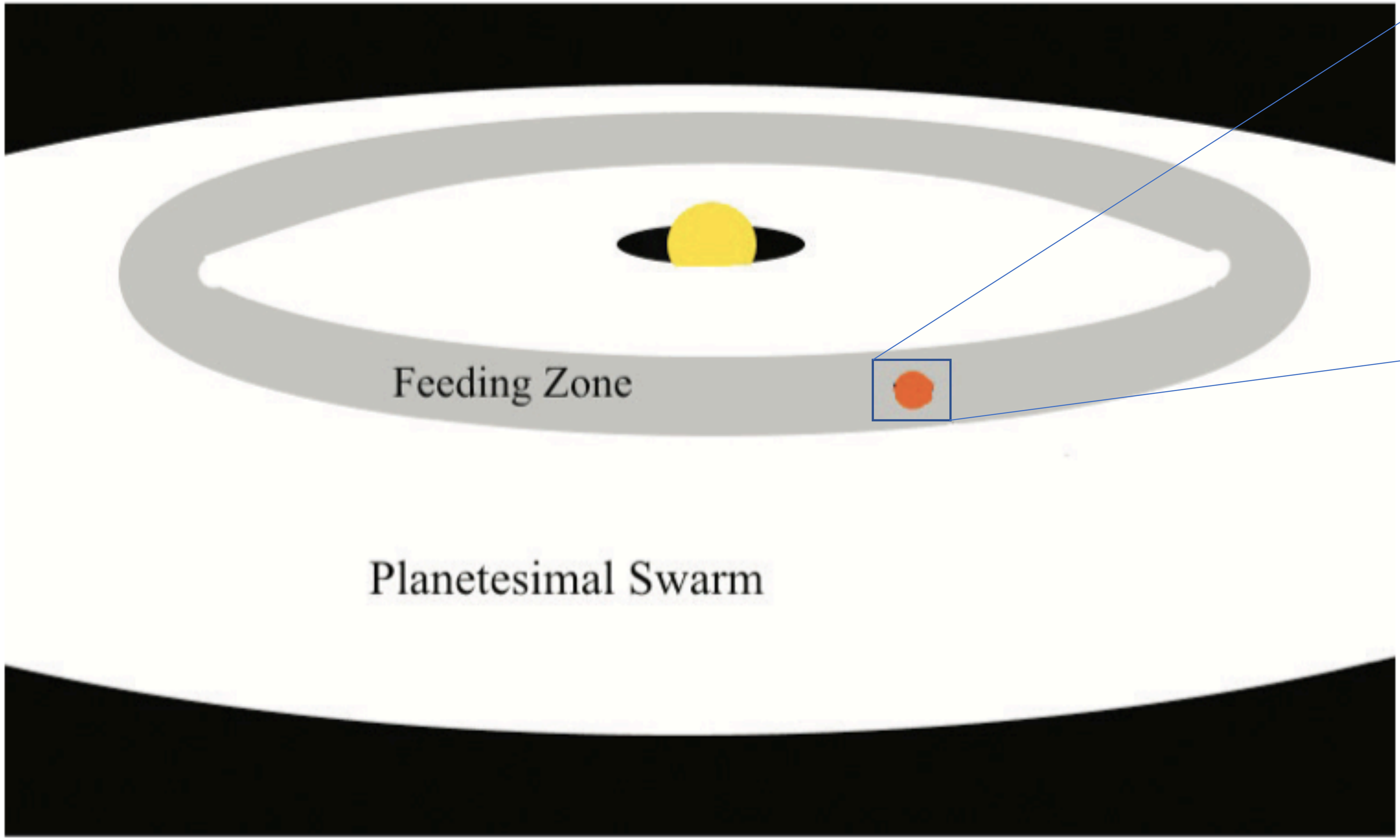
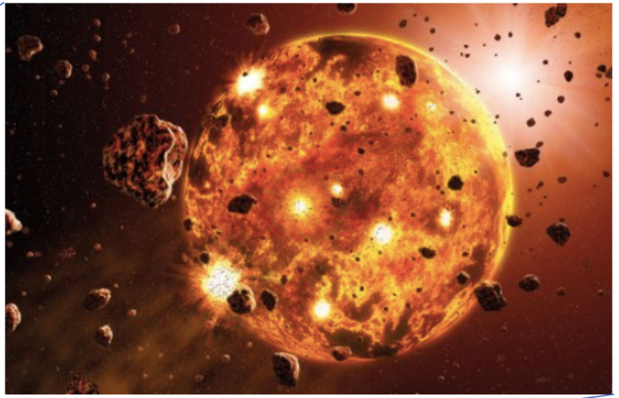
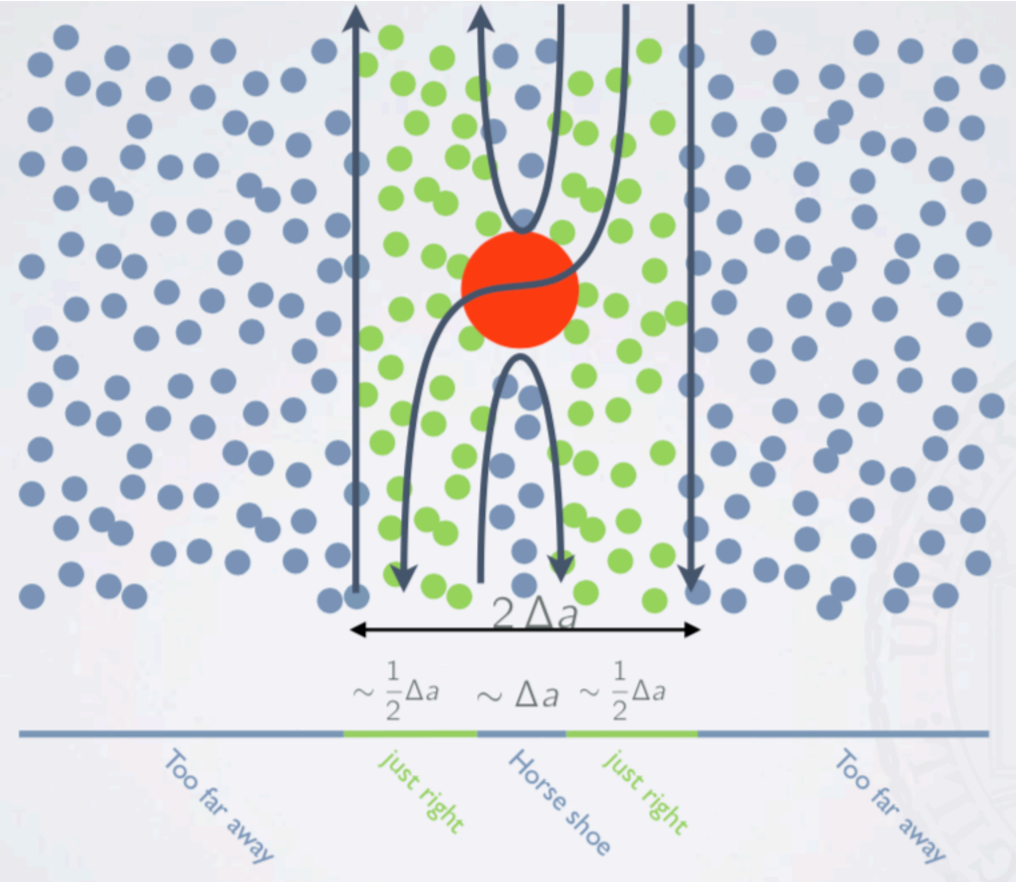
Class 21 – Apr 16^{th}, 2020

