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Rotation of Janus and Epimetheus, and other moons of Saturn

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Janus and Epimetheus, two small satellites of Saturn, share a remarkable co-orbital configuration in that they essentially "swap" orbits every 4.00 yr. Analysis of Cassini images (Tiscareno, Thomas, and Burns 2009, Icarus; hereafter TTB09) has shown that the moons' rotational states are indeed affected by the orbit swap, which, of course, redefines the synchronous rotational state as the orbital periods change.

The moons quickly adopt a rotation at the new synchronous rate with a significant forced libration (i.e. an oscillation about the synchronous state, forced by the moons' slightly eccentric orbits, e$\sim$0.01). Forced librations become large when a moon's principal moments of inertia (A<B<C) are such that the expression (B-A)/C is close to 1/3, which causes the moon's natural libration frequency to be close to resonance with its orbital rate (which is the forcing frequency). Epimetheus' shape suggests that its inertia ratio is even closer to this resonance than is that of Hyperion, which is known to tumble chaotically, but Epimetheus is rescued from that fate by its significantly lower orbital eccentricity. Nonetheless, Cassini images demonstrate that Epimetheus has a rotational forced libration of 6 degrees, placing it in the company of Earth's Moon and Mars' Phobos as the only natural satellites for which forced rotational libration has been detected. In fact, Epimetheus' moment-of-inertia ratio (B-A)/C can be determined more precisely from its rotational libration than from its shape. Janus, which is far less prolate and thus presumably farther from the resonance, has a predicted forced libration of only 0.3 degrees, too small to empirically confirm.

The changing orbital rate must also give rise to a rotational free libration (i.e. a libration that is specified by initial conditions); however, TTB09 showed that the free libration should decay on a timescale much less than that of the orbit swap. For this reason, TTB09 fit the Cassini data with a simplified model in which Janus and Epimetheus always librate at their instantaneous orbital (forcing) rates, even as the latter change.

Two other studies have approached this problem in the past year. Noyelles (2010, Icarus) carried out a detailed numerical model of the rotation of Janus and Epimetheus. His Fourier decomposition of the expected periodicities consists mostly of terms that appear because the orbital rate, as a function of time, is closer to a square-wave function than to a sinusoid (see Salo and Yoder 1988, A&A; Renner and Sicardy 2004, CeMDA), but he found dominating frequencies in general agreement with those derived by TTB09. Noyelles (2010) also found that latitudinal librations were less than a fraction of a degree, justifying the choice of TTB09 to consider only in-plane motions for fitting Cassini data. Robutel, Rambaux, and Castillo-Rogez (2010, Icarus) conducted long-term simulations aimed at determining the effect of the orbit swap upon the libration frequencies.

Work is ongoing to apply similar methods to other Saturnian satellites. Because forced rotational librations depend directly on the moments of inertia, they can confirm or disprove the assumption of homogeneous density by which moments of inertia are derived from the shape. Pandora is likely to have detectable forced librations, as inferred from its system of surface grooves similar to those of Phobos and Epimetheus (Morrison et al. 2009, Icarus), and Prometheus may have detectable librations as well. Librations have also been suggested for Saturn's larger moons, including Enceladus (Hurford et al. 2009, Icarus).