

Effect of Mercury's interior structure on its long-period libration

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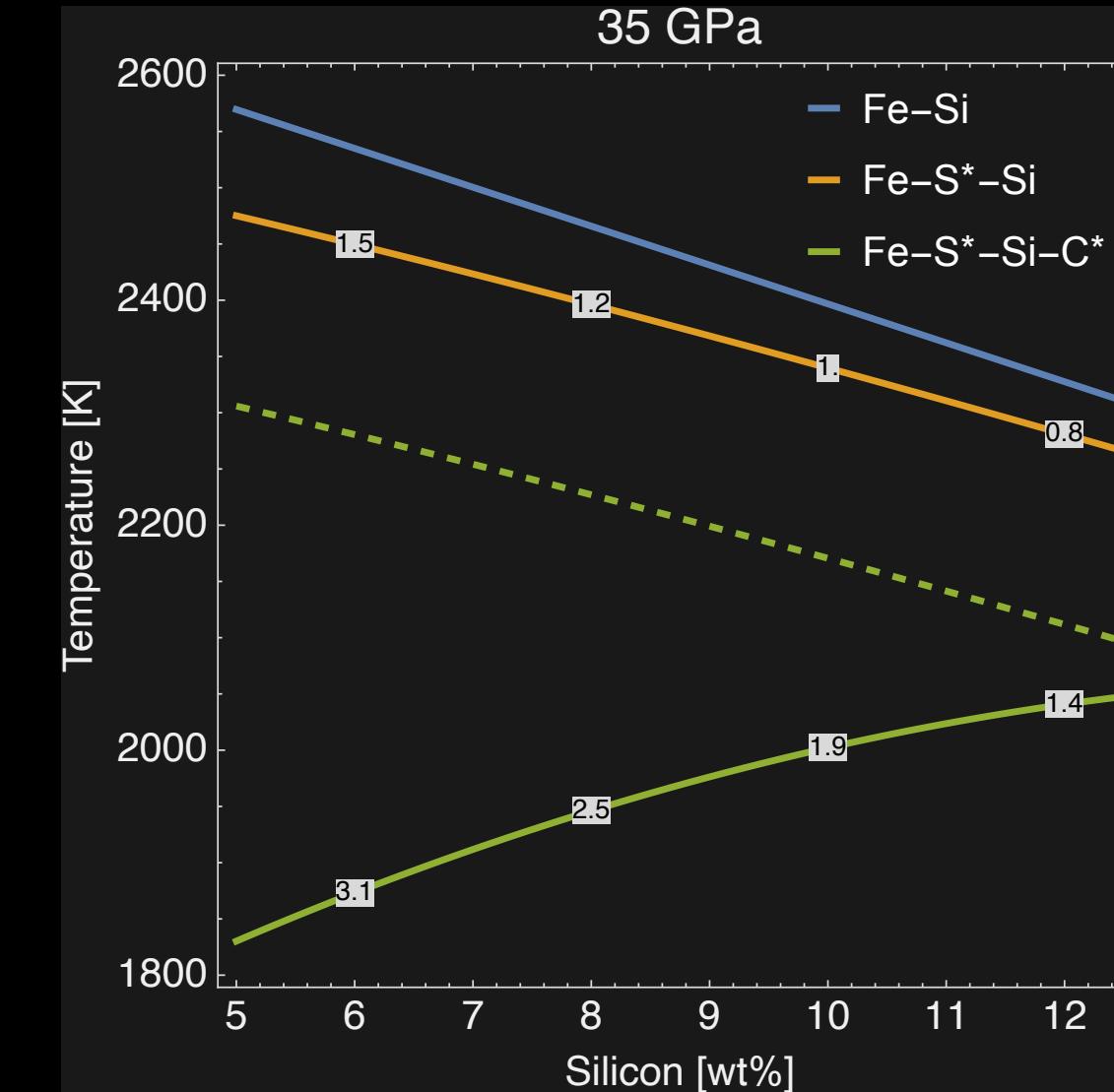
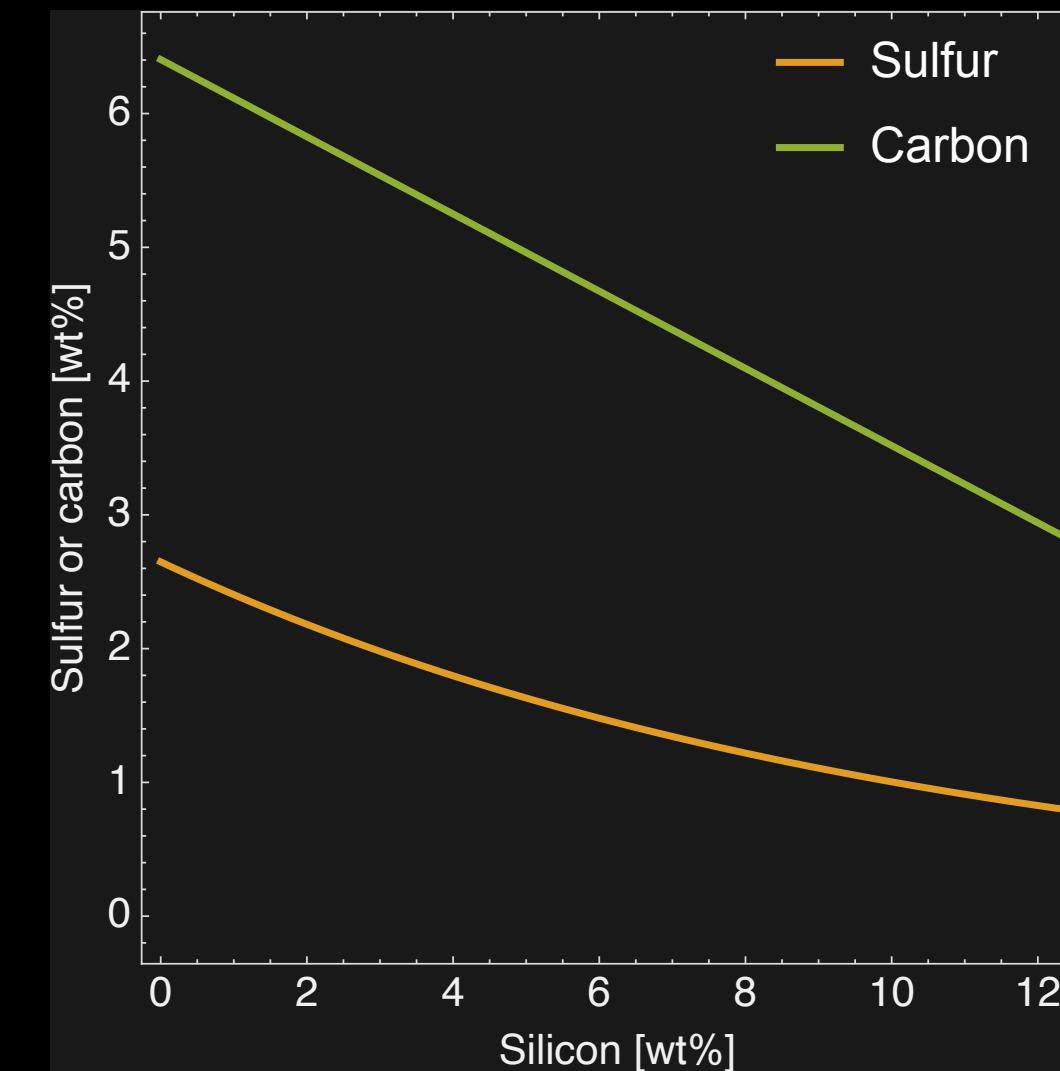
Scope

