Cycle 9 Observing Capabilities

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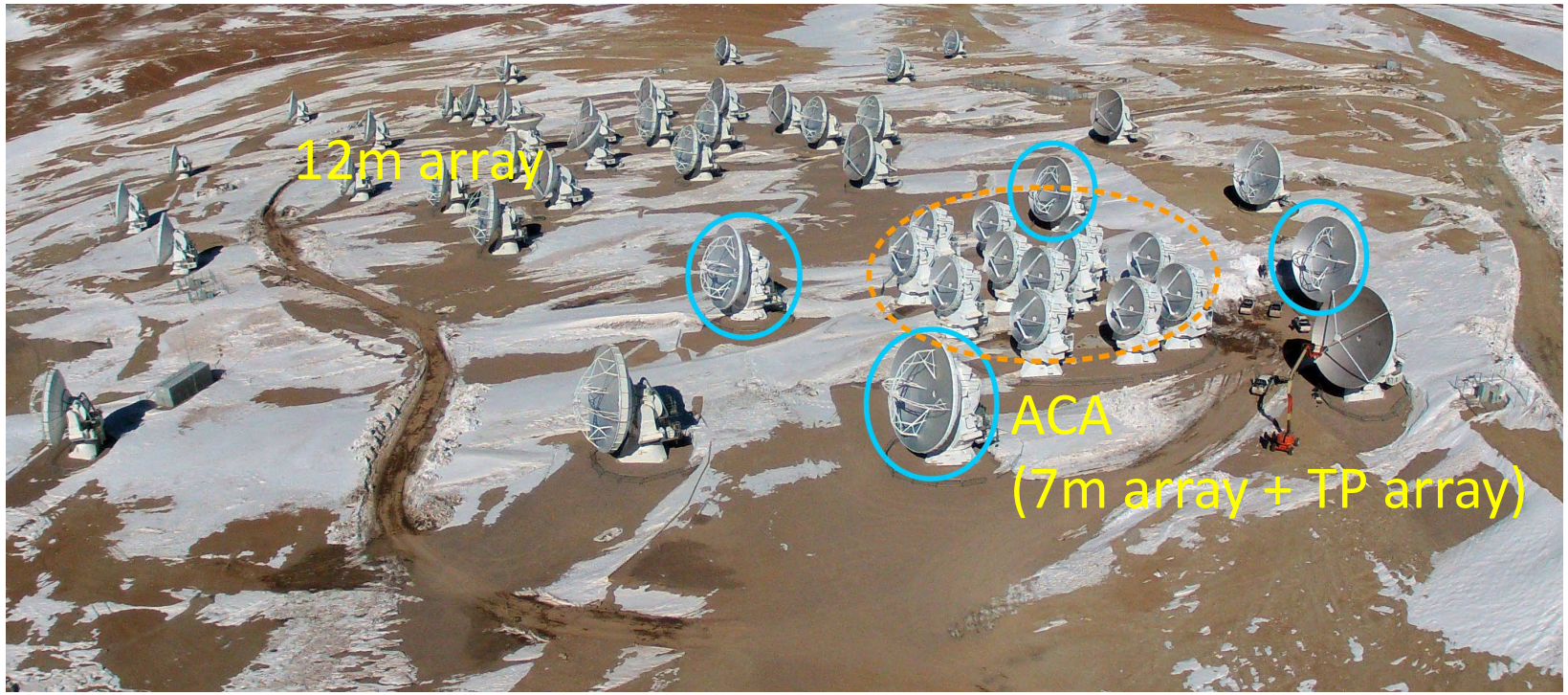
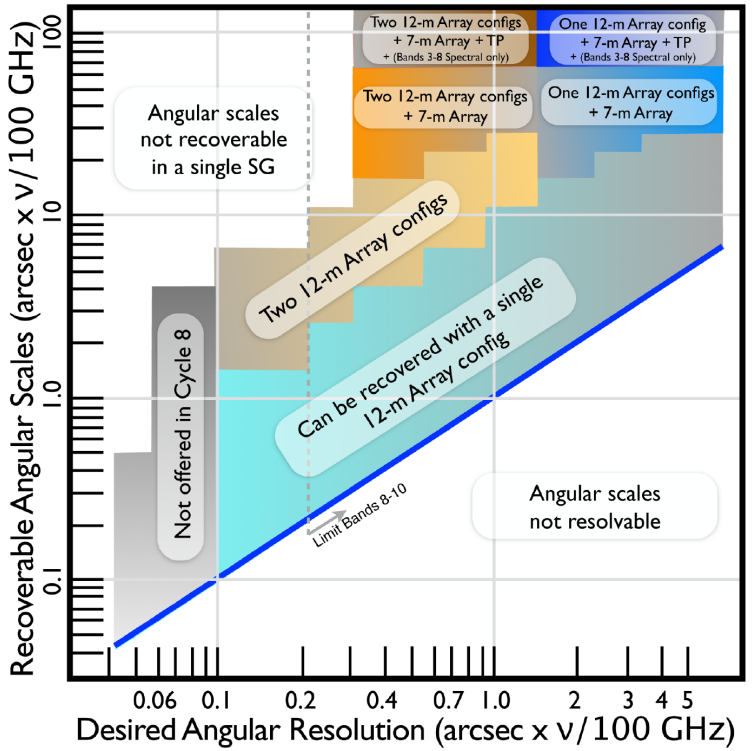
1. ALMA Basics

