The Wideband Sensitivity Upgrade (WSU)

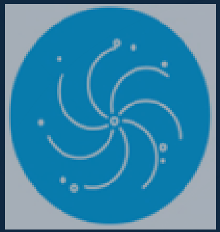
Şeyma Mercimek
UK ALMA Regional Centre Node
Jodrell Bank Centre for Astrophysics
The University of Manchester

SCIENCE CASE

Why the WSU matters

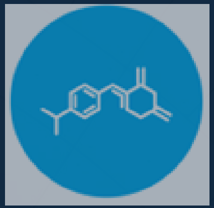
WSU is ALMA's main near-term development program. It is meant to keep the array competitive for the next generation of astronomy by increasing sensitivity, usable bandwidth (at least a factor 2), spectral capability, and upgrading correlator.

1 Galaxy evolution



Trace cosmic evolution of key elements from first galaxies (2>10) by detecting cooling lines (atomic (CII, [OIII]), molecular CO, dust continuum) at a rate of 1-2 galaxies/hour.

2 Chemical complexity



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

3 Planet formation

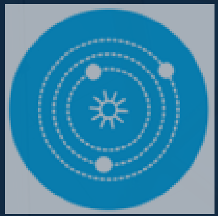


Image protoplanetary disks in nearby (150 pc) star formation regions to resolve the Earth forming zone (-1 au) in dust continuum at <1mm, enabling detection of tidal gaps & inner holes created by planets.

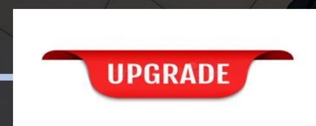
Bottom line: WSU is not only about faster observing - it expands the region of science that ALMA can access efficiently.

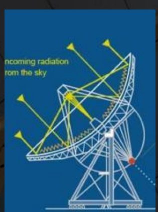
A full signal-chain upgrade

The program reaches from the front end to the archive. That is why users will see changes not only in raw capability, but also in observing setup, data handling, and support workflows.

Upgrade runs in parallel with operations

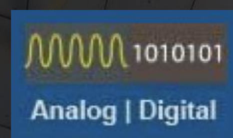
Expect temporary workflow changes until commissioning is complete.





1 Antennas

2 Receivers



3 Back end

4 Correlator (ATAC / TPGS)

5 Data processing

6 Archive

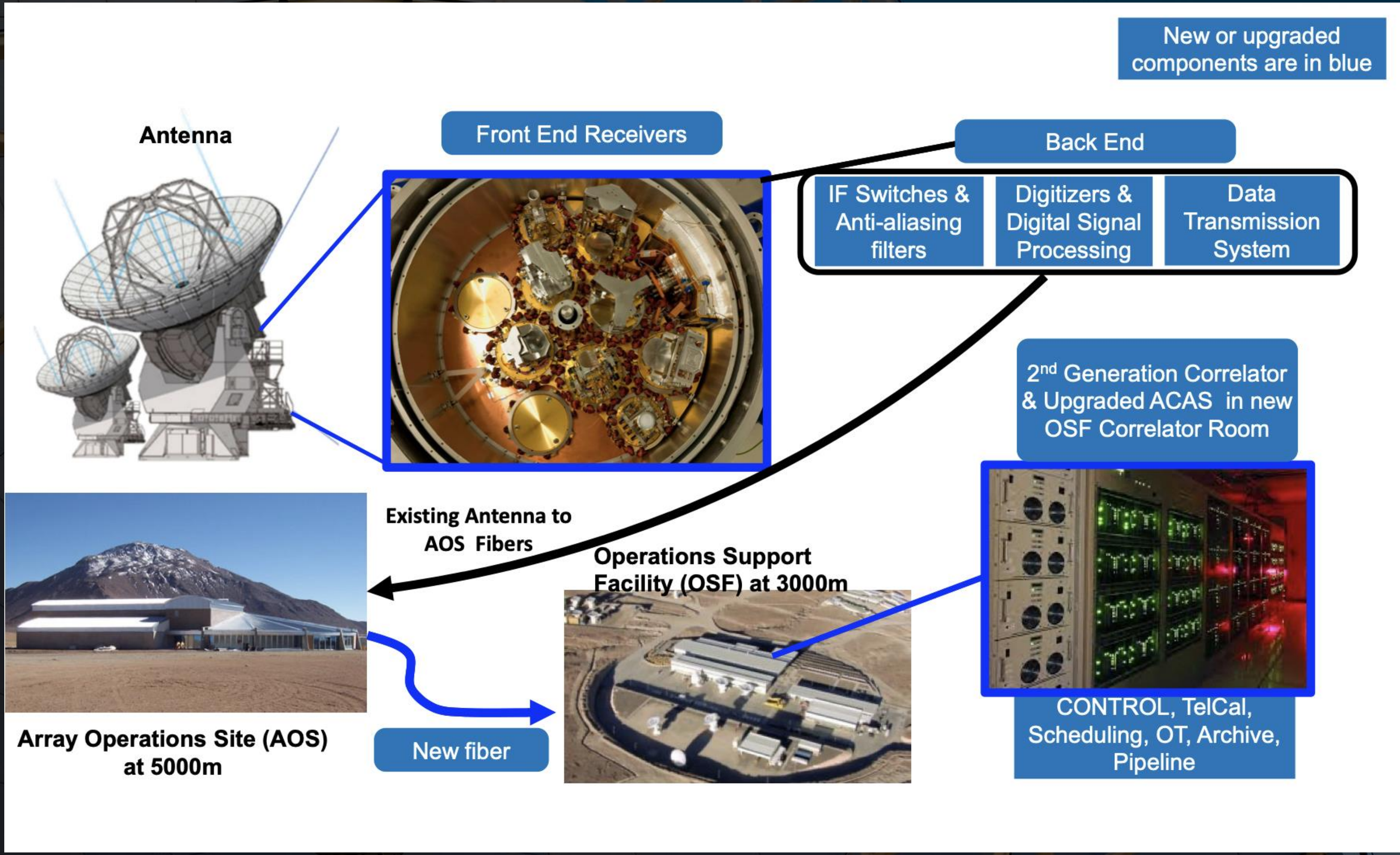
7 Astronomer

- Observation setup will not look exactly like today.
- Handling WSU data will differ from the current workflow.

