

Looking for a needle in a needle stack: A strategic search of NASA's Cassini image database

Task and tools

Cassini (Spacecraft/Data source)

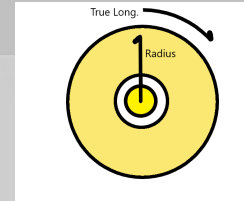
NASA's Cassini spacecraft took a total of 395,927 images [1]. Most of the images were of the Saturn system; spending many years orbiting and sending the highest resolutions images of Saturn seen to date. We focused on data from the Imaging Science Subsystem's (ISS) **narrow angle camera** for the **highest resolution** images in the visible range. This narrow angle camera has a CCD with 1 Megapixel array with a variety of filters. Key features associated with images of space are cosmic rays (a bright anomalous line or spot), dust on the lens forming a ring and dead pixels.

Task

Daphnis is an 8km moonlet that orbits Saturn in the 37km gap called the Keeler Gap, located at the outer edge of Saturn's A ring. Previous research indicates that something is interfering with its orbit. **One possible explanation was that there was a secondary object in the orbit.** NASA's Cassini spacecraft has taken many images of the region but calculations suggest that a secondary object would look identical to the noise. By using **multiple methods concurrently** we can search for signs of this object more efficiently, within the time constraints of the project.

Caviar (Software)

Caviar software is an **astrometry software** developed at QMUL for analysing images from space telescopes such as Cassini. We can use it to view images and find information about each pixel; its brightness value, location within the image and if the image is pointed (calibration using orientation and time at which the image was taken). It can calculate the location of a point within Saturn's coordinate system and label known objects making it easier to find something new.

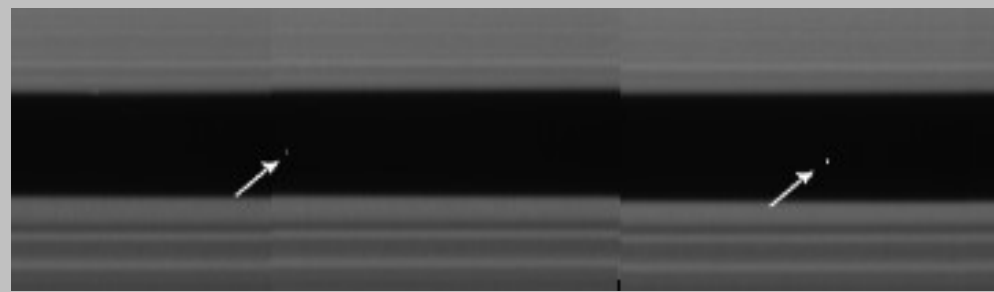


Methods

Direct Observation

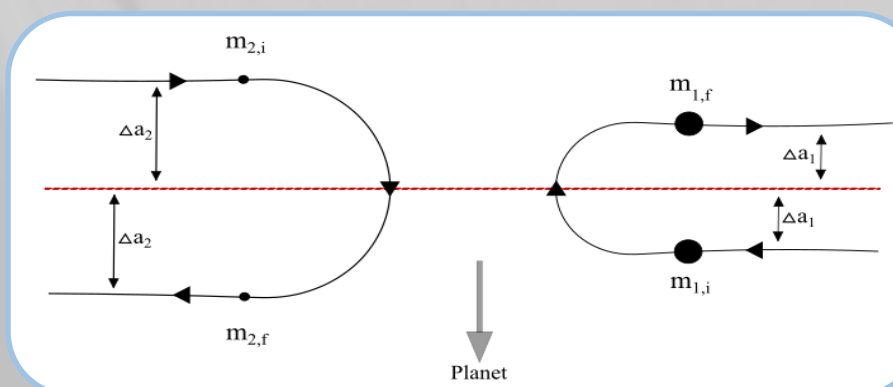
In order to find a new object the simplest method is brute force. Instead of checking every single image we can prioritise collections of images to search (e.g. a **keyword search**). Since we know that changes in the orbit occurred at around (DATE), the object must have been near Daphnis at this time. By viewing images that are targeted at Daphnis at this time it is more likely that an object in a horseshoe orbit will be in the field of view. Adapting this concept we can also use images targeted at Prometheus (Moon) as the Keeler Gap will be in view and we can utilise the sequences of images that were taken to make movies. By creating batch lists and running a script we can stitch these images together according to their location creating a panoramic image called a mosaic.

Mosaics not only make it easier to scan across multiple images, but the process reduces appearance of noise and background stars and makes it more obvious what is travelling in Saturn's orbit. Therefore simplifying the searching although requiring a time consuming process to assemble.



Theoretical Calculations

If there is a second object in the Keeler Gap, it is likely to be in a **horseshoe orbit**. Assuming that the secondary object doesn't leave the Keeler Gap, has similar density to Daphnis and is the sole cause of the variations in orbit, we can constrain the mass and radius of the new object. Given the resolution of the images taken by Cassini's narrow angle camera the object should be the size of a pixel.

