EPSC Abstracts
Vol. 7 EPSC2012-640 2012
European Planetary Science Congress 2012

Spectroscopic identification and comparison of Dione's and Rhea's terrain based on Cassini VIMS data

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Abstract

Saturn's icy satellites were observed several times by the Cassini spacecraft in its nominal and extended mission from 2004 to 2010. We selected 133 Cassini/VIMS (Visual and Infrared Mapping Spectrometer) hyperspectral cubes of Dione and 68 of Rhea in the IR range between 0.85 and 5.1 μm and we applied Spectral Angle Mapper (SAM) clustering technique to classify different surface units on the basis of their spectral properties. We were able to identify nine and twelve different terrain types for Dione and Rhea respectively, correlated to specific surface morphologies.

1. Introduction

Dione has a diameter of 1122 km and a density of ρ = 1.475 g/cm^3. The Voyager spacecrafts observed Dione in 1980 showing a complex surface structure, with both heavily cratered terrains and less cratered plains [1, 2]. Afterwards Dione was observed by the Cassini spacecraft in both its nominal and extended mission from 2004 to 2010. Most of Dione' surface is covered by the heavily cratered terrains, located mainly in the trailing hemisphere and crossed by high-albedo wispy streaks that are likely tectonic features [3, 5]. Rhea is the one of largest and less dense moons of Saturn, with a diameter of 1528 km [4] and a density equal to 1.233 g/cm^3. Voyager spacecraft was the first to observe Rhea' surface, revealing a complexity comparable to Dione [2]. Rhea's trailing side appears to be brighter than the leading one, with high albedo filaments similar to Dione's wispy streaks, possibly formed after resurfacing processes [6].

2. Data set and analysis

The *Visual and Infrared Mapping Spectrometer* (VIMS) instrument onboard the Cassini Orbiter is able to acquire hyperspectral cubes in the overall spectral range from 0.35 to 5.1 μm. We select 133 and 68 VIMS cubes of Dione and Rhea respectively in the IR range between 0.85 and 5.1 μm, selecting those data which show at the same time: 1) a spatial resolution better than 100 km; 2) a phase angle smaller than 40^o and 3) a good S/N ratio (essentially driven by exposure time). We normalize all spectra at λ=2.232 μm in order to minimize photometric effects due to different illumination conditions. We apply a clustering technique to the spectra of each cube based on the supervised method Spectral Angle Mapper (SAM) to emphasize the presence of spectral units. The endmembers used by the SAM for the classification of each terrain type, were selected applying the unsupervised clustering technique K-Mean to the cubes with the highest spatial resolution: $\sim$ 16.1 km/px for Dione and $\sim$ 22.4 km/px for Rhea. In particular, K-mean technique identified nine endmembers for Dione and twelve for Rhea, whose spectra are shown in Figure 1 for Dione and in Figure 2 for Rhea and where each terrain unit is coded with a color.

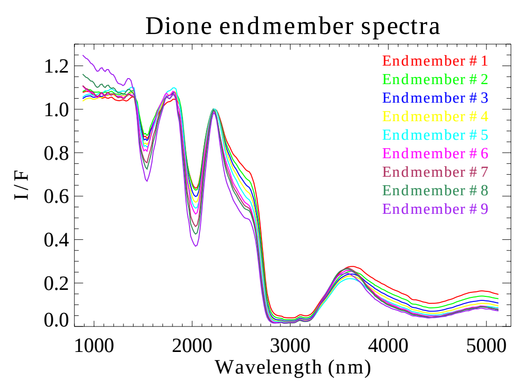

Figure 1: Spectra of Dione's endmember

In the SAM method applied to remote sensing data, each spectrum is represented by a vector in the n-dimensional coordinate system, where n is the number of spectral channels. In this case, n = 256. In order

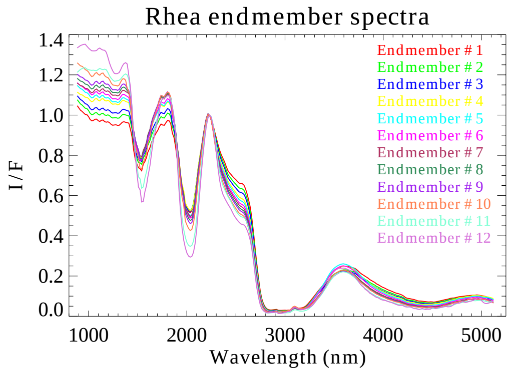

Figure 2: Spectra of Rhea's endmember

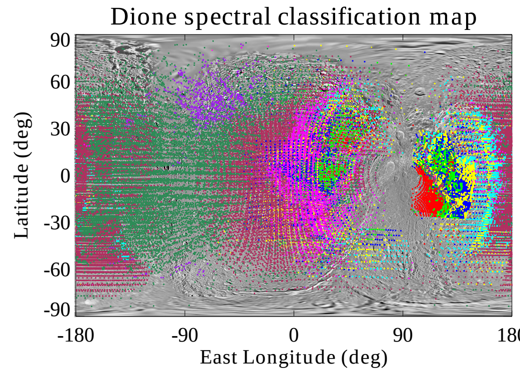

Figure 3: Projection of classified cubes' pixels on a Dione's cylindrical map

to compare the spectrum of each cube's pixel of the target with the endmembers, the algorithm evaluates an angle θ that represents the angular separation between the vector of the spectrum of each endmember (y_i) and the vector representing each pixel's spectrum (x_i) in the data space (256 dimensions). θ is computed as:

$$\theta = cos^{-1}\left[\frac{\sum_{i=1}^{n} x_i y_i}{\left(\sum_{i=1}^{n} x_i^2\right)^{1/2}\left(\sum_{i=1}^{n} y_i^2\right)^{1/2}}\right] \quad (1)$$

Small values of θ are indicative of a higher degree of similarity. We set θ=0.1^o as the maximum allowed angle value.

3. Results and discussion

To summarize the result of the SAM classification, we projected classified cube's pixels on a Dione's cylindrical map (Figure 3).

For both satellites, the infrared spectrum is dominated by the prominent signatures of H_2O ice /OH bands at 1.5, 2.0 and 3.0 μm. For Rhea, the spectral signatures due to water ice at 1.04 and 1.25 μm are observed across the entire surface, while for Dione these features are observed only on small ares of the surface. We conclude that a classification method applied to VIMS hyperspectral data is crucial to understand geochemical processes taking place on the surface of the icy satellites. From our analysis we find that several spectral units on the two satellites are characterized by different values of the spectral indices, such as the water ice bands' depth and the reflectance of the 3.6 μm peak, which is an indicator of the water ice grain size: the higher the peak, the finer the grains. Some classes show also a peculiar trend with respect to the phase angle, possibly related to the physical structure of the surface constituents (e.g, average grain size of the surface regolith). The trend of the water-ice band depth at λ = 1.5 μm against λ = 2,0 μm is indicative of the variation of the ice grain size, which is in general bigger for higher value of the band depth. Comparing the trend of the two satellites, ice grains sizes on Rhea surface seem to be larger than on Dione.

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