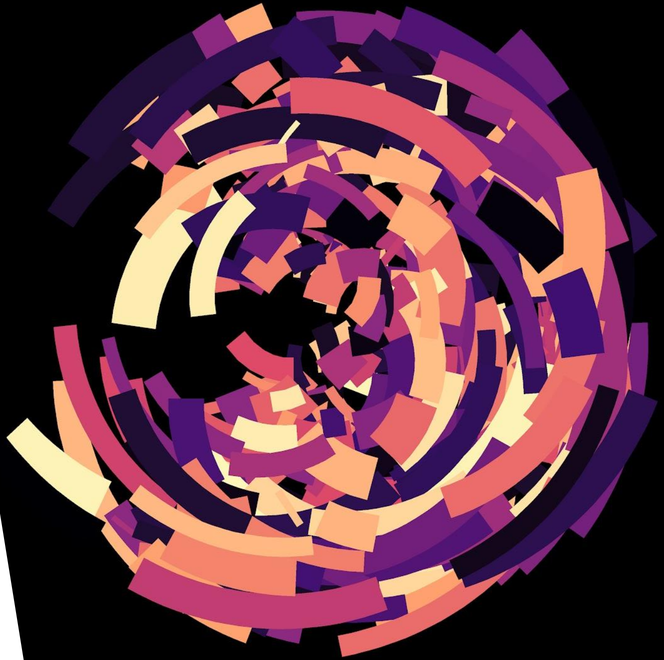
Setting the Stage for Planet Formation

Measurements and Implications of the Fundamental Disk Properties

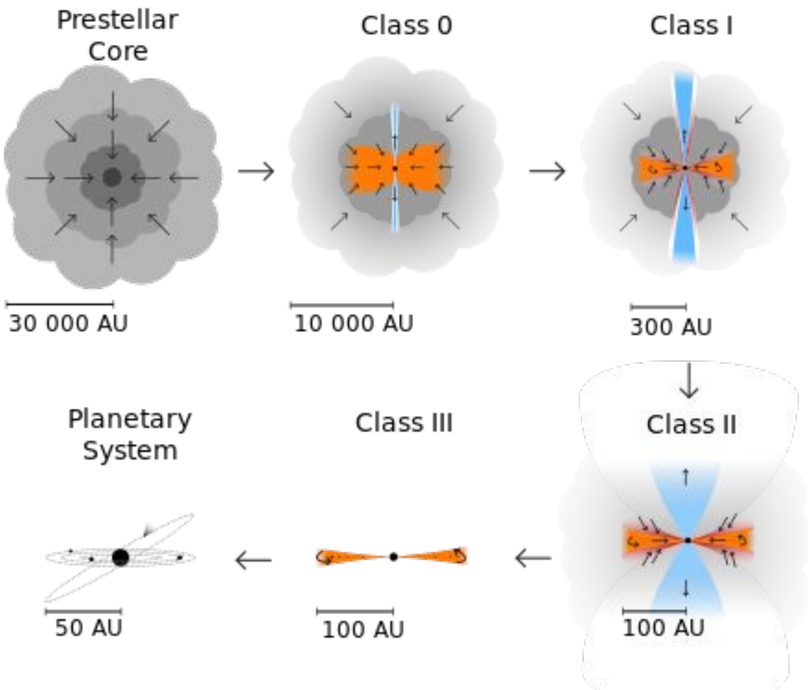


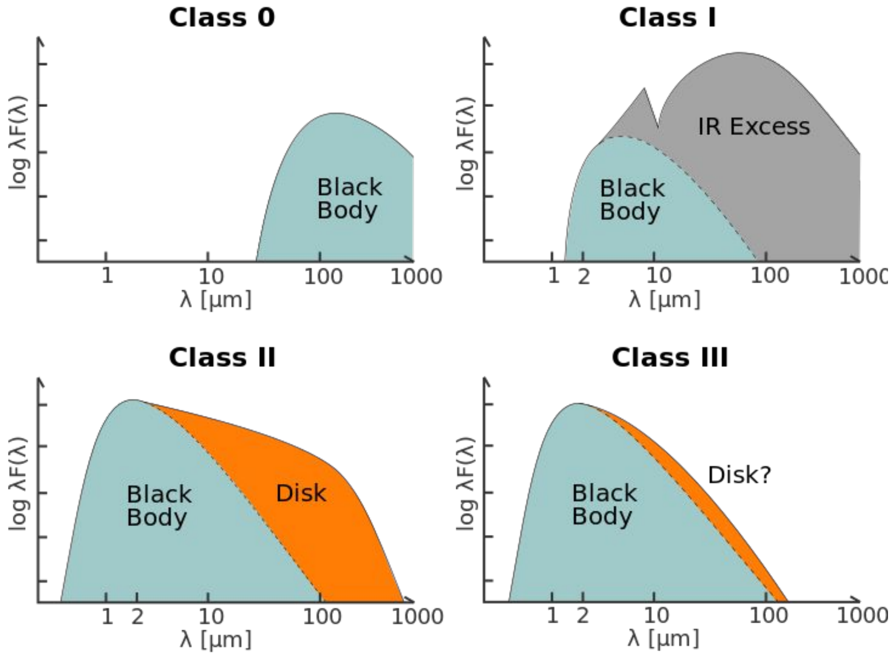
Drishika Nadella

MVSem 2023: Protostars and Planets

Contents

