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Flyby of Mimas: evidence for amorphous water ice from VIMS

D. P. Cruikshank (1), **G. A. Marzo** (2,1), N. Pinilla-Alonso (1), T. L. Roush (1), R. M. Mastrapa (3,1), B. J. Buratti (4), C. M. Dalle Ore (3,1)
(1) NASA Ames Research Center, California, USA, (2) Bay Area Environmental Research Institute, California, USA, (giuseppe.marzo@nasa.gov) (3) SETI Institute, California, USA, (4) Jet Propulsion Laboratory, California, USA.

Abstract

Saturn's moon Mimas, one of the major, is known to have a surface with water ice and no compositional differences have been identified so far. A recent Cassini flyby provided the possibility to study this satellite in greater detail. Several spectroscopic observations of Mimas were mosaicked and analyzed using a cluster analysis technique that identified statistically distinct units on the surface. Some of these units appear enriched with amorphous water ice and spatially correlate with Herschel crater and another region close to the south pole.

1. Introduction

The inner saturnian satellites are embedded in the E-ring, which is composed of very small and pure ice particles [1]. Dynamical models suggest that eccentric particles from the E-ring would hit the surface of Mimas, the innermost of the Saturn's major moons, leading to a selective accumulation of water ice (references in [2]). Previous spectroscopic studies both ground-based (e.g., [3] and references therein) and from orbit (e.g., [2] and references therein) show that the surface of this satellite is dominated by water ice, a result consistent with the dynamical models.

On February 13, 2010 the Cassini spacecraft performed a flyby of Mimas. Using spectral data collected by the Visible and Infrared Mapping Spectrometer (VIMS) [4] during this encounter and a cluster analysis technique [5, 6] we find evidence that different regions of the surface have distinct spectral properties not previously described. In particular, specific locations might correlate with different mixtures of crystalline and amorphous water ice.

2. Processing and analysis

VIMS consists of two imaging spectrometers operating in the visible (0.30-1.05 μm) and the infrared (0.88-5.10 μm) ranges with 96 and 256 spectral bands, respectively [4]. We selected 7 VIMS observations based on their overall quality (i.e., saturated spectral bands, spatial resolution on the ground). Still, these observations suffer from saturation, in particular in the visible part of the spectrum. As a result, we restricted the analysis to the 1.27-5.1 μm spectral range. The 7 VIMS observations were geometrically projected by considering the geometric calibration information of the instruments for each pixel, the position of the Cassini spacecraft, and the pointing data for each observation frame. Each projected observation was then re-sampled to a common spatial resolution using a nearest-neighbor algorithm to guarantee no modifications to the original spectral information. Each observation is spatially oversampled to 1.7 degree/pixel that is the finest surface resolution available from this flyby. The individual observations were

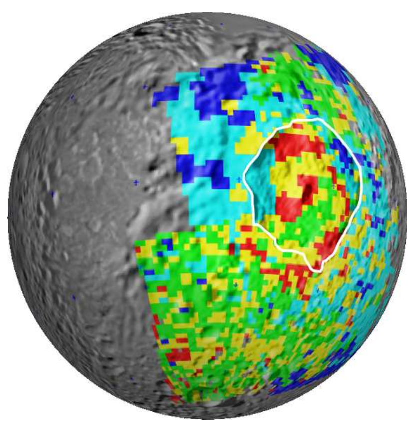

Figure 1: Spectral cluster map overlaying Cassini imagery of Mimas. Different colors represent distinct clusters. Red and Yellow appear associated with an enrichment of amorphous water ice, as opposed to blue and cyan that are more similar to crystalline water ice. Green represents an intermediate case. Solid white outlines the location of the Herschel crater.

then sorted by pixel ground resolution. The final step consisted of combining the different projected observations into a mosaic where the observations with the highest resolution are placed on top.
The VIMS mosaic has been explored using statistical cluster analysis [5, 6]. The technique consists of a partitioning algorithm coupled to a criterion that prevents sub-optimal solutions and tests for the influence of random noise in the measurements. The final cluster configuration is independent of the random noise, yet remains sensitive to systematic errors such as instrumental effects. Each cluster is associated with a cluster average, or centroid, that provides a significant reduction of the original data volume but retains the quantitative properties of the original data set [5, 6]. The clustering technique is agnostic about the meaning of the clusters and scientific interpretation requires their a posteriori evaluation.

3. Results

This preliminary results yielded 5 clusters, proving that the spectral variability across Mimas surface is statistically significant. The location of each cluster is shown in figure 1 using distinct colors. Each centroid is clearly dominated by the water ice 1.5, 2.0, and 3.0 μm absorption bands. To enhance the spectral differences between the centroids, we ratioed the red (242 pixels) and blue (512 pixels) centroids to the green (977 pixels) one, that seems to represent an intermediate case between the two. The results are shown in figure 2 and compared with models of mixtures of different water ice phases [7]. The red ratio shows a local minimum at 1.50 μm and a faint one at 1.56 μm possibly suggesting the presence of some amorphous ice. On the other hand, the blue one presents a sharp minimum at 1.56 μm that is usually apparent in crystalline water ice (and quite common in the Saturnian system [2]). To further test the hypothesis that the red cluster contains some amorphous water ice, we investigated the center of the 2 μm band that is expected to shift with the water ice phase. The Gaussian that best fits this band is centered at 2.00 and 2.02 μm for the red and the blue ratio, respectively. This difference is consistent with the models (Fig. 2). Models and laboratory measurements of water ice at different temperatures and grain size do not reproduce the observed trend. The yellow and the cyan clusters show a similar behavior to the red and the blue clusters, respectively.
The putative amorphous-enriched water ice occurs on the central peak of Herschel crater, on the crater floor, and in faults surrounding the crater. It is interesting to observe that another occurrence of amorphous-enriched ice is present southwest of Herschel crater, close to the south pole.

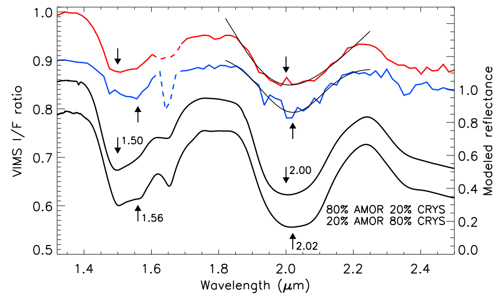

Figure 2: VIMS I/F ratios of the red and the blue clusters. Uncertainties are $\sim$0.005 in this spectral range (higher at wavelengths $>$2.5 μm). Dashed lines indicate spectral bands with calibration issues. These ratios are compared to models of mixtures of crystalline and amorphous water ice [7]. The blue ratio resembles crystalline water ice and the red ratio is more consistent with amorphous water ice. The two Gaussians at 2 μm are the best fit for the band and result shifted in the two spectra. Spectra are offset for clarity.

4. Conclusions

VIMS data from the last Cassini flyby of Mimas were mosaicked and explored by our cluster analysis technique. The results suggest that the surface is a mixture of crystalline and amorphous water ice and that different regions are associated with distinct mixtures. The enrichment of amorphous water ice correlates spatially with the central peak and rim of Herschel crater and a southwestern region close to the south pole.

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