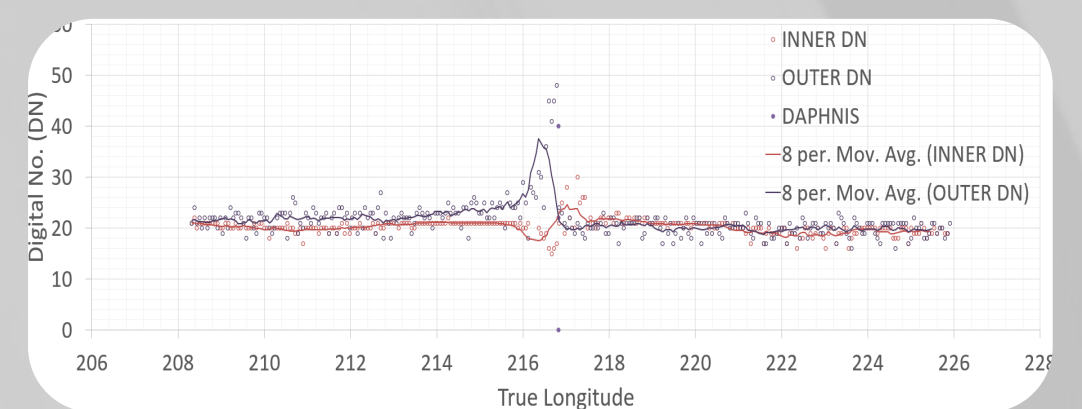


By writing a script we can make quick checks to see if an anomaly is moving at a reasonable speed for an object in orbit.

Indirect Observation

Daphnis causes ripples in the Keeler Gap by gravitationally attracting nearby dust particles. Even though a secondary object in the Keeler Gap would be smaller, if it is large enough to affect the orbit of Daphnis, it should also create similar ripples. Using the capabilities of Caviar, we can measure the **variation of the brightness along the Keeler Gap on either side** and look for peaks and troughs near bright anomalies.

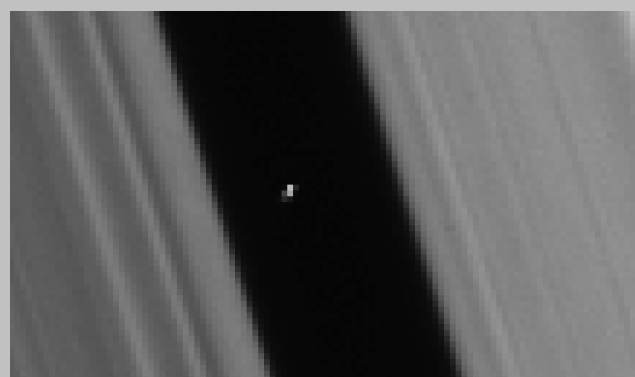
To measure these ripples we record the brightness value (DN) along the Keeler Gap and plot it a DN vs True Longitude graph.



DN value depends on phase angle (albedo) location of the object (e.g. in the shadow of another feature). We are not looking at absolute values of DN. We are looking for relative not absolute changes.

Results

The direct method led to finding 13 possible candidates. To assess their significance we pair candidates to see if they were the same object propagated over the time between images. We also use this method to look for new candidates. In almost all cases the time between images was too long to know with much certainty that it was the same anomaly. However, they appear near Daphnis at the right time and appear to be the correct size. A complete mosaic of the orbit would likely resolve this issue as would viewing other images with lower likelihood that happen to capture the anomaly.



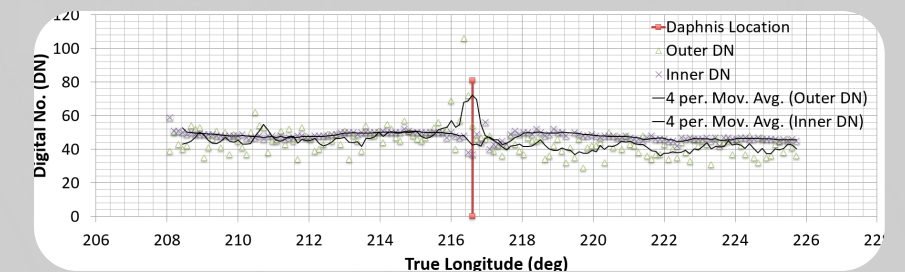
Other observations:

Image A contains a propeller which is a denser region in the ring that attracts nearby particles as it moves along creating its distinct shape.

Image B likely a background star as it was observed to move radially across the Keeler Gap leading to a false positive.



The graphs produced suggest that damping is not as expected. While it initially decays, the amplitude increases again and this appears to match with a similar effect in the other direction on the opposite edge. This would suggest that it is getting an additional kick from another massive object. This echoes the findings of Weiss et al [2] that found that the analytic expression (relating the amplitude of the waves to the mass) over-estimated the mass of Daphnis by ~30% [2]. No additional object can be seen in this image. This could be due the geometry of the image (e.g. the wave itself obscuring the gap partially). It could also be due to turbulence of the Keeler Gap edge particles. This could be explored further with the aid of a simulation and so could be a topic for future research.



Conclusion

The large quantity of images in the database was both a gift and a curse. The object that we were looking for was predicted to look identical to background noise making it only distinguishable from its behaviour and effect on surroundings. By calculating theoretical constraints we reduced our search to a more manageable quantity of images (100s as opposed to 100,000s). By using direct and indirect detection methods we gain more information from each image and also increase certainty. The additional benefit to this strategy was allowing for the discovery of other unexpected objects that can be investigated as part of further research. We were able to find **13 images containing possible candidates**, create a few DN vs True Long graphs as well as images of some other interesting objects. Further investigation would be required to confirm these findings.

Further research could include adapting the scripts from mosaics to plot DN vs True Long graphs, using machine learning to recognise all bright objects in the Keeler Gap to ensure that potential sightings are not missed. It could also include simulations to model the formation of Daphnis and whether that could be an alternative explanation to the change in orbit. To summarise, the case is not closed and there are many avenues to explore to help tie together all these features.



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References

- [1] California Institute of Technology Jet Propulsion Laboratory. Cassini legacy, 2018. <https://saturn.jpl.nasa.gov/>
- [2] Weiss J.W., Porco C.C. and Tiscerano M.S. Ring edge waves and the masses of nearby satellites. *Astronomical Journal*, 138:272-286, 2009

Image Credit: NASA/JPL-Caltech/Space Science Institute