Implications of Mercury’s core composition on its libration and present-day thermal state

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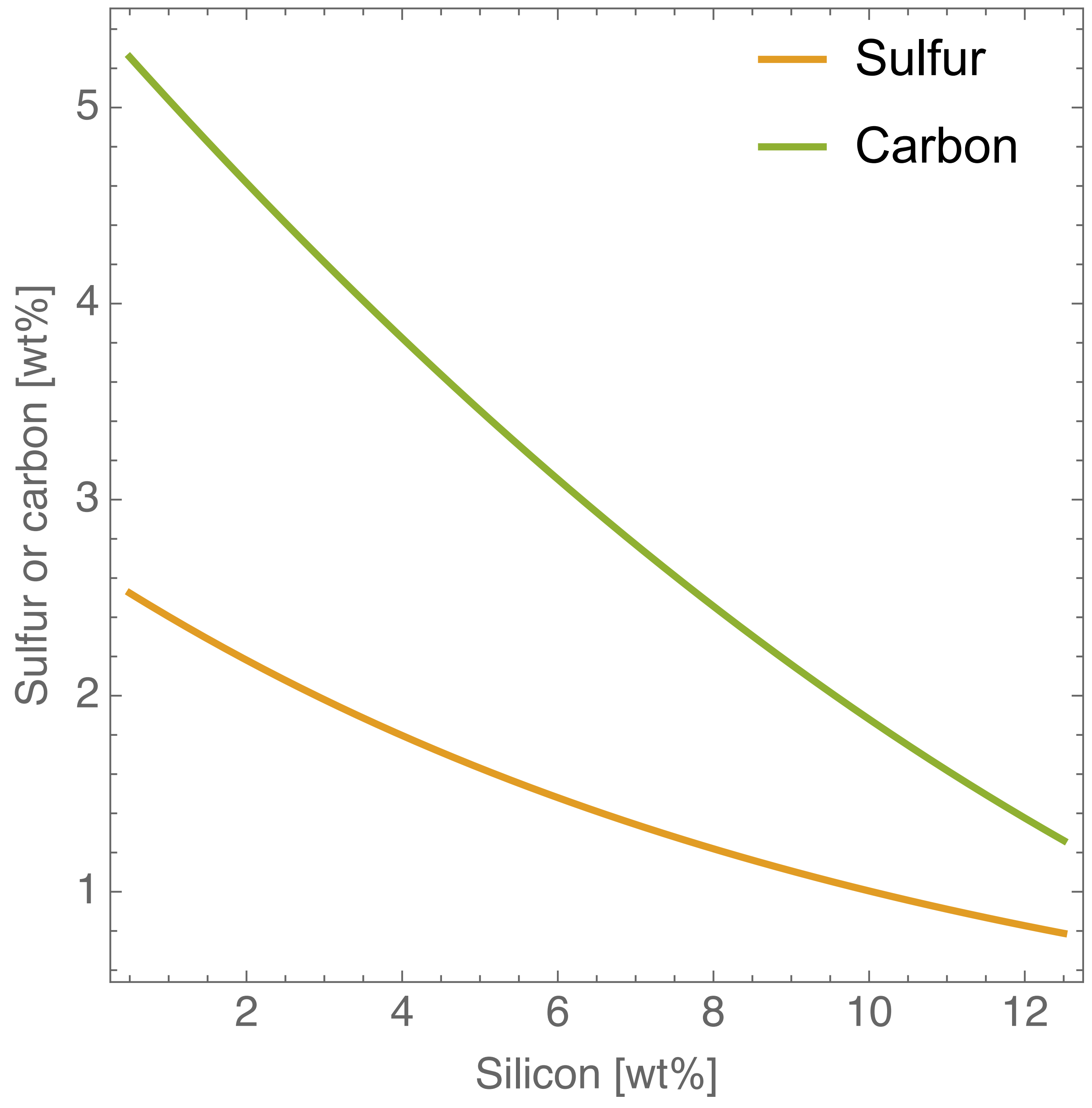
Scope - Core composition

