Compositional evolution of growing terrestrial planet embryos

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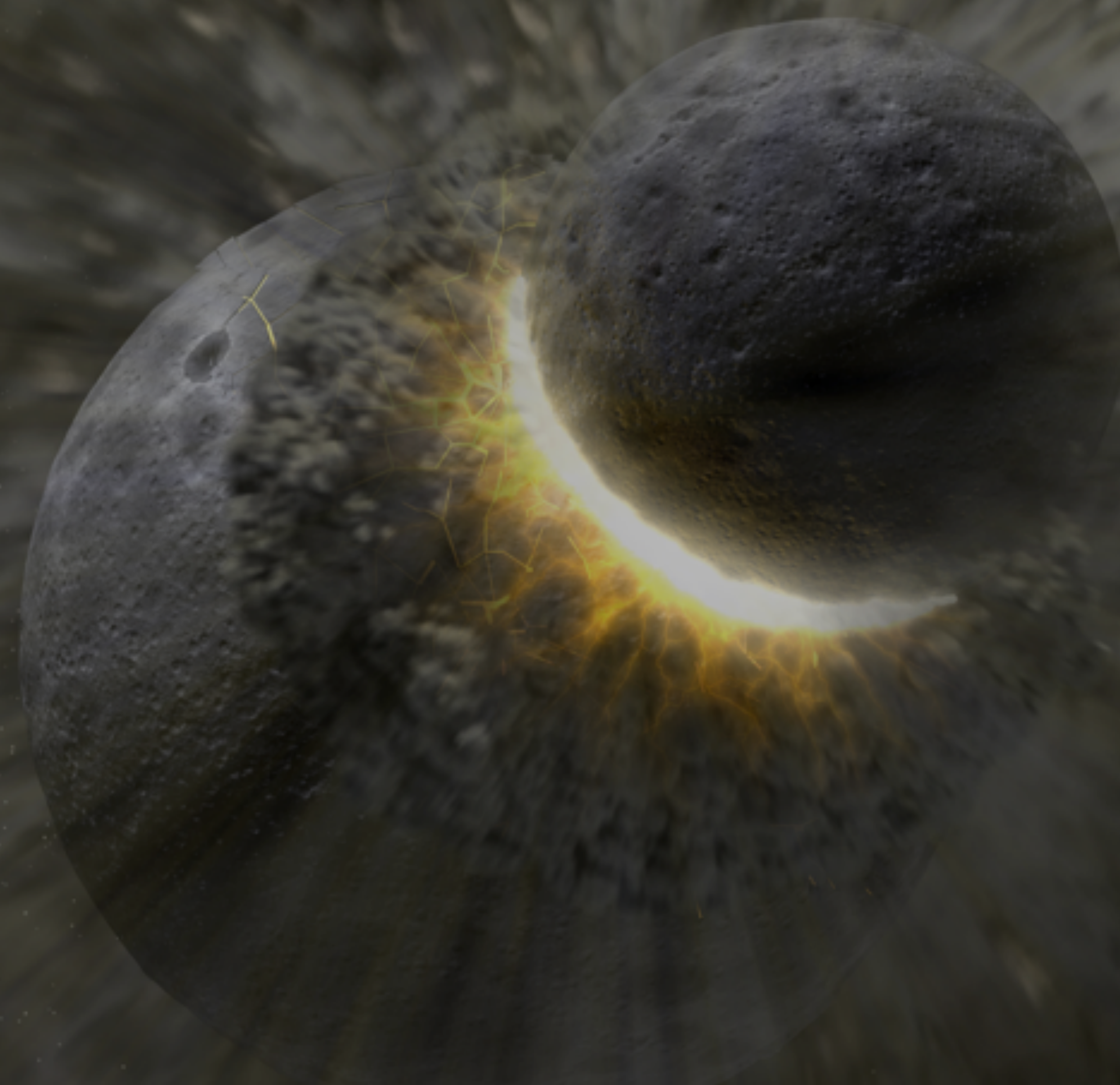


NERC SCIENCE OF THE ENVIRONMENT

University of BRISTOL

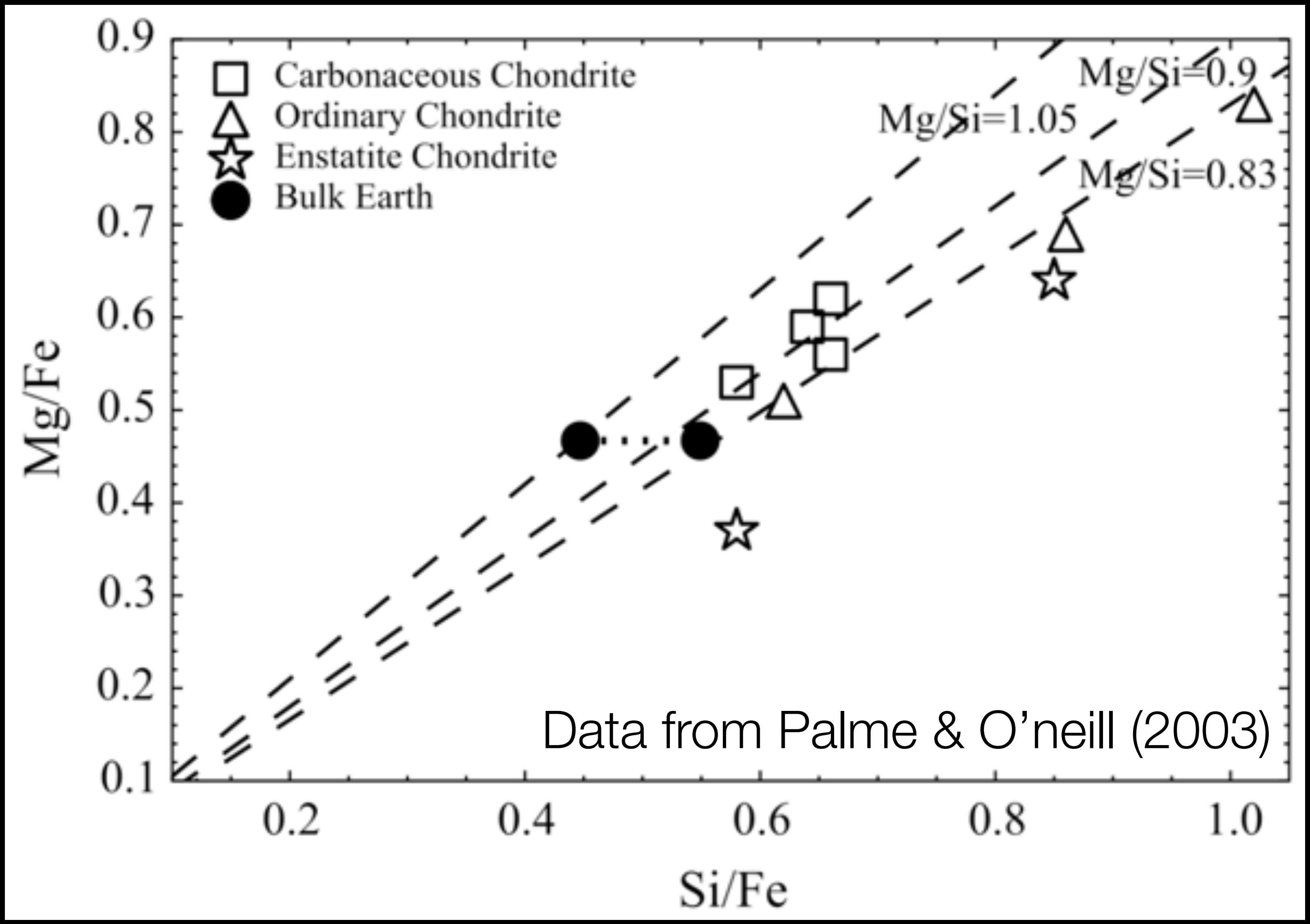
1st April 2016 - UK Exoplanet Meeting

NASA/JPL-Caltech/T. Pyle (SSC)

Introduction

Earth 1.0

Solar system measurements are a key test of planet formation models



Bonsor et al. (2015)