- The ARC network will lead communication and training.

Capability gains and user-facing changes are linked because the whole chain is being modernized together.

A full signal-chain upgrade



RECEIVERS AND INFRASTRUCTURE

Hardware upgrades

Receivers

- Band 2 rolls out first; Bands 6, 7 and 8 are part of the WSU receiver path.
- Wideband design reaches up to 32 GHz per polarization.
- Noise performance improves - about 2x initially, with 4x as the long-term goal.

B2 first
initial rollout

32 GHz
per polarization

2x to 4x
noise-performance target

Supporting systems

- A new digitizer adds another sensitivity boost (~1.23x).
- Data transmission scales from about 120 Gb/s to 1.6 Tb/s over distances up to 80 km.
- A new fiber-optic system links AOS and OSF for the expanded data flow.

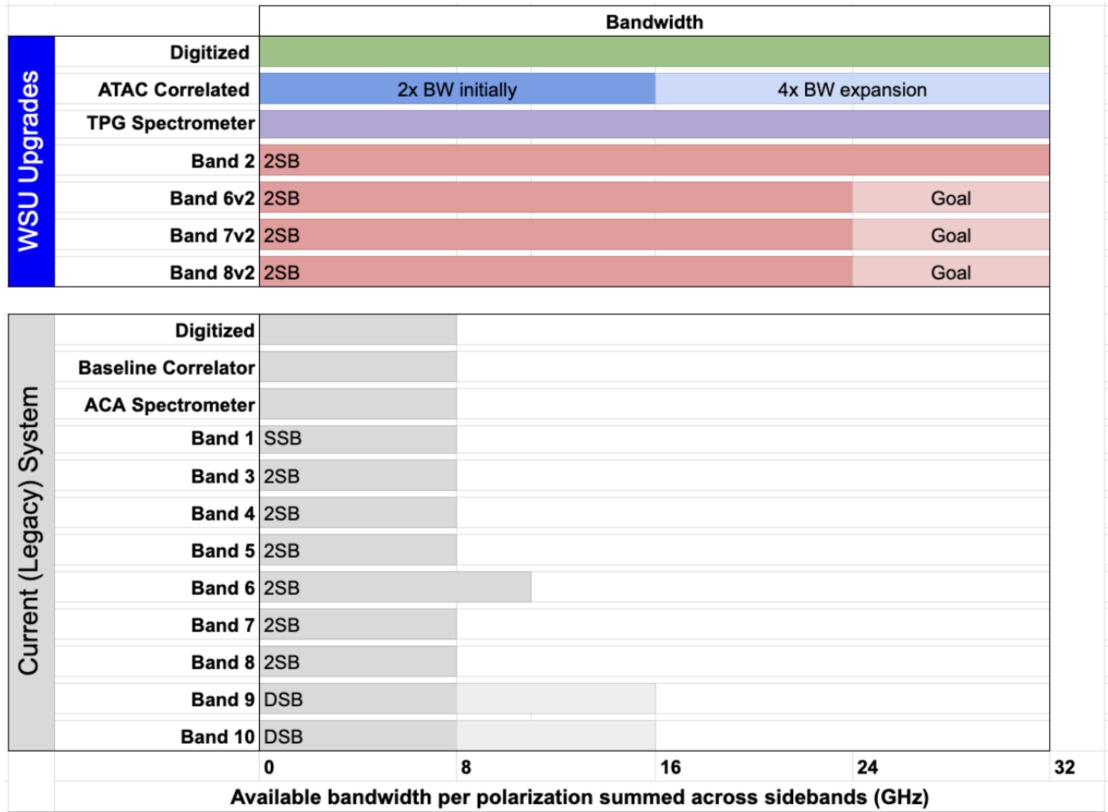
Infrastructure takeaway: more bandwidth at the front end only works if digitization and transport scale with it.

WHAT THE UPGRADE CHANGES IN PRACTICE

Scientific gains

Bandwidth

- Increase of the available bandwidth by a factor 2



Notes:

1. Legacy bands will be usable in the WSU System with their current IF bandwidth.

2. In the Legacy System DSB receivers are processed using 90 degree Walsh switching to recover the image sideband.

3. The maximum usable bandwidth in the Legacy System is 7.5 GHz, and is only available at relatively coarse minimum channel width 488.28 kHz (with a spectral resolution 2x poorer due to the need for Hanning Smoothing online).

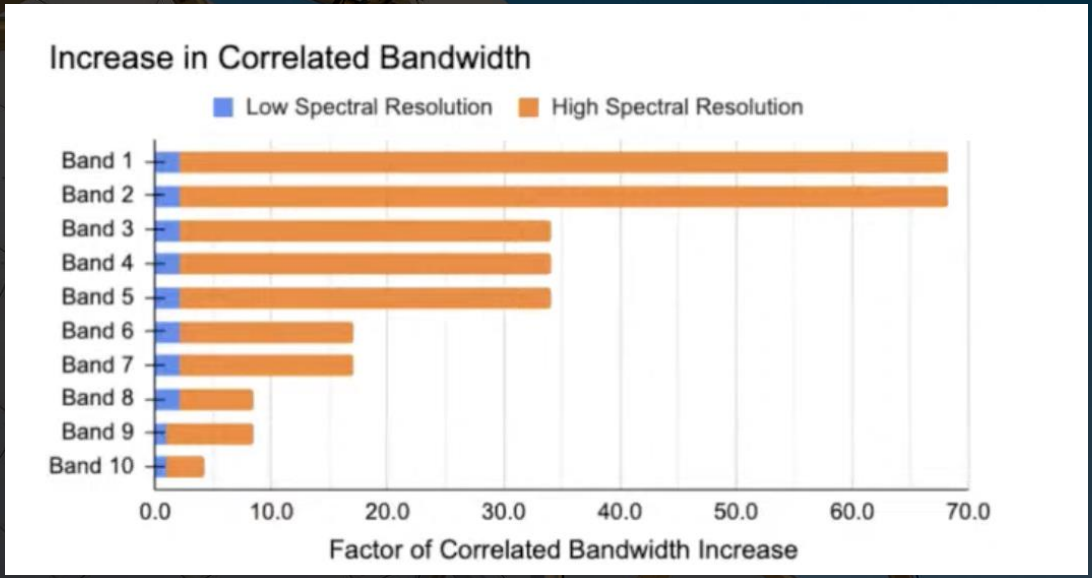
4. The full ATAC and TPGS bandwidth is usable for channels as fine as 13.5 kHz, a factor of 72 better in spectral resolution.

