A planet population dichotomy from isotopic enrichment?

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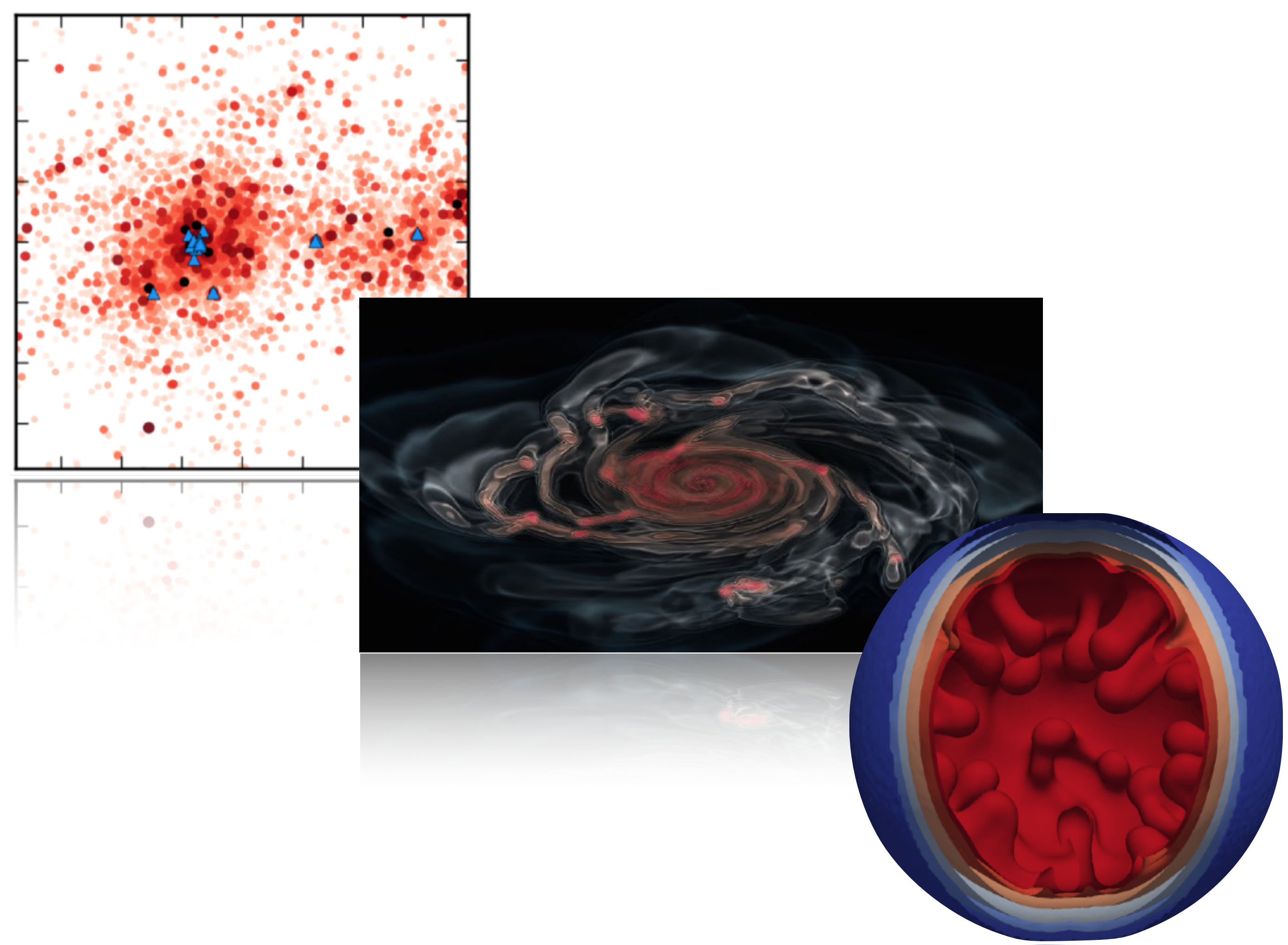


ETH zürich

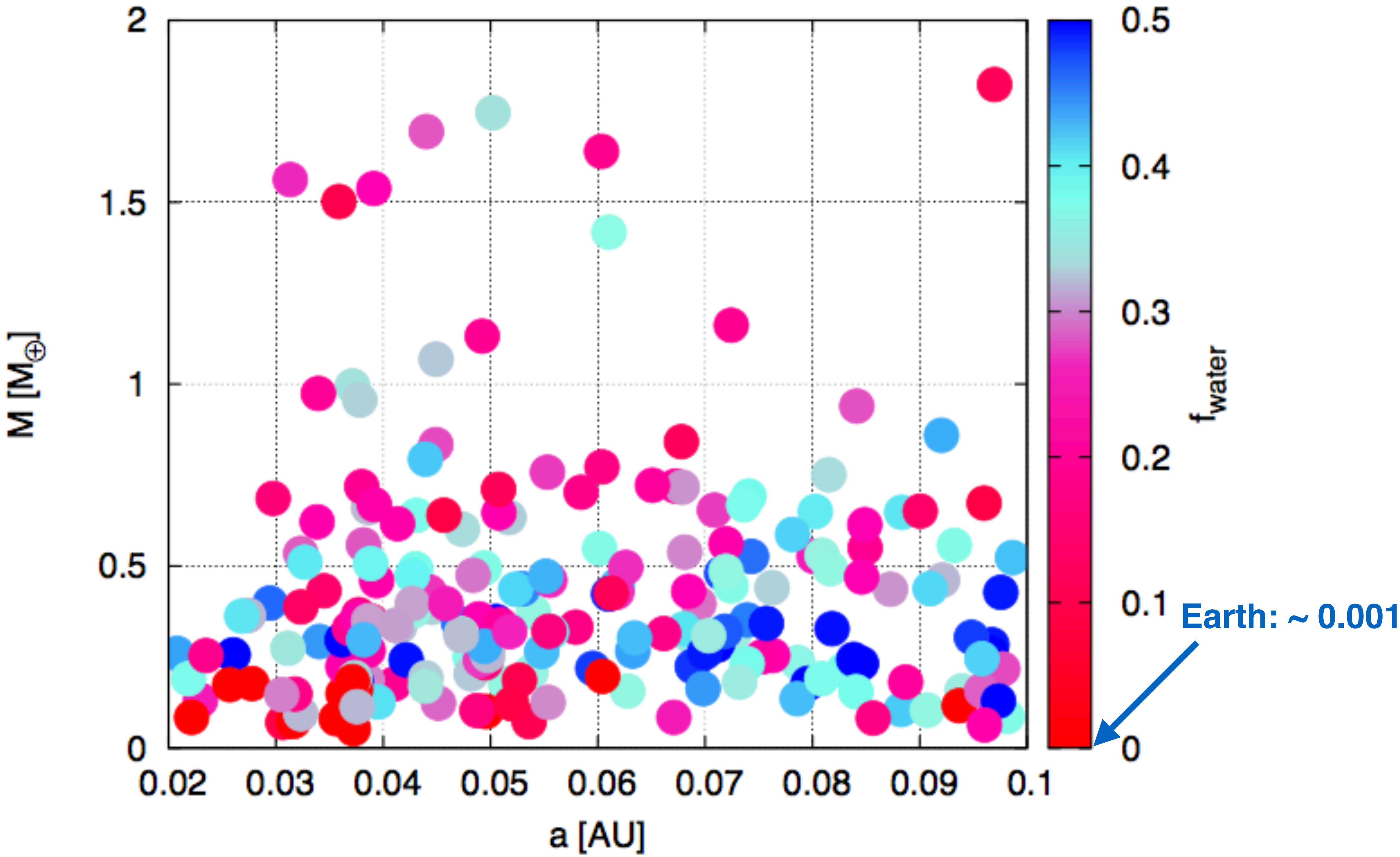
Outline

1. Grand perspective

2. Short-lived radionuclide (SLR) injection via supernova pollution

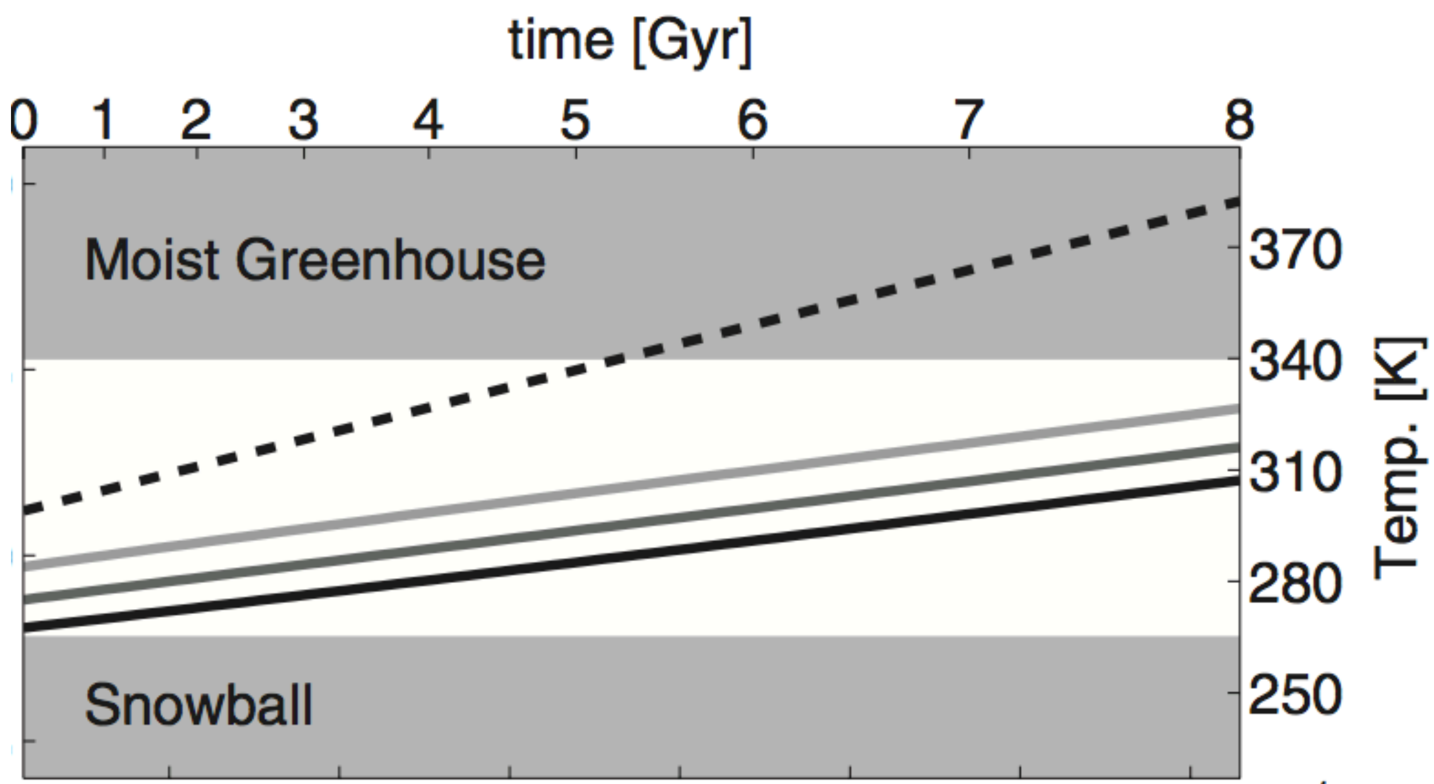
3. Implications for planetesimal evolution and planet formation

Lots of water worlds?