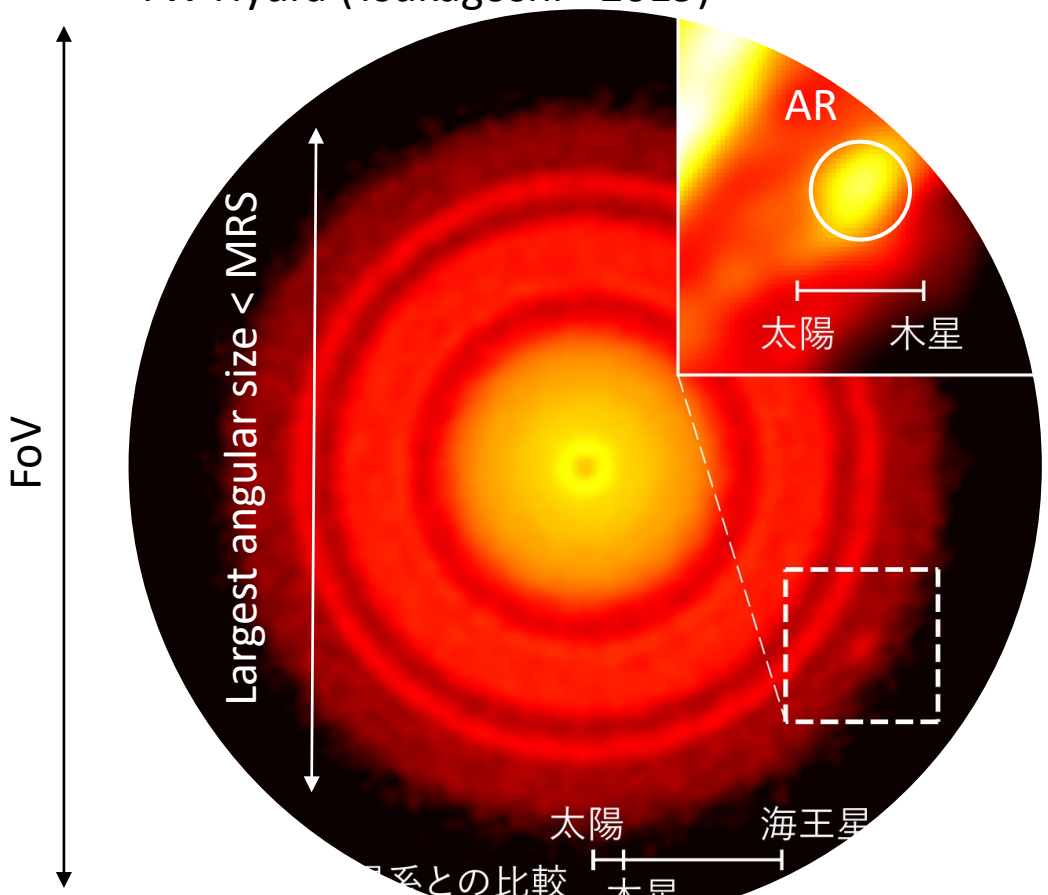
ALMA Arrays


12m array
ACA
(7m array + TP array)


Two 12-m Array configs + 7-m Array + TP + (Bands 3-8 Spectral only)
One 12-m Array config + 7-m Array + TP + (Bands 3-8 Spectral only)
Two 12-m Array configs + 7-m Array
One 12-m Array configs + 7-m Array
Angular scales not recoverable in a single SG
Two 12-m Array configs
Can be recovered with a single 12-m Array config
Not offered in Cycle 8
Limit Bands 8-10
Angular scales not resolvable
Recoverable Angular Scales (arcsec x ν/100 GHz)
100
10
1.0
0.1
0.06 0.1 0.2 0.4 0.7 1.0 2 3 4 5
Desired Angular Resolution (arcsec x ν/100 GHz)

Three Important Angular Scales

TW Hydra (Tsukagoshi+ 2019)



Smoothly distributed emission over the disk with some variation.

Angular Resolution (AR)

- Resolution element of image
- Determined by the maximum baseline length (λ/D_{max})

Maximum Recoverable Scale (MRS)

- The largest structure that can be imaged without missing flux
- Determined by the minimum baseline length (λ/D_{min})

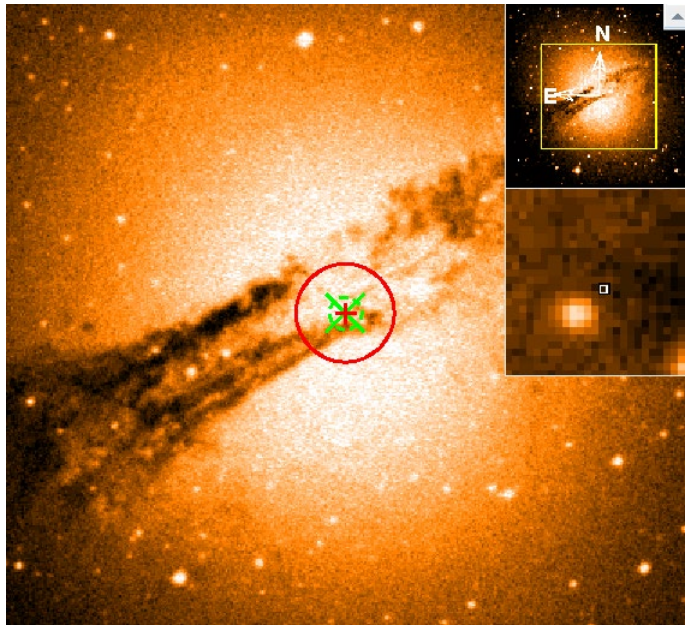
Field of View (FoV)

