Cycle 11 Observing Capabilities

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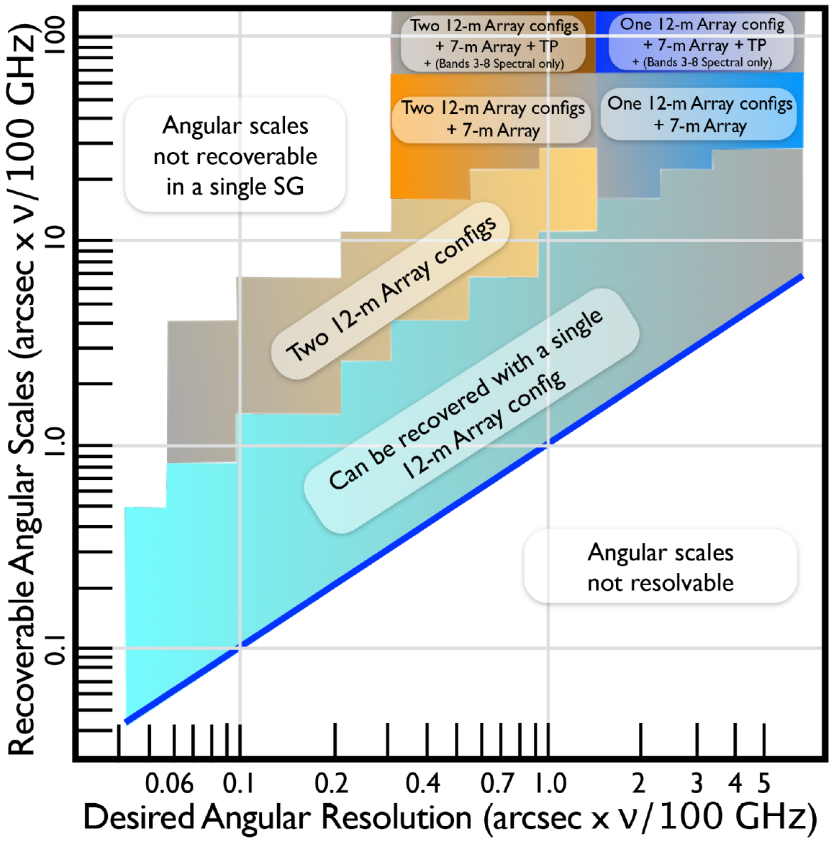
1. ALMA Basics

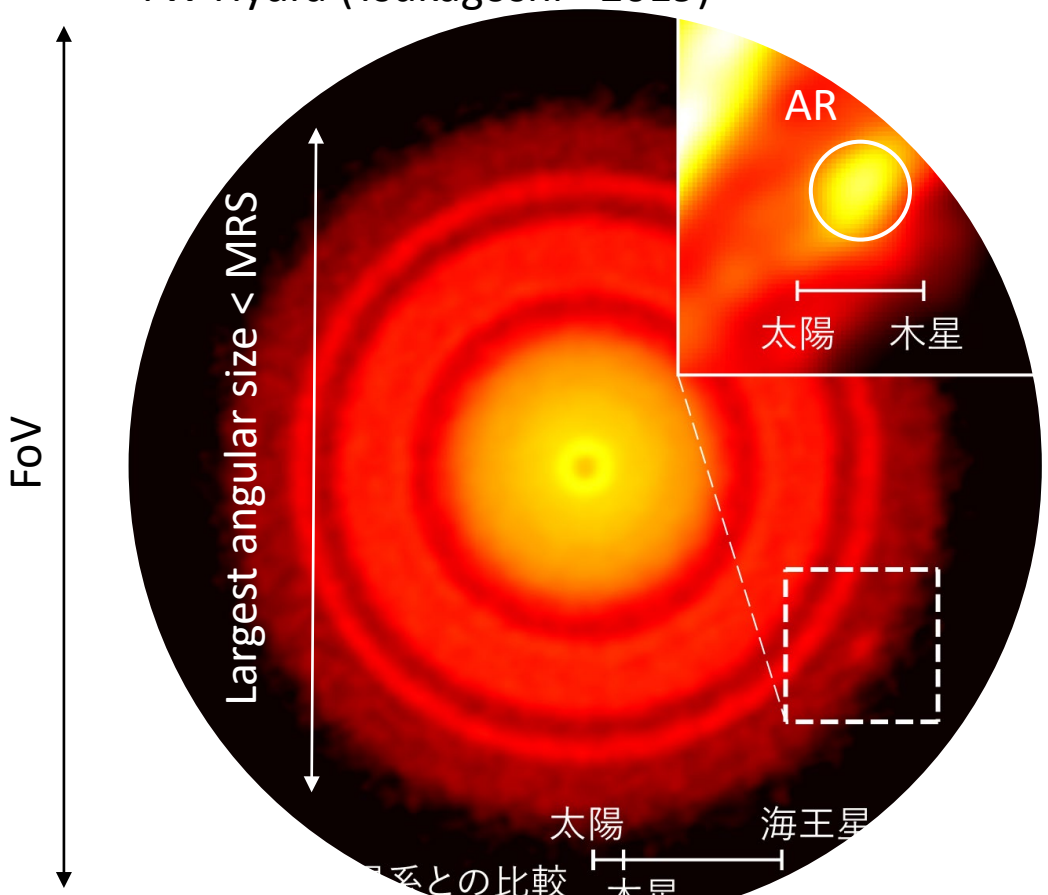
ALMA Arrays

See Cycle 11 “A Primer”



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})

