MASERS AND ALMA

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WHY SUBMM MASERS?

Many transitions available, elucidating different physical parameters in the gas and environment

H_2O $J'_{K'_A K'_C} - J''_{K''_A K''_C}$	Frequency (MHz)	E_U/k (K)
$6_{16} - 5_{23}$	22235.08	642.5
$10_{29} - 9_{36}$	321225.64	1845.9
$5_{15} - 4_{22}$	325152.92	454.4
$17_{4,13} - 16_{5,10}$	354808.9	5764.3
$7_{52} - 6_{61}$	437346.67	1503.7
$6_{43} - 5_{50}$	439150.81	1067.7
$7_{52} - 6_{61}$	443018.30	1503.7
$6_{61} - 5_{51}$	470888.95	1041.8
$5_{51} - 4_{40}$	474689.13	702.3

TABLE 2

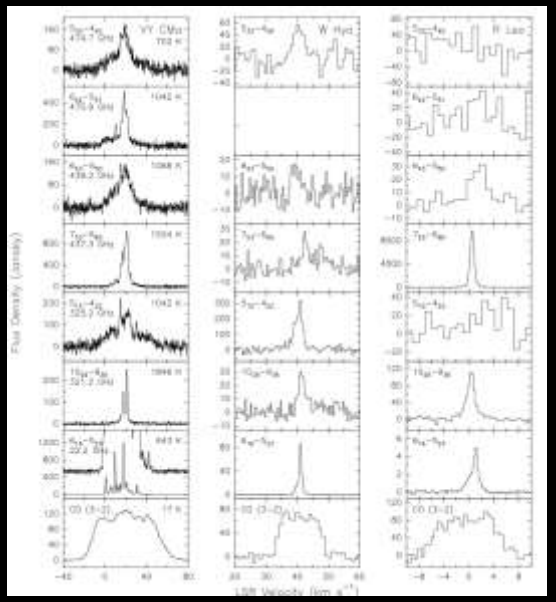
MOLECULAR LINES OBSERVED

Molecule	Transition (J_{upper}–J_{lower})	Rest Frequency (GHz)	Upper State Energy (K)	No. Stars (detected/observed) M	C	S
(a) Transitions observed in this work						
SiO.....	5–4	217.105	31.3	15/15	4/4	4/7
	8–7	347.331	75.1	13/13	5/5	5/7
	10–9	434.120	114.7	2/3	...	...
HCN.....	3–2	265.886	25.5	13/13	4/4	6/9
	4–3	354.505	42.6	11/13	4/4	4/5
(b) Other observed millimeter-wavelength transitions						
SiO.....	1–0	43.424	2.1	...	...	...
	2–1	86.847	6.3	...	...	...
	3–2	130.269	12.5	...	...	...
HCN.....	1–0	88.632	4.3	...	...	...

AVERAGE AND RMS[a] OF INTEGRATED LINE INTENSITY RATIOS BY STELLAR CATEGORY

Stellar Category (1)	SiO Lines[b] 5–4/2–1 (2)	8–7/2–1 (3)	HCN Lines[b] 3–2/1–0 (4)	4–3/1–0 (5)	HCN/SiO Line Ratios[b] 1–0/2–1 (6)	3–2/5–4 (7)	4–3/8–7 (8)
M stars	0.89(0.38)	1.53(0.84)	2.89(2.47)	5.27(4.45)	0.27(0.15)	0.80(0.81)	0.98(0.75)
S stars	1.25(0.59)	2.97(1.33)	1.28(0.20)	2.76(1.07)	1.03(0.43)	1.21(0.49)	1.06(0.39)
C stars	2.32(0.58)	4.15(1.63)	1.64(0.32)	3.44(0.78)	7.23(0.40)	5.49(1.65)	6.31(2.65)

Bieging, Shaked & Gensheimer, 2000



Menten et al, 2007

WHY NOT SUBMM MASERS?

Observing masers, particularly water masers, at high frequencies suffers from a few significant difficulties

- To name a few:
  - Water in the atmosphere
  - Sensitivity
  - Bandpass stability
- What do we need to do?
  - Find a very high dry site
  - Build a LOT of collecting area with SIS receivers
  - Use interferometry for better amplitude stability across the band, and higher resolution

