GEOPHYSICAL EVOLUTION OF PLANETARY BUILDING BLOCKS IN THE SOLAR SYSTEM

Tim Lichtenberg

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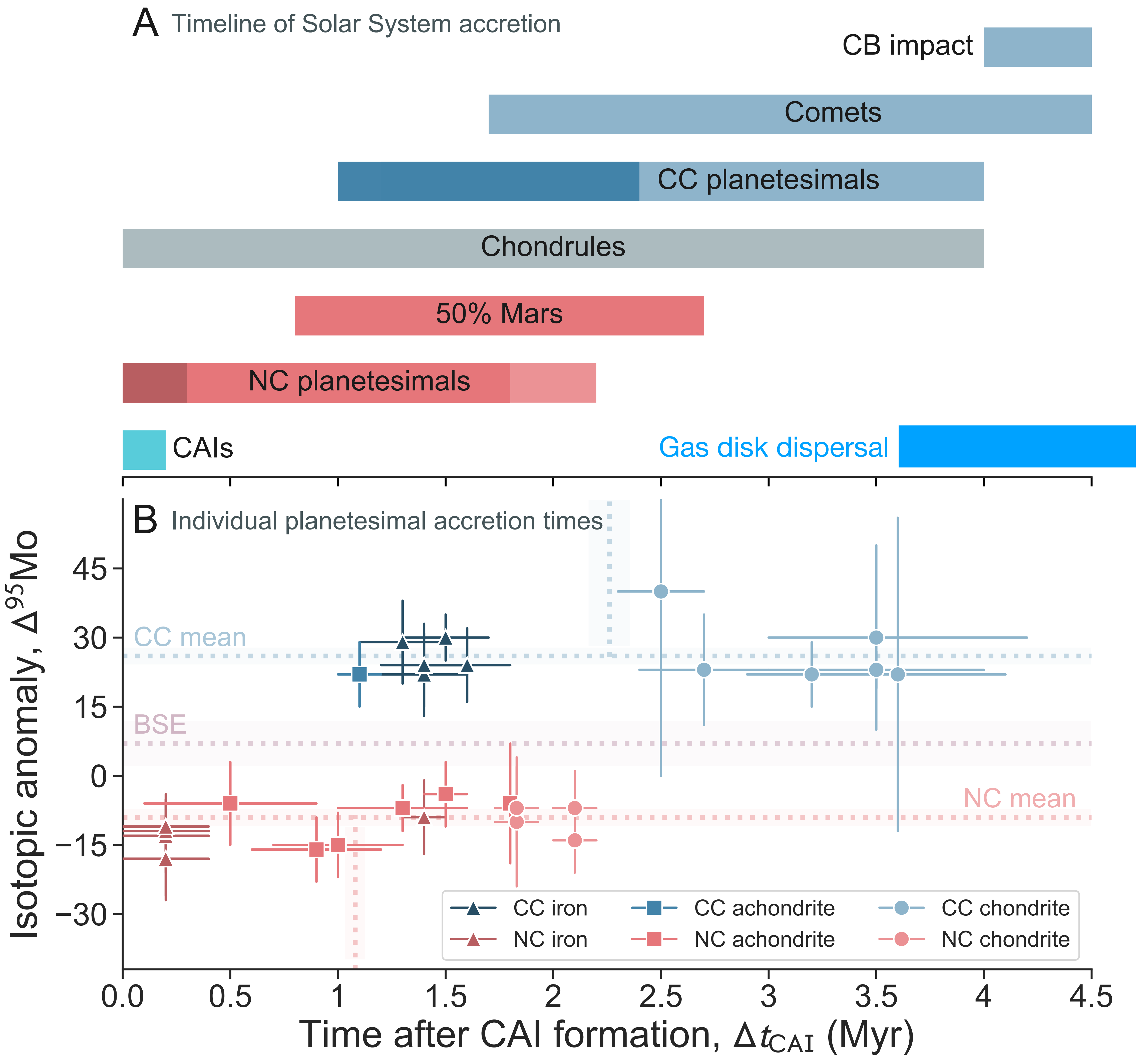
SIMONS FOUNDATION

Temporal fragmentation of planet formation



Early chronology

Lichtenberg, Schaefer, Nakajima, Fischer 2022 (*Protostars & Planets VII, under review*)

Early chronology: CAI & chondrules: Connelly et al. (2012), Mars accretion: Dauphas & Pourmand (2011), comets: Matzel et al. (2010), CB impact: Krot et al. (2005), individual accretion ages: Hunt et al. (2018), Kleine et al. (2020), Kruijer et al. (2014), Golabek et al. (2014), Neumann et al. (2018), Hunt et al. (2017), Sugiura & Fujiya (2014), Blackburn et al. (2017), Bryson & Brennecka (2021), Doyle et al. (2015), Ma et al. (2021). **Late chronology**: (1) Thiemens et al. (2019), (2) Touboul et al. (2007), (3) Jacobson et al. (2014), (4,5) Meyer et al. (2010), Maurice et al. (2020), (6,7) Norman et al. (2003), (5) Nyquist et al. (1995), (8) Nemchin et al. (2009), (9,10) Kleine et al. (2002, 2004), (11) Boyet & Carlson (2005), (12–14) Abe (1997), Lebrun et al. (2013), Solomatov (2000), (15) Wilde et al. (2001), Mojzsis et al. (2001), (16,17) Dauphas & Pourmand (2011), Marchi et al. (2020), (18,19) Bouvier et al. (2018), Kruijer et al. (2020), (20,21) Borg et al. (2016), Debaille et al. (2017).

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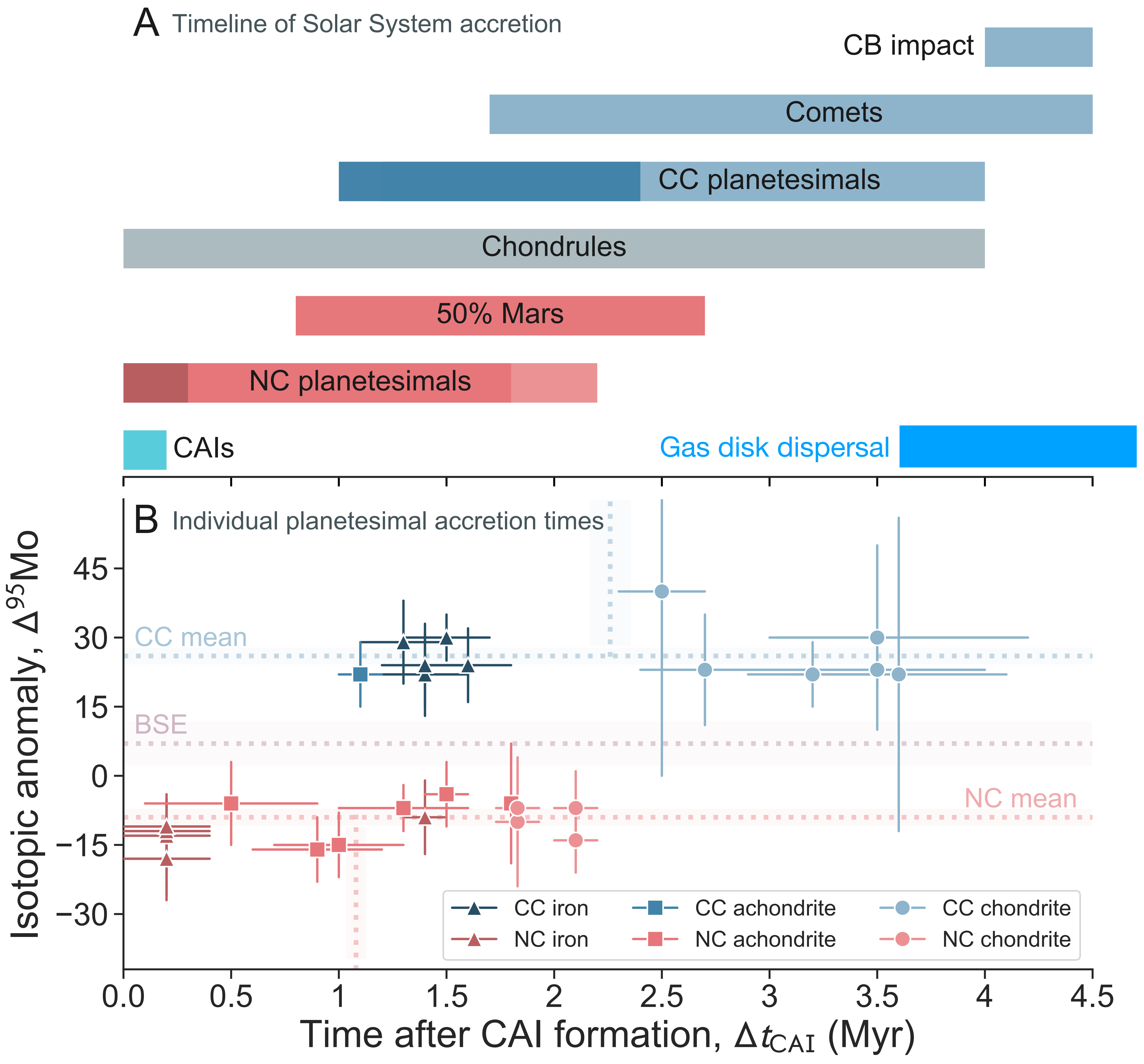

