Satellitesimal Formation with Collisional Growth and Radial Drift of Dust Particles in Steady Circumplanetary Disks

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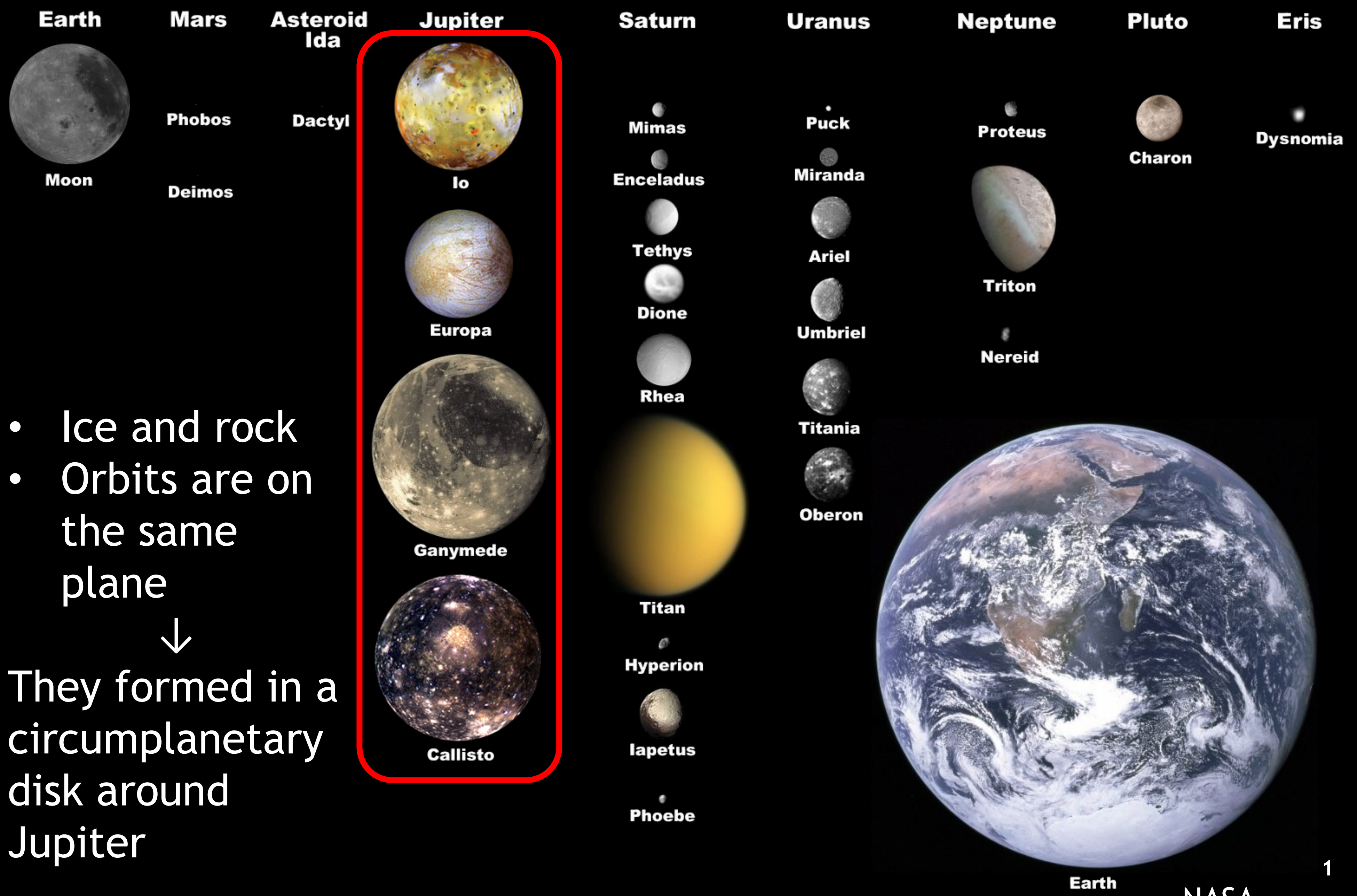
Satellites in the solar system



- Ice and rock
- Orbits are on the same plane

↓

They formed in a circumplanetary disk around Jupiter

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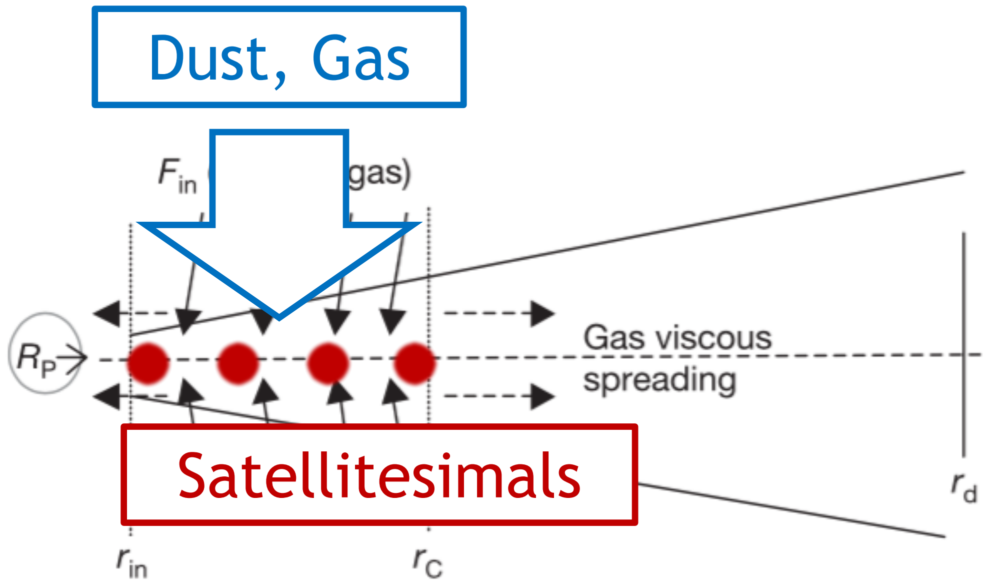
Satellite formation in CPDs

✓ Canup and Ward (2006) etc.

