東京大学
THE UNIVERSITY OF TOKYO

JOVIAL Kick-off Meeting

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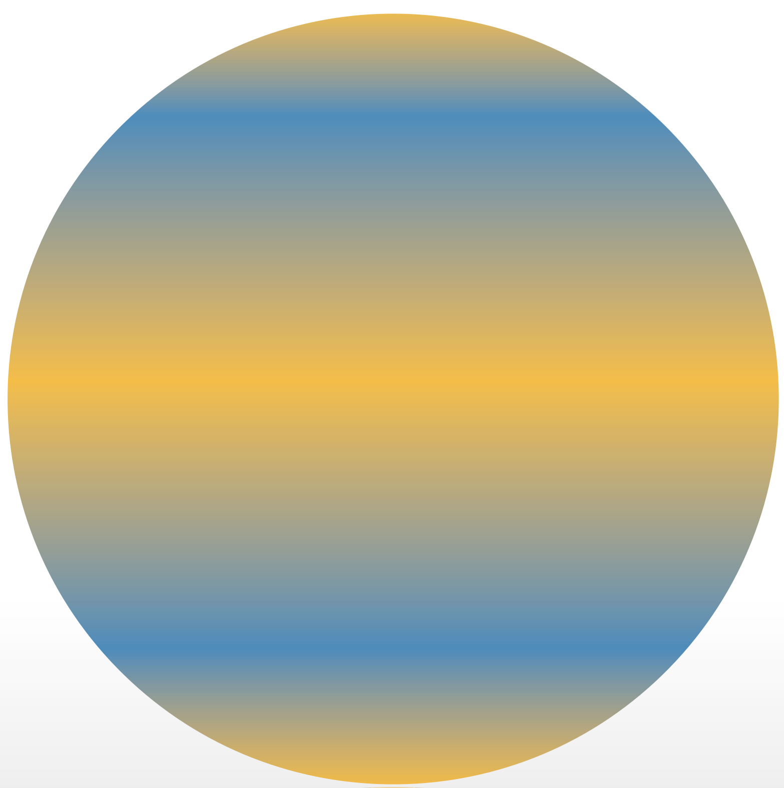
Internal Structure: Implication for Planet Formation



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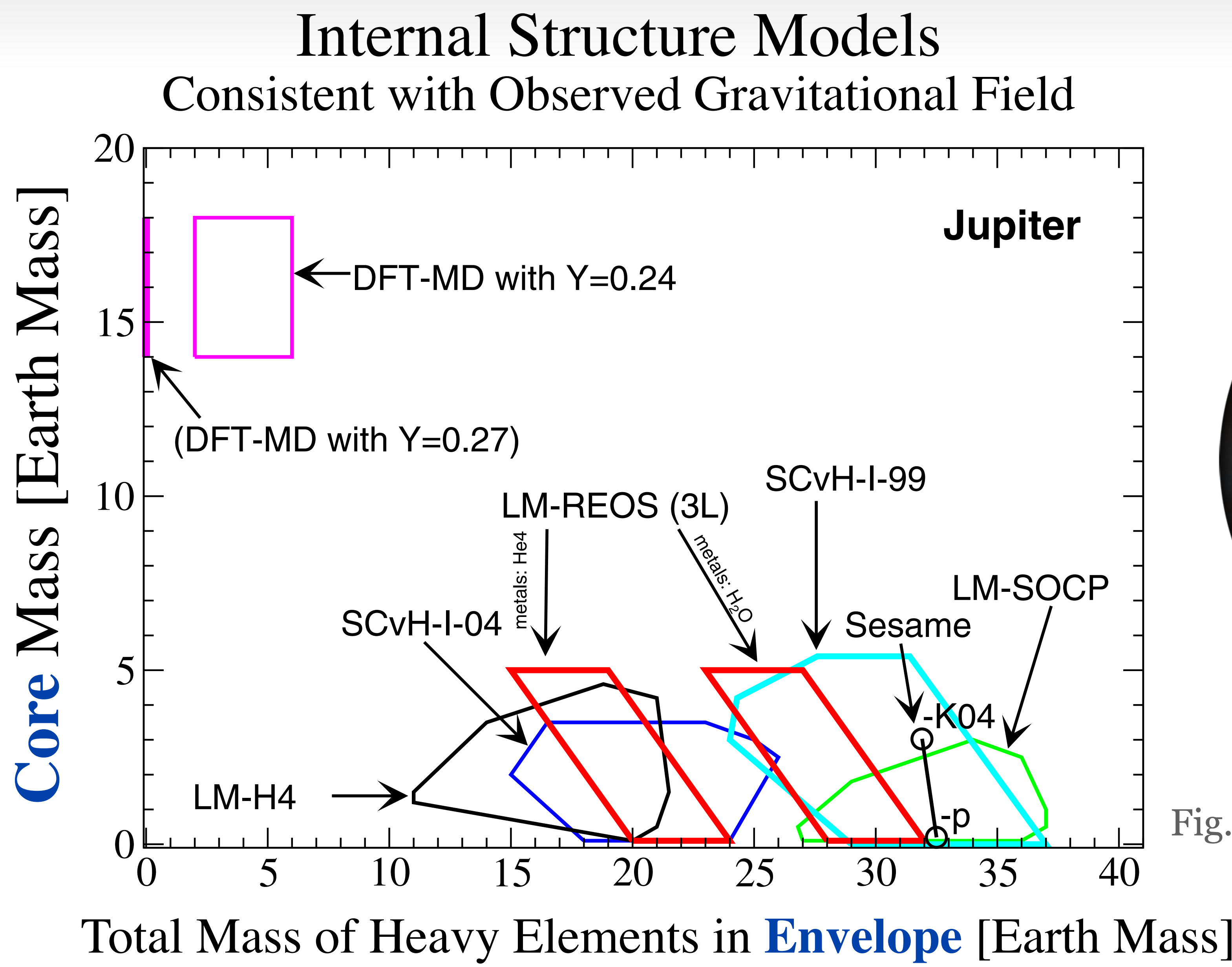
Heavy Elements in Interior



