Size Sorting in Disks

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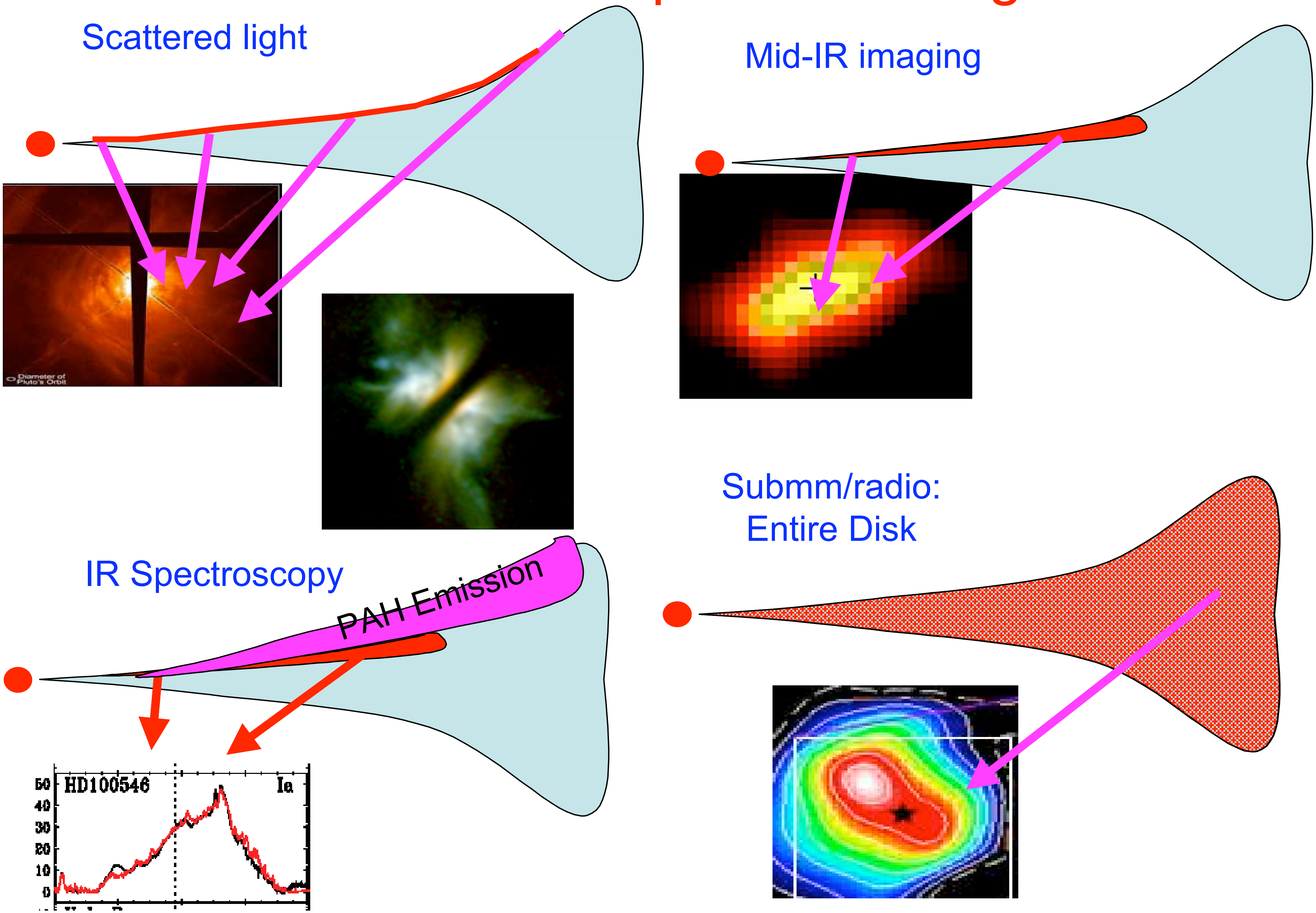
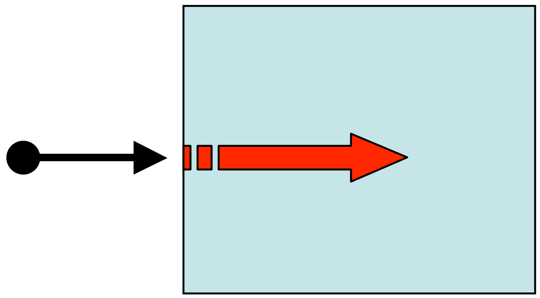
Which observations probe which grains?



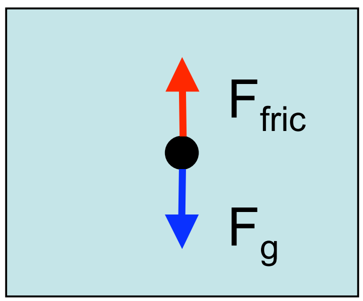
Observations relevant for settling and size sorting

- Height and opacity of edge-on disks (D'Alessio)
- Scattered light asymmetries (Duchene)
- Flaring/Shadowing (Wood, Dullemond, Hartmann Furlan)
- PAH emission: which grains are absorbing?
- Silicate emission: which grains are emitting?
- Silicate feature shape and strength (v. Boekel)
- Dust-to-gas ratio on high inclination sightlines (Rettig/Brittain)

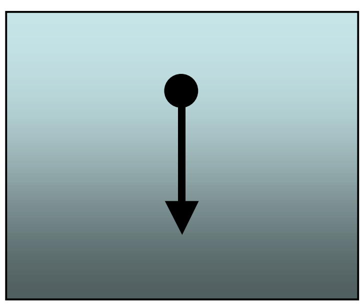
Dust Settling…



$$t_{\rm fric} = \frac{mv}{F_{\rm fric}} = \frac{3}{4 c_s \rho_{\rm gas}} \frac{m}{\sigma}$$



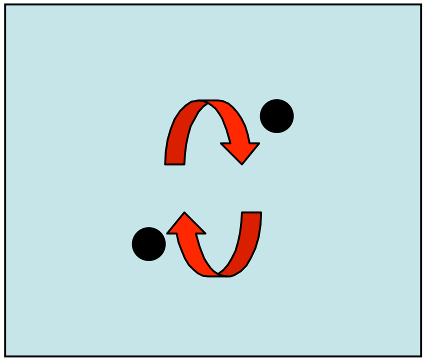
$$v_{\rm sett} = -z\Omega_K^2 t_{\rm fric} = -\frac{3\Omega_K^2 z}{4\rho c_s} \frac{m}{\sigma}$$



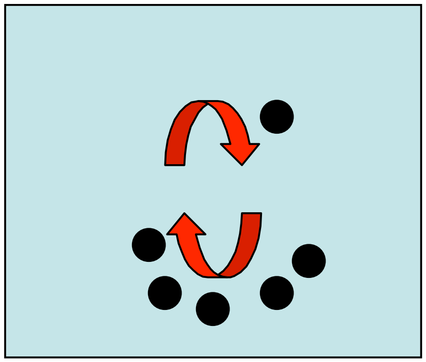
$$t_{\rm sett} = \frac{4}{3\sqrt{2\pi}} \frac{\sigma}{m} \frac{\Sigma}{\Omega_K} \exp\left(-\frac{z^2}{2H_p^2}\right)$$

Safronov 1969, Weidenschilling 1977, Dubrulle et al 1995

… and Vertical Stirring



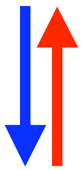
$$D = \frac{D_0}{1 + \frac{t_{\rm fric}}{t_{\rm edd}}}$$



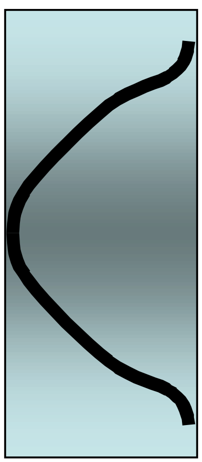
$$D_p \rho_p \frac{d}{dz} \left(\frac{\rho_p}{\rho} \right)$$

e.g. Cuzzi et al 1993, Dubrulle et al 1995

Equilibrium solutions



$$\rho_p v_{\rm sett} = D_p \rho_p \frac{d}{dz}\left(\frac{\rho_p}{\rho}\right)$$



