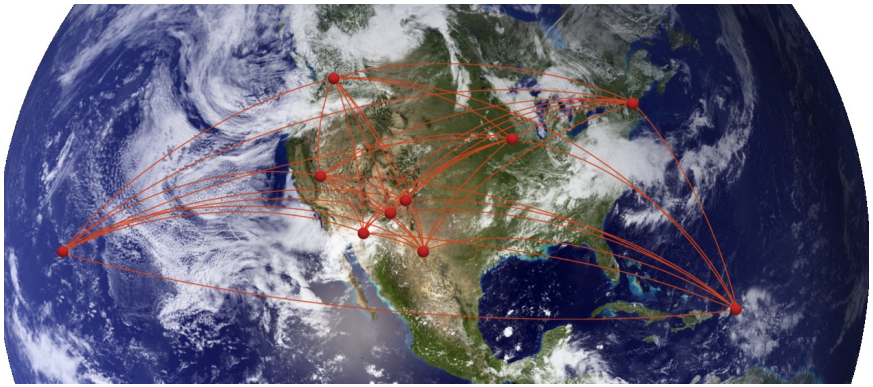
ALMA Basics & Cycle 10 Capabilities

Sarah Wood

Sep 28, 2023 – Morelia CDE

National Radio Astronomy Observatory



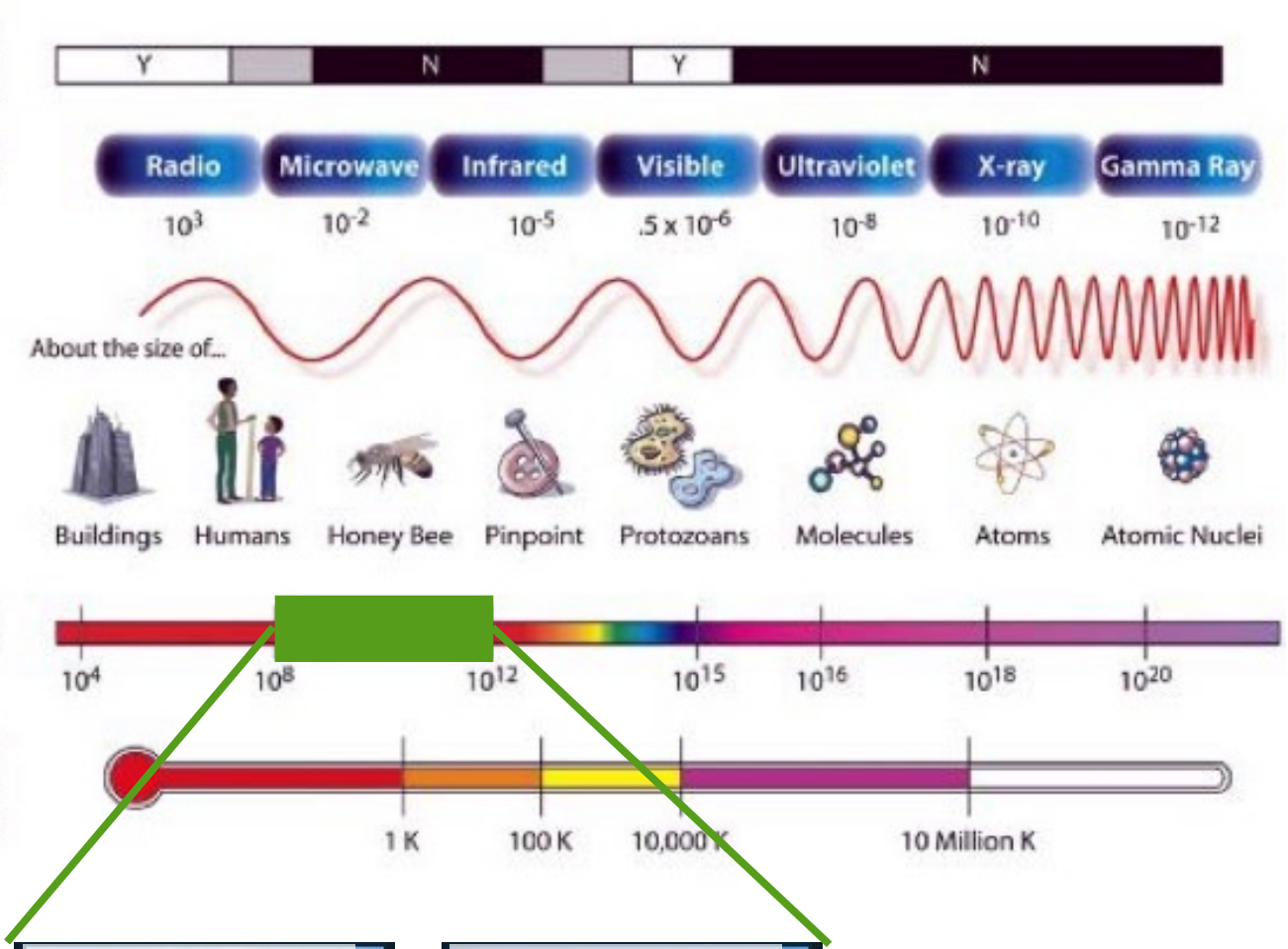
Atacama Large Millimeter/submillimeter Array
Karl G. Jansky Very Large Array
Very Long Baseline Array

NRAO:
One Observatory,
Three World Class Facilities

- Other Affiliated Telescopes and Observatories include the Green Bank Observatory (http://greenbankobservatory.org/).
- NRAO also operates the Central Development Laboratory and the Next Generation Very Large Array Project.

NRAO:
One Observatory,
Three World Class Facilities

Atacama Large Millimeter/submillimeter Array:
a 66-antenna array in Chile


Penetrates Earth Atmosphere?
Y
N
Y
N
Wavelength (meters)
Radio
Microwave
Infrared
Visible
Ultraviolet
X-ray
Gamma Ray
10^3
10^-2
10^-5
.5 x 10^-6
10^-8
10^-10
10^-12
About the size of...
Buildings
Humans
Honey Bee
Pinpoint
Protozoans
Molecules
Atoms
Atomic Nuclei
Frequency (Hz)
10^4
10^8
10^12
10^15
10^16
10^18
10^20
Temperature of bodies emitting the wavelength (K)
1 K
100 K
10,000 K
10 Million K


VLA
~1 - 50 GHz
~300 - 6 mm


ALMA
~35 - 950 GHz
~8.5 - 0.3 mm

Broad Science Topics with NRAO Telescopes

- Sun – coronal mass ejections, magnetic field activity
- Solar system, KBOs – atmospheres, astrometry, composition
- Star-forming regions – dust and gas environment, kinematics (infall, outflows, jets), proto-planetary disks, cores, chemistry, feedback, and natal cloud / star interactions
- Exoplanets – direct imaging, gaps in disks, kinematics
- Pulsars – neutron star physics, pulse morphology, gravity, ISM probe
- Galactic structure – spiral arms, bars, global atomic and molecular gas properties
- Nearby galaxies – molecular / atomic gas content and kinematics, dynamics of galaxies at high resolution, star formation, obscured SF, gas flow
- Galaxy groups and clusters – atomic and molecular gas across systems, star formation efficiency, kinematics, dynamical mass measurements
- Black holes – mass measurements, kinematics
- High redshift galaxies – extragalactic background light, source counts, star formation history and efficiency, evolution of gas content (atomic and molecular)
- Cosmology – H_0 measurement, SZE

What is ALMA?

