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

The ALMA Wideband Sensitivity Upgrade

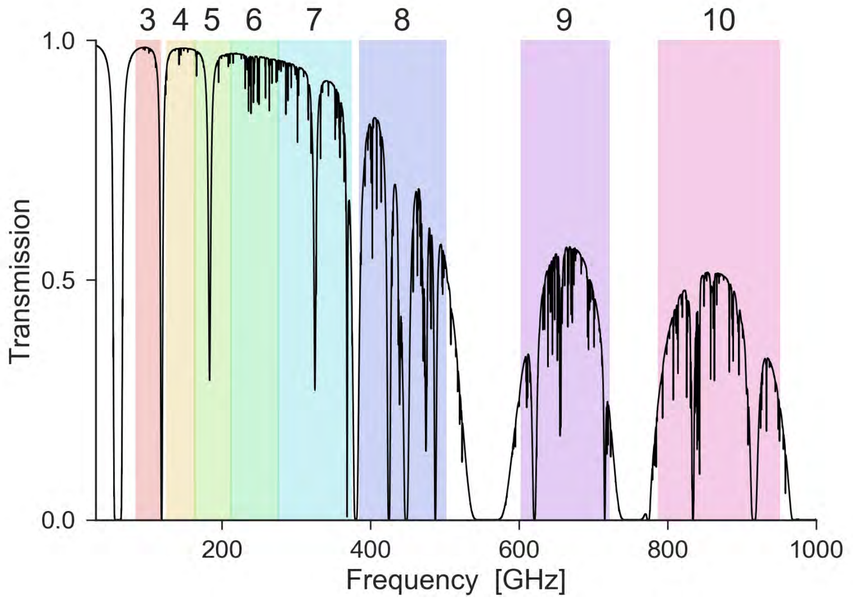
John Carpenter
Joint ALMA Observatory

ALMA - ASTE - 45m Users Meeting 2022
December 20-21, 2022

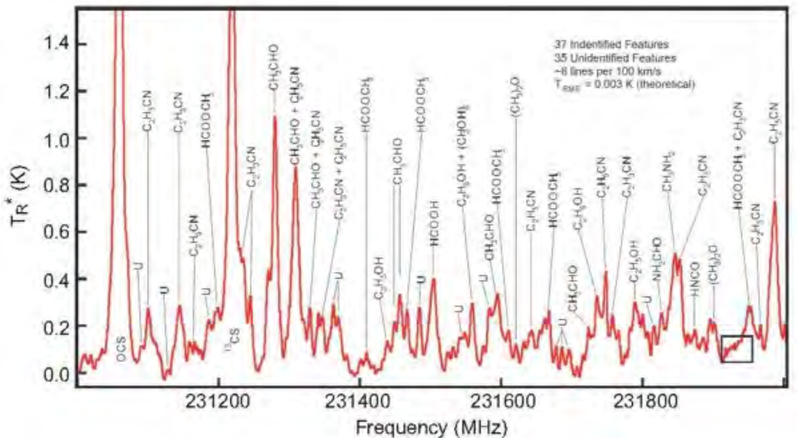
ALMA Capabilities

Imaging

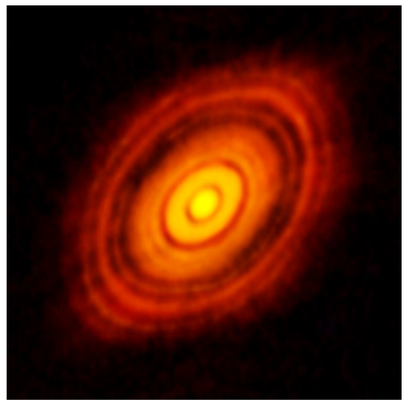
8 receiver bands



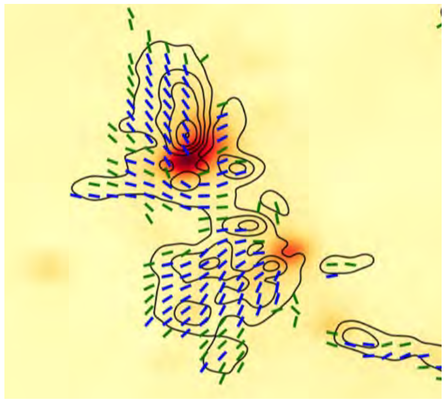
Spectroscopy



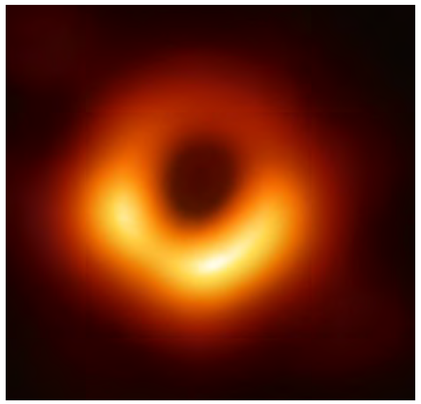
Continuum



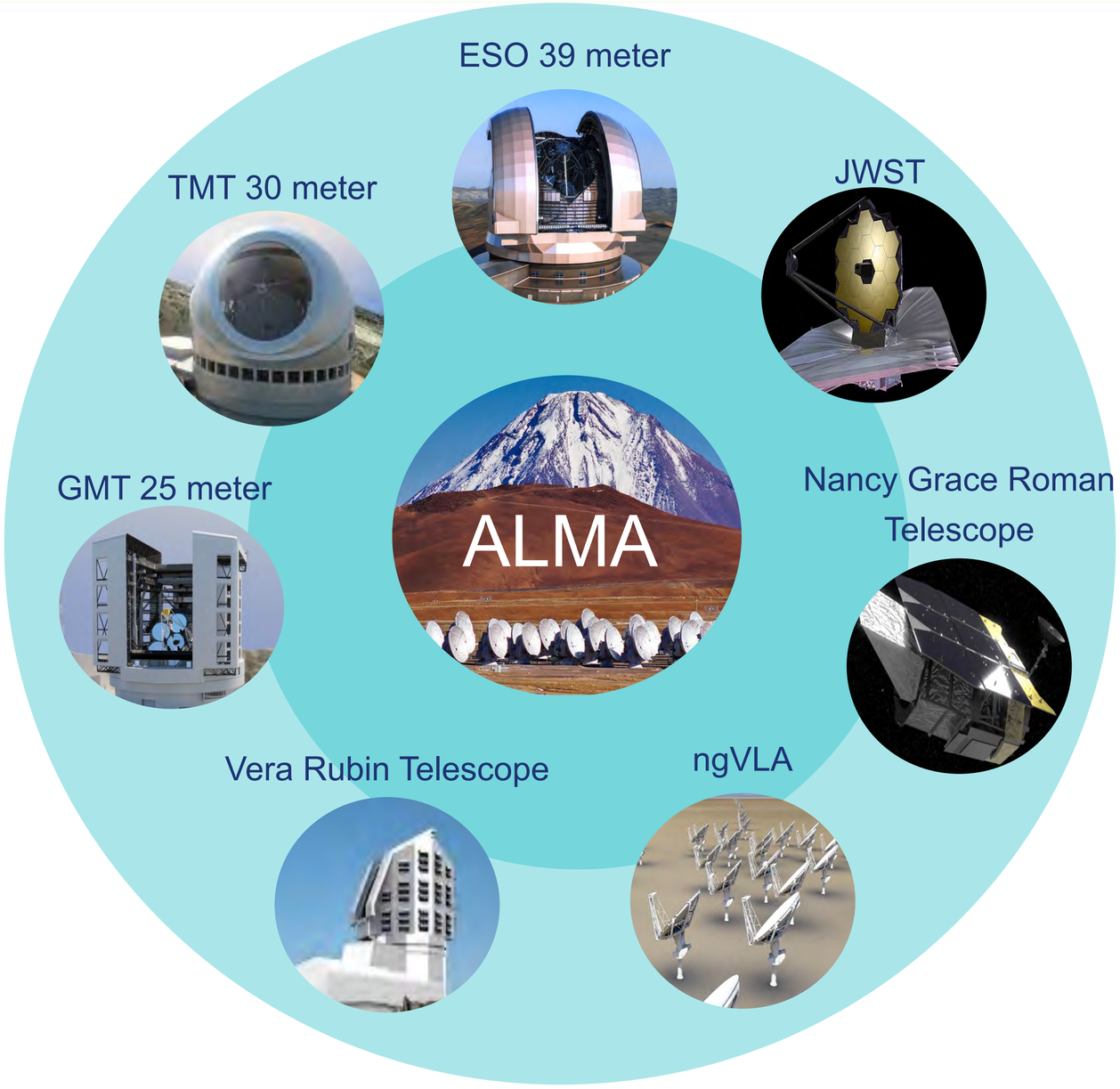
Polarization



VLBI



New facilities in the next decade



ALMA Development Program

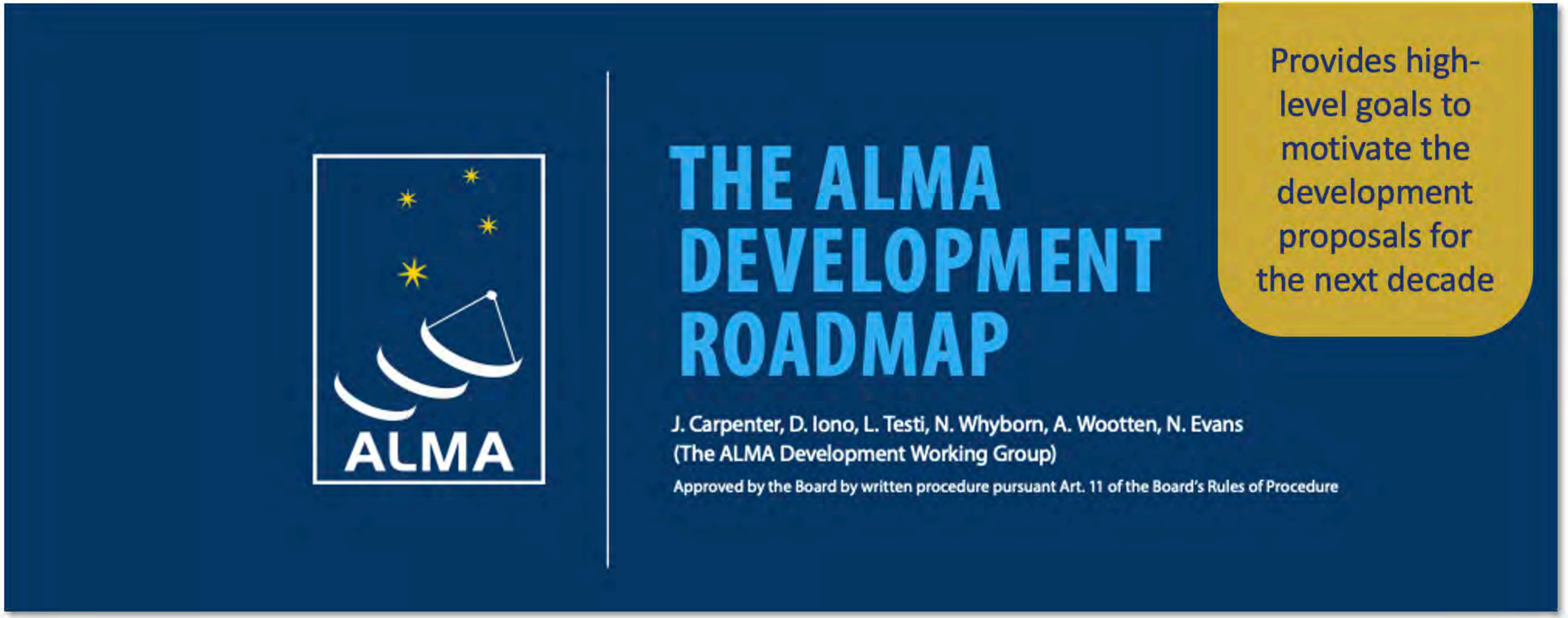
Dedicated funds to enhance ALMA as a world-leading submillimeter facility

