Kinematics and Dynamics of the Uranian Rings

Richard G. French
Dept. of Earth, Atmospheric, and Planetary Sciences
Massachusetts Institute of Technology

A. Test of Self-Gravity Model of Apse Alignment

We have tested the self-gravity model of apse alignment by comparing its predictions about structure within the epsilon ring with an extensive set of observed occultation profiles covering a wide range of ring longitudes. According to the self-gravity model of Goldreich and Tremaine (1979), given a radial mass distribution at one ring longitude, there is a unique distribution of eccentricities across the ring necessary to maintain locked precession. A specific prediction for the epsilon ring is that the radial opacity distribution near periapse and far from periapse would differ significantly, and in particular that the eccentricity gradient across the ring would not be uniform. However, Voyager occultation observations near periapse (Sigma Sgr egress) and near quadrature (radio occultation egress) show very similar shape. The self-gravity model predicts that the near-periapse profile will have its greatest opacity in the inner half of the ring, whereas the observations clearly show that the near-periapse profile has its greatest opacity in the outer half of the ring, just as the near-quadrature profile does.

We conclude that the self-gravity model as presently constructed is inconsistent with the observations. An additional strong test of the model will be possible if the surface mass density of the epsilon ring can be estimated. The model strongly constrains the ring mass by the requirement that the torque on each ring element be just sufficient to maintain the locked precession.

B. Lindblad Resonance Survey

During the past year, we determined that the delta ring has perturbations that are well matched by an $m = 2$ Lindblad resonant perturbation (French et al., 1986b). Based on the information available at the time, we attributed the perturbation to an unseen small satellite inside the orbit of Miranda. No such satellite was found during the Voyager encounter, but from analysis of the Voyager trajectory the mass of Uranus was determined quite accurately (Tyler et al., 1986). They found a mass ratio of the sun to Uranus of 22905.39 ± 0.24, whereas we had used Standish and Campbell's (1984) value of 22951 ± 7, which now appears to be in error by about six times its stated error. The important consequence is that the mean motion of the m = 2 perturbation pattern corresponds to a resonancce radius lying within a few km of the radius of the delta ring, rather than 41 km away, as we had concluded from the less accurate Uranus mass value. It now seems possible that the delta ring exhibits an internal instability of the sort described by Borderies et al. (1985). Whether or not this is the case can best be settled by determining the ring radii to an accuracy of about one km, to see if the resonance truly does lie within the delta ring. This will be done during the coming year. An addition important test is to see if the Voyager occultation observations match the perturbation pattern found using earlier earth-based observations.

C. Shepherd Satellite Ring Perturbations

We are continuing our investigations of variations of ring width as a function of ring longitude and correlated these results with radial perturbations. In order to do this, we will use occultation observations obtained during May 1985 (French et al., 1985), April 1986, and from Voyager to map the rings in width and radius. This will be the major emphasis of our research in the coming year.

D. Ring Orbit Model Enhancement

We have enhanced our kinematical model of the Uranian ring orbits (French et al., 1986a) to accommodate Voyager observations as well as ground-based occultation observations. Most of the past year has been spent on the development and careful testing of this major extension to our existing computer code. The work is now complete, and we are now able to fit for all ring elements, the direction of the planetary pole, and J2 and J4, using the complete set of earth-based and spacecraft observations. We have tested our results very carefully by writing two sets of independent code, and cross-checking intermediate results with the Voyager Navigation Team, the radio science group at Stanford, and with Philip Nicholson at Cornell. We are in the process of performing a definitive set of orbit fits. Much of our effort will involve sensitivity studies to determine realistic uncertainties for the derived orbital elements.

References

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