- A global partnership to deliver a revolutionary millimeter/submillimeter telescope array (in collaboration with Chile)
  - North America
  - Europe
  - East Asia
- Array Operations Site is located at 5000m elevation in the Chilean Andes
- 66 reconfigurable, high-precision antennas
- Array configurations between 150 m and 16.2 km
- 192 possible antenna locations
- Main Array: 50 x 12-m antennas
- Atacama Compact Array (ACA) or Morita Array: 12 x 7-m antennas plus 4 x 12-m antennas for Total Power (7-m Array and TP Array)
- Receiver bands cover 35-950 GHz (since Cycle 10)
- Provides unprecedented imaging and spectroscopic capabilities at mm/submm wavelengths

What is ALMA?

- Array configurations between 160 meters and >16 kilometers
- 192 possible antenna locations

- http://youtu.be/YMISe-C8GUs

ALMA in a Nutshell

- Angular resolution down to ~0.01” (slightly less in longest configurations but not in Cycle 10)
- Sensitive, precision imaging from 35 to 950 GHz (8.5 mm to 0.32 mm). Band 1 (35-50 GHz) starting in Cycle 10.
- State-of-the-art low-noise, wide-band receivers* (7.5 GHz useable bandwidth)
- Flexible correlator with high spectral resolution at wide bandwidth
- Full polarization capabilities including circular.
- Estimated 1 TB/day data rate
- All science data archived
- Pipeline processing

ALMA is 10-30+ times more sensitive and has 10-30 times better angular resolution than other current mm interferometers

In either case, this is using the Time Division Mode (TDM) modes.

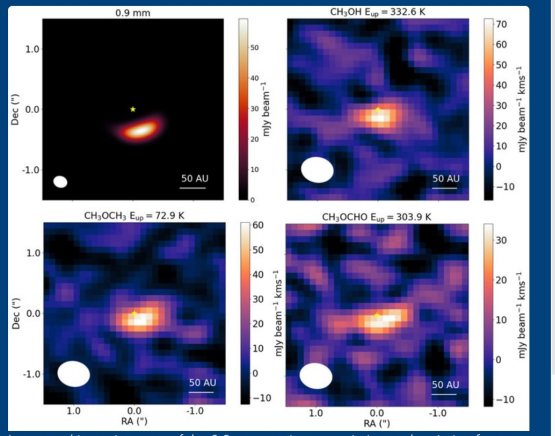
ALMA Science Portal: https://almascience.nrao.edu/ - documentation, info, news and more!

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

About | Science | Proposing | Observing | Data | Processing | Tools | Documentation | Help

Science Highlight

Complex Organic Molecules in a Planet-Forming Disk



Integrated intensity maps of the 0.9 mm continuum emission and emission from several COMs.

Brunken et al. (2022, A&A 659, A29) have detected Complex Organic Molecules (COMs) in the highly asymmetric planet-forming disk around the young star IRS48. The disk around this star has a very pronounced 'dust and ice trap' where material accumulates, and future planet(esimals) may form. Brunken et al. report the first detection of dimethyl ether (CH3OCH3) vapor in a planet-forming disk, and a tentative detection of methyl formate (CH3OCHO) vapor. The presence of these molecules shows that a wide variety of oxygen-carrying COMs are present in the birth environment of planets. As this study illustrates, wherever ALMA turns its 'eye', atoms and molecules leap out at...

More...

Observatory News

ALMA Cycle 10 Pre-Announcement
Jan 18, 2023

ALMA Cycle 9 Proposal Review: Detailed Report
Jan 12, 2023

ALMA announces Joint Proposal agreements for JWST, VLA, and the VLT
Dec 20, 2022

Restart of ALMA Cycle 9 observations and Cycle 10 pre-announcement status
Dec 19, 2022

Update on the configuration schedule for Cycle 9

More...

NRAO Events

Jansky Lecture: Prof. Francoise Combes
Feb 15, 2023

38th New Mexico Symposium
Feb 17, 2023

Jansky Lecture: Prof. Francoise Combes
Feb 17, 2023

New Eyes on the Universe: SKA & ngVLA Conference
May 01, 2023

2023 Gordon Research Conference on Origins of Solar Systems: Chemical and Dynamical Constraints on Planet Formation
Jun 10, 2023

More...

ALMA Status

Configuration Schedule

Refereed publications: 3153
Last observed source: BHR71_IRS2
Current configuration: C-4

More...

The ALMA Science Portal is a one-stop source for information and tools aimed at the scientific community as a whole, including proposers, archive researchers, ALMA staff, journalists, and funding agencies.

Quick Links

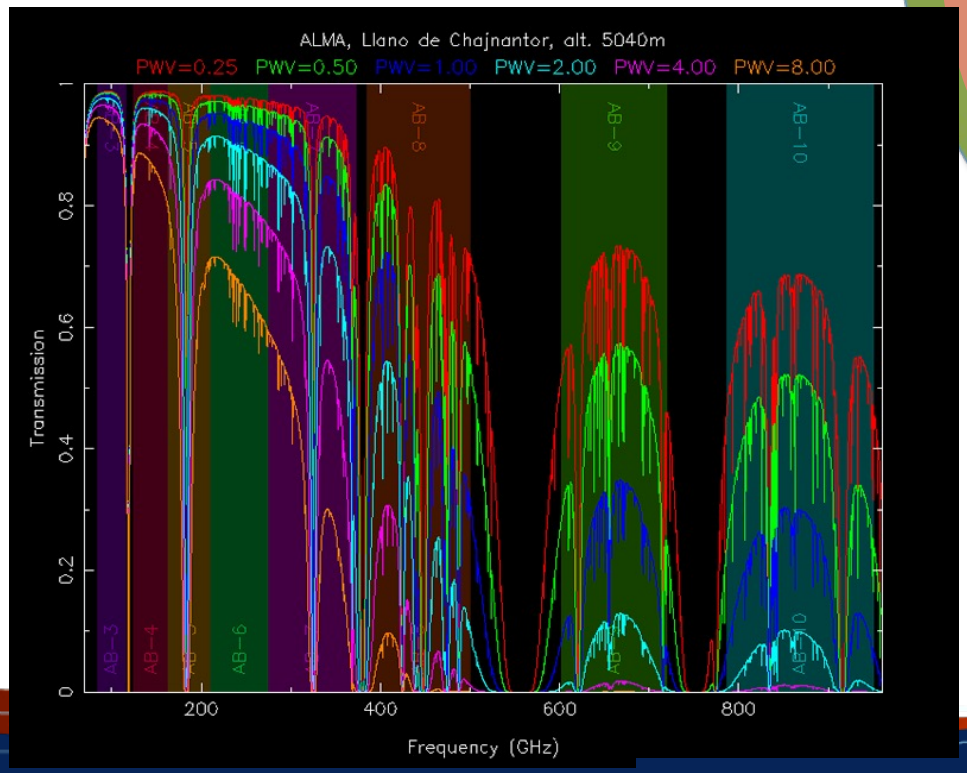
ALMA Basics	ALMA Archive
ALMA Science	SnooPI
ALMA Primer	Configuration Schedule

