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Chemistry of the Protolunar Disk and Volatile Depletion of the Moon

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Abstract

In the giant impact theory for lunar origin, the Moon forms from a circumterrestrial disk of silicate debris produced by the collision of a planetary-sized impactor with the early Earth. Recent accretion models suggest that the final 10-60% of the lunar mass may be provided by the accretion of melt material spreading outward from the inner (Roche-interior) disk over the first ~102 years following the giant impact. The chemical and thermal evolution of the inner disk material is thus expected to strongly influence the bulk chemical composition of the Moon.

In a previous study we explored the chemistry of the melt+vapor protolunar disk in order to examine the vapor pressure of the silicate magma and the chemistry of the protolunar disk atmosphere. Here we combine a chemical model for the disk with lunar accretion simulations and a thermal evolution model in order to explore the chemistry of the accreting lunar material and implications for the bulk lunar composition. A chemical equilibrium code is used to determine the partial pressure of each species in equilibrium with a BSE-composition melt. These vapor pressure results, along with the bulk elemental inventory of the disk, are used to estimate the relative fraction of each element in the melt vs. vapor phase as a function of the mass surface density and temperature of the disk.

The coupled chemistry + lunar accretion + thermal model suggests that the temperature of the melt in the inner disk remains above estimated 50% condensation temperatures for the volatile elements Zn, Na, and K until the Moon has nearly completed its accretion. We thus expect the portion of the lunar material derived from the inner disk to be depleted in these and similarly volatile elements, even in the absence of thermal escape.

Keywords

moon, protolunar disk, chemistry, vapor pressure

Disciplines

Astrophysics and Astronomy

Comments

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Chemistry of the protolunar disk and volatile depletion in the Moon

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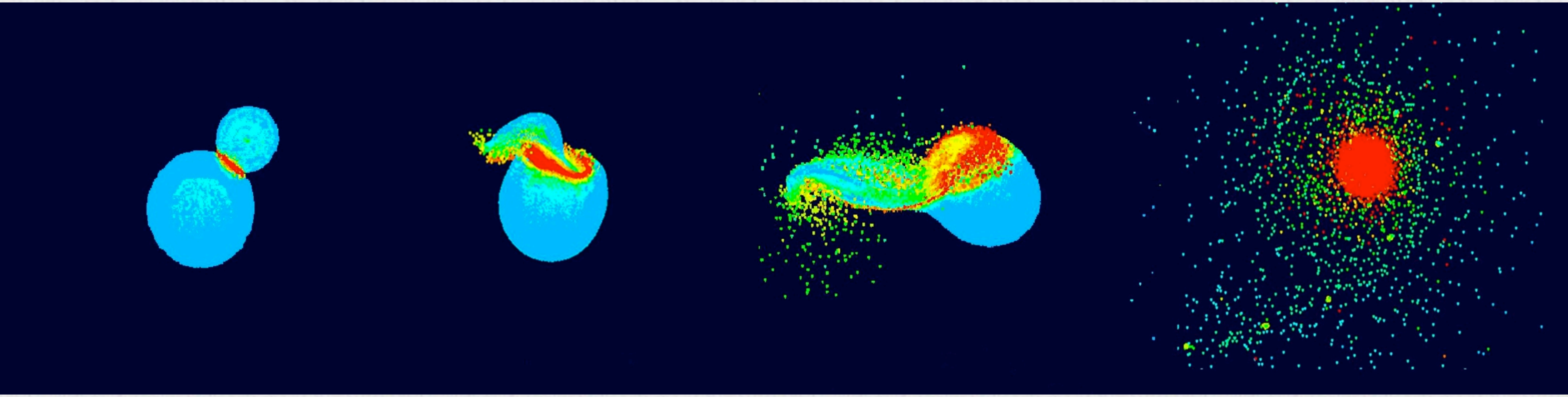
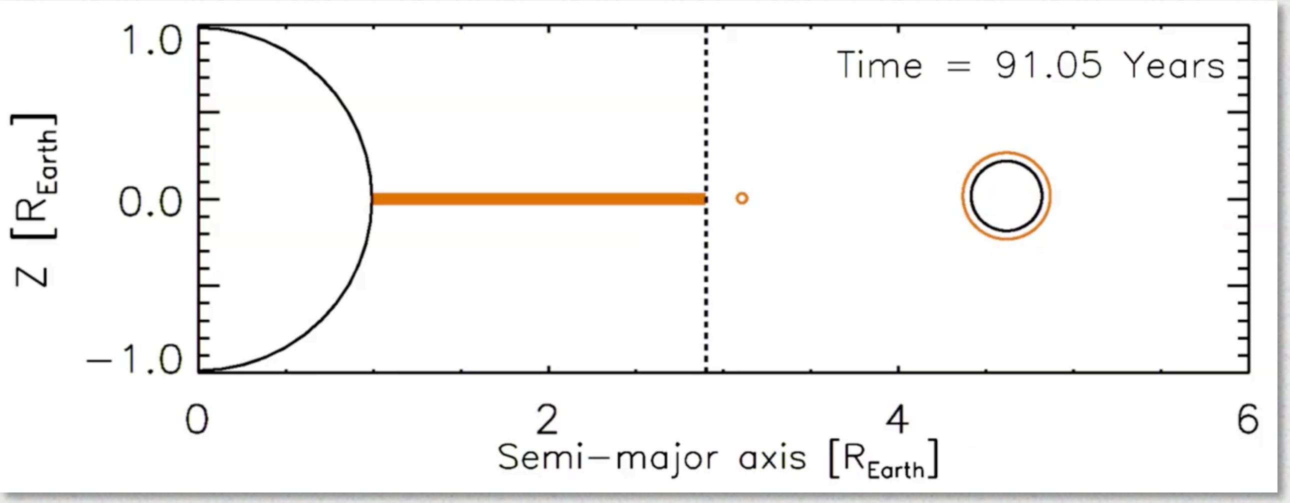
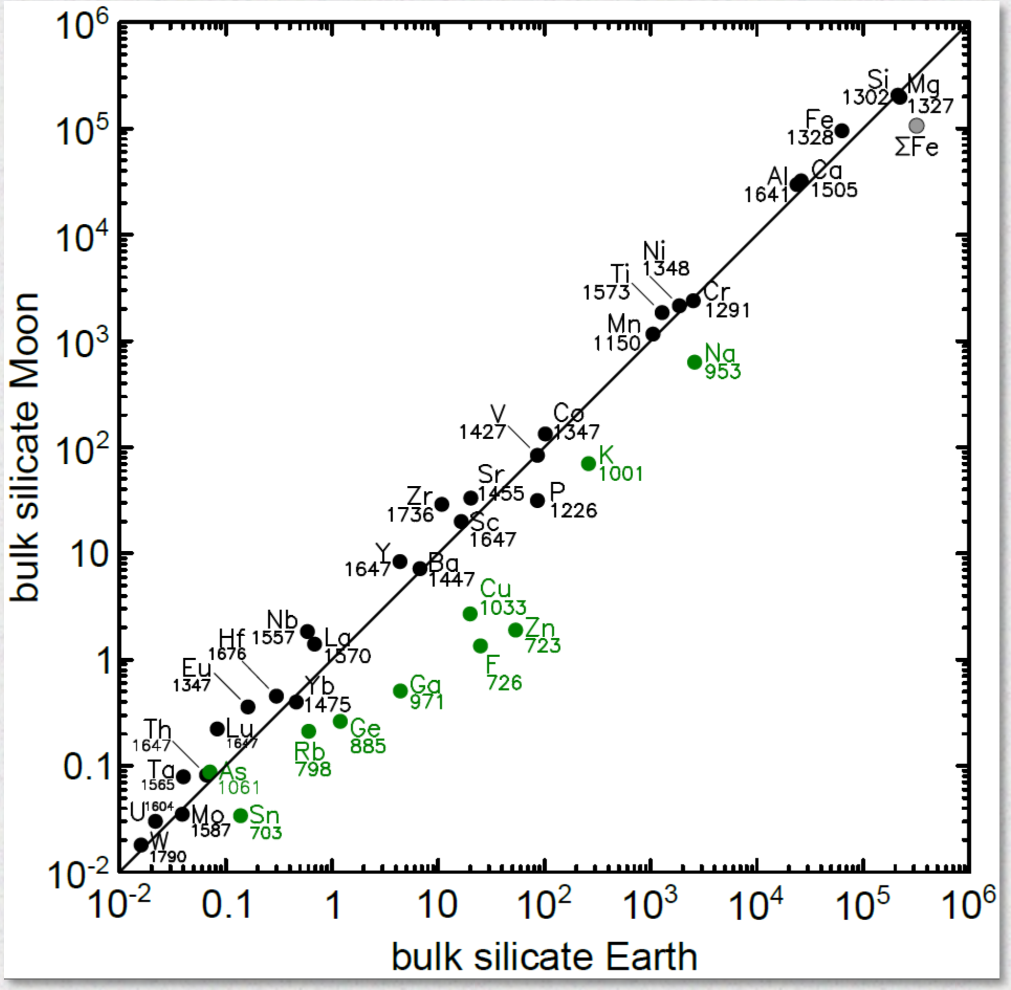




