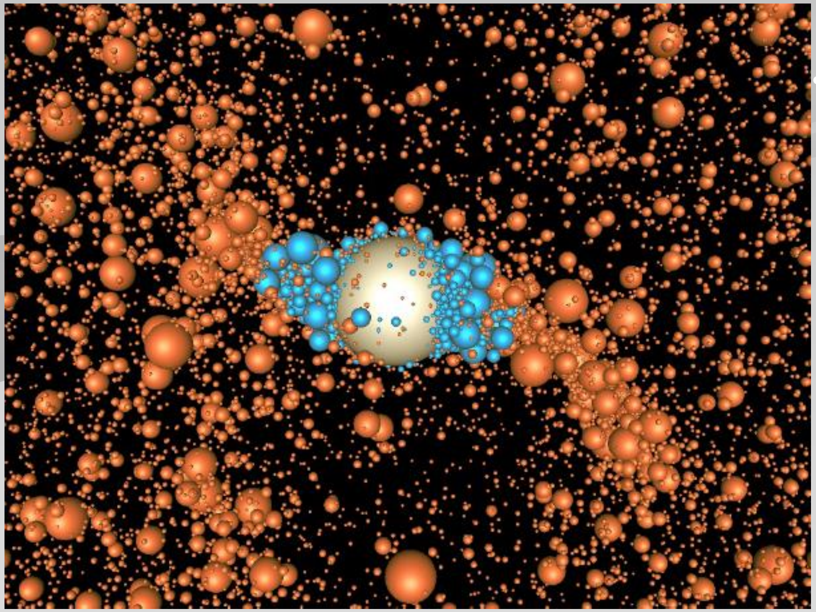
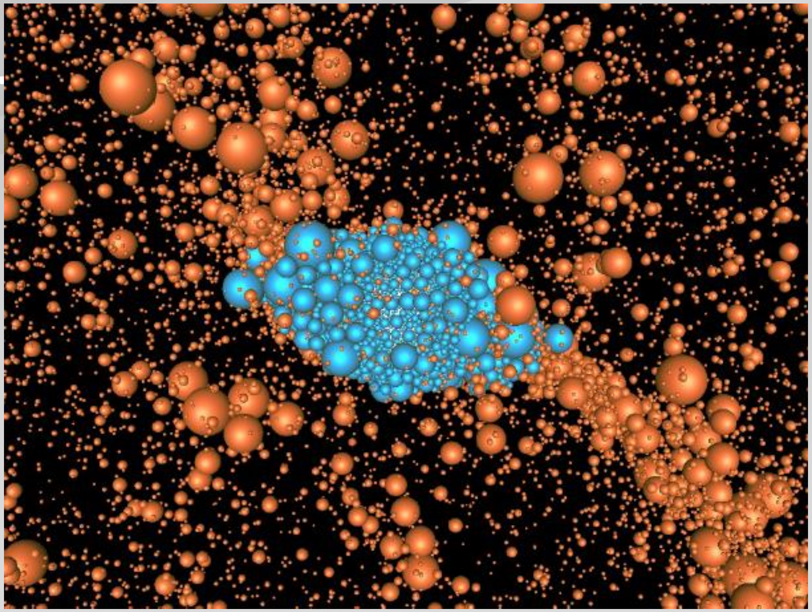
Gravitational Accretion of Particles onto Moonlets in Saturn's Rings

Yuki Yasui[1], Keiji Ohtsuki[1], Hiroshi Daisaka[2]

[1]Kobe U., [2]Hitotsubashi U.





(Yasui, Ohtsuki, Daisaka, submitted to ApJ)

Gravitational Accretion in Ring-Satellite Systems

- Formation of rings and satellites from circum-planetary particle disks

  (Charnoz et al. 2010, Canup 2010, Crida & Charnoz 2012, Hyodo, Ohtsuki, Takeda, in prep)

- Observations of shapes of small moons

  (Porco et al. 2007, Charnoz et al. 2007)

- Observations of ongoing accretion phenomena in Saturn's rings

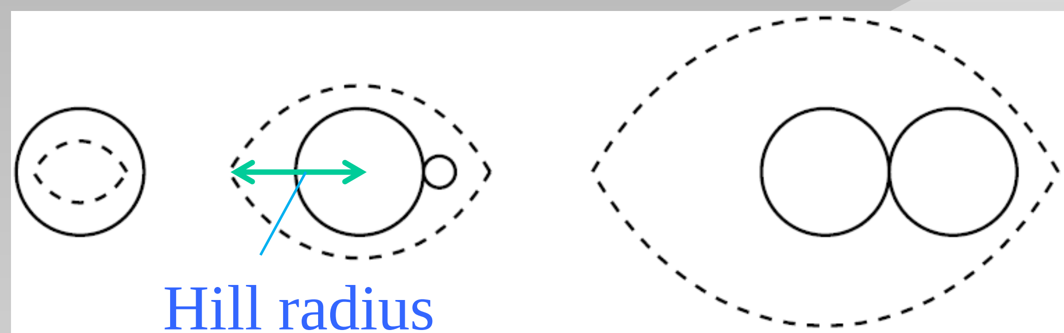
  (Beurle et al. 2010, Murray et al. 2014)

Accretion in the Tidal Environment

- Hill radius vs physical radius

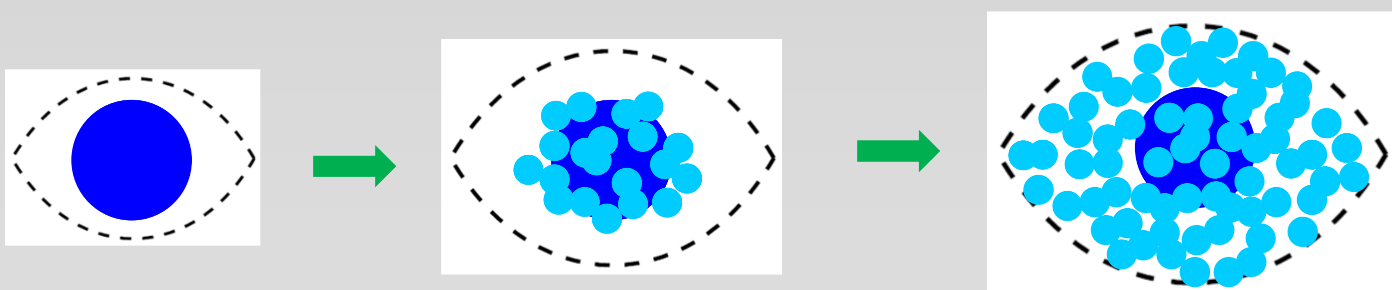
(Ohtsuki 1993, Canup & Esposito 1995, Ohtsuki et al. 2013)

← *Saturn*



- Accretion of porous particles onto dense cores

(Porco et al. 2007)



Accretion Criteria

- Density of an aggregate filling its Hill sphere

(Porco et al. 2007; Tiscareno et al. 2013)

$$\rho_{Roche} = \frac{3M_p}{\gamma a_{orbital}^3}$$

- Critical radial distance for gravitational accretion

(Kaljalainen & Salo 2004)

