# MAPPING THE SPECTRAL DIVERSITY OF ENCELADUS SOUTH POLE WITH CASSINI/VIMS HYPERSPECTRAL IMAGES

S. Le Mouélic[1], C. Buti[1], G. Tobie[1], S. Rodriguez[2], C. Sotin[3], J. W. Barnes[4], R. H. Brown[5], K. H. Baines[3], B. J. Buratti[3], R. N. Clark[6], T. Cornet[2], M. Massé[1], G. Mitri[1], P. D. Nicholson[7],. [1]Laboratoire de Planétologie et de Géodynamique, UMR 6112, CNRS, Université de Nantes, 2 rue de la Houssinière, 44322 Nantes, France. [2]Laboratoire AIM, Centre d'étude de Saclay, IRFU/Sap, Centre de l'Orme des Merisiers, Gif/Yvette, France. [3]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, USA. [4]Department of Physics, University of Idaho, Engineering-Physics Building, Moscow, ID 83844, USA. [5]Department of Planetary Sciences, University of Arizona, Tucson, AZ 85721, USA. [6]Planetary Science Institute, Tucson, USA. [7]Department of Astronomy, Cornell University, Ithaca, NY 14853, USA. (stephane.lemouelic(at)univ-nantes.fr).

**Introduction:** The Visual and Infrared Mapping Spectrometer (VIMS) onboard Cassini acquires up to 64x64 pixels images in 352 spectral channels from 0.35 to 5.12 µm [1]. Since 2004, spectral observations have been gathered during 22 Enceladus close encounters, in addition to more distant surveys. Our objective is to produce a global hyperspectral mosaic of the complete VIMS data set of Enceladus between E-1 (Feb. 17, 2005) and E-22 flyby (Dec. 19, 2015) in order to study spectral variations, particularly at the south pole were heterogeneity and activity have already been reported [2,3,4].

**Methodology:** All the data cubes have been calibrated using the VIMS pipeline described in [5]. An additional correction has been implemented to account for a constant spectral drift of ~10 nm during the entire mission. Quicklook images have been produced for each cube to identify spurious data and manually select the most relevant observations, as was done in [6]. A selection of 350 data cubes has been sorted by increasing spatial resolution, with the highest resolution images on top of the mosaic and the lowest resolution images used as background. Fig. 1 presents the final global mosaic in cylindrical and orthographic (South) projections. Many seams appear between individual images in the raw global mosaic at 2.21µm (Fig. 1d). They are mainly caused by the varying vewing geometry (incidence, emission, phase) between data acquired during the different Enceladus flybys (Fig 1a,b,c). These angles induce significant surface photometric effects. We normalized the viewing geometry using the surface photometric function described in [7], which accounts for incidence, emergence and phase variations, and provided satisfactory first order results (Fig 1e).

**Results**: To emphasize subtle spectral heterogeneities, we produced an RGB composite with the red, green and blue controlled respectively by the 3.09 µm, 2.0 µm and 1.78 µm channels (see spectra in Fig 2). The 3.09 µm accounts for variations in the ice crystallinity peak. The 2.0 µm image is sensitive to the depth of the 2 µm water ice band, and the 1.78µm channel falls in the continuum outside of water ice bands. This color composite reveals striking differences, mostly in the South Pole area. Fig. 3 shows a comparison between our VIMS false color map and the ISS basemap extracted from the planetary photojournal (PIA18435).