what is source of lunar volatile depletion?

- escape following giant impact?
  - implied by isotopic abundances (e.g., Paniello et al 2012)
  - escape from disk appears to be limited (e.g. Nakajima & Stevenson 2014)



conceptual approach & outline

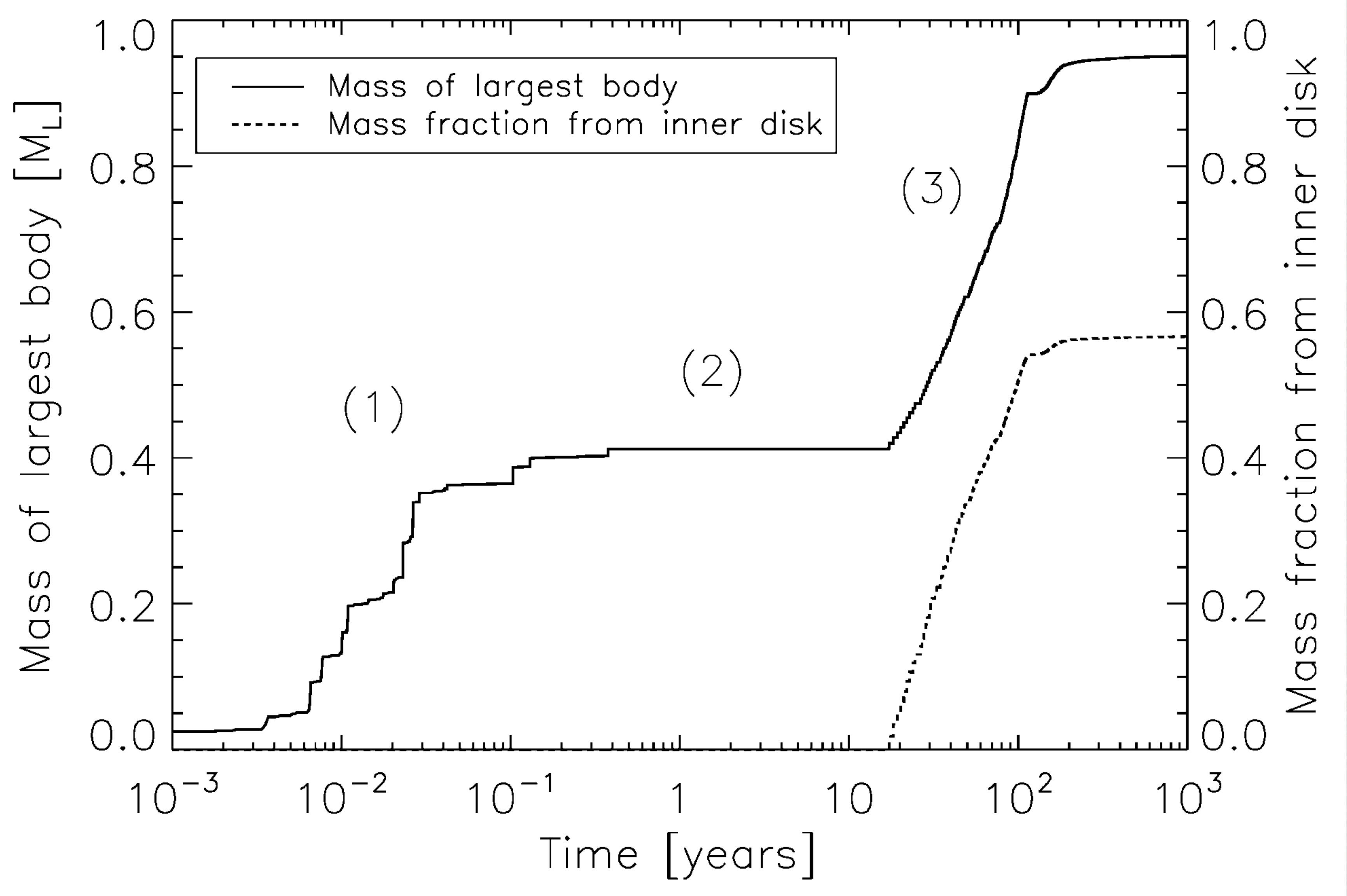
"It is further speculated that the curious composition of the Moon may be a consequence of incomplete condensation rather than evaporation during the giant impact." *-Taylor et al 2006*

- partial condensation concept (in closed system):
  - if Moon is forming from high-temperature melt, volatile elements will not be incorporated into Moon