- reducing formation conditions imply that silicon is the main light element in Mercury's core (e.g. Peplowski 2011)

- surface spectral measurements support the presence of substantial amounts of sulphur (lithophile) and carbon on Mercury's surface and both light element can partition into the core (~few wt%)
  (e.g. Namur 2016, Steenstra 2020)

- the maximal amount of sulphur and carbon in the core decreases with increasing amount of silicon
  (e.g. Namur 2016, Boujibar 2019)



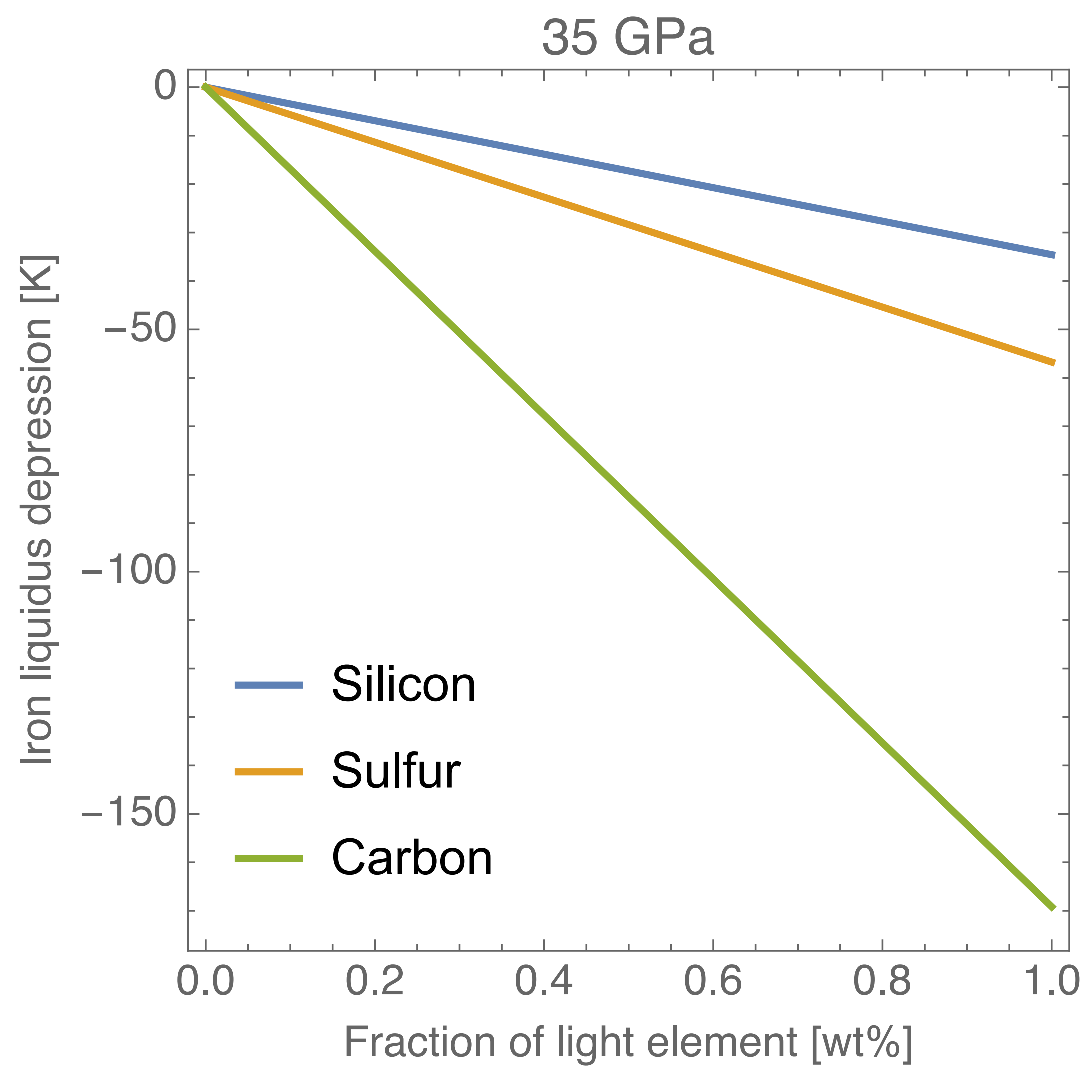
Scope - Thermal state

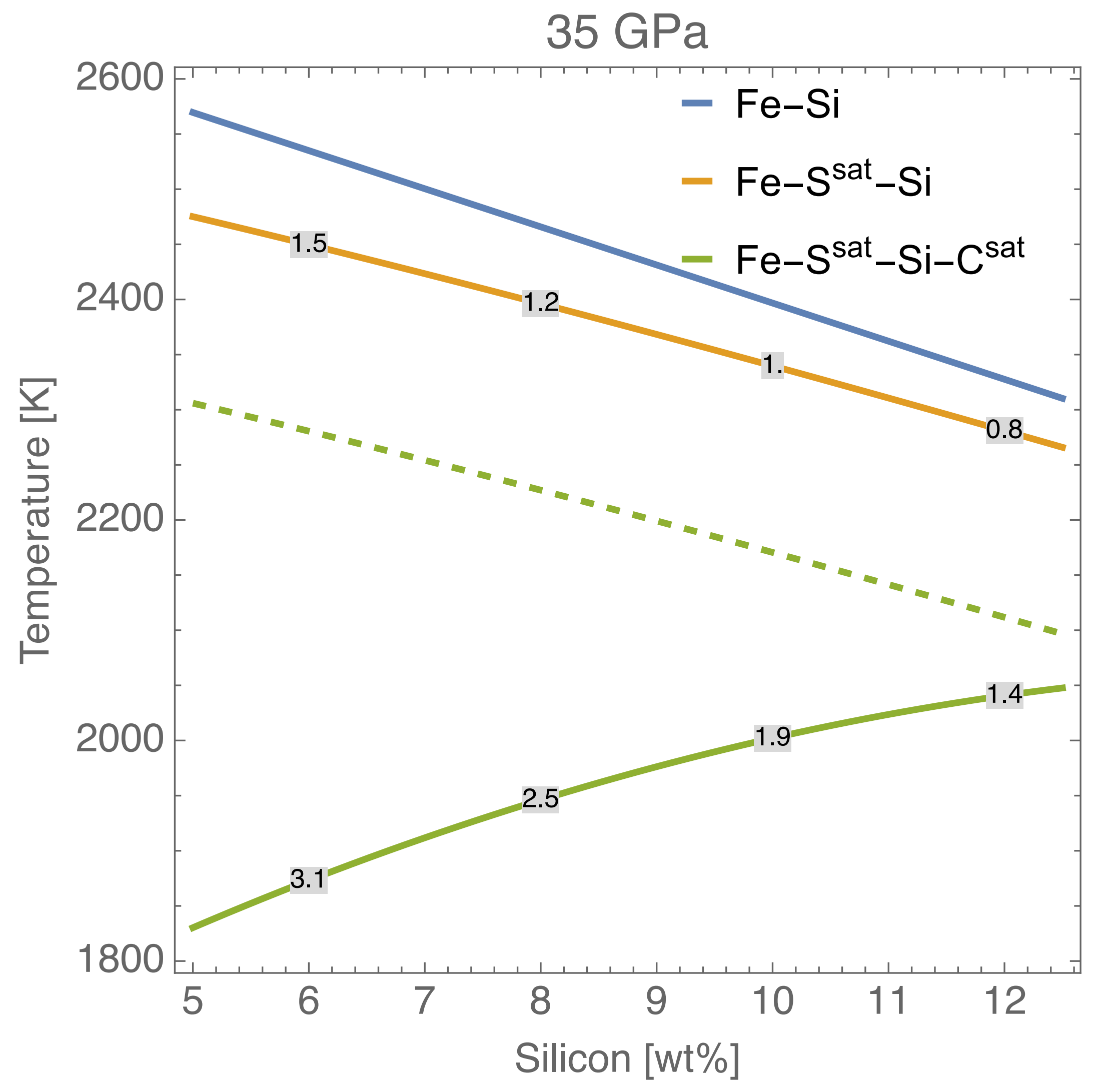
- Unlike Si, S, and even more C have a strong effect on the core liquidus