- FoV of a single telescope pointing
- Equal to antenna beam size

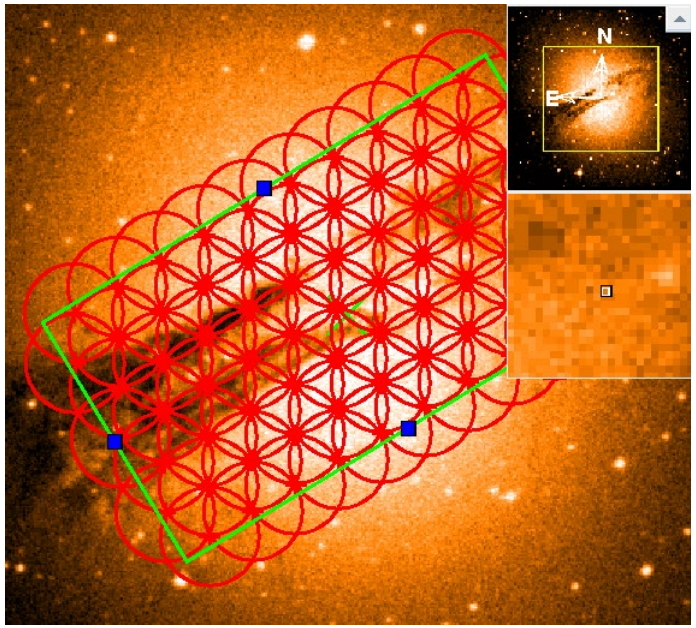
Mosaicking / Multiple Pointing

- Sources larger than single pointing FoV, or multiple sources spread over a larger area, must be mosaiced together using multiple pointings.

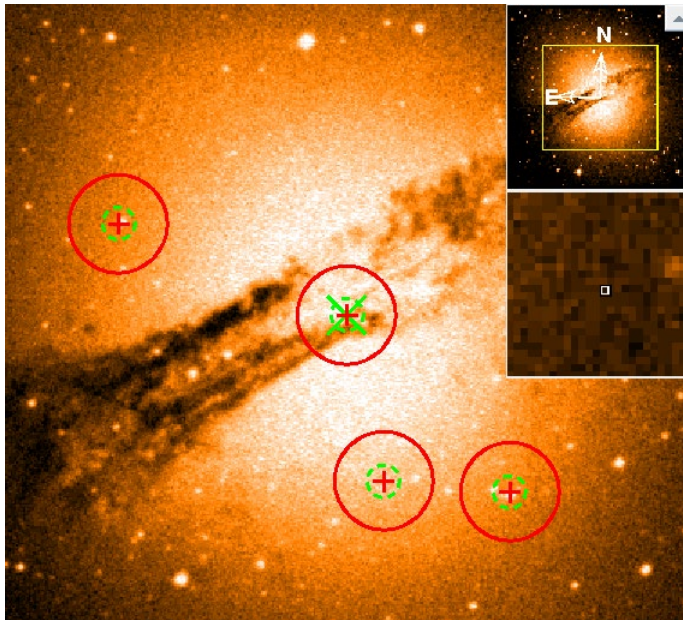
Single pointing



Mosaicking

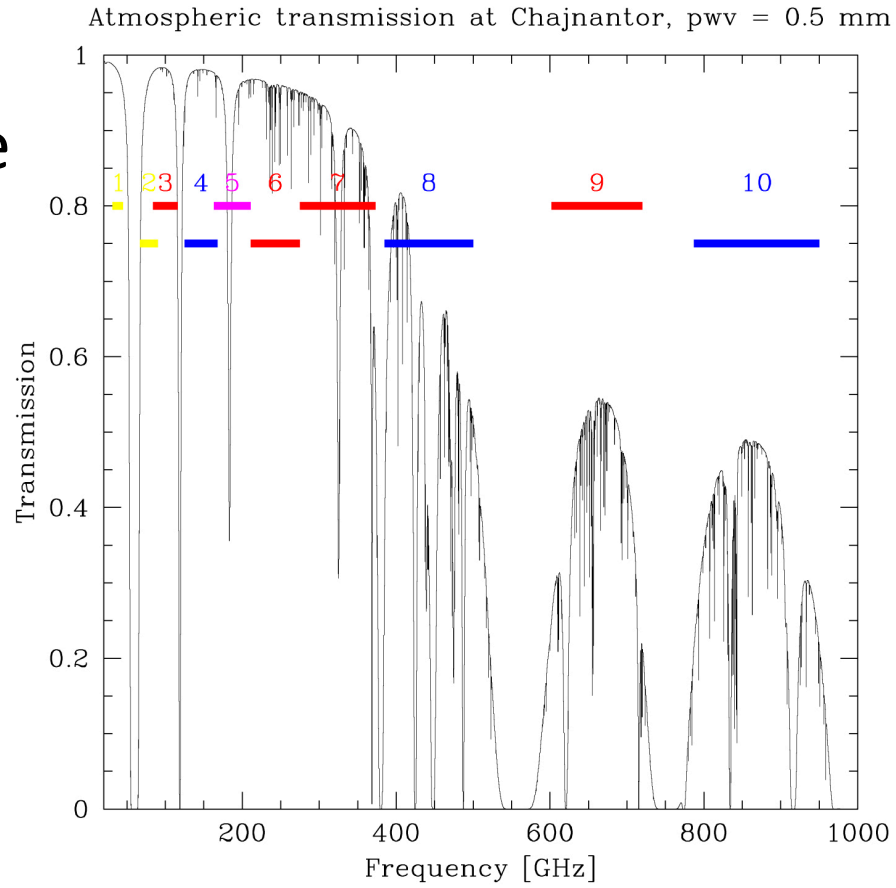


Multiple pointing



Frequency Bands

- 10 receiver bands (Band 1&2 will be available future)
- Multiple band data cannot be taken simultaneously.
- Atmospheric opacity and phase stability tends to be poor at higher frequencies and at frequencies near water absorption lines.
  - Requires good weather condition



Band	Frequency range (GHz)	Type
1	31.3– 45	SSB
2	67 – 90	SSB
3	84 –116	2SB
4	125 –163	2SB
5	163 –211	2SB
6	211 –275	2SB
7	275 –373	2SB
8	385 –500	2SB
9	602 –720	DSB
10	787 –950	DSB