WHAT THE UPGRADE CHANGES IN PRACTICE

Scientific gains

Bandwidth

- Increase of the available bandwidth by a factor 2
- Increase of correlated bandwidth by factors 4 to 70



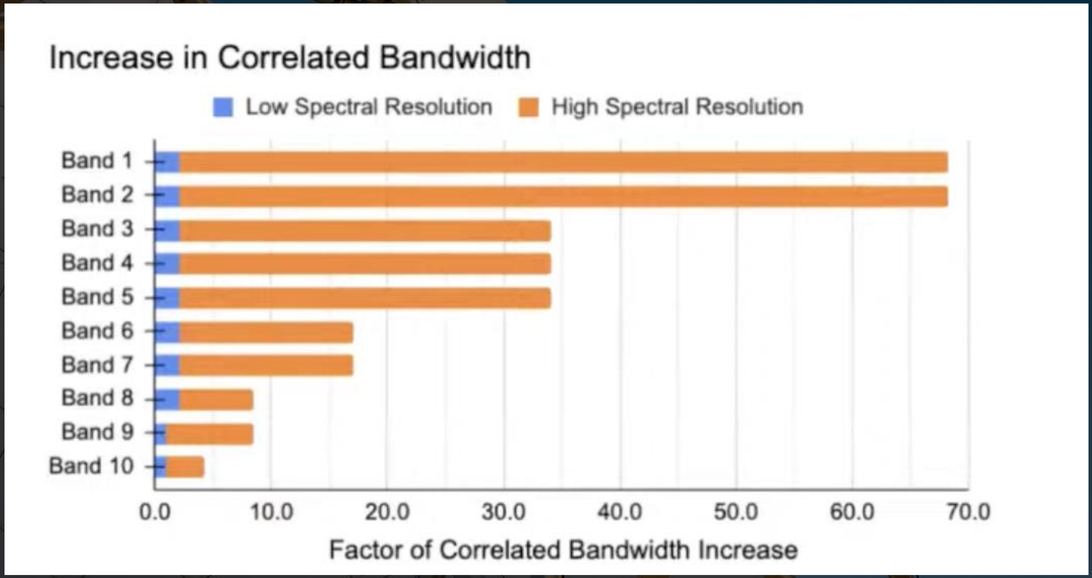
Current ALMA: need to choose narrow bandwidth for high spectral resolution
ALMA 2030: 0.1-0.2 km/s resolution across 16 GHz BW

WHAT THE UPGRADE CHANGES IN PRACTICE

Scientific gains

Bandwidth

- Increase of the available bandwidth by a factor 2
- Increase of correlated bandwidth by factors 4 to 70
- Increase in spectral scan speed



Continuum imaging speed increase by x3 for x2 correlated bandwidth
Spectral line imaging speed increase by ~x2-x3
Spectral scan speed increase by x2-x54

WHAT THE UPGRADE CHANGES
IN PRACTICE

Scientific gains

Improved sensitivity

- Increase in the digital efficiency of the ALMA system: Increasing the number of correlation bits will improve sensitivity by x1.2
- Lower receiver noise temperatures: advances in receiver technology will allow the noise temperature of the future Band 3-8 receivers to be further reduced by ~20-30% (up to 50% at the edges for some of the receivers)
- Upgrading Bands 9 and 10 to sideband separation receivers will improve the spectral line sensitivity by ~70-80%
- Increased continuum bandwidth: sensitivity theoretically improved initially by a factor of 1.46 for 2x correlated bandwidth and eventually 2.06x after the final 4x correlated bandwidth goal is reached

PROCESSING BACKBONE

Correlator and software

New processing systems

ATAC Advanced Technology ALMA Correlator

TPGS Total Power GPU Spectrometer

32 GHz/pol	processing scale per polarization
13.5 kHz	native resolution; zoom mode to ~1.7 kHz
2.4 M channels	about 155x more native channels

Why it matters

32 GHz
correlated bandwidth scale

13.5 kHz
native channel width

1.7 kHz
zoom-mode resolution

- WSU removes the old trade-off between high spectral resolution and wide correlated bandwidth.
- The software stack also changes: data model, control software, and ALMA processing.

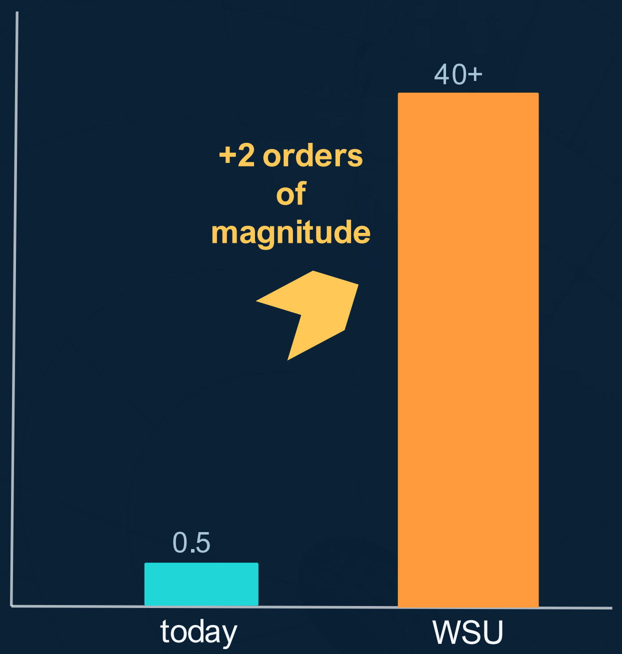
Key message: more of the spectrum can be observed at useful resolution in a single setup.