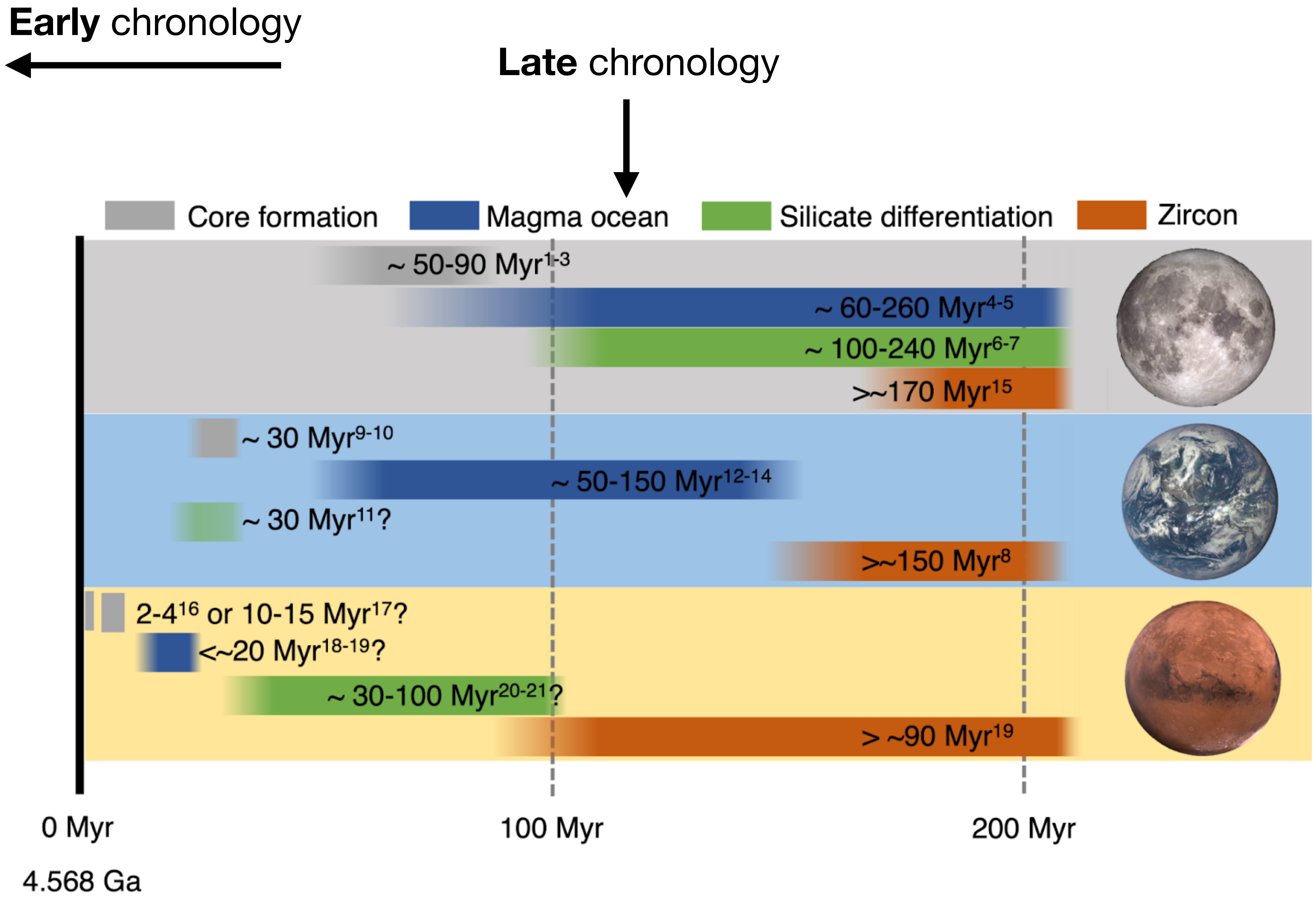

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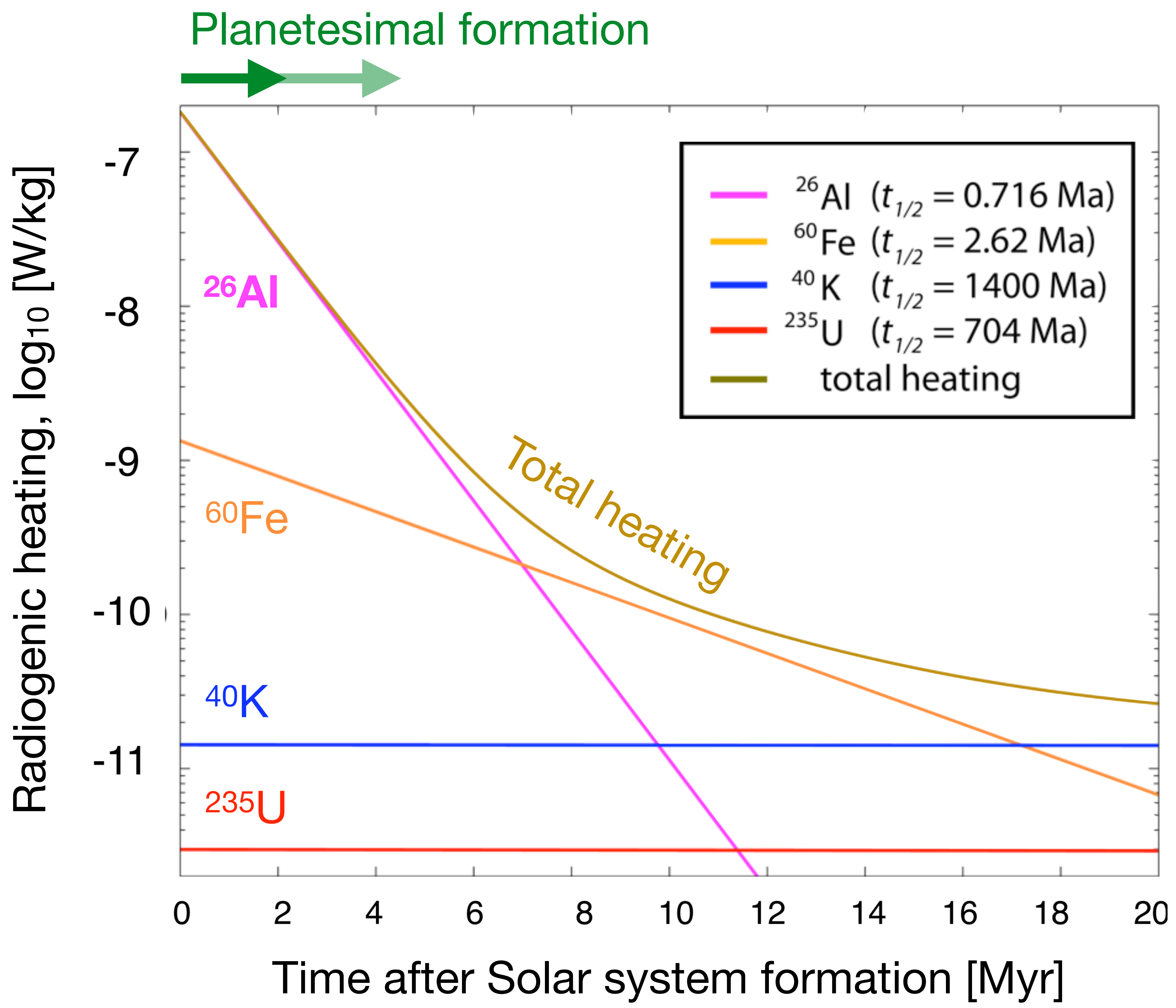
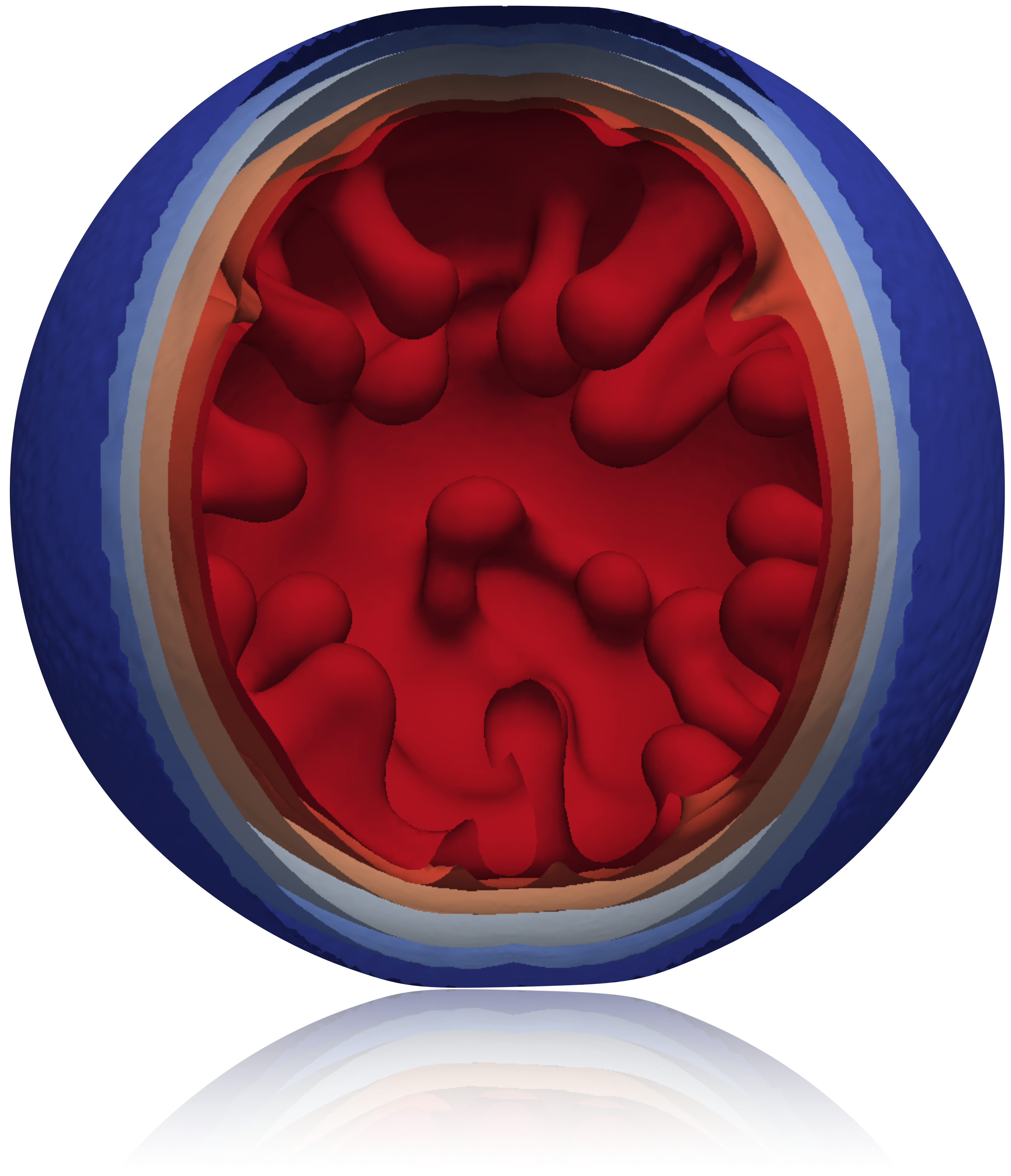
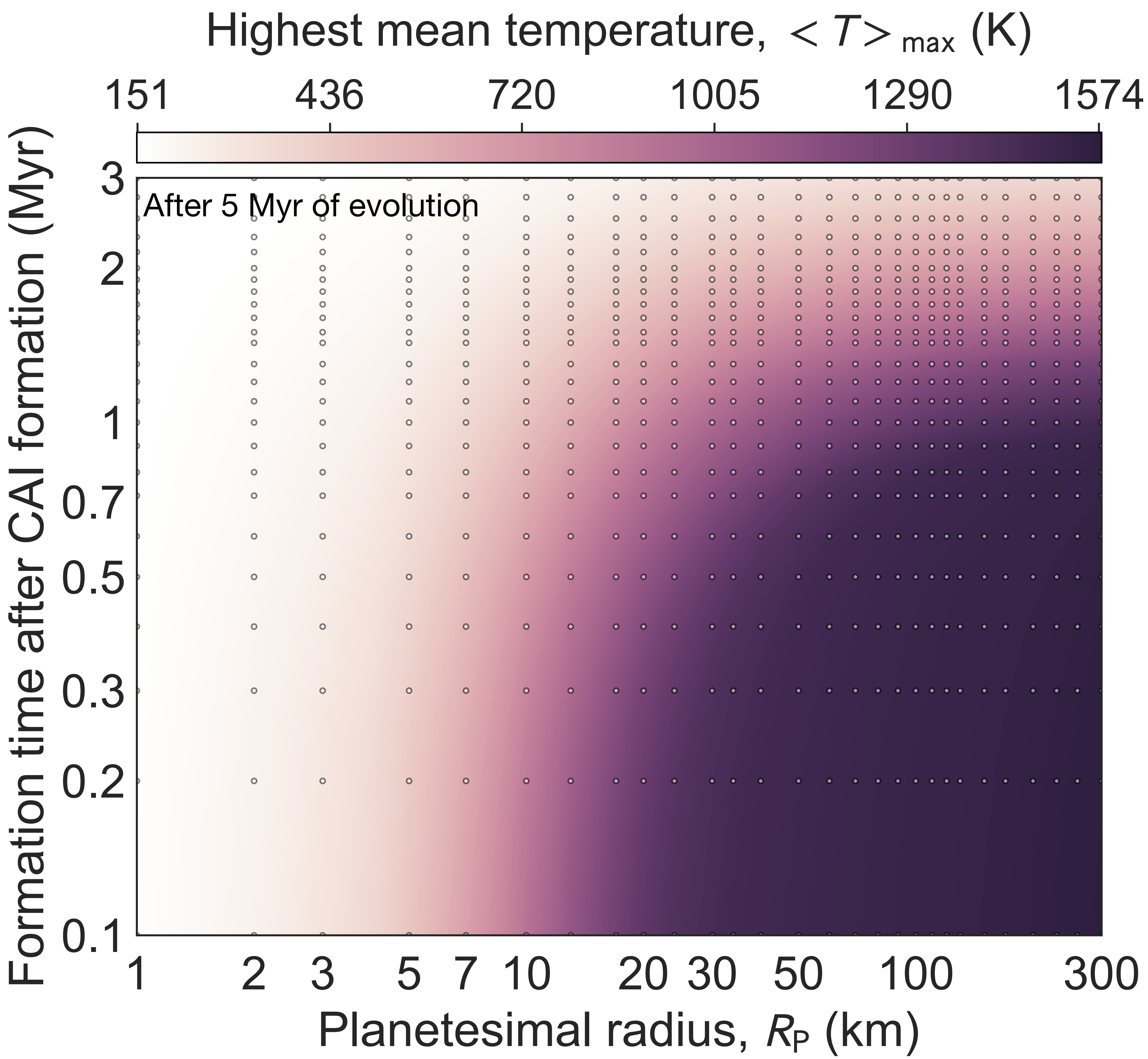
Compositional evolution from radiogenic heating



