Cycle 10 Observing Capabilities

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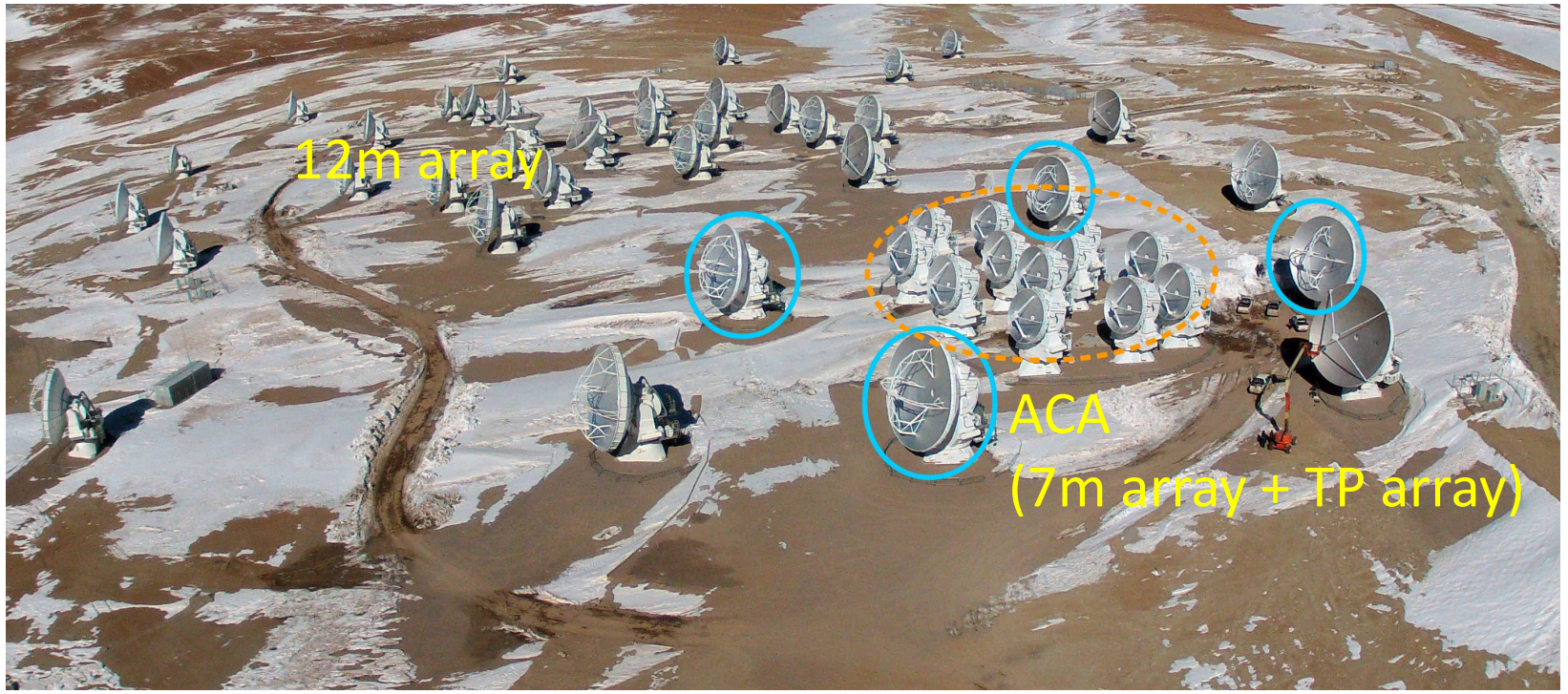
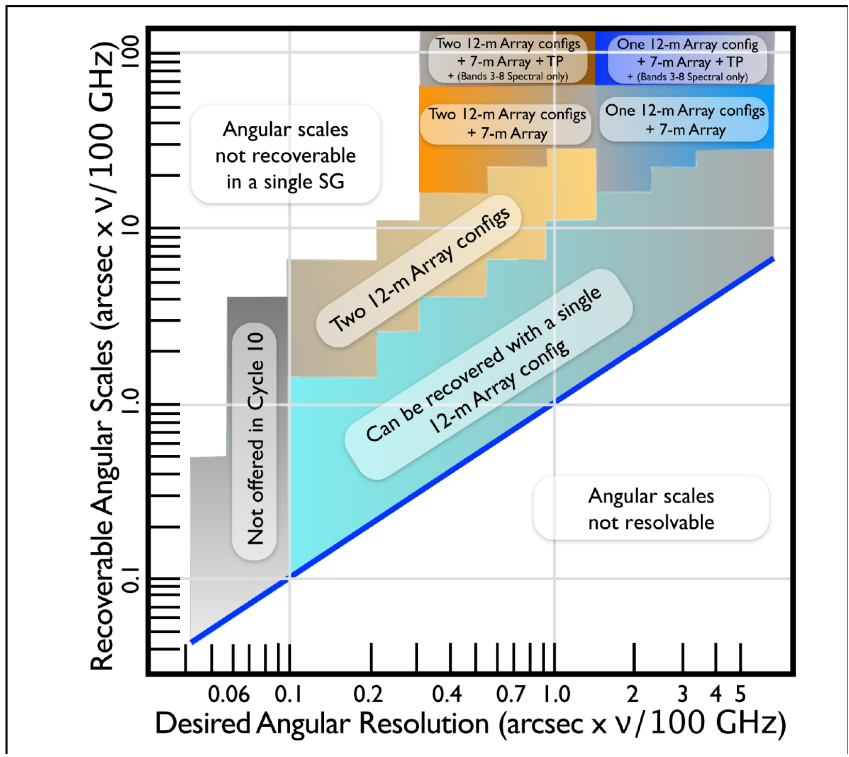
1. ALMA Basics