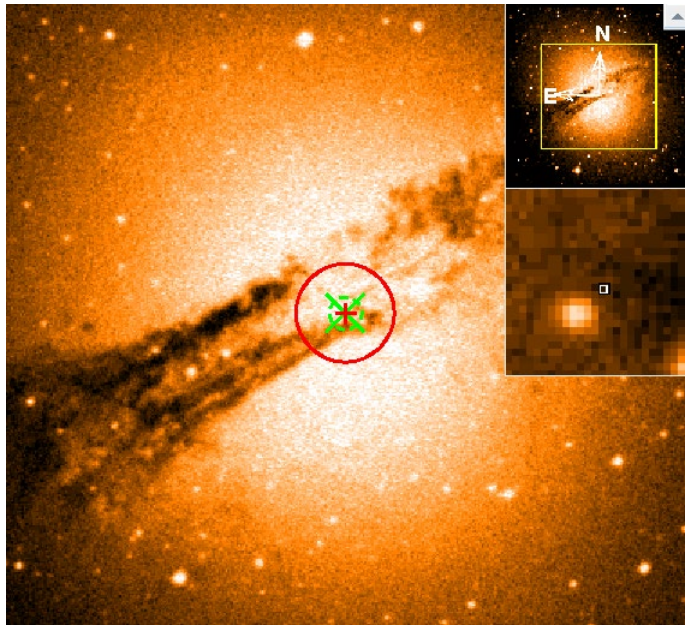
Field of View (FoV)

