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Dynamical tides in icy satellites with subsurface oceans

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1. Abstract

Subsurface oceans are a generic feature of large icy bodies, if not now, then at some point in their past evolution. Various datasets already point to the existence of oceans within Europa, Ganymede, Callisto, Titan, Enceladus, and Mimas, while other bodies like Ceres, Pluto, and Triton await their turn. Subsurface oceans partially decouple the crust and thus greatly enhance tidal effect, unless the crust is very thick and hard. Dynamical effects are usually neglected when computing tidal deformations of solid bodies. It is well known, however, that various oscillation modes have a major impact on tidal dissipation within shallow surface oceans [1]. We show here that the dynamical Love numbers of a non-rotating body exhibit a simple resonant behavior if the ocean is very shallow. We also examine how the resonance is affected by rotation.

2. Methods

As long as there is spherical symmetry, tidal effects can be formulated in terms of four scalars: the tidal potential and three Love numbers depending on the internal structure (density and rheology). Dynamical tides in a non-rotating body can thus be studied with Love numbers which are computed by solving the standard viscoelastic-gravitational equations used in seismic and normal modes analysis. At tidal frequencies, it is a very good approximation to neglect dynamical terms within solid layers while keeping them in the fluid layers. The problem is further simplified by considering an incompressible ocean, in which case either the membrane approach or the propagation matrix method is applicable [2].

Rotation breaks spherical symmetry by introducing Coriolis forces in the viscoelastic-gravitational equations. In that case, all tidal degrees are coupled and the three usual Love numbers do not completely parameterize tidal deformations. We will use numerical codes developed for Earth tides in order to estimate the effect of rotation on the resonance [3].

3. Results

The effect of the crust on dynamical tides is most easily studied with the membrane approach which sums up the rheology of the crust into two effective viscoelastic parameters [2]. The essential physics of the problem are captured by a three-layer model made of an infinitely rigid mantle, an incompressible and homogeneous ocean, and an incompressible crust having the same density as the ocean. In this model, the radial Love number is given by

$$h_2 = \frac{h_2^\circ}{1 + (\Lambda + \Lambda_\omega)\, h_2^\circ}\,, \tag{1}$$

where $h_2^\circ = 5/(5-3\xi)$ is the fluid-crust Love number, $\xi = \rho/\rho_b$ being the ocean-to-bulk density ratio. Λ and Λ_ω are the membrane spring constant (complex) and the dynamical correction (real and negative), which are proportional to the effective shear modulus $\bar{\mu}$ and to the squared tidal frequency ω^2, respectively.

Resonance occurs if the ocean thickness is close to

$$D \sim \frac{\omega^2 R^2}{6g} \left(1 - \frac{3}{5}\,\xi + Re(\Lambda)\right)^{-1}, \tag{2}$$

which is about 160 m for Europa if the crust is thin (so that Λ is negligible). Fig. 1 shows the effect of the res-

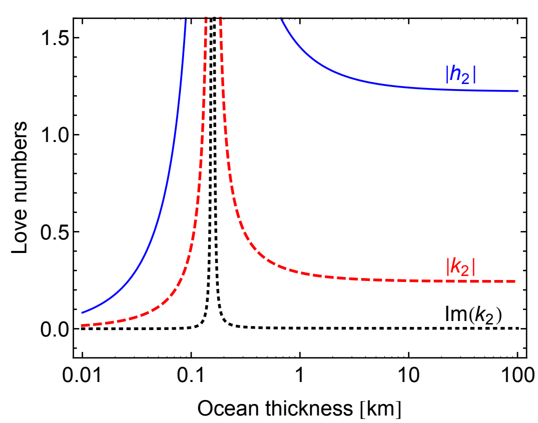

Figure 1: Love numbers of Europa in function of ocean thickness. The crust thickness is small (10 km).

onance on the Love numbers of Europa; $\mathrm{Im}(k_2)$ quantifies tidal dissipation within the crust. The resonance is not only important for very shallow oceans: it significantly decreases the tilt factor $\gamma_2 = 1 + k_2 - h_2$ if the ocean thickness is less than 20 km and may thus lead to underestimating the crust thickness deduced from combined measurements of k_2 and h_2 [4]. If the crust can be neglected ($|\Lambda| \ll 1$), the resonance corresponds to the free oscillation of a surface ocean, or surface gravity mode [5].

For small bodies like Enceladus (assuming a global ocean), the viscoelastic crust has a significant impact, since $|\Lambda| \gg 1$, on the resonant ocean thickness and on the damping of the resonance. We expect that including rotation will displace the resonance and introduce new resonant modes.

Acknowledgements

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References

[1] Tyler, R. (2008), Nature 456, 770.

[2] Beuthe, M. (2015), arXiv:1504.04574v1.

[3] Wahr, J.M. (1981), GJRAS 64, 677.

[4] Wahr, J.M. et al (2006), JGR 111, E12005.

[5] Lamb, H. (1932), Hydrodynamics, 6th ed.