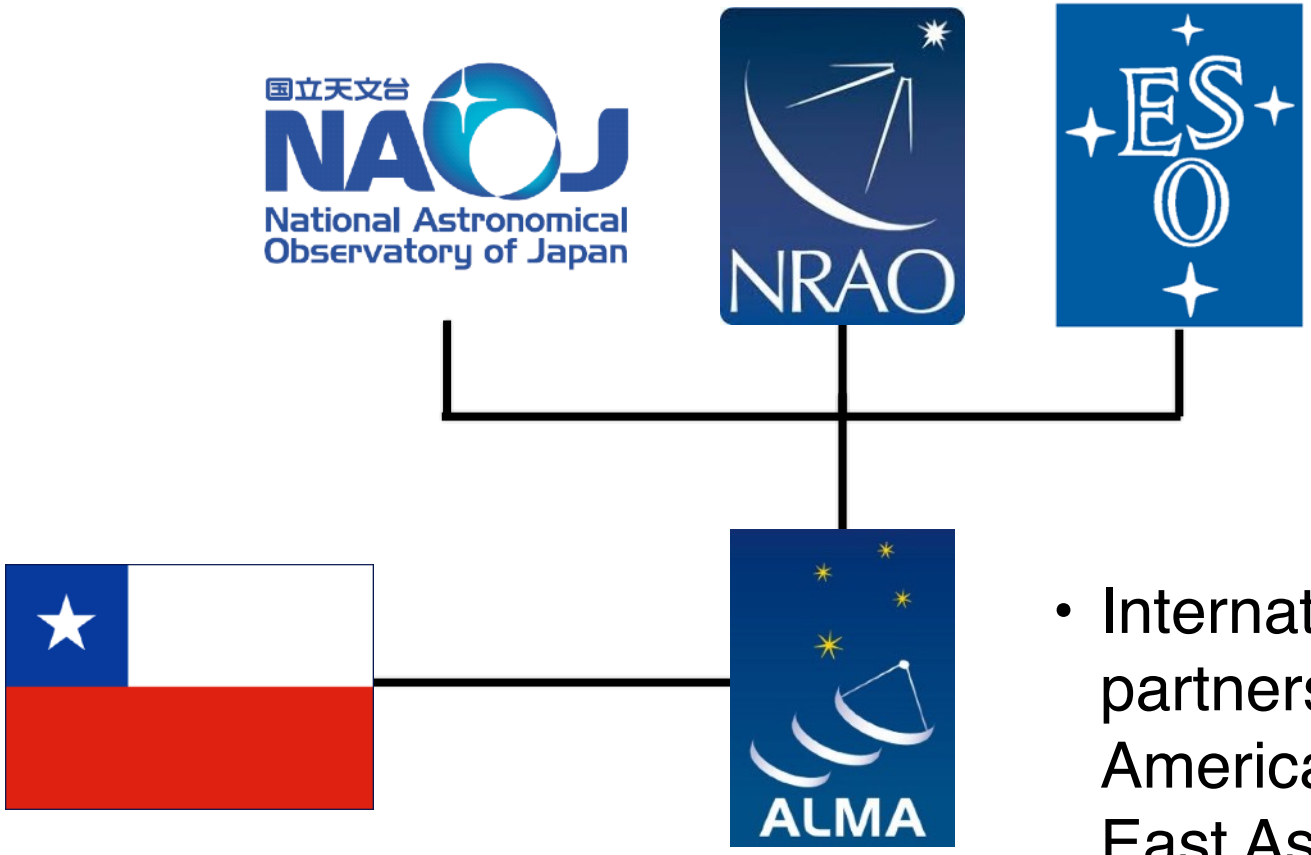
Introduction to ALMA

David Rebolledo
Joint ALMA Observatory

Cycle 10 Proposal Workshop
April 14th, 2023



- International partnership of North America, Europe, East Asia and Chile.

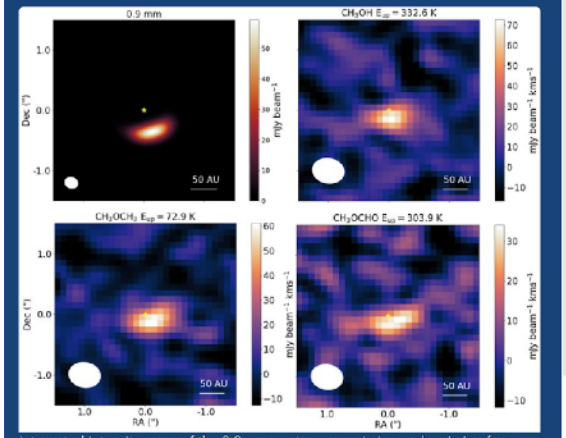
ALMA Science Portal: https://almascience.nrao.edu/ - documentation, info, news and more!

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 (CH_3OCH_3) vapor in a planet-forming disk, and a tentative detection of methyl formate (CH_3OCHO) 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

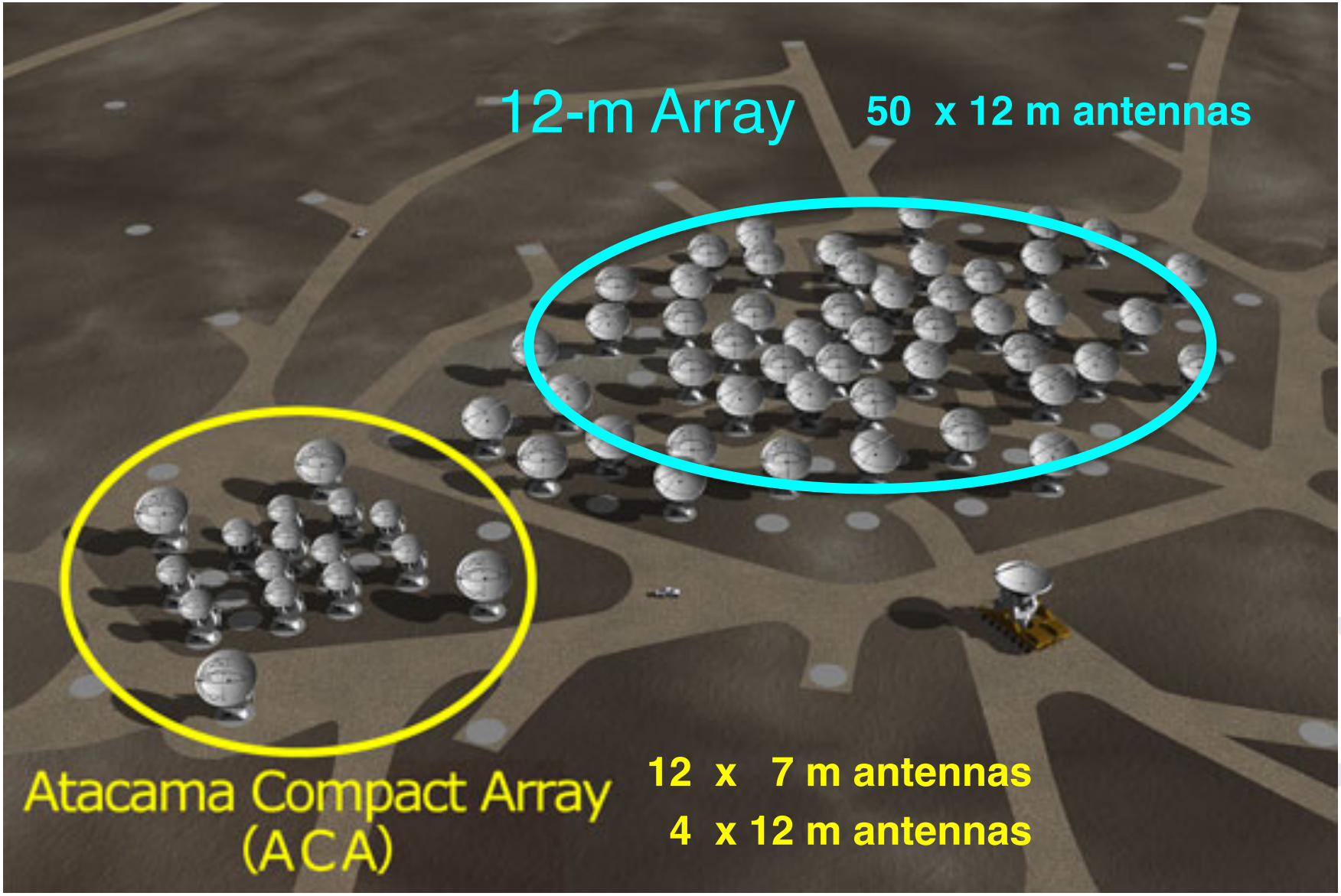
ALMA Basics	ALMA Archive
ALMA Science	SnooPI
ALMA Primer	Configuration Schedule

ALMA is a telescope for *all* astronomers

NRAO NSF AUI

What is ALMA?

- 66 reconfigurable, high precision antennas
- Receiver bands cover 35-950 GHz (since Cycle 10)
- 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 wavelengths.


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

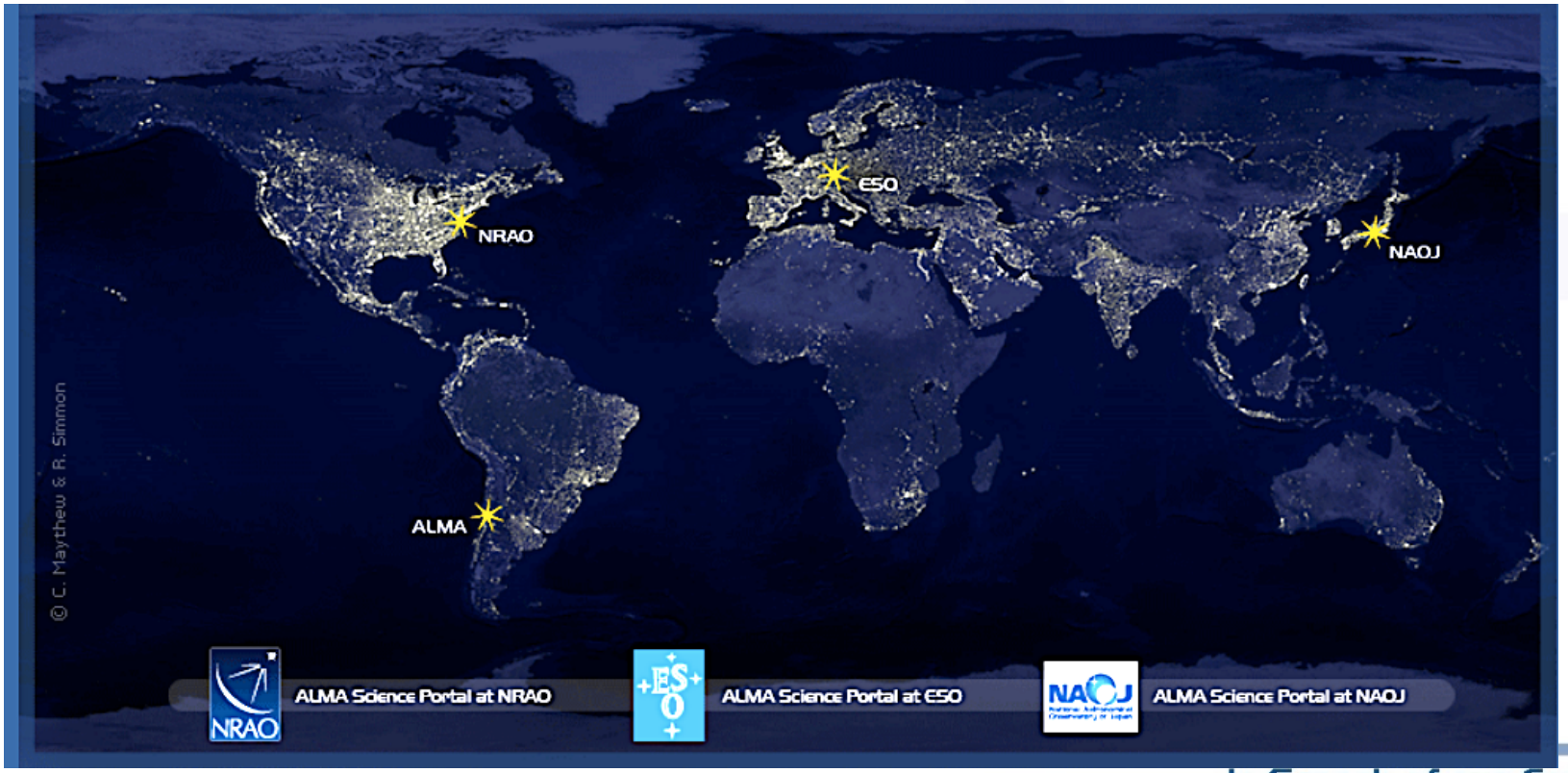
ALMA Operations

The Joint ALMA Observatory (JAO) is responsible for operations in Chile

- Santiago Central Office
- Operations Support Facility (OSF)
- Array Operations Site (AOS)

ALMA User Support is centered at the ALMA Regional Centers:

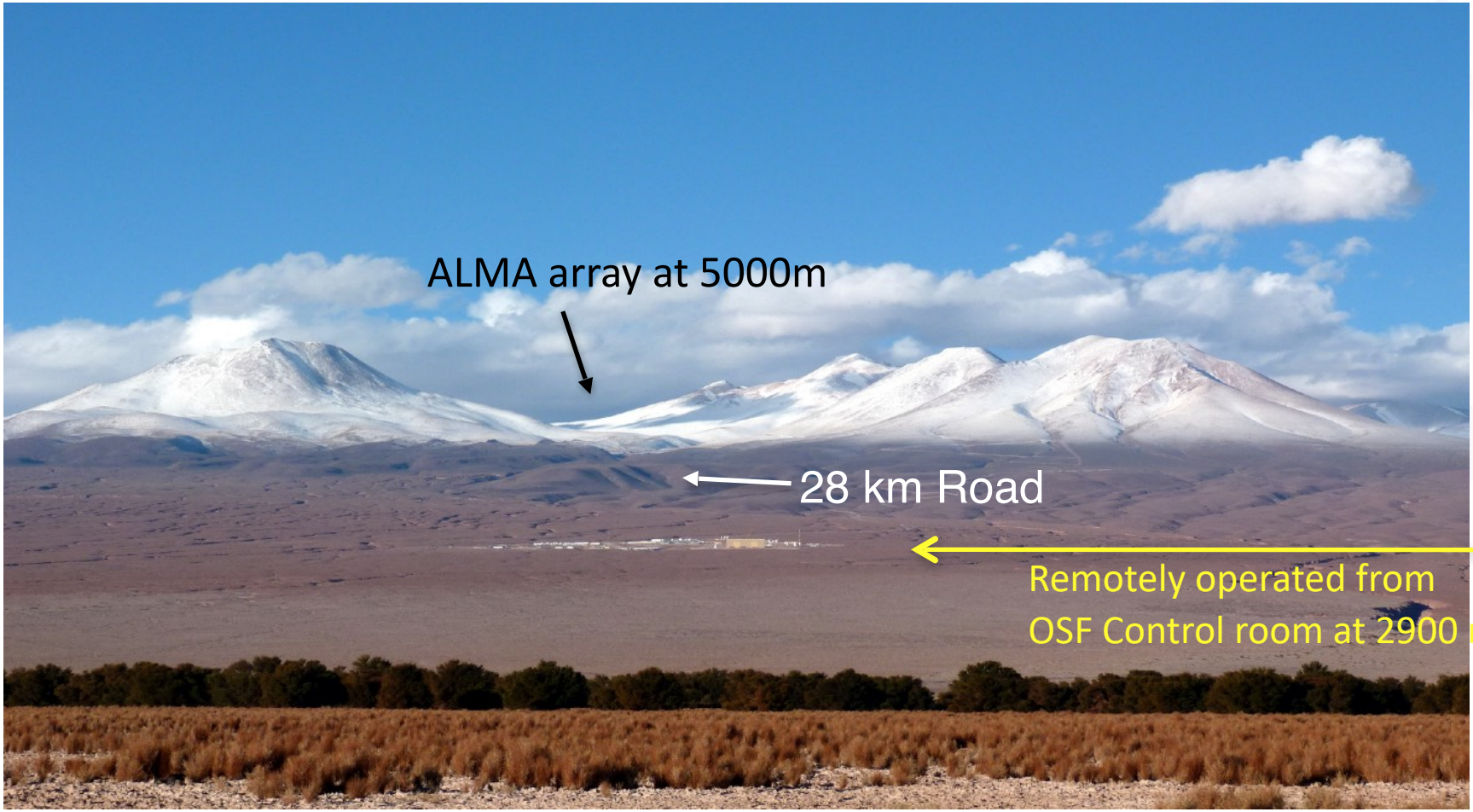
- NA ARC – NRAO, NRC (NAASC)
- EU ARC + ARC Nodes (ESO …)
- EA ARC, ASIAA



