News and Reminders

Homework 5 posted - due Monday, Nov. 18

Proposal reviews - due now

End of semester proposal due dates:

- Abstract due: Monday, Nov. 11
- Proposal due: Monday, Dec. 2

A Solar System Planet Formation Model Must Explain Its Properties

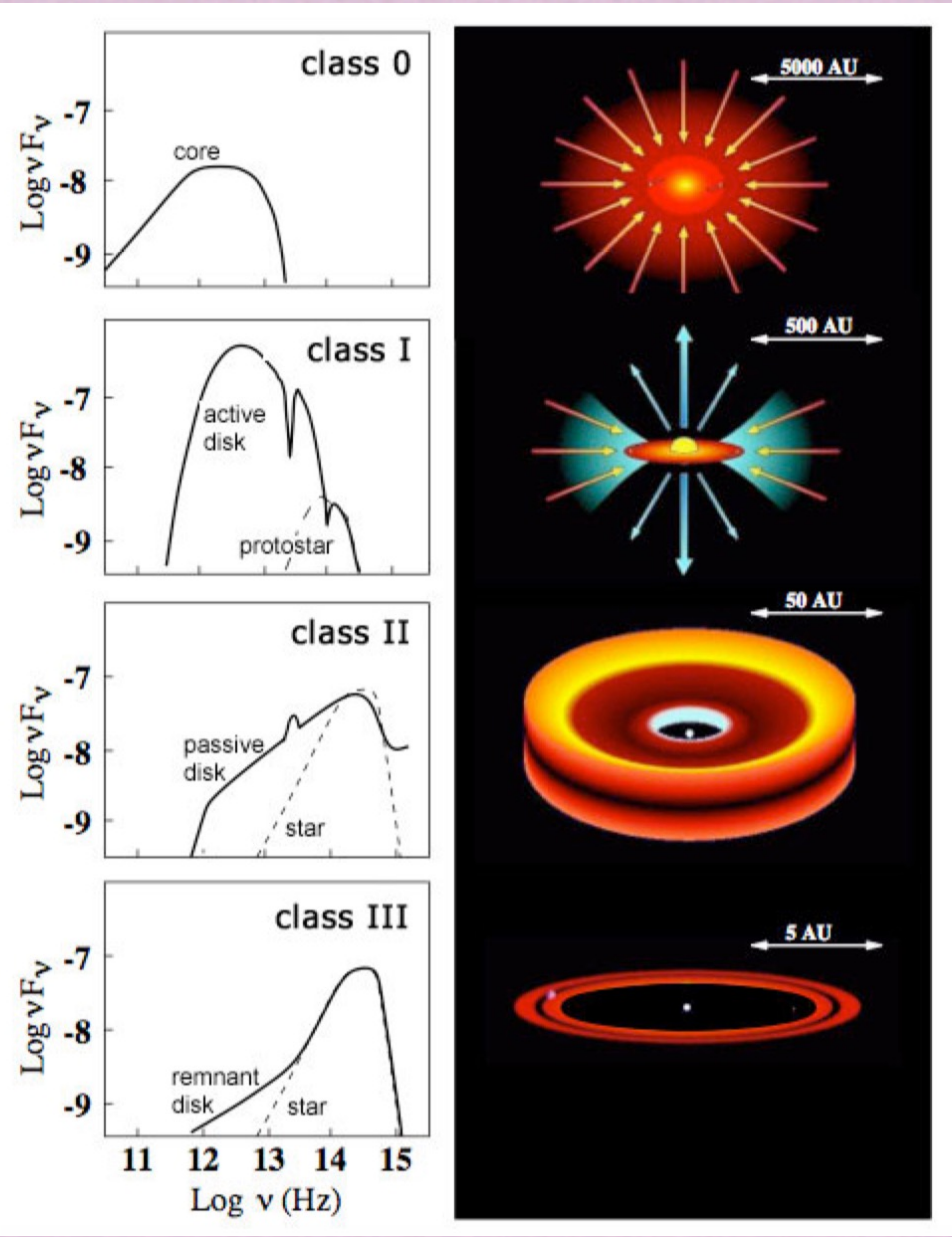
- **Orbits + angular momentum distribution:** circular vs. eccentric; is SS packed?
- **Sizes and densities of planets:** density ~decreases with distance
- **Shapes and densities of small bodies:** porous! esp. R < 100 km
- **Asteroid and Kuiper belts + Comets**
- **Moons**
- **Rings:** interior to largest moons
- **Age:** chondritic meteorites -> 4.568 Gyr -> formed very early; Earth+Moon rocks are younger.
- **Meteorites:** cool grains + heated inclusions -> mixing of solids in the disk; similar ages -> fast accretion period
- **Isotopic composition:** isotopic ratios mostly uniform, some variation from radioactive decay/incomplete mixing; also: where did the short-lived initial isotopes come from?
- **Differentiation:** needs melting -> implies high T at some point in past
- **Composition of atmospheres:** H abundance lower than Sun, metal abundances higher than Sun.
- **Surface structure:** some surfaces are too cratered to explain with today's impact rates

T Tauri star "phase"

