3 years of JWST-MIRI observations of planet-forming disks: Toward a paradigm of chemical evolution of inner disk?

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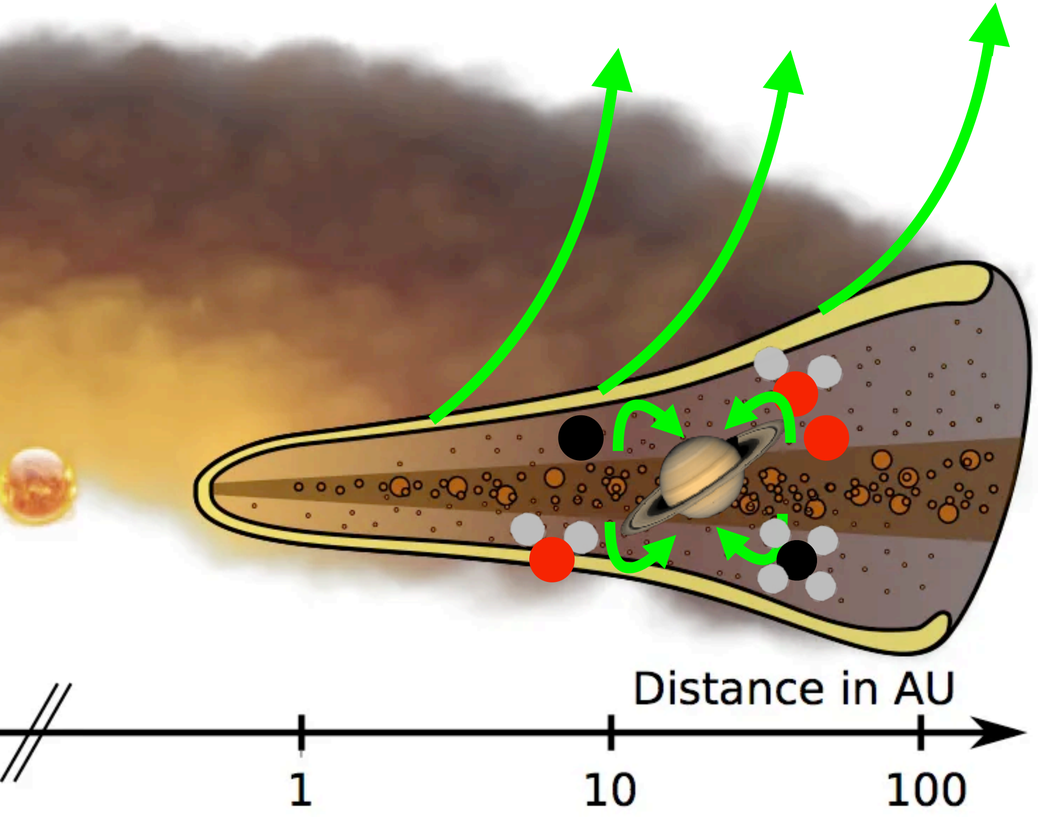
MIRI midINfrared Disk Survey

Exosystème V - April 1 2026

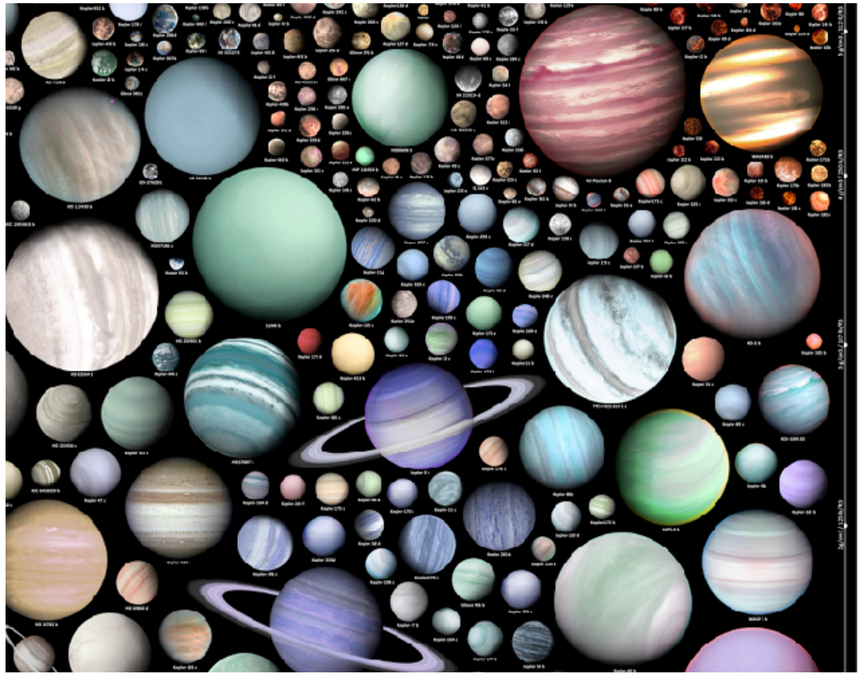
Challenge: linking exoplanet properties to their formation history

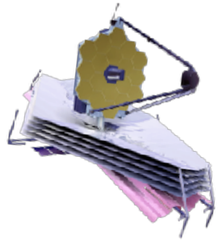
What is the physical, chemical, and dynamical evolution of disks?



Planet formation models

End-product: populations of exoplanets





PLATO Mission Consortium
PLAnetary Transits and Oscillations of stars

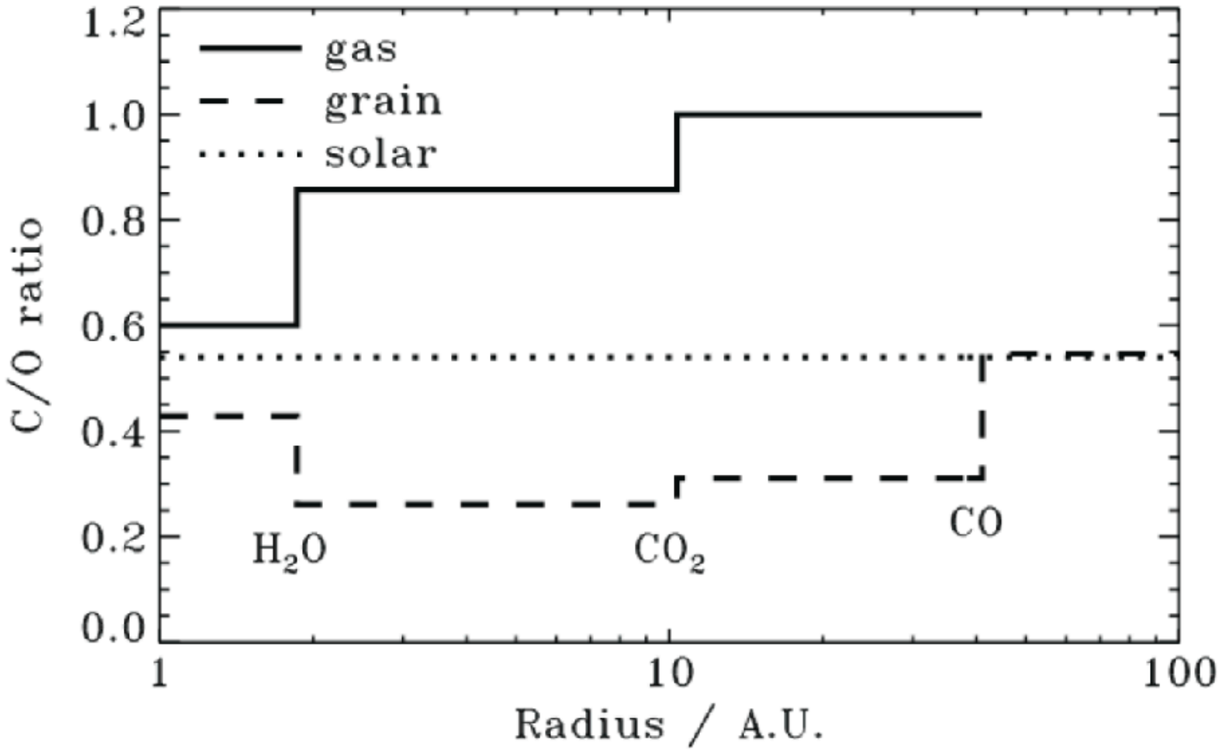
ARIEL
Atmospheric Remote-sensing Infrared Exoplanet Large-survey

2

Scientific motivation of atmospheric characterization of gas-rich exoplanets

The simplest physical process: condensation of volatiles (CO, CO_2, H_2O, CH_4) leads to gradients in elemental abundances in the gas

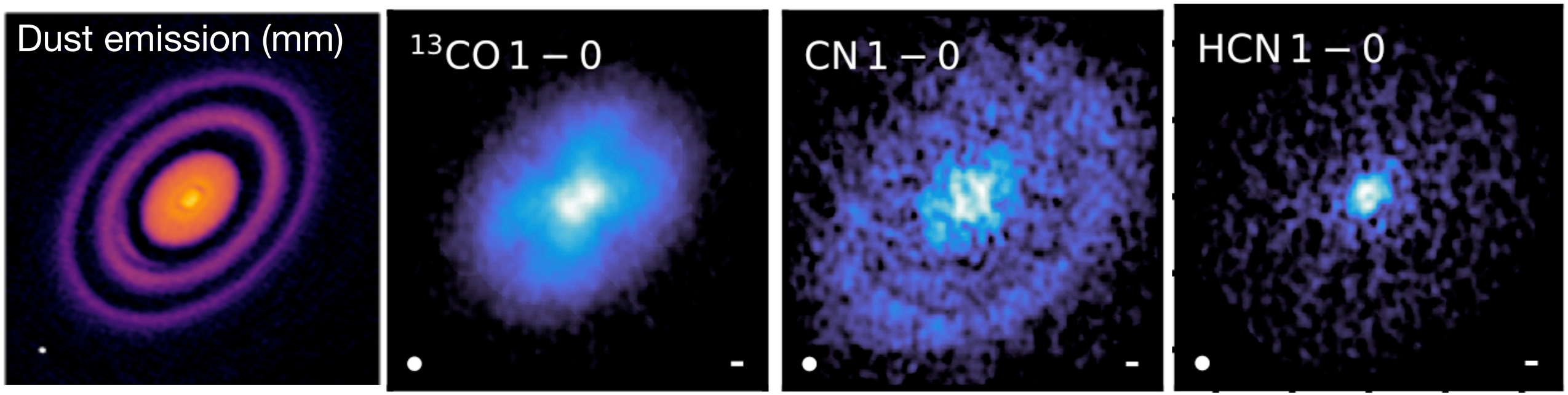
=> composition of gas-rich planets is a record of where and when these planets form…



Evolution of the C/O ratio with radius. Öberg et al. 2011.

