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The influence of the fluid outer core and of the solid inner core on the orientation of the rotation axis of Mercury

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Abstract

Mercury's spin axis nearly occupies an equilibrium state in which the orbit normal and spin axis precess together with a long period of about 300 000 years. We develop a Cassini state model for the equilibrium orientation of the spin axis of Mercury's mantle that takes into account all the effects of pericenter precession, tidal deformations, and couplings between internal layers, including dissipative core-mantle boundary viscous coupling. Such an extended model will be useful for the interpretation of future BepiColombo rotation measurements.

1. Introduction

Mercury's spin axis nearly occupies the Cassini state 1, in which the orbit normal and spin axis precess together with a long period of about 300 000 years. Mercury slightly deviates from that state which is defined for a uniformly precessing rigid planet. The slow precession of the pericenter (period of about 127 000 years) induce variations in obliquity and deviation from the coplanarity between the spin axis, the normal to the orbit and the normal to the Laplace plane, while the short-periodic tidal deformations induce a constant shift over time in mean obliquity and deviation [2].

Measurements of tides [5, 10] and of the longitudinal librations at a period of 88 days [3, 4] indicate that the core of Mercury is at least partially liquid, decoupling the solid mantle and crust from the interior. Peale et al. (2014, 2016) have shown that the internal torques resulting from the presence of a fluid outer core and a solid inner core might increase the equilibrium obliquity and lead to an overestimate of the polar moment of inertia from the measured obliquity [6, 7].

Here, we develop a Cassini state model for the equilibrium orientation of the mantle spin axis that takes into account all the effects of pericenter precession, tidal deformations, conservative torques related to the presence of an outer fluid core and of an inner solid core, dissipative core-mantle boundary viscous coupling.

2. Methodology

We consider three-layer interior models with a silicate shell (consisting of mantle and crust), a liquid outer core and a solid inner core. Those models are constrained by the mass, radius, second-degree gravity field coefficients and libration amplitude [9].

We express the spin axis motion in a frame based on the Laplace plane [1]. We take into account the solar gravitational torque exerted on each layer, the internal gravitational torques between the internal layers and the pressure torques as well as the dissipative viscous torques exerted at the interfaces. We include the effect of tidal periodic deformations and of pericenter precession on each layer, by generalizing the developments for a solid Mercury [2].

We use the extended Cassini state model to reinterpret recent determination of Mercury's orientation (e.g. Stark et al. 2015 [8]) in terms of parameters of Mercury's interior, particularly the polar moment of inertia and the tidal quality factor, and evaluate potential improvements with future data by the BepiColombo mission.

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