Energetic Requirements for Dynamos in the Metallic Cores of Super-Earth and Super-Venus Exoplanets

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Are Massive Exoplanets More Likely to Have Magnetic Fields?

- Super-Earth and Super-Venus exoplanets are defined as planets with Earth (Venus)-like densities, but their masses scale from 1-10 Earth-masses.
- Convection in a metallic core can produce a magnetic field [e.g.,1-6].
- Detecting a magnetic field might help us constrain models of mantle dynamics.
- Any detection of a magnetic field could help us learn more about the habitability of the planet's surface [2].

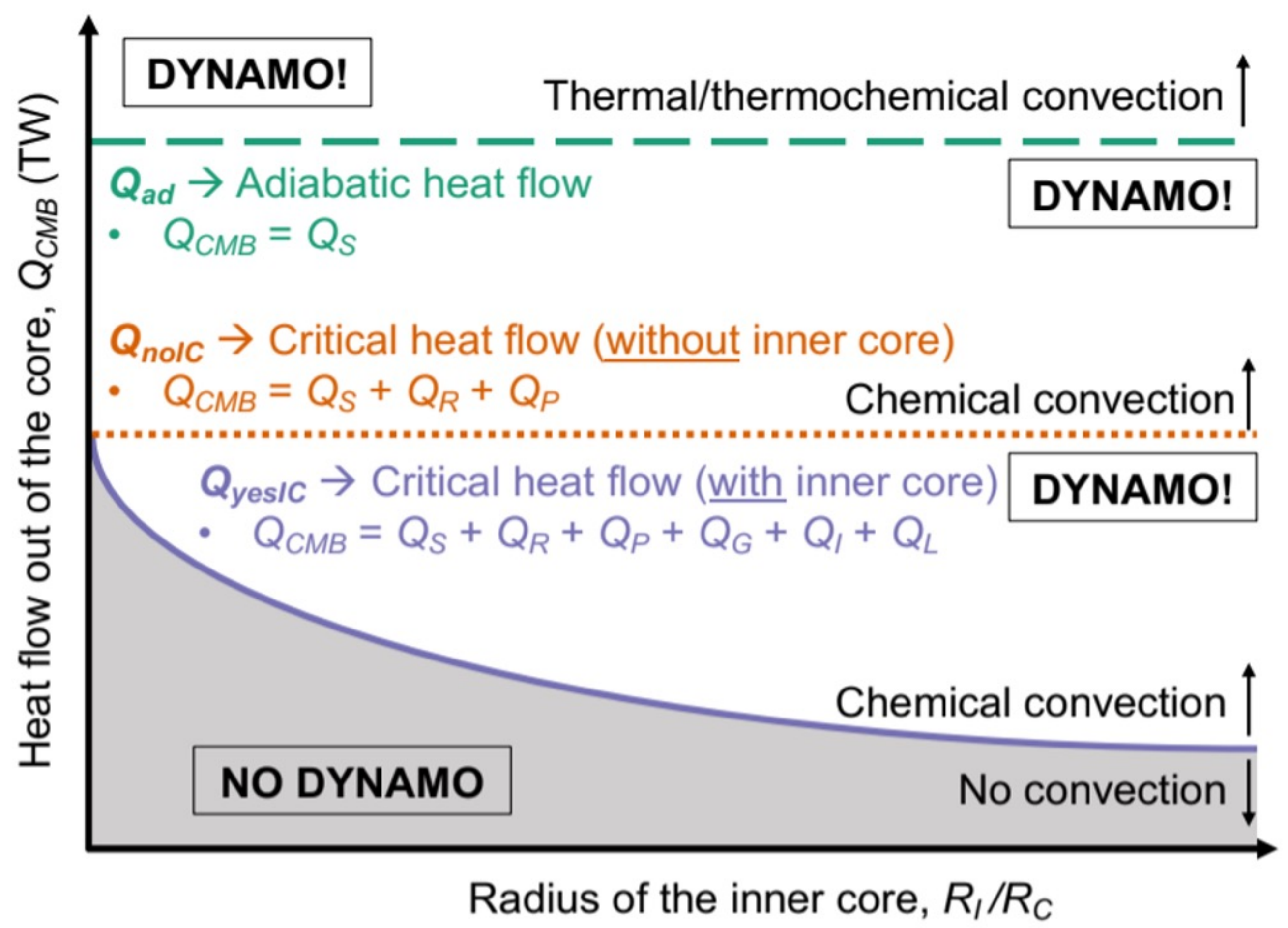
What Do We Know About Earth and Venus?