- S and C saturation in the core implies a core temperature at inner core onset significantly lower than what is assumed for present-day core temperatures

- in this study we assume 1wt% C
  (→ CMB temperature at inner core onset ≲1900K)

- →models with a Fe-Si core cannot explain the present-day magnetic field (Rivoldini 2022)





(isentropic $\Delta T_{core} \sim 500$K)

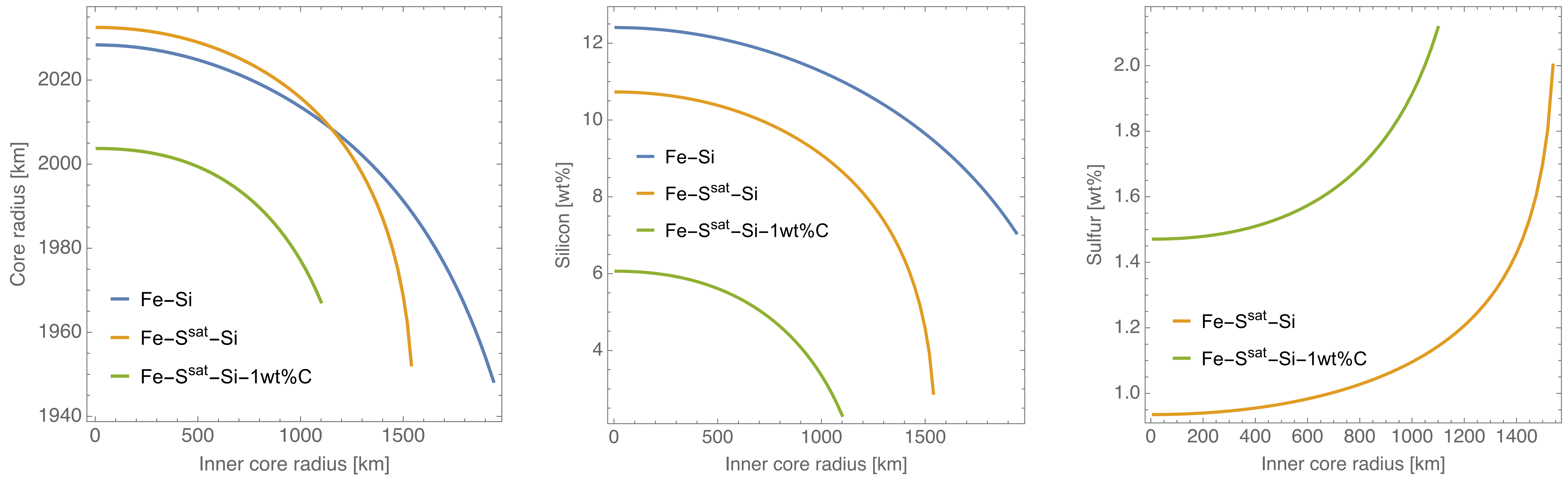
Scope - Libration

- Gravitational torques acting on the ellipsoidal figure of Mercury give rise to longitudinal libration of its solid mantle
- Gravitational coupling between the mantle and inner core affect the libration of the mantle
  (Van Hoolst 2012, Dumberry 2013)
- The coupling strength between mantle and inner-core depends on the density structure within the core and the partitioning behaviour of light elements between the solid and liquid Fe
  (Van Hoolst 2012, Dumberry 2013, Rivoldini 2022)
- Since Si, S, and C partition differently between solid and liquid Fe a substantial effect on the libration can be expected ($D_{\mathrm{S}}^{\mathrm{sol/liq}} \sim 0.$, $D_{\mathrm{Si}}^{\mathrm{sol/liq}} \sim 1.$, $D_{\mathrm{C}}^{\mathrm{sol/liq}} \sim 0.3$)