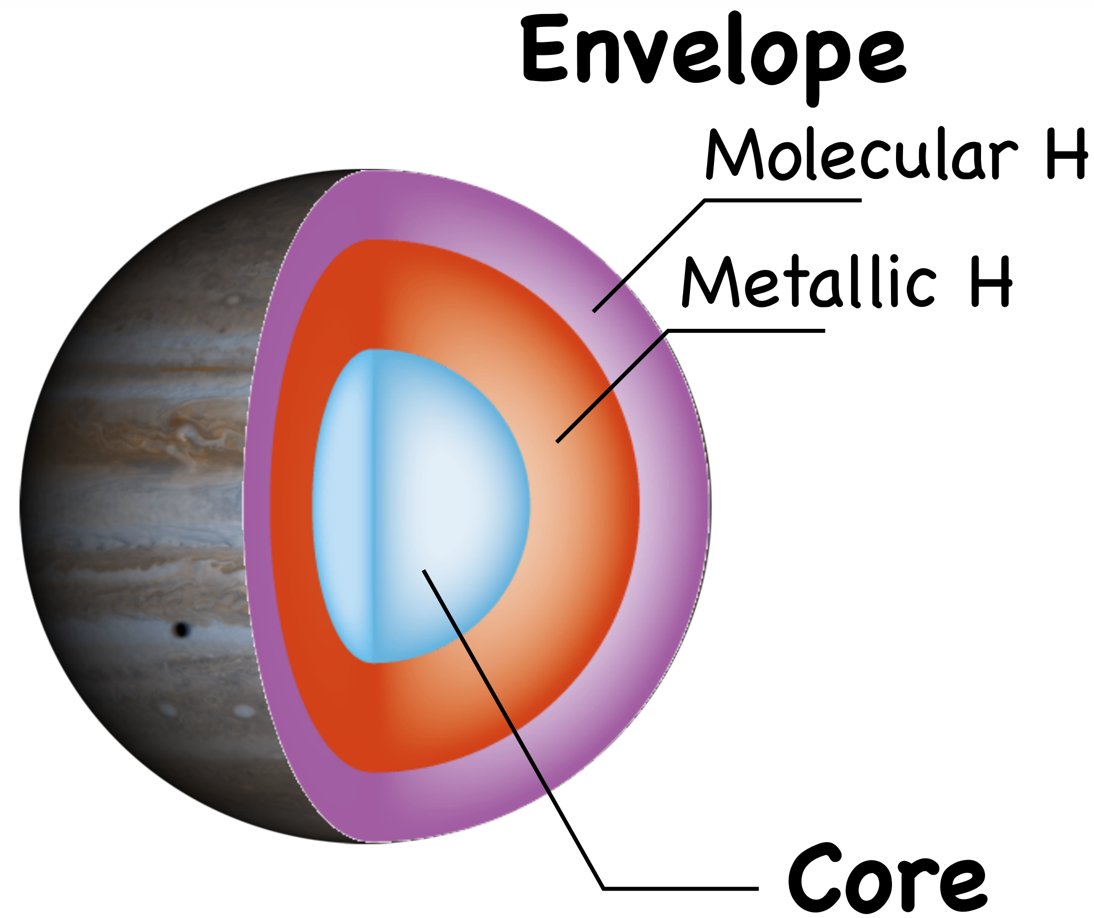
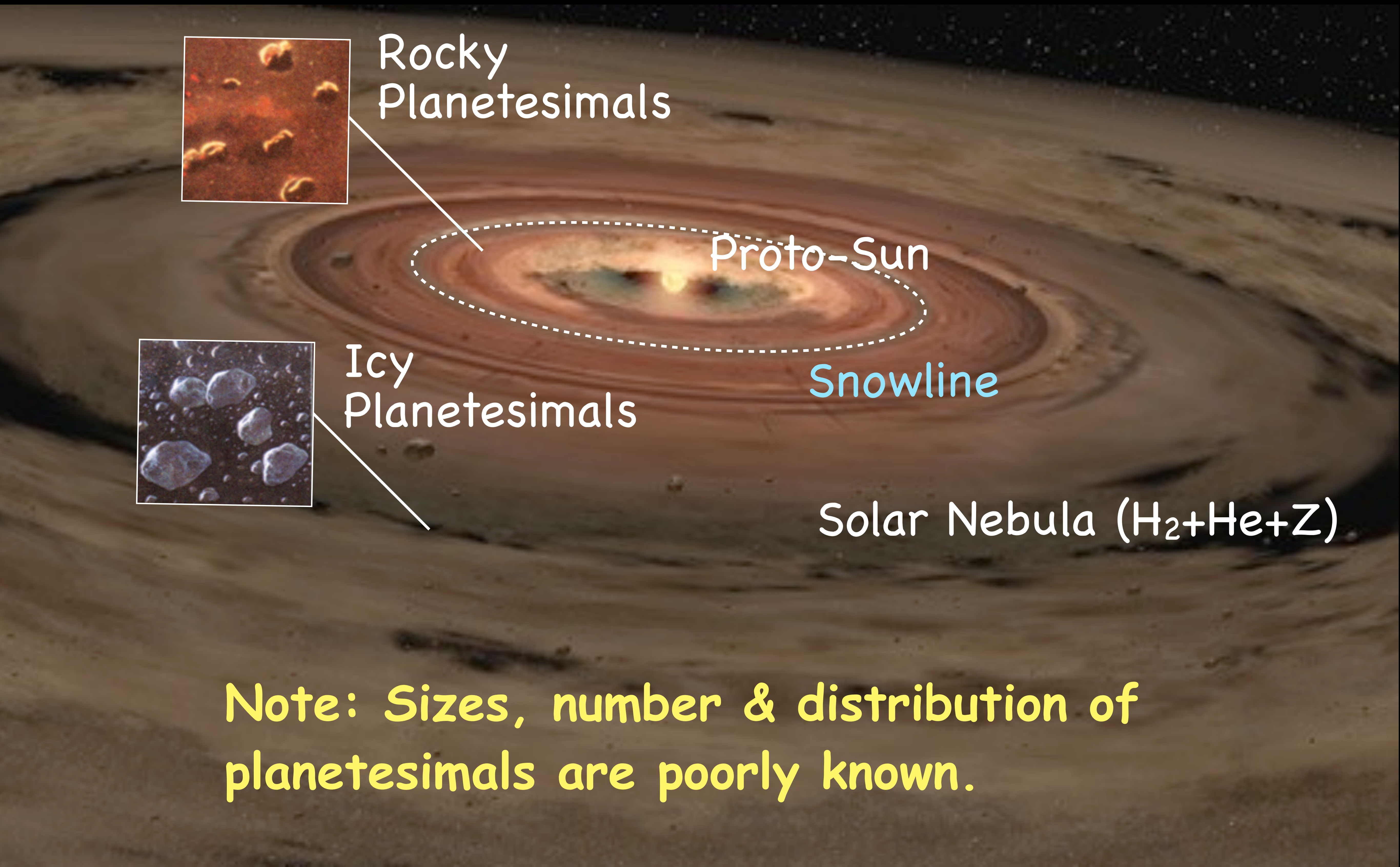


