Comparing Clumps in Saturn's F Ring from Voyager to Cassini

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1. Introduction

Saturn's F ring exhibits dramatic radial and longitudinal variation and changes over time spans ranging from hours to months. We illustrate a new method for efficiently finding clumps (diffuse bright features ~5–50° in longitudinal extent) using wavelet analysis on longitudinal profiles. We track these clumps over time to determine their semimajor axes and we also compare the distribution of clumps seen by Cassini with those seen by Voyager 1 and 2 25–30 years earlier. This poster is an update of French et al. (2012a).

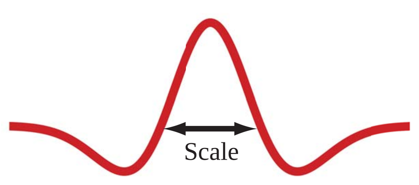
2. The Continuous Wavelet Transform

The continuous wavelet transform (CWT) is used to analyze 1-D data by correlating a shifted and scaled "mother wavelet" with each location in the data and for each scale. This produces a 2-D location-scale representation of the data called a "scalogram". Maxima in the scalogram indicate the locations and scales where the mother wavelet best fits the data. We use both the 2nd derivative of the Gaussian ("Mexican Hat") and the similarly-shaped 4th derivative of the Gaussian ("FDG") wavelets, choosing whichever is the best fit at a given longitude. The CWT can be implemented using the Fast Fourier Transform, allowing its efficient computation.

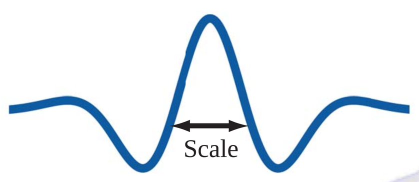
CWT: $$X_w(a,b)=\frac{1}{\sqrt{a}}\int_{-\infty}^{\infty} x(t)\,\psi^*\!\left(\frac{t-b}{a}\right)dt$$

Longitudinal Profile — Mother Wavelet

Mexican Hat Wavelet

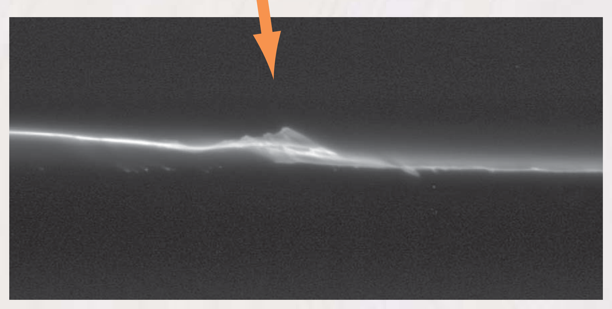


FDG Wavelet

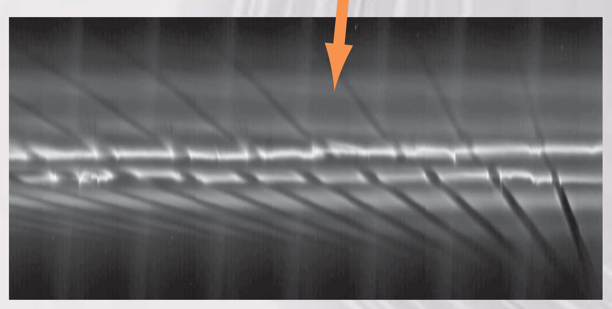


3. Creation of Longitudinal Profiles

We create longitudinal profiles of 68 "movies" taken by Cassini from 2004–2010, each consisting of hundreds of images taken during one F ring orbit. We first orient and reproject these images and combine them into a high-resolution mosaic. We then integrate radial slices through the mosaic, producing a profile of the brightness of the F ring in resolution-independent units called "equivalent width". This profile is passed through a low-pass filter to remove high-frequency fluctuations. All longitudes are measured relative to a reference frame co-rotating with respect to the mean motion of the F ring (assumed to have a semimajor axis of 140,220 km).