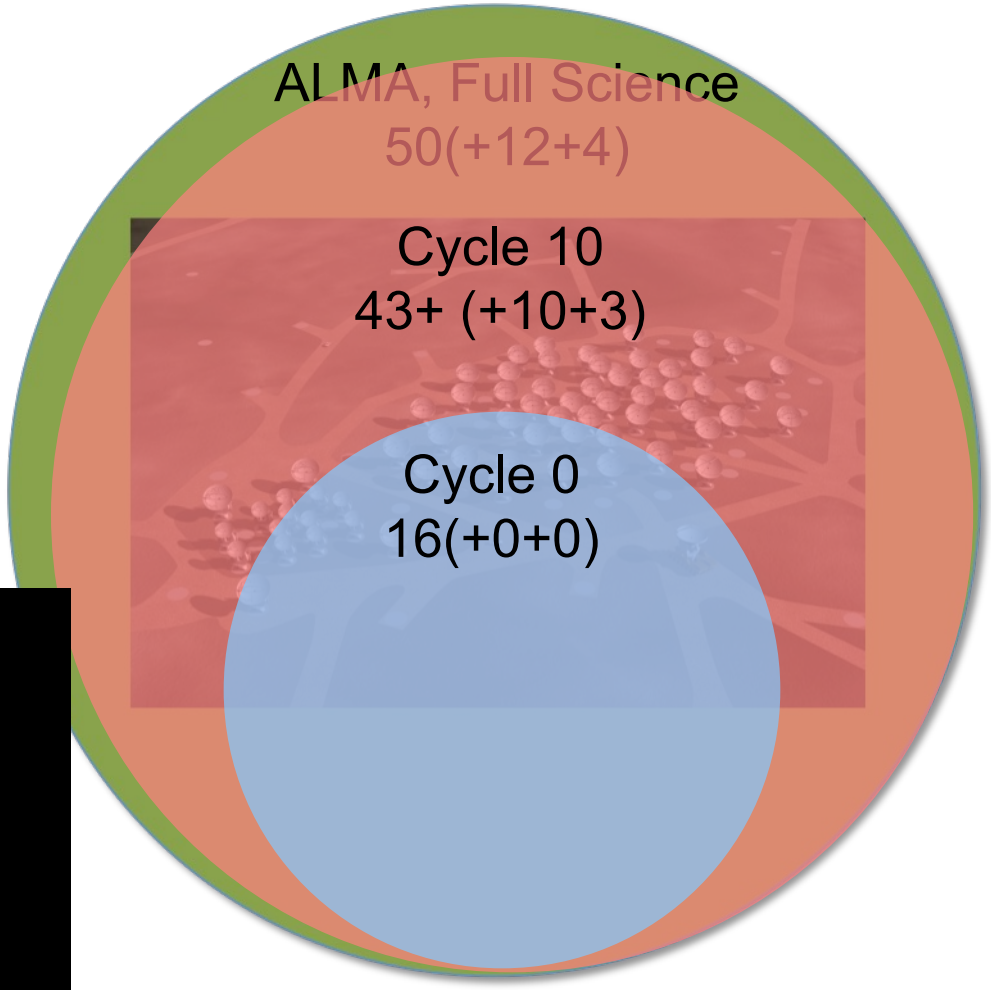
ALMA is a telescope for *all* astronomers

What is ALMA?

Collecting Area

Not only sensitivity but the collecting area (1.6 acres or 6600+ m2) + huge number of baselines provides excellent image fidelity





Spectral Coverage

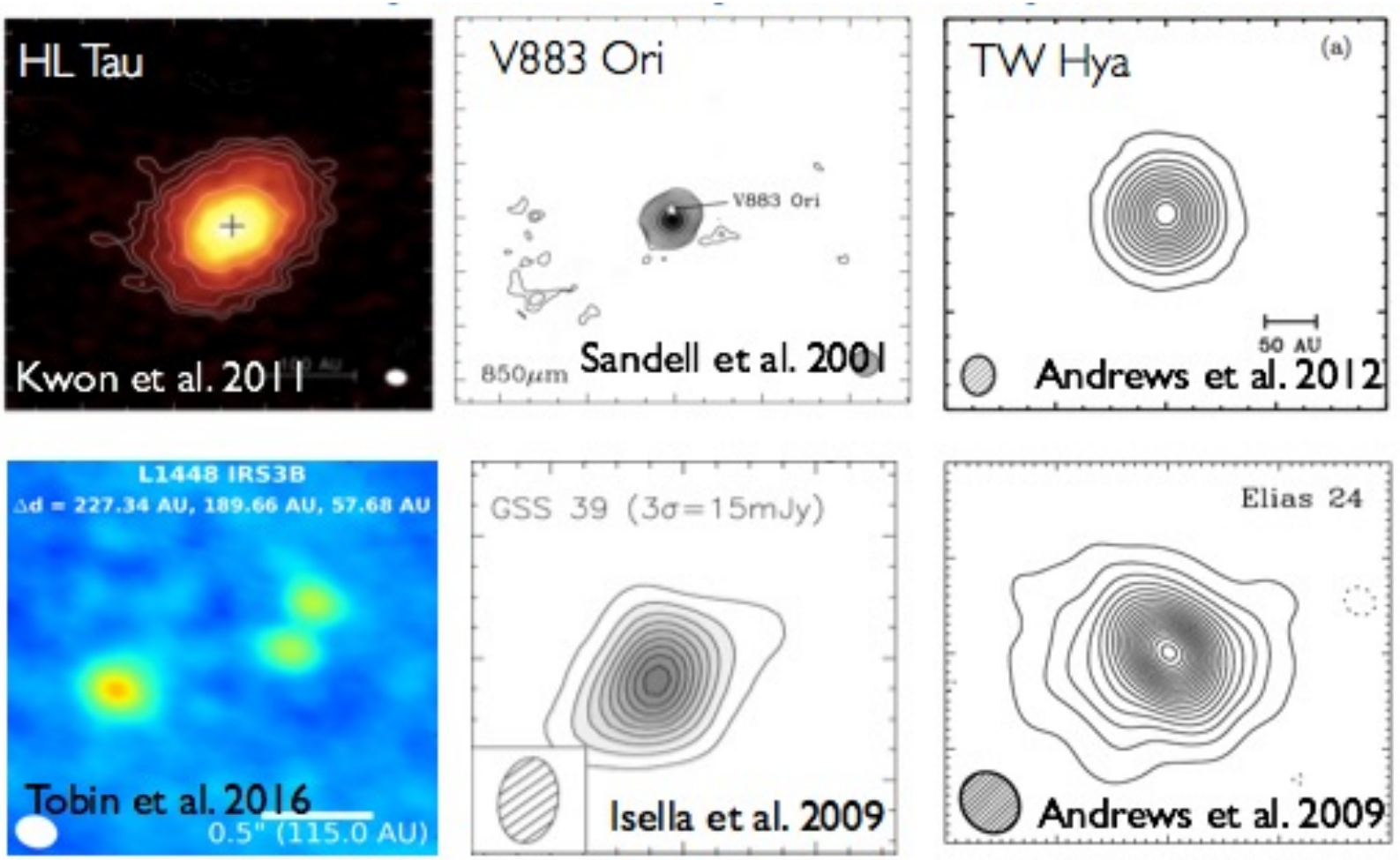
Covers ten atmospheric windows with 50% or more transmission above 35 GHz

