Analysis of Longitudinal Variation in Saturn's F Ring Using Wavelets

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1. Introduction

Saturn's F ring is well known for its dramatic radial and longitudinal variation and its continuing change over time spans ranging from hours to months. In this work, we illustrate a new method for efficiently finding and analyzing clumps (diffuse bright features around 5–20 degrees 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.

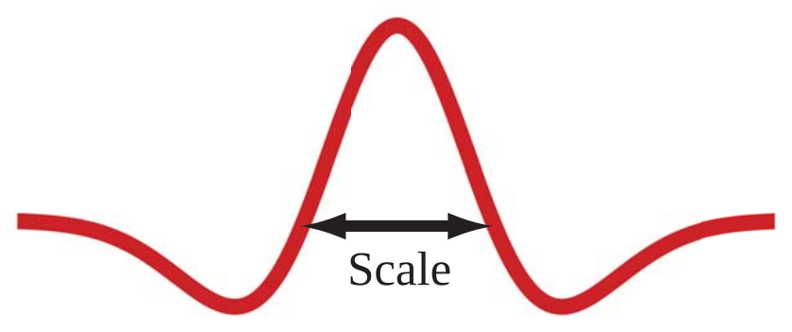
2. The Continuous Wavelet Transform

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". We use the real-valued Second Derivative of the Gaussian ("Mexican Hat") as the mother wavelet because it fits the general shape of clumps in the F ring. Maxima in the result indicate the locations and scales where the mother wavelet best fits the data. The CWT can be implemented using the Fast Fourier Transform, allowing its efficient computation.

CWT:

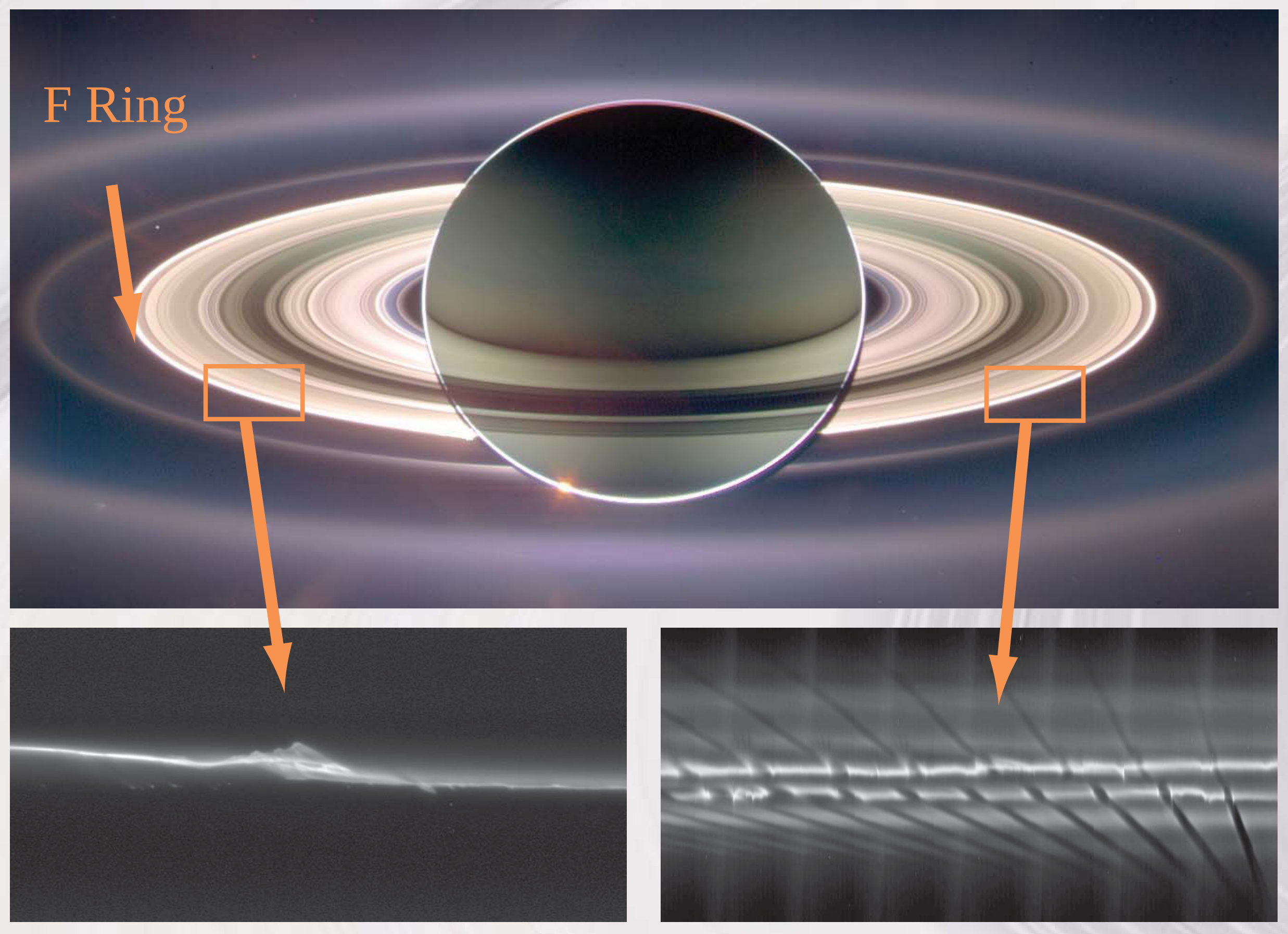
$$X_w(a,b) = \frac{1}{\sqrt{a}}\int_{-\infty}^{\infty} \underbrace{x(t)}_{\text{Longitudinal Profile}} \underbrace{\psi^*}_{\text{Mother Wavelet}}\left(\frac{t-b}{a}\right) dt$$