Simulations

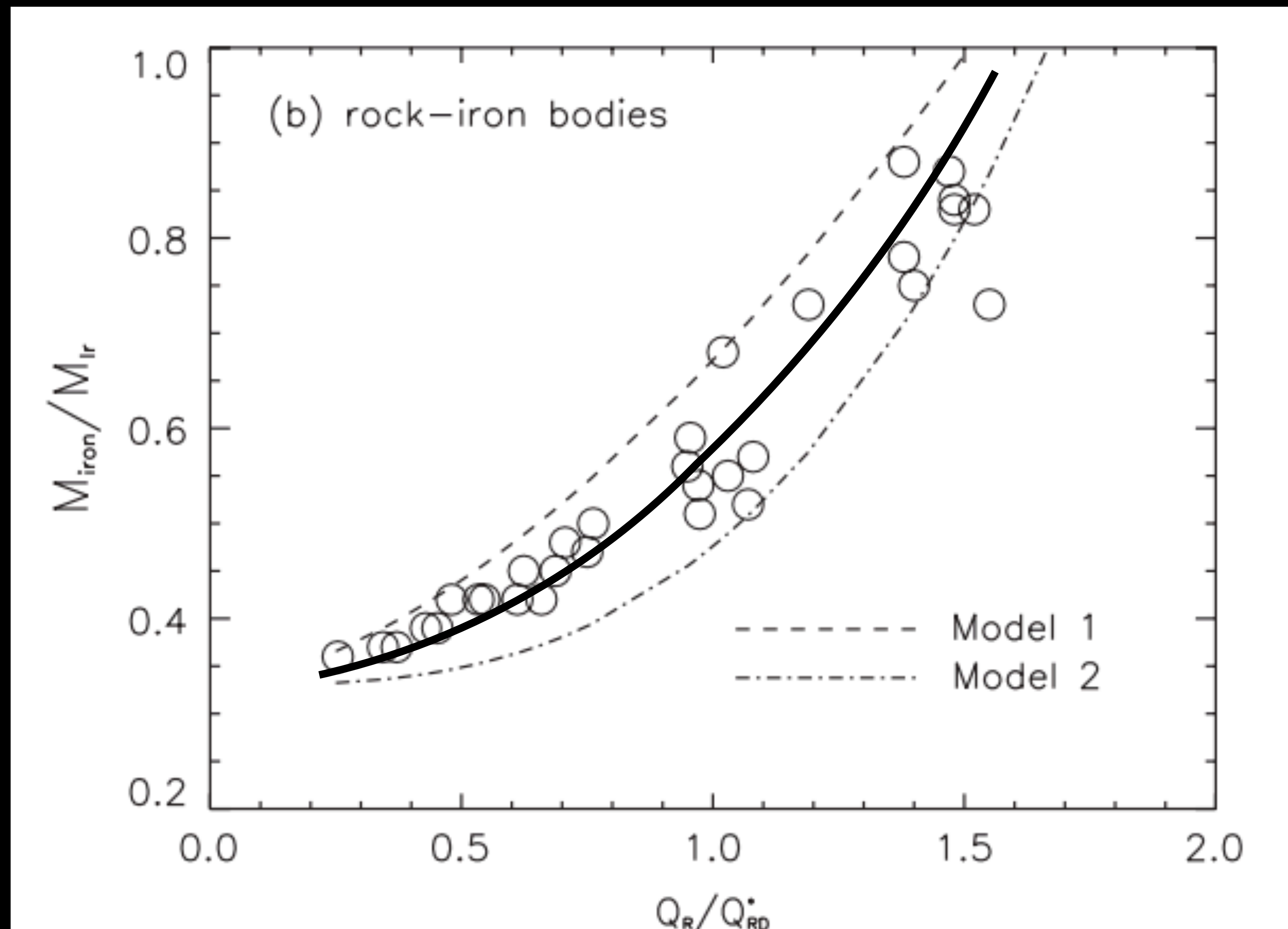
- PKDGRAV - *N* body code (Richardson et al. 2000; Stadel 2001)
- EDACM - Empirically Derived Analytical Collision Model (Leinhardt & Stewart 2012; Leinhardt et al. 2015)
- 100 000 planetesimals, most ~200 km radius — differentiated (e.g. Kruijer et al. 2014)
- Mantle stripping law — favours accretion of core material by largest remnants (Marcus et al. 2010)
- Particle radii inflated by factor f=6 to speed up evolution (Kokubo & Ida 1996, 2002; Bonsor et al. 2015, Leinhardt et al. 2015)
  Run for 600 000 yr, effective time ~20 Myr — end before GI phase
- Calm disc: no giant planets (see Bonsor et al. 2015);
  Grand Tack: inward then outward migration of Jupiter (Walsh et al. 2011)

Mantle stripping law

Favours accretion of core material by largest remnants

GADGET SPH

Core mass fraction



Impact energy

Marcus et al. (2010)

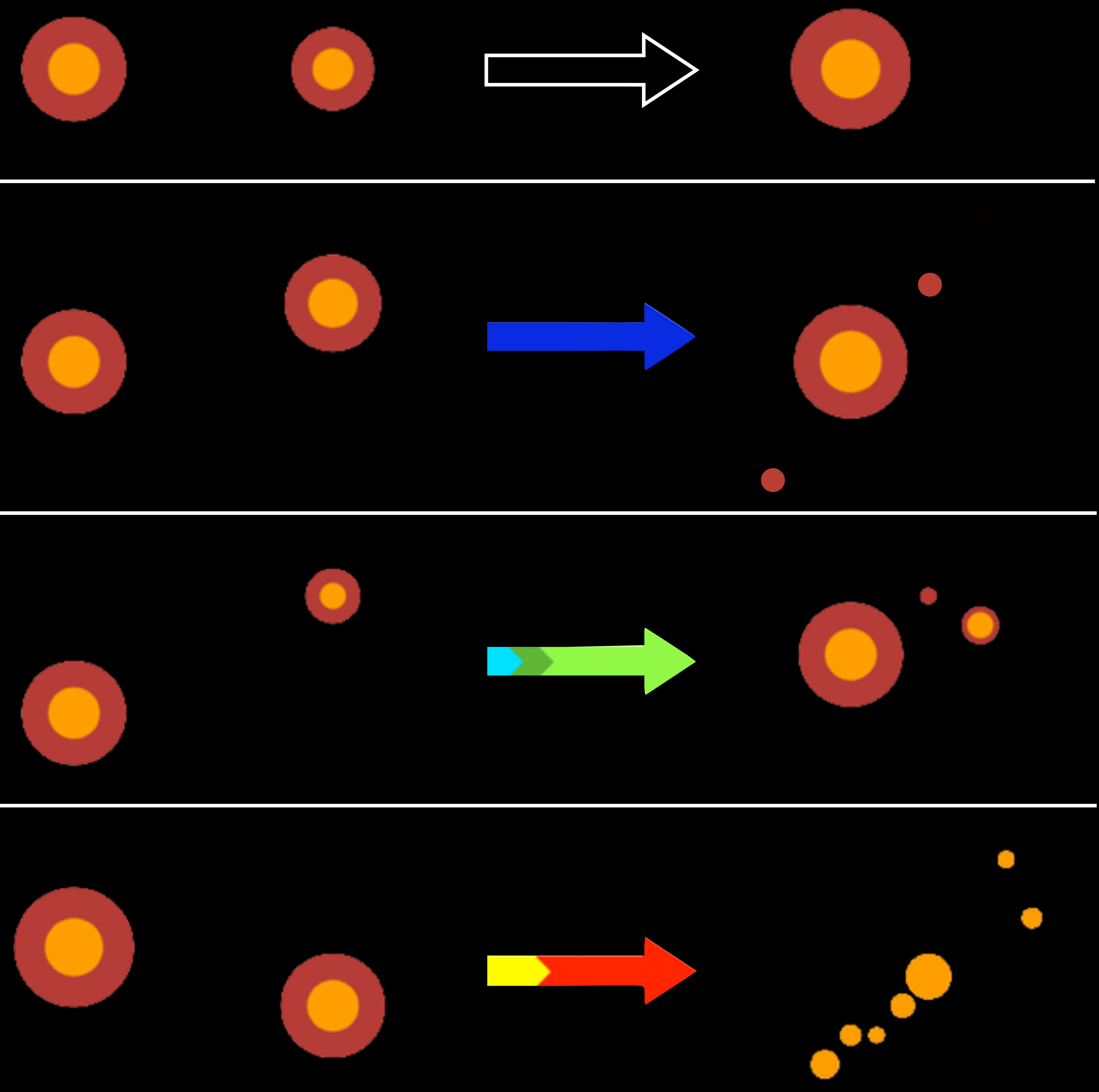
Core vs mantle with EDACM

Perfect merging

Partial accretion

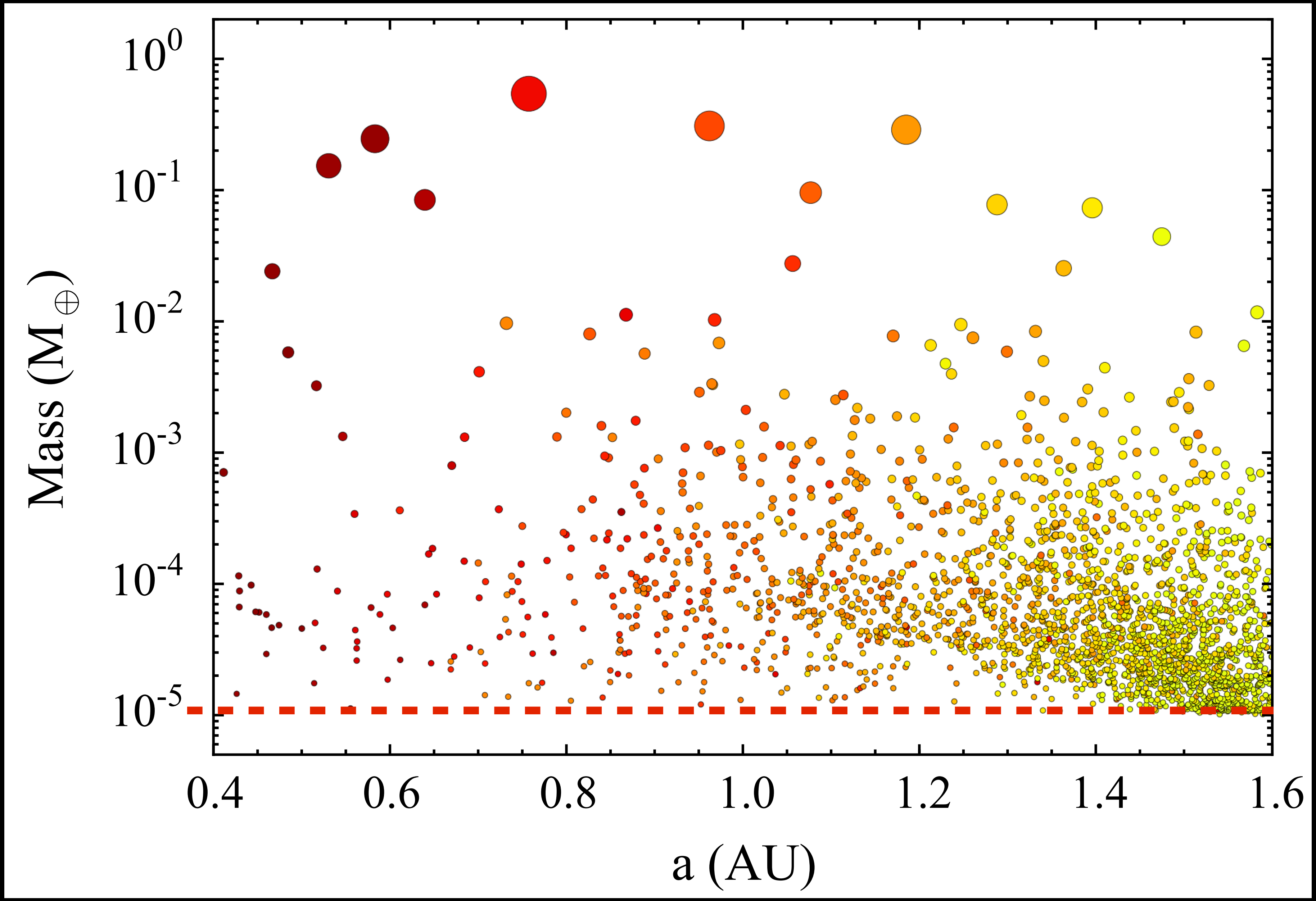
Hit and run
Projectile disrupted

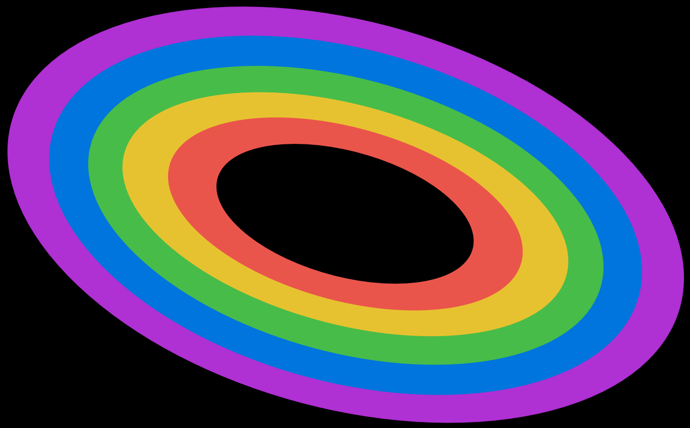
Erosion or supercatastrophic disruption



Resolution limit

Carter et al. (2015); Bonsor et al. (2015); Leinhardt et al. (2015)



