The Aeolian-Erosion Barrier for The Growth of Metre-Size Objects in Protoplanetary-Discs

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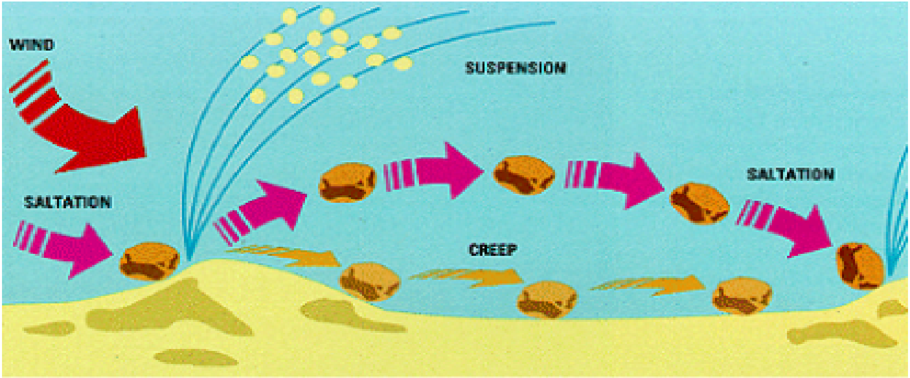
Erosion is a very common destructive process

(a) Wind erosion

(b) Water erosion

There are three types of aeolian-erosion



Suspension takes place in protoplanetary-discs

- Aeolian-erosion is purely mechanical – no need for high temperatures **this is not a thermal ablation** – gas-drag is the 'wind'
- The lifted particles are small – suspension fits better than saltation or creep
- Self-gravity is negligible below $\sim 1\mathrm{km}$, cohesion force plays its role

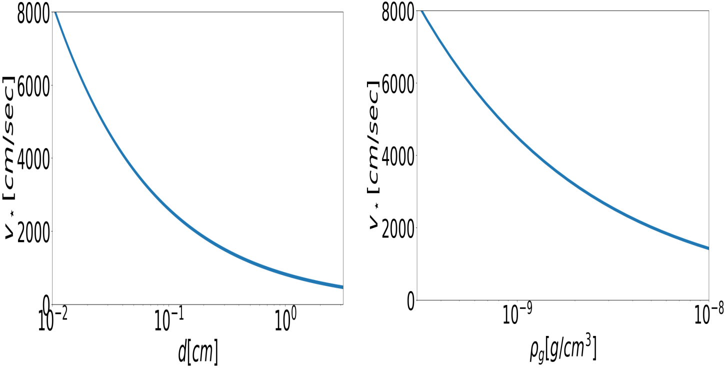
Suspension in the lab, Paraskov et al. 2006

Suspension requires a threshold velocity

- The 'wind' – drag-force – should be strong enough in order to overpower the cohesion.
- Drag-force $F_D = \frac{1}{2}\rho_g C_D \pi R^2 v_{rel}^2$ vs. cohesion $F_c = \beta d$ per particle
- Shao & Lu 2000 (without self-gravity):

$$v_* = \sqrt{\frac{A_N \gamma}{\rho_g d}}$$

The threshold velocity depends on the size of the grain and the gas density



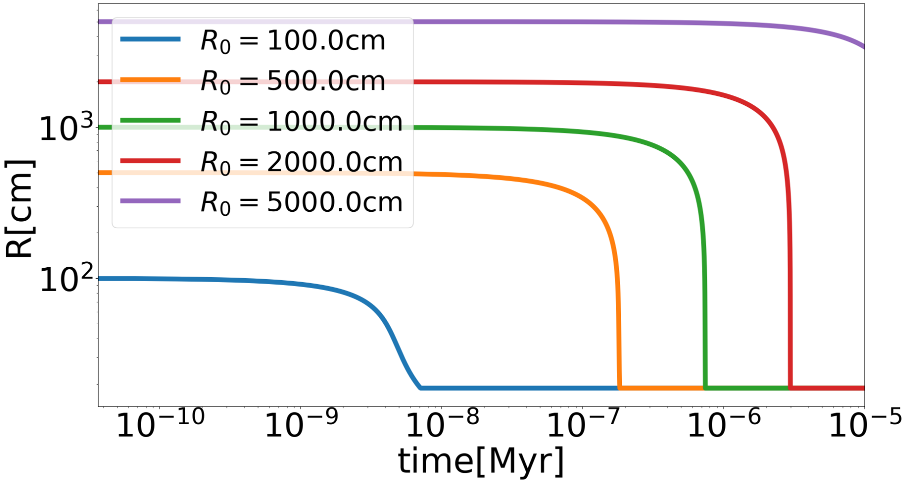
Above the threshold, the erosion rate can be prescribed analytically