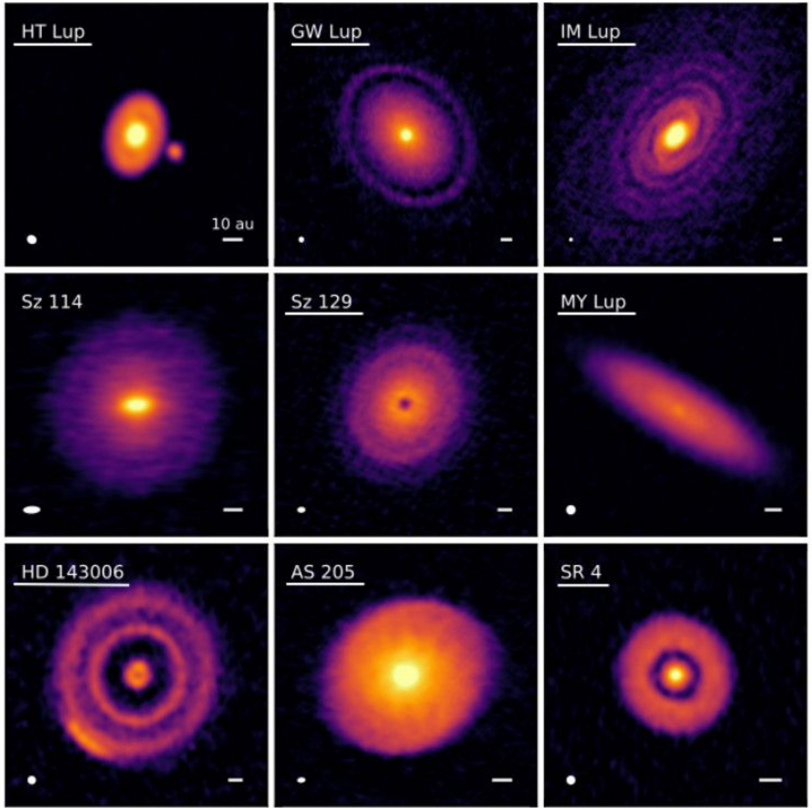
Young Stellar Objects





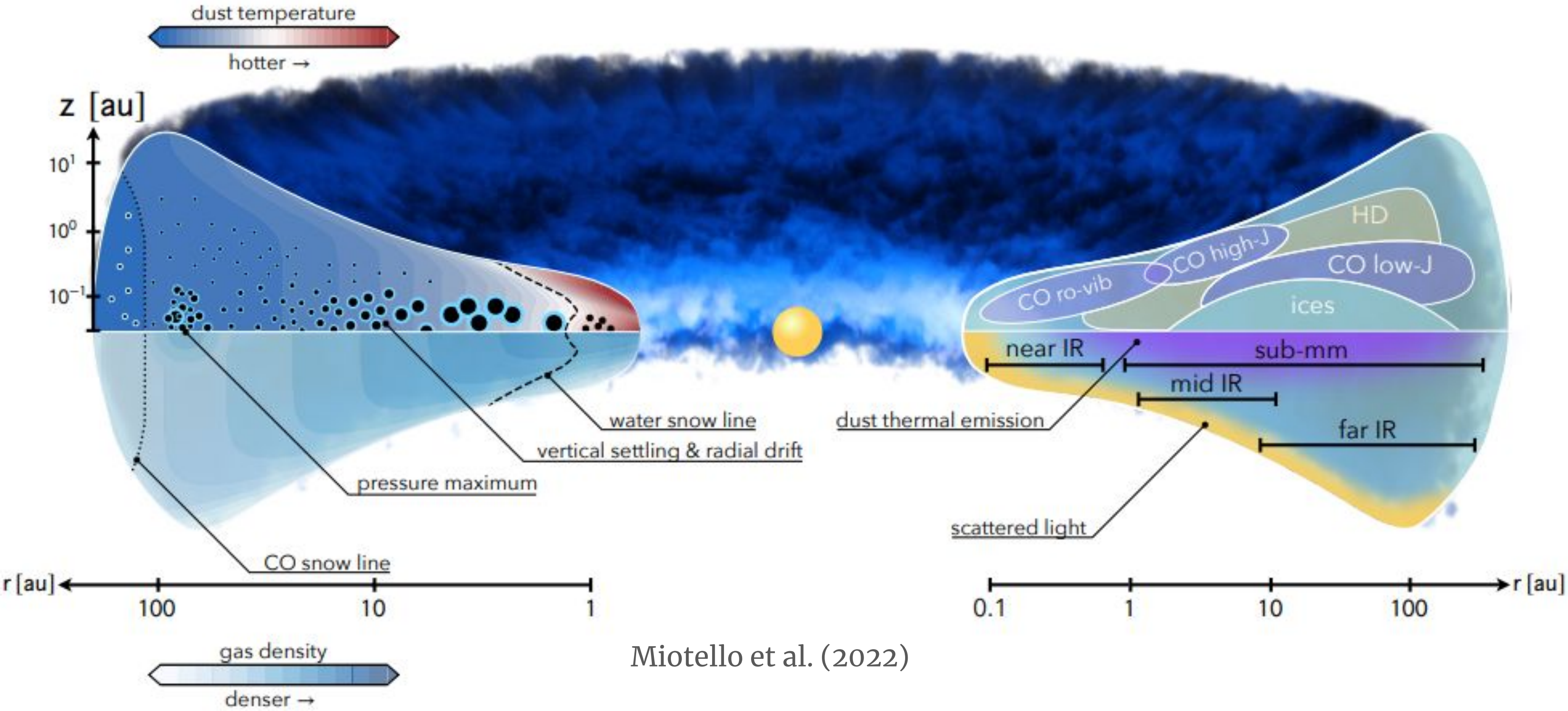
Persson, Magnus Vilhelm (2014). Current view of protostellar evolution

Disk Substructures



DSHARP (2018)

Disk Structure



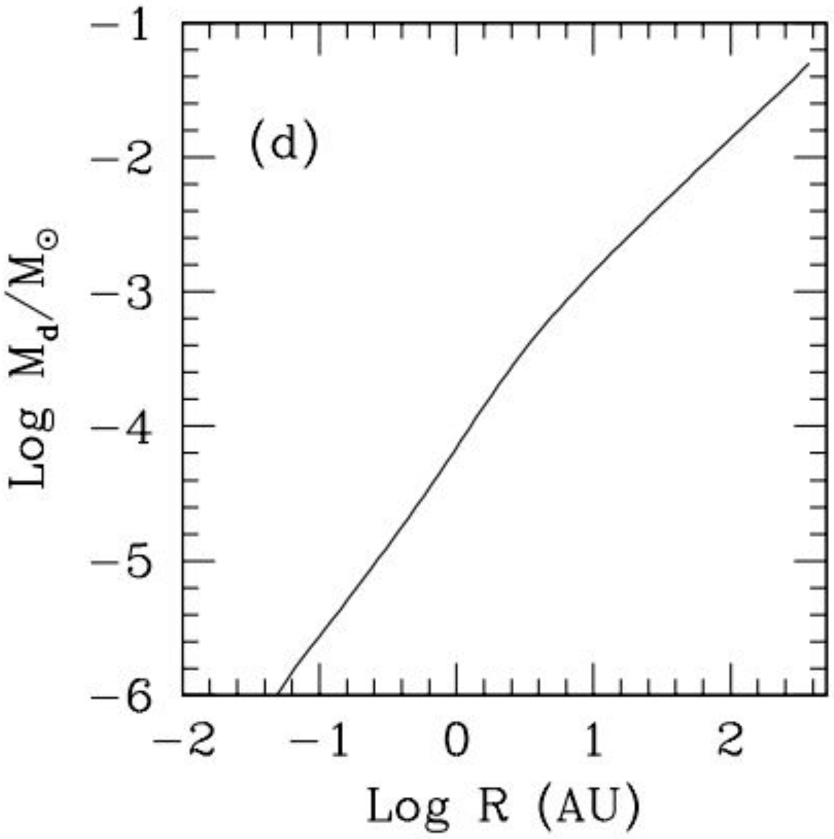
Miotello et al. (2022)

