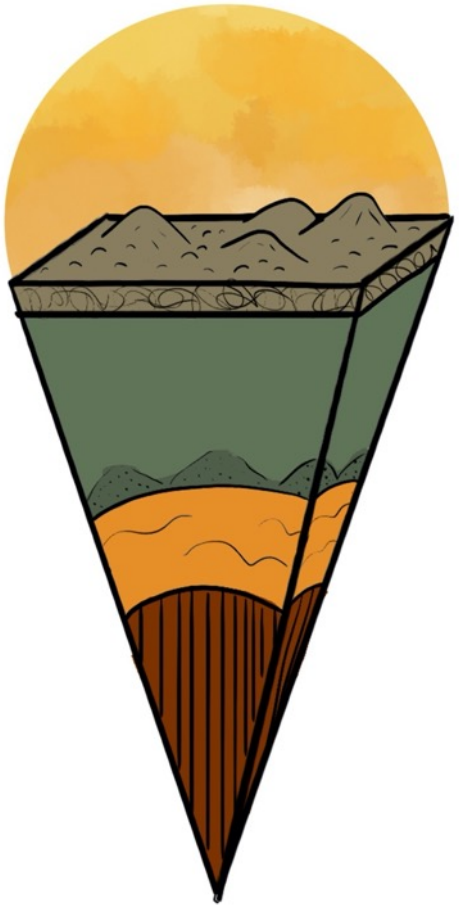
A Basal Magma Ocean in Venus:
Implications for Gravity, Heat Flow, Magnetism, and Noble Gases

Joseph G. O'Rourke

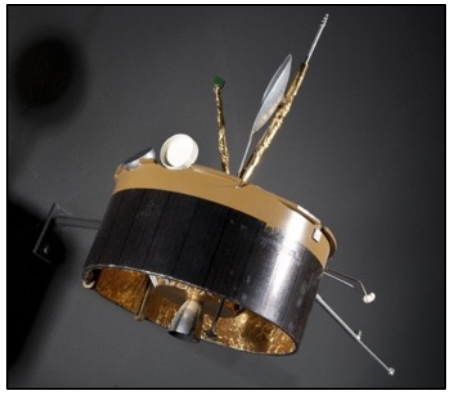
Assistant Professor

Email Me: jgorourk@asu.edu

School of Earth and Space Exploration
Arizona State University



Few Constraints on the Deep Interior



Pioneer Venus Orbiter

- No strong-field dynamo (<10^{-5} times Earth's)

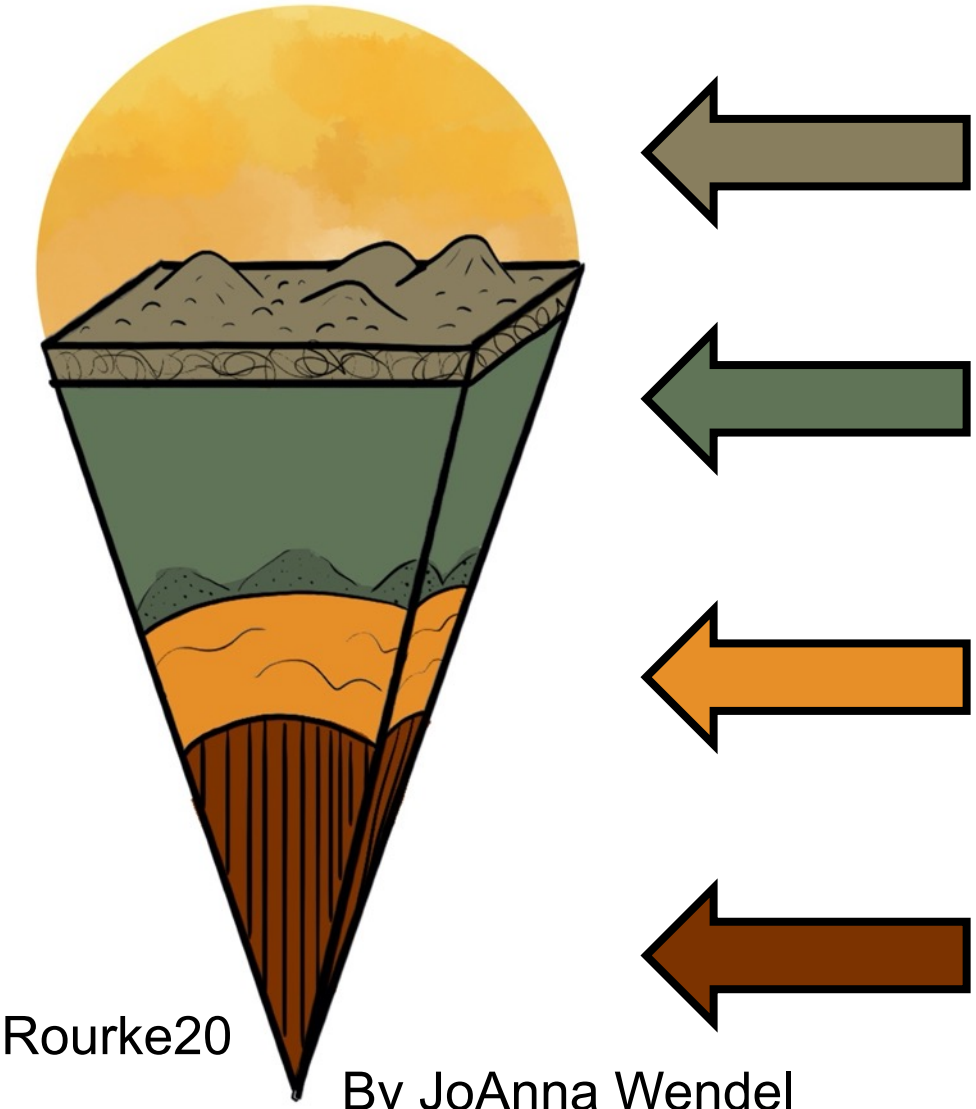
Magellan Mission

- Love number k_2 = 0.295 ± 0.066 (Dumoulin+17)