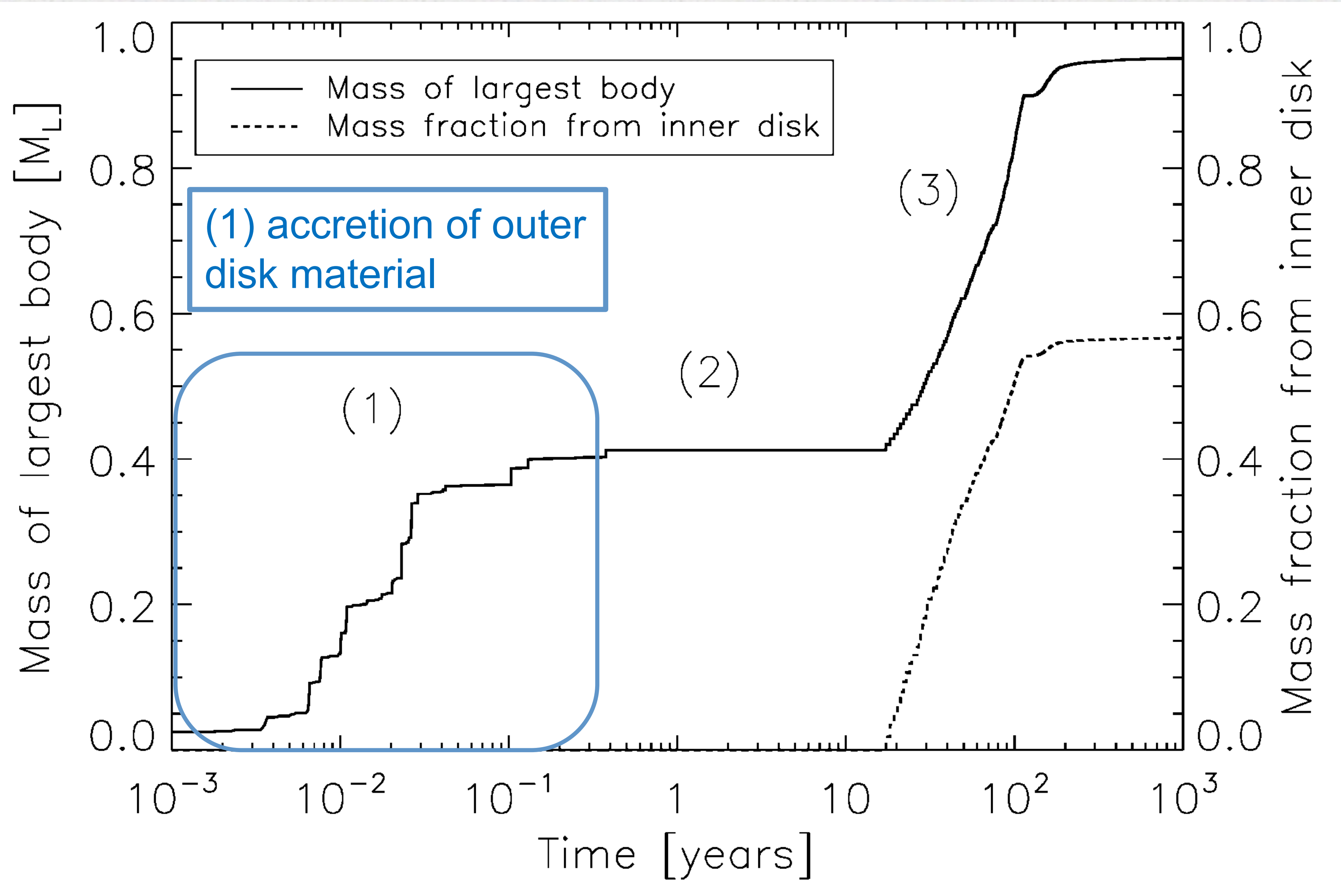
- coupled models of the disk:
  - lunar accretion model (Salmon & Canup 2012, 2014)
  - thermal model (Thompson & Stevenson 1988, Ward 2012)
  - chemical model (Visscher & Fegley 2013)

portion of Moon derived from inner disk will be volatile-depleted

lunar accretion model (Salmon & Canup 2012, 2014)



lunar accretion model (Salmon & Canup 2012, 2014)



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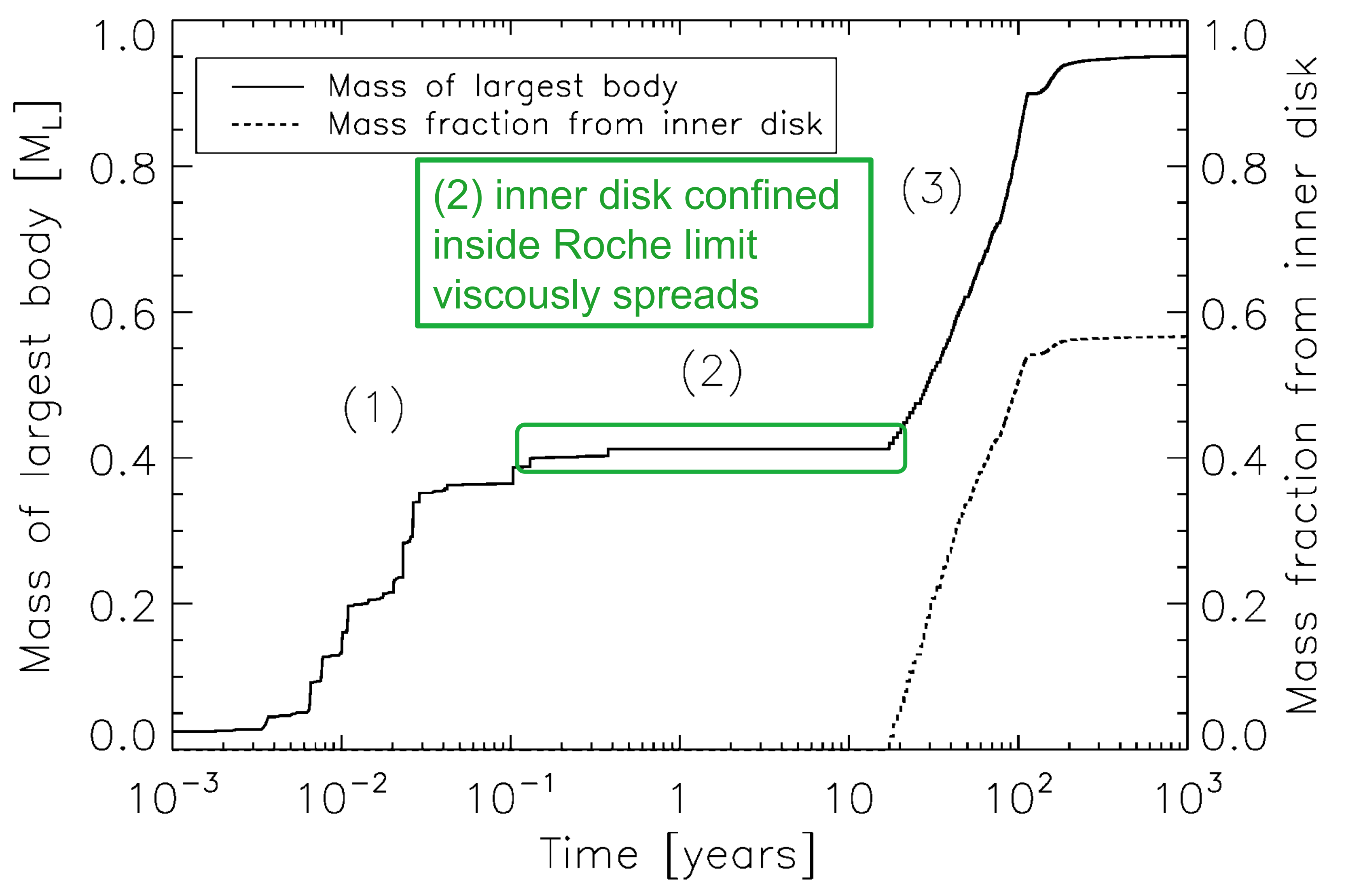