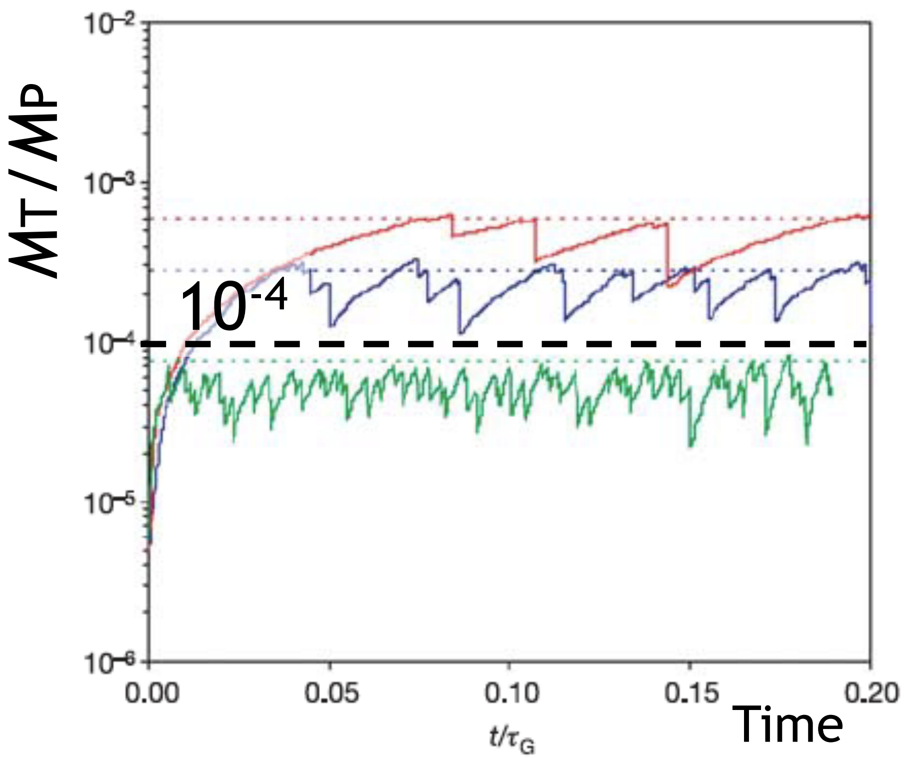
- Gas and dust are supplied from the high altitude of CPD
  - ➤ They assumed the dust particles grow rapidly to satellitesimals



- Satellitesimals grow to satellites

  t_{growth} vs. t_{TypeI}

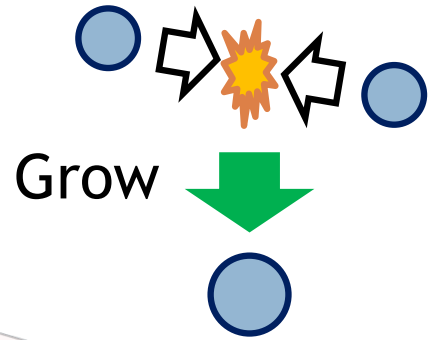
  → $M_T / M_P = 10^{-4}$



✓ How to form satellitesimals?

