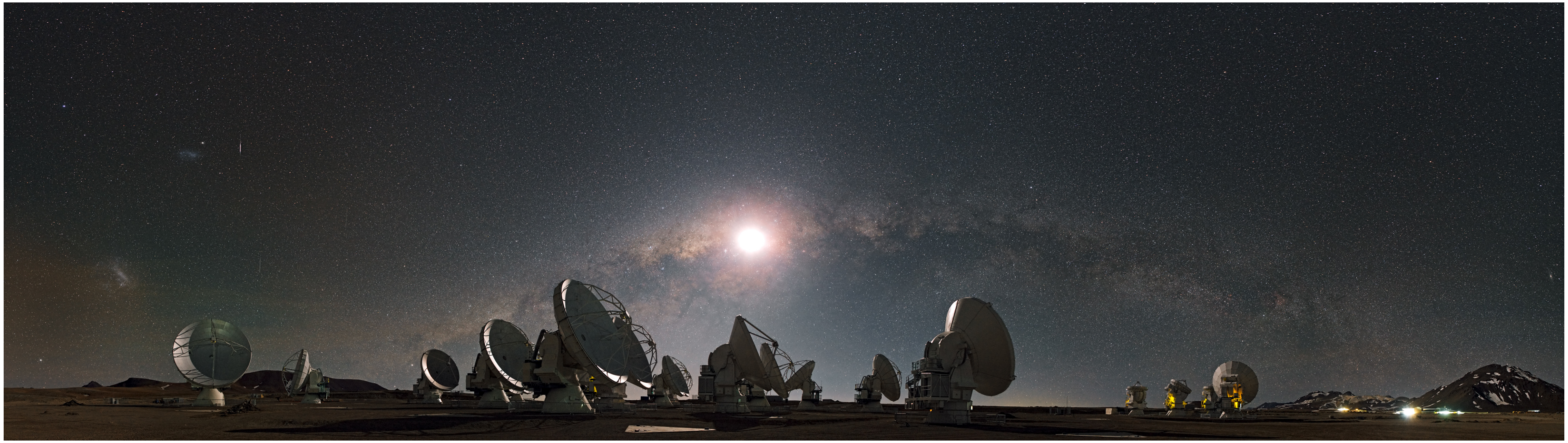
Introduction to ALMA: Capabilities, Early Science

Jan Brand, Rosita Paladino – ALMA Regional Centre, Italian node



ALMA observes the cool (10's – 100's K) universe – thermal radiation at (sub)mm wavelengths: dust (continuum) and molecules (rotational transitions).

Main 'science drivers' ('level 1 science goals') of ALMA:

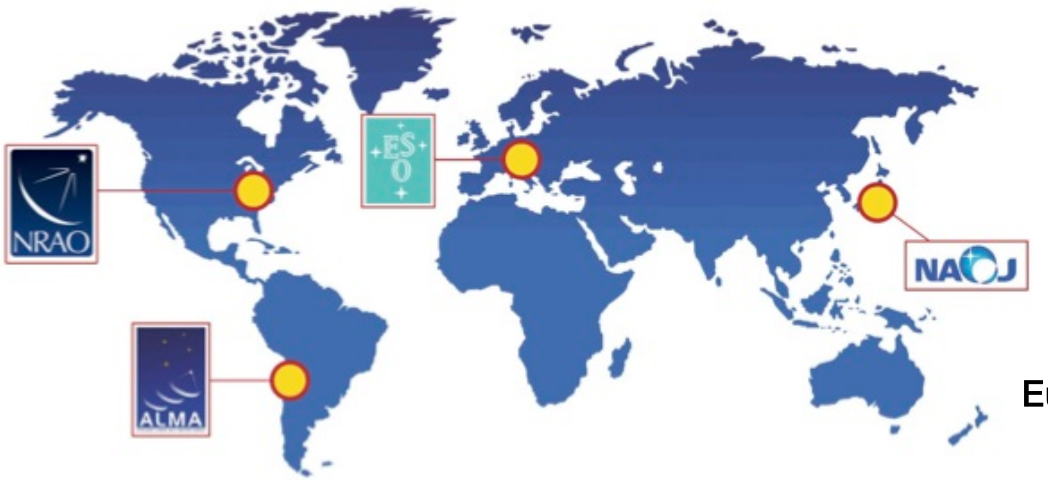
* Detect emission line of CO/C^+ in a normal MW-like galaxy at z=3 in < 24 hrs.
* Image (resolve) the gas kinematics in protoplanetary disks around young Sun-like stars in the nearest molecular clouds (d=150 pc)
* Provide high (~ 1000) dynamic range images at 0.1 arcsec resolution

ALMA operates at frequencies between 30 and 950 GHz. Requires high and dry site (to reduce effect of atmospheric absorption lines of e.g. H_2O, O_2, O_3).

THE AMBITIOUS ALMA PROJECT

# Dry site (low pwv) # low T_{sys} # > 6500 m^2 effective area # 1225 baselines (main array) # short spacings with ACA, TP-ants.	Excellent instantaneous uv-coverage and high sensitivity: < 0.05 mJy @ 100 GHz in 1 hr
# baselines up to b_{max} = 16 km	Sub-arcsec resolution: 40 mas @ 100 GHz 5 mas @ 900 GHz
# 10 spectral bands 30-950 GHz # 70 correlator modes	High flexibility in spectral studies

ORGANIZATIONAL STRUCTURE

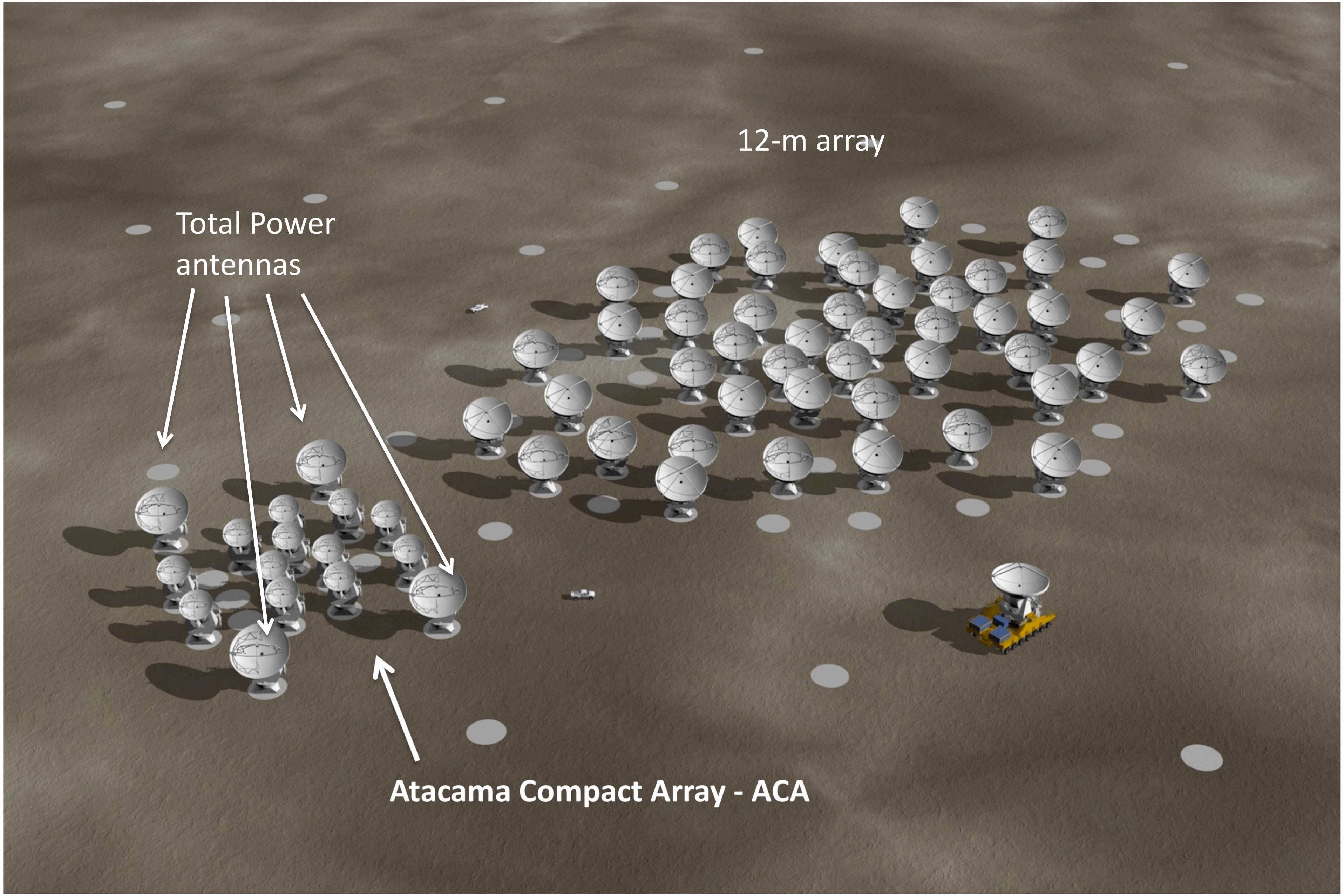


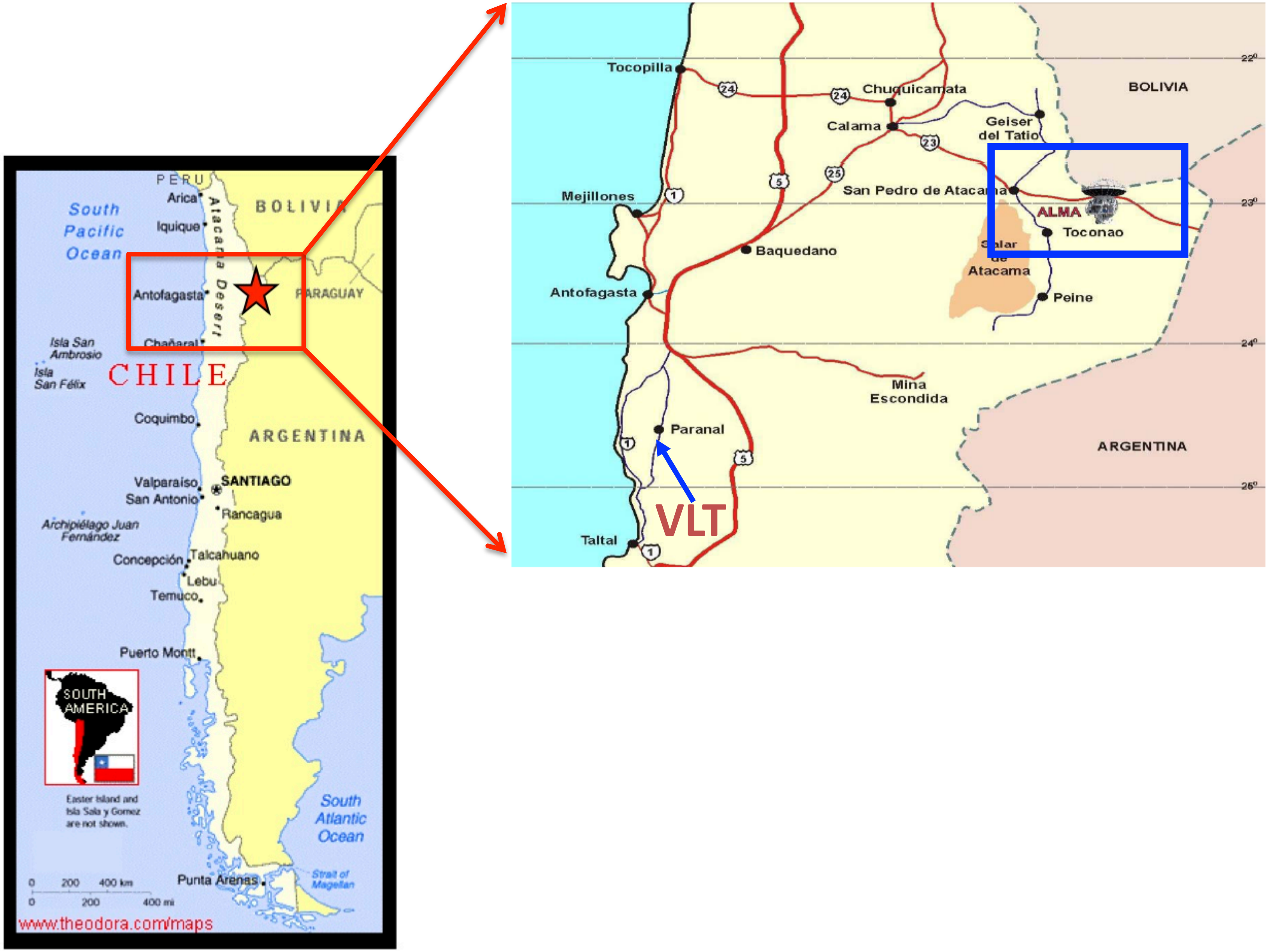
Joint ALMA Observatory:

Europe (ESO): 33.75%
North America (NRAO): 33.75%
East Asia (NAOJ): 22.5%
Chile: 10%