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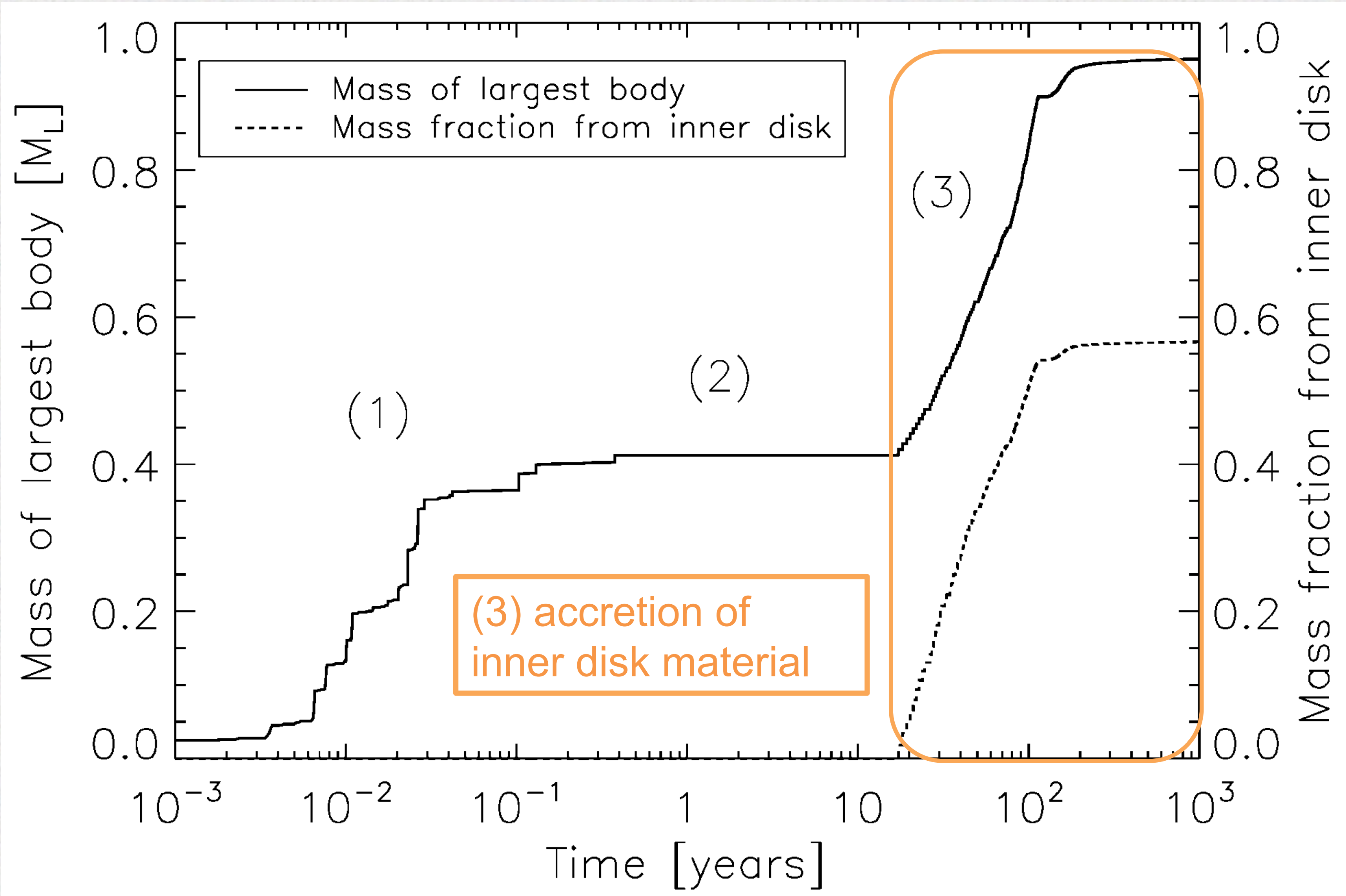
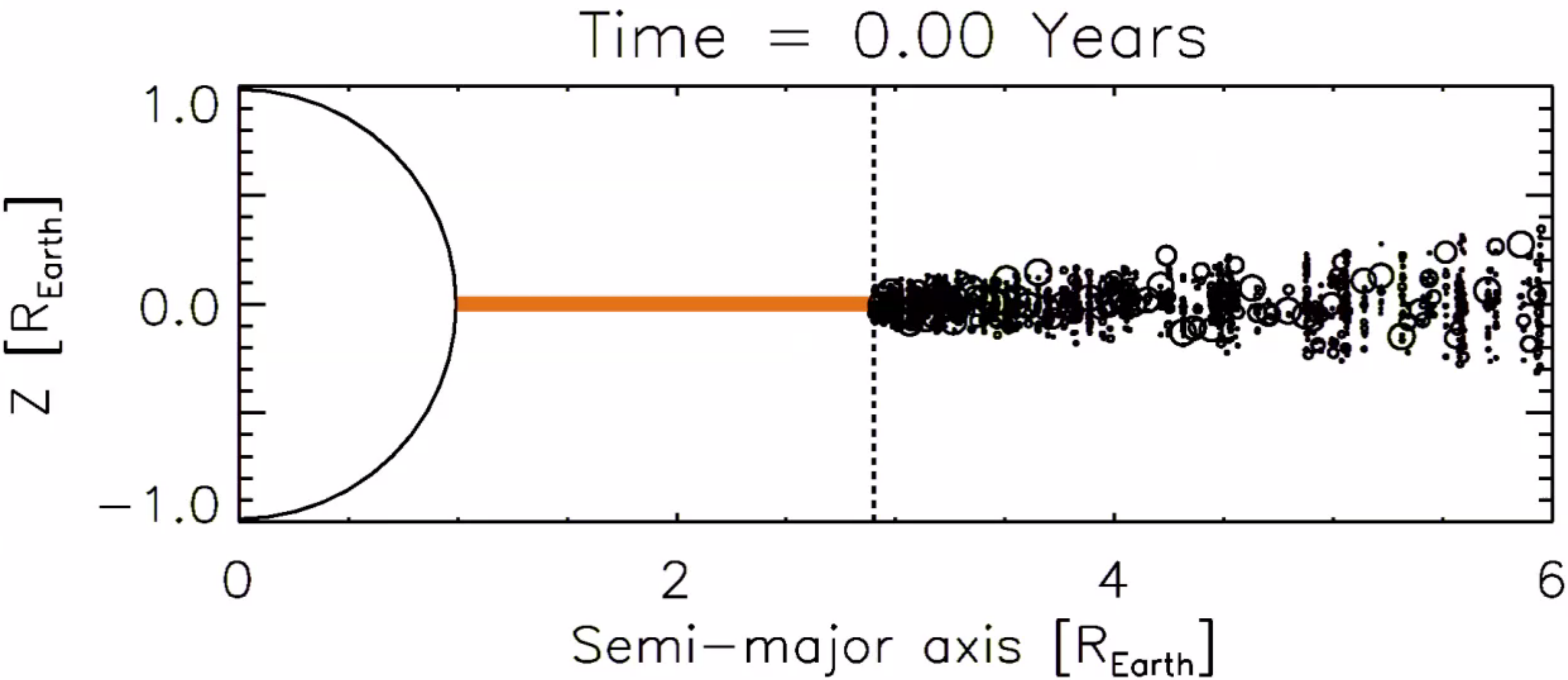


lunar accretion model (Salmon & Canup 2012, 2014)

- early stage 3: **inner disk melt material** is accreted by the Moon
  - separation of melt component from vapor component
  - later: as Moon migrates outward, preferential accretion by Earth



(post-impact)

lunar accretion model (Salmon & Canup 2012, 2014)