Outer disk composition with ALMA

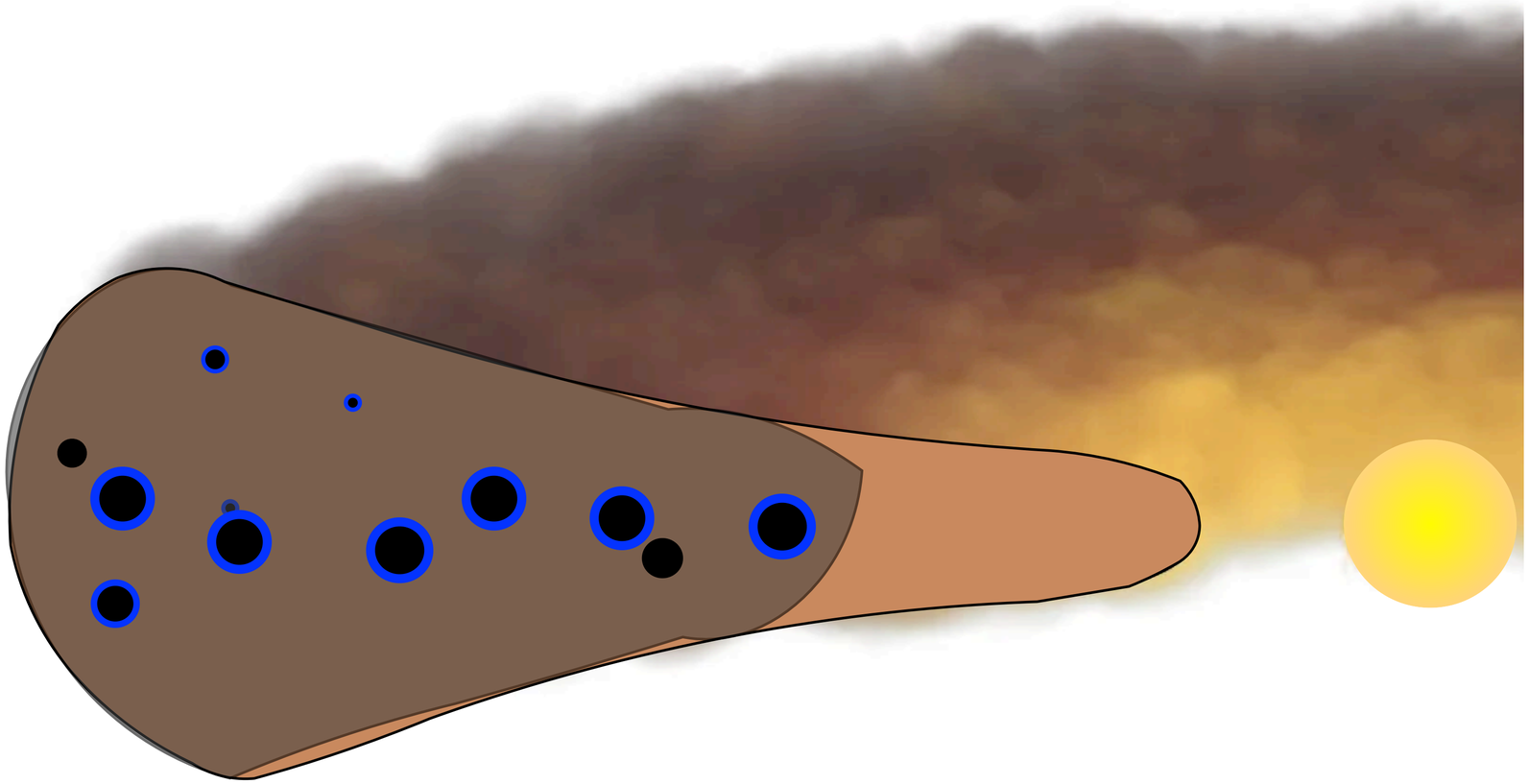
After 10 yrs of operation: outstanding 3D picture of Class II disks



Credit: MAPS ALMA Large Programme, PI: K. Oberg

Outer disk composition with ALMA

- Gas phase CO under abundant => CO trapping and chemical conversion into less volatile species
- Resulting in high C/O and low (C+O)/H in the gas => Oberg picture more extreme for outer disk (>20au)!

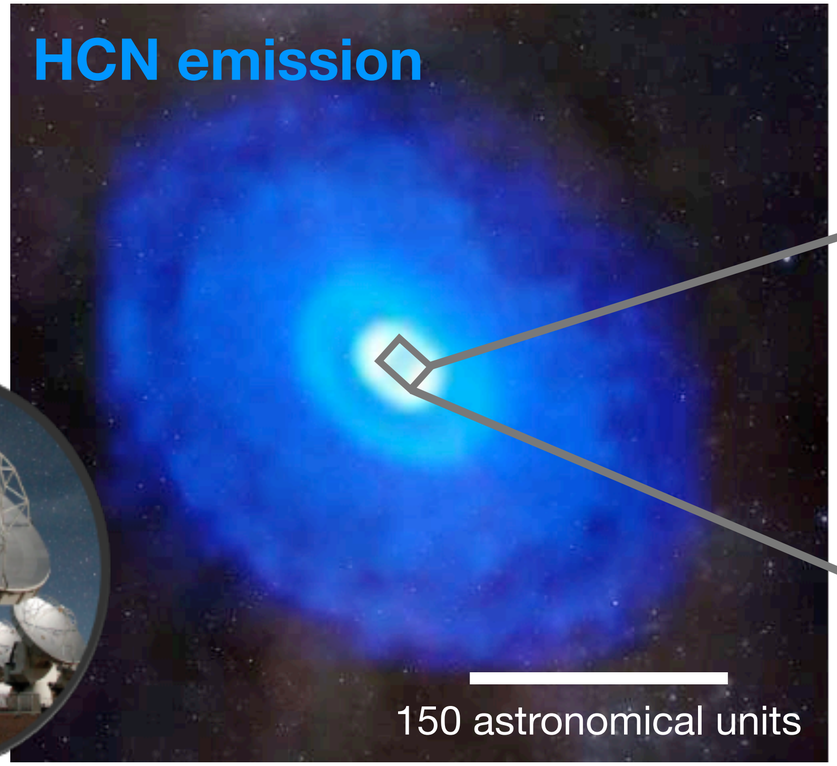


Zhang+2020
Du+2014
Favre+2013
Miotello+2017

Transformative science with JWST

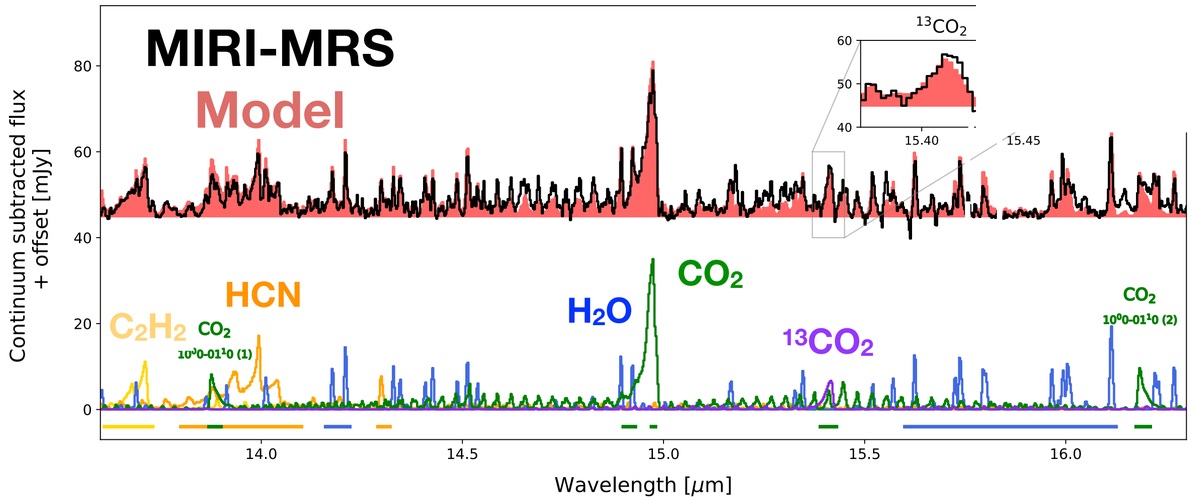
JWST revolutionizes the field by unveiling the inner regions where the majority of (exo)planets are formed ~300 disks aready observed!

