Precision Pointing Reconstruction and Geometric Metadata Generation for Cassini Images

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1. Introduction

The Cassini spacecraft has been in orbit around Saturn since 2004. During that time it has taken more than 300,000 pictures with the Imaging Science Subsystem (ISS) Narrow- and Wide-Angle Cameras (NAC and WAC); these images are freely available to researchers and the general public through NASA's Planetary Data System (PDS). Before an image can be used for research, it is necessary to know where the Cassini camera was pointing in space at that time. Approximate pointing information is provided through SPICE C-kernels, but pointing errors can approach 0.03° (~80 NAC pixels), requiring the researcher to embark on a labor-intensive and time-consuming process to determine the correct pointing. The goal of the three-year project described here is to automate the navigation of every ISS image to an accuracy of ~1 pixel and generate a new set of accurate C-kernels. The results will be made publicly available through the PDS Rings Node.

2. Methodology

We use technology already developed to support Outer Planet Unified Search (OPUS), the PDS Rings Node search engine, to navigate each image. First, based on available SPICE information, we predict which bodies will be present in the image. These bodies may include stars, Saturn, moons, or rings. We then generate a model of how the known bodies should appear and perform a 2-D correlation to find the optimal offset that most accurately aligns the model with the image. As necessary, we apply digital filters and other techniques necessary to make the various features easier to detect. Figures 2 and 3 (right) show examples for star-based and moon-based navigation. In both cases, an accuracy of one pixel is easily achieved.

However, many images are substantially trickier to navigate, and over the next three years we will be developing a suite of techniques to deal with these cases. For example, consider a close-up of Saturn. If present in the image, the main rings, shadows cast by the main rings, or moons are viable navigational references. However, in the general case we need to use the process of *bootstrapping*. This technique relies on the observation that many close-ups of Saturn are taken as part of a series of images used to build a mosaic. Some of these images are likely to have navigable references available, including Saturn's limb. We can then use these solved cases to navigate the remaining images by correlating equivalent atmospheric features. Figure 1 shows a simple example. Changes due to Saturn's rotation, changing viewing geometry, and atmospheric circulation can be accounted for.

Other cases that need to be solved include using crater maps to navigate moon close-ups, accounting for Titan's haze layer, and modeling non-axisymmetric rings.

