ASSESSMENT OF MODELS OF MERCURY'S INTERIOR STRUCTURE USING RECENT MEASUREMENTS OF ITS MOMENT OF INERTIA AND TIDAL RESPONSE. S. Goossens[1], J. P. Renaud[1,2], W. G. Henning[1,3,4], E. Mazarico[1], S. Bertone[1,3,5], A. Genova[6], [1]NASA Goddard Space Flight Center, 8800 Greenbelt Rd, Greenbelt, MD 20771 (email: sander.j.goossens@nasa.gov), [2]Universities Space Research Association, 7178 Columbia Gateway Dr, Columbia, MD 21046, [3]Center for Research and Exploration in Space Science and Technology (CRESST) II, NASA/GSFC, 8800 Greenbelt Rd, Greenbelt MD 20771, [4]University of Maryland, College Park, 4296 Stadium Dr, College Park, MD 20742, [5]University of Maryland, Baltimore County, 1000 Hilltop Cir, Baltimore, MD 21250, [6]Sapienza, University of Rome, Via Eudossiana 18, 00184, Rome, Italy

Introduction: Knowledge of Mercury's interior structure is important as it can help constrain its formation process, and that of the solar system as a whole. Mercury is expected to be in an equilibrium Cassini state, where its spin axis, its orbit normal, and the normal to the invariable plane are co-planar. Because of this, its moment of inertia, which is a measure of the radial density distribution, can be determined from knowledge of its gravity field, its obliquity (axial tilt), and its physical librations (longitudinal oscillations in its spin rate) [1]. In turn, the moment of inertia can constrain models of the interior structure. Earth-based radar data has provided the measurements of Mercury's physical librations [2], and data from the MErcury Surface, Space Environment, GEochemistry, and Ranging (MESSENGER) mission [3] has provided the gravity measurements. Combined, these provide a measurement of Mercury's obliquity.

Recent analysis of MESSENGER data to determine Mercury's rotational state has yielded results that place Mercury unambiguously in the Cassini state. Yet analysis based on Doppler tracking data [4] and Mercury Laser Altimeter (MLA) data [5] obtain different values for the obliquity, resulting in different values for the normalized polar moment of inertia. A value of 0.333 ± 0.005 is obtained from the Doppler analysis, and a value of 0.343 ± 0.006 is obtained from the MLA analysis. This affects our knowledge of the interior, *e.g.*, the size of its core.

A planet's tidal response can also constrain interior structure models. The tidal response is expressed by the Love number k_2, which is a dimensionless parameter that describes how the gravitational potential field of a self-gravitating planetary body changes in response to the second-order spherical harmonic terms of the gravitational field of another body (in this case the Sun). Recent measurements of k_2 for Mercury from MESSENGER data vary between 0.53 [6] and 0.569 [4].

A recent analysis of Mercury's moment of inertia and tidal response has indicated several challenges when the lower moment of inertia value of 0.333 is satisfied by the models [7]. These challenges include low viscosities at the base of the mantle, a large solid inner core, high temperatures at the core-mantle boundary (CMB), and a low mantle density.

Here, we investigate the different moments of inertia and k_2 values and how they affect parameters for models of the interior, using an approach that is different from this recent analysis [7]. We apply a comprehensive Markov Chain Monte Carlo (MCMC) analysis to map parameter distributions based on the moments of inertia, tidal parameters, and their associated errors

. This provides a more complete picture of the distribution of possible interior structure models than focusing on models that match the central values of the same solutions. We investigate models that use the tidal response as a measurement, and models that predict the tidal response. Extensive results are given in our publication presenting this work [8].

Interior structure modeling: We assume a spherically symmetric planet in hydrostatic equilibrium. We numerically integrate the equations for pressure and gravity, while assuming an adiabatic temperature profile in the liquid part of the core, and an isothermal solid inner core. We assume constant (separate) densities in the crust and in the mantle, and relate pressure, temperature, and density in the core through equations of state (EOS). We only consider cores consisting of Fe and Si. Our modeling is based on previous publications [4,8,9]. We assume a structure consisting of four layers: a solid inner core, a liquid core, a mantle, and a crust. For the tidal response, we use our own modified version of the ALMA software [10] where we introduced different rheological laws, and replaced ALMA's Laplace variable with its Fourier counterpart to account for Mercury's orbital frequency in the tidal forcing. We assume a conducting mantle to compute its temperature profile, and then use an Arrhenius relationship to determine the viscosity in the mantle.