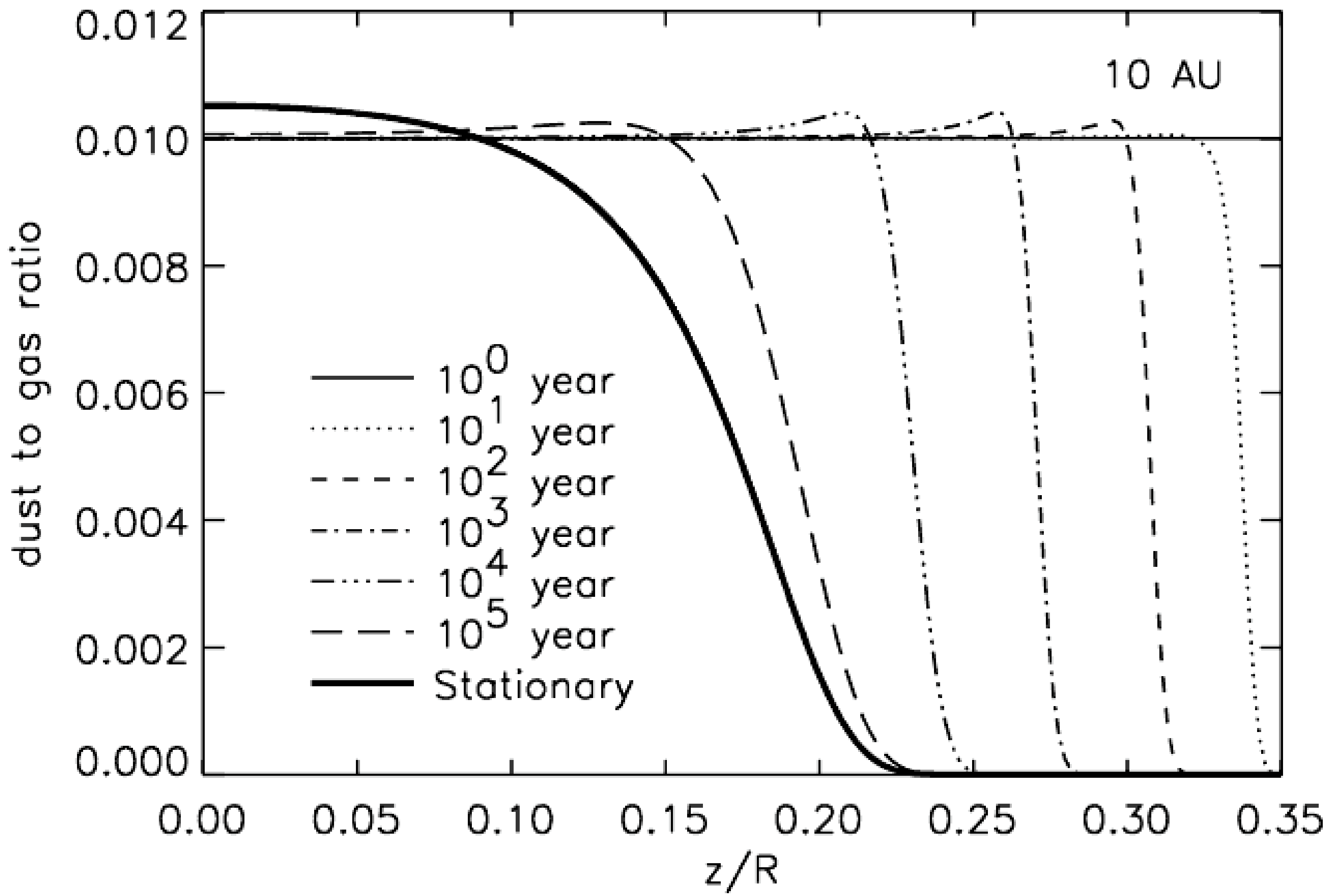
$$\left(\frac{h_{\rm part}}{H_p}\right)^2 = \frac{\alpha}{\frac{t_{\rm fric}}{t_{\rm edd}}\left(1+\frac{t_{\rm fric}}{t_{\rm edd}}\right)}$$

$$\frac{h_{\rm part}}{H_p} \approx \frac{\alpha}{t_{\rm fric}/t_{\rm edd}} \propto \boxed{\frac{\sigma}{m}} \propto a^{-1}$$

constant gas density

compact

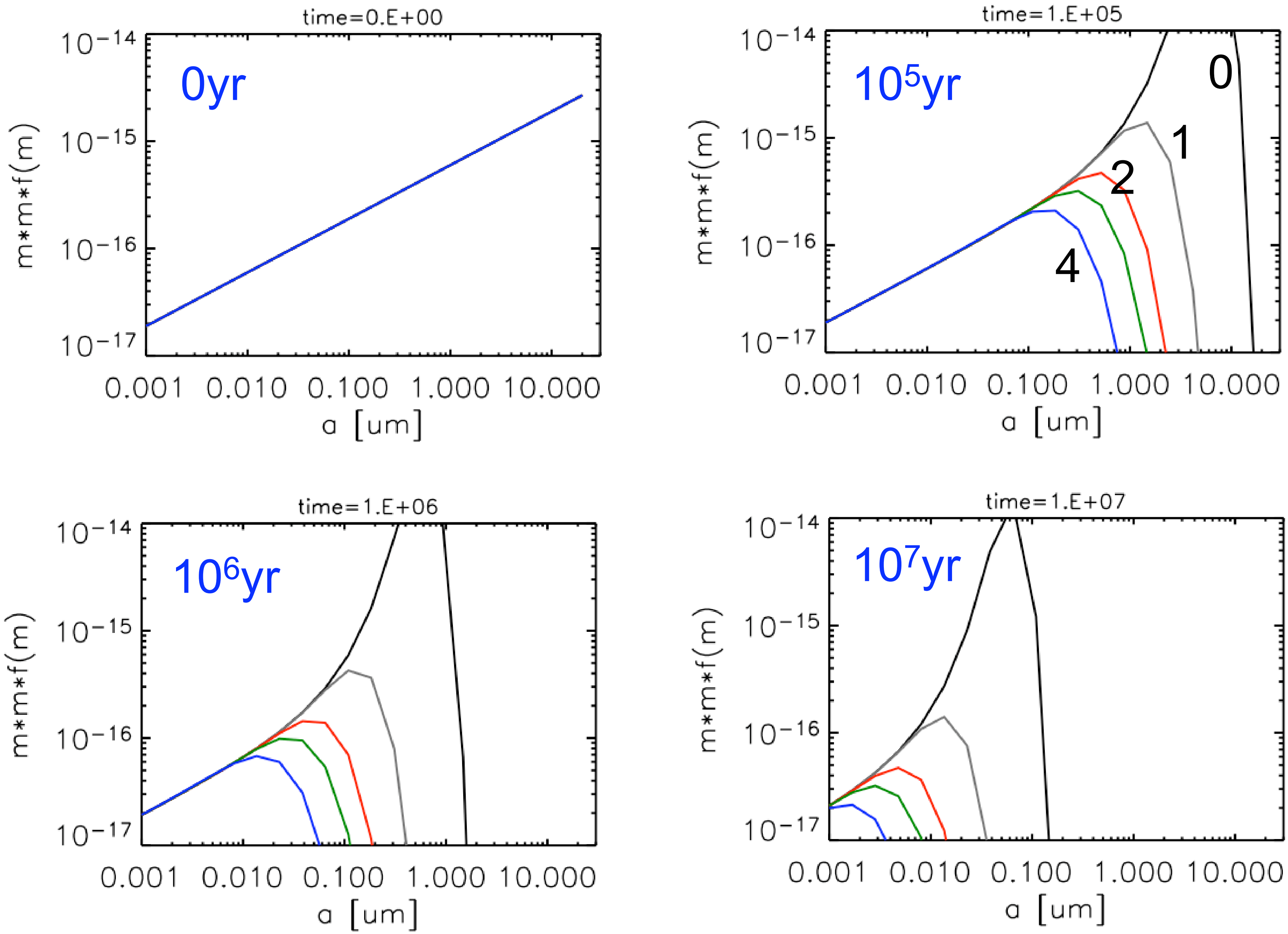
Time evolution of dust-to-gas ratio



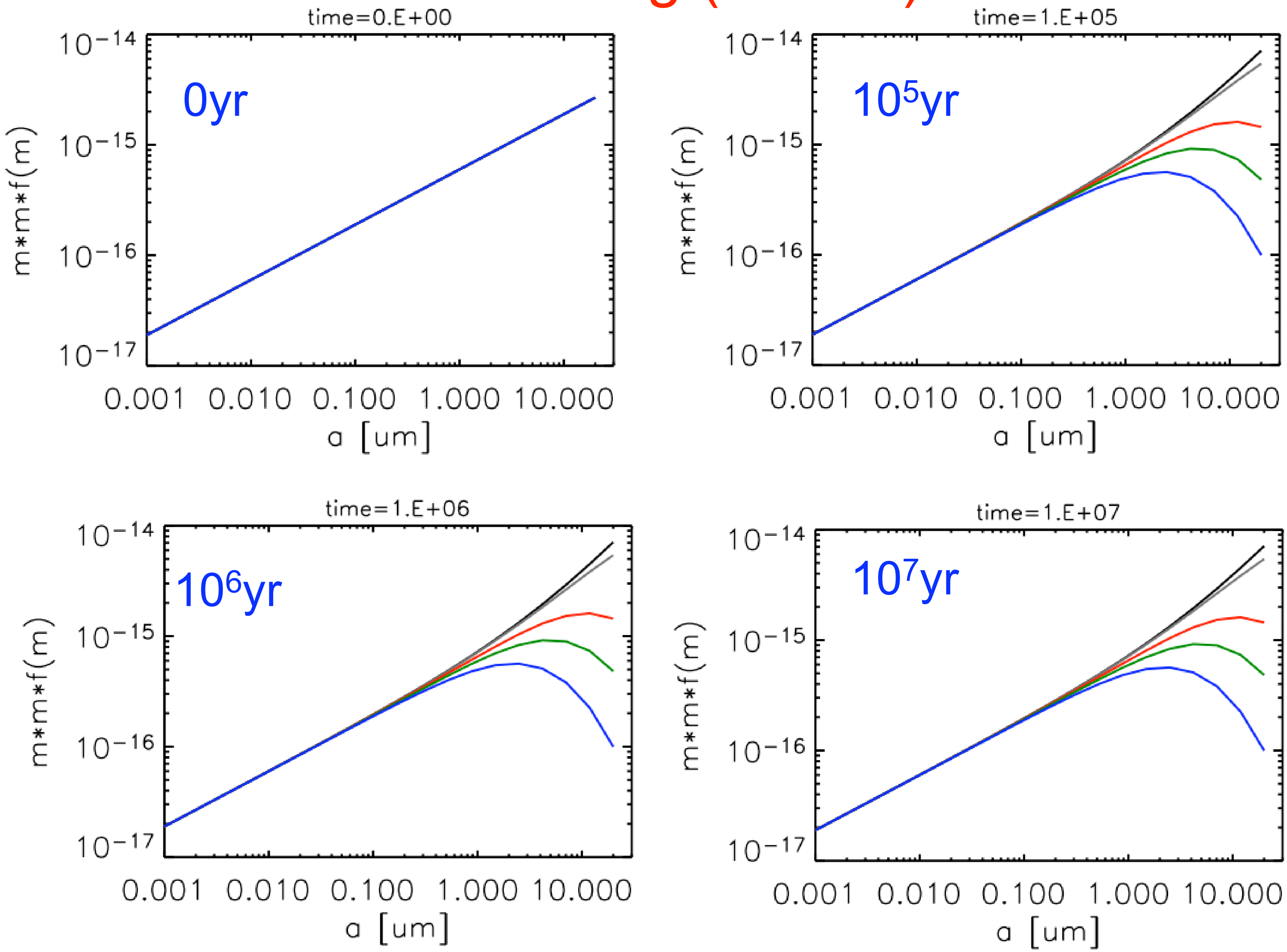
Size distribution at different z

- Start with fully mixed disk
- Follow differential settling over time
- Compute size distribution at different heights (0,1,2,3,4 H)