Planetesimal Accretion

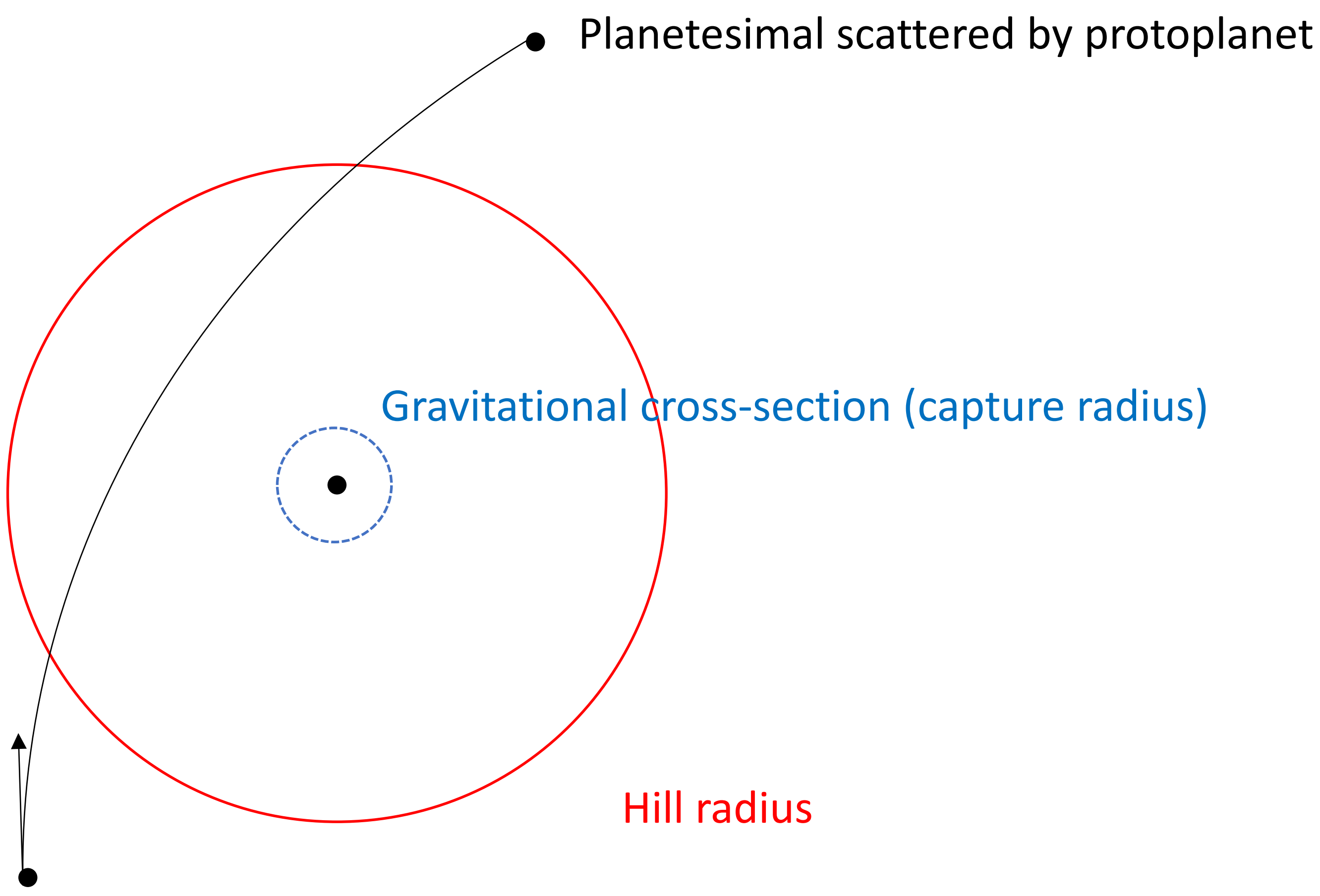


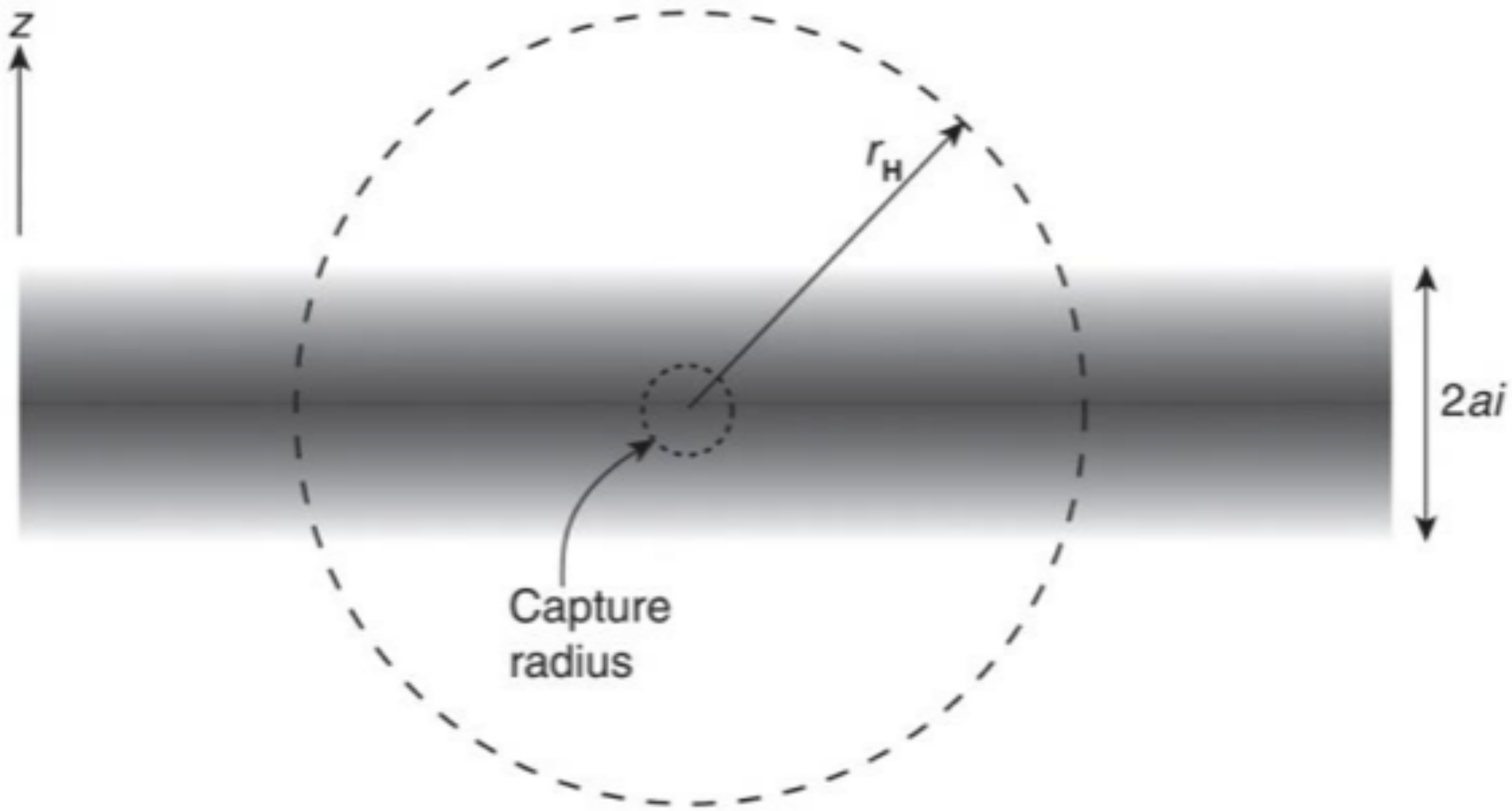


Shear dominated



Planetesimal Accretion is inefficient




z
r_H
2ai
Capture
radius

From runaway growth to oligarchic growth

$$\frac{dm}{dt} = \frac{\sqrt{3}}{2} \Sigma \Omega \pi R^2 f \qquad f = 1 + \frac{{v_{esc}}^2}{{v_{rms}}^2}$$

The growing embryo "heats" the planetesimal disk.

Low v_{rms} ($f >> 1$)

$$\frac{1}{m}\frac{dm}{dt} \propto m^{1/3}$$

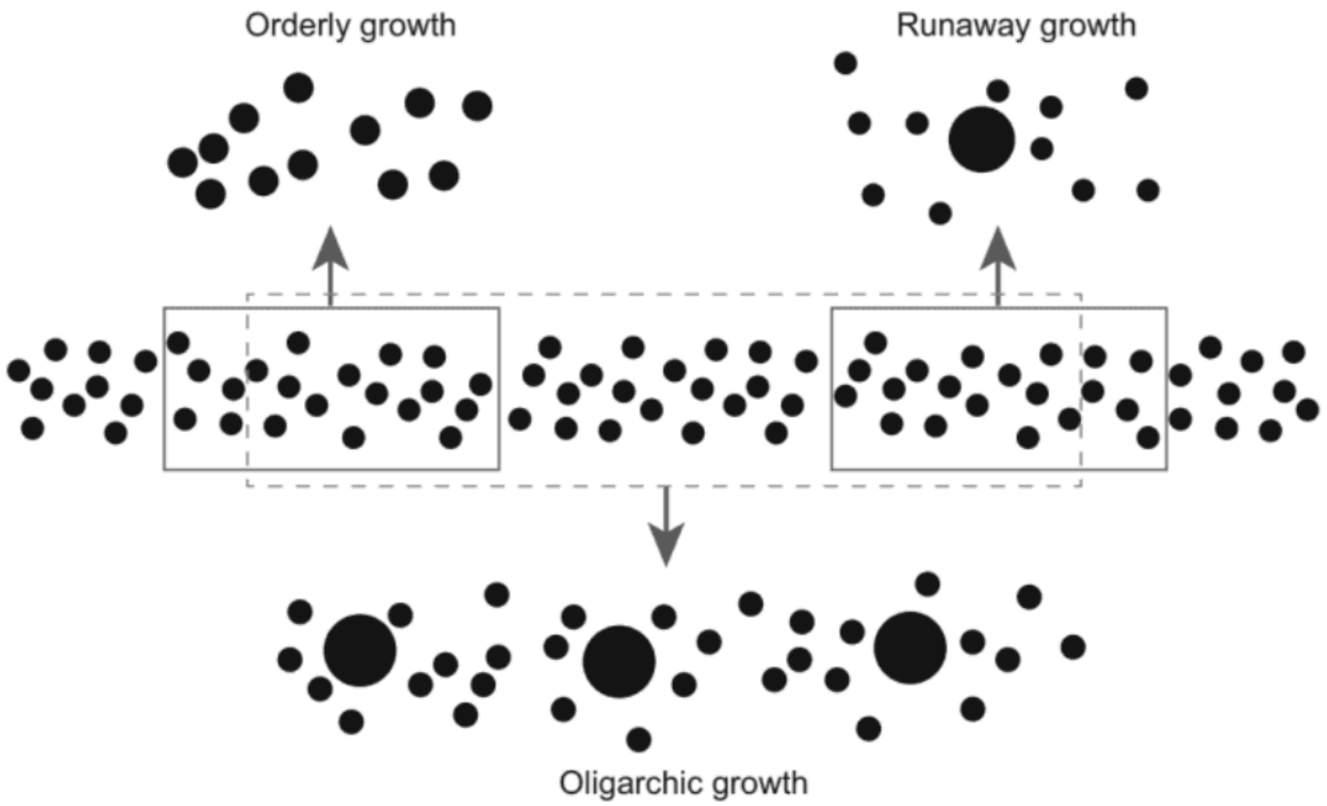
Largest body grows fastest
Runaway growth

High v_{rms} ($f \sim 1$)

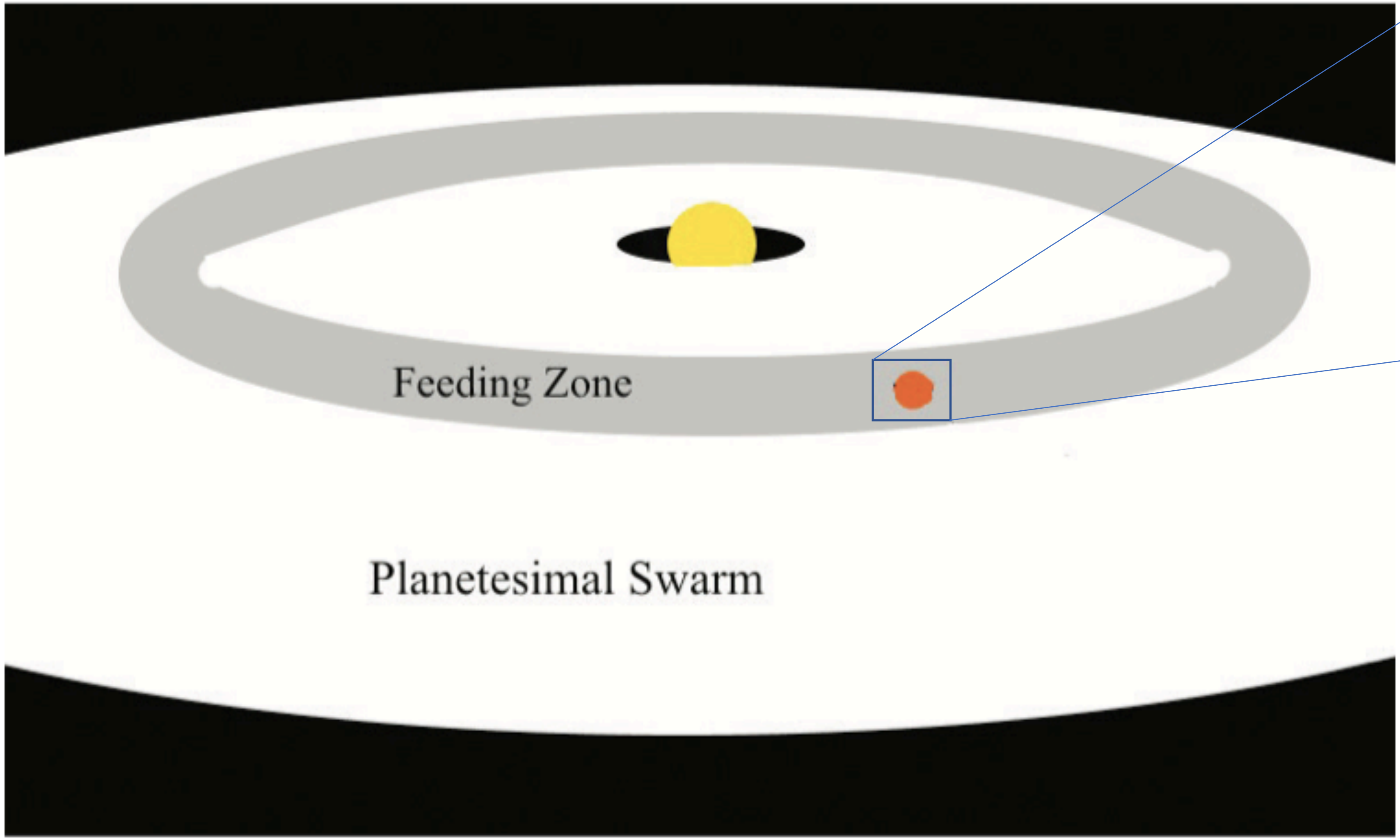
$$\frac{1}{m}\frac{dm}{dt} \propto m^{-1/3}$$

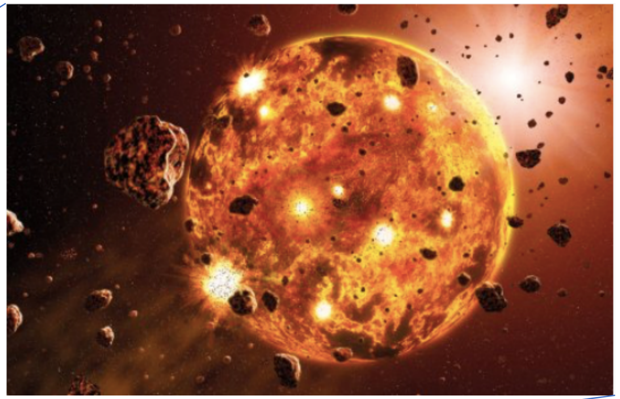
Largest body grows slowest
Oligarchic growth

