# Clues to clumping in Saturn's rings from Cassini UVIS stellar occultations


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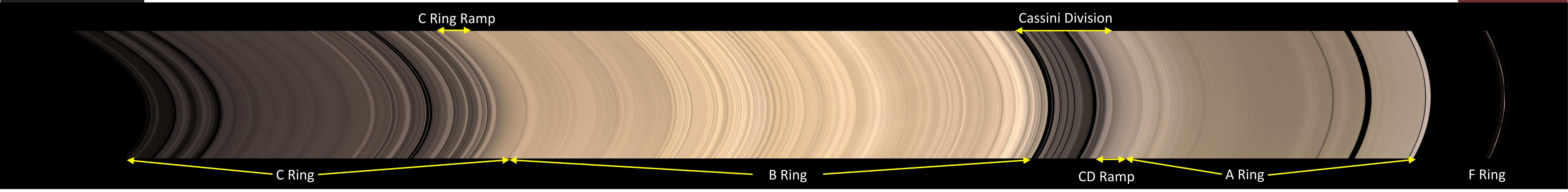


**Introduction:** Several independent lines of evidence point to various forms of particle clumping or aggregation throughout Saturn's rings. The signature of self-gravity wakes, transient gravitationally-bound clumps of particles at the stability limit, is present in multiple datasets across the A ring as well as in much of the B ring. Images of the C ring also show non-axisymmetric structure that is due to either clumps, localized gaps, or a combination of the two. We present observations from the Cassini UVIS stellar occultations that reveal the presence of clumps and gaps across the rings. Self-gravity wakes in the A and B rings produce a characteristic variation in line-of-sight optical depth with viewing geometry. This signature is absent from the C ring and Cassini Division, though there are variations observed that are likely due to the finite vertical extent of the rings. Localized holes have been observed, however, in the C ring and Cassini Division that have been interpreted as the clear zone produced by a nearby massive object (Baillié et al. 2013). We extend the analysis of the statistical moments of the UVIS stellar occultation data to the skewness and kurtosis that place additional constraints on the distribution of particle sizes and the presence of outliers such as large aggregates or localized gaps. In addition some occultations have very slow speeds in the frame of the ring particles, providing a direct measurement of the ring transparency at the scale of the largest particles and clumps.

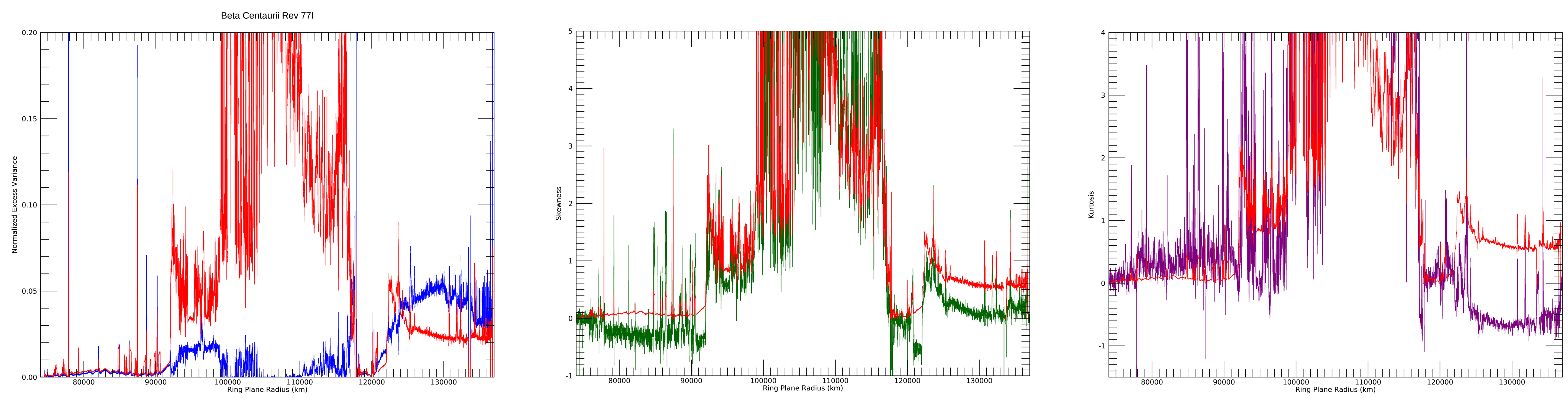


Figure 1: Optical depth (red, scaled by 0.04 in left panel), normalized excess variance (blue), skewness (green), and kurtosis (purple) of Saturn's rings from the Beta Centauri 77I stellar occultation at 10 km radial resolution. The variance is largest in the A ring, dominated by large self-gravity wakes (Figure 2). Skewness is negative in the C ring and Cassini Division, especially in the ramp features, but positive and correlated with optical depth elsewhere. The Kurtosis is negative in the A ring, but barely so in the inner B ring where self-gravity-wake-like behavior is also seen.