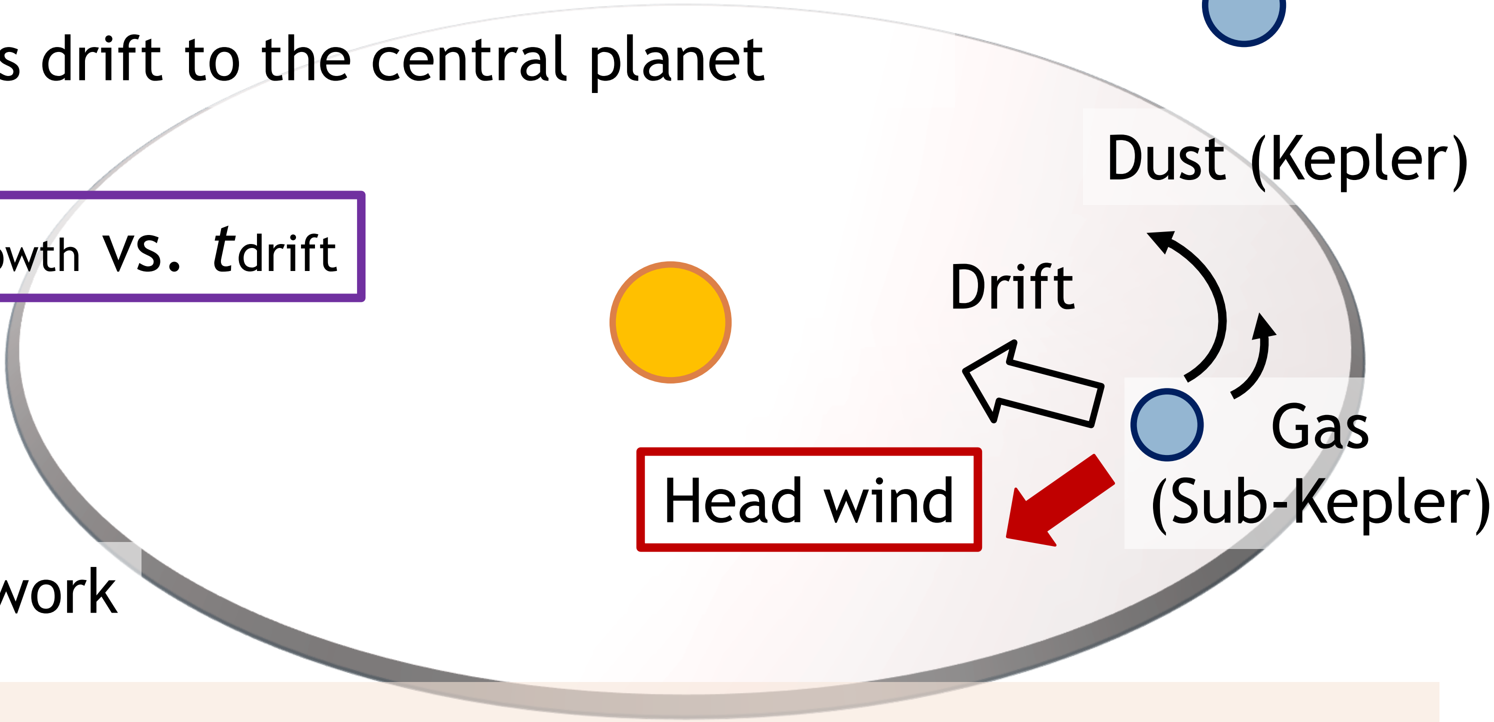
- In-situ formation (Shibaike et al. 2017)
- Planetesimals capture (e.g. Fujita et al. 2013)

Satellitesimal formation via collisional growth of dust particles



- ✓ Dust particles grow larger by pairwise collisions
- ✓ Dust particles drift to the central planet

t_{growth} vs. t_{drift}



- ✓ Aim of this work

Calculate the collisional growth and drift of dust particles

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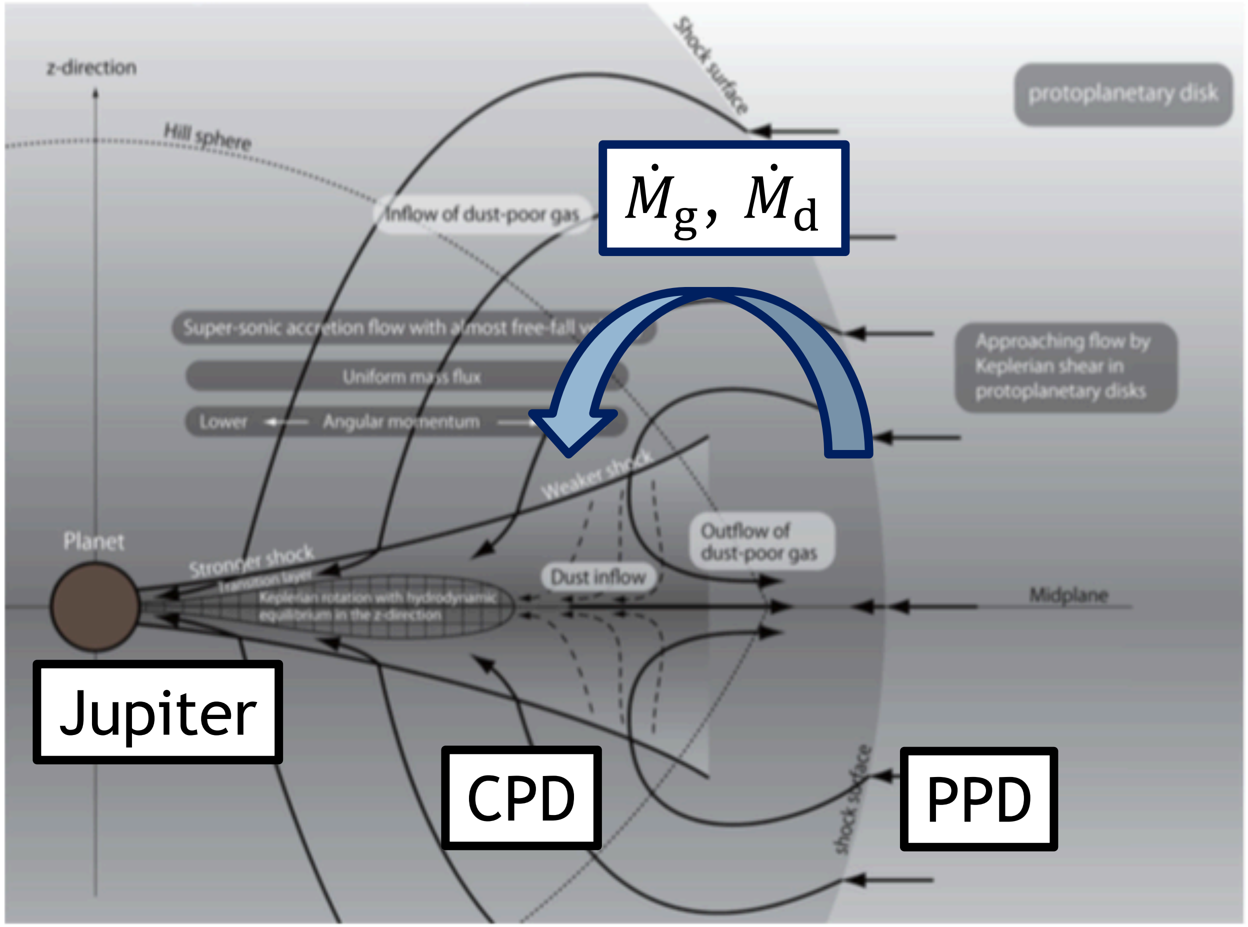
Dust particles can grow to satellitesimals or not?