- early stage 3: **inner disk melt material** is accreted by the Moon
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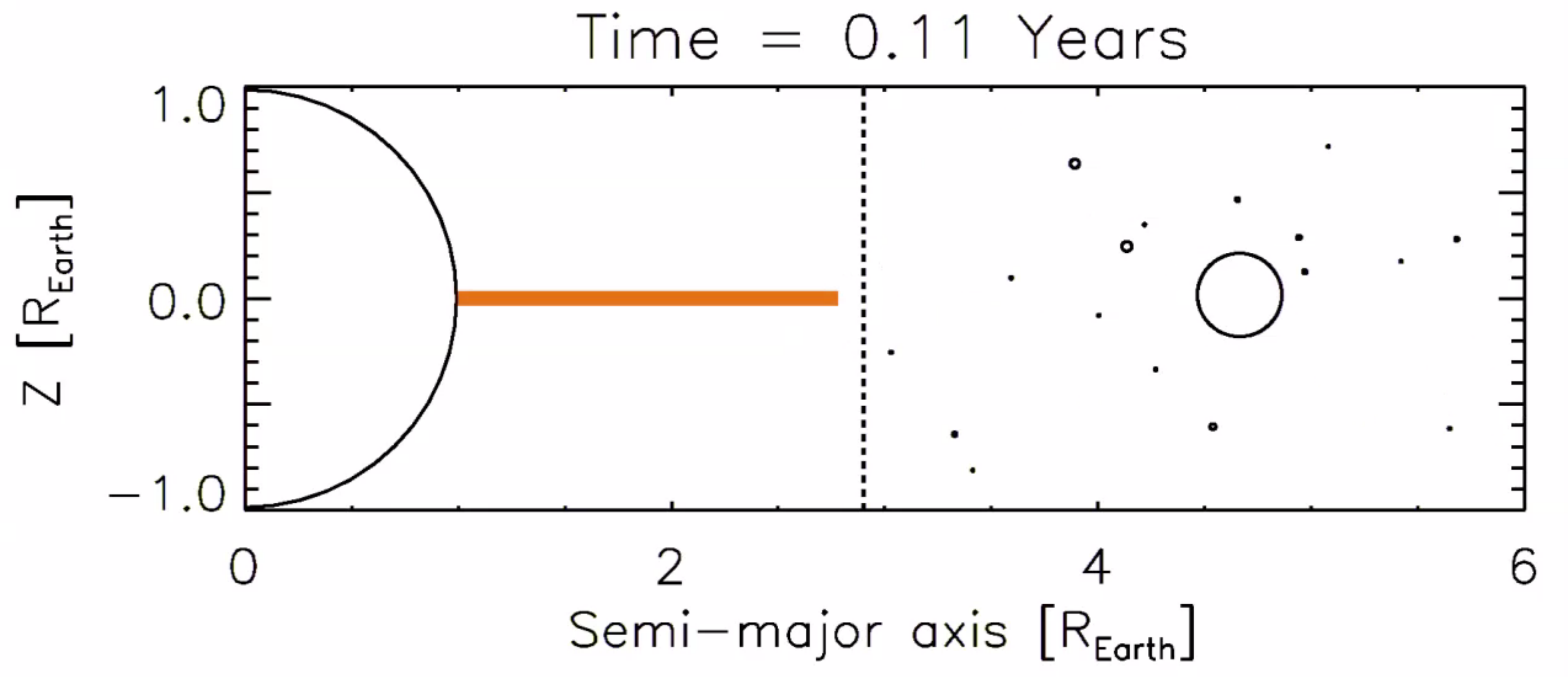

(end of stage 1)

lunar accretion model (Salmon & Canup 2012, 2014)

- early stage 3: **inner disk melt material** is accreted by the Moon
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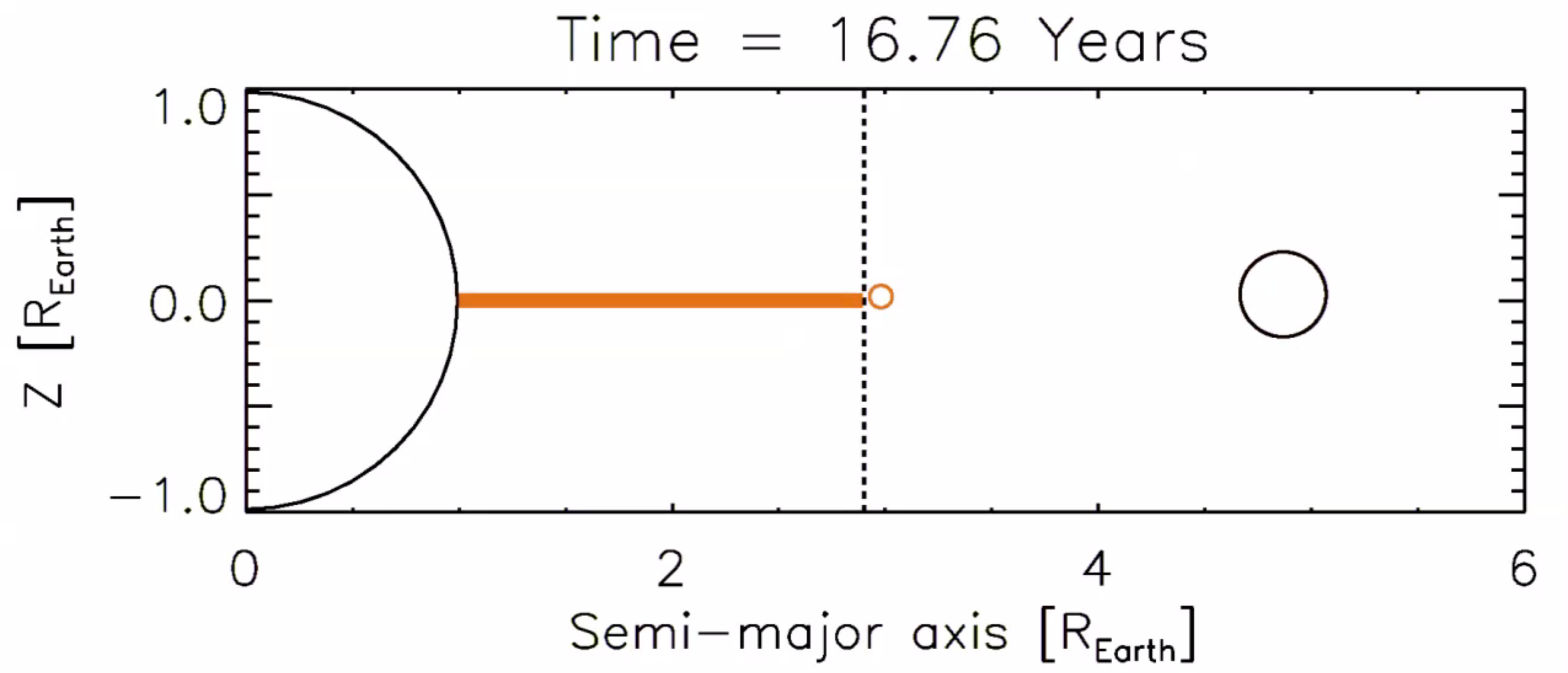
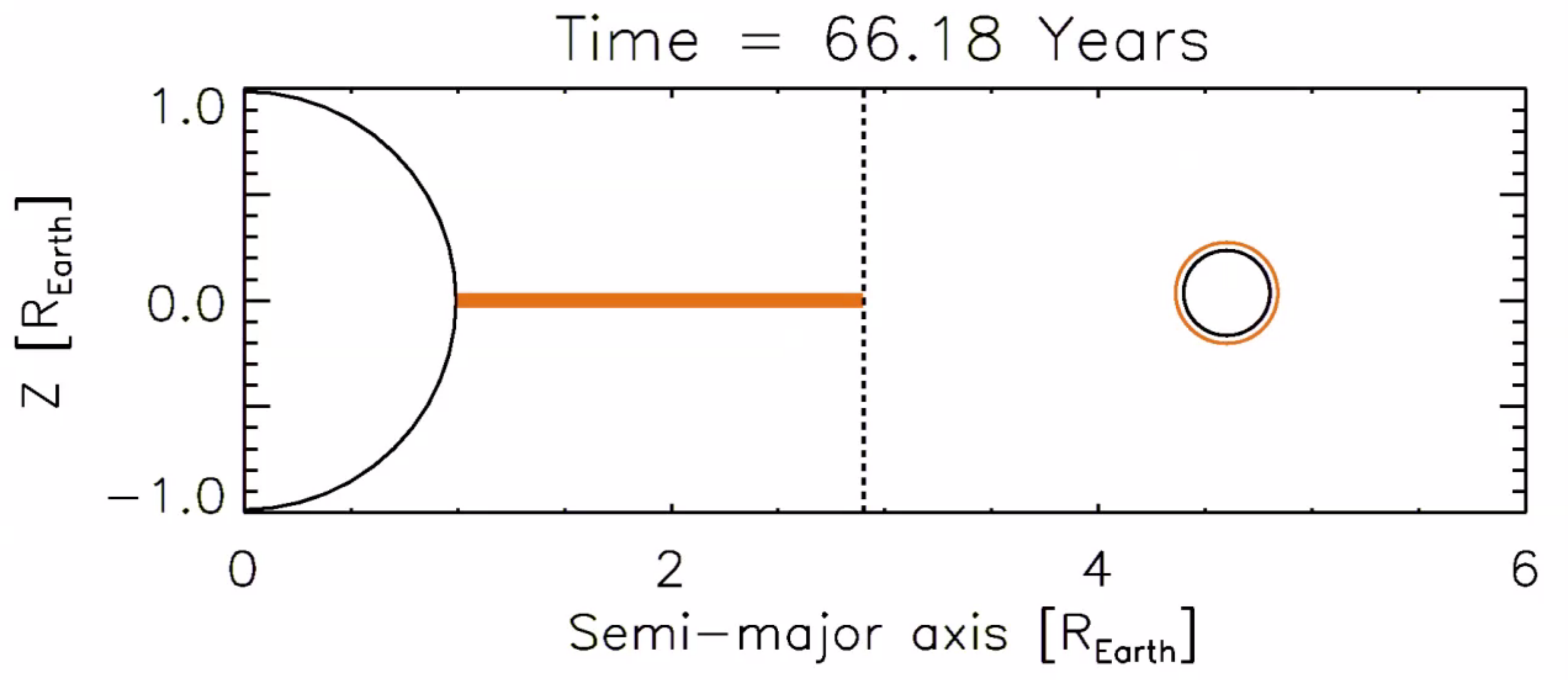


