National Radio Astronomy Observatory

[Your name as presentere here]

Atacama Large Millimeter/submillimeter Array
Expanded Very Large Array

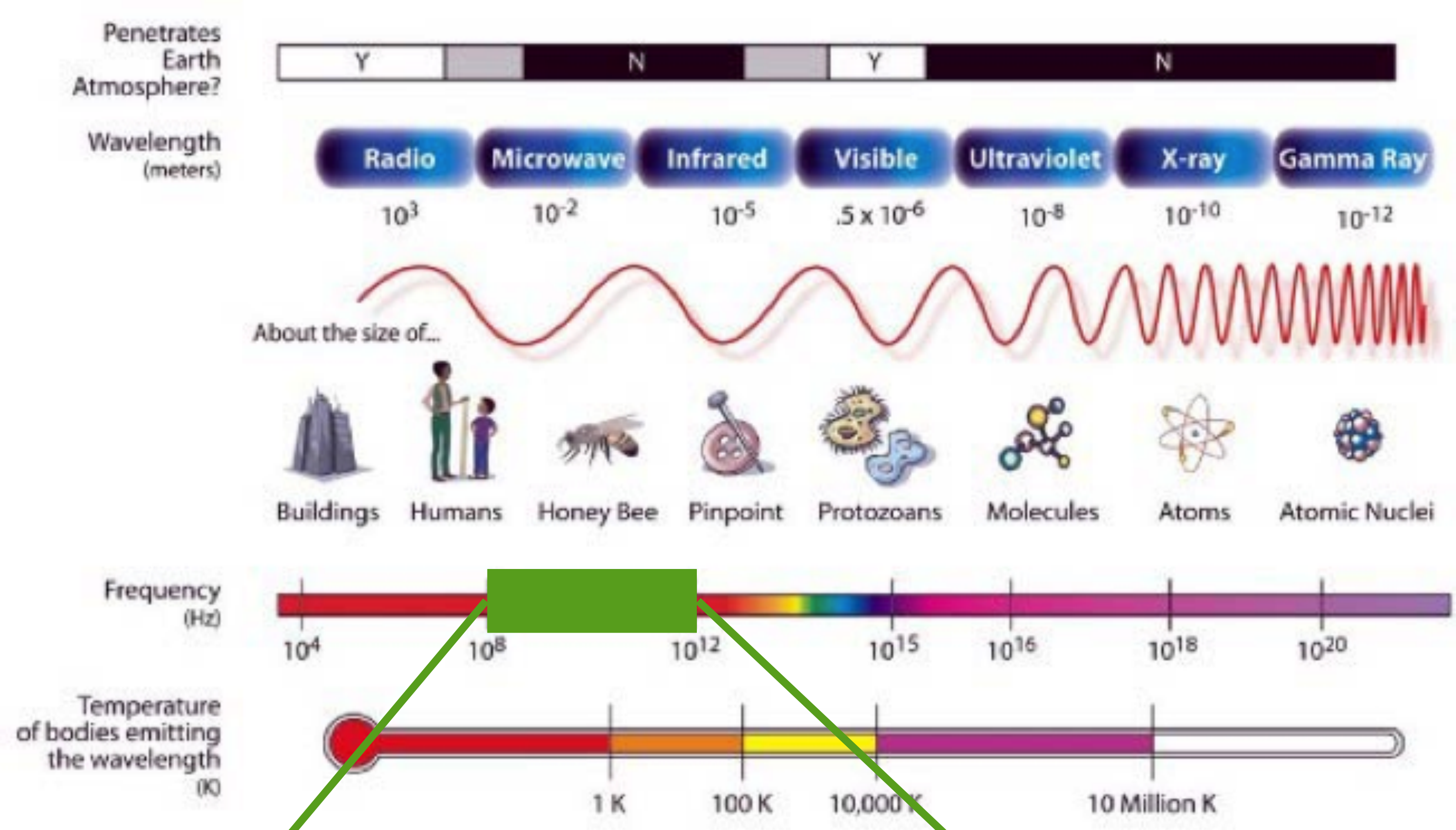
NRAO

NRAO:
One Observatory, Two World Class Facilities

Other Affiliated Telescopes and Observatories include the Green Bank Observatory (http://greenbankobservatory.org/) and the Long Baseline Observatory (https://www.lbo.us/)

NRAO:
One Observatory, Two 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}
$.5 \times 10^{-6}$
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
80 - 950 GHz
3 - 0.3 mm

NRAO

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

NRAO

What is ALMA?

A global partnership to deliver a revolutionary millimeter/submillimeter telescope array (in collaboration with Chile)

- North America
- Europe
- East Asia

66 reconfigurable, high precision antennas
λ ~ 0.3 – 8.6mm. Array configurations between 150 meters and >16 kilometers: 192 possible antenna locations:

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

Array Operations Site is located at 5000m elevation in the Chilean Andes

Provides unprecedented imaging & spectroscopic capabilities at mm/submm λ

What is ALMA?

Array configurations between 150 meters and >16 kilometers: 192 possible antenna locations:

http://youtu.be/YMISe-C8GUs

Documentation

Call for Proposals

Documentation supporting the current ALMA Call for Proposals – **Cycle 4**. 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	An updated ALMA Principles of the ALMA Proposal Review Process

Contents

ALMA is a telescope for *all* astronomers

ALMA in a Nutshell...

- Angular resolution down to 0.015" (at 300 GHz)
- Sensitive, precision imaging 84 to 950 GHz (3 mm to 315 μm)
- State-of-the-art low-noise, wide-band receivers (8 GHz bandwidth)
- Flexible correlator with high spectral resolution at wide bandwidth
- Full polarization capabilities
- Estimated 1 TB/day data rate
- All science data archived
- Pipeline processing

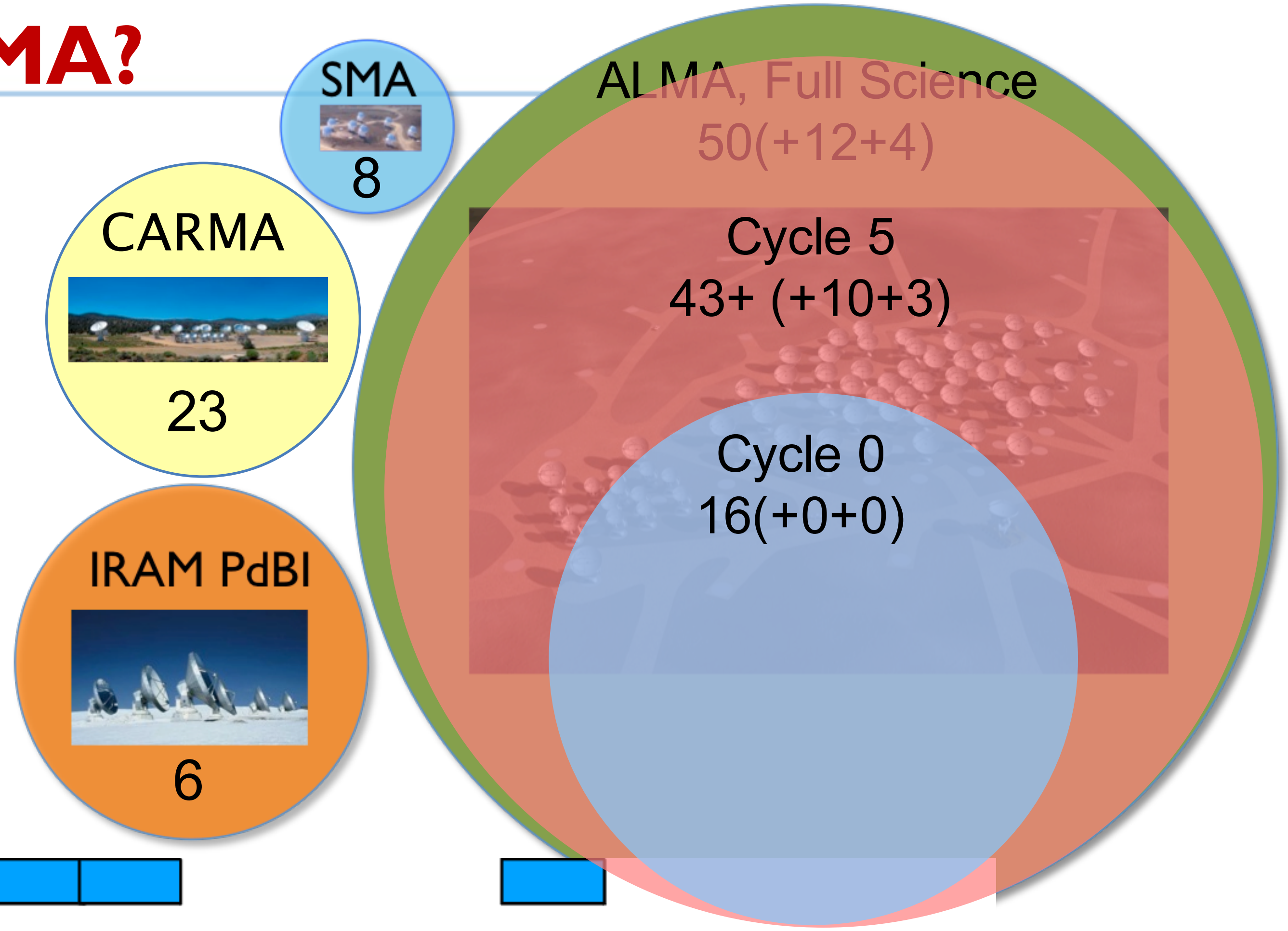
ALMA will be 10-100 times more sensitive and have 10-100 times better angular resolution than current mm interferometers