Frequency vs. Weather

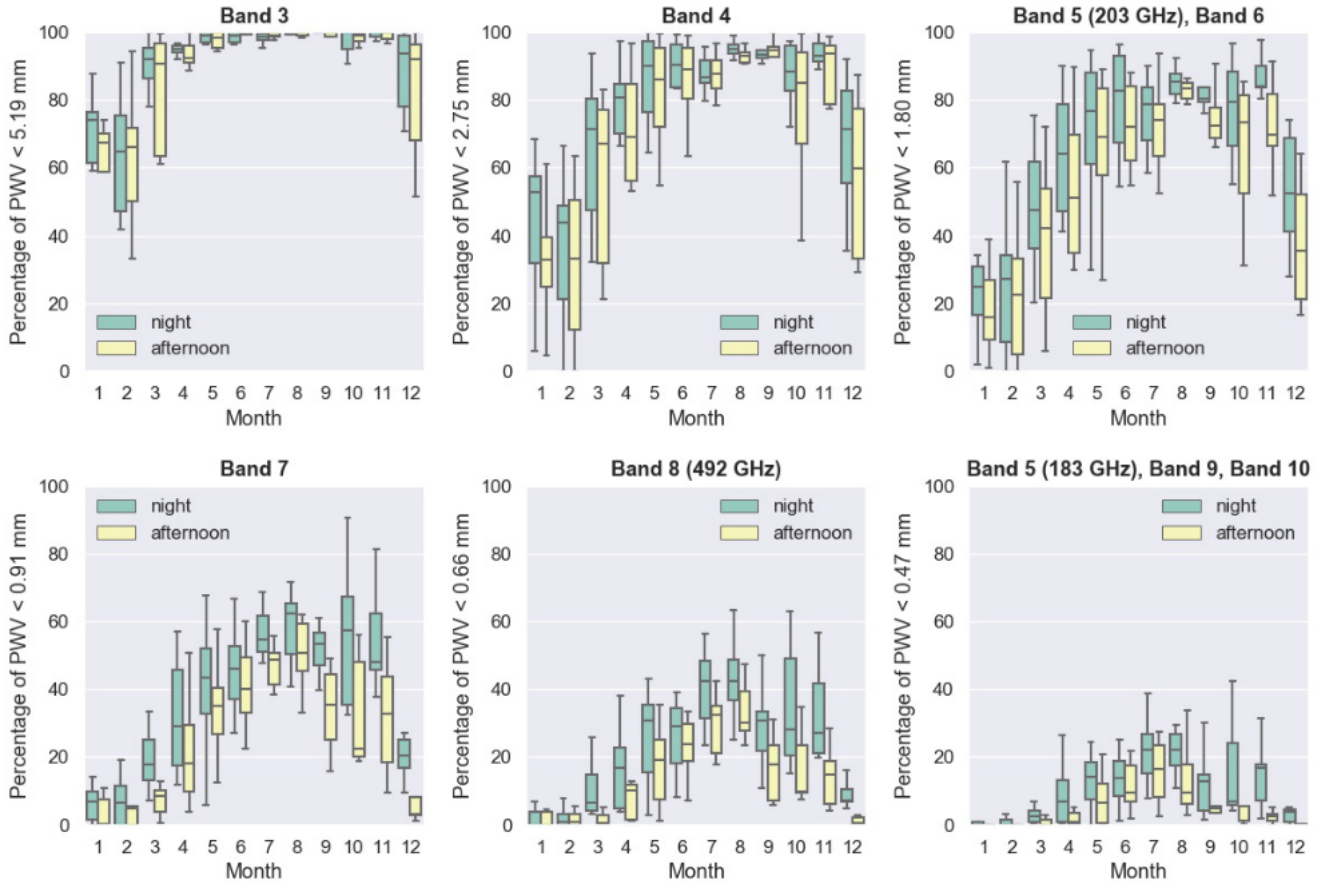
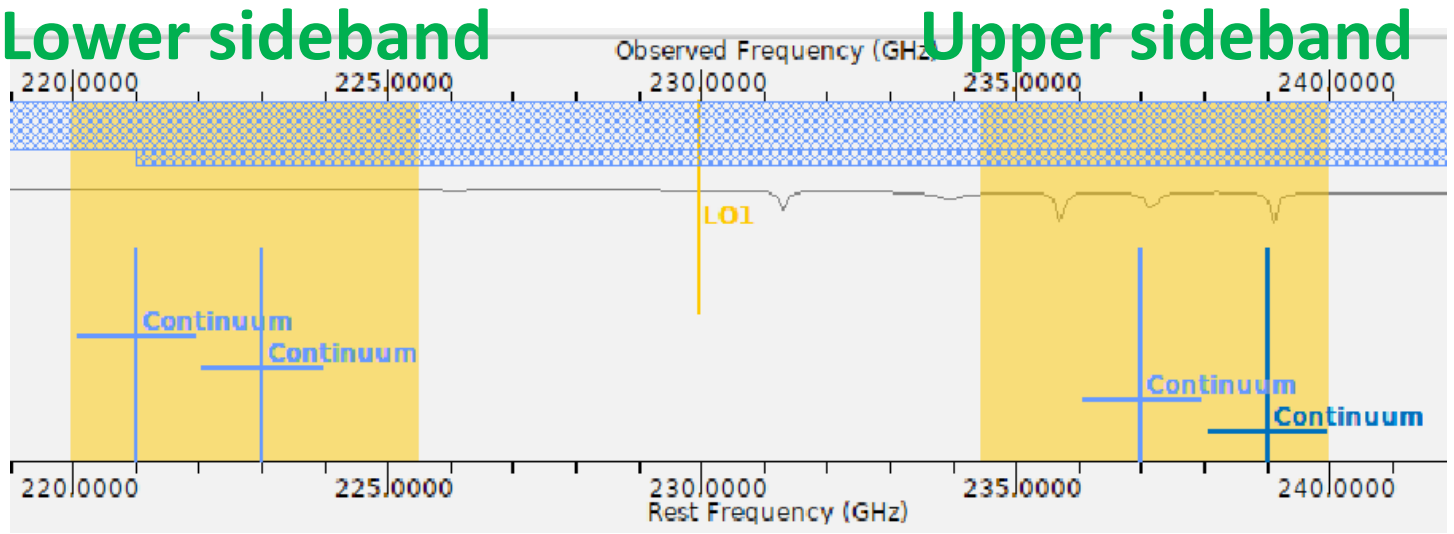
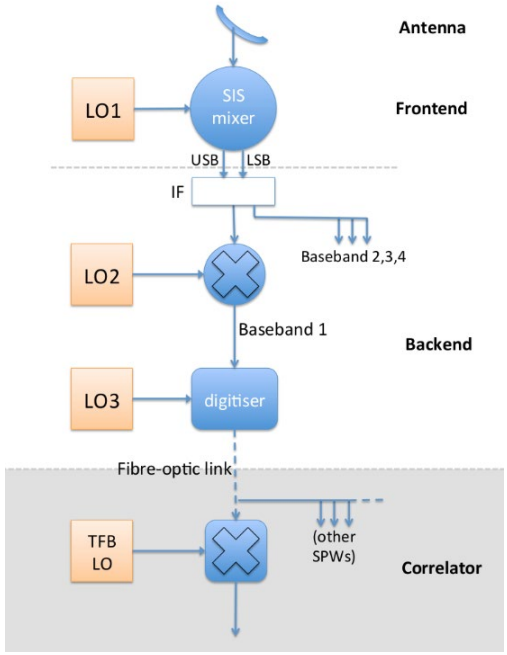