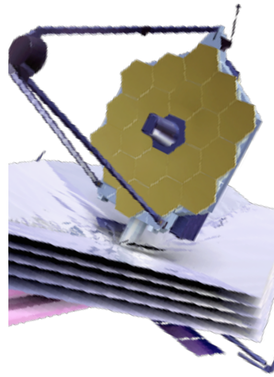
Outer disks seen by ALMA



Oberg+2021

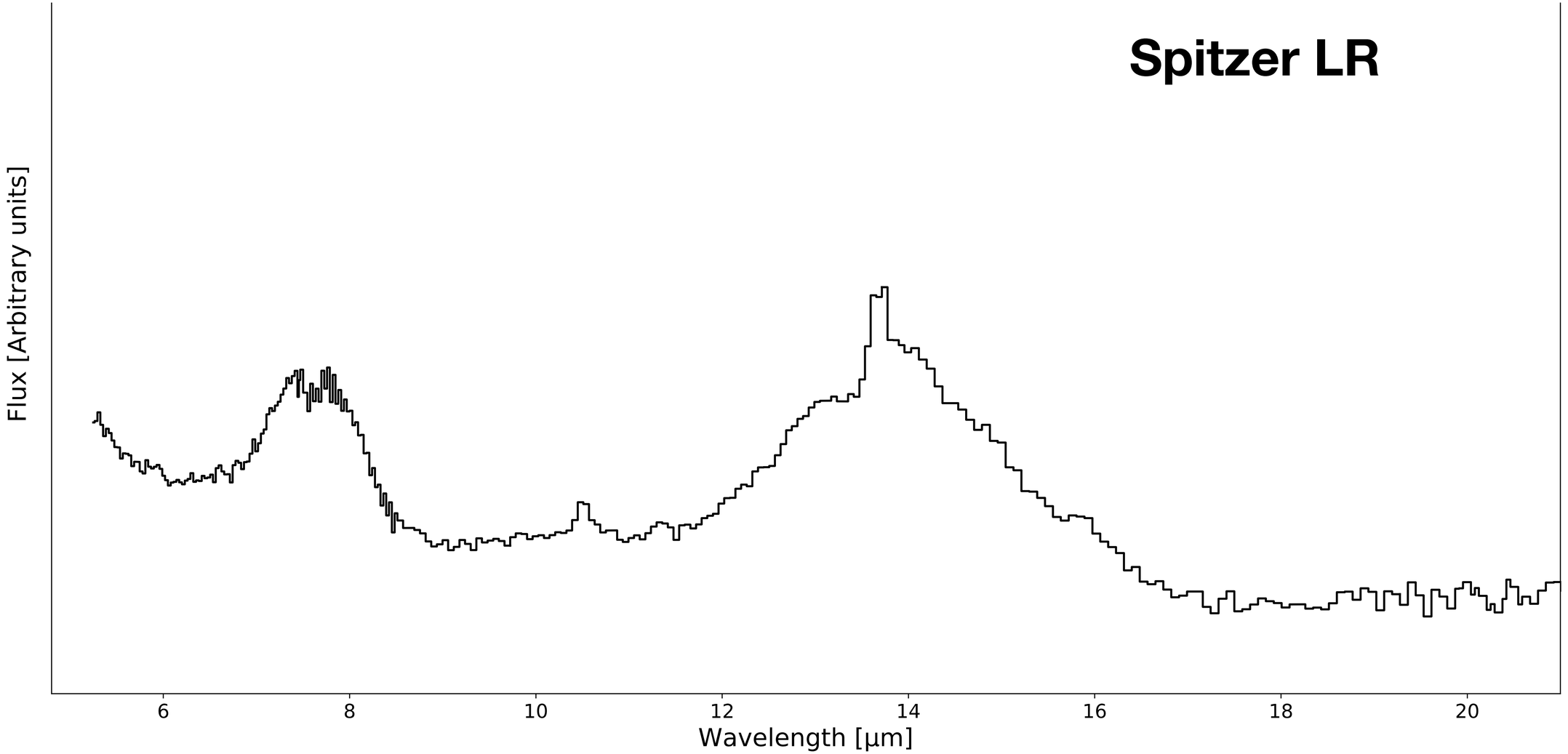
Planet-forming regions probed in the IR
=> major science driver for JWST