DISK MASS

Disk Mass: Dust Mass

- Key to terrestrial planet formation
- Continuum flux emission

$$F_\nu = \frac{B_\nu(\overline{T}_d)\overline{\kappa}}{d^2} M_{dust}$$

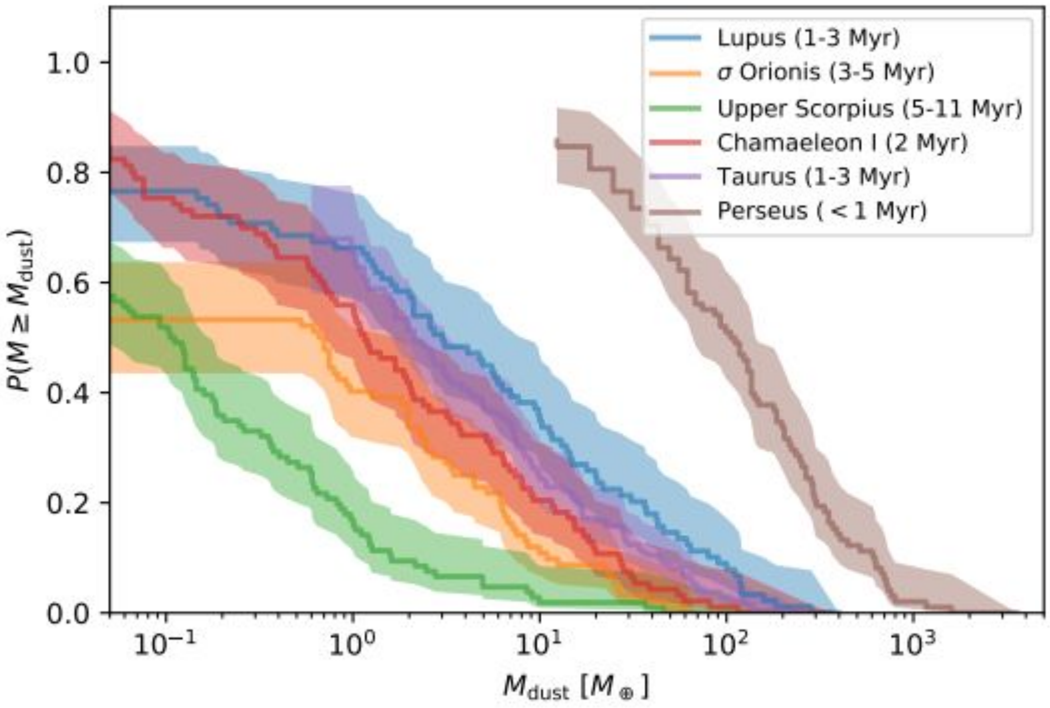


d'Alessio et al. (1999)

Disk Mass: Dust Mass

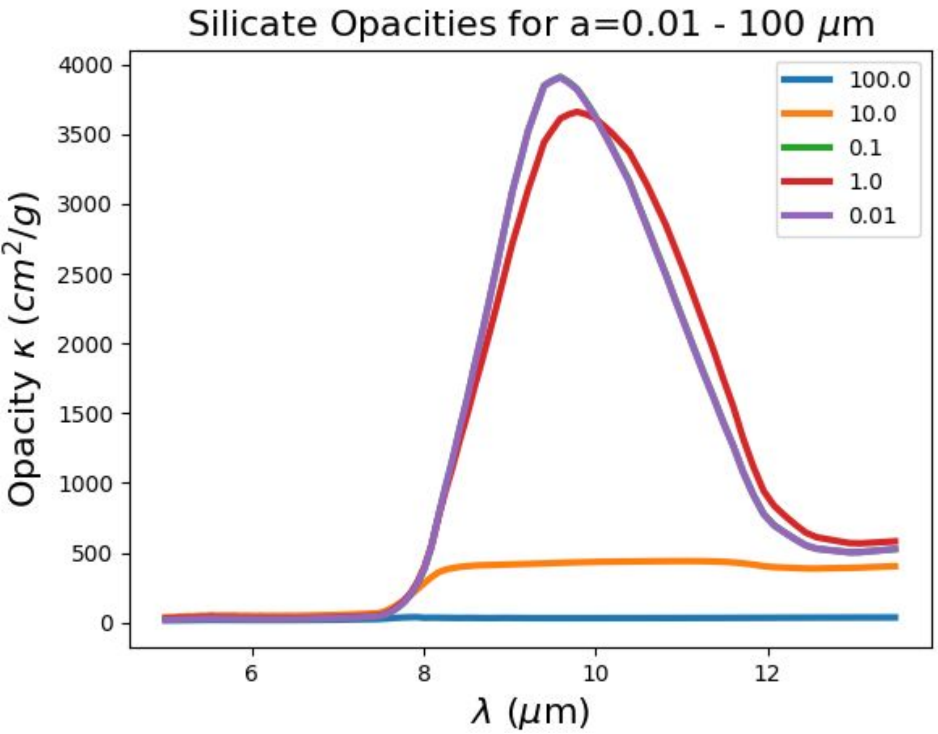
- Dust mass dependent on stellar age

- Caveats:
    - High opacity
    - Grain shape/size

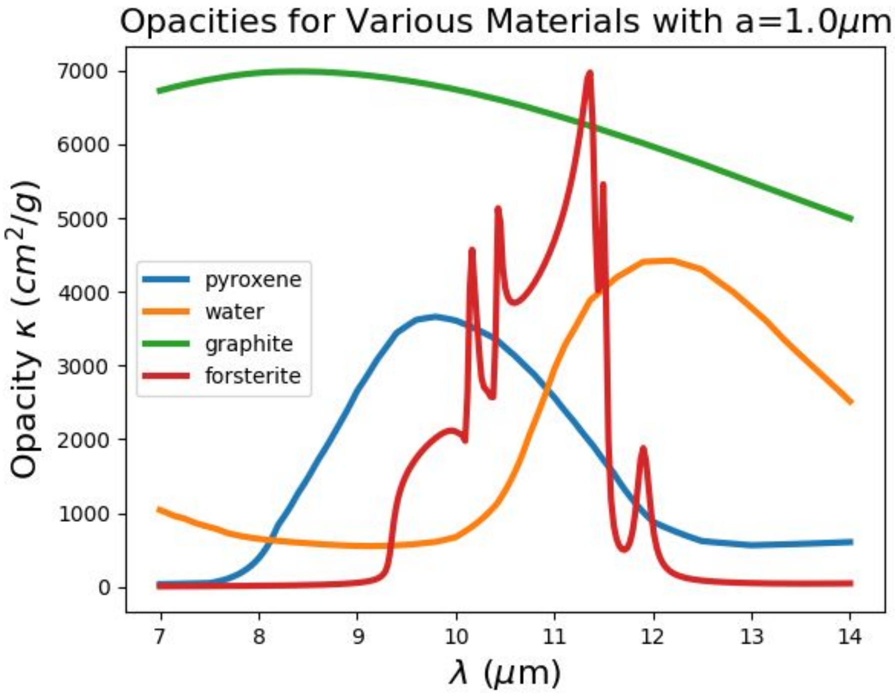


Miotello et al. (2022)

