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Measuring Ganymede's tidal deformation by laser altimetry: application to the GALA Experiment

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Measurements of Ganymede's induced magnetic field suggest a salty water layer under the icy crust (Kivelson et al. 2002), in agreement with thermal models based on heat transfer and energy balance equations (e.g., Spohn and Schubert, 2003). Due to the small density contrast between ice-I and liquid water, interior structure models (e.g. Sohl et al. 2003) consistent with Ganymede's moment of inertia and total mass cannot constrain the ice thickness or ocean depth. In order to reduce the ambiguity of the structural models and to constrain the ice thickness, it has been proposed to measure the dynamic response of Ganymede's ice shell to tidal forces exerted by Jupiter characterized by the Love numbers h2 and k2. Similar strategies have been investigated in application to Europa (Wu 2001, Wahr 2006, Hussmann 2011). The body tide Love number h2 depends on the tidal frequency (main tidal cycle is the 7.15 days period of revolution), the internal structure, and the rheology, in particular on the presence of fluid layers, and the thickness and rigidity of an overlaying ice shell. Combined with measurements of the Love number k2, which can be inferred from radio science experiments, and a simultaneous determination of linear combinations of h2 and k2 the obtained data would significantly reduce the ambiguity in structural models (Wahr et al. 2006).
A way to determine tidal effects in Ganymede's topography and therefore the h2 value by a spacecraft in orbit is the crossover method: Different orbit tracks will intersect at certain surface locations at different times so that the tidal signal can be extracted from a differential altimetry measurement. The Ganymede Laser Altimeter GALA is one of the instruments selected for the Jupiter Icy Moon Explorer (JUICE). The GALA instrument will perform globally distributed altitude measurements from a low circular orbit. The main challenges for the determination of the tidal amplitude are Ganymede's high surface roughness and low albedo regions. Further, the spacecraft position and attitude (i.e. the instrument pointing vector) must be known with high accuracy in order to obtain high-accuracy ranging measurements with precise positional reference.
We have performed numerical simulations to assess the uncertainty of the h2 measurement. Based on the current orbit scenarios, we determine the number of crossovers available for the differential altimetry measurement. The precision of the h2 measurement is inferred from the expected mean range measurement error and the number of possible crossovers. Our model for the range measurement includes a detailed analysis of the instrument performance by taking into account Ganymede's rough small-scale topography. The model is combined with the current JUICE mission scenarios and spacecraft performance design, giving an estimation for the expected accuracy of the range measurement in Ganymede's orbit. Further, we will show that these uncertainties in the determination of h2 are sufficient to unambiguously confirm the existence or to prove the non-existence of an ocean under Ganymede's ice shell. In addition, we estimate the constraints on Ganymede's ice shell thickness as derived from the error budget of the h2 value.