Fig. from Fortney & Nettelmann (2010)

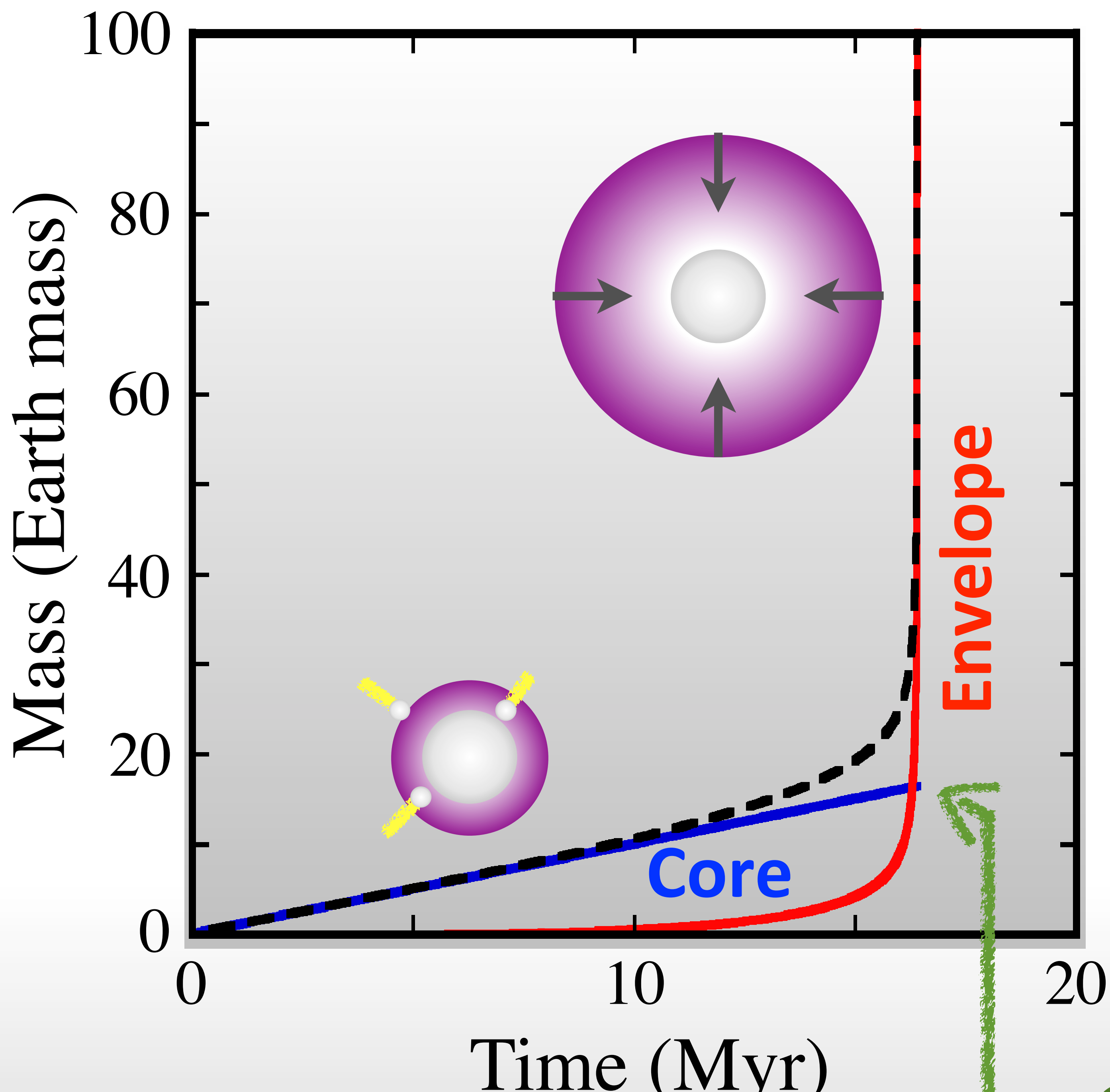
- How massive is the core?
- How much heavy elements are contained in the interior?
- How are heavy elements distributed in the interior?

