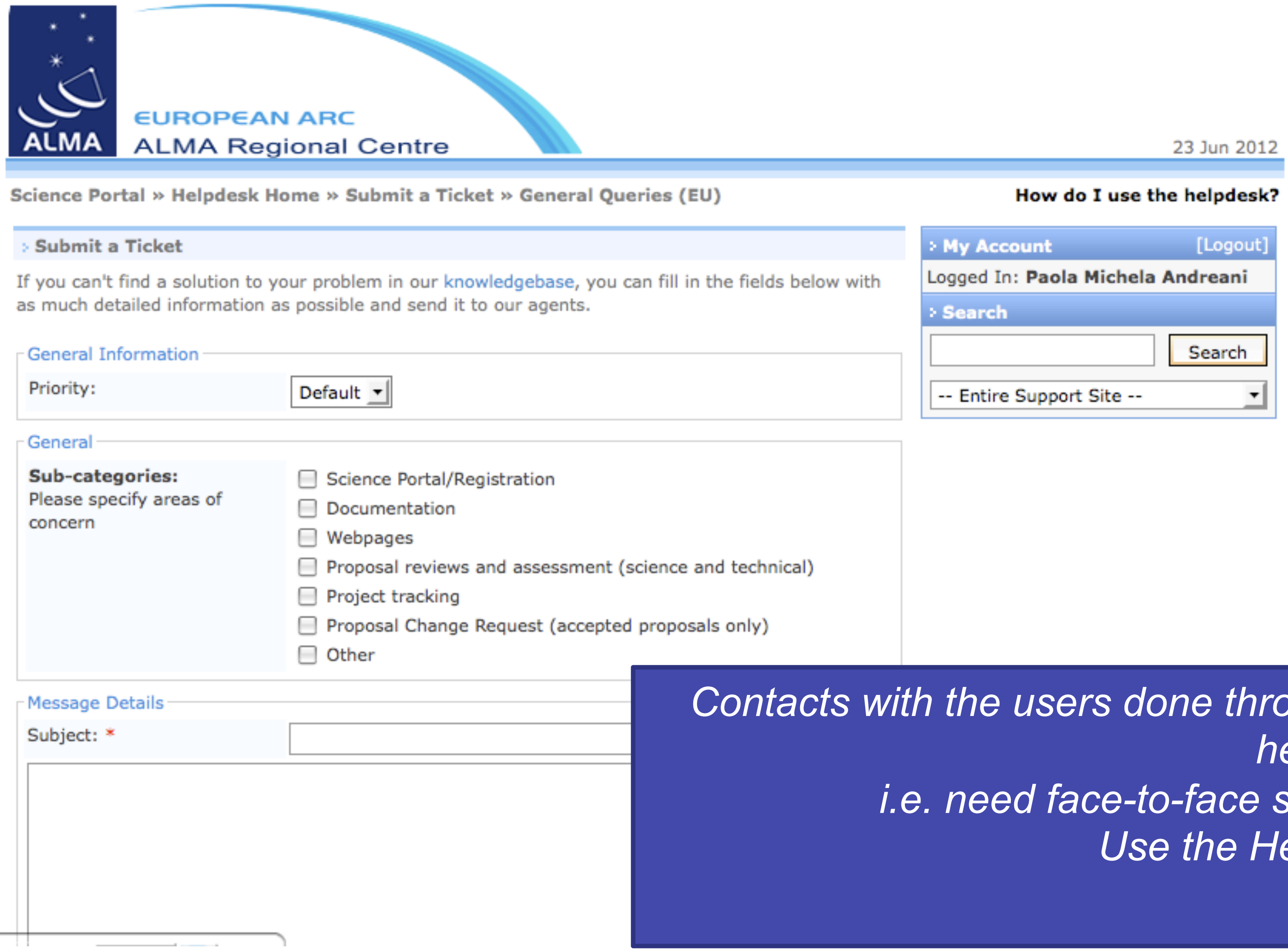
EA-ARC non-core development:

- Joint archive of ALMA, Nobeyama 45m, (SMA?)
- Data base with quality parameters for existing telescope (45m, SMA) data
- Data filler to CASA (45m, SMA, NMA)
- Laboratory molecular line database (Toyama),
  - cross-identification with other-wavelength data
  - http://www.sci.u-toyama.ac.jp/phys/4ken/atlas/
- VO—collaboration with JVO group (NAOJ)

The Science Portal: entry point to ALMA operations and users support

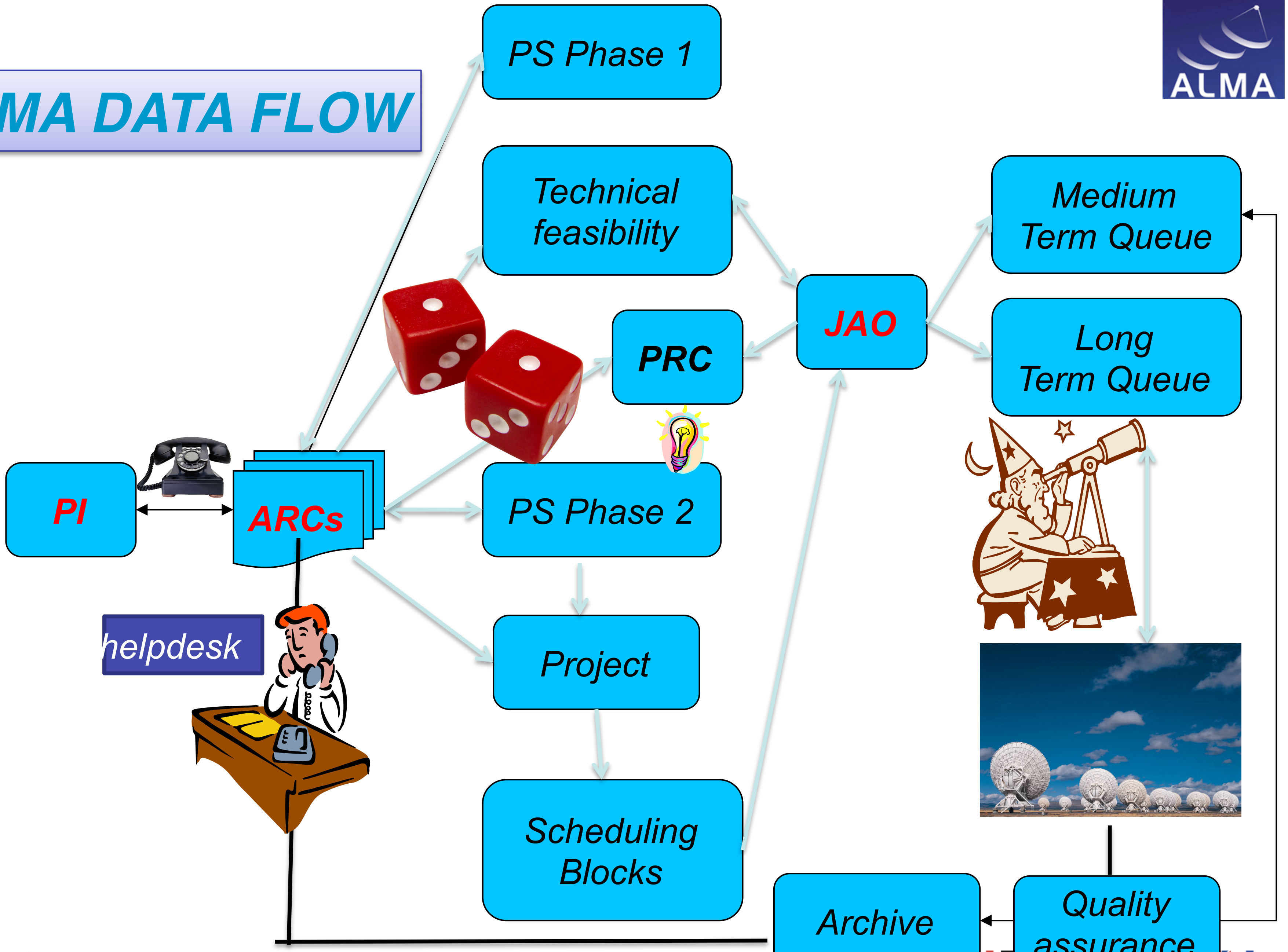


The helpdesk is the entry point to the EU ARC (ESO+nodes)



Contacts with the users done through the helpdesk.
i.e. need face-to-face support?
Use the Helpdesk.

