Planetesimal Collisions as Clues to the Early Dynamic History of the Solar System

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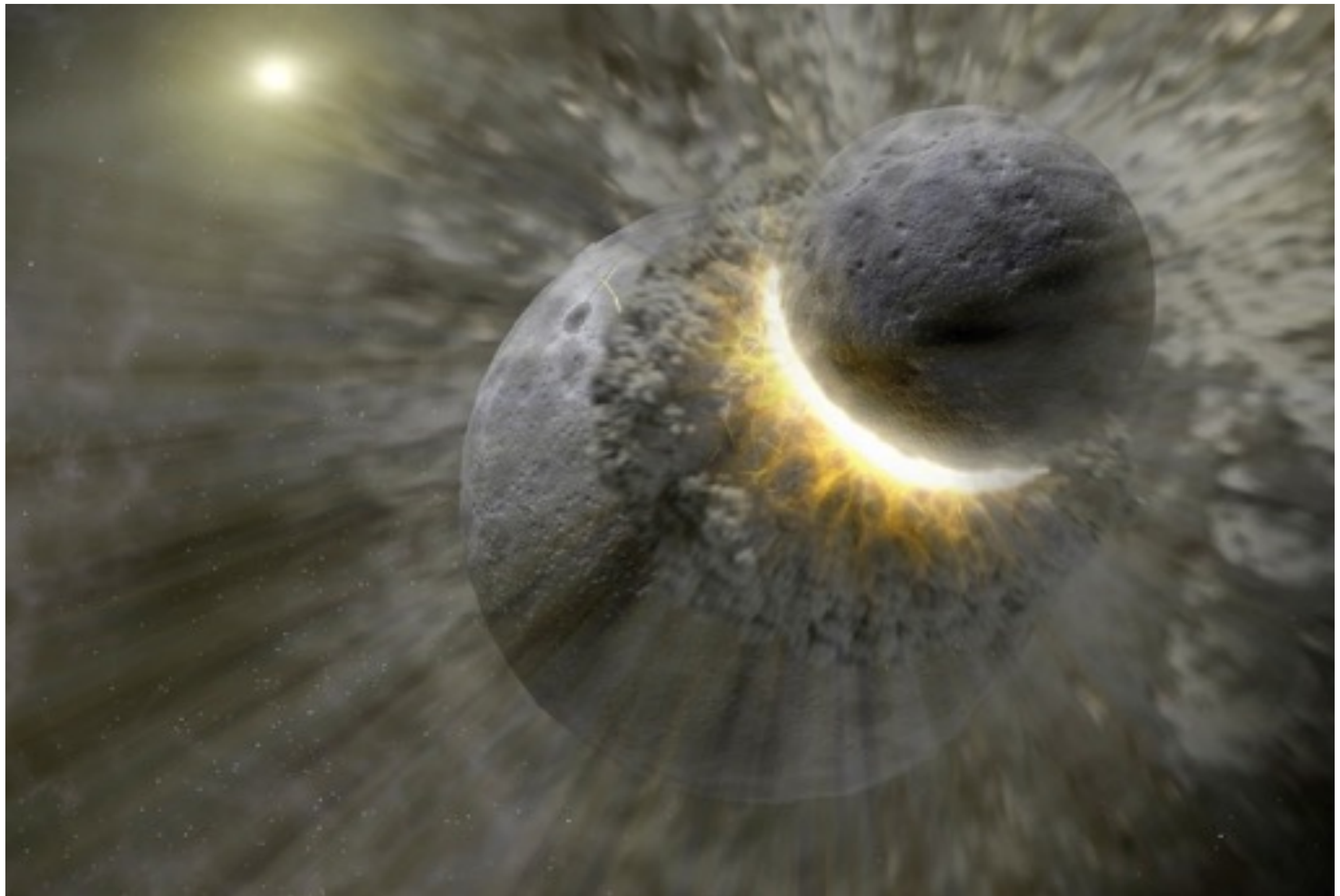
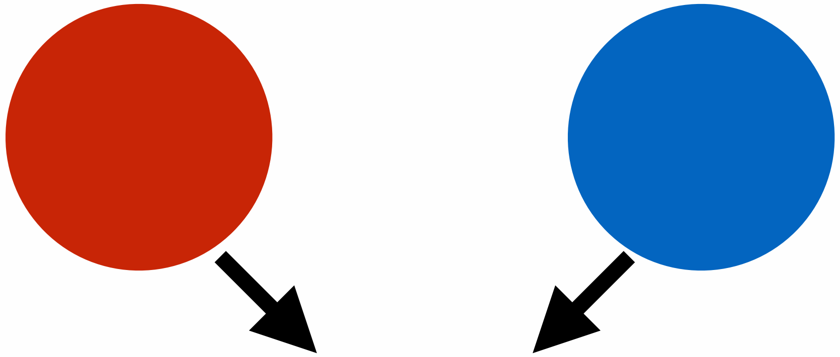



Bill Hartmann Art

Planetesimals begat planets.



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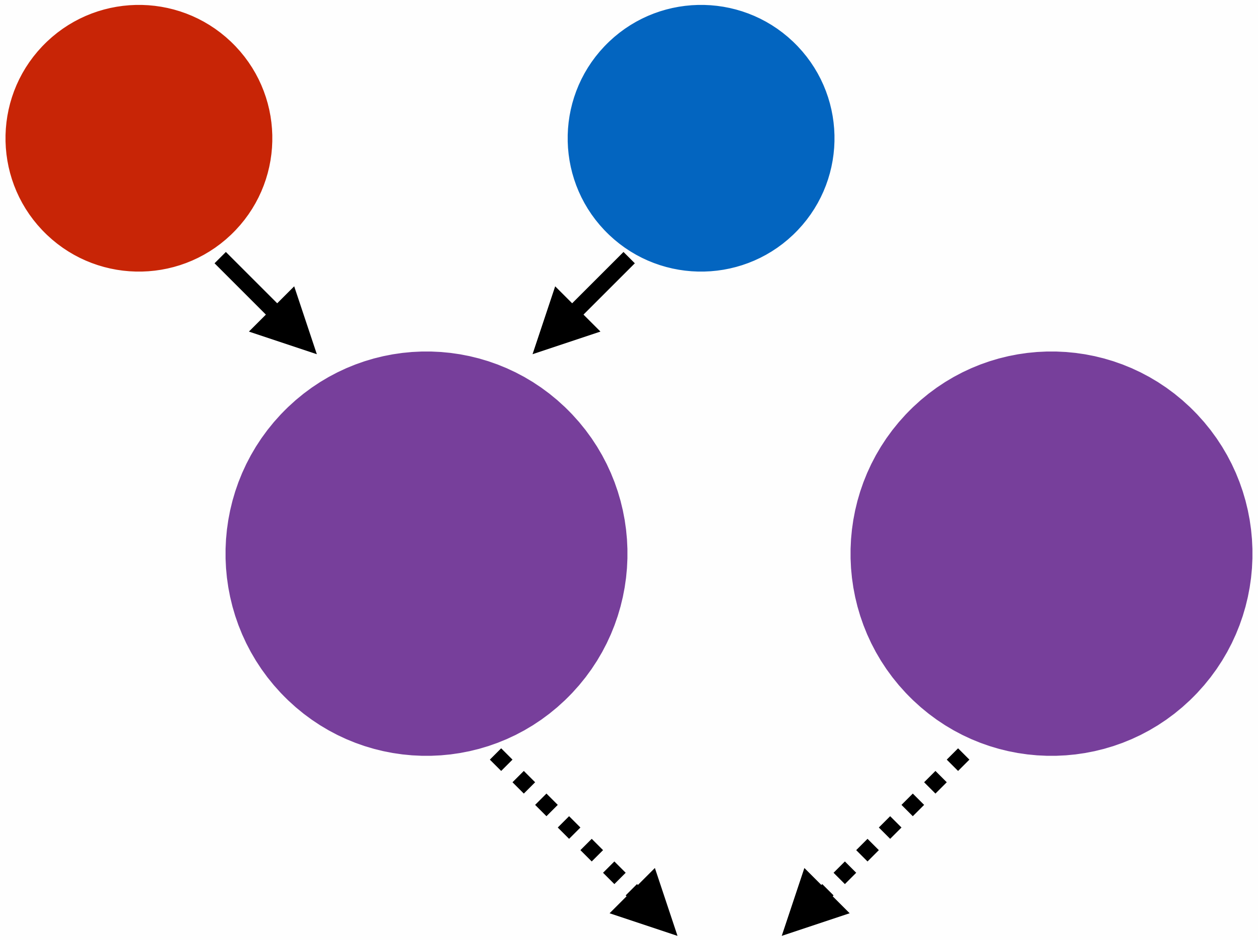

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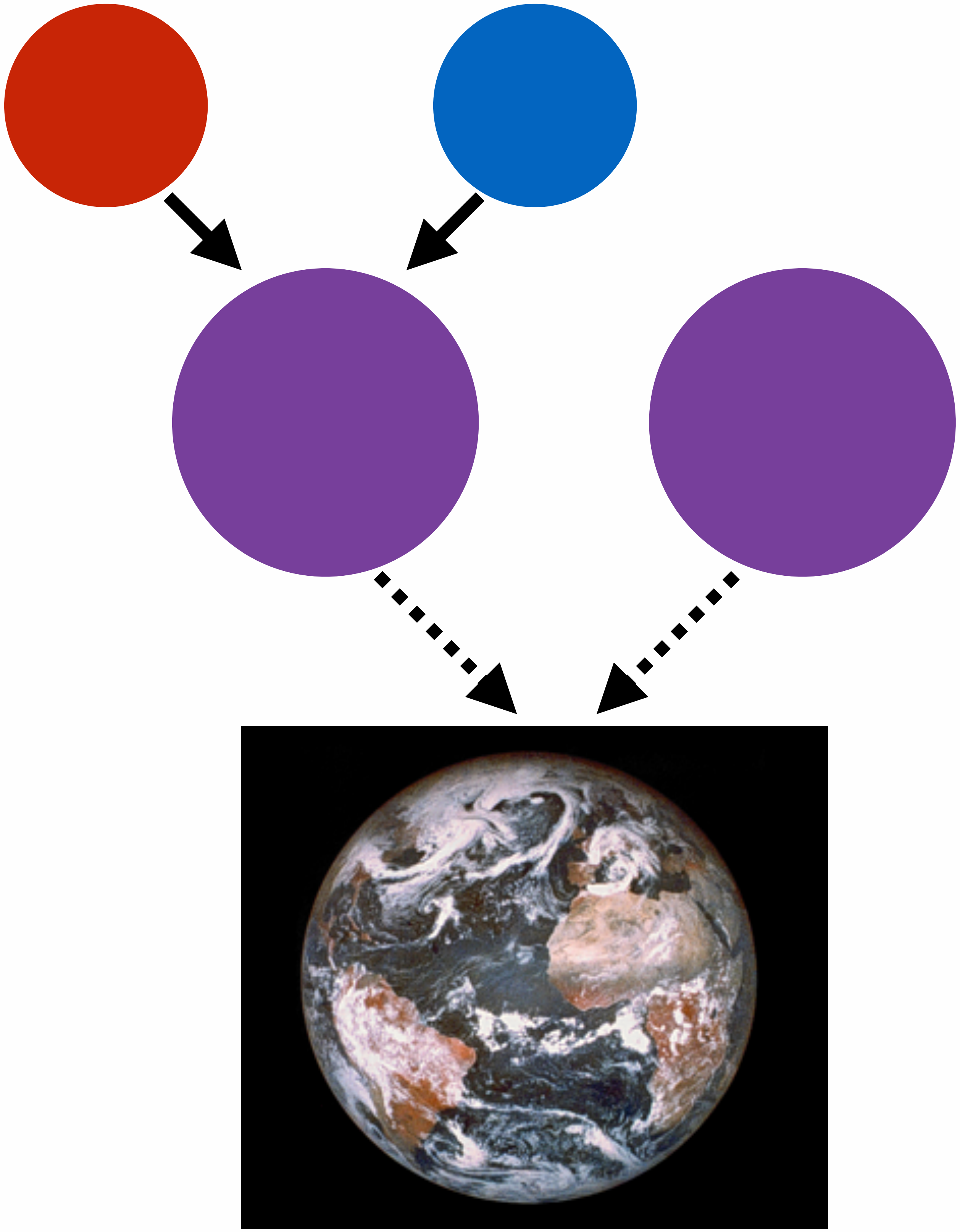

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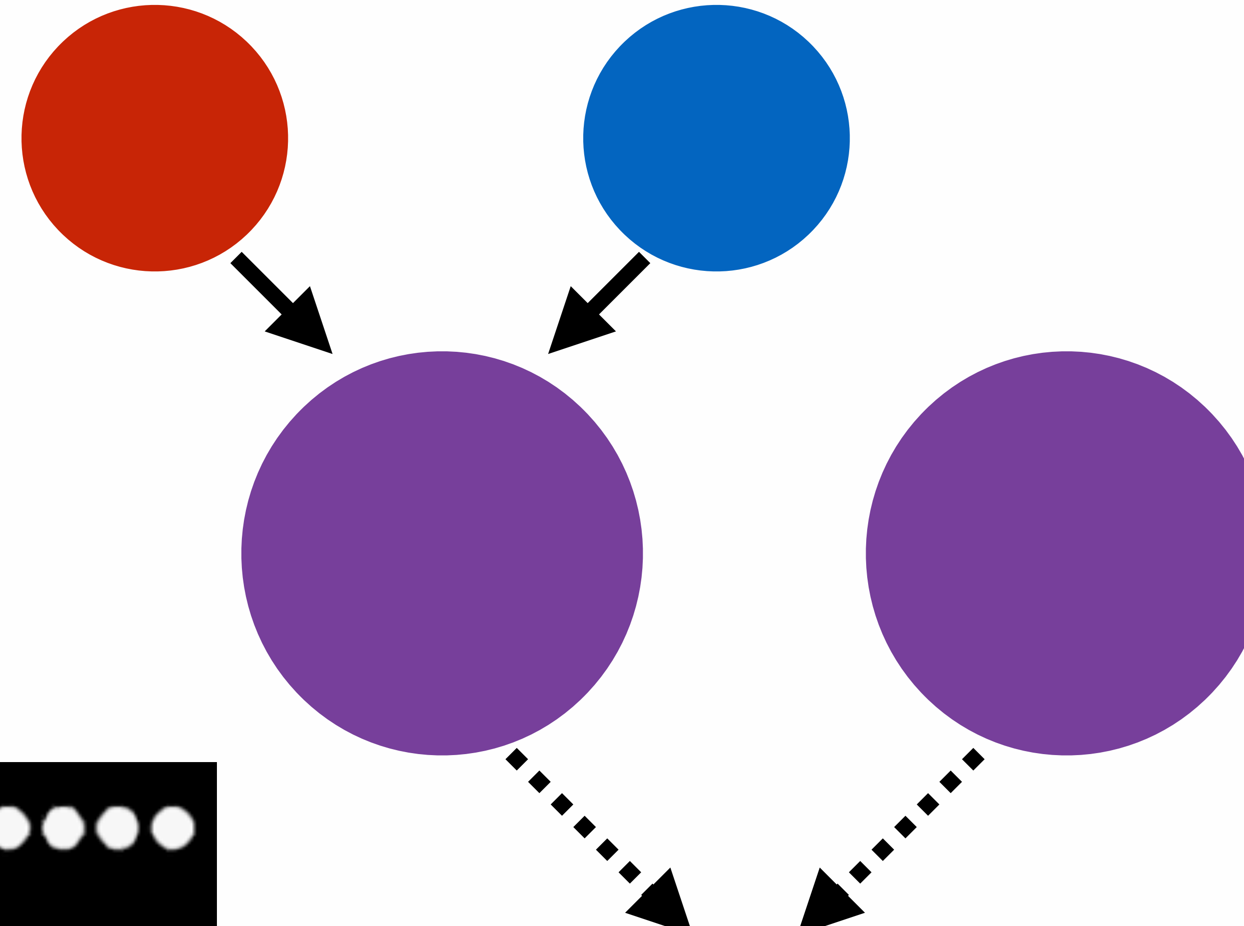

