National Radio Astronomy Observatory

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Carnegie DTM

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

Associated Universities, Inc.

NSF

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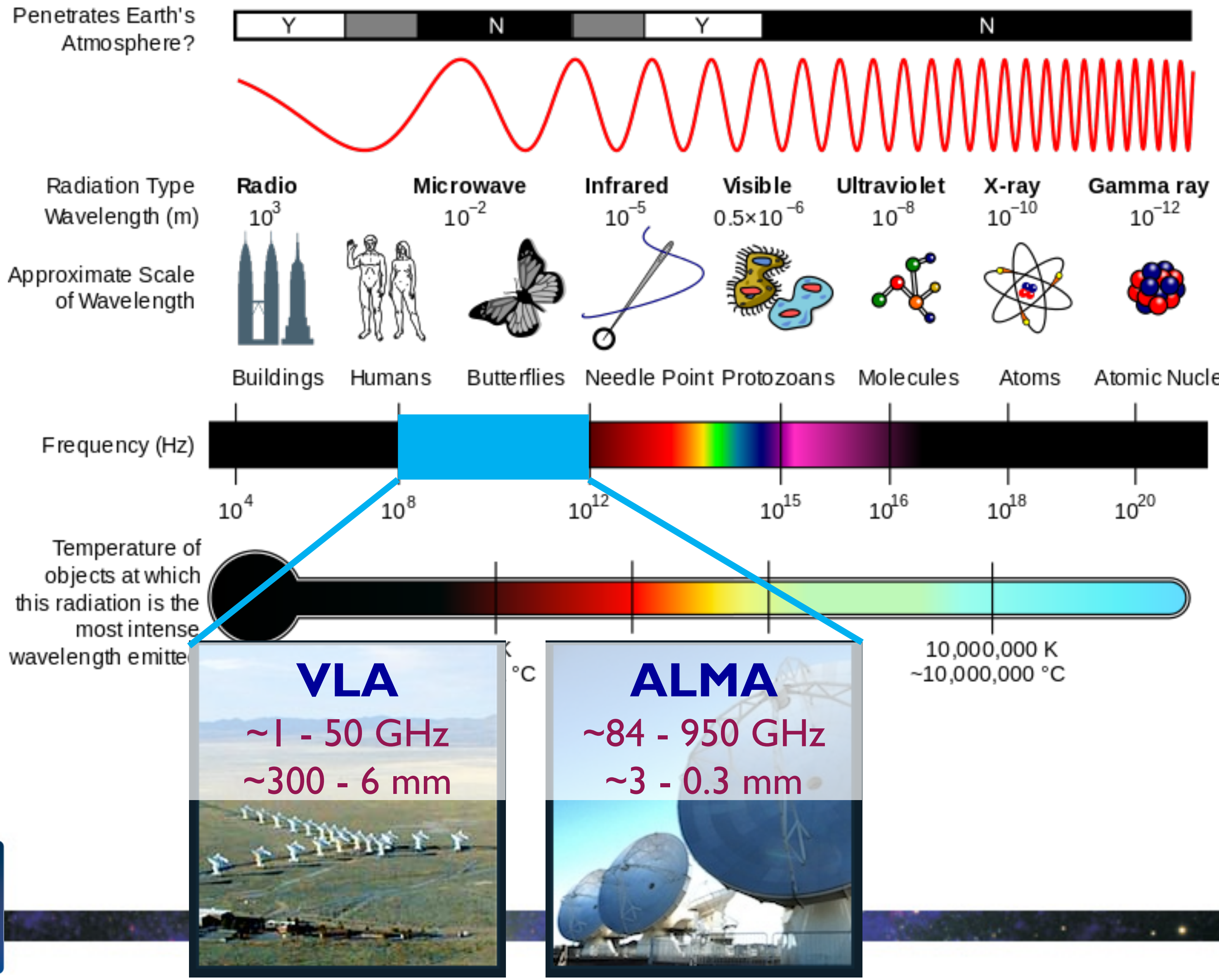
NRAO: One Observatory, Two World Class Facilities

ALMA
Atacama Large Millimeter/ submillimeter Array

VLA
Karl G. Jansky Very Large Array

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

What Are Radio Wavelengths?



What Can We Observe in the Radio?

Sun	coronal mass ejections, magnetic field activity
Solar System	atmospheres, astrometry, composition, KBOs
Star-Forming Regions	dust and gas environment, kinematics (infall, outflows, jets), protoplanetary disks, cores, chemistry, feedback
Exoplanets	direct imaging, gaps in disks, kinematics
Pulsars	neutron star physics, pulse morphology, gravity, ISM probe
Galactic Structure	spiral arms, bars, global atomic/molecular gas properties
Nearby Galaxies	molecular/atomic gas content and kinematics, dynamics of galaxies at high resolution, (obscured) star formation, gas properties
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
Cosmology	H_0 measurement, SZE

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What Is ALMA?

A global partnership between North America, Europe, and East Asia to deliver a revolutionary millimeter/submillimeter telescope array (in collaboration with Chile)

Provides unprecedented imaging and spectroscopic capabilities at millimeter wavelengths

ALMA by the Numbers:

Elevation = 5000 m

Number of Antennas = 66

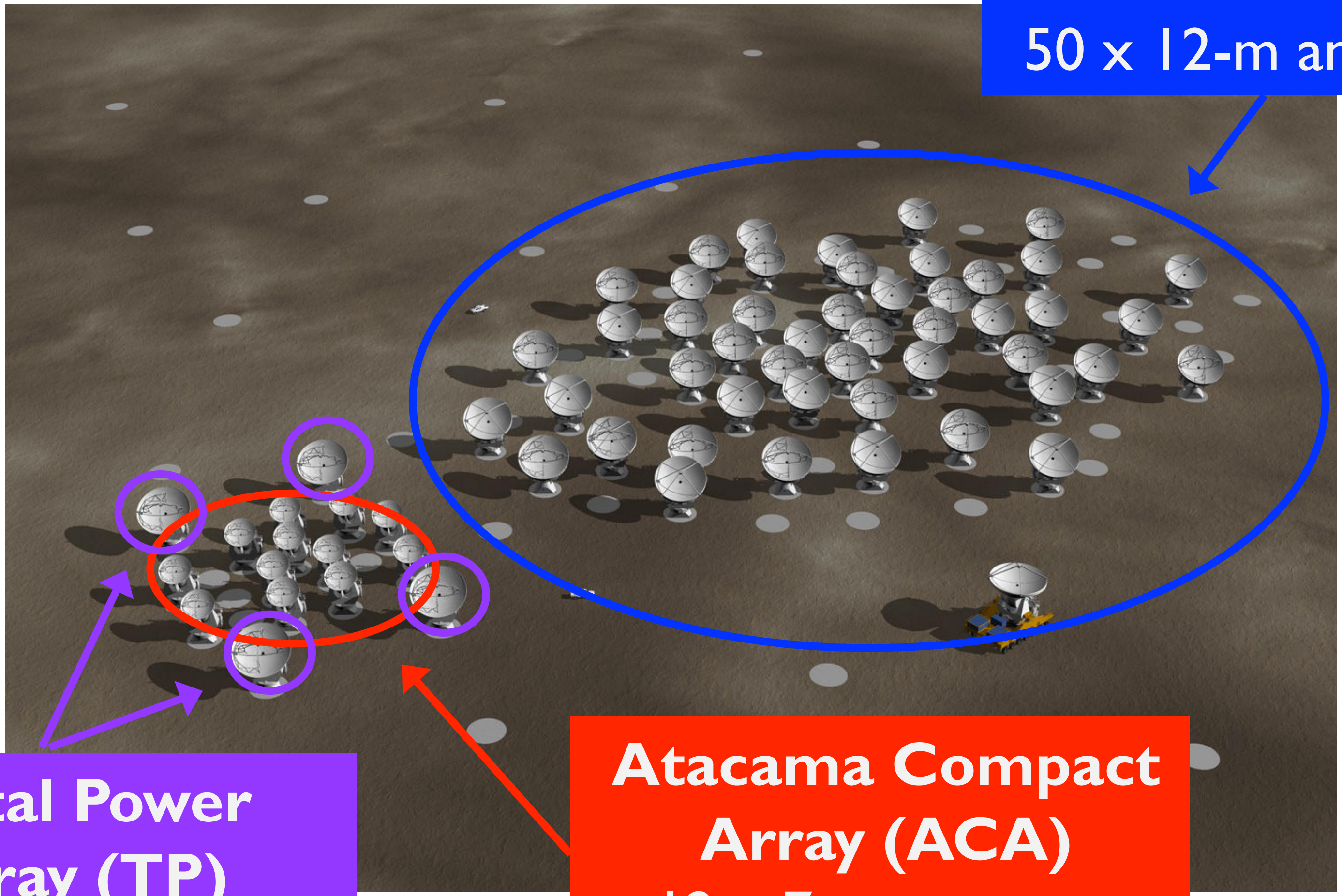
Baselines = 150 m to >16 km

Antenna Locations = 192

Wavelengths = 0.32 – 8.5 mm

Best Resolution = 0.015″ (at 300 GHz)

Array Configurations



Main Array
50 x 12-m antennas

Total Power Array (TP)
4 x 12-m antennas

Atacama Compact Array (ACA)
12 x 7-m antennas

**TP + ACA = Morita Array*

Array Configurations

A 'DC-Centric' View of ALMA Configurations…

Most compact configuration = White House Ellipse

Most extended = Washington Beltway

ALMA Current Status

Construction ended in September 2014

Some construction/verification remains (e.g., wide-field polarization, some modes)