For identical particles with density $0.9 g cm^{-3}$:

temporary aggregates form in the inner A ring

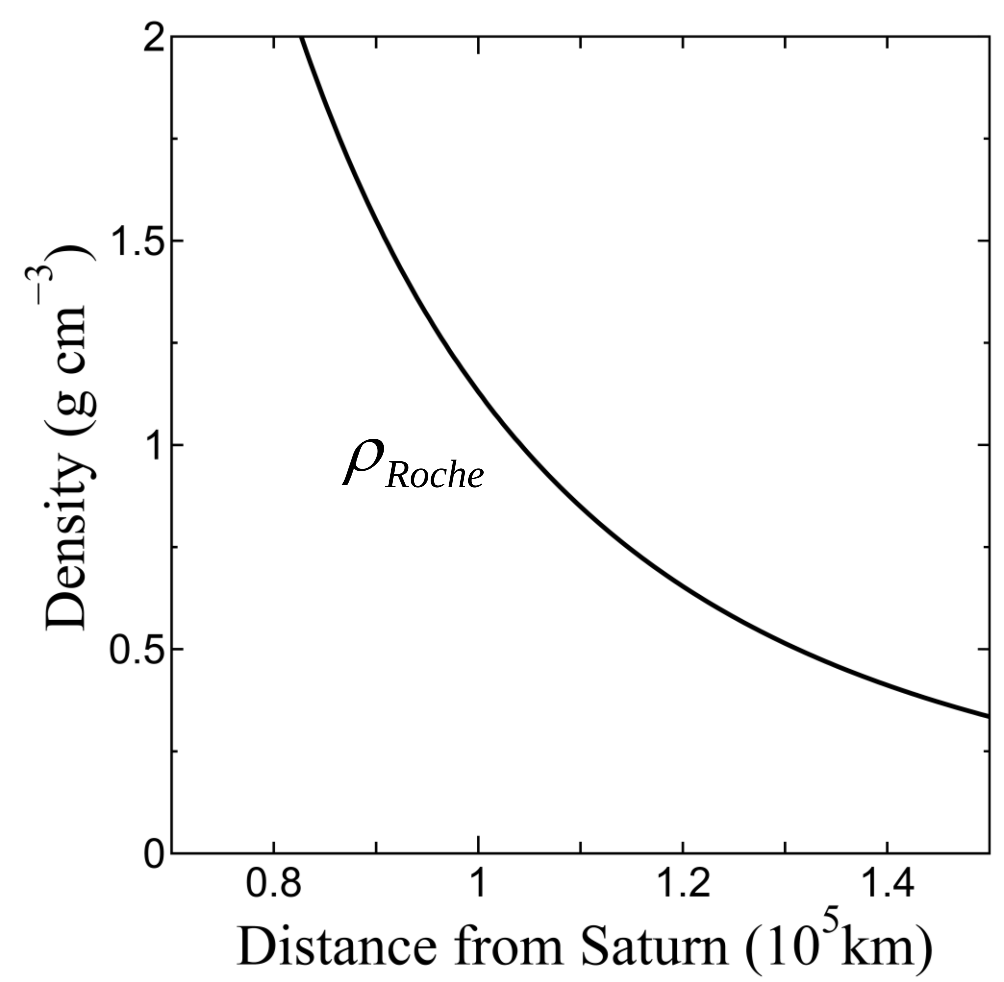
stable aggregates form in the outer A ring

- Critical bulk density of aggregates for tidal disruption

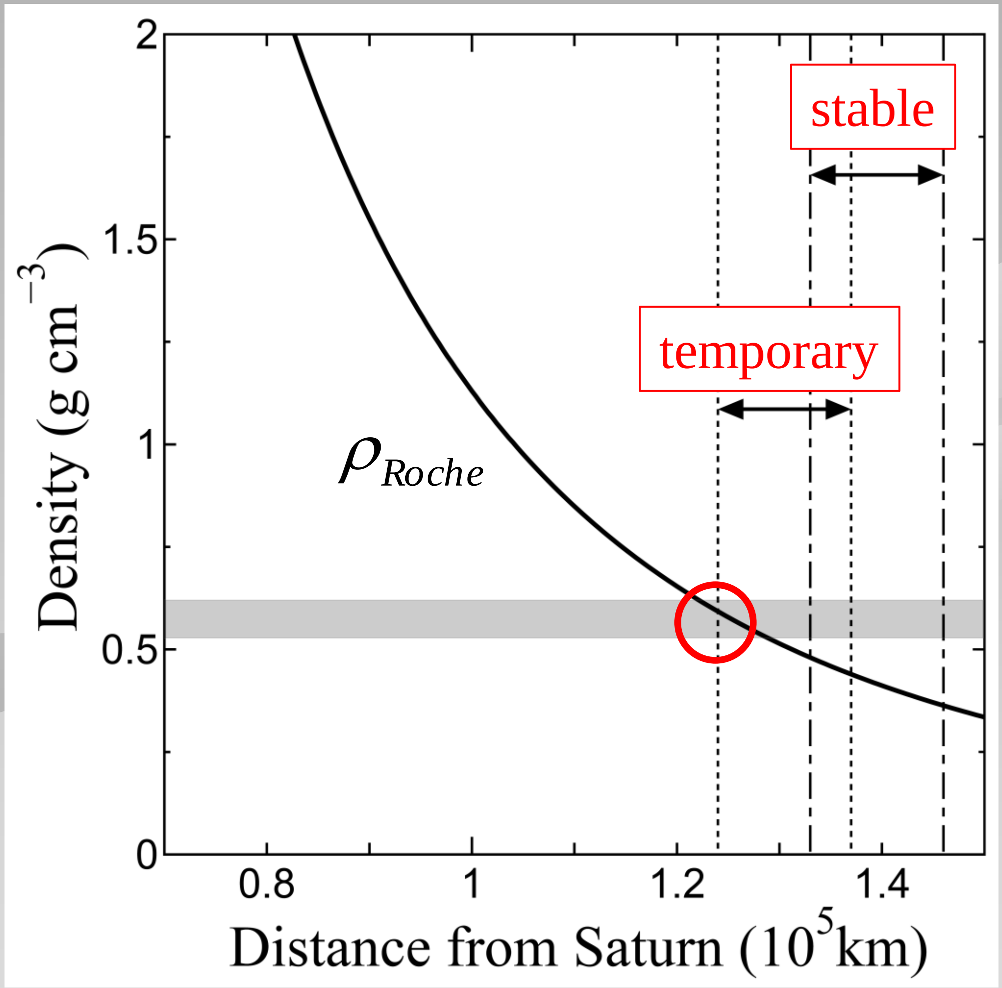
(Leinhardt et al. 2012)