The shear pressure induces a mass loss in rate, similarly to Bagnold's model from 1941

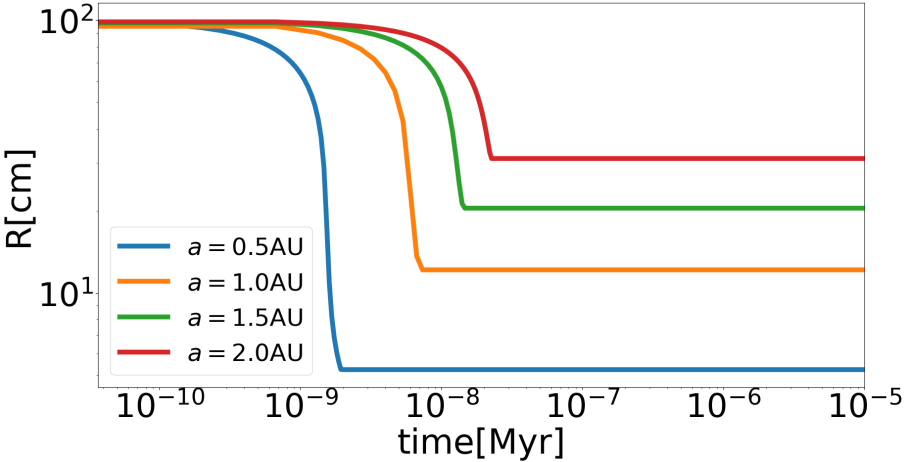
$$\frac{dR}{dt} = -\frac{\rho_g v_{rel}^3}{4\pi R \rho_p a_{cohesion}}$$

- ρ_g - gas density
- $v_{rel} = \sqrt{v_{rel,\phi}^2 + v_{rel,r}^2}$ - velocity relative to the gas
- R -radius of the object
- ρ_p - density of the object
- $a_{cohesion}$ - the acceleration due to cohesion force

