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

ALMA Capabilities in Cycle 7

Antonio Hales
Joint ALMA Observatory/NRAO

ALMA Community Day
Texas Tech. University
May 30, 2019

Outline

- ALMA operations
- Overview of ALMA Science
- Cycle 7 Call for Proposals

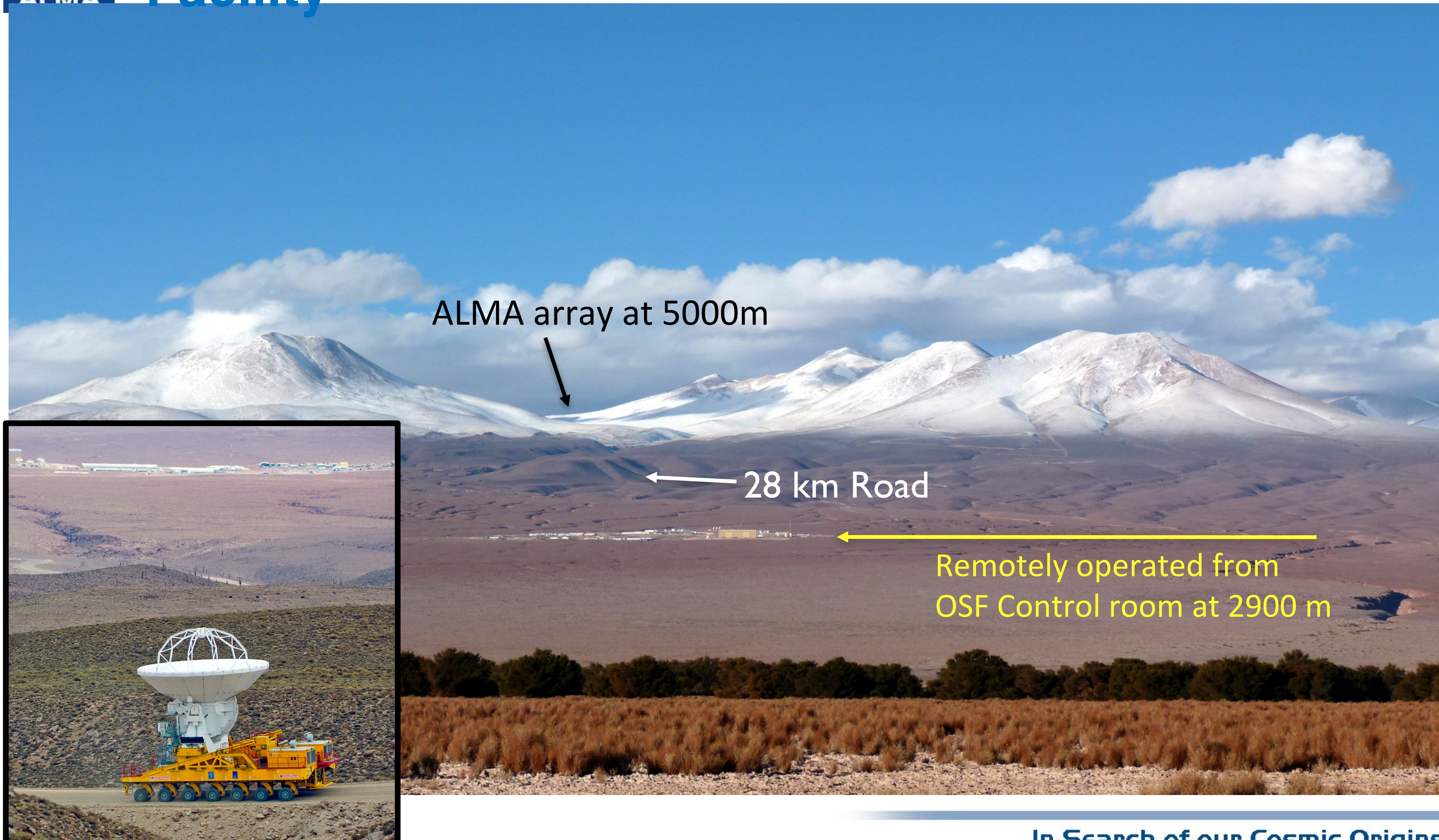
ALMA

In search of our Cosmic Origins

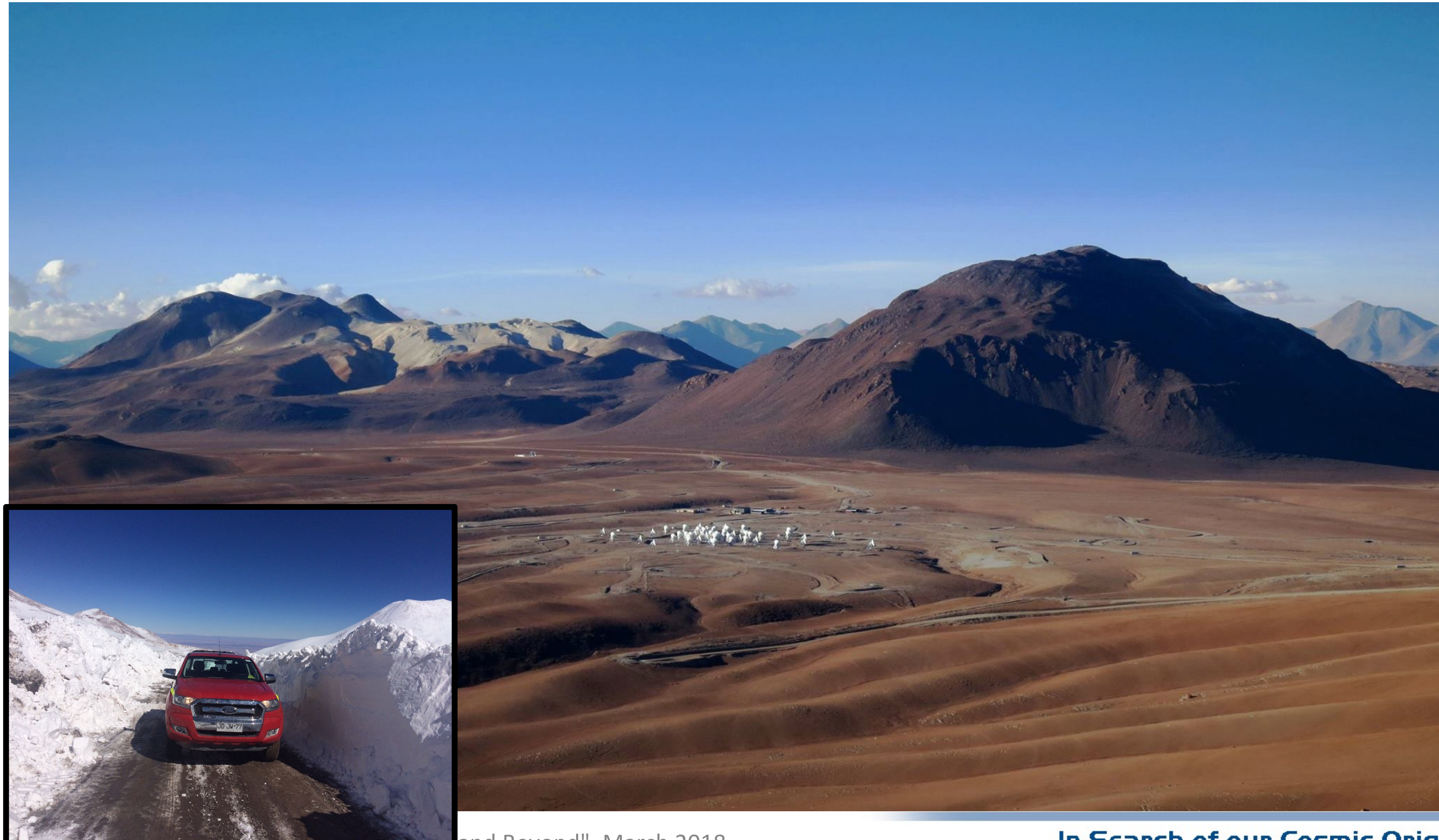
ALMA Overview

- 5000 m site in Atacama desert in Chile
- 66 reconfigurable antennas
- λ ≈ 0.3 - 3.0 mm
- Array configurations between 0.16 and 16 km
  - angular resolution as fine as 0.014” at 300 GHz
- International partnership of North America, Europe, and East Asia

Remote Operation at the Operations Support Facility



Extraordinary High, Dry Site



ALMA Operations

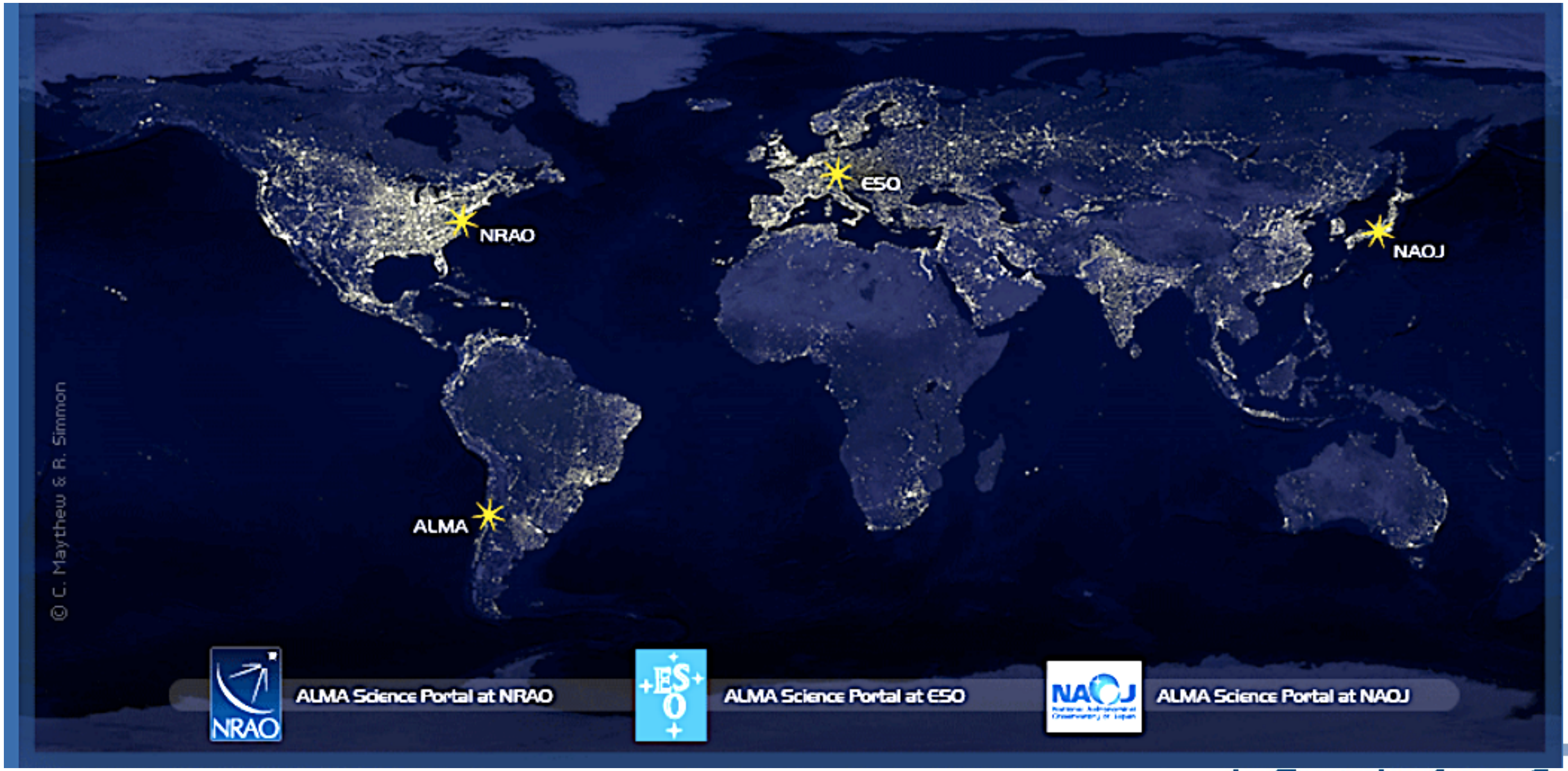
Cycle 7 CfP Now! Deadline April 17, 2019

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

- Santiago Central Office
- Operations Support Facility
- Array Operations Site

ALMA User Support is centered at the ALMA Regional Centers:

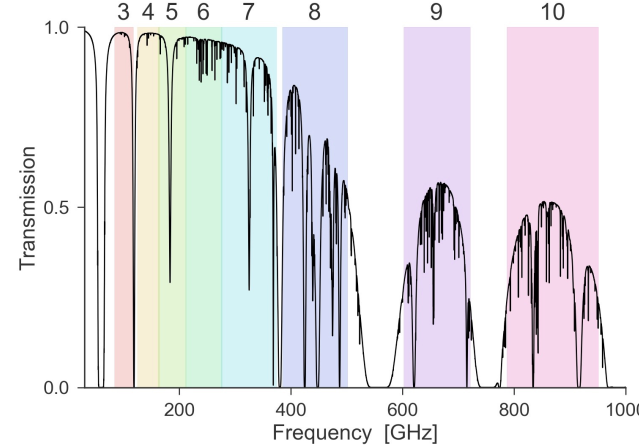
- NA ARC – NRAO, NRC (NAASC)
- EU ARC + ARC Nodes (ESO …)
- EA ARC, ASIAA