Mexican Hat Wavelet:

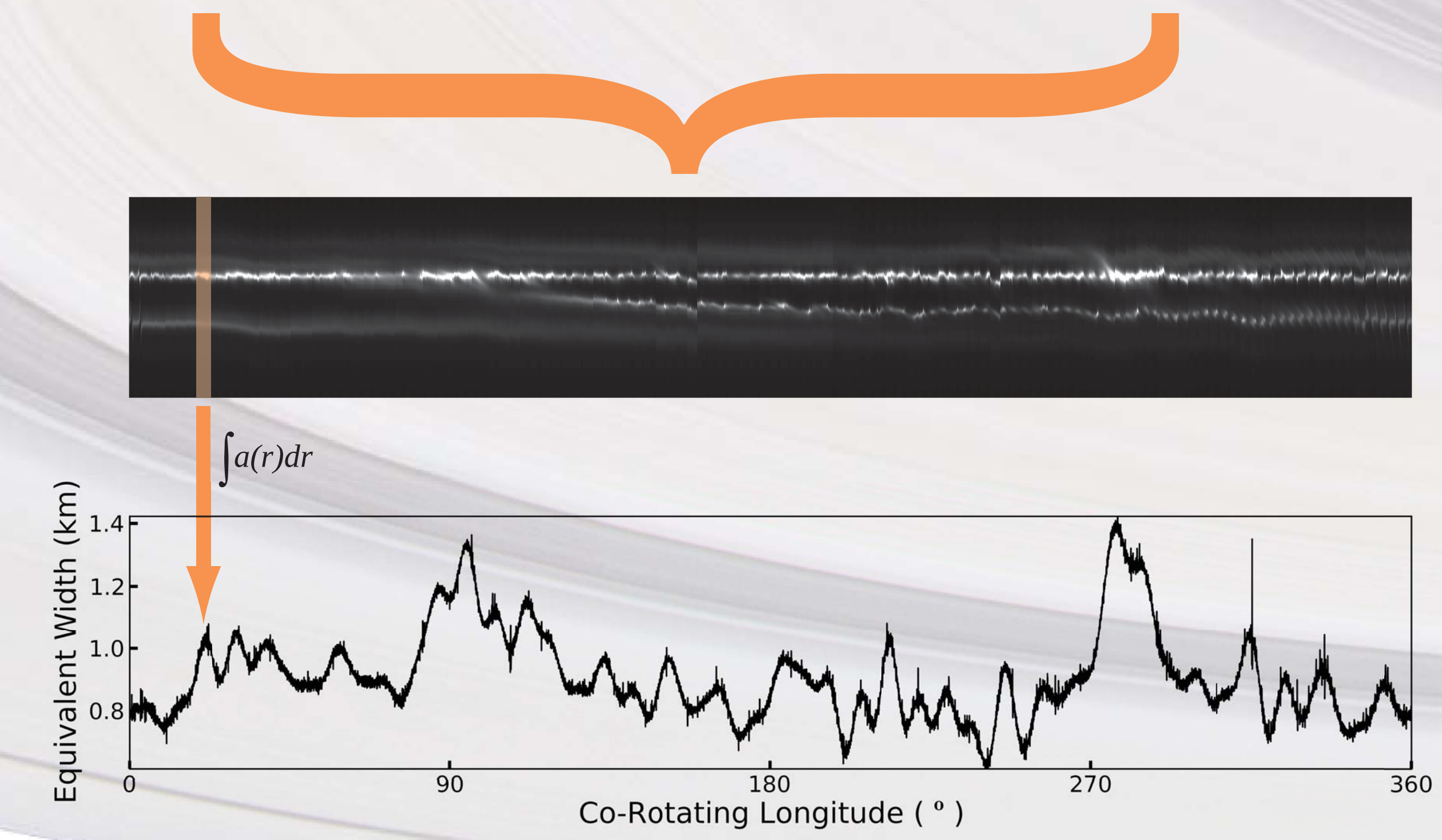


3. Creation of Longitudinal Profiles

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 