DENSITY WAVES OBSERVED BY CASSINI STELLAR OCCULTATIONS AS PROBES OF SATURN'S RINGS. J. E. Colwell, L. W. Esposito, and G. R. Stewart, Laboratory for Atmospheric and Space Physics, University of Colorado, 392 UCB, Boulder CO 80309-0392, josh.colwell@lasp.colorado.edu.

Introduction: Spiral density waves are launched in Saturn's rings at locations of orbital resonances with nearby moons. These waves provide a means of probing fundamental properties of the ring such as mass, thickness, and collision velocities [1, 2]. These properties constrain models of the origin and evolution of Saturn's rings. Density waves are collisionally damped, and the damping therefore provides a measure of the ring viscosity which can in turn be used to estimate a vertical thickness or scale height for the ring disk and a mean interparticle collision velocity. The self-gravity of the disk introduces a dispersion in the wave propagation [3, 4]:

$$\left(\omega - m\Omega(R)\right)^2 = \kappa^2(R) - 2\pi G\sigma|k| \qquad (1)$$

where ω is the frequency of the disturbance from the moon, m is an integer describing the resonance, $\Omega(R)$ is the frequency of azimuthal motion of a ring particle at orbit radius R, G is the universal constant of gravitation, σ is the background surface mass density of the ring at the location of the wave, and $k=2\pi/\lambda$ is the wavenumber of the wave. The radial epicyclic frequency of ring particles on eccentric orbits, $\kappa(R)$, differs from the azimuthal frequency $\Omega(R)$ due to the oblateness of Saturn. Measuring the dispersion of the wave provides an estimate of the surface mass density of the ring material [e.g., 5]:

$$\frac{d\lambda}{dr} = \sigma_0\left(\frac{4\pi^2 G R_L}{3\Omega^2(R_L)(m-1)}\right) \qquad (2)$$

where we have taken $\kappa(R) \approx \Omega(R)$.

Because the waves are rapidly damped, the kinematic viscosity can be estimated from the damping length, x_d, by [e.g., 6]:

$$x_d \approx \frac{2\pi G\sigma\left(R - R_r\right)^2}{\left(\kappa(R)\eta R D^2 R_r^2\right)^{1/3}} \qquad (3)$$

where R_r is the resonance radius and η, the viscosity, is approximately related to the ring scale height, H, by [1]

$$\eta = \tfrac{1}{2} H^2 \Omega\tau / (1+\tau^2)$$

where τ is the ring optical depth. If particles traverse the ring vertical thickness twice per orbit, then the speed of random particle motions can be estimated from $v_{ran} \approx H\Omega/\pi$.

Resonances are more closely spaced close to moons, so most observed density waves are in the A ring, the outer region of Saturn's main ring system. Previous analyses of density waves from Voyager observations have shown the ring thickness to be ~ 10-30 m, random velocities to be less than 1 cm/s, and the surface mass density of the A ring to be 20-50 g cm^{-2} [e.g. 5-10].

Cassini UVIS Stellar Occultations: The Cassini Ultraviolet Imaging Spectrograph (UVIS) has a High Speed Photometer (HSP) which measures the brightness of stars in the spectral range from 110 to 190 nm at rates of 125 to 1000 Hz [11]. During the first year of Cassini's orbital tour of Saturn UVIS observed 7 stellar occultations by Saturn's rings at radial resolutions of 7-20 m, much smaller than the typical density wave wavelength of ~1-10 km. The effective resolution depends on the intensity of the star in the HSP spectral range and the opacity of the ring. The set of occultation profiles reveal density waves throughout the A ring as well as some in the Cassini Division, with the number of usable optical depth profiles depending on the radial coverage of the occultation, the opacity of the ring at the density wave, and the star brightness.

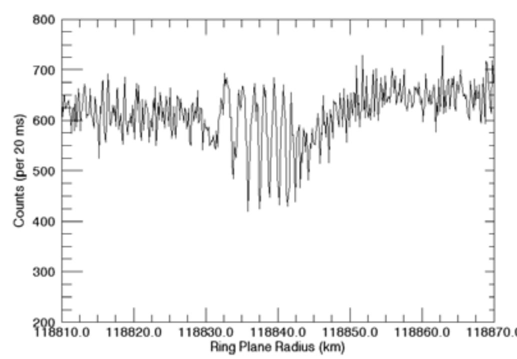

Figure 1: Brightness of the star Alpha Leo measured by the UVIS HSP as it was occulted by the Atlas 5:4 density wave in the Cassini division. The radial extent of the wave is 13±2 km, and the calculated viscosity is 5±2 cm^2 s^{-1} giving a ring thickness of 10 m. The dispersion of the wave gives a surface mass density σ = 1.6 g cm^{-2}.

Results: We use several techniques to measure the dispersion of density waves in HSP occultation data sets to arrive at surface mass densities from Eq. (2). Because of the changing wavelength and relatively short wavetrains of some density waves, only the strongest waves give a clear signal in a simple periodogram. A more effective technique of identifying the frequency distribution of density waves is to use a narrow sliding window and create a two-dimensional map of the frequency power spectrum with location in the rings (Figure 2).

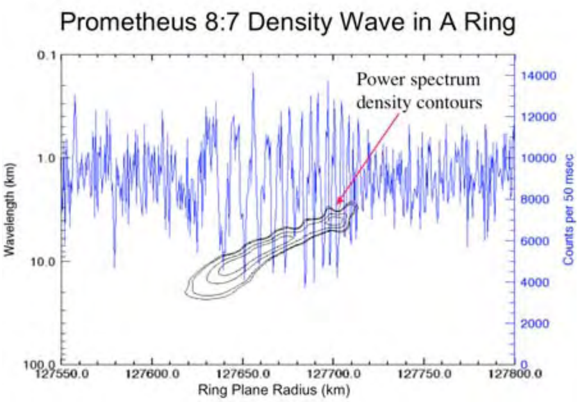

Figure 2: The Prometheus 8:7 density wave in the Alpha Virginis HSP occultation data with the power spectrum contours overplotted showing the decreasing wavelength of the wave with increasing distance from resonance (at left). In this case the power spectrum estimation comes from a wavelet filter [12].

The slope of the power spectrum contours in position-wavelength space is the left hand side of Equation (2). For relatively long wavetrains like that shown in Figure 2 the dispersion of the wave is well-defined. However, in the outer A ring some waves are fully damped within three wavelengths of resonance. Although the narrow power spectrum filter technique illustrated in Figure 2 gives a slope for $d\lambda/dr$ (Equation (2)), different techniques for estimating the power spectrum density can yield slopes which differ by more than the formal uncertainty in the fit to the data. We have used Fast Fourier Transform, Maximum Entropy Method [5], and Wavelet transforms with different filters [12] to analyze density waves in HSP data. In addition, we have measured the wavelength dependence on distance from resonance by manually identifying wave peaks and troughs in the data. While our results are consistent with previously published values, there is considerable scatter between different occultations and between different techniques. The spread in the results from these various techniques suggests that more detailed models of non-linear density waves are necessary to get accurate surface mass densities. Model results need to be compared to the full wave profile, including the phase of the wave at the longitude of measurement, and not just the spacing of wave peaks and troughs. The most reliable method of modeling nonlinear density waves is a fully self-consistent N-body simulation that includes both inelastic collisions and self-gravity. We plan to report the results of such simulations in the near future.

References:

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