Dust Mass: Opacity and Grain Effects



Self-made using optool (Dominik et al. 2021)



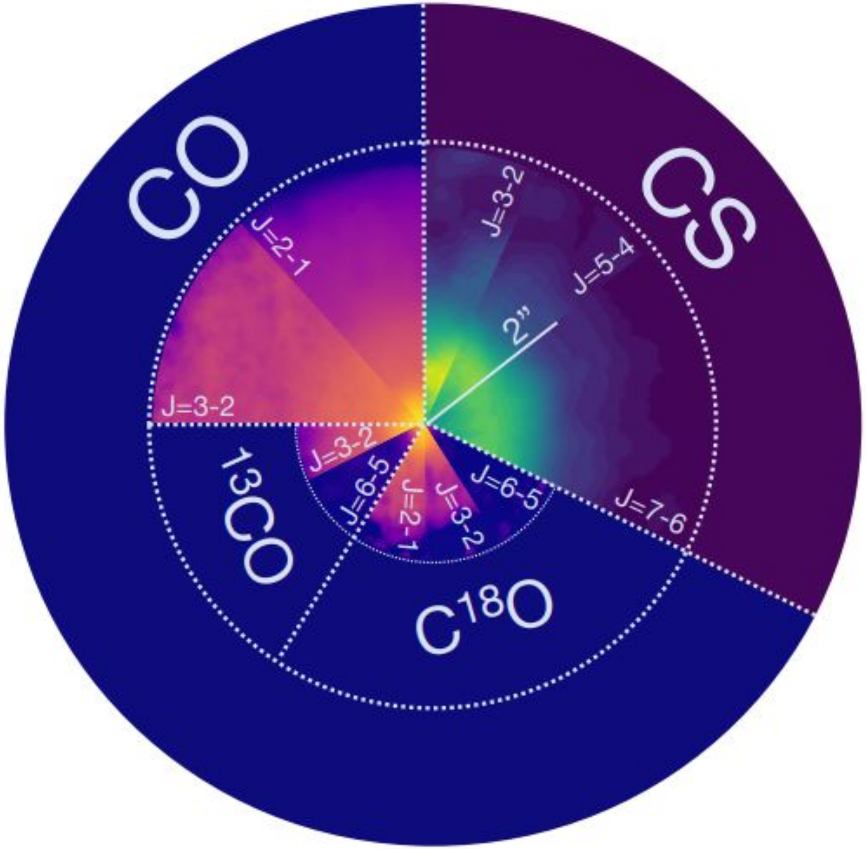
Self-made using optool (Dominik et al. 2021)

Disk Mass: Gas Mass (H_2 / HD emission)

- Forms bulk of disk mass
- Determines disk physics and evolution
- H_2 most abundant species – faint emission
- Proxy: HD emission
- Lack of observations for HD

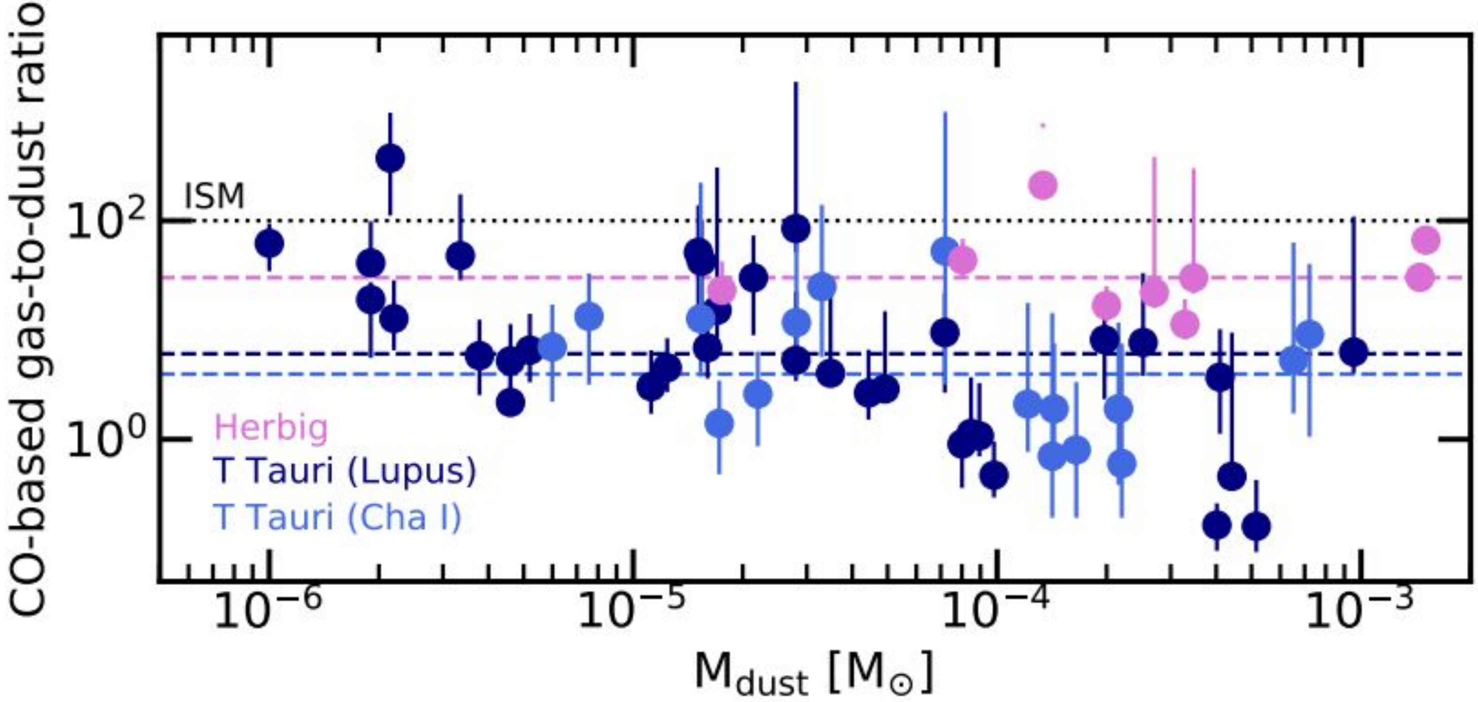
Gas Mass: CO emission

- CO 2nd most abundant species
- Chemically stable
- Several isotopologue tracers
- Probe varying optical depths