Alibert & Benz 17

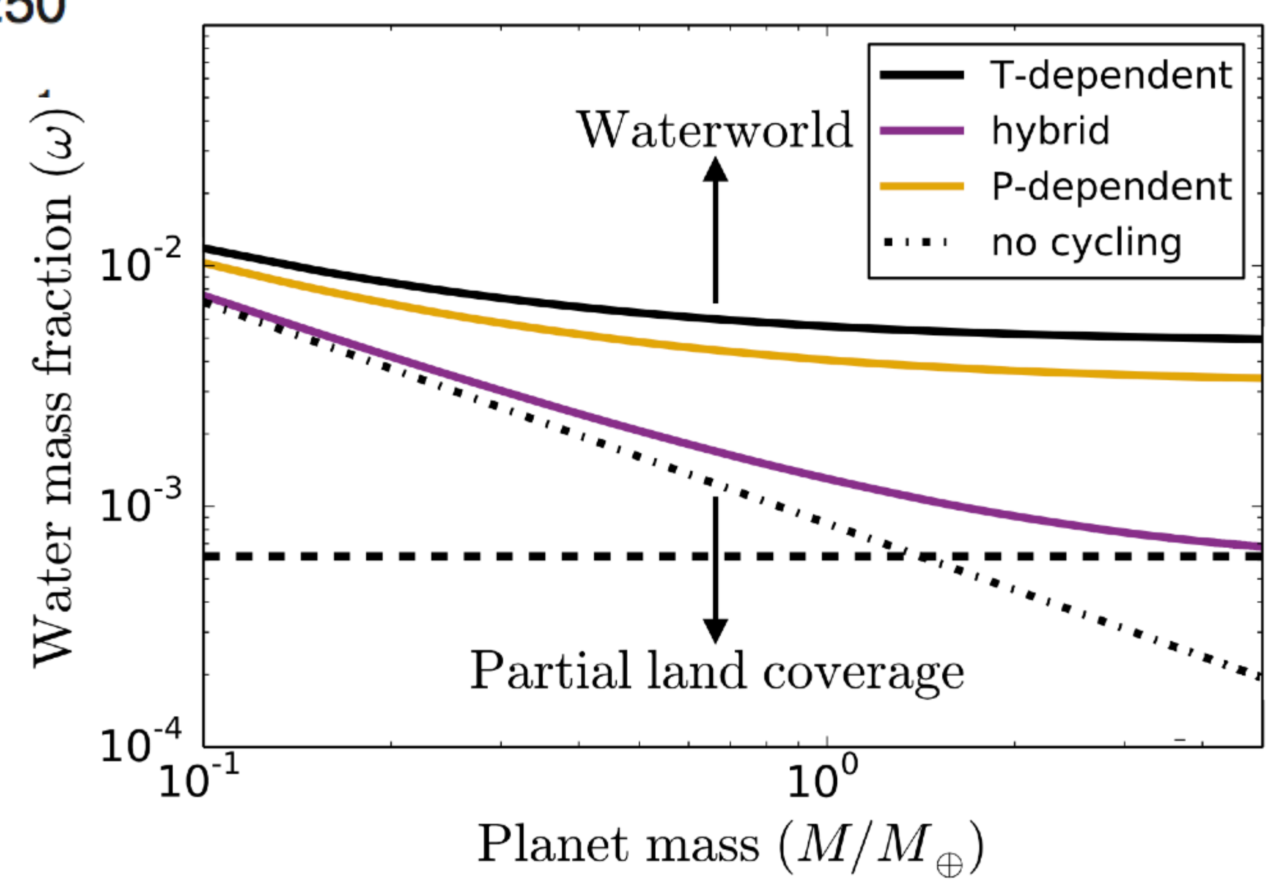
Why too much water is a bad idea



Abbot+ 12

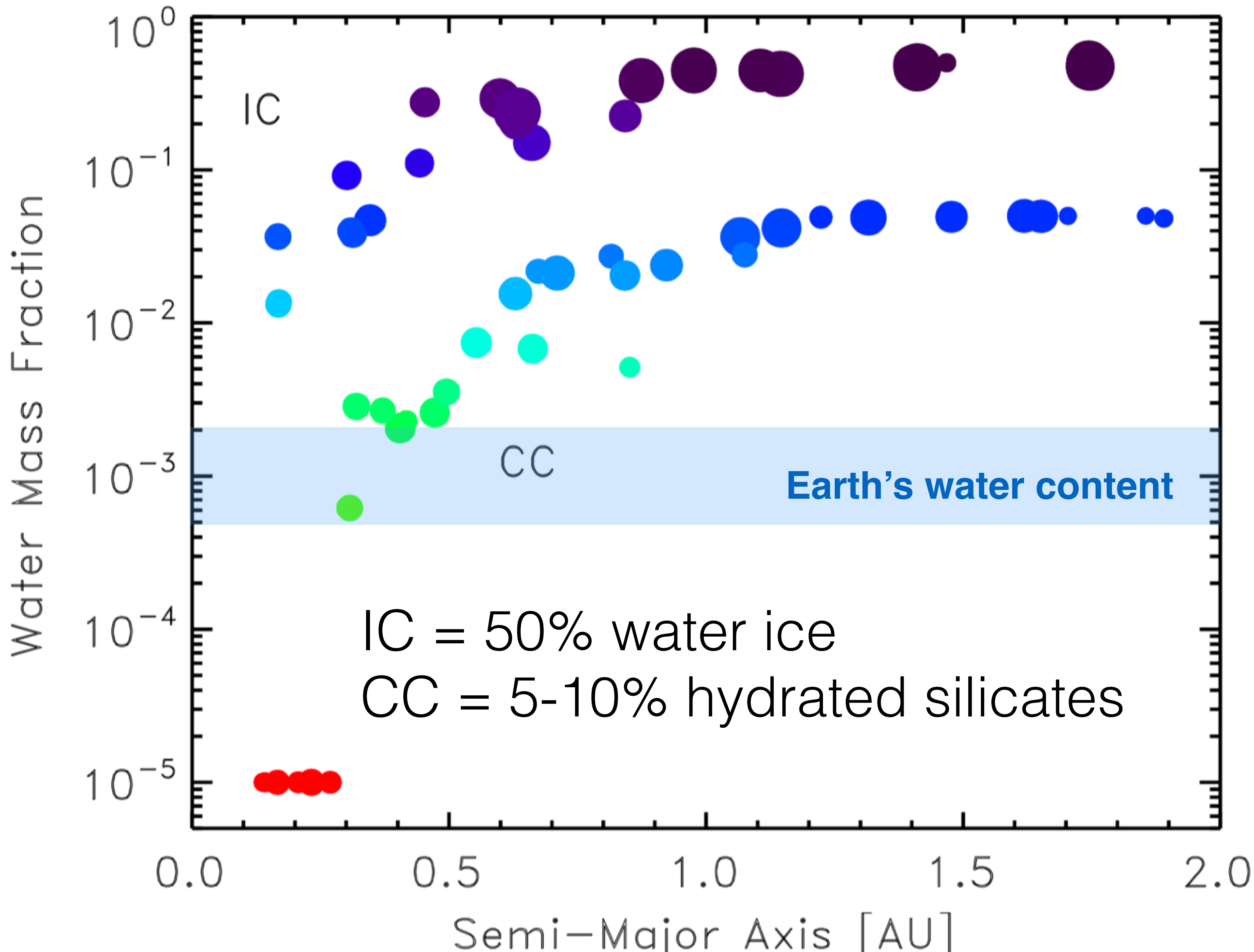
- Absolute threshold to store water in mantle

Komacek & Abbot 16, Cowan & Abbot 14



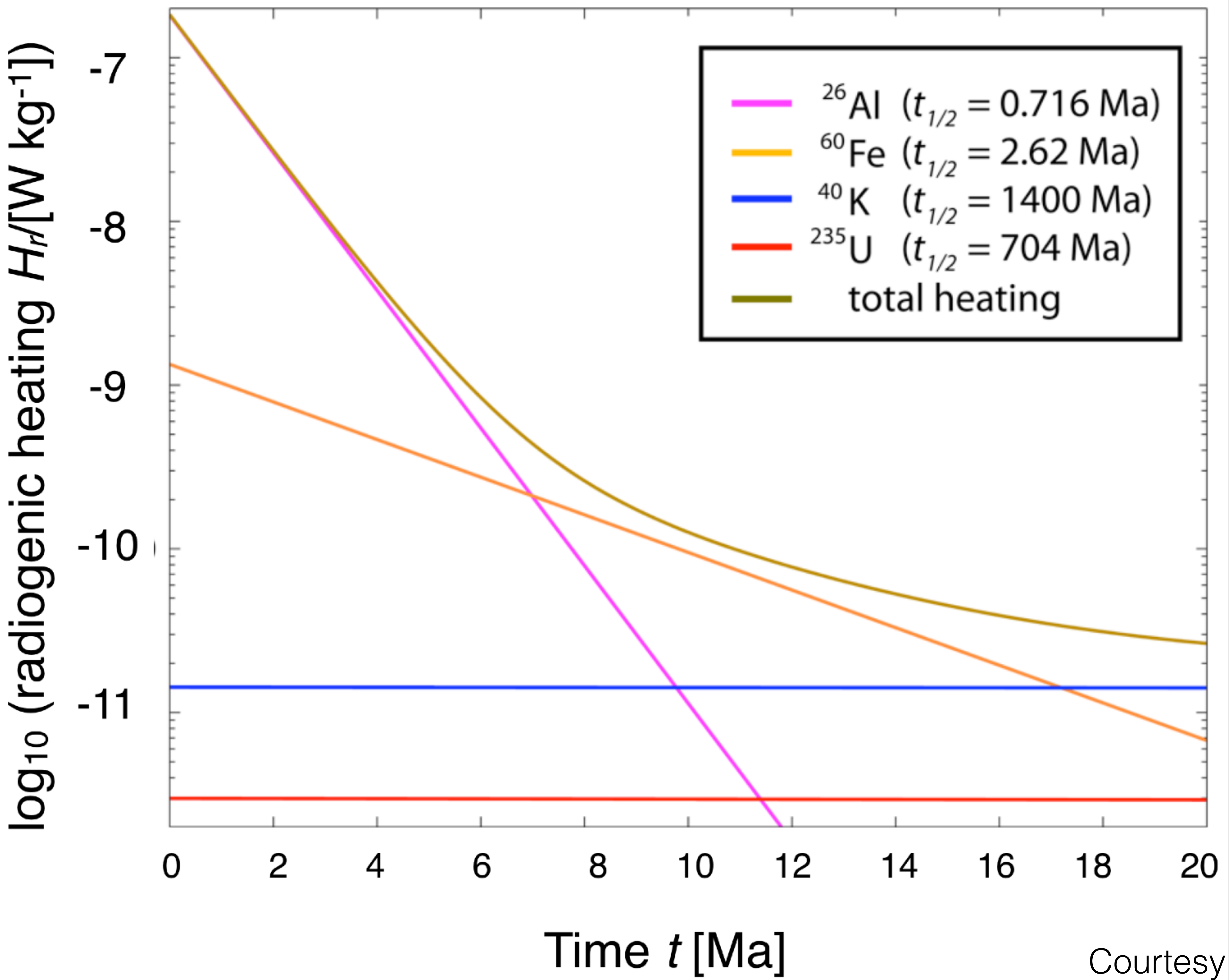
- Continental silicate weathering
- negative feedback, important for carbonate burial

How to dry out planets?



Ciesla+ 15, Mulders+ 15

Radiogenic heating in early Solar system



Courtesy: Gregor Golabek

^{26}Al — the Solar System link to its birth environment

1. Aluminum-26 fused in massive star

↓

2. Transport to nascent Solar System

↓

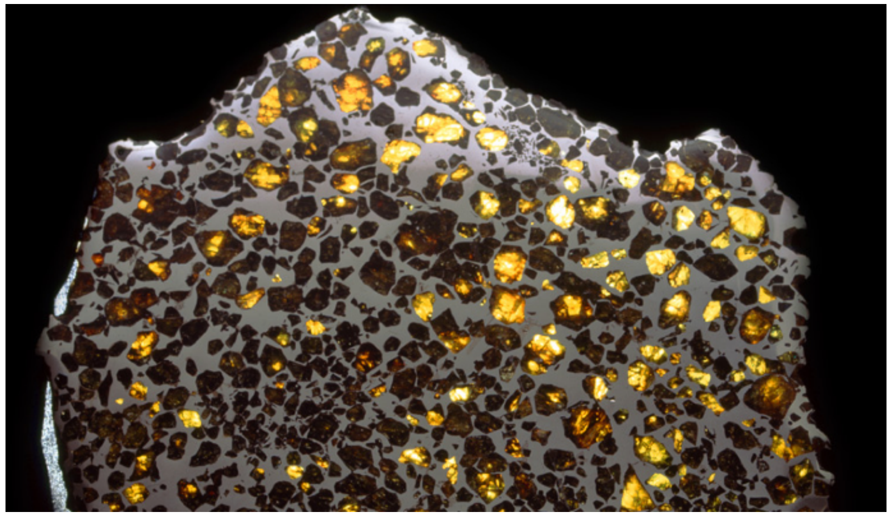
3. Mixing into dust/solid material

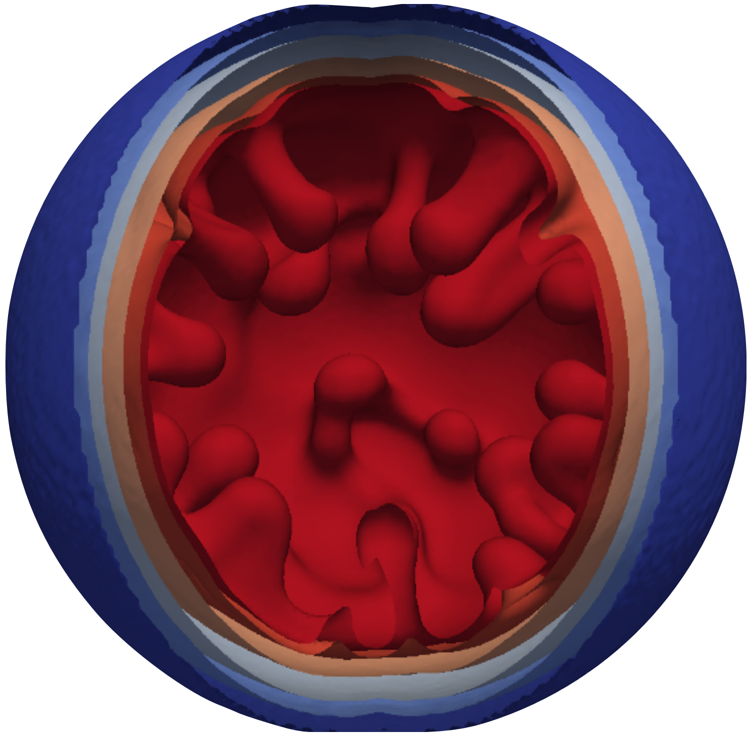
↓

4. Heating of early planetesimals by radioactive decay

➡ Differentiation, serpentinization, volatile degassing, …

NHM, London



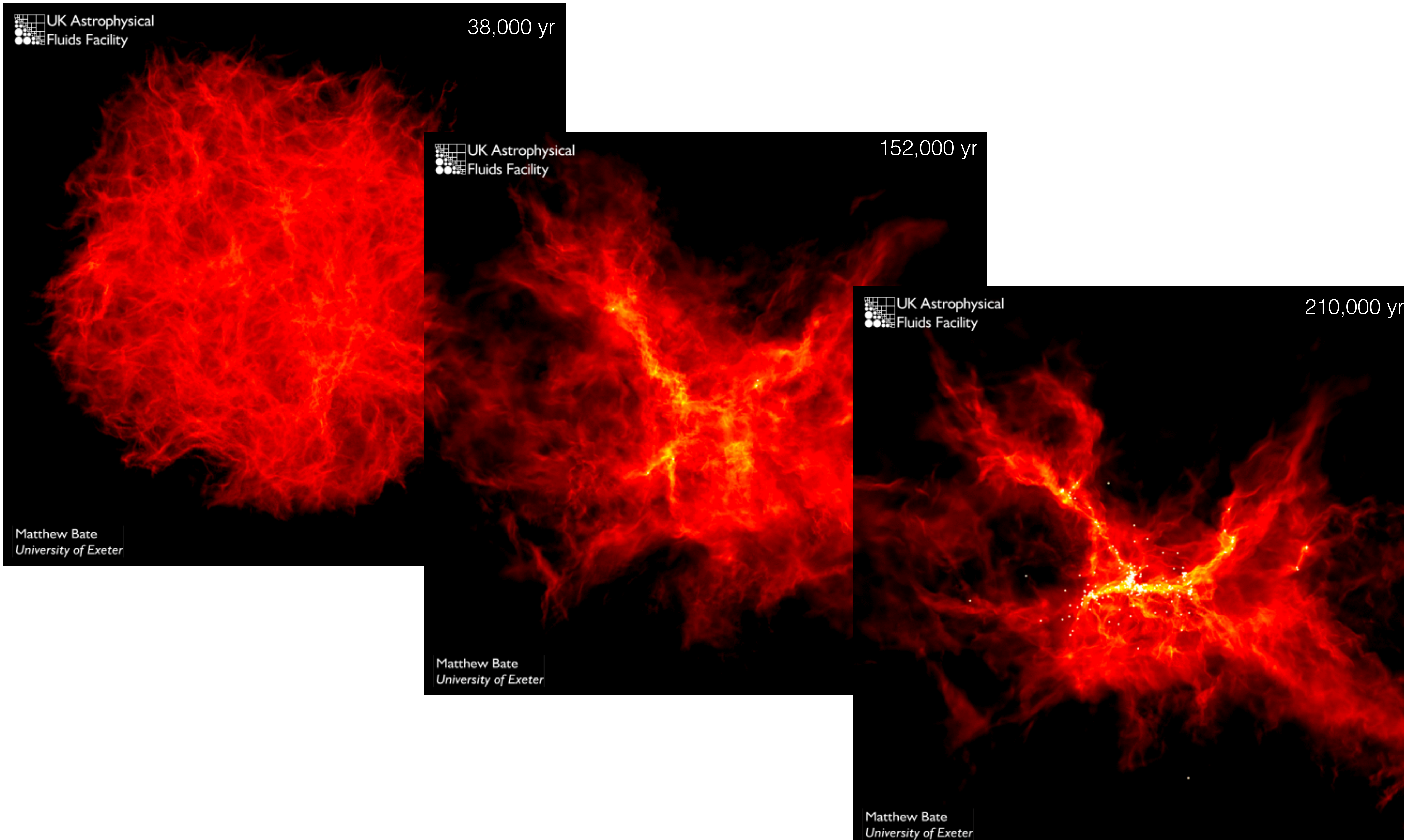


Lichtenberg+ 16a, *Icarus*

Take away I

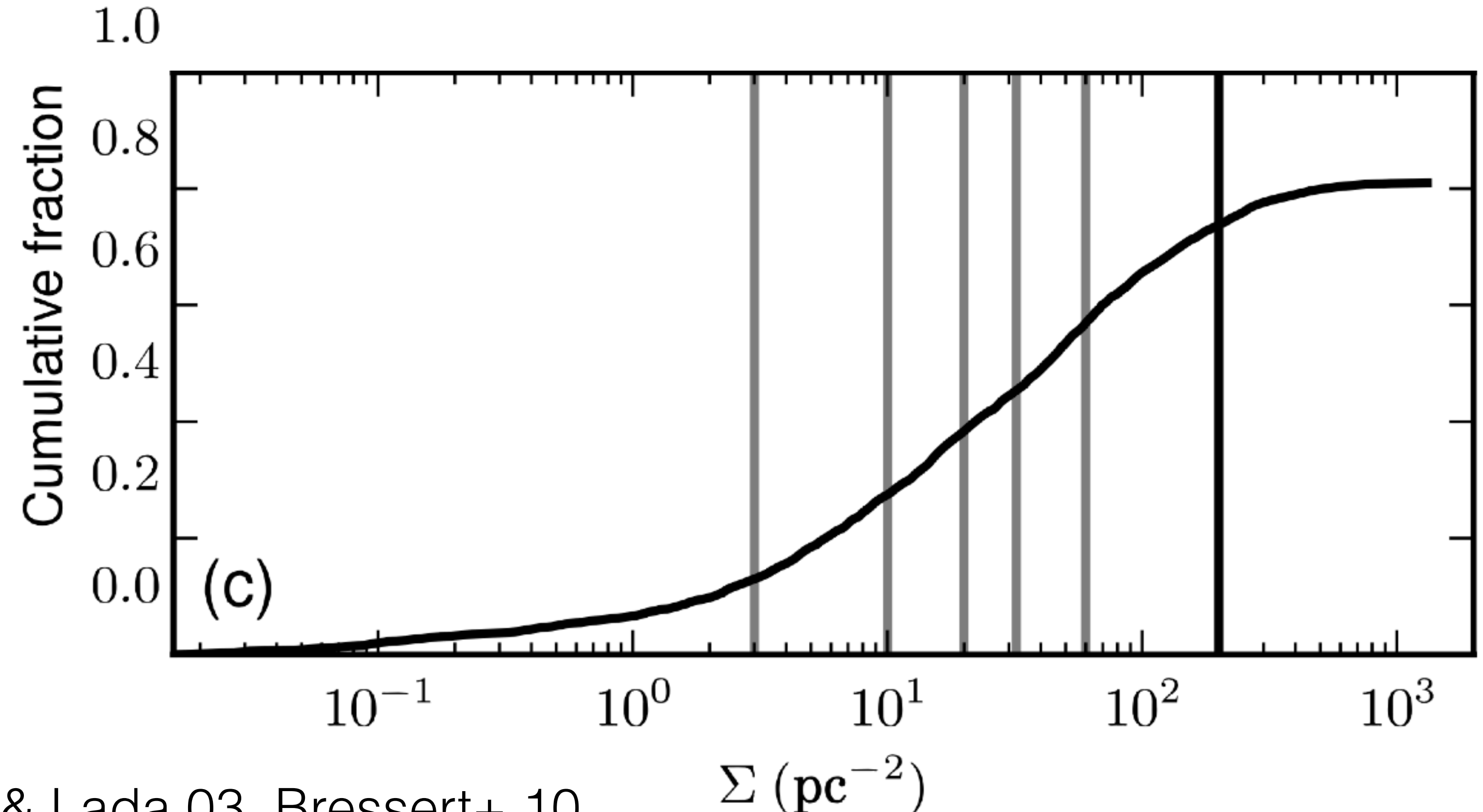
- Planetary water budget crucial for planetary geodynamics, e.g., plate tectonics regime, silicate weathering thermostat
- Earth seems to be a water-depleted terrestrial planet
- Short-lived radionuclides in meteorites determine ages during planet formation and set early interior heat budget

