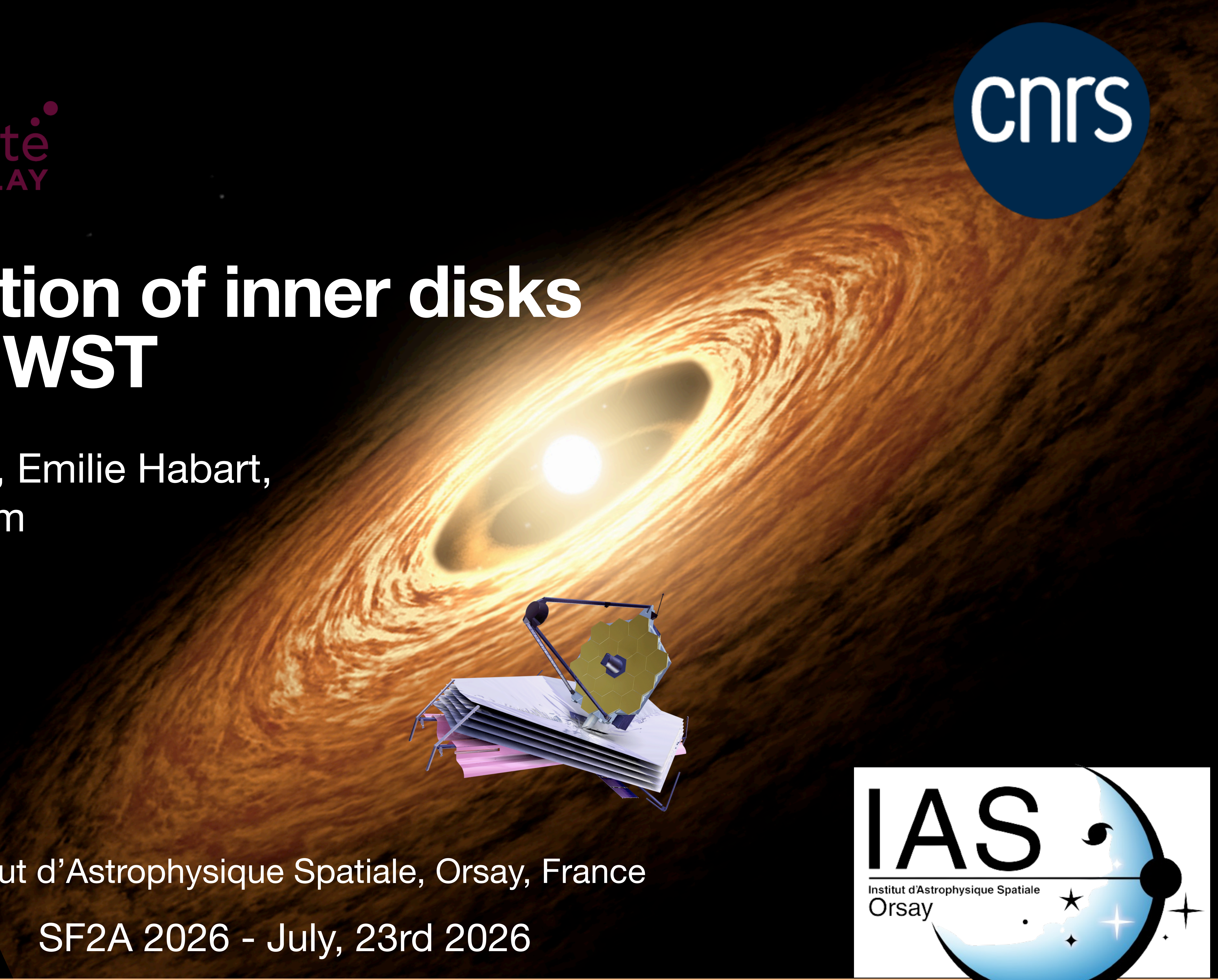
Chemical composition of inner disks with JWST

Pacôme Estève, Benoît Tabone, Emilie Habart,
and the MINDS team



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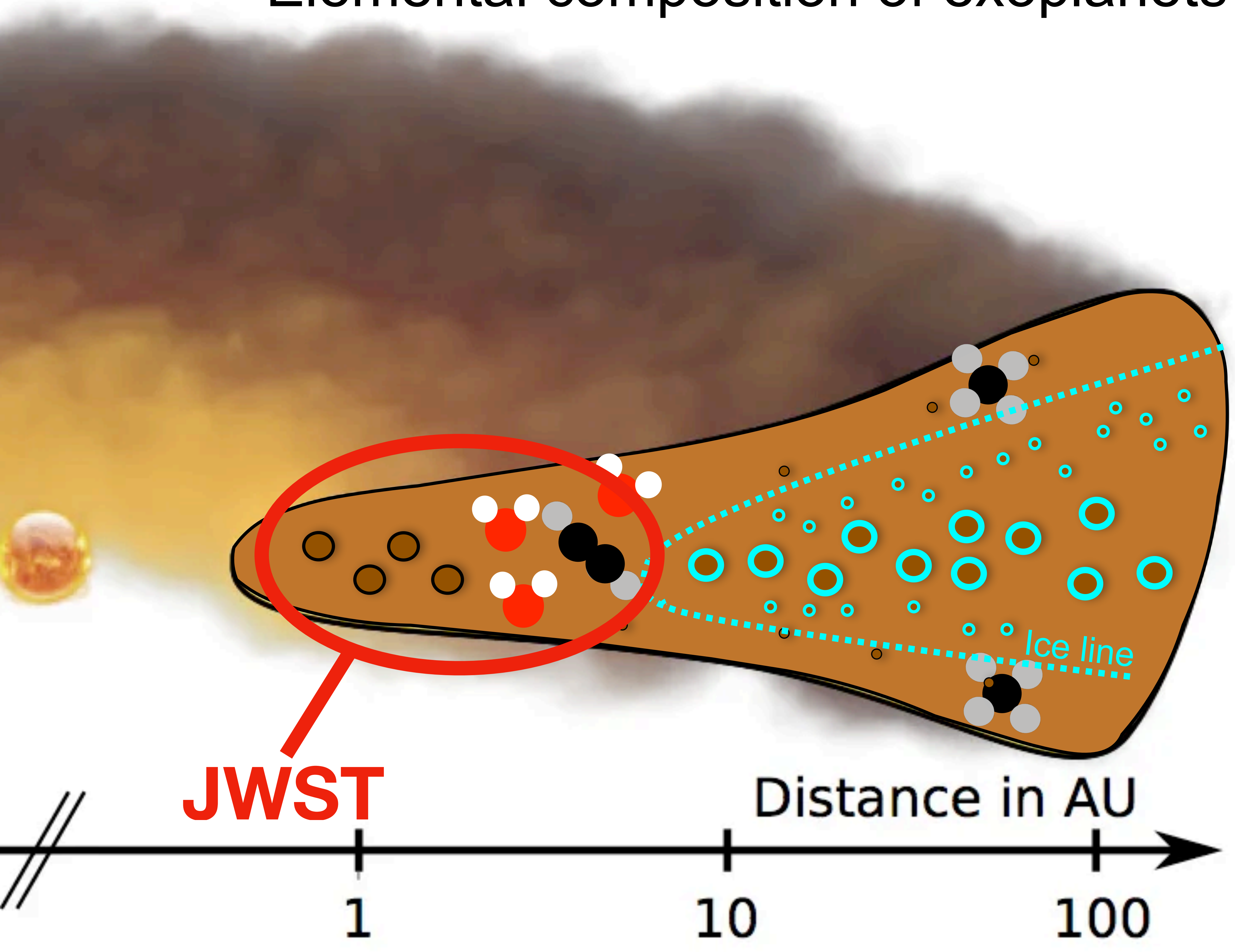
PhD Student

Linking exoplanet to their formation

Planet formation theories need constraints on disk properties to interpret the properties of exoplanets

Chemical composition?

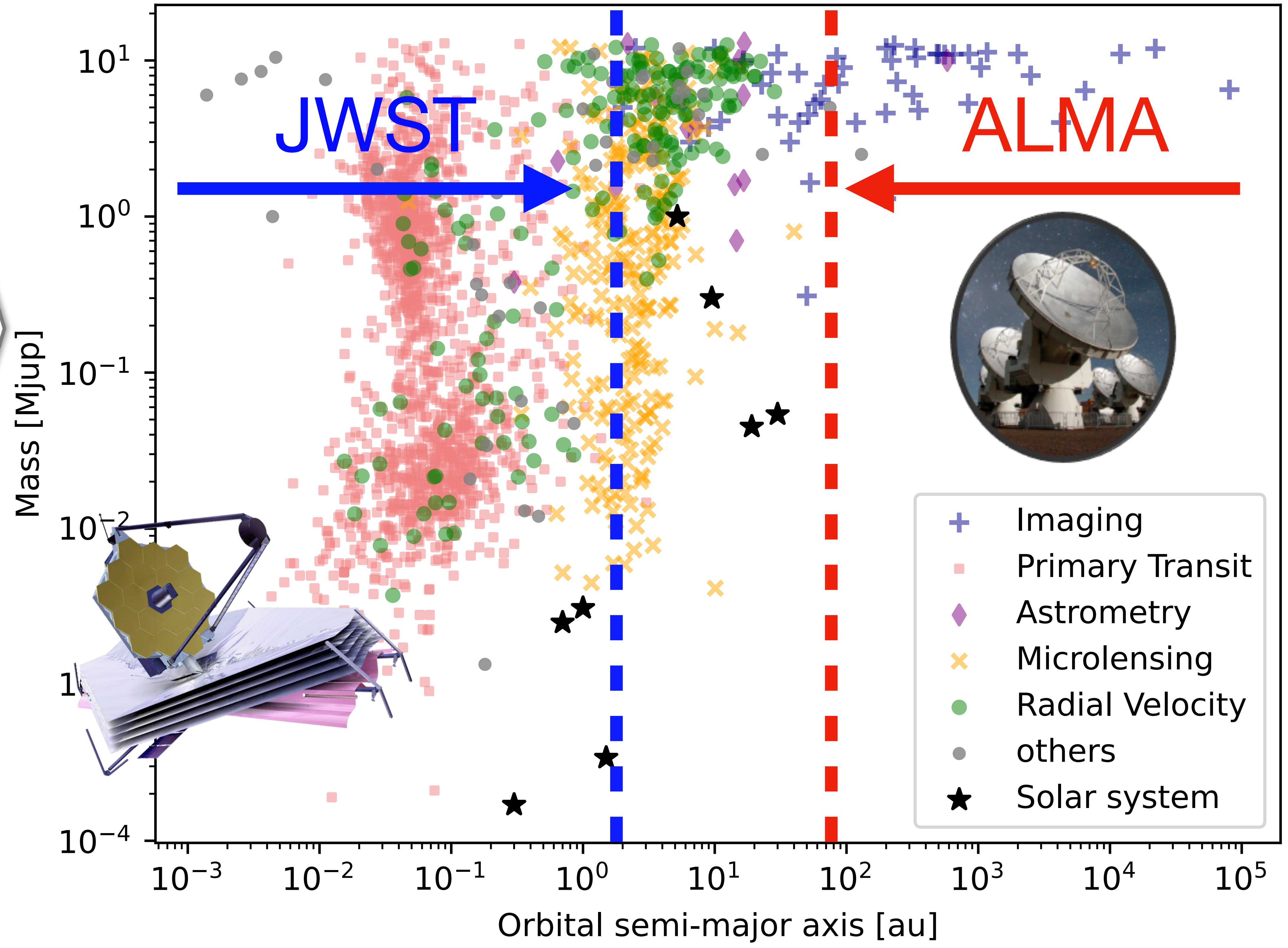
➡ Elemental composition of exoplanets



Planet formation models

End-product: populations of exoplanets

exoplanet.eu

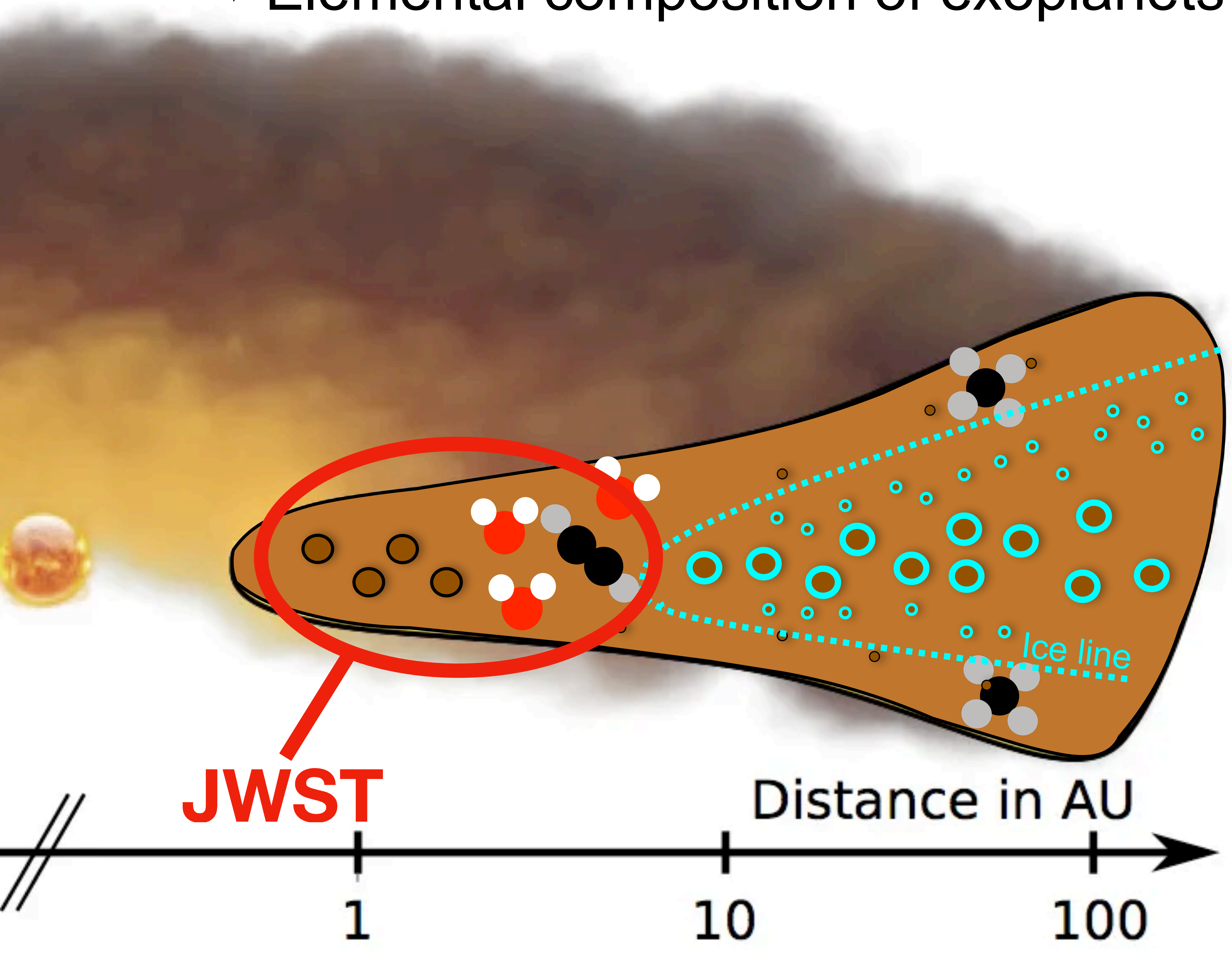


Linking exoplanet to their formation

Planet formation theories need constraints on disk properties to interpret the properties of exoplanets