All 66 antennas accepted

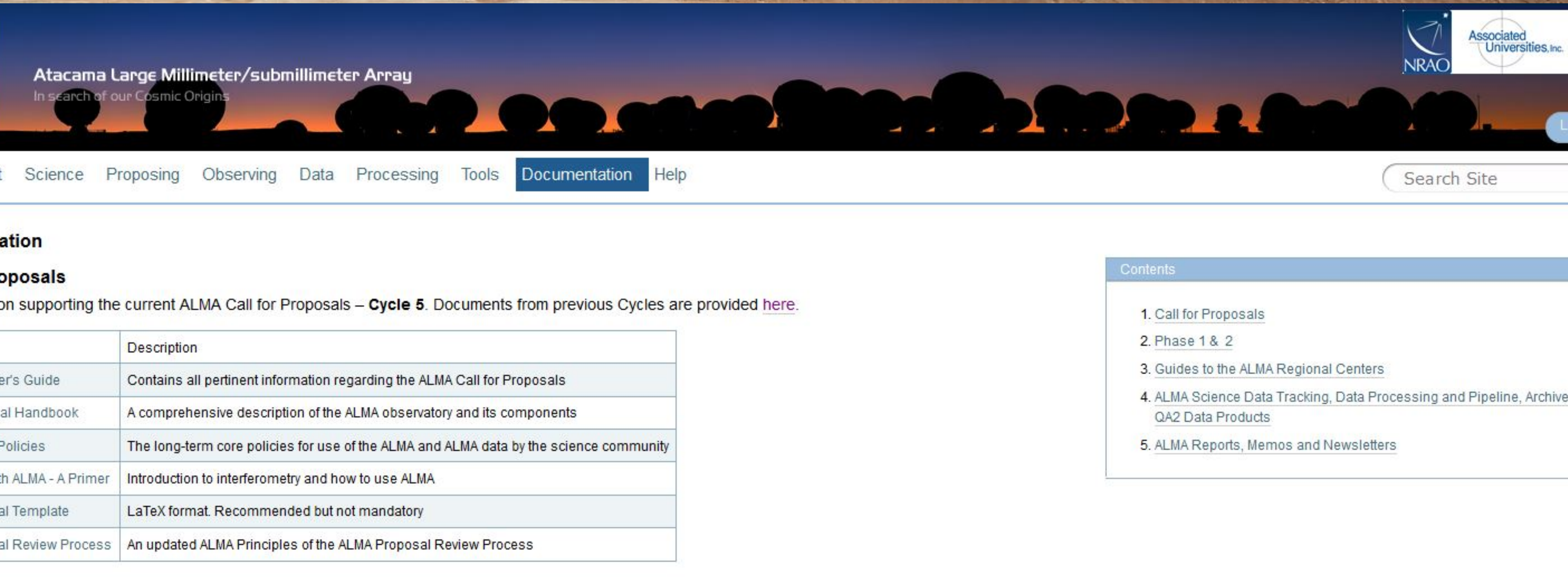
~47 on average (up to max ~54) are being used for Cycle 5 observations

Routine science observing with baselines >12 km (C40-9)

Long Baseline Campaingns in 2014 and 2015

ACA and TP observations currently being used in Cycle 5

ALMA is a telescope for *ALL* astronomers



Atacama Large Millimeter/submillimeter Array

In search of our Cosmic Origins

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t Science Proposing Observing Data Processing Tools **Documentation** Help

Search Site

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oposals

on supporting the current ALMA Call for Proposals – **Cycle 5**. Documents from previous Cycles are provided here.

	Description
er's Guide	Contains all pertinent information regarding the ALMA Call for Proposals
al Handbook	A comprehensive description of the ALMA observatory and its components
Policies	The long-term core policies for use of the ALMA and ALMA data by the science community
th ALMA - A Primer	Introduction to interferometry and how to use ALMA
al Template	LaTeX format. Recommended but not mandatory
al Review Process	An updated ALMA Principles of the ALMA Proposal Review Process

Contents

ALMA Science Highlights

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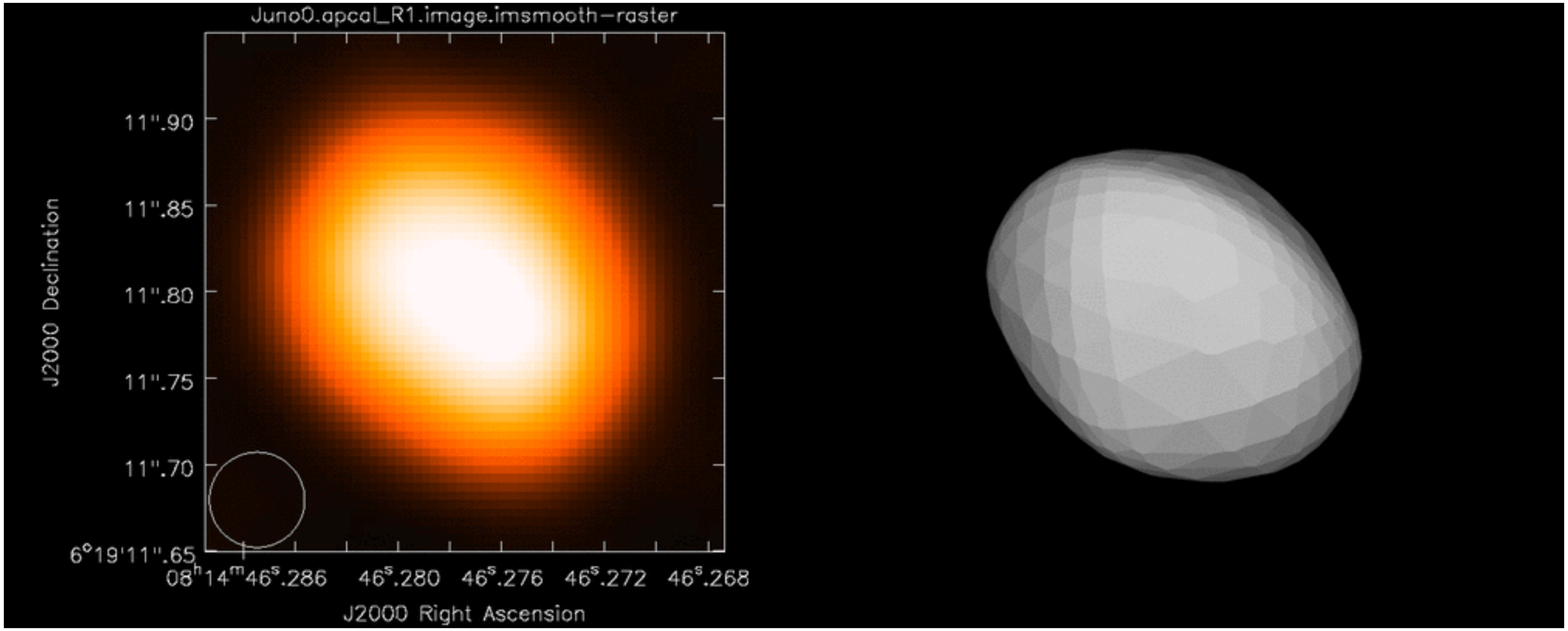
ALMA Images Juno

Science Verification observations in Band 6 (1.3 mm, 233 GHz)

Five consecutive executions over 4.4 hours

Beam size ~0.04″ x 0.03″ (~60 x 45 km)



(ALMA Partnership, Hunter et al. 2015; Model from Durech et al. 2010, 'Database of Asteroid Models from Inversion Techniques')

ALMA Detects Organics on Pluto

CO(3-2) and HCN (4-3) detected in atmosphere

Lines probe abundances and temperature of Pluto's atmosphere

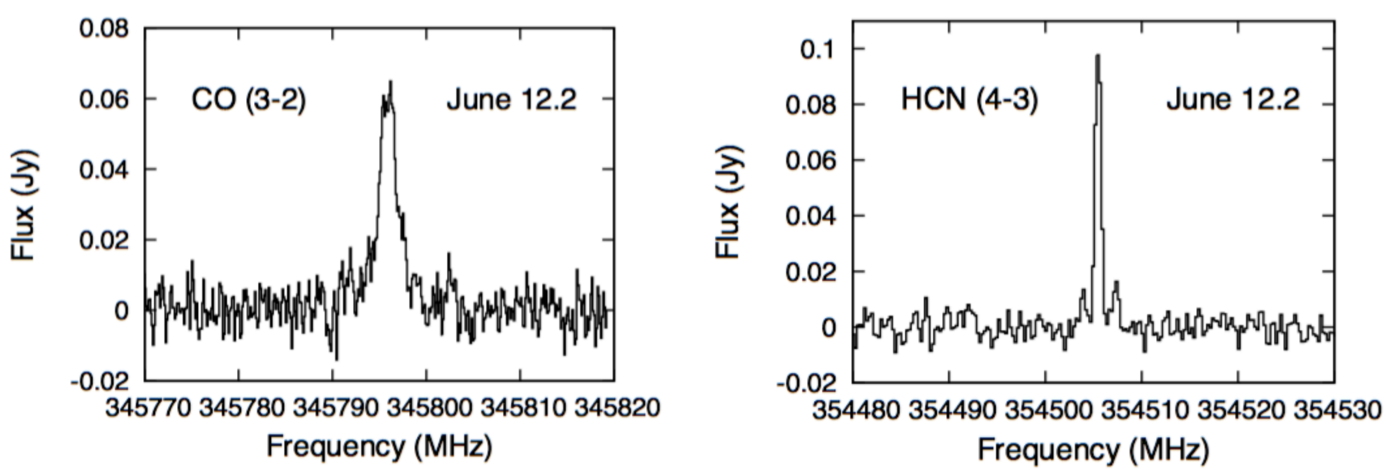
Dayside temperature profile shows decrease (i.e., mesosphere)

