EPSC Abstracts
Vol. 7 EPSC2012-724 2012
European Planetary Science Congress 2012

The effect of a liquid layer and tides on the longitudinal libration of Mercury and of large icy satellites

T. Van Hoolst
Royal Observatory of Belgium, Brussels, Belgium (tim.vanhoolst@oma.be)

Abstract

The gravitational forcing from a central primary body not only induces tides in secondary bodies in spin-orbit resonance around the primary but also small periodic variations in the rotation rate, or forced longitudinal librations. In view of the recent observations of these librations and of the low-degree gravitational field for Mercury, we study the effect of tides and the existence of a solid inner core on the librations of Mercury, which is in a 3:2 spin-orbit resonance. We also theoretically estimate the amplitude of longitudinal librations of Titan and the Galilean satellites, satellites for which accurate rotation data is already available thanks to the Cassini mission or will be measured in the future by the JUICE mission to the Jupiter system, recently selected as the first L-class mission of the cosmic vision program of ESA. We show that observations of rotation data can yield important information on the interior structure.

1 Longitudinal librations

Longitudinal librations represent variations in the rotation rate around the equilibrium rotation. The main libration signal for Mercury and synchronously rotating satellites has a period equal to the orbital period and an amplitude which depends on the non-spherically symmetric shape and on the polar moment of inertia.

For Mercury, it was realized by Peale [2] that observation of the main libration at 88 day would allow determining whether at least the outer part of the core of Mercury is liquid, because that libration is about a factor of two larger for a liquid core than for a solid core. Margot et al. [1], using Earth-based radar observations to estimate the librations, demonstrated that the core is indeed at least 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 [3] and inertial coupling [5] 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 [3], 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 ([3], [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 [6]. We also study the amplitude of longitudinal librations of Titan and the Galilean satellites.

2 Results

Tides reduce the libration amplitude of Mercury by only 1 to 2 m, which is below the (future) observational precision expected to be about 10 m or somewhat smaller [4]. This small effect well below 1% of the total libration amplitude can easily be understood by the fact that the amplitude of periodic tides (of the order of 2 m, [8], [6]) is more than two orders of magnitude smaller than the difference in the two principal equatorial radii (about 1.5 km, [7]).

The effect of an inner core on Mercury's 88 day libration amplitude is also below the observational precision for small inner cores, but could be observed if Mercury's inner core is larger than at least 1000 km and preferably above 1500 km. Since a large inner core in Mercury can currently not be excluded, interpretations of Mercury's libration observations in terms of Mercury's interior structure should take the effect of an inner core into account. Although Mercury's 88 day libration mainly informs on the mantle polar moment of inertia, and therefore on the core size, it also holds the potential of yielding information on the inner core.

In contrast to Mercury, tides can strongly reduce the libration amplitude of large icy satellites. The libration amplitude decresases with increasing thickness of the ice shell and increases sharply for thin shells as a result of a resonance with a free mode. Compared to a solid satellite, the libration amplitude for satellites with a subsurface ocean is about an order of magnitude larger. As a consequence, libration observations can be used to determine the existence of a subsurface ocean and to constrain the thickness of the ice shell, provided that the libration amplitude can be measured with sufficient precision. With an orbiter mission to icy satellites such as with the JUICE mission, recently selected by ESA, for the Galilean satellites, a precision on the order of several meters is expected, which is sufficient to constrain the interior structure.

References

[1] Margot, J.-L., Peale, S.J., Jurgens, R.F.,. Slade, M.A., Holin, I.V., 2007. Nature 317, 710-714

[2] Peale, S.J., 1976. Nature 262, 765-766

[3] Peale, S.J., Phillips, R.J., Solomon, S.C., Smith, D.E., Zuber, M.T., 2002. Meteoritics and Planetary Science 37, 1269-1283

[4] Pfyffer G., Van Hoolst T., Dehant V., 2011. Planetary and Space Science 59, 848-861, 2011

[5] Rambaux, N., Van Hoolst, T., Dehant, V., Bois, E., 2007. Astronomy and Astrophysics 468, 711-719

[6] Rivoldini, A., Van Hoolst, T., Verhoeven, O., 2009. Icarus 201, 12-30

[7] Smith D.E., and 16 co-authors, 2010. Icarus 209, 247-255

[8] Van Hoolst T., Jacobs C., 2003. J. Geophys. Res. Research 108(E11), 5121, doi:10.1029/2003JE002126

[9] Van Hoolst T., Rambaux N., Karatekin Ö., Baland R.-M., 2009. Icarus 200, 256-264

[10] Veasey, M., Dumberry, M., 2011. Icarus 214, 265-274