Proto-Solar System



Giant Planet Formation

Core Accretion Model

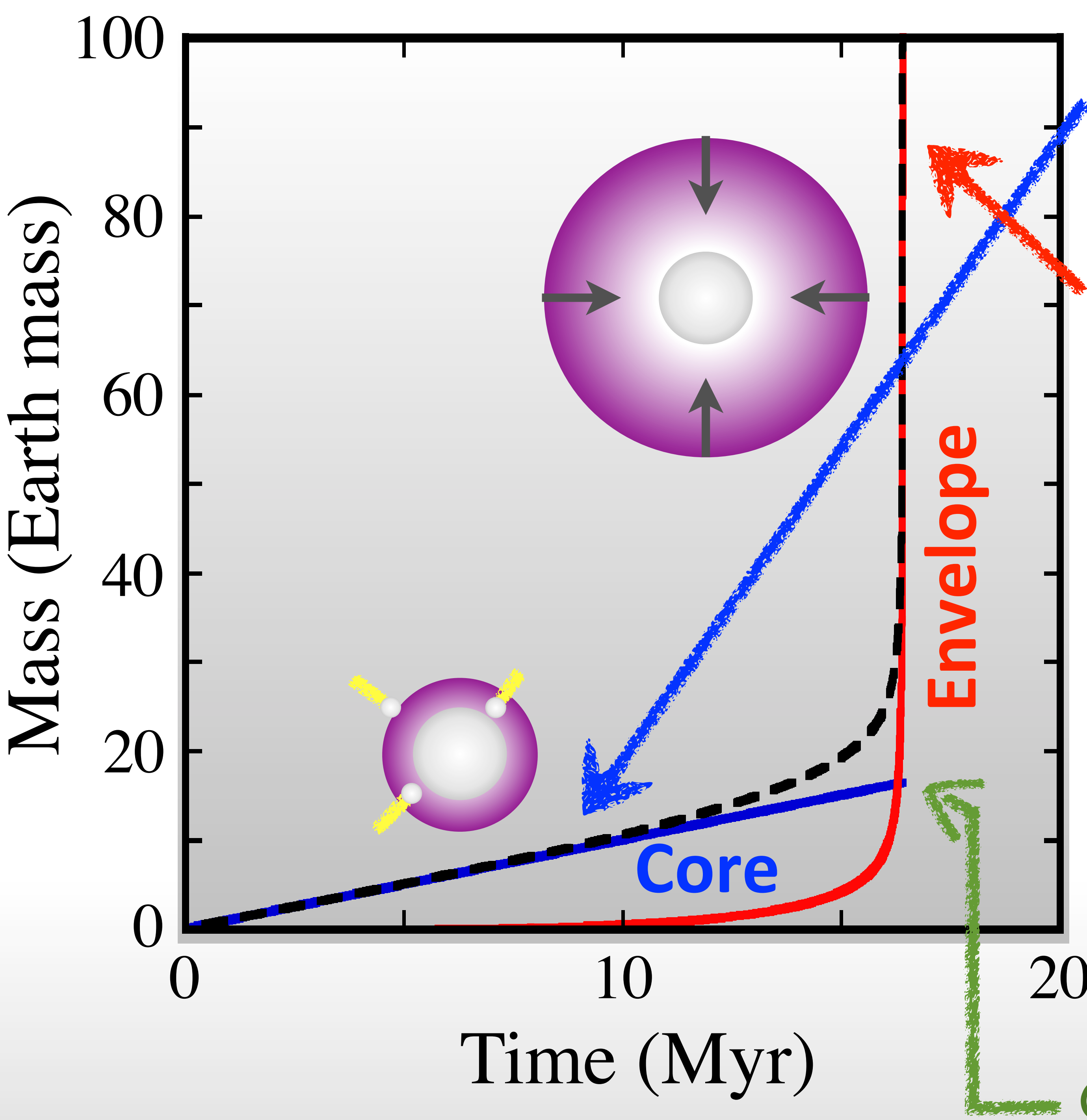


- Growth in separate phases
  1) Critical-mass core formation via planetesimal accretion
  2) Envelope formation via runaway gas accretion
- At the critical point, the core and envelope masses are comparable with each other.
- Most of the envelope accretes in the runaway gas accretion phase.

Crossover mass

$\simeq$ **"Critical core mass"**

When Heavy Elements Accrete?