Growth regimes

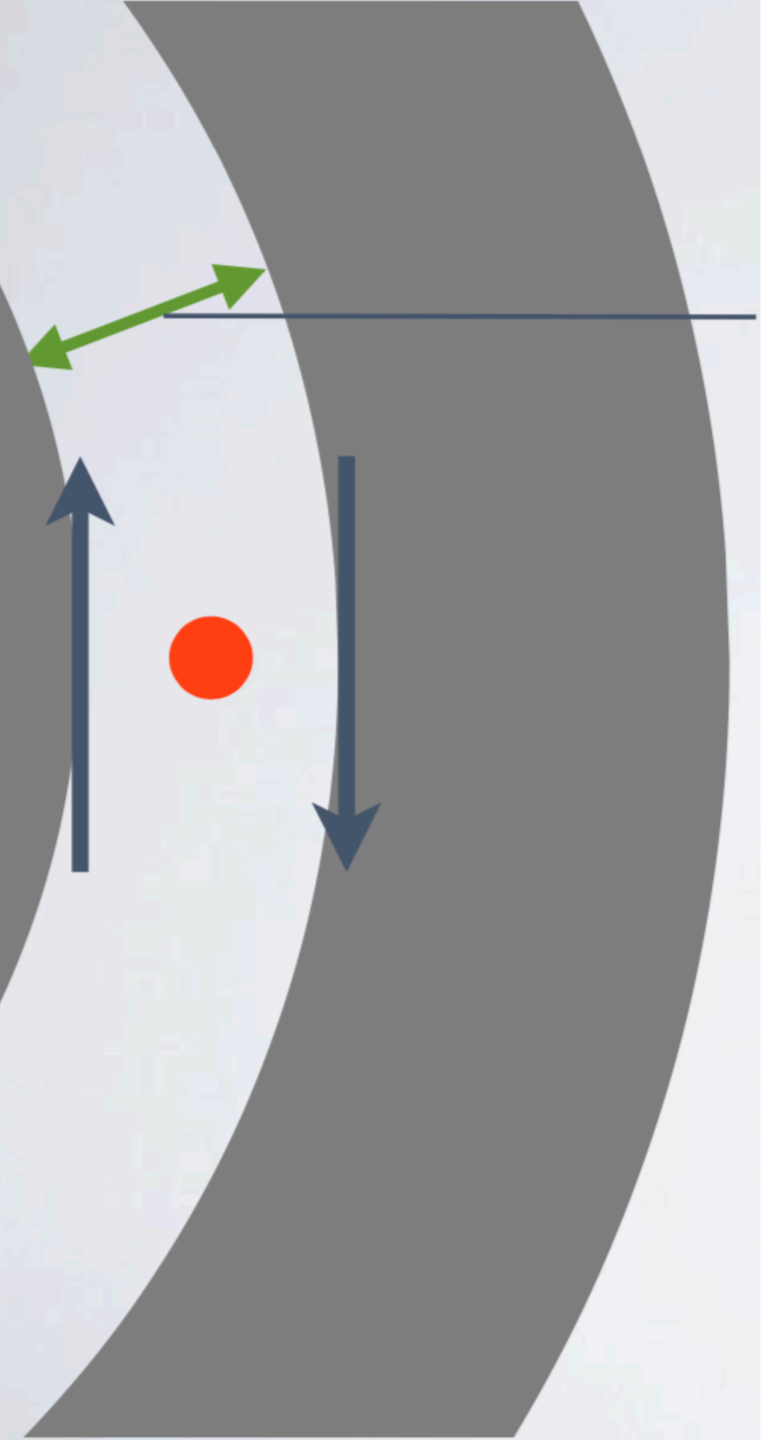


Isolation Mass





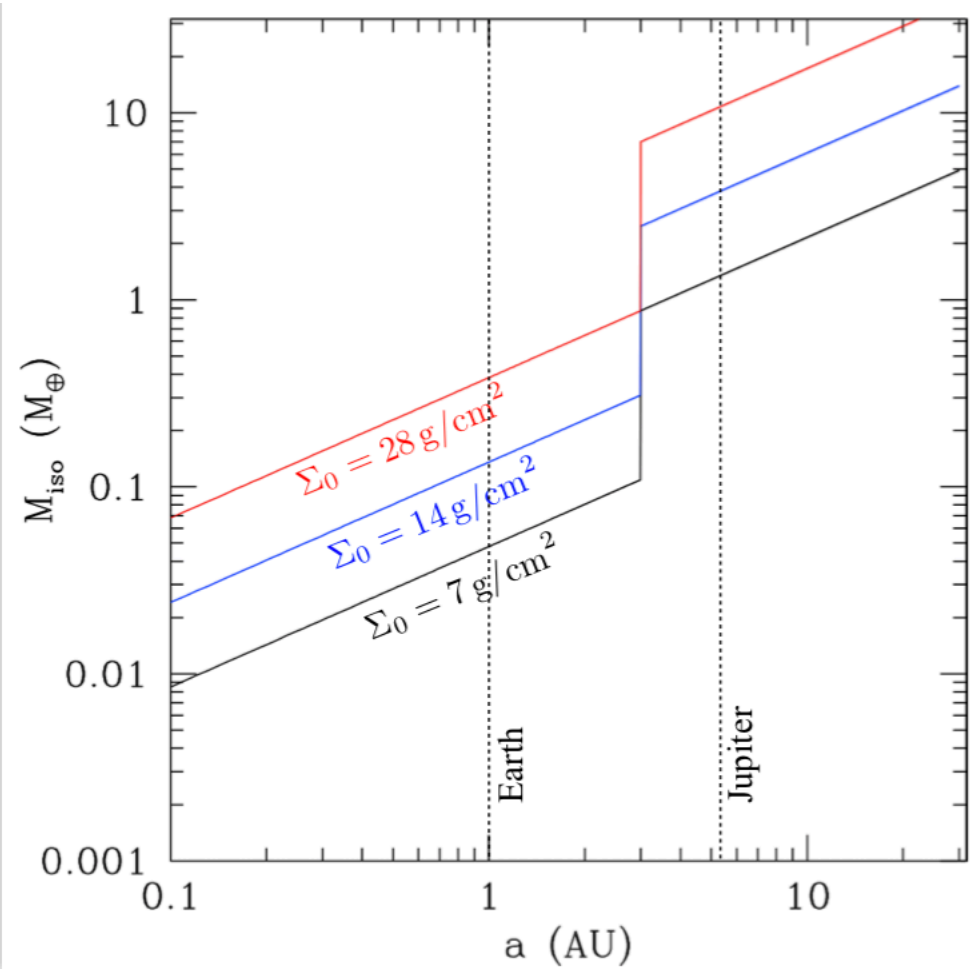
Isolation Mass



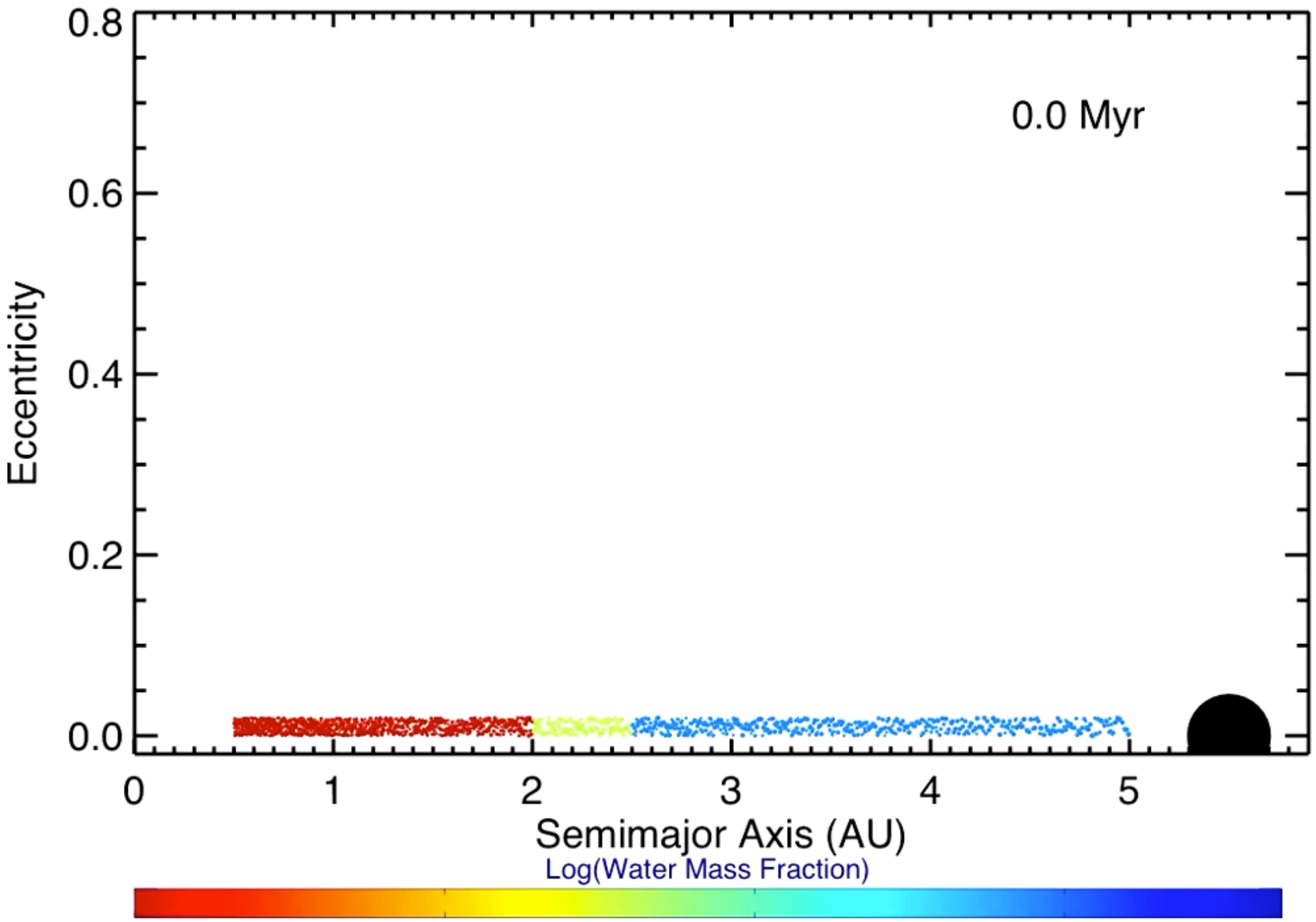
Of the order of the Hill radius

Protoplanet accretes all planetesimals in its feeding zone

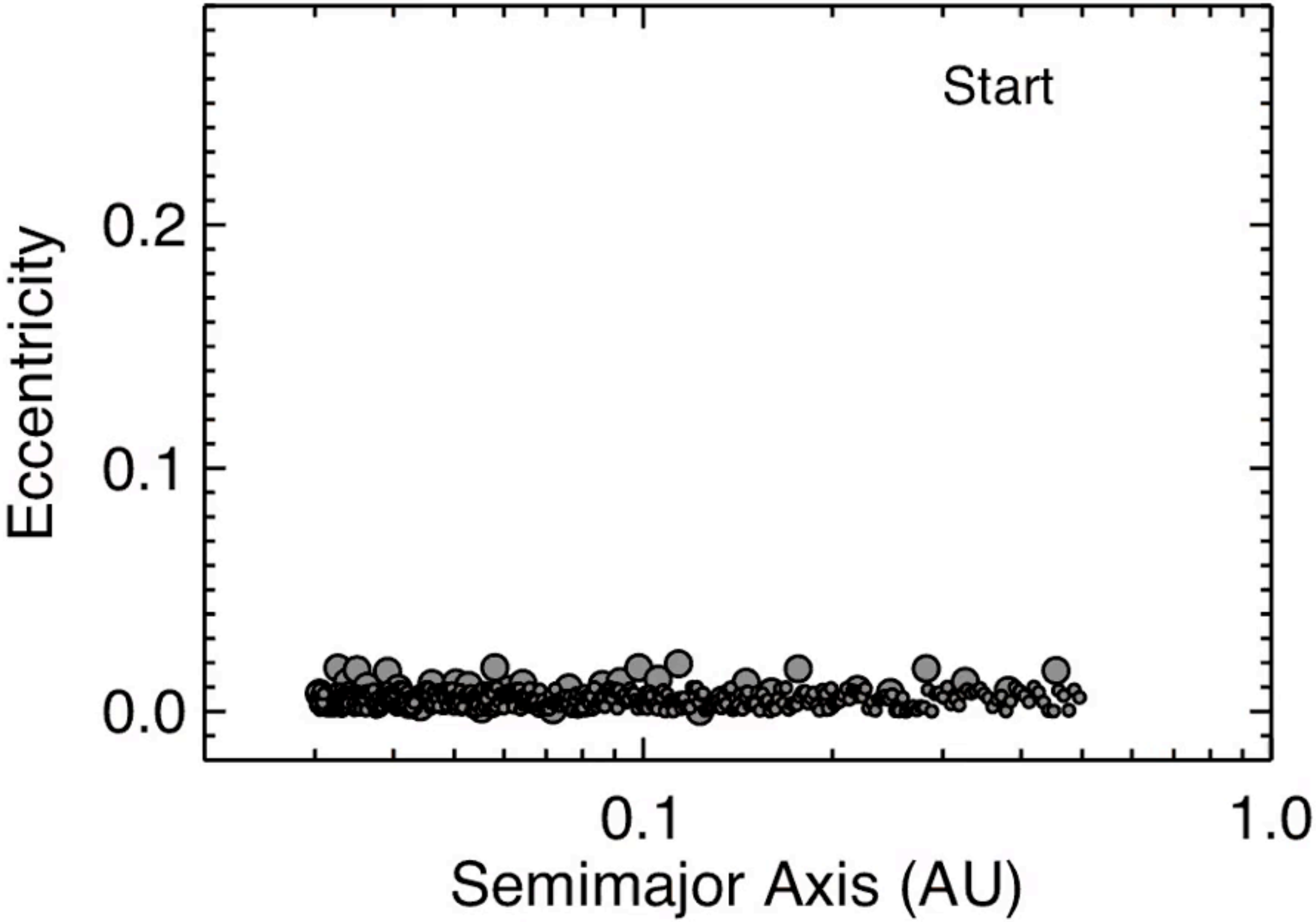
Isolation Mass



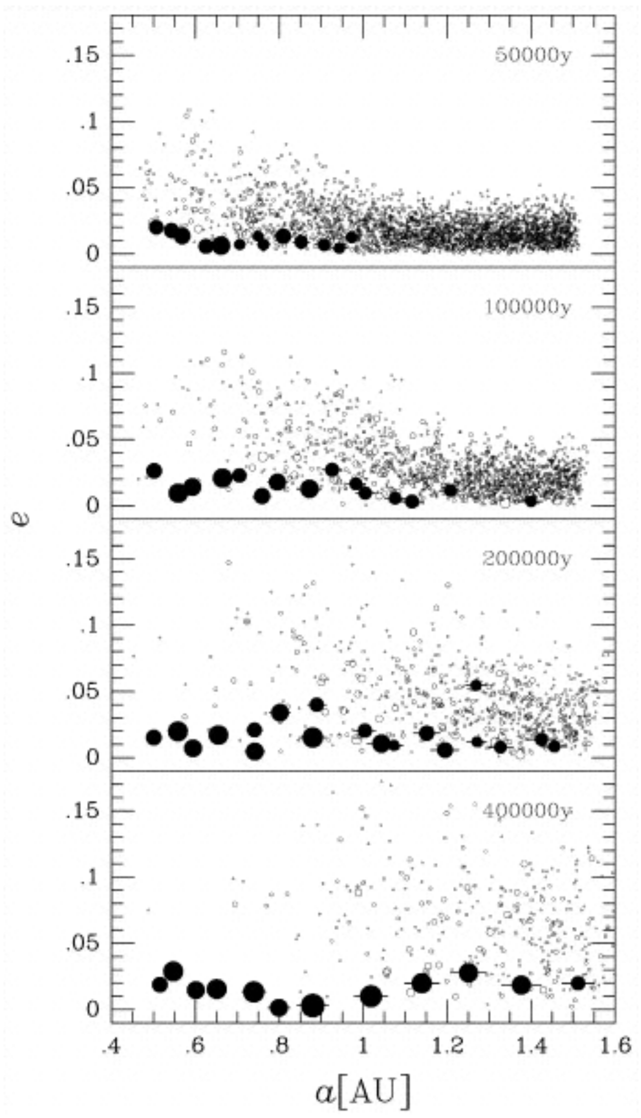
Core Accretion and Oligarchic Growth



Core Accretion and Oligarchic Growth



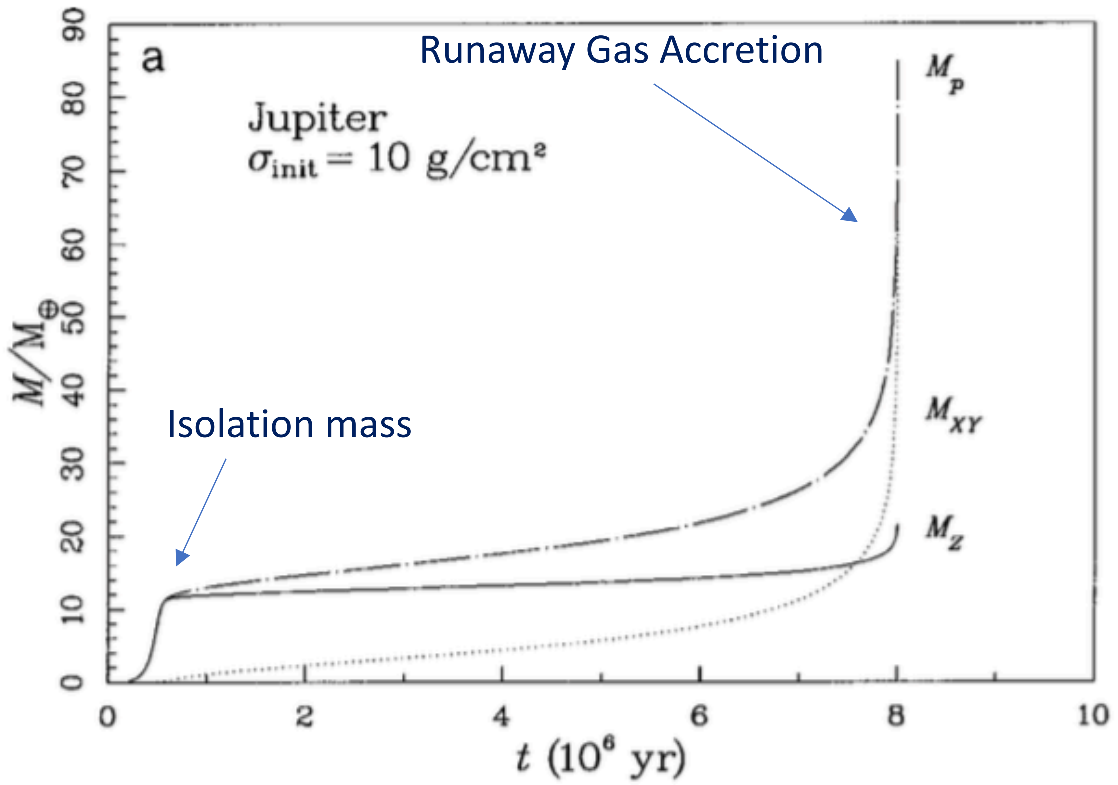
Core Accretion and Oligarchic Growth