ALMA LOCATION:
HIGH ALTITUDE DESERT

ALMA

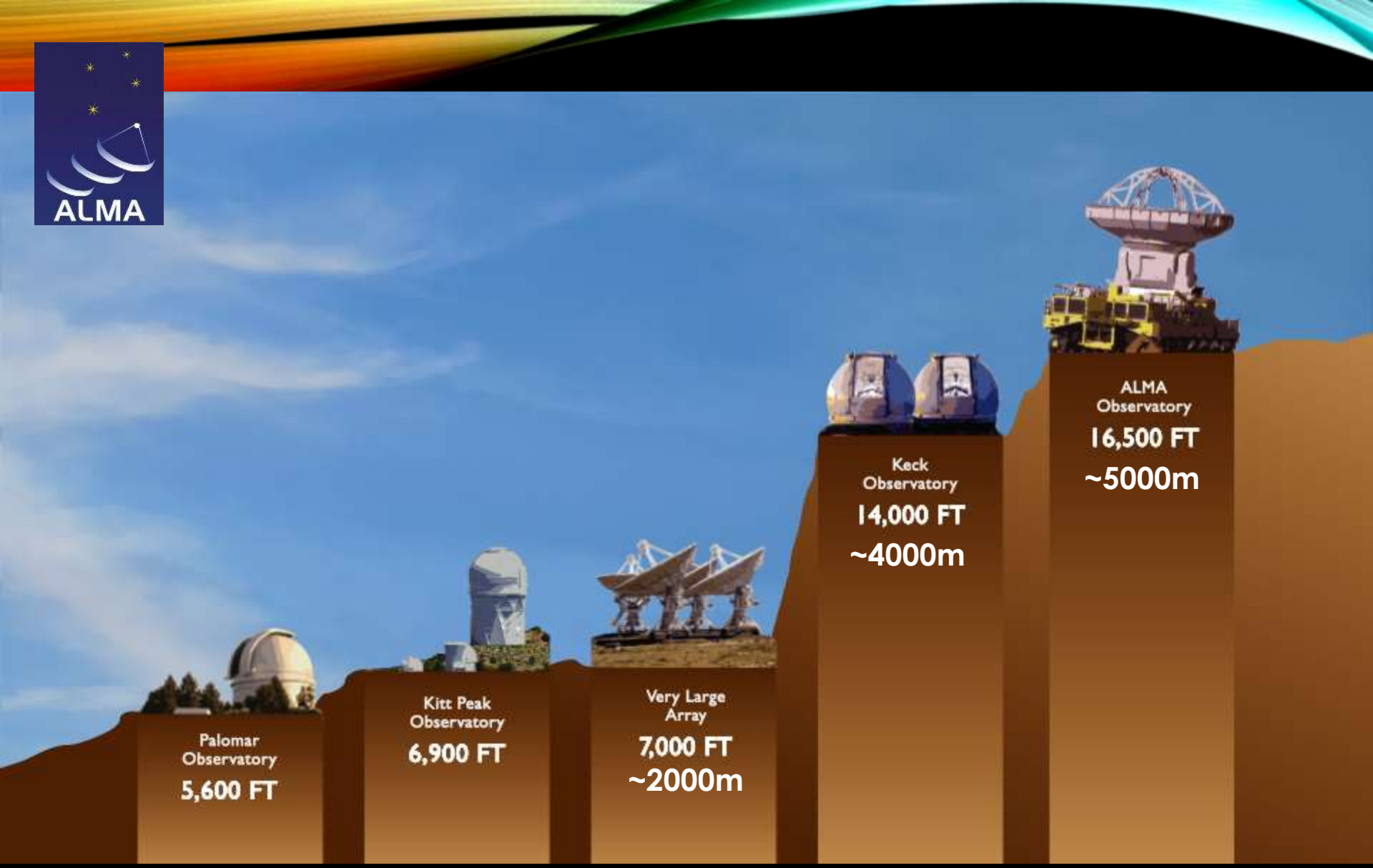
Paranal

La Serena

Santiago

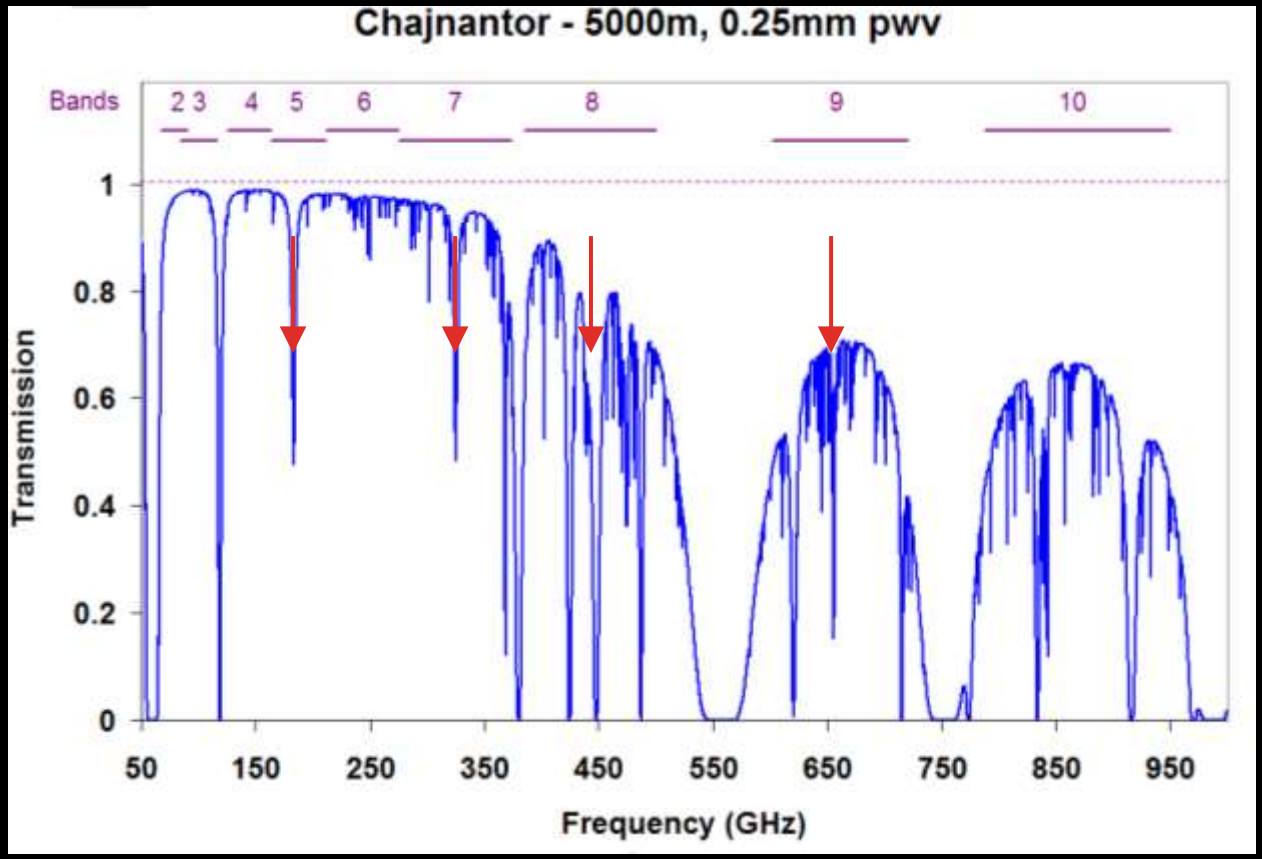





ALMA
Palomar Observatory
5,600 FT
Kitt Peak Observatory
6,900 FT
Very Large Array
7,000 FT
~2000m
Keck Observatory
14,000 FT
~4000m
ALMA Observatory
16,500 FT
~5000m


