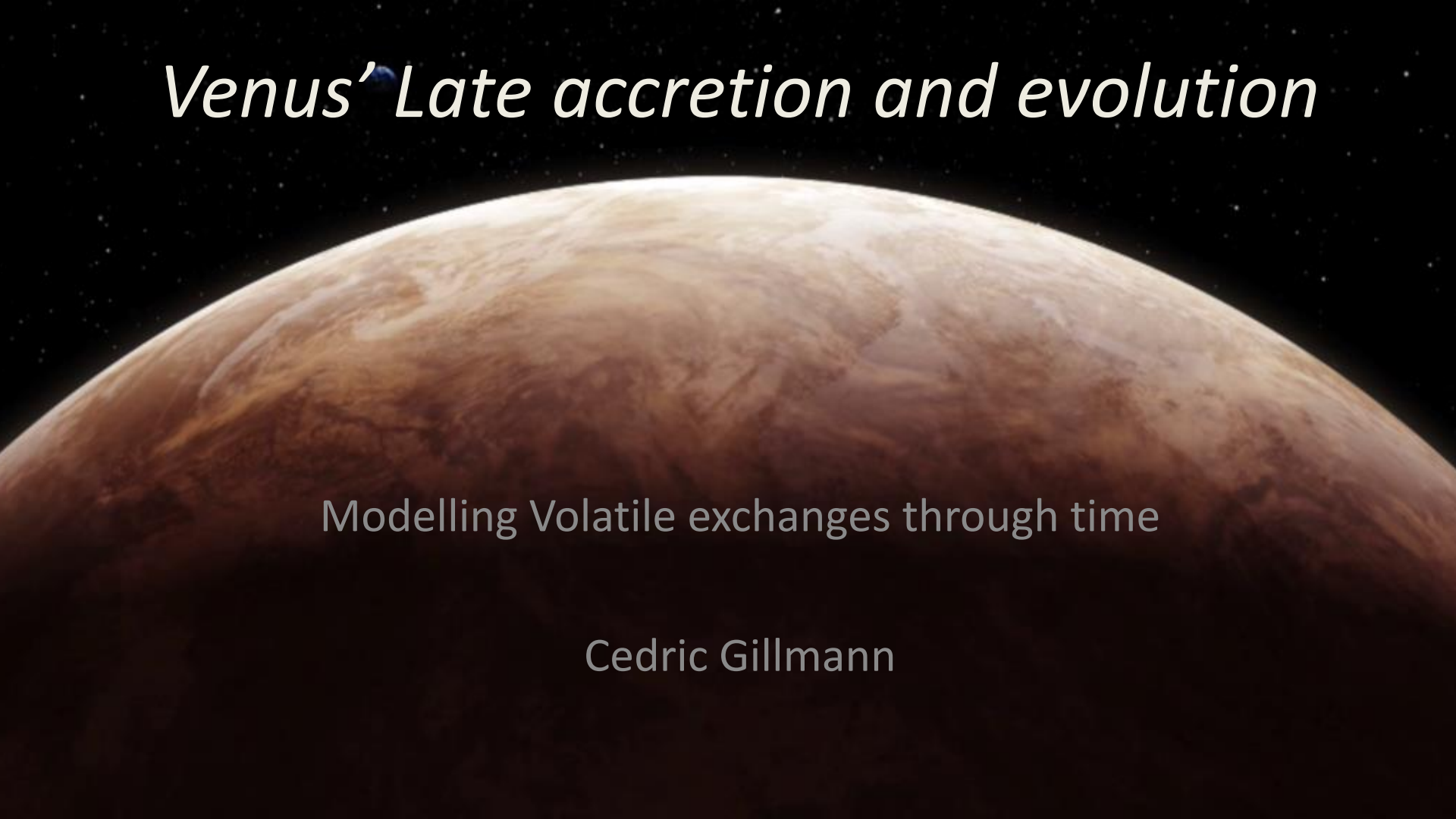
Venus' Late accretion and evolution

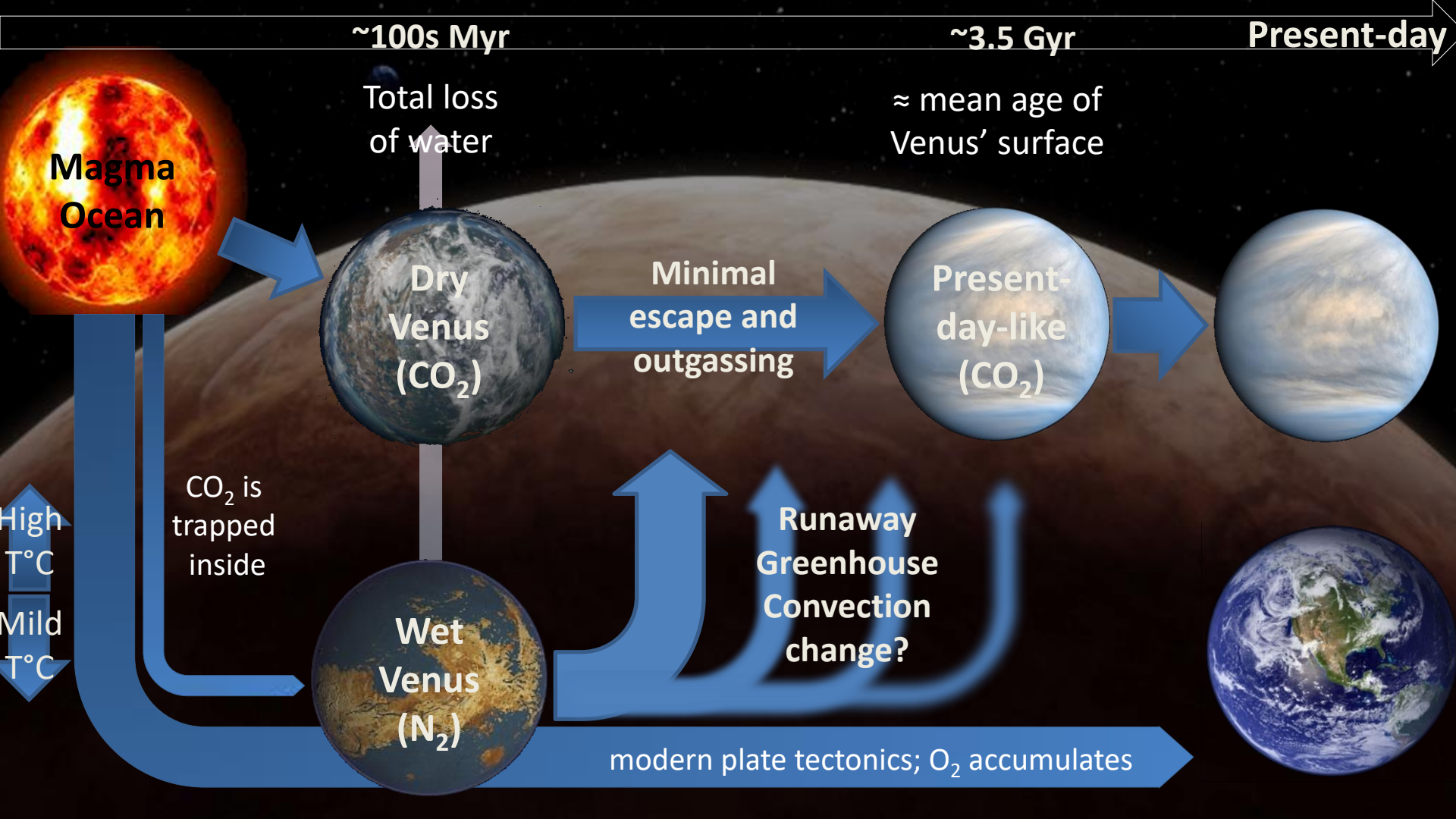


Modelling Volatile exchanges through time

Cedric Gillmann

Comparative planetology: when did Venus and Earth diverge?

- Strong suspicions that the two planets were initially similar, with the same building blocks.
- Main differences:
  - Very little water on Venus
  - Earth's CO_2 is inside, While Venus' is in its atmosphere
- When and Why did Venus and Earth diverge?

