Introduction to ALMA

Ke Zhang

Authors: John Carpenter and others

The Atacama Large Millimeter/ submillimeter Array

What is ALMA?

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

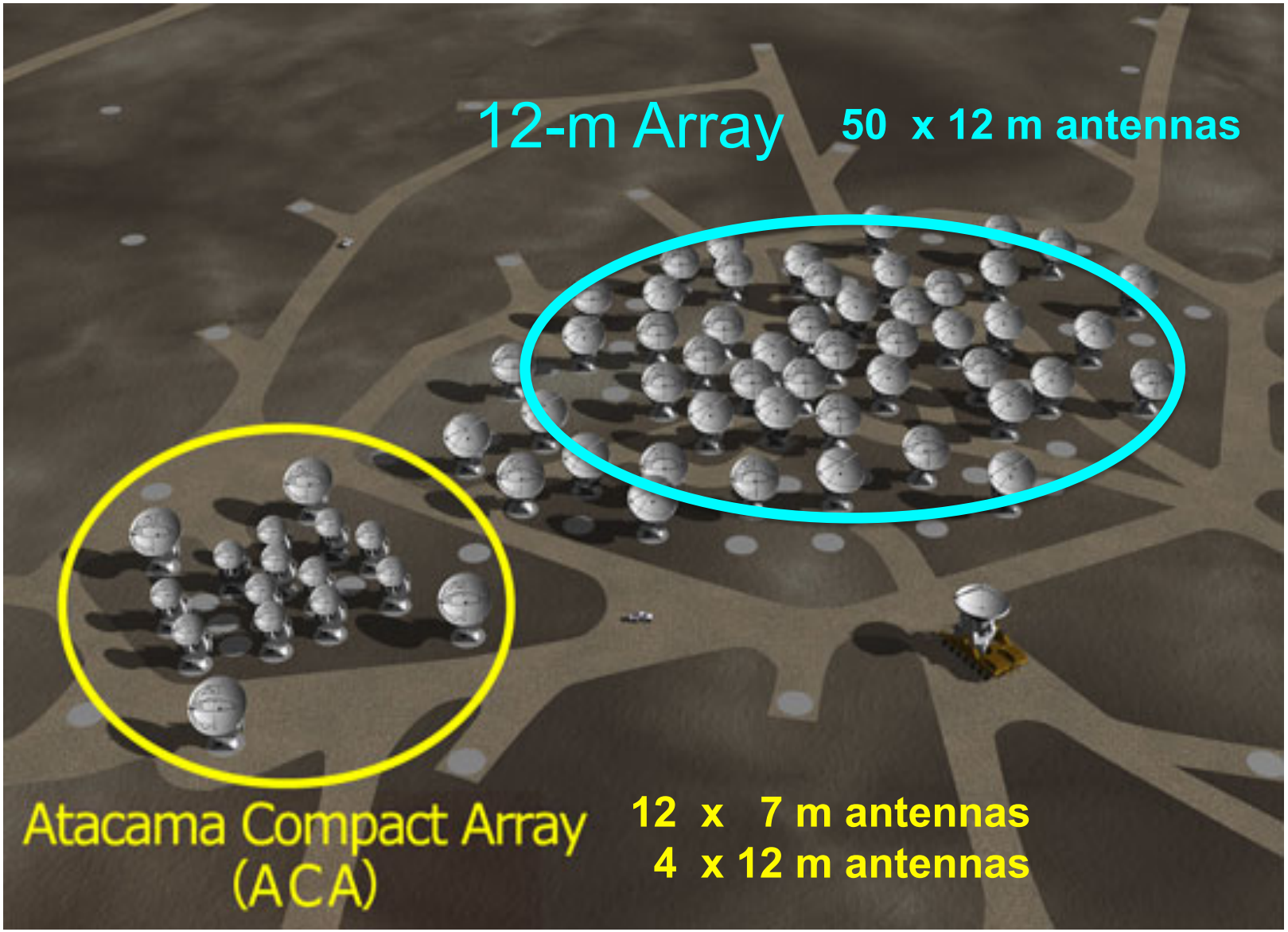
- North America
- Europe
- East Asia

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

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

Provides unprecedented imaging & spectroscopic capabilities at mm/submm λ

What is ALMA?


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

What is ALMA?

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

http://youtu.be/YMISe-C8GUs

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

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

Broad Science Topics with ALMA

- 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
- 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

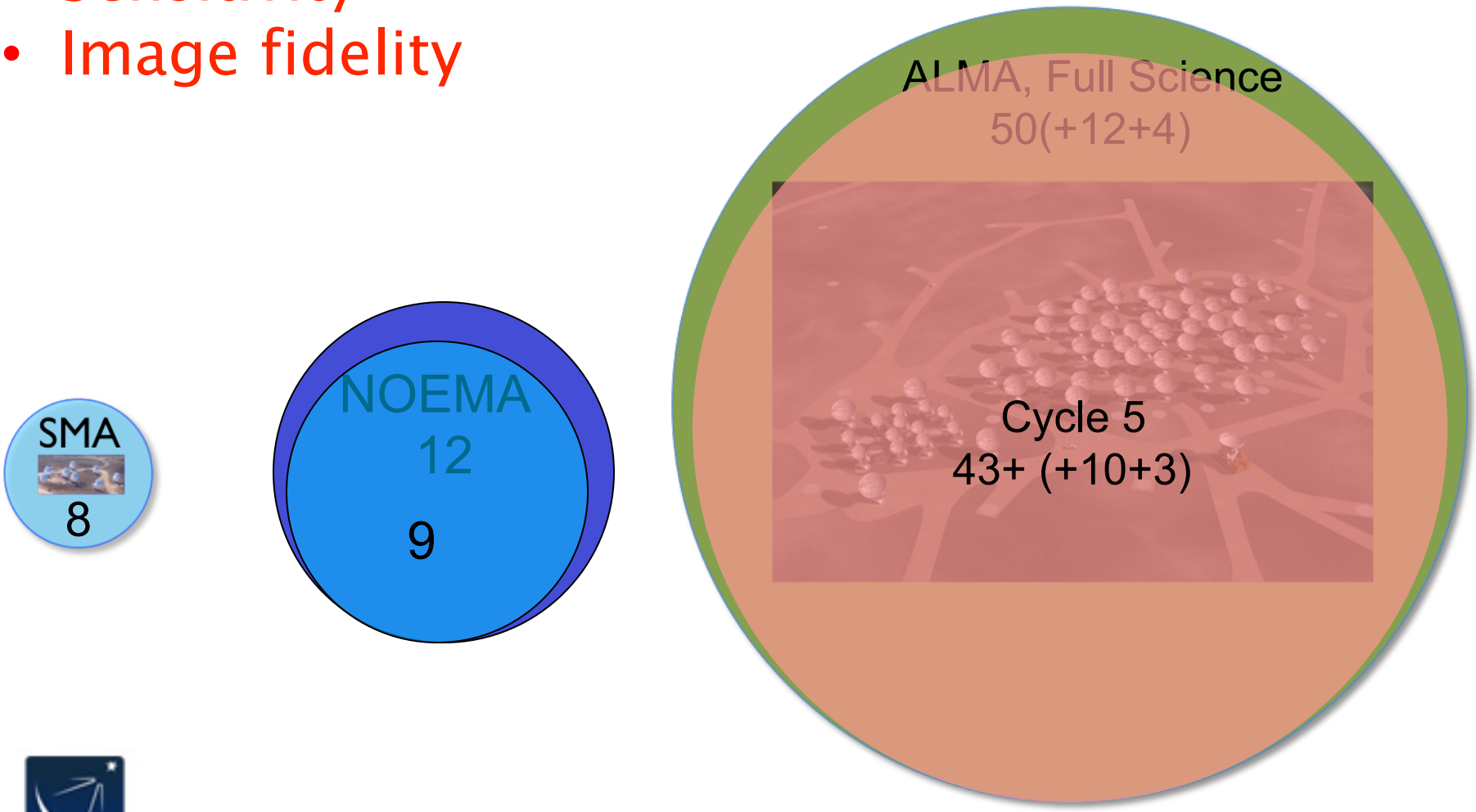
ALMA in a Nutshell...