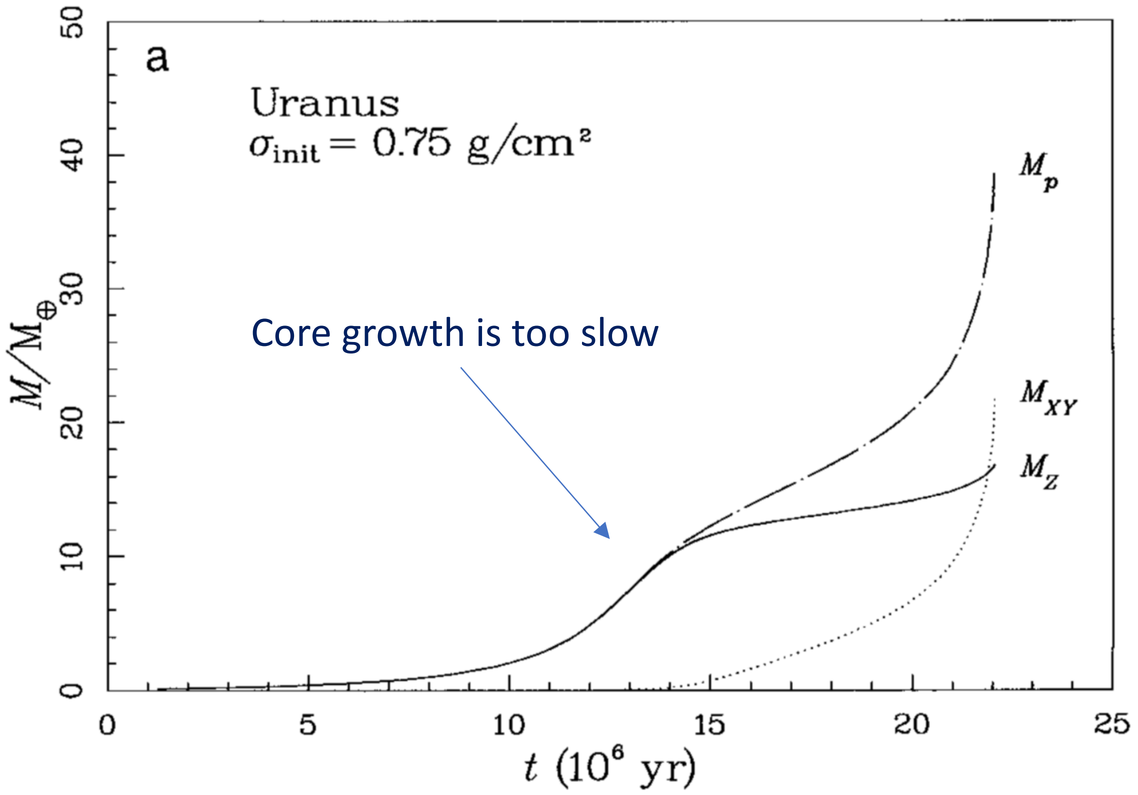


Problem

Planetesimal accretion is TOO SLOW in the outer solar system

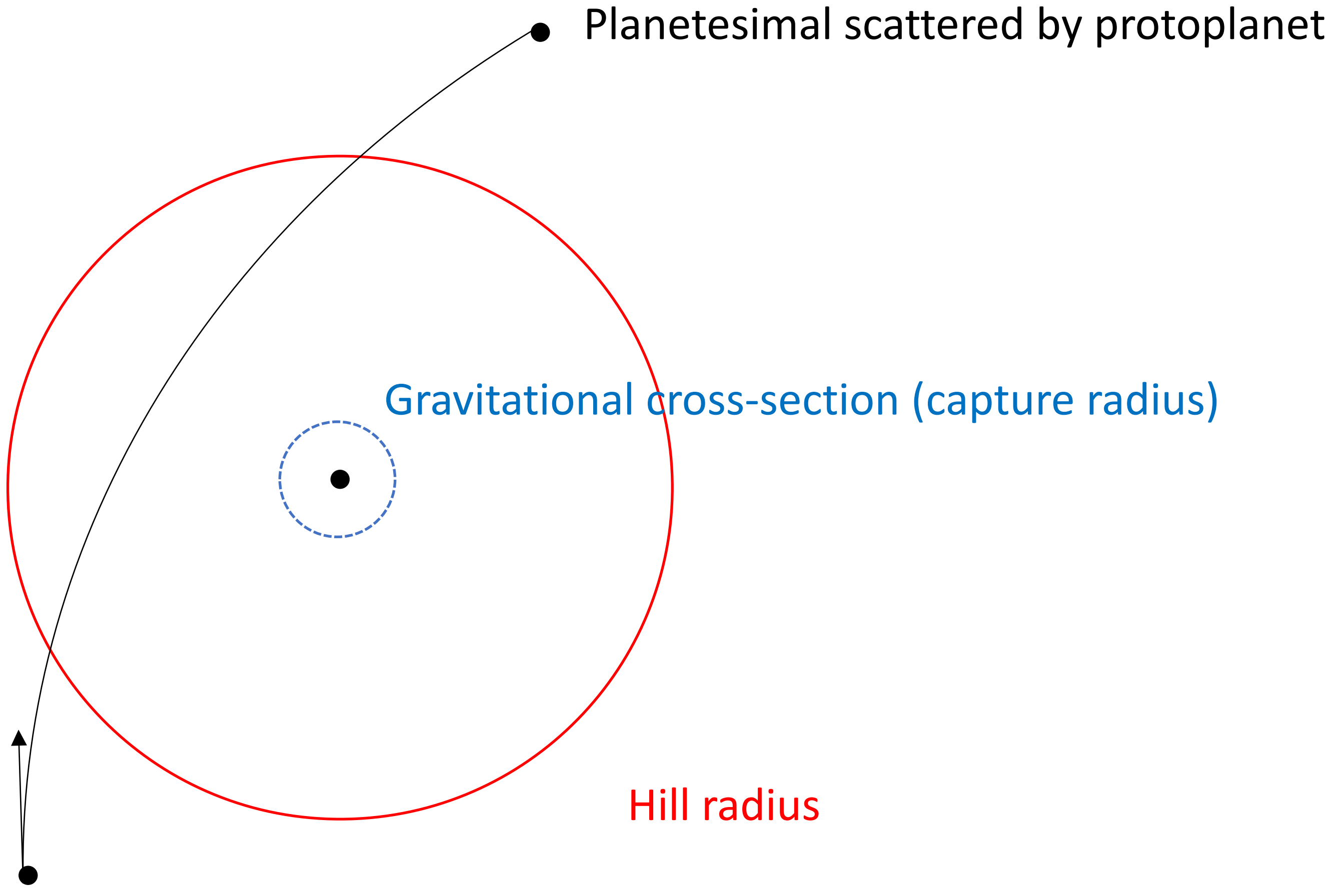
Low growth rates for Uranus and Neptune

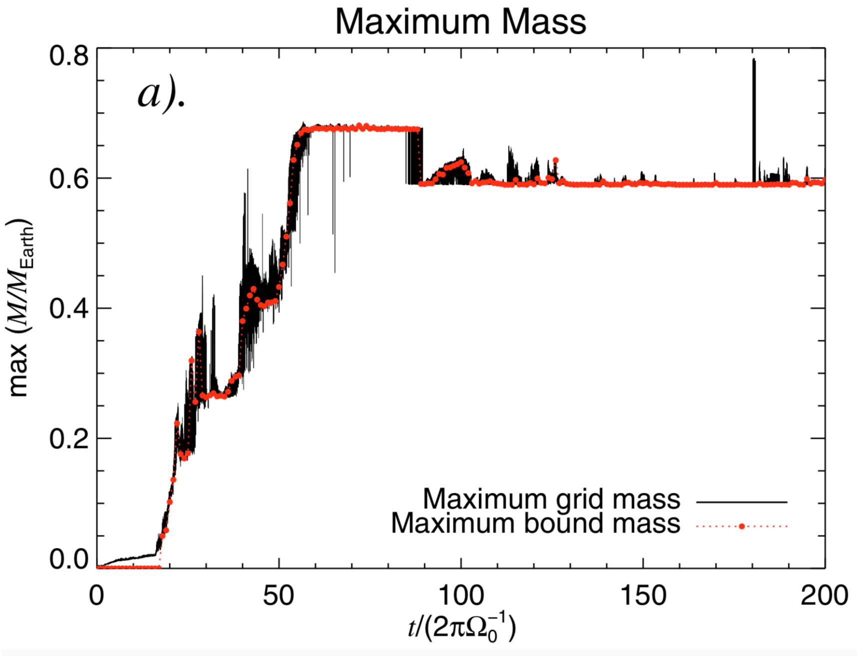


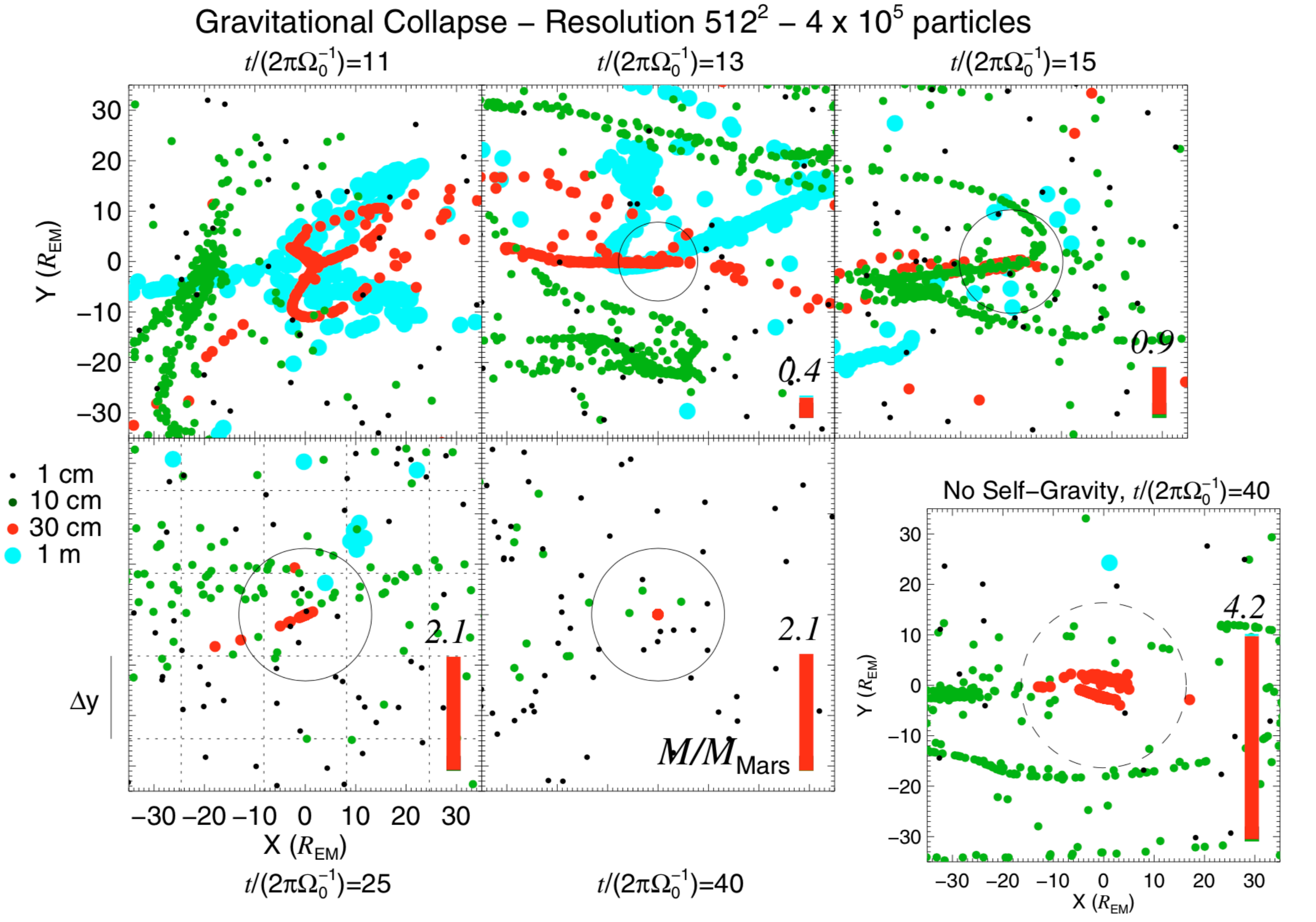


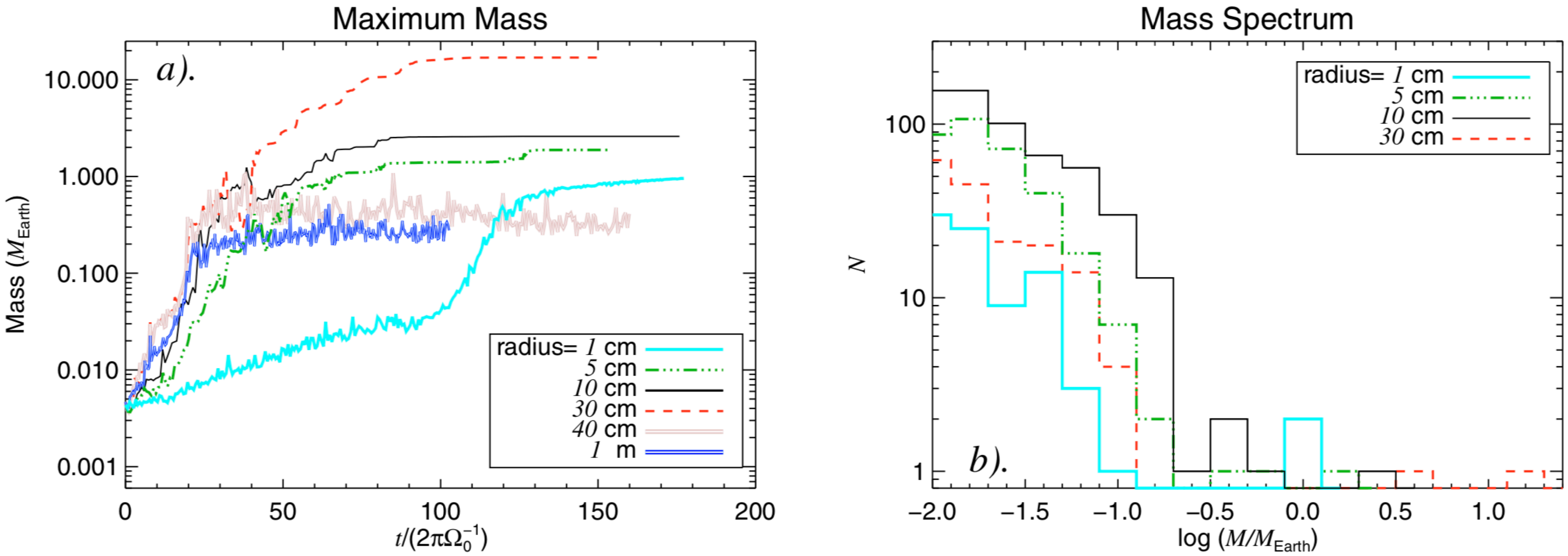
Pollack+ '96

Planetesimal Accretion is inefficient




Maximum Mass
a).
max (M/M_{Earth})
$t/(2\pi\Omega_0^{-1})$
Maximum grid mass
Maximum bound mass


Gravitational Collapse – Resolution 512^2 – 4 x 10^5 particles
$t/(2\pi\Omega_0^{-1})$=11
$t/(2\pi\Omega_0^{-1})$=13
$t/(2\pi\Omega_0^{-1})$=15
Y (R_{EM})
0.4
0.9
1 cm
10 cm
30 cm
1 m
Δy
2.1
2.1
M/M_{Mars}
No Self–Gravity, $t/(2\pi\Omega_0^{-1})$=40
4.2
X (R_{EM})
$t/(2\pi\Omega_0^{-1})$=25
$t/(2\pi\Omega_0^{-1})$=40



Maximum Mass
a).
Mass (M_{Earth})
$t/(2\pi\Omega_0^{-1})$
10.000
1.000
0.100
0.010
0.001
0
50
100
150
200
radius= 1 cm
5 cm
10 cm
30 cm
40 cm
1 m
Mass Spectrum
b).
N
log (M/M_{Earth})
100
10
1
−2.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
radius= 1 cm
5 cm
10 cm
30 cm

