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Slichter mode of large icy satellites

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Abstract

We study the translational oscillation modes of the interior of large icy satellites such as Titan, Europa, Callisto and Ganymede. The observation of these modes could allow constraining the interior structure of icy satellites and in particular the ocean thickness.

1. Introduction

The presence of an ocean below the ice shell of icy satellites such as Europa, Callisto, Ganymede or Titan allow translational oscillation of the interior of these satellites with respect to the ice shell, similarly to the translational oscillation of the inner core of the Earth called the Slichter modes of the Earth (Slichter, 1961). Due to the large interior of the icy satellites and the thin shell thickness, the amplitude of the vibrational modes of icy satellites should be more easily detectable than for the Earth.

2. Interior models of large icy satellites

We consider icy satellites as spherical bodies consisting of a finite number of homogeneous and spherical layers. We construct interior models of icy satellites satisfying the observed mass, radius and moment of inertia using the following random process. The number of layers N of the interior structure of the body is first defined and radius R_k and density ρ_k of each layer is chosen randomly in a certain range of possible values taking into account the composition of the layer considered. The mean density and mean moment of inertia of all the models are then calculated and the models retained are those for which the mean density and mean moment of inertia fall within the error range of the observed values. Using this methodology, we construct a set of four-layer (core, rock or ice mantle, ocean and ice shell) models of Europa, Callisto and Titan and of six-layer (solid core, fluid core, rock and ice mantle, ocean and ice shell) models of Ganymede.

3. Slichter mode period

Using the equation of conservation of momentum of an icy satellite divided into four internal layers and Newton's second law for the interior of these satellites (methodology of Grinfeld and Wisdom (2005) generalized for a body with more than three layers by Coyette et al. (2012)), we obtain the following Slichter mode frequency (Escapa and Fukushima, 2011)

$$\omega^2 = \frac{\frac{4\pi}{3} G\rho_o \left(1 - \frac{\rho_o}{\rho_i}\right)}{1 + \frac{1}{2}\frac{\rho_o}{\rho_i} + \frac{3}{2}\frac{M_i}{M_o}\left(\frac{\rho_o}{\rho_i}\right)^2 - \frac{M_i}{M}\left(1 - \frac{\rho_o}{\rho_i}\right)^2} \quad (1)$$

where ρ_o is the ocean density, ρ_i the interior density, M_o the ocean mass, M_i the mass of the interior and M the total mass of the icy satellite considered.

The Slichter mode periods range from a few hours to a few tens of hours, depending mainly on the ocean thickness. The periods lengthen with decreasing ocean thickness and tend to infinity for small ocean thicknesses as no more oscillations are then possible. For the same ocean thickness, the Slichter mode period slightly decreases with increasing density contrast between the interior and the ocean.

As the Slichter mode periods strongly depends on the ocean thickness, observation of the Slichter mode period would allow constraining the thickness of the ocean. This is especially true for thin oceans where a precision of one hour on the determination of the period would result in an error on the ocean thickness of about 5 km for Europa, 15 km for Callisto and 25 km for Titan.

Ganymede is thought to have two global fluid layers, the outer iron core and the subsurface ocean. It can therefore have two translational oscillations: the translational motion of the inner core with respect to the mantle and the translational motion of the mantle with respect to the ice shell. Using the equation of conservation of momentum of the whole satellite and Newton's second laws for the solid core and the solid mantle, we obtain two Slichter mode frequencies.

The period of oscillation of the mantle with respect to the ocean again strongly depends on the ocean thickness. Observation of the Slichter mode period would therefore allow constraining the thickness of the ocean. A precision of one hour on the determination of the period would result in an error on the ocean thickness of about 50 km.

4. Summary and Conclusions

In order to study the Slichter modes of large icy satellites, we have developed models of the interior structure of icy satellites such as Europa, Callisto, Ganymede and Titan. The Slichter mode periods obtained ranges from a few hours to a few tens of hours depending mainly on the subsurface ocean thickness. Observation of the Slichter modes would therefore allow constraining the thickness of the subsurface ocean.

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