Class 20 – Apr 14th, 2020

Core Accretion: From Planetesimals to Planets

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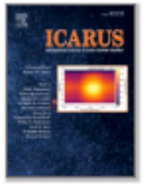
ELSEVIER

Icarus
Volume 124, Issue 1, November 1996, Pages 62-85



Regular Article

Formation of the Giant Planets by Concurrent Accretion of Solids and Gas ☆

James B. Pollack [a2], Olenka Hubickyj [b3], Peter Bodenheimer [b], Jack J. Lissauer [c], Morris Podolak [d], Yuval Greenzweig [d]

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https://doi.org/10.1006/icar.1996.0190

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Abstract

New numerical simulations of the formation of the giant planets are presented, in which for the first time both the gas and planetesimal accretion rates are calculated in a self-consistent, interactive fashion. The simulations combine three elements: (1) three-body accretion cross sections of solids onto an isolated planetary embryo, (2) a stellar evolution code for the planet's gaseous envelope, and (3) a planetesimal dissolution code within the envelope, used to evaluate the planet's effective capture radius and the energy deposition profile of accreted material. Major assumptions

☆ UCO/Lick Observatory Bulletin No. 1341.

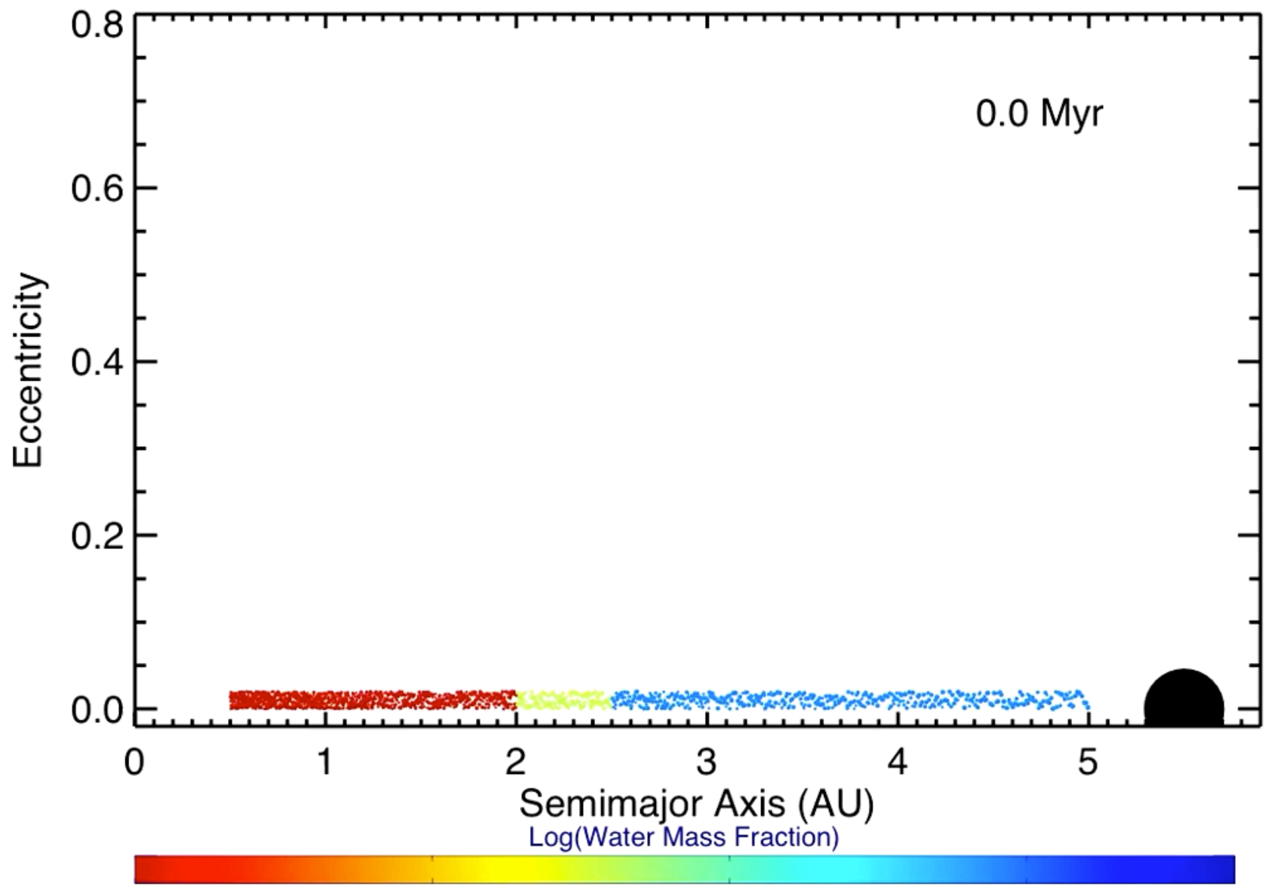
f1 E-mail: peter@helios.ucsc.edu

2 Deceased.

3 Present address: SETI Institute, 2035 Landings Dr., Mountain View, CA 94043.

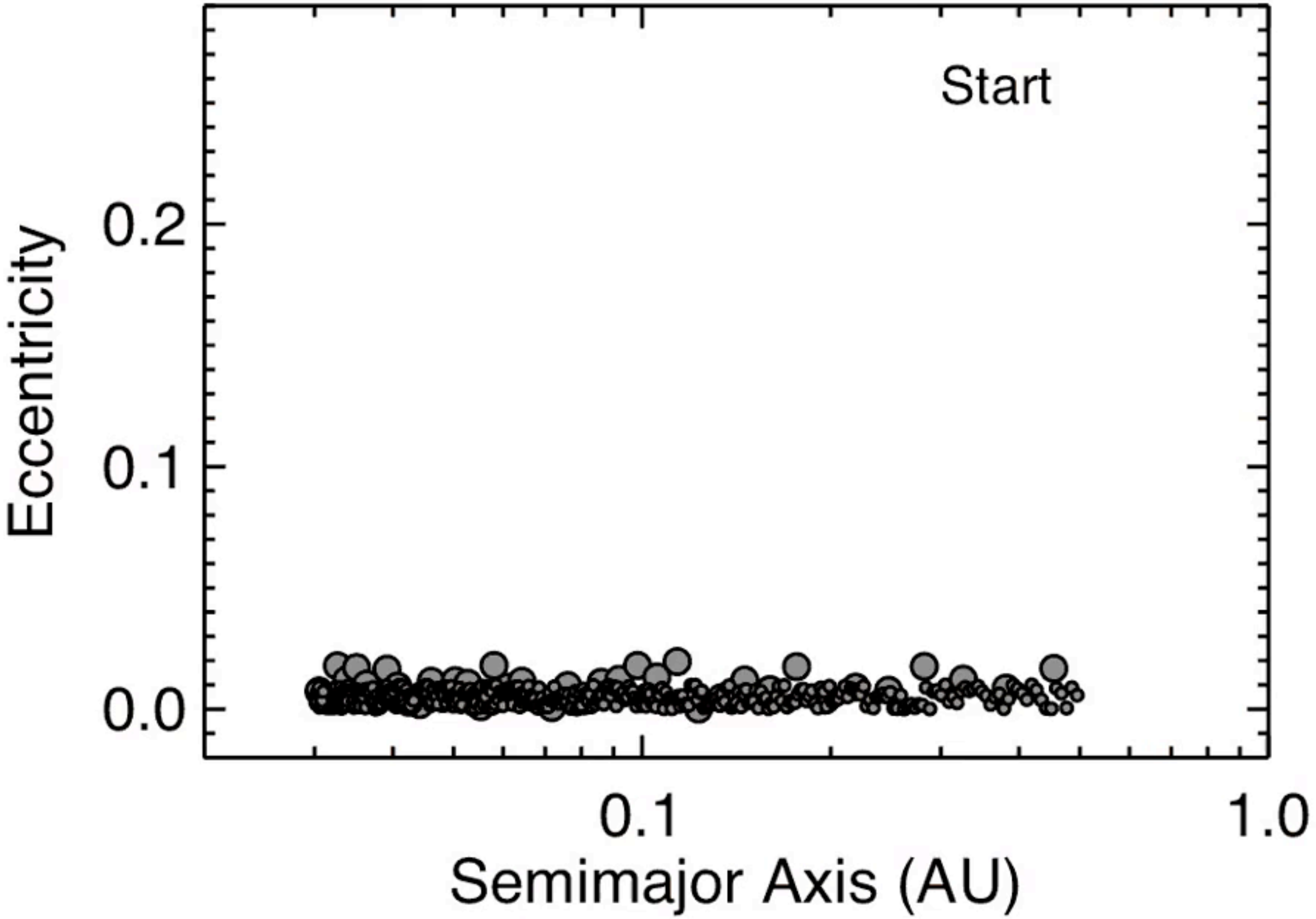
Terrestrial Planet Formation

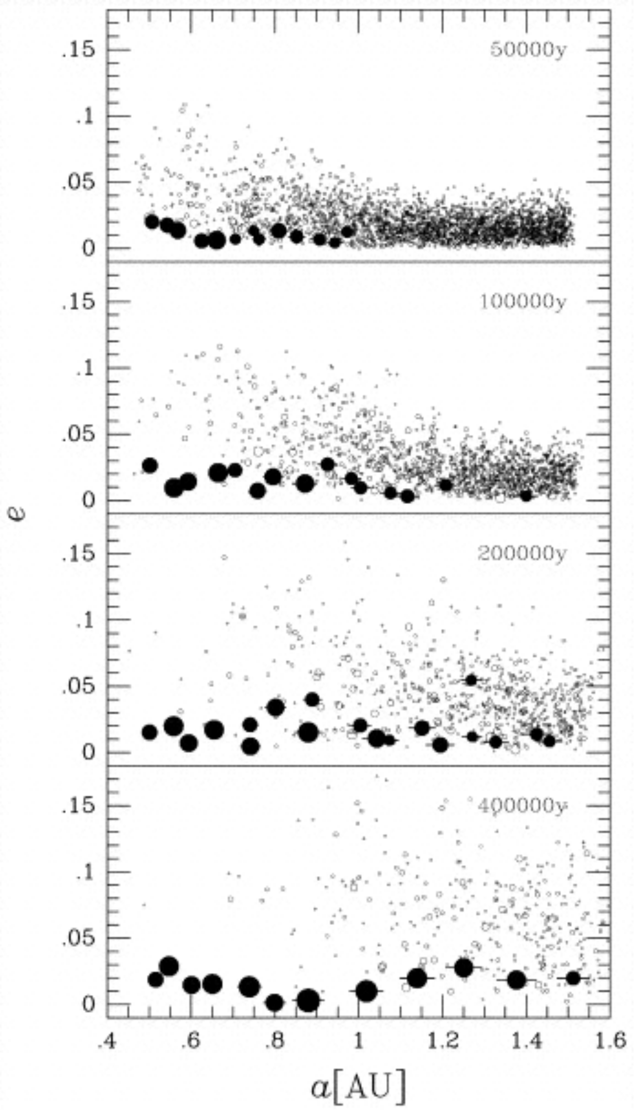
Core Accretion: From Planetesimals to Planets



Terrestrial Planet Formation

Core Accretion: From Planetesimals to Planets





Terrestrial Planet Formation

Core Accretion: From Planetesimals to Planets

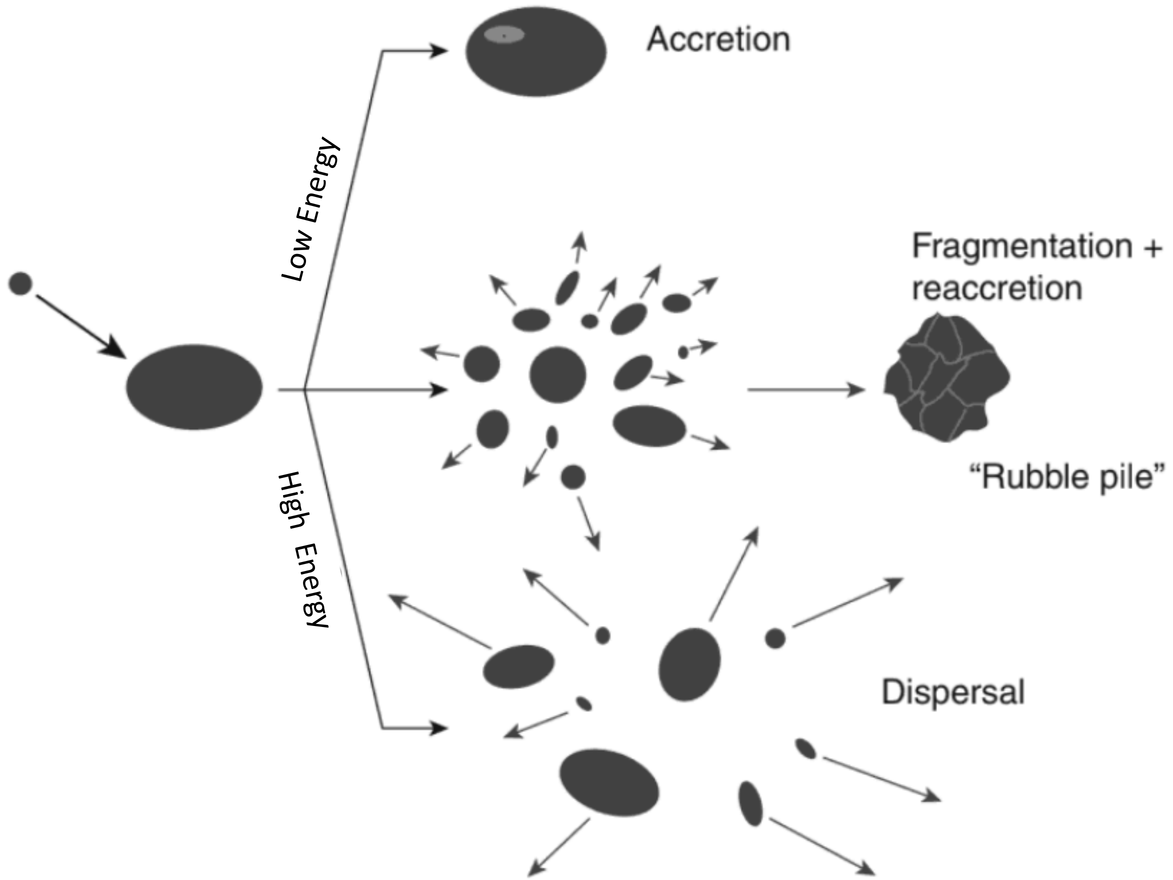
- Hill Dynamics (how cores grow)
- Growth rates (how fast cores grow)
- Isolation mass (how massive cores grow)

Problem

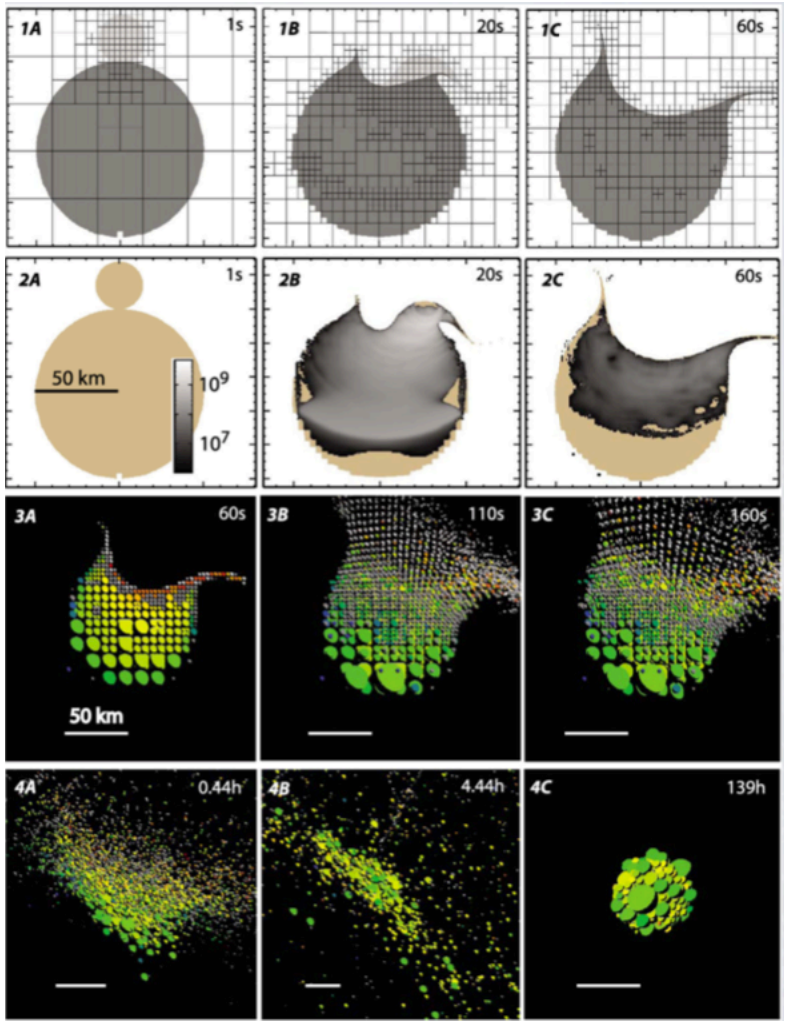
- Growing planets by planetesimal collisions.
  - There are a trillion planetesimals.
    - Statistical treatment needed

Aims

- Find collision rate for planetesimal distribution
- Determine outcome of collisions
- Put it all together in a model