$$\rho_{tidal} = \frac{7.7M_p}{\pi a_{orbital}^3}$$

Accretion Criteria

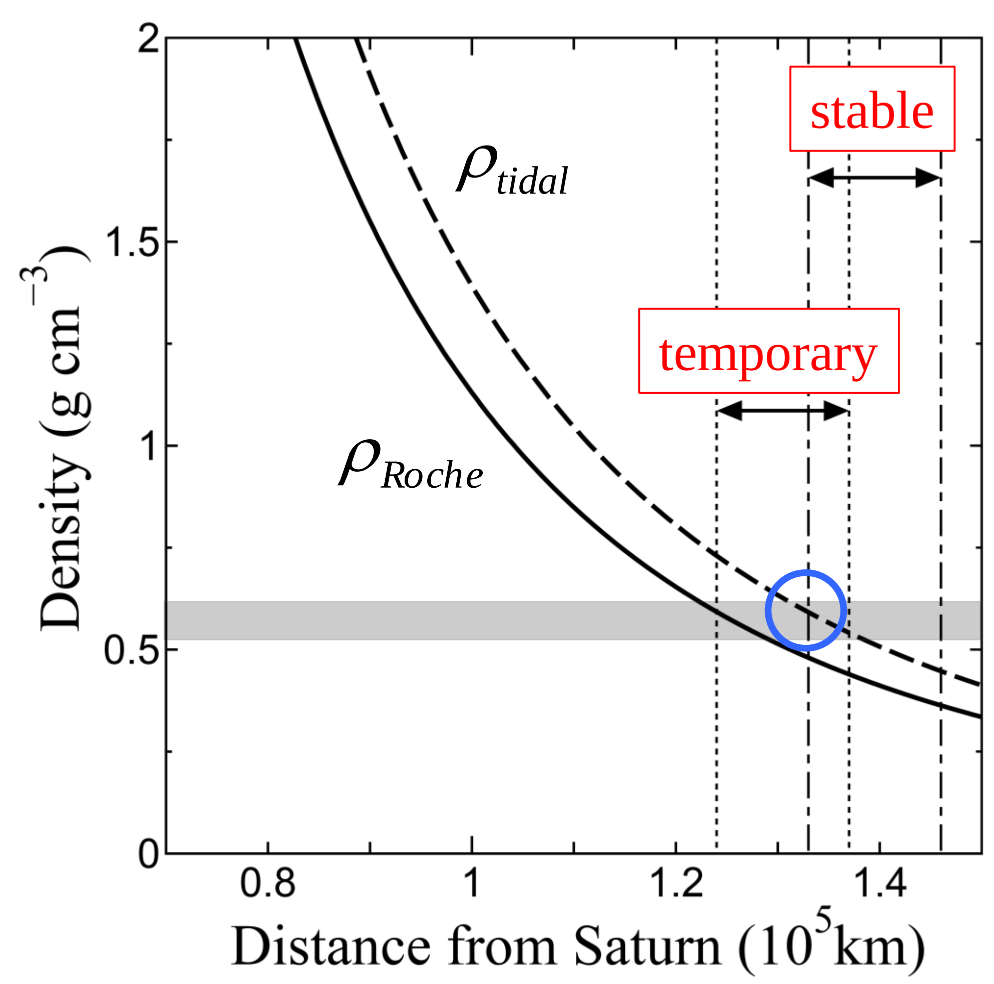


Accretion Criteria



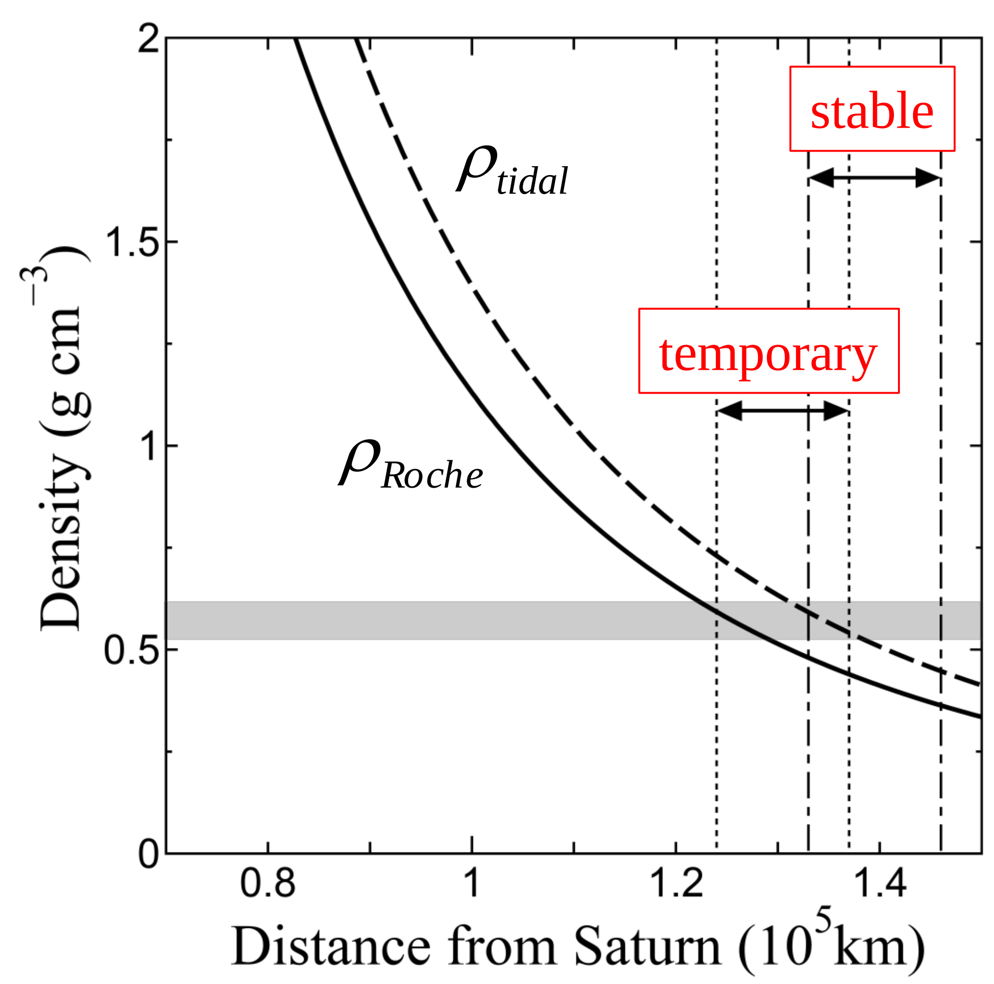
Bulk density of aggregates in N-body simulation

Accretion Criteria



Bulk density of aggregates in N-body simulation

Accretion Criteria



Where is the inner boundary of radial locations for gravitational accretion of particles?

Moonlets in Saturn's rings

- "Propeller moons" in the A & B rings

(e.g., Tiscareno et al. 2006, Sremčević et al. 2012)

- "Large boulders" in the C ring and the Cassini Division

(Baillié et al. 2013)

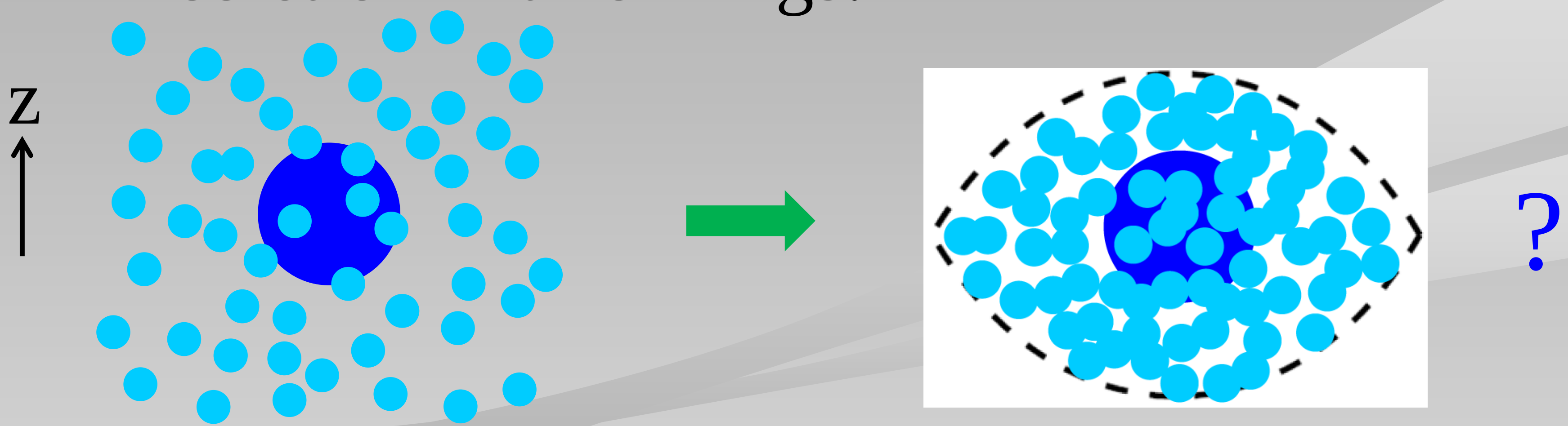
⬇

Origins of these small bodies?

