Intro to the ALMA Wideband Sensitivity Upgrade (WSU)

Jennifer Donovan Meyer (NRAO/NA ALMA Development Team)

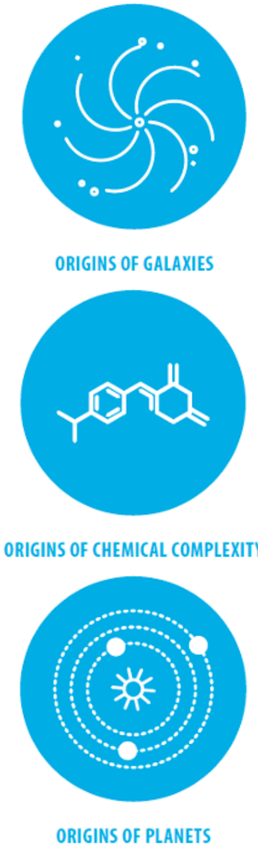
NSF AUI National Radio Astronomy Observatory NRAO

__WSU Special Session__ "New perspectives on protoplanetary disks in the era of JWST and the ALMA WSU" (AAS 245: January 14, 2025)

ALMA 2030 Development Priorities

Based on ALMA Development Roadmap (Carpenter et al. 2018, arXiv 1902.02856)

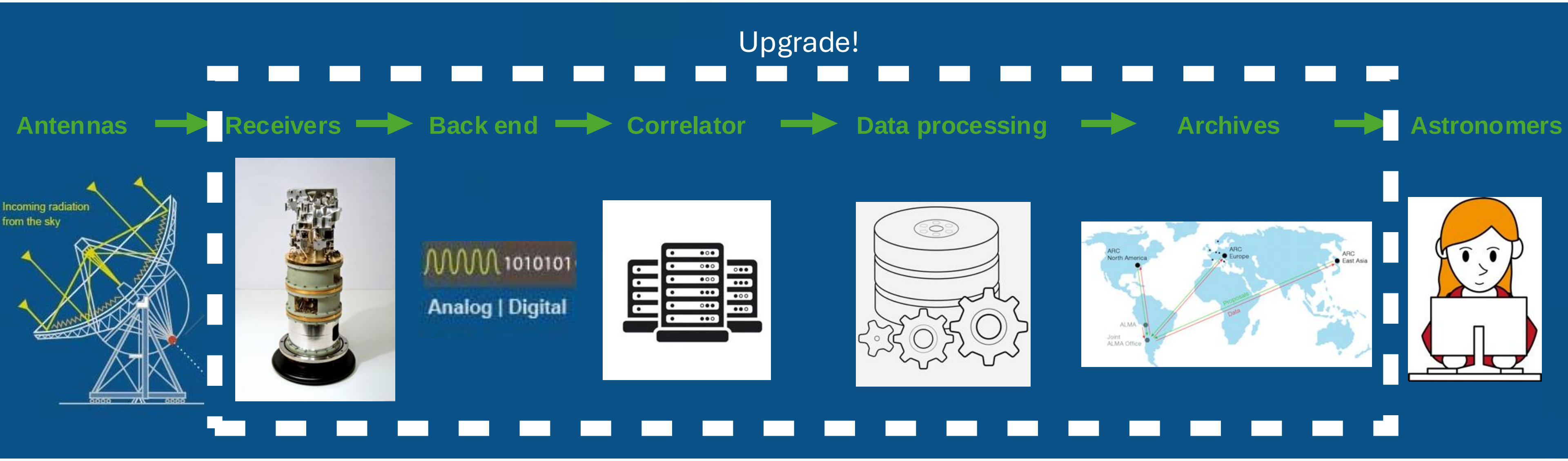
- **Receiver bandwidth** — Expand bandwidth by at least a factor of two — TOP PRIORITY
- **Science archive** — Optimize archive science
- **Angular resolution** — Extend baselines by a factor of 2-3
- **Collecting area** — Develop science cases for increasing the number of 12-m antennas
- **Widefield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



Progress in the three fundamental science drivers require **increased bandwidth and sensitivity** to keep ALMA at forefront of scientific discovery