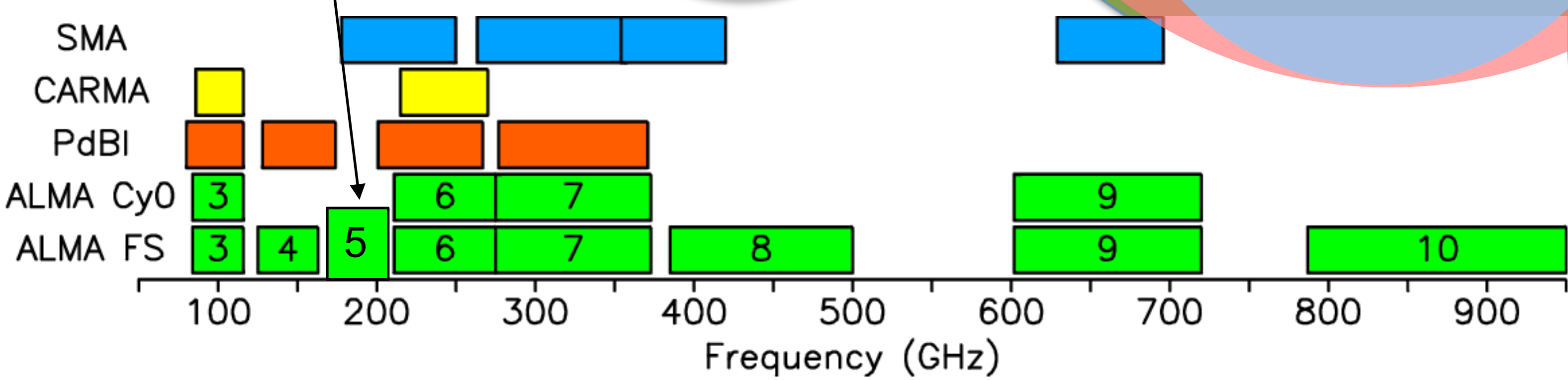
What is ALMA?

Collecting Area

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

New for Cycle 5 – Band 5!





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 12 km baselines (C40-9)** thanks to the highly successful Long Baseline Campaigns in 2014 and 2015
- **All 66 antennas accepted**
  - Currently all 66 antennas are at the high site (AOS), of which ~47 on average (up to max ~54) are being used for Cycle 4 observations
  - Some construction and verification items remain to be finished (e.g., wide-field polarization; various observing modes)
- The ACA (Atacama Compact Array) or Morita Array – up to 12x7m antennas and 4x12m antennas for TP observations – is currently being used for Cycle 4 observations
- More on Capabilities later… however, first on to science!

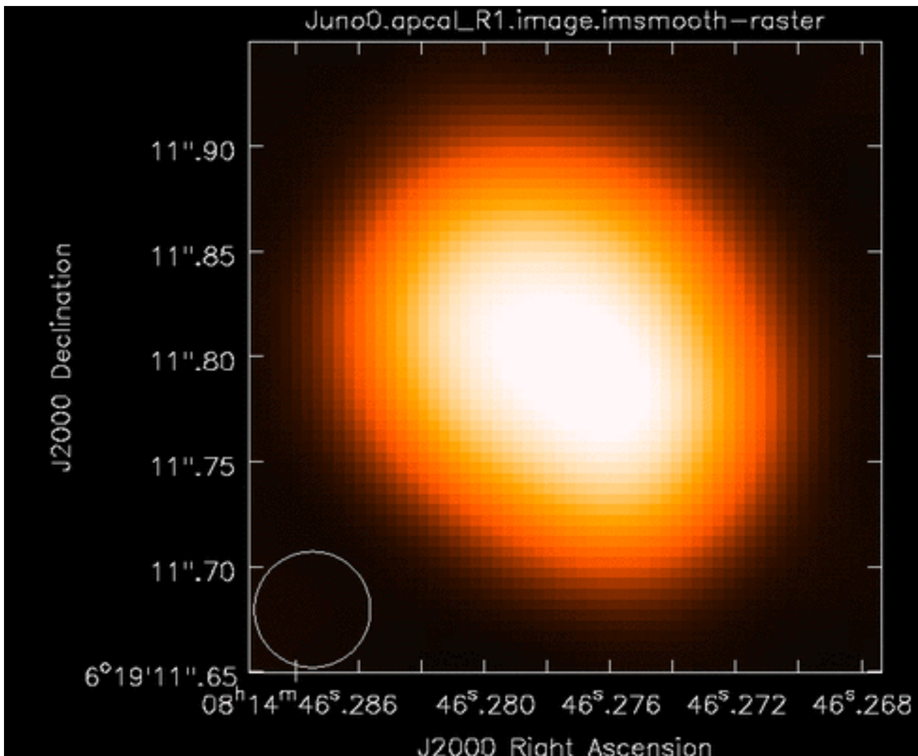
ALMA Science Highlights: Solar System

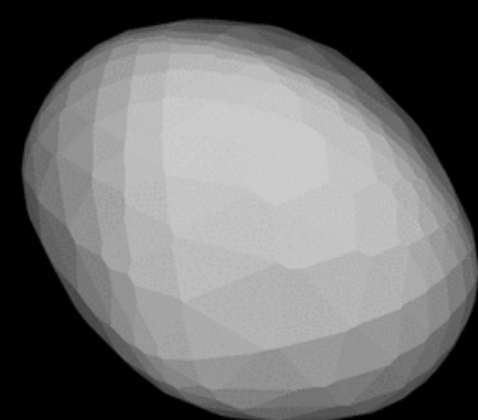
Band 6 Observations of Juno: Frequency = 233 GHz (Science Verification)

Five consecutive executions over 4.4 hours

Beamsize ~ 0.04"x0.03" (~60x45 km)

Model: Durech et al. 2010: **Database of Asteroid Models from Inversion Techniques**



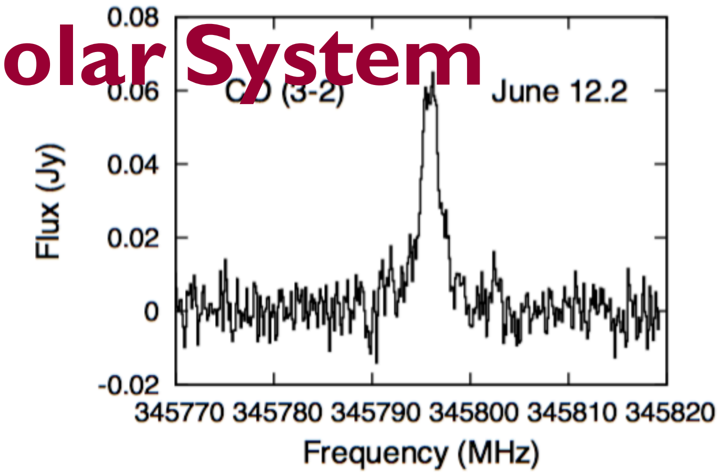


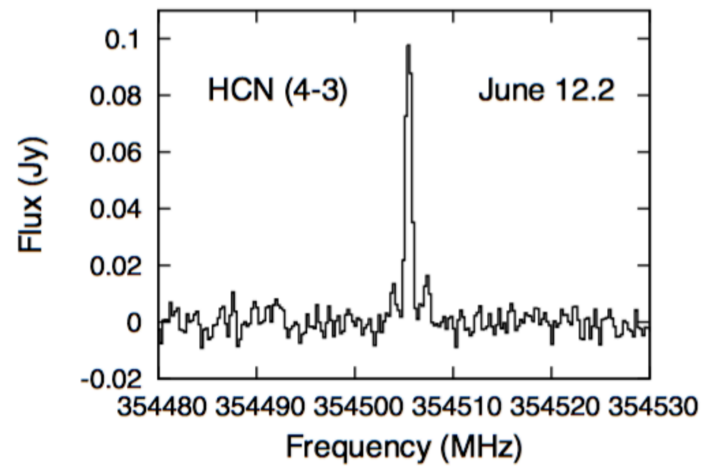
ALMA Image of Juno (ALMA Partnership, Hunter et al. 2015)