Santiago Central Office

- Location of science and technical staff
- Where observatory operations are coordinated

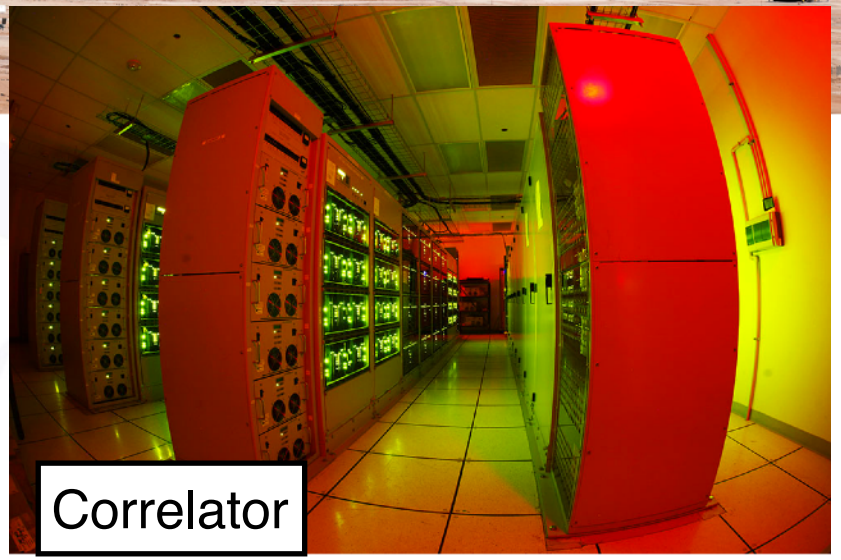
Remote Operation at the Operations Support Facility



Array Operations Site

Array Operations Site

Array Operations Site



ALMA Antenna Movements

from 2009-09-17 to 2014-12-07

- 66 reconfigurable antennas
- Array configurations between 0.16 and 16 km

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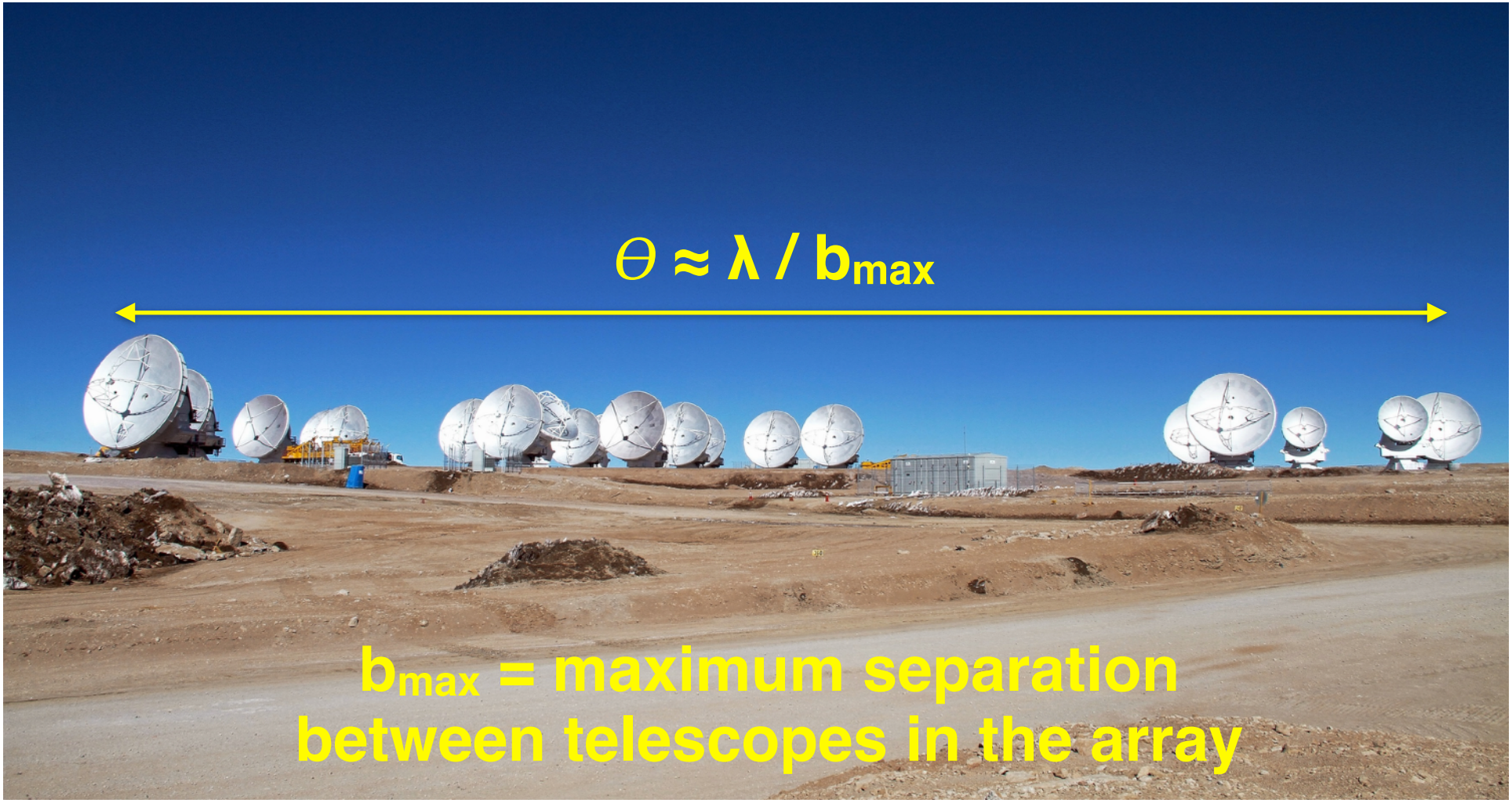
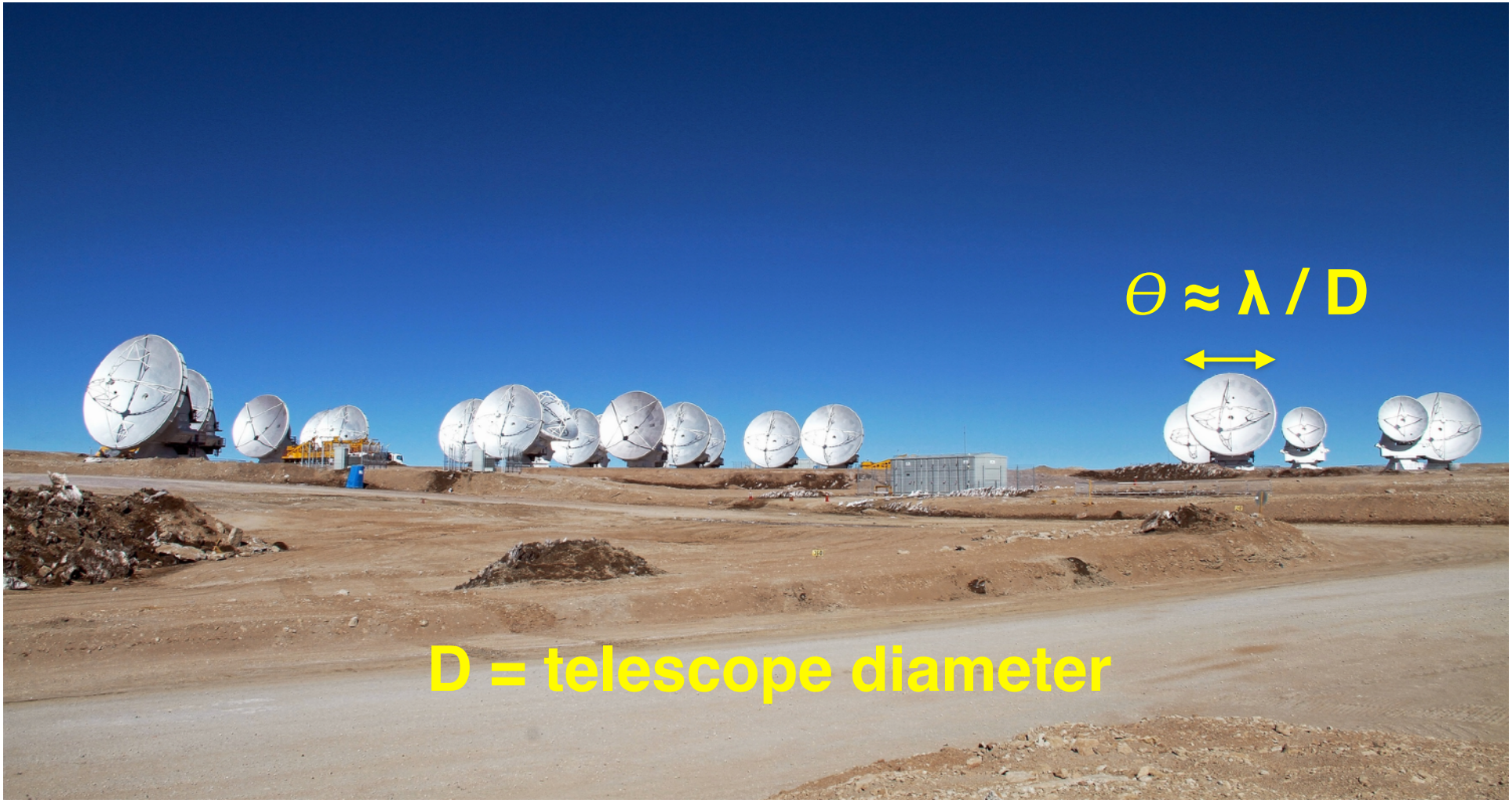
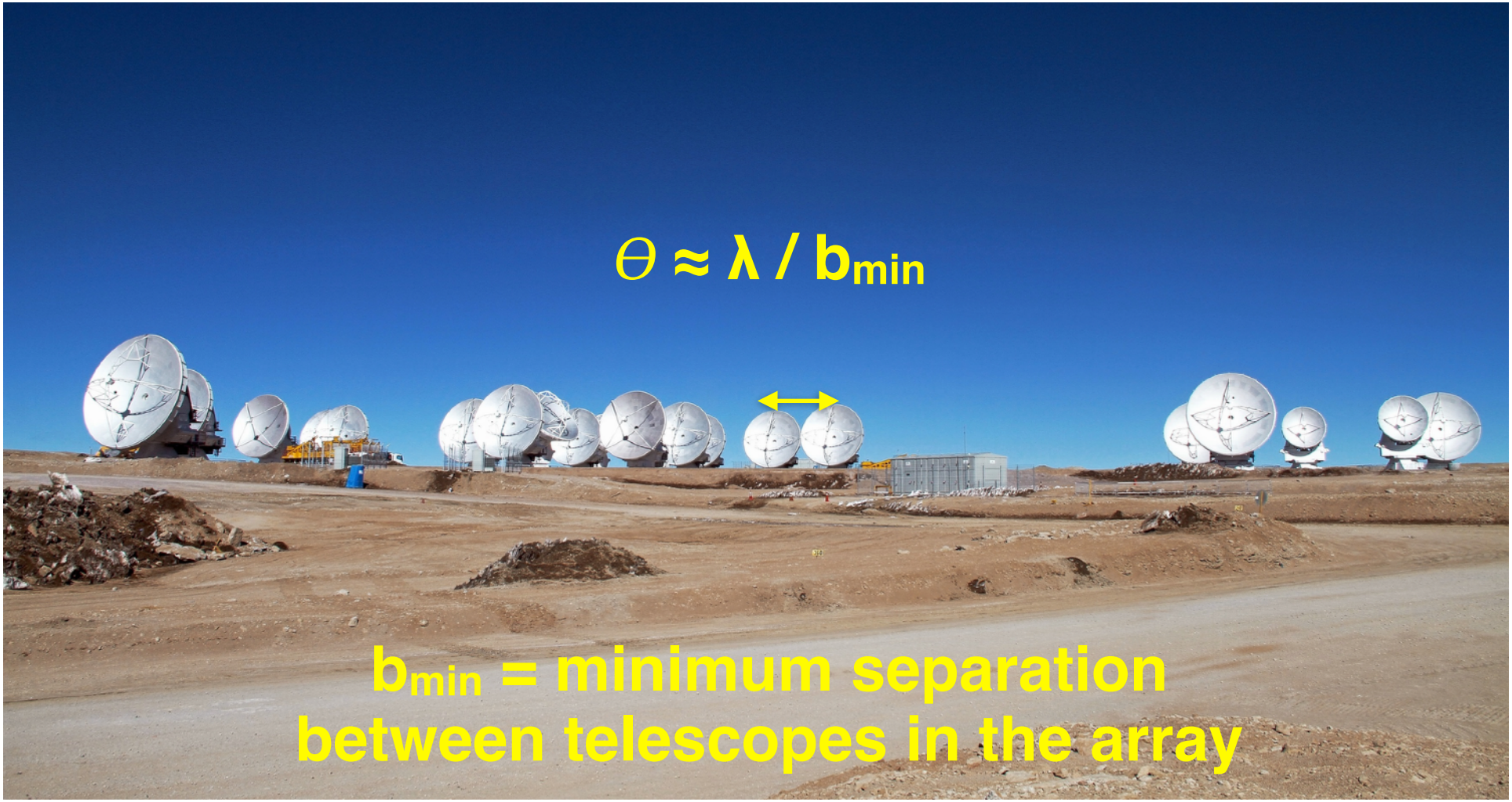
Angular Resolution



Field of View



Largest Angular Scale



Angular scales

Resolution

- given by the largest distance between antennas (~λ / B_{max})

Field of view

- given by the diffraction limit of a single antenna (~λ / D)
- If source is larger than the field of view, then make a mosaic