San Pedro de Atacama,
Atacama Desert, Northern Chile

ATMOSPHERIC TRANSMISSION IN THE MM/SUBMM WAVELENGTH RANGE

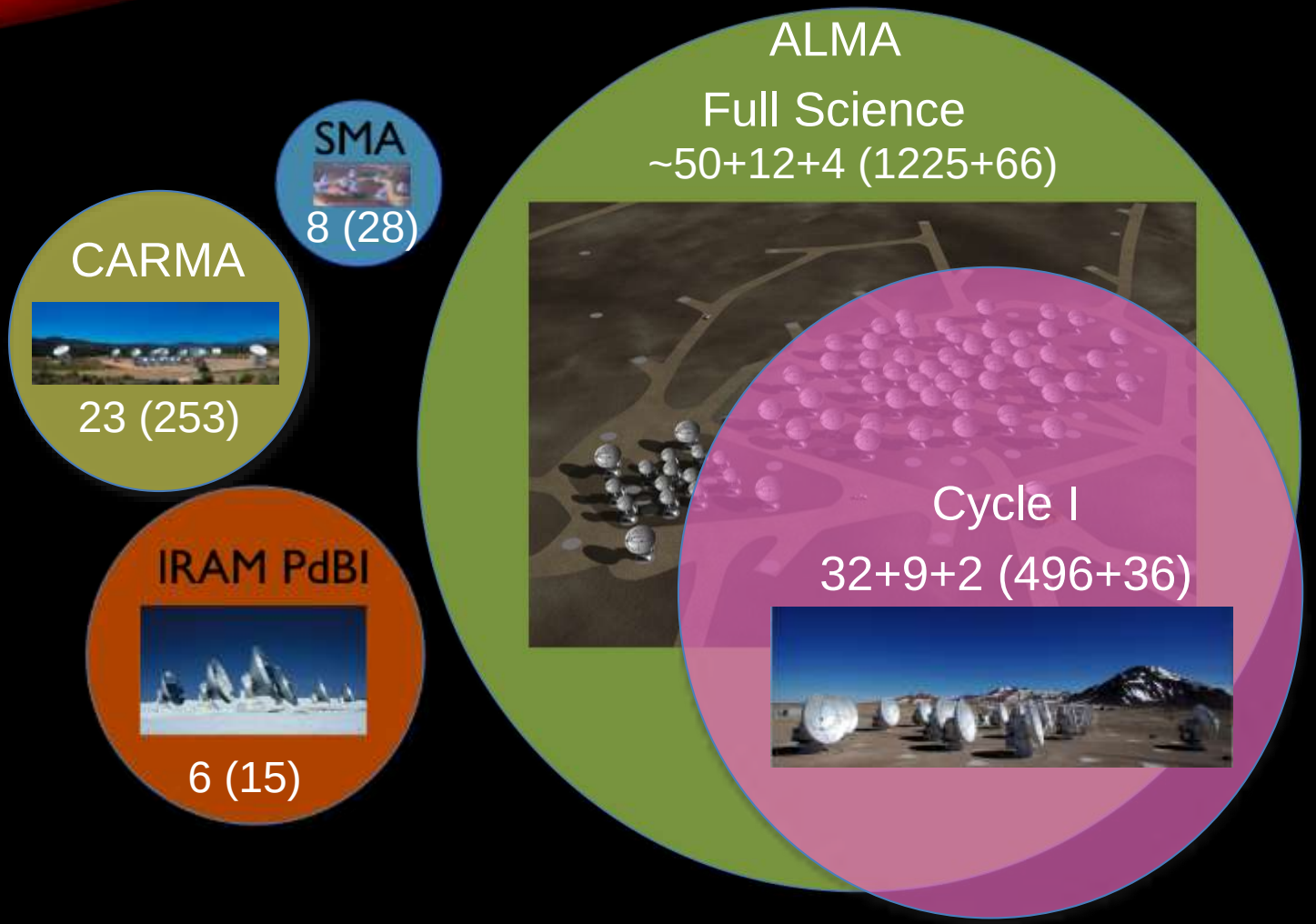


Red arrows show the frequencies of some of the common masers to observe, but to be honest, it's not really necessary, you can see where the water is, by and large, by looking at the dips in sensitivity.

ALMA SPECIFICATIONS

- 54 12-m antennas, 12 7-m antennas, at 5000m site
- Surface accuracy <25 μm, 0.6" reference pointing in 9m/s wind, 2" absolute pointing all-sky.
- Array configurations between 150m and ~15-18km.
- Angular resolutions ~40mas at 100 GHz (5mas at 900GHz)
- **10 bands in 31-950 GHz** (not all yet in production) + 183 GHz WVR.
- **8 GHz BW, dual polarization**.
- Interferometry, mosaicing & total-power observing.
- Correlator: **4096 channels/IF (multiple spectral windows, mixed configurations),** full Stokes.
- Data rate: 6MB/s average; peak 64 MB/s.
- All data archived (raw + images), pipeline processing.

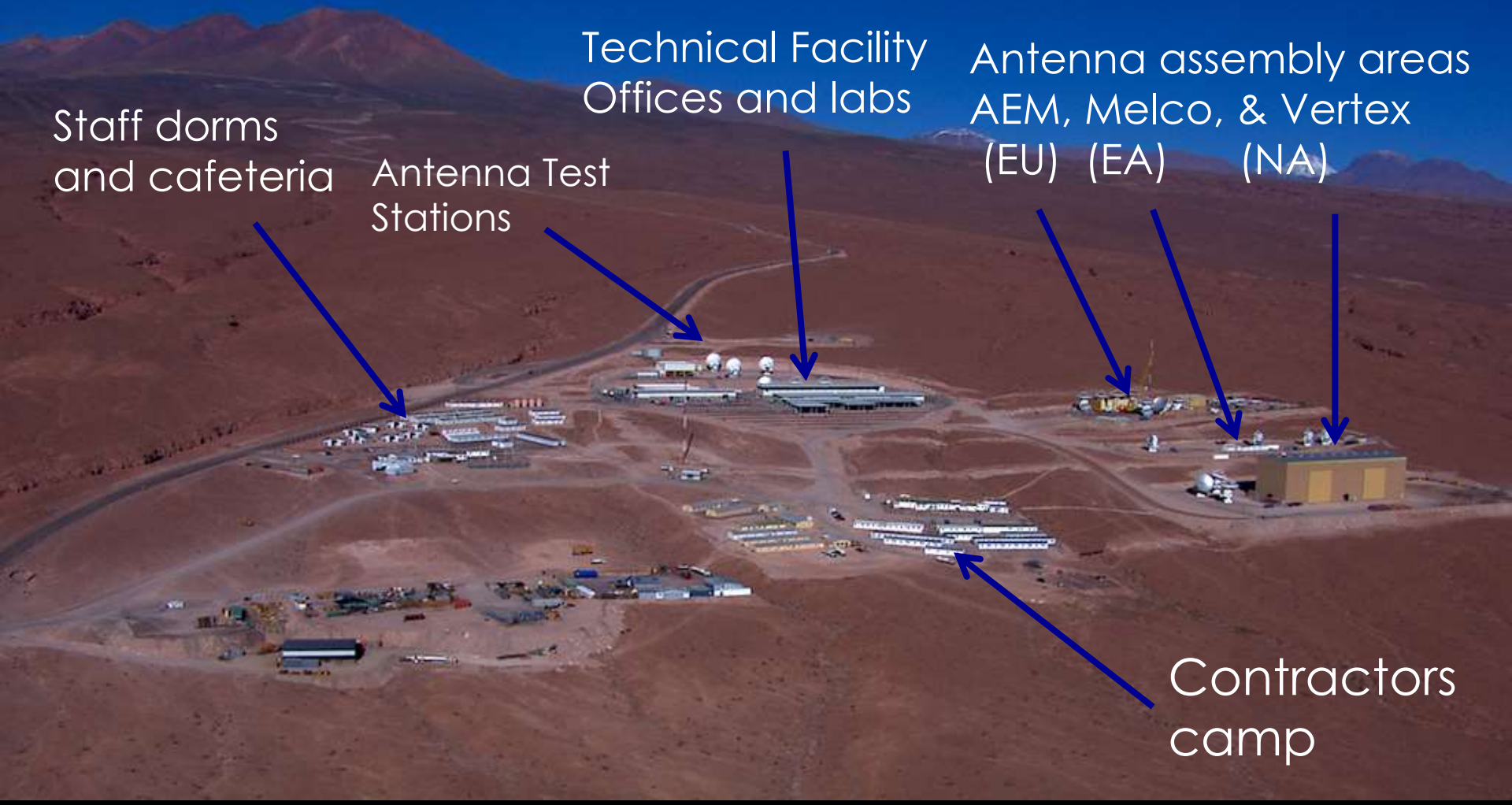
COLLECTING AREA & BASELINES



Circles Show Collecting Area (sensitivity)

