Heating of planetesimals from ^{60}Fe & ^{26}Al

And the effect on the water content of protoplanets

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Outline

- Short-lived Radioisotopes (SLRs)
- SLRs in disks & planetesimal desiccation
- Planetesimal heating simulations
- *N*-body simulations with wind and SNe enrichment
- Results
- Next steps & conclusions
- Questions

Context

Short-Lived Radioisotopes

- SLRs are radioisotopes with half-lives on the order of 1 Myr.
- ^{26}Al and ^{60}Fe.
- Decay of SLRs constituted bulk of heating in early solar system[1].
- OB/WR winds and SNe pollute disks with SLRs before planetary formation.
- Potential other source: AGB "interlopers" in star-forming regions[2].

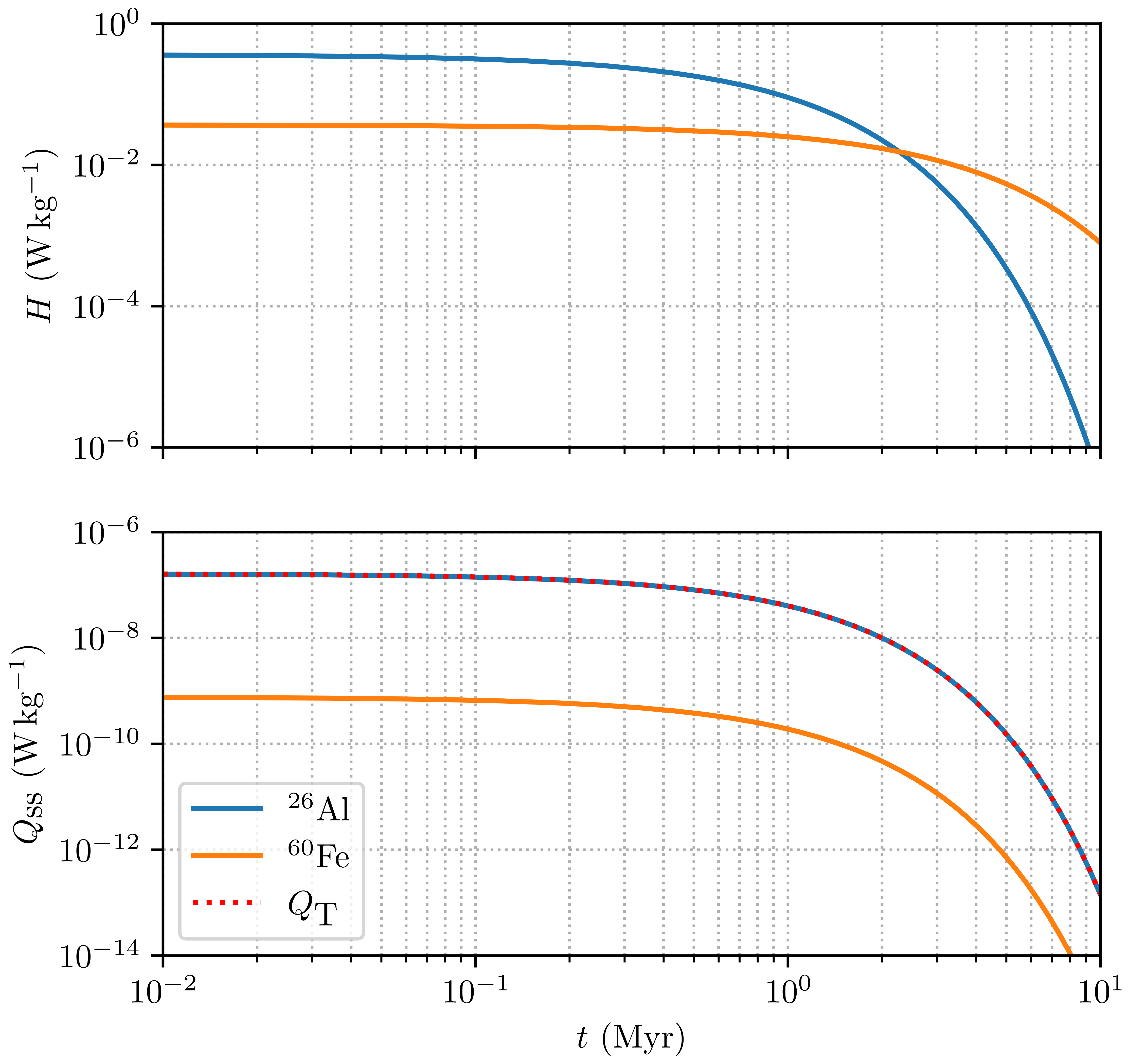


Fig. Eatson+ 2024, [1] Fu & Elkins-Tanton 2014 [2] Parker & Schoettler 2023

Planetesimal desiccation

- Decay heating in planetesimals causes vaporisation and outgassing of volatiles[1].
- In the case of H_2O this leads to planetesimal desiccation & formation of water-poor planets.
- SLR heating keeps planetesimal internals molten.
- Leads to faster stratification and differentiation of rocky body.