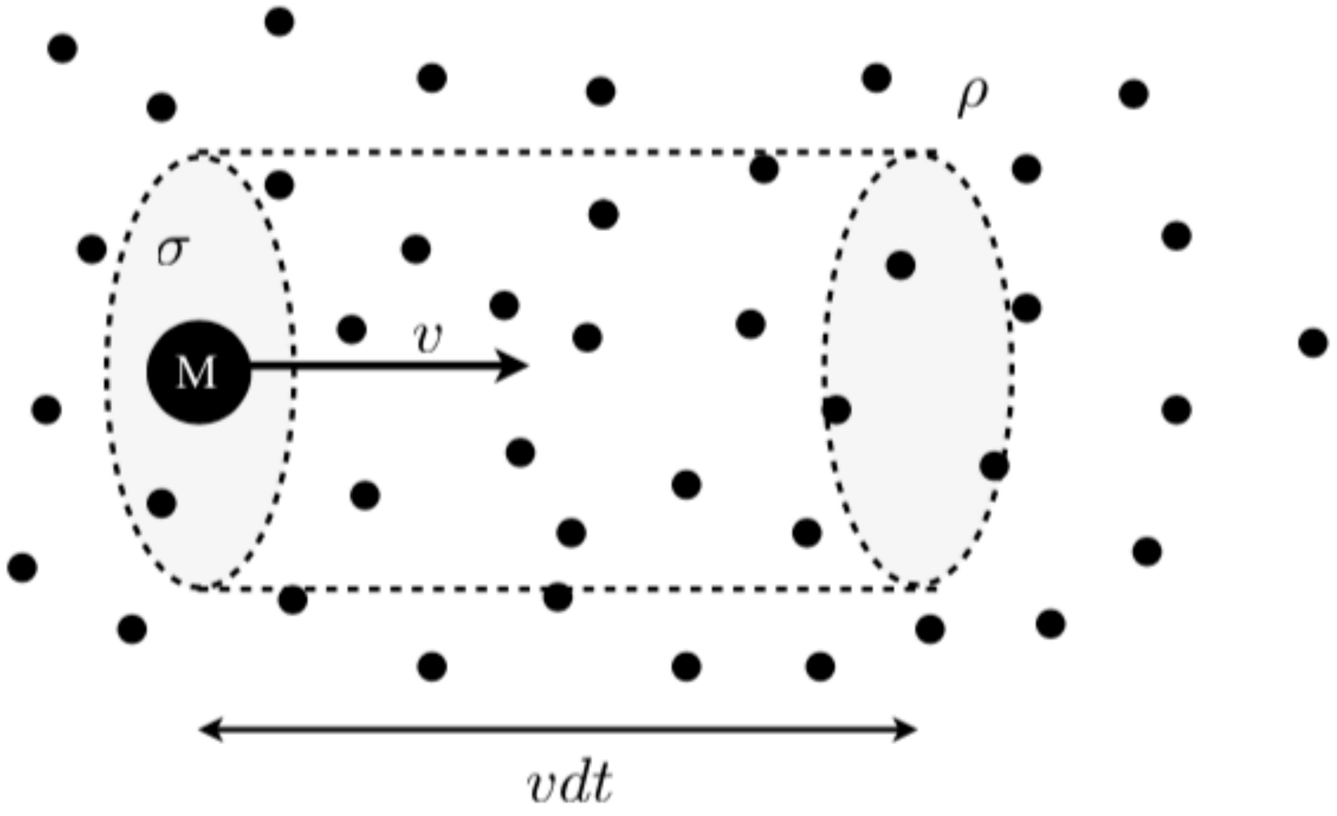


Accretion
Low Energy
Fragmentation +
reaccretion
"Rubble pile"
High Energy
Dispersal

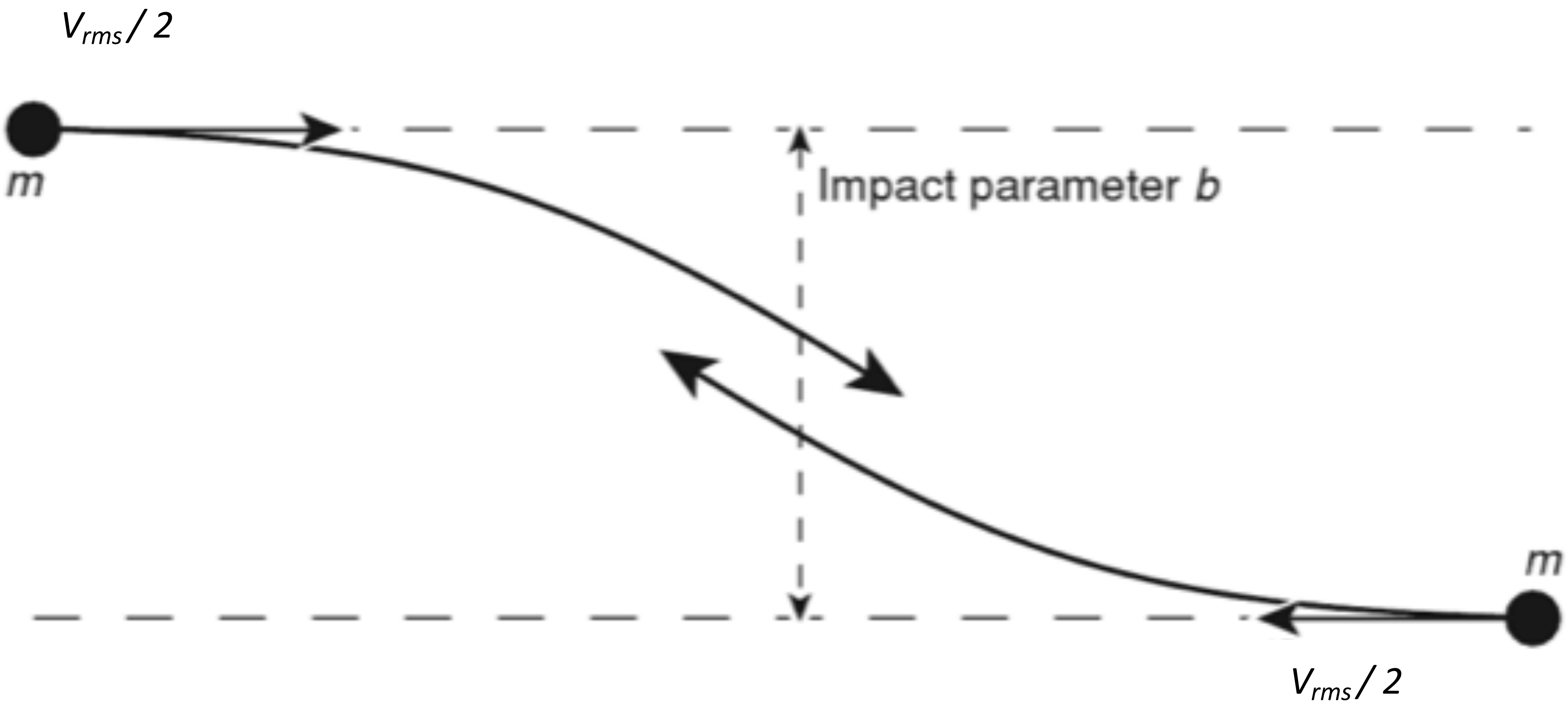


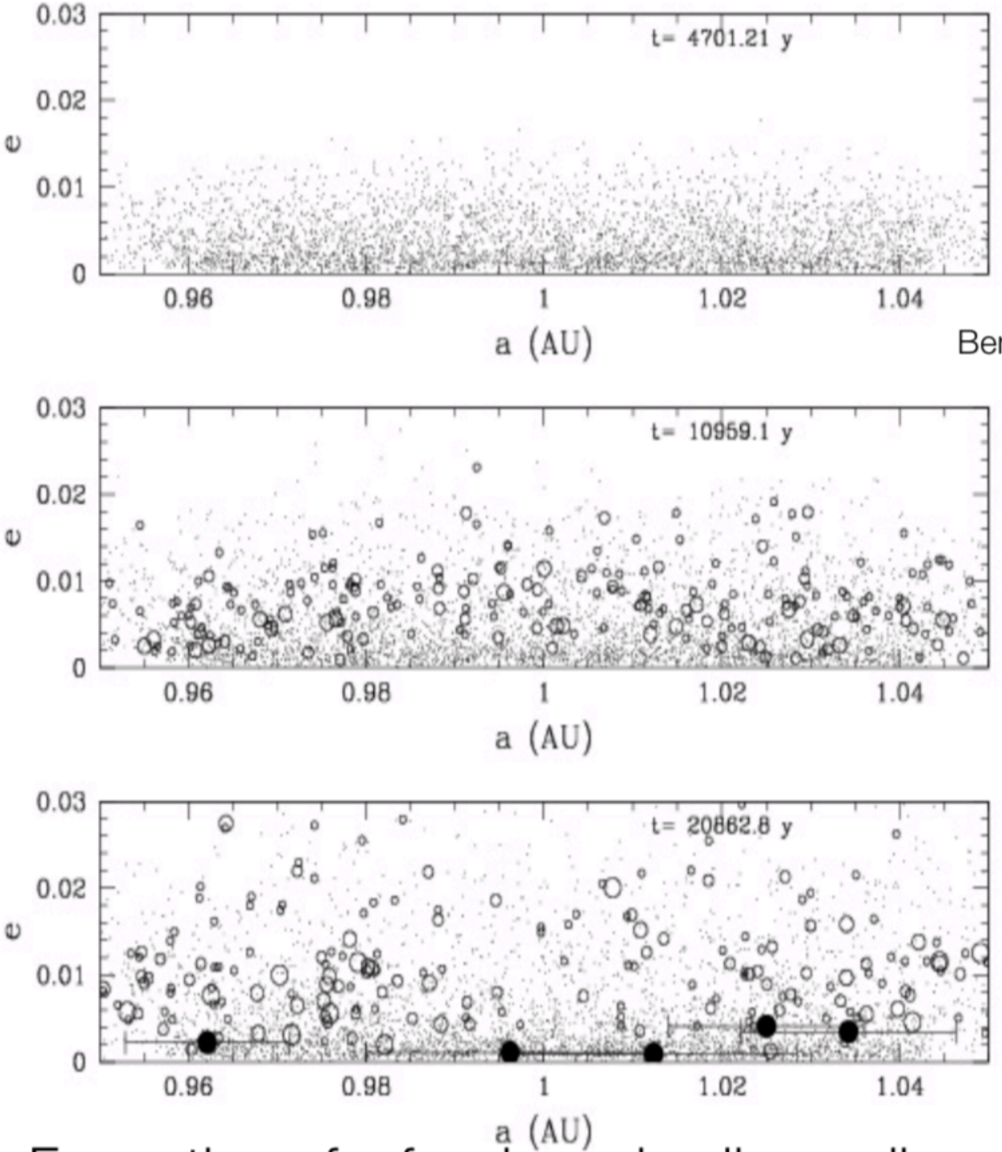
1A
1s
1B
20s
1C
60s
2A
1s
50 km
10^9
10^7
2B
20s
2C
60s
3A
60s
50 km
3B
110s
3C
160s
4A
0.44h
4B
4.44h
4C
139h

