A planet population dichotomy from isotopic enrichment?

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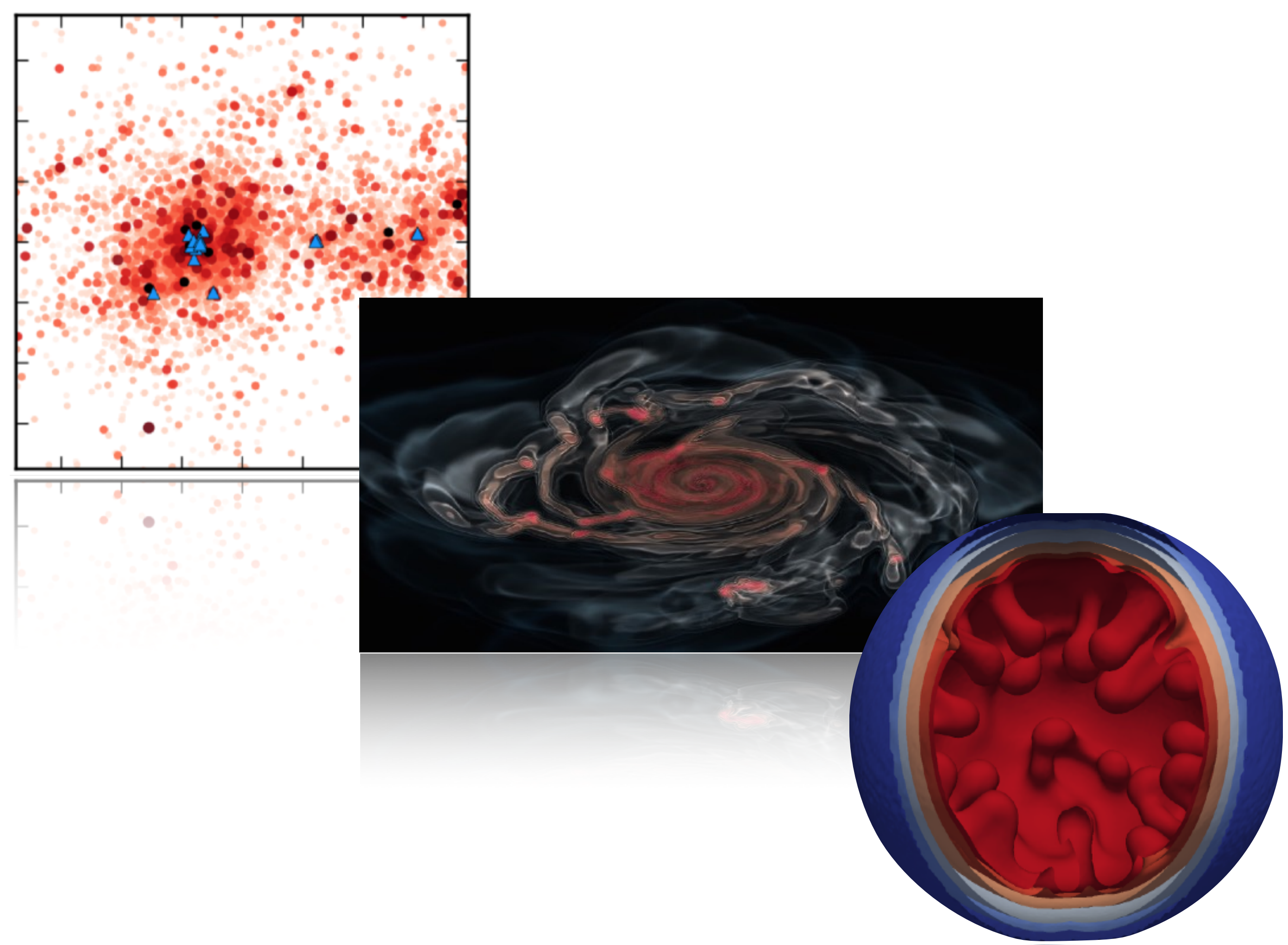


ETH zürich

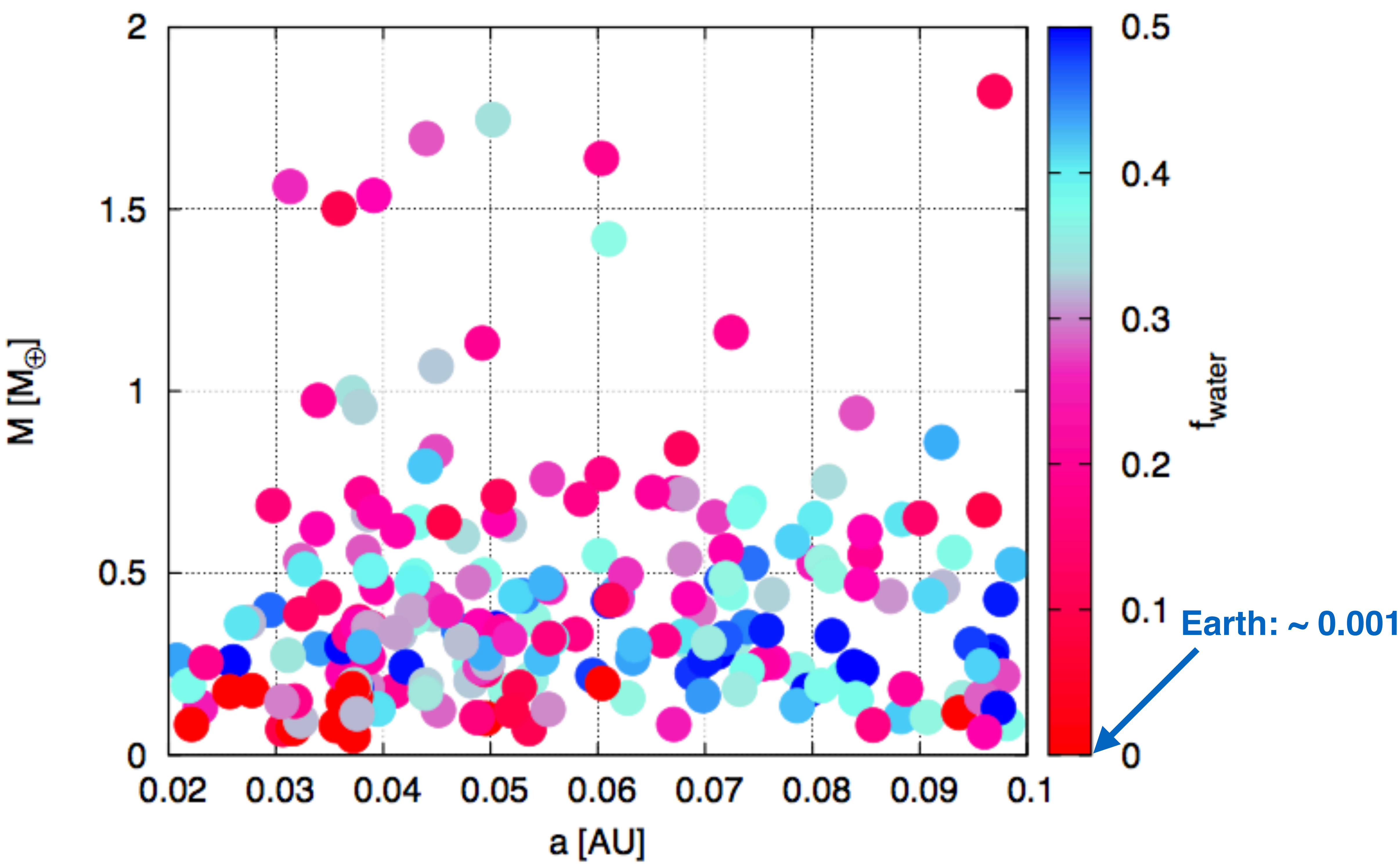
Outline

1. Motivation – planetary water inventory

2. Natal Solar system environment and enrichment of short-lived radionuclides

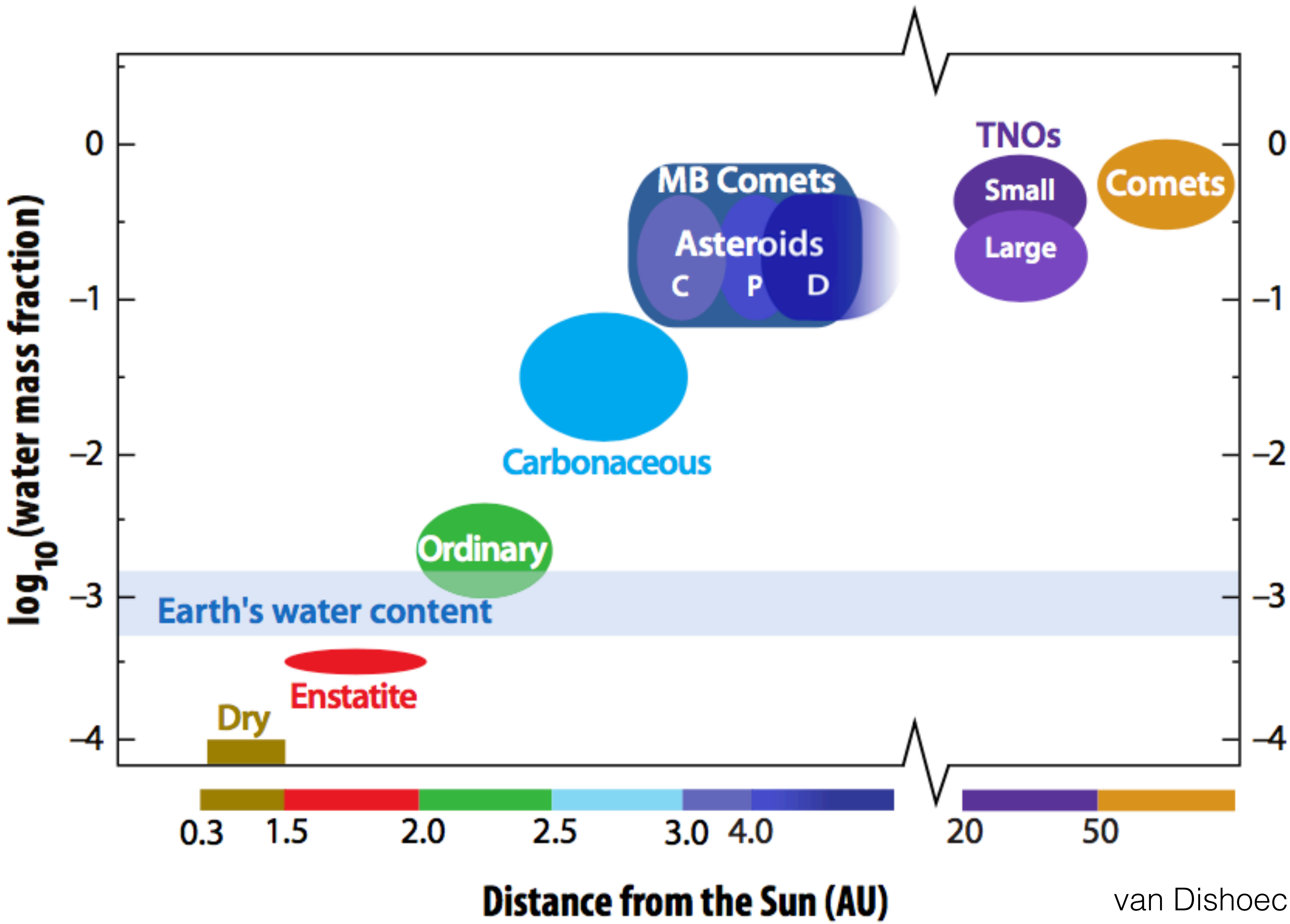
3. Implications for planetesimal evolution (and planets?)