⇒ **Study** the effect of the core composition on the forced and free libration of Mercury

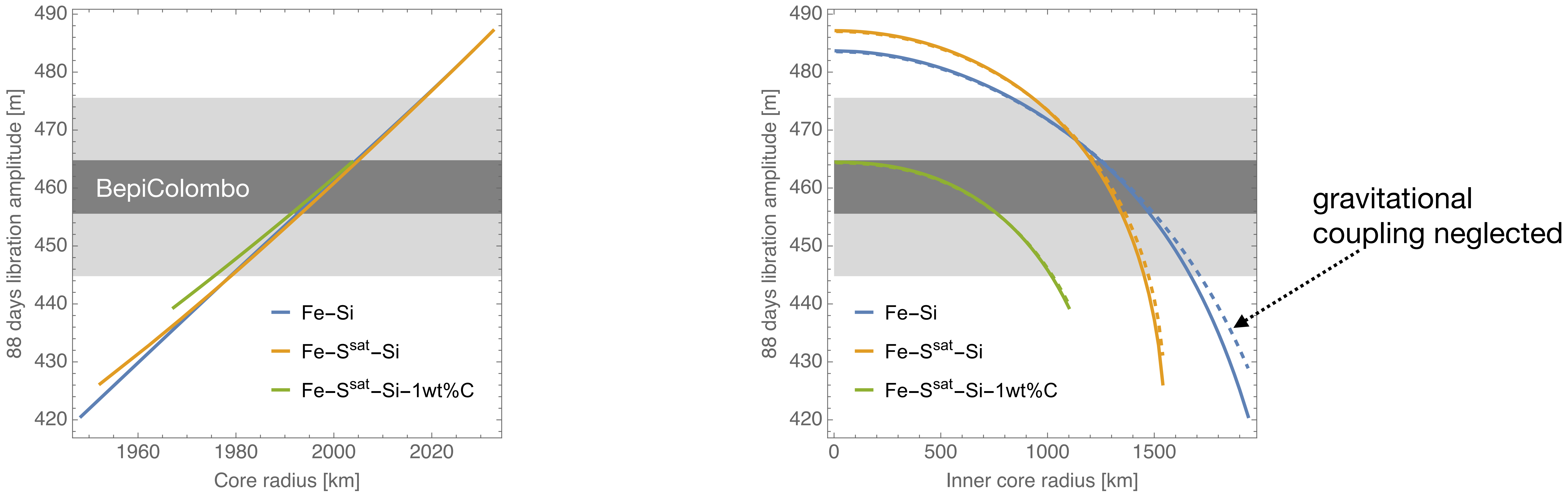
Interior structure models

- assume fixed crust, olivine-pyroxene mantle aggregate, T_{cmb}=1850 K, liquid Fe-S-Si-C outer core, and solid Fe-Si-C inner core, core liquidus parameterisation based on existing Fe-S, Fe-Si, and Fe-C phase diagrams and melting data
- models agree with mass and moment of inertia and Si < Fe-Si eutectic (12.5wt%), 3 core compositions



- core radius decreases with inner core radius (mass conservation) and rate depends on core composition
- inner core radius decreases with amount of light elements and the functional relation is determined by the core liquidus, light element partitioning behaviour, and equation of state