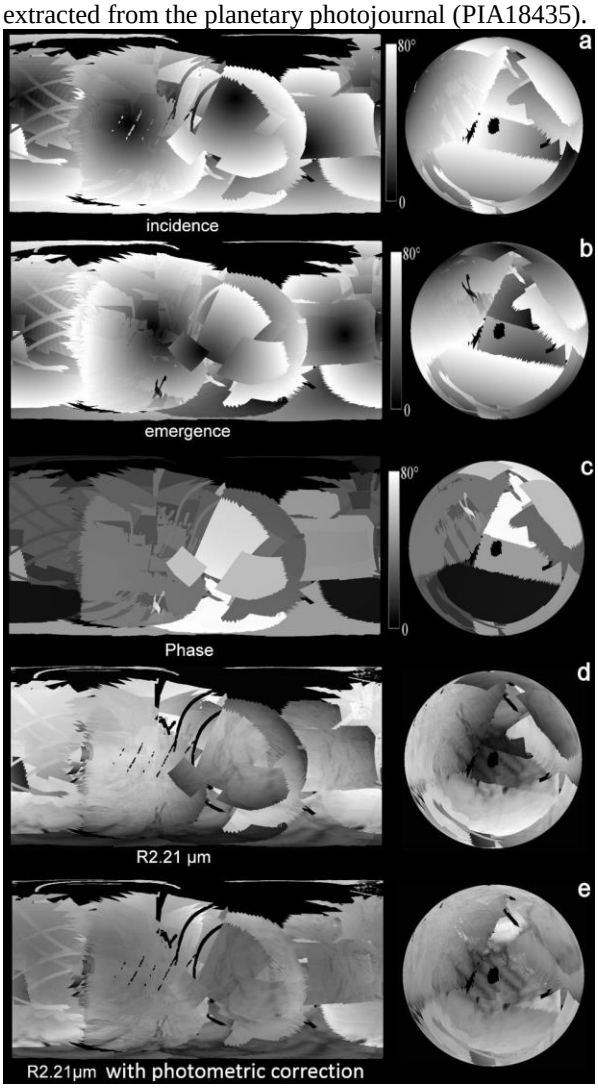


*Figure 1 : Global VIMS maps of Enceladus in cylindrical (left) and orthographic (right, centered on the South Pole) projections. a, b and c correspond to the geometry of acquisition. d and e correspond to mosaics at 2.21 µm before and after the photometric correction.*

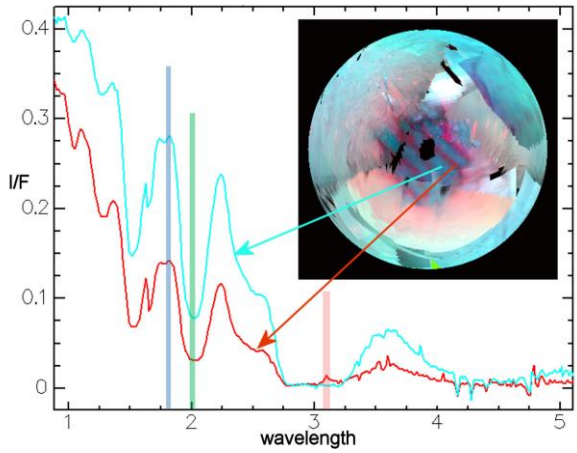


*Figure 2 : Typical spectra extracted from heterogeneous regions on and between the Tiger Stripes. The vertical bars show the position of wavelengths used for the RGB color composite.*

Several types of terrains can be distinguished on the VIMS mosaic. The comparison between VIMS and ISS reveals a correlation between spectral units and the general pattern of fractures encircling the South pole, with for example a pink-blue frontier in the lower left of the map (white arrow in Fig. 3) following prominent tectonique features. This limit appears in several VIMS cubes taken during different flybys and is therefore not an artifact. We attribute this variation to an effect of macroscopic roughness rather than pure compositional difference, according to preliminary radiative transfer modeling tests, which also suggest that the effect is dominated by the smallest fraction of grain sizes. In the South Pole area, the ice in between the active sulci (deep blue tint) display no cristallinity peak and a lower grain size. On the sulci themselves, the 2 µm band appears deeper, suggesting a coarser grain size. This observed behavior is consistent with the findings of [2, 3].