Lots of water worlds?



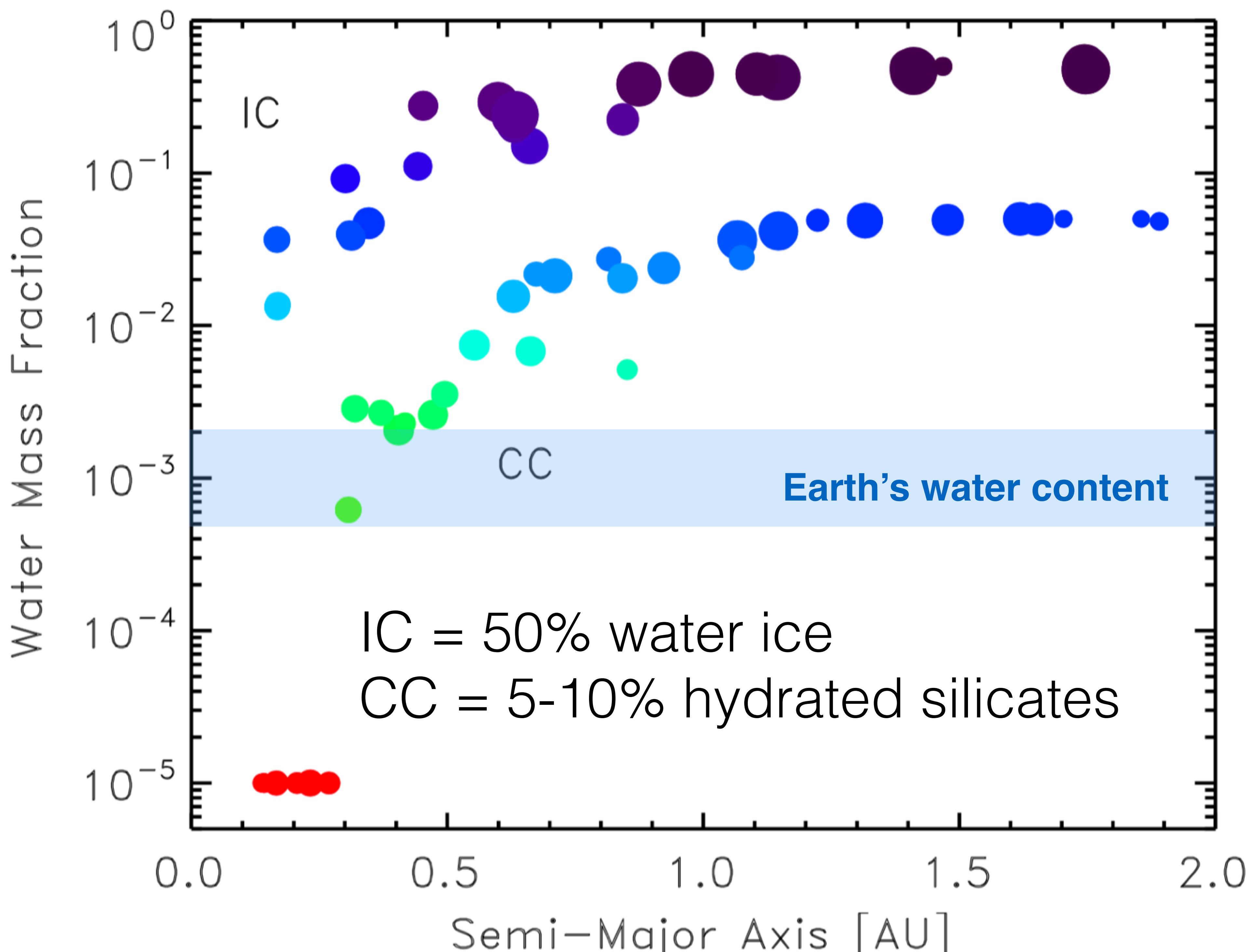
Alibert & Benz 17

The Solar system case



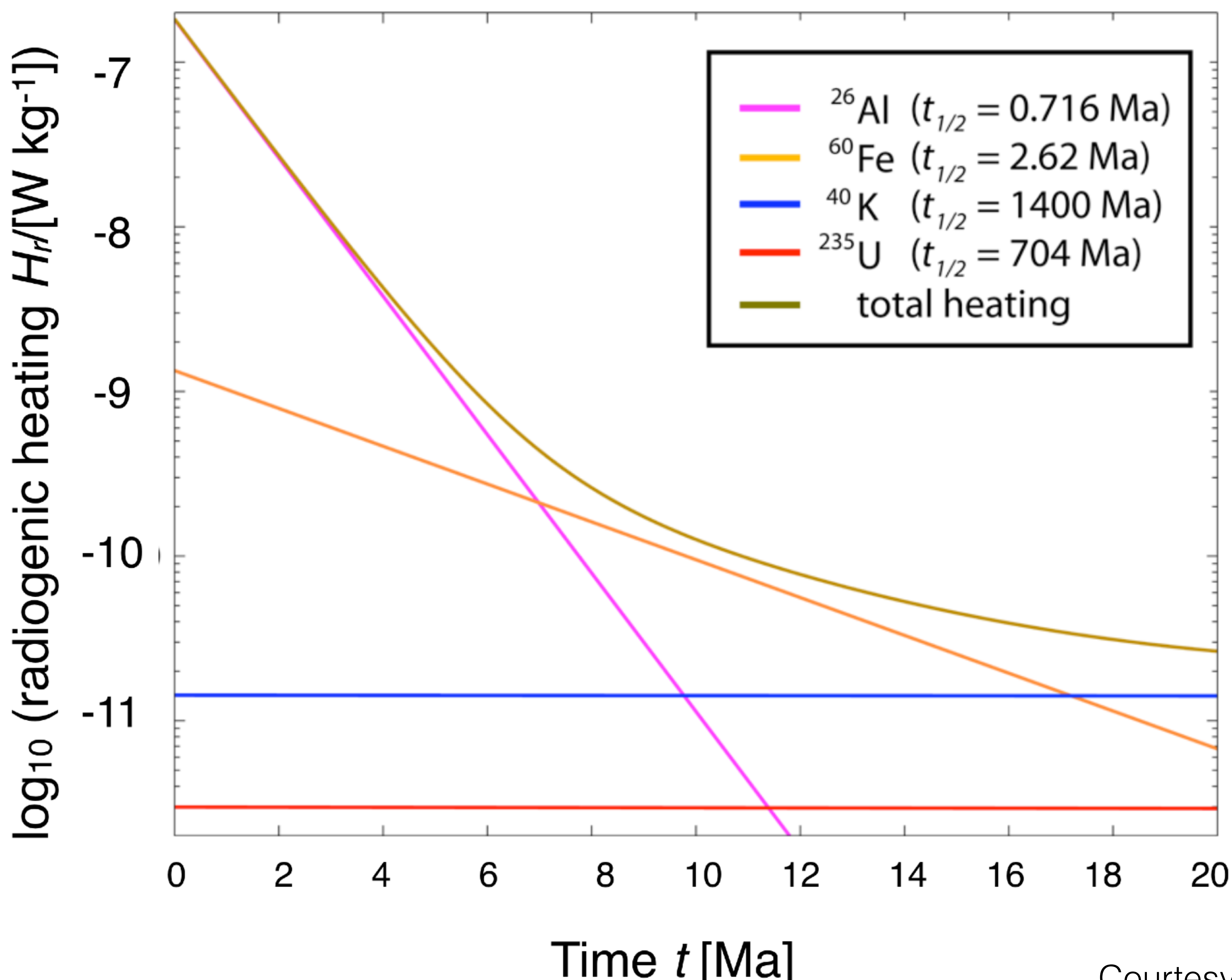
van Dishoeck+ 14, PPVI

Deplete the building blocks



Ciesla+ 15, Mulders+ 15

Short-lived radionuclides in the early Solar system



Lee+ 76

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

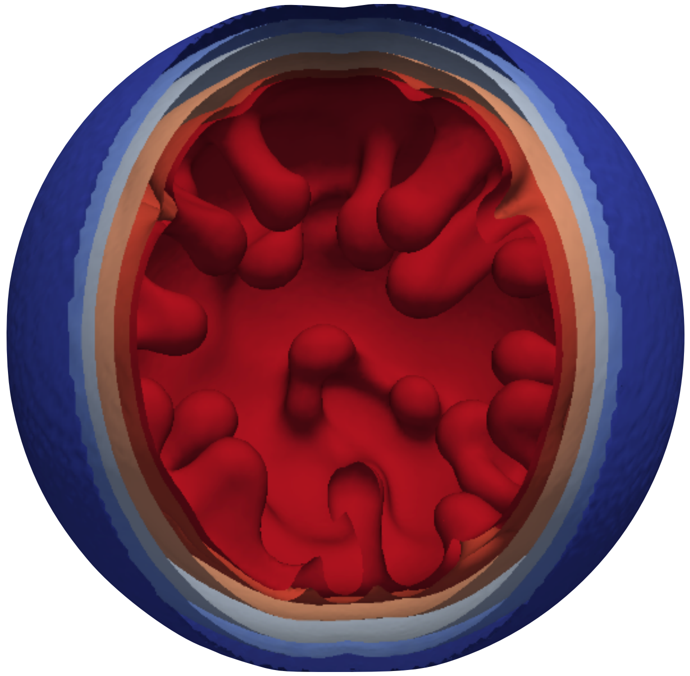
⬇

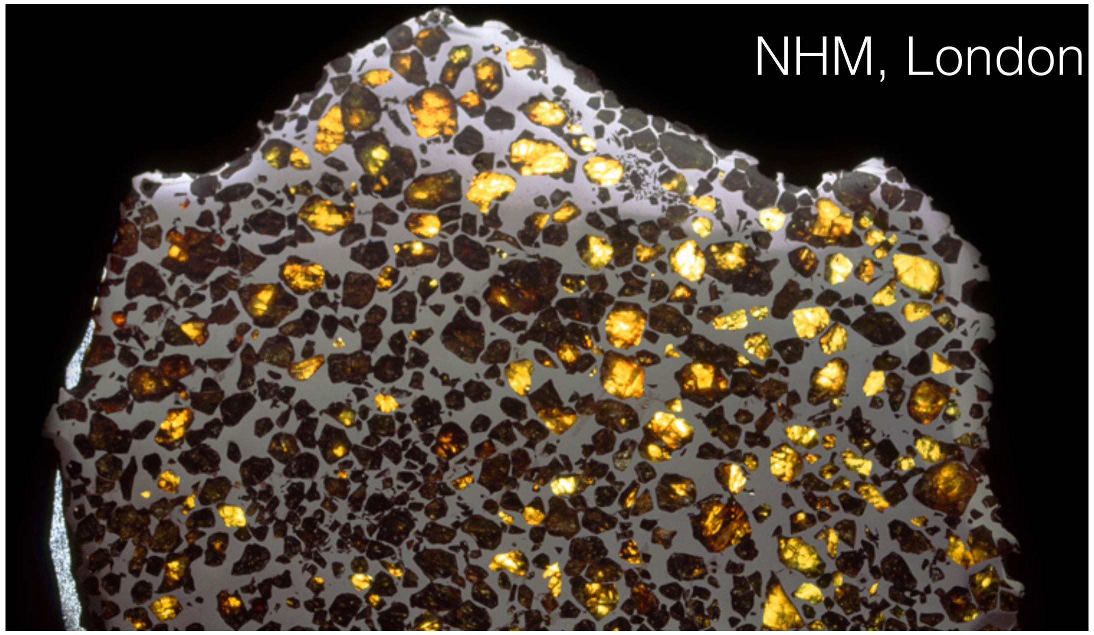
3. Mixing into dust/solid material

⬇

4. Heating of early planetesimals by radioactive decay

➡ Differentiation, serpentinization, volatile degassing, …