Largest angular scale that can be imaged

- given by the shortest distance between antennas (~λ / B_{min})

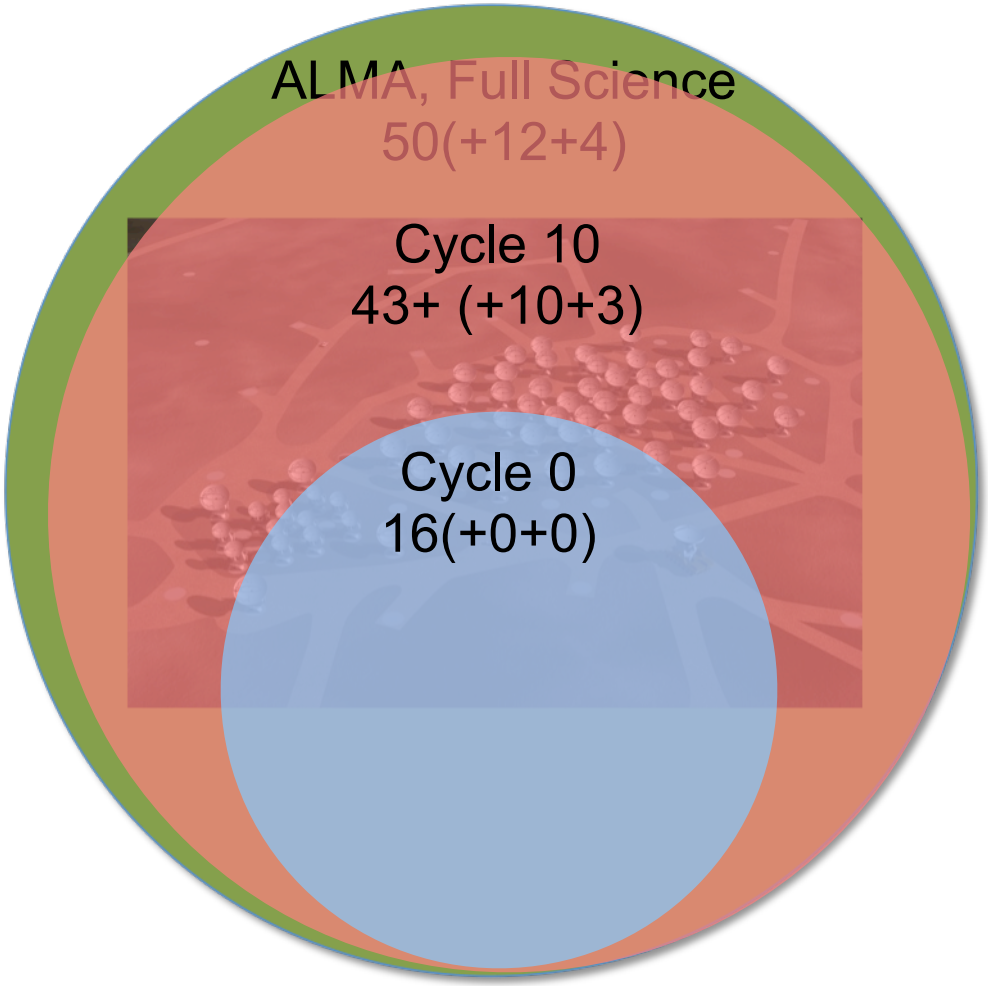
An interferometer is sensitive to a range of angular scales.
Observe in multiple configurations to decrease B_{min} and increase B_{max}.

$$\lambda / B_{max} < \Theta < \lambda / B_{min}$$

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

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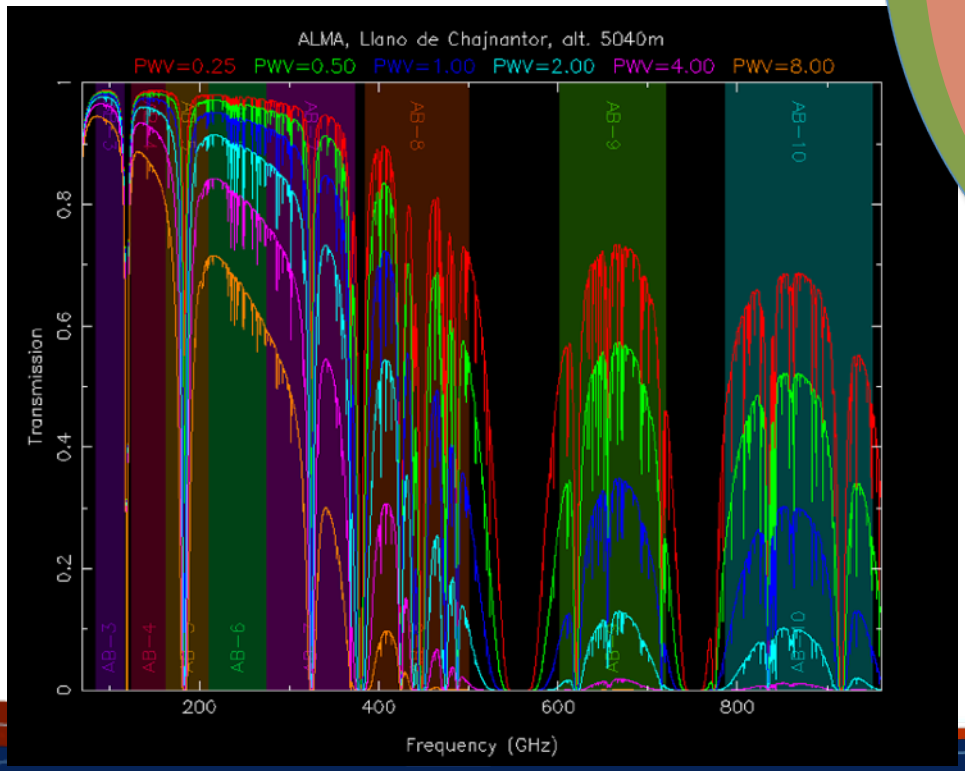

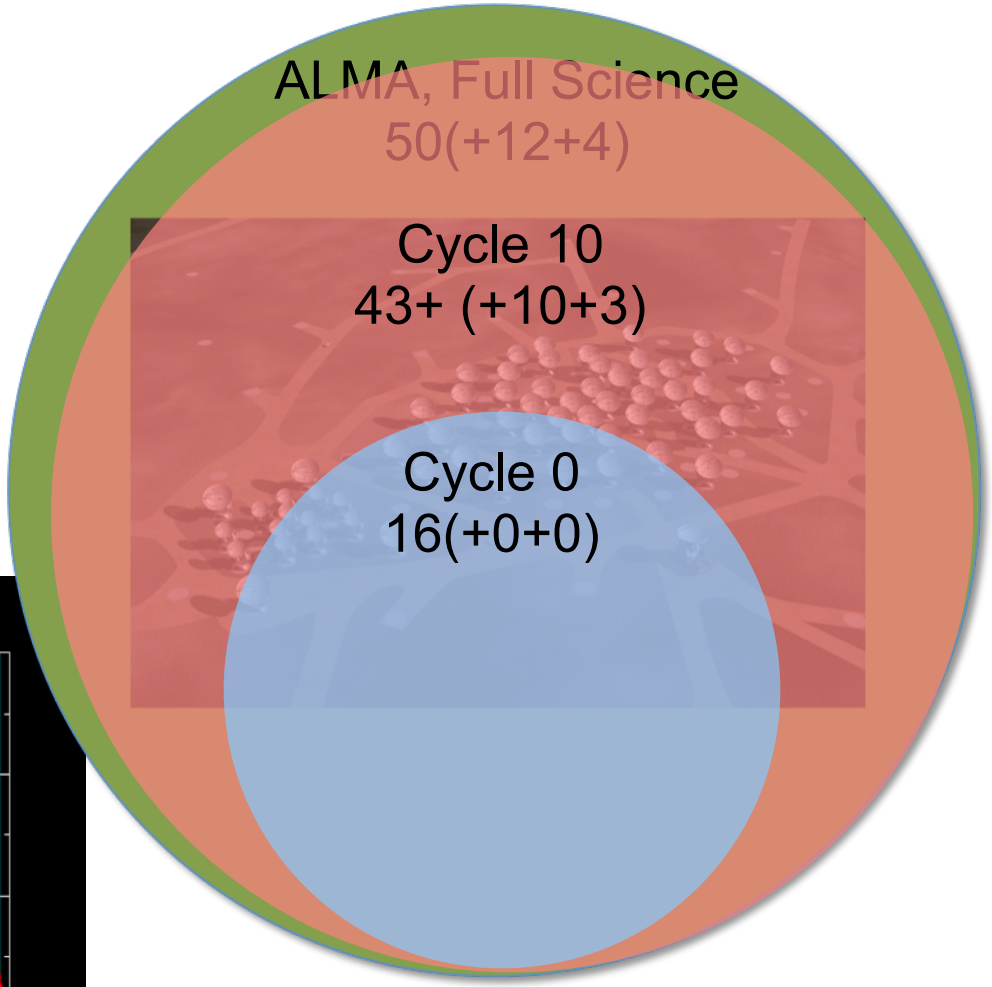

Spectral Coverage

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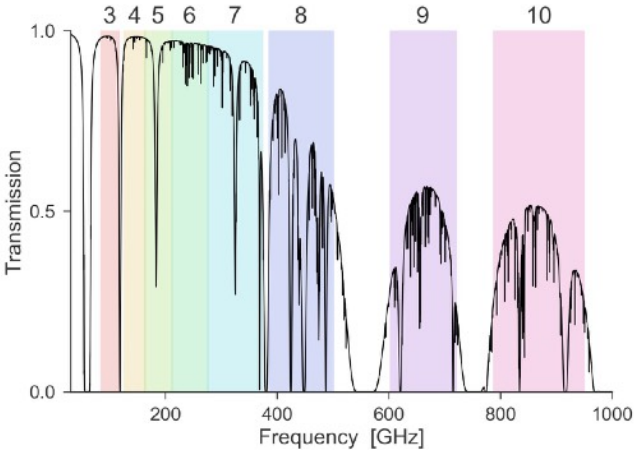
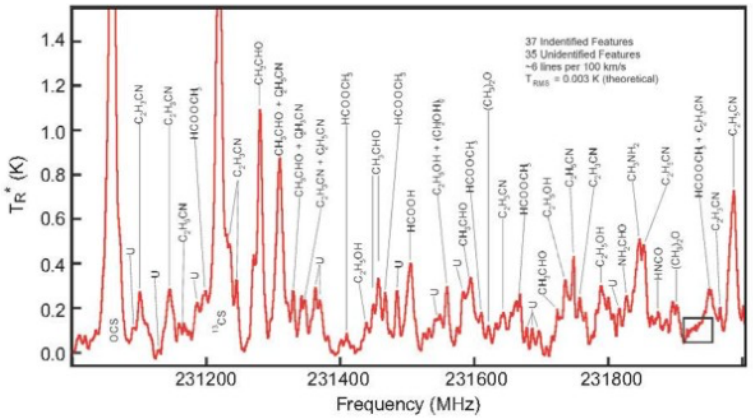
Capabilities

Imaging

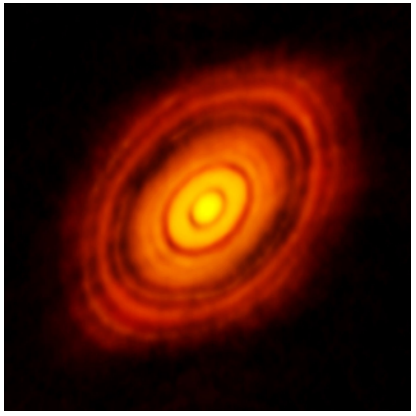
9 receiver bands



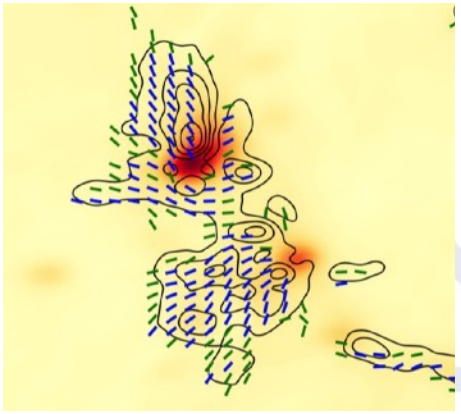
Spectral lines



Continuum



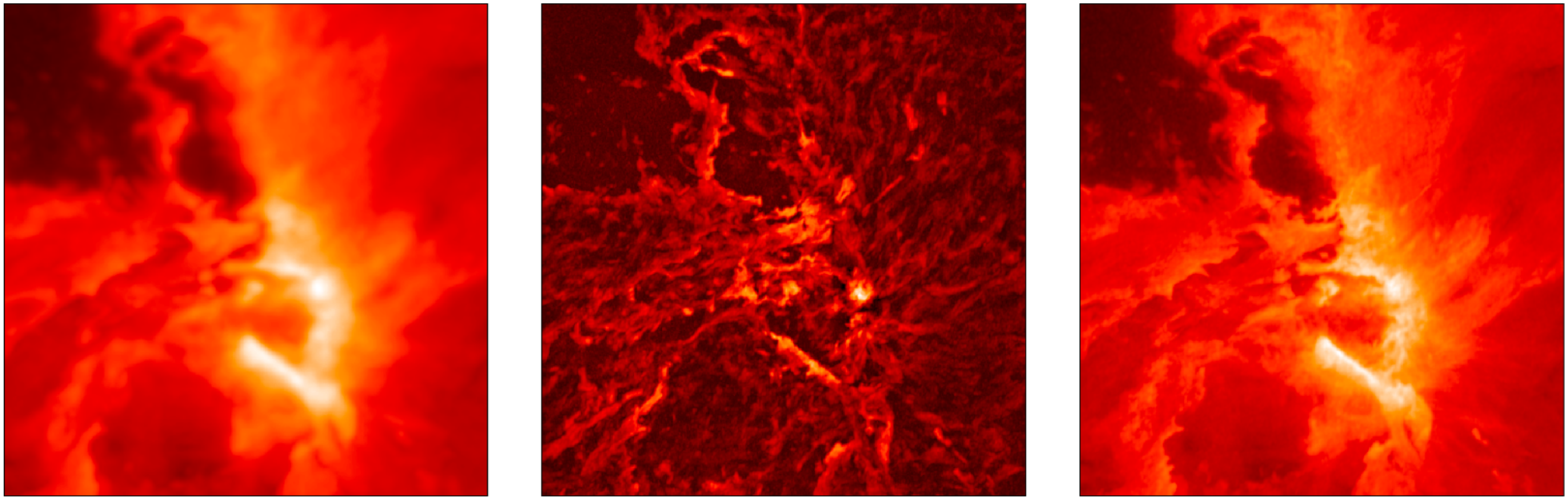
Polarization



VLBI

Single dish + Interferometer

Single dish | **Interferometer** | **Single dish + interferometer**



- 12m array reveals information on small spatial scales
- ACA reveals information on larger scales
- Combine both to recover small and large scales

Kong et al. (2018)

Flux density and brightness temperature

$$S_\nu = \frac{2kT_B}{\lambda^2}\Omega$$

S_ν : flux density (Janskys) 1 Jansky = $10^{-26}\ \frac{\text{Watt}}{\text{meter}^2\ \text{Hz}}$