## Self-gravity wakes

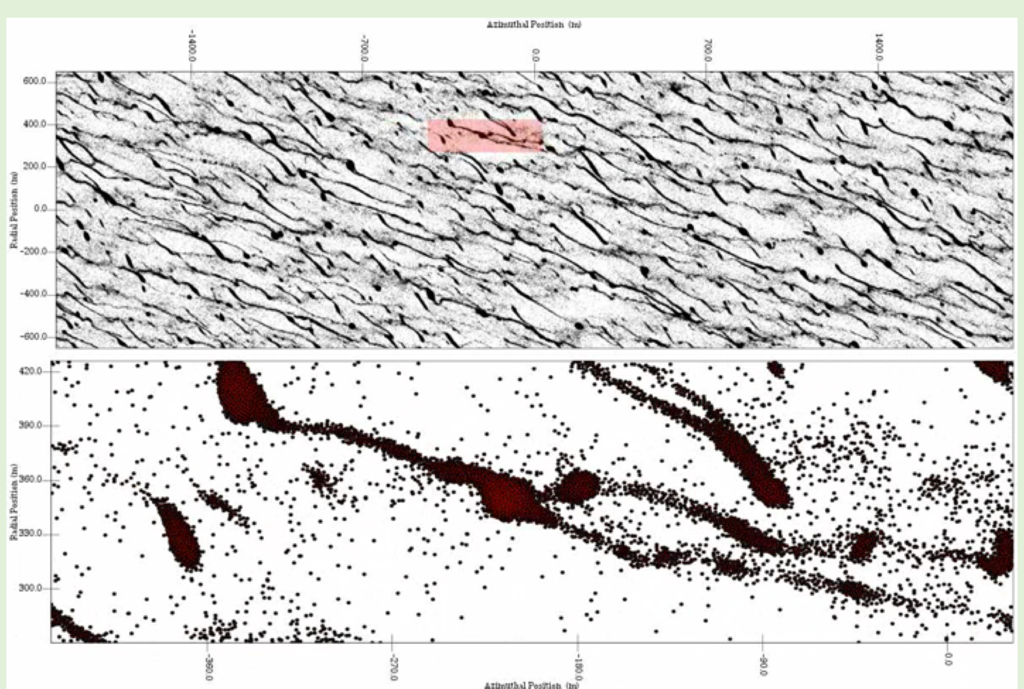

Figure 2: N-body simulation showing the formation of self-gravity wakes with a characteristic cant angle and semi-regular spacing at the Toomre most-unstable wavelength of about 50 m in the A ring. Saturn is down and orbital motion is to the right. The red indicates the formation of a particularly massive clump. If such an object forms in a uniform ring without self-gravity wakes, it can open a truncated propeller gap (Figure 3).

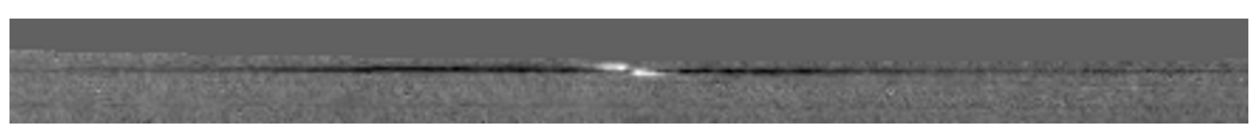

Figure 3: Image of a propeller feature in Saturn's A ring. An unresolved moonlet at the center of the feature perturbs the orbits of the neighboring ring particles opening a truncated gap (black) that is nearly devoid of particles. The area of the gap is much larger than that of the moonlet that produces it, so occultations are much more likely to cross the gap. Baillié et al. (2013) found a distribution of gaps in the C ring and Cassini Division consistent with accreted objects (Figure 4).