Growth rate

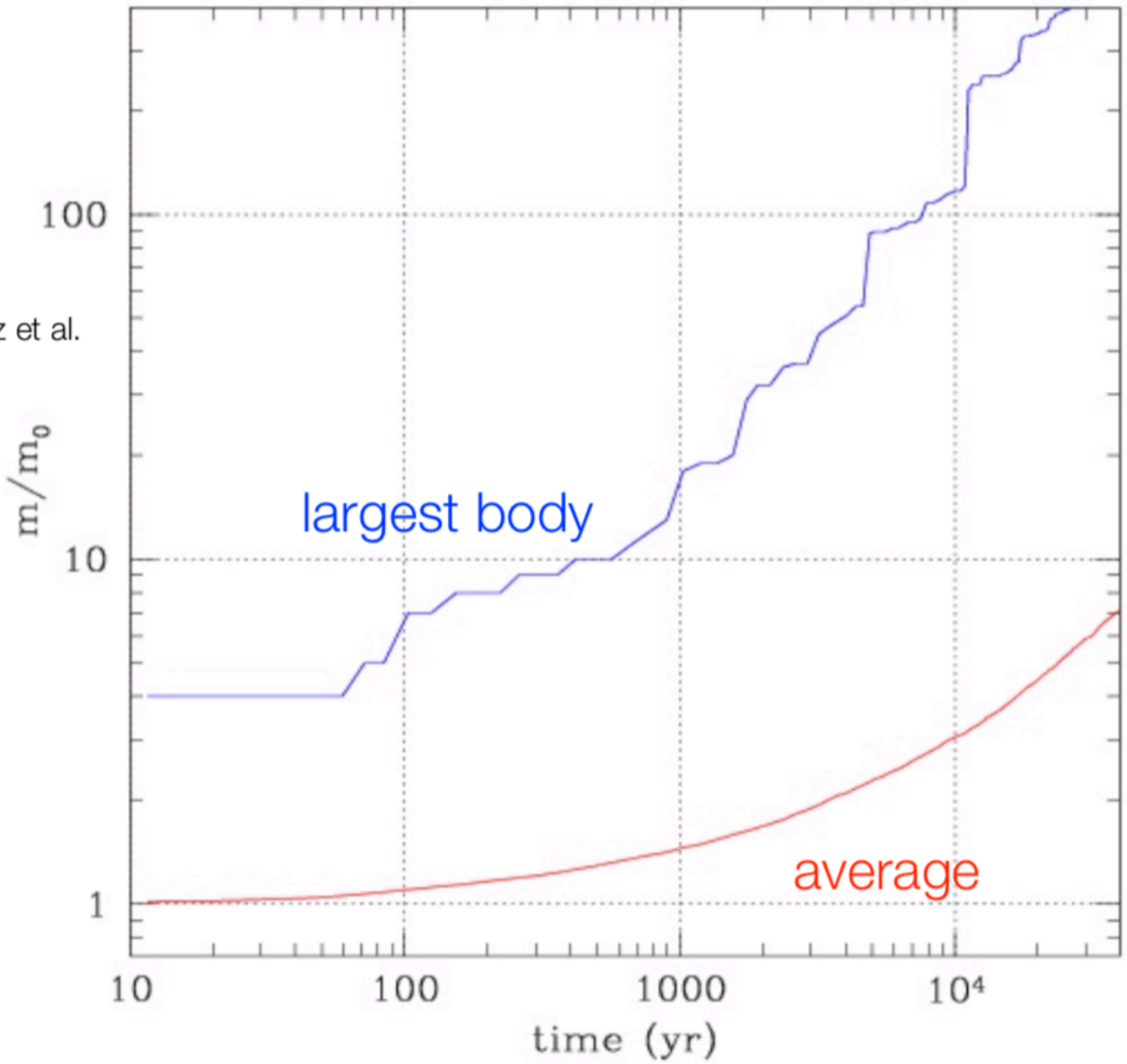


Collisions with Gravity





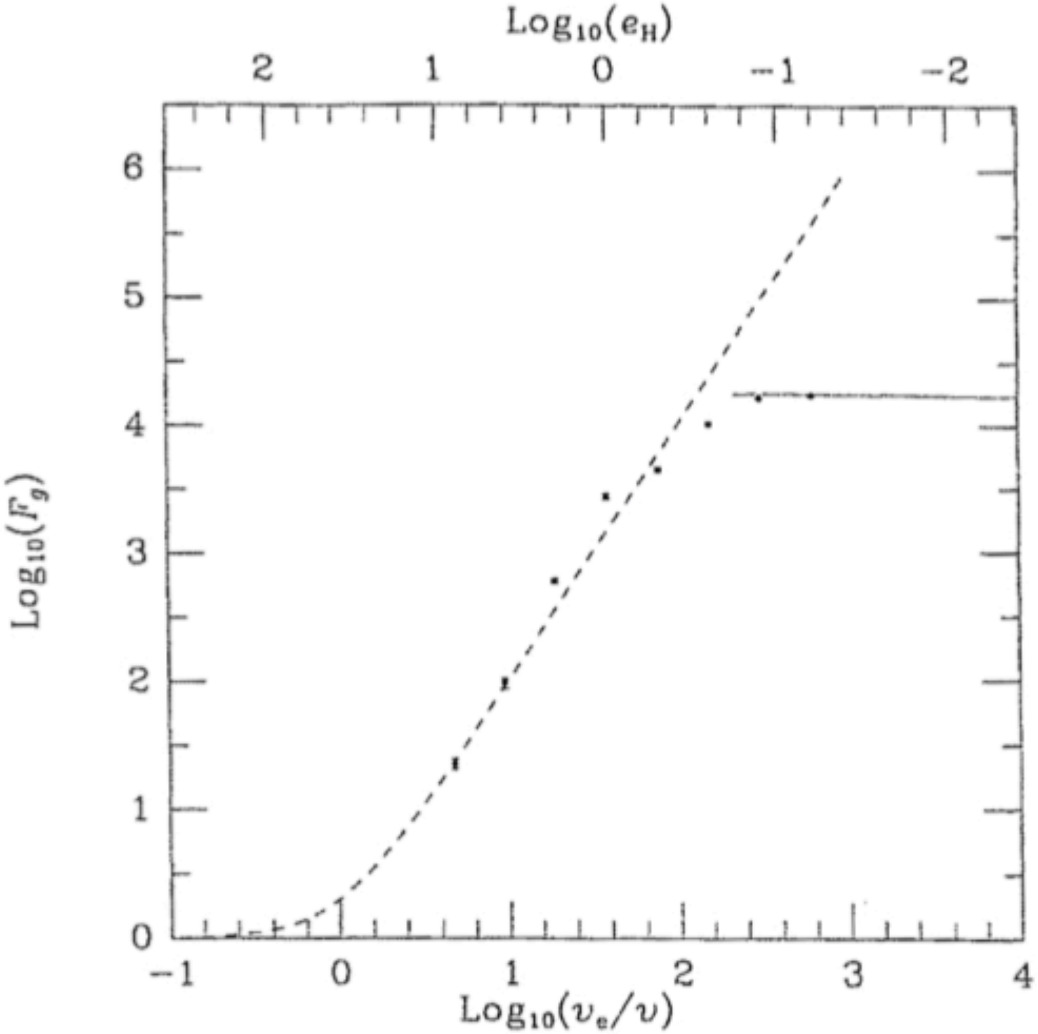
Benz et al.



