DETECTION OF THE LIQUID CORE SIGNATURE IN MARS NUTATIONS FROM INSIGHT-RISE DATA: IMPLICATIONS FOR MARS INTERIOR STRUCTURE.

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Introduction: Fundamental properties of the interior structure and atmosphere dynamics of Mars can be obtained by precisely measuring its rotation [1]. We report the results of almost four Earth years of monitoring the rotation of Mars with the RISE instrument on InSight. Small periodic variations of the spin axis orientation, called nutations, can be extracted from the Doppler data with enough precision to identify the influence of the Martian fluid core. For the first time for a planetary body other than the Earth, we can measure the period of the Free Core Nutation (FCN), which is a rotational normal mode arising from the misalignment of the rotation axes of the core and mantle. In this way, we confirm the liquid state of the core and estimate its moment of inertia as well as its size and composition.

Results: The FCN period depends on the dynamical flattening of the core and on its ability to deform. Since the shape and gravity field of Mars deviate significantly from those of a uniformly rotating fluid body, deviations from that state can also be expected for the core. Models accounting for the dynamical shape of Mars can thus be tested by comparing core shape predictions to nutation constraints. The observed FCN period can be accounted for by interior models having a very thick thermal lithosphere loaded by degree-two mass anomalies at the bottom. The thickness of the lithosphere is in the upper range of estimates obtained from seismic data [2].

The combination of nutation data and interior structure modeling allows us to deduce the radius of the core and to constrain its density, and thus, to address the nature and abundance of light elements alloyed to iron. The inferred core radius agrees with previous estimates based on geodesy and seismic data [3,4,5,6]. Using state of the art equations of state for the core alloy [6] we find that a small weight fraction of hydrogen is required in the iron-sulfur-oxygen-carbon core in order for its composition to agree with geochemical constraints [7]. The large fraction of light elements required to match the core density and in particular a sulfur concentration close to the iron-sulfur eutectic, implies that the core liquidus is significantly lower than the expected core temperature, making the presence of an inner core highly unlikely. Besides, the existence of an inner core would lead to an additional rotational normal mode the signature of which has not been detected in the RISE data.

The presence of an enriched basal silicate layer (BSL) can strongly affect the evolution of the planet and its current state [7] and consequently alter the interpretation of the RISE results in terms of interior structure. In particular, if the BSL allows for the presence of a fully molten silicate layer above the core it can not only act as a deep seismic reflector [7,8] but also rotate in unison with the metallic part of the core relative to the solid mantle and thus affect the nutation. BSL models with a fluid silicate layer that also harbor a soft partially molten lower mantle layer above the effective fluid core (metallic + fluid silicate part) agree with the estimated FCN period. The softer lower mantle increases the core's ability to deform and thus mass anomalies can be placed at shallower depths and models with thin thermal lithospheres can be reconciled with RISE data.

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References: [1] Folkner et al. 2018 doi: 10.1007/s11214-018-0530-5. [2] Khan et al. 2021 doi: 10.1126/science.abf2966 [3] Rivoldini et al 2011 doi: 10.1016/j.icarus.2011.03.024 [4] Stähler et al. 2021 doi: 10.1126/science.abi7730. [5] Durán et al 2022 doi: 10.1016/j.pepi.2022.106851. [6] Irving et al. 2023, PNAS, submitted, [7] Steenstra et al. 2018, doi : 10.1016/j.icarus.2018.06.023. [8] Samuel et al. 2021 doi: 10.1029/2020JE006613 [9] Samuel et al., LPSC abstract 1482, (2023)