Hardware

Software

Infrastructure

ALMA Development Roadmap



ALMA2030 Development Priorities

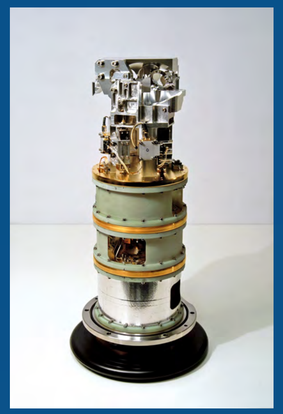
Receiver bandwidth	Expand bandwidth by at least a factor of two **TOP PRIORITY**
Science archive	Optimize archive science
Angular resolution	Extend baselines by a factor of 2-3
Collecting area	Develop science cases for increasing the number of 12-m antennas
Widefield mapping	Study science case and technical feasibility of focal plane arrays

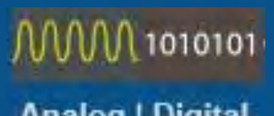
Wideband Sensitivity Upgrade (WSU)

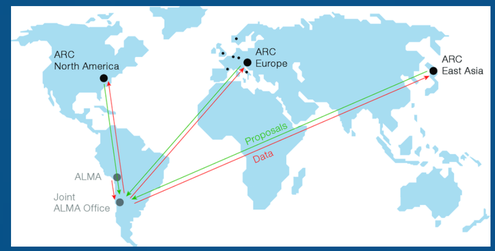
- Upgrade of the bandwidth and throughput of the ALMA system
  - upgraded receivers with increased bandwidth and improved receiver temperatures
  - more powerful correlator
  - increased data reduction capacity

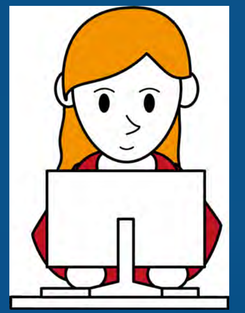
Upgrade!

Antennas → Receivers → Back end → Correlator → Data processing → Archives → Astronomers



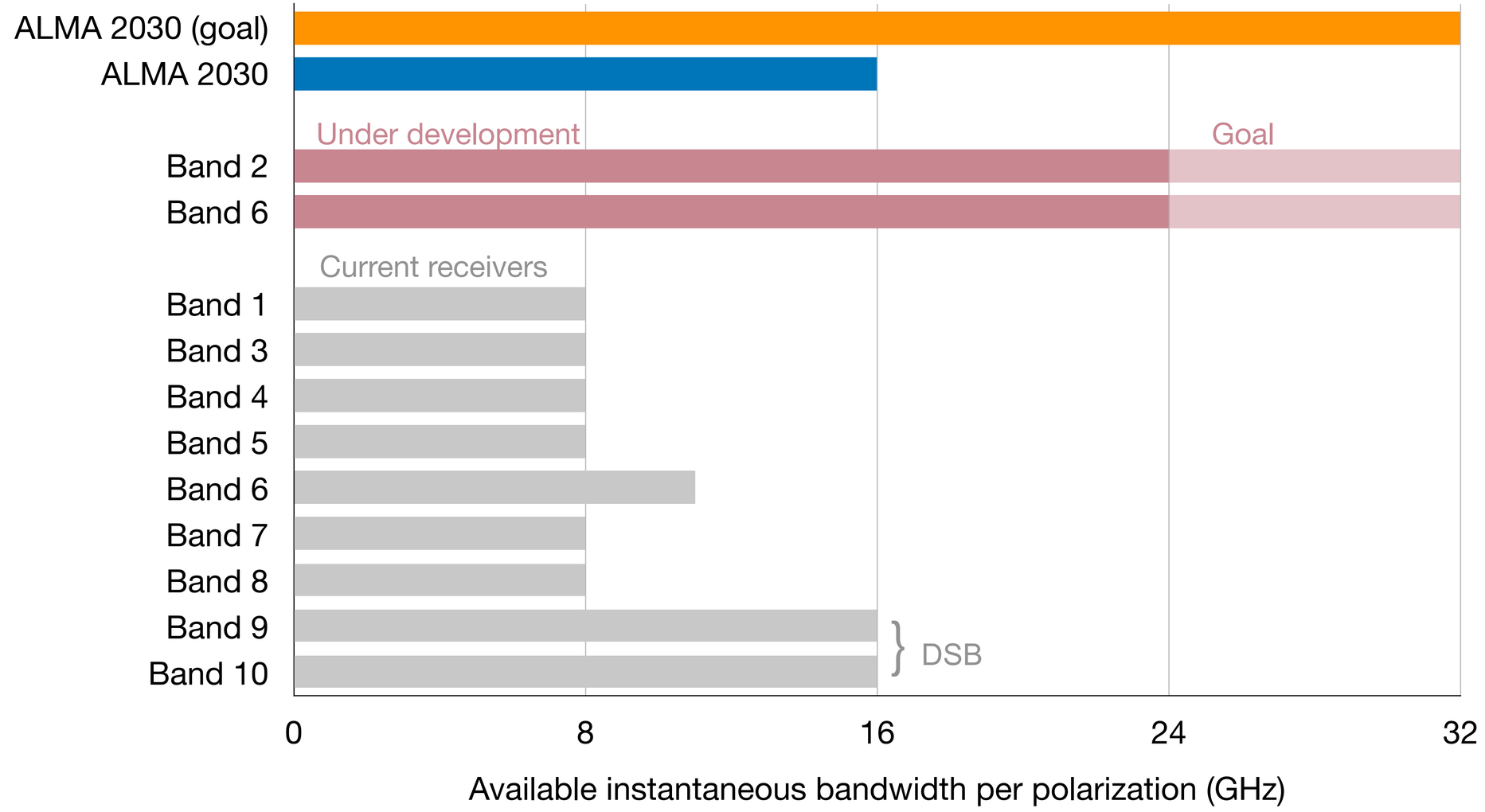






Wideband Sensitivity Upgrade: Overview

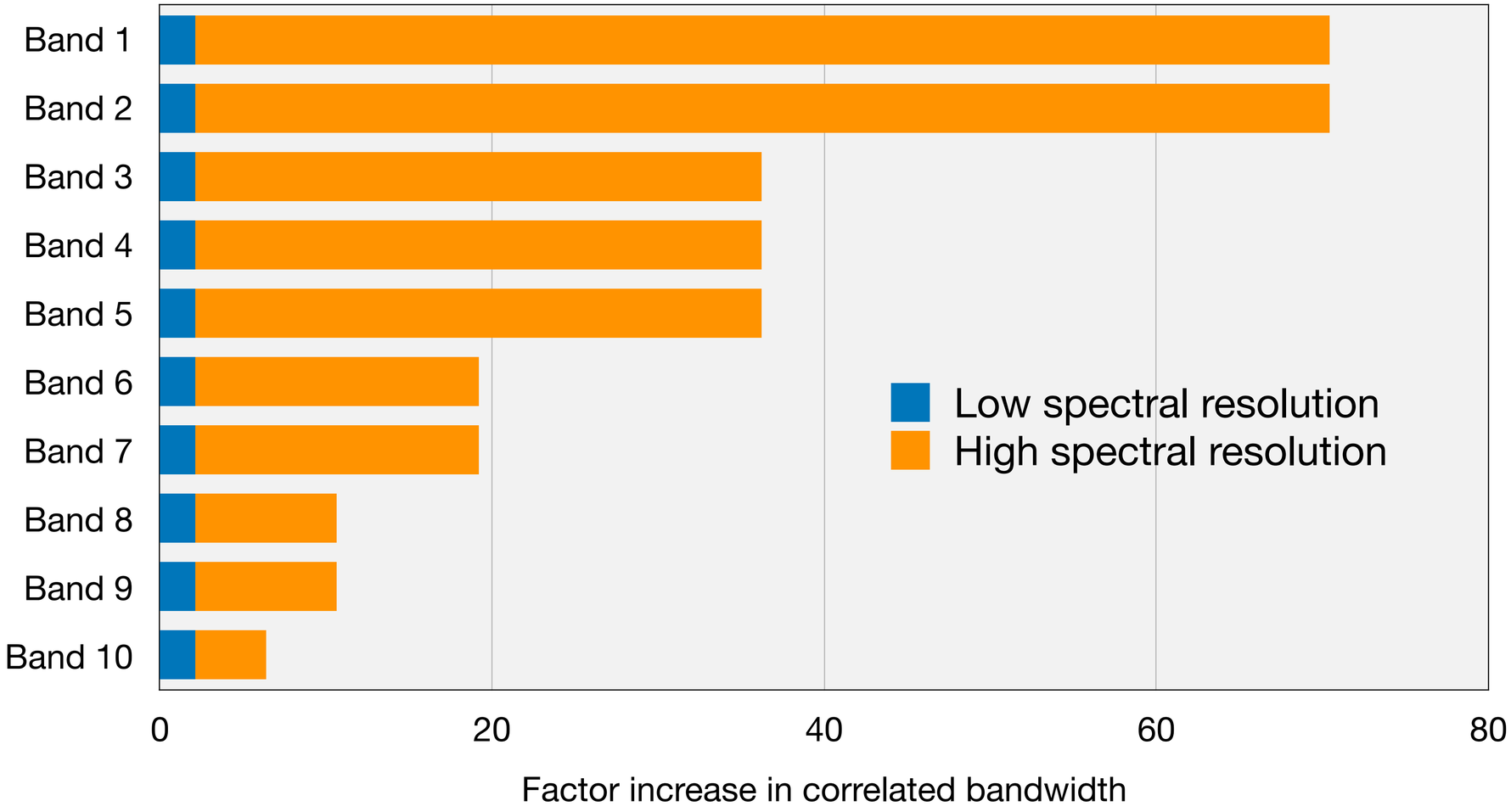
- **Available bandwidth**
- Correlated bandwidth
- Observing speed



Factor of 2-4 increase in the available IF bandwidth.