- Mercury experiences long-period forced librations as a result of periodic gravitational perturbations from other planetary bodies (Venus, Earth, Jupiter, Saturn, ..) on its orbit
- Forced librations can be resonantly amplified when planetary perturbations are close to one of the two free libration normal modes
- Free libration normal modes and librational response dependent on interior structure and coupling between solid shell, outer core, and inner core
- 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 iron

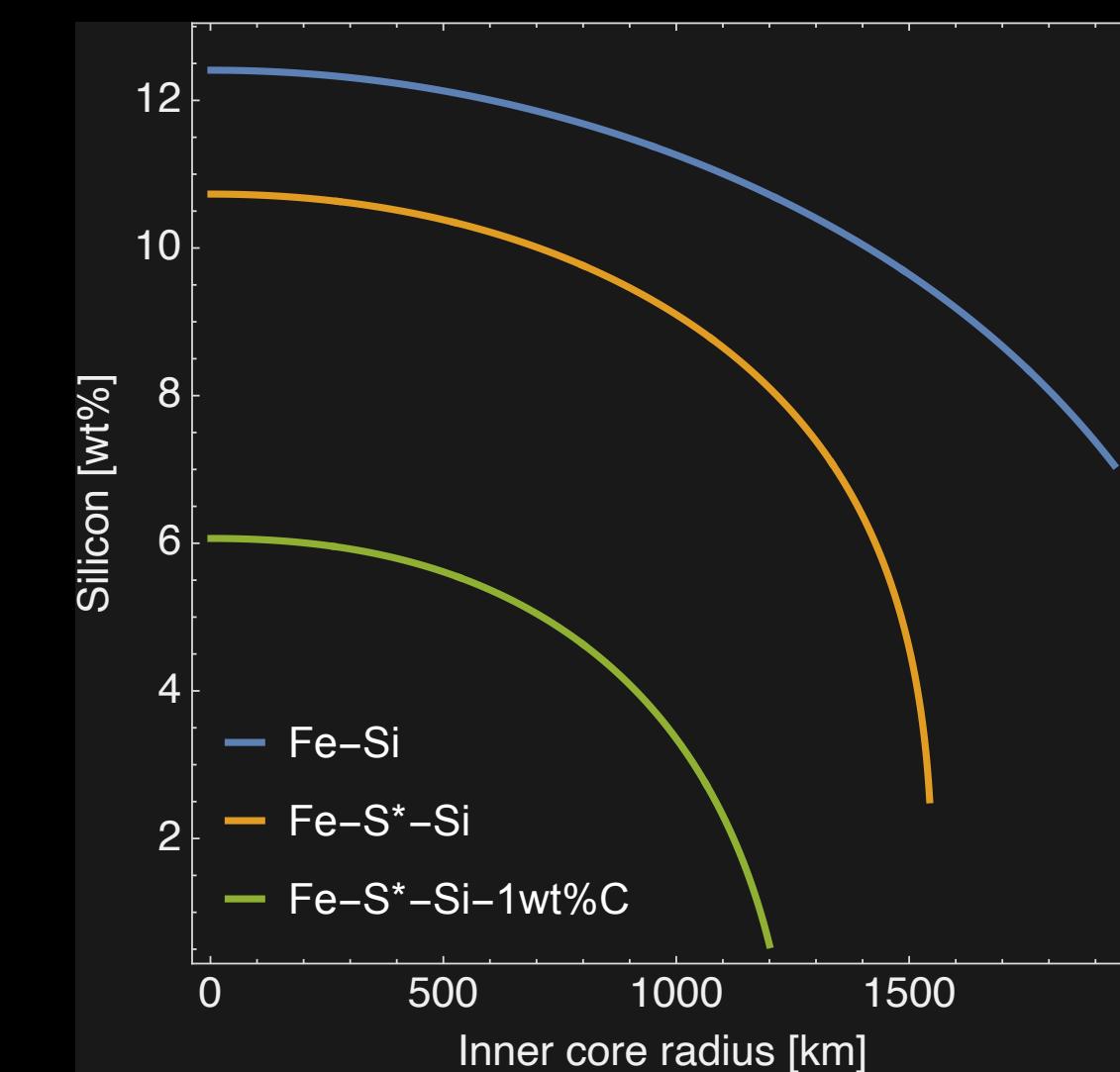
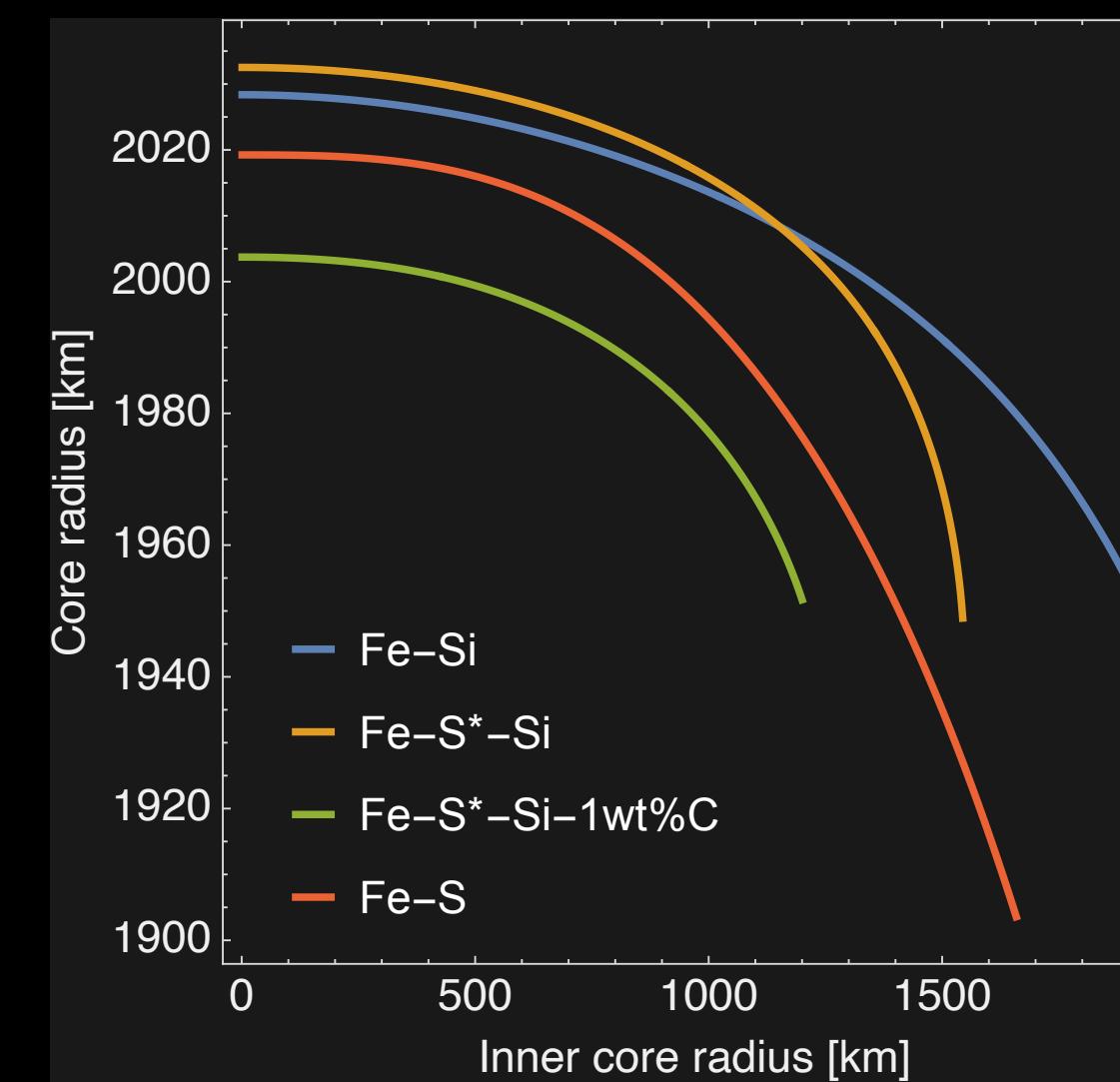
⇒ specific core composition and structure affect long period forced and free libration of Mercury