Aeolian-erosion is very efficient



Aeolian-erosion gets stronger when we get closer

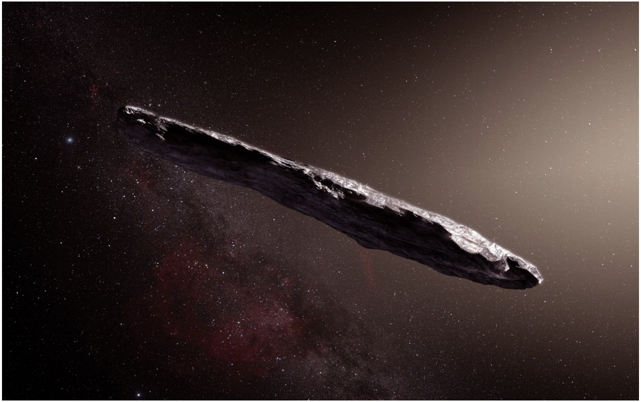


Aeolian-erosion enriches the abundance of small objects in the disc

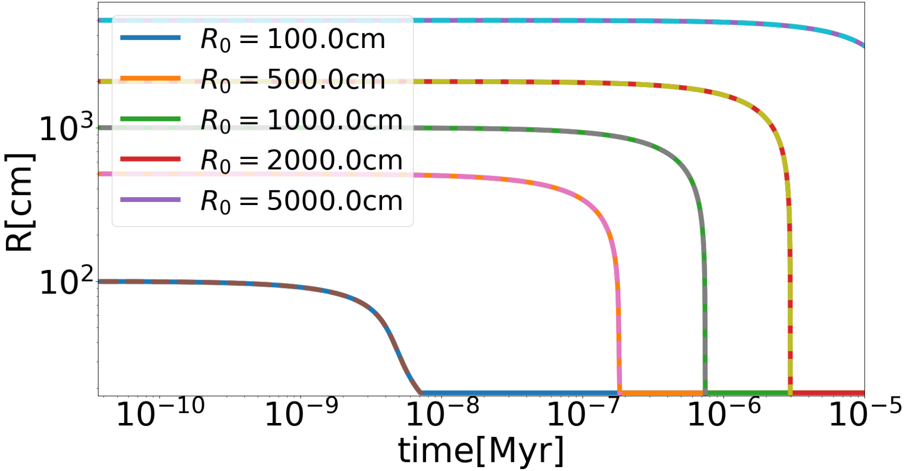
- Aeolian-erosion dictates a final-size which depends on the distance from the centre of the disc
- The final-size is about $\sim 10cm$ (depends on the object and disc parametres)
- Aeolian-erosion creates an abundance of small pebbles, which strengthen pebble-accretion of large objects – once they are formed (somehow...)

Shape could play a role

- Here we assumed a spherical shape during the whole process
- Generally, aeolian-erosion could reshape objects and explain the formation of objects like 'Oumuamua



Radial-drift isn't that strong anymore



Dashed lines include radial-drift

Summary

- Aeolian-erosion sets a new barrier in planet formation
- In order to start the aeolian-erosion, the object should move faster than a threshold velocity
- Above the threshold velocity, aeolian-erosion is very efficient
- Aseloian-erosion assists growth of larger objects via pebble-accretion

Backup Slides

The gas in the disk could be turbulent

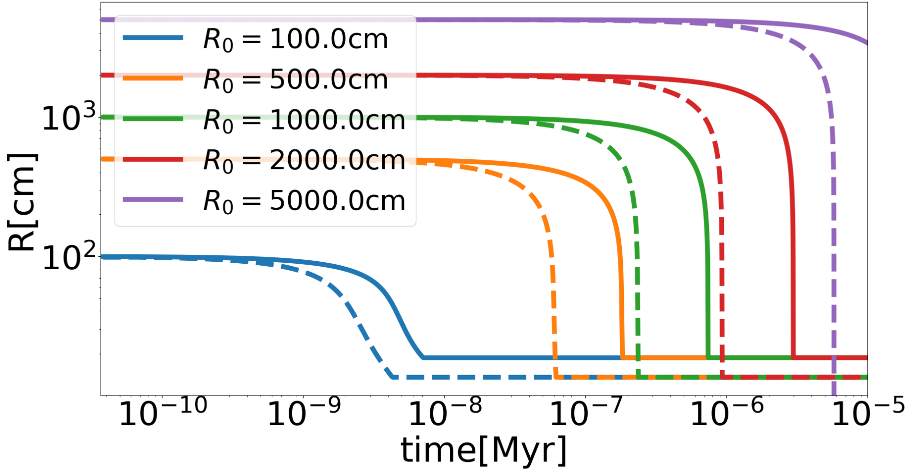
- Turbulence adds random-kicks to the velocity of objects in the disk

$$\langle \delta v^2 \rangle = \langle \delta v_{\mathrm{rel}}^2 \rangle + \langle v_{\mathrm{turb}}^2 \rangle$$

- Ormel & Cuzzi 2007 – and references therein traces back to Völk 1980 – gave expressions for the relative velocities between object in turbulent media

$$v_{pg,t} = v_t St \sqrt{\frac{1 - Re_t^{-1/2}}{(St+1)(St + Re_t^{-1/2})}} \tag{1}$$