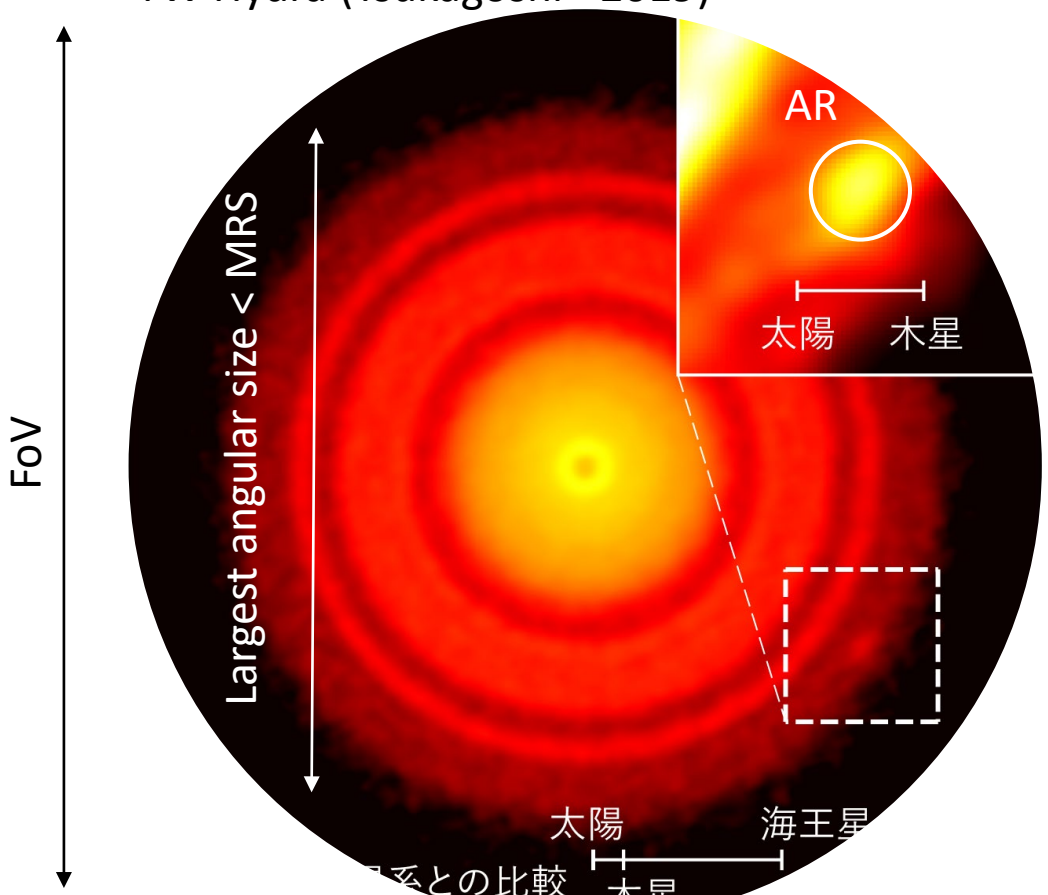
ALMA Arrays


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 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})

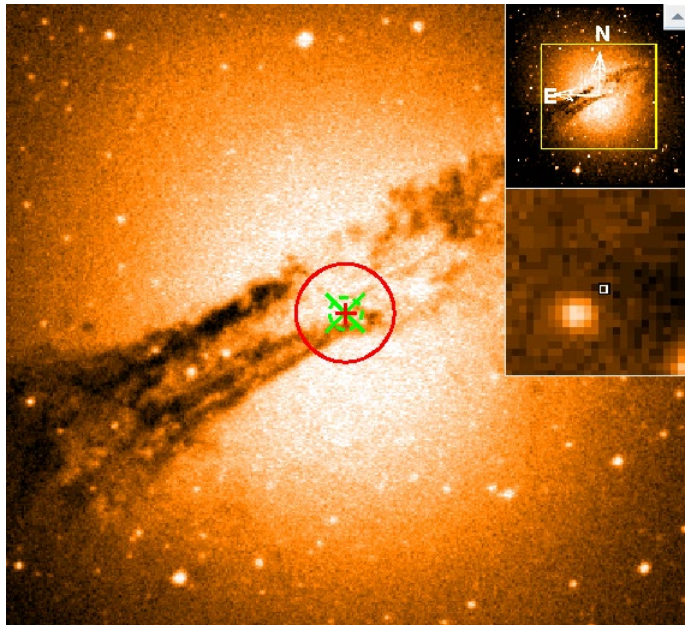
Field of View (FoV)