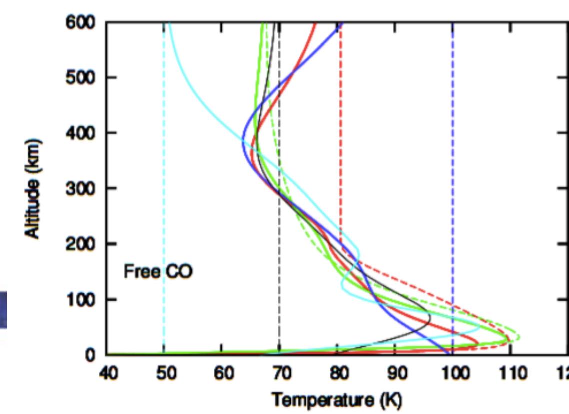
ALMA Science Highlights: Solar System

ALMA detects organics on Pluto

- ALMA has detected CO(3-2) and HCN (4-3) on Pluto (Lellouche et al. 2016)
- The lines probe the abundances and temperature of Pluto's atmosphere up to ~450 km and ~900 km.
- The dayside temperature profile shows a well-marked temperature decrease (i.e., mesosphere) above the 30-50 km stratopause, with T= 70 K at 300 km
  - In agreement with New Horizons solar occultation data.
- The HCN line shape implies a high abundance in the upper atmosphere (450 – 800 km)
  - Suggests a warm (>92 K) upper atmosphere

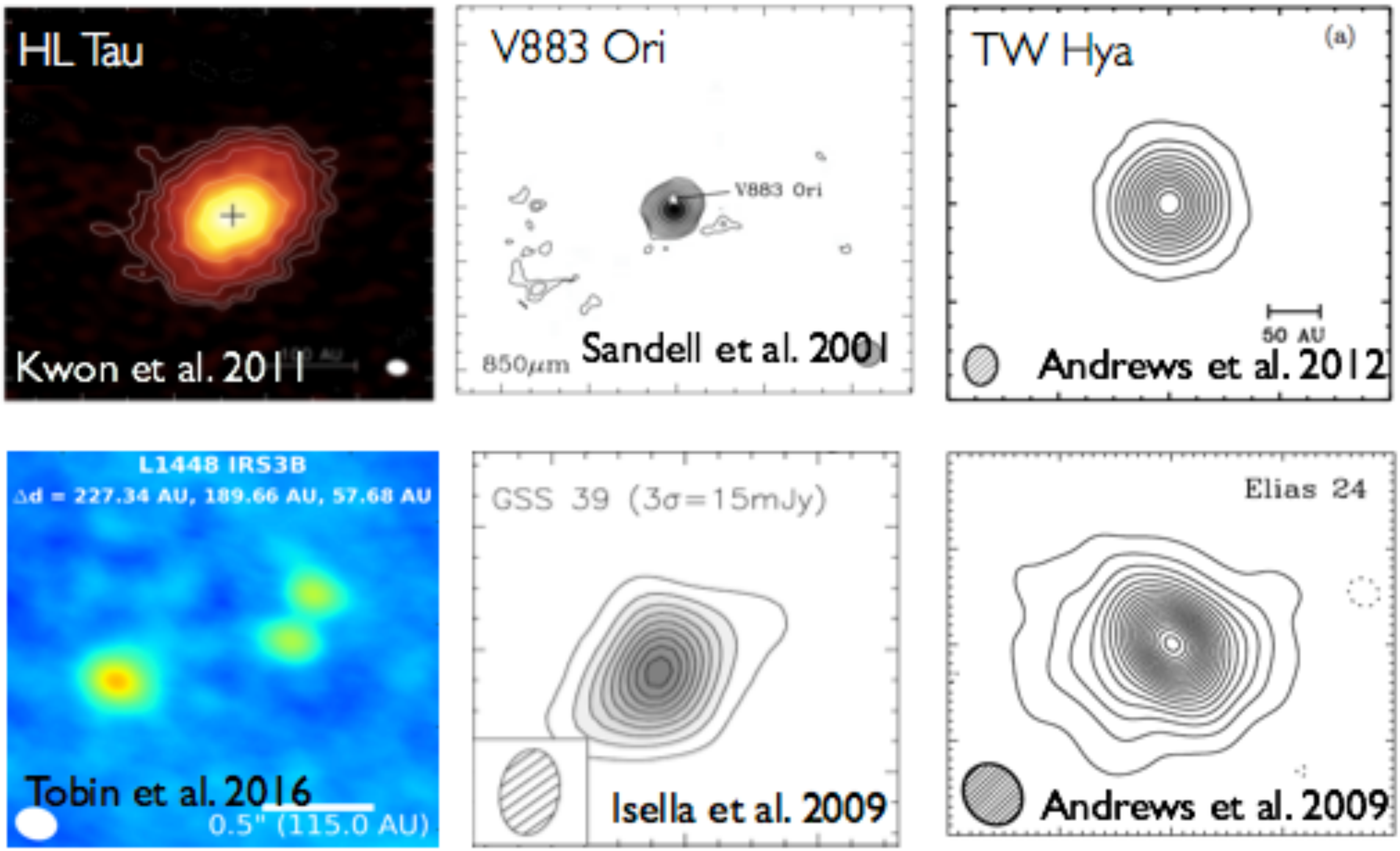






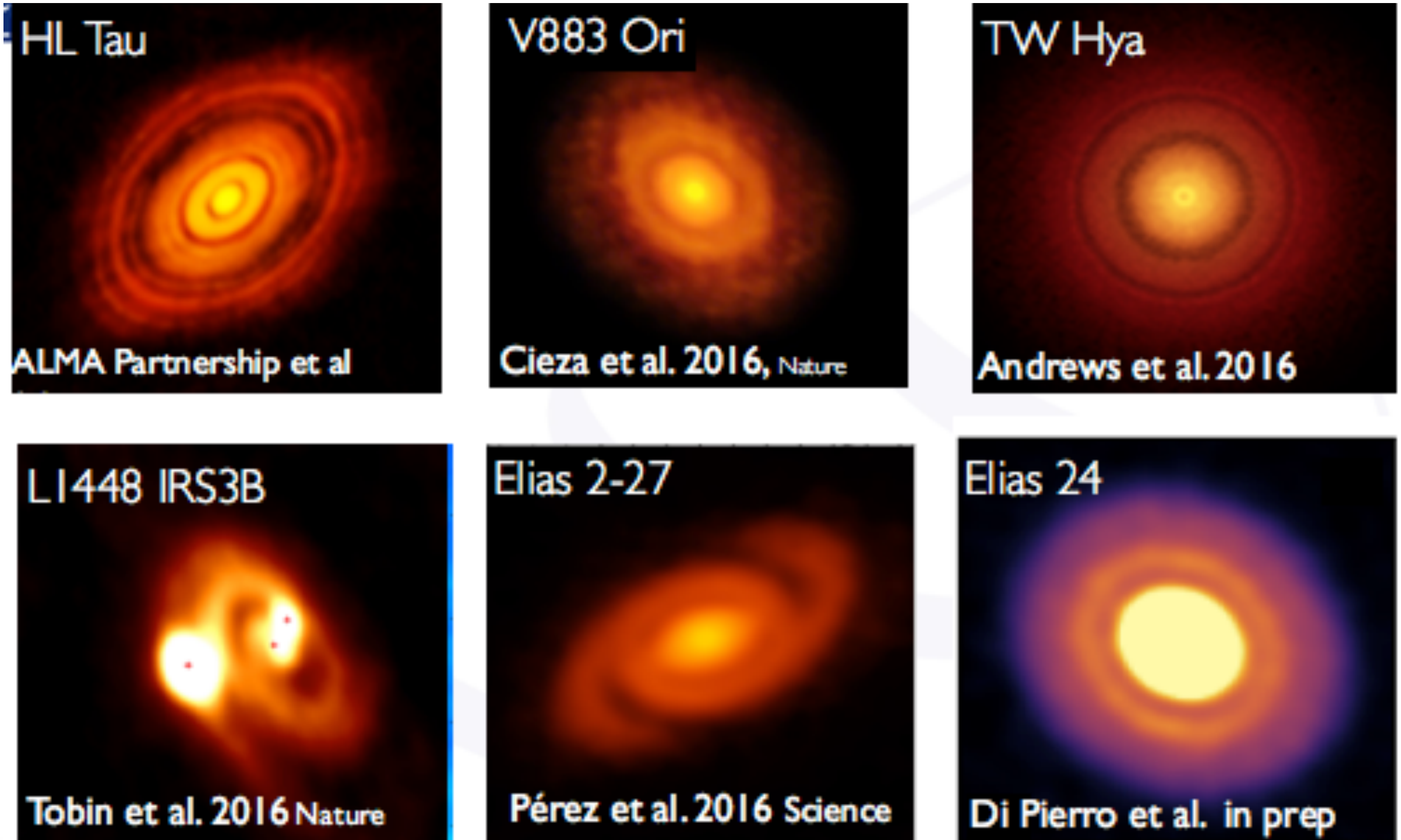
ALMA Science Highlights: Protoplanetary Disks