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

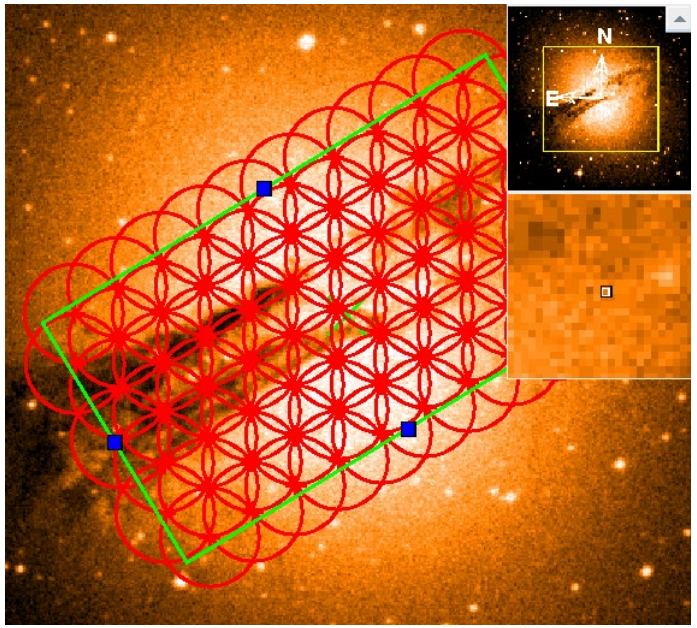
Mosaicking / Multiple Pointing

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

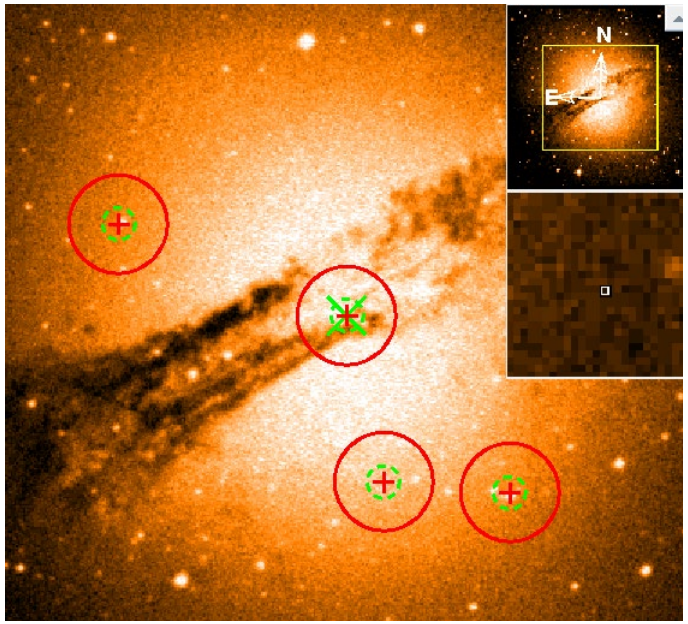
Single pointing



Mosaicking