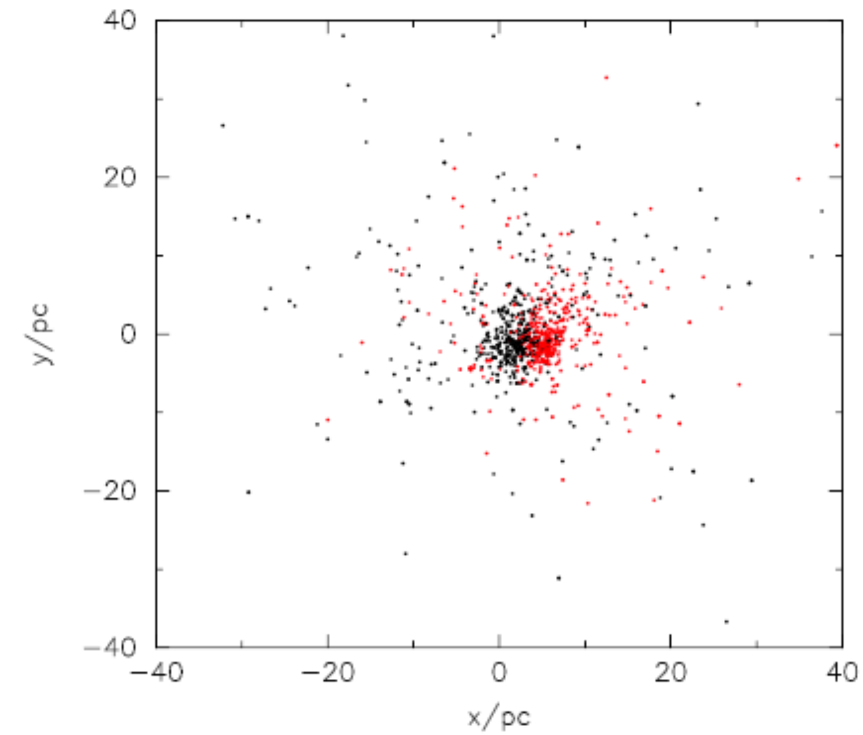
In a nutshell: star formation

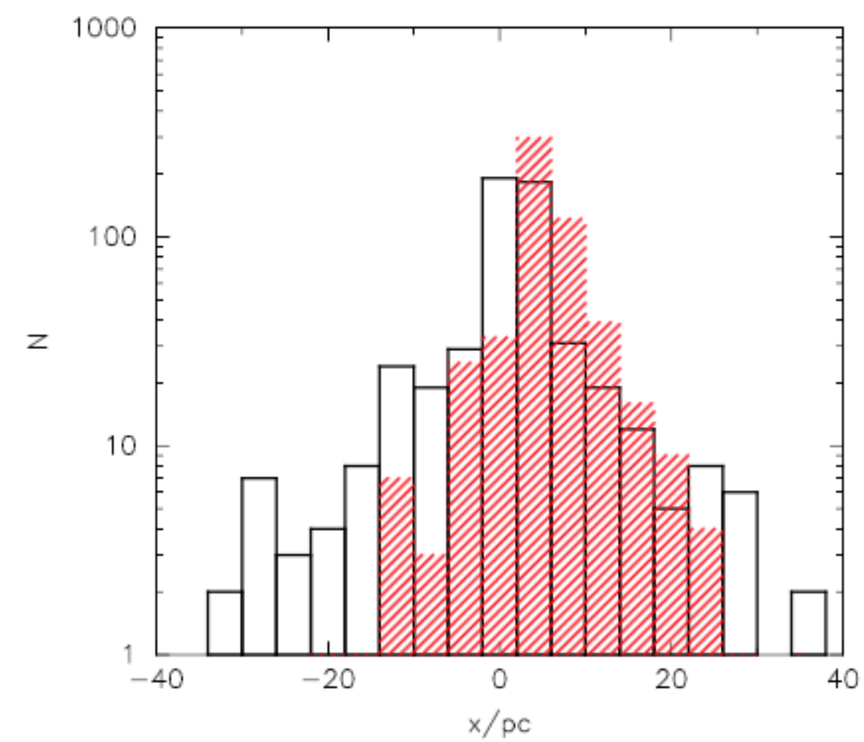


Triggering, age spreads, clusters

- Age spreads < 2 Myr in local (~pc) star forming environments
- Most stars form in clusters > 50 Msun
- Usually fast (< 10 Myr) expansion



