TIM LICHTENBERG, JOANNA DRĄŻKOWSKA, MARIA SCHÖNBÄCHLER, GREGOR J. GOLABEK, THOMAS O. HANDS

BIFURCATION OF PLANETARY BUILDING BLOCKS DURING SOLAR SYSTEM FORMATION

Tim Lichtenberg

Image: Mark A. Garlick / markgarlick.com

Science 371, 6527 (2021)
10.1126/science.abb3091

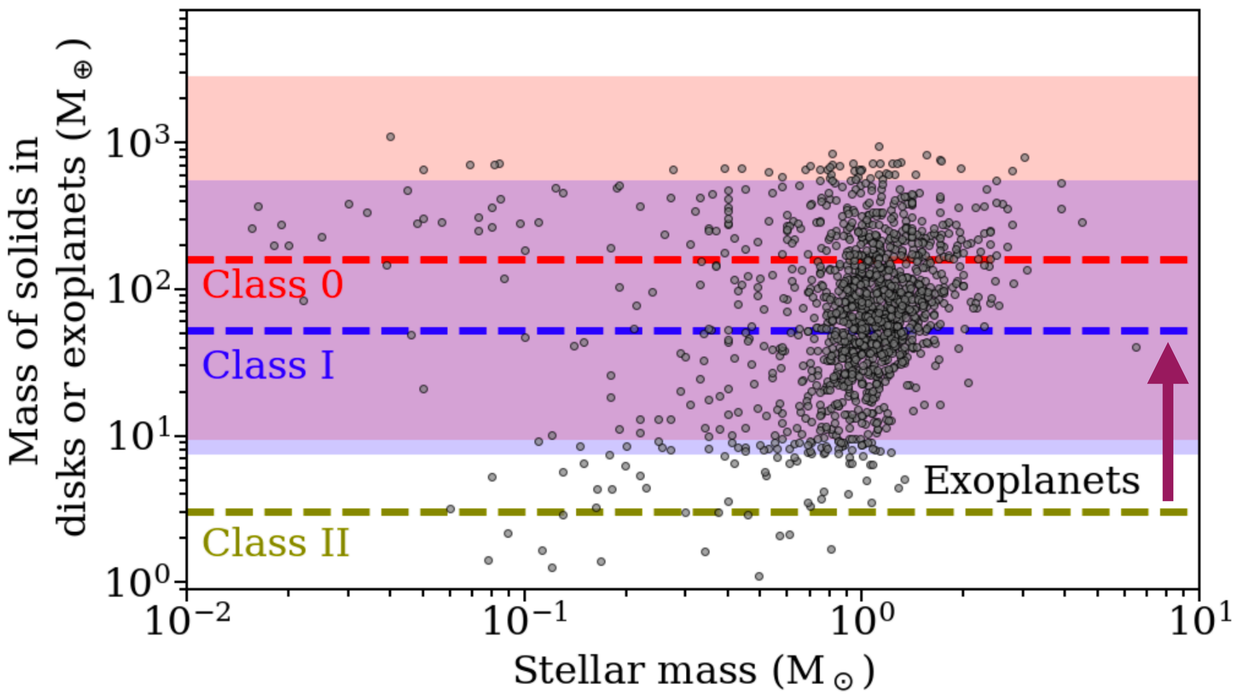
@tim_lichtenberg
timlichtenberg.net

UNIVERSITY OF OXFORD

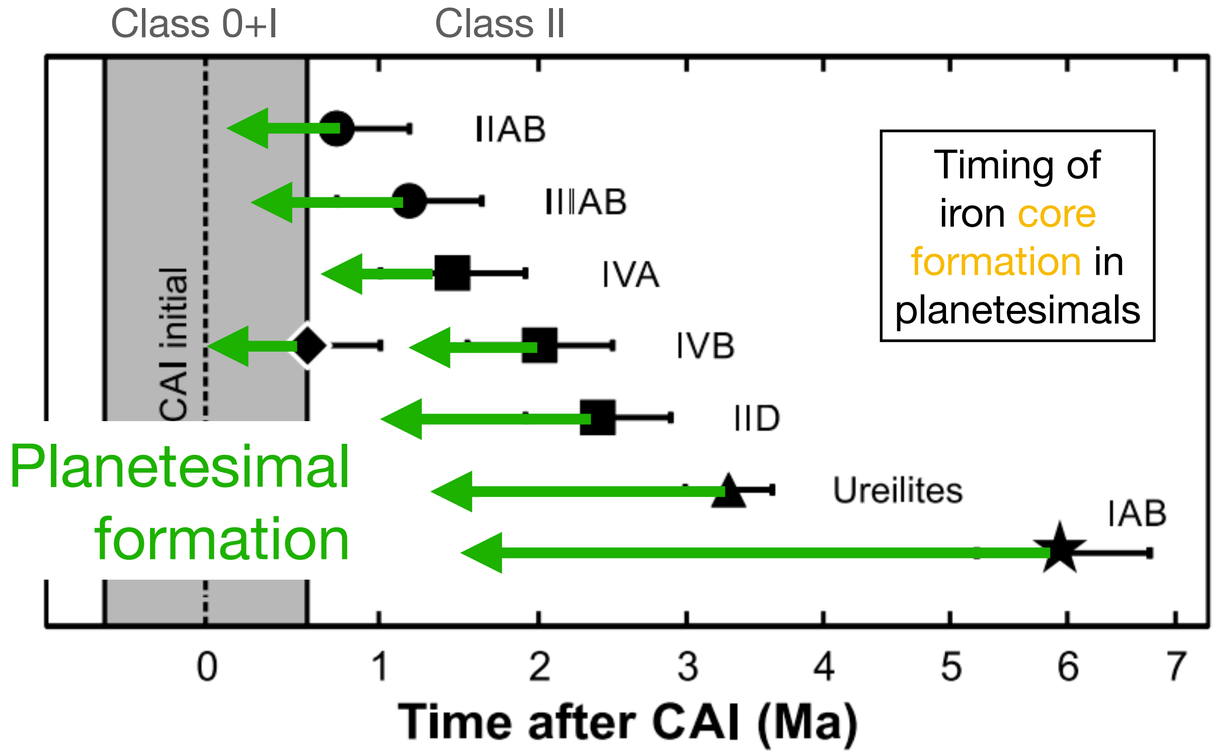
SIMONS FOUNDATION

Temporal fragmentation of planet formation

Exoplanetary systems



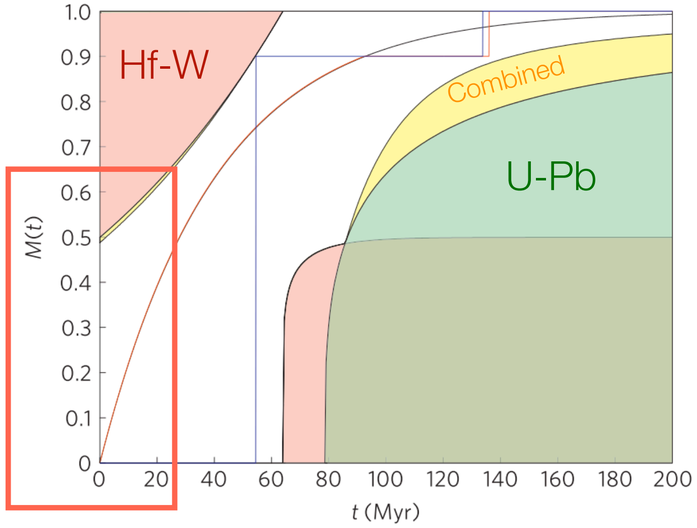
Solar System

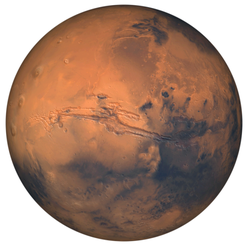


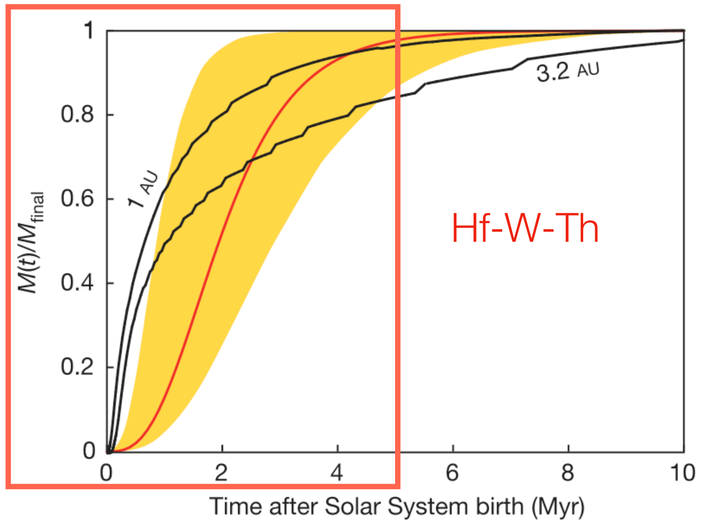
Greaves & Rice 10, 11; Najita & Kenyon 14, Pascucci+ 16, Ansdell+ 17, Manara+ 18, Tychoniec+ 20