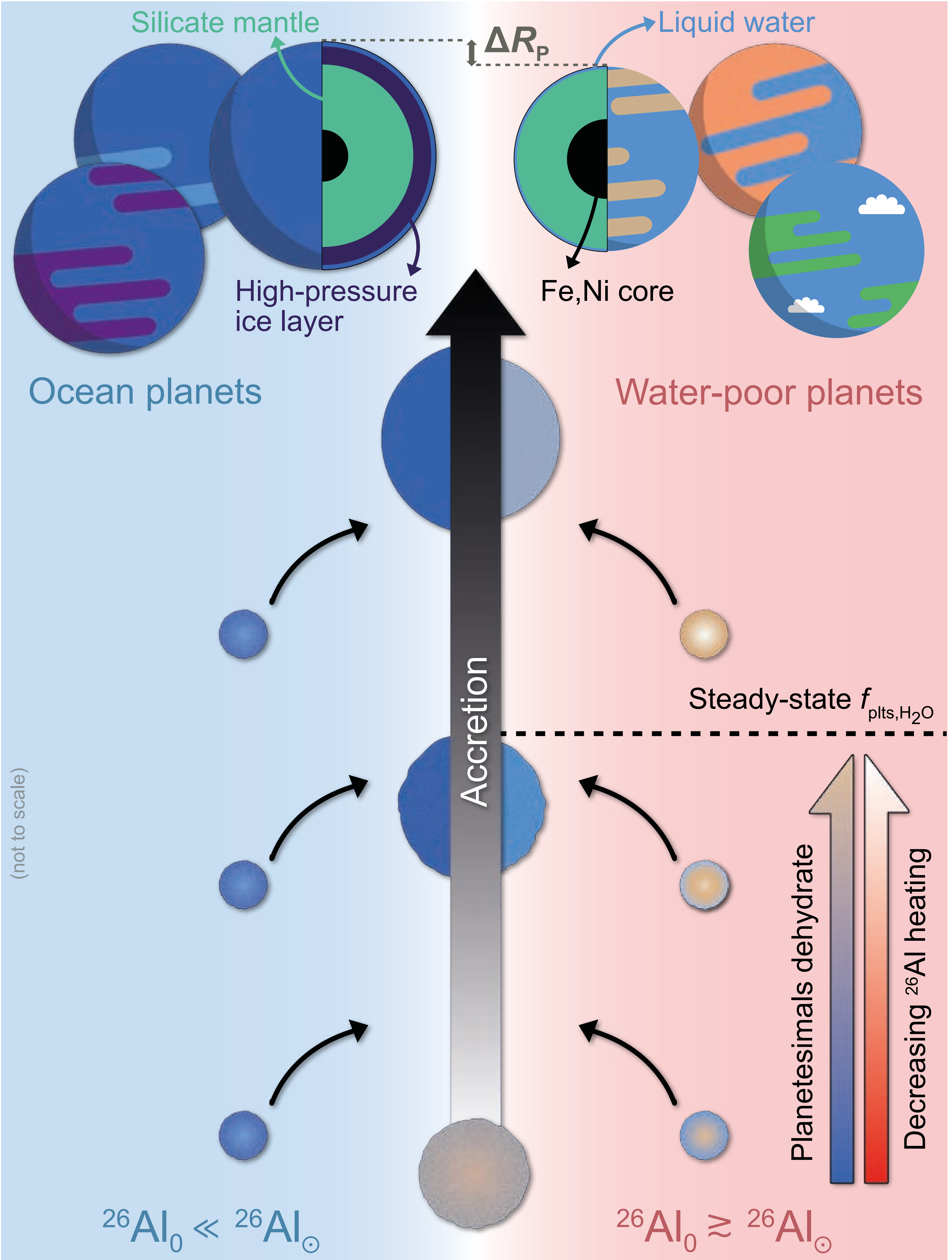


Fig. Lichtenberg+ 2019, [1] Lichtenberg+ 2019

Photoevaporation

- Massive stars also produce copious amounts of ionising FUV/EUV radiation.
- Can destroy the gas component of the disk.
- Less gas → less gas giants.
- Simulations suggest this could be a common occurrence[1].
- SNe would also disrupt the disk through shocks.
- Interlopers?