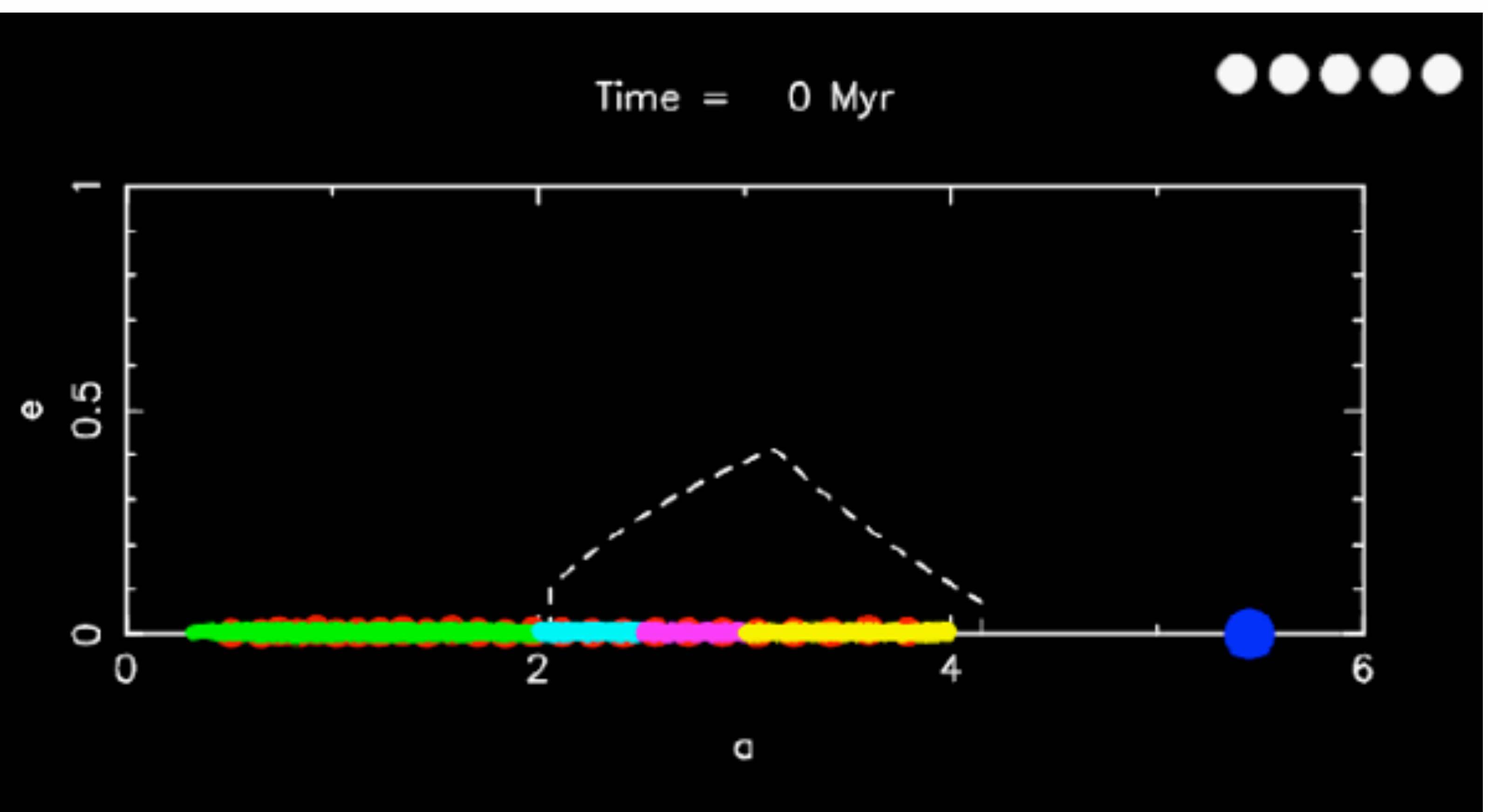

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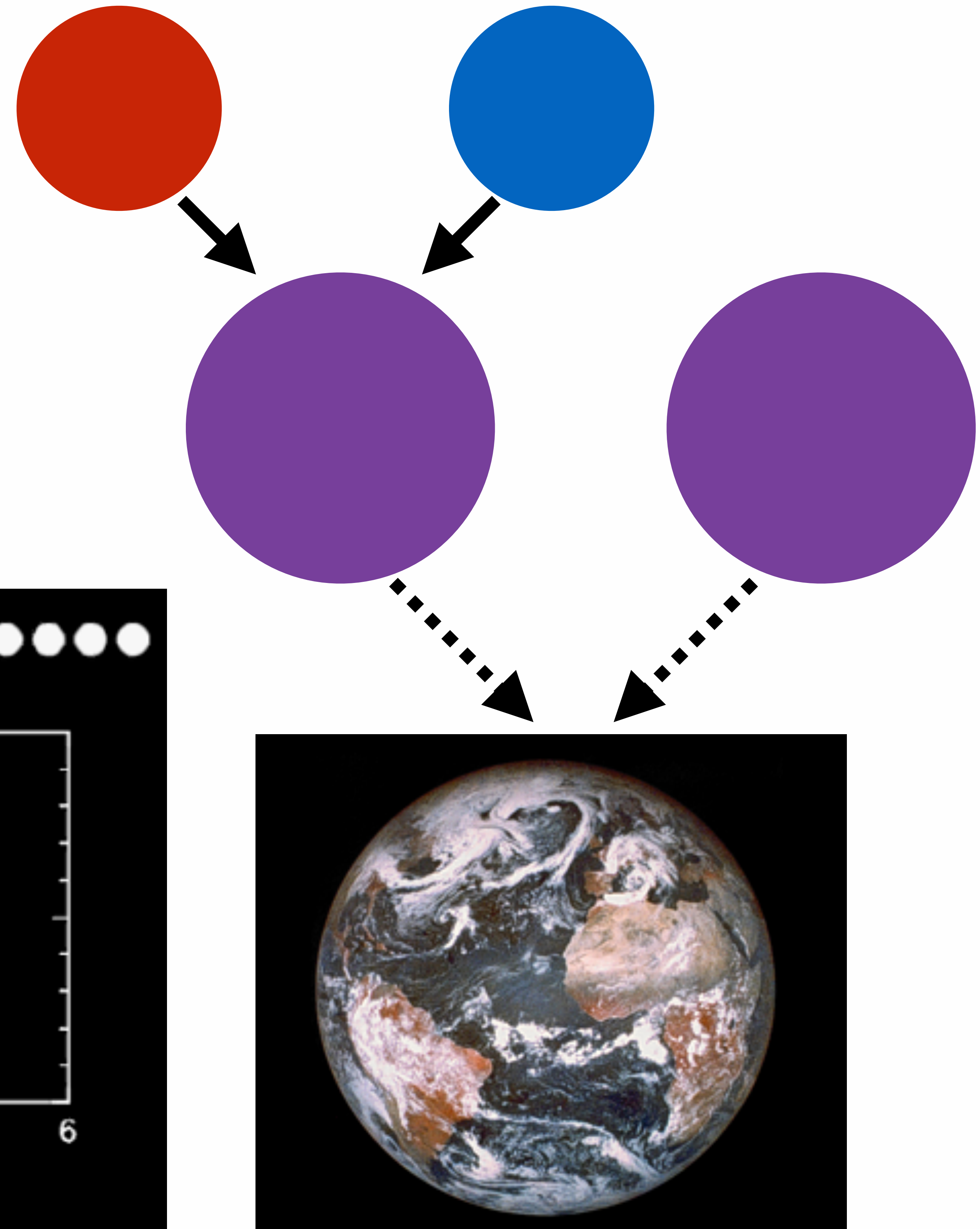

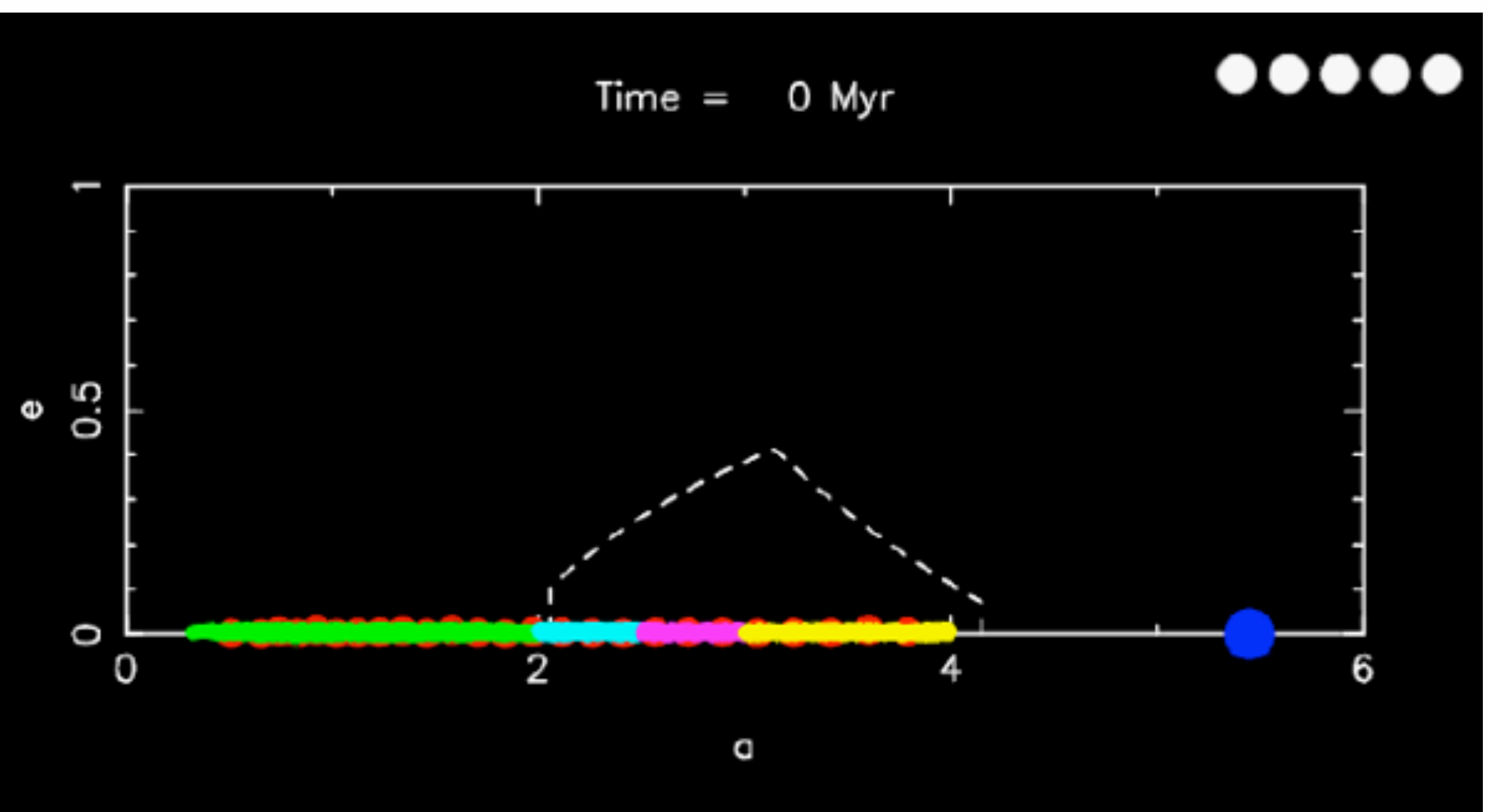

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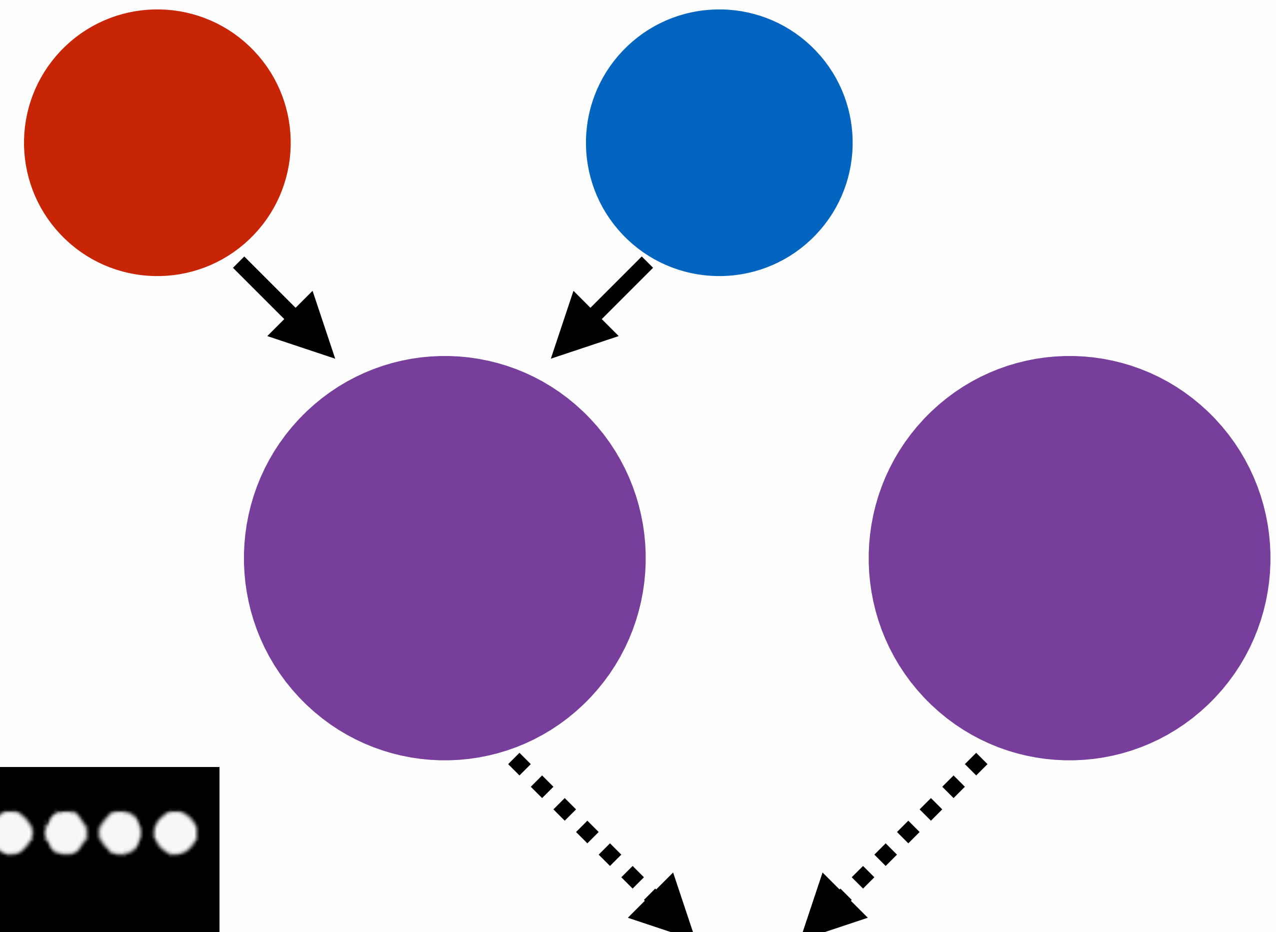
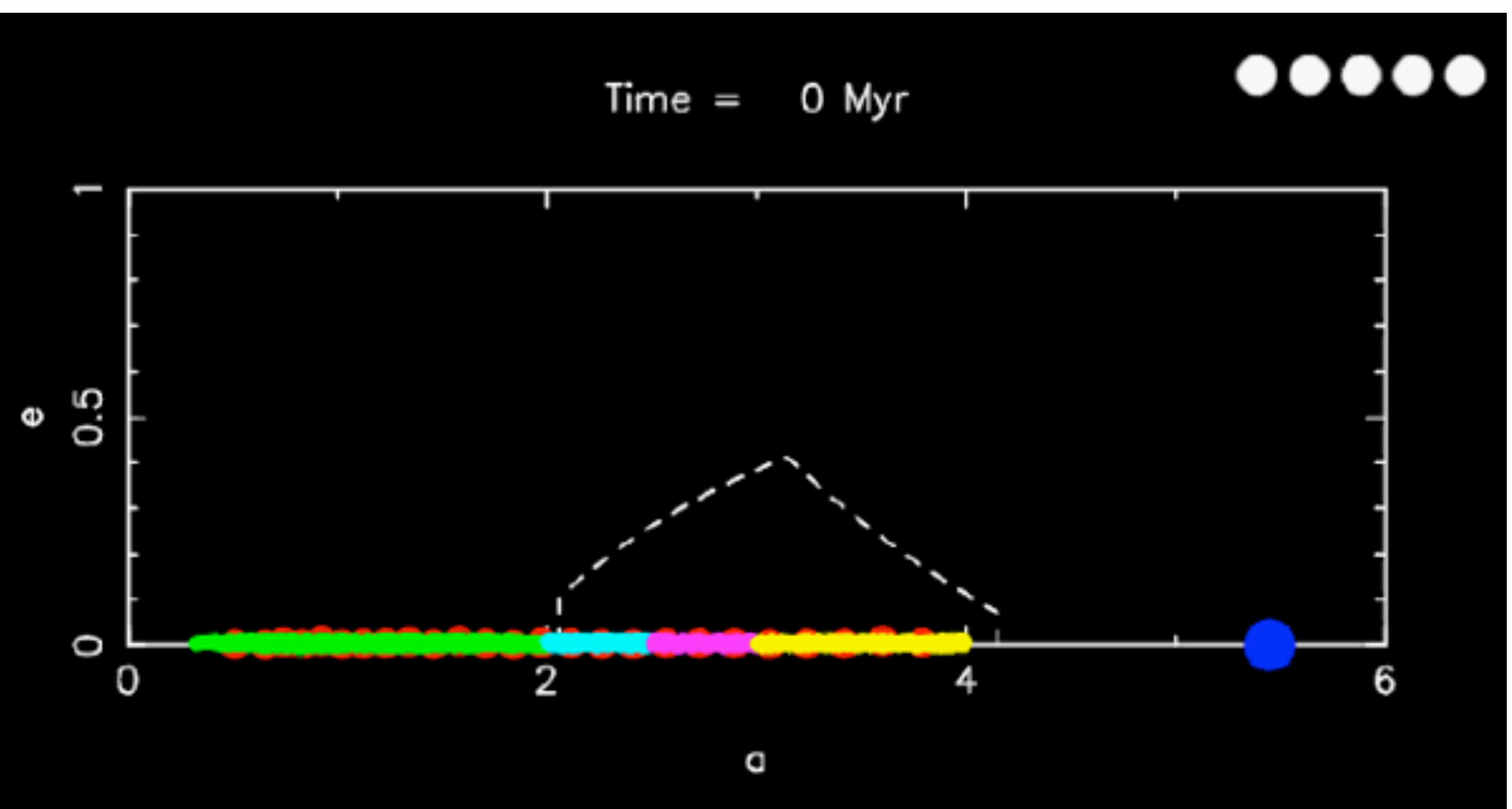
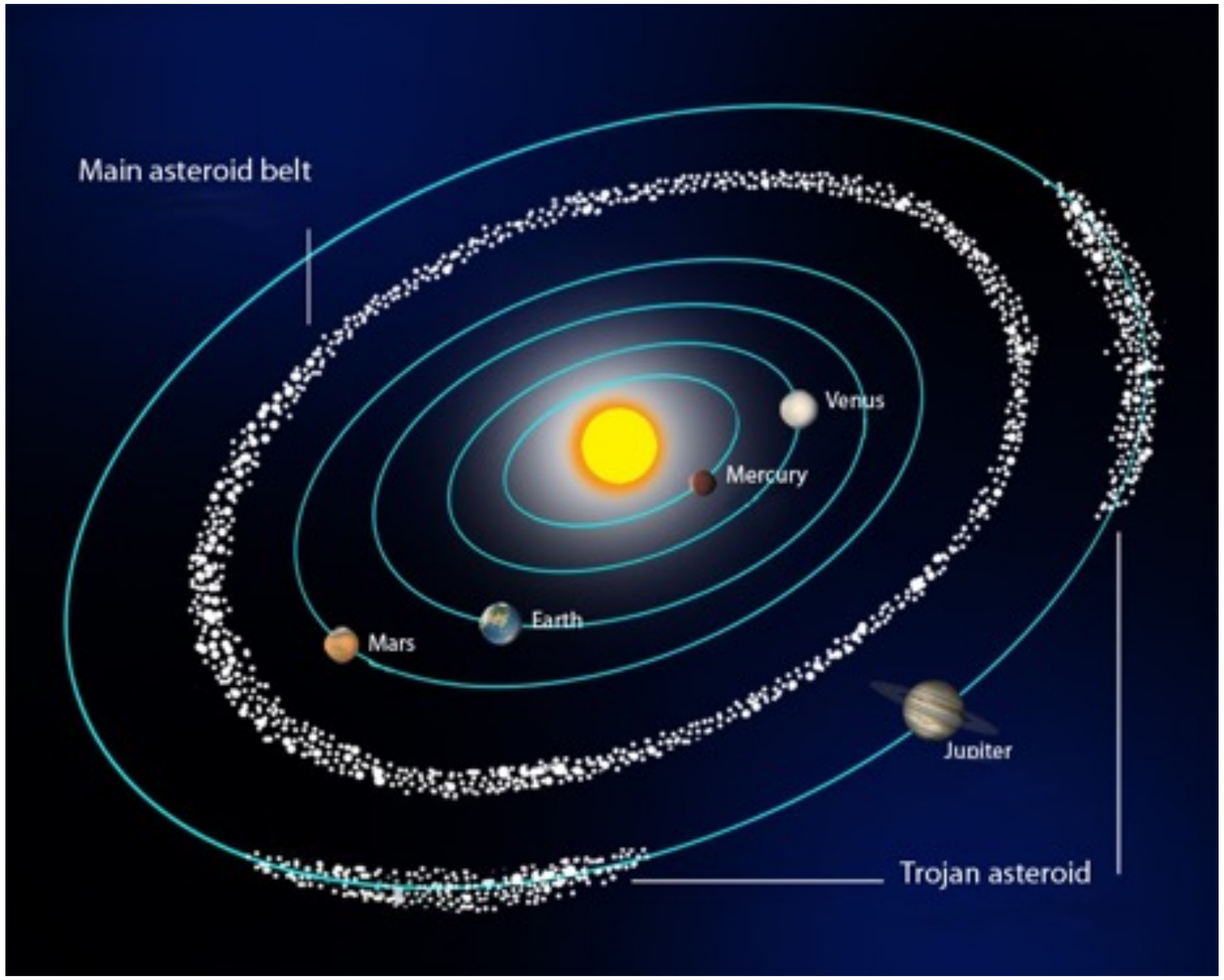




Asteroids are leftover planetesimals and provide clues to the early solar system.