## Ghosts in the rings

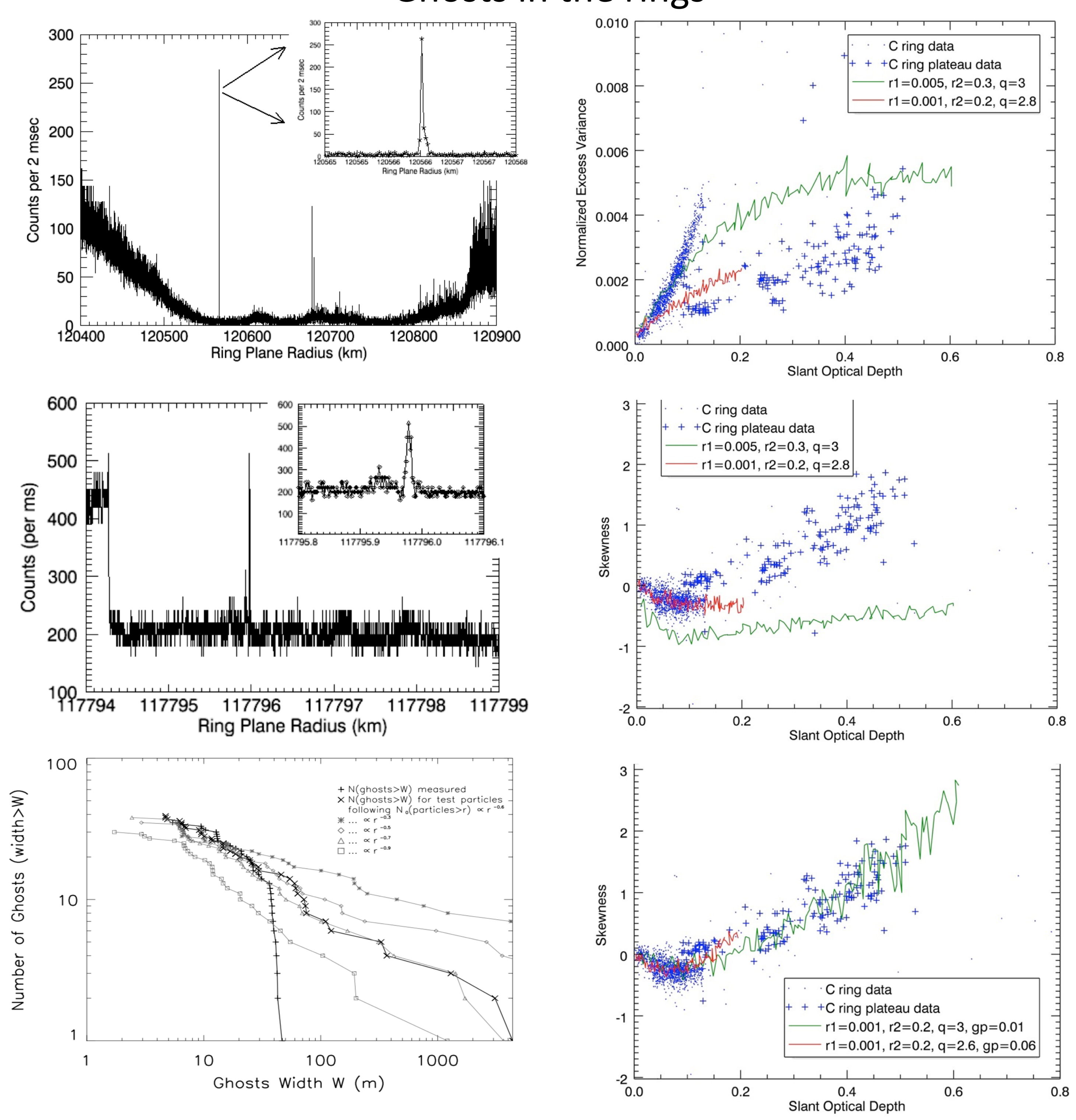


Figure 4: Left: Examples of two "ghosts" in the Cassini Division and the distribution of ghost widths corresponding to a shallower size distribution of boulders or moonlets than a fragmentation distribution (Baillié et al. 2013). Right: While the excess variance of the C ring and its plateaus can be fit with simple power-law distributions (top), to simultaneously fit the observed skewness ghosts must be inserted, with a larger percentage in the plateaus than the background C ring.

## Inferring particle properties from distributions of statistical moments

Distributions of the statistical moments E (excess variance), S (skewness), and K (kurtosis) with optical depth (directly calculated from the first moment, or mean, of the data) provide ready comparisons between different ring regions. Figure 5 shows that the C ring plateaus and background C ring have very different characteristic particle sizes based on E, and the shape of E(τ) in the background C ring suggests a size sorting with optical depth. Figure 6 shows a comparison of all three moments between the structurally similar C ring and Cassini Division ramps.