Effect of composition on core structure

- Candidate core light elements: Si, S,C,.. (e.g. Namur+ 2016, Steenstra+ 2020)
- the maximal amount of S and C decreases with increasing Si (e.g. Namur+ 2016, Boujibar+ 2019)
- unlike Si, S and even more C in the core have a strong effect on its liquidus

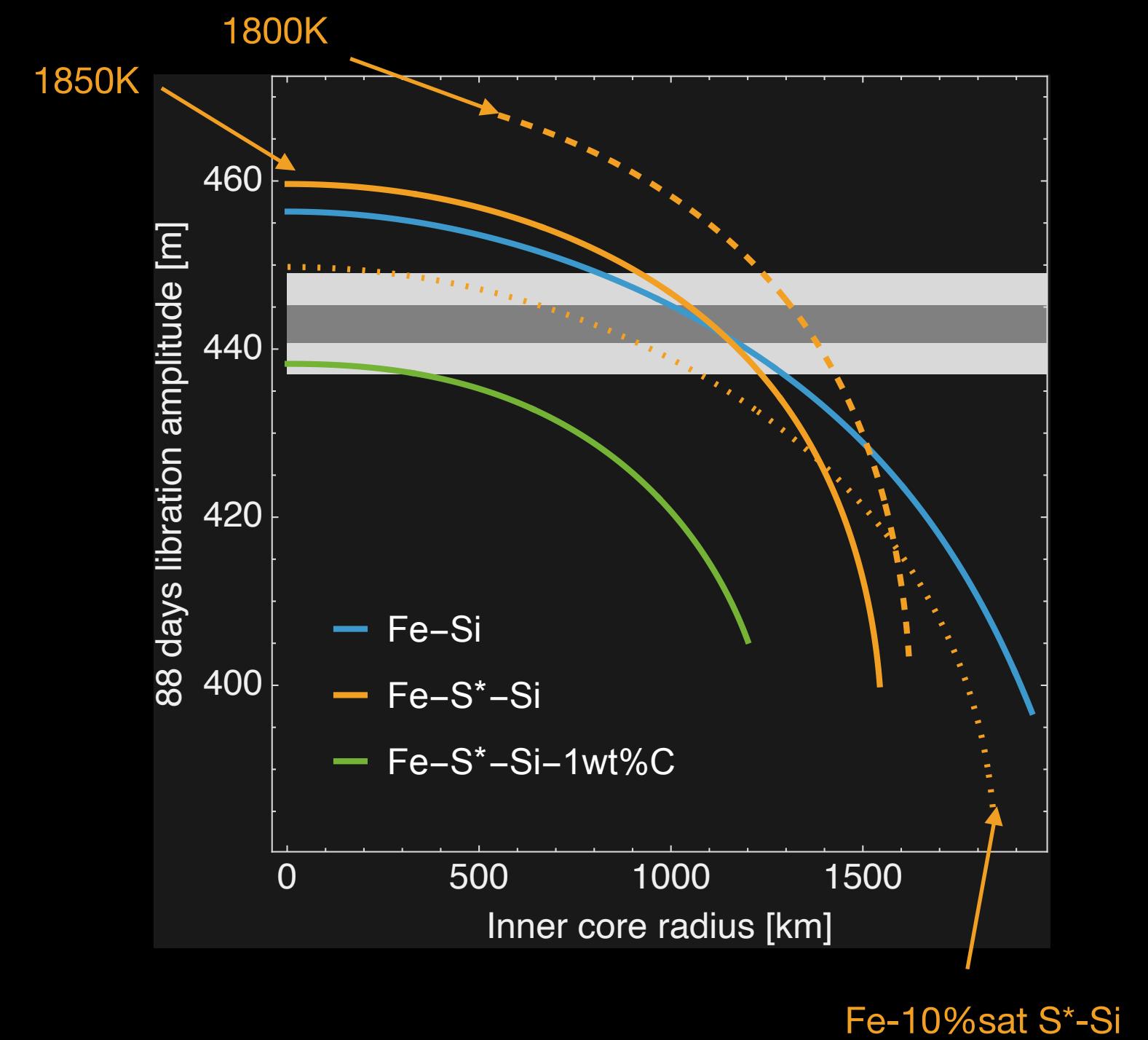