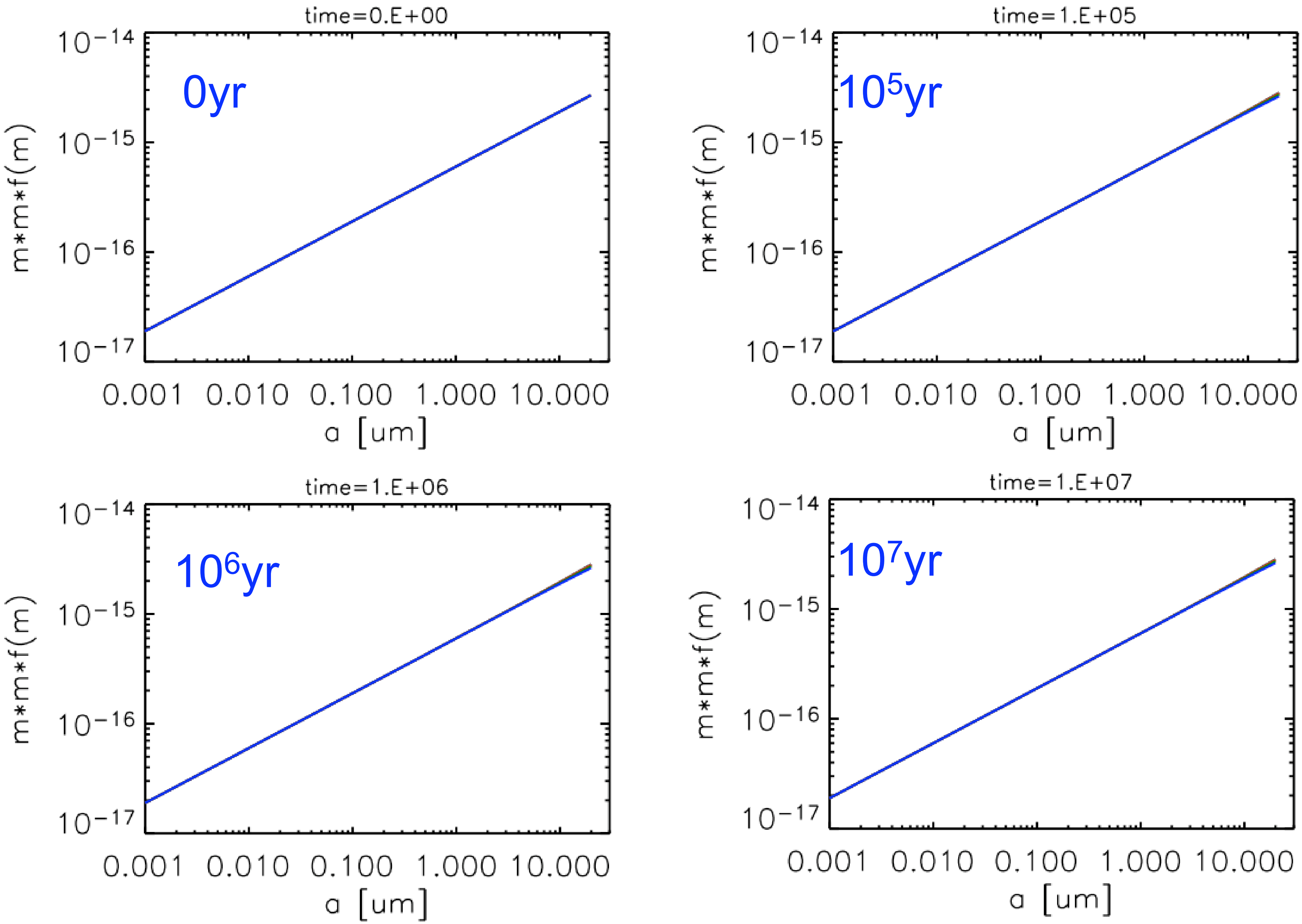
No mixing (α=0)



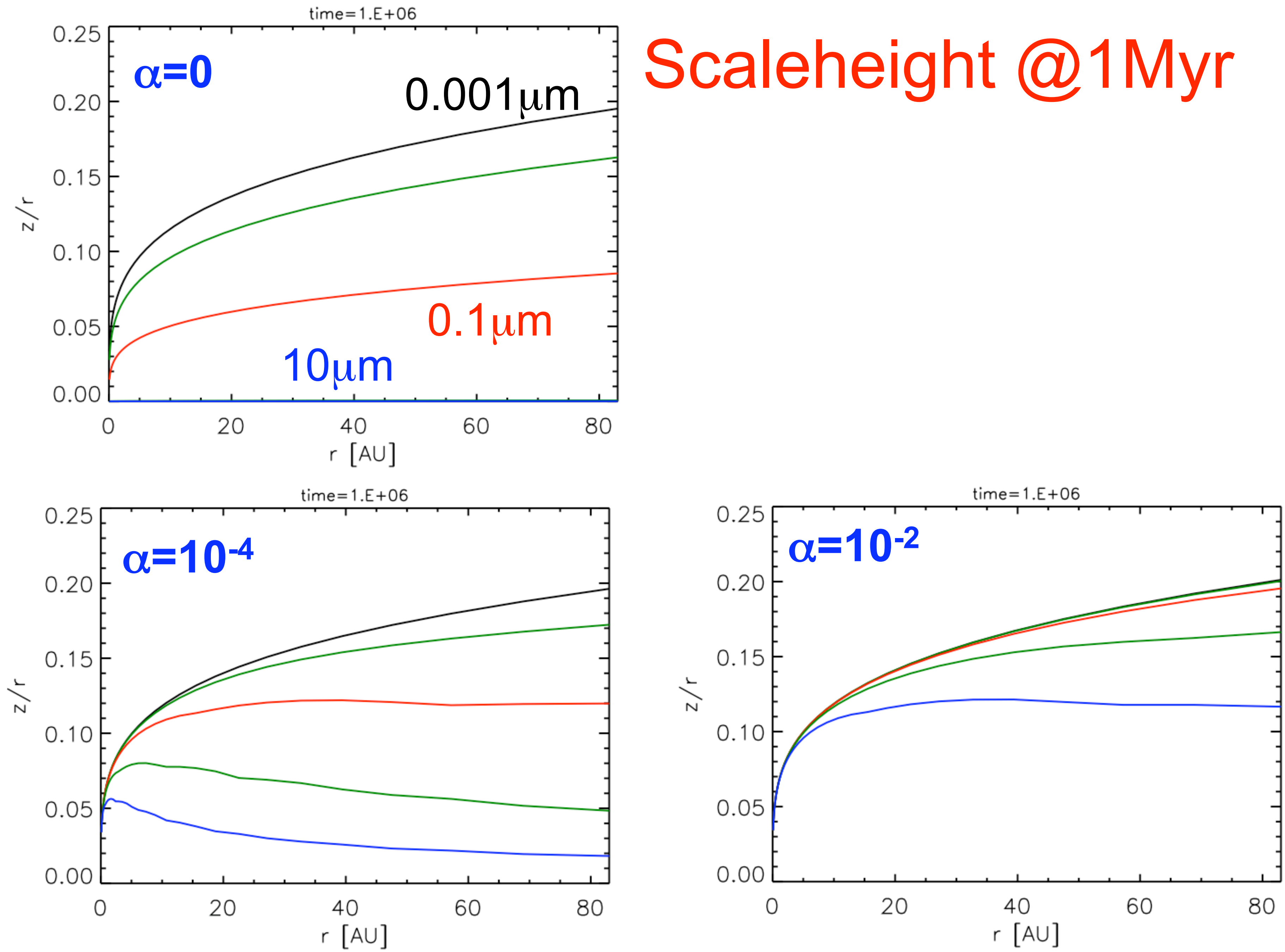
Little mixing ($\alpha=10^{-4}$)