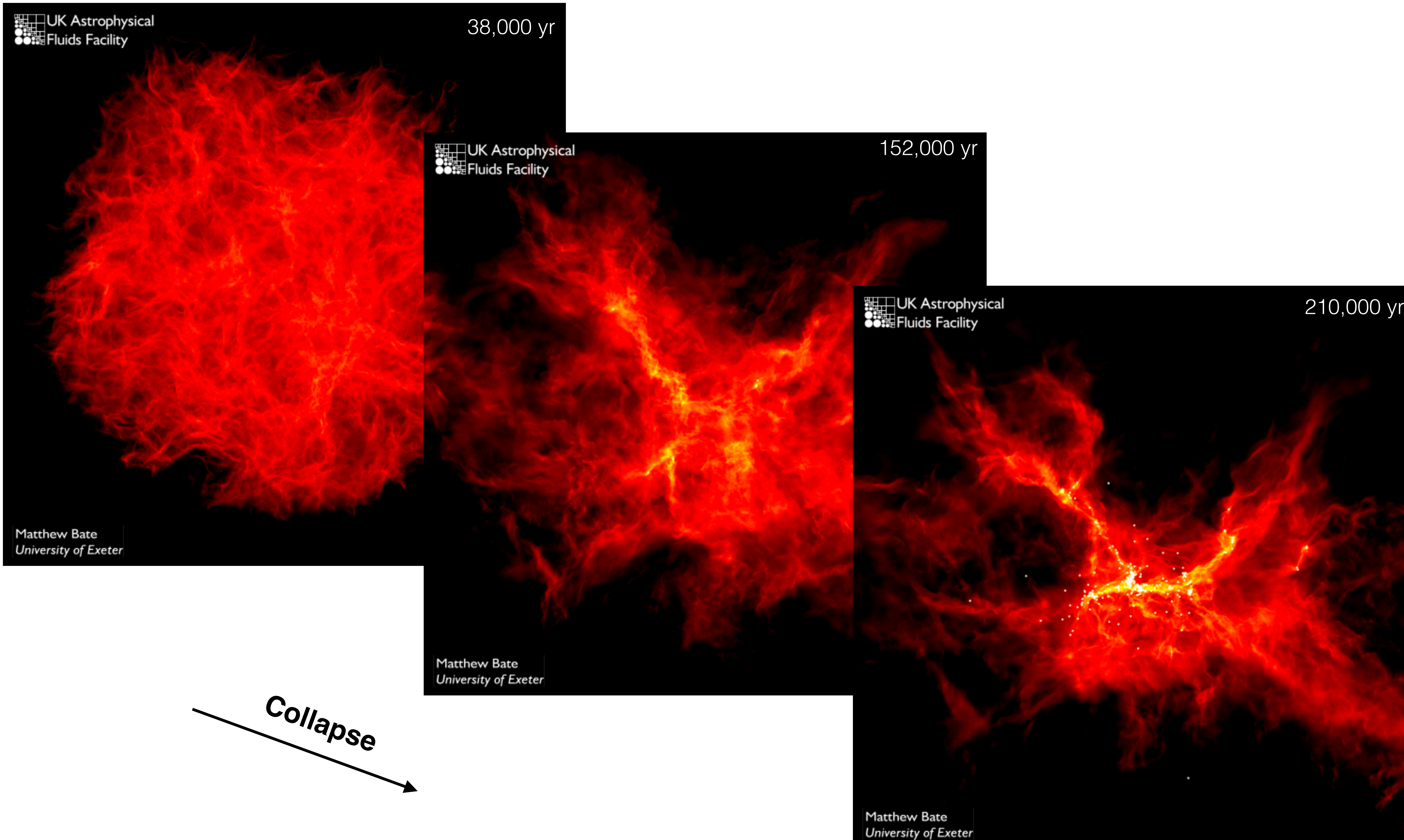
Take away I

- Planetary water budget crucial for planetary geodynamics, e.g., plate tectonics regime, silicate weathering thermostat

- Earth seems to be a water-depleted terrestrial planet

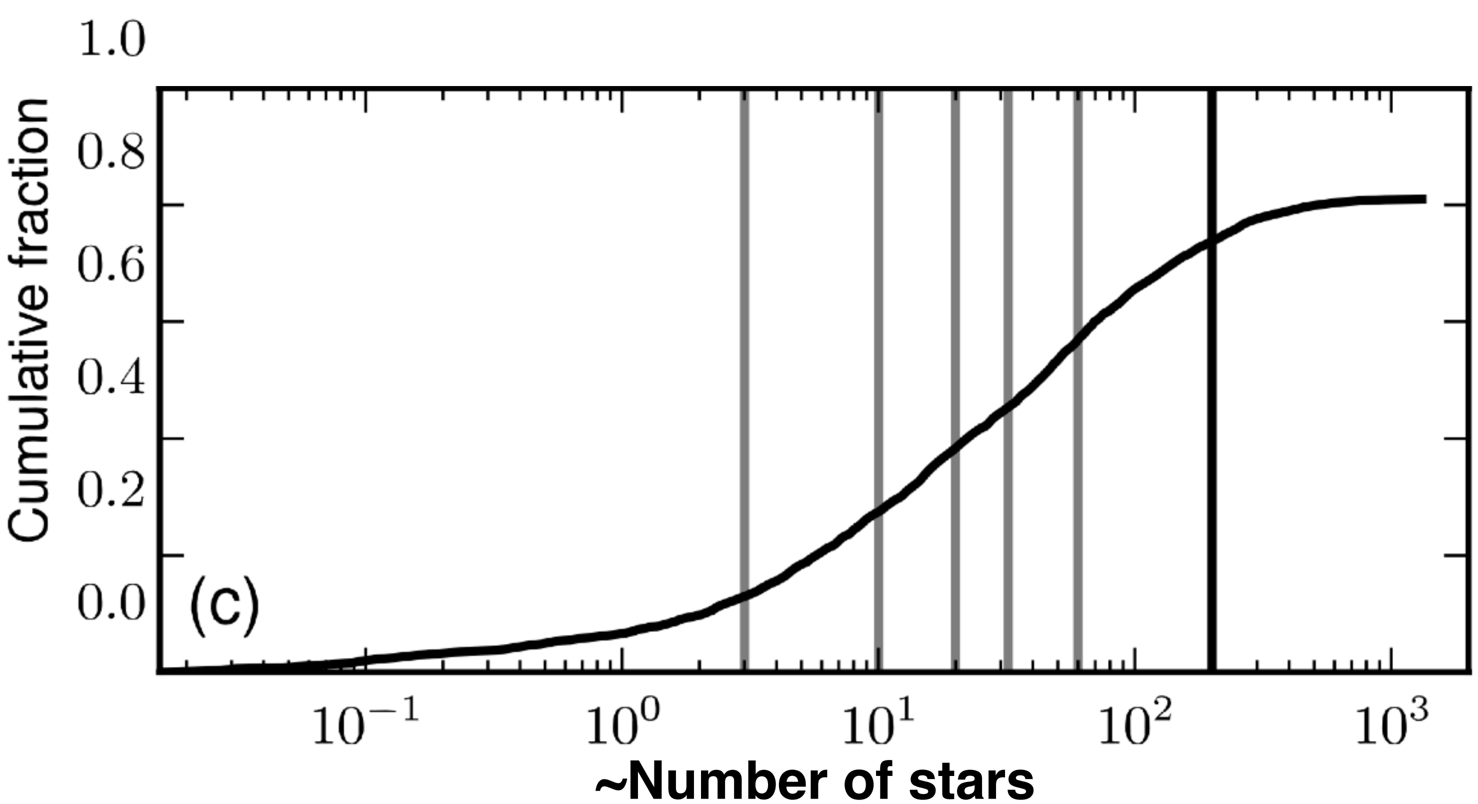
- Short-lived radionuclides in meteorites determine ages during planet formation and set interior heat budget

In a nutshell: star formation



Star formation regions

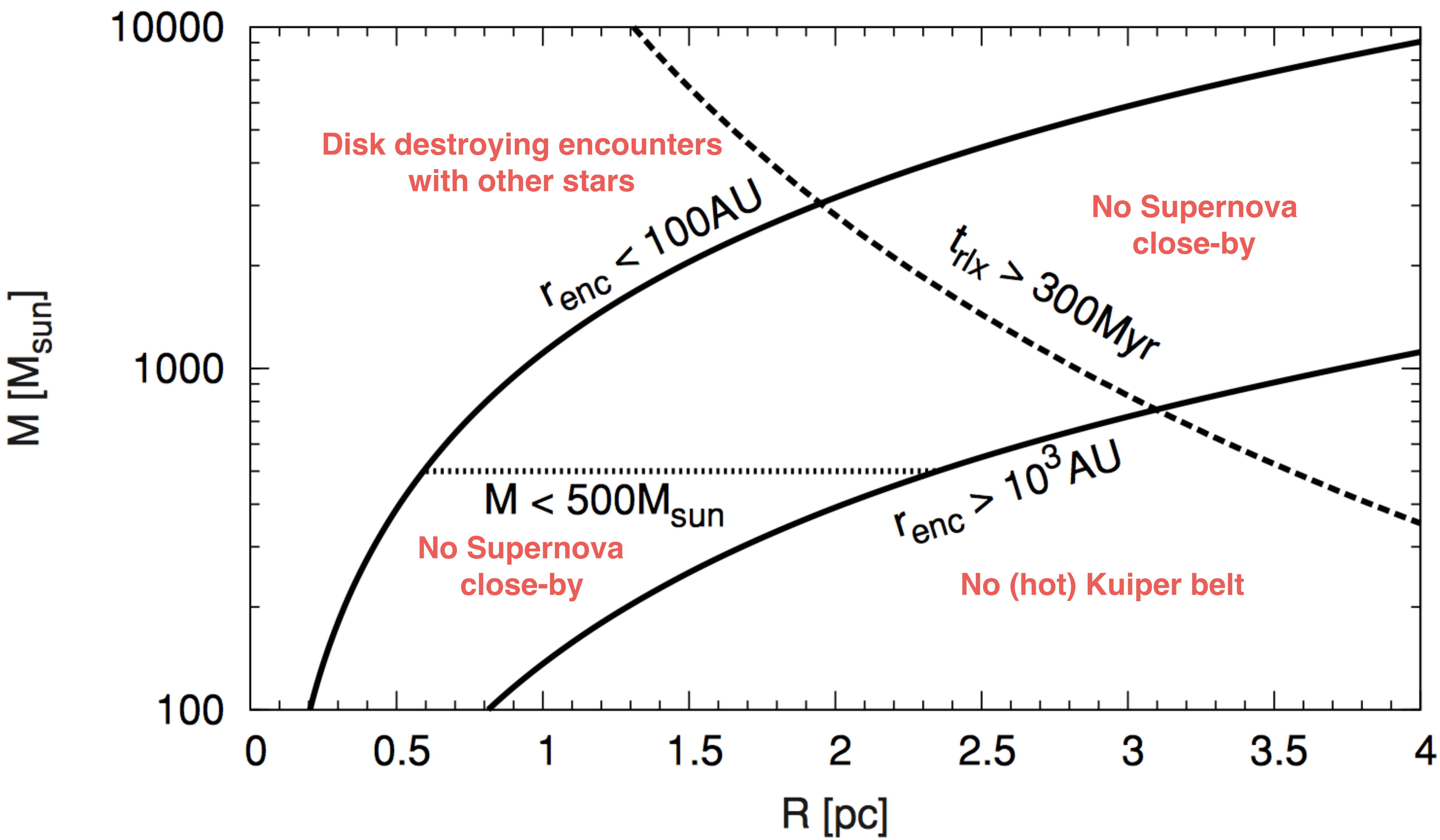
- Age spreads < 2 Myr in local (~pc) star forming environments
- Most stars form in clusters > 50 M_{sun}
- Usually fast (< 10 Myr) expansion



