

Short Version:

We study the volatile history of the atmosphere of Venus and how it evolved depending on volcanism, atmospheric escape, interaction with the surface and collisions with large asteroids.

The focus of this numerical simulation is Late Accretion and its composition: when and how volatiles were delivered to terrestrial planets.

We show that Late Accretion bodies preferentially have a composition similar to that of Enstatites/ordinary chondrites, as opposed to volatile rich carbon chondrites. Venus and terrestrial planets would have therefore received most of their volatiles during the main accretion, before the end of the magma ocean stage.

1. Outline of the model.

Coupled model

We model the following mechanisms:

> Mantle dynamics for mantle evolution and partial melting. Melt is extracted through volcanism and leads to degassing of volatiles into the atmosphere.

> Atmospheric escape. Loss of volatiles and especially water constrains the possible evolution of Venus.

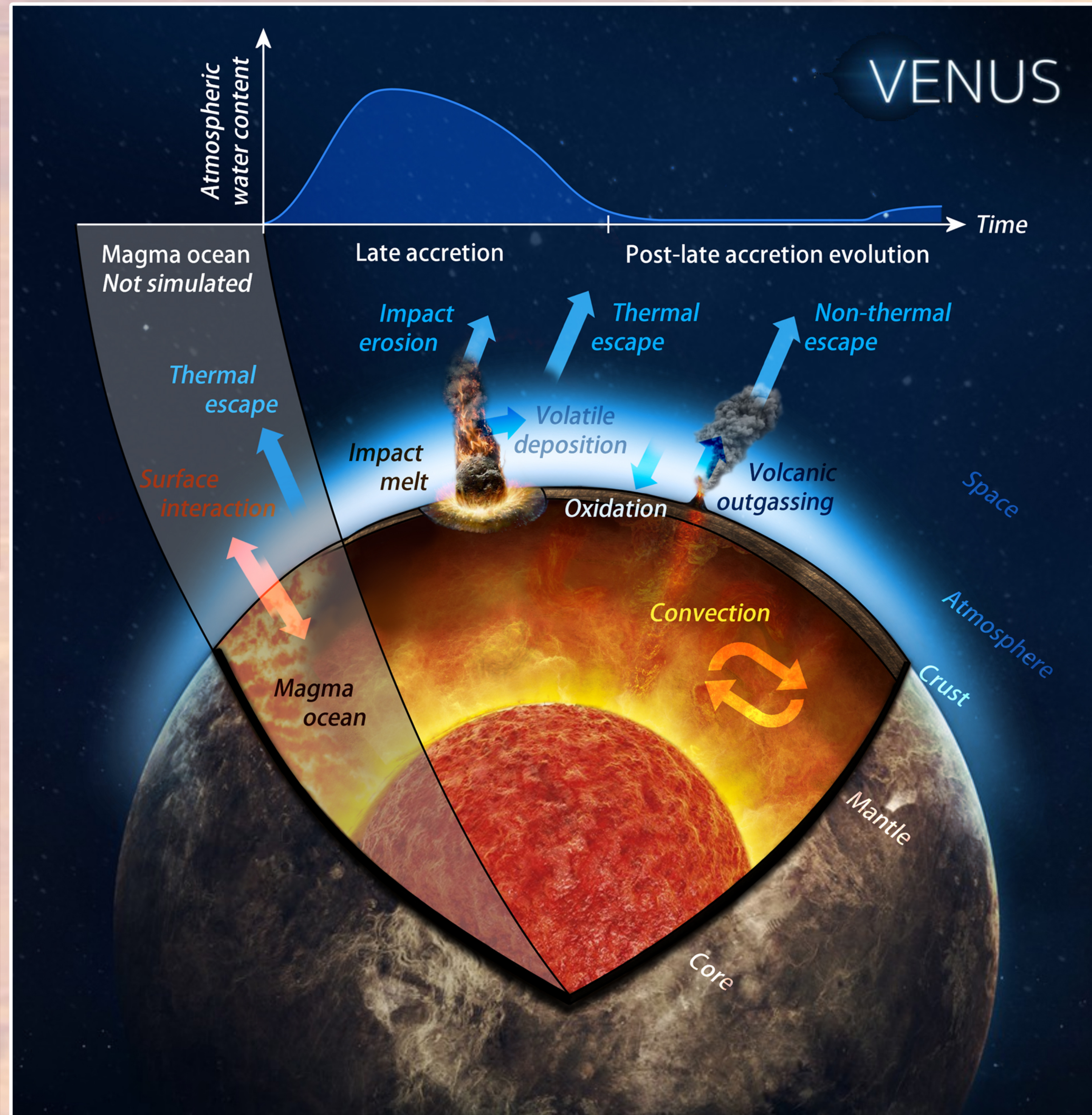
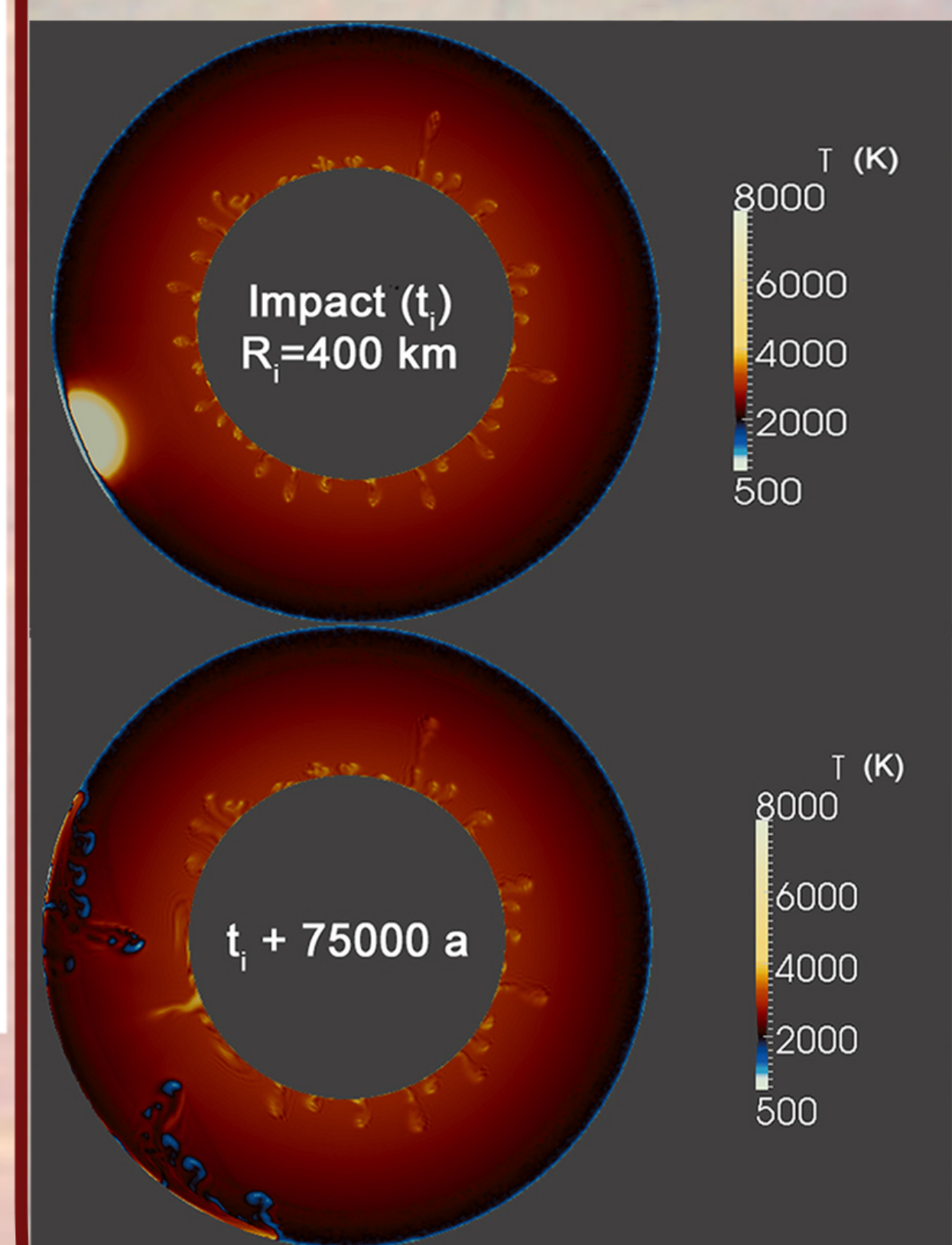
> Greenhouse effect controls the surface temperature and surface conditions.

Impacts I: Mantle dynamics.

> Shock pressure generates heat, leading to a thermal anomaly.

> The anomaly affects convection patterns.