Ω : solid angle of "beam" $\Omega = \frac{\pi\theta^2}{4\ln 2}$

T_B : Brightness temperature (Kelvin)

Sensitivity

System Temperature: product of sky and receiver

Kelvin-Boltzmann constant

$$\Delta S_\nu \propto \frac{k\ T_{sys}}{A\sqrt{N(N-1)\quad \Delta\upsilon\quad t_{\text{int}}}}$$

Area of 1 Antenna

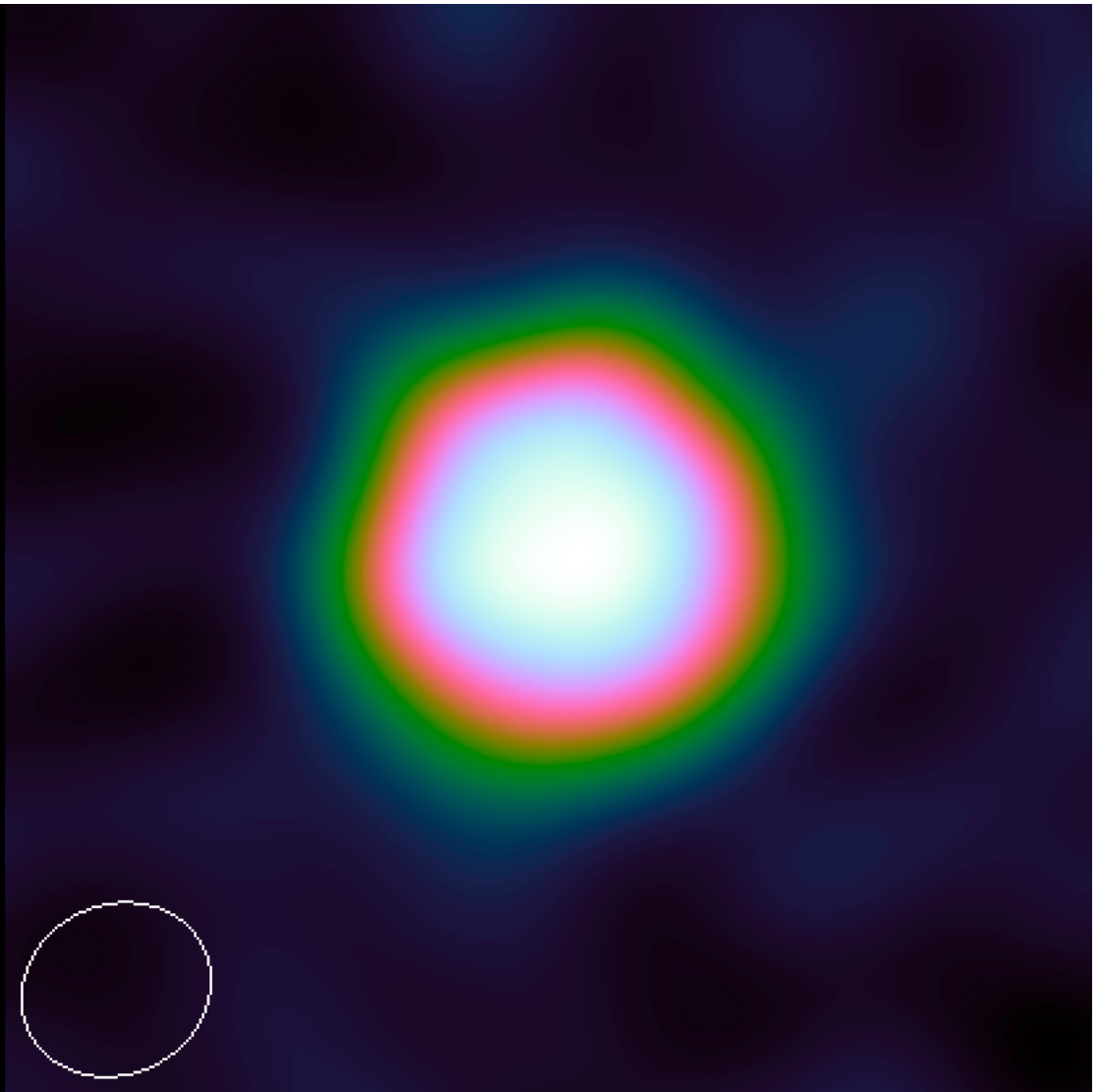
Number of Antennas

Integration Time

Frequency Resolution

ΔS_ν : Independent of the angular resolution. However, $\Delta T_B \propto \frac{\Delta S_\nu}{\theta^2}$

Example: Imaging an extended source



- Source diameter = 12”
- S_{tot} = 15 mJy

Example: Imaging an extended source

- Configuration 1 (3.5 h)
- Θ = 1.7 arcsec @ 230 GHz
- ΔS_v = 9.5 microJy / beam
- ΔT_B = 0.07 milliK

- $N_{beams} \sim (12/\Theta)^2 \sim 50$
- $\langle S_v \rangle$ = 300 microJy / beam
- <SNR> ~ 32

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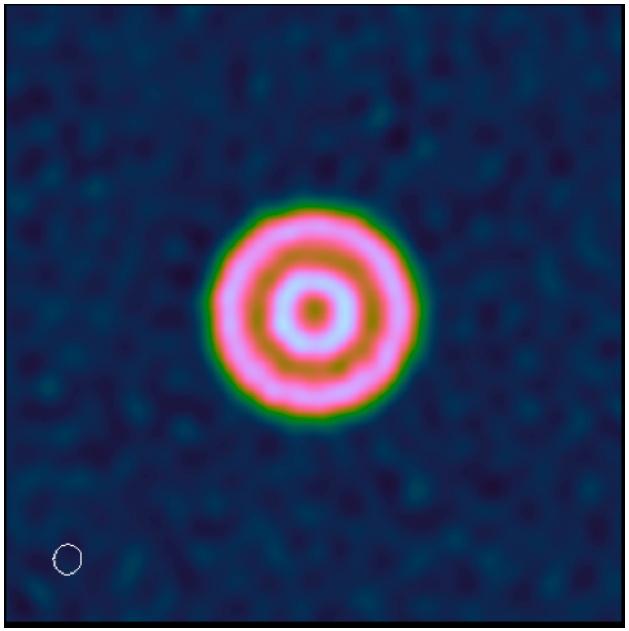

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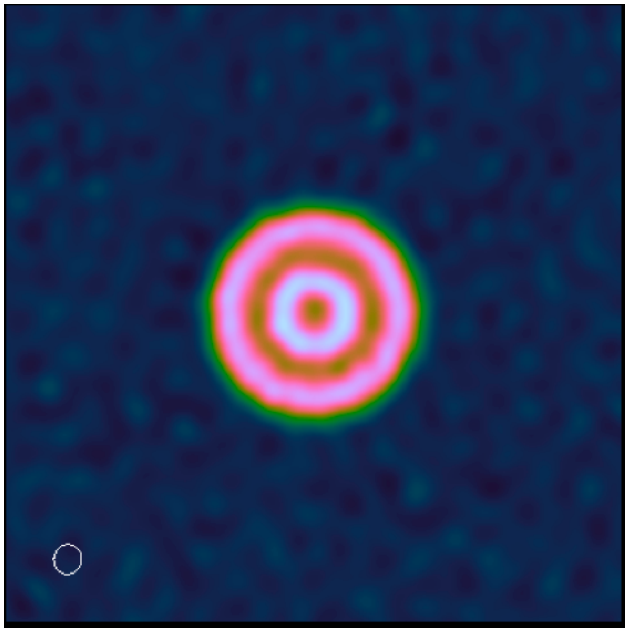

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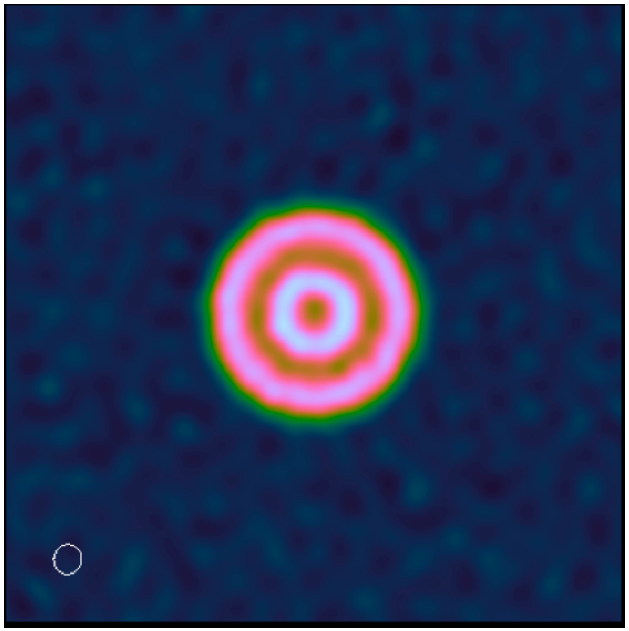
- Configuration 1 and 4
- Θ = 0.52 arcsec
- ΔS_v = 9.5 microJy / beam
- ΔT_B = 0.75 milliK

- $N_{beams} \sim (12/\Theta)^2 \sim 532$
- $\langle S_v \rangle$ = 28 microJy / beam
- <SNR> ~ 3

Example: Imaging an extended source



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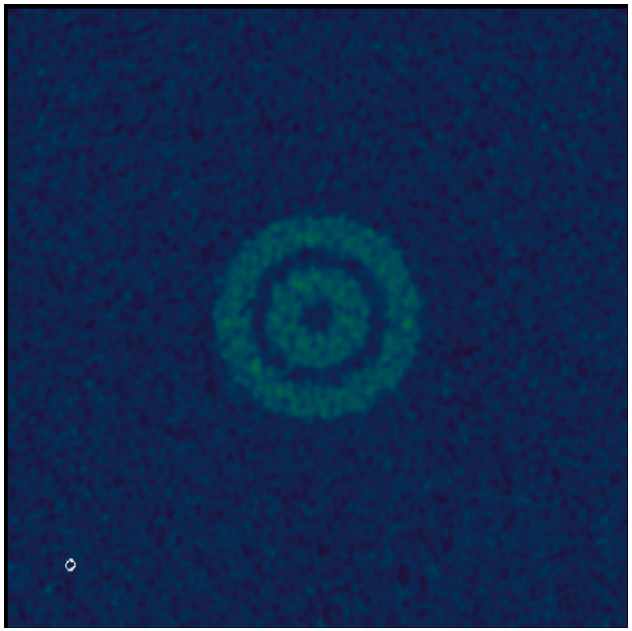

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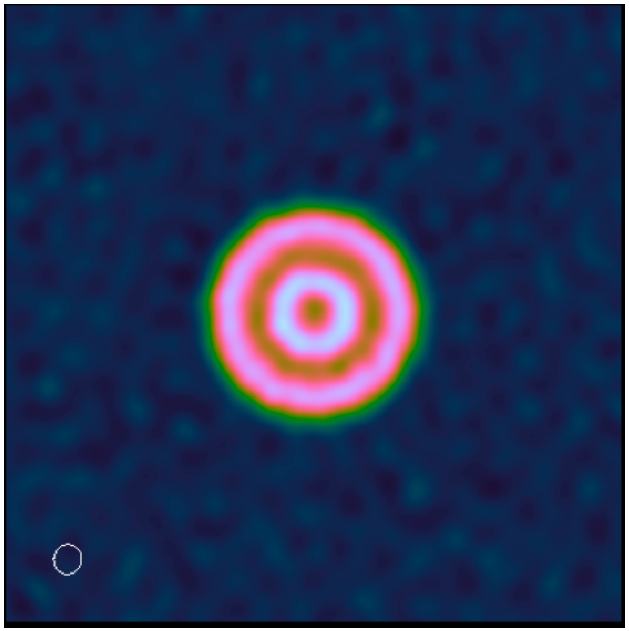

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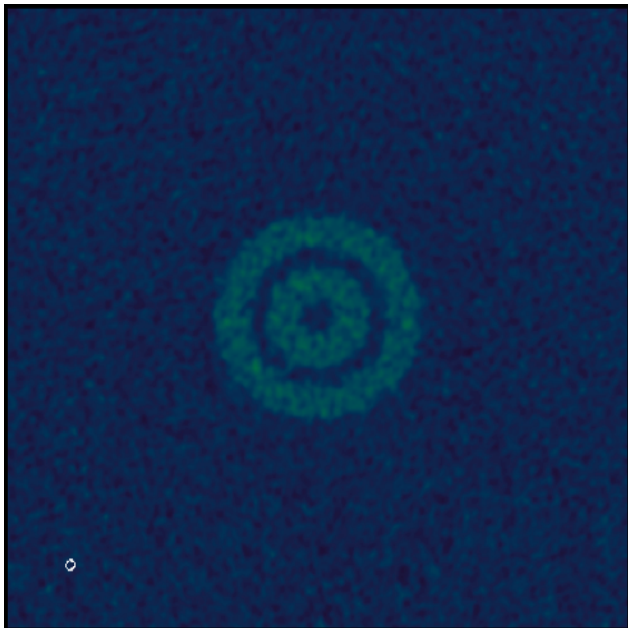

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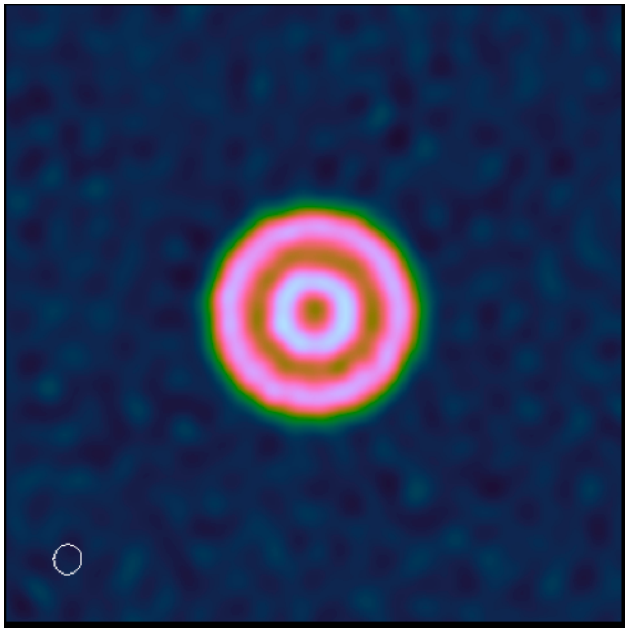
- <SNR> ~ 3

- Configuration 1, 4, and 8
- Θ = 0.086 arcsec
- ΔS_v = 9.5 microJy / beam
- ΔT_B = 27 milliK

- $N_{beams} \sim (12/\Theta)^2 \sim 19000$
- $\langle S_v \rangle$ = 0.8 microJy / beam
- <SNR> ~ 0.1

