

# Introduction to ALMA



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Atacama Large Millimeter/submillimeter Array  
Karl G. Jansky Very Large Array  
Very Long Baseline Array



# THE ELECTROMAGNETIC SPECTRUM

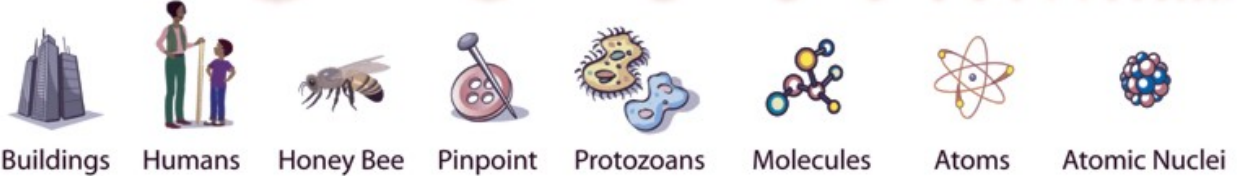
Penetrates Earth Atmosphere?



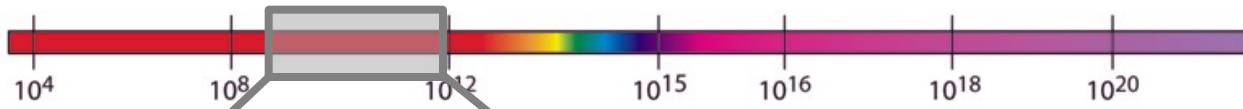
Wavelength (meters)



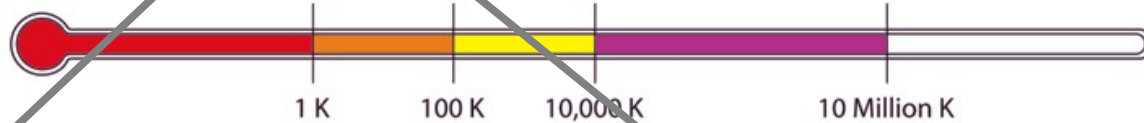
About the size of...



Frequency (Hz)



Temperature of bodies emitting the wavelength (K)



# What is ALMA?

- Global partnership to provide unprecedented imaging & spectroscopic capabilities at mm/submm wavelengths



- ALMA is an array of 66 reconfigurable, high-precision antennas



# ALMA is a Telescope for *all* Astronomers

- ALMA is an open skies telescope – anyone can propose for time!
- Support includes easy to use website + documentation + pipeline data products + proposal and data reduction workshops
- You don't have to be a radio/mm astronomer to use ALMA data!



Atacama Large Millimeter/submillimeter Array  
In search of our Cosmic Origins



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Search Site



## Documentation

### Call for Proposals

Documentation supporting the current ALMA Call for Proposals – **Cycle 6**. Documents from previous Cycles are provided [here](#).

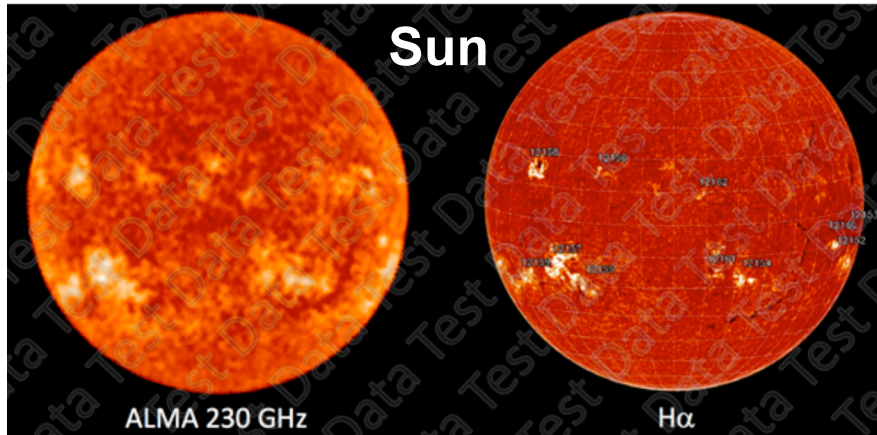
| Document                       | Description  |
|--------------------------------|--|
| ALMA Proposer's Guide          | Contains all pertinent information regarding the ALMA Call for Proposals               |
| ALMA Technical Handbook        | A comprehensive description of the ALMA observatory and its components                 |
| ALMA Users' Policies           | The long-term core policies for use of the ALMA and ALMA data by the science community |
| Observing With ALMA - A Primer | Introduction to interferometry and how to use ALMA                                     |
| ALMA Proposal Template         | LaTeX format. Recommended but not mandatory  |
| ALMA Proposal Review Process   | The latest version of the ALMA Principles of the ALMA Proposal Review Process          |

### Contents

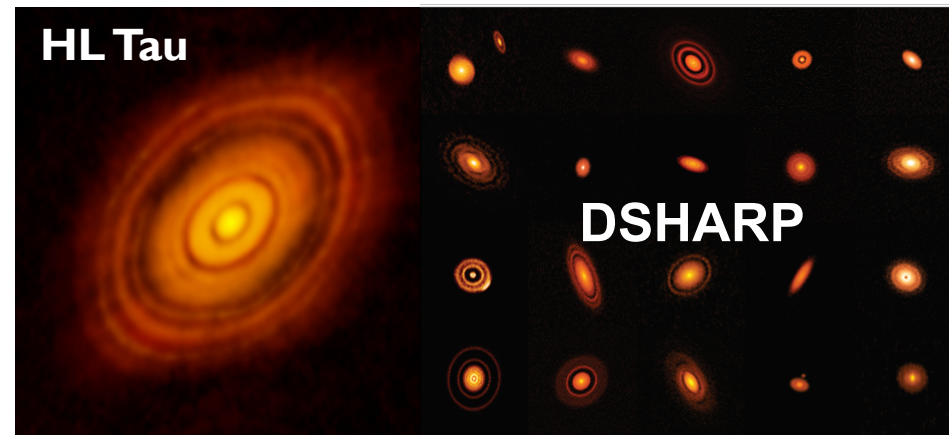
1. [Call for Proposals](#)
2. [Phase 1 & 2](#)
3. [Guides to the ALMA Regional Centers](#)
4. [ALMA Science Data Tracking, Data Processing and Pipeline, Archive and QA2 Data Products](#)
5. [ALMA Reports, Memos and Newsletters](#)