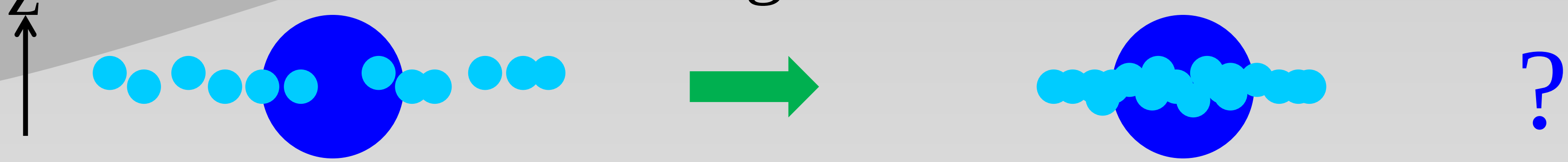
Effects of Ring Thickness on Accretion ?

(e.g., Charnoz et al. 2007)

- Accretion in thick rings:

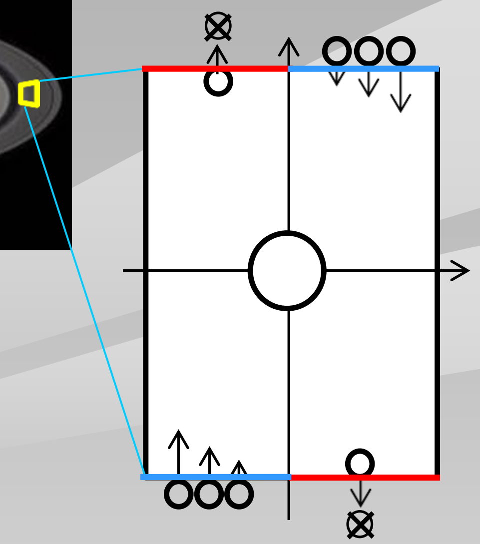


- Accretion in thin rings:



Are thick rings necessary to form Hill-sphere shaped bodies?

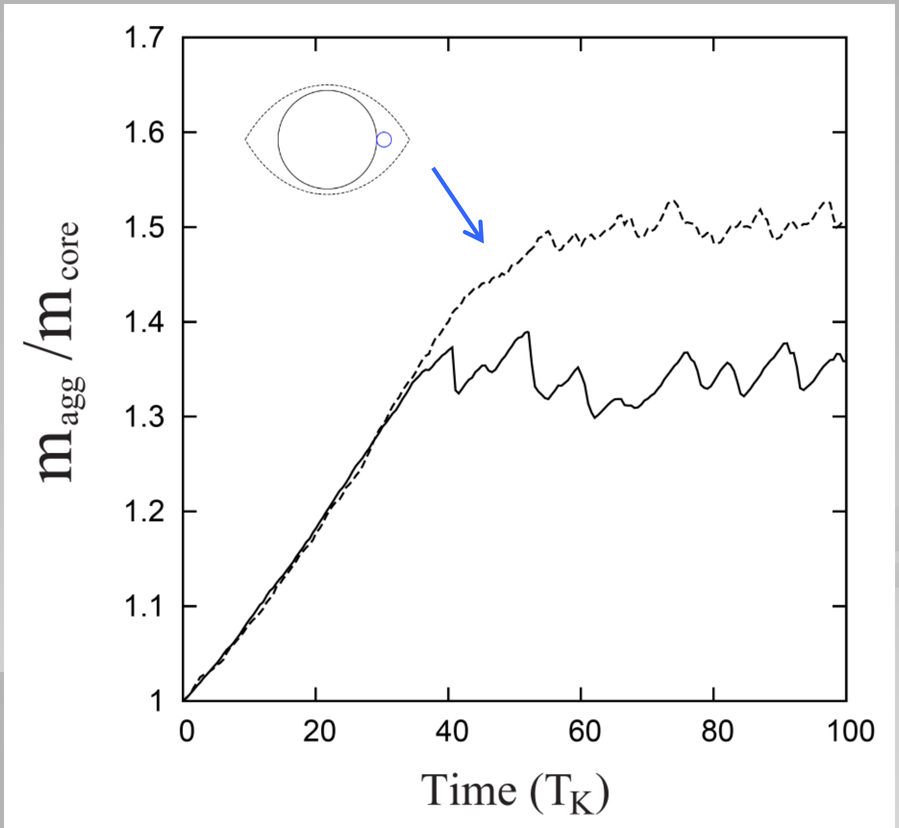
Numerical Methods

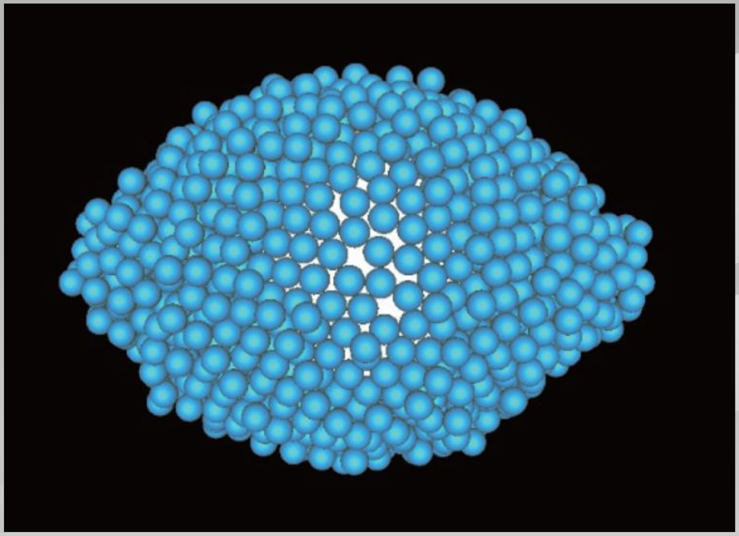


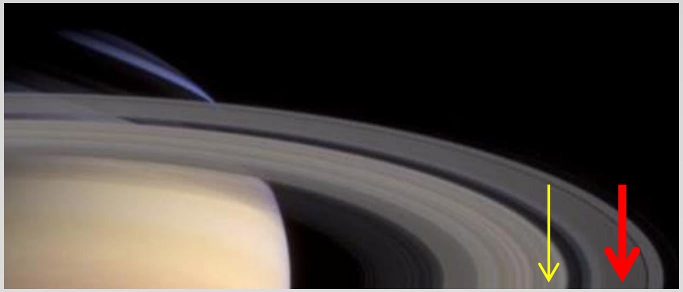
Local N-body simulation

- A moonlet core is placed at the origin of the coordinate system
- Unperturbed, fresh particles are continuously added to the simulation cell
- Collision and gravitational interactions are taken into account
- Particles leaving the cell are removed