Captions give # of antennas and # of baselines (fidelity)

OPERATIONS SUPPORT FACILITY (2900M LEVEL)



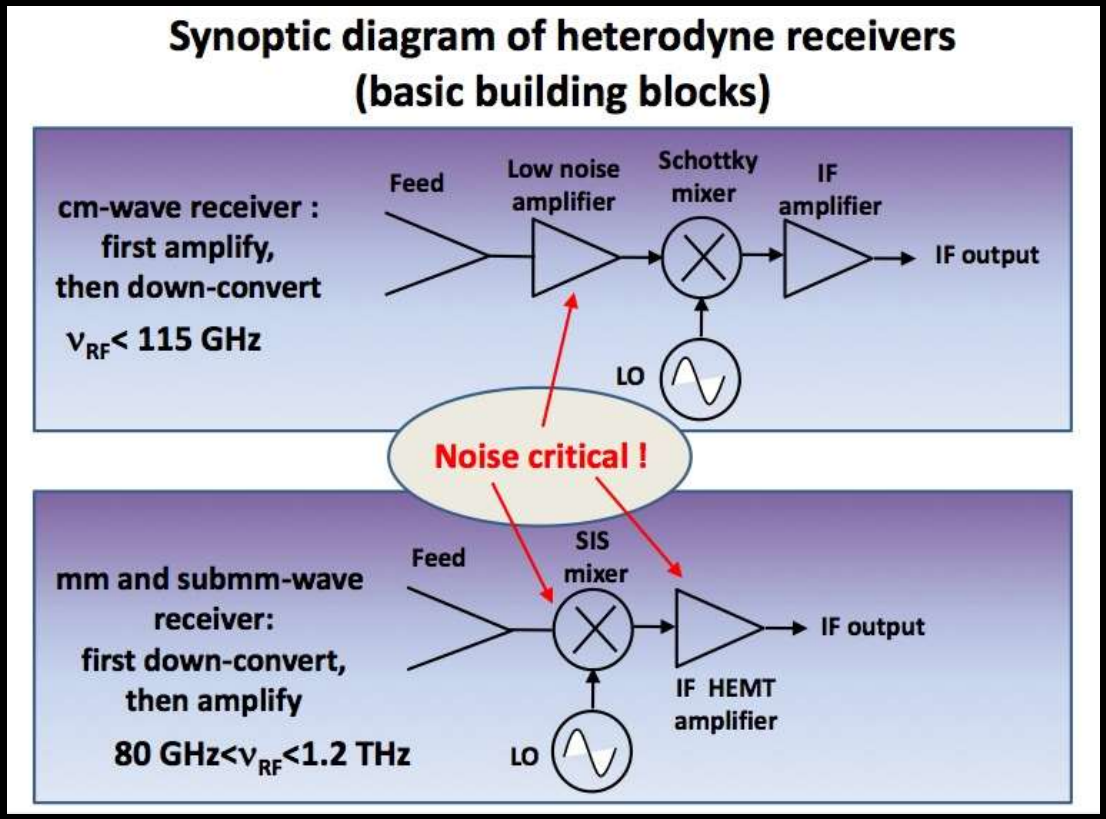
DV01 MAKES THE CLIMB FROM THE SUPPORT FACILITY TO THE HIGH SITE



AOS TECHNICAL BUILDING
(CORRELATOR, OFFICES, GUARDS, EMERGENCY FACILITIES)



ALMA RECEIVERS AND TECHNOLOGY

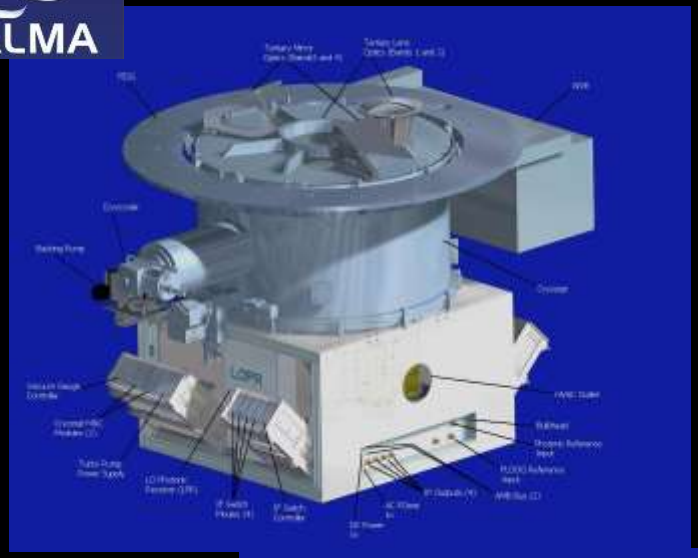


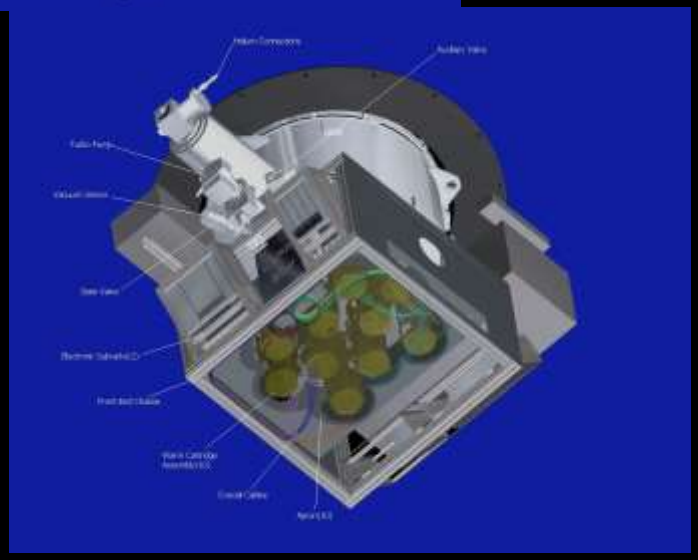
Challenge:

For frequencies higher than ~100 GHz, we require SIS mixers for good sensitivity, and these must be cooled to 4K. They must be robust enough to operate in harsh conditions at a remote site.

