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Spectroscopic investigation of Dione' surface using Cassini VIMS images

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Abstract

Dione was observed several times by the Cassini spacecraft in its nominal and extended mission from 2004 to 2010. We have selected 76 Cassini/VIMS hyperspectral cubes of Dione in the IR range between 0.85 and 5.1 μm and we have applied the Spectral Angle Mapper (SAM) clustering technique to classify different surface units on the basis of their spectral properties. We identify nine different terrain types correlated to specific Dione' surface morphologies.

1. Introduction

With 1122 km in diameter, Dione is the second largest inner moon of Saturn and the third densest after Enceladus and Titan (ρ = 1.475 $\pm$ 0.003 g/cm^3). It orbits Saturn at a distance of 377,396 km in coincidence with the outer part of the E ring. The Voyager spacecraft observed Dione in 1980 showing a complex surface structure. Afterwards, Dione was observed by the Cassini spacecraft in both its nominal and extended mission from 2004 to 2010. Dione' surface is composed primarily by water ice with minor abundances of volatiles such as CO_2 and CN [3]. Dione's terrain can be divided in some distinct classes: heavily cratered terrains and less cratered plains [5], which are subdivided in lobate deposits and bright wispy material [4]. Most of Dione' surface is covered by the heavily cratered terrains, mainly located in the trailing hemisphere and crossed by high-albedo wispy streaks. The origin of dark material that covers the heavily cratered terrains is still unknown, while wispy units are likely tectonic features [7].

2. Data set and analysis

The *Visual and Infrared Mapping Spectrometer* (VIMS) instrument onboard the Cassini Orbiter is able to acquire hyperspectral image cubes in the overall spectral range from 0.35 to 5.1 μm, using two separate subsystems devoted to the VIS and IR range, respectively. We select 76 VIMS cubes of Dione in the IR range between 0.85 and 5.1 μm, choosing those data which show at the same time: a spatial resolution better than 100 km, a phase angle smaller than 40^o and a high 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 observation conditions. We apply a clustering technique to the spectra of Dione, based on the supervised method Spectral Angle Mapper (SAM), in order to emphasize the presence of spectral units. For each terrain type we chose one pixel in the image, whose infrared spectrum is used to drive the SAM classification. We begin by selecting two end-member pixels, one representing a dark terrain and the other one indicative of a wispy terrain. Since two pixels are not enough to properly represent all terrain types as seen in various VIMS cubes, we added further pixels from different cubes until all pixels of the dataset were classified in a terrain unit. In particular, we selected nine different reference pixels, whose spectra are shown in Figure 1.

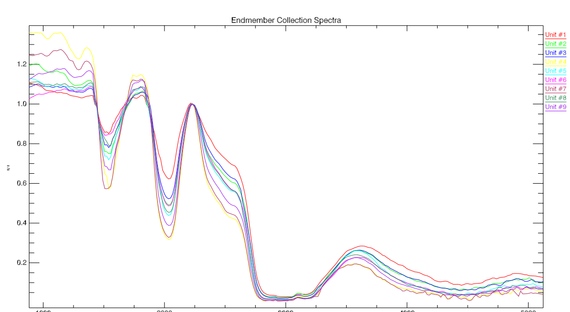

Figure 1: End-member pixels spectra used to drive Spectral Angle Mapper (SAM) classification method. Different colors identify each reference unit.

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 the case of VIMS-IR, $n = 256$. In order to compare the spectra of the target as seen in the hyperspectral cube of the target with the reference pixel/spectrum selected a priori, the algorithm evaluates an angle θ that represents the separation between the vector of the mean spectrum of the reference pixels (y_i) and the vector representing the spectrum of any other pixel (x_i) in the data space. θ is computed as:

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

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

The most prominent features in the infrared spectra of Dione are H_2O ice / OH bands at 1.52, 2.02 and 3.00 μm, while the peak around 3.10 μm is due to Fresnel's reflection in ice grains. The dark terrains are represented by units #1 and #6, characterized by a smaller depth of water ice absorptions at 1.5 and 2.0 μm with respect to other units and to the average of the entire satellite, which is indicative of non-ice contaminants on the surface (Figure 1). On the basis of this analysis, it is not possible to clearly identify contaminants' features. The nature of the dark terrain of Dione is still debated: [3] suggests it could be of exogenic origin, caused by charged particles bombardment. The major part of the bright wispy terrain is categorized in unit #3. Between 0.8 and 1.4 μm its spectrum is similar to that of unit #1, but the absorption features at 1.5 and 2.0 μm are deeper. In units #2, #4, #5, #7, #8 and #9 it is possible to observe spectral signatures due to water ice at 1.04 and 1.25 μm. These units cover just a few percentage of Dione' surface. These absorption bands are well correlated to wispy terrains and could indicate the presence of fresh H_2O-ice [6]. In the other units the latter water ice absorptions are less contrasted or even absent. To summarize our results we show the location of the spectral unites inferred from the classification of VIMS infrared spectra, projected onto a map of Dione derived from the best optical images returned by Cassini (Figure 2).

4. Future work

These results are the first step of a more general PhD work devoted to develop a thermal model of Dione.

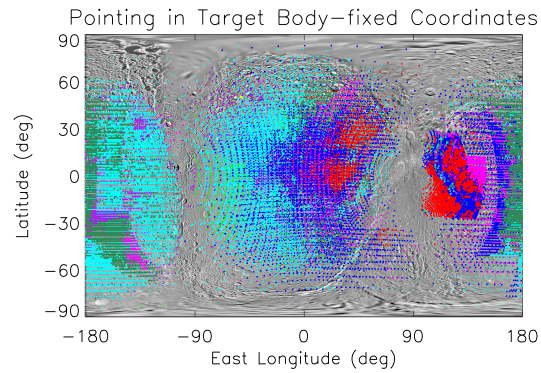

Figure 2: Projection of classified cubes' pixels on a Dione's map

Given the typical temperatures of the icy Saturnian satellites, the infrared range explored by VIMS does not allow one to retrieve surface temperatures of these bodies including Dione; however, starting from these data it is possible to investigate the compositional and photometric characteristics of the main terrain types. The chemico-physical state of the surface provides a robust boundary condition for the modeling. Additionally, we plan to model the observed spectral features using radiative transfer theory in order to derive a quantitative evaluation of the contaminants abundance on the surface materials.

References

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