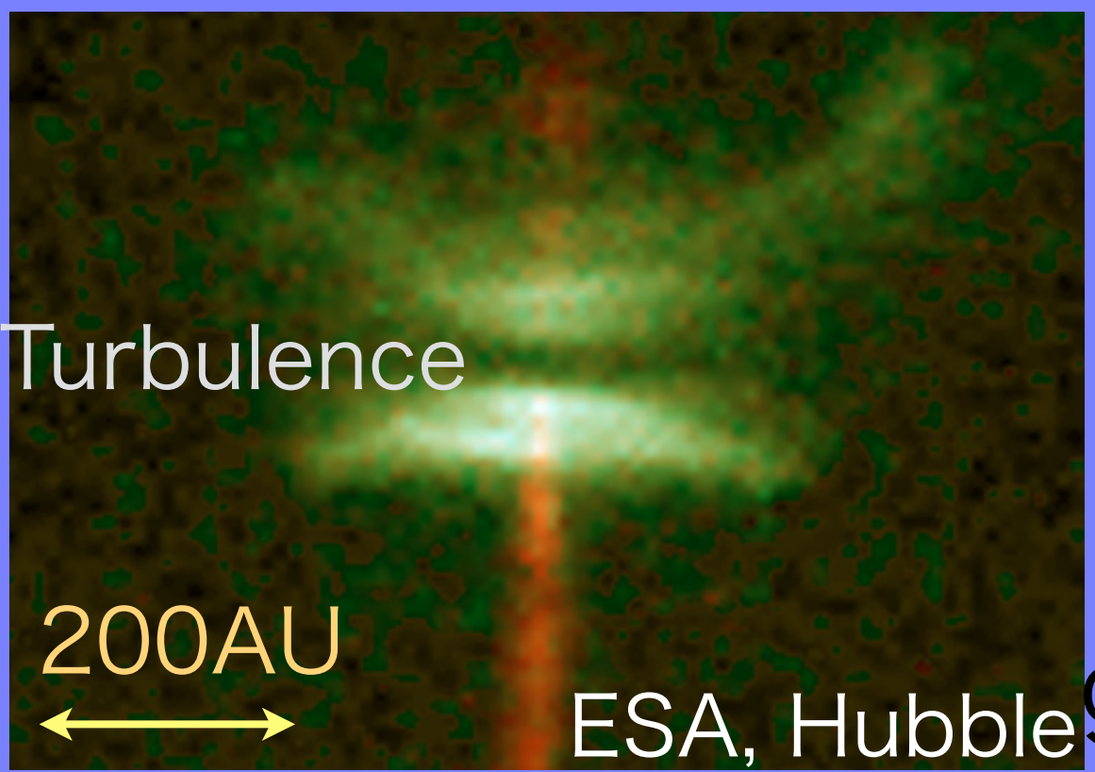
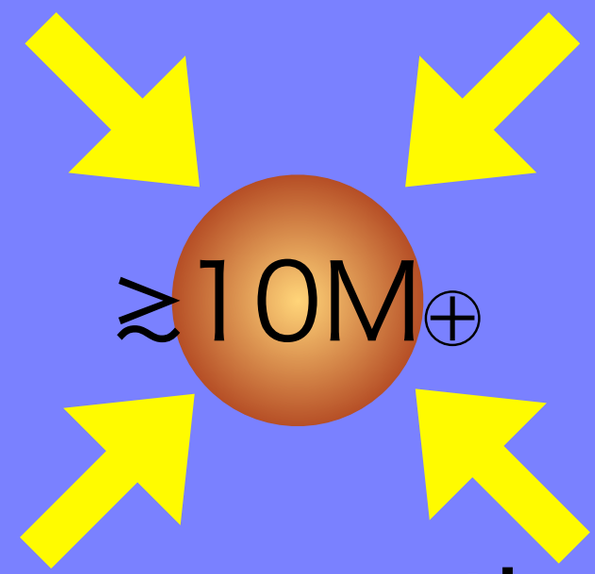
Planet Formation around Snowline
27-39 Nov. 2017, Tokyo

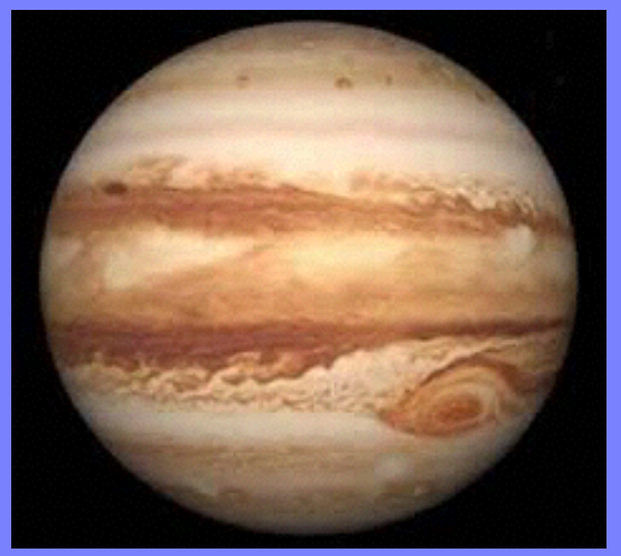
From Planetesimals to Planets in a Turbulent Disk