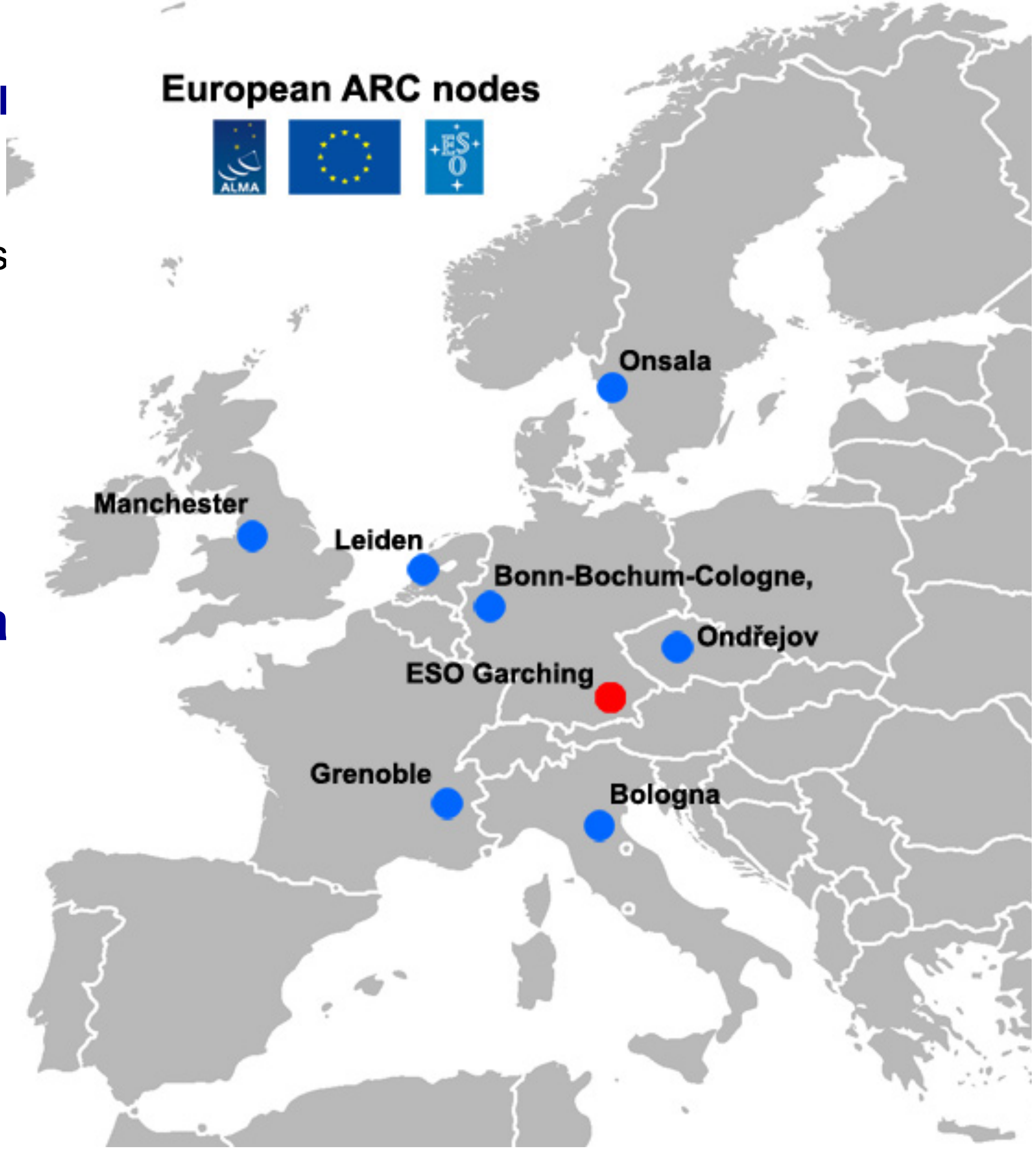
ALMA DATA FLOW



Role of the ARC nodes

- **Provide face to face suppo**
  - Proposal preparation
  - Contact scientists
  - SBs preparation together with PIs
  - Help in quality assessment
  - Data reduction
- **Participate in the ALMA helpdesk**
- **Participate in Commissioni**
- **Develop/suggest new SW a data reduction technique**

- **Community outreach and tutoring**



Expertise @ the EU ARC used in the helpdesk/ face-to-face visits

High-frequency observing	Allegro (NL)
Wide-field and high-dynamic-range imaging	IRAM/UK/NL
Molecular spectroscopy, catalogues, models	DE/CZ/NL
Polarimetry	IRAM/UK/DE/I
Astrometry	Nordic/UK/DE
Multi-frequency synthesis	Nordic/UK
Array combination imaging	UK
Solar physics	CZ

Helpdesk triage at the 3 ARCs (ESO, NA and EA)
Tickets dispatched to "experts" at all ends

2013 EU ARC events
and preparation of cycle 2

EU ARC RETREAT
June 10-12

29-31 May 2013
Nordic Science with ALMA

28-31 January 2013
Astrochemistry in the ALMA era

Sept 2-3 2013
UK Community days

Sept 8-13
European Radio Interferometry school

Nov 5-6 2013
German Community days

19-20 March 2013
Science with ALMA band 11

14-17 January 2013
Solar ALMA workshop

IRAM workshop Nov 14 2013

24-29 June 2013
CESRA 2013 Meeting with ALMA session,

Sept 13-20 2013
IRAM single dish school

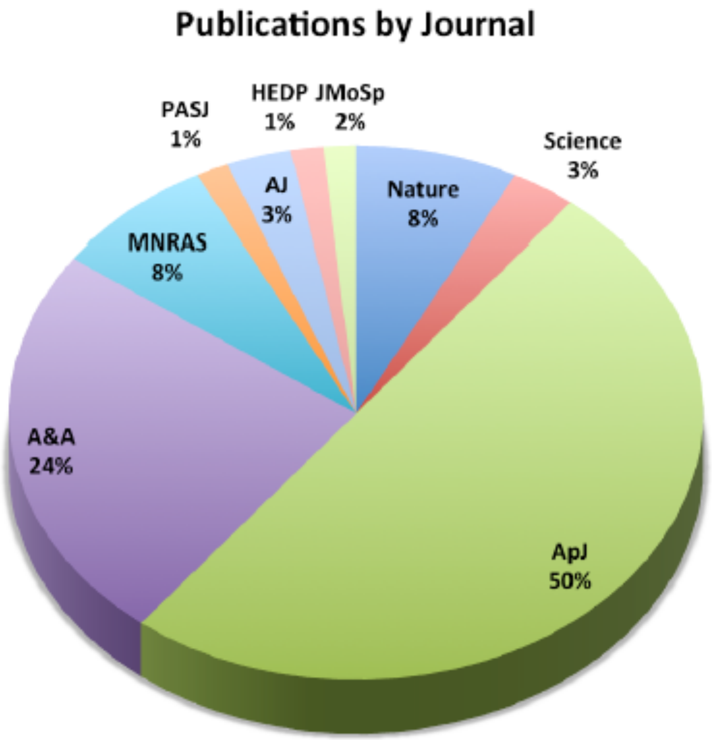
21-22 February 2013
Cycle 1 PI CASA tutorial

ALMA Early Science

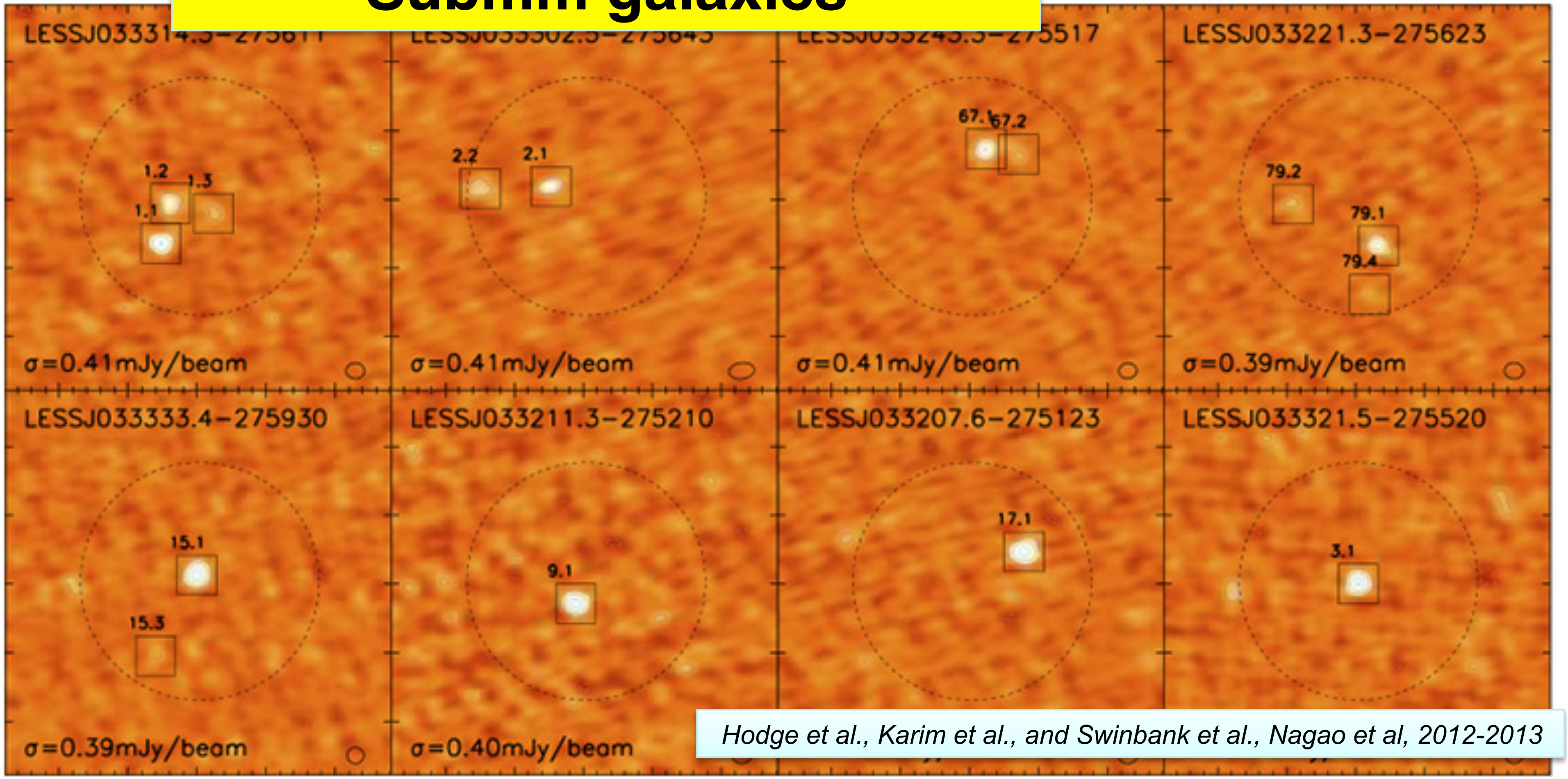
- Cycle 0:
  - Call on March 30, 2011
  - Capabilities: 16 antennas, bands 3,6,7, and 9
  - 919 proposals: 111 highest priority, 52 filler projects (500h)
    - 108 highest projects got data (77 projects completed + 21 projects Partially delivered (passed QA2)
    - 11 filler started (6 completed, 3 partially delivered)
- Cycle 1:
  - Call on May 31, 2012
  - 1131 Proposals: 197 High Priority projects, 92 fillers (800h)
  - January 2013 – May 31, 2014 → delayed
  - Capabilities: 32 antennas + ACA, Bands 3, 6, 7 and 9, baselines to 1 km
- Cycle 2:
  - Call for proposals: end of October 2013
  - Start of observations: June 1, 2014