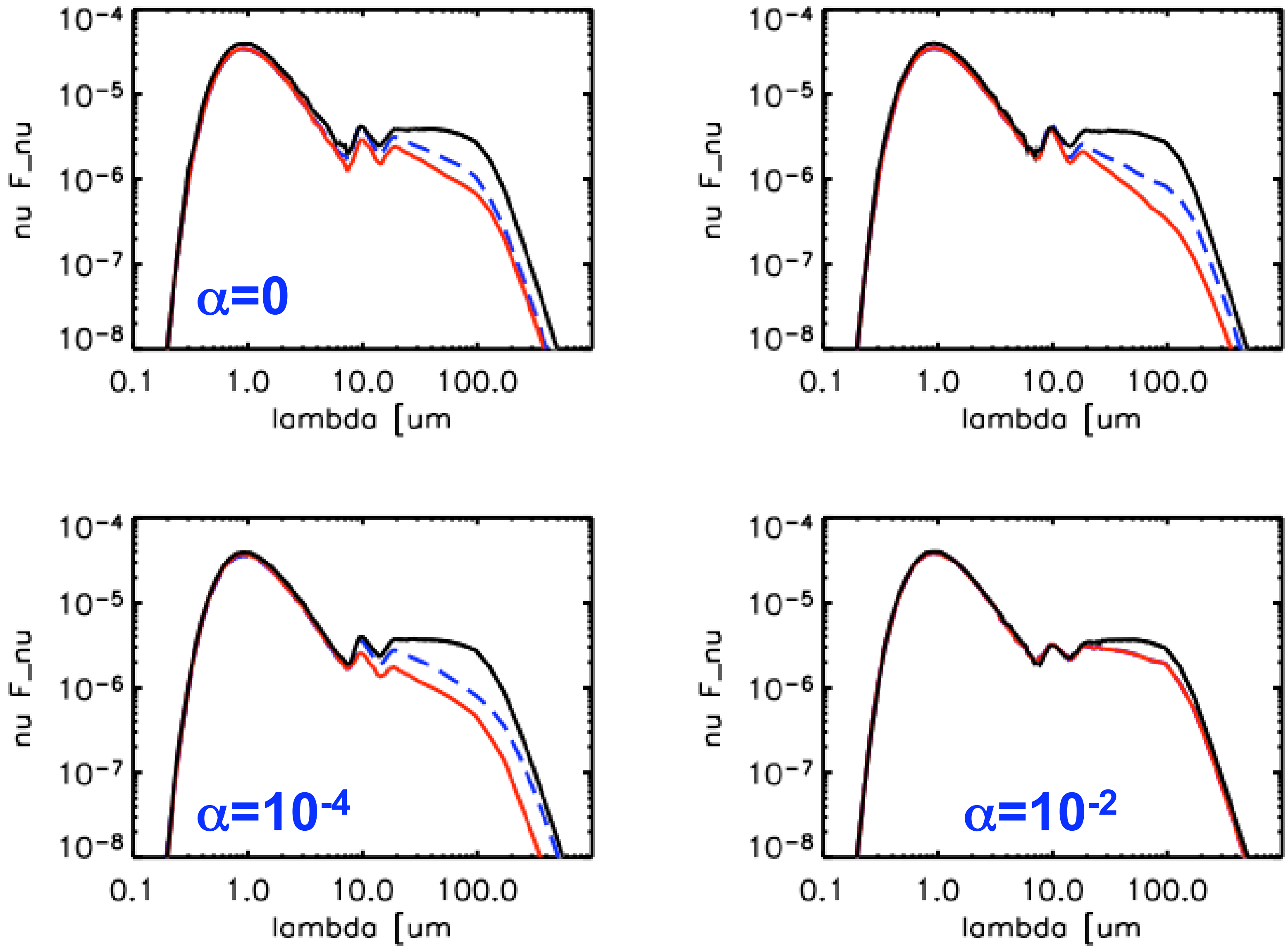
Heavy mixing ($\alpha=10^{-2}$)