H. Kobayashi (Nagoya U.)
with H. Tanaka, S. Okuzumi, K. Wada





gas accretion

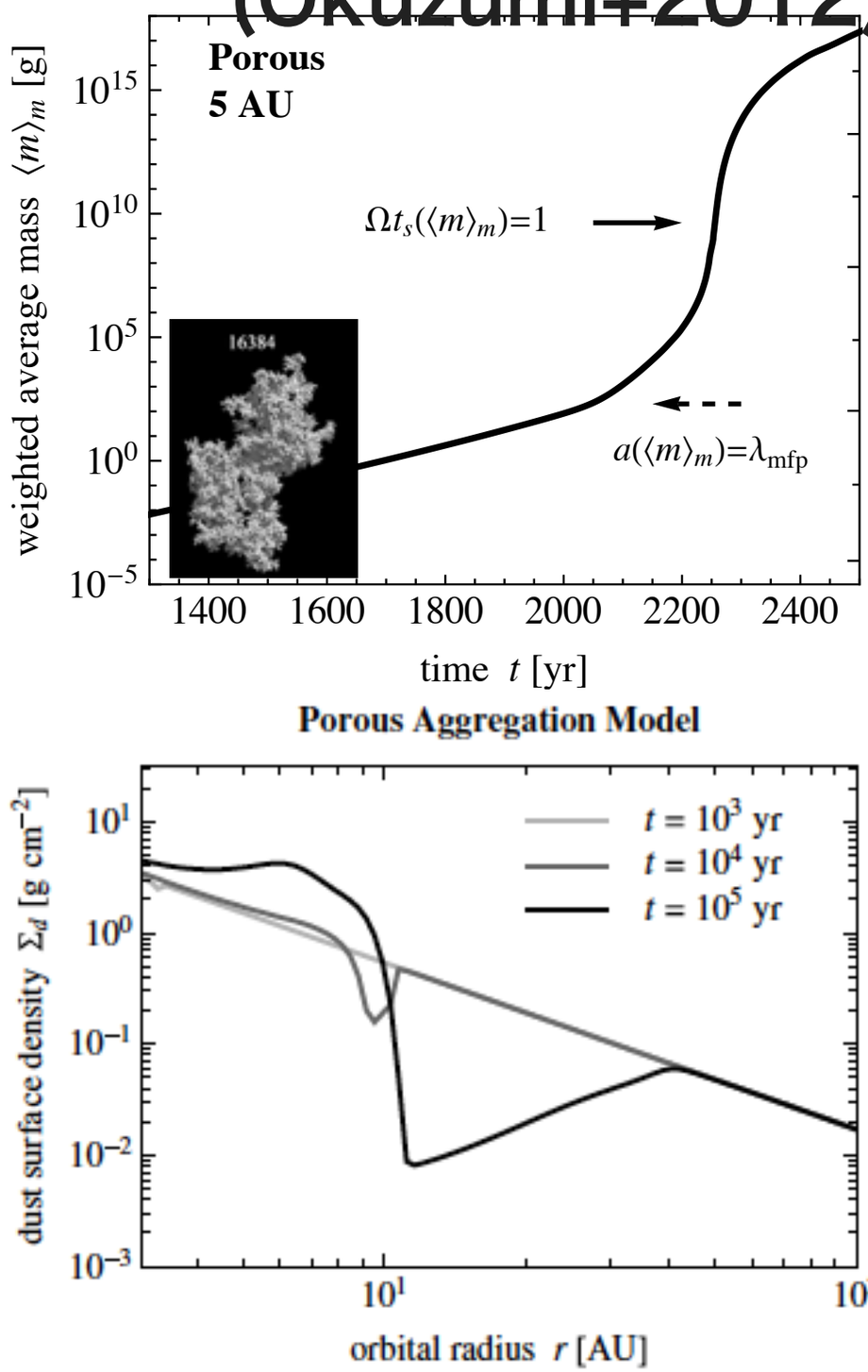


gas giants

Full Collisional Growth

- Vd ~ 80m/s (Wada+09,11,13)
- Fluffy dust aggregates overcome the drift barrier due to transition into Stokes regime.
- Aggregates avoiding the drift barrier accumulate, resulting in the solid enhancement.

(Okuzumi+2012)



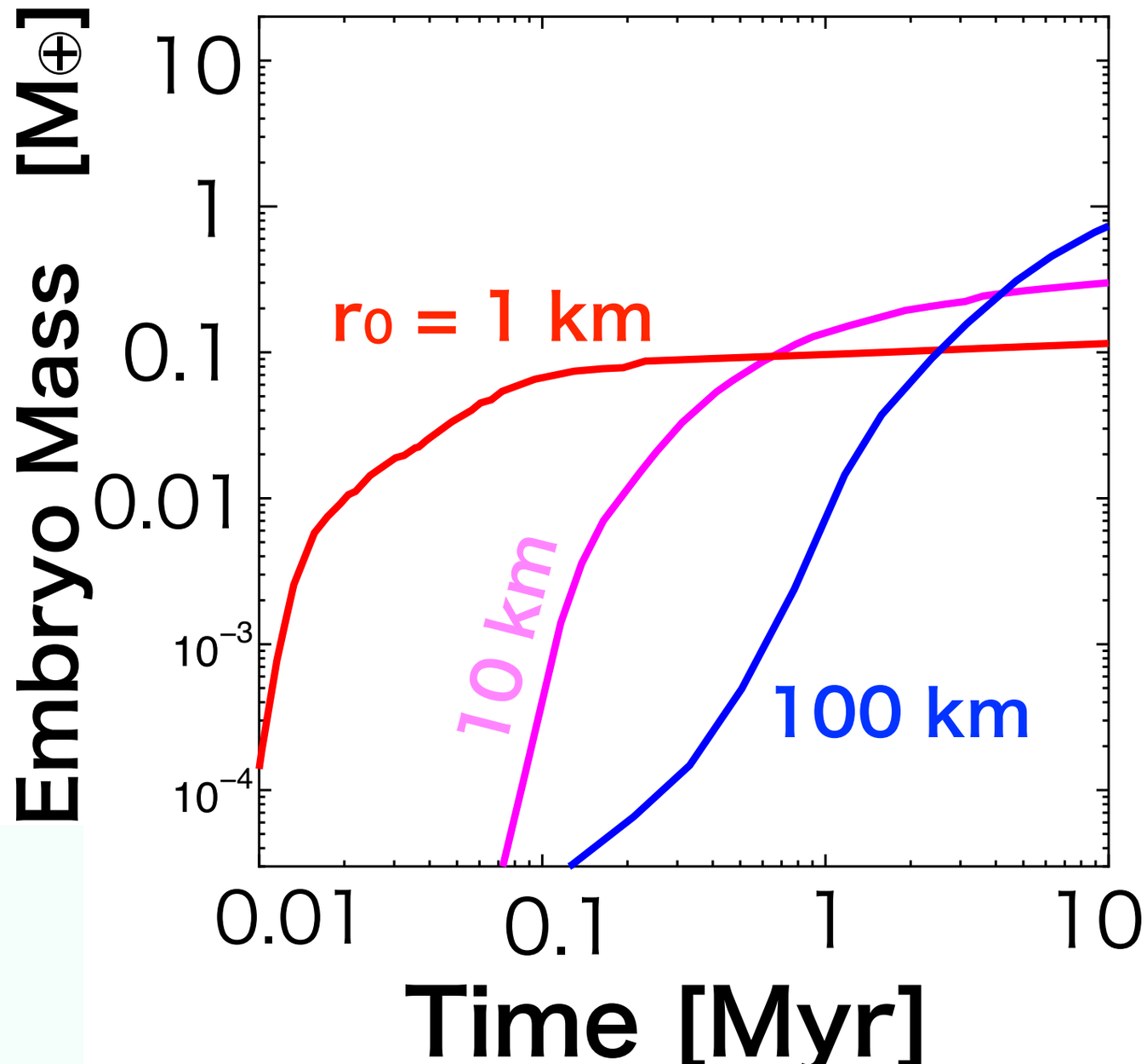
Collisional growth from dust to planet is possible.

Planetary Embryo Growth

- Initially set a single size population of planetesimals.
- Collisional fragmentation of planetesimals stalls embryo growth.
- The accretion timescale and efficiency depend on the initial planetesimal size.

