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Physical Structure and Tidal Distortion of Ganymede: Implications for the JUICE mission

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Abstract

Since the ESA-led mission JUICE (Jupiter Icy moons Explorer) has been selected for launch in 2022, Ganymede, Jupiter's largest satellite, has become of major scientific interest. Hence, we have constructed models of Ganymede's interior that satisfy the satellite's mean density and polar moment-of-inertia factor to obtain key structural parameters such as the radial displacement Love number h_2. If a global subsurface ocean is present on Ganymede, h_2 can be expected in the range of 1.16 to 1.50 governed primarily by the size of the liquid reservoir. Precise measurements of h_2 will provide constraints on the thickness and rheology of Ganymede's ice and liquid layers and help to distinguish between individual structural models. Furthermore, our modeling yields tidal amplitudes of the order of a few meters, which are measurable by the GALA (GAnymede Laser Altimeter) experiment on board of the JUICE spacecraft. We also calculated the expected amplitude patterns of diurnal tidal stresses at Ganymede's surface and find values up to 5 kPa.

1. Introduction

The largest of the Galilean satellites, Ganymede, has a bulk composition of roughly 60 % rock and 40 % ice [1]. Owing to the satellite's small moment of inertia, Ganymede is believed to be highly differentiated. Furthermore, Ganymede has a self-sustained magnetic field [2,3], which is presumably generated in the satellite's liquid metallic core. Ganymede orbits Jupiter with an eccentricity of 0.0015 and an orbital period of 7.154553 days [4]. Hence, Ganymede is subject to solid body tides exerted by Jupiter on the time-scale of its orbital period. The tidal response is periodic and depends on the satellite's interior structure, thermal state, tidally effective rheology, and the frequency of tidal forcing. If a global liquid reservoir underneath Ganymede's outermost ice shell exists, tidal amplitudes at the surface are significant. Measurements of such tidally induced deformations represent an indirect detection method for the search of potential life-sustaining habitats within the solar system [5]. Furthermore, the tide-induced internal redistribution of mass results in tidal stress variations, which could play a major role for Ganymede's geological surface record.

2. Model

We subdivide Ganymede's interior into five spherically symmetric and chemically homogeneous reservoirs. Hence, our structural model includes a liquid iron alloy core, a silicate rock mantle, a high-pressure water-ice layer, a putative subsurface water-ammonia ocean, and a low-pressure water-ice crust. The phase relationships of the water-ammonia system are used to determine the sizes of the three H_2O-dominated layers, e.g., the slope towards the high-pressure ice polymorphs is evaluated from the latest data compilation according to [6]. All model calculations are required to satisfy Ganymede's mean density of 1940 km m^{-3} [1] as well as its polar moment-of-inertia factor of 0.3115 [4] as derived from Galileo measurements of the moon's low-degree gravitational field. The structural models of Ganymede's interior are then used to assess the magnitude of tide-induced stresses prevailing at the satellite's surface.

3. Results and Discussion

Figure 1 shows the calculated radial displacement Love number h_2 as a function of the subsurface ocean thickness and the crustal thickness. Since additional volatiles usually delay the solidification of a water ocean, we have included ammonia (NH_3) as a case study to better assess the effects of suchlike volatiles on the interior structure of Ganymede. Depending on the actual NH_3 concentration, subsurface oceans of up to 430 km in size and outer ice shells with thicknesses up to 185 km can be realized. While the highest values of h_2 are correlated to interior models with the most massive oceans and the smallest crustal layers, a low h_2 is indicative for a thin subsurface ocean and a large outer ice shell. Therefore, the precise determination of the radial displacement Love number h_2 is the key to pin down the size of Ganymede's subsurface ocean and its crustal thickness.

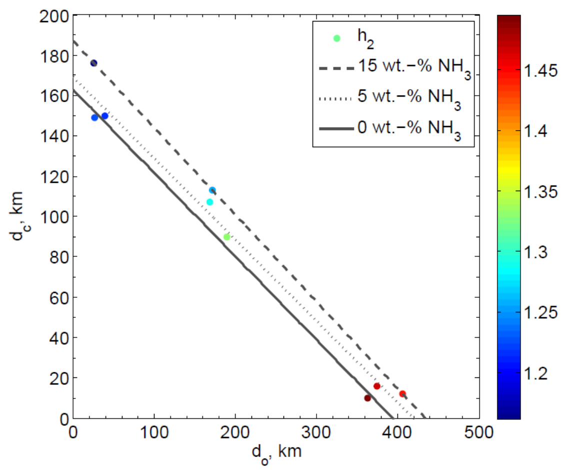

Figure 1: Radial displacement Love number h_2 as function of subsurface ocean d_o and crustal thickness d_c.

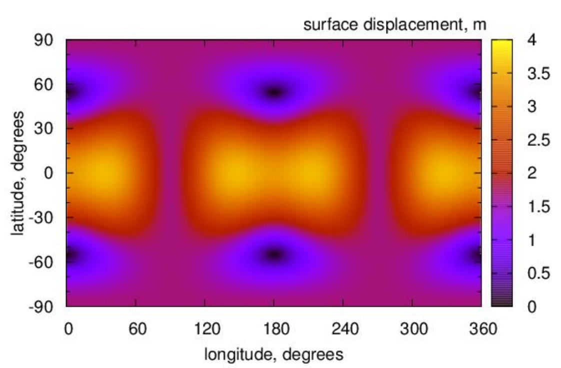

Figure 2: Global maximum pattern of surface displacement for a diurnal tidal cycle.

Figure 2 shows the expected tidal deformation pattern of Ganymede's surface. With respect to the underlying structural model, which assumes a subsurface ocean underneath the satellite's icy crust, we obtain a tidally induced displacement of up to 4 m. The GALA experiment is capable to detect that kind of periodic surface deformations from an orbit of 200 and 500 km, respectively [7]. Furthermore, we find amplitudes of diurnal tidal stresses of up to 5 kPa, significantly less than that expected for Titan [8] or Europa [9].

4. Summary and Conclusions

In the presence of a subsurface ocean on Ganymede, the radial displacement Love number h_2 can be expected in the range of 1.16 to 1.50 governed primarily by the size of the liquid reservoir. It appears that the thickness of the outermost shell and the radial extent of a subsurface ocean are strongly correlated with each other. Key information on Ganymede's interior can be gained by monitoring its tidally induced surface deformations from an orbiting spacecraft such as the forthcoming JUICE mission.

Acknowledgements

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