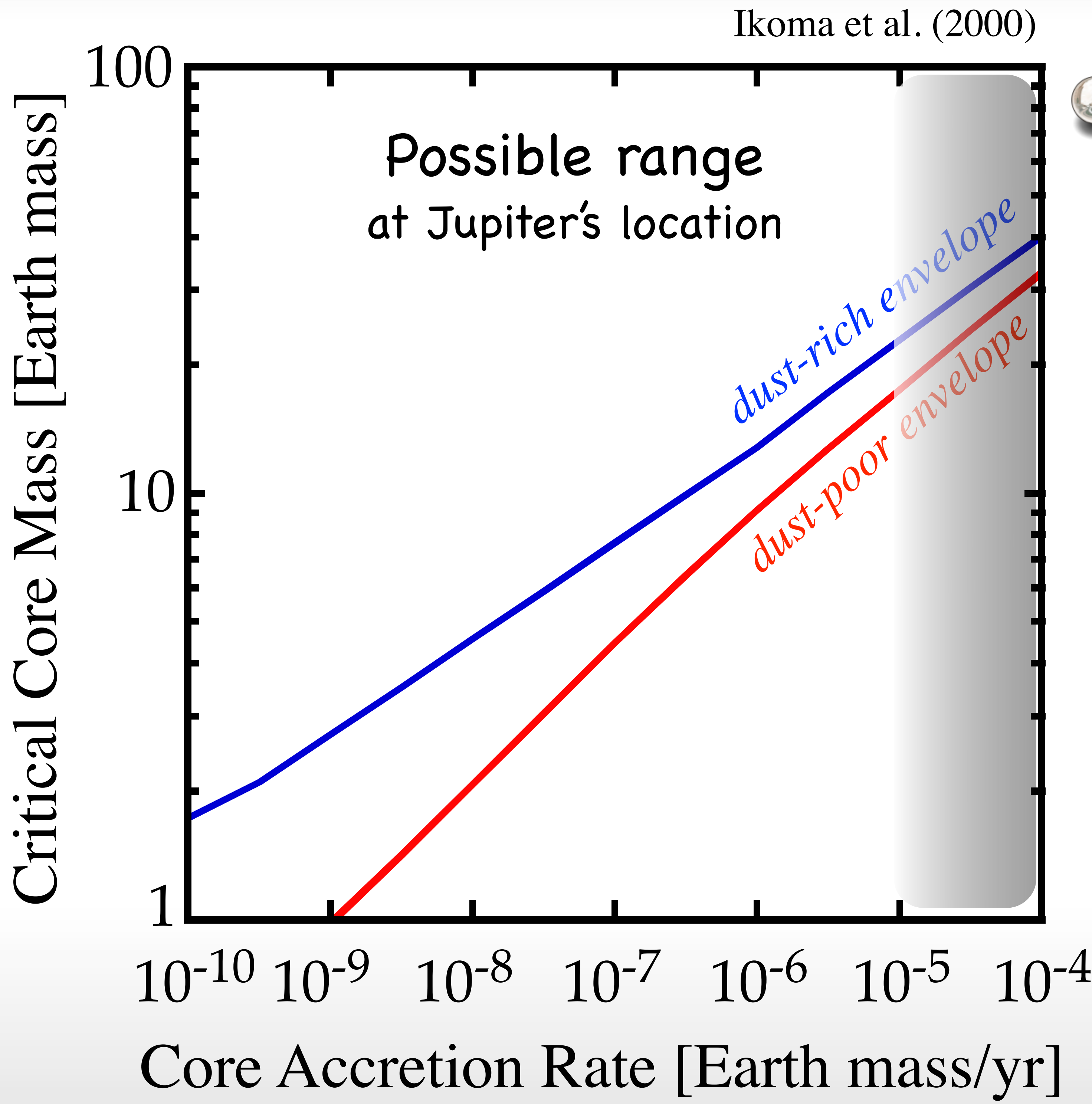


1) Core-forming stage

2) Late runaway accretion phase (see S. Ida's talk)

Crossover mass
$\simeq$ **"Critical core mass"**

Critical Core Mass

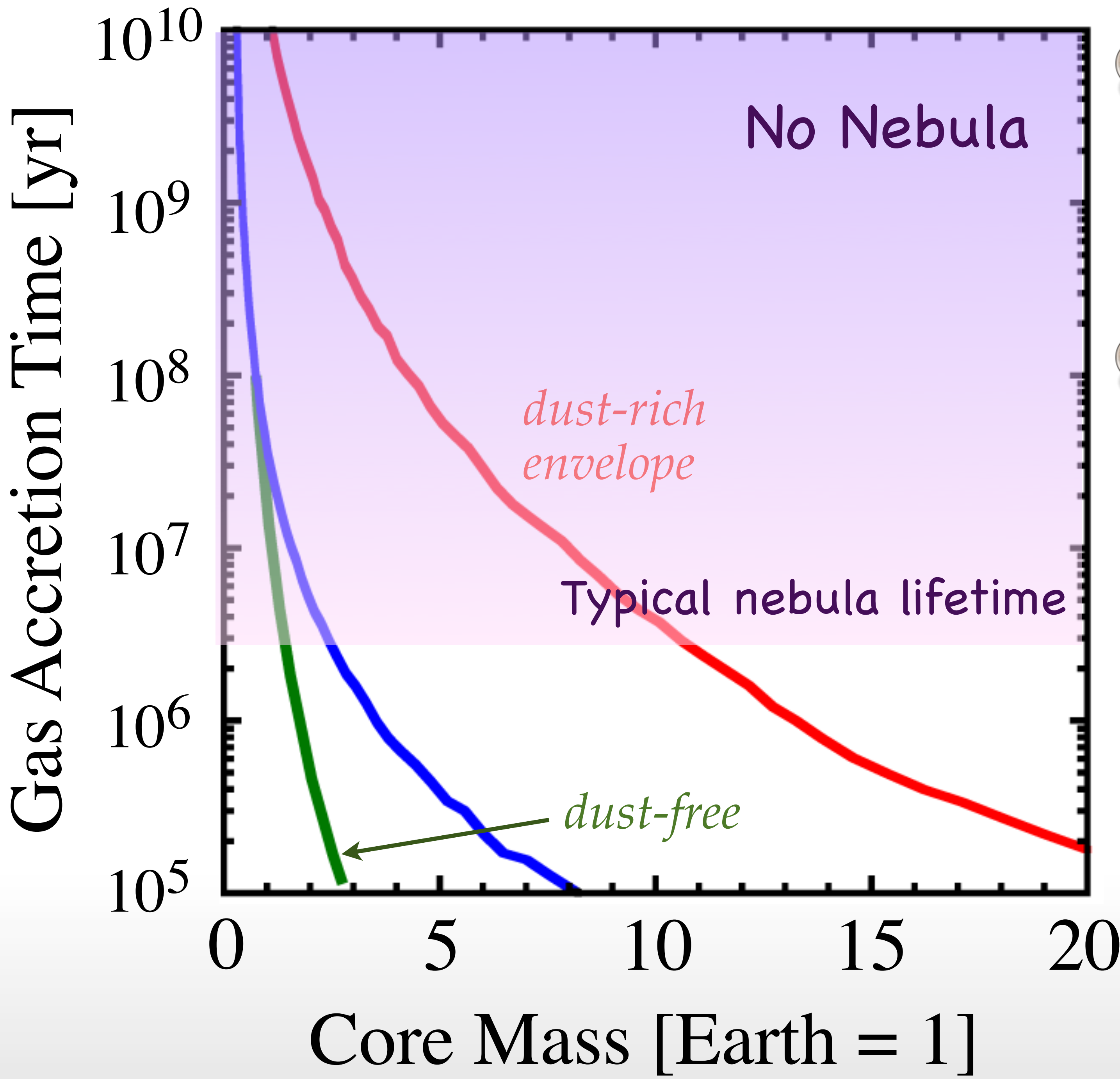


- The critical core mass depends on core accretion rate

➜ The mass of the core is linked with planet accretion process

Time Constraint

Ikoma & Genda (2006); Hori & Ikoma (2010)