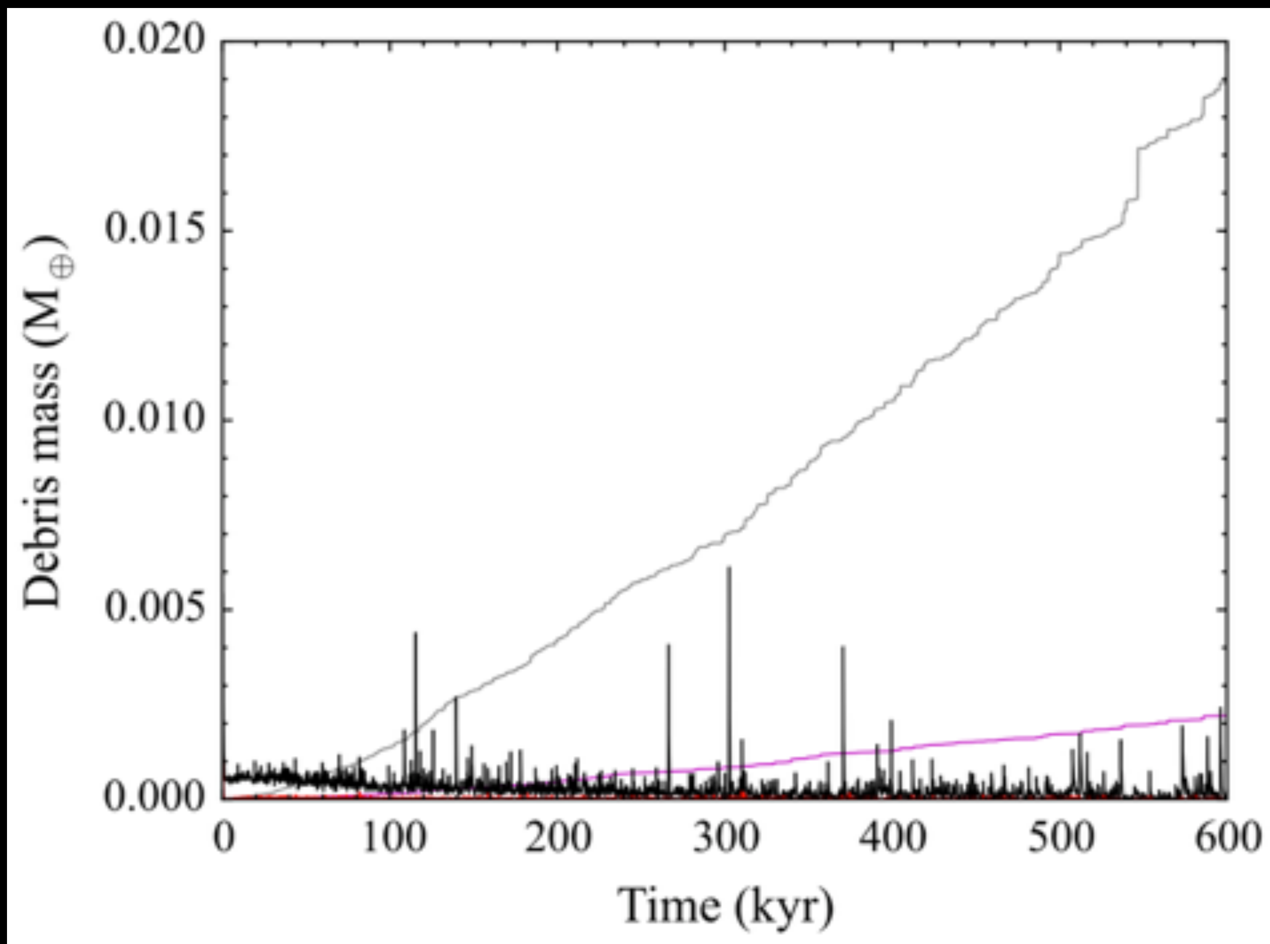


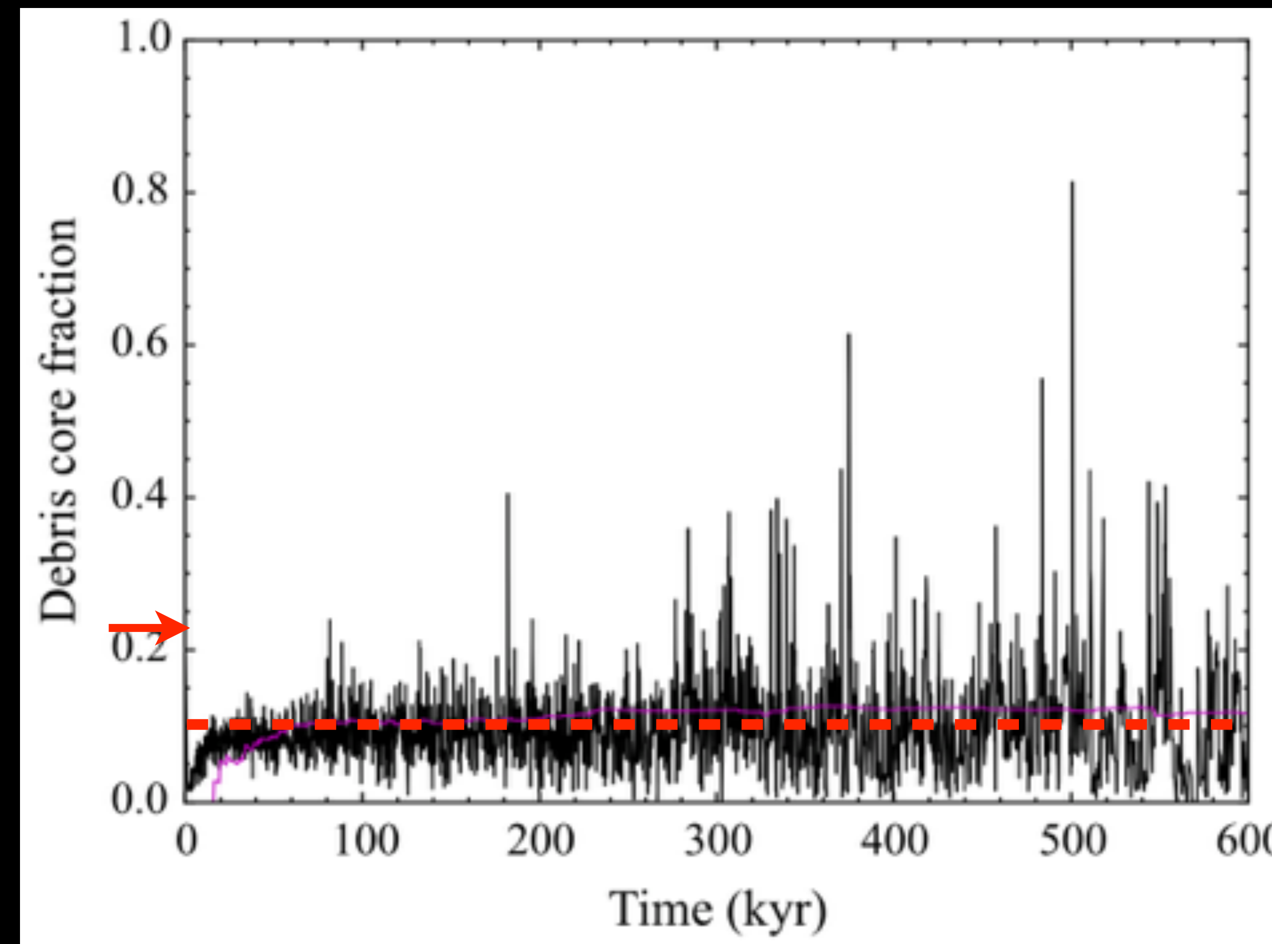
Collisions can produce debris,

Resolved planetesimals reaccrete (see Leinhardt et al. 2015)

— cycling of material through debris bins

Unresolved mass





Carter et al. (2015)