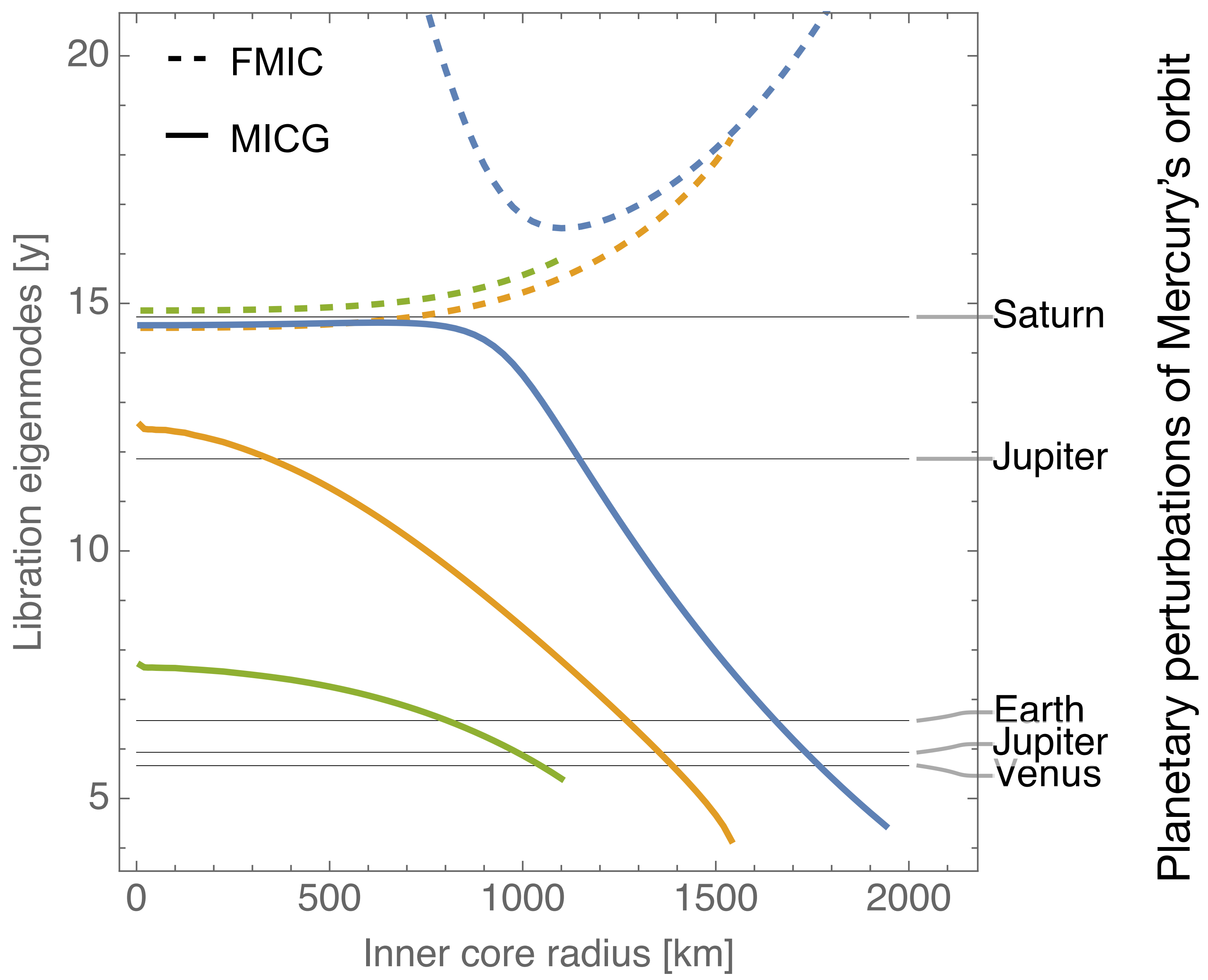
88 days libration amplitude

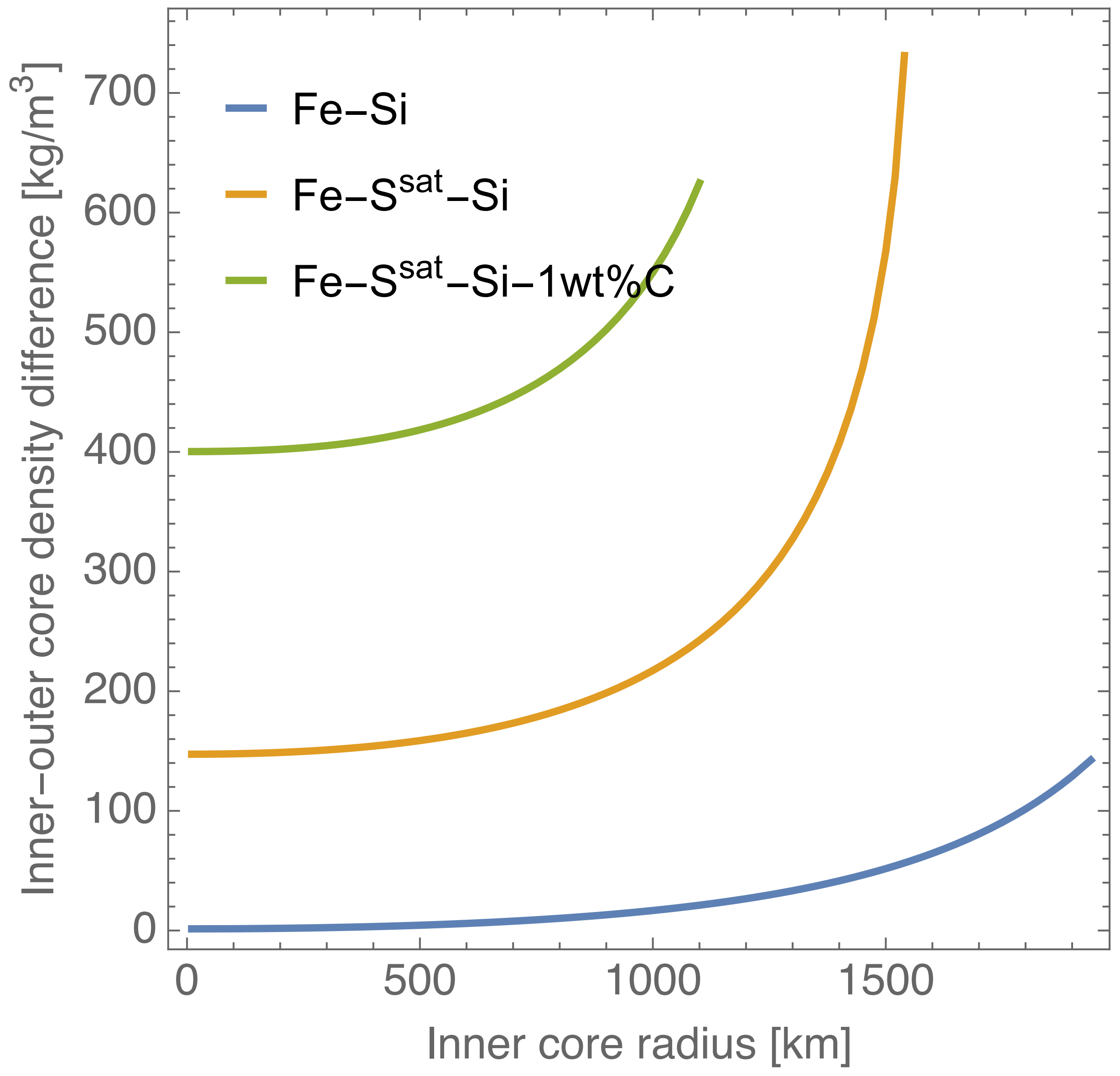


- libration amplitude increases with core radius and decreasing mantle moment of inertia, but specific core compositions have only a small effect → 88d libration amplitude is a robust estimate for the core radius
- gravitational coupling between inner core and mantle increases with density difference at inner core-outer boundary (largest for Fe-S-Si-C) but likely only detectable by BepiColombo if inner core radius >1000km
- inner core radius can only be constrained from libration amplitude with prior knowledge about core composition and thermal state