Hunt+ 18

Temporal fragmentation of planet formation



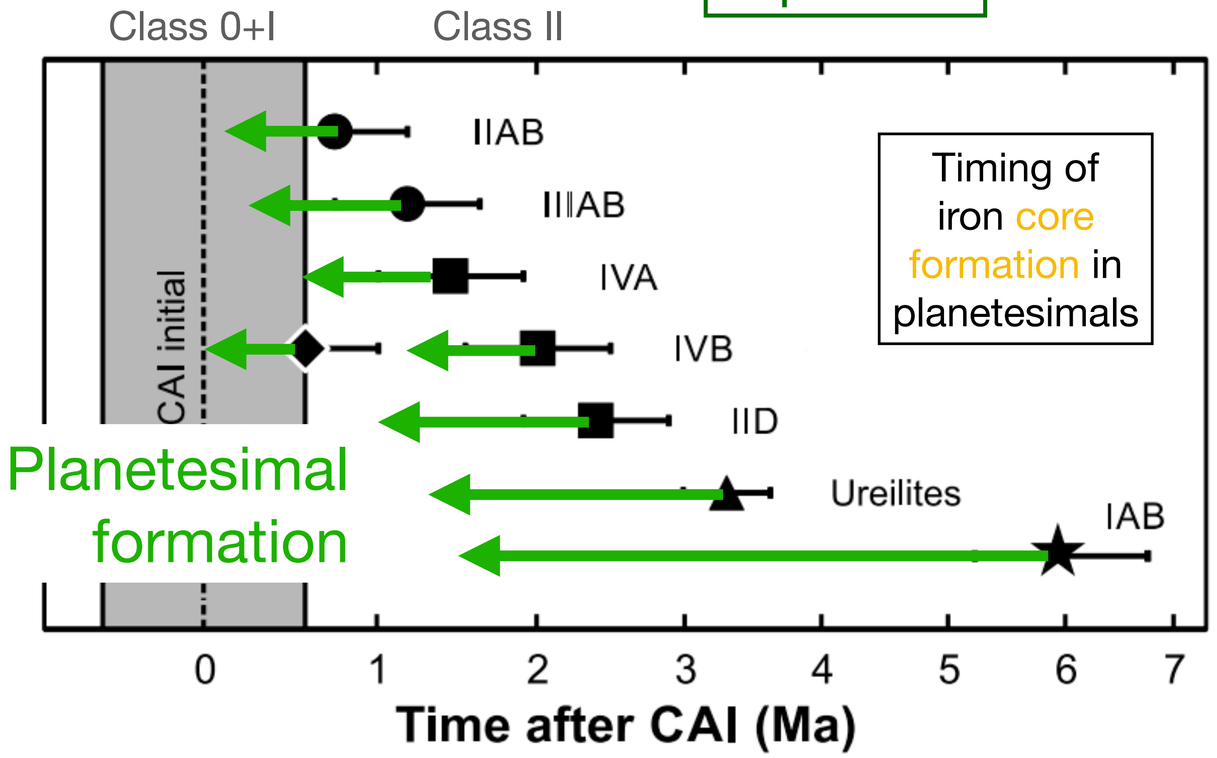




Protracted finish

Solar System

Rapid start

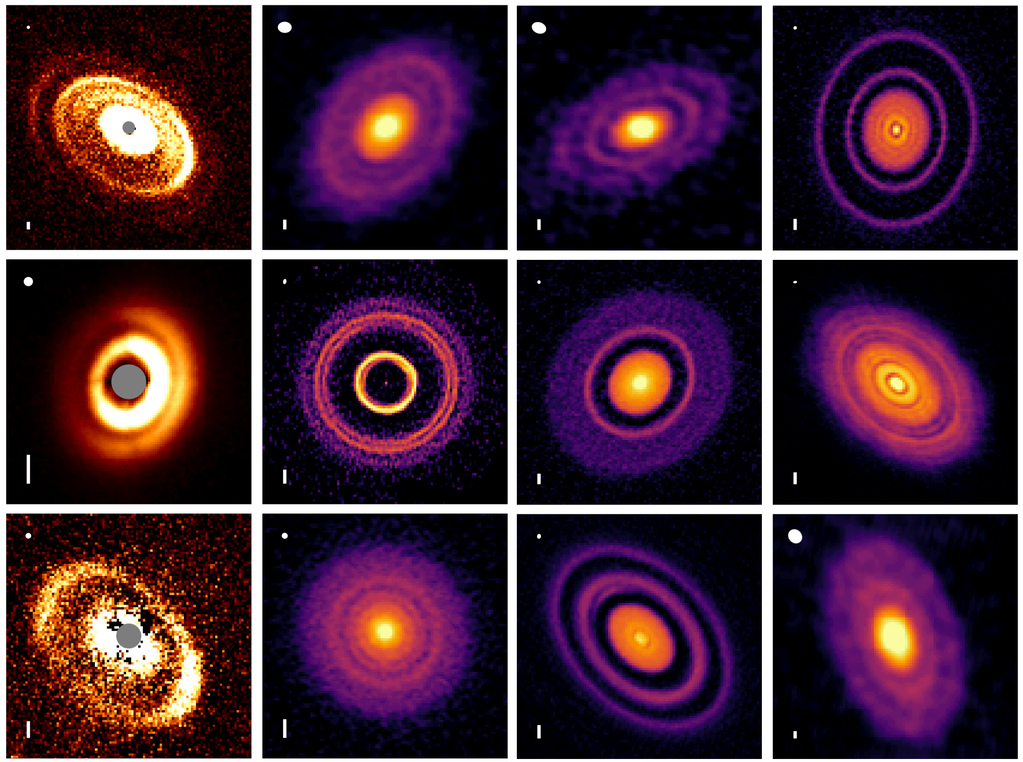


Rudge+ 10; Dauphas & Pourmand 11; Nimmo+ 18

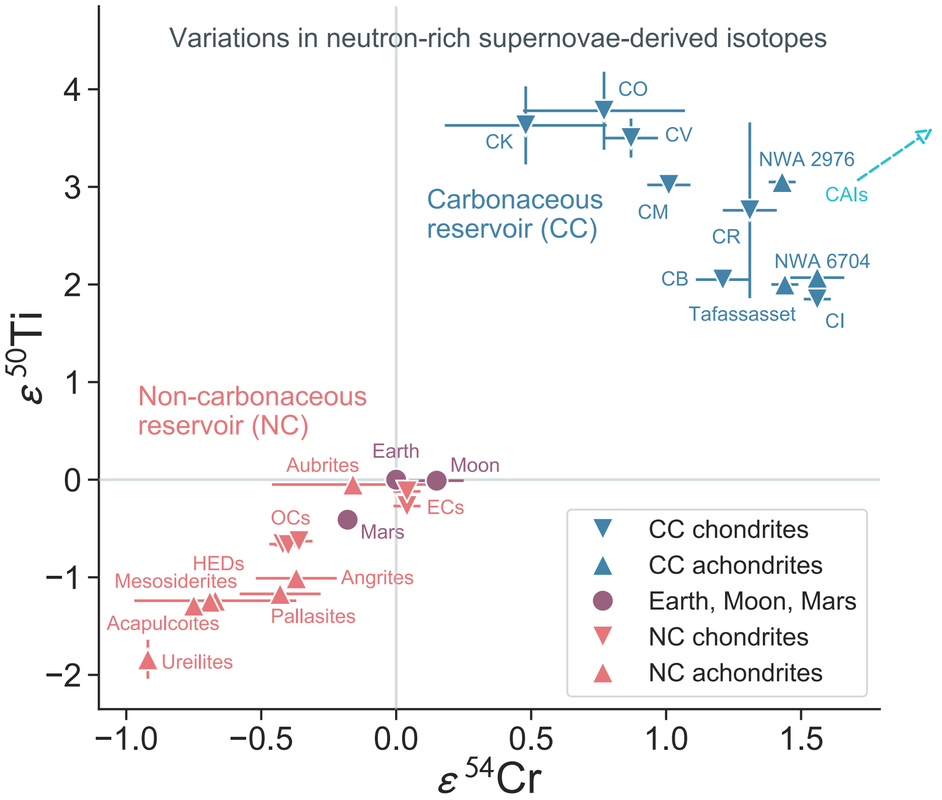
Hunt+ 18

Spatial fragmentation of planet formation

Exoplanetary systems



Solar System

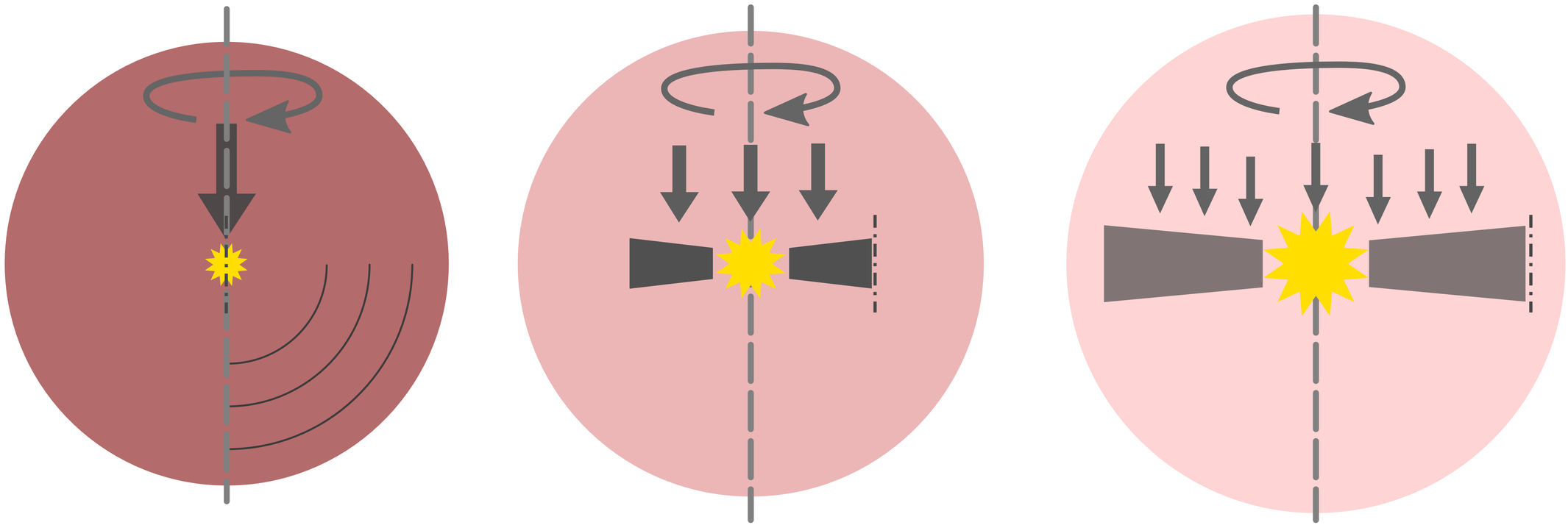


Andrews 20

Trinquier+ 07; Leya+ 08; Warren 11; Burkhardt+ 11; Kruijer+ 17; Desch+ 18; Mezger+ 20

Inside-out rotating infall model

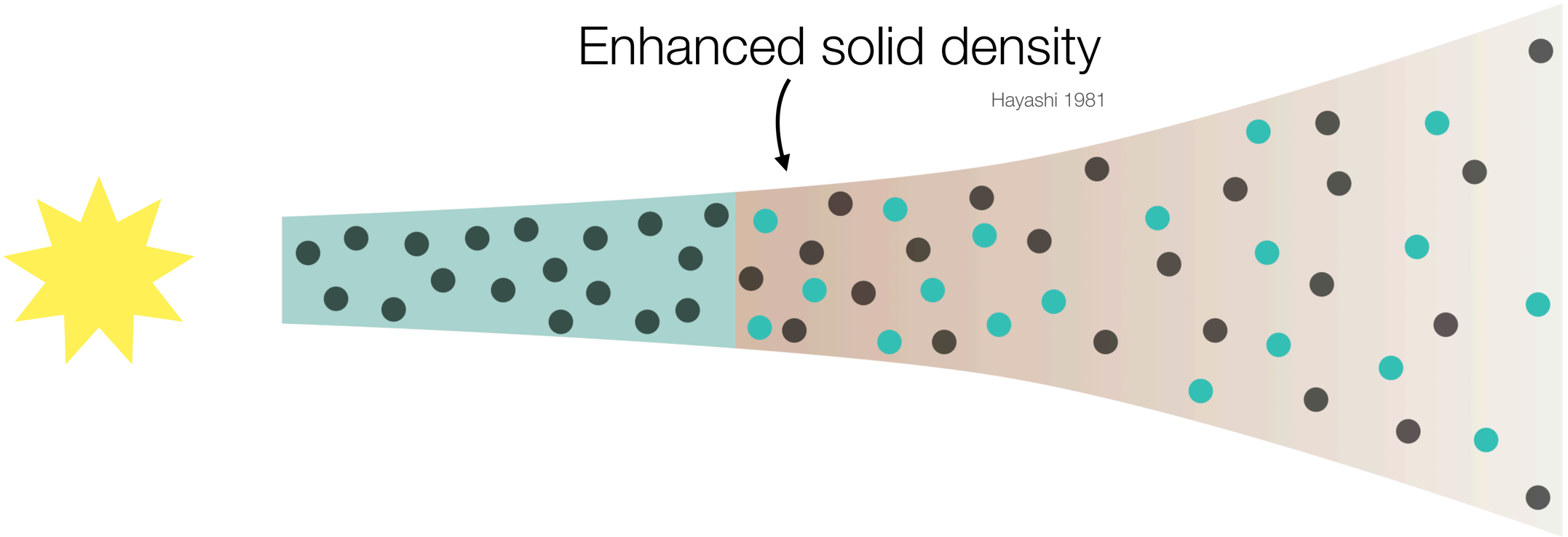
— the disk starts small



Slide courtesy J. Drążkowska

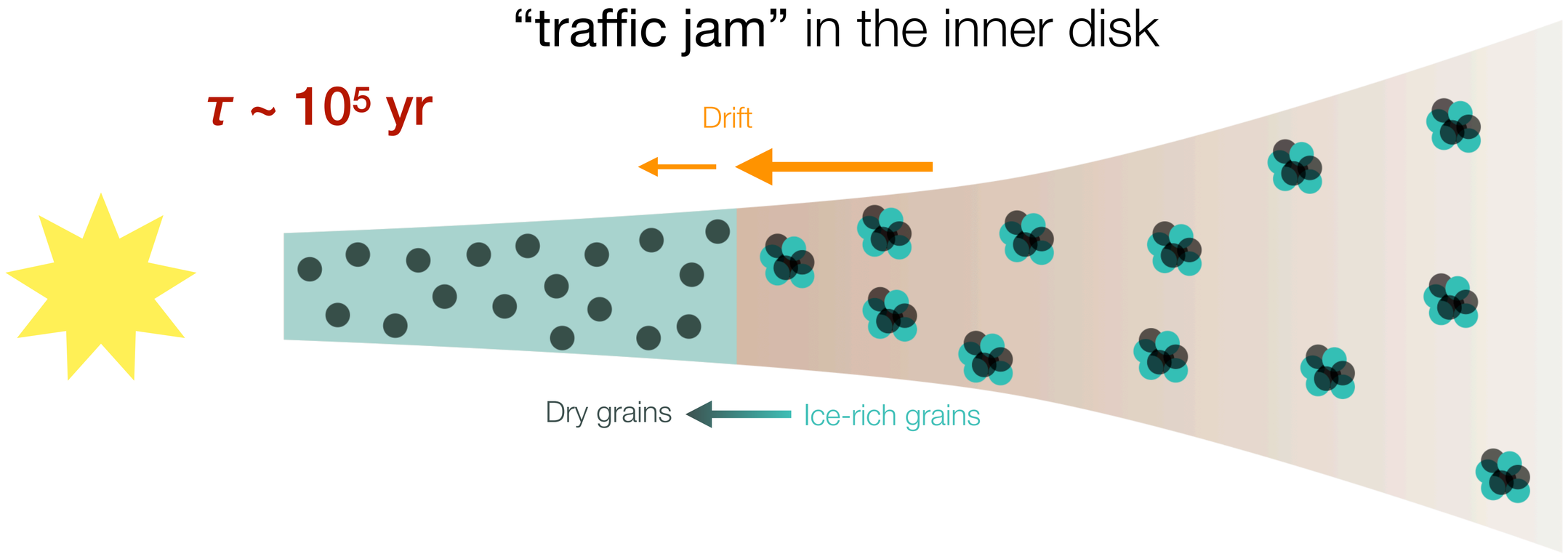
Shu 77, Ulrich 76, Hueso & Guillot 05, Dullemond+ 06, Yang & Ciesla 12

Dust coagulation & drift during the disk phase



Drążkowska & Alibert 2017, Schoonenberg & Ormel 2017

Planetesimal formation at the snowline



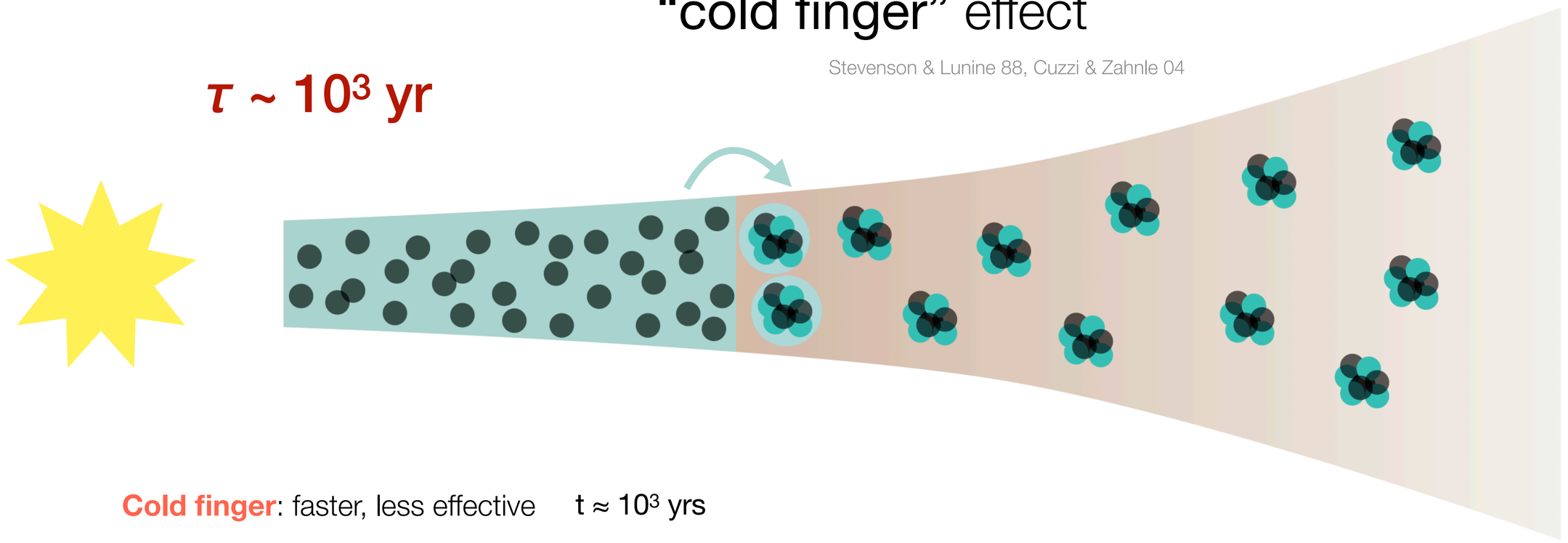
Drążkowska & Alibert 2017, Schoonenberg & Ormel 2017