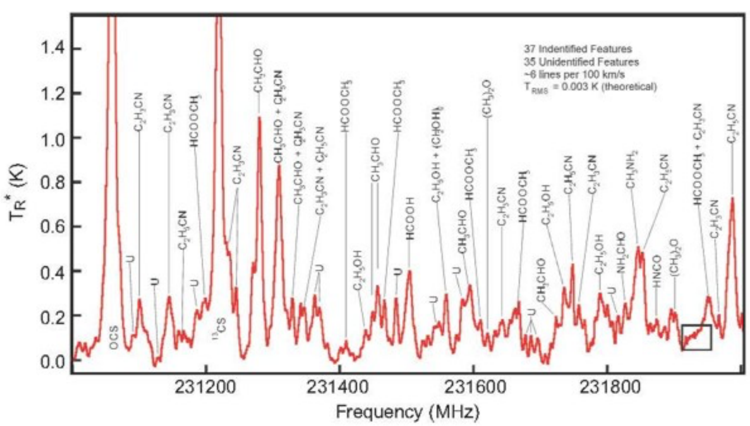
Capabilities

Imaging

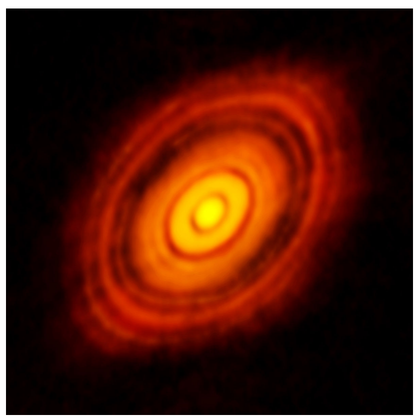
8 receiver bands



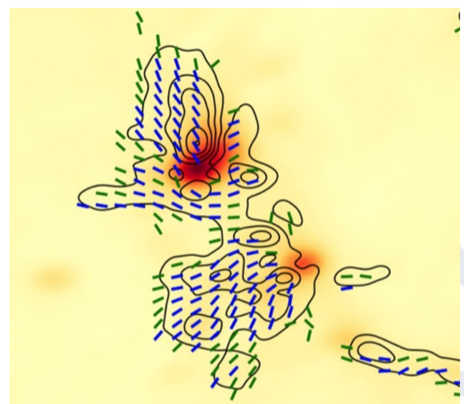
Spectral lines



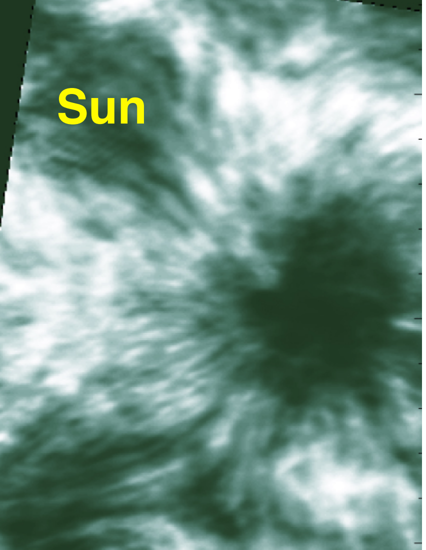
Continuum

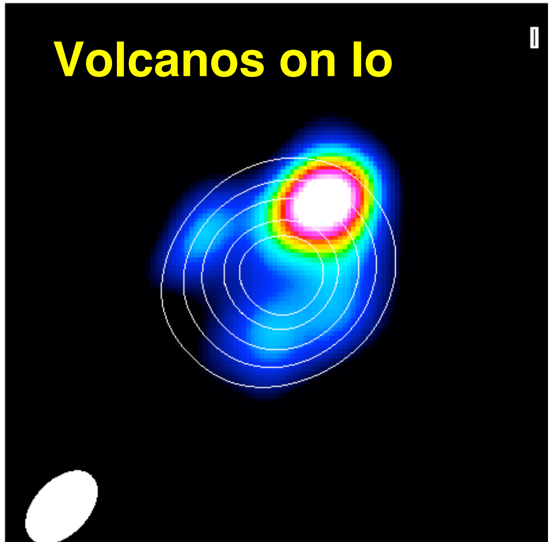


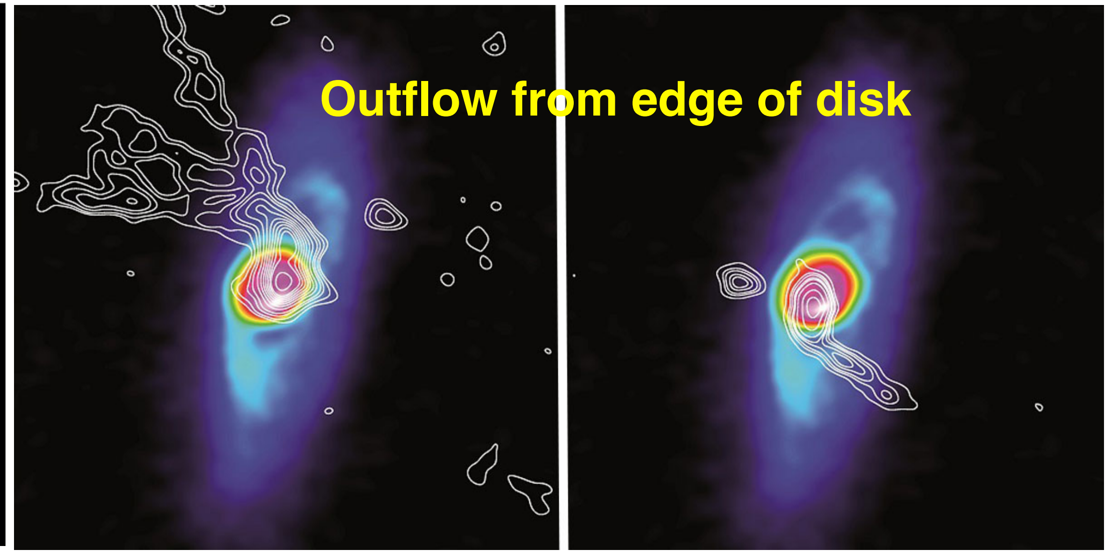
Polarization

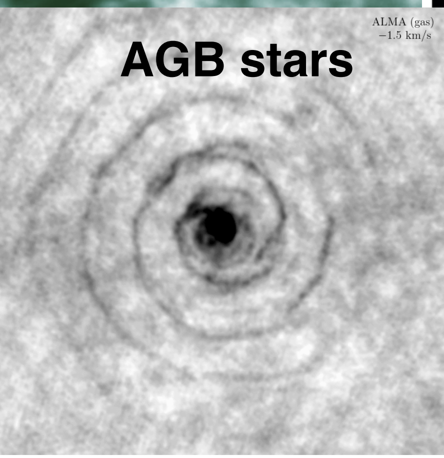


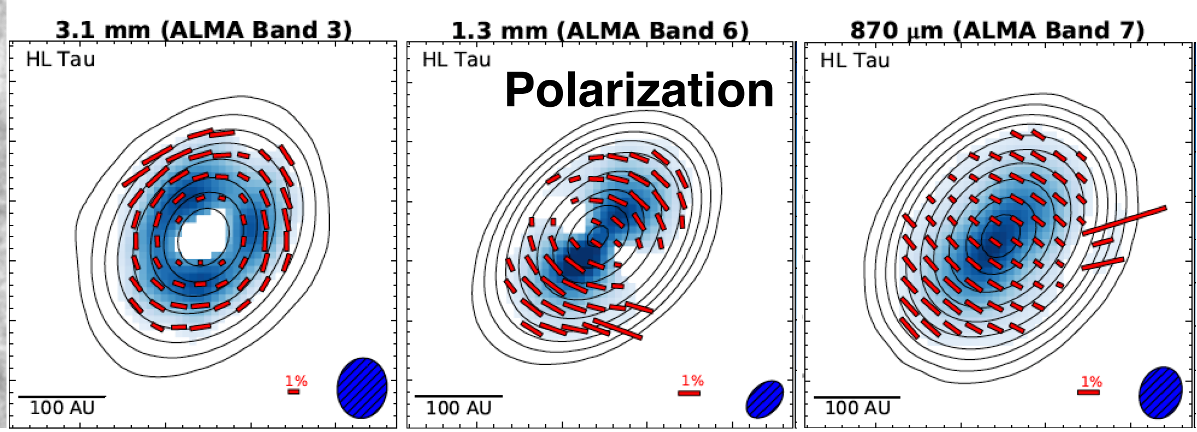
VLBI

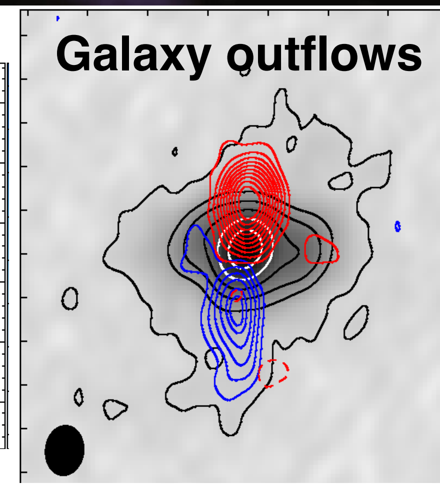

Sun

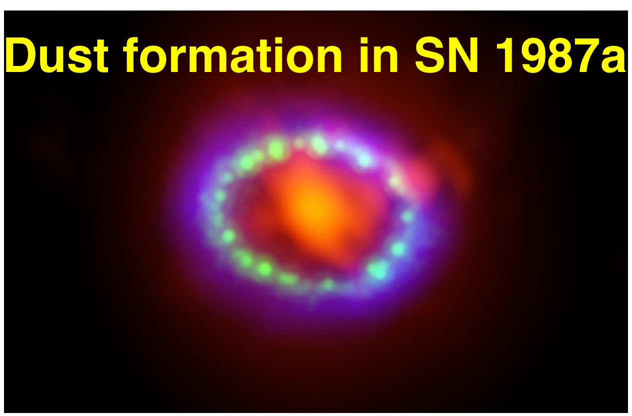

Volcanos on Io

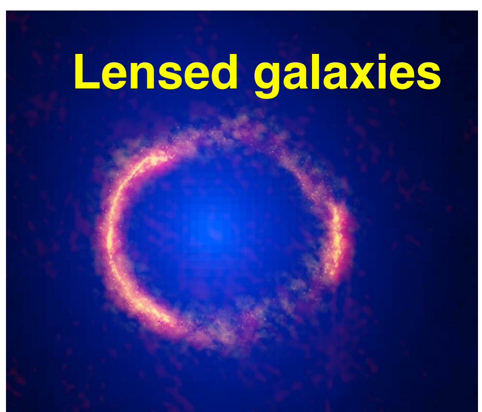

Outflow from edge of disk

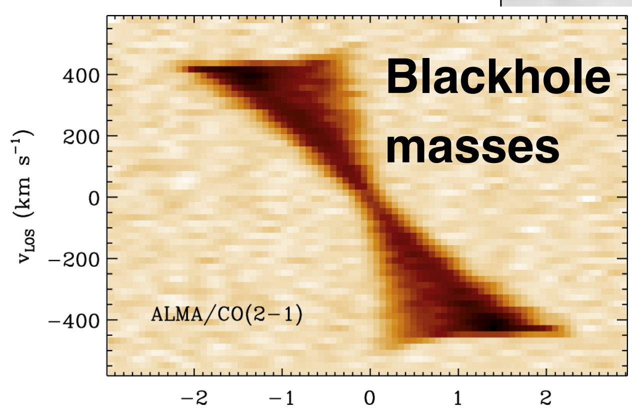

AGB stars
ALMA (gas)
−1.5 km/s

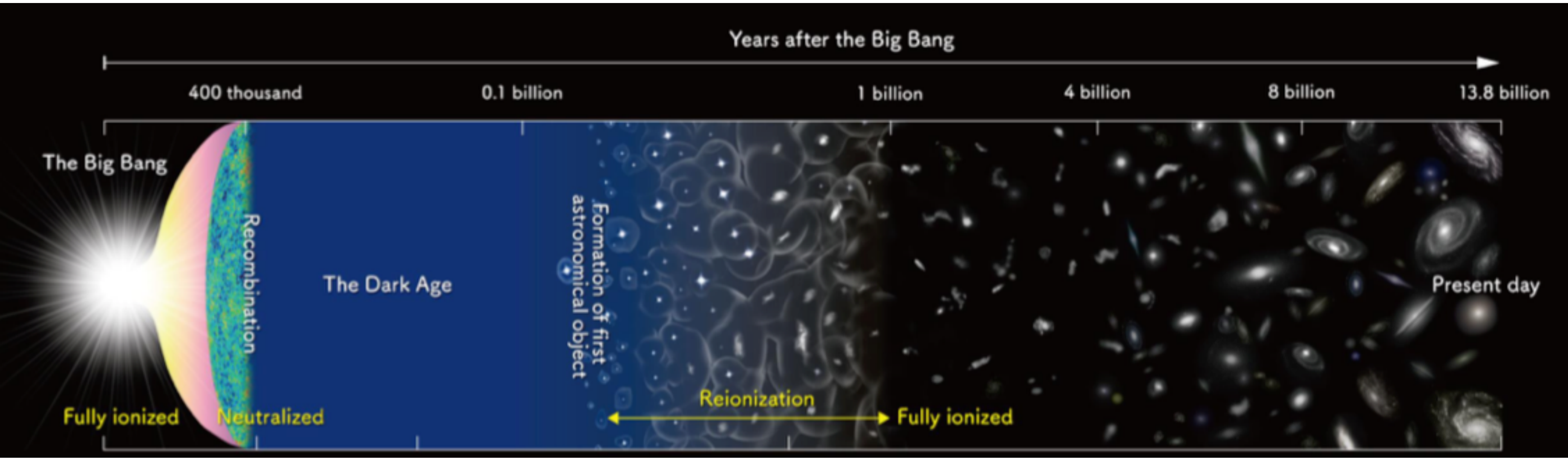

3.1 mm (ALMA Band 3)
1.3 mm (ALMA Band 6)
870 μm (ALMA Band 7)
HL Tau
Polarization
1%
100 AU

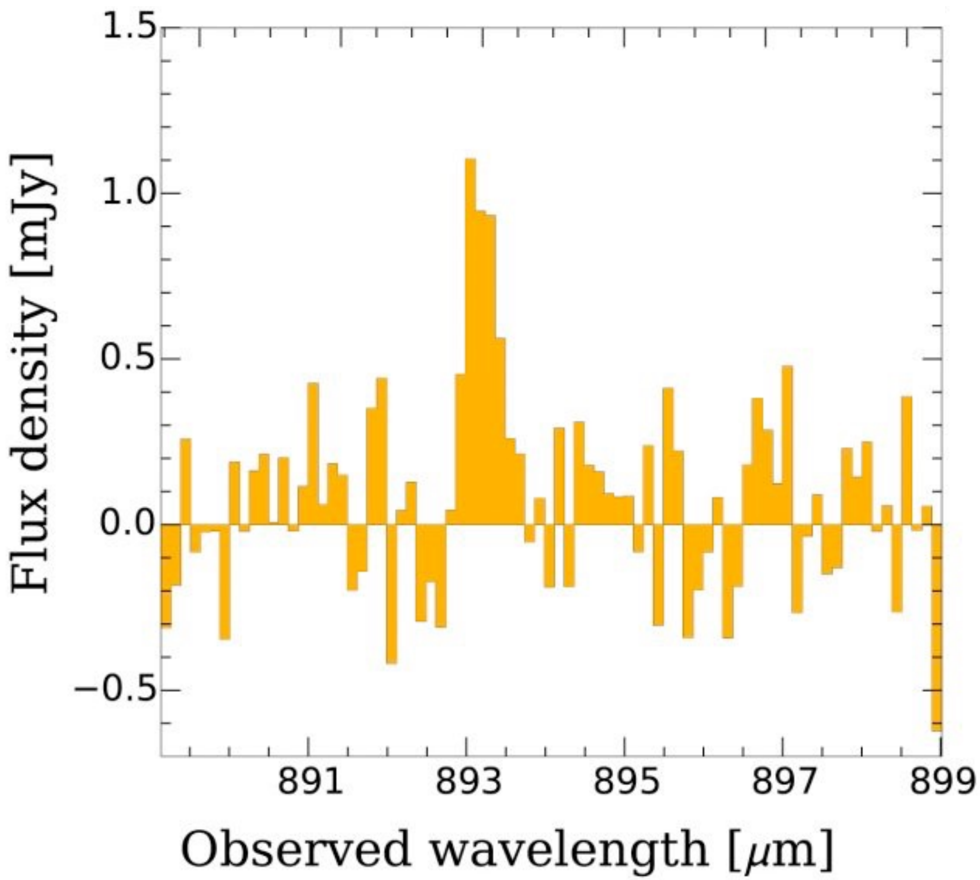

Galaxy outflows


Dust formation in SN 1987a

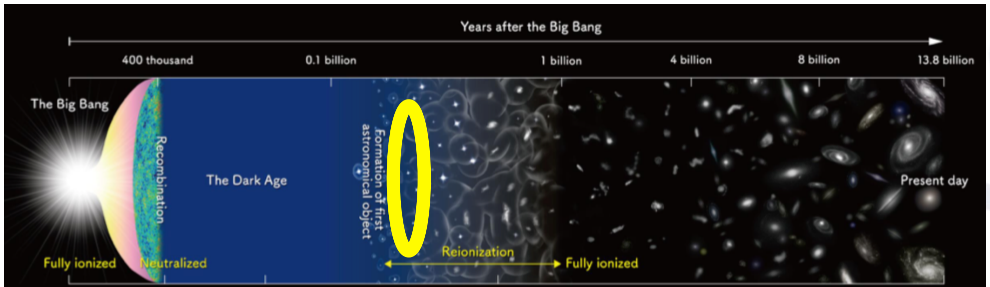

Lensed galaxies


Blackhole
masses
ALMA/CO(2−1)
v_LOS (km s^−1)
400
200
0
−200
−400
−2
−1
0
1
2


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



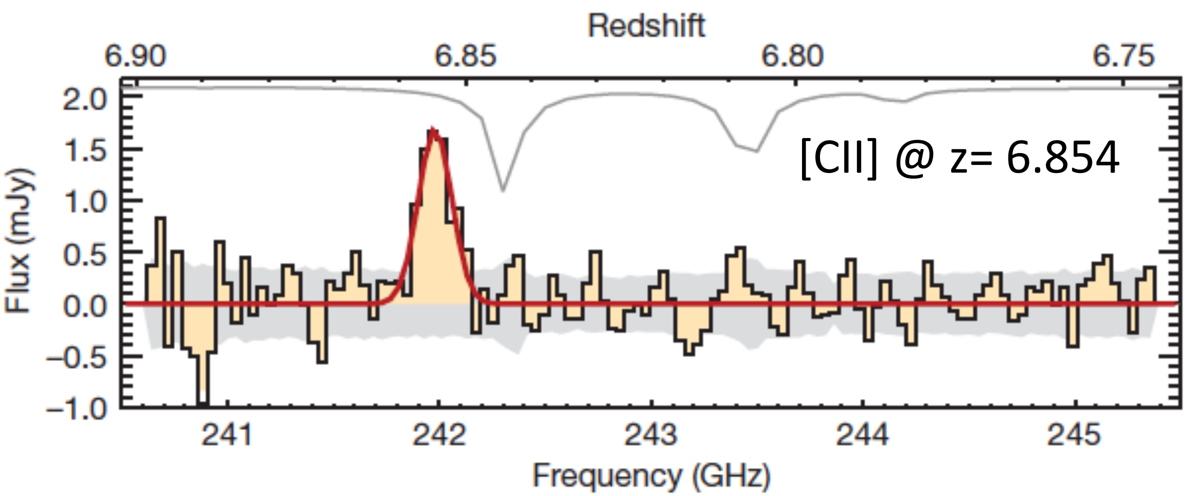
- Locate the earliest galaxies a few hundred of million years after the Big Bang.
- Oxygen [OIII] present at z=9.11 when Universe is 350 Myr old!
- Implies star formation started 250 Myr after Big Bang

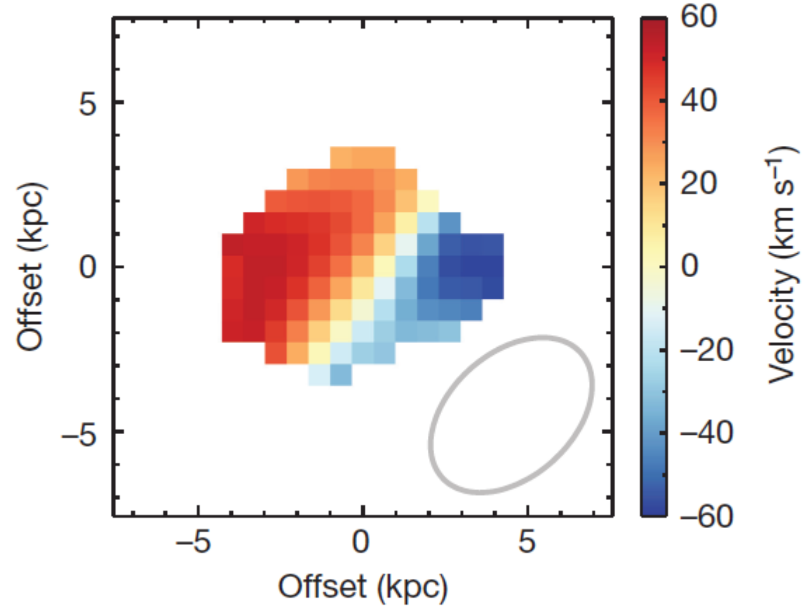


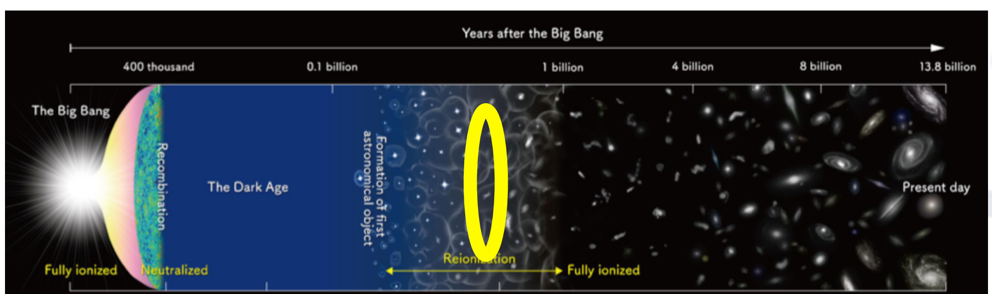
Hashimoto et al. (2018)

Rotation in [CII]-emitting gas in two galaxies at a redshift of 6.8

Kinematics consistent with rotation-dominated disk

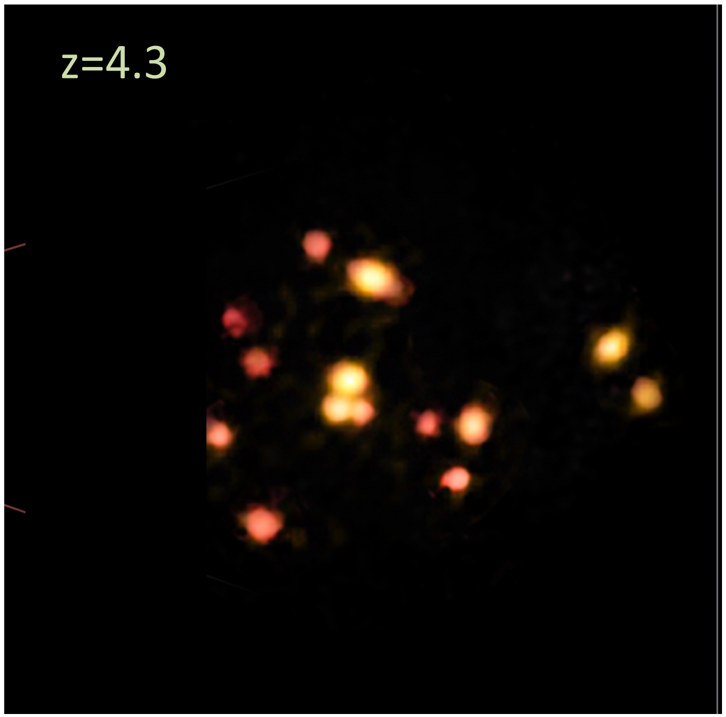


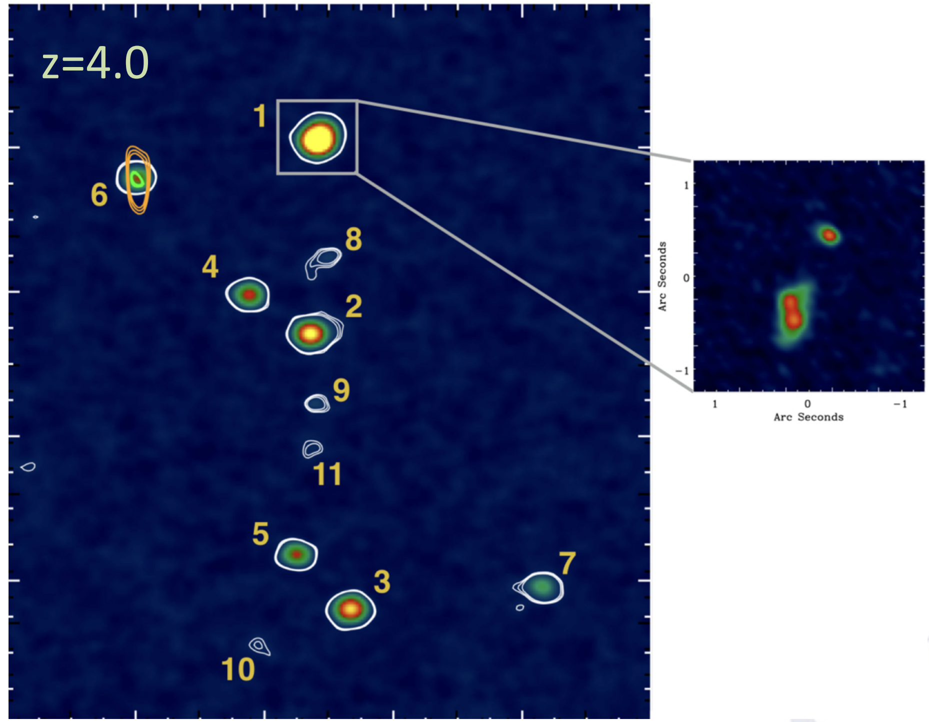


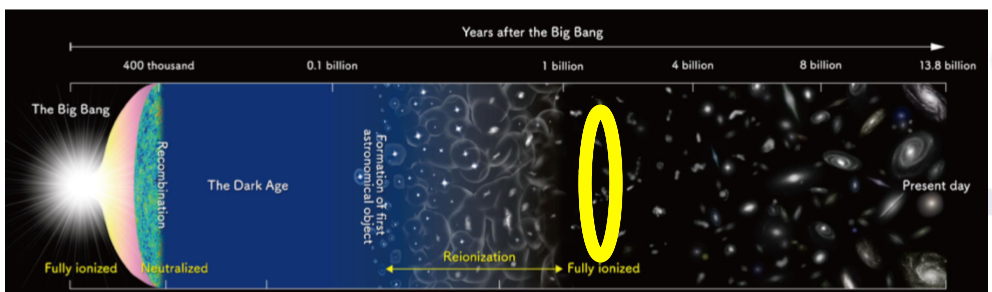


Smit et al. (2018)

