EPSC Abstracts
Vol. 6, EPSC-DPS2011-265-2, 2011
EPSC-DPS Joint Meeting 2011

Uncovering of Small-Scale Quasi-Periodic Structure in Saturn's Ring C and Possible Origin

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Abstract

Quasi-periodic ring structure of mean wavelength $\lambda \approx$ 1.3 km is uncovered in Cassini radio occultation optical depth (τ) profiles of the innermost region of Ring C ($\sim$74,480$-$77,740 km). The structure is characterized by two interfering "tones" separated in λ by few 100 meters. The mean λ increases slowly with ring radius. The observed behavior is consistent with presence of vertical ring corrugations few to 10 m in height. The corrugations are likely caused by a past event that slightly tilted the mean ring-plane and by subsequent differential nodal regression of particle orbits [1], [2]. The small mean λ implies an event $\sim$600 years old (late 1300's) and the two-tone separation suggests two sub-events $\sim$50 years apart.

1. Radio Occultation Observations

Three especially designed ansa-to-ansa radio occultations of Saturn's rings were recently completed. The Rev 123 occultation on December 25, 2009, and the Rev 125 occultation on January 26, 2010, both sampled ring opening angle $B \approx 4.8°$. The Rev 133 occultation on June 18, 2010 sampled $B \approx 1.9°$, the smallest ever captured. The longer radio path through the rings when B is small enhances sensitivity to ring features of small optical depth, especially in Ring C, the Cassini Division, and in the vicinity of ring gaps. The observations were nearly noise-limited over other optically thick ring regions, complementing in objectives earlier observations at larger B.

The occultations were conducted using three coherent monochromatic signals of wavelength 0.94, 3.6, and 13 cm (Ka-, X-, and S-band, respectively). The observed diffraction-limited optical depth profiles were reconstructed to remove diffraction effects, yielding few 100 meters radial resolution Ka- and X-band profiles (coarser resolution at S-band).

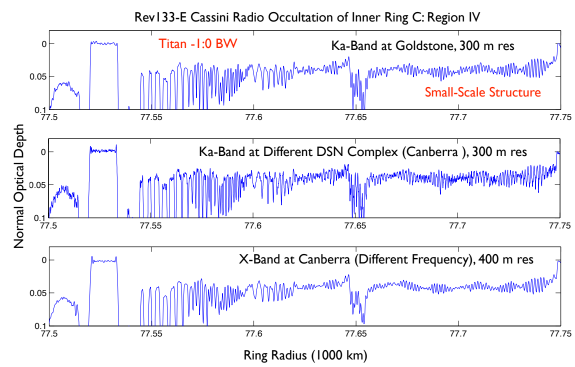

Figure 1: The Ring C structure was observed at multiple frequencies and multiple observing ground stations

2. Quasi-Periodic Ring C Structure

Surprisingly, spectrograms (power-spectra vs. time) of the Rev 133 ($B \approx 1.9°$) egress data revealed spectral features over the innermost $\sim$4000 km of Ring C that are reminiscent of diffraction by a giant diffraction-grating, suggesting presence of small-scale quasi-periodic ring structure similar in general nature to that previously observed over most of the width of Ring B and over inner Ring A [3]. While gravitational overstabilty was invoked as potential cause of the quasi-periodic structures within these relatively dense ring regions [3], a much smaller background normal optical depth $\tau \approx 0.05$ at radio-λ (Fig. 1) strongly suggests different cause.

The structure was also detectable in the Rev 123 and Rev 125 occultations (albeit clearer for some observation geometries than others). It was also detectable in both the Ka- and X-band observations, and at multiple Deep Space Network (DSN) stations located at separate physical sites (Fig. 1).

More surprising is that in computed fine spectral-resolution spectrogram of the observed optical depth profiles, the spectral line corresponding to the main diffraction grating lobe is actually split into two distinct spectral lines (dual-tone) that are close in spatial frequency (in spatial λ). The mean $\lambda \approx 1.3$ km, however, there is clear slow systematic increase in λ with increasing ring radius. The split spectral lines are particularly detectable over 4 distinct sub-regions: 74,510−74,880, 75,060−75,730, 76,500−76,730, and 77,630−77,740 km − regions I to IV, respectively. Either measurement SNR or true absence limited detection over other Ring C regions.

The Ring C structure was also directly detectable in reconstructed high-resolution Ka- and X-band optical depth profiles (Fig. 1). Here too, the quality of the detection varied among the six observation longitudes and the 2 ring opening angles, depending on the exact observation geometry. Observed packet-like behavior is consistent with constructively and destructively interfering tones (Fig. 1).

3. Vertical Corrugation Origin?

Analogous intriguing Ring C structure of much longer spatial wavelength ($\lambda \approx 30$ to 50 km across the full extent of Ring C) observed in Cassini images is attributed to small regular variations in ring material height above the mean unperturbed ring plane [1]. Dubbed "vertical corrugations," they are envisioned to be caused by some past event (comet collision) that tilted the mean ring plane ever so slightly. In the presence of Saturn's oblateness, the line-of-nodes of an inclined particle orbit regresses at a rate determined by its distance from Saturn, among other factors. The differential nodal regression across Ring C creates a tightly wound spiral pattern hence the vertical corrugations [1].

Could the quasi-periodic radio structure in inner Ring C be caused by similar vertical corrugations? Because the corrugations modulate the local slope of the ring plane, they change the path length within the rings and consequently the measured oblique optical depth, resulting in observed regular τ-fluctuation. The fluctuations are so small (< few percent; Fig. 1) and hence are usually undetectable, except when the ring opening angle B is small.

We test this hypothesis two different ways. We first compute the theoretical spiral pattern winding-rate and use the result to predict variation of the structure frequency (wavelength) with ring radius and compare with the observed spectrogram. The agreement is good in general. The notable difference is that the measured structure frequency decreases at somewhat slower rate with increasing radius than the theoretical model prediction. It's not clear if the difference can be accounted for by other neglected factors such as the influence of the ring mass, a possibility we continue to investigate.

We also test the hypothesis by exploring direct local NLS fits to selected subset of observed optical depth packets. In principle, assuming the corrugation model, predicted optical depth fluctuations can be computed for two interfering sinusoidal height perturbations of any assumed wavelength, amplitude, and phase. The fit results correctly capture the general packet behaviour observed and consistently imply corrugation height in the few to 10 m range, also consistent with the Cassini imaging results [1]. Results variability among multitude of observed packets imply more complex model than just two interfering tones of radius independent parameters. Nonetheless, the excellent quality of local packet fits strongly suggests validity of the general primes.

4. Summary and Conclusions

A dual-tone quasi-periodic structure is observed over the innermost 4,000 km of Ring C. The mean wavelength $\lambda \approx 1.3$ km and the tone separation is order few 100 m. The data appears to support the hypothesis that vertical corrugations caused by past ring tilting effect may be responsible, as first proposed in [1]. If true, the short λ compared with $\lambda \approx 30$ km in inner Ring C reported in [1] implies a separate event that is nearly 600 years older (late 1300's). The dual-tone suggests two sub-events, perhaps of the same initial origin, separated in time by $\sim$50 years. Together with reported detection of similar corrugations within the tenuous Jovian rings [2], the collective observations suggest that these ring plane tilting events may not be rare. The events provide interesting and unusual windows on past dynamical encounters with ring systems.

References

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