Reduced Atmospheres of Post-Impact Worlds: Hiding Reducing Power in the Planet Core

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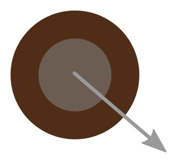
(1) The Role of Iron in Large Impacts

In the time after Moon formation (4.5~4.3 Ga), **large differentiated bodies** still existed in the Solar System, and likely hit the early Earth.

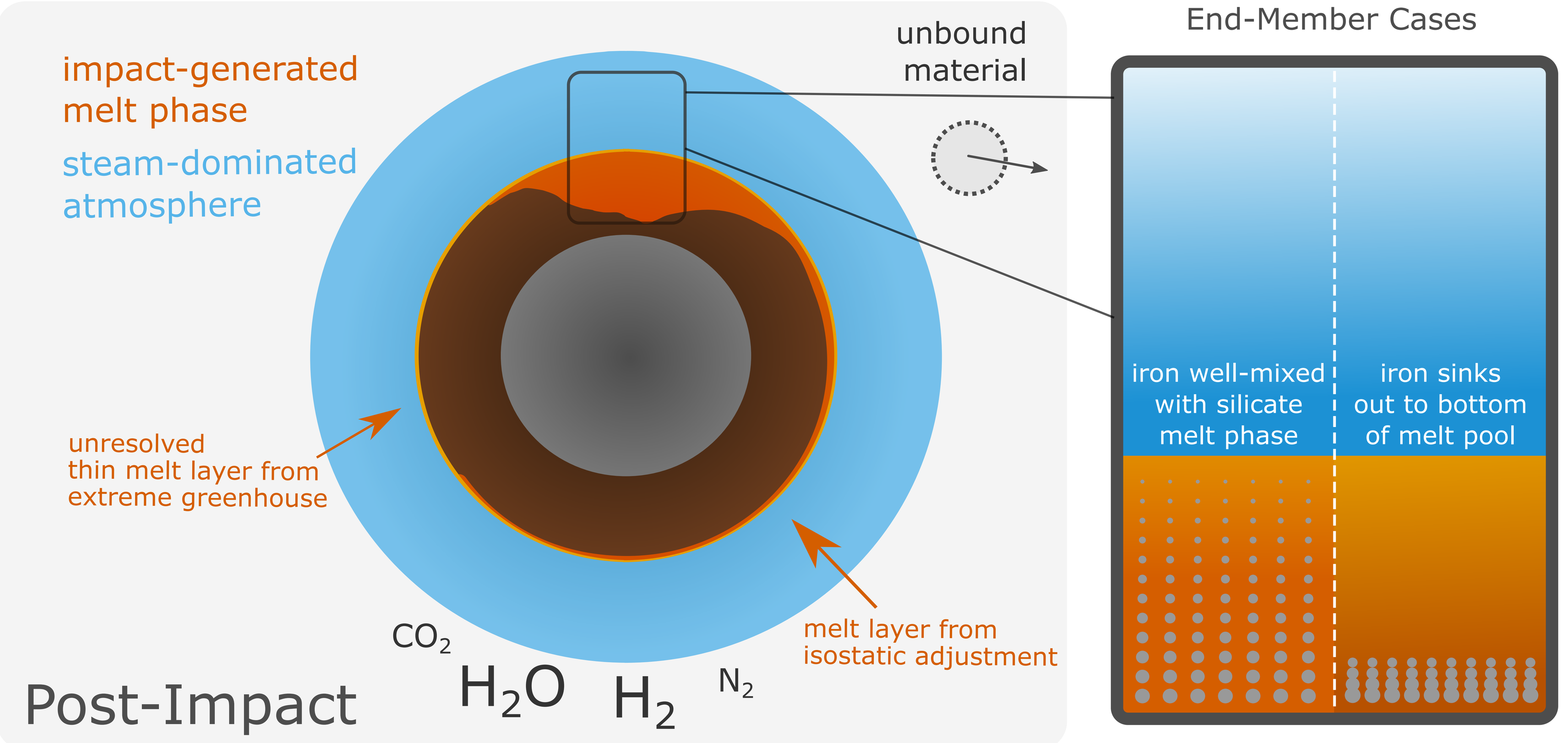


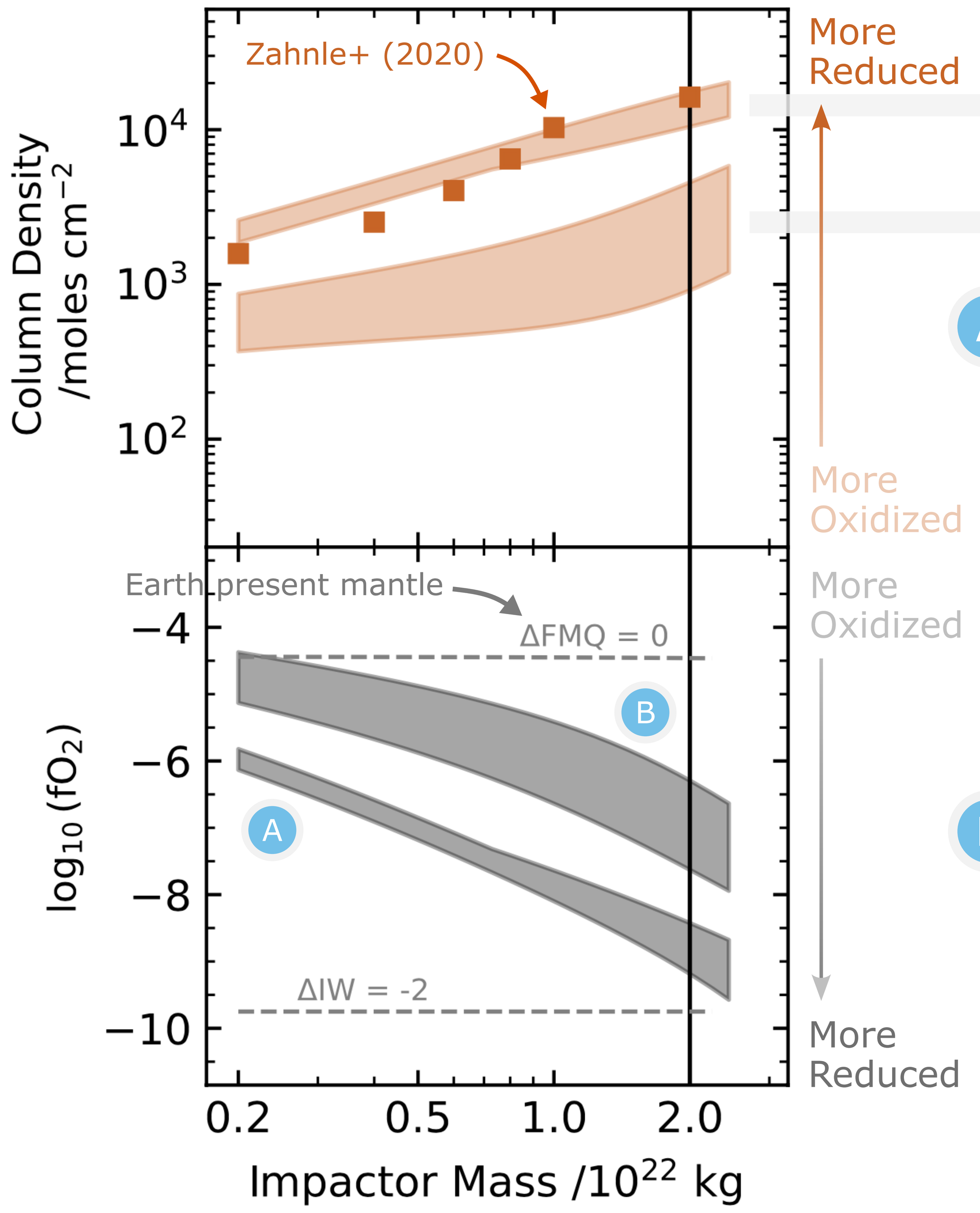
Chemical reactions of the iron can lead to the **production of reduced species** useful for prebiotic chemical pathways (e.g., NH3, HCN).