Image from Alessandro Navarrini (IRAM)

EACH CRYOSTAT CAN HOUSE 10 RECEIVER INSERTS





3 receivers powered up at any time, making it very fast to switch between them

Band 3



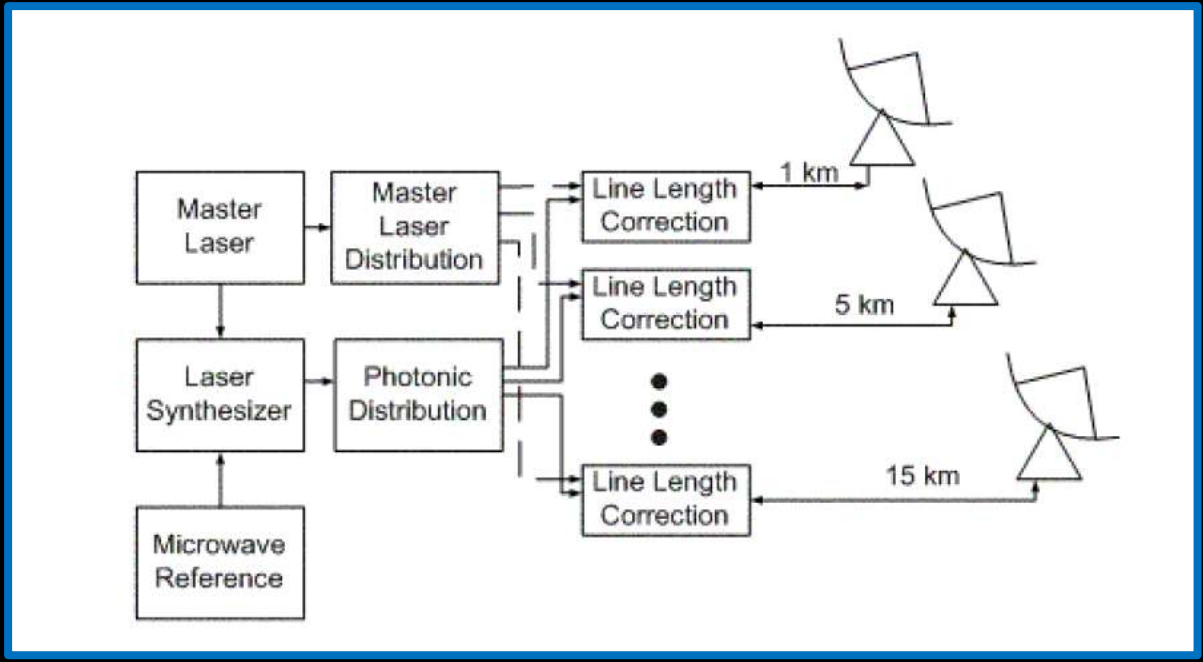
Picture from ALMA CSV, more inserts available now!

Band 7

Band 6

Band 9

PRECISE TIMING REQUIRED
TO SYNCHRONIZE SIGNALS

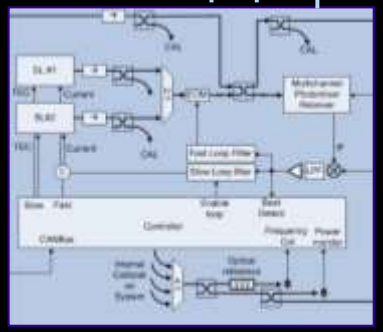


Reference signal can be generated at radio frequencies, but ALMA makes extensive use of photonics to stabilize the fiber between antennas and to synchronize the receivers which has to be done at the ~25 femto-second level. (One-wavelength error at 900GHz = 1picosec, and we need << wavelength precision)











Signal from each antenna digitized and sent to correlator, averaging 50 antennas = 600 GB/sec for correlator to process

CORRELATOR: FIRST QUADRANT AT AOS

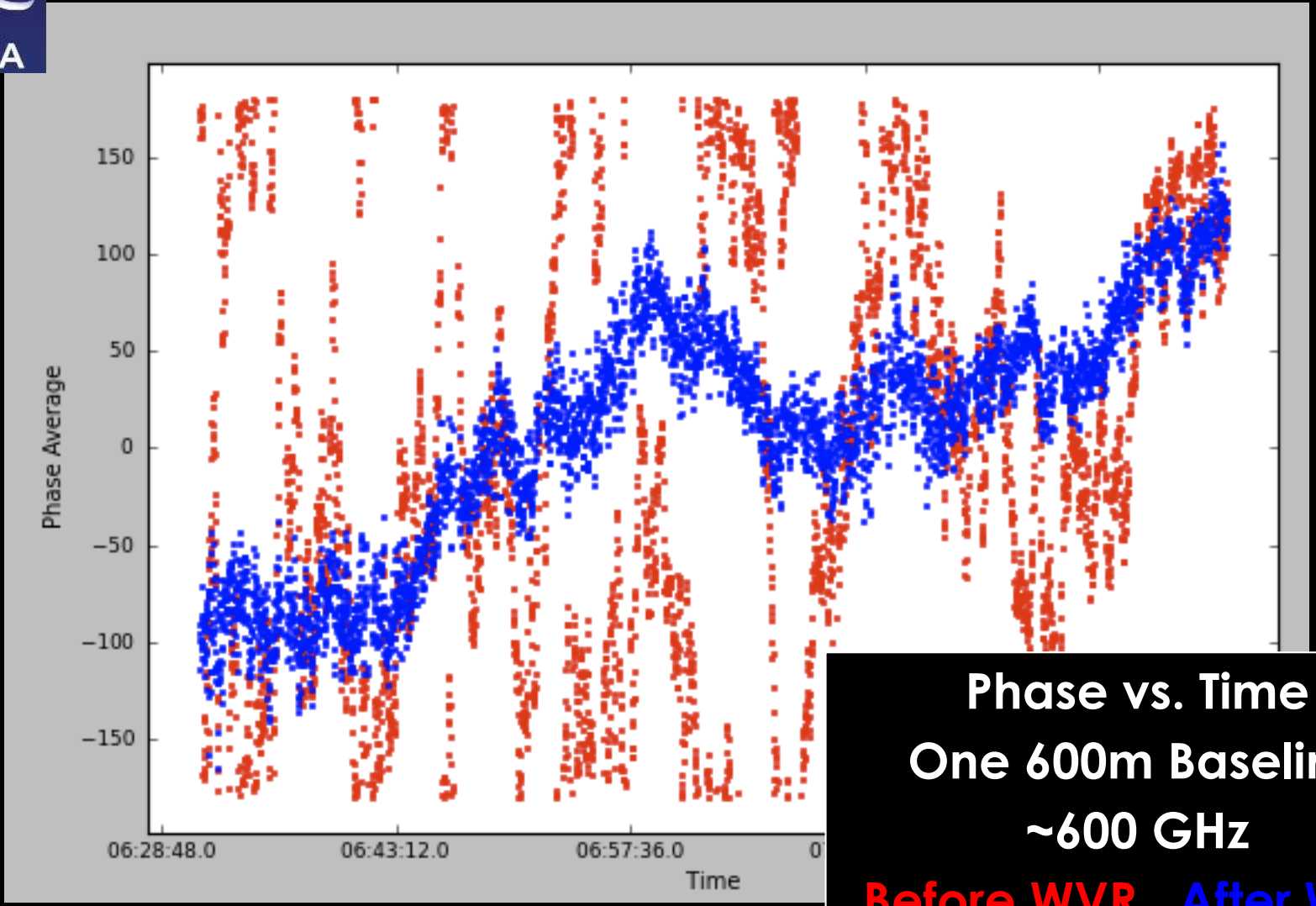




Assembled and tested in Charlottesville, then shipped

These rooms at the high site were oxygenated during the installation and wiring!

