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Disk-resolved photometry of Vesta and Ceres

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Abstract

We summarize the results obtained by the VIR spectrometer on board the NASA/Dawn mission about photometry of Vesta and Ceres. Phase functions and photometric behavior of absorption bands are mainly affected by optical properties, but in localized regions an important role is also played by surface roughness.

1. Introduction

The NASA/Dawn mission [1] orbited Vesta and is still orbiting Ceres, and hyperspectral images of the two bodies were acquired by means of the Visible and InfraRed (VIR) mapping spectrometer [2].
VIR confirmed Vesta as parent body of the HED achondrite clan [3]. The Vesta spectra are characterized by two deep absorption bands, due to pyroxene and centred at about 1 μm and 2 μm. Vesta is the asteroid with the largest albedo variation on its surface, because of the occurrence of carbonaceous chondrites [4], which darken the surface and makes the pyroxene bands shallower in several locations [5].
Ceres is a C-type asteroid, and its spectra are characterized by reflectance absorption at 2.7 μm (phyllosilicates), 3.1 μm (ammonium), 3.4 μm (ammonium and carbonates) and 3.9 μm (carbonates) [6,7]. Whereas Ceres is an overall dark body (I/F~0.03 at 0.55 μm and 30° phase), it shows two localized regions, i.e. the Occator faculae, having an albedo up to seven times higher than the Ceres average. They are the result of aqueous alteration, and show a larger abundance of phyllosilicates and especially carbonates, as revealed by the larger depth of the corresponding absorption bands.
We studied the photometric behavior, i.e. trend with incidence, emission and phase angle, of the spectral parameters describing the Vesta and Ceres spectra. This study is not only fundamental for data reduction (because leads all the observations to the same observation geometry), but also gives insights about physical and optical properties of the surface regolith.

2. Method

The method consists in a statistical analysis of the VIR dataset [8, 9, 10], and applies in the following steps: 1) retrieval and application of the disk function, among those defined in literature, which best removes the influence of incidence and emission angle on reflectance; 2) definition of reflectance families, where each family is given by the xx% (with xx=10, 20 … 80, 90) of largest reflectance value measured at each phase angle bin of width 1°; 3) for each reflectance family, retrieval of the function which best fit the behavior of reflectance, band depths and spectral slopes as a function of phase angle; 4) correction, i.e. retrieval of the value at a defined phase angle (0° or 30°).
To better describe the reflectance vs phase angle curve (phase function) we defined two parameters: R30, i.e. the retrieved reflectance at 30° phase angle, and PCS (Phase Curve Slope), i.e. the steepness of the phase function between 20° and 60° phase angle. These parameters were compared with those obtained on other asteroids explored by space missions.

3. Results

Vesta. Visible and infrared reflectance phase function is flatter in the bright terrains and steeper in the darker ones (Figure 1). This was ascribed to the more important role in bright terrains of multiple scattering, which redistribute the incident radiation at all the phase angles. For the same reason, the deepening of the pyroxene bands at increasing phase angle is more evident in dark terrains and almost absent in the bright ones. The photometric behaviour of the two band depths is similar, in agreement to the fact that their carrier is the same. Finally, a dependence of band centers on incidence angle was observed, in agreement with the HED band center dependence on temperature measured in laboratory experiments [11].

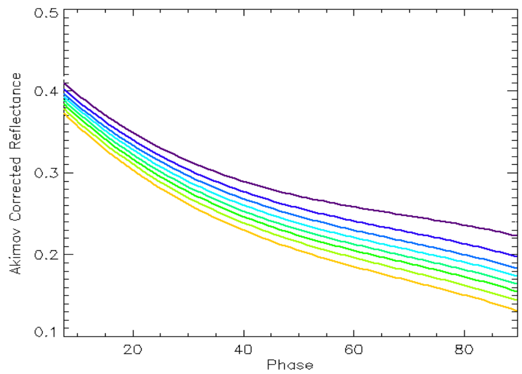

Figure 1. Phase functions corresponding to different Vesta's reflectance families. Cold (hot) colors correspond to bright (dark) terrains.

Ceres. Ceres is much more homogeneous than Vesta in terms of albedo, and its photometric properties are also constant across its surface, except in the Occator's faculae. Whereas the high steepness of the Ceres phase function of Ceres is justified by its low albedo, the high PCS of the Occator's faculae cannot be justified by optical properties only (PCS of asteroids having the same R30 of Occator is much lower, see Figure 2). It is therefore possible that the high roughness of this region [12] affects its photometric properties. For the Ceres average, all the band depths and the spectral slope increase with phase, as expected. The only exception is the 3.9 μm band depth, generated by a bright carrier (carbonates) and hence independent of phase. For the Occator's faculae, the 2.7 μm band depth decrease with phase is two times larger, while 3.4 and 3.9 μm are both phase-independent. The first behaviour can be explained again with the highest roughness of the faculae region. The second one is instead due to the fact that in this region the 3.4 μm absorption is due almost exclusively to carbonates (contrarily to the Ceres average) and hence has the same photometric behaviour of the 3.9 μm band depth. Spectral slope is also phase-independent on Occator, and this could be explained with absence of phase reddening for carbonates.

4. Conclusions

Disk-resolved photometry of Vesta and Ceres (and, more generally, of other asteroids) is mainly driven from optical properties, i.e. albedo and role of multiple/single scattering. The R30-PCS combination is a tool to discriminate different taxonomic classes. In addition, mixtures between two taxonomic types (e.g., the Vesta dark terrains consist in a HED-CC mixture) show intermediate photometric parameters between the classes.

However, we have found at least one location (the Occator's faculae on Ceres) where physical properties, specifically the surface roughness, also strongly affect the photometry.

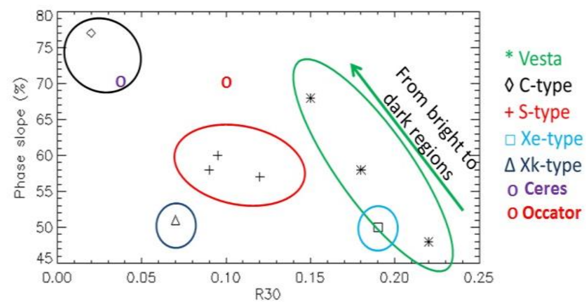

Figure 2: R30 vs PCS scatterplot for Vesta's dark, intermediate and bright terrains, Ceres average, Occator's faculae and other asteroids [9].

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