# Science with ALMA:

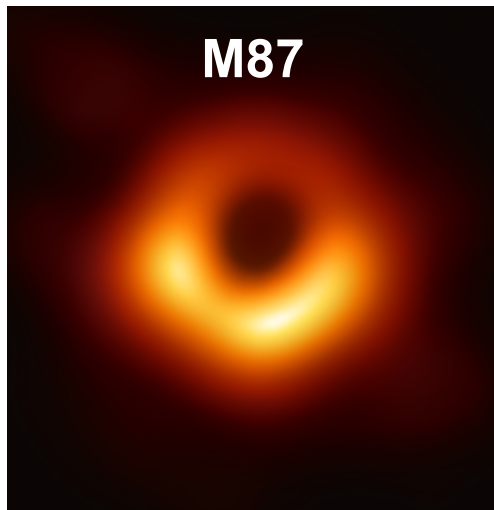
From the solar system to the high-redshift universe



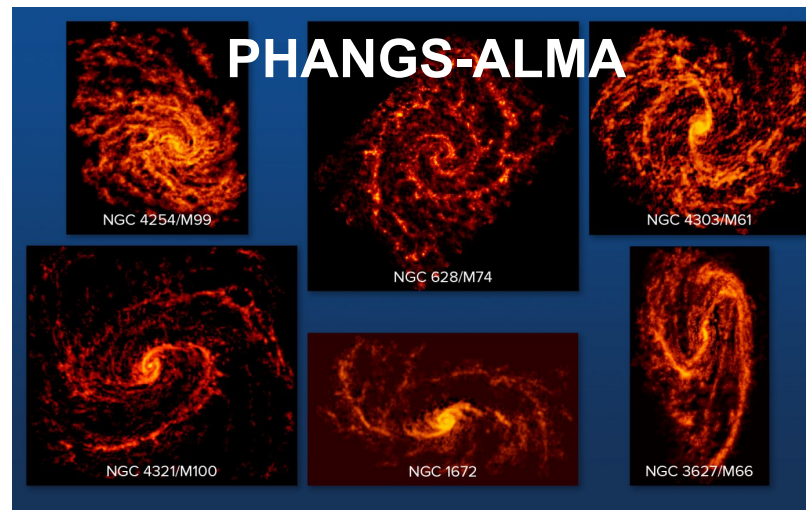
Wedemeyer et al. 2016



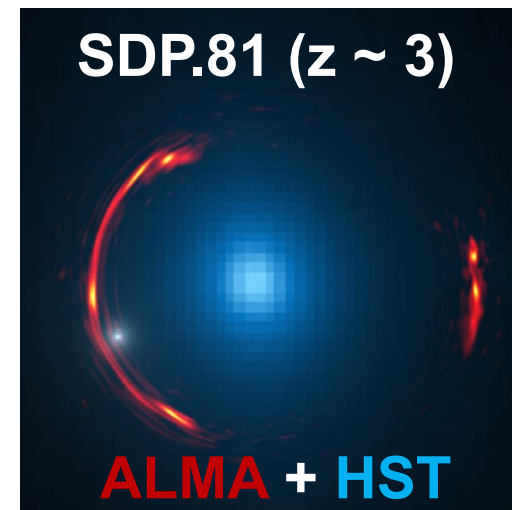
ALMA Partnership 2015; Andrews et al. 2018



EHT Collaboration 2019

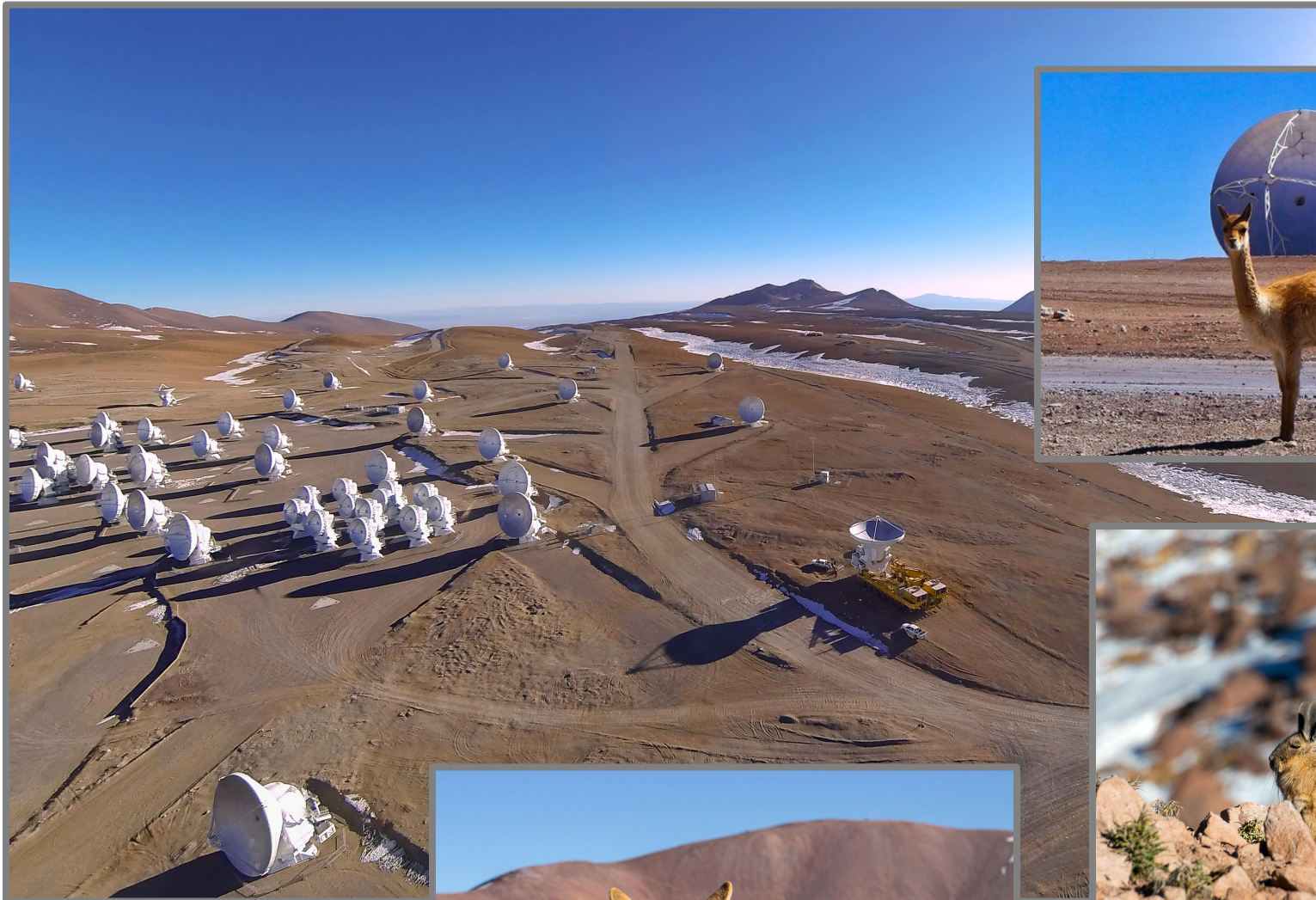


Leroy et al. (in prep)