Identification of extreme protoclusters of galaxies in the early universe

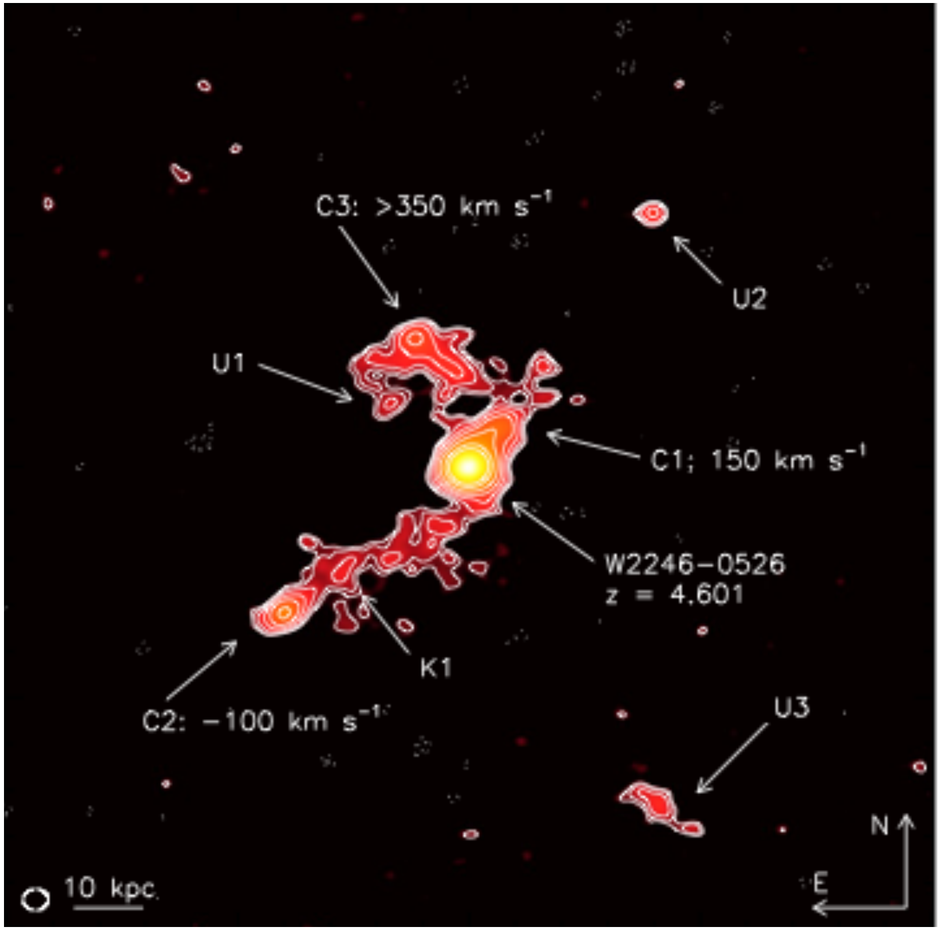




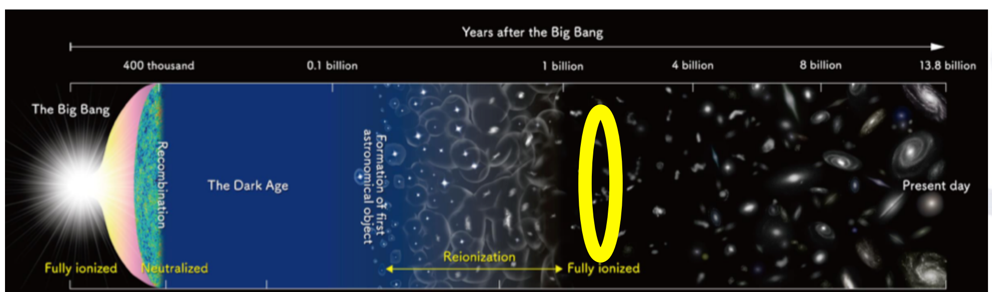


Protoclusters

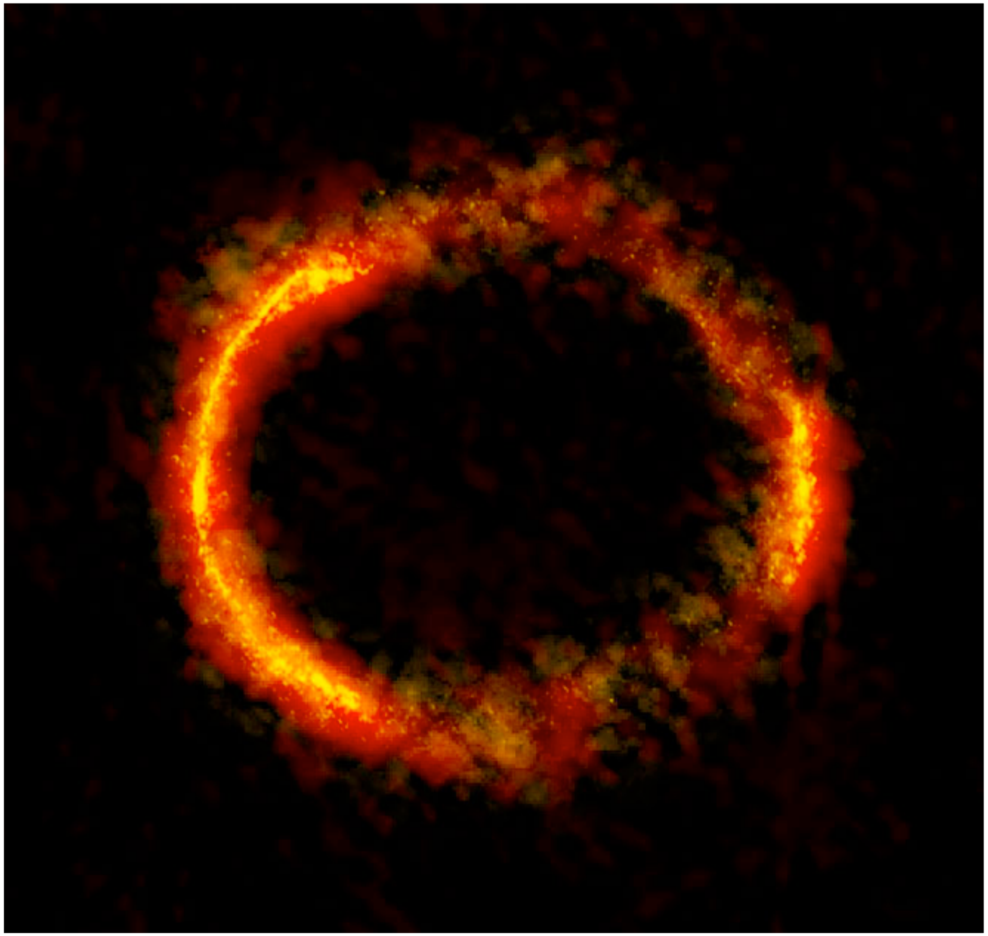
Oteo et al. (2018)
Miller et al. (2018)



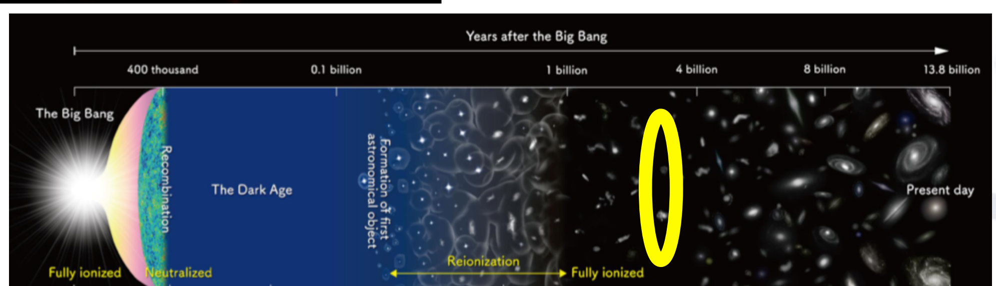
- W2246–0526: Most luminous known galaxy (z=4.6)
- At least 3 companion galaxies
- Dusty bridges show W2246-0526 is accreting is neighbors



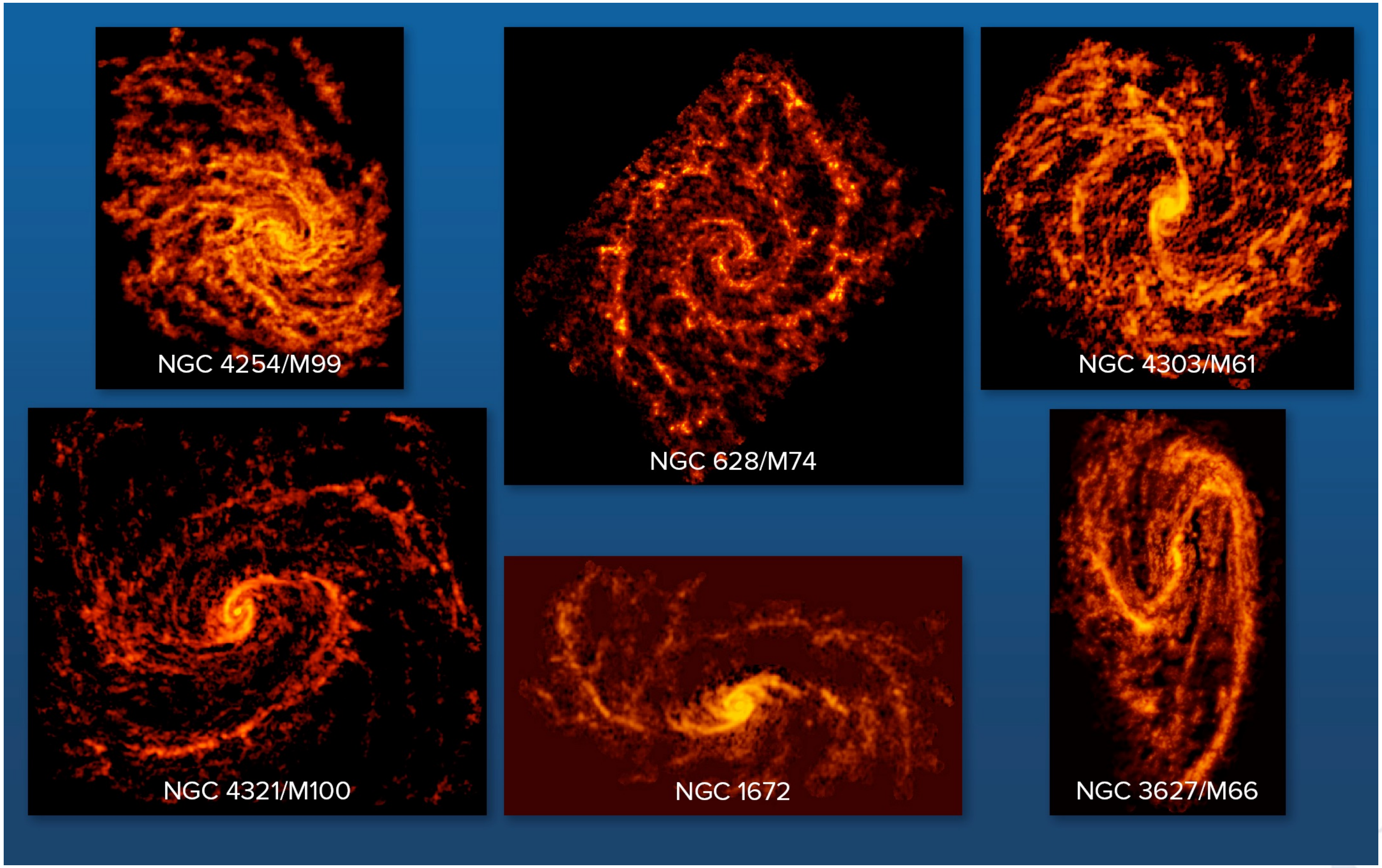
Diaz Santos et al. (2018)

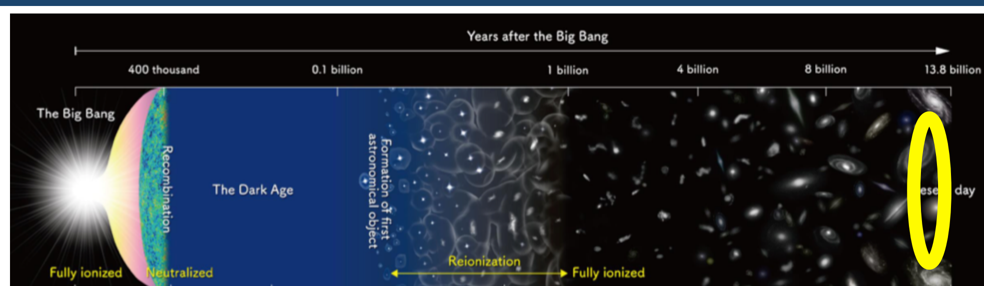


- SPD.81: Lensed galaxy at redshift = 3
- Inverting the lens provides a resolution of 60 pc

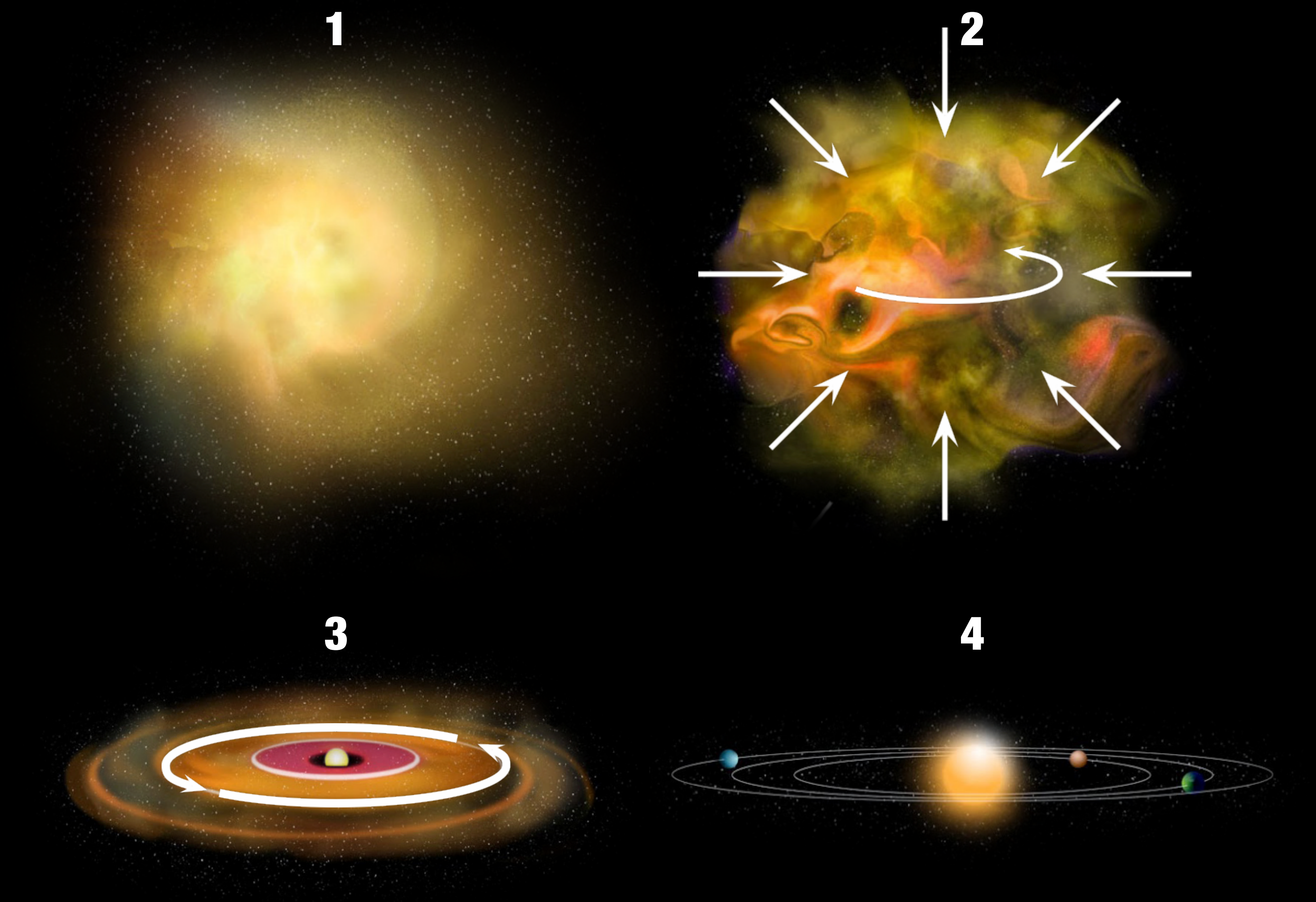


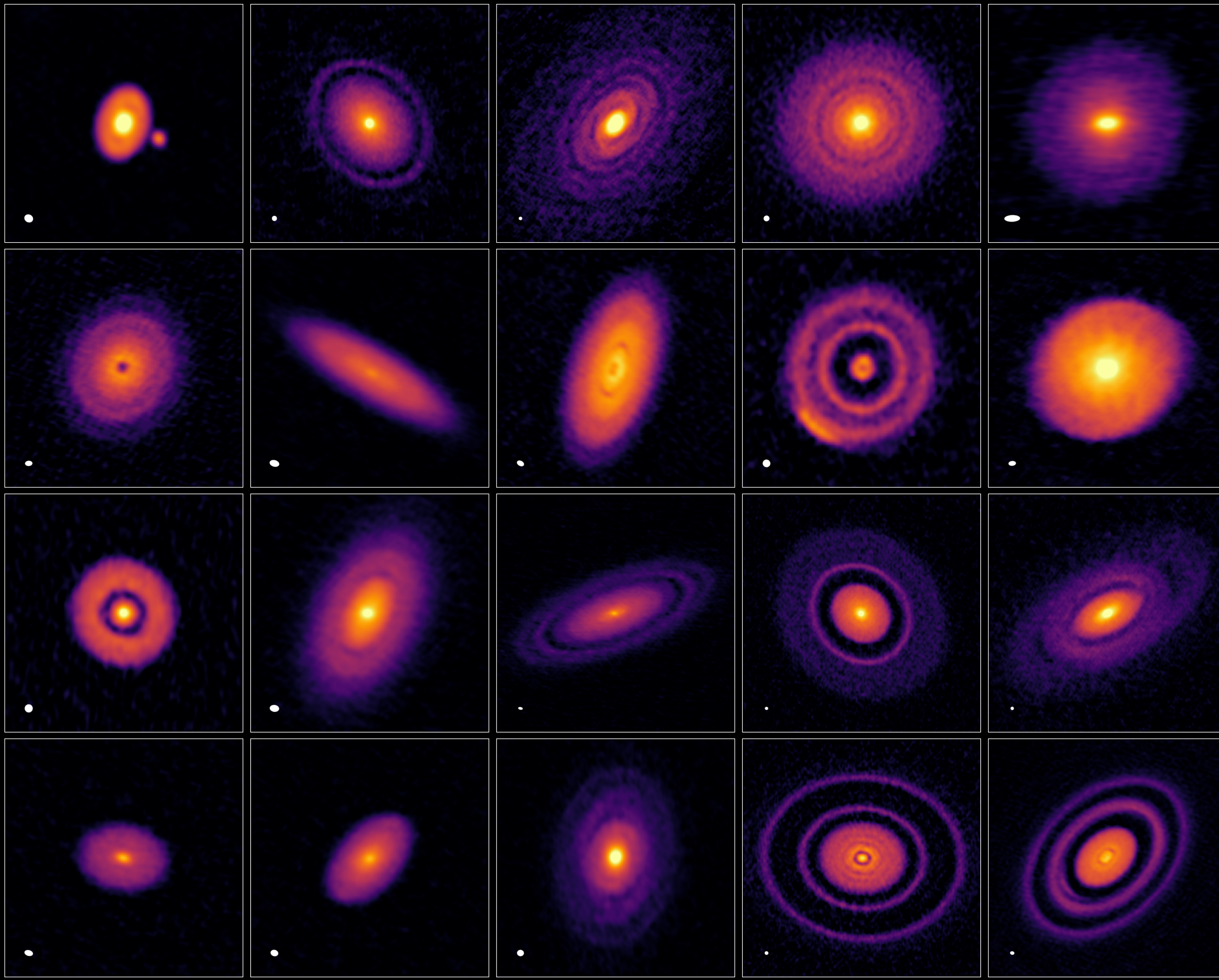
ALMA Partnership et al. (2015)



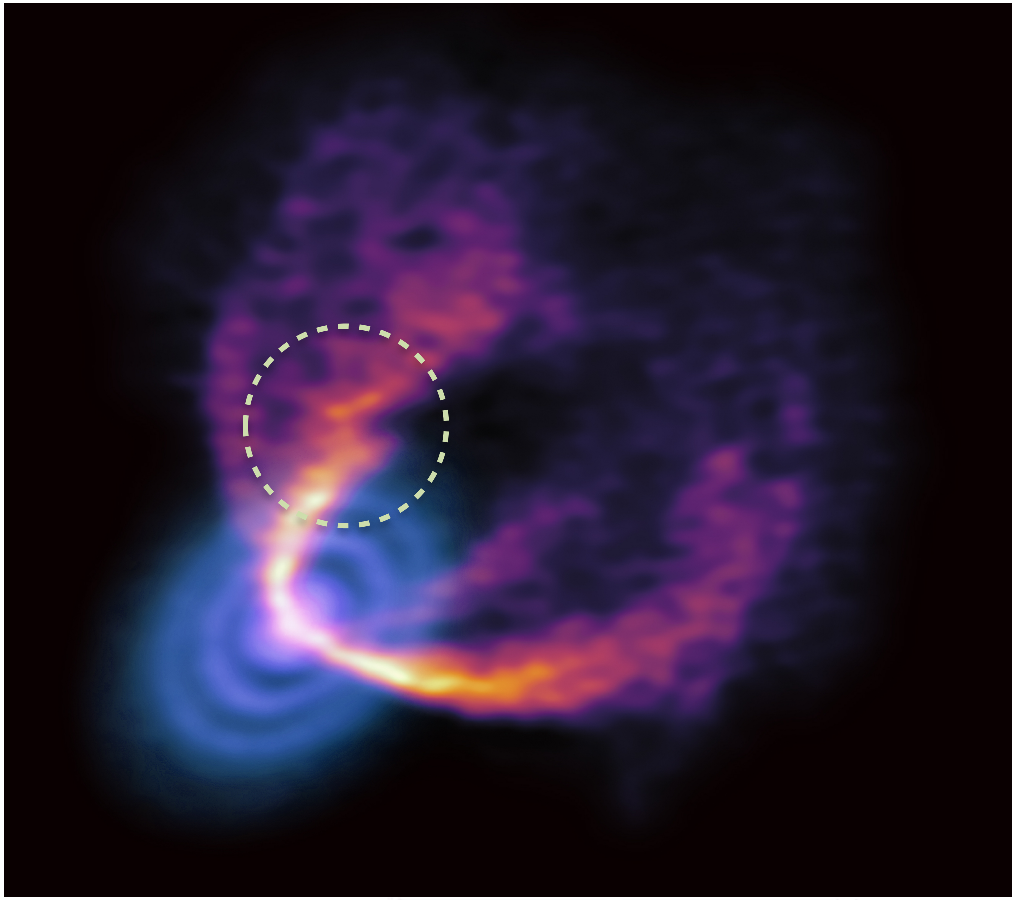


Schinnerer et al. 2019

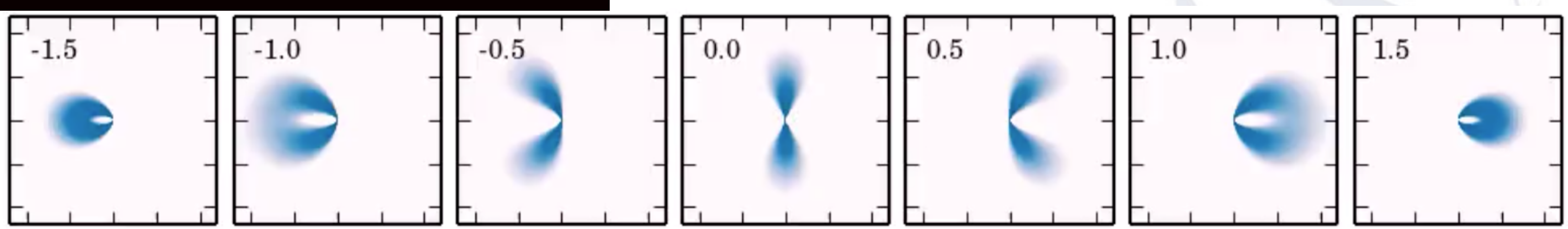

1
2
3
4



Kinematic evidence for embedded planets?