Planetesimal formation at the snowline

“cold finger” effect

Stevenson & Lunine 88, Cuzzi & Zahnle 04

$\tau \sim 10^3$ yr

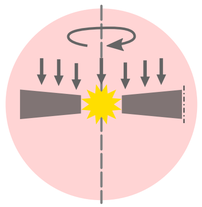


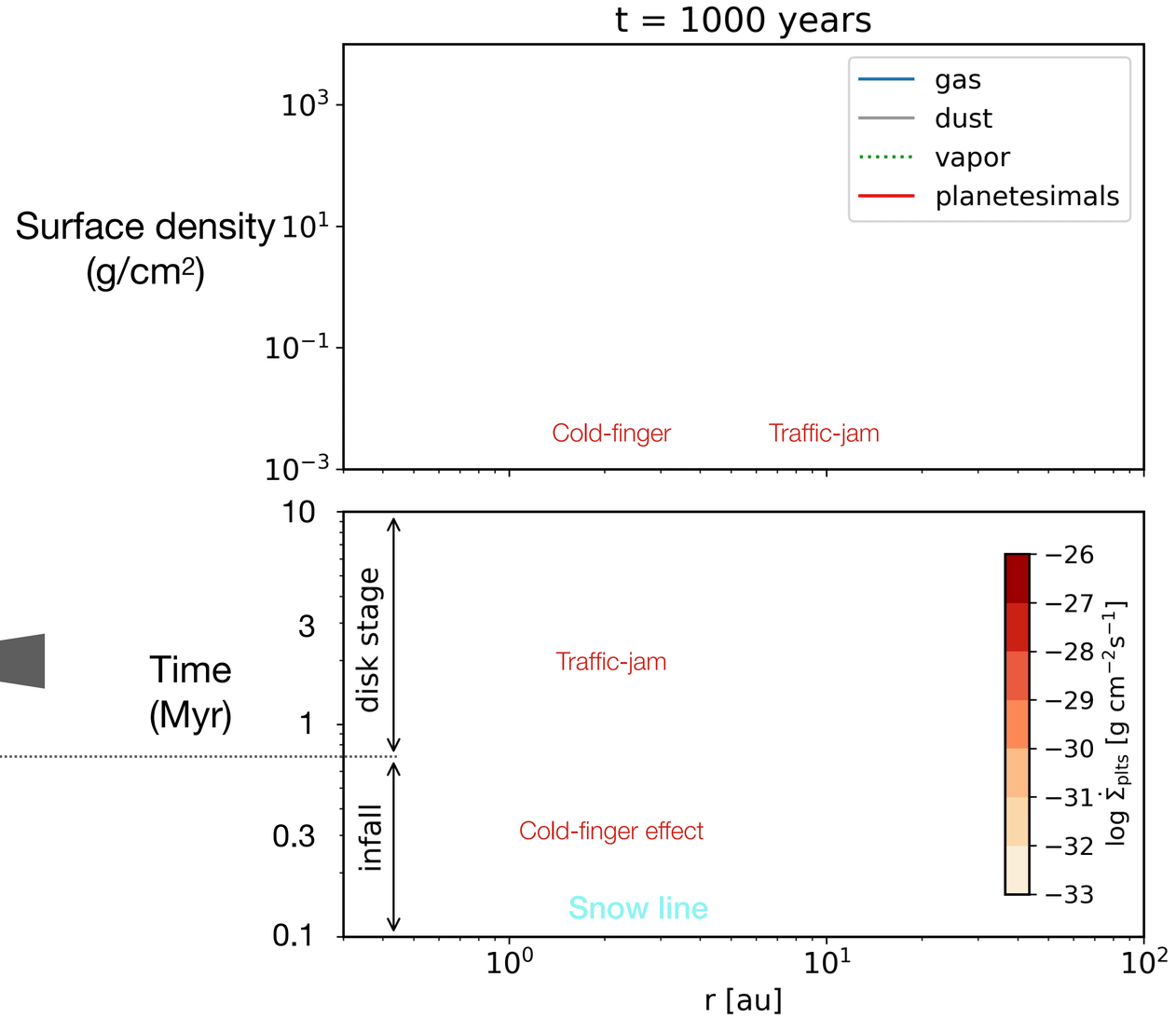
Cold finger: faster, less effective $t \approx 10^3$ yrs

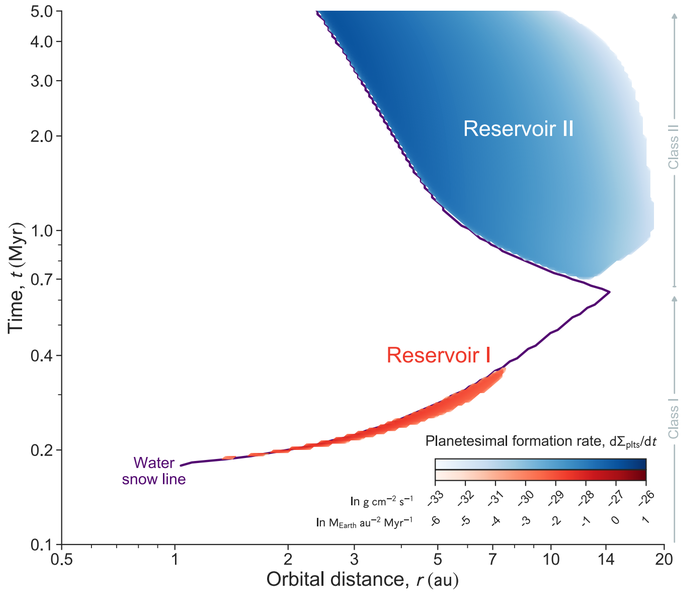
Traffic jam: slower, more effective $t \approx 10^5$ yrs

Drążkowska & Alibert 2017, Schoonenberg & Ormel 2017

Planetesimal formation during **disk buildup**



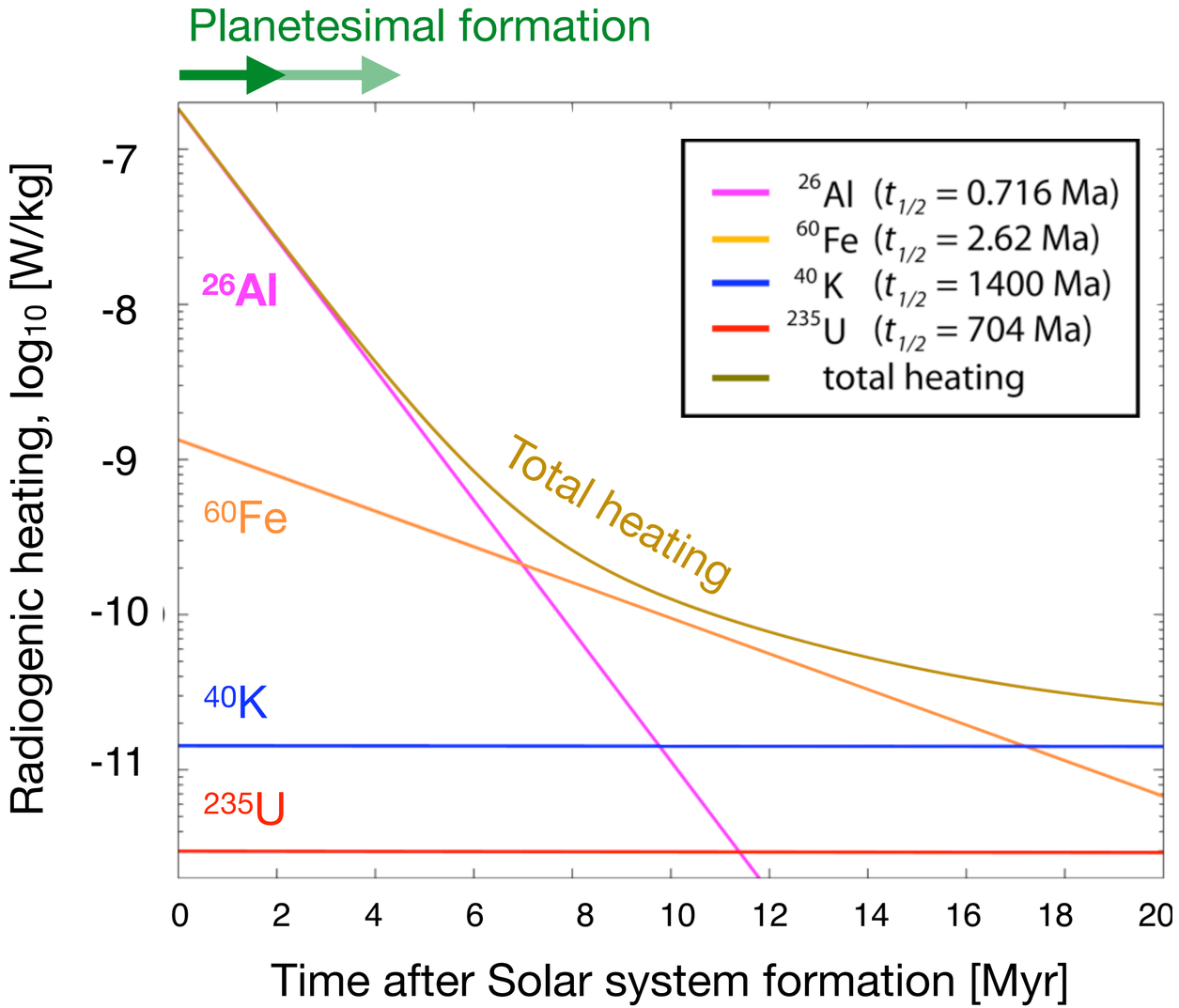


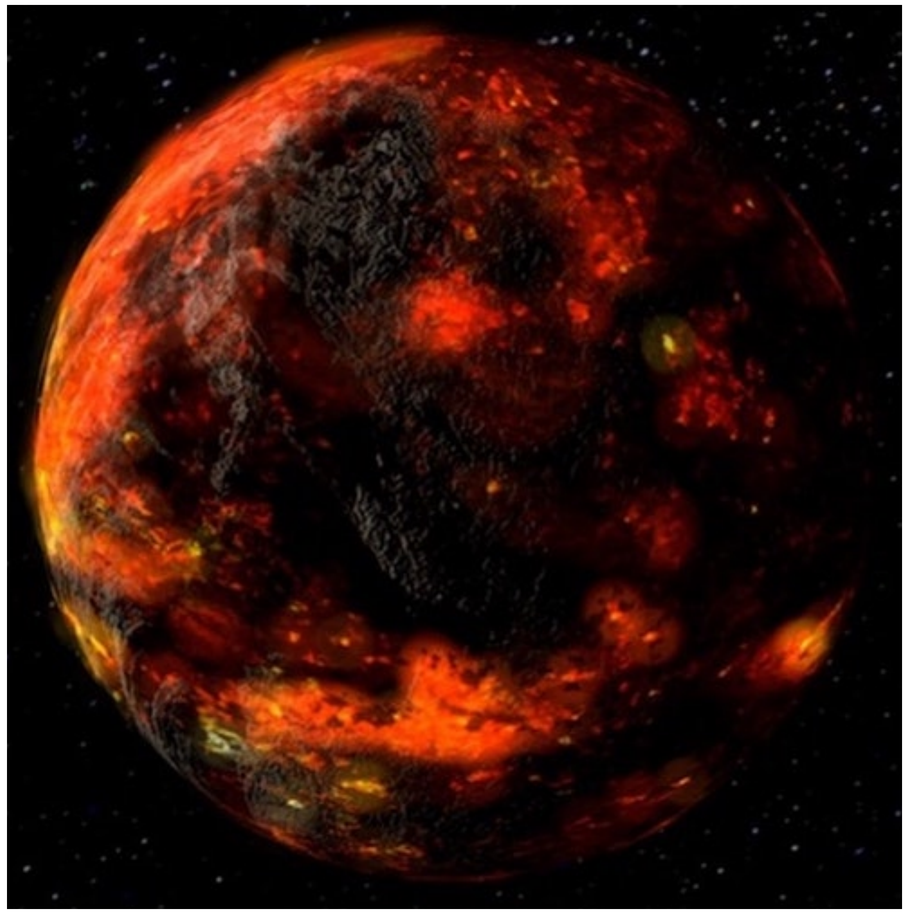


Planetesimal formation rate (change in surface density per time)

Drążkowska & Dullemond 2018

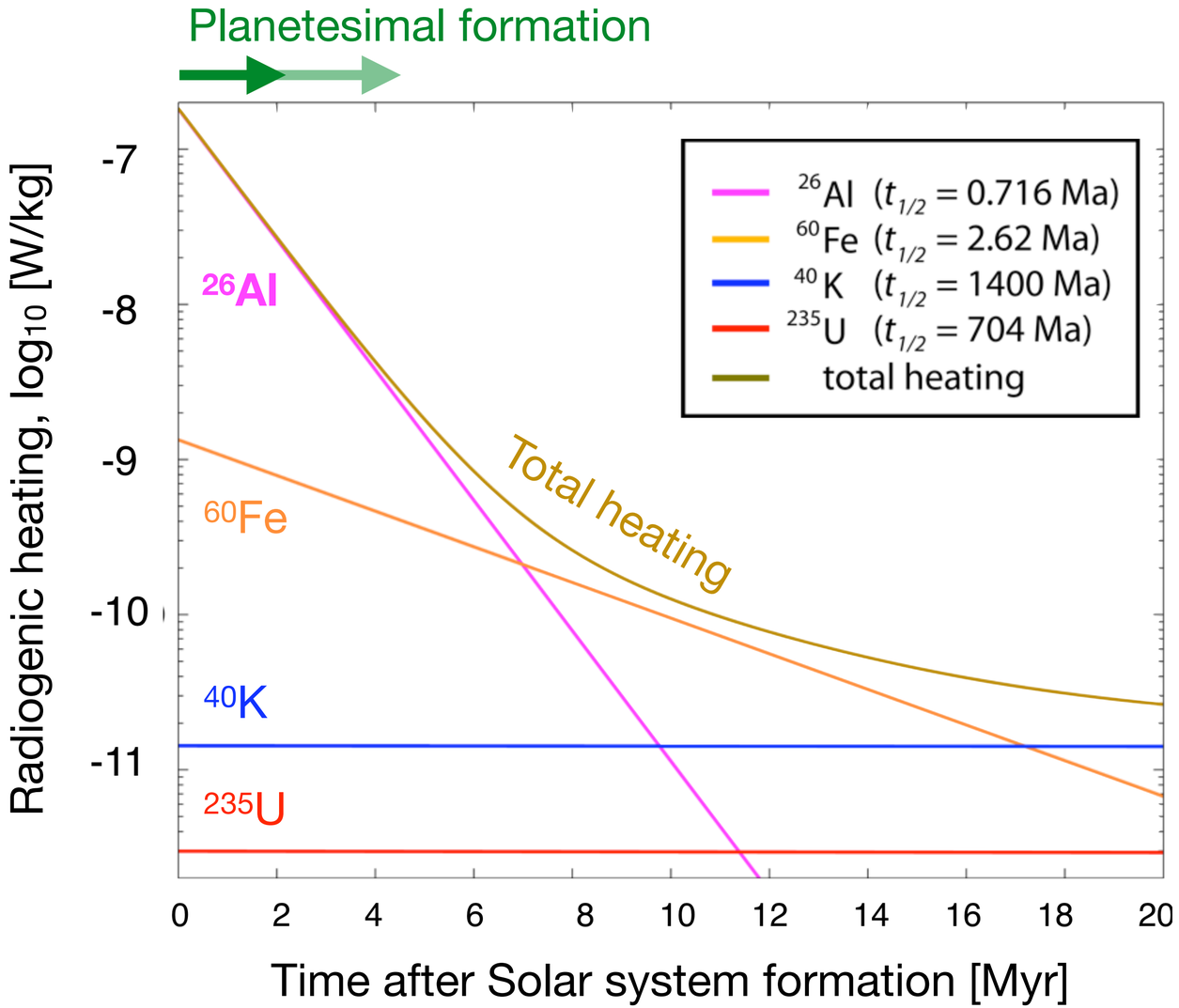
Compositional evolution from radiogenic heating