ALMA Partnership 2015; Hezaveh et al. 2016

# The ALMA Site

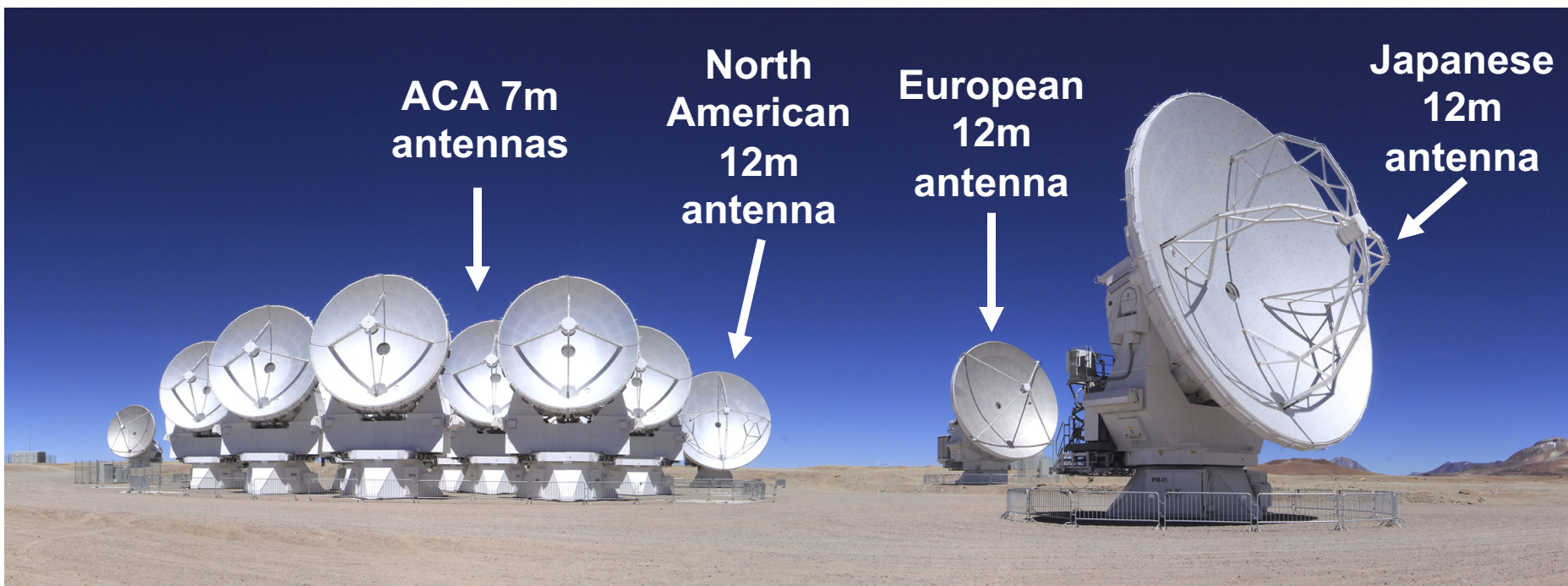


# ALMA Basics: Antennas

- **Main 12m Array:** 50 x 12m antennas
- **Atacama Compact Array (ACA):** 12 x 7m antennas
- **Total Power (TP):** 4 x 12m antennas
- **TP + ACA (Morita Array)**

**Complementary!** →

*Sensitive to emission on  
different spatial scales*



# ALMA Basics: Receiver Bands

| Cycle 7 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. $\Delta T_{\text{line}}$ (K) | Angular Resolution (mas) | Approx. Max. Scale (") (see P.24) | Spectral Sens. $\Delta T_{\text{line}}$ (K) |
| 3                      | 84-116          | 3.6-2.6         | 73-53                 | 0.088                            | 4.0-2.9                | 34-25                             | 0.16  | 50-36                    | 0.59-0.43                         | 1075  |
| 4                      | 125-163         | 2.4-1.8         | 49-38                 | 0.12                             | 2.7-2.1                | 23-18                             | 0.18  | 34-26                    | 0.40-0.30                         | 1104  |
| 5                      | 158-211         | 1.9-1.4         | 37-29                 | 0.12                             | 2.1-1.6                | 18-13.5                           | 0.15  | 26-20                    | 0.30-0.24                         | 962   |
| 6                      | 211-275         | 1.4-1.1         | 29-22                 | 0.12                             | 1.6-1.2                | 14-10                             | 0.14  | 20-15                    | 0.24-0.18                         | 947   |
| 7                      | 275-373         | 1.1-0.8         | 22-16                 | 0.22                             | 1.23-0.91              | 10.4-7.6                          | 0.2   | 15-11                    | 0.18-0.13                         | 1307  |
| 8                      | 385-500         | 0.78-0.6        | 16-12                 | 0.42                             | 0.88-0.68              | 7.4-5.7                           | 0.35  | 55-42                    | 0.67-0.52                         | 91  |
| 9                      | 602-720         | 0.5-0.42        | 10-8.5                | 2.0                              | 0.56-0.47              | 4.7-4.0                           | 1.2   | 35-29                    | 0.43-0.36                         | 312   |
| 10                     | 787-950         | 0.38-0.32       | 7.8-6.5               | 4.6                              | 0.43-0.36              | 3.6-3.0                           | 2.5   | 27-22                    | 0.33-0.27                         | 662   |

See the ALMA Cycle 7 Primer at:

<https://almascience.nrao.edu/documents-and-tools>



# ALMA Basics: Configurations



| Start date | Configuration                      | Longest baseline | LST: Best conditions |
|------------|------------------------------------|------------------|----------------------|
| 1-Oct-19   | C-4                                | 0.78 km          | 22-10                |
| 20-Oct-19  | C-3                                | 0.50 km          | 23-11                |
| 10-Nov-19  | C-2                                | 0.31 km          | 1-13                 |
| 30-Nov-19  | C-1                                | 0.16 km          | 2-14                 |
| 20-Dec-19  | C-2                                | 0.31 km          | 4-15                 |
| 10-Jan-20  | C-3                                | 0.50 km          | 5-17                 |
| 1-Feb-20   | No observations due to maintenance |                  |                      |
| 1-Mar-20   | C-4                                | 0.78 km          | 8-21                 |
| 20-Mar-20  | C-5                                | 1.4 km           | 9-23                 |
| 20-Apr-20  | C-6                                | 2.5 km           | 11-1                 |
| 20-May-20  | C-7                                | 3.6 km           | 13-3                 |
| 20-Jun-20  | C-8                                | 8.5 km           | 15-5                 |
| 11-Jul-20  | C-9                                | 13.9 km          | 16-6                 |
| 30-Jul-20  | C-10                               | 16.2 km          | 17-7                 |
| 20-Aug-20  | C-9                                | 13.9 km          | 19-8                 |
| 10-Sep-20  | C-8                                | 8.5 km           | 20-9                 |