Green Bank & Goldstone Telescopes

- Moment of inertia ~0.34 ± 0.03 (Margot+19)

A Basal Magma Ocean May Exist



O'Rourke20

By JoAnna Wendel

Surface/Lithosphere

- Low heat flow relative to Earth

Mantle (solid)

- Iron-rich "piles" at base

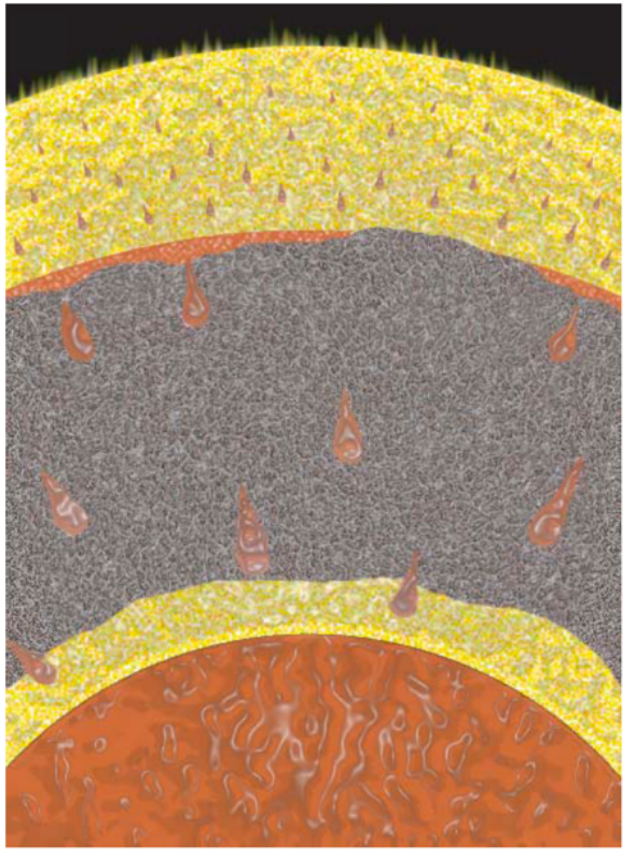
Basal magma ocean (liquid)

- Plausibly ~200 to 400 km thick

Core (liquid)

- Hot but conductive & stagnant

Magma Oceans Naturally Exist



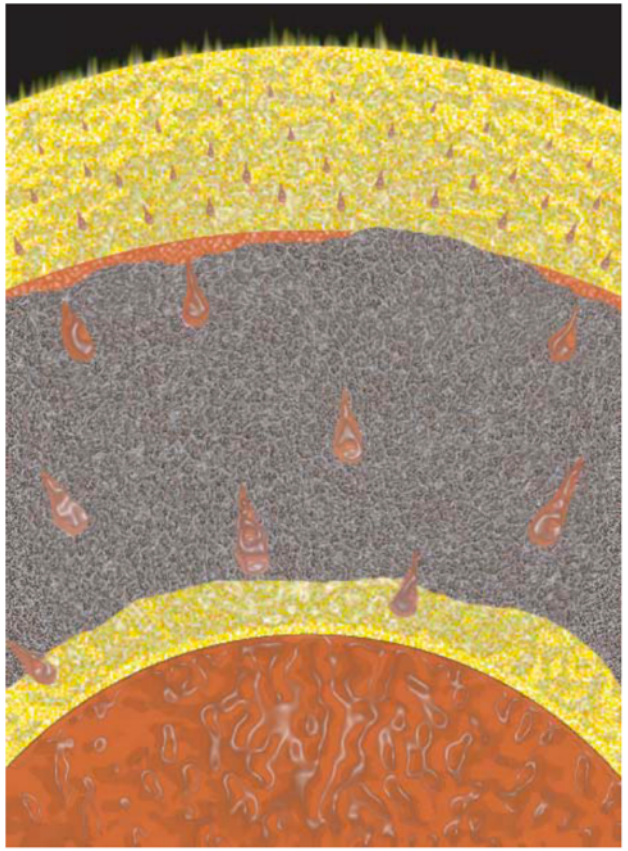
t ~ 0 Myr

Labrosse+07

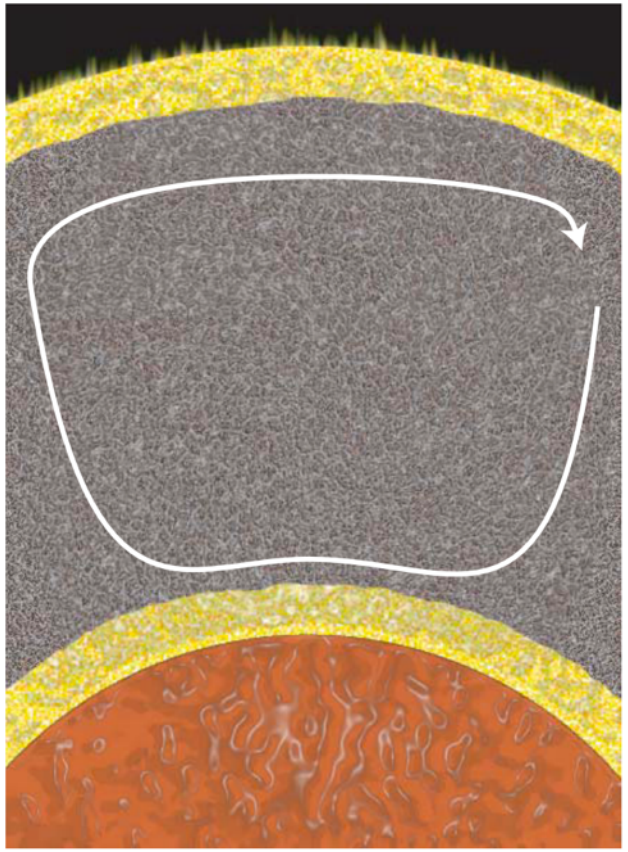
Mantles of rocky planets may solidify from the middle outwards

