THE (STILL) PROBLEMATIC CASE OF MERCURY'S INTERIOR STRUCTURE. G. Steinbrügge[1], A. Rivoldini[2], M. Dumberry[3], G. Schubert[4], D.M. Schroeder[1], K.M. Soderlund[5], [1]Department of Geophysics, Stanford University (gbs@stanford.edu), [2]Royal Observatory of Belgium, [3]Department of Physics, University of Alberta, [4]Department of Earth, Planetary, and Space Sciences, University of California Los Angeles, [5]Institute for Geophysics, University of Texas at Austin

Introduction: Great progress has been achieved in understanding Mercury's interior structure and the origin of the weak magnetic field thanks to the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft [1] which orbited the innermost planet between 2011 and 2015. The radio science experiment provided the gravity field of the planet including the tidal Love number k_2 [2,3]. Measurement of Mercury's obliquity and libration amplitude [4,5,6] further constrains the moment of inertia (MoI) of the whole planet and that of its mantle, under the assumption that Mercury is in a Cassini State. From these geodetic constraints, we can state with high certainty that Mercury possesses a large, at least partially liquid, iron core with a radius of about 2000 km overlain by a silicate mantle. Estimates based on a set of geodetic constraints obtained by ground based and MESSENGER observations [4] indicated a core with about 2050 km in radius and favored models with small or no solid inner cores [7]. Recent re-evaluations by Genova et al. [8] of the gravity data suggests a significantly lower MoI than previous estimates, as well as a higher k_2 value. Further, new high-pressure laboratory experiments provide updated equations of states for solid iron and liquid iron-alloys [9]. Here, we re-investigate how models of the interior structure of Mercury are compatible with the new geodetic constraints and high-pressure laboratory experiments and outline a number of issues that would require a new perspective on Mercury's interior.

Methods: We compute interior structure models based on the methods presented in Dumberry and Rivoldini [7]. Rheological models and the computation of tidal Love numbers are performed using the same approach as in Steinbrügge et al. [10]. Our models consider iron-snow regimes and are consistent with the mean density, the MoI, the ratio of the mantle to whole planet MoI (Cm/C) of Mercury, as well as with the tidal Love number k_2. For Mercury's core, we consider Fe-S as well as Fe-Si compositions. The equation of state for non-ideal mixing of Fe-S and Fe-Si have been derived from the laboratory measurements presented in Terasaki et al. [9]. The melting temperature for Fe-S is applied from Anzellini et al. [11]. We use a fixed crustal thickness which is set to 26 km and the crustal density to 2974 kg/m^3 [12] since the crust has only a minor implication on the overall solution. Models are instead controlled by the inner core radius and solved for the central pressure and temperature as well as for the mantle density, outer core radius and sulfur/silicon content of the core [6] (Figure 1). The structural models are then complemented by a rheological model using an Andrade rheology for the mantle and a Maxwell rheology for the core as well as for the crust. The tidal Love number is k_2 is then calculated using a matrix propagation method assuming a wide range of rigidities and grain sizes.

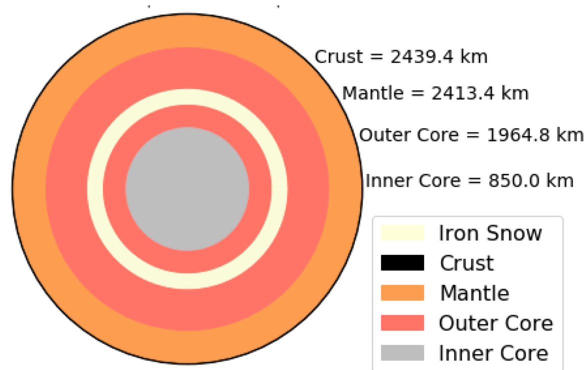

Figure 1: An example of a model of Mercury's interior structure that matches the geodetic constraints given in [8] for an assumed inner core radius of 850 km. The CMB temperature is ~ 2050 K and the mantle density is 3040 kg/m^3 for this specific model.