ARCHIVE AND COMPUTING

Data volume becomes a major challenge

Illustrative daily data-volume jump

~0.5 TB/day today → >40 TB/day in the WSU era



Project-scale implications

- Typical visibility-data increase in the source deck: about 4.6x.
- Some correlator configurations can reach roughly 180x larger datasets.
- A few projects may exceed 4 PB, larger than the current archive by about a factor of two.

This is why archive, science-platform, and computing upgrades are part of the WSU story.

USER-FACING IMPACT

What changes for observers?

Because the upgrade is commissioned during operations, users should expect gradual changes in tools, setup choices, and support material rather than a single switch-over moment.

Observation setup

Updated observing configurations and reduced execution times as capabilities expand.

WSU data handling

New data model, new processing software, and different handling compared with the current workflow.

Training and support

The ARC network is expected to lead timely communication, documentation, and user training.

The telescope does not shut down for a long maintenance closure - the transition is staged, so staying informed matters.

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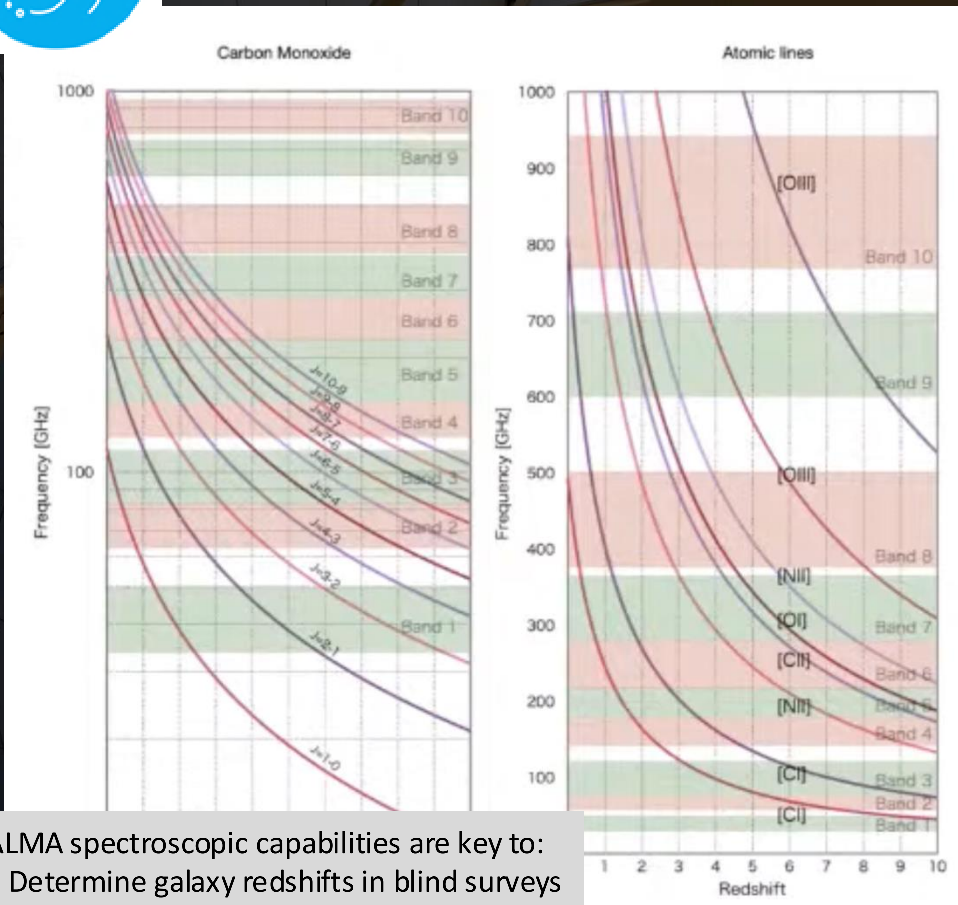
Why the WSU matters

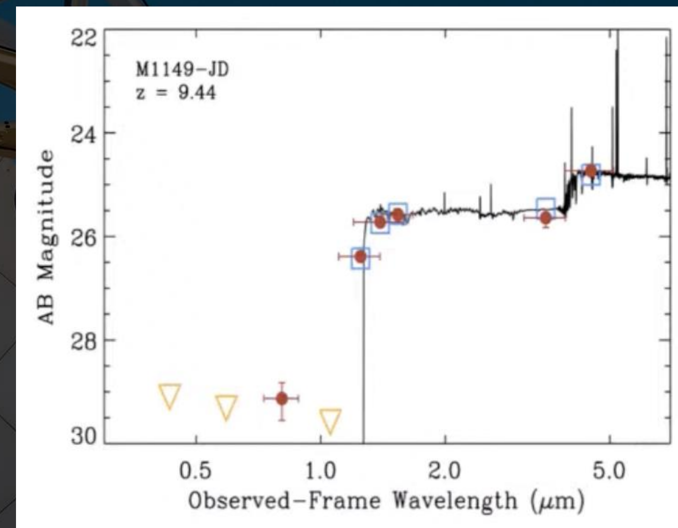
ALMA can observe CO and atomic lines in galaxies



ALMA spectroscopic capabilities are key to:
- Determine galaxy redshifts in blind surveys
- Confirm and/or accurately determine redshifts photometrically discovered

