# The effect of tides and an inner core on the forced 88 day libration of Mercury

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## Introduction

The rotation speed of Mercury is not constant but shows small periodic variations. These longitudinal librations are due to the torque exerted by the sun on the aspherical shape of Mercury. It was realized by Peale [3] that observation of the main libration at 88 days would allow determining whether the core of Mercury is (at least partially) liquid, because that libration is about a factor of two larger for a liquid core than for a solid core. Margot et al. [2], using Earth-based radar observations to estimate the librations, demonstrated that the core is indeed highly likely partially liquid.

Besides giving information on the core state, an accurate determination of the libration will also allow constraining the mantle density and the size, density, and composition of the core. However, in order to be able to make accurate inferences on the interior structure of Mercury, all relevant effects on the libration have to be known more precisely than the observational precision. It is usually assumed that the core is spherically symmetric and that its rotation is not coupled to the rotation of the mantle on the short period of libration. The core, however, can be aspherical and can be coupled to the mantle by various physical mechanisms. Electromagnetic coupling, topographic coupling, viscous coupling [4] and inertial coupling [6] between the liquid core and the mantle have been shown to be sufficiently small so that their influence can be neglected given the current and future spacecraft precision on the libration. Gravitational coupling between the mantle and a solid inner core is thought to have a similarly small influence on the libration amplitude [4], although the influence of the inner core could lead to a noticeable difference in the libration on a timescale of several years [10].

Here we investigate the influence of tides on the librations of Mercury, which have up to now not been accurately quantified. We moreover rediscuss and modify previous analyses [4, 10] of the effect of a solid inner core on Mercury's libration. Numerical results are presented for a wide range of recent models of the interior structure of Mercury [7].

## Tides

Tides affect the librations of Mercury in two ways. First, periodic tidal deformations of Mercury change the solar torque on Mercury and therefore also change the librations. Secondly, zonal tides change the polar moment of inertia, and therefore also the rotational response of Mercury to a given torque. In addition to the tidal deformations, we also take into account the changes in the polar moment of inertia due to the variable centrifugal acceleration during libration.

We estimate the induced changes in the libration for a large set of interior structure models of Mercury with inner core radius varying between zero and almost the total core radius [7]. The models use a wide range of chemical compositions of the core and mantle and two temperature profiles to describe hot and cold models. Five different mantle compositions are considered and the core is assumed to consist of iron and sulfur. The models make use of recent data on thermo-elastic properties of the relevant liquid metal alloys and their melting properties to obtain an accurate description of the core in terms of a solid inner core and a liquid outer core. The final models used are characterized by the radius of the inner core and outer core, the mean density of the inner core, outer core and silicate shell, and the mean rigidity of the inner core and silicate shell. For each of the ten possible choices in mantle composition and temperature profile, a set of interior structure models is constructed with increasing inner core radius, from almost zero kilometer to about the radius of the outer core.

The libration amplitudes of these models, expressed as a shift at the surface of the orientation of the long axis with respect to that for the mean rotation rate, are decreased by about 1 to 2 m (0.2% and 0.5%) due to the tides, which is below the (future) observational precision expected to be about 10 m or somewhat smaller [5]. The main cause of the difference is the change in the torque. Tides also slightly increase the free libration period by about 0.1% to 0.25%. The librations are calculated for the value of Smith et al. [8] for $C_{22} = 0.81\,10^{-5}$ and suggest that Mercury's core size is between about 1870 km and 2000 km (Fig. 1).

## Inner core

The presence of an inner core modifies the libration of the silicate shell (mantle + crust) because the inner core can rotate differentially with respect to the silicate shell and the librations of the shell and inner core are coupled through gravitational and pressure torques [e.g 1, 9]. As-

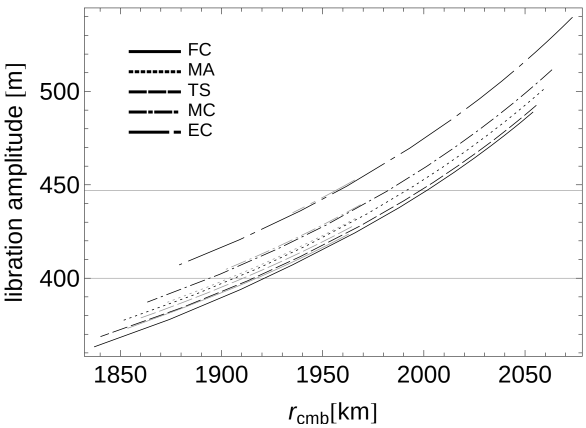


Figure 1: Libration amplitude with the inclusion of the effects of tides and centrifugal accelerationfor as a function of core radius for hot (gray) and cold (black) models. The two horizontal lines indicate the observational estimate of Mercury's 88 libration amplitude as $35.8 \pm 2$ arc seconds [2]

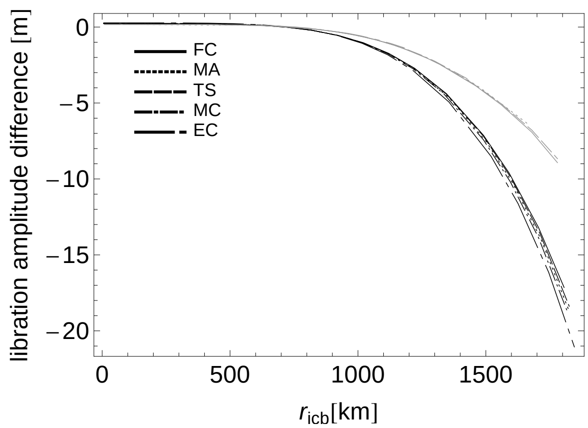


Figure 2: Difference in libration amplitude (in m) due to the inner core as a function of inner core radius for hot (gray) and cold (black) models

suming a constant density in the outer core, it can then be shown that the libration amplitude of the silicate shell of Mercury can be well approximated by

$$g_m \approx \frac{3}{2}(1-11e^2+\cdots)\frac{(B_m - A_m) + (B_{oc,t} - A_{oc,t})}{C_m},$$

where $e$ is Mercury's orbital eccentricity, $C_m$ the polar moment of inertia of the silicate shell, and $B - A$ the equatorial principal moment of inertia difference for the silicate shell (subscript $m$) and for the thin layer in the outer core between the core mantle boundary and the largest sphere in the outer core (subscript $oc, t$). We note that in the limit case of no solid innner core this equation reduces to the classical expression for the libration amplitude of Mercury [4].

The existence of an inner core decreases the libration amplitude by up to 20 m (5%) for the largest inner cores considered, which have an outer core with a thickness of only a few tens of km (Fig. 2). The effect of the inner core increases sharply with increasing inner core radius, but is below the current observational accuracy of 2 arc seconds, or about 24 m [2] even for the largest inner cores considered. With the BepiColombo mission, the accuracy on the libration amplitude is expected to be about 1 arc second or better [about 10 m, 5] and the influence of an inner core is therefore larger than the expected observational error for inner core radii larger than about 1500 km.

The existence of an inner core leads to a second free period between about 2.5 and 4.5 years and lengthens the classical eigenperiod to between about 10-18 years. The period lenthening increases with increasing inner core radius by up to more than 25%. Because of this large effect, a future determination of this free libration period would hold the potential of yielding important information on the inner core of Mercury.

## Acknowledgments

This work was financially supported by the European Space Agency in collaboration with the Belgian Federal Science Policy Office.

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