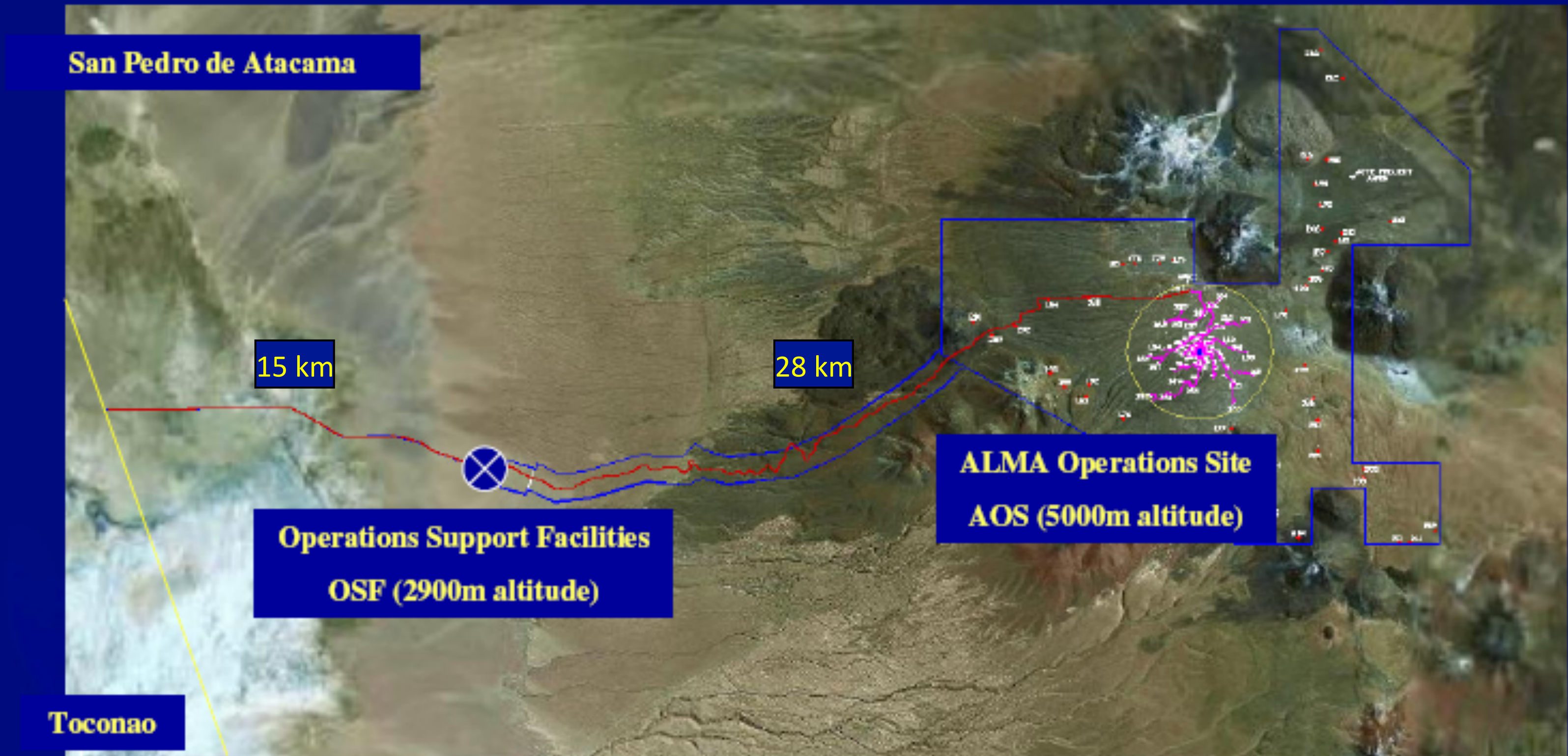
European ARC nodes

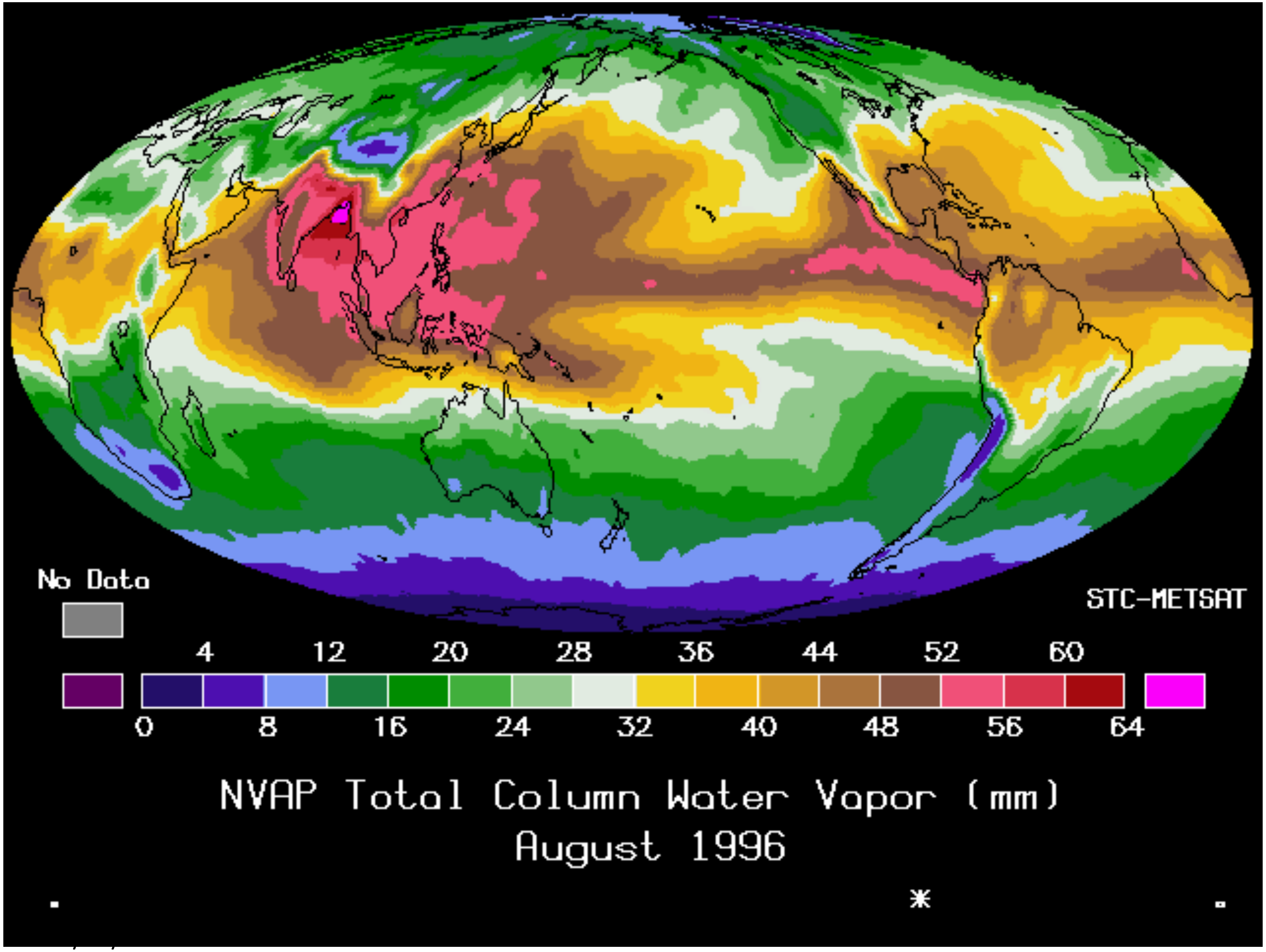
In Europe:
A network of 7 ARC-nodes and
1 Centre of Expertise, coordinated
by the central node at ESO.


12-m array
Total Power antennas
Atacama Compact Array - ACA

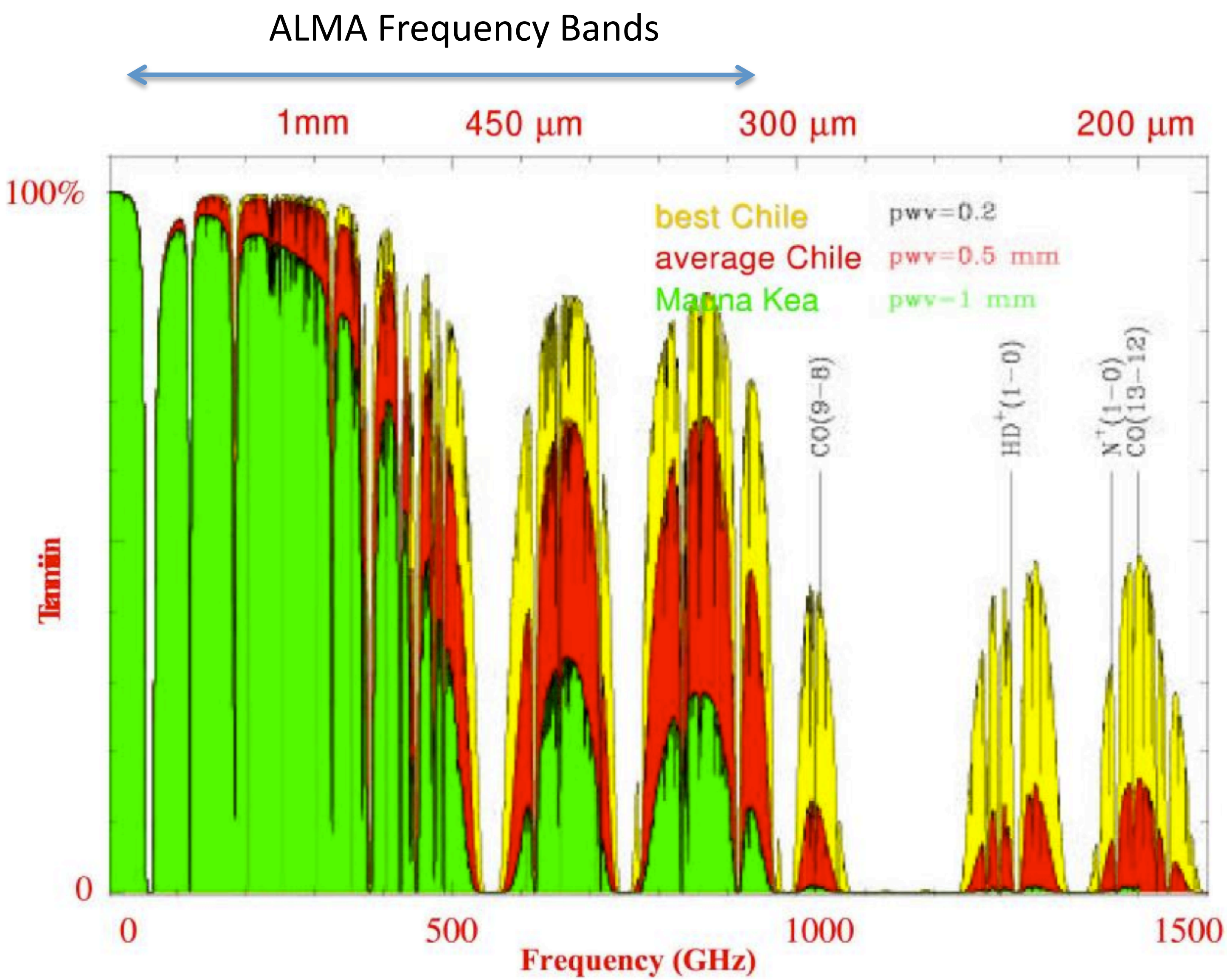

PERU
Arica
Iquique
BOLIVIA
South Pacific Ocean
Atacama Desert
Antofagasta
PARAGUAY
Chañaral
Isla San Ambrosio
Isla San Félix
CHILE
Coquimbo
ARGENTINA
Valparaíso
San Antonio
SANTIAGO
Rancagua
Archipiélago Juan Fernández
Concepción
Talcahuano
Lebu
Temuco
Puerto Montt
SOUTH AMERICA
Easter Island and Isla Sala y Gomez are not shown.
South Atlantic Ocean
Strait of Magellan
Punta Arenas
0 200 400 km
0 200 400 mi
www.theodora.com/maps
Tocopilla
Chuquicamata
Calama
BOLIVIA
Geiser del Tatio
Mejillones
San Pedro de Atacama
ALMA
Toconao
Baquedano
Salar de Atacama
Antofagasta
Peine
Mina Escondida
Paranal
ARGENTINA
VLT
Taltal
22°
23°
24°
25°

ALMA Site

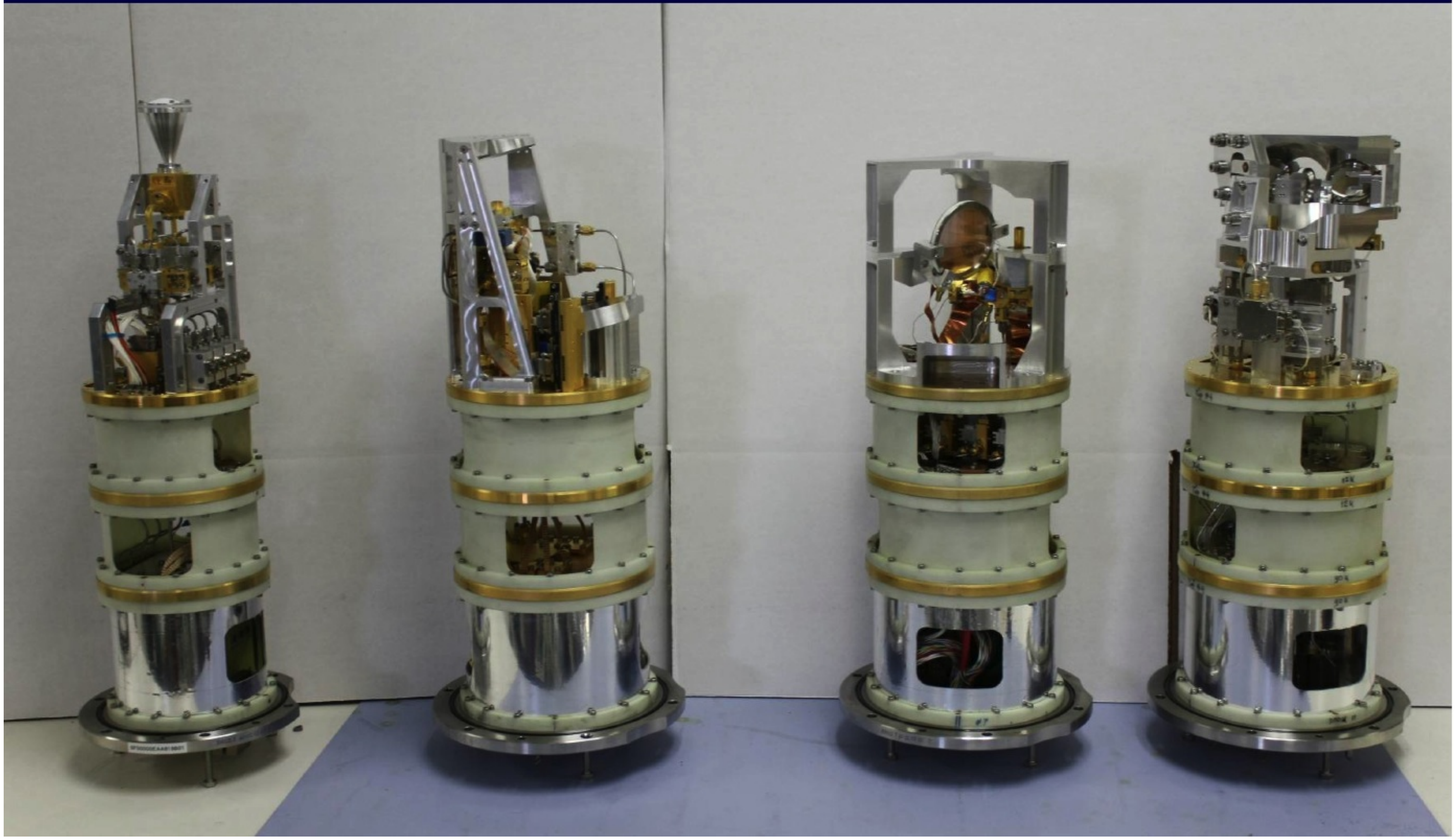

San Pedro de Atacama
15 km
28 km
Operations Support Facilities
OSF (2900m altitude)
ALMA Operations Site
AOS (5000m altitude)
Toconao


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

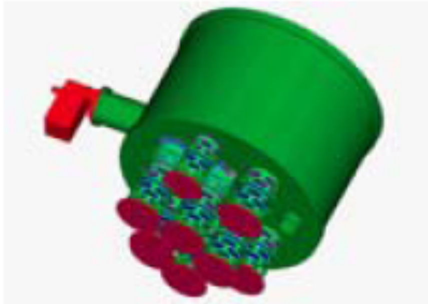
ATMOSPHERIC TRANSMISSION

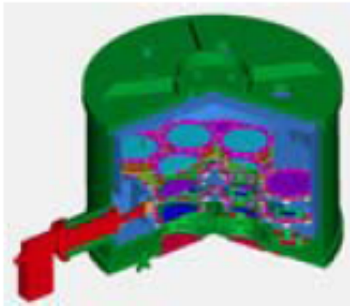


Bands 3 (84-116 GHz), 6 (211-275 GHz), 7 (275-373 GHz), and 9 (602-720 GHz) SIS “cartridges”



