Supporting Online Material for

Saturn’s Small Inner Satellites: Clues to Their Origins

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SATURN’S SMALL INNER SATELLITES: CLUES TO THEIR ORIGINS

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Abstract:

Cassini images of Saturn’s small inner satellites (radii of less than \(~100\) kilometers) have yielded their sizes, shapes, and in some cases, topographies and mean densities. This information, and numerical \(N\)-body simulations of accretionary growth, have provided clues to their internal structure and origins. The innermost ring-region satellites have likely grown to the maximum sizes possible by accreting material around a dense core about a third to a half the present size of the moon. The other small satellites outside the ring region either may be close to monolithic collisional shards, modified to varying degrees by accretion, or may have grown by accretion without the aid of a core. We derive viscosity values of \(87 \text{ cm}^2/\text{sec}\) and \(20 \text{ cm}^2/\text{sec}\), respectively, for the ring material surrounding ring-embedded Pan and Daphnis: These moons almost certainly opened their respective gaps and then grew to their present size early on when the local ring environment was thicker than it is today.

Data and Reduction Methods:

In this work, we have used the best Cassini images available of each body and the reconstructed relative geometry of the Cassini spacecraft and the satellite. Errors in positions are not a significant factor in this work. We assume synchronous rotation; repeat observations are consistent with synchronous rotation for all satellites except for objects with insufficient
observations, such as Methone, Anthe, Pallene, Helene, and Polydeuces. For these objects, in principle rotation states other than synchronous are possible, though they are not expected. The spin states of Janus and Epimetheus have been detected to change approaching and following their early 2006 orbital switch. To avoid the need to make an adjustment for varying spin, we have modeled their shapes only with images obtained before the end of 2005.

For some objects such as Janus, Epimetheus, Pandora, and Telesto which have been seen from different directions with good resolution (> 100 pixels/diameter), we do stereo control point analysis. For objects with small numbers of images, matching 5°×5° shape models with limb and terminator positions replaces the usual control point solutions. Estimated uncertainties (treated as 2-σ numbers) in the radii of objects imaged at low resolution derive largely from their irregular shapes and the amount of coverage necessary to constrain peaks and depressions. For small objects, projected cross sections are controlled to ~0.5 pixels by individual scans across illuminated and silhouetted disks. The best limb scans of Atlas and Pan illustrate some of the limitations. Pan is partly obscured by rings, and other parts of the limb are not sharply defined. Additionally, fitting limbs to small images (those with diameters less than ~30 pixels) runs afoul of changing photometry within 5 pixels of the limb which biases the limb-fitting. Uncertainties in these shape models reflect resolution and coverage, not simply irregular shapes.

We present the best shape models currently available in Figures S1, S2 and S3 for those moons imaged at sufficient resolution and coverage. Figure S4 illustrates what Pan and Atlas might look like with their equatorial ridges removed.
FIGURE S1: Observed shapes of Pan, Daphnis, Atlas, and Prometheus. Views are, left to right, looking from Saturn at the sub-Saturn point with north up, looking at the leading hemisphere with north up, and looking from the North with leading hemisphere down. Mapped colors are gravitational topography, similar to height above an equipotential. These objects are all assumed to have cores of density 0.9 g cm\(^{-3}\), and mantles of density 0.15 g cm\(^{-3}\). The image scales vary; the images have been re-scaled to the same apparent size.
FIGURE S2: Observed shapes of Pandora, Janus, Epimetheus and Pallene. Views and mapped colors are the same as in Fig. S2 except only Pandora is modeled as having a core. Janus and Epimetheus are modeled as homogeneous with mean densities given in Table 1. Pallene, for which no mass is currently available, is assumed to have a density of 0.55 g cm$^{-3}$. 
FIGURE S3: Observed shapes of Telesto, Calypso, Helene, and Polydeuces. Views and mapped colors are the same as in Fig. S3. All bodies shown here, for which masses are unavailable, are assumed to have homogeneous interiors of density of 0.55 g cm\(^{-3}\).
FIGURE S4: Orthogonal views of the underlying assumed shape of Pan and Atlas after their ridges were removed by assuming a smooth profile underlying the ridge across the moon’s equator. With ridge removed, Atlas’ volume decreases by ~ 25%, Pan’s by ~ 10%. West longitudes are labeled. Top two panels view satellites from the leading side; bottom panels from anti-Saturn point.