Collisions can produce debris,

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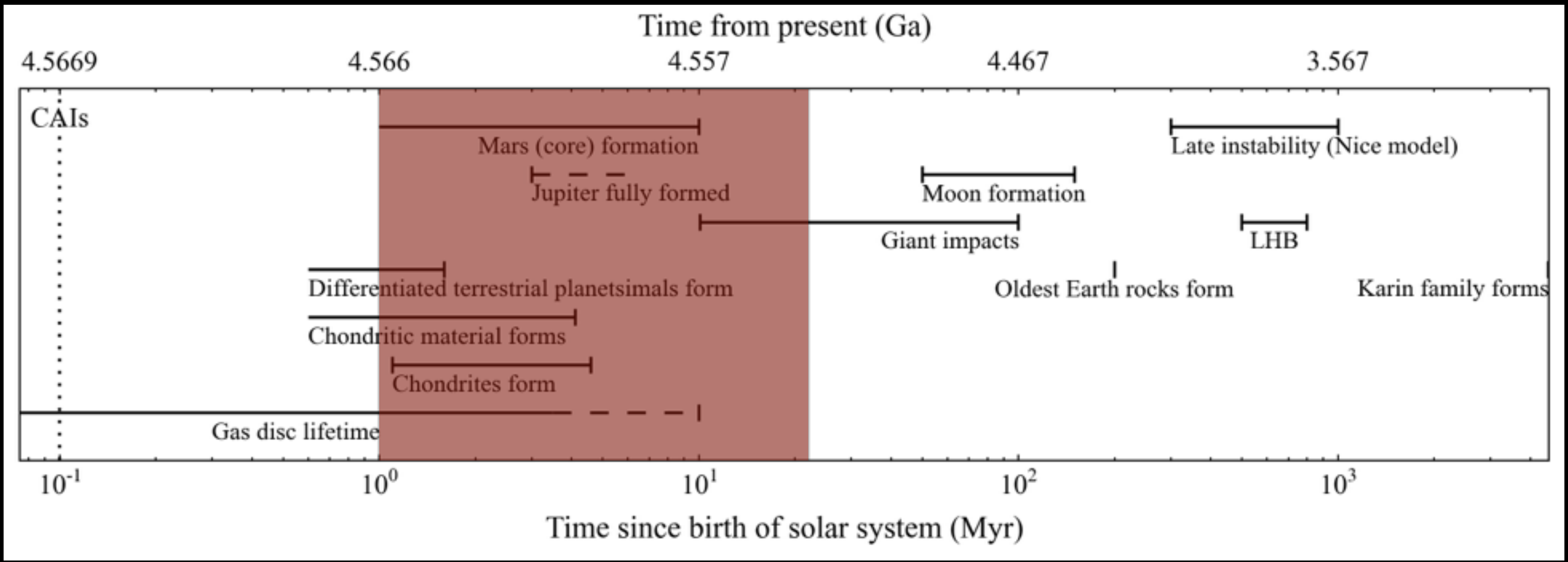
Time



Particle radii inflated by factor f=6 to speed up evolution

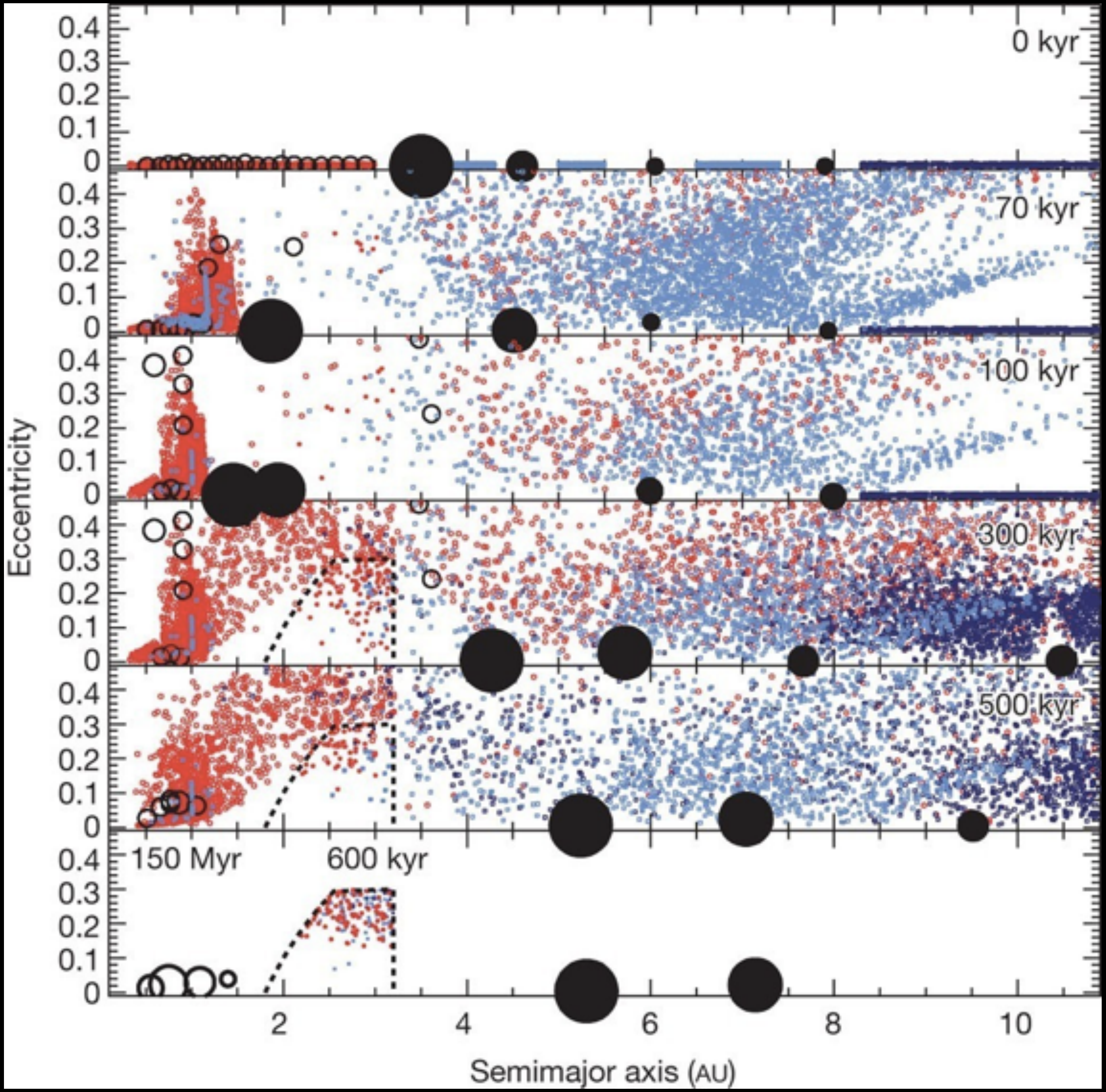
(Kokubo & Ida 1996, 2002; Bonsor et al. 2015, Leinhardt et al. 2015)

Run for 600 000 yr, effective time ~20 Myr — end before GI phase

The Grand Tack

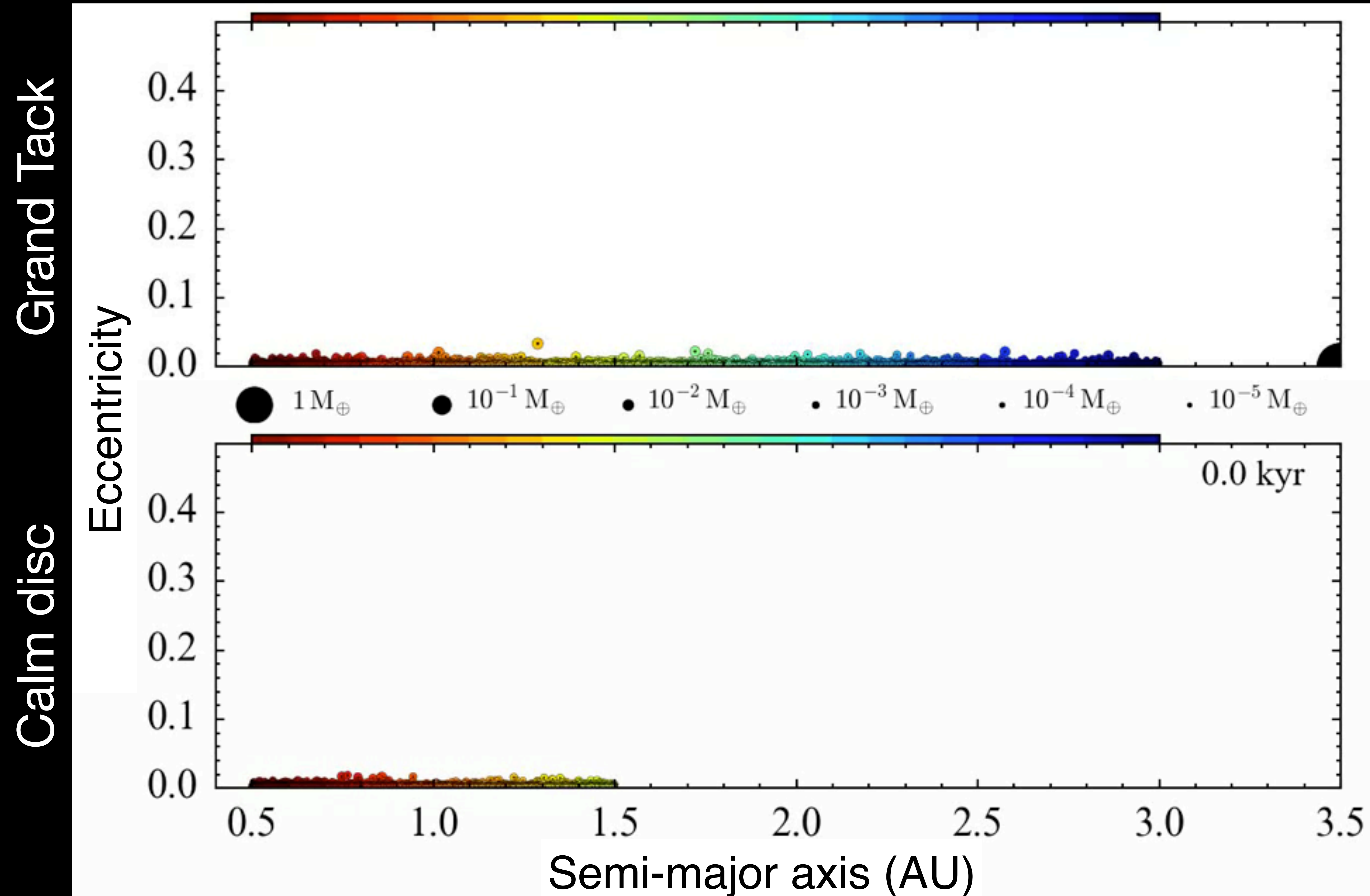
Calm disc: no giant planets (see Bonsor et al. 2015)
Grand Tack: inward then outward migration of Jupiter

(Walsh et al. 2011)