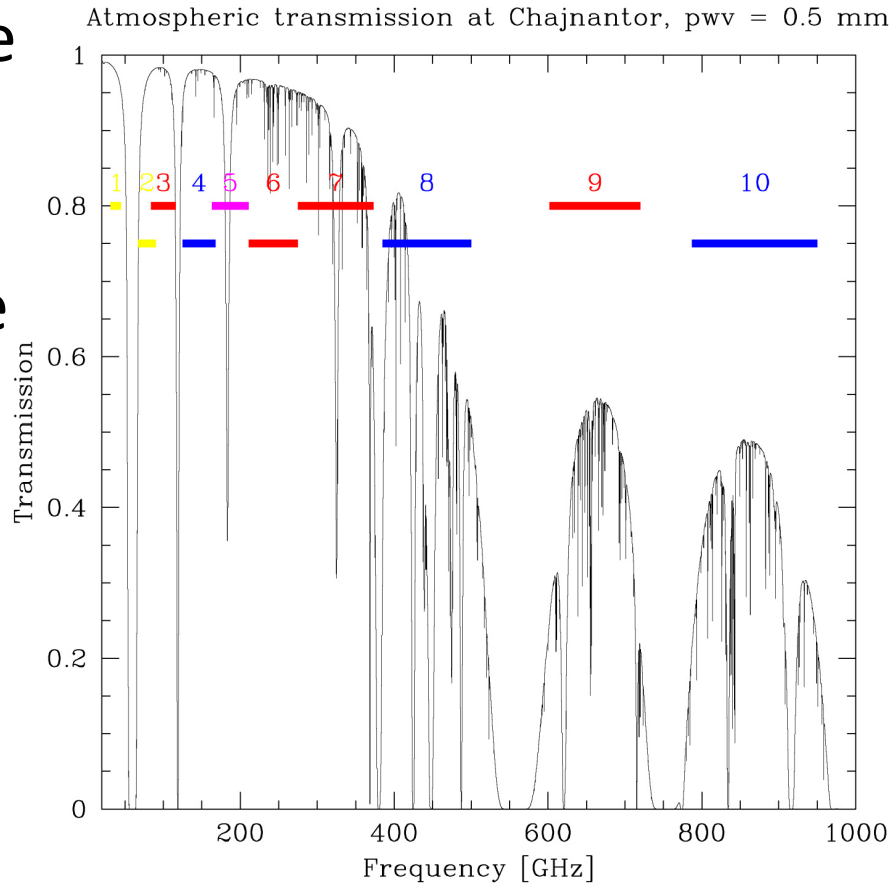


Multiple pointing



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

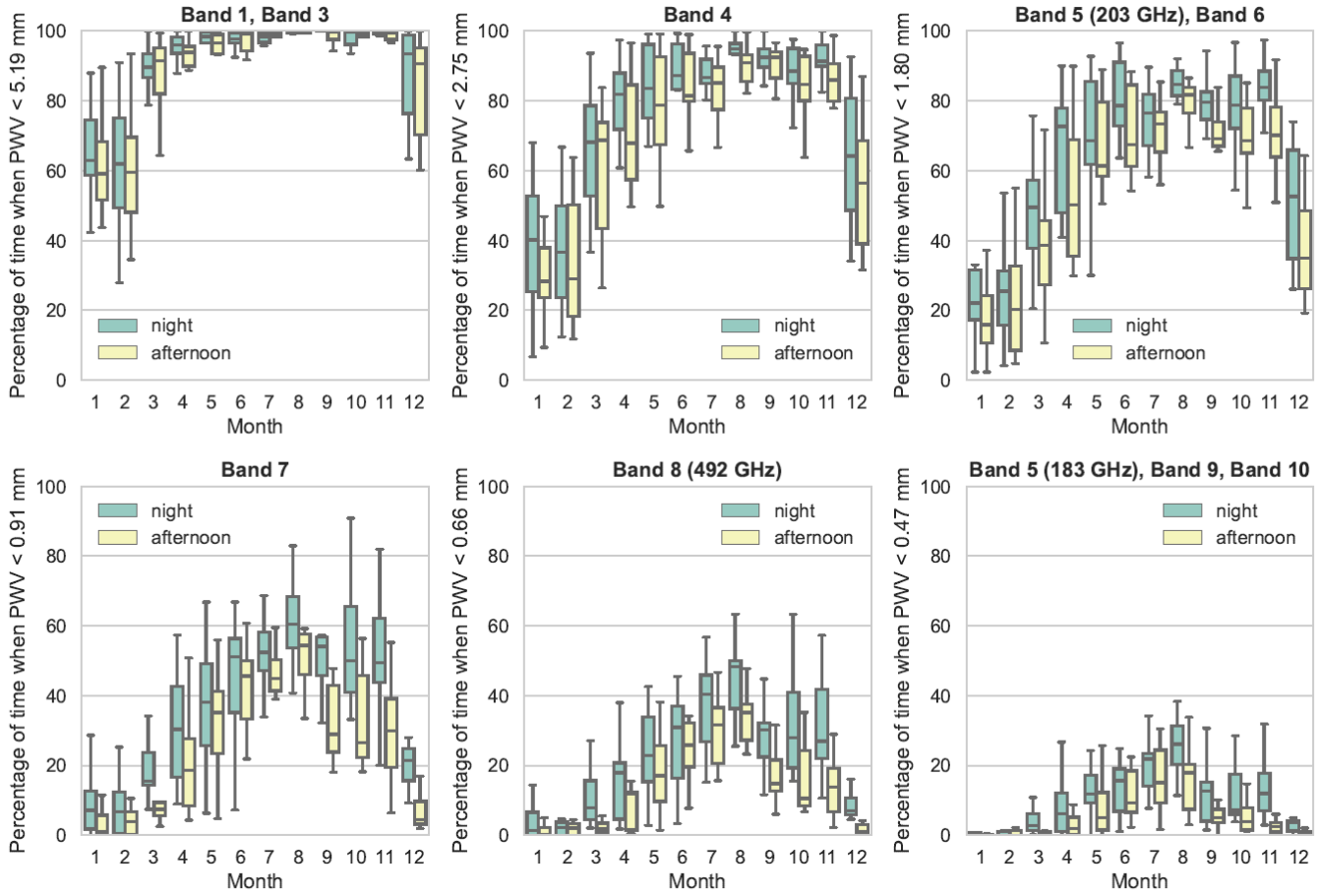
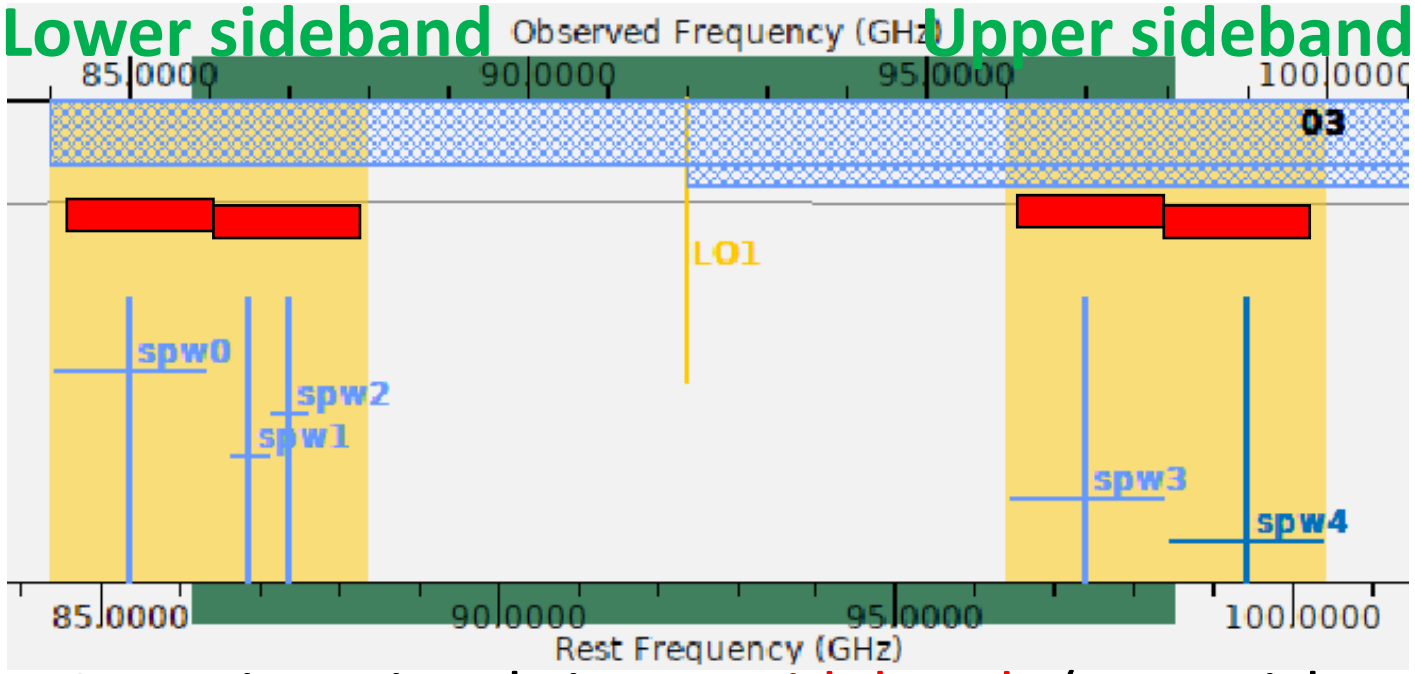
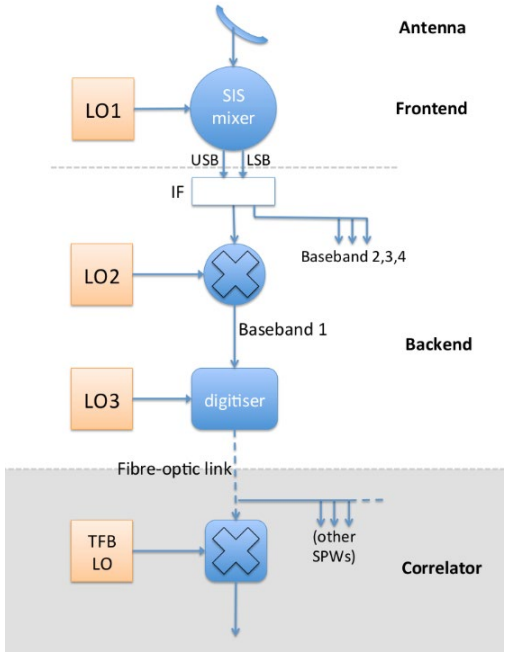