ESA/Hubble

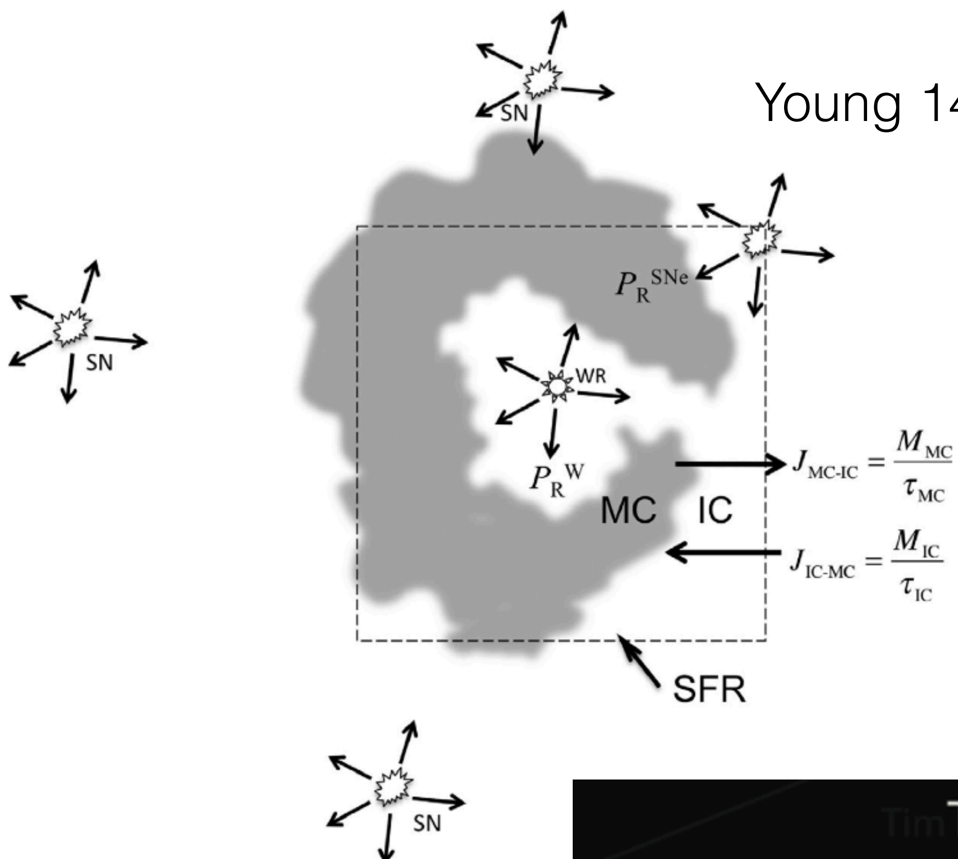
Lada & Lada 03, Bressert+ 10

The Solar birth cluster

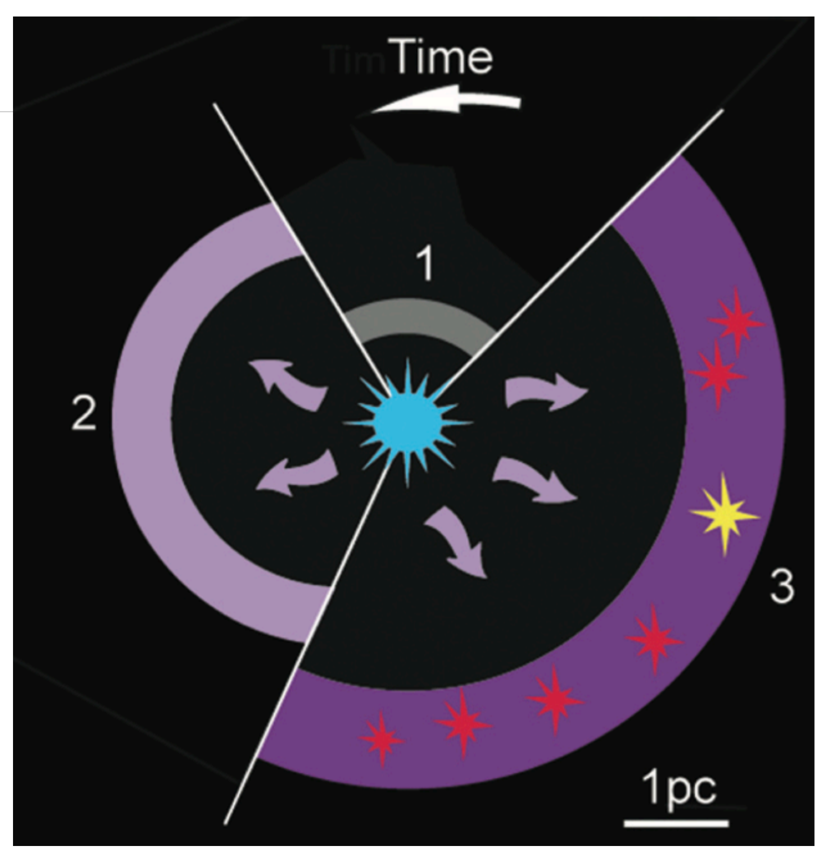


Portegies Zwart 09

Origin of short-lived radionuclides



Young 14,16

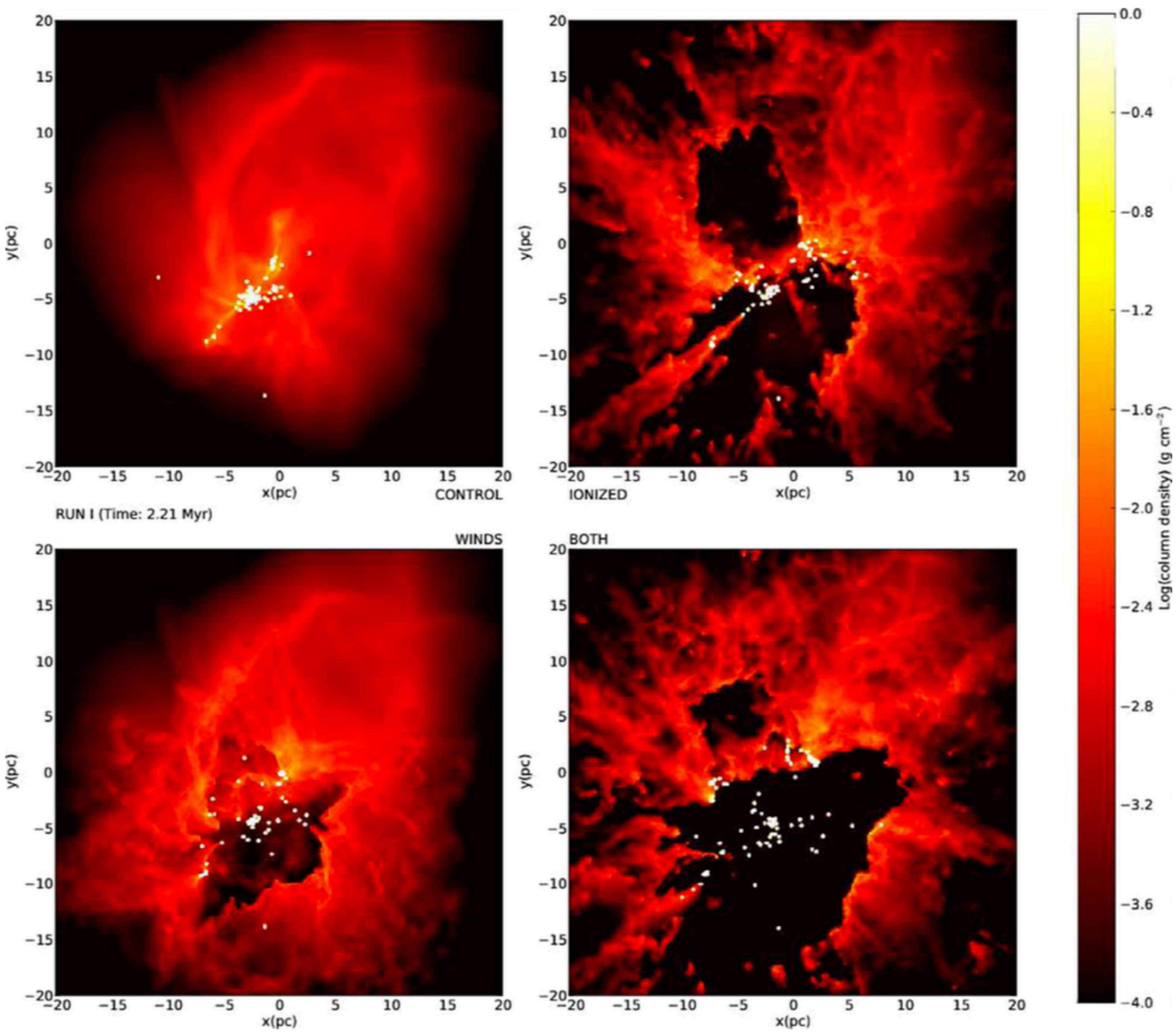


Gounelle & Meynet 12; Pfalzner+ 15

- 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)