0 kyr
70 kyr
100 kyr
300 kyr
500 kyr
150 Myr

Growth of terrestrial embryos



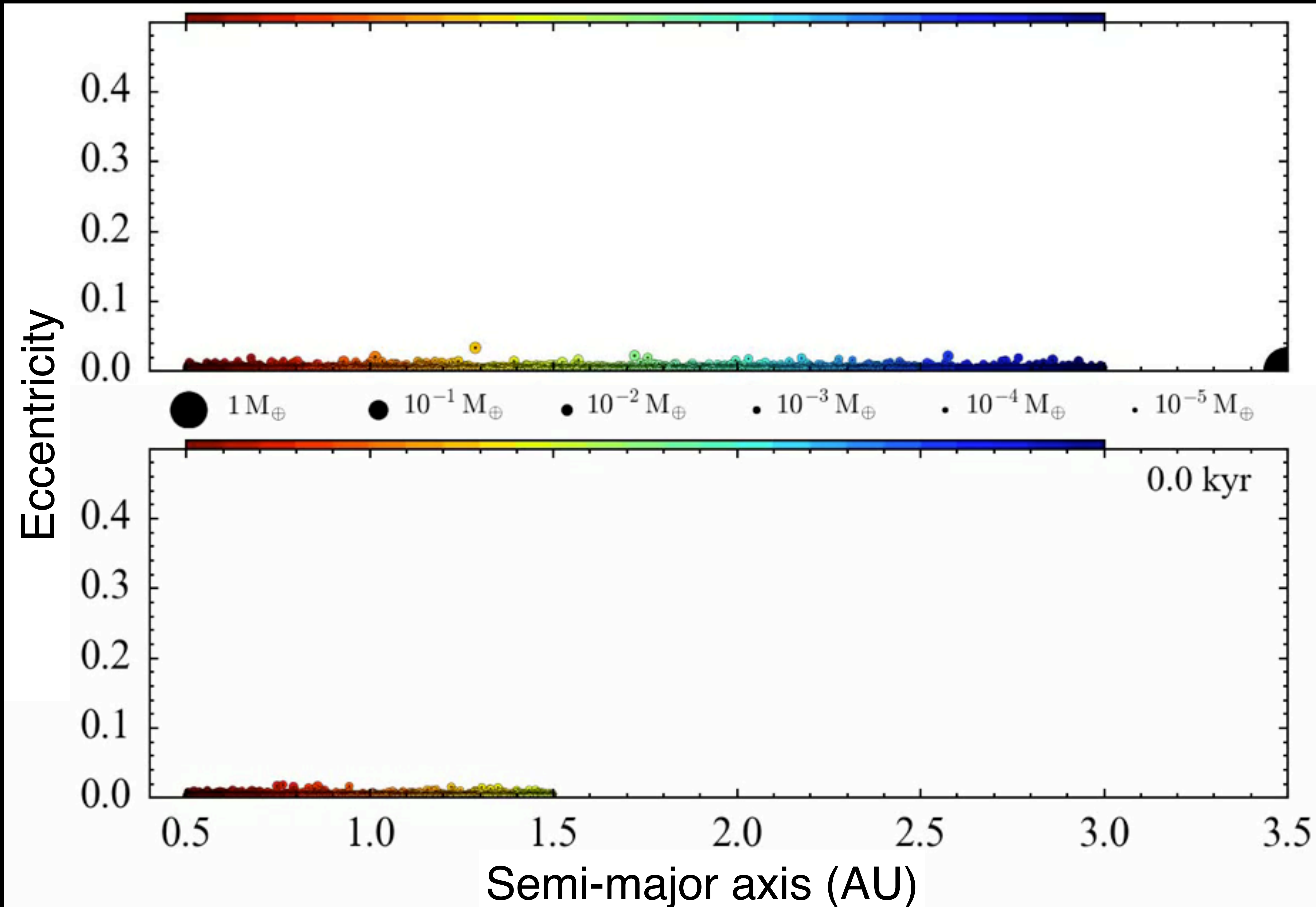
More movies available online

Carter et al. (2015)

Growth of terrestrial embryos

Grand Tack

Calm disc



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Carter et al. (2015)

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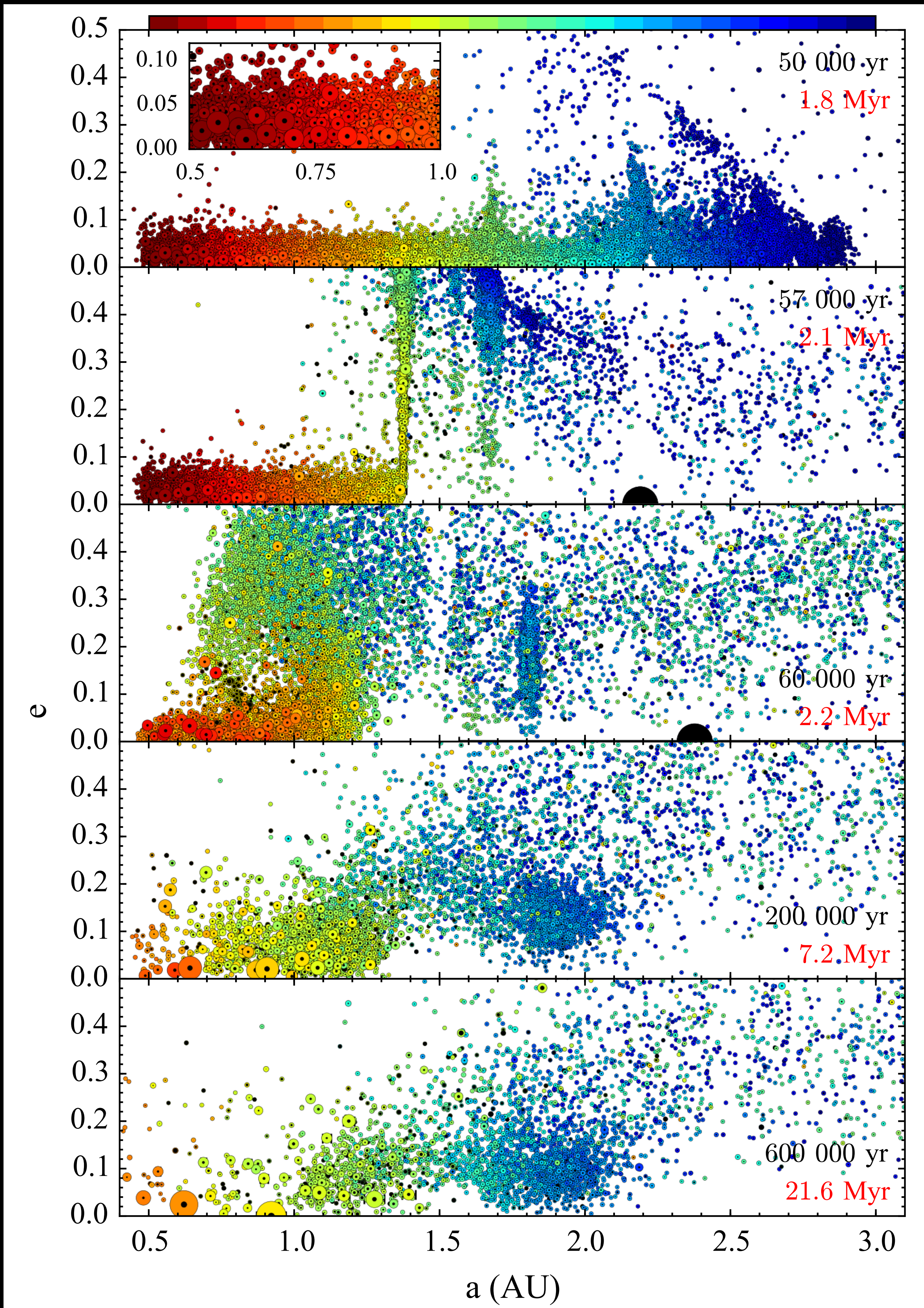
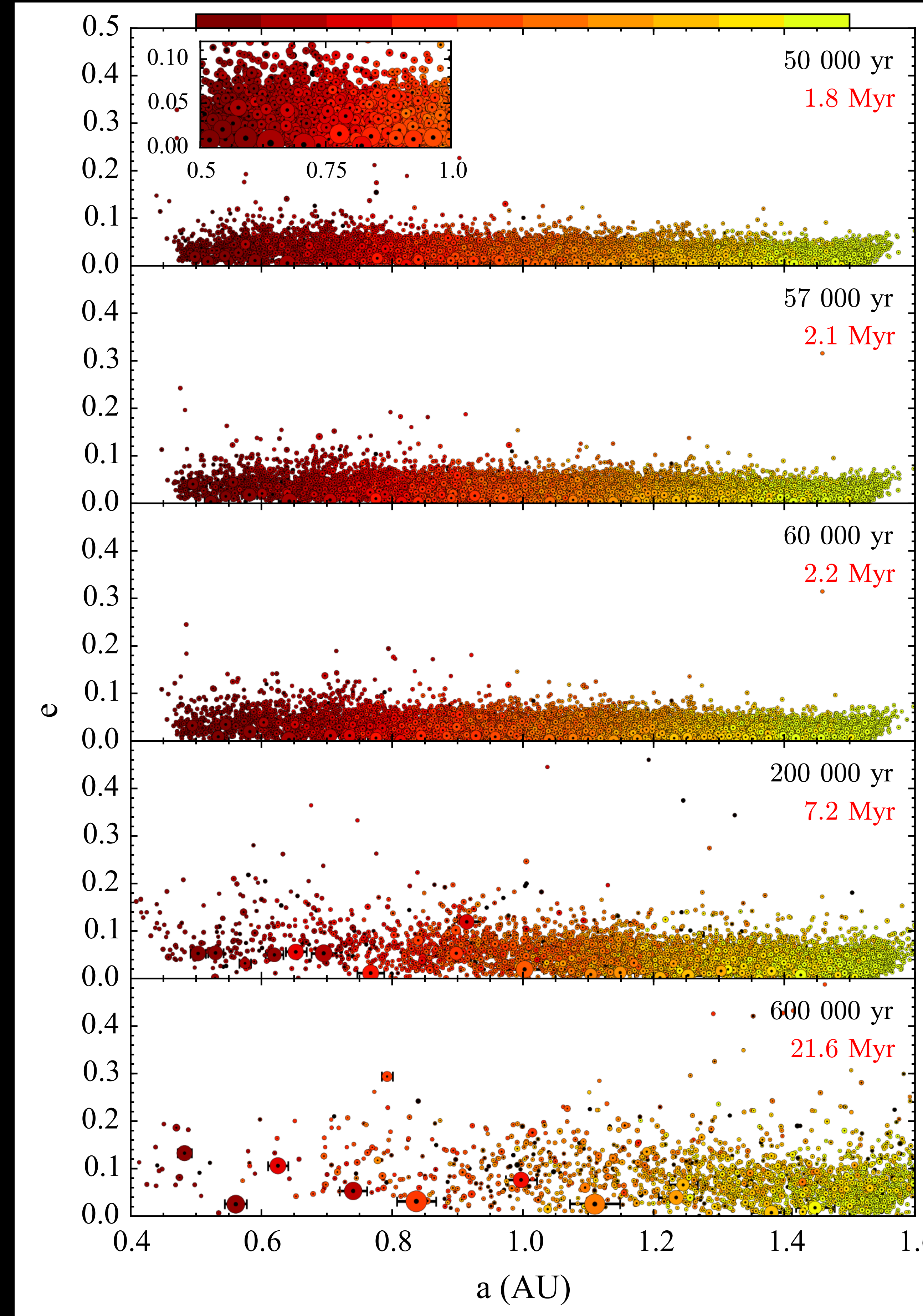