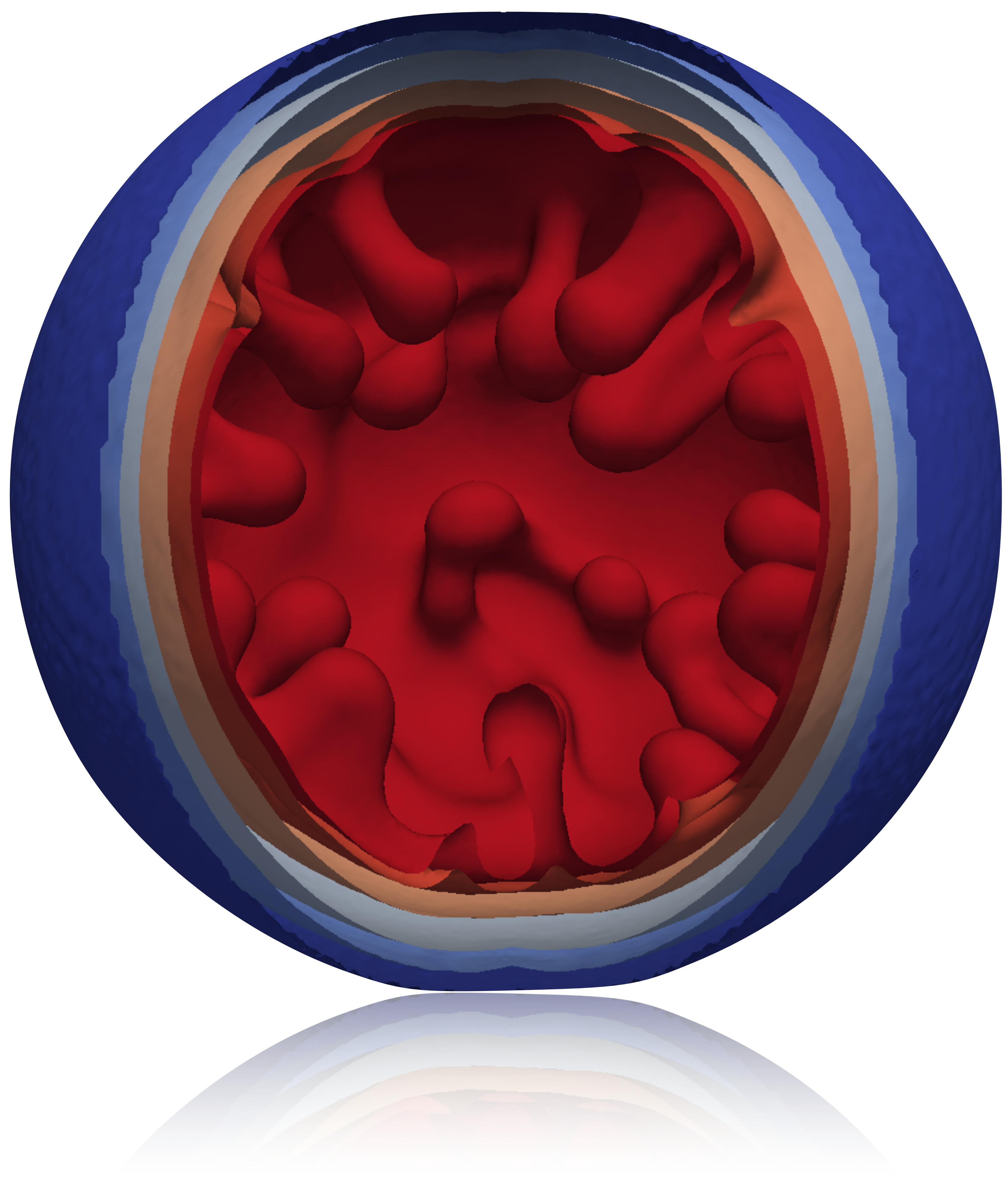


Lichtenberg+ 16a, 18, 19a,b

Radiogenic heating drives thermal evolution

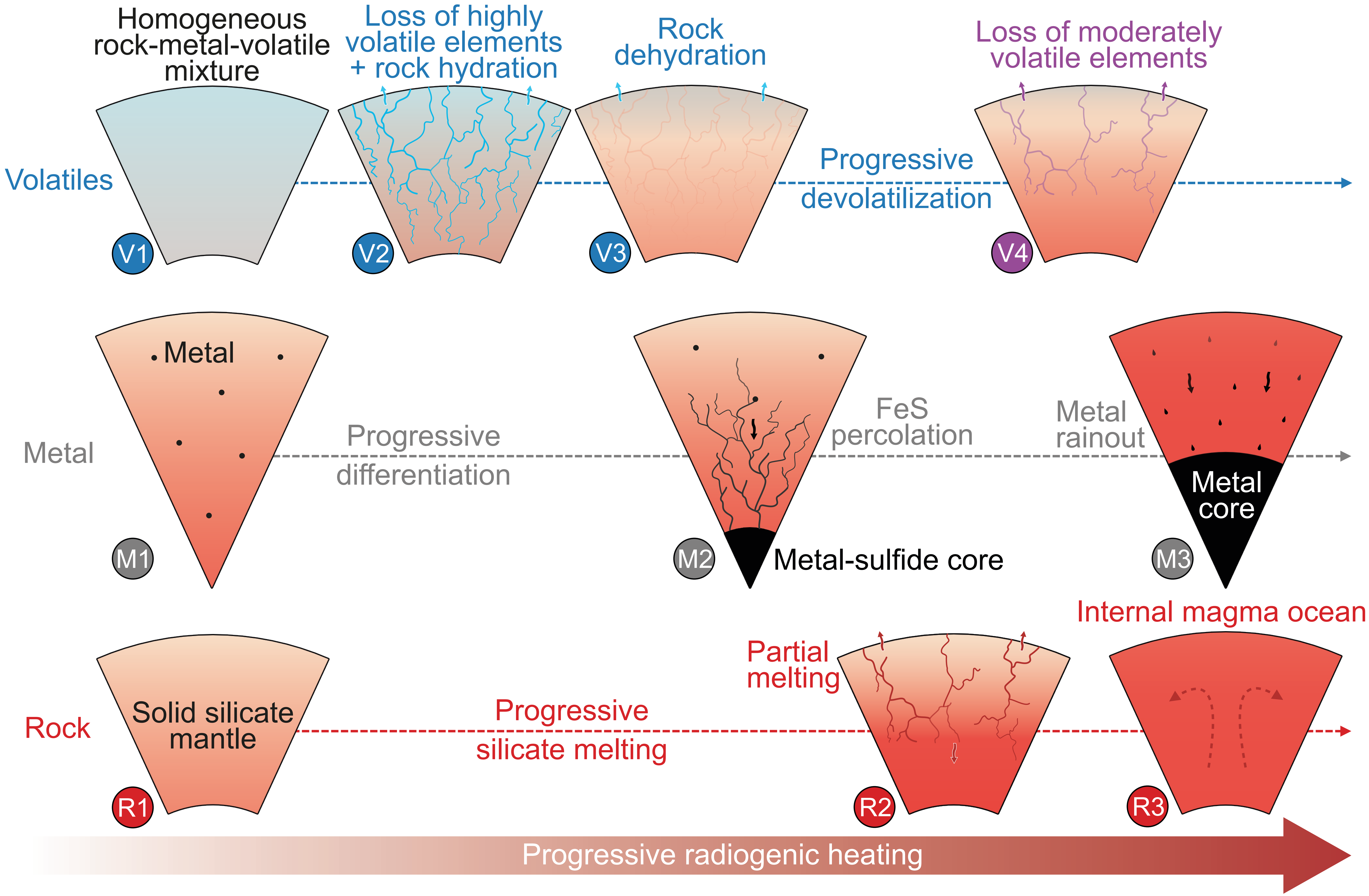


Lichtenberg, Drążkowska+ 21



Lichtenberg+ 16a, 18, 19a,b

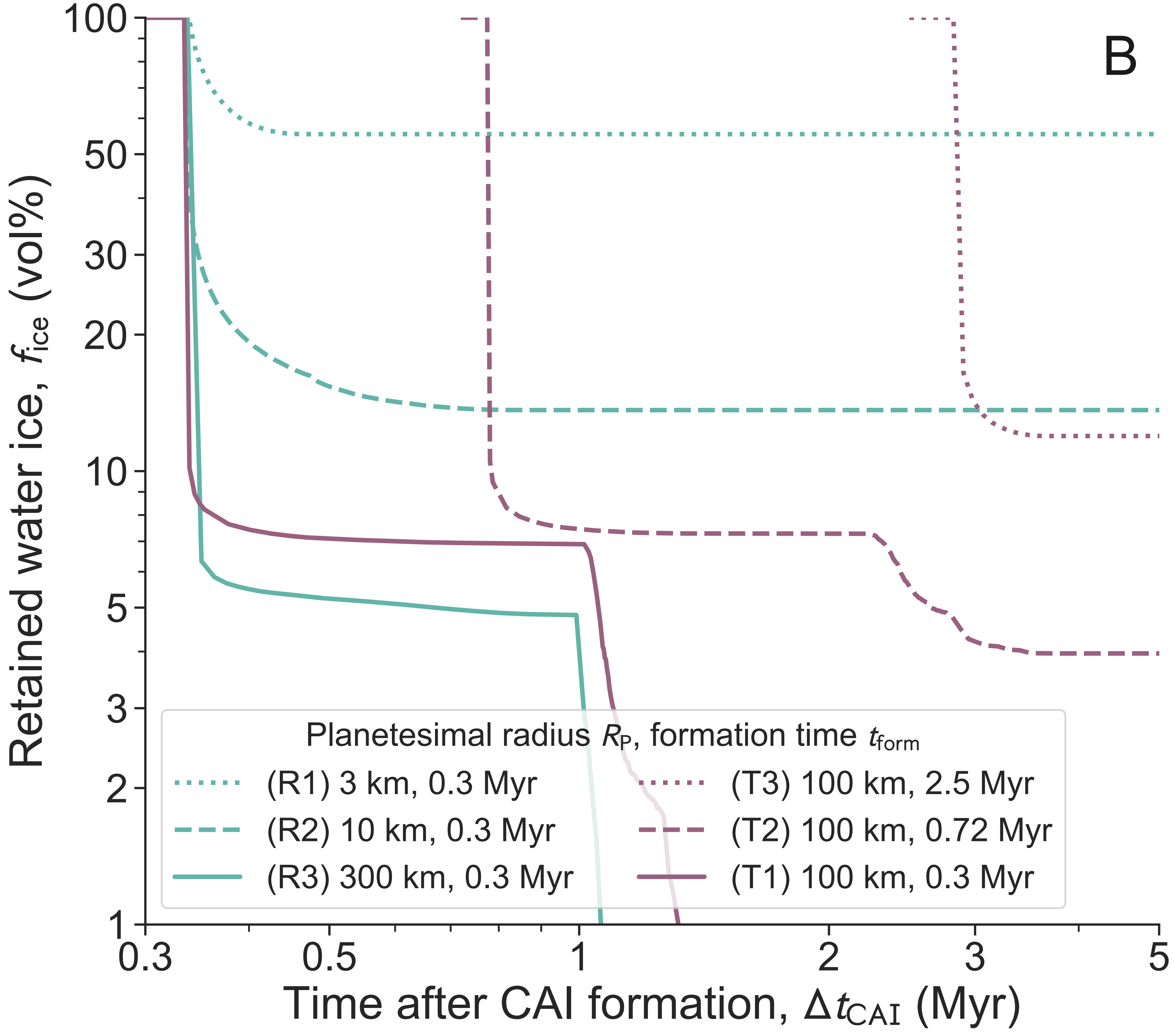
Thermal and compositional evolution **highly time sensitive**



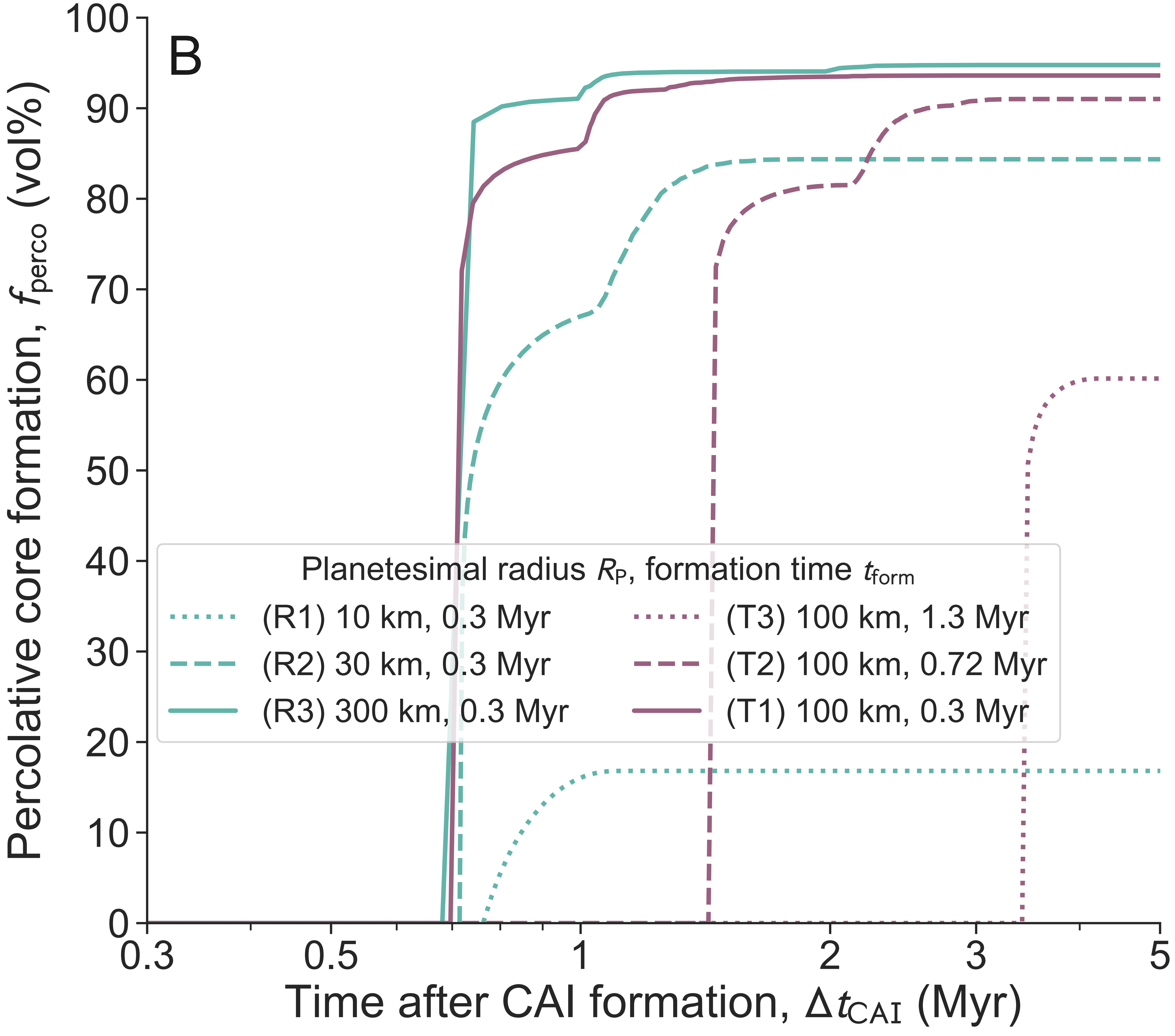
Lichtenberg+ 22, *PPVII*

Thermal and compositional evolution **highly time sensitive**

Planetesimal dehydration



Initial core formation



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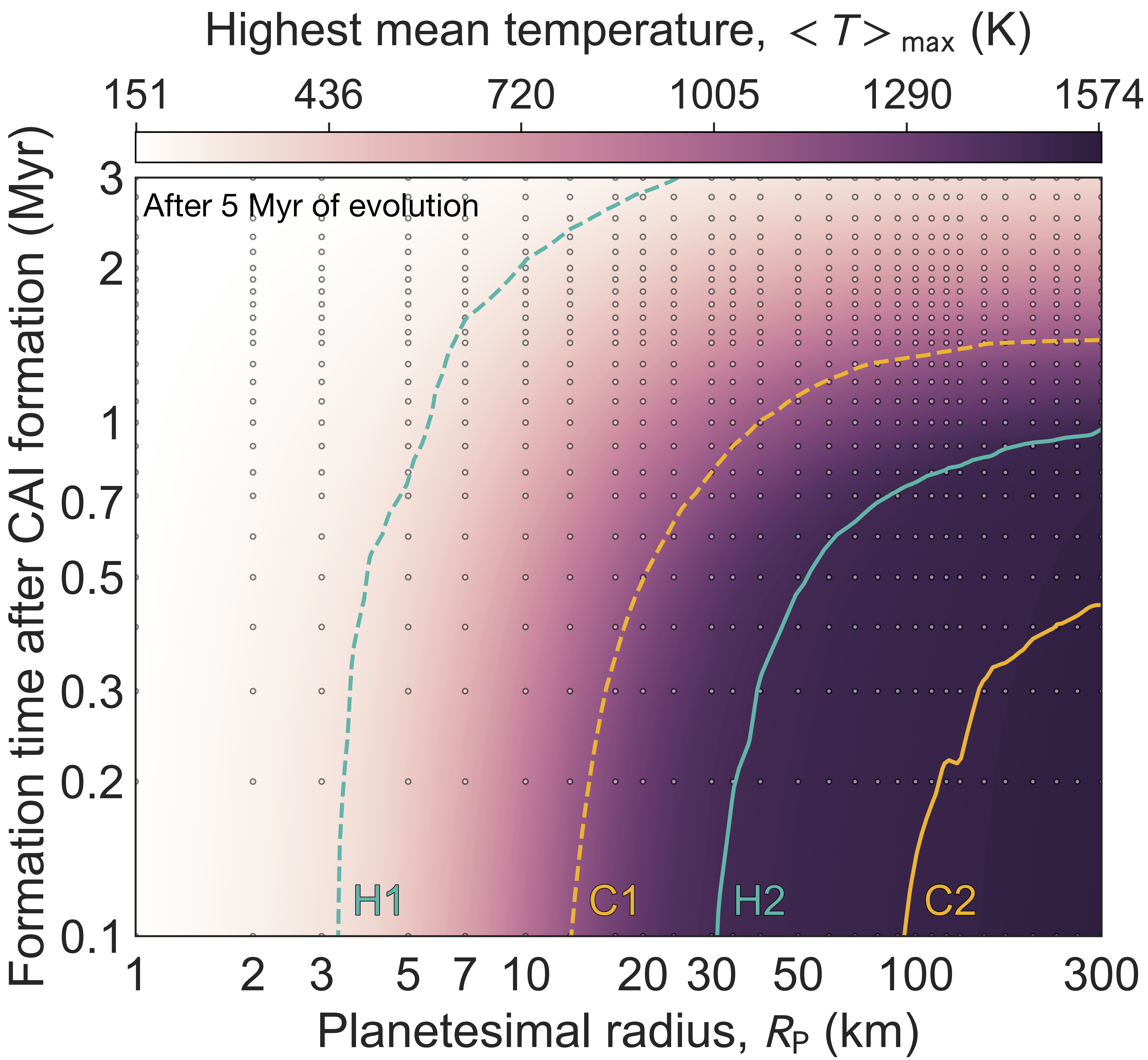
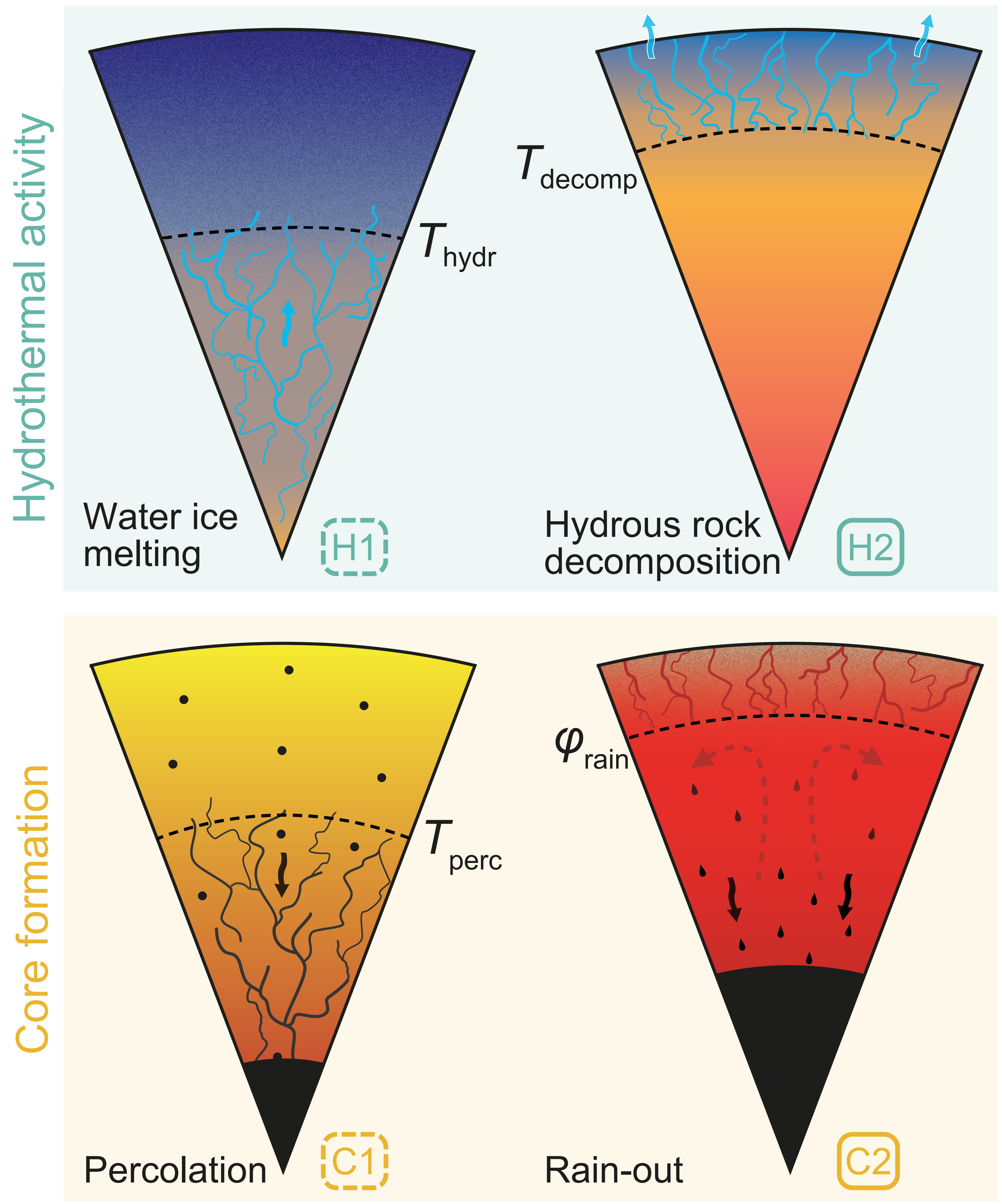
Compositional bifurcation by radiogenic heating