ALMA spectral scan search for Oxygen in MACS1149-JD

Candidate galaxy at photometric redshift of z=9.4



Candidate galaxy at photometric redshift of z=9.4

Spectroscopy needed to determine redshift

- Large uncertainties
- Containants at lower redshift

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

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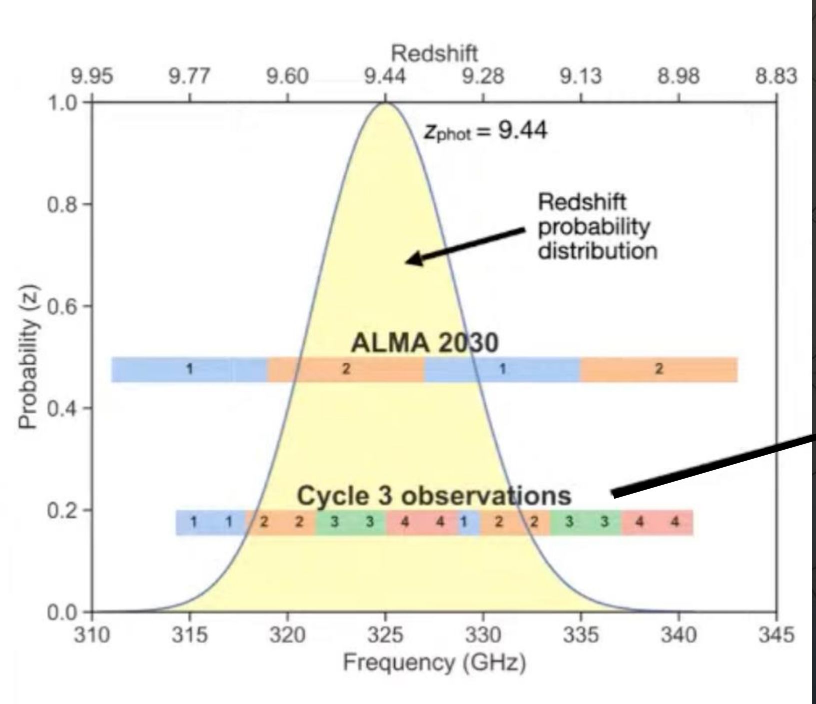
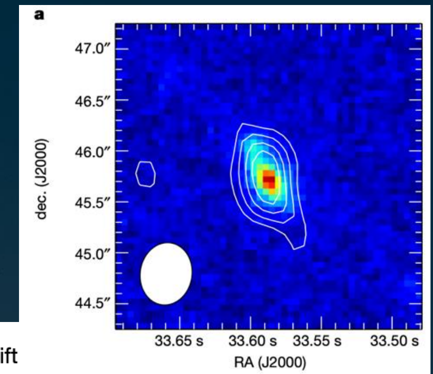
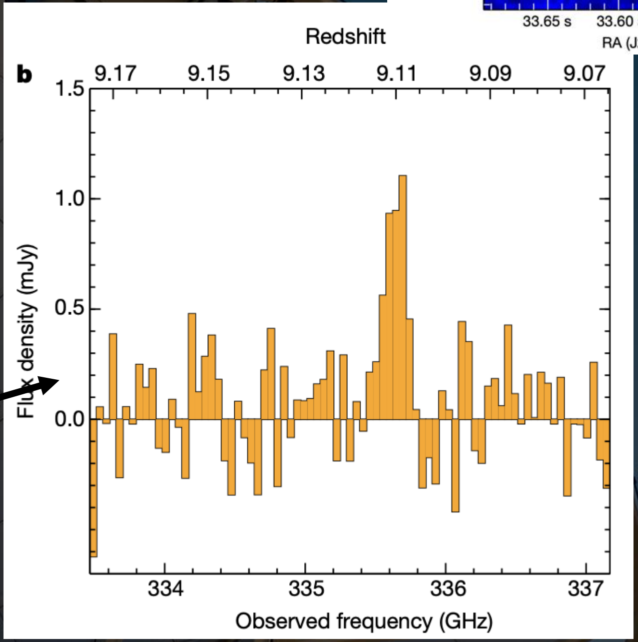
Why the WSU matters

ALMA spectral scan search for Oxygen in MACS1149-JD



[O III]





Hashimoto et al. (2018)

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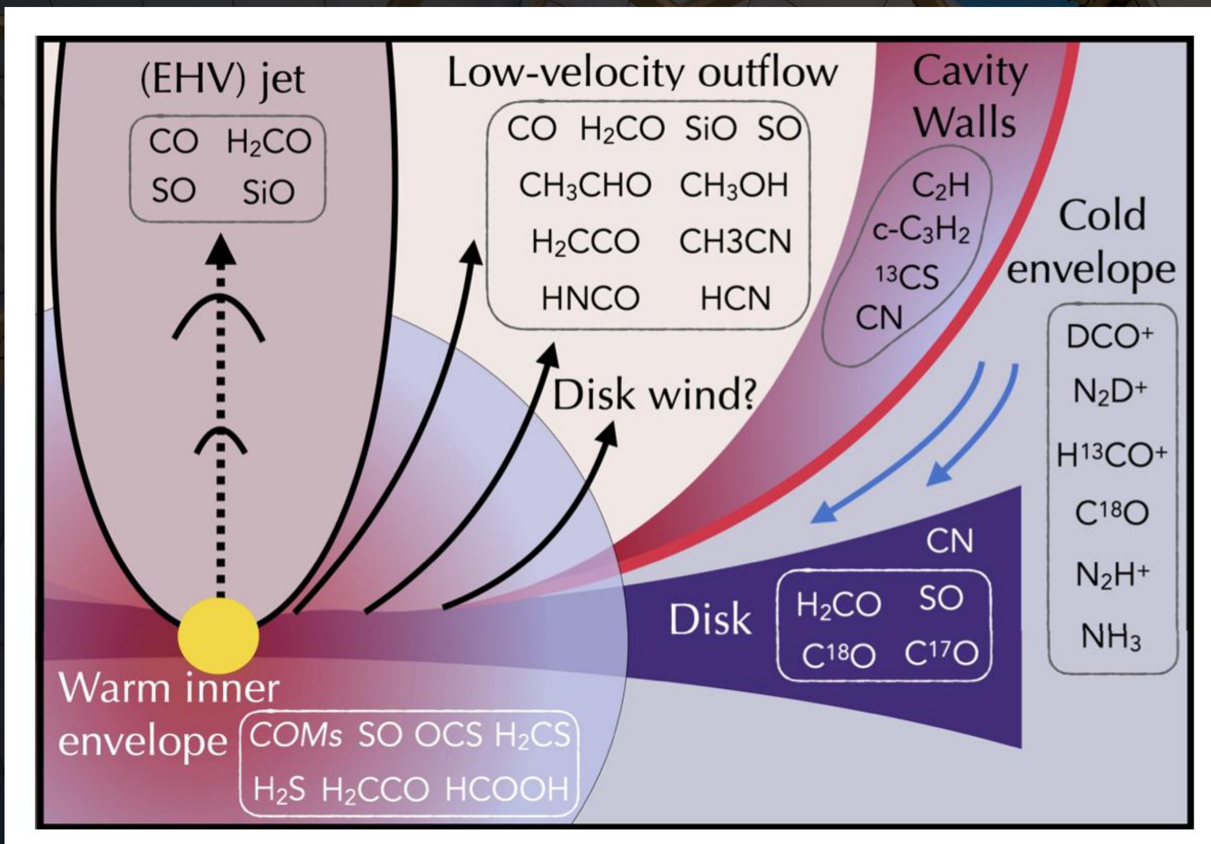
Why the WSU matters