(Sample Image)



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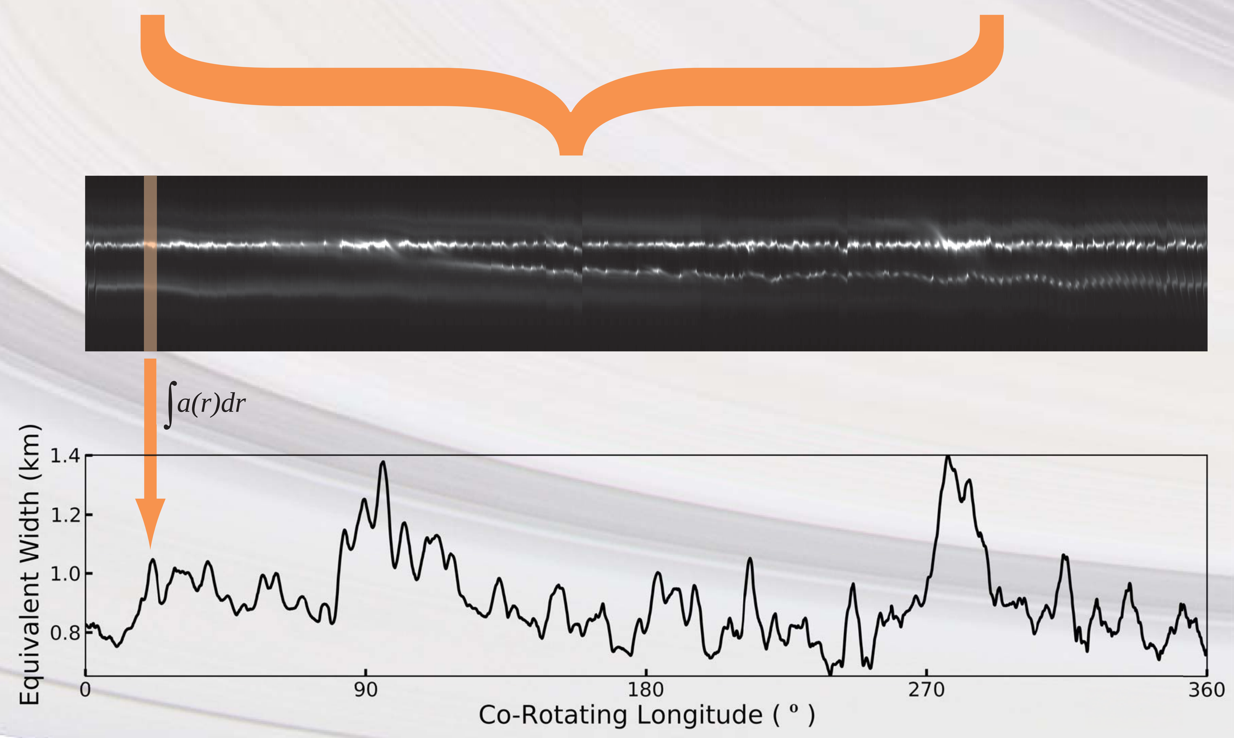
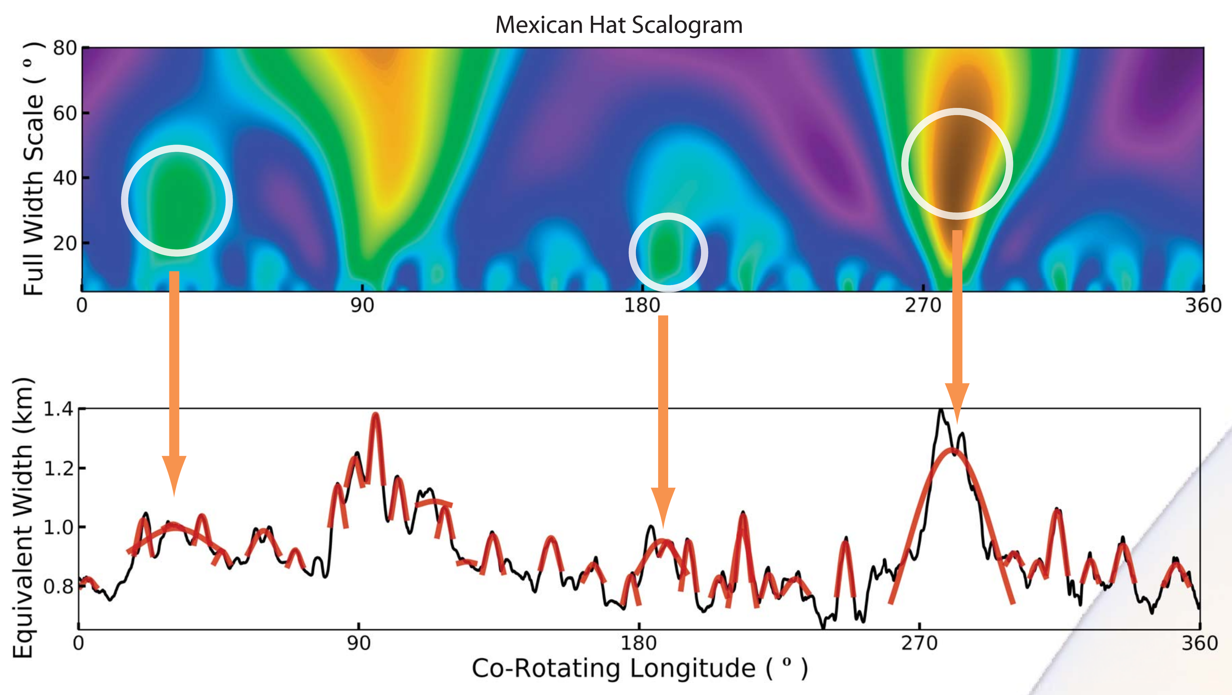