Model: Dust and gas inflow



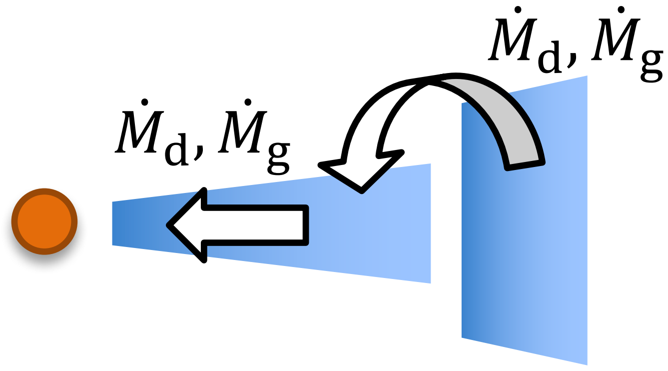
(Tanigawa et al. 2012)

- ✓ Gas is supplied from the high altitude of CPD
  - ➢ $\dot{M}_g$: Gas inflow mass flux
- ✓ Dust flows to CPD with gas
  - ➢ $\dot{M}_d$: Dust inflow mass flux

Dust to gas inflow mass flux ratio:
$\dot{M}_d/\dot{M}_g = 1, 0.1, 0.01,$ and 0.001

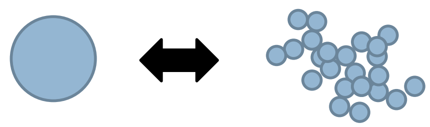
Model

✓ Steady condition



✓ Viscous accretion disk
✓ No local structure
✓ Viscous heating

✓ Simple dust collisional growth model
- Representative size
- Perfect sticking
- Compact dust (↔ fluffy dust)
- Supply at the outer edge of the gas inflow region



✓ Calculate the size(mass) and surface density of dust particles at each r

- Equation of continuity

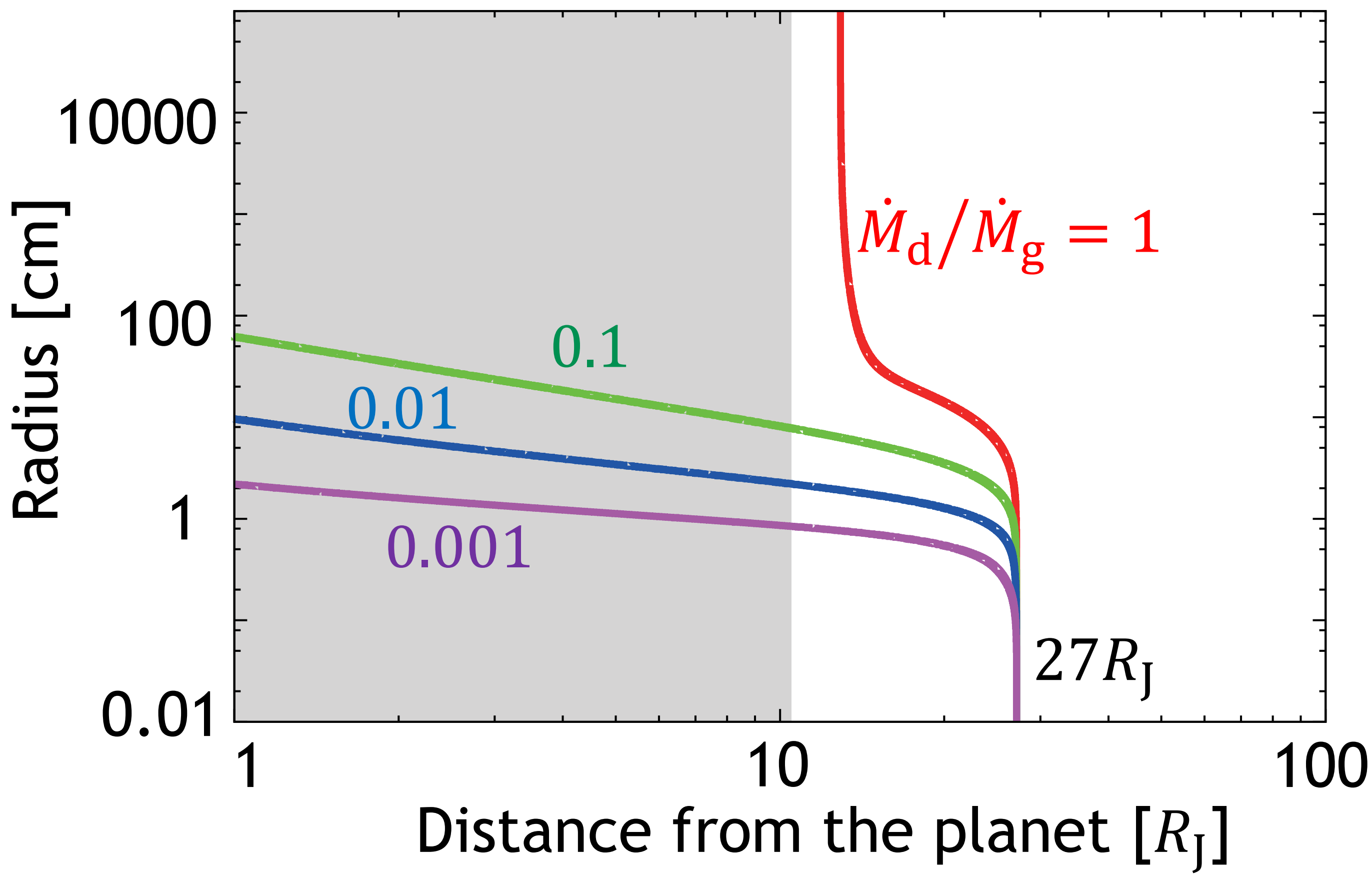
$$\dot{M}_{\rm d} = 2\pi r |v_{\rm r}| \Sigma_{\rm d}$$