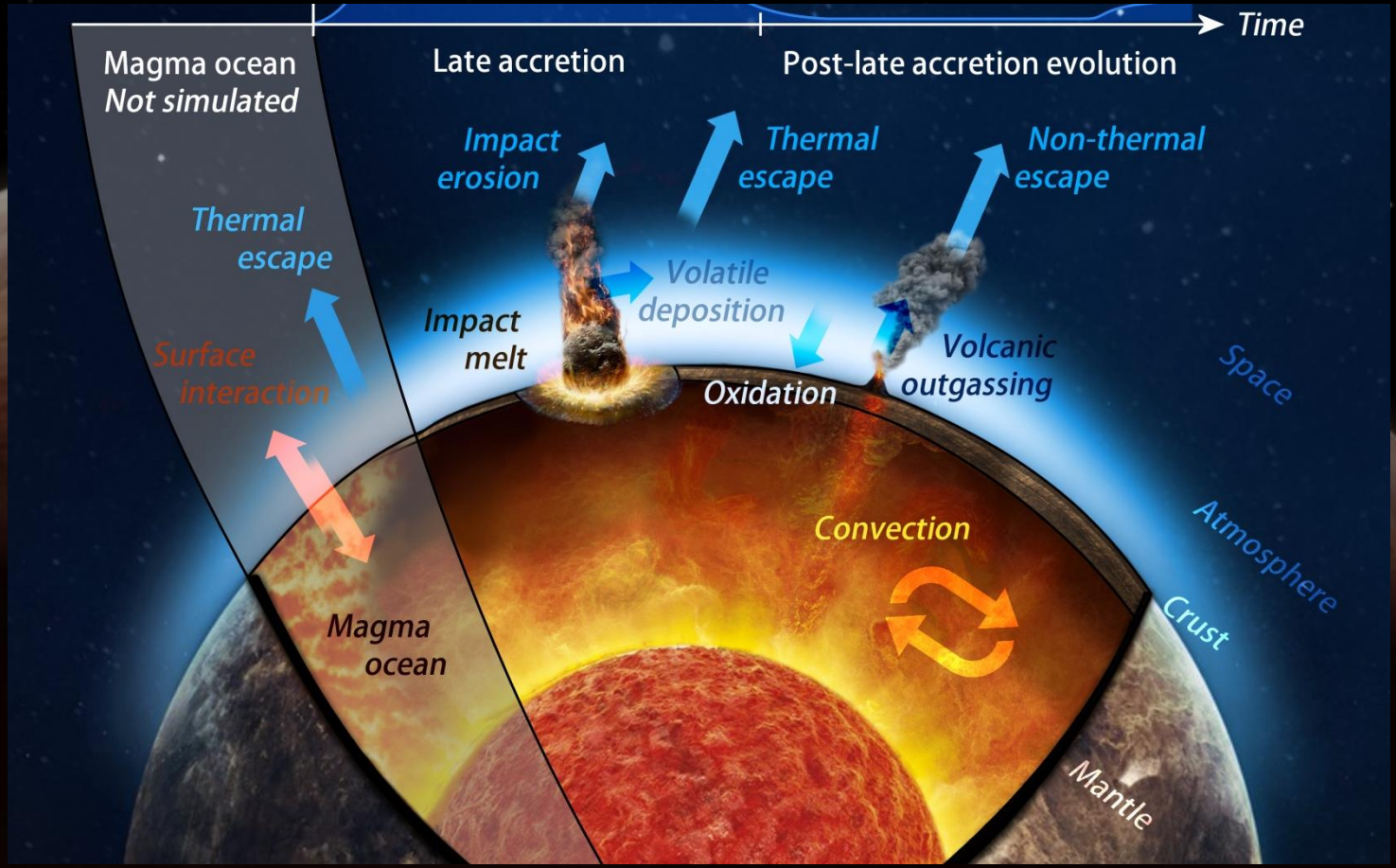

~100s Myr
~3.5 Gyr
Present-day
Total loss of water
≈ mean age of Venus' surface
Magma Ocean
Dry Venus (CO_2)
Minimal escape and outgassing
Present-day-like (CO_2)
CO_2 is trapped inside
High T°C
Mild T°C
Wet Venus (N_2)
Runaway Greenhouse Convection change?
modern plate tectonics; O_2 accumulates

Mechanisms

We model the mechanisms affecting volatiles.

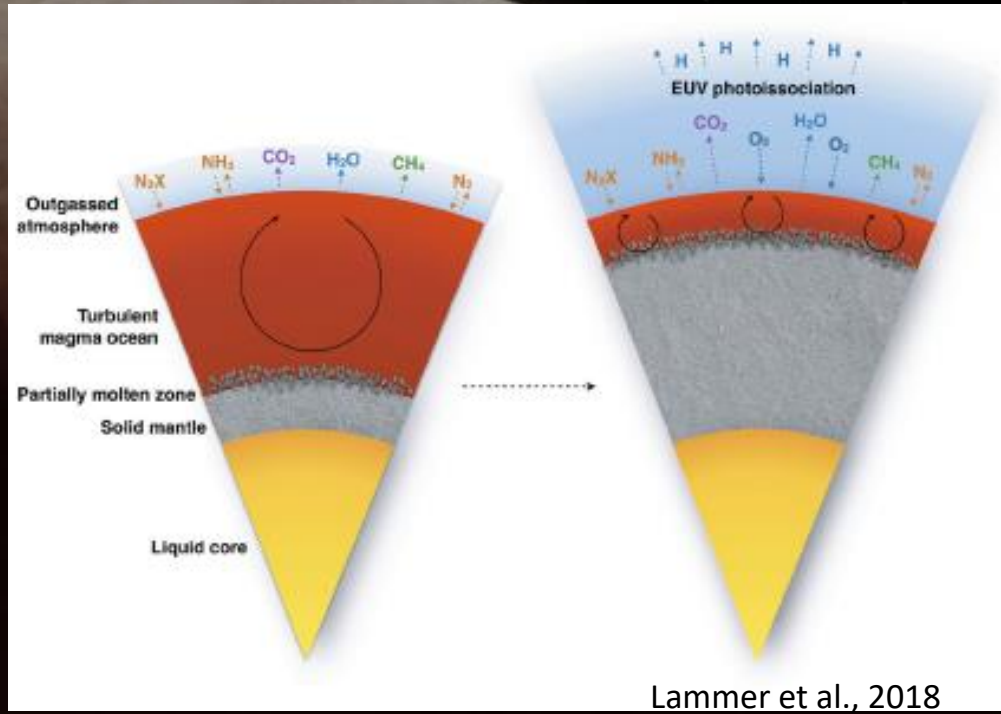
To have access to ancient Venus we need to model all what it went through since then.

We test those evolution scenarios against present-day observation.