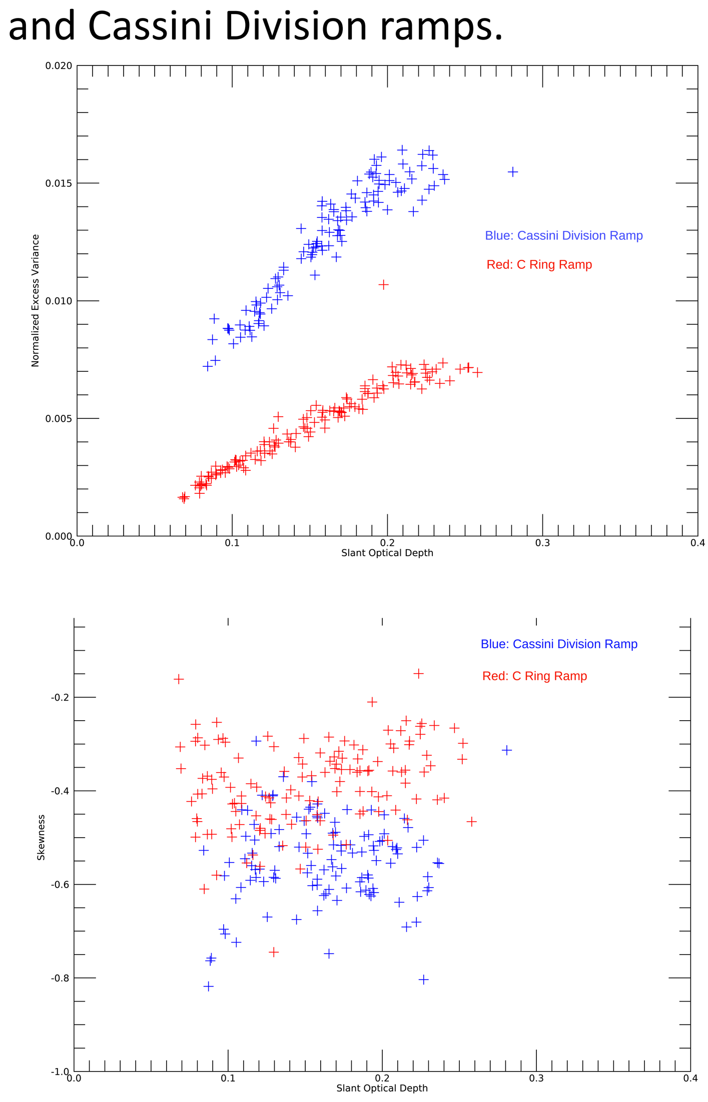


Figure 6: Although the optical depths and overall structure are similar, the two "ramps" in the rings exhibit different particle sizes and gaps as revealed in distributions of E and S.

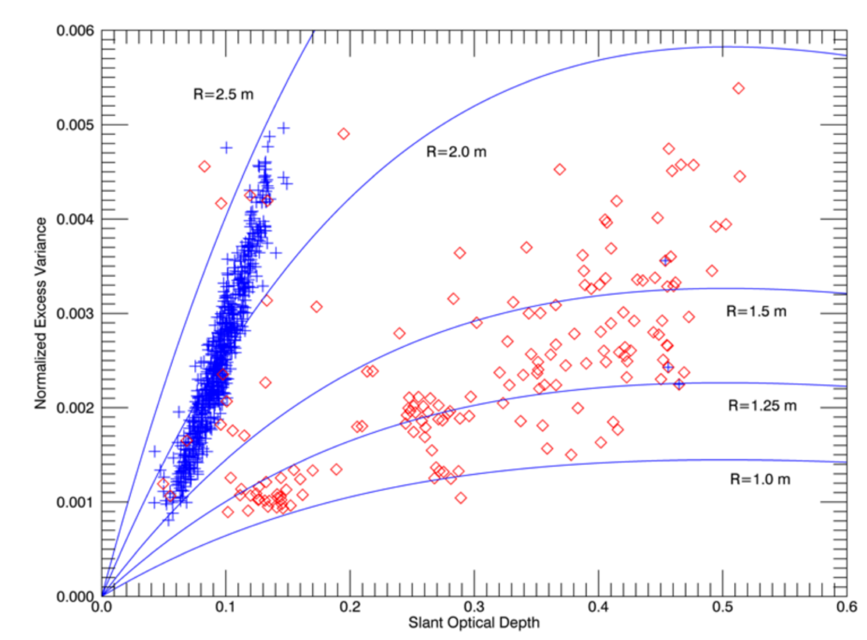


Figure 5: Distribution of E in the C ring for the low-t regions and the plateaus with single-sized-particle models from Colwell et al. (2018).

Summary: higher order moments of UVIS stellar occultations reveal differences between ring regions beyond the effective particle or clump size revealed by the excess variance, E. Skewness is diagnostic of the presence of gaps or "ghosts" in the C ring. Kurtosis appears to be particularly diagnostic of the strong self-gravity wake structure in the A ring.


References: Baillié et al., 2013, *Astron J.* **145**, 171. Colwell et al., 2018, *Icarus* **300**, 150.



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