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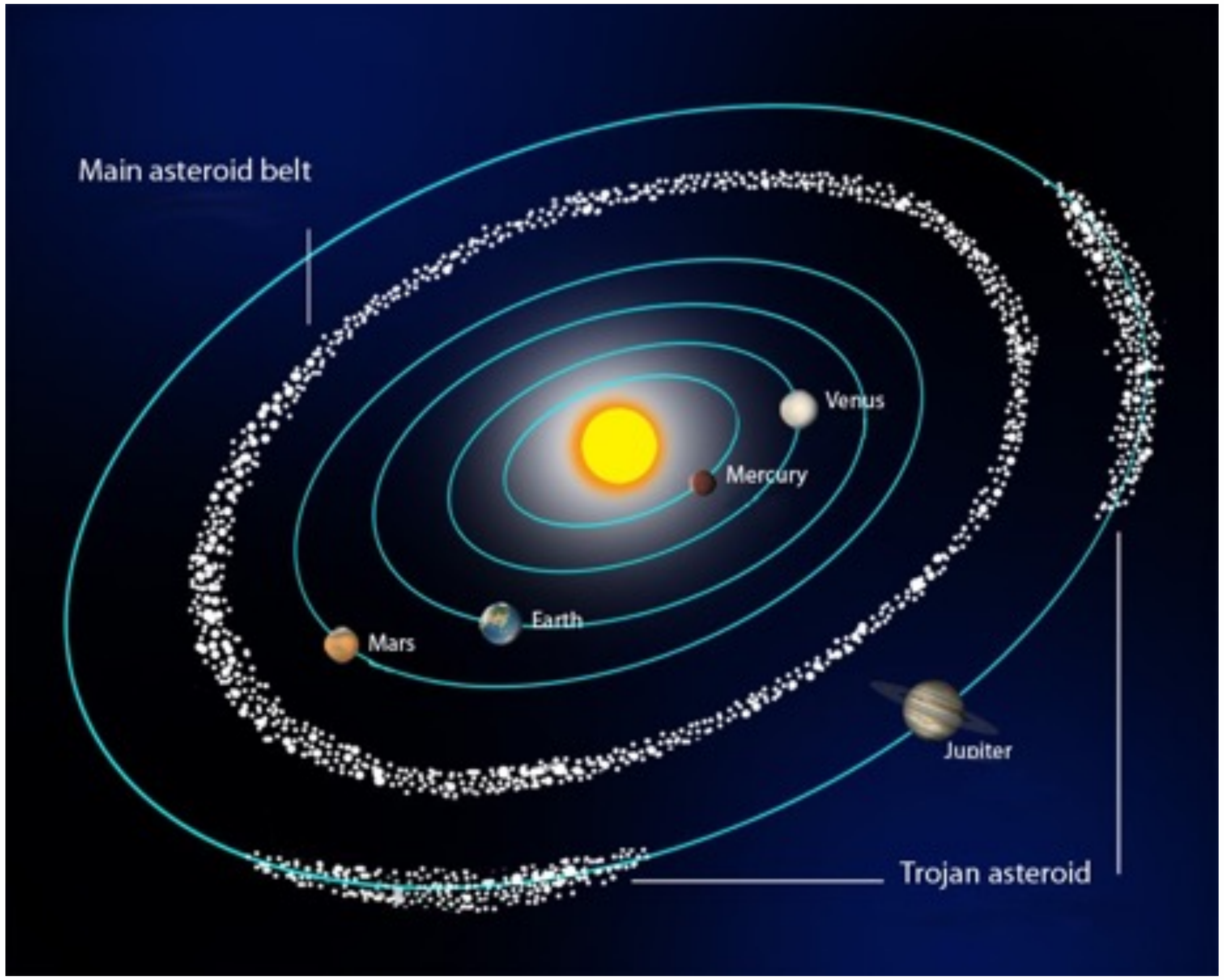
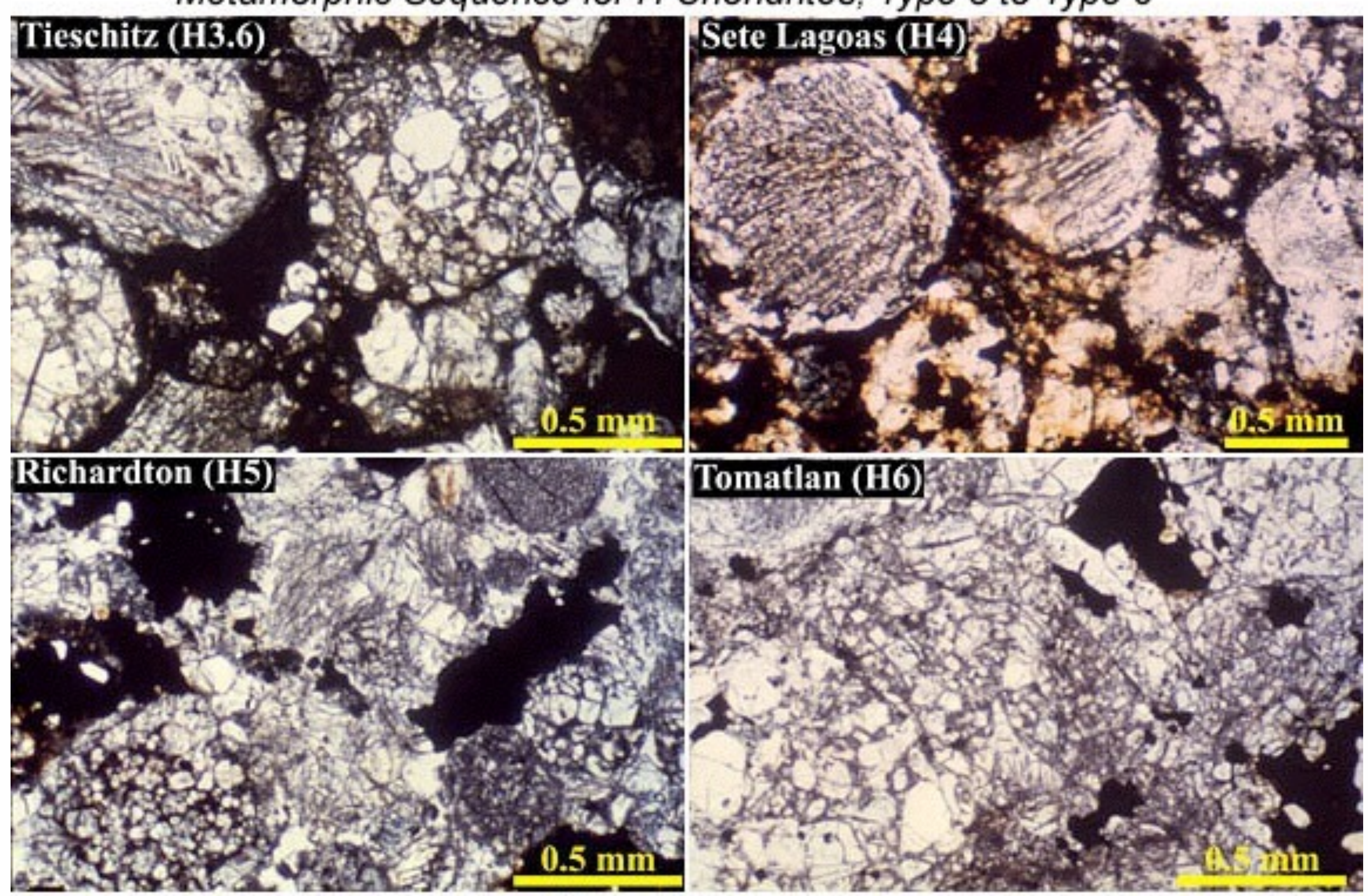


Few meteorites are perfectly pristine samples.

- Meteorites record significant geophysical processing on their parent bodies
    - *Melting and Differentiation of Irons and Achondrites*
    - *Metamorphism in Chondritic meteorites*
- This alters the physical and chemistry properties of the bulk meteorite and their individual components.

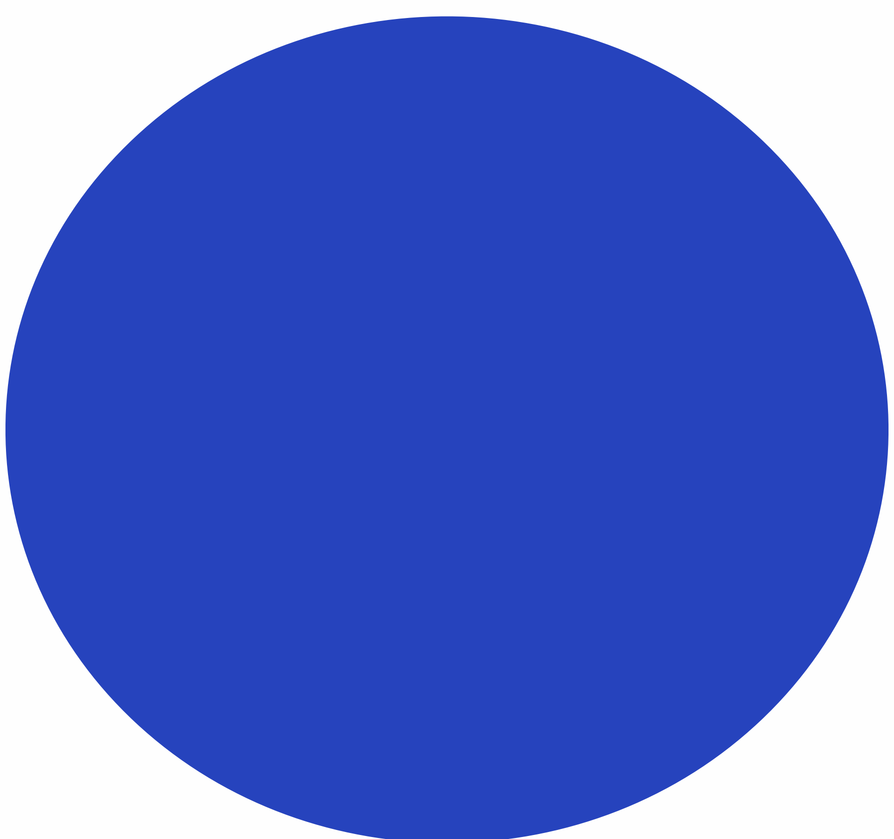
Metamorphic Sequence for H Chondrites, Type 3 to Type 6



Radiogenic heating is believed to be largely responsible for planetesimal processing.

- Decay of short-lived radionuclides provided energy to heat early Solar System bodies
  - ^{26}Al - $t_{1/2} = 0.7$ *Ma*

- Favored as the most important (or only) heat source



$^{26}\mathrm{Al} \longrightarrow {}^{26}\mathrm{Mg} + \mathrm{Heat}$

$$\rho C_p \frac{\partial T}{\partial t} = \frac{1}{r^2}\frac{\partial}{\partial r}\left(K r^2 \frac{\partial T}{\partial r}\right) + A_0(r, t)$$

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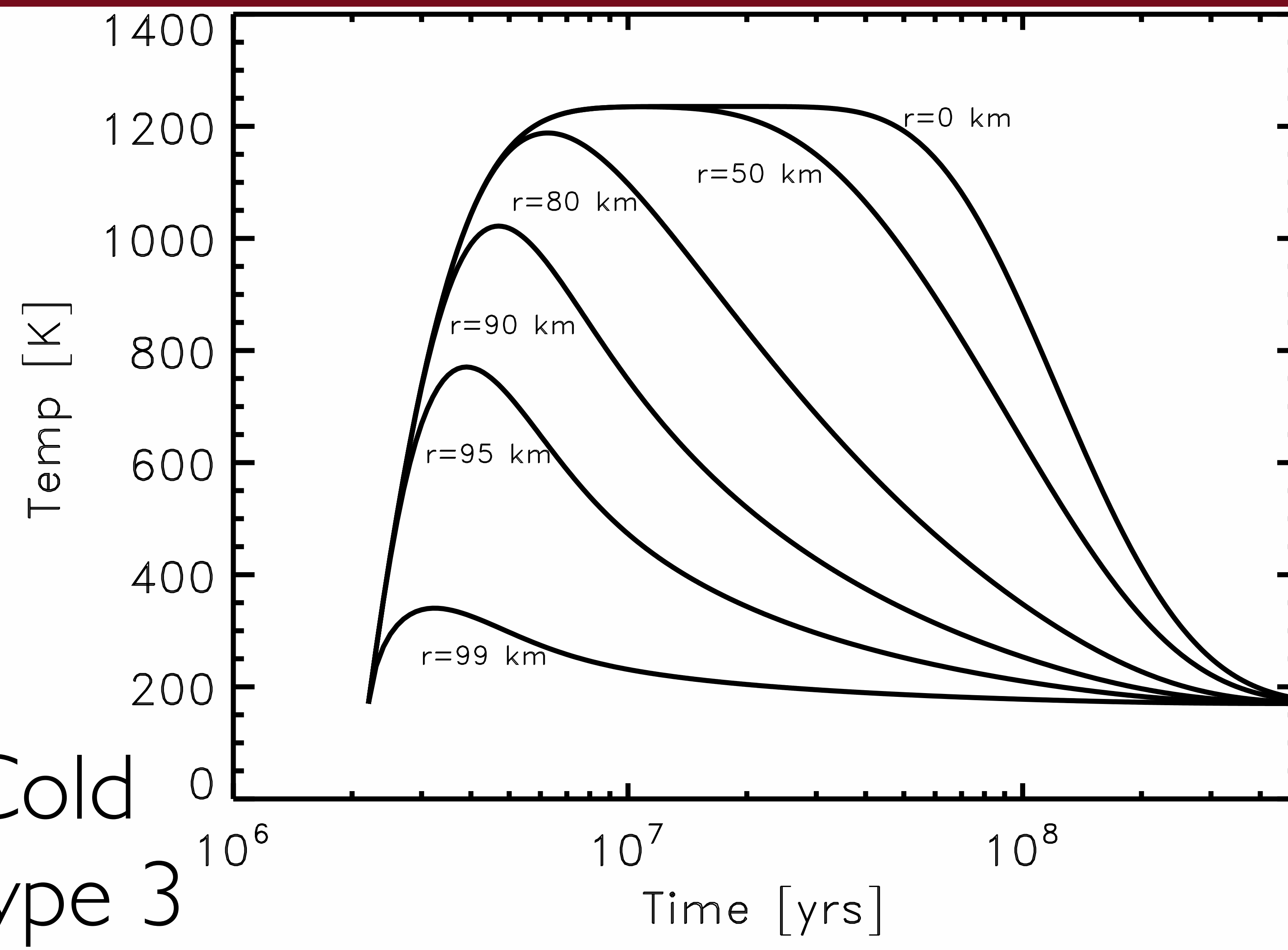