Results: Complete coverage of moonlet surface





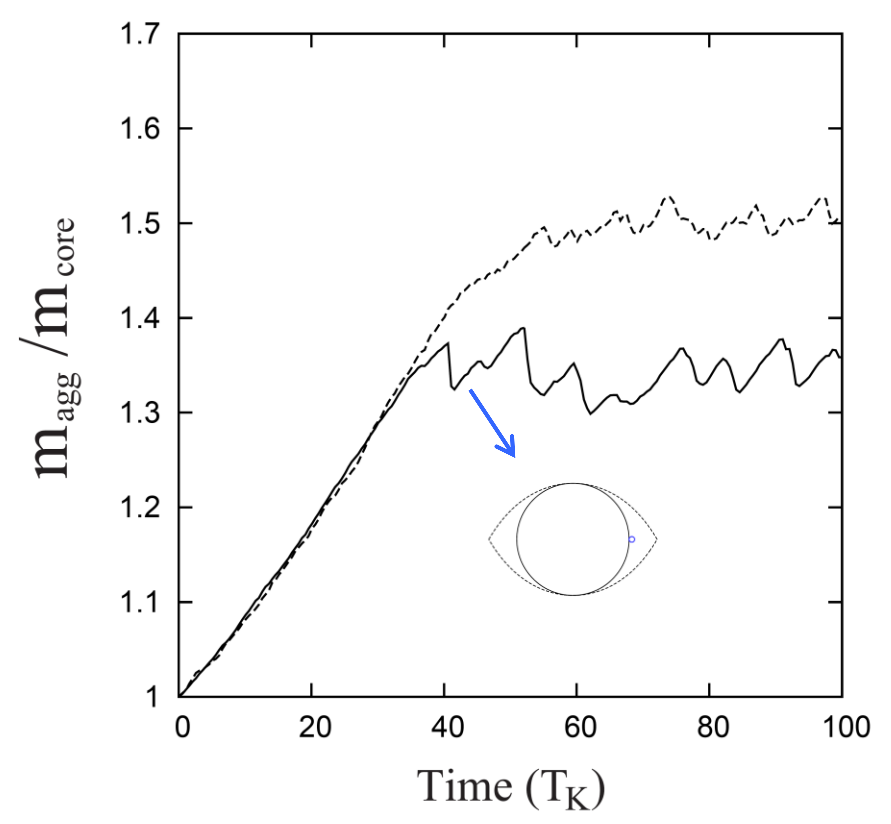


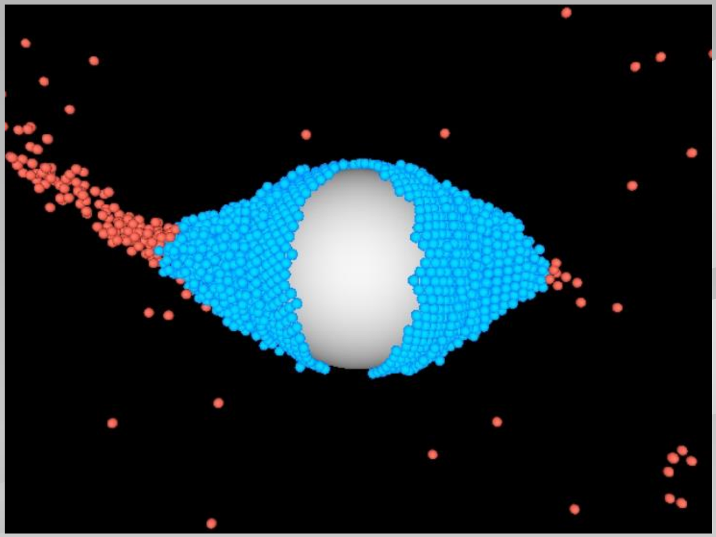
$a = 1.3\times 10^5$ km

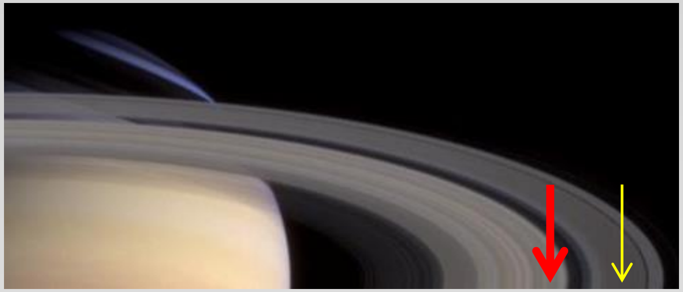
$\rho_{core} = 0.9$ g cm^{-3}, $\rho_p = 0.4$ g cm^{-3}