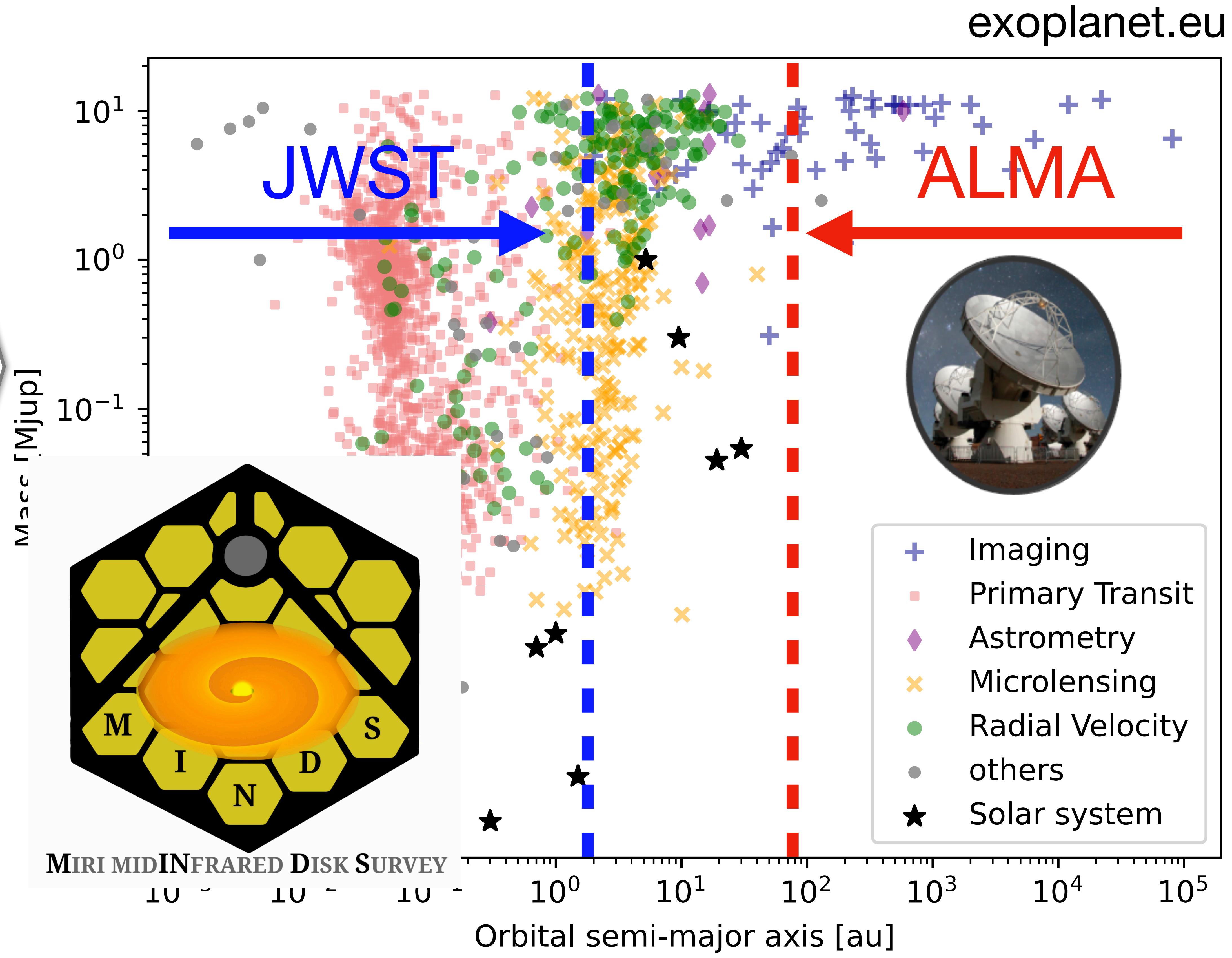
Chemical composition?

➡ Elemental composition of exoplanets



Planet formation models

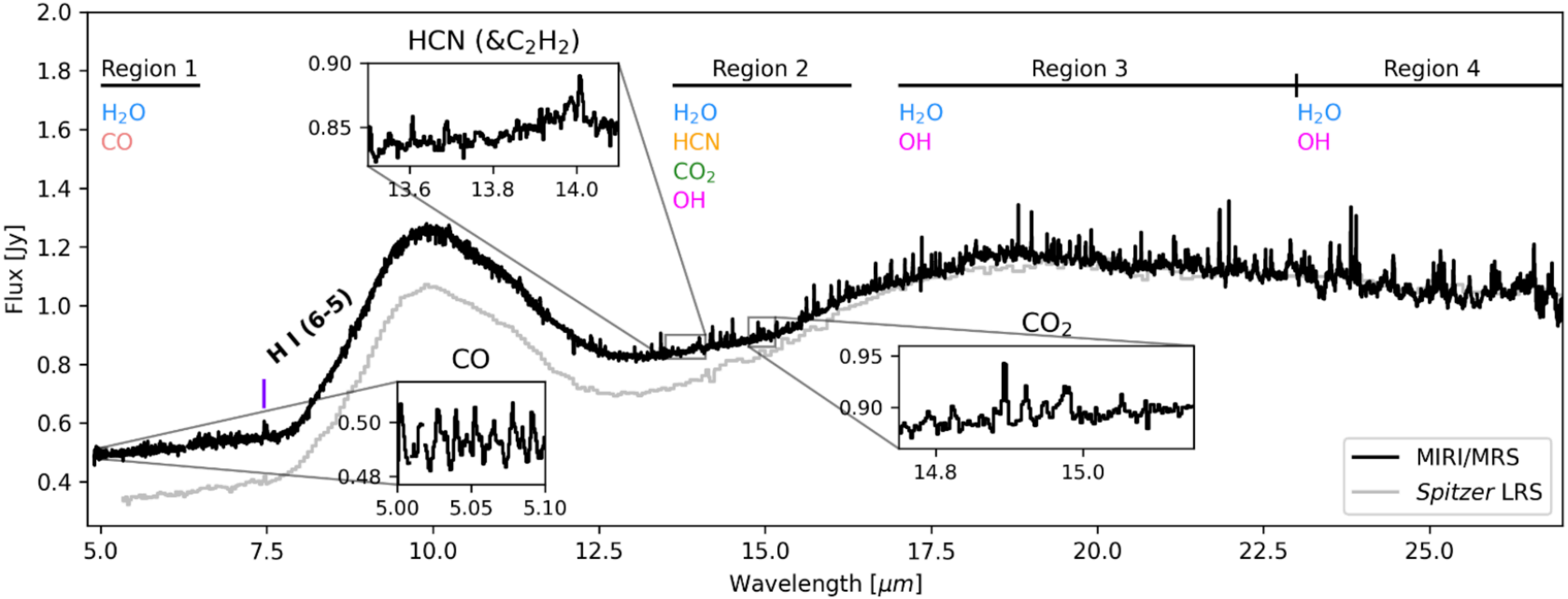
End-product: populations of exoplanets



Unveiling the inner regions with JWST

JWST reveals the chemical content of inner region of protoplanetary disks

- → *Sensitivity never achieved before* → *detection of new species*
- → *Good spectral resolution for a very wide spectral coverage* → *characterization of species*

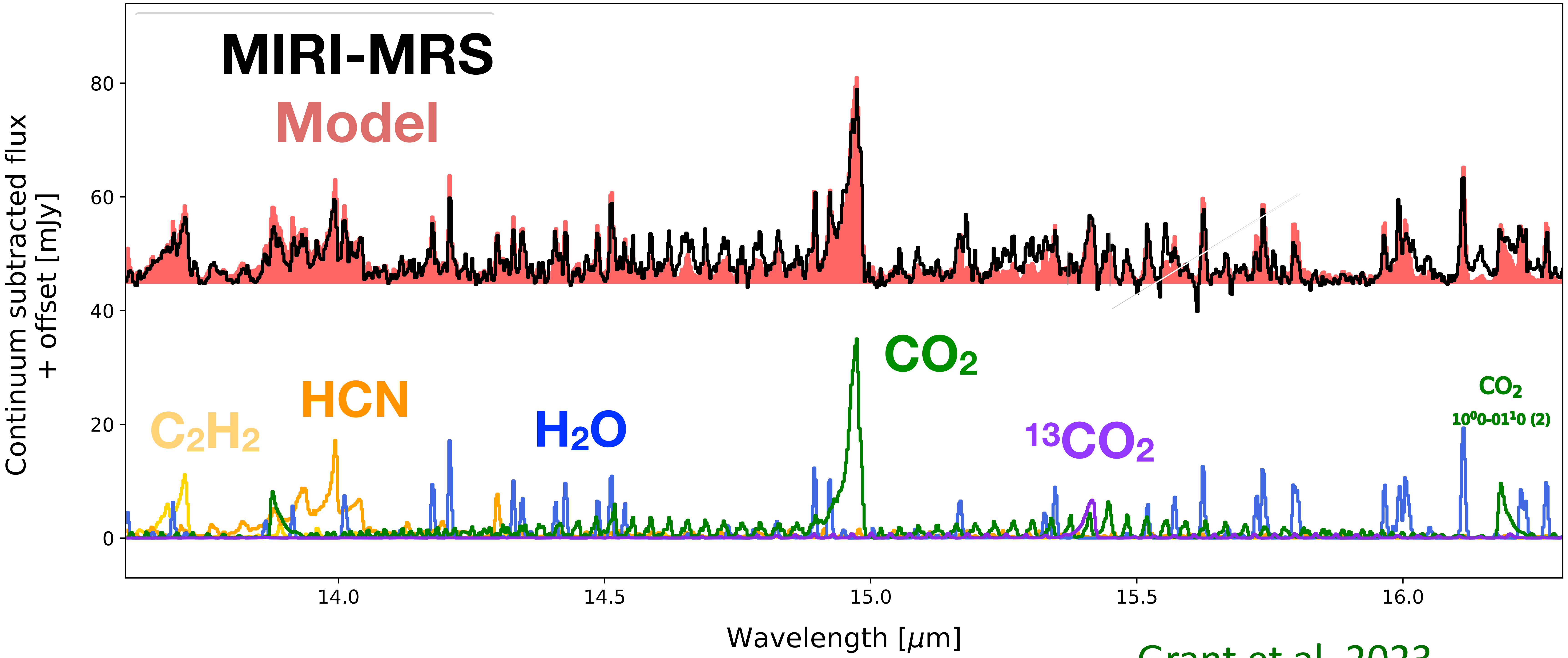


JWST/MIRI spectrum of Sz 98. From Gasman et al. 2023.

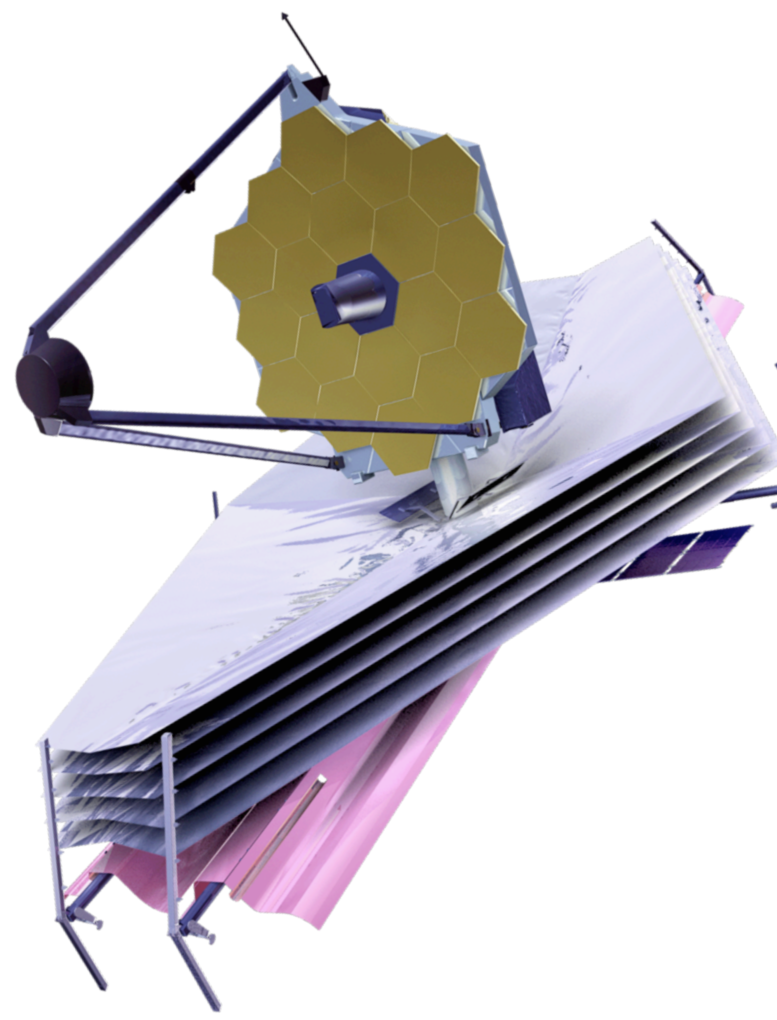
Unveiling the inner regions with JWST

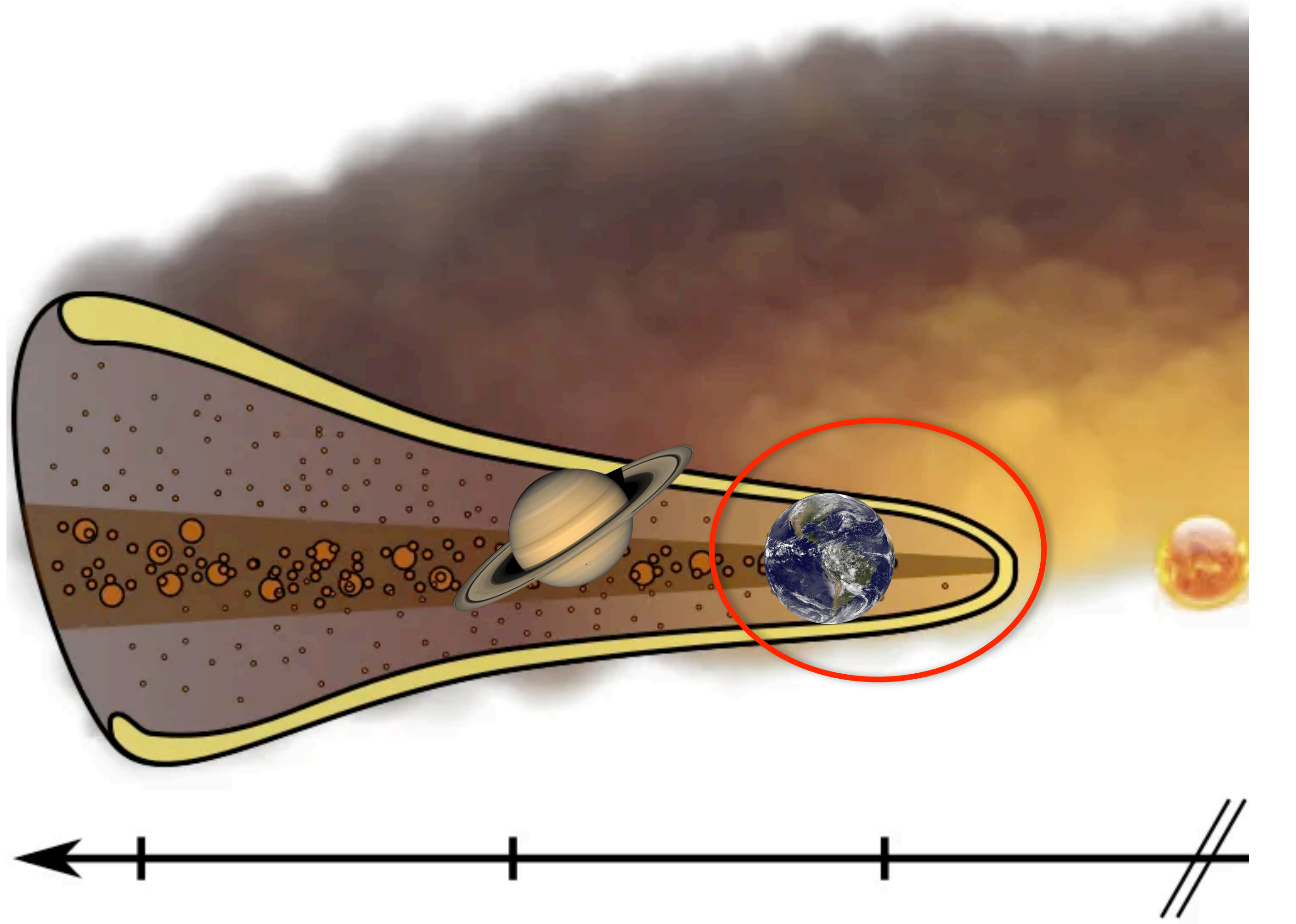
Mid-infrared: inner < 5 au disk

- H_2O, C_2H_2, HCN, OH, CO_2, CO *widely detected*
- *main C, N, and O carriers observable + mineralogy of small grains*



