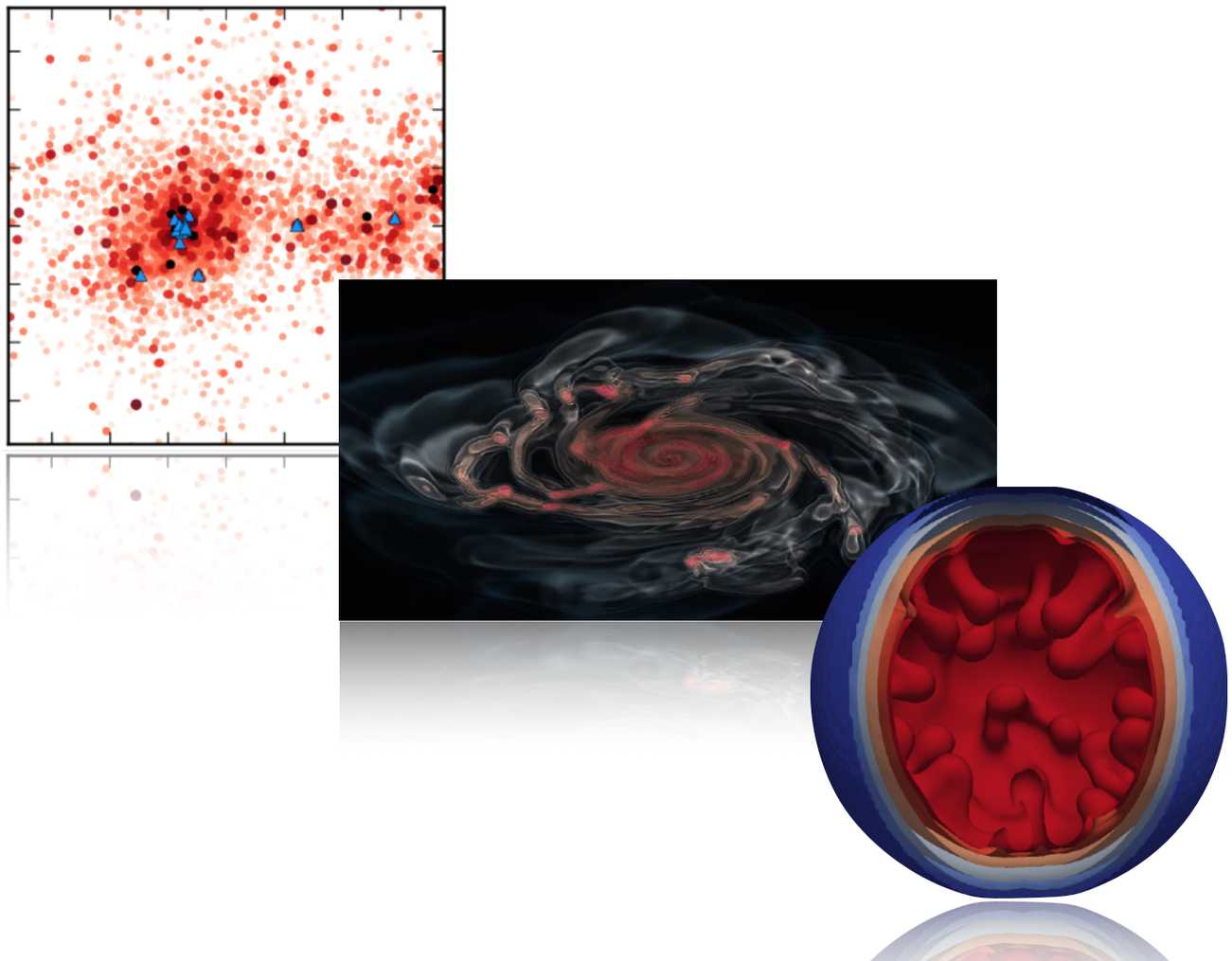
A planet population dichotomy from isotopic enrichment?

Tim Lichtenberg

Richard J. Parker (U Sheffield)
Michael R. Meyer (U Michigan)
Gregor J. Golabek (BGI Bayreuth)
Taras V. Gerya (ETHZ)

ETH zürich



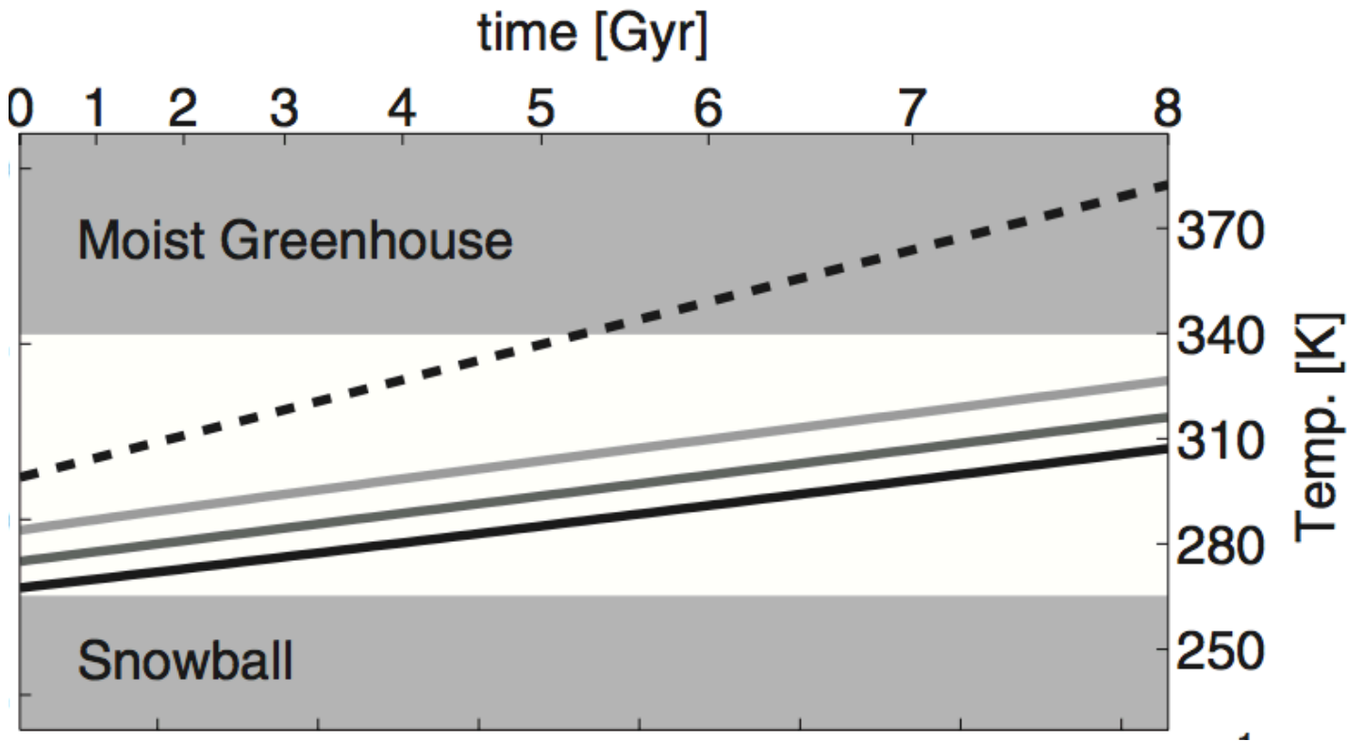
Outline

1. Grand perspective

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

3. Implications for planetesimal evolution and planet formation

Why too much water is a bad idea

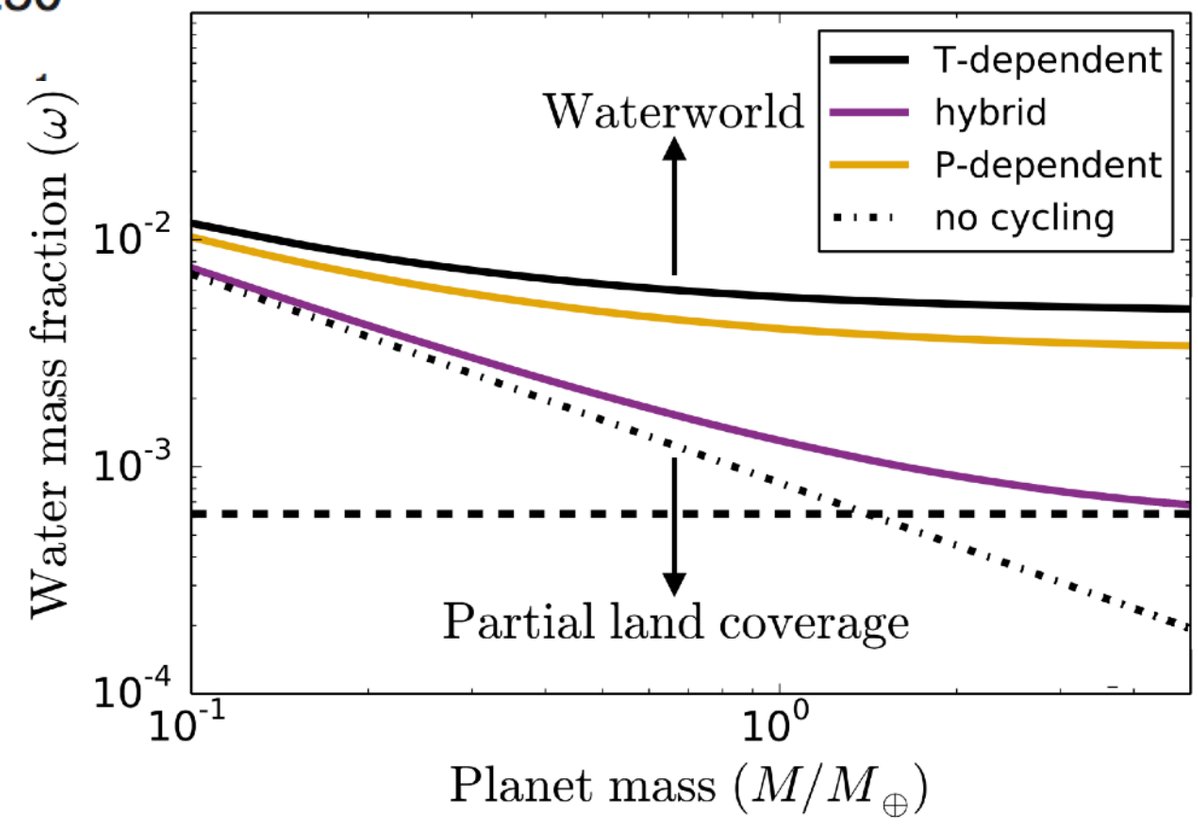


Abbot+ 12

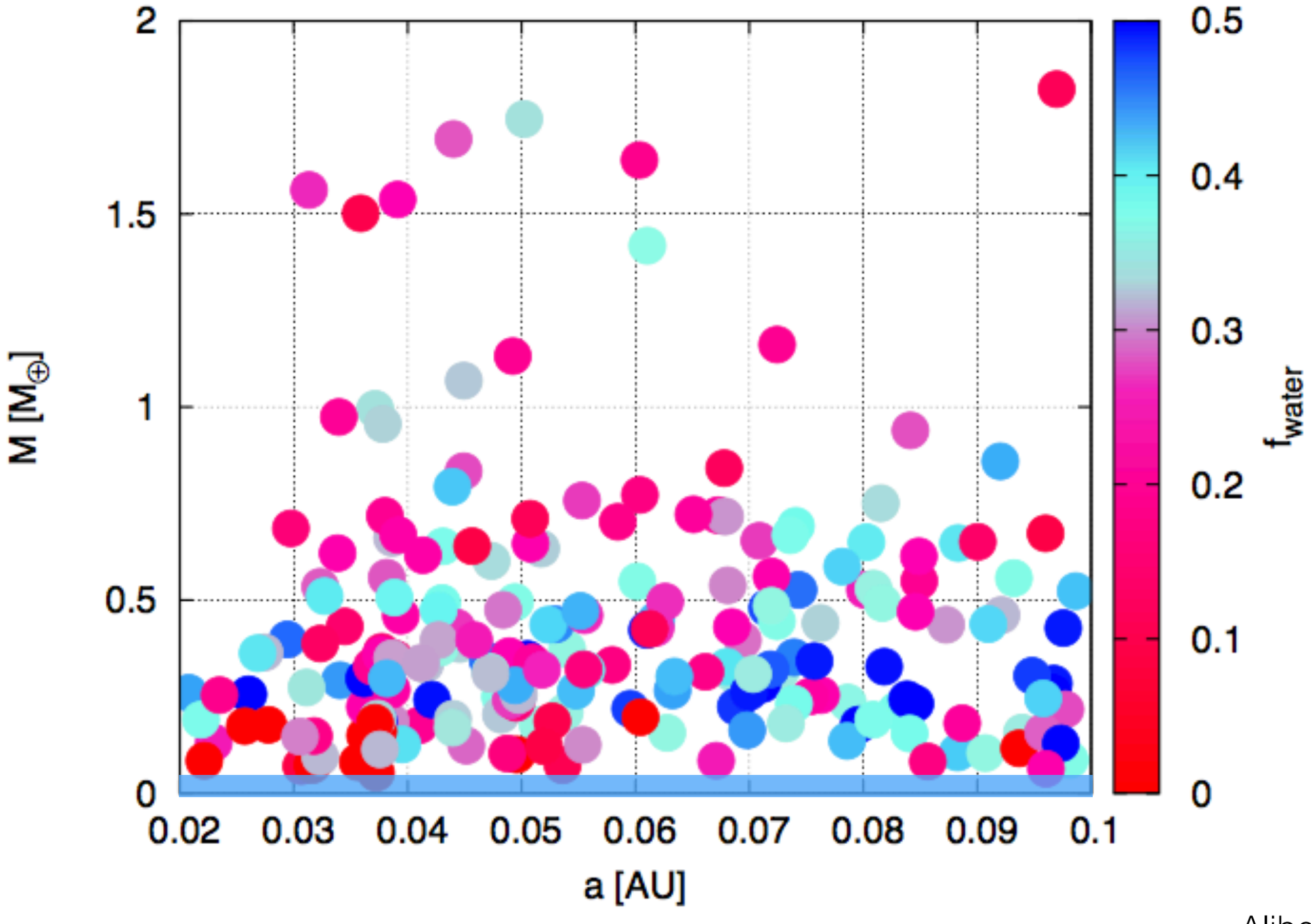
- Continental silicate weathering
- negative feedback, important for carbonate burial