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

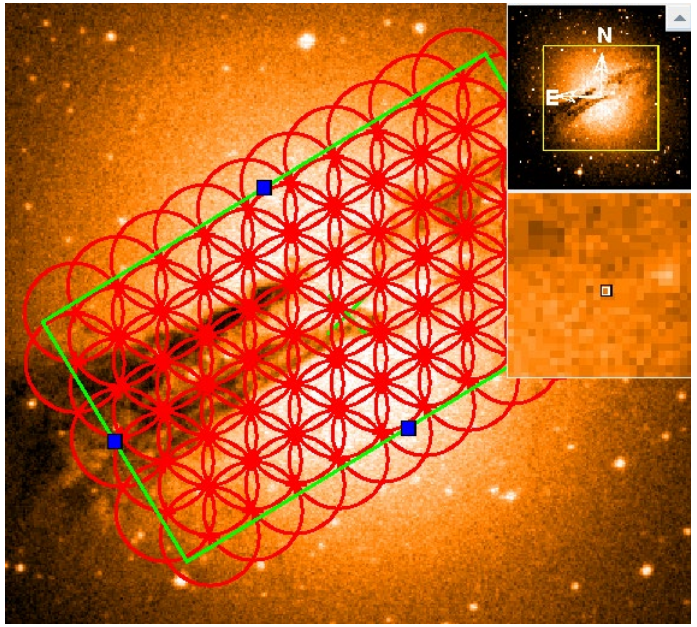
Mosaicking / Multiple Pointing

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

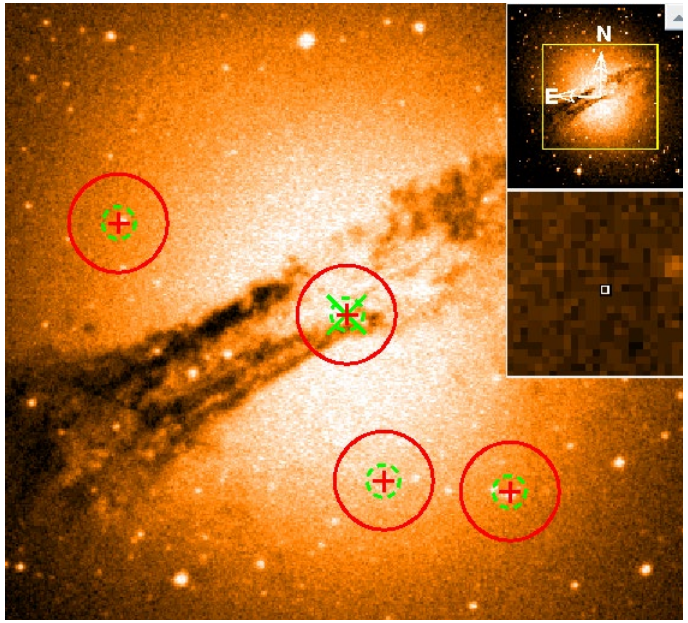
Single pointing



Mosaicking

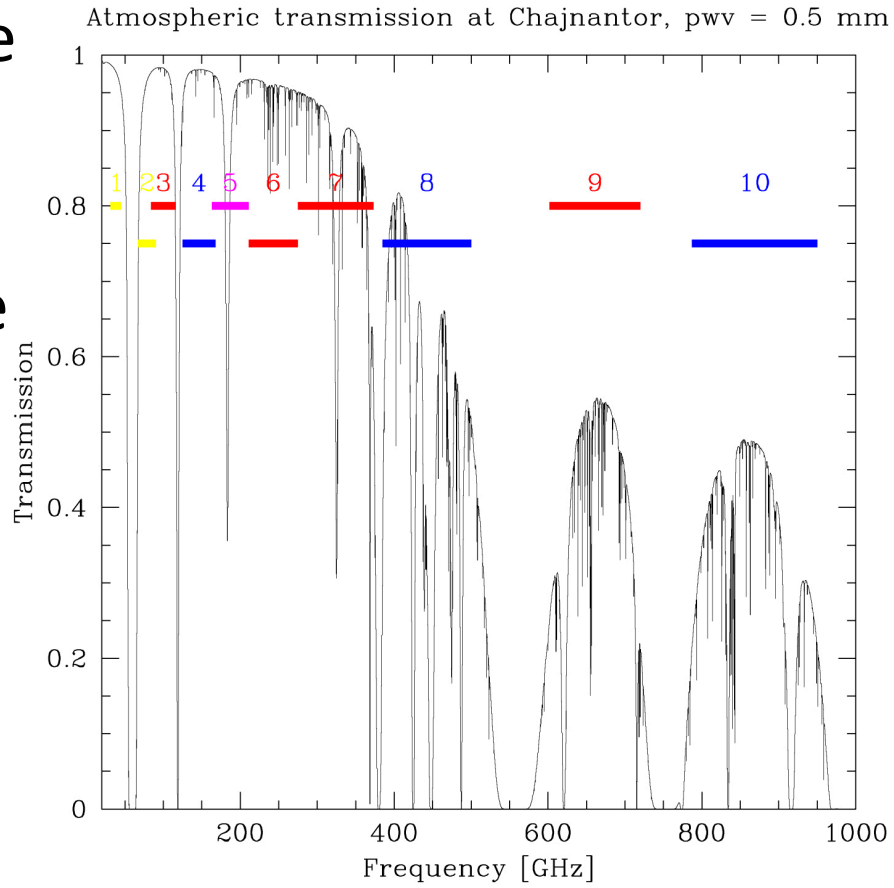


Multiple pointing



Frequency Bands

- 10 receiver bands (Band 2 will be available in future)
- Multiple band data cannot be taken simultaneously in a single execution.
  (except for B2B phase transfer)
- 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