Image NASA/JPL-Caltech/T. Pyle, [1] Patel+ 23

Devolatilization of extrasolar planetesimals by ^{60}Fe and ^{26}Al heating

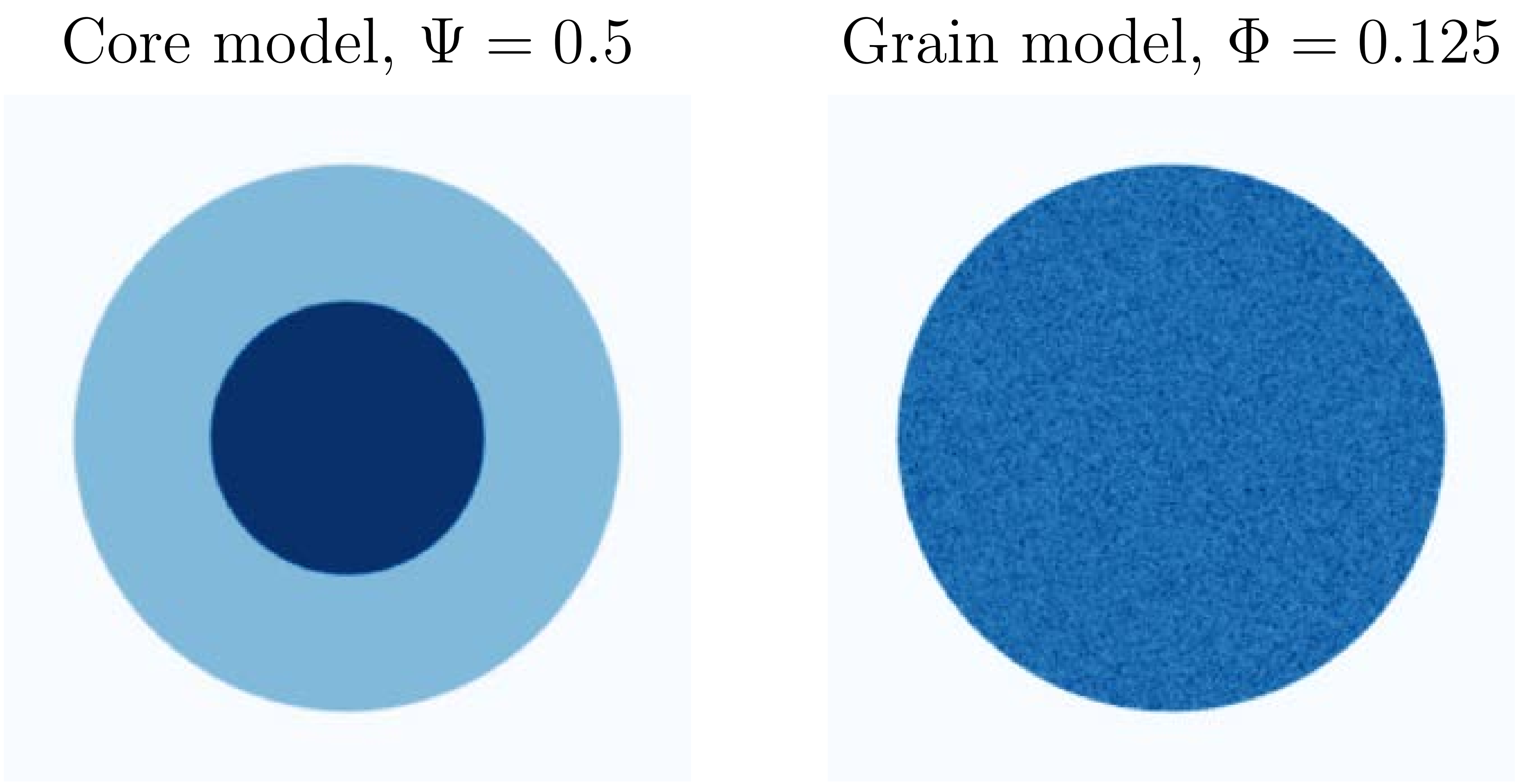
Eatson, Lichtenberg, Parker & Gerya 2024 - MNRAS

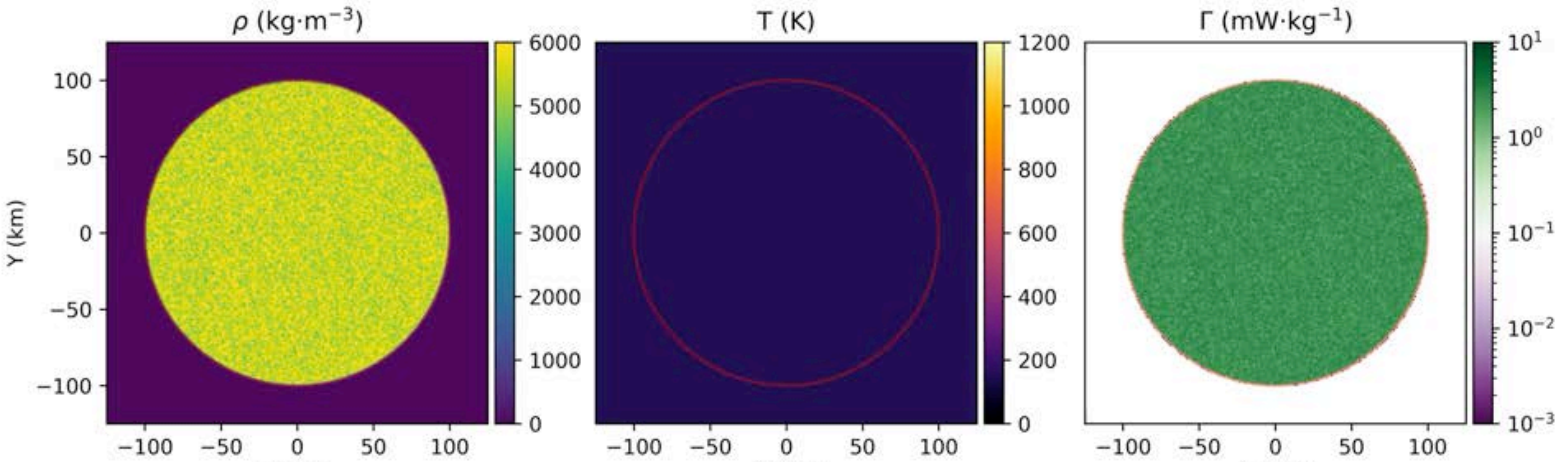
Motivation

- How much does the SLR ^{60}Fe influence heating?
- ^{26}Al has a high heating rate, has been simulated, ^{60}Fe has not.
- How does distribution of Iron within planetesimals affect heating?
- What is the minimum level of enrichment required for significant desiccation?

Methodology

- Series of simulations using I2ELVIS 2D geodynamic numerical code[1].
- Two ^{60}Fe propagation models:
    - Solid Fe core.
    - Undifferentiated Fe grains.
- Parameter space explored varying ^{26}Al & ^{60}Fe enrichment and Fe content.
- Measuring water retention fraction.