Wideband Sensitivity Upgrade (WSU): Top Priority of the ALMA 2030 Roadmap

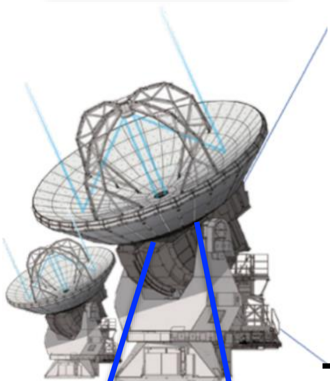
- Upgrade of the bandwidth and throughput of the ALMA system
  - upgraded receivers with increased bandwidth and improved receiver temperatures (and revamp of entire signal chain)
  - more powerful correlator
  - increased data reduction capacity



ALMA Wideband Sensitivity Upgrade

New/upgraded components per WSU shown in blue.

Front End



Antenna

Receivers

Back End

IF Switches & Anti-aliasing filters

Digitizers & Digital Signal Processing

Digital Transmission System

Array Operations Building at 5,000m

New Fiber

Operations Support Facility at 3,000m

2nd Generation Correlator in new OSF Correlator Room

CONTROL, TelCal, Scheduling, OT, Archive, Pipeline

Development Roadmap Priority Goal: Expand system bandwidth by at least 2x with improved sensitivity

WSU Status (December 2024)

Completed Preliminary Design Reviews
ATAC Correlator
OSF Correlator Room
Data Transmission System
Wideband IF Processor (Digitizer)

Completed Conceptual Design Reviews
Total Power GPU Spectrometer

Receivers in production
Band 2 (67-116 GHz)

Receivers in development
Band 6v2 (209-281 GHz);
Band 8 (385-500 GHz)

Current WSU Hardware Status

- First wideband receivers in construction or prototypes in development
  - Band 2 (IF=2-18 GHz), Band 6v2 (IF=4-18 GHz), Band 8v2 (IF=4-18 GHz)
  - Remaining bands are under study for future upgrades
- Digital Signal Chain
  - Digitizer prototype in development: 4x current bandwidth, 6% sensitivity improvement
  - DTS prototype in development with 10x higher capacity
- Advanced Technology ALMA Correlator (ATAC)
  - Prototype testing underway with initial 4x BW ingest and 2x BW correlation
  - 1.2 million spectral channels (and flexible online averaging) available
  - Flexible subarrays to process 12-m and 7-m arrays concurrently
  - 6-bit correlation for 13% improvement in sensitivity compared to BLC
- Total Power GPU Spectrometer
- OSF Correlator Room

Proposed Stages of WSU Implementation *

WSU program under planning and review; meets 2030 Development Roadmap requirements

Initial WSU System (IWS)

- Prepared for the first Cycle of WSU Scientific Observations offered to the community **(target Cycle 16, Oct 2029)**
- At least 36 antennas connected to WSU Signal Chain and ATAC, OCRO, Band 2, AOS to OSF Optical Fibers, necessary updates to software and infrastructure

Minimum WSU System (MWS)

- IWS, Band 6v2, Band 8v2, TPGS, necessary updates to software and infrastructure

* Subject to review outcomes/ALMA Board approval

Proposed Stages of WSU Implementation *

WSU program under planning and review; meets 2030 Development Roadmap requirements

Initial WSU System (IWS)

- Prepared for the first Cycle of WSU Scientific Observations offered to the community **(target Cycle 16, Oct 2029)**
- At least 36 antennas connected to WSU Signal Chain and ATAC, OCRO, Band 2, AOS to OSF Optical Fibers, necessary updates to software and infrastructure

Minimum WSU System (MWS)

- IWS, Band 6v2, Band 8v2, TPGS, necessary updates to software and infrastructure

---

Follow-on WSU initiatives to meet full vision of the 2030 Development Roadmap; post-2030, subject to funding availability

Goal WSU System (GWS)

- MWS, Band 7v2, ATAC upgrade to process 4x bandwidth, necessary updates to software and infrastructure

Full WSU System (FWS)

- Allows the implementation of additional enhancements to complete the WSU System through the ALMA Development Program
- Band 1v2, Band 4+5, Band 9v2, Band10v2, necessary updates to software and infrastructure