Protoplanetary Disks: Pre- ALMA



ALMA Science Highlights: Protoplanetary Disks

Protoplanetary Disks: With ALMA

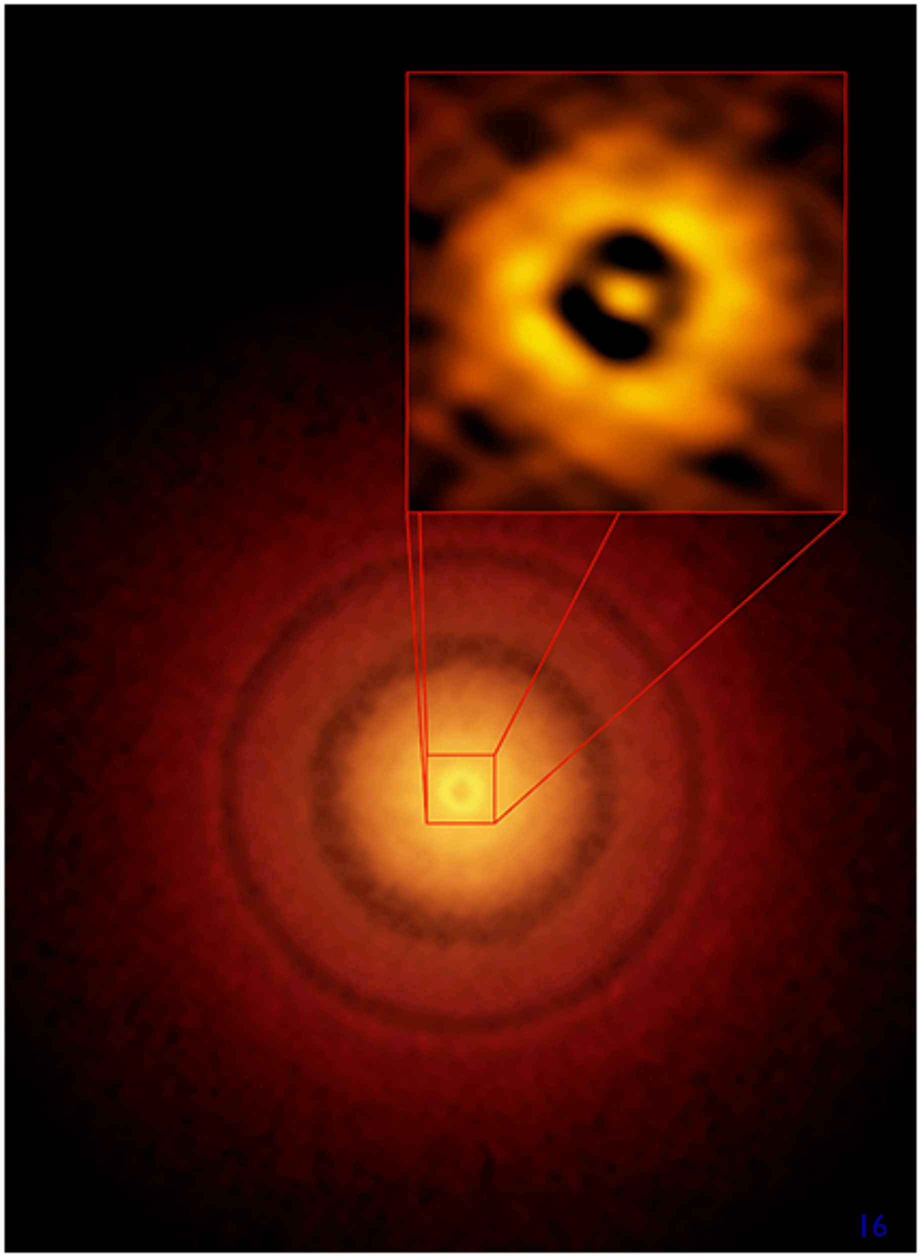


ALMA Science Highlights: Protoplanetary Disks

TW Hydrae

ALMA's better-than Hubble resolution details as small as the Earth's distance from the Sun may be discerned in this young (10Myr) nearby (175 light years) planet forming Sun-like star

Andrews et al. 2016



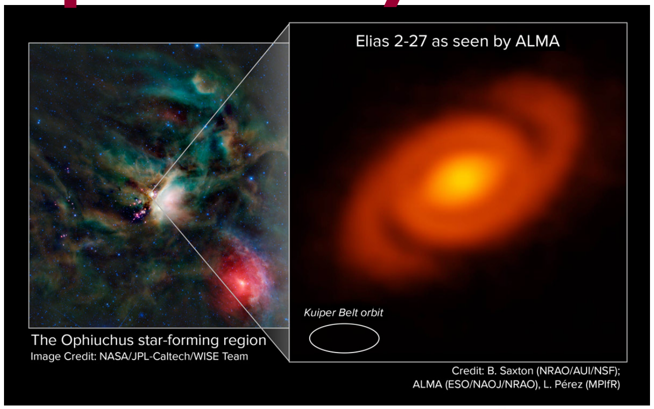
ALMA Science Highlights: Protoplanetary Disks

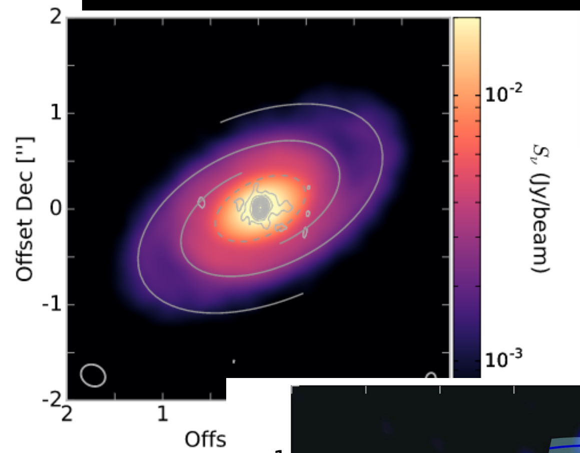
Protoplanetary Disks: With ALMA

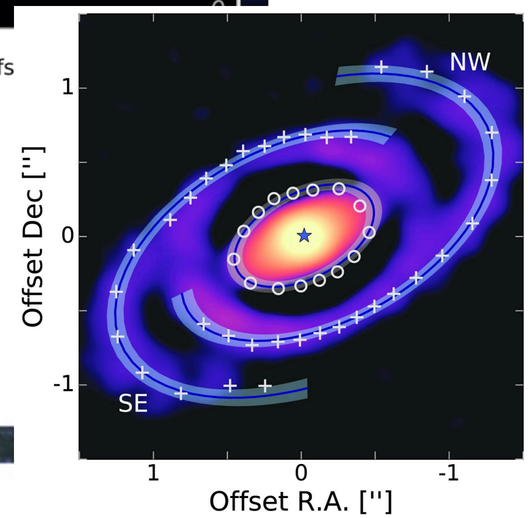
A Spiral Density Wave Observed in a Protoplanetary Disk

Perez et al. Science 353, 1519 (2016)

- Gravitational instabilities in protoplanetary disks might be excited by e.g. planet-disk interactions or gravitational instabilities
- Disk mid-plane structure provides a sensitive probe for these instabilities; optical observations probe the disk surface but radio wavelength observations probe the disk density structure.
- ALMA imaging (dust and CO, 33 AU resolution) reveals two symmetric spiral arms (r~150AU) emanating from an elliptical emission ring (r~71AU) in the disk Elias 2-27, in the nearby ρ Oph cloud
- A spiral density wave fits the observations well. Fragmentation of such spirals remains the only plausible formation mechanism for planets and companions at large disk radii, where core-accretion becomes inefficient.