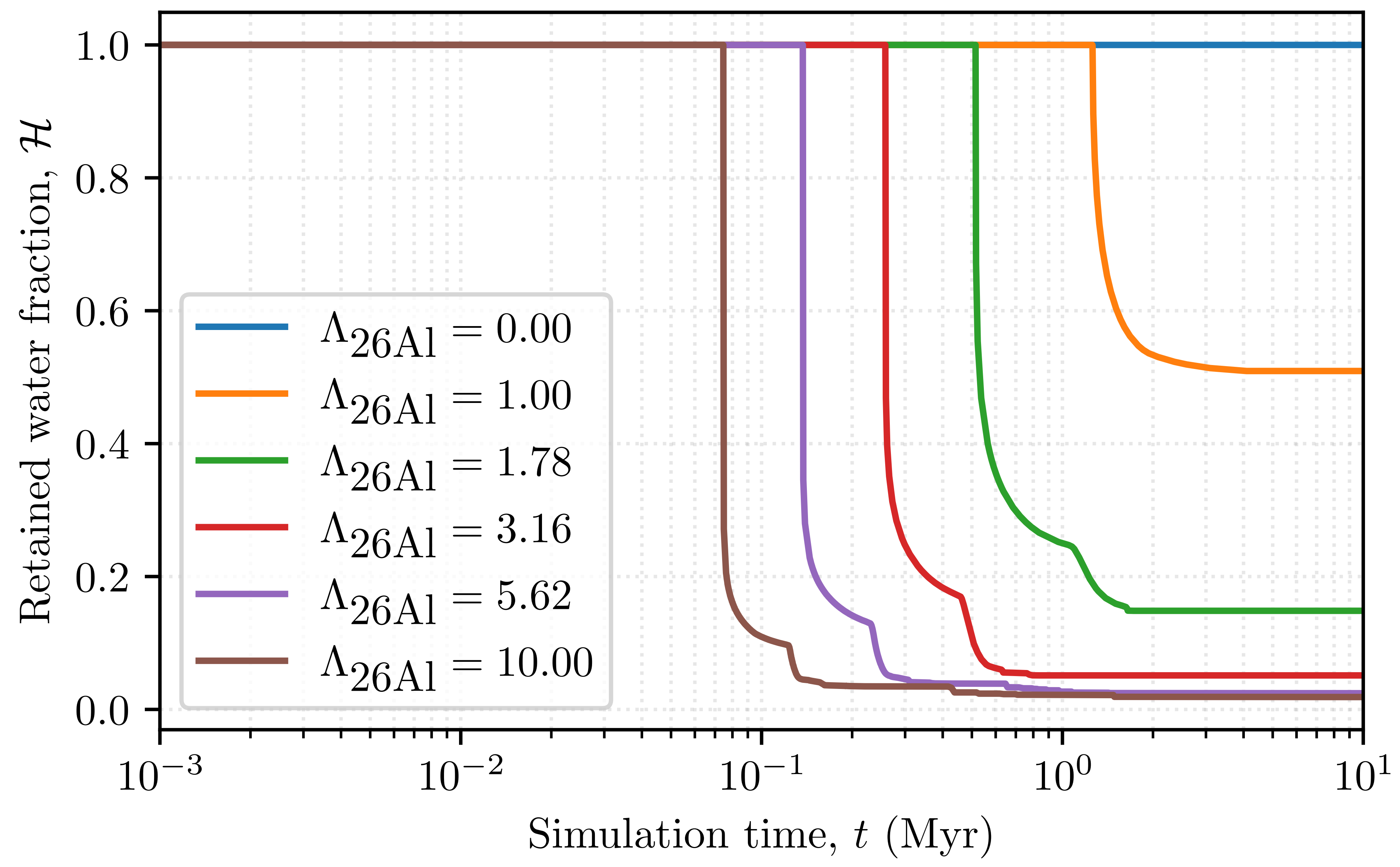


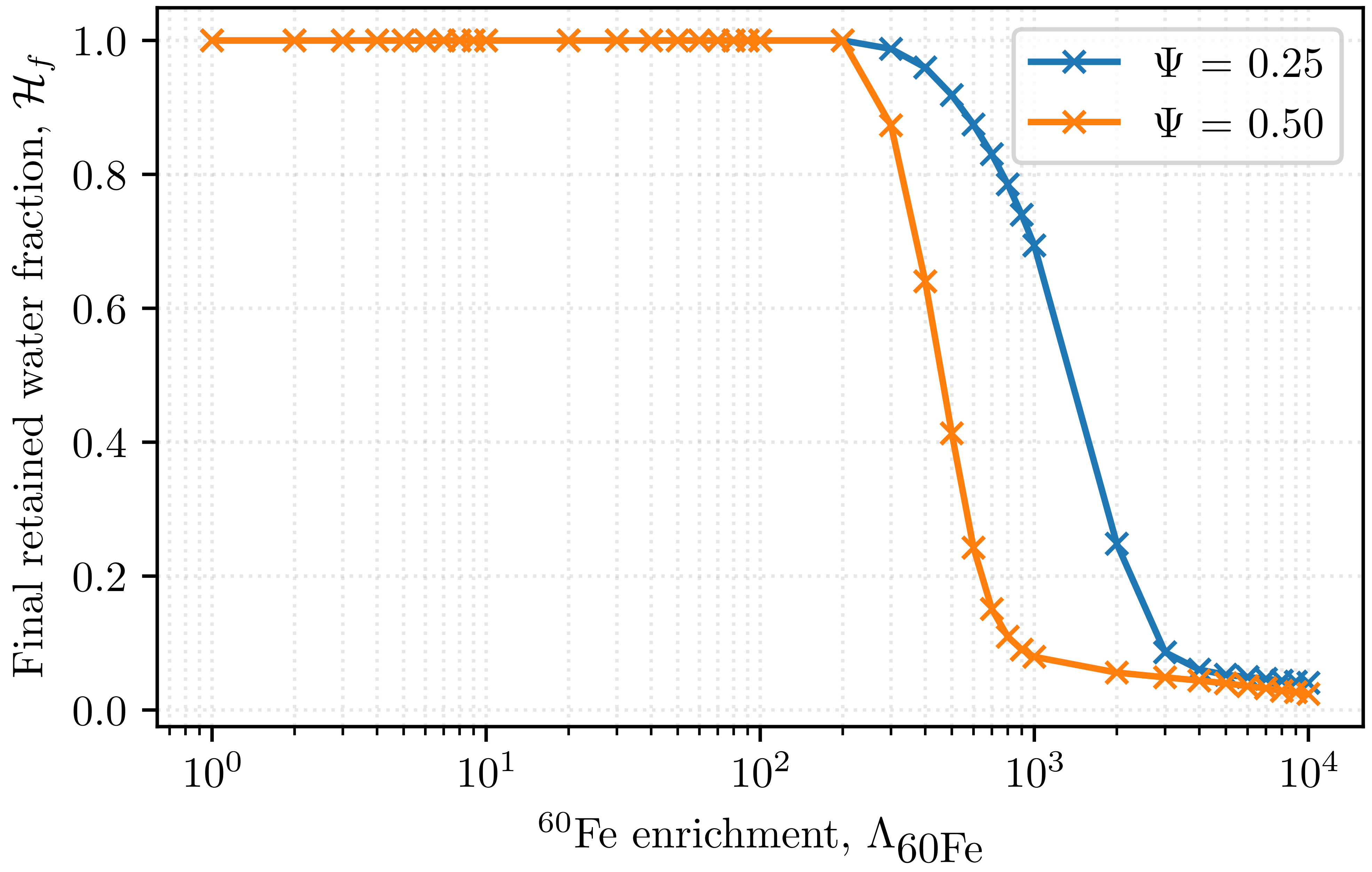
[1] Gerya (2019), github.com/FormingWorlds/i2elvis_planet