During impact, the impactor core fragments and **core material is distributed** between:

(1) Escaping the planet (unbound)
(2) Accreting to the atmosphere or impact-generated melt phase
(3) Accreting to the planet core

(Genda et al., 2017; Marchi et al., 2018; Benner et al., 2020; Zahnle et al., 2020; Citron et al., 2022; Itcovitz et al., 2022)





A All **iron accreted** to melt phase reacts:

$$\mathrm{Fe^{metal} + Fe_2O_3^{melt} \rightleftharpoons 3\,FeO^{melt}}$$

Melt-atmosphere interactions then restore reducing power the atmosphere:

$$\mathrm{Fe_2O_3^{melt} + H_2^{gas} \rightleftharpoons 2\,FeO^{melt} + H_2O^{gas}}$$

$$\mathrm{FeO^{melt} + H_2^{gas} \rightleftharpoons Fe^{metal} + H_2O^{gas}}$$

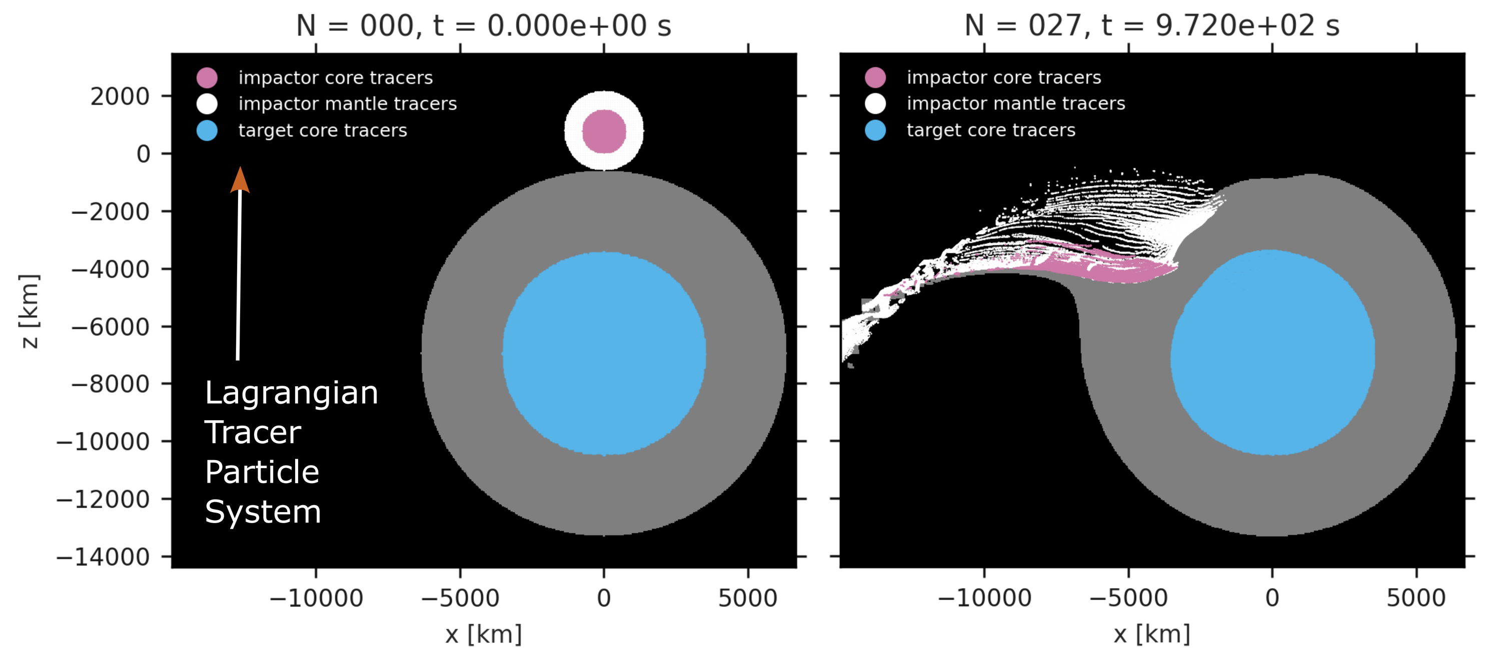
B **None** of the iron accreted to melt phase reacts but instead **sinks to the planet core** as large molten blobs.

Reducing power of the core material is **hidden from the atmosphere,** leaving it in a more oxidized state.