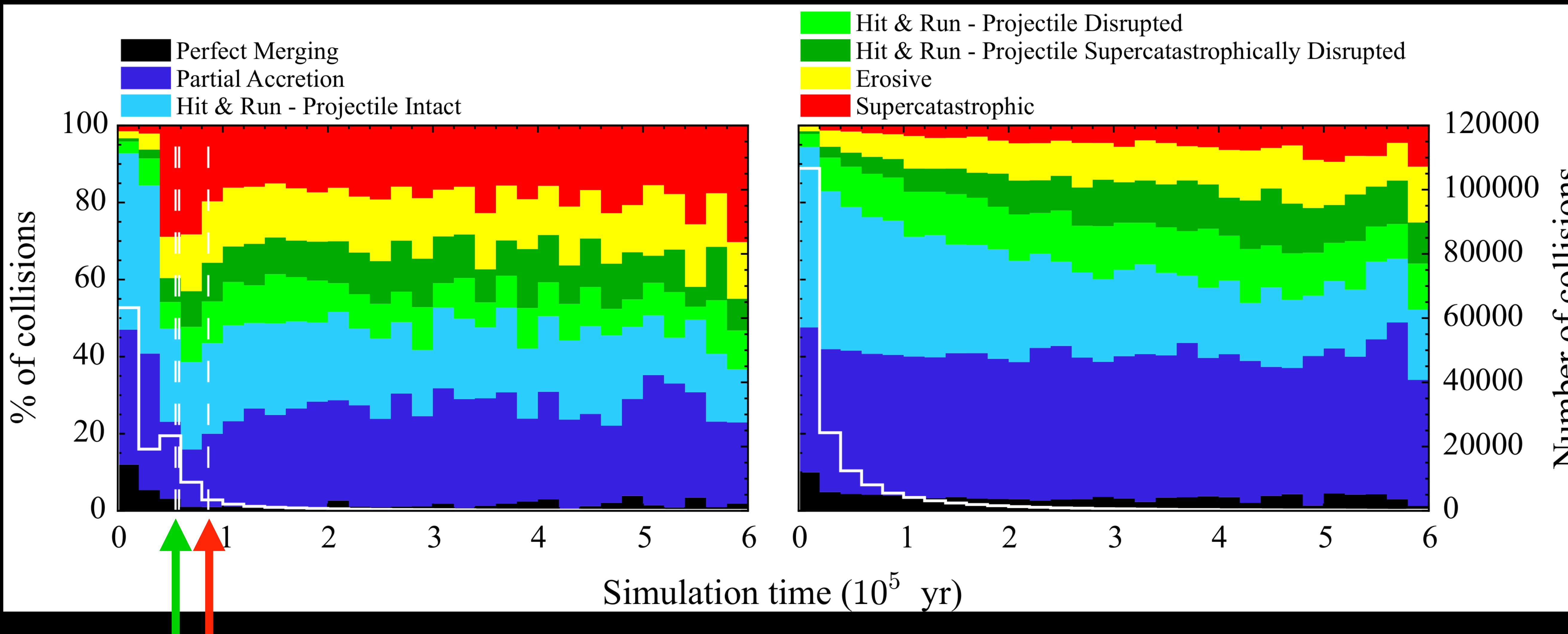
Grand Tack



Calm disc

Collisions during embryo growth

Carter et al. (2015)



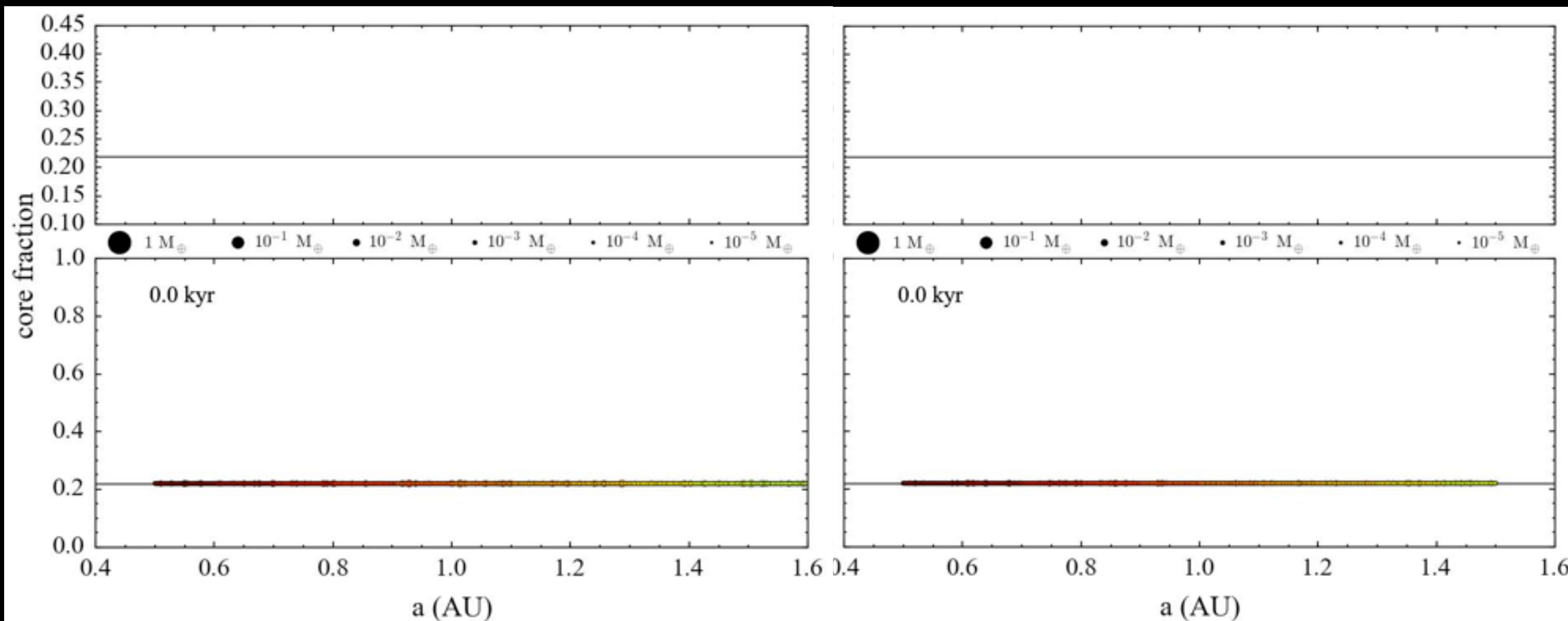
2 Myr

Grand Tack

Calm disc

Jupiter’s migration excites the inner disc, causing many more erosive collisions

Composition of terrestrial embryos

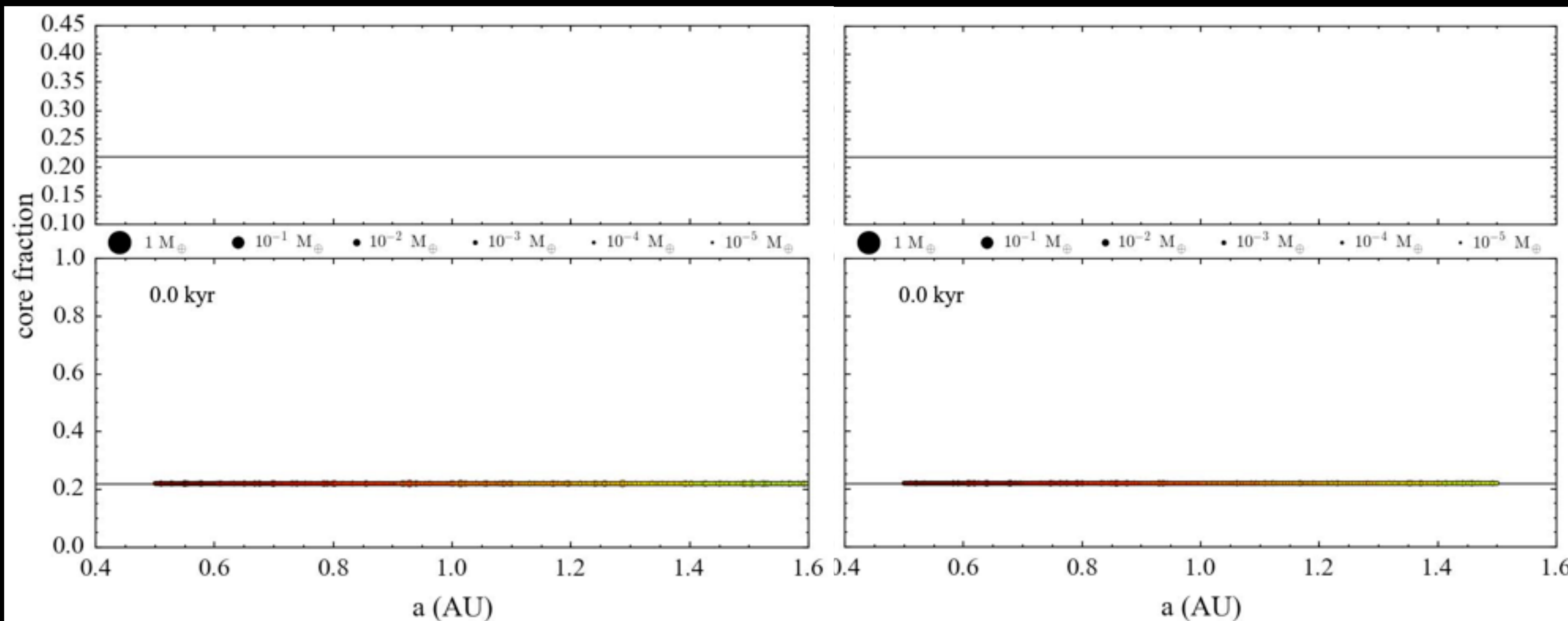


Grand Tack

Calm disc

Carter et al. (2015)