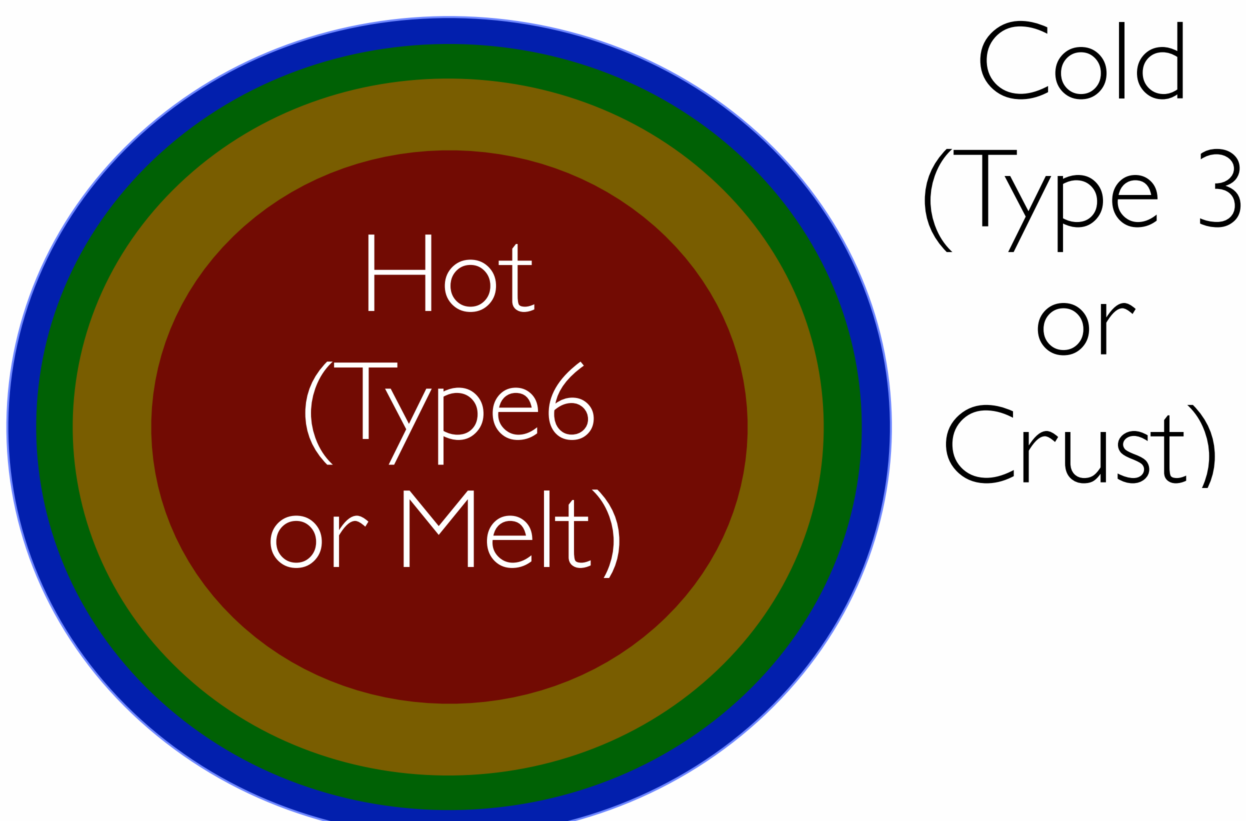

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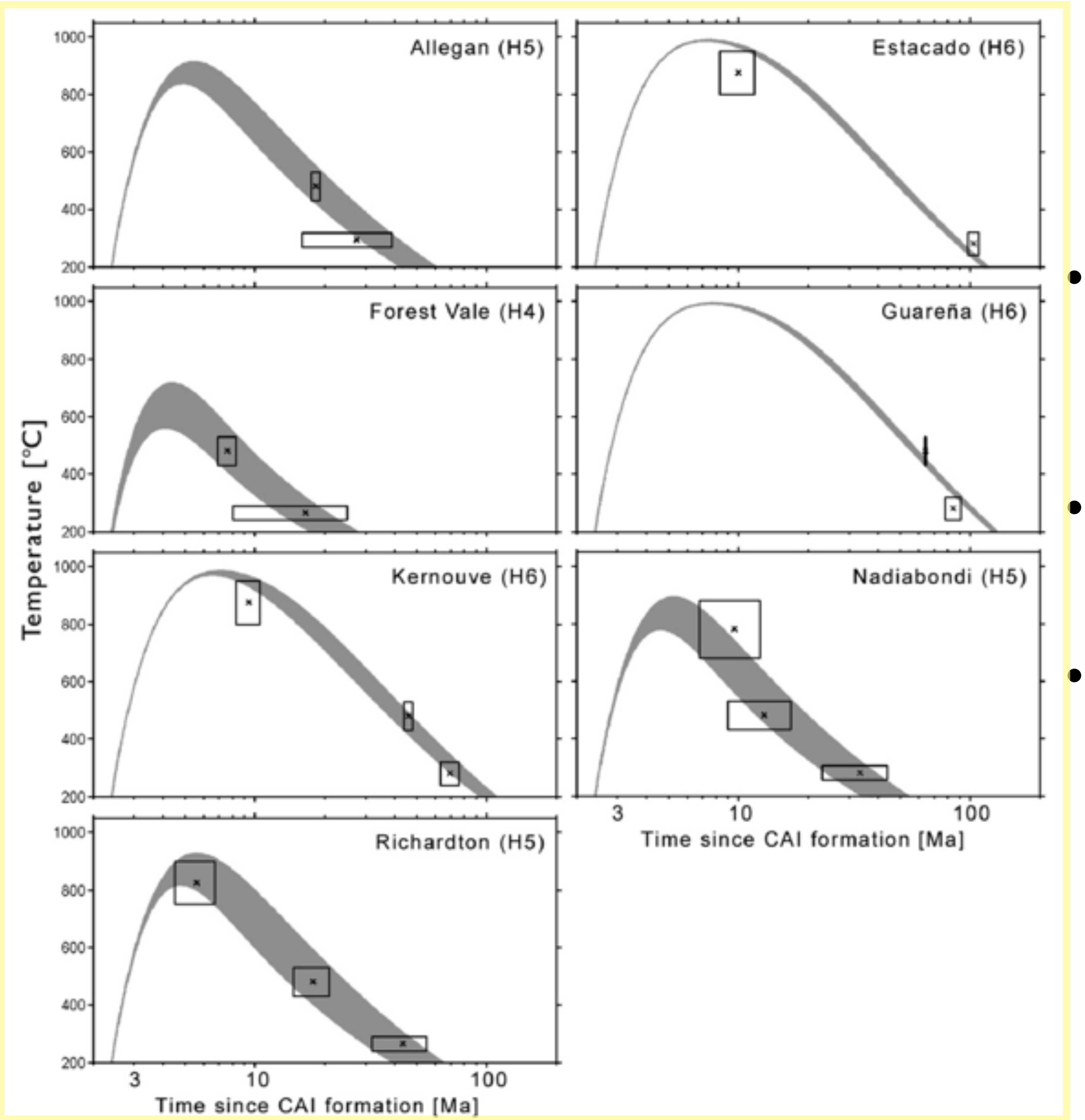
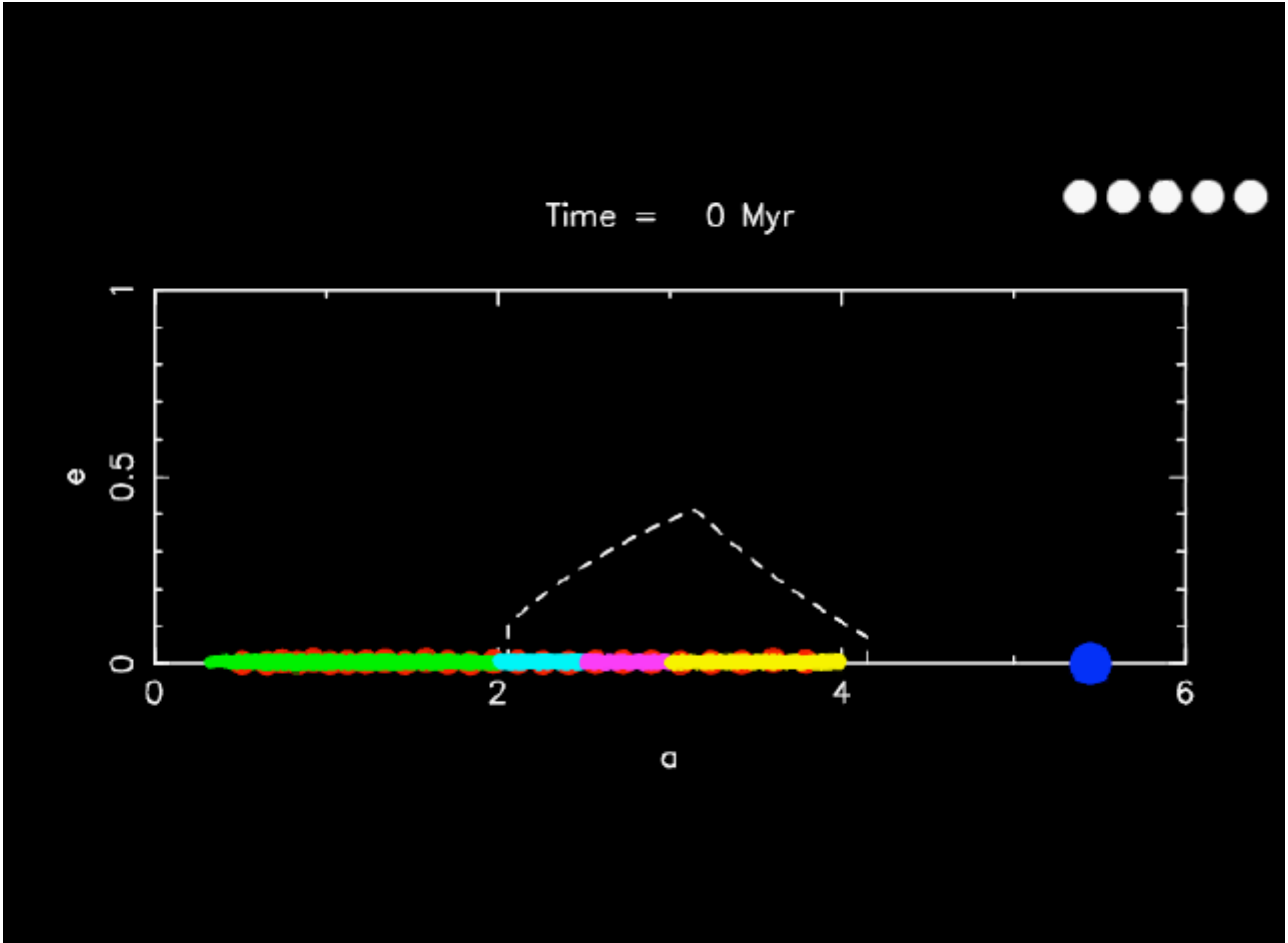
Models for thermal evolution do *fairly* well in matching data.



- 8 H chondrites with chronological constraints on cooling
- Harrison and Grimm (2010) model matched 7 meteorites
- H-chondrite parent body constrained to be R_p~100 km and form 2.2 Myr into Solar System evolution

Planetesimal collisions were most frequent and energetic during planetary accretion.



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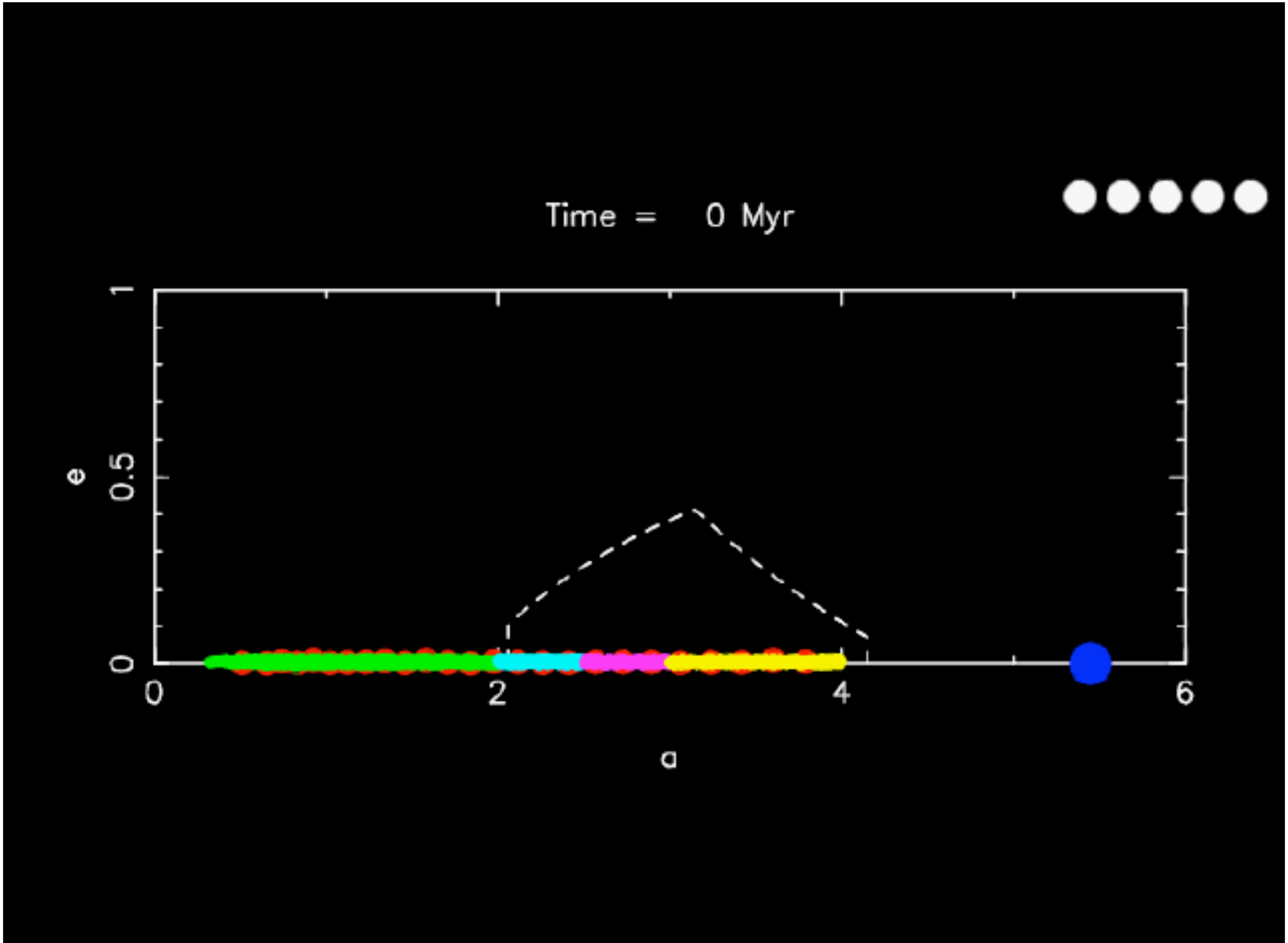

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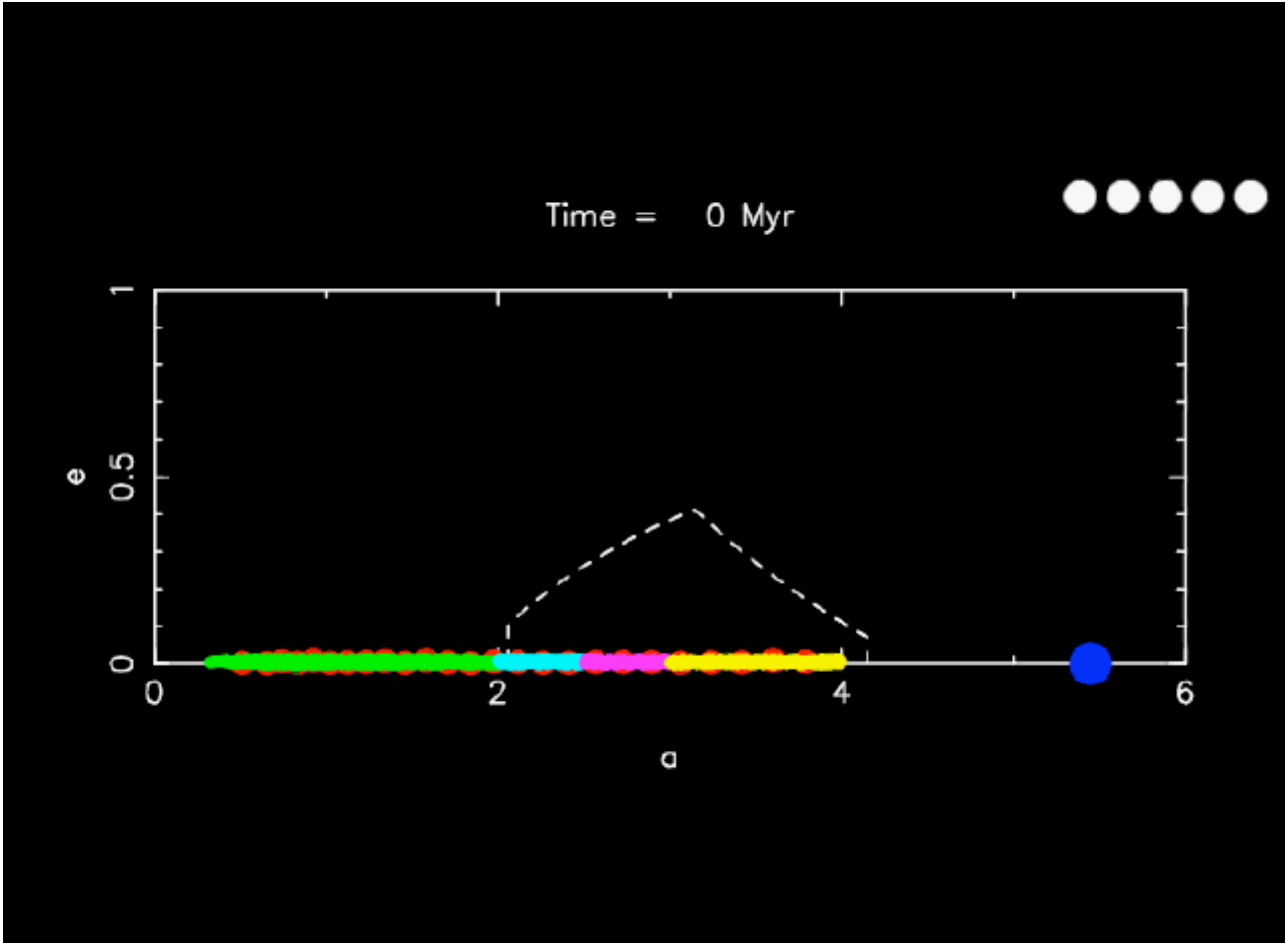
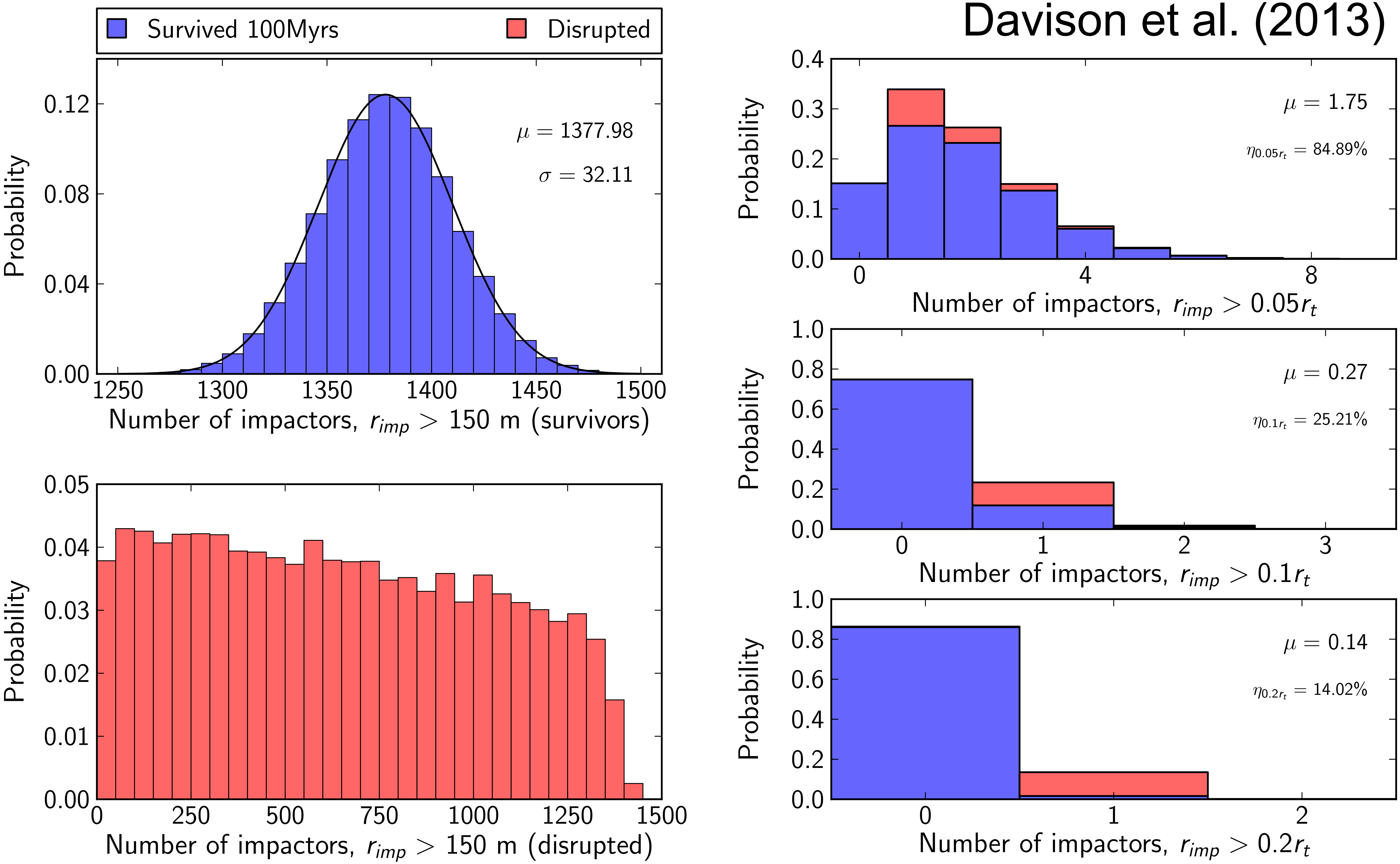