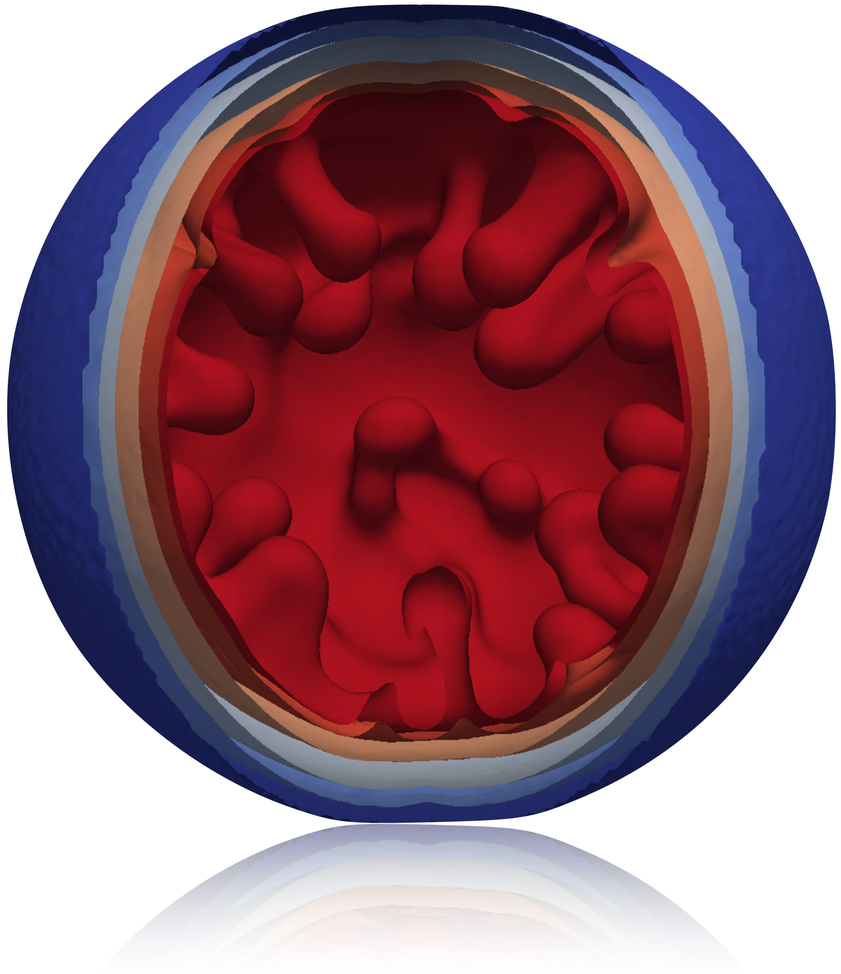




Lichtenberg+ 16a, 18, 19a,b

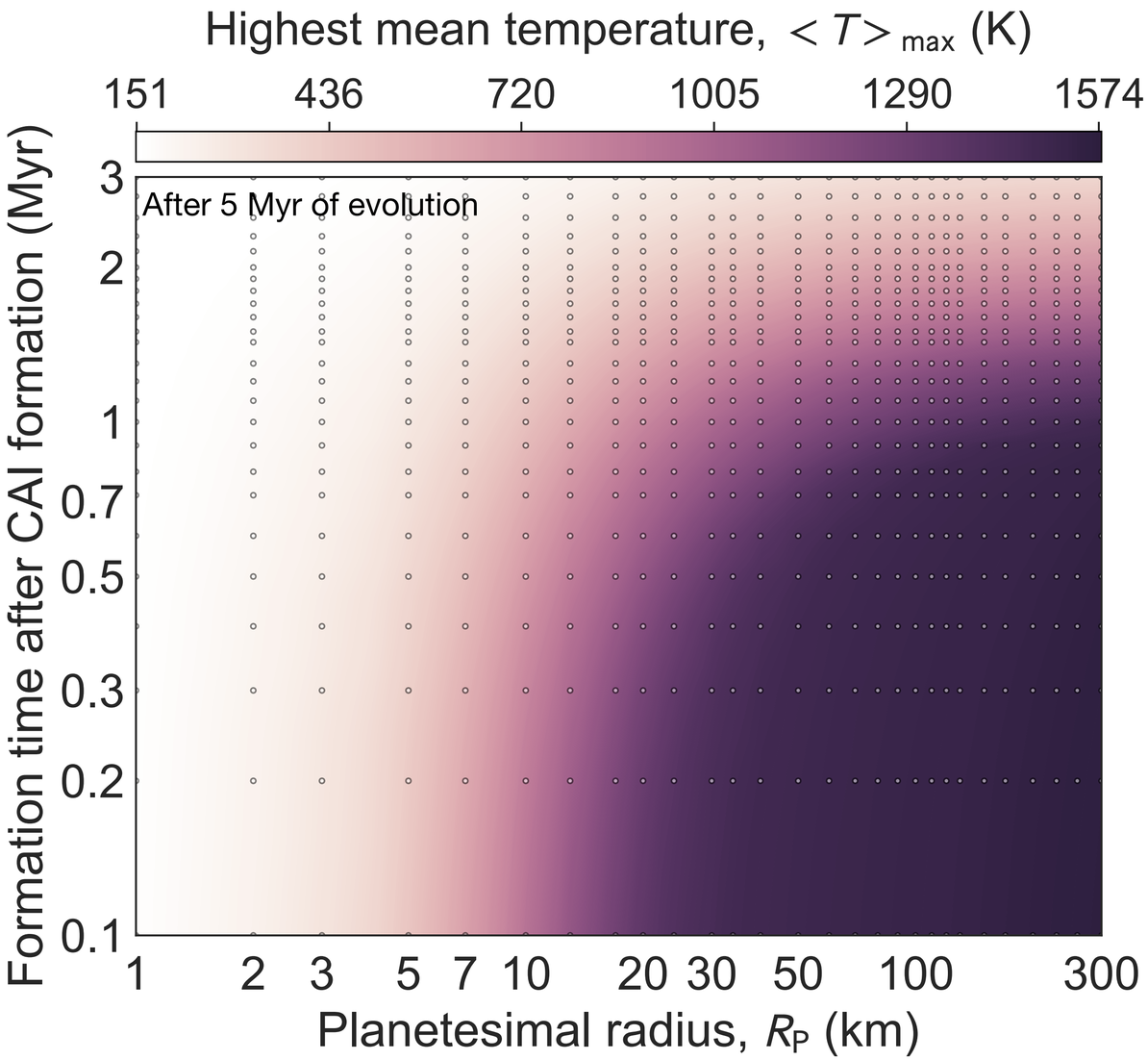
Compositional evolution from radiogenic heating

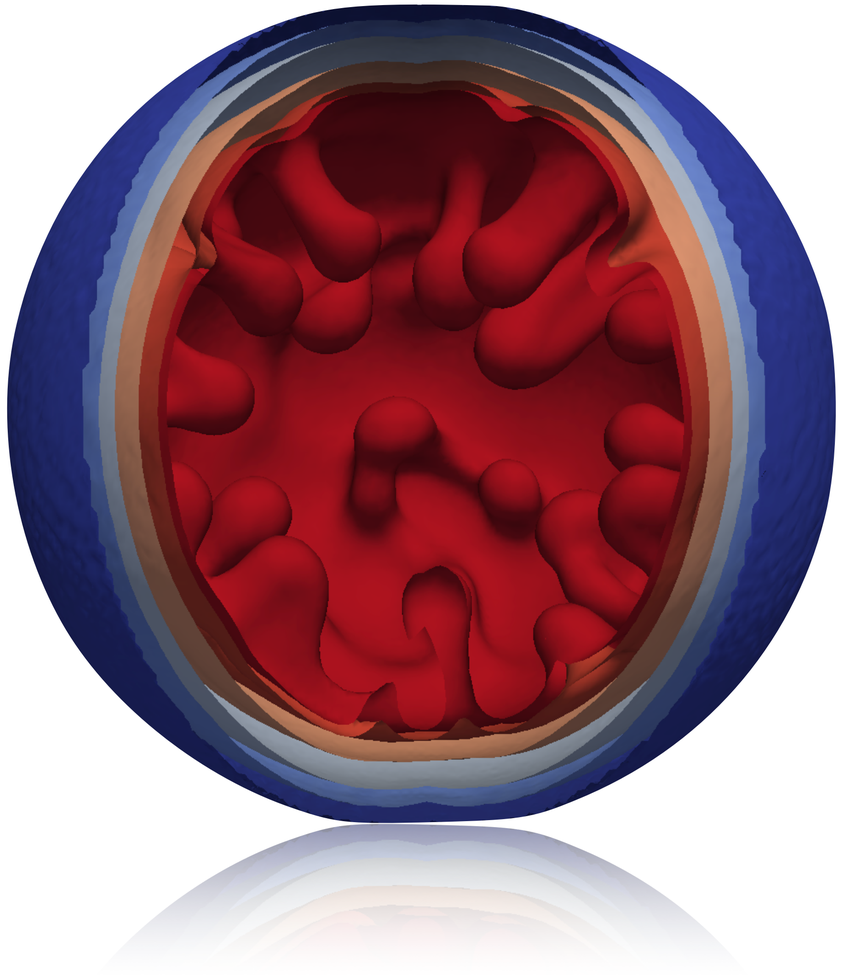




Lichtenberg+ 16a, 18, 19a,b

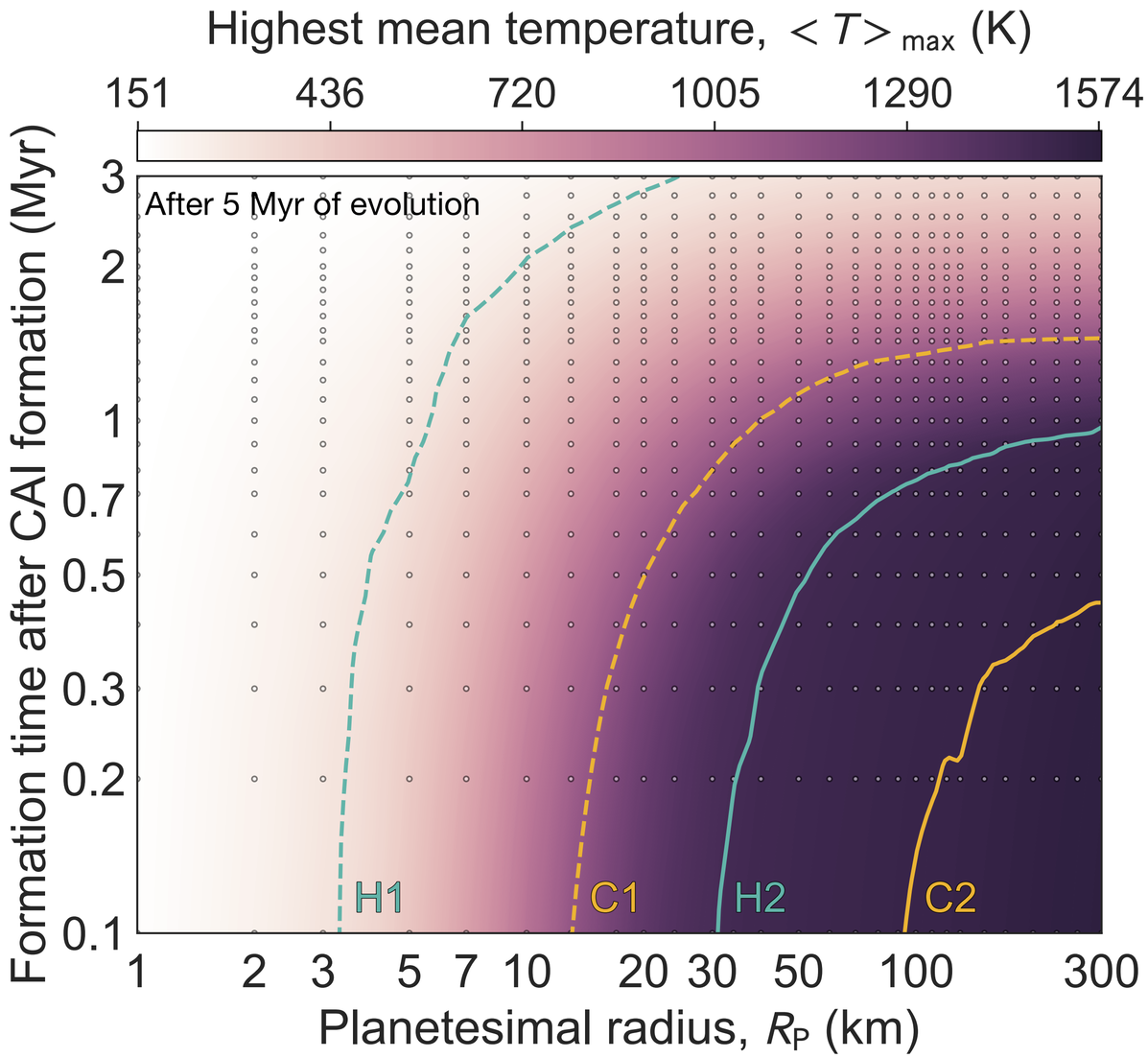
Radiogenic heating drives thermal evolution