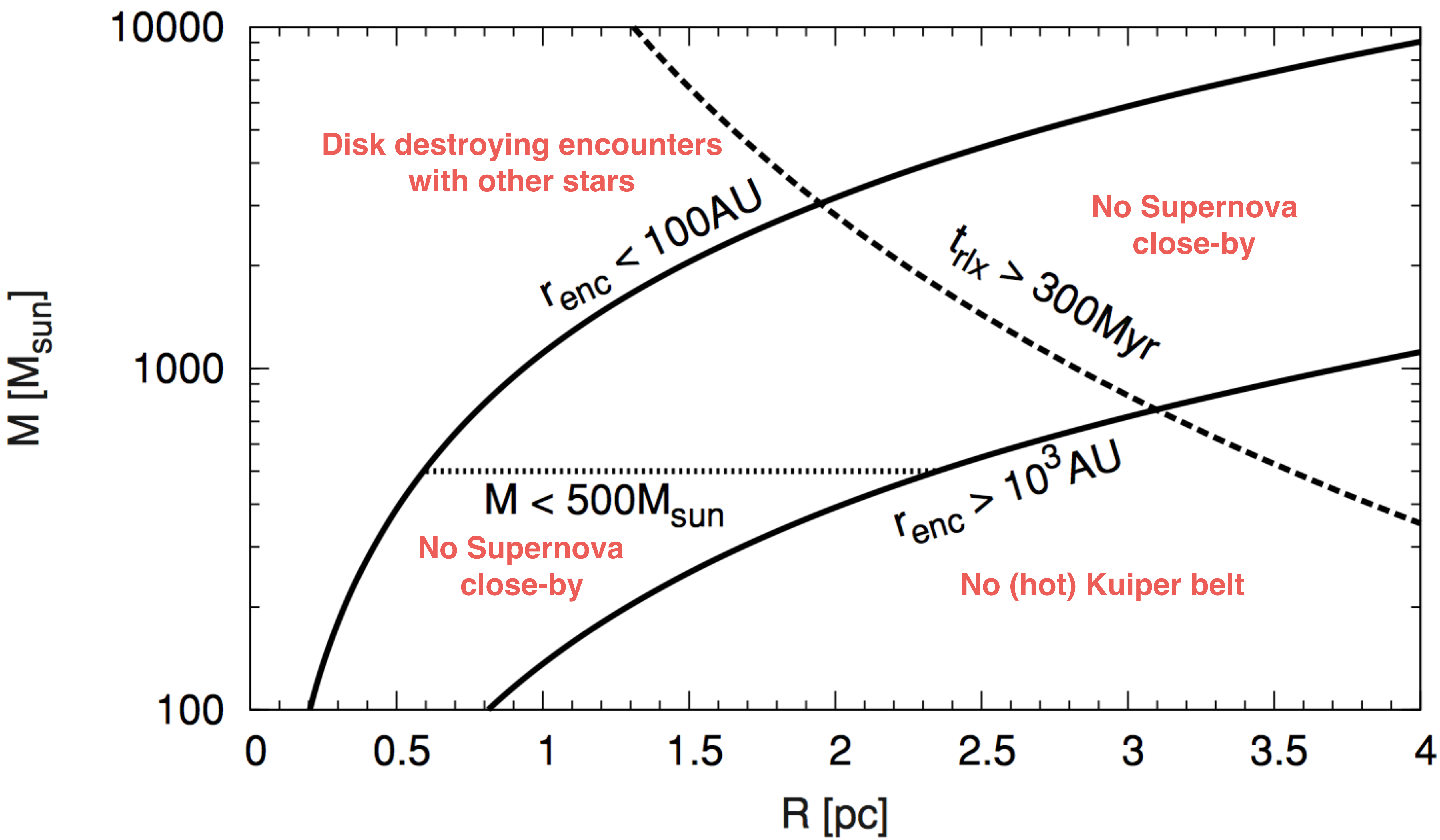




Lada & Lada 03, Bressert+ 10

Parker+ 16

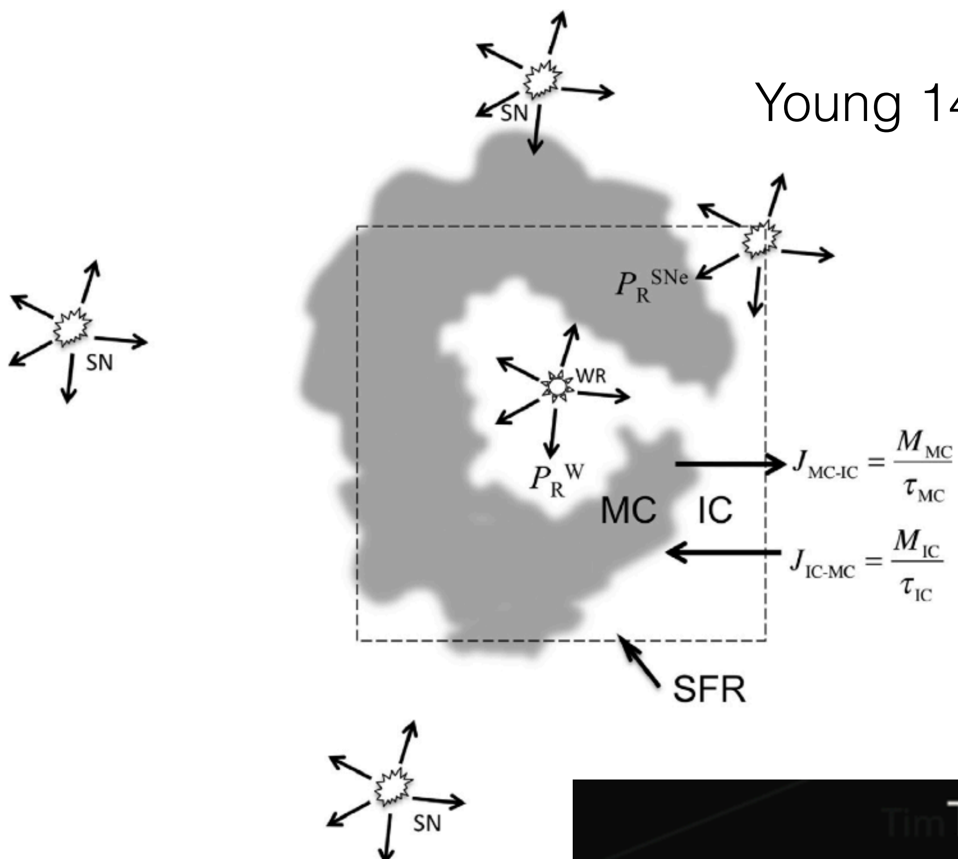
The Solar birth cluster

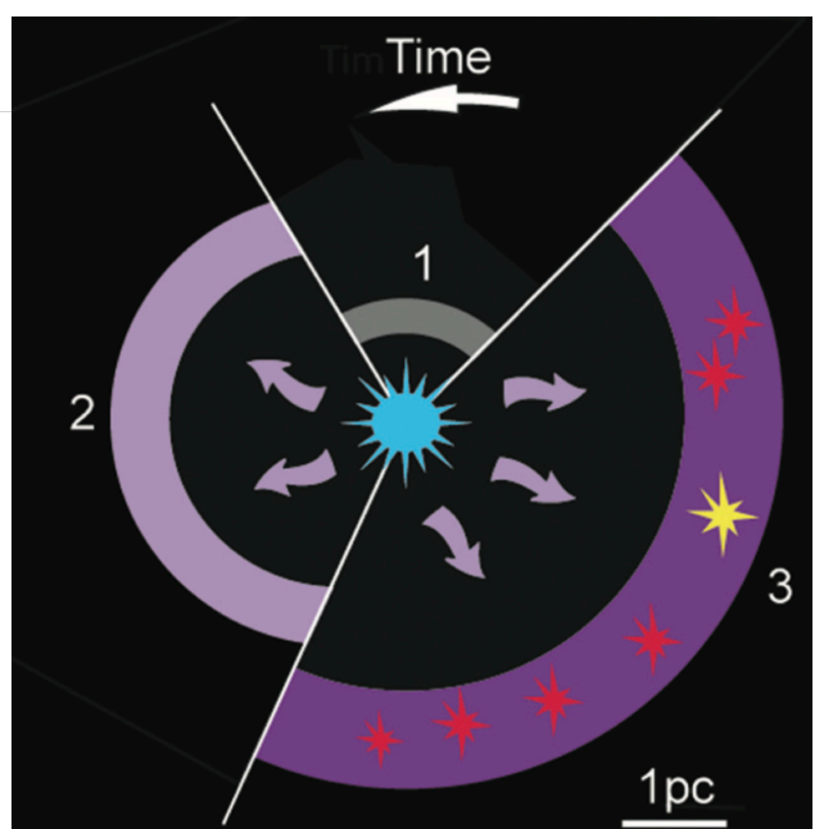


Portegies Zwart 09

Origin of short-lived radionuclides

Young 14,16



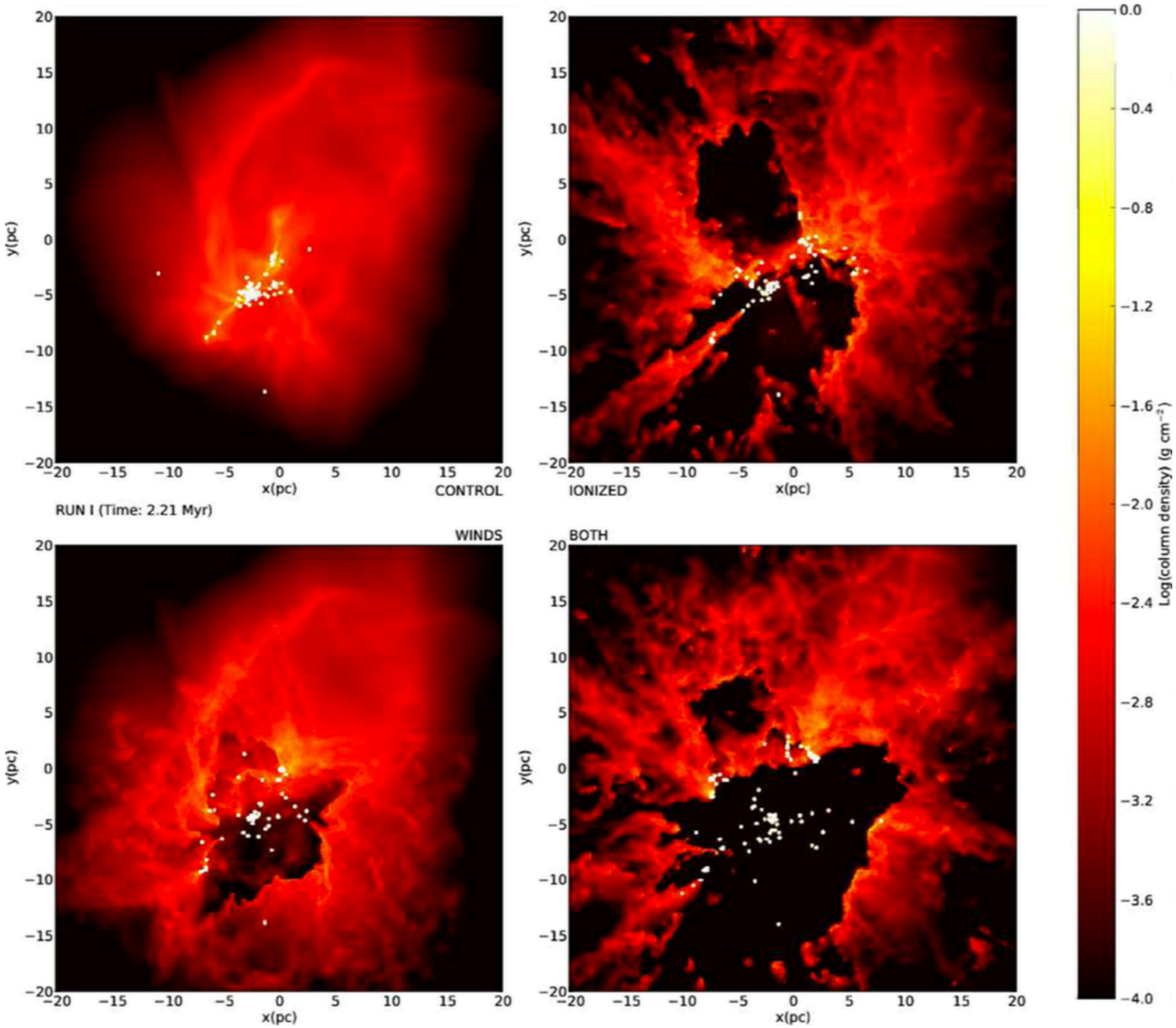


Gounelle & Meynet 12;
Pfalzner+ 15

- Self-enriched molecular cloud cores
  (Young 14, 16; Vasileiadis+ 13; Küffmeier+16)
- Triggered formation
  (Boss+ 00s/10s; Gaidos+ 09; Gounelle+ 09, 12; Pan+ 12)
- Intra-cluster injection
  (Ouellette+07, 09; Parker+ 14; Lichtenberg+16, Nicholson+ 17)

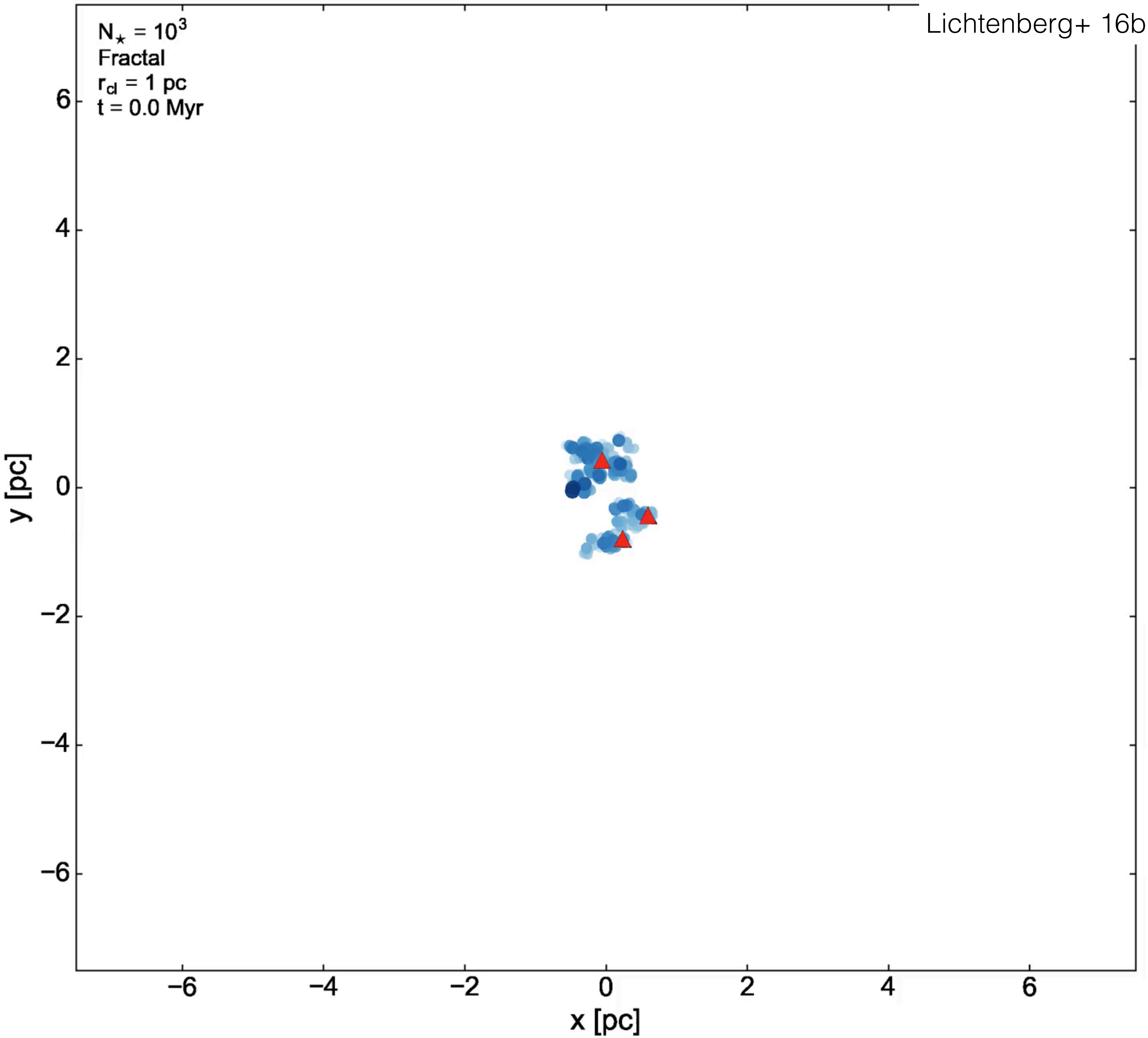
Reviews: Adams 10; Davis+ 14; Pfalzner+ 15