- **Earth** has plate tectonics and a core-hosted dynamo. The heat flow out of the core may be super- or sub-adiabatic.
- **Venus** has no plate tectonics, and no dynamo due to a low total heat flow relative to Earth, or a different core composition/structure

Earth has a magnetic field
Credit: Discover Magazine

Venus does not
Credit: NASA/JPL-Caltech

Scaling Law #1 – Required Heat Flow



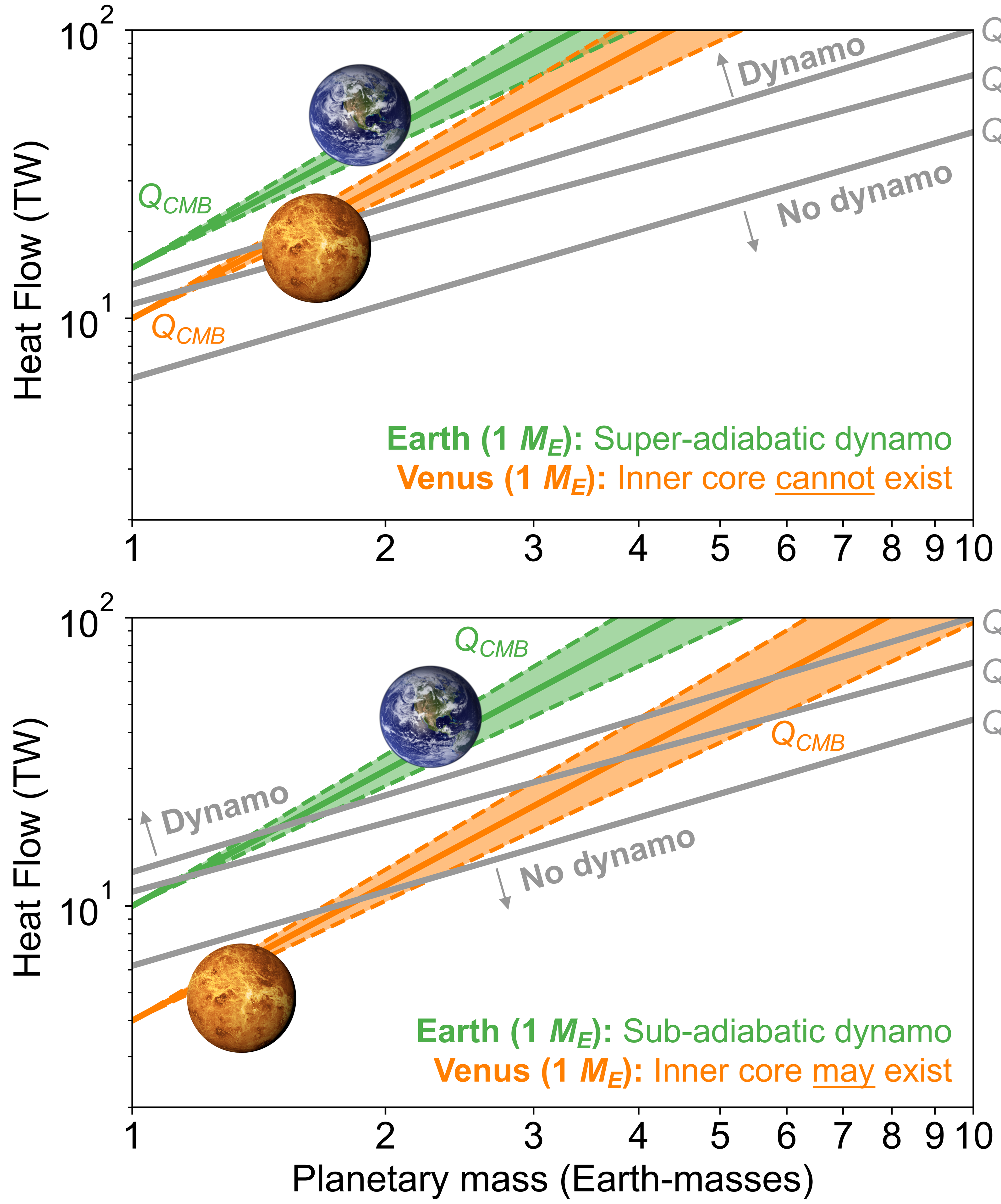
- We calculated **3 possible threshold values** of the total heat flow required to drive convection depending on available sources [3,4].

Q_S = Secular cooling of the outer core
Q_R = Radiogenic heating in the outer core
Q_P = Chemical precipitation at the core-mantle boundary
Q_G = Gravitational energy driven from convection below
Q_I = Heat flux associated with cooling at inner core boundary
Q_L = Latent heat associated with freezing of inner core

Q_{CMB} is the heat flow across the core-mantle boundary.