- 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 1TB/day data rate
- All science data archived
- Pipeline processing

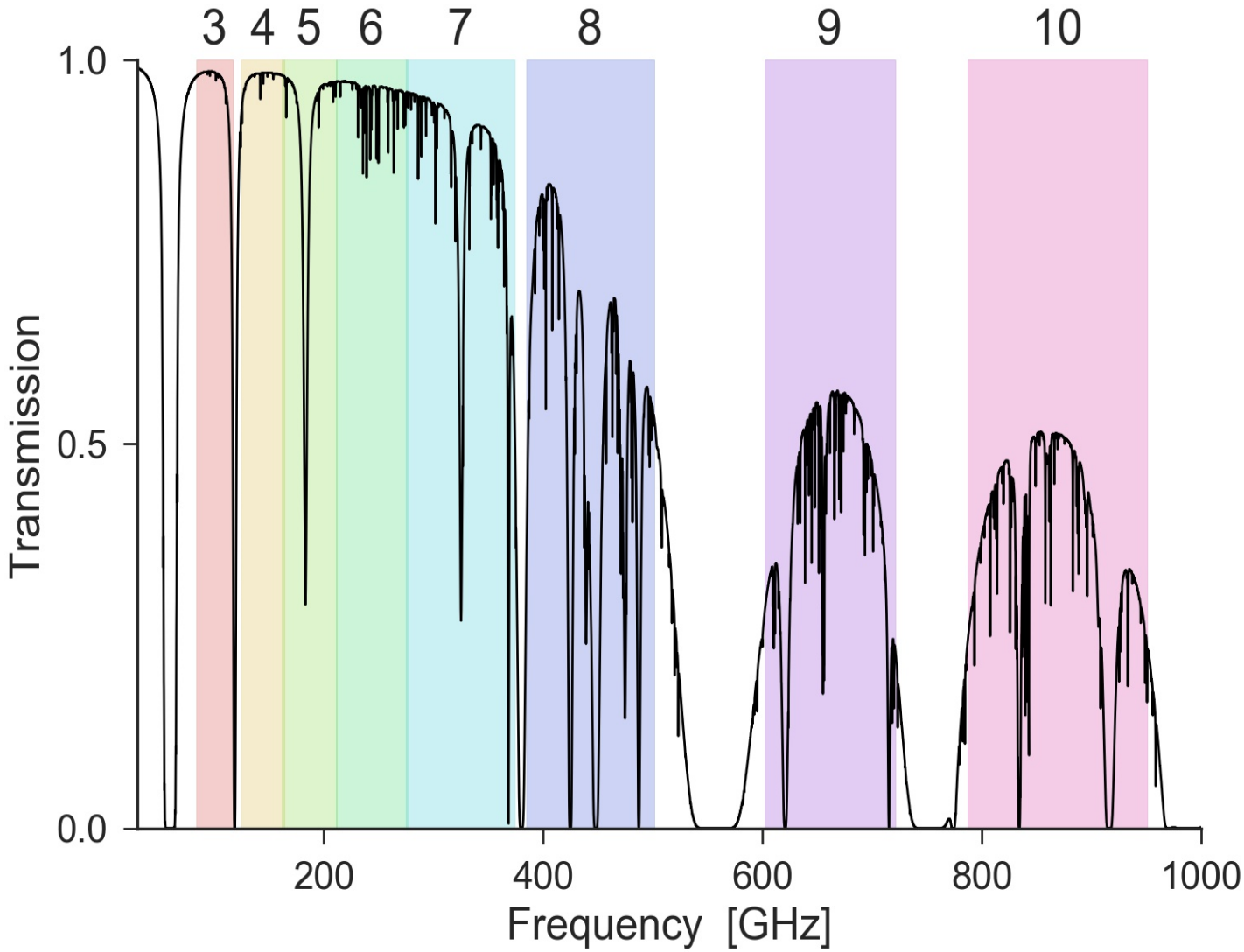
ALMA will be 10-100 times more sensitive and have 10-100 times better angular resolution than current mm interferometers

What is ALMA?

- Collecting Area
- Sensitivity
- Image fidelity



ALMA Receiver Bands in Cycle 5



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) – up to 12x7m antennas and 4x12m antennas for TP observations – has been accepted and is being used for Cycle 4 observations
- More on Capabilities later… however, first on to science!

Amazing science done by ALMA

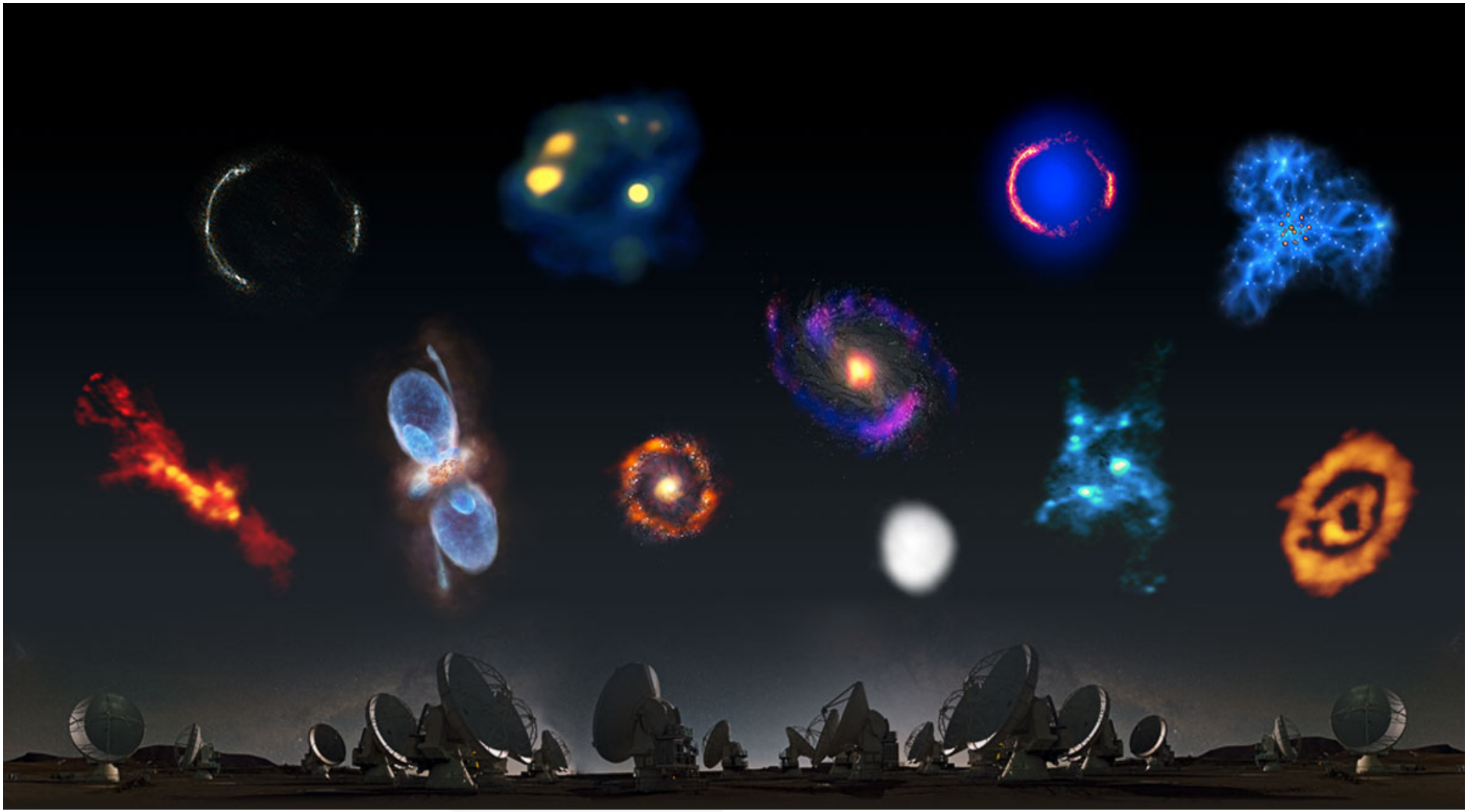
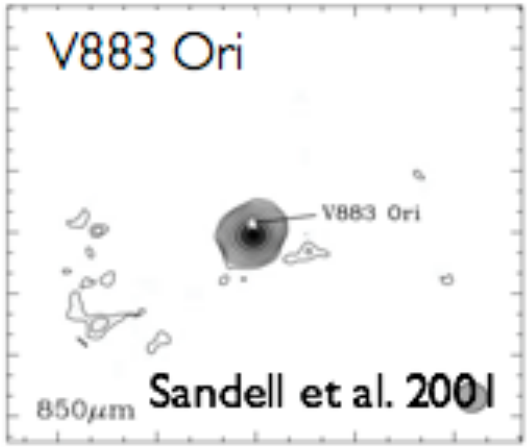
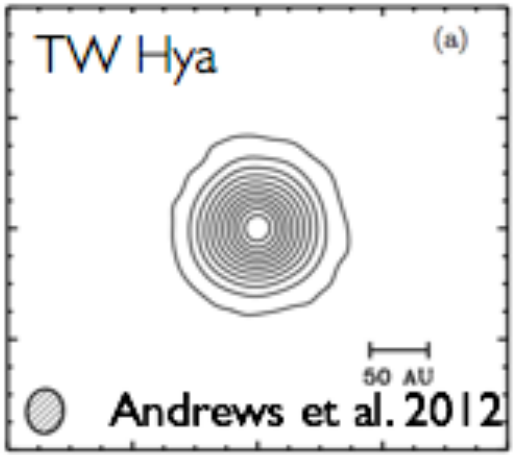