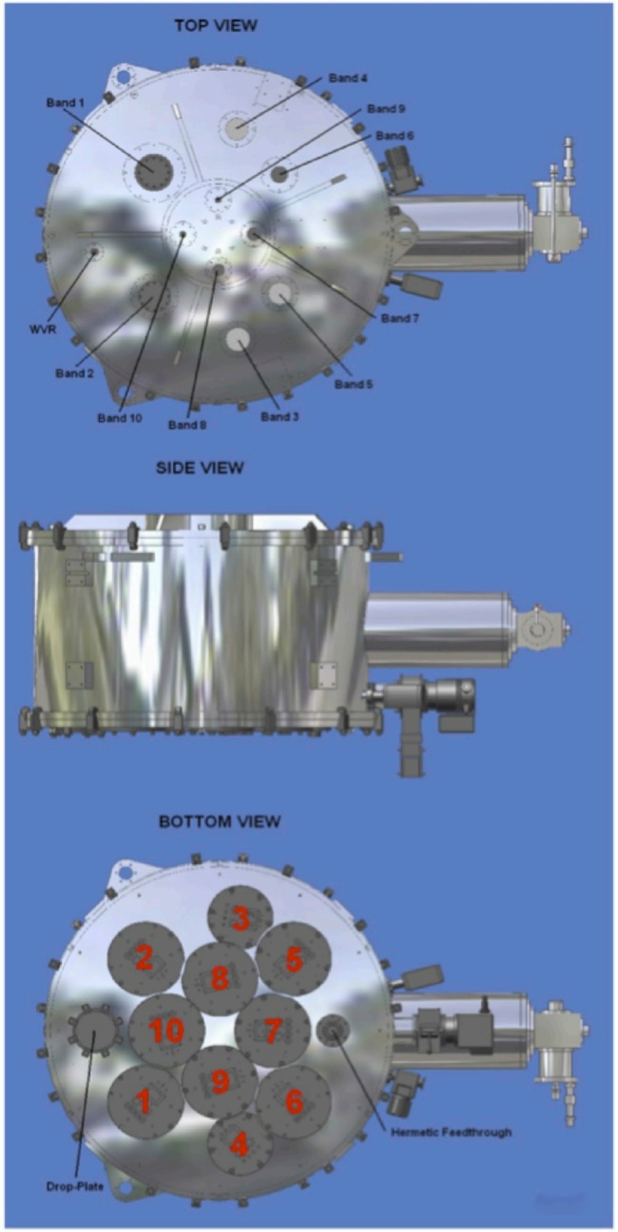
Front End Design





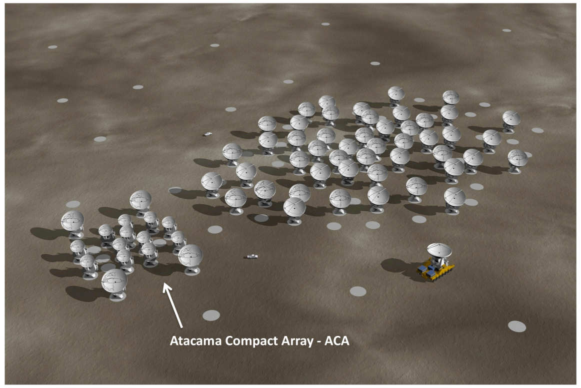
- Diameter ~ 1 m
- External optics top of dewar

- 10 Cartridges plugged from bottom
- Each cartridge contains one frequency



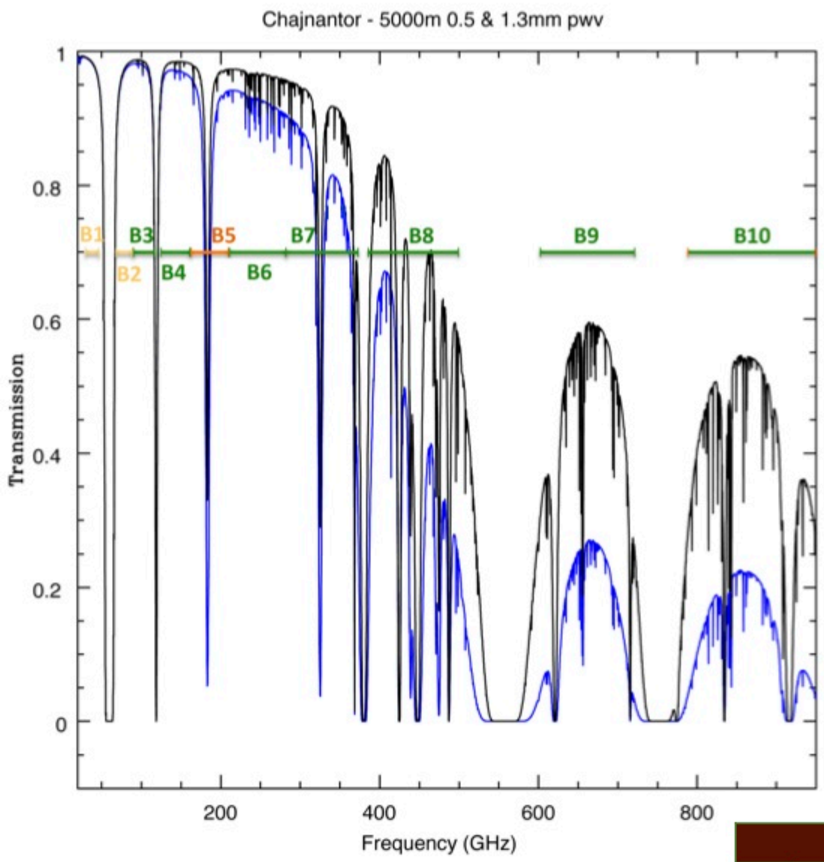
ALMA *Full Operations Specifications*

	Specification
Number of Antennas	*50×12 m (12-m Array), plus 12×7 m & 4×12 m (ACA)*
Maximum Baseline Lengths	*0.15 - 16 km*
Angular Resolution (")	*~0.2" × (300/ν GHz) × (1 km / max. baseline)*
12 m Primary beam (")	*~20.6" × (300/ν GHz)*
7 m Primary beam (")	*~35" × (300/ν GHz)*
Number of Baselines	*Up to 1225 (ALMA correlators can handle up to 64 antennas)*
Frequency Coverage	*All atmospheric windows from 84 GHz - 950 GHz (with possible extension to ~30 GHz)*
Correlator: Total Bandwidth	*16 GHz (2 polarizations × 4 basebands × 2 GHz/baseband)*
Correlator: Spectral Resolution	*As narrow as 0.008 × (300/ν GHz) km/s*
Polarimetry	*Full Stokes parameters*



Been ramping up to this since Cycle 0.
Not quite there yet… expected by Cycle 5

Also with incomplete array one can do groundbreaking science.
Since 2011 ALMA is offered to users in "Early Science".
The fifth cycle (Cycle 4) has just started (30 Sept.).
More antennas, receivers, observing modes etc. with each cycle.



CYCLE 4 AVAILABLE RECEIVERS

(Oct. 2016 – Sep. 2017)

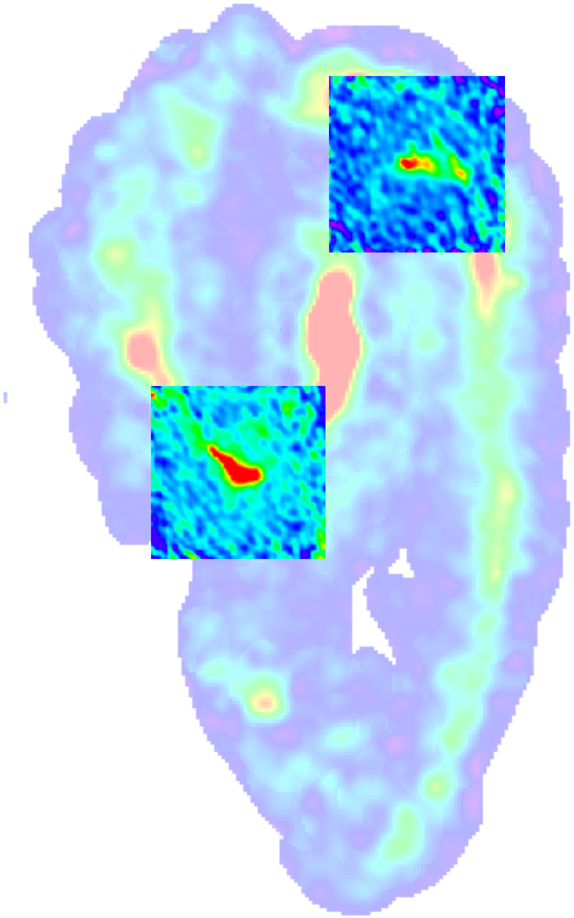
Green: bands available in Cycle 4

Table 1: *Receiver Bands and Selected Properties*

Cycle 4 Receiver Bands					Most Compact			Most Extended		
Band	Frequency (GHz)	Wavelength (mm)	Primary Beam (FOV; ″)	Continuum Sensitivity (mJy/ beam)	Angular Resolution (″)	Approx. Max. Scale (″) (see P.24)	Spectral Sens. ΔT_{line} (K)	Angular Resolution (mas)	Approx. Max. Scale (″) (see P.24)	Spectral Sens. ΔT_{line} (K)
3	84-116	2.6-3.6	73-53	0.095	4.4-3.2	34-25	0.075	78-57	0.93-0.68	230
4	125-163	1.8-2.4	49-38	0.13	3.0-2.3	23-18	0.10	53-41	0.63-0.48	310
6	211-275	1.1-1.4	29-22	0.13	1.8-1.4	14-11	0.11	31-24	0.37-0.29	315
7	275-373	0.8-1.1	22-16	0.24	1.35-0.99	10.6-7.8	0.19	43-32	0.48-0.35	180
8	385-500	0.6-0.8	16-12	0.46	0.96-0.74	7.6-5.8	0.36	53-41	0.46-0.36	115
9	602-720	0.4-0.5	10-8.5	2.3	0.61-0.51	4.8-4.0	1.73	34-29	0.30-0.25	525
10	787-950	0.3-0.4	7.8-6.5	5.2	0.47-0.39	3.7-3.1	4.0	26-22	0.23-0.19	1240

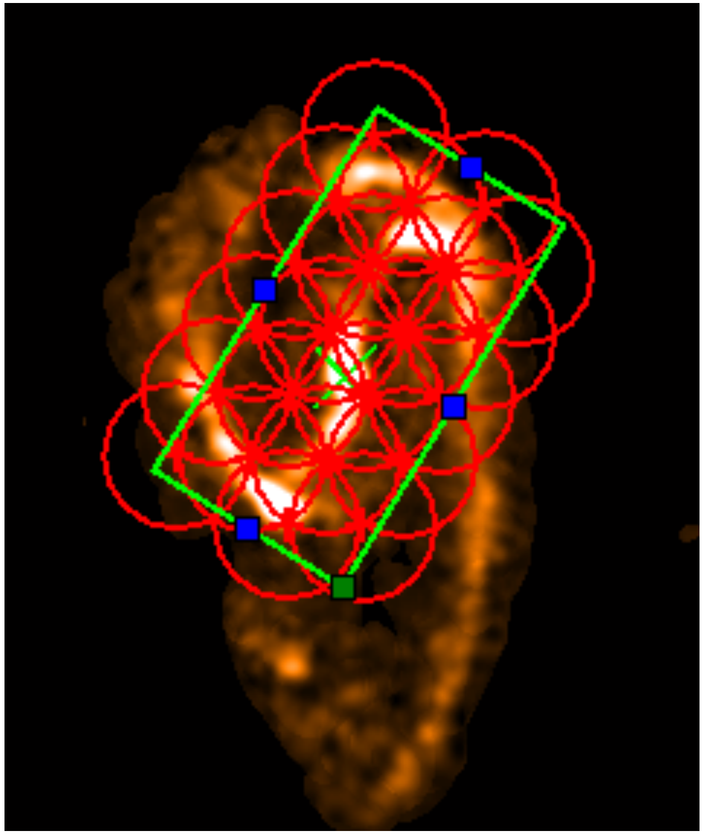
*Note: These sensitivities were calculated using the expected receiver temperatures at the time of writing, and may not represent the values that are currently available. For the most up-to-date values, use the ALMA Sensitivity Calculator. To convert sensitivity in *K* to sensitivity in *Jy/beam*, see page 36. Quoted angular resolutions are for sources which transit at the zenith.

ALMA's incredible sensitivity: NGC3627 ALMA Cycle 3 proposal Rosita



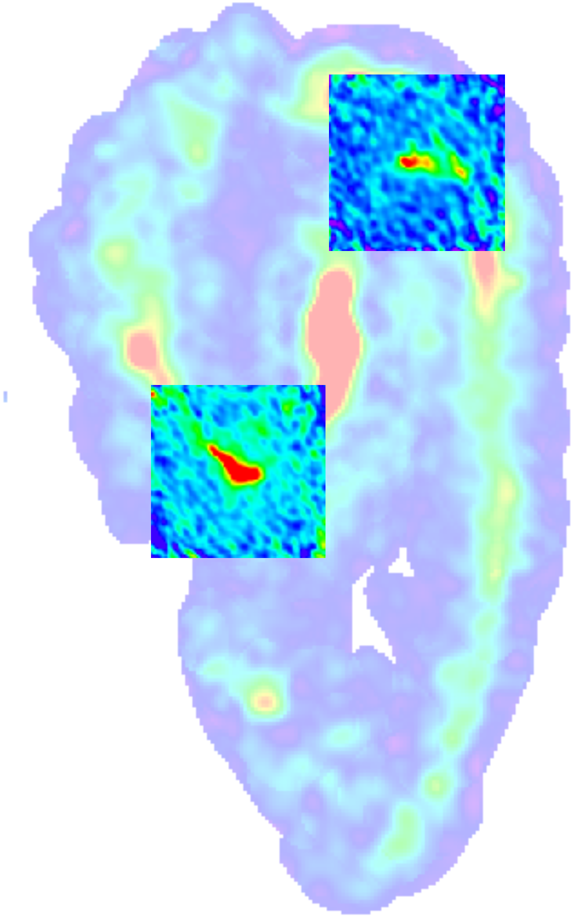
CO(1-0) with IRAM PdBI
8 hrs per pointing
Resolution ~ 2 arcsec ~ 100 pc