- Bridgmanite crystals are neutrally buoyant at ~50 GPa (Caracas+19)

Surficial Magma Oceans Cool Quickly



t ~ 0 Myr



t ~ 10–100 Myr

Heat lost directly to space

- Solidification in <10 and 100 Myr for Type I and II planets (Hamano+13)

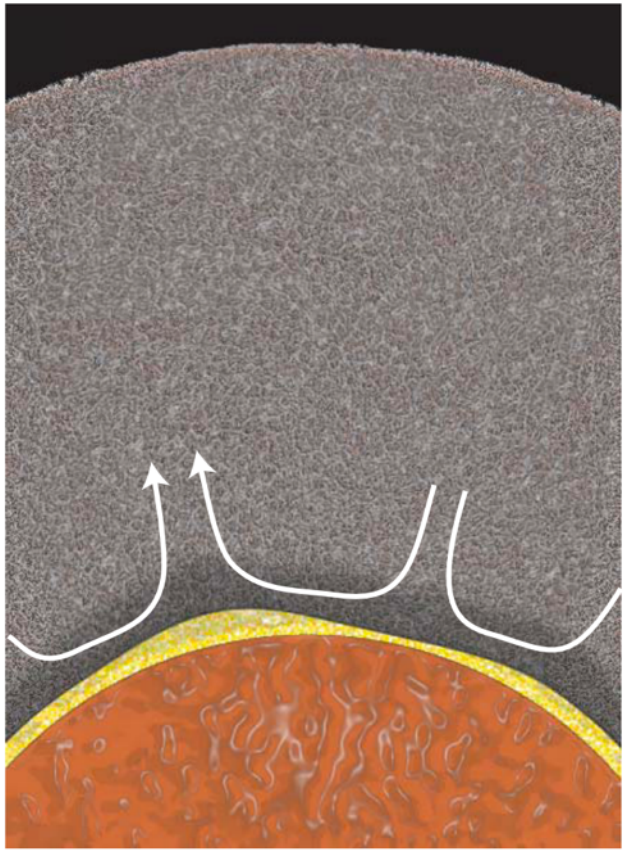
Labrosse+07

Basal Magma Oceans Cool Slowly

Solid-state convection limits the cooling rate

Radiogenic and latent heat in the BMO