ALMA SV+C0 Results

- Many results in published papers:
  - High-z, Disks, ISM, Star Formation, Local Universe, Solar System, Stellar Evolution, Supernovae, Cosmology, Fundamental Physics
  - For a sample, the First Year of ALMA Science Conference:
    - http://www.almasc.org/2012/
  - 67 refereed publications
  - 29 based on SV data
  - 38 used cycle 0 data
  - 10% in Nature/Science



Submm galaxies



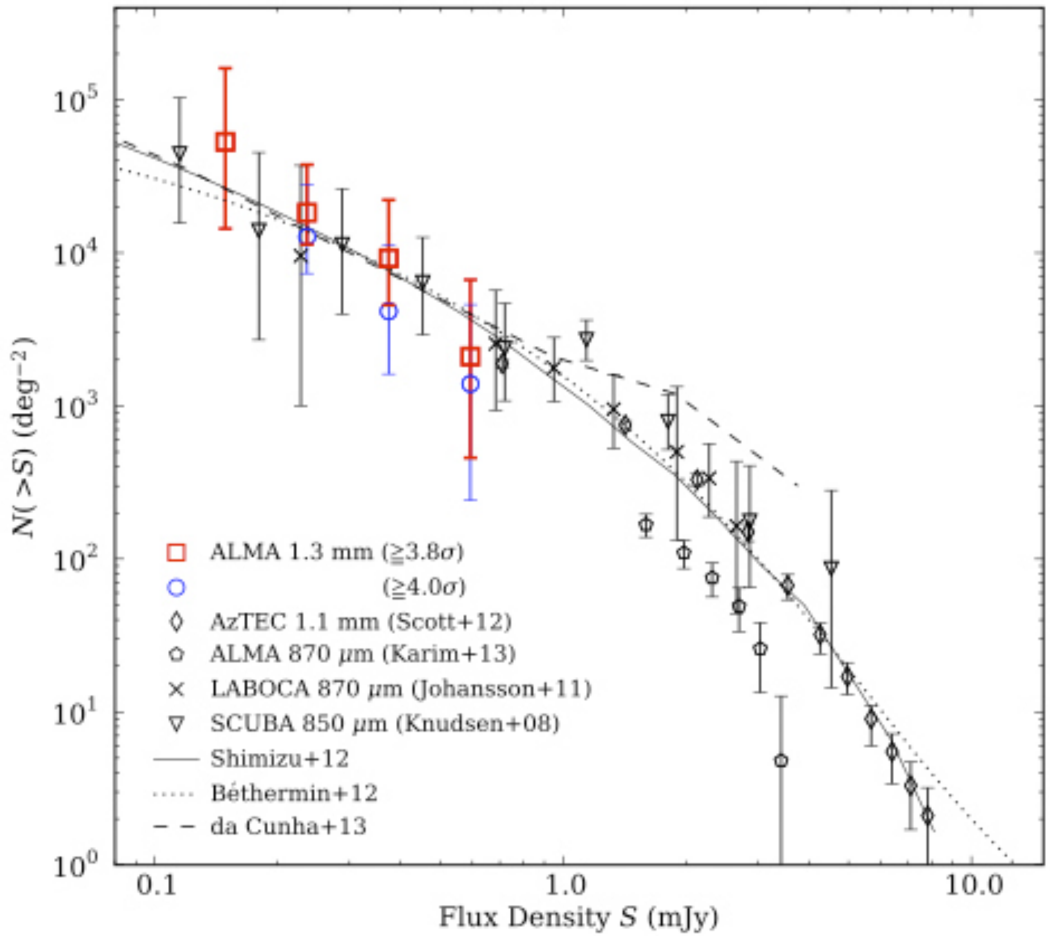
Hodge et al., Karim et al., and Swinbank et al., Nagao et al, 2012-2013

122 submm sources selected from the LABOCA Extended Chandra Deep Field South Submillimeter Survey (LESS) in Band 7. With 1.5" resolution, they were able to pinpoint the SMGs contributing the submillimeter emission in the LABOCA map, showing that the brightest sources in the original LESS sample comprise emission from multiple fainter SMGs. Serendipitously detected bright emission lines in the two SMG spectra which are likely [CII] 158 micron emission at z=4.42 and z=4.44, demonstrating that ALMA is able to detect the dominant fine-structure cooling lines from SMGs even with short (2 min) integrations.

In Band 6, Nagao et al. observed a z=4.8 SMG selected from the LESS and detected [NII] 205 micron emission line and assessed the metallicity of the SMG from the [NII] 205 micron and [CII] 158 micron flux ratio.

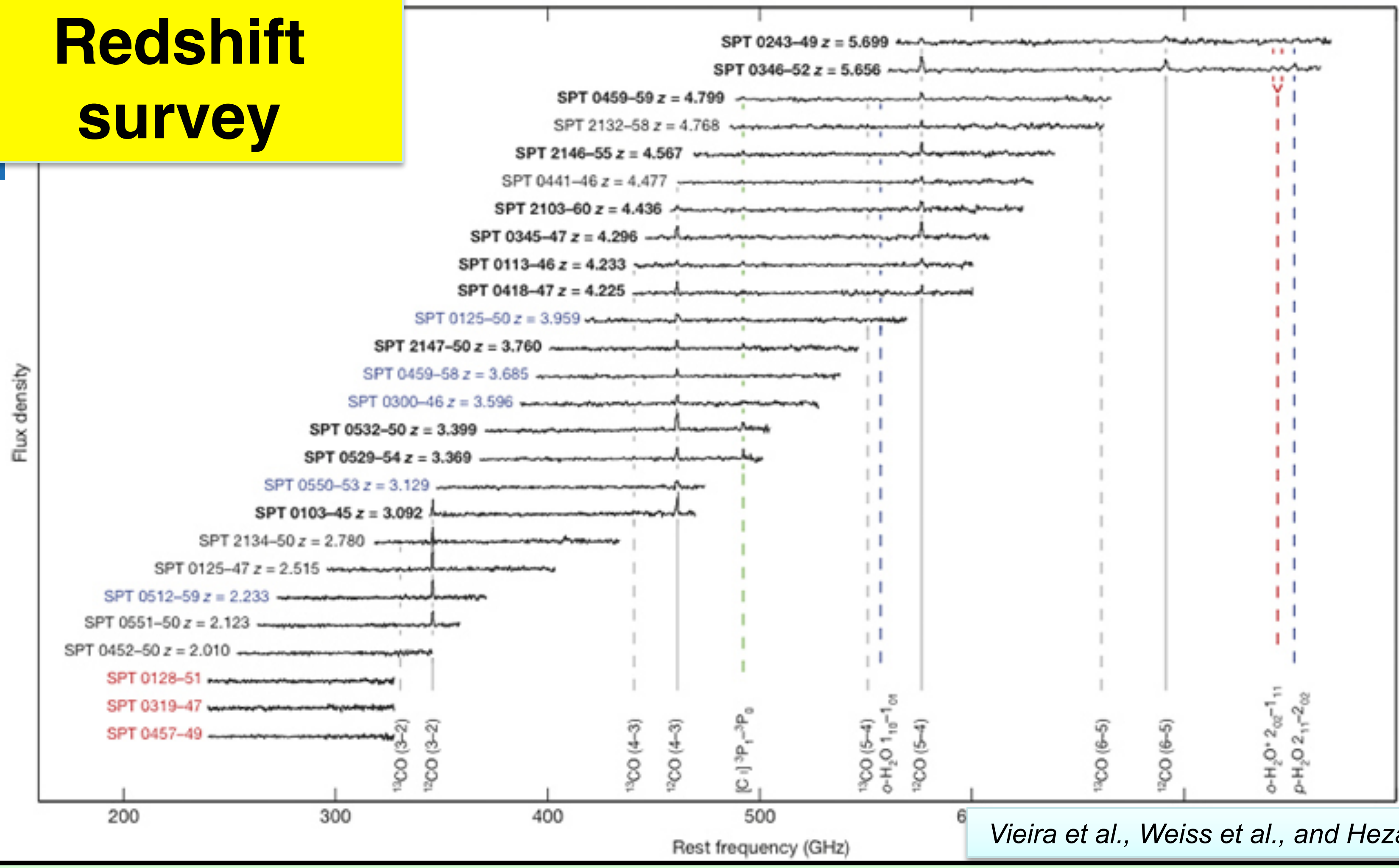
ALMA galaxy counts

Hatsukade et al. serendipitously detected 15 faint "sub-mJy sources" in the Band 6 data targeted for the 20 star-forming galaxies at z~1.4. They obtained source number counts at the faintest flux range among surveys at mm wavelengths, suggesting that ~80% of the extragalactic background light at mm /submm wavelengths come from such fainter galaxies.



ALMA Band 6 observations constrain the faint mm source number counts Hatsukade et al. 2013, ApJ, 769, 27

Redshift survey



Vieira et al., Weiss et al., and Hezaveh et al.

ALMA Bands 3 and 7: strongly gravitationally lensed sources from the South Pole Telescope (SPT) survey: sources are composed of multiple components, indicative of gravitational lensing.

Their gravitational lensing model suggests that the sources are amplified by factor 4 - 22, which suggests that the lensed sources are ultra luminous starburst galaxies at high-z.

Their blind redshift search in band 3 resulted in line detections in 23 sources, with 44 line features in the spectra, providing secure redshifts for ~70% of the sample. Their new analysis gave a mean redshift of z=3.5, and found that a significant portion of SMGs are indeed at high-z (z>4). These new findings will impact our current understanding of the formation of massive galaxies at high-z.

ALMA Band 3 CO(1-0) emission in NGC 253

Imaging a galaxy-scale molecular outflow

ALMA has imaged expanding molecular shells in the starburst nucleus of NGC 253 at 50-parsec resolution. The extraplanar molecular gas closely tracks the Hα filaments, and connects to expanding molecular shells located in the starburst region. The molecular outflow rate is 3-9 M_o/yr, implying a ratio of mass-outflow rate to star-formation rate of at 1 – 3, indicating that the starburst-driven wind limits the star-formation activity and the final stellar content. These observations support the idea that the growth of large galaxies may be limited by strong wind-driven outflows. This suggests that the star formation activity in the galaxy is regulated by the starburst-driven wind and will therefore determine the final stellar content

The sensitivity of the ALMA data is an order of magnitude better than previous ^{12}CO image of NGC253.