Grant et al. 2023

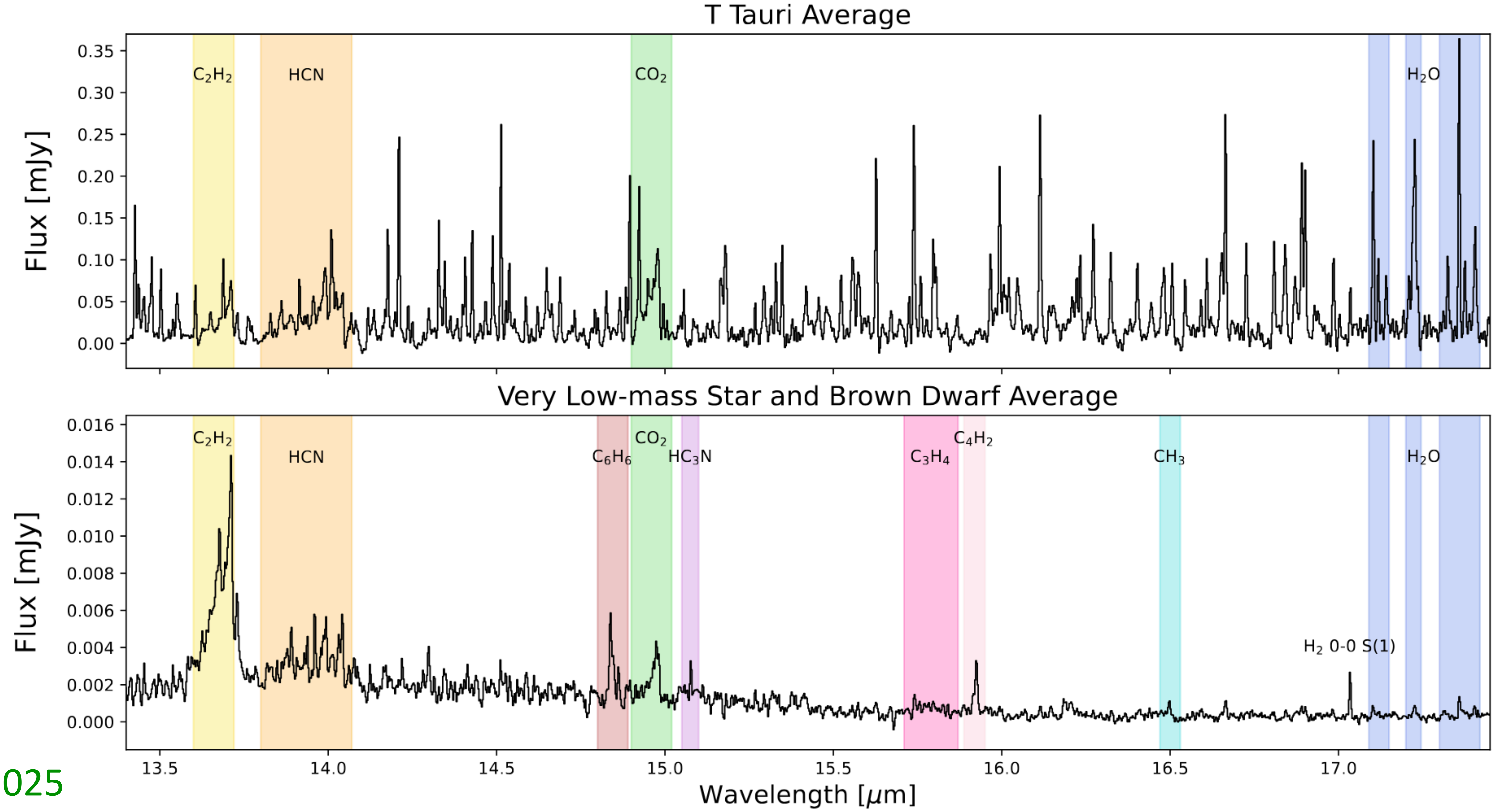




Molecular composition of inner disk depends on stellar mass

- *VLMS disks show prominent* C_2H_2, C_6H_6 *and little* H_2O
- *T Tauri disks show prominent* H_2O *and little* C_2H_2

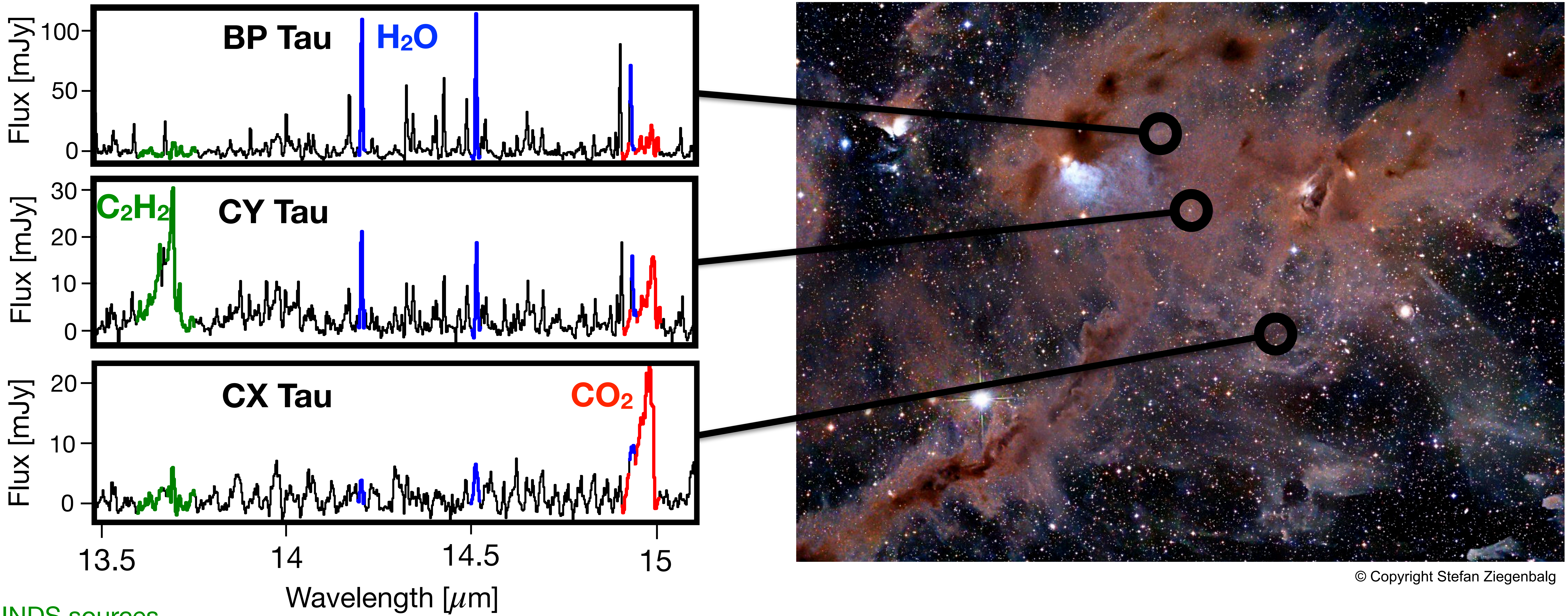
→ ***Composition of disks highly dependent on stellar mass***



Grant+2025

Emergence of the diversity of disks unveiled by JWST

- → *Same type, same age but very different JWST spectra*
- → *Diversity of exoplanet atmospheres ?*



JWST spectra of disks around 0.4 $M_\odot$ stars

The Taurus molecular cloud

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MINDS sources

Emergence of the diversity of disks unveiled by JWST

Inner disks inherit their composition from the icy pebbles of the outer disk

→ *Initially, solar C/O in the inner disk and super-solar C/O in outer disk*

Emergence of the diversity of disks unveiled by JWST

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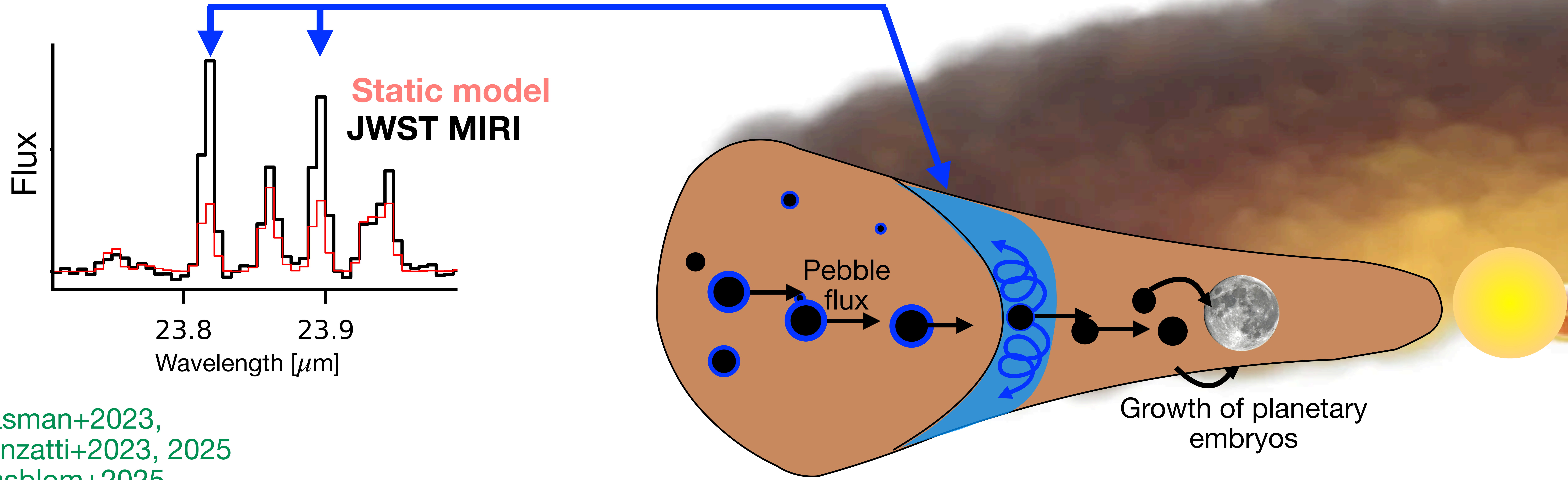
Water sublimation from cold water lines

Excess of cold water in compact disks

→ *interpreted as inflow of H_2O-rich pebble followed by diffusion but based on few H_2O lines*

→ *molecular lines not only tracing chemistry but also dynamical processes*



Gasman+2023,
Banzatti+2023, 2025
Vlasblom+2025

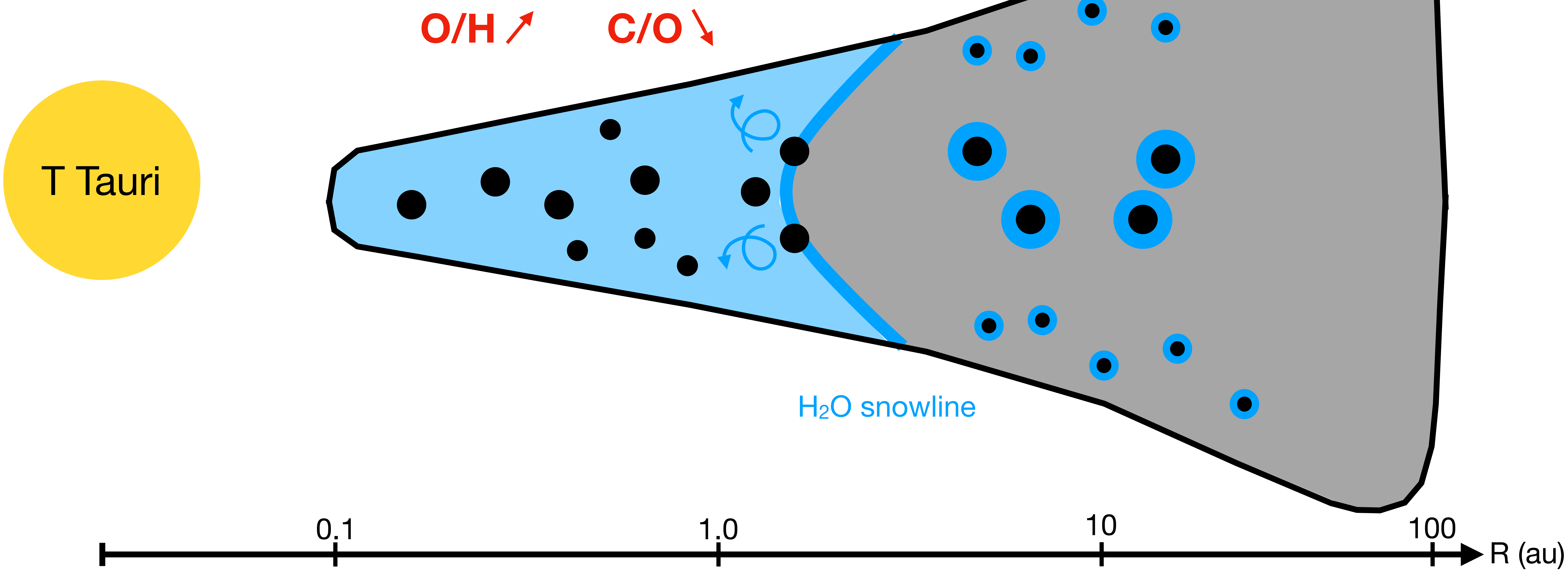
Emergence of the diversity of disks unveiled by JWST