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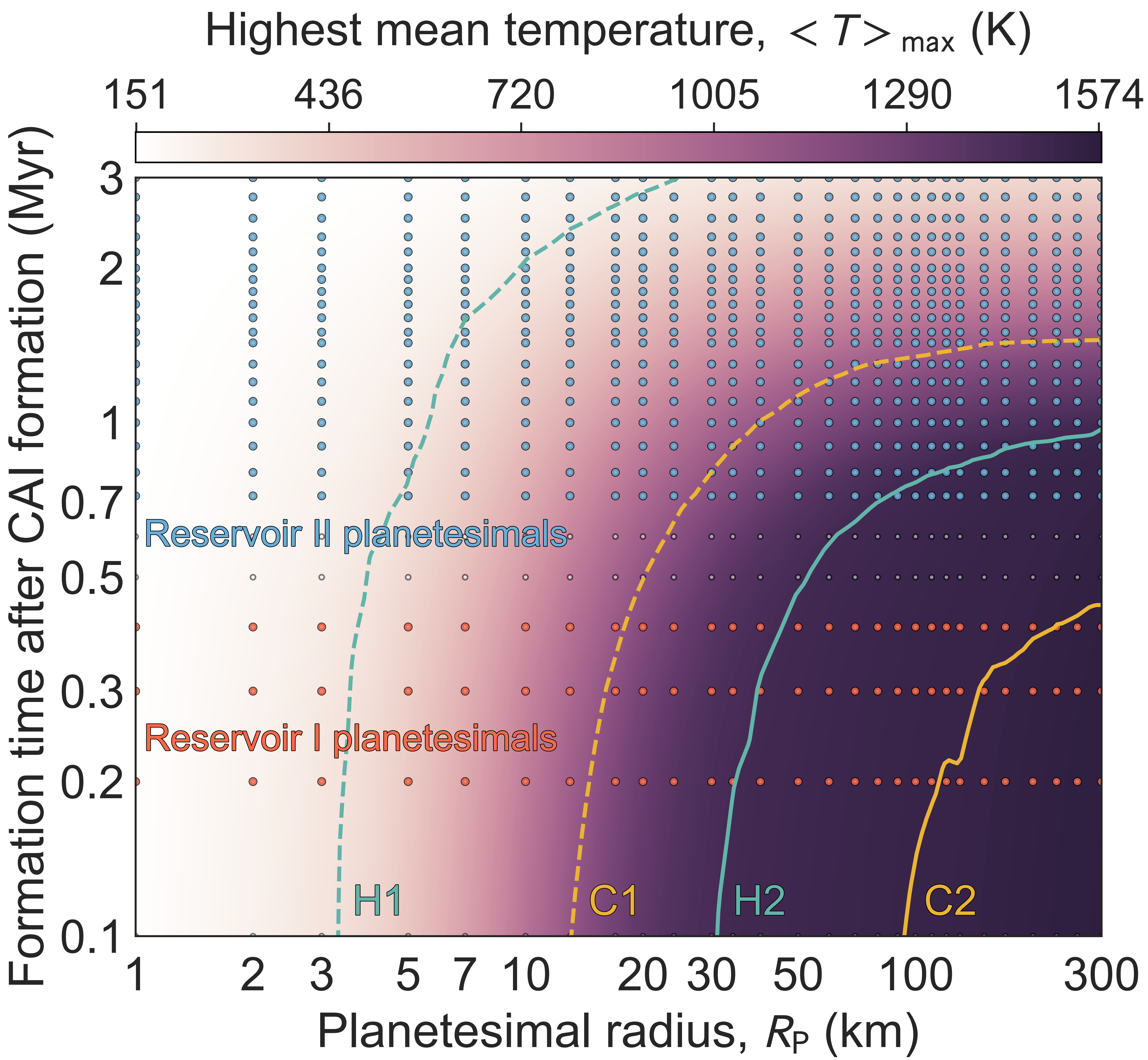

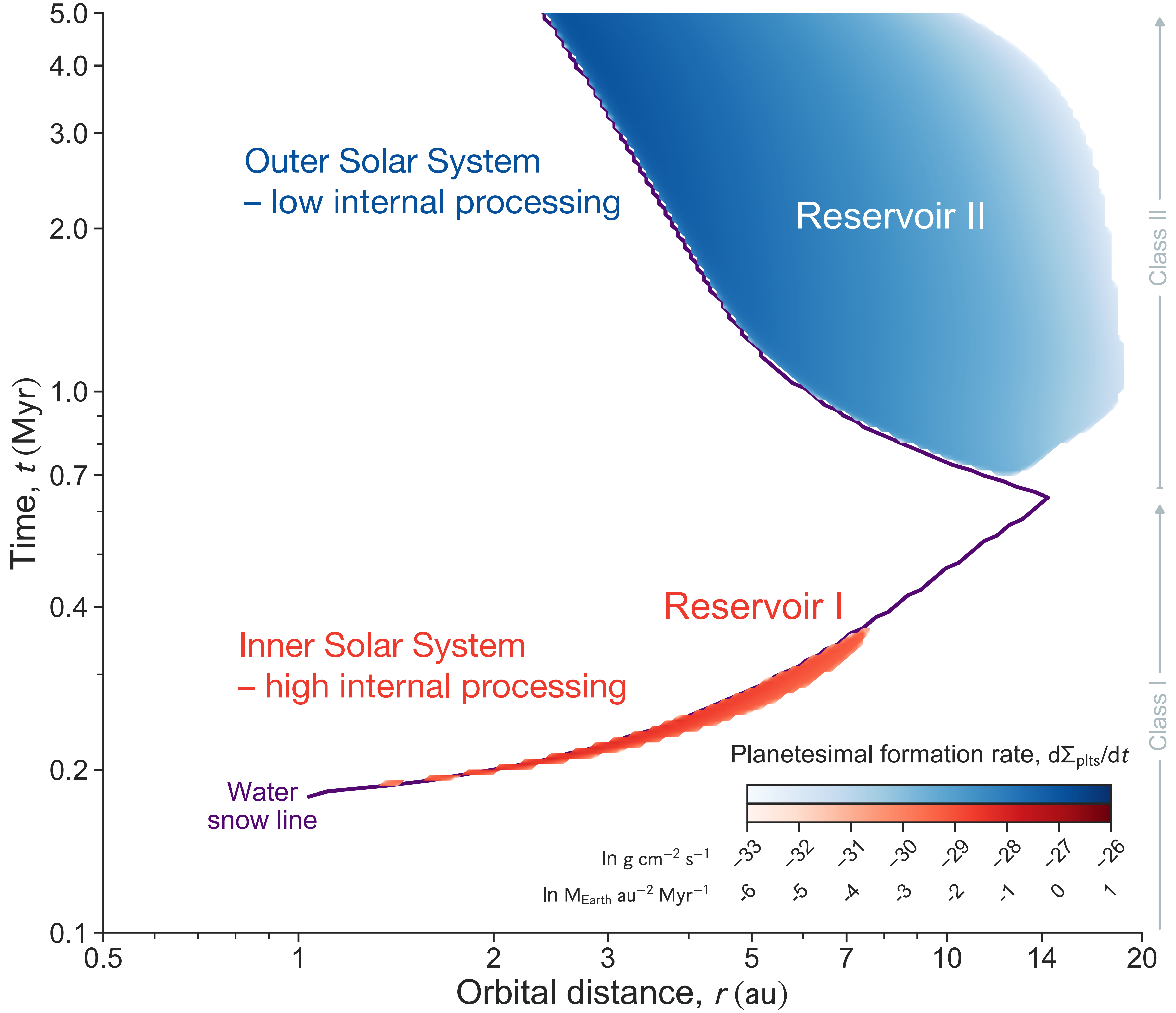

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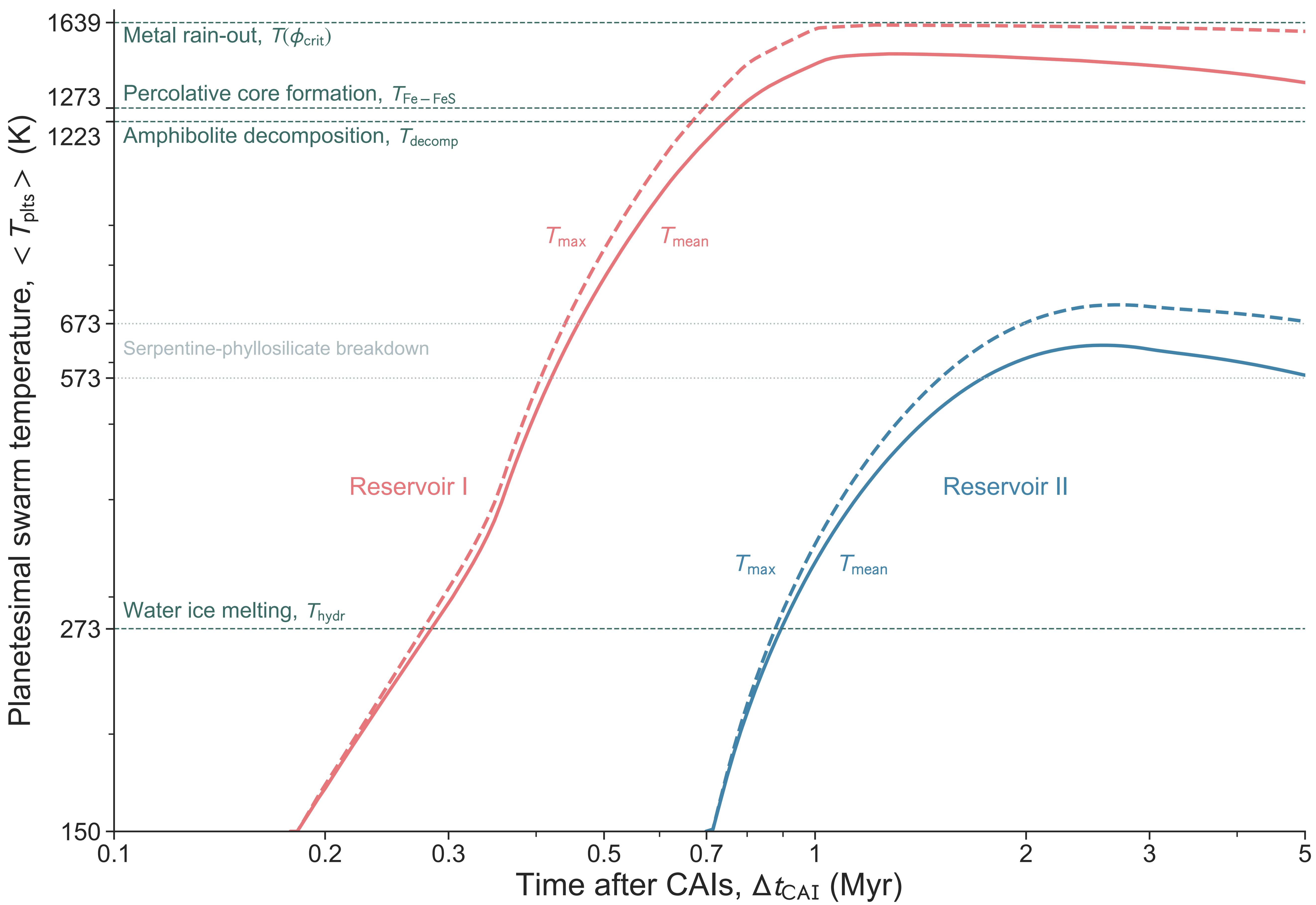
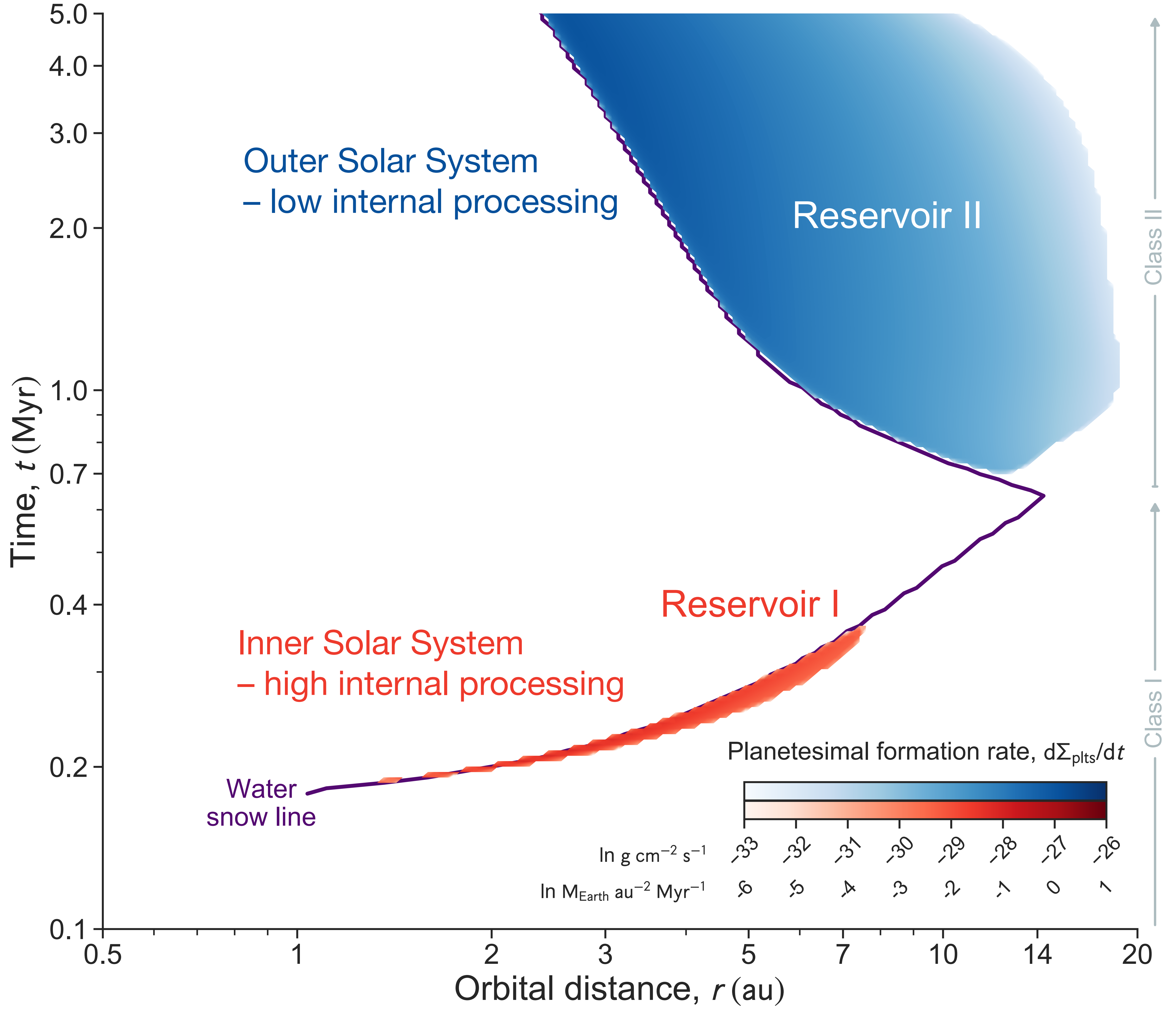
Compositional bifurcation by radiogenic heating