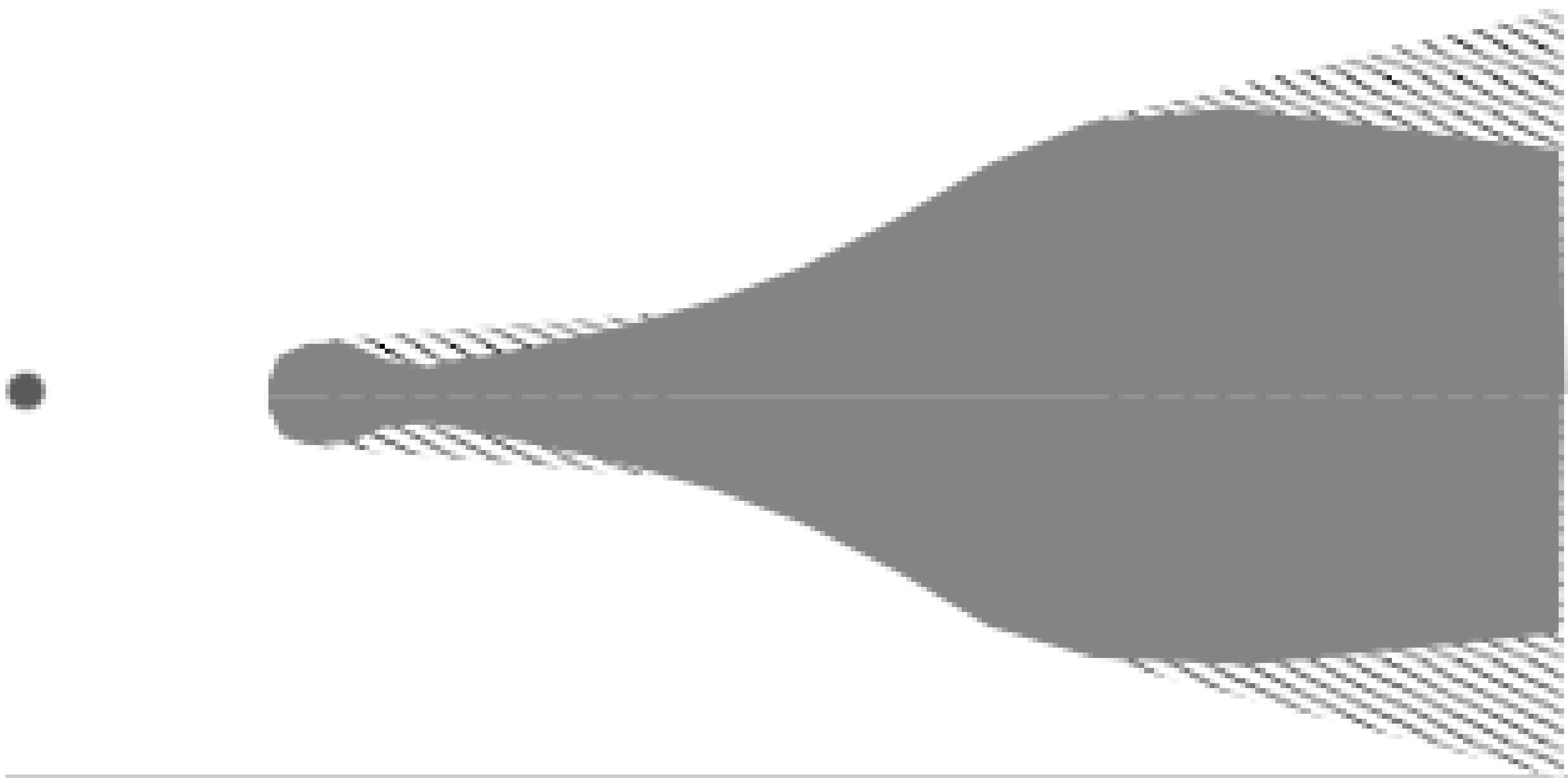
Scaleheight @1Myr



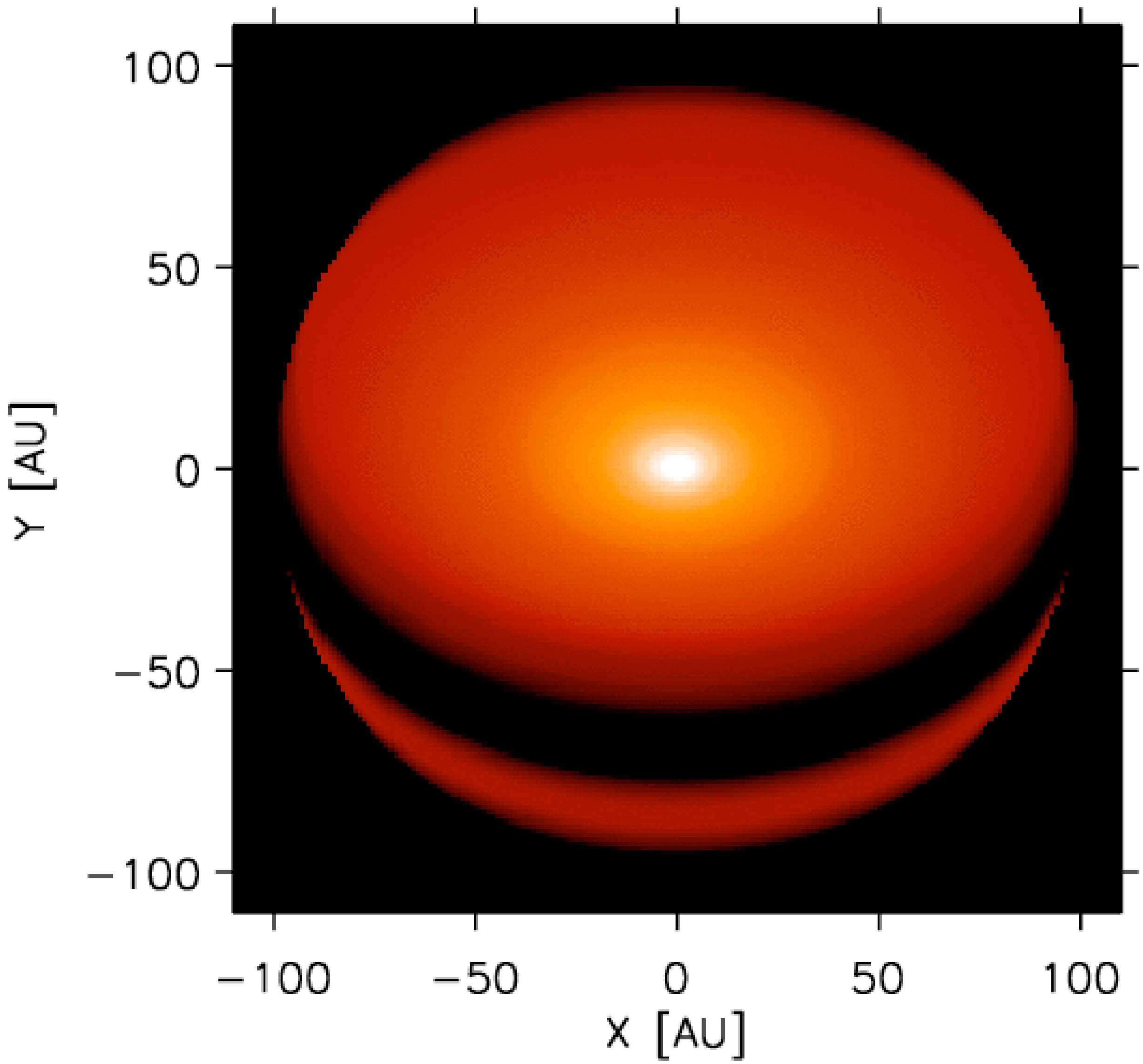
SED @0,1,10Myr



Shadowing induced by settling

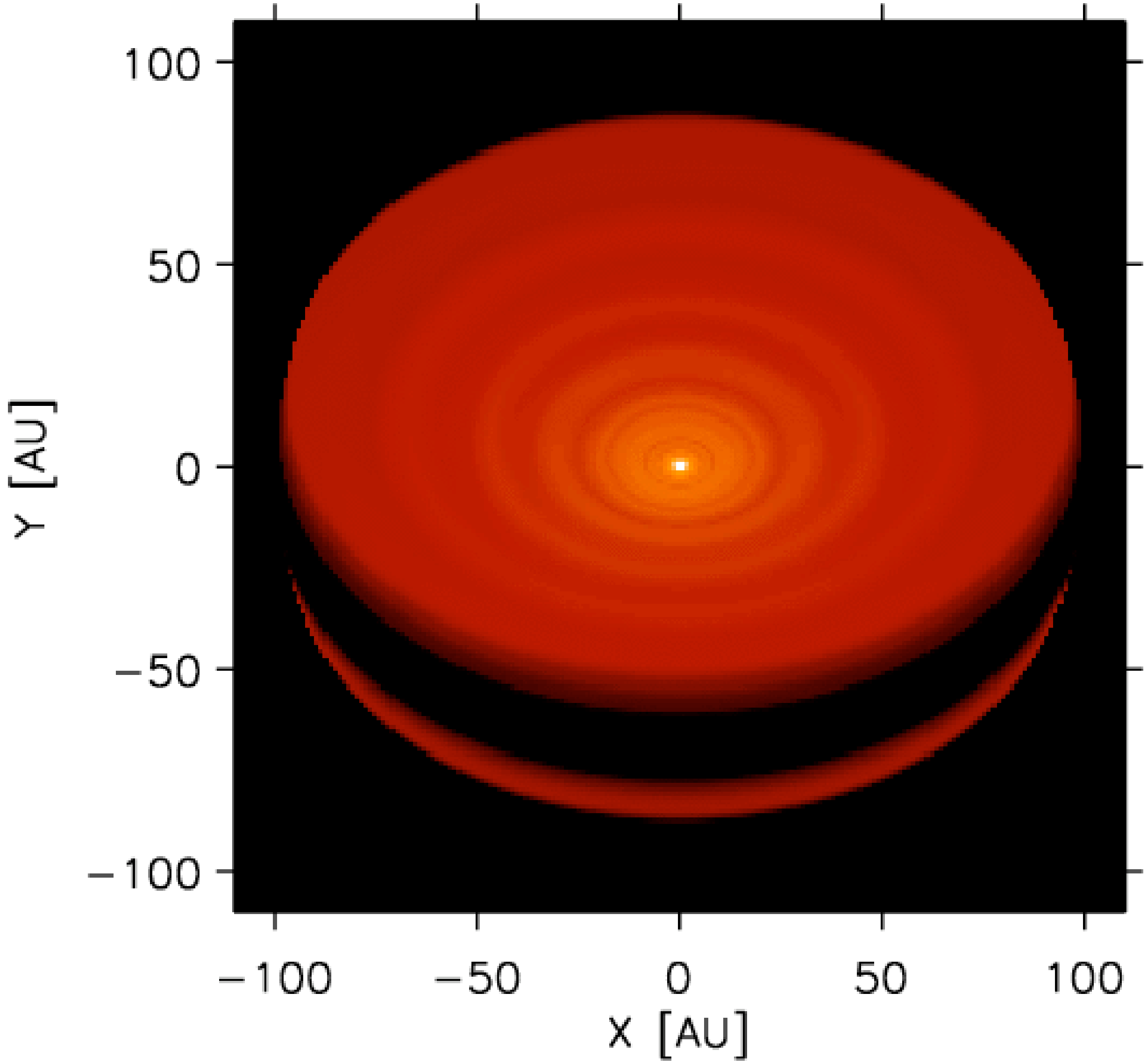


t=0



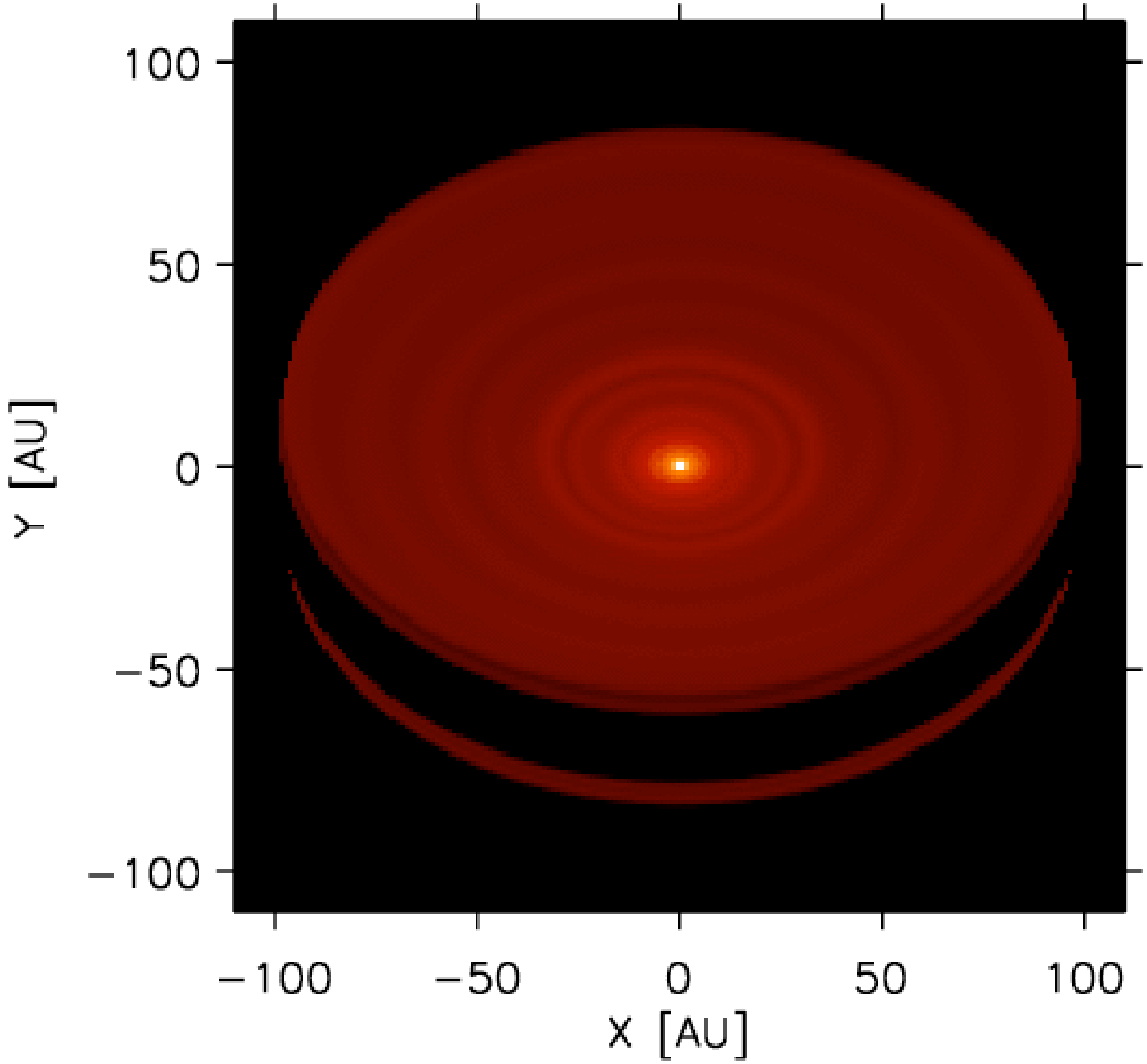
Dullemond & Dominik 2004

$t=10^4$years



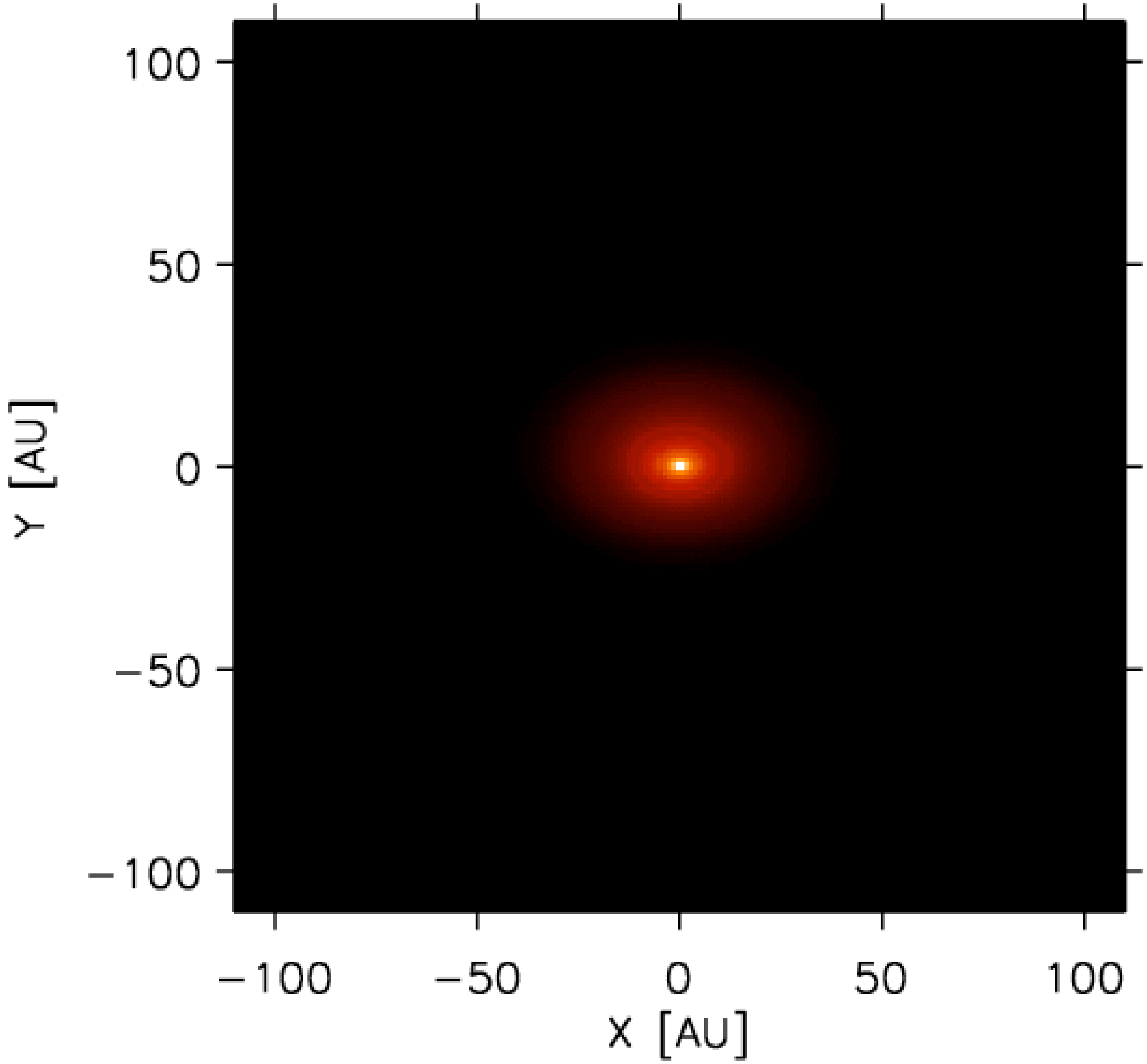
Dullemond & Dominik 2004

t=10^5years



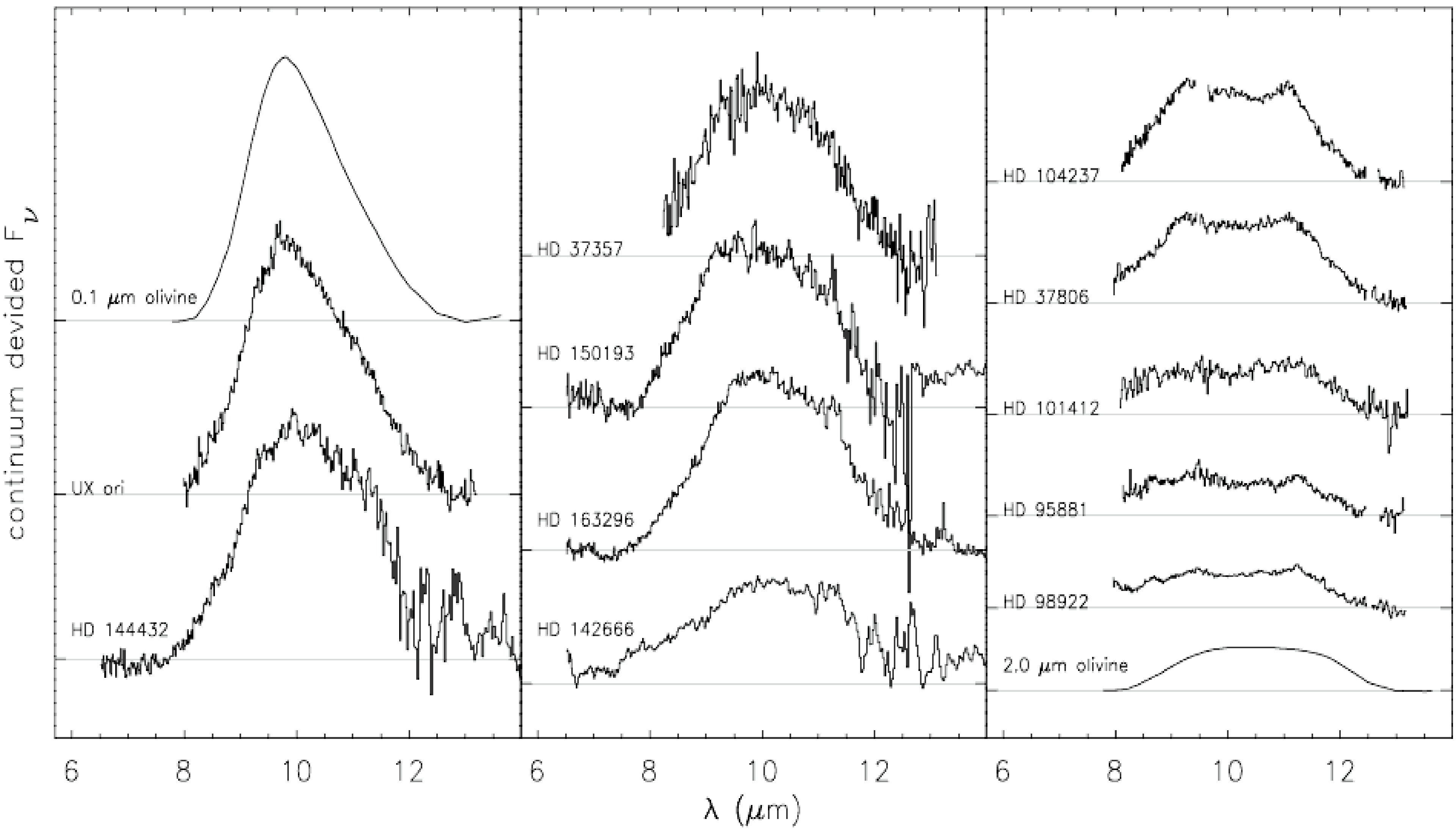
Dullemond & Dominik 2004

t=10^6years