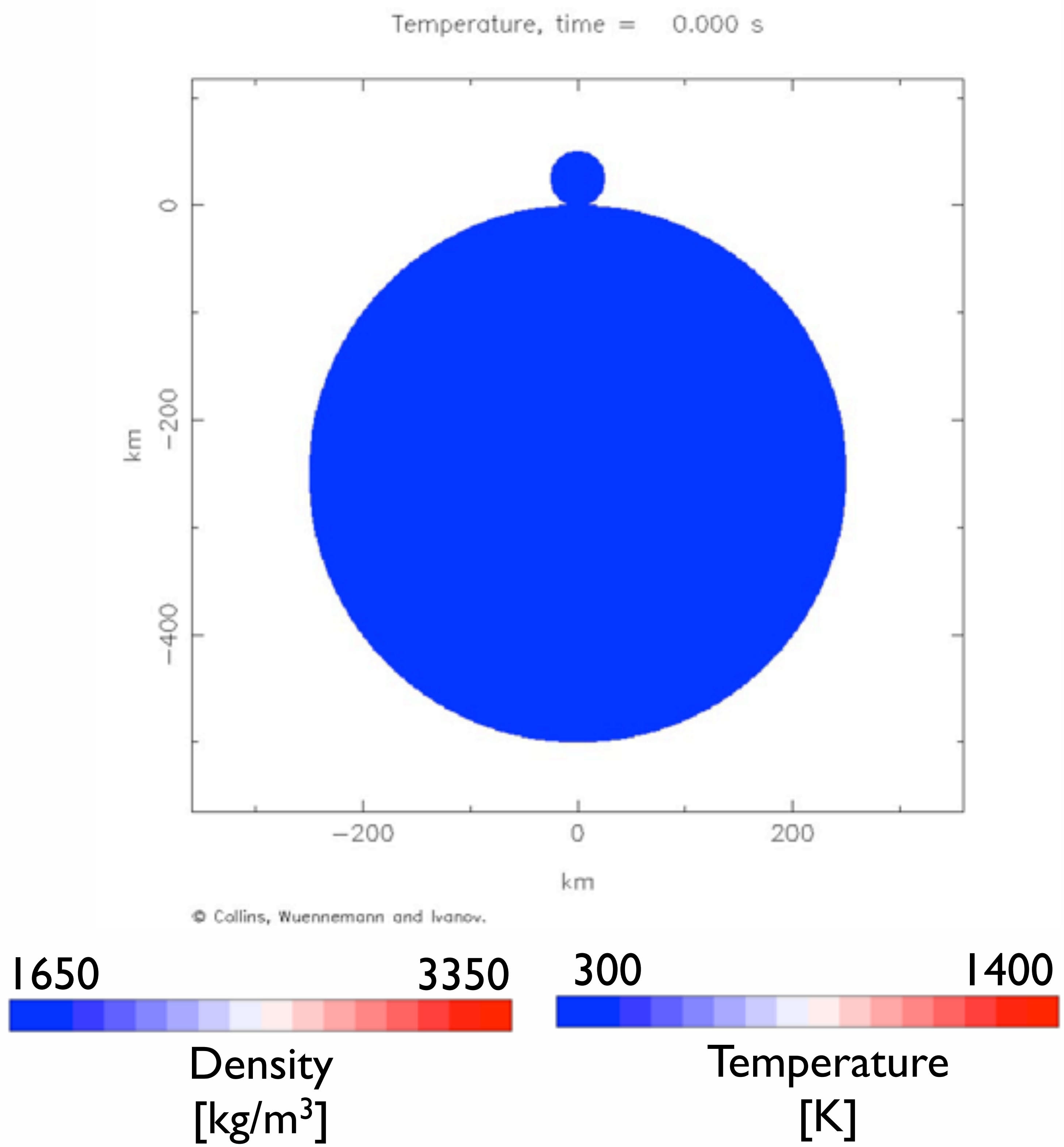
All planetesimals experience collisions throughout the first 100 Myr.

Davison et al. (2013)



Impacts create localized effects, affecting a small fraction of the body.

- iSALE hydrocode simulations of impact
- 100 km radius dunite target
- 10 km radius dunite impactor @ 4 km/s
- Equivalent energy of the most energetic impact 100% of bodies of this size would experience.



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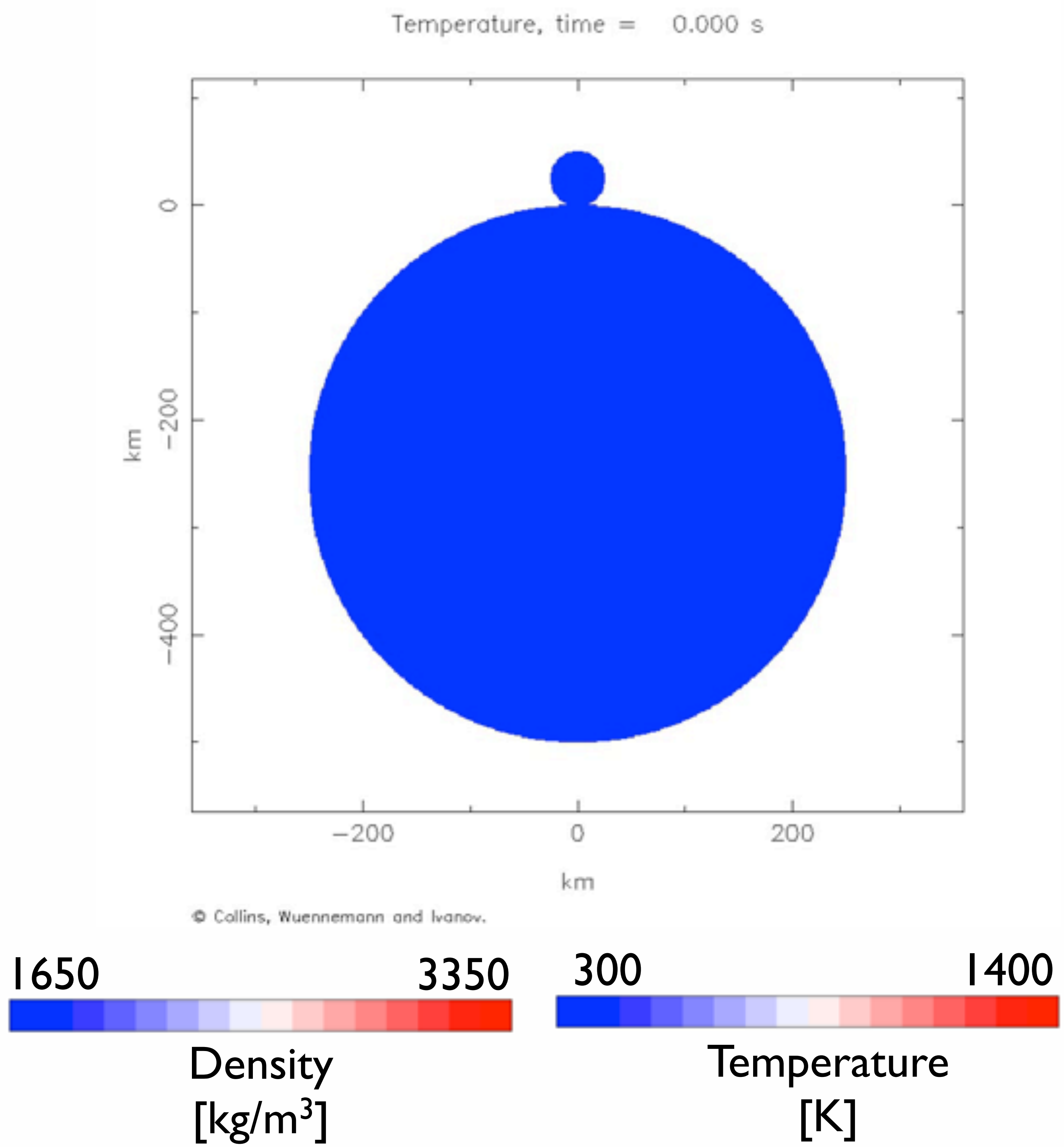

Heat from an impact can persist for same time as radiogenic heat.

- Solve 2D heat equation
  - No radiogenic heat
- Evolution of post-impact temperature anomaly
  - 10 Myrs, T_{peak} > 1100K
  - 20 Myrs, T_{peak} > 900K
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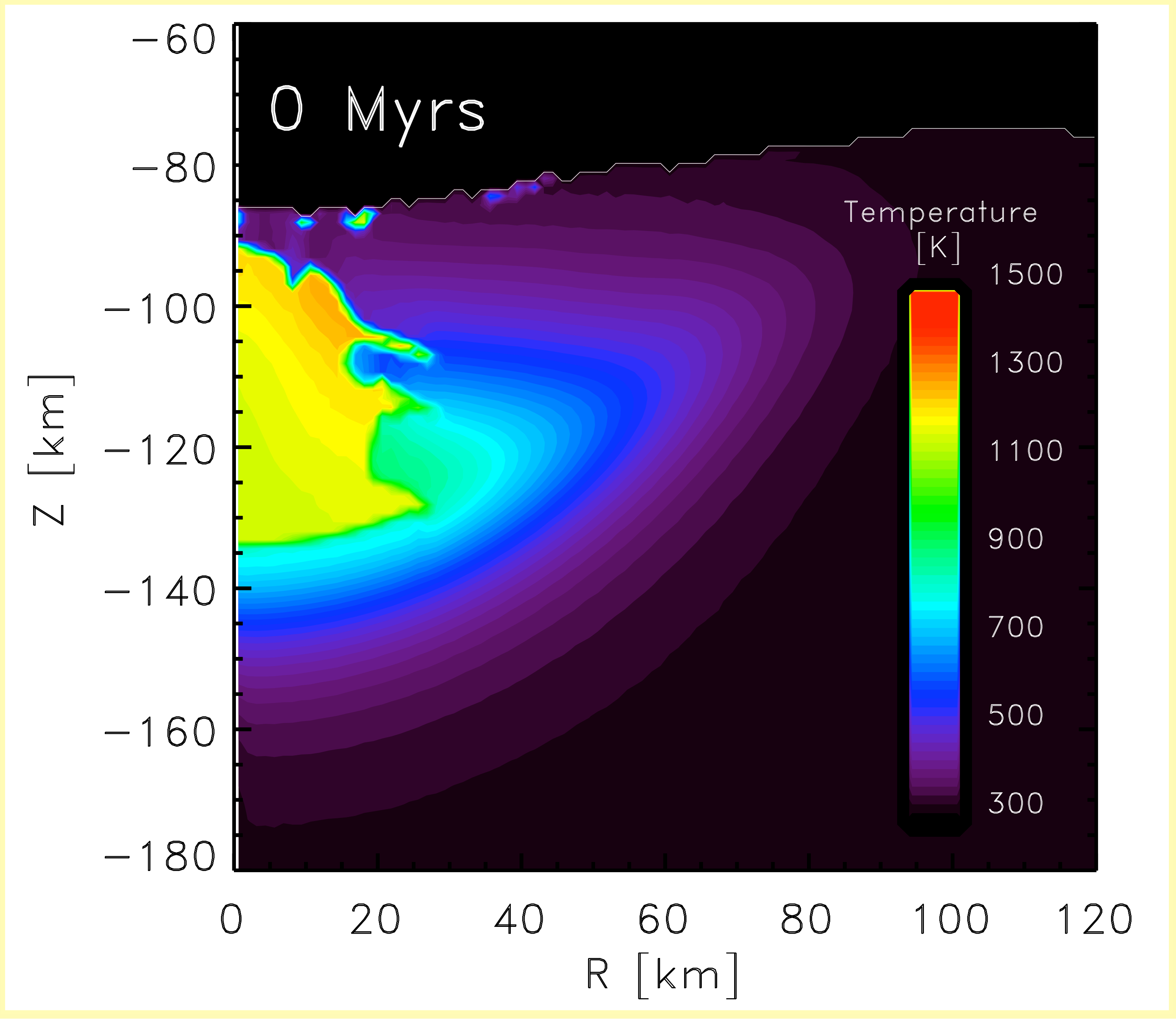

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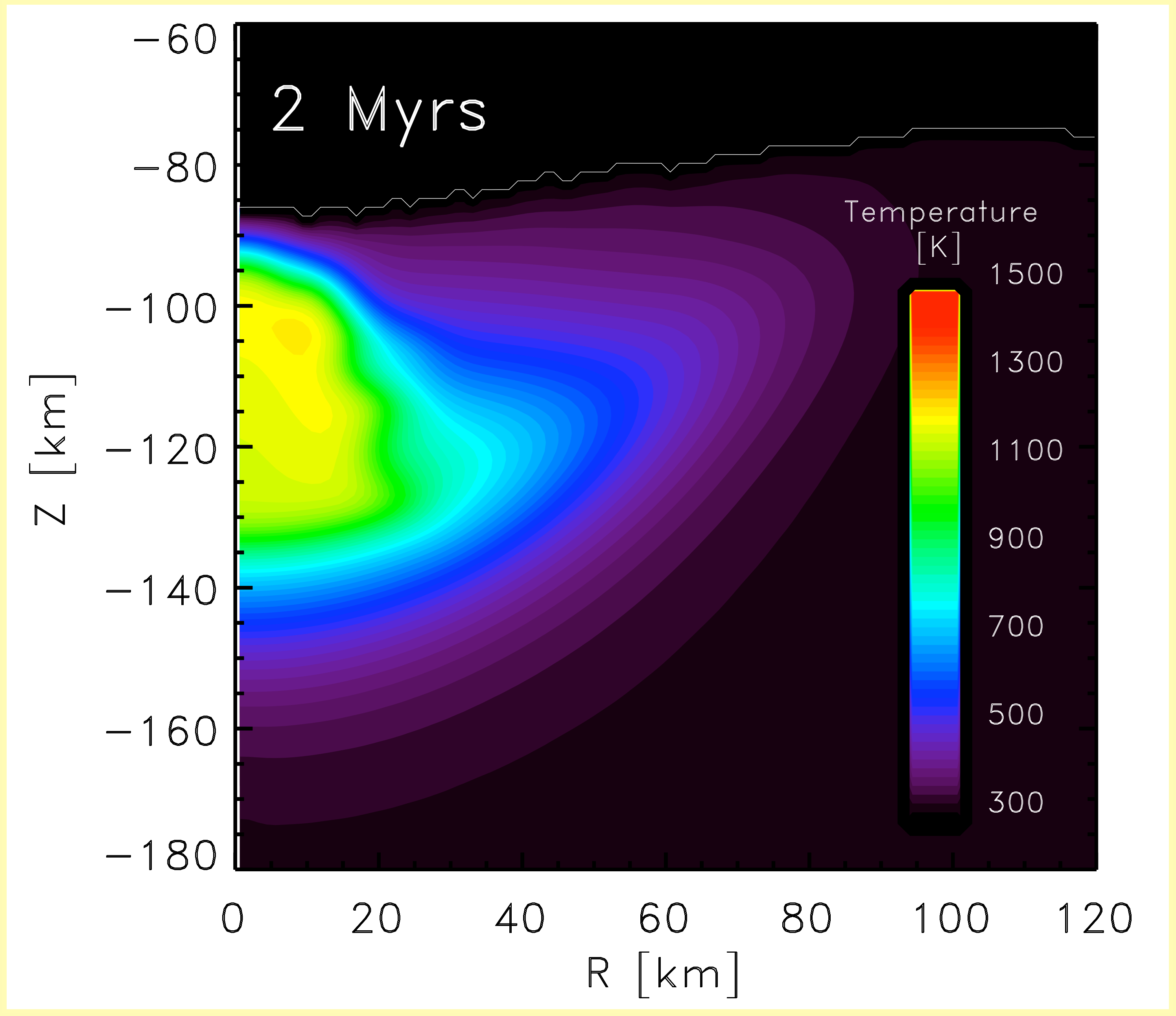

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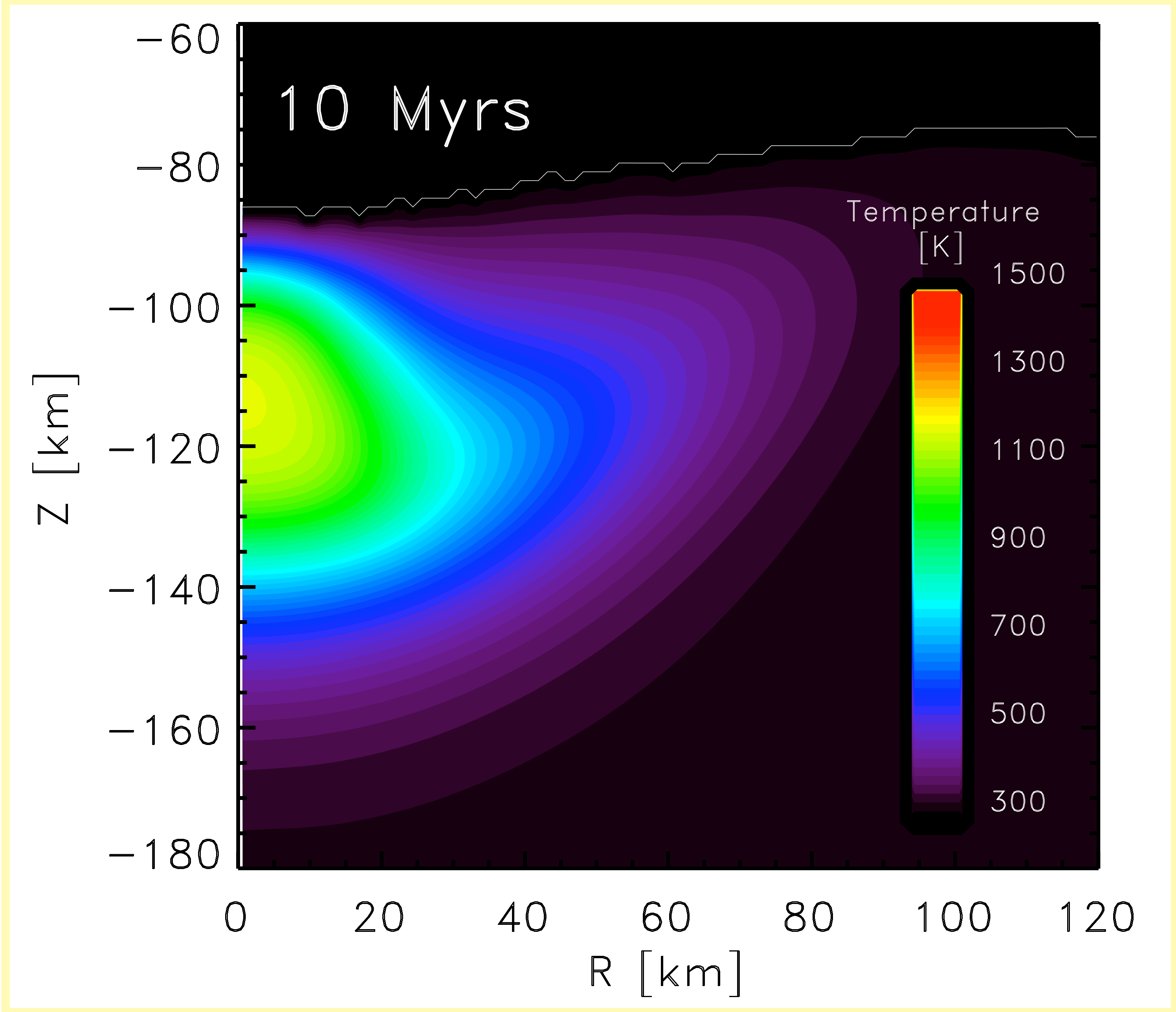