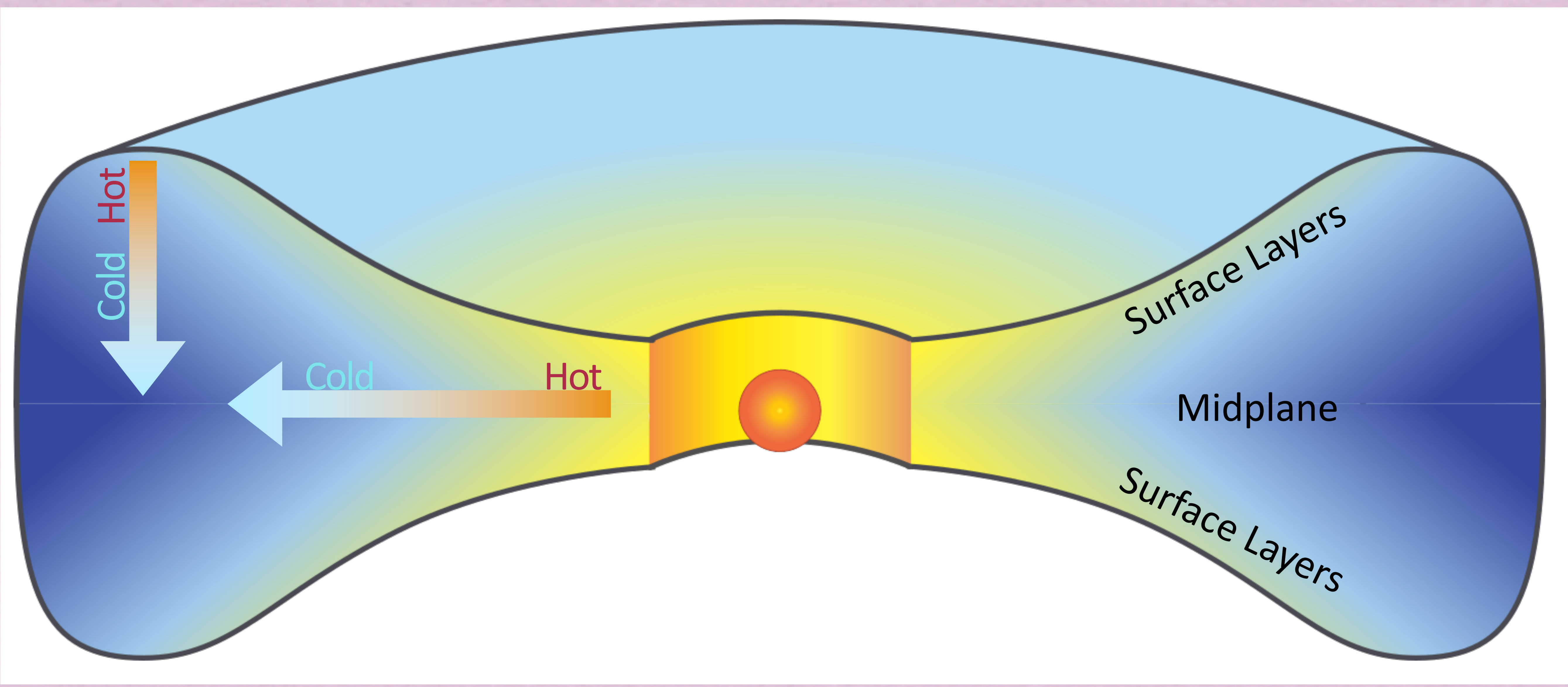
10^4 years

10^5 - 10^6 years

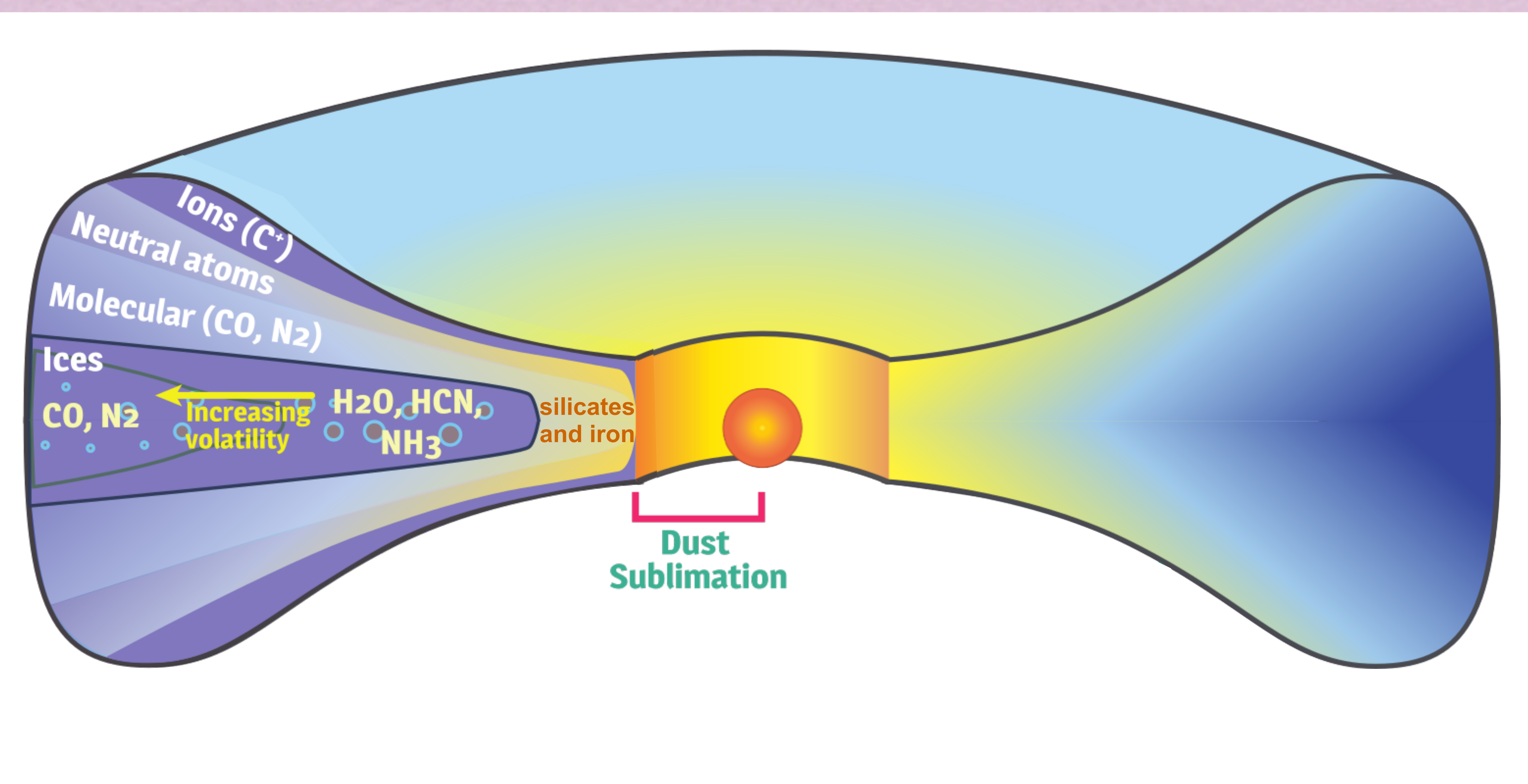
10^6 - 10^7 years



Disk Structure



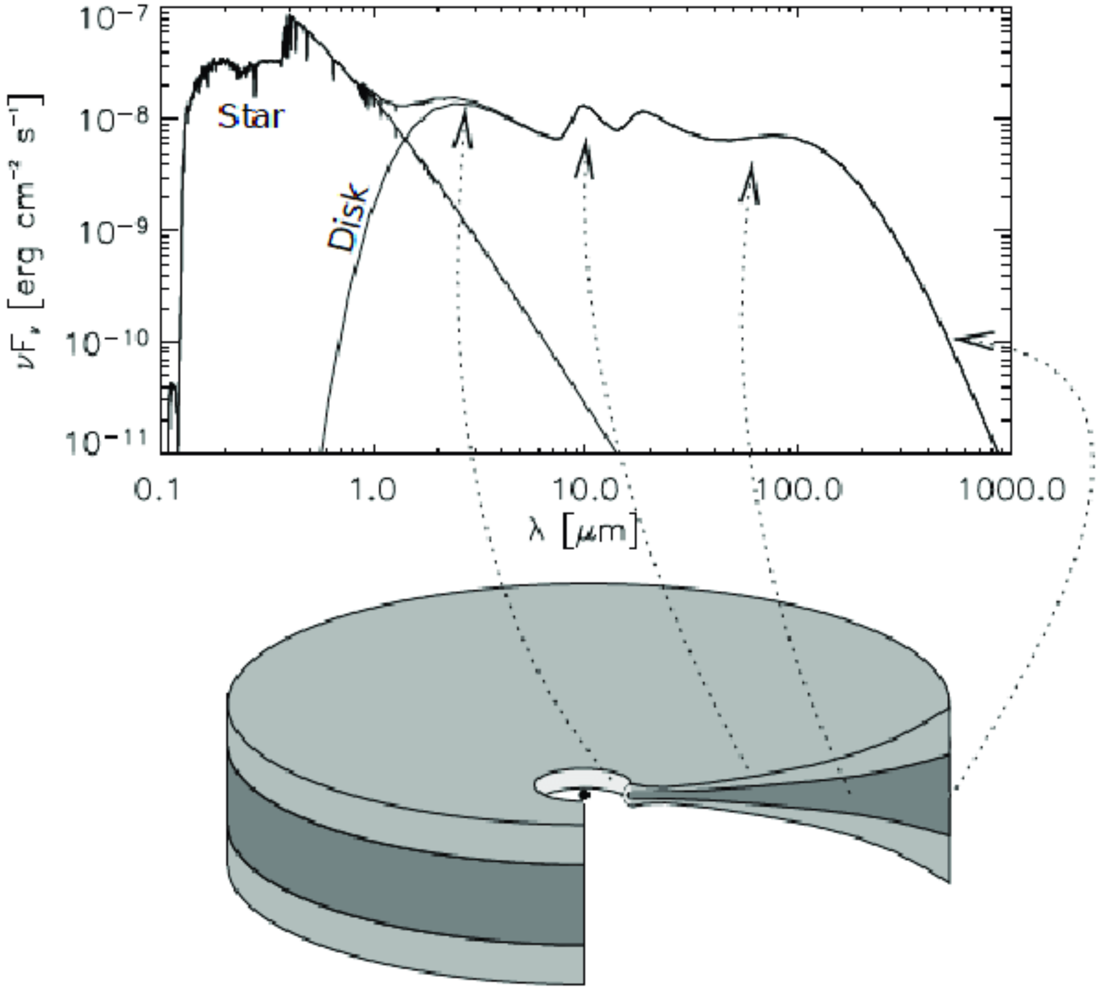