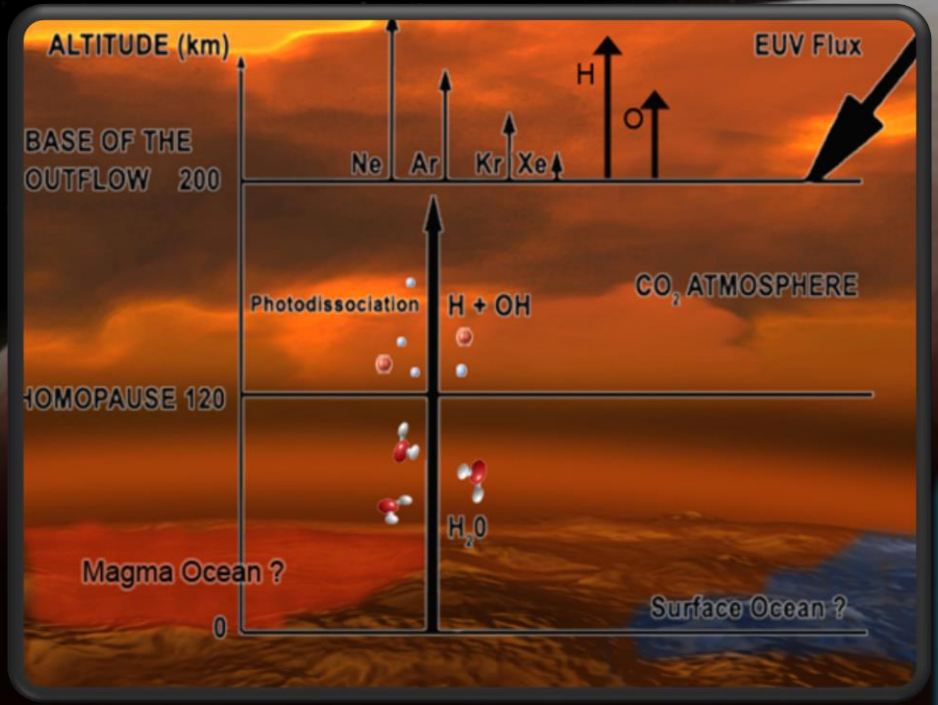
Initial state for the evolution: the magma ocean

- One or several magma oceans are created during accretion from impacts. Depending on the state of the atmosphere, they can be short- or long-lived.
- The Magma ocean controls the early compositional differentiation of the interior and affects the initial volatile budget of the planetary body.
  - It sets the initial composition for the interior and atmosphere.
- When the Magma ocean freezes, it stops most largescale exchanges between the layers of the planet.



