**IDENTIFICATION AND DISTRIBUTION OF THE DIFFERENT SPECTRAL UNITS ON CERES. RESULTS FROM SURVEY AND HAMO PHASE.** F. Zambon[1], M. C. De Sanctis[1], F. Tosi[1], A. Longobardo[1], M. Ciarniello[1], J. Ph. Combe[2], G. Carrozzo[1], A. Raponi[1], E. Ammannito[3], M.T. Capria[1], S. Fonte[1], M. Formisano[1], A. Frigeri[1], M. Giardino[1], E. Palomba[1], C. Pieters[4], C. T. Russell[3], C. A. Raymond[5] and The Dawn/VIR Team.

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**Introduction**

Ceres, the largest object of the main asteroid belt [1], has been recently observed by the Dawn spacecraft [2]. In almost ten months, Dawn covered large part of Ceres surface at different spatial resolutions. Dawn's Visible and InfraRed (VIR) mapping spectrometer, acquired data in two different spectral channels, covering the overall wavelength range 0.25-5.1 µm [3]. VIR spectra of Ceres show a strong spectral feature at 2.7 µm [4] due to OH-bearing material and another at 3.1 µm associated with the $NH_4$-phyllosilicate [4,5,6,7]. Other spectral features have been identified at 3.3-3.5 µm and at 3.95 µm [4]. In addition, the spectral slope is sensitive to the composition and the freshness of surface materials, as generally, space weathering tends to make the regolith redder (positive spectral slope). By analyzing and combining the various spectral characteristics of Ceres we made a classification that define several spectral units on Ceres, which are related to different albedo regions.

**Dataset analysis and methods**

In this work we produced a global map of homogeneous spectral units, as found on Ceres on the basis of specific spectral parameters. We used VIR data obtained in Survey (nominal resolution ~1.1 km/px) and High Altitude Mapping Orbit (HAMO) (nominal resolution ~0.36 km/px), to achieve a broader coverage of Ceres surface. After calibration, VIR data have been photometrically corrected by means of a Hapke model [8,9]. We analyze several spectral parameters up to ~3.2 µm in wavelength, and we further selected those that display a larger variability. In particular: spectral slope between 0.44 and 0.55 µm, band depth at 2.7 µm and band depth at 3.1 µm. Band depths have been calculated using the criterion described in [10].

Range of values found for the spectral slope and for the 2.7-µm band depth were divided in three intervals, while values found for the the band depth at 3.1 µm were divided in two intervals, since this parameter has a lower variation (**Table 1**). Each homogeneous unit arises from the combination of the values found in the sub-ranges of these three parameters. However, to map the results we retained only the most populated units (**Fig. 1**, **Table 2**).

**Results**

Based on these three spectral parameters we obtain that Ceres surface is dominated by four main spectral units. In **Table 2** we report the range of values of the spectral parameters that characterized each unit. The most extended unit has a moderate spectral slope and strong absorption bands at 2.7 and 3.1 µm (green class in **Fig. 1**). The other three units are localized in smaller areas. Materials with a moderate spectral slope and moderate absorption band depths (in blue) are associated with the dark regions around specific craters. The cyan unit corresponds to similar spectral characteristics than the blue unit, except with a deeper absorption band depth at 3.1 µm; it is often present around the blue one but is more extended. Areas with strong positive spectral slope and strong absorption band depth at 2.7 and 3.1 µm (orange class) is found only in the Dantu area that is one of the brightest region on Ceres. To summarize, the units seem to be associated with albedo variations. The variability observed in homogeneous units seems to follow the changes observed in the albedo map [9]. The blue unit, which correspond to darker regions (with the exception of Haulani) has also lower values of the spectral parameters (small band depths and slope), while the orange unit is typical of the brighest areas and is characterized by the highest values of the spectral parameters (large band depths and steep slope). The large value in the depth of the two considered bands, compared to the rest of Ceres, might indicate a lower abundance of opaque material with respect to the region corresponding to the blue unit. Despite we found four main homogeneous spectral units, their average spectra are quite similar to each other, indicating an overall homegenous surface.

**Future work**

To improve our analysis and the definition of homogeneous spectral units, we will consider the entire spectral range of VIR. Moreover, a comparision with

geologic maps [11] will certainly prove to be useful to infer a relation between spectral and geological units.

