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Dissipation in the deep interiors of Ganymede and Europa

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Jupiter's satellites are subject to strong tidal forces which result in variations of the gravitational potential and deformations of the satellites' surfaces on the diurnal tidal cycle. Tidal flexing in the deep interiors can be a significant heat source for the satellites' thermal-orbital evolution. Whereas typical structure models of Europa consist of a core, a silicate mantle, an ocean and an outer ice-I shell [1], pressures inside Ganymede are sufficient for high-pressure ice phases to occur between the silicate mantle and the ocean [2]. With current data it is unknown whether the deep interiors (i.e. Europa's silicate shell and Ganymede's silicate mantle and/or high-pressure ice layer) are dissipative. Other possibilities would be that the dissipation rates are in general very low (unlikely at least for Europa due to recent observations) or that dissipative processes are mainly occurring in the ice-I shell and/or ocean. Thus, for evaluations of the heating state of these satellites, it is important to measure the magnitude of the interior dissipation. However, observation of the interior layers such as high-pressure ice layers is more challenging than that of the surface ice-I layer. Here we suggest a method to constrain the dissipation states of the deep interiors of Ganymede and Europa by altimetry and gravity measurements from an orbiting or multi-flyby spacecraft.
Tidal variations are generally described by the Love numbers k2 and h2 for the tide-induced potential variation due to internal mass redistribution and the radial surface displacement, respectively. The phase-lags of these complex numbers contain information about the rheological and dissipative states of the satellites. For the satellites we assume a decoupling of the outer ice-shell from the deep interior by a liquid subsurface water ocean. We show that, in this case, the phase-lag difference between the lags of k2 and h2 can provide information on the rheological and thermal state of the deep interiors if the viscosities of the deeper layers are small (the phase-lag difference is almost independent of the dissipation in the surface layer). In case of Ganymede, phase-lag differences can reach values of a few degrees for high-pressure ice viscosities of 1e13-1e14 Pa s (around the lower boundary at its melting temperature) and would indicate a highly dissipative state of the deep interior. In this case, in contrast to the phase lags itself, the phase-lag difference is dominated by dissipation in the high-pressure ice layer rather than dissipation within the ice-I shell. These phase lags would be detectable from spacecraft in orbit around the satellite [3]. For Europa the phase-lag difference could reach values exceeding 20 deg if the silicate mantle contains melt and phase-lag measurements could help distinguish between (1) a hot dissipative (melt-containing) silicate mantle which would in thermal equilibrium correspond to a very thin outer ice-I shell and (2) a cold deep interior implying that dissipation would mainly occur in a thick (several tens of km) outer ice-I shell. These measurements are highly relevant for ESA's Jupiter Icy Moons Explorer (JUICE) and NASA's Europa Multiple Flyby Mission, both targeted for the Jupiter system.

References:
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