- Absolute threshold to store water in mantle

Komacek & Abbot 16, Cowan & Abbot 14

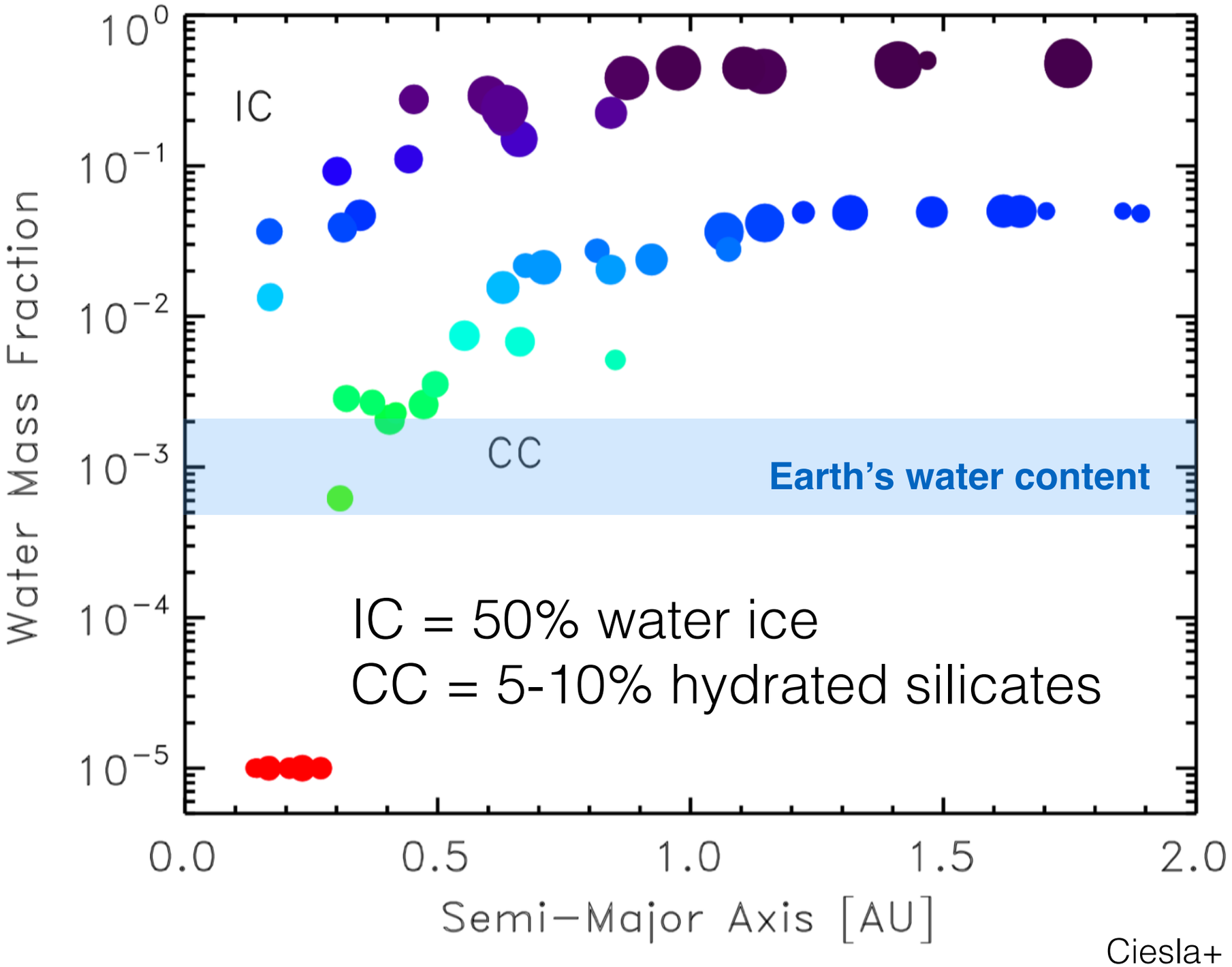


Excess water fractions in planets?



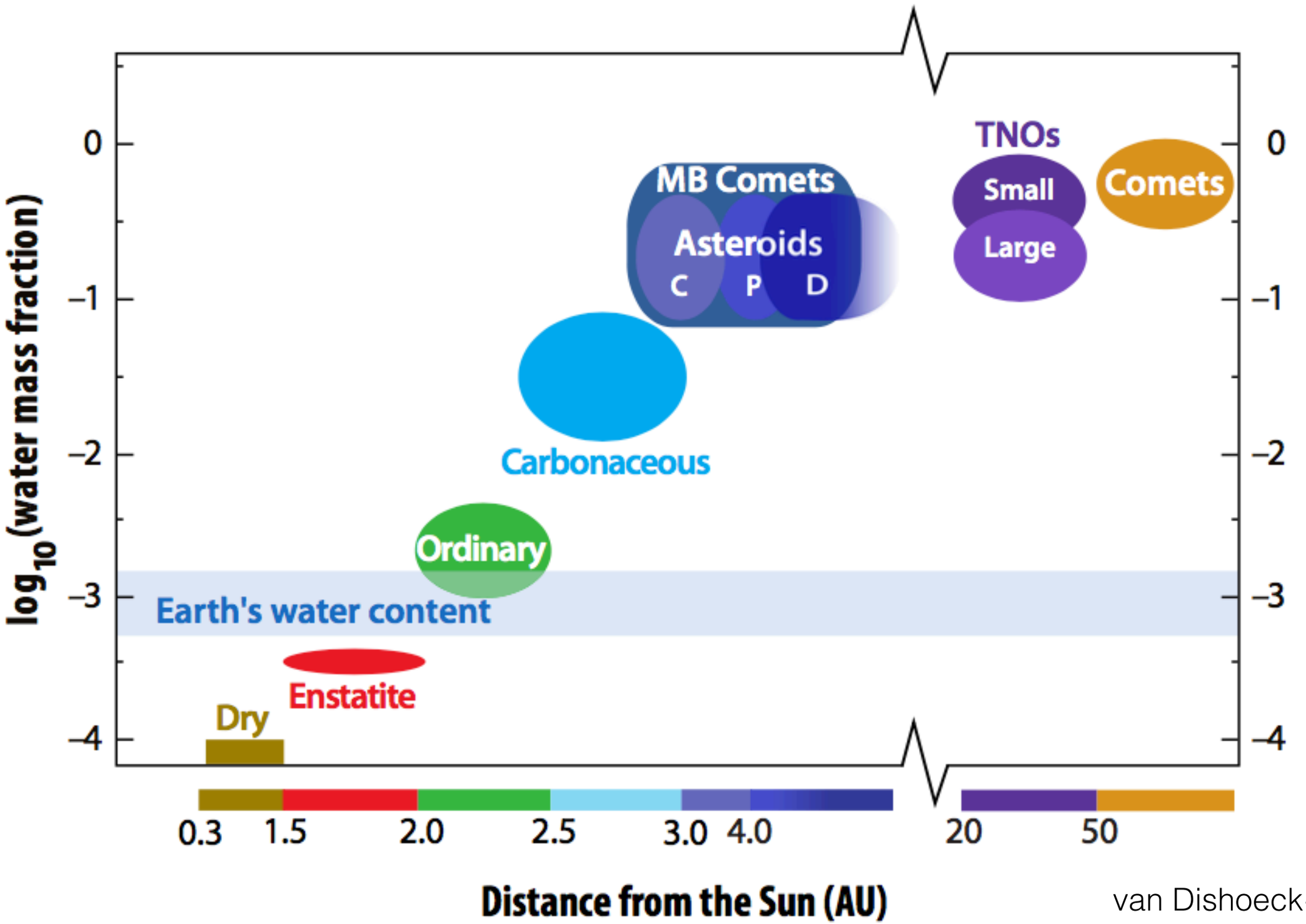
Alibert & Benz 17

How to dry out planets?



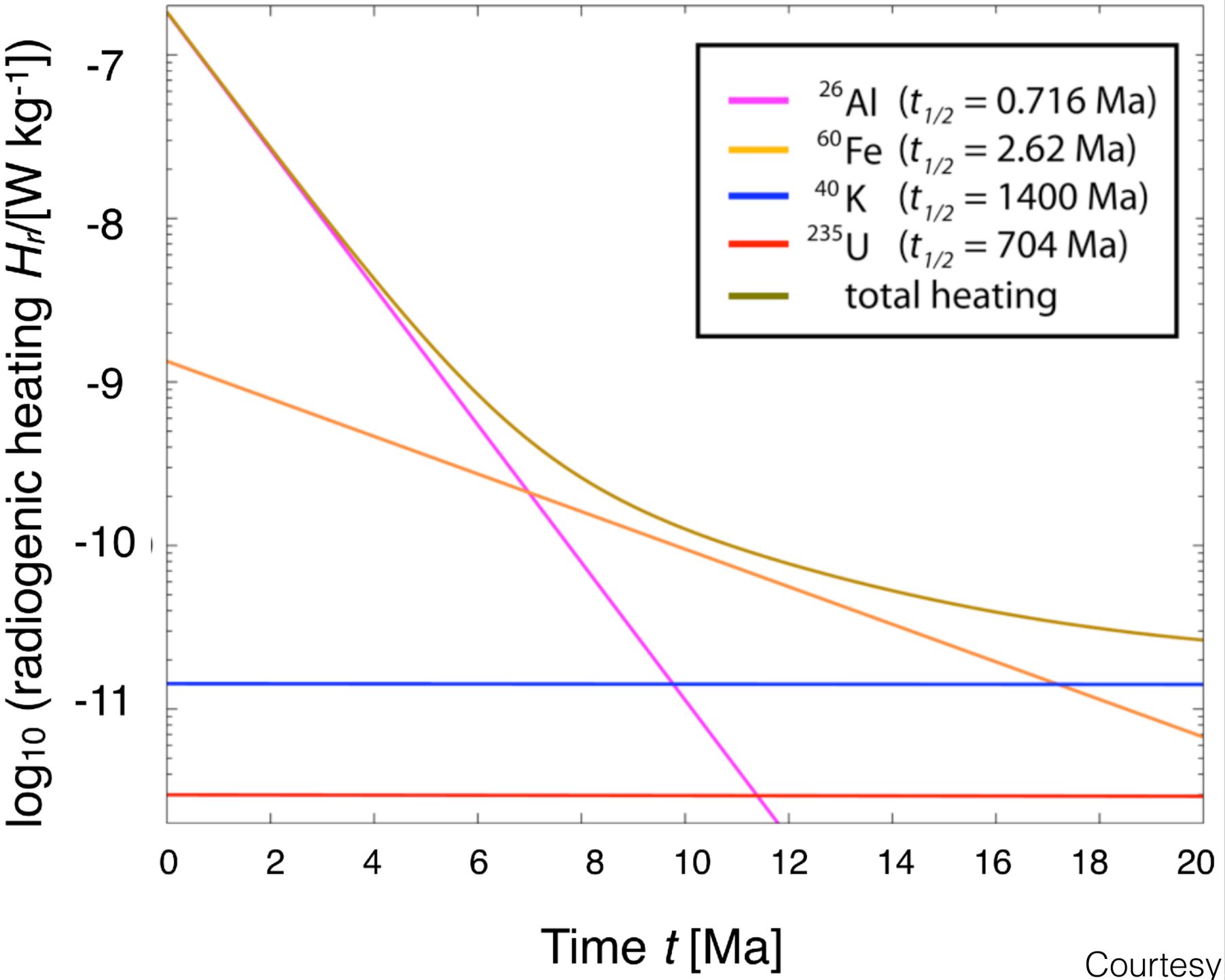
Ciesla+ 15, Mulders+ 15

The Solar system case



van Dishoeck+ 14, PPVI

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

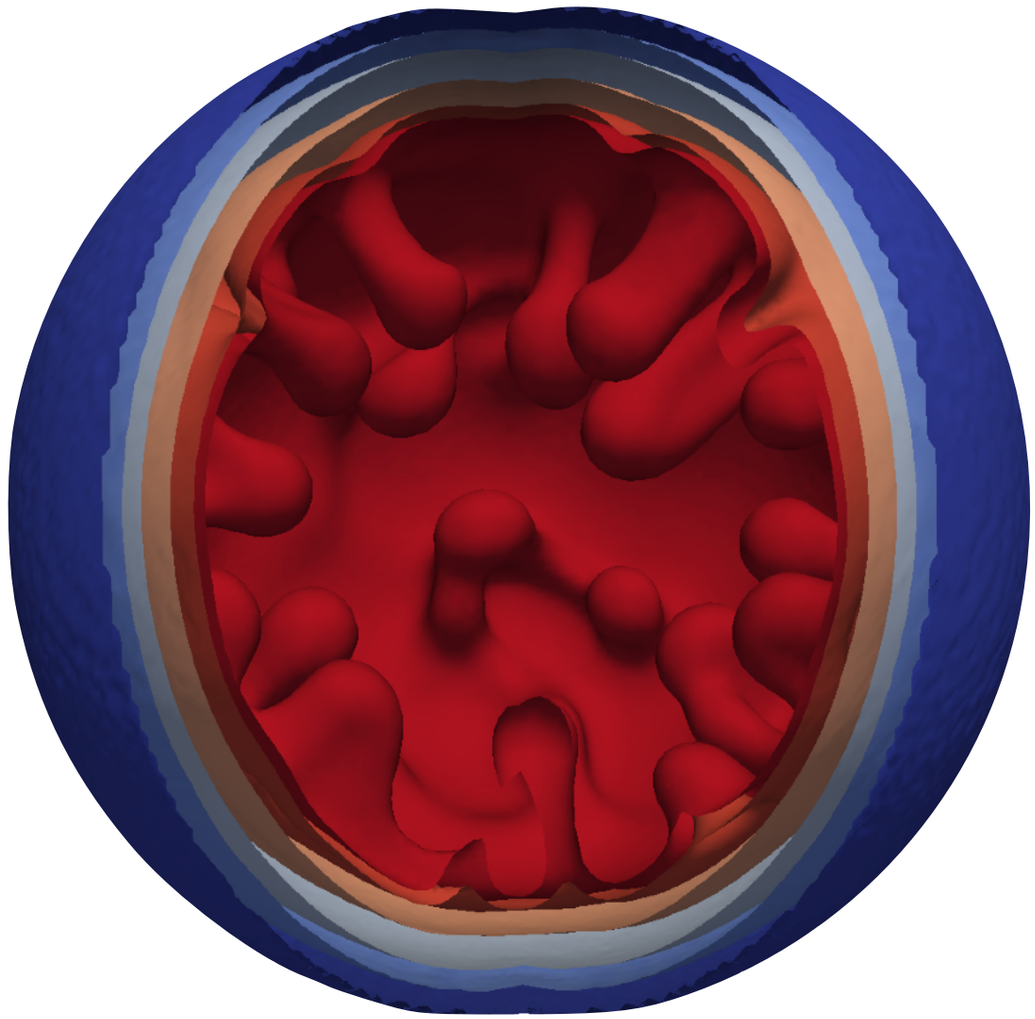
↓

3. Mixing into dust/solid material

↓

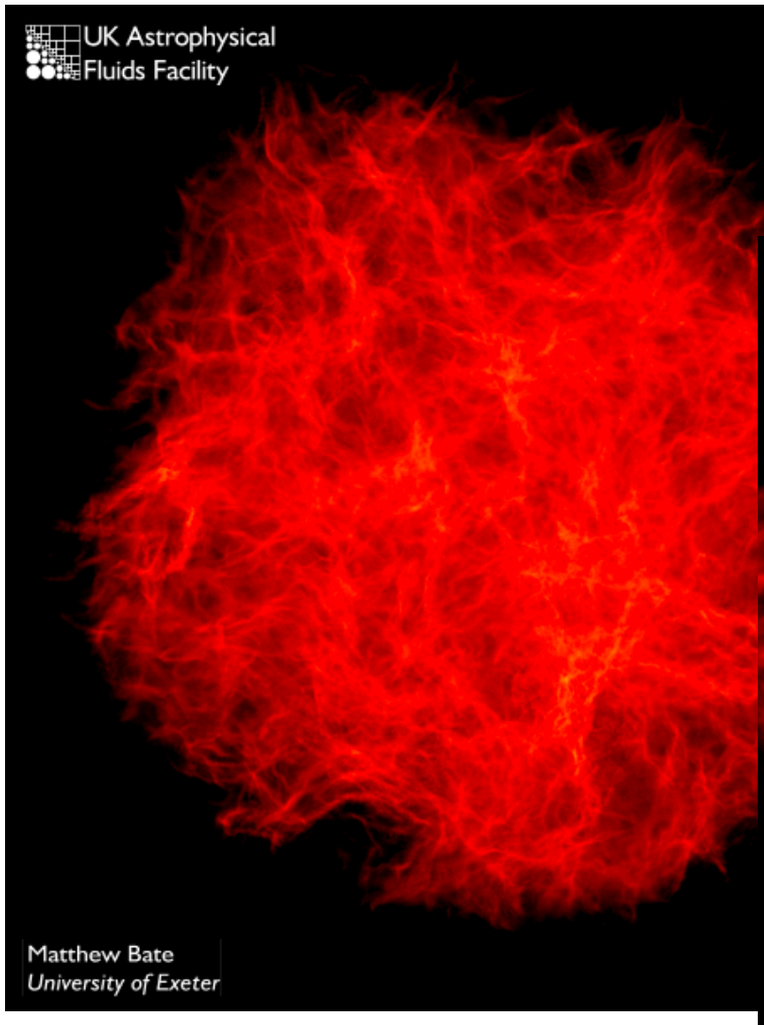
4. Heating of early planetesimals by radioactive decay