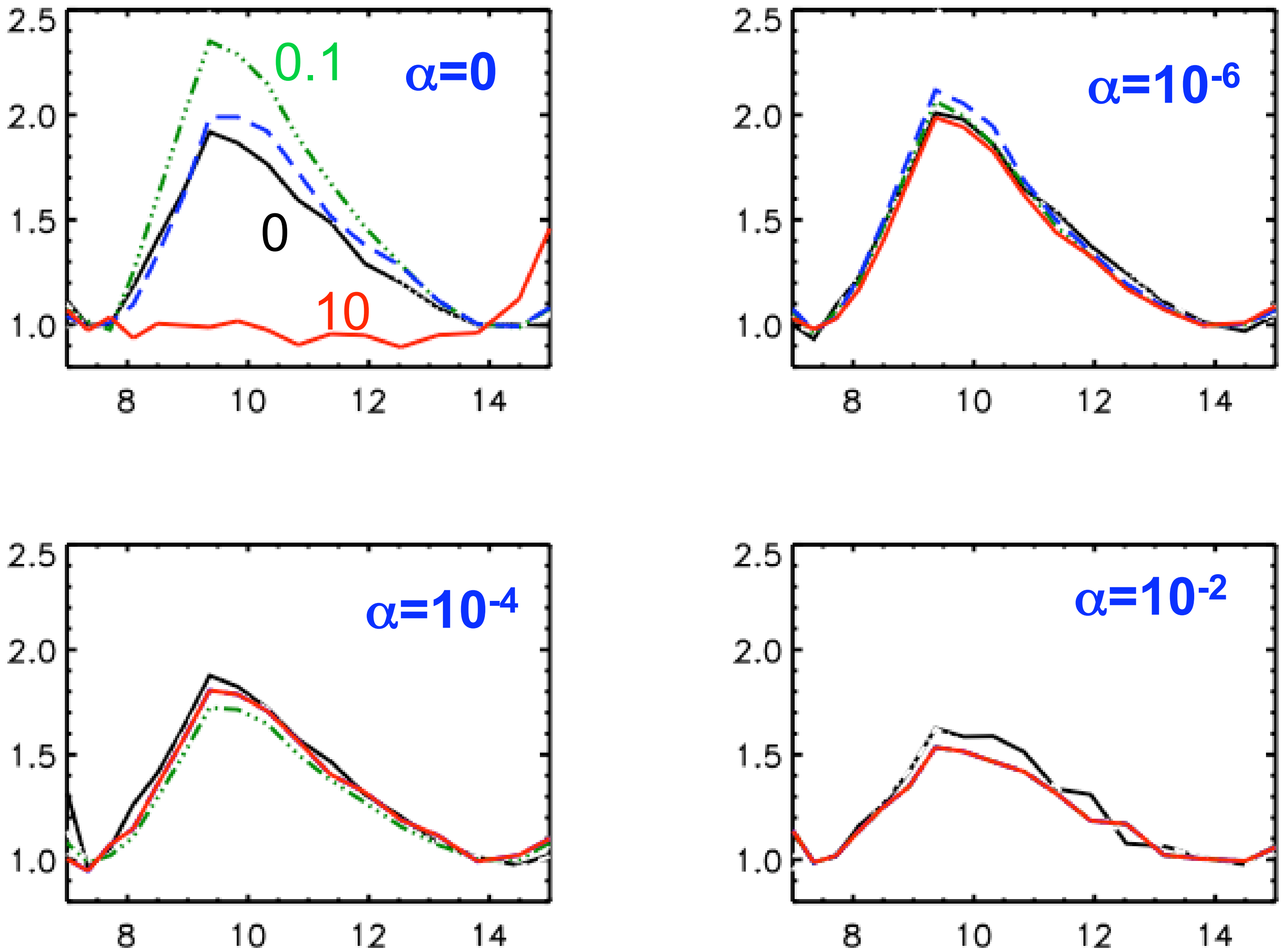
Dullemond & Dominik 2004

Grain size reflected in silicate feature strength



v. Boekel et al 2003

N band @0,0.1,1,10Myr, a_{gr}>0.01um

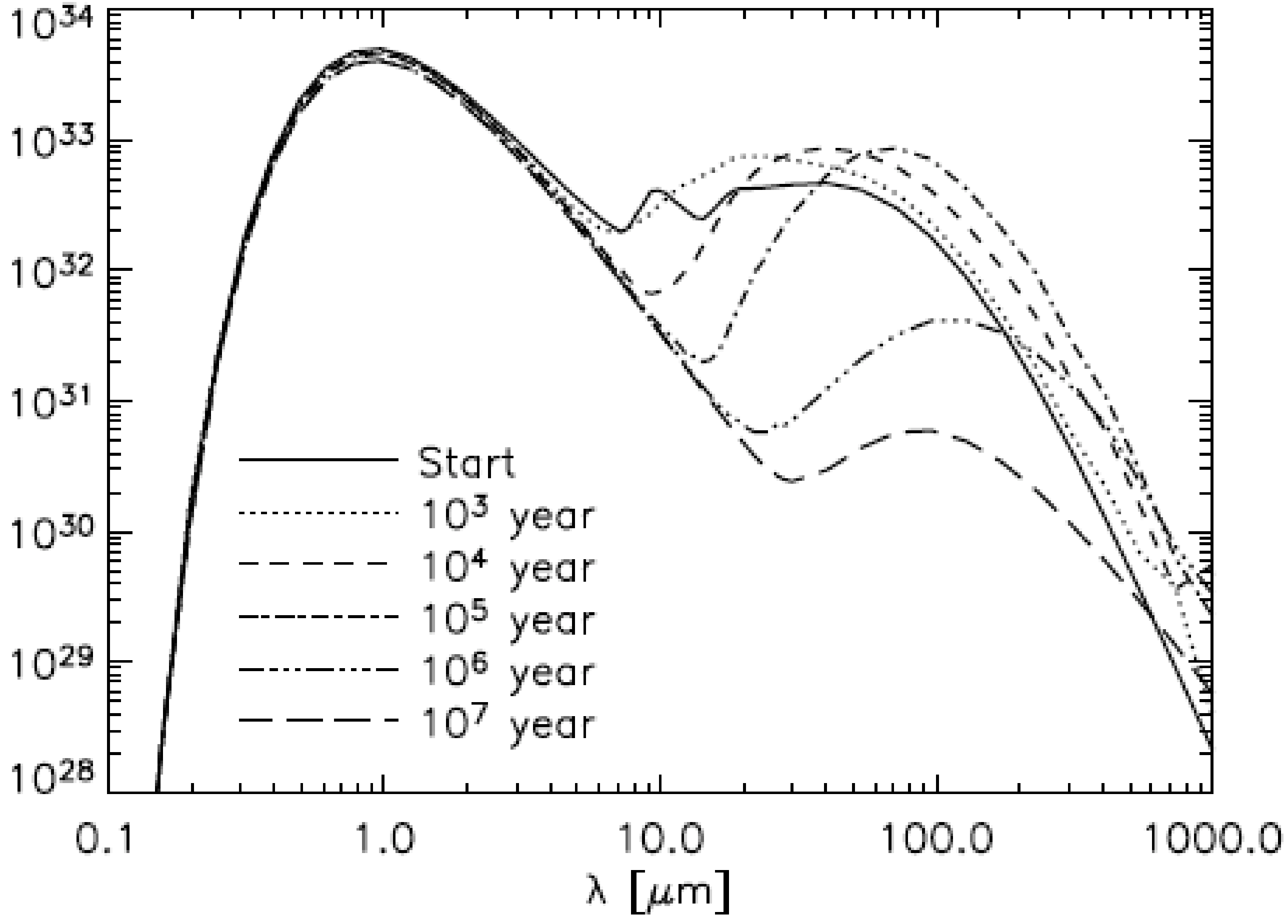


Grain growth/aggregation

- Effects of aggregation (grain growth)
  - PAH-like grains do not settle nor aggregate in atmosphere (density, charge)
  - Mixing cold bring them to high densities, where aggregation does work (Dullemond & Dominik, 2005)