Formation of a few large bodies well separated (~ 5 R_{hills}). Note their low eccentricity

The largest body is growing faster than the average body. It decouples from the background planetesimals.

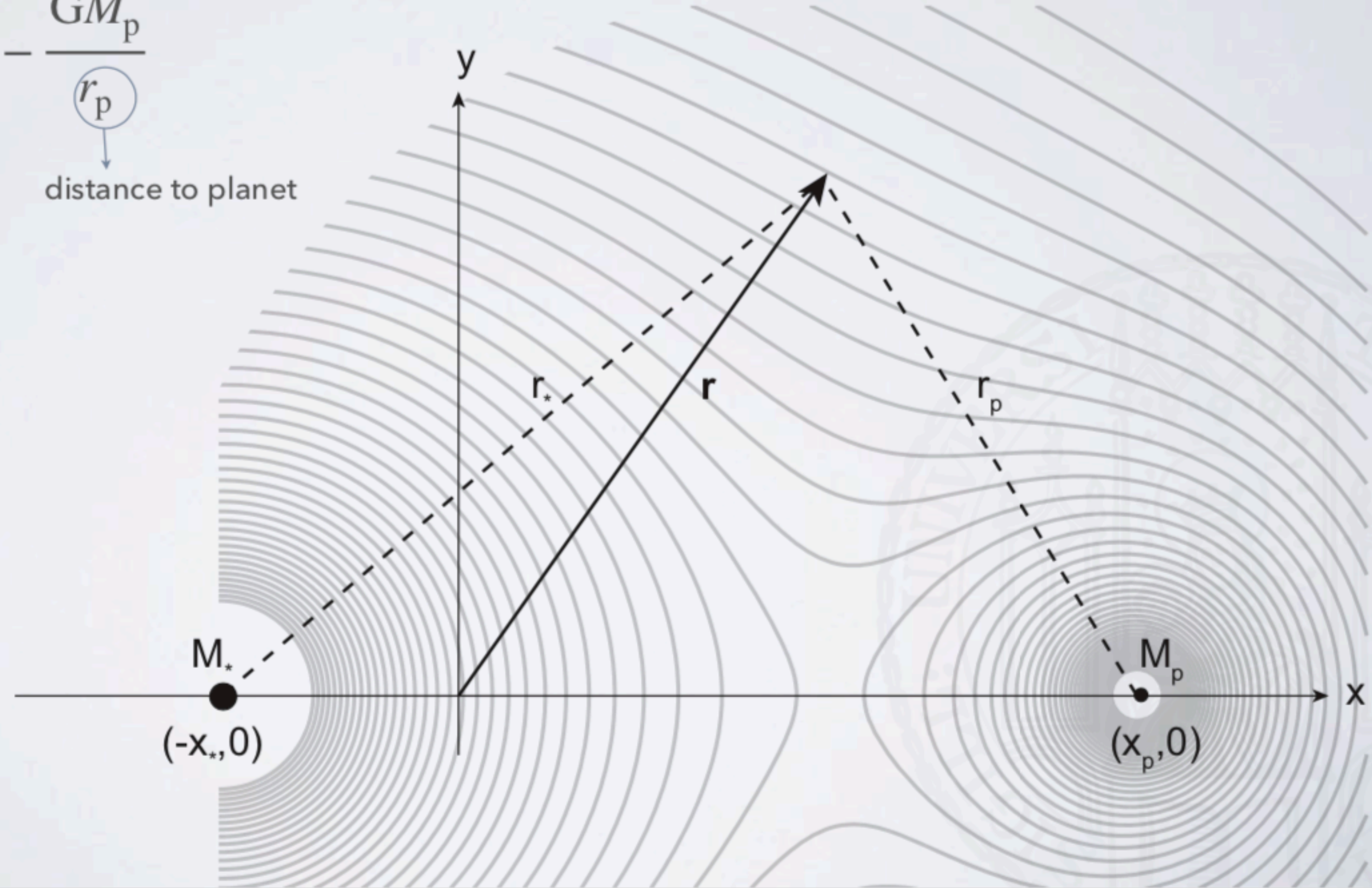
Limits to Growth



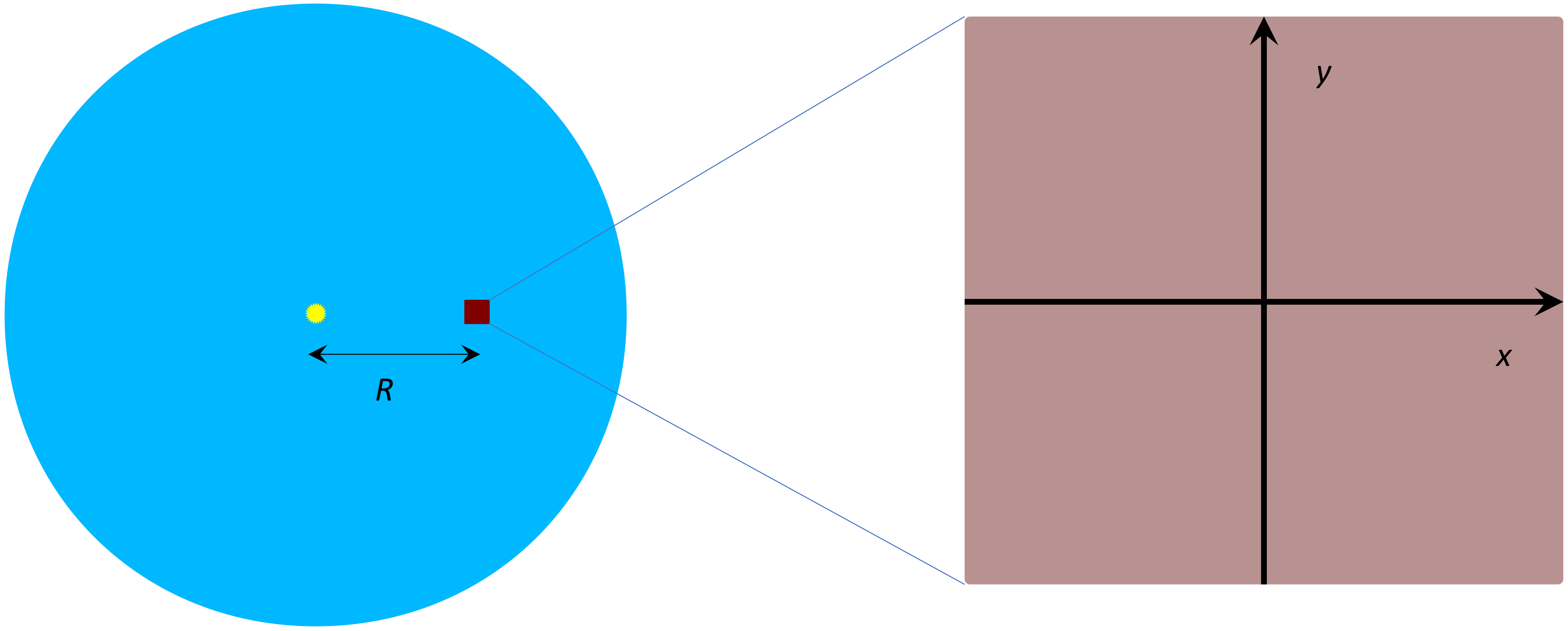
$$\ddot{\mathbf{r}} = -\nabla\Phi \overbrace{-2\,(\Omega\times\dot{\mathbf{r}})}^{\text{coriolis force}} \overbrace{-\Omega\times(\Omega\times\mathbf{r})}^{\text{centrifugal force}}$$

