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Polar motion of icy satellites in synchronous rotation

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Abstract

We study the influence of the presence of a global subsurface ocean on the polar motion of large icy satellites such as Europa, Callisto and Titan.

1. Introduction

Due to the presence of a global subsurface ocean under the ice shell of icy satellites such as Europa, Callisto, Ganymede and Titan, the rotation of the ice shell can differ from the rotation of the interior of these satellites, leading to additional torques between the different layers. For instance, the influence of the global subsurface ocean on the librations of icy satellites has already been studied (e.g. [1]-[5]). We here study the impact of the presence of a subsurface ocean on the polar motion of large icy satellites.

2. Polar motion

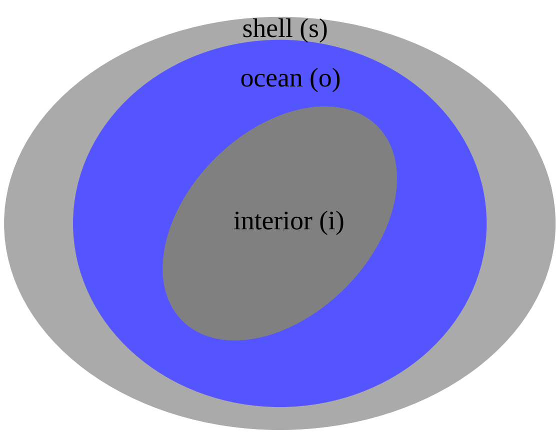

Figure 1: Schematic representation of the different orientations of the interior and the ice shell in the presence of a global subsurface ocean (not to scale).

We assume that the different homogeneous internal layers of icy satellites are flattened due to their rotation and to the tides. The interfaces between two adjacent layers are considered as triaxial ellipsoids with their longest axis approximately in the direction to the central planet. With the presence of a subsurface ocean, the rotational variations of the different internal layers of an icy satellite are not equal but coupled through various torques. The rotation of the interior of Europa, Callisto and Titan can then differ from the rotation of the ice shell of these satellites.

The angular momentum $\mathbf{L}$ of the j-th layer (interior i or ice shell s) is given in the body frame (BF) of this layer by the Euler-Liouville equations

$$\frac{d\mathbf{L}_j}{dt} + \boldsymbol{\omega}_j \times \mathbf{L}_j = \boldsymbol{\Gamma}_j \quad (1)$$

where $\boldsymbol{\omega}_j$ is the rotational vector axis and $\boldsymbol{\Gamma}_j$ the total torque exerted on the j-th layer. In the the body frame of the satellite with equatorial axes x and y and polar axis z, the rotational vector axis $\boldsymbol{\omega}$ is written as $(\omega_x, \omega_y, \omega_z)$ where (ω_x, ω_y) expresses the polar motion or wobble.

The z-component of Eq. (1) gives the longitudinal libration that has already been studied (e.g. [1]-[5]). The polar motion of icy satellite can be extracted from the x and y components of Eq. (1).

The total torque $\boldsymbol{\Gamma}_j$ acting on any layer j is the sum of the pressure and gravitational torques. The electromagnetic and viscous torques are neglected here as Europa, Callisto or Titan do not harbor a global magnetic field and due to the large timescale of viscosity effects in comparison with the timescale of the polar motion [1].

The gravitational torque can be divided into the external torque due to the central planet and the internal torques between the different internal layers. The effect of the tides on both torques are included and we also compute the additional torques due to the misalignment of the static/periodic tidal bulges of the different layer. These additional torques cannot be neglected as they have shown to have a large impact on the libration amplitude (see [2] and [5]).

By expressing these different torques into the Euler-Liouville equation for the different layers (expressed in the BF of the shell), we can find both the libration (z-component of the Euler-Liouville equation) and the polar motion (x and y components).

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