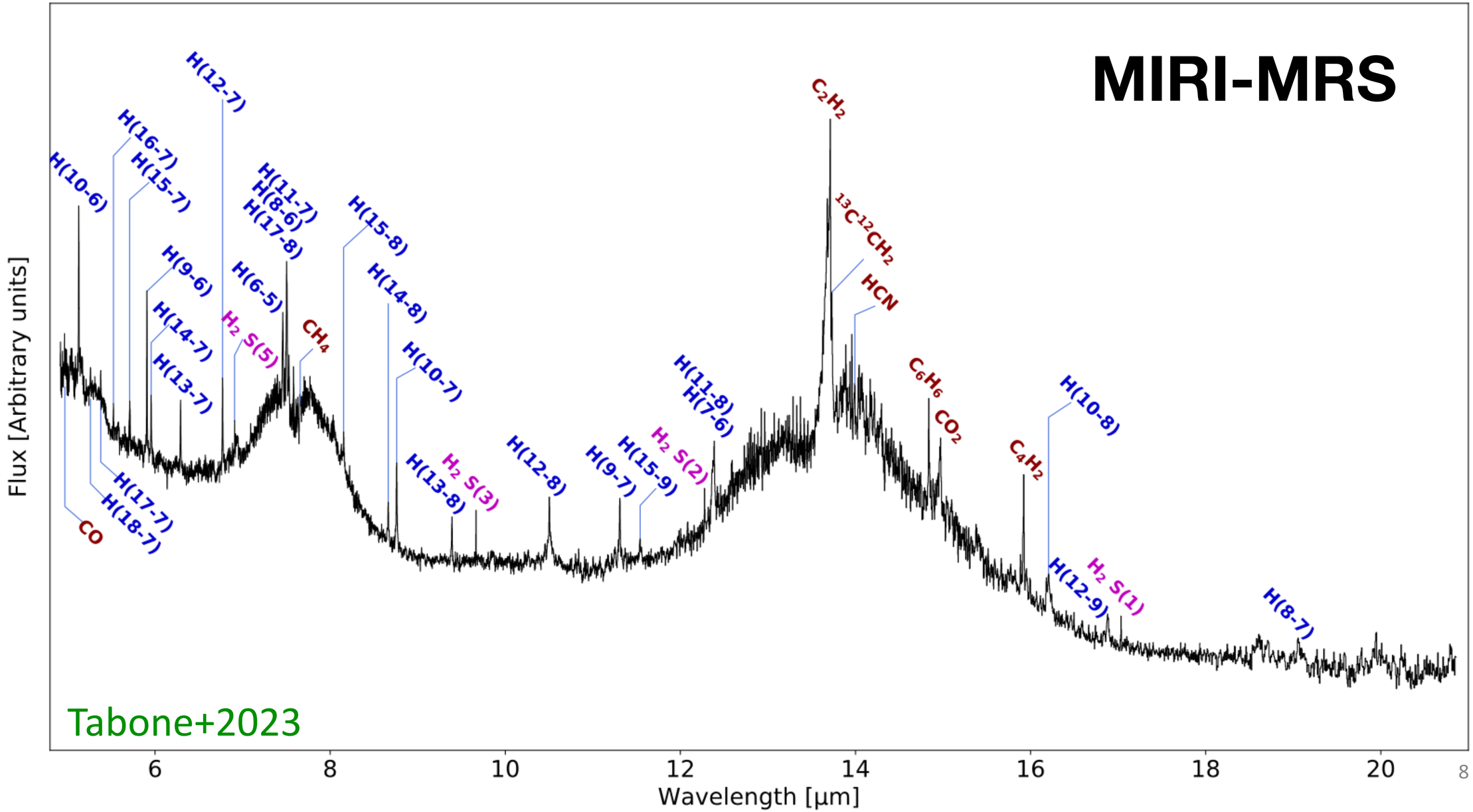
Grant et al., incl. Tabone 2023

Spectroscopy with JWST



Credit: G. Bettoni

Spectroscopy with JWST

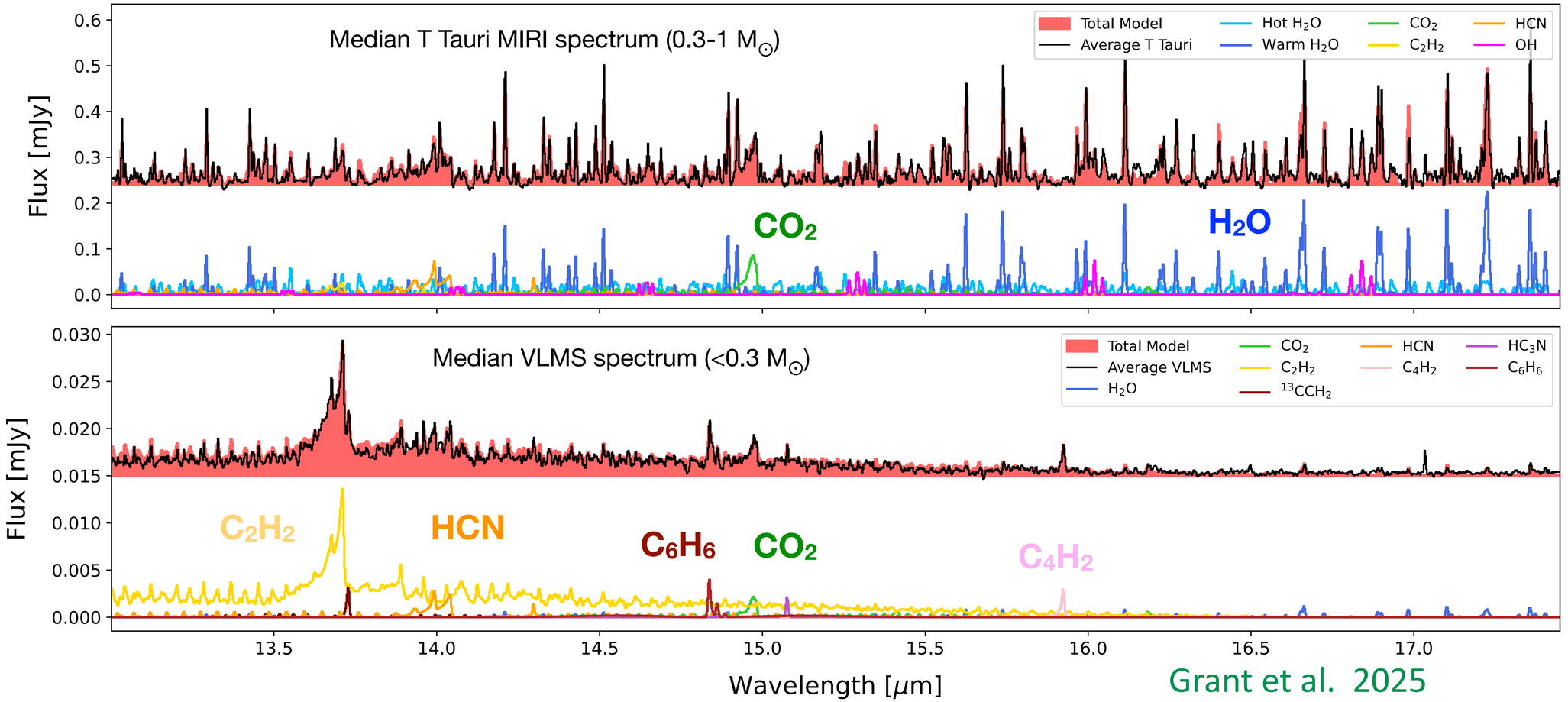


Tabone+2023

Molecular makeup of inner disk depends on stellar mass

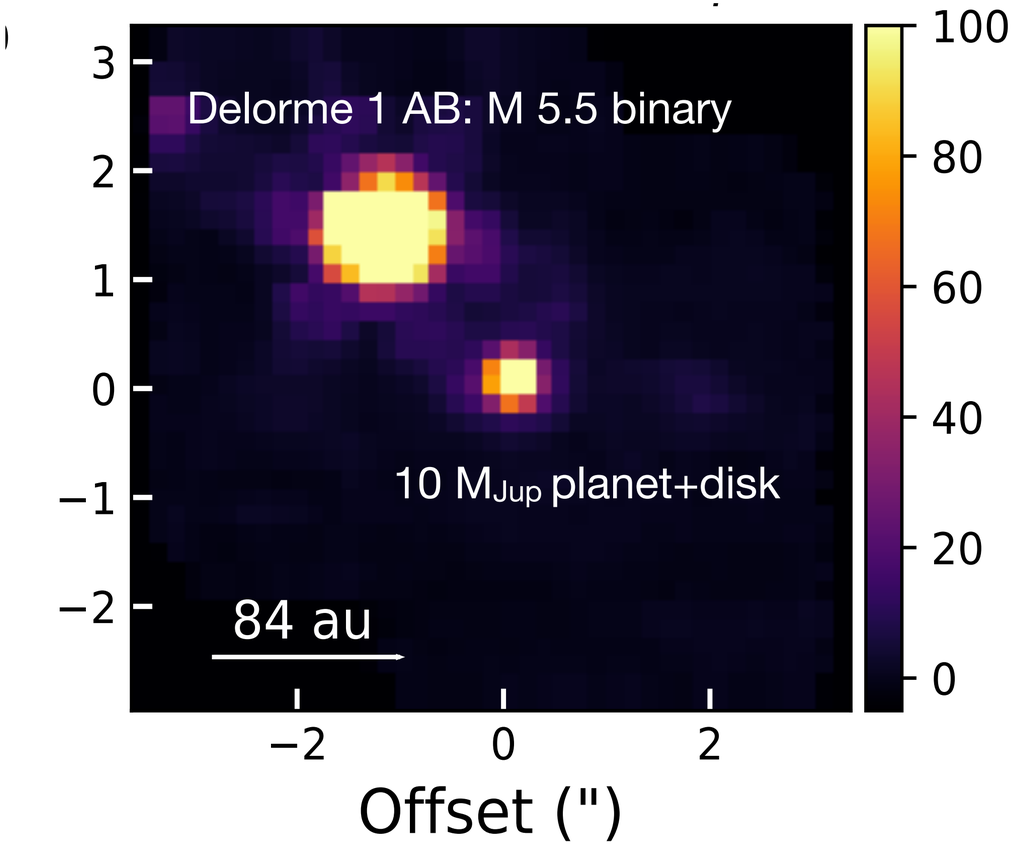
VLMS (« M-dwarf »): full of gas-phase carbon =/= Sun-like stars: full of oxygen

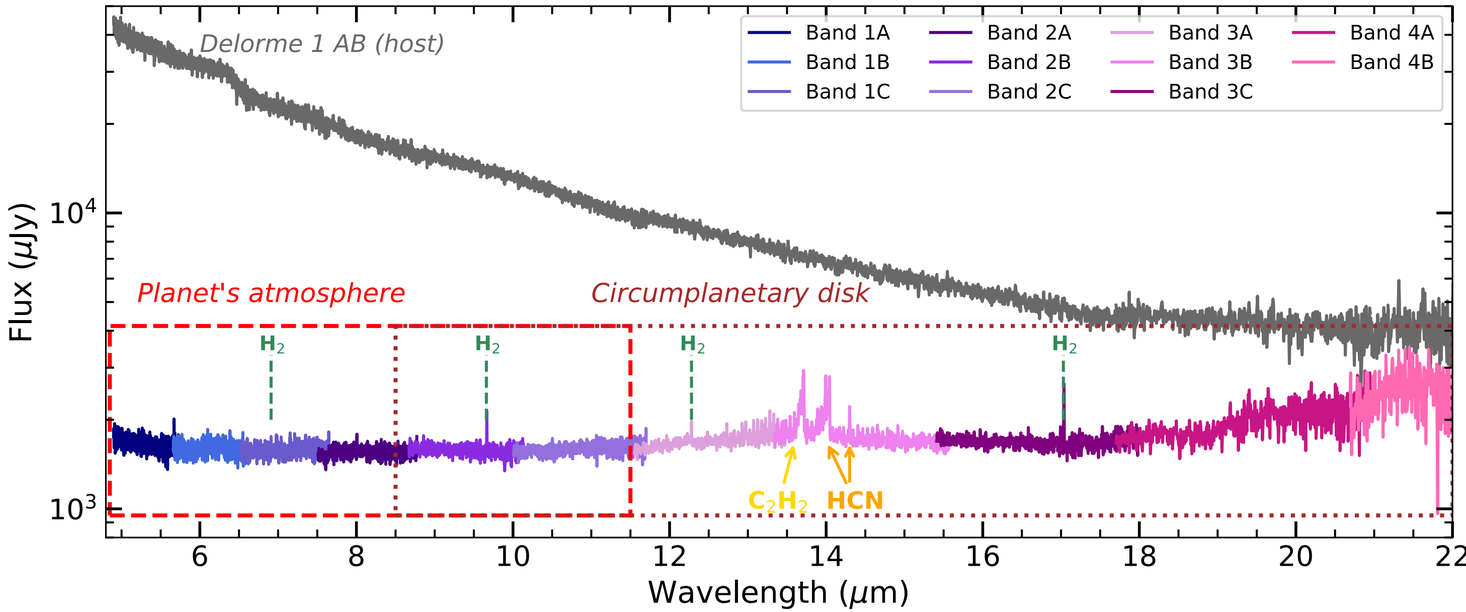
=> *the composition of exoplanet are likely highly dependent of the stellar mass!*



Grant et al. 2025

Trend continues toward brown dwarf disks and CPDs!



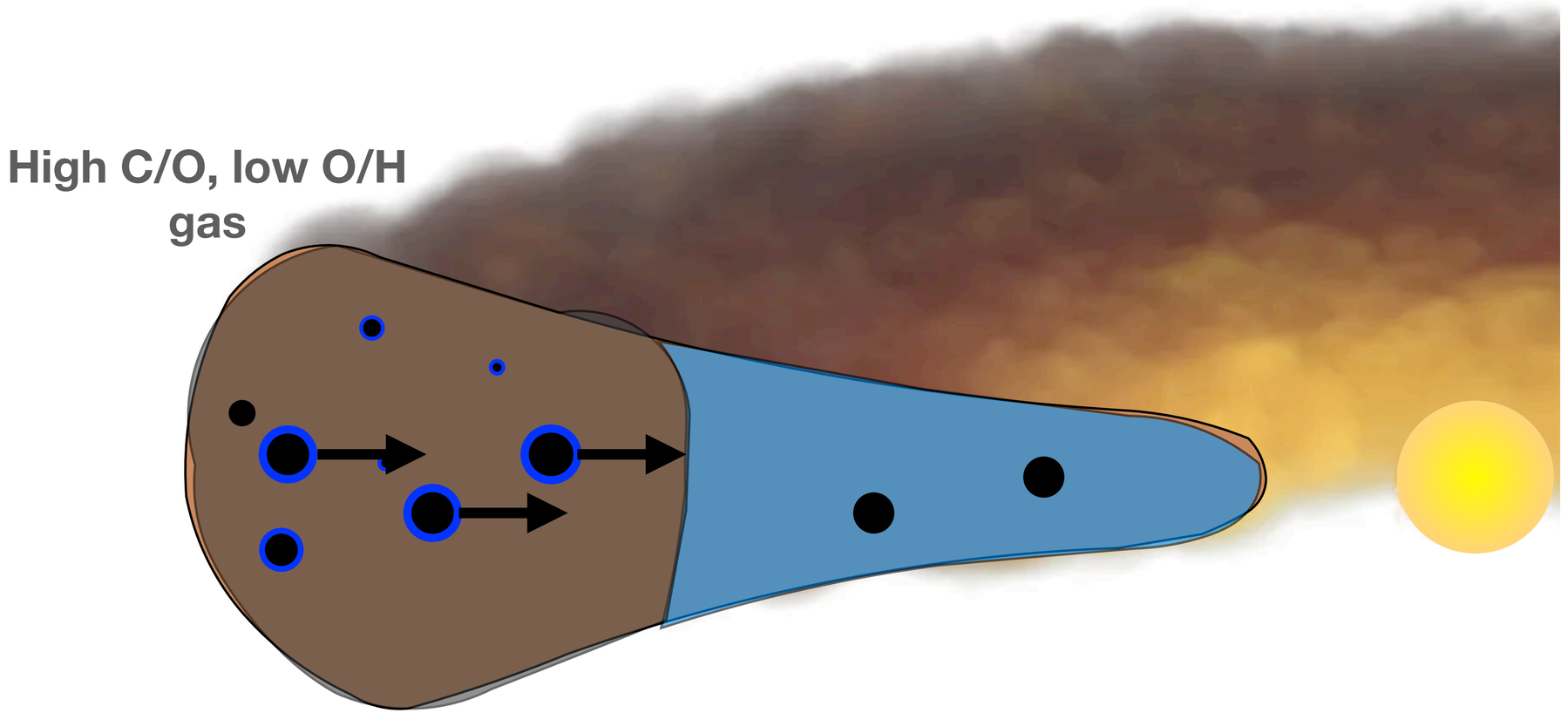


Mâlin et al. 2025

Origin of the diversity: dust radial transport?

Mstar dependency is inconsistent with sublimation front in static disks

Emerging paradigm: inner disk chemical makeup set by advection of C-rich gas and O-rich icy pebbles from outer disk