$$\Phi = -\frac{GM_\star}{r_\star} - \frac{GM_\mathrm{p}}{r_\mathrm{p}}$$

$r_\star$: distance to star r_p: distance to planet



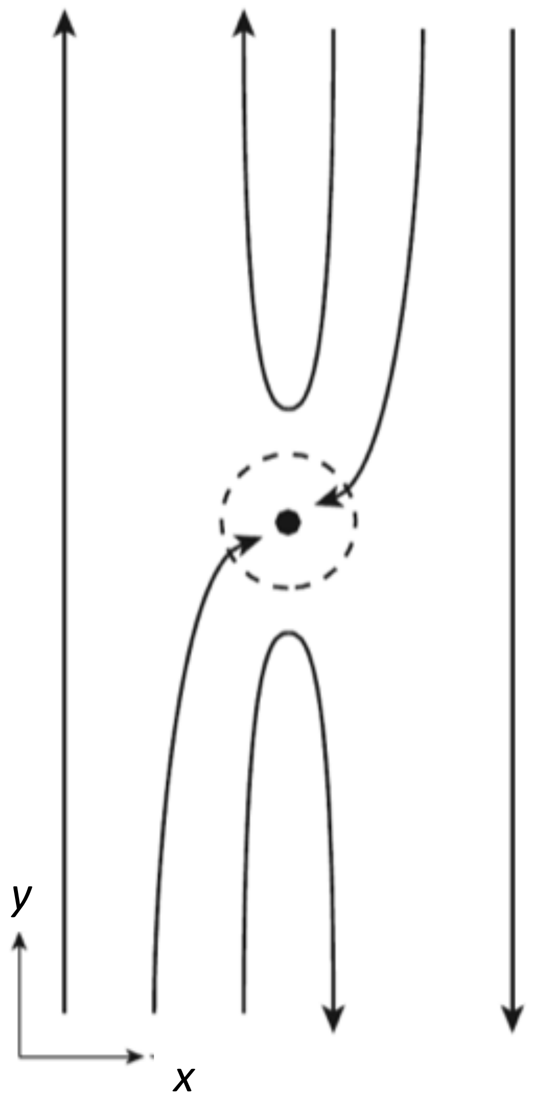
Hill (local) approximationx



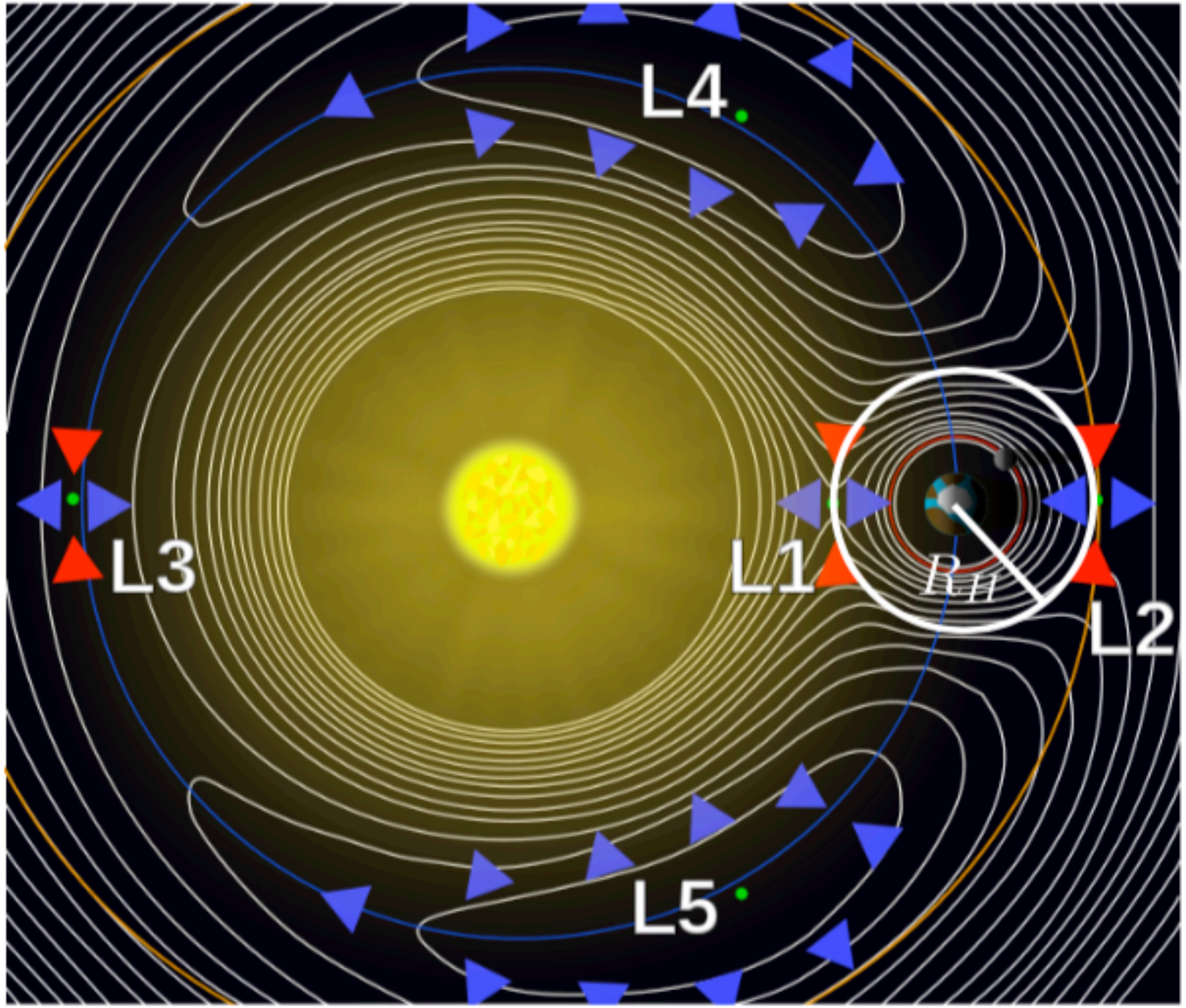
Hill (local) approximation

Hill Radius

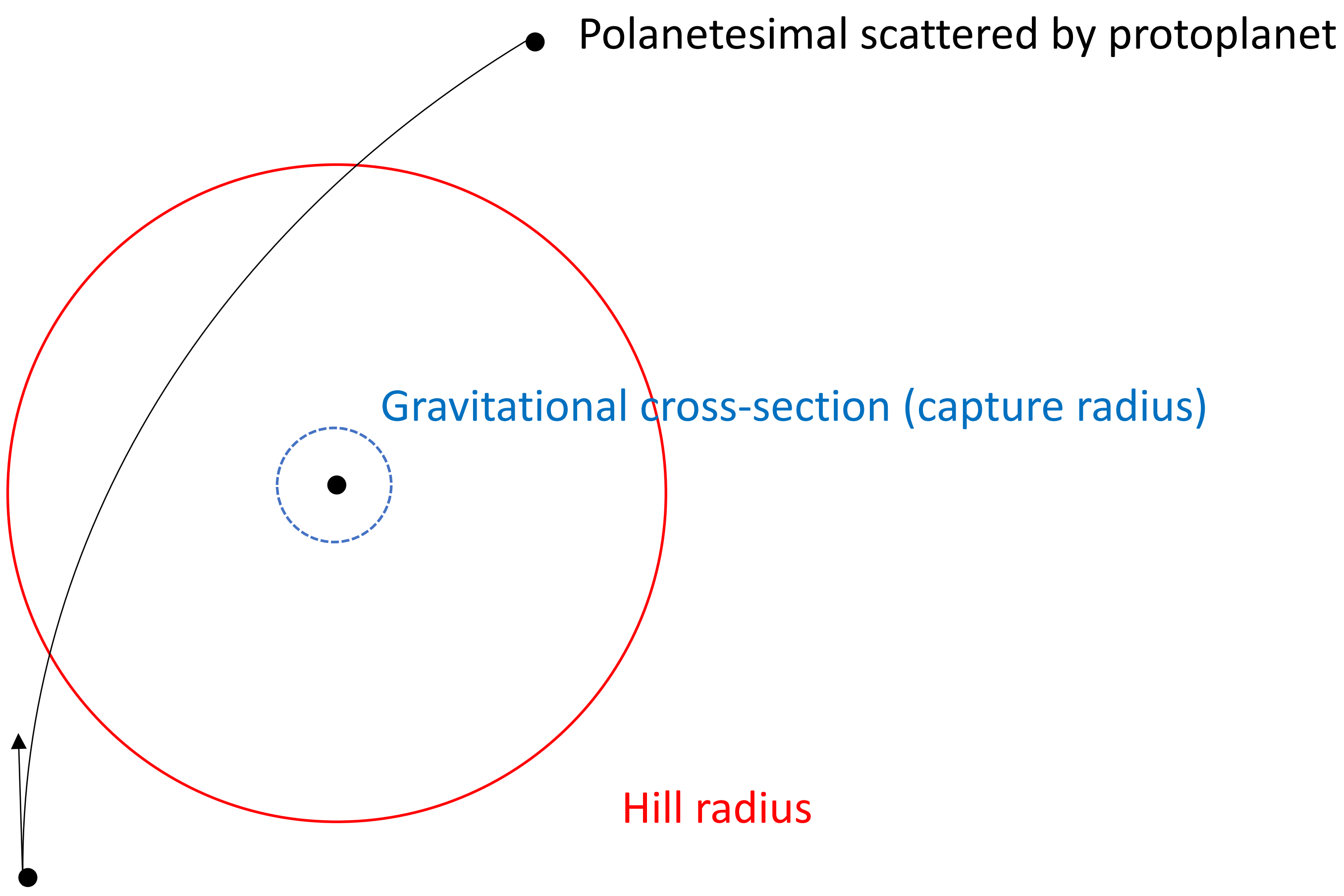
$R_H = a\,[M_{planet} / (3M_{star})]^{1/3}$