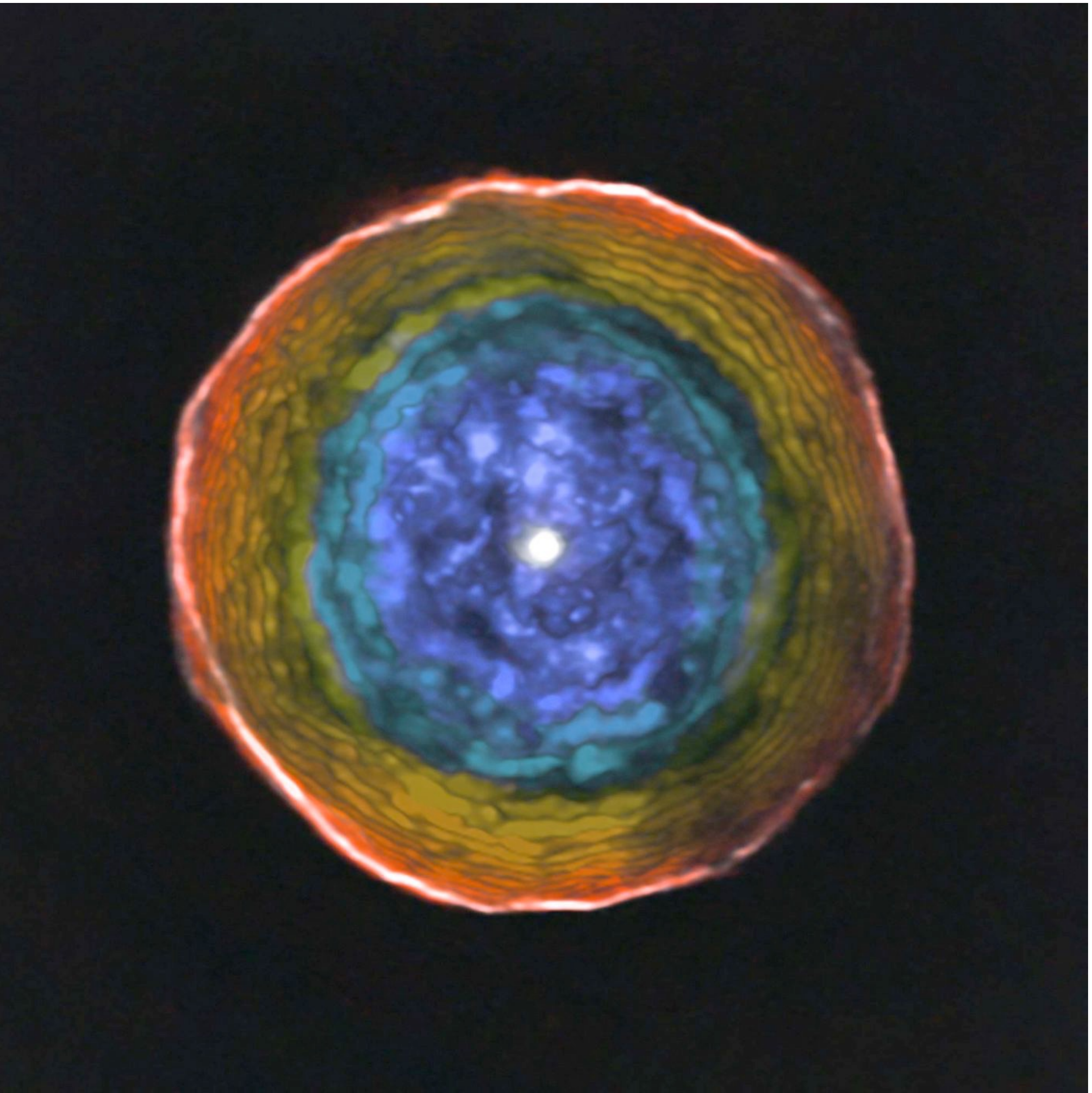


- CO channel map in HD 163296
- Perturbation in velocity field (dashed circle) suggests presence of embedded planet with mass 2 Jupiter masses at 260 au!!



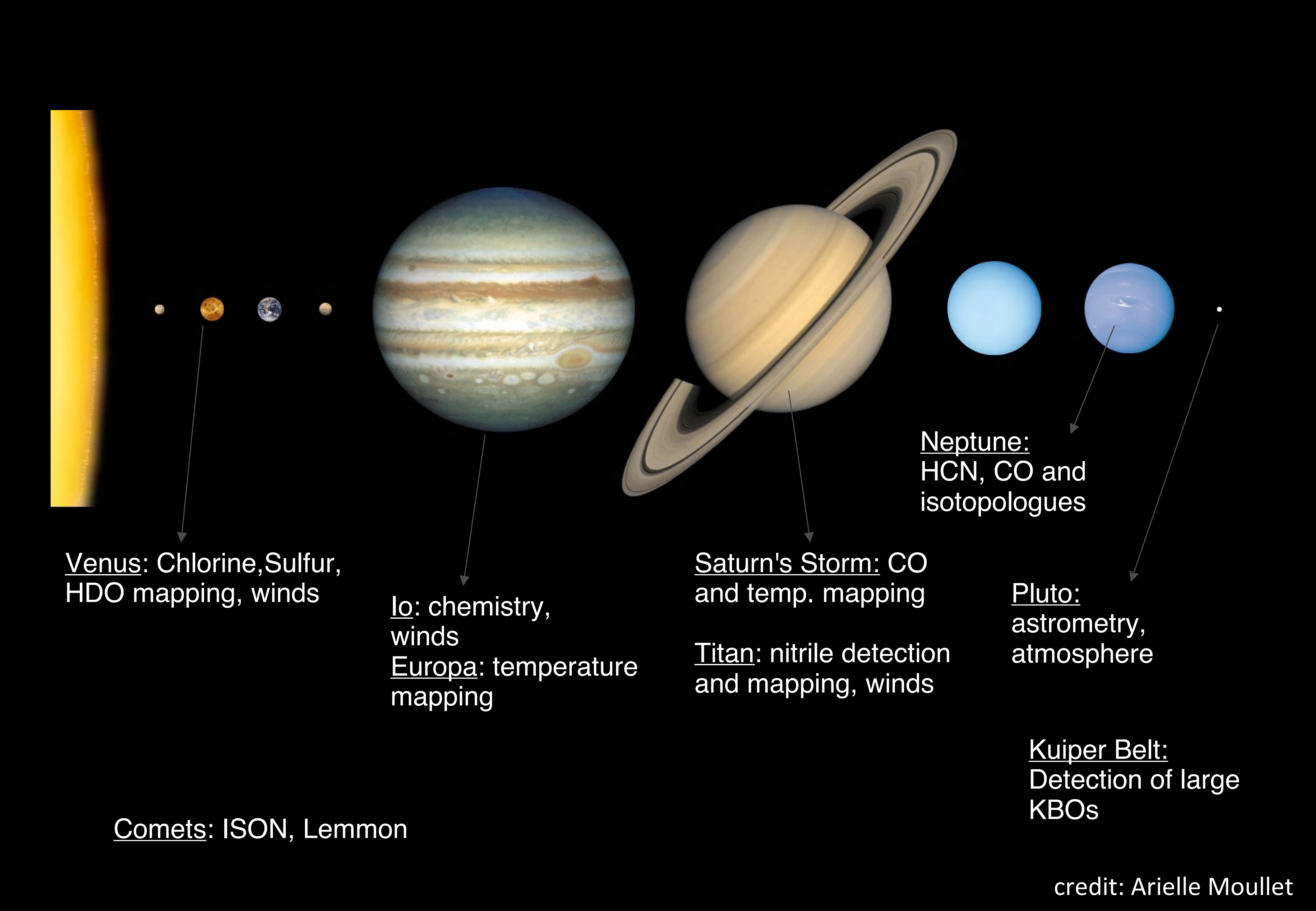
Pinte et al. (2018)

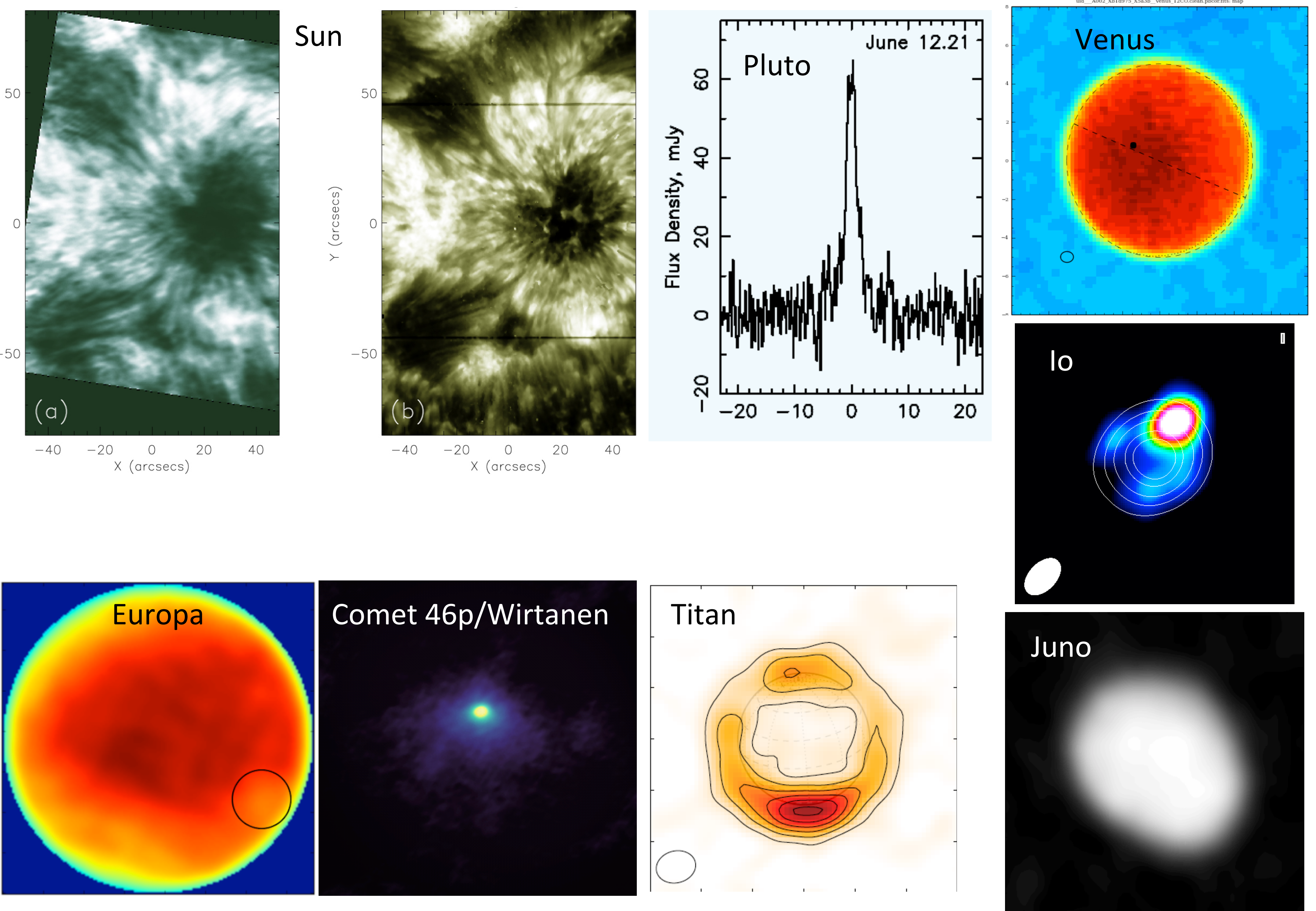
Evolved Stars



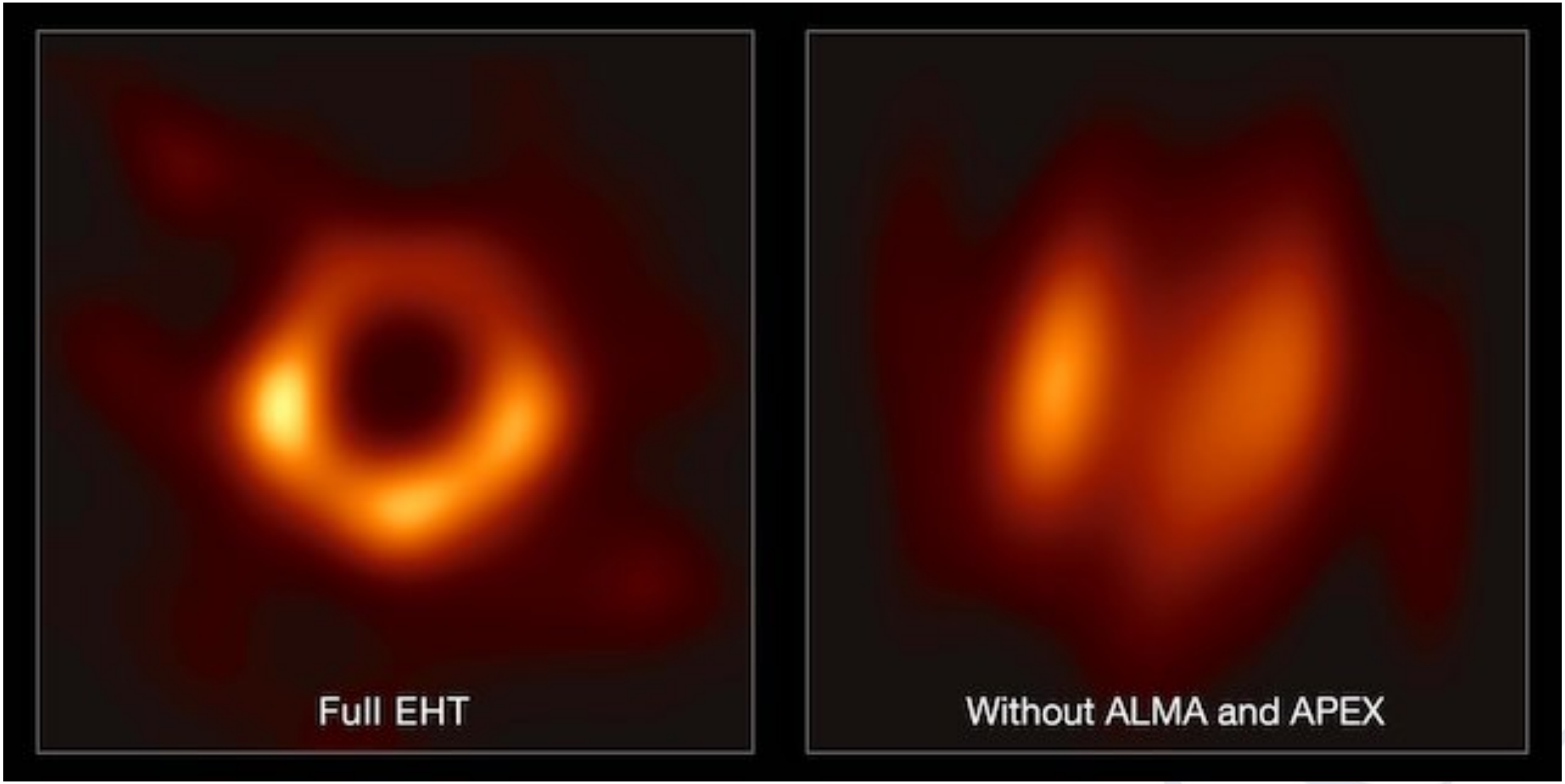
- U Antlia (carbon star)
- CO shells

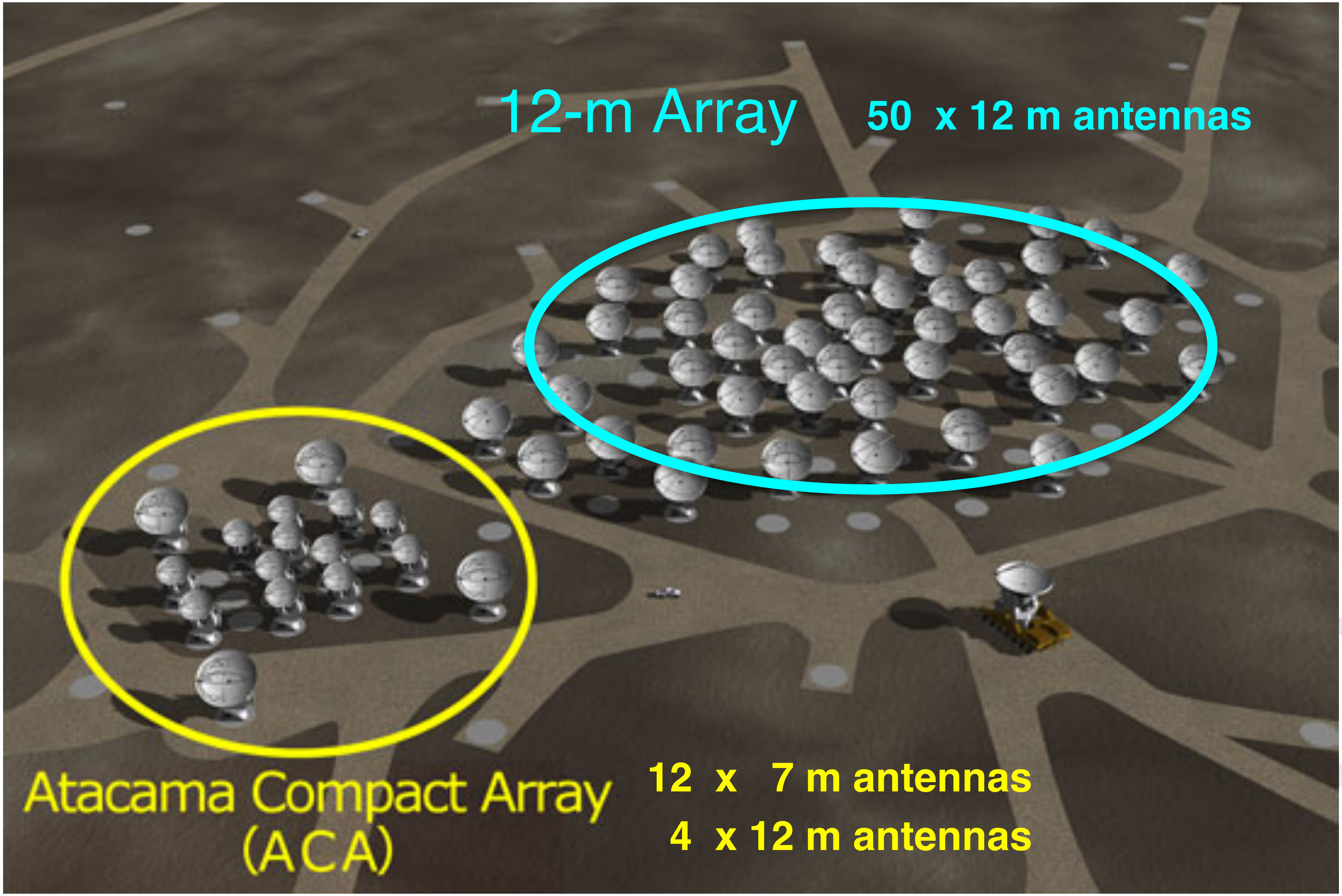
Kerschbaum et al. (2017)


Venus: Chlorine,Sulfur,
HDO mapping, winds
Io: chemistry,
winds
Europa: temperature
mapping
Saturn's Storm: CO
and temp. mapping
Titan: nitrile detection
and mapping, winds
Neptune:
HCN, CO and
isotopologues
Pluto:
astrometry,
atmosphere
Kuiper Belt:
Detection of large
KBOs
Comets: ISON, Lemmon
credit: Arielle Moullet


Sun
(a)
(b)
X (arcsecs)
X (arcsecs)
Y (arcsecs)
50
0
−50
−40
−20
0
20
40
Pluto
June 12.21
Flux Density, mJy
60
40
20
0
−20
−10
10
Venus
Io
Europa
Comet 46p/Wirtanen
Titan
Juno

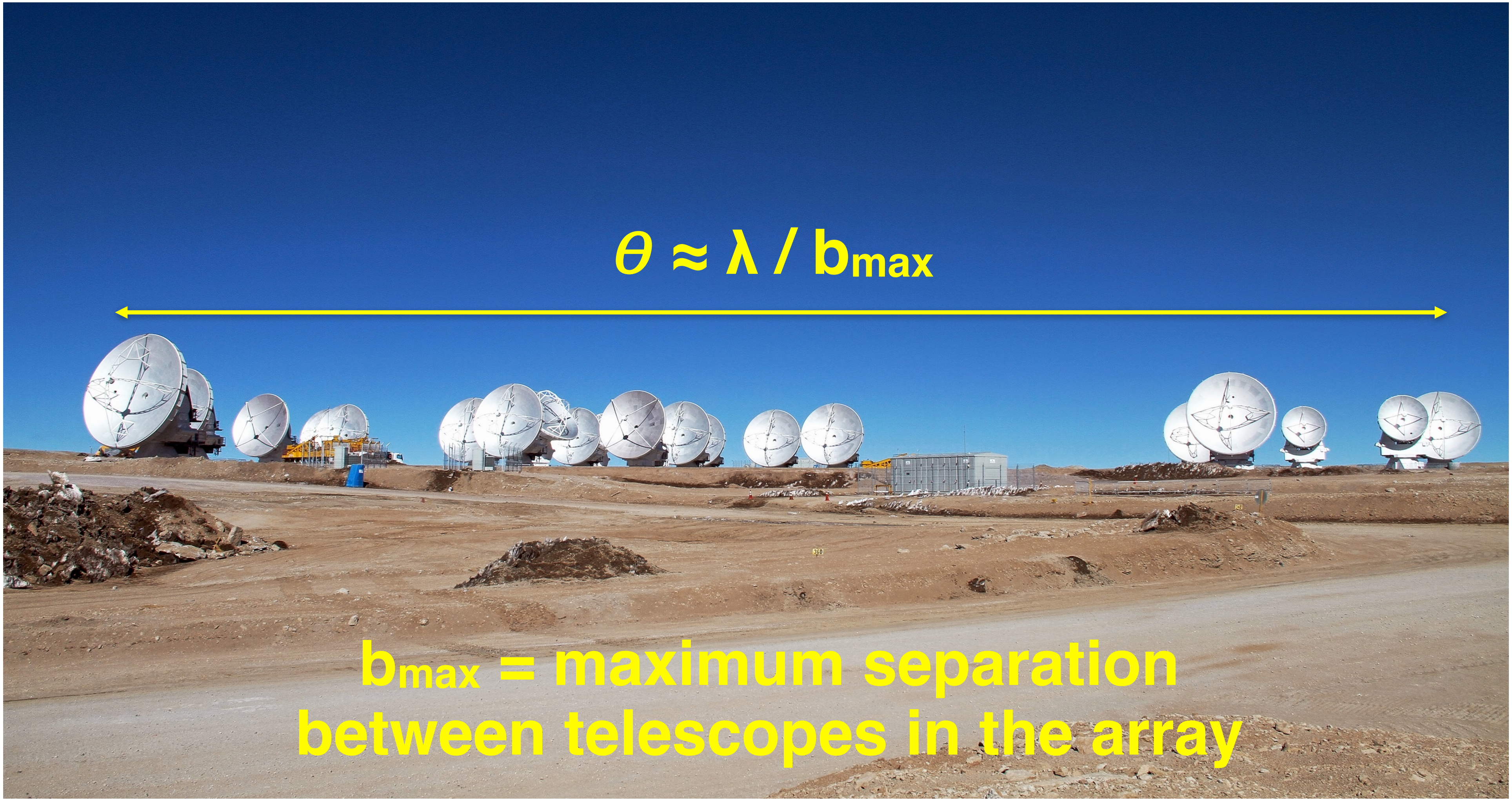
First Image of a Black Hole (M87)