Pebble Accretion


VIEW

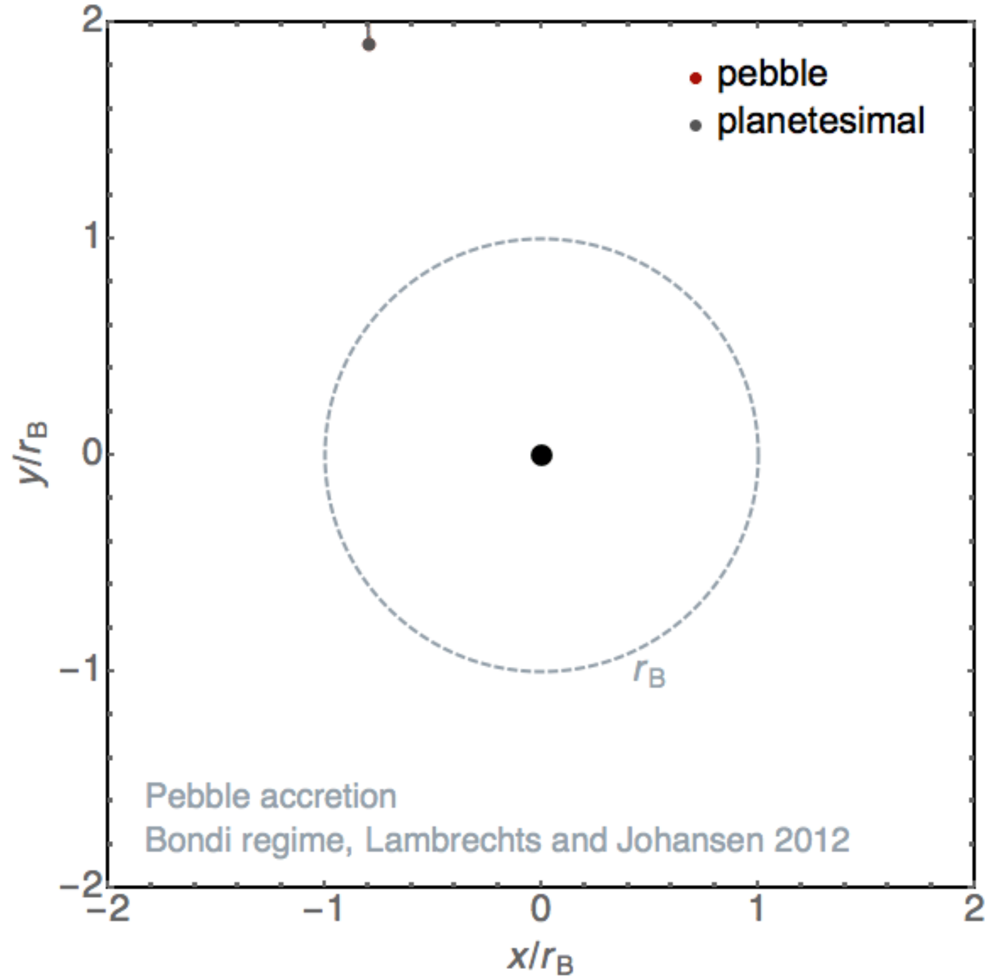
- Abstract
- Citations (355)
- References (72)
- Co-Reads
- Similar Papers
- Volume Content
- Graphics
- Metrics
- Export Citation

Rapid growth of gas-giant cores by pebble accretion

Show affiliations

Lambrechts, M.; Johansen, A.

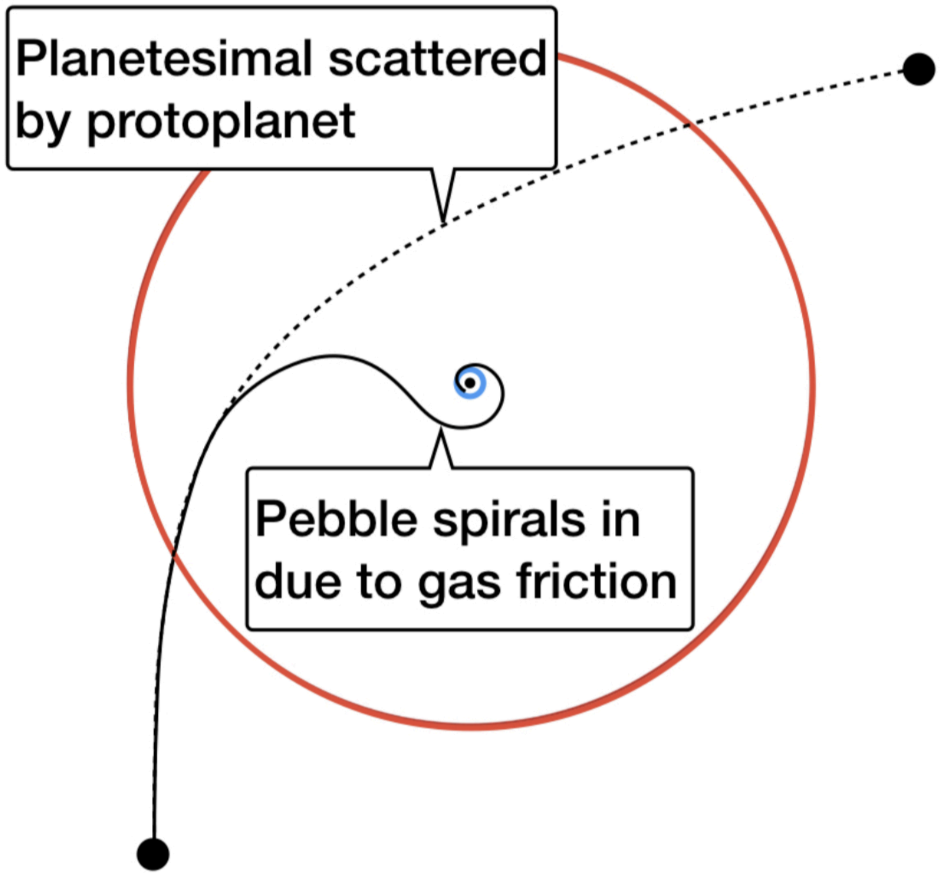
The observed lifetimes of gaseous protoplanetary discs place strong constraints on gas and ice giant formation in the core accretion scenario. The approximately 10-Earth-mass solid core responsible for the attraction of the gaseous envelope has to form before gas dissipation in the protoplanetary disc is completed within 1-10 million years. Building up the core by collisions between km-sized planetesimals fails to meet this timescale constraint, especially at wide stellar separations. Nonetheless, gas-giant planets are detected by direct imaging at wide orbital distances. In this paper, we numerically study the growth of cores by the accretion of cm-sized pebbles loosely coupled to the gas. We measure the accretion rate onto seed masses ranging from a large planetesimal to a fully grown 10-Earth-mass core and test different particle sizes. The numerical results are in good agreement with our analytic expressions, indicating the existence of two accretion regimes, one set by the azimuthal and radial particle drift for the lower seed masses and the other, for higher masses, by the velocity at the edge

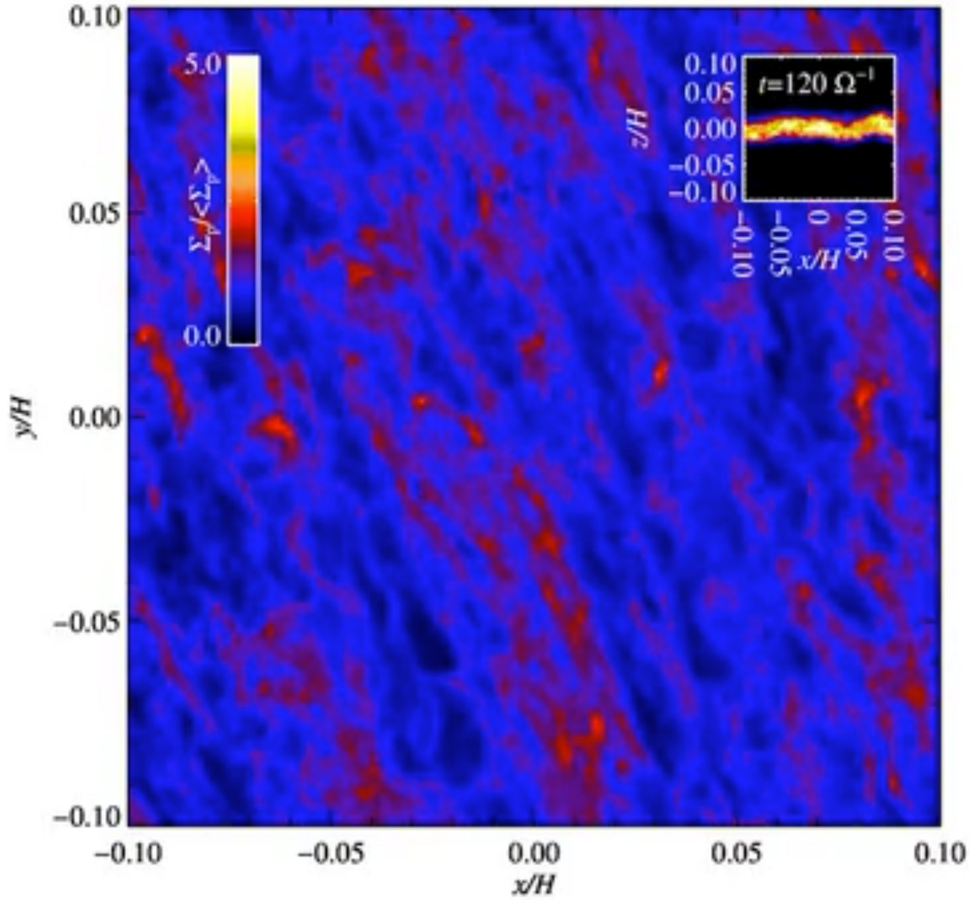


Klahr & Henning '97, Klahr '06, Inaba & Barge '08, Lyra+ '08, '09ab
Ormel & Klahr '10, **Lambrechts & Johansen '12,**

See Johansen & Lambrechts '17 for a review

Pebble Accretion





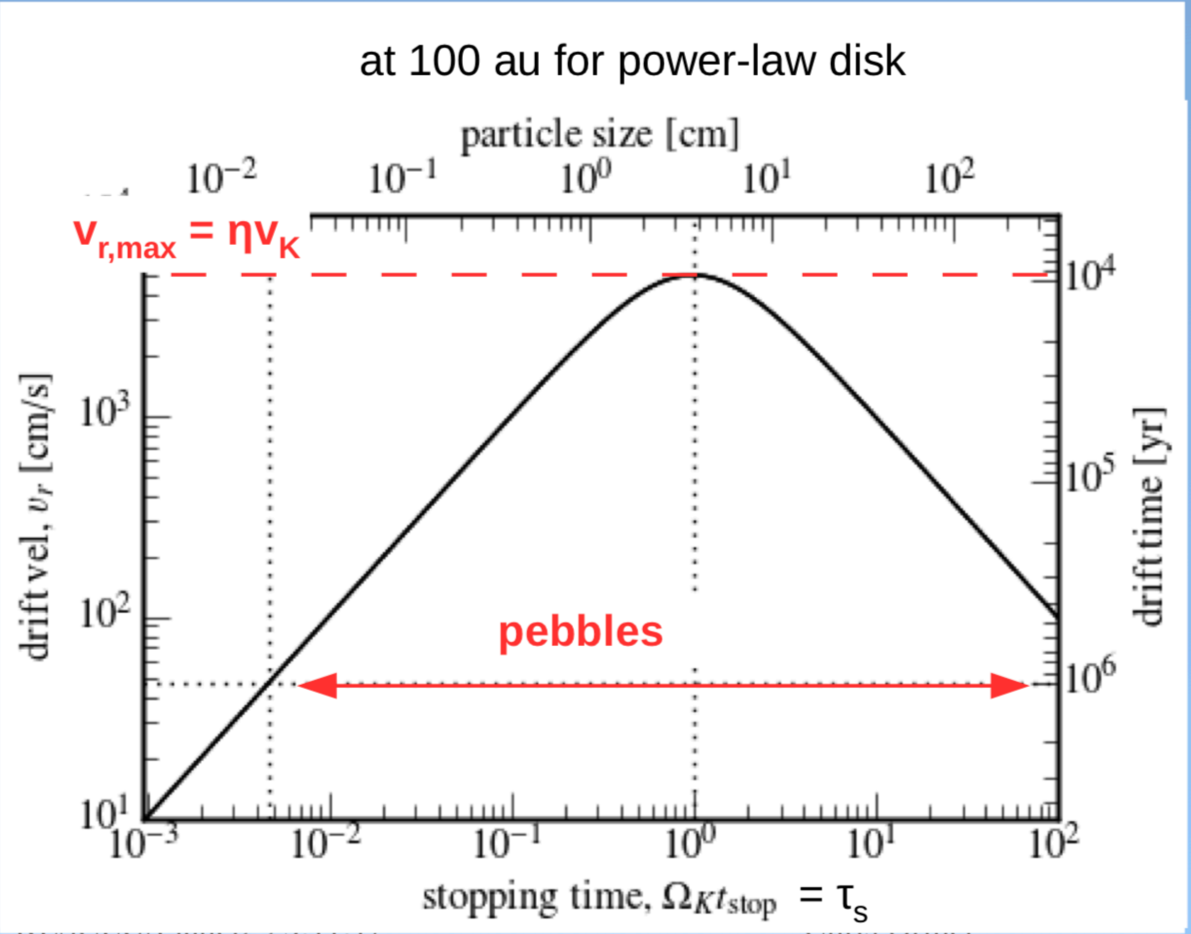
Klahr & Henning '97, Klahr '06, Inaba & Barge '08, Lyra+ '08, '09ab
Ormel & Klahr '10, **Lambrechts & Johansen '12,**