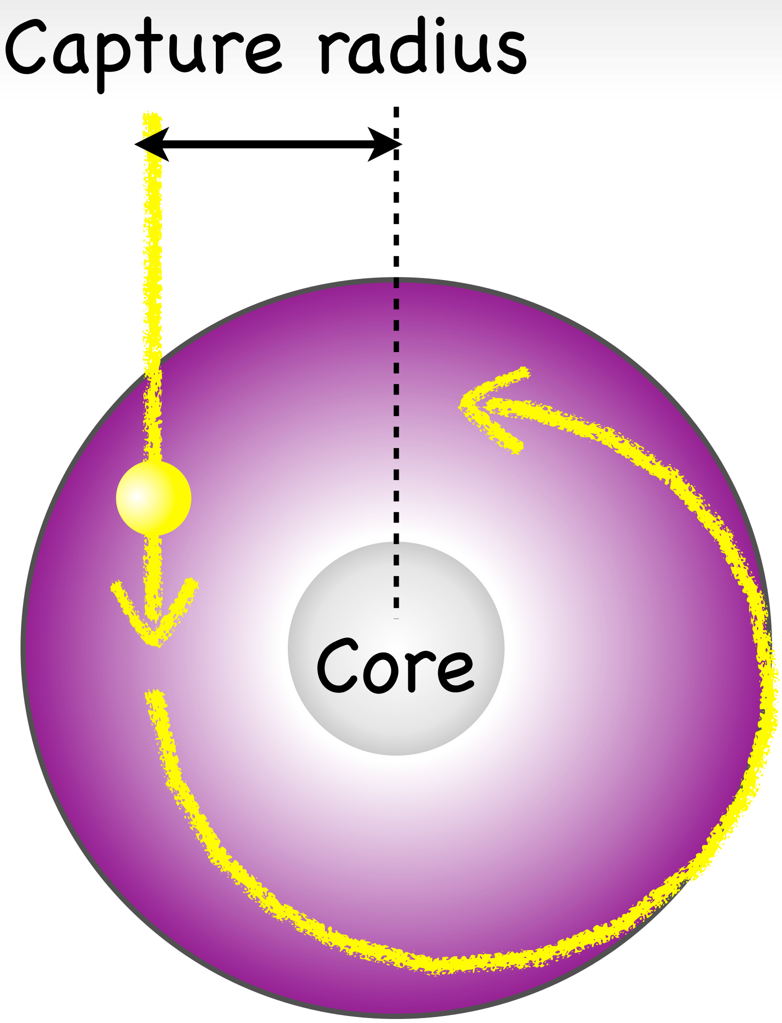


- The gas accretion timescale increases rapidly as the core mass decreases.
- The mass of the core must be **more than 1-2 Earth masses**; otherwise, the envelope formation is not completed by nebular dispersal.

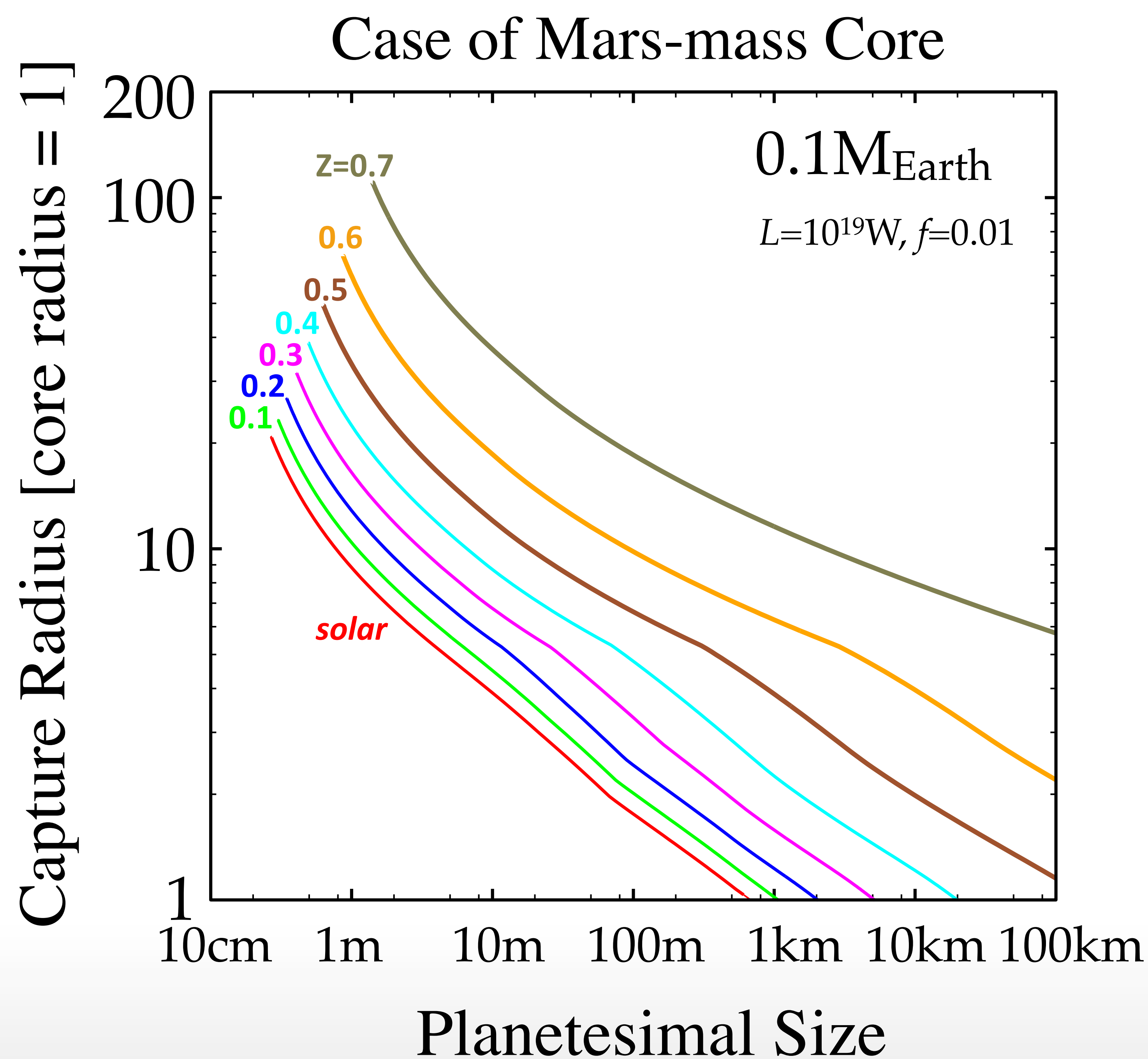
Planetesimals of small size evaporate on the way toward the core

Heavy elements are deposited in the envelope
→ polluting the envelope

Envelope Pollution



Ikoma & Kobayashi (2016, in prep.)



