

## MASS OF SATURN'S A RING

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The mass of Saturn's A ring is reestimated using the behavior of spiral density waves embedded in the ring. The Voyager photopolarimeter (PPS) observed the star  $\delta$  Scorpii as it was occulted by Saturn's rings during the Voyager 2 flyby of Saturn in 1981 [1] (see Figure 1), producing a radial profile of the rings. We examined forty spiral density waves in the Voyager PPS data of the A ring, including 10 weaker waves that have not been previously analyzed, using an autoregressive power spectral technique called Burg. The strengths of this new method for ring studies are that weaker, less extended waves are easily detected and characterized. This method is also the first one which does not require precise knowledge of the resonance location and phase of the wave in order to calculate the surface mass density [2]. Uncertainties of up to 3 km are present in the currently available radial scales for Saturn's rings.

Spiral density waves are gravitational perturbations in the ring produced by discrete, non-overlapping orbital resonances with satellites orbiting just outside the ring. The material in these waves is alternately compressed then rarefied producing horizontal oscillations in ring opacity. This changing pattern of ring particle density transfers energy and angular momentum to the satellite until the wave is damped. The behavior of the wave as it disperses is one tool for probing the physical characteristics of the ring. Key ring properties, including surface mass density, are determined from the dispersion of the waves. Surface mass density, the mass of ring particles per unit area, is then used to estimate the total ring mass.

The bulk of the density waves disperse in a linear fashion. This dispersion behavior is used to calculate the local surface mass density in the vicinity of each wave. We assume that the surface mass density in a spiral density wave is representative of more extended ring regions around the wave. For purposes of comparison, the A ring is divided into three sections, using the Encke and Keeler gaps as boundaries. Average surface mass densities were calculated for each of these regions. The region inward from the Encke gap has an average surface mass density of  $44.6 \text{ gm/cm}^2$ . The region between the Encke and Keeler gaps has an average surface mass density of  $28.9 \text{ gm/cm}^2$  and the region from the outer Keeler gap edge to the edge of the A ring has an average surface mass density of  $30.3 \text{ gm/cm}^2$ . The mass of each section of the A ring was then computed from these average values.

The reestimated mass for the A ring is  $5 \times 10^{21} \text{ gm}$ , equivalent to the mass of a satellite (composed of ice) with a radius of 110 km. This new mass estimate is about 15% smaller than estimates from previous studies. Those studies attempted to perform linear fits to some of the density waves that we found to disperse non-linearly in this study. Those earlier estimates of surface mass density may have been a factor of 2 to 4 too high for some of the strongest density waves, leading to a slight overestimate in A ring mass.

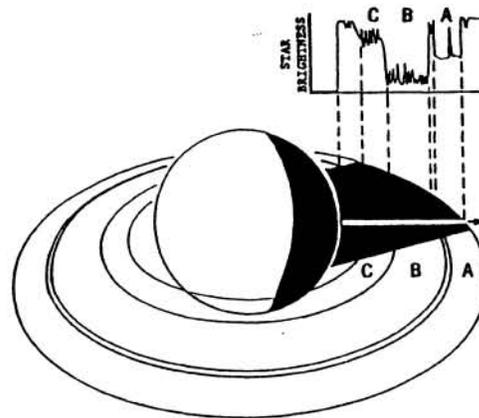


Figure 1: Voyager 2 PPS Occultation Scan.

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The total Saturn ring mass was initially estimated by Esposito [3] using 13 waves from the PPS data and by Holberg [4] using fewer and lower resolution waves from the Voyager ultraviolet data. Each group assumed that the ratio of mean optical depth near the first wave crest to the surface mass density was more or less constant. Then, assuming a constant particle size distribution across the ring system, the mass was estimated. Our results indicate that the ratio of optical depth to surface mass density is not constant, especially in the outer A ring.

The A ring surface mass density generally tends to decrease with increasing radial distance from Saturn. The region, from the beginning of the A ring to the Encke gap, has typical surface mass densities of 40 to 60 gm/cm<sup>2</sup>. The typical surface mass densities for the region outside the Encke gap are 20 to 30 gm/cm<sup>2</sup>, a significant decrease given that the average optical depth is roughly 10% greater for the region outside the Encke gap than for the region interior to the Encke gap. This behavior indicates that the ring particle size and composition are not uniform throughout the A ring. If they were similar the surface mass density and optical depth would increase or decrease concurrently.

Surface mass densities were calculated for the weak waves outside the Keeler gap for the first time. Surface mass densities in this region are also uncorrelated with optical depth, indicating that particle size and composition are not uniform in this region of the A ring. These measurements are significant because the photometric properties of the particles in this ring region are quite different from those in the remainder of the A ring [5].

One notable exception to the general trend is the Prometheus 9:8 density wave in the inner portion of Saturn's A ring. This density wave is driven by the satellite Prometheus where the ratio between the ring particle mean motion and Prometheus mean motion is 9/8. This wave has a surface mass density of  $70.5 \pm 6.1$  gm/cm<sup>2</sup>, the largest surface mass density of any of the density waves we studied. Even with the large error bars, the Prometheus 9:8 surface mass density does not fall within the error bars of other measured density waves in this study. The only published surface mass density for this wave is from Rosen [6], using the Voyager radio occultation data taken one year earlier. Rosen's value is more than a factor of 2 smaller for this wave. No other known density waves or wakes lie close to this region. The large disparity between results in this study and Rosen's calculated surface mass density is in need of an explanation. Perhaps an azimuthal variation within the ring or a temporal effect within the wave over the one year which separates the measurements might explain the large difference in surface mass density measurements. Both the rings of Uranus and Neptune display azimuthal variability so such variability should not be ruled out for Saturn's rings.

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