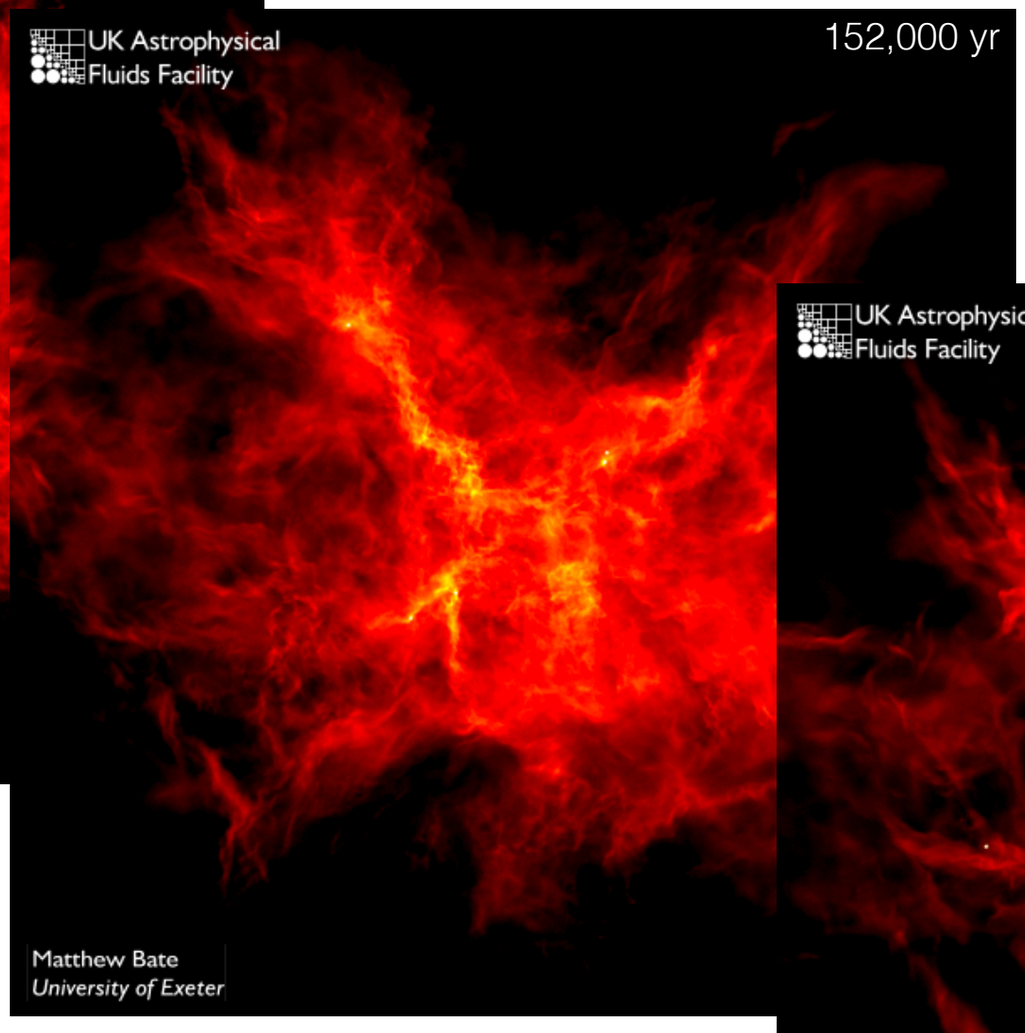
➡ Differentiation, serpentinization, volatile degassing, …

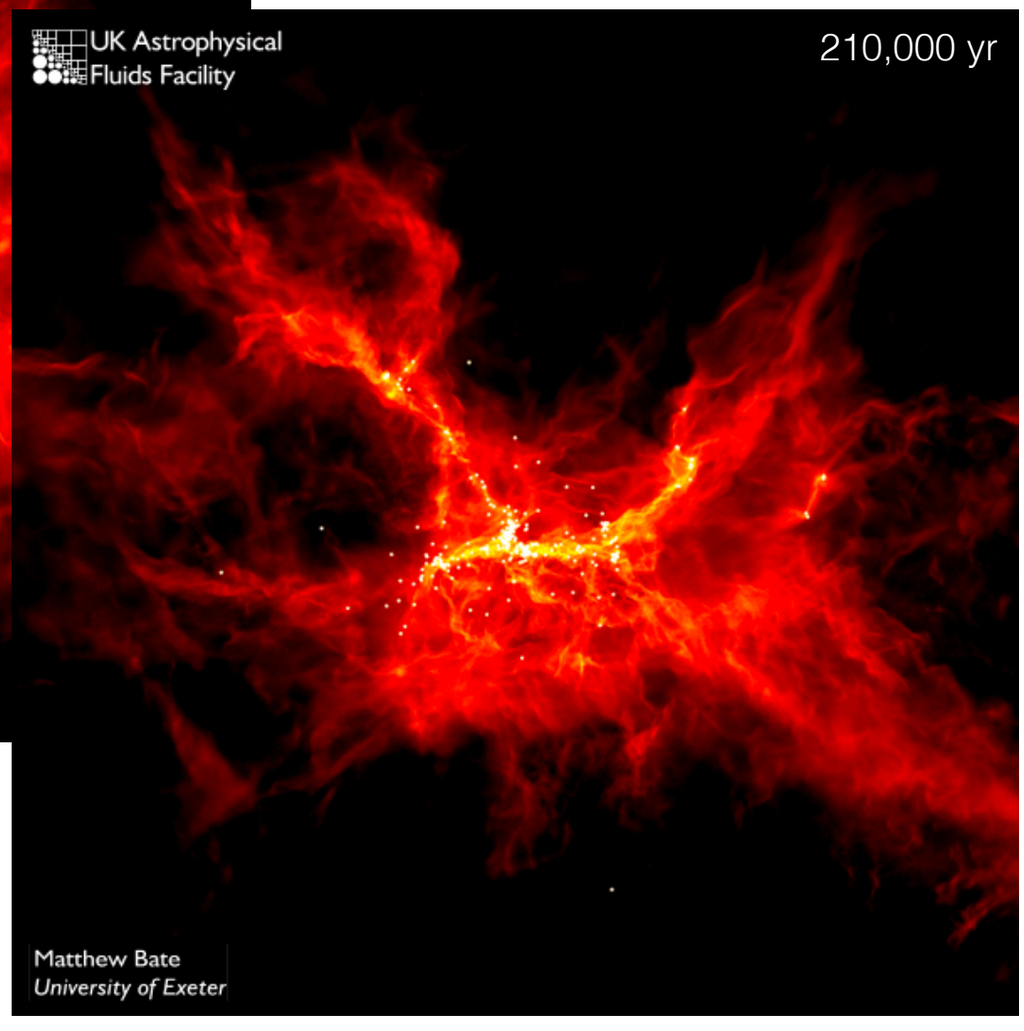


Lichtenberg, Golabek, Gerya, Meyer (2016)