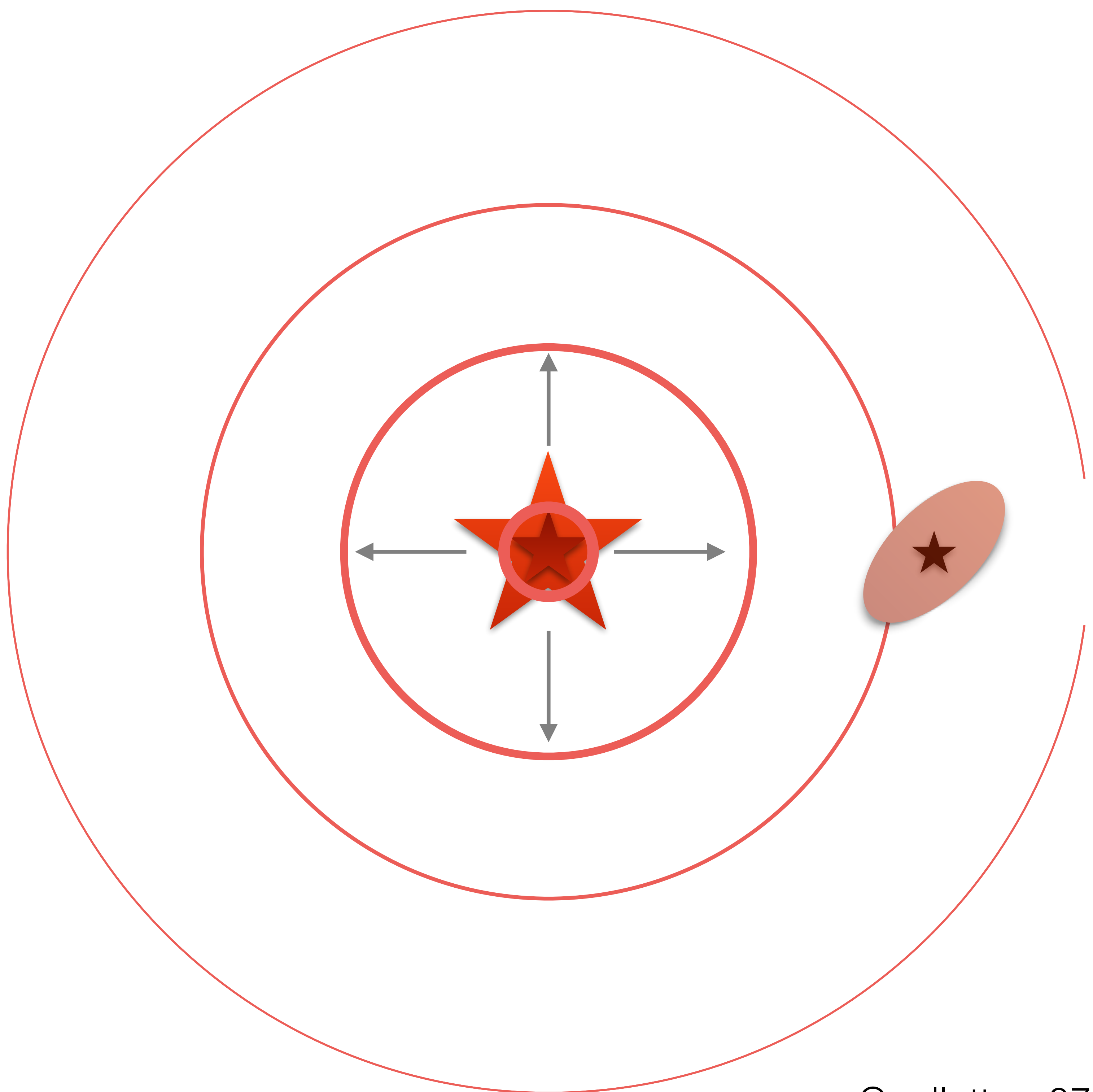
Reviews: Adams 10; Davis+ 14; Pfalzner+ 15