Paladino et al., 2008

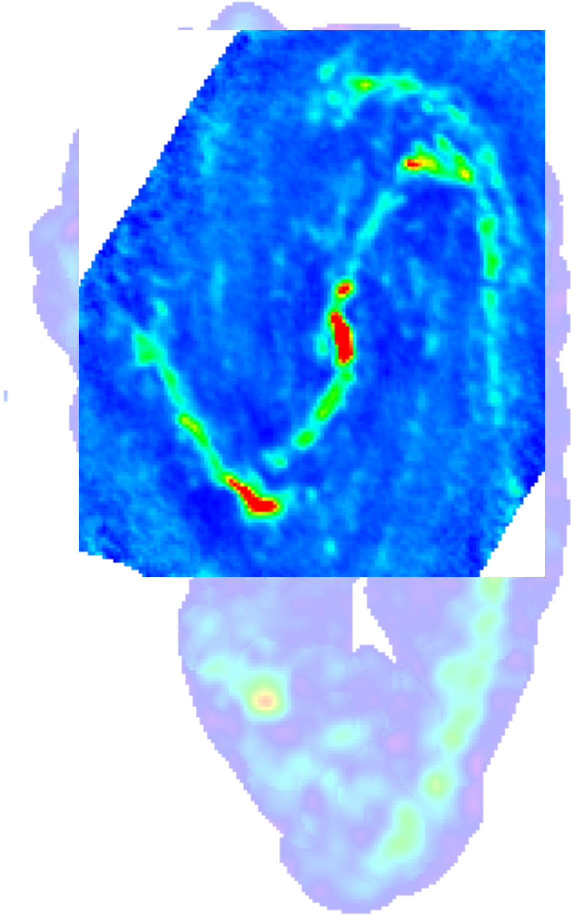


Proposal ALMA Cycle3
Mosaic of 22 pointings in band 3 (**7 hrs**) and 81 pointings in band 6 (**1hr**)
Resolution of **0.5 arcsec ~ 30 pc**

NGC3627 ALMA compact configuration data



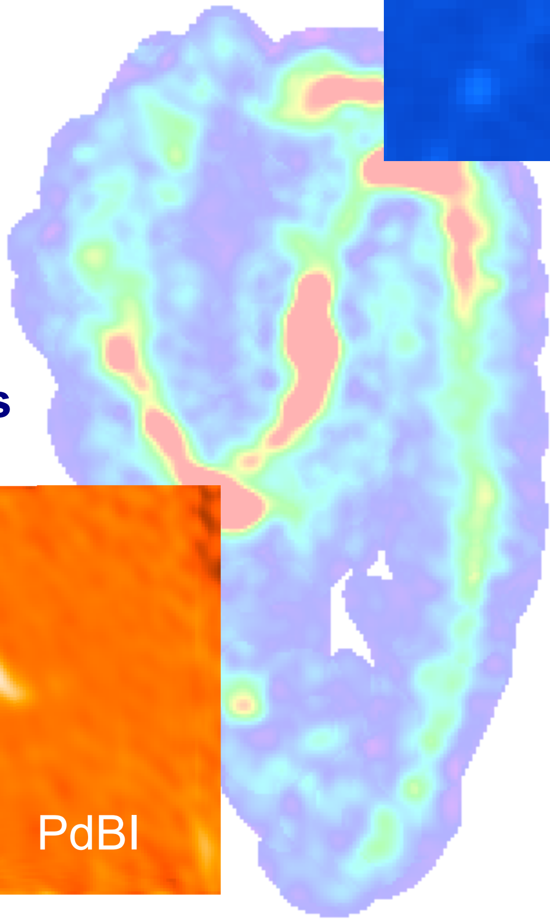
CO(1-0) with IRAM PdBI
Resolution ~ 2 arcsec ~ 100 pc
8 hrs per pointing

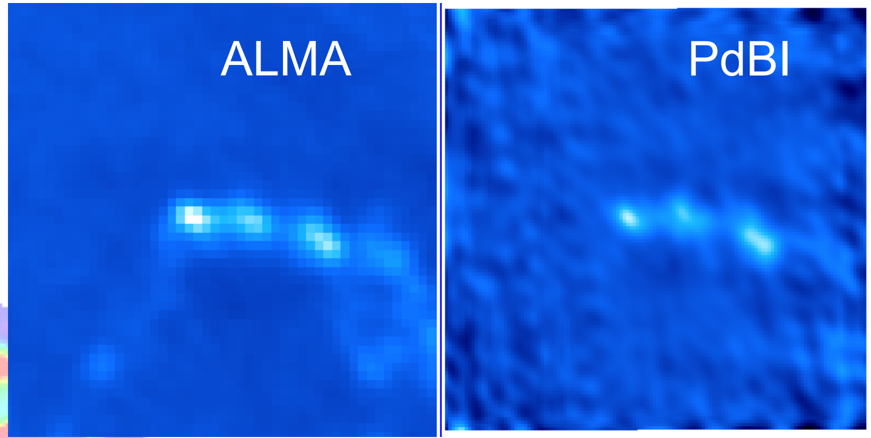


CO(1-0) with ALMA
Resolution ~ 2 arcsec ~ 100 pc
Observing time 1.5 hrs

Paladino et al.

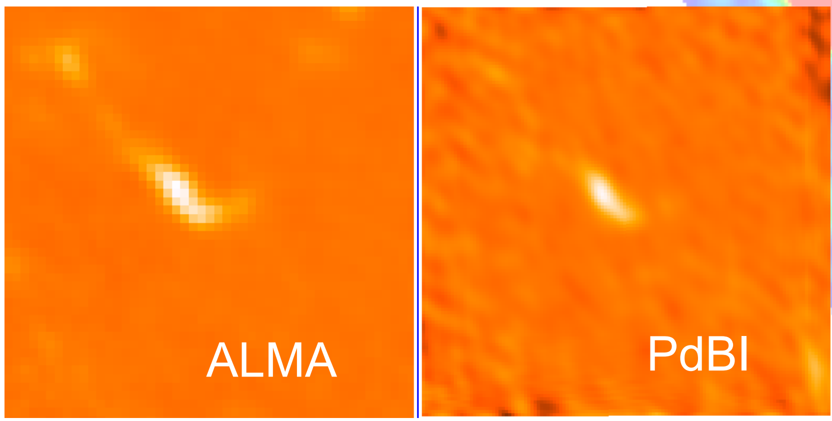
ALMA compact configuration data





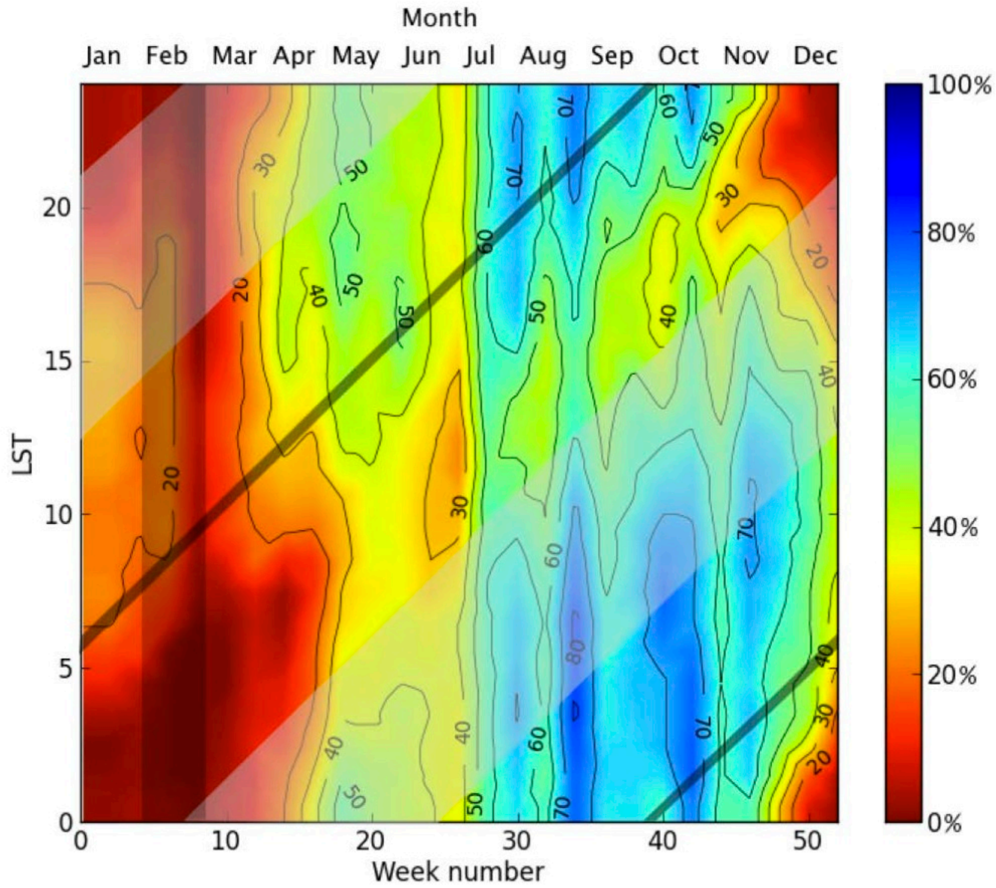
Velocity channel 630 Km/s

Velocity channel 850 Km/s



ALMA is 3 times more sensitive

% of time pwv < 1mm



Limitations to ALMA use due to opacity (PWV) and atmospheric phase stability, especially in higher-freq. bands and freqs. near water abs. lines.

Yearly- and diurnal cycle. Best times are late southern winter and late night and early morning.

Proposers do not need to anticipate weather conditions when writing proposals.

Table 2: Estimated maximum fraction of observing time suitable for observations in each band in Cycle 4

ALMA Band	Band 3	Band 4	Band 6	Band 7	Band 8	Band 9	Band 10
Fraction of time	100%	90%	70%	40%	20%	10%	10%

Notes for Table 2:

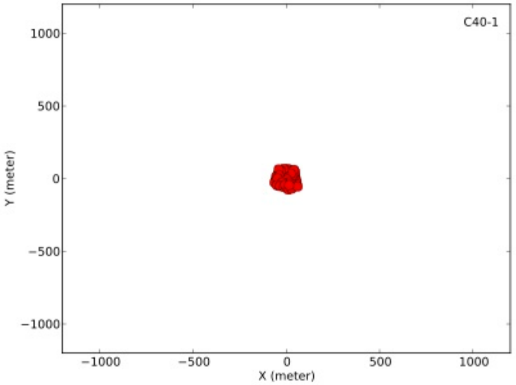
1. Times exclude total weather shutdowns.
2. These estimates are based on 1998-2011 atmospheric transmission statistics from the ALMA Site Characterization and Monitoring program and APEX radiometer in combination with the ALMA Cycle 0 experience from October 2011 to March 2012.

Fraction of time expected to be useful for obs's in each band.

ARRAY CONFIGURATIONS

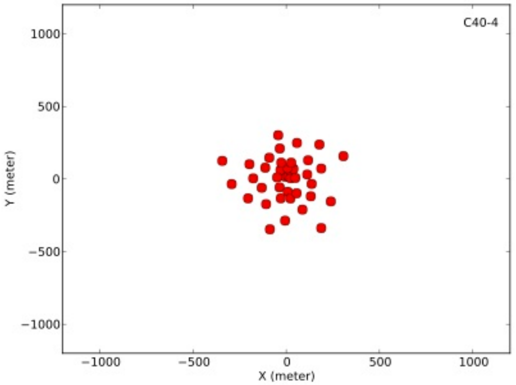
ALMA is a reconfigurable interferometer for (sub)mm astronomy.
There will be ca. 13 reconfigurations during Cycle4 at the end of which the array is expected to have imaging properties similar to one of the nine representative configurations used to characterize the advertised imaging capabilities and to estimate the observing times.

C40-1

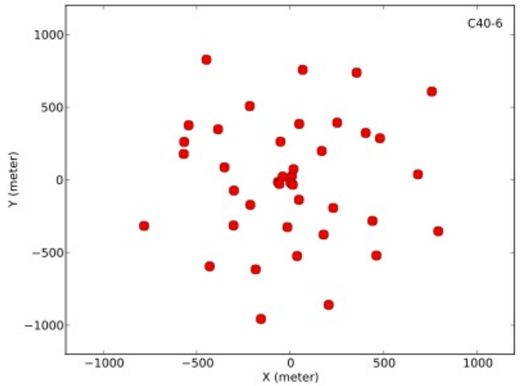


2 km

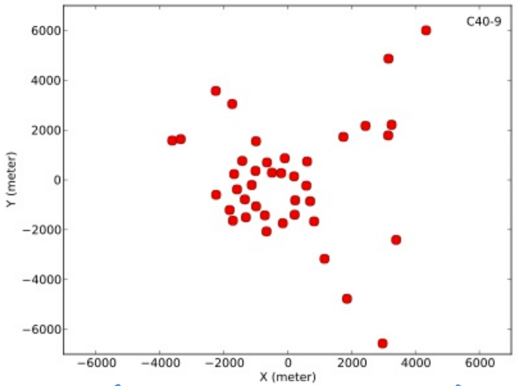
C40-4



C40-6



New configuration every 2-3 weeks.



C40-9

12 km

ARRAY CONFIGURATIONS CALENDAR

Table 3: Planned 12-m Array Configuration Schedule for Cycle 4

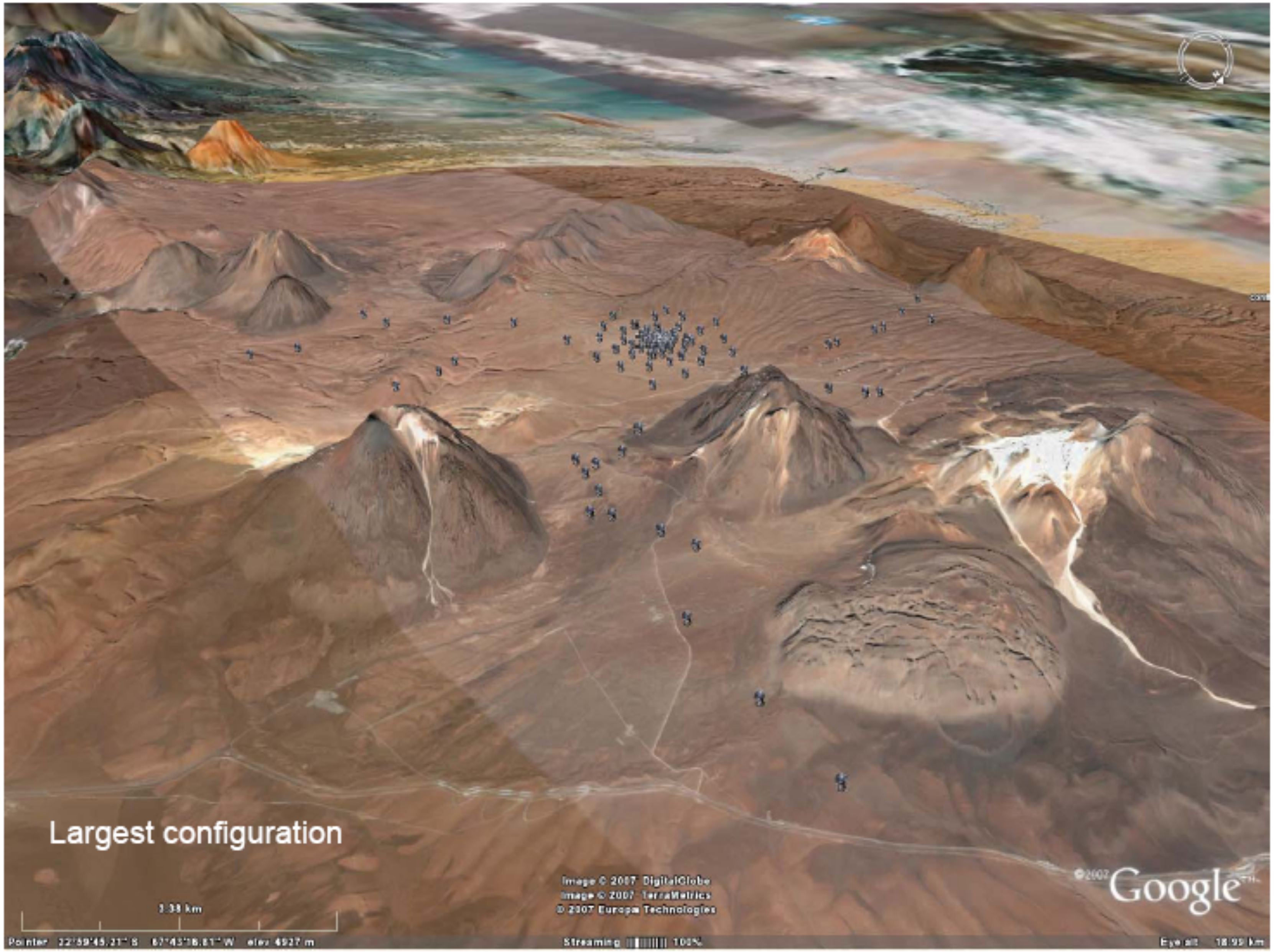
(1) Planned Start Date	(2) Configuration (planned campaigns)	(3) Longest baseline	(4) LST with best observing conditions	(5) LST with unstable observing conditions	(6) PI Observing Time (days)
14 October 2016	C40-7	3.7 km	~22h - 11h	~11h-22h	13
4 November 2016	C40-6	1.8 km	~23h - 12h	~12h-23h	11
25 November 2016	C40-5	1.1 km	~1h - 13h	~13h-1h	7
9 December 2016	C40-4	0.70 km	~2h - 14h	~14h-2h	7
23 December 2016	C40-3 (Solar)	0.46 km	~3h - 15h	~15h-3h	11
19 January 2017	C40-2 (Solar)	0.27 km	~4h - 17h	~17h-4h	9
1 February 2017	*February maintenance period*				
16 March 2017	C40-1 (Solar/VLBI)	0.15 km	~8h - 22h	22h-8h	17
6 April 2017	C40-3 (Solar/VLBI)	0.46 km	~9h - 23h	~23h-9h	11
27 April 2017	C40-5	1.1 km	~10h - 1h	~1h-10h	7
11 May 2017	*Move to configuration C40-9*				
8 June 2017	C40-9	12.6 km	~12h - 3h	~3h-12h	16
6 July 2017	C40-8	6.8 km	~14h - 5h	~5h-14h	22
17 August 2017	C40-7	3.7 km	~17h - 8h	~8h-17h	23