Lammer et al., 2018

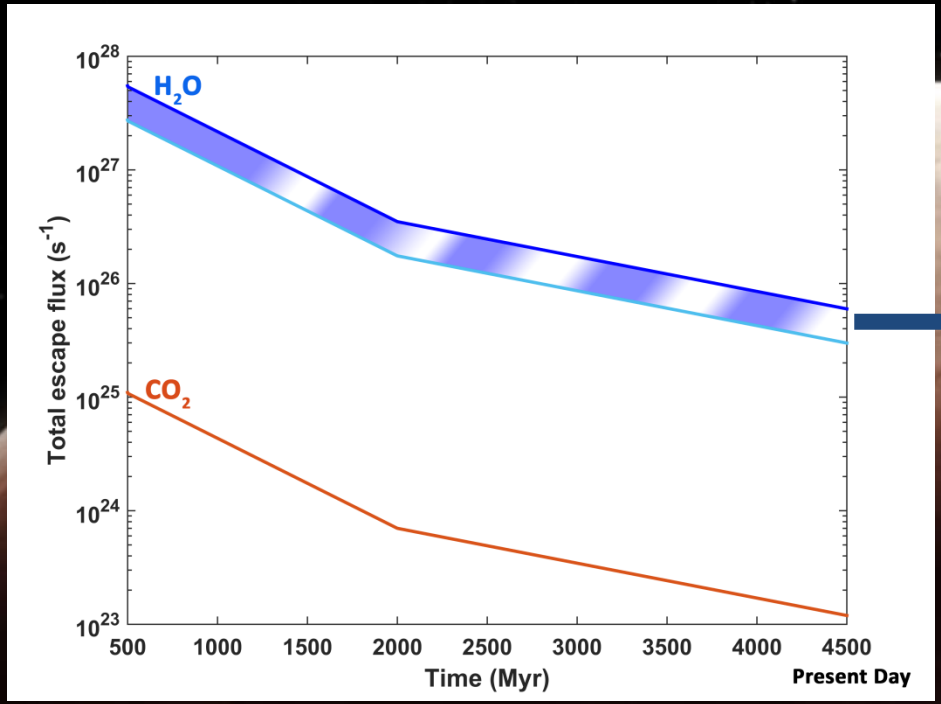
Early evolution and Hydrodynamic escape

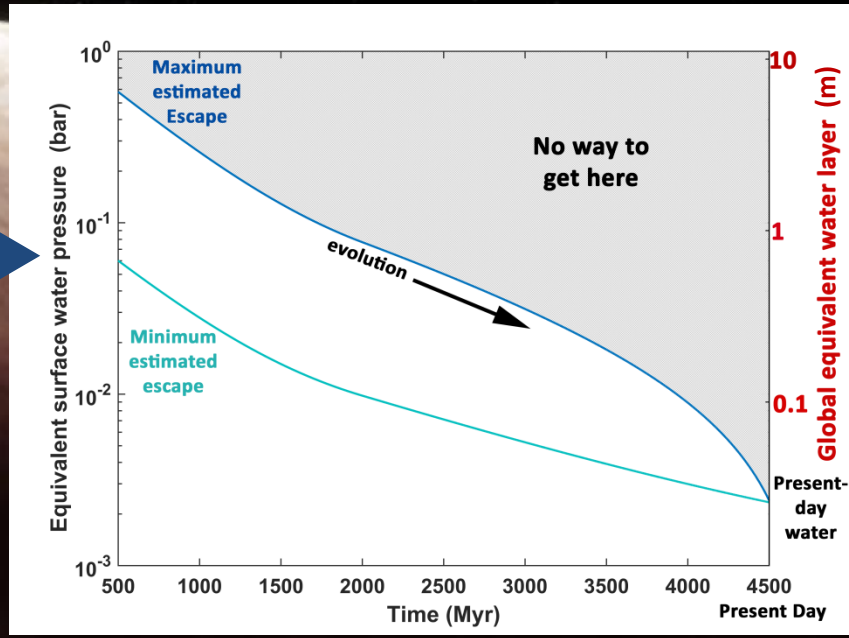


- Very efficient: Likely to remove at least several Earth oceans worth of Hydrogen.
- Fractionates noble gases (but non-unique scenarios).

- Preferentially removes H over O, leading to an excess of Oxygen.
- We need a way to get rid of O!