Feedback: how stars shape their formation

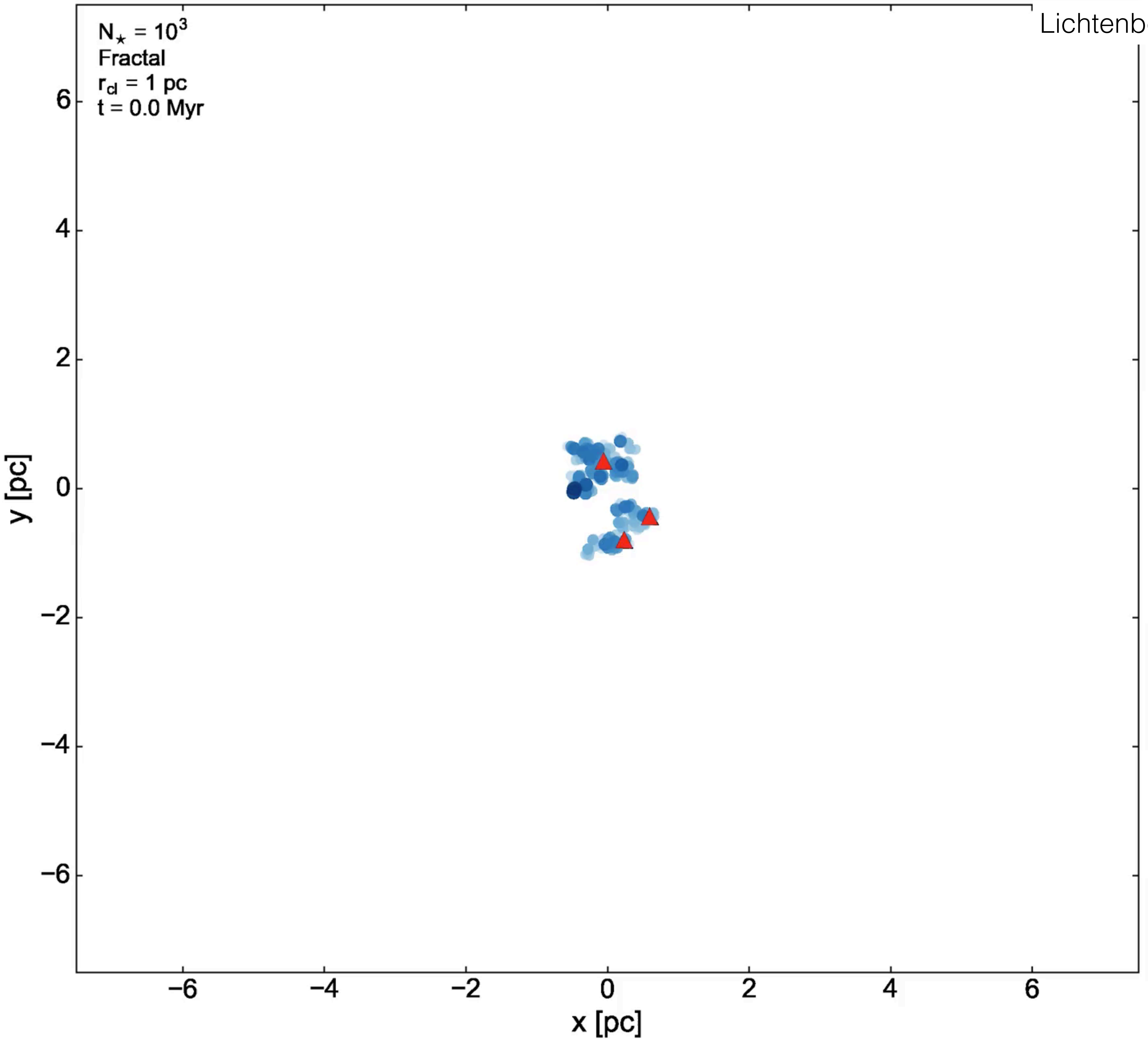


Dale 15,
Federrath 15,
Gavagnin+ 17

Late ^{26}Al injection from supernova pollution

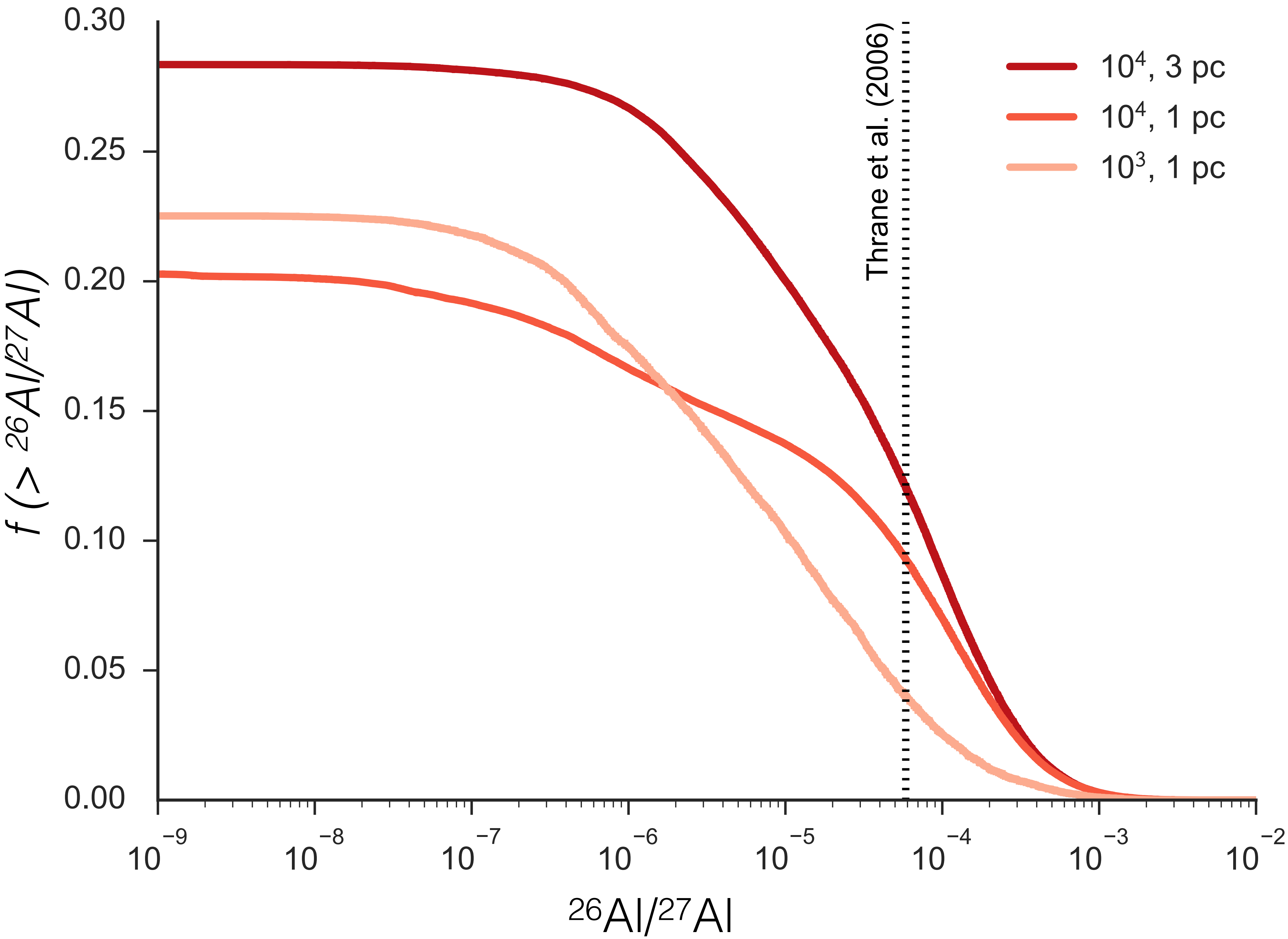


Clayton 77; Chevalier 00;
Ouellette+ 07, 09, 10; Parker+14; Nicholson+17



Lichtenberg+ 16b

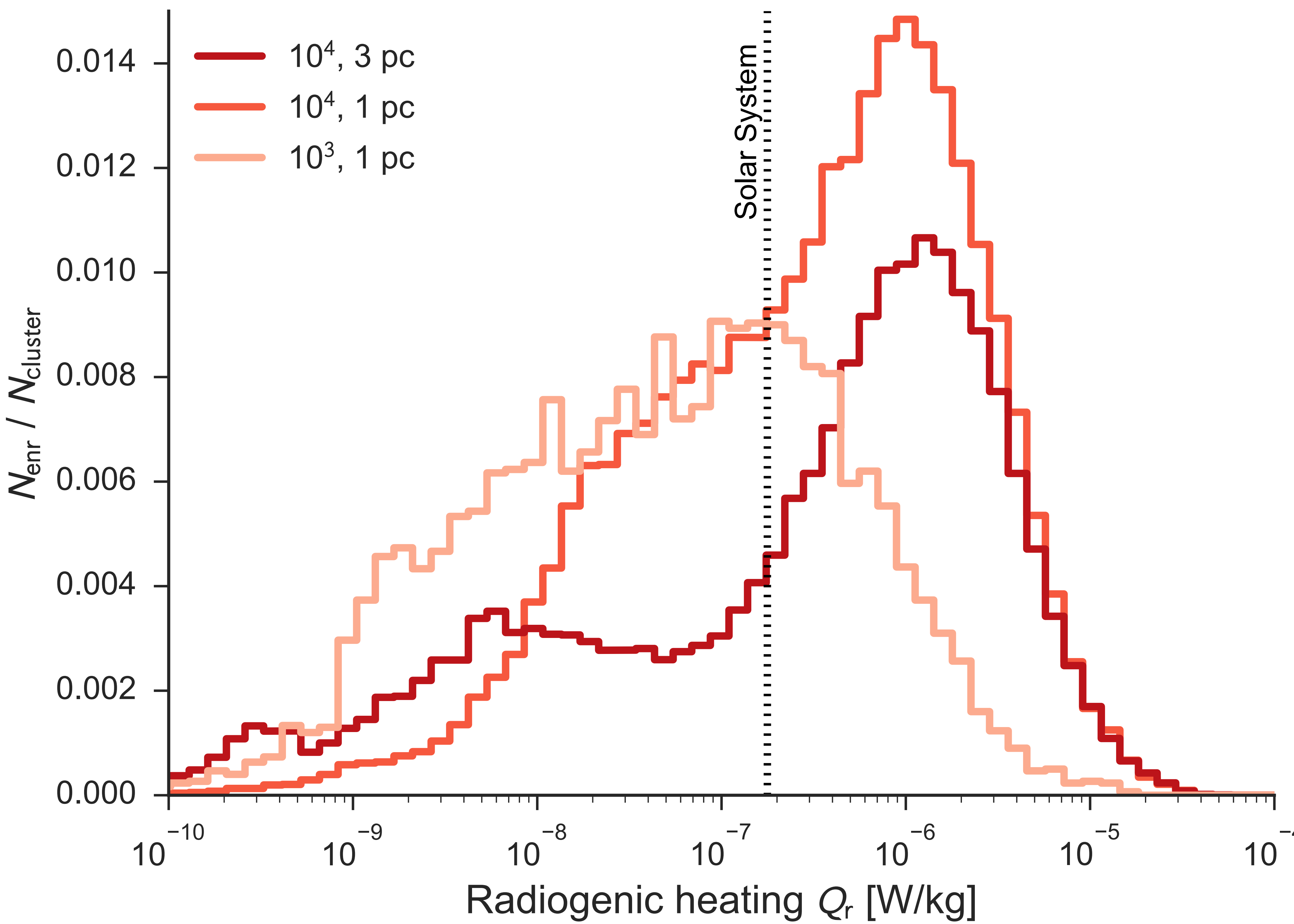
Enrichment distribution $^{26}Al/^{27}Al$



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

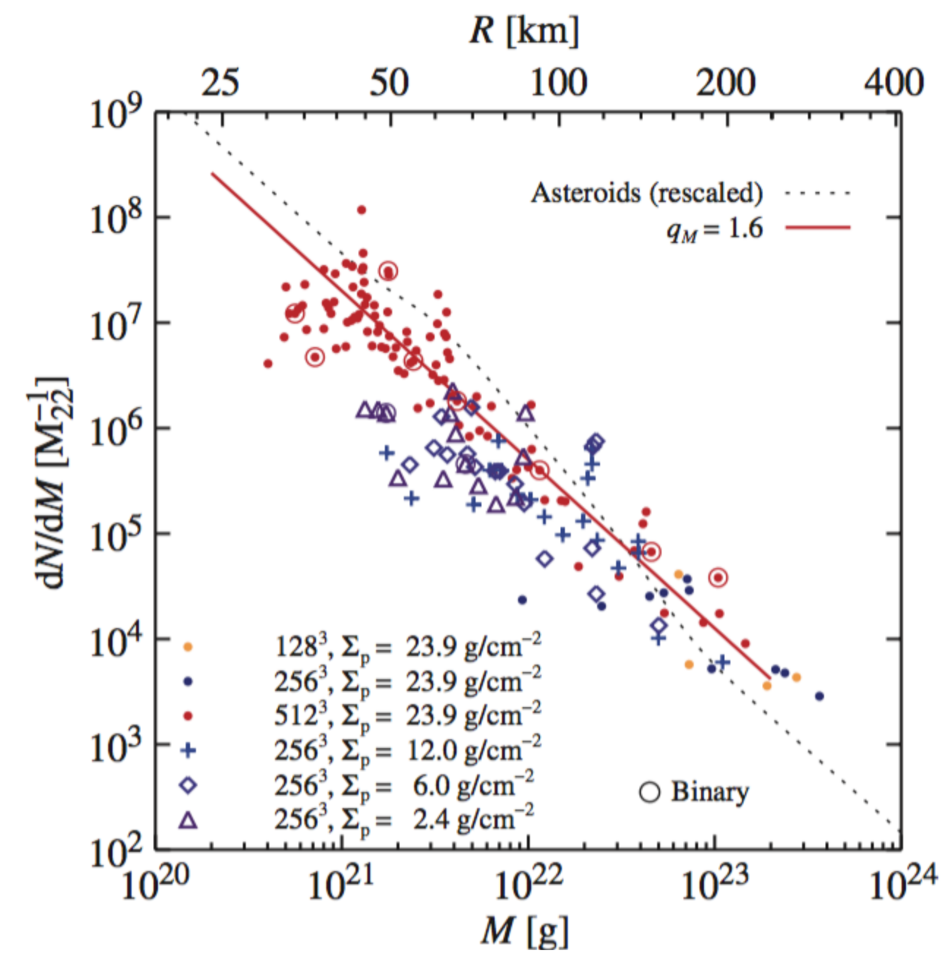
Planetesimal heat budget



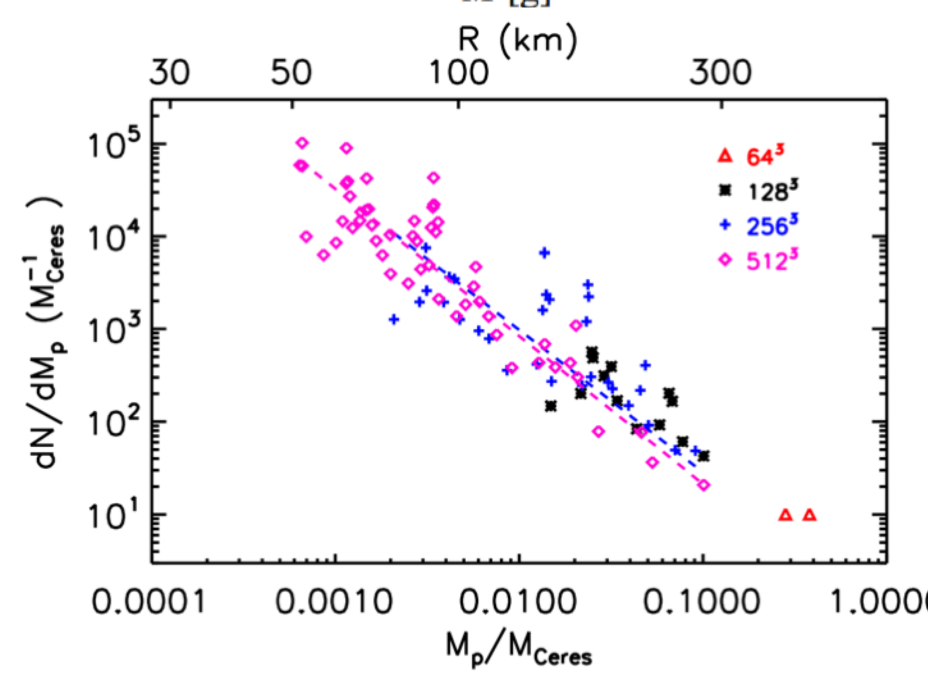
Constraints on planetesimal formation sizes

Recent IMF estimates:

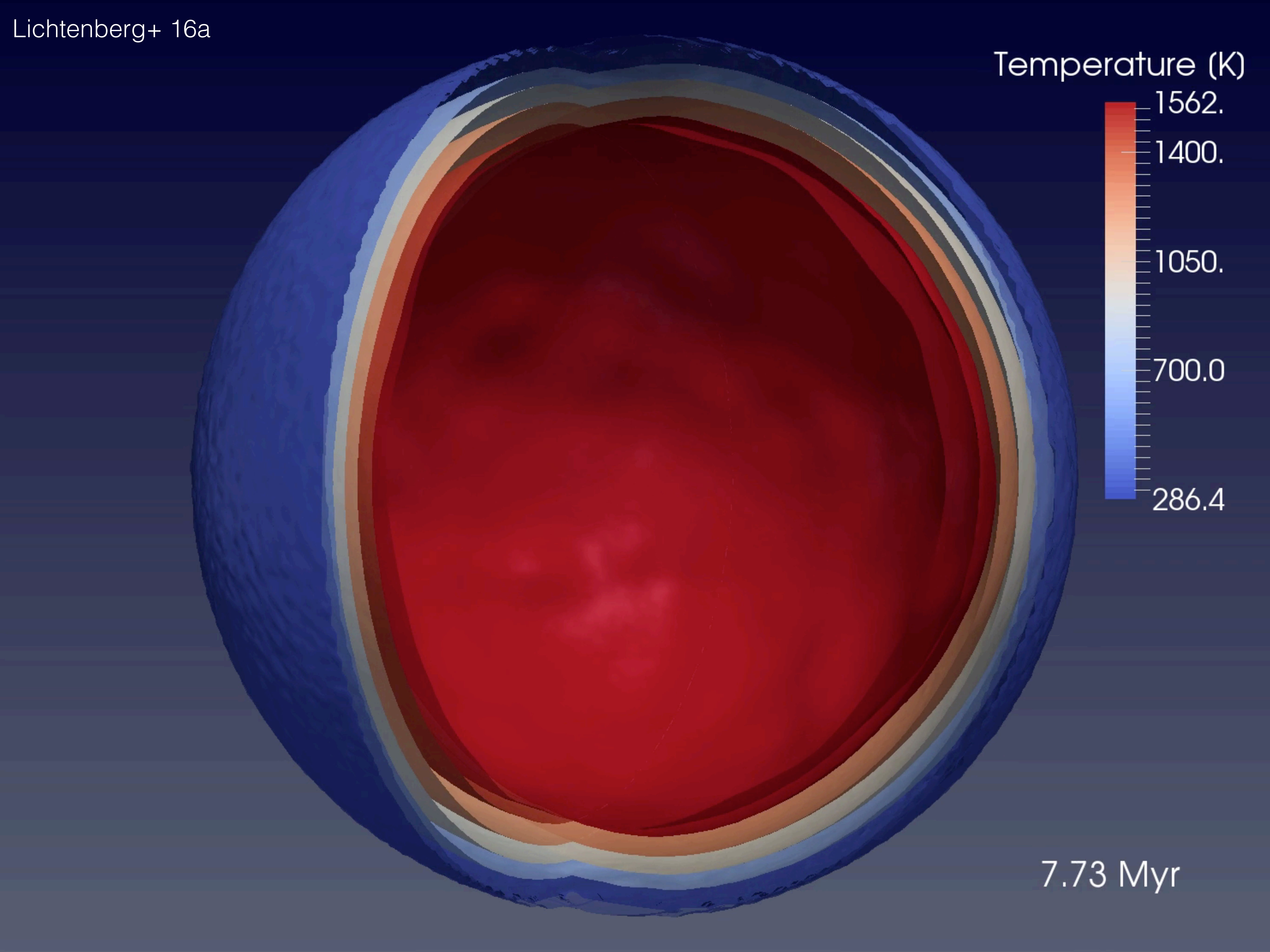
- ***r* = 10—100 km** *(Cuzzi+08)*
- ***r* = 100—1000 km** *(Morbidelli+09)*
- ***r* = 50—200 km** *(Chambers 10)*
- ***r* = 25—200 km** *(Johansen+15, Simon+16)*
    - ➡ $dN/dR \sim R^{-2.8}$
    - ➡ $dN/dM \sim M^{-1.6}$
- $M \sim 10^{16}$—10^{21} kg