Results

Core model

- Desiccation occurs extremely rapidly after simulation onset.
- Due to both isotopes enrichment, particularly ^{26}Al.
- ^{60}Fe requires extremely large quantities of enrichment, ~200x higher than solar system levels!

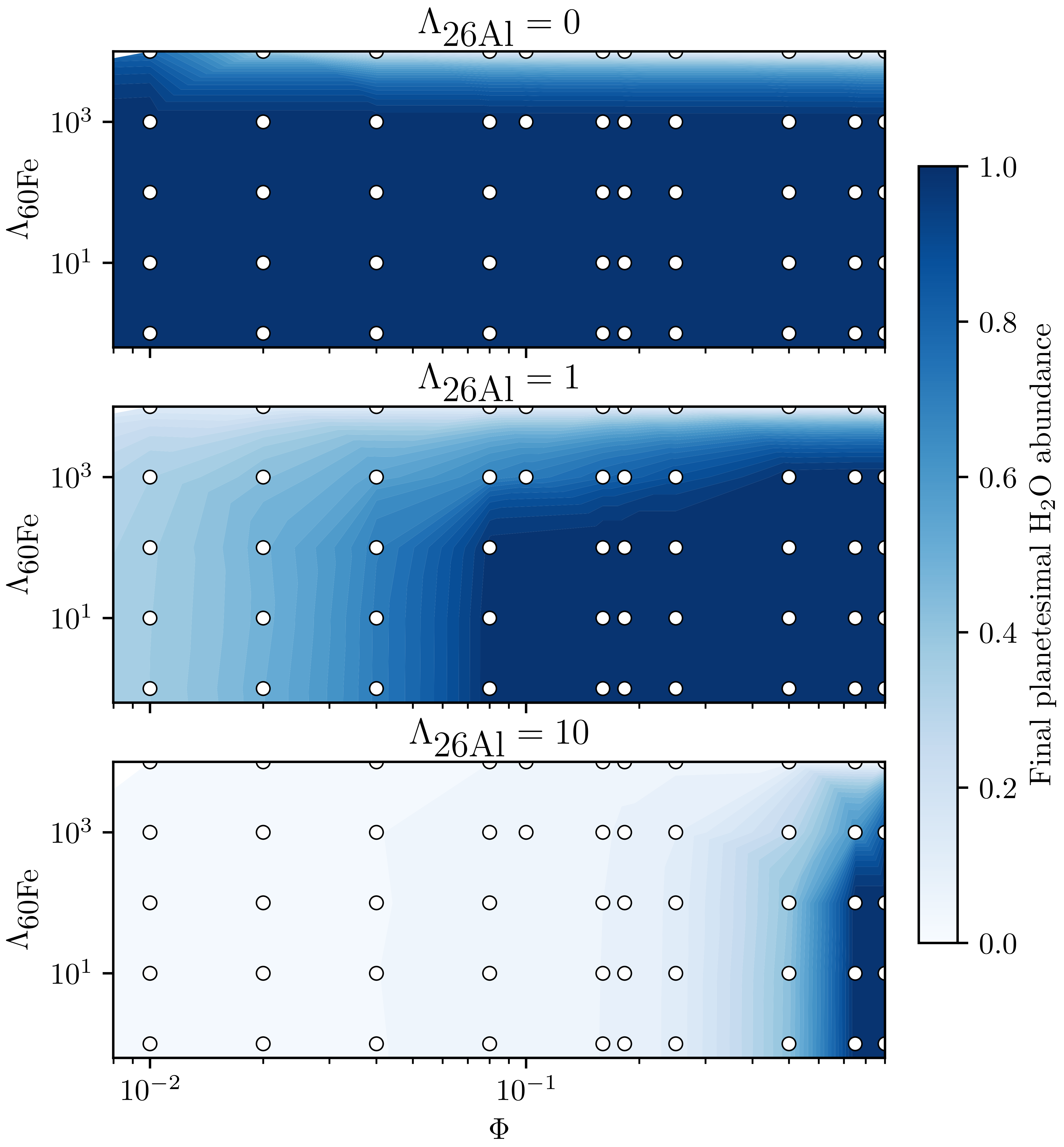




Results

Grain model and discussion

- Grain model relatively similar.
- Increasing ^{26}Al enrichment by a factor of 10 can completely desiccate a planetesimal.
- 10^4x solar ^{60}Fe enrichment needed to produce the same effect.
- How likely is this amount of enrichment?



