EPSC Abstracts
Vol. 6, EPSC-DPS2011-624, 2011
EPSC-DPS Joint Meeting 2011

Noncircular features in Saturn's Rings: I. The Cassini Division

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1. Introduction

Although Saturn's rings appear at first glance to be axisymmetric, more precise measurements reveal that many of the gap edges and narrow ringlets within the rings are in fact noncircular, a characteristic they share with the narrow uranian rings [1]. A careful study of these features is of interest for several reasons: (i) resonantly-forced perturbations are believed to restrain the rings from spreading under the influence of collisions [2], (ii) unforced distortions, mostly eccentricities, can lead to estimates of the surface mass density and viscosity of the rings [1], and (iii) accurately-measured apsidal precession rates provide information on Saturn's zonal gravity harmonics [3]. We present preliminary results from a comprehensive study of noncircular features in the Cassini Division, based on occultation data from the *Cassini* mission. A companion paper presents our results for features in the C ring.

2. Data analysis

The data used in this study come from three *Cassini* experiments, and cover the period from May 2005 to September 2010. Over 120 stellar occultations have been observed by the Ultraviolet Imaging Spectrometer (UVIS) and by the Visual and Infrared Imaging Spectrometer (VIMS), at wavelengths of 0.15 and 2.9 μm. The effective radial resolution of these data ranges from less than 100 m to $\sim$ 400 m, depending on sampling rate, SNR, and occultation geometry.

In addition, 12 occultations of the spacecraft's radio Radio Science Subsystem (RSS) by the rings were observed on Earth in May-September 2005, at wavelengths of 1.3, 3.5 and 13 cm. Here, we use the 3.5 cm results, diffraction-corrected to a uniform radial resolution of 1 km, sampled every 250 m.

In both types of experiment, either the recorded spacecraft clock time or the earth-receive time is then converted to radius in the ring plane using the reconstructed *Cassini* trajectory and either the Hipparcos-catalog coordinates of the star, adjusted for proper motion and parallax at Saturn, or the planetary ephemeris. Also critical is Saturn's pole orientation. To take full advantage of the remarkable intrinsic resolution of the occultation data, we must correct the radial scale of each occultation profile for small errors in the spacecraft trajectory, typically ~ 1 km. This is done in an iterative fashion by identifying what appear to be 'circular' features and using them to adjust the raw radius scale. We start with the features identified by [4], but our final list is considerably shorter, consisting of only 26 features in the Cassini Division, B and C rings, and none in the A ring. Post-fit rms residuals for these features are ~ 250 m.

3. Results

The simplest noncircular features can be modeled as inclined Keplerian ellipses, freely precessing under the influence of Saturn's oblate gravity field. These include the four dense ringlets that inhabit the Huygens, Herschel and Laplace gaps, three of which also have measurable inclinations with respect to the mean ring plane. In agreement with similar fits to the VIMS occultation data alone [5], we also find that the *inner edges* of 7 of the 8 gaps within the Cassini Division are eccentric, with amplitudes ranging from 0.9 km to 28.3 km (see upper panel in Fig. 1). Generally, the eccentricities decrease outwards. Curiously, most of the outer gap edges are near-circular.

In addition to simple eccentricities, we also find a surprisingly rich assortment of 'normal modes' on the edges of both ringlets and gaps. The pattern speed of such a mode, with m radial minima and maxima, is given by [1]:

$$\Omega_P = [(m-1)n + \dot{\varpi}]/m \qquad (1)$$

where n and $\dot{\varpi}$ are the mean motion and apsidal precession rate of the edge, respectively. (An $m = 1$

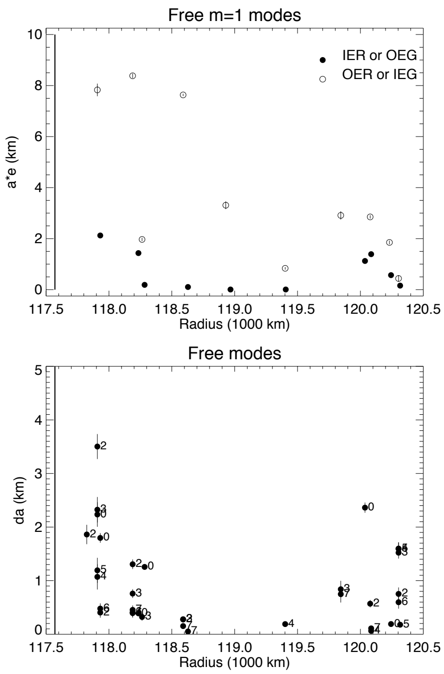

Figure 1: Fitted amplitudes for eccentric features in the Cassini Division, plotted against mean radius (top). Fitted amplitudes for normal modes other than $m = 1$ (bottom). A number attached to each point gives the value of the azimuthal wavenumber, m.

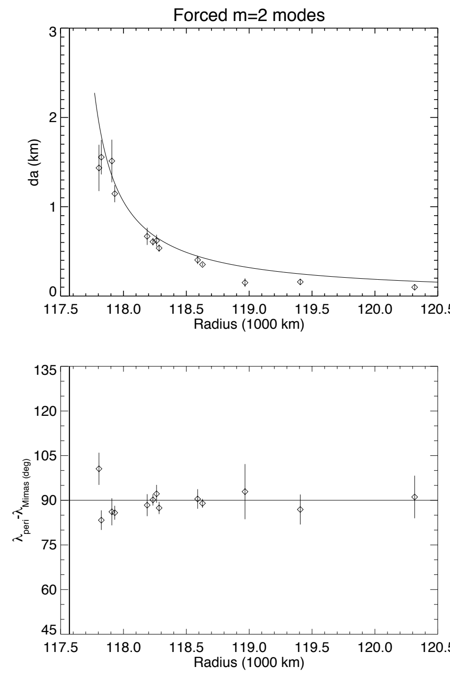

Figure 2: Fitted amplitudes (top) and orientations (bottom) for the $m = 2$ perturbations driven on ringlet and gap edges by the Mimas 2:1 ILR. The curved line shows the amplitude predicted by a simple test-particle model [5], while the vertical line at left in each panel shows the radial location of this resonance.

mode is equivalent to a Keplerian ellipse.) We have searched for modes with m as high as 8, and find convincing evidence for modes with $m = 0$, 2, 3, 4 and 5, all with amplitudes of 1 km or greater (see lower panel in Fig. 1). In some cases, as many as 3 or 4 normal modes coexist at a single edge with comparable amplitudes.

Our fits also reveal the pervasive effects of the strong Mimas 2:1 inner Lindblad resonance (ILR), which has long been recognized to define the outer edge of the B ring [2, 6]. Not only do we see the time-varying $m = 2$ distortion of this feature, as previously described by [5] and [7], but we find that *almost all* sharp-edged features in the Cassini Division exhibit a small but detectable $m = 2$ variation whose apoapse is locked to Mimas (Fig. 2). The amplitudes of these distortions decrease with distance from the resonance, and nicely conform to a simple analytical model for isolated test particles perturbed by the resonance [5].

Acknowledgements

We acknowledge the outstanding work of the *Cassini* RSS, UVIS and VIMS teams, and the NASA Cassini Data Analysis Program for research support.

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