- Collisional growth

$$v_{\rm r} \frac{\partial m_{\rm d}}{\partial r} = \frac{2\sqrt{\pi} {R_{\rm d}}^2 \Delta v_{\rm dd}}{H_{\rm d}} \Sigma_{\rm d}$$

Results: Radius

$\alpha = 10^{-4}, \dot{M}_g = 0.02\ M_J/\mathrm{Myr}$



1. Dust particles flow to the CPD at the outer edge of the gas inflow region (assumption)
2. They grow rapidly on the spot ($t_{growth} < t_{drift}$)
3. They start to drift ($t_{growth} > t_{drift}$)
4. They stop drifting and grow to satellitesimals ($\dot{M}_d/\dot{M}_g = 1$) or they drift to the planet ($\dot{M}_d/\dot{M}_g = 0.001, 0.01, 0.1$)

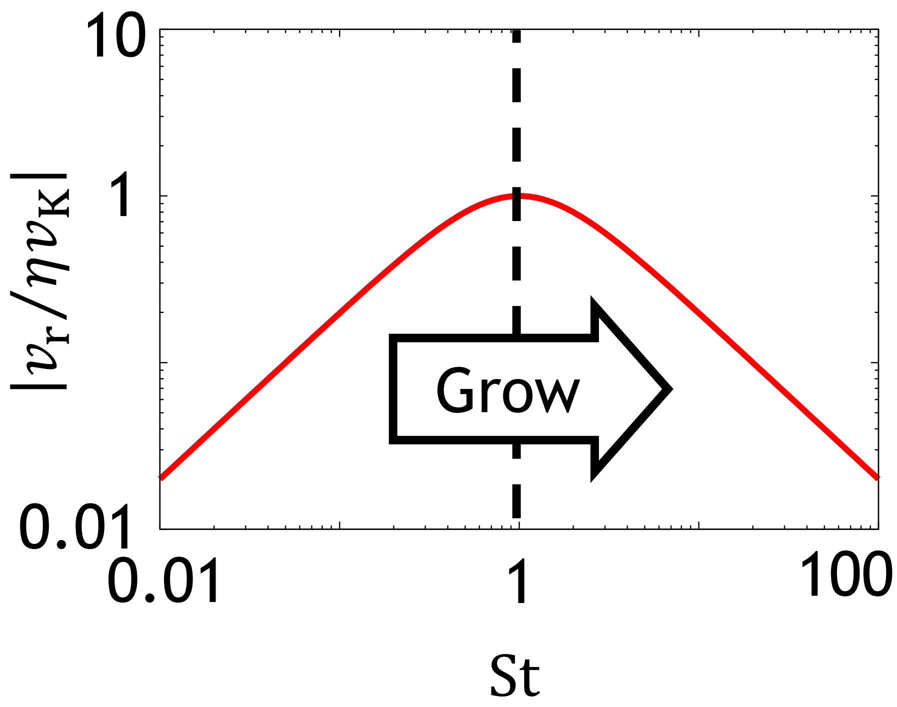
Condition for satellitesimal formation

✓ Stokes number St(≒ Size)

- Determining the motion of dust particles in gases
- St
= (Stopping time)/(Kepler time)

$$\mathrm{St} = \frac{8}{3C_{\mathrm{D}}} \frac{\rho_{\mathrm{int}} R_{\mathrm{d}}}{\rho_{\mathrm{g}} \Delta v_{\mathrm{dg}}} \Omega_{\mathrm{K}}$$