be centered on 140,220 km from Saturn's center).

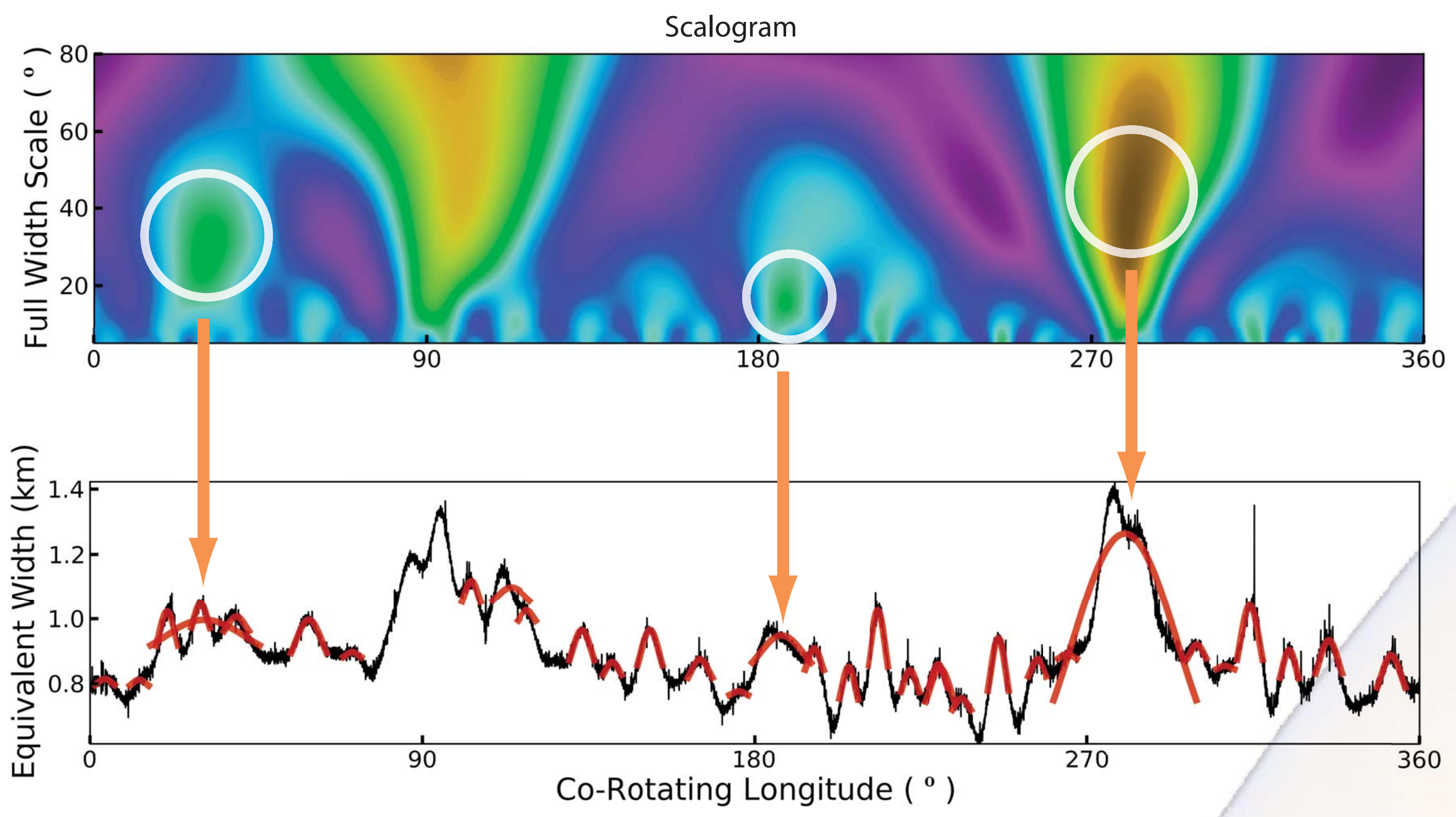


(Sample Image) (Sample Image)