Notes for Table 3:

1. Dates include relocation time at the end of every configuration.
2. Configuration properties are given in Section A.2. Dates are subject to change – see text.

Restrictions:

1. Band 9, 10 obs's not scheduled in LST-ranges in column 5.
   Band 7, 8 may be, but not recommended;
2. Bands 7, 8, 9, 10 not recommended around Altiplanic winter (esp. Dec-Feb) at any LST;
3. Projects that have imaging (config) requirements and time constraints that do not coincide cannot be scheduled.


Largest configuration
Image © 2007 DigitalGlobe
Image © 2007 TerraMetrics
© 2007 Europa Technologies
©2007 Google
3.38 km
Pointer 22°59'45.21" S 67°43'18.81" W elev 4927 m
Streaming 100%
Eye alt 18.99 km

The ALMA Antenna Transporter

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


First Move of an ALMA Antenna
(July 8, 2008)
SCHEUERLE
ALMA

MRS and Angular resolution

MRS = Maximum Recoverable Scale

Resolution (arcsec): 0.2 x (300GHz/f) (1km/b_{max})

MRS (arcsec): 124 x (1m/b_{min}) (300GHz/f)

FOV (arcsec): 20.6 x (300GHz/f)

MRS is a "guideline for the largest angular structure on which some of the flux of a smooth structure can be reasonably recovered by the interferometer." (Cycle4 primer)

i.e. anything much larger will (start to) be 'resolved out': the **missing flux** problem, intrinsic to interferometers.

To recover this emission, additional observations needed, including observations with More compact configurations (with the 12-m array, the 7-m array, or single-dish [TP])

Only certain combinations of arrays are allowed – see next slides

Table A-1: Angular Resolutions (AR) and Maximum Recoverable Scales (MRS) for the Cycle 4 Array configurations

Config	Lmax / Lmin	Band / Freq	Band 3 100 GHz	Band 4 150 GHz	Band 6 230 GHz	Band 7 345 GHz	Band 8 460 GHz	Band 9 650 GHz	Band 10 870 GHz
7-m Array	45 m	AR	12.5"	8.4"	5.4"	3.6"	**2.7"**	**1.9"**	**1.4"**
	9 m	MRS	66.7"	44.5"	29.0"	19.3"	**14.5"**	**10.3"**	**7.7"**
C40-1	155 m	AR	3.7"	2.5"	1.6"	1.1"	**0.80"**	**0.57"**	**0.42"**
	15 m	MRS	29.0"	19.4"	12.6"	8.4"	**6.3"**	**4.5"**	**3.3"**
C40-2	273 m	AR	2.4"	1.6"	1.0"	0.69"	**0.52"**	**0.37"**	**0.27"**
	15 m	MRS	22.1"	14.8"	9.6"	6.4"	**4.8"**	**3.4"**	**2.5"**
C40-3	460 m	AR	1.5"	0.97"	0.63"	0.42"	**0.32"**	**0.22"**	**0.17"**
	15 m	MRS	13.7"	9.1"	5.9"	4.0"	**3.0"**	**2.1"**	**1.6"**
C40-4	704 m	AR	0.93"	0.62"	0.40"	0.27"	**0.20"**	**0.14"**	**0.11"**
	15 m	MRS	8.9"	5.9"	3.9"	2.6"	**1.9"**	**1.4"**	**1.0"**
C40-5	1.1 km	AR	0.54"	0.36"	0.23"	0.16"	**0.12"**	**0.083"**	**0.062"**
	17 m	MRS	6.0"	4.0"	2.6"	1.7"	**1.3"**	**0.93"**	**0.69"**
C40-6	1.8 km	AR	0.35"	0.23"	0.15"	0.10"	**0.076"**	**0.054"**	**0.040"**
	15 m	MRS	3.1"	2.1"	1.3"	0.90"	**0.67"**	**0.48"**	**0.36"**
C40-7	3.7 km	AR	0.21"	0.14"	0.090"	0.060"	**0.045"**	**0.032"**	**0.024"**
	81 m	MRS	1.8"	1.2"	0.77"	0.52"	**0.39"**	**0.27"**	**0.20"**
C40-8	6.8 km	AR	0.12"	0.079"	0.052"	**0.034"**	N/A	N/A	N/A
	168 m	MRS	1.3"	0.87"	0.57"	**0.38"**			
C40-9	12.6 km	AR	0.066"	0.044"	0.029"	N/A	N/A	N/A	N/A
	271 m	MRS	0.78"	0.52"	0.34"				

Notes for Table A-1:

3. See Chapter 7 of the Technical Handbook for relevant equations and detailed considerations.
4. Values evaluated for source at zenith. For sources transiting at lower elevations, the North-South angular measures will increase proportional to 1/sin(ELEVATION).
5. Lmax and Lmin are the maximum and minimum baseline lengths in the array.
6. All angular measures scale inversely with observed sky frequency.
7. Bold blue text indicates non-standard modes (Section 5.2)

$\Theta_{res} \; \alpha \; \lambda/b_{max}$

$\Theta_{max} \; \alpha \; \lambda/b_{min}$

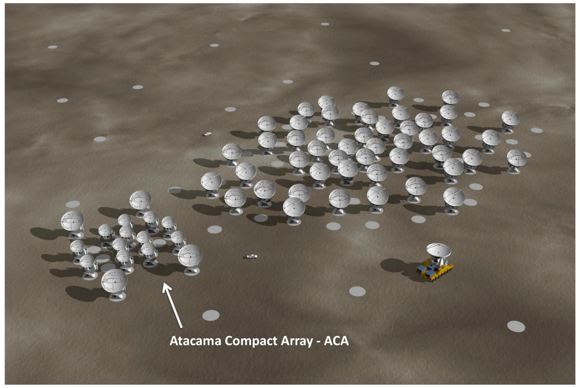
FOV $\alpha \; \lambda/D$

Resolution (arcsec):
0.2 x (300GHz/f) (1km/b_{max})

MRS (arcsec):
124 x (1m/b_{min}) (300GHz/f)

FOV (arcsec):
20.6 x (300GHz/f)

Blue: non-standard



Role of ACA

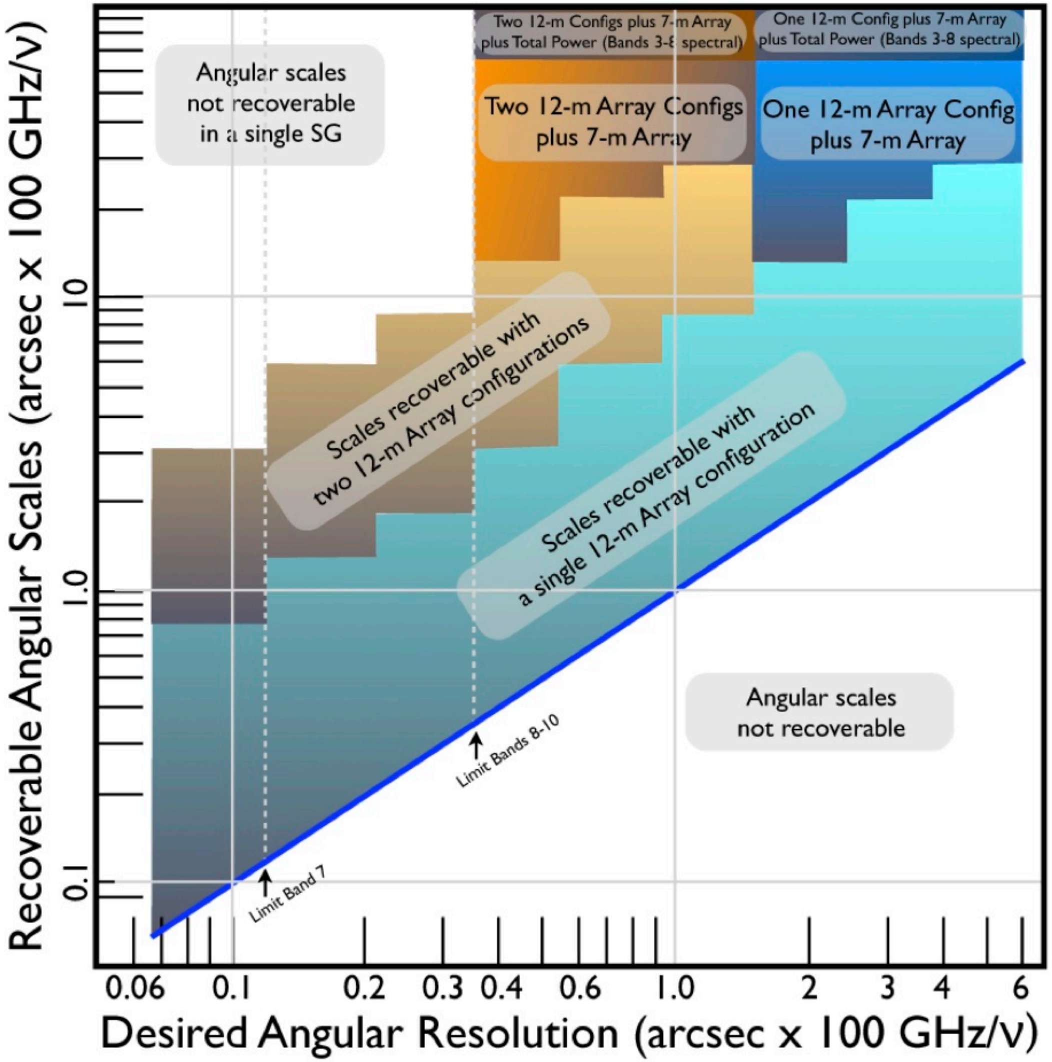
- **Supplement the 50-element array data with**
  - **Short baseline data (7-m antennas)**
  - **Total power data (12-m antennas)**

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

- **Stand-alone mode of operation**

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

MRS and Angular resolution



Useful figure to help you find whether more than one 12-m array configuration or a combination of arrays is needed to accommodate the MRS and angular resolution required by your project.

Example: want to observe at 300GHz, with 0.”4 res. And 10” MRS. Scaled to 100 GHz this becomes 1.”2 and 30”. From the figure we see that one needs 2 configurations of the 12-m array plus the ACA to recover all angular scales.

Spectral setup: sidebands, basebands & spectral windows

Observed sky frequencies need to be down-converted before being sent to the correlator.

For this to occur, the signal from the source is mixed with that of a (set of) Local Oscillator(s) which results in the creation of 2 sidebands, 'upper' and 'lower':

For the lower sideband (LSB): (F_{LO1} - IF_{lo}) to (F_{LO1} - IF_{hi})
For the upper sideband (USB): (F_{LO1} + IF_{lo}) to (F_{LO1} + If_{hi})

NB: for both polarizations!

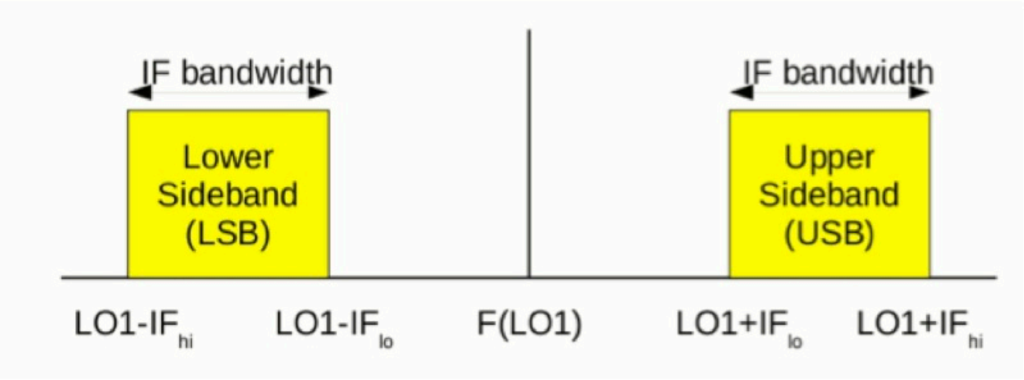
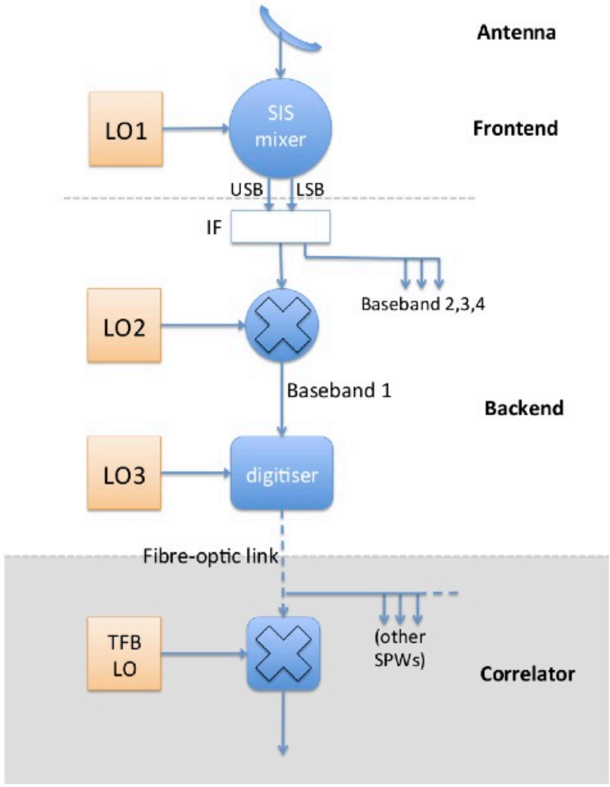


Figure 4.2: IF ranges for the two sidebands in a heterodyne receiver.