Feedback



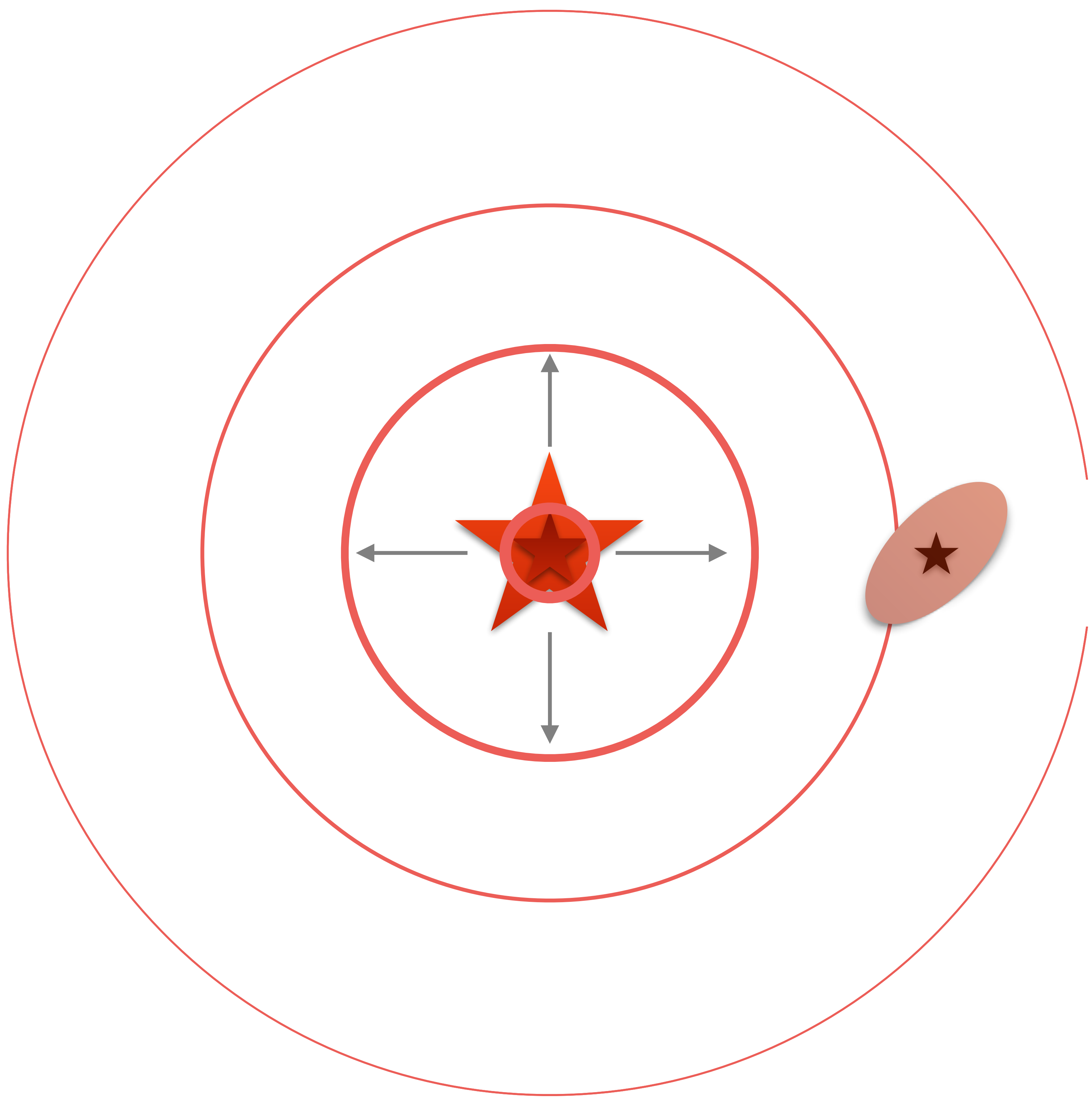
Dale 15

Lichtenberg+ 16b, *MNRAS*



Lichtenberg+ 16b, *MNRAS*

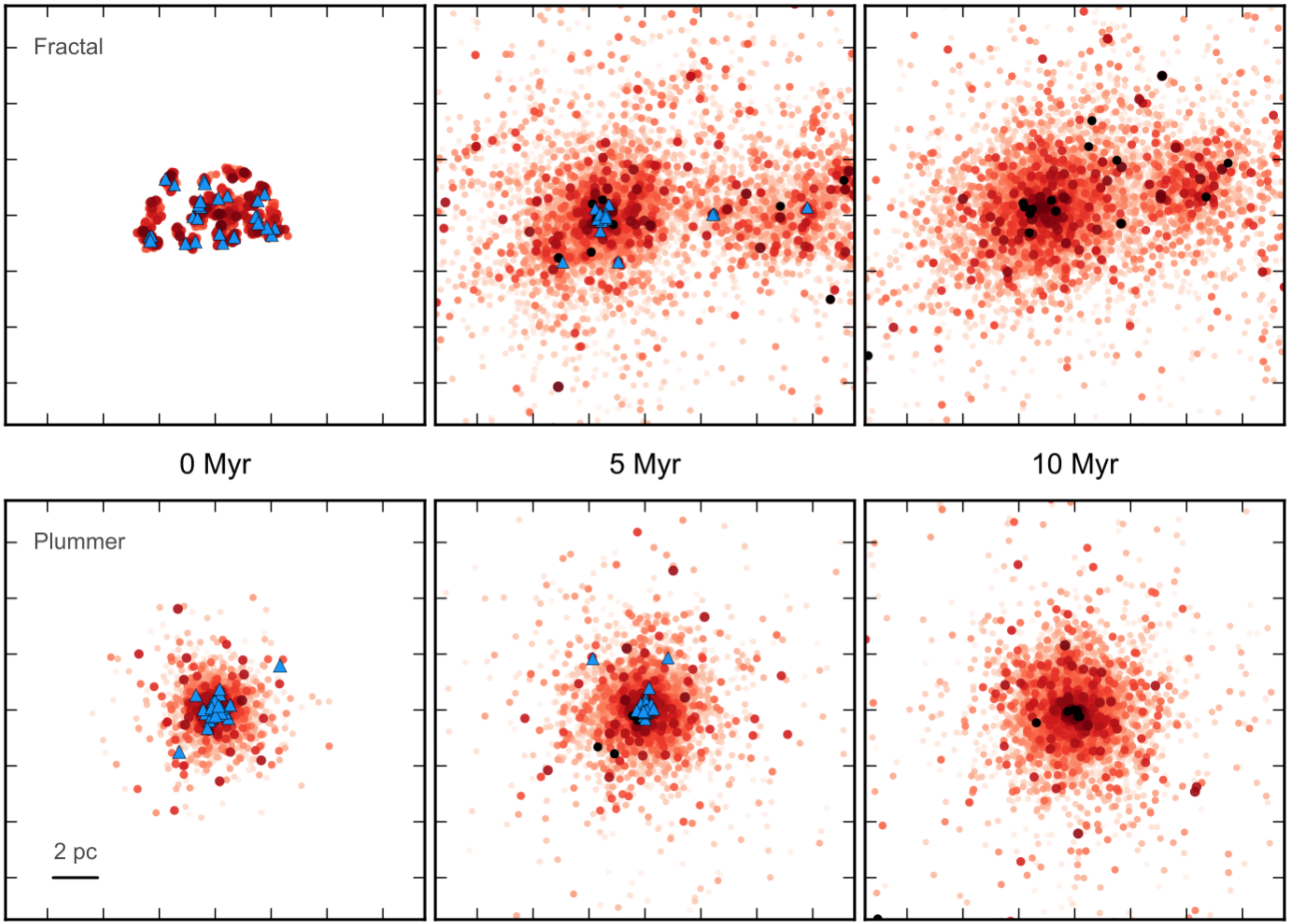
In a nutshell: supernova pollution



Clayton 77, Chevalier 00

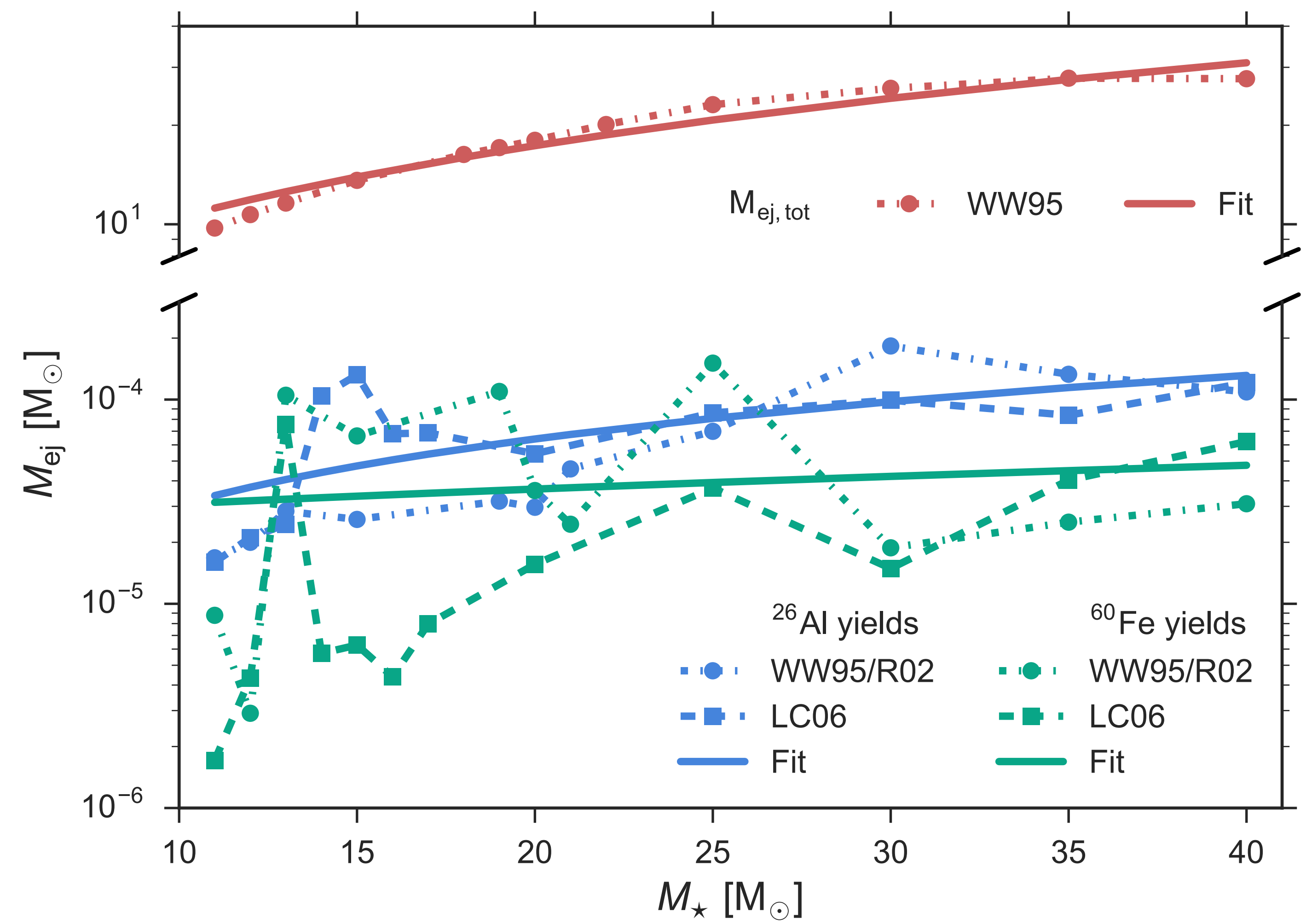
Lichtenberg+ 16b, *MNRAS*

Early cluster evolution



Enrichment post-processing

- *N*-body simulations of mid-sized stellar clusters
- Enrichment via supernova ejecta cross-section
- Time-dependent α-disk model ($\alpha = 10^{-2}$, $t_{1/2} = 3.5$ Myr)
- Radioactive decay, homogenous mixing
- Disk destruction mechanisms: photoevapoation, close-encounter perturbations, SN disruption



Woosley & Weaver 95, Rauscher+ 02, Limongi & Chief 06

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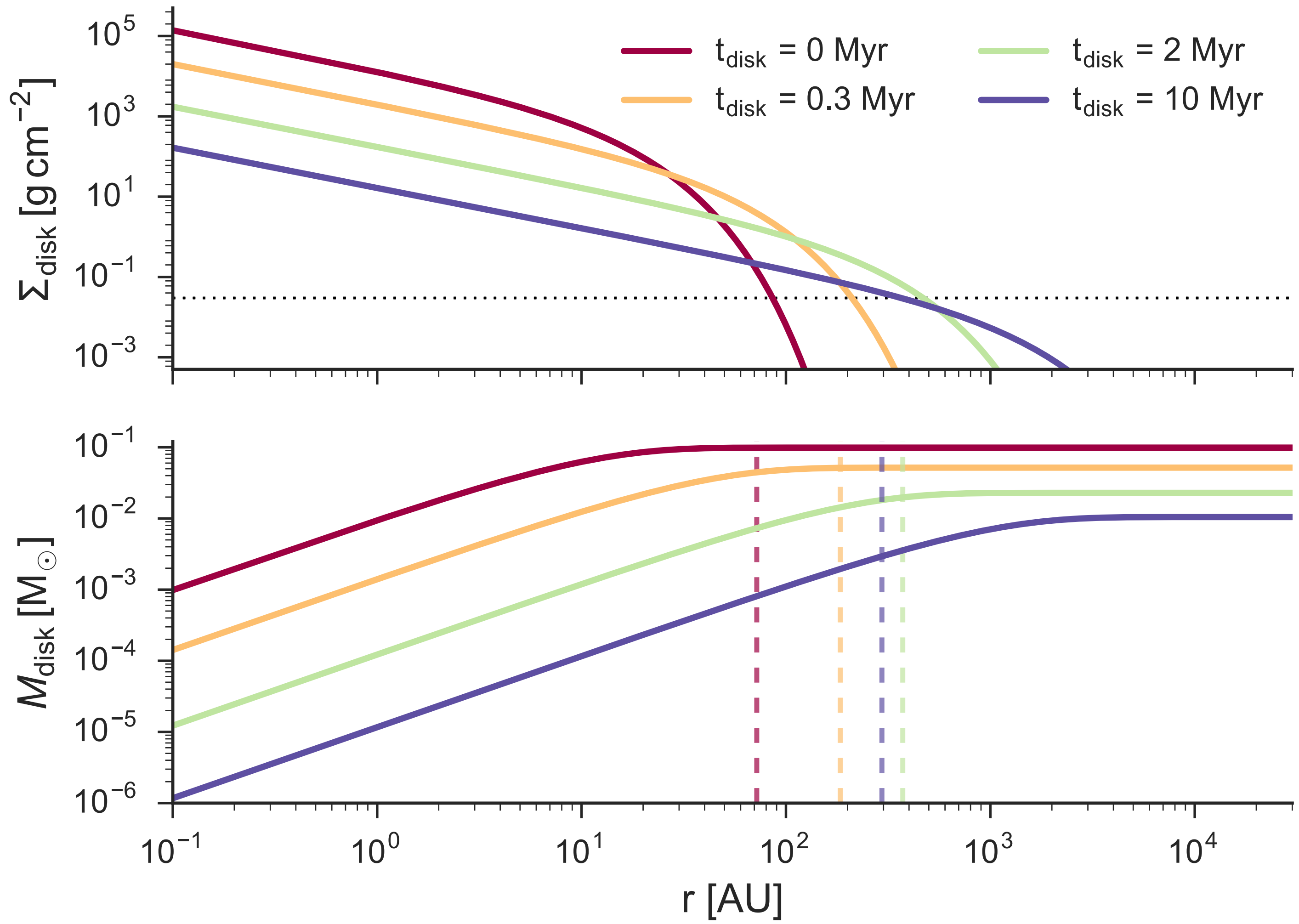
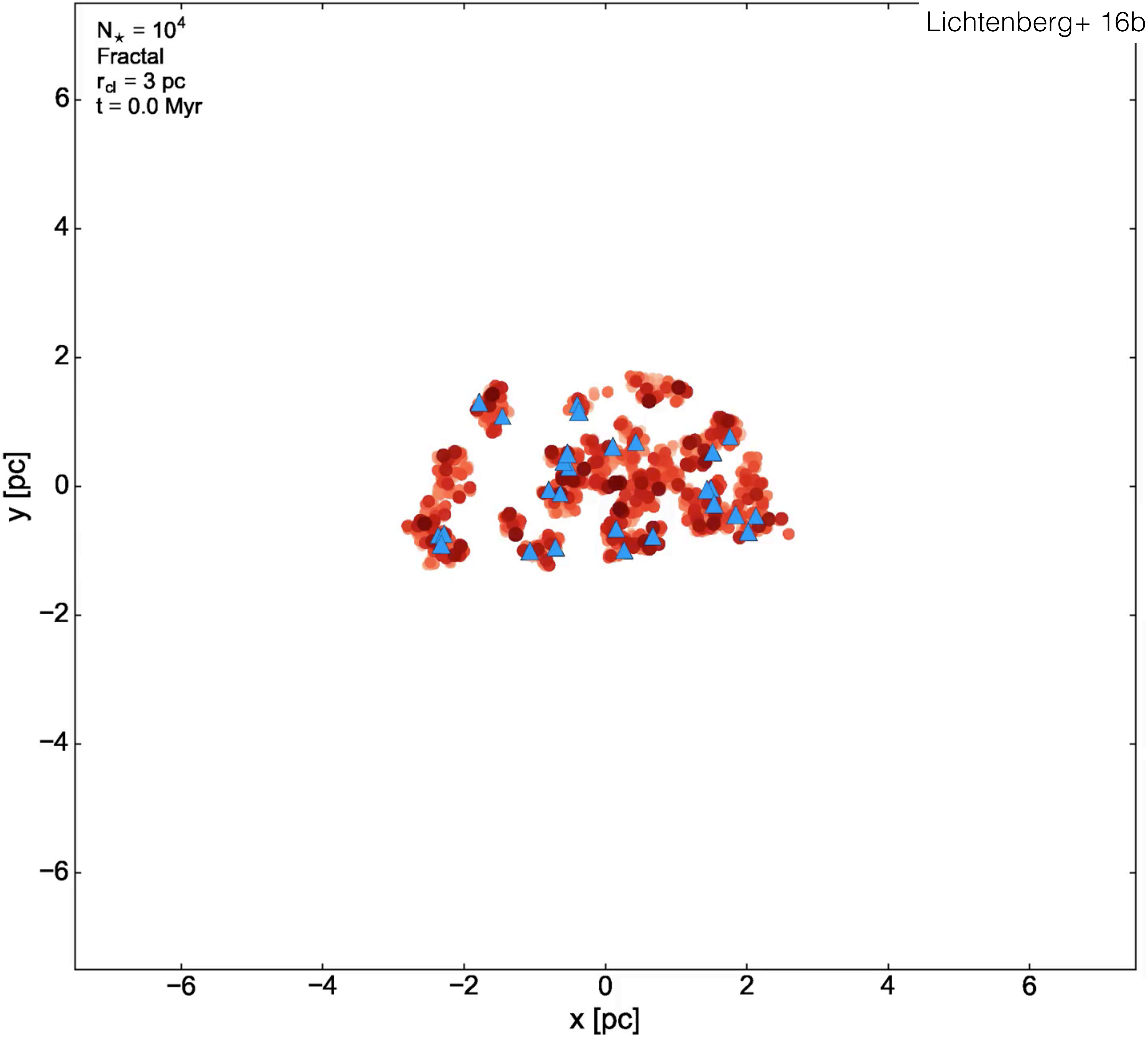
$\alpha_{disk} = 10^{-2}$
$t_{1/2} = 3.5$ Myr