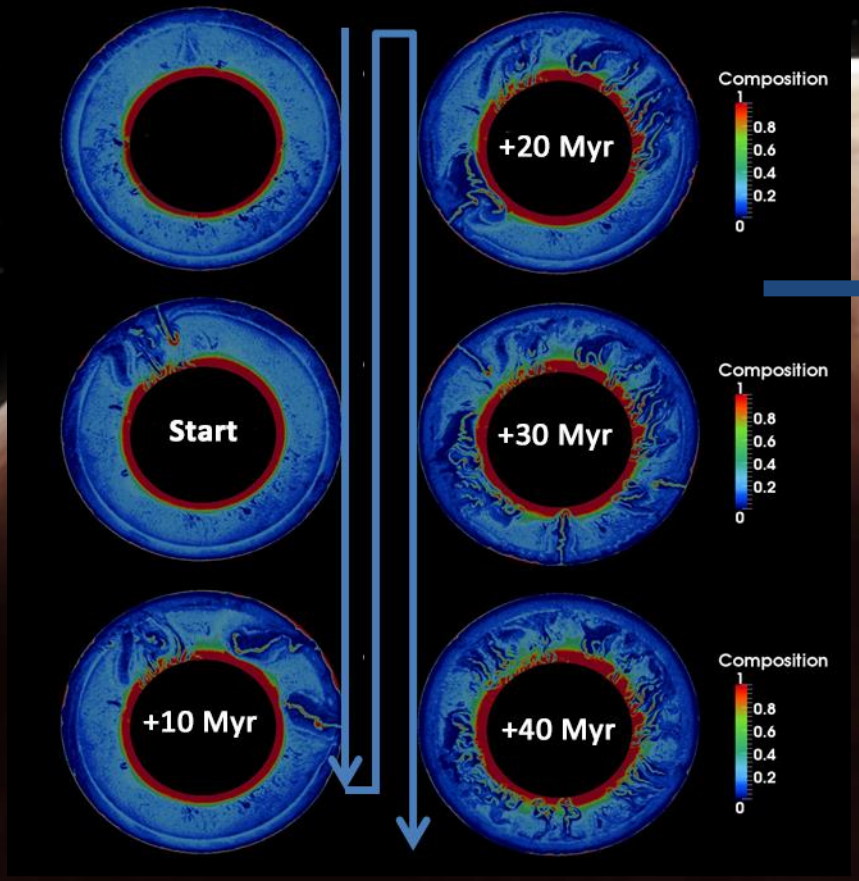
Focus on Late Escape

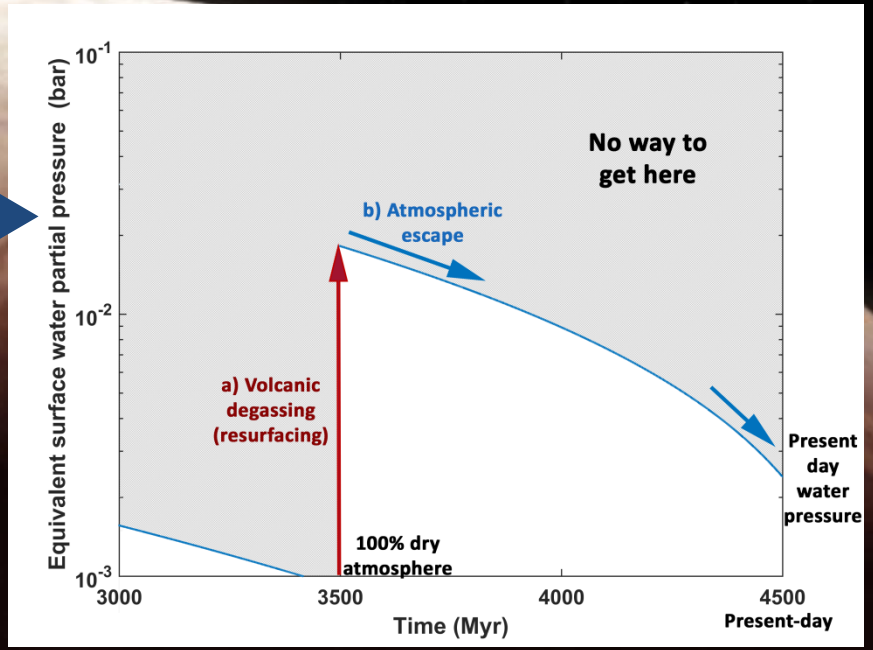




- Present-day non-thermal escape rates are one of the few direct observation about evolution processes we have.

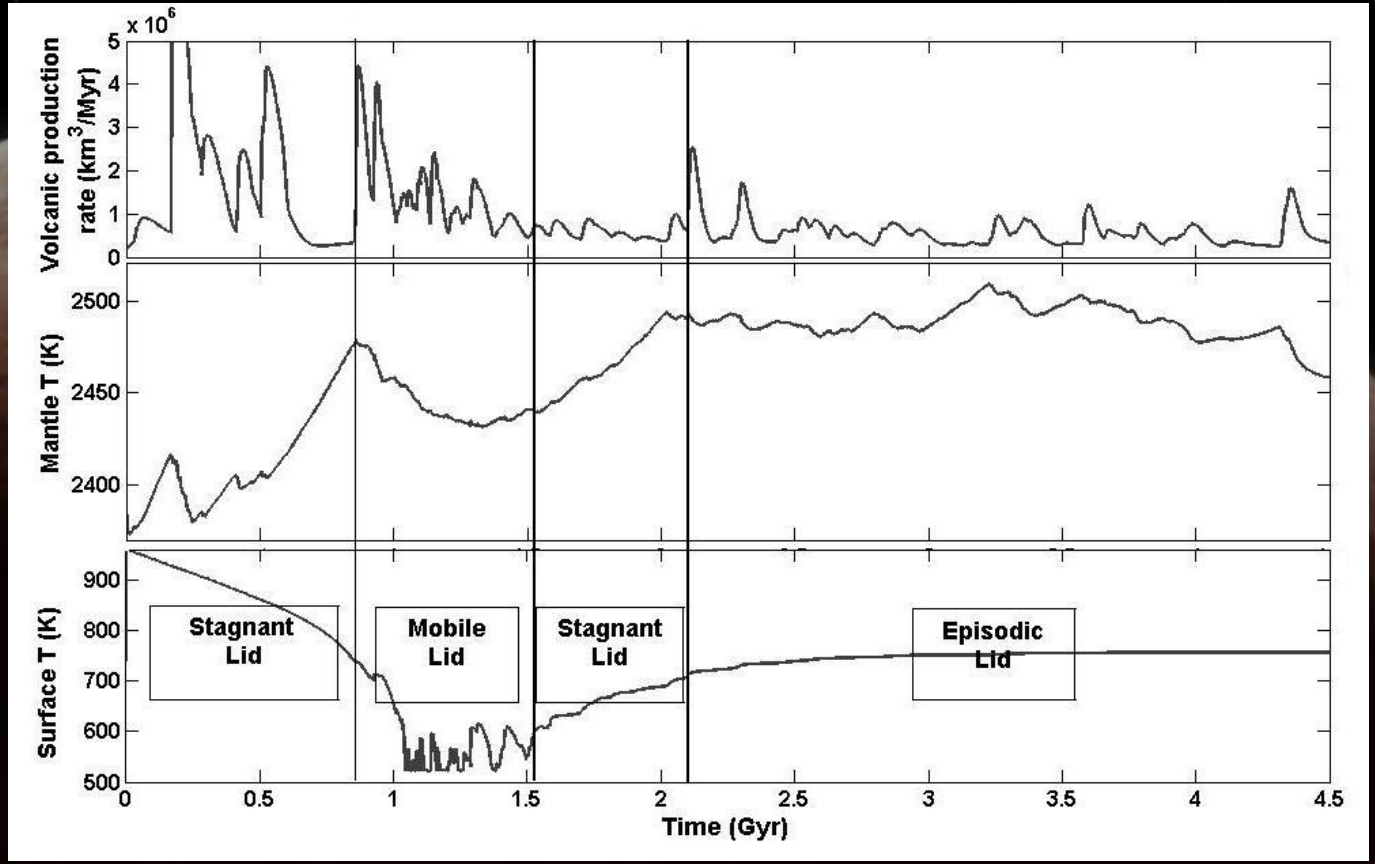
A link with volcanism





Convection regime and consequences

- Surface conditions make a difference.
- Low surface temperatures trigger a mobile lid regime.
- Possible mobile lid regime opens quite a few possibilities.



Late Accretion

- The last 0.5-2% of Earth's accretion, after the core was formed
- consequences on planets' volatile distribution/evolution.
- Usually investigated throught isotopic studies.