> **Very high temperatures generated favor melting of the mantle and degassing.**

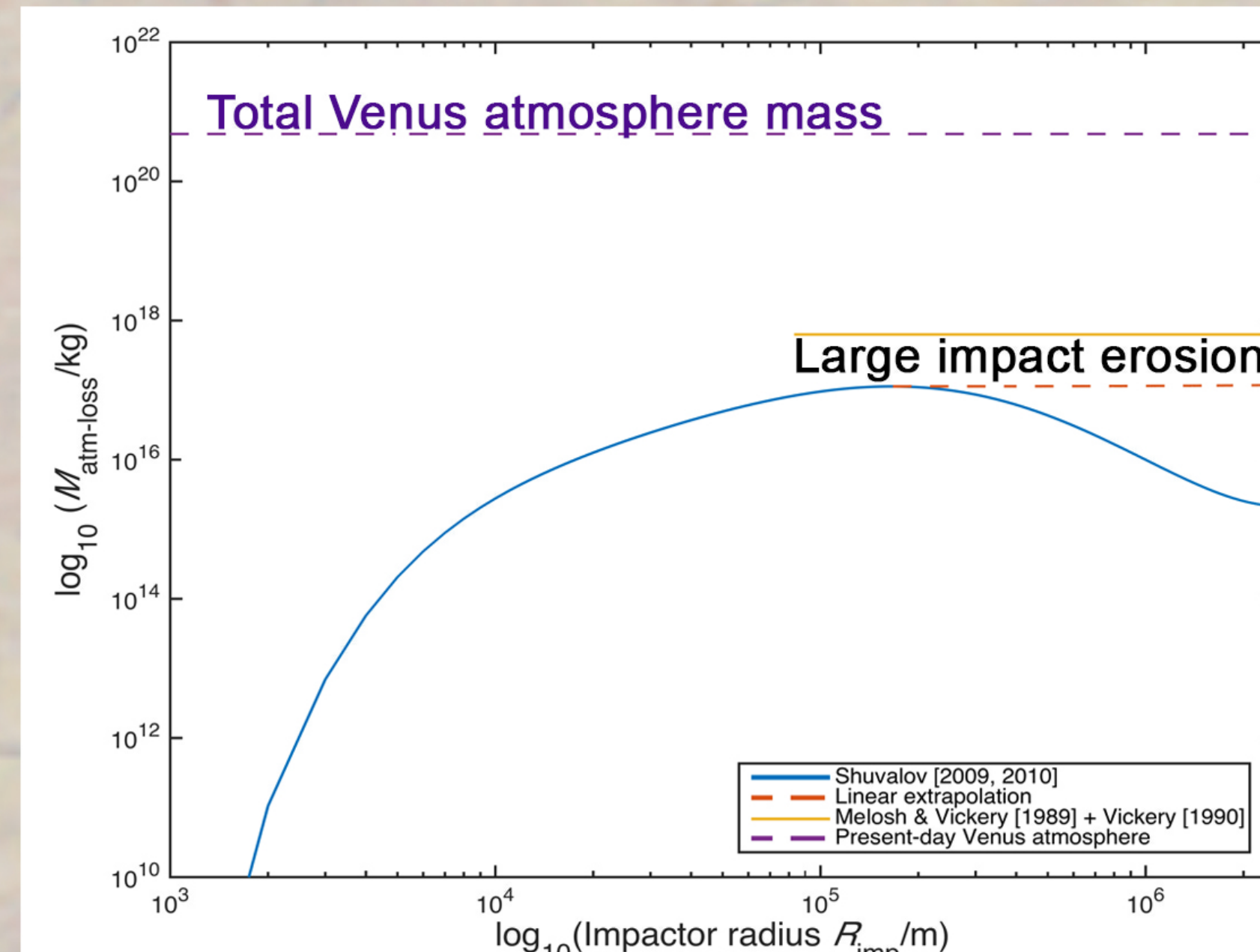


Impacts II: Atmospheric Erosion

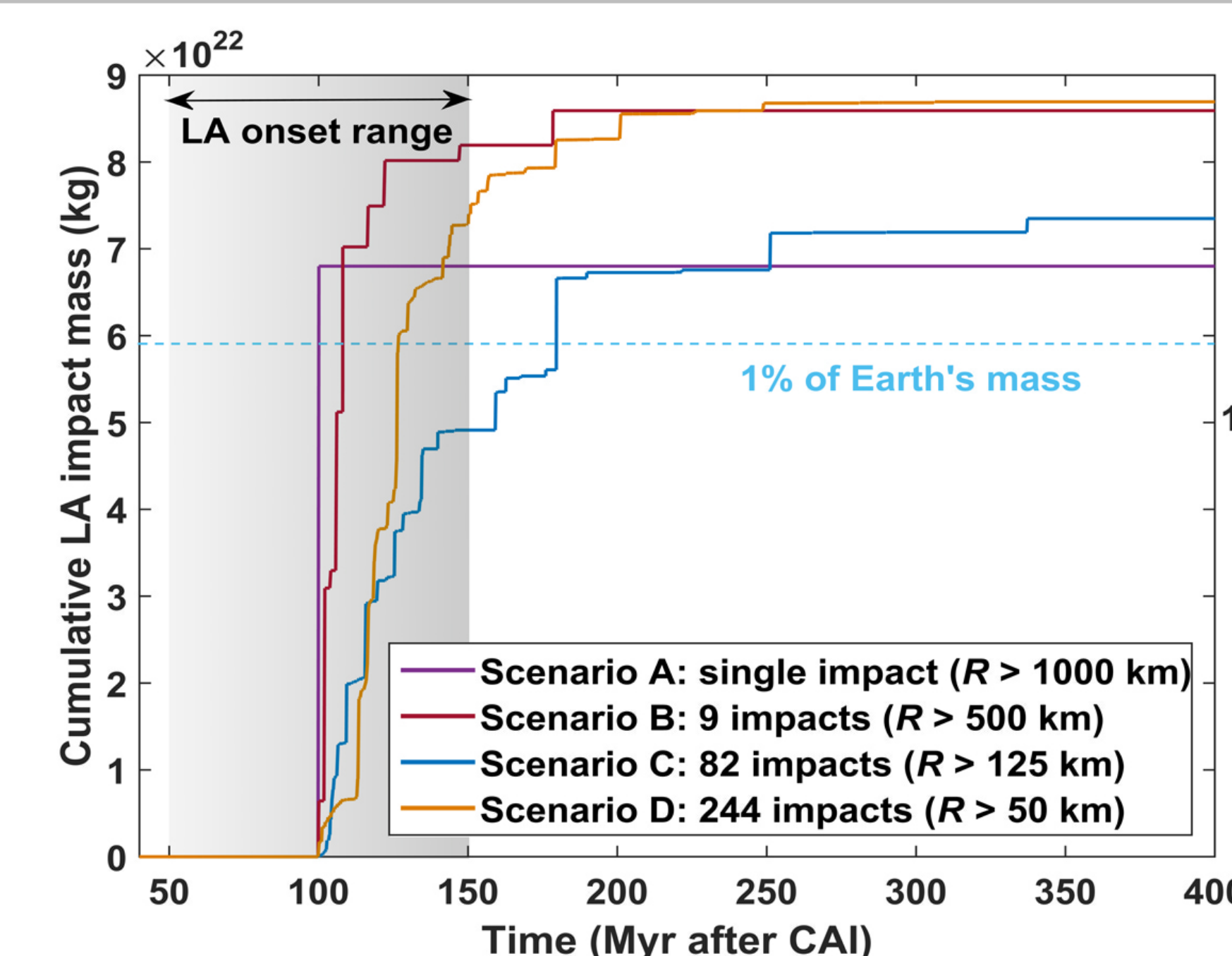
> Escape mechanisms include atmosphere compression, effects of solid ejectas, vapor plume expansion.

> We use the SOVA hydrocode and the tangent plane model.