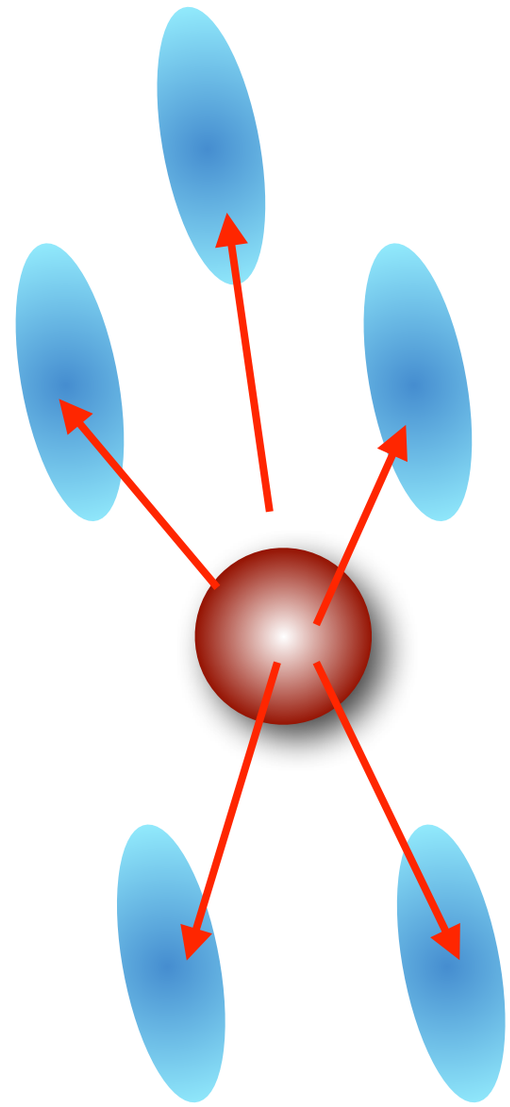
(Kobayashi+10,11)

5AU in 3MMSN



Intermediate Sized Bodies

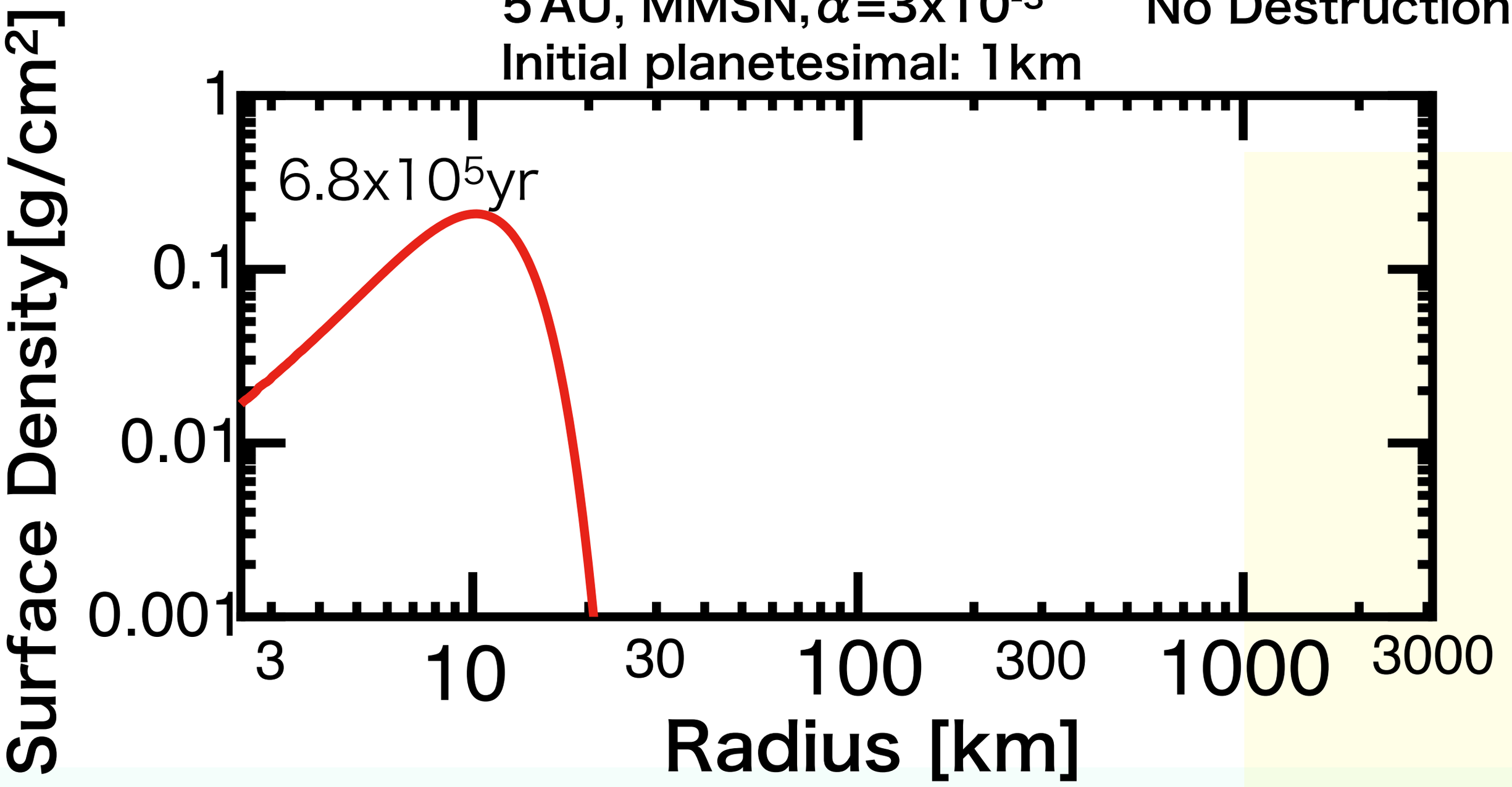
- Bodies that overcome the barrier further grow through collisions.
- Random velocities of bodies control their growth.
- Density fluctuation by turbulence strongly affects the random velocity (Ormel & Okuzumi 2013).



This effect is additionally taken into account.