(end of stage 2)

lunar accretion model (Salmon & Canup 2012, 2014)

- early stage 3: **inner disk melt material** is accreted by the Moon
  - separation of melt component from vapor component
  - later: as Moon migrates outward, preferential accretion by Earth



(early stage 3)

lunar accretion model (Salmon & Canup 2012, 2014)

- early stage 3: **inner disk melt material** is accreted by the Moon
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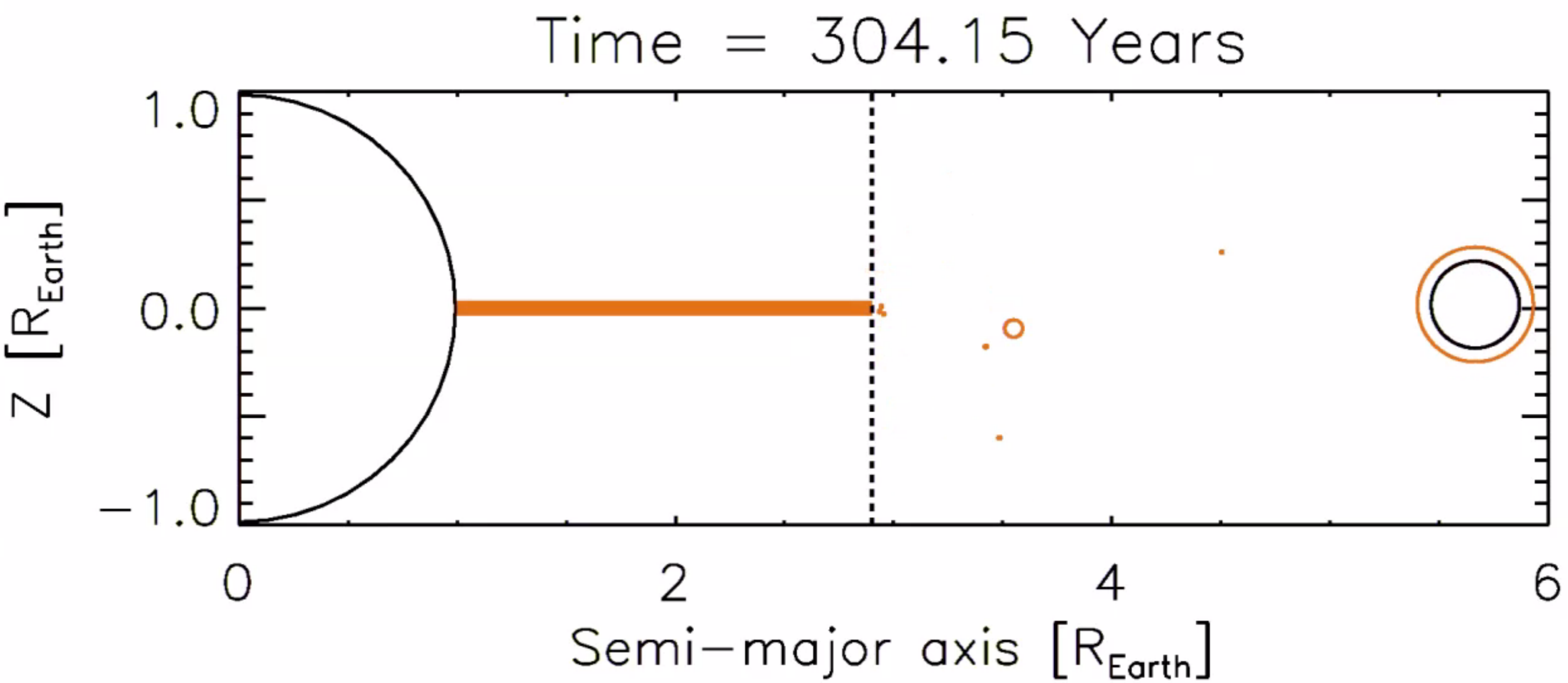
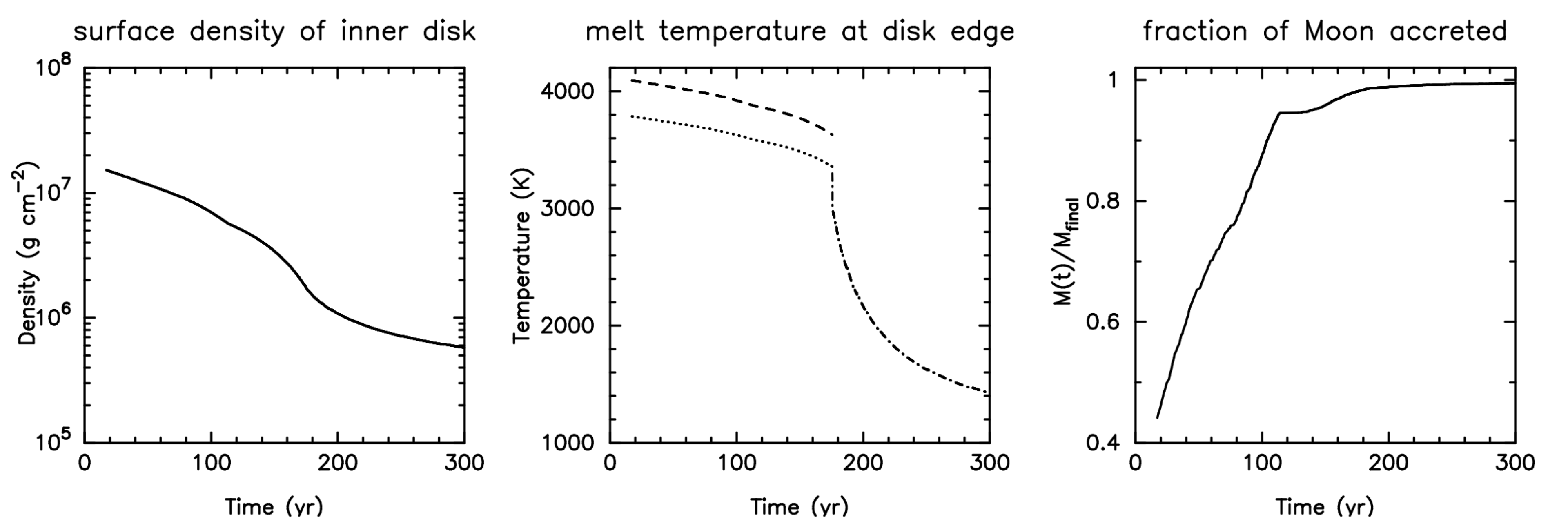


(late stage 3)