Disk Structure



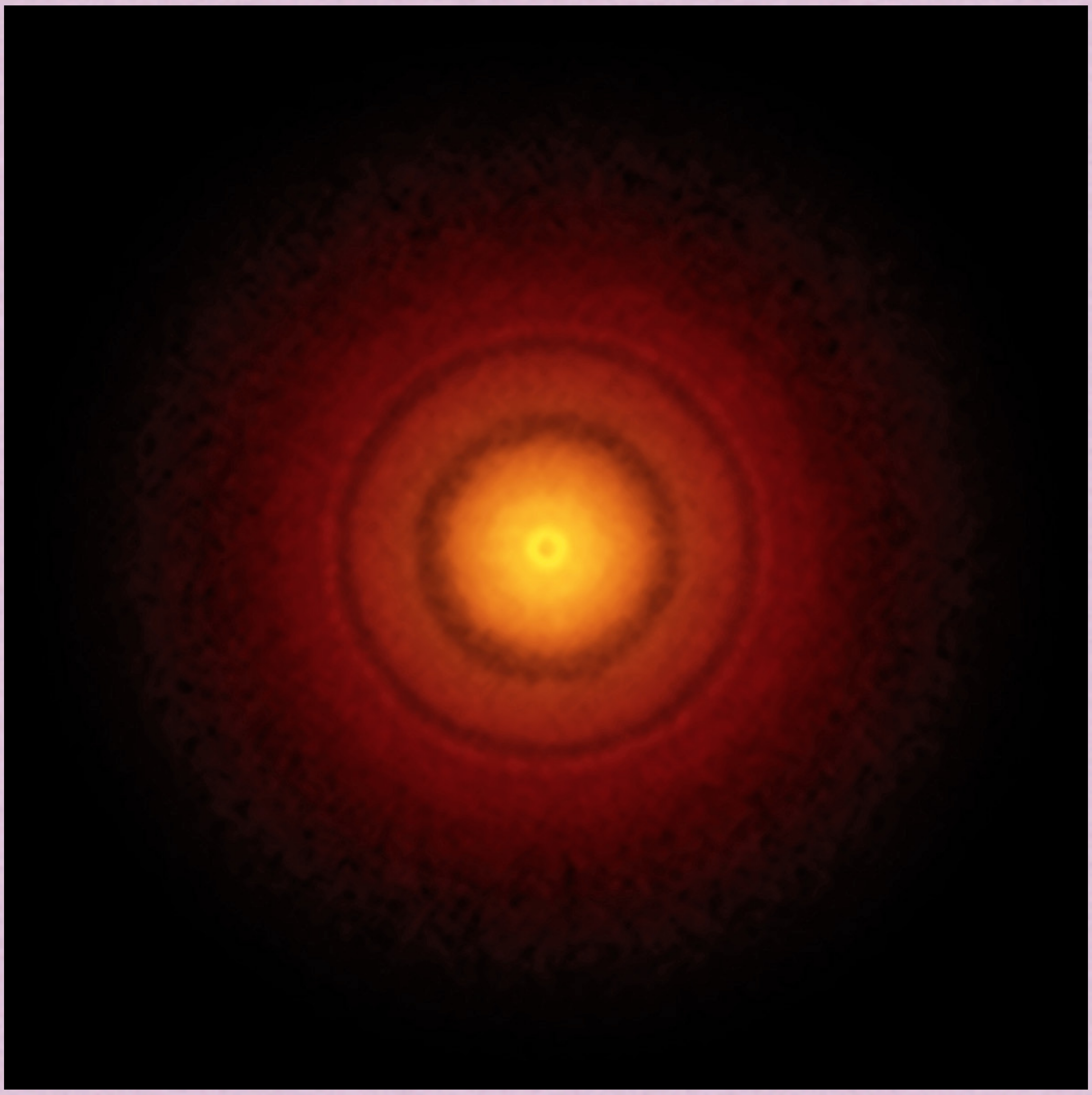
Disk Structure

- IR = disk surface closer to the star (0.1 - 10s of AU)
- sub-mm = larger distances and deeper into the disk