**10 configs with baselines between 150 m and 16.2 km; 192 possible antenna locations**

# ALMA Basics: Resolution

| Config    | Lmax    |     | Band 3  | Band 4  | Band 5  | Band 6  | Band 7  | Band 8  | Band 9  | Band 10 |
|-----------|---------|-----|---------|---------|---------|---------|---------|---------|---------|---------|
|           | Lmin    |     | 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 | 28.5"   | 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"   | 0.16"   | 0.13"   | 0.089"  | 0.067"  | 0.047"  | 0.035"  |
|           | 15 m    | MRS | 4.1"    | 2.7"    | 2.2"    | 1.8"    | 1.2"    | 0.89"   | 0.63"   | 0.47"   |
| C43-7     | 3.6 km  | AR  | 0.21"   | 0.14"   | 0.11"   | 0.092"  | 0.061"  | 0.046"  | 0.033"  | 0.024"  |
|           | 64 m    | MRS | 2.6"    | 1.7"    | 1.4"    | 1.1"    | 0.75"   | 0.56"   | 0.40"   | 0.30"   |
| C43-8     | 8.5 km  | AR  | 0.096"  | 0.064"  | 0.052"  | 0.042"  | 0.028"  | N/A     | N/A     | N/A     |
|           | 110 m   | MRS | 1.4"    | 0.95"   | 0.77"   | 0.62"   | 0.41"   |         |         |         |
| C43-9     | 13.9 km | AR  | 0.057"  | 0.038"  | 0.031"  | 0.025"  | 0.017"  | N/A     | N/A     | N/A     |
|           | 368 m   | MRS | 0.81"   | 0.54"   | 0.44"   | 0.35"   | 0.24"   |         |         |         |
| C43-10    | 16.2 km | AR  | 0.042"  | 0.028"  | 0.023"  | 0.018"  | 0.012"  | N/A     | N/A     | N/A     |
|           | 244 m   | MRS | 0.50"   | 0.33"   | 0.27"   | 0.22"   | 0.14"   |         |         |         |

Configuration details from Table A-1 of the ALMA Cycle 7 Proposer's Guide

# ALMA in a Nutshell

- **Angular resolution** down to 0.015" (at 300 GHz)
- **Frequency range** of 84-950 GHz (3 mm-320  $\mu\text{m}$ )
- **Wide-band receivers\*** (8 GHz bandwidth)
- **Flexible correlator** capable of tunings with wide bandwidths + high spectral resolution
- **Full polarization** capabilities (linear + circular).
- **Pipeline** processing + extensive **observer support**

**ALMA is 10-100X more sensitive and has 10-100X better angular resolution compared to previous mm arrays**



\*16 GHz instantaneous bandwidth for 90 degree Walsh Switching in Bands 9 and 10 (TDM mode only)

# ALMA Status: Steady State Operations

- Construction Project ended in September 2014
- Science observing with **>16 km baselines (C43-10)** commissioned in 2014/2015
- **All 66 antennas operational**
  - Minimum of 43 x 12m-array antennas for Cycle 7 obs
- Commissioning still in progress for some modes (e.g., widefield polarimetry)



# New Cycle 7 ALMA Capabilities

- Spectral scans are 25% more efficient and are now offered as standard modes!
- Data rate limitations significantly relaxed – long baseline + high spectral resolution modes possible (less high-data-rate warnings in OT)
- Band 7 at longest baselines\* (16.2 km)
- Solar observations in Band 7 in compact configs
- Improved sensitivity for full spectral resolution linear polarization (on-axis only)

**Non-  
standard  
modes**

**\*Non-standard mode if no suitable calibrator found within 5 deg**

# Full ALMA Capabilities (Cycle 7 Plus:)

## Receiver bands:

- Inclusion of Bands 1 (35-50 GHz) and 2 (65-90 GHz)

## Baselines:

- Observations in all bands out to 16 km

## Non-Standard modes:

- Decrease in fraction of non-standard modes to ~10%

## Observing Time:

- Up to 4500 hrs for successful PI programs on the 12m array

## Observing Modes:

- Widefield (including mosaics) polarimetry (12m + 7m arrays)



# Key Observing Considerations

**Source location** - coordinates, velocities, redshift, proper motions, ephemerides

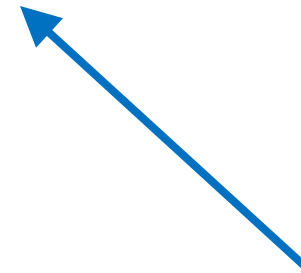
**Spatial scales of interest** - angular resolution and largest angular scale

**Correlator set-up** - frequency, bandwidth, and spectral resolution

**Mapping area** - if  $>1/3$  the size of the primary beam, mosaicking may be necessary

**Sensitivity** – consider impact of source extent, expected line widths, etc.

**Calibration and overheads** – overheads may be high – check ALMA OT early



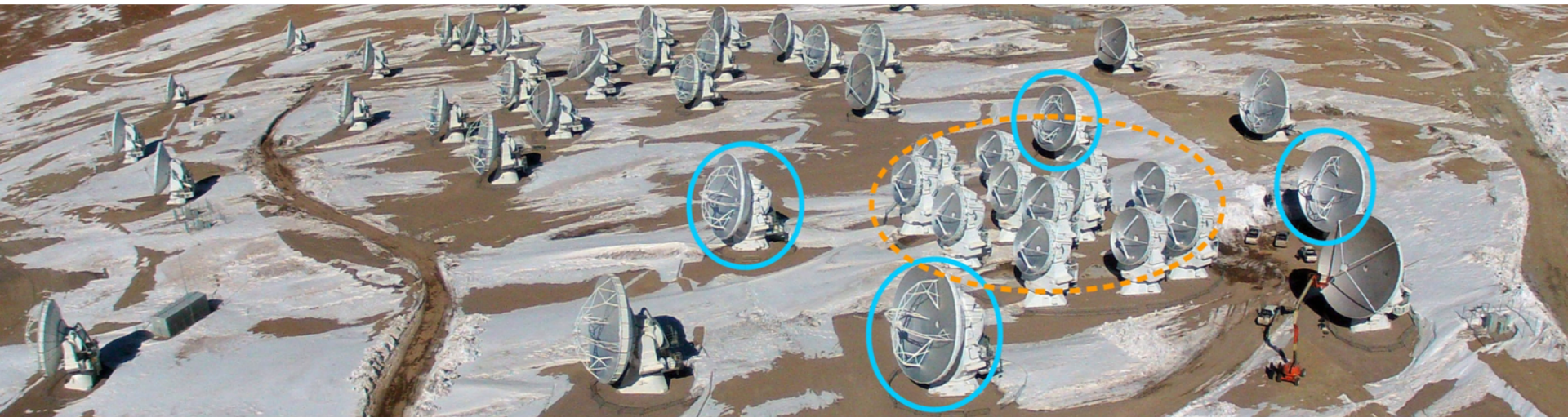
**Dec. limit for ALMA is +47° (20° max elevation)**