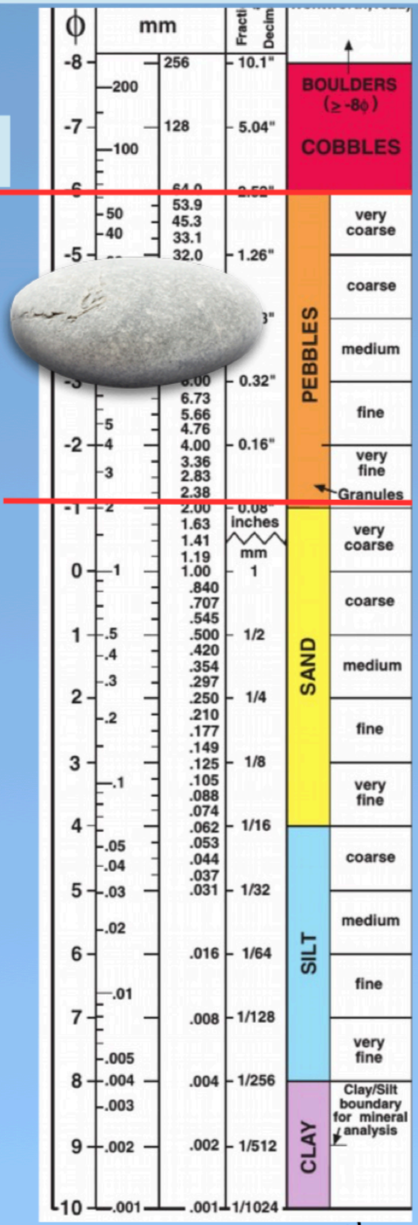
See Johansen & Lambrechts '17 for a review

Pebble definition

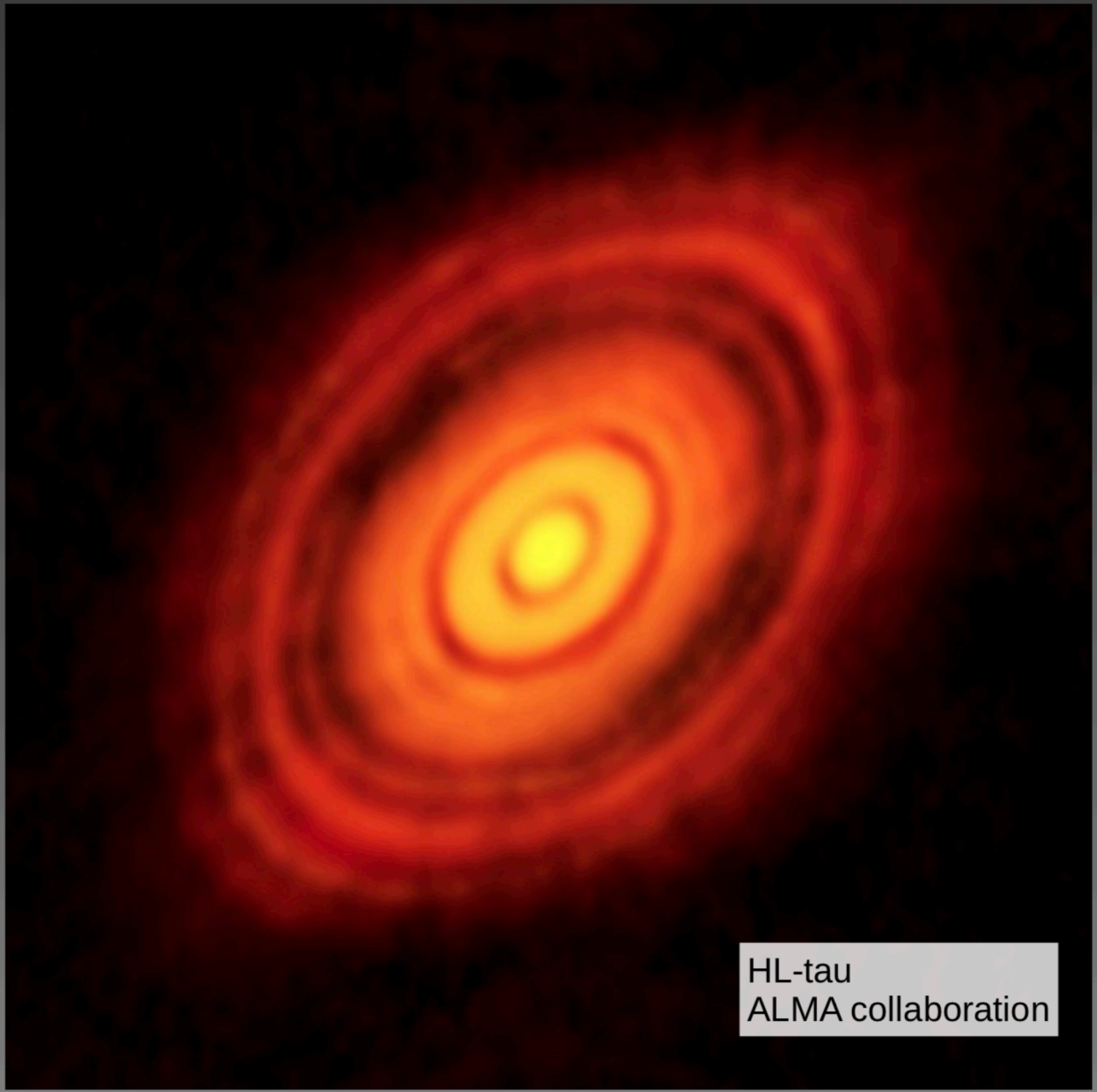
Geologist: *particles 2 mm < d < 6.4 cm*