Disks are optically thick in infrared and optically thin in millimeter

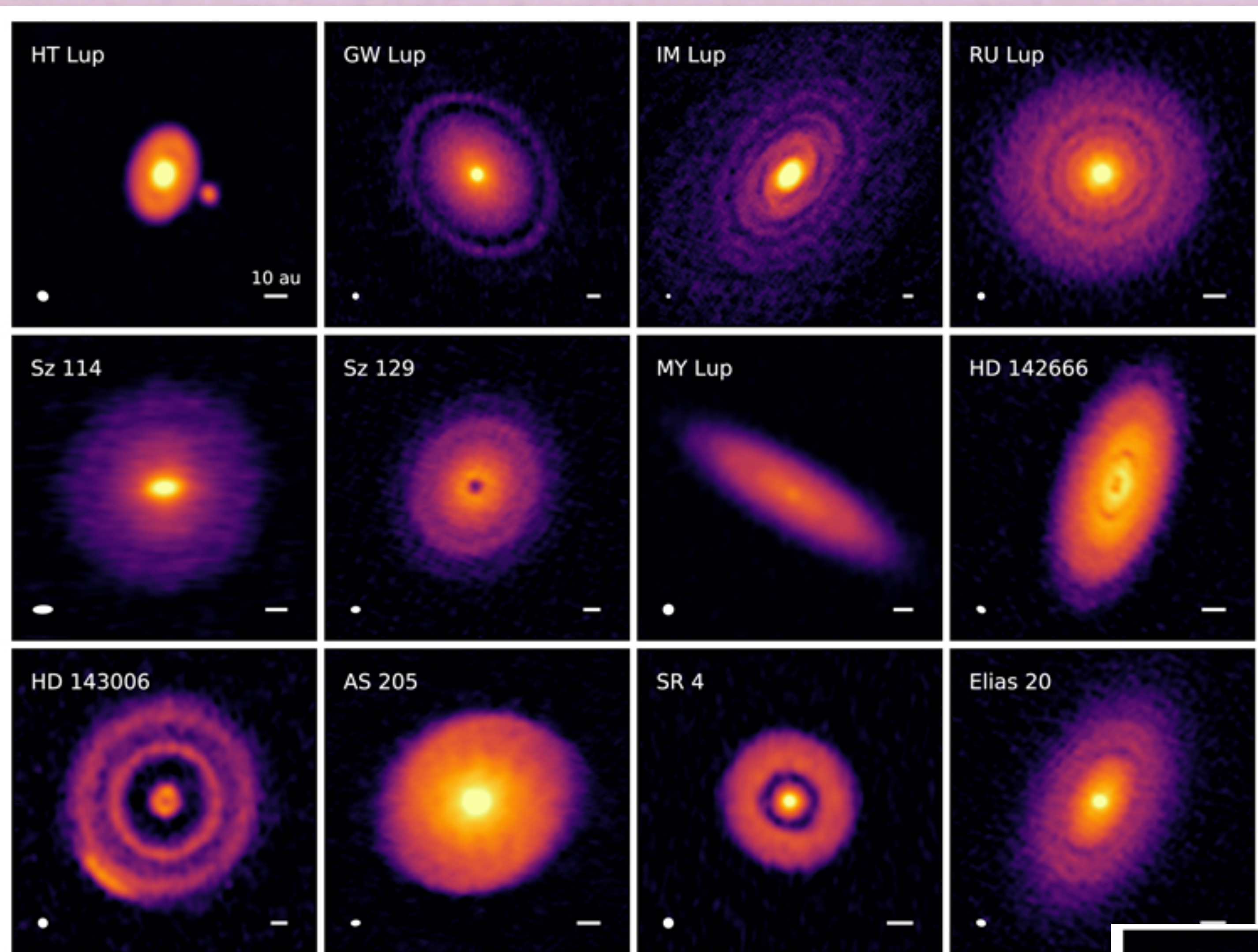


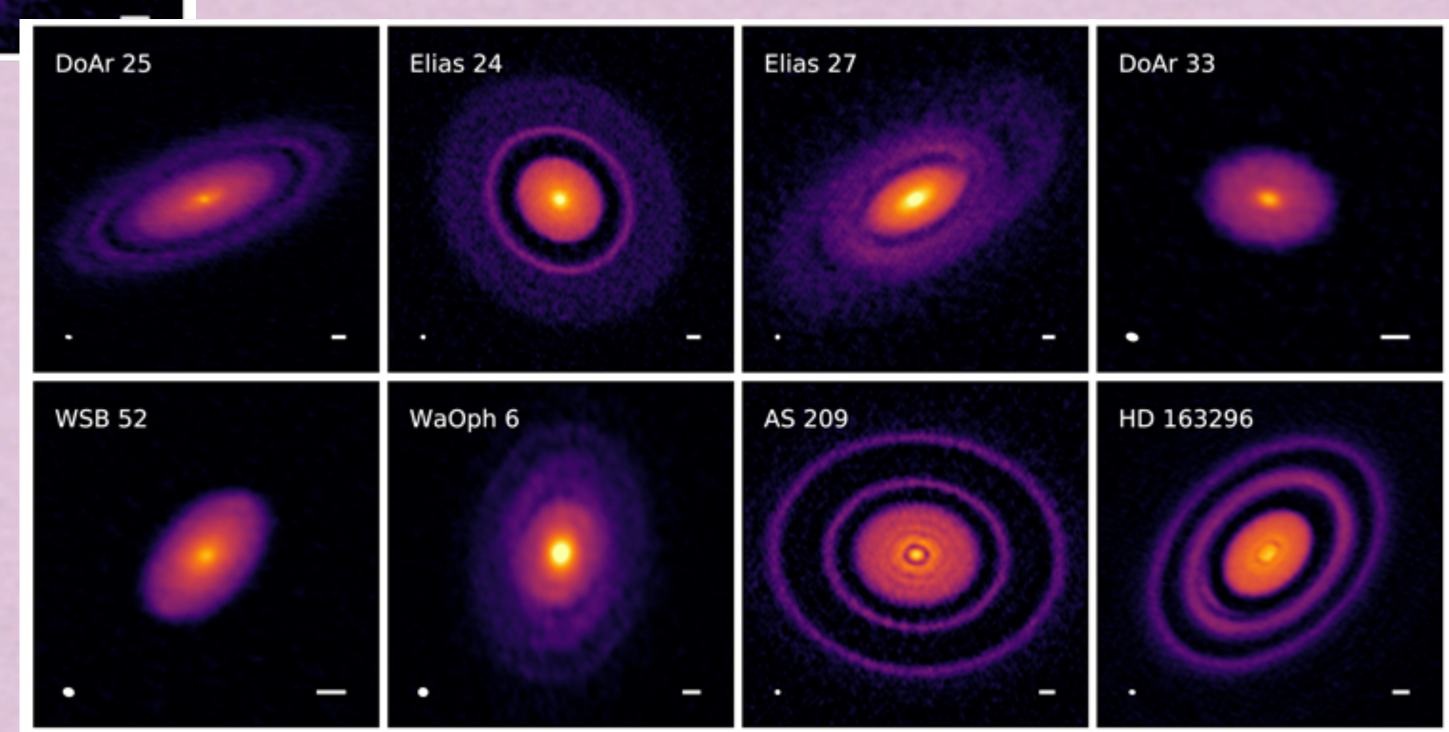
TW Hydrae (ALMA image)



Andrews et al. (2016)

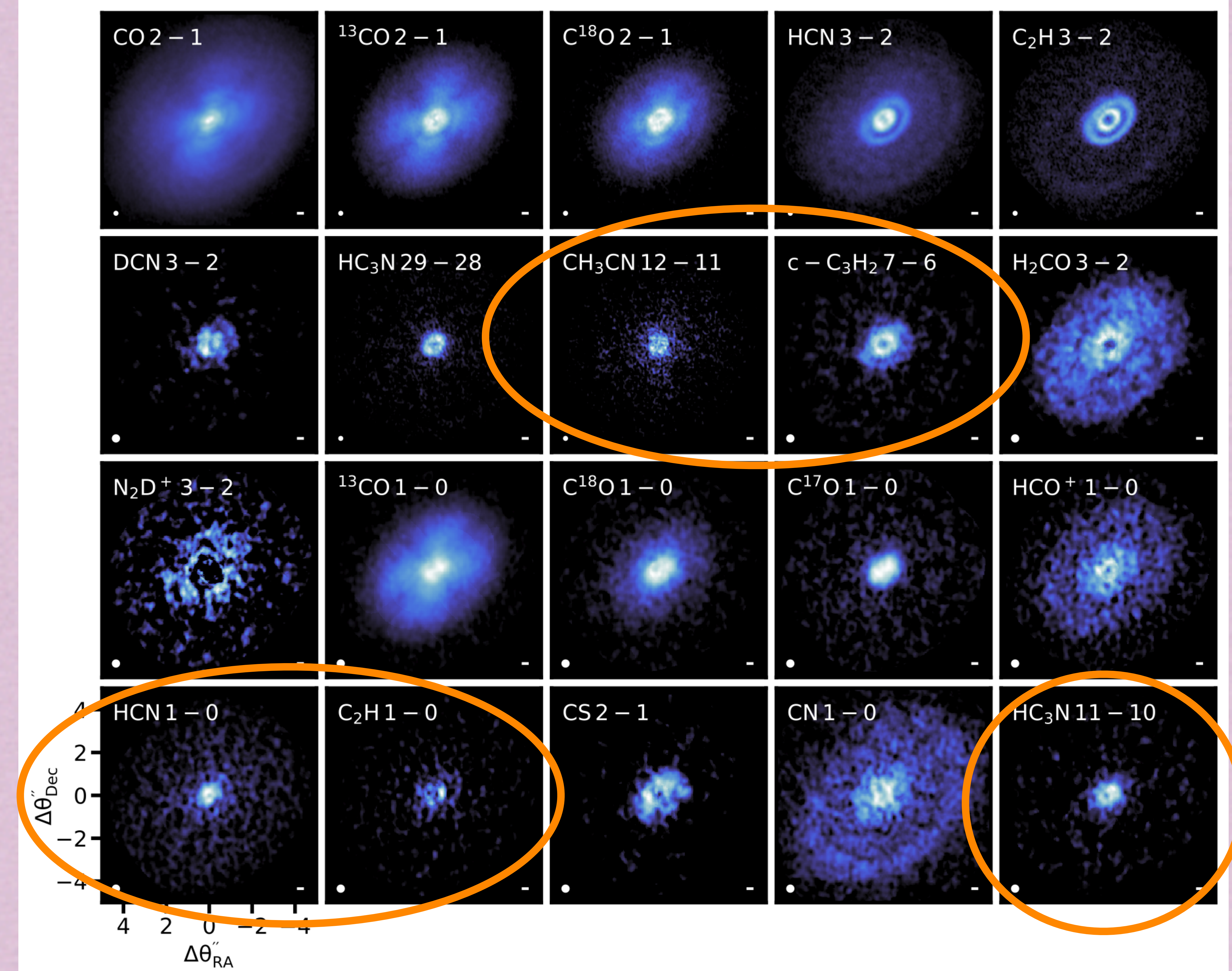
Images of Disks (mm)



