Searching for structure in the rings of Saturn

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Objectives

This work is guided by the following objectives:

- Smallest substructures of meter-scale have been identified by Cassini UVIS instrument.
- Esposito et al.[1] developed a model that creates larger substructures from smaller ones by agglomeration.
- Correlating locations of prevalence of mid-scale structures [1..tens of km] near the locations of smallest substructures would support this model
- Defining methods to objectively identify structures of different size scales becomes imperative.

Introduction

Cassini data have shown that the rings of Saturn are much more dynamic in their behavior than it was known after the Voyager observations. Occultation profiles of the edges of the rings from Cassini's UVIS instrument show wide variability, indicating perturbations by local mass aggregations. The timescales for aggregation and disaggregation range from hours to months, this collective behavior of the ring particles can be described by a mass-based predator-prey system as described in [1]. We present a study testing out several signal processing methods for identifying oscillations near the strongest spiral density waves that fit either the description of straw-like features as identified in [2] or that of Lindblad resonances as investigated by our group in [3].

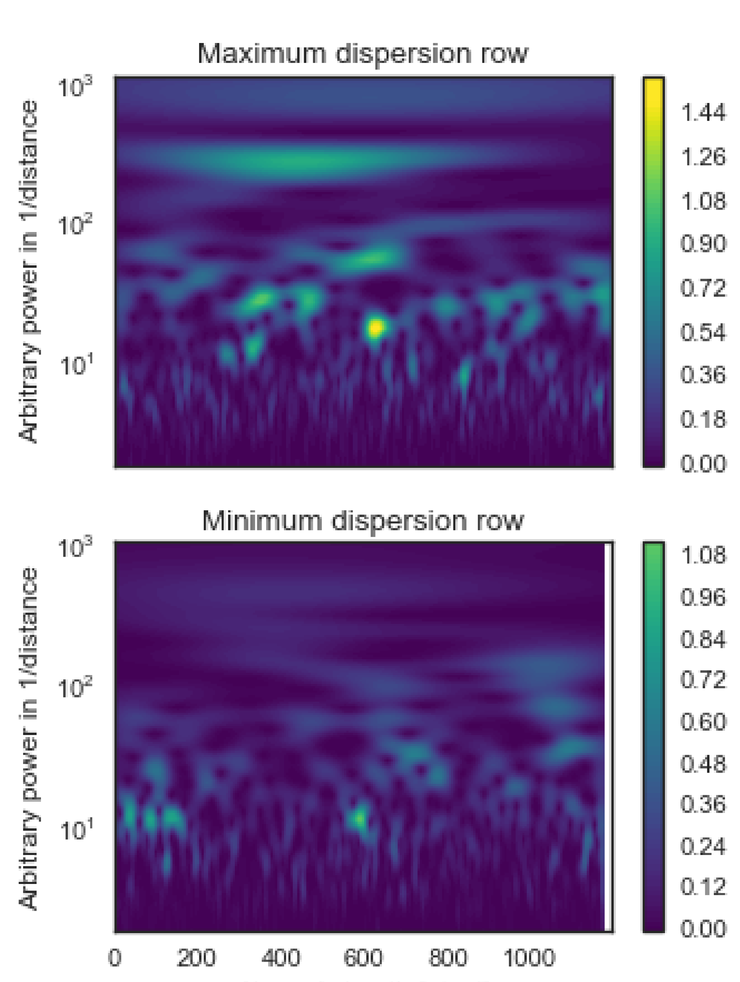

Figure 1: Example wavelet analysis

Materials

In the current work, image data from Cassini's Imaging Science Subsystem (ISS) taken during the Saturn orbit injection (SOI) phase are being analyzed (very high resolution). We developed a calibration and filtering pipeline based on the ISIS software toolkit, published as an open source Python-based library called "pyciss" [4].
As part of this pipeline we project the ring data into a Saturn-centered cylindrical coordinate system (see Fig. 2) based on CASSINI SPICE kernels. The advantage of this is that the azimuthally symmetric structure of the rings become parallel and one can integrate mathematical operations on the data for a better signal to noise ratios of any feature being studied.

Method 1 (cont.)