Wideband Sensitivity Upgrade: Overview

- Available bandwidth
- **Correlated bandwidth**
- Observing speed



High spectral resolution ~ 0.1 km/s

Wideband Sensitivity Upgrade: Overview

- Available bandwidth
- Correlated bandwidth
- **Observing speed**

Increase in Band 6 observing speed with ALMA 2030

Observing mode	Increase in speed over current system*
Continuum	4.8x (with goal of 9.6x)
Spectral line	2.2-4.7x

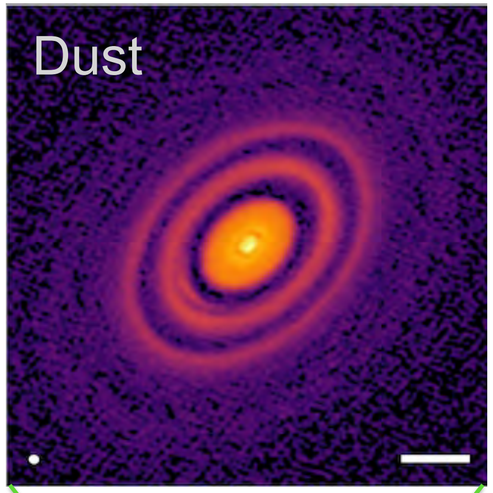
* To reach same sensitivity as current system with single tuning

Increase in observing speed results from
- improved receiver temperatures
- improved digital efficiency
- wider bandwidth (continuum)

Spectral scans will see further speed increases due to larger correlated bandwidth.

The power of molecular spectroscopy in disks

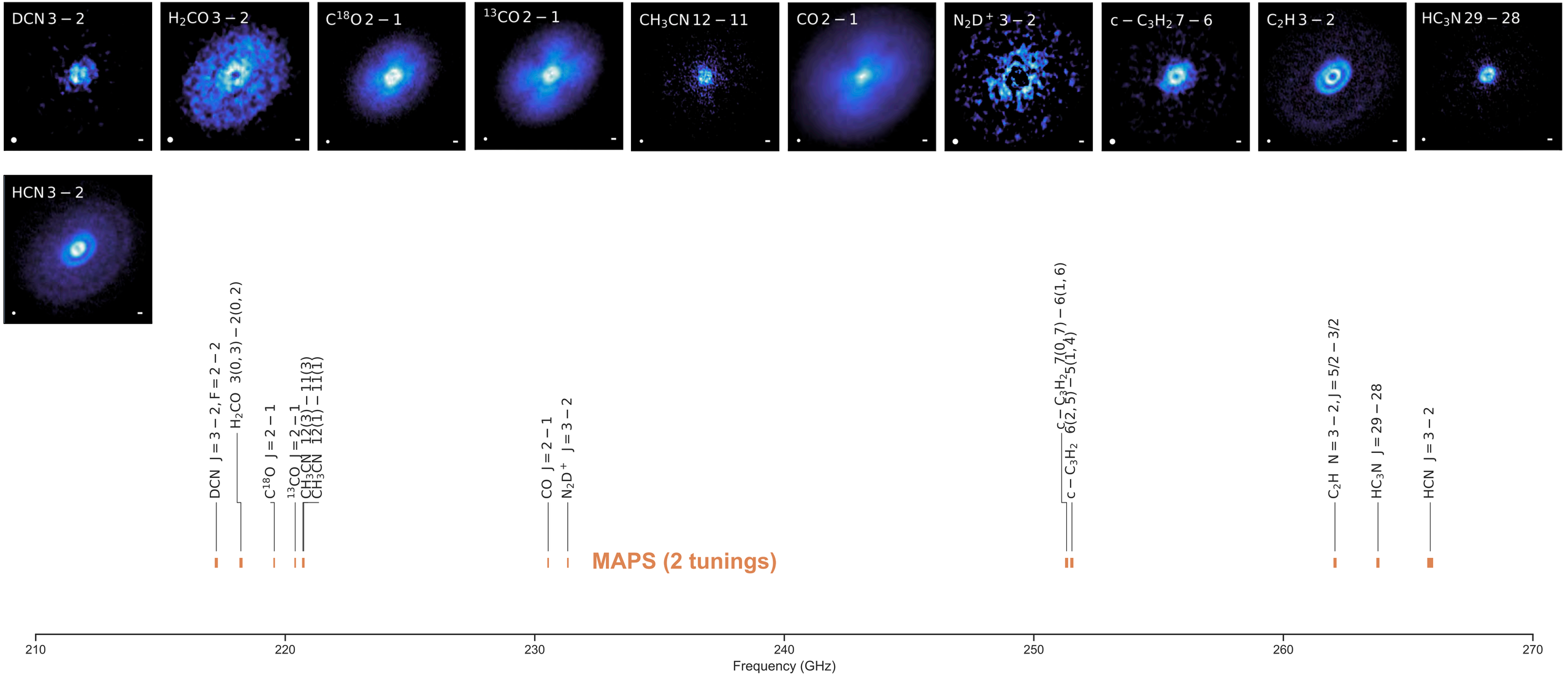
HD 163296



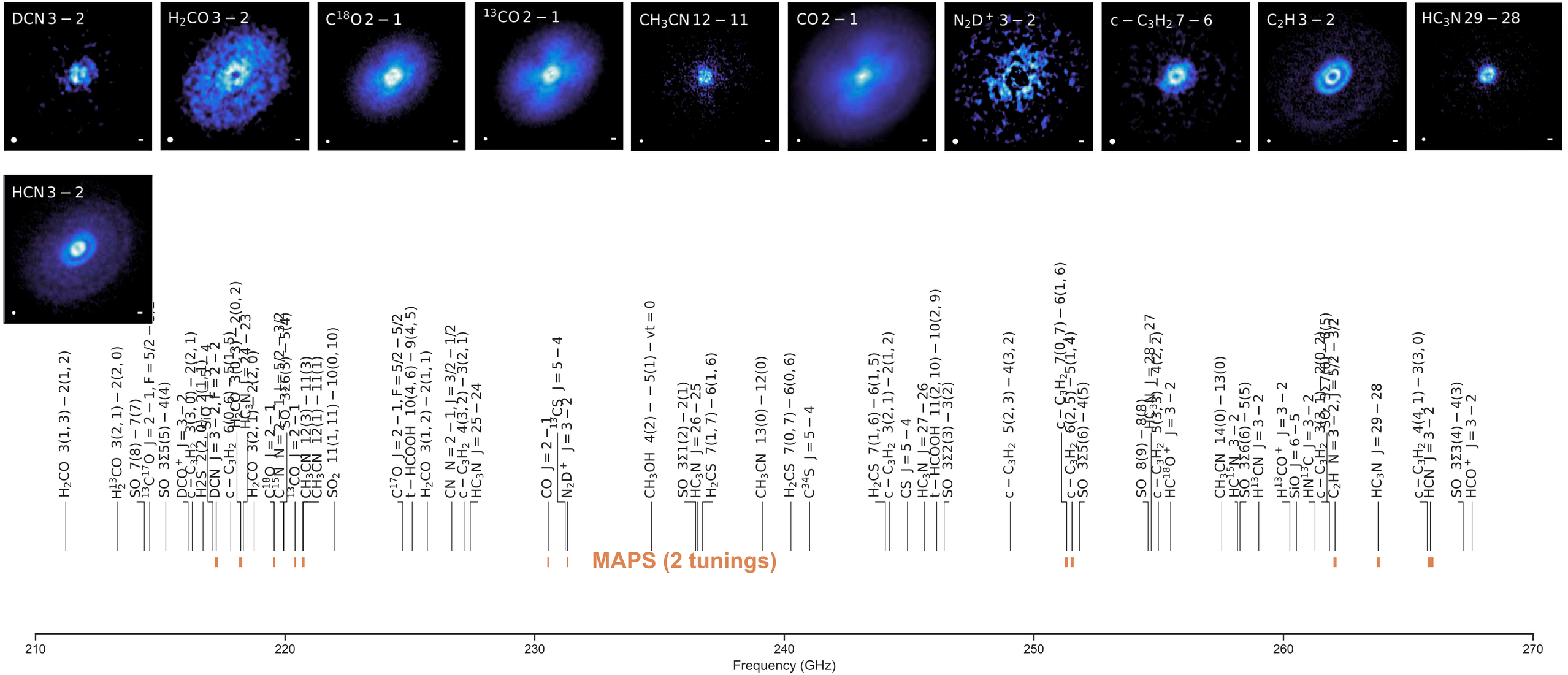
- Gas mass
  - dust traces only ~ 1% of the total disk mass
  - use molecules to trace the dominant disk component (H_2)
- Chemistry and the chemical compositions of planets
- 3D velocity and temperature structure of disks
- Detect embedded planets through velocity distortions
- **With vastly improved spectral grasp and improved line (and continuum!) sensitivity, the Wideband Sensitivity Upgrade will be a tremendous advance for disk studies.**

Öberg et al. (2021)