* Subject to review outcomes/ALMA Board approval

WSU 2025 Major Program Reviews

July 2025

- System PDR

  Review scope

  - Requirements, specifications, and interfaces
  - System Design Description (HW, SW, SciOps)
  - Design compliance matrix (by design)
  - Assembly, Integration, Verification, and Commissioning (AIVC) plans and strategy
  - Transition to WSU Operations plans, including Array Configuration Plan
  - Project Management Plan (WBS, schedule, organization, risk management)
  - Product Assurance Plan, Safety Plan

September 2025

- Cost Review

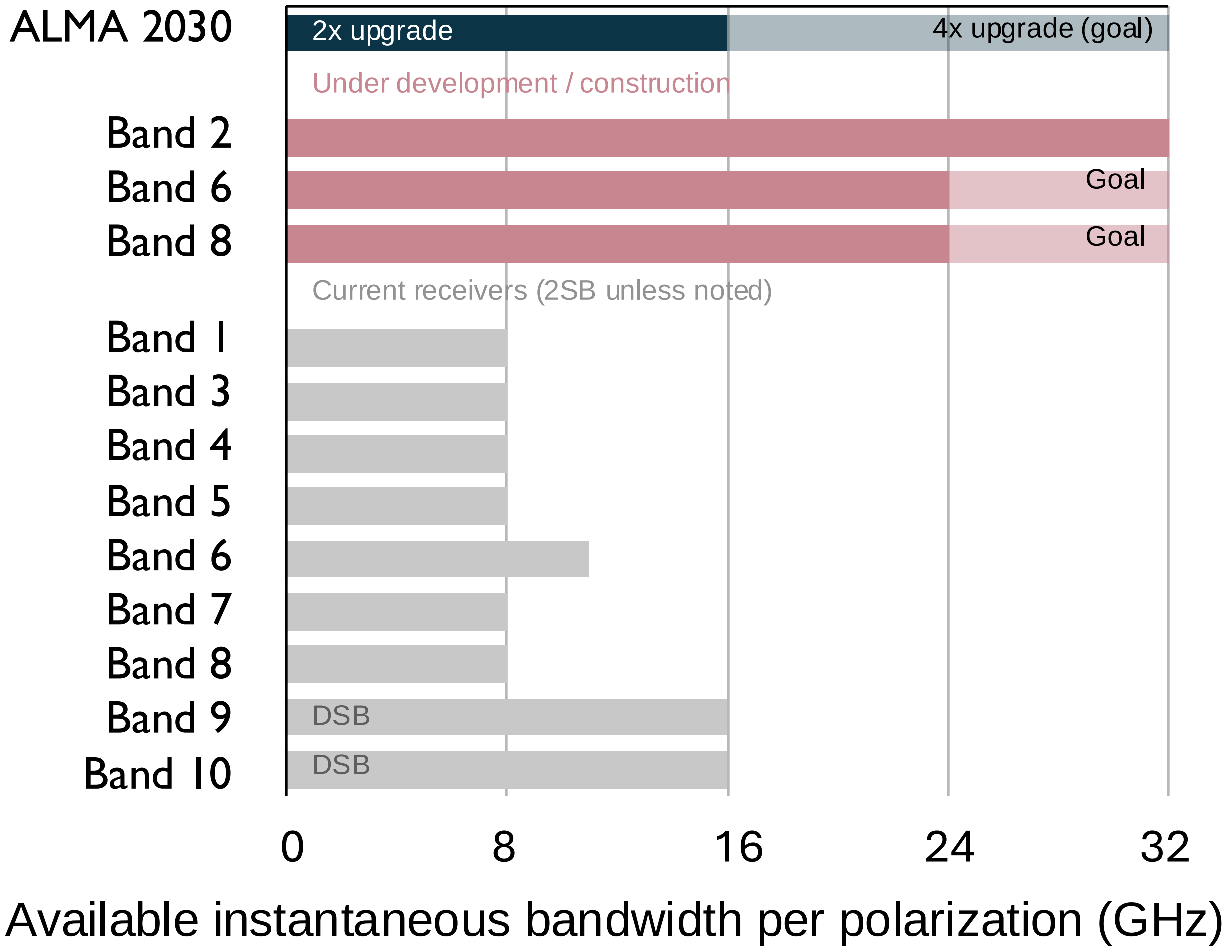
  Review scope

  - Cost estimation methodology and standards
  - Cost consistent with the WSU Work Breakdown Structure
  - Cost estimate maturity