We therefore apply a more robust median-based variance measure of dispersion called "*median absolute deviation*" (MAD), which is defined as the median of the absolute deviations from the data's median, i.e.

$$\mathrm{MAD} = \mathrm{med}_i \left(\left| X_i - \mathrm{med}_j \left(X_j \right) \right| \right) \quad (1)$$

with $X_1, X_2, \ldots, X_n$ a uni-variate data set and "med" the median of a set of data.
The MAD value has therefore a similar relationship to the *median* value as the *standard deviation* has to the *mean*; it also has previously been applied to gray-scale and color image analysis, e.g. in [5].

Dispersion asymmetry across density waves

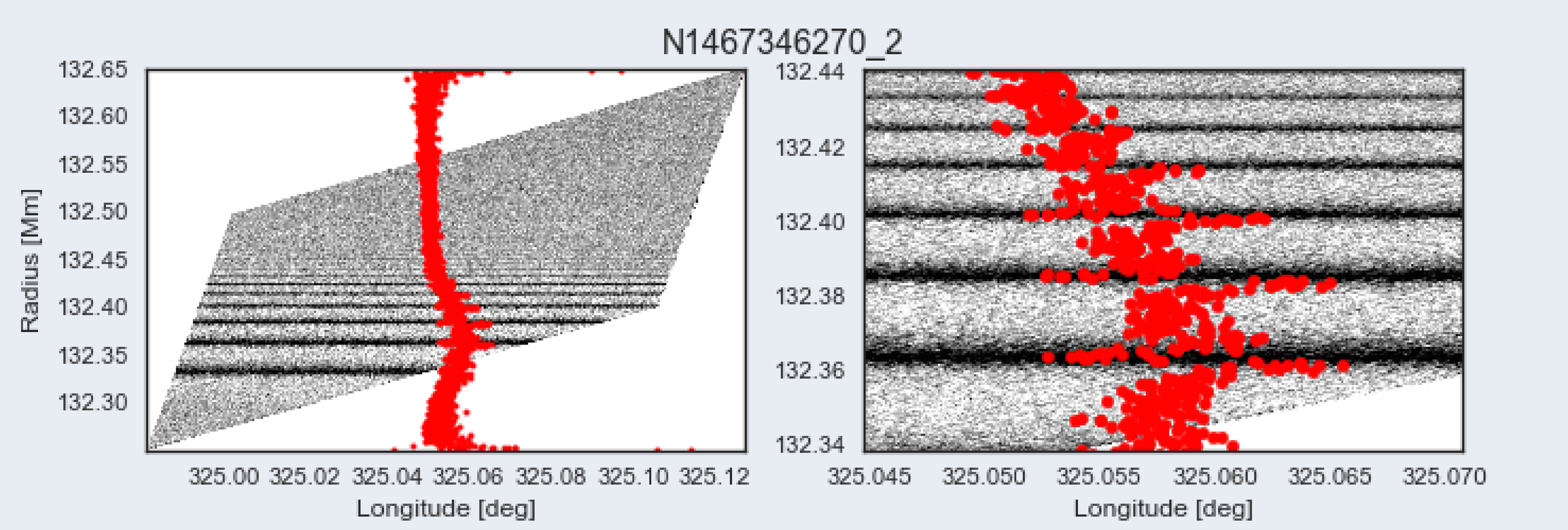

Figure 2: Applying a robust variance estimator on each line of the cylindrically projected ring image. The values of the estimator are drawn as red scatter points with low values towards the left. One notes the general increase of variance at the location of the biggest density waves. The right-hand side shows a zoomed in view that shows that the precise location of the variance differences is asymmetric around the crests of the density wave. One side of the density wave trough (troughs are bright in un-illuminated ring images) shows reduced variance while the other side is increased. This pattern is visible over several waves.

Method 1

Measure of azimuthal dispersion along radius

With this method we want to test the hypothesis that clumping in the rings can be identified by changes in the statistical dispersion of the photo-metric signal in ISS images along the azimuth when compared at different radii of the rings. Because some of the pixels of the ISS CCD are prone to be outliers even after applying the published calibration routine, a simple standard deviation per radius row of the CCD array could be heavily biased by these outliers.

Results

We are finding frequent dispersion asymmetry across density waves, interestingly, not always with the same direction (see Fig. 3).