**Consider impact of shadowing in compact configs for declinations  $<-65^\circ$  or  $>+20^\circ$**

# Cycle 7 Supplemental Call for the ACA

- 750 hrs of ACA (7m array or 7m + TP) observing time
- Observations between January 2020 and September 2020
- Proposal deadline is October 1, 2019
- Standard observing modes only
- Proposals submitted to the supplemental call will be peer reviewed through a distributed system

<https://almascience.nrao.edu/proposing/7m-array-supplemental-call>





# Cycle 7 Supplemental Timeline

| <b>Date</b>            | <b>Milestone</b>   |
|------------------------|--|
| 03 September 2019      | Call for Proposals and Supplemental Call submission server opened                    |
| <b>01 October 2019</b> | <b>Deadline to submit Supplemental Call proposals</b>                                |
| 15 October 2019        | Proposals released to reviewers  |
| 22 October 2019        | Deadline for reviewer to report conflicts of interest on proposal review assignments |
| 12 November 2019       | Deadline to submit reviews and ranks   |
| Early December 2020    | Notification emails sent to PIs  |
| January 2020           | Successful Supplemental Call proposals enter the observing queue                     |

**750 hrs of additional ACA time (standard modes)**

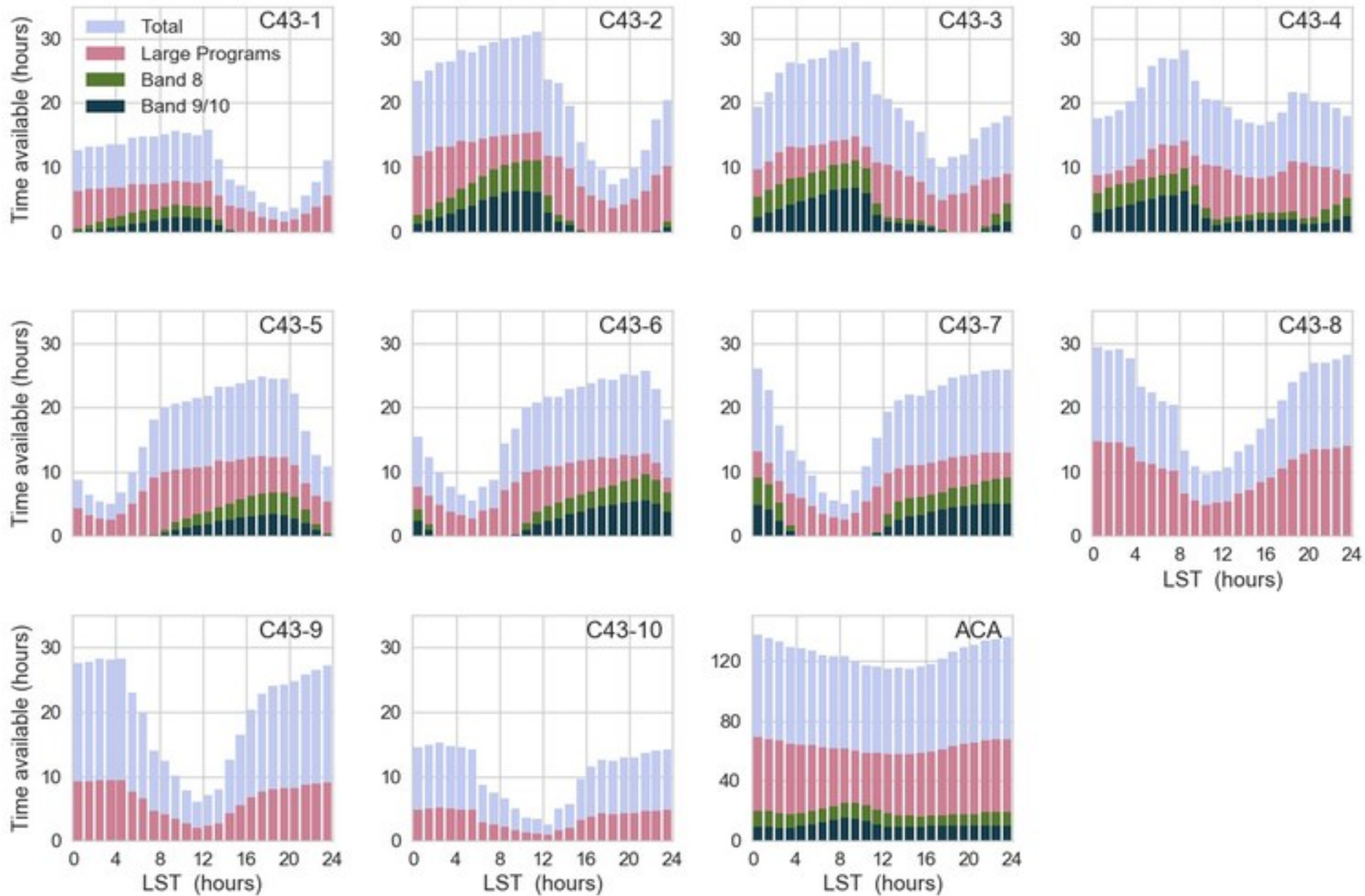
# NAASC Sources of Support

- **ALMA Helpdesk:** User support is a priority so questions are usually answered within 48 hours (with around the clock staffing in the week leading up to the proposal deadline) - <https://help.almascience.org>
- **Student Observing Support:** Successful ALMA proposals will be invited to apply for up to \$35k to support undergraduate or graduate student involvement - <https://science.nrao.edu/opportunities/student-programs/sos>
- **Page Charges:** Upon request NRAO covers page charges for authors at US institutions when reporting results from ALMA/VLA - <https://library.nrao.edu/pubsup.shtml>
- **Face-to-face Visitor Support:** NRAO will cover the travel expenses of up to 2 people from 2 teams per week to come to the NAASC to get support for data reduction, proposal preparation, etc... We also have long term visitor support as well - <https://science.nrao.edu/facilities/alma/visitors-shortterm>

