1. Scope

The thermal evolution of Mercury is strongly related to its interior structure and therefore can be used to put constraints on it, in particular on the inner core. Compositional deformation features on Mercury's surface indicate that Mercury has contracted during its evolution by as much as 7 km. Contraction is mainly due to secular cooling and resulting inner core growth; therefore it provides insight on the existence, formation, and size of an inner core.

Recent measurements of Mercury's rotation and gravitational field strongly constrain the size and density of the core, but provide little information about a solid inner core. Both an entirely liquid core and a solid large inner core surrounded by a liquid outer core are consistent with those observations. The present-day global magnetic field is likely driven by thermo-chemical convection in the liquid outer core mainly resulting from the crystallization of an iron-rich alloy.

The thermal evolution of the core is controlled by the amount of heat extracted by the mantle from the core. We therefore study the interior structure of Mercury. The thermal evolution of the planet is modeled by studying the energy balance of the core and the mantle and the presence of an internally generated magnetic field is deduced from the entropy balance of the core.

We assess which interior structure models that agree with geodesy data, contraction and geodetic constraints, tides, and crust formation timing allow for dynamo action in the core.

2. Interior model

Thermal evolution of the core and the mantle based on global energy balance and assessment of core dynamics by entropy balance.

Core:
• core thermal evolution model based on Witt (2007) and Christensen and Wicht (2008)
  • assume core radius of 1500 km and 2050 km, in agreement with moment of inertia and libration amplitude
  • initial core-mantle boundary temperature between 1900 K and 2200 K
  • Fe-S-Si ideal solution (Dumberry and Rivoldini 2015); liquids Fe-S from Dumberry and Rivoldini (2015); Fe liquids from Anselmi et al. (2013)
  • thermal conductivity depends on sulfur concentration, temperature, and pressure (Sicco et al. 1989 and Konkovleva et al. 2016)
  • neglect gravitational power produced by iron snow

Silicate shell:
• crust: density 2900 kg/m³ and thickness 40 km
• mantle: olivine (60 wt%)-orthopyroxene (40 wt%) with Mg# = 1 non-elastic (Jackson and Faul 2010)
• thermal evolution model of the mantle based on Morschhauser et al. (2011) and Grott et al. (2011)
• radioactive element concentration from Pepinowski (2011); factor of enrichment in radiogenic elements with respect to the mantle from Toivi et al. (2013)
• initial thickness of stagnant lid: 50 km

3. Geodetic constraints

- Fe-Si cores must be too warm to have a molten core: S is required together with Si to lower the liquidus. Another solution is to decrease S concentration and therefore to form a more easily a solid inner core.

- Main contribution to both energy and entropy budgets is latent heat. In Fe-Si-Si core, latent heat contribution is larger than in Fe-S-Si core (25% for energy and 30% for entropy), but gravitational energy and entropy contributions are small as a result of equipartition in solid and liquid phase of Fe-Si alloys.

- Fe-S large core models (2050 km): only early dynamo (first 200 Myrs); no inner core because of large sulfur concentrations (4.6 - 5.7 wt%).

- Fe-S small core models (1950 km): sufficient entropy to drive a dynamo in the first 200 Myrs, later dynamo possible for hot initial core temperature (2200 K) when inner core formation starts. Connection stops when iron snow layer reaches the inner core (after about 3.5 Gyr).

- Fe-S-Si cores with 5 wt% Si (core radius: 2050 km): a dynamo is possible during a large part of the evolution until today. With 5 wt% Si - 3 wt% S, late dynamo at odds with early-magnetization. Models with 10 wt% Si - 1 wt% S is in disagreement with contraction constraints.

4. Energy and entropy budgets: coupled models

- \( \text{Si} \) concentration must be too low for a solid inner core. The Fe-S-Si core: addition of 5 wt% Si (with 3 wt% S) is sufficient for a solid inner core and a liquid outer core today with a present-day dynamo.

- Core cooling below 150 K during the last 4 Gyr: in agreement with contraction constraints.

- Lower mantle likely melted during a substantial part of the evolution: in contradiction with old majoritic constraints.

- Radioactivity: addition of 5% (small core models) - 10% (large core models) of the crustal concentration in radiogenic elements is needed for a partly convective core today.

- Fe-S-Si core: addition of 5 wt% Si (with 3 wt% S) is sufficient for a solid inner core and a liquid outer core today with a present-day dynamo. But dynamo begins late, at odds with early magnetization. Models with 10 wt% Si are in contradiction with contraction constraints. Even with the addition of Si, the lower mantle is melted during a large part of the evolution.

5. Stratification

6. Conclusions

- Fe-S core:
  - no model without core heating that has sufficient entropy to drive a dynamo today but a dynamo action is possible during the first Myrs of the evolution.
  - small core models: power generated by the inner core growth not sufficient to drive a dynamo; convection likely stops after about 3.5 Gyr by iron-rich snow reaching the inner core boundary.
  - large core models: no solid inner core because of large sulfur concentration; only early dynamo.
  - inner core sizes in small core models much larger than 300 km: in contradiction with contraction constraints.
  - core cooling below 150 K during the last 4 Gyr: in agreement with contraction constraints.

- Fe-S-Si core: with 5 wt% Si - 3 wt% S; still partially stratified today, after a long episode (~1.5 Gyr) without convection. Fe-S-Si cores with 10 wt% Si - 1 wt% S: entirely convective today; smaller Si concentration allows for an earlier inner core, but the core experiences an entirely stratified episode during ~100 Myrs.

- possible for a dynamo to reappear after an episode without convection due to core stratification? If not, models with 5-10 wt% Si are likely ruled out.