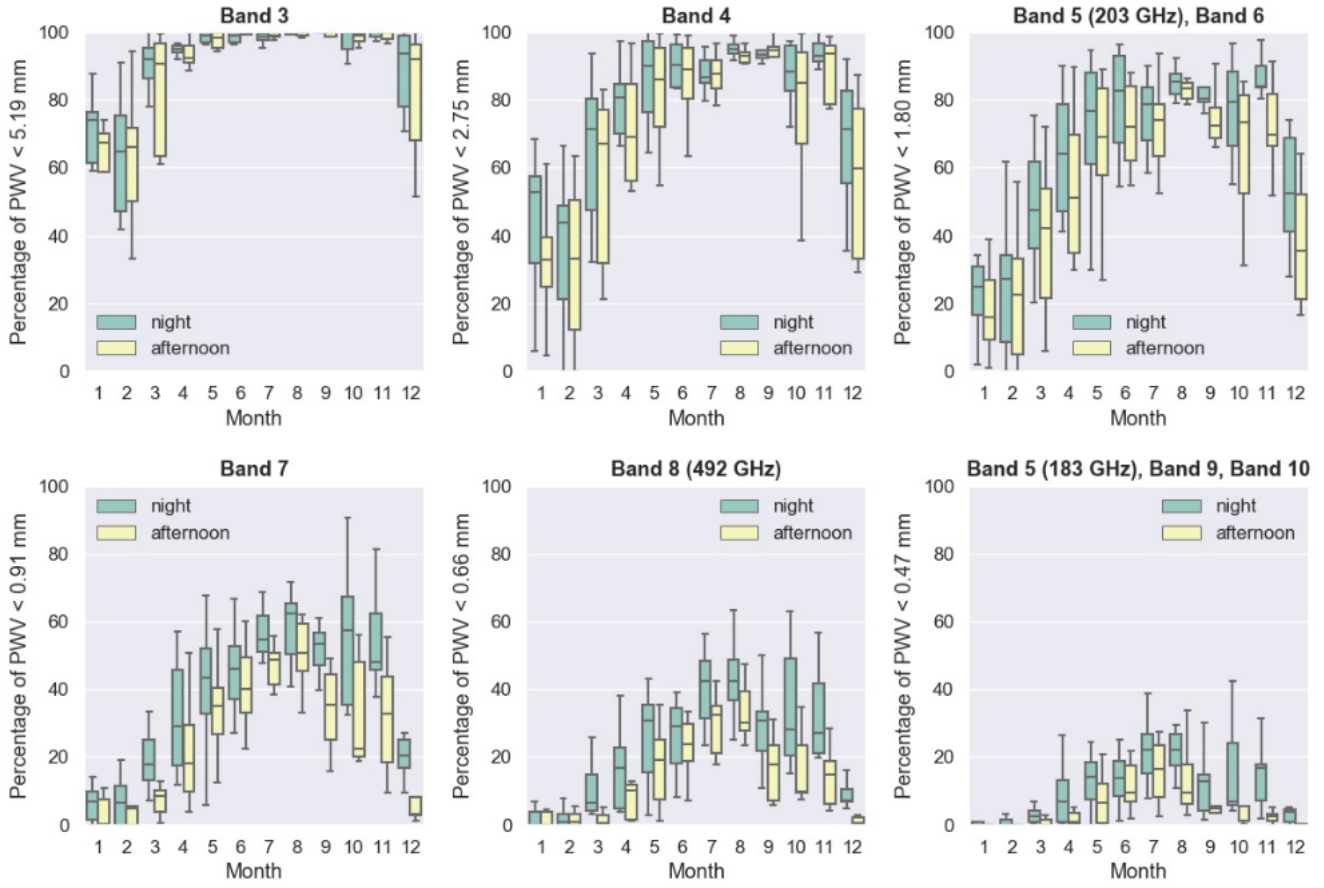
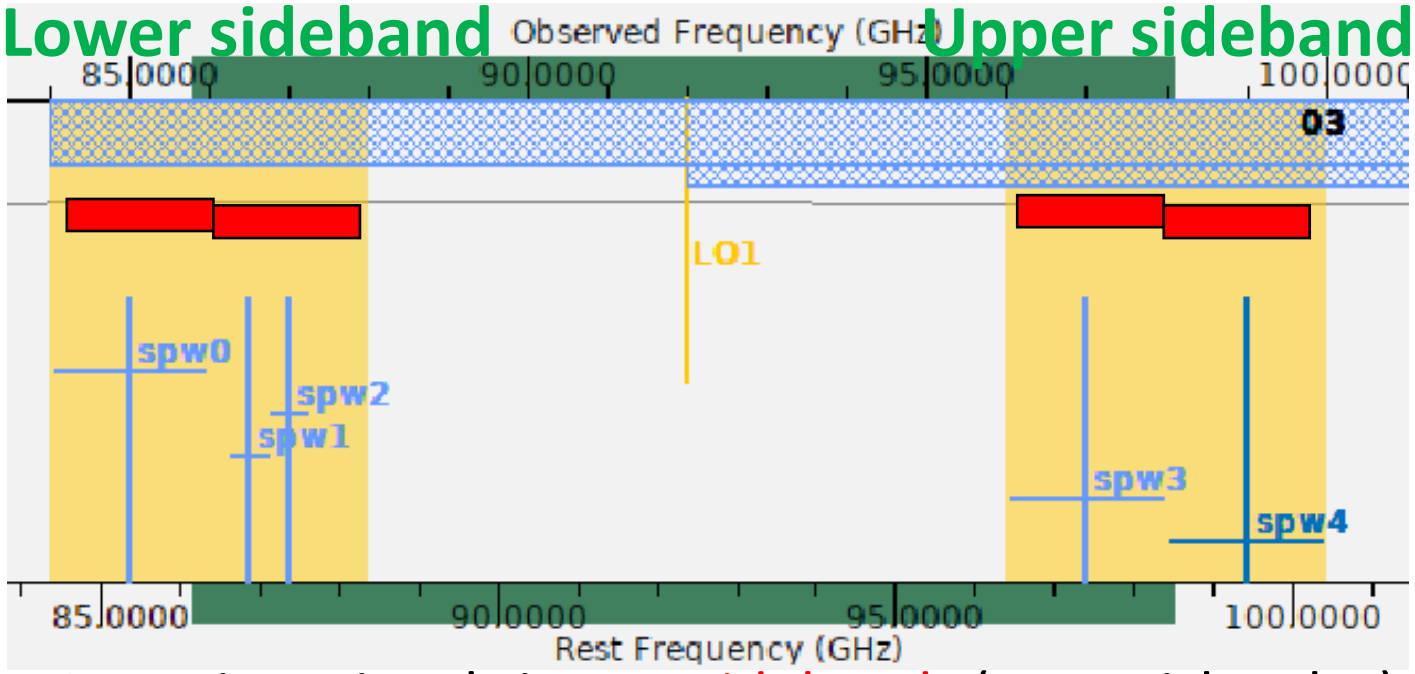
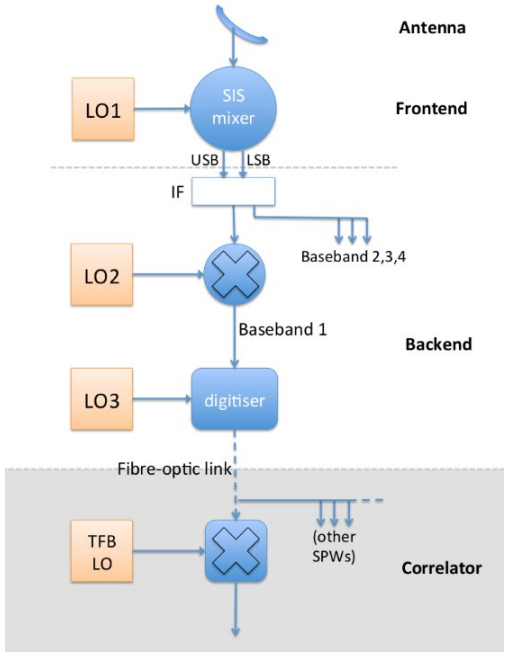


Figure 3: The percentage of time when the PWV is below the observing thresholds adopted for the various ALMA bands for night-time (green) and afternoon (yellow) and for an elevation of 60 degrees. The horizontal line within the box indicates the median. Boundaries of the box indicate the 25th- and 75th-percentile, 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.

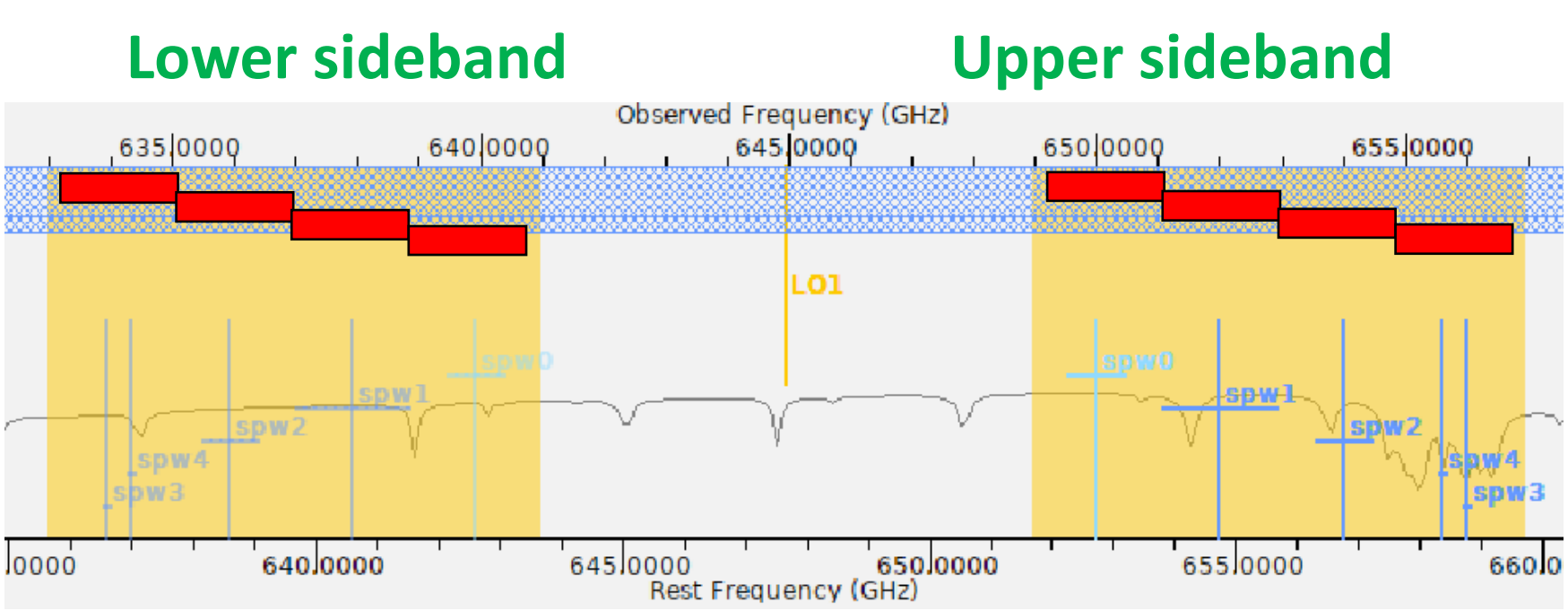
Instantaneous frequency coverage (B3-8)