Planetesimal swarm evolution





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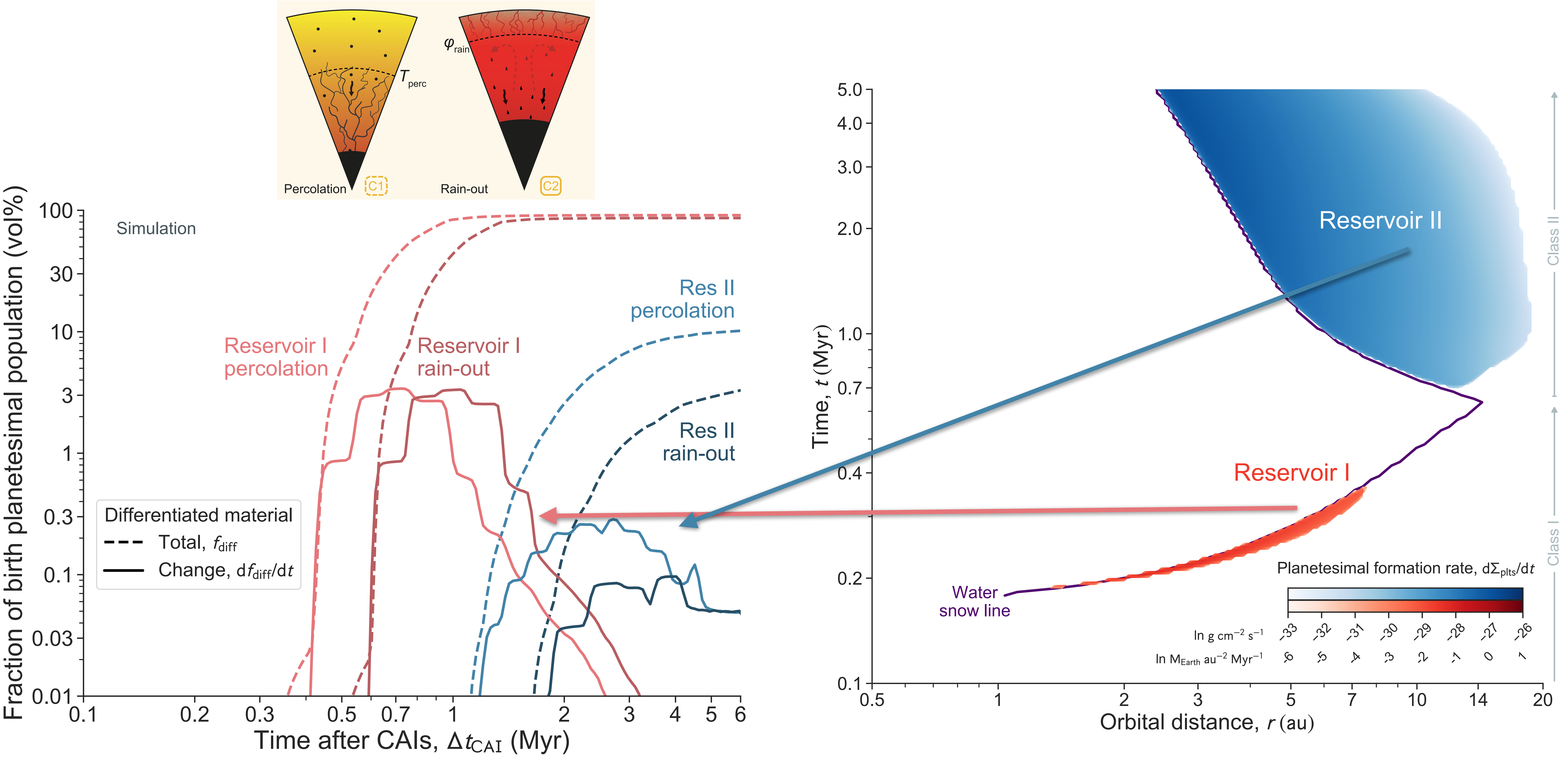
Iron core formation: meteorites vs. model



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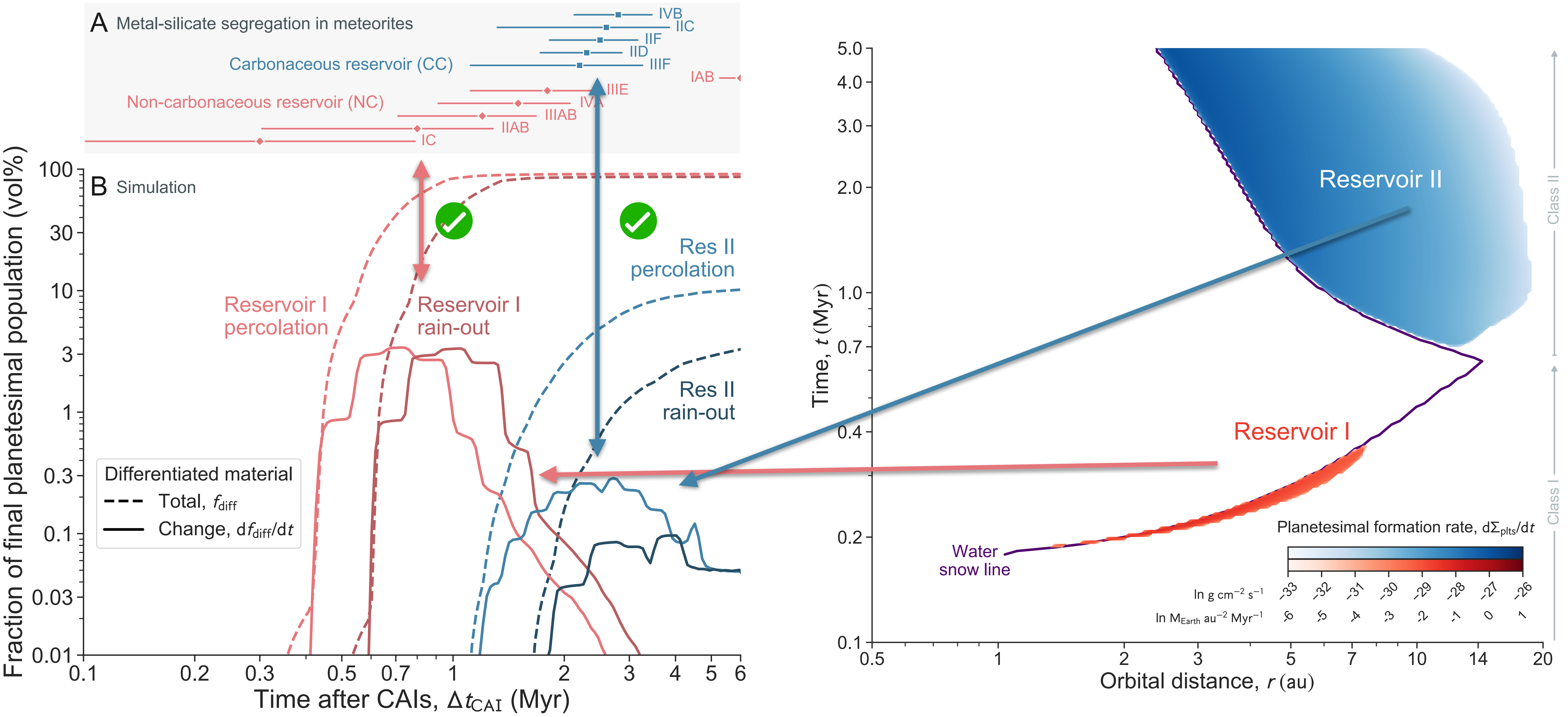

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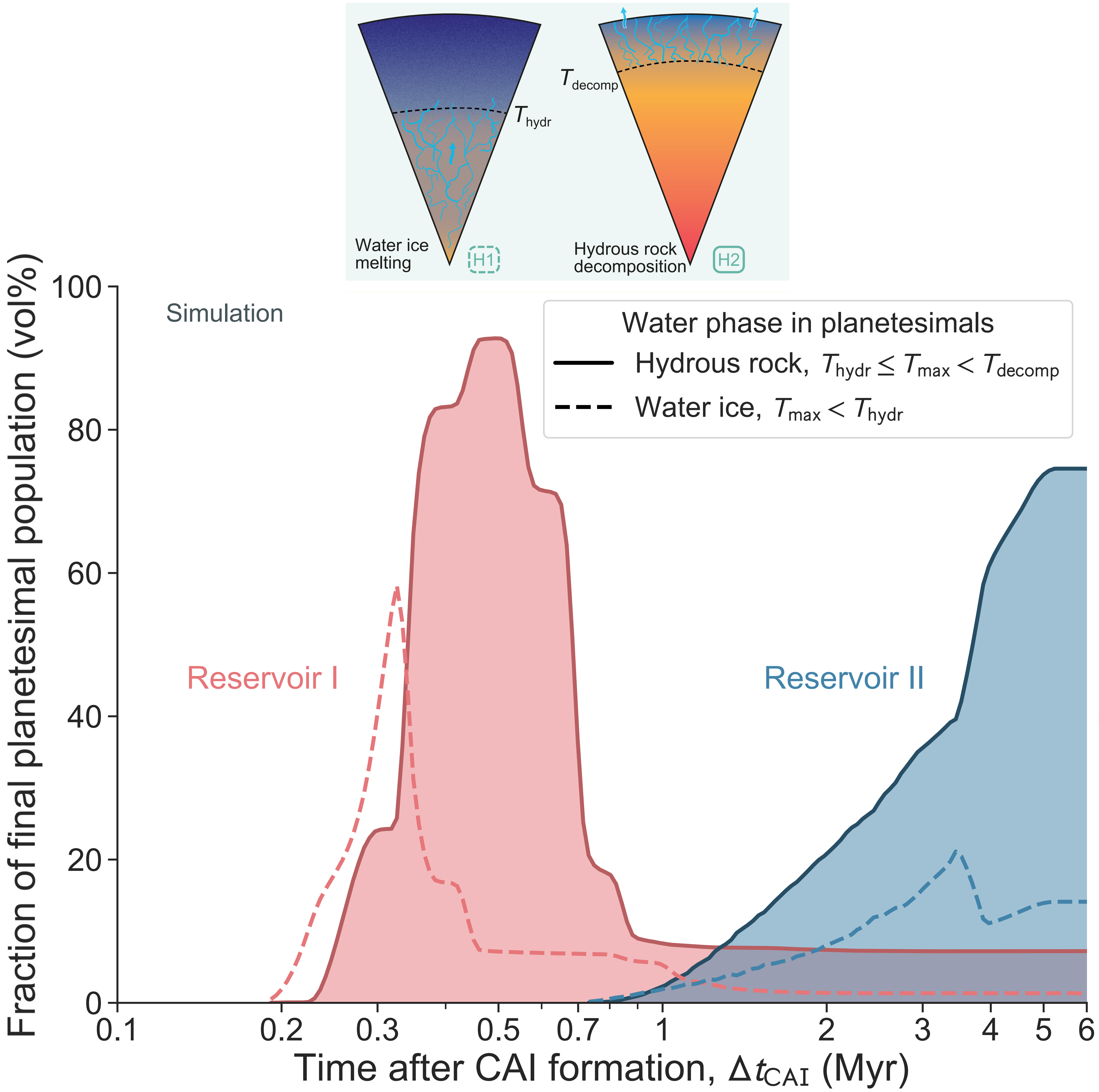
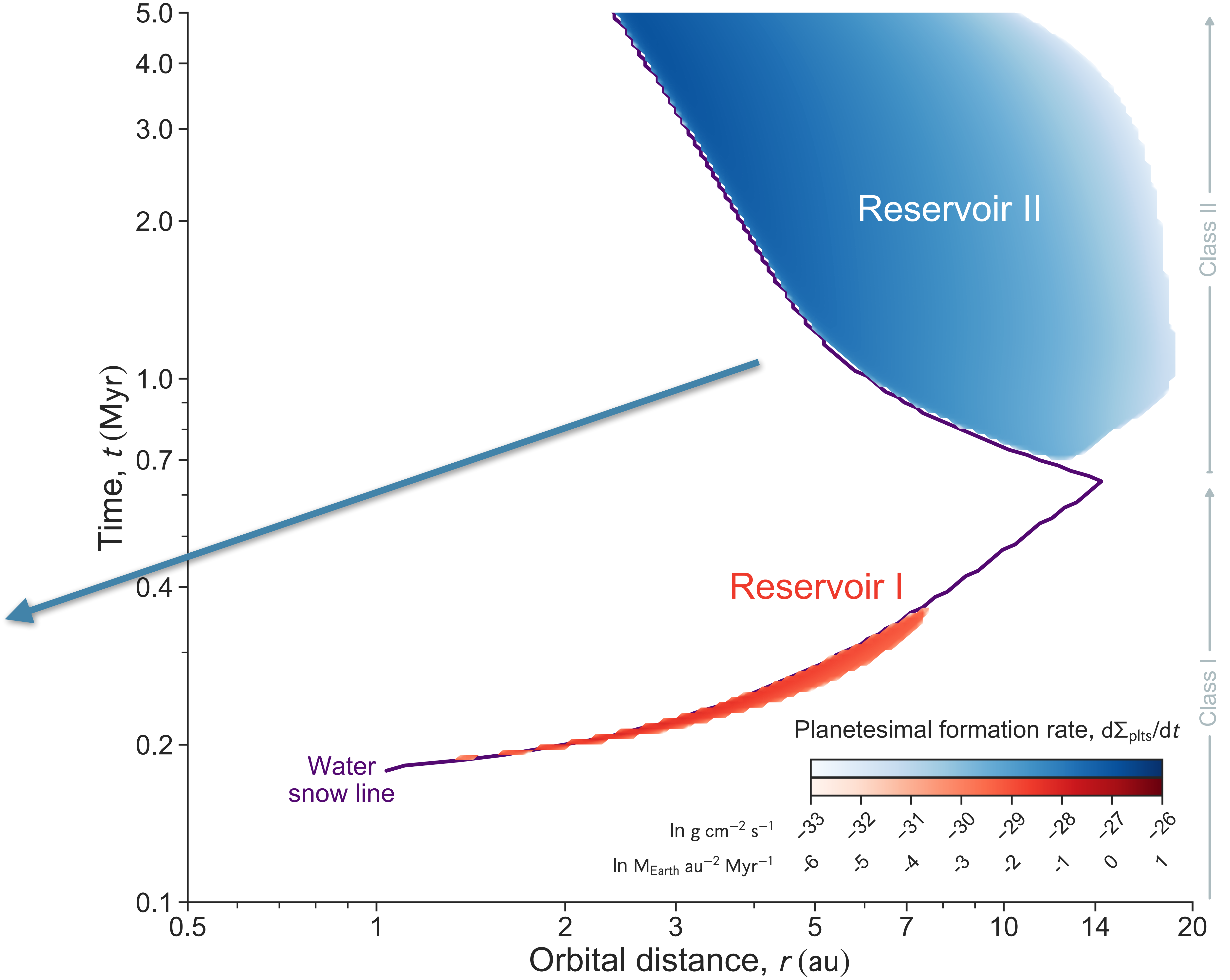
Aqueous alteration: meteorites vs. model