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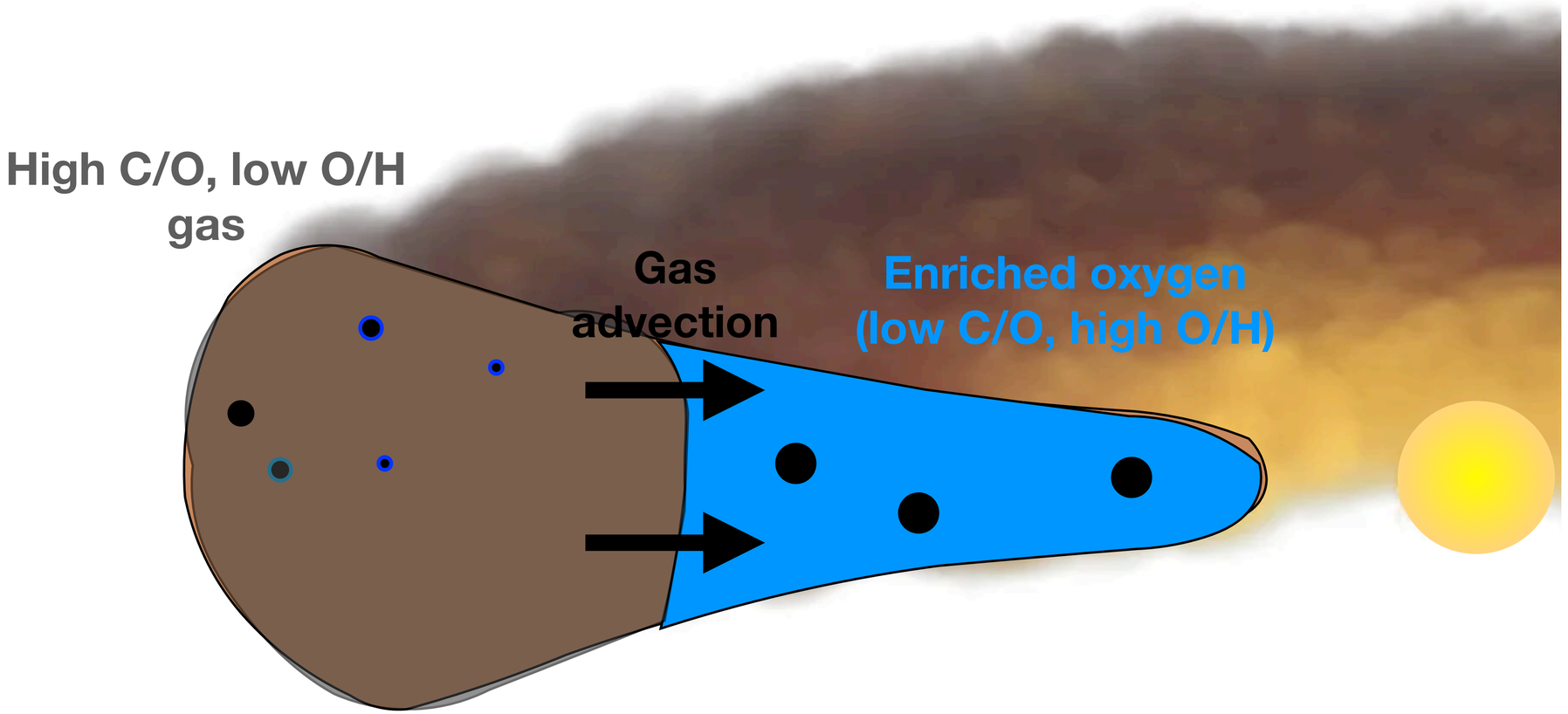
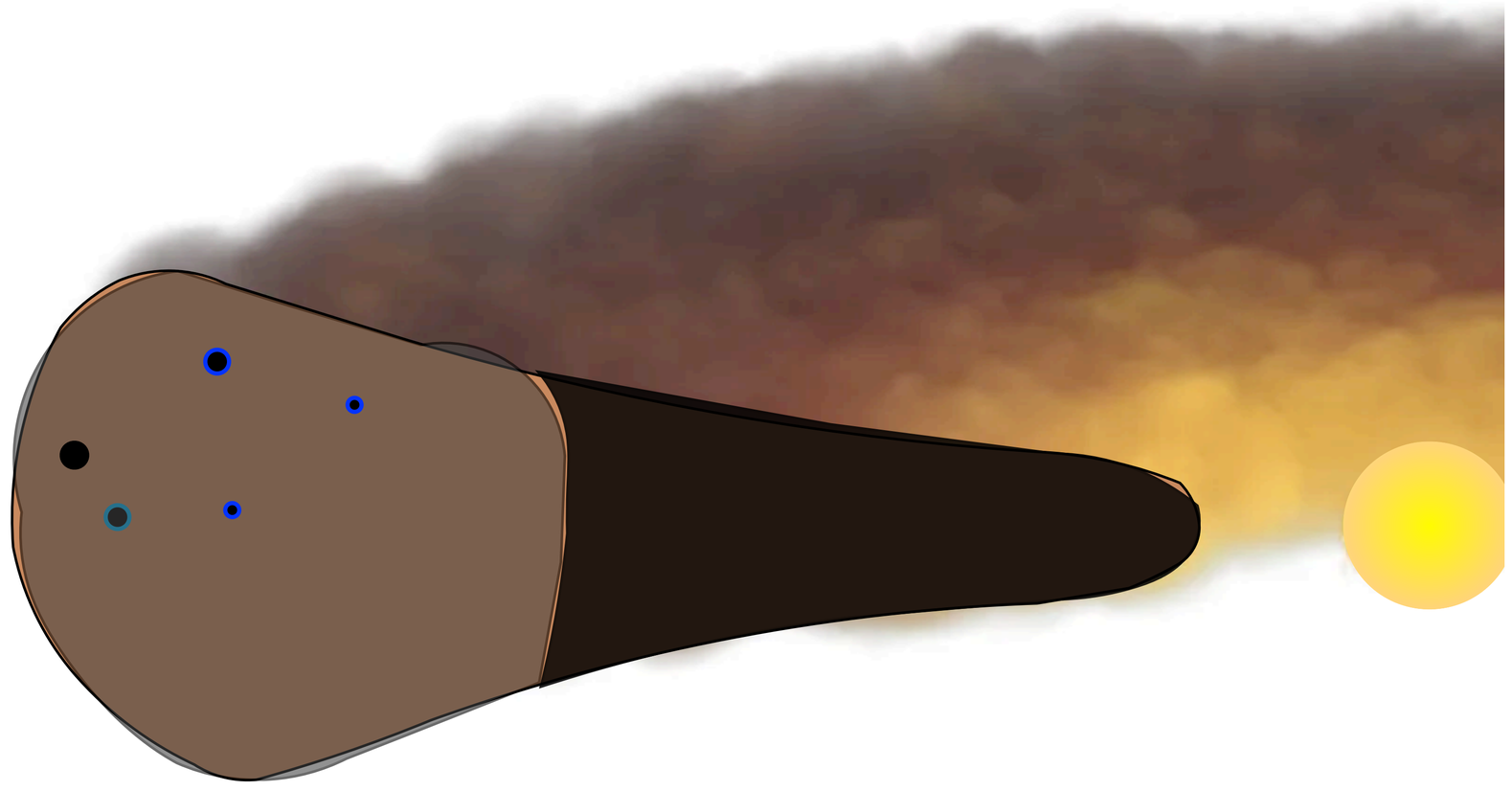
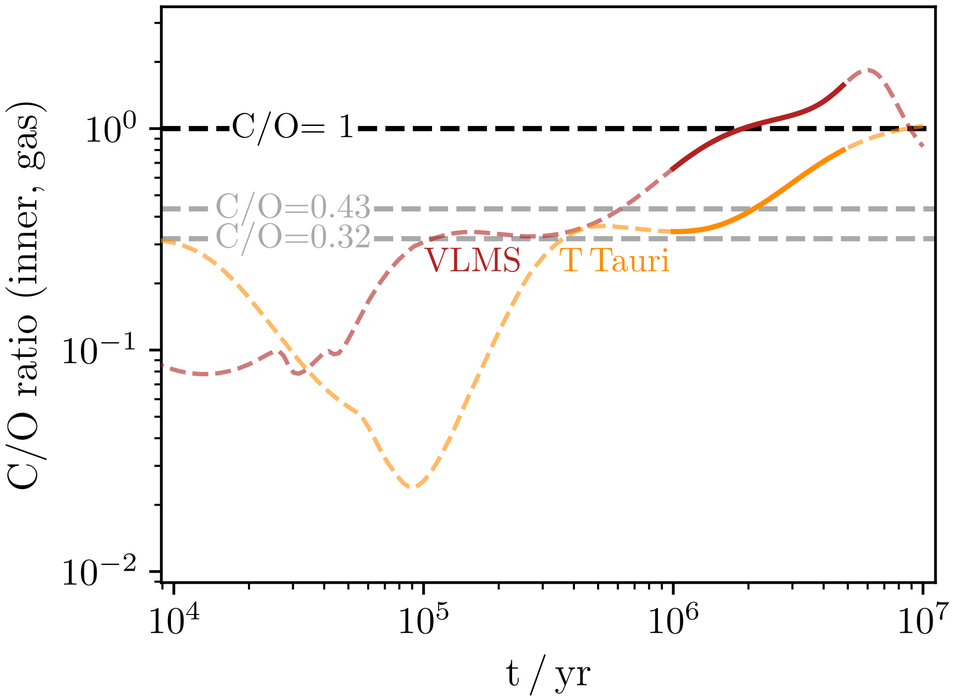


Origin of the diversity: dust radial transport?

Emerging paradigm suggest that inner disk chemical makeup set by advection of gas and icy pebbles from outer disk

=> diversity in inner disk linked to the location of various substructures?
=> first JWST-ALMA results challenge this interpretation but mismatch in scale