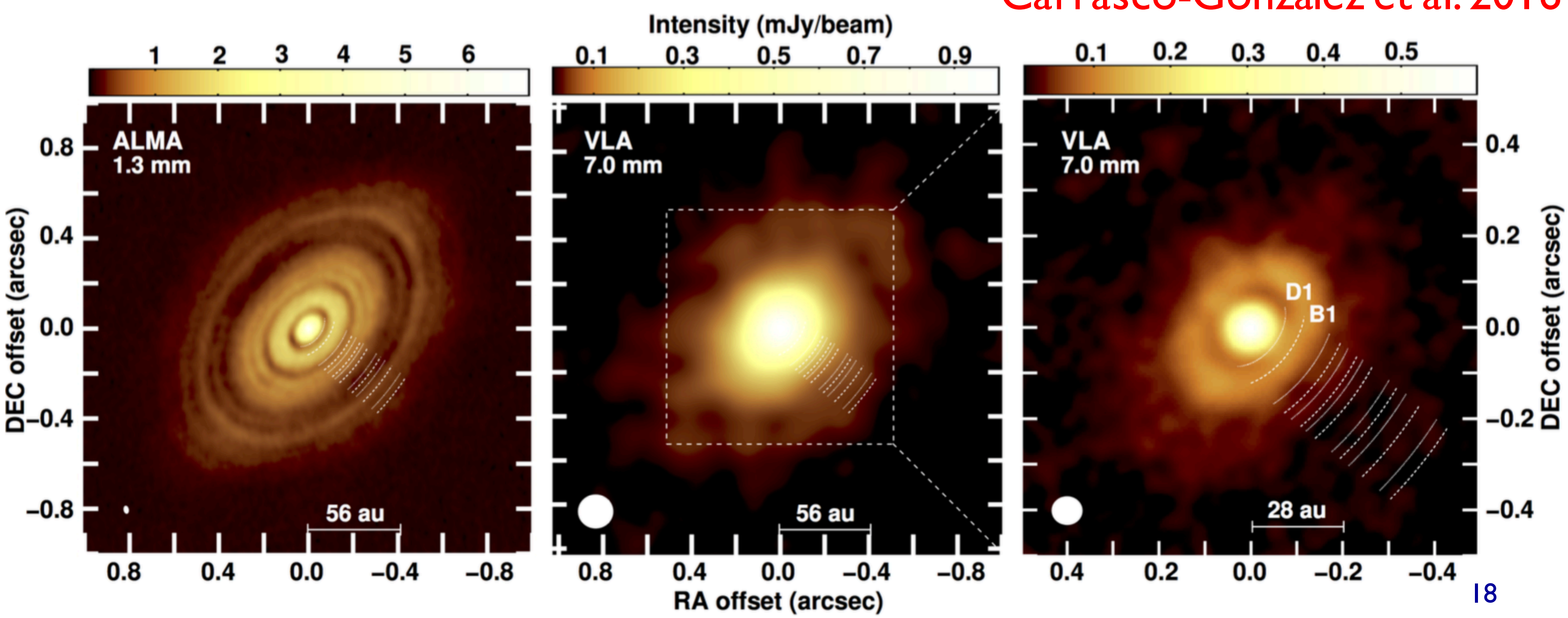


ALMA Science Highlights: Protoplanetary Disks

Protoplanetary Disks: With ALMA and VLA

- Emission from inner regions of HL Tau still optically thick at ALMA wavelengths
- VLA can image the disk at comparable resolution to ALMA at 7mm where emission is optically thin
- Combination of ALMA+VLA helps differentiate between formation theories with info on grain growth, fragmentation, and formation of dense clumps: suggest HL Tau disk is in very early stage of planet formation with planets not yet in the gaps but set for future formation in the bright rings

Carrasco-González et al. 2016



ALMA Science Highlights: Star Formation Peak

Scoville et al. (2016 ApJ 820 83)

"ISM Masses and the star formation law at z = 1 to 6: ALMA observations of dust continuum in 145 galaxies in the COSMOS survey field"

ALMA Cycle 2 observations of long-wavelength dust emission were used to probe the evolution of the star-forming interstellar medium (ISM). Sample size: 145 galaxies

Found a single high-z star formation law -- an approximately linear dependence on the ISM mass and an increased star formation efficiency per unit gas mass at higher redshift.

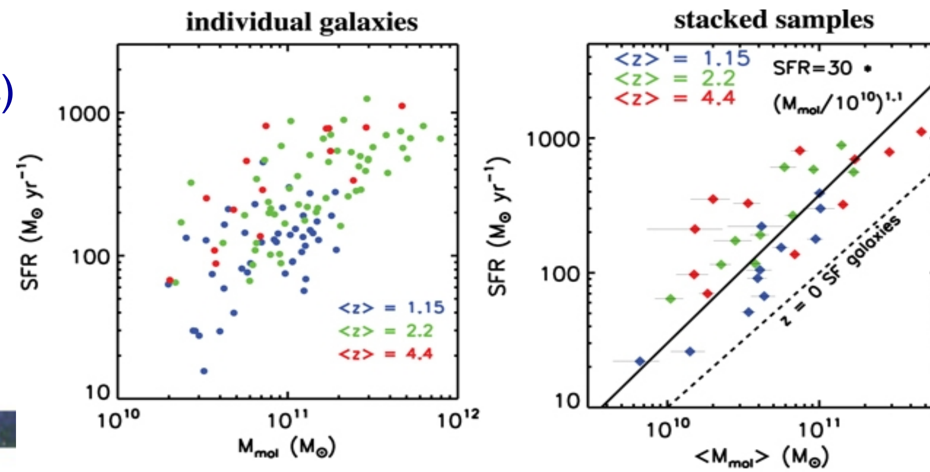
Several notable conclusions from the survey – among them:

At z > 1, the entire population of star-forming galaxies has ~2–5 times shorter gas depletion times than low-z galaxies.