Example: Imaging an extended source



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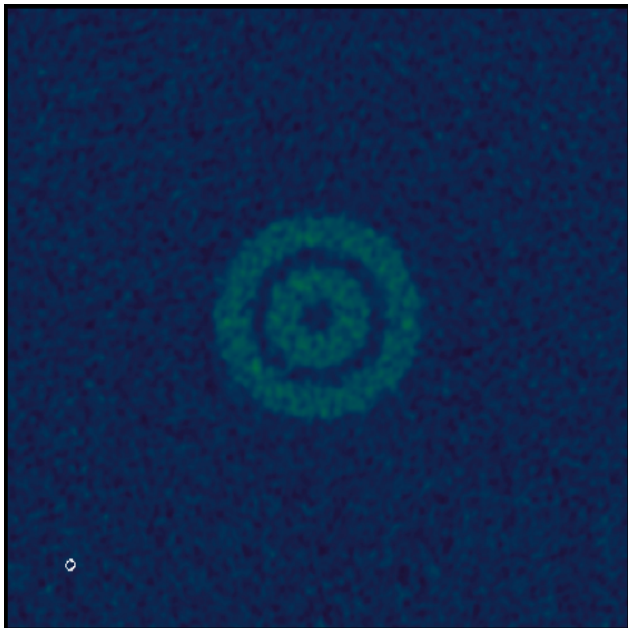

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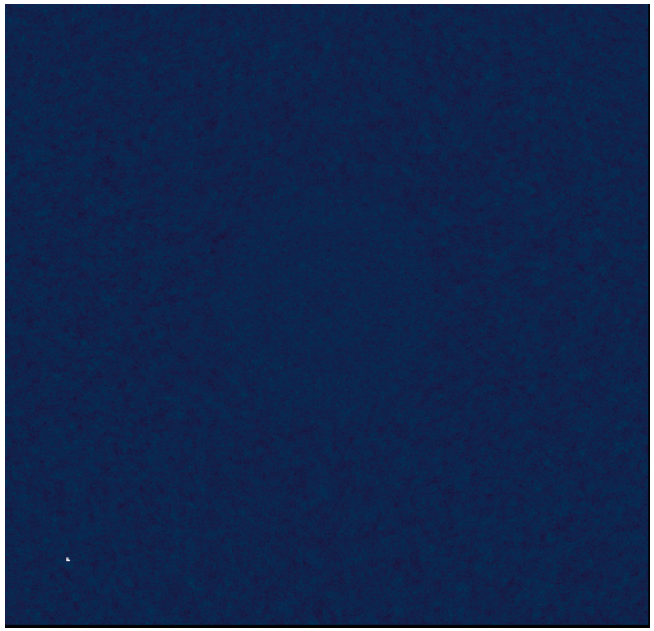

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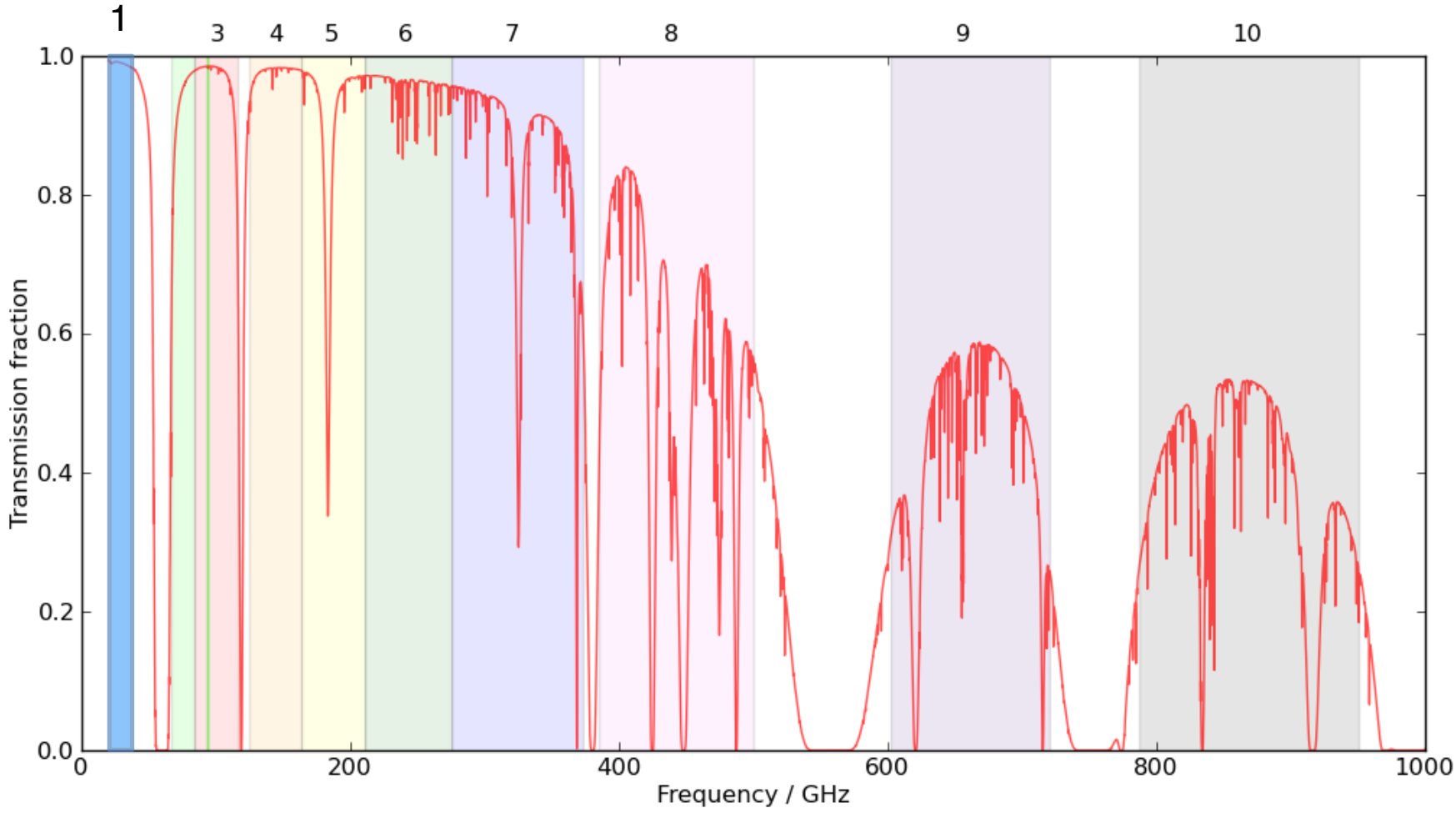
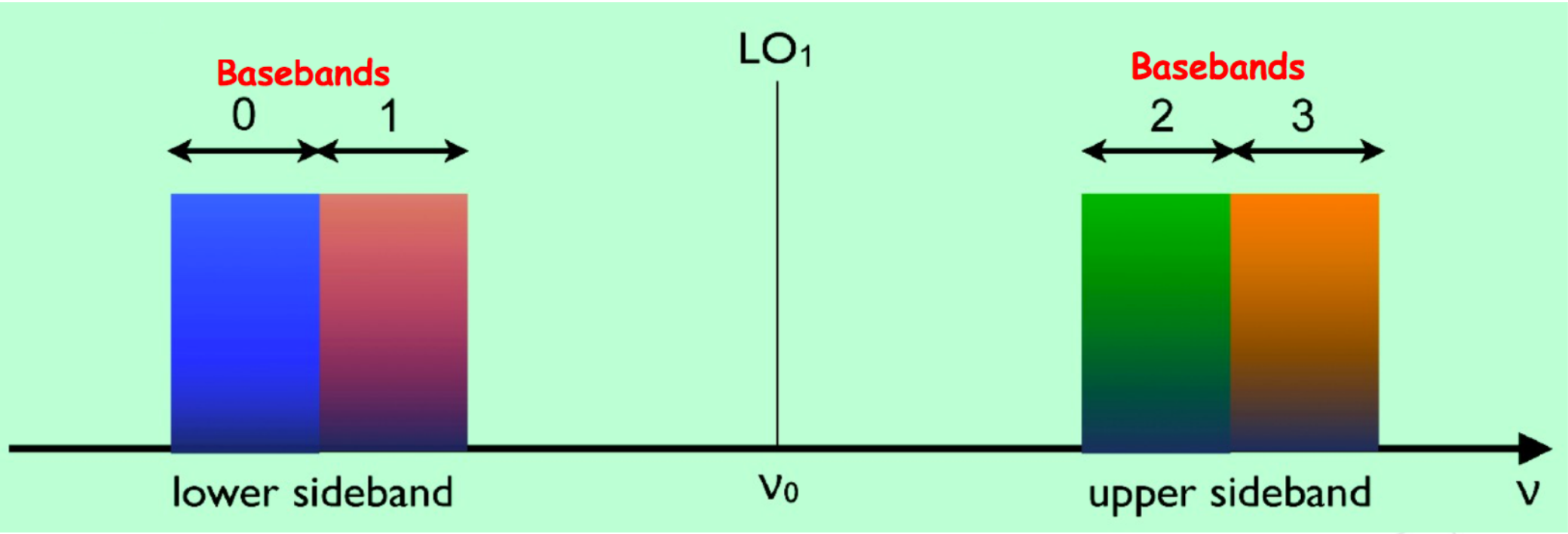
ALMA Receiver Bands in Cycle 10



Top quartile weather conditions

Setting up the correlator: Basebands



- Each baseband is a 2 GHz wide
- The 4 basebands can be in one sideband or distributed between the two
- Each baseband can be split into 4 spectral windows

Spectral windows

Bandwidth (MHz)	Spectral resolution (MHz)	Spectral resolution @ 345 GHz (km/s)	Number Channels
1875	31.2	27.1	120
1875	0.976	0.85	3840
938	0.488	0.42	3840
469	0.244	0.21	3840
234	0.122	0.11	3840
117	0.061	0.051	3840
58.6	0.0305	0.027	3840

"continuum"

"spectral line"

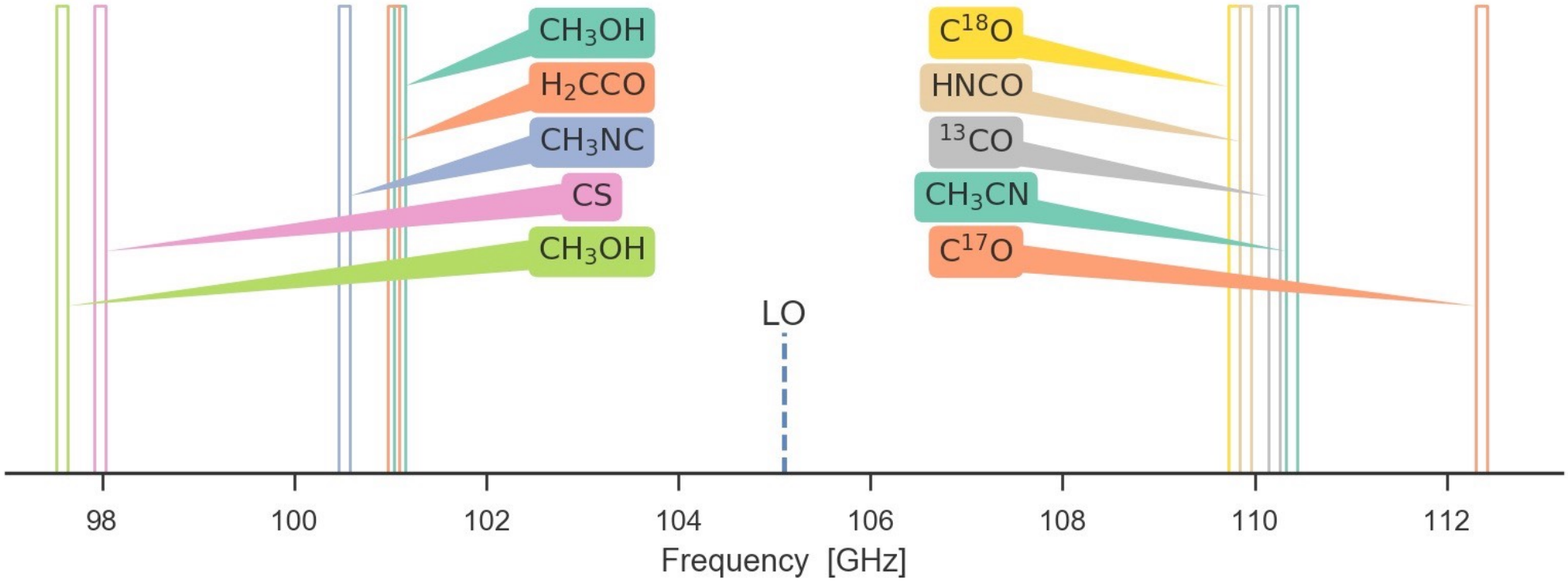
Higher spectral resolution reduces processed bandwidth.

More spectral windows per baseband reduces spectral resolution.