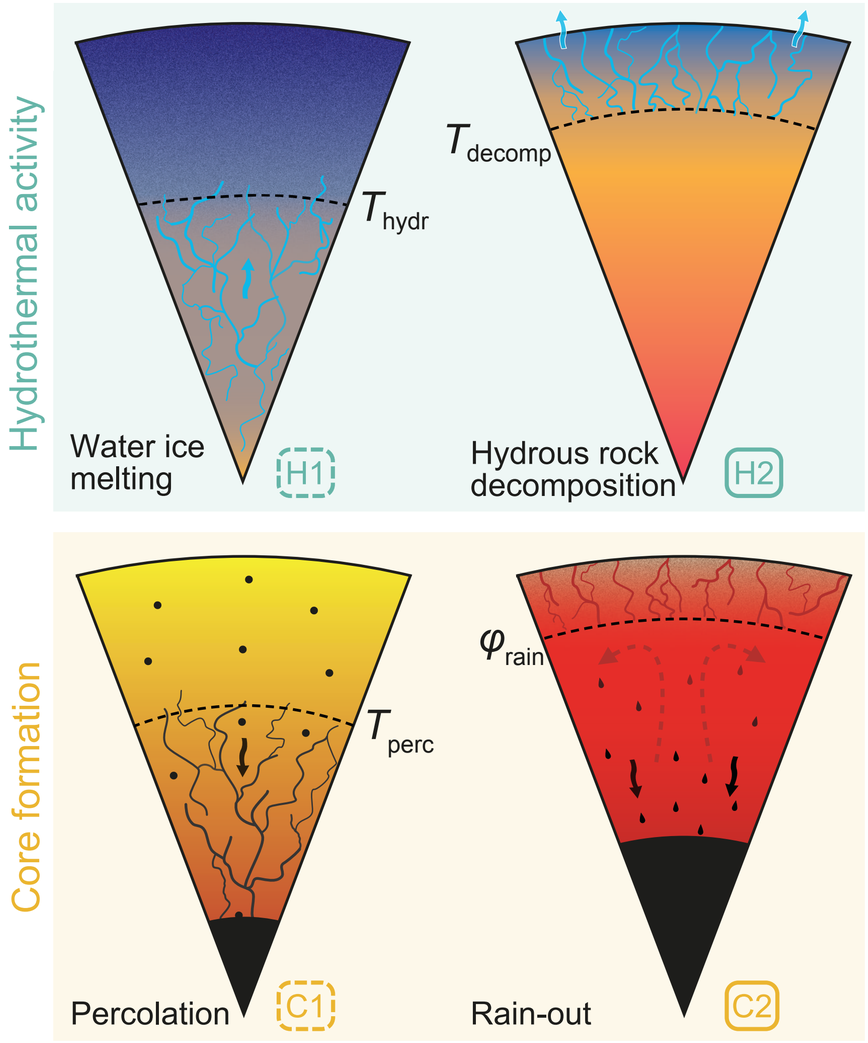




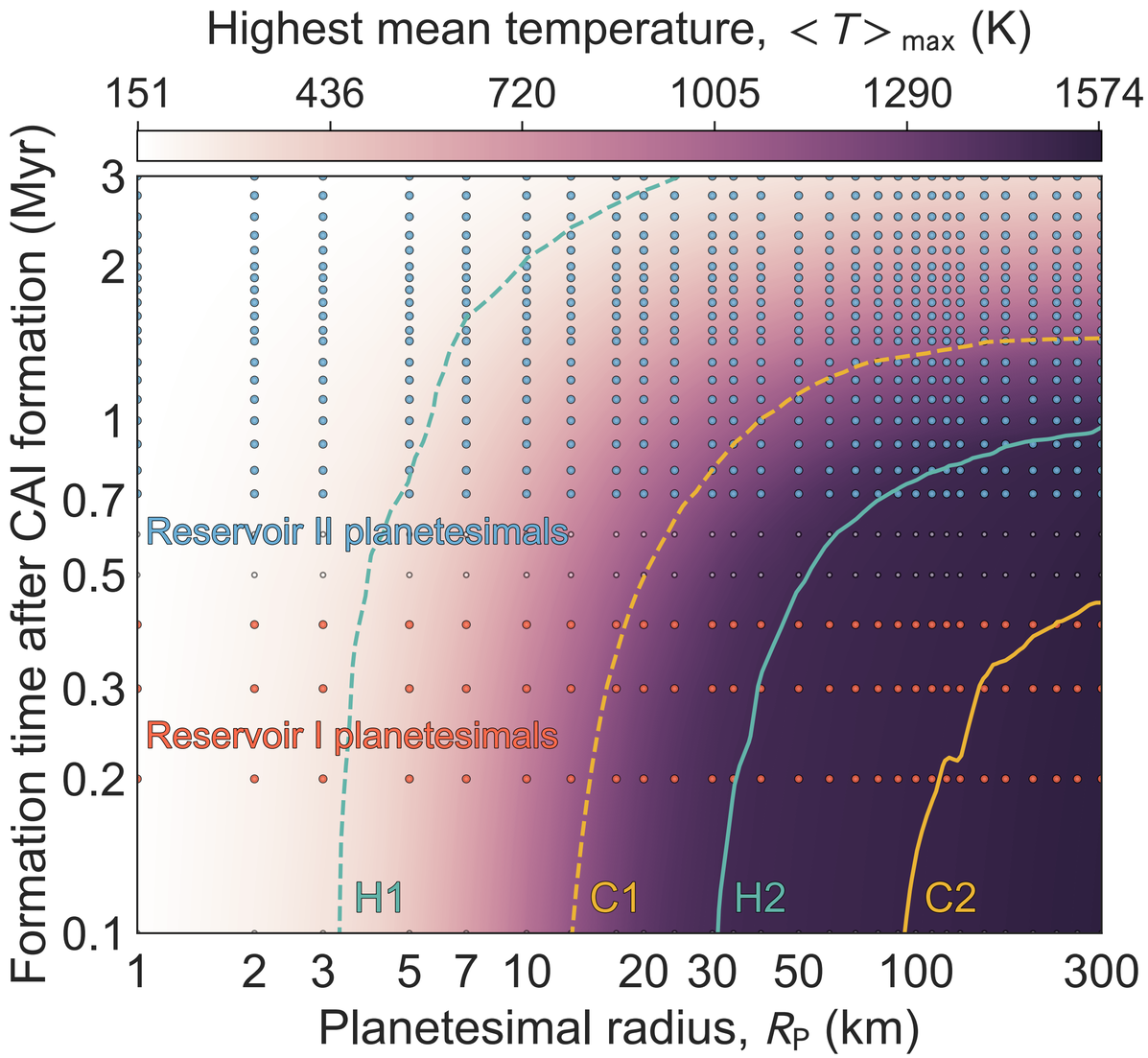
Lichtenberg+ 16a, 18, 19a,b

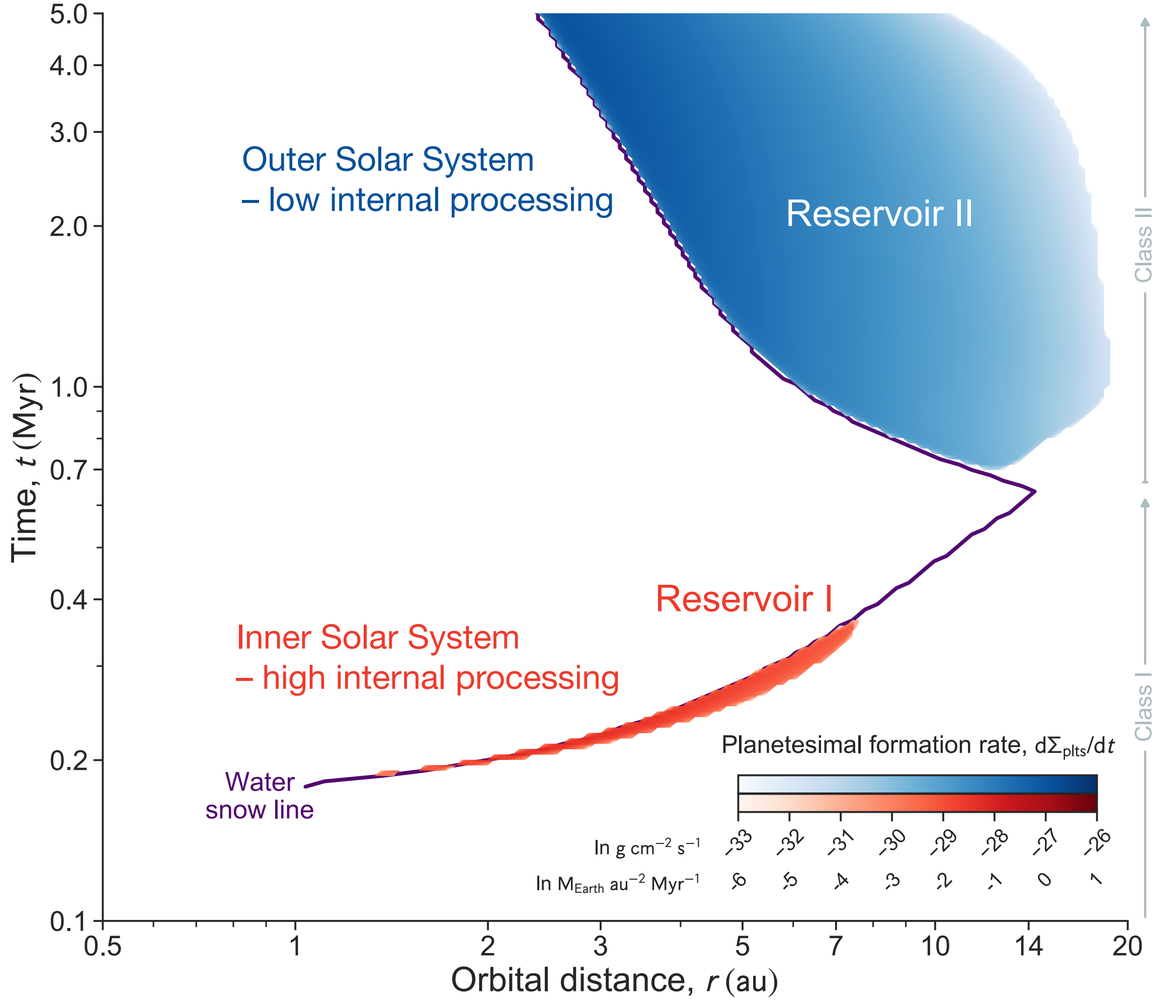
Radiogenic heating drives thermal evolution



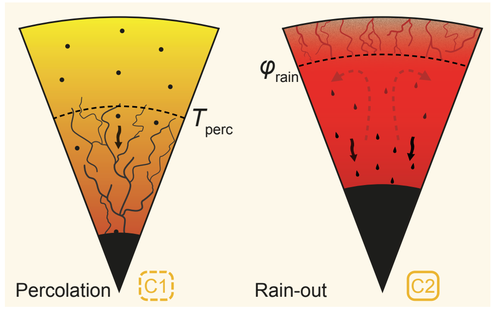


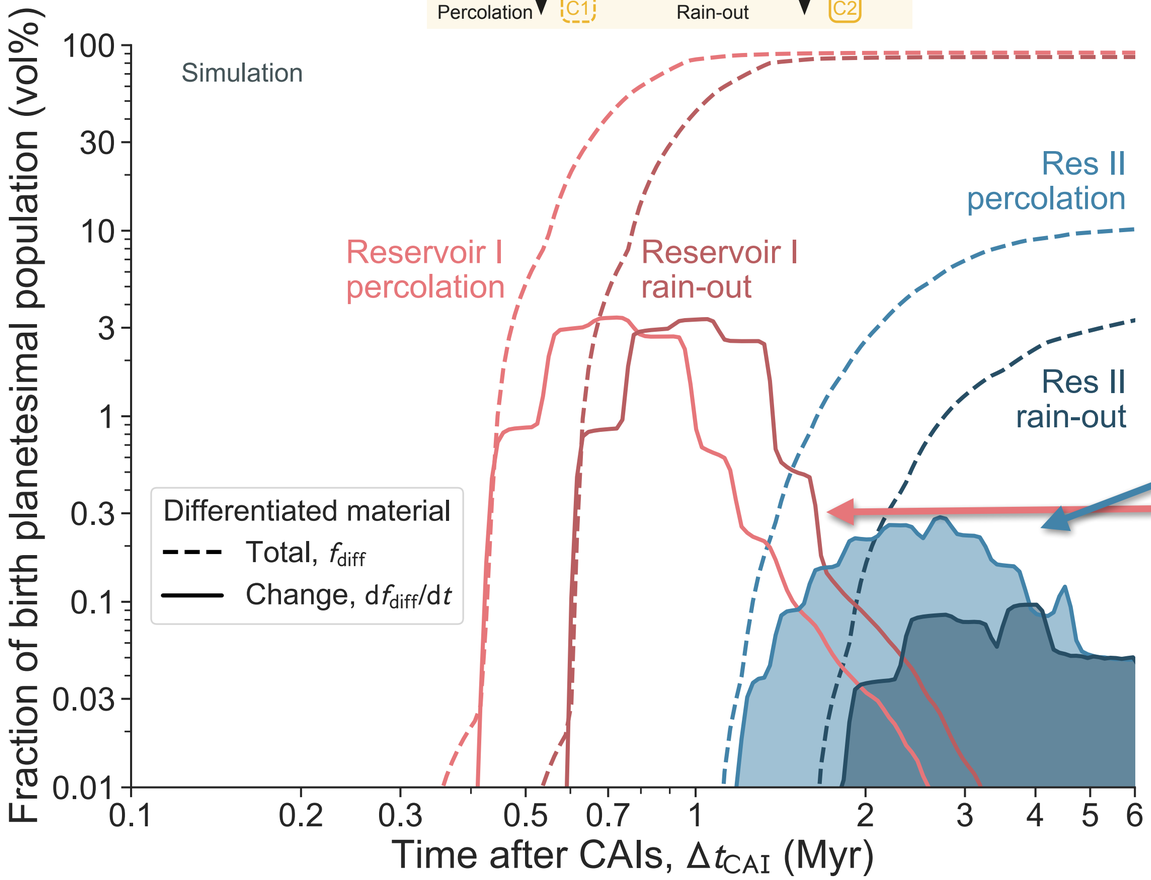
Radiogenic heating drives thermal evolution

