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Tidal Signatures of Geochemically Rigorous Interior Structure for Ganymede

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Abstract

We assess the tidal (both gravimetric and altimetric) properties k_2, h_2, and Q, corresponding to plausible formation and evolution of Ganymede, for the range of C/MR^2 permitted by *Galileo* radio science results. We base our calculations on interior structures linked to likely chondritic materials. We track the partitioning of Fe, S, and H_2O between an iron core, rocky layer, and overlying hydrosphere.

1. Introduction

The interior of Ganymede is differentiated and includes multiple distinct rheological layers, each thicker than ~50 km: ice Ih, a salty ocean, ices V and VI, a rocky interior, a liquid iron core, and possibly a solid inner core. The composition and configuration of the many different layers in Ganymede's interior will determine the details of the tidal response. Recent progress in material thermodynamics and computational speed has enabled the easy calculation of detailed self-consistent interior structure properties, and the corresponding tidal responses [1].

Here, we describe detailed structural models for Ganymede that build on our prior investigations [1]. We use these models to explore the variation in tidal response with in the permitted by the range of C/MR^2 inferred from *Galileo* radio science data.

2. Methods

We use compute the thermodynamic properties of Ganymede's many layers using the PlanetProfile software [1]. Boundary conditions of present-day radius, bulk modulus, mean surface temperature, and ice Ih bottom melting temperature are supplied. The thickness of the ice Ih prescribes the heat flow. We apply parameterized solid-state convection in the ice Ih. The ocean is convective and follows an adiabatic temperature profile prescribed by the compressibility, density, and heat capacity of the fluid. The underlying ice V and VI follow the melting curves, approximating two-phase convection consistent with the cold upper thermal boundary layer [2,3]. Bulk densities of the rocky region and iron core are iteratively tuned to match model predictions. Thermodynamics of the ice and ocean are from Vance et al. [1]. Here we consider a representative ocean composition of 10 Wt% $MgSO_4$, acknowledging that alternative compositions containing NaCl or the addition of ammonia would lower temperature of the ocean and would also lead to less ice for a given heat flux. The main objectives is to test, for a fixed ocean composition, how tidal signals are sensitive to the rocky interior composition and structure, in particular the partitioning of iron and sulphur between the rock mantle ant the iron core.

CM chondrites are hypothesized to have accumulated at early Jupiter due to a radial pressure maximum early solar nebula. We thus assume a CM composition for Ganymede. We compute the mineral properties of the rocky interior and solid iron core using Perple_X [4], assuming all of the core Fe and S are endogenous. We consider core S content from 0-20 Wt%. Geothermal profiles are computed for ice Ih thicknesses in the range of 55-125 km, corresponding to internal heating of 1-2 TW (15-25 mW m^{-2}). Fluids generated in the rocky portion are removed into the ocean. The predicted radial structure properties include bulk and shear moduli. These are used to compute the tidal response.

The tidal Love number k_2 describes the gravitational potential perturbation at the surface, while h_2 describes the amplitude of the radial surface displacement. They can be obtained from gravity field measurements and laser altimetry, respectively, by the ESA JUICE mission for Ganymede [5]. We calculate both k_2 and h_2 for different interior structural models to quantify their tidal responses. From the profiles of density, elasticity (shear and bulk modulus), and viscosity structure determined for Ganymede, we compute the viscoelastic response of the interior to tidal forcing assuming an Andrade rheology and using the numerical methods of Tobie et al. [1,6]. The dissipative part is represented by the imaginary part of the Love number k_2, or by the dissipation function, Q^{-1}, which corresponds to the ratio between the imaginary part and the modulus of k_2.

3. Results

Figure 1 shows computed values of the tidal Love numbers k_2, h_2, the quantity $1+k_2-h_2$ that is mostly sensitive to the ice thickness, and the dissipation factor Q, at the lower, mean, and upper values of the gravitational moment of inertia C/MR^2 permitted by *Galileo* gravity results {0.3087, 0.3115, 0.3143}. Corresponding solid iron core sizes are ~{550,450,350} km. Love numbers k_2 and h_2 vary with ice thickness and ocean salinity. They vary less with C/MR^2, but show sensitivity to core S content inversely proportional to C/MR^2. The size and composition of the core have little effect on the inferred dissipation Q or ice thickness factor $1+k_2-h_2$; the composition of the ocean also has little effect on these quantities.

Ice shell thicknesses inferred from the tidal Love numbers k_2 and h_2 and the quantity $1+k_2-h_2$, together with CM/R$_2$ can be used to put constraints on the interior composition, in particular ocean density (related to salt content) and iron core size (related to S content). The interpretation remains ambiguous, however, due to the combined effects of ocean composition and iron core composition. This ambiguity can be reduced by constraining the ocean thickness and composition from magnetic induction and surface composition.

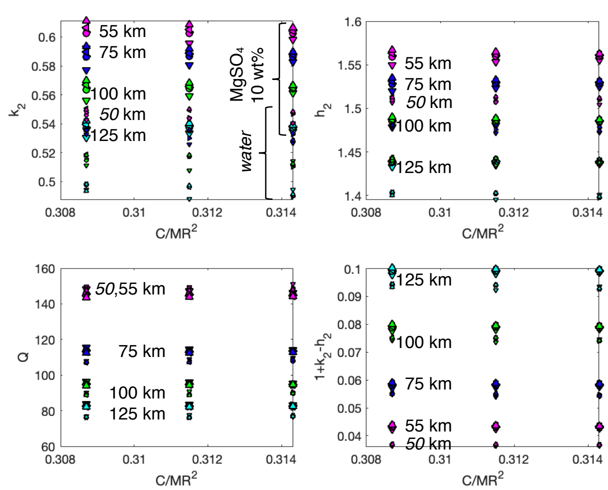

Figure 1. Computed values of tidal Love numbers k_2, h_2, $1+k_2-h_2$, and Q *vs* C/MR^2. Shapes indicate the core S from 0 (▼) to 20wt% (▲). Clustered symbols correspond to different ice thicknesses. Small symbols are for pure water oceans; larger symbols are for oceans with 10wt% $MgSO_4$.

4. Summary and Conclusions

The present work sets the stage for more comprehensive models of Ganymede's composition and resulting geophysical state. This ongoing work includes the assessment of the fate of volatiles and aqueous species extracted from Ganymede's interior, and the influence of a liquid outer iron core.

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