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Measurements of the spin states of Europa and Ganymede

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1. Motivation

Measuring the spin states of the Galilean satellites holds the key to fundamental interior and surface properties. First, the spin state can reveal the presence of a subsurface ocean: a decoupling between the icy shell and the interior results in a different spin signature than that of a solid body. Second, the value of the obliquity combined with the known gravitational harmonics can provide a direct measurement of the polar moment of inertia, a crucial constraint on interior models. Finally, the obliquity may explain remarkable surface features, such as the distribution and shape of cycloids on Europa, and the direction of strike-slip faults.

2. Existing theoretical estimates

No reports of direct observations of the spin axis orientations of Europa and Ganymede exist in the literature. The current IAU spin orientation models use the theoretical framework developed by Lieske in 1979 [1]. Two more recent theoretical studies predict obliquities for a solid Europa of $(0.097 \pm 0.007)^\circ$ [2] and 0.055° (<10% uncertainties) [3], respectively. On the basis of estimates of the gravitational harmonic coefficients C_{21} and S_{21}, Anderson et al [4] could have placed an upper bound of $\sim$1-10° on the obliquity of Europa, but they chose not to. This may indicate a lack of confidence in the values or uncertainties of the gravity coefficients obtained on the basis of a small number of useful spacecraft flybys.

3. Existing model-based estimates

On the assumption that cycloidal lineaments and strike-slip fault patterns can be explained by tidal stresses, Rhoden et al [5, 6] compared models and observations to infer obliquity estimates for Europa of $\sim 1^\circ$. These estimates depend on assumptions regarding material properties (shear modulus, Poisson's ratio, h_2 tidal Love number) and tidal interactions. They also refer to the epoch at which the surface features were created and may not capture current conditions.

4. Direct observations

Here we present the first direct observations of the spin axis orientations of Europa and Ganymede. We use the same Earth-based radar technique that provided measurements of Mercury's obliquity at the subarcminute level, observational evidence that the core is molten, and core size estimates [7, 8]. The measurements make simultaneous use of the Goldstone Solar System Radar and the Green Bank Telescope located $\sim$3200 km away. It is the correlation of radar echoes received at these two stations that yields superb leverage on the spin state of the illuminated body. Because the Galilean satellites are further away than Mercury, and because they spin faster than Mercury, the signal-to-noise ratio of the observations is reduced by a factor of $\sim$3000. Nevertheless, the telltale correlations are clearly detected in our data. Using measurements at 13 epochs in 2011 and 4 epochs in 2012, we are able to pinpoint Europa's spin axis orientation with a precision of $\sim 0.1^\circ$, and our result is inconsistent with either one of the theoretical estimates or the model-based estimates described above. For Ganymede, we secured measurements at 3 epochs in 2011 and 2 epochs in 2012, and the larger signal-to-noise ratio results in a comparable precision for the spin axis orientation.

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