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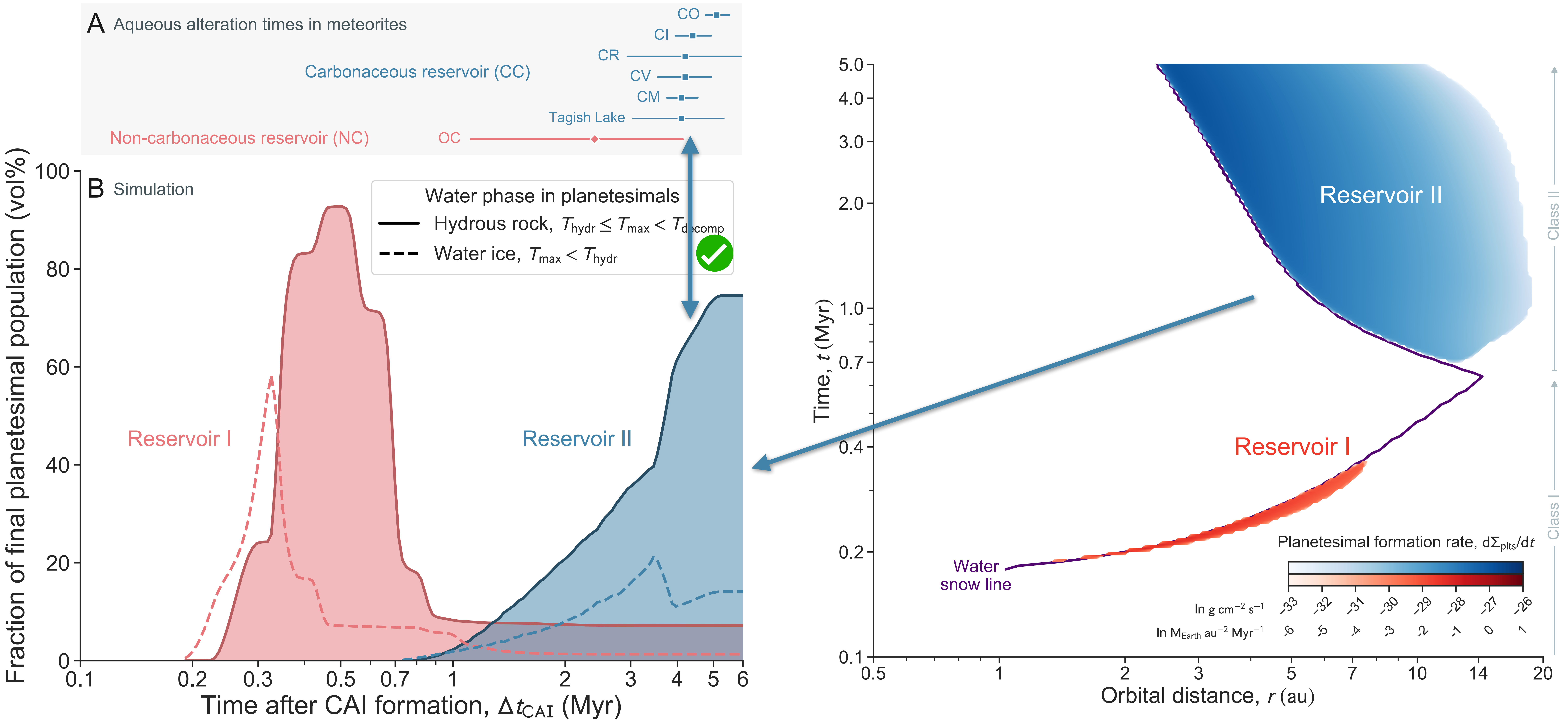
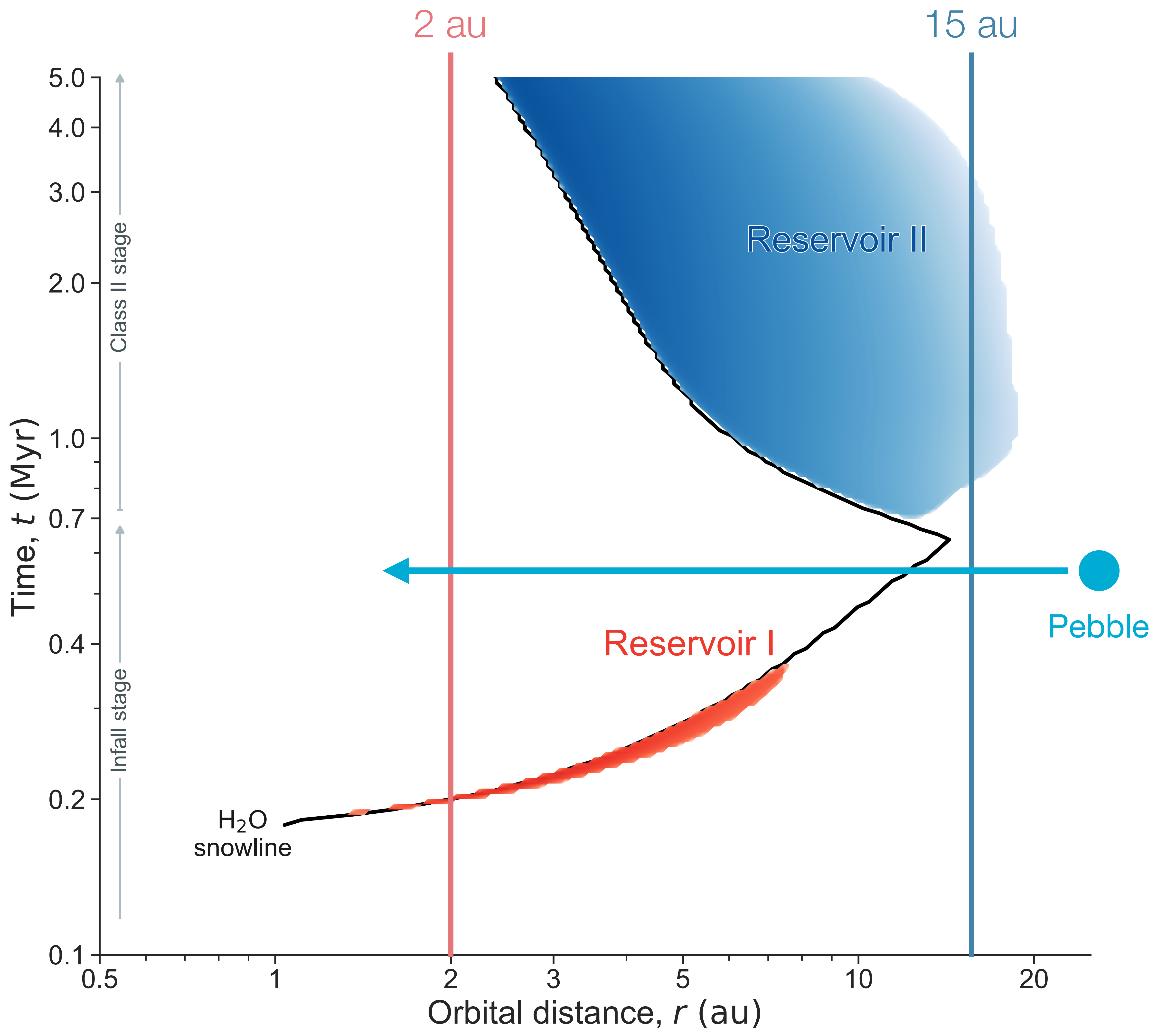
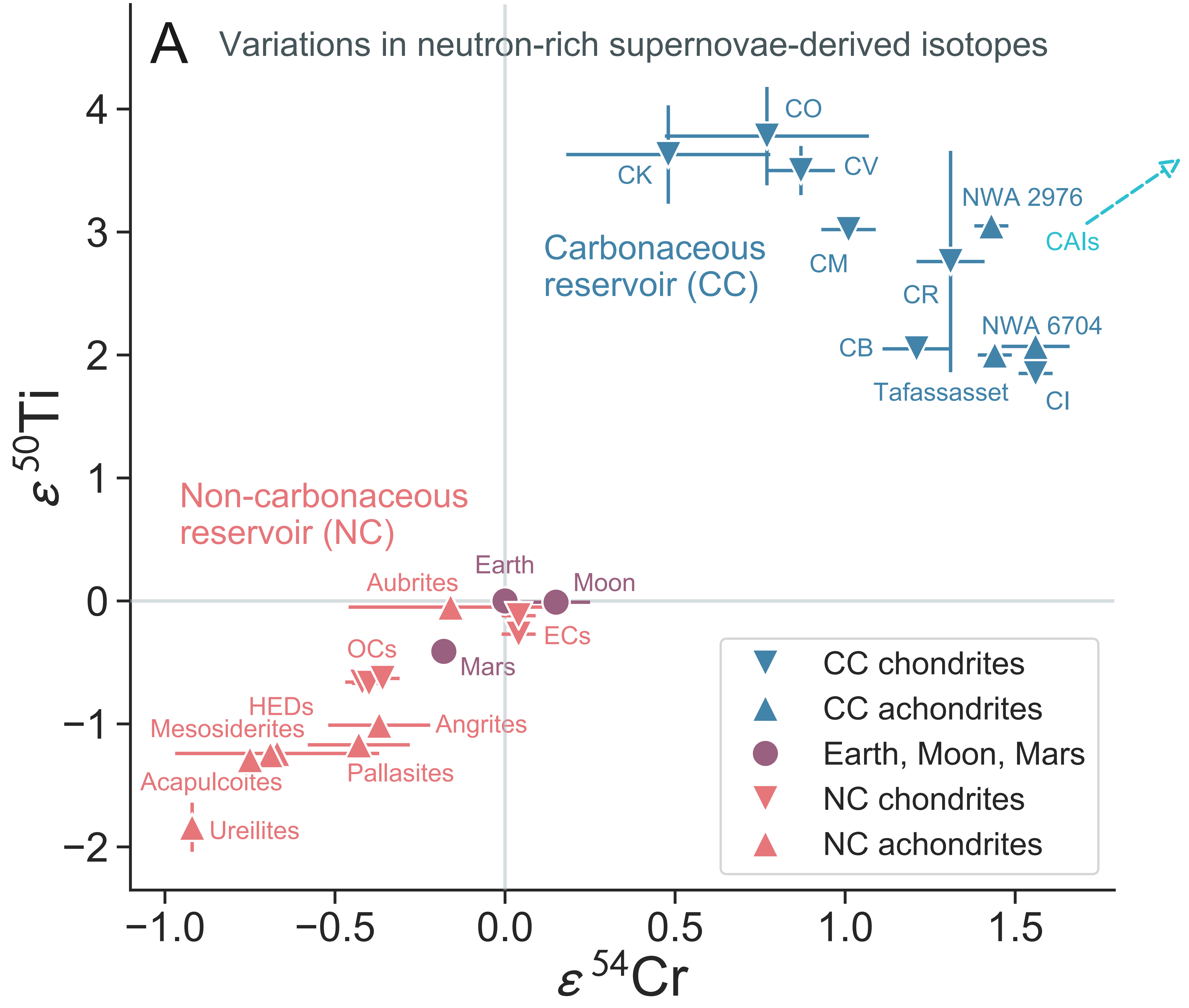