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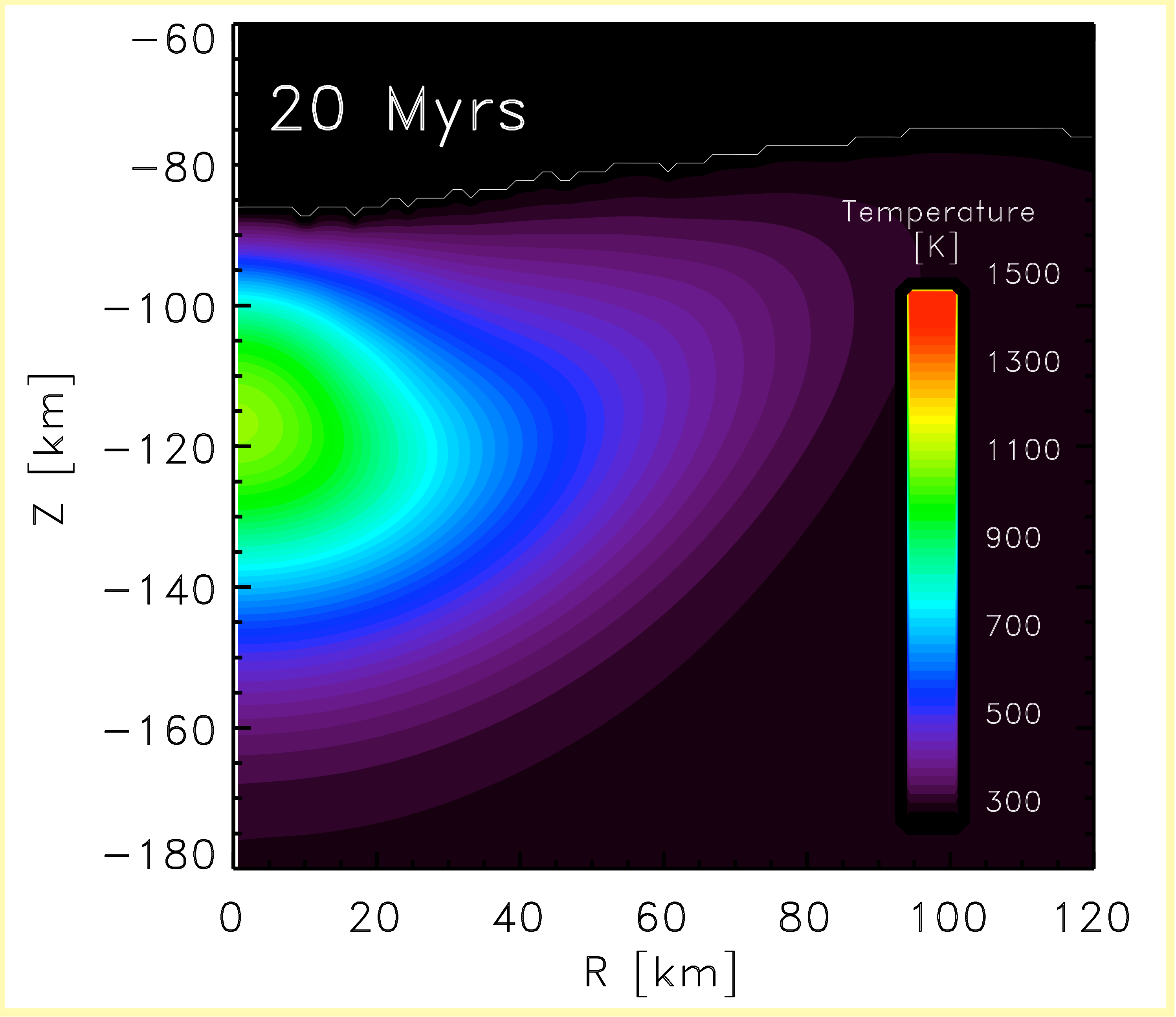

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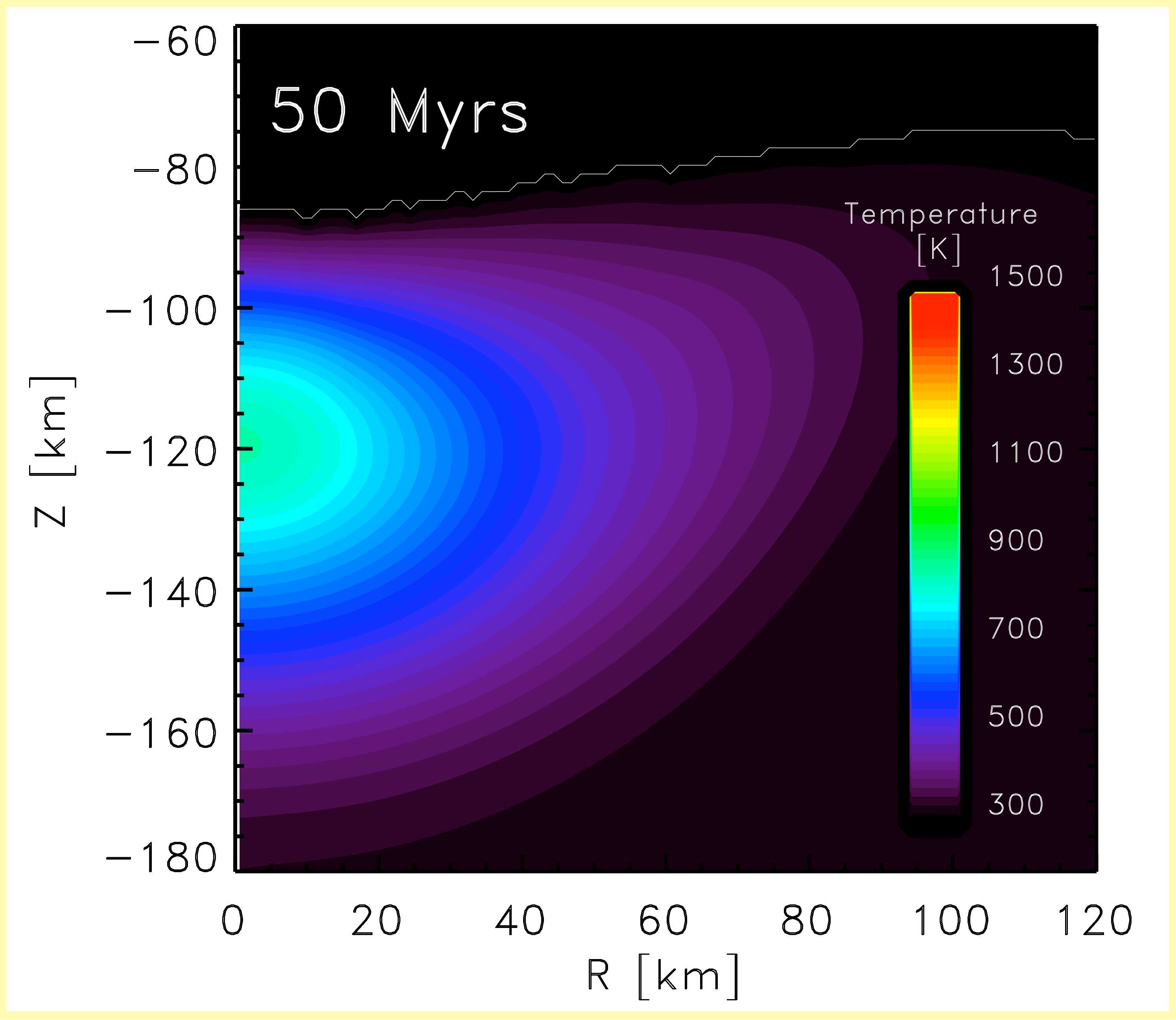

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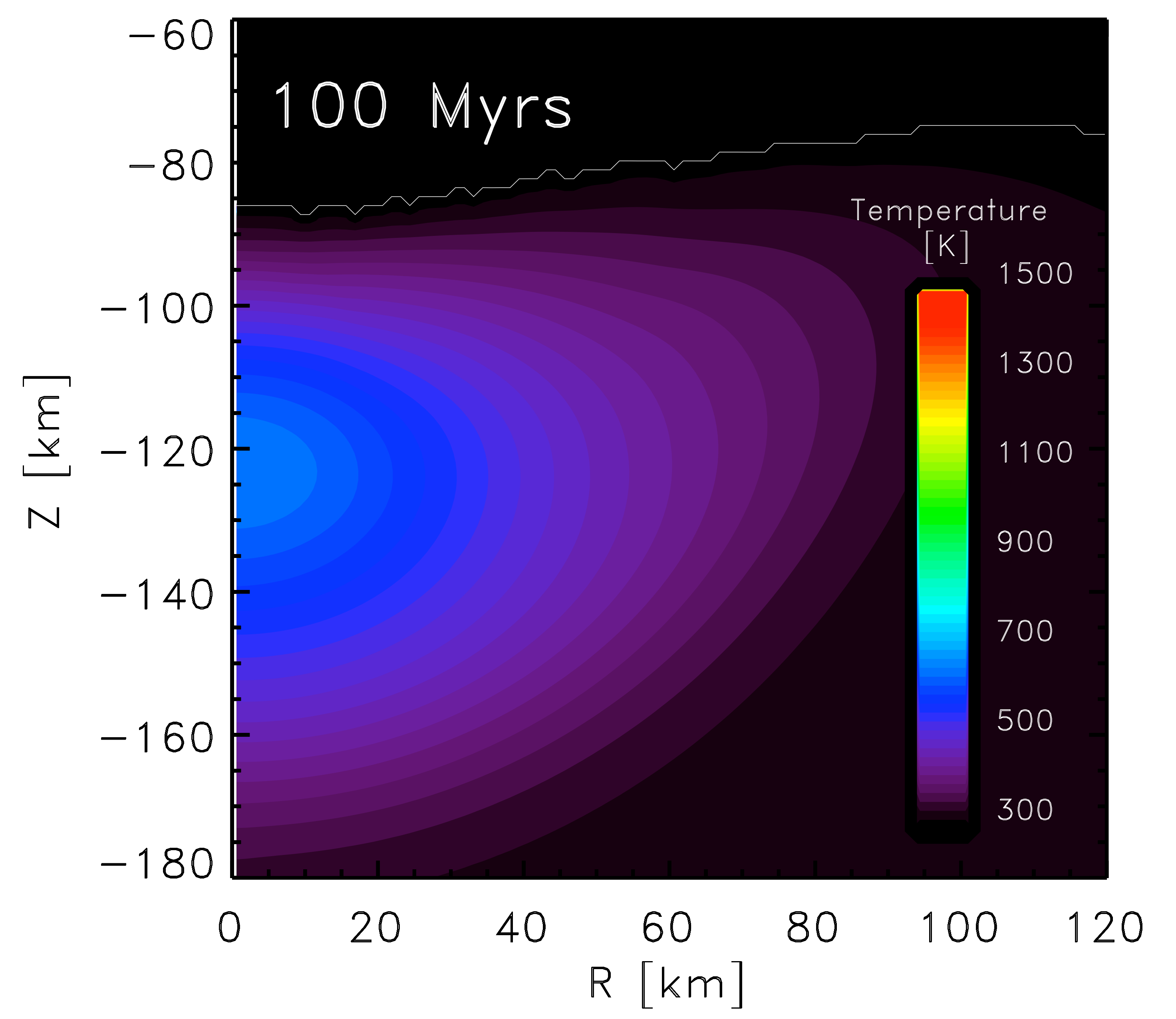
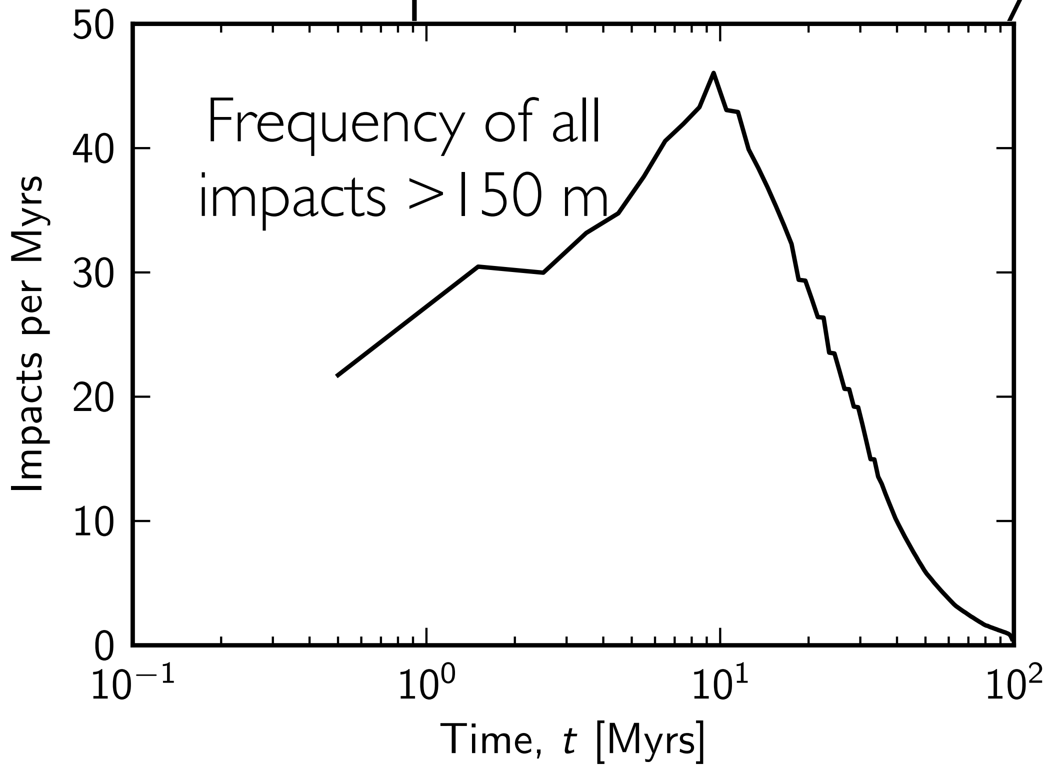
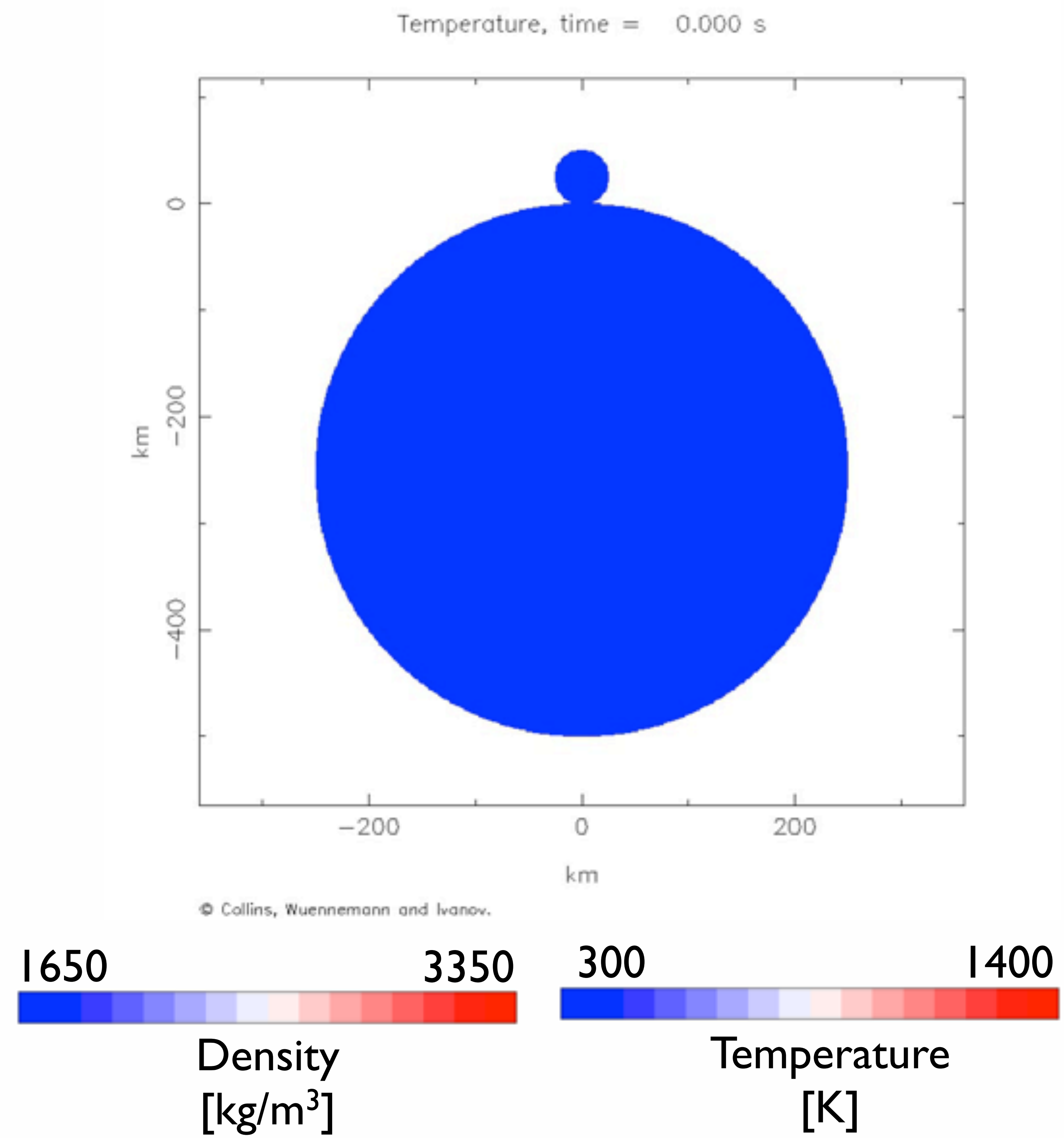


Planetesimals were not cold, dense objects in the early Solar System.

