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Viscoelastic Tides of Mercury and Implications for its Inner Core Size

G. Steinbrügge[1,3] (gregor.steinbruegge@dlr.de), S. Padovan[1], H. Hussmann[1], T. Steinke[2], A. Stark[1] and J. Oberst[1].
[1]German Aerospace Center (DLR), Institute of Planetary Research, Berlin, Germany, [2]Delft University of Technology, Delft, Netherlands, [3]Institute for Geophysics, University of Texas at Austin, Austin, TX, USA

1. Introduction

This work studies the tidal deformation of Mercury based on the currently published geodetic constraints from the MESSENGER mission and shows that a future determination of the tidal Love number h_2 can yield important constraints on the inner core when combined with the available (or future) measurements of k_2. We further studied the potential range of tidal phase-lags and resulting tidal heat dissipation in Mercury's mantle. All parameters discussed in this contribution might be measured by the upcoming BepiColombo mission [1] scheduled for launch in 2018 and operated by the European Space Agency (ESA) and the Japan Aerospace Exploration Agency (JAXA).

2. Method

All constructed models consist of three chemically separated layers: A core surrounded by a mantle and covered by a crust. While the crust is kept as one single layer, the mantle and the core are further subdivided. Each sublayer is characterized by its thickness, density, temperature, pressure, viscosity and rigidity. The parameter space is spanned by the the volatile content of the core, where we account for sulfur and silicon, the temperature of the core-mantle boundary as well as by the crustal thickness and density. The remaining parameters are solved for in order to obtain self-consistent models. The construction of the models follows a two-step process. In a first step each model is initialized by a given value of each of the parameter listed above as including a set of three geodetic constraints, namely the mean density, the mean moment of inertia and the fractional part of the moment of inertia which is due to the mantle to solve for the radius of the outer core, the reference liquid core density as well as for the mantle density. A solution is only considered valid if the resulting model is hydrostatic and if the solved parameters are consistent with laboratory measurements. In the second step each solution for the structural model is provided with a set of different mantle rheologies parametrized by the unrelaxed rigidity and the grain size. Based on these, the tidal Love number k_2 is calculated and compared against the measurement. Models which are not consistent with the measurement inside its 3-σ error bar are discarded.

The nominal value used for k_2 is 0.451 ± 0.014 [4] but the error bar also accounts for the value determined by [5]. The used mean moment of inertia is 0.346 ± 0.014 [6]. The assumed C_m/C value is 0.421 ± 0.025 [7]. However, within the used error intervals the C_m/C is also consistent with the value 0.431 ± 0.021 [6].

3. Results

Typical k_2 values range between 0.45 and 0.52 implying that the measured value argues for a high mantle rigidity and / or high grain-sizes as well as a lower temperature at the core-mantle boundary in agreement with previous work [8]. In the considered range of models the tidal Love number h_2 ranges between 0.77 and 0.93. The corresponding tidal amplitudes range from 1.93 to 2.33 m at the equator and 0.24 to 0.29 m at the poles.

An important advantage of having both tidal Love numbers is that certain dependencies can be suppressed by combining them. The main parameter controlling the value of k_2 and h_2 is the existence of a liquid core. Further, the amplitude of the deformation is controlled by the mantle rheology. However, when considering the Love numbers individually, the presence of a solid inner core has only a moderate effect on the amplitude in comparison to the

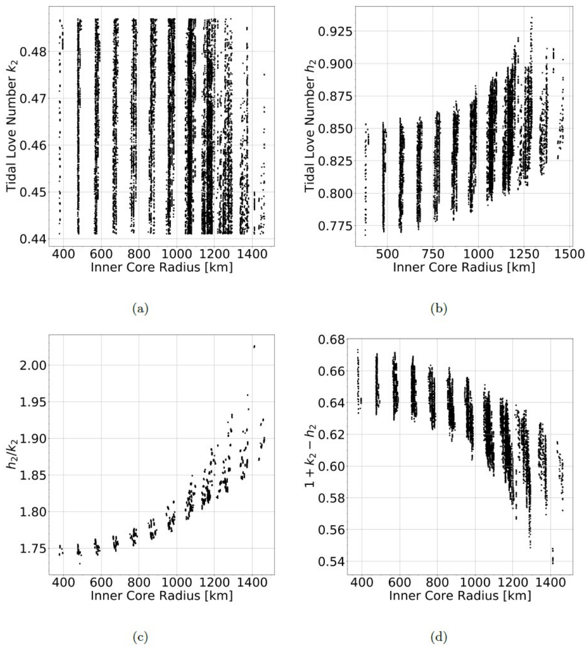

Figure 1: (a) Tidal Love number k_2 as a function of inner core size. (b) The tidal Love number h_2 as a function of the inner core size. (c) Using the ratio h_2/k_2 is less ambiguous and therefore allows setting an upper limit on the core size. (d) The same effect can be principally observed using the linear combination $1+k_2-h_2$, however provides a less strict constraint.

rheological properties of the mantle (compare to Figure 1). A linear combination as well as the ratio h_2/k_2 cancels out the ambiguity to a certain extent. What is left are the changes in the gravity field due to a redistribution of mass inside the core. Since a density contrast between a solid core an a liquid core is present, the size and density of an inner core are noticeable when combining both Love numbers. The linear combination is known as the diminishing factor, which has been proposed previously to better constrain the ice thickness of Jupiter's moon Europa [2] but is also applicable to other icy satellites e.g. Ganymede [3]. For small solid cores, the effect is barely noticeable, so in the case of the core being small a measurement of the respective ratio or linear combination would allow the determination of an upper bound for the size of the inner core but a determination of the actual inner core size would only be feasible with a significant uncertainty due to the remaining ambiguity. The ratio h_2/k_2 is affected by a similar behaviour, however is less ambiguous. Therefore, for cores > 700 km in radius the size can potentially be inferred but a measurement accuracy in the order of 1% in h_2 would be required.

Since the tidal Love numbers are complex numbers they are not only characterized by their amplitude but also by a phase which is a function of the rheologic parameters and indicates the amount of tidal dissipation. A particularity of the 3:2 resonance is that the tidal dissipation barely depends on the eccentricity. The main source of tidal dissipation on Mercury is the mantle; however the maximum values for $\mathrm{Im}(k_2)$ consistent with the geodetic constraints are between 0.02 and 0.03. This result is consistent with the maximum value estimated from the spin orientation [9]. The maximum tidal dissipation would then correspond to a surface flux of < 0.16 mW/m^2 .

4. Discussion

A measurement of the tidal Love number h_2 should fall most likely in the predicted range of 0.77 to 0.93. A refined measurement of the moment of inertia, C_m/C and k_2 are likely to further constrain the value. In case of a compliant measurement the remaining range of possible values is valuable to discriminate between the remaining models to get additional constraints on the inner core size. In case of a small core however, the inner core size is unlikely to be constrained any further due to the remaining ambiguity in the interior models. In case of an inner core with a radius above 1000 km the size can be constrained with an accuracy of 50 to 200 km due to the exponential growth of the h_2 over k_2 ratio. Therefore, it would also allow to reassess the moment of inertia if necessary and to provide valuable information for models addressing Mercury's core dynamic and magnetic field generation.

References

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