# Saturn's F Ring During 13 Years of Cassini ISS Observations

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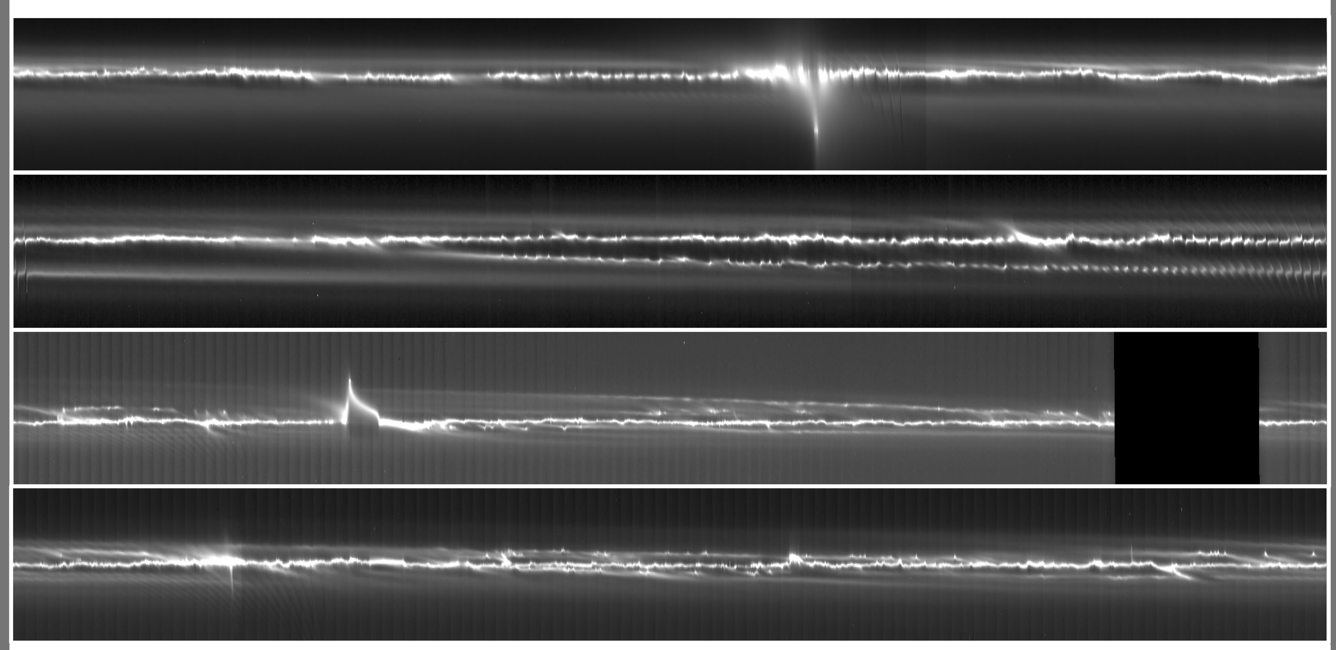
## Introduction