Inner disks inherit their composition from the icy pebbles of the outer disk

→ *Initially, solar C/O in the inner disk and super-solar C/O in outer disk*

→ *By drifting, the icy pebbles cross the water snowlines*

→ *Enrichment of the inner disk in oxygen*

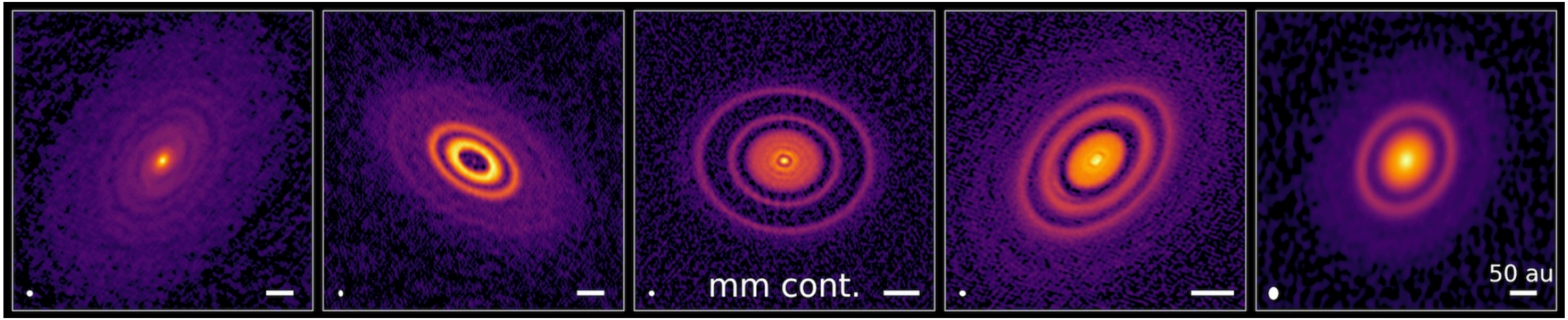


ALMA revealed highly structured disks

The substructures modify the delivery of elements in planet-forming regions

→ *Most of disks show substructures : rings, gaps, spirals …*

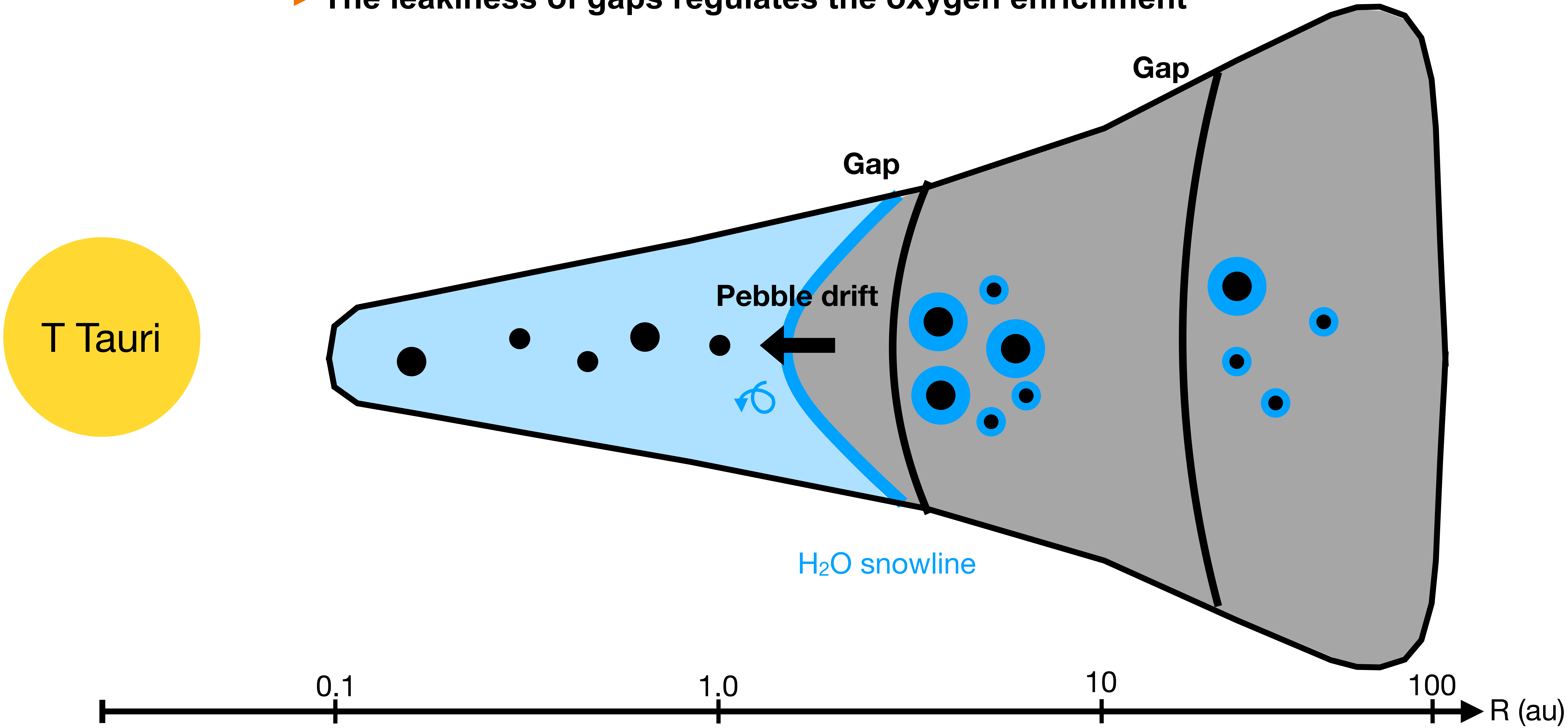
→ *The gaps prevent pebbles from enriching the inner regions in volatile species*



From ALMA large program MAPS (PI: Öberg, K)

Emergence of the diversity of disks unveiled by JWST

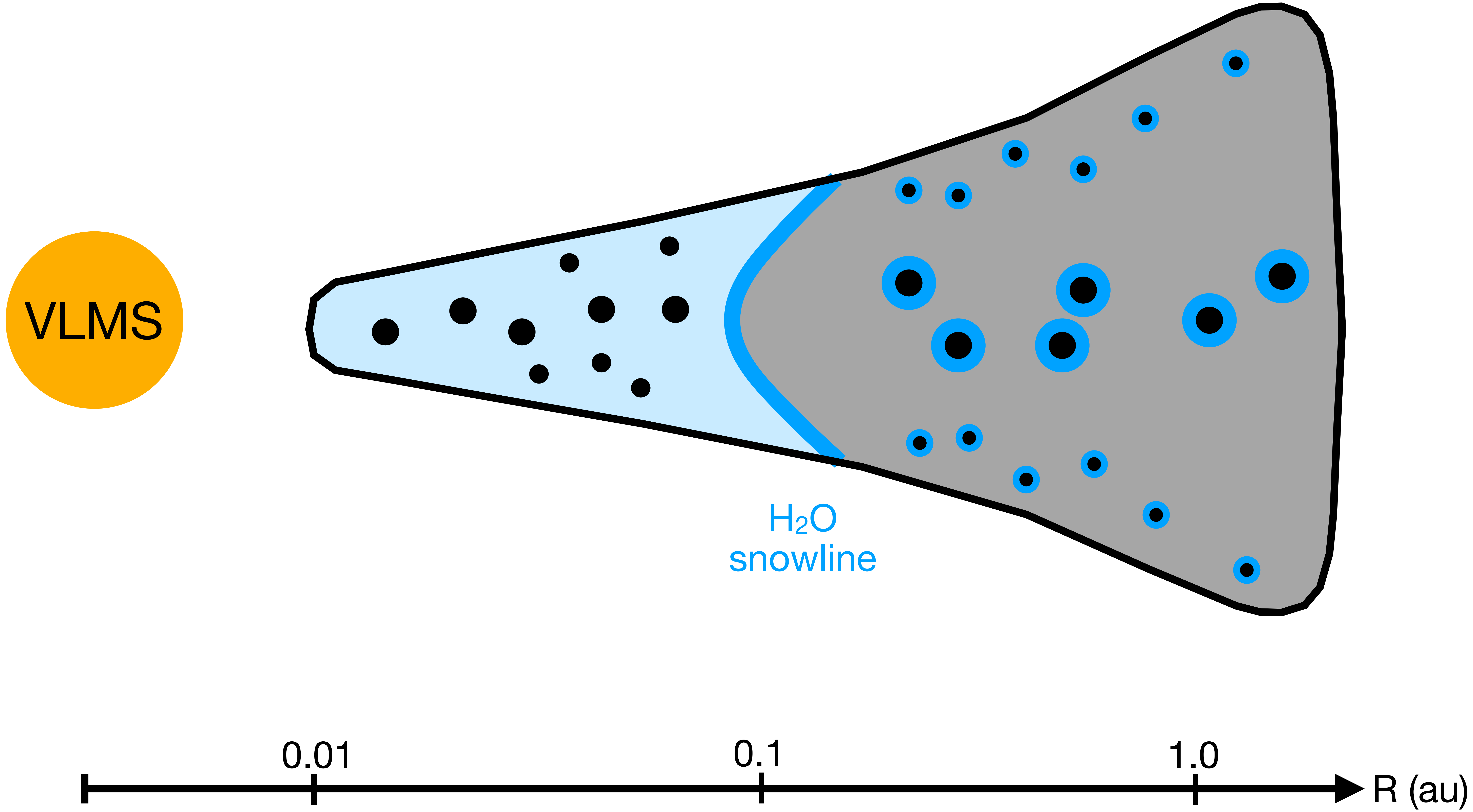
→ **The leakiness of gaps regulates the oxygen enrichment**



Molecular composition of inner disk depends on stellar mass

Evolution of VLMS is faster than T Tauri disks

→ *First steps: same as T Tauri stars*



Molecular composition of inner disk depends on stellar mass

Evolution of VLMS is faster than T Tauri disks

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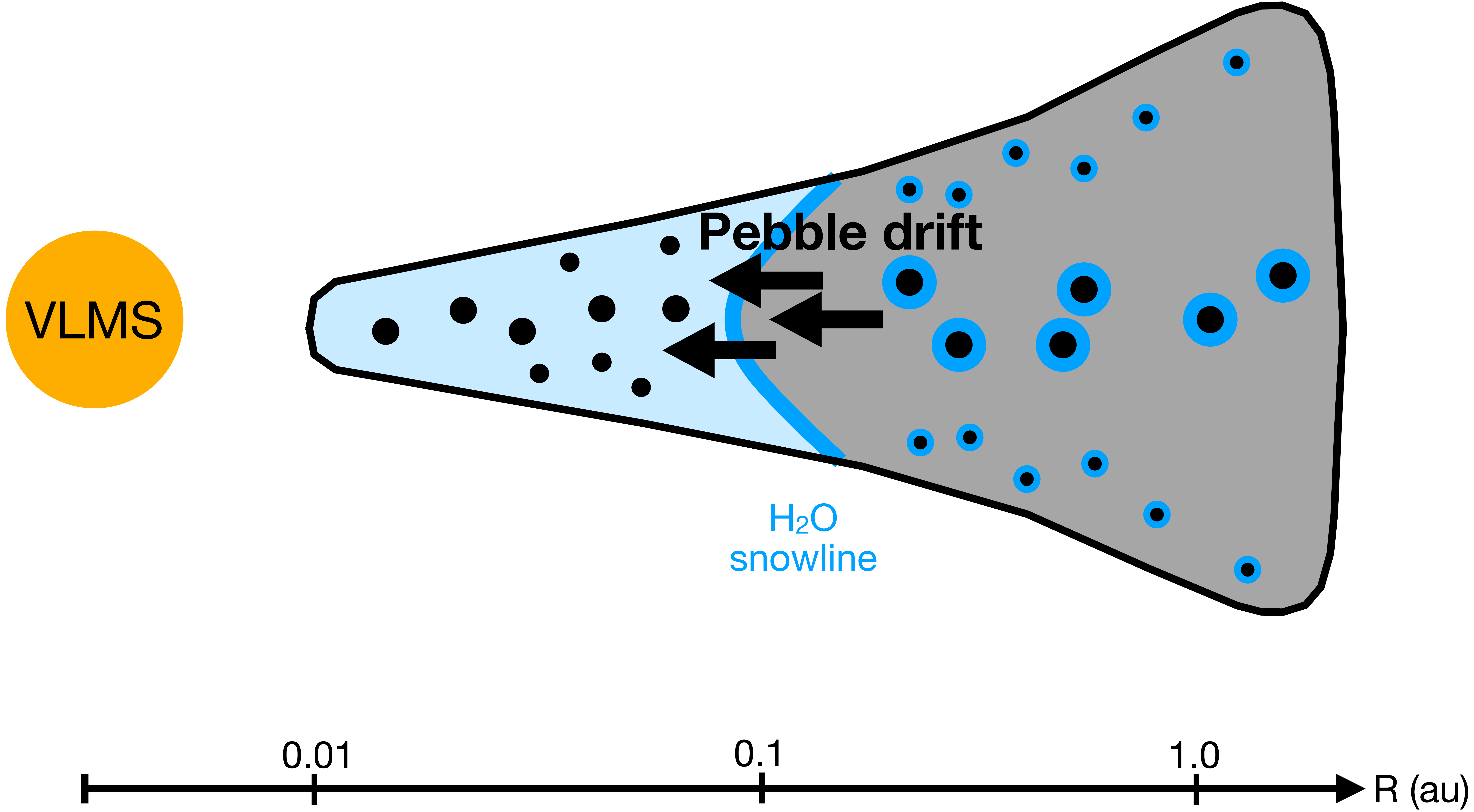
→ *As the disk is much smaller, these steps are much quicker*



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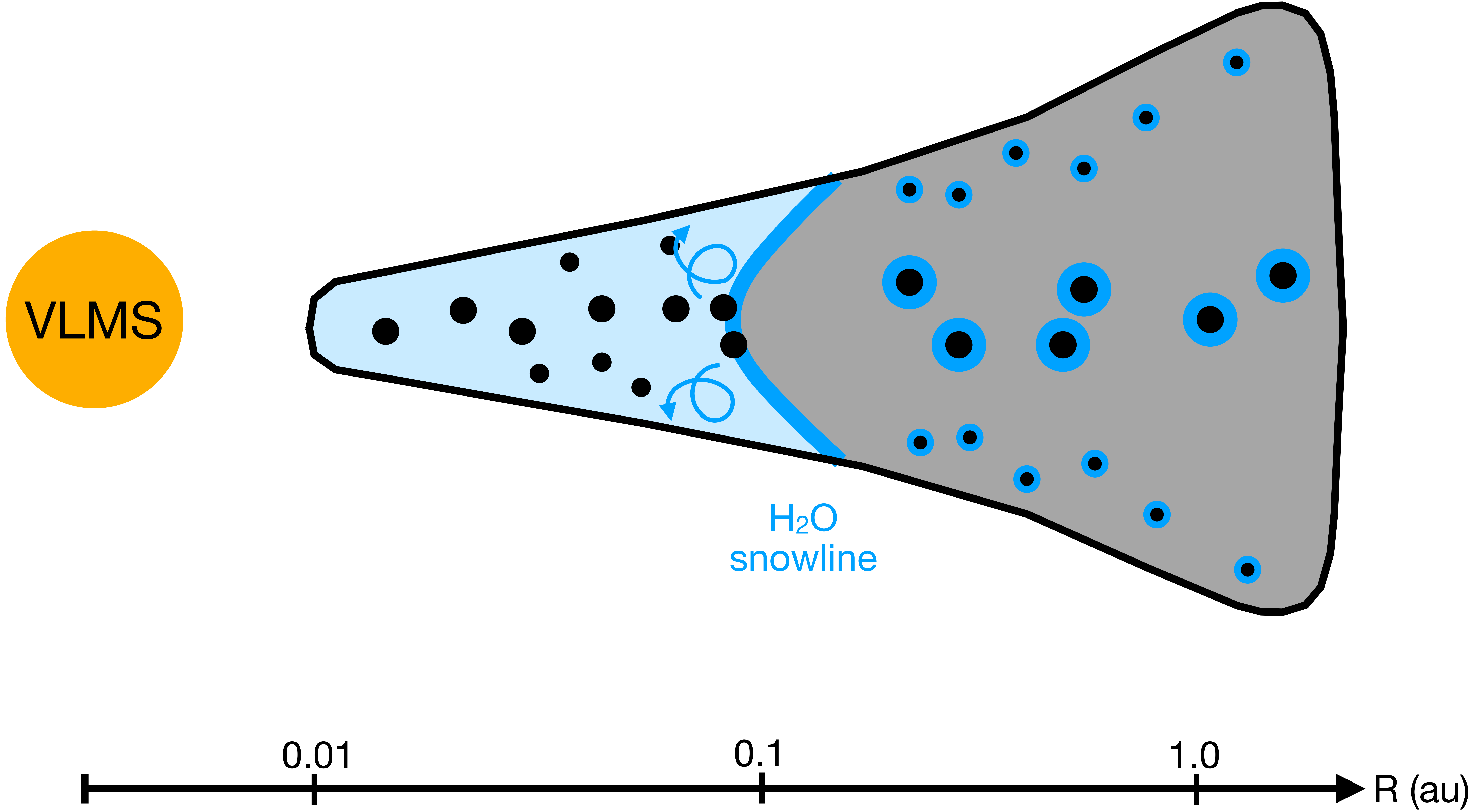