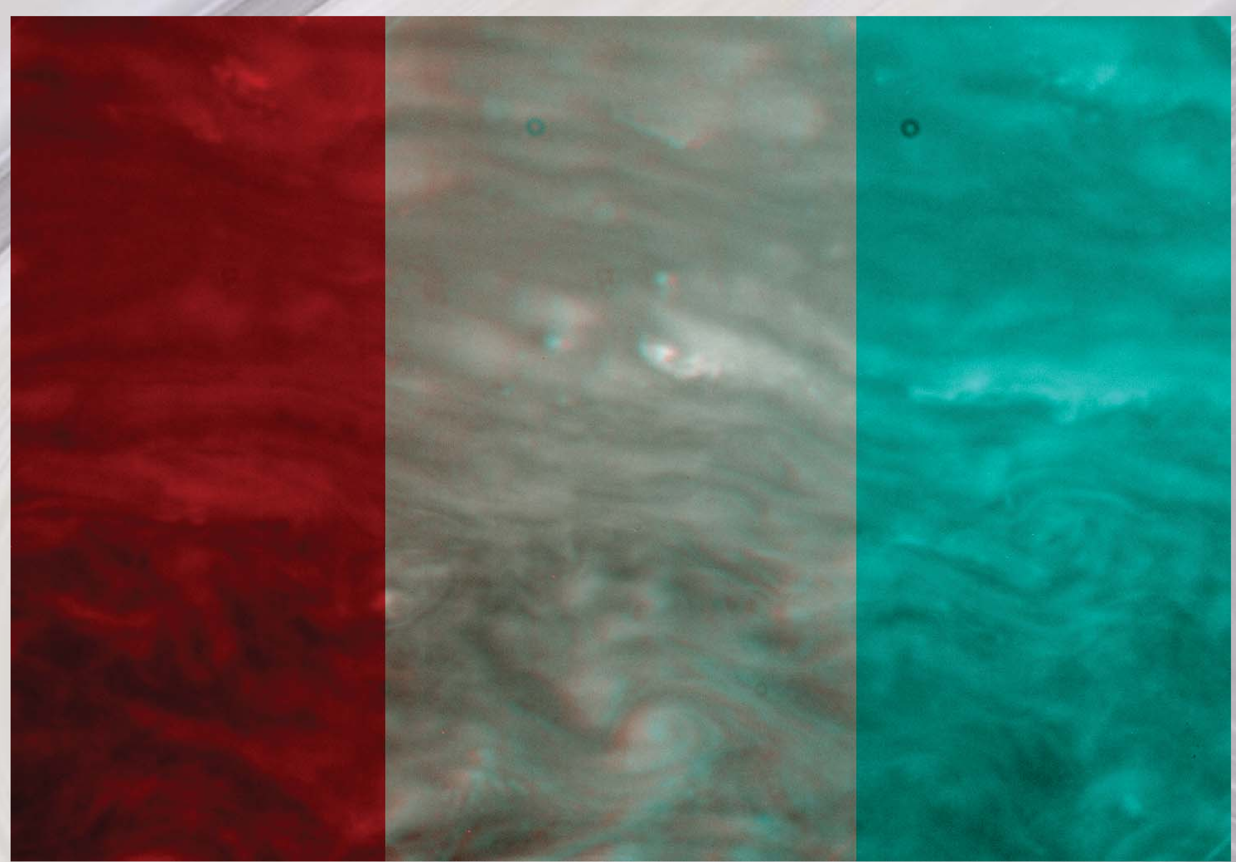

Figure 1: Navigation using atmospheric features of Saturn. Images N1677190715 (red) and N1677191297 (cyan) have overlapping features that are shown in the center region. Some features have moved during the 9.7 minutes between the exposures, but there is still enough commonality to produce a reasonable navigation solution.