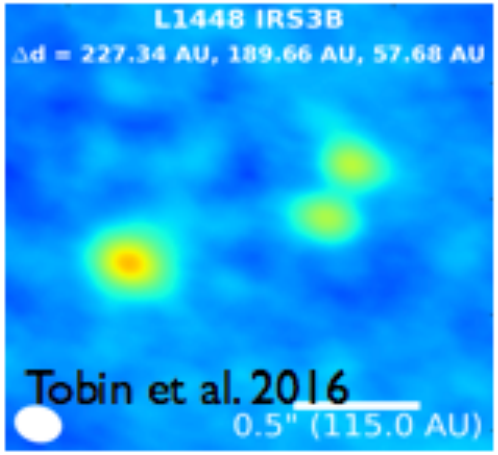
Image from Pierre Cox's talk

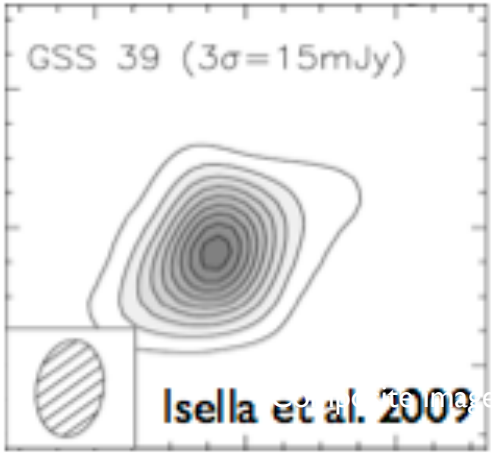
ALMA Science Highlights

Protoplanetary Disks: Pre- ALMA





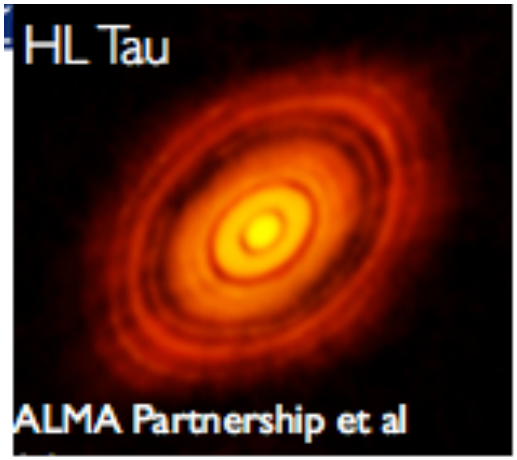


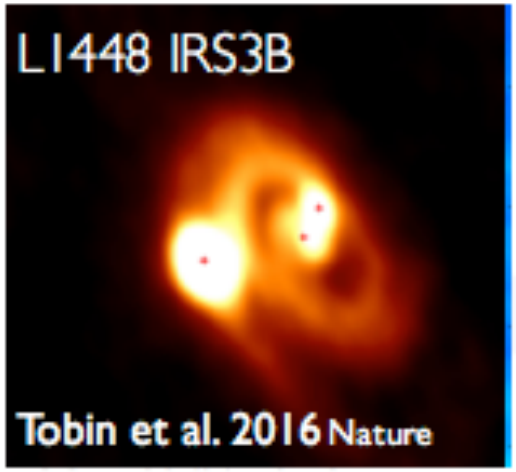


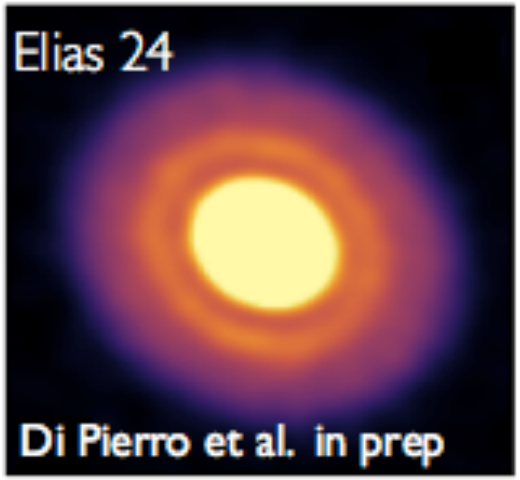
All image courtesy Andrews et al. 2009

ALMA Science Highlights

Protoplanetary Disks: With ALMA





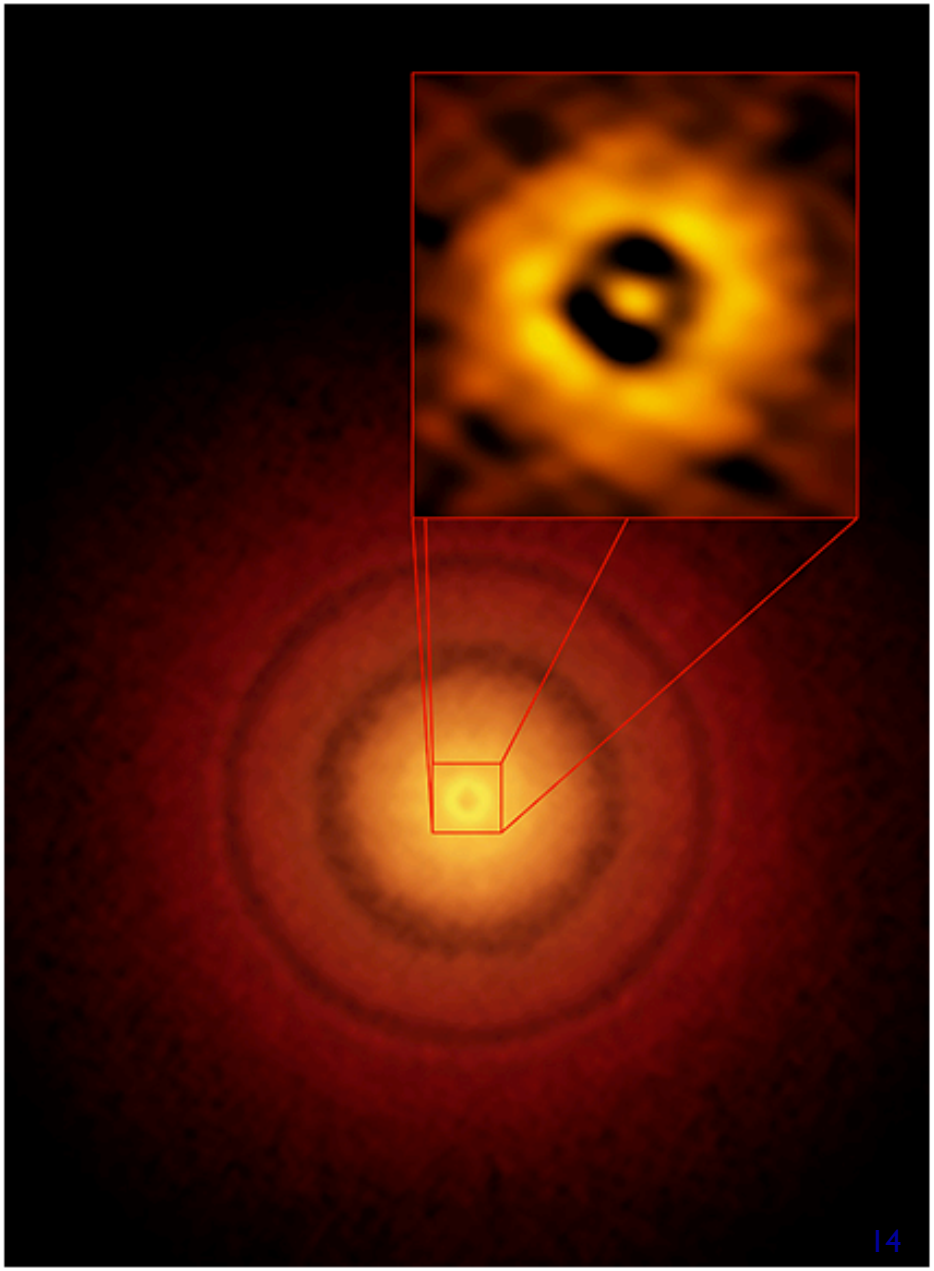