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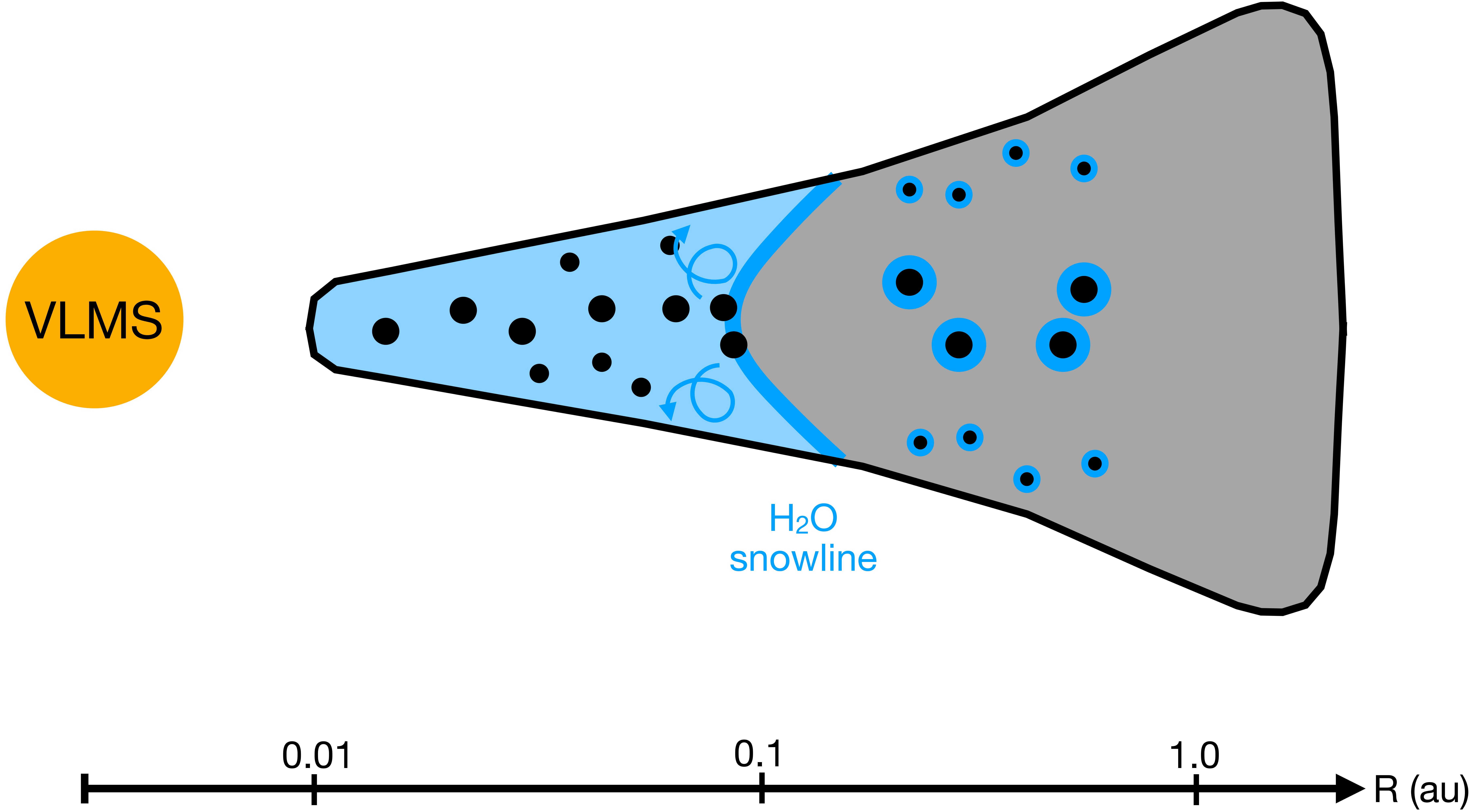

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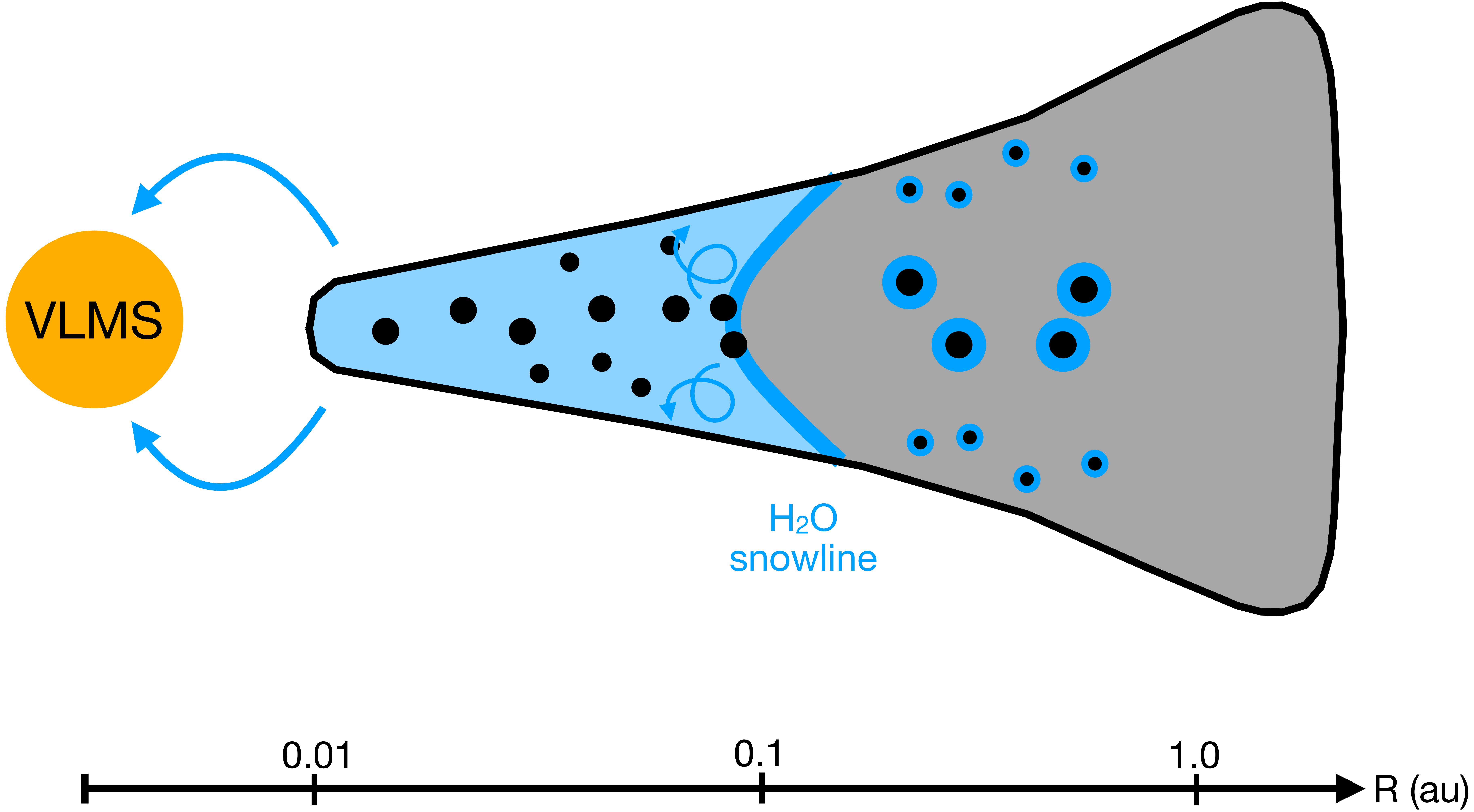
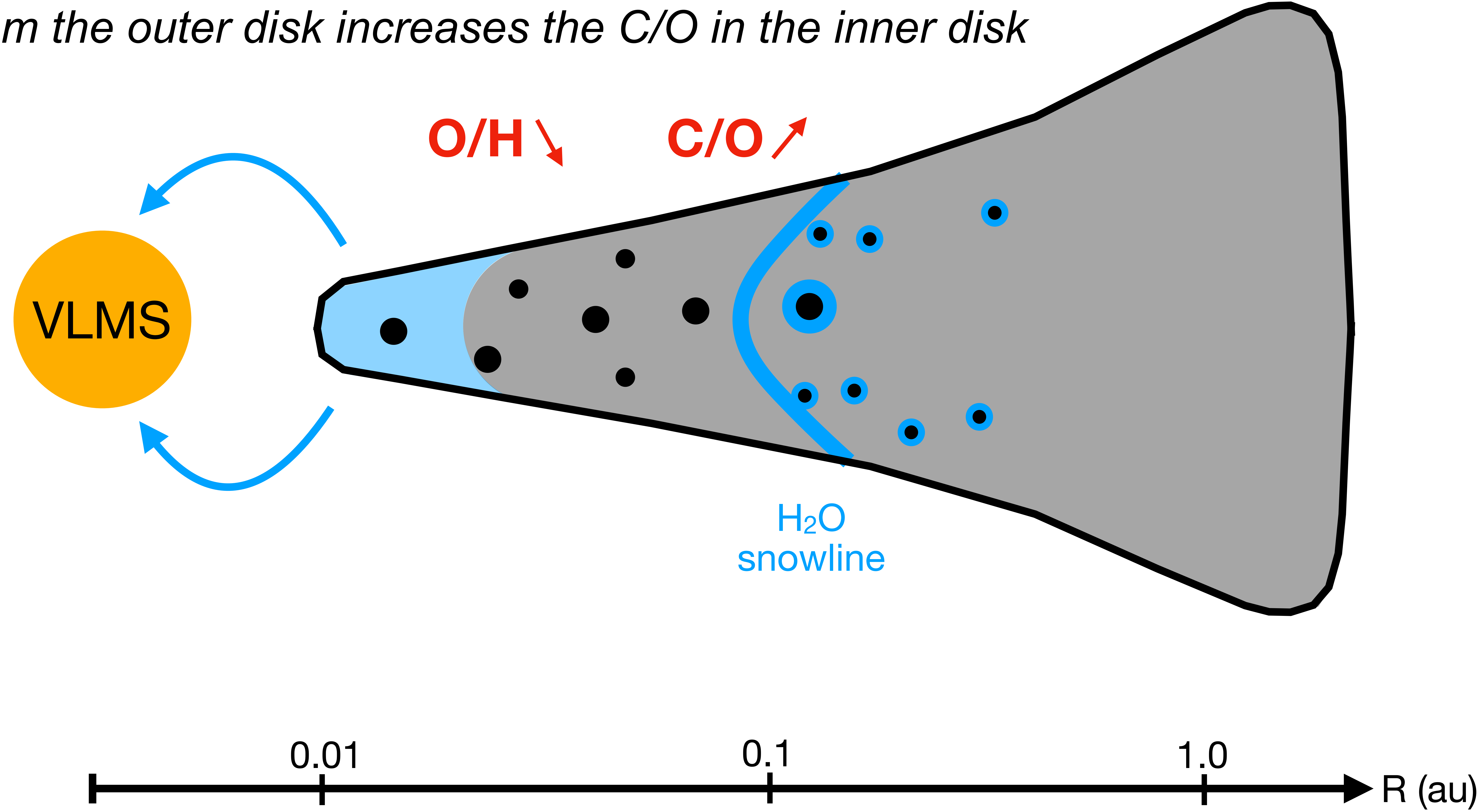


Molecular composition of inner disk depends on stellar mass

Evolution of VLMS is faster than T Tauri disks

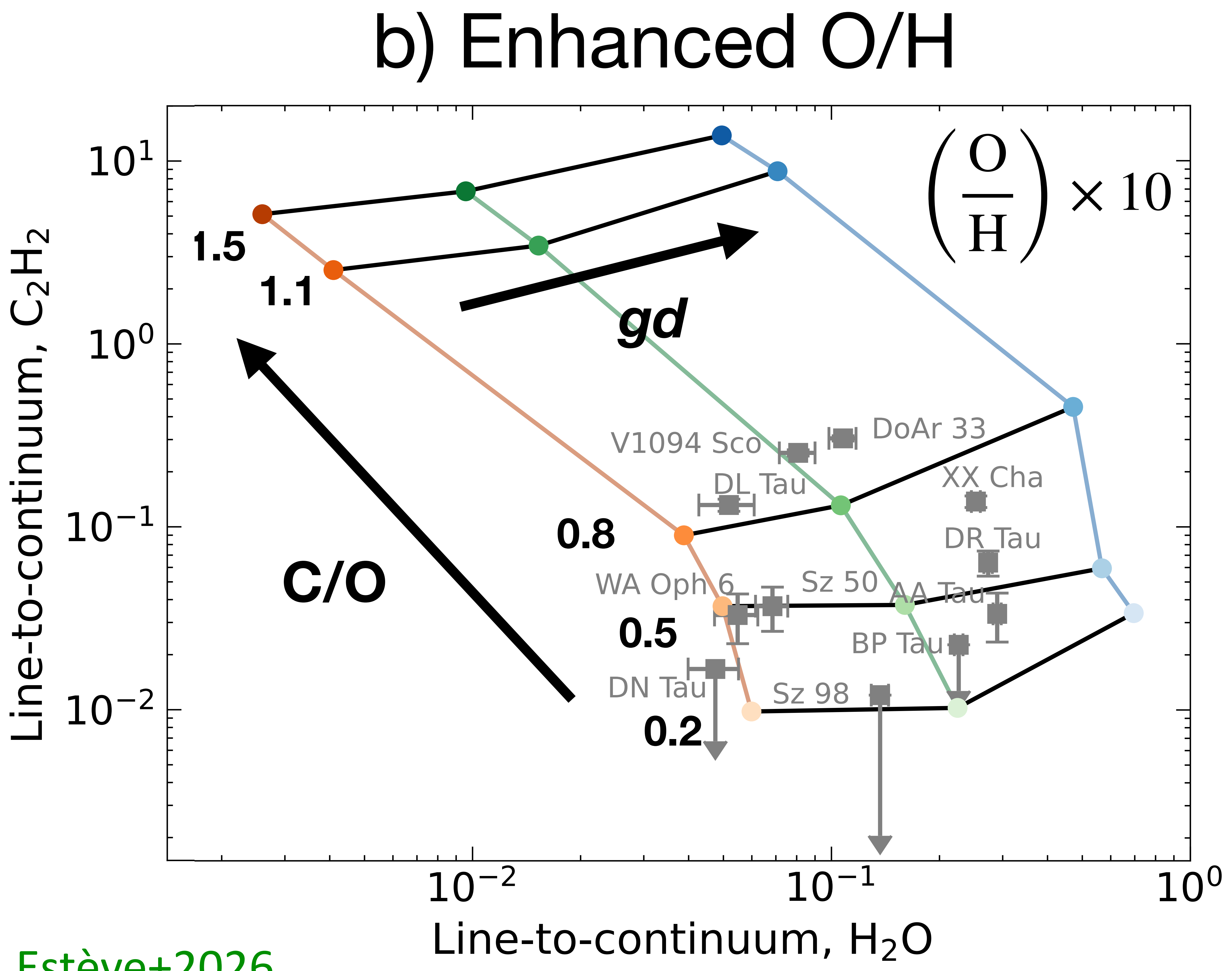
- → *First steps: same as T Tauri stars*
- → *As the disk is much smaller, these steps are much quicker*
- → *The gas from the outer disk increases the C/O in the inner disk*