ALMA Current Status

- Construction Project ended in September 2014
- Routine science observing has been out to **greater than 16 km baselines (C-10)** thanks to the highly successful Long Baseline Campaigns in 2014 and 2015
- **66 antennas: 54 12-m antennas (incl. 4 for TP) + 12 7-m antennas**
  - Nominally, minimum of 43 antennas and potentially up to maximum of 50 (usually up to 46 or 47) antennas are used for PI science observations on the 12-m Array
  - Nominally, minimum 10 antennas and up to a maximum of 12 antennas are used for the 7-m Array
  - Antennas not used for PI science are usually undergoing maintenance
- 9 out of the 10 bands are now offered as of Cycle 10 (only Band 2 remaining to come in future)
- More on Capabilities later… however, first on to science!

ALMA Science Highlights: Protoplanetary Disks

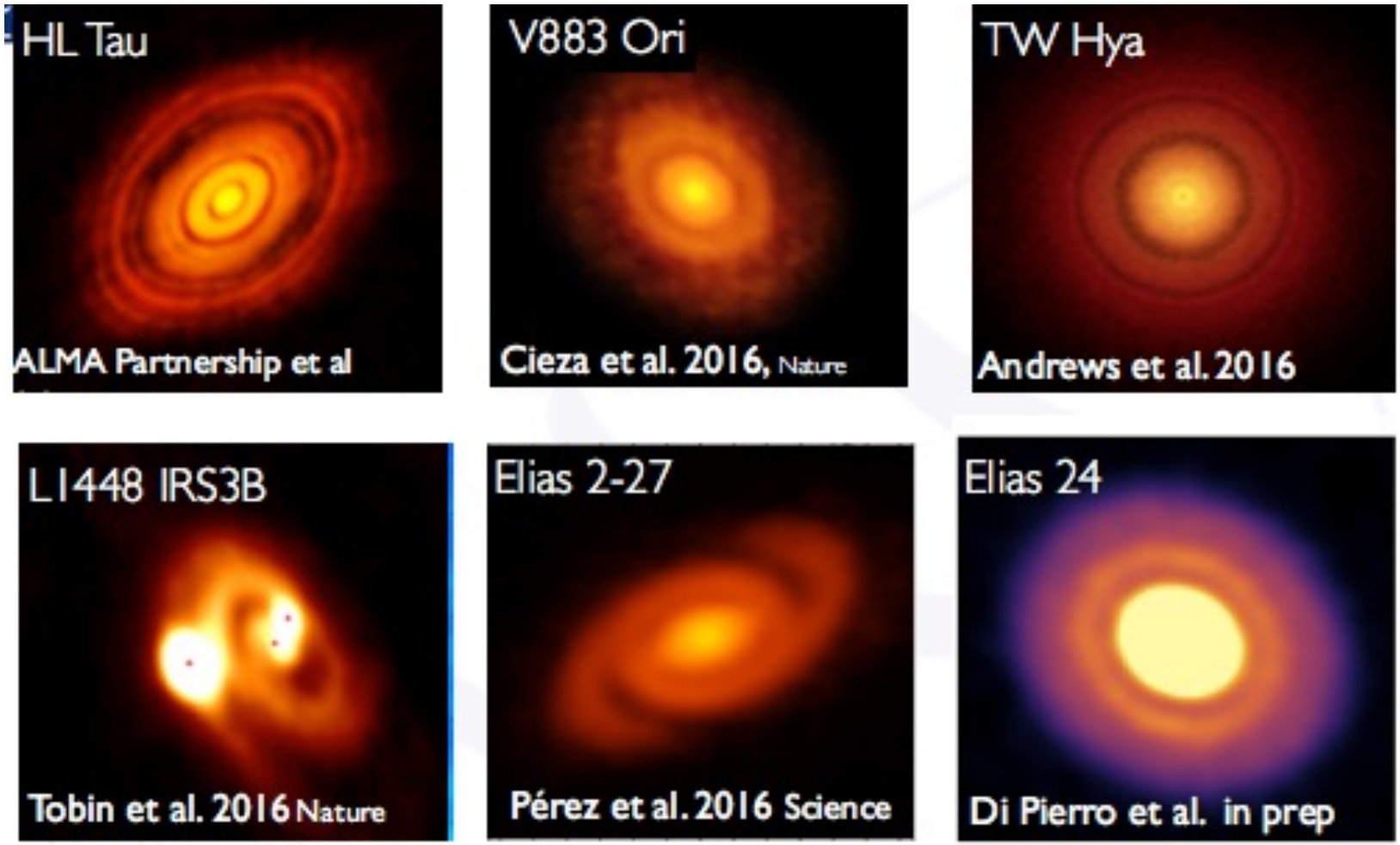
Protoplanetary Disks: Pre- ALMA



Composite image courtesy J. Carpenter / A. Wootten (ALMA / NRAO)

