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Tidal deformation of Ganymede and effects of a subsurface ocean: a model calculation in preparation for JUICE

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One of major objectives of the JUICE (JUpiter Icy moons Explorer) mission is to characterize the extent of subsurface oceans of the moons, in particular Ganymede, and GALA (GAnymede Laser Altimeter) is planned to detect and monitor tidal deformation, which is sensitive to the interior structure. A previous study indicates that the viscosity of the icy shell is the major controlling factor of the amplitude of tidal deformation [Moore and Schubert, *Icarus*, 2003]. This result, however, is based on simple calculation results assuming a shell with uniform viscosity. For a conductive shell, the actual viscosity will depend strongly on depth; the viscosity is very high at a shallow depth and is low at the base of the shell; such a large variation in viscosity should affect tidal deformation. Thus, a detailed investigation for tidal deformation of Ganymede in light of a depth-dependent viscosity is necessary prior to the JUICE mission. In this study, we investigate the amplitude and the phase lag of tidal deformation of Ganymede assuming a depth-dependent viscosity shell model.

Preliminary results assuming a constant temperature gradient and an Arrhenius-type rheology suggest that the main control on tidal deformation is not reference viscosity (i.e., viscosity at the melting temperature) but is rigidity if the subsurface ocean is thick (>10 km). For a conductive shell the fluid limit of tidal deformation is unlikely to be achieved even if the reference viscosity is extremely low (i.e., 10^{10} Pa s) because of the high viscosity near the surface. The thickness of the ocean is found to be a minor control as long as a subsurface ocean exists. The phase lag can be up to several degrees, though the range of its variation for a depth-dependent viscosity model is much smaller than that for a uniform model. These results indicate that the presence of a high-viscosity near-surface layer, which has been ignored previously, has a large effect on tidal deformation on Ganymede.

On the other hand, if a subsurface ocean does not exist, the major control on tidal deformation is the viscosity of a high-pressure (HP) ice layer; the near-surface layer plays a minor role in contrast to a thick ocean case. If a HP ice layer has an extremely low viscosity (~10^{12} Pa s), such a layer behaves as fluid, leading to amplitude and phase lag similar to those for a thick ocean case. If a HP ice layer has a moderate or high viscosity, the tidal Love number h_2 would be <0.5, which is much smaller than that for a thick ocean case (i.e., $h_2 >1$). GALA measurements should distinguish such a difference in tidal amplitude.
Keywords: Tidal deformation, Ganymede, Subsurface ocean, JUICE, GALA