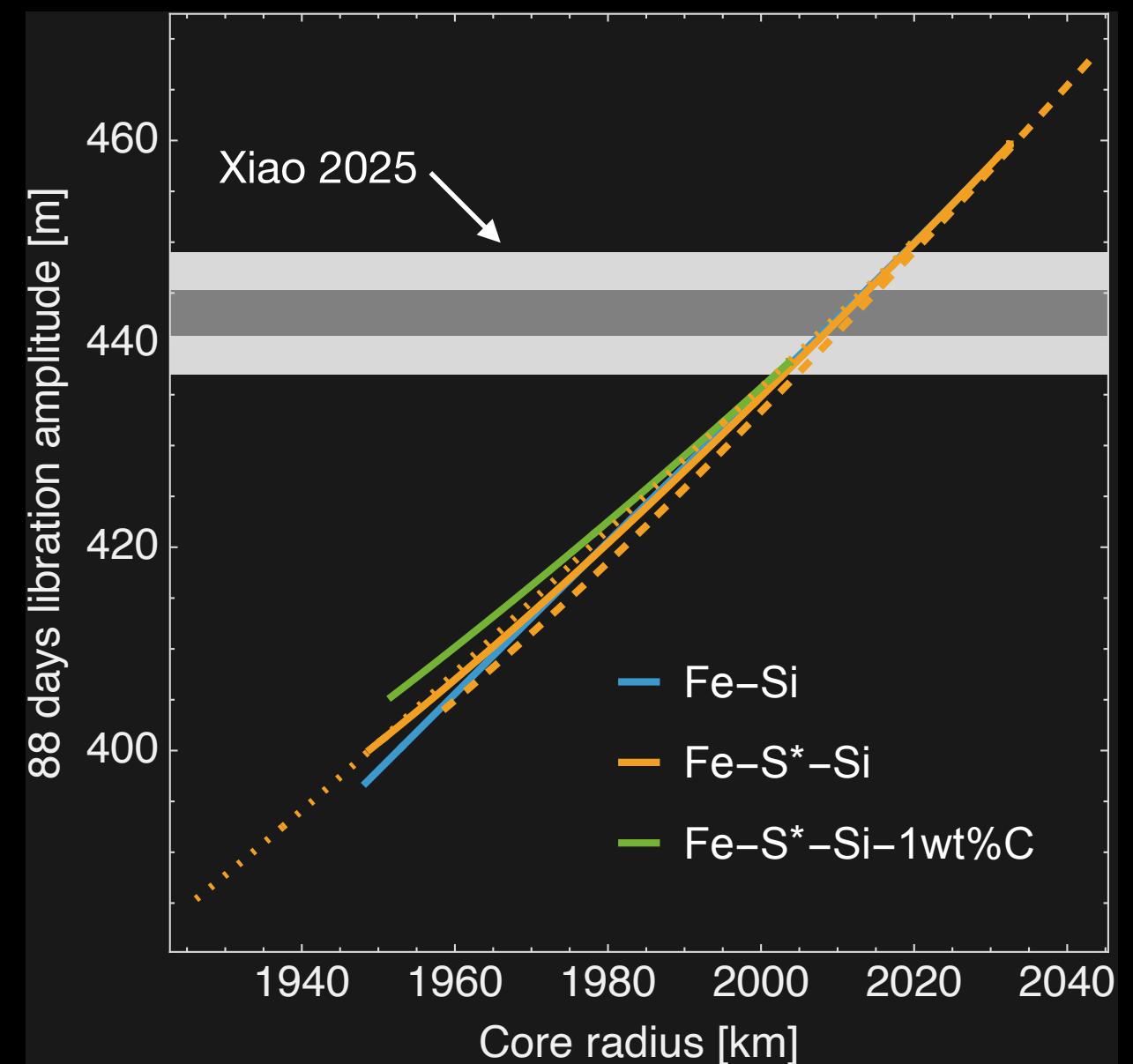


- r_{cmb} decreases with increasing r_{icb} (mass conservation) and rate depends on core composition
- r_{icb} decreases with amount of light elements (liquidus) also depends on equation of state and partitioning of light elements:
 $D_S^{\text{sol/liq}} \sim 0.$, $D_{Si}^{\text{sol/liq}} \sim 1.$., $D_C^{\text{sol/liq}} \sim 0.3$