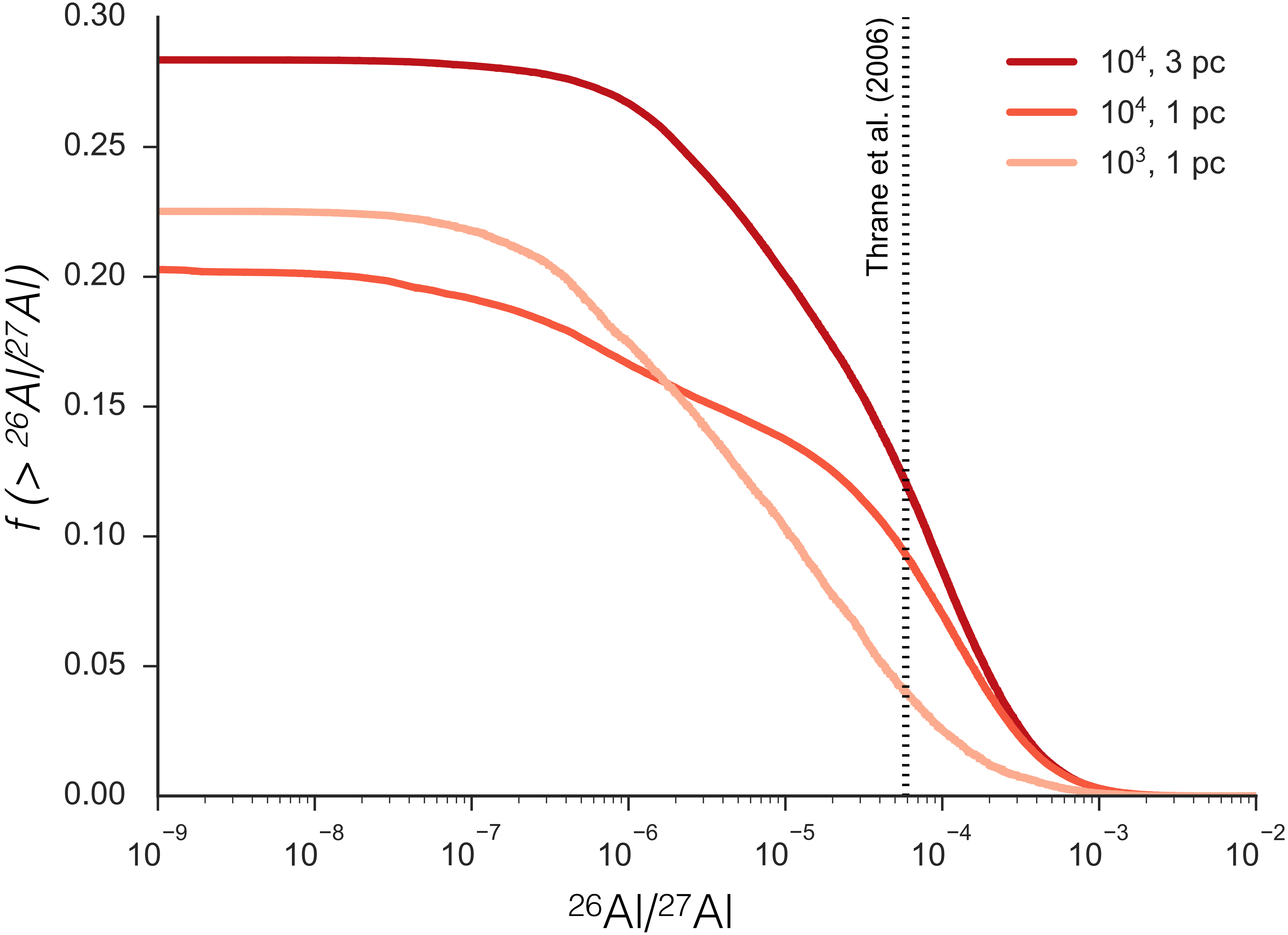
Hartmann 03

Lichtenberg+ 16b, *MNRAS*



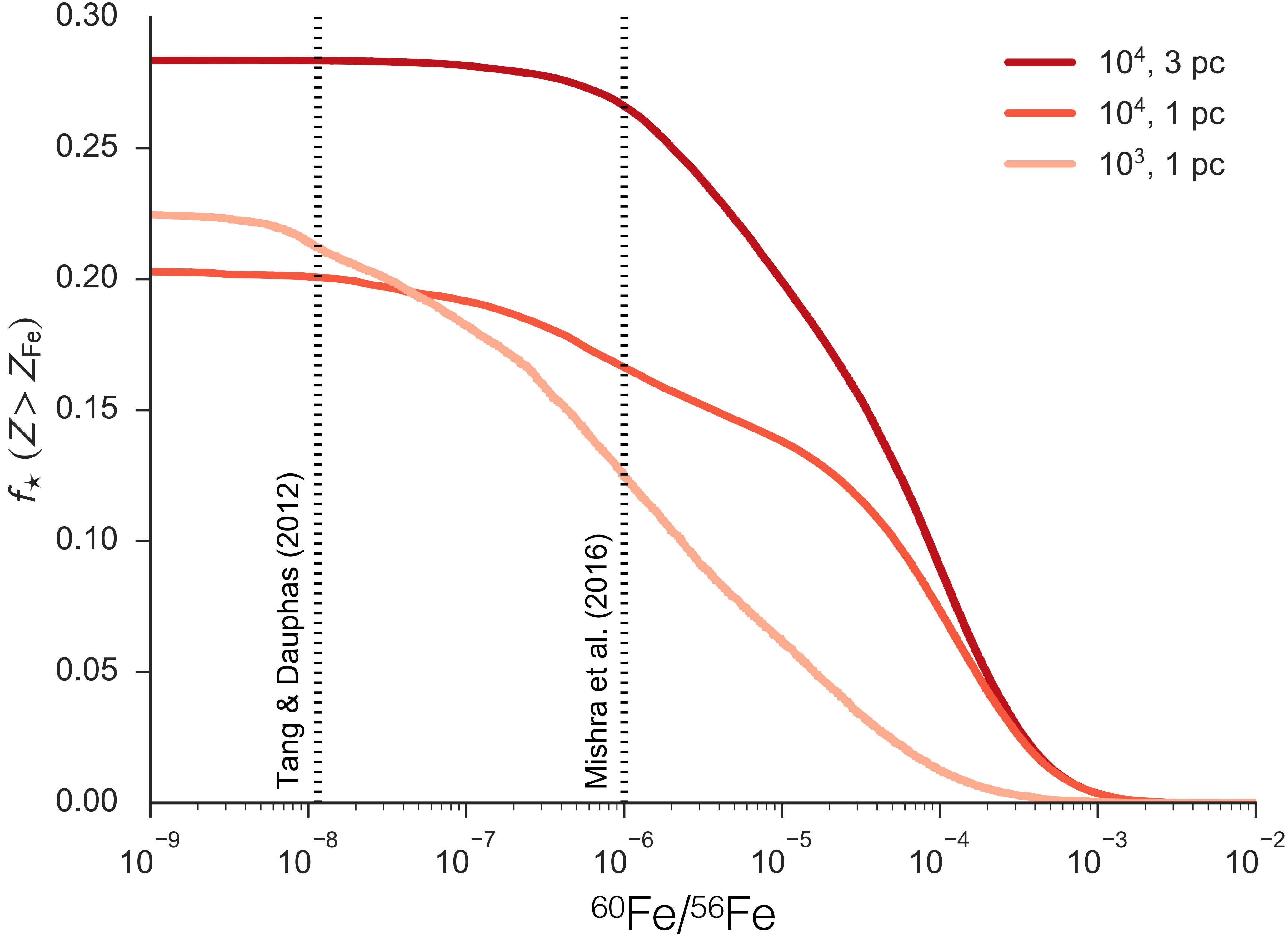
Lichtenberg+ 16b, *MNRAS*

Enrichment distribution ^{26}Al/^{27}Al

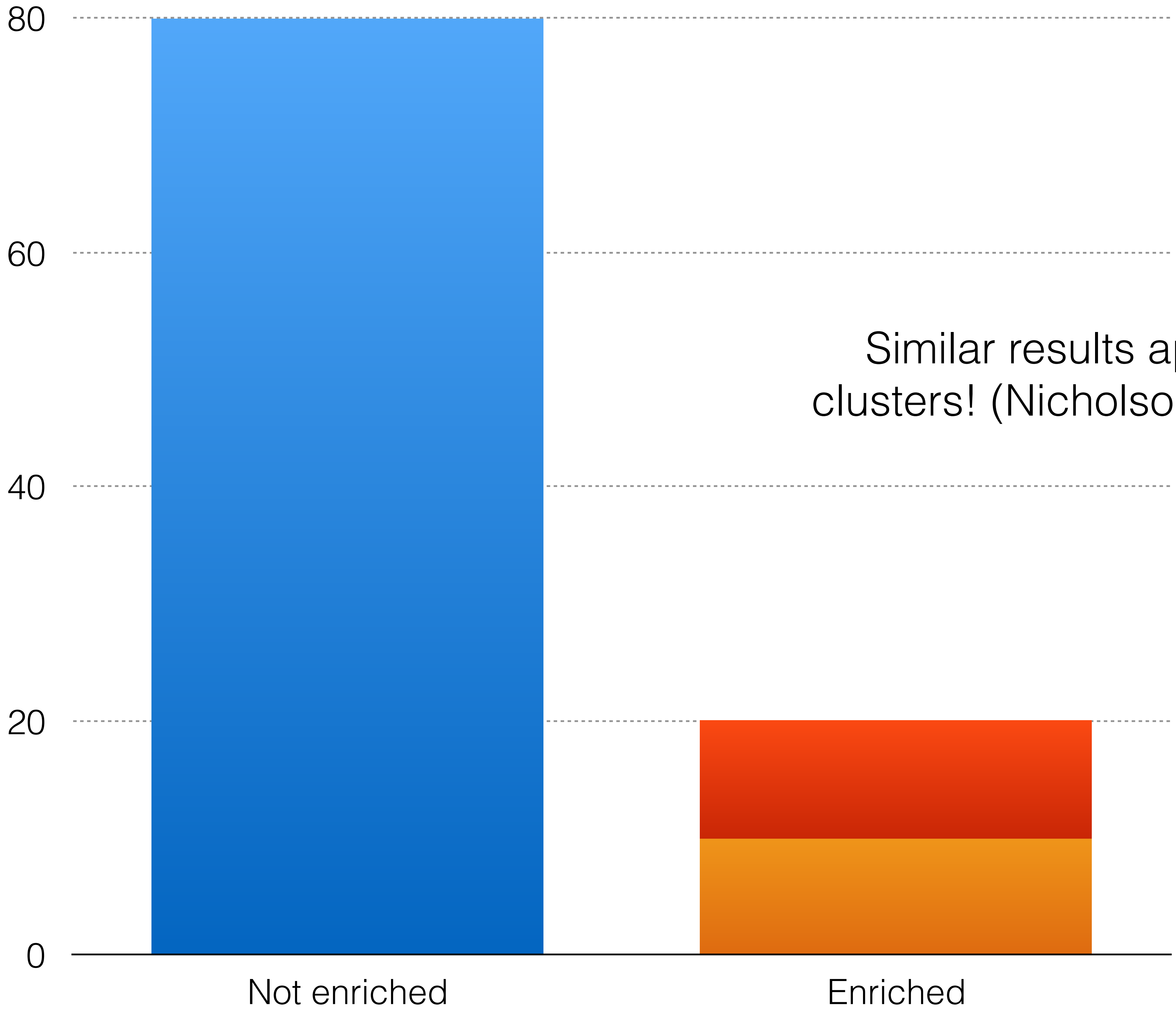


Lichtenberg+ 16b, *MNRAS*

Enrichment distribution $^{60}Fe/^{56}Fe$



Enrichment dichotomy



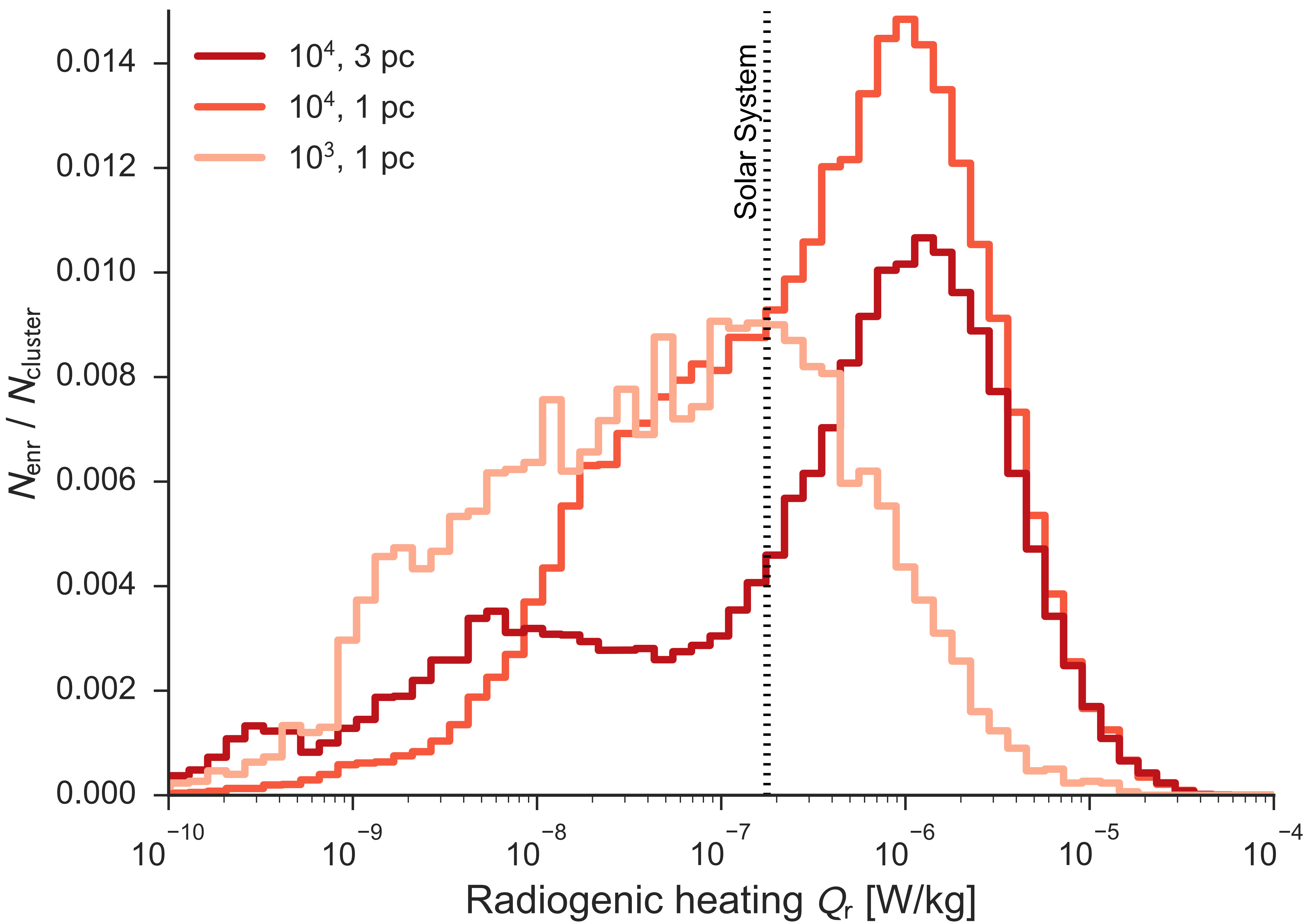
Similar results apply for 10^2 clusters! (Nicholson & Parker 17)

Take away II

- Stars form in cluster environments, which shapes the planetary system architecture
- The Sun formed in the direct vicinity of a massive star, which enriched Solar nebula with ^{26}Al
- The injection mechanism is heavily debated, but usually yields a certain distribution of short-lived radionuclides

Lichtenberg+ 16b, *MNRAS*

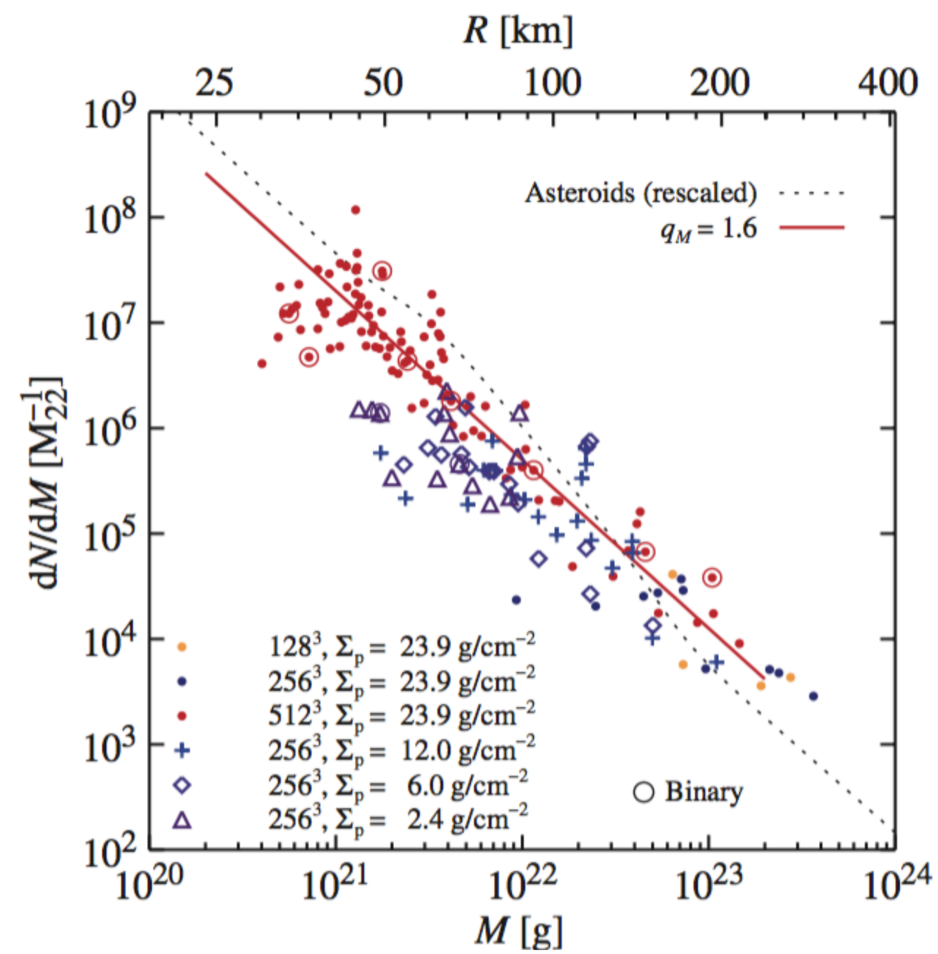
Planetesimal heat budget



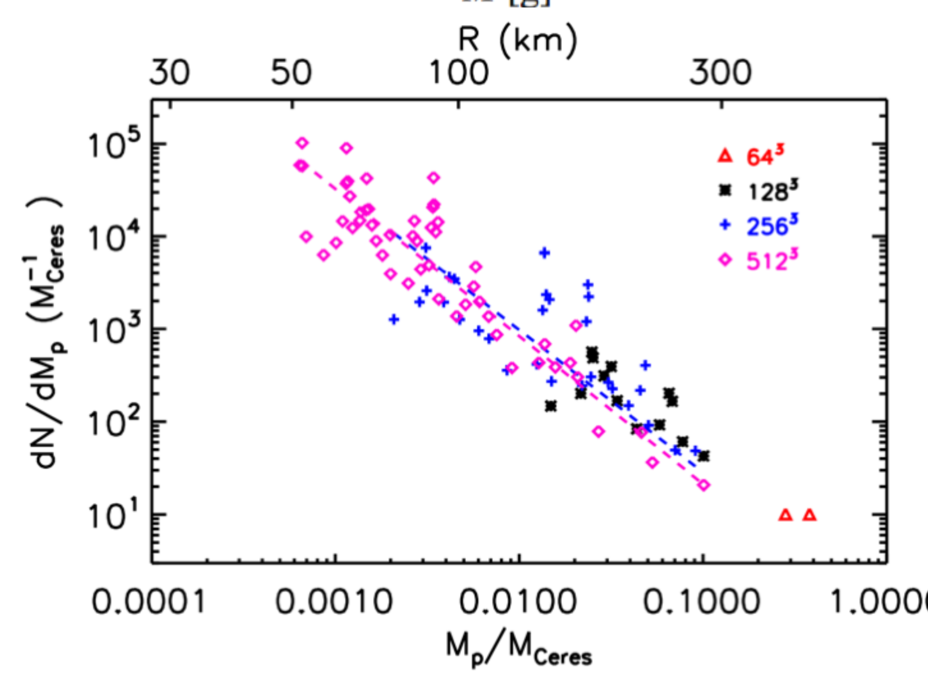
Constraints on planetesimal formation

Recent IMF estimates:

- ***r*** = 10—100 km *(Cuzzi+08)*
- ***r*** = 100—1000 km *(Morbidelli+09)*
- ***r*** = 50—200 km *(Chambers 10)*
- ***r*** = 25—200 km *(Johansen+15, Simon+16)*
  - ➡ $dN/dR \sim R^{-2.8}$
  - ➡ $dN/dM \sim M^{-1.6}$
- ***M*** ~ 10^{16}—10^{21} kg

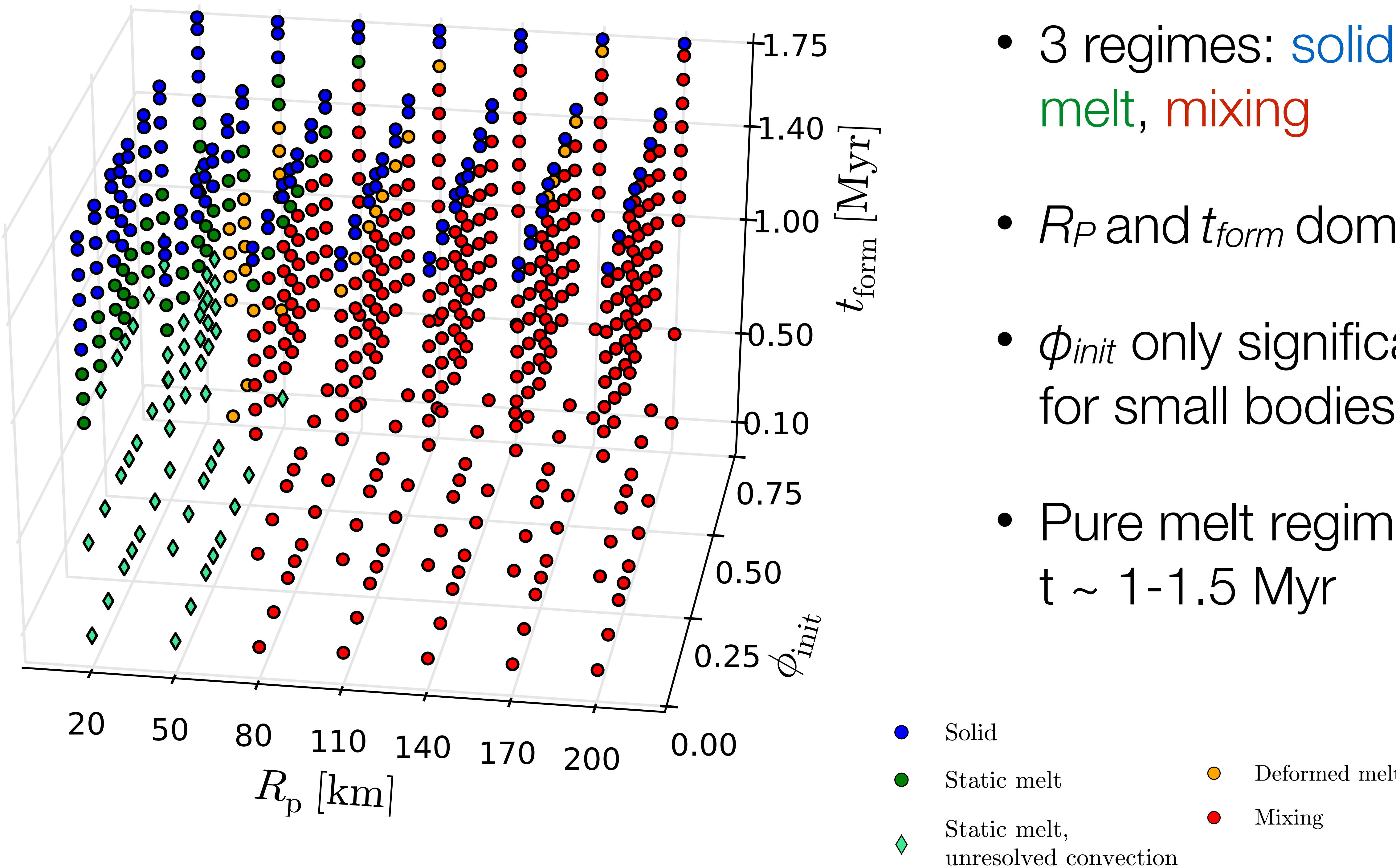


Johansen+15

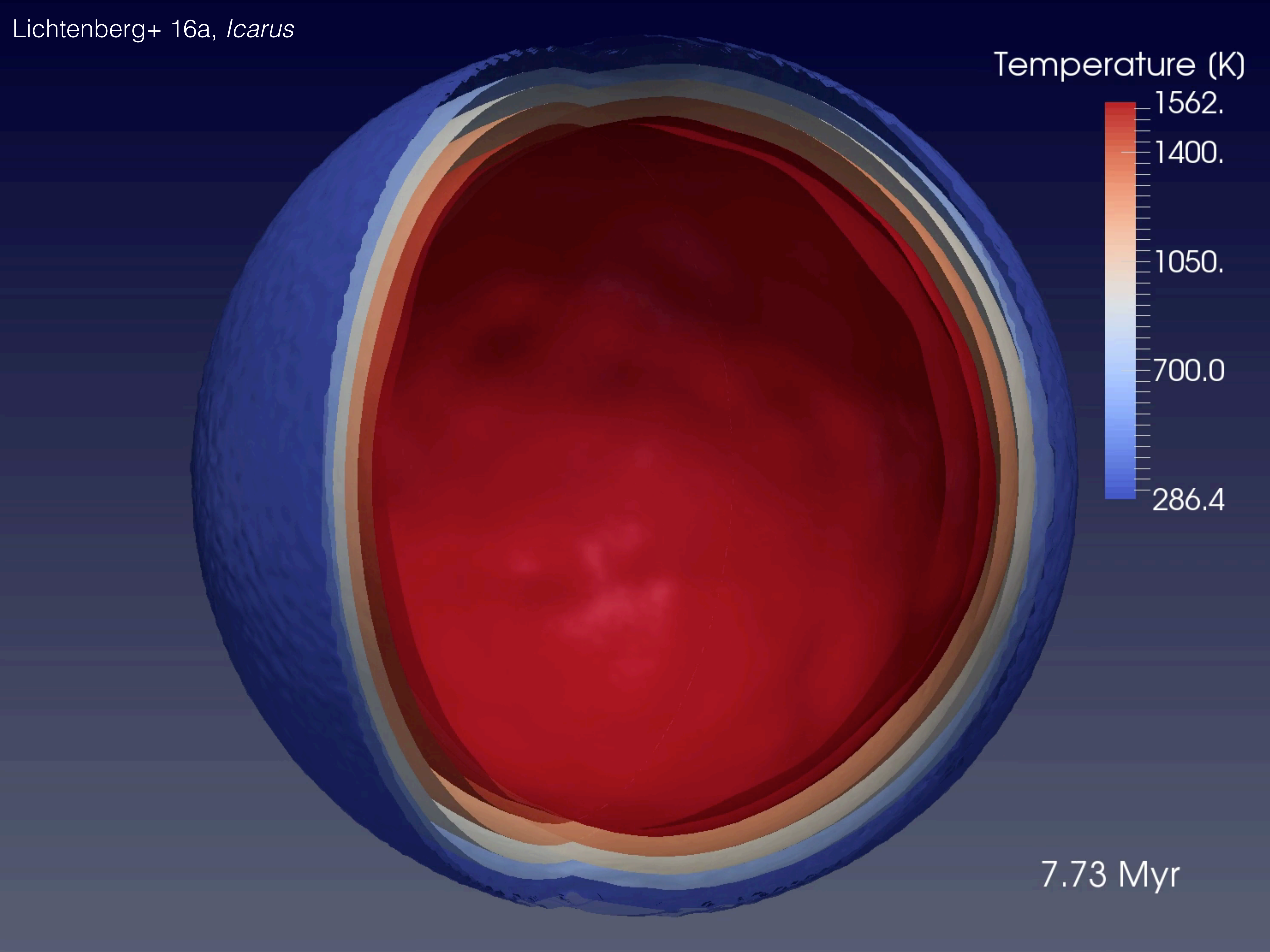


Simon+16

Thermo-mechanical regimes

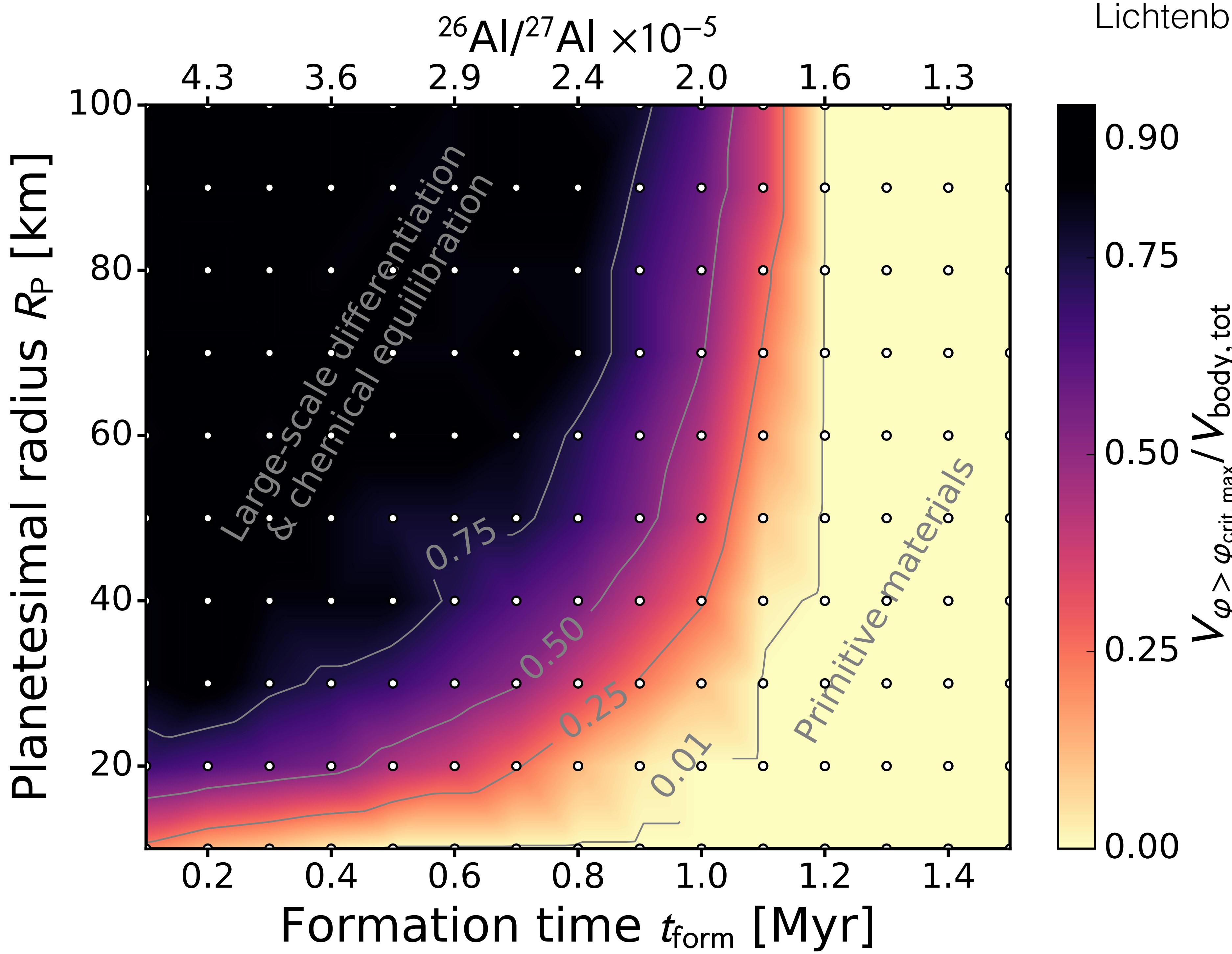


- 3 regimes: solid, melt, mixing
- R_P and t_{form} dominant
- ϕ_{init} only significant for small bodies
- Pure melt regime: t ~ 1-1.5 Myr


Lichtenberg+ 16a, *Icarus*
Temperature (K)
1562.
1400.
1050.
700.0
286.4
7.73 Myr

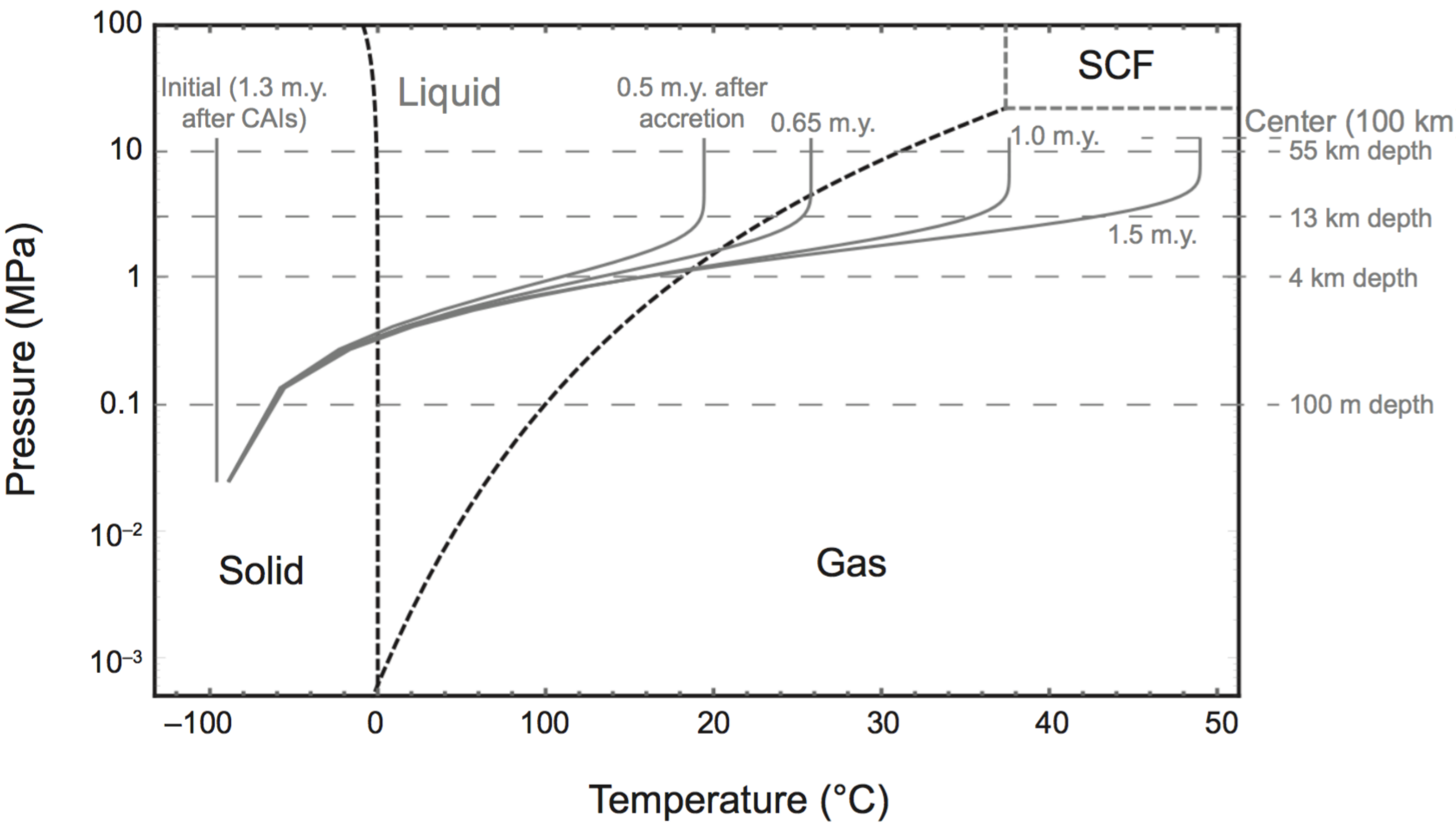
Planetesimal interior evolution

Lichtenberg+ 17, in prep.



