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High-precision measurements of planetary spin states: Mercury, Venus, Galilean Satellites

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1. Introduction

Profound developments in our understanding of the Earth and Moon have arisen as a direct outcome of rotation studies (e.g., [1, 2, 3, 4]). Likewise, measurements of the rotation of other bodies can provide powerful probes of planetary interior structure and processes. This talk will describe ongoing high-precison measurements of the rotation of Mercury, Venus, and the Galilean Satellites. The data are obtained by recording radar speckles at two separate stations, as advocated by Holin [5, 6].

2. Mercury

Observations of radar speckle patterns tied to the rotation of Mercury establish that the planet occupies a Cassini state with obliquity 2.11 +/- 0.1 arcminutes. The measurements show that the planet exhibits librations in longitude that are forced at the 88-day orbital period, as predicted by theory [7, 8]. The amplitude of the oscillations together with spacecraft determinations of the gravitational harmonic coefficient C_{22} indicates that the mantle of Mercury is decoupled from a core that is at least partially molten [9]. Combining the obliquity, libration amplitude, and gravity information yields the polar moment of inertia of the planet as well as an estimate of the size of the core [7, 8]. Because MESSENGER will deliver gravity coefficients with <1% errors [10], the uncertainty in the core size determination will be dominated by the precision of the spin state estimates.

If present and measurable, departures from the exact Cassini state and long-term libration signatures can inform us about core-mantle interactions.

3. Venus

Earth-based radar observations show that the spin period of Venus is not constant. The variations are compatible with percent-level changes in atmospheric angular momentum transferred to the solid planet. Monitoring these fluctuations provides important constraints on the atmospheric dynamics and climate of Venus. As on Earth a rich spectrum of secular and seasonal trends can be expected, with excitations on a wide range of timescales that are diagnostic of diverse geophysical phenomena. Securing a well-sampled time history of length-of-day variations and polar motion at Venus will reveal much about the planet closest in size and mass to Earth.

There are no data constraints on the polar moment of inertia of Venus, a fundamental quantity that can be derived by measuring the spin precession. The motion of the pole in inertial space is only 2 arcseconds/year due to the small obliquity [11]. Because the Magellan estimates of the spin orientation have uncertainties of 15-45 arcseconds [12, 13], much larger than the precision required, prospects for linking these data to modern estimates are limited. Earth-based observations spanning a decade have the potential to track the spin orientation to a few arcseconds, and to provide a measurement of the moment of inertia.

4. Europa

Measuring the spin state of Europa holds the key to fundamental interior and surface properties. The amplitude of the longitude libration is strongly dependent on the thickness and rheology of the icy shell, perhaps the most important determinants of Europa's astrobiological potential. Europa's obliquity may explain remarkable surface features, such as the distribution and shape of cycloids, and the direction of strike-slip faults. We have proposed an observing campaign with the Goldstone radar and the Green Bank Telescope to quantify the obliquity and libration, starting in Sep. 2011. We anticipate a detection of a non-zero ($>0.1°$) obliquity, and a possible detection of the longitude libration, depending on its amplitude. Because of stringent signal-to-noise and geometry requirements, there is no comparable opportunity for these measurements until 2023. If successful, we will consider similar measurements of Ganymede.

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