Towards a unified injection model of short-lived radioisotopes in N-body simulations of star-forming regions

Eatson, Parker & Lichtenberg 2024 - ApJ, submitted

Motivation

- How common are highly enriched ^{60}Fe disks?
- How likely are solar system enrichment amounts for *either* SLR?
- Are disks enriched through SNe or early-type stellar winds?
- How dependent is enrichment on star forming region density?

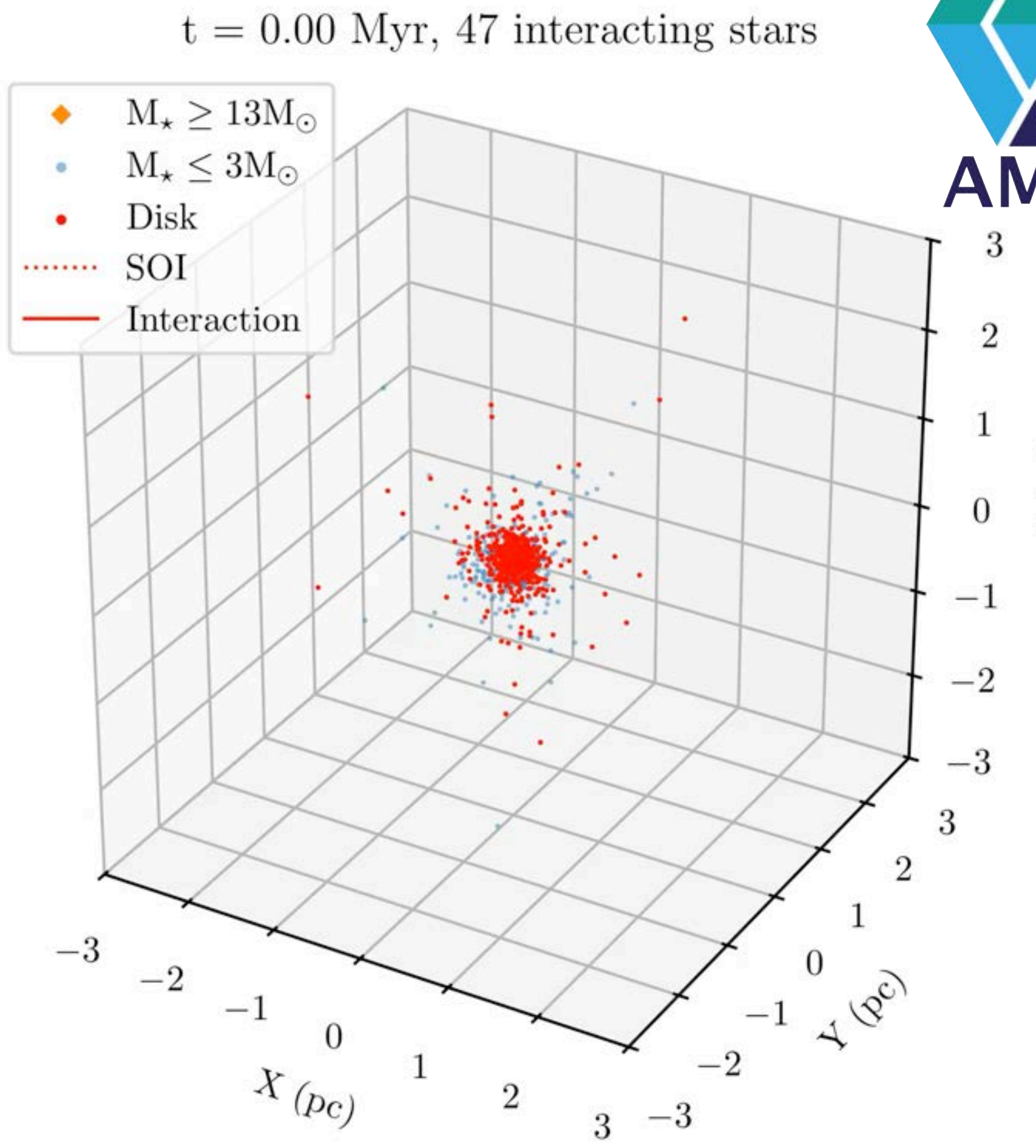
Methodology

- AMUSE[1] library used to combined N-body and stellar evolution codes.

- Fractal cluster generated[2] that includes high-mass stars.

- Disks evolve to a protoplanetary system over time.