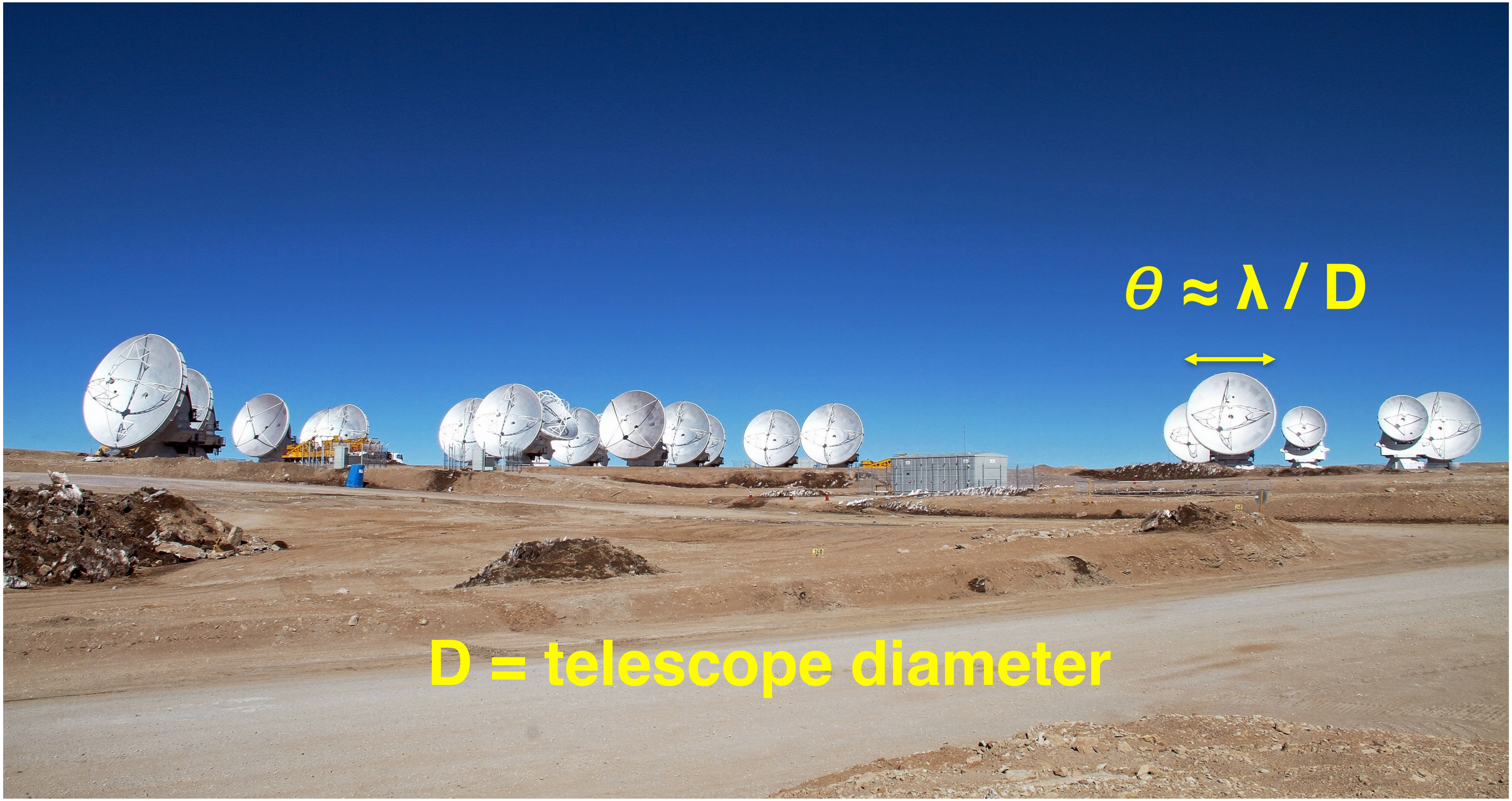

12-m Array
50 x 12 m antennas
Atacama Compact Array
(ACA)
12 x 7 m antennas
4 x 12 m antennas

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

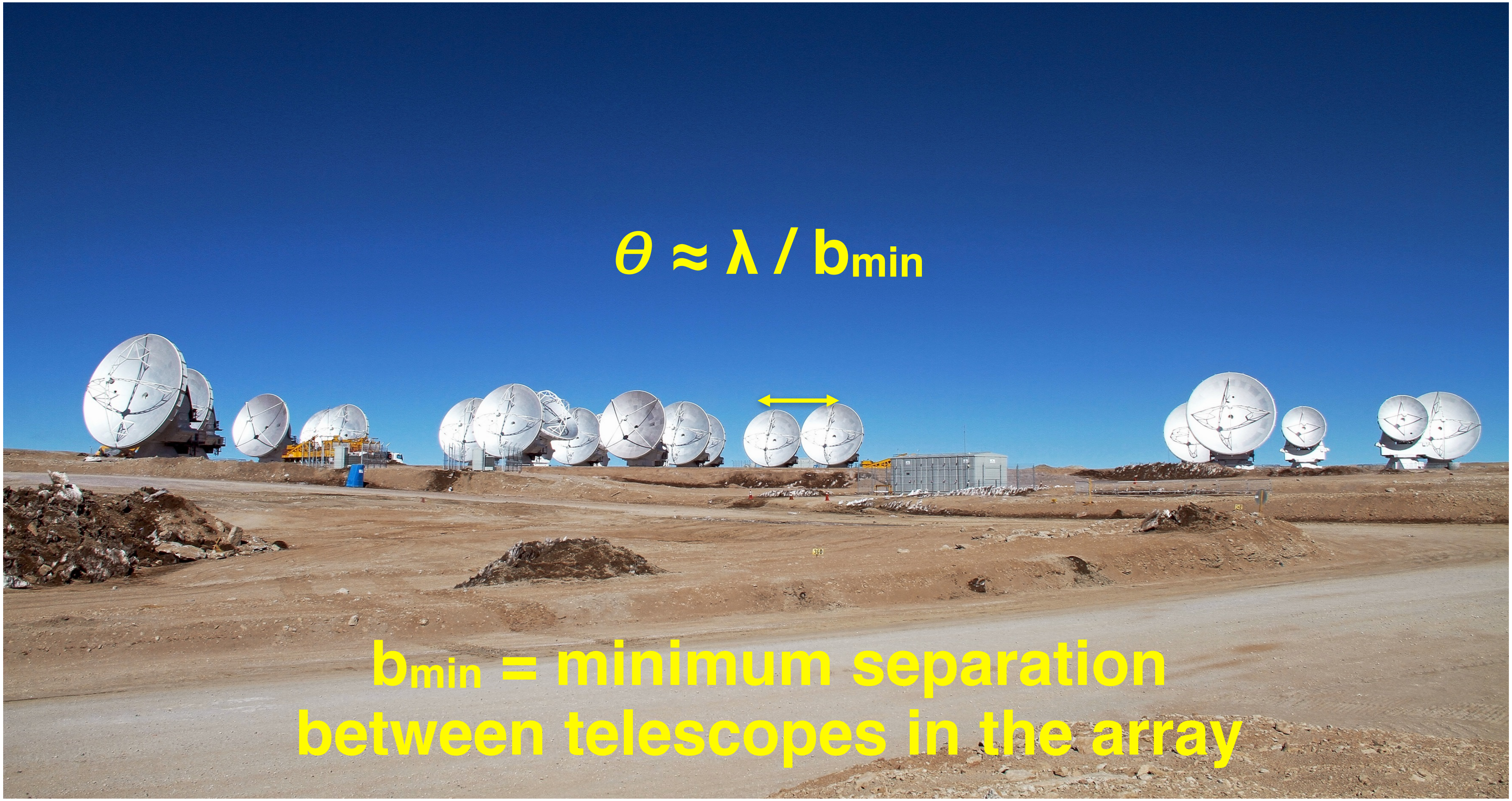
Angular Resolution



Field of View



Largest Angular Scale



Angular scales

Resolution

- given by the largest distance between antennas ($\sim\lambda / B_{max}$)

Field of view

- given by the diffraction limit of a single antenna ($\sim\lambda / D$)
- 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 ($\sim\lambda / B_{min}$)

An interferometer is sensitive to a range of angular scales.

Observe in multiple configurations to decrease B_{min} and increase B_{max}.

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

Angular Scales available in the Proposer's

Table A-1: Angular Resolutions (AR) and Maximum Recoverable Scales (MRS) for the Cycle 7 Array configurations

Config	Lmax		Band 3	Band 4	Band 5	Band 6	Band 7	Band 8	Band 9	Band 10
	Lmin		100 GHz	150 GHz	183 GHz	230 GHz	345 GHz	460 GHz	650 GHz	870 GHz
7-m Array	45 m	AR	12.5"	8.4"	6.8"	5.4"	3.6"	2.7"	1.9"	1.4"
	9 m	MRS	66.7"	44.5"	36.1"	29.0"	19.3"	14.5"	10.3"	7.7"
C43-1	161 m	AR	3.4"	2.3"	1.8"	1.5"	1.0"	0.74"	0.52"	0.39"
	15 m	MRS	28.5"	19.0"	15.4"	12.4"	8.3"	6.2"	4.4"	3.3"
C43-2	314 m	AR	2.3"	1.5"	1.2"	1.0"	0.67"	0.50"	0.35"	0.26"
	15 m	MRS	22.6"	15.0"	12.2"	9.8"	6.5"	4.9"	3.5"	2.6"

Angular resolution

Min/max antenna separations

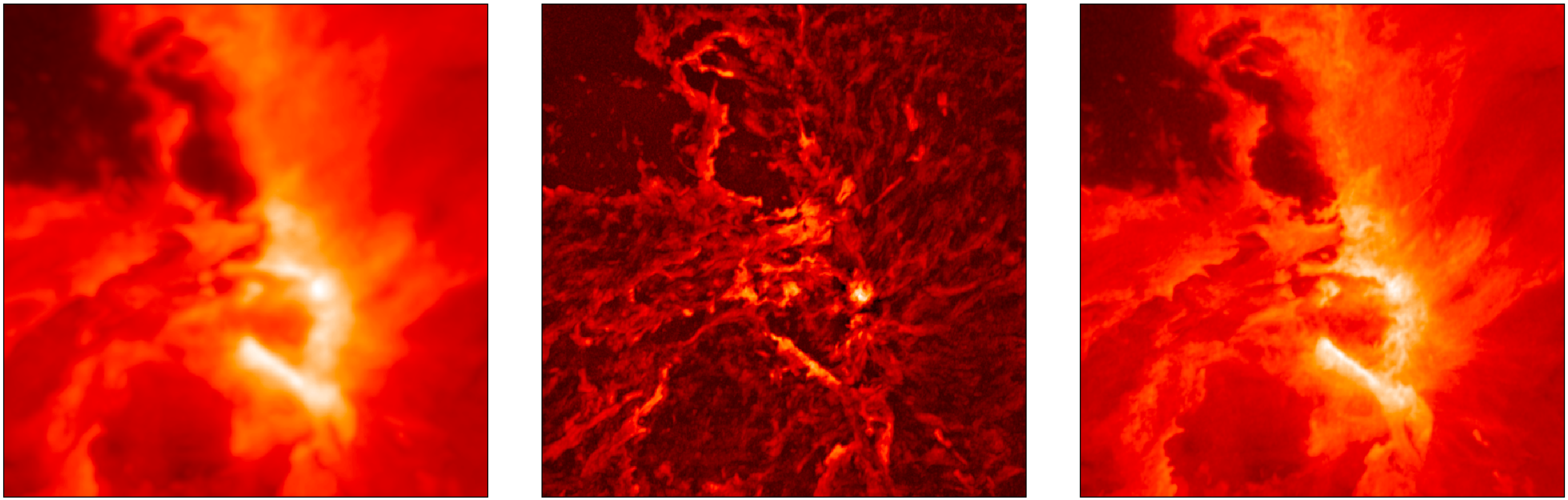
Maximum recoverable scale (largest angular scale)

Configuration

Need to correct resolution of maximum elevation of your source!

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

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

Area of 1 Antenna

Integration Time

Number of Antennas

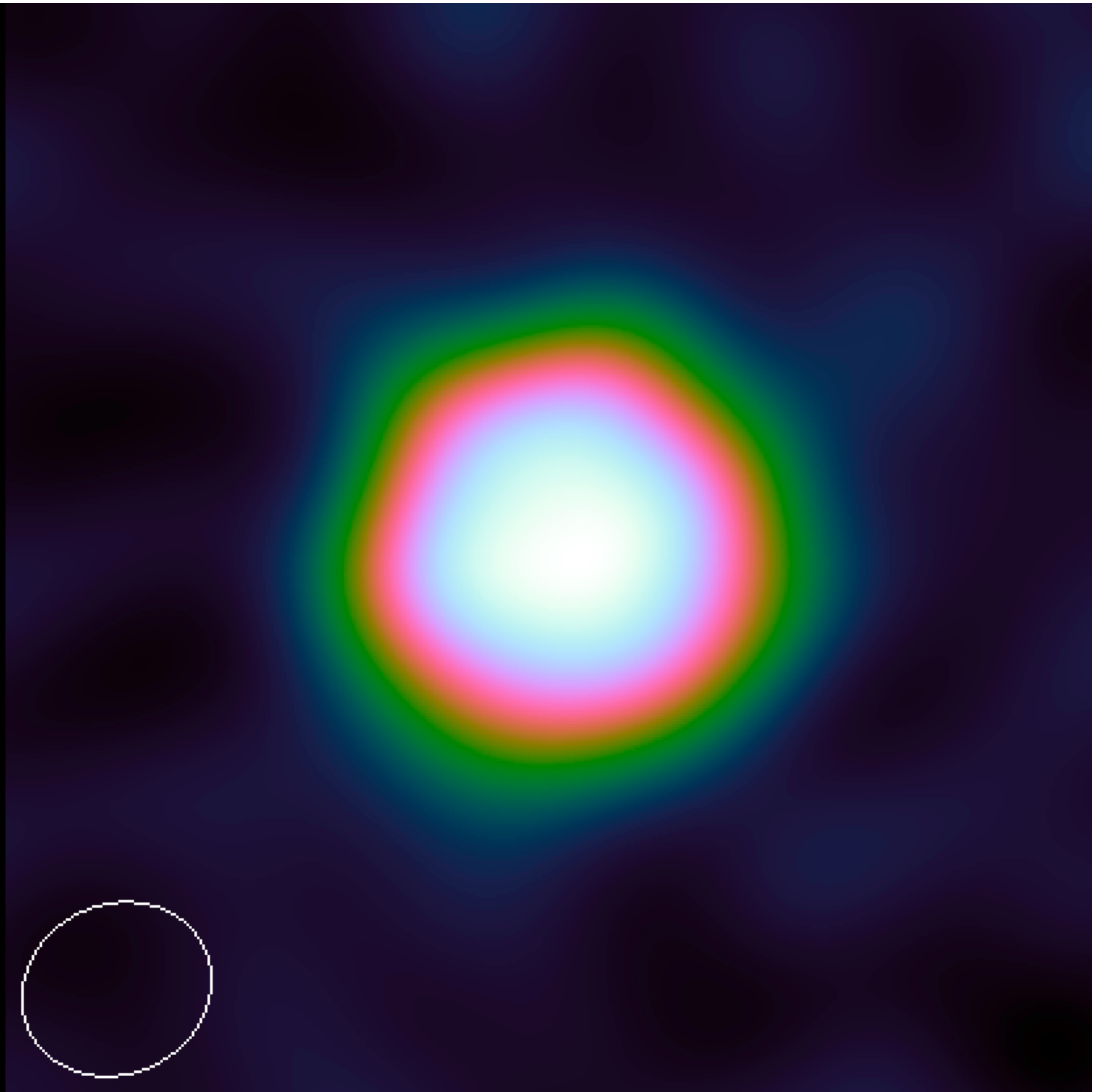
Frequency Resolution

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

Units

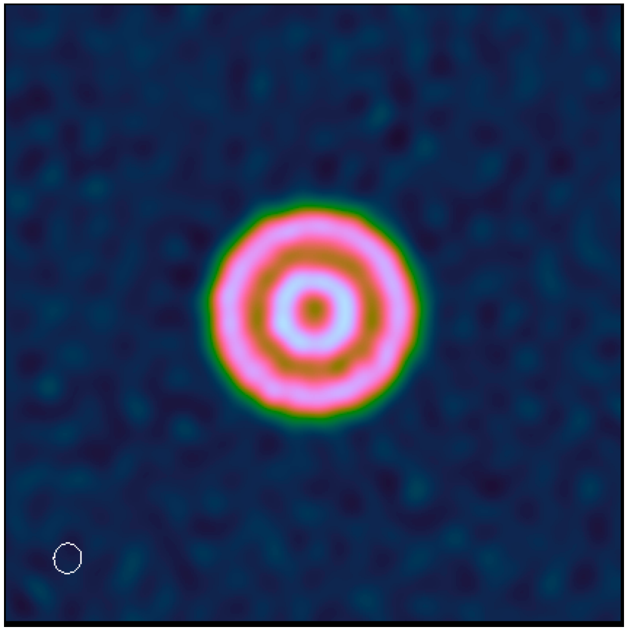
Janskys	Specific flux (energy/area/time/frequency) = 10^{-23} erg/s/Hz/cm^{-2}
Janskys / beam	Specific intensity (energy/area/time/frequency/solid angle). **Useful For:** point sources (the beam doesn't matter). **Be Careful:** depends on the beam and so on the observation.
Kelvin	Also specific intensity (temperature of equivalent blackbody). **Useful For:** surface brightness and extended sources. **Be Careful:** point source observed with different resolutions has different brightness temperatures ("beam smearing").