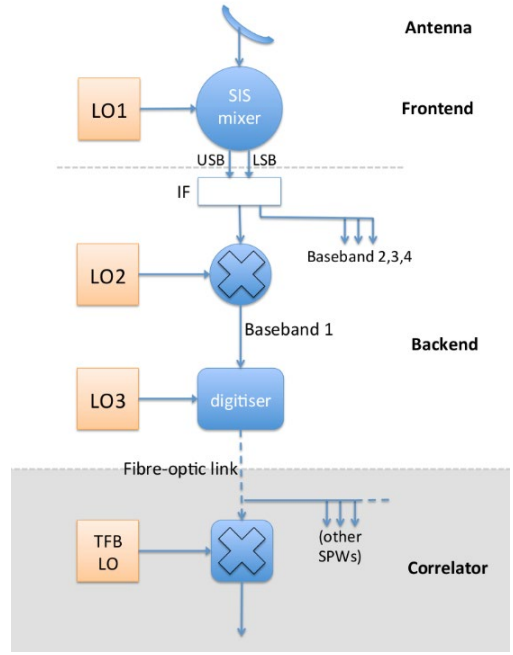




- ALMA receives signals in two sidebands (green-ish color).
- Up to four basebands with 2-GHz width can be placed either in a sideband or two sidebands. (Red boxes. Not possible to put 3 in one sideband and 1 in the other.)
- Allows to place up to four spectral windows (spws) in each of these basebands (blue-ish bars) .
- Each spw forms a final contiguous spectrum (You will not receive data outside of spws)

Instantaneous frequency coverage (B9-10)

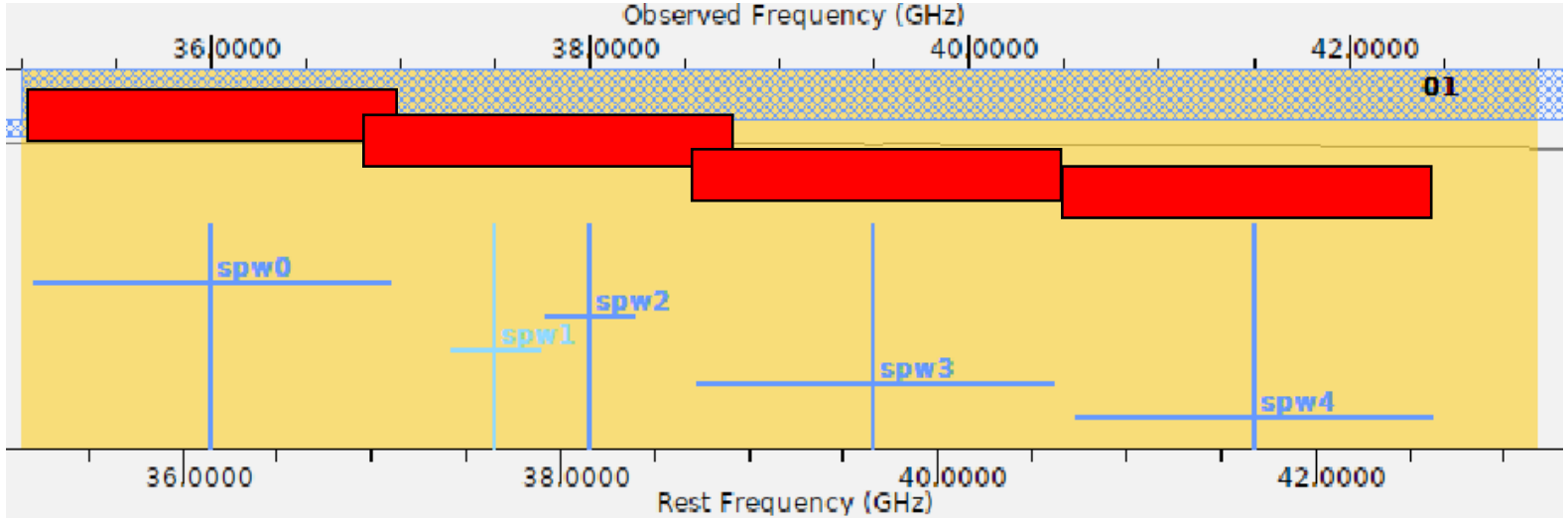


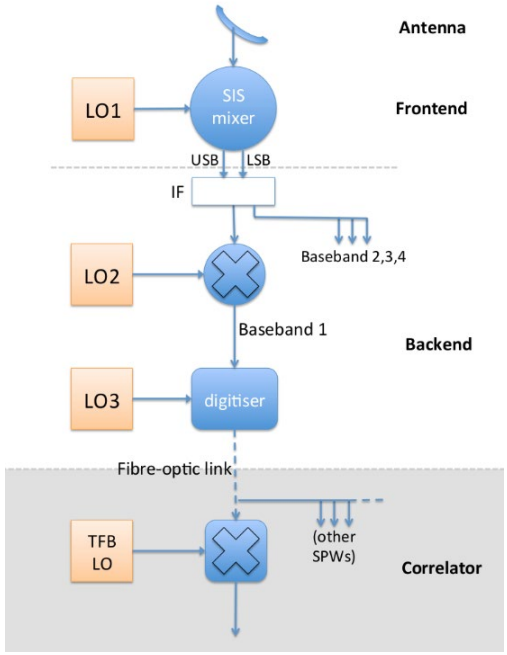


- For Bands 9 and 10 (Double Sideband system), up to four basebands can be placed in a sideband. The same number of basebands is automatically placed in an opposite sideband.
- Allows to place up to four spectral windows (spws) in each of these basebands (blue-ish bars) .
- You may suppress one sideband by using LO-offsetting only if TDM or FDM with 1.875GHz BW is selected.