ALMA Science Highlights: Protoplanetary Disks

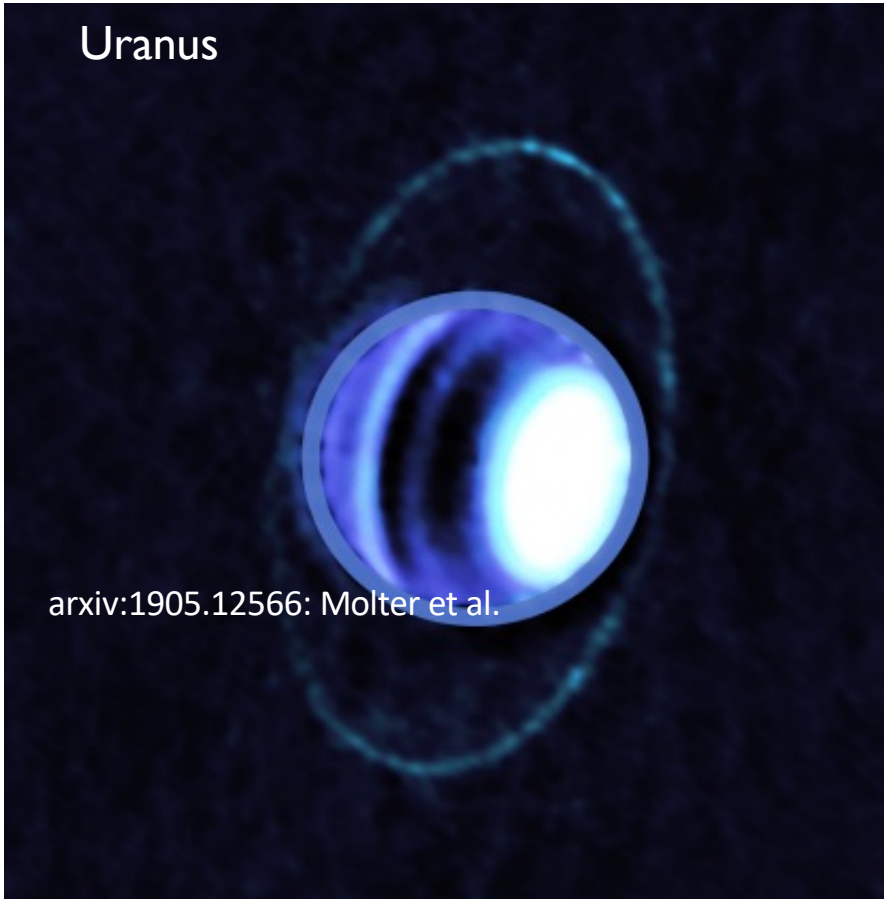
Protoplanetary Disks: With ALMA



Composite image courtesy J. Carpenter / A. Wootten (ALMA / NRAO)

Extraordinary ALMA Images of Our Own Backyard

- Thermal emission from the Uranus **ε** ring shows micron-sized dust is not present in the ring system.
- Confirms the hypothesis, proposed based on radio occultation results (Gresh et al. 1989), that the main rings are composed of centimeter-sized or larger particles
- Temperature of rings: 77+-2K
- The other main rings are visible in a radial (azimuthally-averaged) profile at millimeter wavelengths.



Dust Polarization Toward Embedded Protostars in Ophiuchus with ALMA

Sarah I. Sadavoy, Ian W. Stephens, Philip C. Myers, Leslie Looney, John Tobin, Woojin Kwon, Benoit Commercon, Dominique Segura-Cox, Thomas Henning, Patrick Hennebelle 1909.02591

- 0.25" (35AU) resolution 1.3mm dust polarization images
- 37 Oph YSOs (all embedded protostars plus others)
- 9/14 of detected sources consistent with dust self-scattering in optically thick disks
  - All 6 youngest (Class 0) sources detected
  - 44% of Class I sources detected
  - no agreement between the polarization morphology on clump scales as seen from monolothic telescopes with the polarization morphology detected on < 100 au scales from the ALMA data
- Dust polarization may not be a good tracer of magneticfield structures on disk scales, particularly for inclined disks
- Remaining sources may trace magnetic fields

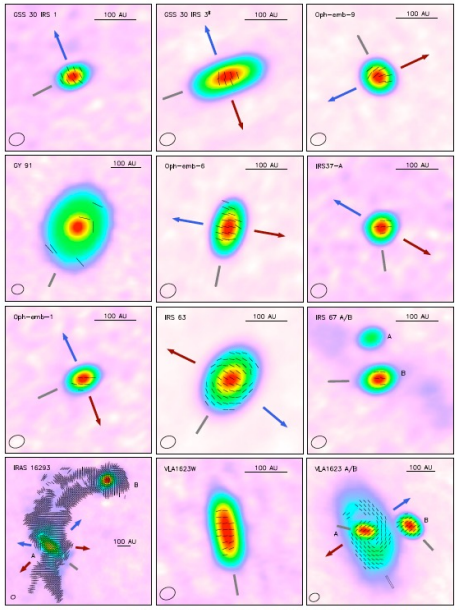


Figure 3. The 14 continuum sources with polarization detections. Background images show the Stokes I maps on a logarithmic color scale (see Appendix A for the flux scale) and the black line segments show the normalized e-vectors. Sources with ‡ are outside of the inner third of the primary beam FWHM. The blue and red arrows indicate the outflow position angle, if known (see Section 4.1 for details). The grey bars show the semi-major axis position angle of the continuum sources detected in polarization, except IRAS 162933 as this source is near face-on and does not have a well constrained continuum position angle. For VLA 1623 A, we show two grey bars: the solid one shows the position angle of the compact disk from Harris et al. (2018) and the open one shows the position angle of the extended disk.

ALMA Cycle 10 Capabilities

ALMA Capabilities in Cycle 10

- **Observing Time**
  - 4300 hours anticipated on the 12-m Array + 4300 hours on the ACA (4300 each for the 7-m Array and Total Power Array)
  - **Cycle 10 will *not* include a Supplemental CfP for stand-alone ACA observations**
  - The community is encouraged to submit ACA stand-alone proposals for targets, especially in the LST range of 20h to 10h, for the May 2023 deadline
  - The community is also strongly encouraged to submit proposals in the highest frequency bands, Bands 8, 9 and 10
- **Proposal Review Process**
  - All proposals that are not Large Programs will be reviewed via Distributed Peer Review
  - Large Programs (>50 hours on the 12-m Array, >150 hours on the 7-m Array), will be reviewed by a panel
  - All Cycle 10 proposals will be dual-anonymous (it is the responsibility of investigators to preserve their anonymity when writing proposals)

ALMA Capabilities in Cycle 10

Encourage "Medium size" proposals between 25 – 50 hours

- "But ALMA doesn't accept long proposals. I have a better chance of submitting a shorter proposal because it will be accepted, right?!?!? → **WRONG!!!!**
- Most Cycle 9 proposals requested between 2 and 20 hours of 12-m Array time but the average time per proposal has increased over the cycles and the success rate of proposals was independent of proposal length up to at least 30 hours and maybe even higher up to about 40 hours