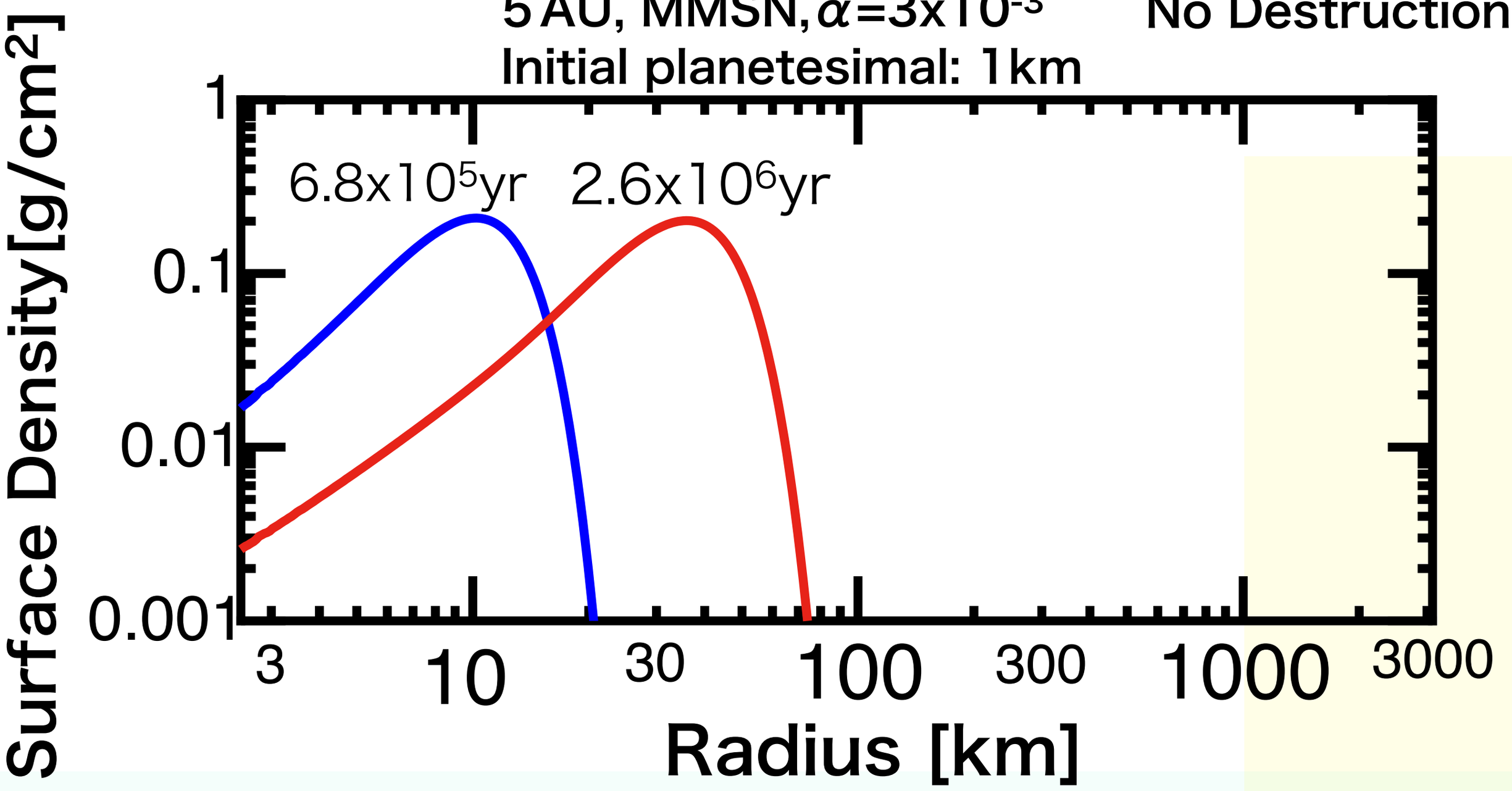
$$\left.\frac{de^2}{dt}\right|_{\rm sdf} = f_{\rm d}\left(\frac{\Sigma_{\rm g}a^2}{M_*}\right)^2\Omega \qquad \left.\frac{di^2}{dt}\right|_{\rm sdf} = \epsilon^2\left.\frac{de^2}{dt}\right|_{\rm sdf}$$

Size distribution



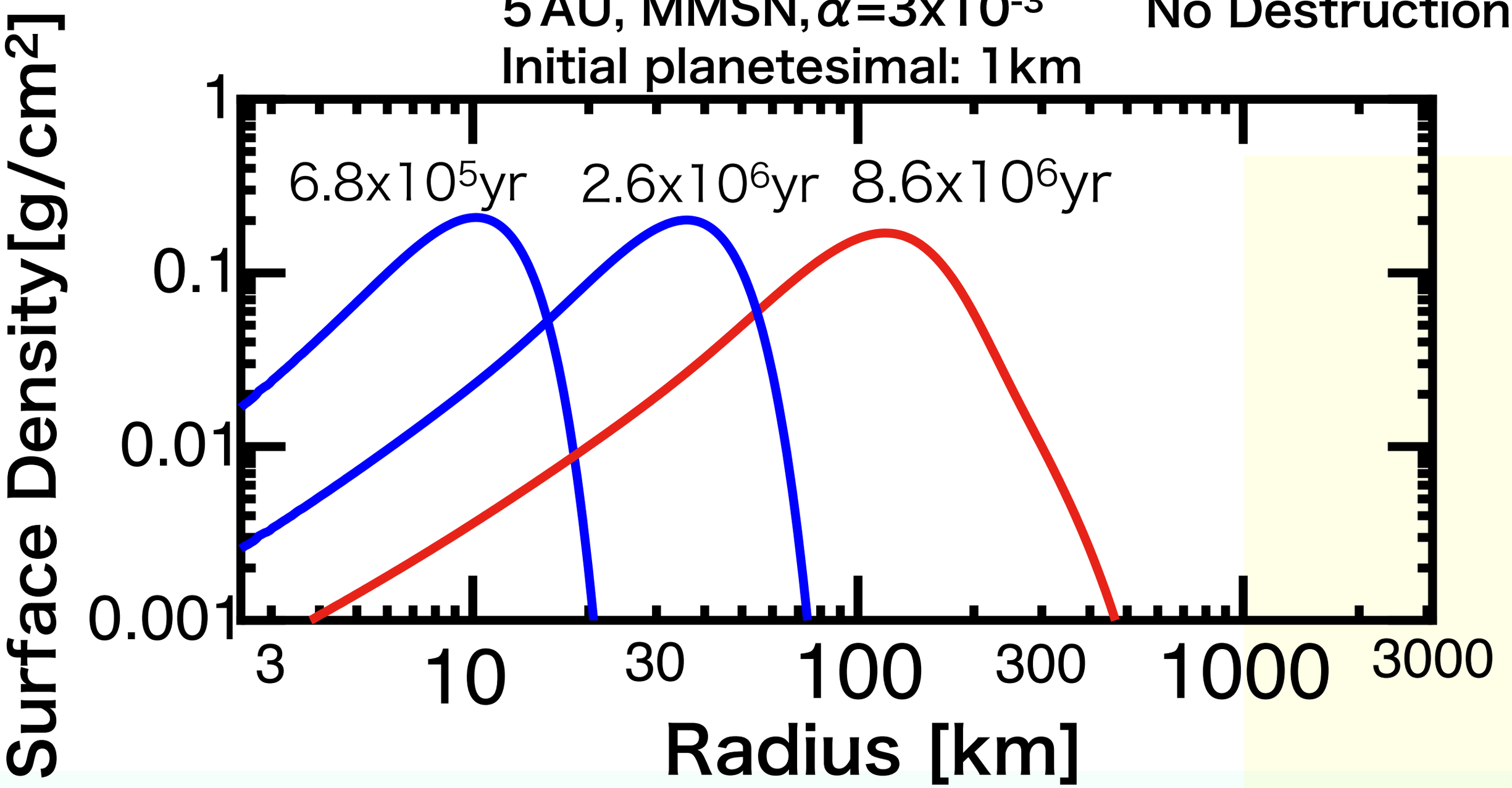
(Kobayashi+16)