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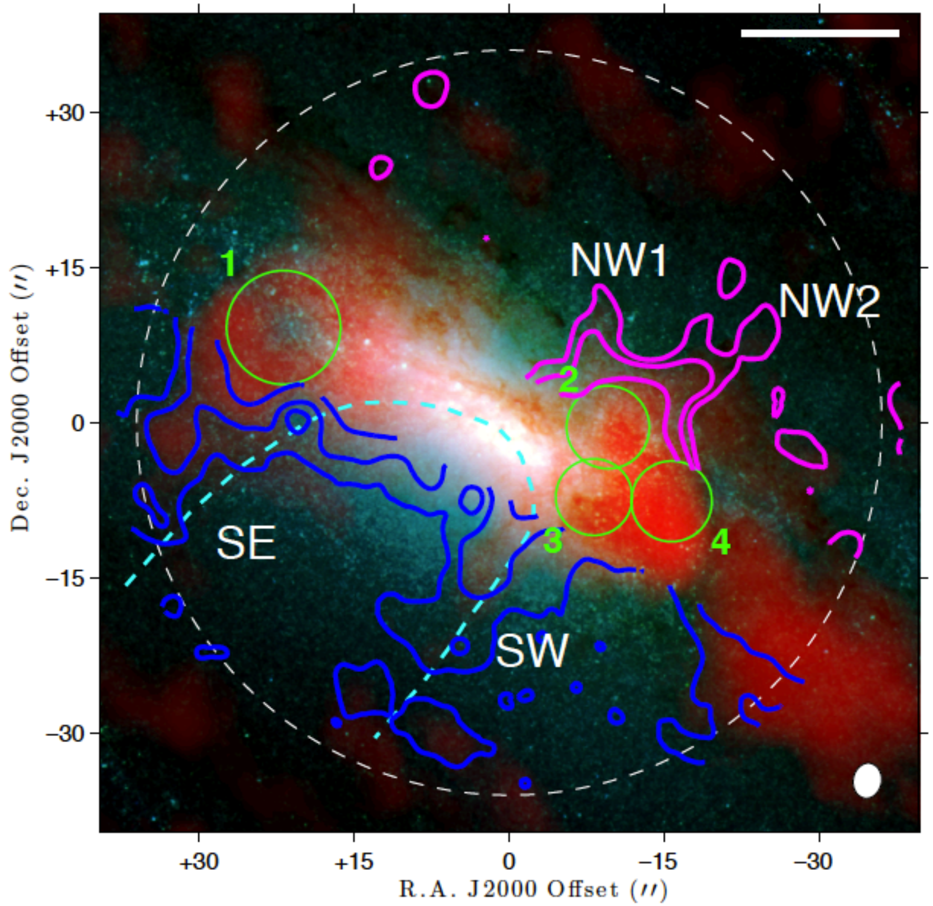


Blue and magenta contours are CO(1-0) emission at +/- 100 km/s around the nucleus of NGC 253 (Bolatto ea. 2013)

Merging galaxies: Antennae

***The nearest face-on galaxy merger, the Antennae* galaxy NGC4038/4039**

an ideal target for studying how galaxy interactions affect the interstellar medium and star formation

Herrera et al. (2012) used the Science Verification data of ALMA Band 7 study the CO(3-2) emission and compare the VLT/SINFONI H_2 image

The distribution of CO and H_2 are closely related, and suggests that the observed variations in the H_2/CO line ratio may indicate that the SGMCs are dissipating their turbulent kinetic energy at different rates

Espada et al. (2013) also studied the same data-set in detail, and found 10 molecular clumps that are associated with the tidal arm south of NGC 4039, resembling a morphology of beads on a string with an almost equidistant separation between the beads of about 350 pc, which may represent a characteristic separation scale for giant molecular associations.

HST and CO ALMA images of the central part of the Antennae galaxies)

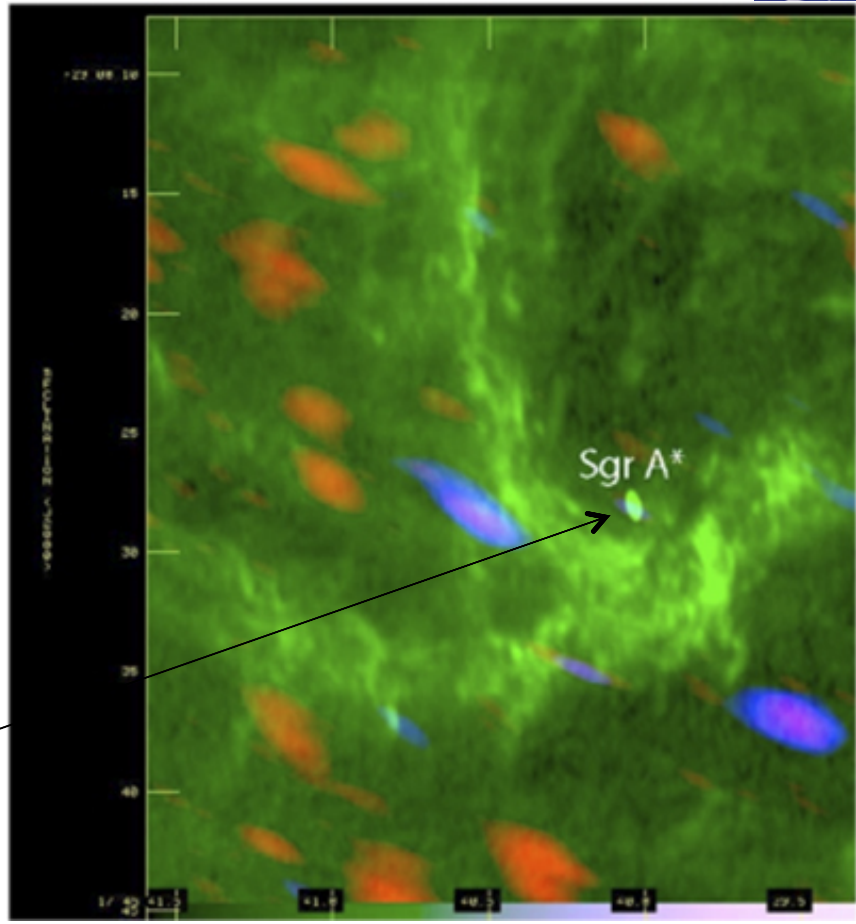
Herrera, C., et al., 2012, A&A, 538, 9; Espada, D., et al., 2012, ApJ, 760, 25

Central region of the Galaxy: *Sgr A**

SiO emission near the central region of the Milky way:

the interior of the circumnuclear molecular ring is not completely filled with ionized gas but it is a site of molecular clumps and on-going star formation. These clumps are not gravitationally bound, and suggesting outflows from YSOs. This would be the first time that star formation was observed so close to the galactic center

Supermassive black hole



Combined ALMA and Very Large Array (VLA) image of the galactic center:
The red and blue areas, taken with ALMA, map the presence of silicon monoxide, an indicator of star formation. The blue areas have the highest velocities, blasting out at 150-200 kilometers per second. The green region, imaged with the VLA, traces hot gas around the black hole and corresponds to an area 3.5 by 4.5 light-years. Credit: Yusef-Zadeh et al.,)

Imaging of the CO Snow Line in a Solar Nebula Analog

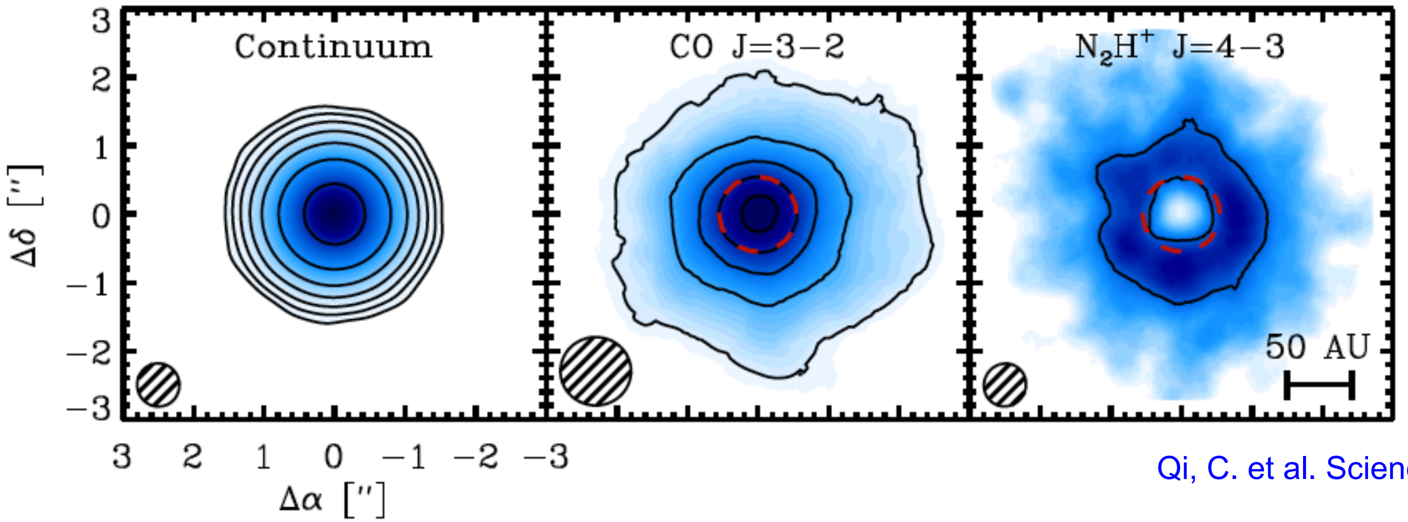
ALMA has imaged the CO 'snow line' around TW Hya,

The formation efficiency of the planets in the discs around young stars intimately linked to the protoplanetary disc locations of "snow lines" of abundant volatiles.

N2H+, a reactive ion present in large abundance only where CO is frozen out is distributed in a large ring, with an inner radius that matches CO snow line model predictions.