ALMA Science Highlights: Protoplanetary Disks

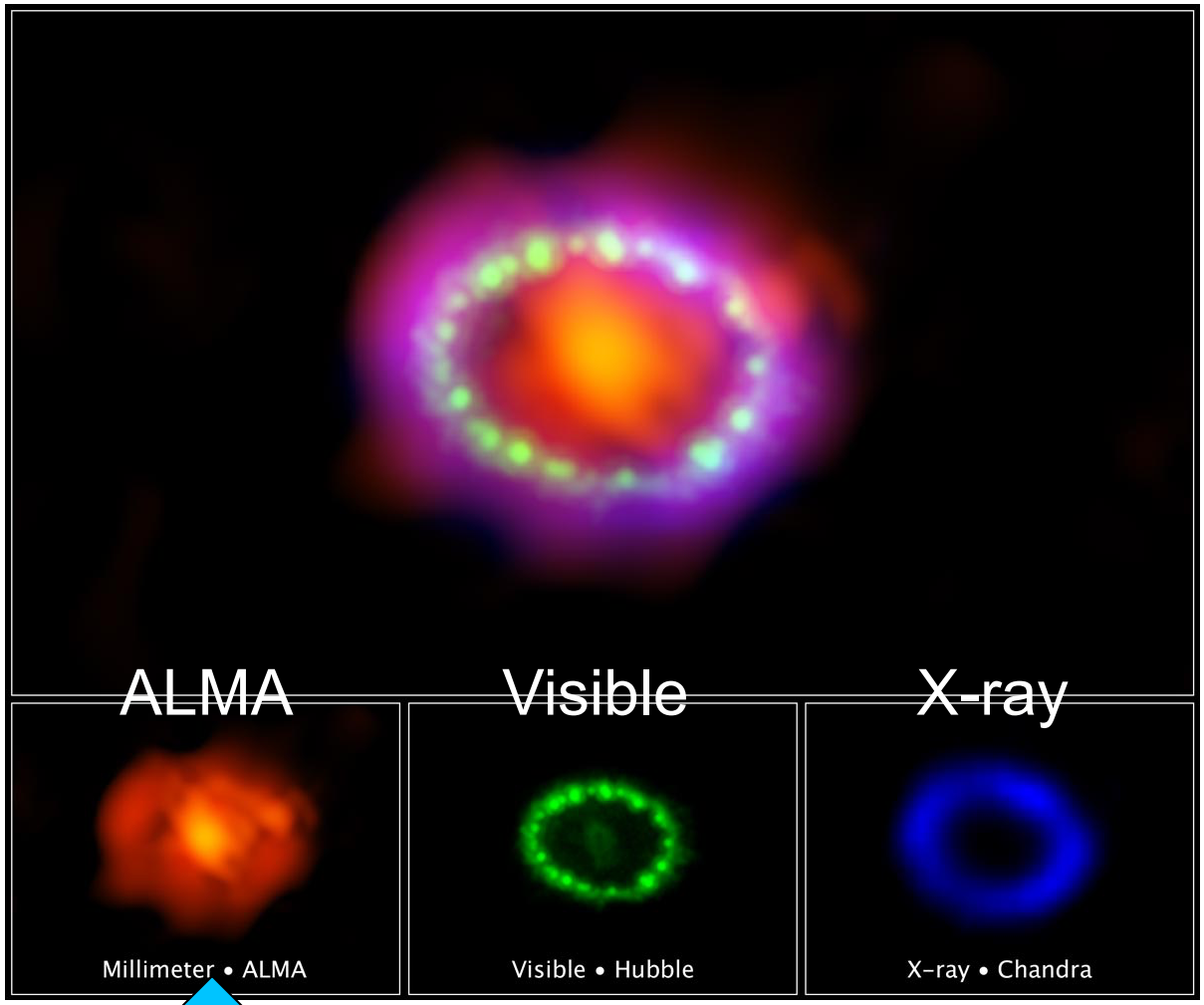
TW Hydrae

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



SN 1987A



Newly formed dust in the center of the the supernova remnant

Image Credit: NASA, ESA, and A. Angelich (NRAO)

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.

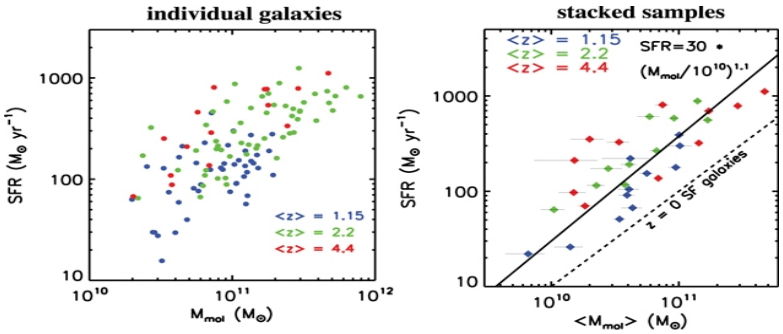
Several notable conclusions from the survey – among them:

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**

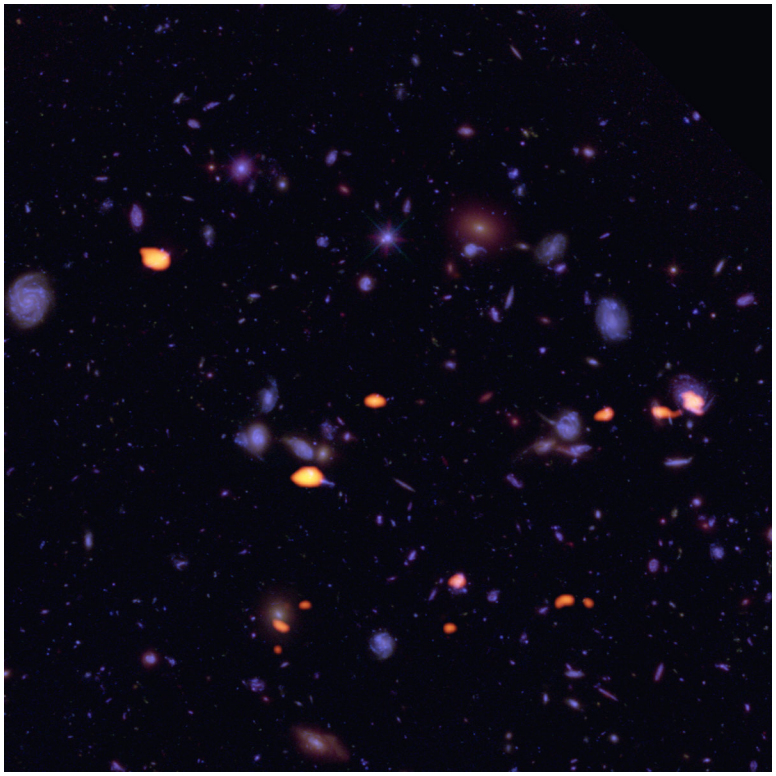
most likely dynamically driven by compressive, high-dispersion gas motions—a natural consequence of the high gas accretion rates.

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



ALMA Science Highlights: the Distant Universe
ALMA Deep Field

- 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.



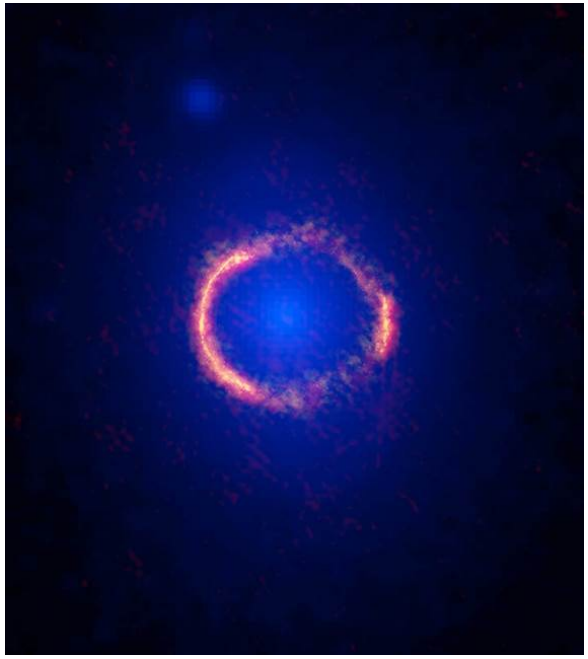
Dunlop et al. 2017

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 $10^{8.96\pm0.12}$ 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.

How to apply for ALMA time?

- ALMA proposal call is released once a year.
- Regular proposal deadline is usually at the end of April
  Cycle 5: April 20th, 2017)
- DDT proposals can be submitted anytime

- Important Documents:
  - Call for Proposals
  - Proposer's Guide
  - ALMA Primer
  - OT Guide
  - ALMA Tech Handbook

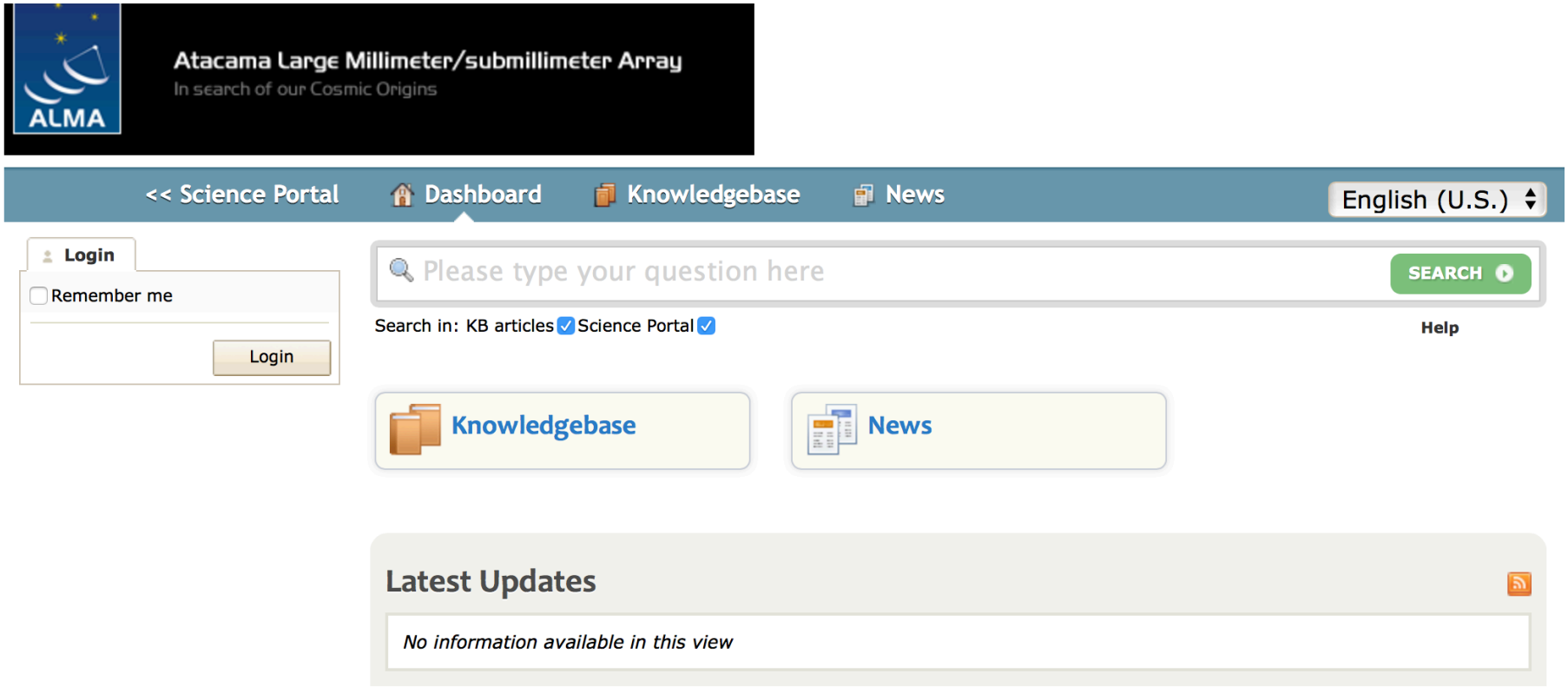
How to get ALMA data?

- PIs of accepted proposals
  - ALMA staff will observe and deliver fully calibrated dataset to you!
  - One-year proprietary period (6 month for DDT proposals)
  - Funded trips for the PI and a student to NRAO to reduce your data and ask questions!