WSU Receiver and Correlated Bandwidth

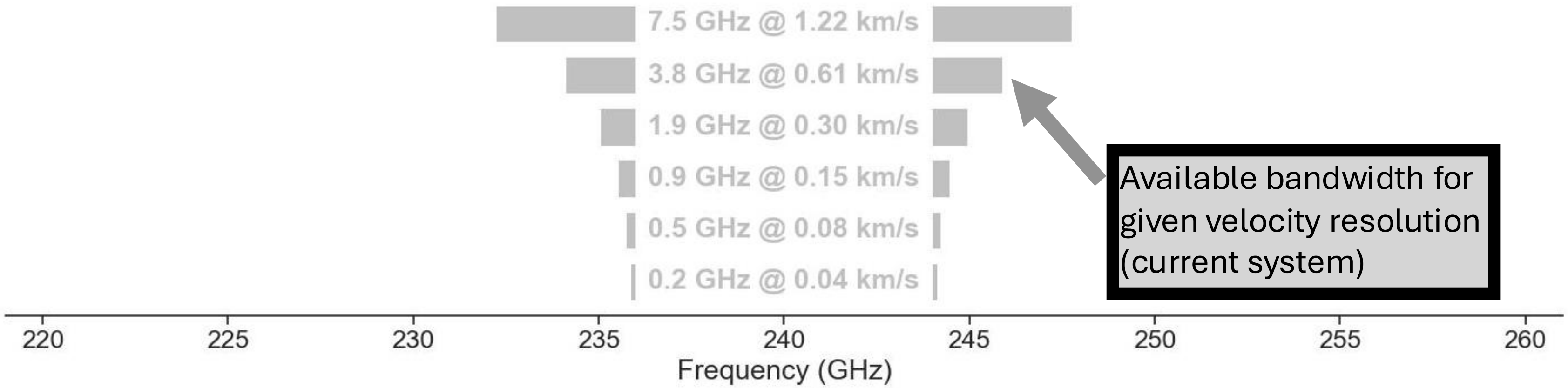
- **Receiver bandwidth**
- Correlated bandwidth
- (Observing speed)