Example: Imaging an extended source



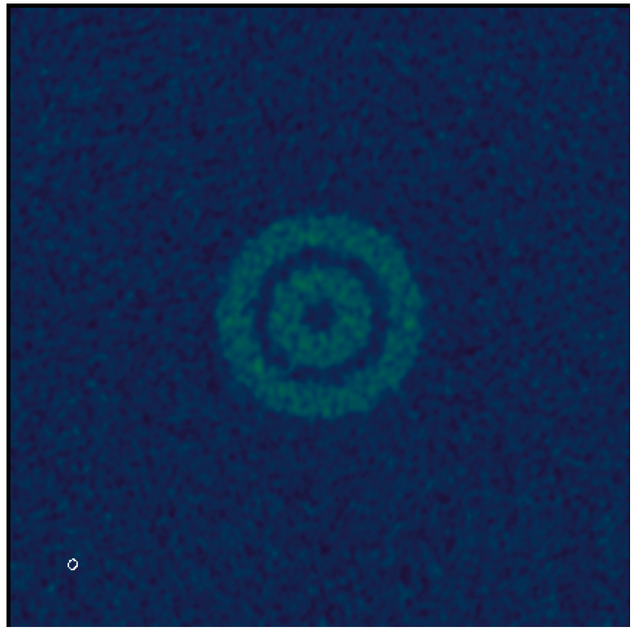
- Source diameter = 12”
- S_{tot} = 15 mJy

Example: Imaging an extended source



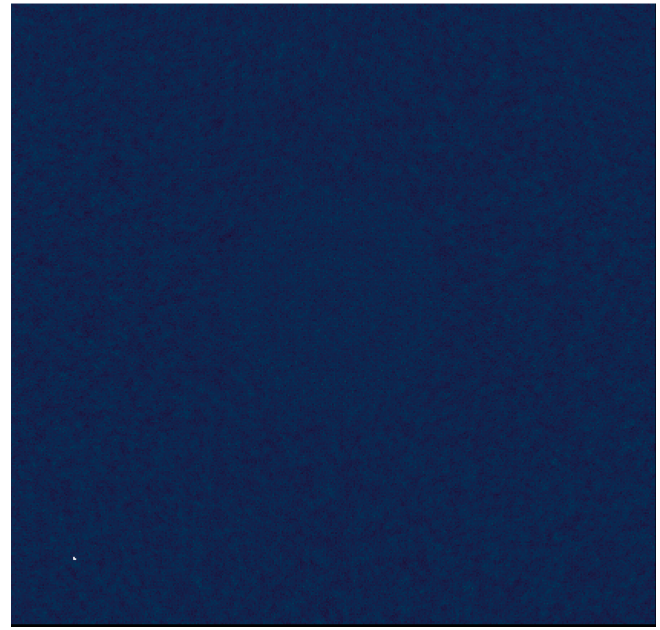
- Configuration 1 (3.5 h)
- θ = 1.7 arcsec @ 230 GHz
- ΔS_ν = 9.5 microJy / beam
- ΔT_B = 0.07 milliK

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



- Configuration 1 and 4
- θ = 0.52 arcsec
- ΔS_ν = 9.5 microJy / beam
- ΔT_B = 0.75 milliK

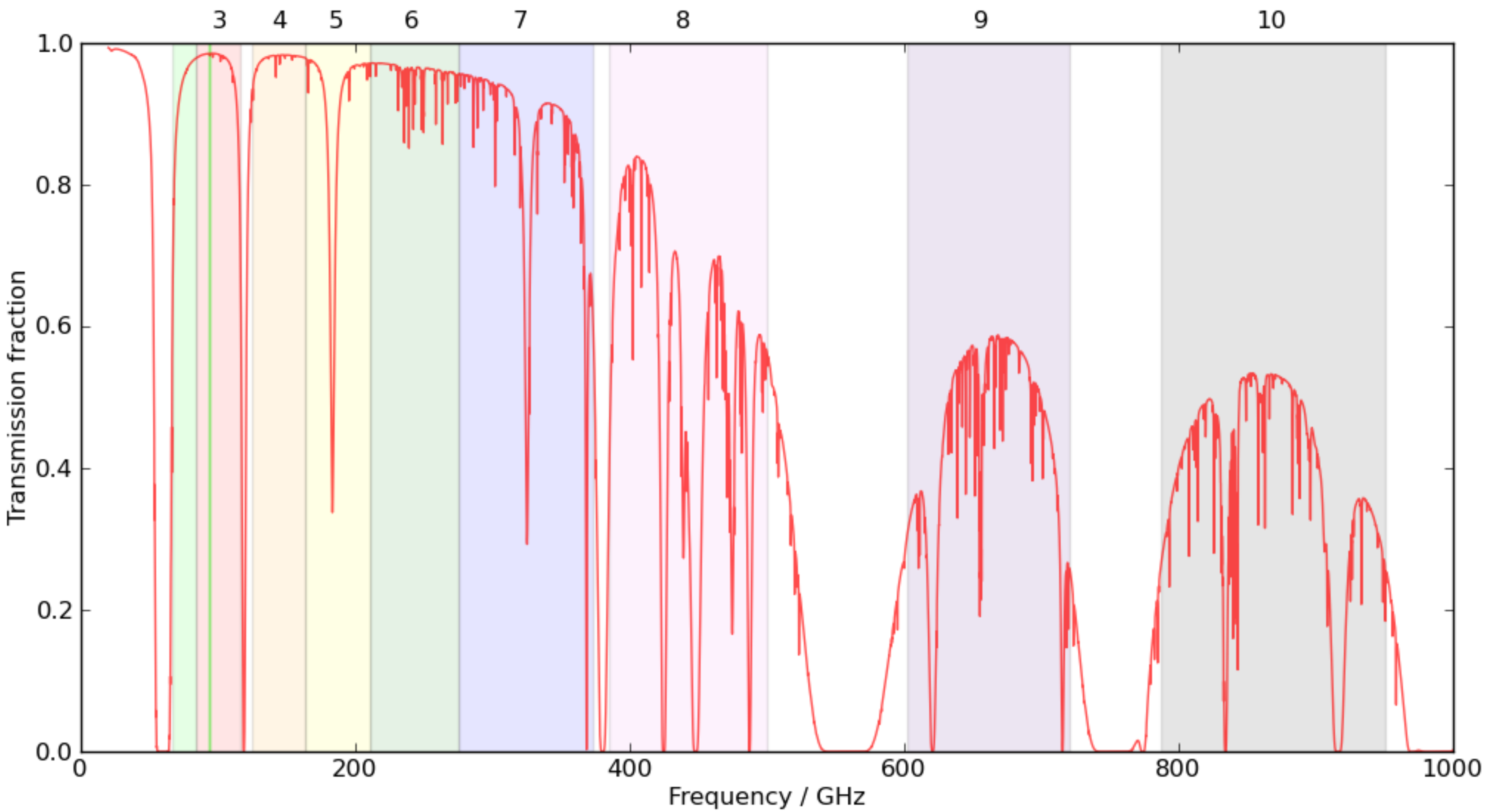
- $N_{beams} \sim (12/\theta)^2 \sim 532$
- $\langle S_\nu \rangle$ = 28 microJy / beam
- <SNR> ~ 3



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

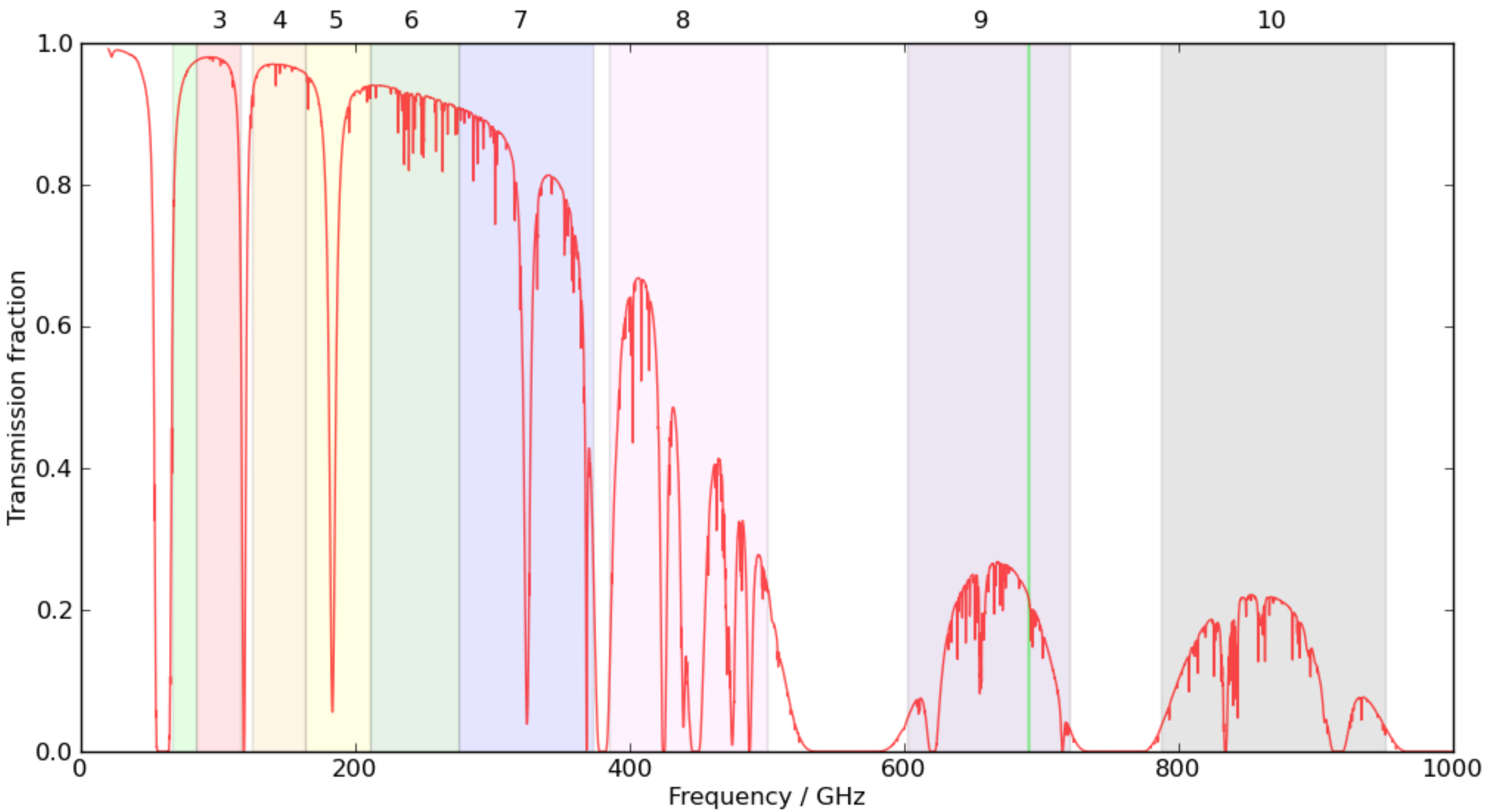
- $N_{beams} \sim (12/\theta)^2 \sim 19000$
- $\langle S_\nu \rangle$ = 0.8 microJy / beam
- <SNR> ~ 0.1

ALMA Receiver Bands in Cycle 7



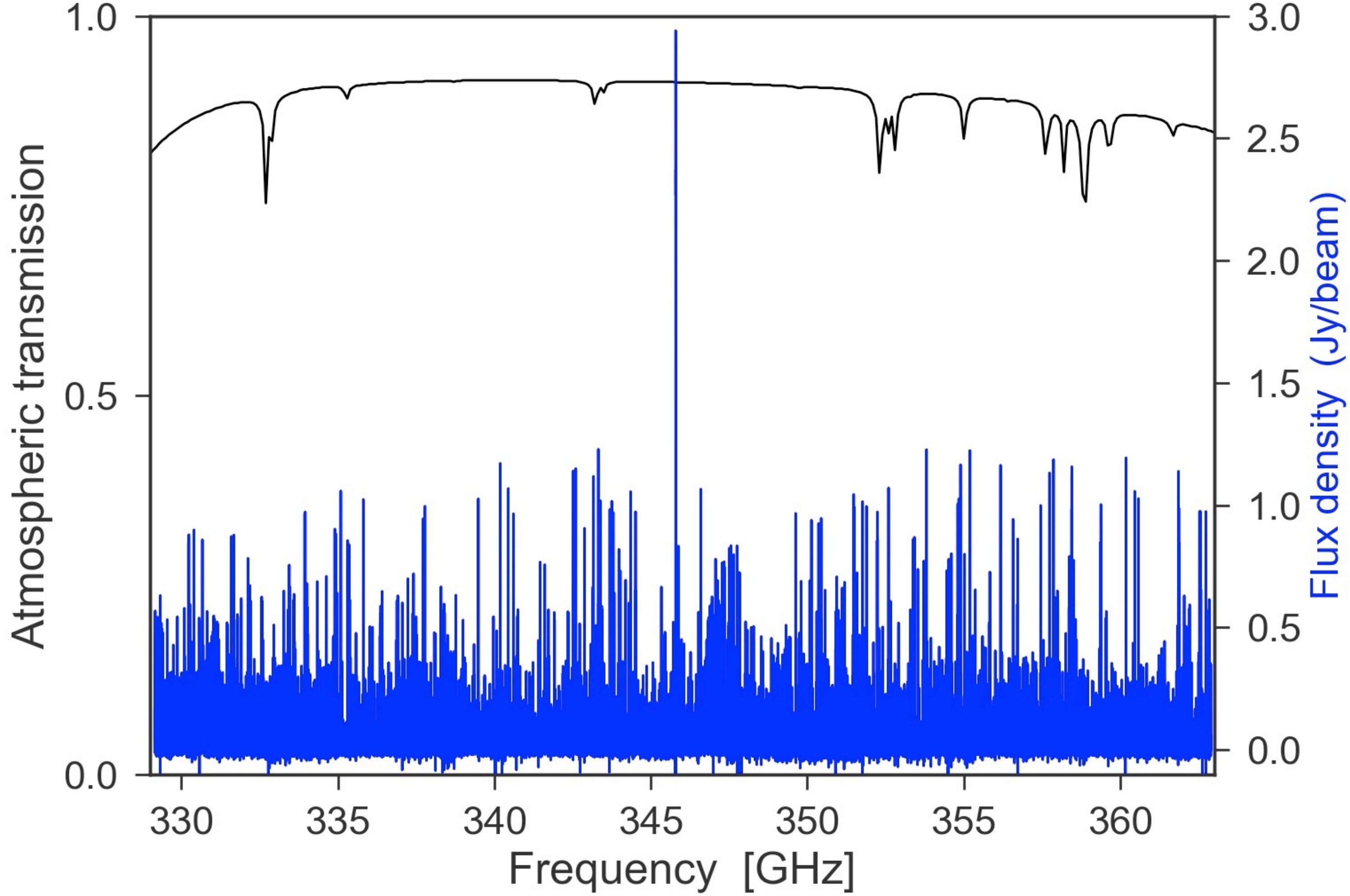
Top quartile weather conditions

ALMA Receiver Bands in Cycle 7



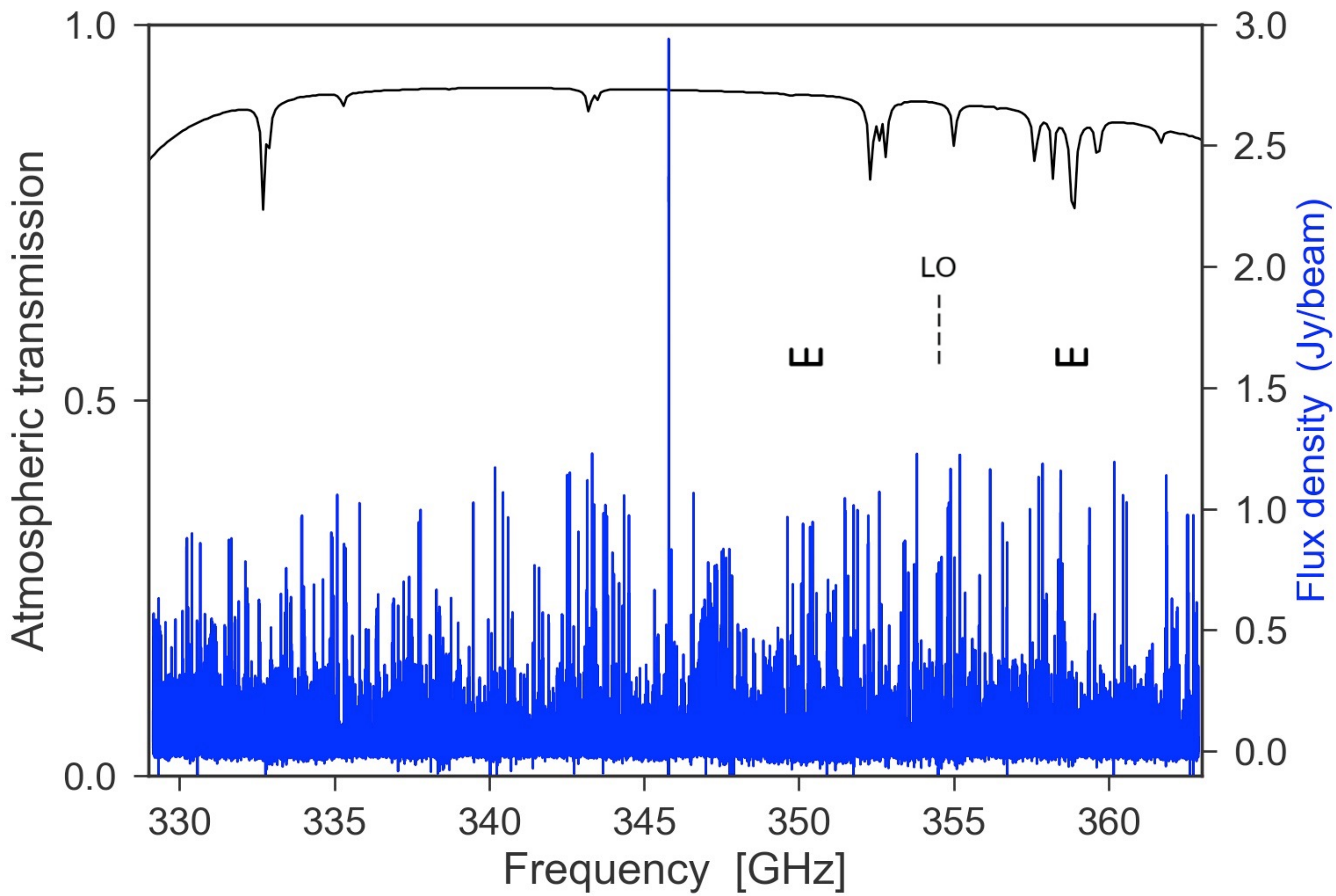
Median weather conditions

Setting the Correlator



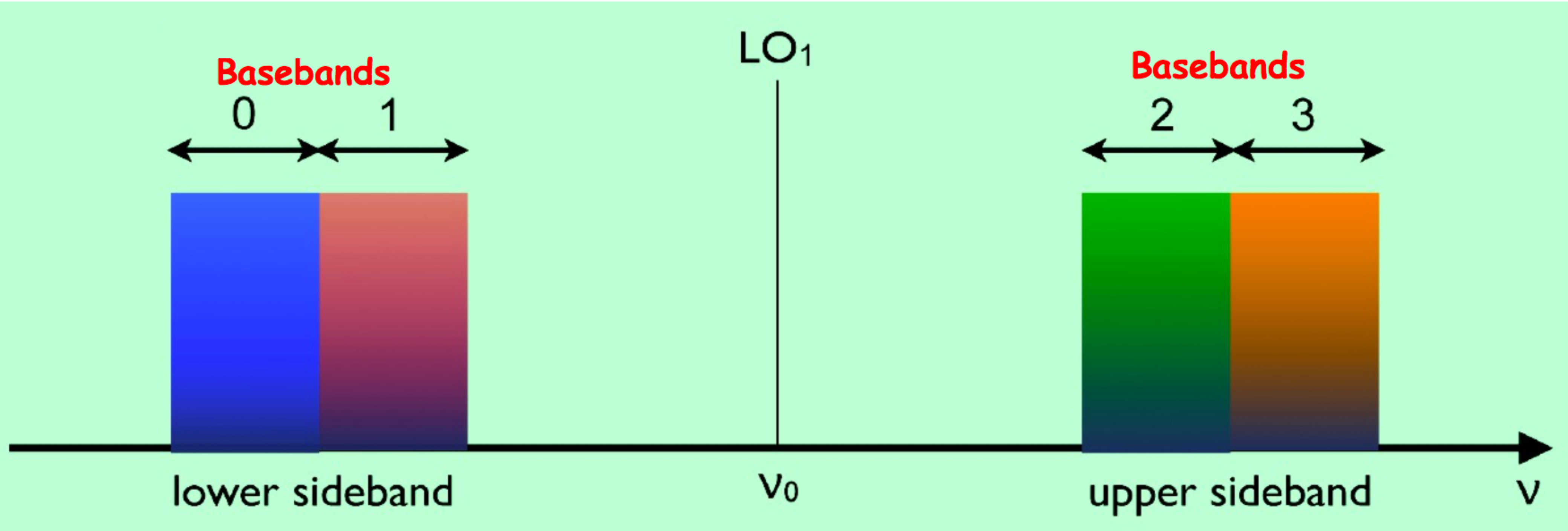
PILS spectrum of IRAS 16293-2422b

Setting the Correlator



PILS spectrum of IRAS 16293-2422b

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" (first row)

"spectral line" (remaining rows)

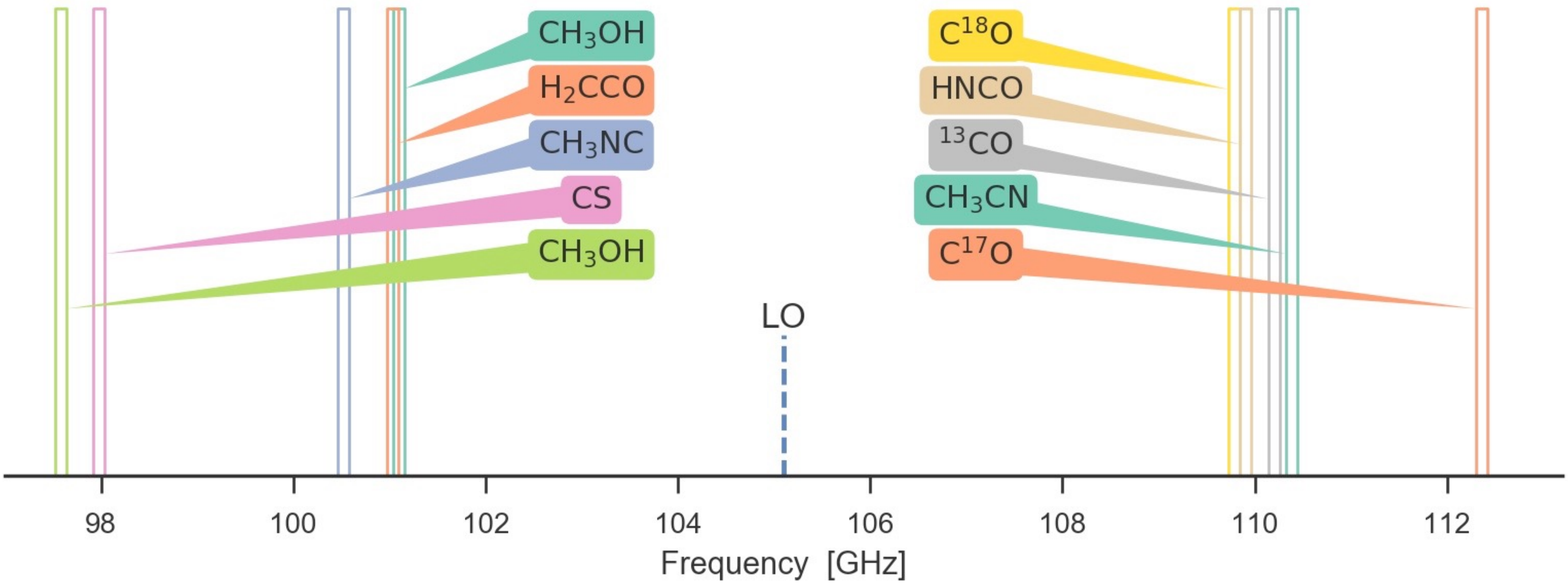
Higher spectral resolution reduces processed bandwidth.

More spectral windows per baseband reduces spectral resolution.