Young stellar objects



Tychoniec et al. (2021)

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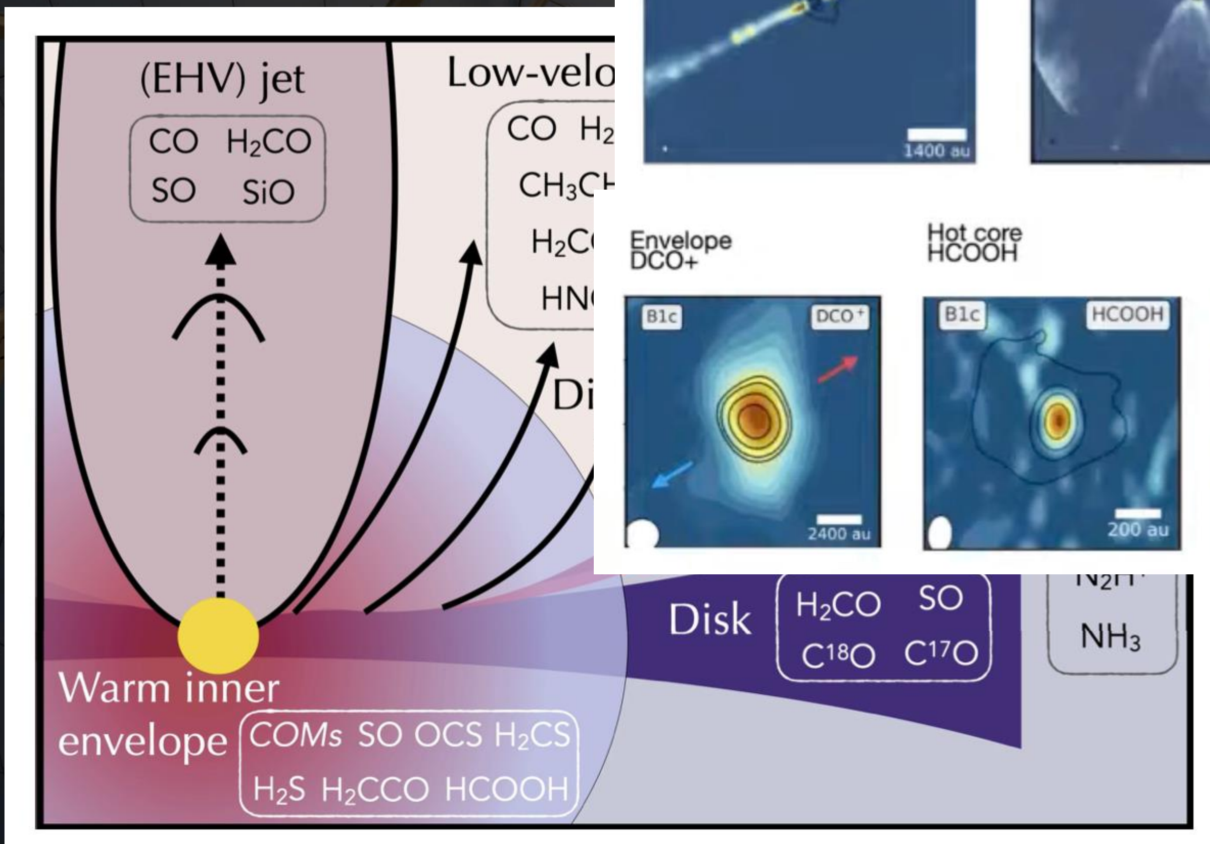
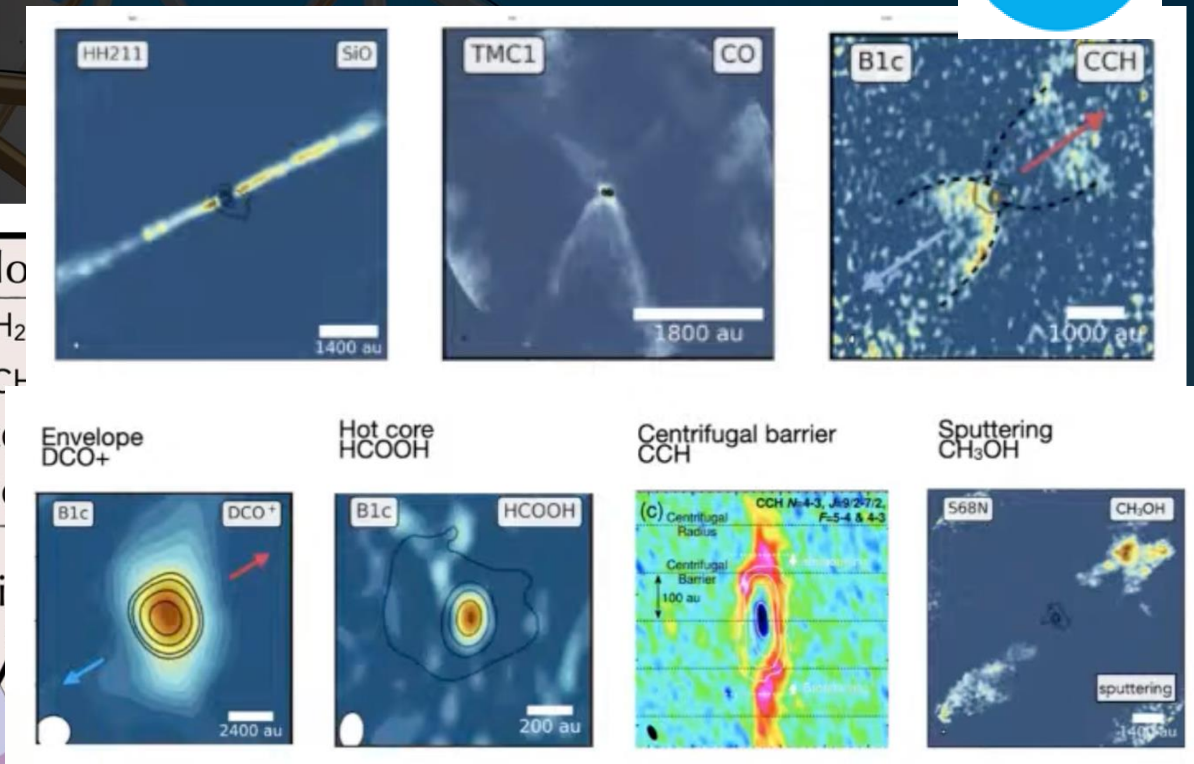
Why the WSU matters

Young stellar objects





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

Tychoniec et al. (2021)

This story is the result of independent efforts carried out over the years.