Figure 3: The percentage of time when the PWV is below the observing thresholds adopted for the various ALMA bands for night-time (green) and afternoon (yellow) and for an elevation of 60 degrees. The horizontal line within the box indicates the median. Boundaries of the box indicate the 25th- and 75th-percentile, and the whiskers indicate the highest and lowest values of the results. The data were obtained with the APEX weather station, ALMA measurements, and weather forecast data between September 2010 and February 2019.

Instantaneous frequency coverage





- ALMA receives signals in two sidebands (green-ish color).
- Up to four basebands can be placed either in a sideband or two sidebands. (not possible to put 3 in one sideband and 1 in the other.)
- Possible to place up to four spectral windows (spws) within each of these basebands (blue-ish bars) .
- Each spw forms a final contiguous spectrum (You will not receive data outside of spws)

Intermediate Frequency (IF) Range

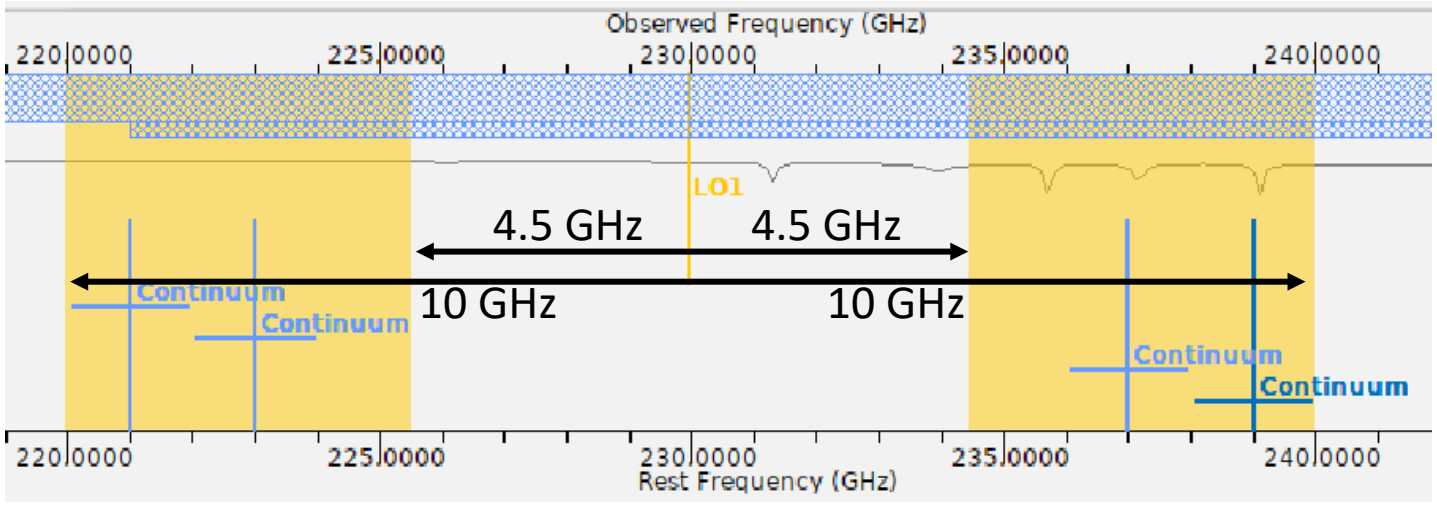


Table A-3: Properties of ALMA Cycle 9 Receiver Bands

Band	Frequency range[1] (GHz)	Wavelength range (mm)	IF range (GHz)	Type
3	84 – 116	3.6 – 2.6	4 – 8	2SB
4	125 – 163	2.4 – 1.8	4 – 8	2SB
5	158 – 211	1.9 – 1.4	4 – 8	2SB
6	211 – 275	1.4 – 1.1	4.5 – 10	2SB
7	275 – 373	1.1 – 0.8	4 – 8	2SB
8	385 – 500	0.78 – 0.60	4 – 8	2SB
9	602 – 720	0.50 – 0.42	4 – 12	DSB
10	787 – 950	0.38 – 0.32	4 – 12	DSB

For the case of Band 6, IF range is from ν_{LO1}+/- 4.5 GHz to ν_{LO1}+/- 10 GHz, and therefore the width of each sideband is 5.5 GHz.