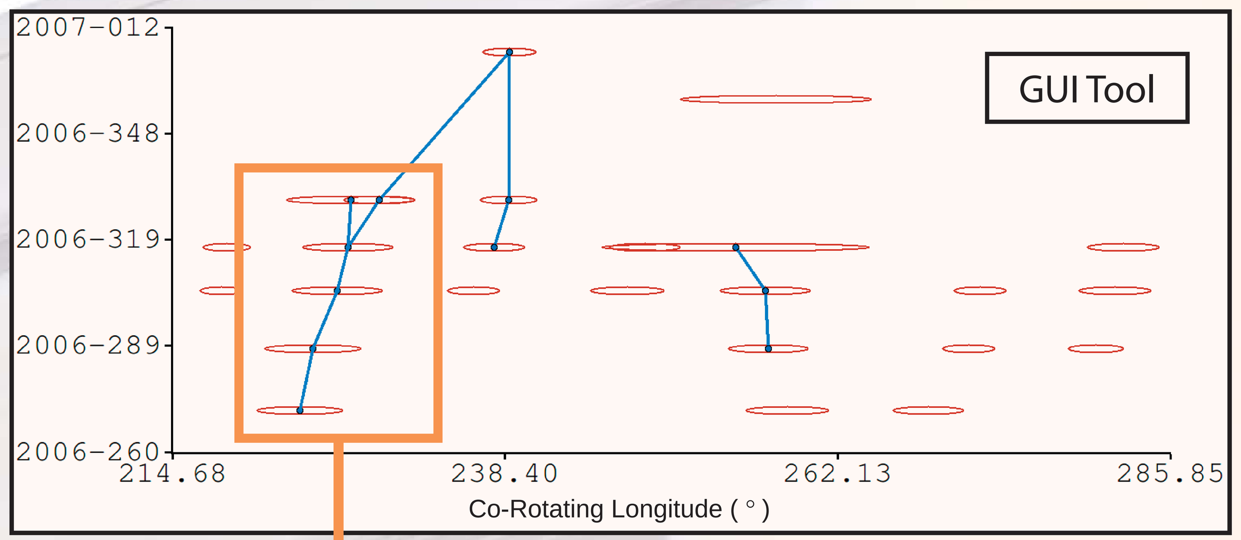
4. Detection of Clumps Using Wavelets

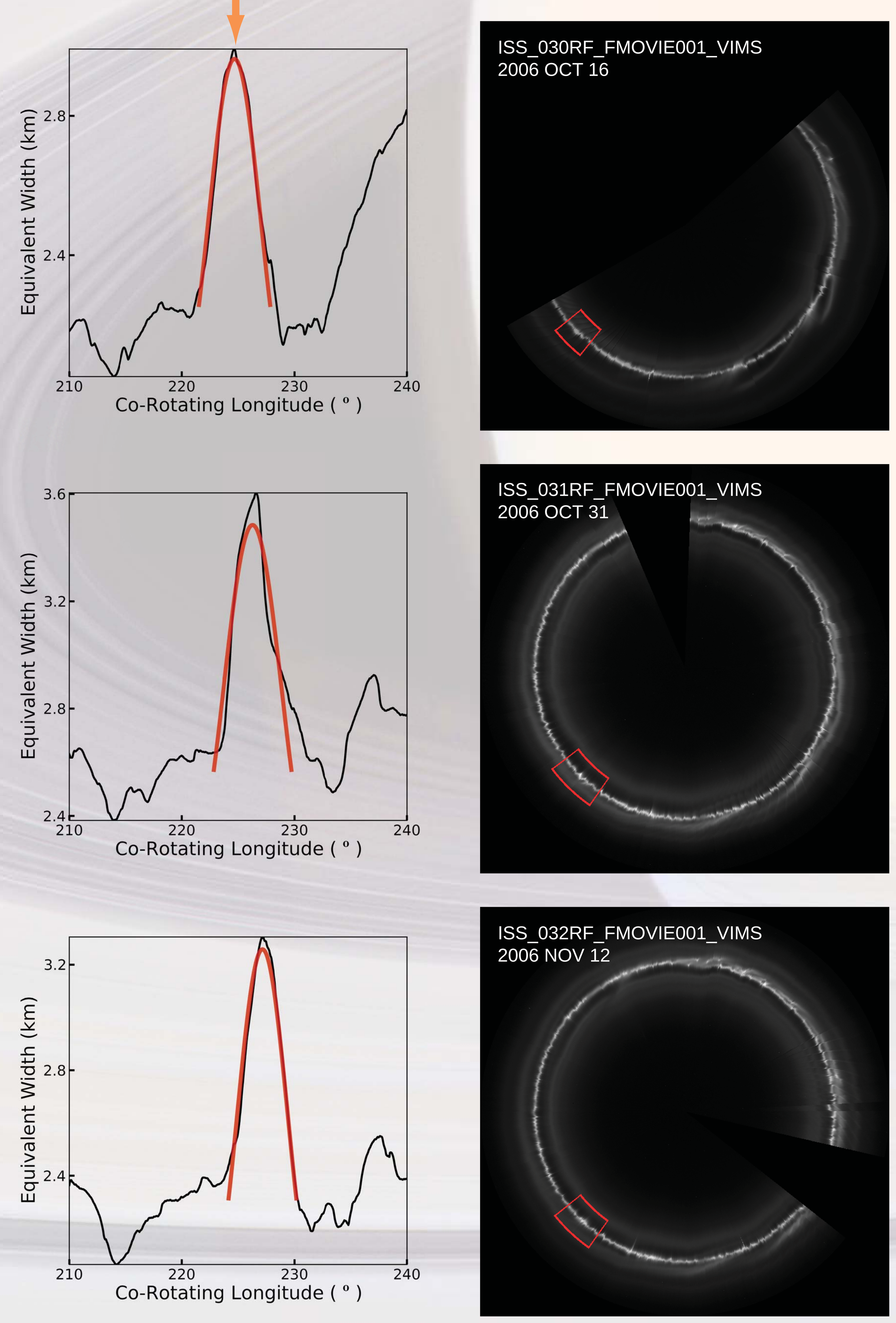
We compute the CWT for each profile. Within each scalogram, every local maximum indicates the location and scale of a potential clump. Multiple clumps may overlap with different scales.