Figure 3: The percentage of time when the PWV is below the observing thresholds adopted for the various ALMA bands for afternoon (yellow; based on 17:00–21:00 UT) and night (green; based on 01:00–05:00 UT) and for an elevation of 60 degrees. The horizontal line within the box indicates the median. Boundaries of the box indicate the 25^{th}- and 75^{th}-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 January 2010 and January 2022.

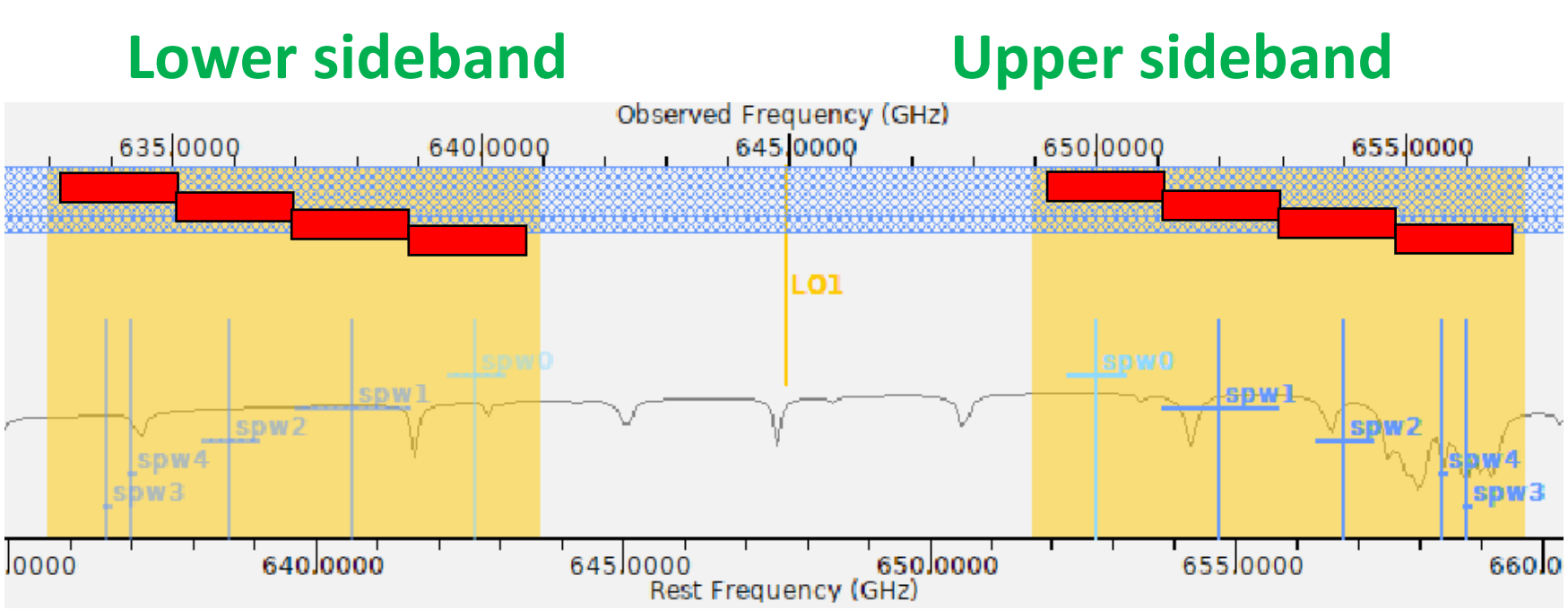
Instantaneous frequency coverage (B3-8)

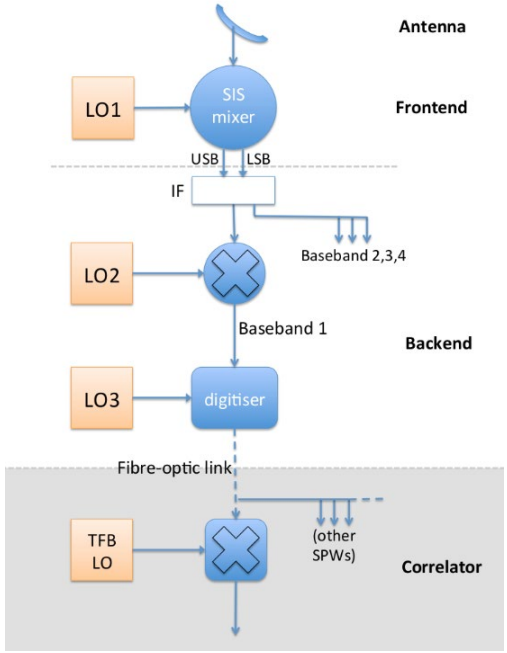




- ALMA receives signals in two sidebands (green-ish color).
- Up to four basebands with 2-GHz width can be placed either in a sideband or two sidebands. (Red boxes. Not possible to put 3 in one sideband and 1 in the other.)
- Up to four spectral windows (spws) in each of basebands (blue-ish bars) .
-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

Instantaneous frequency coverage (B9-10)