**References:**

[1] Rivkin, A. S. et al., Space Sci Rev., 163, 95–116, 2006.
[2] Russell, C.T. et al., Science, 336, 684, 2012.
[3] De Sanctis M.C. et al., SSR, doi:I10.1007/s11214-010-9668-5 , 2010.
[4] De Sanctis M.C. et al., Nature, 2015, doi:10.1038/nature16172.
[5] King, T.V.V. et al., Science 255, 1551–1553, 1992.
[6] Rivkin, A. S. et al., Icarus 185, 563–567, 2006.
[7] Lebofsky et al., Icarus 48, 453–459. 1981.
[8] Hapke, B., Cambridge University Press, 1993.
[9] Ciarniello, M. et al., LPSC 2016.
[10] Roush, T. and Clark, R., JGR, 89, 6329-6340, 1984.
[11] Williams, D. et al. LPSC, 2016.

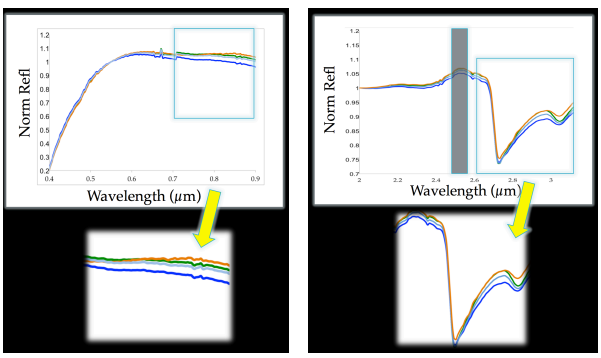


**Figure 2:** Spectra of the four main homogeneous units shown in the VIS (left) and IR (right) ranges, after normalization at 0.55 μm and 2 μm, respectively.

| Slope 0.44-0.55μm | BD 2.7μm | BD 3.1μm |
|---|---|---|
| 0.10 - 0.14 | 0.20- 0.23 | 0.03-0.05 |
| 0.14 - 0.18 | 0.23- 0.26 | 0.05-0.09 |
| >0.18 | 0.26-0.29 | |

**Table 1:** Range of values defined for each of the three considered spectral parameters.

| Units | Slope 0.44-0.55μm | Band depth 2.7μm | Band depth 3.1μm |
|---|---|---|---|
| Green | 0.14 – 0.18 | 0.26 – 0.29 | 0.05 - 0.09 |
| Blue | 0.10 – 0.14 | 0.23 – 0.26 | 0.03 – 0.05 |
| Cyan | 0.10 – 0.14 | 0.23 – 0.26 | 0.05 – 0.09 |
| Orange | > 0.18 | 0.26 – 0.29 | 0.05 – 0.09 |

**Table 2:** Values of spectral parameters defining the four most populated spectral units.

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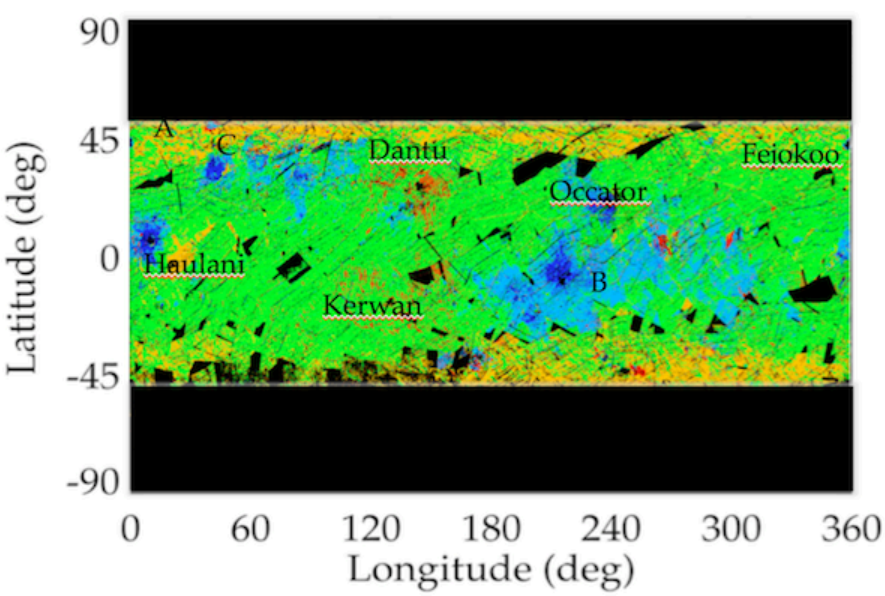


**Figure 1:** The four main homogeneous spectral units mapped across the surface of Ceres. Regions above 47°N and below 47°S have been masked because of limitations of the photometric correction.