Instantaneous frequency coverage (B1)

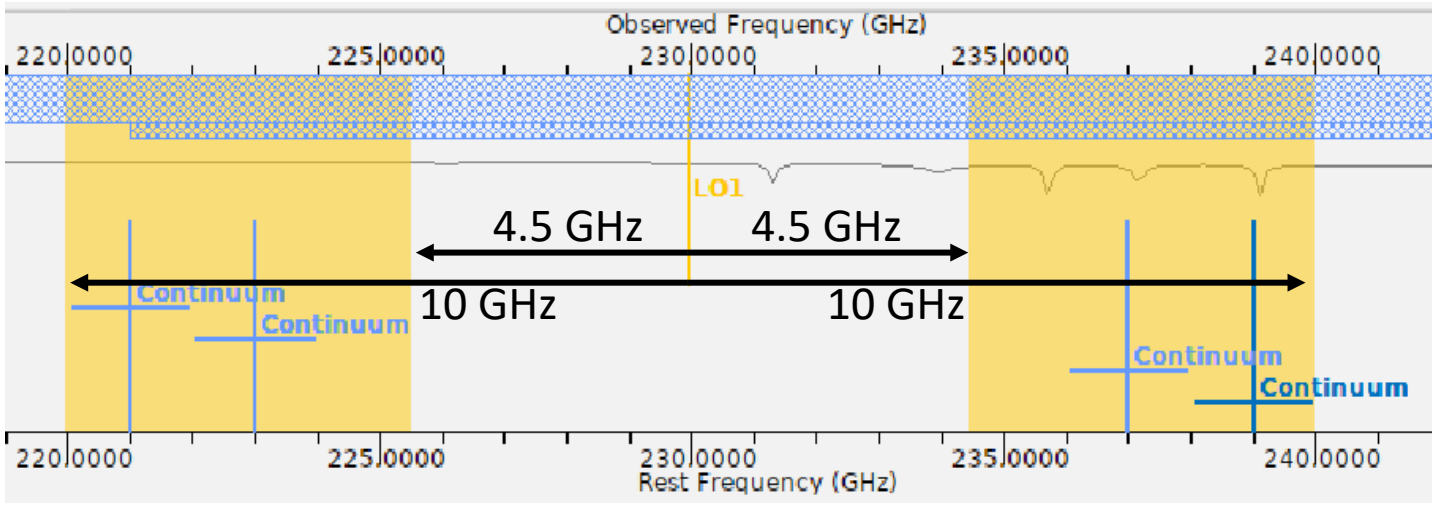
Single sideband





- Band 1 employs single-sideband system (SSB).
- Up to 4 basebands with 2-GHz width are placed in a sideband.
- Allows to place up to four spectral windows (spws) in each of these basebands (blue-ish bars) .

Intermediate Frequency (IF) Range



Band	Frequency range (GHz)	Wavelength range (mm)	IF range (GHz)	Type
1	35 – 50	8.5 – 6	4 – 12	SSB
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

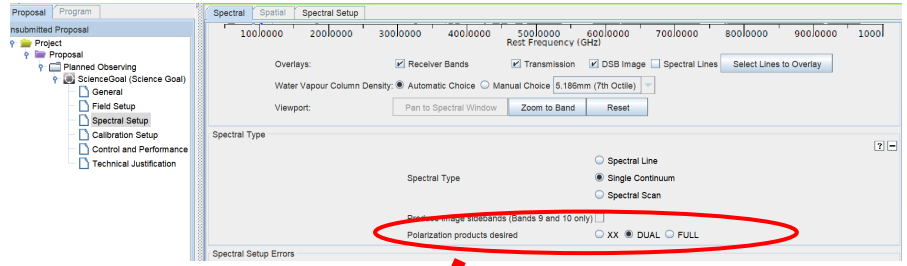
For the case of Band 6, IF range is from ν_{LO1}+/- 4.5 GHz to ν_{LO1}+/- 10 GHz, and therefore the width of each sideband is 5.5 GHz.

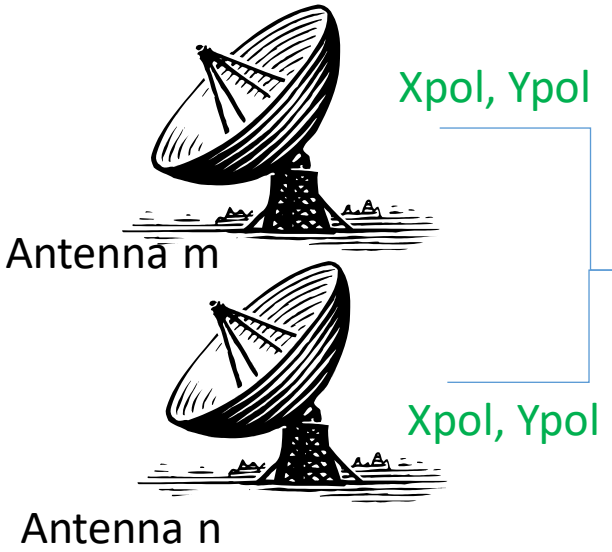
Frequency Resolution

Bandwidth (MHz)	Channel spacing (MHz)	Spectral resolution (MHz)	Number of channels	Correlator mode	Bit Mode
1875	15.6	31.2	120	TDM	
938	0.976	1.952	1024	FDM	4x4 ⋆
1875	0.488	0.976	3840	FDM	2x2
469	0.488	0.976	1024	FDM	4x4
938	0.244	0.488	3840	FDM	2x2
234	0.244	0.488	1024	FDM	4x4
469	0.122	0.244	3840	FDM	2x2
117	0.122	0.244	1024	FDM	4x4
234	0.061	0.122	3840	FDM	2x2
58.6	0.061	0.122	1024	FDM	4x4
117	0.0305	0.061	3840	FDM	2x2
58.6	0.0153	0.0305	3840	FDM	2x2

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.