- ALMA archive database
  - Search and Download!
  - https://almascience.nrao.edu/aq/

ALMA helpdesk

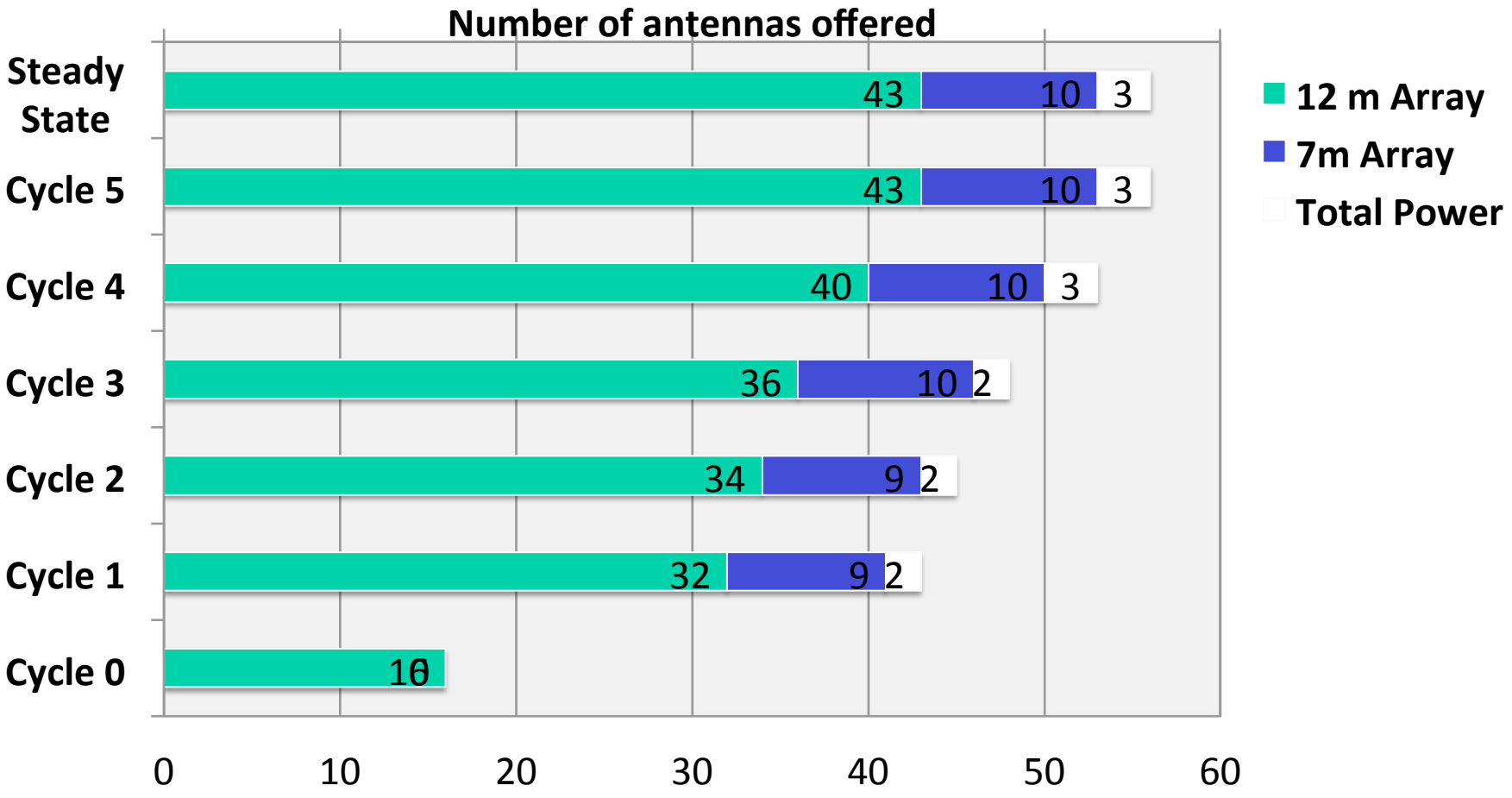
- Have a question?
  - Submit a ticket to the ALMA helpdesk



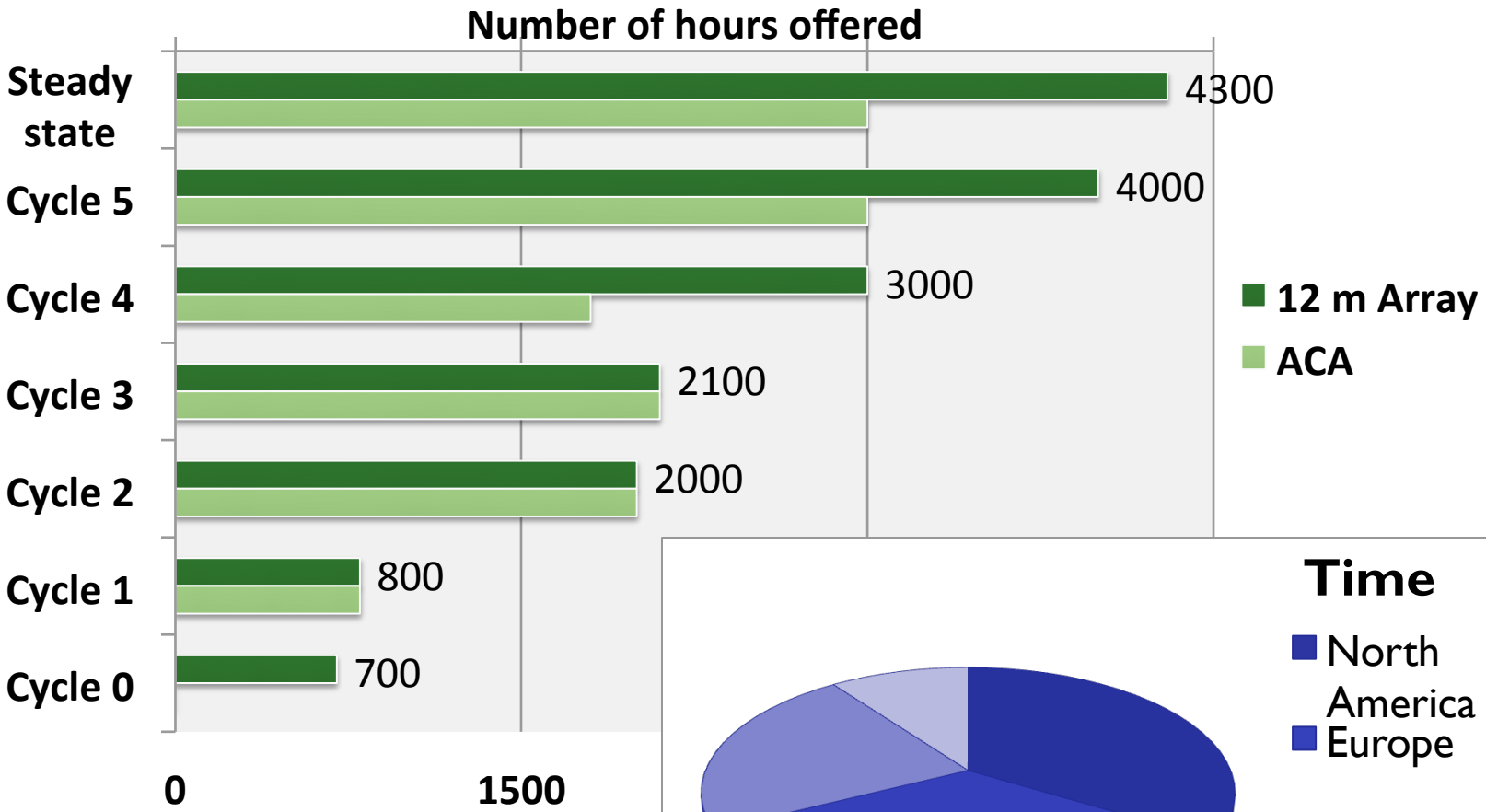
ALMA Cycle 5 Capabilities

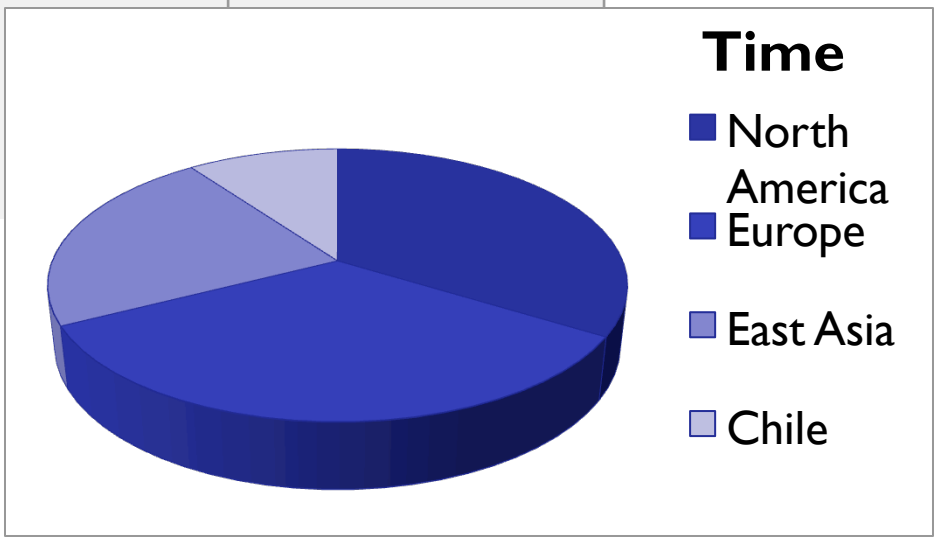
Atacama Large Millimeter/submillimeter Array
Karl G. Jansky Very Large Array
Robert C. Byrd Green Bank Telescope
Very Long Baseline Array