Above the 30-50 km stratopause, with T= 70 K at 300 km

In agreement with New Horizons solar occultation data

HCN line shape implies high abundance in upper atmosphere

Suggests a warm (>92 K) upper atmosphere (450 – 800 km)



Lellouche et al. (2016)

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TransNeptunian Object DeeDee

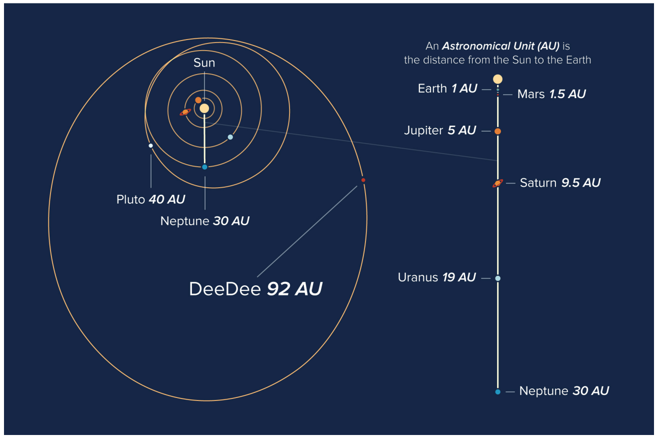
ALMA imaged UZ_{224} (DeeDee) at 1.3 mm

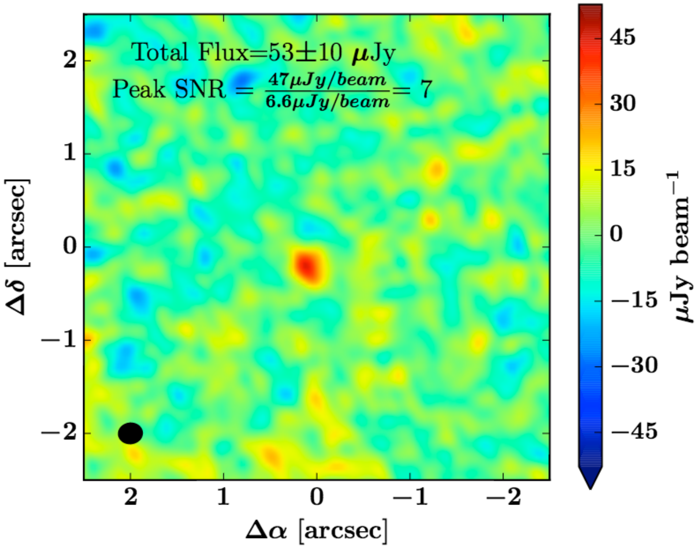
DeeDee is at 92 AU, twice the distance of Pluto

- 2nd most distant confirmed Solar System object with a temperature of 30K

Data suggest a diameter of 635 km, 2/3 that of Ceres

- Very dark with an albedo of 13%





Gerdes et al. (2017)

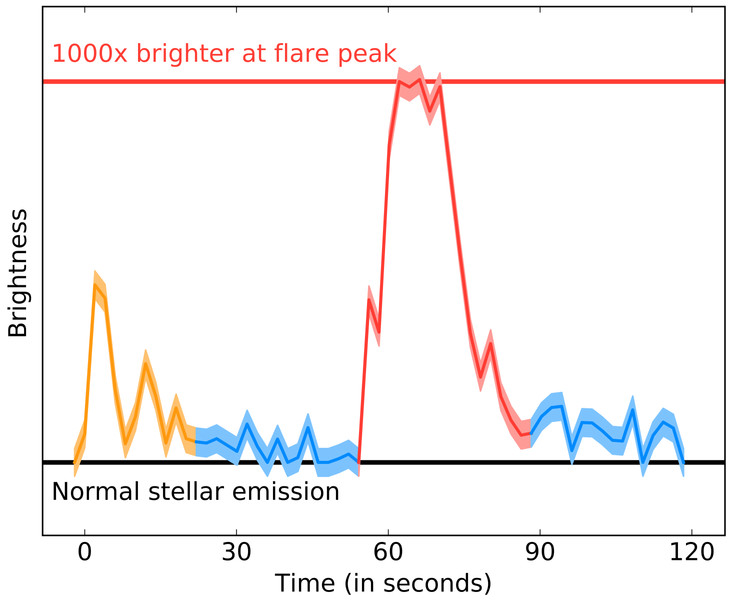
Detection of a Flare from Proxima Cen

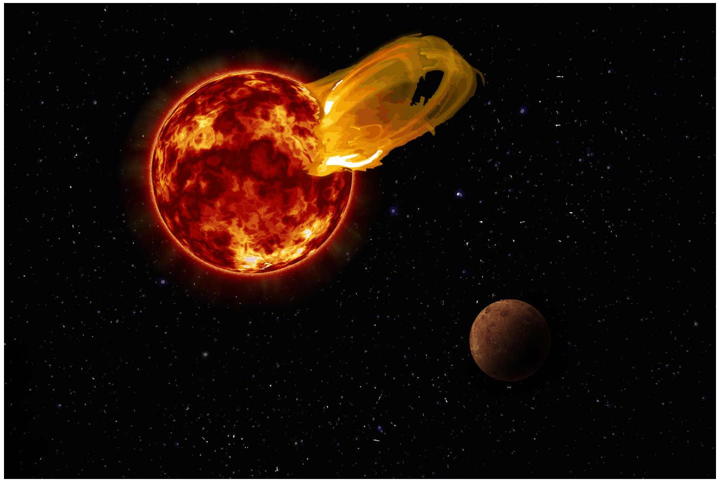
ALMA 12-m and ACA observations at 1.3 mm

Star underwent a significant flaring event, brightening by a factor of 1000

- 10x brighter at peak than solar flares observed at millimeter wavelengths
- Also observe change in polarization and spectral index during the flare

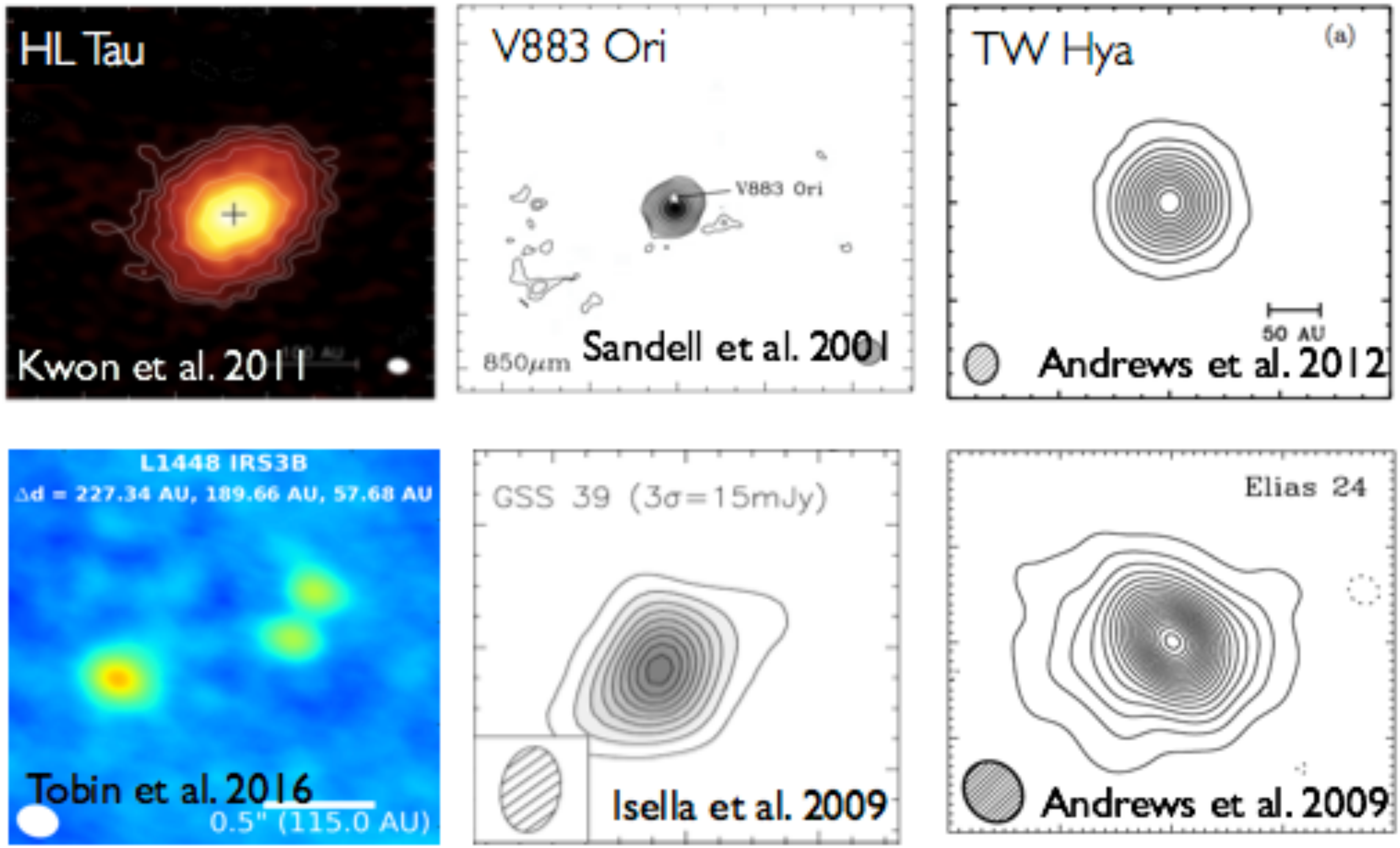
Disproves hypothesis of multiple dust belts in the system