WATER VAPOR CORRECTION ON ALMA



Phase vs. Time
One 600m Baseline
~600 GHz
Before WVR, After WVR

CONTROL ROOM -- NIGHT SHIFT

IT TAKES A VILLAGE…



COMPLETED ANTENNAS







Photos by Pablo Carrillo

NEW RESIDENCIA





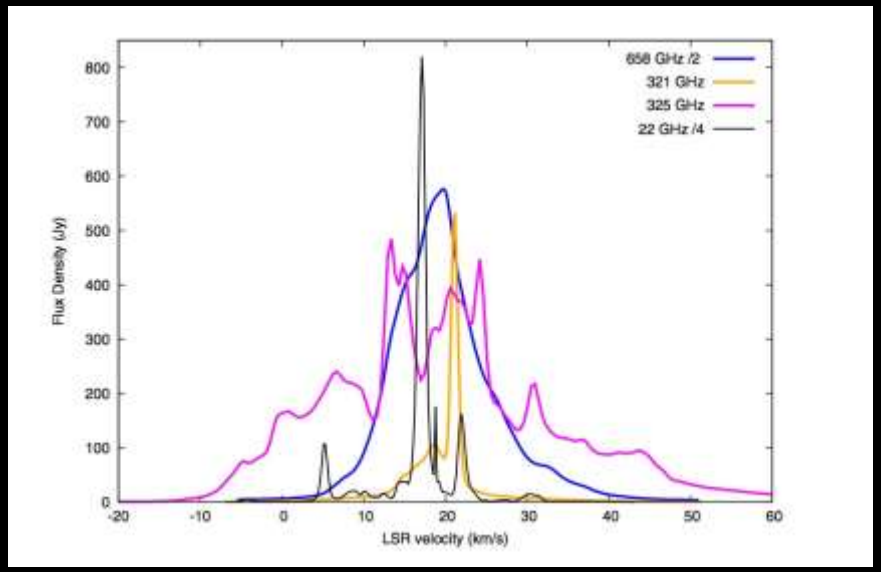


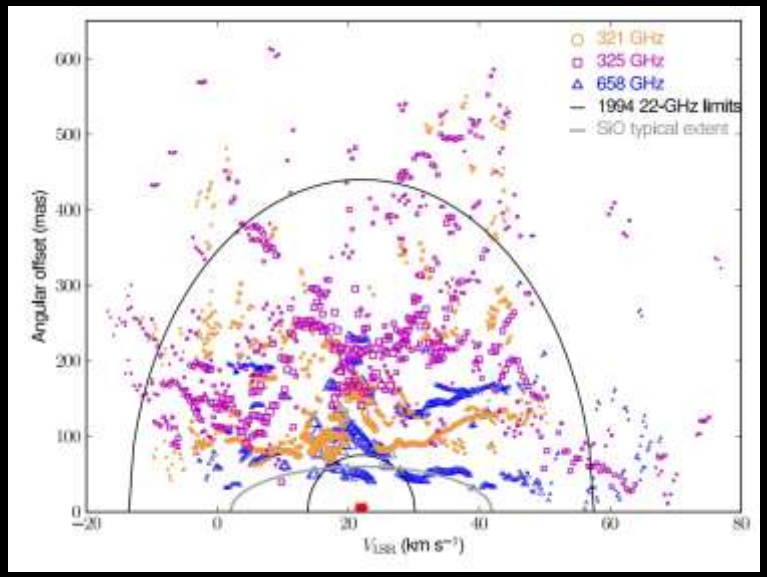


Photos by Pablo Carrillo

SCIENCE VERIFICATION RESULTS

Data can be downloaded from Science Portal

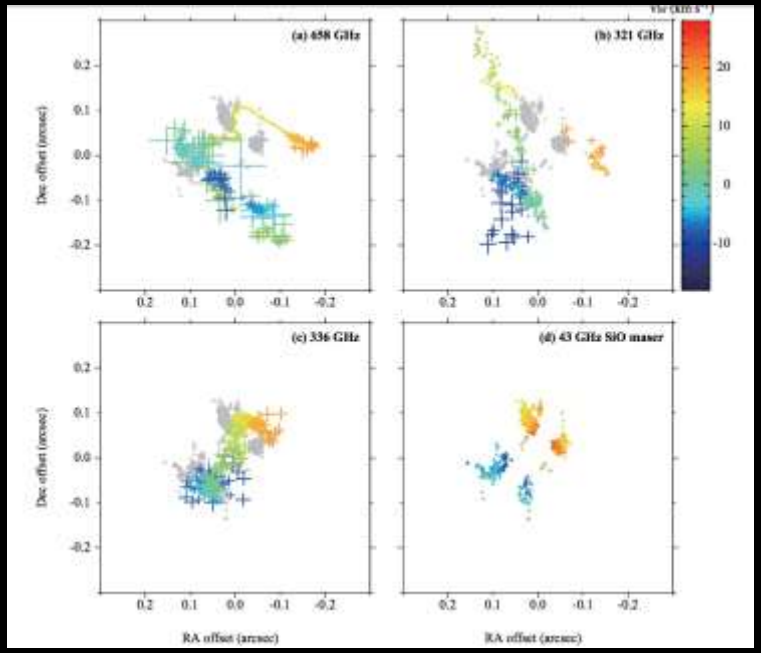




VY CMa
Richards et al 2014

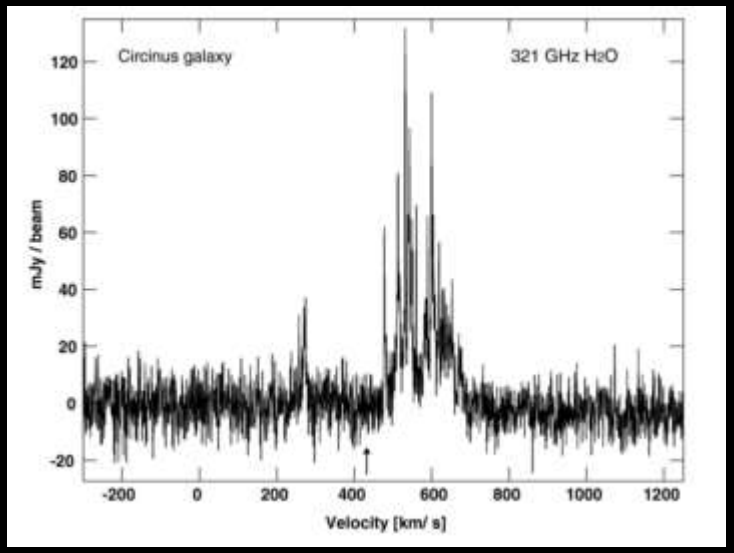
ADDITIONAL RESULTS

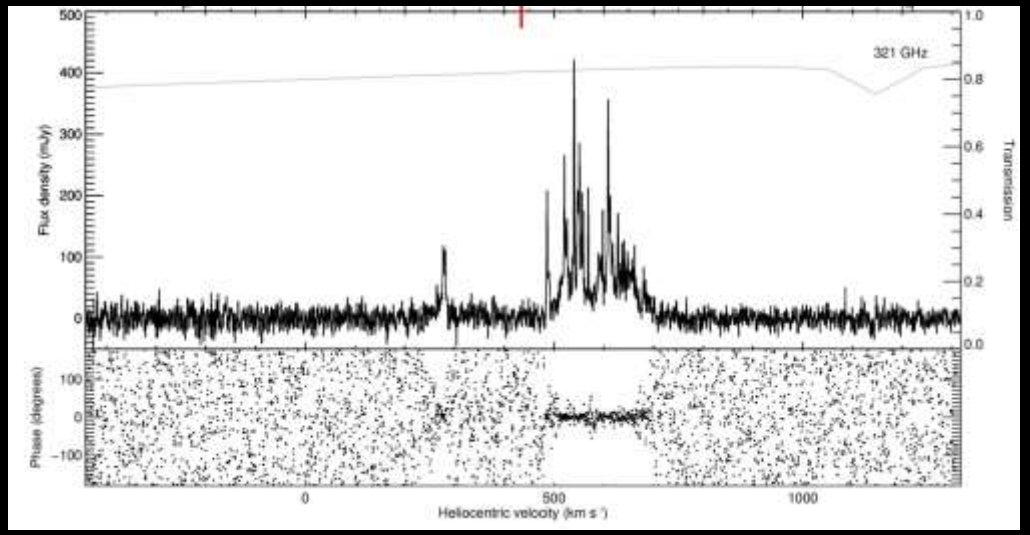
Orion water masers, B7 and B9 from ALMA Cycle 0
(also uses some Science Verification Data)



Hirota, Kim & Honma 2016

ADDITIONAL RESULTS





Circinus

Hagiwara et al 2013

Pesce, Braatz & Impellizzeri 2016

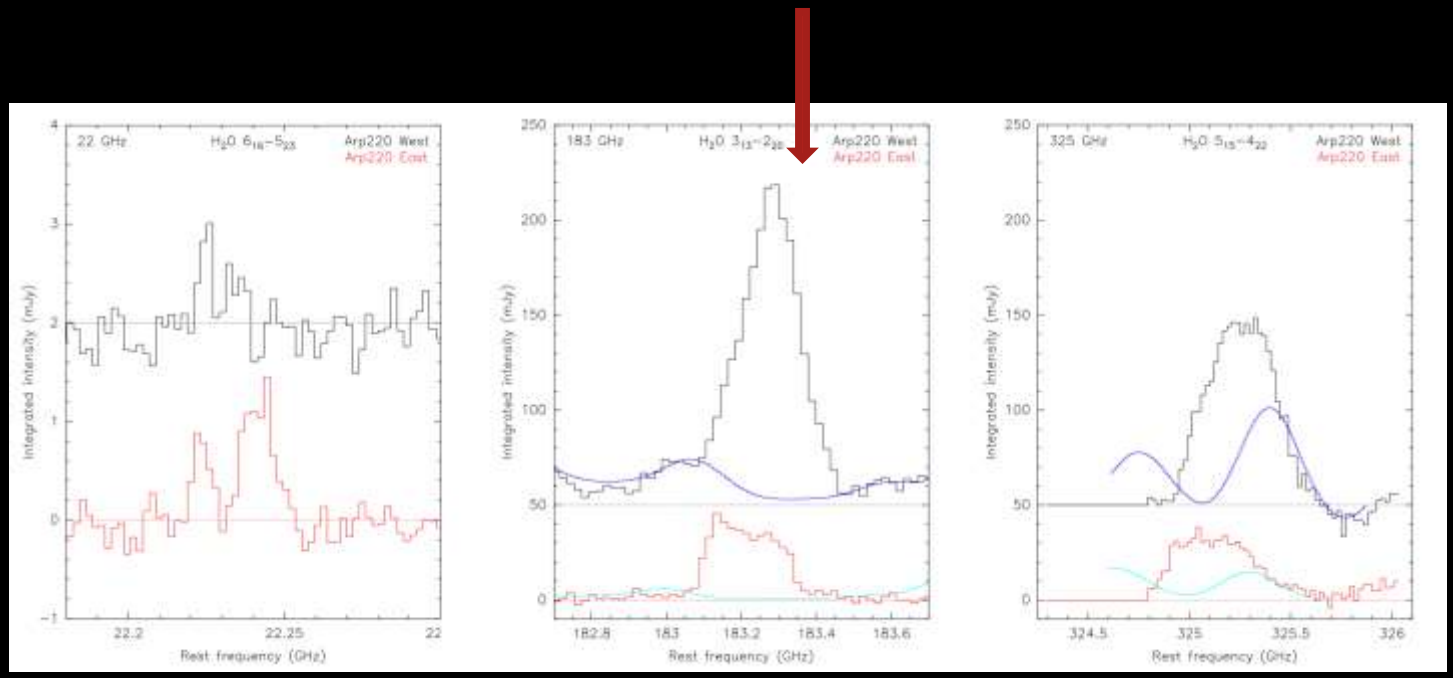
See also Humphreys, Tafoya and others here

CURRENT CAPABILITIES

- At least 43 antennas in the 12-m Array, 10 7-m antennas, 3 single-dish 12-m antennas
- Receiver bands 3, 4, **5**, 6, 7, 8, 9 and 10 (wavelengths of about 3.1, 2.1, 1.6, 1.3, 0.87, 0.74, 0.44 and 0.35 mm, respectively)
- Maximum baselines for the antenna configurations from 0.15 km to 16 km
  - Maximum baselines of 3.6 km for Bands 8, 9 and 10
  - Maximum baselines of 8.5 km for Band 7
  - Maximum baselines of 16 km for Bands 3, 4, 5 and 6
- Spectral line, continuum, and mosaic observations
- Single field interferometry (all bands) and mosaics (Bands 3 to 9) with the 12-m Array and the 7-m Array
- Single pointing, on axis, **full (linear) polarization** for continuum and **full spectral resolution** observations in Band 3, 4, 5, 6 and 7 on the 12-m Array.

PRELIMINARY B5 RESULTS

Arp 220 at 183 GHz
Band 5 Science Verification data available!!



Konig et al 2017 – Definitely water, maybe masers.