  - What happens if aggregates get back up into atmosphere?
- Silicate feature shape in aggregates?

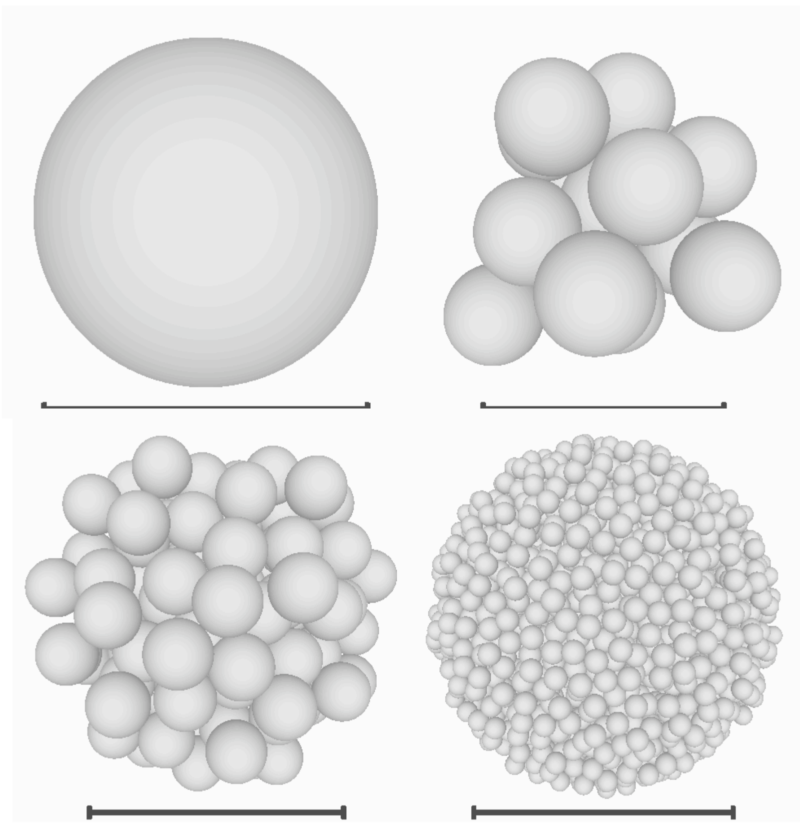
Dust growth going wild

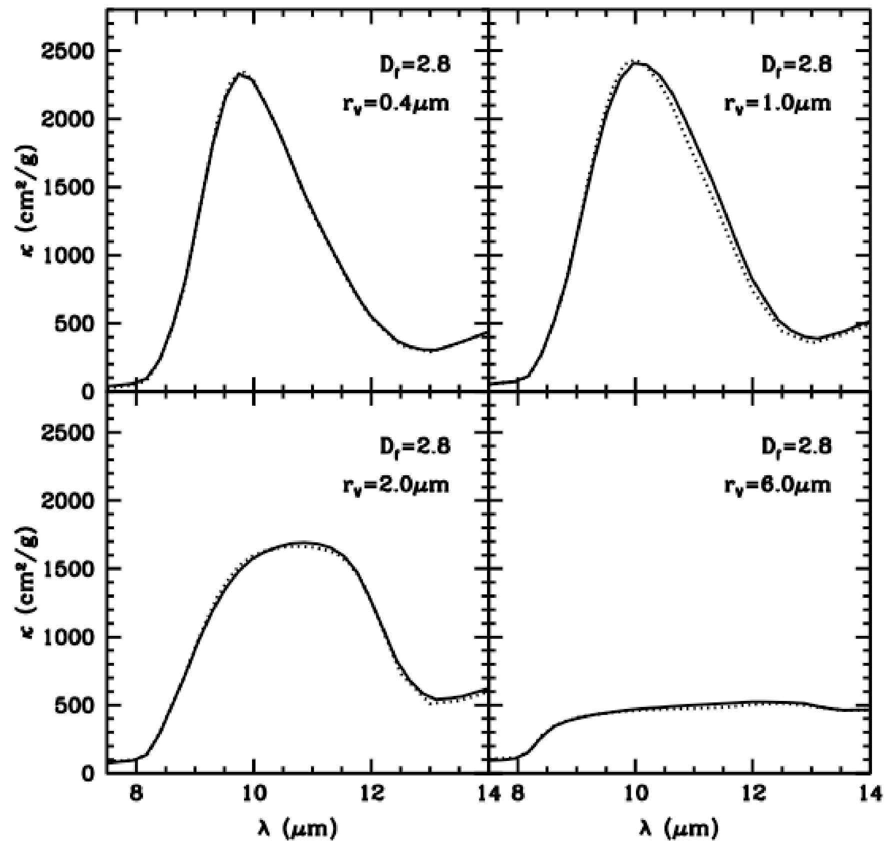
- Global aggregation models
- Including turbulent mixing and aggregation
- Fragmentation needed to replenish small grains



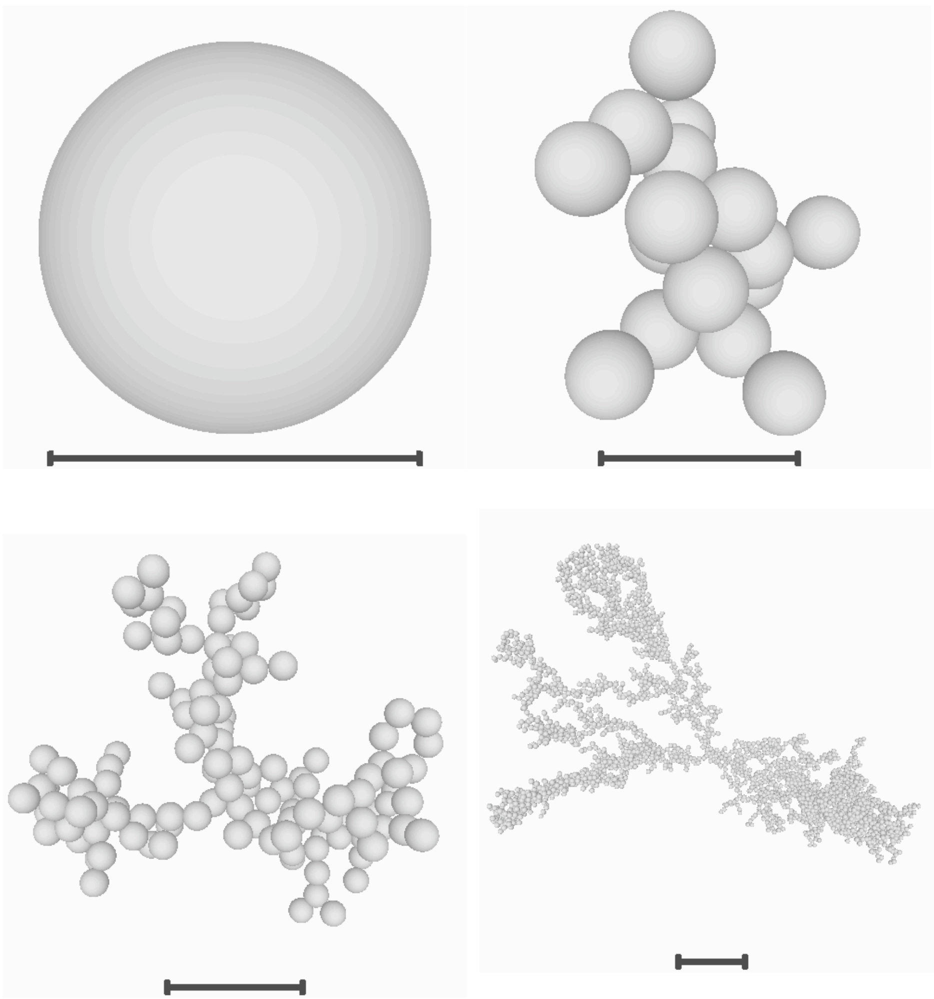
Dullemond & Dominik 2005 see also poster Tanaka et al