Composition of terrestrial embryos

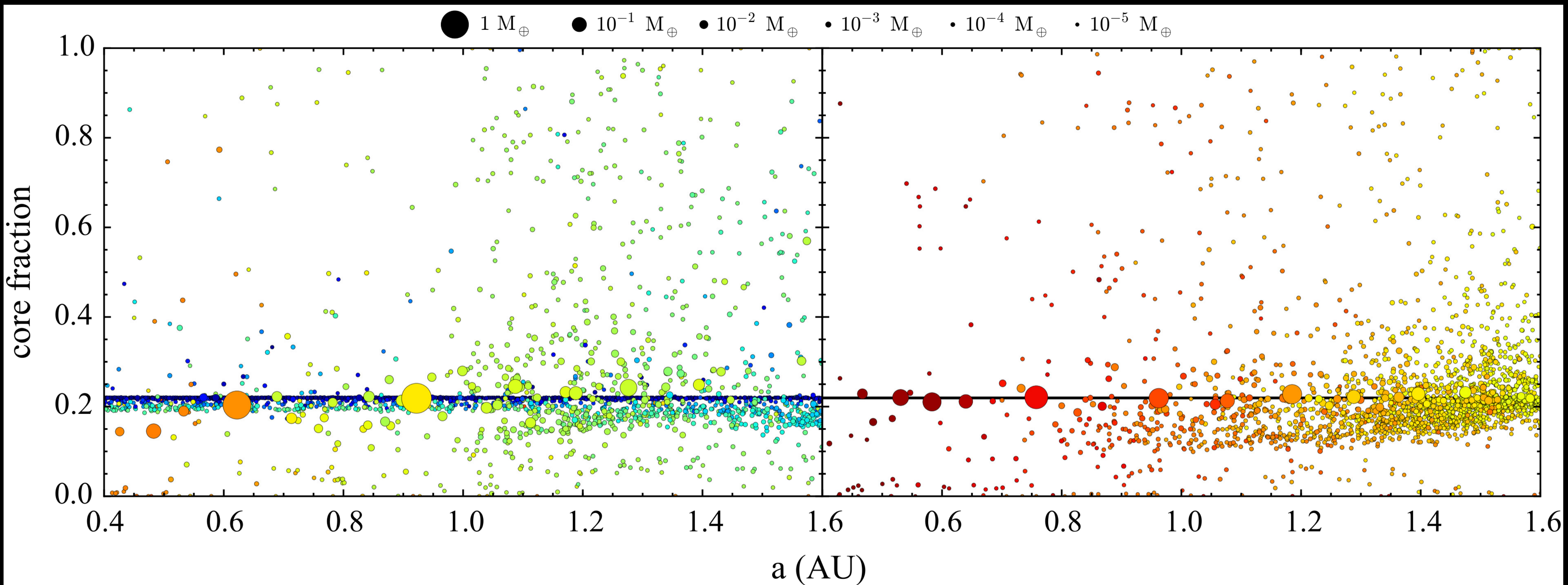


Grand Tack

Calm disc

Carter et al. (2015)

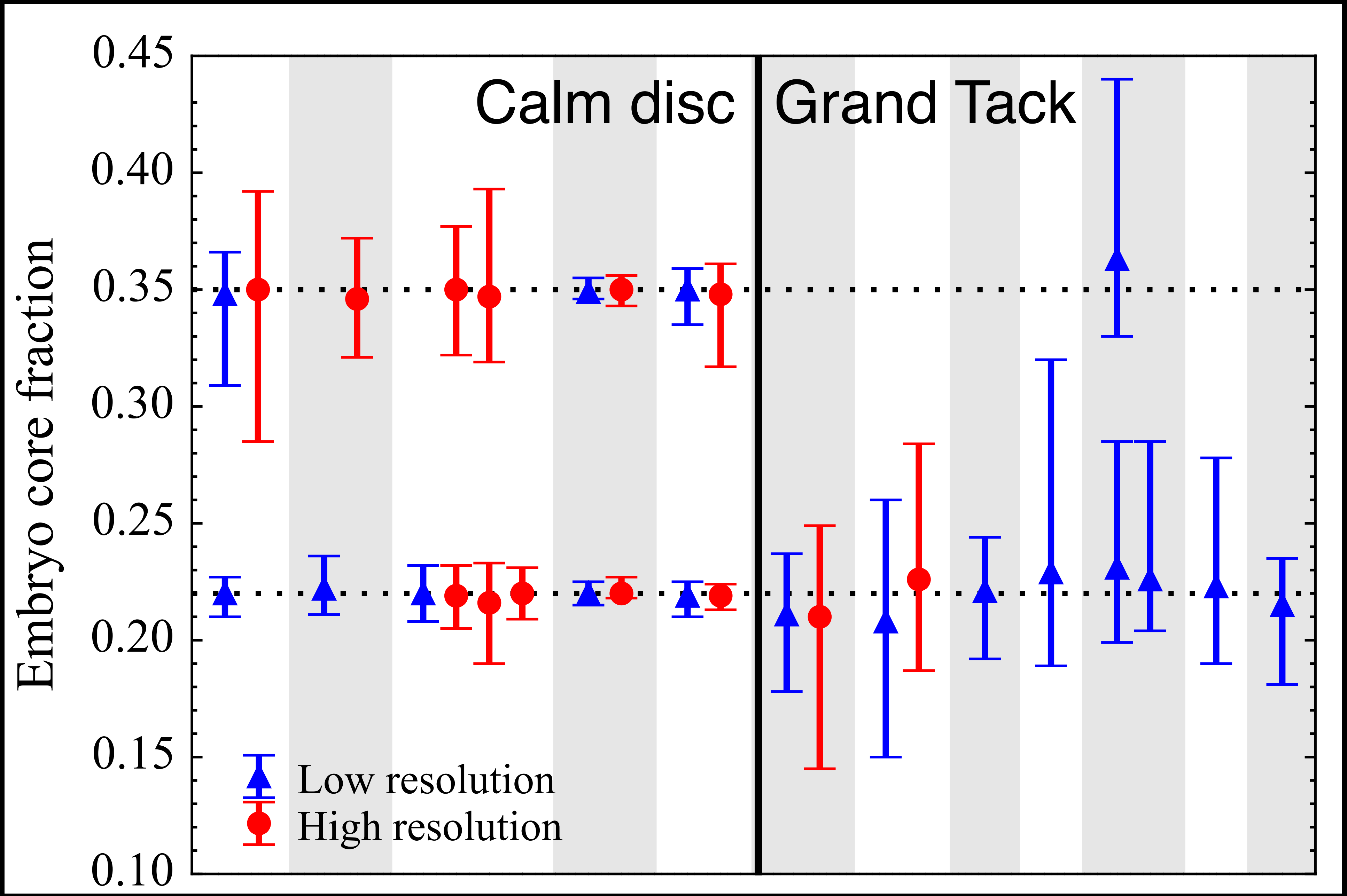
Composition of terrestrial embryos



Carter et al. (2015)