5. Detection of Clump Motion

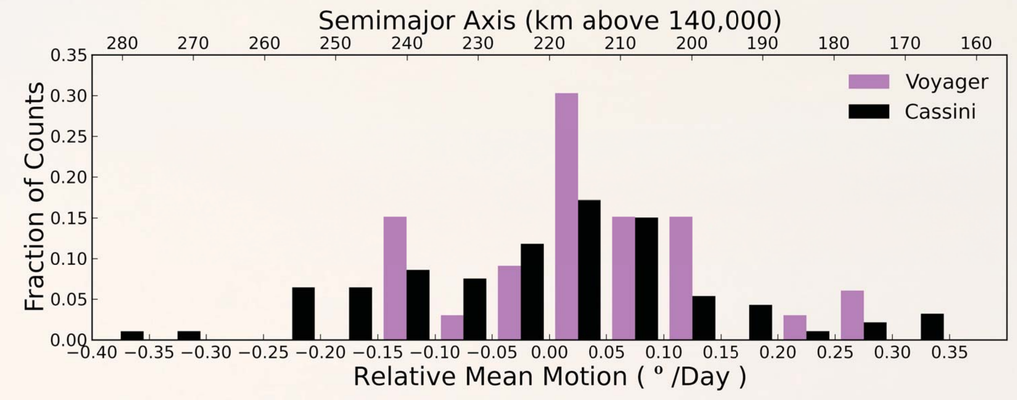
We automatically detect the presence of the same clump in multiple (two or more) movies by looking for a near-linear change in longitude with time. A GUI interface allows us to easily examine the detected moving clumps to determine their validity. One moving clump is shown below (motion relative to the F ring core is 0.0686°/day).