Based on these interior models, we use MCMC to map the distribution of estimated parameters such as layer radii and densities. For each self-consistent model we compute the moments of inertia and tidal response, which we then compare to the measurements. The parameters we vary are: the radii of the solid inner core and liquid core, the thickness of the crust, the mantle density, temperature at the CMB, and the weight fraction of Si in the core. For the tidal response additional parameters include the grain size, unrelaxed crust and mantle rigidities, and a reference viscosity.

Constraining measurements consist of the planet's average density, normalized polar moment of inertia, and the crust-mantle moment of inertia. In two separate sets of tests, we considered k_2 both as a constraining measurement, or as a value to predict.

Results: We use two main sets of measurement values: one based on an earlier analysis of MESSENGER data [11] with a polar moment of inertia similar to later analysis (0.349 ± 0.014) , as well as an estimate of k_2 (0.451 ± 0.014), and a more recent analysis [4] with a lower polar moment of inertia (0.333 ± 0.005) and a higher value for k_2 (0.569 ± 0.025). We denote the former as "M14" [11], and the latter as "G19" [4]. We choose these solutions because they co-estimated k_2 together with the gravity field, which allows consistency in our analysis. Other works that obtain similar polar moments of inertia did not estimate k_2.

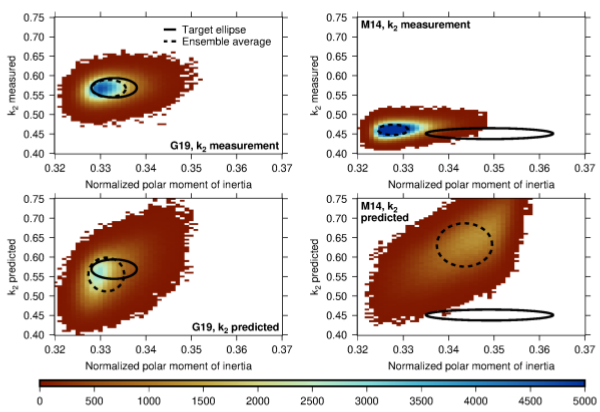

Figure 1 Heat map of the normalized polar moment of inertia versus k_2 for different measurements. The parameter k_2 was either a measurement, or predicted. G19 refers to ref. [4] and M14 to ref. [11].

In Figure 1 we show heat maps of the models' resulting polar moment and k_2, for the different measurements, and for cases where k_2 was either a measurement or predicted. We evaluated ~10 million models for each case, which we then randomly down-selected to about 450,000 to streamline further investigations. For each model the polar moment and k_2 were evaluated. The results were binned to generate the heat maps shown in Figure 1. The results clearly indicate that we can both fit and predict the results for the lower polar moment of inertia and higher k_2 (G19; left column), as both the target ellipse (central value and associated error) and ensemble ellipse (from the average and standard deviation) overlap. However, we cannot simultaneously fit the moment of inertia and k_2 for M14 (right column), as indicated by ellipses that do not overlap. The measurements of M14 are thus incompatible, and the MCMC results are heavily biased to its k_2 measurement because of its small error. Moreover, this shows that the lower polar moment of inertia and the higher k_2 are entirely compatible. If we predict k_2 from the higher moment of inertia from M14, we find an even higher k_2 value (~0.63, Fig. 1 bottom right), although the spread is also large.

In Figure 2 we show results for the CMB radius, using different measurements. The lower polar moment of inertia results in a smaller (liquid) core. Higher moments of inertia result in larger liquid cores.

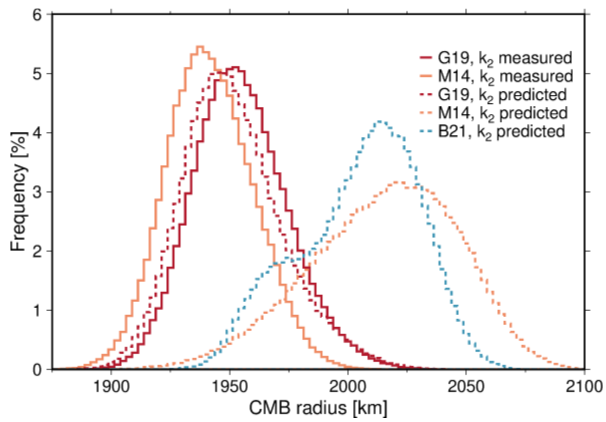

Figure 2 Distribution for the CMB radius from our MCMC analysis using different measurements. B21 refers to ref. [5].

We also investigated additional model parameters such as temperatures and viscosities. Contrary to a recent analysis [7] we do not find relatively high temperatures at the CMB. While we find low viscosity values at the CMB, we equally find higher values. As the results from our MCMC analysis as shown in Figure 1 indicate, we find no issues in fitting the newer, higher Love number k_2 from G19.

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