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Characterizing the deviations of Mercury's bulk composition from solar abundances

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Abstract

Mercury is characterized as an iron-rich planet, who experienced particular chemical conditions during its formation. From the latest MESSENGER data and laboratory experiments, we investigate the interior of this planet with a precise description of both core and mantle materials. We show that the measured moments of inertia of the planet favor a dense mantle, possibly containing a non-negligible fraction of iron, and a core containing silicon rather than sulfur. We finally derive the bulk composition of the planet fitting both the moments of inertia and the solar S abundance.

1. Introduction

Compared to the other terrestrial planets of the solar system, Mercury presents several unique characteristics. It is both the smallest and densest (uncompressed) planet, indicative of a composition significantly rich in iron. Formation scenarios specific to Mercury thus invoked different methods of fractionation between iron and silicates. Recent studies revealed another unique feature of this planet, namely that it formed in chemically reducing conditions [1]. This has strong implications on the materials forming Mercury, favoring the formation of metallic iron and silicon, and of sulfides in the mantle. The mantle of Mercury is thus believed to be strongly depleted in silicate iron, enriched in sulfur, and the core believed to harbor both silicon and sulfur as alloying elements. Several of these characteristics were strengthened by results of the MESSENGER mission, who analyzed the surface composition of the planet, but also derived constraints on its structural parameters.

2. Modeling the interior

We use a model designed for exploring the interior of terrestrial planets [2], that we adapt to the case of Mercury. The modeled body is differentiated into a metallic core surrounded by a silicate mantle, whose respective sizes are governed by the core mass fraction (CMF). The model varies the CMF to converge towards the planetary mass and radius of Mercury. Modeling the metallic core is done with an equation of state of the complete Fe-S-Si system, as both silicon and sulfur are potential alloying elements present in the core of Mercury. Coupling our model to the PerpleX code [3] allows us to use a complete description of the mineralogy of the silicate mantle. We can thus study the impact of both core and mantle compositions on the internal structure of Mercury, and derive the bulk elemental composition of the planet.

We employ a Monte-Carlo approach to constrain Mercury's bulk parameters, by launching a large number of simulations with different bulk compositions. The ternary diagram of the Fe-S-Si system is uniformly explored, whereas we select a set of five compositions for the mantle, chosen to span large ranges of density and composition (estimates of the Earth mantle, Mercury mantle, and meteorites). The results obtained for all explored compositions are then refined by selecting only simulations that reproduce Mercury's moments of inertia, as deduced from MESSENGER data [4].

3. Reproducing Mercury

Our results confirm previous estimates of Mercury's structural parameters, with a CMF within the 72–76% range, corresponding to a mantle thickness of 430±40 km. The constraints placed by the moments of inertia tend to favor a dense mantle, as our best fit is obtained with an Earth mantle, the only investigated composition with a significant fraction of silicate iron (7.5wt%). This density could however also be revealing of a lower mantle temperature compared to previous estimates. Although a large fraction of light elements can theoretically be incorporated in the core, the moments of inertia are only reproduced with 1–9wt% of Si or 2–16wt% of S.

The relative abundances of Fe, Mg, and Si in Mercury can give important hints for the formation of

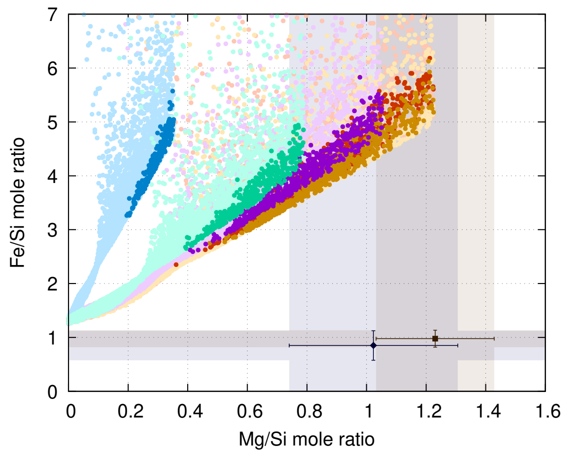

Figure 1: Map of the Fe/Si ratio as a function of the Mg/Si ratio, for all simulations (light) and those compatible with the moments of inertia (dark). Colors denote the different mantle compositions (see text). Two solar estimates are shown for reference.

the planet, as these refractory elements have similar condensation temperatures in protosolar nebula conditions. We thus aim at quantifying the deviations of Mercury's ratios from the solar values. Figure 1 shows the areas of the Mg/Si-Fe/Si map that are covered by our simulations. A pure Fe core thus yields a solar Mg/Si ratio but an Fe/Si ratio enriched $\sim$5 times the solar value. Incorporating S in the core does not change the planetary Mg/Si ratio, but Fe/Si increases towards higher values. On the opposite, Fe/Si is brought closer to solar values when the core contains Si, but this also reduces the Mg/Si ratio to sub-solar values. On the planetary scale, Mercury was suggested to be strongly enriched in S, but we show that solar abundances can be reached, especially since Si can replace S in the core. Moreover, the moments of inertia are best reproduced with an Fe-Si core than with Fe-S. We thus derive the bulk composition of Mercury which fits the solar S abundance, that we obtain for a core containing 4.4wt% of Si and 1.8wt% of S (see Figure 2).

4. Discussion

The presence of a significant amount of Si in Mercury's core, at the expense of S which was the first candidate for an alloying element, are in agreement with the latest studies on Mercury's composition from laboratory experiments. The mantle of this planet is thus likely to be rich in S, in contrast to the core, allowing to

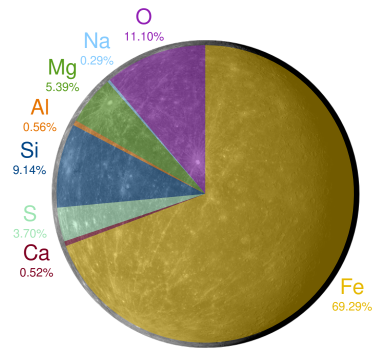

Figure 2: Bulk composition obtained for a Mercury mantle with addition of 9wt% S, and an Fe-$_{1.8\%}$S-$_{4.4\%}$Si core (values are in wt%). *Picture credits: NASA*

reach a bulk abundance of S similar to the solar value. This favors a formation scenario invoking a depletion of mantle material, increasing the planetary Fe/Si ratio, and decreasing both Mg/Si and S/Si ratios. Such characteristics could thus be revealing of a particular formation mechanism which could be extended to the study of exoplanets sharing one of Mercury's feature, namely a high mean density. A finer knowledge of Mercury's interior is thus essential to allow for a better characterization of these "super-Mercuries".

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References

[1] Nittler, L. R., Starr, R. D., Weider, S. Z., et al. 2011, Science, 333, 1847

[2] Brugger, B., Mousis, O., Deleuil, M., & Deschamps, F. 2017, ApJ, 850, 93

[3] Connolly, J. A. D. 2009, Geochemistry, Geophysics, Geosystems, 10, Q10014

[4] Margot, J.-L., Peale, S. J., Solomon, S. C., et al. 2012, Journal of Geophysical Research (Planets), 117, E00L09