Most impacts occur early





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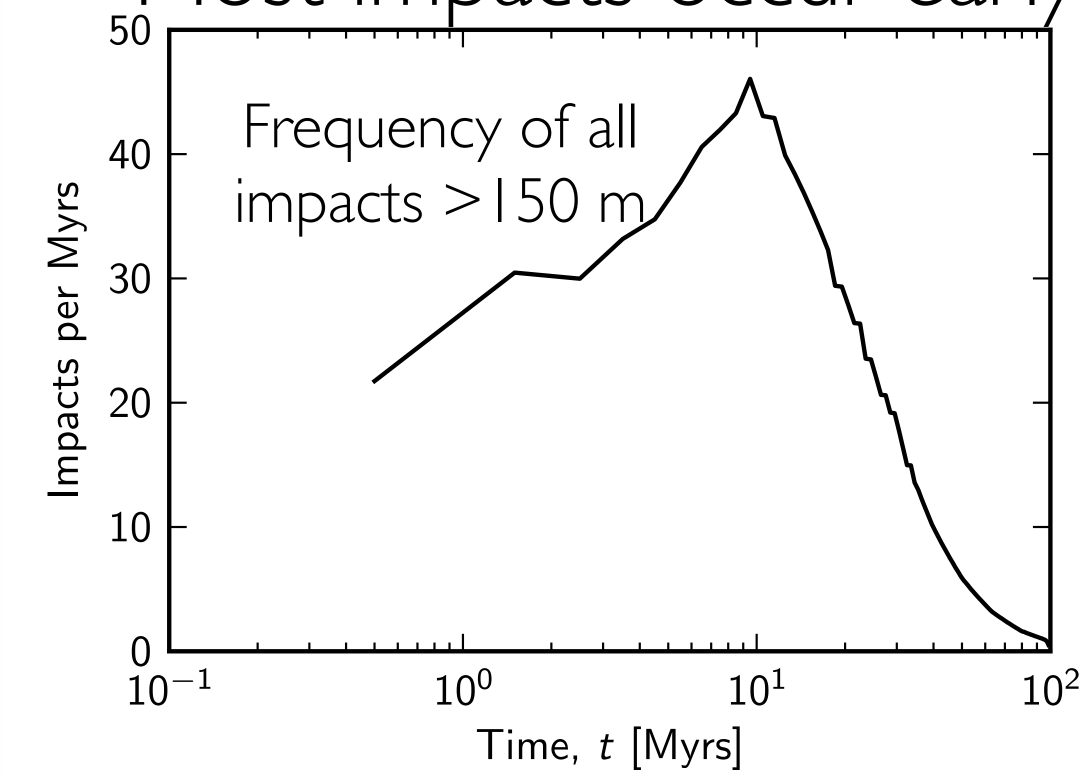
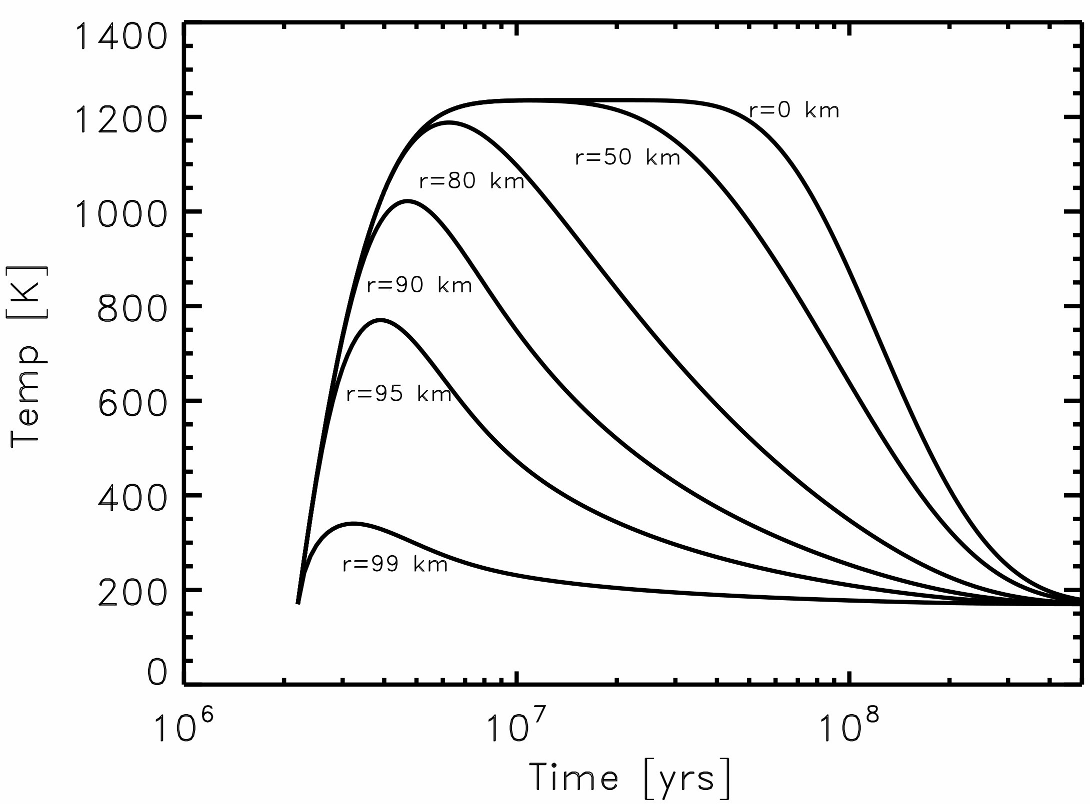
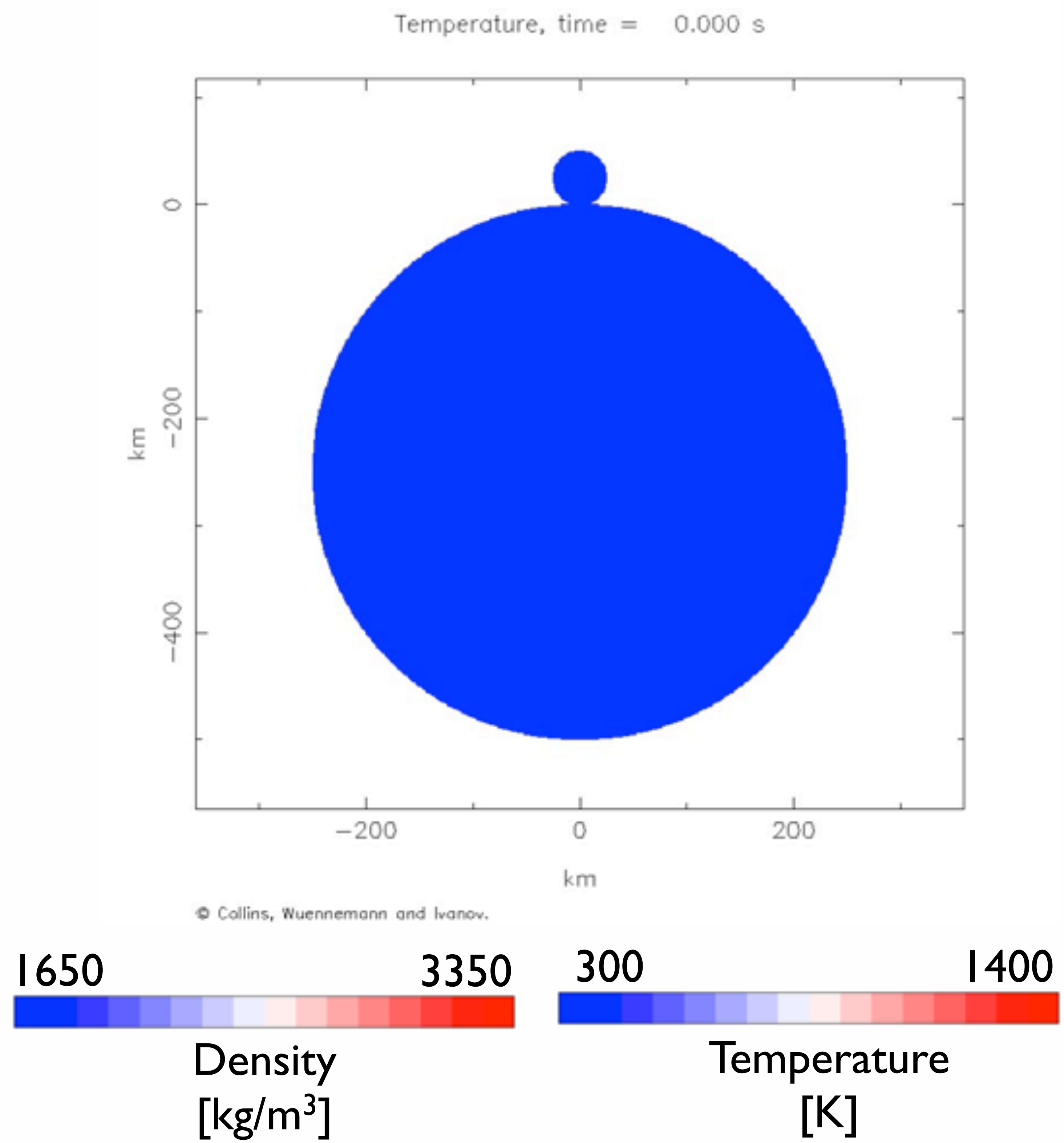
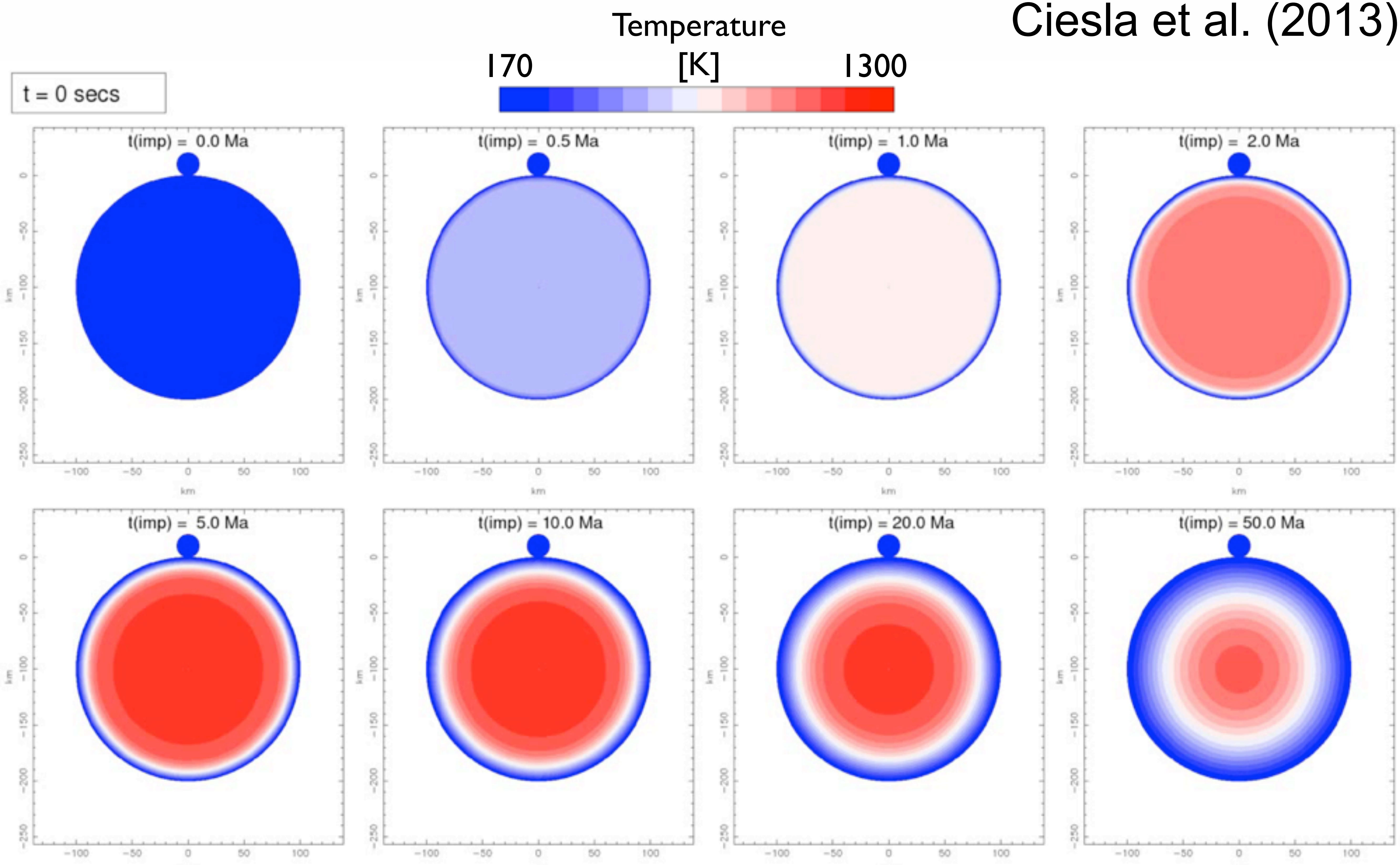






Impact outcomes strongly depend on state of the target body.

Ciesla et al. (2013)



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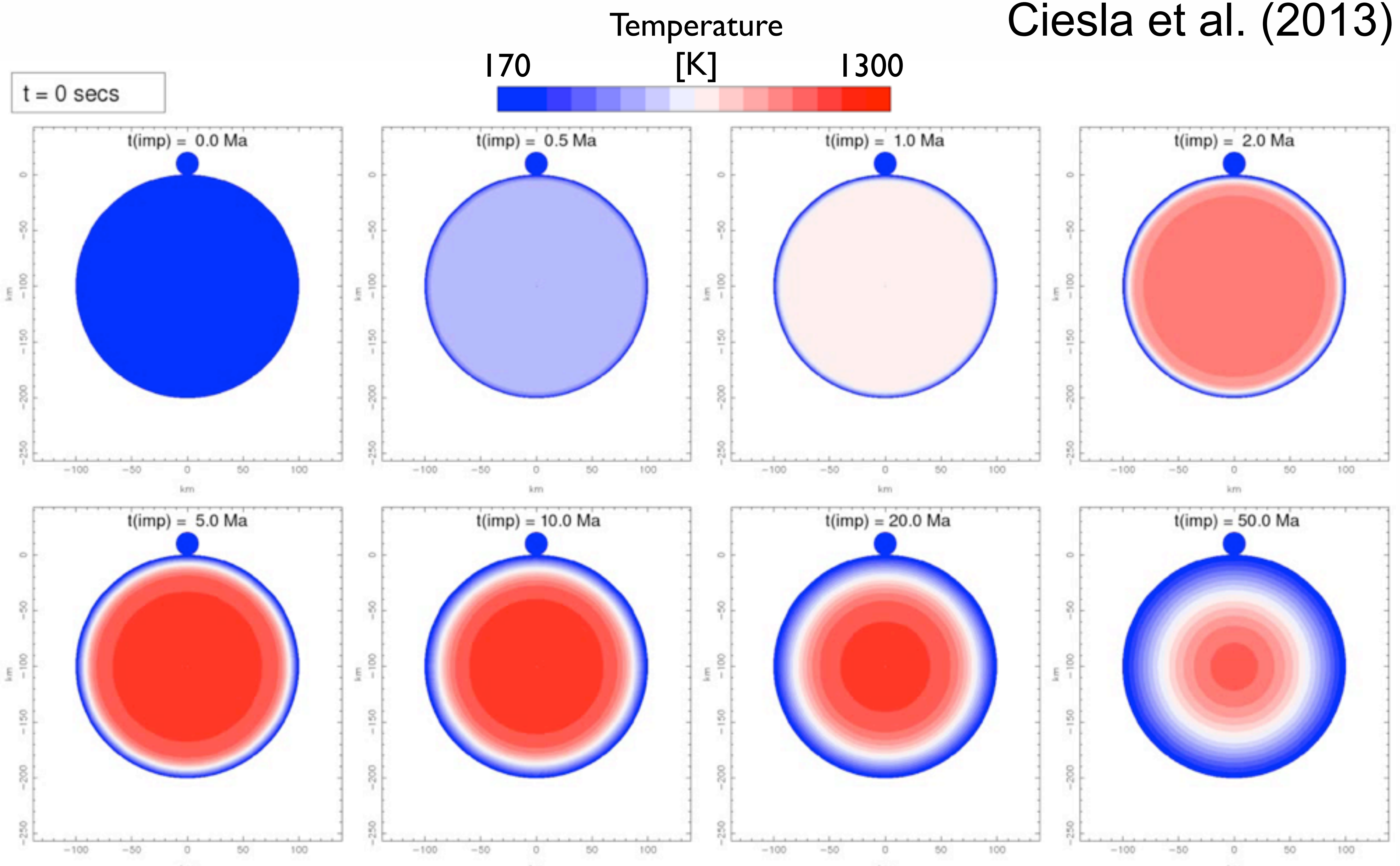
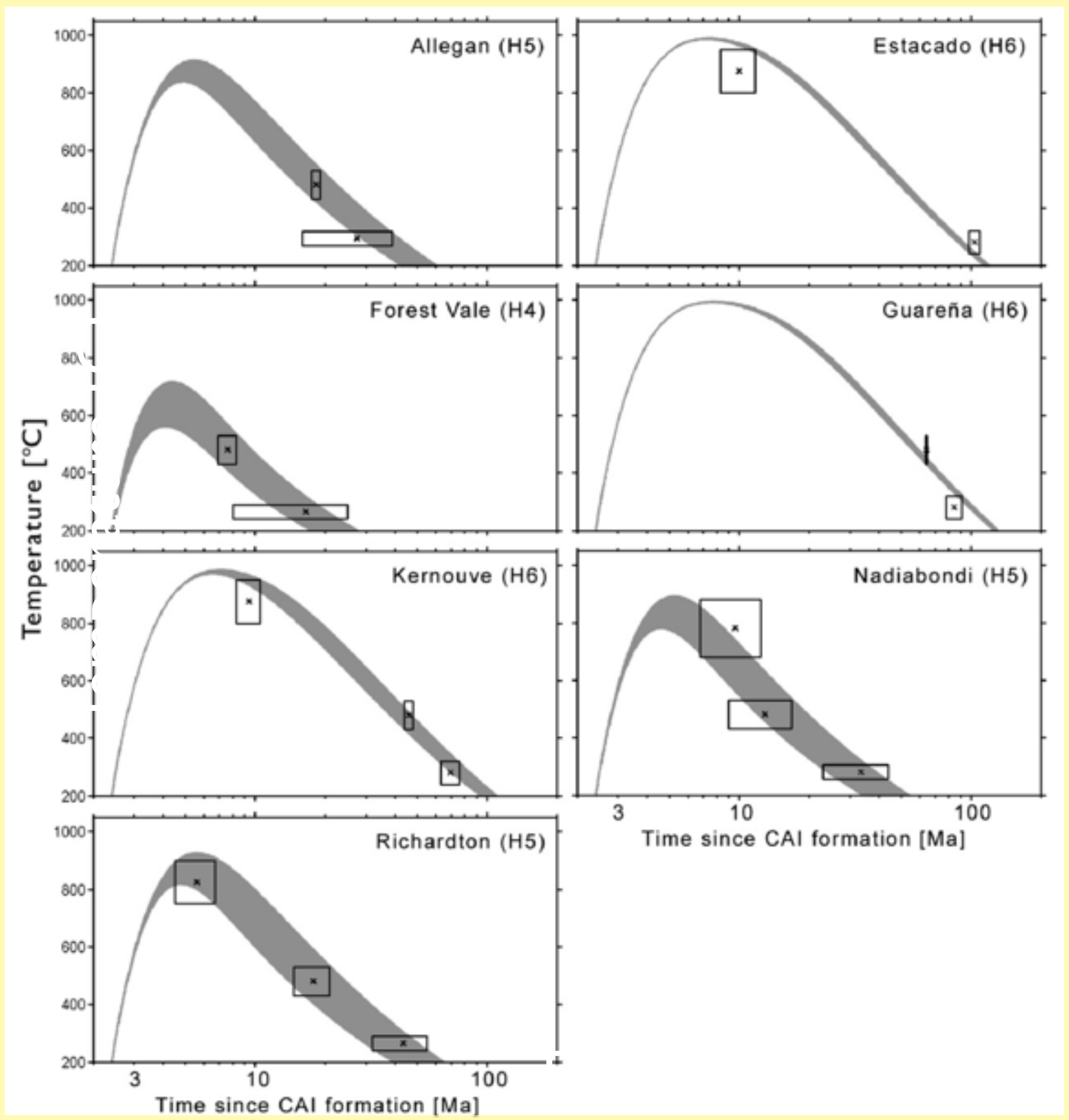


Impacts may explain anomalous meteorites, provided constraints are met.