SCAN ME

(2) Impact Simulations: iSALE3D

*** *iSALE details & availability can be found at:* https://github.com/isale-code/isale-wiki/



Stages of Impact

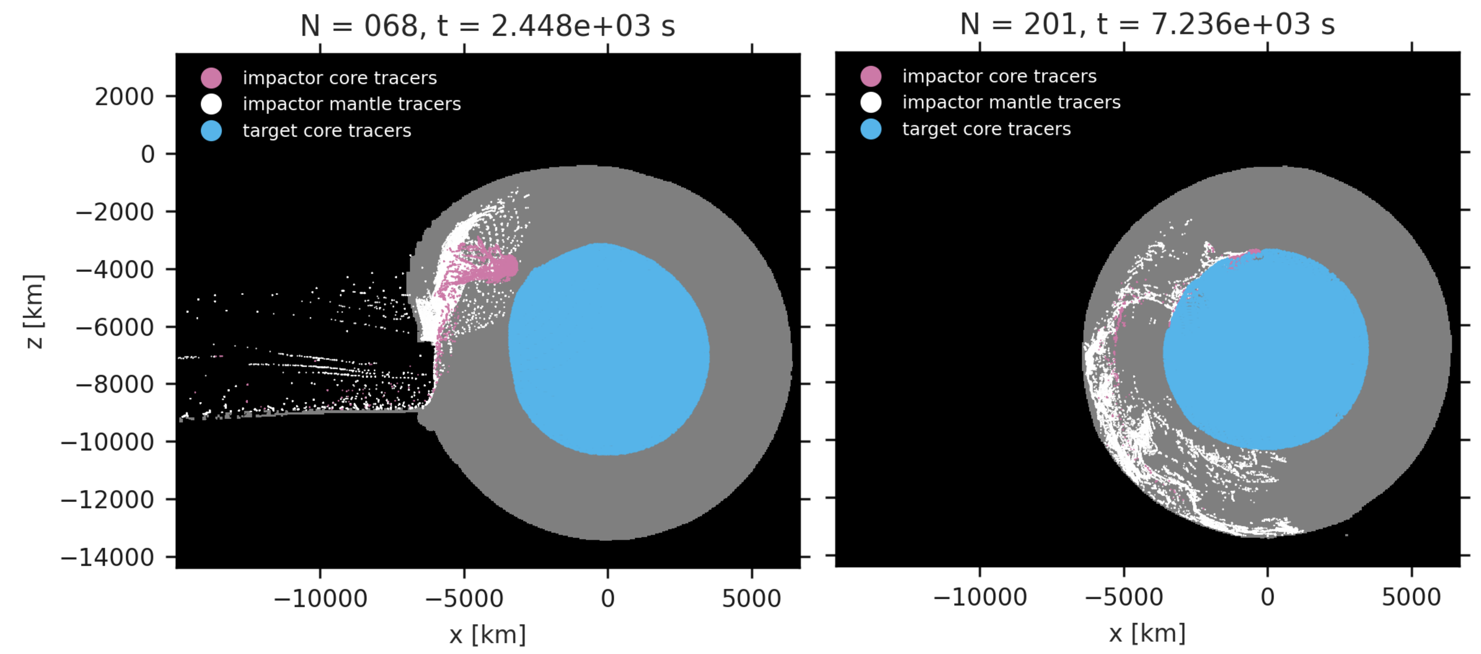
FRAME	WHAT DO WE SEE?
000	Initial setup for large impactor, 2640 tracers in impactor core (2x10^{22} kg, 45°, 16.0 km s^{-1})
027	Pancaking & fragmenting of the impactor core, excavation of the target mantle
068	Rebounding of the target mantle, sinking of iron blobs through melt
201	Target recovered spherical shape, iron sank to core or buoyant in molten mantle

Why iSALE?

iSALE is a **shock physics code** that represents materials in an Eulerian grid. (Wünnemann et al., 2008)

Additional physics can included, such as material strength & damage models, that **SPH codes do not** include.

iSALE can thus more properly account for the **sinking behaviour of molten iron** through the impact-generate melt phase.