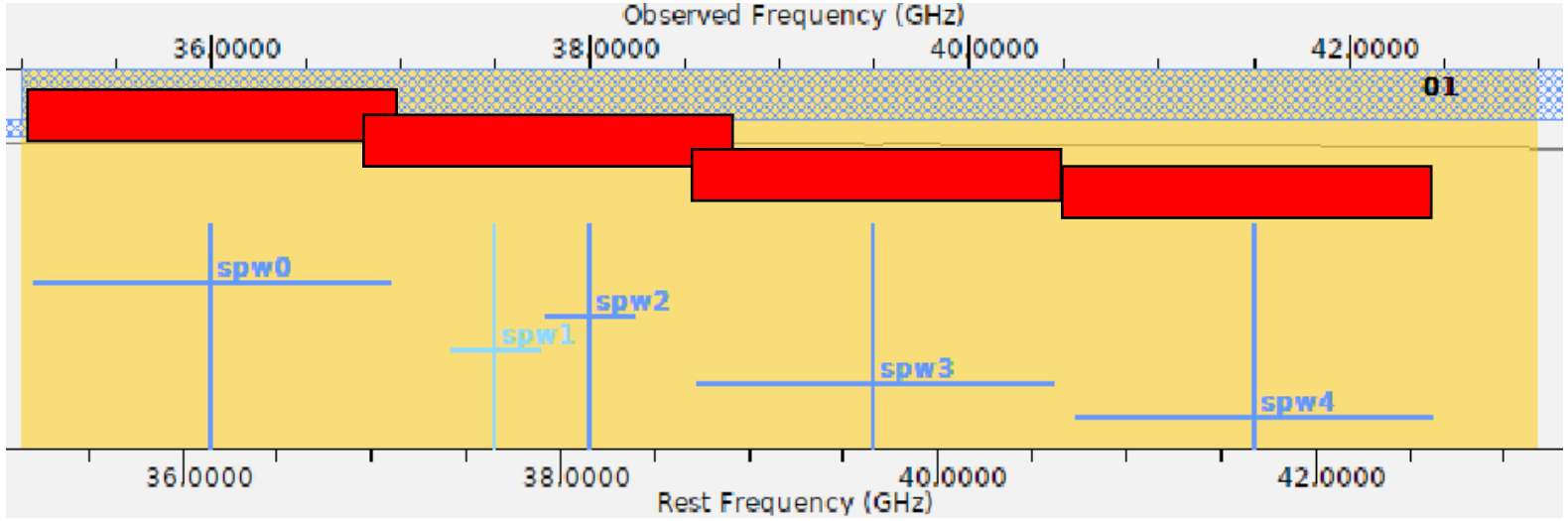


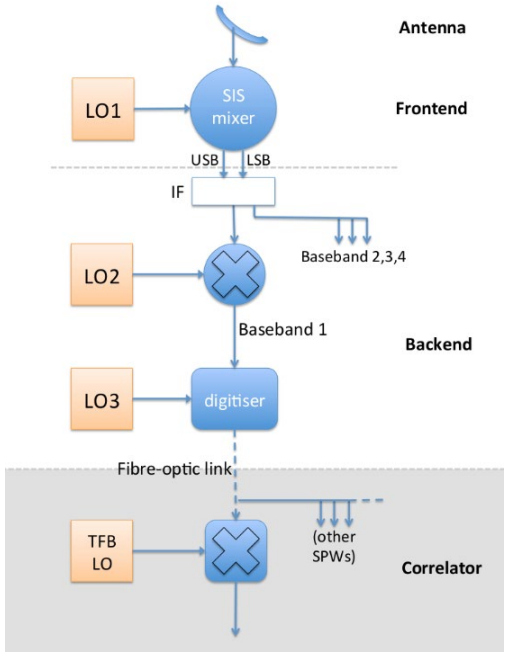


- For Bands 9 and 10 (Double Sideband system), up to four basebands can be placed in a sideband. The same number of basebands is automatically placed in an opposite sideband.
- Allows to place up to four spectral windows (spws) in each of basebands (blue-ish bars) .
- You may suppress one sideband by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

Instantaneous frequency coverage (B1)

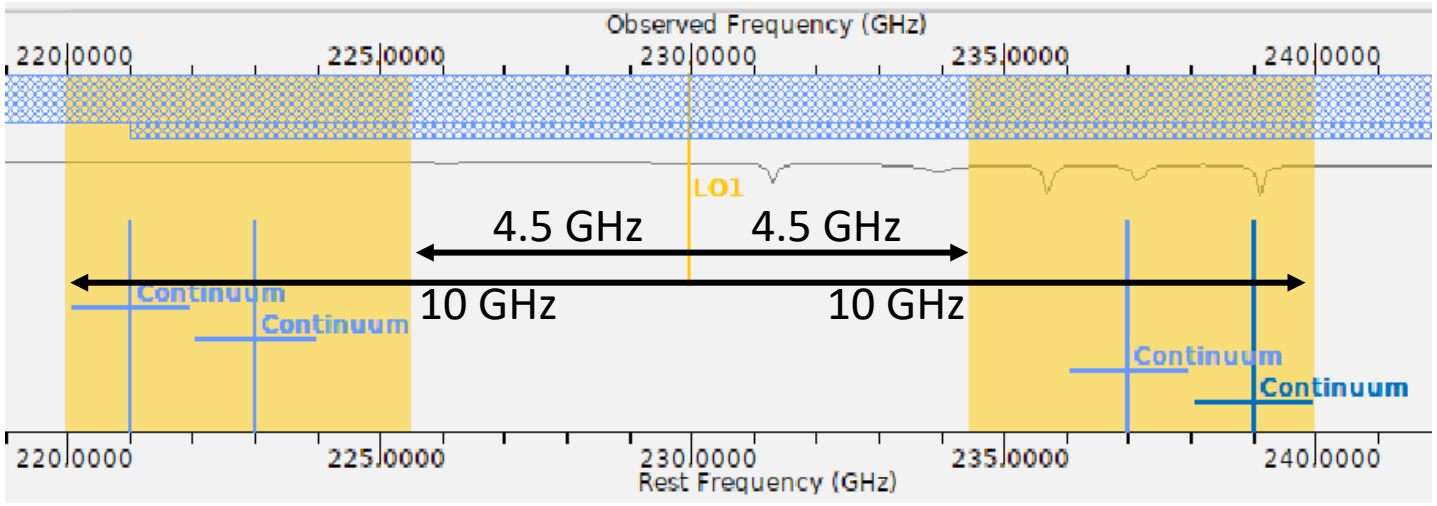
Single sideband





- 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

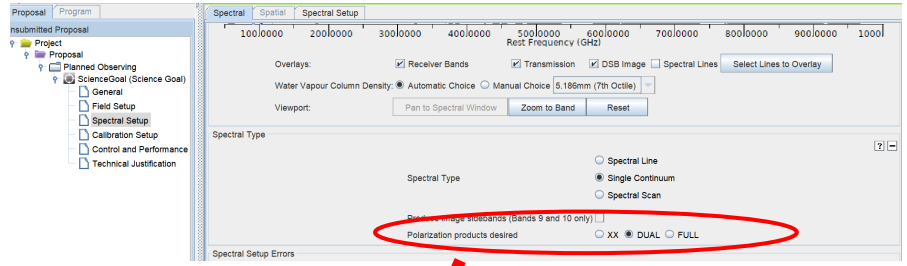
- For the case of Band 6, IF range is from ν_{LO1}+/- 4.5 GHz to ν_{LO1}+/- 10 GHz, and therefore the width of each sideband is 5.5 GHz.

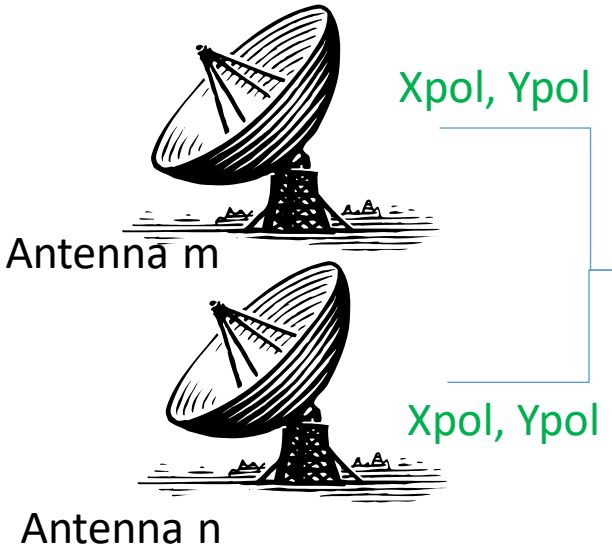
Frequency Resolution

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.