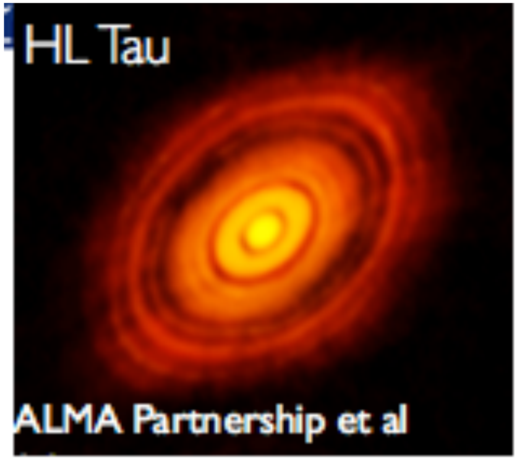


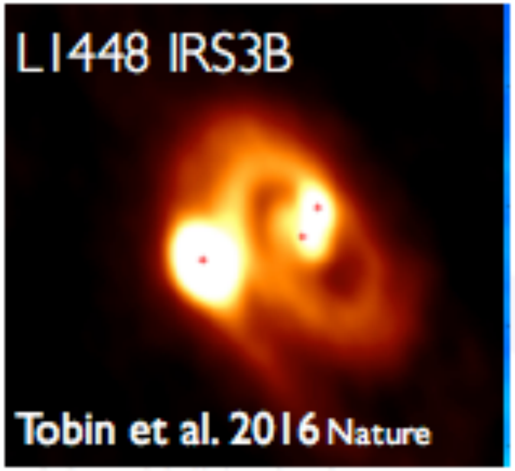
MacGregor et al. (2018)

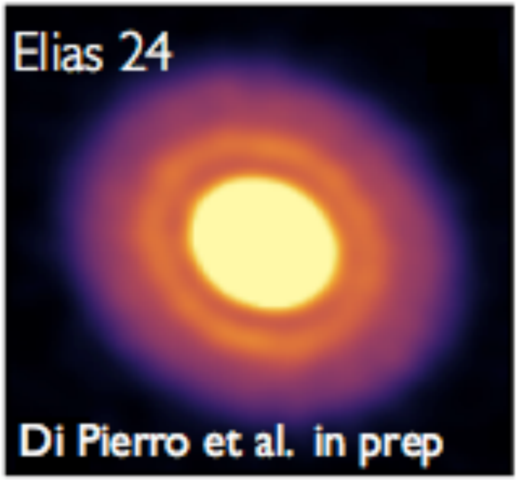
Protoplanetary Disks: Pre-ALMA



Protoplanetary Disks: With ALMA







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ALMA Images TW Hya

Imaged in Band 7 (870 microns)

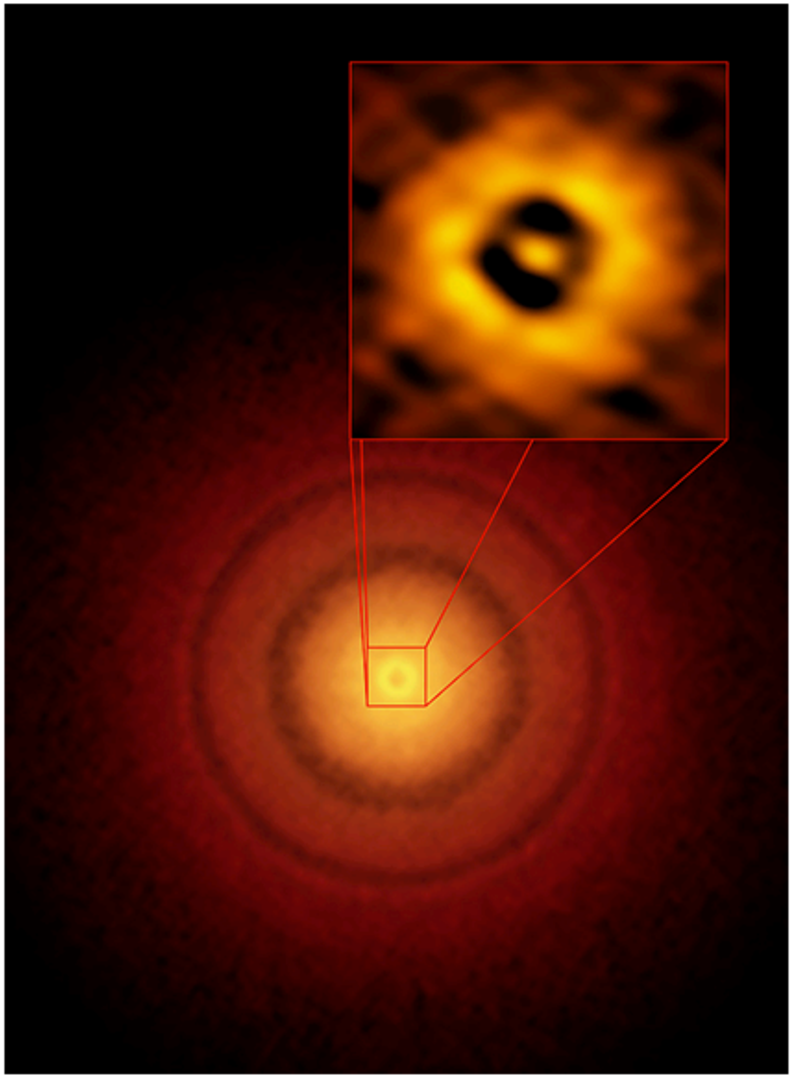
Young (10 Myr-old) system at 175 light years

Series of concentric ring-shaped substructures (1-6 AU wide)

- Concentrations of solids stopped by local gas pressure maxima

Narrow dark annulus located only 1 AU from the star

- Could indicate interactions between the disk and young planets



Andrews et al. 2016

First Map of Fomalhaut Debris Disk

Complete map of disk at 1.3 mm with a 7-pointing mosaic

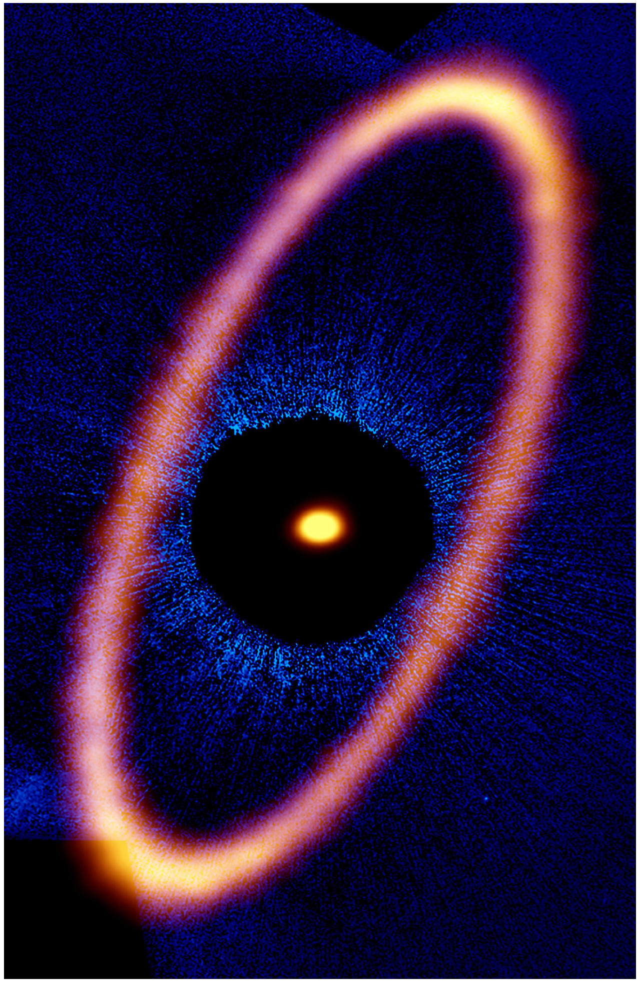
440-Myr-old system at 7.7 pc

- Comparable in age to when our Solar System underwent Late Heavy Bombardment

Disk is radially confined and eccentric (e = 0.12)

First observational evidence for apocenter glow

- Disk appears brighter at apocenter due to a surface density enhancement from bodies on eccentric orbits



MacGregor et al. (2017)

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ALMA Catches Massive Stellar Outburst

NGC6334I-MM1 dust continuum outburst

Dimming of the HCHII region by a factor of 4

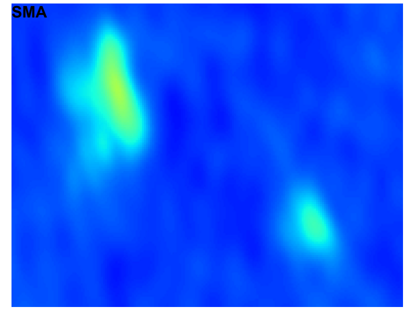
Suppression of UV photons

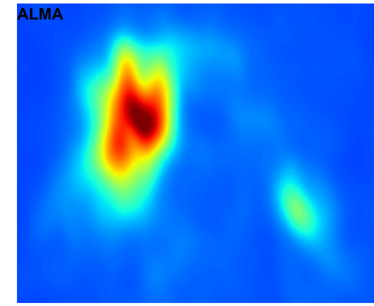
Candidate compact disk/ outflow system

Disk traced by hot SO_2
Outflow traced by $C^{34}S$ and 6 cm jet direction, and maser flare

