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On the Distribution of Particle Sizes in Saturn's Rings

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Abstract

We propose a new kinetic model for the evolution of the size distribution in a planetary ring, including coagulation and fragmentation of ring particles. Asymptotically the size-distribution approaches a power law with an exponential cut-off above a certain particle size, similar to the observed size distribution of Saturn's main rings.

Background

Analysis of the light scattering properties of Saturn's rings suggests that the ring particles follow a steep size distribution $p(r) \propto r^q$ that can be approximated by a power law with an exponent near q=-3 (Zebker et al., 1985; French and Nicholson, 2000). The sizes are limited roughly to the range 1 cm $<$ r $<$ 10 m, where the precise limits depend on the radial distance from Saturn.

Also a population of larger particles from r $>$ 10 m to a few hundreds of meters was inferred from the observation (Tiscareno et al., 2006, 2008; Sremcevic et al., 2008) of density signatures they induce in the ring (Spahn & Sremcevic 2000, Sremcevic et al., 2003). These larger particles probably exist only at certain distances from the planet and they obey a much steeper distribution with -6 $>$ q $>$ -9. Such an overall distribution of ring particles in form of a broken power law was proposed by Cuzzi et al., 1984.

Previous Models

It was suggested that the distribution of the smaller population may follow from a balance of coagulation and fragmentation, ring particles eventually forming fluffy aggregates called Dynamic Ephemeral Bodies (DEBs) (Davis et al., 1984).

The existence of the upper cut off in the distribution of the smaller (main) population of ring particles is still poorly understood. It was argued that the upper size cut off may result from tidal disruption, preventing further growth of aggregates larger than a certain size limitv (Davis et al., 1984). However, even a minute tensile stress provided by adhesional sticking should allow for aggregate sizes well above 10 meters. On the other hand, Longaretti (1989) proposed an analytical model for the size distribution and argued that aggregates of size D would typically collide with each other at relative speeds $\Omega\, D$, so that a certain critical speed leading to disruption would correspond to a maximal size D of particles found in the ring. However, the aggregation kinetics, including the disruption and re-accumulation of the largest aggregates, was not modelled self-consistently in Longaretti's (1989) approach. The time-scale for their re-formation could easily be faster than the frequency of their mutual disruptive collisions, so that the argument does actually not hold.

The New Model

Here, we propose a new model for the aggregation kinetics of Saturn's ring particles. We assume that ring particles consist of smaller building blocks, which tend to coagulate in low velocity collisions, forming gradually larger particles. At a certain small rate, however, collisions are assumed to be disruptive, releasing all building blocks from colliding aggregates. These disruptive collisions would correspond to the upper part of ring particles' speed distribution, with collisional kinetic energies sufficiently large to overcome an aggregate's binding energy. Alternatively, disruption may be provided by occasional destruction in meteoroid impacts on the rings.

We show that the system evolves to a power law size distribution with an exponential cut-off above a certain size, very similar to the observed one. The cut-off size depends in this case on the frequency of disruptive collisions relative to the frequency of coagulating collisions. The rate of restituting collisions (i.e. only energy loss, but no fragmentation and no sticking of particles) changes the timescale for the relaxation to the asymptotic size-distribution.