TIDAL EFFECTS ON SATURN RING PARTICLES: IMPLICATIONS FOR RING EVOLUTION, C.R. Chapman, D.R. Davis, S.J. Weidenschilling, and R. Greenberg, Planetary Science Institute, Tucson, AZ, 85719

Saturn's rings are commonly thought of in terms of continuum processes. The recent Voyager studies of the rings have failed to reveal any of the discrete particles of which the rings are composed (except in the case of moonlets and suspected moonlets associated with the F-ring). Nevertheless, the physics of the rings demands attention to the essential particulate nature of the component particles. The size-distribution of the ring particles is still not well characterized and constraints from a variety of sources of evidence (Voyager radio and stellar occultation, ground-based radar, optical-scattering models, etc.) still permit the existence of very sizable bodies, e.g., of kilometer scales, which might contain a substantial fraction of the mass of the system. Both the origin of the rings and their continuing dynamical evolution demand consideration of such bodies.

Saturn's ring system is an example of a collisionally interacting swarm of particles which are colliding at speeds far too small to shatter individual particles, unless they are extraordinarily weak. Most collisions result in inelastic rebound, frequently leading to particles accreting onto one another. What then prevents the system from evolving into a family of discrete moonlets? The traditional explanation for Saturn's ring system depends on the system being inside Roche's limit. The classical Roche limit, the minimum distance from a primary about which a homogeneous, tidally deformed fluid body can orbit without being disrupted, is a function of the satellite's density. The density that would prevent disruption ranges from 0.75 g/cm^3 at the outer edge of the A-ring to 2.5 g/cm^3 at the inner edge of the B-ring. Moreover, ring particles are not fluid bodies; tensile and shear strengths allow them to resist disruption by tidal stresses within the Roche limit. The required strengths are quite small, ~10^2 - 10^3 dynes/cm^2 for km-sized bodies in the B-ring. Hence, a more realistic model for ring particle interactions, including finite strengths (1) and tidal effects on trajectories of colliding particles, must be invoked.

We have been studying the collisional evolution of planetary ring systems from the perspective of a collisionally interacting system of discrete particles having sufficient strength to avoid tidal disruption. The numerical model described by Greenberg et al. (2) and Davis et al. (3) has been modified to represent the Saturn ring system by including the dominant effects of tidal perturbations. Tidal effects can play a major role in the evolution of a collisionally-interacting system, principally by aiding the escape of rebounding particles and causing "spontaneous" leakage of accreting particles from the surface. The effective surface gravity on a ring particle results from inward gravitational acceleration being reduced by outwardly directed tidal and centrifugal accelerations. For a spherical particle, gravity is, of course, constant over the surface, but the latter two accelerations, and hence the effective gravity, are position-dependent. When the sum of the latter two forces exceeds the gravitational force, the effective gravity has an outwardly directed radial component, so particles having collisionally accreted can then drift apart. Fig. 1 shows the distance from Saturn at which the minimum net force over the particle's surface first vanishes as a function of ring particle density and for a plausible range of particle rotation rates.

We have developed a collisional outcome algorithm that describes tidal leakage of accreted particles. Results based on numerical integration with a restricted three-body model indicate that a radially-outward component of the effective surface gravity is not sufficient to produce escape -- rather

particles are ballistically transported to more stable regions of the particle surface. Hence, for tidal stripping to occur, the particle must be well inside the zero acceleration contours shown in Fig. 1 for a given density and spin period.

Without tidal modifications of collisional outcomes, rapid accretion occurs in a Saturn-like ring particle distribution with bodies several kilometers in size forming from meter-sized bodies. Saturn's tidal forces serve to inhibit accretion -- but by no means completely so. We believe that the physical constitution of the larger meter-sized particles (which, apart from any of the unobserved larger bodies, apparently dominate the mass of the system according to radio occultation inferences(4)) may be loosely compacted swarms of smaller bodies, constantly accreting smaller particles while simultaneously leaking particles off the ends of a quasi-equilibrium figure. Their failure to accrete into km-sized or larger bodies implies extremely low strengths and densities, or still-unmodeled tidal or rotational effects.

References

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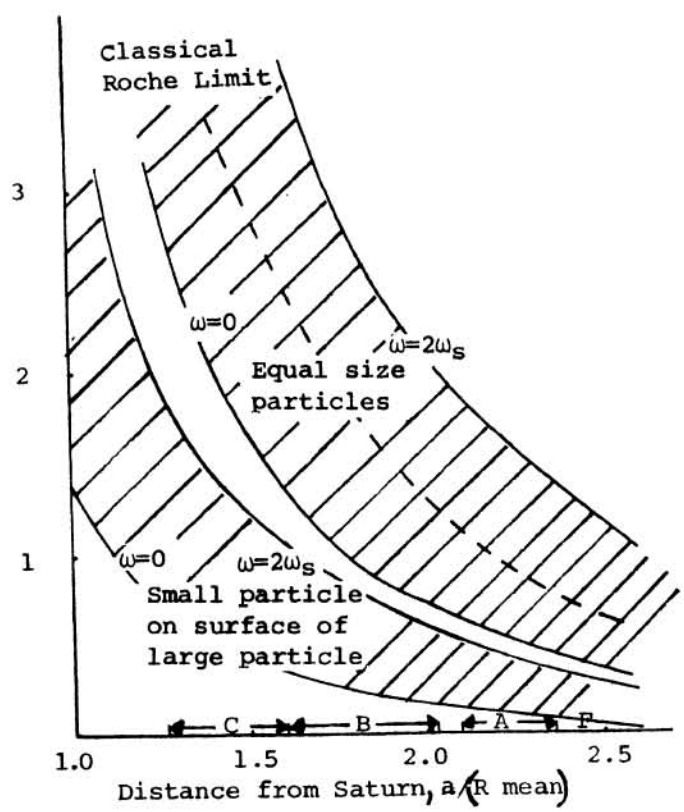

FIGURE 1: Distance from Saturn for which the net attractive force between two particles vanishes in the radial direction from Saturn. Result for the limiting cases of equal size particles and for a negligible size particle on the surface of a larger particle are shown. ω is rotational angular velocity of the ring particle and ω_s is the orbital angular velocity.