Inferring elemental abundances with thermochemical models

Firsts constraints on elemental abundances in inner T Tauri disks

- → *Most T Tauri disks show C/O < 1 and possibly oxygen enhancement*
- → *In line with the pebble drift scenario!*



Estève+2026

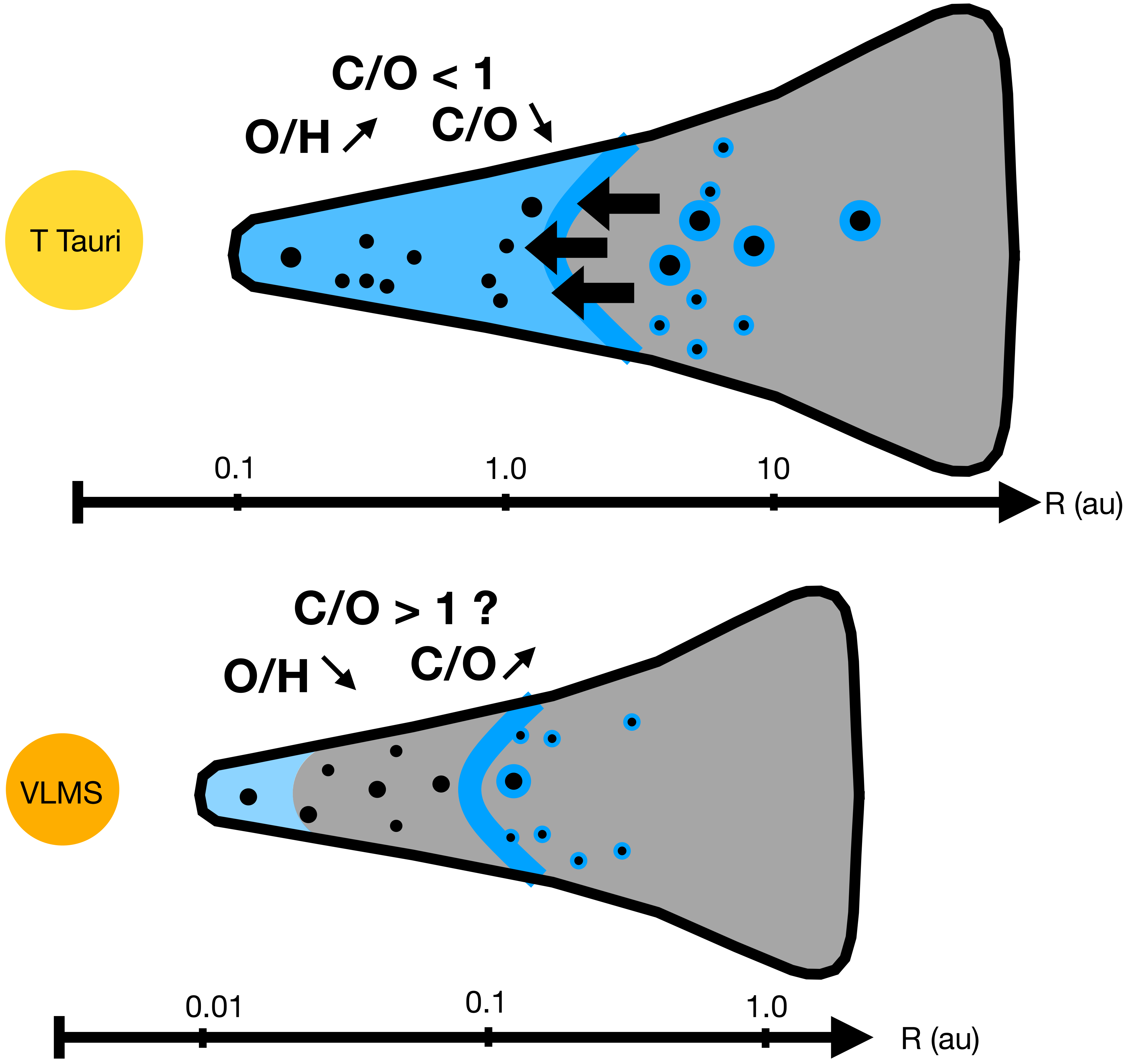
Summary

- **Elemental abundances** in planet-forming regions of disks are key to contrain **the formation history of exoplanets**

- **JWST revealed a diversity of inner disk composition,** interpreted as the result of the pebble drift with different efficiencies depending **on the leakiness of gaps.**

- The outer disk material sets the elemental abundances of the inner disk: **link between ALMA and JWST communities?**

- **Thermochemical models indicate C/O < 1 for inner T Tauri disks,** with possibly oxygen enrichment, consistent with pebble drift



Backup slides

Water sublimation from cold water lines

Excess of cold water in compact disks

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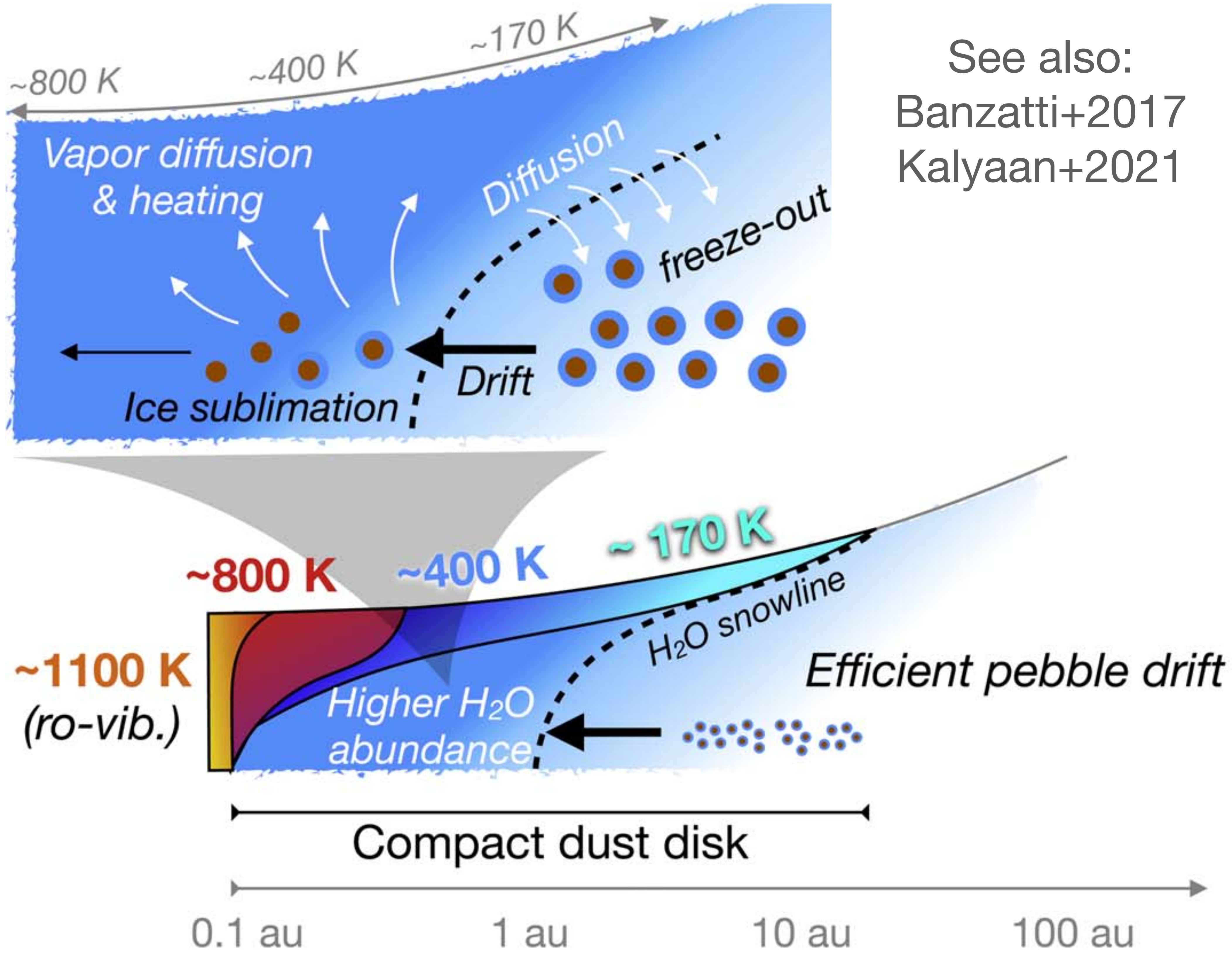
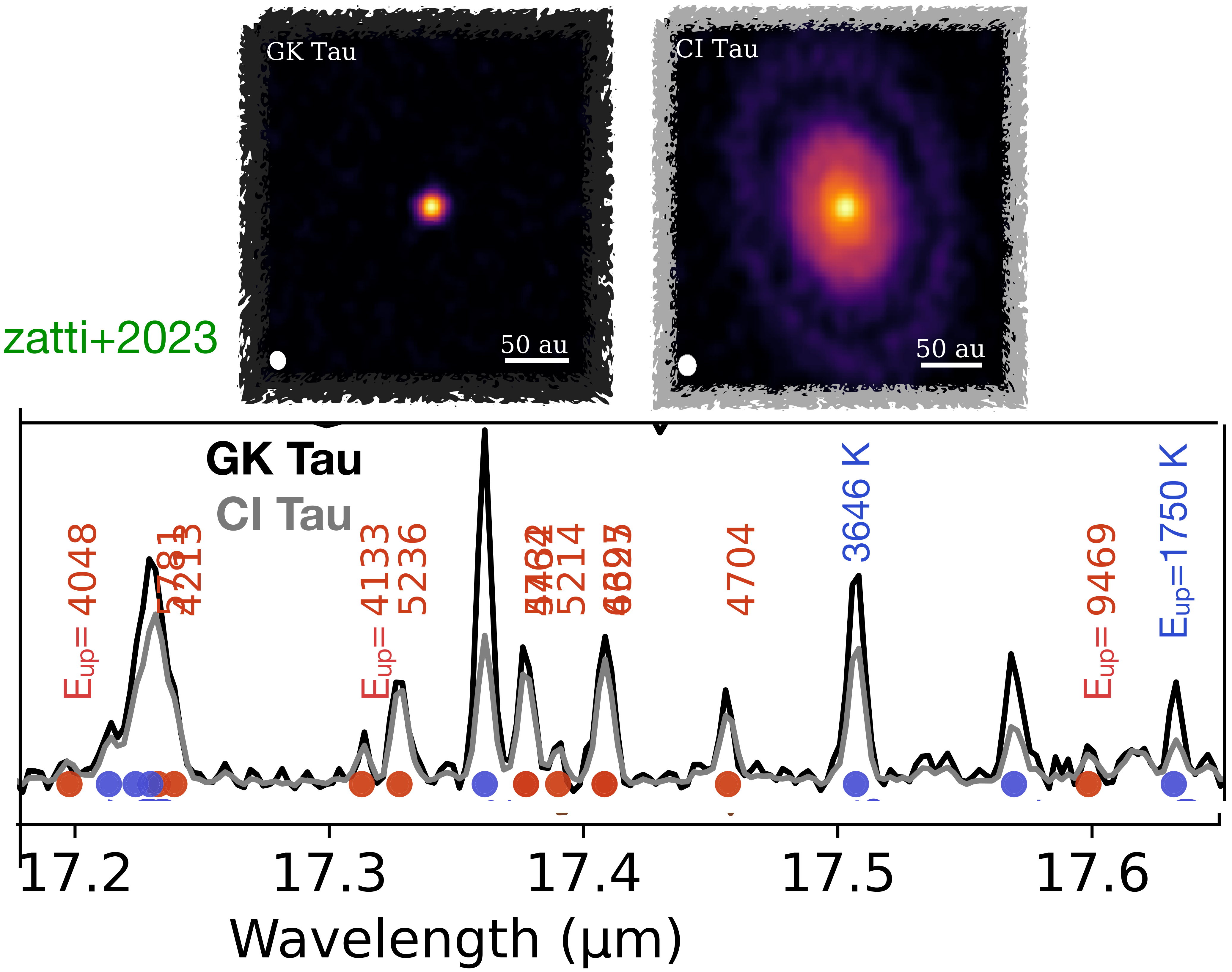
→ *molecular lines not only tracing chemistry but also dynamical processes*



See also:
Banzatti+2017
Kalyaan+2021

Excess of cold water emission in a compact disk

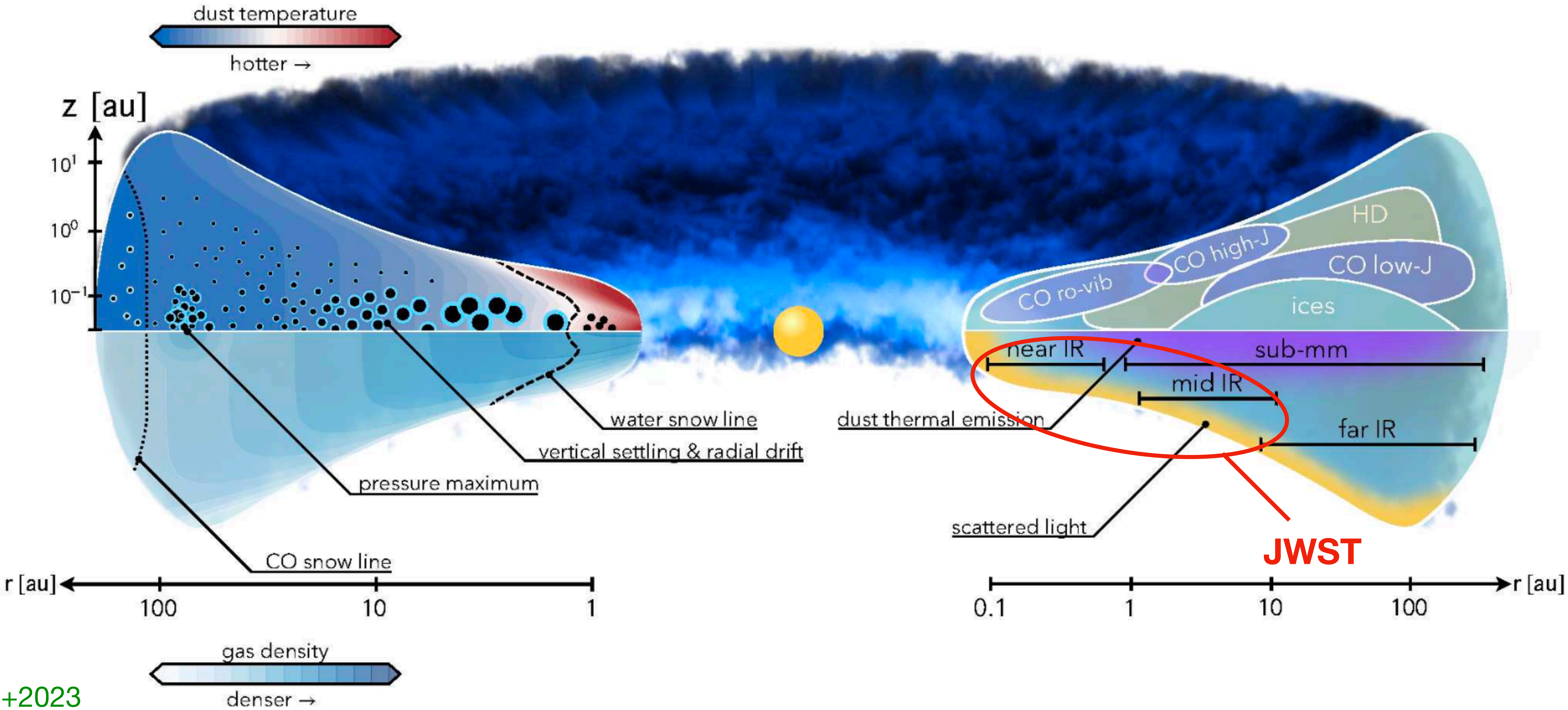
Banzatti+2023



JWST: a revolution for protoplanetary disks

JWST reveals the chemical content of inner region of protoplanetary disks

- *Sensitivity never achieved before → detection of new species*
- *Good spectral resolution for a very wide spectral coverage → characterization of species*