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



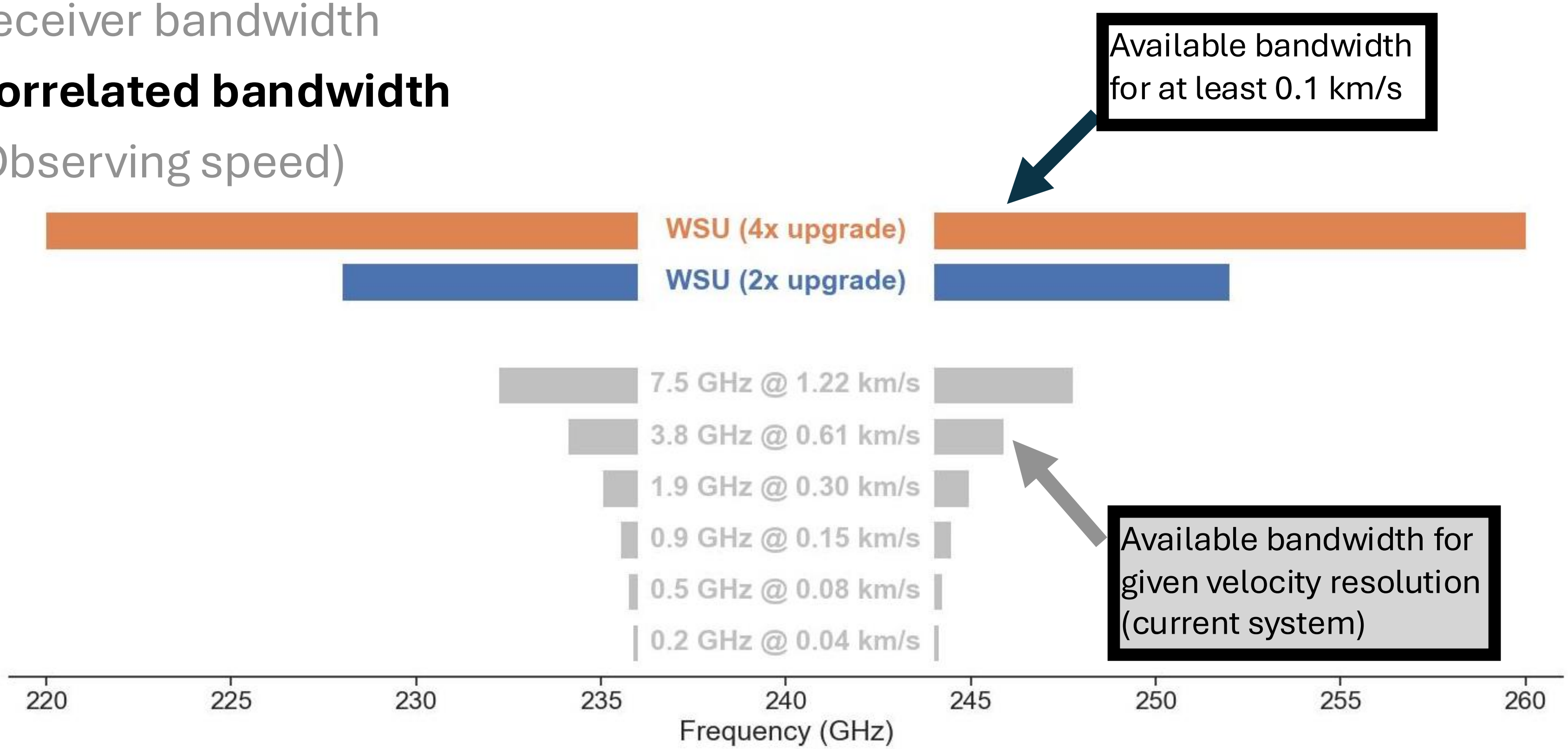
WSU Receiver and Correlated Bandwidth

- Receiver bandwidth
- **Correlated bandwidth**
- (Observing speed)

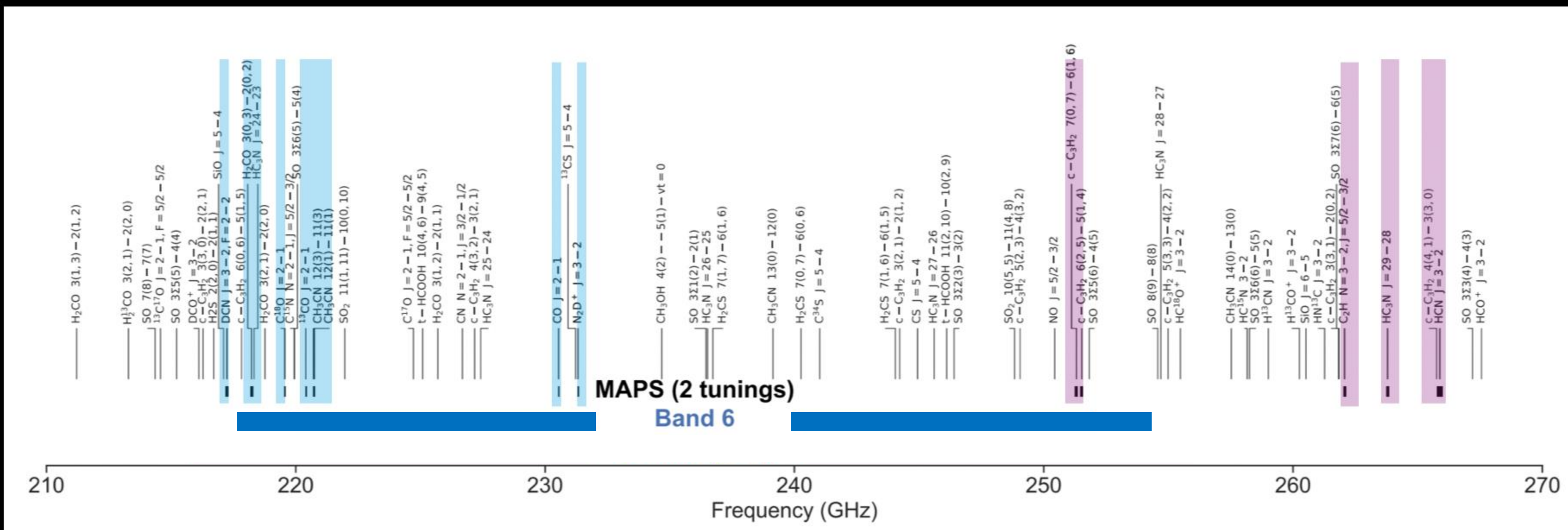


WSU Receiver and Correlated Bandwidth

- Receiver bandwidth
- **Correlated bandwidth**
- (Observing speed)