The extracted CO snow line radius of ~ 30 AU is a key parameter in constraining models of the formation dynamics of planetary systems

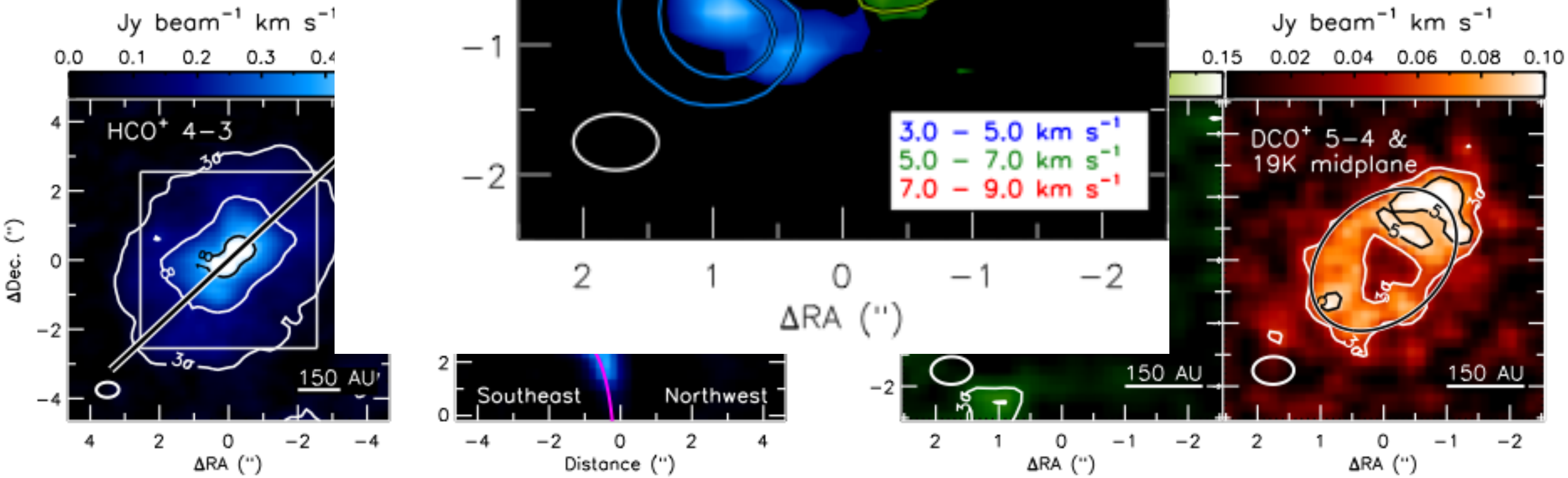
ALMA and SMA images of dust, CO and N2H+ emission toward TW Hya.
The red circle is the CO snow line prediction.

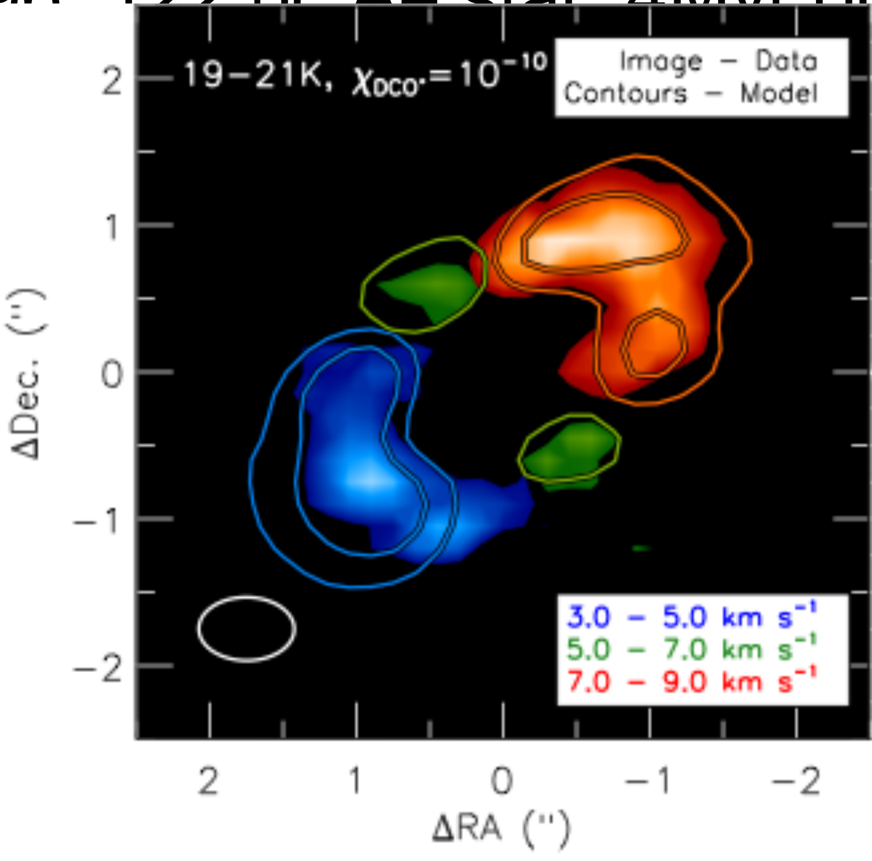


Qi, C. et al. Science Express, July 18, 2013

ALMA Observation of the CO-Snowline Ring HD163296

- HD163296: 122 pc Ae star, 4Myr old, ~0.08M_{sun} disk
- Luminc ar. Massive: high cc
  - Qi et ~19K from ^{13}CO



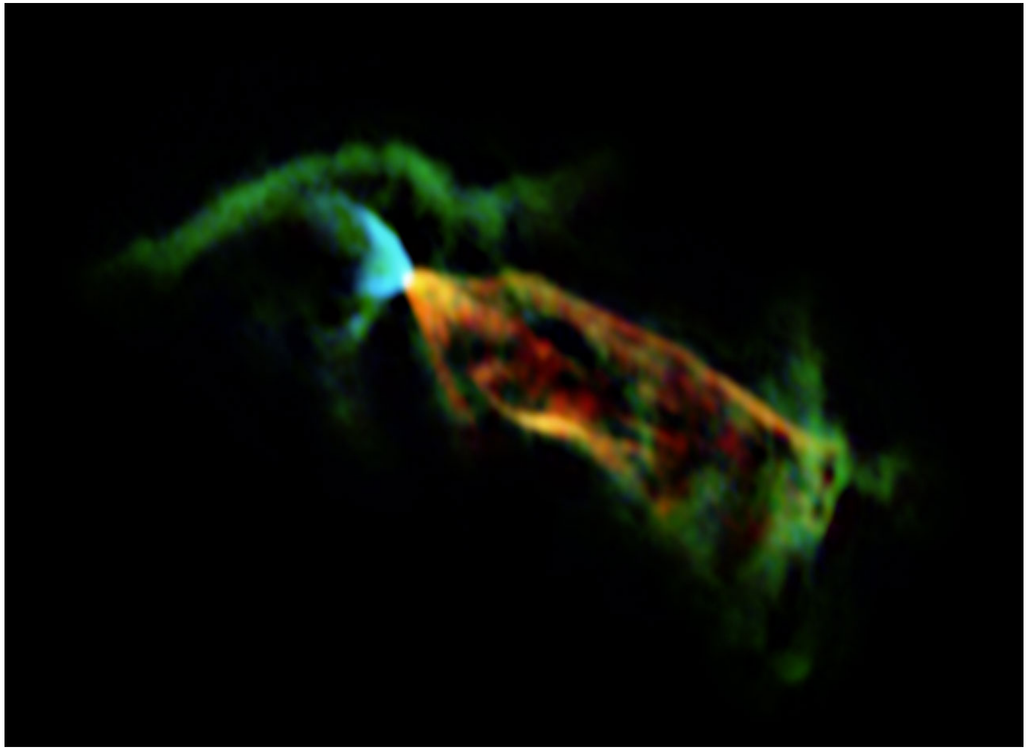


ALMA Observations Give New Insights into Protostars: the HH 46/47 molecular outflow

- *Blue colors show gas approaching us from HH46/47 and red shows receding gas.*
  - *The outflow shows both broad and collimated components; near the source velocities reach >30 km s^{-1}*
  - *Discontinuities suggest episodic bursts on 100 yr timescales*
- *The new high sensitivity and wide field ALMA observations show for the first time the full details of the flow and allowed the authors to reveal a much higher velocity component of the outflow than previously know*

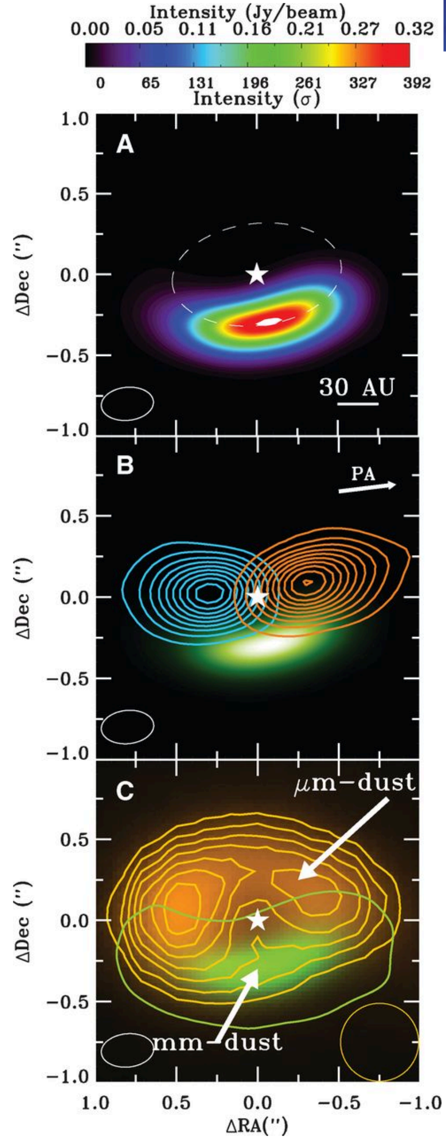
CO emission from the outflow in HH46/47 imaged by ALMA has revealed ultrafast gas, depositing energy and momentum into the nearby medium

Arce, Mardones, Corder et al. 2013 ApJ 774, 39



ALMA Images ‘Dust Trap’ Around Distant Star

- IRS 48 dust and gas observations.The inclined disc around IRS 48 as observed with ALMA 0.44mm observations, centred on the star (white star symbol).
  - **A:** ALMA observations, dashed ellipse shows a 63AU radius circle.
  - **B**: Integrated CO J=6-5 emission showing symmetric gas disk with Keplerian rotation ($i=50^{o}$)
  - **C**: VLT VISIR image at 18.7μm
- Proposed mechanism creates a dust trap in the disk of IRS 48:
  - A massive planet creates an annular gap in the gas disk.
  - A high-pressure vortex forms at the gap edge, collecting and trapping millimeter-sized dust particles that would otherwise spiral rapidly inward through the disk.