For dual polarization mode and for 1 spectral window per baseband

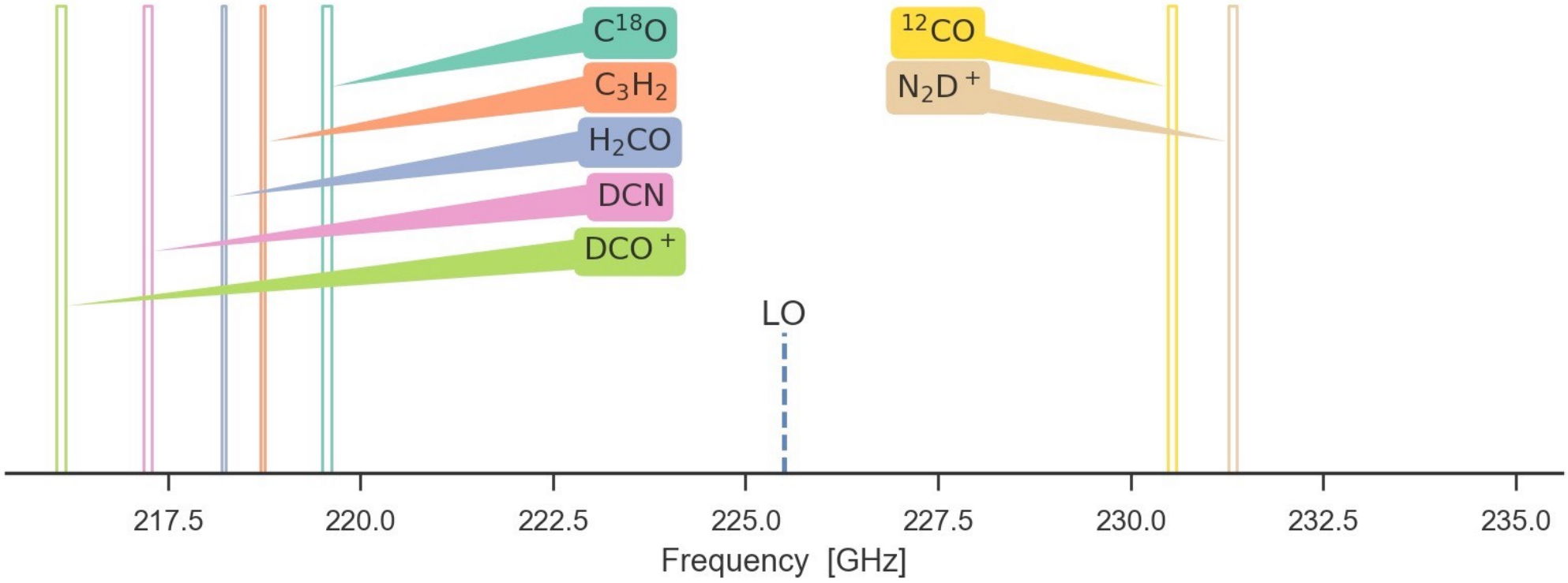
Example Correlator Setups: Band 3

CO isotopologues and chemical survey



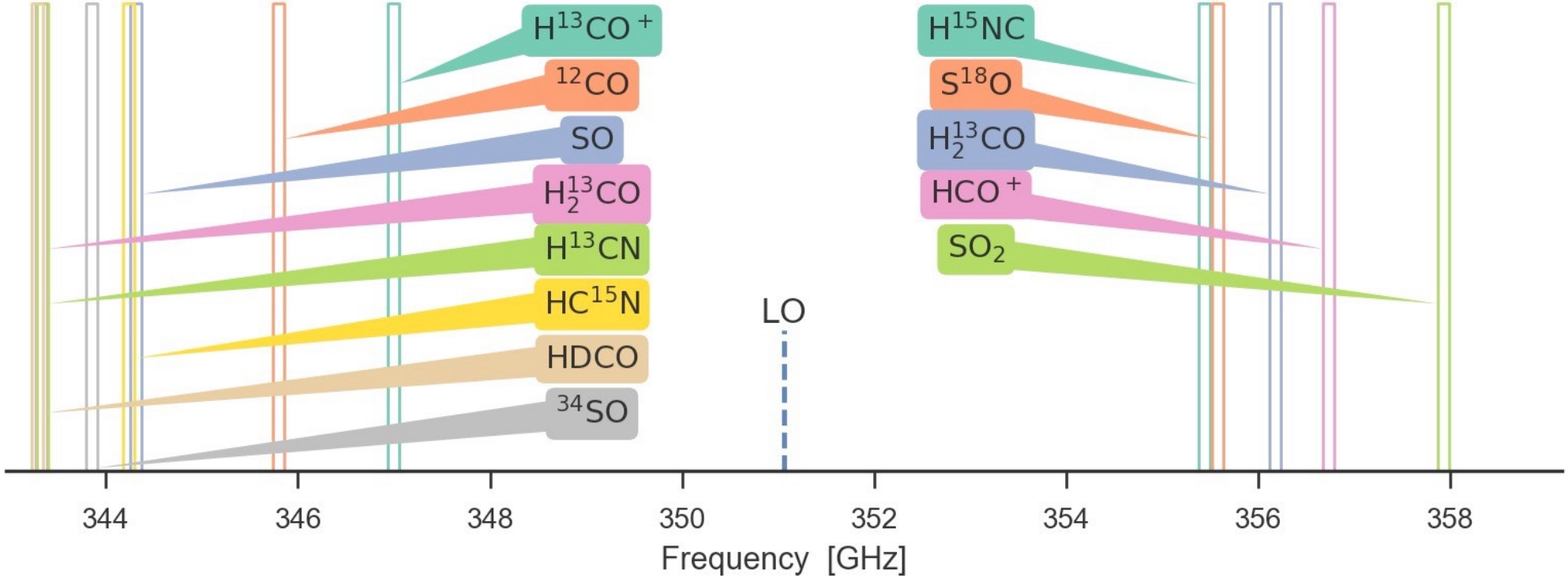
Example Correlator Setups: Band 6

Deuterated chemistry



Example Correlator Setups: Band 7

Chemical survey of disks



Applying for ALMA Time

- ALMA Call for Proposals released once a year
- Regular proposal deadline is mid of May
  - **Cycle 10: May 10th, 15 UTC.**
- Director's Discretionary Time (DDT) proposals accepted any time

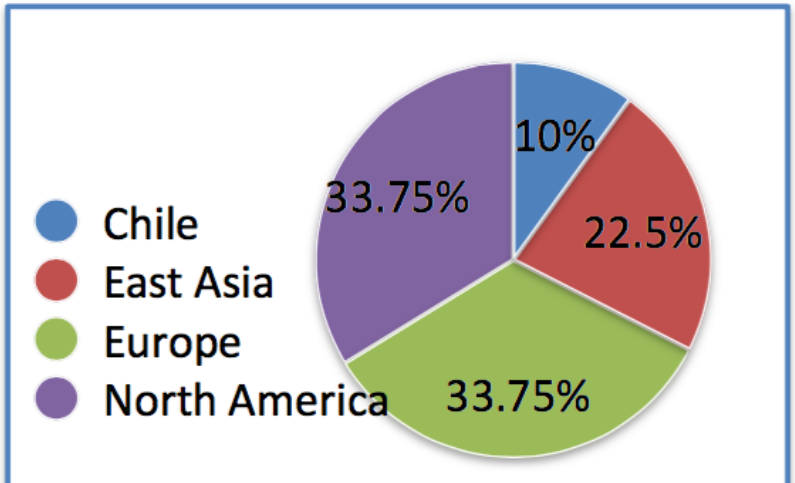
- Important documents @ ALMA Science Portal
  - Proposer's Guide
  - ALMA Technical Handbook
  - ALMA Primer
  - Observing Tool Guide

Applying for ALMA Time

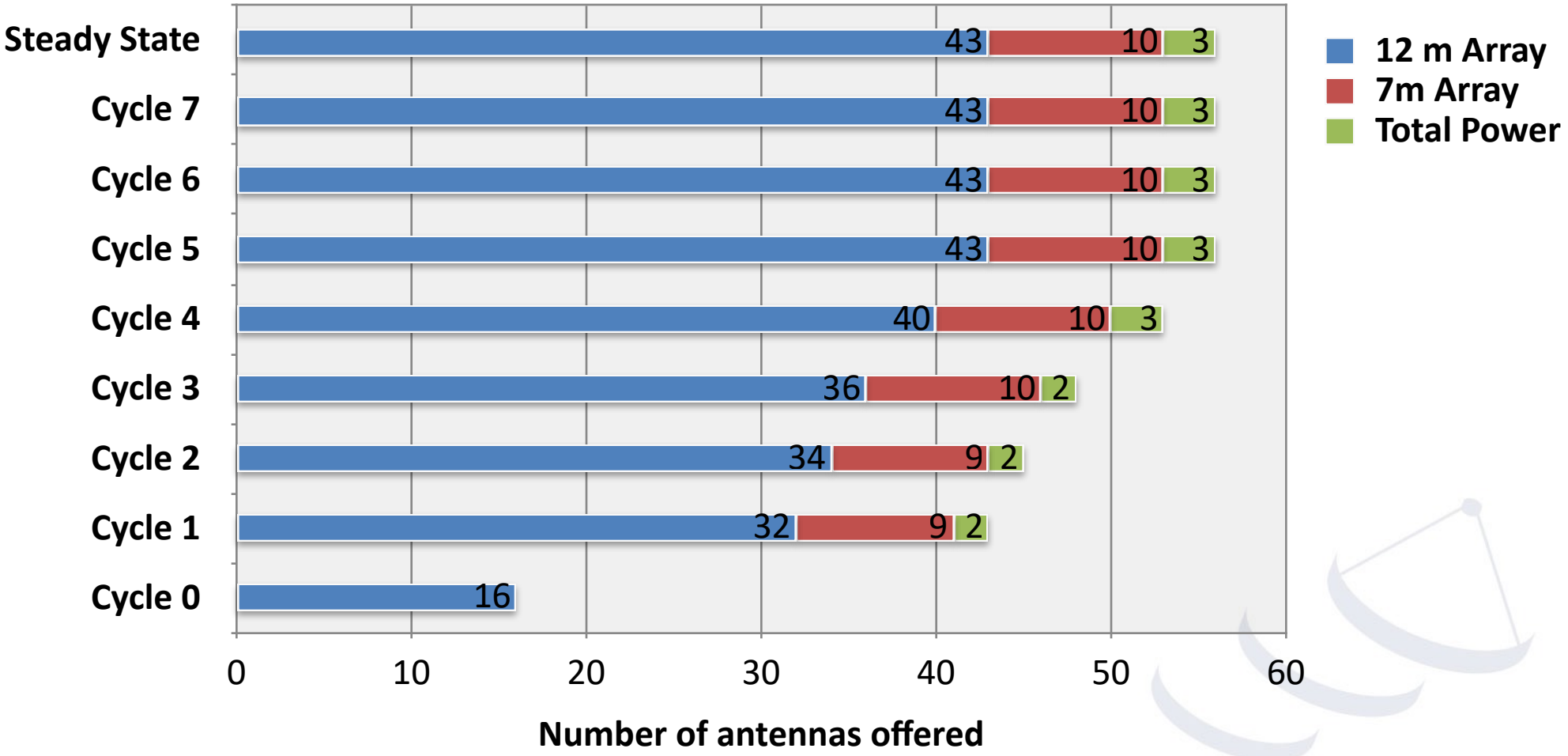
- ALMA is available to everyone!
- Each region guaranteed a share of time
  - all regions contribute toward Open Skies
- ALMA operates in "queue" observing mode
  - data obtained, calibrated, and imaged by ALMA staff

Oversubscription Rate in Cycle 7 on 12-m array

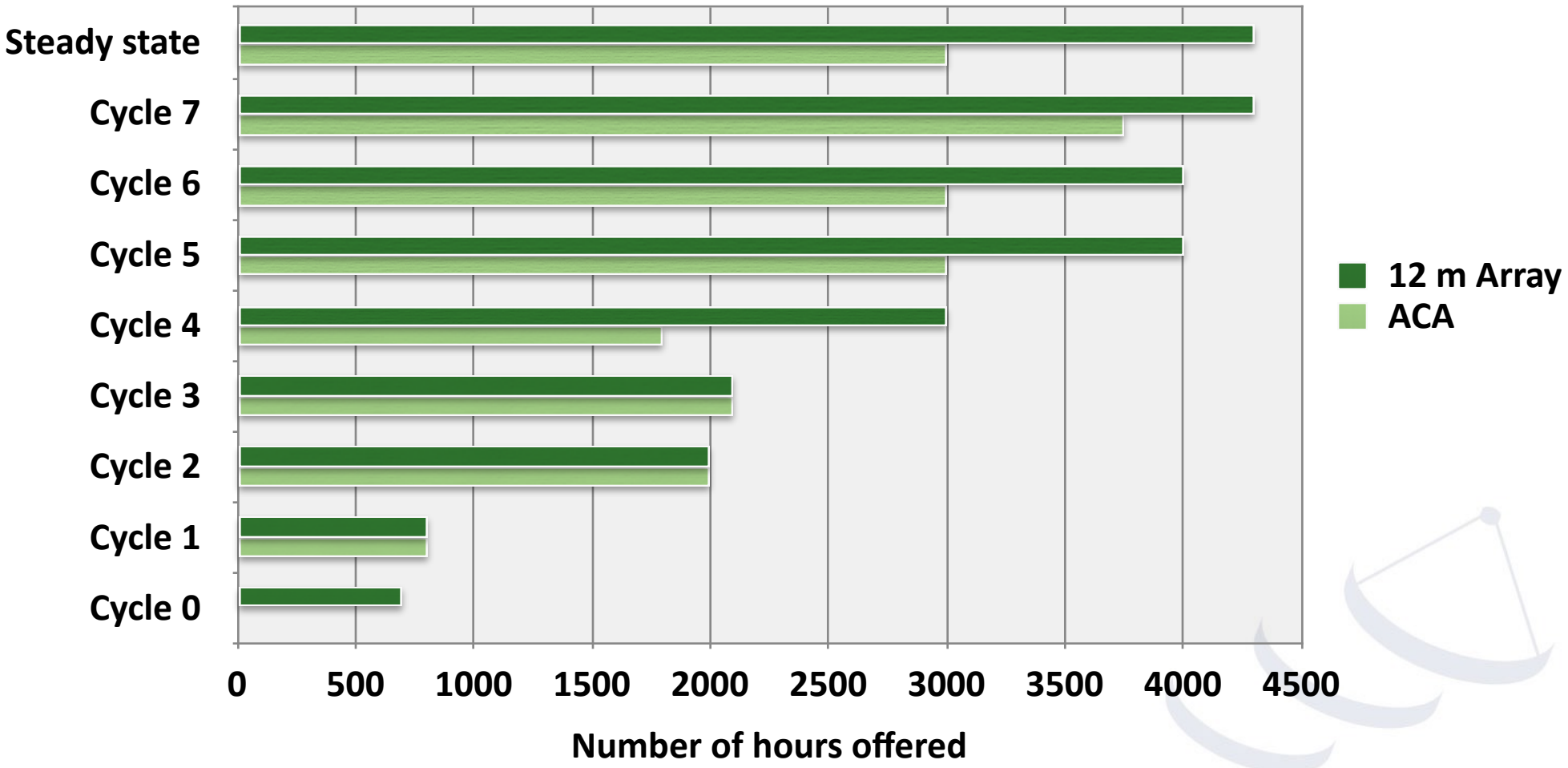
Chile	East Asia	Europe	North America
2.4	4.1	5.7	3.6



Minimum number of antennas



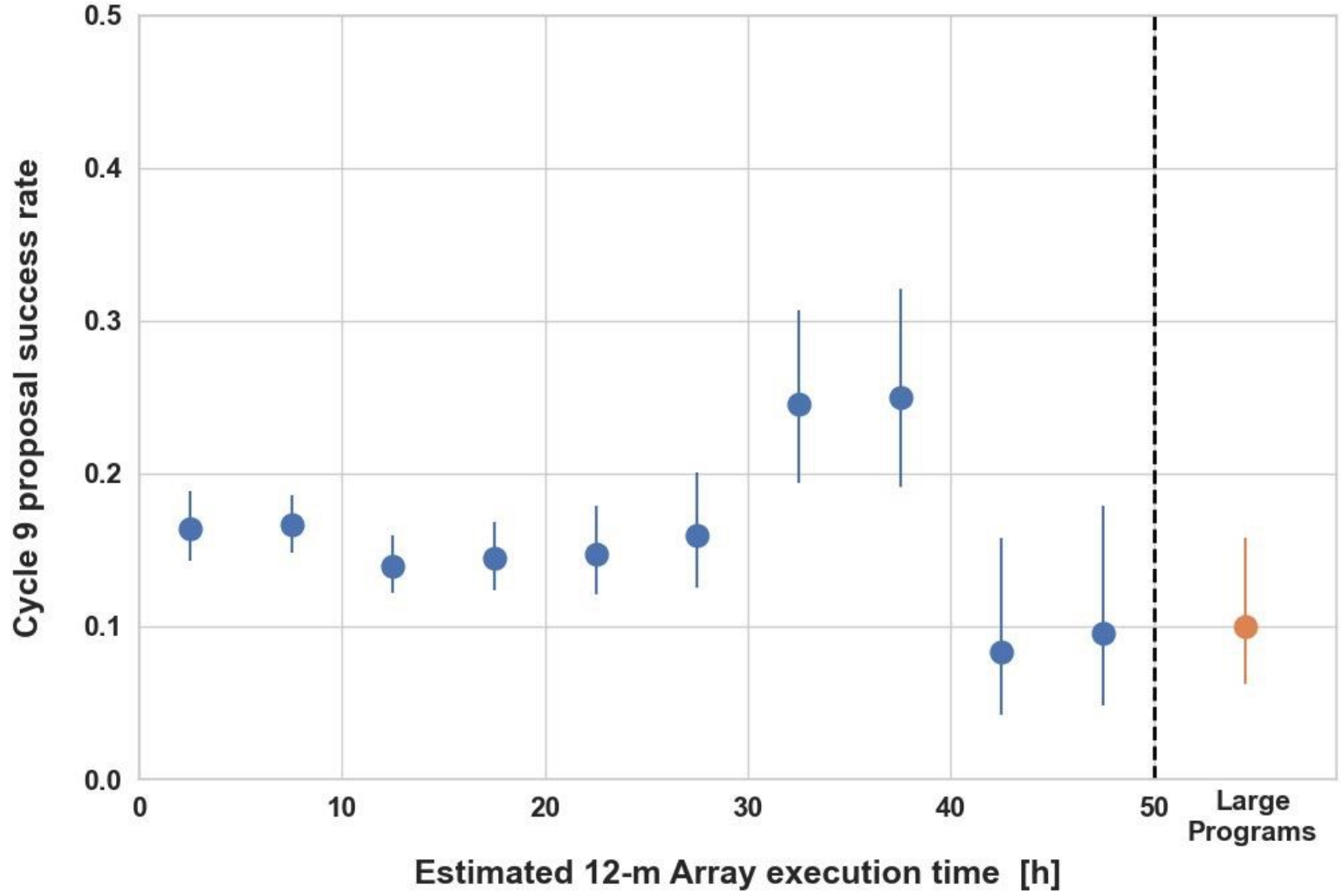
Hours of observing time



How much time can I ask for?