Disk chemical inventories are biased due to bandwidth limitations



Carpenter+ 2022

A huge increase in "Spectral Grasp" => science from a single observation/tuning

The ALMA WSU will benefit <u>all</u> observations

Enhanced Capability	WSU Improvement for 2x BW Correlation (16 GHz per pol)	Future Improvement with 4x BW
Receiver bandwidth increase	2-4x in instantaneous bandwidth (as receiver bands are upgraded) • **Fewer tunings to cover a receiver band**	…
Correlated Bandwidth increase	2x for low spectral resolution Up to 4x (Band 10) and 68x (Band 1) for 0.1 km/s spectral resolution • **No more trade-offs between resolution and bandwidth**	Up to Additional 2x
Spectral scan <u>speed</u> increase	2x for low spectral resolution Up to 4x (Band 10) and 64x (Band 1) for 0.1 km/s spectral resolution • **Improved spectral scan speed**	Up to Additional 2x
Spectral line Imaging <u>speed</u>	~2.2x from improved receiver noise temperatures and digital efficiency* • **Improved line imaging speed**	…
Continuum Imaging <u>speed</u>	≥ 4.8x from correlated bandwidth increase, improved receiver noise temperatures and digital efficiency* • **Improved continuum imaging speed**	Up to Additional 2x
Ultra-high spectral resolution	• **Access to 0.01 km/s at <u>all</u> ALMA frequencies for the first time**	…

* Increased bit-depth in digitization and correlation stages will yield ~20% improvement in sensitivity, *even for receiver bands that have not yet been upgraded*

➢ Equivalent to adding 1000 additional hours of observing time per cycle

Want to learn more?

- At AAS:
  - WSU Community Chats at NRAO Exhibit in the Exhibit Hall
    - Tuesday and Wednesday, 1.30 - 2pm
  - Poster Session 206 (flash slides next!)

- WSU Details in ALMA White Paper
  - ALMA Memo 621 (arXiv:2211.00195)

- Keep up with us at
  - WSU page
    - go.nrao.edu/ALMA-WSU
  - ALMA Observatory WSU project page
    - almaobservatory.org/en/scientists/alma-2030-wsu

www.nrao.edu
science.nrao.edu
public.nrao.edu

The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

Poster 206.02

Expanding possibilities of protoplanetary disk characterization with HITRAN2024

Robert J. Hargreaves, Iouli E. Gordon, Vladimir Makhnev, Thibault Bertin, Laurence S. Rothman

