The effect of Mercury's core composition on its longitudinal libration

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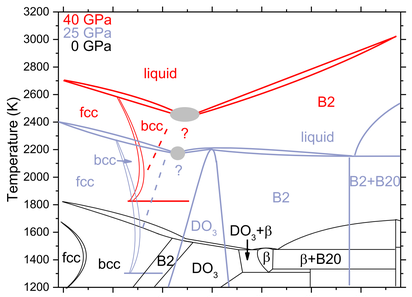
Introduction

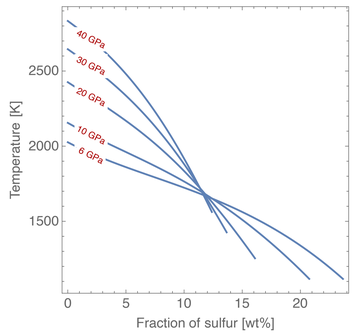
- Gravitational torques acting on the ellipsoidal figure of Mercury give rise to longitudinal libration of its solid shell
- Gravitational coupling between the shell and inner core affect the libration of the shell
- The effect of a large inner core on libration is expected to be detectable by BepiColombo observations (Van Hoolst 2012, Dumberry 2013)
- The coupling strength between shell and inner-core depends on the density structure within the core and the partitioning behavior of light elements between the solid inner and liquid outer core
- The highly reducing conditions prevailing at Mercury's formation favor silicon over sulfur as the principal core light element
- Since sulfur does almost not partition between solid and liquid iron and silicon partitions almost equally a significant difference on the libration amplitude can be expected between a sulfur-rich and silicon-rich core

Scope

Study the effect of the core composition on the forced and free libration of Mercury by using recent results about equations of state of liquid Fe-S and Fe-Si as well as the stable solid Fe-Si phases present in the inner core.

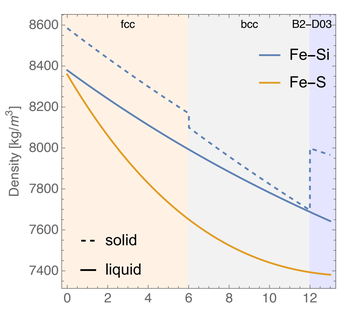
Interior structure model





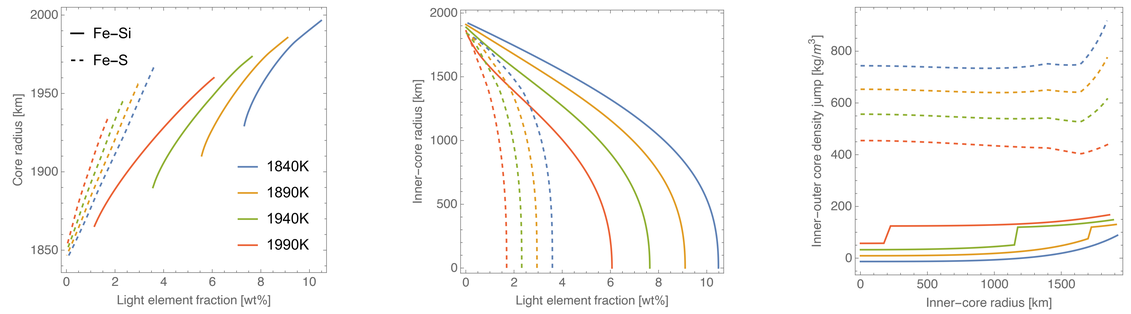
Fe-Si phase diagram (left) including stable solid phases and Fe-S melting temperatures (right) up to eutectic concentration.

- liquid core: liquid Fe-S and Fe-Si (Terasaki 2019)
- solid inner: solid fcc Fe (Dorogokupets 2017), solid fcc, bcc, and B2 Fe-Si (Edmund 2022)
- core liquidus parameterization based on existing Fe-S melting data and new Fe-Si melting data and phase diagram (Edmund 2022)
- assume equipartition of Si between solid and liquid metal and no partition of S in solid metal
- assume olivine-pyroxene mantle aggregate and plausible range of mantle temperatures



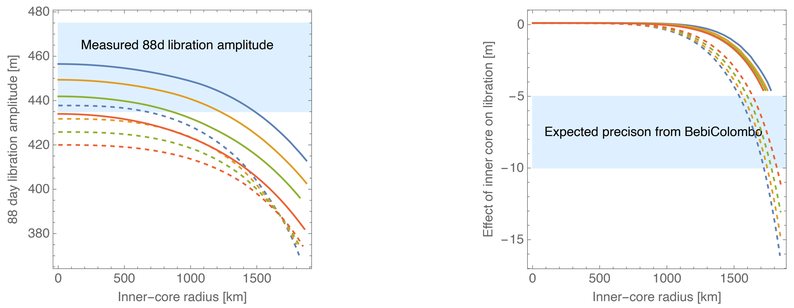
Density as a function of sulfur or silicon for liquid (full) Fe-Si and Fe-S and solid (dashed) Fe-Si at 30 GPa along core Fe-Si/Fe-S liquidus. Stability regions of solid Fe-Si phases are shown by shaded regions.

Structure functions

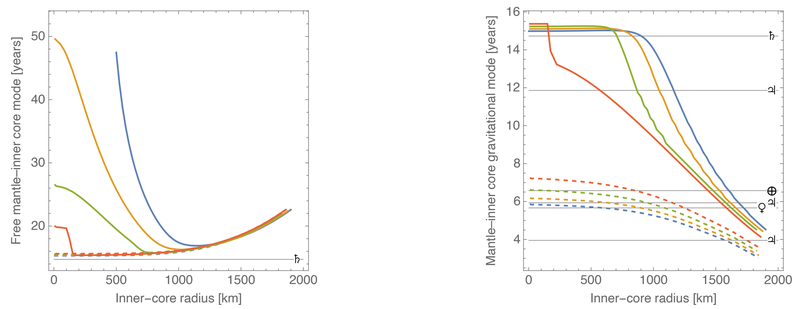


Core radius and inner core radius as a function of bulk core light element fraction for different core-mantle boundary temperatures as well as density jump at the inner-outer core boundary as a function of inner core radius for Fe-Si (full) and Fe-S (dashed) models.

Libration amplitude and free libration normal modes



88 day libration amplitude and effect of gravitational coupling between the solid inner-core on libration.



Free mantle-inner core and mantle-inner core gravitational libration modes and periods and periods of main planetary perturbations (♀: Venus, ⊕: Earth, ♃: Jupiter, ♄: Saturn).

Conclusions

- the equipartition of Si between solid and liquid Fe reduces the density jump at the inner-outer core boundary significantly compared to S that does not partition into solid Fe
- as a consequence the gravitational coupling between the inner-core and shell is strongly reduced and the effect on the 88d libration is likely not detectable by BepiColombo even if the inner core is large and the core contains no S
- long period libration amplitudes can be resonantly amplified when the planetary perturbation periods are close to one of the two free liberation modes, they differ appreciably for Fe-Si and Fe-S cores
- measuring long period librations can thus provide constraints on the structure and composition of the inner-core

Van Hoolst 2012: 10.1016/j.epsl.2012.04.014; Dumberry 2013: 10.1016/j.icarus.2013.03.001; Dorogokupets 2017: 10.1038/srep41863;
Terasaki 2019: 10.1029/2019JE005936; Edmund 2022;10.1038/s41467-022-27991-9

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