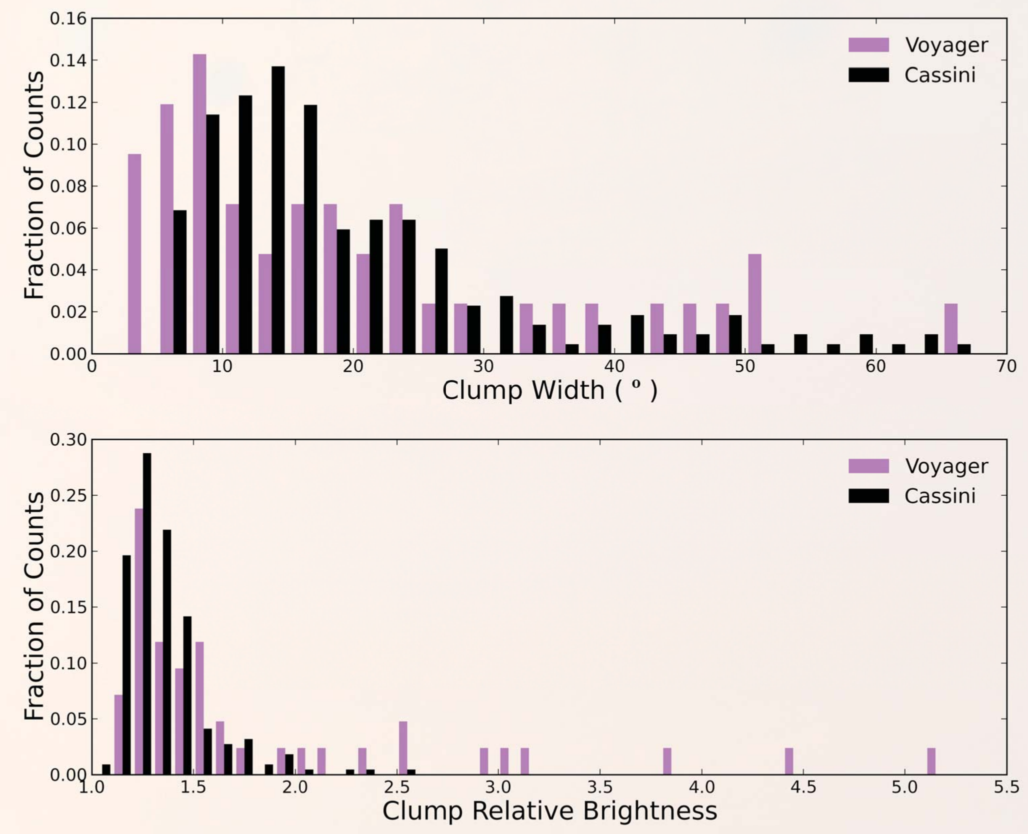
6. Analysis of Clump Motion

We have verified 93 valid moving clumps in our Cassini data. The longest-lived clump survived 61.8 days. We have tracked a single clump through at most 4 movies. We derive the semimajor axis of a clump by measuring its mean motion from movie to movie. A similar methodology was used by Showalter (2004) to find moving clumps in Voyager data. Both data sets are similar (Cassini 0.05±0.12 °/day, Voyager 0.02±0.18 °/day) and approximately normally distributed (χ^2 Cassini $p = 0.98$, Voyager $p = 0.41$):



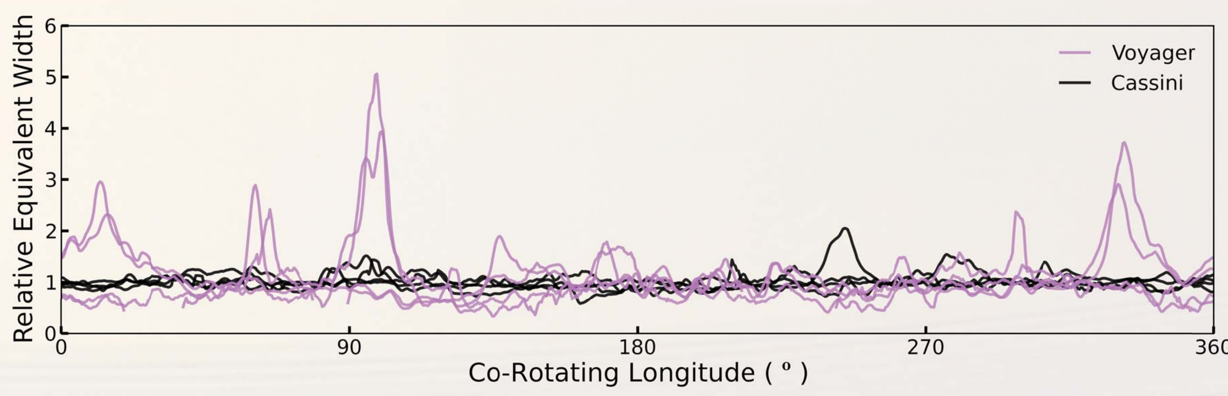
7. Comparison of Clump Attributes

Applying wavelet analysis to the clumps identified by Showalter (2004) and comparing them using Kolmogorov-Smirnov tests with the moving clumps we found in 68 Cassini profiles, we find that Voyager saw more clumps at a given time (10.0±0.5 vs. 4.0±3.5, $D = 0.75$, $p < 0.01$) and the clumps were brighter ($D = 0.61$, $p < 0.01$). Although visual inspection shows that the Voyager clumps were also narrower, confidence is low ($D = 0.19$, $p = 0.70$).



8. Analysis and Conclusion

In previous work (French et al. 2012b), we showed that the F ring was, on average, twice as bright and 2–3 times wider in 2004–2010 (Cassini) as it was in 1980–1981 (Voyager 1 and 2), which is consistent with more material being present in the "wings" and less material being concentrated in the core. Our new measurements show that the ring had many more clumps during the Voyager era, and the clumps were brighter and more concentrated. Even a cursory glance at ring profiles shows that the F ring today is much less "clumpy" and has fewer large localized changes in brightness ($\sigma_{Cassini}/\sigma_{Voyager} = 0.43$):



These observations combine to show that during the Voyager era, ring material was located closer to the core and was concentrated in more and brighter clumps, while during the Cassini era ring material is more spread out and there is less material in clumps. The cause of these changes in the ring is the subject of ongoing research.

References

French, R. S. et al. 2012a, AAS DPS Abstract #414.06
French, R. S. et al. 2012b, Icarus, 219, 181
Showalter, M. R. 2004, Icarus, 171, 356

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