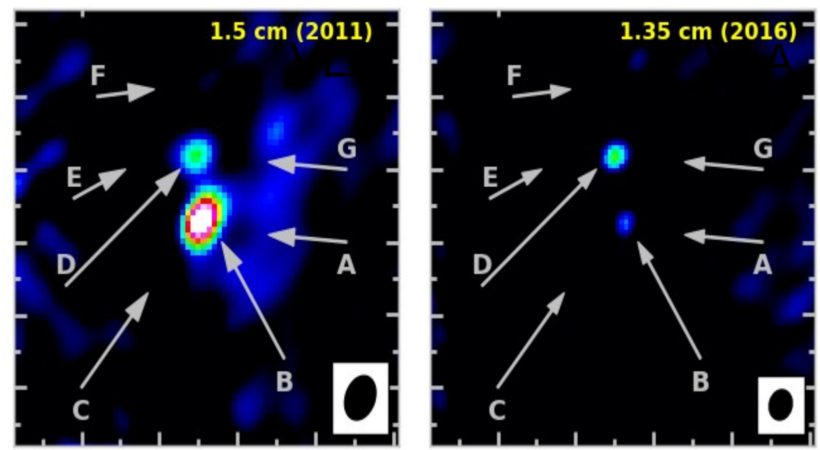
Consistent with a B4 ZAMS star

Accreting >= $0.1 M_{\odot}$ in short period





Pre-outburst **Post-outburst**



Hunter et al. 2017 ApJ 837, L29

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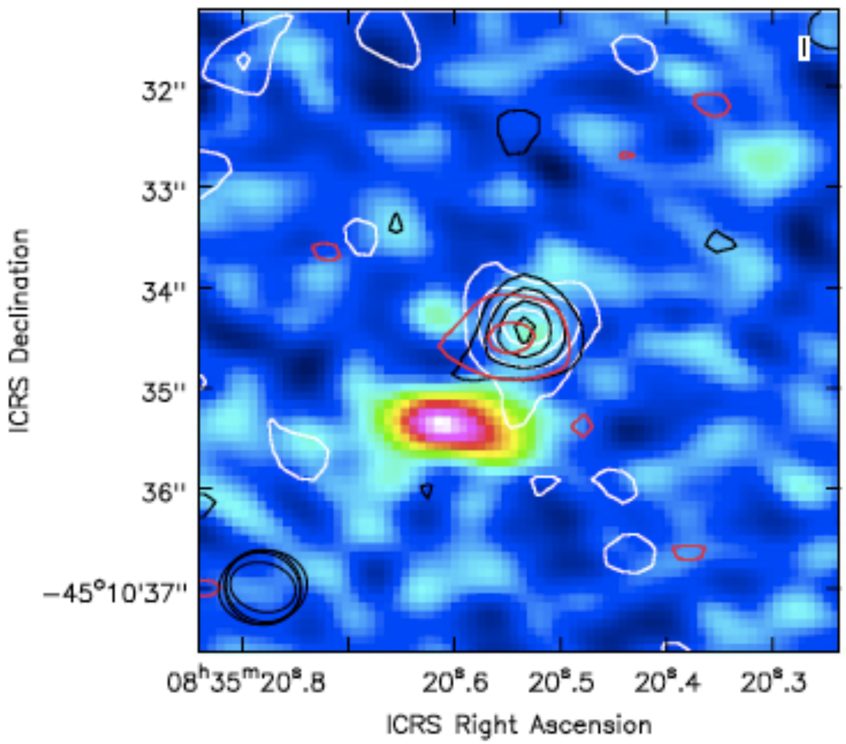
ALMA Images Vela Pulsar

ALMA Development Study results on pulsar observations will appear soon

Detections in non-time resolved mode made of Vela Pulsar, SgrA* magnetar, and Crab Pulsar

- Vela pulsar detected in Bands 3, 4, 6, 7
- Extended structure in Band 7 may be counter jet protruding from pulsar

Allows array to be used as a single receiving station for VLBI



Magnani et al. 2017

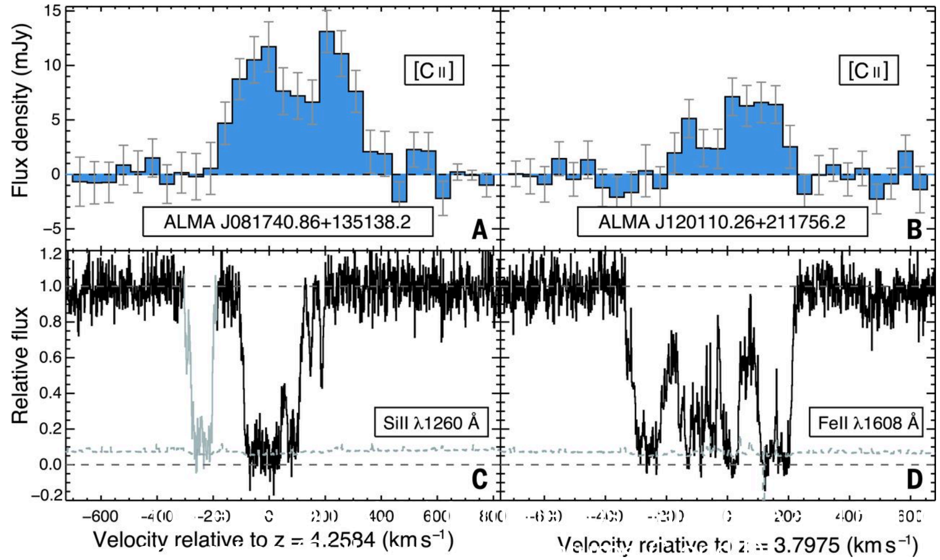
ALMA Bands 3,4,6 (colored contours) on Band 7 image

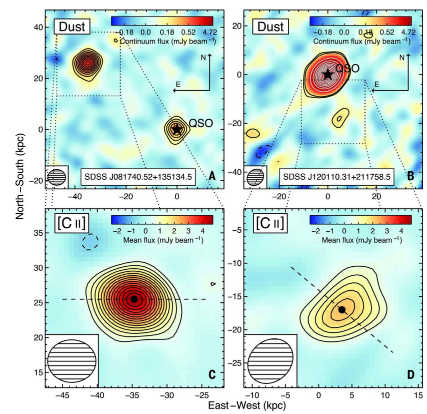
Haloes of Early Milky-Way-like Galaxies

Observed young Milky-Way-like galaxies at z~4 and probed their haloes by measuring even more distant QSOs through them

QSO-galaxy offsets probed the halo beyond ~5 kpc

- Host galaxy has enriched its inner gaseous halo
- Halo is bound to host and will eventually be accreted and enrich star-forming gas



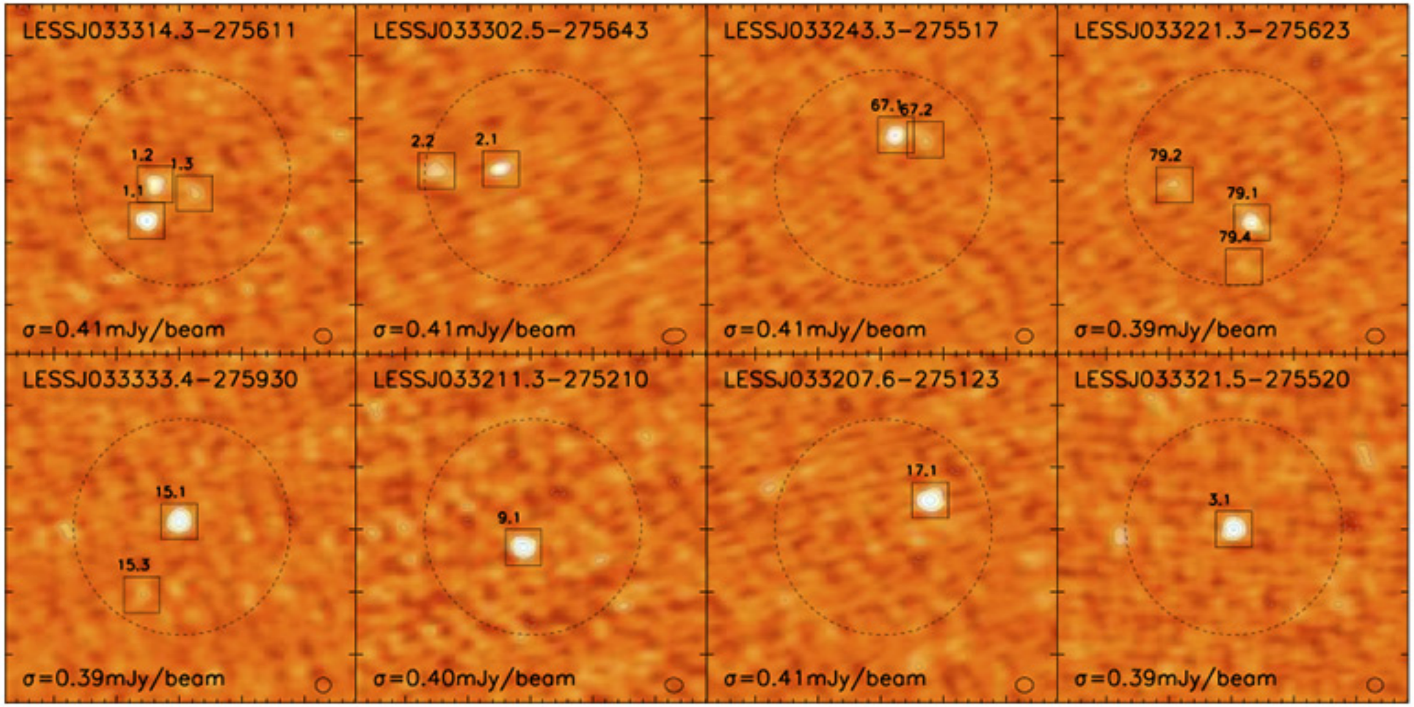


Neeleman et al. (2017)