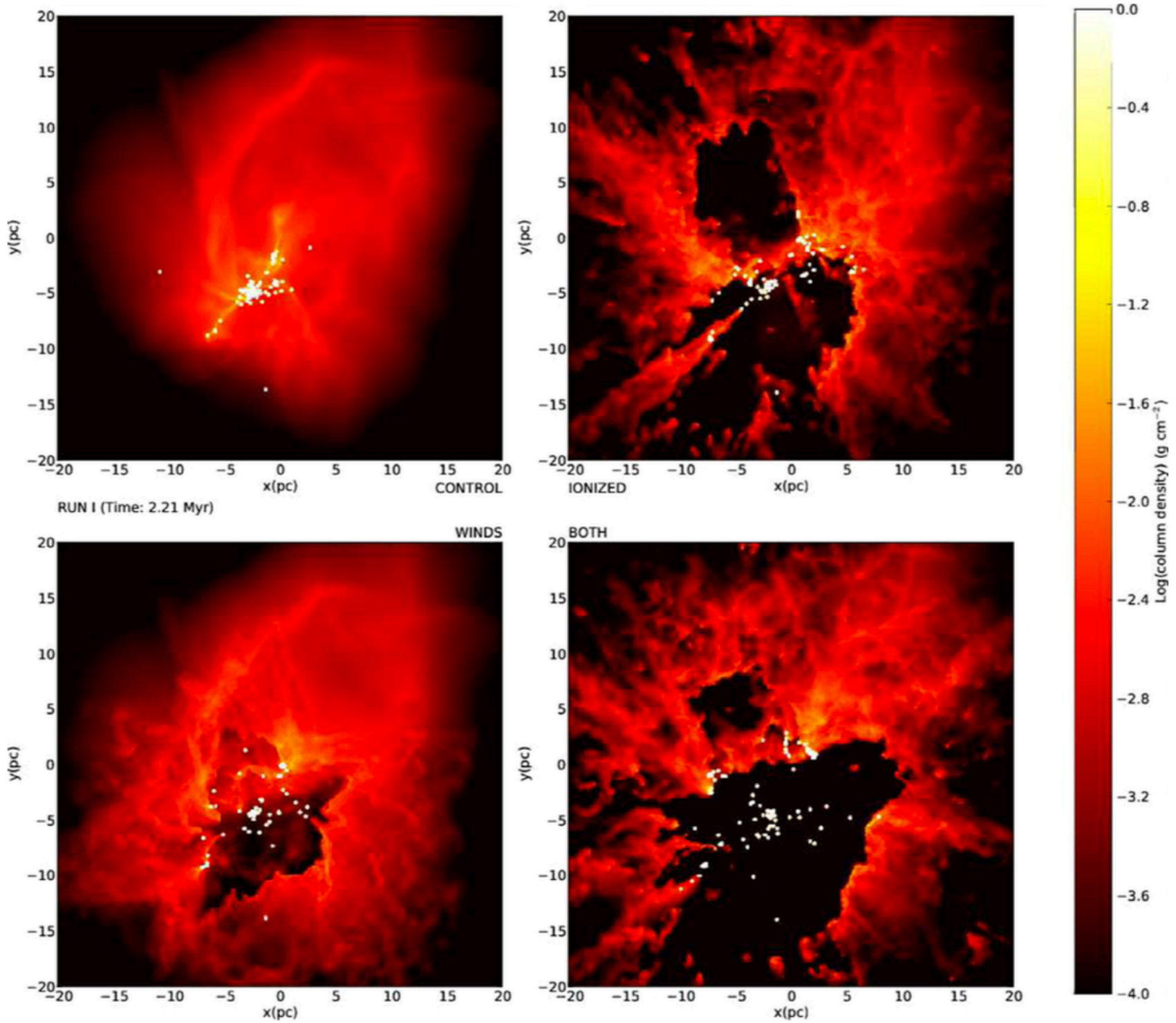
In a nutshell: star formation





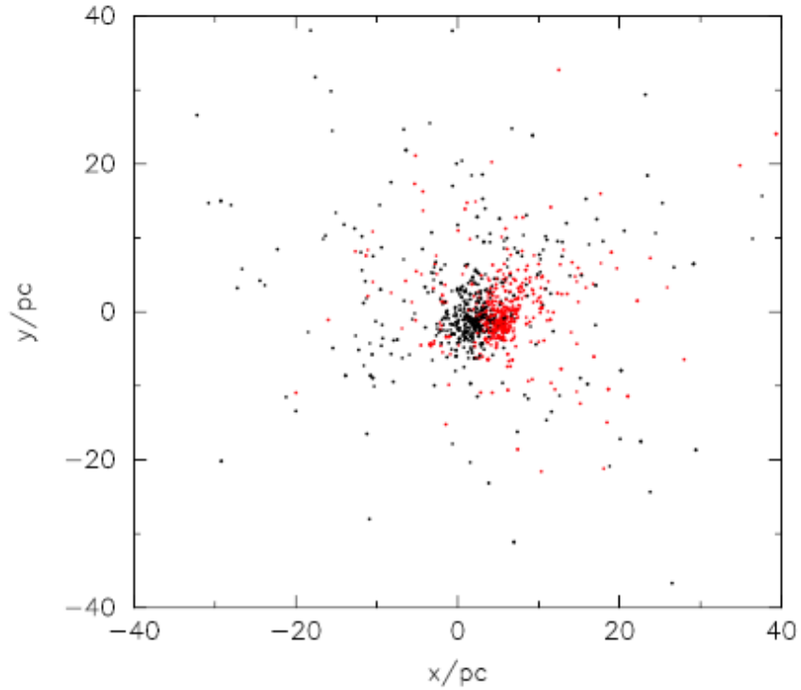


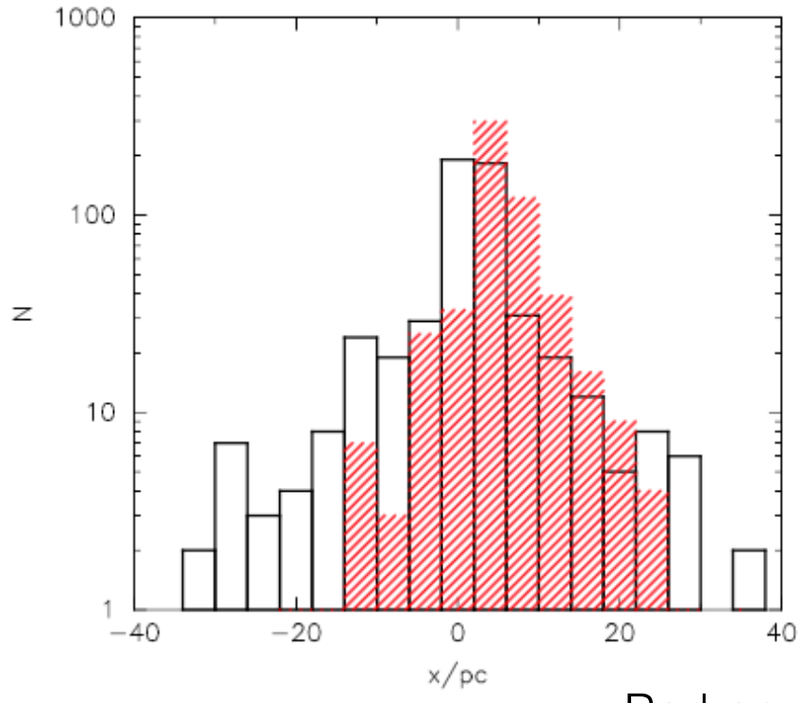
Feedback

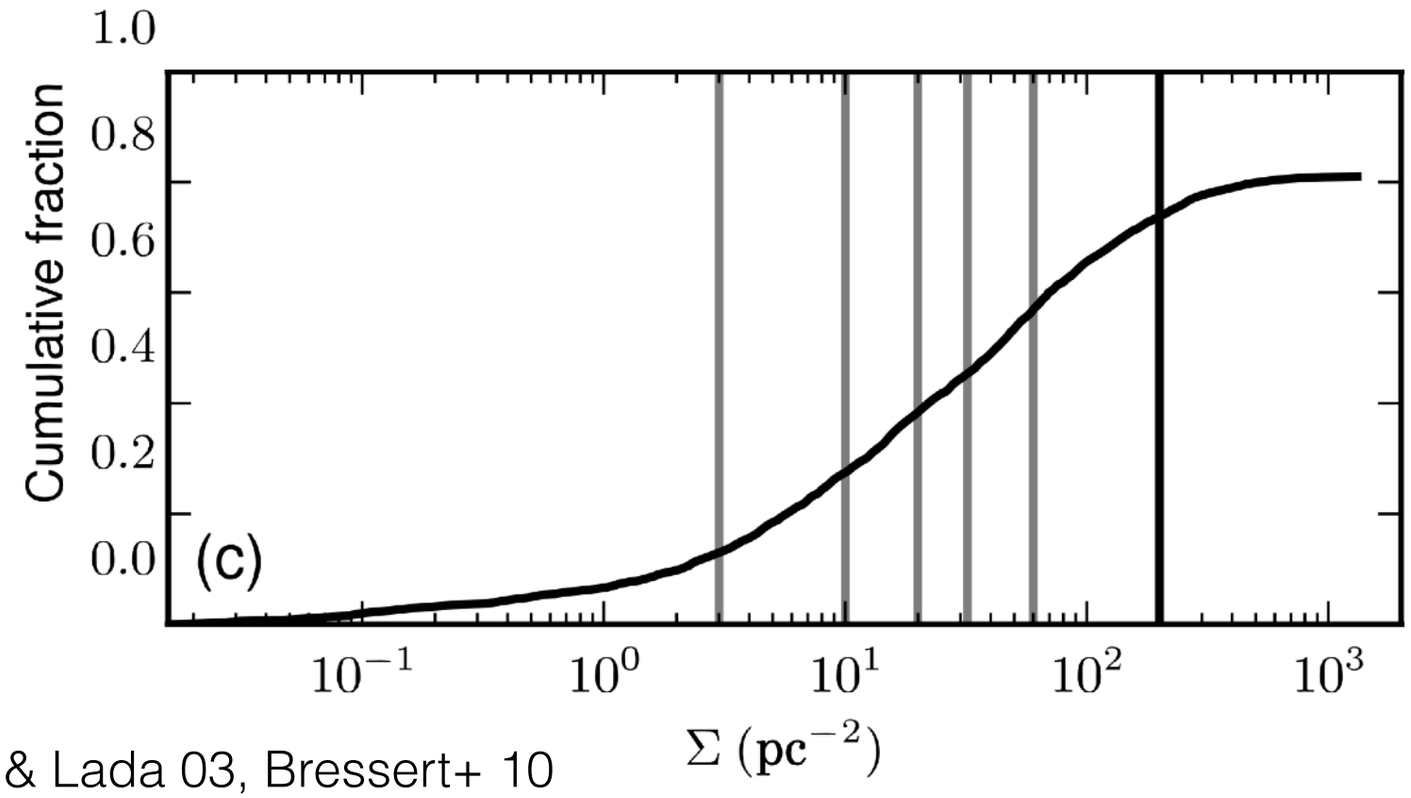

CONTROL
IONIZED
WINDS
BOTH
RUN I (Time: 2.21 Myr)
x(pc)
y(pc)
Log(column density) (g cm^{-2})
0.0
−0.4
−0.8
−1.2
−1.6
−2.0
−2.4
−2.8
−3.2
−3.6
−4.0

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



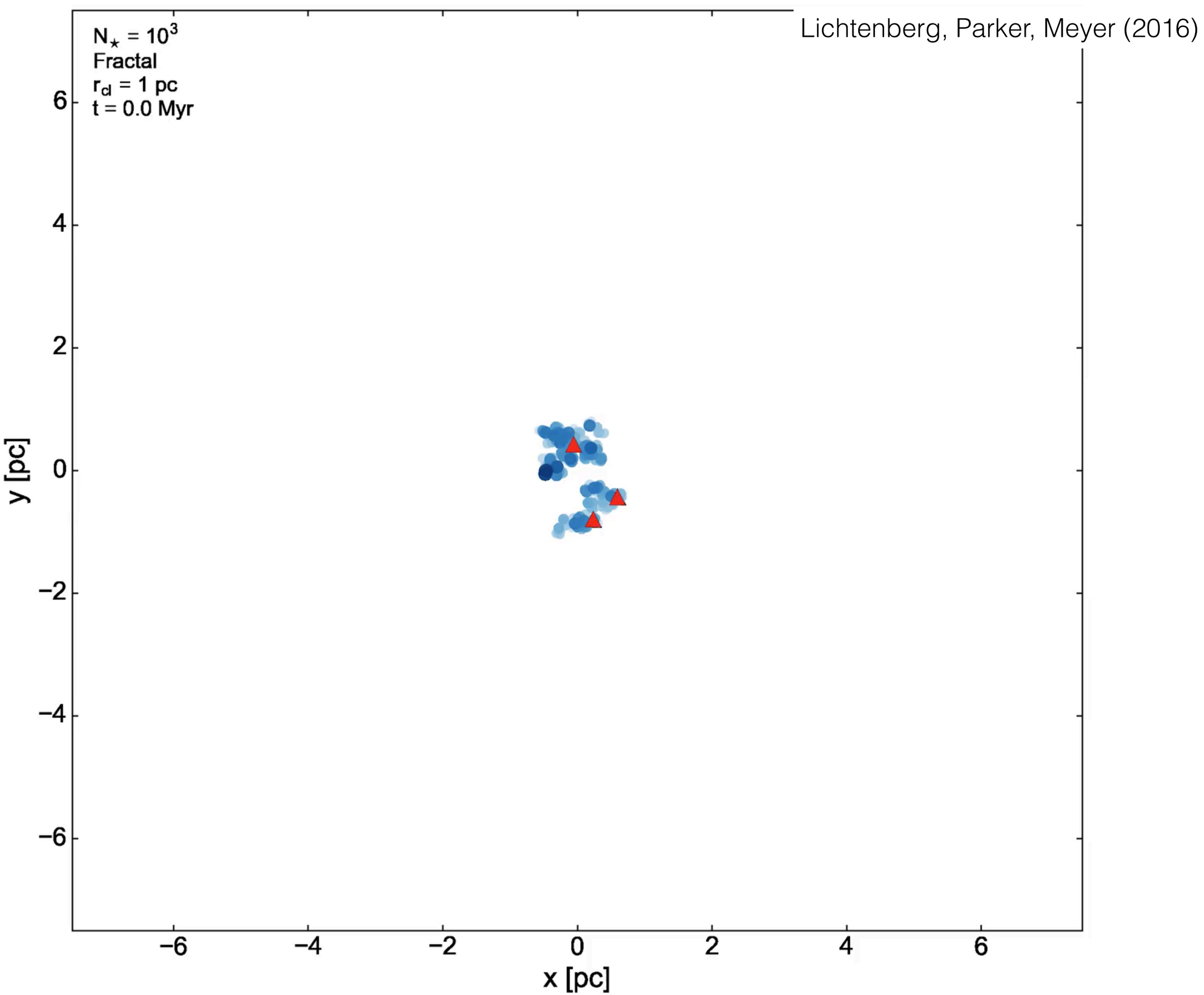




Lada & Lada 03, Bressert+ 10

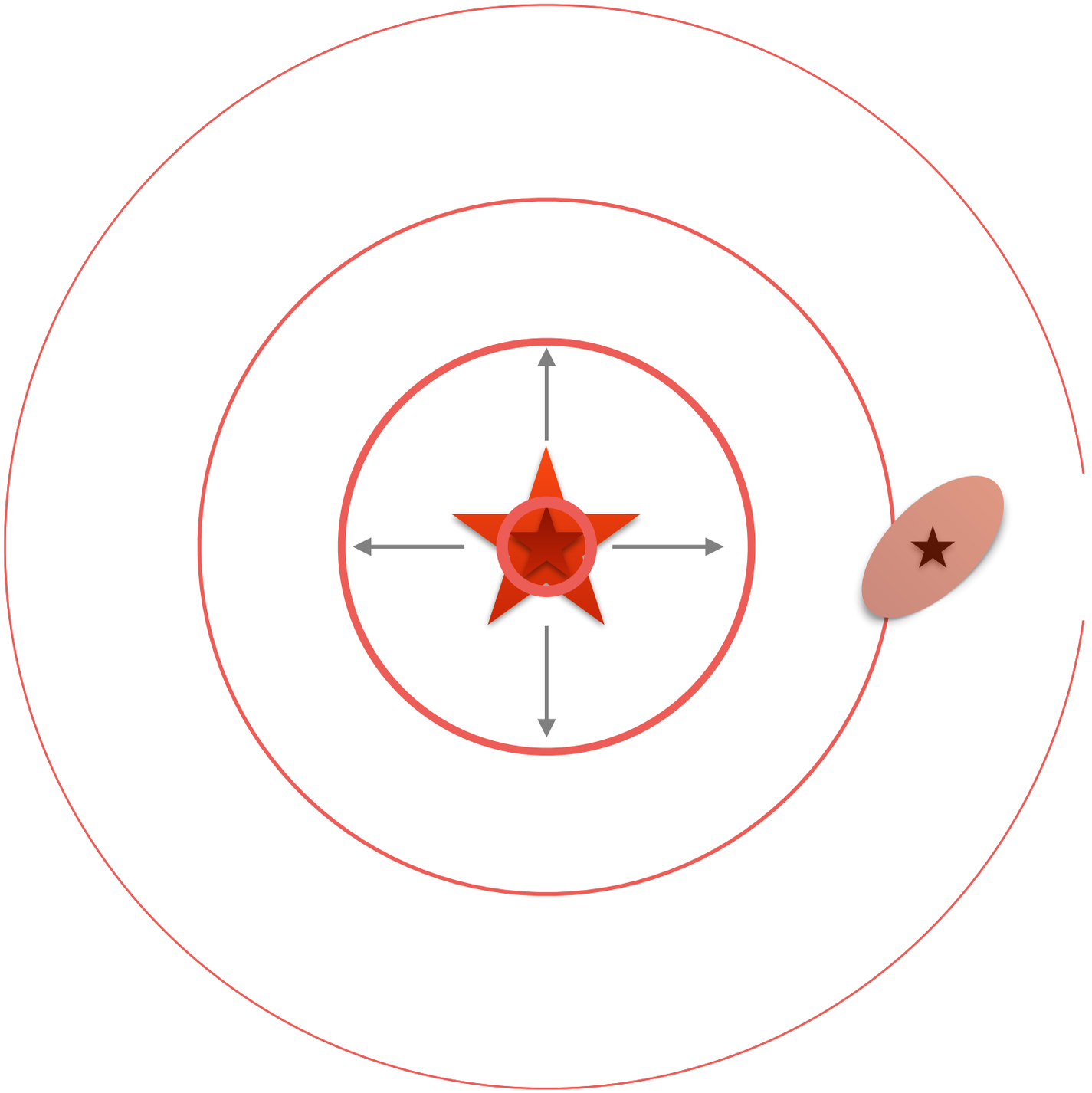
Parker+ 16

Lichtenberg, Parker, Meyer (2016)



Lichtenberg, Parker, Meyer (2016)

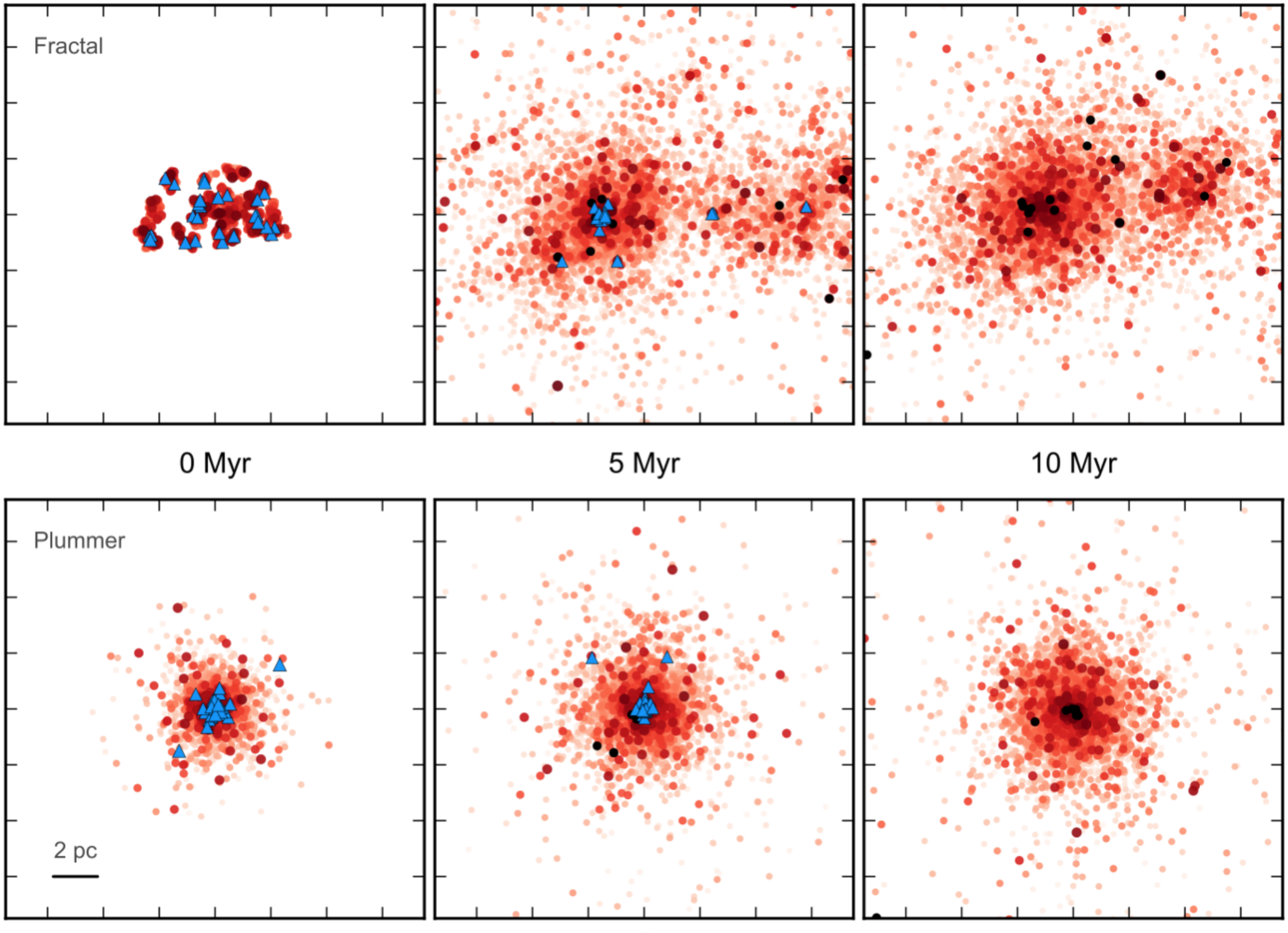
In a nutshell: supernova pollution



Clayton 77, Chevalier 00

Lichtenberg, Parker, Meyer (2016)