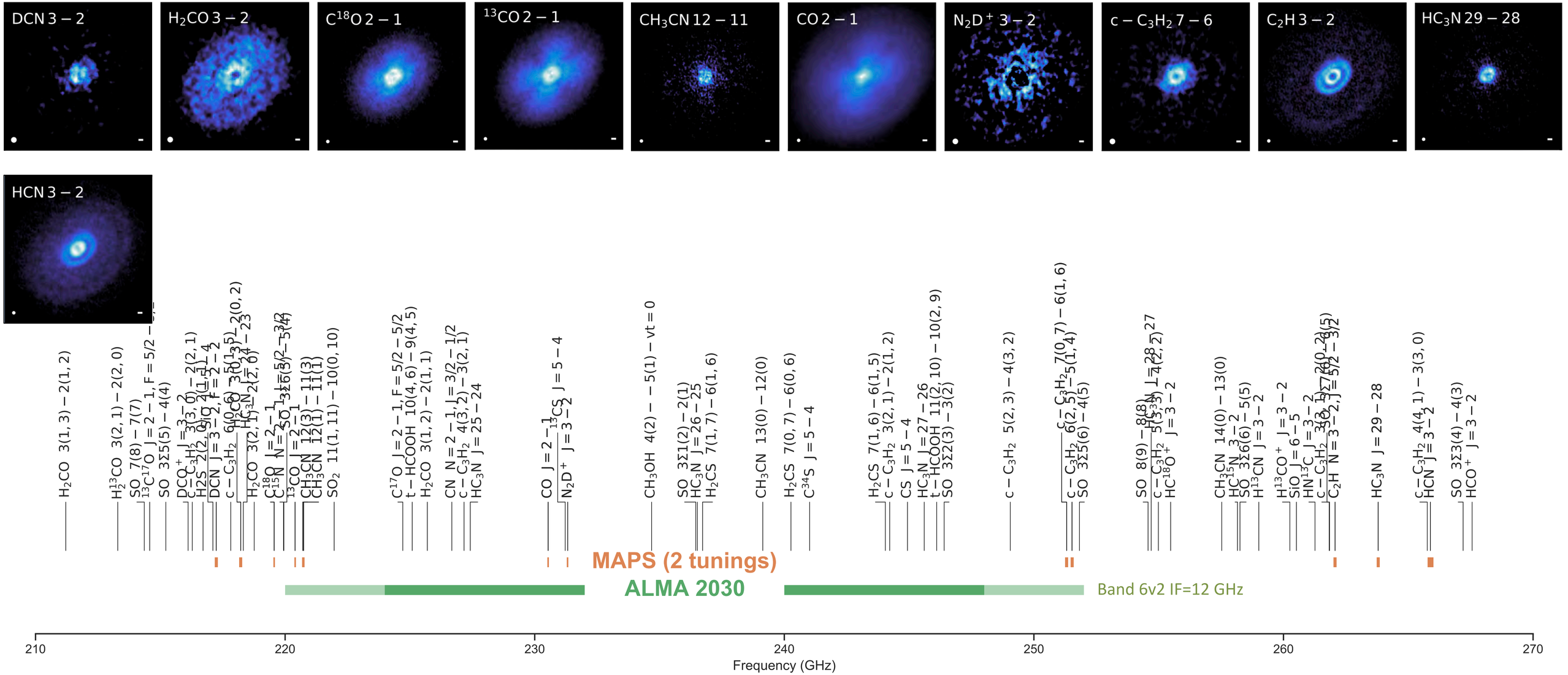
The WSU Advantage



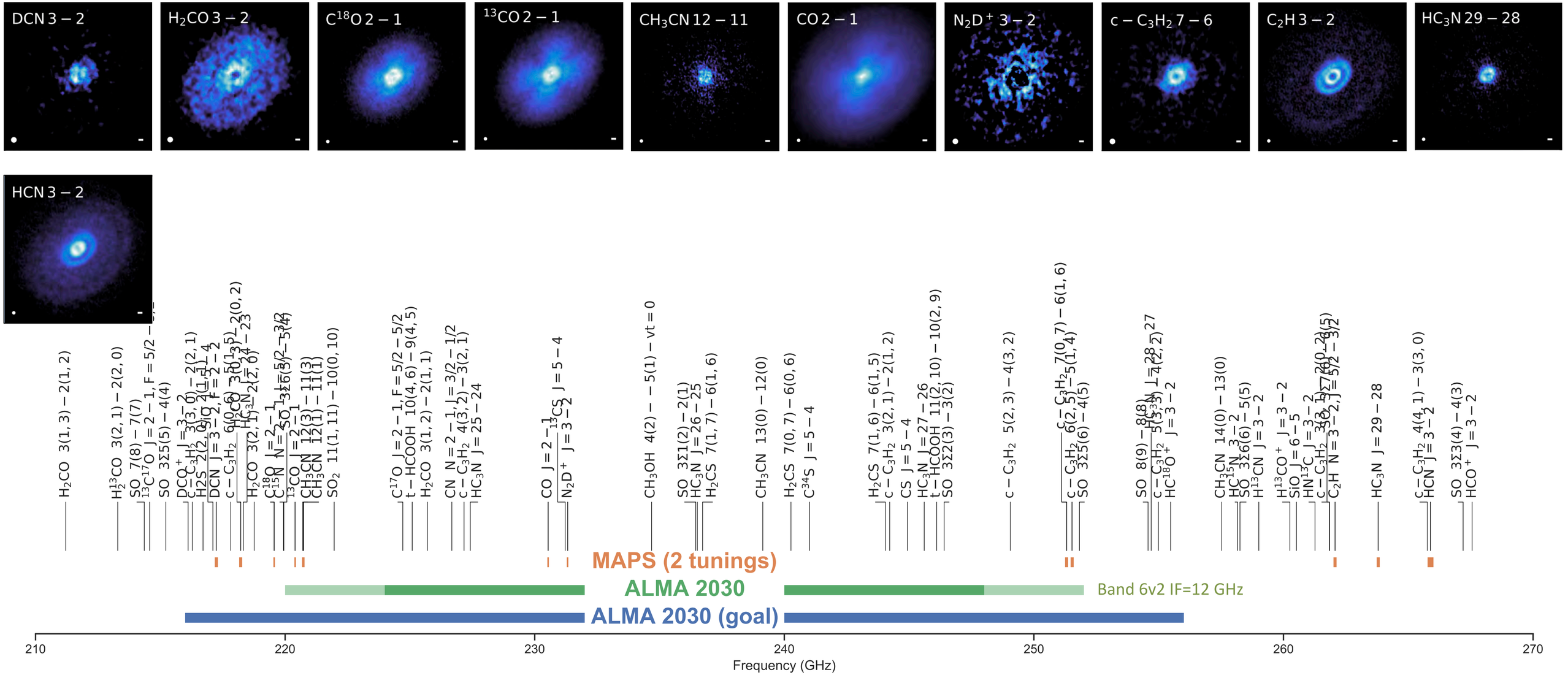
The WSU Advantage



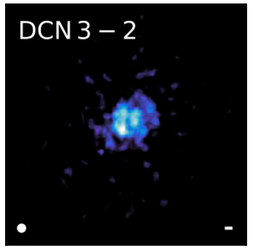
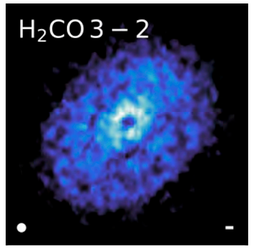
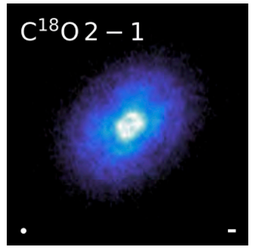
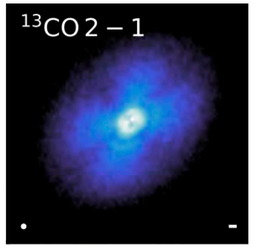
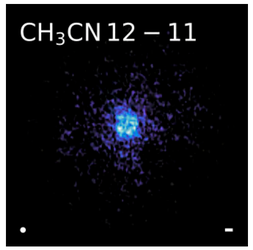
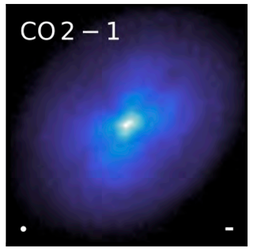
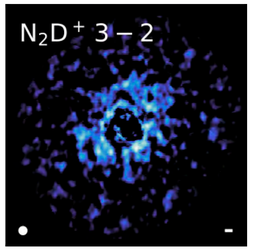
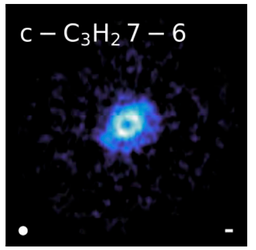
The WSU Advantage



The WSU Advantage

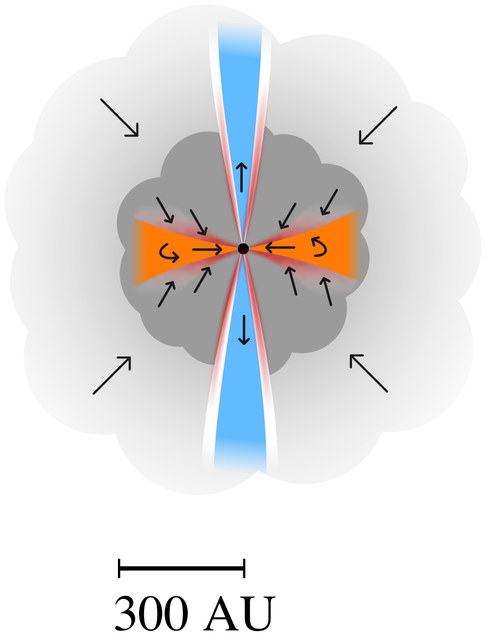


The WSU Advantage

								DCO^+ J=3-2	NO J=5/2-3/2
SO_2 10(5,5)-11(4,8)	H_2S 2(2,0)-2(1,1)	SiO J=5-4	c-C_3H_2 6(0,6)-5(1,5)	HC_3N J=24-23	H_2CO 3(2,1)-2(2,0)	$C^{15}N$ N=2-1	SO 3Σ 6(5)-5(4)	SO_2 11(1,11)-10(0,10)	$C^{17}O$ J=2-1
t-HCOOH 10(4,6)-9(4,5)	H_2CO 3(1,2)-2(1,1)	H_2CS 7(0,7)-6(0,6)	H_2CS 7(1,6)-6(1,5)	CN N=2-1	c-C_3H_2 4(3,2)-3(2,1)	c-C_3H_2 3(2,1)-2(1,2)	CS J=5-4	HC_3N J=25-24	HC_3N J=27-26
^{13}CS J=5-4	$C^{34}S$ J=5-4	t-HCOOH 11(2,10)-10(2,9)	SO 3Σ 2(3)-3(2)	c-C_3H_2 5(2,3)-4(3,2)	SO 3Σ 5(6)-4(5)	SO 3Σ 8(9)-8(8)	HC_3N J=28-27	c-C_3H_2 5(3,3)-4(2,2)	$HC^{18}O^+$ J=3-2

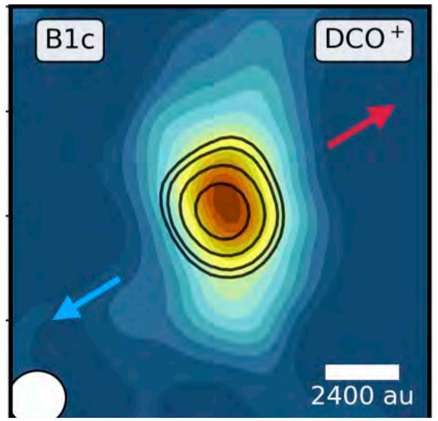
… and up to 40 additional spectral windows!

