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①

Dust settling timescales

Assume Epstein drag:  $\vec{F}_{\text{drag}} = -4\pi r_p^2 \rho_g c_s \vec{v}_{\text{rel}}/3$

Evaluate @  $r = 1 \text{ AU}$ ,  $z = 0.1 r = 0.1 \text{ AU}$  from "MMSN, no visc, dust/gas =  $10^{-4}$ , Dust settling"

Conditions:

$$n_H \approx 10^{11.5} \text{ cm}^{-3}$$

$$c_s \approx 1.5 \text{ km s}^{-1} (?)$$

$$(T_{\text{dust}} \approx 300 \text{ K})$$

Put  $r_p = 1 \mu\text{m}$  w/

Settling ~~the~~ speed:  $\vec{v}_d = \vec{v}_{\text{rel}}$

Settling time

Balance  $F_d$  against gravity:

$$\frac{4\pi}{3} r_p^2 \rho_g c_s v_{\text{rel}} = \frac{4\pi}{3} r_p^3 \rho_p g$$

$$\rho_p \sim 3 \text{ g cm}^{-3}$$

$$g = \Omega^2 z$$

$$v_{\text{rel}} = \frac{\rho_p}{\rho_g} \frac{g r_p}{c_s} \rightarrow \frac{\rho_p}{\rho_g} \frac{\Omega^2 r_p z}{c_s}$$

$$\text{Settling time} = z/v_{\text{rel}} = \frac{\rho_g}{\rho_p} \frac{c_s}{\Omega^2 r_p}$$

$$\rho_g \approx n_H m_H \approx 10^{-12.3} \text{ g cm}^{-3}$$

$$\Omega = 2\pi/\text{yr} = 2 \times 10^{-7} \text{ s}^{-1}$$

$$c_s \approx 10^5 \text{ cm/s}$$

$$r_p = 10^{-4} \text{ cm}$$

solid density of grains  
 $\rho_p \approx 3 \text{ g cm}^{-3}$

$$\Rightarrow \tau_{\text{settling}} \approx 10^{2.14} \left( \frac{n_H}{10^{11.5} \text{ cm}^{-3}} \right) \left( \frac{c_s}{1 \text{ km s}^{-1}} \right) \left( \frac{r_p}{1 \mu\text{m}} \right)^{-1} r_{\text{AU}}^3 \text{ yr}$$

ie few  $\times 10^9$  seconds, not years!