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Meter-sized boulder population in Saturn's C ring and Cassini Division

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Abstract

The UVIS instrument onboard Cassini provides the best ring plane radius resolution for the examination of fine structures by the observations of stellar occultations. These data make possible the detection and analysis of structures of a few tens of meters wide. Voyager [9] estimated that the particles in the C ring and the Cassini Division had sizes between 10 cm and a couple tens of meters, and followed power-law size distributions ($N(\geq r) \propto r^{-Q}$) with a cumulative power-law index $Q = 2.1$ in the C ring and $Q = 1.75$ in the Cassini Division. No boulder with a size between a couple tens of meters and the size of Daphnis (4 km radius) was known in the main rings until the first observations of 100 m-objects in the A ring were reported [8], verifying the "propellers" models [2, 5, 6].

Scanning the ring system, we observed isolated and unexpected high photon counts in places where the photon counts reach the brightness of the occulted star. This defines a new type of structure named "ghosts" [1]. We identified 35 of these holes in the C ring plateaus and 265 in the Cassini Division Ringlets and Plateaus (mainly in the Huygens Ringlet, the Triple Band and the Cassini Division ramp). No real meaningful spatial distribution can be drawn from our observations since we selected the places where we were observing. However, these features are not circular and we estimate their radial width W.

These ghosts can be explained by some boulders creating propeller structures. The existence of these holes is related to the presence of gravitational disturbances in the ring material: models show that depletion zones are formed on the outer trailing and inner leading sides of an embedded boulder inside the rings [2, 5, 6, 3] while satellite wakes appear a little further. We estimated the width of these ghosts ($5.4 - 46.7$ m in the C ring and $1.7 - 277$ m in the Cassini Division).

The Hill sphere of a boulder of mass M_{boulder} and of semi-major axis a_{boulder} is the region in which its attraction dominates Saturn's attraction. The radius of this sphere is $r_H = a_{boulder} \left(\frac{M_{\text{boulder}}}{3(M_{\text{Saturn}} + M_{\text{boulder}})} \right)^{1/3}$, where M_{Saturn} is Saturn's mass. From numerical tests on various boulder and particle sizes, it appears that the primary depletion zone extensions are not subject to particle size variations as long as they remain at least three times smaller (assuming the same density for the particles and the boulder) than the boulder. In addition, we notice that both radial and azimuthal extensions of the primary lobe seem to grow linearly with the boulder radius, validating the previous estimates [6, 7] stating that $\Delta r \approx 3\ r_H$. However, previous work [4, 6] calculated that the azimuthal extension was supposed to grow as the cube of the Hill radius of the boulder. As we are looking at the primary gaps rather than at the bright structures from images, we are not measuring the same structure azimuthal extent, and our simulations suggest the following for the azimuthal extension $r\ \Delta\phi = (33.4 \pm 2.0)\ r_H$.

Assuming that the holes observed by UVIS are part of the propeller signatures created by boulders orbiting the rings, we are able to estimate the Hill radii for these boulders and therefore derive their actual radii. This process however does not take into account the fact that our stellar occultation resolutions are not uniform: even though the UVIS instrument has a constant integration time, each occultation has a specific navigation and geometry configuration that changes the spatial resolution in the ring plane. The fact that each occultation has its own resolution introduces a bias in our hole width measures. In order to estimate the impact of this variability and in order to model the difference between the observable widths and the observed widths, we use a Monte Carlo algorithm designed to model the statistical impact of our occultation resolution variations. This algorithm will evalu-

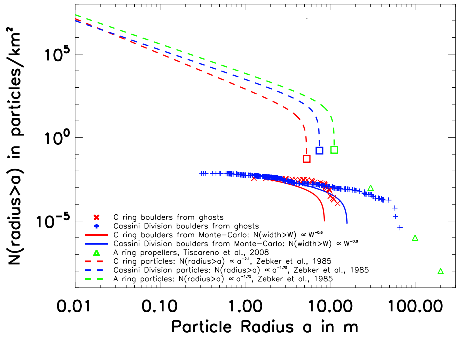

Figure 1: **Cumulative particle size distribution for the C ring (red), the Cassini Division (blue) and the A ring (green)**. Smaller particle populations [9] are displayed with dashed lines while potential boulders at the origin of propellers are shown in scattered points and the source distribution estimated from the Monte-Carlo algorithm is displayed in solid lines. The squares delimits the upper cutoff [9] in the particle size distributions.

ate the modeled observed hole widths from a known particle size distribution. We assume that the particle size distribution in the Cassini Division can be modeled as a power-law. The initial cumulative particle size distribution that reproduce the best the observed width distributions are $N(\geq r) \propto r^{-0.6}$ in the C ring and $N(\geq r) \propto r^{-0.8}$ in the Cassini Division, where $N(\geq r)$ is the number of particles with a radius larger than r.

Fig. 1 compares particle size distributions and boulder size distributions for the C ring and the Cassini Division. The boulders do not follow the previous trend of the particle size distributions. The scatter points were directly derived from the holes widths, assuming that a hole was systematically scanned at its maximal radial extension and that the occultation resolution was smaller. Therefore, the comparison, in Fig. 1, between the estimated radii of the boulders, and the inferred power-law size distribution obtained from the Monte-Carlo algorithm shows the relative importance of the resolution bias. In particular, we believe that the steeper parts of the size distribution appear for lower radii in the Monte-Carlo results because of the azimuthal bias in our hole widths measurements: since we considered that the holes were always observed at the azimuth where their depletion zone is maximal, it is normal that individual boulder radii are over-estimated.

Our boulders constitute evidence of a secondary population of bigger particles (reaching 5 m in the C ring and up to 20 m in the Cassini Division) that cannot be obtained by extrapolation of the previous particle size distribution models. We conclude that this population is the result of accretion in the rings.

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