=> **different mode of star formation in the early universe**

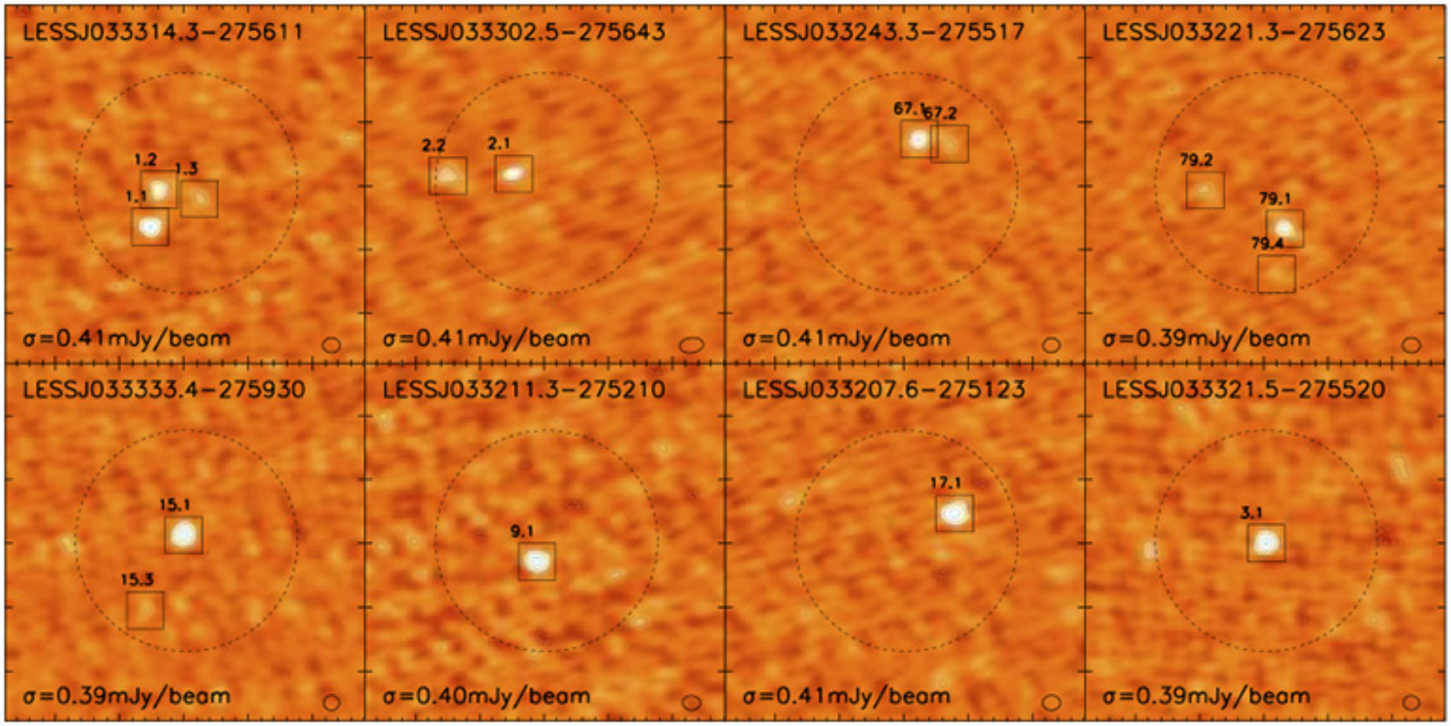
most likely dynamically driven by compressive, high-dispersion gas motions—a natural consequence of the high gas accretion rates.

36 citations to date (power of well-designed surveys)



ALMA Science Highlights: the Distant Universe

Resolving High-z Submm Galaxies



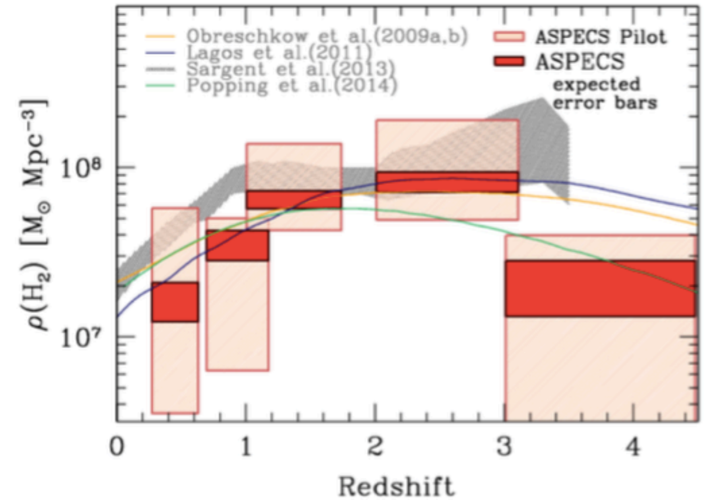
Hodge et al. 2013

- 126 submm sources observed with ALMA at 870 μm
- 2x deeper, 10x higher angular resolution than previous surveys
- **99 sources detected in 88 fields, integration time ~120 sec (!!)**
- Significant multiplicity (35-50%) found at 0.2" resolution

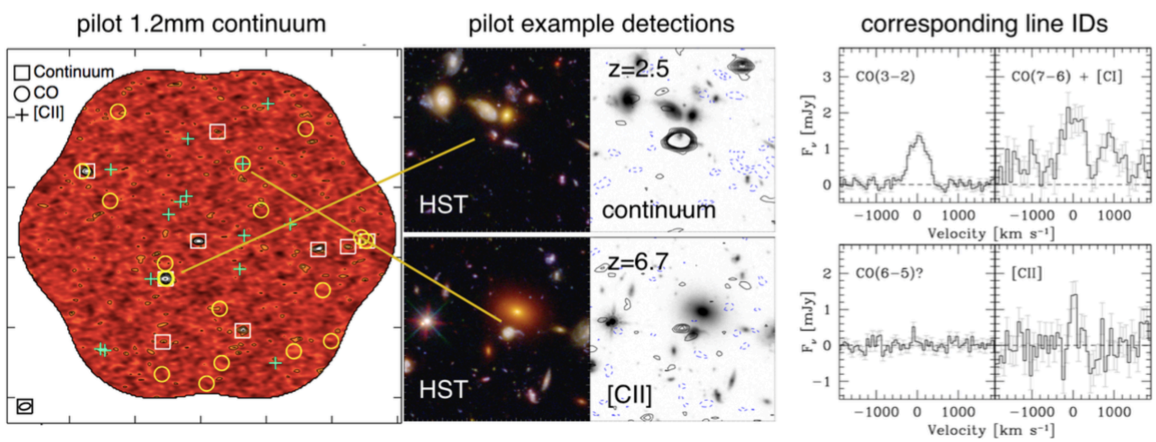
ALMA Science Highlights: the Distant Universe

ALMA Deep Fields: a new era of cosmological surveys

- ALMA has opened a new window on the cosmos: large volume surveys for cold gas throughout the Universe = the fuel for star formation. ASPECS is the first line deep field, involving full frequency scans of Band 3 and 6 in the Hubble UDF.
- 21 candidate line galaxies were detected, including CO emission from galaxies at z=1 to 5, and [CII] at z > 6, plus 9 dust continuum sources at 1.2mm
- These data determine the dense gas history of the Universe, the necessary complement to the star formation history of the Universe.



Examples of line and continuum sources from the ASPECS program, plus constraints on the dense gas history of the Universe (see papers by Walter, Decarli, Aravena)

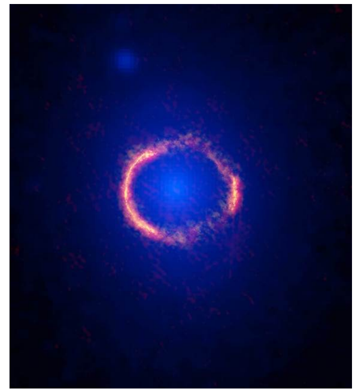


ALMA Science Highlights: the Distant Universe

- Hezaveh et al (2016) show ALMA's potential to advance understanding of dark matter substructures

- ALMA's SDP.81 observations are analyzed to detect a subhalo with a mass of $10^{8.96 \pm 0.12} M_{sun}$

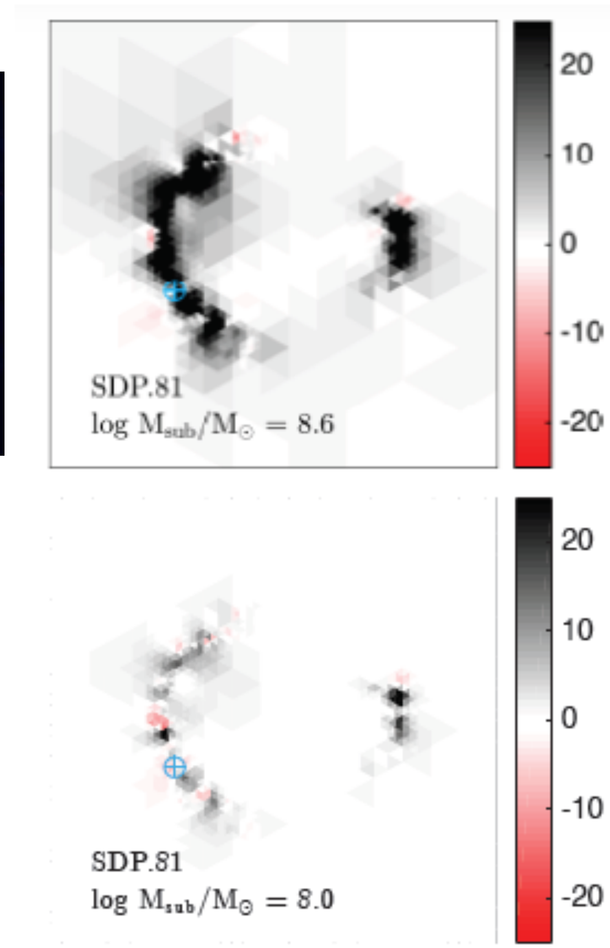
- Consistent with theoretical expectations



The SDP.81 system.