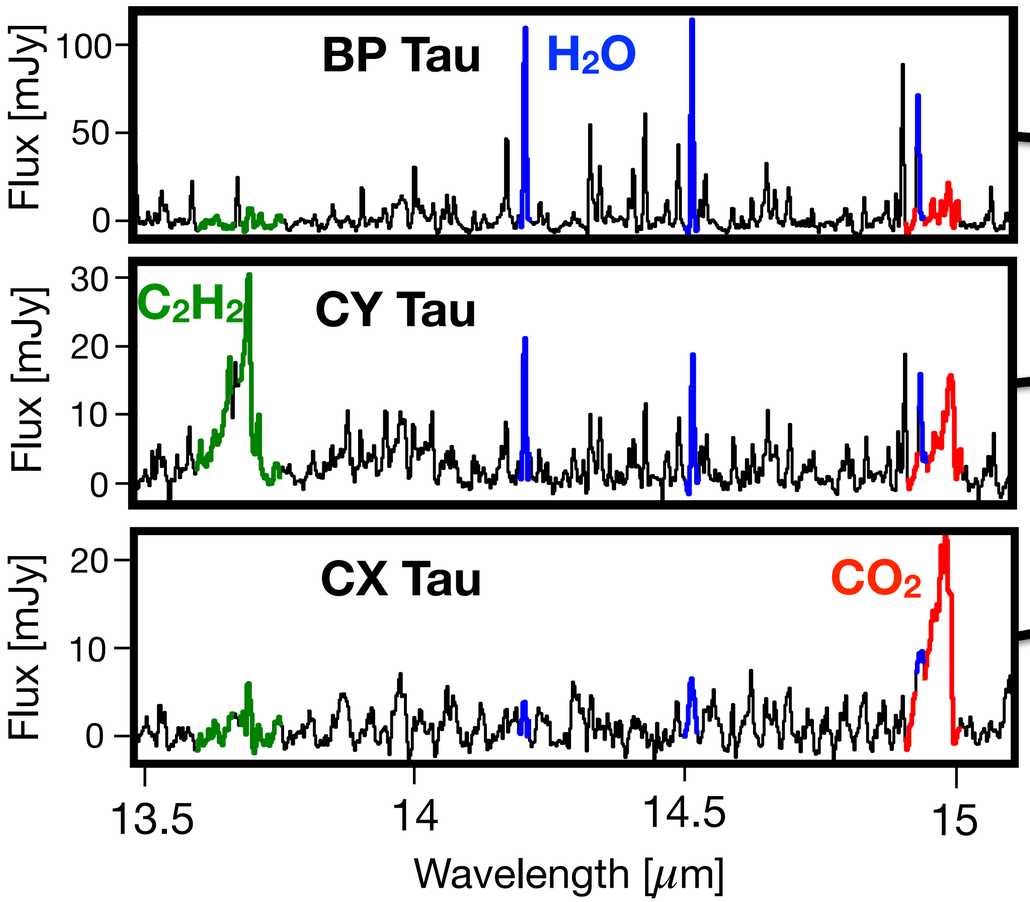


Sellek et al. 2025

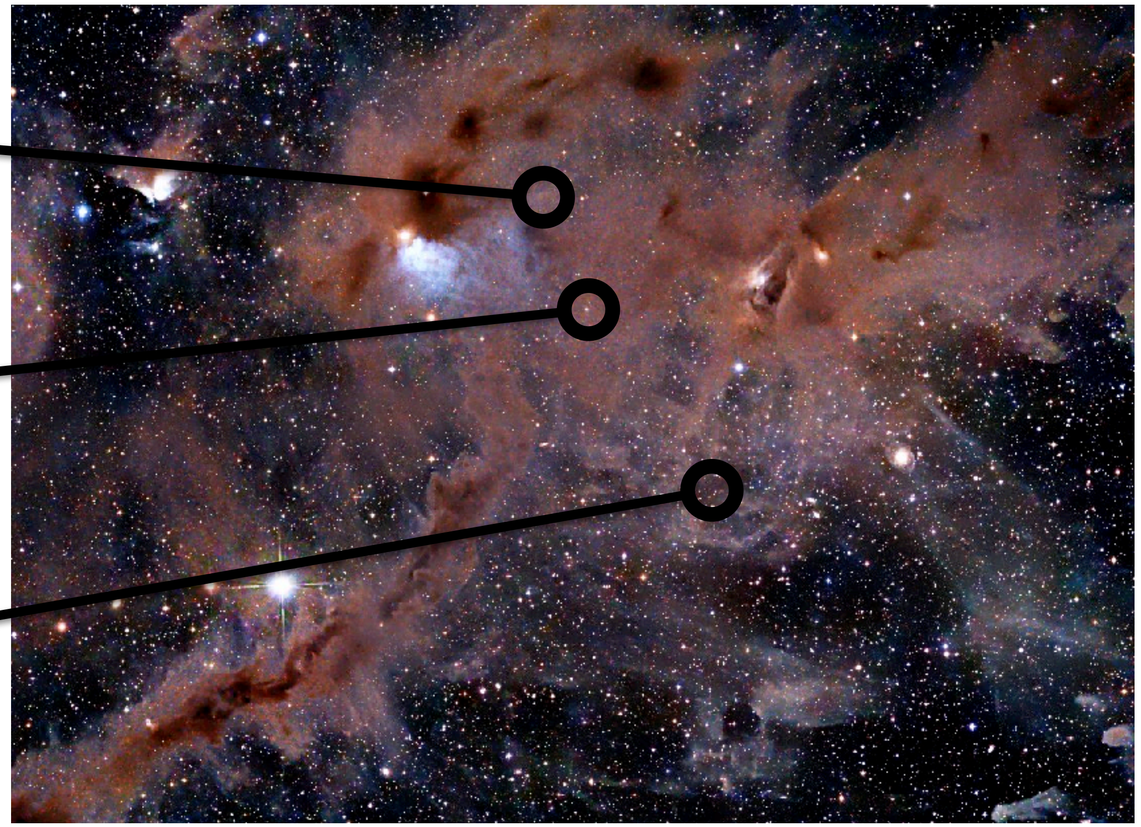
Diversity of disks around « Sun-like » stars

Witnessing the emergence of the diversity even before the gas is accreted by the planets!

JWST spectra of disks around 0.5 $M_\odot$ stars

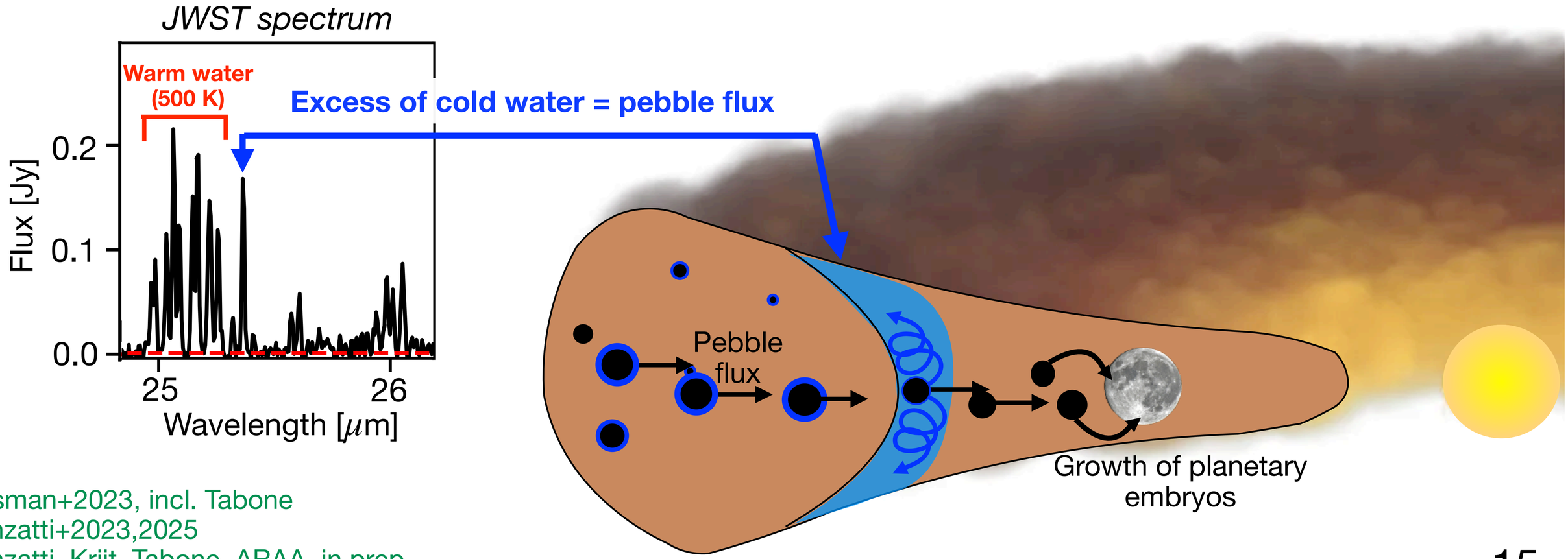


The Taurus molecular cloud



Evidence of pebble drift in Sun-like stars

Cold water excess = on-going sublimation of pebbles



Gasman+2023, incl. Tabone
Banzatti+2023,2025
Banzatti, Krijt, Tabone, ARAA, in prep.

Evidence of pebble drift in Sun-like stars

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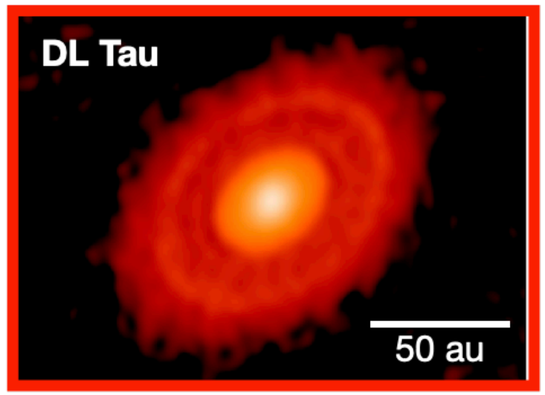
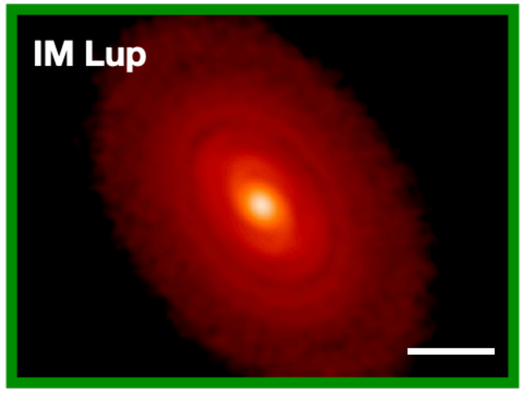
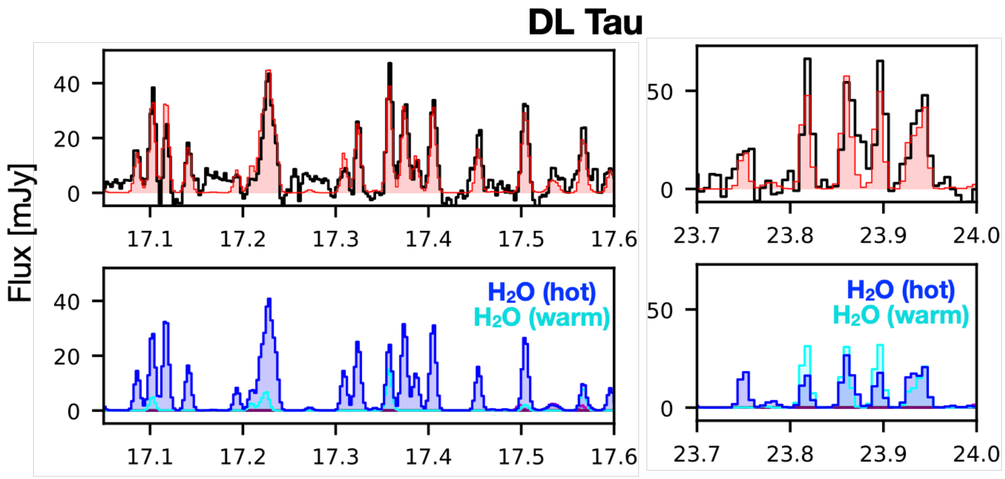
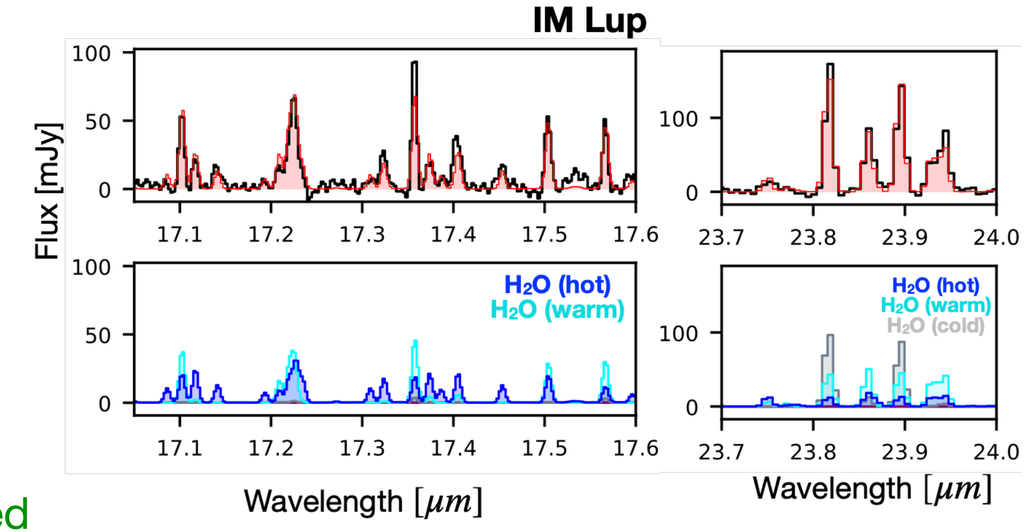
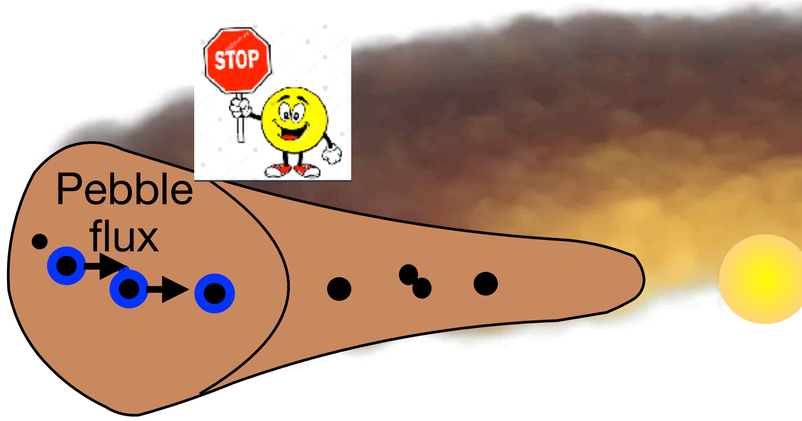
=> would produce high O/H and low C/O in the gas