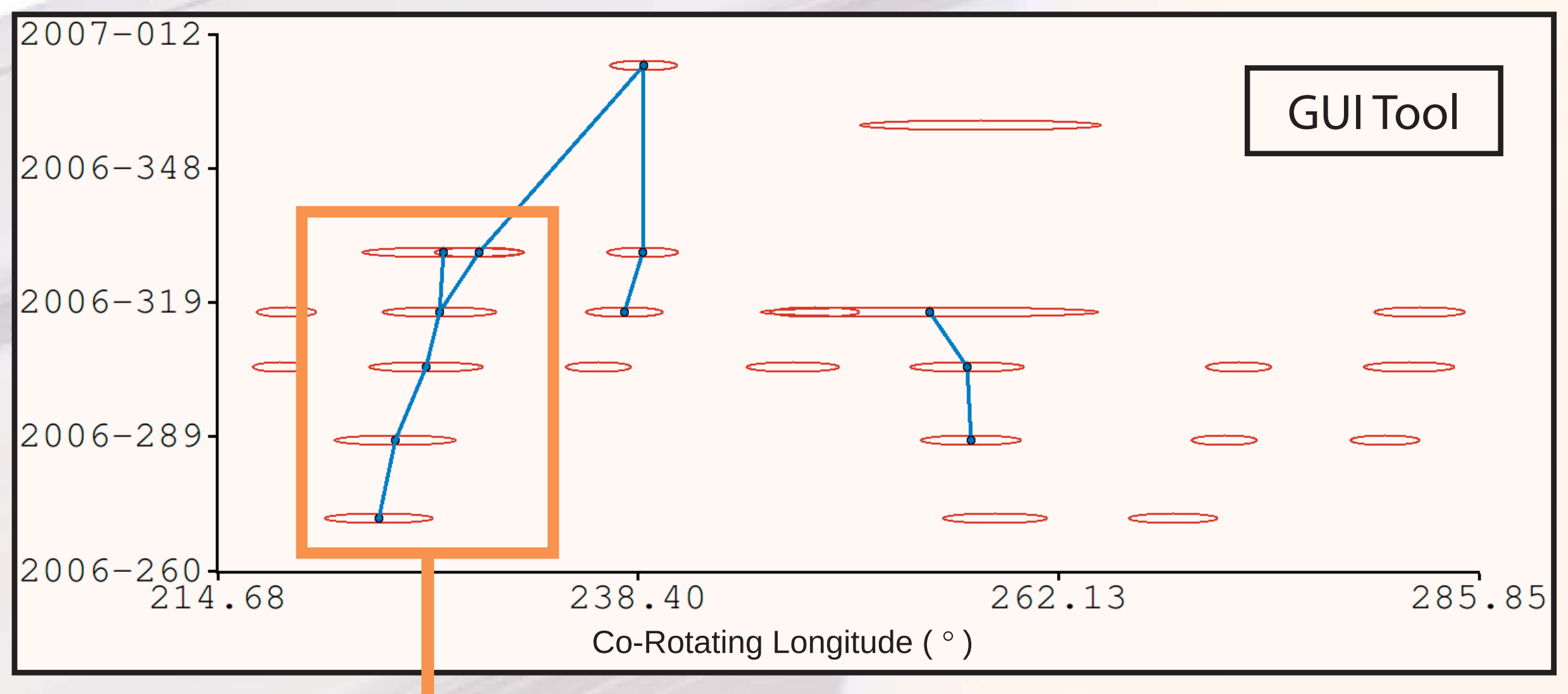
4. Detection of Clumps Using Wavelets

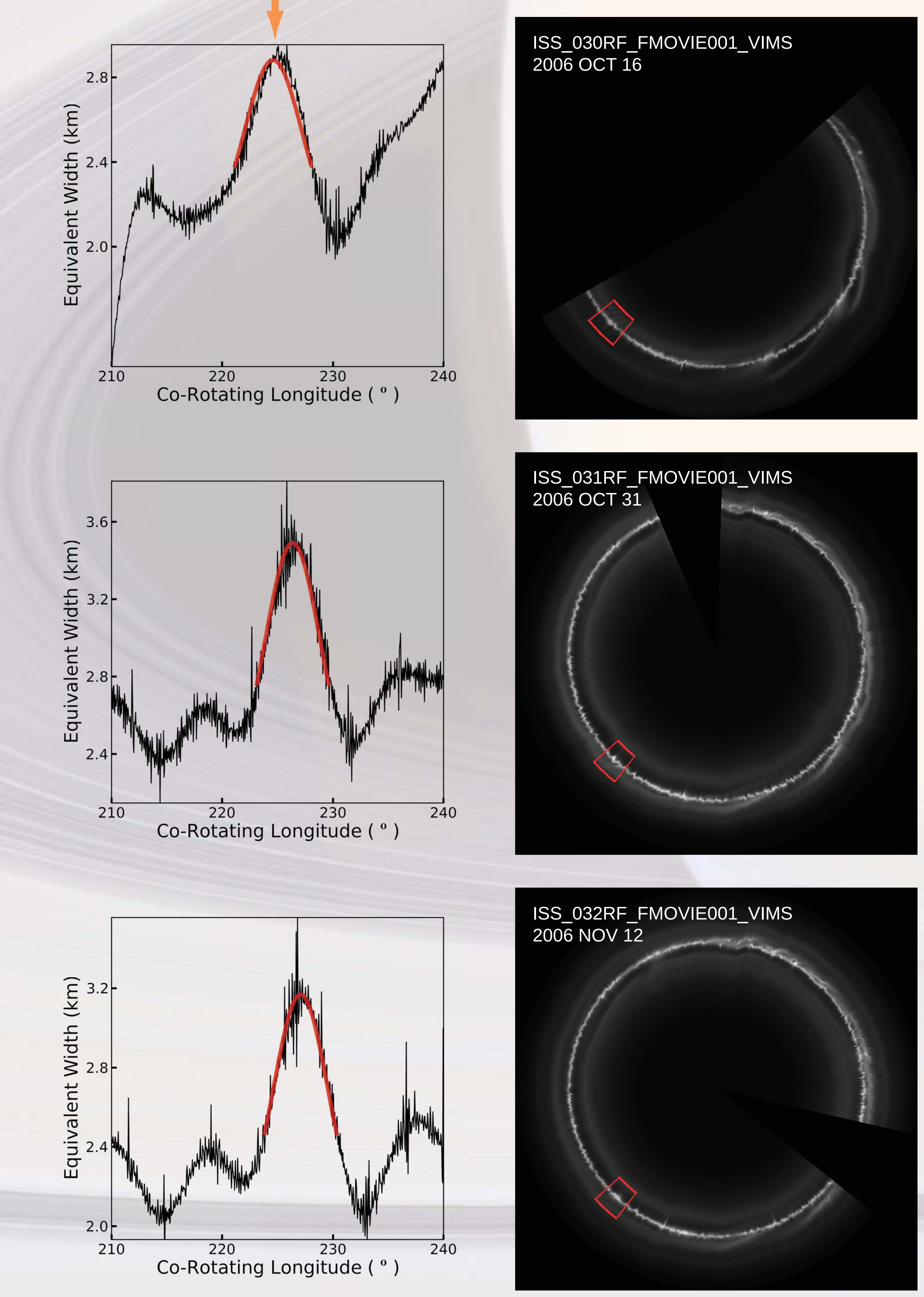
We compute the CWT for each profile. Within each scalogram, every local maximum indicates the location and scale of a potential clump. Multiple clumps may overlap with different scales.