Spectral setup: sidebands, basebands & spectral windows

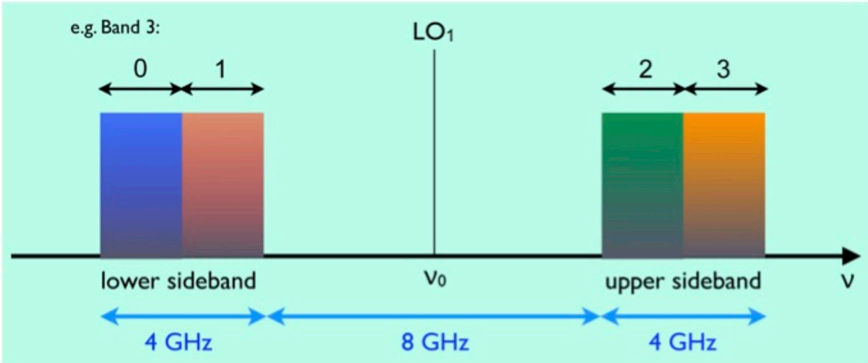


Figure 31: *A graphical view of basebands and sidebands. Basebands may be tuned to overlap if the user wishes, or may be located so as to maximize the total bandwidth (as shown). Each baseband may be further subdivided into as many as 8 spectral windows. Up to four spectral windows per baseband will be available during Cycle 4.*

Within these sidebands, ALMA produces 4 x 2 GHz basebands that can be placed inside each sideband.

NB: basebands are not independent: overlapping BBs do not reduce noise

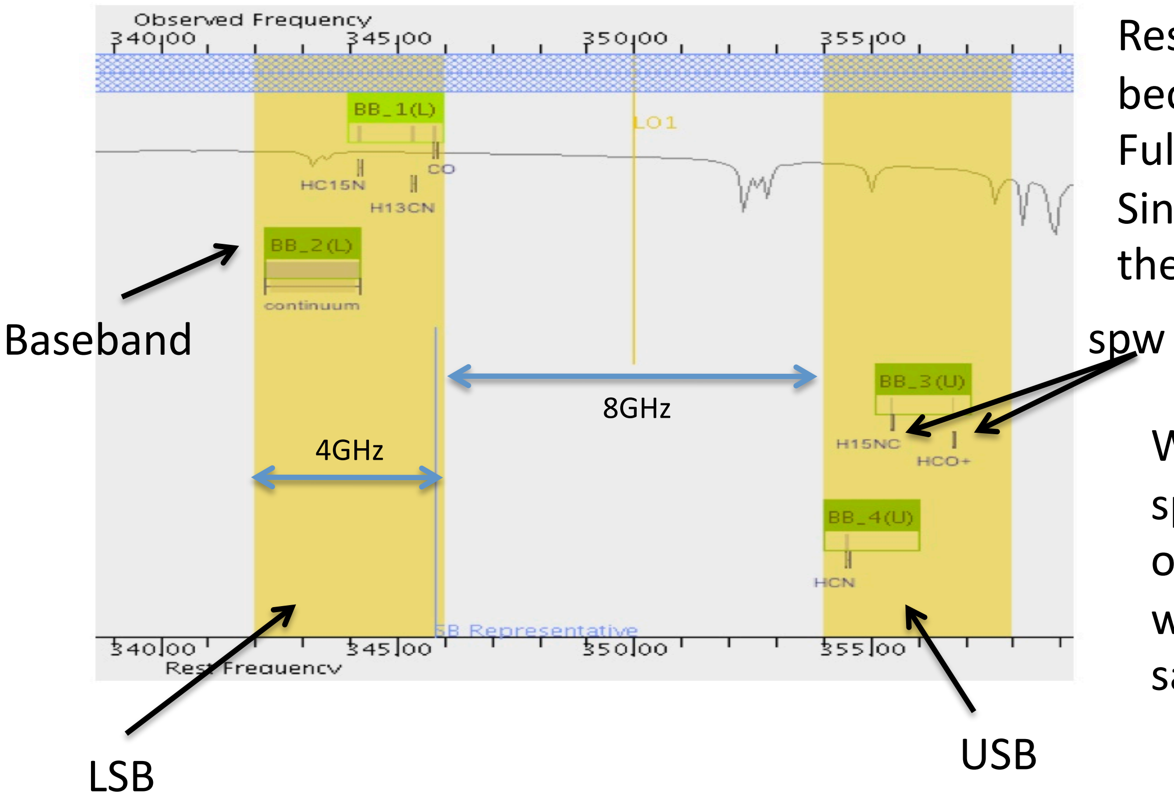
Spectral setup: sidebands, basebands & spectral windows

Table A-4: Properties of ALMA Cycle 4 Correlator Modes, dual-polarization operation [1,2]

Bandwidth (MHz)	Channel spacing[3] (MHz)	Spectral resolution (MHz)	Number of channels	Correlator mode[4]
1875	15.6	31.2	120	TDM
1875	0.488	0.976	3840	FDM
938	0.244	0.488	3840	FDM
469	0.122	0.244	3840	FDM
234	0.061	0.122	3840	FDM
117	0.0305	0.061	3840	FDM
58.6	0.0153	0.0305	3840	FDM

Continuum (BW_{tot} = 7.5GHz)

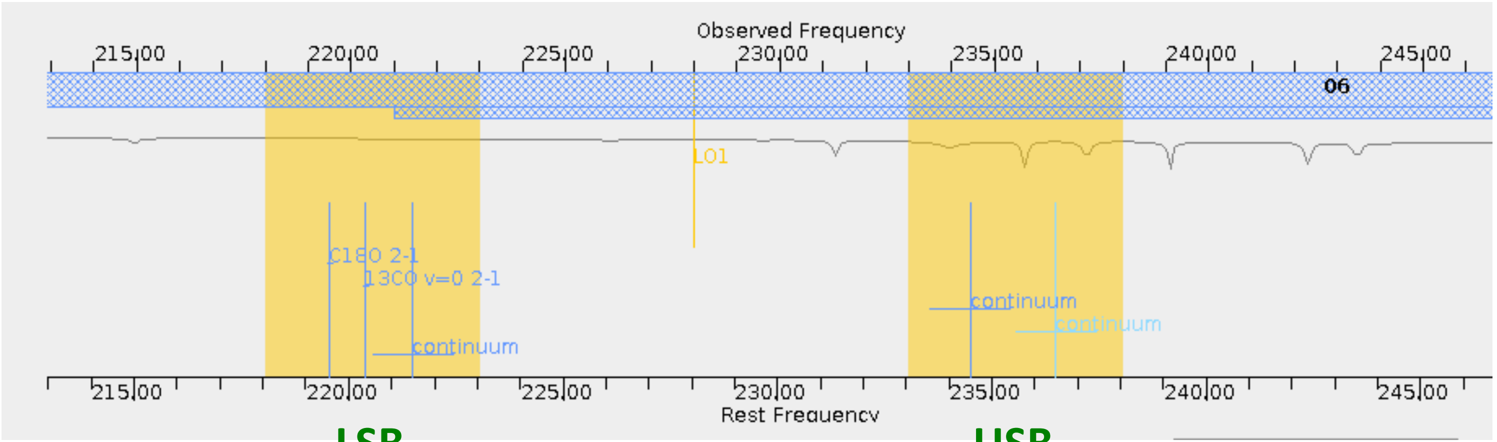
Spectral lines



Resolution = 2x channel spacing because of default Hanning smoothing.
Full Stokes => half the channels.
Single pol (instead of Dual): double the channels.

Within each baseband up to 4 spectral windows can be placed to observe lines. All spectral windows within a baseband must have the same resolution.

Example: spectral setup of my Cycle 4 proposal, Band 6



LSB **USB**

LSB

Baseband-1

Fraction	Centre Freq (rest,lsrk)	Centre Freq (sky,bar)	Transition	Bandwidth, Resolution (smoothed)	Spec. Avg.	Representative Window
1/2	220.39868 GHz	220.32617 GHz	13CO v=0 2-1	117.188 MHz(159 km/s), 122.070 kHz(0.166 km/s)	1	○
1/2	219.56036 GHz	219.48812 GHz	C18O 2-1	117.188 MHz(160 km/s), 122.070 kHz(0.167 km/s)	1	○

Select Lines to Observe in Baseband-1... Add Delete

Baseband-2

1(Full)	221.50000 GHz	221.42712 GHz	continuum	1875.000 MHz(2539 km/s), 31.250 MHz(42.310 km/s)	1	◉

Select Lines to Observe in Baseband-2... Add Delete

USB

Baseband-3

1(Full)	234.50000 GHz	234.42284 GHz	continuum	1875.000 MHz(2398 km/s), 31.250 MHz(39.964 km/s)	1	○

Select Lines to Observe in Baseband-3... Add Delete

Baseband-4

1(Full)	236.50000 GHz	236.42219 GHz	continuum	1875.000 MHz(2378 km/s), 31.250 MHz(39.626 km/s)	1	○

1 BB with 2 spw

3 BBs for continuum

ALMA evolution and proposal statistics Early Science Cycles 0 - 4

	Cycle 0	Cycle 1	Cycle 2	Cycle 3	Cycle 4
	Sep. 2011 - Jan. 2013	Jan. 2013 - May 2014	Jun. 2014 - Oct. 2015	Oct. 2015 - Sep. 2016	Oct. 2016 – Sep. 2017
Telescope					
Hours x Science	**800**	**800**	**2000**	**2100**	**3100+**
Antennas	**> 12x12-m**	**>32x12-m +9x7-m+2TP**	**>34x12-m +9x7m+2TP**	**>36x12-m +10x7-m+2TP**	**>40x12-m +10x7-m+3TP**
Bands	**3, 6, 7, 9**	**3, 6, 7, 9**	**+4, 8**	**+10**	**+VLBI, Solar, LPs, ACA standalone (1800 hrs)**
Wavelengths [mm]	3, 1.3, 0.8, 0.45	as in Cycle0	+2, 0.7	+0.35	3 to 0.35
Baselines	≤ 400m	≤ 1000m	≤1500m	**≤10km**	**≤12.6km**
Polarisation	single dual	single dual	**full**	**full**	**full**

Proposal outcome					
Submitted	950	1108	1383	1589	1573
Highest priority	112	196	353	401	475
Filler	51	92	159	235	232
Success rate [%]	12 (17)	18 (26)	26 (37)	25 (40)	30 (45)
Pressure* global	8.5	5.7	3.9	4.0	3.3
Pressure Europe	11.9	9.1	4.9	4.9	4.1

*: submitted/accepted(A+B)

Early science: observations with incomplete array, limited suite of receivers, selected observing modes, restricted baseline range – since 2011 (5 Calls for Proposals so far).

And already it has obtained beautiful and unexpected results!

Check out:

-Press releases (http://www.almaobservatory.org/en/press-room/press-releases)

-Published papers (http://telbib.eso.org; from there get direct access to the data!).

ALMA proposal science categories

Cosmology and the high redshift universe

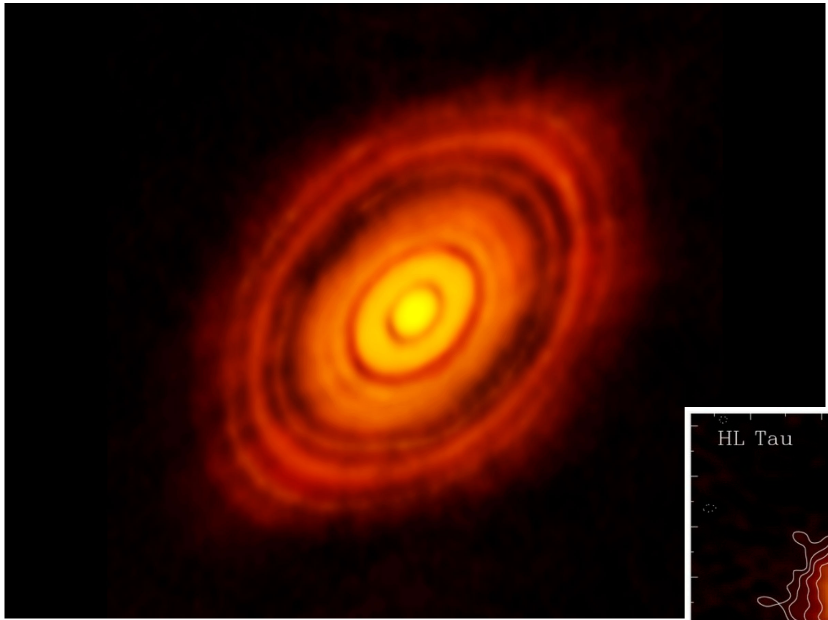
Galaxies and galactic nuclei

ISM, star formation and astrochemistry

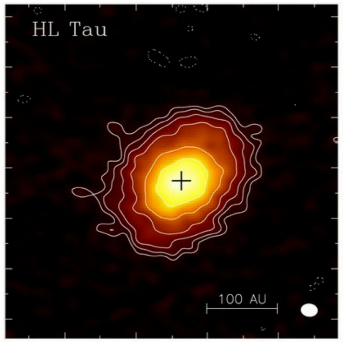
Circumstellar disks, exoplanets and the solar system

Stellar evolution and the Sun

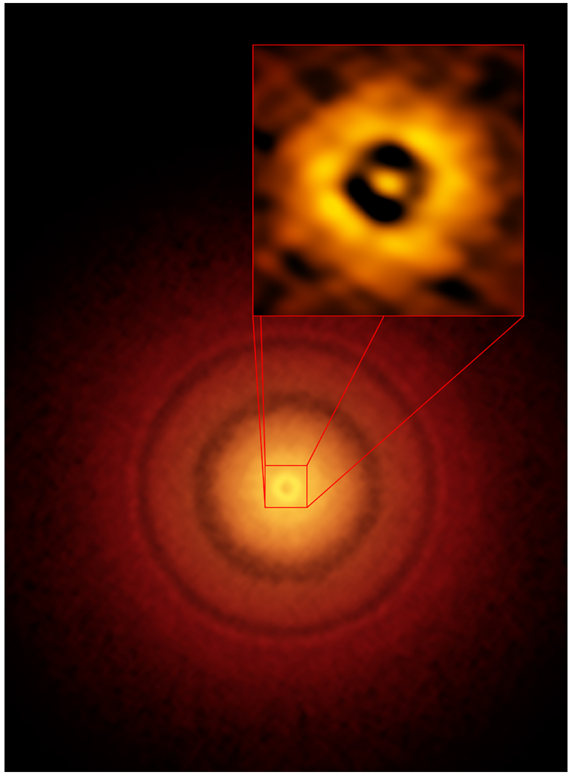
Planet formation: circumstellar disks



TW Hya, d=175 lightyr (54pc). Age ~ 10^7 yr.
Planet-forming disk. Gaps at same distance as Earth, Uranus, Pluto from Sun.
Band 7: 870µm cont.; b_{max}=14 km; 31-36 ants.
Res: 30 mas (1.6AU).Detail: 24x18 mas^2 (1.3x1.0 AU^2). Andrews et al. 2016, ApJLett



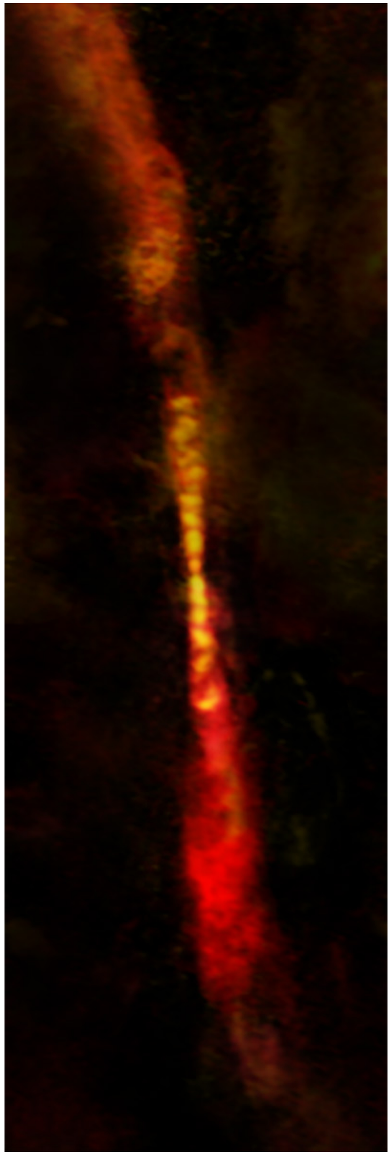
Previous best: CARMA obs.
0".17x0".13



HL Tau, d=450 lightyr (138pc)
Observed during long-baseline campaign (ALMA collab. 2015) b_{max} = 15.24 km
Band 6; res. 0."035; int. time 4.5 hrs

Gaps in disk are result of planet formation.