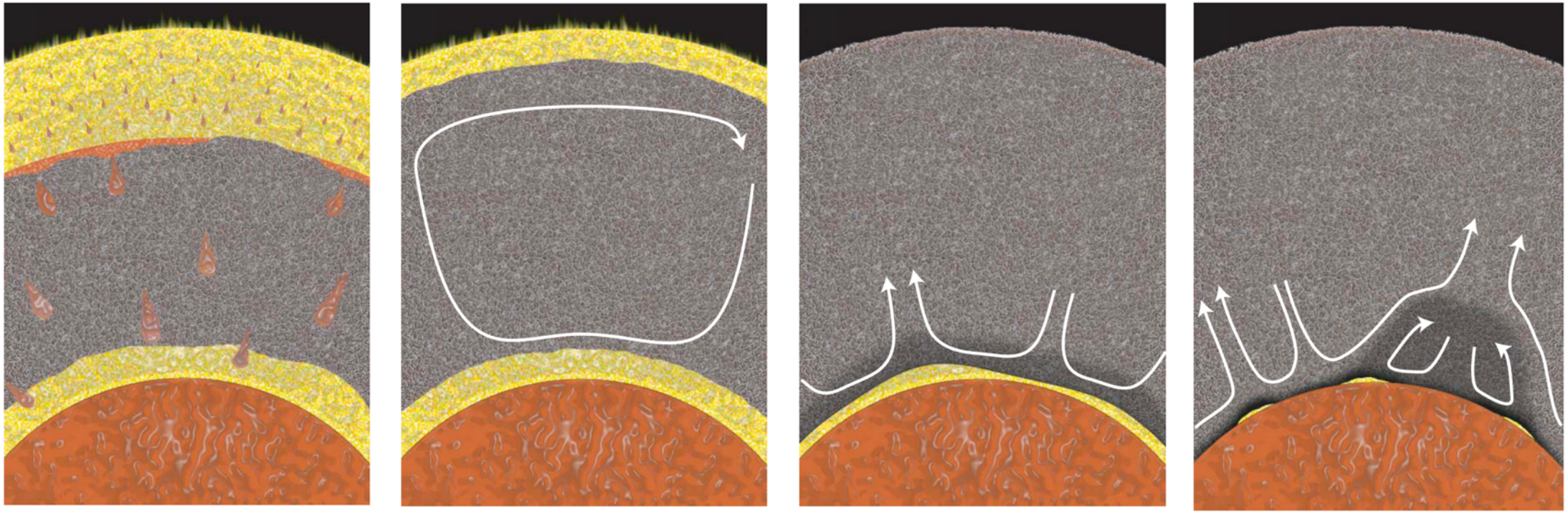
The core and BMO must cool in tandem



t ~ 100–4500 Myr

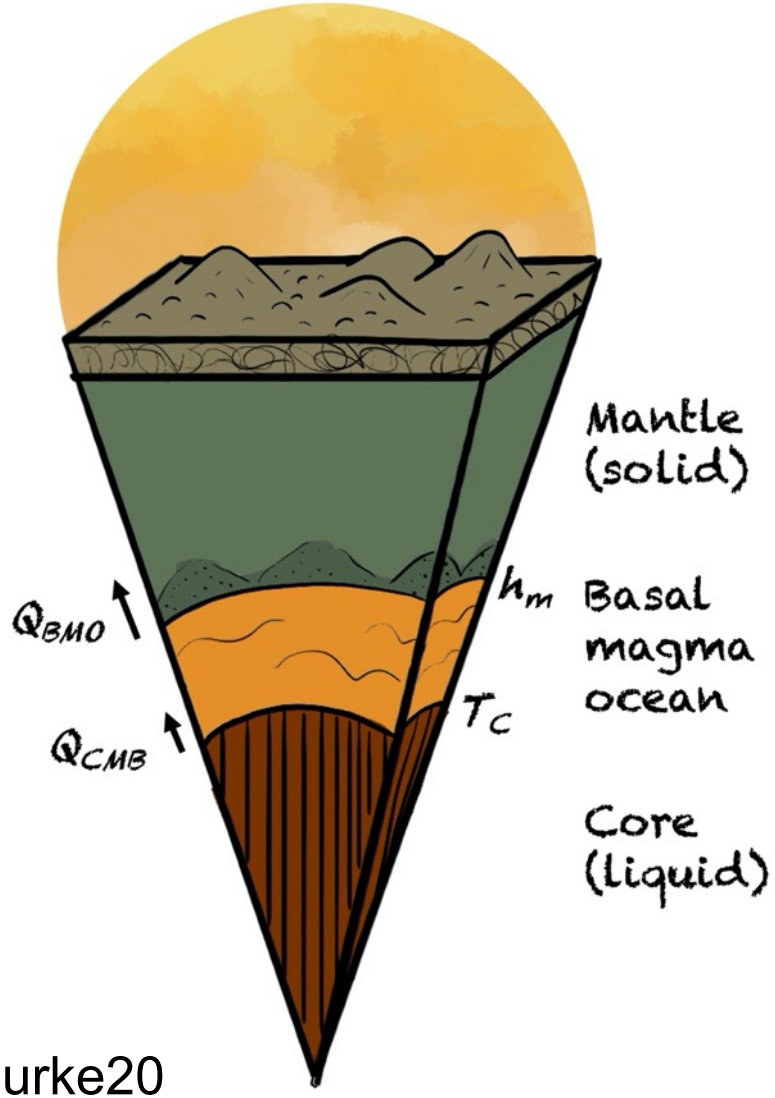
Labrosse+07

Venus Cools More Slowly Than Earth



Labrosse+07

Calculate the Global Heat Budget



Total heat flow into the solid mantle

Cooling of the core

$$Q_{BMO} = Q_{SM} + Q_{RM} + Q_{LM} + Q_{CMB}$$

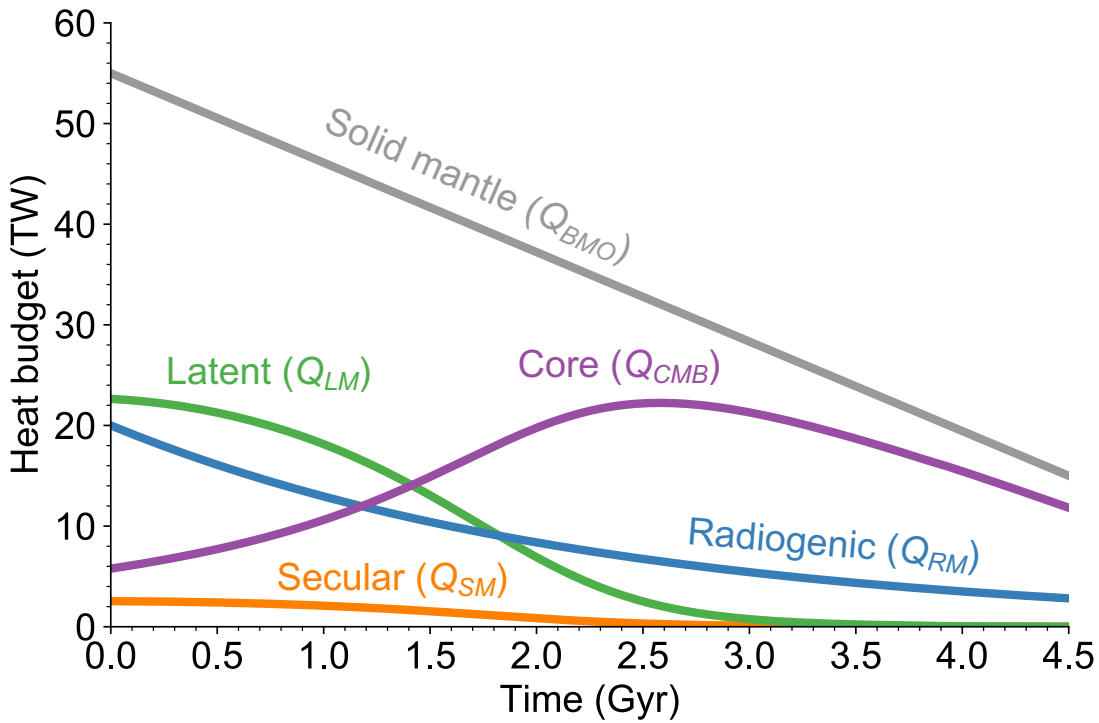
Secular cooling