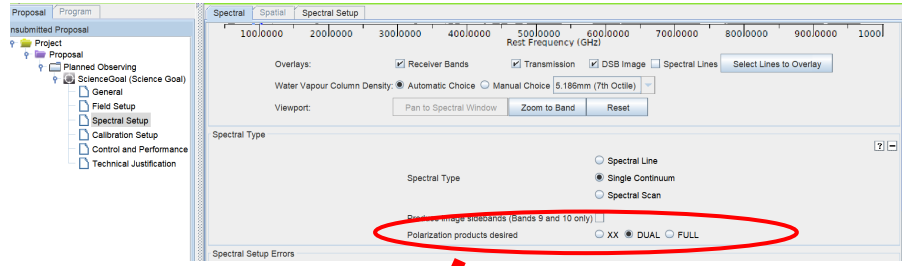
Frequency Resolution

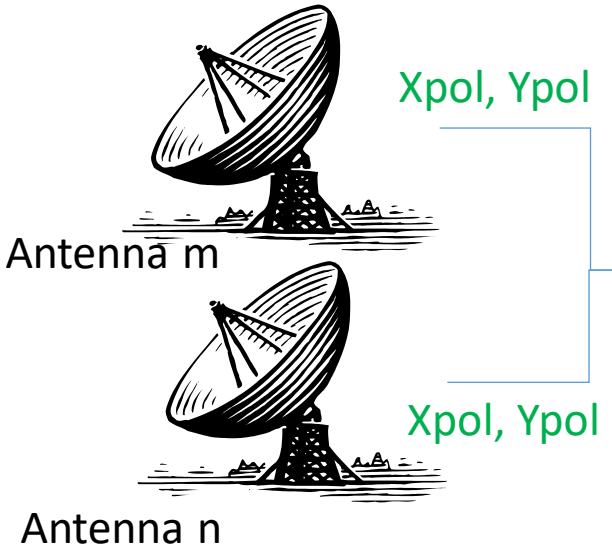
Table A-4: Properties of ALMA Cycle 9 Correlator Modes, dual-polarization operation [1,2]

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

Polarization

OT⇒





ALMA correlator

$$X_m X_n^* = I + Q \rightarrow \text{XX}$$
$$Y_m Y_n^* = I - Q$$
$$X_m Y_n^* = U + iV$$
$$Y_m X_n^* = U - iV$$

Dual

Full

- ALMA can provide full polarization products (XX, YY, XY, YX) so that one can produce Stokes I, Q, U, and V images.
- At least ~3-hrs observation is required to calibrate instrumental polarization.

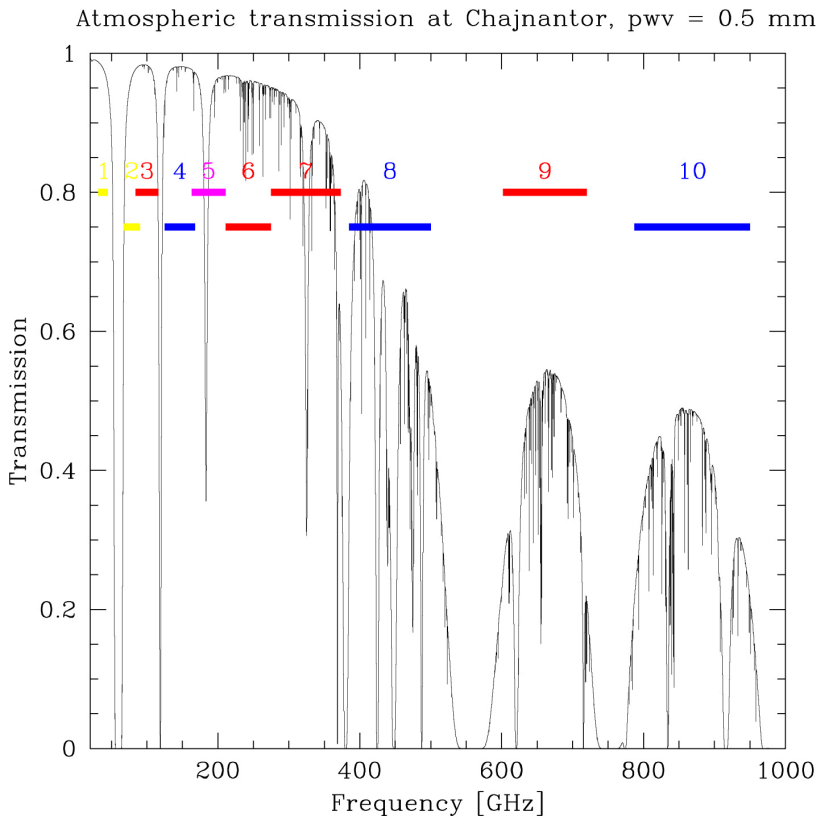
2. Cycle 9 Capabilities

New in Cycle 9

- Fast regional mapping for solar total power observations
- Spectral line VLBI in Band 3
- Band 7 Continuum VLBI
- Band 8 up to C-10, Band 9 up to C-9, Band 8 up to C-8

Antennas, Receiver Bands

- **Number of antennas**
  - **≧43 antennas in the 12-m Array.**
  - **≧10 7-m antennas (for short baselines) and 3 12-m antennas (for single dish) in the ACA.**
- **Receiver bands**
  - **Bands 3, 4, 5, 6, 7, 8, 9, and 10.**



Configuration

Table A-1: Angular Resolutions (AR) and Maximum Recoverable Scales (MRS) for the Cycle 9 configurations