**Conclusion and perspectives** : VIMS provides a way to look for spectral heterogeneities on Enceladus thanks to its spectral dimension, and reveals interesting variations related to water ice, and also $CO_2$ (not discussed here. A detailed comparison with ISS high spatial resolution images, which requires a more precise geometric reprojection of both data sets, is currently underway. We also plan to determine the optimal photometric function to reduce the remaining discrepancies between the different data sets and then to derive grain size and temperature variations using the method described in [8], which relies on a work performed on experimental data acquired on pure water ice samples manually crushed at different grain sizes and characterized at different temperatures. The VIMS archive on Enceladus will remain the main source of hyperspectral information up to the end of the next decade, when a new mission will explore again the Saturnian system.

**References:** [1] Brown R.H. et al., Space Sci. Rev., 115, 111-168, 2004. [2] Brown et al., Science 311, 1425-1428, 2006. [3] Jaumann et al., Icarus 193, 407-419, 2008. [4] Porco et al., Science 311, 1393-1401, 2006. [5] Barnes et al., *Icarus*, 186, 242-258, 2007. [6] Le Mouélic S. et al., *PSS*, 73, 178–190, 2012. [7] Cornet T. et al., Icarus, 218, 788-806, 2012. [8] Taffin et al., PSS, 61, 124-134, 2012.

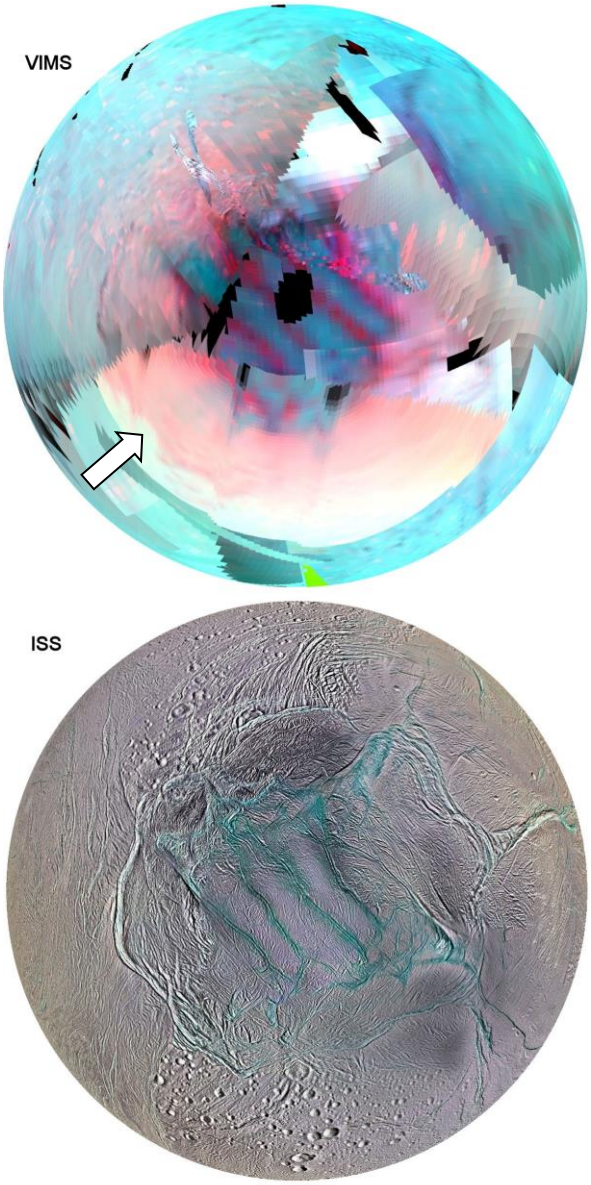


*Figure 3 Up : VIMS RGB composite of the South Pole of Enceladus, with the Red, Green and Blue controlled by the 3.09 µm, 2.0 µm and 1.78 µm channels respectively. Bottom : ISS basemap (PIA18435).*