Star formation

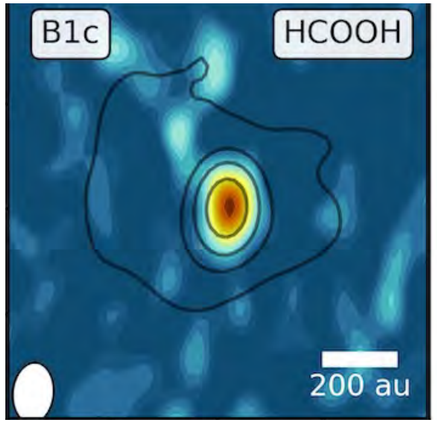


300 AU

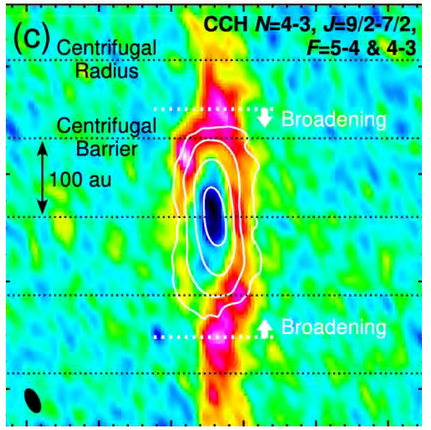
Envelope
DCO^+



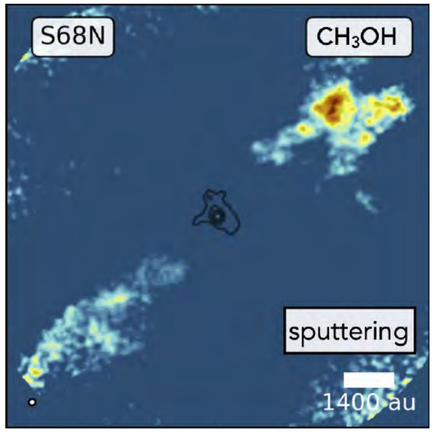
Hot core
HCOOH



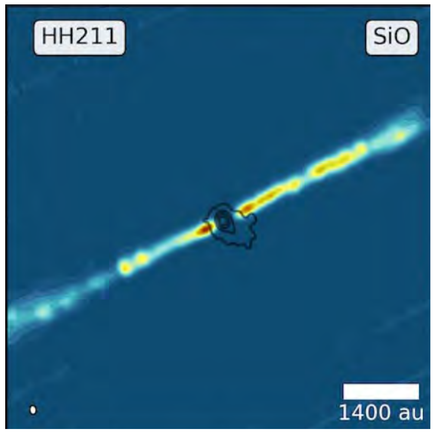
Centrifugal barrier
CCH



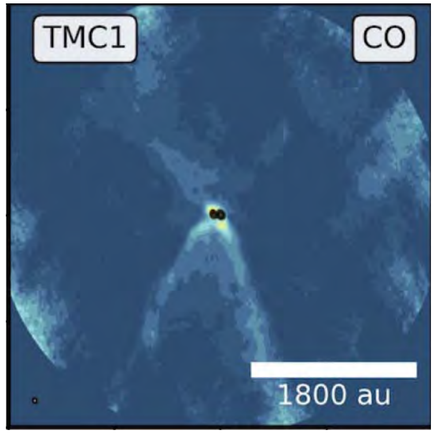
Sputtering
CH_3OH



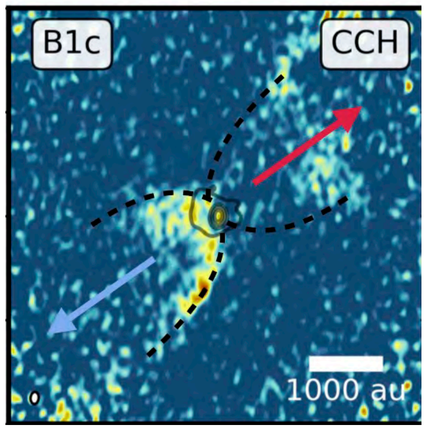
High velocity jet
SiO



Low-velocity flow
CO

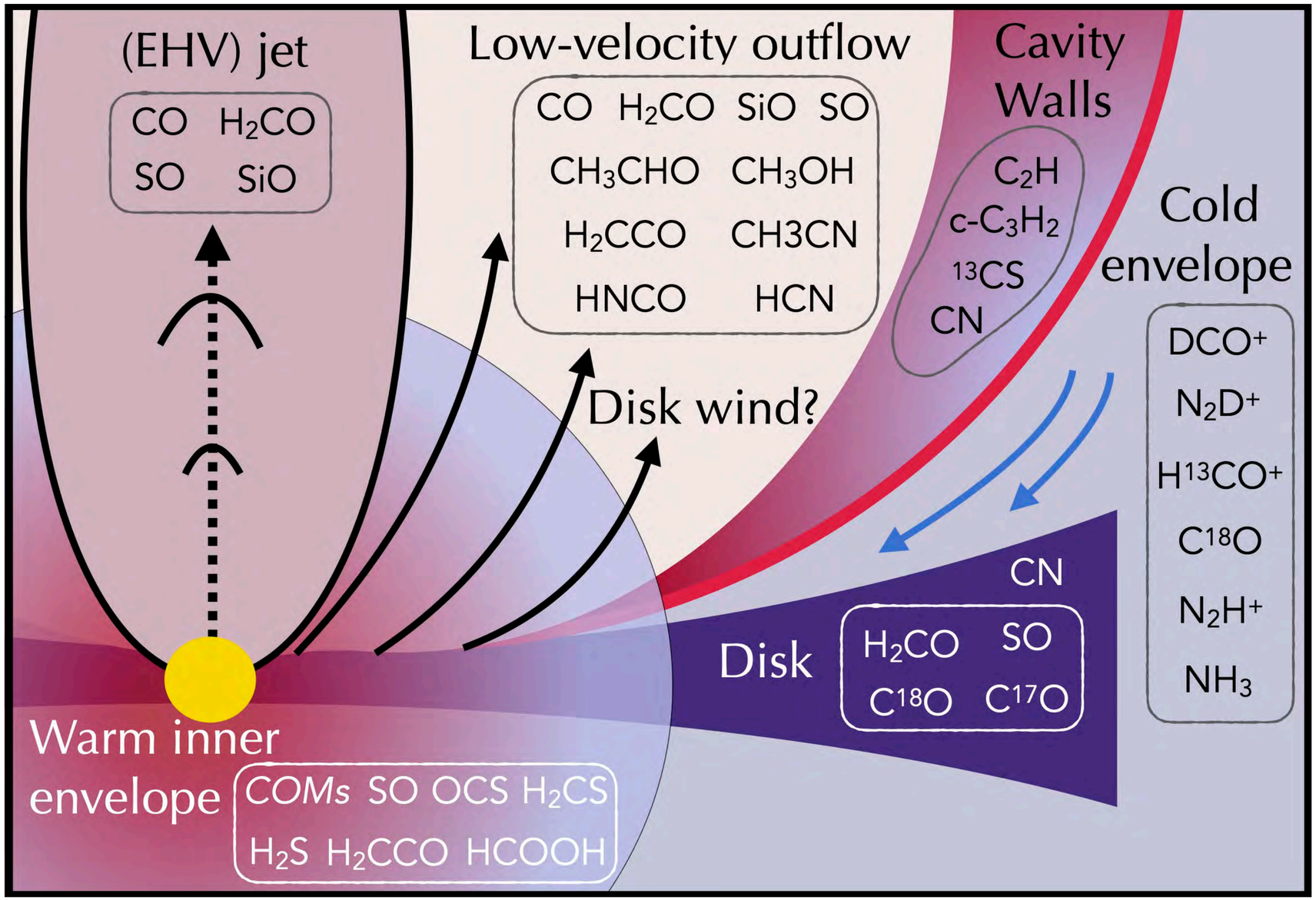


Outflow cavity
CCH



Sakai et al. (2017)
Tychoniec et al. (2021)

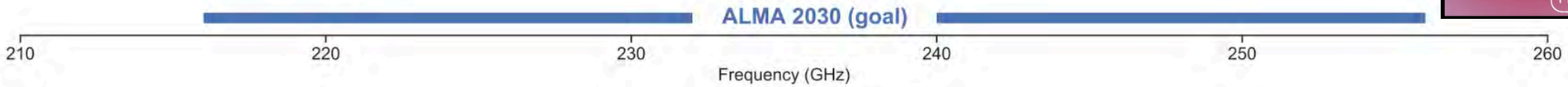
Molecular probes of star formation with ALMA 2030

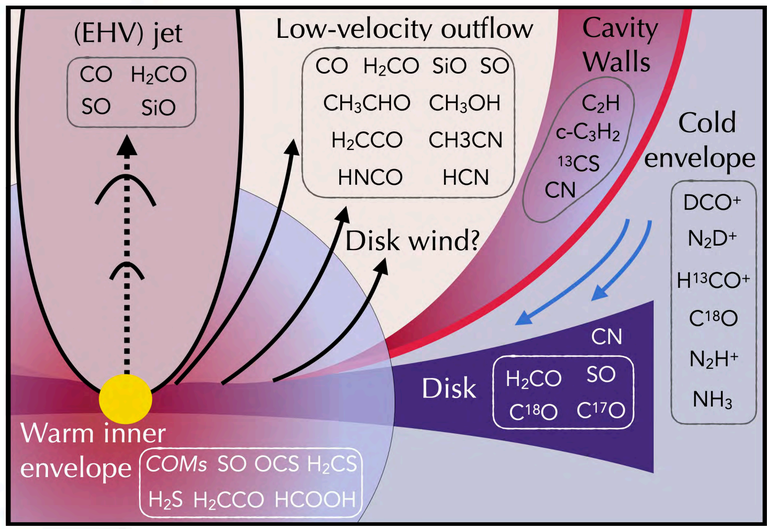


Tychoniec et al. (2021)

