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Evolution of Structure and Composition in Saturn's Rings Due to Ballistic Transport of Micrometeoroid Impact Ejecta

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Abstract

We introduce improved numerical techniques for simulating the structural and compositional evolution of planetary rings due to micrometeoroid bombardment and subsequent ballistic transport of impact ejecta. Our current, robust code, which is based on the original structural code of [1] and on the pollution transport code of [3], is capable of modeling structural changes and pollution transport simultaneously over long times on both local and global scales. We provide demonstrative simulations to compare with, and extend upon previous work, as well as examples of how ballistic transport can maintain the observed structure in Saturn's rings using available Cassini occultation optical depth data.

1. Introduction

The rings' huge surface area-to-mass ratio ensures that they are particularly susceptible to the effects of extrinsic meteoroid bombardment. These impacts produce a large amount of particulate ejecta, the vast majority of which are ejected at speeds much less than the velocity needed to escape the rings. As a result, this process can lead to a copious exchange of mass and angular momentum between different ring regions via ballistic transport (BT) of impact ejecta that can facilitate the evolution of structure and composition on both local and global scales.

Previous studies of BT were able to explain several observed ring features, such as the fairly abrupt inner edges of the A and B rings, and the very similar "ramp" features which connect them to the Cassini division and C ring, respectively [2], as well as their compositional evolution on a similar timescale to structural studies [3]. However these works were limited by computational constraints, and a lack of adequate data for basic ring properties such as the surface mass density σ and the opacity κ, which also influence the viscosity ν. We have developed a new, parallelized dynamical code that simultaneously models both structure and composition over a broad range of spatial and time scales, and is robust enough to incorporate new physics; meanwhile, Cassini continues to improve our understanding of key ring properties in support of this ongoing work. Here, we confirm a claim made by [2] that BT can maintain a sharp inner edge with a large optical depth contrast τ over long periods due to an impact ejecta distribution that is prograde-biased [4], as well as explore the effects of BT in maintaining observed C ring structure.

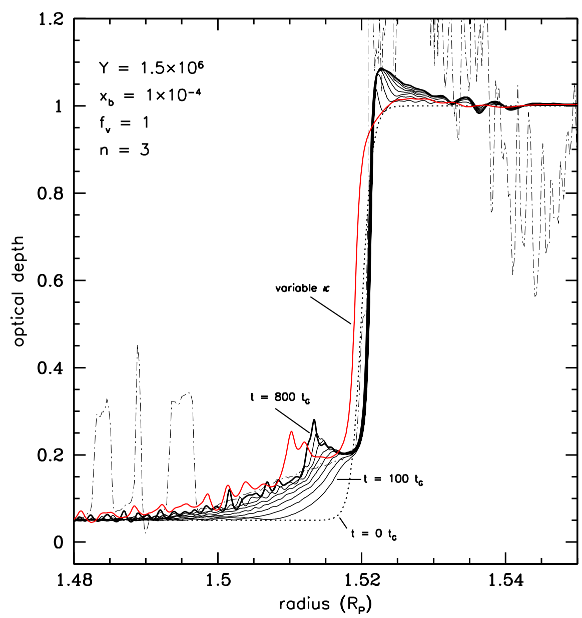

Figure 1: Simulation of the C ring /inner B ring transition using a kinematic viscosity [5], a constant opacity and a prograde-biased ejecta distribution for several curves up to 800 t_G ($\sim 7 \times 10^6$ years for the chosen parameter set). The red curve shows the same simulation, but with a variable opacity $\kappa(\tau)$.

2. Stability of the B ring Edge

Durisen and colleagues [2] concluded from the results of their simulations that the observed sharpness of the inner B ring edge (and presumably the inner A ring) could be maintained indefinitely through a balance between viscous spreading and the sharpening effects of BT; however, they were only able to demonstrate this over 100 "gross erosion" times t_G, where t_G (which also depends on the impact yield Y, and the micrometeoroid flux) is the time to erode away a ring of surface density σ if nothing returned. In Figure 1, we have simulated the C ring/inner B ring transition over 800 t_G using a similar set of parameters to [2]. We find for the chosen set of parameters that the inner edge sharpens and approaches a steady-state, as do the undulations in the inner B ring. The ramp region that connects the edge to the C ring grows over time acquiring a slope similar to what is observed(dashed curve), but develops structure that propagates inwards.

3. Simulations of C ring Structure

A number of factors can influence the effectiveness of BT in evolving ring structure and composition, such as the magnitude of the kinematic viscosity, the ejecta yields and the upper and lower bounds (and form) of the ejecta velocity distribution. In Figure 2, for a given choice of Y and ν, we show how the evolution of a plateau feature is sensitive to the lower bound x_b of the ejecta velocity distribution. BT (using a prograde ejecta distribution) tends to sharpen plateau *outer* edges, while ν counters this effect. Lowering the value of x_b has a similar "softening" effect as increasing ν, but the overall sharpness of plateau outer edges remain similar. On the other hand, smaller x_b creates the least amount of structural change locally which allows the ring to maintain its local compositional identity for longer periods (lower panel). The simulation is only conducted for 2 t_G because the inner edge smears out quickly due to viscosity (see below).

4. Summary

BT continues to demonstrate that it can have a significant influence on observed ring structure. Our preliminary results here imply that one very key piece missing from our efforts is the inclusion of a retrograde-biased ejecta component which would lead to sharpening of plateau *inner* edges. Such a component would come about if impacts were destructive rather than simply cratering, and/or if other micrometeoroid populations different than the cometary one assumed here are considered. We are currently integrating this into our code. We acknowledge that recent Cassini observations suggest that the micrometeoroid flux may be considerably lower than previously thought. We will discuss the implications of this result for ring age.

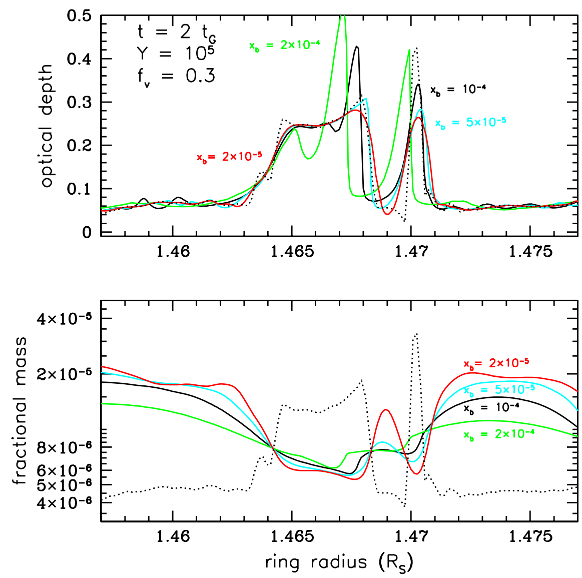

Figure 2: Evolution of a C ring plateau feature. The lower bound of the ejecta velocity distribution $f(x) \propto x^{-3}$, x_b (where x is the ratio of ejecta velocity to local Kepler velocity) is varied. Upper panel: structure. Lower panel: composition. The initial plateau feature is given by the dotted curve. See text.

Acknowledgments

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