For dual polarization mode and for 1 spectral window per baseband

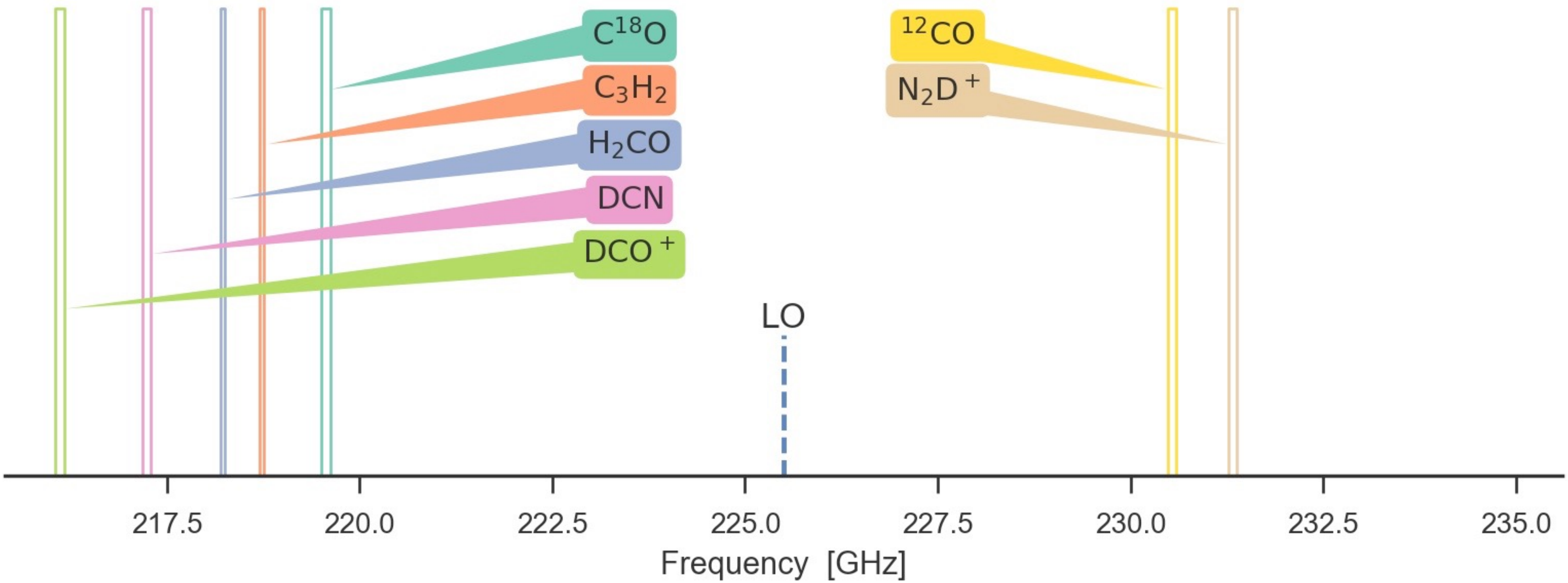
Example Correlator Setups: Band 3

CO isotopologues and chemical survey



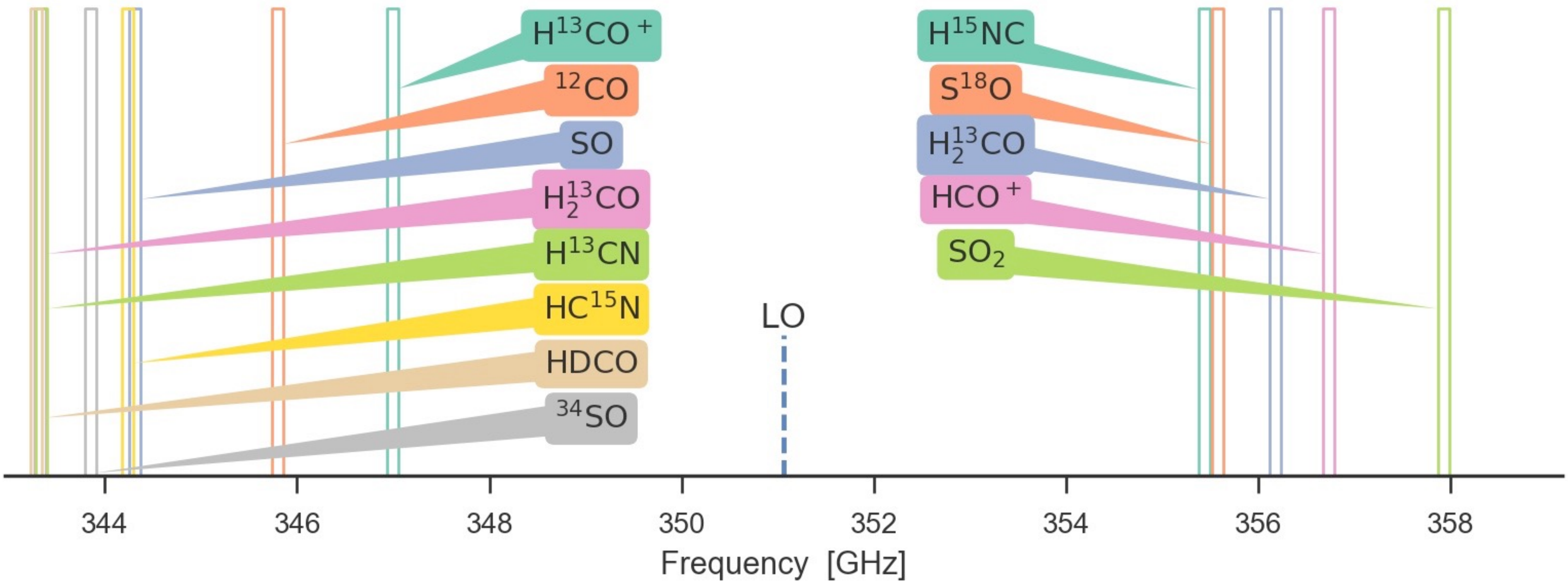
Example Correlator Setups: Band 6

Deuterated chemistry



Example Correlator Setups: Band 7

Chemical survey of disks



Applying for ALMA Time

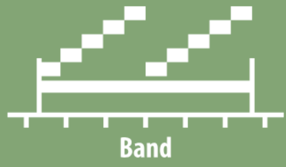
- ALMA Call for Proposals released once a year
- Regular proposal deadline is end of April
  - Cycle 7: April 17, 2019
- Director's Discretionary Time (DDT) proposals accepted any time

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

New in Cycle 7

4,300 h in 12 m & 3,000 h +750 h in ACA

Band 7 Long Baseline Observations

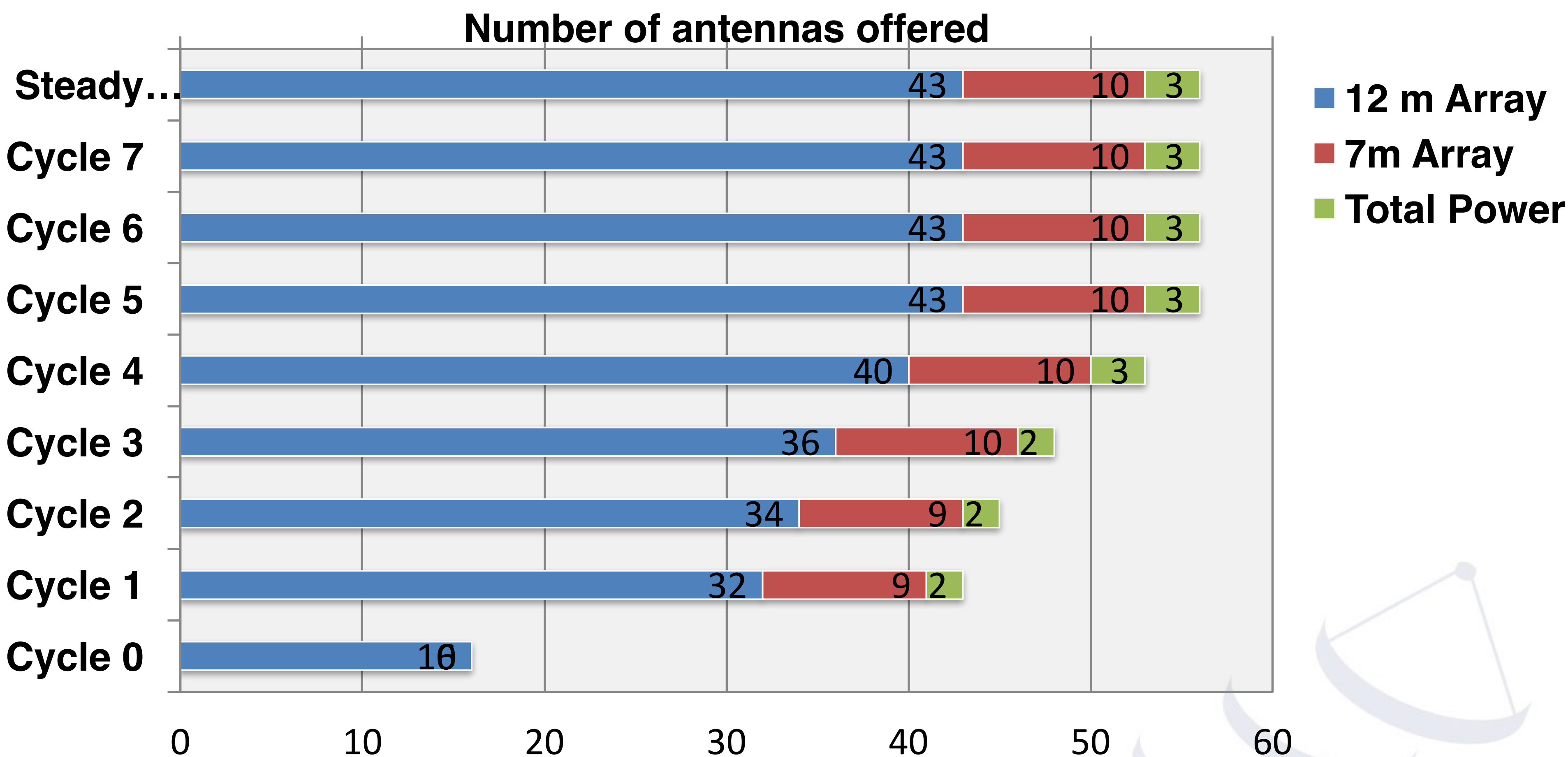


Standard Mode for Spectral Scan (25% faster)

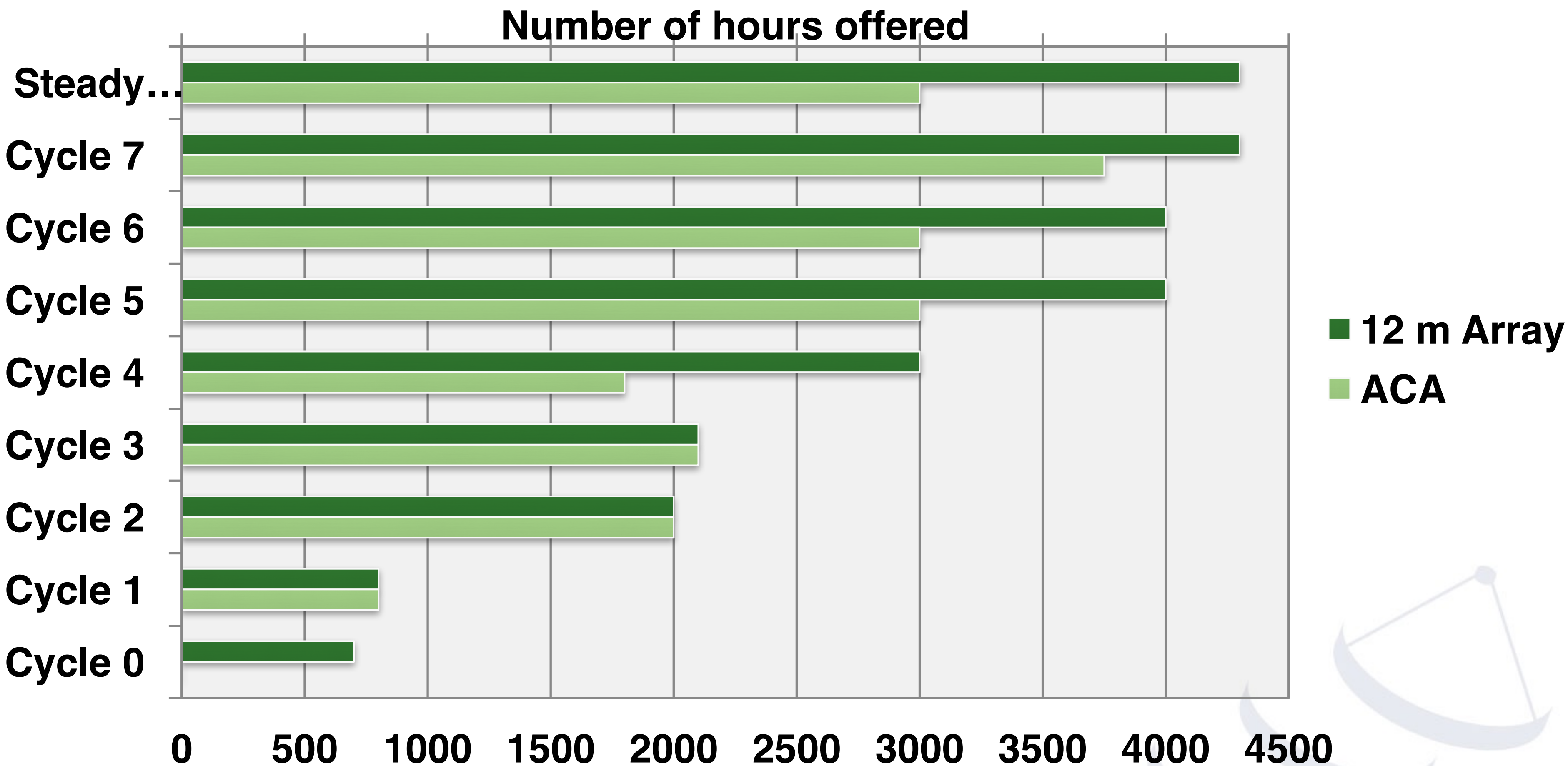
Band 7 Solar Observations

ACA Supplemental Call

Minimum number of antennas



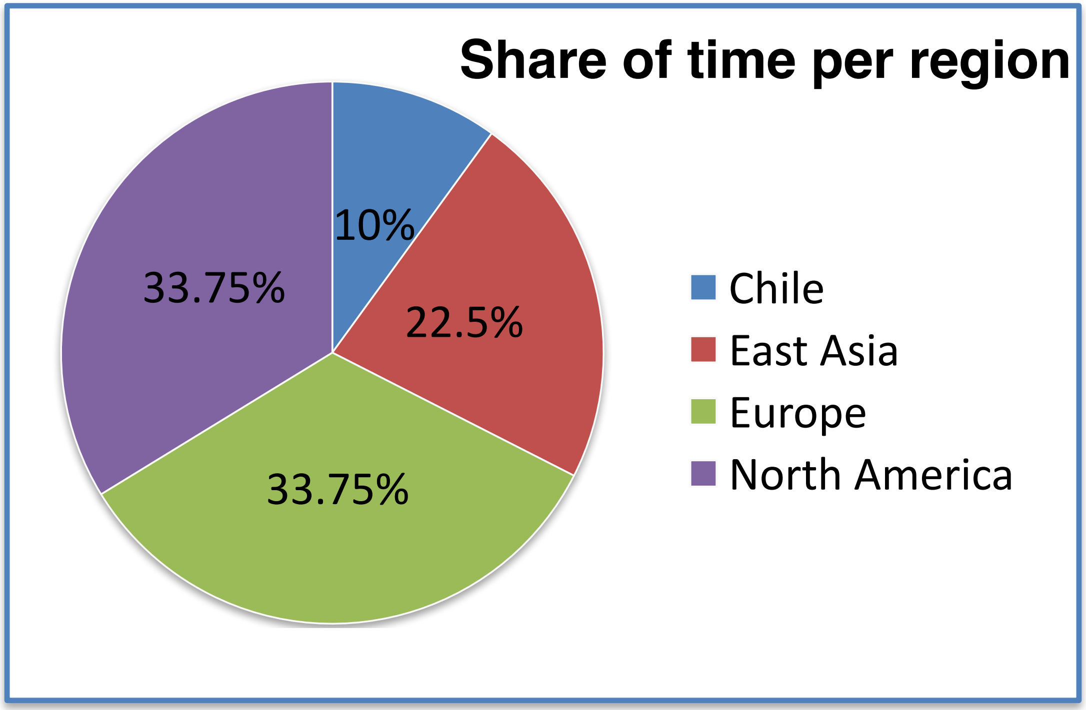
Hours of observing time



Cycle 6 Oversubscription Rates

Oversubscription Rate in Cycle 6

	Chile	East Asia	Europe	North America
12-m Array	3	4.5	6.2	4.3



Definition of Regular Proposals

Regular Proposals

- < 50 hours on 12 m array

- and -

- < 150 hours on ACA standalone

Review process

- Assigned to a panel of similar (but broad) topics
- 6 reviewers per panel with a range of expertise
- Proposals should appeal to a broad and knowledge review, but not necessarily an expert in your subtopic

Definition of Large Programs

Large Programs

- > 50 hours on 12 m array

- or -

- > 150 hours on ACA standalone

Time available

- Up to 645 hours on the 12-m array
- Up to 450 hours on the ACA array in standalone mode

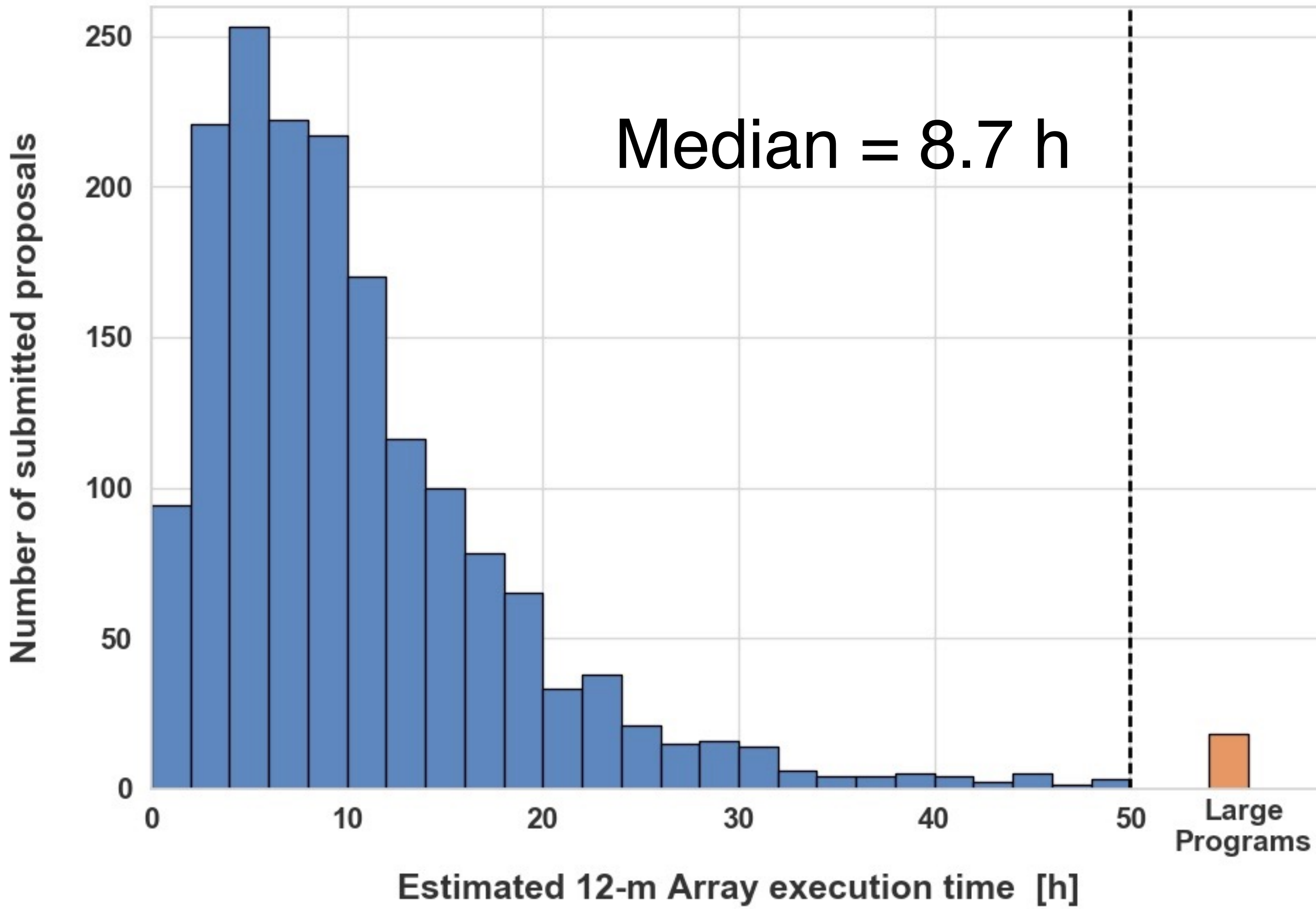
Reviewed by individual panels and all Panel Chairs

- Large Programs need to appeal to both experts and non-experts

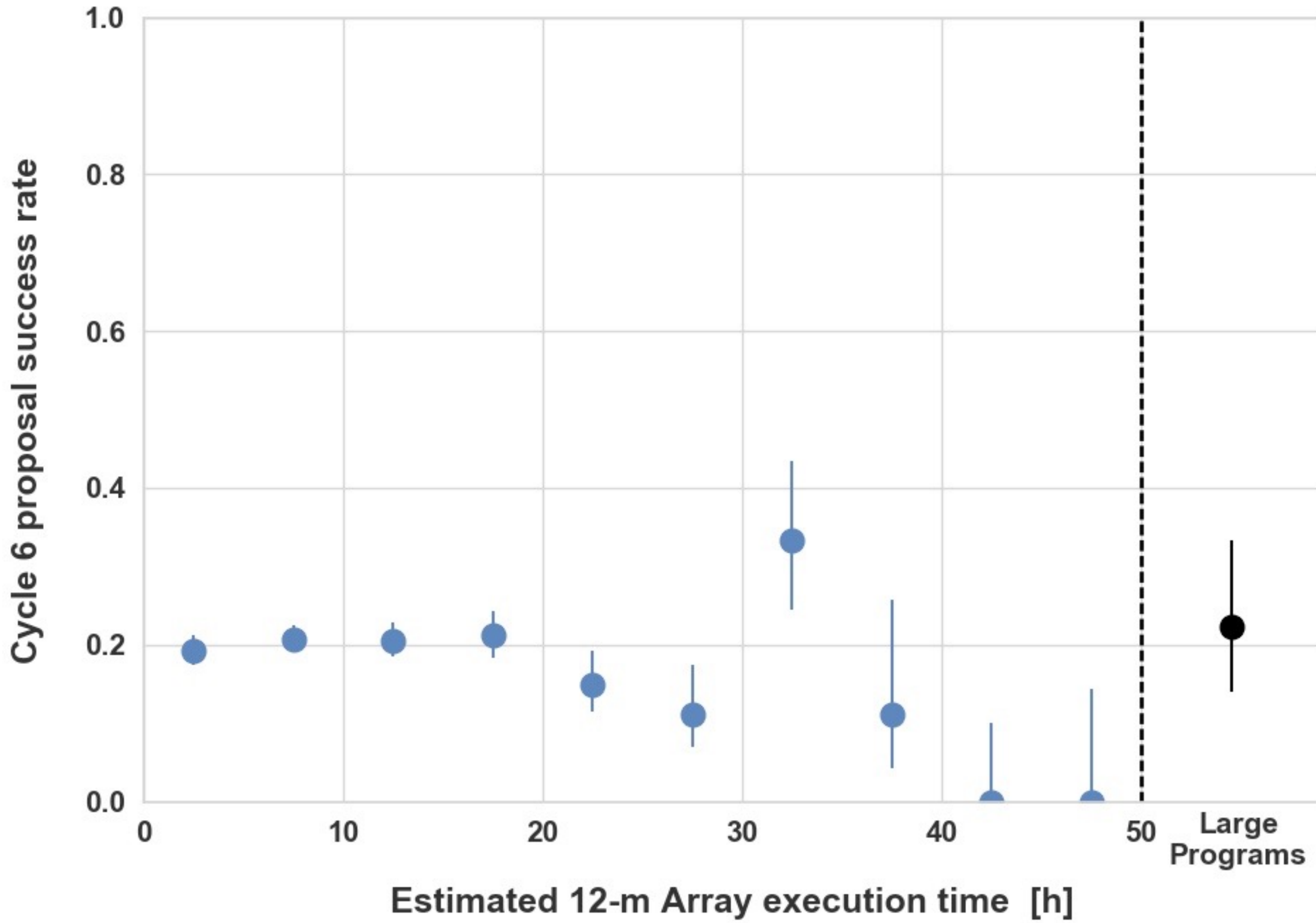
How much time can I ask for?