Molecular probes of star formation with ALMA 2030

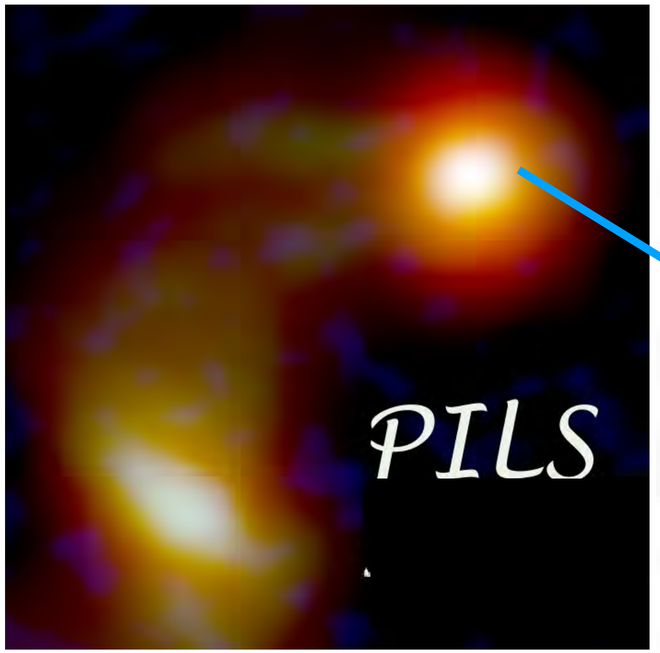
Jet	Low-velocity outflow		Cavity walls	Cold envelope	Warm envelope		Protostellar disk	
^{12}CO J=2-1	^{12}CO J=2-1	SiO J=5-4	CN N=2-1	DCO^+ J=3-2	SO several	OCS J=18-17 J=19-18	CN N=2-1	SO several
SiO J=5-4	SO several	H_2CO several	^{13}CS J=5-4	N_2D^+ J=3-2	H_2CS several	H_2S 2(2,0)-2(1,1)	H_2CO several	$C^{18}O$ J=2-1
SO several	CH_3CN several	H_2CCO several	HCCCH several	$C^{18}O$ J=2-1	H_2CCO several	HCOOH several	$C^{17}O$ J=2-1	
H_2CO several	HNCO 11(0,11)-10(0,10)	CH_3CHO several						
	CH_3OH several							

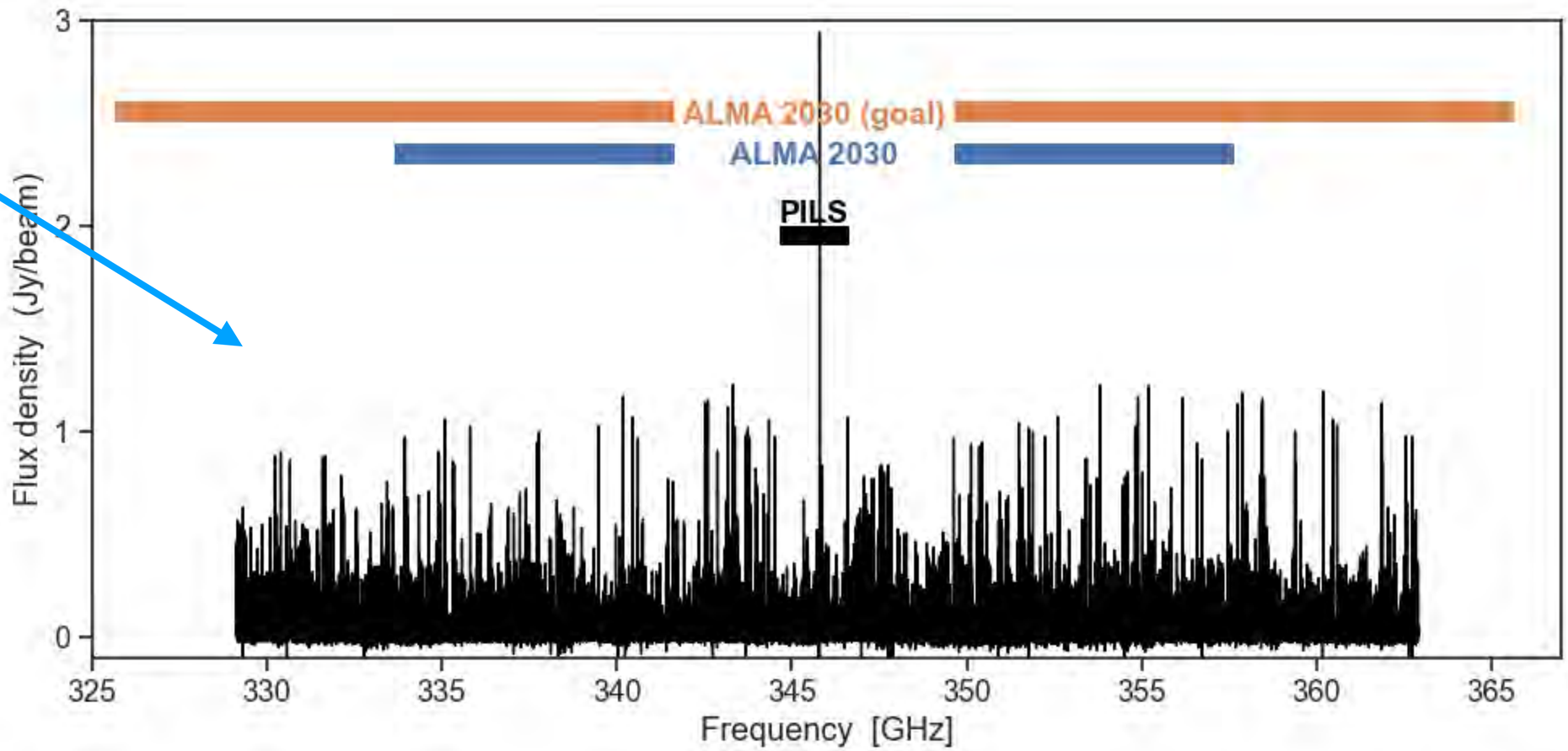




Tychoniec et al. (2021)

Efficient spectral scans of protostars

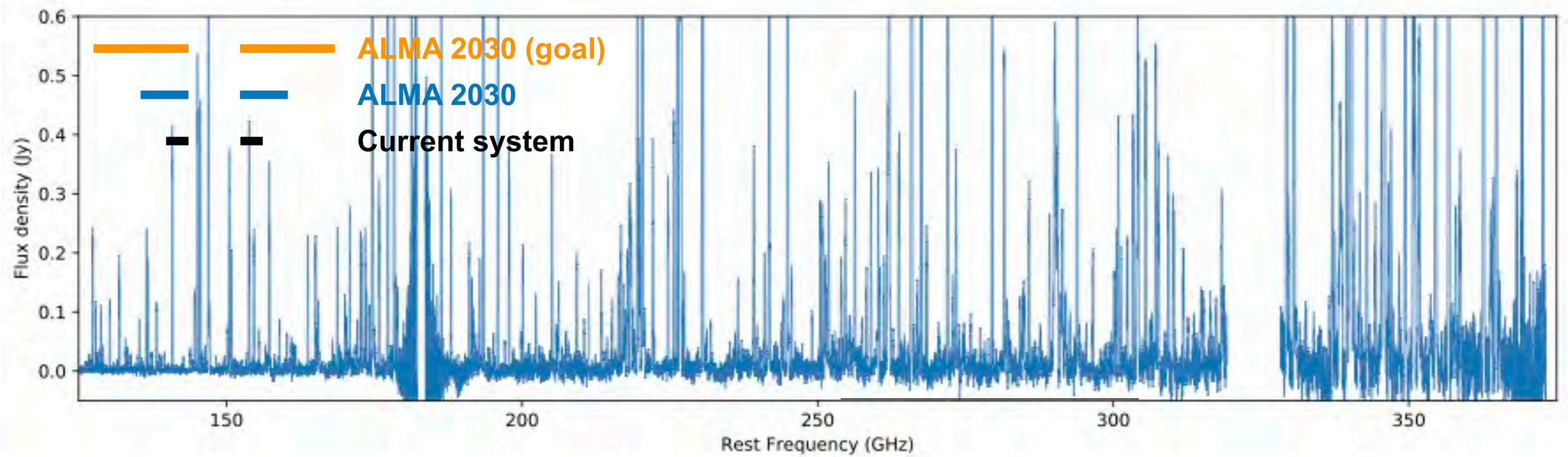




- PILS survey of IRAS 16293 protostar required 18 tunings
- ALMA 2030 will need only 2 tunings!

Jørgensen et al. (2016)