CENTER FOR ASTROPHYSICS | HARVARD & SMITHSONIAN

Numerous molecules detected in protoplanetary disks with JWST

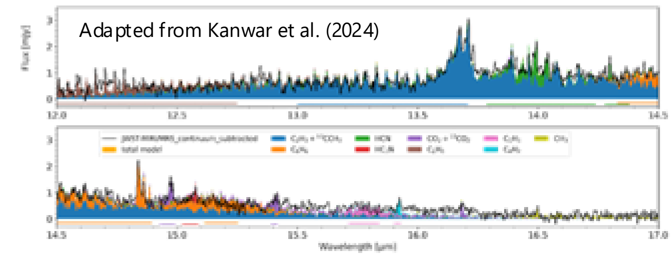


Table 1 - Line-by-line portion of HITRAN2024

H_2O (7)	**NO (3)**	**HCl (4)**	N_2 (2)	COF_2 (2)	NO^+ (1)	**C_4H_2 (1)**	**SO (1)**	**CH_3 (1)**
CO_2 (12)	SO_2 (4)	HBr (4)	**HCN (3)**	**SF_6 (1)**	HOBr (2)	**HC_3N (1)**	**CH_3F (2)**	**S_2 (1)**
O_3 (5)	**NO_2 (3)**	HI (2)	CH_3Cl (2)	**H_2S (3)**	**C_2H_4 (2)**	**H_2 (2)**	GeH_4 (4)	**COFCl (2)**
N_2O (5)	**NH_3 (3)**	ClO (2)	**H_2O_2 (1)**	**HCOOH (2)**	**CH_3OH (1)**	**CS (4)**	**CS_2 (4)**	**HONO (1)**
CO (6+3*)	**HNO_3 (2)**	**OCS (6)**	**C_2H_2 (3)**	HO_2 (1)	CH_3Br (2)	SO_3 (1)	**CH_3I (1)**	**$ClNO_2$ (2)**
CH_4 (4)	**OH (3)**	**H_2CO (3)**	**C_2H_6 (3)**	O (1)	**CH_3CN (1)**	C_2N_2 (1)	NF_3 (1)	
O_2 (3)	HF (2)	**HOCl (2)**	**PH_3 (1)**	$ClONO_2$ (2)	CF_4 (1)	$COCl_2$ (2)	**H_3^+ (1)**	

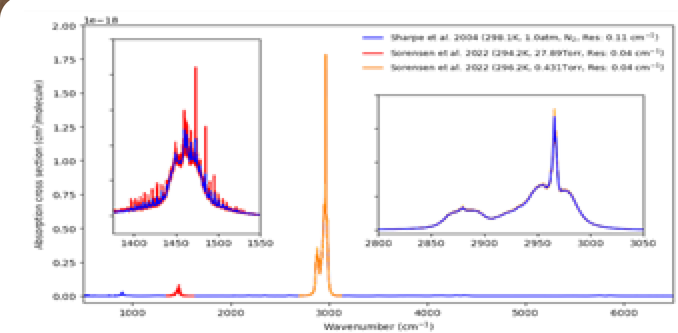
Molecules that will be updated/extended with respect to HITRAN2020 are in **bold text**

New molecules or additional isotopologues for existing molecules are highlighted in red

Line-by-line lists expanding for **HITRAN2024** to **61** molecules

www.hitran.org

Many absorption cross-sections to be added for **HITRAN2024**, in addition to **+300** already included (inc. multiple hydrocarbons)



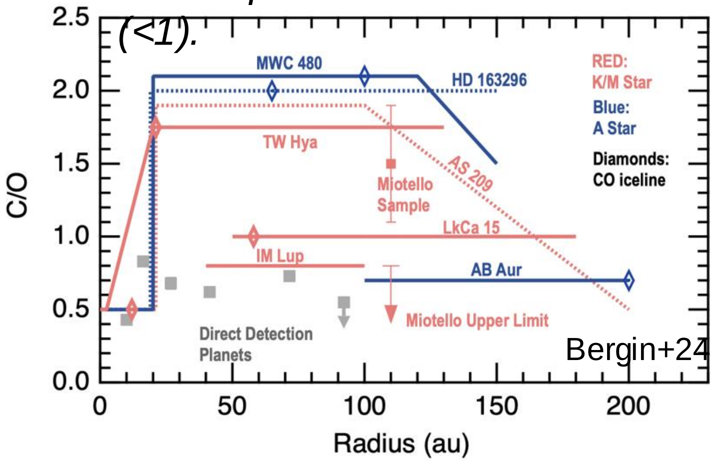
Early Results from the Disk-Exoplanet C/Onnection (DECO) Large Program

Charles J. Law, Ilse Cleeves, & the DECO Team – **Poster 206.04**

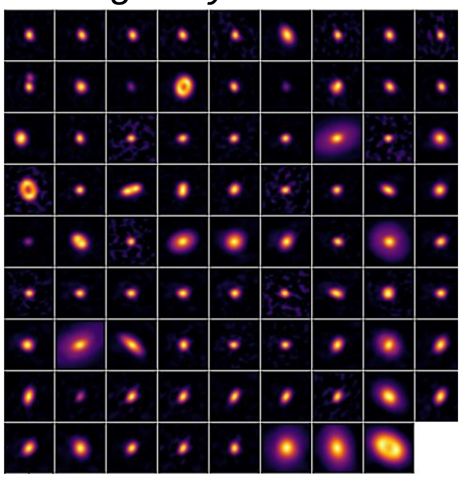
- DECO *(PI: I. Cleeves)* is an ALMA Cycle 9 LP
- Main lines are CO isotopologues, C_2H, & N_2H^+
- Spatial & velocity resolutions of 0.”2–0.”5 & 0.15 km/s

Bonus lines: H_2CO, CS, ^{13}CS, SO, H_2CS, HCN, c-C_3H_2, DCN, N_2D^+, CH_3OH….