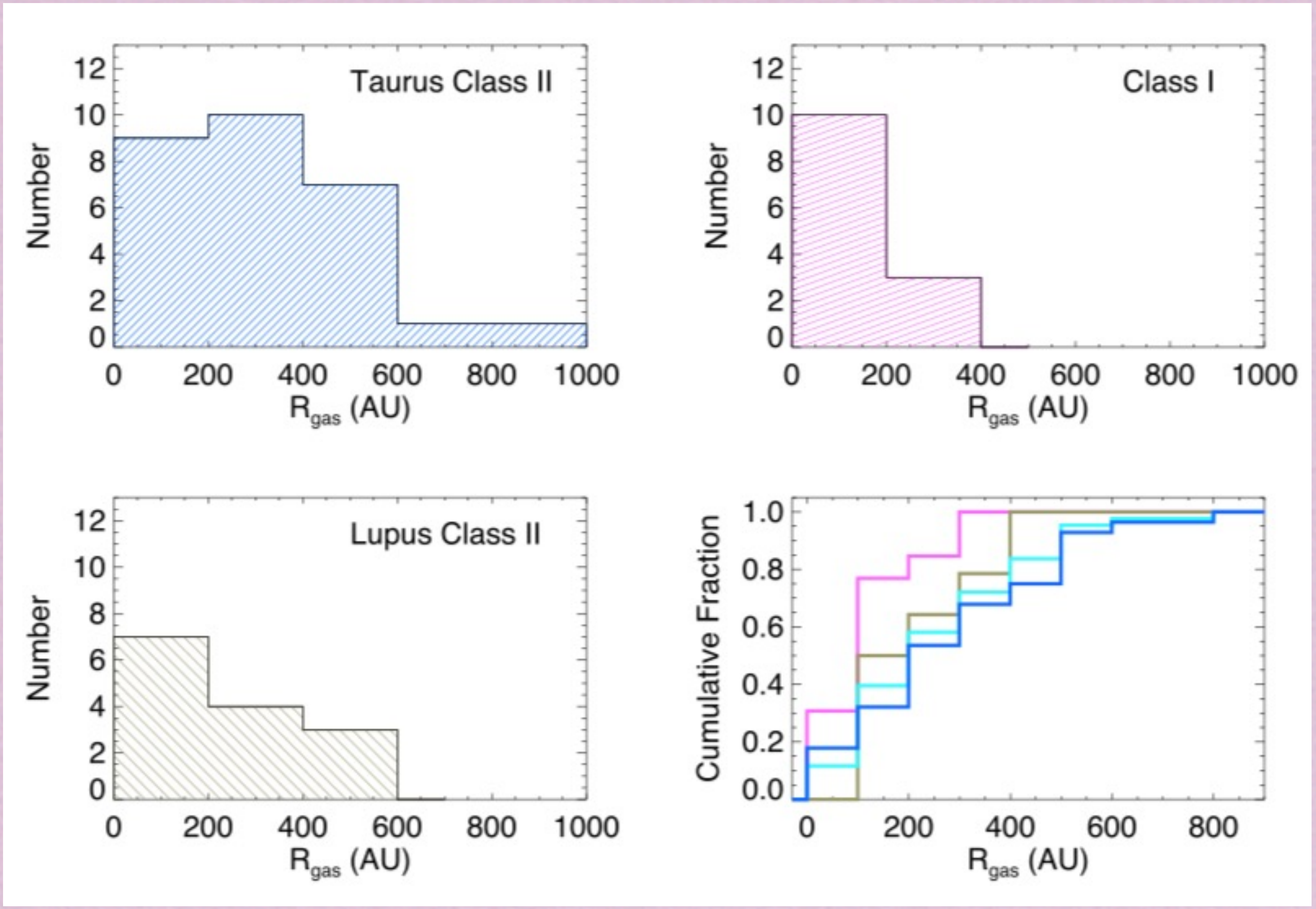


Andrews et al. (2018)

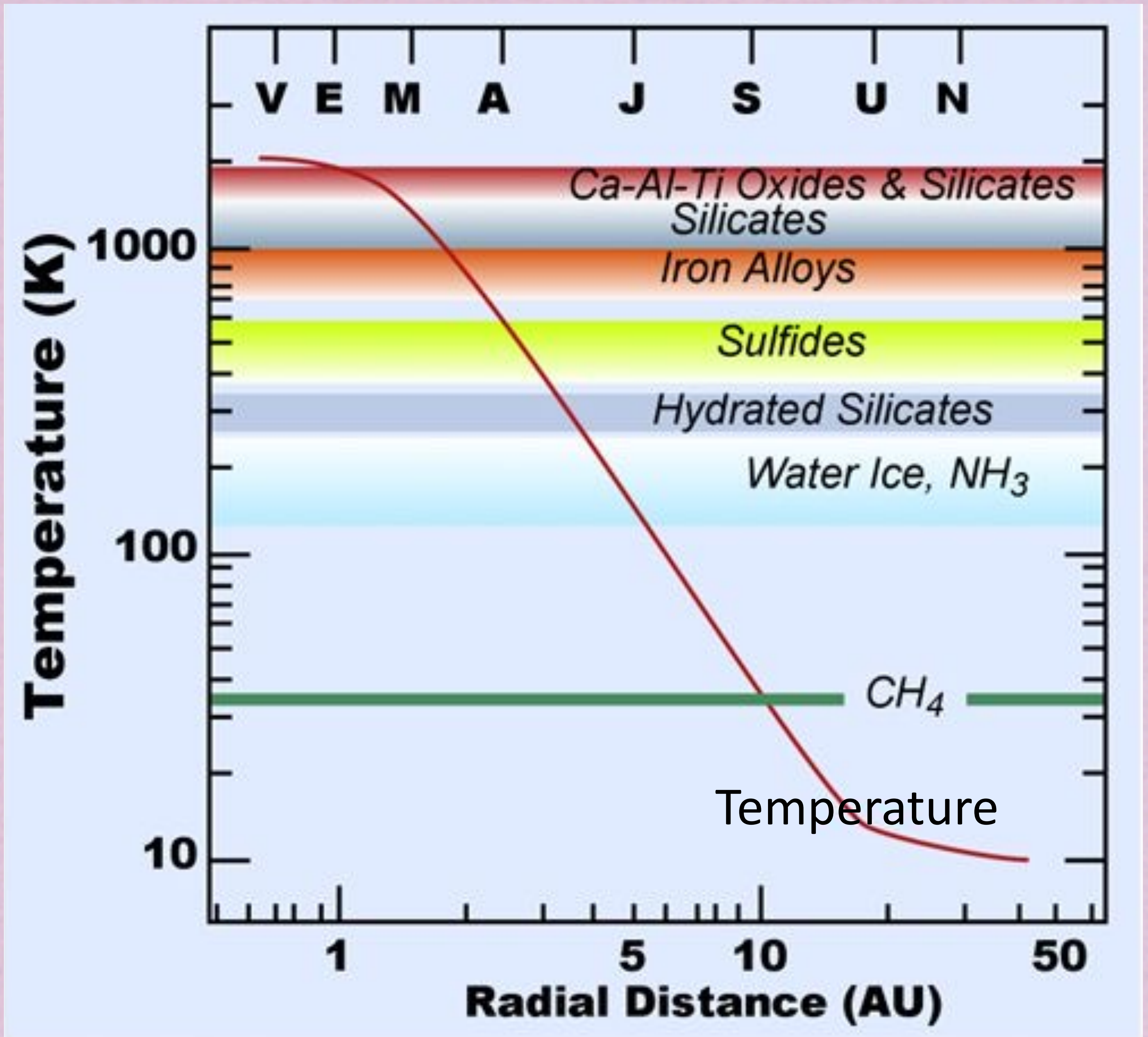
Images of HD 163296 disk (ALMA - gas component)