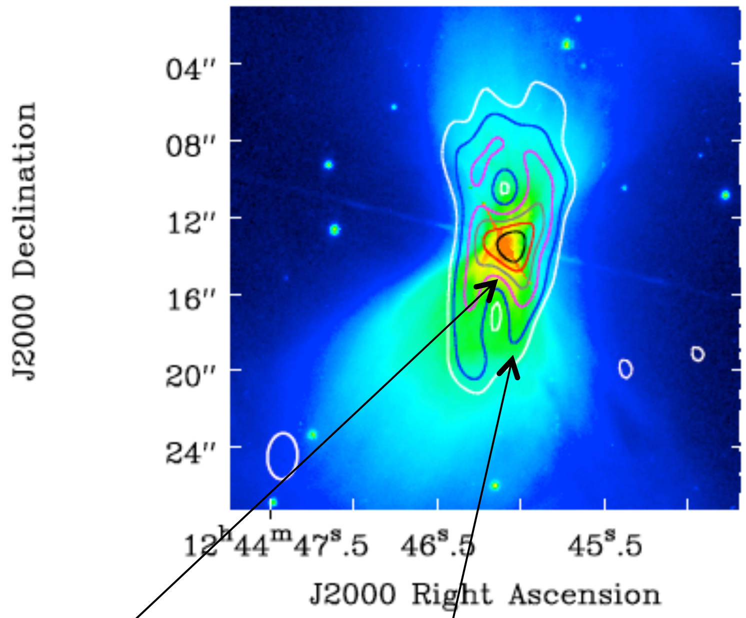


Van der Marel, van Dishoeck, Bruderer, et al. Science 340,1199

ALMA Observes the Coldest Place in the Universe: The Boomerang Nebula

- Boomerang: a central hourglass-shaped Pre-Planetary nebula surrounded by a patchy, but roughly round, cold high-velocity outflow centered on a dense waist containing large grains
- Adiabatic expansion has cooled the envelope substantially below the CMB temperature.
- Outer regions of the CO flow are rewarmed, probably by photoelectric grain heating.

Sahai, Vlemmings, Huggins, et al. ApJ, in press.



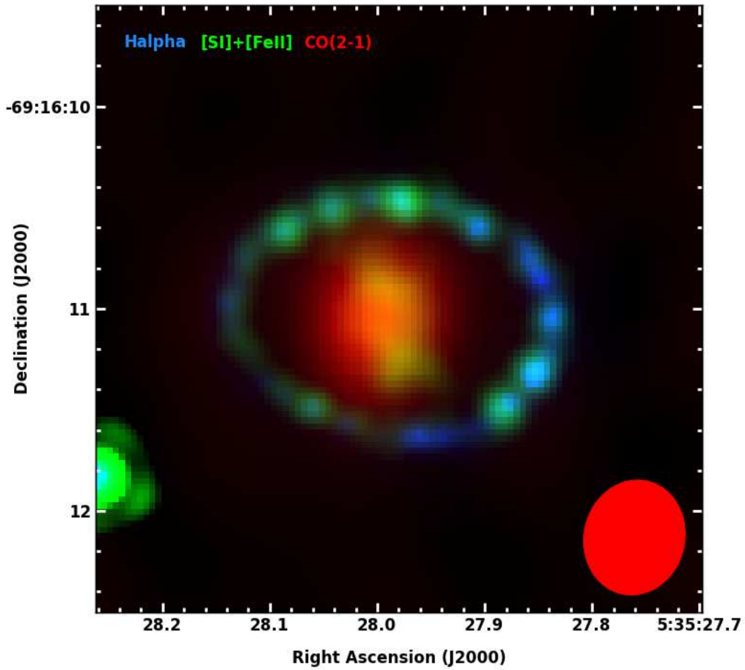
A dense waist of large grains

Rewarmed CO flow

ALMA Opens a Powerful New Window into Supernova Ejecta

Kamenetzky, McCray, Indebetouw et al 2013 ApJ, 773, 34

ALMA's unprecedented sensitivity and resolution identify CO in the SN87A inner ejecta. SiO is also seen. Although the data were too fragmentary for an analysis, both abundant Si isotopes, ^{28}Si and ^{29}Si were imaged over partial velocity extents.This suggests that ALMA might probe the nucleosynthetic character of the debris around the remnant, illuminating the evolution of its central star

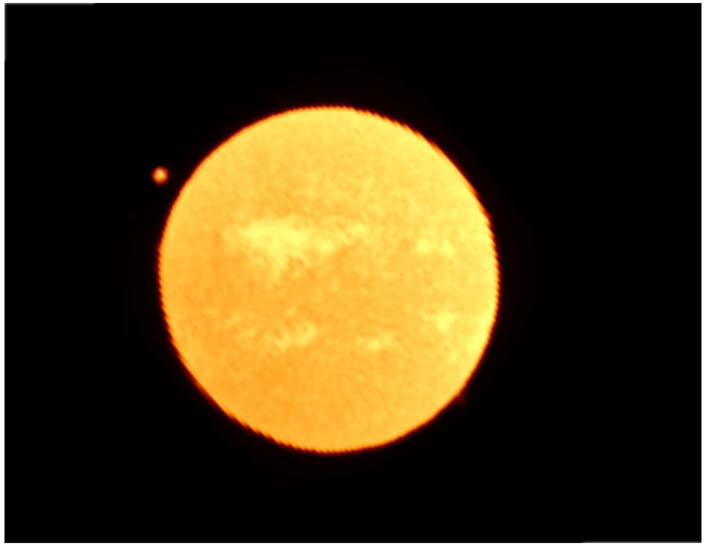


The C/O clumps in SN1987A contain at least 0. 01 $M_{\odot}$ of ^{12}CO, an order of magnitude greater than measured in the first few years after the explosion: ^{12}CO and dust have continued to form over the past 25 years.

ALMA views the full velocity range of emission, unobscured by dust. Doppler tomography will be possible with the completed ALMA in CO and other molecules that will probe the spatial, chemical and kinetic environment within the inner ejecta.

Outlook on future

- ALMA is now in a consolidation phase, focusing at completing construction
- Additional capabilities will be added in the coming years in Cycle 2, 3 and towards Full Science
  - Polarization, Solar, Long baselines, additional bands
- APEX Extension/ARO
  - Submm Survey Telescopes
- Full Science & Development
  - Expected from 2014/2015

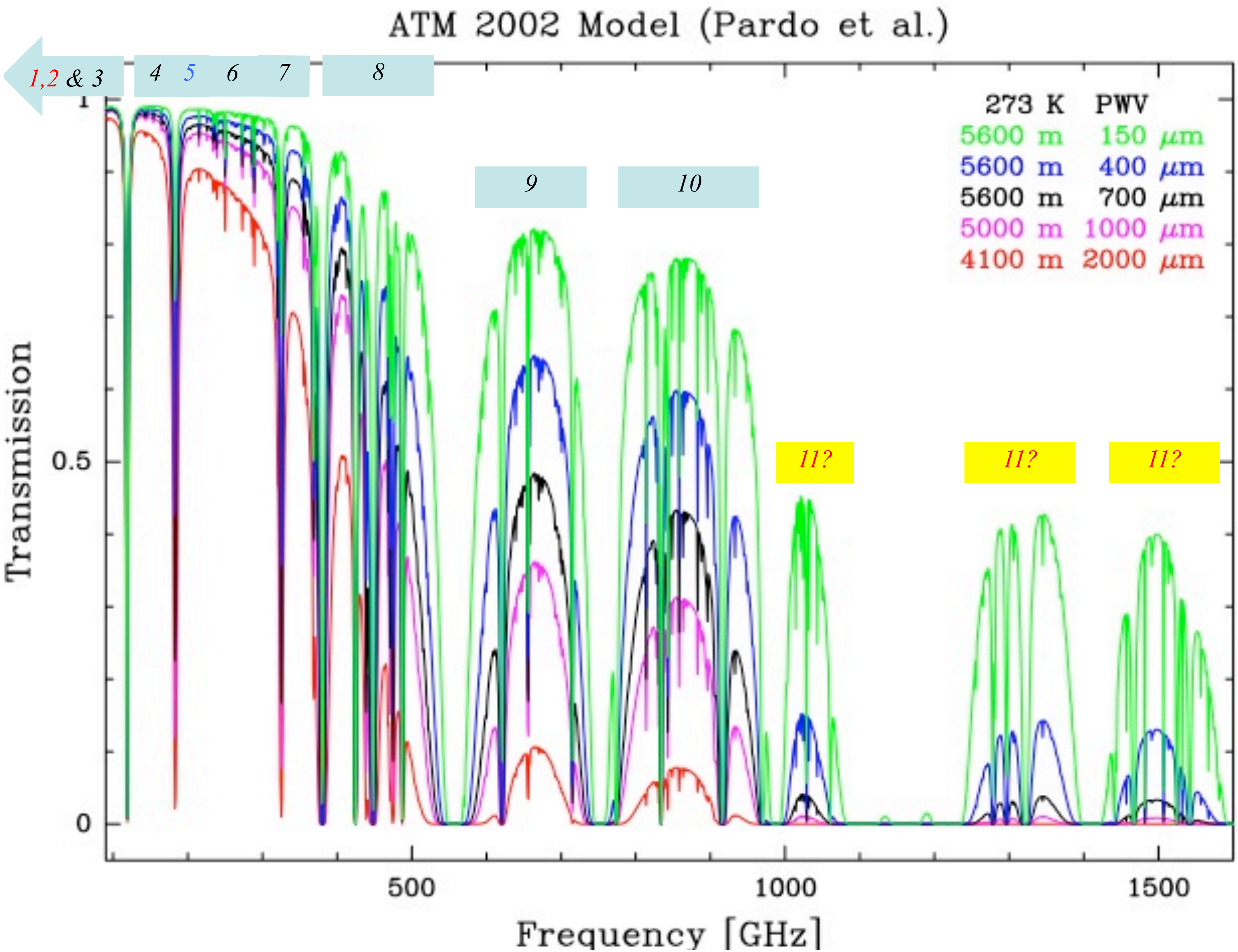


ALMA beyond ALMA

- ALMA will allow transformational science thanks to the sensitivity, angular resolution, spectral coverage and image fidelity, but...