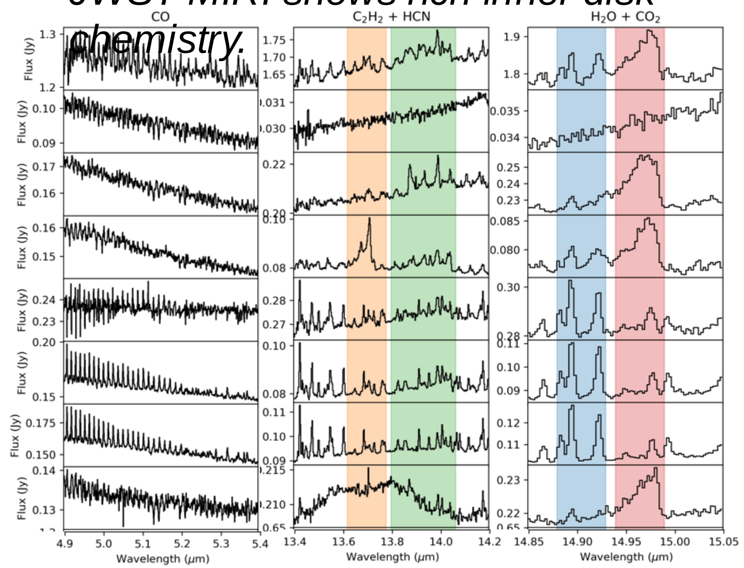
Disks show high (>1) C/O ratios, but exoplanets have lower values (<1).



Dust gallery of DECO disks



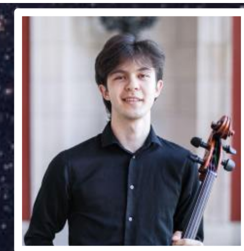
JWST-MIRI shows rich inner disk chemistry.



DECO will measure the C/O ratio in a statistical sample of 80 “typical” protoplanetary disks to compare with existing/forthcoming exoplanet measurements.

Free Fallin': Mapping the Trajectory of Infalling Mass around Protostars

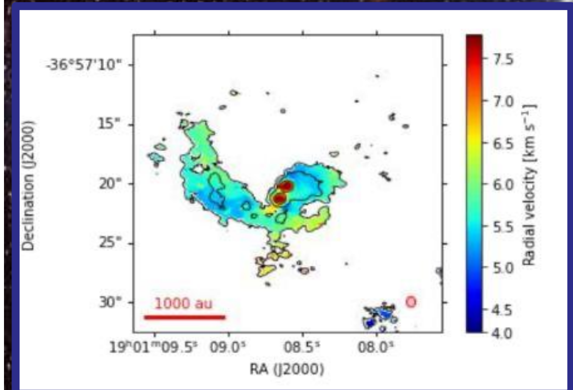
Vincent Louis Claes[1], Lee Hartmann[1], Aashish Gupta et al[2]
[1]University of Michigan - Ann Arbor; [2]European Southern Observatory

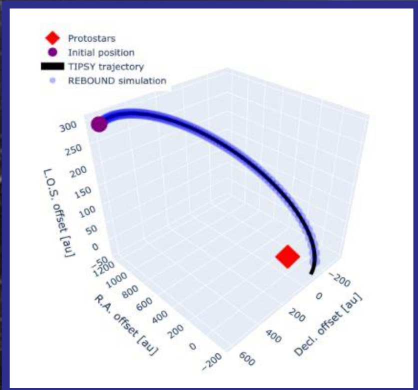


TIPSY Simulation Results

Right: The parameters found from the results of Mendoza
Bottom left/right: TIPSY simulations of dust orbitals

Quantity	S CrA
Stellar mass [$M_\odot$]	2
Distance [pc]	160
Specific energy [km^2 / s^2]	-1.15±0.10
Specific angular momentum [AU km / s]	791±218
Infall time [yr]	8301±1358





Our Simulation Results

Right: Legend for radial velocity of dust orbital
Bottom left/right: Model of singular dust orbital

Color	Radial Velocity [km / s]
Red	>4.5
Orange	>5.0
Green	>5.5
Blue	>6.0
Indigo	>6.5