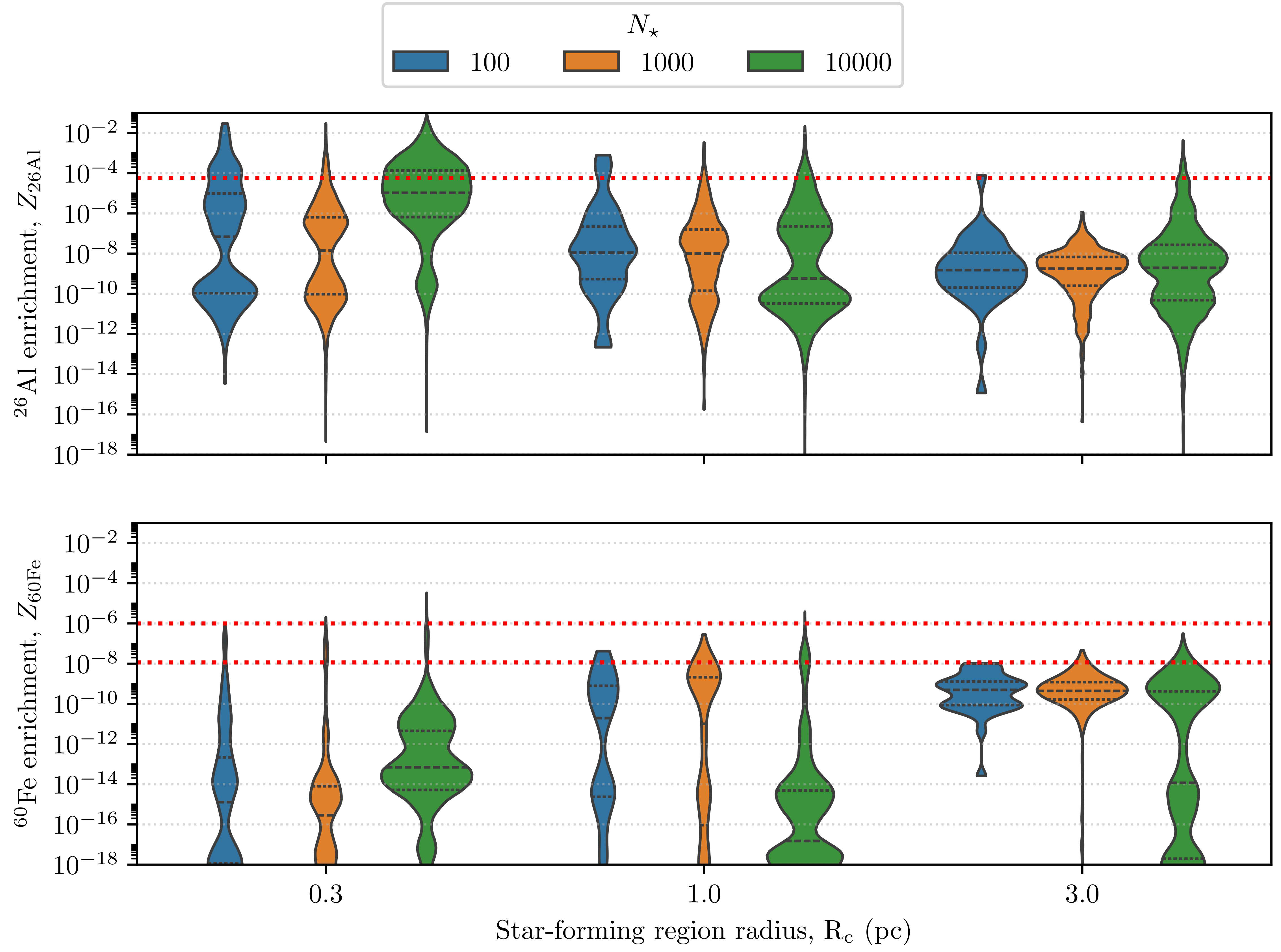
- Another parameter space exploration, varying star-forming region radius and population size.