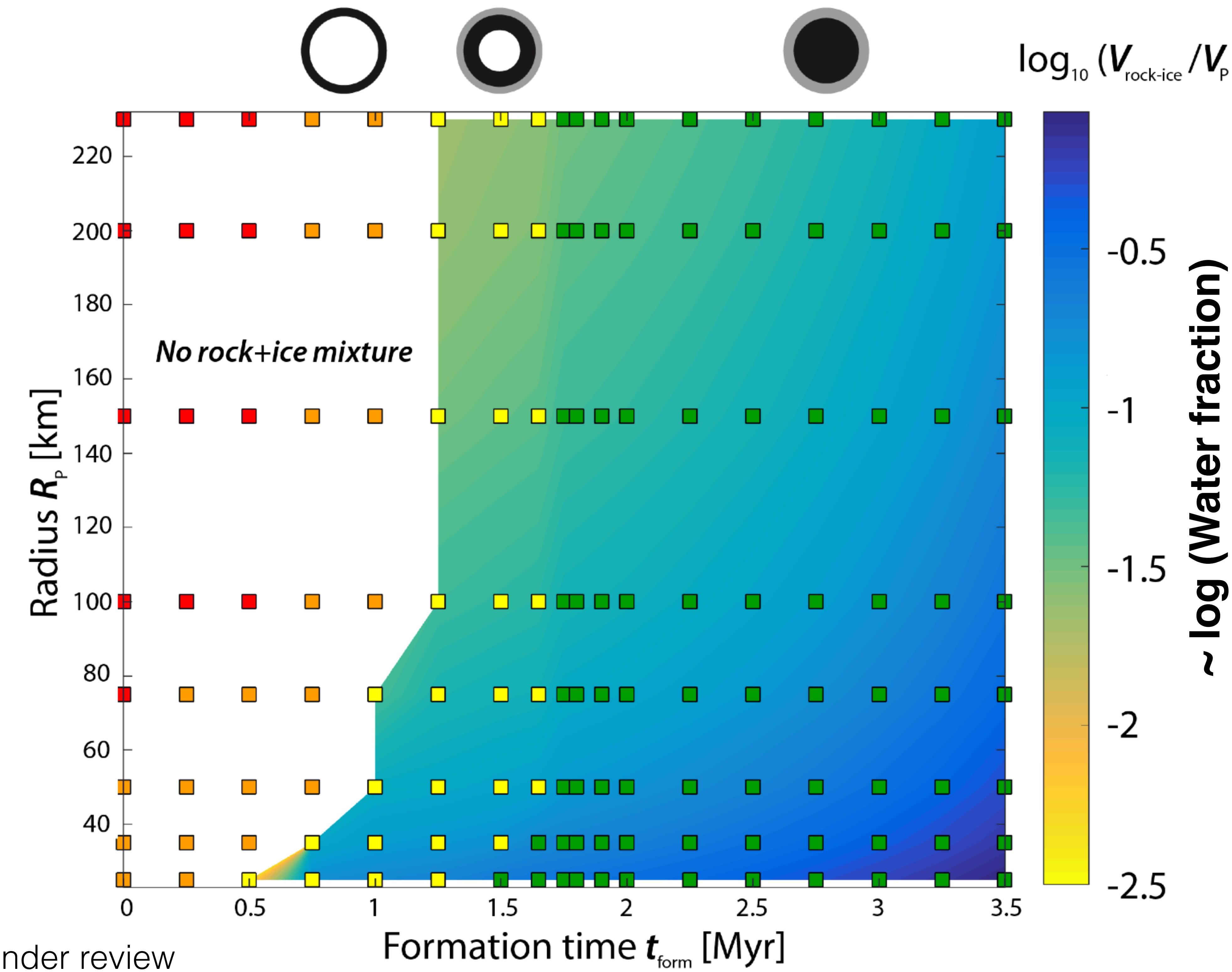
See also: Elkins-Tanton 10, “Asteroids IV” (Michel, DeMeo, Bottke); “Planetesimals” (Weiss & Elkins-Tanton)

Planetesimal hydrology



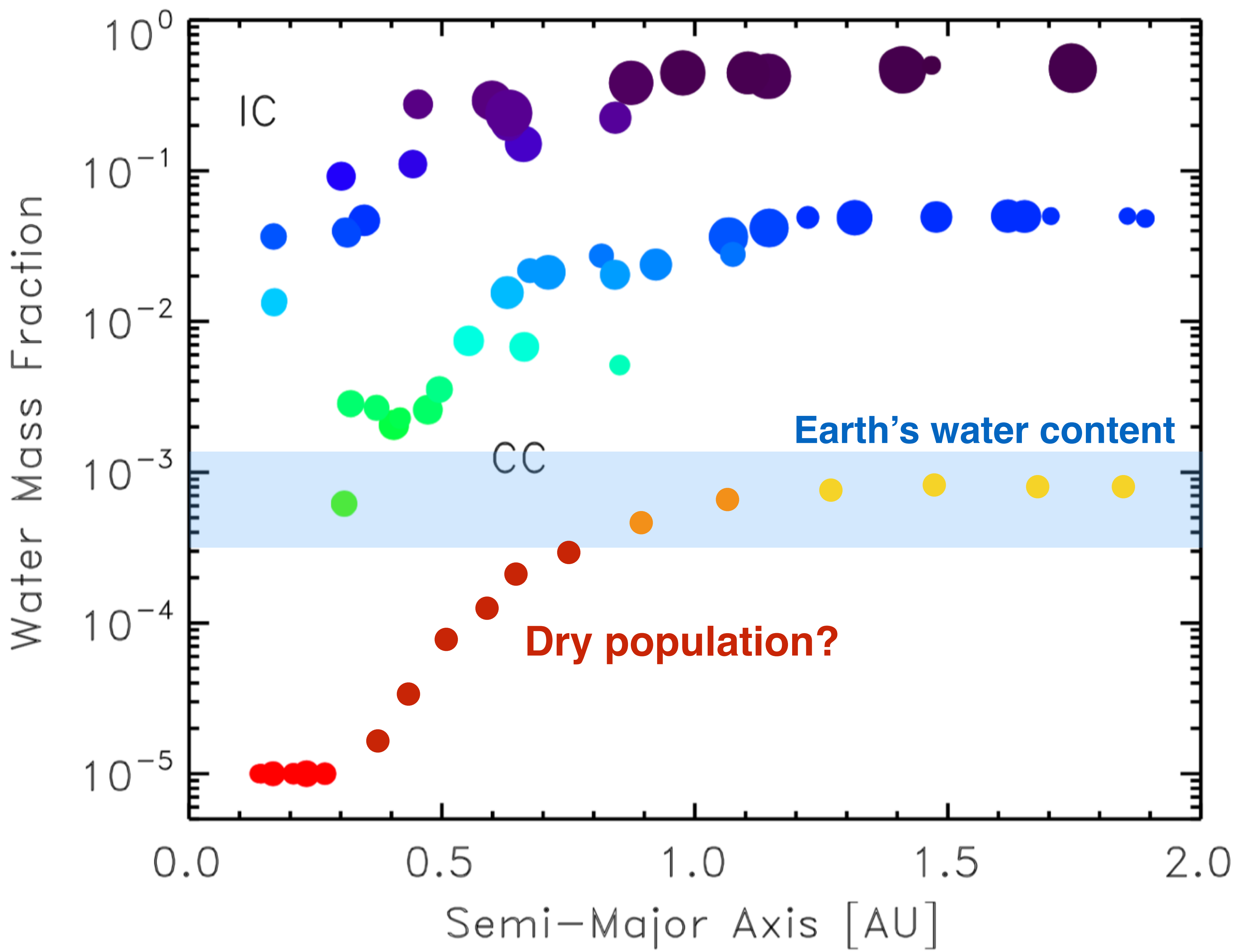
Young+ 03; Zhou+ 13; Zolotov+ 14; Fu+ 15, 17; Scheinberg+ 16

Dehydration from internal heating

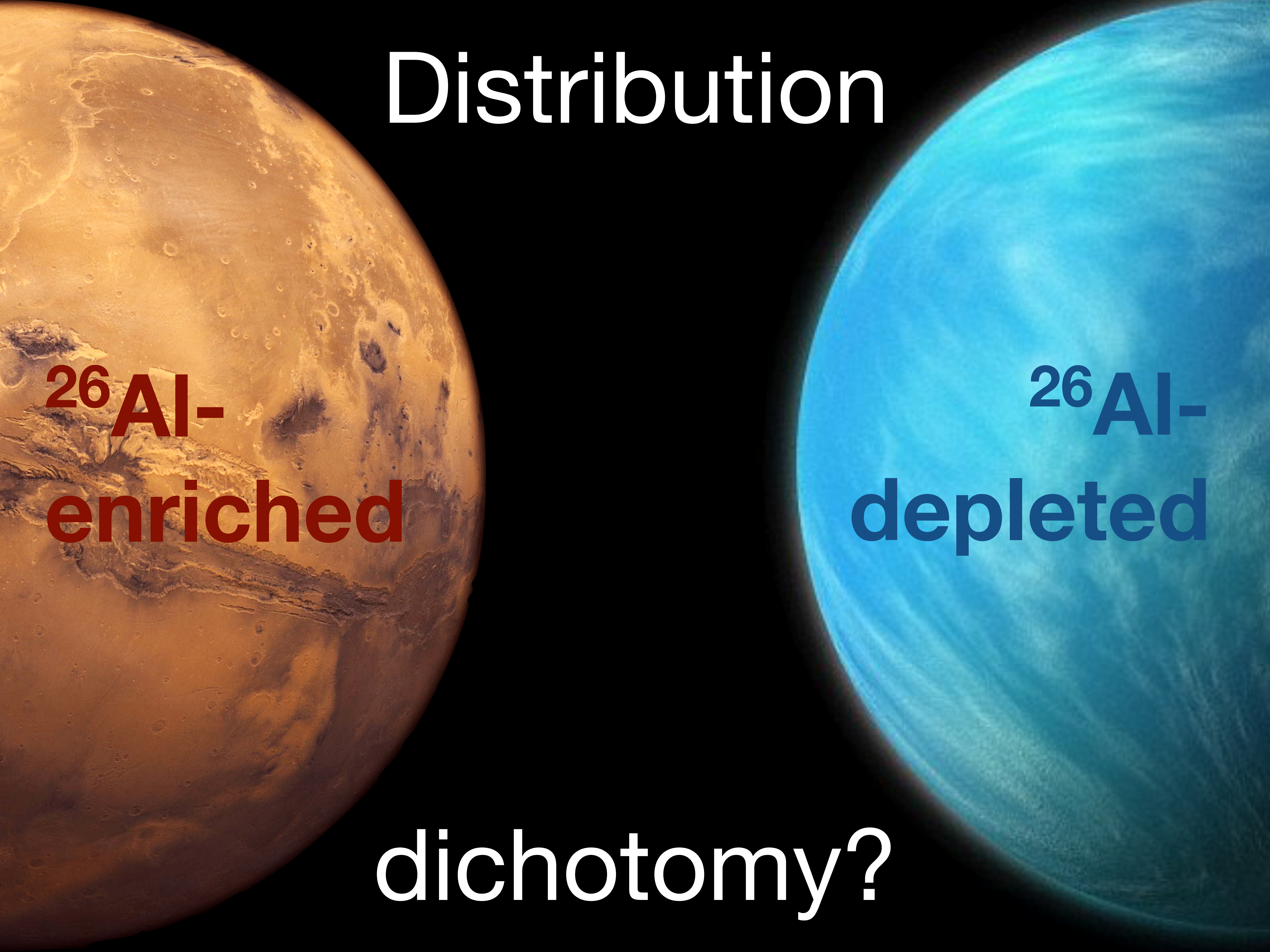


Monteux+ 17, under review

‘Initial’ water abundances integrated



Ciesla+ 15


Distribution
^{26}Al-
enriched
^{26}Al-
depleted
dichotomy?

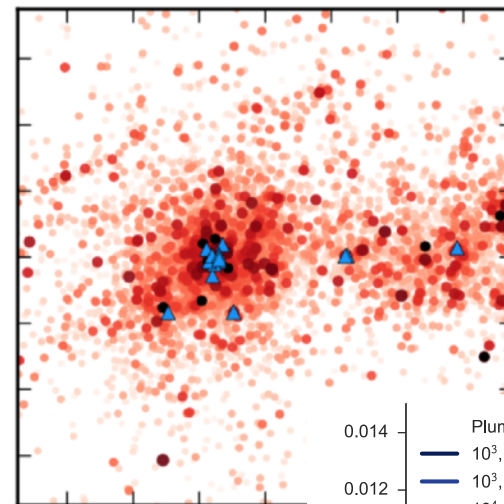
Take away

1. Distribution dichotomy of short-lived radioisotope abundances from late injection

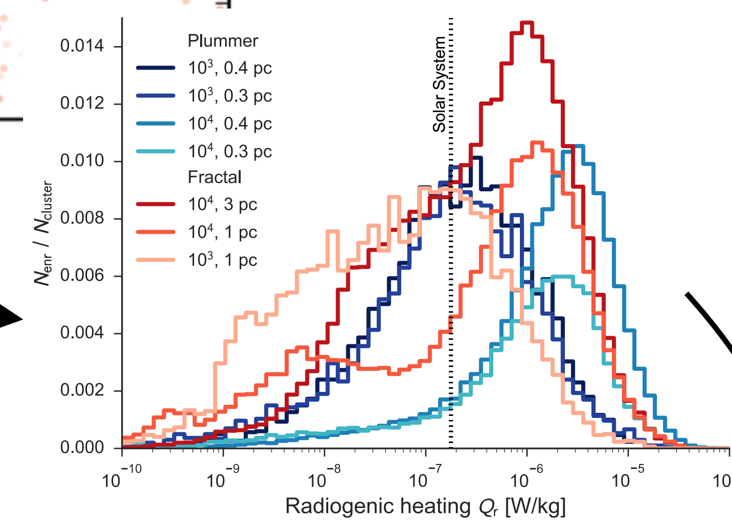
2. Radiogenically driven

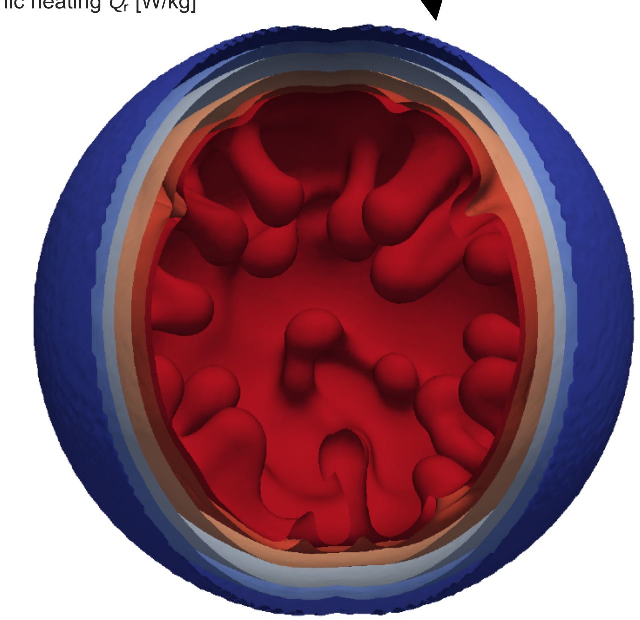
    - Interior evolution
    - Serpentinization
    - Volatile degassing

➡ Planet population synthesis?



Lichtenberg, Parker, Meyer (2016), MNRAS





Lichtenberg, Golabek, Gerya, Meyer (2016), Icarus