Kicks from turbulence enhance aeloian-erosion



Cohesion (see Shao&Lu 2000)

$$F_{cohesion} = \beta d, \ \beta \approx 10^2 \frac{cm \cdot g}{sec} \tag{2}$$

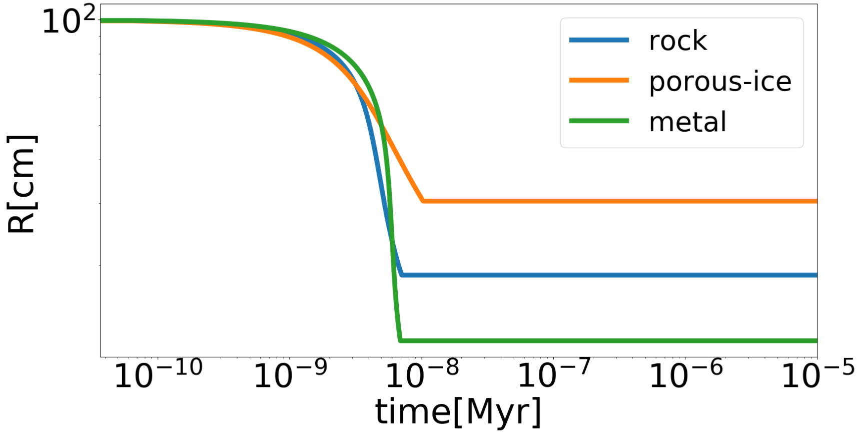
where β engulfs parameters that arise from Van-der-Waals interaction and electrostatic force.

$$\beta \propto \sqrt{\frac{A_N \gamma}{\rho_g}} \tag{3}$$

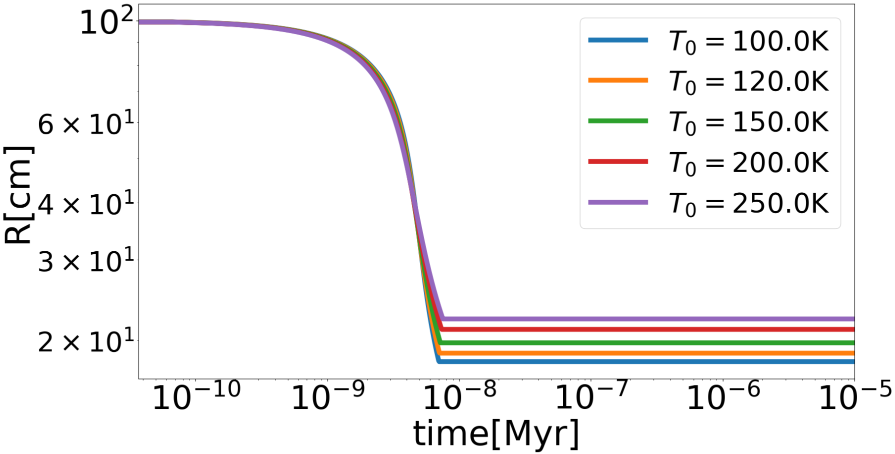
We used

$$\gamma = 0.165 \frac{g}{sec^2}, A_N = 0.0123 \tag{4}$$

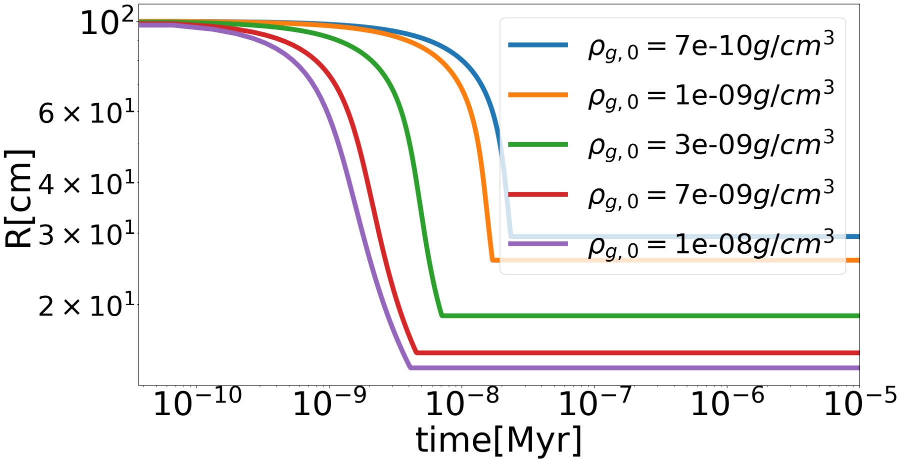
Dependence on material



Dependence on temperature



Dependence on gas-density



Dependence on η