> **Only a fraction of the atmosphere removed at each impact.**



2. Volatile delivery in the Late Veneer era.

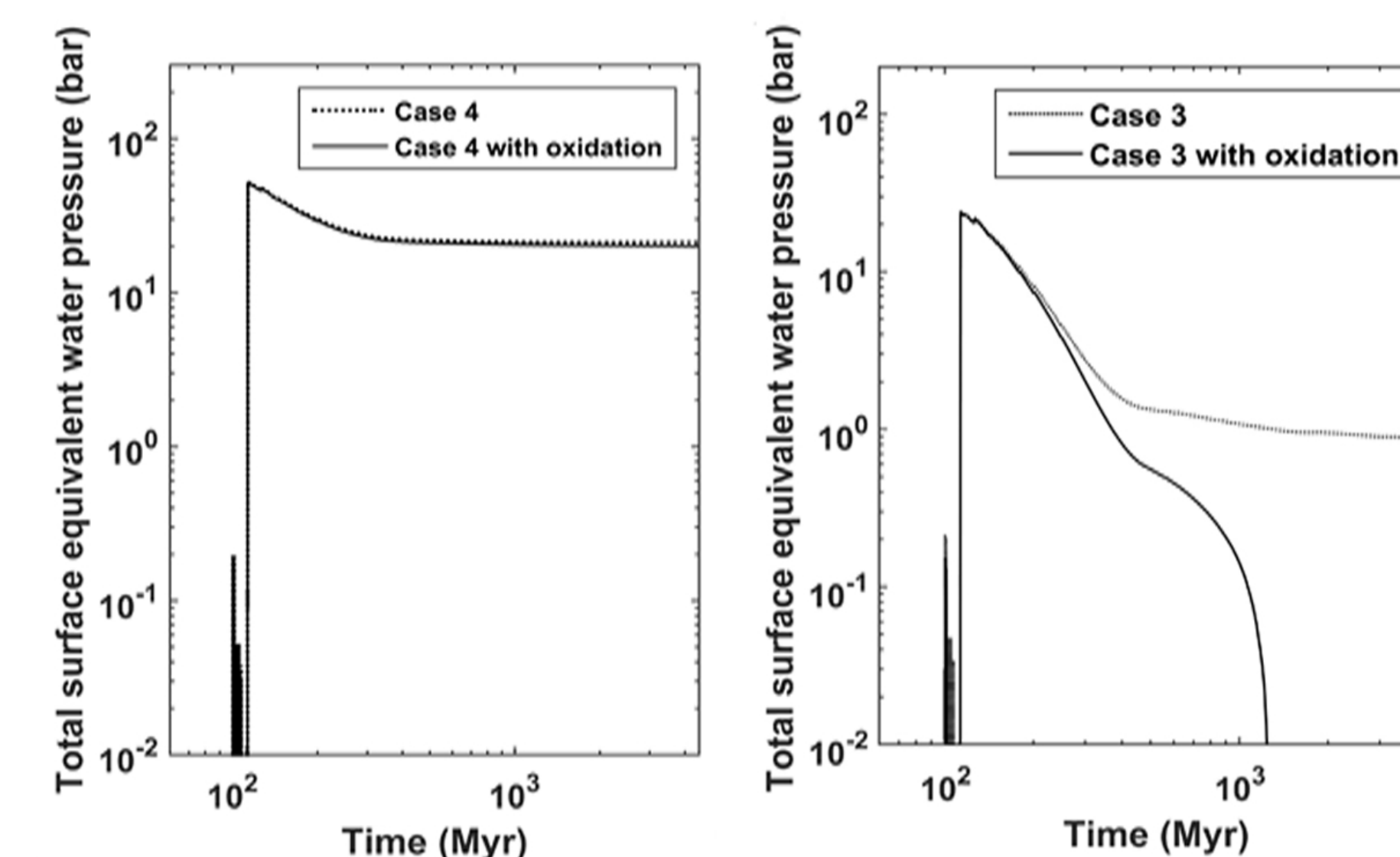


Atmosphere water content evolution

> Early on, Hydrogen is lost easily through hydrodynamic escape but Oxygen stays behind. The lack of present day oxygen implies it must be removed during the evolution.

> Non-thermal escape can remove a limited amount of Oxygen, thus placing an upper limit on water delivery.

> Therefore, we can set a limit to Late accretion water content and composition.



Late Veneer delivery

> We compare volatile content modelled after 4.5 Gyr evolution and present-day observation for H₂O, CO₂ and N₂.

> All four size-frequency distributions lead to similar results. The total mass of Late Accretion is more important than the individual size of impactors.

> Late Accretion is mainly composed of dry material with a maximum of 5% Carbonaceous Chondrites.

