MERCURY'S THERMAL EVOLUTION AND MAGNETIC FIELD GENERATION WITH AN FE-SI CORE. J. S. Knibbe* and W. van Westrenen, Faculty of Earth and Life Sciences, Vrije Universiteit Amsterdam, Netherlands, *j.s.knibbe@vu.nl.

Introduction: The present-day large iron (Fe) - rich partially liquid core of Mercury has been difficult to reconcile with planetary formation and thermal evolution schemes. The planet's high bulk metallic Fe content and low FeO surface abundance suggest that Mercury's bulk oxygen fugacity is much lower than that of the other terrestrial planets, which is best explained by having Mercury composed of refractory (and oxygen-poor) early condensates that originated close to the Sun. The measured high sulfur/silicon (S/Si) surface ratio of Mercury indicates that the moderately volatile element S is abundant in the crust and mantle. A substantial amount of S is also often assumed to reside in Mercury's core to explain the core's present day partially liquid state, because S lowers the core melting temperature. As a result, the bulk S content of Mercury would be among the highest amongst the terrestrial planets, which is at odds with the refractory nature implied by the dominantly metallic state of Mercury's main elemental constituent (Fe).

Another peculiar characteristic of Mercury is its magnetic field with low surface field strength and low-order spatial geometry. In a scenario of a stable liquid core layer overlying a convective liquid core layer, magnetic fields have been simulated that are roughly consistent with observations [1]. In these simulations, thermal buoyancy (largely generated by the latent heat release of core solidification) and compositional buoyancy (generated by the compositional gradient of S's preferential fractionation in liquid metal) are combined in a single co-density buoyancy variable, assuming a similar molecular diffusivity for compositional and thermal gradients. [2] has shown that the much higher diffusivity of compositional buoyancy propagates to a stronger surface field than is observed, unless compositional buoyancy is near-absent. This indicates that Mercury's magnetic field is most likely generated solely by thermal buoyancy fluxes and that the core may be devoid of S.

The metal/silicate fractionation of S (low) and of Si (high) in high pressure experiments under the low-oxygen fugacity conditions inferred for Mercury suggest that not S, but Si is the dominant light element in Mercury's core [3,4]. In light of these considerations, the high S/Si and Mg/Si fractions of Mercury's surface could be a feature of increased siderophile behavior of Si and increased lithophile behavior of S during Mercury's differentiation. An Fe-Si core also places Mercury compositionally closer to primitive chondrites that are potential building blocks of the planet [3].

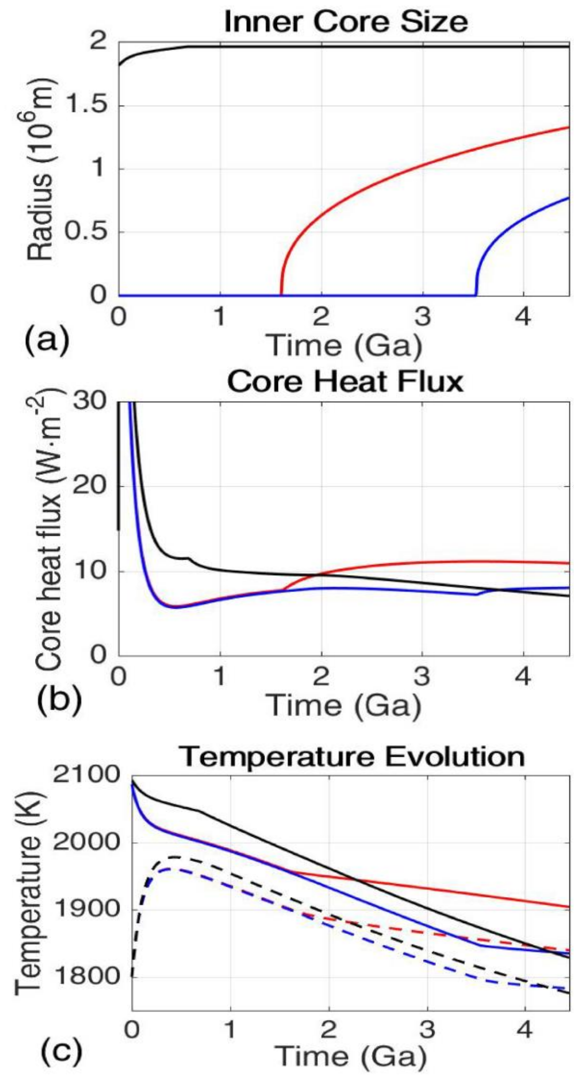

Figure 1: A representative evolution of (a) inner core radius, (b) CMB heat flux, (c) CMB temperature (solid line) and upper mantle temperature (dashed line), for a pure Fe (black), Fe (83wt%)-Si (17wt%) (red) and Fe (77wt%)-Si (23wt%) (blue) core.

Interesting properties of Fe-Si metal include a high latent heat of fusion, a lower melting temperature compared to pure Fe and a non-preferential fractionation of Si between solid and liquid metal. It is the aim of this study to examine the implications of Si as the dominant light element in the core for Mercury's thermal evolution and magnetic field generation.

Methods: We performed one-dimensional thermal evolution schemes based on [5], incorporating an increased latent heat of fusion for Fe-Si metal and the FeSi melting curve of [6].