Miotello+2023

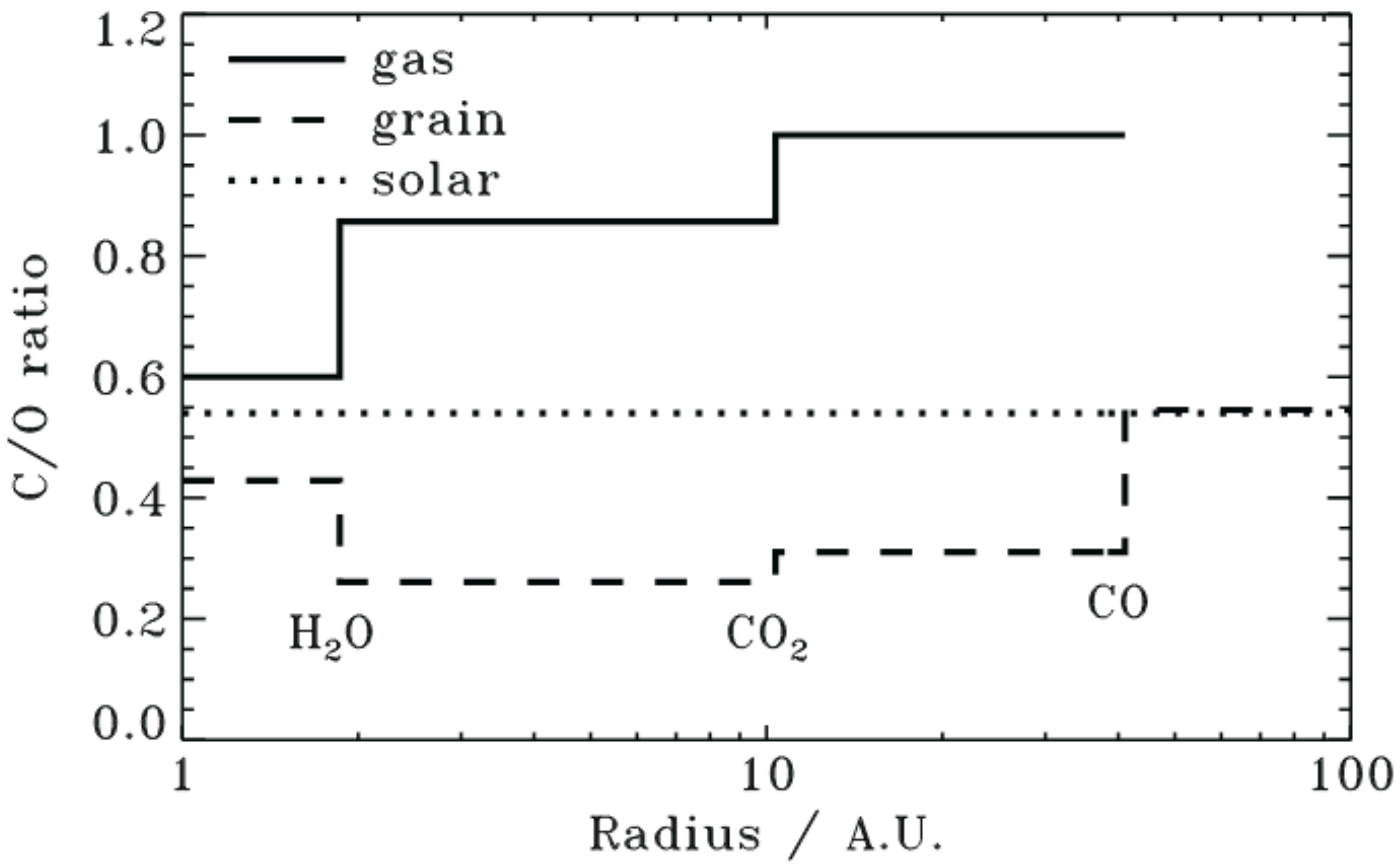
Linking exoplanet to disks: the era of chemistry

The elemental abundances of the gas and in solids (dust+ice) vary in time and space

→ *opportunity to constrain the formation history of planets (e.g., ultimate goal of the ARIEL mission)*

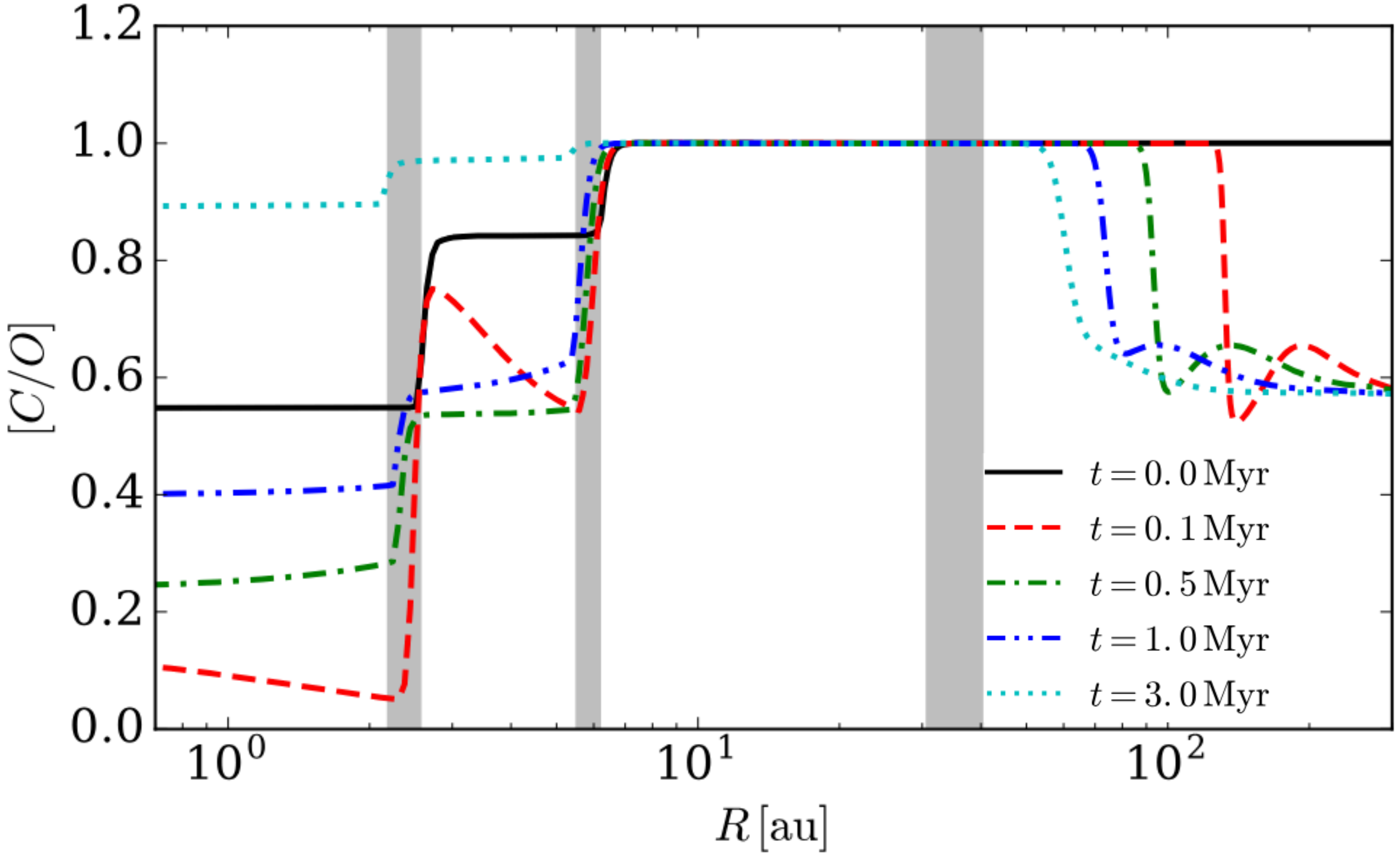
→ *large number of processes changing the disk elemental abundances*