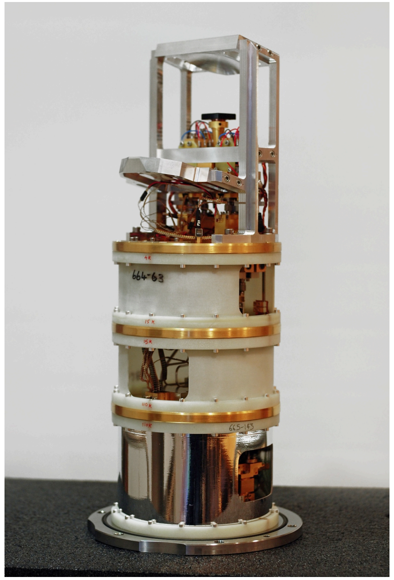
- The baseline ALMA project will only achieve a fraction of the full potential of the site and instrument

- Incomplete Receiver Complement
- Limited Wide Field Capabilities
- Limited Correlator and Data Rate Capabilities
- Extended baselines (30-50km), VLBI (200-10000km)
- Advanced Calibration, Software, Science Tools....


ATM 2002 Model (Pardo et al.)
1,2 & 3
4
5
6
7
8
9
10
11?
11?
11?
273 K PWV
5600 m 150 μm
5600 m 400 μm
5600 m 700 μm
5000 m 1000 μm
4100 m 2000 μm
Transmission
1
0.5
0
500
1000
1500
Frequency [GHz]

Band 5 Full Production Study

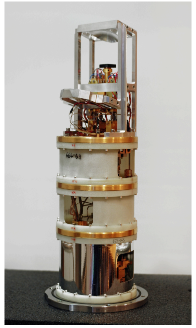
- Optimization of B5 design for production
- Completed Feb 2012
- Full production proposal prepared as part of the study - Approved Apr 2012
- Full production started on Feb 2013
  - Consortium led by NOVA (NL), includes GARD (S), with important contributions from NRAO
  - 67 cartridges to be delivered by 2017

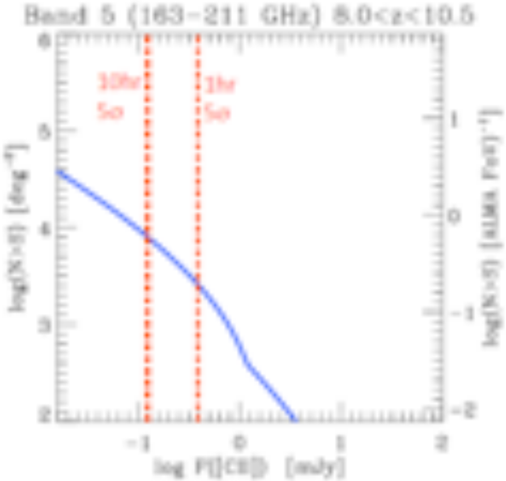


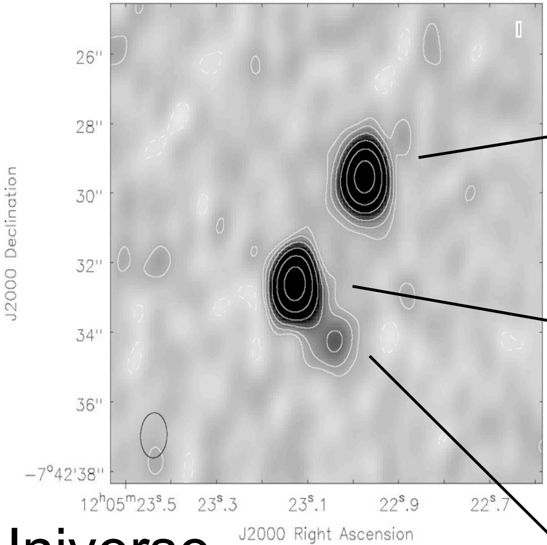
SIXTH FRAMEWORK PROGRAMME

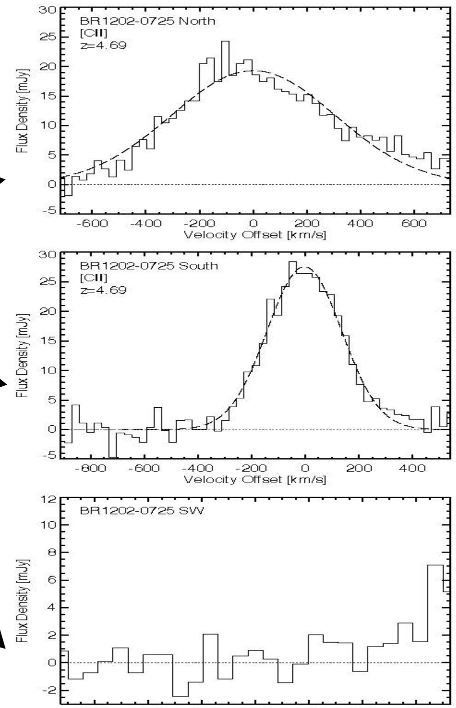
Band 5 Science

- [CII] in z~(8-10) and high-ex CO at high-z



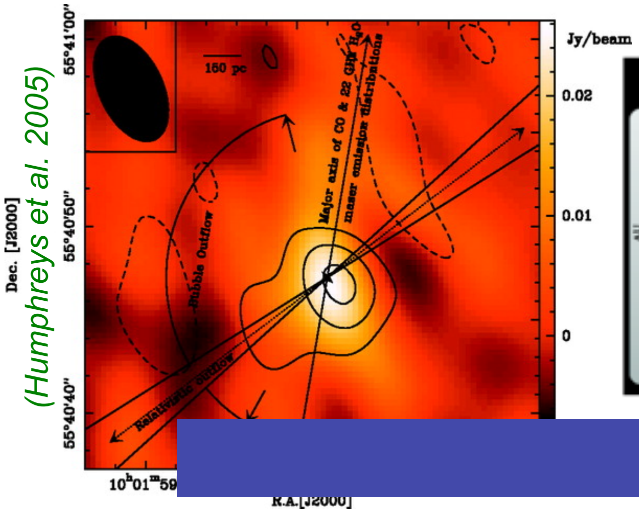




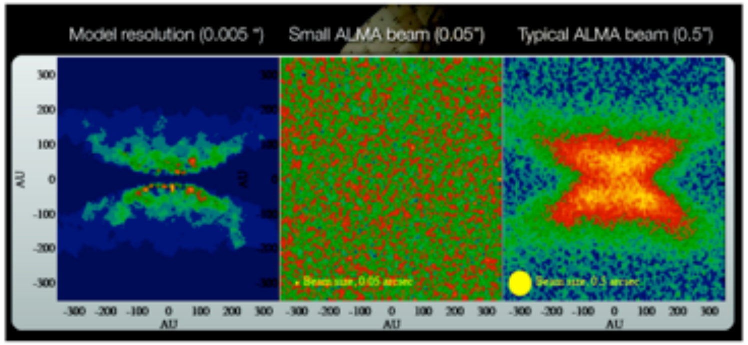


(Wagg et al. 2012)

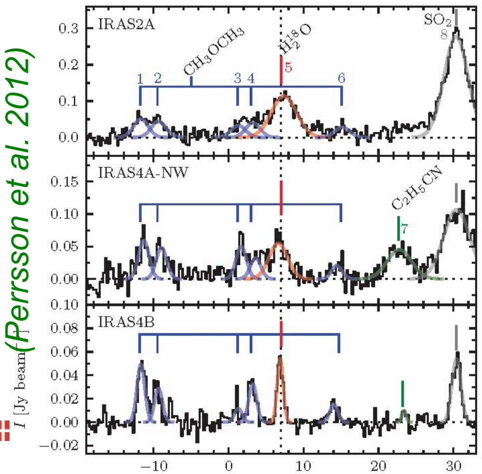
- Water in the local Universe



(Humphreys et al. 2005)



(Brinch 2010)

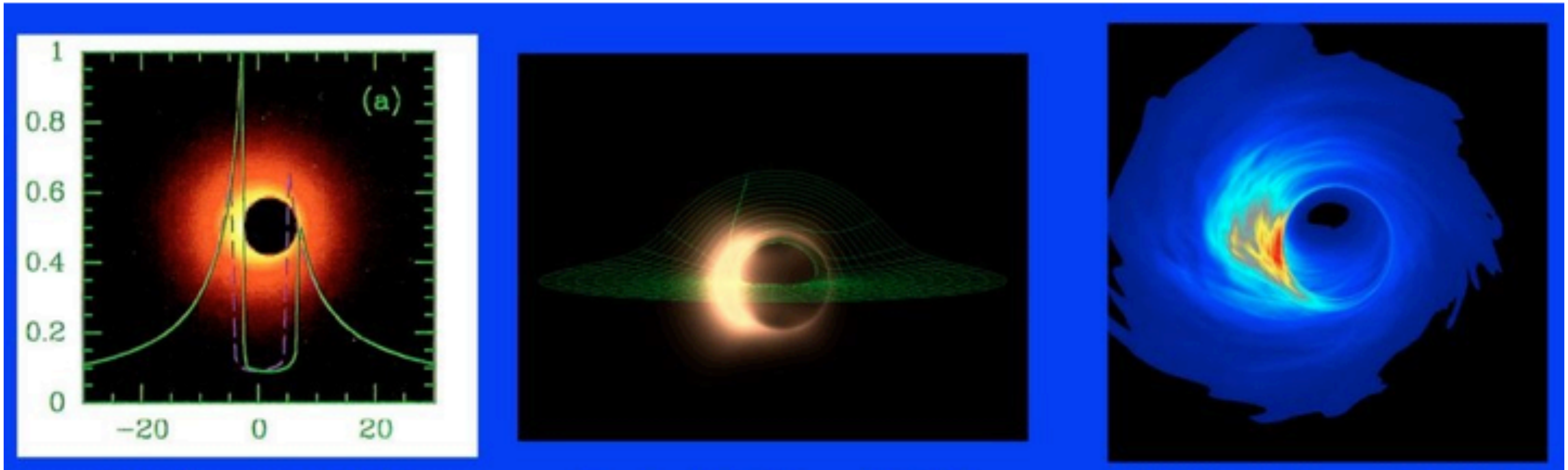


(Persson et al. 2012)