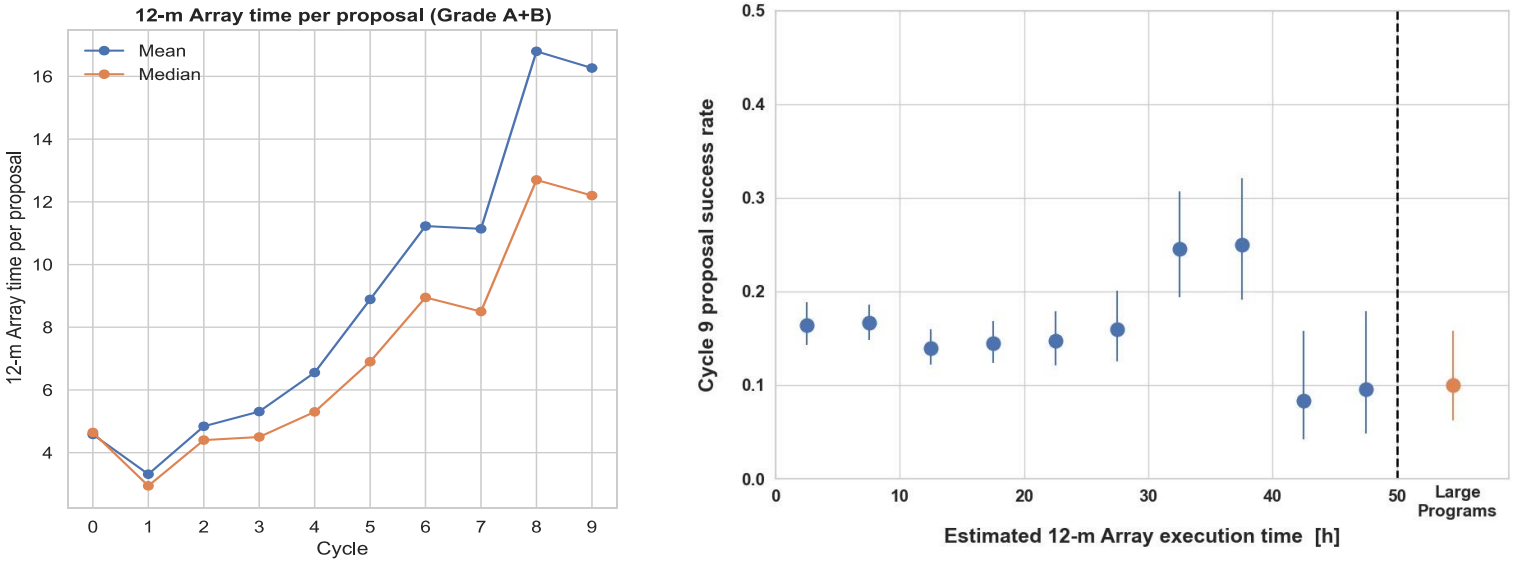


Figure 1: Cycle 9 - (Left) Requested 12-m Array time per proposal assigned Grade A or B. (Right) Fraction of proposals (with 1s confidence intervals) that are assigned Grade A or B as a function of the estimated 12-m Array time.

ALMA Capabilities – NEW in Cycle 10!!!

In Cycle 10, NEW technical capabilities will include:

- **Band 1 on the 12-m Array.** Observations for Stokes I only (no Stokes Q/U/V). Band 1 is anticipated to be available from March 2024 so is only available in configurations C-1 to C-6 (*not C-7 and C-8*). Frequency range 35-50 GHz (8.5-6 mm)
- **Spectral scans that include Total Power observations**
- **4x4-bit spectral mode for improved sensitivity on the 12-m Array (dual polarization only).** 4x4 bit mode significantly reduces the time required for specific spectral-line observations to reach a given rms, by 25% (or a 12% increase in sensitivity for fixed spectral resolution and integration time). 4x4 bit mode is ***not*** recommended for continuum observations because it reduces the available bandwidth compared to the standard 2x2 bit mode.
- **Solar observations with 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.
- **VLBI (continuum and spectral line) in Bands 1 ,3, 6 and 7,** including flexible tuning.

Joint Proposals also offered in Cycle 10 (see later slide)

ALMA Capabilities in Cycle 10

- **The Cycle 10 capabilities are be fully described in Appendix A of the ALMA Proposers Guide available at https://almascience.nrao.edu/proposing/proposers-guide (Cycle 10 version available from April 12). In summary:**
- **Number of antennas**
  - At least forty-three (43) antennas in the 12-m Array
  - At least ten (10) 7-m antennas (for short baselines) and three (3) 12-m antennas (for making single-dish maps) in the ACA
- **Receiver bands**
  - Receiver Bands 1, 3, 4, 5, 6, 7, 8, 9, and 10 (wavelengths of about 7.5, 3.0, 2.0, 1.6, 1.3, 0.85, 0.65, 0.45, and 0.35 mm, respectively) → **Band 1 (7.5 mm) offered for the first time in Cycle 10, anticipated to be available from March 2024**
- **12-m Array Configurations**
  - Cycle 10 includes configurations C-1 through C-8. **(C-7 and C-8 not available in Band 1)**
  - Maximum baselines between 0.16 km and 8.5 km depending on array configuration
  - https://almascience.nrao.edu/observing/observing-configuration-schedule/long-term-configuration-schedule
  - Files containing ***representative*** antenna configurations for the 12-m and 7-m Arrays suitable for Common Astronomy Software Applications (CASA) simulations are available from the ALMA Science portal (https://almascience.nrao.edu/tools/casa-simulator)

ALMA Capabilities in Cycle 10

- **Spectral line, continuum, and mosaic observations**
  - Spectral line and continuum observations with the 12-m Array and the 7-m Array Bands 3-10. Band 1 only with the 12-m Array (spectral line and continuum).
  - Single field interferometry (Bands 3-10) and mosaics (Bands 3 to 9) with the 12-m Array and the 7-m Array. Band 1 only with the 12-m Array.
  - Single-dish spectral line observations in Bands 3 to 8
- **Polarization**
  - Single-pointing, on-axis, full linear and circular polarization for both continuum and full spectral resolution observations in Bands 3 to 7 on the 12-m Array. The field of view of linear and circular polarization observations is limited to the inner one third and the inner one tenth of the primary beam, respectively.
  - Mosaicking of continuum linear polarization observations in Bands 3 to 7 with the 12-m Array.
  - Single-pointing, on-axis, linear polarization with the stand-alone 7-m Array in Bands 3 to 7. The field of view is limited to the inner third of the primary beam. A maximum of 75 hours is offered for this mode.
    - Combined 7-m Array and 12-m Array polarization observations are *not* supported.

ALMA Capabilities in Cycle 10

Band-to-band phase calibration

- Observations in Bands 7-10 with the 12-m Array (new: any configuration) or the 7-m Array may require band-to-band (B2B) calibration in order to find a suitable nearby and sufficiently bright phase calibrator, to ensure phase calibration quality.
- The ALMA OT will *automatically* check the availability of suitable phase calibrators during proposal validation and will automatically trigger B2B where needed.
- Some science targets – especially in Band 10 and with the longest baselines (C-8 in Cycle 10) – may not be observable even with B2B. The ALMA OT will give an error and won't validate the proposal if a target does not have a suitable calibrator.
- It is recommended to begin preparing High Frequency proposals – and validate in the OT – early to ensure there is a suitable phase calibrator available.
- A maximum of 65 hours is available for Band-to-Band on the 12-m Array; and a maximum of 85 hours on the 7-m Array.