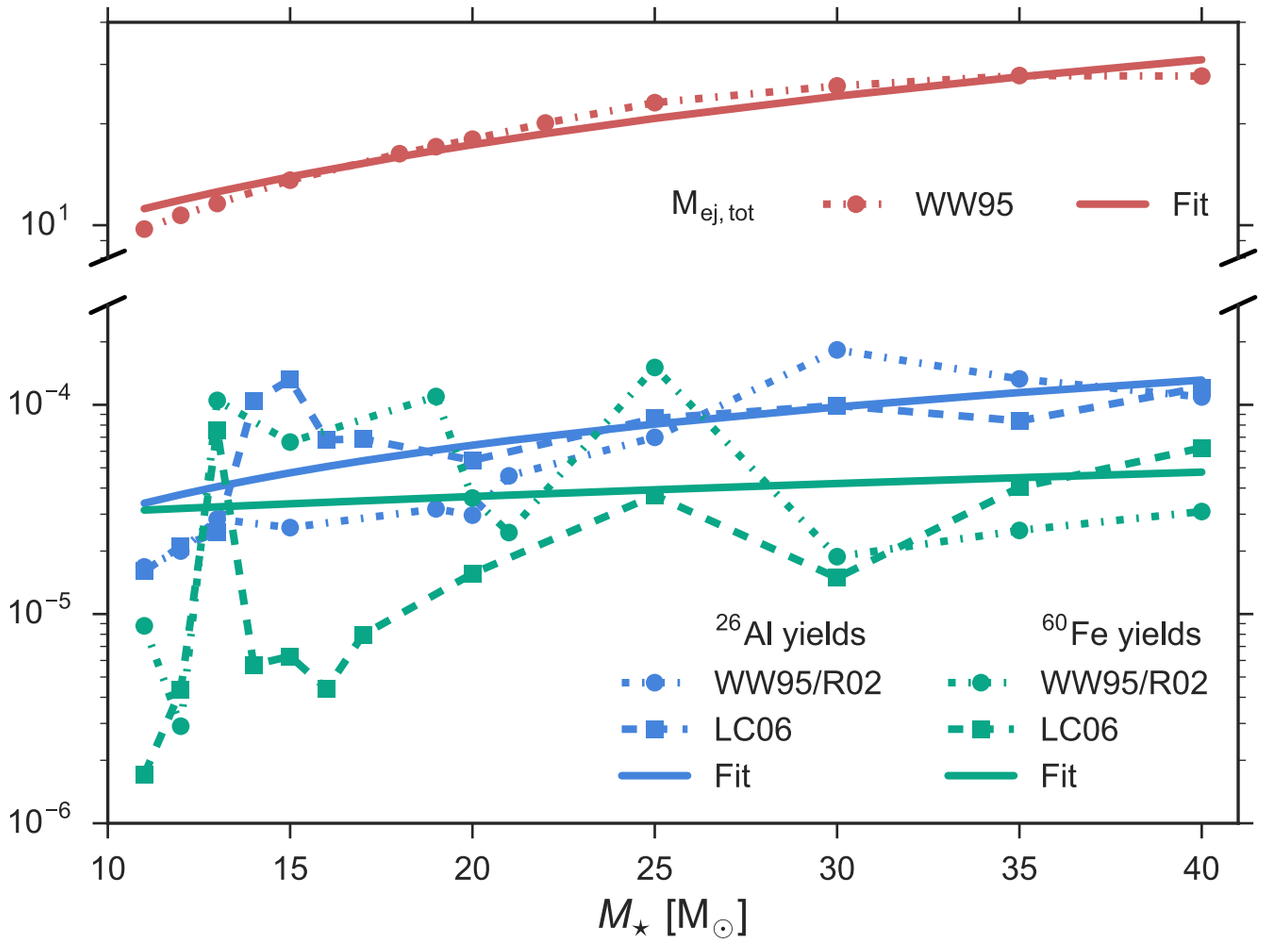
Early cluster evolution



Lichtenberg, Parker, Meyer (2016)

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

Lichtenberg, Parker, Meyer (2016)

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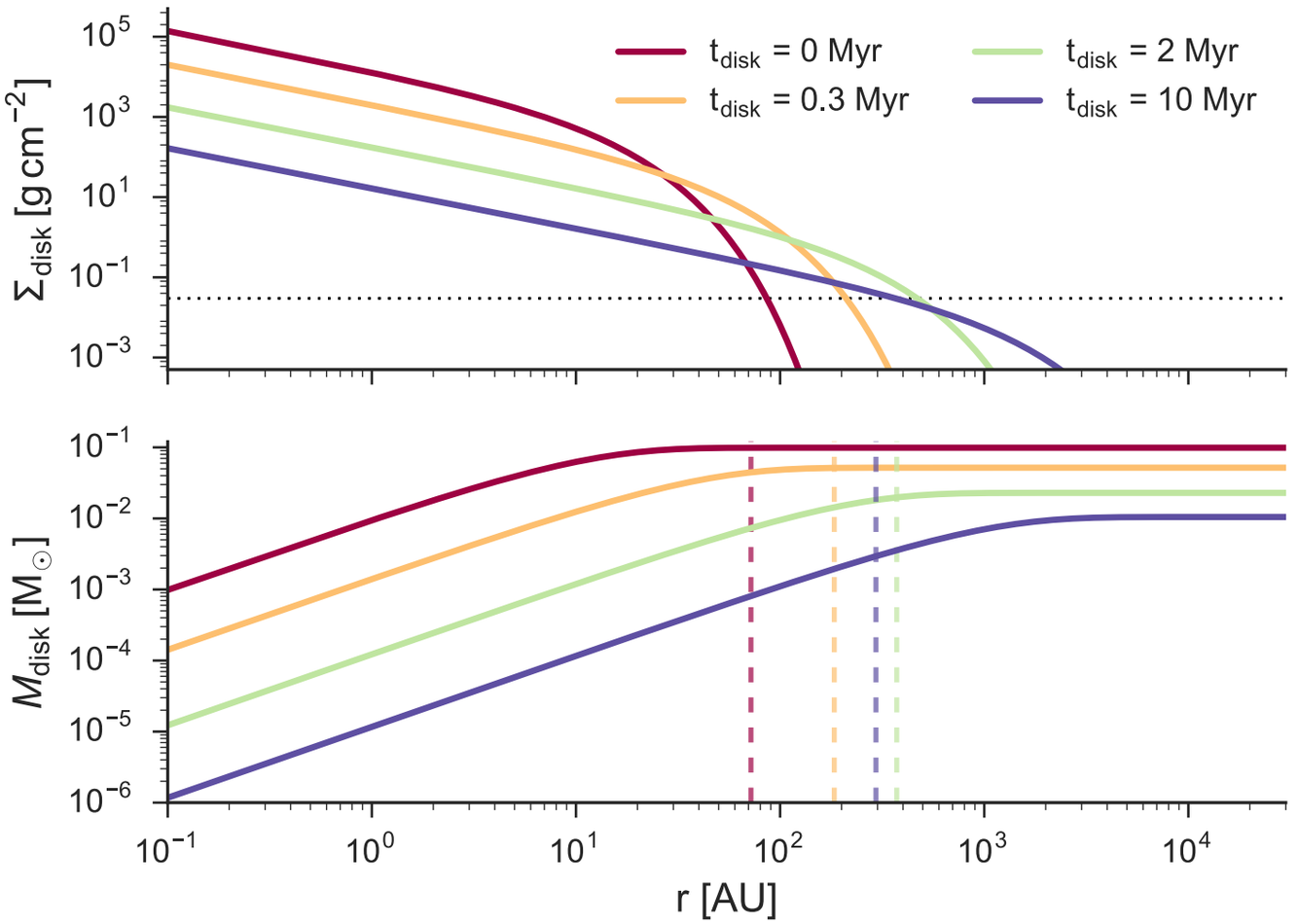
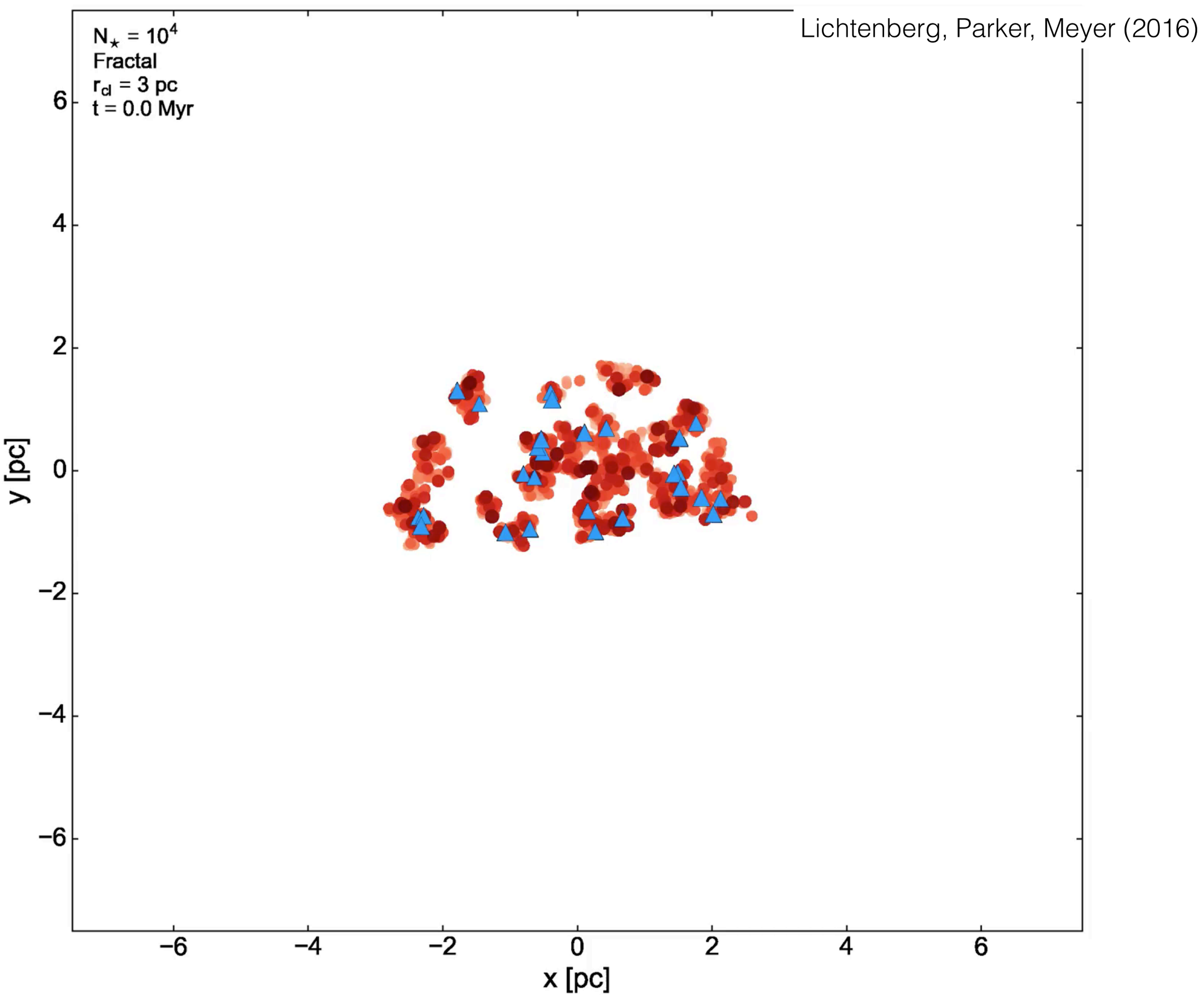
$\alpha_{disk} = 10^{-2}$
$t_{1/2} = 3.5$ Myr