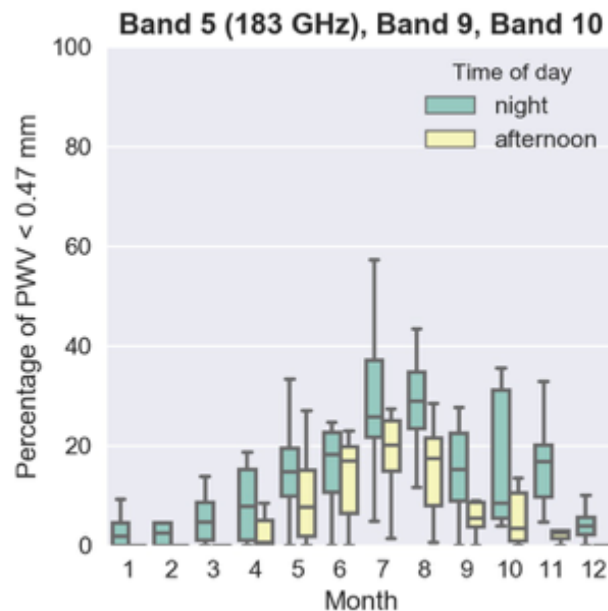
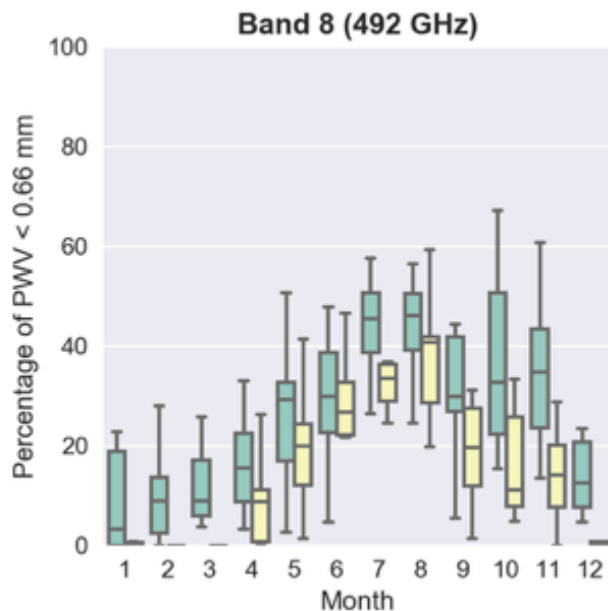
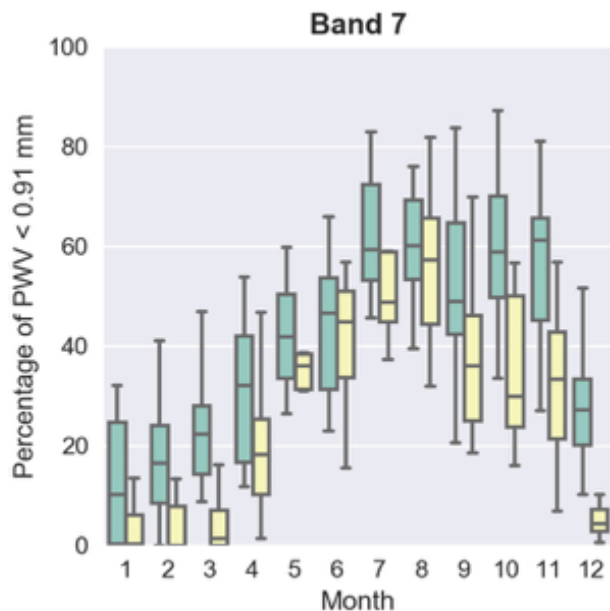
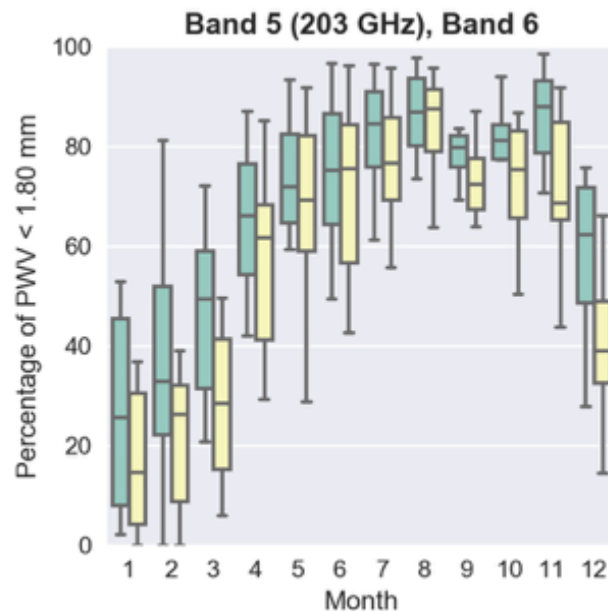
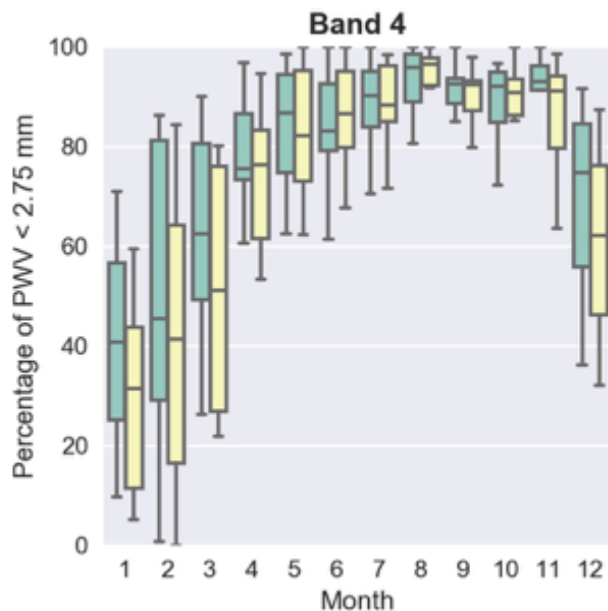
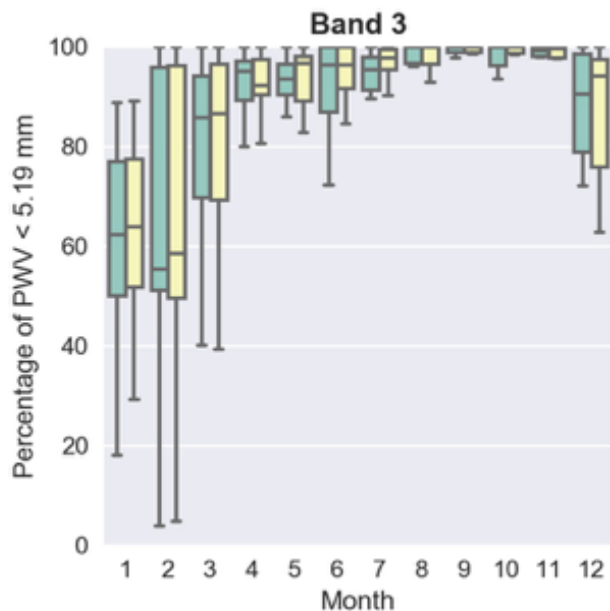