Another major player , early on…

- Effects of impacts

Volatile Sink

- Erosion of the atmosphere means an additional loss process.
- It seems relevant only for a very large number of small impacts, though.

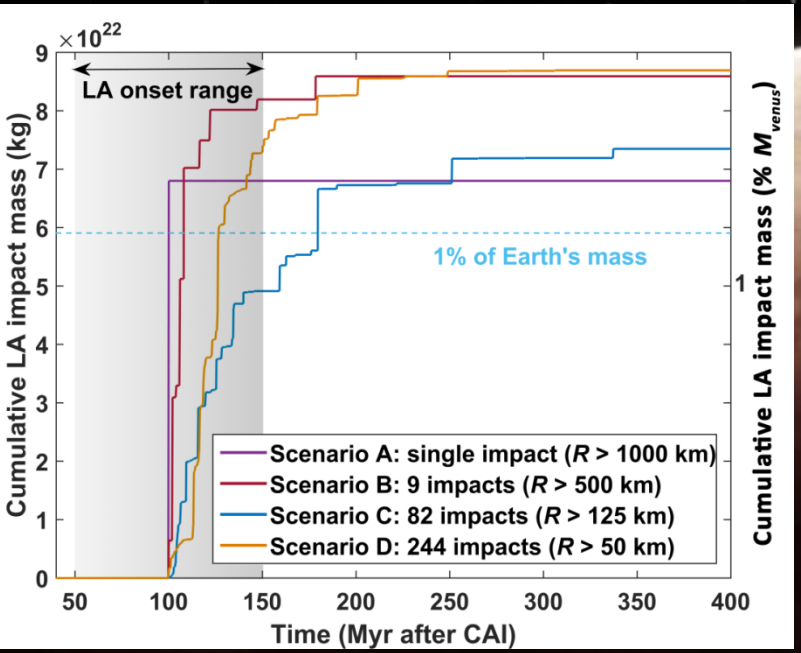
Volatile source

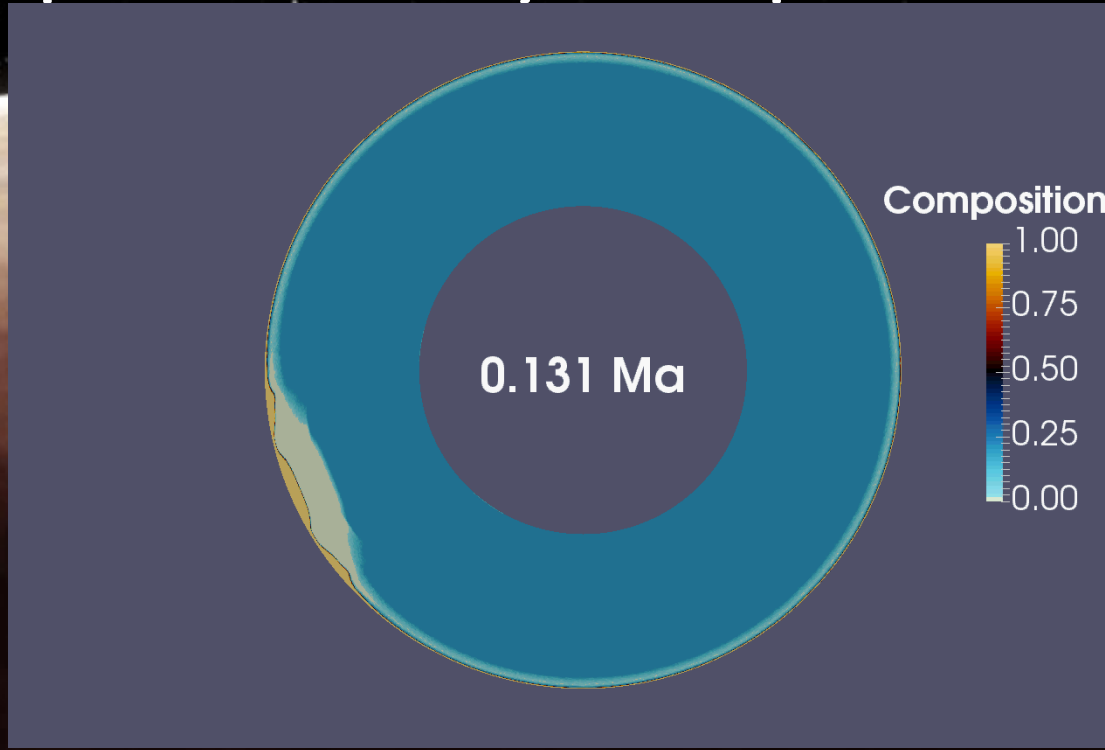
- Volatile delivery by the impactors can replenish the atmosphere.
- Potentially the larger effect but depends on composition.

Energy Source

- Energy delivery to the solid planet affects the interior and can cause melting.
- Release depends on mantle and atmosphere conditions.