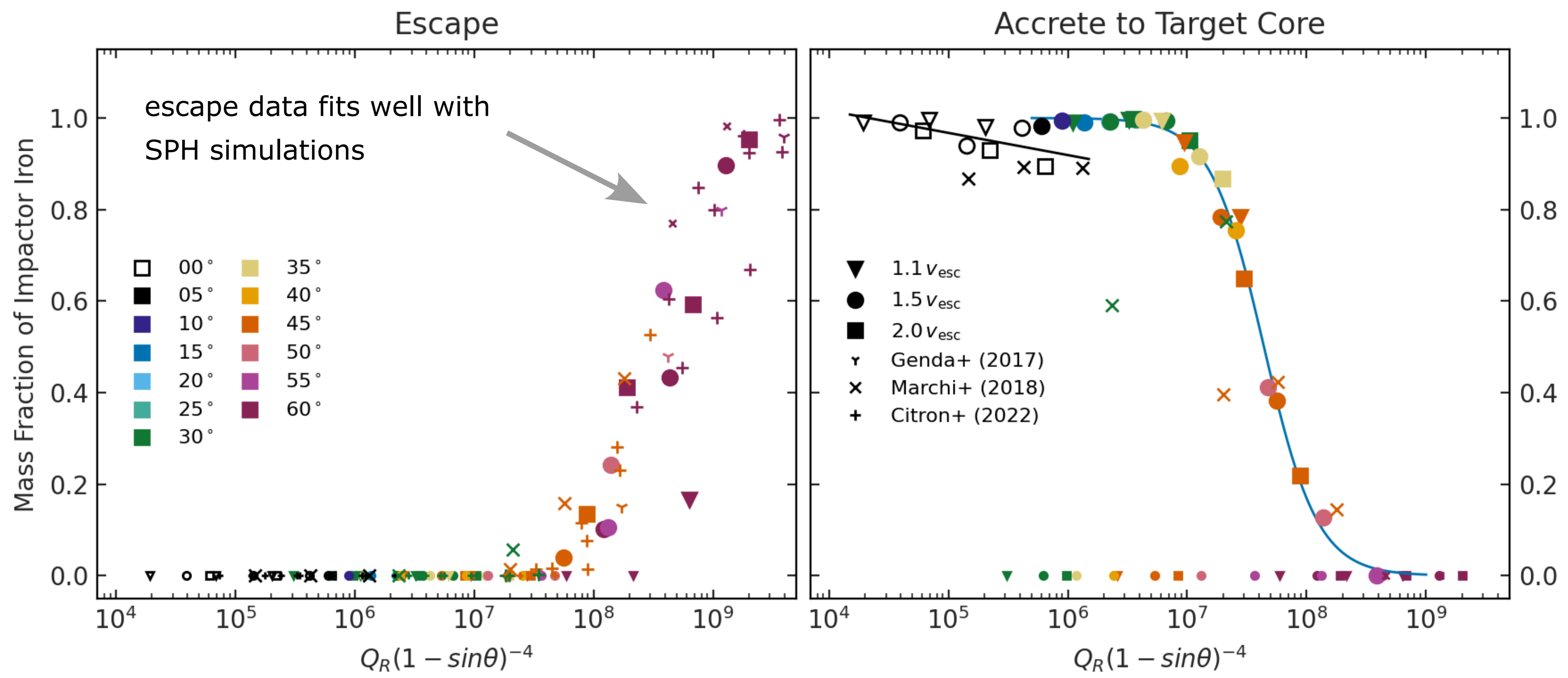


IMPACT SIMULATION REPOSITORY

SCAN ME

Recommend download VLC Media Player on device

(3) How much iron remains in the planet mantle?



Empirical fit using the speficifc energy of impact, Q_R, modified by the impact angle, θ

Fit displays **3 regimes** of target core accretion:
(1) head-on collisions (linear)
(2) oblique collisions (linear)
(3) semi-oblique (exponential curve)

Depends on Geometry!

Geochemical Evidences

Abundances of **Highly Siderophile Elements** in the Earth's mantle can place limits on the **mass accreted** after Moon formation.
(e.g., Bottke et al., 2010; Day et al., 2016)

Analysis of iron distribution during impacts can help re-assess accretion limits & inform models of **Earth & Solar System history**

Earth mantle chemical & isotopic heterogeneities

Planetesimal population size-number statistics

References

- Wünnemann et al. (2008) Numerical modeling of impact melt production in porous rocks
- Bottke et al. (2010) Stochastic late accretion to Earth, the Moon, and Mars
- Day et al. (2016) Highly Siderophile Elements in Earth, Mars, the Moon, and Asteroids
- Genda et al. (2017) The terrestrial late veneer from core disruption of a Lunar-sized impactor
- Marchi et al. (2018) Heterogeneous delivery of silicate and metal to Earth by large planetesimals
- Benner et al. (2020) When did life emerge on Earth in an RNA-first process?
- Zahnle et al. (2020) Creation & evolution of impact-generated reduced atmospheres of early Earth
- Citron et al. (2022) Large impacts onto the early Earth: Planetary sterilization and iron delivery
- Itcovitz et al. (2022) Reduced atmosphere of post-impact worlds: The early Earth