Above: ~400 GHz continuum emission near two QSOs

Left: Mean flux density over the full [C II] 158-μm line profile

Resolving High-z Submillimeter Galaxies



Hodge et al. (2013)

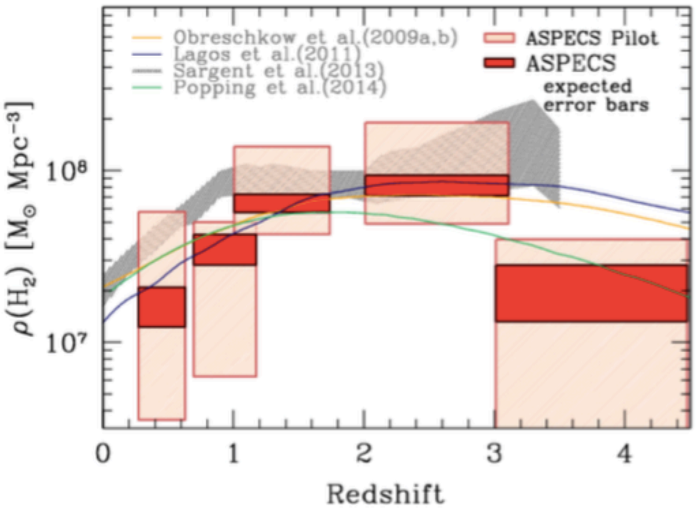
126 submillimeter sources observed with ALMA at 870 μm

2x deeper, 10x higher angular resolution than previous surveys

99 sources detected in 88 fields, integration time ~120 sec (!!)

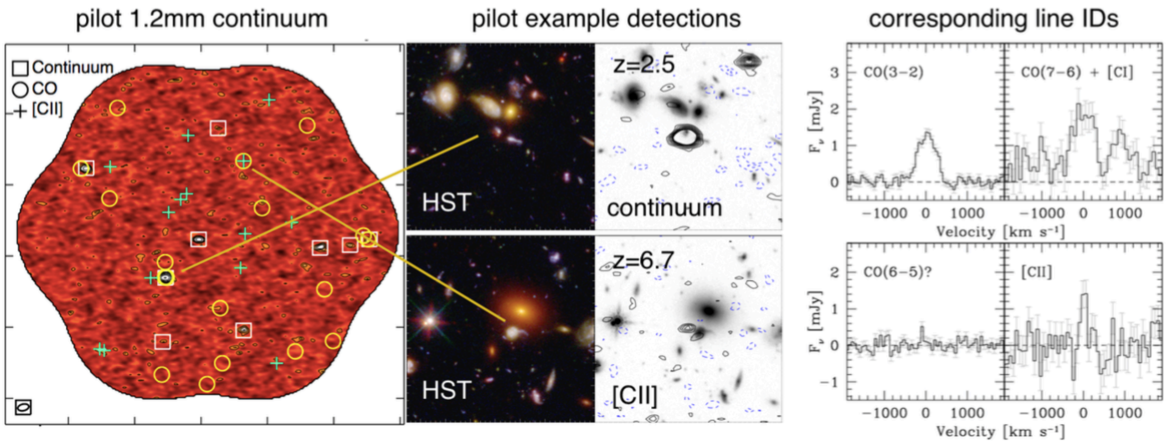
ALMA Deep Fields

Large volume surveys for cold gas throughout the Universe



ASPECS is the first line deep field, involving full frequency scans of Band 3 and 6 in the Hubble UDF

- 21 candidate line galaxies detected
- CO emission at z = 1 to 5, [CII] at z > 6
- 9 dust continuum sources at 1.2 mm



See papers by Walter, Decarli, Aravena

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ALMA Cycle 6 Capabilities

Overview of ALMA Capabilities

Number of Antennas

12-m Array	7-m Array	12-m TP
43 (50)	10 (12)	3 (4)

Receiver Bands and 12-m Array Configurations

Band:	3	4	5	6	7	8	9	10
Wavelength (mm):	3.1	2.1	1.6	1.3	0.87	0.74	0.44	0.35
Frequency (GHz):	100	150	183	230	345	460	650	870
Max Baseline (km):	16	16	16	16	8.5	3.6	3.6	3.6
Max Resolution ("):	0.042	0.028	0.021	0.018	0.028	0.046	0.033	0.024

For future reference, see Appendix A of the ALMA Proposer's Guide available at: https://almascience.nrao.edu/documents-and-tools

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Overview of ALMA Capabilities

Available Observing Time

	12-m Array	7-m Array	12-m TP
Time (hours):	4000*	3000	3000

* Includes DDT, Cycle 5 carryover and resubmissions

Spectral Line, Continuum, and Mosaic Observations

- **Spectral line and continuum:** 12-m Array and the 7-m Array, All Bands
- **Single pointing:** 12-m Array, 7-m Array, All Bands
- **Mosaics:** 12-m Array, 7-m Array, Band 3-9
- **TP spectral line (no continuum):** Bands 3-8

Polarization

- Single pointing, on axis, full (including circular) polarization for both continuum and full-spectral-resolution in Band 3, 4, 5, 6, and 7 offered for 12-m Array
- Minimum detectable degree of circular polarization = 1.8% of peak flux
- Only for on-axis sources with an angular size <10% of FWHM primary beam

New Cycle 6 Capabilities!

Band 6 Bandwidth Increase

Increased by 0.5 GHz for simultaneous observations of ^{12}CO, ^{13}CO, and $C^{18}O$

Circular Polarization

Only for Band 3, 4, 5, 6, and 7

Time Simultaneous Observations

Restrictions between 12-m and 7-m Arrays from Cycle 5 lifted

Band 8 as Standard Observing Mode

Allows for ACA-only observations in Band 8

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Standard vs. Non-Standard Modes

What does 'non-standard' mean?

Do not guarantee that observations can be reduced with the standard pipeline

~20% of time in Cycle 6 will go to non-standard modes

Non-standard observing modes include …

- Bands 9 and 10 observations
- Band 7 observations with maximum baselines >5 km
- All polarization observations
- Spectral scans
- Bandwidth switching projects (<1 GHz aggregate bandwidth all spectral windows)
- Solar observations
- VLBI observations
- Non-standard calibrations (user-defined calibrations selected in the OT)
- Astrometric Observations

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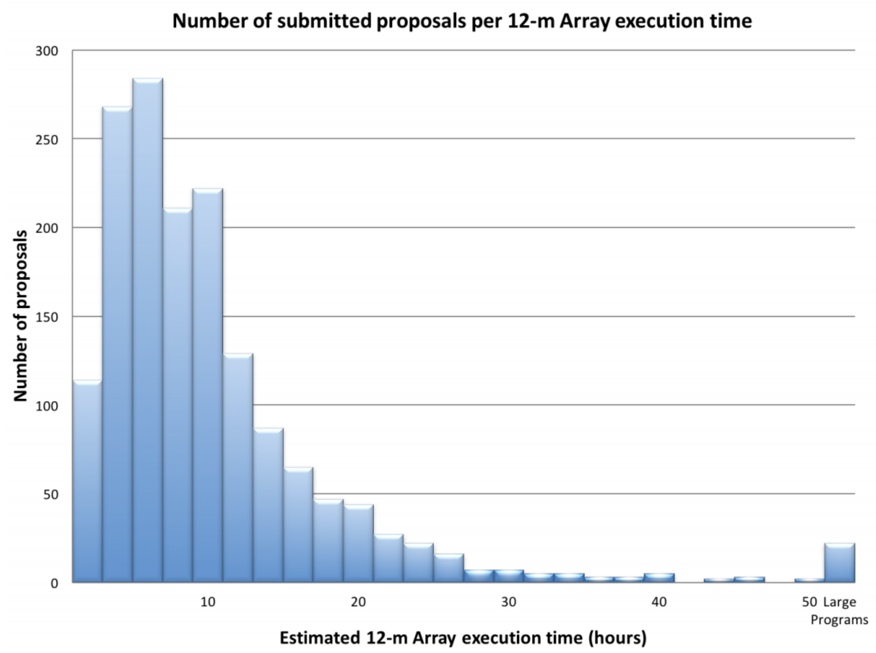
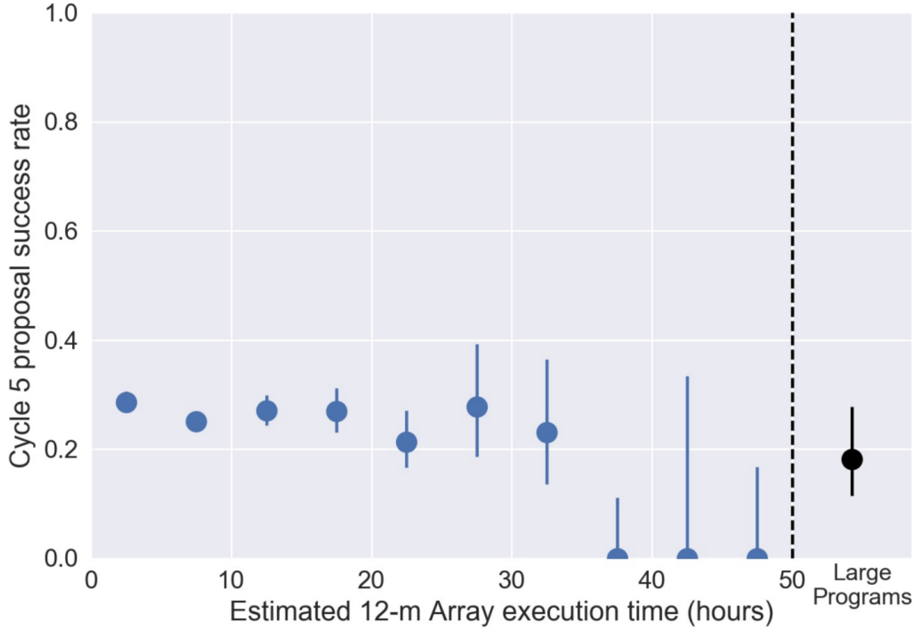
A Note On Proposal Length