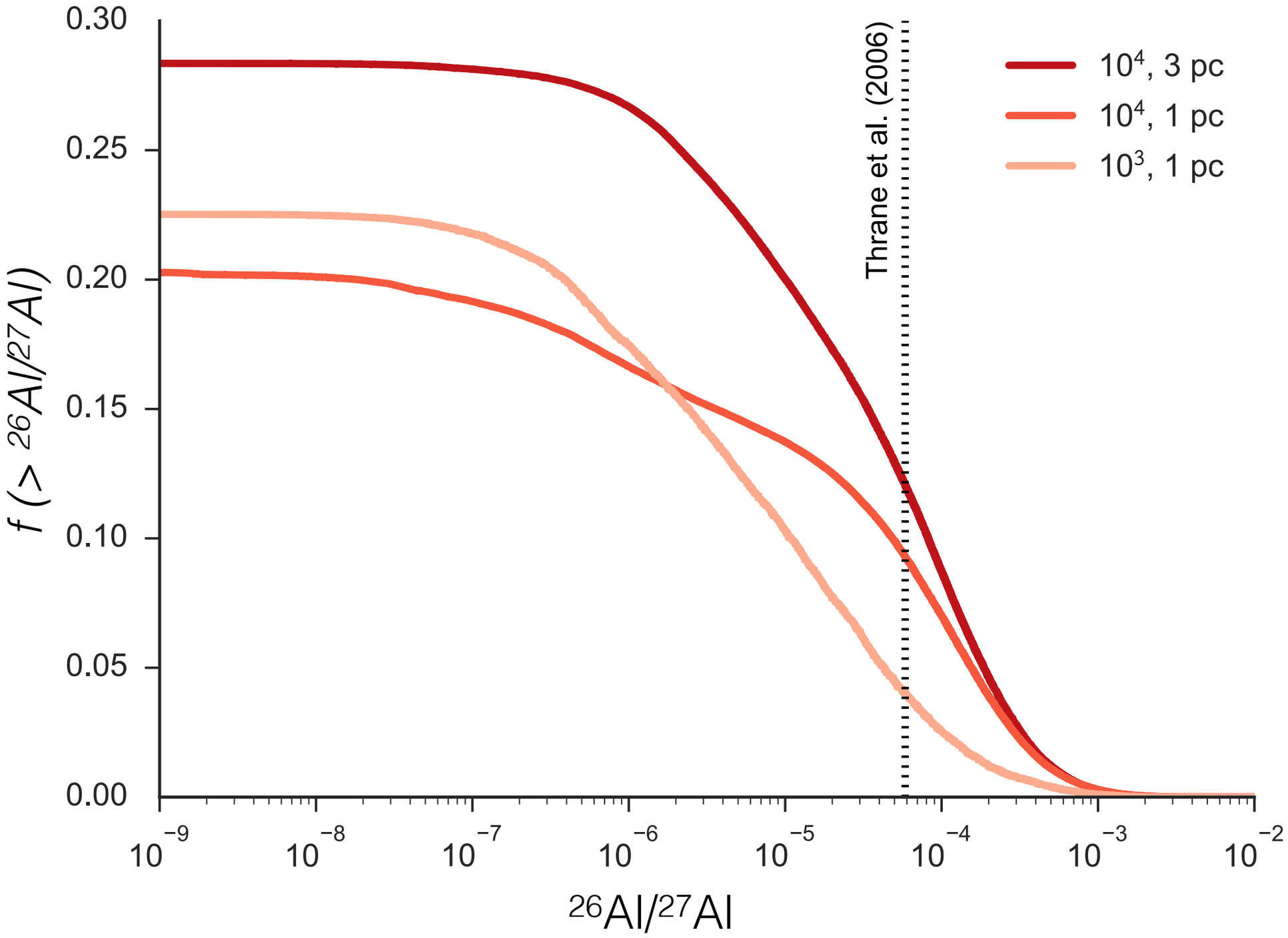
Hartmann 03

Lichtenberg, Parker, Meyer (2016)



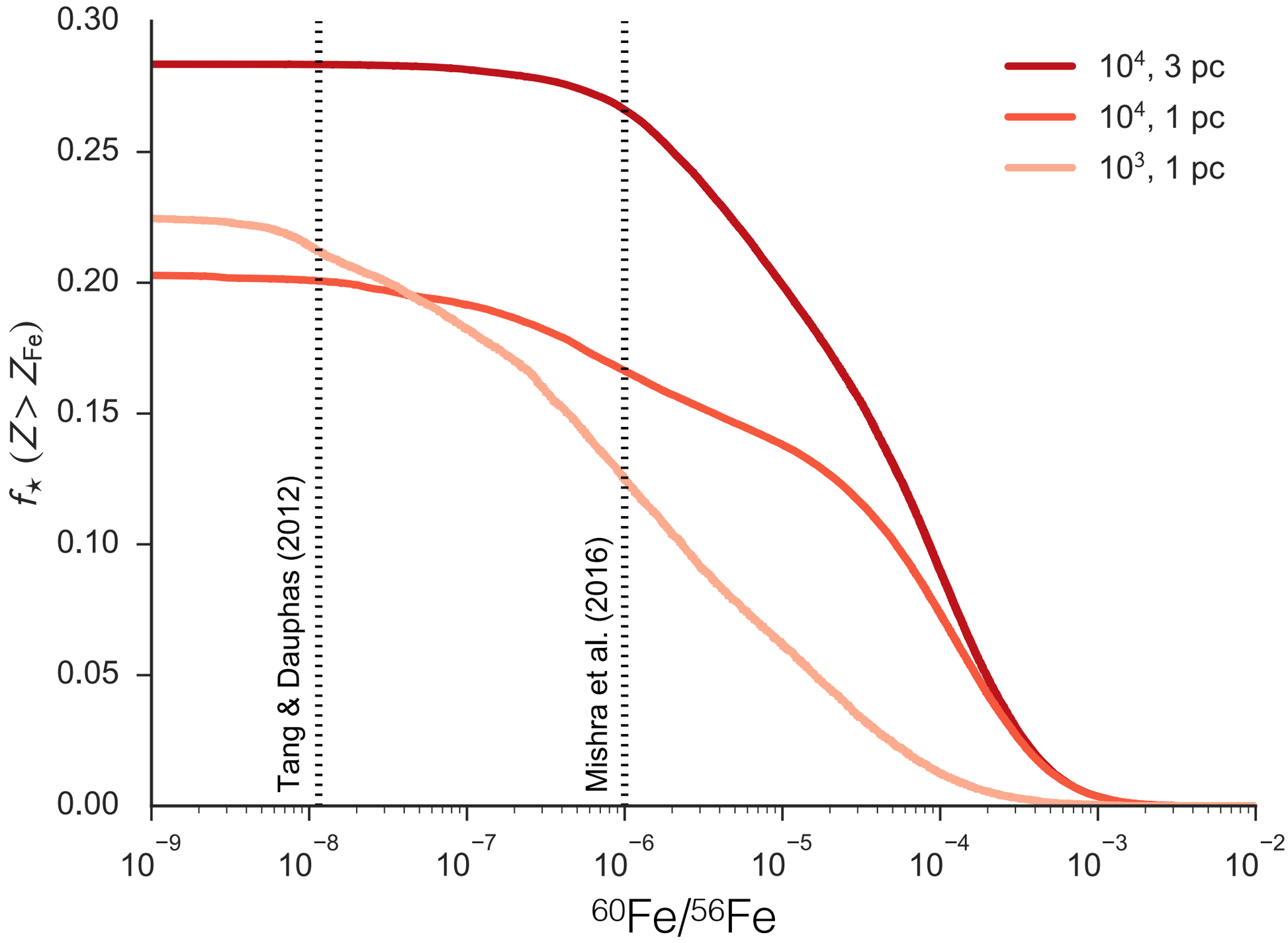
Lichtenberg, Parker, Meyer (2016)

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



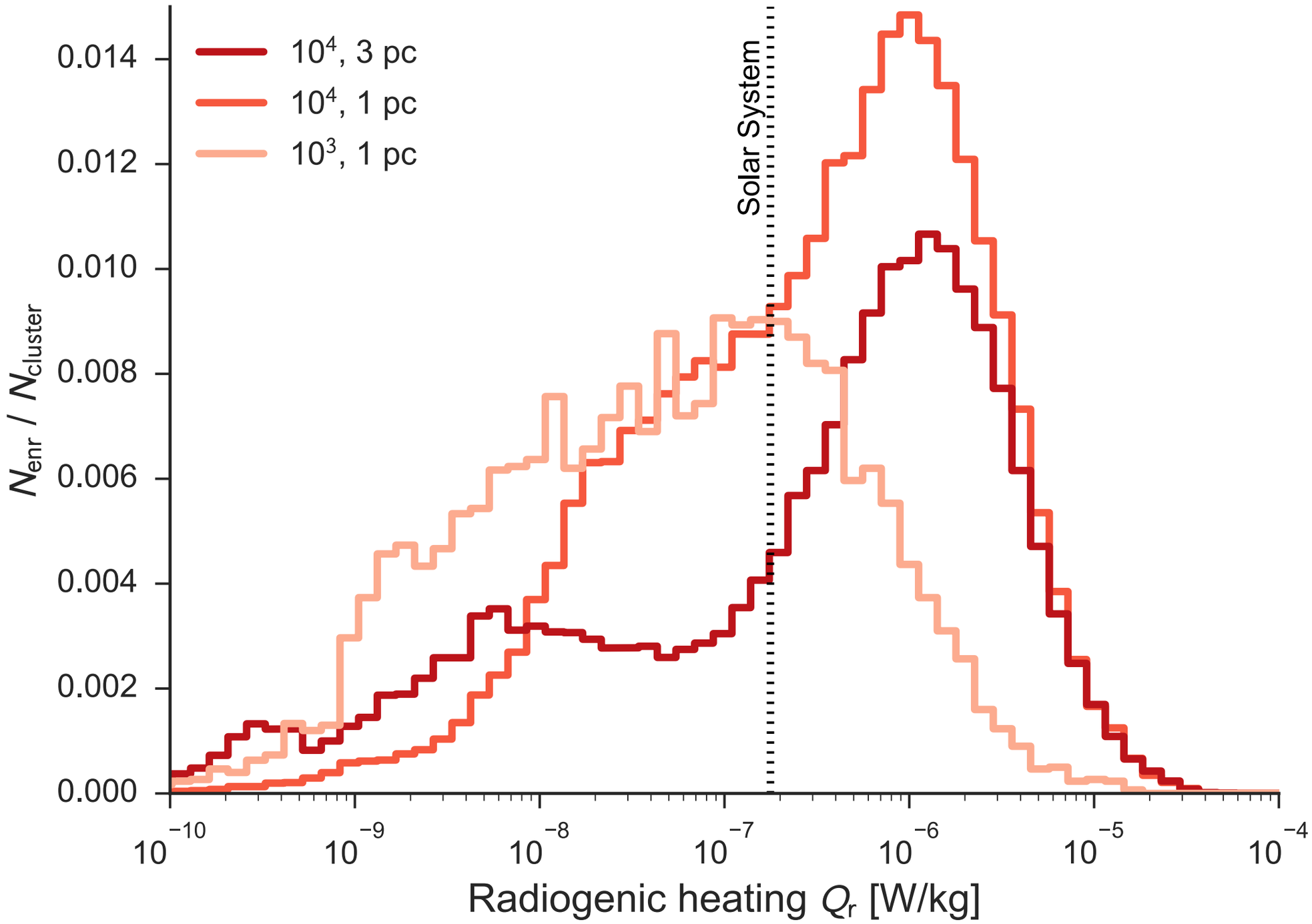
Lichtenberg, Parker, Meyer (2016)

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



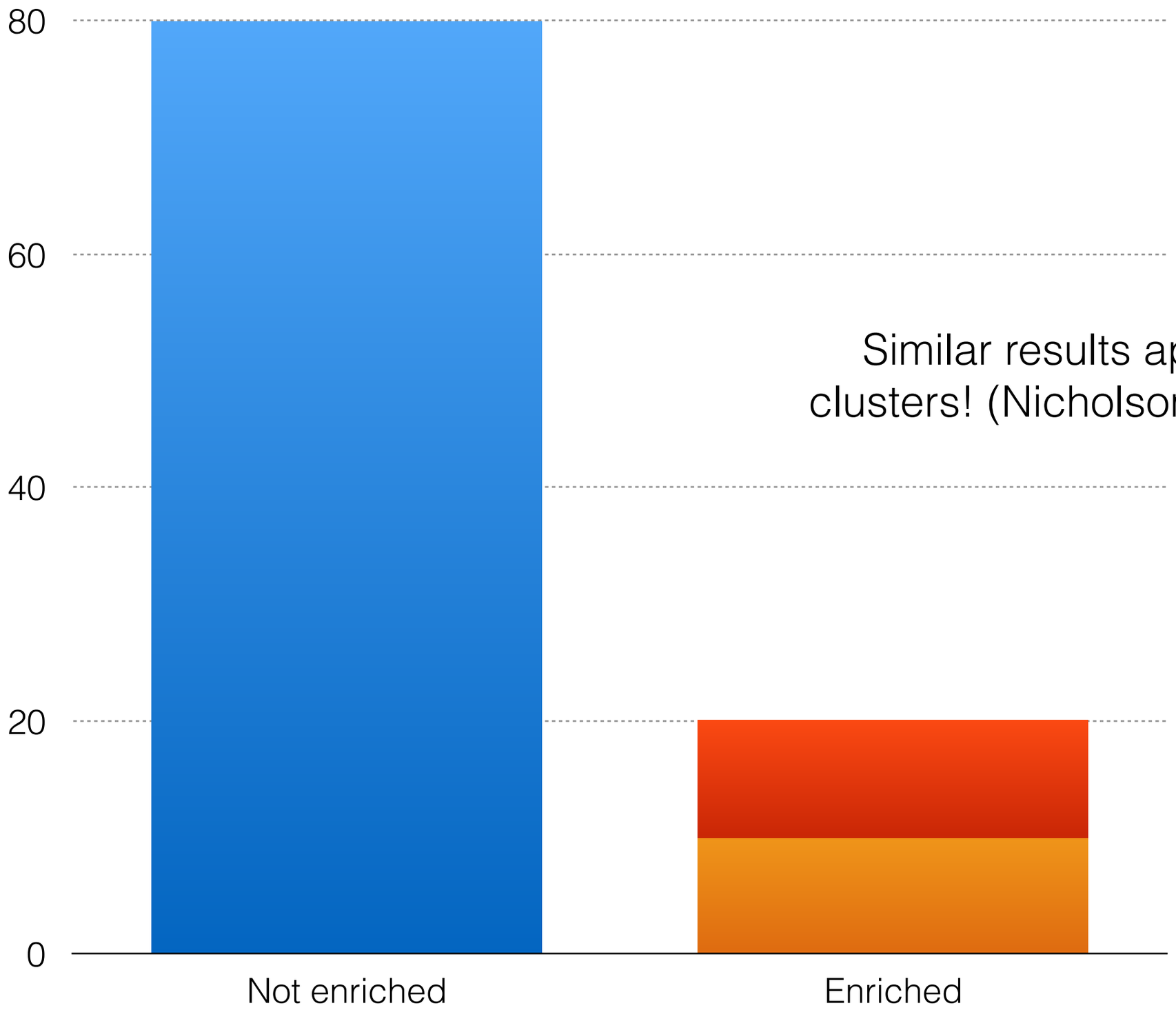
Lichtenberg, Parker, Meyer (2016)

Planetesimal heat budget



Lichtenberg, Parker, Meyer (2016)