Astrophysical: *particles that drift*

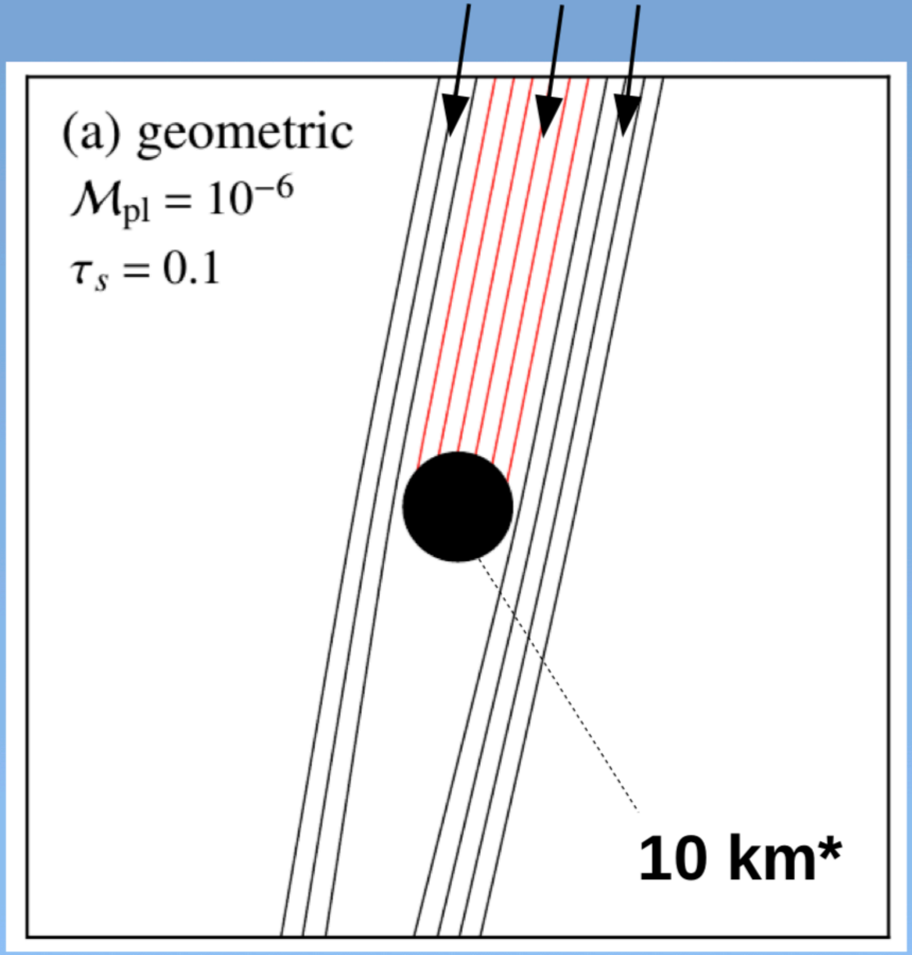


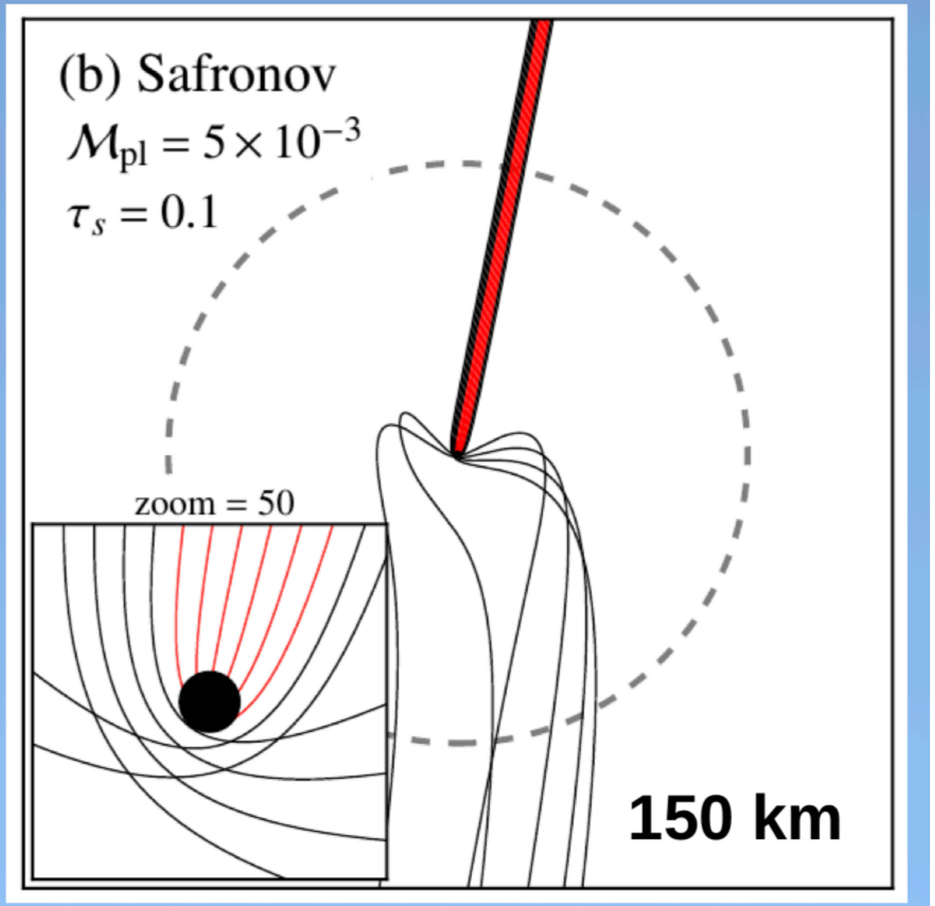


A pebble disk



No pebble accretion

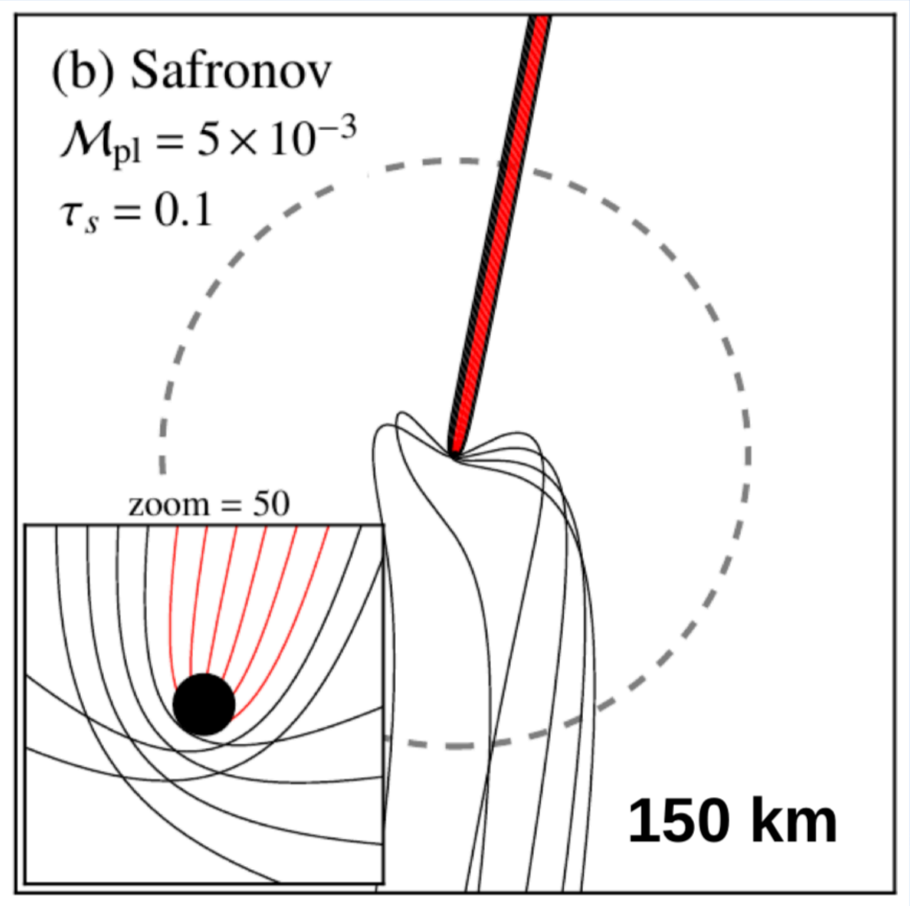




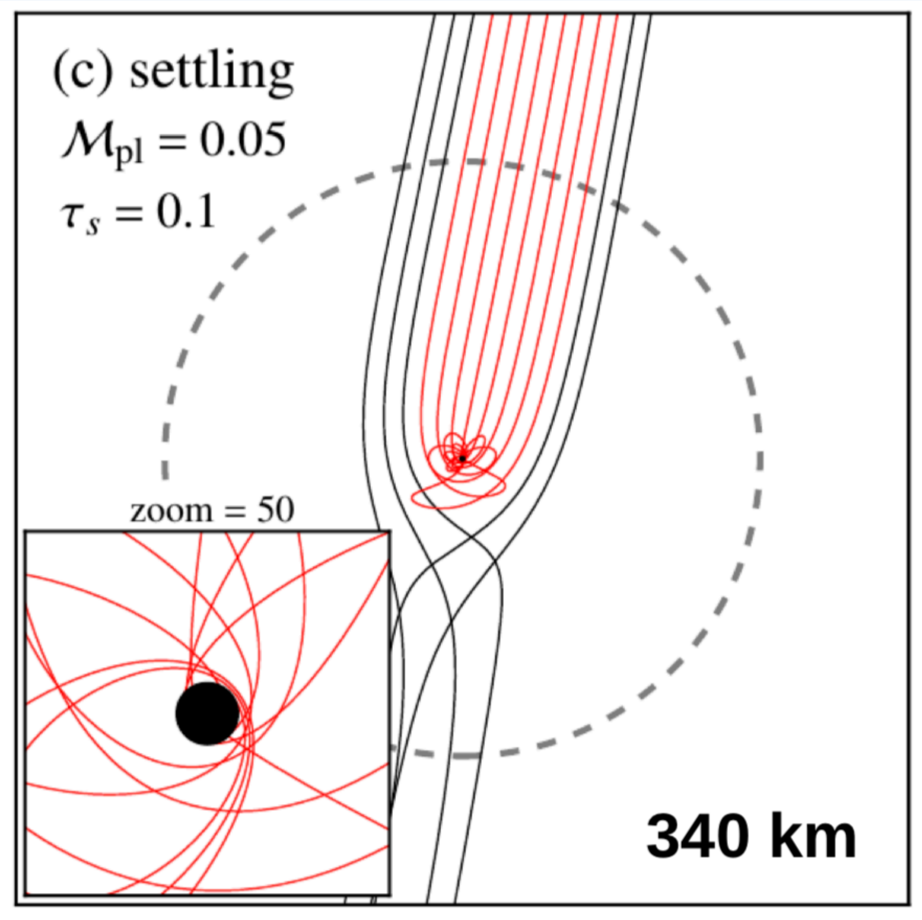
* 1 au, solar-mass star, disk headwind 50 m sec^{-1}

Ormel (2017)

Onset pebble accretion

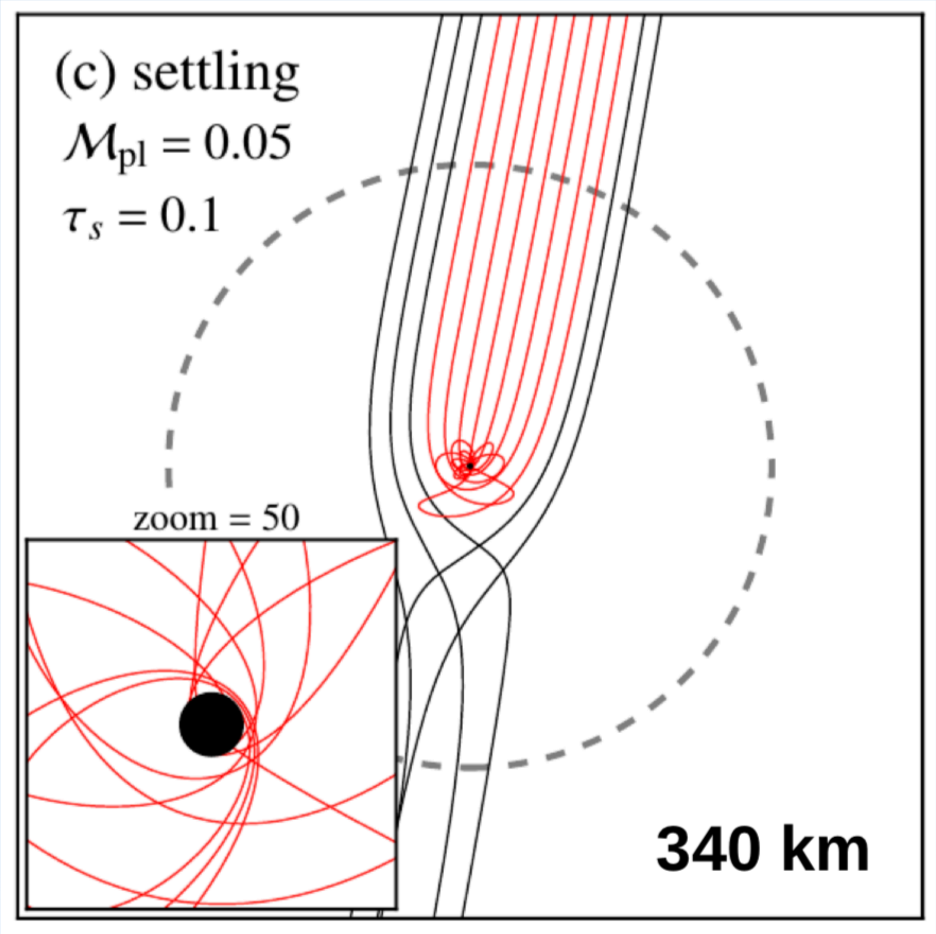


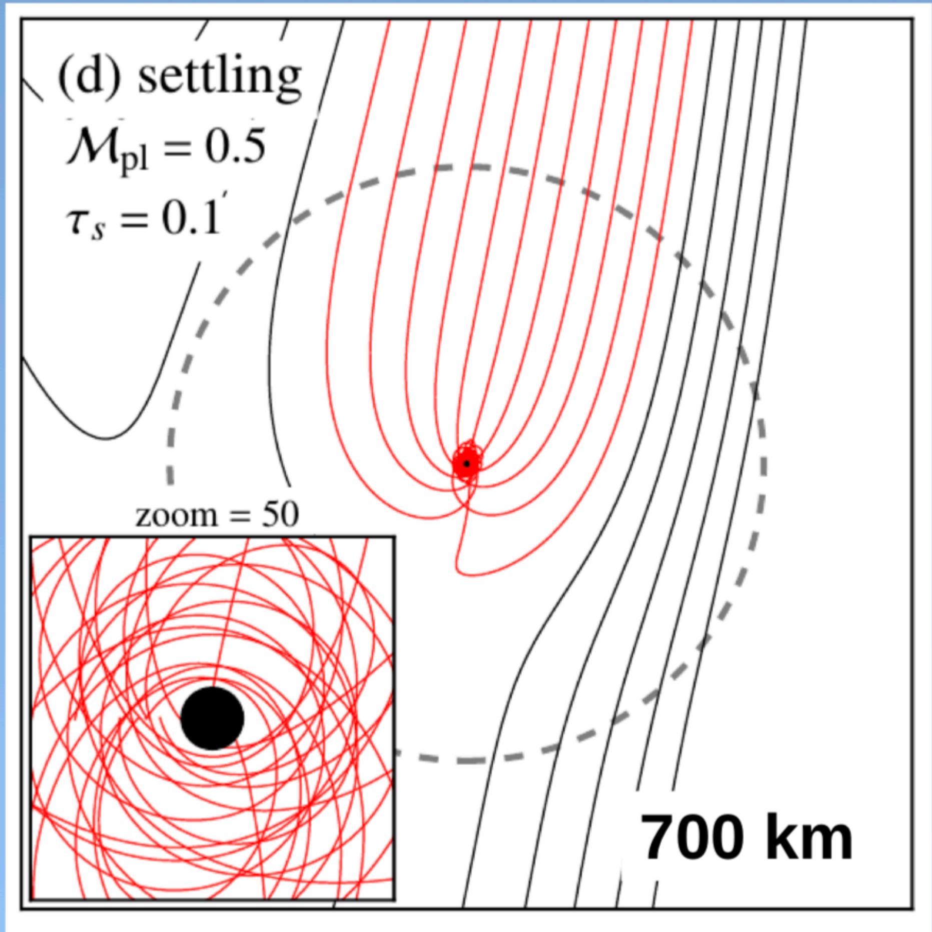
No Pebble accretion



Pebble accretion

Onset pebble accretion





Ormel (2017)

ANNUAL REVIEWS

Annual Review of Earth and Planetary Sciences

Forming Planets via Pebble Accretion

Anders Johansen[1] and Michiel Lambrechts[2]

[1]Lund Observatory, Lund University, 221 00 Lund, Sweden; email: anders@astro.lu.se

[2]Laboratoire Lagrange, Observatoire de la Côte d'Azur, Université Côte d'Azur, 06304 Nice Cedex 4, France; email: michiel.lambrechts@oca.eu

The emerging paradigm of pebble accretion

Chris W. Ormel

Abstract Pebble accretion is the mechanism in which small particles ('pebbles') accrete onto big bodies (planetesimals or planetary embryos) in gas-rich environments. In pebble accretion, accretion occurs by settling and depends only on the mass of the gravitating body, not its radius. I give the conditions under which pebble accretion operates and show that the collisional cross section can become much larger than in the gas-free, ballistic, limit. In particular, pebble accretion requires the pre-existence of a massive planetesimal seed. When pebbles experience strong orbital decay by drift motions or are stirred by turbulence, the accretion efficiency is low and a great number of pebbles are needed to form Earth-mass cores. Pebble accretion is in many ways a more natural and versatile process than the classical, planetesimal-driven paradigm, opening up avenues to understand planet formation in solar and exoplanetary systems.

1 Introduction