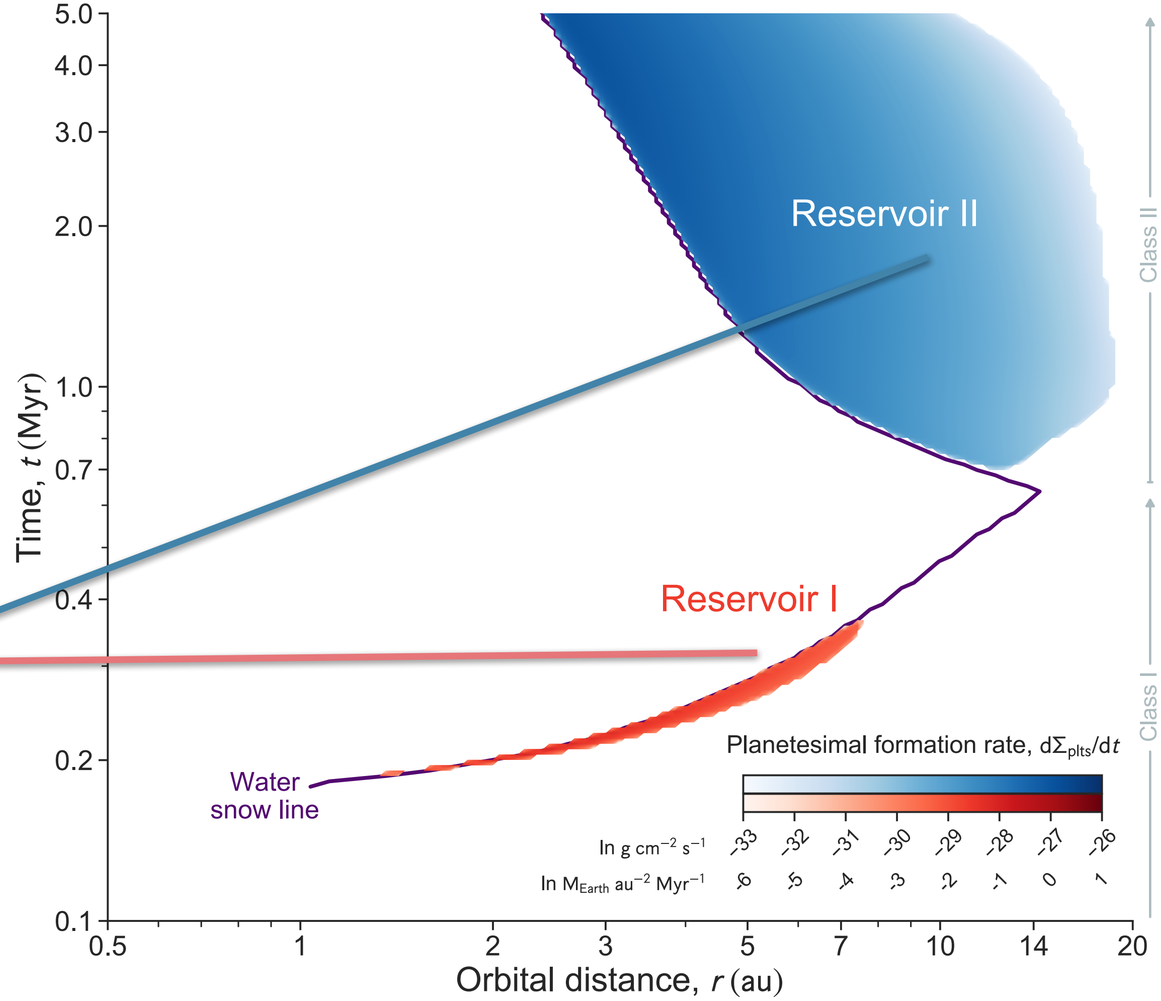




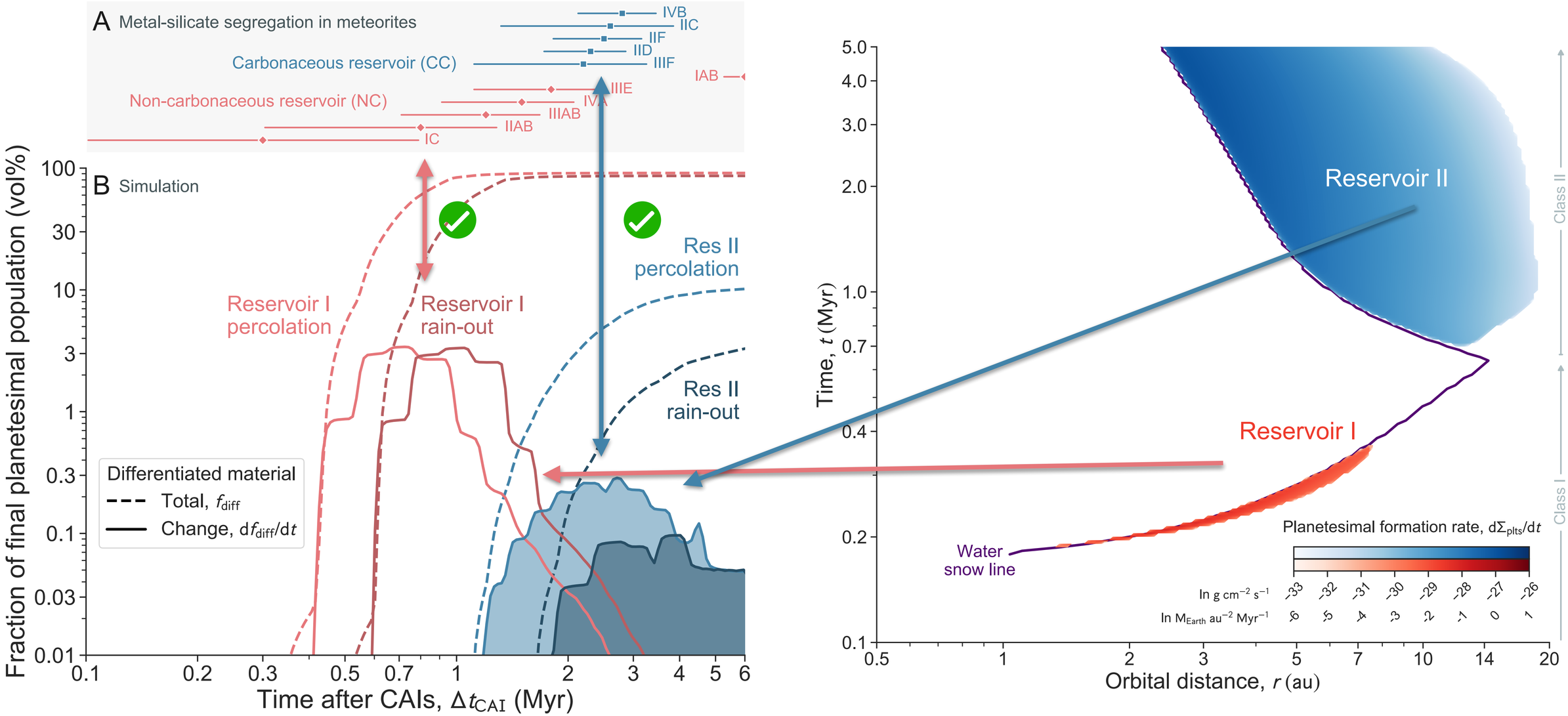
Iron core formation: meteorites vs. model



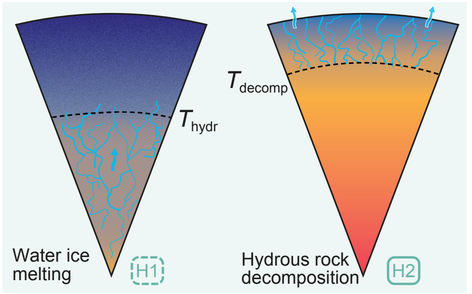


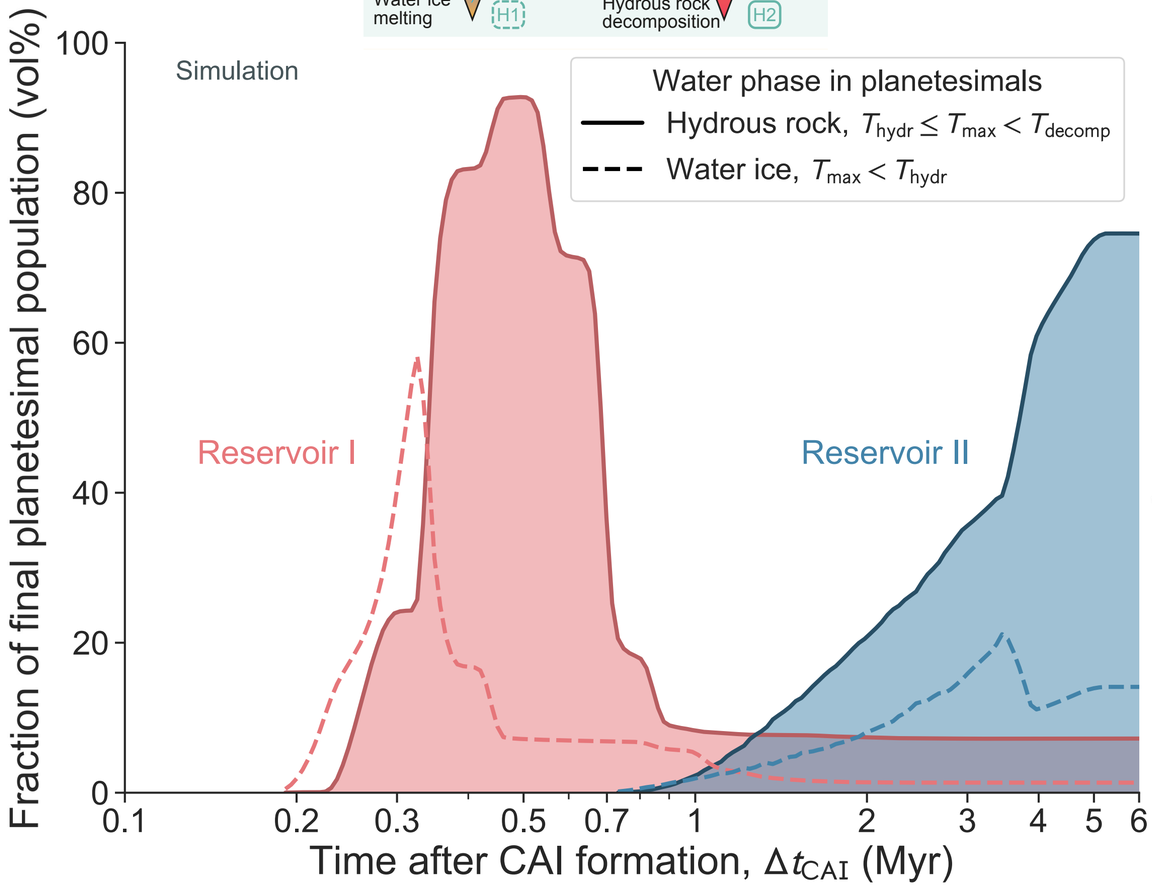


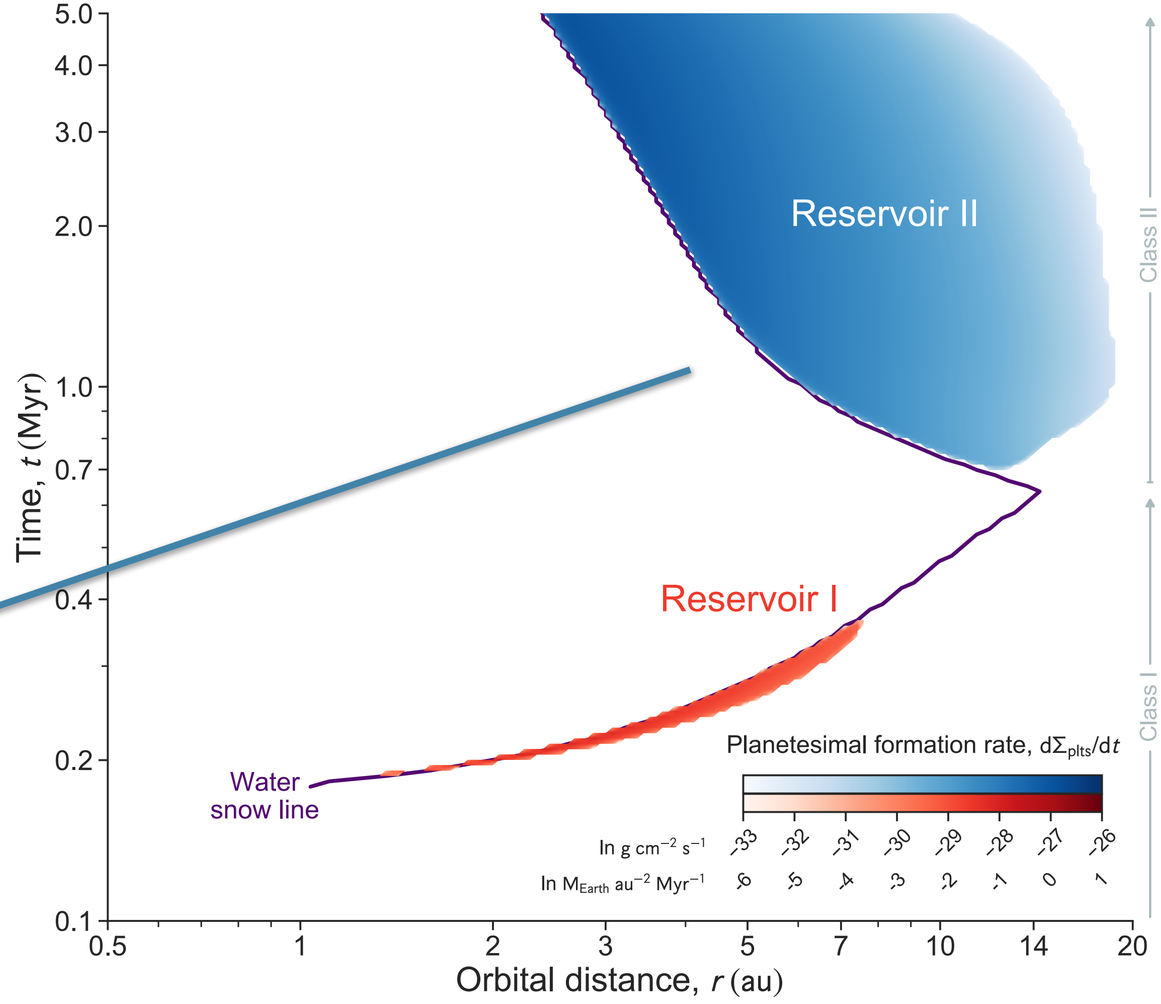
Iron core formation: meteorites vs. model



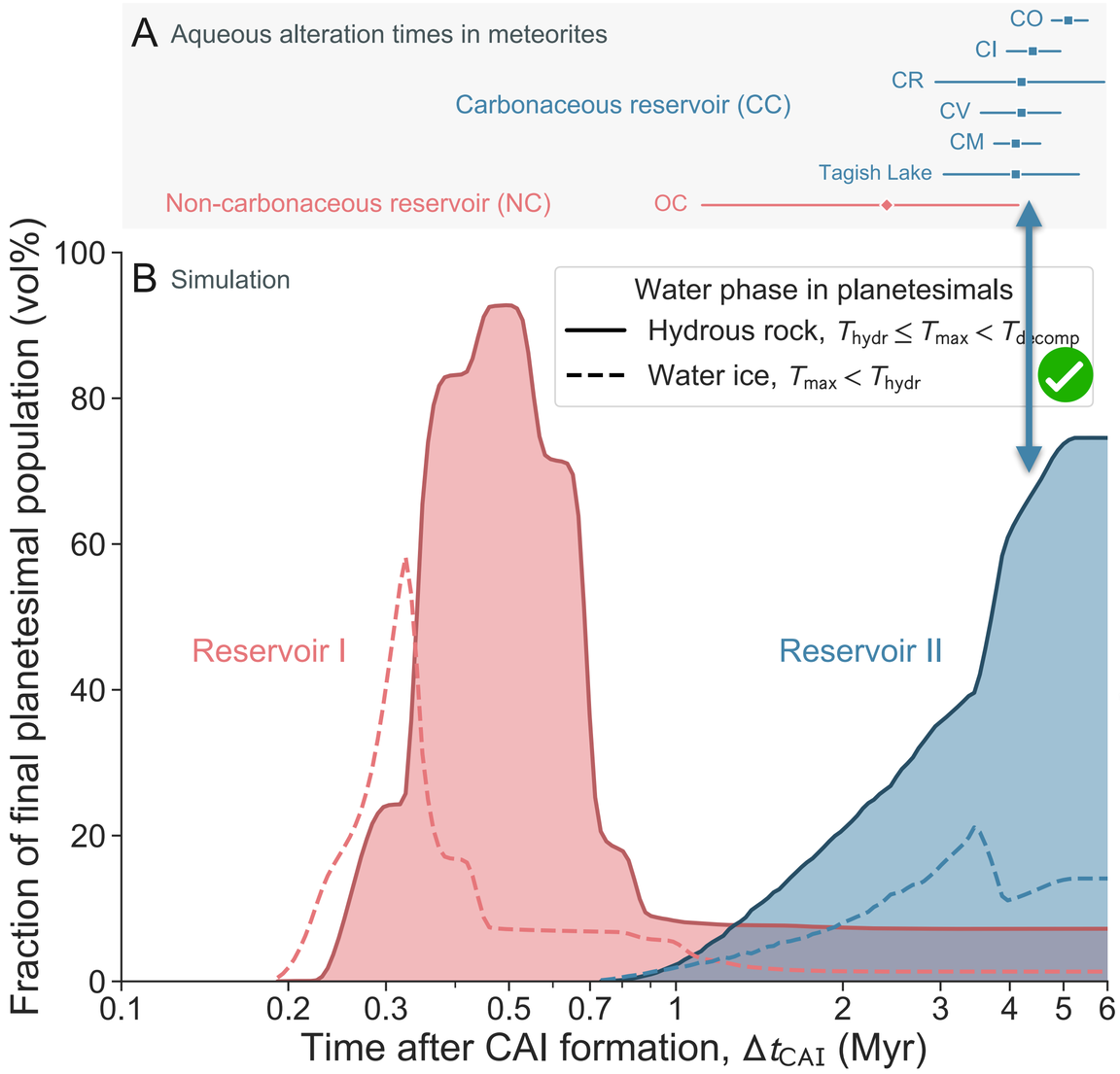
Aqueous alteration: meteorites vs. model