Paola Andreani

Phasing ALMA for VLBI

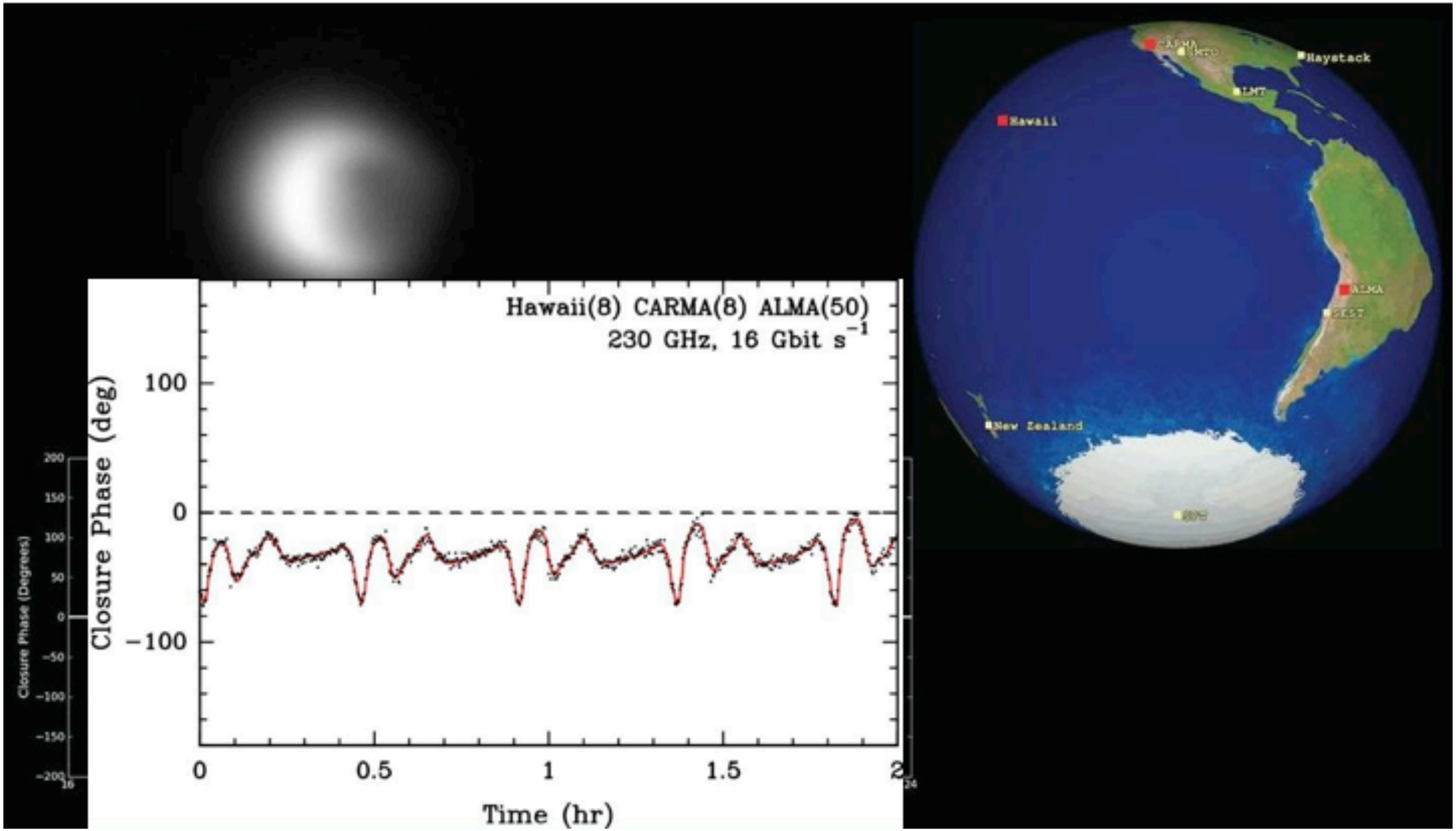
- The Even Horizon Telescope and Sgr A*



Falcke et al 2000 | Broderick & Loeb 2009 | Noble & Gammie 2007

Phasing ALMA for VLBI

- The Even Horizon Telescope and Sgr A*



ALMA Development ESO

- Underlying concepts
  - Work with institutes in ESO MS (expertise and funding opportunities)
  - Develop a strategy based on science priorities from the user community
- Procedures and policies
  - Follow standard ESO practices, adapted for the ALMA context
  - Competitive open Calls for Studies to develop science cases, designs, limited R&D in synergy with European/national/institute funding
  - Mature study results are brought to ALMA for implementation as projects
- Overarching goal
  - Future key science requires: expanded frequency range, improved sensitivity, efficiency in spectral scans
  - Strategy: fill in missing bands, develop next generation wideband-wideIF receivers, develop backend/correlator/software to handle these
  - Develop a strategic approach to full system upgrade

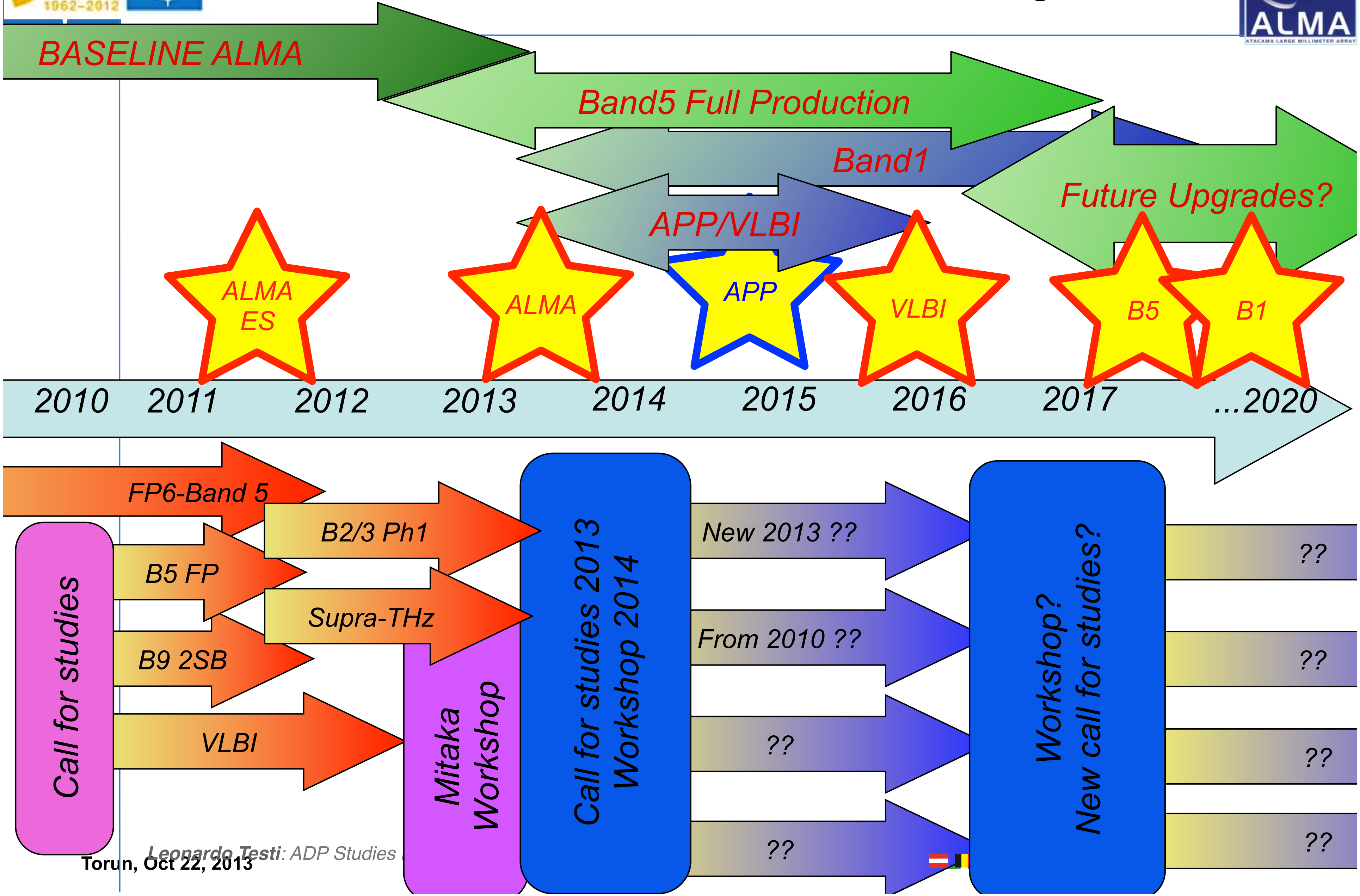
The ALMA Context

- Four ALMA Development Projects running
  - Fiber link to Calama
  - Full production of Band 5 (2013-2017)
  - Prototype and Production of ALMA Band 1 (2013-2018)
  - ALMA Phasing Project (2013-2015) and mmVLBI (2015-2016?)

- Studies in the other regions
  - Yearly study cycles in NA since 2012 (note also call for projects in 2013)
  - Different selection process in EA

- Coordination
  - Process started independently in the three regions
  - Executives-ASAC workshop in Feb 2013
  - Working on planning a community workshop in 2014

Timeline summary



Summary

- ALMA is producing transformational science!
  - Key role of the ARC Network in Europe (thanks!!)

- ALMA ES is just the beginning!
  - Cycle 2 – Dec 5th – additional capabilities and time
    Full Science Operations in 1-2yrs

- ALMA is a long lifetime observatory with a healthy Development Plan
  - Participation in the ALMA Upgrade Studies is important


Thank You !