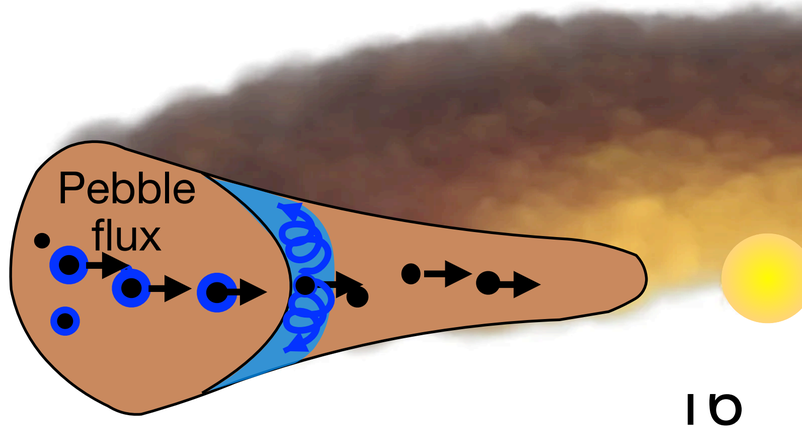












Tabone et al. submitted

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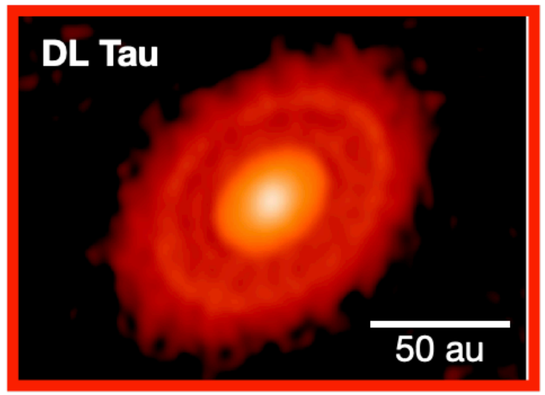
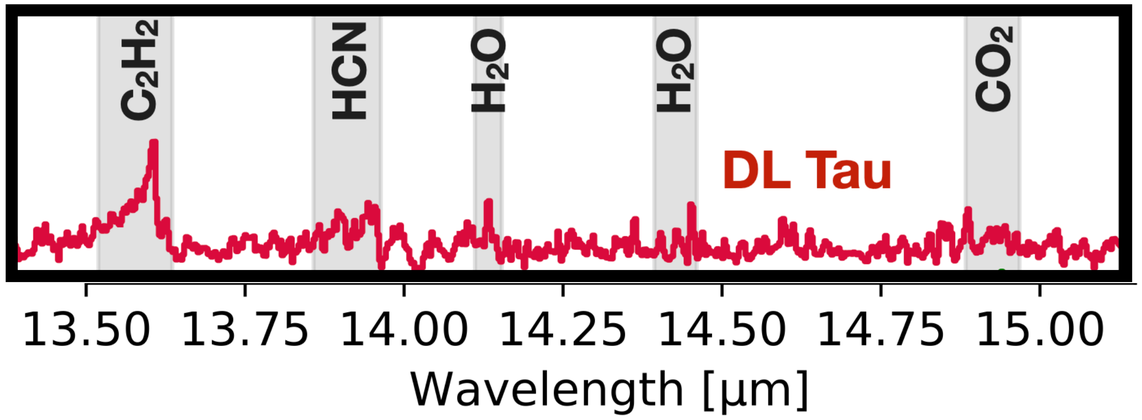
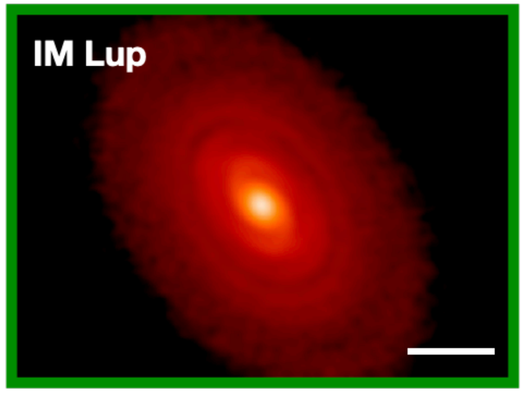
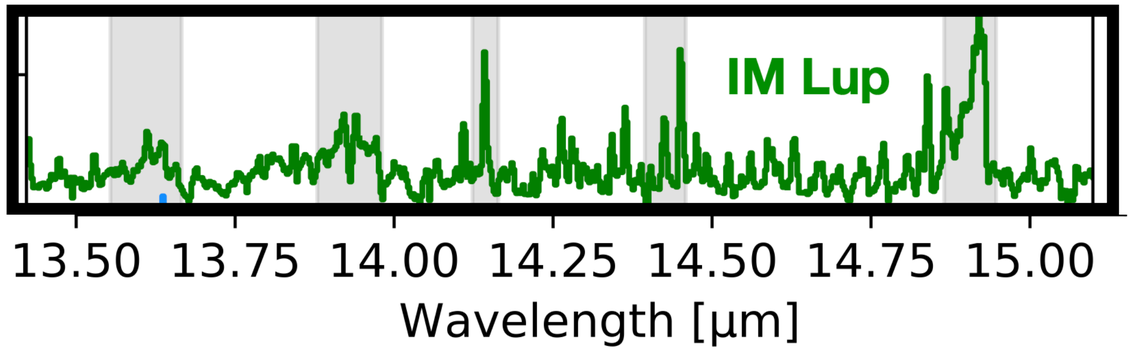
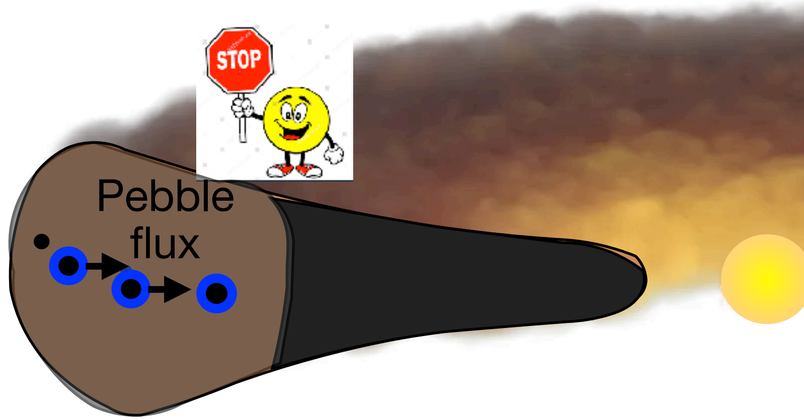
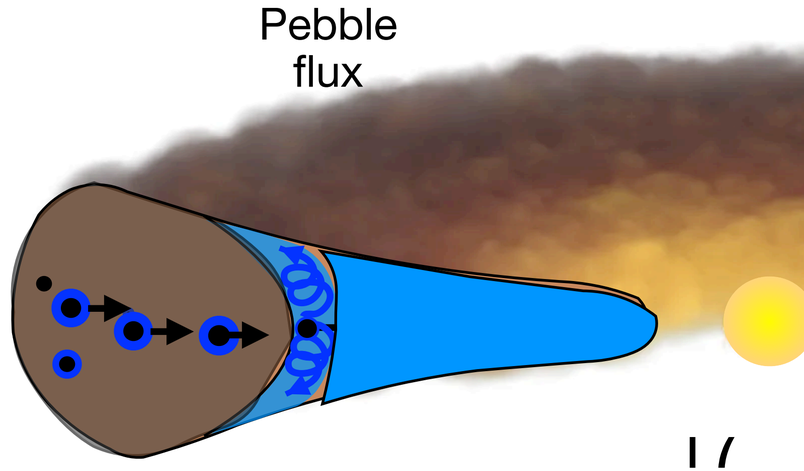