Late Veneer, a complex but key component

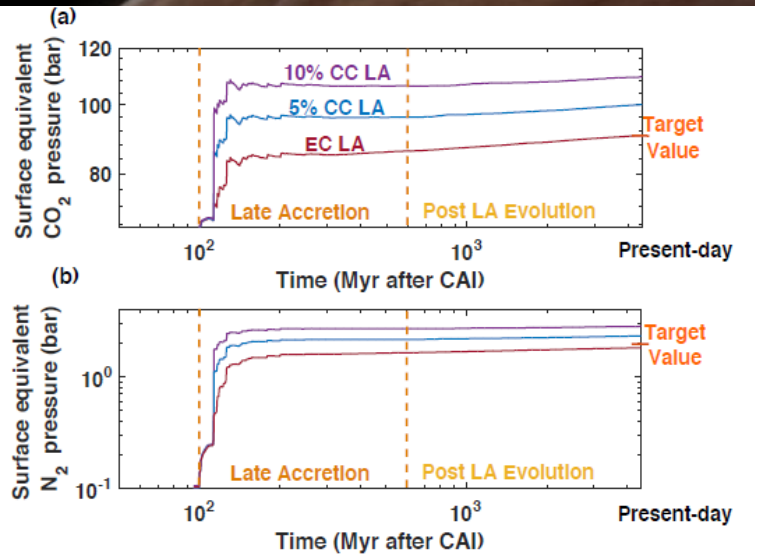


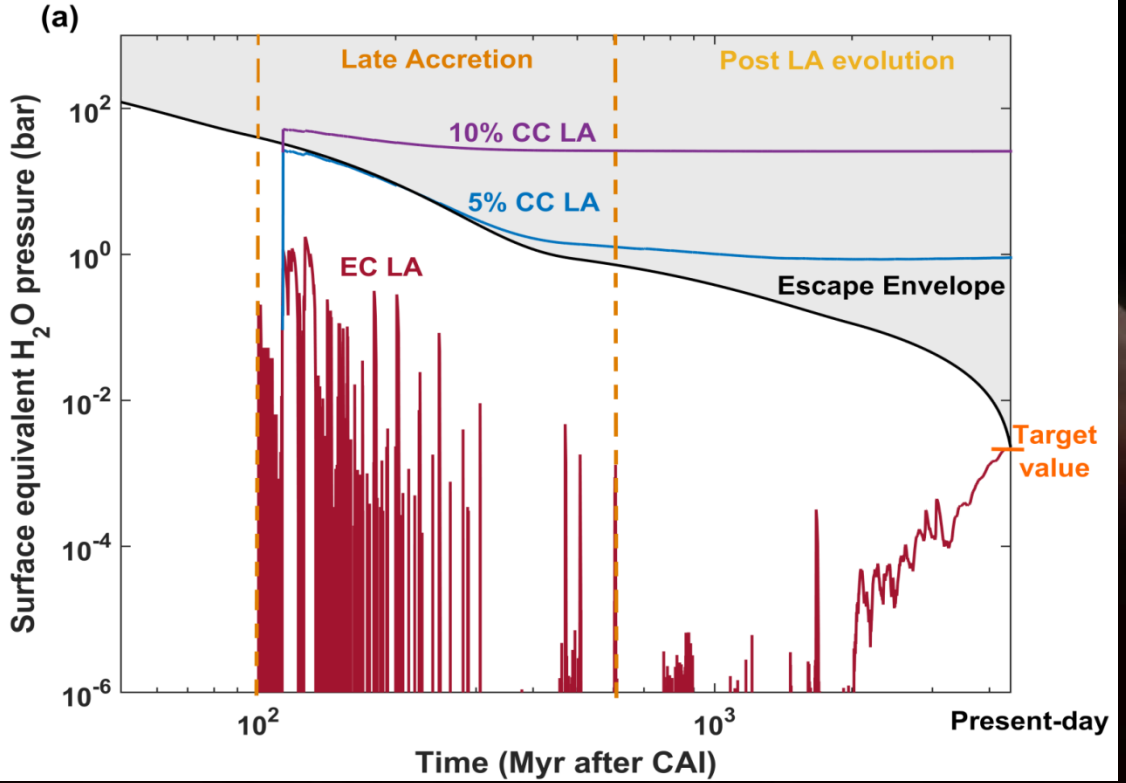


- It delivers volatiles and affects the mantle (depletion?)

Volatile delivery dominates early evolution

- Accreting wet material is difficult, as mentionned before.
- Erosion is marginal.





Conclusions

- Despite the lack of measurements, through devious means (modelling the long term evolution), we could obtain constrains on the nature and timing of volatile delivery.

- Our results are consistent with isotopic measurements for Earth. The Late Accretion was probably mostly Enstatite Chondrite with low volatile content.

- Water was likely already delivered to terrestrial planets early on, during the main accretion phase, and in the case of Earth, before the moon-forming impact.

➢ We are investigating the role of surface oxidation as a oxygen sink.

Future exploration

- Venus science could benefit from refinements in *any* area, due to the relatively limited observational data we possess, especially when it comes to past Venus.

- The interior of Venus, however, remains the biggest unknown. Venus interior models are based on Earth's. We need to know how different the interiors of those planets are from each other.

- Any new clues of interior structure, composition, volatile content and past behaviour would be appreciated. Missions like VERITAS, DAVINCI+ and ENVISION could help with that.

- Going further, measurements of remnant magnetic field would be useful, and not yet included on future missions.