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Physical Processes in Planetary Rings

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Perturbed Narrow Rings. Kolvoord *et al.* (*Nature* **345**, 695-697) used a Fast-Fourier-Transform technique to show that the longitudinal brightness distribution of Saturn's F ring contains only a few distinct wavelengths rather than the continuum of values mentioned in the original 30-day *Science* reports. The wavelength corresponding to the gravitational signature of the inner shepherd Prometheus is found to be prominent in both Voyager 1 and 2 data; on the other hand, since Pandora is more distant and less massive than Prometheus, the outer shepherd's signature is not expected to be seen and is not. Several other wavelengths can be identified: one is nothing more than the spacing of two unusually bright clumps noticed in the Voyager 1 data while most other detected wavelengths seem to result from the beating between known signals. However, there is at least one other signal that appears real and that we ascribe to an as-yet undocumented nearby moonlet. From the signal's wavelength we are able to infer the perturber's separation in semimajor axis a. Given such a separation, the only way for the responsible perturber to have been missed in spacecraft images, while still imprinting its strong signal on the ring, is if the moonlet is on an elliptical orbit ($e \sim 10^{-3} - 10^{-2}$) that brushes against the ring. Voyager 2 data give similar, but less convincing, identifications. The presence of as-yet unseen moonlets on slightly elliptical and inclined rings in the environs of the F ring had been earlier suggested from magnetospheric data.

The consequences of a close satellite perturbing a narrow ring had been previously investigated numerically and analytically in 2-D by Showalter and Burns (1982). The 3-D version of this problem has now been pursued by Kolvoord and Burns (1991a, in preparation) who find, from the nature of out-of-plane motions in Saturn's F ring, that these displacements become noticeable only for certain configurations of the orbits of the perturbing satellite and the ring: closest approach between the ring and the satellite must occur near the time when the satellite reaches its maximum elevation above the ring plane. Since the satellite's argument of pericenter precesses at 2.7 °/day due to Saturn's oblate gravity field, the ability of Prometheus to produce significant out-of-plane motion will vary appreciably over relatively short timescales. The implication is that, if the braids develop by a mechanism like this, they will vary significantly with time and will not be present around the entire ring.

"Collisions" have been added by Kolvoord and Burns (*BAAS* **22**, 1042; 1991b, in preparation) to their 2-D numerical simulation to ascertain the circumstances under which the ring's organization is disrupted. These "collisions" are modelled as random impulses to ring-particle velocities that are introduced in a Monte Carlo manner so as to be consistent with the impacts caused by a sea of background objects having orbital characteristics that are similar to those of the studied particles; energy loss can be included in an ad hoc fashion. As expected, such stirring of the system destroys the organized flow that is needed if the periodic signature of the shepherds is to be identified. Of course, in the specific case of the actual F ring, clumps and knots are seen even though, according to the high optical depths in the core of the ring, collisions must be common. This condundrum suggests that some key feature yet needs to be added to our model.

Dynamics of Circumplanetary Dust. Studies of the motion of circumplanetary dust under the action of radiation pressure and various electromagnetic processes have been emphasized during the past year. This emphasis is partly a result of a collaboration with M. Horanyi during my sabbatical year and partly due to an attempt to prepare for publication various results originally obtained in the 1989 Ph.D. dissertation of L. E. Schaffer.

The dynamics of circumplanetary charged dust grains has not been widely explored even though it is recognized that tenuous dust disks are an important component of planetary rings. We have started a systematic explanation of the curious consequences of some of the perturbations that act on small particles. Lorentz resonances occur when orbital periodicities match the frequencies of electromagnetic forces. Orbital evolution through such Lorentz resonances has now been studied by Schaffer and Burns (1991b, submitted to *Icarus*), who find that large jumps in eccentricity and inclination are induced during resonance passage and that they persist after the particle leaves the region of the resonance. The electrical charging of a grain traveling through a magnetospheric plasma occurs stochastically but the resulting variability of the charge rarely limits the effectiveness of the Lorentz resonance (Schaffer and Burns 1991c, in preparation). Orbital evolution due to delayed, periodic charge oscillations have been studied numerically and qualitatively in the last few years. These models have now been analytically extended by Schaffer and Burns (1991d, submitted to *JGR*). Horanyi and Burns (1991, submitted to *JGR*) have followed the effects of the planetary shadow on the dynamics of charged grains orbiting through the shadow. An orbital resonance happens in this circumstance owing to the periodic oscillation in the photoelectric current as the latter shuts off on each passage through the shadow; hence energy can be transferred to the orbit. Nevertheless, because the orbit also precesses due to these same forces and therefore enters the shadow differently, no long-term evolution occurs.

A slightly different circumstance occurs for dust circling Mars, where no appreciable planetary magnetic field is present. Here the Lorentz force arises from passage through the solar wind's magnetic field (rather than the planet's field) that is being convected past the planet. Even though orbital resonances do not occur, Horanyi *et al.* (*Geophys.Res.Ltrs.* **17**, 853-856) demonstrate that Lorentz forces can dramatically alter the nature of the trajectories, resulting in prolonged lifetimes for submicron-sized grains.

Electromagnetic processes may be very important on the micron-sized particles that are inferred to be the primary constituent of Saturn's E ring, the diffuse band that extends from 3 to 8 Saturnian radii and that peaks near the orbit of Enceladus at $4R_s$. Burns and Horanyi (*BAAS* **22**, 1042; also IAU presentation) have shown that solar radiation pressure alone will rapidly cause particles injected at Enceladus to spread out widely ($3 \rightarrow 5\ R_s$). If the particles are charged, the resulting distribution, which is asymmetric about the planet's orbital velocity vector, depends critically on the charge-to-mass ratio.

Hamilton *et al.* (*BAAS* **22**, 1043-1044) have started to address the origin and fate of Neptunian dust, some of which is curiously located over the polar regions. Their preliminary results suggest that such highly inclined orbits can develop in at least two ways: the orbits of distant particles, which are weakly bound to the planet, are tilted up by radiation forces, or by passage through Lorentz resonances of Neptune's highly distorted B field.