ALMA Capabilities – Joint Proposals

- ALMA has entered into agreements with JWST, VLA and VLT.
- Joint Proposals must require observations with two or more observatories to achieve their scientific goals.
- A Joint Proposal is submitted to a single observatory, so it is no longer necessary to submit two separate proposals to each observatory, avoiding “double jeopardy” – just reviewed once.
- Starting in Cycle 10, ALMA will be able to allocate up to:
  - 115 hours of JWST time
  - Up to 5% of the available time on the VLA.
  - 50 hours of VLT time
- JWST can allocate up to 115 hours of ALMA time per cycle (starting with JWST cycle 2; Nov 2022; VLT and VLA can allocate up to 50 hours per year starting with Period 112 and Semester 2023B (CfP Feb & Jan 2023), respectively.
- See https://almascience.nrao.edu/news/alma-announces-joint-proposal-agreements-for-jwst-vla-and-the-vlt

ALMA Capabilities – Joint Proposals

- More information can be found in the respective Calls for Proposals.
- For ALMA, see the Cycle 10 Proposer's Guide.
- For VLA, see:
  - https://science.nrao.edu/observing/call-for-proposals/2023b/new-opportunity-joint-observations-with-alma and https://science.nrao.edu/observing/call-for-proposals/2023b/joint-proposals
- For VLT, see: https://www.eso.org/sci/observing/phase1/JointVLT-ALMA.html
- For JWST, see here.
- Some important notes:
  - Proposals need to clearly demonstrate that *both* ALMA and the other observatory observations are scientifically required.
  - Proposals must submitted to the observatory that requires the most observing time ("Main observatory").
  - Proposals may not be submitted to both observatories at the same time.
  - If two or more non-ALMA observatories are required, ALMA must be the "Main observatory".
  - Joint Proposals submitted to ALMA must be explicitly specified as such using the "Is this a Joint Proposal?" button in the ALMA OT.

ALMA Capabilities in Cycle 10

Proposal types in Cycle 10 will include:

- Regular, VLBI, Phased Array, Target of Opportunity, and Large Programs.
- VLBI proposals work in concert with the Global mm-VLBI Array (GMVA) or Event Horizon Telescope (EHT). GMVA programs also had to submit a proposal to the GMVA by its 1 February 2023 deadline.

Restrictions on certain modes or proposal types:

- The distinction between "standard" and "non-standard" modes was removed starting in Cycle 8 2021 (in earlier cycles there was a 20% cap on the time request for non-standard modes)
- There are still some time caps on certain modes, however. Namely, high frequency observations requiring Band-to-Band phase calibration or full polarization observations on the 7-m Array.

Large Program Observing Modes are STILL restricted. They CANNOT include:

- Time Critical or ToO Observations
- Full Polarization observations
- Solar observations
- VLBI or Phased Array observations
- Bandwidth switching projects (having <1 GHz aggregate bandwidths over all spectral windows)
- Band-to-Band calibration projects
- Astrometric Observations
- Band 1 (in Cycle 10)

ALMA Capabilities in Cycle 10

Large Program Preparation and Support

- If you are planning to submit a Large Program, it is strongly recommended to contact your local ARC for support NOW to help with preparing your large programs.
- The ARCs have both proposal preparation and data processing support available.
- Large Programs require a Management Plan. This needs to describe both the team and their responsibilities within the project and the computing resources the team has access to for processing and storing the data. The ARCs offer access to computing resources. If it is the intention to utilize those resources, it is recommended you discuss and agree your computing needs with the ARC well in advance so you can include the use of these resources in the Management Plan.
- Review the documentation off the science portal on how to prepare “value added” data products.

ALMA Capabilities for Cycle 11++

- **Receiver bands**:
  - Band 2 (Band 2 summary report from 2019: https://zenodo.org/record/3240407)
- **Baselines:**
  - All observing bands out to 16 km.
- **Observing Modes:**
  - Full operations include full Stokes plus circular polarization at all observing bands including mosaics and Total Power

ALMA is getting a major upgrade in the next several years – the **Wideband Sensitivity Upgrade** – that will bring many new capabilities. See e.g. :

- https://public.nrao.edu/news/alma-correlator-upgrade/
- https://arxiv.org/abs/2211.00195
- https://science.nrao.edu/facilities/alma/science_sustainability/March22_WSU_Webinar_NAASC.pdf/view

→ This may potentially limit the rollout of other new capabilities in the short term.

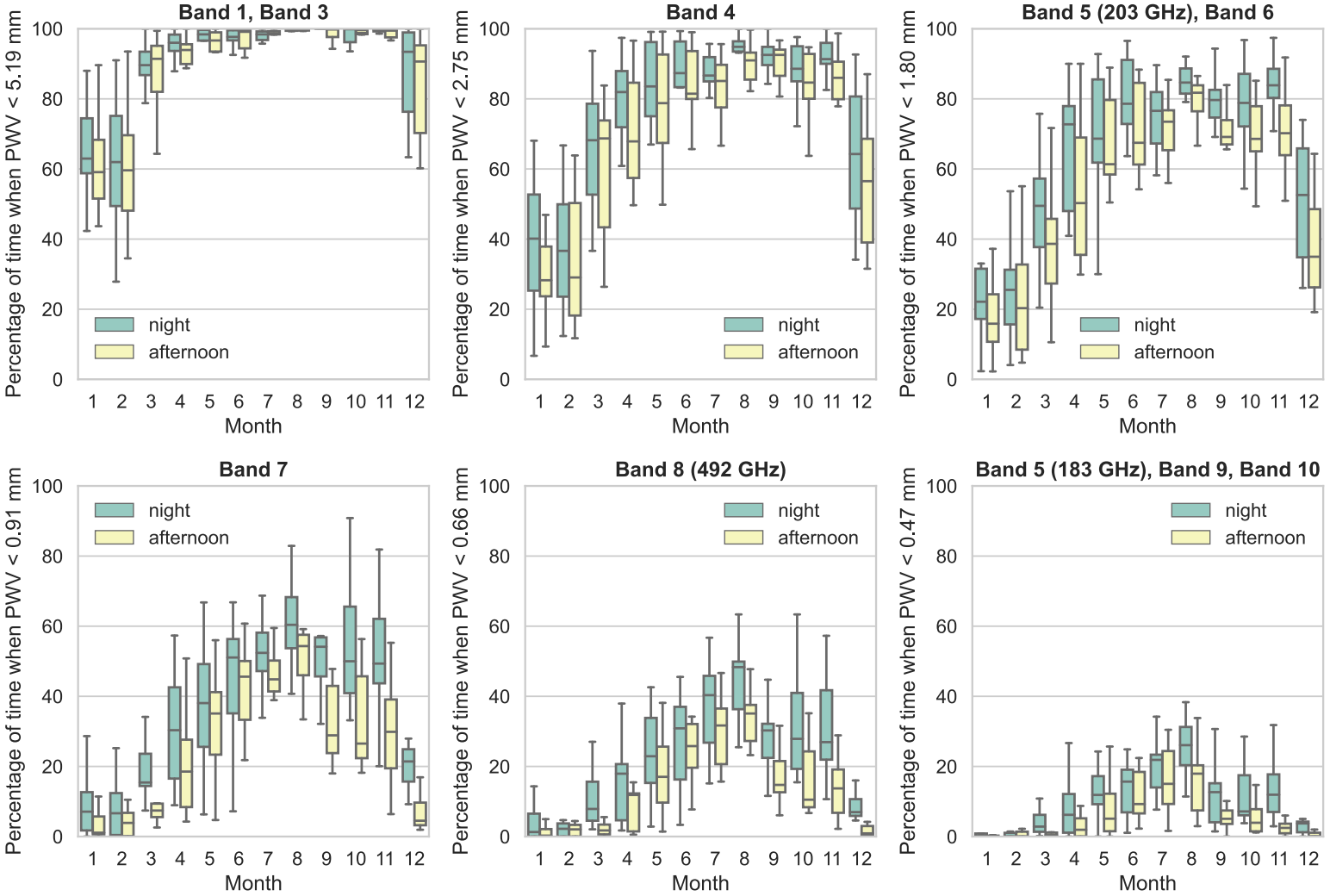
ALMA Array Configuration Schedule (Cycle 10)