$\tau = 0.01$, $\varepsilon_n = 0.5$

Results: Partial coverage of moonlet surface





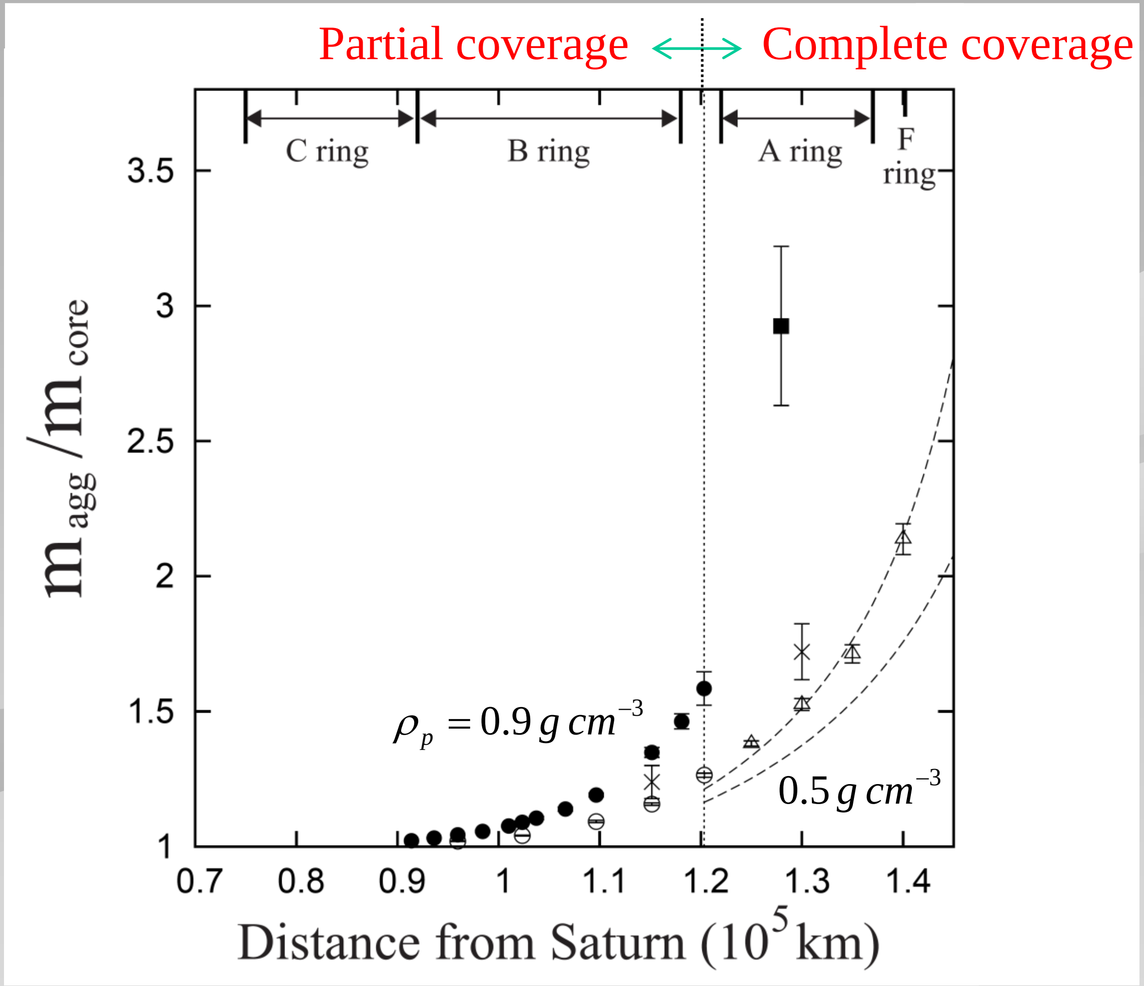


$a = 1.15 \times 10^5$ km

$\rho_{core} = 0.9$ g cm^{-3}, $\rho_p = 0.9$ g cm^{-3}

$\tau = 0.01$, $\varepsilon_n = 0.5$

Dependence on the Distance from Saturn

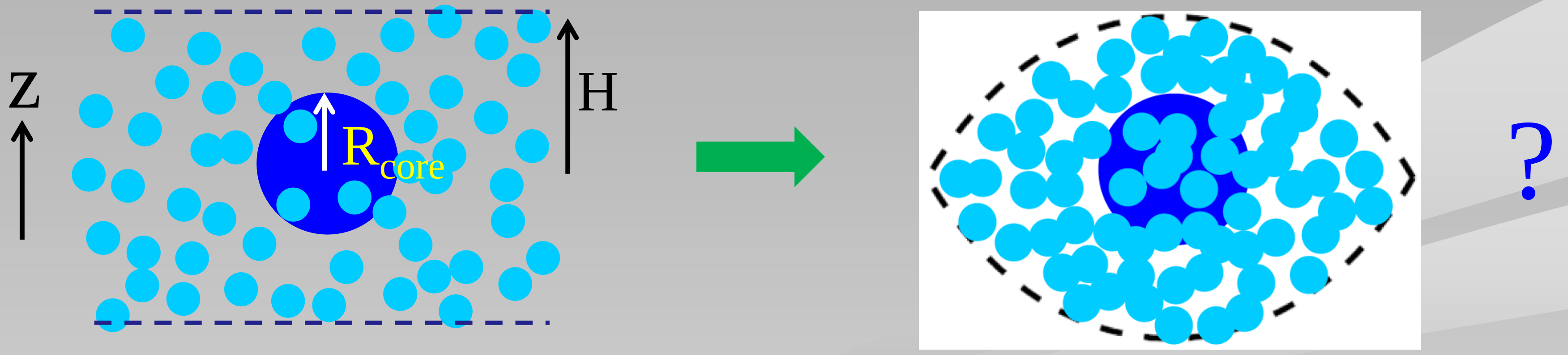


$\rho_{core} = 0.9\,g\,cm^{-3}$

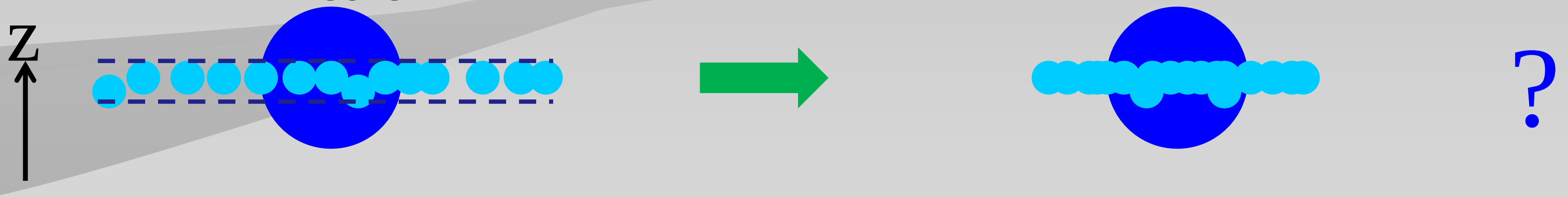
Gravitational accretion is negligible in the C ring

Effects of Ring Thickness on Accretion

$H = 2R_{core}$



$H = 0.2R_{core}$



➡ Are thick rings necessary to form Hill-sphere shaped bodies?