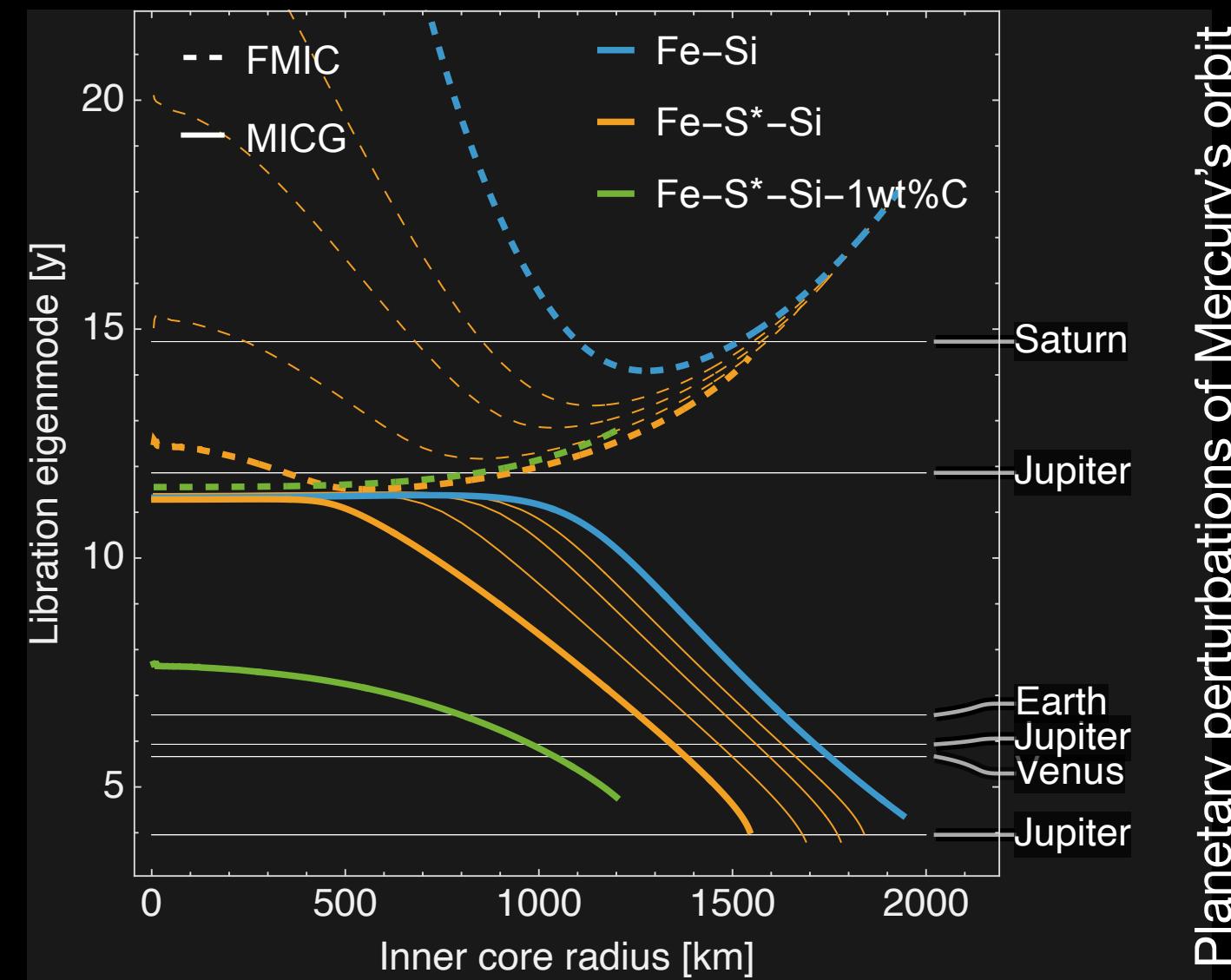
Effect of thermal state and composition on 88 d libration

- libration amplitude increases with core radius (decreasing mantle moment of inertia)
- specific core composition and temperature have a small effect on libration amplitude
⇒ robust proxy for core radius
- without detailed compositional and thermal prior knowledge
weak constraint on inner core radius

