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Tidal Deformation of Ganymede

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Abstract

To measure the tidal deformation of the icy surface of Ganymede is a means to indirectly infer the presence of a subsurface ocean. In combination with other measurements, simple characteristics, e.g. the thickness or depth of an ocean may be derived. For Ganymede tidal amplitudes are of the order of a few meters if an ocean is present. Based on modelling of the periodic deformation the implications for such measurements from orbit and at the surface itself are discussed.

Introduction

Ganymede –the largest of the Galilean Moons– orbits Jupiter with a period of T=7.15 days at a mean distance of about $a=15R_J$. Its orbit is elliptic with a free eccentricity of e_{free}=0.0015. In addition to that there is a forced contribution of e_{forced}=0.0006 due to the 2:1 resonance with Europa. Its orbit is almost equatorial with sin I= 0.0034, where I is the (free) inclination, referred to Jupiter's equator [1]. Whereas the inclination is negligible to first order the small but finite values of eccentricity are important for the tidal deformation of the satellite. In spite of the 1:1 spin-orbit coupling, tidal interaction with Jupiter is still occurring at present on a detectable level because of the orbital eccentricity e. Geometric librations are caused by the discrepancy between orbital angular velocity and spin rate. Whereas the former varies along the orbit, according to Kepler II (faster at perijove, slower at apojove) the latter remains constant to first order.[1] The Jupiter-facing side of Ganymede is thus librating about the sub-jovian point with an amplitude of 2e and a period of T [e.g., 2]. Hence, the direction to Jupiter varies slightly and causes a periodic forcing on a 7.15 day cycle (librational tides). Furthermore, the distance to Jupiter is varying with the same frequency because of the elliptical orbit (radial tides). In response to both these contributions Ganymede is deformed periodically. The presence of a liquid layer underneath the outermost ice-shell enhances the tidal amplitudes at the surface significantly. The latter are thus a means to indirectly detect Ganymede's subsurface ocean [3]. Such a method would be complementary to other indirect evidence, e.g. from the induced magnetic signals [4].

[1] Due to physical librations (periodic variations in spin rate due to Ganymede's slightly non-spherical mass distribution) the spin is not exactly constant. However, this is not addressed here.

The Model

Interior Structure

As indicated by its small moment of inertia and by the presence of a self-sustained magnetic field presumably generated in a liquid iron core, Ganymede is believed to be highly differentiated. Typical models include an iron core, a silicate mantle, a high-pressure ice layer, a liquid water layer, and the outermost ice-I layer. Typical models that are consistent with the moment of intertia of (0.3115 +/- 0.0028) MR^2, where M and R are Ganymede's mass and radius, respectively [5] consist of an iron core, a silicate mantle and an H_2O-layer. The latter can be subdivided in HP-ice layers, a subsurface ocean and an ice-I layer.

Tidal Deformation

As the simplest Model a viscoelastic Maxwell rheology is assumed. In that case two parameters, the viscosity and the rigidity, are required to describe the deformation of ice and rock, respectively. The sensitivity of the obtained results to the choice of rheology is studied by using also alternative models including the Burgers or Caputo rheologies. These models are more general but do require 4 and 3 parameters, respectively. The tidal deformation is fully described by the complex Love numbers h_n (radial deformation), l_n

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(lateral deformation), and k_n (potential), where n is the degree up to which the potential is developed.

Measuring Tidal Deformation

The tidal deformation of Ganymede is of the order of a few meters if there is a subsurface ocean present underneath approximately 80 km of ice-I. In case of the absence of an ocean the resulting deformation is on the order of a few cm's, only. In principle there are two ways to detect the m-scale deformations: (1) Using laser altimetry from a close orbit (altitude ~ 200 km) or (2) placing instruments (camera, radio beacon, tiltmeter, strainmeter etc.) on Ganymede's surface. Implications on both these methods with respect to future missions will be discussed.

References

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