Miotello et al. (2022)

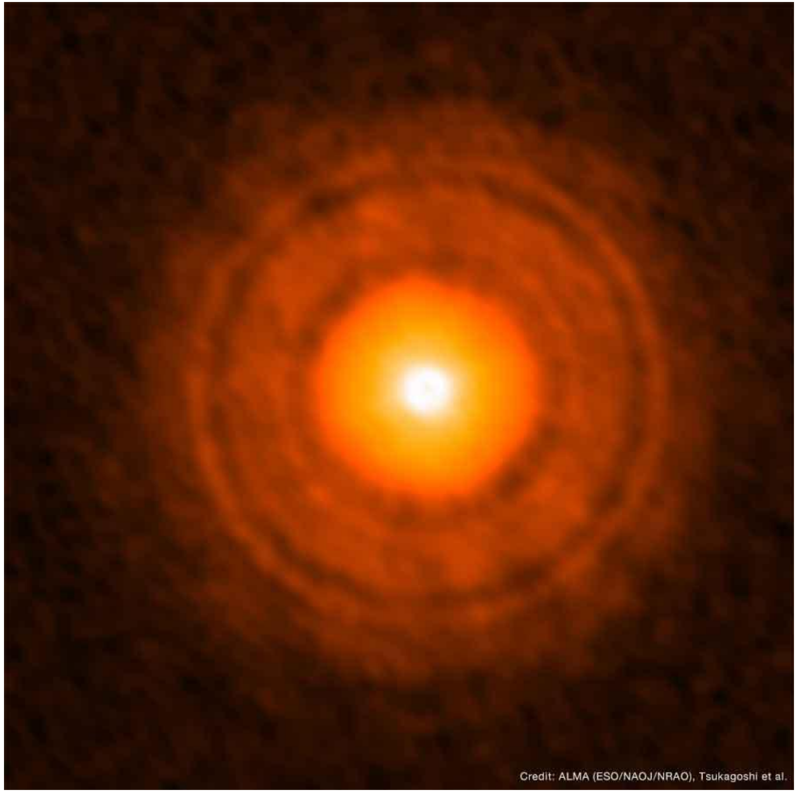
Disk Mass: Gas Mass (CO emission)



Miotello et al. (2022)

Disk Mass: Case Study with TW Hya

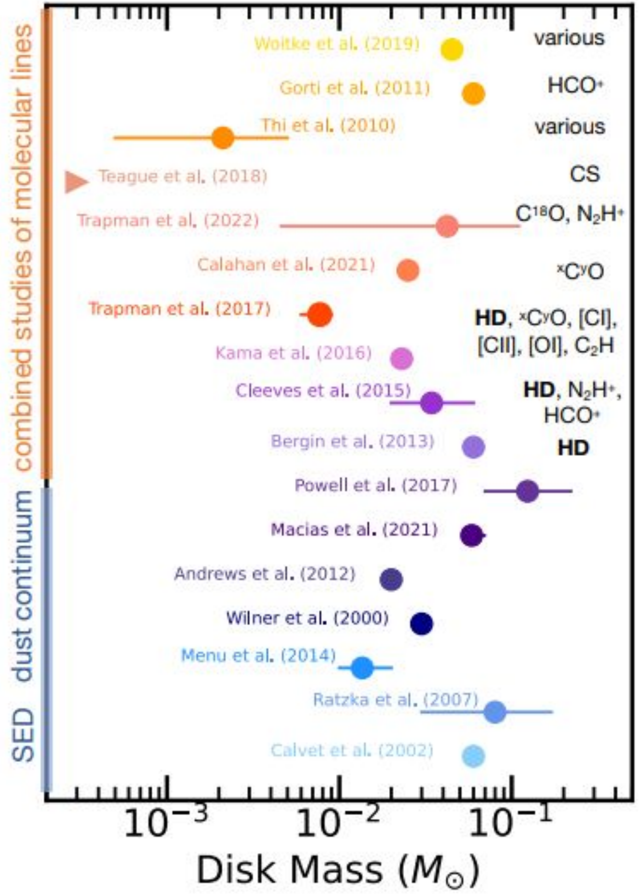
- Pre-main sequence star
- 59 +/- 1 pc (Gaia Collab et al. 2018)
- Highly studied disk



ALMA (ESO/NAOJ, NRAO) Tsukagoshi et al. (2016)

Disk Mass: Case Study with TW Hya

- Disk masses vary widely based on method and tracer
- Not enough mass to form planets
- Planet formation may begin at Class 0/I stage



Miotello et al. (2022)

Disk Mass

Dust Mass: Continuum emission
Gas Mass: CO emission
Highly entangled with a_{grain}, τ and T
Large uncertainties

DISK SURFACE DENSITY

Disk Radial Structure: Dust Surface Density $\Sigma_d(r)$

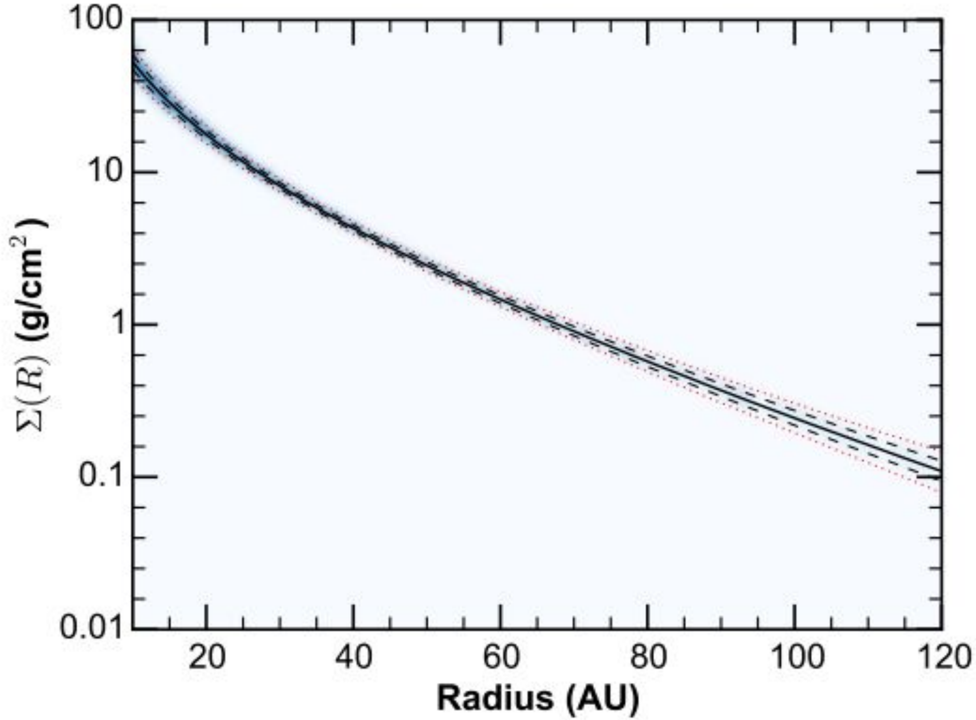
- Determines planet architecture

- Inferred from SEDs

- Minimum mass solar nebula:
  (Weidenschilling 1977, Hayashi 1981)