- Request what you need to do your science
- Yeah, but how much time can I really ask for?

Cycle 9 Acceptance Rate (Grade A+B) vs. Requested Time



What is coming to ALMA?

- Band 1 (wavelength 7.5 mm) in Cycle 10
- Band 2 (wavelength 3.8 mm) under development
- Roadmap to ALMA in 2030

ORIGINS OF GALAXIES

Trace the cosmic evolution of key elements from the first galaxies (z>10) through the peak of star formation (z~2–4) by detecting their cooling lines, both atomic ([CII], [OIII]) and molecular (CO), and dust continuum, at a rate of 1-2 galaxies per hour.

ORIGINS OF CHEMICAL COMPLEXITY

Trace the evolution from simple to complex organic molecules through the process of star and planet formation down to solar system scales (~10-100 au) by performing full-band frequency scans at a rate of 2-4 protostars per day.

ORIGINS OF PLANETS

Image protoplanetary disks in nearby (150 pc) star formation regions to resolve the Earth forming zone (~ 1 au) in the dust continuum at wavelengths shorter than 1mm, enabling detection of the tidal gaps and inner holes created by planets undergoing formation.

ALMA Support

- Documentation on ALMA Science Portal

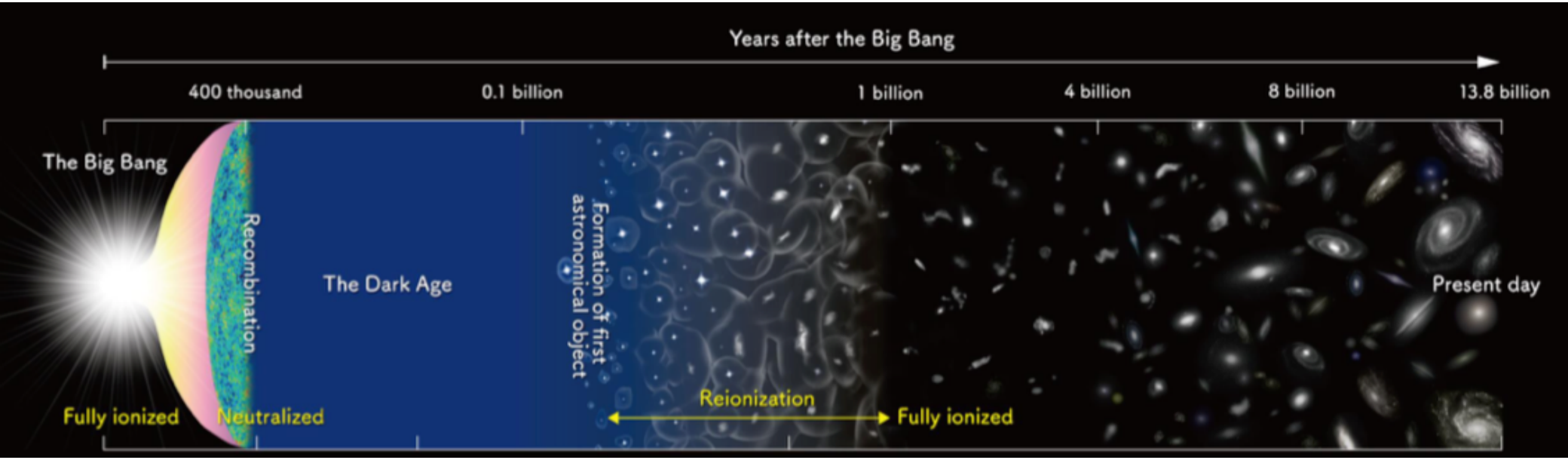
- Help Desk https://help.almascience.org
  - Questions usually answered in 2 days
  - around-the-clock staffing near the ALMA proposal deadline

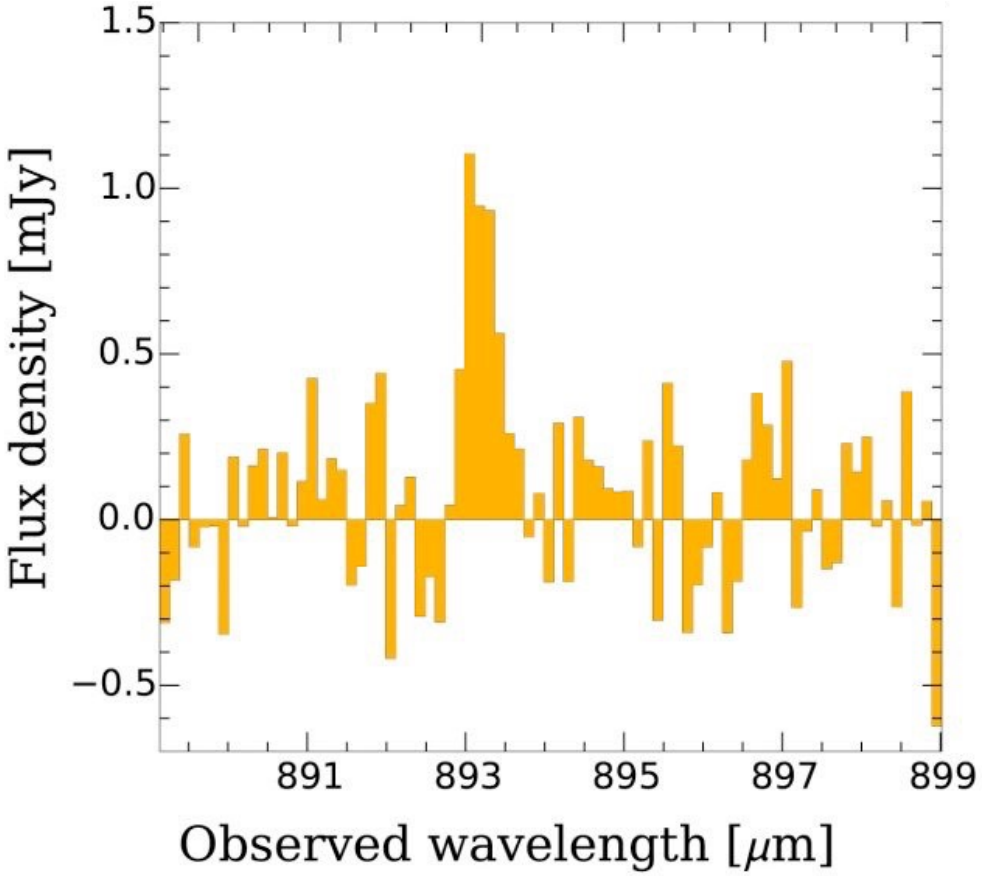
- ALMA provides calibrated data and representative images

- ALMA Archive http://almascience.org/aq
  - 1 year proprietary period (6 months for DDT)
  - provides calibrated data and images

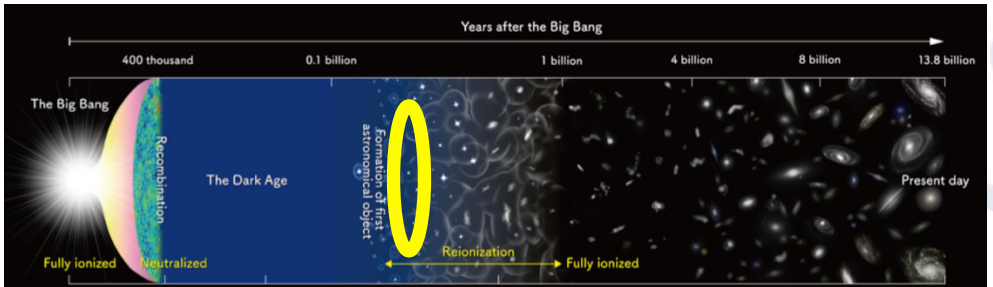

A big thanks to everyone who make ALMA such a success

Science!


Years after the Big Bang
400 thousand
0.1 billion
1 billion
4 billion
8 billion
13.8 billion
The Big Bang
Recombination
The Dark Age
Formation of first astronomical object
Present day
Fully ionized
Neutralized
Reionization
Fully ionized



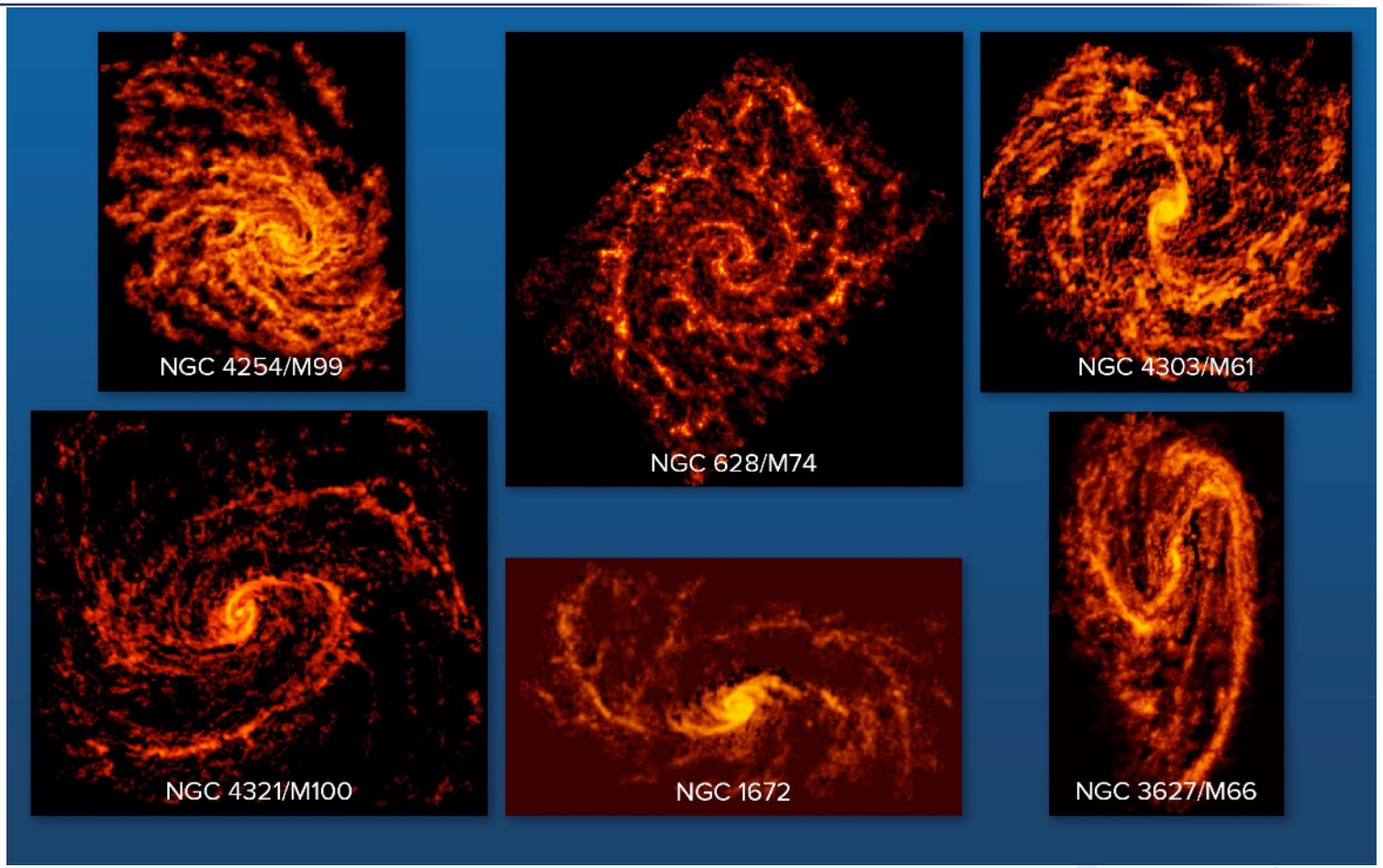
- Locate the earliest galaxies a few hundred of million years after the Big Bang.
- Oxygen [OIII] present at z=9.11 (13.28 billion light-years away) when Universe is 350 Myr old!
- Implies star formation started 250 Myr after Big Bang!

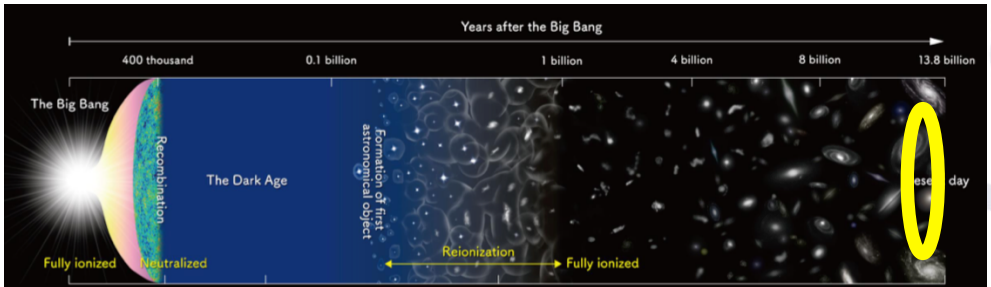


Hashimoto et al. (2018)

PHNAGS Large Program – Schinnerer et al; 17 papers.