Lichtenberg, Drążkowska+ 21

Isotope dichotomy by pebble flux suppression





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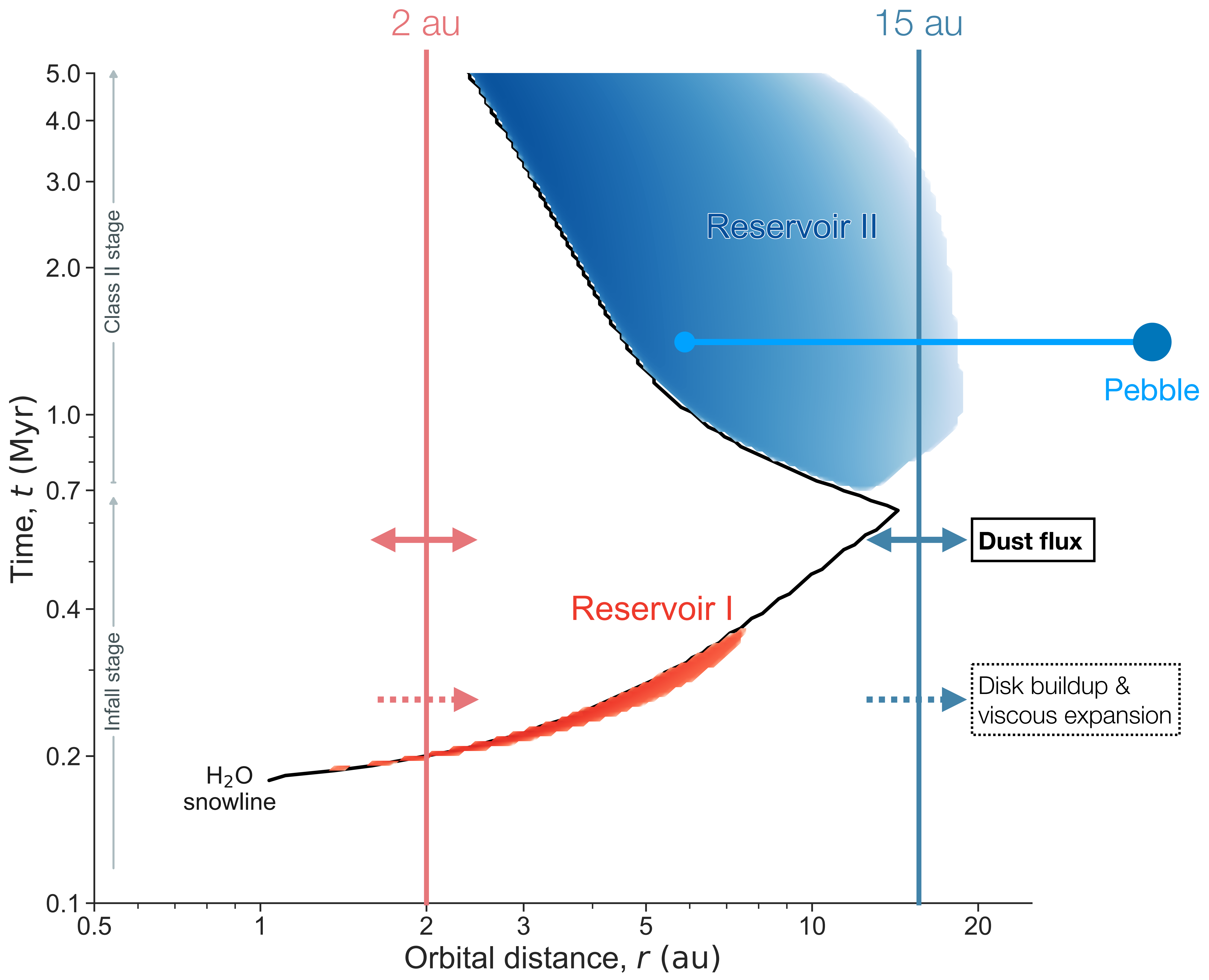
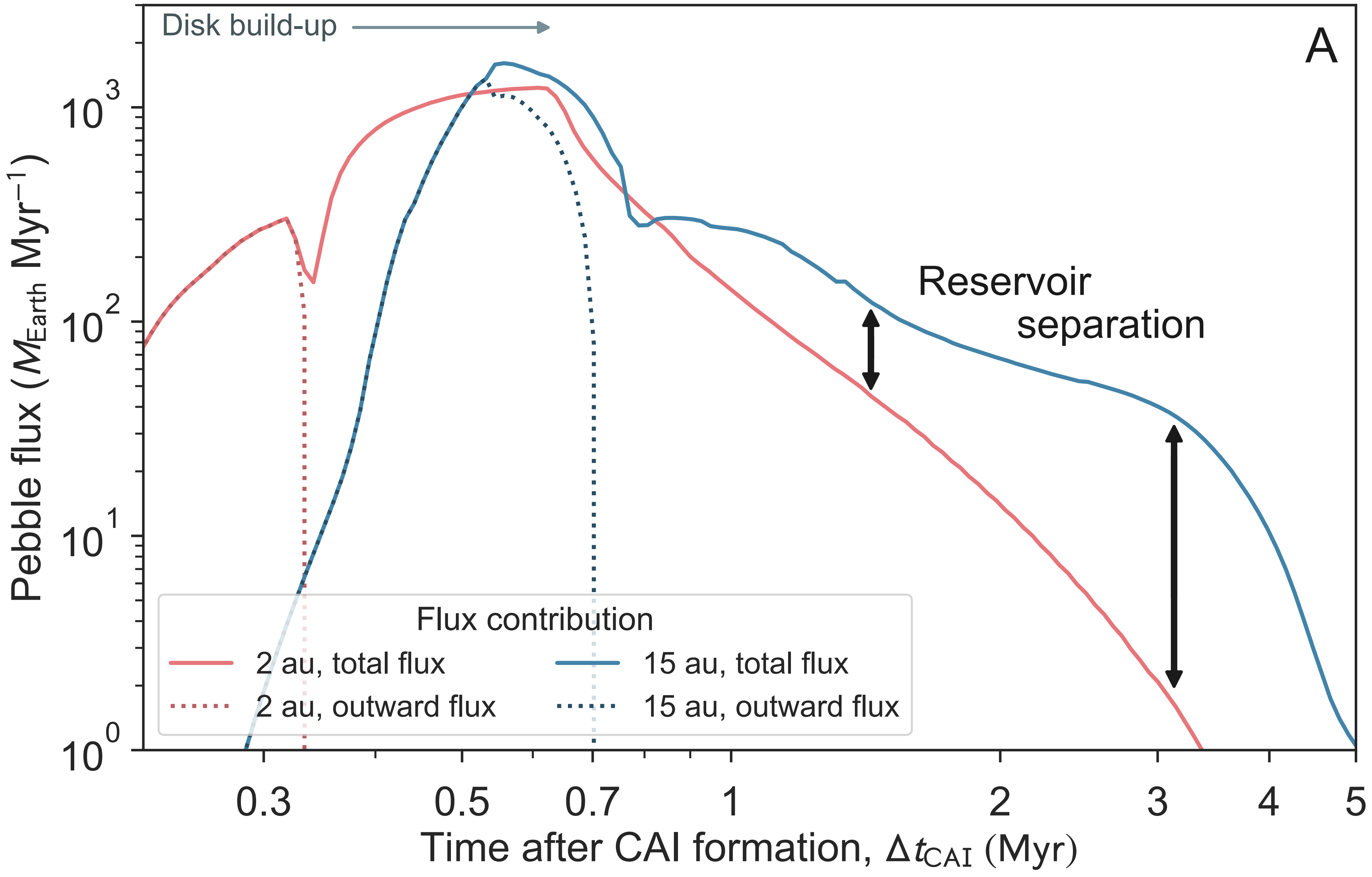
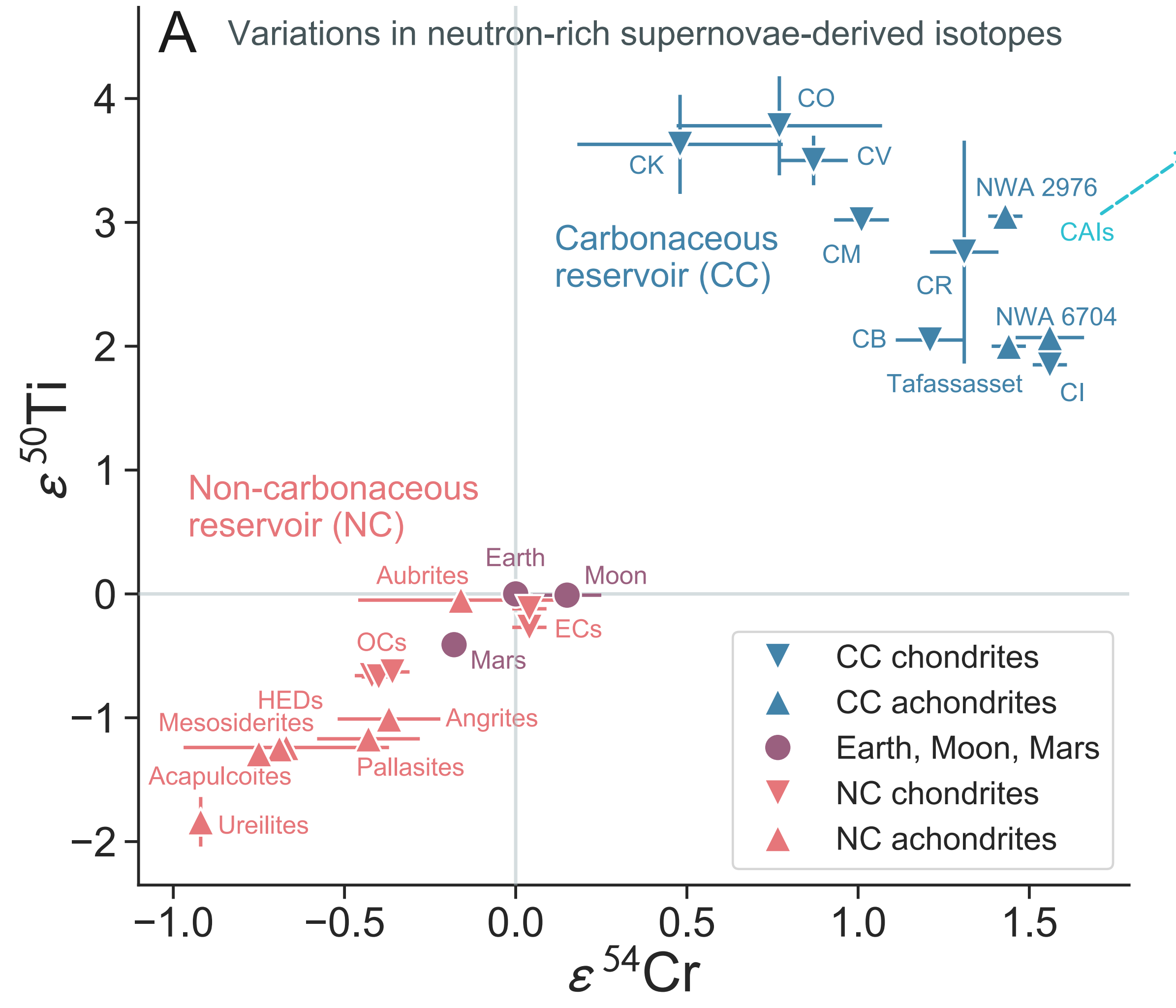
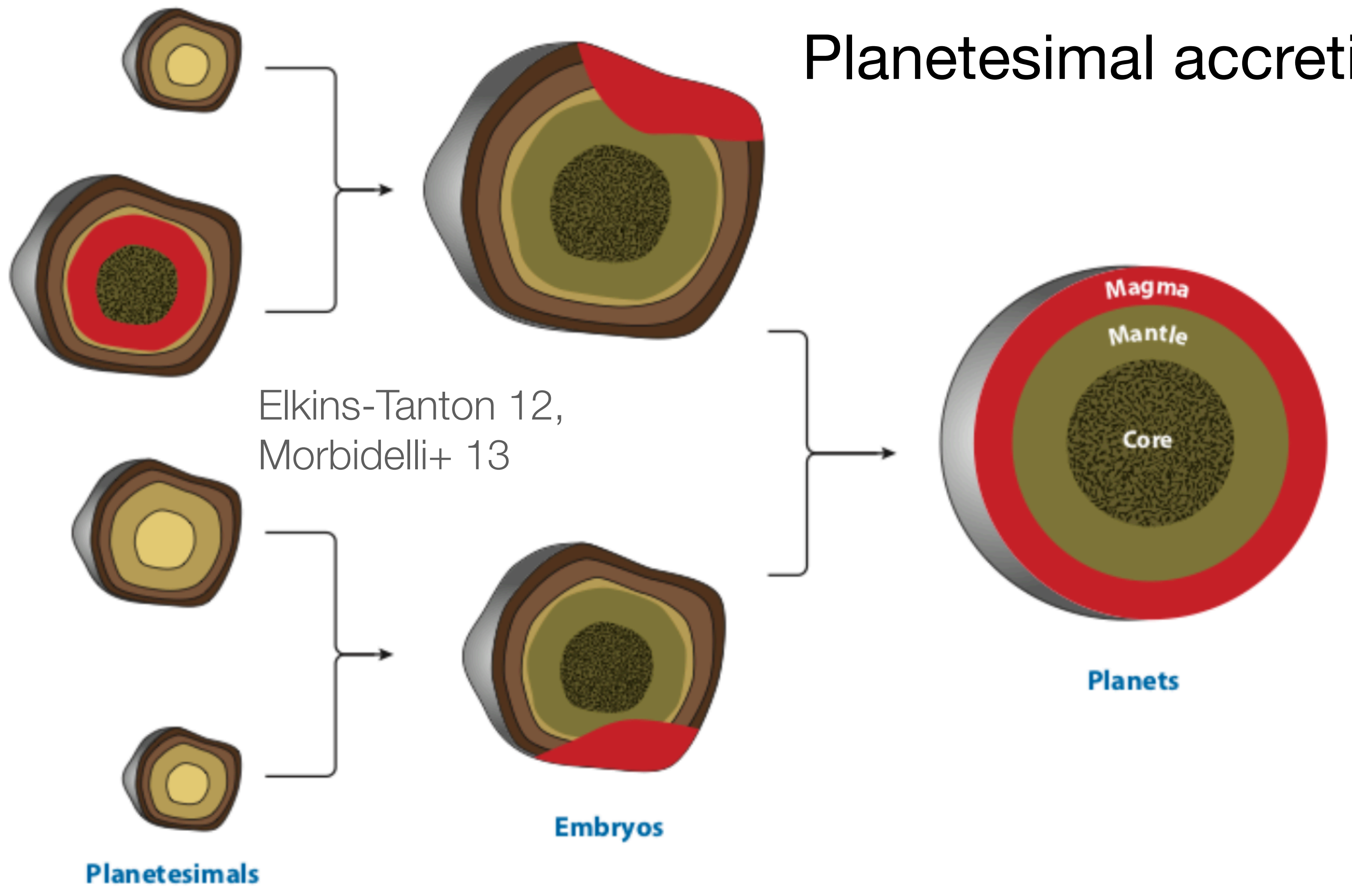