Config	Lmax		Band 3	Band 4	Band 5	Band 6	Band 7	Band 8	Band 9	Band 10
	Lmin		100 GHz	150 GHz	185 GHz	230 GHz	345 GHz	460 GHz	650 GHz	870 GHz
7-m	45 m	AR	12.5”	8.35”	6.77”	5.45”	3.63”	2.72”	1.93”	1.44”
	9 m	MRS	66.7”	44.5”	36.1”	29.0”	19.3”	14.5”	10.3”	7.67”
C-1	161 m	AR	3.38”	2.25”	1.83”	1.47”	0.98”	0.74”	0.52”	0.39”
	15 m	MRS	28.5”	19.0”	15.4”	12.4”	8.25”	6.19”	4.38”	3.27”
C-2	314 m	AR	2.30”	1.53”	1.24”	1.00”	0.67”	0.50”	0.35”	0.26”
	15 m	MRS	22.6”	15.0”	12.2”	9.81”	6.54”	4.90”	3.47”	2.59”
C-3	500 m	AR	1.42”	0.94”	0.77”	0.62”	0.41”	0.31”	0.22”	0.16”
	15 m	MRS	16.2”	10.8”	8.73”	7.02”	4.68”	3.51”	2.48”	1.86”
C-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”	7.50”	6.08”	4.89”	3.26”	2.44”	1.73”	1.29”
C-5	1.4 km	AR	0.55”	0.36”	0.30”	0.24”	0.16”	0.12”	0.084”	0.063”
	15 m	MRS	6.70”	4.47”	3.62”	2.91”	1.94”	1.46”	1.03”	0.77”
C-6	2.5 km	AR	0.31”	0.20”	0.17”	0.13”	0.089”	0.067”	0.047”	0.035”
	15 m	MRS	4.11”	2.74”	2.22”	1.78”	1.19”	0.89”	0.63”	0.47”
C-7	3.6 km	AR	0.21”	0.14”	0.11”	0.092”	0.061”	0.046”	0.033”	0.024”
	64 m	MRS	2.58”	1.72”	1.40”	1.12”	0.75”	0.56”	0.40”	0.30”
C-8	8.5 km	AR	0.096”	0.064”	0.052”	0.042”	0.028”	0.021”	0.015”	0.011”
	110 m	MRS	1.42”	0.95”	0.77”	0.62”	0.41”	0.31”	0.22”	0.16”
C-9	13.9 km	AR	0.057”	0.038”	0.031”	0.025”	0.017”	0.012”	0.0088”	N/A
	368 m	MRS	0.81”	0.54”	0.44”	0.35”	0.24”	0.18”	0.13”	
C-10	16.2 km	AR	0.042”	0.028”	0.023”	0.018”	0.012”	0.0091”	N/A	N/A
	244 m	MRS	0.50”	0.33”	0.27”	0.22”	0.14”	0.11”		

Config. Schedule

Table 2: Planned 12-m Array Configuration Schedule for Cycle 9

Start date	Configuration	Longest baseline	LST for best observing conditions
2022 October 1	C-3	0.50 km	~ 22—10 h
2022 October 20	C-2	0.31 km	~ 23—11 h
2022 November 10	C-1	0.16 km	~ 1—13 h
2022 November 30	C-2	0.31 km	~ 2—14 h
2022 December 20	C-3	0.50 km	~ 4—15 h
2023 January 10	C-4	0.78 km	~ 5—17 h
2023 February 1	*No observations due to maintenance*		
2023 March 1	C-4	0.78 km	~ 8—21 h
2023 March 20	C-5	1.4 km	~ 9—23 h
2023 April 20	C-6	2.5 km	~ 11—1 h
2023 May 20	C-7	3.6 km	~ 13—3 h
2023 June 20	C-8	8.5 km	~ 15—5 h
2023 July 11	C-9	13.9 km	~16—6 h
2023 July 30	C-10	16.2 km	~17—7 h
2023 August 20	C-9	13.9 km	~19—8 h
2023 September 10	C-8	8.5 km	~20—9 h

Time Multiplier

Table A-2: Allowed Array Combinations and Time Multipliers

Most Extended configuration	Allowed Compact configuration pairings	Extended 12-m Array Multiplier	Multiplier if compact 12-m Array needed	Multiplier if 7-m Array needed	Multiplier if TP Array needed and allowed
7-m Array	TP			1	1.7
C-1	7-m Array & TP	1		7.0	11.9
C-2	7-m Array & TP	1		4.7	7.9
C-3	7-m Array & TP	1		2.4	4.1
C-4	C-1 & 7-m Array & TP	1	0.34	2.4	4.0
C-5	C-2 & 7-m Array & TP	1	0.26	1.2	2.1
C-6	C-3 & 7-m Array & TP	1	0.25	0.6	1.0
C-7	C-4	1	0.23		
C-8	C-5	1	0.22		
C-9	C-6	1	0.21		
C-10	-	1			

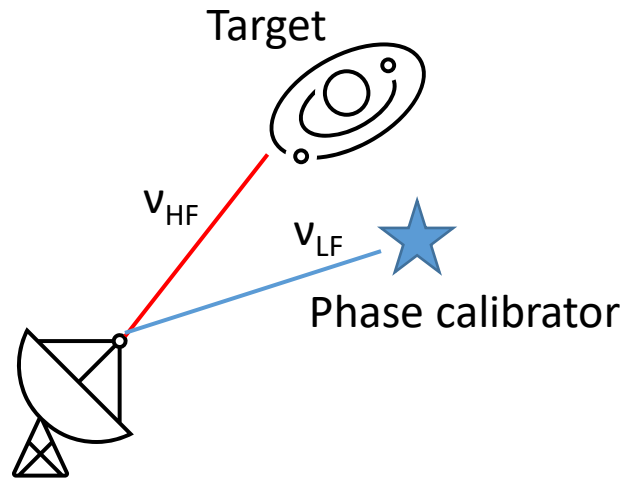
Basic Observing Modes

- **Spectral line, continuum, mosaic observations**
  - **Spectral line and continuum observations with the 12-m Array and the 7-m Array in all bands**
  - **Single field interferometry (all bands) and mosaics (Bands 3 to 9) with the 12-m Array and the 7-m Array**
  - **Single dish spectral line observations in Bands 3 to 8**
- **Spectral scan (useful for spectral survey and redshift search)**
  - **Up to 5 different tunings can be requested.**
- **Target of Opportunity**
- **Large program**
  - **>50 hours for 12m array**
  - **>150 hours for 7m array**

