The effect of a thermally stratified layer in the outer core of Mercury on its internally generated magnetic field

Attilio Rivoldini[1], Marie-Hélène Deproost[1], Yue Zhao[1], Jurien Knibbe[1], and Tim Van Hoolst [1,2]

1: Royal Observatory of Belgium 2: KU Leuven, Institute of Astronomy, Leuven, Belgium (Attilio.Rivoldini@oma.be)

Scope:

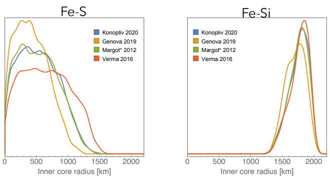
- Dynamo models indicate that a stably stratified layer overlying the convective liquid core is needed to explain the observed magnetic field
- Thermal evolution studies show that a a sub-adiabatic heat flow at the core-mantle boundary can occur during a significant fraction of Mercury's history
- The likely long-lived Mercury dynamo and the presence of a stable layer place important constraints on the interior structure and evolution of the core and planet.

This study:

- Couple mantle and core thermal evolution to investigate the necessary conditions for a long-lived and present-day dynamo inside Mercury's core by taking into account an evolving stable layer overlying the convecting outer core
- 1-D mantle model (Thiriet et al. 2019) coupled to core thermal evolution model (Greenwood 2021) that takes into account the formation of a stably stratified layer in the core
- parameters governing scaling laws in 1-D mantle models are calibrated to match results of 2-D dynamic evolution models (core-mantle boundary and surface heat flow, mantle temperature profile, cessation of convection)

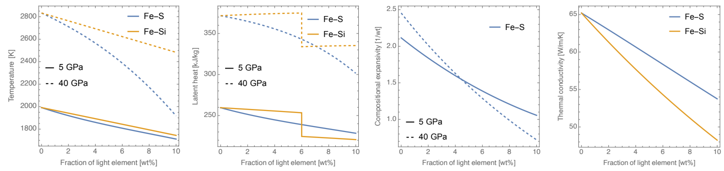
Constraints on Mercury's core

- reducing formation conditions require that the core is mostly Fe-Ni-Si with a smaller fraction of S or C (e.g. Namur 2016, Steenstra 2020)
- geodesy data (moment of inertia, libration amplitude at 88d, tidal Love number k2) imply a core radius 2000±50km (e.g. Rivoldini 2019, Knibbe 2020, Steinbrügge 2020)
- Mercury models that agree with geodesy data require an inner core radius 0-1500km if the core is an Fe-S alloy and 1300-2010km if the core is an Fe-Si alloy
- Mercury models that agree with geodesy data without an inner core are possible but difficult to reconcile with the past and present core generated dynamo

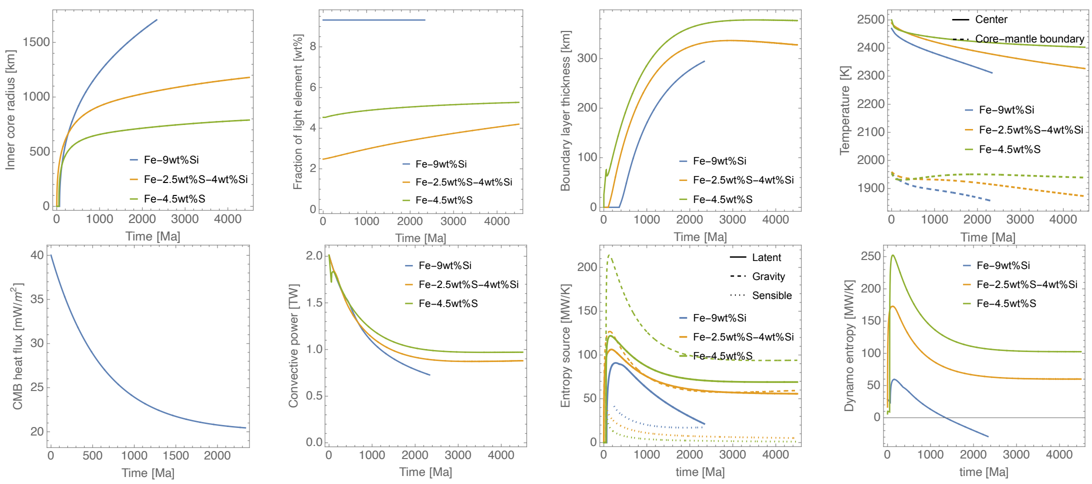


Core thermodynamic and transport properties:

- Fe-S-Si core (Terasaki et al 2019, Edmund et al. 2022)
- New core liquidus (e.g. Rivoldini et al. 2011, Edmund et al. 2022)
- equipartition of Si between liquid and solid Fe and not partitioning of S in solid Fe
- Fe-Si inner core (fcc or bcc)
- Fe-S-Si thermal conductivity Wagle et al 2019)



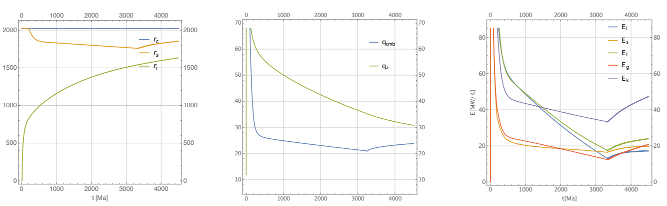
Thermal evolution of the core (core radius 2000km)



- inner core grows faster for Fe-Si case because of higher core liquidus
- stable layer growth rate comparable because of comparable convective power
- after ~2340My liquid Fe-Si core is fully stratified (inner core radius ≈ bottom of boundary layer)
- ohmic dissipation Ej increases with increasing amount of S because latent and gravitational entropy increases with S (unlike Si, S does not partition into the solid inner core)
- ohmic dissipation drops to zero for Fe-Si core before whole liquid core is stratified
- Fe-Si models that agree with geodesy and have a present-day dynamo are unlikely

Coupled evolution:

- the cessation of mantle convection increases the heat flow at the core-mantle boundary
- decreases the thickness of the stable layer
- and increases ohmic dissipation in the core



Summary:

- a small fraction of S (or C) is required to have an inner core larger than 1000km and a long lived dynamo
- a 2.5wt%S+4wt%Si model produces a present-day inner core of ~1200km, a ~300km thermal boundary layer, and generates sufficient ohmic dissipation to drive a past and present dynamo
- preliminary results show that the cessation of mantle convection decreases the thickness of the thermally stratified layer and increases ohmic dissipation
- preliminary result show that iron-rich snow does not occur in Fe-S-Si cores if S≤3w%

This work was financially supported by the Belgian PRODEX program managed by the European Space Agency in collaboration with the Belgian Federal Science Policy Office and by the BRAIN.be20.0 programme..