Acceptance rate does **NOT** depend on proposal length

Encourage… Medium length 10-25 hour proposals

ACA-only proposals





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ALMA Cycle 6 Timeline

Date	Milestone
20 March 2018 (15:00 UT)	Cycle 6 Call for Proposals, Observing Tool & supporting documents are released Archive opens for proposal submission
19 April 2018 (15:00 UT)	Proposals due!!!
End of July 2018	Results of the proposal review process announced
10 September 2018	PIs submit Phase 2
October 2018	ALMA Cycle 6 science observations start
September 2019	ALMA Cycle 6 ends

Cycle 6 Array Configuration Schedule

Array configuration schedule cycles every few years to accommodate range of LST

Cycle 6: Extended configurations during southern hemisphere winter for more high frequency observations

*NOTE: No PI observing in February!

Start date	Configuration	Longest Baseline	LST for best observing conditions
2018 October 1	C43-6	2.5 km	~ 22h – 10h
2018 October 15	C43-5	1.4 km	~ 0h – 12h
2018 November 25	C43-4	0.78 km	~ 2h – 14h
2018 December 15	C43-3	0.50 km	~ 4h – 15h
2019 January 5	C43-2	0.31 km	~ 5h – 16h
2019 January 20	C43-1	0.16 km	~ 6h – 17h
2019 February 1-28	No observations due to February shutdown		
2019 March 1	C43-1	0.16 km	~ 8h – 21h
2019 March 15	C43-2	0.31 km	~ 8h – 22h
2019 April 1	C43-3	0.50 km	~ 9h – 23h
2019 April 15	C43-4	0.78 km	~ 10h – 0h
2019 May 1-31	No observations due to major antenna relocation		
2019 June 1	C43-10	16.2 km	~ 13h – 3h
2019 June 20	C43-9	13.9 km	~ 14h – 5h
2019 July 10	C43-8	8.5 km	~ 16h – 6h
2019 August 1	C43-7	3.6 km	~ 18h – 8h
2019 September 5	C43-6	2.5 km	~ 20h – 9h

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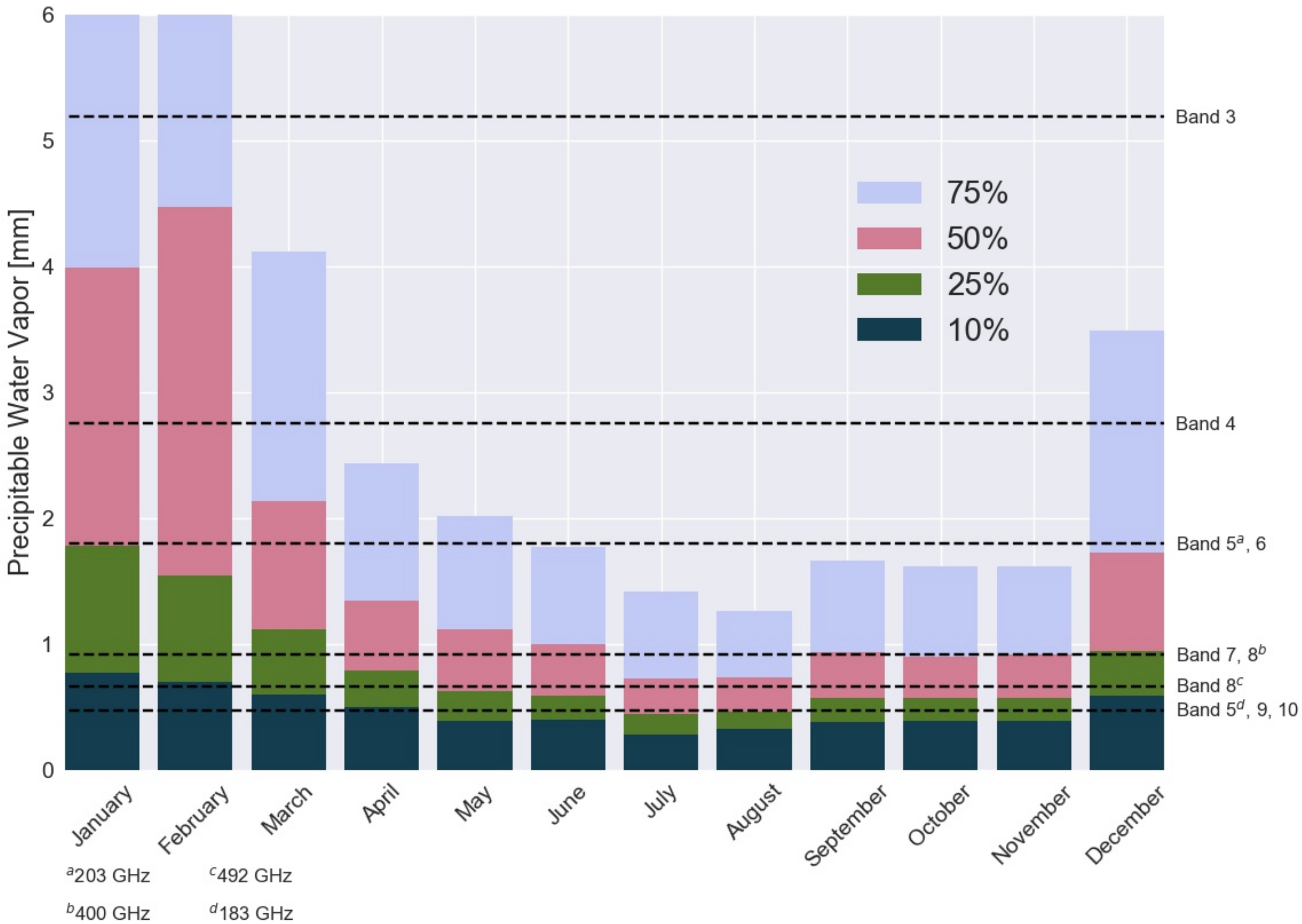
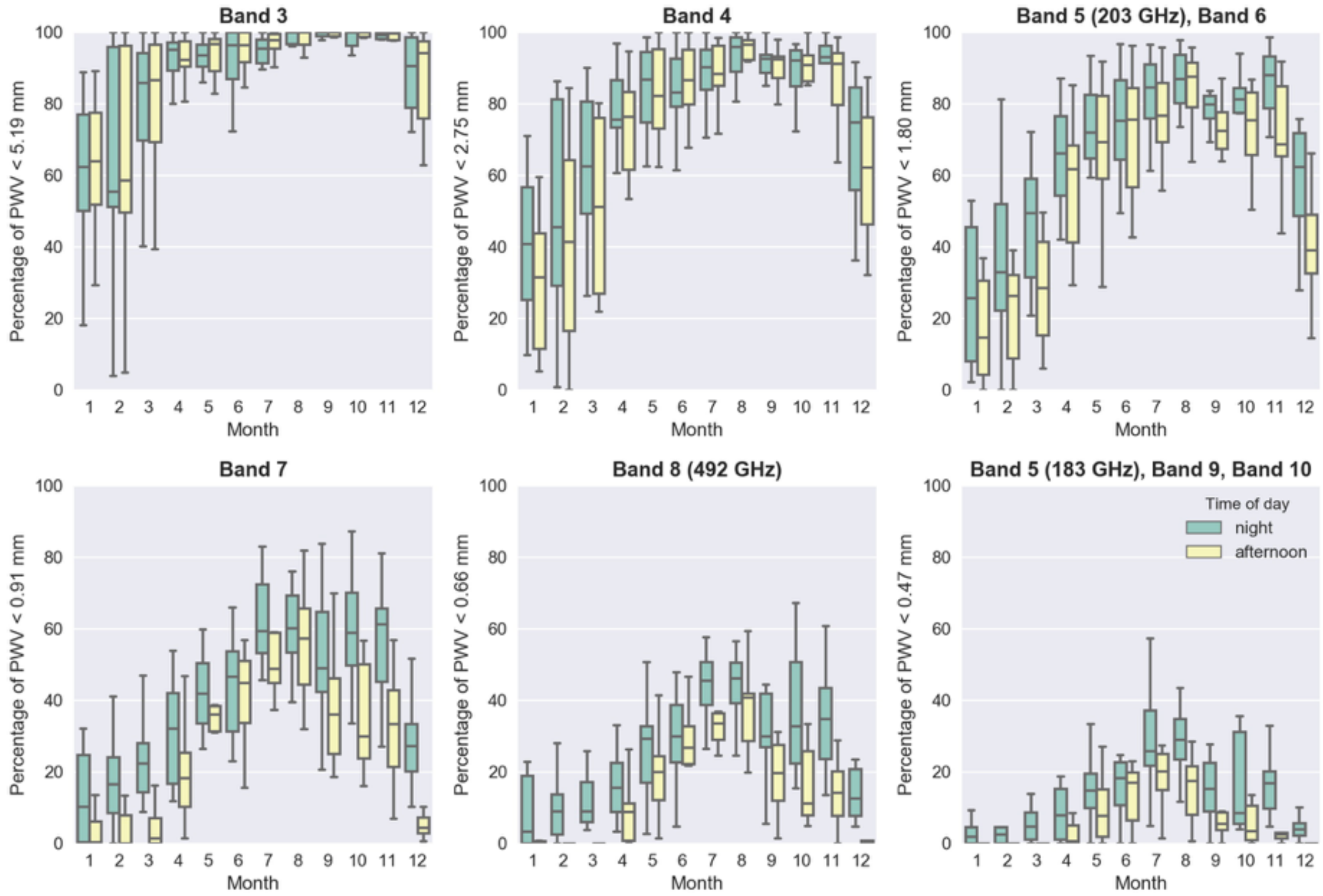
ALMA Weather Conditions