Results: From the geodetic constraints found by Genova et al. [8], all imposed inner core sizes up to a maximum radius of about 1250 km have valid solutions, and also no inner core models are conceivable. However, models with small inner cores tend to have lower sulfur/silicon contents leading to generally higher temperatures. As a consequence we find high mantle temperatures above 2000 K at the core mantle boundary (cmb) which would be higher than the melting temperature of most mantle forming rocks. Due to the absence of volcanism on Mercury such models are therefore questionable. Since models with larger inner cores have lower core temperatures, the cmb temperatures are lower (<1800 K) and therefore more consistent with the observed state of Mercury's mantle. However, such models lead to surprisingly low mantle densities (~3000 kg/m^3) inconsistent with the currently assumed mineralogical composition of Mercury's mantle (Figure 2). Further, the new k_2 value is higher than the previous estimate. Since the updated geodetic constraints generally favor smaller liquid iron cores and a large solid iron core, the expectation would be a lower tidal Love number. A higher k_2 number in this configuration is hence only achievable with a structurally much weaker mantle with a grainsize below the range assumed in Padovan et al. [13]. Iron snow regimes also only occur with large inner cores > 800 km due to the high temperature and low sulfur content for small cores. Deep snow zones occur for inner cores > 900 km.

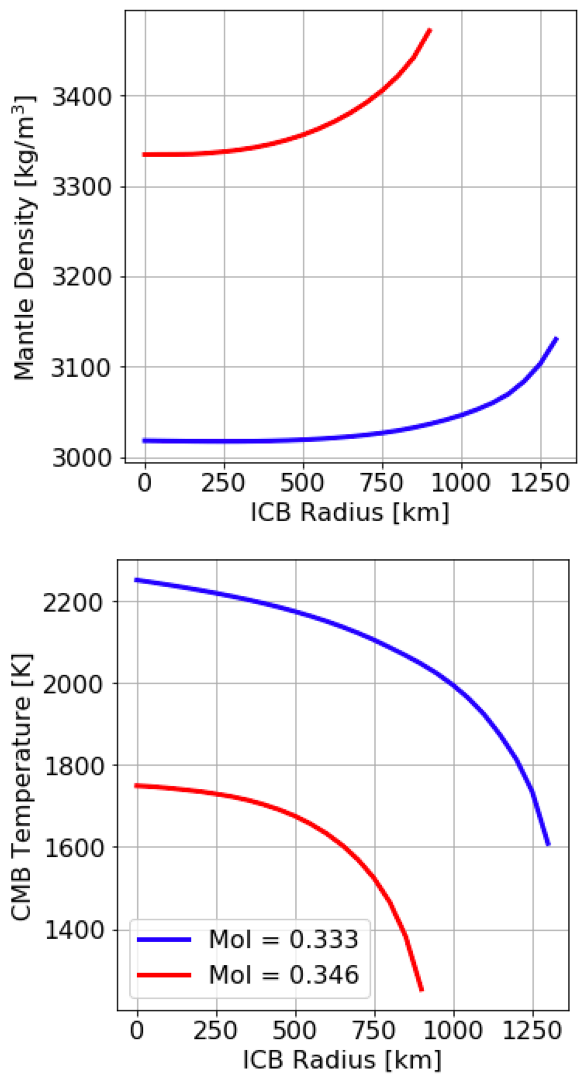

Figure 2: Mantle Density (top) and temperature at the cmb (bottom) as a function of inner core radius for the geodetic constraints originally provided by Margot et al. [4] and the updated solution from Genova et al. [8].

Discussion: The ensemble of models derived from the new set of geodetic constraints has significant implications on the interior structure of Mercury. While models with large inner core size are preferred in terms of mantle temperature, these come with the caveat of low mantle density not in agreement with current mantle composition models. Further, the tidal Love number k_2 implies a very weak mantle, which in combination with the high mantle temperature could be contradicting the absence of recent volcanism without assuming a very low cooling rate. Even within the error bars of the respective constraints it becomes difficult to satisfy all assumptions previously made on the interior structure of Mercury. The weak, high-temperature, low density mantle would require e.g., significant amounts of partial melt or a composition similar to that of crust.

Hence, the structure of Mercury's interior remains ambiguous and still leaves room for speculation. Considering the implications for the mantle density, the size of the inner core remains uncertain. Possible new constraints could come from thermal evolution models, further laboratory measurements, especially for Fe-Si compositions under Mercury core conditions or a more precise measurement of the geodetic constraints as envisioned by BepiColombo mission [14] which is currently on its way to Mercury. A further constraint on the size of the inner core could also be obtained by measuring the tidal Love number h_2 [10] as envisioned by the Laser Altimeter BELA [15] onboard the Mercury Planetary Orbiter [16].

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