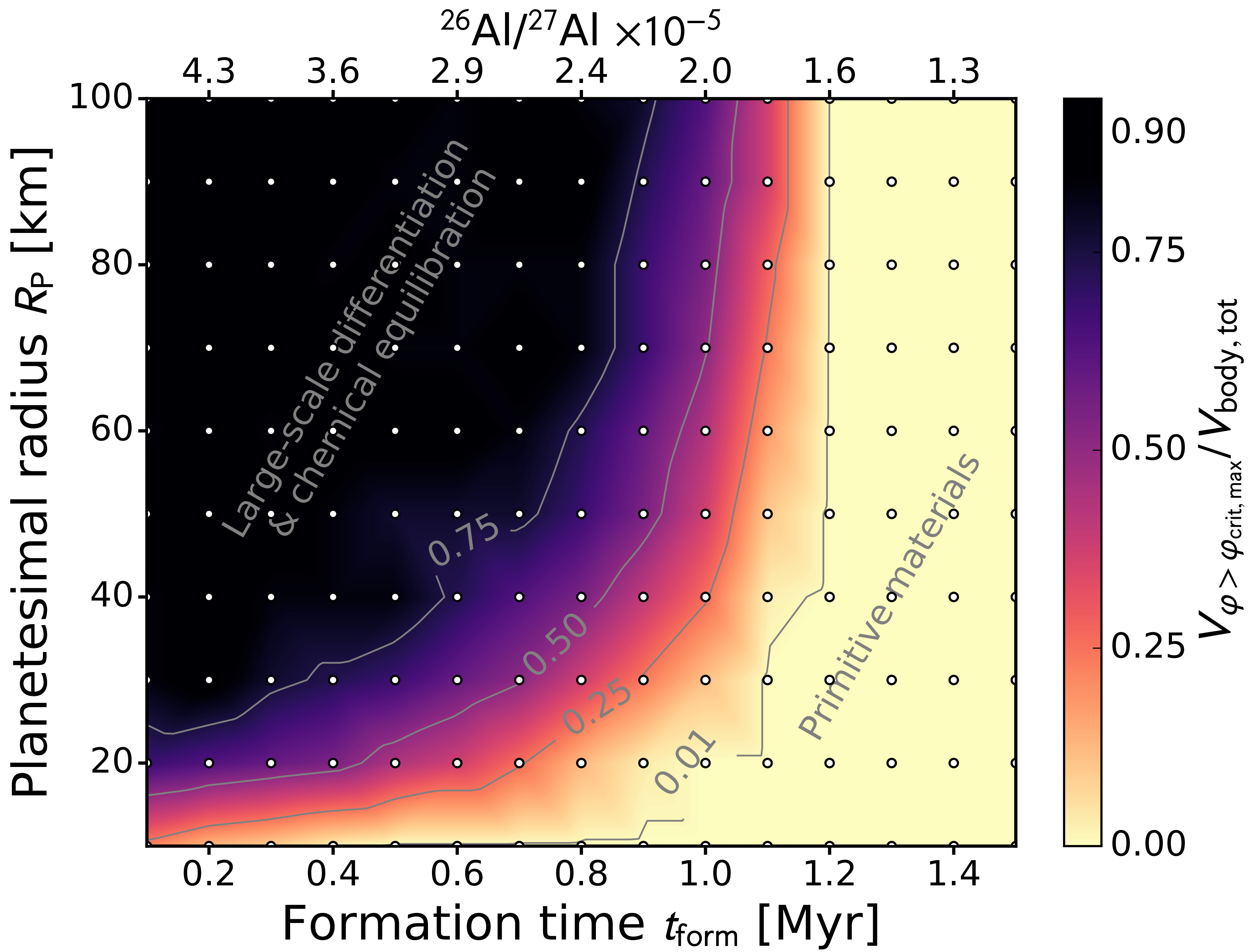
Johansen+15



Simon+16

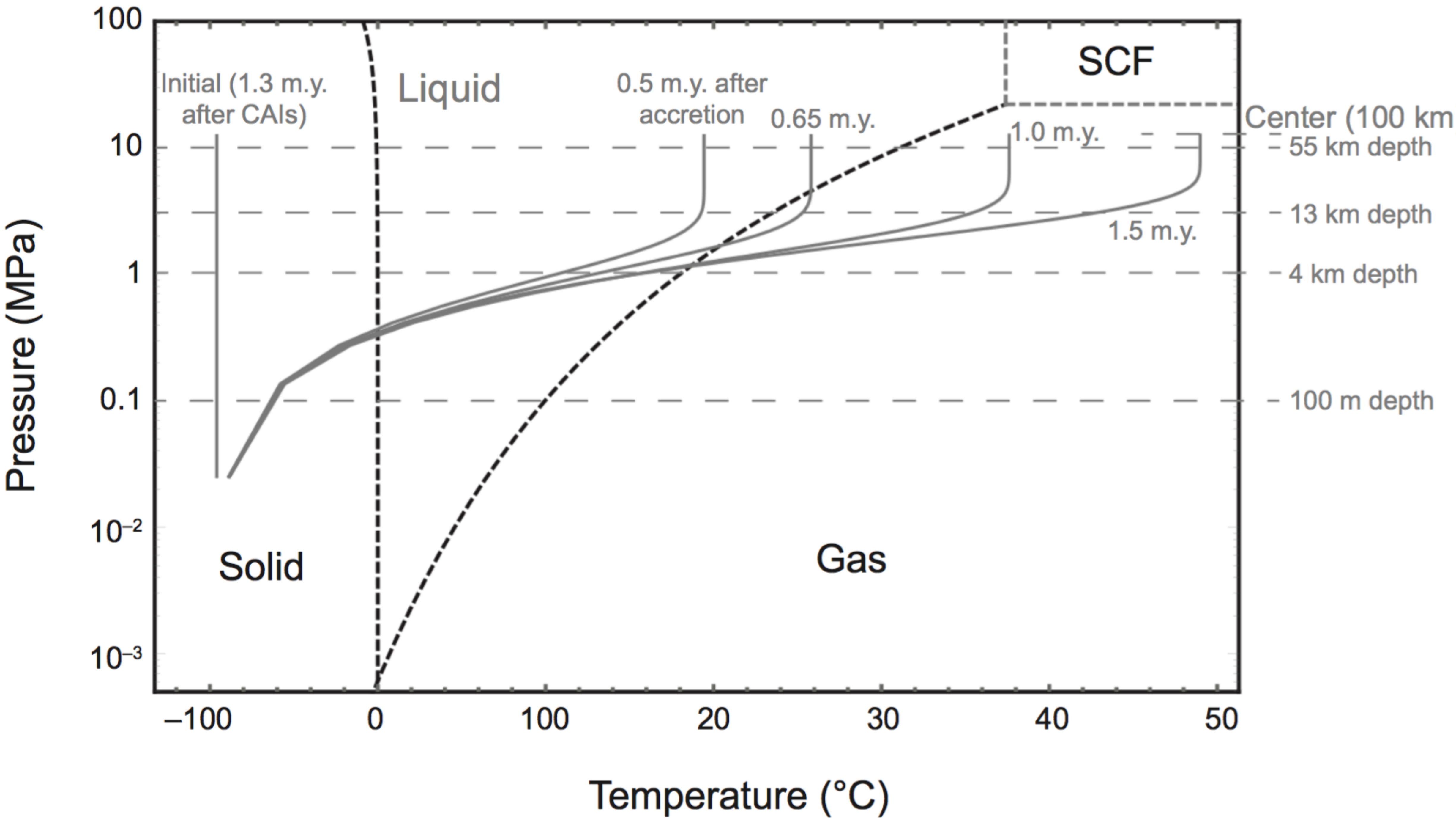

Lichtenberg+ 16a
Temperature (K)
1562.
1400.
1050.
700.0
286.4
7.73 Myr

Planetesimal interior evolution



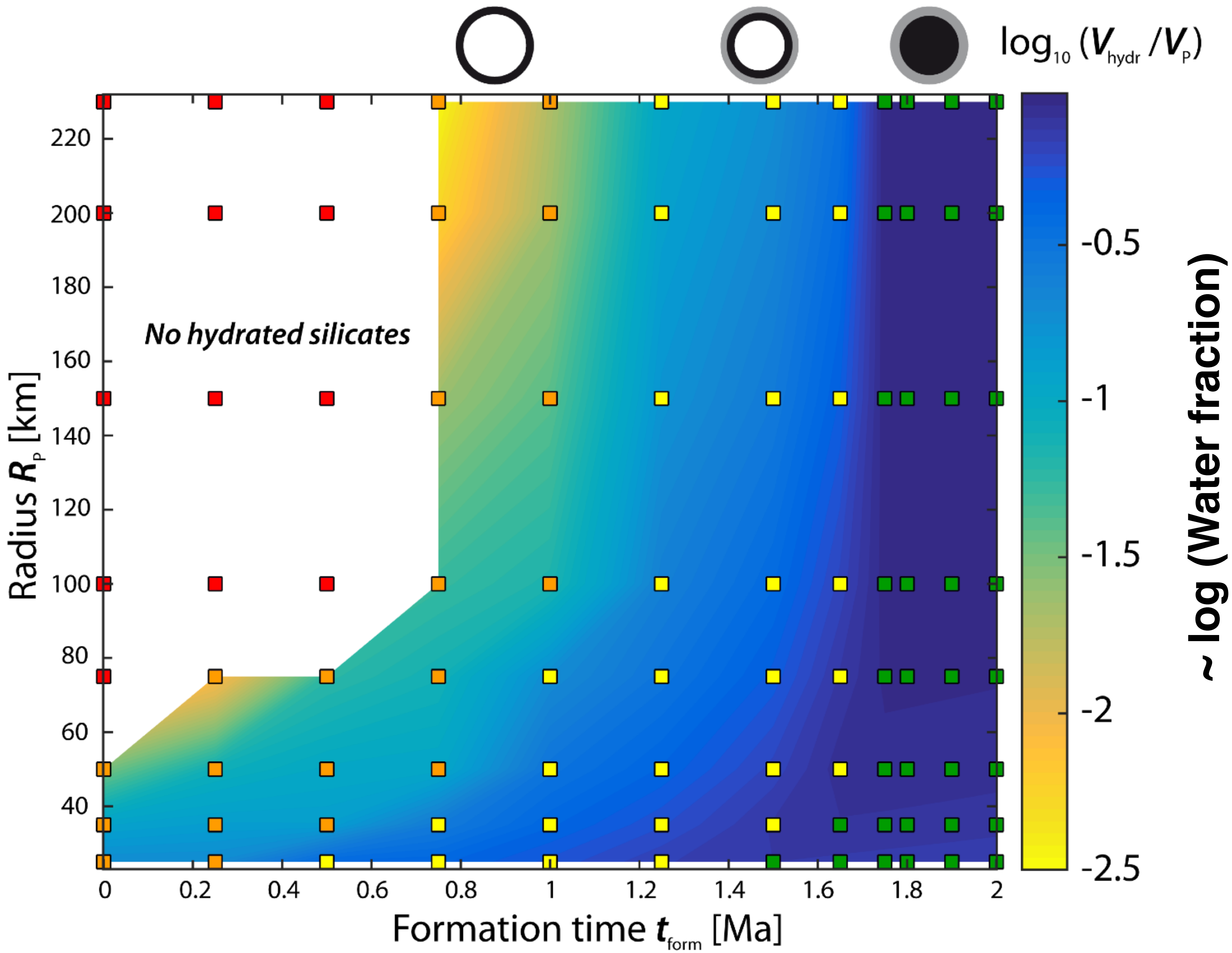
See also: Elkins-Tanton 10, "Asteroids IV" (Michel, DeMeo, Bottke); "Planetesimals" (Weiss & Elkins-Tanton)

Planetesimal hydrology



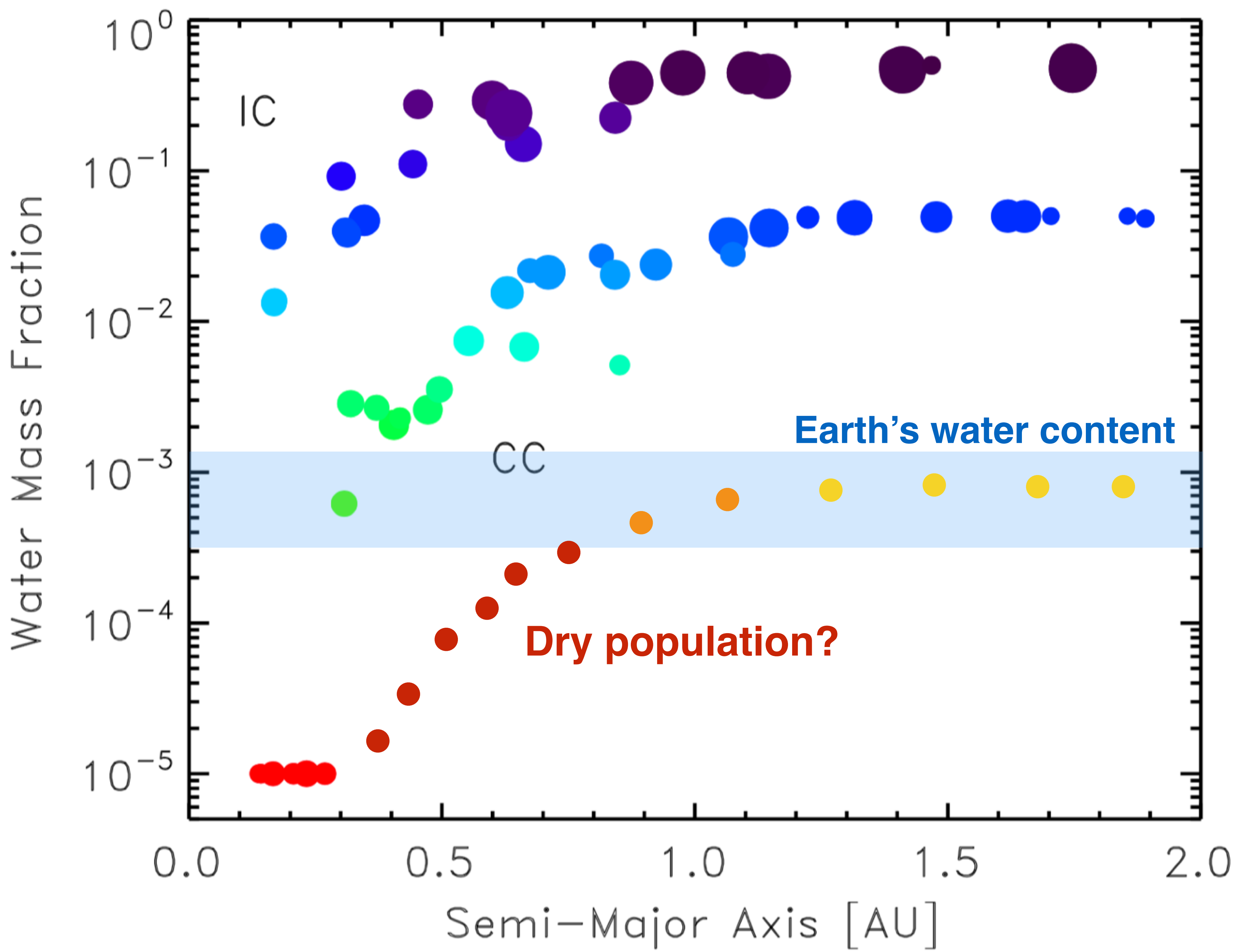
Young+ 03; Zhou+ 13; Zolotov+ 14; Fu+ 15, 17; Scheinberg+ 16

Dehydration from internal heating



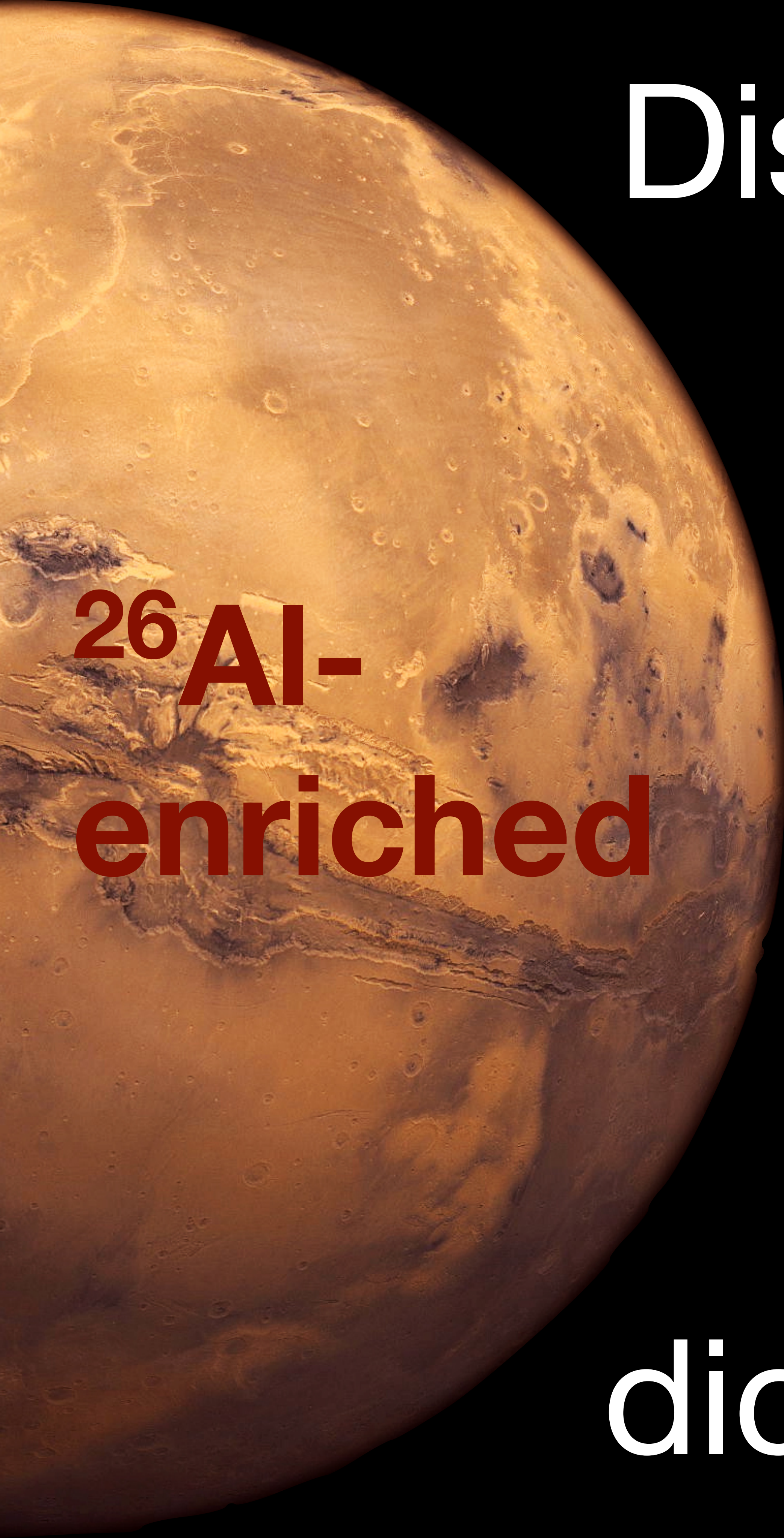
Courtesy Gregor Golabek

‘Initial’ water abundances integrated



Ciesla+ 15

Distribution dichotomy?



Take away – Summary

1. ^{26}Al distribution of young planetary system
   - Source: massive star in close vicinity of young Sun
   - Debated distribution in star-forming regions
2. ^{26}Al-driven planetesimal interior evolution in enriched systems
   - How does this shape the planetary formation process?
   - Does it alter habitability conditions?