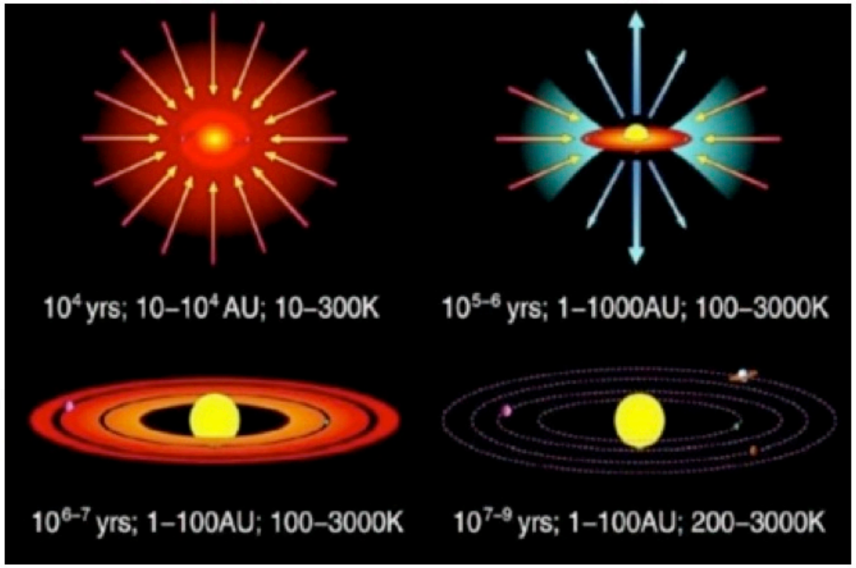
Episodic outflow from protostar



Highly collimated jet from protostar in Serpens.
Gaps in the emission indicate **22 separate ejection events** (possibly separated by ca. 100 years).
Offers insight into environment of the accretion disk around this protostar (d=415 pc).

Band 6: ^{12}CO, ^{13}CO, $C^{18}O$ (2-1)
Res. 0".9 x 0".6
12-m array + ACA

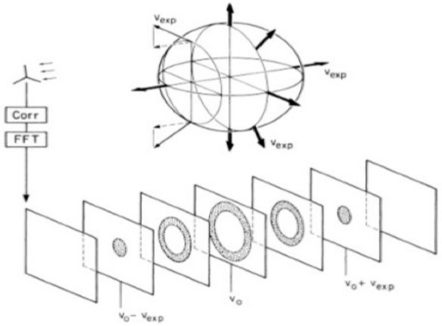
Plunkett et al. 2015 Nature



after Shu et al. 1987

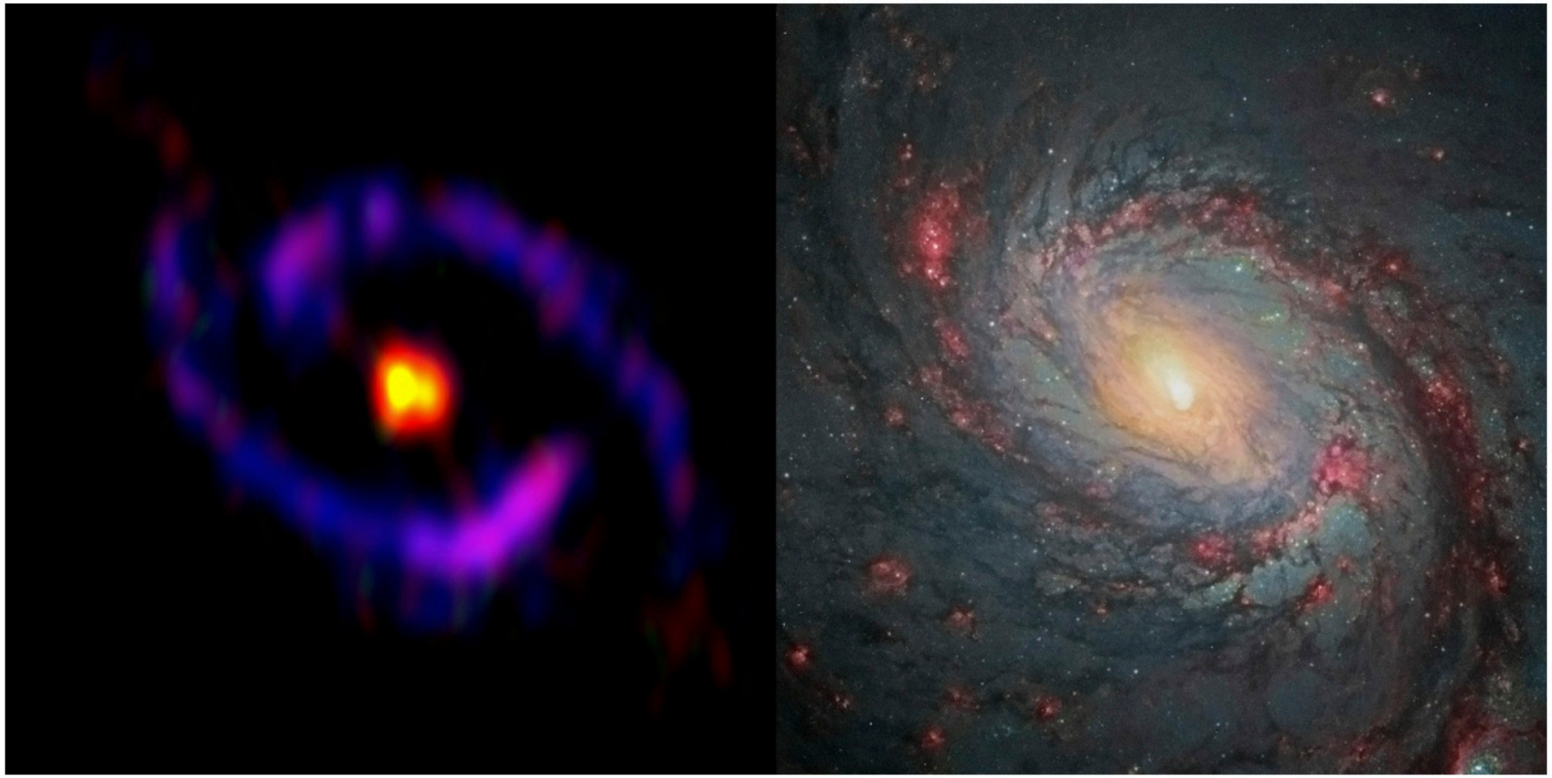
AGB star
R Sculptoris

~15antennas,~4hrs
Band 7: CO(3-2),
resolution=1.3''
45-point mosaic (50'' x 50'' field)



Maercker et al. 2012; Vlemmings et al. 2013)

Circumnuclear disk AGN – NGC1068

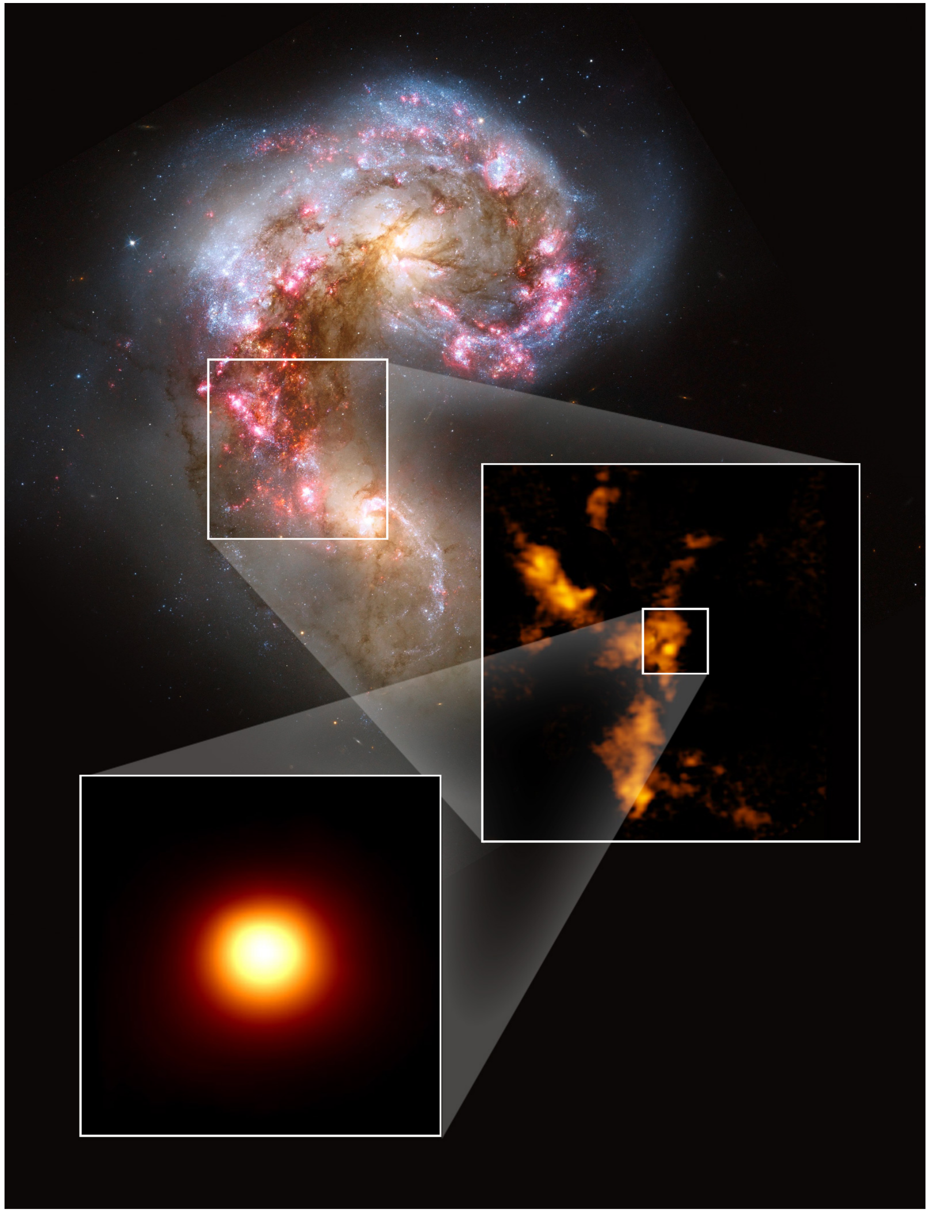


Left: ALMA yellow: HC_3N / red: CS / blue: CO

Unexpected detection of HC_3N and CH_3CN in NGC1068

Takano et al. 2014; Garcia-Burillo et al. 2014; Nakajima et al. 2015

Interacting galaxies: the Antennae

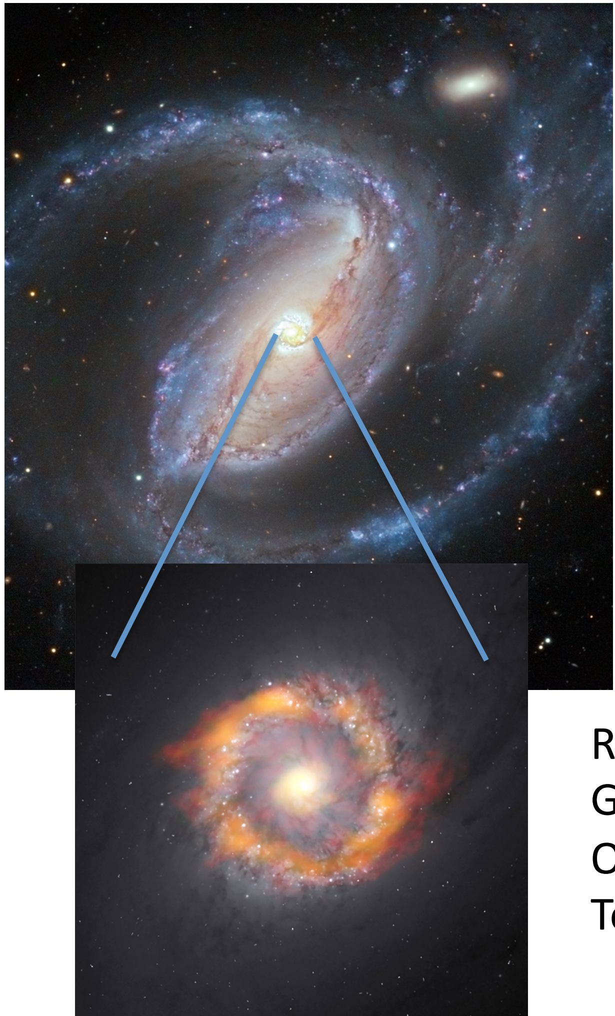


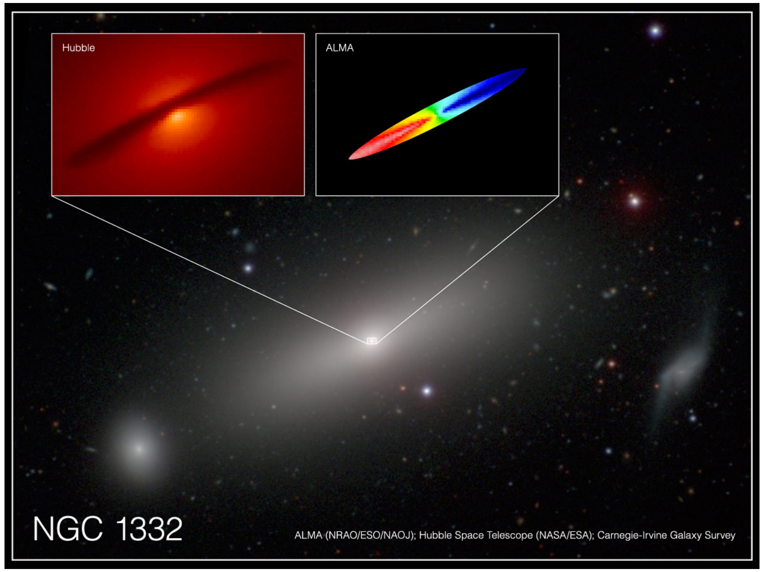
A globular cluster about to be born?
"An incredibly massive, extremely dense, cloud of molecular gas, which has all the characteristics of a globular cluster but has not yet begun to form stars."