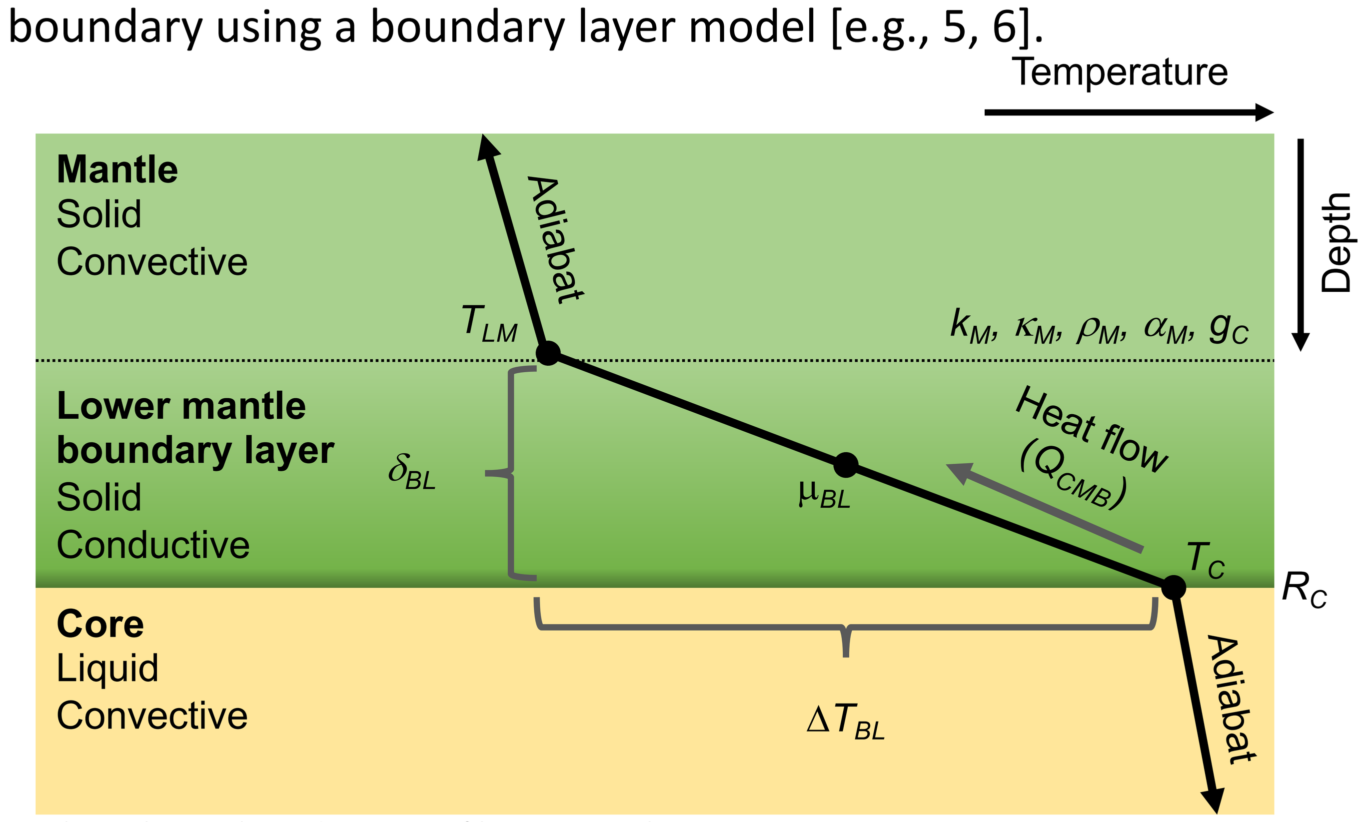
- Dependent on the thermal conductivity of the mantle, **not** the thermal conductivity of the core!

Results: Required vs. Actual Heat Flow Across the CMB



Scaling Law #2 – Actual Heat Flow

- We estimated the actual heat flow across the core-mantle boundary using a boundary layer model [e.g., 5, 6].



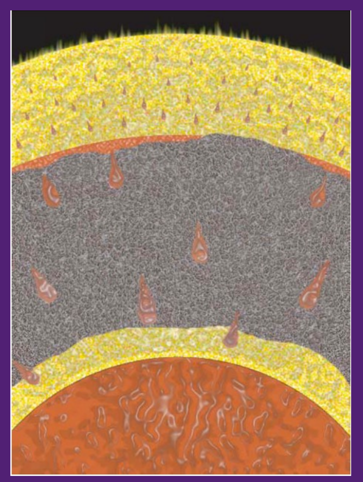
k_M = thermal conductivity of lower mantle
κ_M = thermal diffusivity
α_M = coefficient of thermal expansion
ρ_M = density
g_C = gravitational acceleration at CMB
R_C = radius of the core
T_{LM} = temperature of lower mantle
δ_{BL} = thickness of boundary layer
μ_{BL} = average viscosity
ΔT_{BL} = thermal contrast across mantle base
T_C = temperature at CMB

Yes! Massive Exoplanets are More Likely to Have Magnetic Fields.

- The **actual heat flow** out of the metallic cores of exoplanets may **increase faster** with planetary mass than the values required for a dynamo.
- Super-Earth exoplanets may have ubiquitous magnetospheres—even without inner cores.
- Super-Venus exoplanets may also host dynamos in their cores if they are sufficiently massive—even without plate tectonics.
- Overall, magnetic fields may not provide a unique test for plate tectonics at massive exoplanets.

Future Work

- Determine if basal magma oceans can host dynamos in massive exoplanets and their effects on cores
- Test a wider range of assumptions about mantle dynamics and the composition of the core
- Further out: Detect magnetic fields in exoplanets to constrain models



Credit: Labrosse et al. 2007

Credit: ESA

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