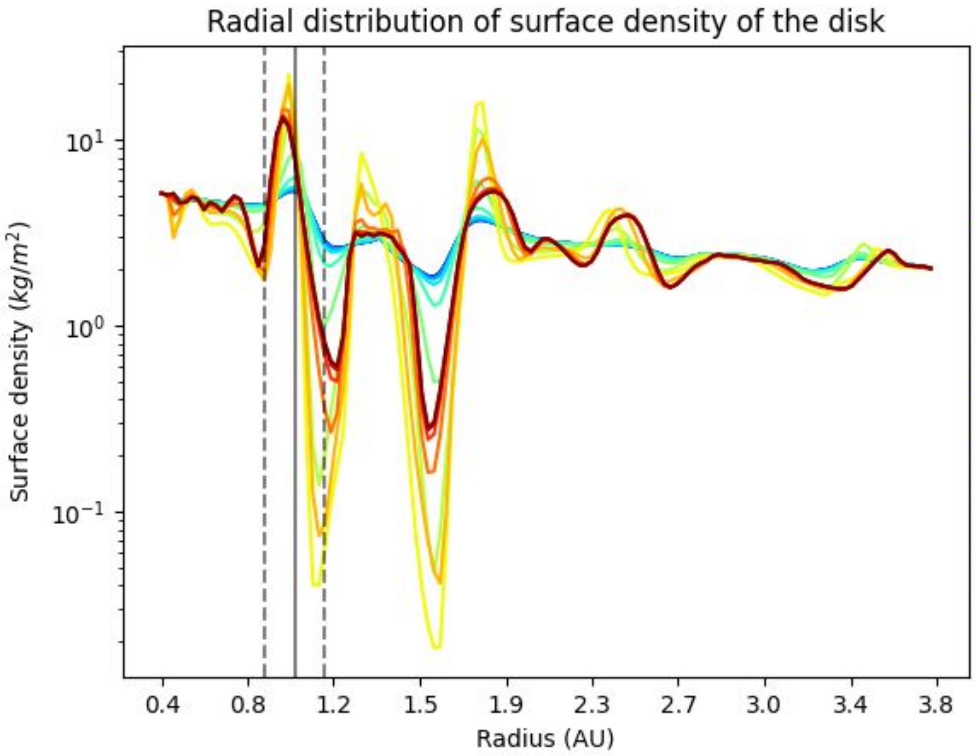
$$\Sigma(r) = 1700 \left(\frac{r}{1AU}\right)^{-\gamma} g/cm^2$$

- a_{grain} and τ uncertainties



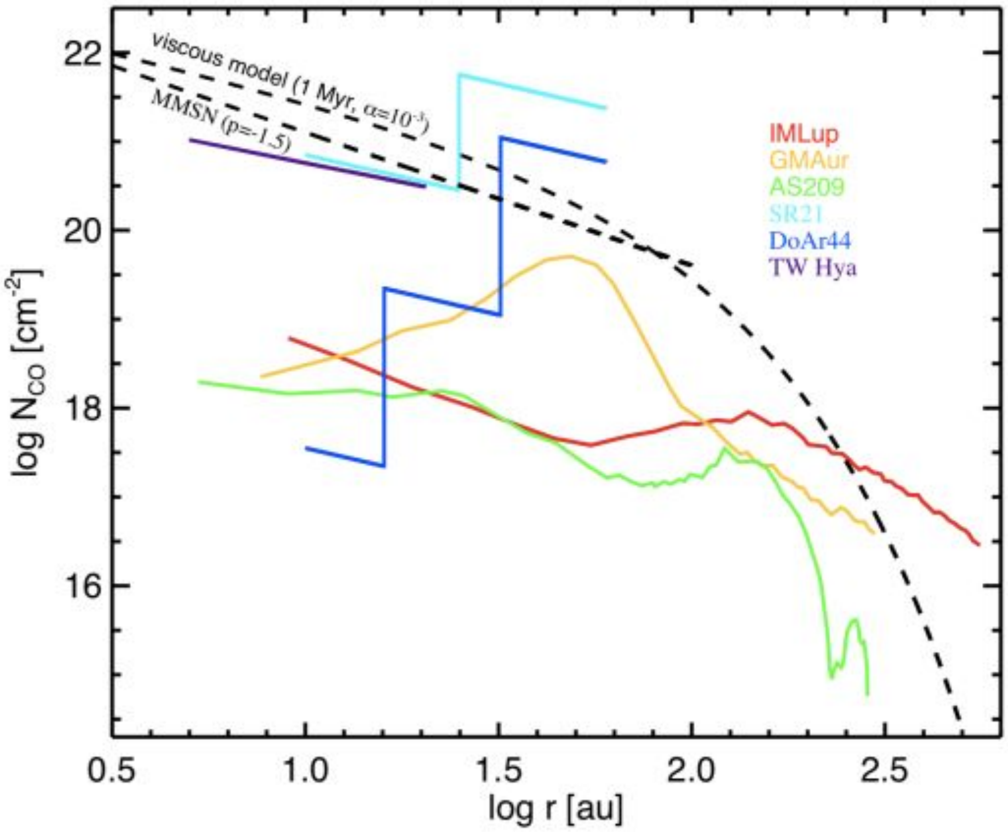
Tazzari et al. (2016)

Disk Radial Structure: $\Sigma_d(r)$ with Substructures



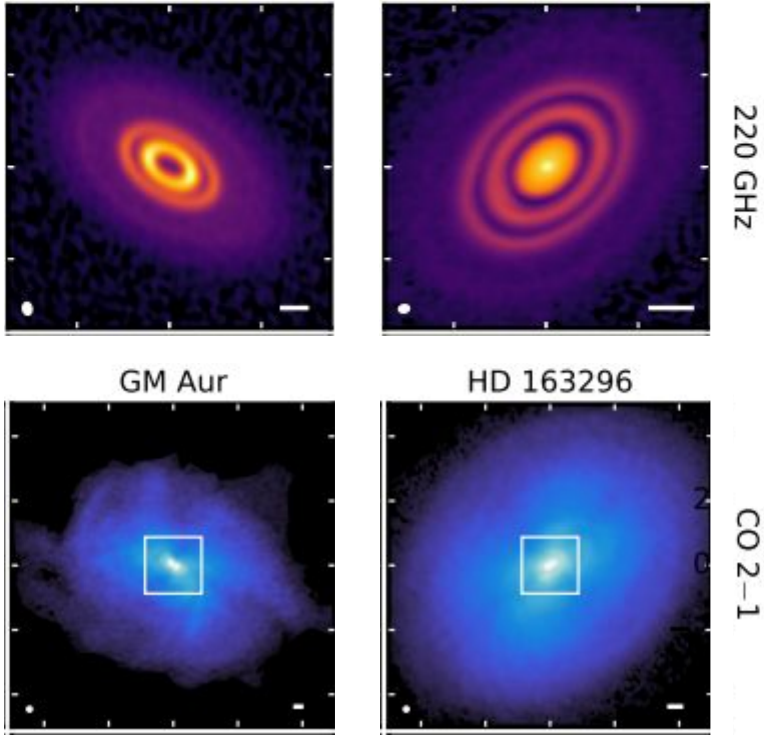
Self-made

Disk Radial Structure: Gas Surface Density $\Sigma_g(r)$



Miotello et al. (2022)