Effects of Ring Thickness on Accretion

$a = 130{,}000\ km$

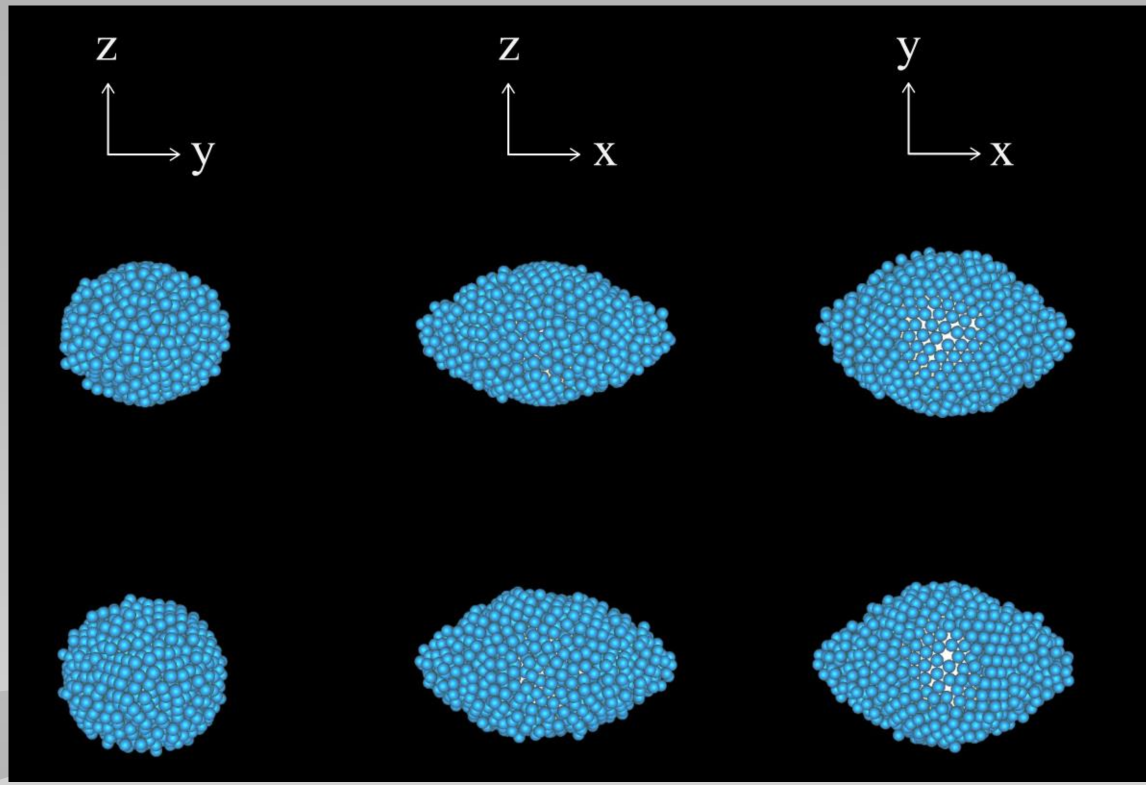
$\rho_{core} = 0.9\ g\ cm^{-3}$

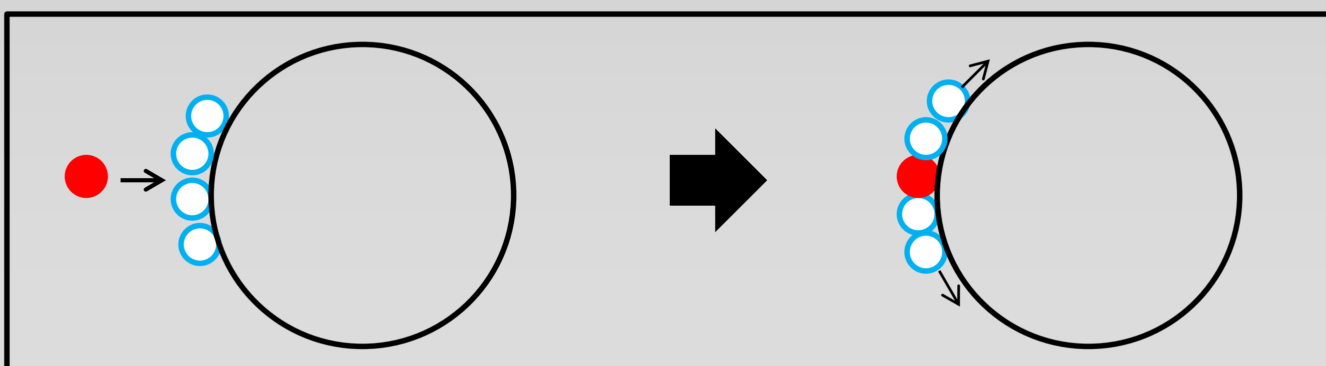
$\rho_p = 0.4\ g\ cm^{-3}$

$\tau = 0.1$

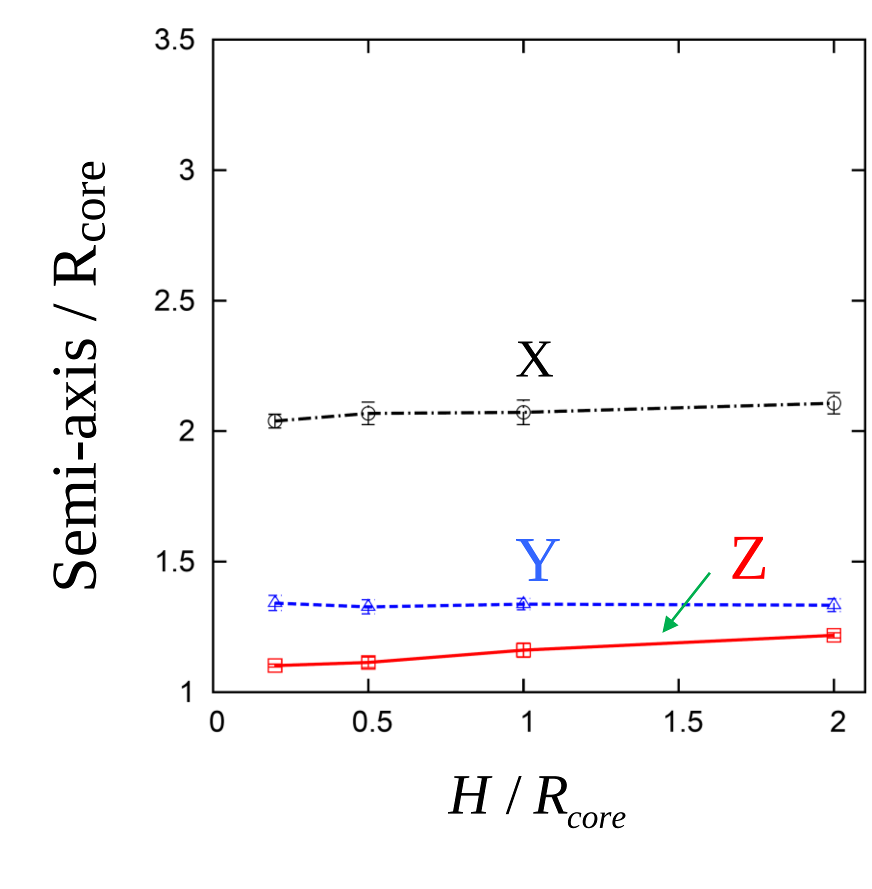
$H = 0.2R_{core}$

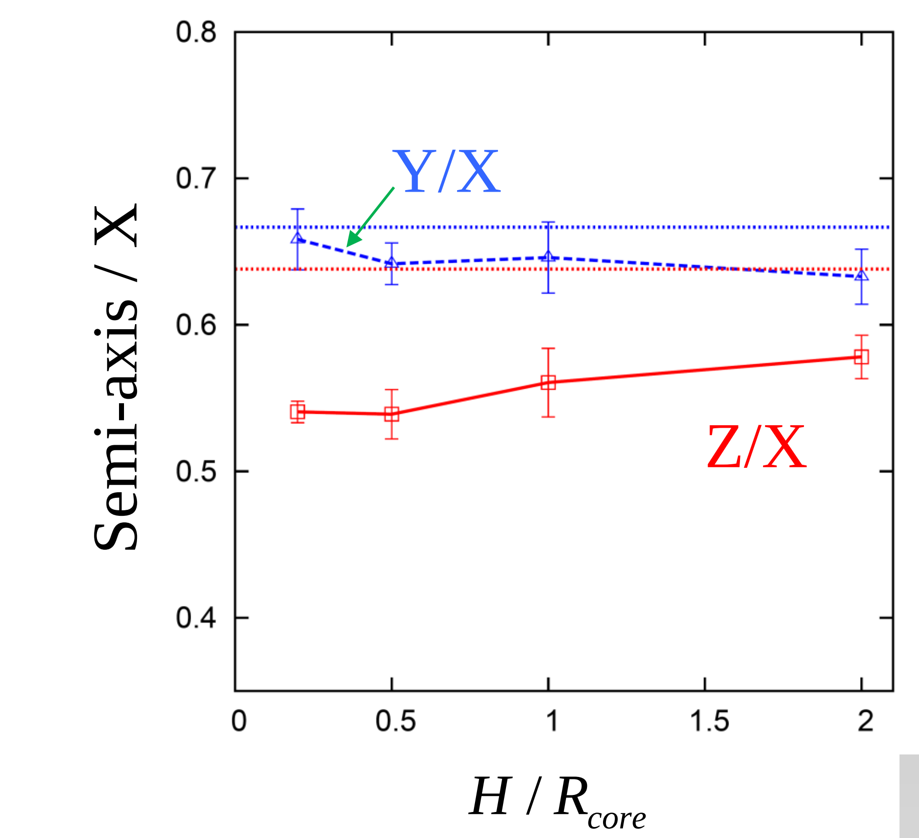
$H = 2R_{core}$

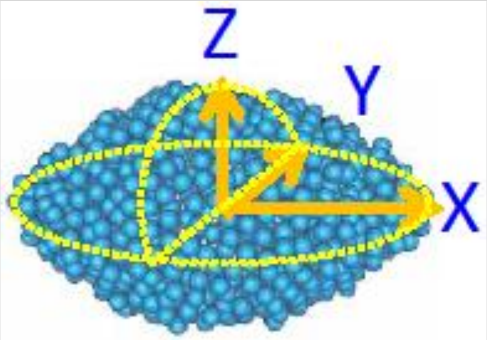




Effects of Ring Thickness on Accretion







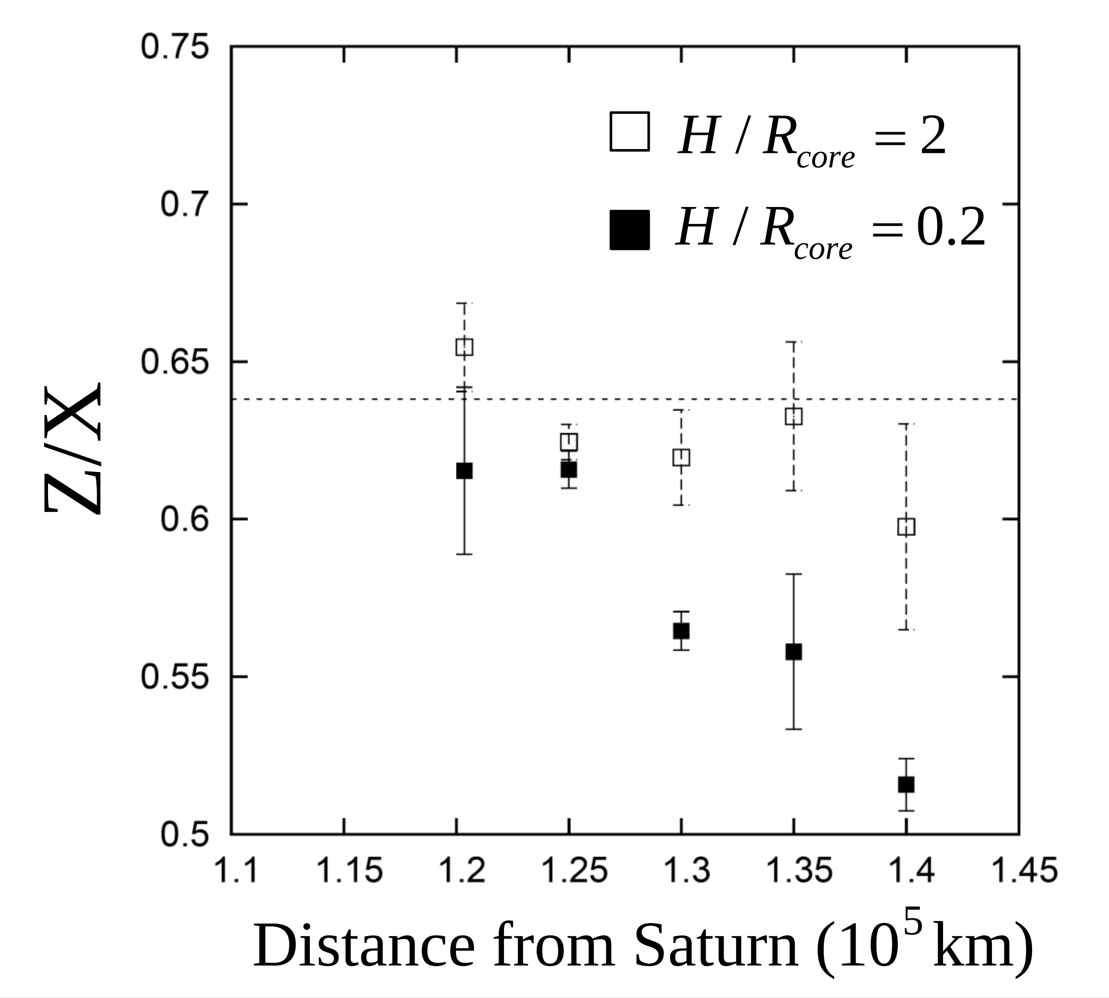
$a = 130{,}000\ km$

$\rho_{core} = 0.9\, g\, cm^{-3}$

$\rho_p = 0.4\, g\, cm^{-3}$

$\tau = 0.1$

Effects of Ring Thickness on Accretion

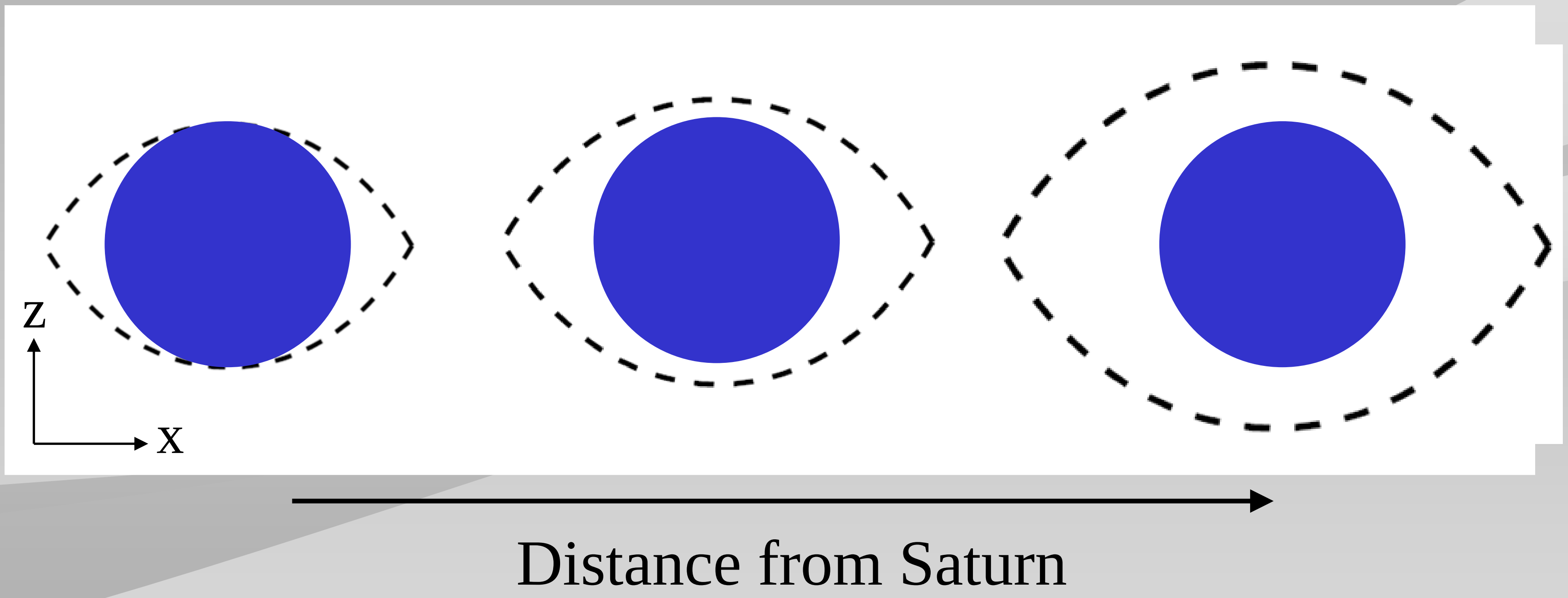


$\rho_{core} = 0.9\, g\, cm^{-3}$

$\rho_p = 0.4\, g\, cm^{-3}$

$\tau = 0.01$

Effects of Ring Thickness on Accretion



Shapes of the moons in the outer regions may reflect ring thickness at the time of accretion

Conclusions

- Gravitational accretion of particles onto moonlet cores is negligible in the C ring

→ large boulders that create “transparent holes” were not formed locally by gravitational accretion

- Particles can accrete onto high-latitude regions of core surfaces even when ring thickness is smaller than the core’s radius

→ rings were not necessarily dynamically hot when these small moons were formed

→ shapes of the moons near the ring outer edge may reflect ring thickness at the time of accretion