Best observing weather in June through August

ALMA Weather Conditions



Can observe in Band 3 and 4 nearly all of the time

Band 5, 8, and 9 are *hard* nearly all of the time

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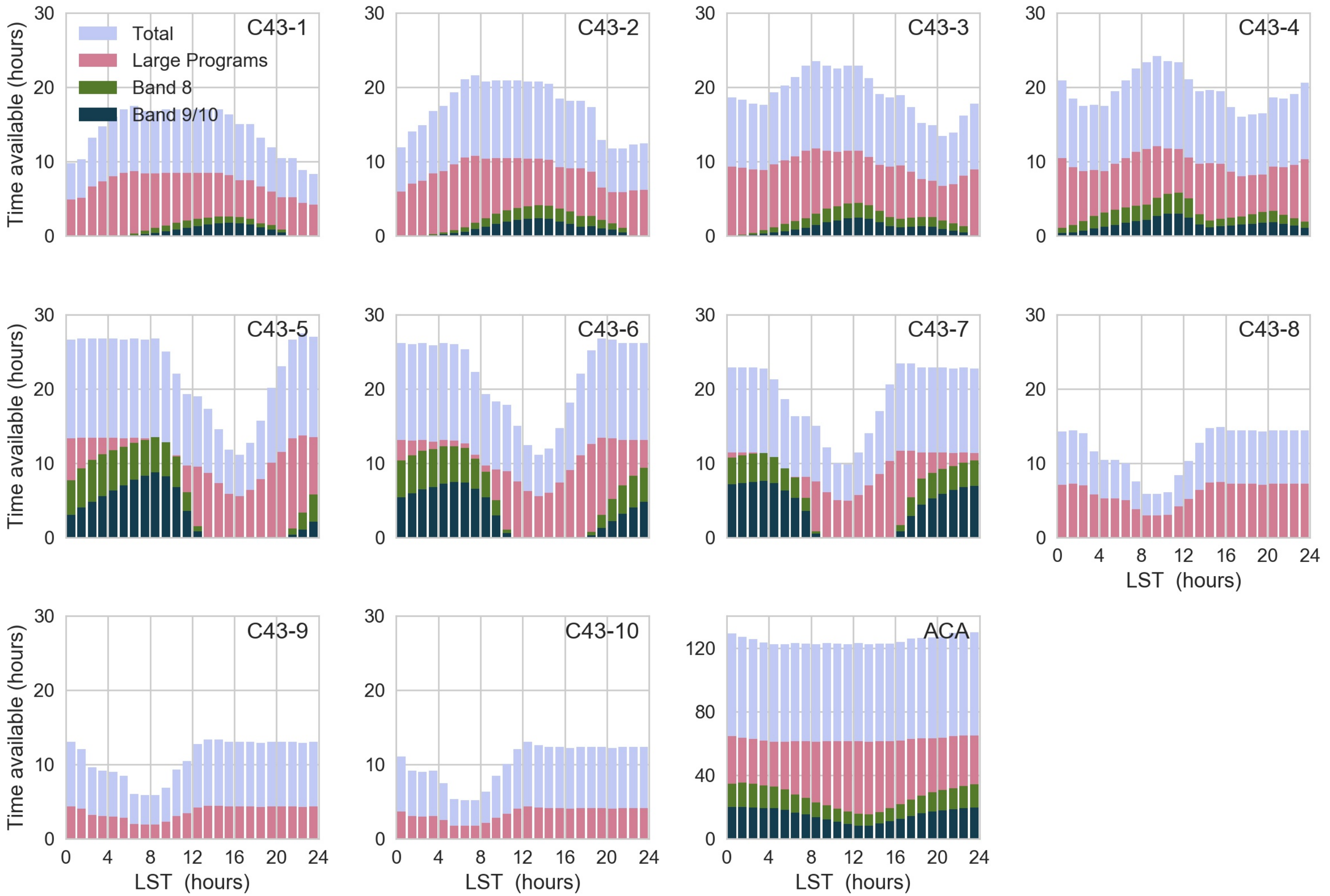
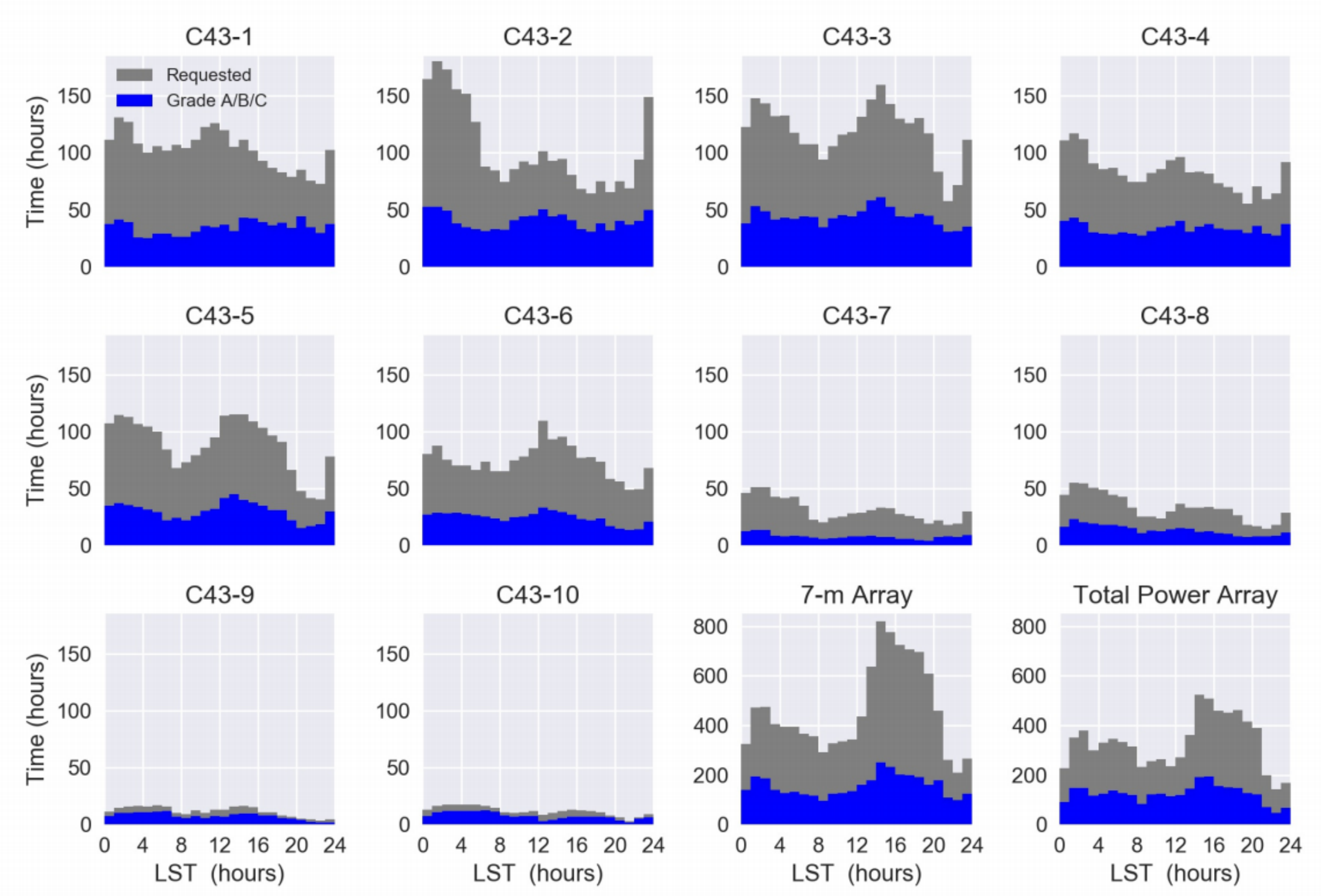
Available Observing Time



Less time available in Bands 8, 9, and 10

Available Observing Time



Less time available in more extended configurations

But, don't hesitate to ask for these configurations if you need them to achieve your science goals

NAASC Sources of Support

ALMA Helpdesk	Questions answered within 48 hours (around the clock staffing in the week leading up to the proposal deadline) https://help.almascience.org
Student Observing Support	Up to $35k to support undergraduate or graduate student involvement in successful ALMA proposals https://science.nrao.edu/opportunities/student-programs/sos
Page Charges	Support available upon request for authors from US institutions reporting ALMA/VLA results https://library.nrao.edu/pubsup.shtml
Face-to-face Visits	NRAO covers travel expenses for up to 2 people from 2 teams per week to get support for data reduction, proposal preparation, etc. at the NAASC https://science.nrao.edu/facilities/alma/visitors-shortterm
ALMA Ambassadors	You too can become an ALMA Ambassador! https://science.nrao.edu/facilities/alma/ambassadors-program

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