Disk Radial Structure: Role of Substructures in $\Sigma(r)$



MAPS Survey, Law et al. (2021)

Gas shows less substructure compared to dust

Disk Surface Density

Dust Σ: Power law profile

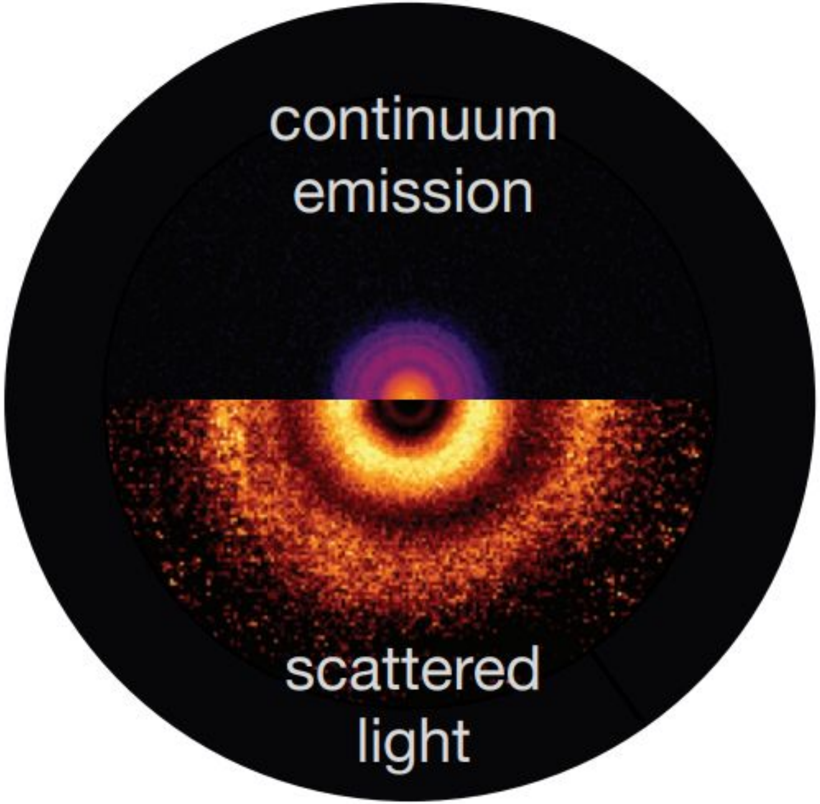
Gas Σ: CO emission

Gas substructure < Dust substructure

DISK OUTER RADIUS

Disk Radial Structure: Dust Outer Radius R_{dust}

- R_N: Radius that encircles N% of luminosity
- Typically, N=68 (Tripathi et al. 2017)
- Continuum vs scattered light disk radius



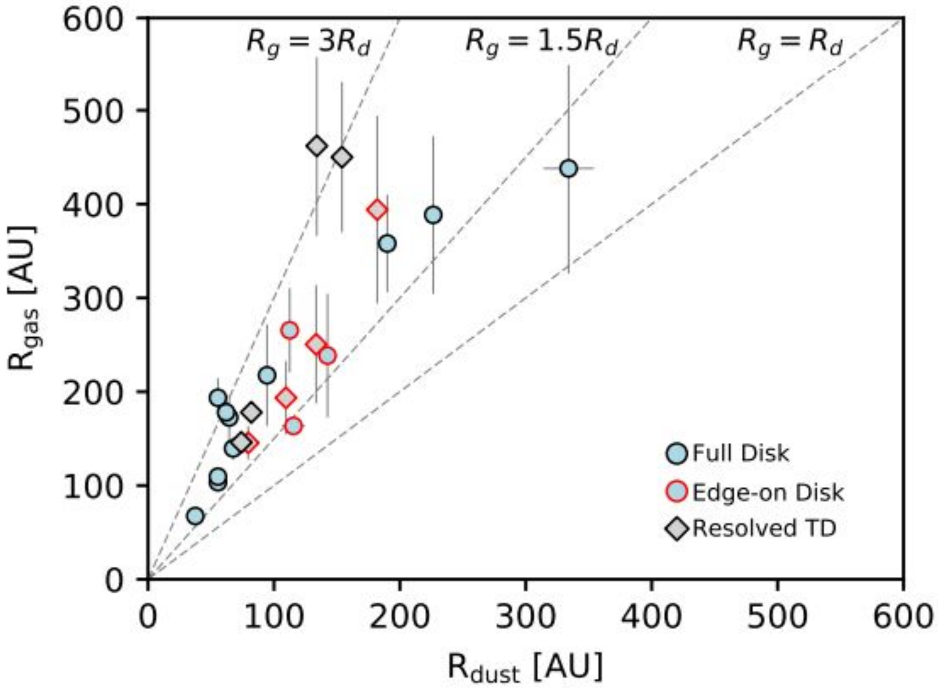
Miotello et al. (2022)

Disk Radial Structure: Gas Outer Radius R_{CO}

- R_{CO}: 90% of measured ^{12}CO flux

- R_{CO} greater than R_{dust}

- Faint CO emission: Compact disks



Ansdell et al. (2018)