Size distribution



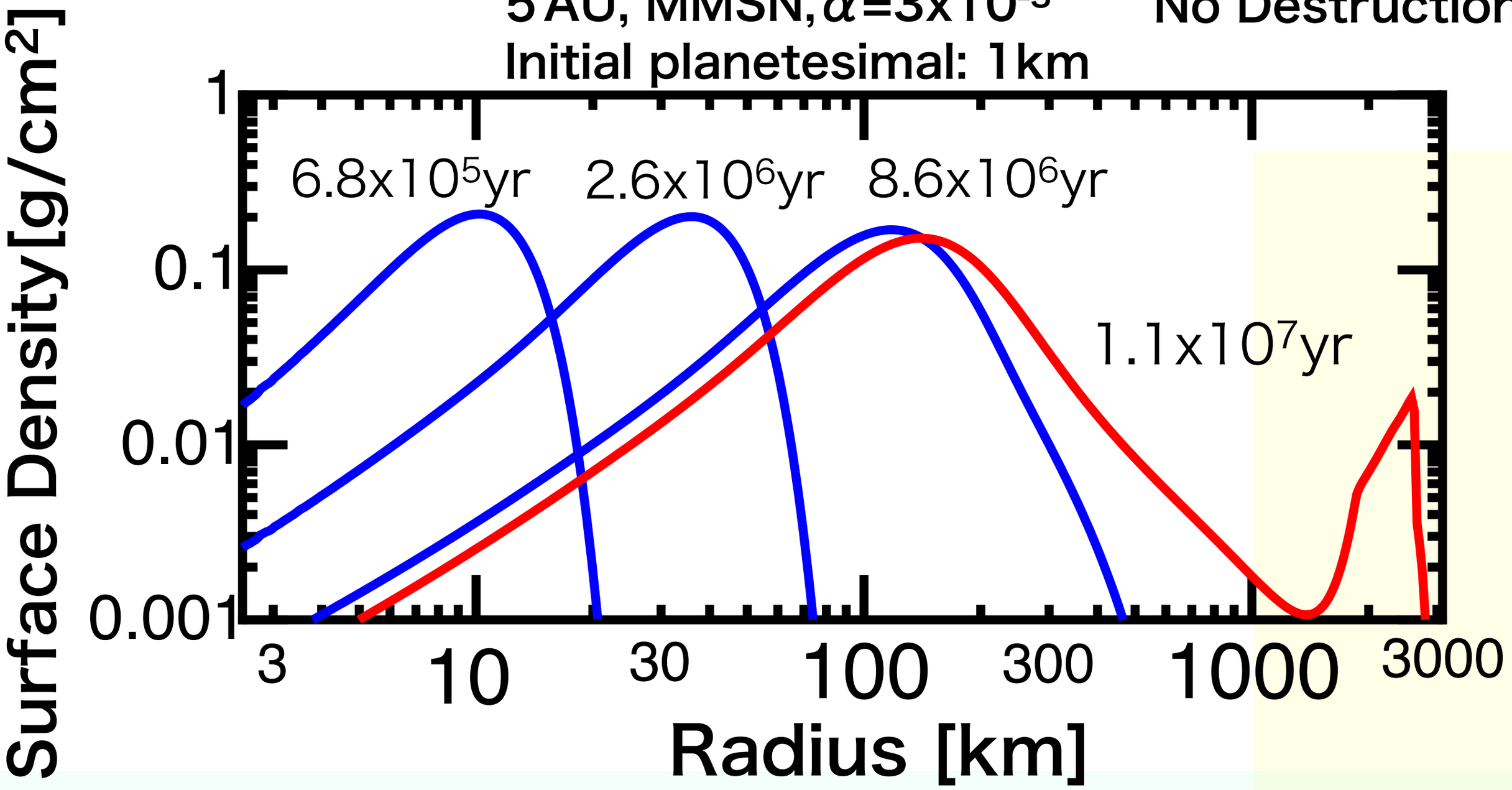
(Kobayashi+16)

Size distribution



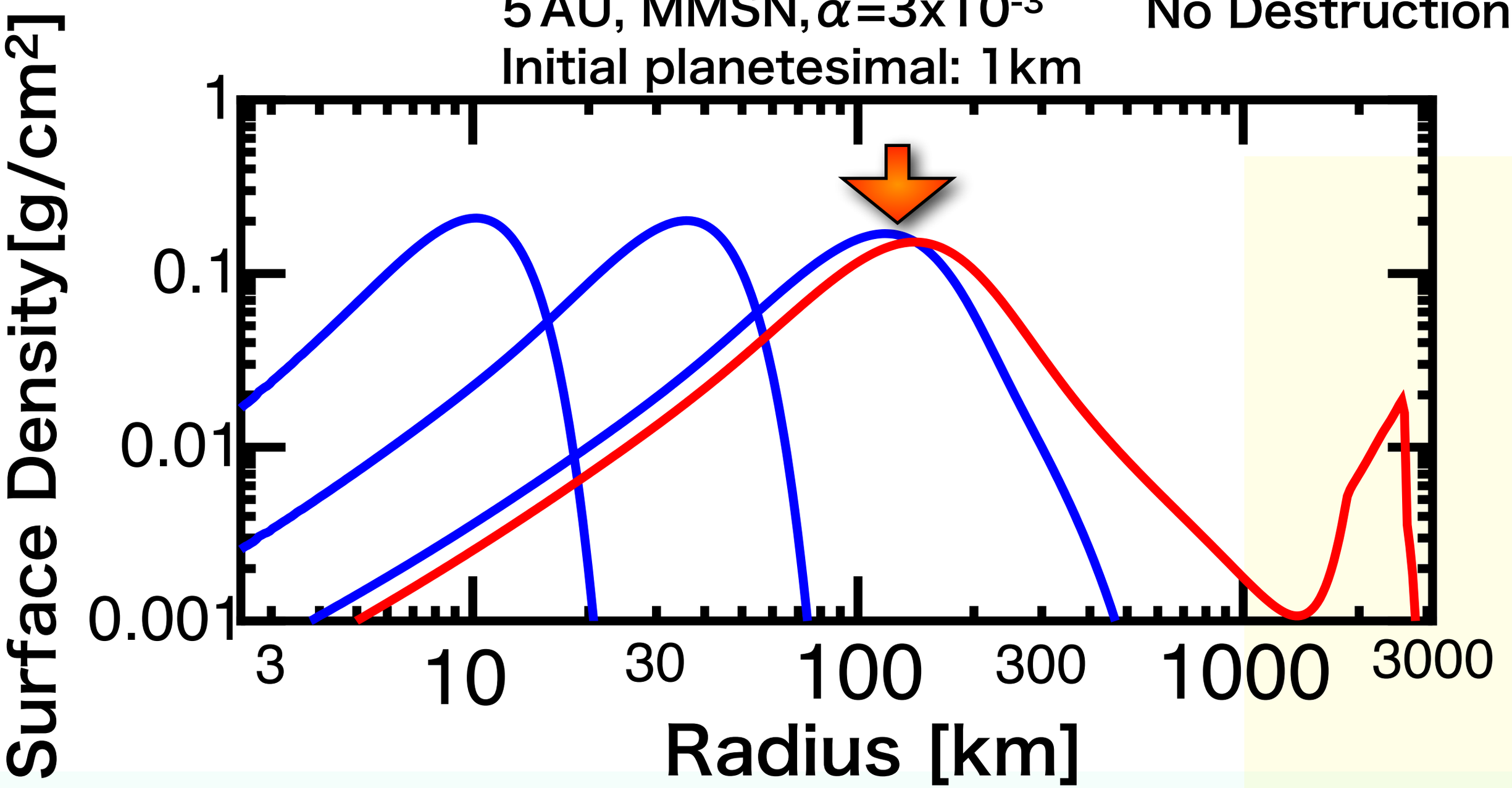
(Kobayashi+16)