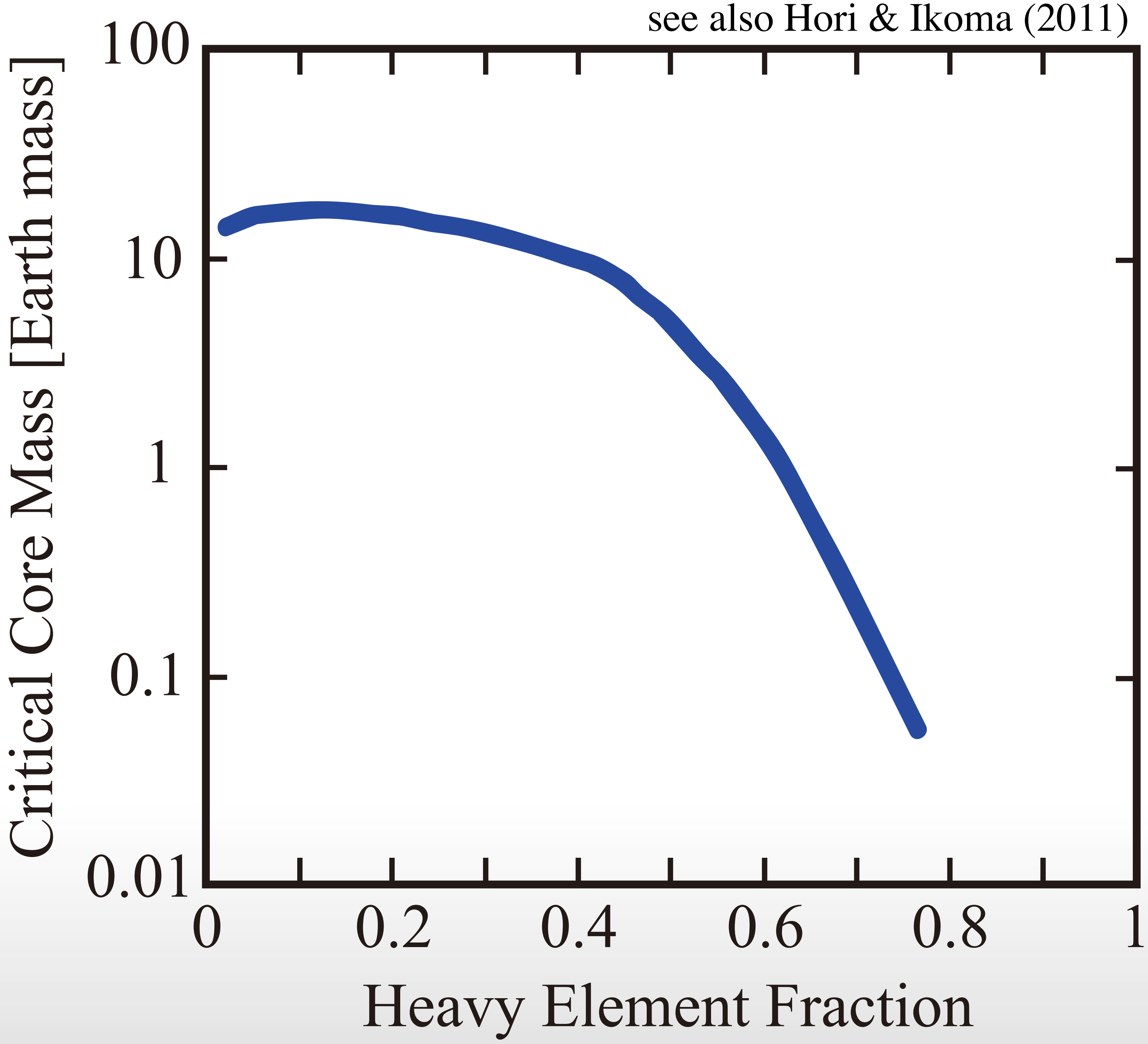
- Planetesimals of <~ 100m are captured and ablated in the solar-composition envelope.

    ➜ polluting the envelope

- Capture radius becomes large rapidly with pollution ➜ polluting the envelope more

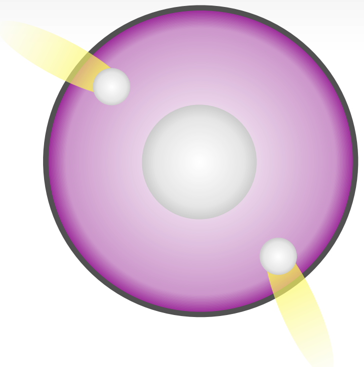
Effect of Envelope Pollution on the critical core mass

Venturini, Alibert, Benz, & Ikoma (2015)
see also Hori & Ikoma (2011)



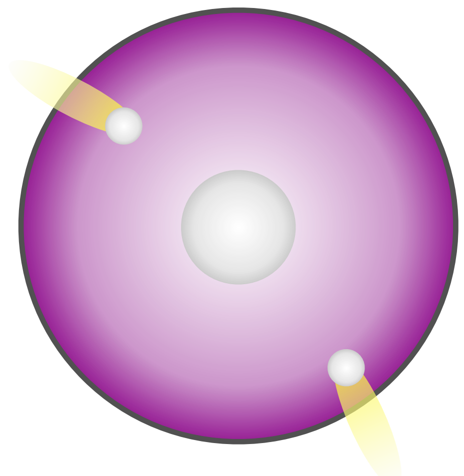
- The critical core mass is reduced greatly by addition of heavy elements in the envelope.
- Highly polluted envelopes result in critical mass of as small as Martian mass.