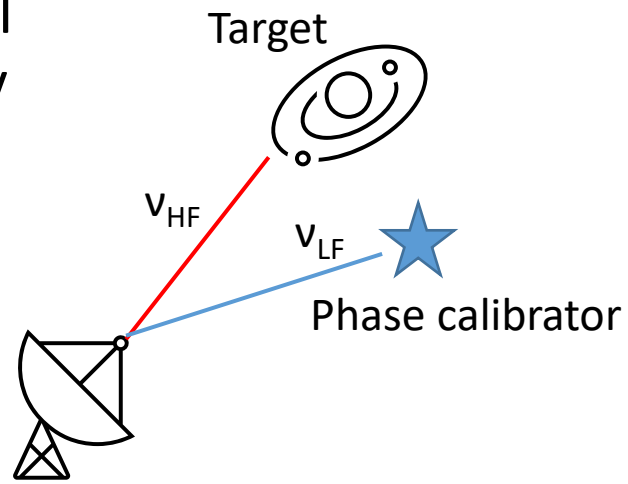
2. Cycle 10 Capabilities

What's New in Cycle 10?

- Band 1 on the 12-m array
  - Observations will be available for Stokes I only (no Stokes Q/U/V) and are anticipated to be available from March 2024. Band 1 will not be available in configurations C-7 and C-8.
- Spectral scan that includes the Total Power observations
- 4 x 4-bits spectral line observations on the 12-m array.
  - This will provide an increase in sensitivity by 12%.
- Solar observations in full polarization in Band 3 using only the 12-m Array.
- Phased array mode in Bands 1, 3, 6 and 7.
  - The total time available for this mode will be limited to 50 hours.
- Continuum and spectral line VLBI in Bands 1, 3, 6 and 7, including flexible tuning.

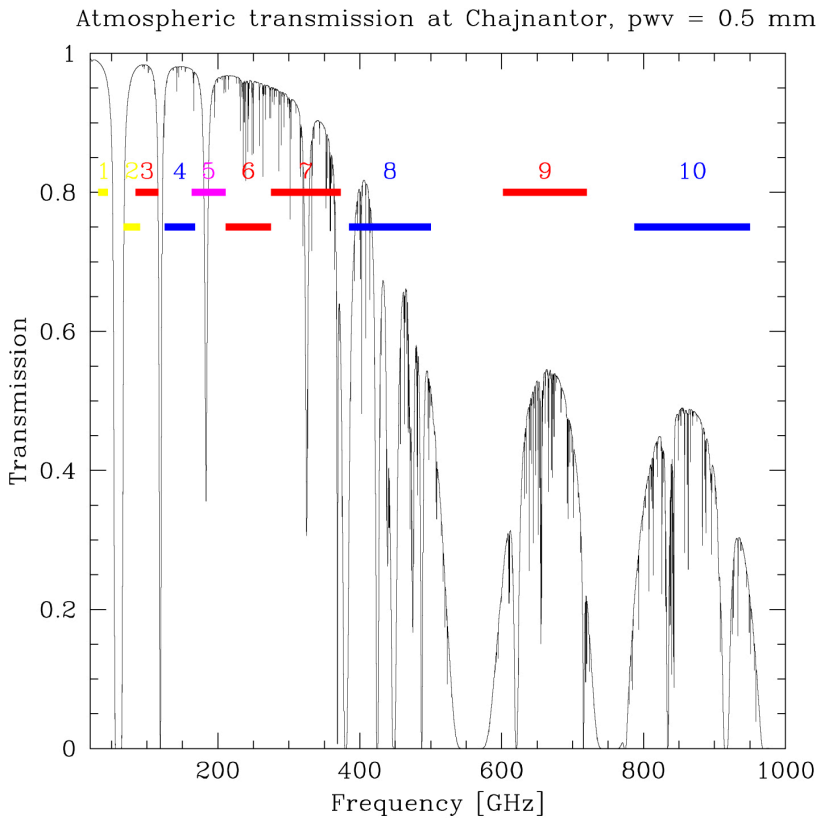
Additional New Items

- TP data will be correlated using the ACA spectrometer, which is a new GPU spectrometer developed by EA, instead of traditional ACA correlator.
  - No action is needed on the user side.
- B2B phase transfer method is also applicable for all array configurations.
  - In case that no phase calibrator can be found within a nominal separation angle at the target frequency, the OT automatically triggers the B2B mode.
  - For the B2B mode, phase calibrator is observed at lower frequency and transfer the phase calibration to the target (high) frequency. This will increase a chance to find phase calibrator.
  - A maximum of 65 hours for 12-m and 85 hours for 7-m array.



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 1, 3, 4, 5, 6, 7, 8, 9, and 10.**



Configuration

		Band	1	3	4	5	6	7	8	9	10
Config.	**L_{max}**	**Freq. (GHz)**	**40**	**100**	**150**	**185**	**230**	**345**	**460**	**650**	**870**
	L_{min}										
7-m	**45 m**	θ_{res} (arcsec)	31.5	12.5	8.35	6.77	5.45	3.63	2.72	1.93	1.44
	9 m	θ_{MRS} (arcsec)	167	66.7	44.5	36.1	29.0	19.3	14.5	10.3	7.67
C-1	**161 m**	θ_{res} (arcsec)	8.45	3.38	2.25	1.83	1.47	0.98	0.74	0.52	0.39
	15 m	θ_{MRS} (arcsec)	71.2	28.5	19.0	15.4	12.4	8.25	6.19	4.38	3.27
C-2	**314 m**	θ_{res} (arcsec)	5.75	2.30	1.53	1.24	1.00	0.67	0.50	0.35	0.26
	15 m	θ_{MRS} (arcsec)	56.5	22.6	15.0	12.2	9.81	6.54	4.90	3.47	2.59
C-3	**500 m**	θ_{res} (arcsec)	3.55	1.42	0.94	0.77	0.62	0.41	0.31	0.22	0.16
	15 m	θ_{MRS} (arcsec)	40.5	16.2	10.8	8.73	7.02	4.68	3.51	2.48	1.86
C-4	**784 m**	θ_{res} (arcsec)	2.30	0.92	0.61	0.50	0.40	0.27	0.20	0.14	0.11
	15 m	θ_{MRS} (arcsec)	28.0	11.2	7.50	6.08	4.89	3.26	2.44	1.73	1.29
C-5	**1.4 km**	θ_{res} (arcsec)	1.38	0.55	0.36	0.30	0.24	0.16	0.12	0.084	0.063
	15 m	θ_{MRS} (arcsec)	16.8	6.70	4.47	3.62	2.91	1.94	1.46	1.03	0.77
C-6	**2.5 km**	θ_{res} (arcsec)	0.78	0.31	0.20	0.17	0.13	0.089	0.067	0.047	0.035
	15 m	θ_{MRS} (arcsec)	10.3	4.11	2.74	2.22	1.78	1.19	0.89	0.63	0.47
C-7	**3.6 km**	θ_{res} (arcsec)		0.21	0.14	0.11	0.092	0.061	0.046	0.033	0.024
	64 m	θ_{MRS} (arcsec)		2.58	1.72	1.40	1.12	0.75	0.56	0.40	0.30
C-8	**8.5 km**	θ_{res} (arcsec)		0.096	0.064	0.052	0.042	0.028	0.021	0.015	0.011
	110 m	θ_{MRS} (arcsec)		1.42	0.95	0.77	0.62	0.41	0.31	0.22	0.16

