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The effect of tides on the longitudinal libration of Ganymede

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Abstract

The gravitational force exerted by Jupiter deforms Ganymede (tides) and periodically changes its rotation (librations). Tides and librations are usually studied separately but we here show that tides can substantially reduce the libration amplitude of Ganymede. Periodic tides affect libration in three ways: first the periodic tidal bulges modify the gravitational torque exerted by Jupiter, second the gravitational and pressure torques between the different internal layers of Ganymede are both quantitatively and qualitatively altered, and third the zonal tides periodically change the polar moment of the satellite, which acts as the inertia for rotational motion. Here we report on a new analytical method developed to study these elastic effects on the longitudinal librations of icy satellites and present numerical results for Ganymede.

1 Introduction

Longitudinal librations of Ganymede represent variations in the rotation rate around the equilibrium rotation. The main libration signal has a period equal to the orbital period of 7.15 days and an amplitude which depends on the non-spherically symmetric shape of Ganymede and the orbital eccentricity. The librations are due to the gravitational torque of the central planet on the aspherical satellite.

2 Solid Ganymede

Libration amplitudes are usually calculated by assuming that the satellites react rigidly to the gravitational torque. The corresponding amplitude for Ganymede, expressed as a shift at the surface of the orientation of the long axis with respect to that for the mean rotation rate, is 10.1 m [1, 2].

When tidal deformation is included, the libration amplitude g can be expressed approximately as

$$g_{\text{solid}} = -6\left(1 - \frac{5}{6}\frac{k_2}{k_f}\right)\frac{B-A}{C}e \qquad (1)$$

where A, B, and C are the principal moments of inertia of Ganymede, e is the orbital eccentricity, k_2 is the degree-two gravitational tidal Love number and k_f the fluid Love number. It follows that tidal deformation reduces the the amplitude of libration by a factor $\left(1 - \frac{5}{6}\frac{k_2}{k_f}\right)$ with respect to the classical amplitude for a rigid solid satellite. The torque on the periodic tidal bulges is responsible for a reduction in the amplitude by a factor $(k_f - k_2)/k_f$. The increasing effect of the changes in polar moment of inertia due to zonal tides on the libration amplitude is a factor 6 times smaller than the effect of the torque on the periodic tides. For an entirely solid Ganymede but deformed by periodic tides ($k_f = 0.80$, $k_2 = 0.067$, [3]) the libration amplitude is 9.4 m at the equator, which is 6.9% smaller than the rigid amplitude.

3 Ganymede with a subsurface ocean

For Ganymede, as for Europa and Callisto, an induced magnetic field has been observed by the Galileo mission at the synodic rotation period of Jupiter. Although Ganymede also has a not well-known intrinsic magnetic field of probable dynamo origin, the best explanation for these observations is that Ganymede has a salinic ocean beneath an ice shell [4]. We have shown before that a deep liquid core has a negligible effect on the libration of the ice shell when considering rigid solid layers [2], and here only consider the effect of a subsurface ocean.

Like the surface, interfaces between solid and liquid layers are flattened due to rotation and static tides. The interfaces are then triaxial ellipsoids (Fig. 1), with the longest axis approximately in the direction to the central planet. In addition, the periodic tides raise tidal bulges on each layer and constitute additional deviations of the shape of the layers from a spherically symmetric shape. Because of these non-spherically symmetric static and periodic mass distribution of the internal layers (Fig. 1), the central planet exerts a gravitational torque on each layer forcing a libration of these layers, with in general different amplitudes. As for an entirely solid satellite, these torques can be expressed in terms of fluid and dynamic potential Love numbers.

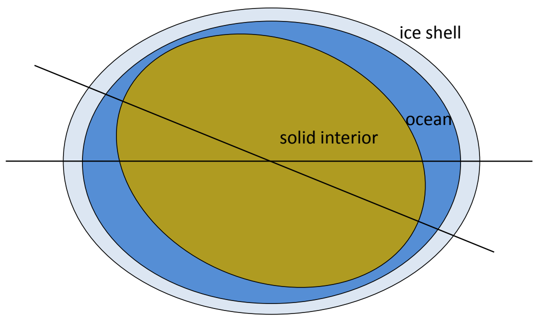

Figure 1: Schematic representation of the different orientations of the internal regions

Besides the torques associated with the central planet, also torques between layers have to be considered. Since the static tidal bulges of layers can be oriented differently when the layers rotate differently, an interlayer gravitational torque will arise [5, 6, 7]. In addition, a gravitational torque will exist between the static tidal bulge of a layer and the periodic tidal bulge of another layer and also a torque between the periodic tidal bulges of different layers because all these tidal bulges can be oriented differently. Because the periodic tidal bulges are small compared to the static bulge, the torques between periodic tidal bulges can be neglected and we only retain the gravitational torques between the periodic librational tidal bulge of a layer and the static tidal bulge of another layer. We also include pressure torques related to the gravitational torques.

4 Results

Because of the large periodic tidal deformation of the shell, the total torque of the central planet on the ice shell is strongly reduced with respect to the torque on a rigid shell. Moreover, the periodic forcing of the static interior bulge on the periodic tidal bulge further strongly reduces the total torque on the shell. As a result, the libration amplitude of Ganymede is essentially independent of the thickness of the icy shell, in contrast to previous results for a rigid shell and has a value close to the value for an entirely solid Ganymede. [8] already mentioned this property of libration of ice shells of synchronously rotating satellites by assuming that the satellites are entirely liquid underneath their shell.

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