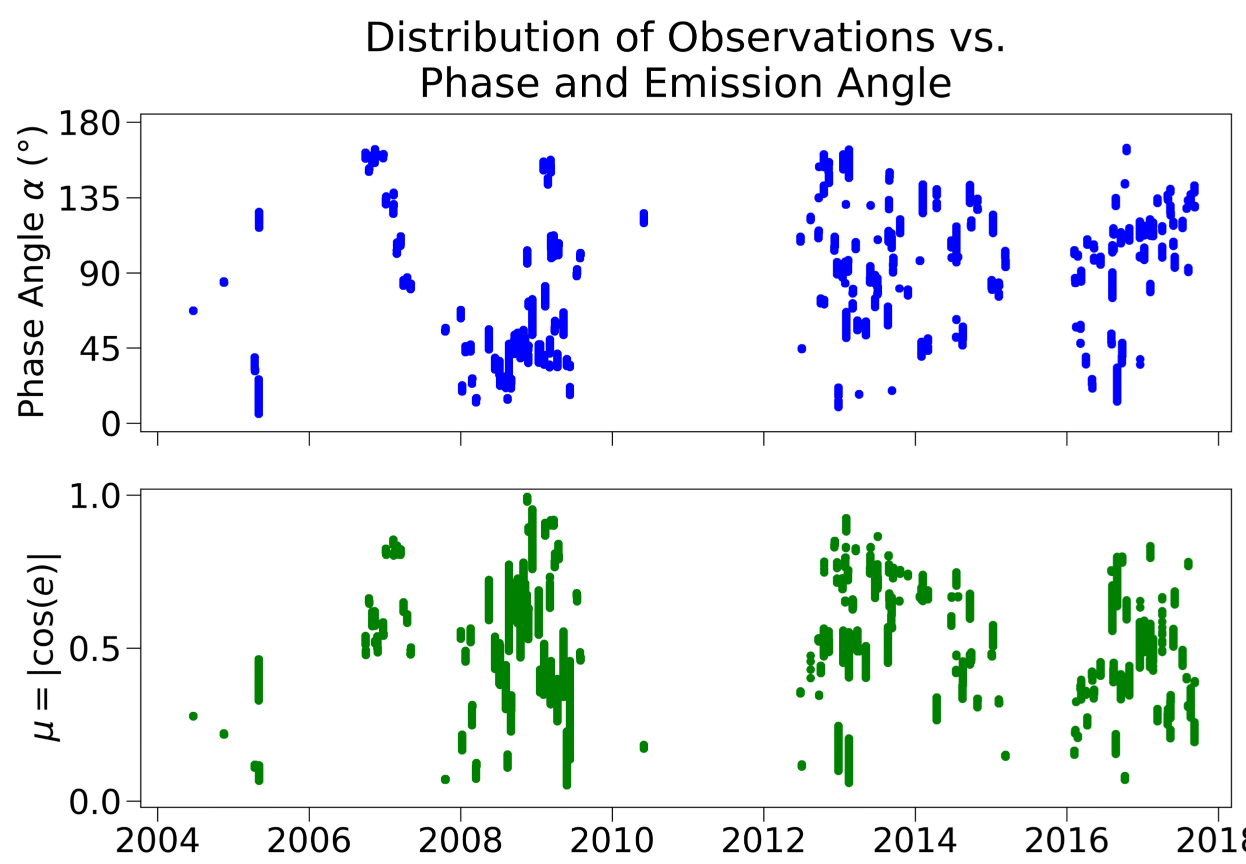
- Located in Saturn's Roche zone and sandwiched between the small satellites Prometheus and Pandora, the narrow F ring occupies one of the most dynamically interesting locations in the solar system.
- In French *et al.* (2012, Icarus 219), we compared the ring's mean brightness from observations by Voyagers 1&2 (1980–1981) and Cassini (2004–2009), finding a dramatic increase in brightness during the ~25 year observational gap.
- We hypothesized that Prometheus, which closely approaches the F ring core every ~17 years, could be responsible for exciting the ring material, thus causing the brightening.
- However, we found no change in brightness during the five years leading up to Prometheus' closest approach in late 2009, and did not have the data to observe any possible subsequent change in brightness.
- **Here we extend that work with observations covering the entire Cassini mission at Saturn (2004–2017).**

## Methodology

- The Cassini Imaging Science Subsystem took a series of "movies" of the F ring, each containing dozens to hundreds of images taken at a fixed inertial longitude while the ring rotated underneath.
- We selected 212 movies consisting of ~17,000 images; for each movie, we:
  - navigated every image using fiducial features such as stars or the edge of the A ring;
  - reprojected the images onto a regular grid of radius&longitude;
  - merged the reprojected images together into a mosaic:

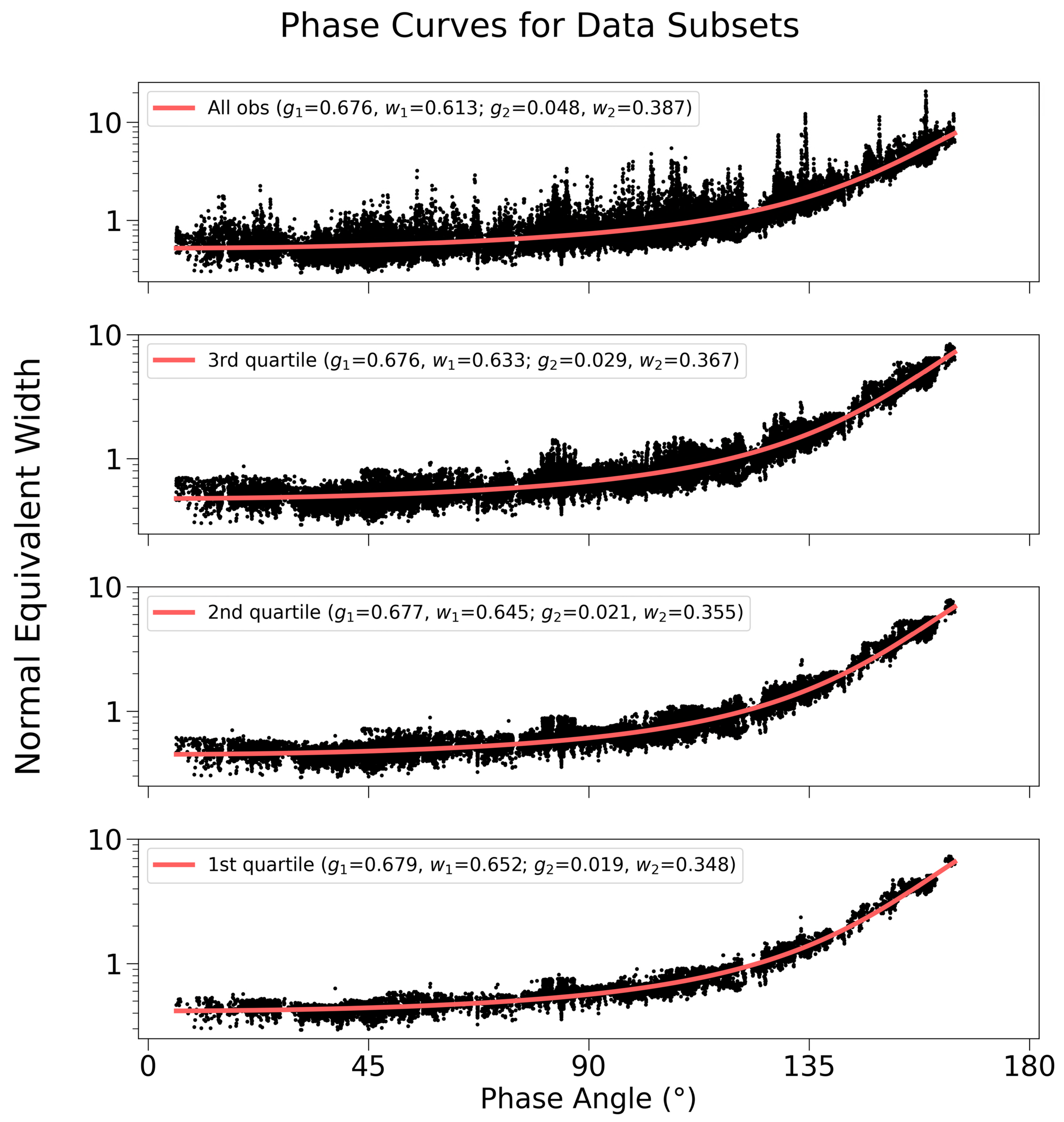


- Each mosaic was adjusted to remove background gradients and then processed in 1°-of-longitude increments to compute the mean "equivalent width" (EW), which is the integrated brightness of a radial slice times its radial resolution.
- To eliminate the geometric effect of observer position, the EW was then multiplied by $\mu = |\cos(e)|$, where $e$ is the emission angle, to produce the "normal equivalent width".
- **In total, we had 39,129 of these 1° slices spanning 4,827 days available for analysis.**
- Due to the vagaries of mission observation planning, the movies were taken at a wide range of emission and phase angles, and were taken at non-uniform time intervals; in particular, there were substantial gaps in coverage while Cassini was orbiting in Saturn's equatorial plane from 2010–2012.