→ *need to characterize the chemical composition of disks across space and time*



C/O ratio due to the freeze out of volatiles

Oberg+2011

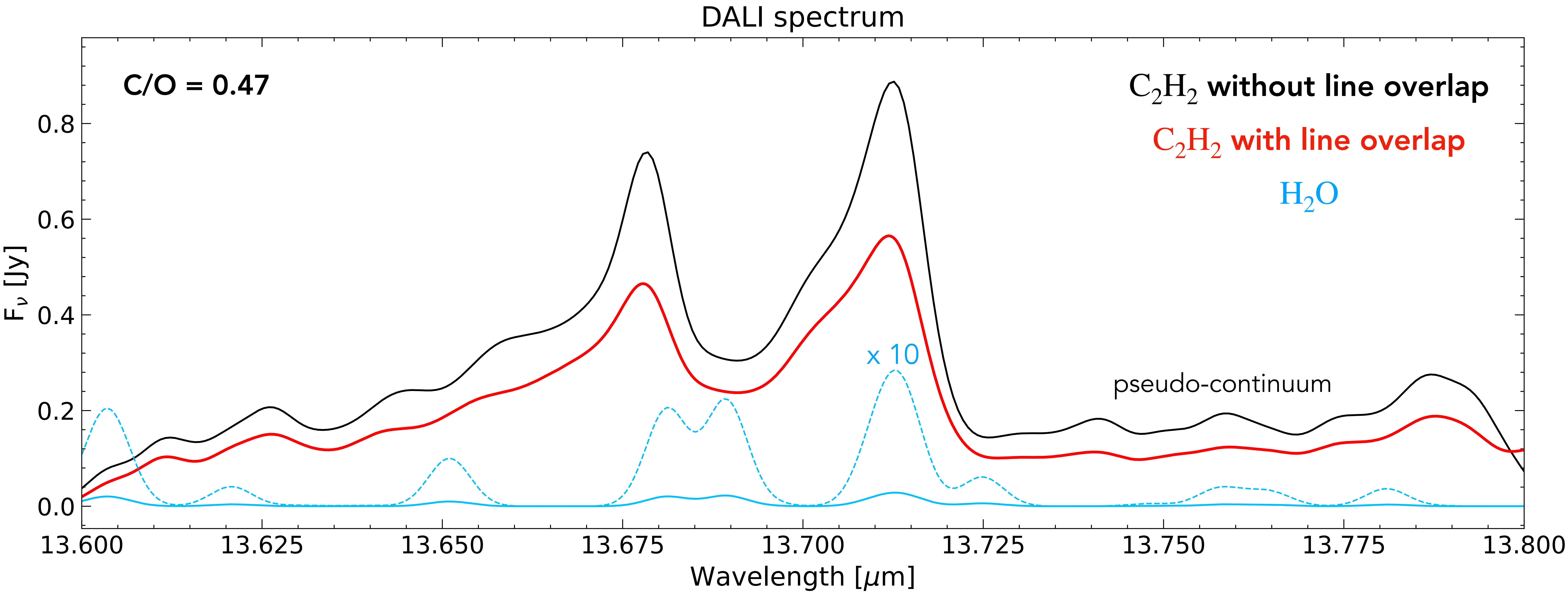


C/O ratio due to the freeze out of volatiles and radial drift

Booth+2017

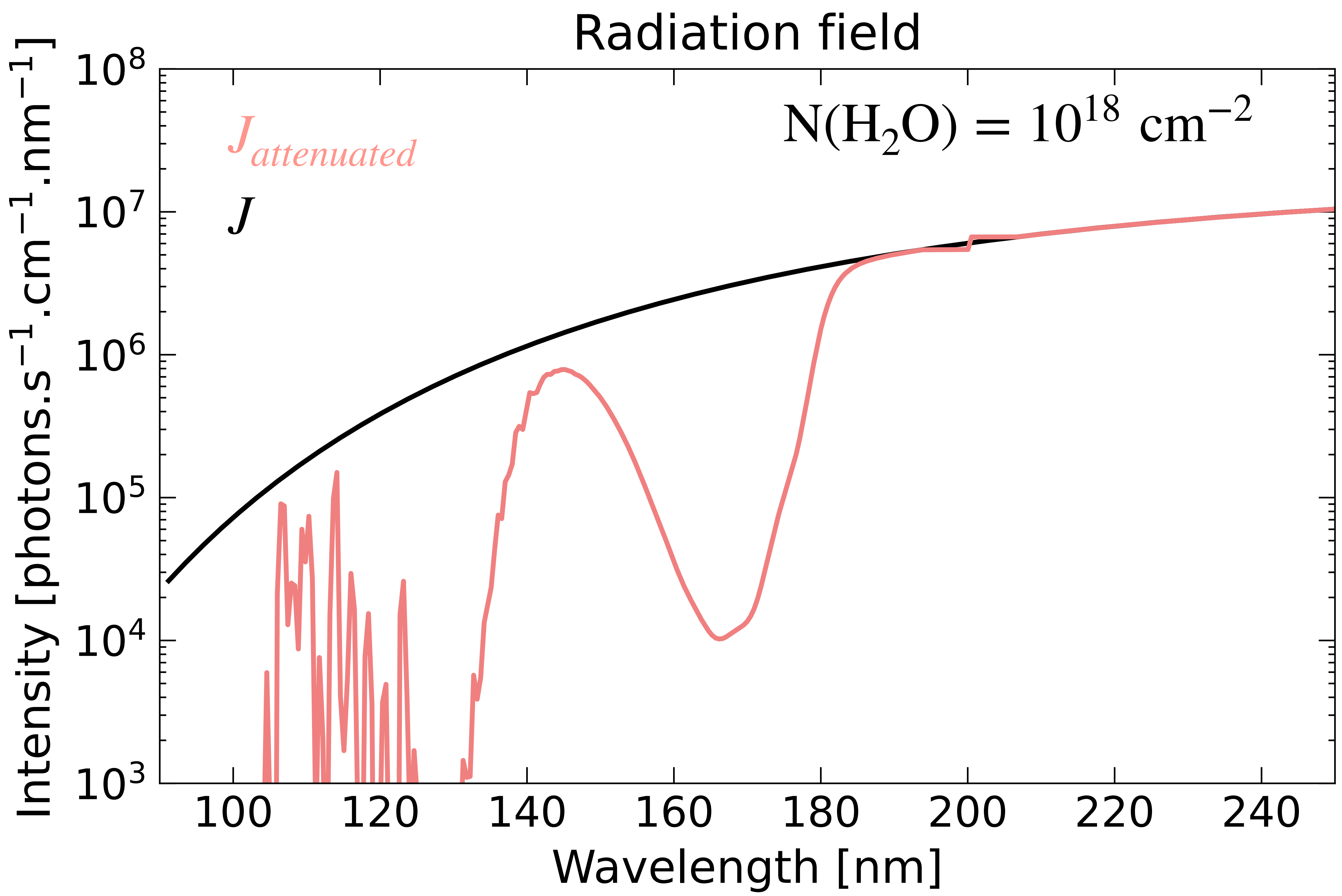
Line overlap implementation

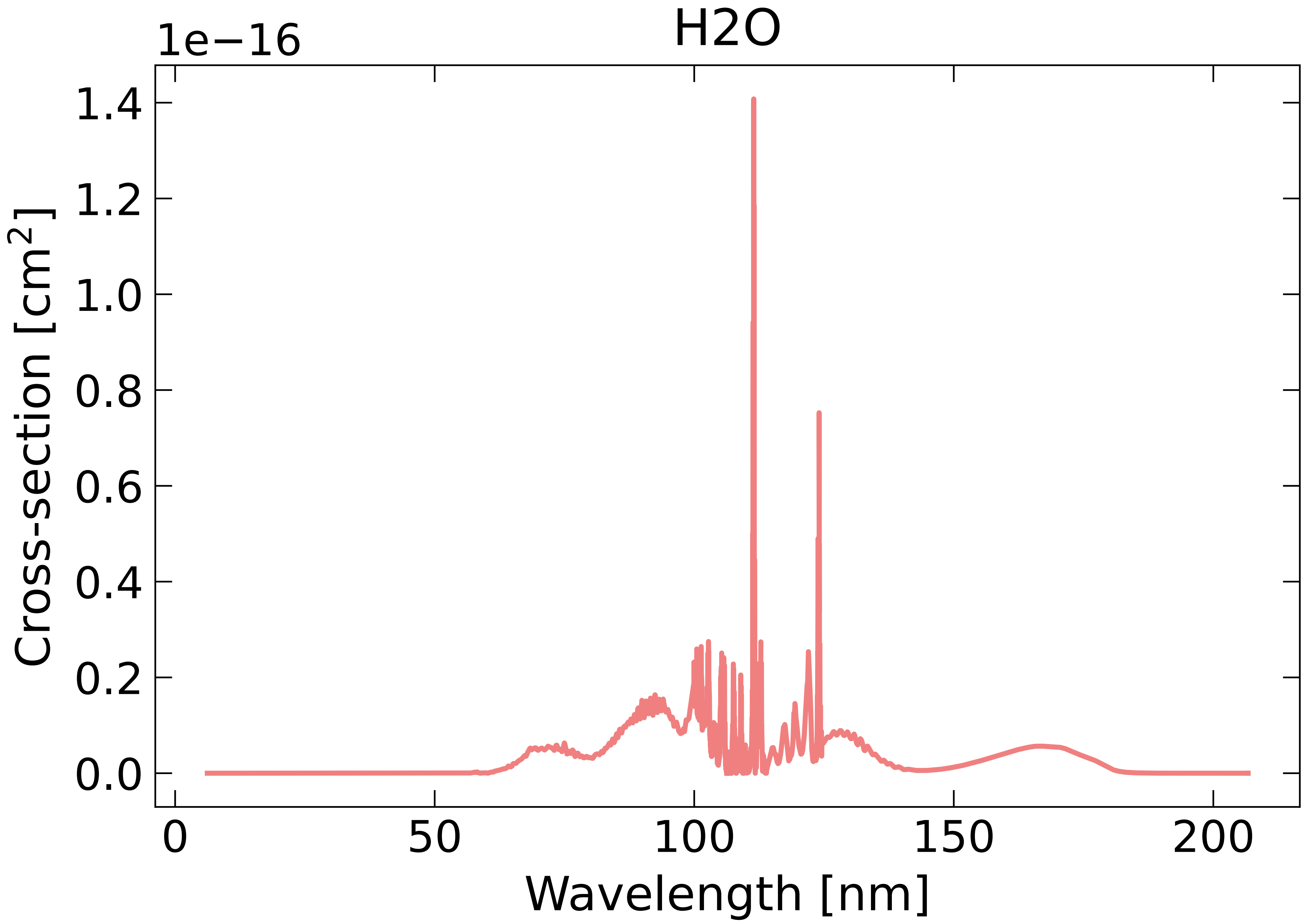
- Effect of the line overlap prominent in the main Q-branch feature of C_2H_2
- With a Solar C/O ratio, C_2H_2 remains ~10x too bright



UV shielding

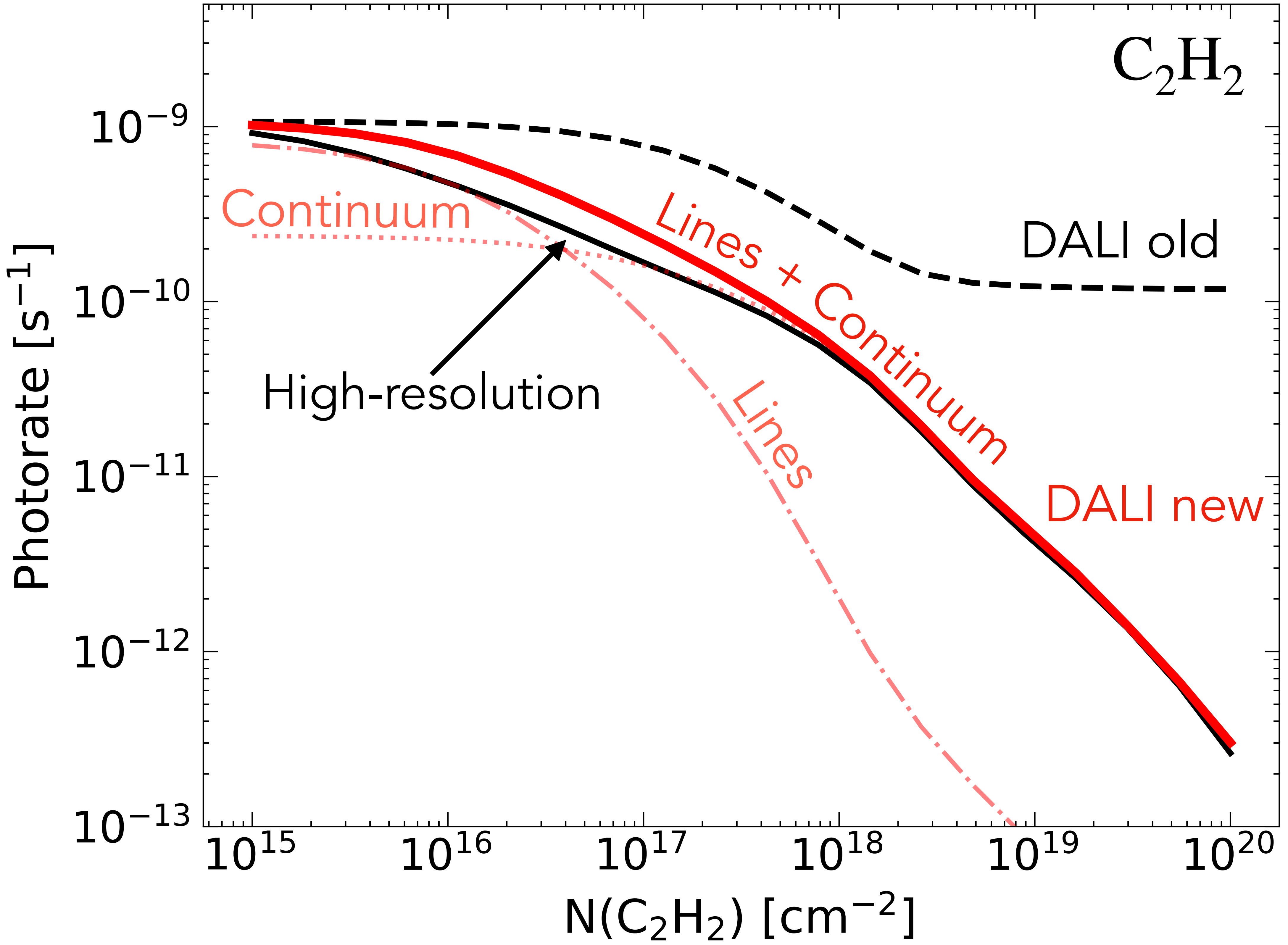
→ Molecules can absorb UV photons and attenuate the UV field: $\sigma_\nu N_i$





UV shielding

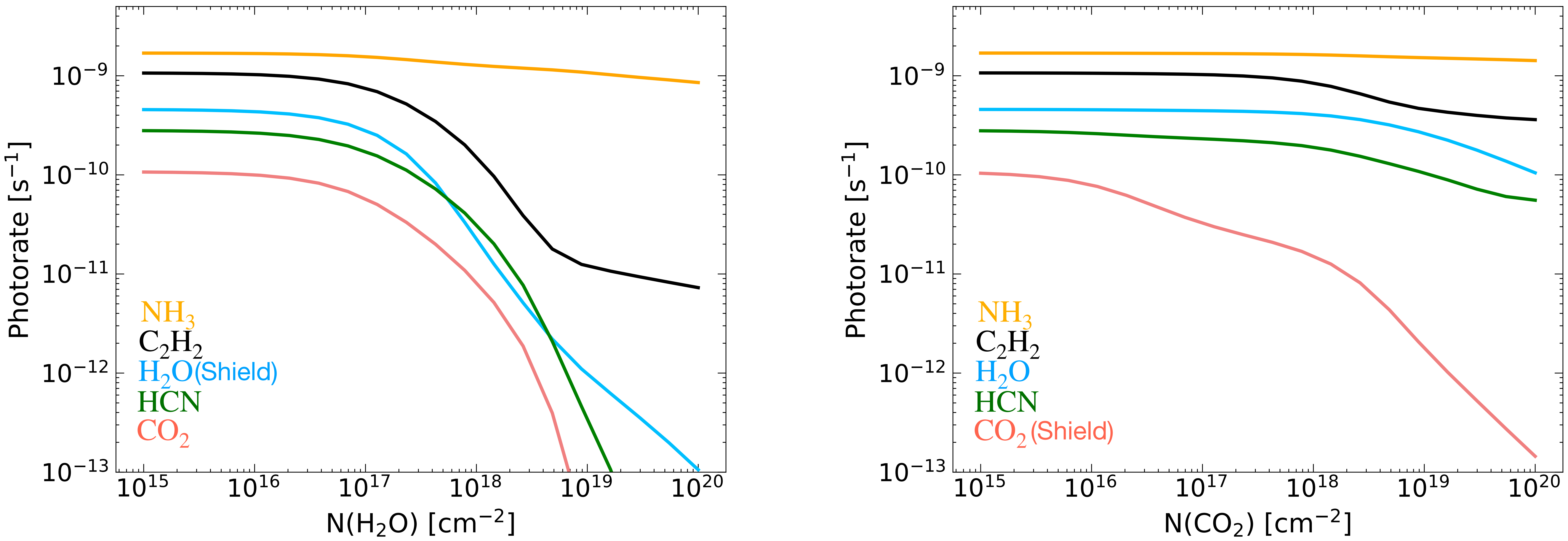
- Separation line/continuum reproduces very well the « real » self-shielding
- Crucial role of self-shielding at low column densities



Photodissociation rate of C_2H_2 as a function of the column density (shielding)

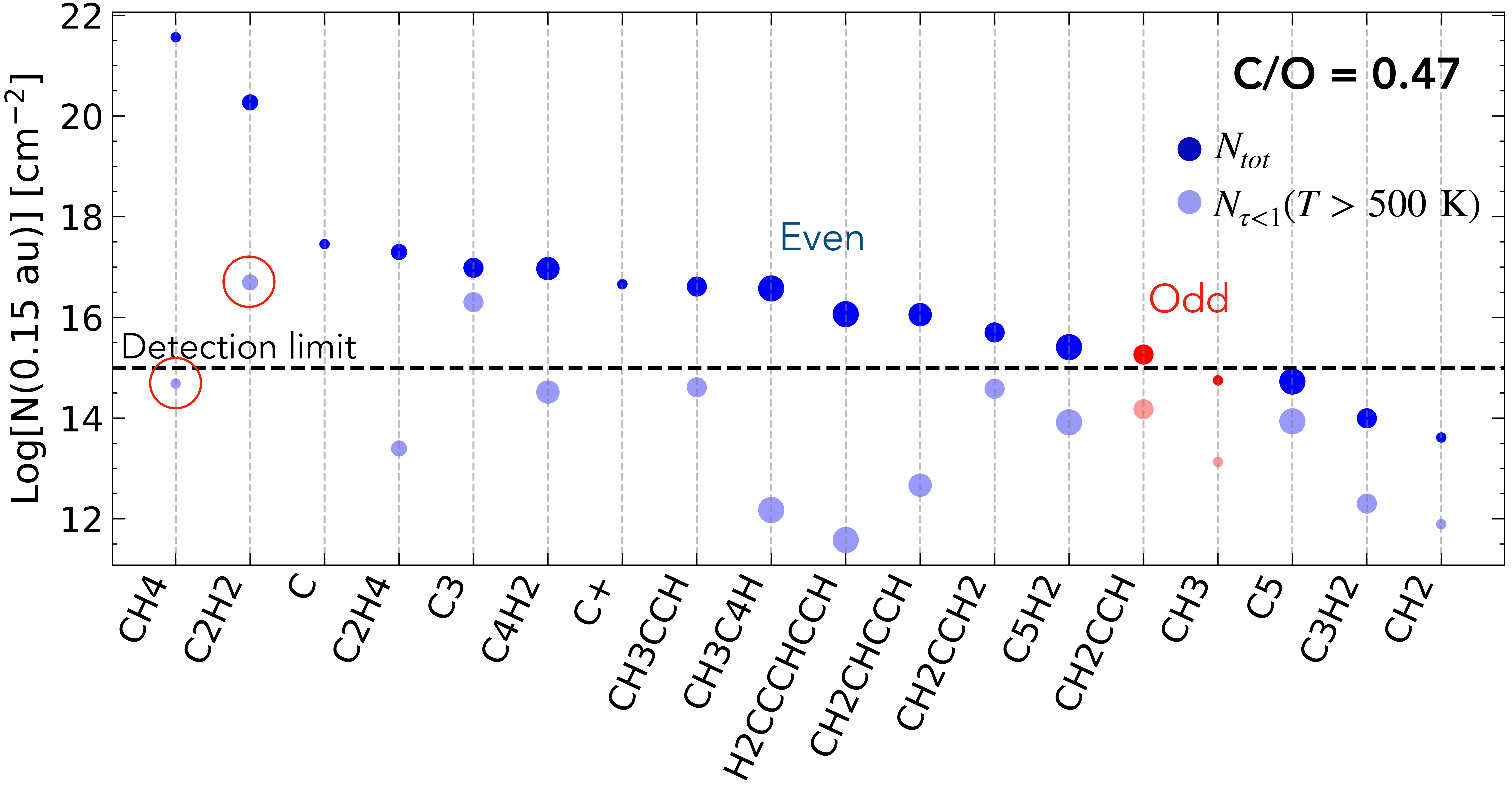
UV shielding

- Mutual shielding as implemented in DALI (shielded by continuum only)
- Mutual shielding particularly efficient for: H_2O, C_2H_4, C_3, (C_2H_2)
- Mutual shielding not efficient for: CO_2, CH_4, NH_3, HCN



Distribution of hydrocarbons

→ The main hydrocarbon is $\mathrm{CH_4}$ but the brightest is $\mathrm{C_2H_2}$, consistent with JWST observations



Distribution of hydrocarbons

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→ Other hydrocarbons are also bright: C_3, C_3H_4 (Arabhavi et al. 2024) and C_4H_2 (Tabone et al. 2023)