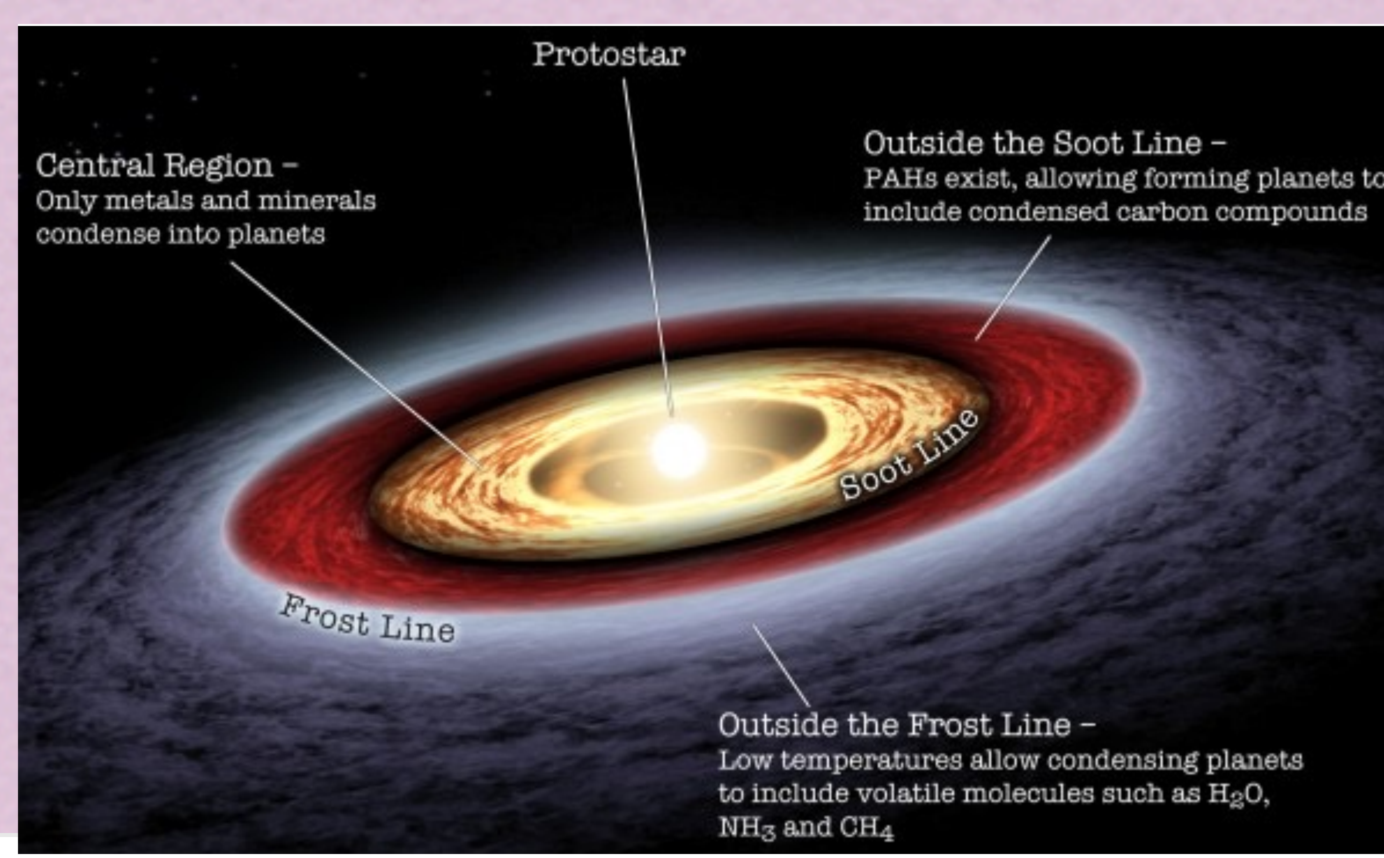
Disk Size Distribution



Condensation Sequence

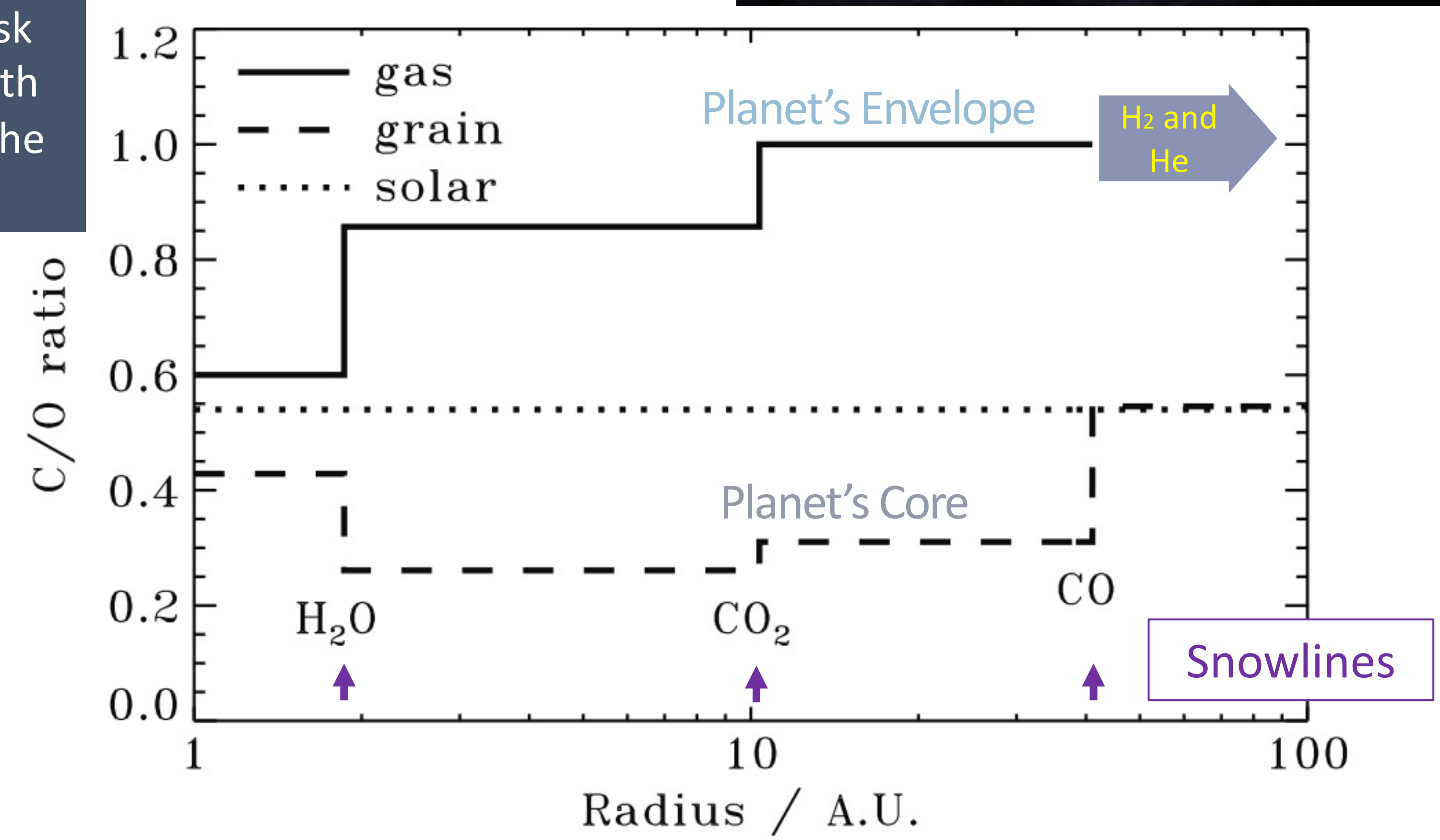


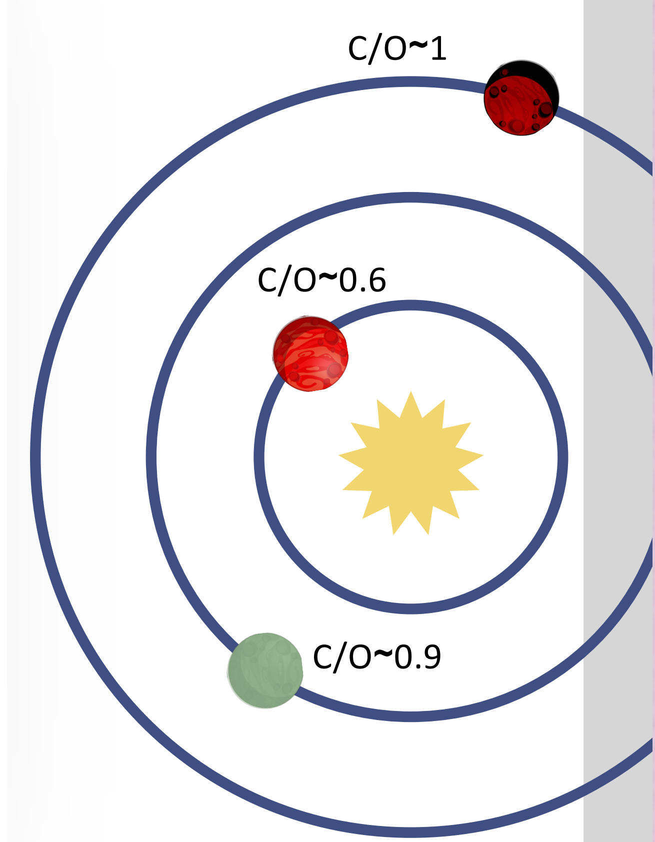
Snowlines



<u>Baseline expectation:</u> freeze-out changes the chemical environment from which planets accrete