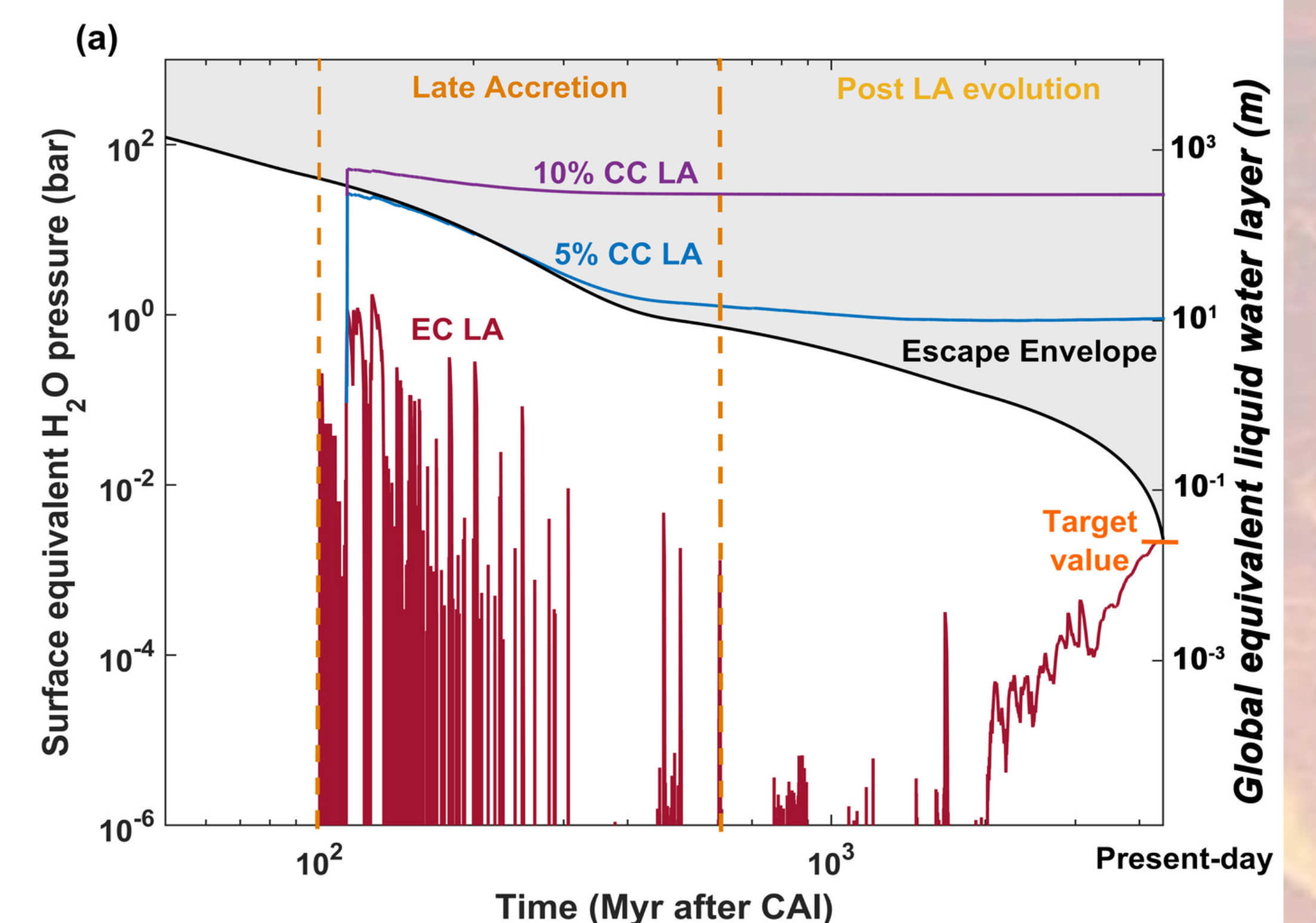
> Most Volatiles on terrestrial planets must have been delivered before Late Accretion, during the main accretion phase.

Impacts III: Late Accretion Delivery

> After core formation ceased the accretion of additional ≈ 0.5 -2.5% of Earth's mass, the so-called Late Accretion, established the highly siderophile elements abundances in Earth's mantle.

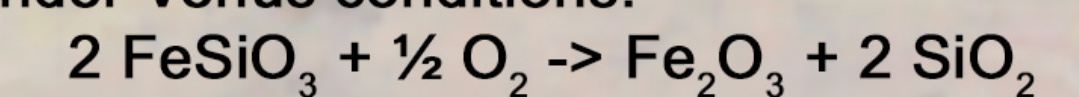
> We use a series of N-body simulations to generate Late Veneer scenarios with different size-frequency distributions, timing and other characteristics.

> We test volatiles composition of the Late Accretion ranging from dry Enstatite likebodies to "wet" Carbonaceous chondrites (CC).



The role of surface interaction.

> Oxidation of the surface is a potential sink of oxygen. Using the following reaction to model the oxidation of surface basaltic material under Venus conditions:



> The complete oxidation of basalt by the oxygen from one Eath Ocean would result in a 50km thick hematite layer.

> However such a process is inefficient with solid basalt and relies on oxygen diffusion in the molten lava, reducing total oxidation by a factor 100 to 1000.