[www.nrao.edu](http://www.nrao.edu)  
[science.nrao.edu](http://science.nrao.edu)

# ALMA Observing Time by LST



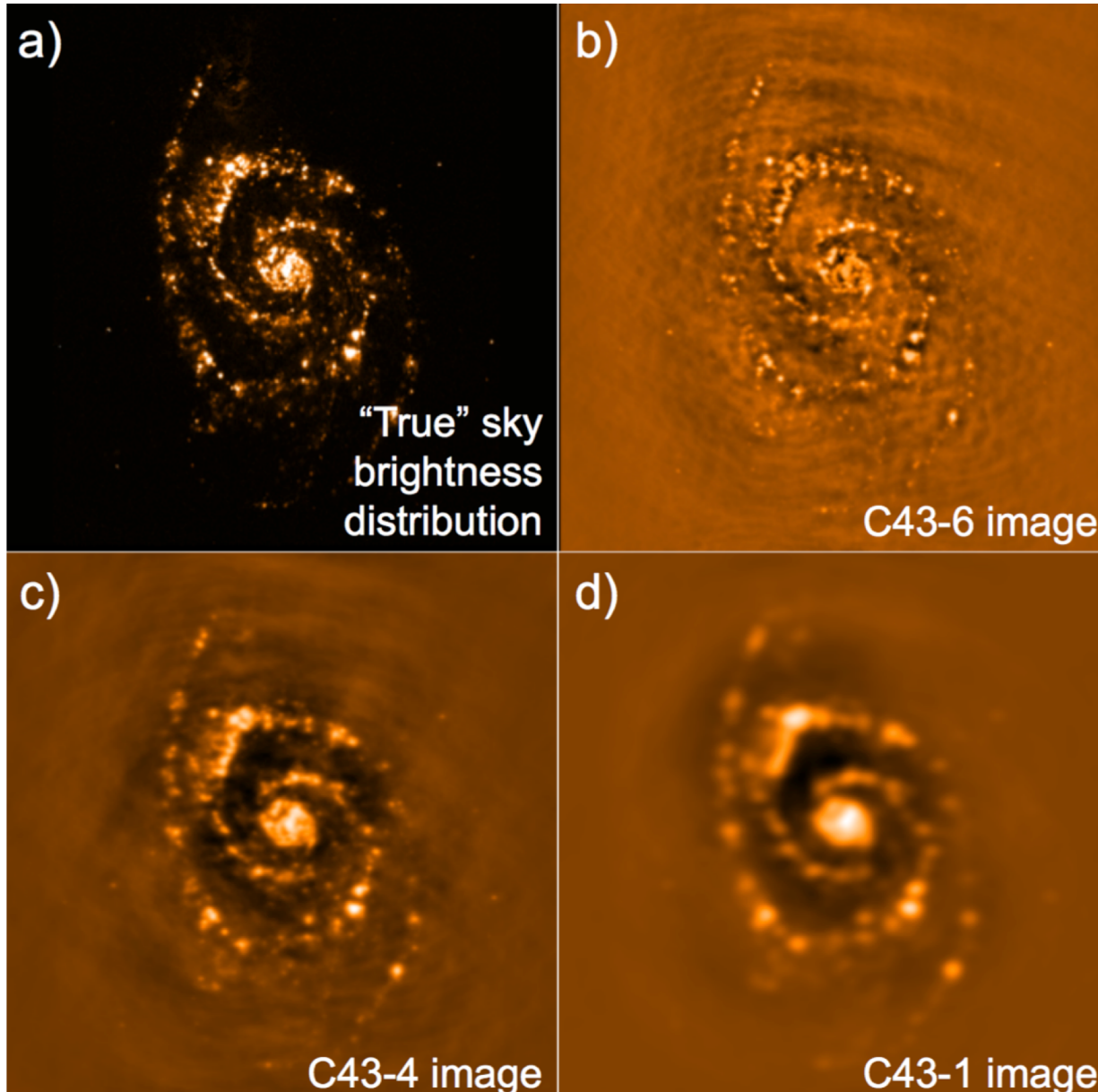
# ALMA Weather Constraints



# Configurations

|               | Band                    | 3     | 4     | 5      | 6      | 7      | 8      | 9      | 10     |
|---------------|-------------------------|-------|-------|--------|--------|--------|--------|--------|--------|
|               | Frequency (GHz)         | 100   | 150   | 185    | 230    | 345    | 460    | 650    | 870    |
| Configuration |                         |       |       |        |        |        |        |        |        |
| 7-m           | $\theta_{res}$ (arcsec) | 12.5  | 8.35  | 6.77   | 5.45   | 3.63   | 2.72   | 1.93   | 1.44   |
|               | $\theta_{MRS}$ (arcsec) | 66.7  | 44.5  | 36.1   | 29.0   | 19.3   | 14.5   | 10.3   | 7.67   |
| C43-1         | $\theta_{res}$ (arcsec) | 3.38  | 2.25  | 1.83   | 1.47   | 0.98   | 0.735  | 0.52   | 0.389  |
|               | $\theta_{MRS}$ (arcsec) | 28.5  | 19.0  | 15.4   | 12.4   | 8.25   | 6.19   | 4.38   | 3.27   |
| C43-2         | $\theta_{res}$ (arcsec) | 2.3   | 1.53  | 1.24   | 0.999  | 0.666  | 0.499  | 0.353  | 0.264  |
|               | $\theta_{MRS}$ (arcsec) | 22.6  | 15.0  | 12.2   | 9.81   | 6.54   | 4.9    | 3.47   | 2.59   |
| C43-3         | $\theta_{res}$ (arcsec) | 1.42  | 0.943 | 0.765  | 0.615  | 0.41   | 0.308  | 0.218  | 0.163  |
|               | $\theta_{MRS}$ (arcsec) | 16.2  | 10.8  | 8.73   | 7.02   | 4.68   | 3.51   | 2.48   | 1.86   |
| C43-4         | $\theta_{res}$ (arcsec) | 0.918 | 0.612 | 0.496  | 0.399  | 0.266  | 0.2    | 0.141  | 0.106  |
|               | $\theta_{MRS}$ (arcsec) | 11.2  | 7.5   | 6.08   | 4.89   | 3.26   | 2.44   | 1.73   | 1.29   |
| C43-5         | $\theta_{res}$ (arcsec) | 0.545 | 0.363 | 0.295  | 0.237  | 0.158  | 0.118  | 0.0838 | 0.0626 |
|               | $\theta_{MRS}$ (arcsec) | 6.7   | 4.47  | 3.62   | 2.91   | 1.94   | 1.46   | 1.03   | 0.77   |
| C43-6         | $\theta_{res}$ (arcsec) | 0.306 | 0.204 | 0.165  | 0.133  | 0.0887 | 0.0665 | 0.0471 | 0.0352 |
|               | $\theta_{MRS}$ (arcsec) | 4.11  | 2.74  | 2.22   | 1.78   | 1.19   | 0.892  | 0.632  | 0.472  |
| C43-7         | $\theta_{res}$ (arcsec) | 0.211 | 0.141 | 0.114  | 0.0917 | 0.0612 | 0.0459 | 0.0325 | 0.0243 |
|               | $\theta_{MRS}$ (arcsec) | 2.58  | 1.72  | 1.4    | 1.12   | 0.749  | 0.562  | 0.398  | 0.297  |
| C43-8         | $\theta_{res}$ (arcsec) | 0.096 | 0.064 | 0.0519 | 0.0417 | 0.0278 | -      | -      | -      |
|               | $\theta_{MRS}$ (arcsec) | 1.42  | 0.947 | 0.768  | 0.618  | 0.412  | -      | -      | -      |
| C43-9         | $\theta_{res}$ (arcsec) | 0.057 | 0.038 | 0.0308 | 0.0248 | -      | -      | -      | -      |
|               | $\theta_{MRS}$ (arcsec) | 0.814 | 0.543 | 0.44   | 0.354  | -      | -      | -      | -      |
| C43-10        | $\theta_{res}$ (arcsec) | 0.042 | 0.028 | 0.0227 | 0.0183 | -      | -      | -      | -      |
|               | $\theta_{MRS}$ (arcsec) | 0.496 | 0.331 | 0.268  | 0.216  | -      | -      | -      | -      |