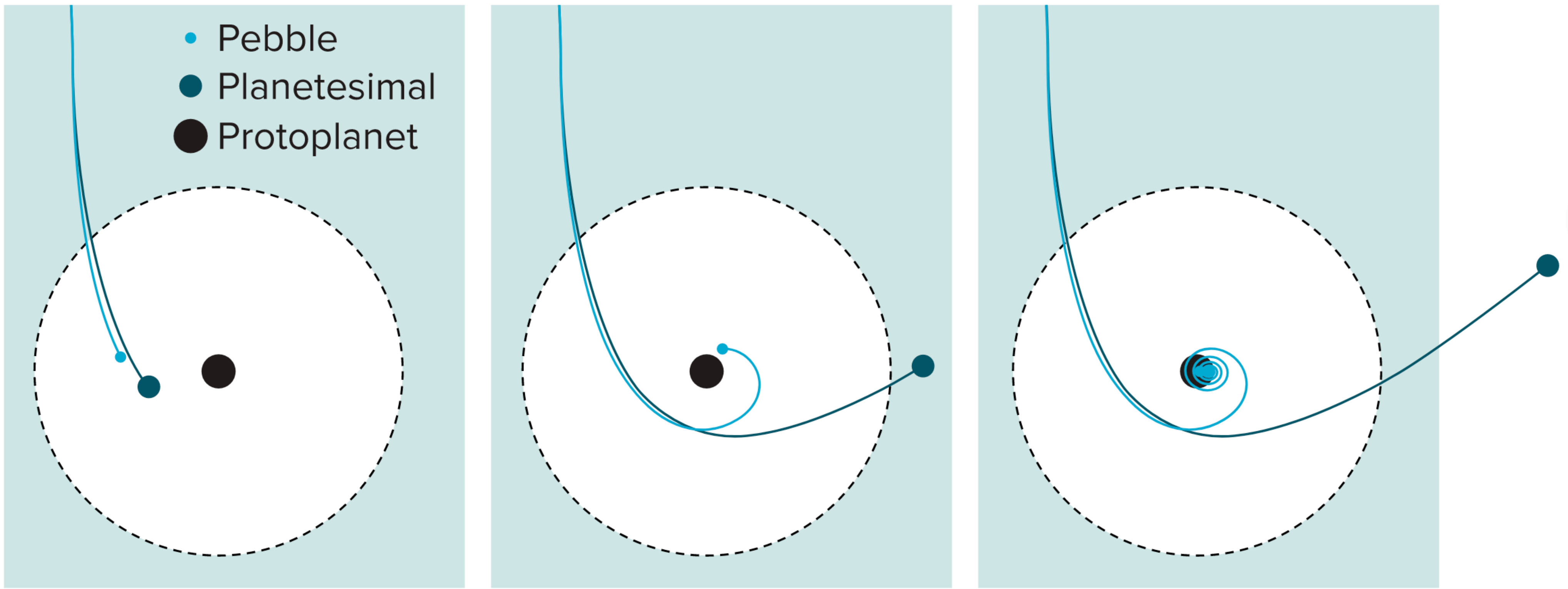
Growth mode

Planetesimal accretion

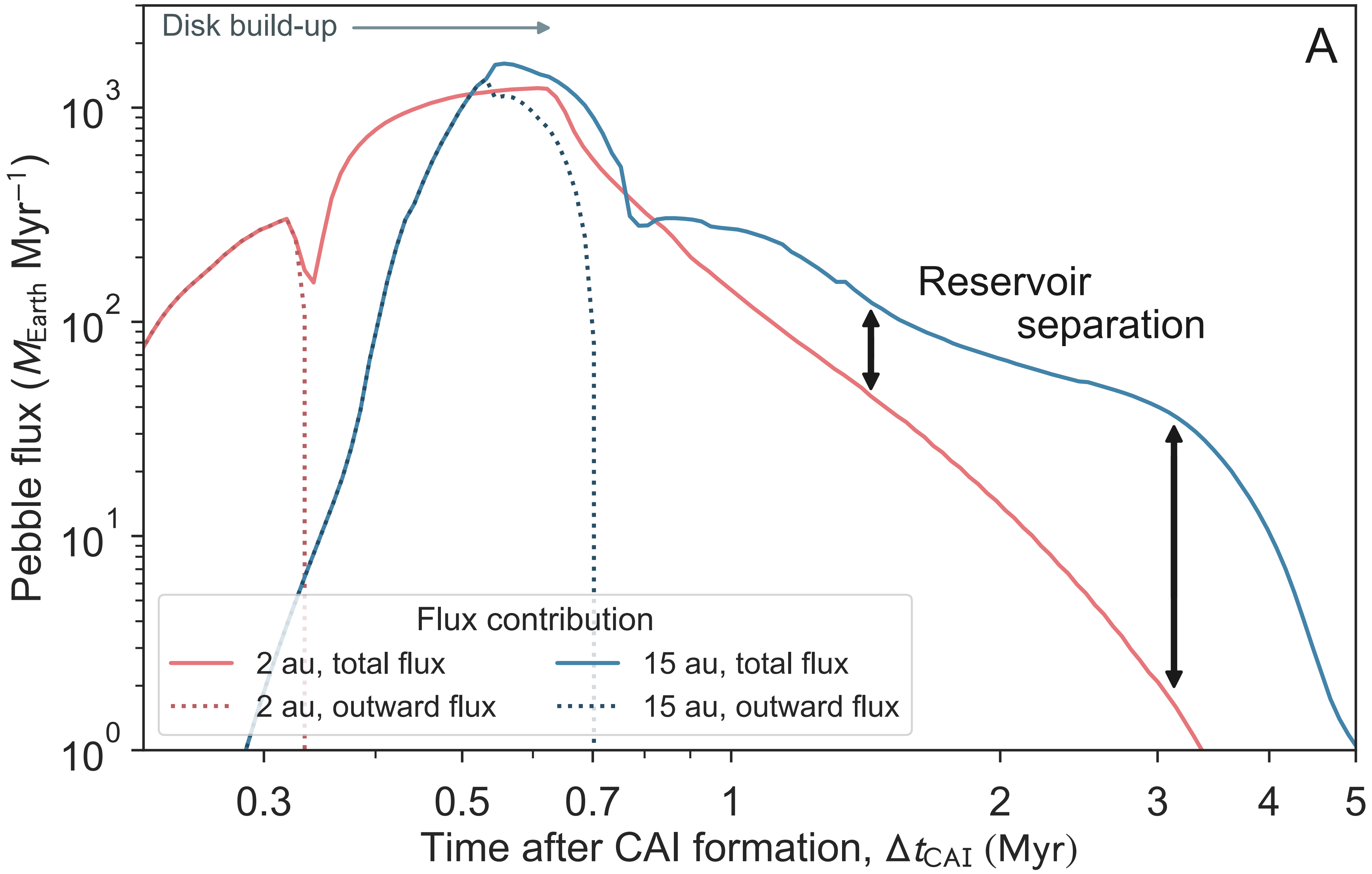


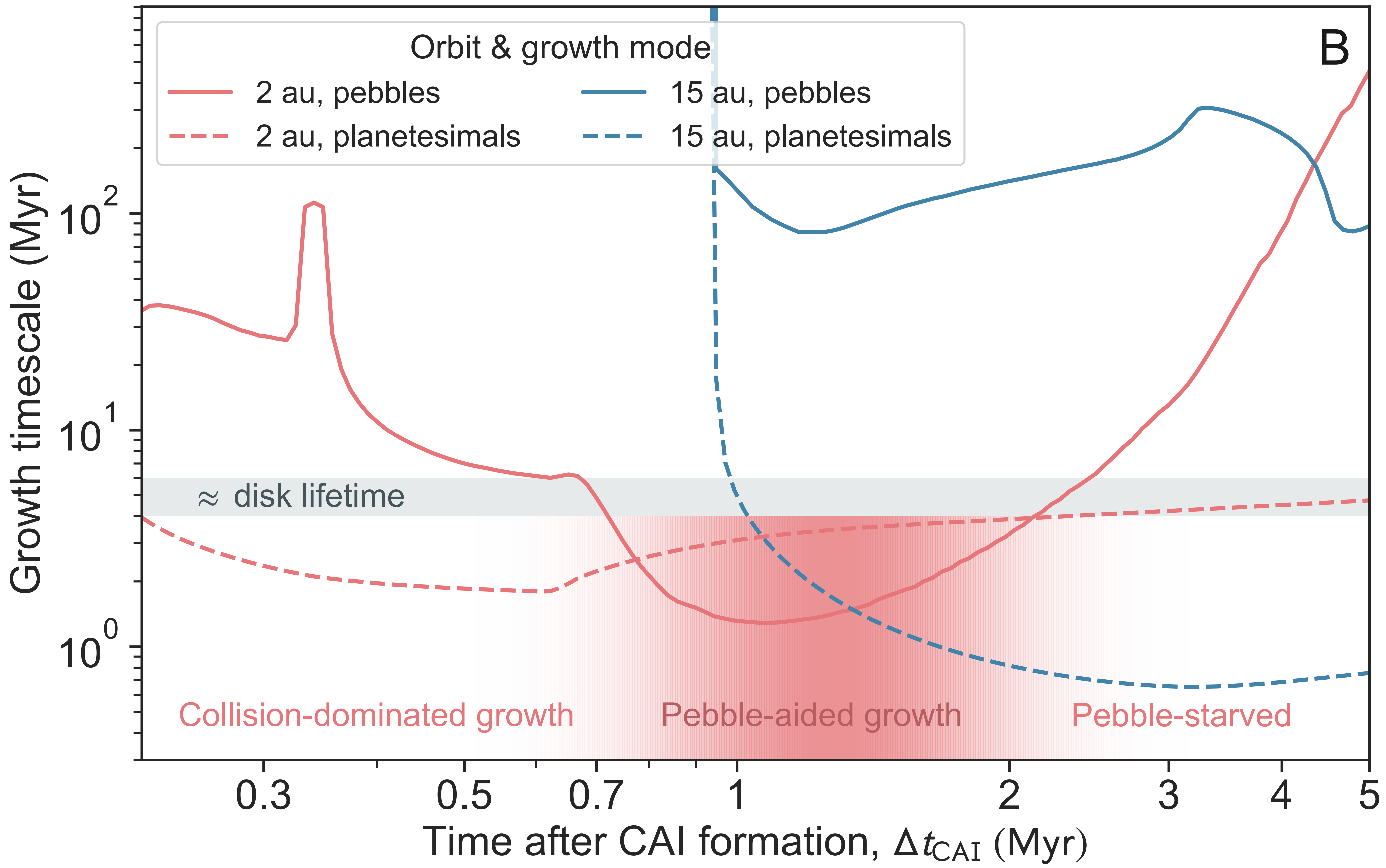
Elkins-Tanton 12, Morbidelli+ 13

Pebble accretion



Johansen & Lambrechts 17, Ormel 17





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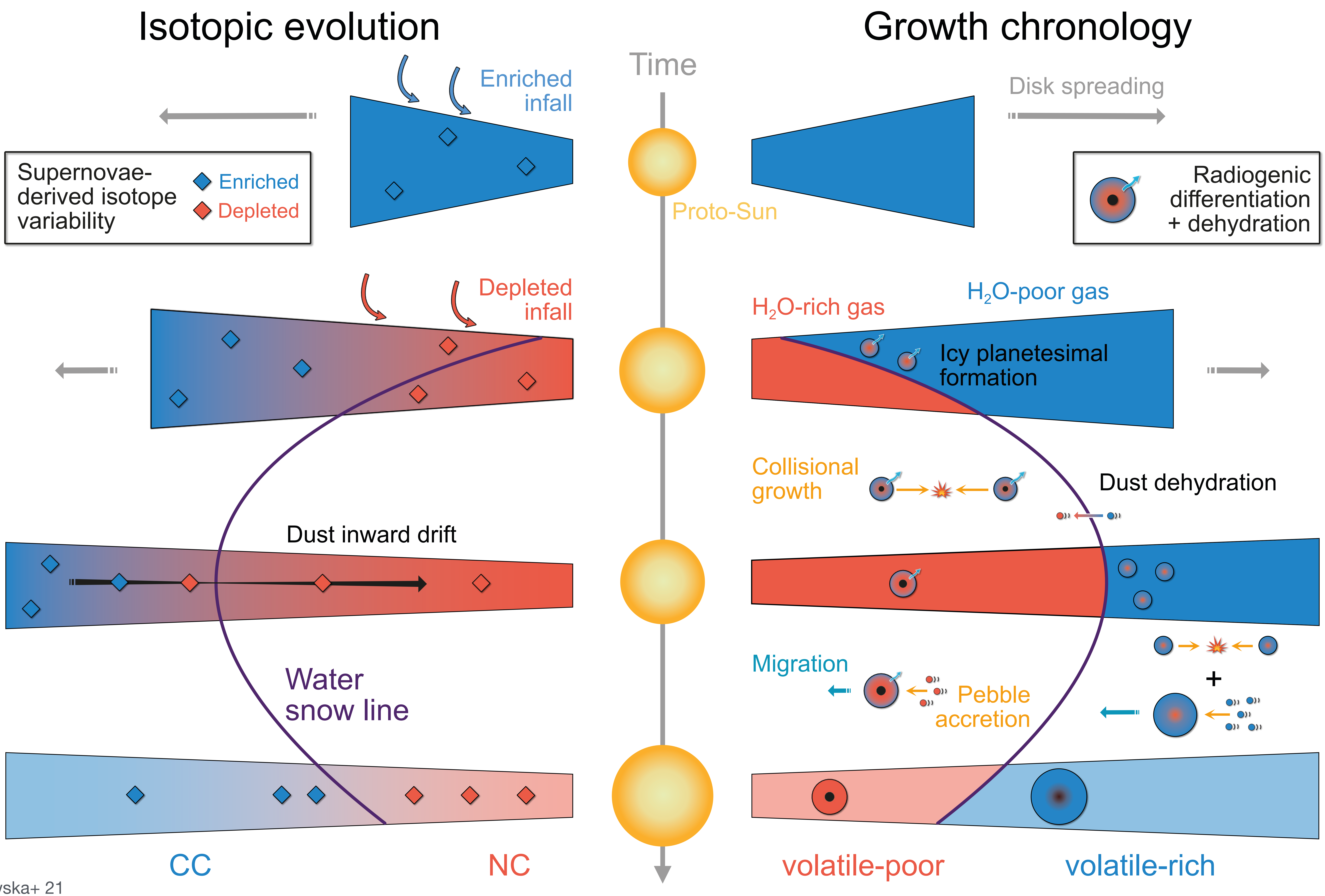


Lichtenberg, Drążkowska+ 21

Predictions & falsifiability

Astronomical constraints

- Low viscosity disk mid plane ($\alpha_{mid} \lesssim 10^{-4}$) >> wind-driven?
- **Abundance and distribution of ^{26}Al among exoplanets**
  - **Terrestrial exoplanet bulk volatile distribution (*Lichtenberg+ 19a, Lichtenberg & Krijt 21*)**
- **Secondary origin for ordinary & enstatite chondrites**
  - **Collisional recycling >> chondrule age peak at ~2 Myr (*Lichtenberg+ 18*)**
  - Secondary accreted lids from pebble accretion >> planetesimal paleodynamos *(Maurel+ 20)*
- Limited *primordial* mixing in asteroid belt
- Delayed and far-out giant planet formation
- Disk rings as sites of planetesimal formation *(Dullemond+ 18, Stammler+ 20)*
- Class I dust coagulation and structure *(Segura-Cox+ 20)*

Geochemical constraints

- Early source of volatiles in inner disk
  - Hydrogen *(Piani+ 18, 20)*
  - Nitrogen *(Grewal+ 21)*
  - ***C/S (Hirschmann+ 21)***
- **NC irons variable redox state (>EC)** (*Bonnand & Halliday 18*)
- **Fluid flow in OCs** (*McSween & Labotka 92)*
- Refractory (Mg) isotope fractionation *(Young+ 19, Benedikt+ 20)*
- Isotopic spread among comets & TNOs *(Alexander+ 18, Altwegg+ 20)*

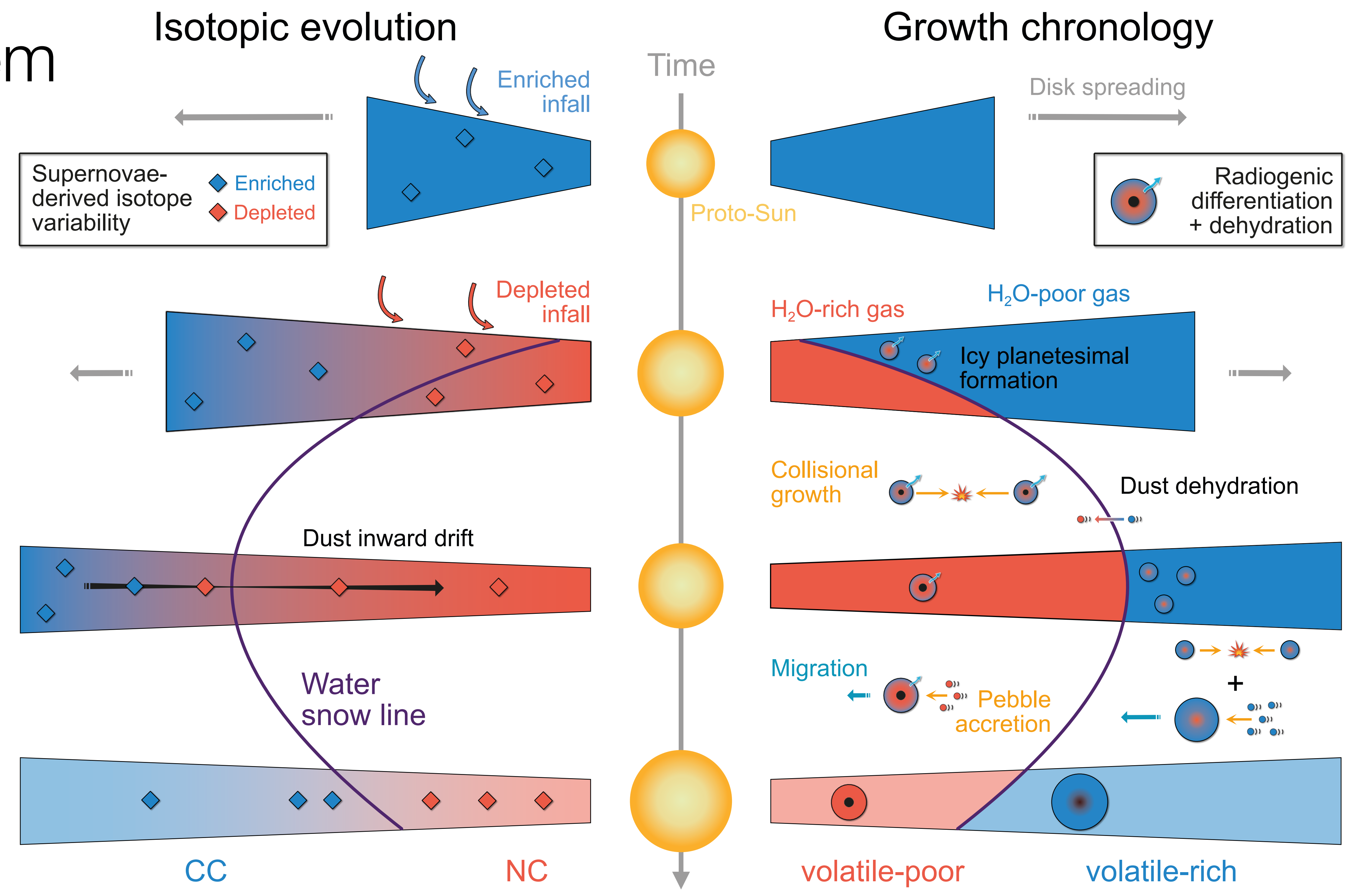
Bifurcation of planetary building blocks during Solar System formation

- Physical forward model suggesting explanations for
  - **Meteoritic chronology** in inner & outer Solar System
  - Heterogeneous **mode & timescale of accretion**

    Collisions ➡ pebbles ➡ collisions

  - Compositional & isotopic **reservoir separation**
- Solar System dichotomy result of:
  - **Spatio-temporally distinct** planetesimal bursts
  - **Geophysical evolution** driven by radiogenic heating (^{26}Al)
  - Volatile accretion sequence to inner Solar System:

    volatile-depleted ➡ dry (➡ volatile-rich)



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