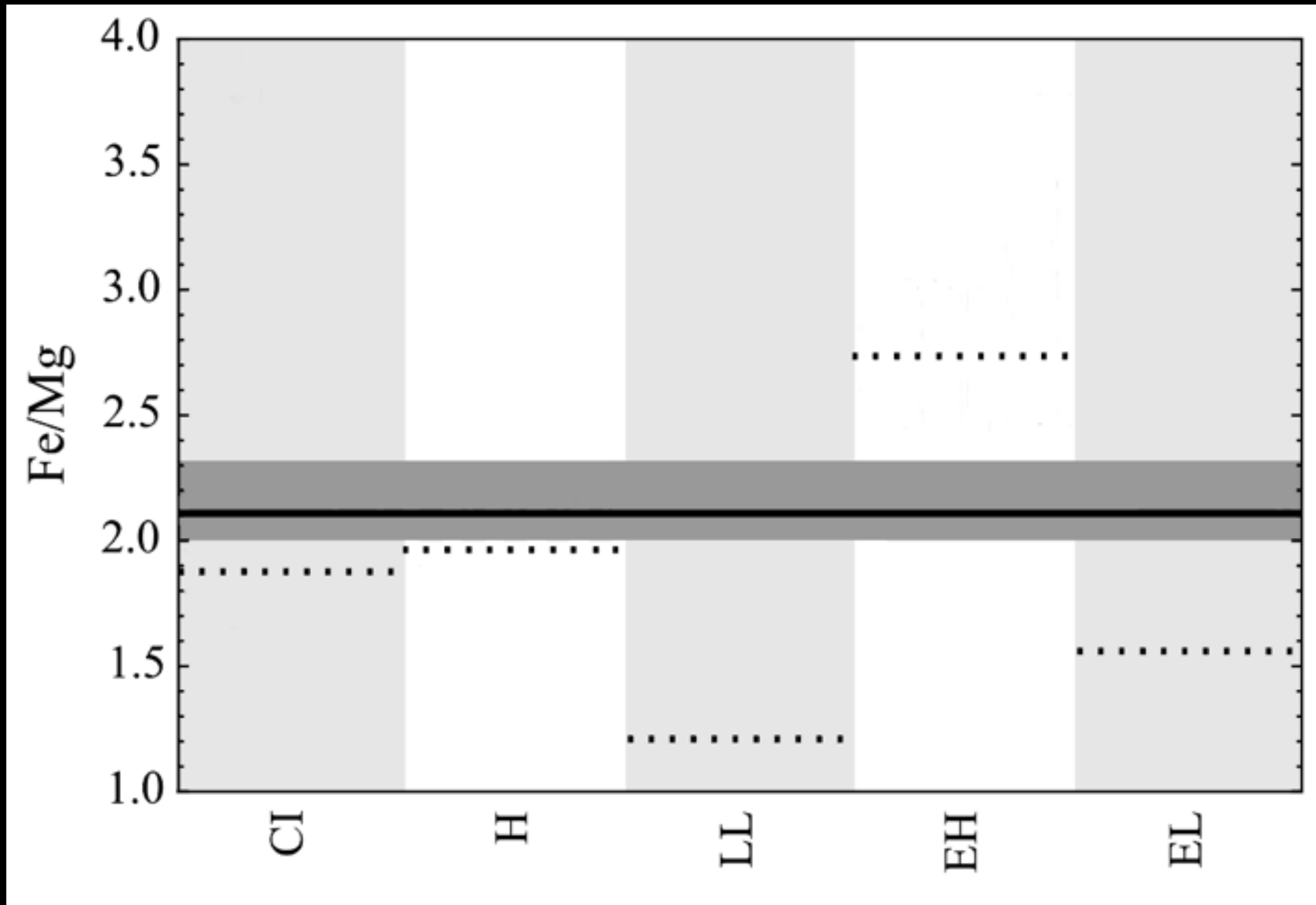
Final core fraction

Carter et al. (2015)



Apply these changes to chondritic meteorite compositions: form core, calculate mantle composition; apply final core fraction, calculate bulk composition.

What does this mean for the composition?

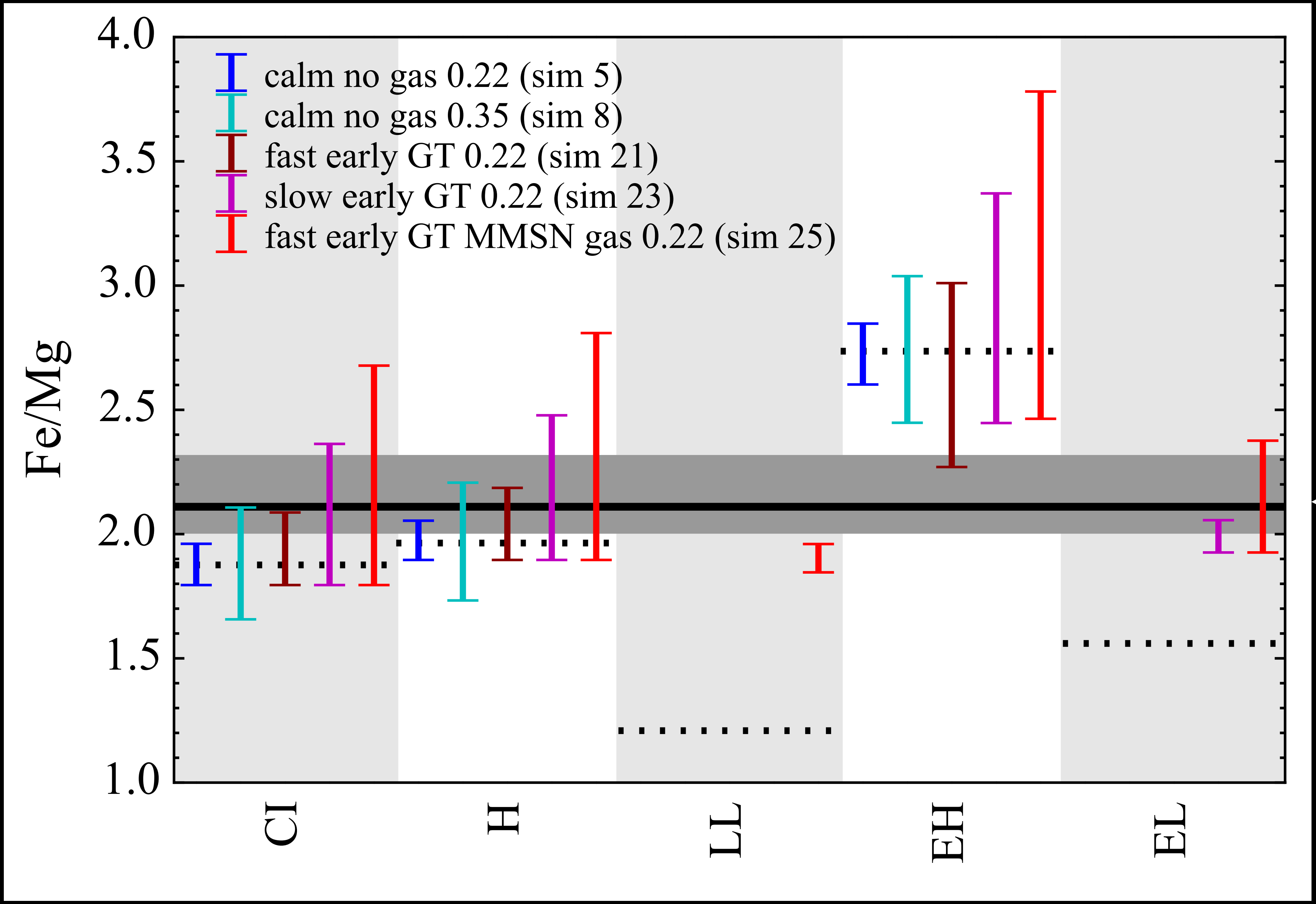


Carter et al. (2015)

Earth
(O'Neill & Palme 2008)

What does this mean for the composition?

Calm disc
Grand Tack



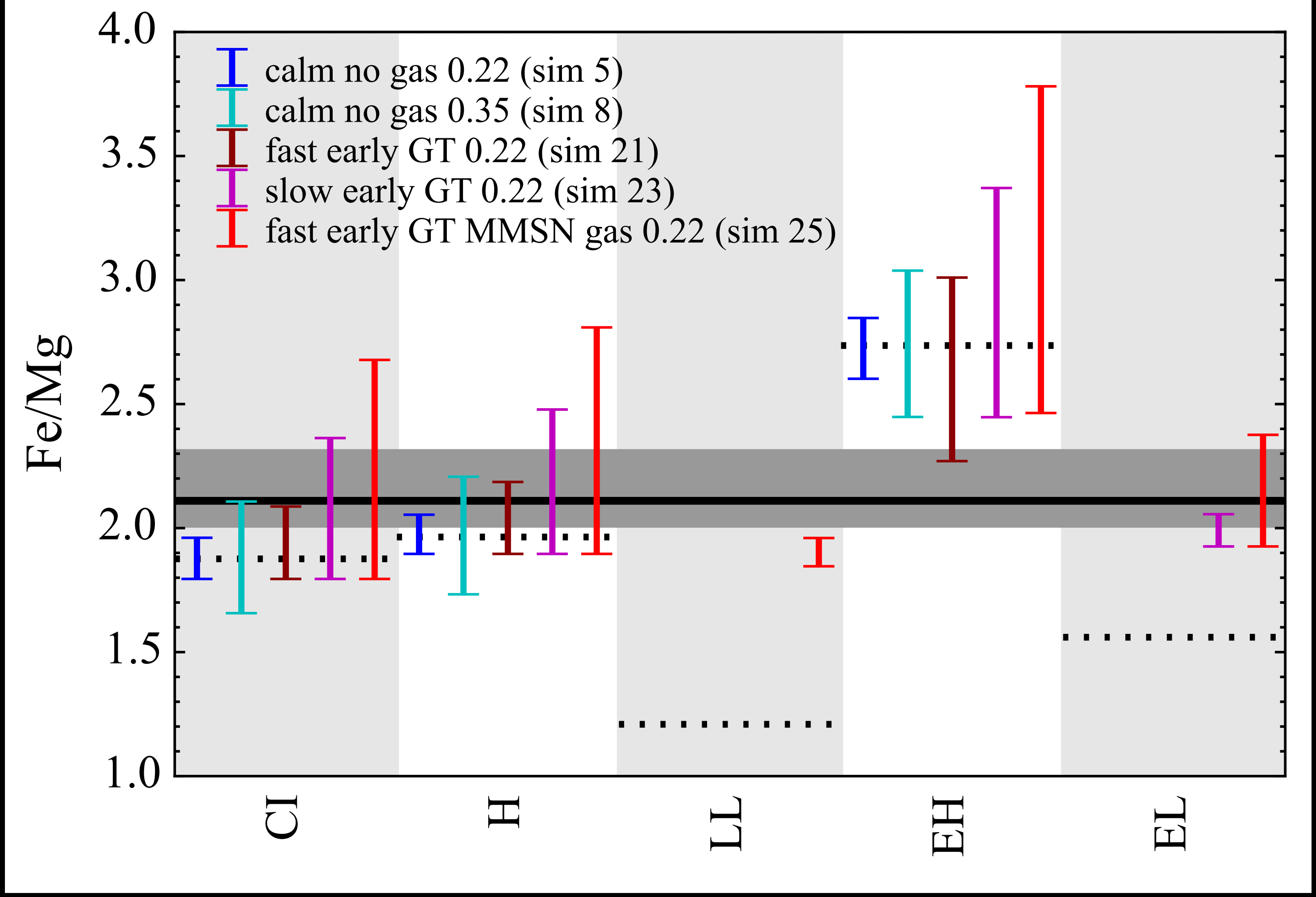
Carter et al. (2015)

Earth
(O'Neill & Palme 2008)

Grand Tack or highly reduced calm disc can naturally account for the Earth's non-chondritic Fe/Mg through collisional accretion during the intermediate stages of formation

Summary

Carter et al. (2015)



The collisions during accretion can significantly alter the chemical composition of terrestrial planet embryos, especially if excited by giant planet migration.

- Compositional changes work both ways. Some embryos show “core enhancement” others show “mantle enhancement”.
- Collisional accretion during the growth of terrestrial embryos may do enough to explain the non-chondritic nature of the Earth. The giant impact phase may further enhance the compositional changes.

For more PKDGRAV see posters by D Veras and S Lines

Mixing

Carter et al. (2015)