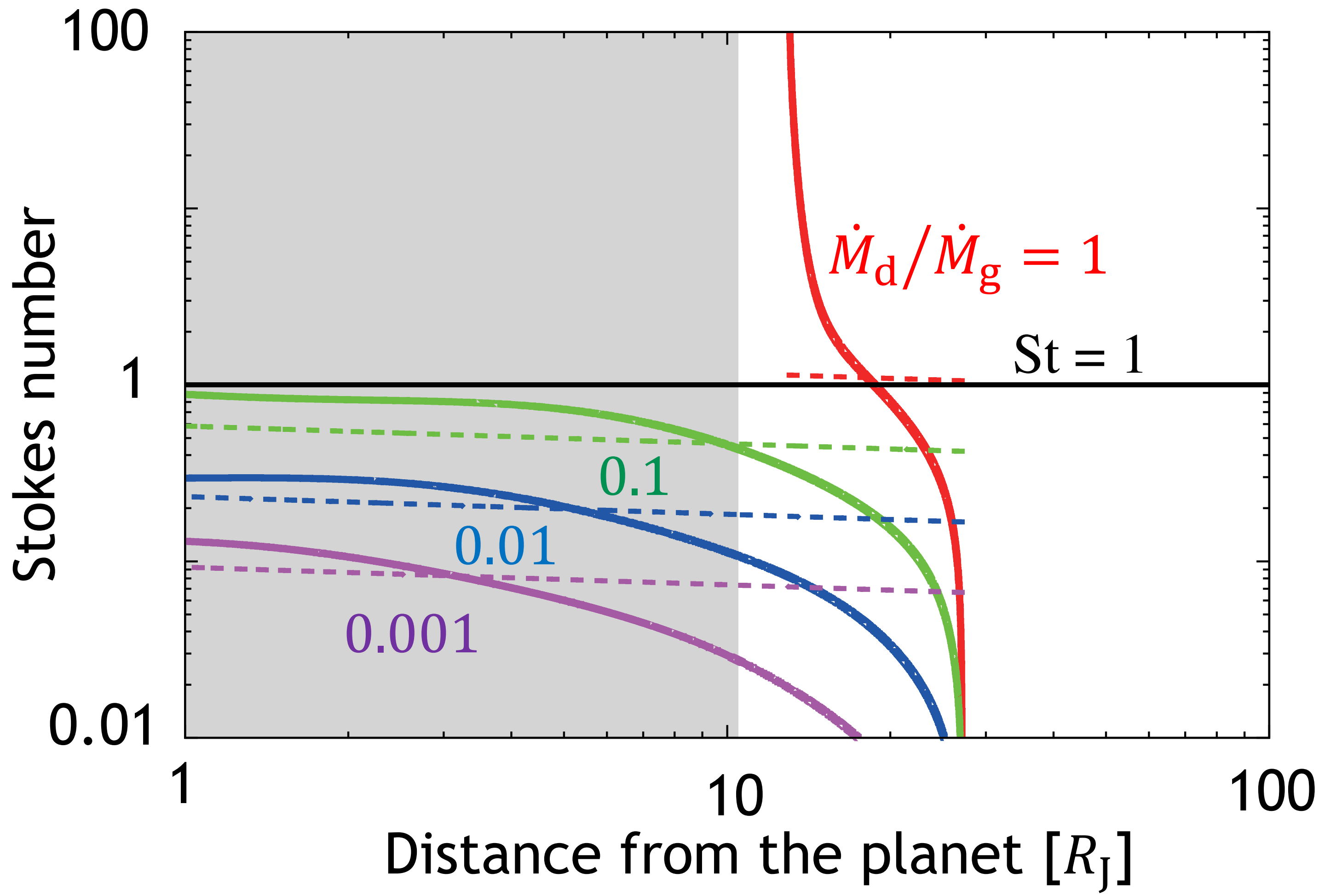
✓ Drift speed v_{r} becomes the fastest when $\mathrm{St} = 1$