Free libration modes

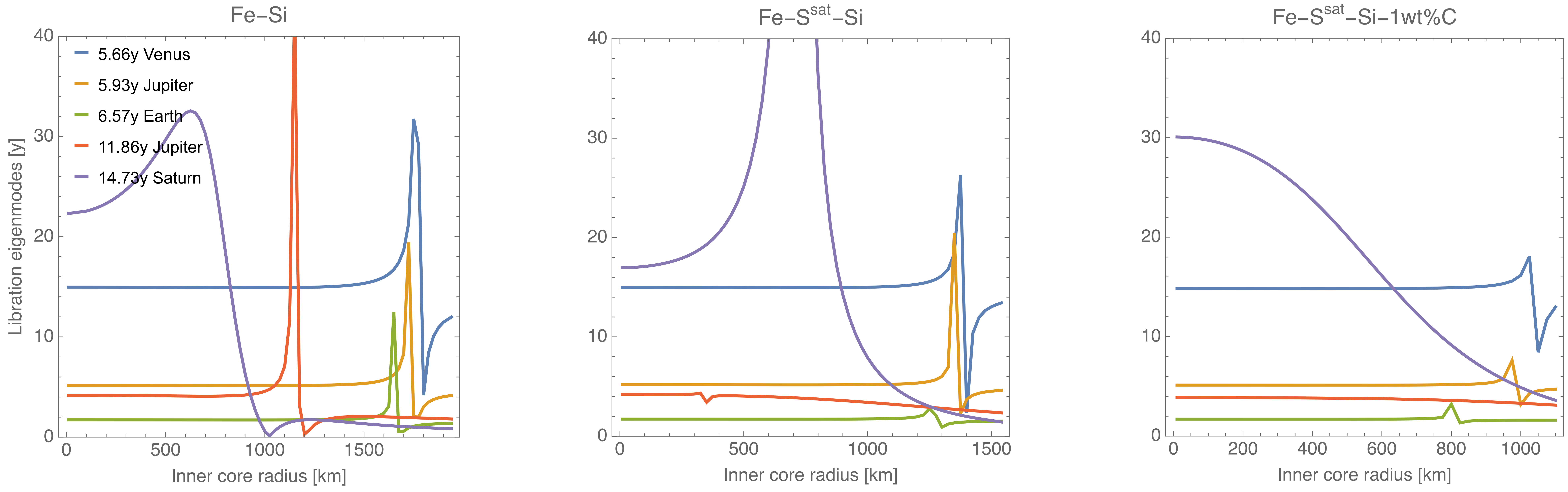
- gravitational oscillation of the combined figures of the mantle and inner core → **F**ree **M**antle–**I**nner **C**ore mode (FMIC)
- mutual out-of-phase gravitational oscillation between inner core and mantle → **M**antle-**I**nner **C**ore **G**ravitational mode (MICG)





- FMIC increases with inner core radius, expect for Fe-Si models where it decrease initially until the inner ≳ 1200km
- MICG decreases with increasing inner core radius and increasing density contrast between solid and liquid core
- core composition (density structure and light element partitioning) have a significant effect on the period of libration normal modes
- several long period forced libration can be resonantly amplified for small or large inner core radii

Long period forced libration amplitudes



- if the inner core radius ≲ 1000km the 14.7y libration can be significantly affected
- shorter period librations are only amplified for a narrow inner core radius range
- detecting long-period forced libration will reduce the possible parameter space of interior structure governing parameters

Conclusions

- the partitioning behaviour of S, Si, and C between solid and liquid Fe has a substantial effect on the core density structure and density contrast at the inner-outer core boundary

- core composition affects libration normal modes and long-term forced libration amplitudes

- detecting long-period forced libration will help to reduce the parameter space of plausible interior structure governing parameters

- however, to obtain more precise information about the core will require to combine measured libration amplitudes with other geodesy data (obliquity, tides), geochemical constraints, and constraints from thermal evolution studies that account for the presence of a core dynamo