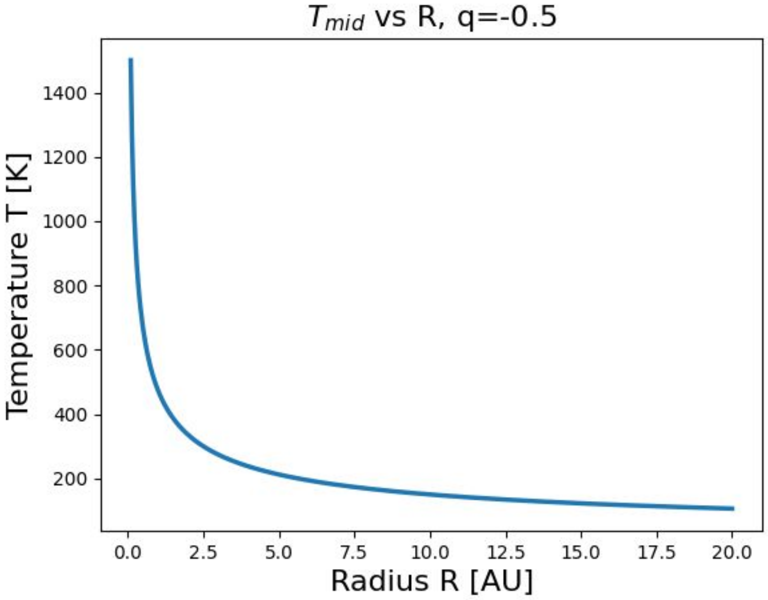
DISK TEMPERATURE

Disk Radial Structure: Dust Temperature $T_d(r)$

- Controls disk chemical composition

- Stellar radiation intercepted by grains

- Decreases radially outward



Self-made

$T \propto R^q$

Disk Radial Structure: Gas Temperature $T_g(r)$

Inner disk (1–3 AU):

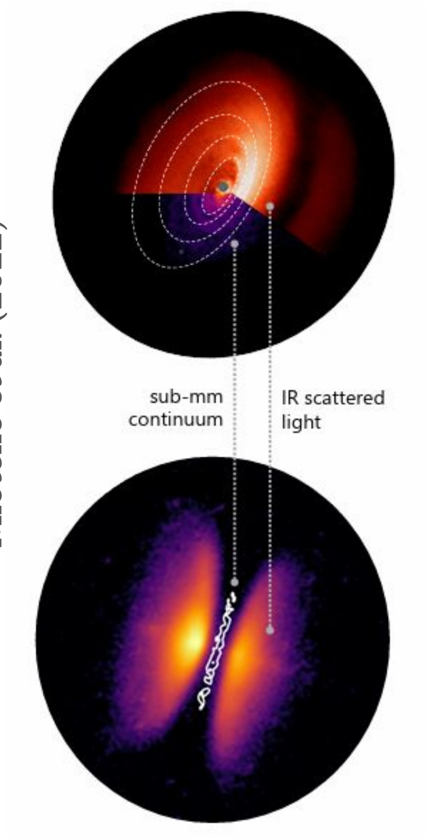
- Terrestrial planets
- CO, OH, H_2O emission lines
- 500 – 1700K

Outer disk (10–few 100 AU):

- Outer planets
- Abundant molecular lines (HCN vs CN)
- CO Snowlines
- ~20K

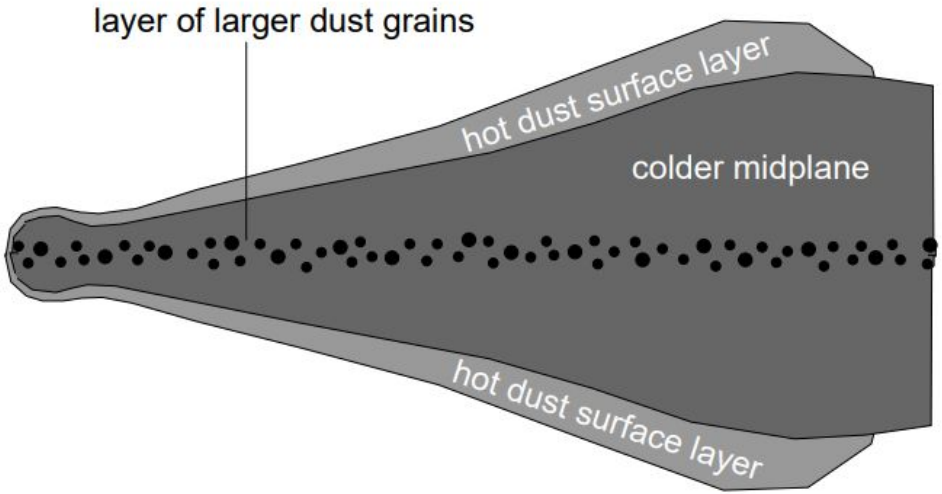
DISK VERTICAL STRUCTURE

Disk Vertical Structure



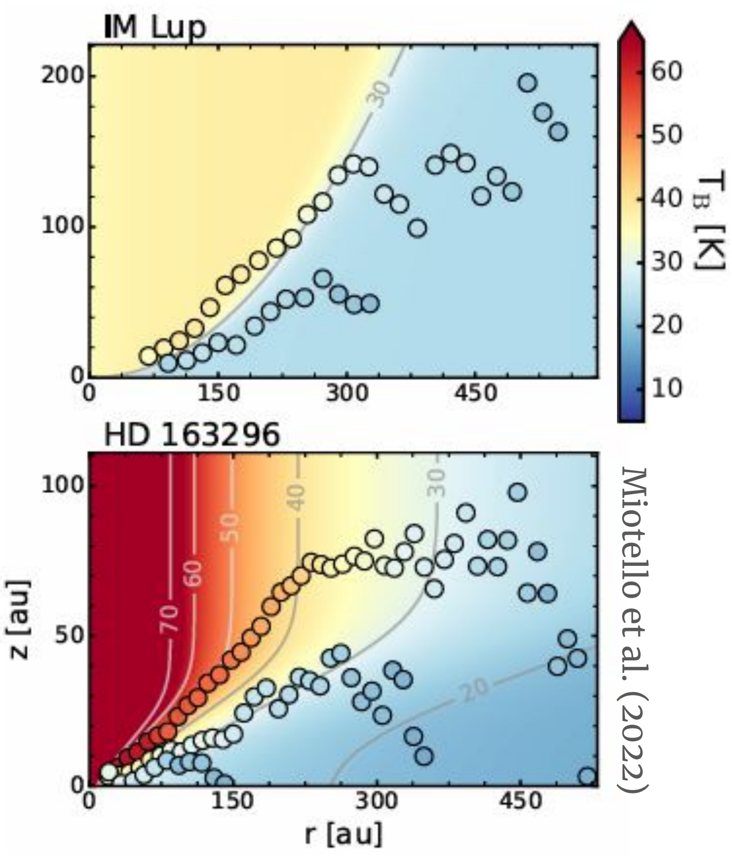
Miotello et al. (2022)

Flared Disk



Dullemond et al. (2007)

Disk Vertical Structure: Temperature T(z)



- Surface layers warmer
- Optically thick CO emission
  - Snowlines to infer T
- Substructures can affect profile

Conclusions

1. Disk properties determine planet architecture and composition
2. M_{disk} not well-constrained, underestimated
3. Gas has greater spatial extent, lesser substructures
4. Disk vertical structure important
5. Better measurement techniques and more observations required

Sources

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