Dust particles have to grow to over $\mathrm{St} = 1$ to form satellitesimals

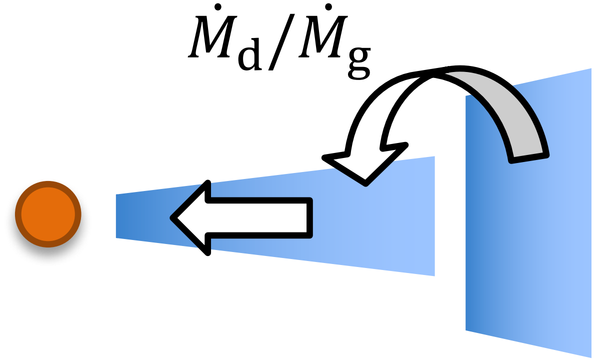
Results: Stokes number

$\alpha = 10^{-4}, \dot{M}_{\rm g} = 0.02\ M_{\rm J}/{\rm Myr}$



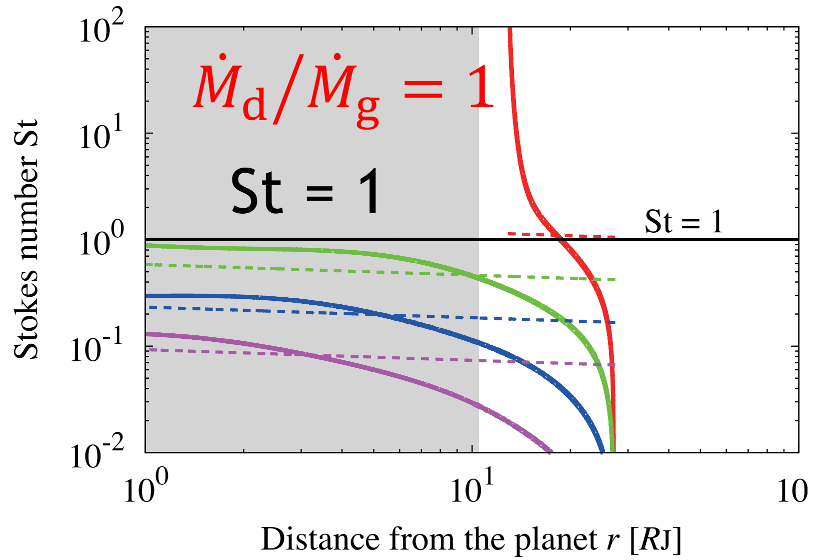
- Dust particles grow to satellitesimals only when $St > 1$
- The $\dot{M}_{\rm d}/\dot{M}_{\rm g}$ is larger, the Stokes number is larger
- Satellitesimals can form only when $\dot{M}_{\rm d}/\dot{M}_{\rm g} = 1$

Effects of $\dot{M}_{\rm d}/\dot{M}_{\rm g}$



✓ When $r \to 0$
the Stokes number can be approximated as

$$\mathrm{St} \approx 1.2 \left(\frac{\dot{M}_{\rm d}/\dot{M}_{\rm g}}{1}\right)^{2/5} \left(\frac{\alpha}{10^{-4}}\right)^{1/5} \times \left(\frac{T}{160\ \mathrm{K}}\right)^{-2/5} \left(\frac{M_{\rm cp}}{1\ M_{\rm J}}\right)^{2/5} \left(\frac{r}{10\ R_{\rm J}}\right)^{-2/5}$$



➢ $\mathrm{St} \propto (\dot{M}_{\rm d}/\dot{M}_{\rm g})^{2/5}$

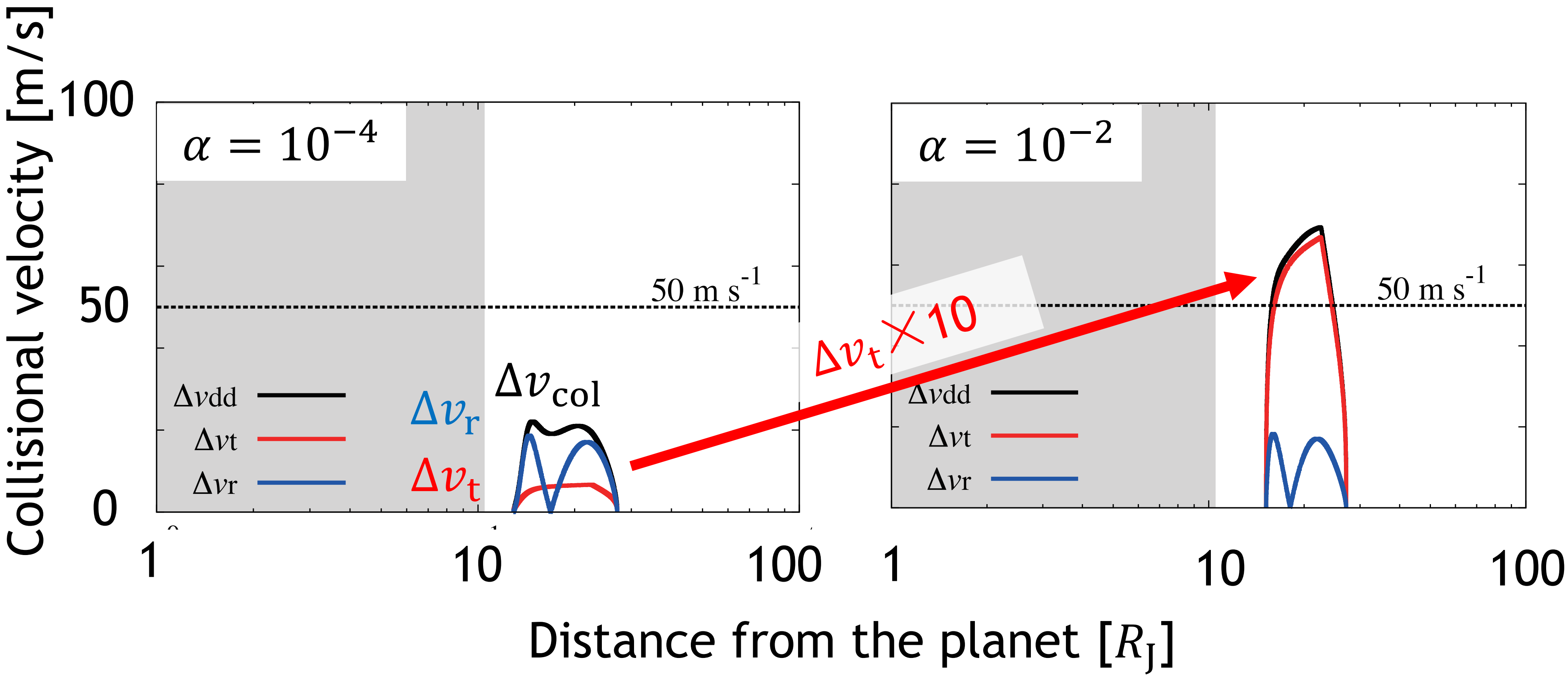
- $\dot{M}_{\rm d}$ ↑, $\Sigma_{\rm d}$ ↑, Collision rate ↑, St ↑
- $\dot{M}_{\rm g}$ ↓, $\Sigma_{\rm g}$ ↓, St ↑