5. Detection of Clump Motion

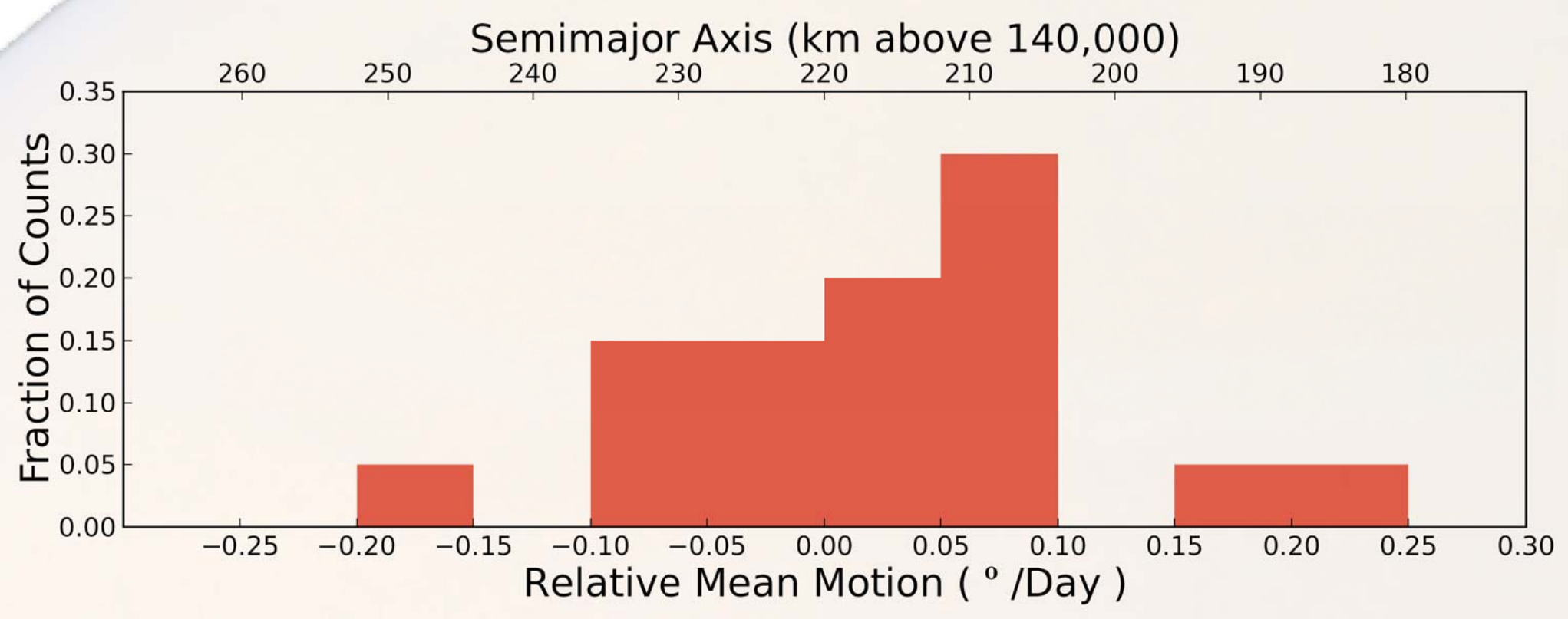
We automatically detect the presence of the same clump in multiple (three or more) movies by looking for a near-linear change in longitude with time. A GUI interface allows us to easily examine the detected moving clumps to determine their validity. One moving clump is shown below (motion relative to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