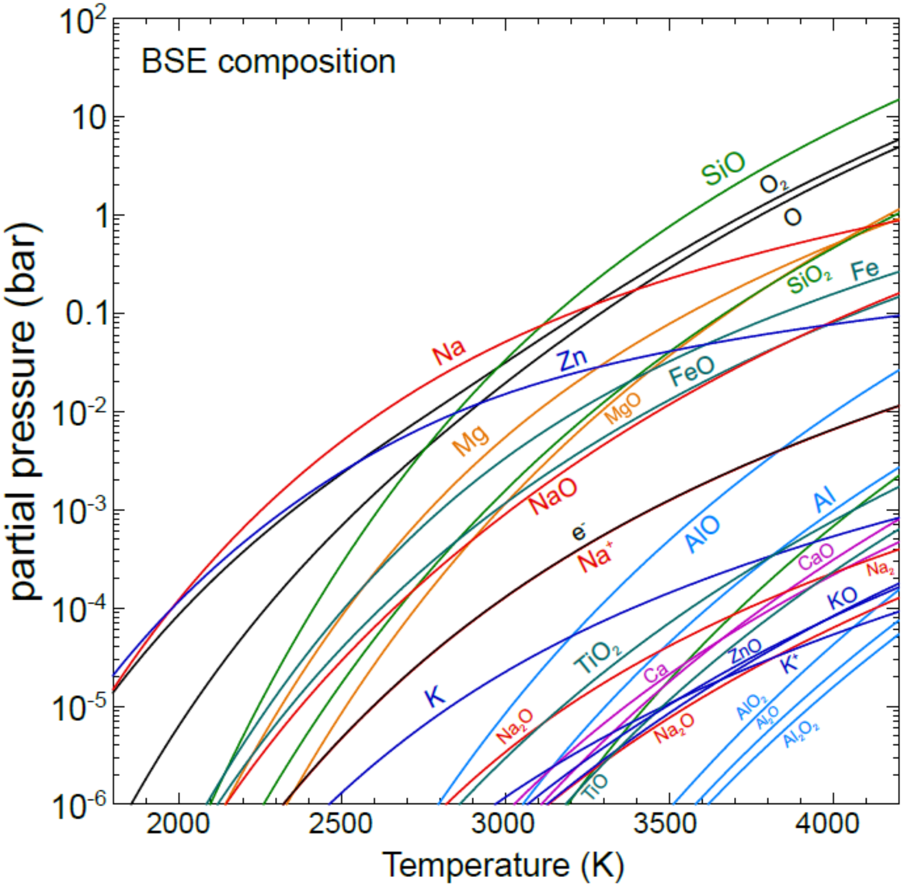
thermal model

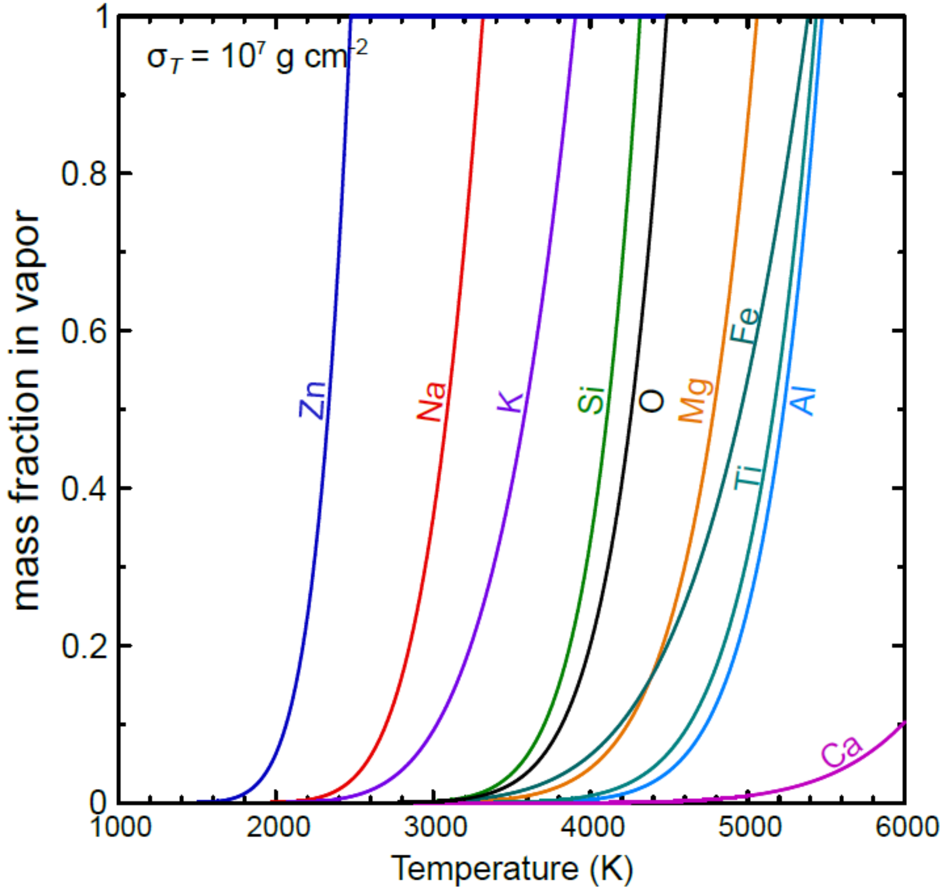
- what is temperature of melt at (Roche limit) edge of inner disk?
  - initial two-phase, melt+vapor disk (Thompson & Stevenson 1988, Ward 2012)
  - after cooling, heating by viscous dissipation & Earth luminosity



chemical model

- what is distribution of elements between melt and vapor?
  - MAGMA code for melt-vapor equilibria (Visscher & Fegley 2013)
  - estimate melt-vapor distribution for each element (cf. Petaev et al 2014)