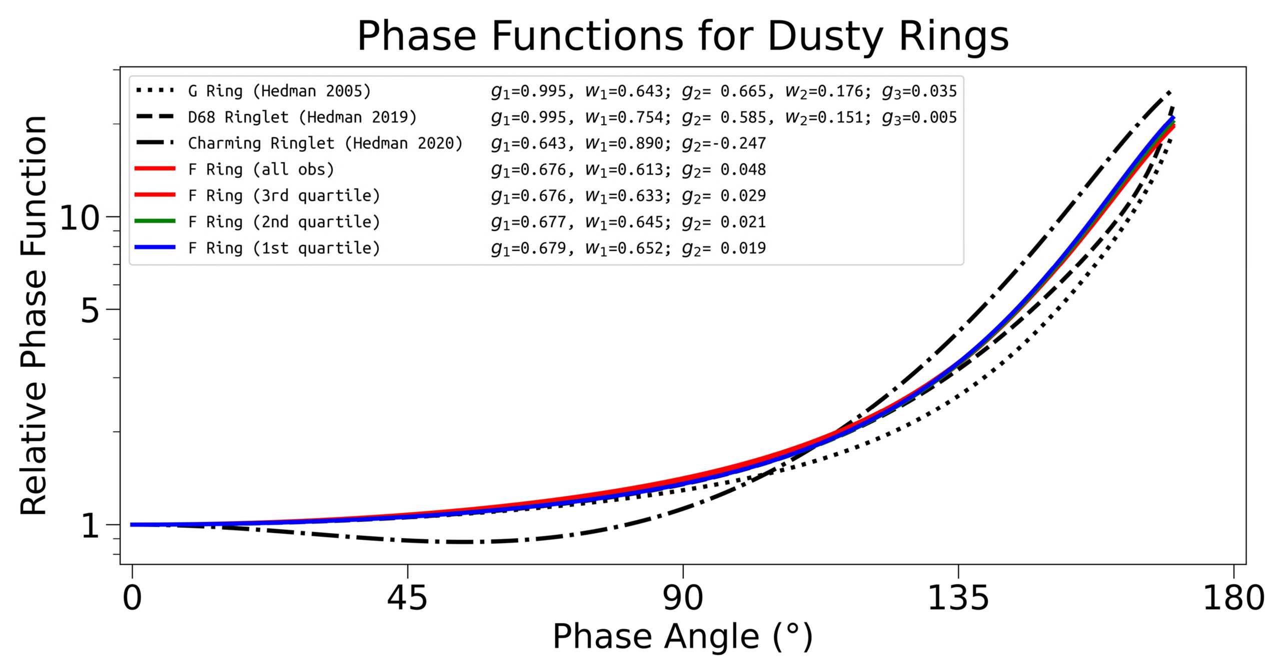

## Phase Curve

- Because of the F ring's intrinsic brightness variability due to the ever-changing presence of small and extended clumps, multiple strands, jets, and streamer-channels, it is difficult to define a single phase curve for the ring.
- We have experimented with finding phase curves for multiple data subsets, each time eliminating some fraction of the brightest longitudes in each mosaic in an attempt to find the "baseline brightness" of the ring.
- The Henyey-Greenstein (HG) function is most commonly used to describe the scattering/phase function of debris disks. It is characterized by the asymmetry parameter $g$.
- For each of our data subsets, we find that the phase curve is well-approximated by the weighted sum of two HG functions; adding a third function does not increase the goodness-of-fit.
- Below we show the phase curves and associated HG parameters ($g$ for the two functions and their relative weights) for four data sets. The first includes all 39,129 slices. The others remove the brightest 25%, 50%, or 75%, respectively, slices from each mosaic, thus reducing the influence of less-frequent structures such as clumps. Overall, even when the brightest 75% of measurements are removed, the general shape of the phase curve does not change much, with the primary component having $g_1$ in the vicinity of 0.677 and the secondary component having $g_2$ in the vicinity of 0.03.