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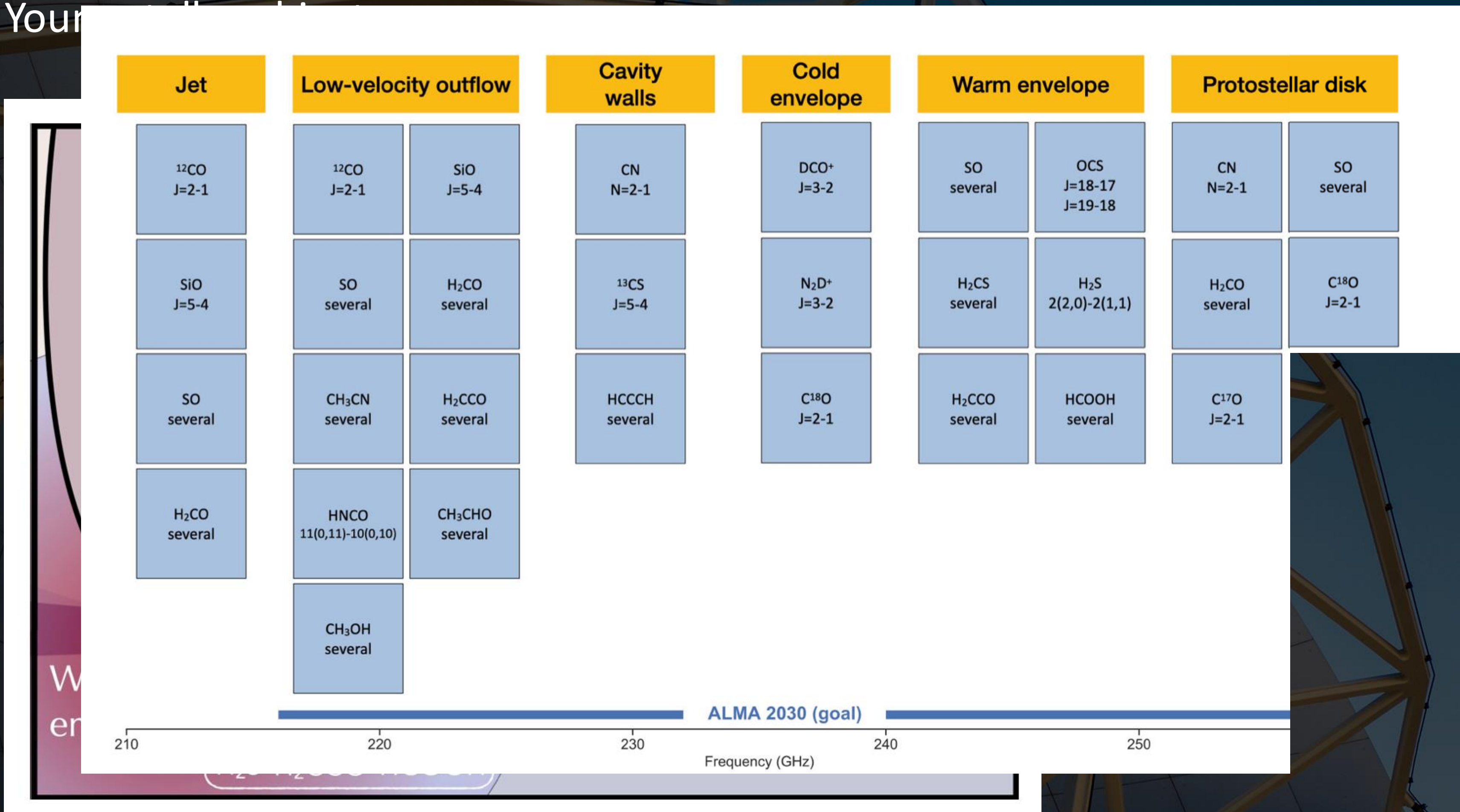
Why the WSU matters

WSU and molecular probes of star formation

Your



Tychoniec et al. (2021)