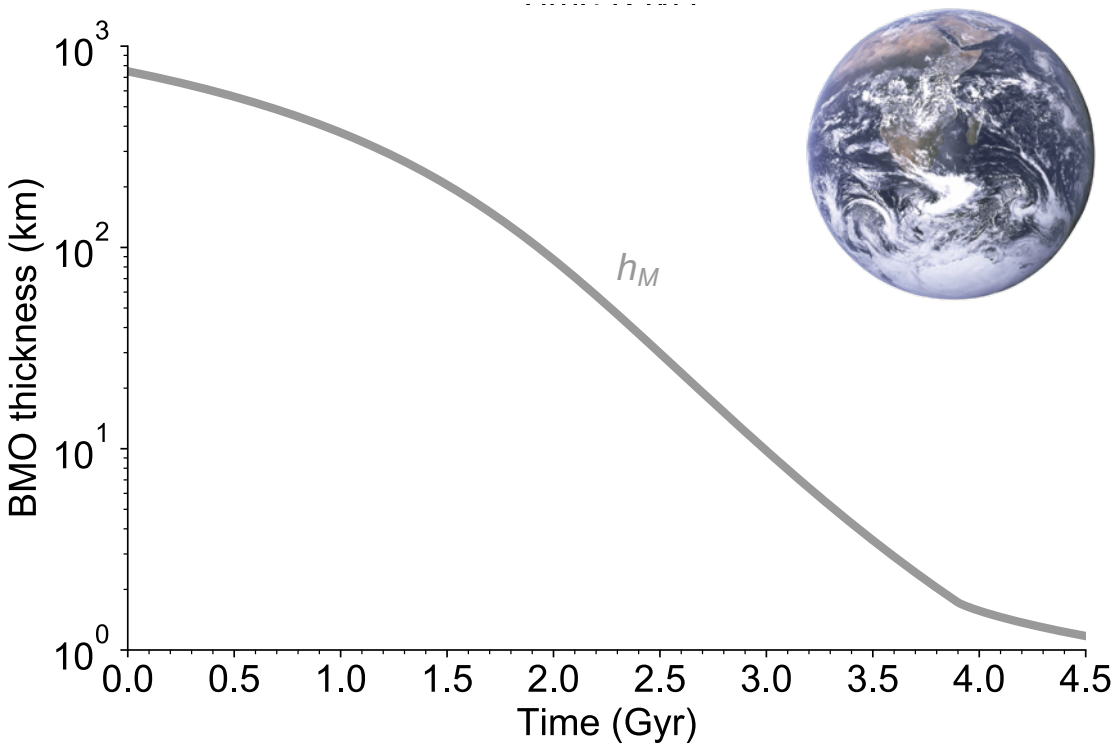
Radiogenic heat

Latent heat

O'Rourke20

Models of Earth Are the Benchmark

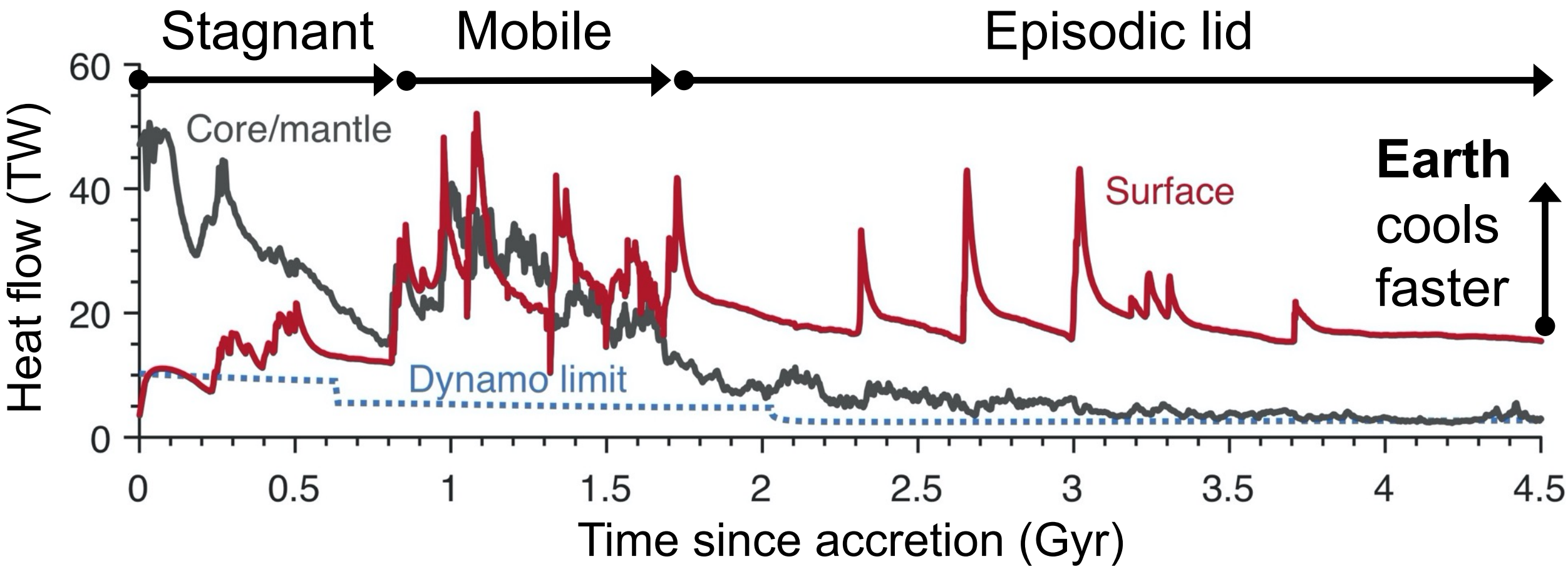




In Earth, the basal magma ocean must fully solidify

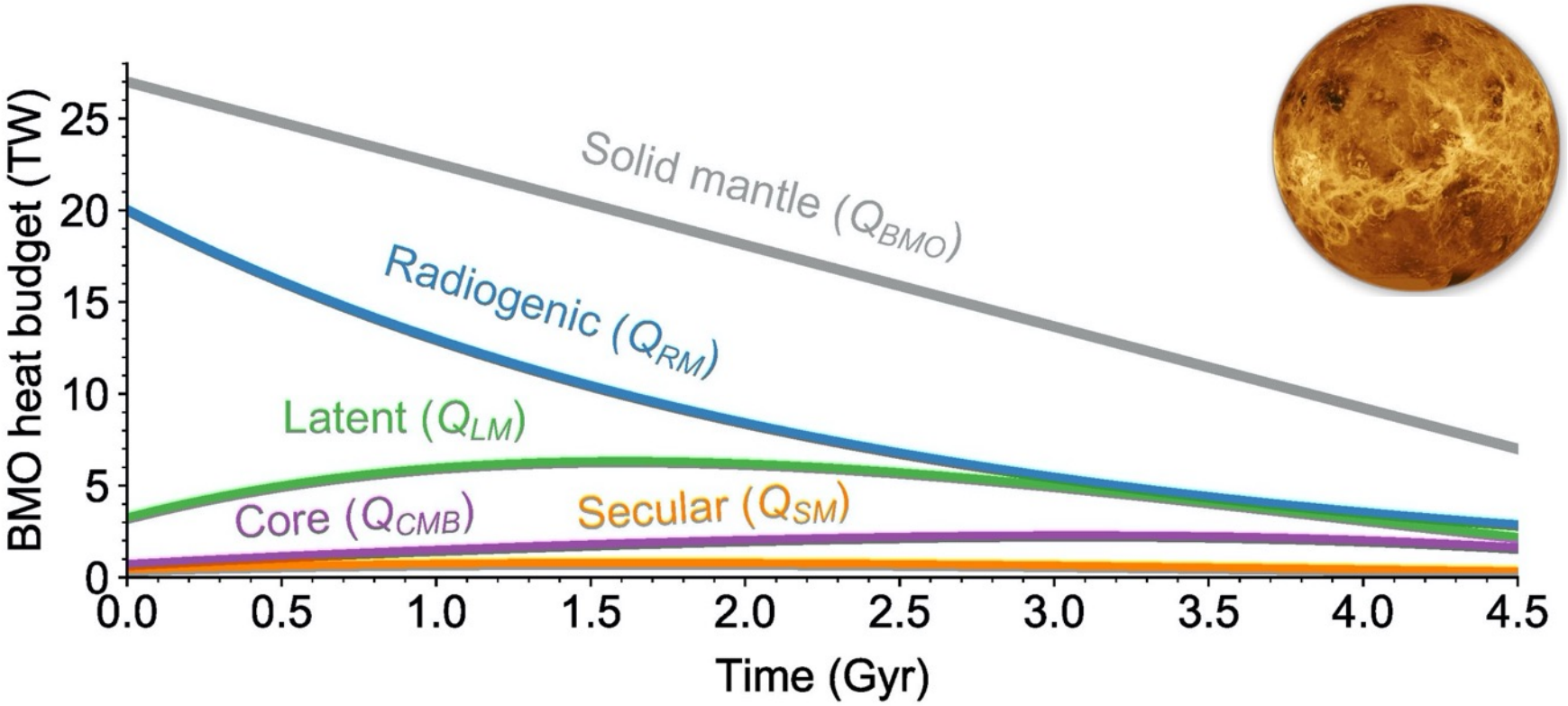
O'Rourke20. See Blanc et al. 2020 (EPSL) for detailed models.

Venus Is Assumed to Cool Slowly



O'Rourke et al. (2018, *EPSL*); Gillmann & Tackley (2014, *JGR*)