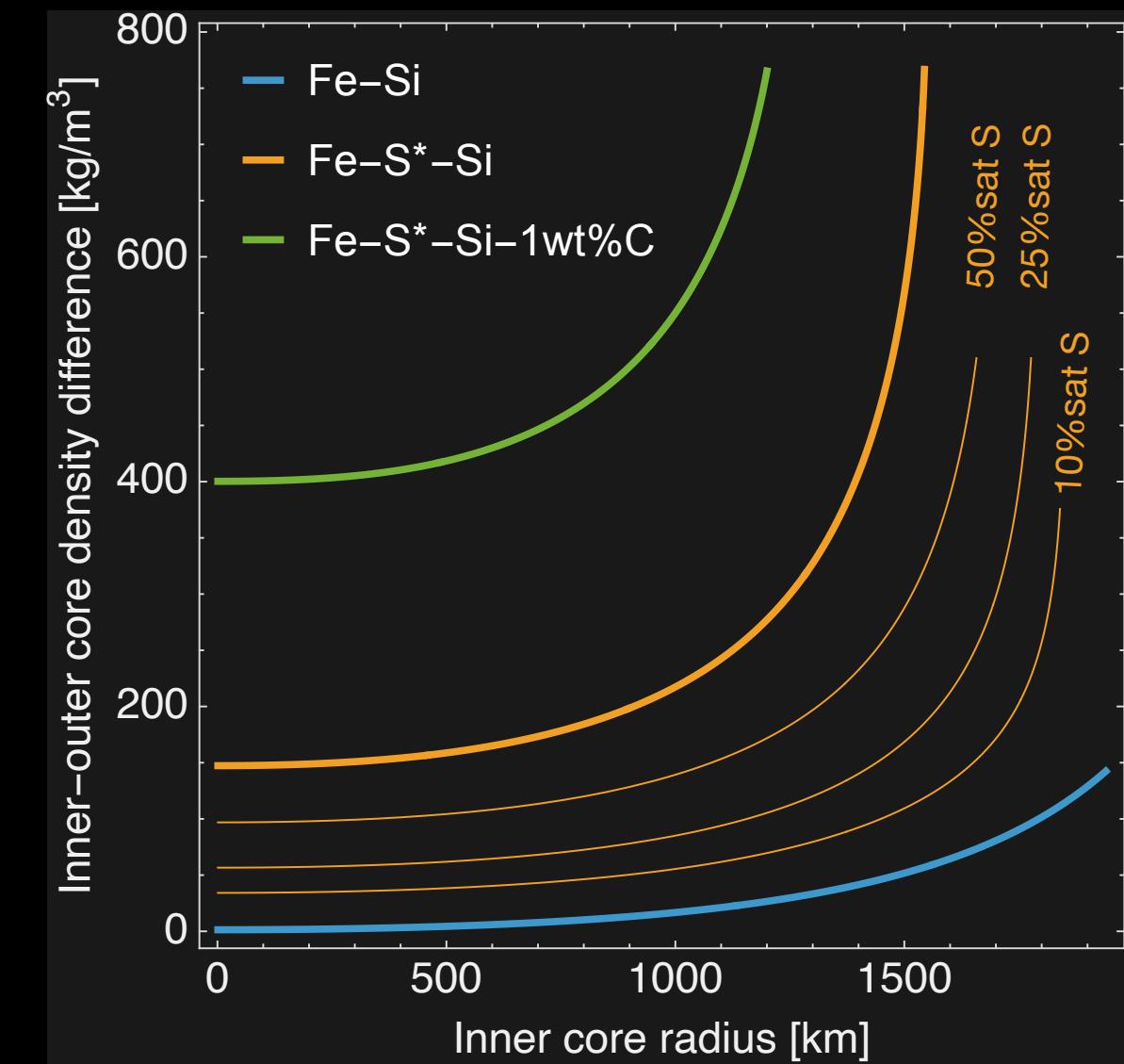


Effect of compositions on free libration modes

- oscillation of the combined figures of the mantle and inner core → Free Mantle–Inner Core mode (FMIC)
- mutual out-of-phase oscillation between mantle and inner core → Mantle–Inner Core Gravitational mode (MICG)



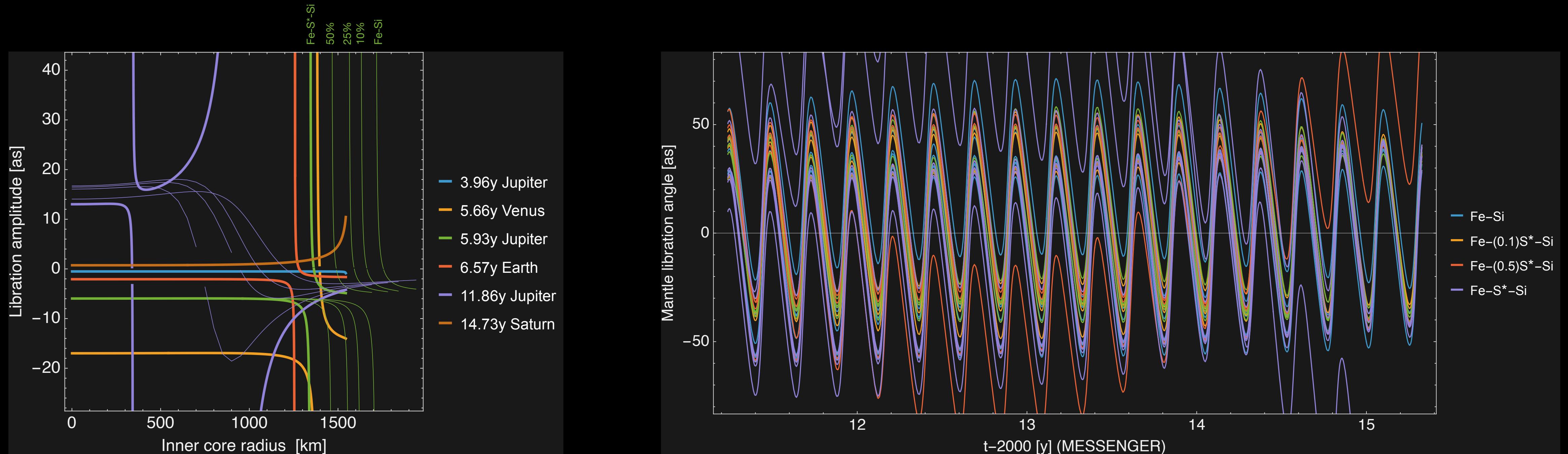
Planetary perturbations of Mercury's orbit