Blue: HST/WFC3 F160W data shows lensing elliptical at z~0.3

Red: ALMA Bands 4/6/7 combined emission.



(Right Top) a map of parameter for a second subhalo of mass $10^{8.6}$ M_{sun} after inclusion of one subhalo of mass 10^{9} M_{sun} at the location of the blue symbol.
(Bottom) results from similar analysis for a lower mass subhalo, showing marginal improvement at another point near the first detection.

ALMA Cycle 5 Capabilities

ALMA Performance

Towards Steady State (Cycle 5)

The Cycle 5 capabilities are fully described in Appendix A of the ALMA Proposers Guide available at:

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

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 3, 4, 5, 6, 7, 8, 9, and 10 (wavelengths of about 3.1, 2.1, 1.6, 1.3, 0.87, 0.74, 0.44, and 0.35 mm, respectively)

12-m Array Configurations

- Maximum baselines for the antenna configurations between 0.15 km and 16 km
- Maximum baselines of 3.6 km for Bands 8, 9 and 10
- Maximum baselines of 8.5 km for Band 7
- Maximum baselines of 16 km for Bands 3, 4, 5 and 6
- 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 (http://almascience.org/documents-and-tools/cycle5/alma-configuration-files)

ALMA Performance

Towards Steady State (Cycle 5)

Spectral line, continuum, and mosaic observations

- Spectral line and continuum observations with the 12-m Array and the 7-m Array in all bands
- Single field interferometry (all bands) and mosaics (Bands 3 to 9) with the 12-m Array and the 7-m Array
- Single-dish spectral line observations in Bands 3 to 8

Polarization

- Single pointing, on axis, full (linear) polarization capabilities for continuum and full spectral resolution observations in Bands 3, 4, 5, 6 and 7 on the 12-m Array.
- While PIs will receive data that will allow them to generate circular polarization data, the quality and/or accuracy of that data is not assured in this cycle, and such data should not be used for scientific purposes.

Observing Time:

- 4000 hours for successful proposals of PI programs expected on the 12m Array (includes DDT, Cycle 4 Carryover and resubmissions)
- 3000 hours available on the ACA
- 3000 hours available on the Total Power Array

ALMA Performance

Towards Steady State (Cycle 5)

Standard vs Non-Standard modes:

Cycle 5 should still be around 20% of the time going to non-standard modes.

This fraction will get smaller as we go into Full Operation and the amount of new capabilities decreases.

The fraction of time available for testing of new capabilities in Cycle 5 drops to ~15%

and continues to drop to a steady state of ~10% in Full Operations.

Non-Standard Observing Modes include:

- Bands 8, 9 and 10 observations
- Band 7 observations with maximum baselines > 5 km
- All full polarization observations
- Spectral scans
- Bandwidth switching projects (having less than 1 GHz aggregate bandwidths over all spectral windows)
- Solar observations
- VLBI observations
- Non-standard calibrations (user-defined calibrations selected in the OT)

ALMA Performance

Towards Steady State (Cycle 5) and Full Operations (Cycle 7)

Performance-based, vis-à-vis operational metrics

Capability-based, vis-à-vis the science reference plan & baseline deliverables

Antennas:

At least 43,12-m antennas in the main array

Full operations will target 45

ten 7-m antennas and three12-m antennas (for single-dish maps) in the ACA.

Receiver bands:

3, 4, 5, 6, 7, 8, 9, & 10 (wavelengths of about 3.1, 2.1, 1.5, 1.3, 0.87, 0.74, 0.44, and 0.35 mm, respectively).

Full operations will include Band 1 and 2 (Cy 7+).

Baselines:

up to 3.7 km for Bands 8, 9 and 10 / up to 6.8 km for Band 7 / and >15 km for Bands 3, 4, 5 & 6.

Full operations will have all baselines available for all observing bands. Some long baseline observations may never be considered "standard" observing modes.

Standard vs Non-Standard modes:

Cycle 5 should still be around 20% of the time going to non-standard modes.

This fraction will get smaller as we go into Full Operation and the amount of new capabilities decreases.

The fraction of time available for testing of new capabilities in Cycle 5 drops to ~15%

and continues to drop to a steady state of ~10% in Full Operations.

ALMA Performance

Towards Steady State (Cycle 5) and Full Operations (Cycle 7)

Observing Time:

- 4000 hours for successful proposals of PI programs expected on the 12m Array (includes DDT, Cycle 4 Carryover and resubmissions)
- 3000 hours available on the ACA
- 3000 hours available on the Total Power Array

Observing Modes (All Cycle 4 Modes plus…):

- Band 5
  - Full Operations include Bands 1 and 2
- Wide field polarization capabilities (12m + 7m arrays) including Band 5
  - Full operations include full Stoke plus circular polarization at all observing bands including mosaics and Total Power
- Improved spectral scan mode using differential gain calibration and more efficient calibration strategies including the use of sessions (sessions -> using already observed calibrators between science goals)

ALMA Performance

Towards Steady State (Cycle 5) and Full Operations (Cycle 7)

New Observing Modes for Cycle 5:

- 90 Degree Walsh switching at Band 9 and 10 for both the 12m and ACA
  - Full operations including Total Power observations at all observing bands including continuum with either fast scanning techniques or nutator
- Mixed correlator modes (both high and low frequency resolution in the same observation).
- Solar Observations (Interferometry + Total Power continuum) at selected frequencies in Bands 3 and 6.
  - Full operations include full spectral line and continuum, full polarization observations at all frequency bands
- VLBI full polarization continuum observations at selected frequencies in Bands 3, 6 and 7.
  - Full operations include full spectral line and continuum, full polarization observations at arbitrary frequencies (in Band 3, 6 and 7)
  - Full operations include the high sensitivity array – cross correlation observations between all antenna (12m + 7m)

ALMA Timelines and Milestones

The ALMA Cycle 5 Timeline

Date	Milestone
21 March 2017 (15:00UT)	Release of Cycle 5 Call for Proposals, Observing Tool & supporting documents and Opening of the Archive for proposal submission
20 April 2017 (15:00 UT)	Proposal submission deadline
End of July 2017	Announcement of the outcome of the Proposal Review Process
15 September 2017	Submission of Phase 2 by PIs
October 2017	Start of ALMA Cycle 5 Science Observations
September 2018	End of ALMA Cycle 5

ALMA Array Configuration Schedule (Cycle 5)