Size distribution



(Kobayashi+16)

Size distribution

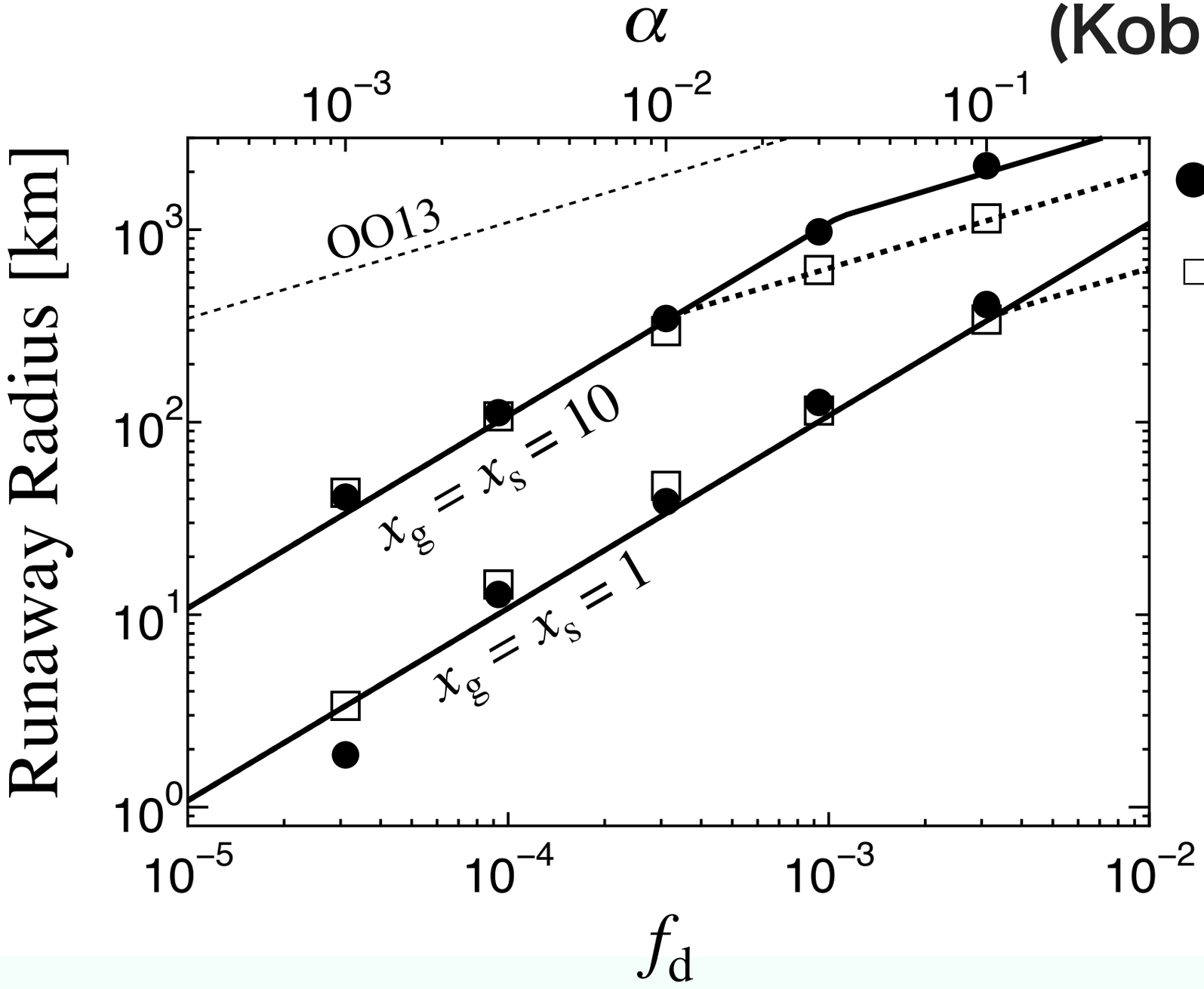


The mass of bodies is determined by bodies with the radius at the onset of Runaway Growth.

(Kobayashi+16)

Runaway Radius

(Kobayashi+16)



