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Phase functions of Vesta and other asteroids: implications for the spectral classification

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Abstract

In this work photometric parameters of Vesta and Lutetia have been obtained and compared with those relative to other asteroids of different spectral classes. We found that Vesta bright regions have a photometric behavior similar to other achondritic surfaces, whereas dark regions have intermediate properties between achondrites and carbonaceous chondrites. Lutetia is instead photometrically different than all the asteroids considered in this study.

1. Introduction

The behavior of reflectance as function of illumination and viewing angles (i.e. incidence *i*, emission *e* and phase *φ*) is driven by regolith grain size, surface roughness and relative role of single and multiple scattering. For this reason, its study reveals optical and physical properties of an asteroid surface.
In addition, to understand these behaviors is fundamental to compare images/spectra taken at different illumination conditions.
Using ground-observations of seventeen asteroids, [1] found an interesting link between photometric parameters (e.g. V-band albedo and phase coefficient) and spectral classification of asteroids. In particular, they observed an albedo decrease and a phase coefficient increase from E-type to F-type asteroids (passing through S, M, G and C asteroids)
Space missions data allow to infer photometric parameters of disk-resolved phase functions and to refine the relation between photometry and spectral classification.
In addition, disk-resolved phase functions make it possible to obtain a photometric characterization of different regions of a inhomogeneous asteroid. This is the Vesta case, which presents bright [2] and dark regions [3].

In this work, disk-resolved phase functions of Vesta and Lutetia have been retrieved and their photometric parameters have been compared with the ones of other asteroids in order to study the link between photometry and spectral classification.

2. Vesta and Lutetia phase functions

A statistical analysis has been performed on data provided by the VIR (Visible and InfraRed) mapping spectrometer, mounted on the Dawn spacecraft [4]. The analysis consists in an empirical definition of reflectance families [5] and in the retrieval of a relation between reflectance and phase angle for each reflectance family [6].
The decrease of visible and infrared reflectance with phase has been found to be steeper in low-albedo regions and more moderate as albedo increases (Figure 1). This has been ascribed primarily to the more important role in bright units of multiple scattering, which redistributes the incident radiation, causing a flattening of the phase curve [6].
The same analysis has been applied on Lutetia data acquired by the VIRTIS-Rosetta [7] imaging spectrometer. However, the reflectance variations across Lutetia are much lower than those observed on Vesta, we have considered an average phase curve rather than reflectance families.

3. Comparison between asteroids

We selected two parameters to describe the photometric behaviour of Vesta and Lutetia: the reflectance *R30* which would be observed at a 30° phase, and the phase slope *PS*, i.e. the reflectance percent decrease between 20° and 60° phase.

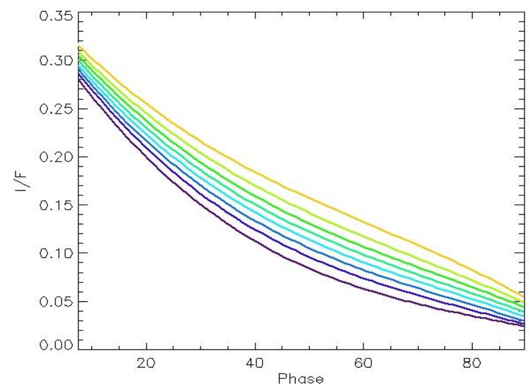

Figure 1: 1.2 μm reflectance as function of phase angle for different Vesta families (reflectance increases from purple to yellow).

These two parameters have been calculated on the retrieved phase functions of Vesta (bright, intermediate and dark regions) and Lutetia, as well as on disk-resolved phase functions available in literature, relative to the S-type Eros [9], Ida [10], Gaspra [10] and Annefrank [11], the C-type Mathilde [12] and the E-type Steins [13].

The *R30-PS* scatterplot (Figure 2) shows that S asteroids are grouped together, whereas the C-type Mathilde shows the lowest *R30* and the highest *PS* due to its low albedo and the negligible role of multiple scattering. On the contrary, the E-type Steins has a larger *R30* and a lower *PS*.

The *R30* and *PS* parameters found in bright material units on Vesta are similar to those found for Steins, suggesting a photometric analogy between achondritic surfaces. We argue that the different photometric behavior of achondrites compared to chondrites is driven by their optical properties (i.e. larger albedo and efficiency of multiple scattering). Based on physical properties, Vesta should have a *PS* value similar to S-type asteroids (because its grain size is similar on average [14,4]) or a larger one (since roughness is larger on Vesta [15]).

Dark material units on Vesta show an intermediate behavior between achondrites and C-type asteroids, confirming the fact that these regions are characterized by mixtures of HED and carbonaceous chondrites [4].

The photometric properties of Lutetia (low *R30* and low *PS*) cannot be grouped within other asteroid spectral classes. Since in the Bus classification [16] Lutetia is commonly classified as a C, an E or a M type (the latter has photometrical similarities with S asteroids [1]), our result seems to suggest that Lutetia has physical or optical properties significantly different than other asteroids of its own class.

However, according to the De Meo classification [17], Lutetia is a Xc asteroid, furthermore we can suppose that the region of the *R30-PS* scatterplot filled by Lutetia is characteristic of this spectral class.

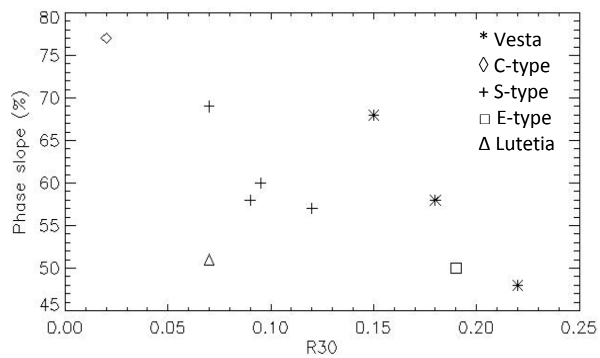

Figure 2: Phase slope and 30° reflectance of asteroids visited by space missions. The three asterisks relative to Vesta refer to its bright, intermediate and dark regions.

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