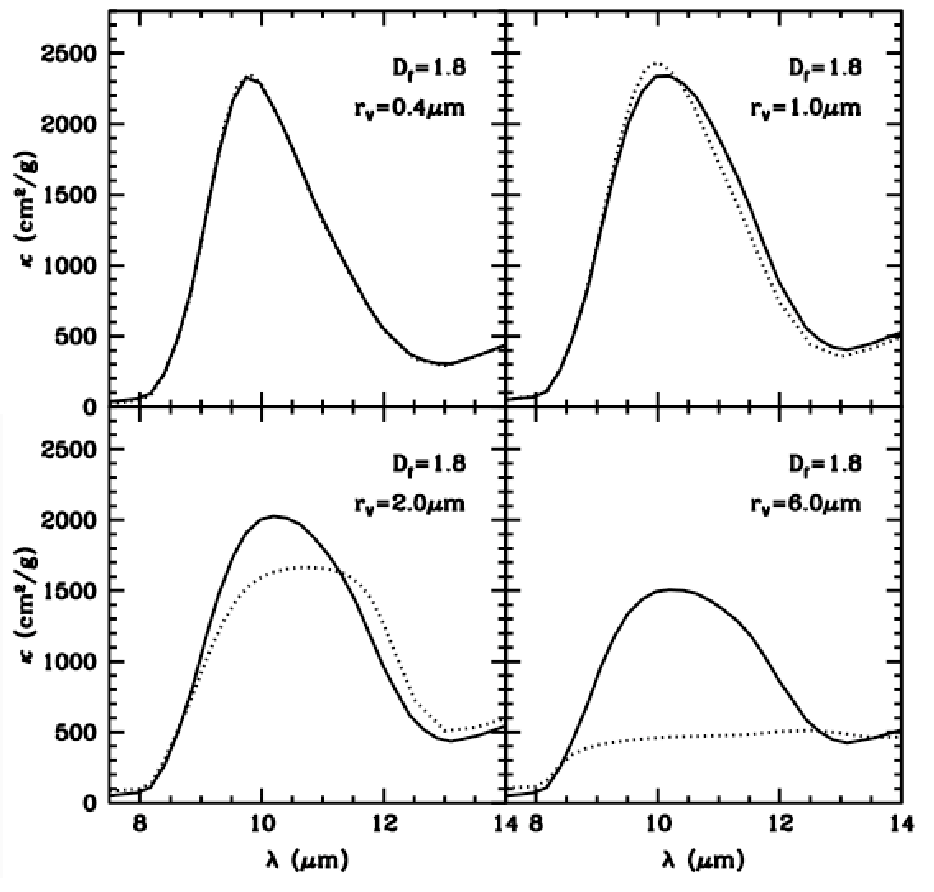
Compact aggregates (D=2.8)



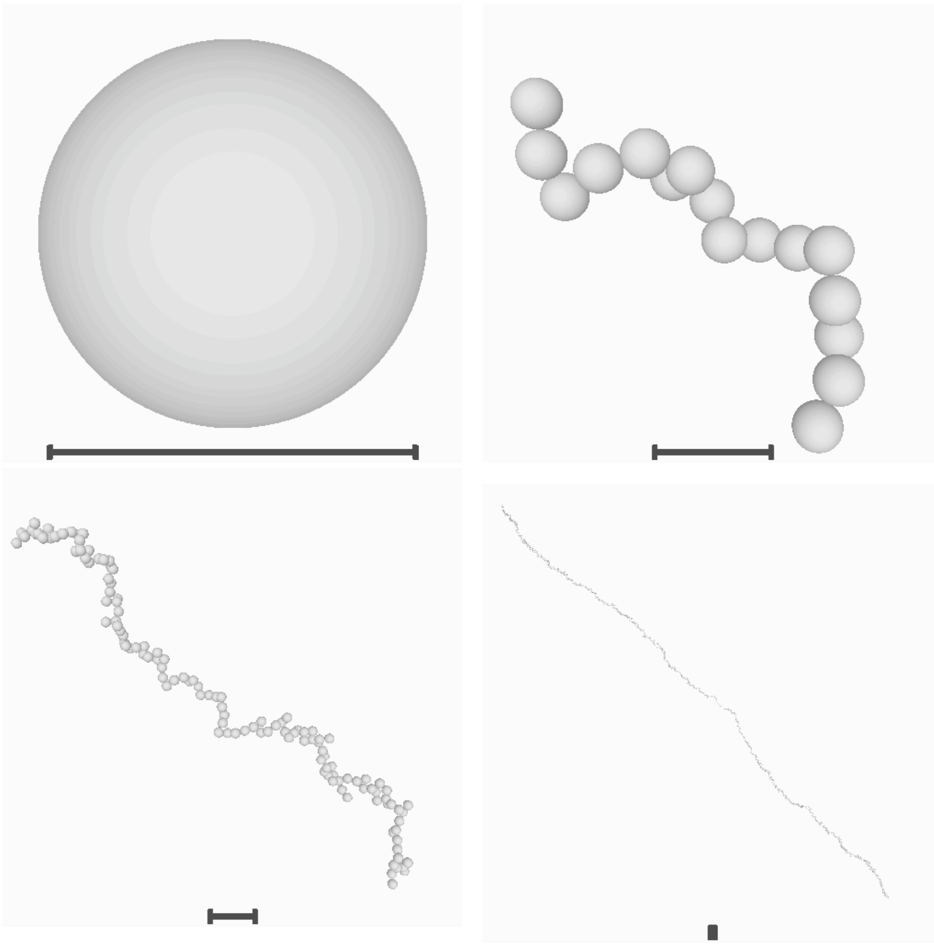


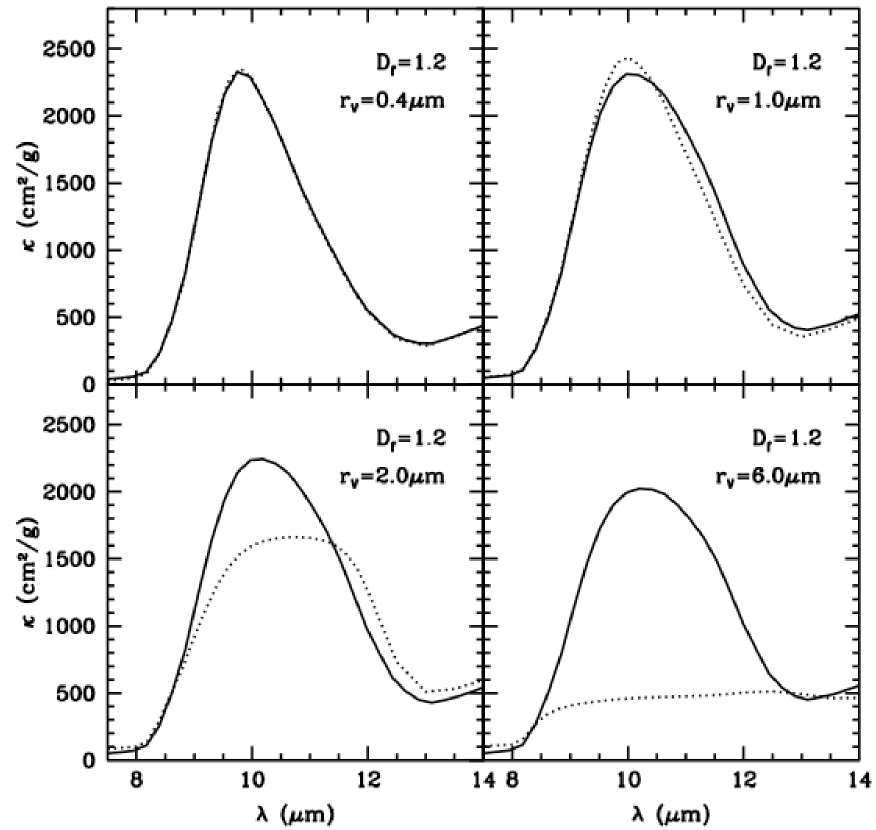
Intermediate aggregates (D=1.8)





Very open aggregates (D=1.4)





Conclusions

- Interplay between setting and mixing is determining grains distribution
- Distribution is according to σ/m, not “size”
- Strong mixing limits impact on SED and features
- How representative is surface dust?
  - Mixing is required to keep 1µm grains visible: Mineralogical contact w. midplane
  - α=0.01: Small grains in surface representative up to few µm.
  - $\alpha=10^{-4}$: Small grains are not representative.
- “Large grain” silicate feature may mean aggregates of >50 µm diameter.