Minimum number of antennas

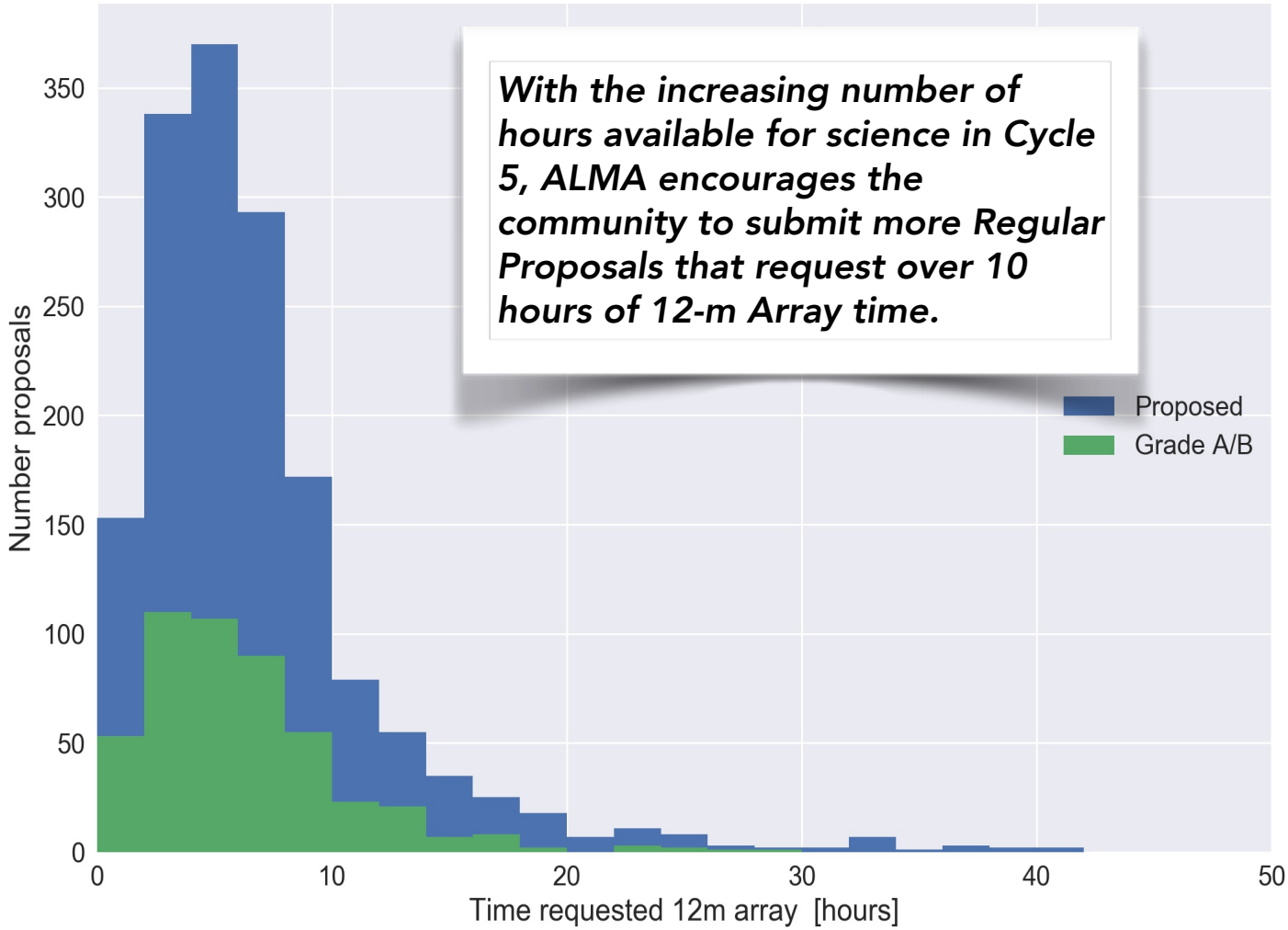


Hours of observing time





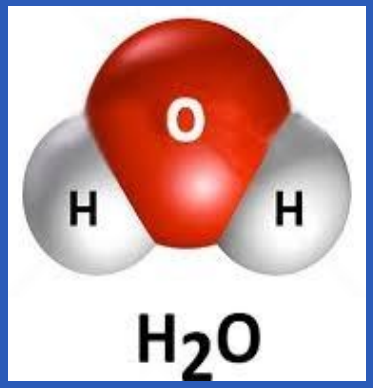
Time Requests on the 12 m array: Cycle 4



With the increasing number of hours available for science in Cycle 5, ALMA encourages the community to submit more Regular Proposals that request over 10 hours of 12-m Array time.

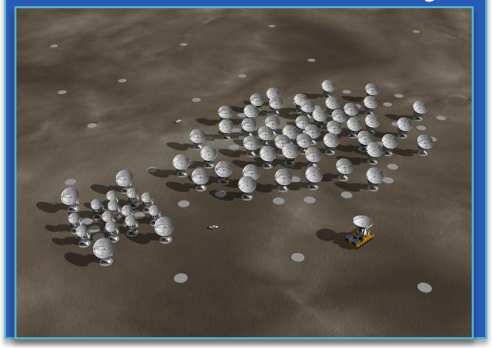
New in Cycle 5

Band 5

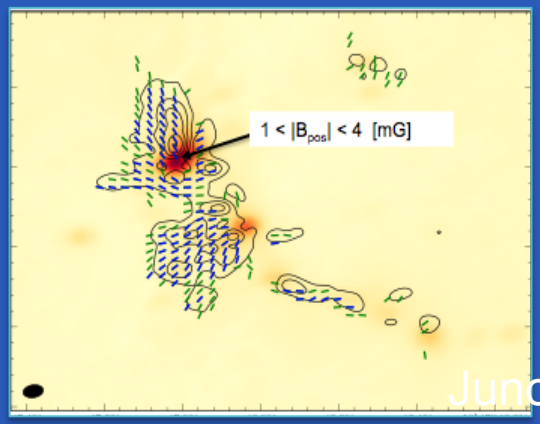


16 km baselines

Simultaneous 12m+7m array



Band 4 + 5 polarization



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:

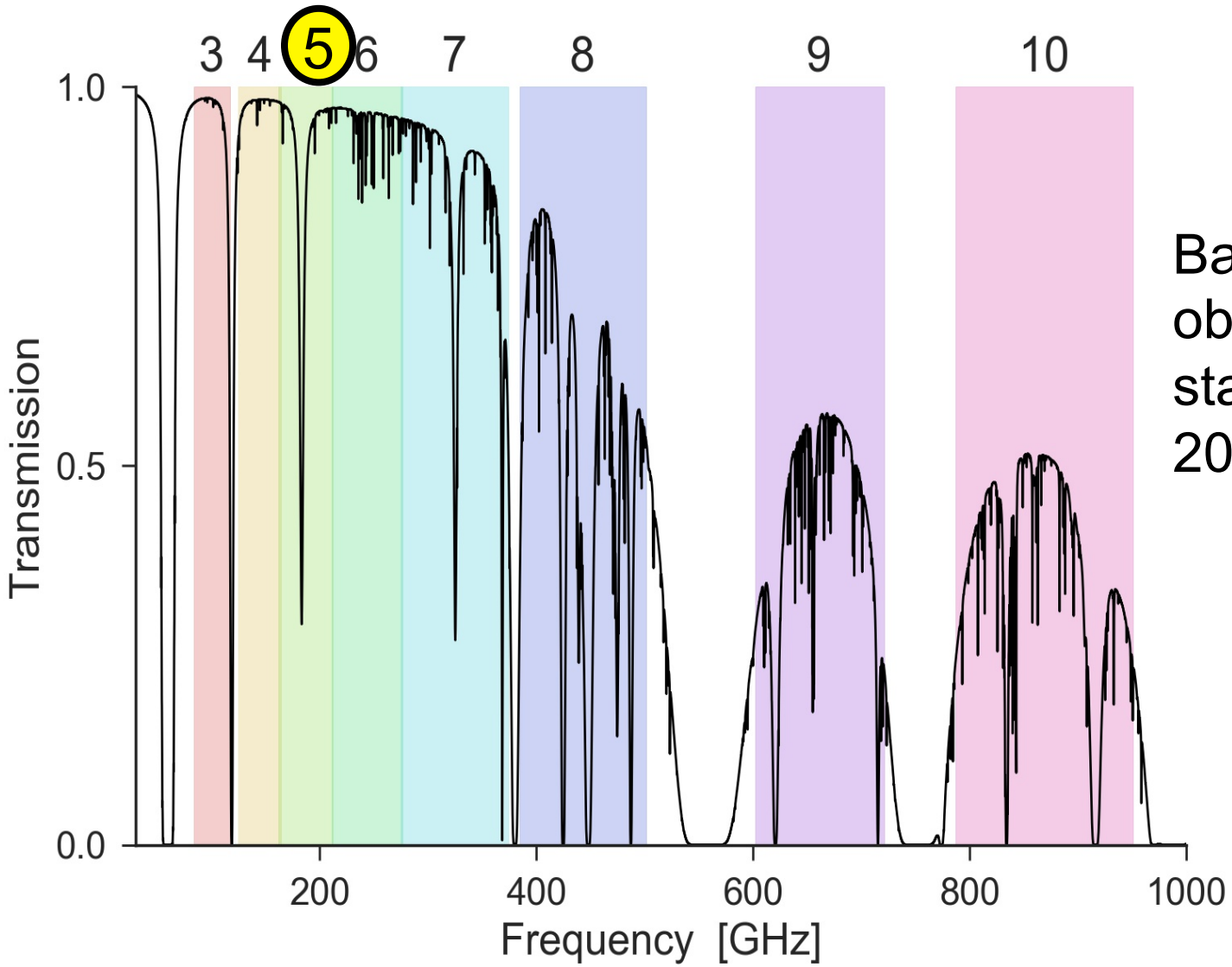
Cycle 5 should still be around 20% of the time going to non-standard modes.

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 Receiver Bands in Cycle 5



Band 5 observations start in March, 2018

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)

Observing Modes (All Cycle 4 Modes plus…):

- 90 Degree Walsh switching at Band 9 for both the 12m and ACA
  - Full operations include Band 10
  - 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)

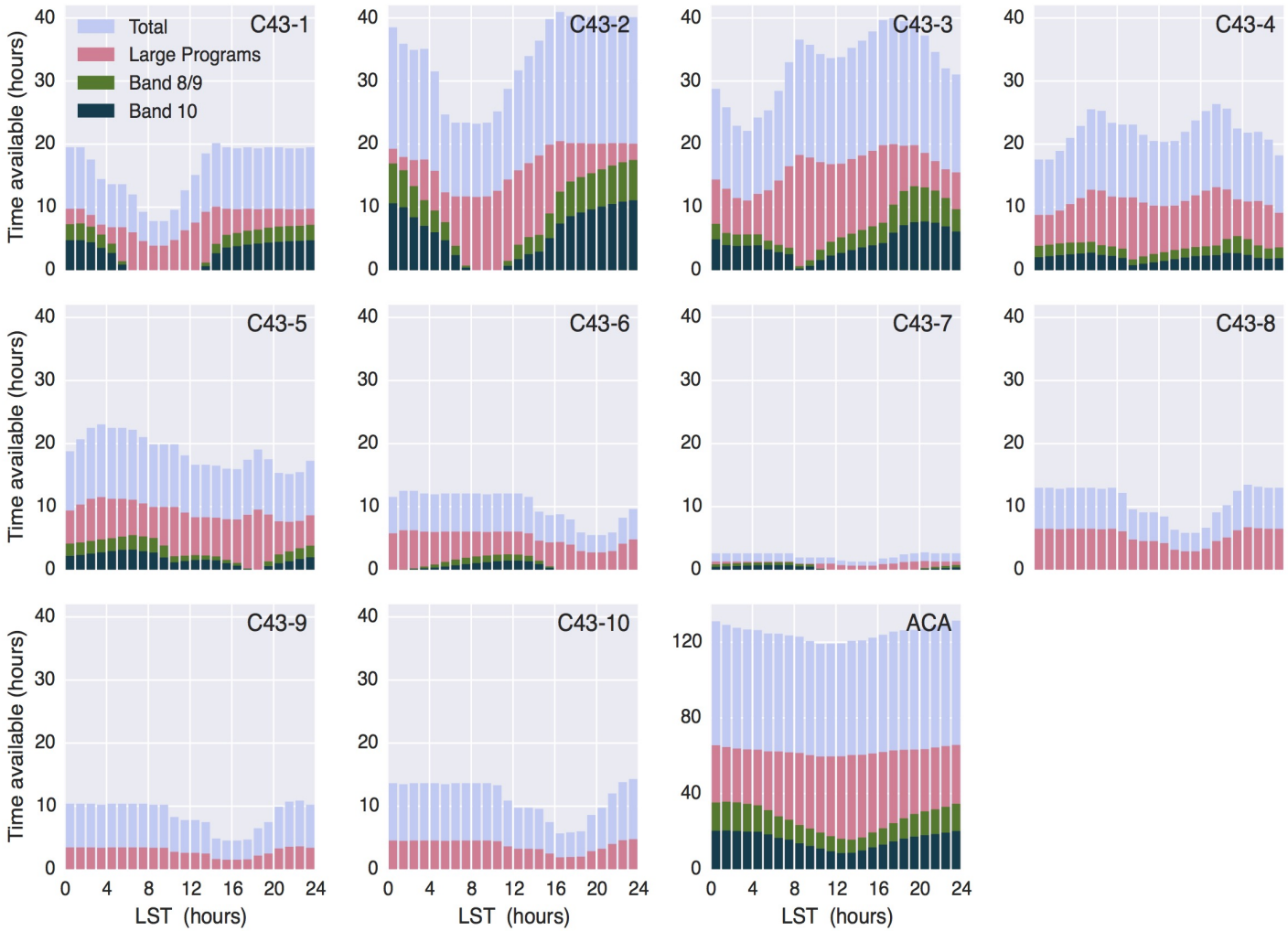
Table 1: Cycle 5 configuration schedule

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

Long baselines
(up to 16 km)

Compact configurations
n Chilean winter. Optimal
for high frequency.

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 Timelines and Milestones

December 15, 2016	Pre-announcement
February 1, 2017	Configuration schedule & Large Program information
March 21, 2017	Call for Proposals released and submission server opened
April 20, 2017	**Proposal deadline!**
June 18-23, 2017	Proposal Review meeting in Antwerp, Belgium
Late July 2017	Proposal review results announced
October 2017	Start of Cycle 5 observations

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