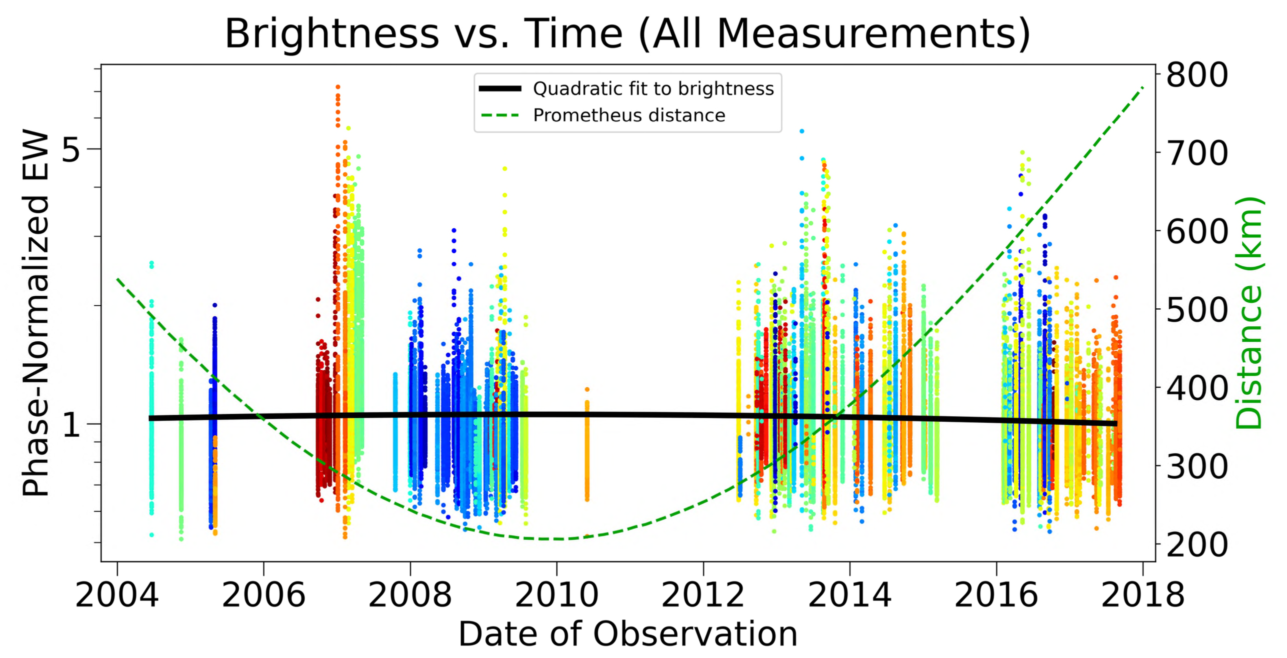

## Comparison to Other Dusty Rings

- Below we compare the four F ring phase curves above to those for other Saturn dusty rings. For ease of comparison, each phase curve is normalized to agree at α=0. Despite their different environments, all of the phase curves are remarkably similar, especially given the noise on each measurement.




## Brightness Over Time

- To measure the brightness variation of the F ring over time, we first remove the influence of phase angle by dividing each measurement by the phase function evaluated at that measurement's phase angle.
- The full set of measurements is plotted against date below.
- To show that phase angles are well-distributed over the time period, and thus unlikely to bias the results, measurements are colored: blue (low phase angle) through red (high phase angle).
- We fit a second-order polynomial to all of the phase-normalized data points to look for any brightening trend.
- To emphasize the original hypothesis, the distance of closest approach of Prometheus to the F Ring core is shown on the right axis.




- **As can be readily seen, there is no systematic change in the brightness of the ring during the Cassini mission, re-creating and extending the results from French *et. al.* (2012) but invalidating the hypothesis that Prometheus was the cause of the brightening seen between the Voyager and Cassini missions.**

## What Caused the Brightening?

- The dramatic brightening between the Voyager and Cassini missions remains unexplained.
- Our next project will be to carefully validate the calibration of the Voyager images, as the camera technology was very different from Cassini's ISS and the software tools available for calibration were of questionable quality.
- Visual inspection of the mosaics shows that the rate of generation of bright clumps appears to be relatively steady throughout the Cassini observations, unaffected by the closeness of Prometheus to the ring.
- More bright clumps were visible during the Voyager missions.
- It may be that the brightness change was not a cyclical event, but that we are observing the long-term change of a relatively young ring.

### *Did You Know?*

All mosaics and reprojected images from this project are being archived in PDS4 bundles with the Ring-Moon Systems Node and will be available for public download.

*How to reach me in person:* I will not be at the meeting in person, but please say hi virtually!

*How to reach me virtually:* I will check Slack regularly during the meeting. Please feel free to send me a direct message to ask questions, make comments, chat, or to set up a zoom meeting. You can also always reach me at rfrench@seti.org

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