Enrichment dichotomy



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

Constraints on planetesimal formation

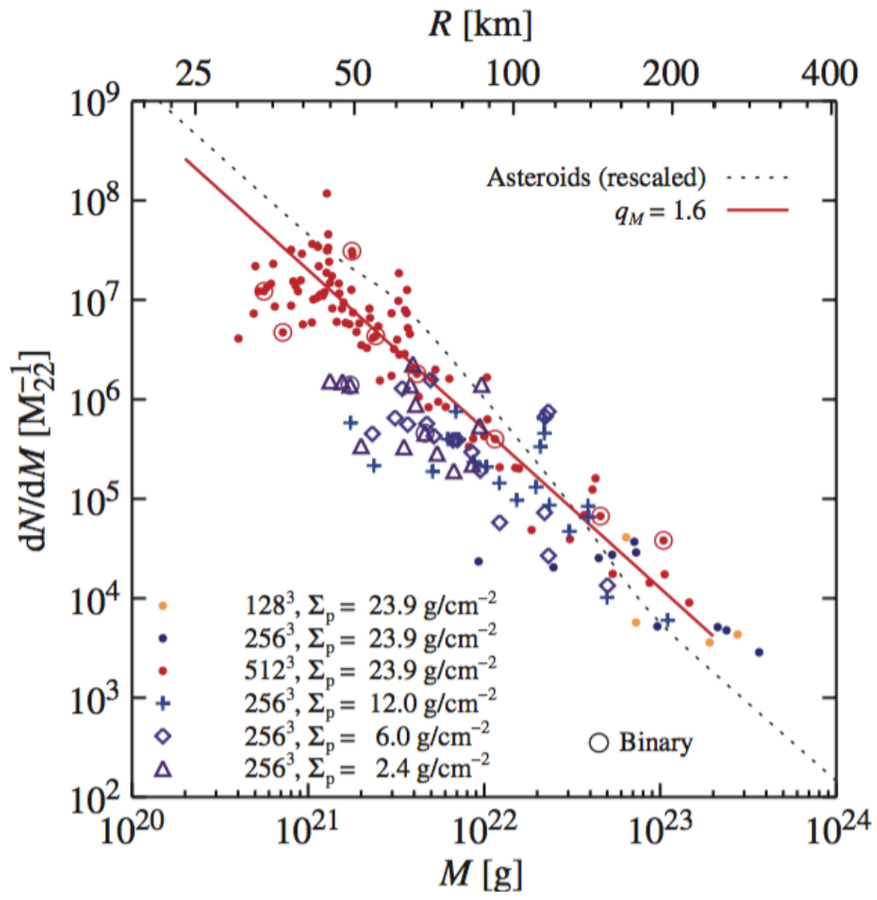
Recent IMF estimates:

- ***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)*

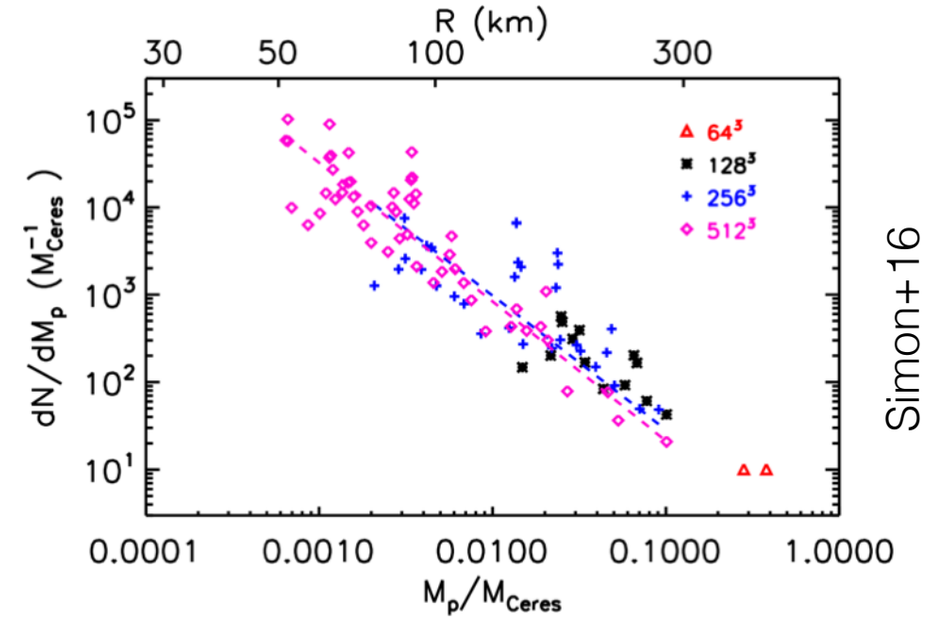
  ➡ ***dN/dR ~ R$^{-2.8}$***

  ➡ ***dN/dM ~ M$^{-1.6}$***

- ***M*** ~ 10^{16}—10^{21} kg



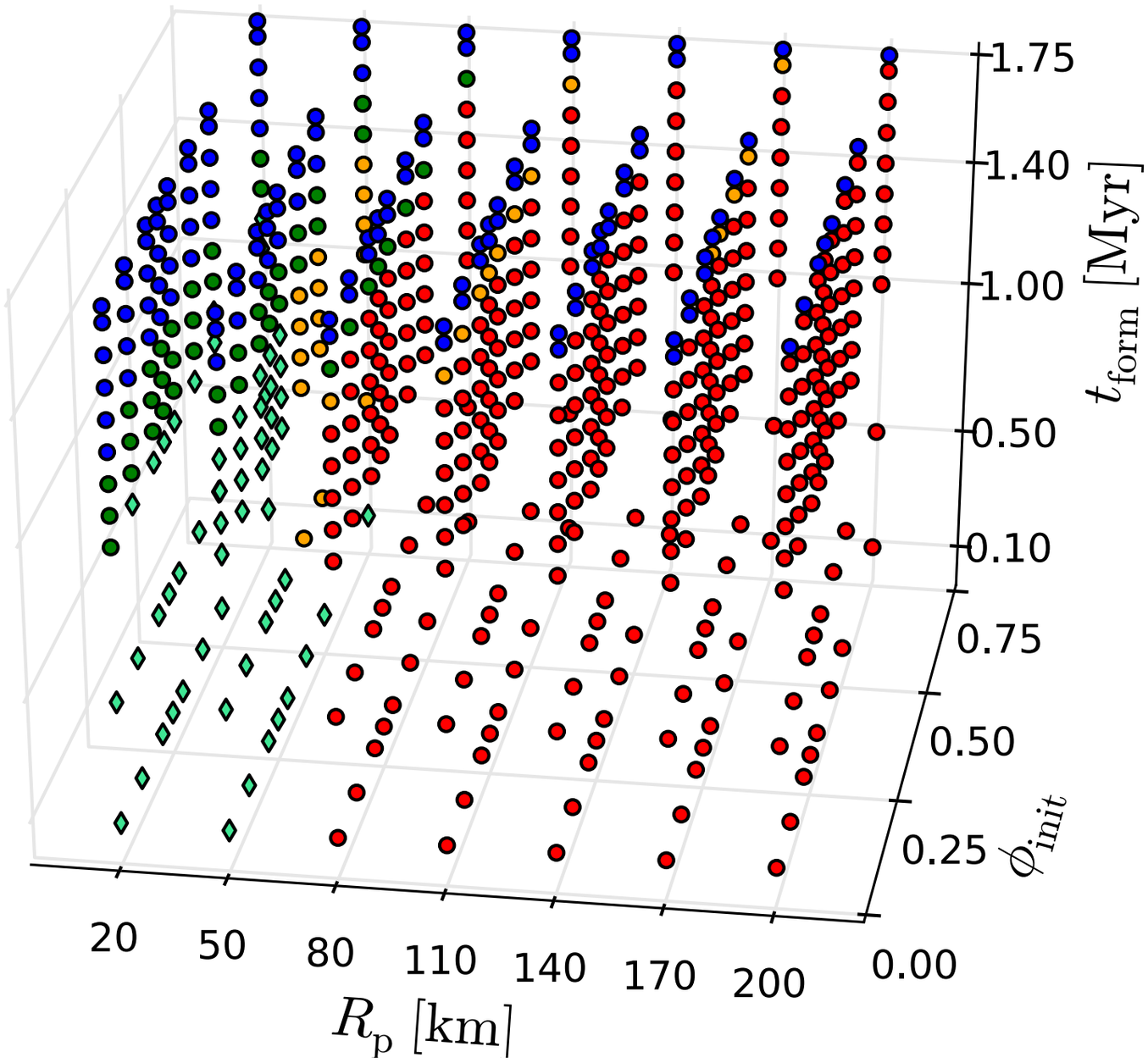
Johansen+15



Simon+16

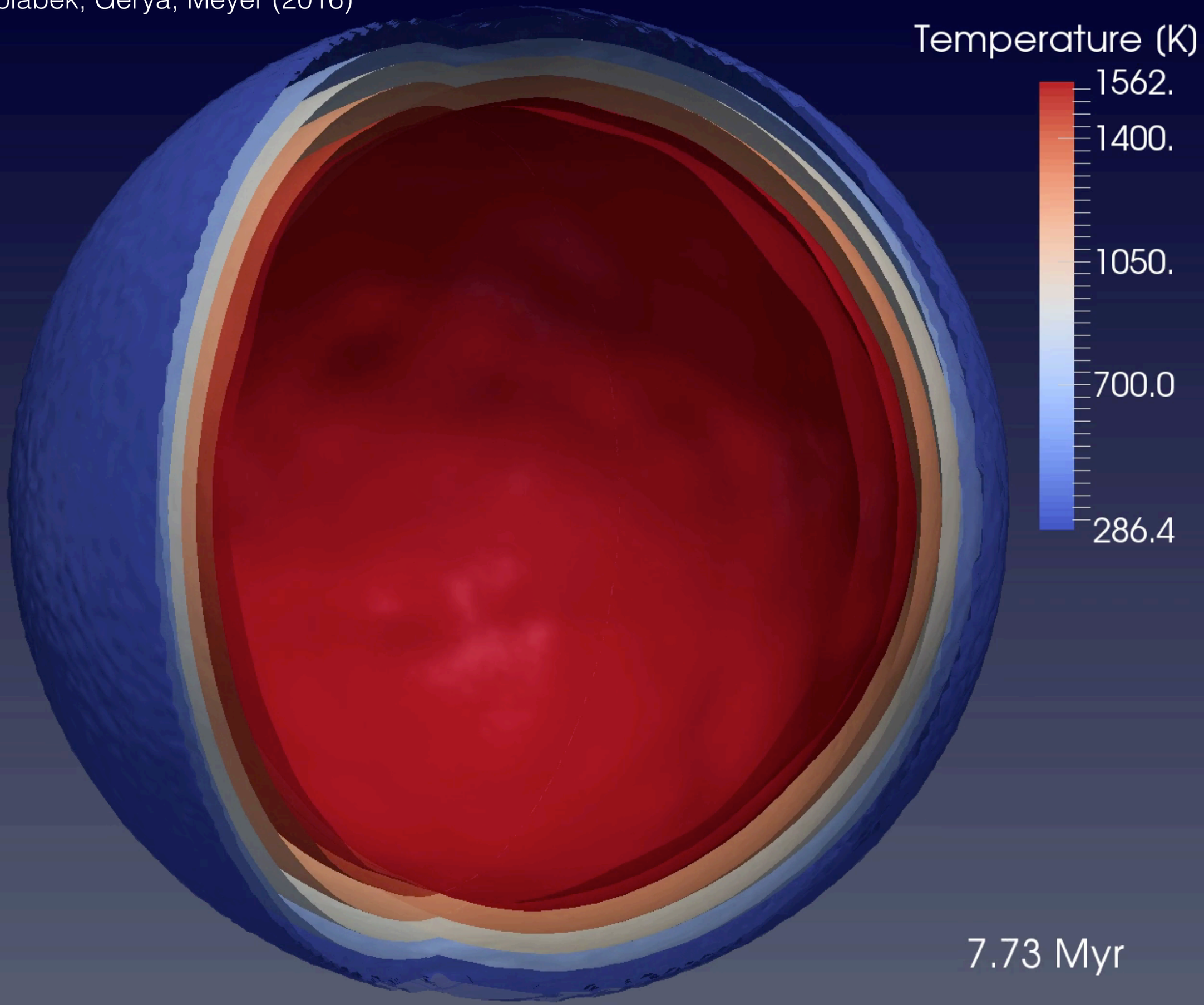
Lichtenberg, Golabek, Gerya, Meyer (2016)