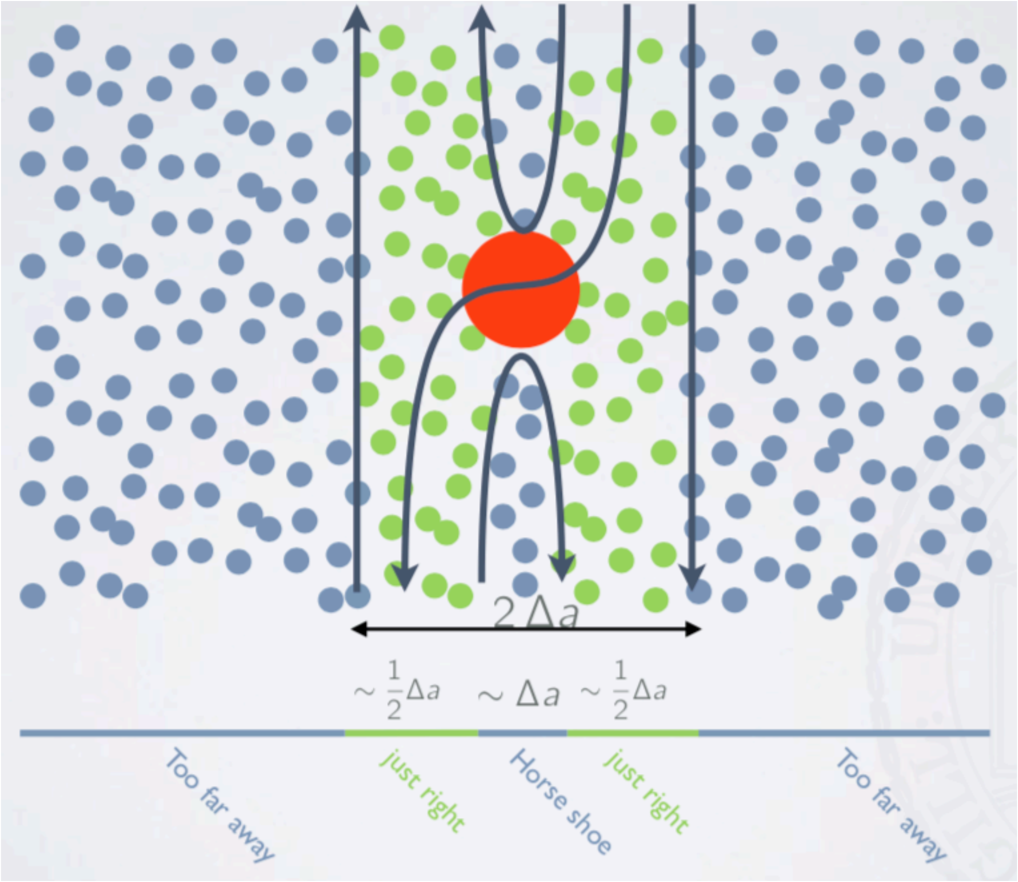
Hill Sphere = Roche Lobe

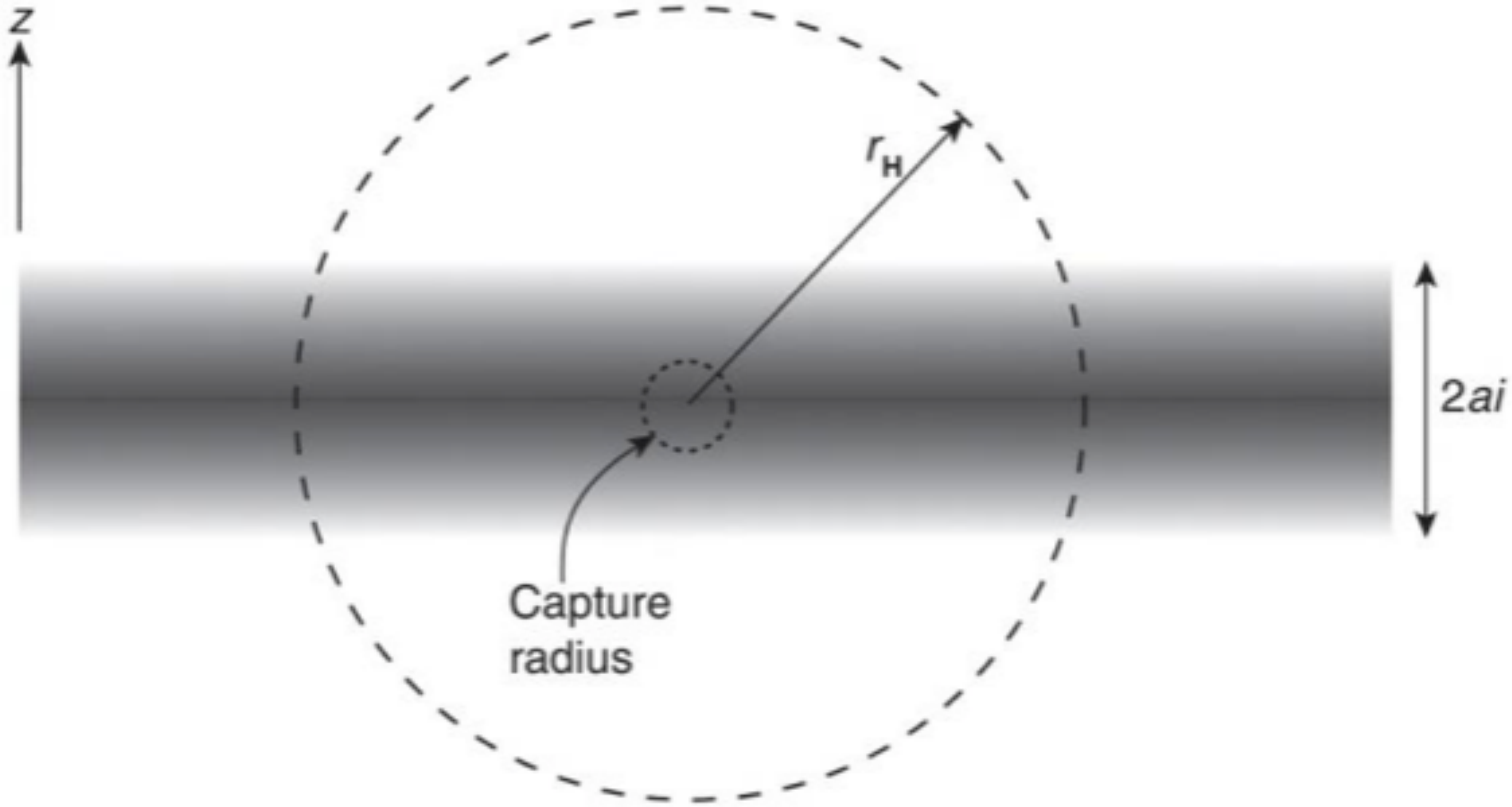


Planetesimal Accretion is inefficient



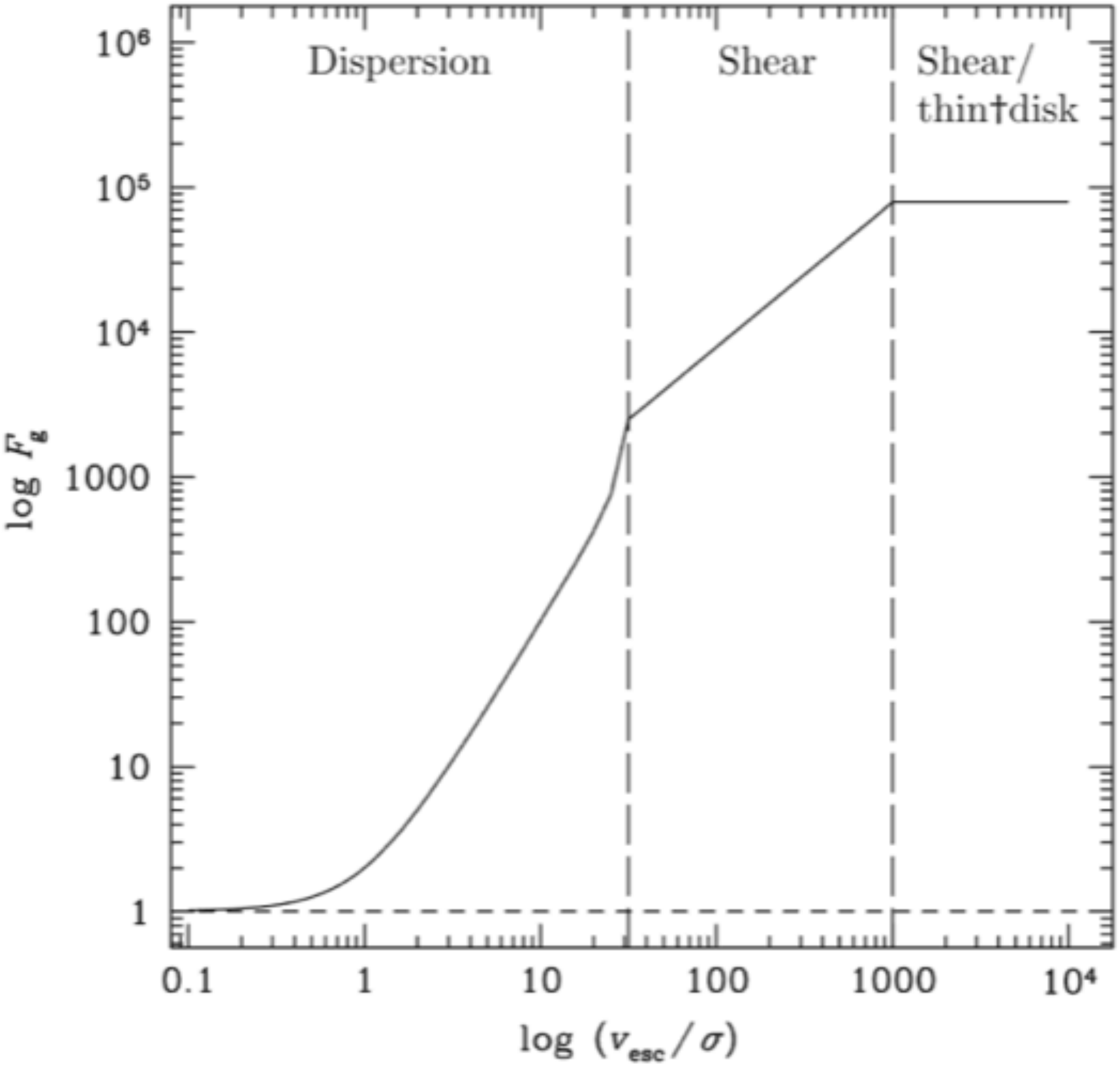
Shear dominated