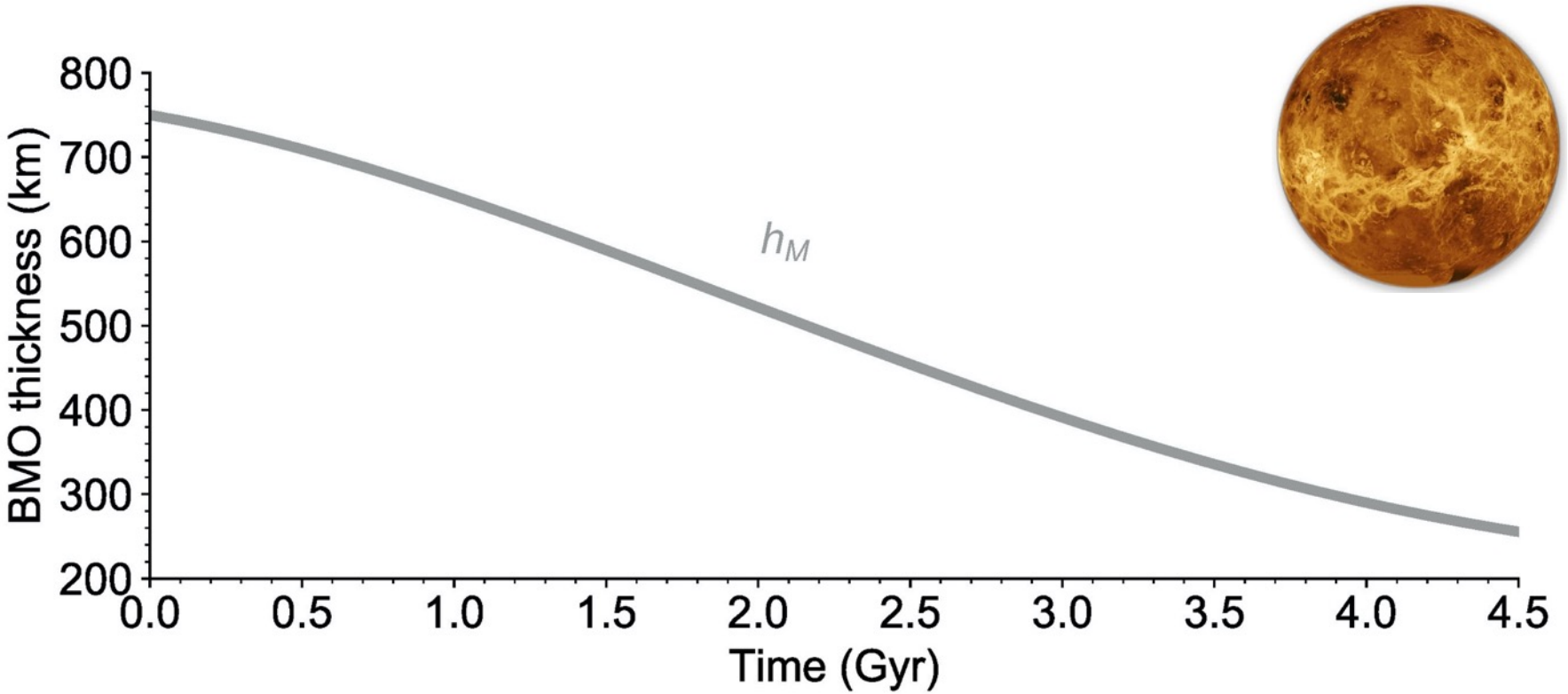
Venus is Assumed to Cool Slowly



Total heat flow is always simply halved

O'Rourke20

Venus: BMO Remains Molten Today



Halving the total cooling rate **doubles** the lifetime

O'Rourke20

Relevance to EnVision & VERITAS

Gravity science could reveal a basal magma ocean