Thermo-mechanical regimes

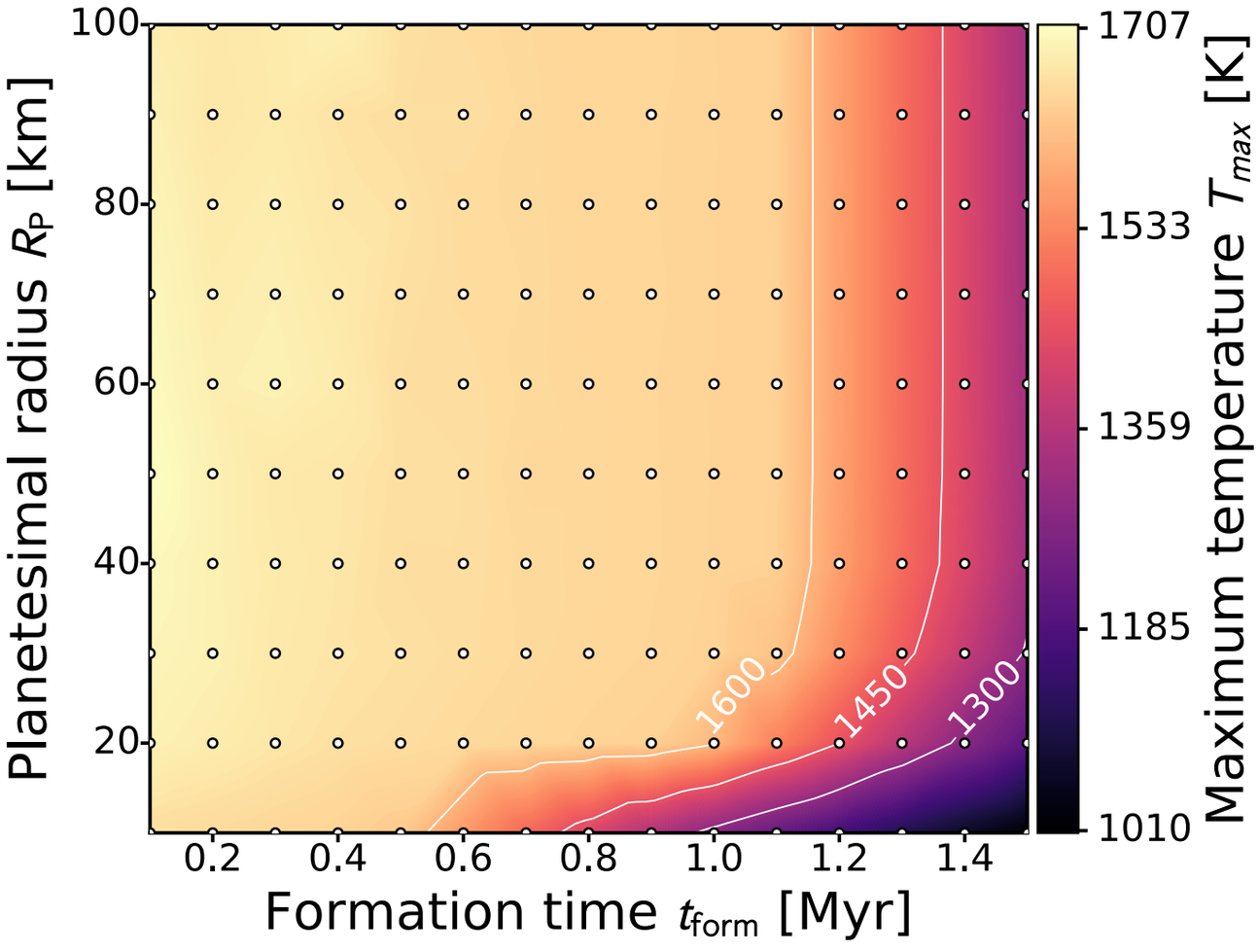


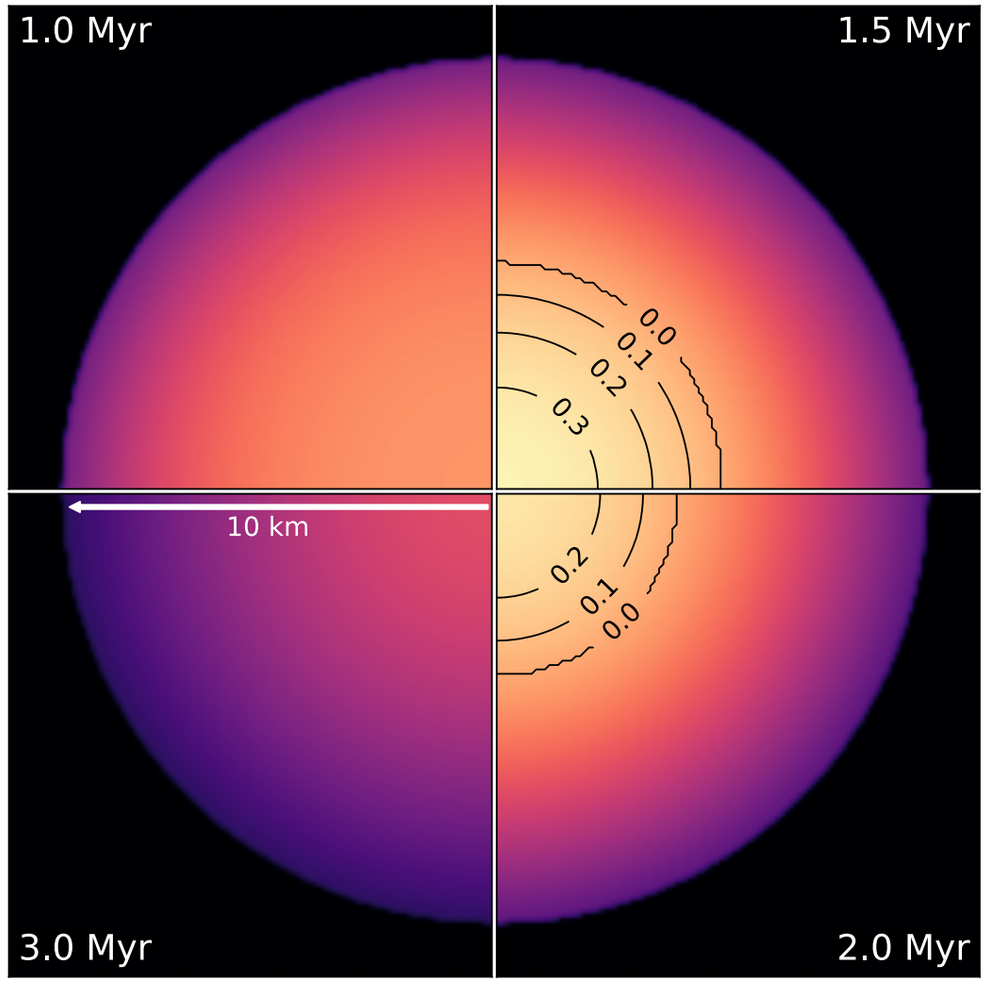
- 3 regimes: solid, melt, mixing
- R_P and t_{form} dominant
- ϕ_{init} only significant for small bodies
- Pure melt regime: t ~ 1-1.5 Myr

Lichtenberg, Golabek, Gerya, Meyer (2016)



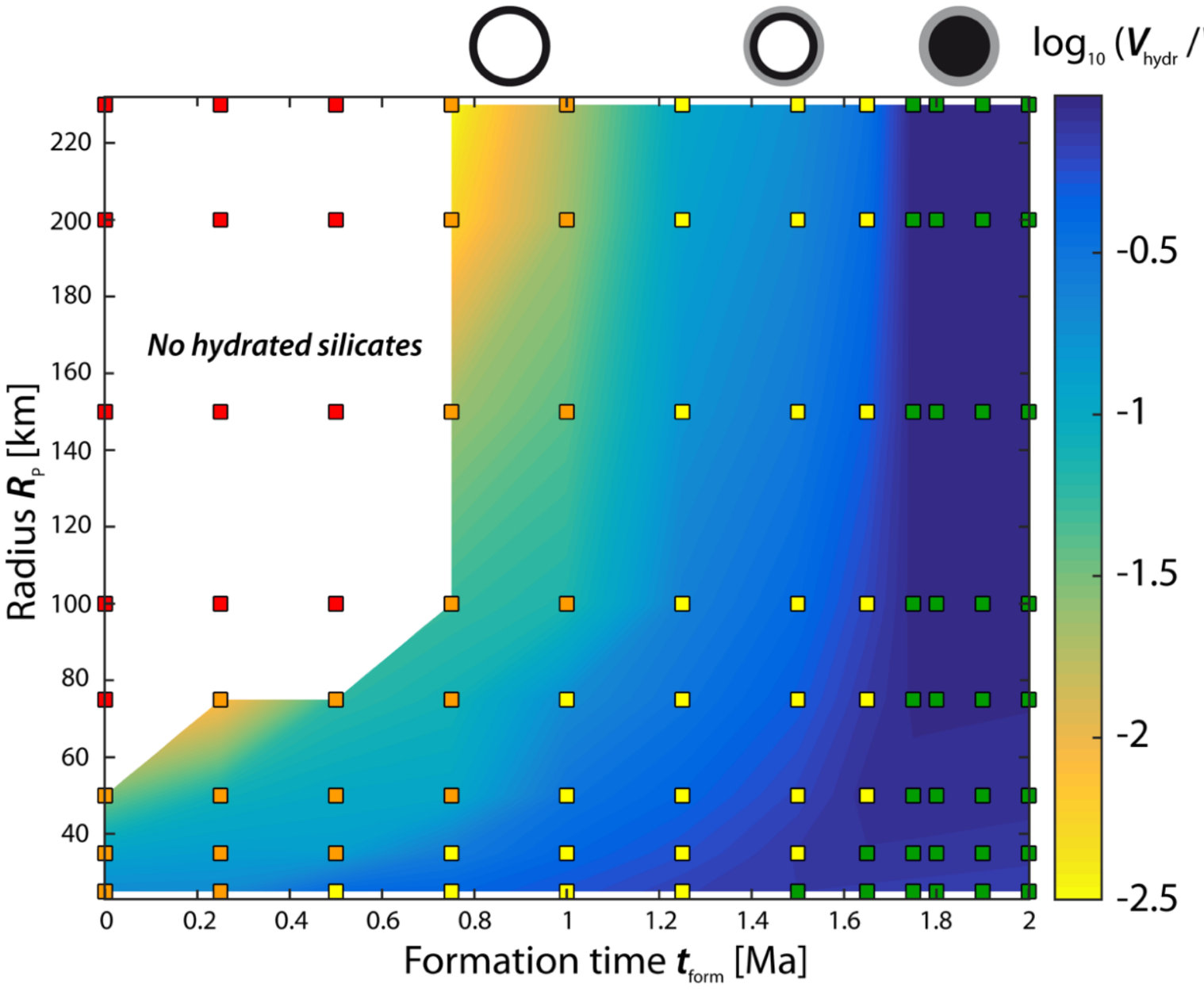
2D planetesimal evolution





Lichtenberg+ 17, under review

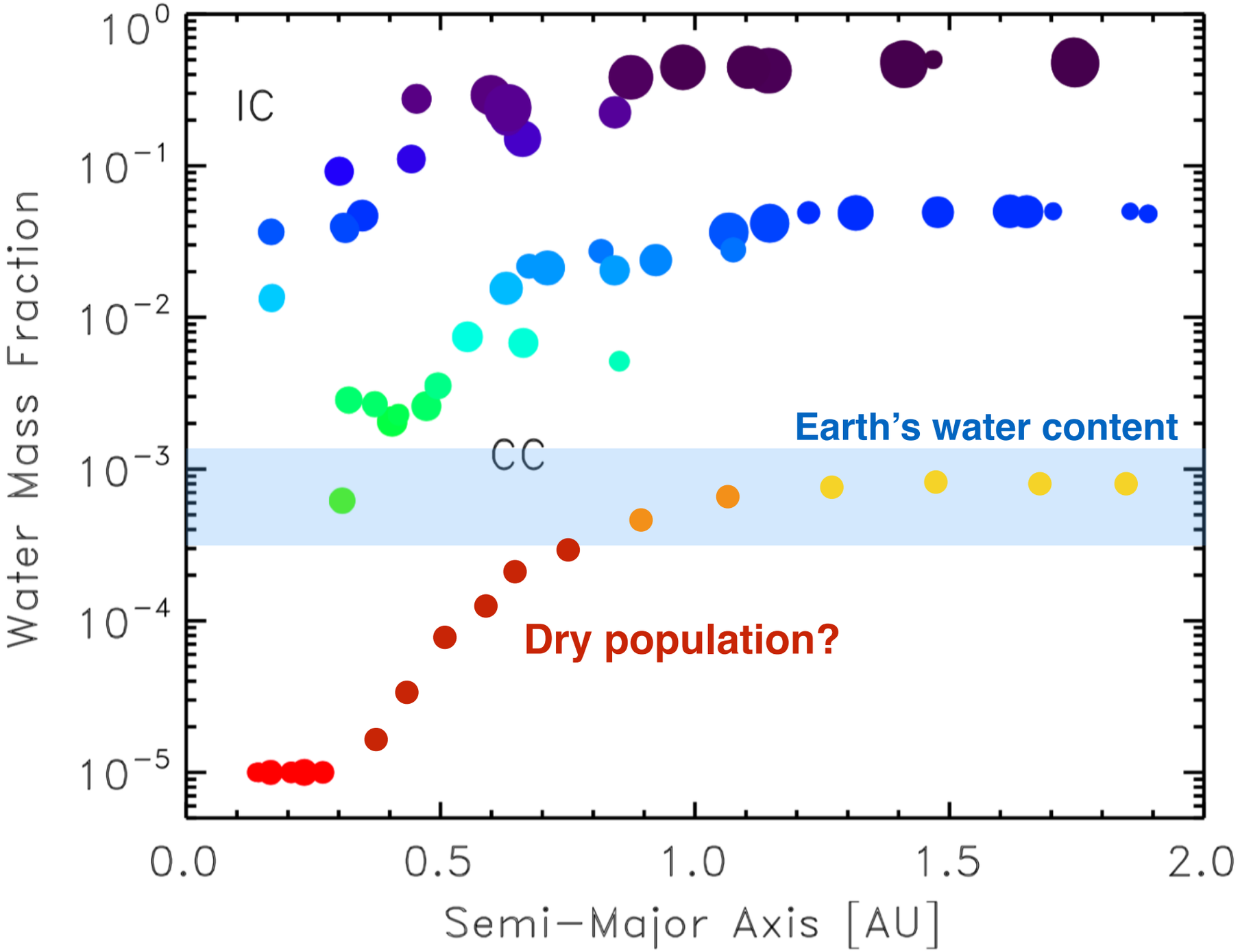
Radiogenic heating ⟷ Volatile budget



- In some bodies W/R > 1-10
  (Hewins+14, Molotov 14)
- Ceres outer mantle currently ~20-30%
- Aqueous alteration omnipresent
  (Doyle+15)

Courtesy: Gregor Golabek

‘Initial’ water abundances integrated



Ciesla+ 15

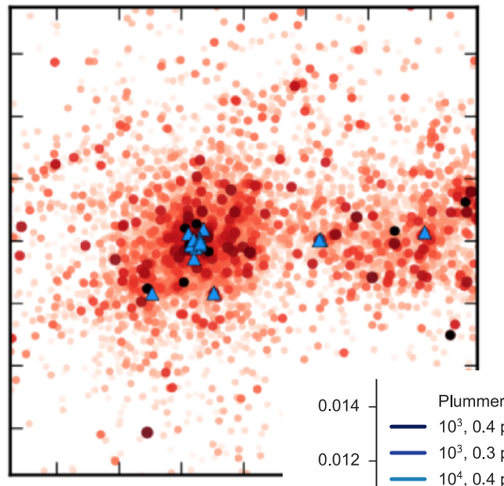
20%

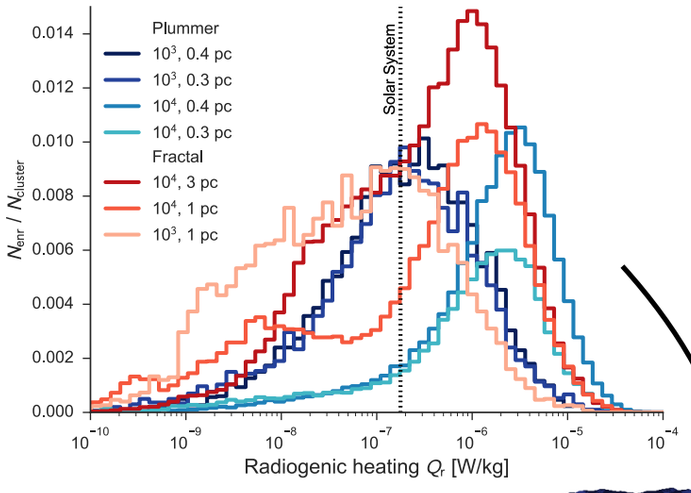
?

80%

Take away

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

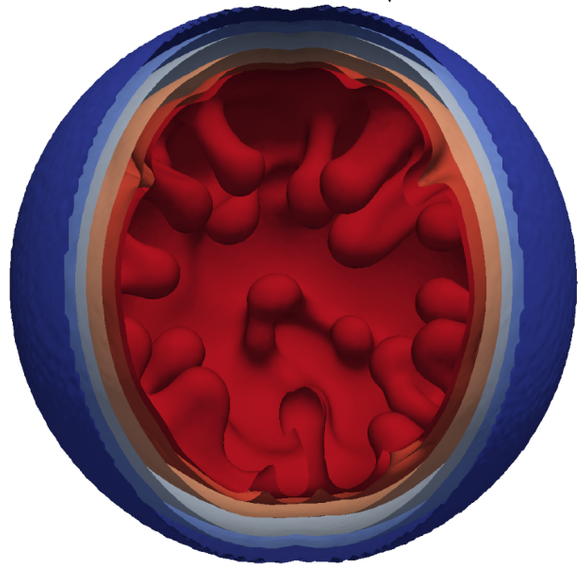




Lichtenberg, Parker, Meyer (2016), MNRAS

2. Radiogenically driven
   - Interior evolution
   - Serpentinization
   - Volatile degassing

➡ Planet population synthesis?



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