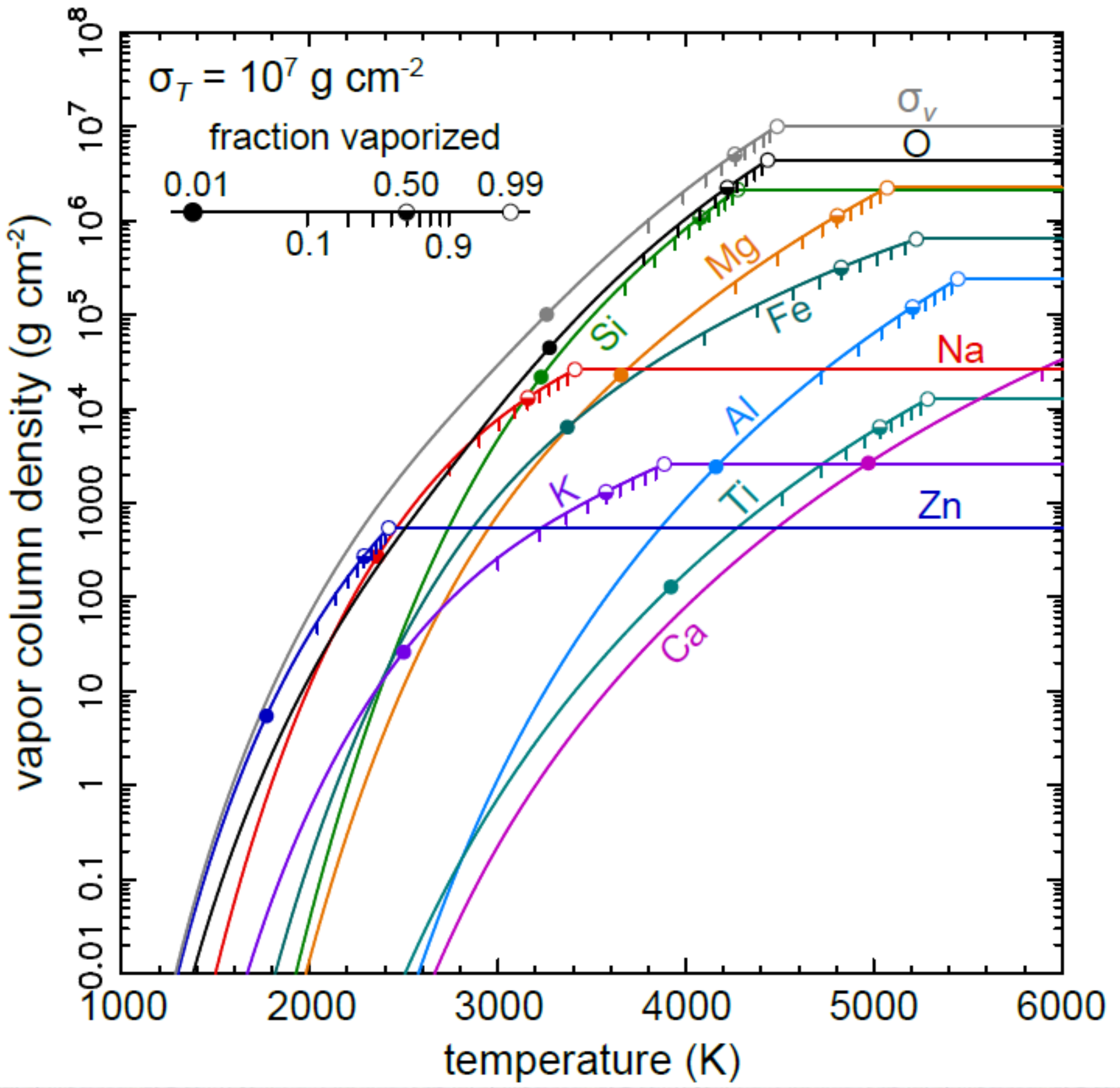


chemical model

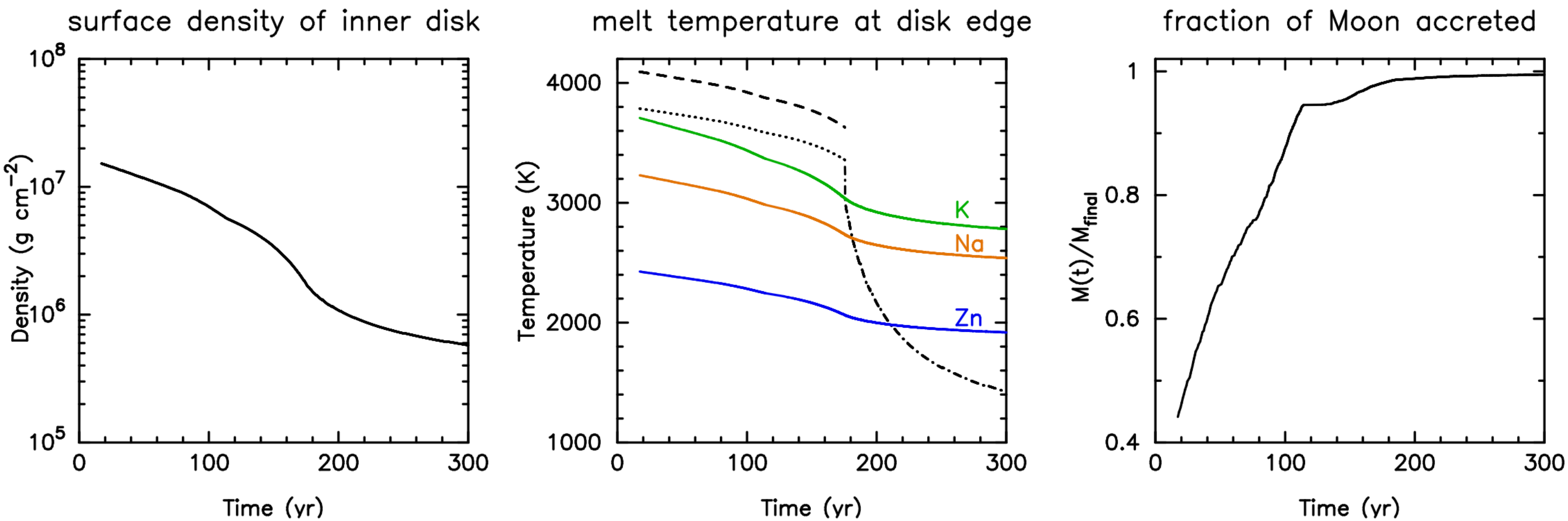
- vapor column density of each element as function of T and total disk density (σ_T)

for a given disk density:

- estimate 50% condensation temperatures
- determine abundance of elements in melt (=moonlets)



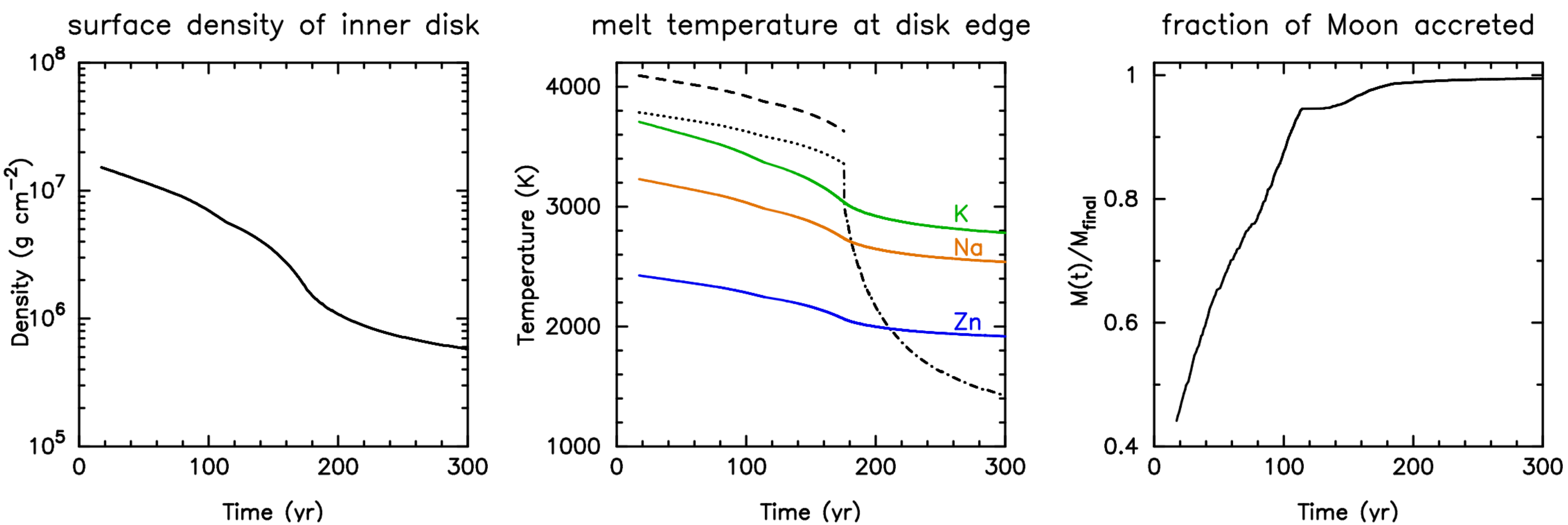
results: coupled accretion+thermal+chemical model



- 50% condensation temperatures (T_{50}) shown for K, Na, Zn

- **condensed melt material at edge of disk (source of accreting moonlets) has $T > T_{50}$ and will contain very little K, Na, Zn**

results: coupled accretion+thermal+chemical model



- accretion nearly complete *prior* to substantial condensation of K, Na, Zn

- ***even without escape*, portion of Moon's mass derived from the inner disk would be depleted in these elements**
  - predicted condensation sequence consistent with depletion order
  - 10-60% of lunar mass from inner disk material