KINKS, CLUMPS, AND ACCRETION IN SATURN'S F-RING, S.J. Weidenschilling and D.R. Davis, Planetary Science Institute, Tucson, AZ 85719

Saturn's F-ring exhibits enigmatic non-axisymmetric features such as braids, clumps, and kinks. Some of these are almost surely due to perturbations by the nearby shepherd satellites, but numerical simulations (1) have not reproduced the observed features in detail. Also, kinks and clumps have been observed in some ringlets for which no shepherds are known. Some such features may be due to the presence of large bodies within the ringlets themselves. Gravitational encounters and collisions among the ring particles must be considered in order to account for these phenomena.

We have modeled numerically the effect of a large embedded body on the local structure of a ringlet, including mutual gravity and collisions. A many-body integration program with a hierarchy of time steps (2) is used to compute explicitly trajectories of interacting particles in the region of interest. The computation is carried out in two dimensions in a rotating reference frame centered on the large body. Computer capacity imposes a practical limit of $n \approx 250$, but this is effectively doubled by performing the calculation in a half-space and assuming symmetry through the origin (particles feel gravitational attraction of the "images" in the opposite half-space).

Figure 1 shows a sample calculation with angular frequency and Saturn's tidal pull appropriate to the F-ring. A 40-km segment of a ringlet 10 km in width is shown with a large body 1 km in radius. The small particles have radii of 50m, giving a mean free path between collisions of about 1/3 the ringlet width. For the assumed density of 1 g/cm^3, the surface density is $\approx$33 g/cm^2 (excluding the large body). Initial particle positions are assigned randomly, but with the restriction that no two are closer than $1/\sqrt{2}$ times the mean spacing. Initial velocities correspond to circular orbits, with small ($\lesssim$ 5 cm/s) random radial and transverse velocity perturbations. A coefficient of restitution of 0.5 is assumed for collisions.

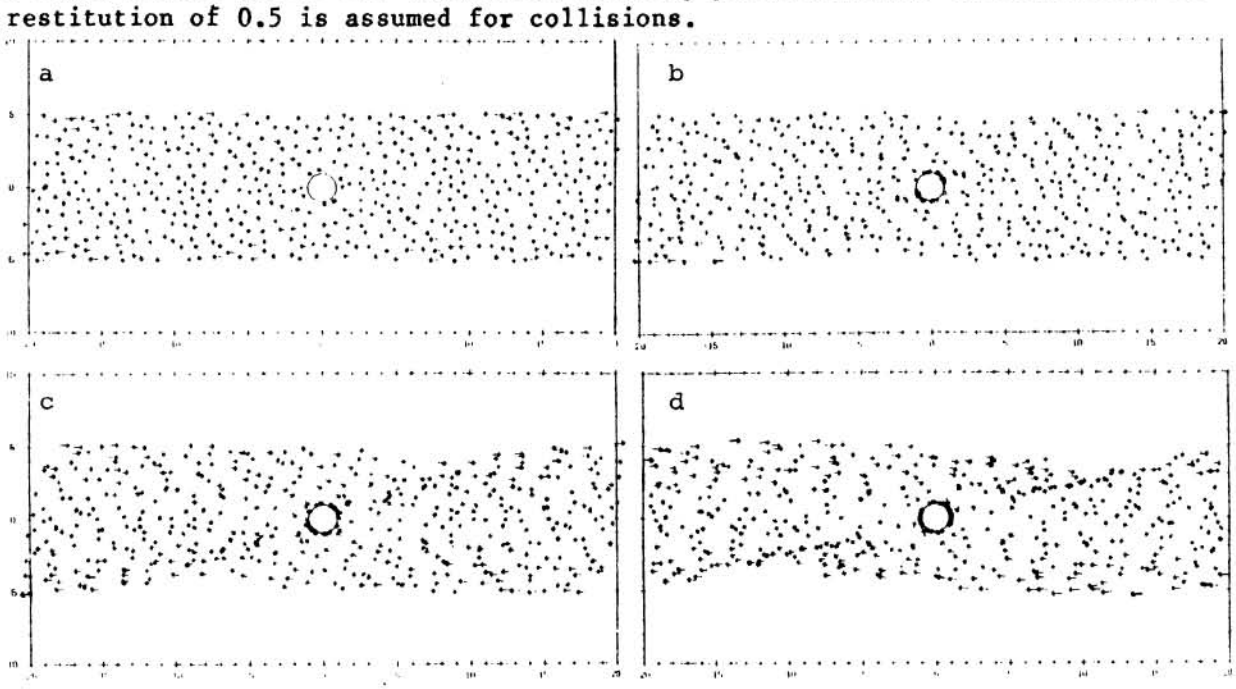

FIGURE 1: Four stages in development of a kink due to perturbations by a large ring particle. Dimensions are in km.

This simulation covers about 6 hr elapsed time. The ringlet develops leading/trailing regions of enhanced density in which particle collisions are frequent. A few particles that avoid collisions are being scattered into wider orbits. Collisions tend to confine the ringlet; a similar run without collisions showed a much greater scattered component and less prominent density enhancements. The kink is similar to some features seen by Voyager 1, and has the same orientation with respect to orbital motion. The photos suggest that a better match would be provided by a larger body (relative to the ringlet width) and shorter mean free path.

Particles colliding with the large body are accreted, generally after a few bounces. Some of the smaller particles also form gravitationally-bound pairs after collisions. This behavior is not surprising, as the assumed density places the ring outside the Roche limit (critical density $\simeq 0.7$ g/cm^3). However, the surface gravity still has a net inward component for $\rho \geq 0.15$, and accretion of small particles by a large one will occur. Hence, the continued existence of the F-ring appears incompatible with its containing bodies large enough to produce the observed kinks, unless one or more of the following mechanisms is operating:

(a) Any large F-ring bodies may have the density and texture of loose powder snow. However, such low density would imply they are made up of very irregular particles, "snowflakes" rather than more or less equiaxial grains. The origin of such particles and their continued existence in a collisional environment would need explanation.

(b) Accretion produces aggregate bodies with $\rho \lesssim 0.7$ g/cm^3 so they are within Saturn's Roche limit, and having very low shear strengths ($\lesssim 10 - 10^2$ dyne/cm^2) so that they are tidally disrupted when they reach kilometer sizes. It seems hard to reconcile both low strength and density. Random packing of spherical particles typically yields ~20 - 30% void space. Irregular particles yield lower density, but interlocking would raise the shear strength.

(c) The shepherd satellites may interfere with accretion in the F-ring. The nominal values of orbital radii and eccentricities apparently allow the inner shepherd to make close approaches to the ring when their lines of apsides are near 180° apart, as was the case during the Voyager encounters (3). The minimum approach distance is comparable to the satellite's dimension. The resulting tidal force due to the satellite ($\propto m/r^3$) may equal or exceed that due to Saturn. The stresses due to the planet and satellite are additive, and may disrupt ring condensations that would otherwise be stable. Very low shear strengths are still required, but bodies with higher densities $\gtrsim 1$ g/cm^3 could be disrupted. If the apsides of the ring and shepherd are not locked in resonance, their differential precession allows a series of close approaches at intervals ~20 yr. The appearance of the F-ring may vary significantly on this timescale due to alternating periods of accretion and tidal disruption.

This scenario suggests a common origin for the F-ring and the two shepherds by collisional disruption of a single parent body orbiting near the Roche limit. Most of the fragments reaccreted to form two closely spaced satellites. Their perturbations confined the remaining mass into a narrow ring by gravitational torques, but also prevented it from accreting into a third satellite. Such an event may have been fairly recent in solar system history.

References

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