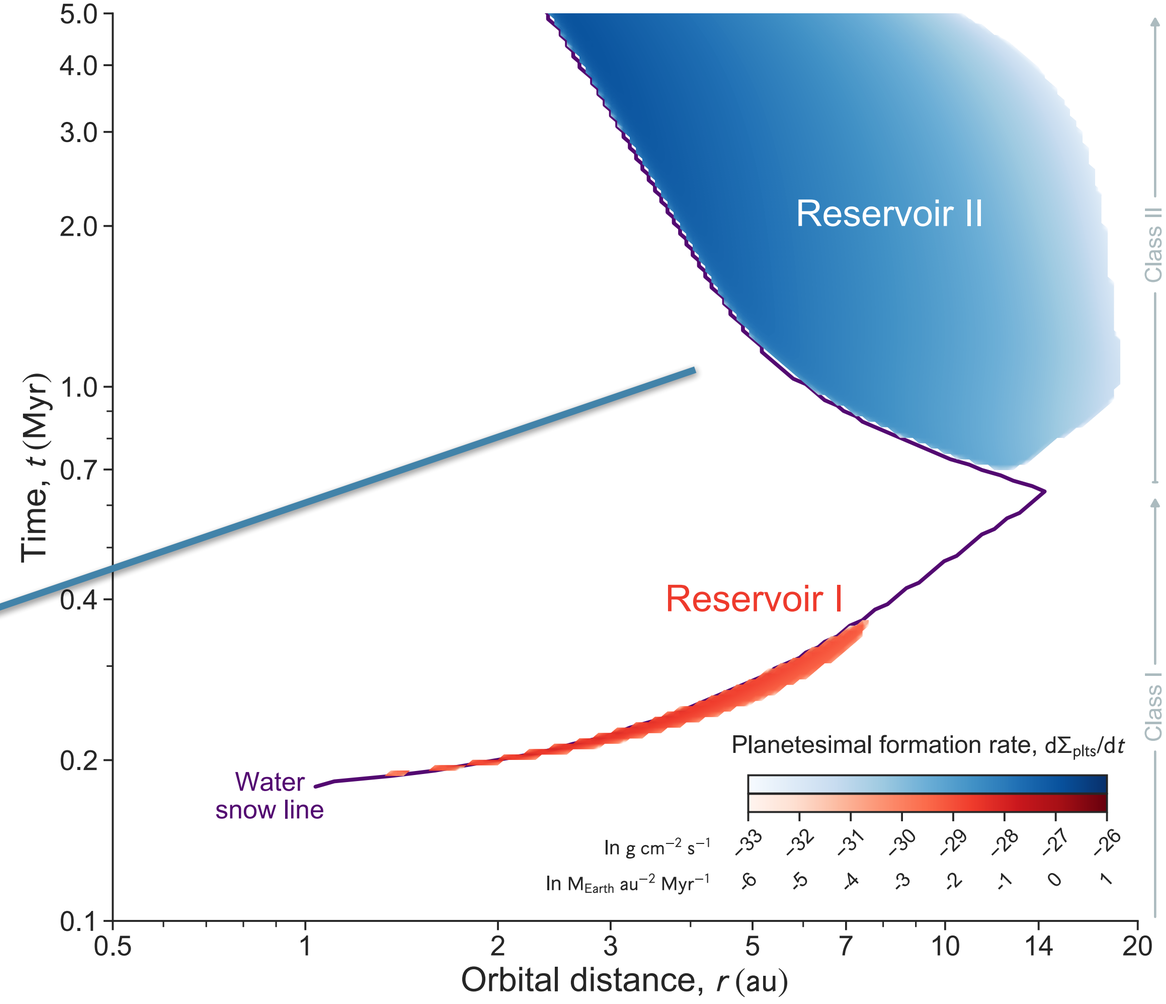




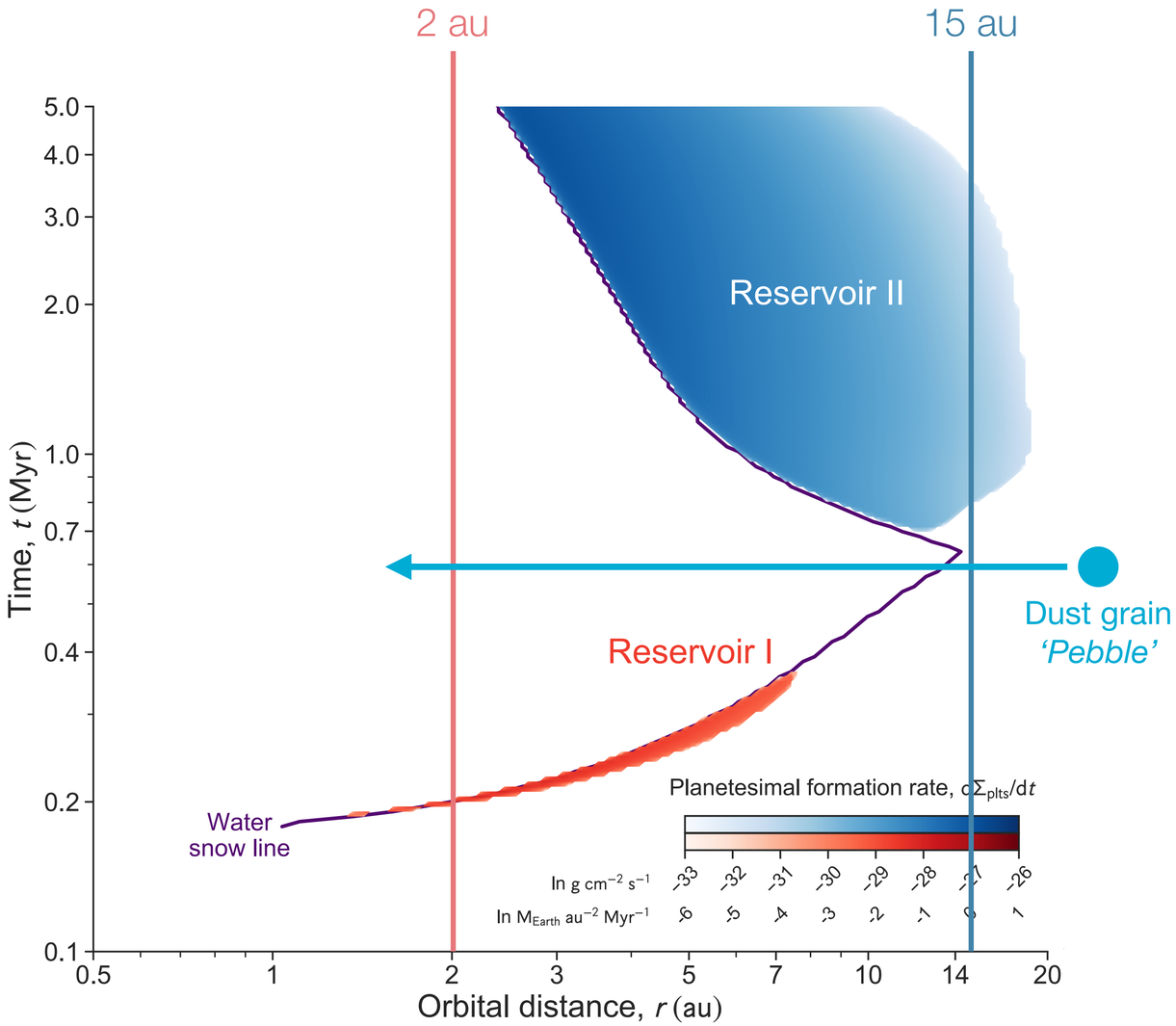


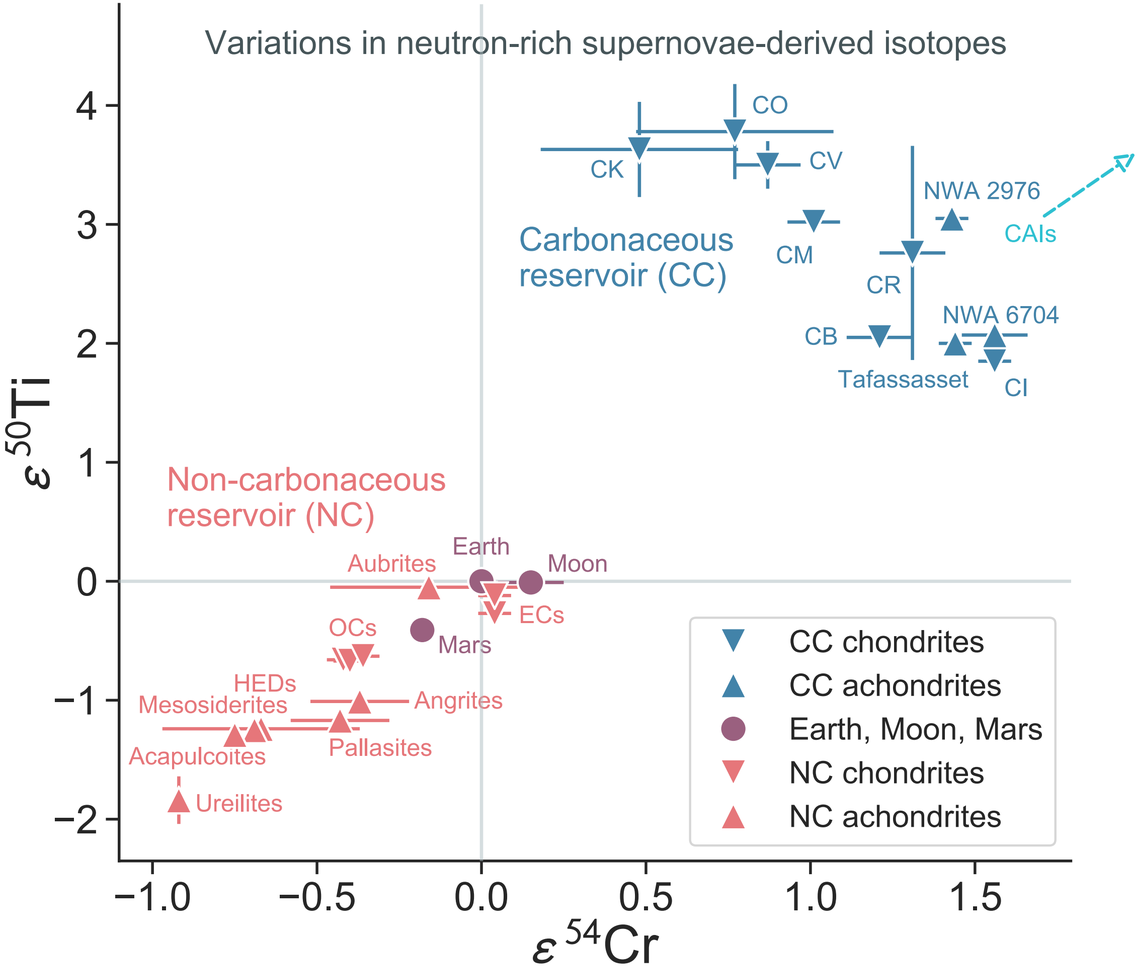
Aqueous alteration: meteorites vs. model