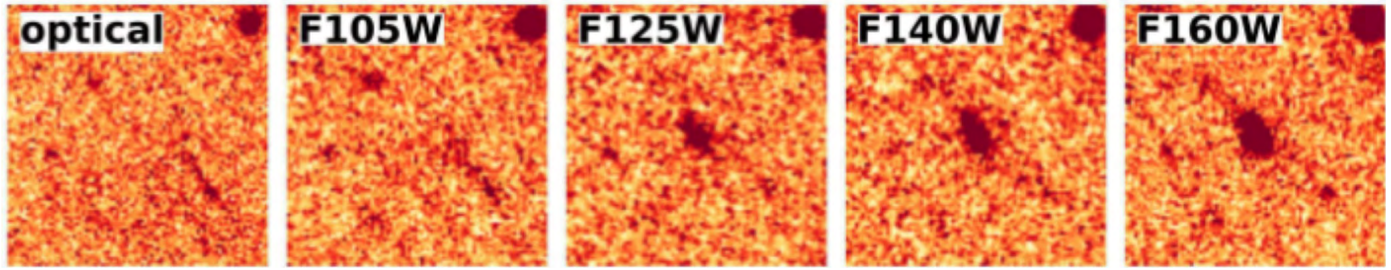
ALCHEMI survey of NGC 253

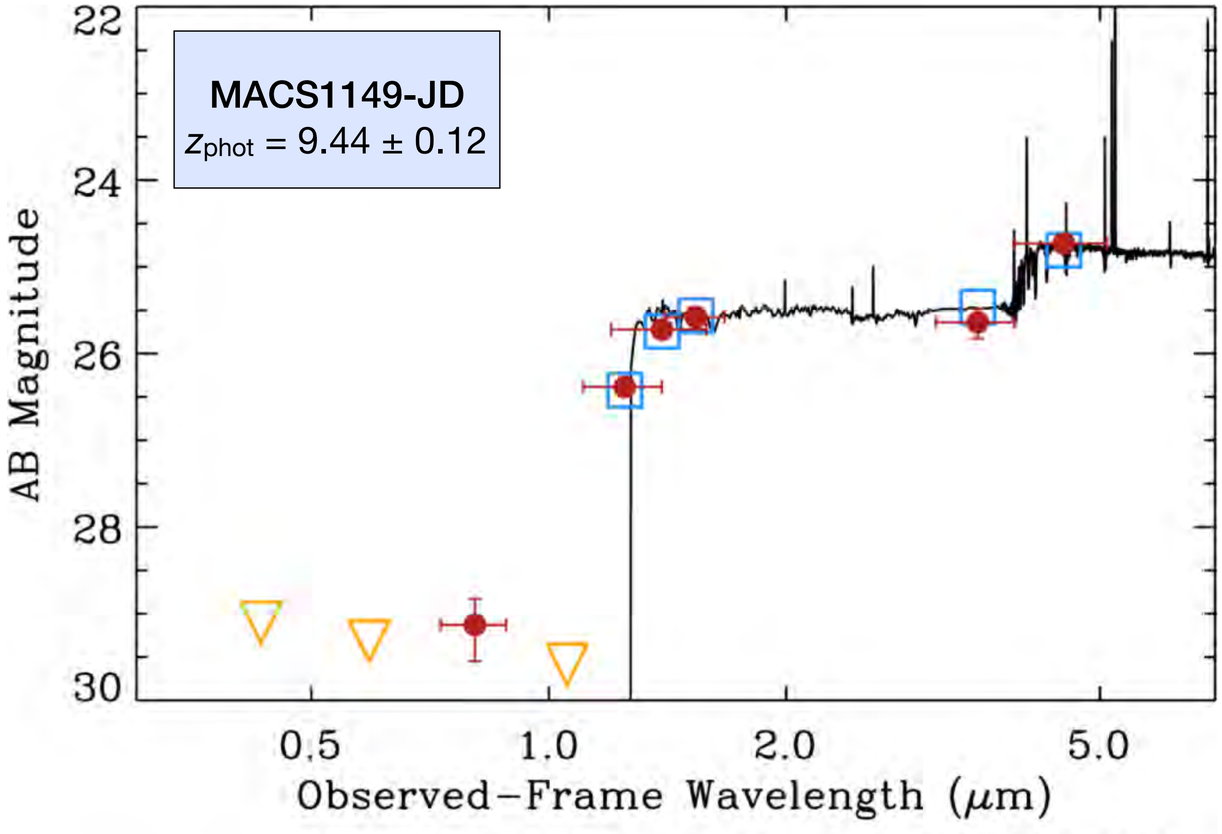


- Survey speed with ALMA 2030 will increase by a factor of 3-6 plus any gains from improved receiver temperatures.

Martín, Harada et al. (2021)

Probing the origins of galaxies

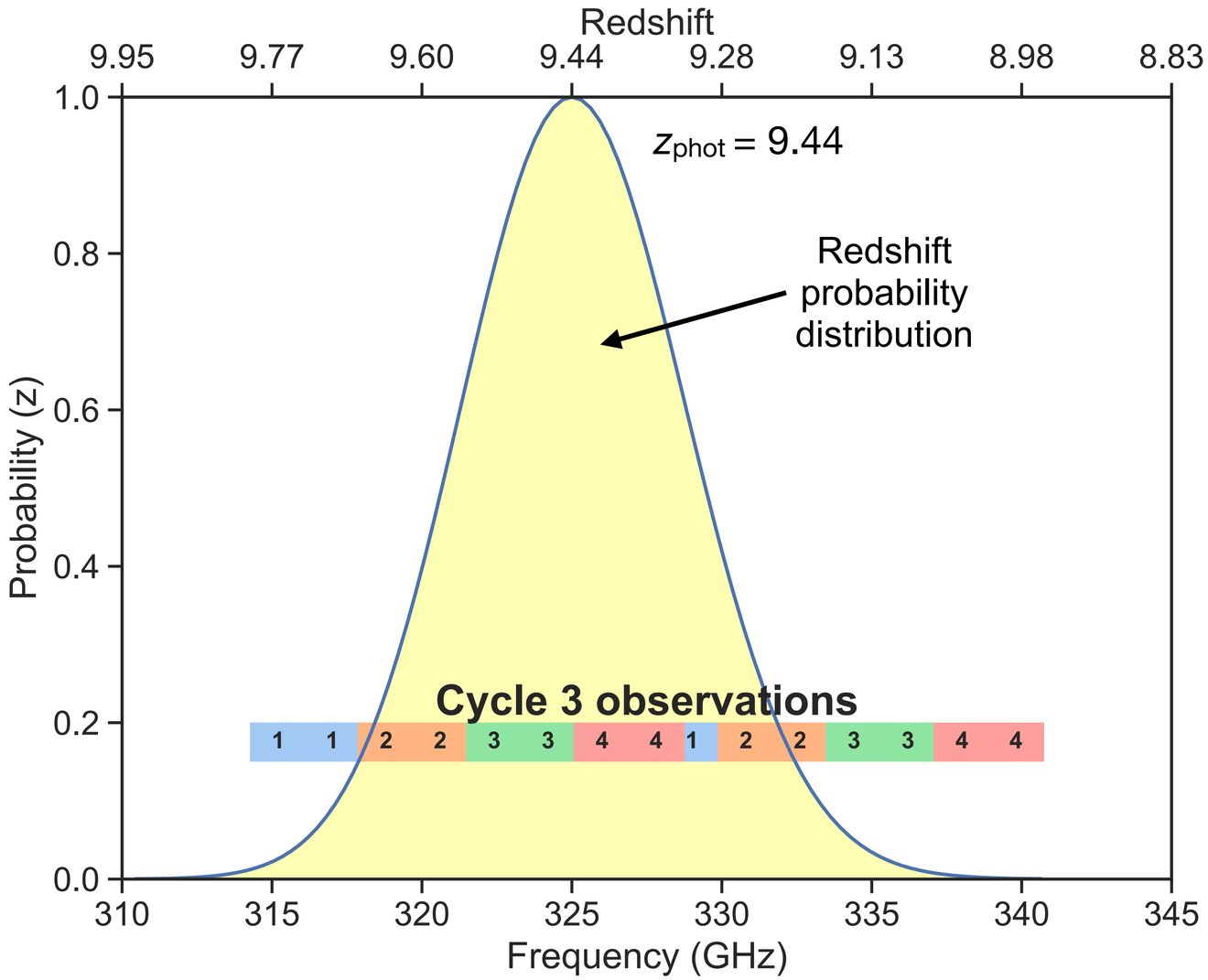




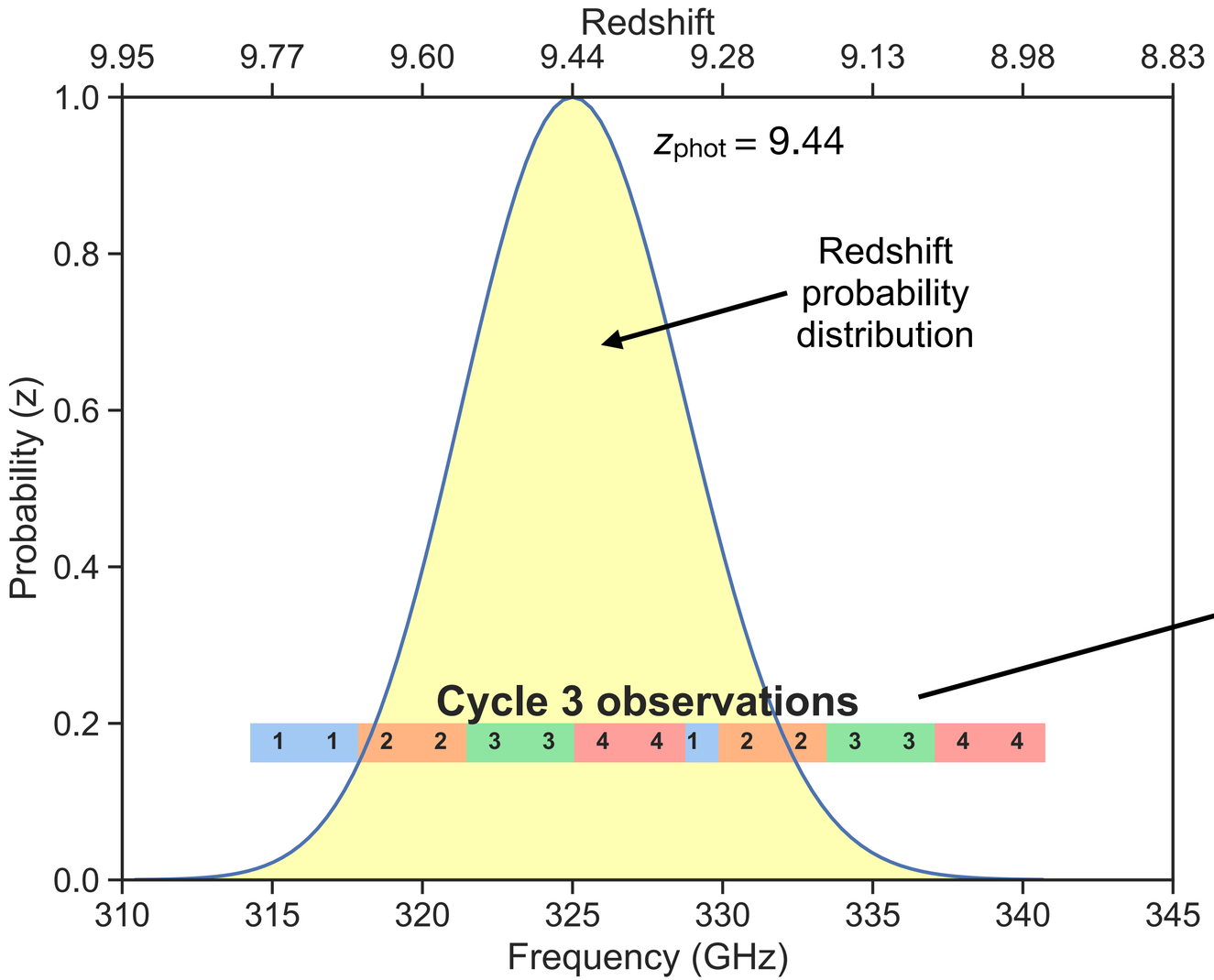
- Candidate galaxy at photometric redshift of z=9.4
- Universe only 500 Myr old!
- Spectroscopy needed to determine redshift
  - large uncertainties
  - contaminants at lower redshift