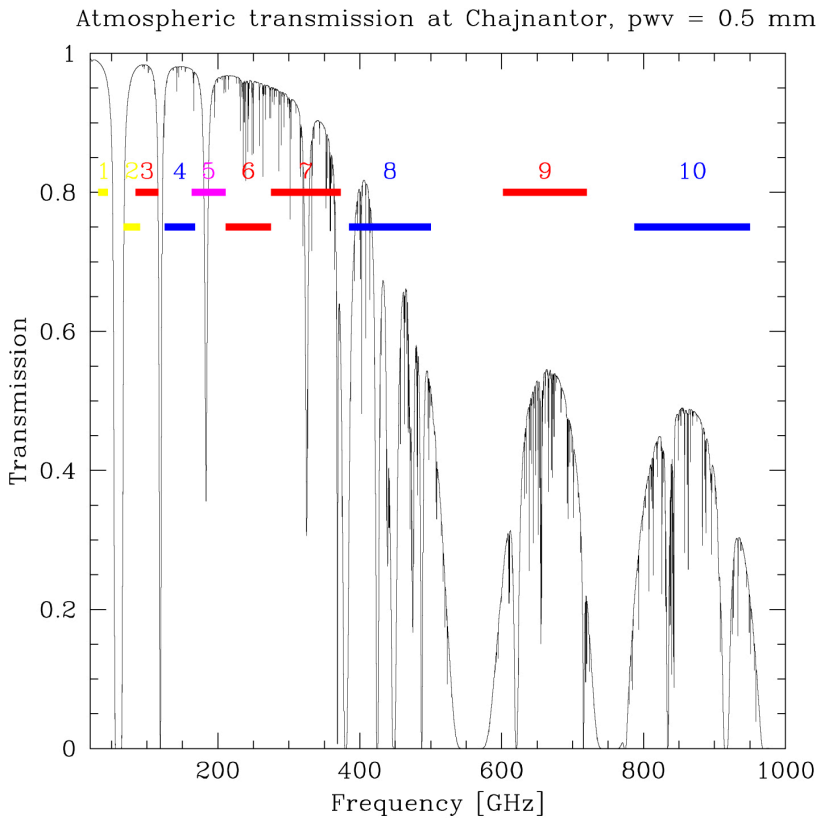
2. Cycle 11 Capabilities

What’s New in Cycle 11?

- Full-polarization in Band 1 on the 12m array. The polarization accuracy and capability will be the same as in Bands 3-7.
- Band 1 on the 7m array for Stokes I only.
- High-frequency and long-baseline observations with Band 9 in C-10 configuration, and Band 10 in configurations of C-9 and C-10.
- 4x4-bit spectral mode on the 7-m Array (dual polarization).

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)	0.53	0.21	0.14	0.11	0.092	0.061	0.046	0.033	0.024
	64 m	θ_{MRS} (arcsec)	6.45	2.58	1.72	1.40	1.12	0.75	0.56	0.40	0.30
C-8	**8.5 km**	θ_{res} (arcsec)	0.24	0.096	0.064	0.052	0.042	0.028	0.021	0.015	0.011
	110 m	θ_{MRS} (arcsec)	3.55	1.42	0.95	0.77	0.62	0.41	0.31	0.22	0.16
C-9	**13.9 km**	θ_{res} (arcsec)	0.14	0.057	0.038	0.031	0.025	0.017	0.012	0.0088	0.0066
	368 m	θ_{MRS} (arcsec)	2.03	0.81	0.54	0.44	0.35	0.24	0.18	0.13	0.093
C-10	**16.2 km**	θ_{res} (arcsec)	0.11	0.042	0.028	0.023	0.018	0.012	0.0091	0.0065	0.0048
	244 m	θ_{MRS} (arcsec)	1.25	0.50	0.33	0.27	0.22	0.14	0.11	0.077	0.057

See Technical Handbook

Config. Schedule

Start date	Configuration	Longest baseline	LST for best observing conditions
2024 October 1	C-3	0.50 km	~ 22—10 h
2024 October 20	C-2	0.31 km	~ 23—11 h
2024 November 10	C-1	0.16 km	~ 1—13 h
2024 November 30	C-2	0.31 km	~ 2—14 h
2024 December 20	C-3	0.50 km	~ 4—15 h
2025 January 10	C-4	0.78 km	~ 5—17 h
2025 February 1	*No observations due to maintenance*		
2025 March 1	C-4	0.78 km	~ 8—21 h
2025 March 20	C-5	1.4 km	~ 9—23 h
2025 April 20	C-6	2.5 km	~ 11—1 h
2025 May 20	C-7	3.6 km	~ 13—3 h
2025 June 20	C-8	8.5 km	~ 14—5 h
2025 July 11	C-9	13.9 km	~ 16—6 h
2025 July 30	C-10	16.2 km	~ 17—7 h
2025 August 20	C-9	13.9 km	~ 19—8 h
2025 September 10	C-8	8.5 km	~ 20—9 h

Notes on 4x4-bits (introduced from Cycle 10)

- User can choose 2x2-bits or 4x4-bits in the Spectral Setup.
- 4x4-bits provide a better sensitivity at fixed spectral resolution and integration time.
- This mode is only allowed for the 5 FDM setups with the 12-m and 7-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.