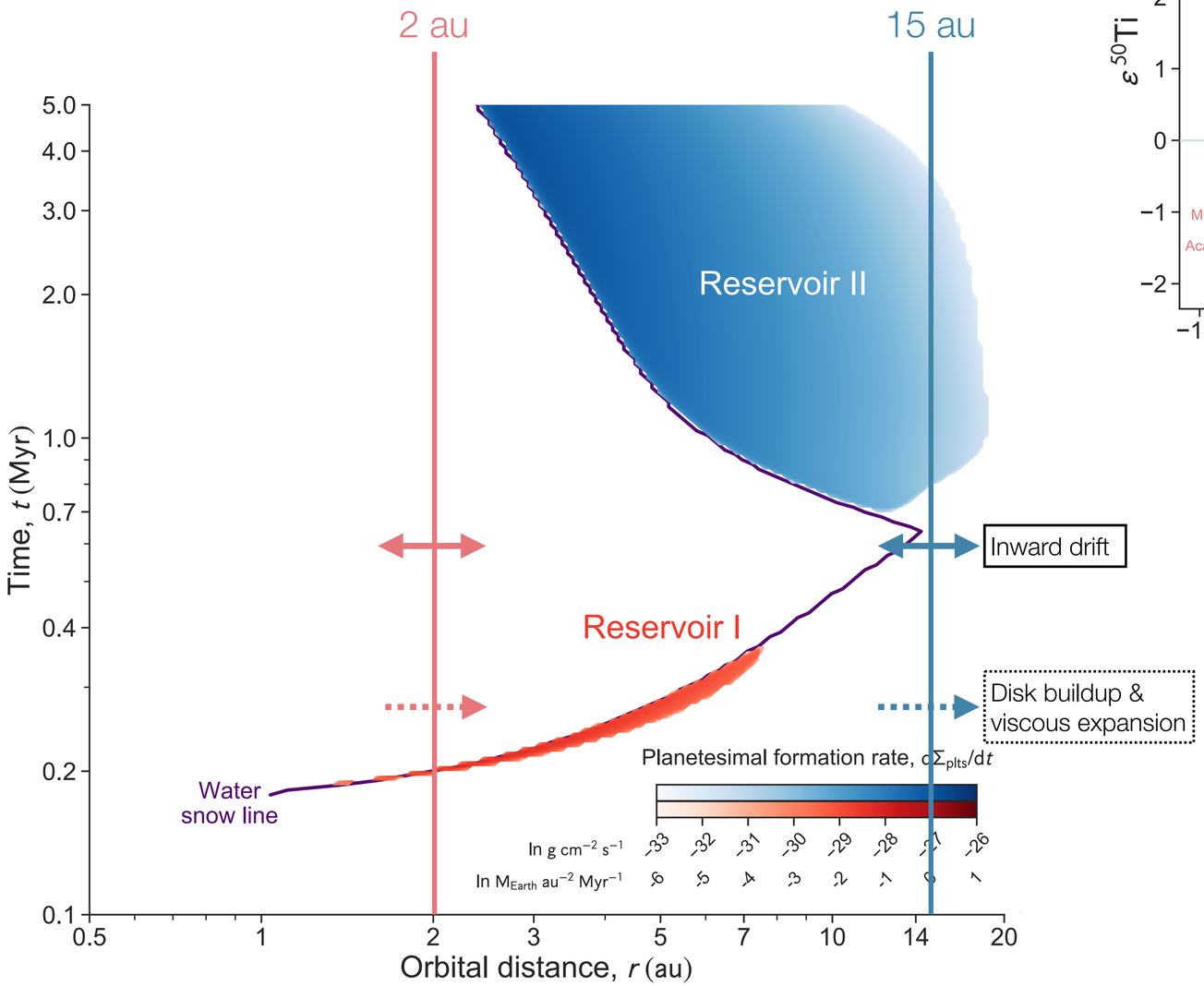


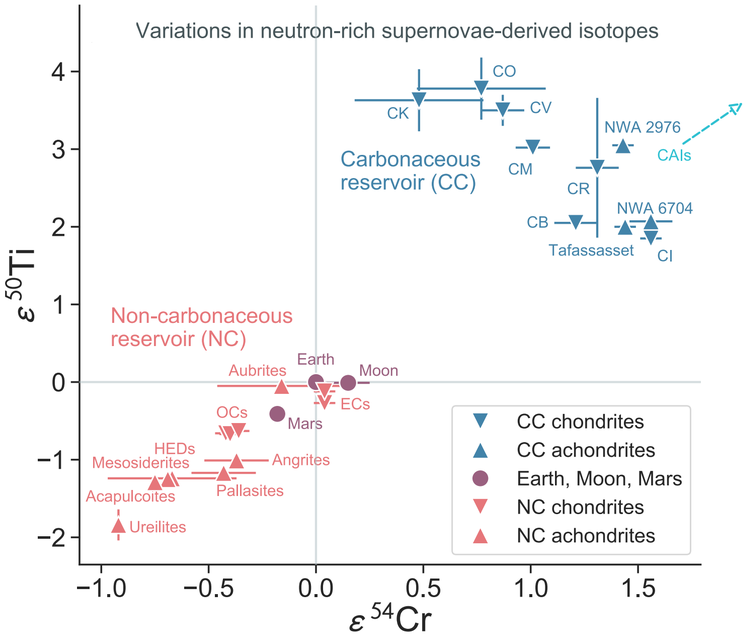
Isotope dichotomy

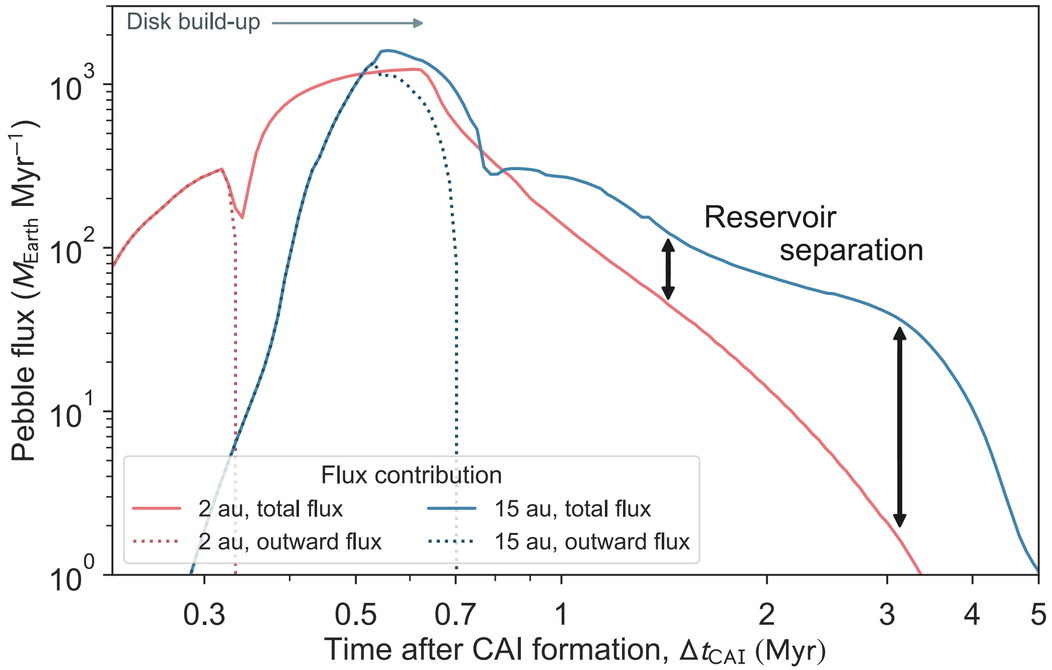




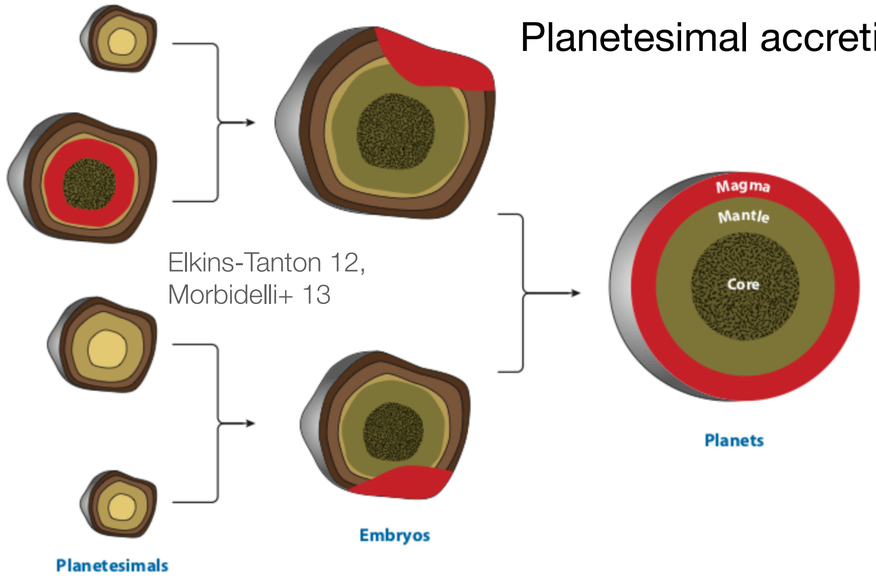
Isotope dichotomy

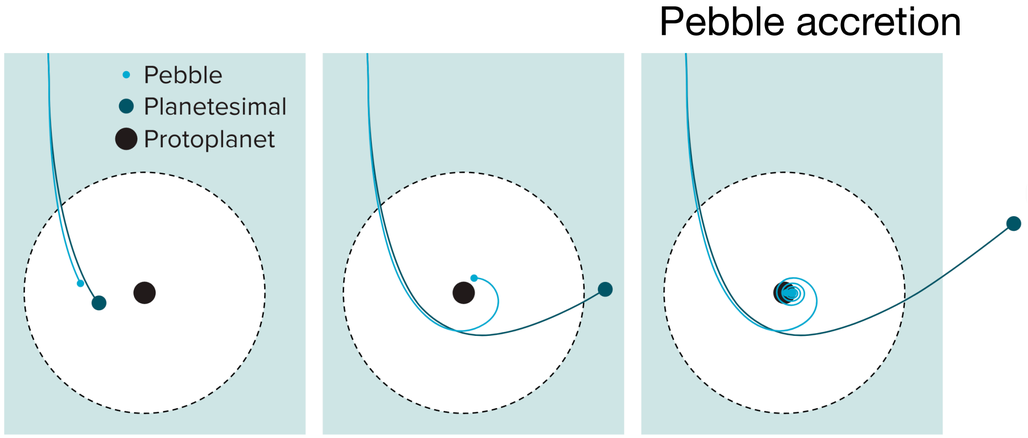




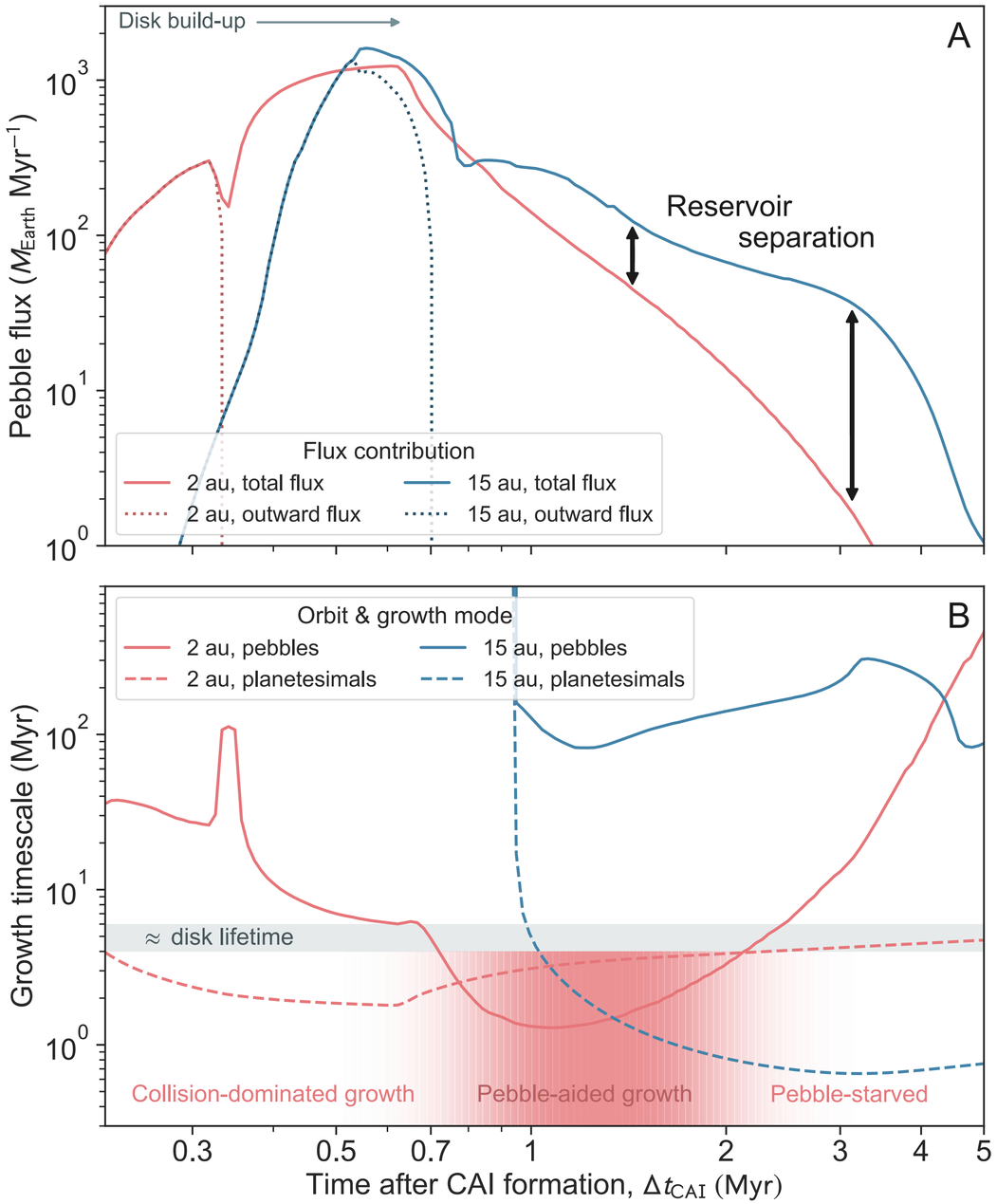


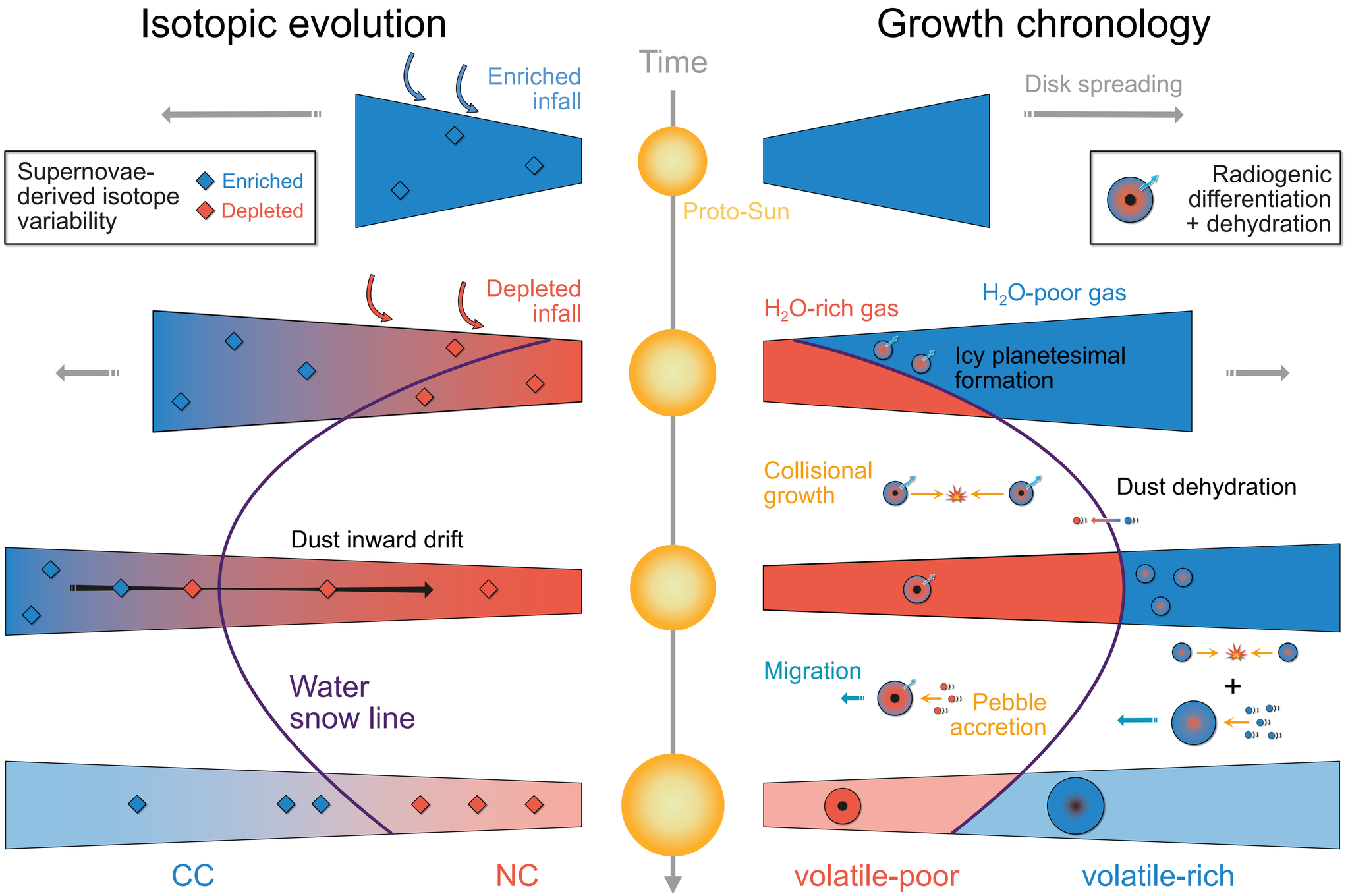
Growth mode





Johansen & Lambrechts 17, Ormel 17




Isotopic evolution
Growth chronology
Time
Enriched infall
Supernovae-derived isotope variability
Enriched
Depleted
Proto-Sun
Disk spreading
Radiogenic differentiation + dehydration
Depleted infall
H2O-rich gas
H2O-poor gas
Icy planetesimal formation
Collisional growth
Dust dehydration
Dust inward drift
Water snow line
Migration
Pebble accretion
+
CC
NC
volatile-poor
volatile-rich

TIM LICHTENBERG, JOANNA DRĄŻKOWSKA, MARIA SCHÖNBÄCHLER, GREGOR J. GOLABEK, THOMAS O. HANDS

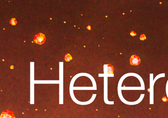
BIFURCATION OF PLANETARY BUILDING BLOCKS DURING SOLAR SYSTEM FORMATION

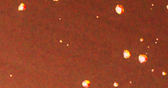
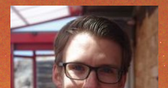
Reservoir separation initiated by protoplanet seeding

- Inner Solar System starts accreting first, but protracted
- Heterogeneous growth of planets

Compositional dichotomy of Solar System result of:

- Spatially and temporally distinct planetesimal bursts
- Divergent geophysical evolution from ^{26}Al heating

Science 371, 6527 (2021)
10.1126/science.abb3091

tim.lichtenberg@physics.ox.ac.uk