Tabone et al. submitted

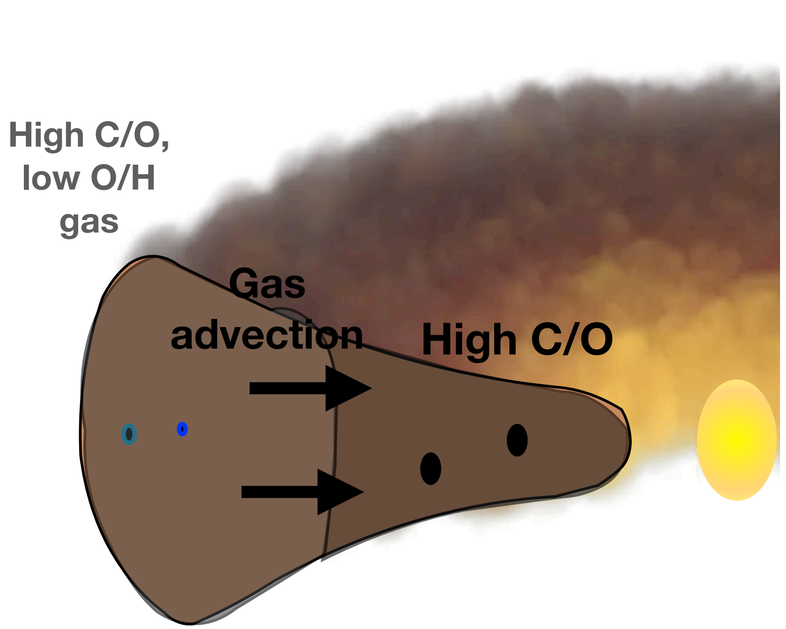
Summary: diversity of inner disks driven by dyanamics

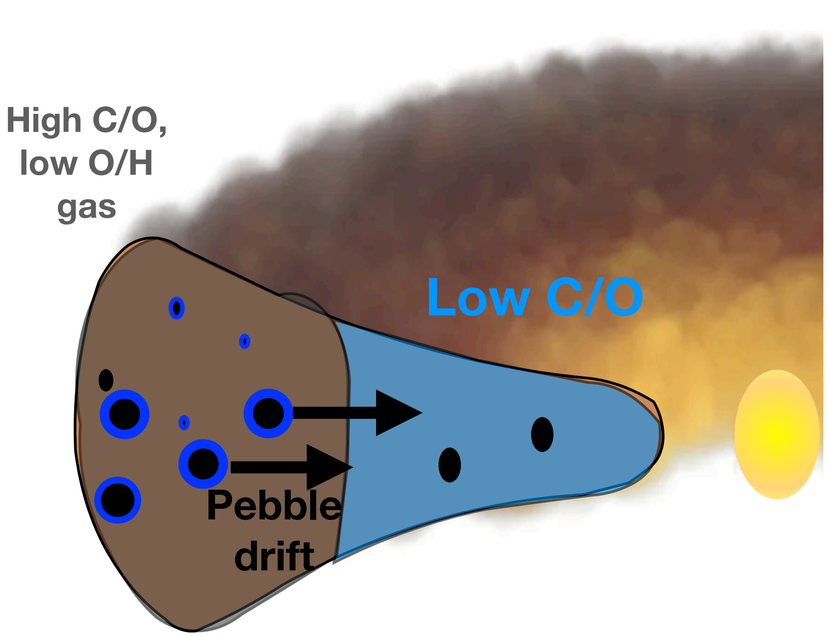
Very-low mass stars: Dramatic avalanche of O-rich pebbles producing C-rich inner disks

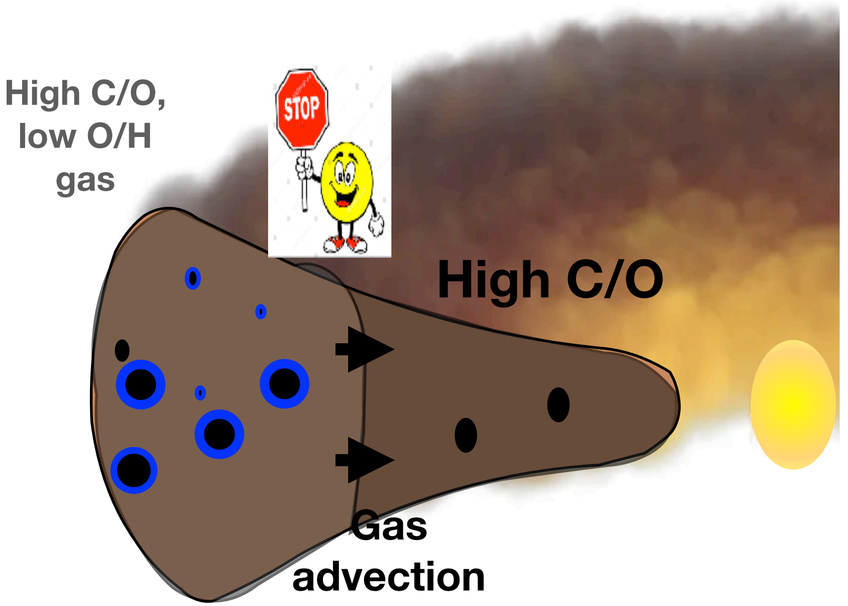
Sun-like stars
Slow delivery of O-rich pebbles along with high C/O gas

Active pebble drift

Full pebble blocking

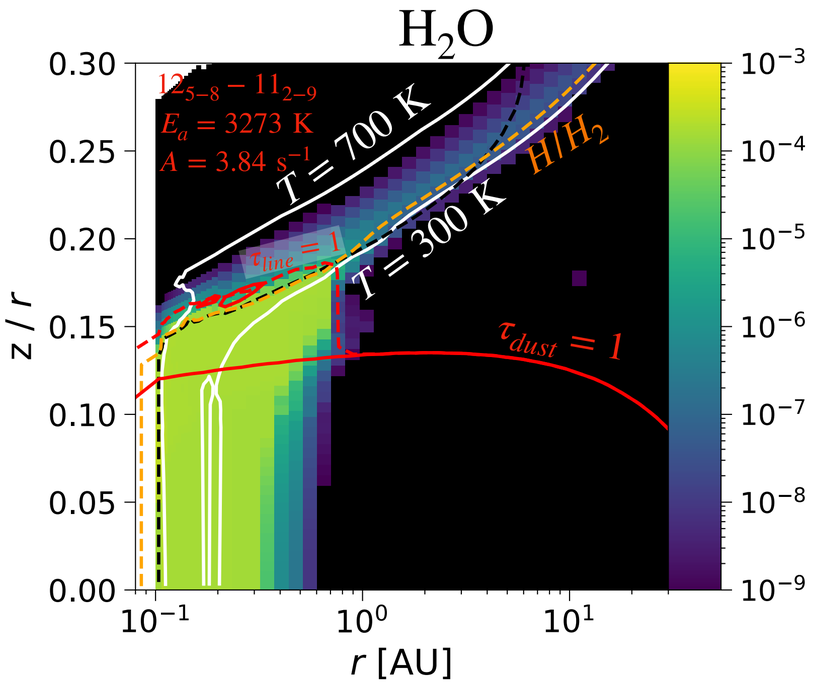




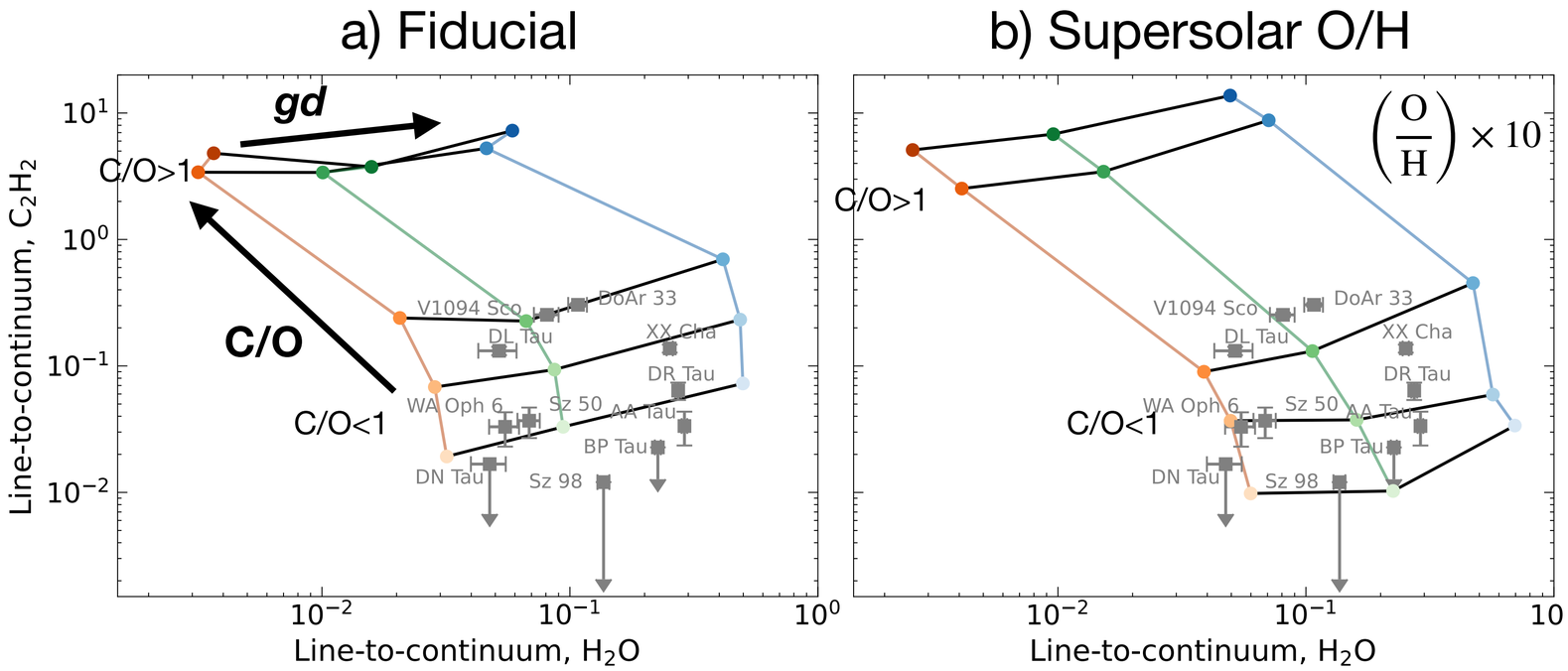


Need for forward models to estimate elemental abundances

- Thermocheical models essential to convert a MIRI spectrum to an estimated C/O ratio
- C/O and O/H major drivers of the C2H2/H2O line fluxes
- In Sun-like stars: C/O<1 and for some O/H super solar



Abundance map of water



Estève, Tabone et al. submitted

Conclusion: toward a complete picture of disk chemistry in inner planet-forming regions

- Outstanding diversity of inner disk seen by MIRI!
- Strong dependency on the stellar mass extending down to the planetary mass regime
- Even for very similar kind of disk: strong variation likely due to variation in elemental abundances
- Transport of gas versus ice could be the key process settling the elemental abundances in inner disks
- Preliminary thermochemical models points toward high O/H and C/O<1 for T Tauri

Perspectives

- ELT-METIS key to pointpoint forming planets at 10au scale and understand their feedback on inner most regions
- We need a far-IR mission to access the 1-20 au scales!
- We need next generation of thermochemical models coupling chemistry and dynamics