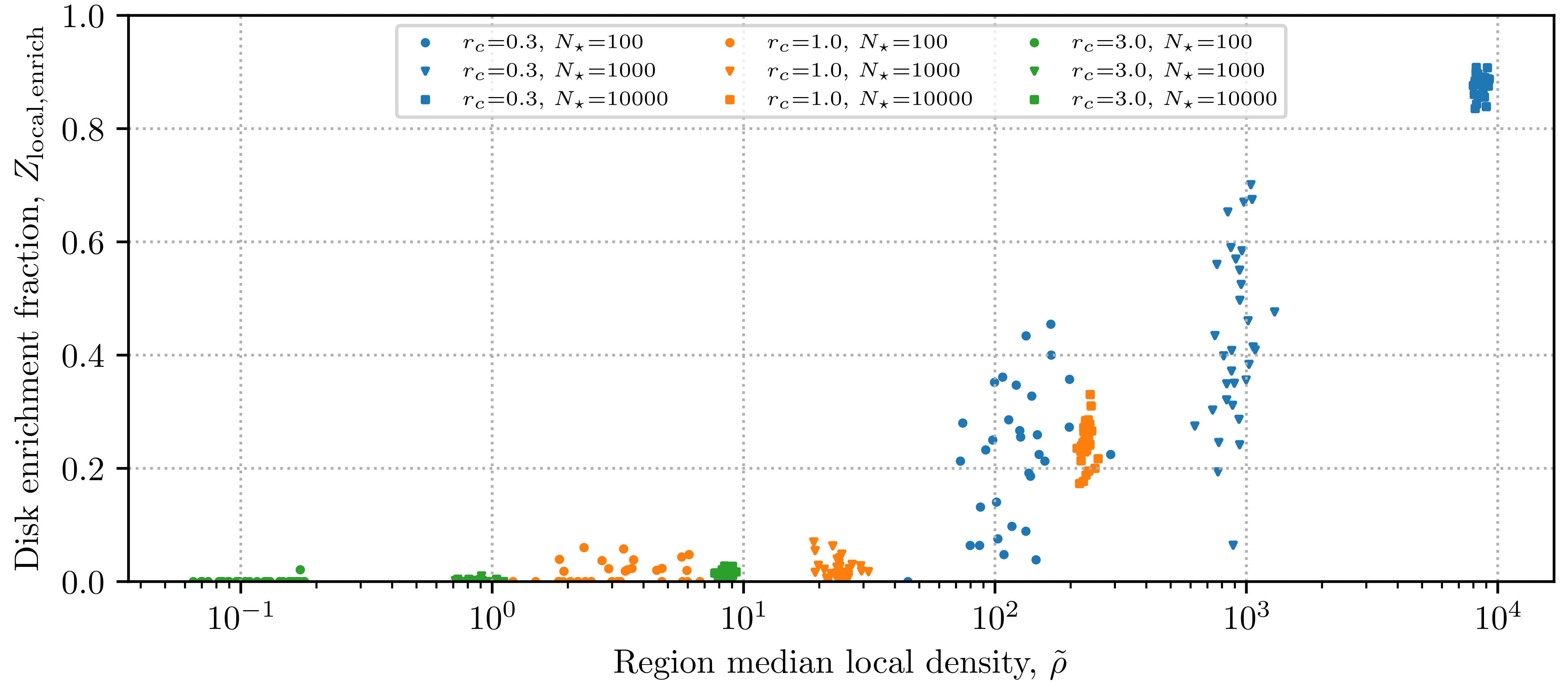


X,Y,Z axes: position in parsecs

Results

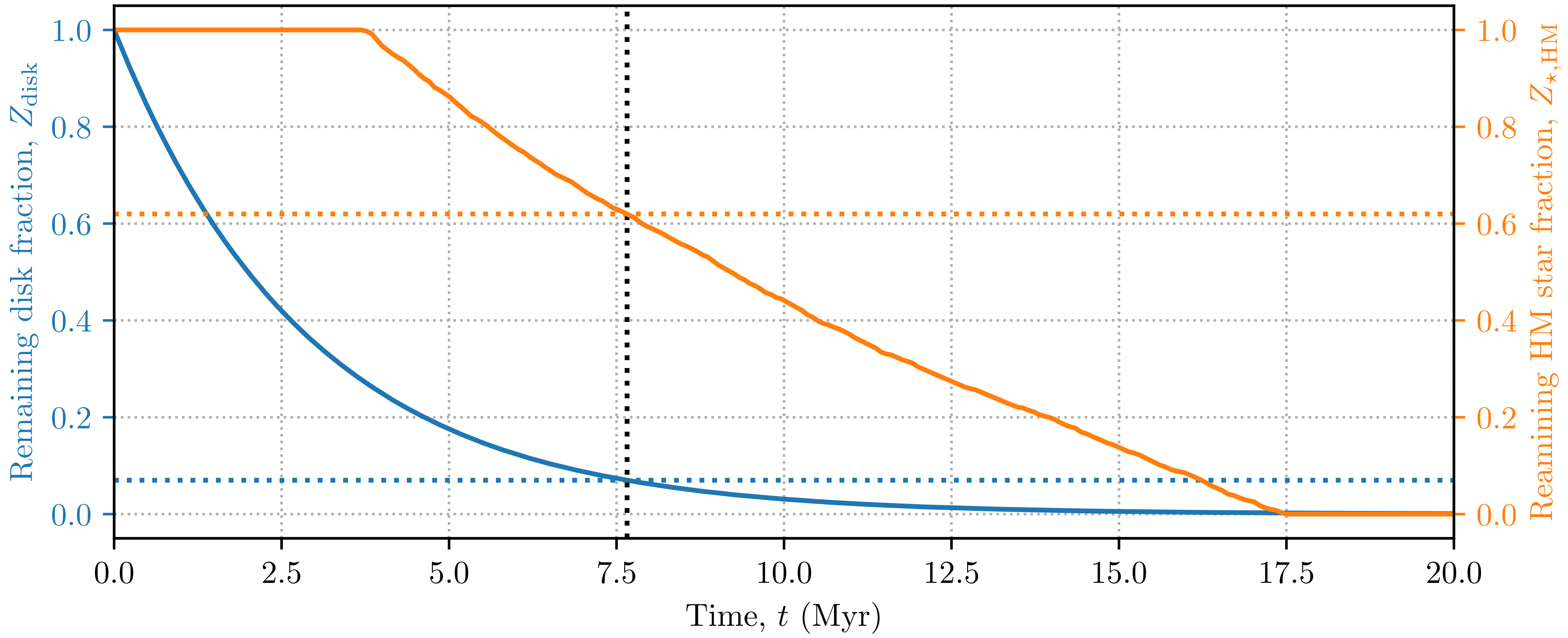
- Useful ^{26}Al enrichment above solar system levels somewhat common.
- Useful ^{60}Fe enrichment is significantly less common, solar system-level enrichment unusually high!
- Strong dependence on median local density and enrichment.





Discussion

- ^{26}Al enrichment is wind driven, ^{60}Fe enrichment is SNe driven.
- SNe that produce significant quantities of ^{60}Fe ($M_\bigstar$<25$M_\odot$[1]) occur late, when most disks have progressed into PP systems.
- Wind & SNe also would cause disruption of disks, large star-forming regions unfavourable to enrichment in themselves.



X-axis: time

Y-axis left: Remaining disks

Y-axis right: Remaining high-mass stars

Wrapping up

Conclusions
And next steps

- Decay heat from SLRs in disks causes desiccation of planetesimals.
- Decay heating mainly through ^{26}Al, sims show ^{60}Fe needs high enrichment.
- N-body sims show that ^{60}Fe enrichment levels leading to desiccation unlikely.
- Solar system particularly ^{60}Fe enriched.
- Next steps:
  - Better enrichment models, better heating models.
  - Better disk model, variable size & photoevaporation.
  - Interloping AGB stars?

Questions?

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