- Tidal Love number (k_2) and tidal phase lag (Kervazo+20)

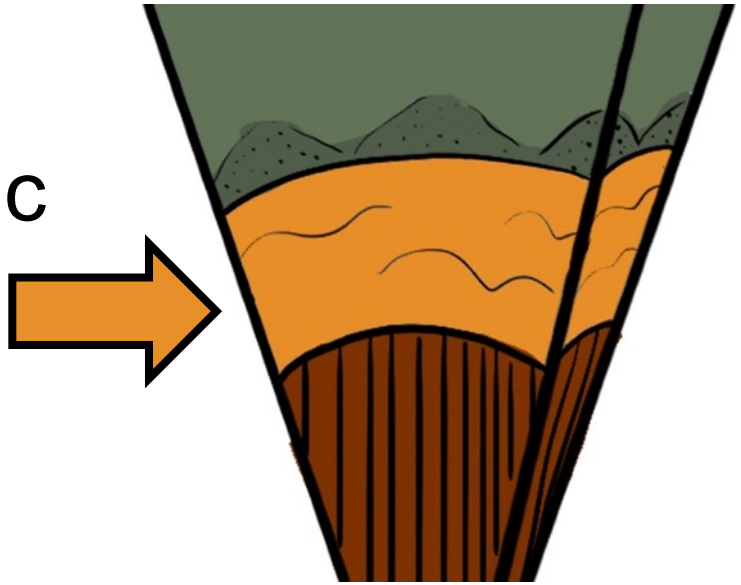
Complements investigations of global heat flow and lithosphere

Relevance to Noble Gases (DAVINCI+)

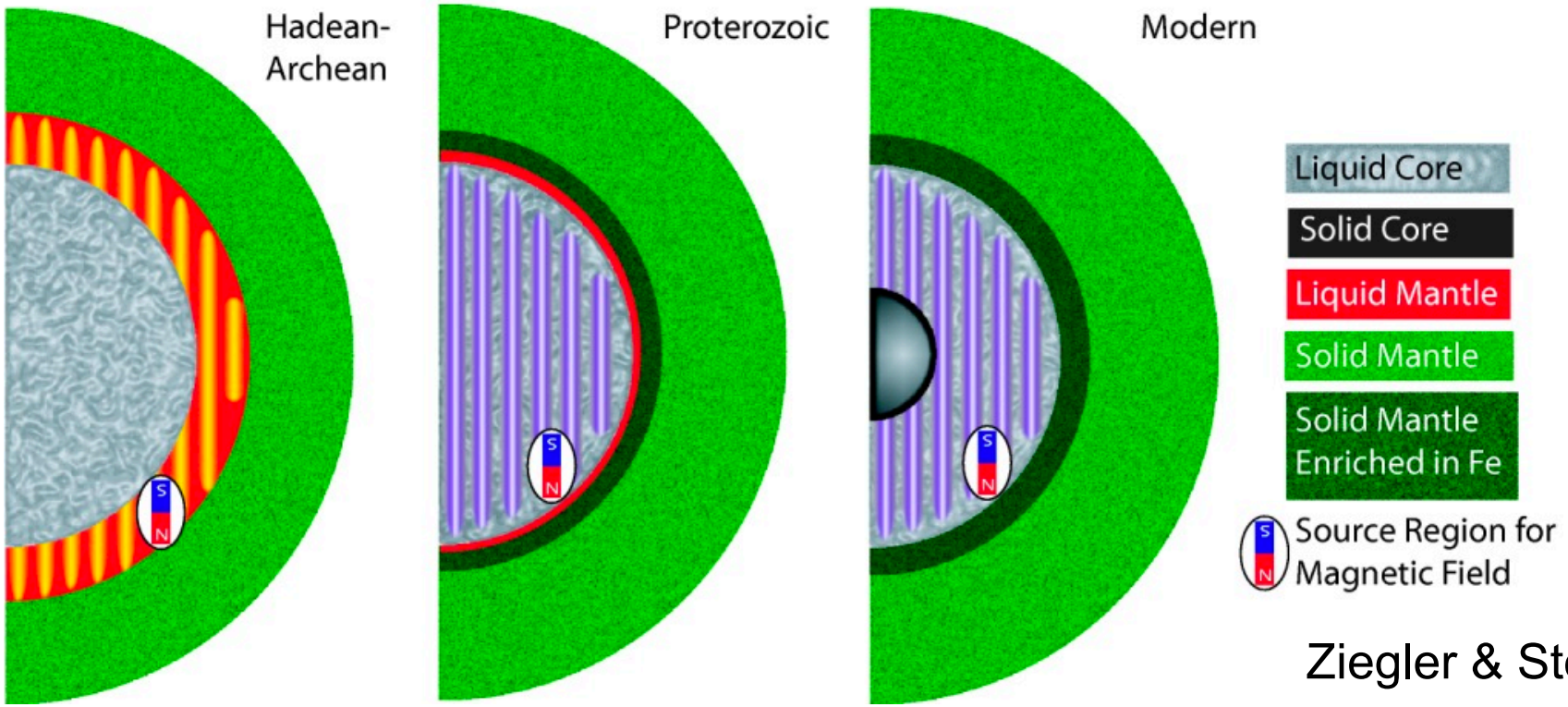
Basal magma ocean is a <u>hidden reservoir</u> of incompatible elements

