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Noncircular Features in Saturn's Rings: II. The C Ring

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1. Introduction

Since the *Voyager* encounters in 1980/81, it has been known that many of the narrow ringlets within Saturn's broad rings are noncircular [1, 2], a characteristic they share with the narrow uranian rings [3]. A careful study of these features is of interest because (i) measurements of eccentricities and apsidal 'twists' can lead to estimates of the surface mass density and viscosity of the rings [3], and (ii) accurately-measured apsidal precession rates provide information on Saturn's zonal gravity harmonics [4]. We present preliminary results from a comprehensive study of noncircular features in the C Ring, based on occultation data from the *Cassini* mission. A companion paper presents our results for features in the Cassini Division.

2. Data analysis

The data used in this study come from three *Cassini* experiments, and cover the period May 2005 to September 2010. They include over 120 stellar occultations observed by the Ultraviolet Imaging Spectrometer (UVIS) and by the Visual and Infrared Imaging Spectrometer (VIMS), with radial resolutions which range from less than 100 m to $\sim$ 400 m, along with 12 radio occultations observed in May–September 2005. The latter were processed to a uniform radial resolution of 1 km, sampled at 250 m. The radial scale of each occultation profile was corrected for small errors in the spacecraft trajectory using a subset of the 'circular' features identified by [5]. Fits to these features yield RMS residuals of $\sim$ 250 m. For further details see the Abstract by French *et al.*

3. Results

3.1. Eccentric ringlets

The simplest noncircular features can be modeled as inclined Keplerian ellipses, precessing under the influence of Saturn's oblate gravity field. These include the two dense ringlets which inhabit the Colombo and Maxwell gaps, originally studied by [1] and [2].

In agreement with the *Voyager* studies, we find that the Colombo (aka 'Titan') ringlet precesses at virtually the same rate as Titan's mean motion, $22.5770°$ d^{-1}, with an apoapse oriented to within $4°$ of Titan's mean longitude (see Fig. 1). We can thus confirm that this ringlet is locked in the Titan 1:0 inner Lindblad (or 'apsidal') resonance, as discussed by [4]. However, the new data show that both edges of this ringlet also exhibit what appear to be free normal modes, with $m = 0$ on the inner edge and $m = 2$, 3 and 4 on the outer edge. The amplitudes of these modes range from 1.0 to 4.0 km.

Unlike its sibling, the Maxwell ringlet is freely-precessing, at a rate which is consistent with that predicted using recent solutions for Saturn's zonal gravity harmonics [7]. As noted by [2], this ringlet exhibits an unusually large eccentricity gradient, $q = ade/da$, comparable to that of the uranian ϵ ring [3] and strongly suggesting that self-gravity is acting to counter differential precession [6]. In this case, we see no evidence for additional normal modes on either edge.

Neither the Maxwell nor Titan ringlet has a measurable inclination wrt the mean ring plane. The relevant fit parameters are given in Table 1.

Table 1: Fitted parameters: eccentric ringlets

Parameter	Titan R.	Maxwell R.
a (km)	77878.5	87509.8
ae (km)	22.4	38.5
$\dot{\varpi}$ (° d^{-1})	22.575	14.694
δa (km)	23.1	59.1
q	0.434	0.662
rms resid. (km)	0.92	0.28

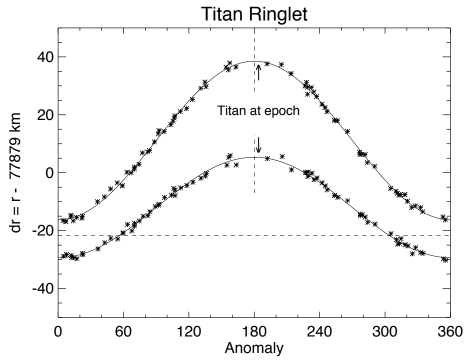

Figure 1: Measured radii of the inner and outer edges of the Titan ringlet, plotted against mean anomaly and with normal modes subtracted. Vertical arrows indicate the mean longitude of Titan, while a horizontal dashed line shows the theoretical location of the Titan apsidal resonance, calculated using data from [7].

3.2. Resonant perturbations

The two other gaps in the outer C ring are each associated with a pair of moderately strong resonances [8]. The inner edge of the 20 km-wide ringlet within the Bond gap coincides with the Mimas 3:1 inner vertical resonance, while its centerline falls very close to the Prometheus 2:1 ILR [9]. Our fits show that the ringlet's *outer edge* is indeed perturbed by the Prometheus resonance, with an amplitude of 1.2 km and a pattern speed almost equal to the moon's mean motion of 587.2852° d^{-1} [10]. Curiously, there are also indications of as many as five different normal modes on this edge, with m = 3, 4, 5, 6 and 7 and amplitudes of 0.3–0.5 km. By contrast, the ringlet's inner edge shows no comparable resonant or free distortions, and instead appears to be circular to within ± 0.2 km.

The inner edge of the $\sim$ 20 km-wide Dawes gap coincides with the Mimas 3:1 ILR, and is only 30 km exterior to the Pandora 2:1 ILR [9]. Here we again see evidence for multiple distortions: a resonantly-forced $m = 2$ perturbation with an amplitude of 5.2 km matching the predicted pattern speed for the Mimas 3:1 ILR of 572.4914° d^{-1}, superimposed on a freely-precessing ellipse with an amplitude of 5.9 km. Here also, there are indications of free normal modes, with $m = 3$ and 5 and amplitudes of 0.7–1.5 km. (We note here that previous work [8, 9] had clearly shown this edge to be noncircular, with variations of up to 9 km, but no successful model had been found.)

Table 2: Fitted parameters: resonant edges

Parameter	Bond ringlet	Dawes gap
a (km)	88719.1	90200.3
resonance	Prom 2:1 ILR	Mimas 3:1 ILR
m	2	2
Δa (km)	1.2	5.2
Ω_P ($^\circ$ d^{-1})	587.295	572.505
ae (km)	—	5.9
$\dot{\varpi}$ ($^\circ$ d^{-1})	—	13.176
rms resid. (km)	0.29	0.88

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