The $\dot{M}_{\rm d}/\dot{M}_{\rm g}$ is larger, the Stokes number is larger

Fragmentation

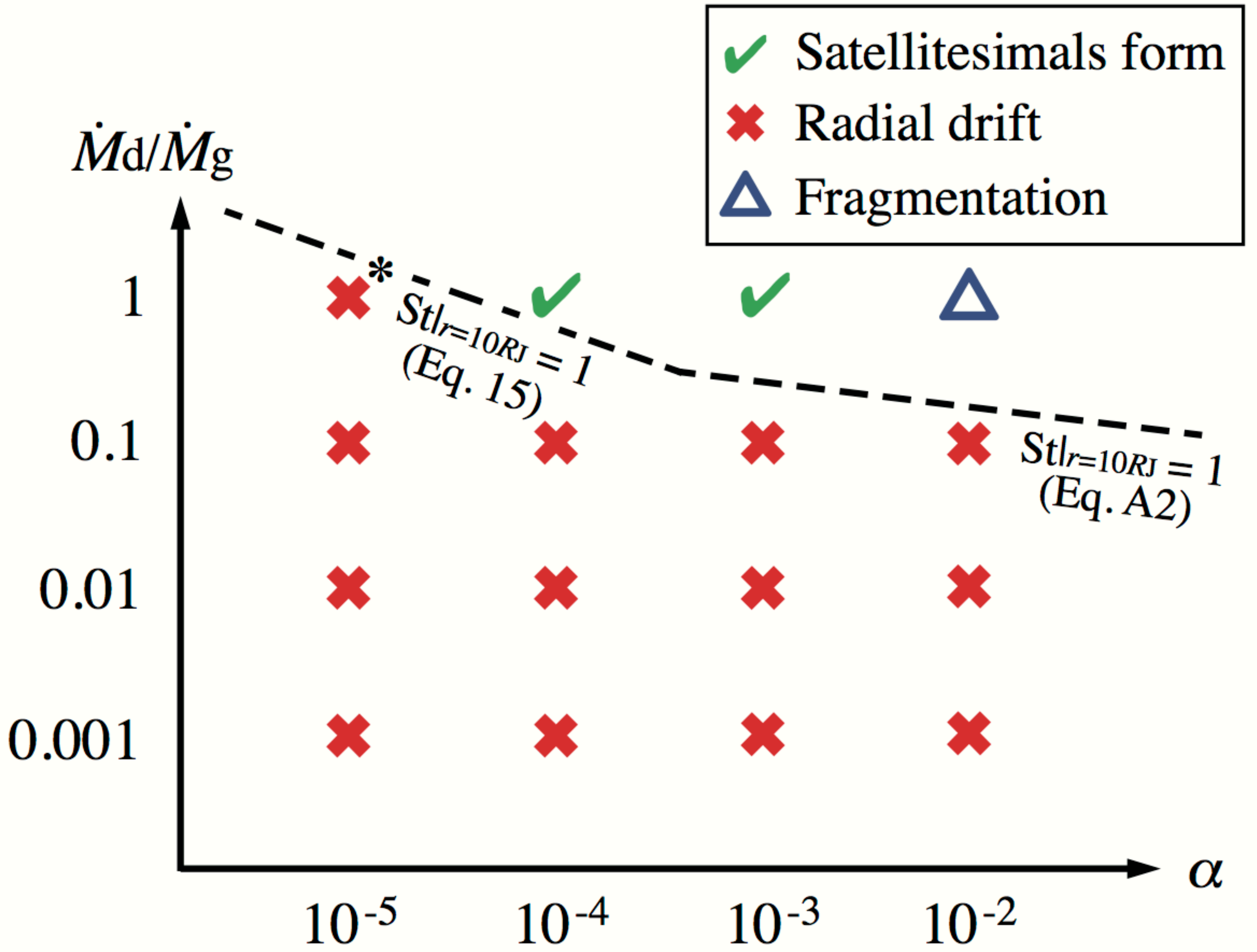
$\dot{M}_{\rm d}/\dot{M}_{\rm g} = 1, \dot{M}_{\rm g} = 0.02\ M_{\rm J}/{\rm Myr}$

- ✓ Fragmentation occurs when the collisional velocity is faster than 50 [m/s] (Wada et al. 2009)



When $\alpha = 10^{-2}$, the collisional velocity is faster than 50 m/s
→ Difficult to form satellitesimals

Condition for satellitesimal formation



Condition for satellitesimal formation is

$\dot{M}_d/\dot{M}_g \geq 1$ and $10^{-4} \leq \alpha < 10^{-2}$

→ This condition is generally difficult to achieve…

Summary

✓ We examined if dust particles can grow to satellitesimals

- We calculated the size and surface density of dust particles at each r (distance from Jupiter)
- We changed the dust-to-gas inflow mass flux ratio and strength of turbulence

✓ We found that…

- The $\dot{M}_{\mathrm{d}}/\dot{M}_{\mathrm{g}}$ is larger, the Stokes number is larger
- When $\alpha = 10^{-2}$, fragmentation occurs
- Condition for satellitesimal formation in steady CPDs is $\dot{M}_{\mathrm{d}}/\dot{M}_{\mathrm{g}} \geq 1$ and $10^{-4} \leq \alpha < 10^{-2}$
- This condition is generally difficult to achieve