C/O ratio of disk gas changes with distance from the central star





Öberg, Murray-Clay and Bergin 2011

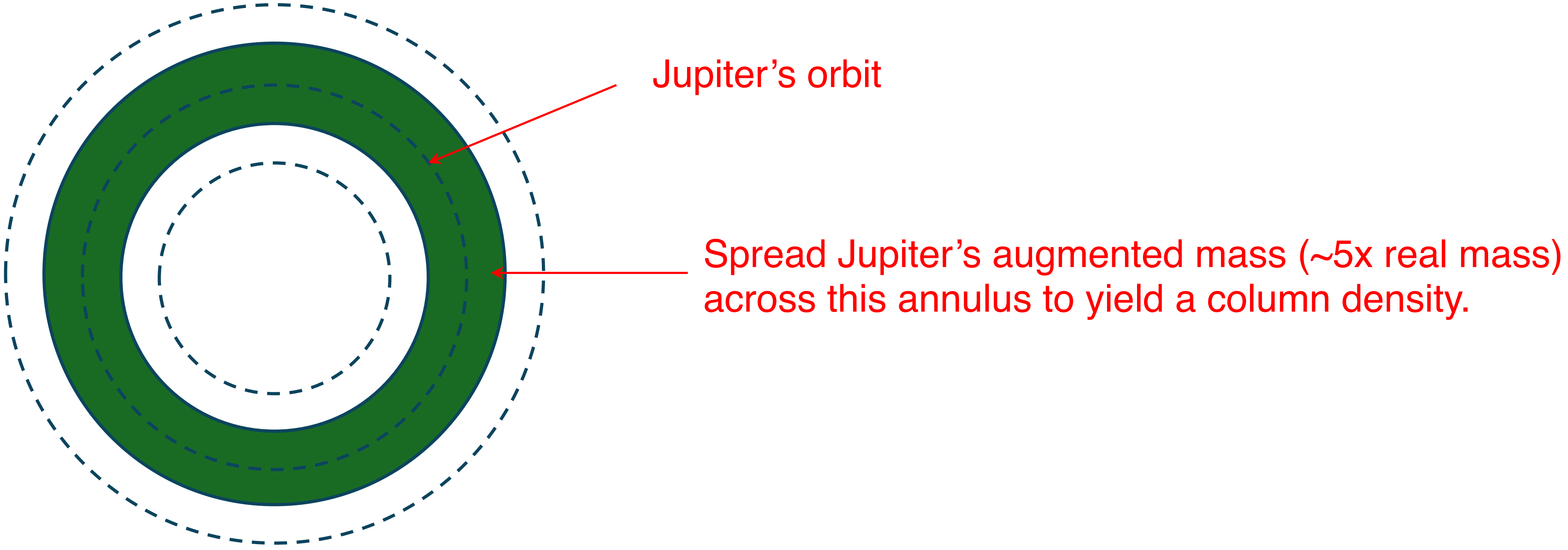
Minimum-Mass Solar Nebula (MMSN)

How much mass was needed to form the planets?