- Maximum baseline in Cycle 10 will be 8.5 km in configuration C-8.
- Configurations C-9 and C-10 with maximum baselines of 13.9 km and 16.2 km, respectively, will NOT be available until Cycle 11.
- **NOTE: No PI observing takes place in February – maintenance shutdown!**
- The forward-looking configuration schedule (through Cycle 11) can be found at: https://almascience.nrao.edu/observing/observing-configuration-schedule/long-term-configuration-schedule

Cycle 10

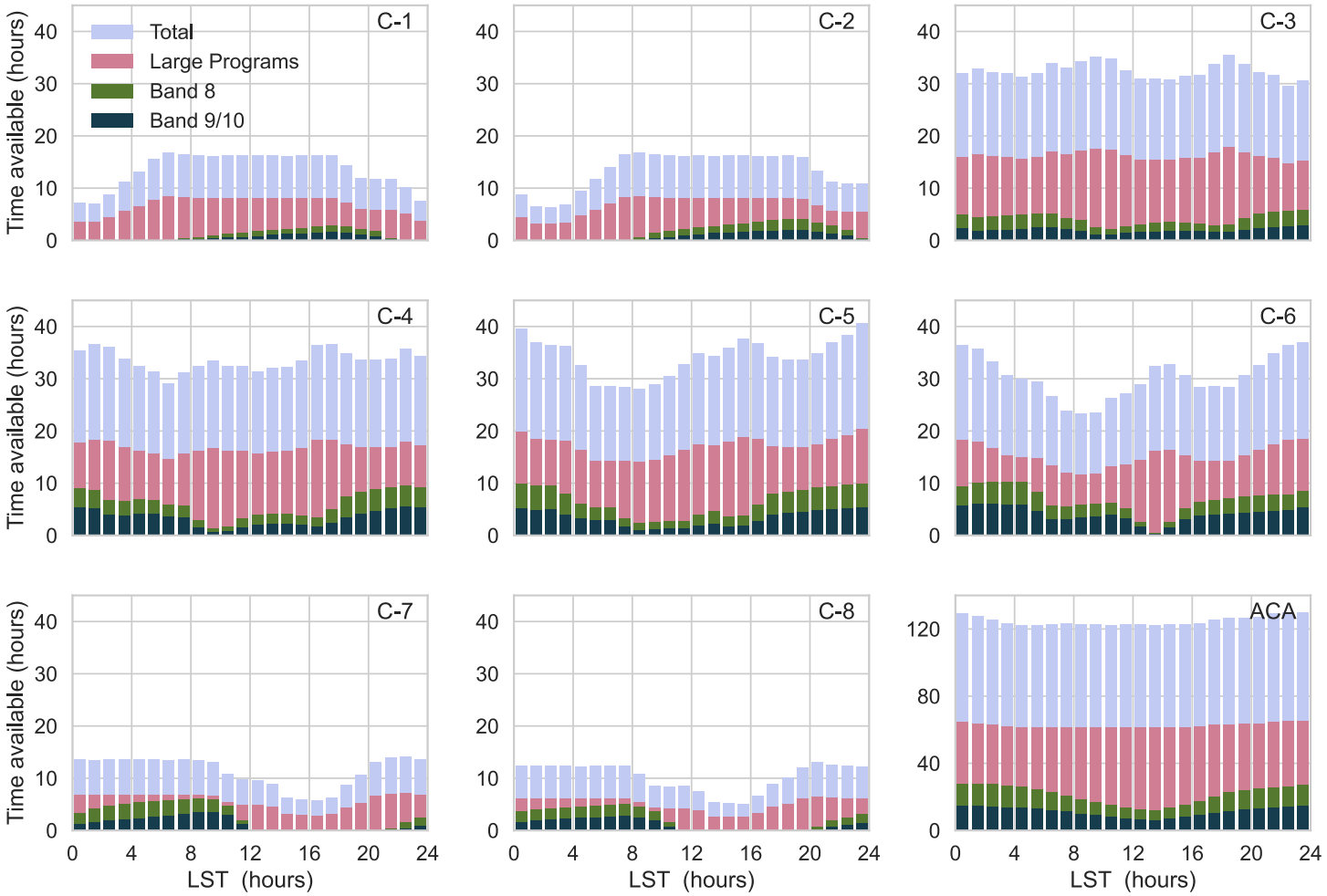
Start Date	Configuration	Longest baseline	LST: Best conditions
1-Oct-2023	C-8	8.5 km	22-10
20-Oct-2023	C-7	3.6 km	23-11
10-Nov-2023	C-6	2.5 km	1-13
1-Dec-2023	C-5	1.4 km	2-14
20-Dec-2023	C-4	0.78 km	4-15
10-Jan-2024	C-3	0.50 km	5-17
1-Feb-2024	No observations due to maintenance		
1-Mar-2024	C-1	0.16 km	8-21
26-Mar-2024	C-2	0.31 km	9-23
20-Apr-2024	C-3	0.50 km	11-0
10-May-2024	C-4	0.78 km	12-2
31-May-2024	C-5	1.4 km	13-4
23-Jun-2024	C-6	2.5 km	15-6
28-Jul-2024	C-5	1.4 km	17-7
18-Aug-2024	C-4	0.78 km	19-8
10-Sep-2024	C-3	0.50 km	20-9

ALMA Observing Strategies



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 January 2010 and January 2022.

ALMA Observing Strategies



Estimated observing time available per configuration for executing PI projects, based on precipitable water vapor (PWV) only. For example, approximately 30 hours are expected to be available in C-4 at LST 05 h for all observations and up to 15 h of those may be allocated to Large Programs. The time available for Large Programs is shown in pink and time for high-frequency observations in green and dark blue. The configuration schedule and, consequently, the total number of hours available per configuration may change in response to proposal pressure (Section 4.3.3 of the Cycle 10 PG).

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.
  - Also can ask for a "NAASC Chat" through the f2f department which is more than a ticket but less than a full virtual f2f visit!

- **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

- **NAASC Financial Support for Workshop/Conferences:** The NAASC invites scientists to apply for funding in support of upcoming conferences and workshops. - https://science.nrao.edu/facilities/alma/community1/NAASC-Conference-and-Workshop-Support

NAASC Sources of Support

- **Page Charges:** Upon request NRAO covers page charges for authors at US institutions when reporting results from ALMA/VLA. See: https://library.nrao.edu/pubsup.shtml

- **Face-to-face Visitor Support:** Upon request 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. See: https://science.nrao.edu/facilities/alma/visitors-shortterm

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