- FMIC has complex behaviour with r_{icb} and composition
- MICG decreases with r_{icb} radius and increasing $\Delta\rho_{icb}$
- core composition (density structure and light element partitioning) have a significant effect on libration normal modes
- several long period forced libration can be resonantly amplified for small or large r_{icb}

Predicted libration amplitude time series (Yseboodt+ 2013)

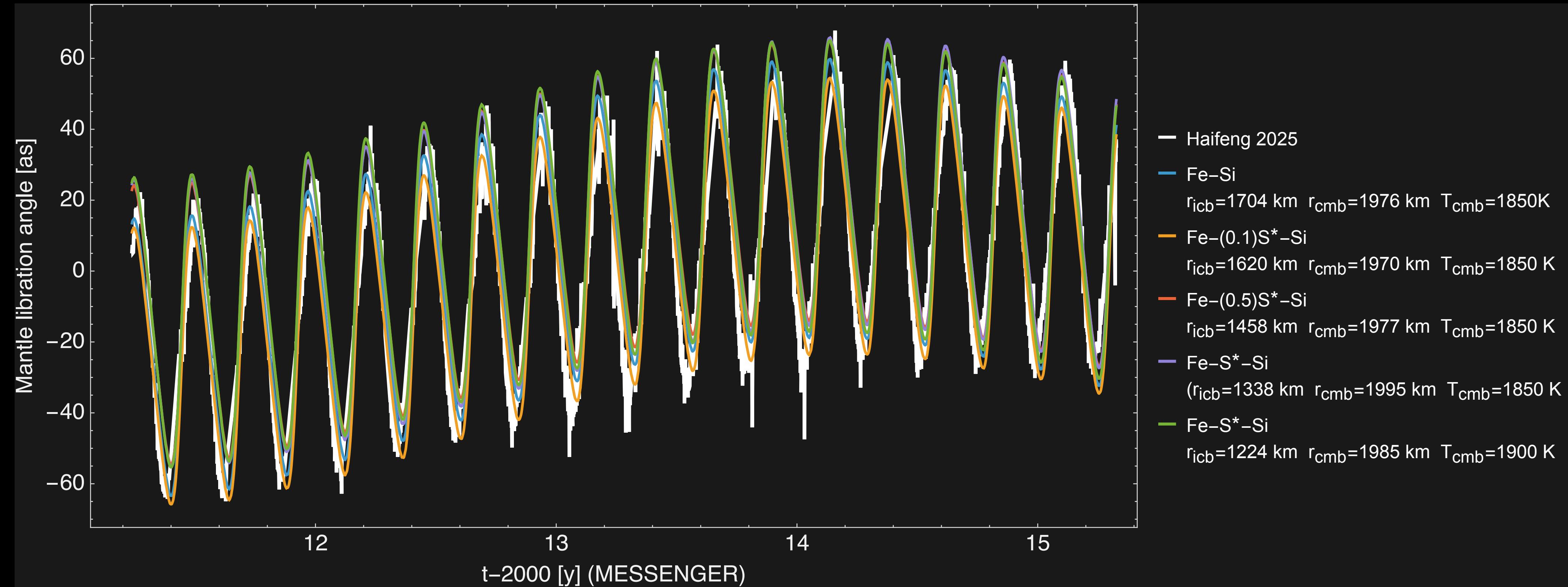
Fe-100% sat S-Si \rightarrow Fe-Si



- width of resonances resulting from MICG are very narrow (\Rightarrow for given T_{cmb} and core composition quite narrow r_{icb} range)
- libration can be resonantly amplified by planetary perturbations of Venus, Jupiter, and Earth if $r_{icb} \gtrsim 1000$ km
- resonance shift to smaller r_{icb} with increasing S in Fe-S^{*}-Si
- core structure and composition have a strong effect on the libration time series

Predicted libration time series versus measured time series during MESSENGER period: Fe-S*-Si \rightarrow Fe-Si

Deduced from self-registration of MESSENGER Laser Altimeter profiles (Xiao+ 2025, this session)



- observation can be explained if structure models have eigendmodes close to Earth (6.6 y), Venus (5.7 y), or Jupiter (5.9 y) orbit perturbations
- several very specific Fe-(0<S_{max}) S-Si models can well reproduce the reconstructed time series (minimal misfit)

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
- combining libration time series with other geodesy data will help to reduce the parameter space of plausible interior structure governing parameters