CURRENTLY AVAILABLE RECEIVERS AND ASSOCIATED CONFIGS

Blue text indicates "non-standard modes"

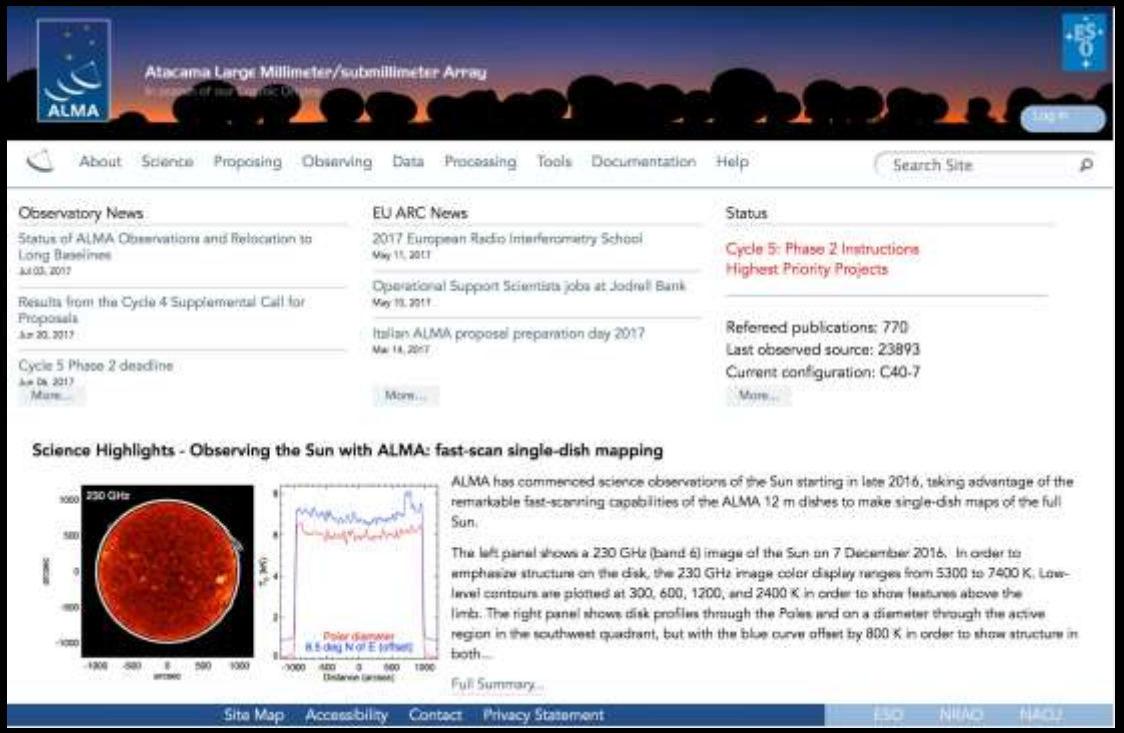
Config	Lmax	Band	Band 3	Band 4	Band 5	Band 6	Band 7	Band 8	Band 9	Band 10
	Lmin	Freq	100 GHz	150 GHz	183 GHz	230 GHz	345 GHz	460 GHz	650 GHz	870 GHz
7-m Array	45 m	AR	12.5"	8.4"	6.8"	5.4"	3.6"	2.7"	1.9"	1.4"
	9 m	MRS	66.7"	44.5"	36.1"	29.0"	19.3"	14.5"	10.3"	7.7"
C43-1	161 m	AR	3.4"	2.3"	1.8"	1.5"	1.0"	0.74"	0.52"	0.39"
	15 m	MRS	29.0"	19.0"	15.4"	12.4"	8.3"	6.2"	4.4"	3.3"
C43-2	314 m	AR	2.3"	1.5"	1.2"	1.0"	0.67"	0.50"	0.35"	0.26"
	15 m	MRS	22.6"	15.0"	12.2"	9.8"	6.5"	4.9"	3.5"	2.6"
C43-3	500 m	AR	1.4"	0.94"	0.77"	0.62"	0.41"	0.31"	0.22"	0.16"
	15 m	MRS	16.2"	10.8"	8.7"	7.0"	4.7"	3.5"	2.5"	1.9"
C43-4	784 m	AR	0.92"	0.61"	0.50"	0.40"	0.27"	0.20"	0.14"	0.11"
	15 m	MRS	11.2"	7.5"	6.1"	4.9"	3.3"	2.4"	1.7"	1.3"
C43-5	1.4 km	AR	0.54"	0.36"	0.30"	0.24"	0.16"	0.12"	0.084"	0.063"
	15 m	MRS	6.7"	4.5"	3.6"	2.9"	1.9"	1.5"	1.0"	0.77"
C43-6	2.5 km	AR	0.31"	0.20"	N/A	0.13"	0.089"	0.067"	0.047"	0.035"
	15 m	MRS	4.1"	2.7"		1.8"	1.2"	0.89"	0.63"	0.47"
C43-7	3.6 km	AR	0.21"	0.14"	N/A	0.092"	0.061"	0.046"	0.033"	0.024"
	64 m	MRS	2.6"	1.7"		1.1"	0.75"	0.56"	0.40"	0.30"
C43-8	8.5 km	AR	0.096"	0.064"	N/A	0.042"	0.028"	N/A	N/A	N/A
	110 m	MRS	1.4"	0.95"		0.62"	0.41"			
C43-9	13.9 km	AR	0.057"	0.038"	N/A	0.025"	N/A	N/A	N/A	N/A
	368 m	MRS	0.81"	0.54"		0.35"				
C43-10	16.2 km	AR	0.042"	0.028"	N/A	0.018"	N/A	N/A	N/A	N/A
	244 m	MRS	0.50"	0.33"		0.22"				

THE ALMA SCIENCE PORTAL

https://almascience.org

Hub for project-wide materials:

- Observing Tool
- Sensitivity Calculator
- Proposer's Guide
- Technical Handbook
- Science Verification Data
- CASA & Simulations
- Tutorials
- Helpdesk



Registration required to propose



FOR MORE INFO:

http://www.almascience.org

The Atacama Large Millimeter/submillimeter Array (ALMA), an international astronomy facility, is a partnership of Europe, North America and East Asia in cooperation with the Republic of Chile. ALMA is funded in Europe by the European Organization for Astronomical Research in the Southern Hemisphere (ESO), in North America by the U.S. National Science Foundation (NSF) in cooperation with the National Research Council of Canada (NRC) and the National Science Council of Taiwan (NSC) and in East Asia by the National Institutes of Natural Sciences (NINS) of Japan in cooperation with the Academia Sinica (AS) in Taiwan. ALMA construction and operations are led on behalf of Europe by ESO, on behalf of North America by the National Radio Astronomy Observatory (NRAO), which is managed by Associated Universities, Inc. (AUI) and on behalf of East Asia by the National Astronomical Observatory of Japan (NAOJ). The Joint ALMA Observatory (JAO) provides the unified leadership and management of the construction, commissioning and operation of ALMA.