New Picture for Growth

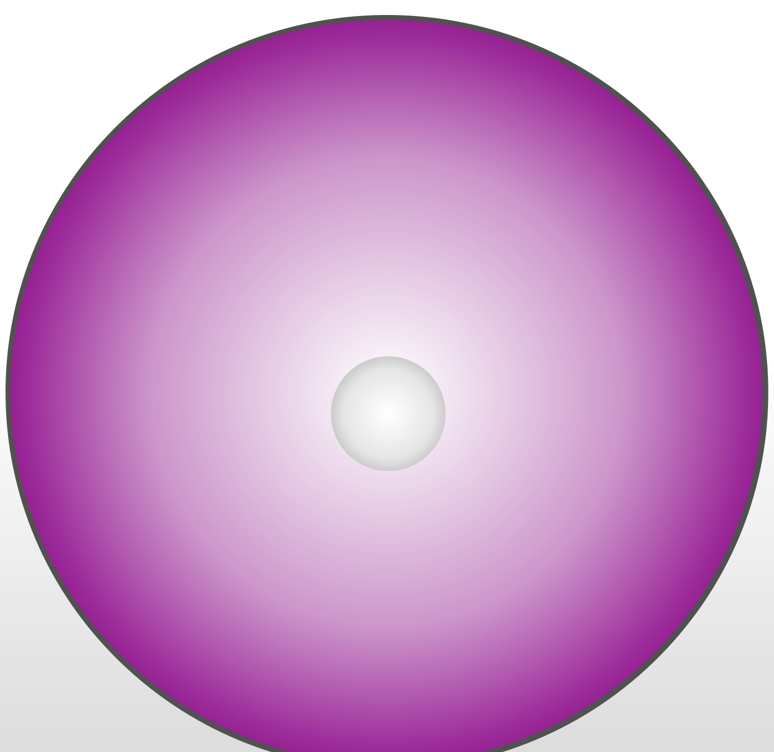


Small core (of e.g. Mars-mass) is surrounded by highly polluted envelope.

The polluted envelope contracts and collects H/He nebula gas, which results in slowing gas accretion

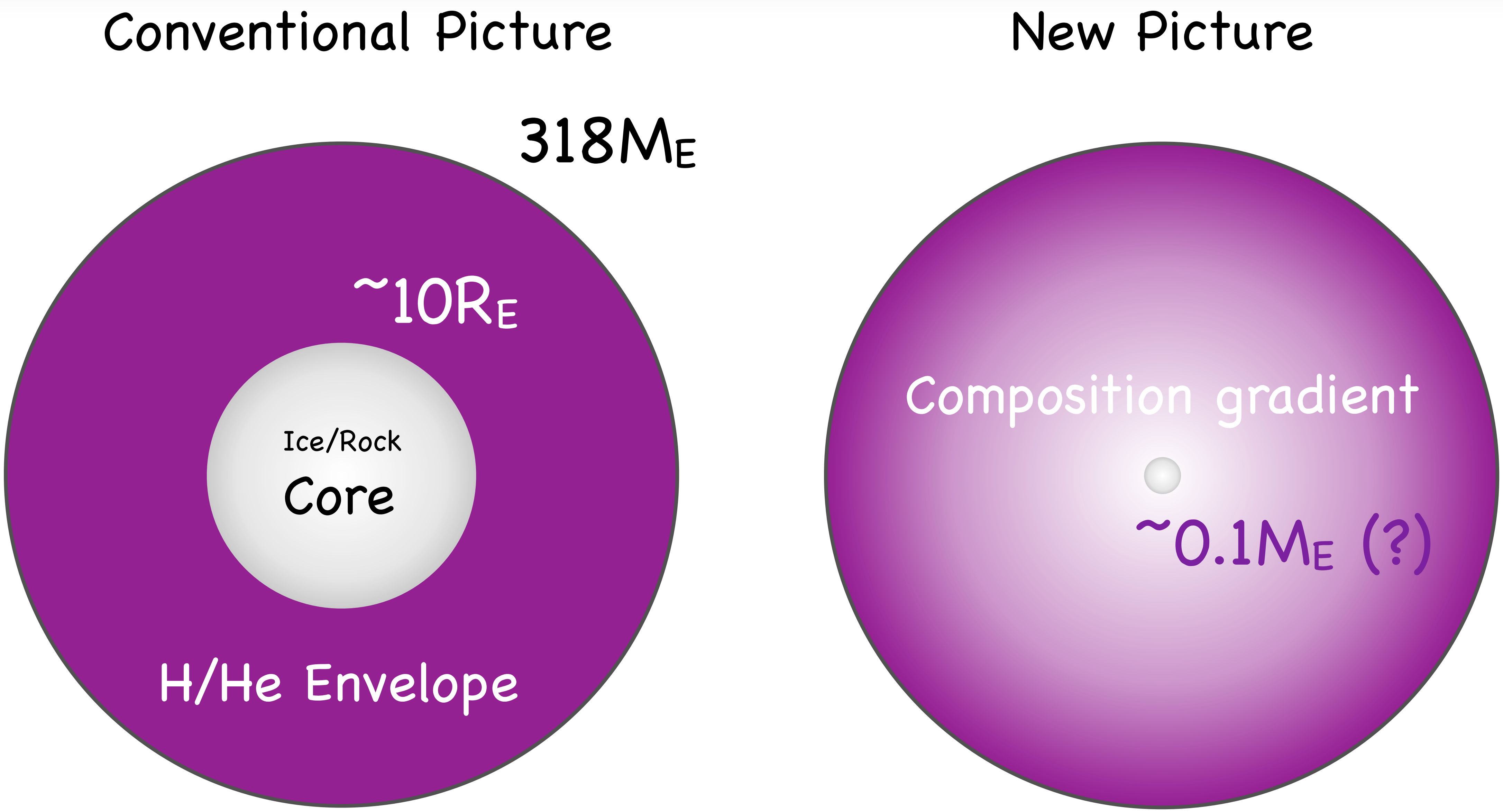


Gas accretion proceeds in balance with the rate of planetesimal accretion.



Once planetesimal accretion becomes unable to catch up with nebula gas accretion, the nebula gas accretion becomes runaway, forming a massive envelope.

Predicted Internal Structure



Other effects to be taken into account

- Late stage solid accretion (see S. Ida's talk)
- Sedimentation or mixing of heavy elements

Summary

- The amount and distribution of heavy elements in the interior provide important constraints to formation of the giant planets.
- Accurate determination of the core masses is crucial.
- The cores are expected to be very small, above which there is a zone with compositional gradient.
- Effects of late stage solid accretion and secondary mixing must be taken into account to quantify the conclusion.