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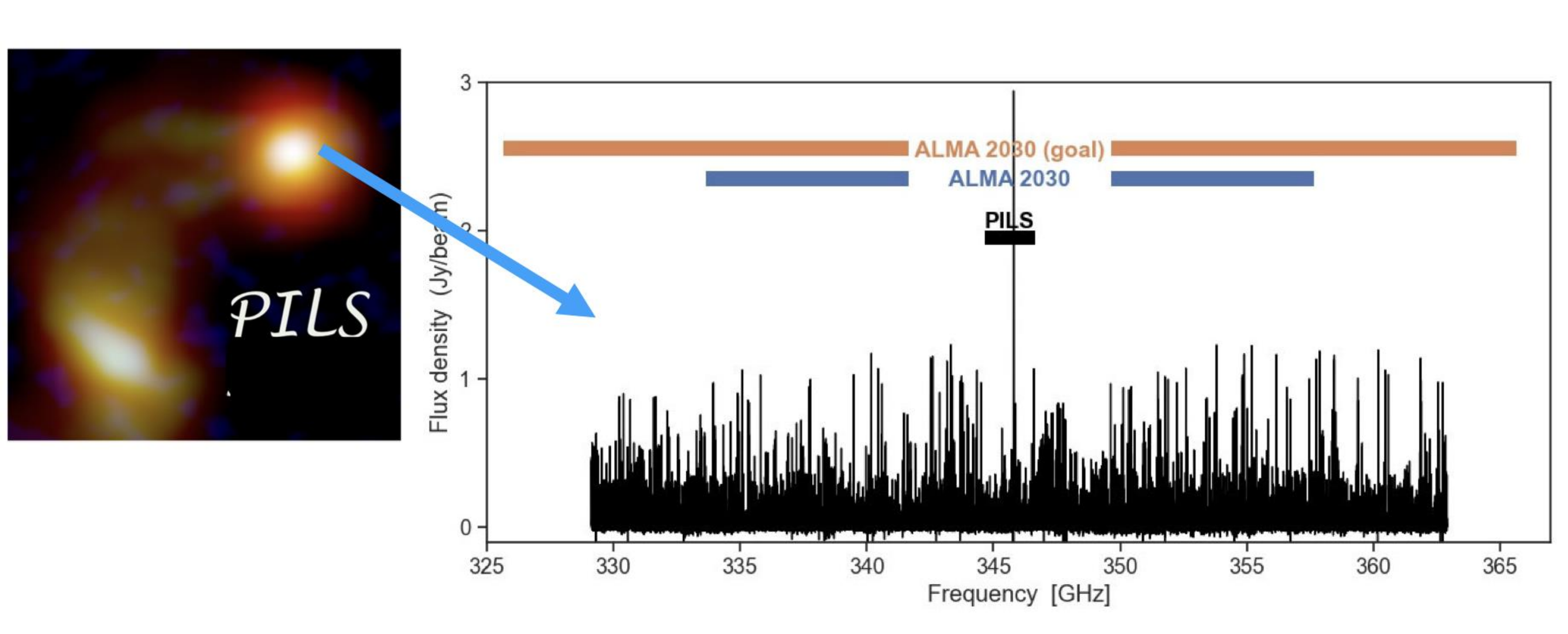
Why the WSU matters

WSU and efficient spectral scans of protostars e.g. PILS



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

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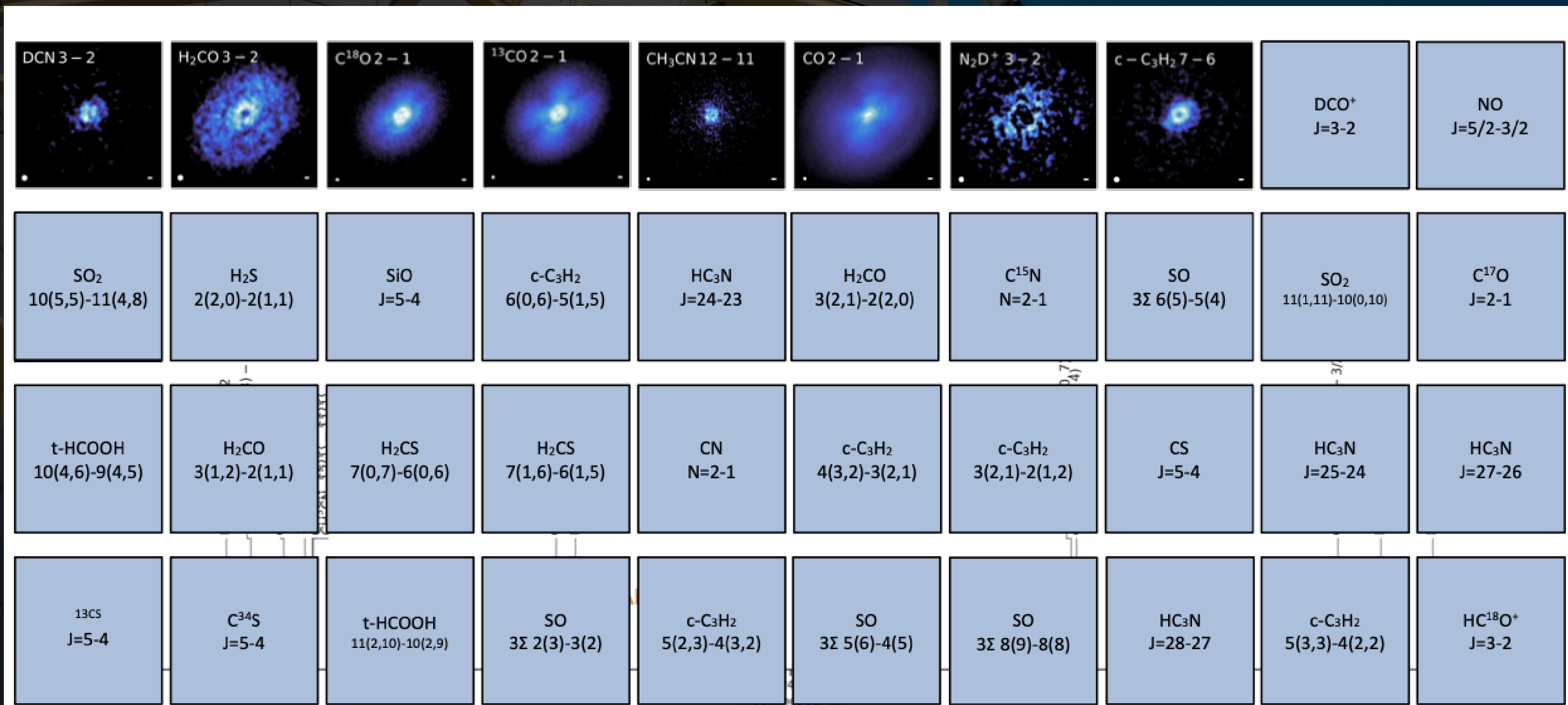
Why the WSU matters

Protoplanetary disks, e.g., MAPS



Öberg et al. (2021)

TIMELINE

Roadmap to 2030

2026-2027

- Band 2 available for science
- New web-based OT

2028

- Construction / deployment work
- Digitizers completed

2029

- ATAC completed
- WSU commissioning
- New control software

2030

- Cycle 1 WSU capabilities
- New data-management software

By 2030 the source presentation expects Cycle 1 WSU capabilities: B2, 6, and 8 with 2x bandwidth, ATAC and TPGS, at least 36 retrofitted antennas, and enhanced spectral capability (up to 150,000 channels).

Thank you