# Spatial Filtering



# NRAO Observatories: Comparison



**ALMA  
(Chile)**

**Atacama Large  
mm/submm Array**

**Antennas:** 66 total  
(54 x 12m + 12 x 7m)

**Freq:** 84 – 950 GHz

**Lambda:** 0.3 – 3 mm

**theta:** 0.02 – 3.5"

(10 configurations)



**VLA  
(NM, USA)**

**Karl G. Jansky  
Very Large Array**

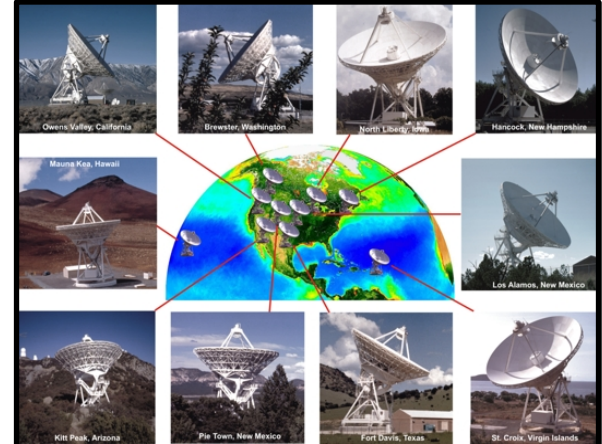
**Antennas:** 27 x 25m

**Freq:** 1 – 50 GHz  
(plus 2 bands < 1 GHz)

**Lambda:** 6 – 300 mm

**theta:** 0.05 – 45"

(A, B, C, D configs)



**VLBA  
(USA)**

**Very Long  
Baseline Array**

**Antennas:** 10 x 25m  
(now fiber connected!)

**Freq:** 0.33 – 85 GHz

**Lambda:** 0.3 – 90 cm

**theta:** 0.12 – 22 mas

( $B_{\max} = 8611$  km)



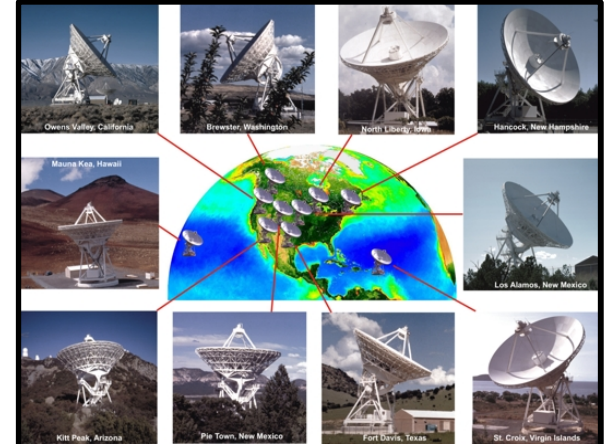
# NRAO Observatories



**ALMA**  
**(Chile)**



**VLA**  
**(NM, USA)**



**VLBA**  
**(USA)**

**One observatory, three world-class facilities**  
**([science.nrao.edu](http://science.nrao.edu))**



**Affiliated observatories**  
**include Green Bank**  
**Observatory**  
**([greenbankobservatory.org](http://greenbankobservatory.org))**



**GBT**  
**(WV, USA)**

# ALMA Antennas, Bands & Configs

## Number of antennas

- At least forty-three (43) antennas in the 12-m Array
- At least 10 7m antennas (for short baselines) and 3 12m antennas (for making single-dish maps) in the ACA

## Receiver bands

- Receiver Bands 3, 4, 5, 6, 7, 8, 9, and 10
- Wavelengths of 3.1, 2.1, 1.6, 1.3, 0.87, 0.74, 0.44, and 0.32 mm

## 12-m Array Configurations

- Max baselines between 0.15 km and 16 km
- Max baselines of 3.6 km for Bands 8, 9 and 10
- Max baselines of 16 km for Bands 3, 4, 5, 6 and 7

**See the ALMA Proposer's Guide at:**

**(<https://almascience.nrao.edu/documents-and-tools>)**

# Standard vs. non-Standard Modes

**Cycle 7 will allocate ~20% of the total time to non-standard modes (with 10% of available for testing new capabilities)**

## **Non-Standard Observing Modes include:**

- Band 7 observations with baselines  $>5$  km & phase calibrator  $>5$  degrees from the science target
- Bands 9 and 10 observations
- Bandwidth switching projects
- Solar observations
- All polarization observations
- VLBI observations
- Non-standard calibration strategy (e.g., user-defined calibrators in the OT)
- Astrometric Observations

# ALMA Polarimetry

- All polarimetric observations are non-standard in Cycle 7
- Single pointing, on axis, full (including circular) polarization for both continuum and full-spectral-resolution observations in Band 3, 4, 5, 6, and 7 are offered on the 12m Array.
- Improved sensitivity for linear polarization for full spectral resolution
- The minimum detectable degree of circular polarization, defined as three times the systematic calibration uncertainty, is currently 1.8% of the peak flux for both TDM and FDM observations.
- Circular polarization will be offered only for sources that are on-axis with an angular size less than 10% of the FWHM primary beam.