● ρ_s = 1 g/cc

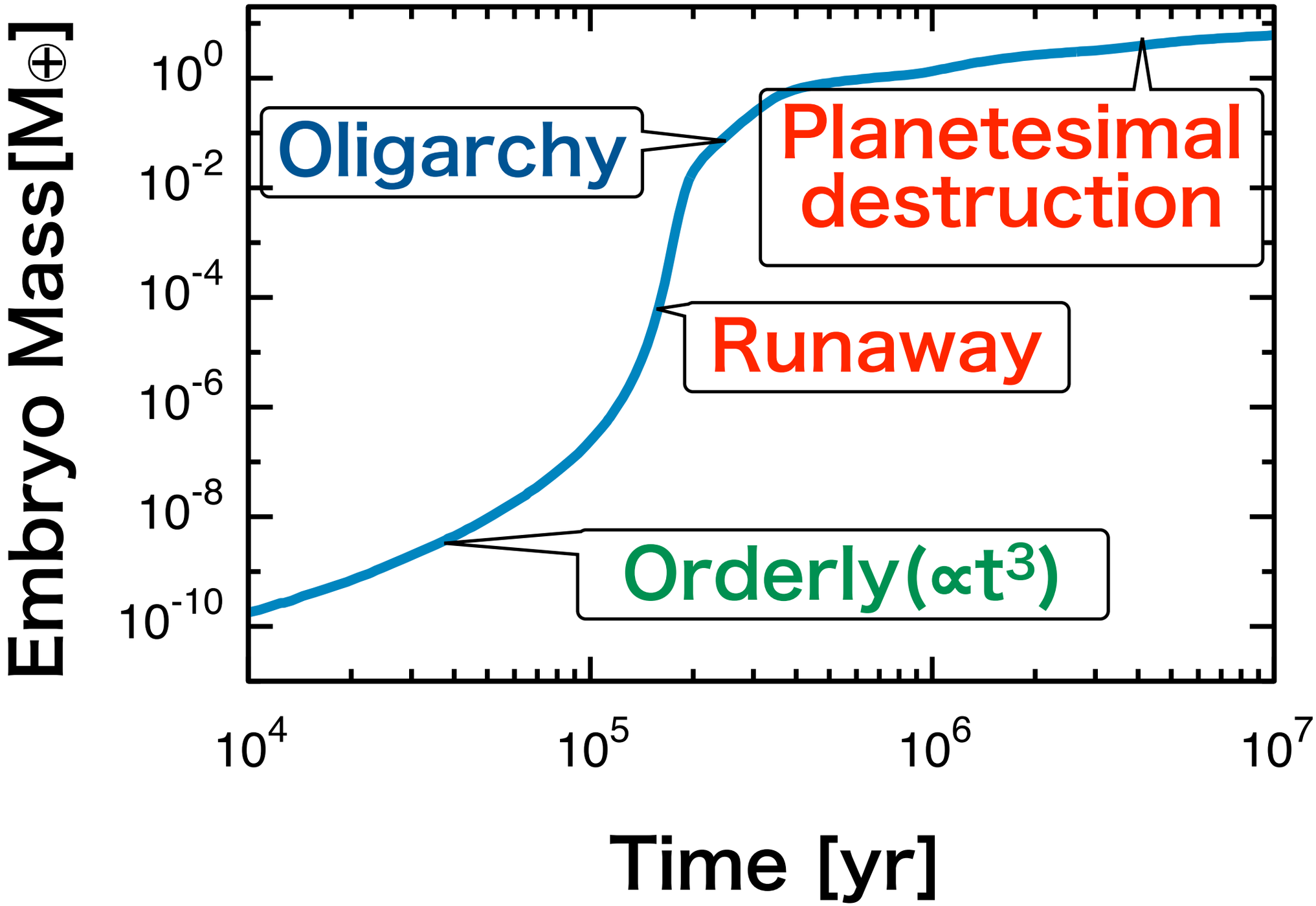
□ ρ_s = 0.1 g/cc

$$\left.\frac{de^2}{dt}\right|_{\rm sdf} = f_{\rm d}\left(\frac{\Sigma_{\rm g}a^2}{M_*}\right)^2\Omega$$

The radius of bodies at the onset of runaway growth depends on turbulent strength.

Embryo growth

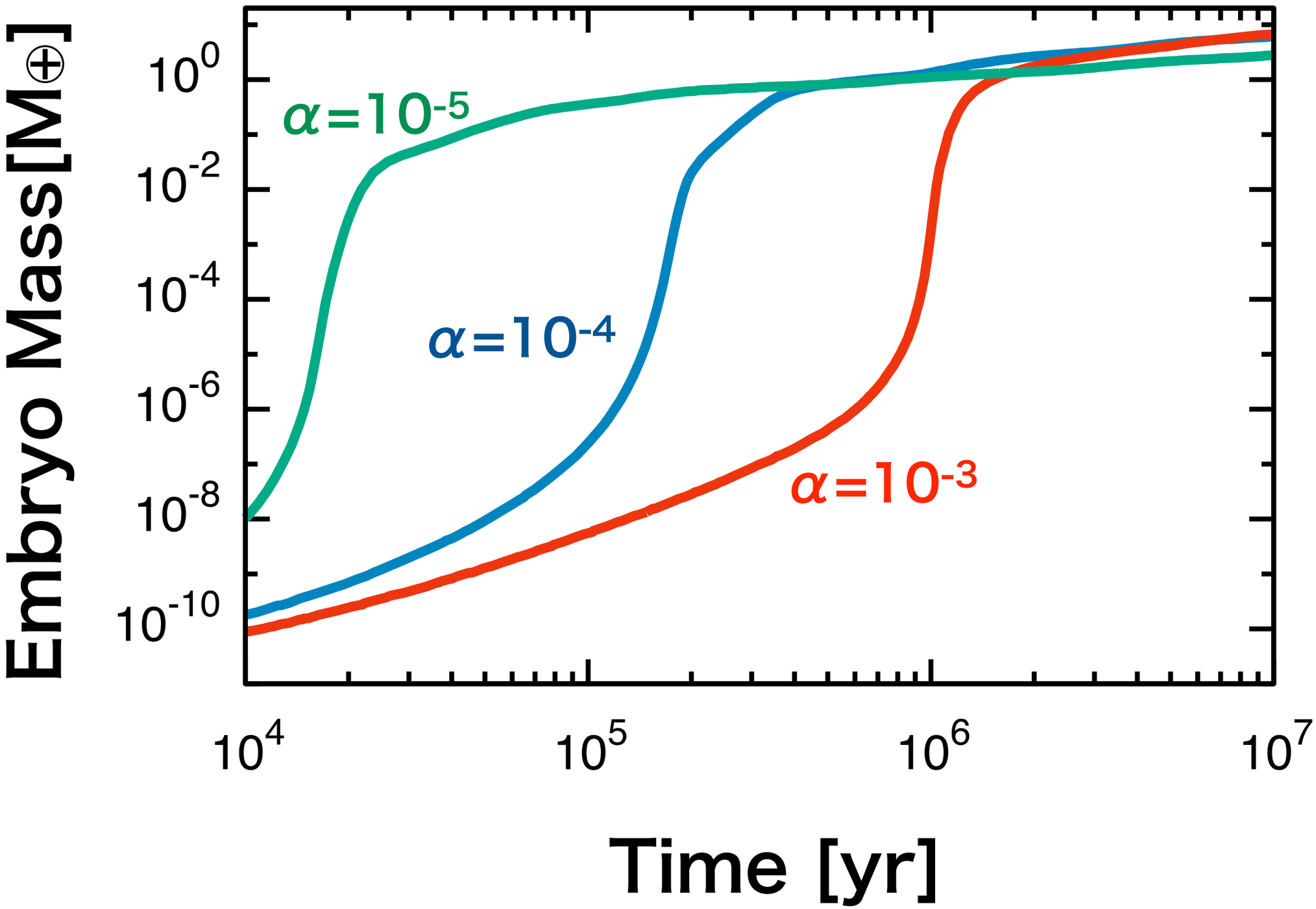
Comet strength, gas：2MMSN, solid/gas：4MMSN, $\alpha=10^{-4}$



(Kobayashi+17 in prep.)

