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Transient Clumps in Saturn's F Ring

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Abstract

The Cassini Ultraviolet Imaging Spectrograph has detected 27 statistically significant features in 101 occultations by Saturn's F ring since July 2004. Of those 27 features, 17 likely correspond to transient clumps of material. We calculate from these observations the total number and total mass of transient clumps in the F ring. Constraints from observations place an upper limit on the number and total mass of such clumps. In turn, an upper limit on mass indicates that the clumps are not solid, spherical objects, rather they are loosely-packed, triaxial ellipsoids elongated in azimuth and vertically flattened. The total mass of clumps in the F ring is thus 6.1 x 10^{14} kg, the equivalent of a 6.8 km icy moon with a density equivalent to that of Prometheus. The differences in optical depth and morphology of the 17 significant features considered here also lead us to believe porosity differences exist among clumps. We investigate how the size distribution of clumps of different porosities evolves and how compaction of such clumps could lead to denser states that resemble moonlets, which describes 2 of the 17 features observed. The results presented here lead to a better model of how transient clumps form, evolve, and survive.

1. Introduction

Since its discovery [7], Saturn's F ring has been the focus of observations related to clumping processes. [5] attributed Pioneer 11 depletions in magnetospheric particles in the region to small moonlets (<10km). [9] found periodic brightness enhancements in Voyager images of the F ring that are consistent with Prometheus apoapse passages. During the 1995 ring plane crossing, edge-on observations identified small bodies ([3], [14]). The Cassini spacecraft has targeted the F ring for study of small body formation and ring evolution. [6] report 1-10 km bodies and temporal variability from UVIS stellar occultation observations. VIMS (e.g. [8]) co-observed at least one of these features. ISS images show clumps in the F ring ([4], [12], [13]). [2] show that Prometheus makes it possible for "distended, yet long-lived, gravitationally coherent clumps" to form.

Numerical models have attempted to explain the distribution of small bodies in the F ring as the equilibrium between accretion and fragmentation. [1] predict that the F ring evolves to a bimodal distribution of bodies that has a large population of dust as well as a few km-sized bodies. N-body simulations of the A and B rings show short-lived clumping of material that could also occur in the F ring [10]. Thus, the F ring is an interesting place of exploration as a testing ground to compare to clumping processes elsewhere in the rings (e.g., A ring propeller belt or B ring edge).

2. Mass of Clumps in the F ring

Seventeen of the significant features seen in the UVIS occultations are likely caused by transient aggregations of ring material [11]. Given the number of observed objects N_{obs} of observed radial width w_r seen in N_{occ} occultations, we extrapolate the total number of bodies in the entire F ring. We assume clump shape can be described as an ellipse, where $R_{axes}=a/b=b/c$ is the axial ratio. We assume the radial semi-major axis of a clump is half the observed radial width and the density of the clump is half that of Prometheus such that ρ_{clump}= 235 kg m^{-3}. Then we calculate the mass of each clump and sum to find the total mass of clumps in the F ring:

$$M_{total} = \sum_{size=small}^{large} \left[\left(\frac{N_{obs} 2\pi R}{N_{occ} R_{axes} w_r} \right) \left(\frac{\pi}{6} \rho w_r^{\ 3} \right) \right] \quad (1)$$

We find the total mass of spherical (R_{axes}=1) clumps in the F ring to be 6.1 x 10^{15} kg. This much mass would cause a change in the precession rate of Prometheus above the observational threshold of approximately 10^{-5} degree per day, a threshold constrained by observations over the last three decades.

Since no such precession has been observed, we modify our calculation so that the total mass would fall below the observation threshold. Assuming the clumps are elongated in azimuth and are vertically flattened, R_{axes}=10, the total mass of clumps in the F ring is 6.1 x 10^{14} kg. This mass is the equivalent of an icy moon with a density equal to that of Prometheus (470 kg m^{-3}) that is 6.8 km in radius. This would cause a change of 2.76x10^{-6} degrees per day in Prometheus's precession rate, which is below the detection threshold.

3. Changes in porosity of clumps

Among the 17 features observed by UVIS that correspond to clumps, two are classified as "moonlets" . These appear opaque in occultation and are likely denser objects than the other 15 "icicles." If looser clumps of material ("icicles") compact into denser, less porous aggregates they may be observed as an opaque "moonlet" in an occultation. Since [11] observe only two moonlets, it seems that this compaction state is rare, which is consistent with a cycle of aggregation and disaggregation that only infrequently results in formation of a coherent object. We investigate the evolution of the size distribution of clumps in the F ring as it relates to porosity changes among clumps. We model accretion and fragmentation in the F ring, considering both radial size and porosity of bodies, to determine how easily porous clumps compact to build moonlets.

6. Conclusions

Observations of the F ring constrain the total mass of transient clumps therein. The mass constraint and the features observed in Saturn's F ring by Cassini UVIS indicate clumps are azimuthally-elongated, vertically-flattened ellipsoids. The number of opaque, probably-solid objects compared to those of lower opacity that are probably loose aggregates indicates that while clumping may be a common process, consolidation into an opaque object, like a moonlet, is not. When we consider the evolution of the porosity of loose aggregates, we find porous material compacts into denser objects that can more easily accrete into larger bodies. Thus, we can expect the F ring to be filled with transient, loosely-aggregated clumps, but the population of consolidated moonlets to be relatively small.

Acknowledgements

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