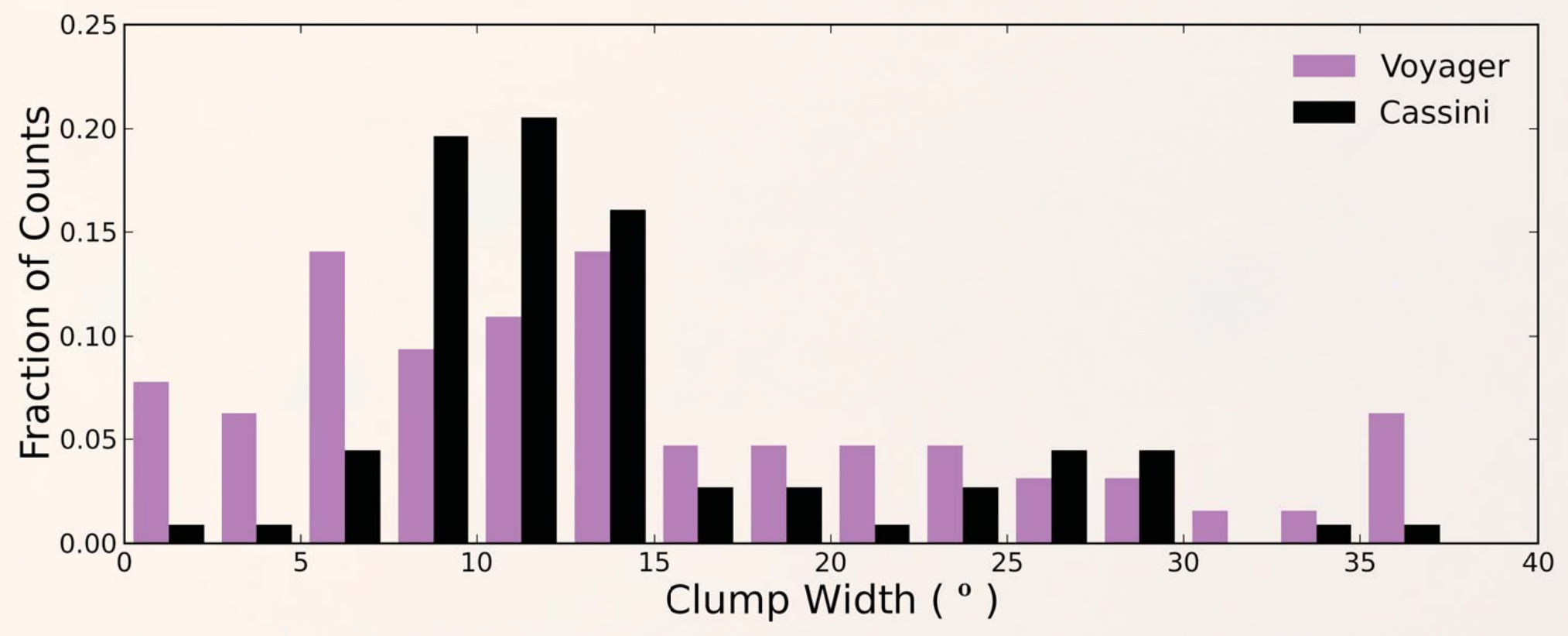
6. Analysis of Clump Motion

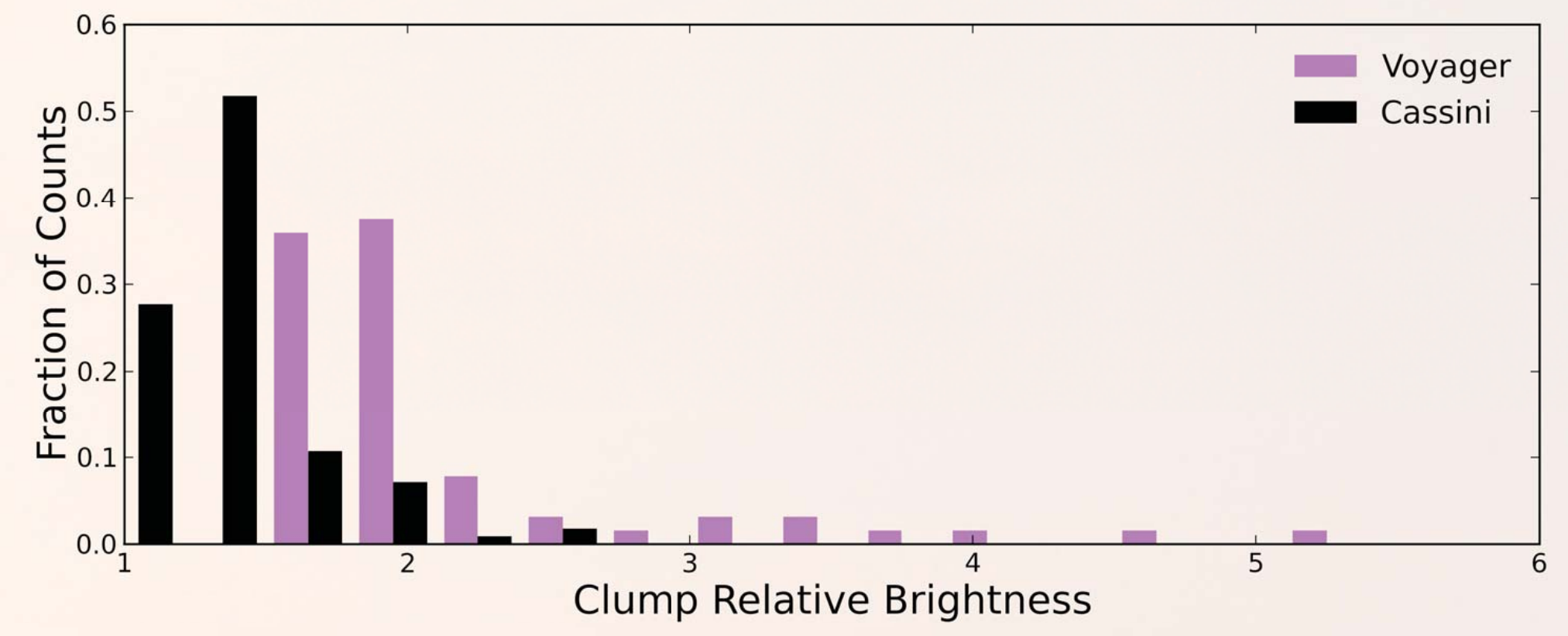
To date we have verified 19 valid moving clumps in our data. The longest-lived clump survived 77 days. We have tracked a single clump through at most 5 movies. We derive the semimajor axis of a clump by measuring its mean motion from movie to movie. All clumps are located within 40 km of the F ring's core and the distribution of semimajor axes is shown below:



7. Comparison with Voyager

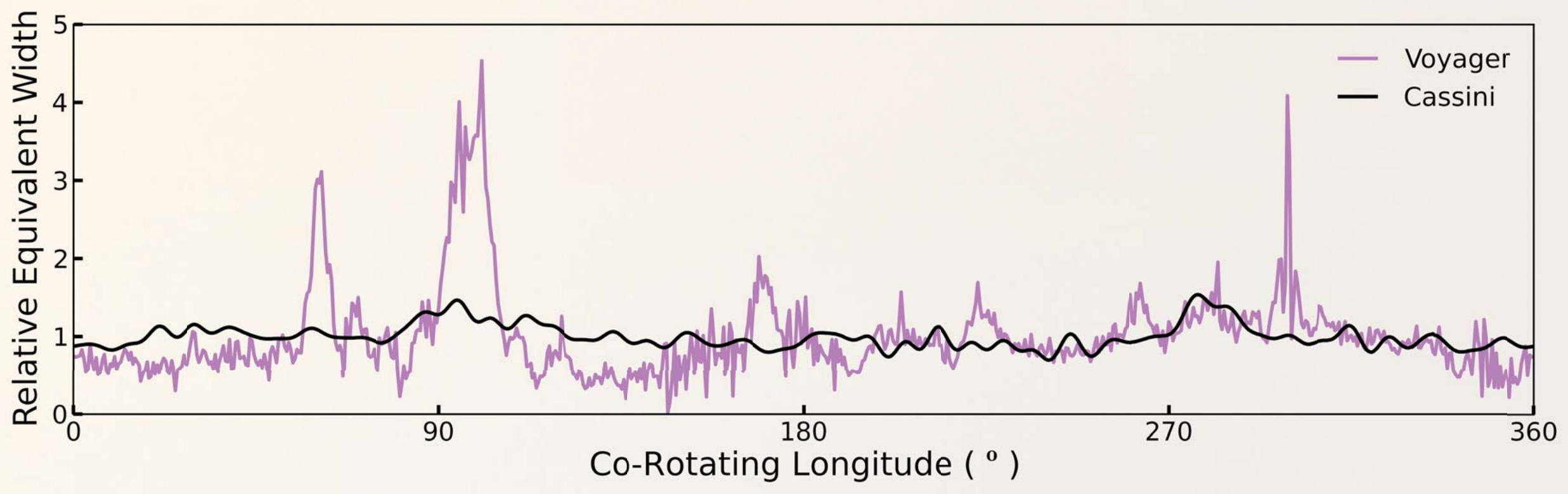
Applying wavelet analysis to four complete Voyager profiles (Showalter 2004, Icarus, 171, 356) and comparing them with 10 complete Cassini profiles, we find that Voyager saw more clumps at a given time (16±5.6 vs. 10±7.7) and the clumps were both narrower (15±10° vs. 21±17°) and brighter (relative brightness 2.2±1.0 vs. 1.36±0.27).





8. Analysis

In previous work (French et al. 2012, Icarus, 219, 181), we showed that the F ring was, on average, twice as bright in 2004–2010 (Cassini) as it was in 1980–1981 (Voyager 1 and 2). We also showed that the ring was 2–3 times wider during Cassini, 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 ($\sigma_{\text{Cassini}}/\sigma_{\text{Voyager}} = 0.43$):



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.

9. Conclusion

Wavelet analysis provides a simple and efficient way to detect clumps in the F ring. Using wavelets, we have detected clumps that live across multiple movies and characterized their motion. Our research shows that the F ring changed both qualitatively (general variation) and quantitatively (number, width, and height of clumps) from the Voyager era to the Cassini era. These changes are in addition to a previously detected change in the overall brightness and width of the ring, showing that the F ring has fundamentally changed during the 30 years of available data.

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