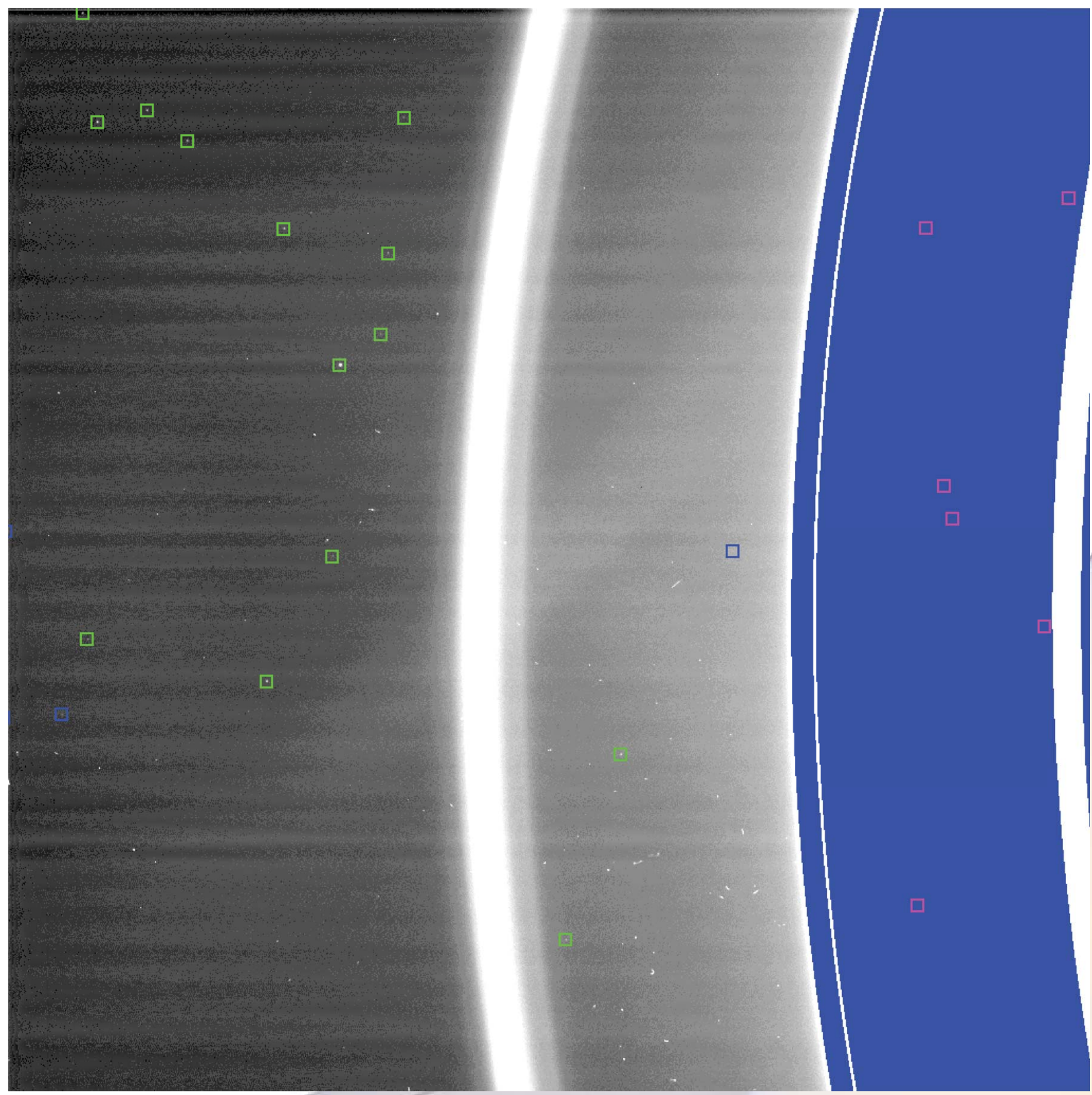

Figure 2: Navigation using stars. Boxes surround star catalog entries: photometric match (green), photometric non-match (blue), and conflict with the main rings (magenta). The model of the main rings is blue on the right, and could have been used for navigation if sufficient stars were not available. The arc in the middle is the F ring, which is not modeled due to its unpredictable shape. (Image N1561689030, heavily contrast enhanced)