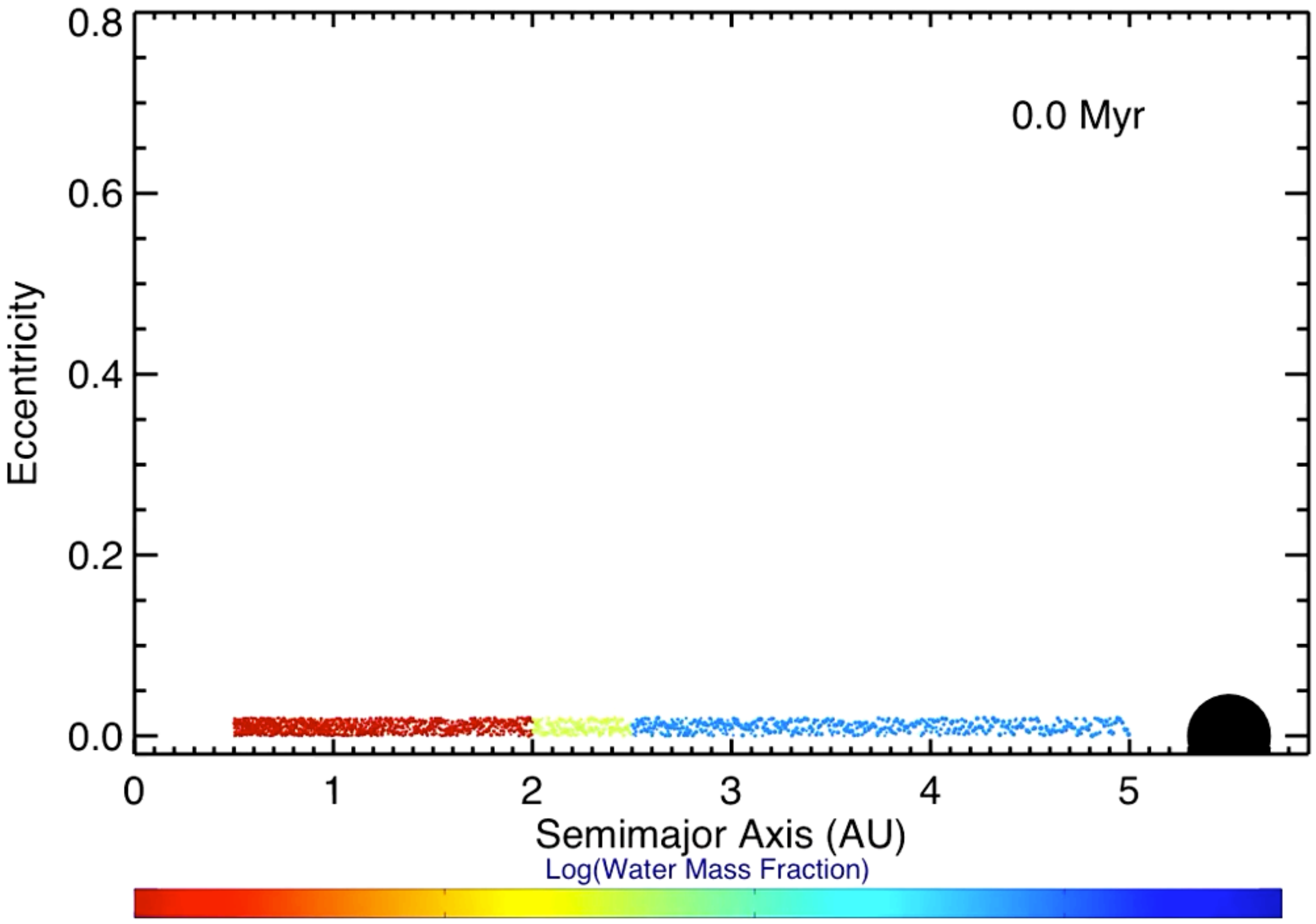


z
r_H
2ai
Capture
radius

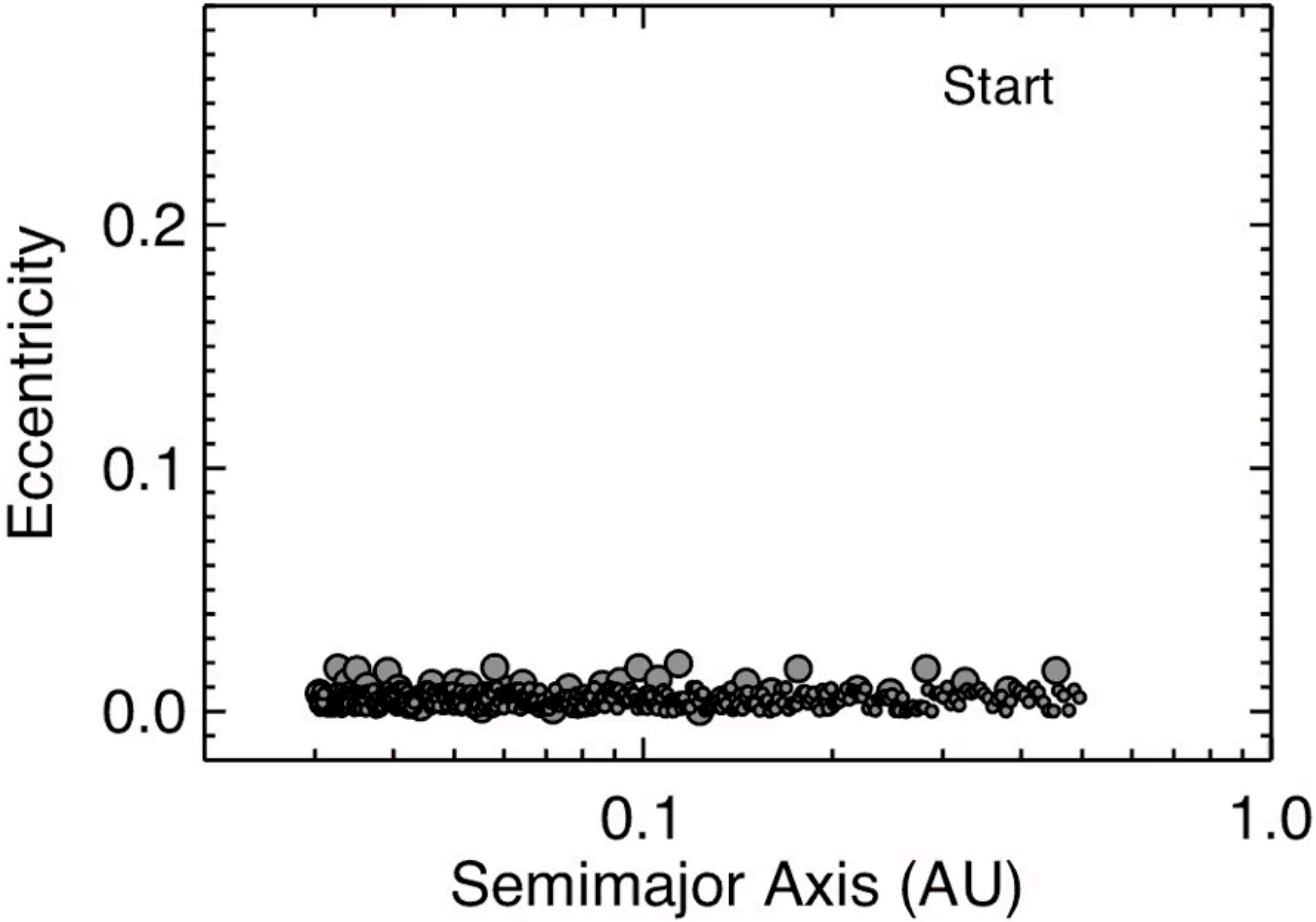
Regimes of Accretion



Core Accretion and Oligarchic Growth



Core Accretion and Oligarchic Growth



Core Accretion and Oligarchic Growth