1. Take the mass in each planet

2. Increase H/He to solar composition

3. Spread the mass into an annulus around each orbit



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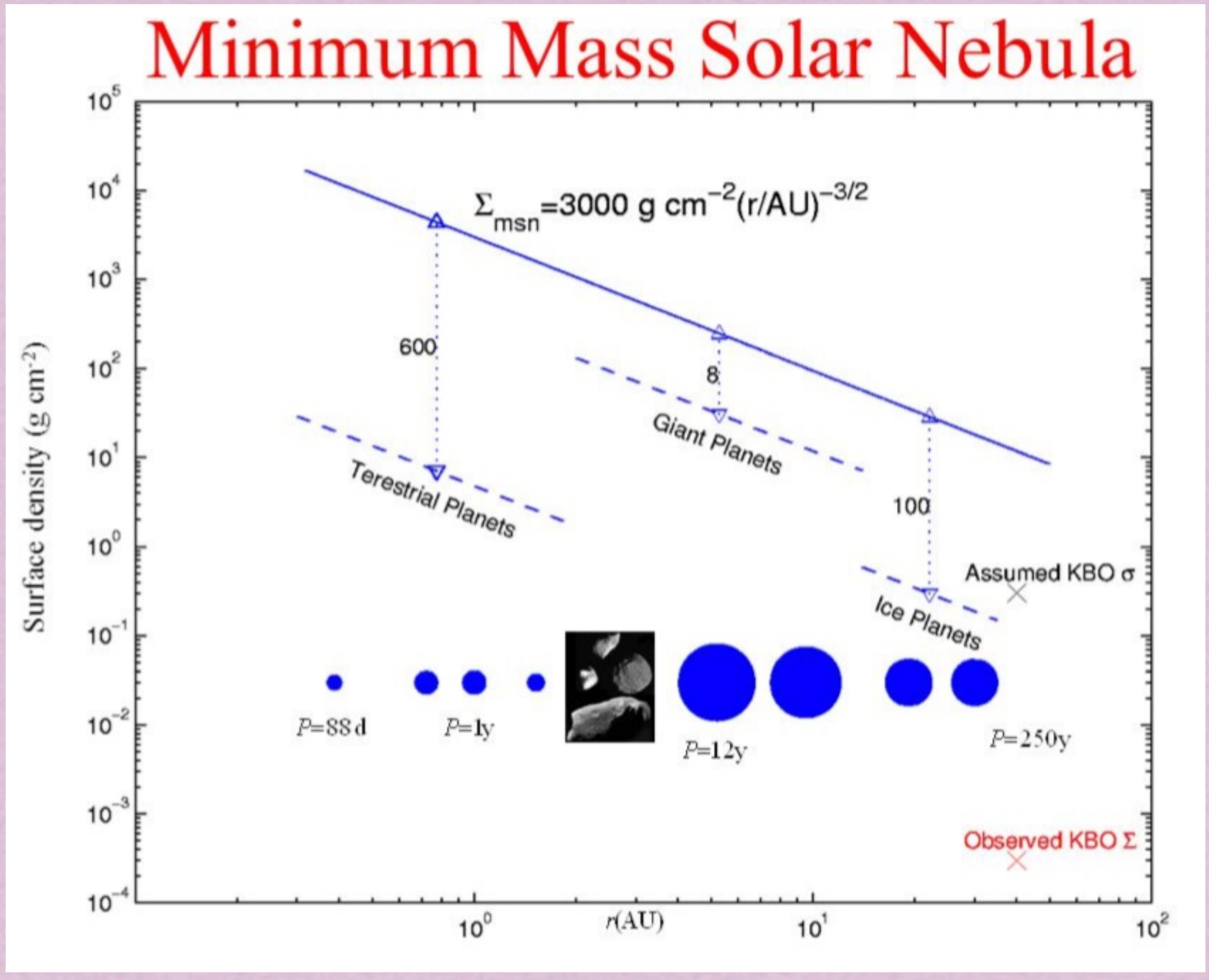
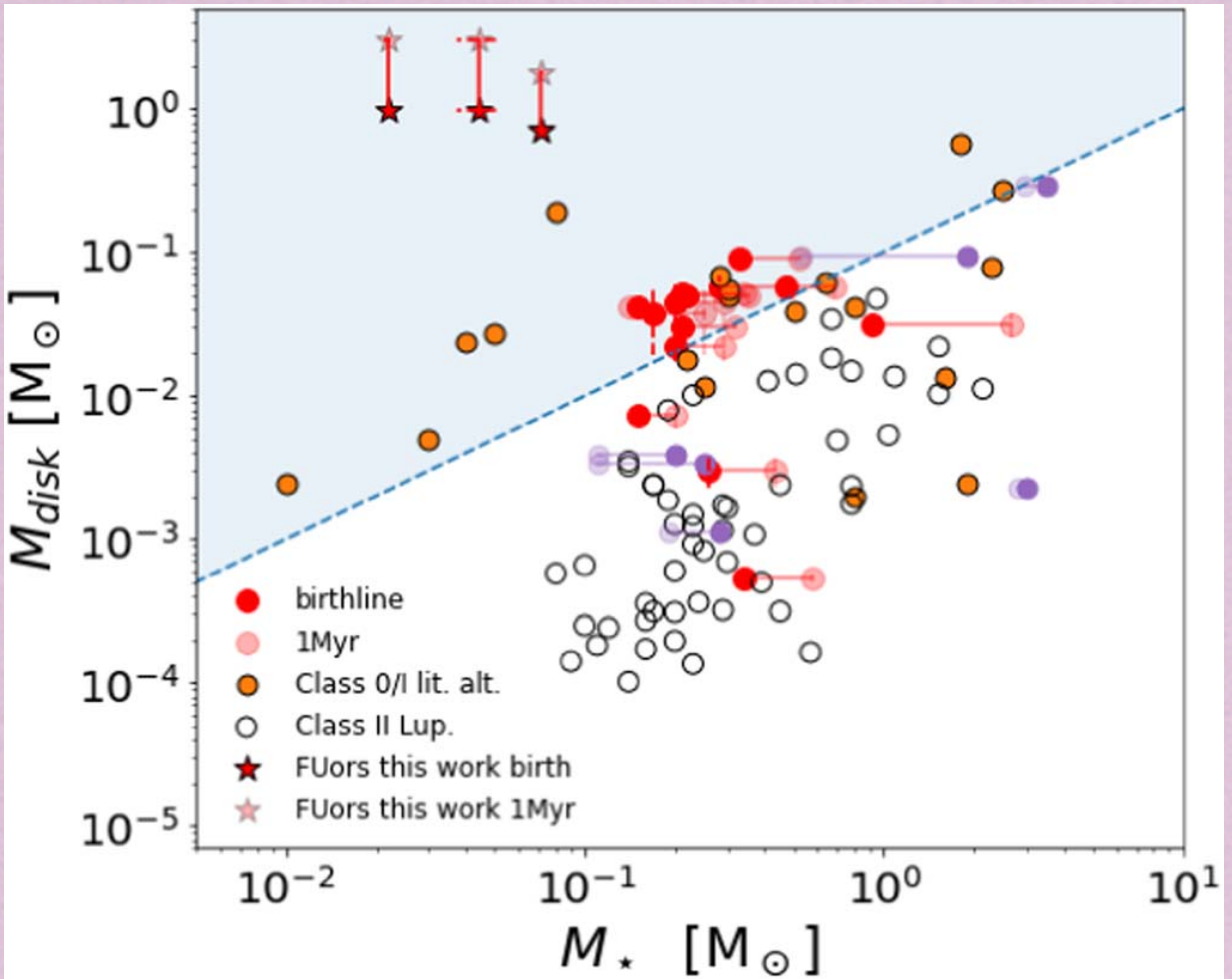


Disk Masses



10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
M_{disk} [$M_\odot$]
10^{-2}
10^{-1}
10^0
10^1
$M_\star$ [$M_\odot$]
birthline
1Myr
Class 0/I lit. alt.
Class II Lup.
FUors this work birth
FUors this work 1Myr