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

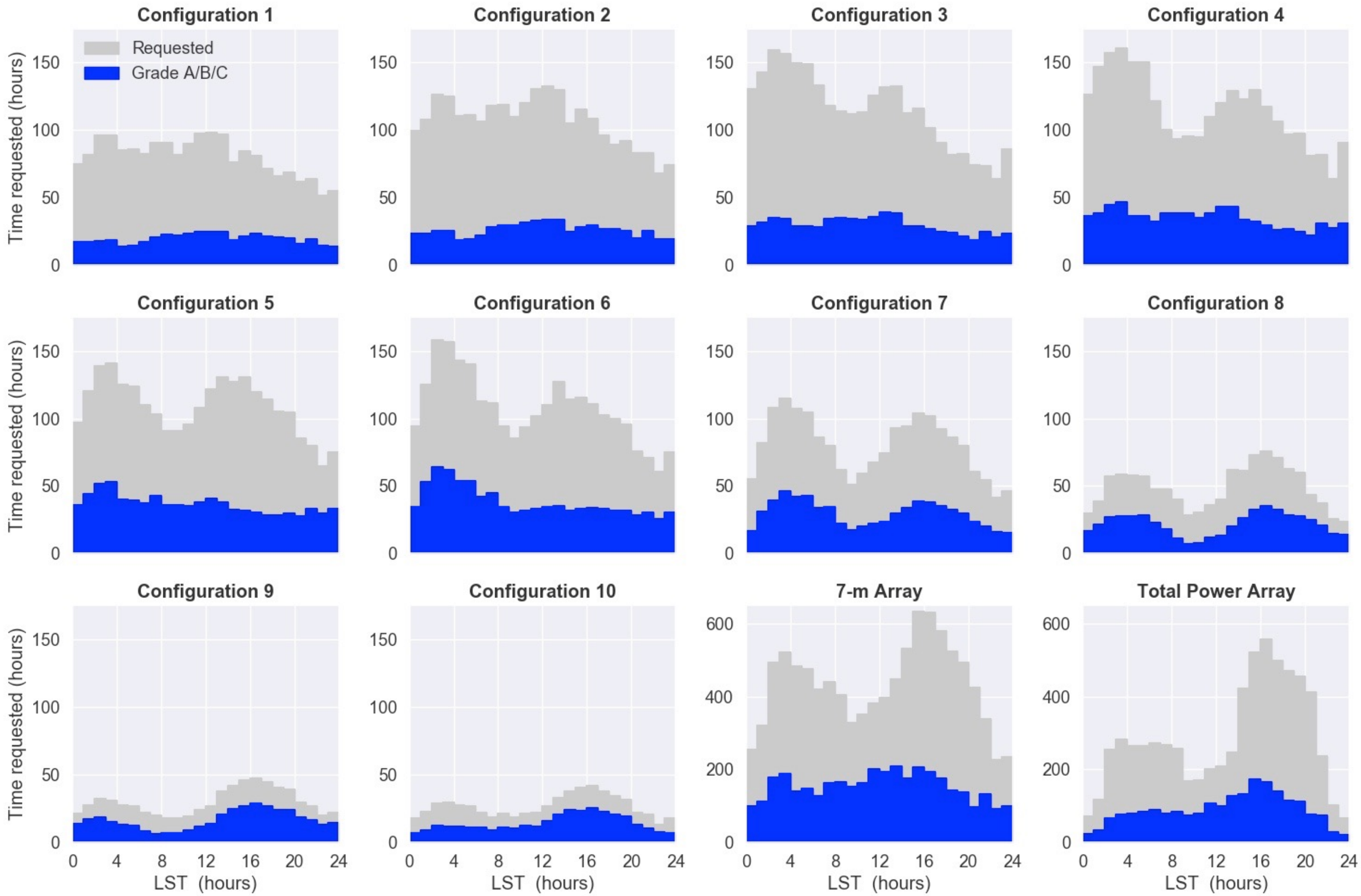
Time requested on the 12-m Array in Cycle 6



Cycle 6 Acceptance Rate (Grade A+B) vs. Requested Time



Proposal pressure per configuration in Cycle 6



Cycle 7 Configuration Schedule

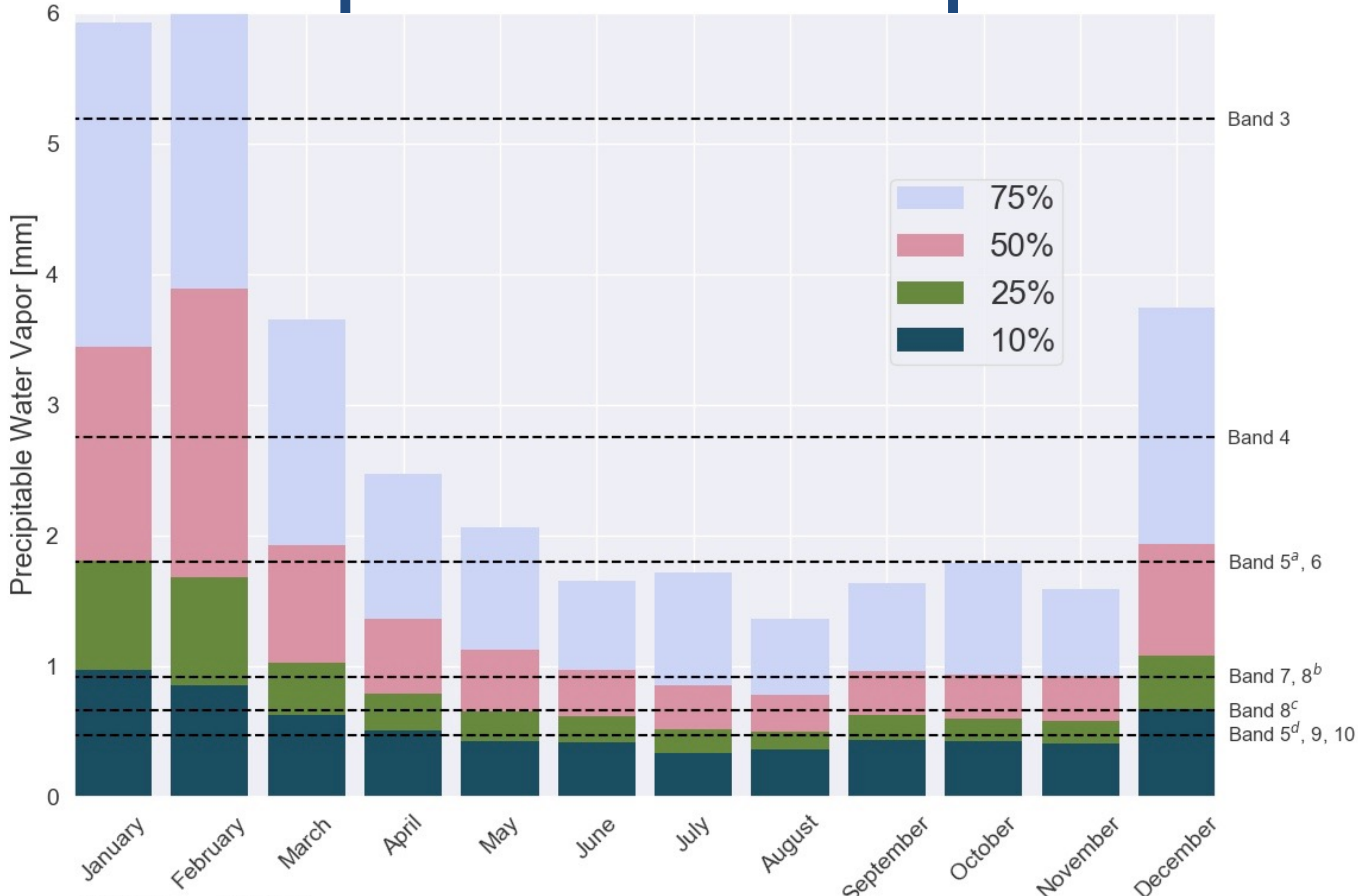
Atacama Large Millimeter/submillimeter Array
In search of our Cosmic Origins

Start date	Configuration	Longest baseline	LST for best observing	Resolution at 300 GHz (arcsec)
2019 October 1	C43-4	0.78 km	~ 22 - 10 h	0.31
2019 October 20	C43-3	0.50 km	~ 23 - 11 h	0.47
2019 November 10	C43-2	0.31 km	~ 1 - 13 h	0.77
2019 November 30	C43-1	0.16 km	~ 2-14 h	1.13
2019 December 20	C43-2	0.31 km	~ 4-15 h	0.77
2020 January 10	C43-3	0.50 km	~ 5-17 h	0.47
2020 February 1	No observations due to maintenance			
2020 March 1	C43-4	0.78 km	~ 8 - 21 h	0.31
2020 March 20	C43-5	1.4 km	~ 9 - 23 h	0.18
2020 April 20	C43-6	2.5 km	~ 11 -1 h	0.10
2020 May 20	C43-7	3.6 km	~ 13 - 3 h	0.07
2020 June 20	C43-8	8.5 km	~ 15 -5 h	0.032
2020 July 11	C43-9	13.9 km	~ 16 -6 h	0.019
2020 July 30	C43-10	16.2 km	~ 17 - 7h	0.014
2020 August 20	C43-9	139 km	~ 19 - 8 h	0.019
2020 September 10	C43-8	8.5 km	~ 20 - 9 h	0.032

Not offered in Cycle 8!

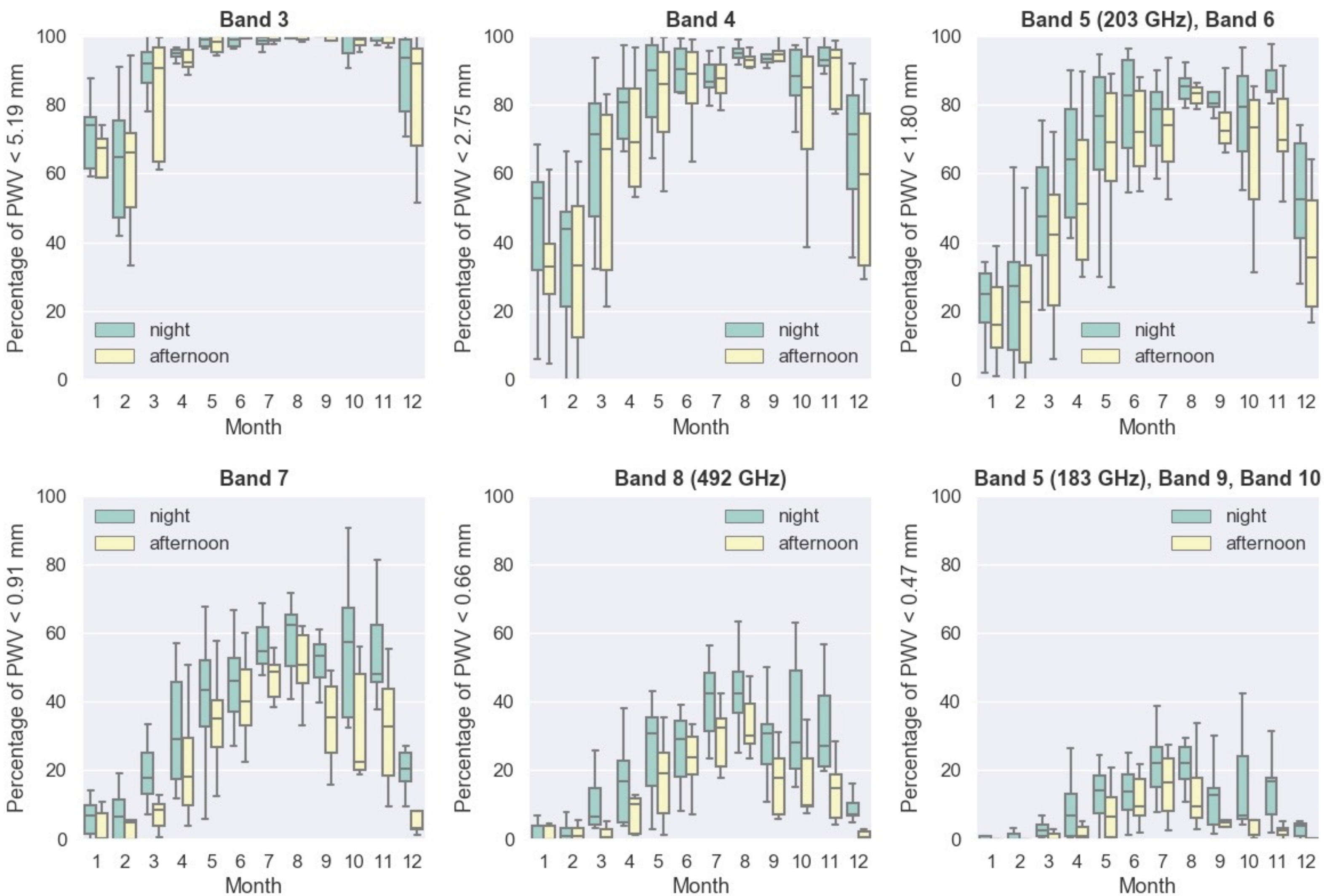
Atacama Large Millimeter/submillimeter Array
In search of our Cosmic Origins

Precipitable Water Vapor



[a]203 GHz
[b]400 GHz
[c]492 GHz
[d]183 GHz

Percentage of Time Available Per Band



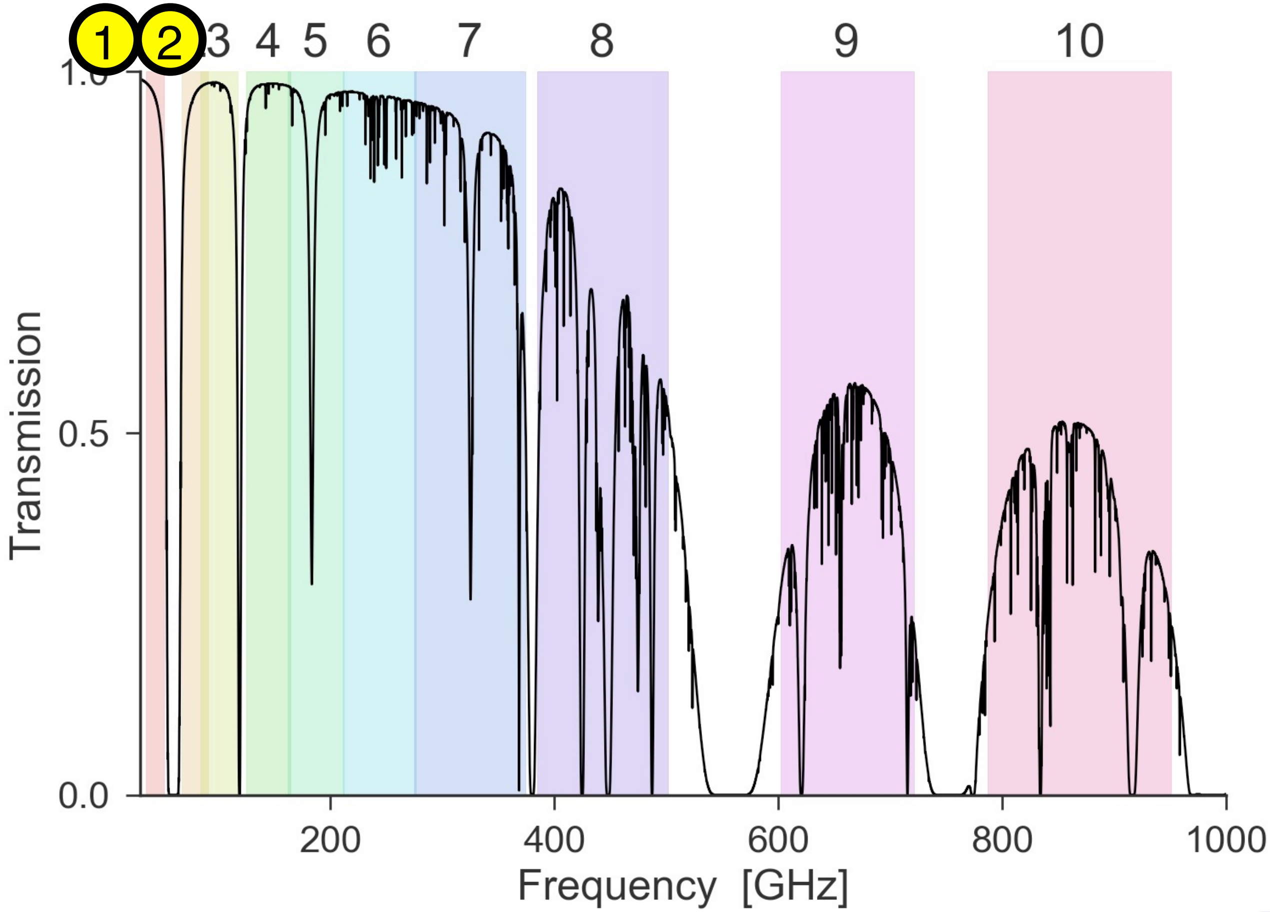
High priority capabilities for Cycle 7 and 8

Single dish
- continuum single dish
- Band 9-10 single dish

Polarization
- mosaicking
- better limits for linear and circular

High frequency
- long baselines
- ACA standalone
- “standard” mode

ALMA Receiver Bands



	Freq. (GHz)	Timescale	Key Science
Band 1	35-50	2020/21	Grain growth in disks, redshifted CO
Band 2	67-90+	Prototype under development	Deuterated molecules, redshifted CO

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

ALMA Support in North America

- North American ALMA Science Center (NAASC) - https://science.nrao.edu/facilities/alma
  - provides general support for the North American community
- Student support - https://science.nrao.edu/facilities/alma/opportunities/student-programs
  - Successful ALMA proposals will be invited to apply for up to $35k to support undergraduate and graduate student involvement
- Face-to-face visitor support - https://science.nrao.edu/facilities/alma/visitors-shortterm
  - Teams can visit the NAASC for data reduction or proposal writing support. Up to 2 team members per visit and 2 teams per week.
- Page charges - https://library.nrao.edu/pubsup.shtml
  - Upon request, NRAO covers page charges for authors at US institutions when reporting ALMA results
- ALMA Ambassadors - https://science.nrao.edu/facilities/alma/ambassadors-program
  - Research grants and training of postdocs who wish to host their own ALMA Proposal Workshops

ALMA Cycle 7 Timeline

Date	Milestone
March 19, 2019	Call for Proposals released
April 17, 2019	**Proposal deadline!**
June 16-21, 2019	Proposal review meeting in Atlanta, Georgia, USA
Late July 2019	Proposal review results announced

Stand-alone ACA Supplemental Call for Proposals

- In Cycle 7, ALMA will offer a ACA Supplemental Call for Proposals
  - Will offer at least 750 h of observing time on the ACA
- Proposals submitted to the Supplemental Call will be peer reviewed through a distributed system
  - One person from the proposal team reviews 10 proposals

Date	Milestone
September 3, 2019	Stand-alone ACA Supplemental Call for Proposals released
October 1, 2019	Proposal deadline for supplemental call
October 15, 2019	Proposals sent to reviewers
November 12, 2019	Deadline to submit reviews
December 2019	Results announced