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1875	15.6	31.2	120	TDM	
938	0.976	1.952	1024	FDM	4x4 ⋆
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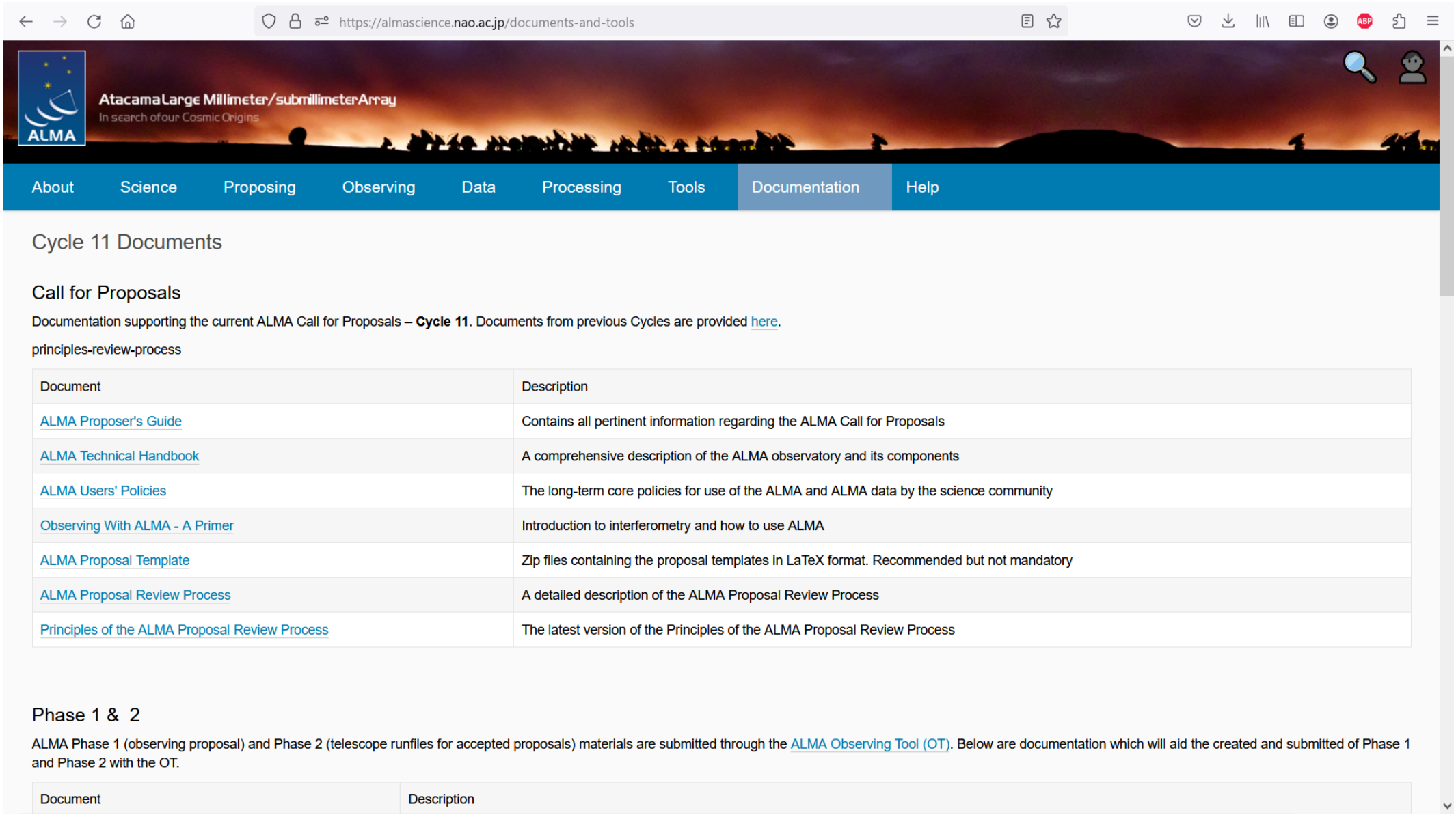


https://almascience.nao.ac.jp/documents-and-tools

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		

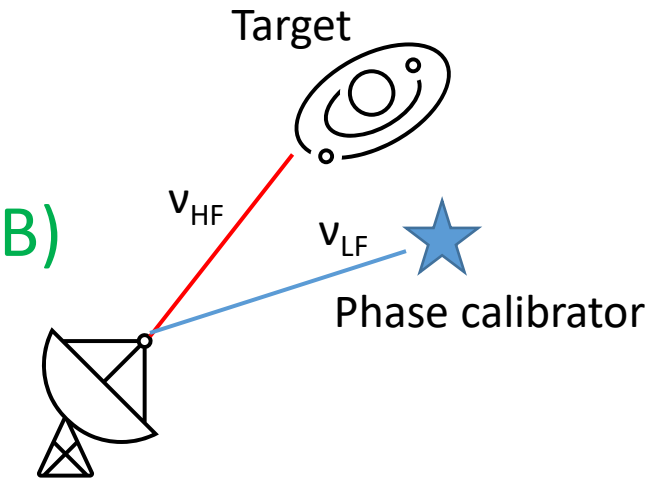
Basic Observing Modes

- **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 PB) of continuum and spectral line polarimetry are offered in Bands 1, and 3-7 for linear polarization.**
  - **Only continuum linear polarimetry for mosaicking with default continuum setup.**
  - **Only single pointing within 1/10 of PB is offered in Bands 1, and 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.**

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.
- No cap for B2B projects

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 (as of Cycle 10)

- 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

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.

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.