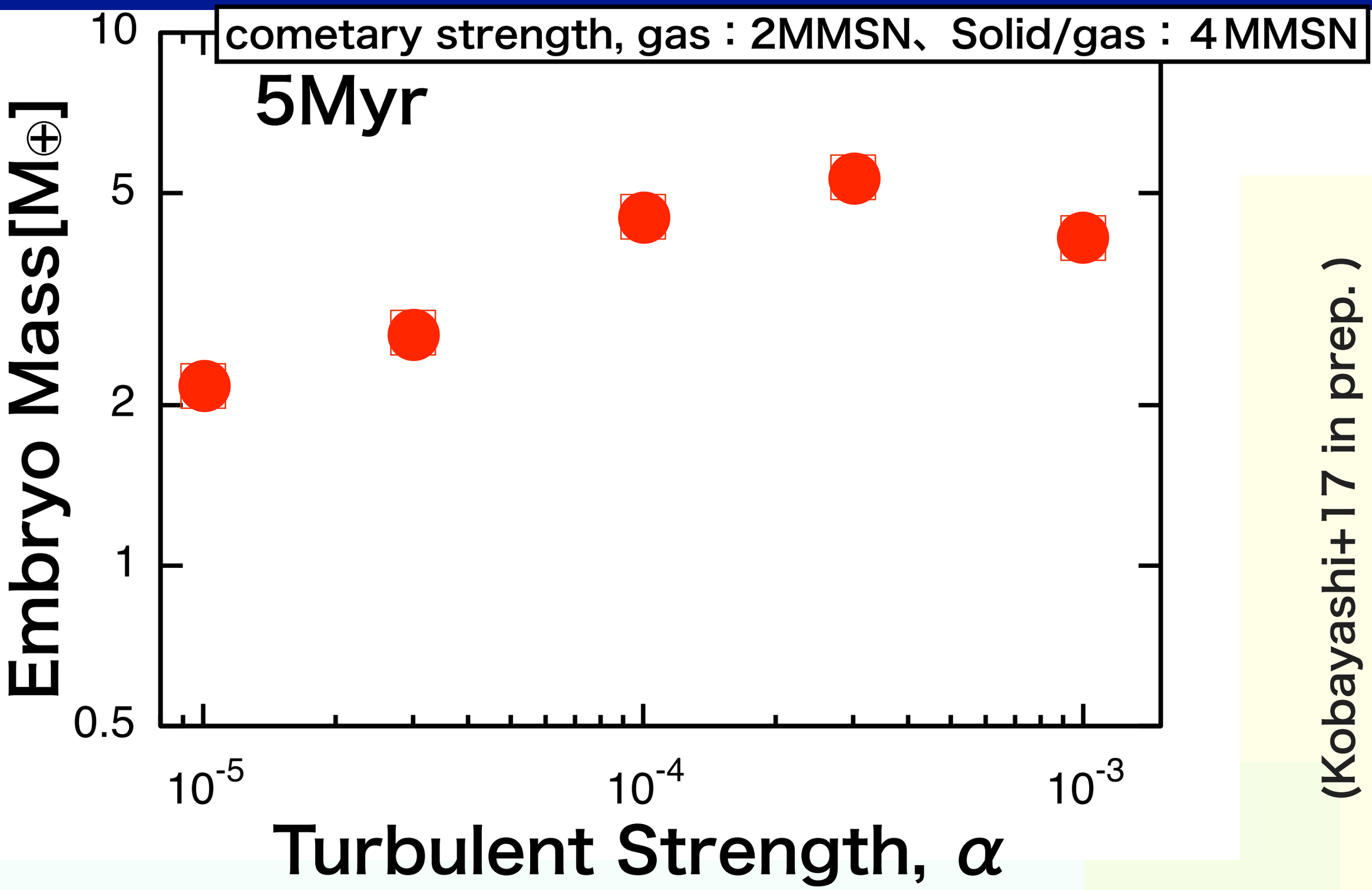
Turbulence and Growth

Comet strength, gas：2MMSN, solid/gas：4MMSN



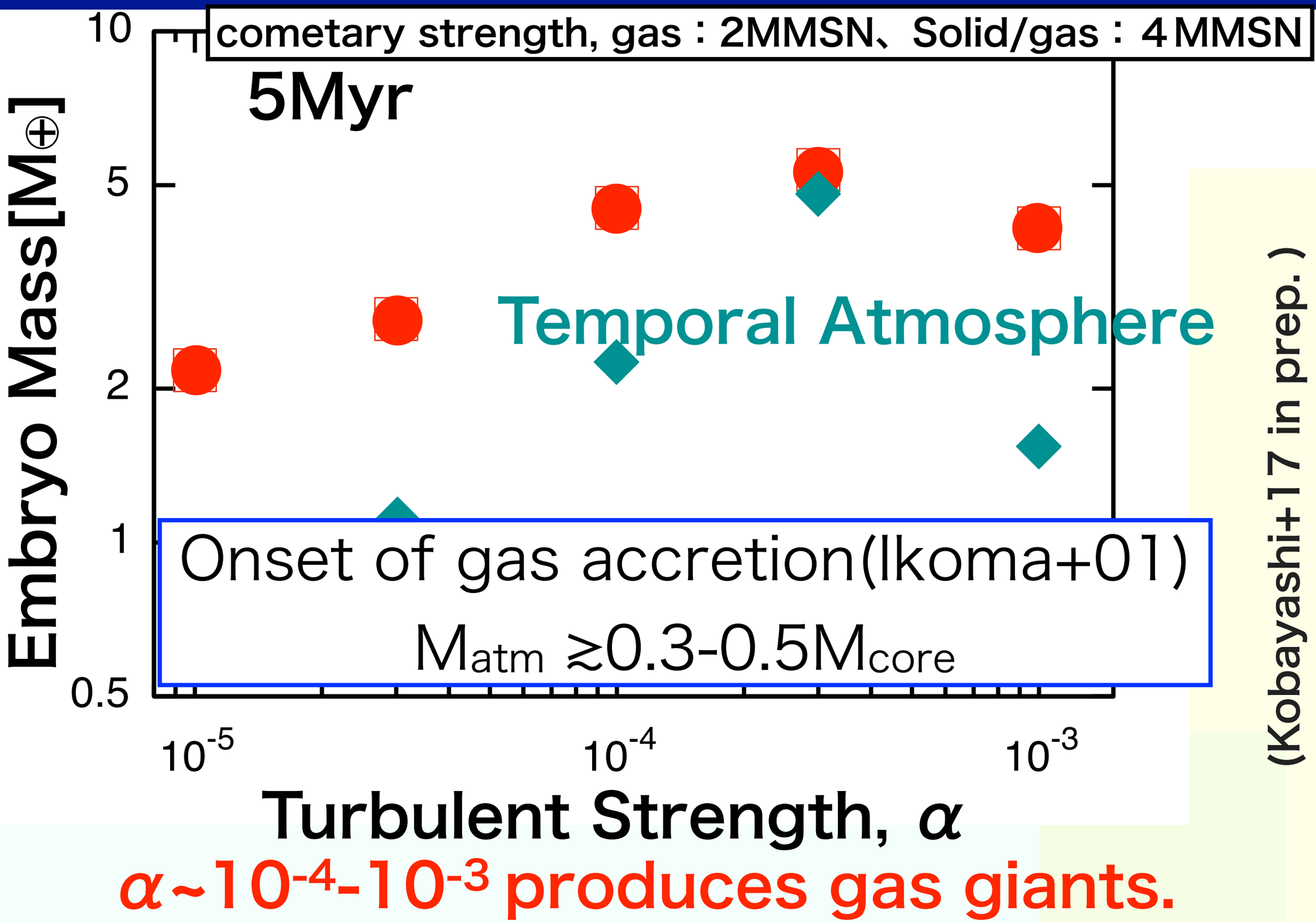
(Kobayashi+17 in prep.)

Final Mass and Turbulence



Strong turbulence tends to produce massive cores.

Gas Accretion



α~10^{-4}-10^{-3} produces gas giants.

Summary

- Planetesimal growth in a turbulent disk.
- Strong turbulence tends to produce massive embryos.
  - A delay of the onset of runaway growth produces strong planetesimals, which result in massive embryos.
- The collisional strength of intermediate sized bodies (~1km) is important.