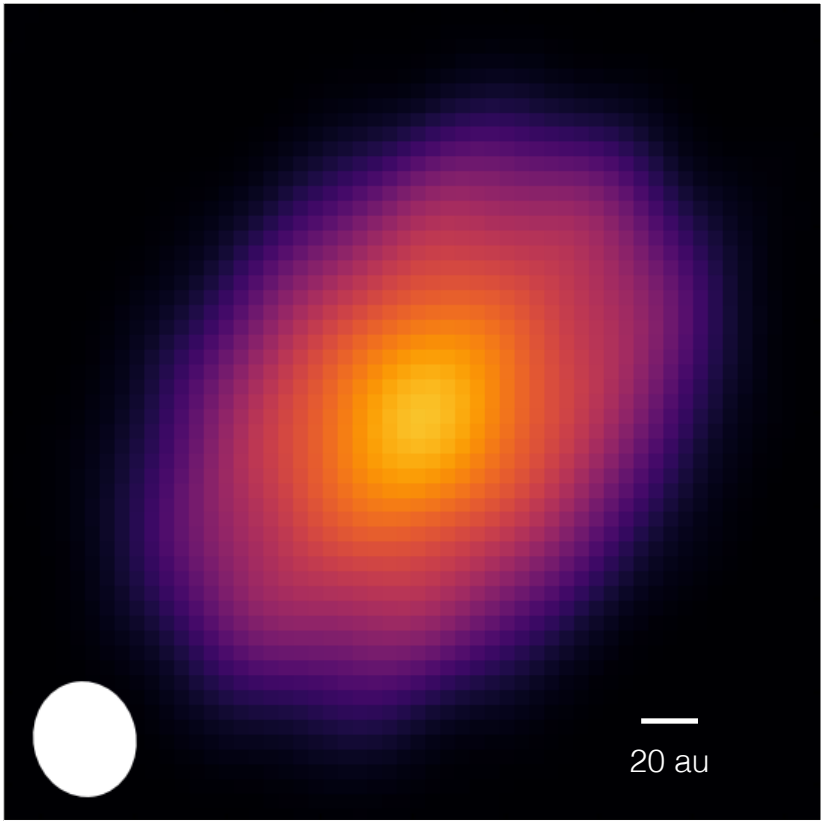
- Sample of 74 nearby galaxies.
- CO observations.
- 100,000 molecular clouds.



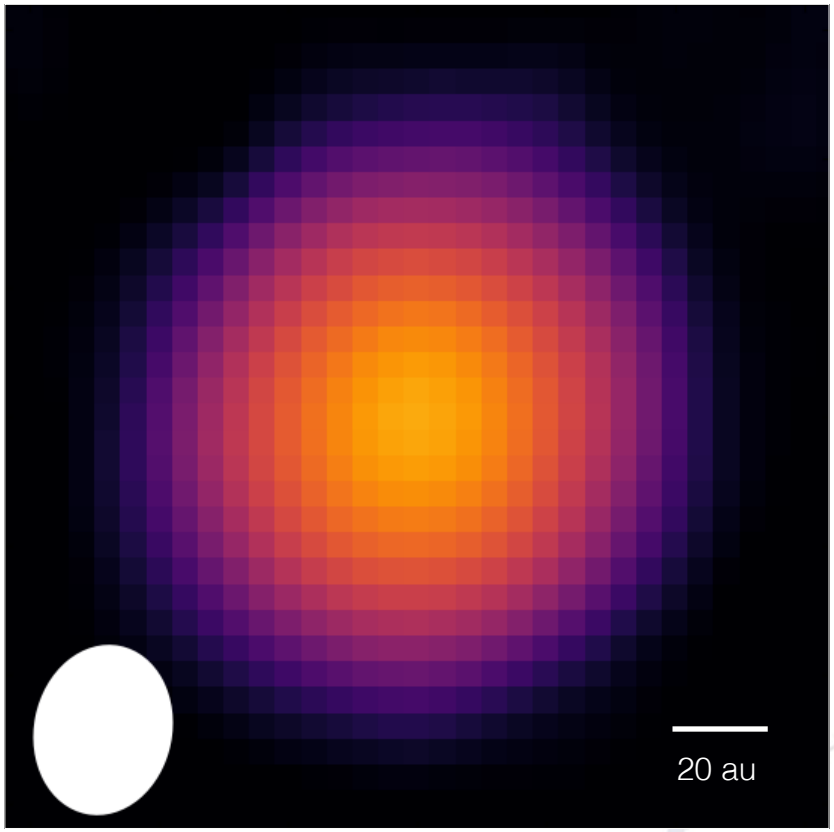


Proto-planetary disks before ALMA

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



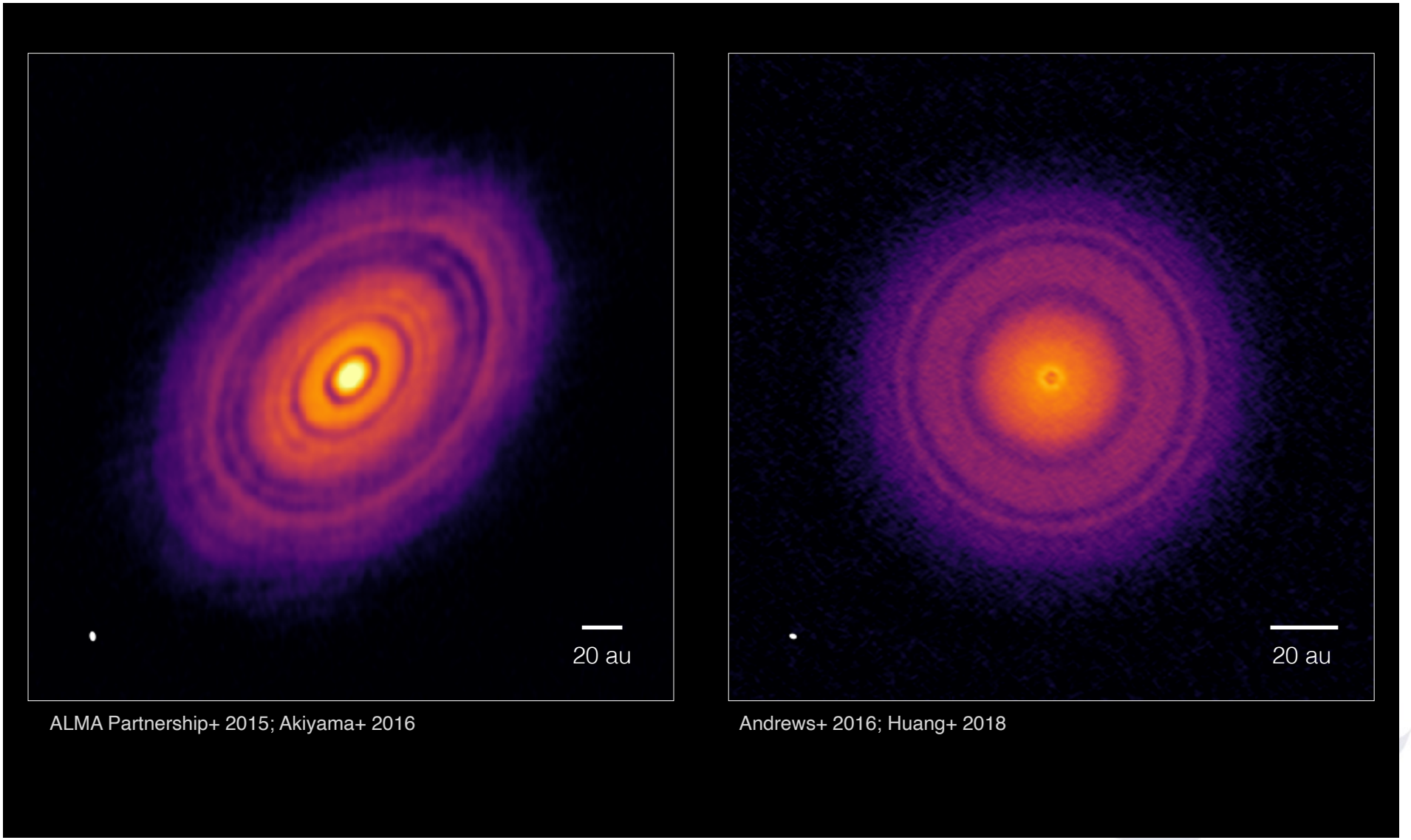
Kwon+ 11



Andrews+ 12

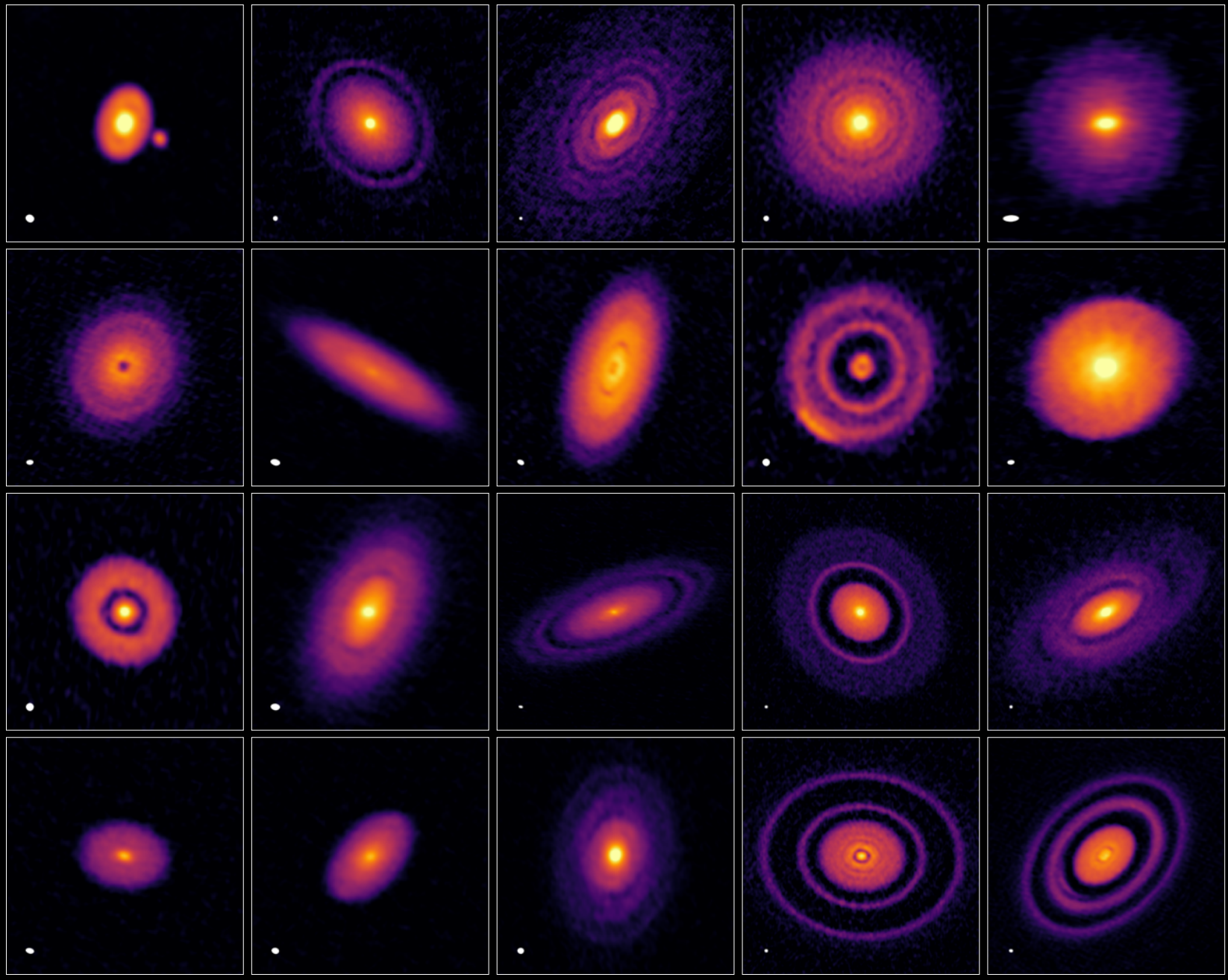
Proto-planetary disks with ALMA

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



ALMA Partnership+ 2015; Akiyama+ 2016

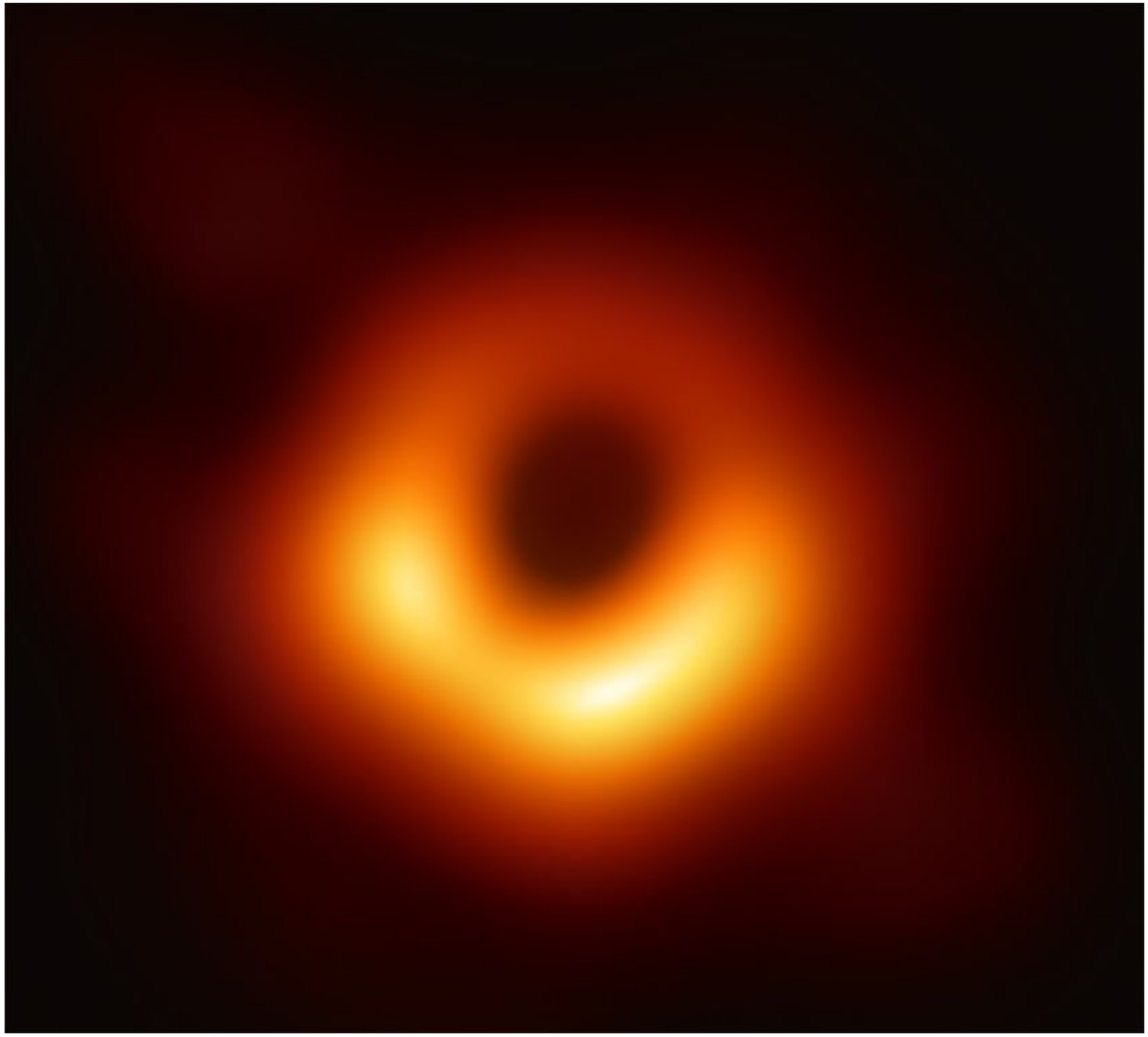
Andrews+ 2016; Huang+ 2018



DSHARP Cycle 4 Large Program – Andrews et al; 10 papers, 2019, ApJL 869

EHT – 1st image of a black-hole shadow

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



2020 Breakthrough Prize

EHT Collaboration et al, 2019
- 6 papers in ApJL 875