- K, U, Th, Ar, noble gasses…

Missing atmospheric argon-40 hides in the BMO today?

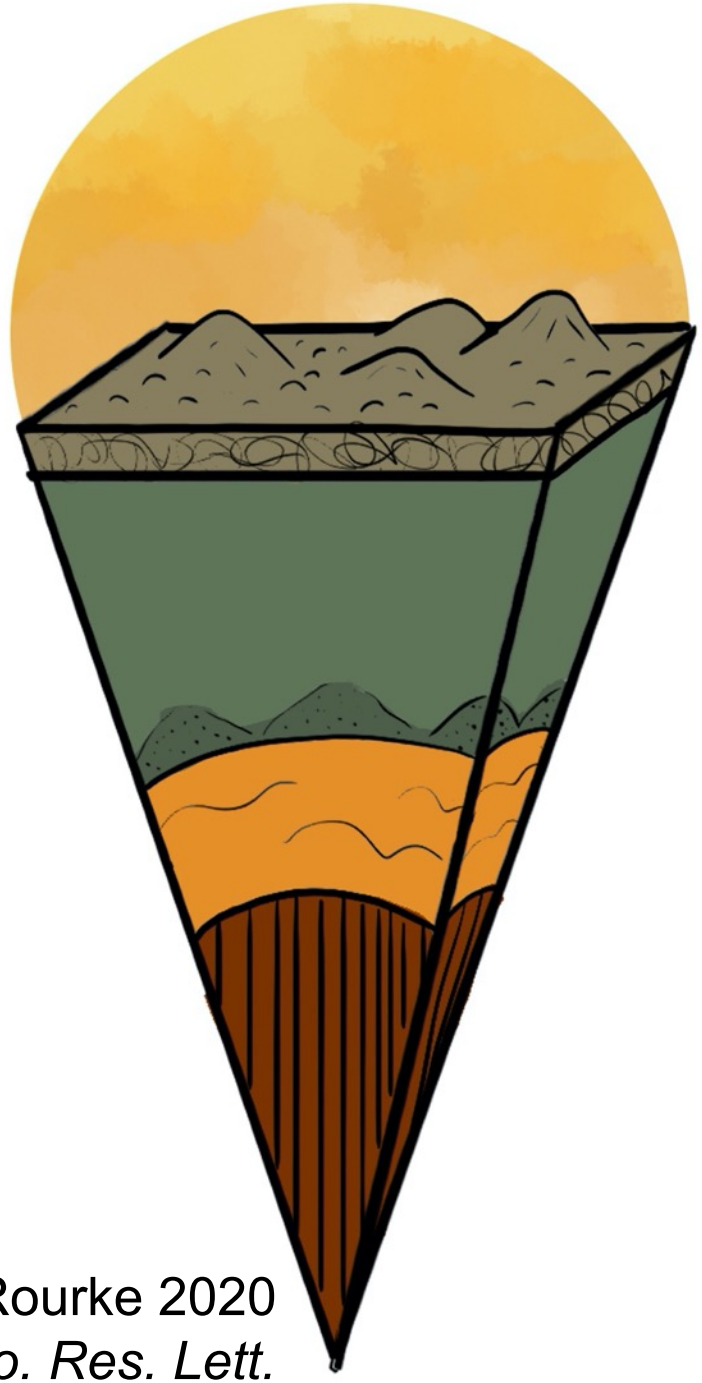


The BMO Obviates a Core Dynamo



Ziegler & Stegman (2013)

But the BMO *itself* could host a dynamo in the recent past—
liquid silicates are electrically conductive at high T/P



O'Rourke 2020
Geo. Res. Lett.

Conclusions

Venus: A Thick Basal Magma Ocean May Exist Today

- Signature of reduced internal cooling of Venus compared to Earth
- Detect via gravity (k_2 and phase lag)
- Hidden reservoir for incompatible elements such as noble gases
- May have hosted a dynamo within the past ~1 Gyr—crustal magnetism?