Config. Schedule

Start date	Configuration	Longest baseline	LST for best observing conditions
2023 October 1	C-8	8.5 km	∼ 22—10 h
2023 October 20	C-7	3.6 km	∼ 23—11 h
2023 November 10	C-6	2.5 km	∼ 1—13 h
2023 December 1	C-5	1.4 km	∼ 2—14 h
2023 December 20	C-4	0.78 km	∼ 4—15 h
2024 January 10	C-3	0.50 km	∼ 5—17 h
2024 February 1	*No observations due to maintenance*		
2024 March 1	C-1	0.16 km	∼ 8—21 h
2024 March 26	C-2	0.31 km	∼ 9—23 h
2024 April 20	C-3	0.50 km	∼ 11—0 h
2024 May 10	C-4	0.78 km	∼ 12—2 h
2024 May 31	C-5	1.4 km	∼ 13—4 h
2024 June 23	C-6	2.5 km	∼ 15—6 h
2024 July 28	C-5	1.4 km	∼ 17—7 h
2024 August 18	C-4	0.78 km	∼ 19—8 h
2024 September 10	C-3	0.50 km	∼ 20—9 h

Band 1 start →

Notes on Band 1

- Will start to offer in March 2024.
  - Users must choose the requested angular resolution and MRS that can be achieved with C1-C6 in their proposals. The OT does not give warning/error even if you set angular resolutions that cannot be achieved C1-C6 configurations.
  - Both continuum and spectral line including spectral scan are allowed.
  - No polarization (only Stokes I).
  - No 7m nor TP.

Notes on 4x4-bits

- User can choose 2x2-bits or 4x4-bits in the Spectral Setup.
- 4x4-bits provide a better sensitivity at fix spectral resolution and integration time.
- This mode is only allowed for the 5 FDM setups with the 12-m array.
- 4x4-bits mode cannot be used in the same baseband with 2x2 bit modes, but a mixture of basebands using 4x4 and basebands using 2x2 is allowed.
- Don’t worry to use 4x4-bits, though the OT returns a warning message.

Bandwidth (MHz)	Channel spacing (MHz)	Spectral resolution (MHz)	Number of channels	Correlator mode	Bit Mode
1875	15.6	31.2	120	TDM	
938	0.976	1.952	1024	FDM	4x4 ⋆
1875	0.488	0.976	3840	FDM	2x2
469	0.488	0.976	1024	FDM	4x4
938	0.244	0.488	3840	FDM	2x2
234	0.244	0.488	1024	FDM	4x4
469	0.122	0.244	3840	FDM	2x2
117	0.122	0.244	1024	FDM	4x4
234	0.061	0.122	3840	FDM	2x2
58.6	0.061	0.122	1024	FDM	4x4
117	0.0305	0.061	3840	FDM	2x2
58.6	0.0153	0.0305	3840	FDM	2x2

Notes on Solar Polarization

- Only in Band 3
- Although the interferometric component of Solar observations will be conducted using a special combined array comprising both 12-m and 7-m antennas, no 7-m antennas will be provided for Band 3 polarimetry.

Backup slides

Time Multiplier

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		

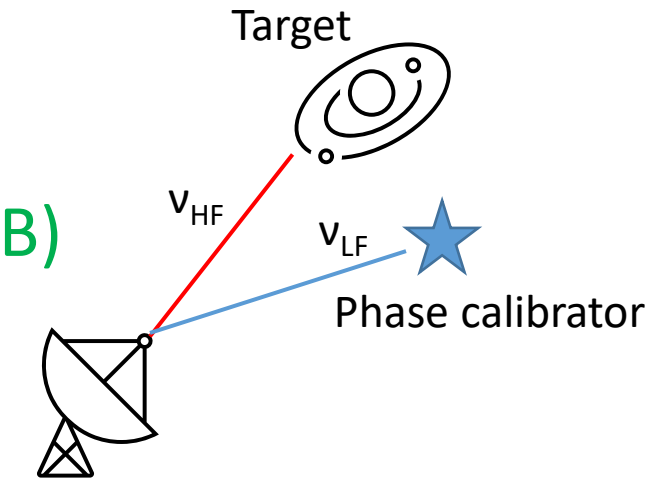
Basic Observing Modes

- **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 (Bands 3-10) and mosaics (Bands 3 to 9) with the 12-m Array and the 7-m Array. In Band 1, single-field interferometry and mosaics are only available with the 12-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 per SG.**
  - **Single-dish spectral scan is also allowed in bands 3-8 from this Cycle.**
- **Target of Opportunity**
- **Large program**
  - **>50 hours for 12m array**
  - **>150 hours for 7m array**

Polarization (no change from previous cycle)

- **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.**

High Frequencies



- Observations 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 65 hours for 12-m and 85 hours for 7-m array will be available for the observations requiring B2B calibrations.

VLBI

- VLBI observations in Bands 1, 3, 6, & 7 will be conducted using a "campaign mode" (actual date will be set after the proposal review).
- Both continuum and spectral line with flexible tuning are allowed.
- 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 (phased-array mode)

- Users can propose pulsar observations with the aid of phase-up mode that works as “a large single dish” in Bands 1, 3, 6, and 7.
- 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.
- The total time available for this mode will be limited to 50 hours.

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) except for polarization observation in Band 3.
- Full polarization (XX, YY, XY, YX) are only offered in Band 3 with the 12-m array.

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 1-5, ~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). Band 1 spectral DR has not been extensively tested, but we will expect to achieve ~1000.
- 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.