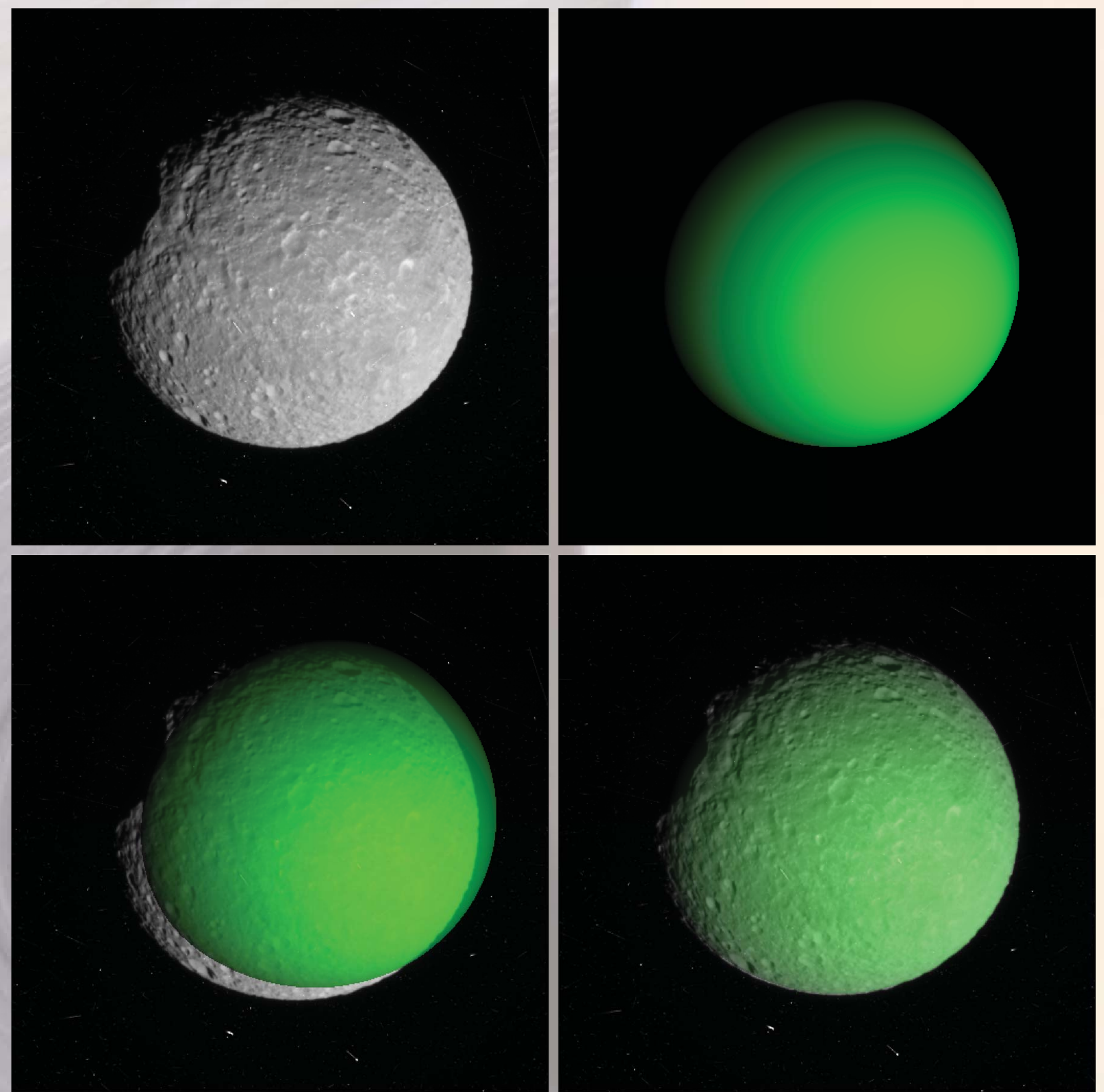

Figure 3: Navigation using a moon (Mimas). In many cases, a simple Lambert law model (based on the cosine of the incidence angle) is sufficient, even in the presence of additional detail such as craters. This technique generally only fails with moons that have an atmosphere (e.g. Titan) or images where the moon has no well-defined edge. The top two images are the original image (left) and simple Lambert law model (right). The bottom two images show the model overlaid on the image based on the SPICE-derived pointing information (left) and the final location after we navigate the image. (Image N1561689030)

3. Geometric Metadata

In addition to the reconstructed pointing information, we intend to provide geometric metadata for each pixel of each image. This metadata will include:

- Identification of the frontmost body occupying the pixel
- Latitude and longitude of the frontmost body, or radius and inertial longitude in the ring plane
- Incidence, emission, and phase angles at the surface of the frontmost body or ring plane

When possible, the same information will be provided for data from the VIMS, UVIS, and CIRS instruments using pointing derived from ISS.

4. Case Study: Saturn's F Ring

Research of Saturn's F ring often starts with the creation of mosaics representing the state of the ring at one point in time. These mosaics are created by combining the geometric reprojections of individual images. However, before an image can be reprojected, it is necessary to know exactly where the F ring is located in the image, a difficult task as the F ring is highly dynamic. Until now, this has required manual analysis of each image, an extremely time-consuming and boring process that has been repeated by multiple research groups.