Polarization

- **12m**
  - **Single pointing (within 1/3 of primary beam) of continuum and spectral line polarimetry are offered in Bands 3-7 for linear polarization.**
  - **Only continuum linear polarimetry for mosaicking with default continuum setup.**
  - **Only single pointing within 1/10 of primary beam is offered in Bands 3-7 for circular polarization.**
  - **Systematic error (minimum detectable degree of polarization)**
    - **Linear polarization: 0.1-0.2% of peak Stokes I flux and 1 degree in polarization position angle within 1/3 of PB in both continuum and spectral line observations.**
    - **Linear polarization mosaicking: Within the FWHM of a given pointing, the estimated upper limits are 4 degrees in polarization position angle and 0.5% in polarization percentage.**
    - **Circular polarization: 1.8% of peak Stokes I flux in both continuum and spectral resolution observations.**
- **7m**
  - **Only single pointing (<1/3 PB) or multiple pointings (each of pointing with 1<3 PB FoV), linear polarization of continuum and spectral line is offered in Bands 3-7. No circular polarization, no mosaicking.**
  - **The systematic error is the same as the 12m case.**
  - **Data combination of 12m and 7m will not be supported.**
  - **A maximum of 75 hrs will be offered.**

Long Baseline at High Frequencies



- C-8/9/10 in Bands 7-10 may require Band-to-Band (B2B) phase transfer calibration in order to find a nearby and sufficiently bright phase calibrator to ensure phase calibration quality.
- The OT will automatically check the availability of suitable phase calibrators during proposal validation and will automatically trigger the B2B mode where required.
- The OT will emit an error if a source does not have a suitable calibrator even with B2B. PIs are advised to begin preparing their proposals early to ensure that a suitable calibrator is available for their targets.
- A maximum of 45 hours observations will be available for the observations requiring B2B calibrations.

VLBI

- VLBI observations in Bands 3, 6 (both continuum and spectral line), & 7 (only continuum in Band 7) will be conducted using a “campaign mode” (actual date will be set after the proposal review).
- VLBI observations will be permitted for science targets with correlated flux densities < 0.5 Jy through use of a passive phasing mode. The user must select a bright (>0.5 Jy) phase calibrator (phasor), ideally within 6 or 3 degrees of the science target.
- The proposers are required to enter a VLBI total time requested.
- ALMA’s VLBI observing window in a given cycle will not exceed two weeks, so if multi-epoch observations are requested, they must fit within that time frame and the total time request must be the aggregate time of all observations.

Pulsar observations

- Users can propose pulsar observations with the aid of phase-up mode that works as “a large single dish”.
- Only pulsar-science projects will be accepted for this mode.
- Both time domain data in PSRFITS format and standard interferometric data will be provided.
- Time resolution of time domain data is an integer multiple of 8 μs.

Solar Observations

- Proposals will be accepted for ALMA interferometric and Total Power observations.
  - Will be conducted only during the periods when the 12-m Array is in one of the allowed configurations for the requested band, namely C-1 to C-4 for Band 3, C-1 to C-3 for Band 5, C-1 to C-3 for Band 6, and C-1 to C-2 for Band 7.
  - The interferometric component of Solar observations will be conducted using a special combined array comprising both 12-m and 7-m antennas (to ensure sufficient short baselines).
- Observations may be performed using dual linear polarization (XX, YY) or single polarization (XX) correlations; full polarization measurements are not currently offered

Solar Observations

- The Total Power component of solar observations consists of fast-scanning mapping observations to recover the largest angular scales for interferometric observations. Proposals requesting only Total Power single-dish observations will not be accepted. The Total Power observations will be taken contemporaneously with the interferometric observation.
  - Time cadence of full-sun images is about 10, 13, 15 and 25 minutes for Bands 3, 5, 6, and 7, respectively.
  - Time cadence of fast regional mapping (small FoV around a region of interest)

Table A-7: Time cadence of images obtained with FRM

FOV Diameter	Band 3	Band 5 and Band 6	Band 7
100 arcsec	n/a[1]	11 sec	14 sec
200 arcsec	13 sec	21 sec	27 sec
300 arcsec	19 sec	32 sec	40 sec

Calibration Accuracies

- Image dynamic range (I_{peak}/rms)
  - ~100 for compact 12m arrays and ACA, ~50 for more extended than ~2km and at Bands 8,9, and 10 for nominal phase calibration.
  - Self-calibration will be required to achieve image DR of ~1000 or larger.
- Absolute flux accuracy
  - ~5% in Bands 3-5, ~10% in Bands 6-8, ~20% in Bands 9-10
- Spectral dynamic range (desired SNR per spectral resolution element)
  - Demonstrated ~1000 in Bands 3-6 (except for Ozone line at 183GHz in Band 5), ~400, 250, 170, and 150 in Bands 7, 8, 9, and 10, respectively, but spectral DR can depend on the brightness of bandpass calibrator (see THB 10.4.6 for more details).
- Total power calibration accuracy
  - 5% in Bands 3-7, 15% in Band 8
- Astrometric accuracy
  - At best ~5% of synthesized beam for angular resolution > 150 mas, ~10% of synthesized beam for higher angular resolution.
  - Choose “enhanced position accuracy” in the OT if you need astrometric accuracy better than the nominal one.