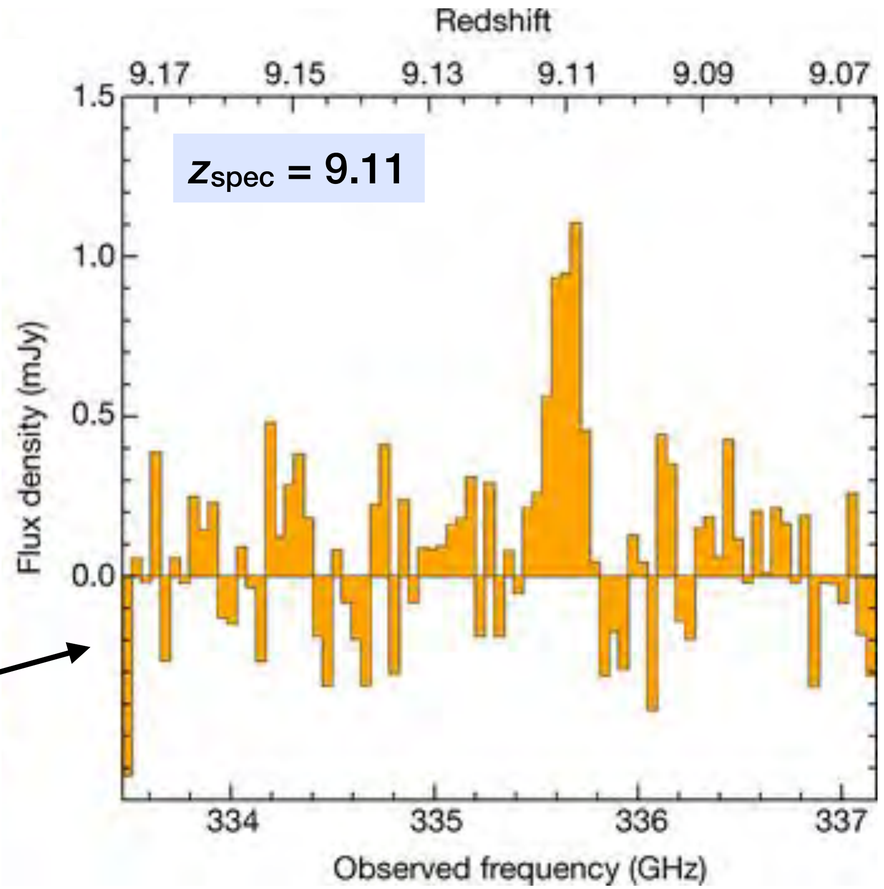
Zheng et al. (2017)
McLead et al. (2016)

ALMA spectral scan search for Oxygen in MACS1194-JD



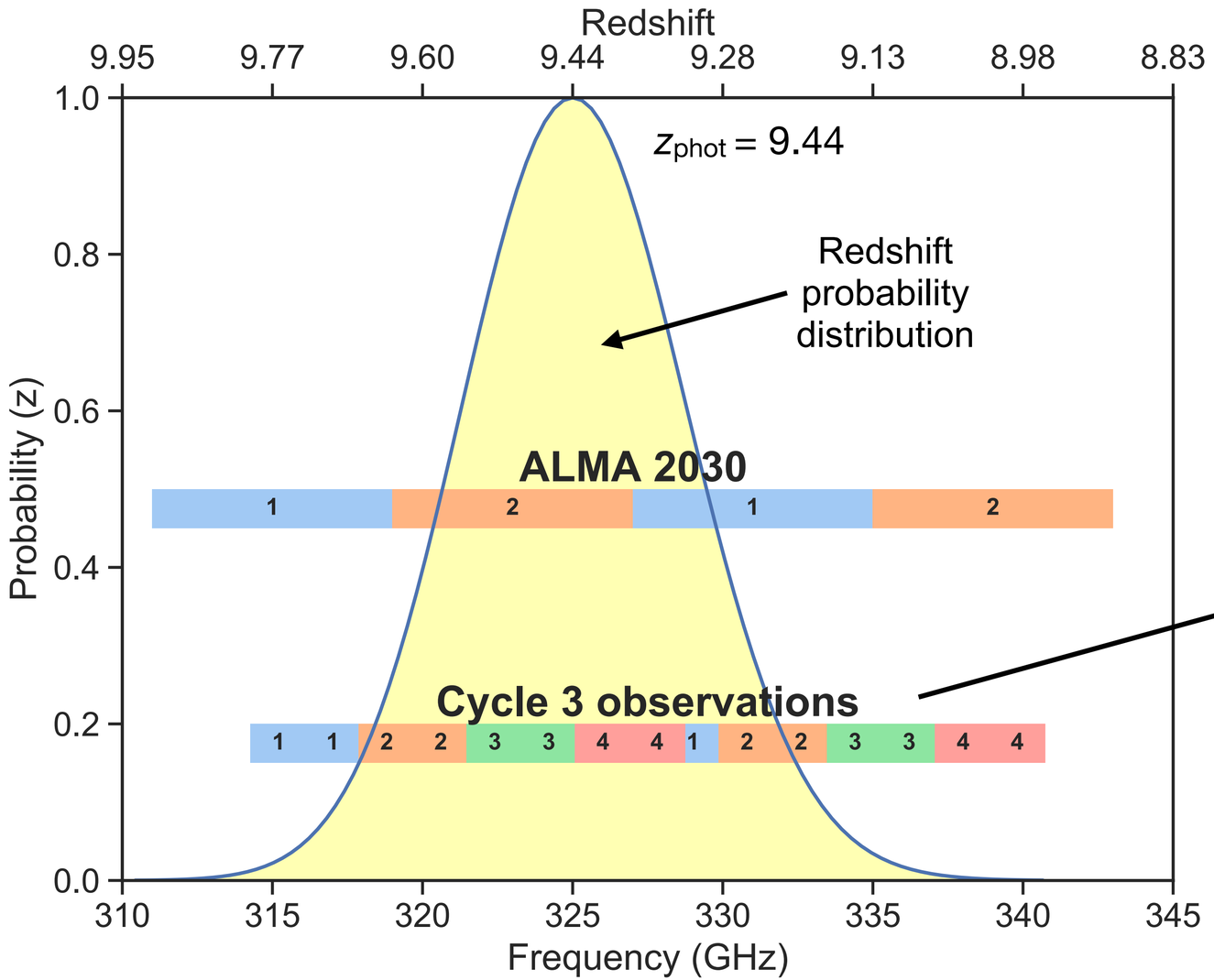
ALMA spectral scan search for Oxygen in MACS1194-JD

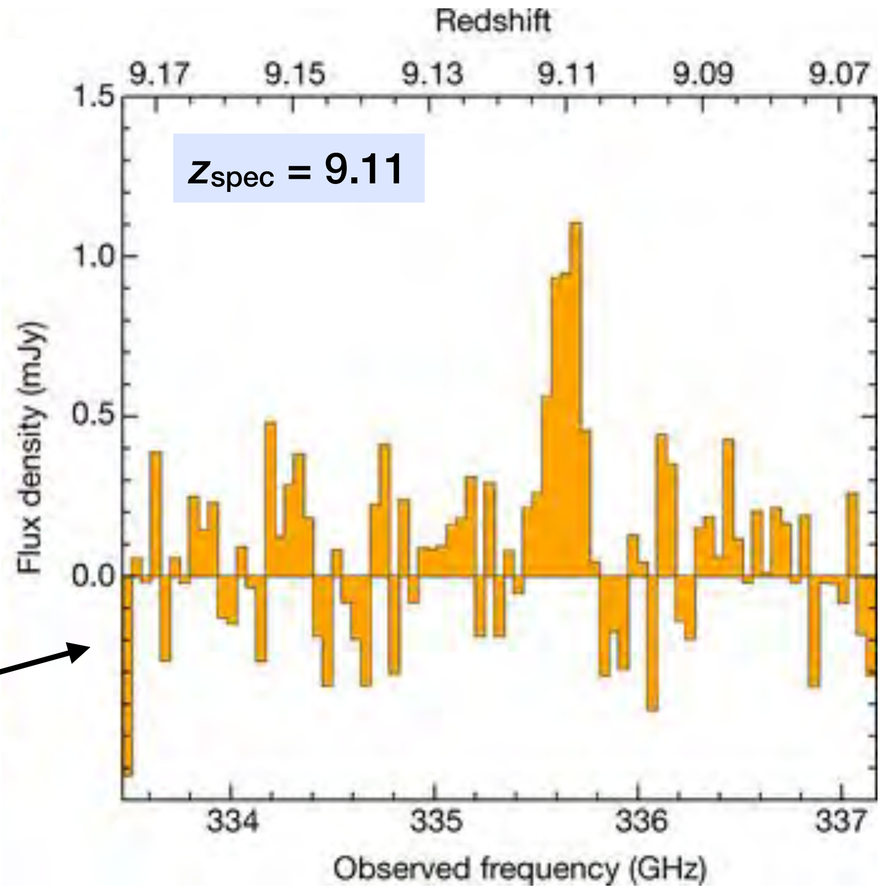




Hashimoto et al. (2018)

ALMA spectral scan search for Oxygen in MACS1194-JD





- ALMA 2030 upgrade will be at least 3 times faster plus any improvements from lower receiver noise

Hashimoto et al. (2018)

Summary

- Technical upgrades
  - Available bandwidth : factor of 2-4 increase
  - Correlated bandwidth : more than an order of magnitude increase with ~ 0.1 km / s resolution
  - Observing speed : 2.2-4.7x faster for spectral lines, 4.8x faster for continuum (Band 6 upgrade)

ALMA Memo 621

arXiv 2211.00195

- Scientific impact
  - Planet formation : comprehensive studies of physical, kinematic, and chemical structure of disks
  - Star formation : efficient surveys of all stages in the star formation process
  - Galaxy formation : probe the formation and evolution of galaxies across cosmic time

- Timeline
  - Band 1 : available starting in Cycle 10
  - Band 2 : expecting production to start in 2023
  - Band 6 : prototype under development
  - Correlator : 5 years for construction and commissioning
  - Digital Transmission System (DTS): East Asia project approved by ALMA Board in November 2022
  - Digitizers : European project approved by the ALMA Board
  - Upgrade of most other receiver bands are under study