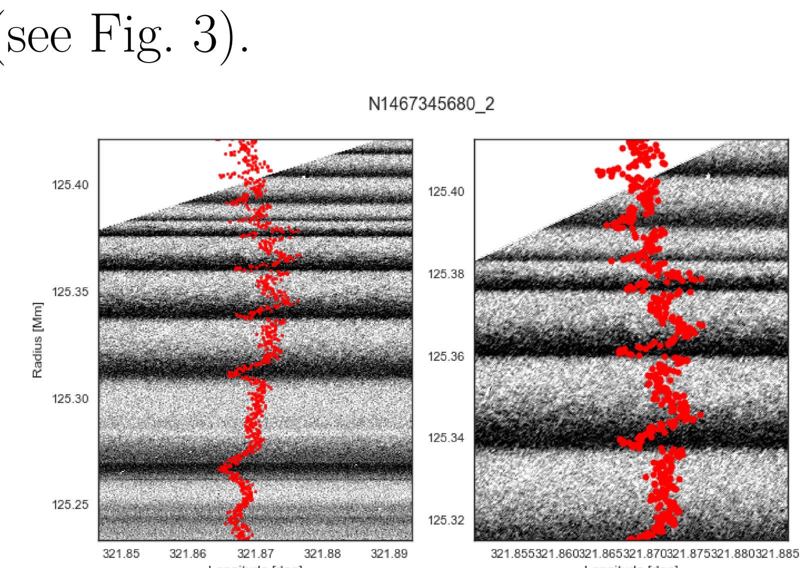

Figure 3: Example of a case where the dispersion gradually increases after the maximum of the density wave, without showing a strong dispersion peak before the maximum, unlike the behavior in Fig. 2.

Method 2: Wavelets

As discussed in [6], a classical windowed Fourier transform represents an inaccurate and inefficient method of time-frequency localization, as it imposes a scale or "response interval" T into the analysis. For analyses where a predetermined scaling may not be appropriate because of a wide range of dominant frequencies, a method of time-frequency localization that is scale independent, such as wavelet analysis, should be employed [6]. Figure 1 shows a very preliminary example of applying a wavelet analysis to the previously identified interesting rows of minimum and maximum statistical dispersion rows in Figure 2.
Identifying reliable interpretation of the power scales of wavelet analysis has been found difficult and this is a work in progress. We furthermore are developing means to identify aligned structures as seen in Fig. 4.

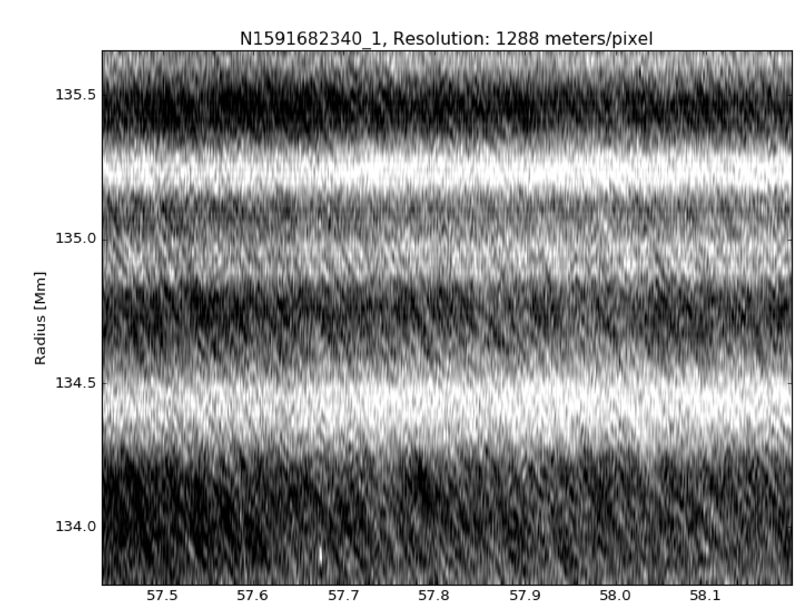

Figure 4: Example of aligned structures.

References

[1] Esposito, LW, Albers, N, Meinke, BK, et al. *Icarus*, 217:103–114 (2012).
[2] Porco, CC et al. *Science*, 307:1226–1236 (2005).
[3] Rehnberg, M et al. *AAS*, 47:#104.04 (2015).
[4] Aye, KM. *pyciss* (2015). doi:10.5281/zenodo.34134.
[5] Khalil, HH et al., 2008, IEEE
[6] Torrence, C and Compo, GP. *Bulletin of the American Meteorological Society*, 79:61–78 (1998).

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