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VIS-IR spectrograms of Saturn's rings retrieved from Cassini-VIMS radial mosaics

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Abstract

Context: Cassini-VIMS has harvested a large number of Saturn's rings radial mosaics at very different observation geometries. *Aims:* This work is focused on the retrieval of rings average composition (water ice and red cromophores), regolith grain sizes and photometric parameters. *Method:* We have implemented a procedure to build ring spectrograms, e.g., 2D arrays that contain the full spectral (0.35 – 5.0 μm) and spatial (from 73.500 to 141.375 km) information sampled at 400 km/bin spatial resolution. This processing is applied to several mosaics acquired at different illumination phases (12° to 136°) and opening angles (-21° to +5°). *Results:* Ring spectra show reddening at VIS wavelengths while maintaining a strong similarity to water ice in the IR. Differences both in VIS reddening, water ice abundance and grain sizes are retrieved across different rings regions. *Conclusions:* Two important findings are that 1) both VIS reddening and water ice band depths increase at high phases, thus indicating that the red contaminant is intimately mixed in water ice grains; 2) typical regolith grain sizes are between 10-40 μm in the C ring, 40-60 μm in the Cassini Division (CD) and >100 μm in the A and B rings.

1. Observations and spectrograms

Among the solar system's planets, Saturn has the most prominent and complex ring system extending along radial distance from 74658 km (inner C ring) to 136780 km (outer A). Thanks to VIMS imaging capabilities it is possible to collect VIS-IR reflectance spectra of the entire rings structure at moderate spatial resolution [1]. In this work we have considered 7 radial mosaics with solar phases ranging between 12° and 136° and with rings plane inclination between 5° and -21°. As we are interested in retrieving the spectral variations of the rings along the radial direction, a method to build spectrograms, e.g. 2D arrays which contain the full spectral (0.35-5.0 μm) and spatial (from 73.500 to 141.375 km) information is applied. The method is based on the following steps: 1) Selection of 50 tie points, corresponding to very sharp, well-defined spatial structures (edges, gaps, ringlets) placed at known radial distances as observed in Voyager's reflectance profile [2]. The a-priori knowledge of these points, evenly distributed across A, B, C rings and Cassini division, allow us to define a reference radial grid of distances for VIMS mosaics. 2) On each mosaic's line VIMS pixels are sorted along the radial axis by linear interpolation between adjacent tie points. 3) As the illumination variations across the azimuthal direction are a few percent, is possible to average the radial profiles on the same distance grid to boost signal-to-noise ratio and improve the radial resolution; on these datasets a grid at 400 km/sample resolution allows us to obtain a uniform radial reconstruction of the VIMS data. 4) VIMS VIS and IR channels are spectrally bridged and merged at 0.98 μm. 5) Spectrograms (radial distance vs. wavelength) are obtained, one for each rings ansae mosaics.

2. VIS reddening

As discussed in [3, 4], the 0.35-0.55 μm spectral slope is highly sensitive to the presence of contaminants and darkening agents bound at the intra-molecular level in water ice regolith covering the rings particles. Analyzing radial profiles shown in Fig. 1, we observe that the maximum values of the slope are seen across the A (outer region) and B rings; slope decreases towards the inner part of the A ring, corresponding to an increase of contaminants with respect to the outer regions. Across the B ring the blue slope has a local maximum around 107.000 km and a minimum around 105.000 km. In these regions we observe similar variations in the water ice 2 μm band depth (see next Fig. 2). The "blue" peak placed at 100.000 km could identify a region with purer ice because it is measured here at a maximum both in slope and in water ice band depth [5]. The minimum blue slope is reached in correspondence of the CD and C ring where there are more contaminated and small particles and where the optical depth is minimum. Finally, forward scattering is the process that causes an increase in reddening with solar phase.

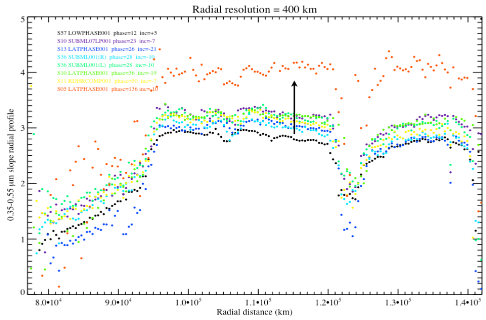

Figure 1: Radial profile of the VIS slope and reddening variations at different phase angles.

3. 2.0 µm water ice band

Water ice abundance is retrieved from the 2.0 µm band depth which is more intense than the 1.5-1.25 µm bands. The band depth reaches maximum values in the A (from a radius of about 130.000 km to the Encke gap as shown in Fig. 2) and B rings (from 104.000 to 116.000 km); a smooth decrease is measured in the inner part of the A ring moving from 130.000 km towards the inner edge of the A ring. As discussed in [5], the transition zone between CD and A ring has peculiar properties: comparing the profiles shown in Fig. 1-2 in this zone, we observe that both the 0.35-0.55 µm slope and the 2.0 µm band depth profiles decrease with a similar trend moving inwards: the only way to obtain this effect is to have a progressive increase of contaminants bound in water ice grains at the molecular scale. Moving across the B ring, three different distinct regions are observed: 1) external to the B ring (from 104.000 to 117.000 km), where band depth (BD) is almost flat with a local minimum at 109.000 km; 2) central B ring (from 98.500 to 104.000 km), where at least 5 ringlets with higher band depth are observed (corresponding to the density wave region observed in the visible slopes profiles shown in Fig. 1). These features can be explained with the presence of purer, resurfaced water ice caused by collisional processes; 3) internal B ring (92.000 to 98.500 km), where flat to moderately decreasing band depth profiles are seen moving inward and without showing any evidence of local structures. The 2-µm band depth reaches minimum values across the C ring. As shown in Fig. 2 the band depth increases with phase because at high phases the relative contribution of the multiple scattering is less relevant with respect to single scattering.

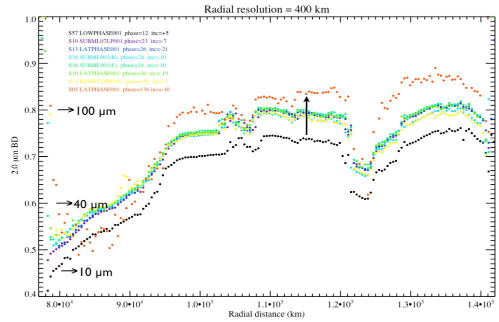

Figure 2: Radial profile of the 2 µm water ice band depth. Typical regolith grain sizes for pure water ice are indicated along the band depth axis

4. Summary and Conclusions

Ring spectrograms are an effective method to correlate spatial and spectral information for observations taken at different phase angles. We have found that both VIS reddening and water ice band depth increases at high phases, thus indicating that the red contaminant is intimately mixed in water ice grains. Moreover we retrieved average regolith grain sizes between 10-40 µm in the C ring, 40-60 µm in the CD and about 100 µm in the A and B rings.

References

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