Band7: CO(3-2) + 870μm cont.
13-point mosaic
Res: 0".56 x 0"43 (59x45 pc^2)

Johnson et al. 2015 ApJ

Weighing black holes – using kinematics of molecules





NGC1097

Red: ALMA HCO^+
Green/orange: ALMA HCN
Optical images:
Top: VLT; bottom: HST

M_{BH}=140 10^6 $M_\odot$

Onishi et al. 2015 ApJ

NGC1332

Band 6: CO(2-1)
Res: 44 mas

M_{BH}=660 (±10%) 10^6 $M_\odot$

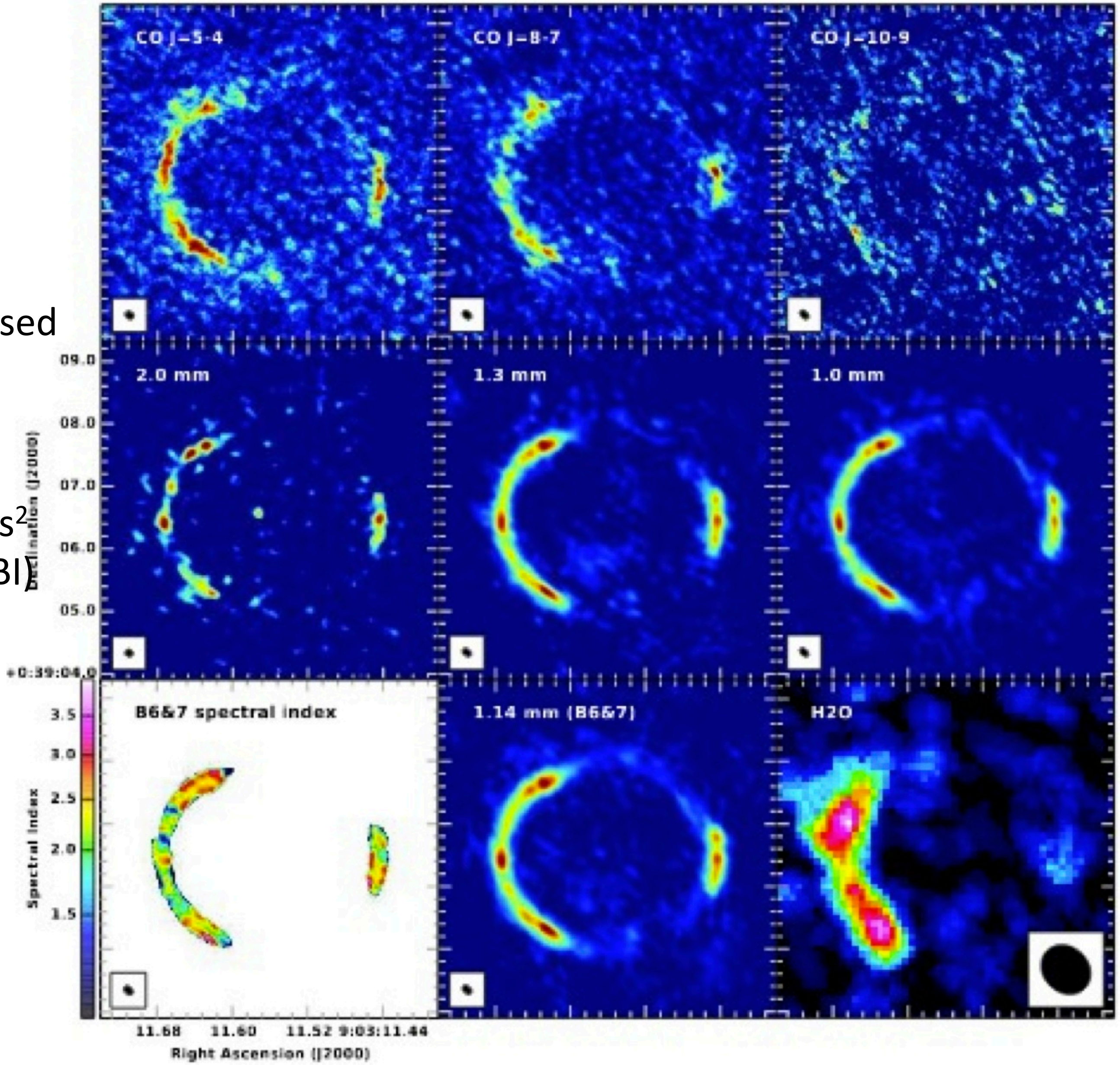
Barth et al. 2016 ApJLett

Einstein ring Sdp.81

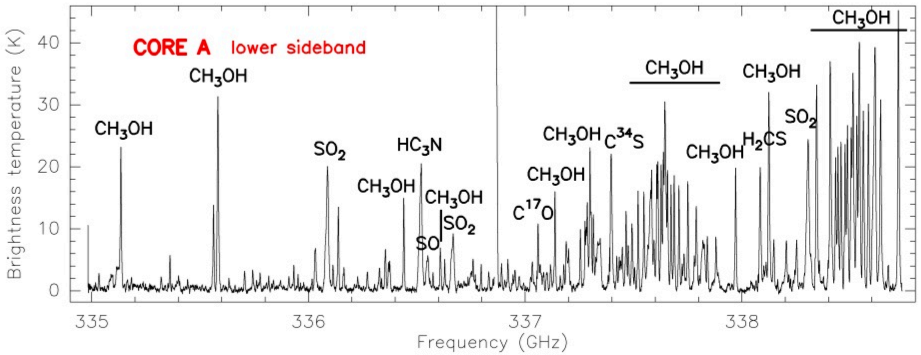
ALMA Partnership 2015
Long-baseline campaign;
b_{max}=15km

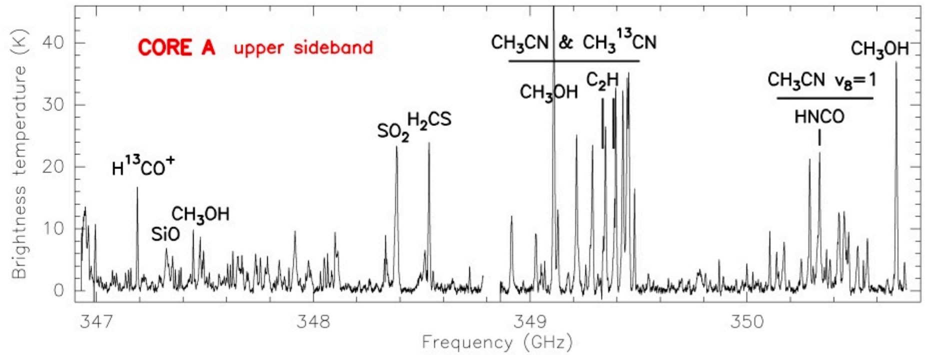
Submm galaxy at z=3.042 lensed
By elliptical galaxy at z=0.299

Bands 4,6,7
Res: 60x54, 39x30, 31x23 mas^2
(20-80x better than SMA, PdBI)



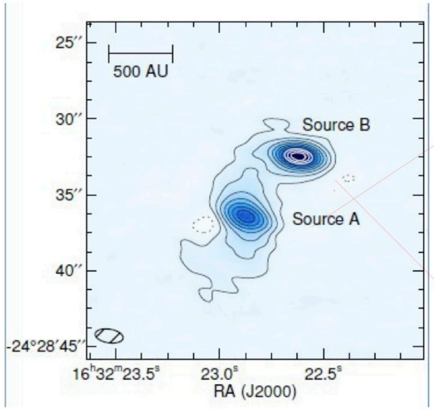
Astrochemistry I



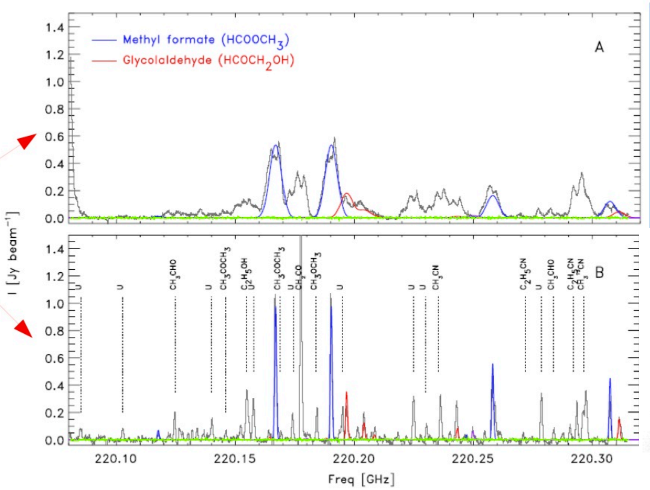


Beltran et al. 2014

The proto-binary IRAS 16293-2422

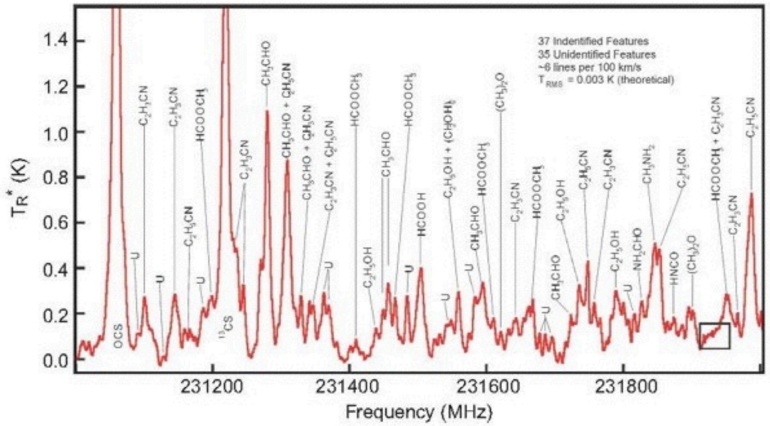


ALMA Continuum map



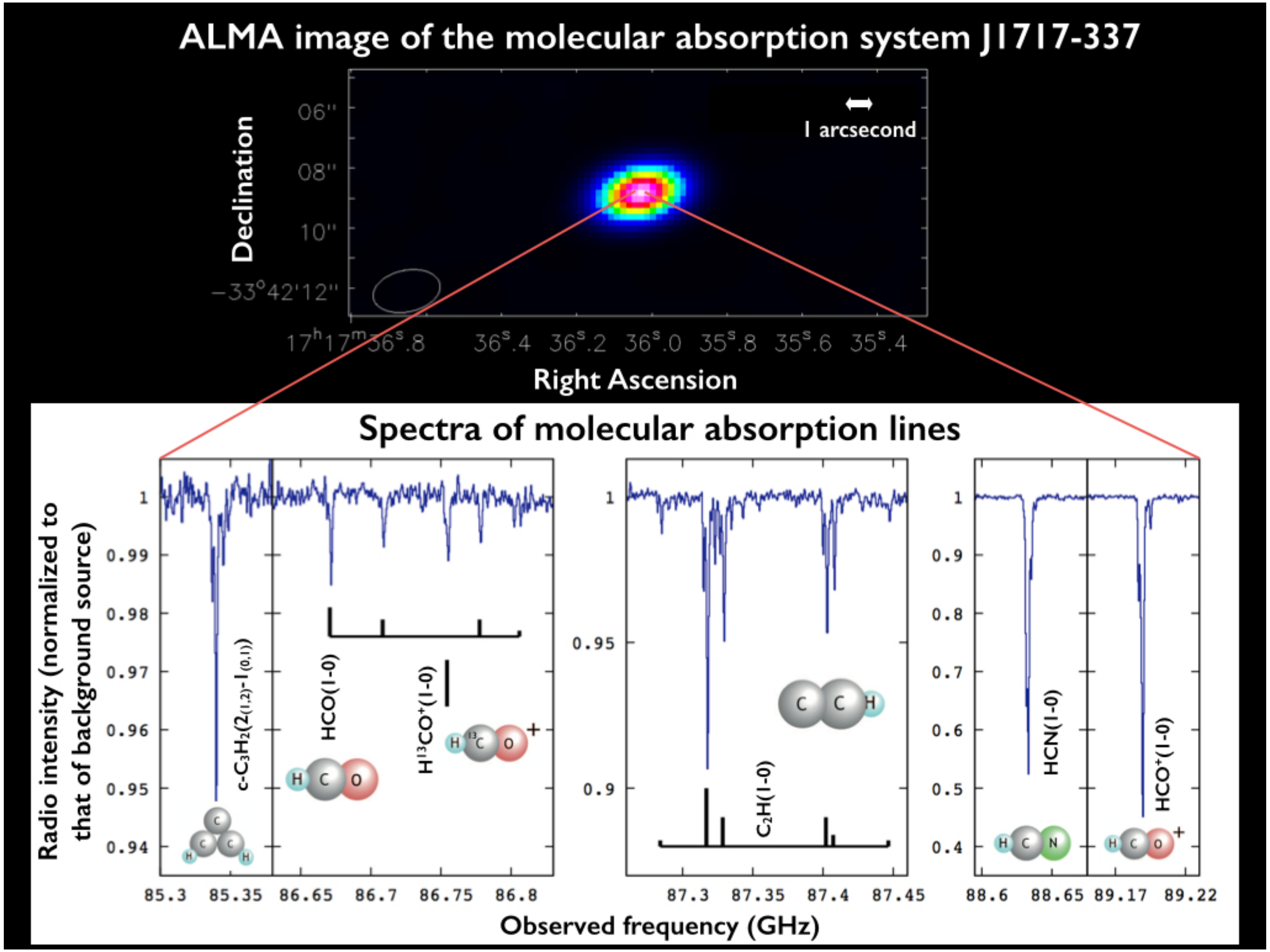
6 lines of glycolaldehyde detected

Jorgensen et al. 2013



Glycolaldehyde is a pre-biotic molecule (first step in a reaction to form ribose, backbone of DNA)

Astrochemistry II



Ando et al. 2015 PASJ

… and there is much, much more.

For news and press releases:
www.almaobservatory.org

For ALMA status, proposals, archive mining:
www.almascience.eso.org

For publications using ALMA data:
telbib.eso.org

Also www.eso.org/sci/publications/messenger/ often has ALMA news, images etc.

Website Italian node of the EU ALMA Regional Centre:
www.alma.inaf.it