Gravity constraints on the interior structure of Europa

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We assess the gravity constraints on the interior structure of Europa in anticipation of the Europa Clipper mission.

Moore and Schubert (2000) illustrated that the diurnal tide amplitude, quantified by the diurnal (tidal) Love numbers, \( k_2^d \) and \( h_2^d \), can be used to determine the presence of a subsurface liquid ocean due to the significant increase in tidal amplitudes associated with the mechanical decoupling of the shell with a subsurface ocean. However, they considered a limited range of possible interior parameters except the ice shell rigidity, which was assumed to be in the range of 1-10 GPa. We consider a wider range of possible interior structure parameters and a more realistic ice shell rigidity range of 1-4 GPa. Inferring the presence of a subsurface ocean is slightly easier than previously thought (Verma & Margot 2018), with required absolute precisions of 0.08 for \( k_2^d \), and 0.44 for \( h_2^d \).

Previous work have considered diurnal (tidal) gravity constraints alone or static gravity constraints alone using a forward modeling approach (e.g. Anderson et al., 1998; Moore and Schubert, 2000; Wahr et al., 2006). We evaluate constraints on interior structure parameters using Bayesian inversion with the mass, static gravity, and diurnal gravity as constraints, allowing a probabilistic view of Europa’s interior structure. Given the same relative uncertainties, the static Love numbers provide stronger constraints on the interior structure relative to those from the mean moment of inertia (MOI). Additionally, the static Love numbers can be inferred directly from the static gravity field whereas inferring the MOI requires the Radau-Darwin approximation.

Jointly considered with the static shape, the static gravity field can constrain the average and long-wavelength thickness of the shell. For an isostatically compensated shell, it is usual to conceptualize the crust as a series of independently floating columns of equal cross-sectional area which, by application of Archimedes' principle, should have equal mass above the depth of compensation. However, this approach is unphysical in the presence of curvature and self-gravitation. We consider alternative prescriptions of Airy isostasy: the equal-pressure prescription (Hemingway and Matsuyama, 2017), and the minimum-stress prescription (Dahlen 1982; Beuthe et al., 2016; Trinh et al., 2019). The gravitational coefficients are more sensitive to shell thickness than would be expected from the classical (equal-mass) approach, illustrating that the equal-mass prescription can lead to large errors in the inferred average shell thickness and its lateral variations.
Diurnal gravity data alone can only constrain the product of the shell rigidity and thickness (Moore and Schubert, 2000; Wahr et al., 2006). An additional observational constraint that is sensitive to these parameters is the libration amplitude, which can be obtained from direct imaging or from altimeter data. We show that a joint gravity and libration analysis is able to separately constrain the shell thickness and rigidity.