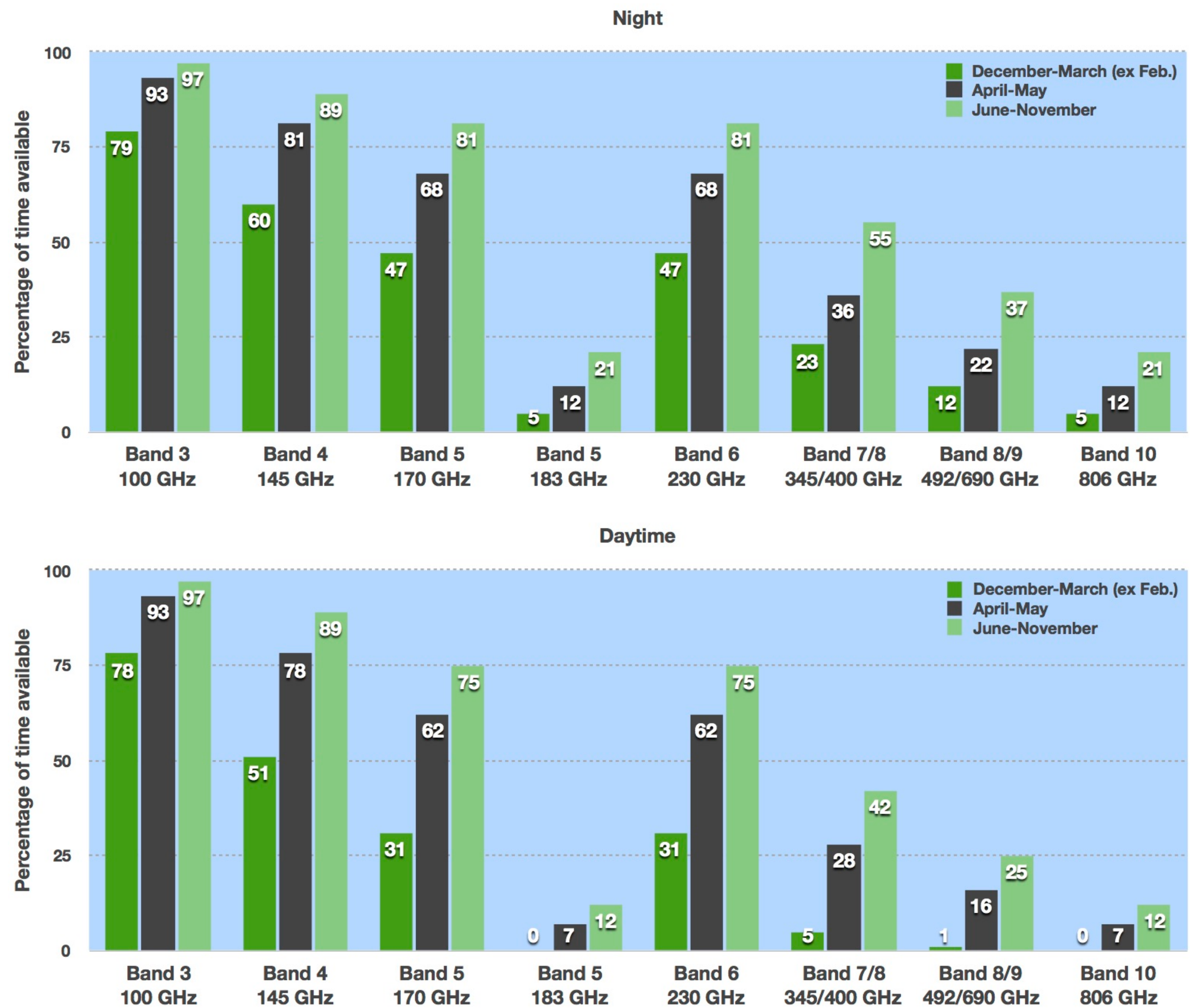
For Cycle 5, the compact array configurations will be in the southern hemisphere winter in order to accommodate more high frequency observations. The array configuration schedule will cycle every 3-5 years to accommodate the range of LST.

NOTE: No observing takes place in Feb!

Table 1: Cycle 5 Configuration Schedule

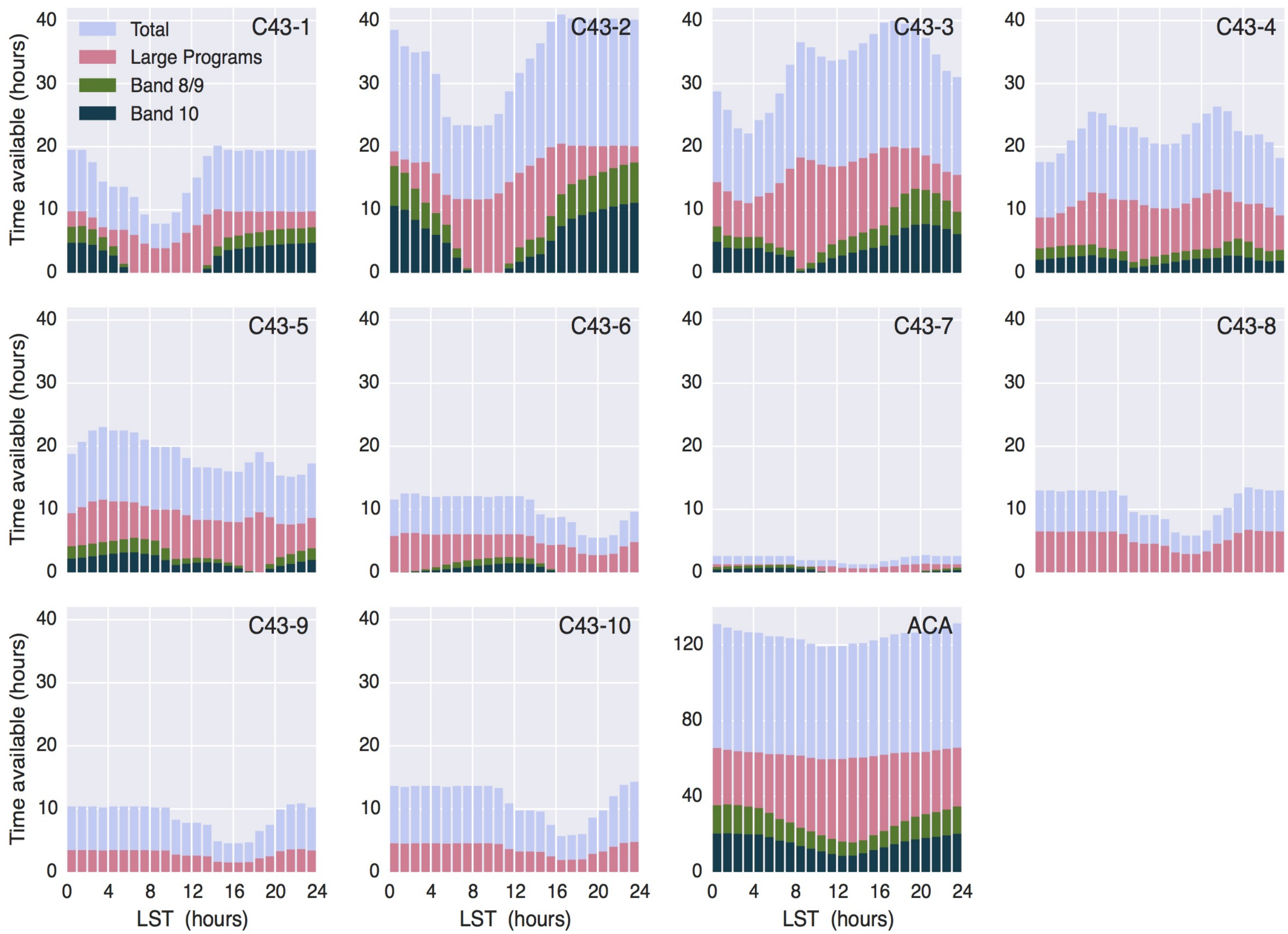
Start date	Configuration	Longest baseline	LST for best observing conditions
2017 October 1	C43-7	3.7 km	~ 21h - 10h
2017 October 5	C43-8	6.8 km	~ 22h - 11h
2017 October 25	C43-9	12.8 km	~ 23h - 12h
2017 November 10	C43-10	16.5 km	~ 1h - 13h
2017 December 1-18	No observations due to large antenna reconfiguration		
2017 December 19	C43-6	1.8 km	~ 4h - 15h
2018 January 10	C43-5	1.1 km	~ 5h - 17h
2018 February 1-28	No observations due to February shutdown		
2018 March 1	C43-4	0.7 km	~ 8h - 21h
2018 March 30	C43-3	0.46 km	~ 10h - 0h
2018 May 15	C43-2	0.27 km	~ 12h - 3h
2018 June 15	C43-1	0.15 km	~ 14h - 5h
2018 July 15	C43-2	0.27 km	~ 17h - 7h
2018 August 15	C43-3	0.46 km	~ 18h - 8h
2018 August 30	C43-4	0.7 km	~ 19h - 9h
2018 September 15	C43-5	1.1 km	~ 20h - 10h

ALMA Observing Strategies (Cycle 5)



Histograms of the percentage of time when the precipitable water vapor is below the observing thresholds adopted for the various ALMA bands. The PWV measurements were obtained by the APEX weather station between 2007 and 2016. Results are shown for nighttime (top) and daytime (bottom) observations assuming a source elevation of 60 deg.

ALMA Observing Strategies (Cycle 5)



Histograms of the anticipated amount of observing time available versus LST for the antenna configurations in Cycle 5. Also shown are histograms of the time available for Large Programs, as well as high frequency observations (Bands 8, 9, and 10) based on historical PWV data

ALMA 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

www.nrao.edu
science.nrao.edu