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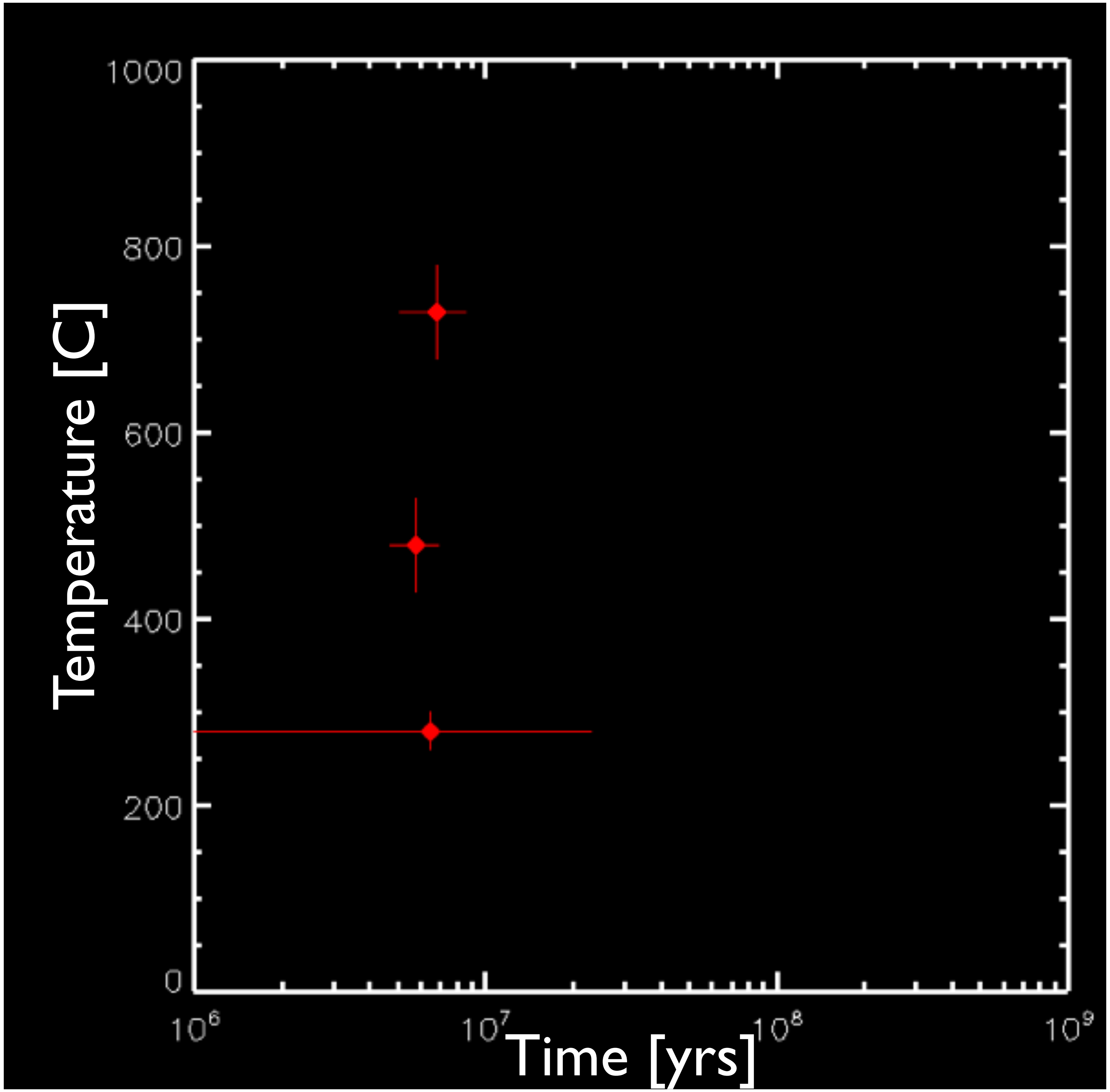

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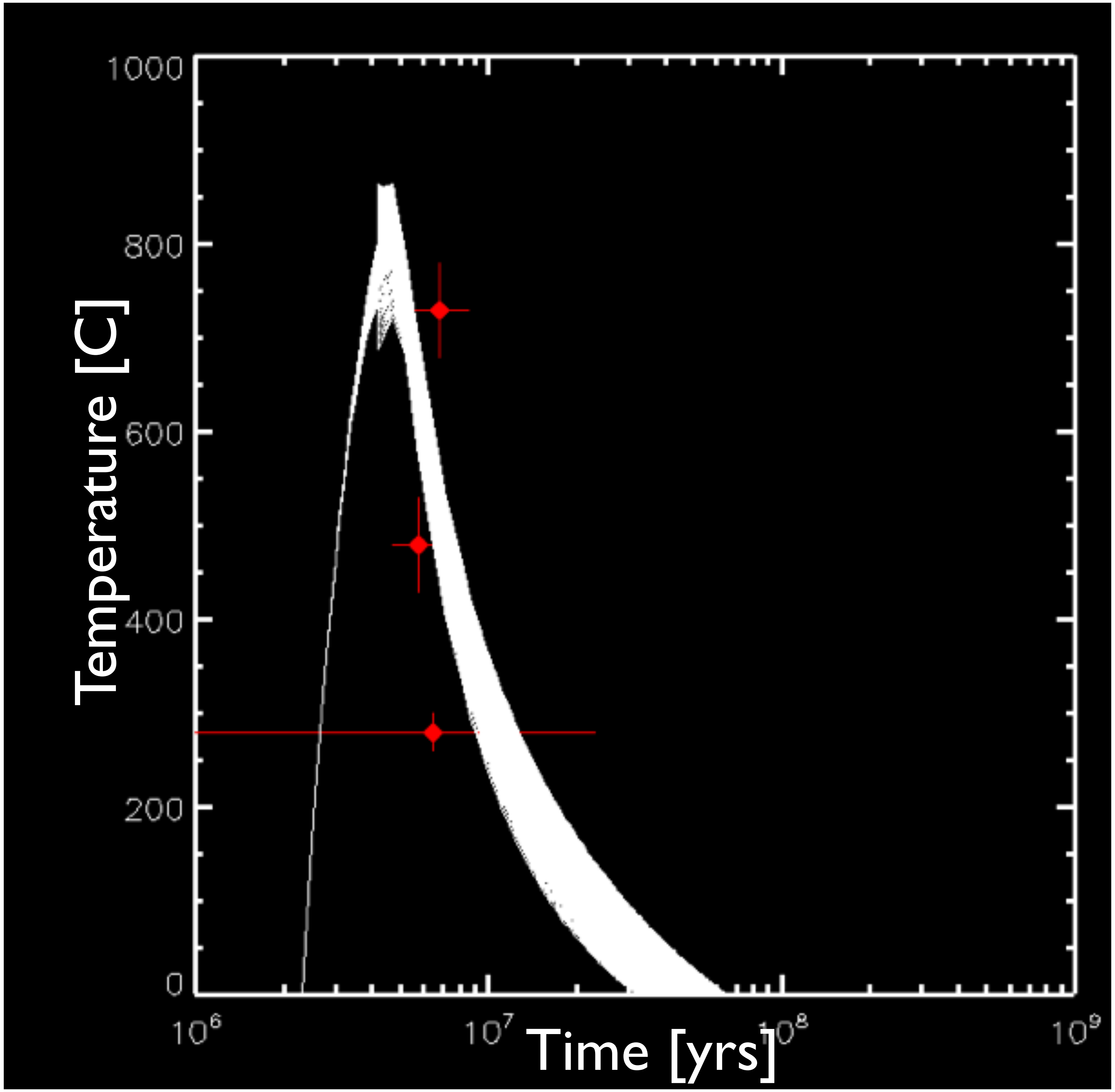

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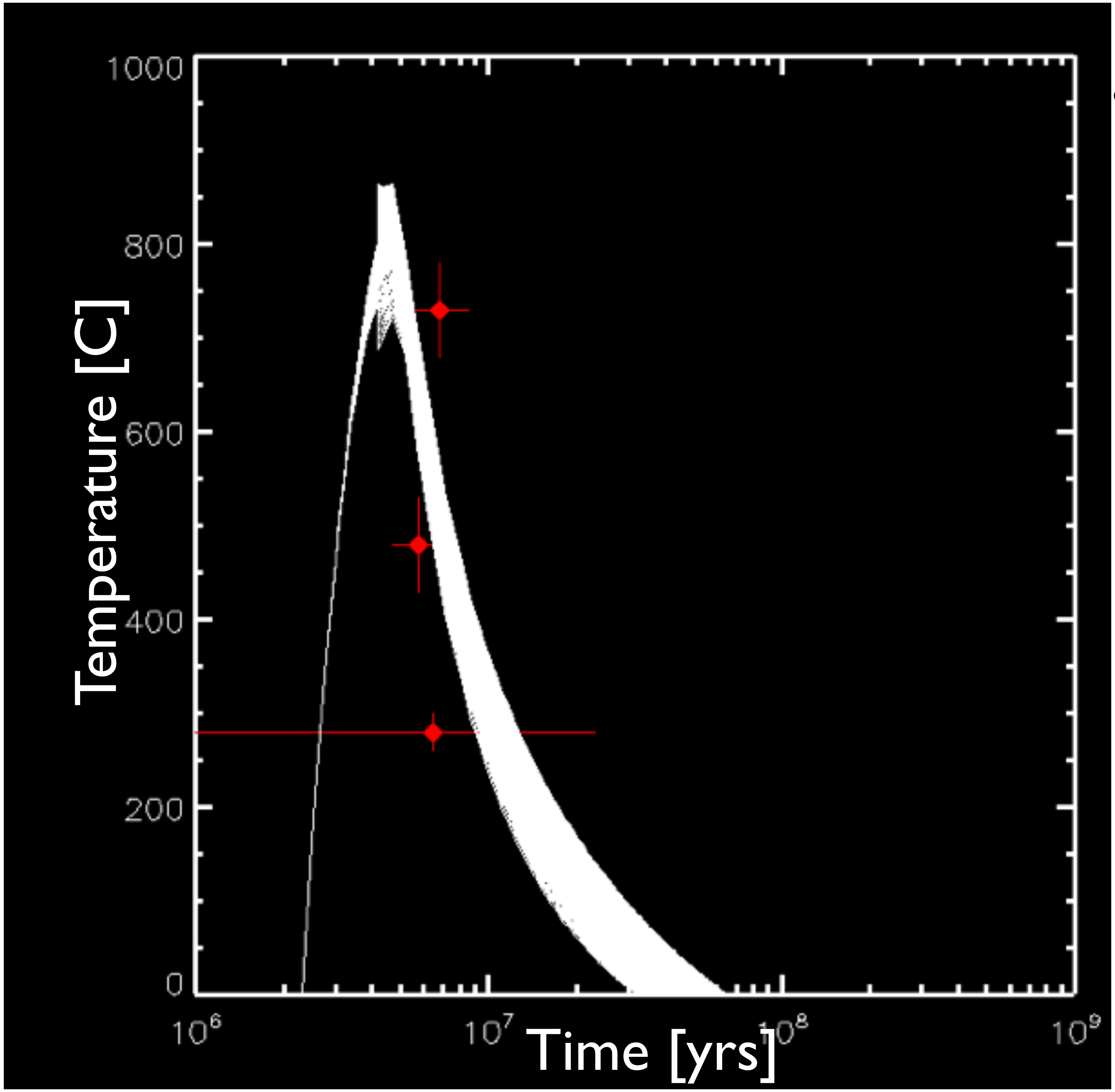
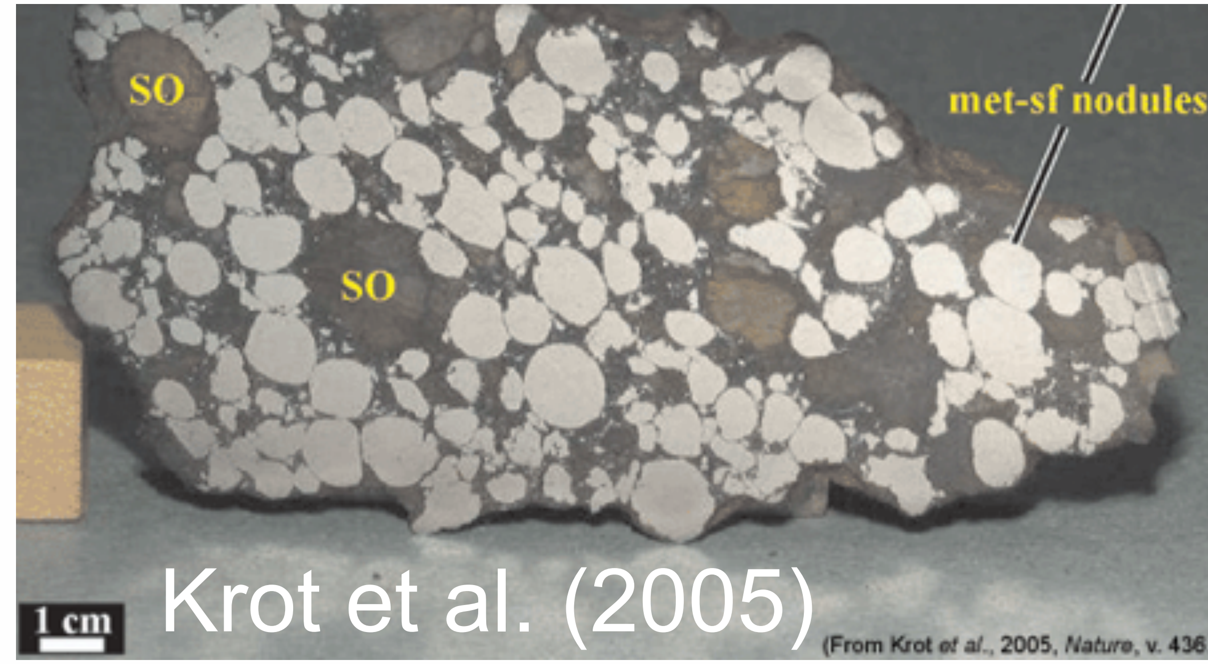
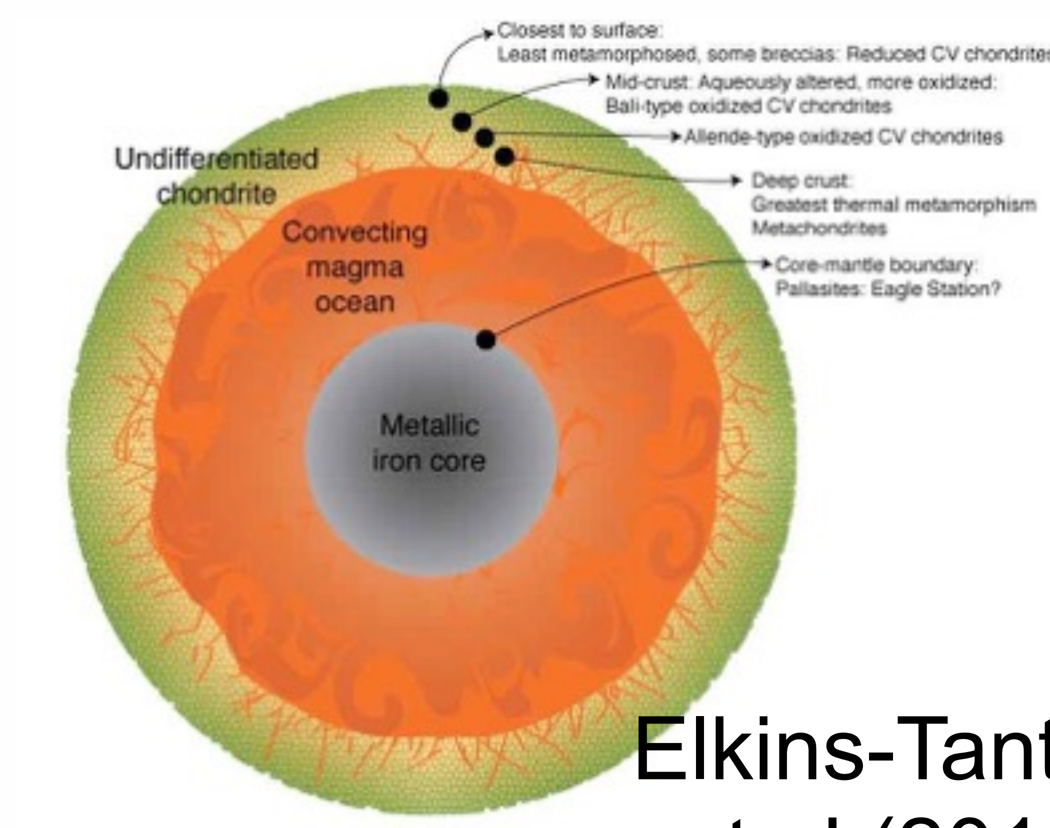


- The anomalous meteorite, Ste. Marguerite, can be explained by impact into radiogenically heated body
  - ✦ Must occur between 2-5 Myr after Solar System formation
  - ✦ Must be energetic enough to liberate materials from depth of ~20 km.

Evidence for/against other impacts exists in meteorite record.

- Thermal alteration of the Iron IAB/Winonaite meteorites (Schulz et al. 2009)
    - Heating to 1000-1100 K at t~14 Myr
- Vaporization and condensation of CB chondrite metal (Campbell et al. 2001, Krot et al 2005)
    - Metal vaporization requires lots of energy at ~5 Myr.
- Preservation of CV chondrites in crust of large planetesimal over ~50 Myr (Elkins-Tanton et al. 2011)
    - Must avoid impacts almost entirely, but such bodies tend to experience most impacts, and most energetic ones.





Elkins-Tanton et al (2011)

Conclusions/Summary

- Planetesimal collisions were most frequent and energetic during the first 10-100 Myr of Solar System history.
  - Impacts into warm/uncompacted bodies had greater collateral effects than in previous models. Important for debris disks?
- Meteorites record a number of energetic (large bodies, high velocity) impacts 3-15 Myr into Solar System history.
- Preservation of pristine materials limits number and scale of impacts.
  - Impacts <1-3 km/s during "compaction phase" of chondrites.
  - Preservation of "pristine crust" means some bodies avoided significant collisions outright.

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