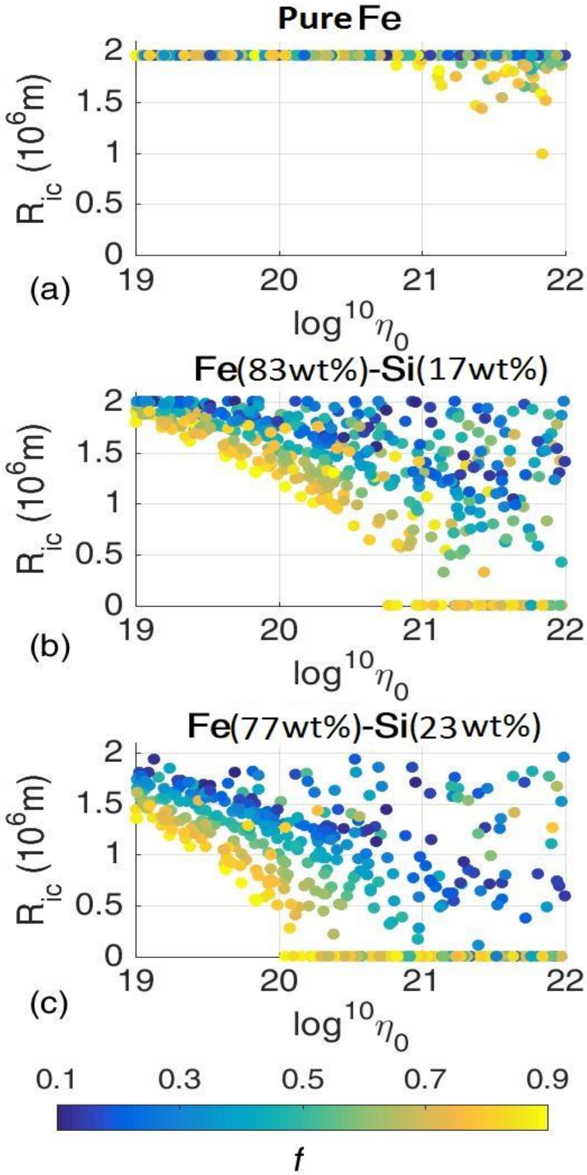

Figure 2: Present-day inner core radius (R_{ic}) related to reference viscosity (η_0) and the fraction (f) of mantle radiogenic heat production relative to that measured on Mercury's surface for (a) a pure Fe, (b) a Fe (83 wt%)-Si (17 wt%) and (c) a Fe (77 wt%)-Si (23wt%) core.

Results: We run thermal evolution schemes with three different core compositions (pure Fe, Fe(83 wt%) - Si(17 wt%), and Fe(77 wt%) - Si(23 wt%)) with variable initial conditions and thermal parameters (e.g. conductivity and viscosity). Fig. 1 shows CMB temperature and inner core size for a representative scenario of Mercury's evolution. The initial core is near-completely solid for a pure Fe core, but remains partially liquid up to the present in most Fe-Si runs. Outcomes of the present-day inner core radius are set out against the adopted mantle viscosity and amount of heat producing elements in the mantle in figure 2.

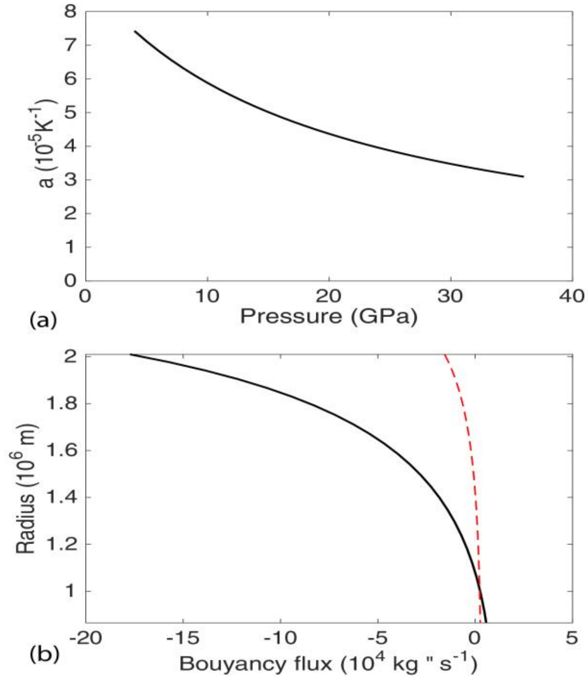

Figure 3: (a) Thermal expansion of iron rich metal at Mercury-core pressures. (b) (solid line) The buoyancy flux through the liquid core (with ICB radius at 860 km) for an Fe-Si core with the thermal expansion coefficient of (a) and (red dashed line) that calculated by [2].

Discussion: Our results show that Mercury's core can remain partially liquid at present with Si as sole core-alloying element. Due to Si's unpreferential solid/liquid metal fractionation, core solidification does not produce a compositional gradient, consistent with the requirements suggested by [2]. An Fe-Si core produces more heat upon core solidification than an Fe-S core, resulting in a stronger thermal buoyancy flux in the lower convective core layer. In previous convection considerations, the stable upper core layer shrinks at the expense of an increased buoyancy flux. These considerations assumed a constant thermal expansion coefficient (α) of ~$3\cdot10^{-5}$ K^{-1} throughout the outer core. In reality, α increases dramatically at the low pressures of Mercury's outer core, steepening the adiabat and increasing the maximum heat conduction through the stable outer liquid layer (figure 3). Hence, vigorous convection of a deep core layer will not substantially affect the size of the stable layer. The implications of a strong thermal bouyancy in a deep liquid core layer for Mercury's magnetic field should be examined.

References: [1] Christensen (2016), *Nature, 444*, 1056-1058. [2] Manglik et al. (2010), *EPSl, 289*, 619-628. [3] Chabot et al. (2014), *EPSL, 390*, 199-208. [4] Putter et al. (2017), *LPSC* (this meeting). [5] Morschhauser et al. (2011), *Icarus, 212*, 541-558. [6] Morard et al, (2010), *Phys. Chem. Min., 38*, 767.