We have analyzed 8,999 images of the F ring taken from 2004 to 2010. Of these, 7,359 (82%) could be accurately navigated using stars and 1,361 (15%) could be navigated using the location of the main rings. Only 155 (2%) images could not be navigated due to the lack of sufficient landmarks. An additional three images produced an incorrect result, and 124 (1%) had missing SPICE information. The results of the process for a single observation set are shown in Figure 4. Once navigation was complete, geometric metadata including ring radius and longitude were computed, allowing for reprojection. A sample mosaic consisting of 175 images taken from Cassini observation ID ISS_044RF_FMOVIE001_VIMS is shown at the bottom of the poster.

5. Solicitation of Community Involvement

If you have a research project that involves the navigation of Cassini data, we would like to talk to you. We are looking for early adopters and volunteer peer reviewers who will work with us to ensure the usefulness and quality of our data products.

6. Acknowledgments

We gratefully acknowledge the support of NASA's Cassini Data Analysis Program through grant NNX14AE23G to the SETI Institute.

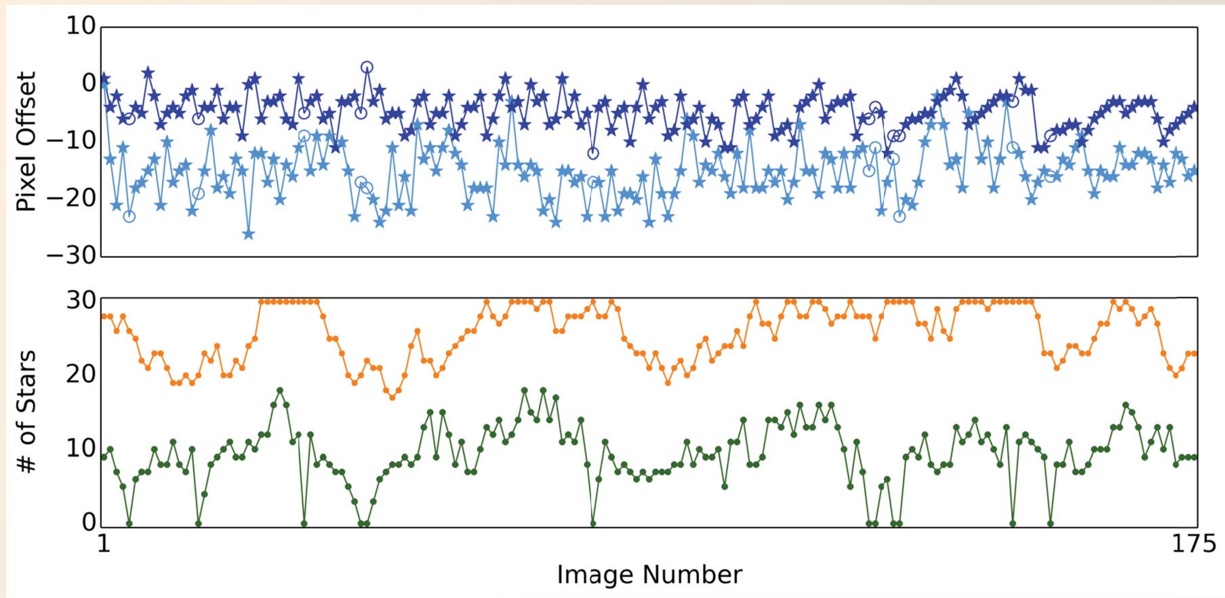

Figure 4: Results of navigating 175 images from Cassini observation ID ISS_044RF_FMOVIE001_VIMS taken over a 15 hour period. The top panel shows the offset in X (light blue) and Y (dark blue) from the nominal SPICE-derived pointing for each image. Images navigated using stars are marked with a star and images navigated using the main rings are marked with a circle. The bottom panel shows the total number of stars available in each image (orange, max 30) and the number that were successfully identified and used (green).