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An empirical model to remove the influence of illumination and viewing angles

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Abstract

We show an innovative approach to correct spectral data for illumination and viewing angles, based on a statistical analysis of observations and empirical definition of reflectance families. The method has been successfully applied to planetary surfaces (Vesta and Lutetia) and atmospheres (Venus) and is planned to be applied to Churyumov-Gerasimenko data from Rosetta VIRTIS spectrometer.

1. Introduction

The observation of a planetary surface is affected by illumination and viewing angles, i.e. Solar incidence i, emission e and phase φ. As a matter of fact, the light absorption and scattering by dust regolith is not isotropic and is often more effective for low incidence and emission angles. This affects the measured reflectance, getting tricky the interpretation of data (e.g. confusion between terrains observed at extreme illumination conditions and dark terrains).

The photometric correction (e.g. removal of illumination and viewing angles influence) is often based on theoretical functions, modelling the interaction light-dust (e.g. [1], [2]).

We present here an innovative approach, based on a statistical analysis on observations of the studied planetary body, and an empirical definition of reflectance families.

This approach is independent of assumptions of each specific model, and requires a low number of parameters. In addition, it allows to analyse the variations of photometric properties across the surface. Finally, it can be applied for any spectral parameter (e.g. band depth) and to study any behaviour (e.g. band center as function of surface temperature [3]). This makes the approach adaptable to any planetary surface, but also to planetary atmospheres.

The empirical model has been successfully applied to two planetary surfaces (Vesta and Lutetia) and one planetary atmosphere (Venus), giving interesting insights about the surface/atmosphere physical and optical properties. Moreover, we discuss its possible application to Churyumov-Gerasimenko, target of the Rosetta mission.

2. Method

The correction method here explained is relative to the removal of phase angle φ effect on the reflectance I/F. The approach can be generalized with any parameter.

The following steps apply:

1. Consider the scatterplot I/F as function of φ Define φ bins (e.g. 1° width)
2. Consider for each bin the reflectance value corresponding to p% of brightest pixels (where p can be 10, 20, 30 … 90). Each p value defines a reflectance family (Figure 1)
3. For each reflectance family, retrieve the phase function I/F vs φ (e.g. fitting a line, a polynomial or an exponential).
4. For each pixel of the dataset, identify the relative reflectance family and apply the corresponding phase function in order to infer the reflectance value at a fixed phase angle $\varphi*$ (e.g. 0°).

At the end of these steps, we have reflectance values phase-corrected and a comparison between observations taken at different geometry becomes meaningful.

3. Application to Vesta and Lutetia

The method has been applied to the VIR spectrometer [4] observations of Vesta, in order to study the following behaviors [5]: reflectance vs phase (Figure 1), band depth vs phase and band center vs temperature. This allowed to obtain the first VIR albedo maps of Vesta (Figure 2).

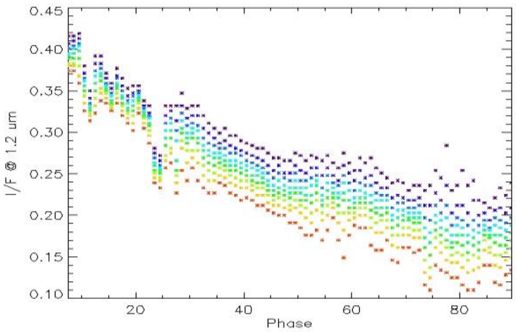

Figure 1. 1.2 µm reflectance families defined on the dataset of VIR observations of Vesta. Each colour identify a *p* value, i.e. a reflectance family.

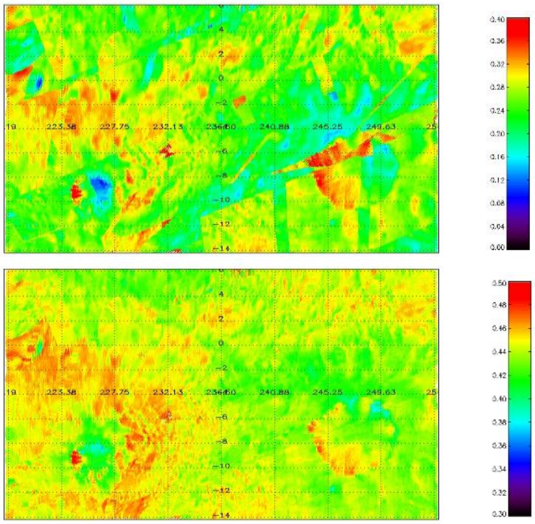

Figure 2: Reflectance maps of the Vesta region Cornelia/Numisia before (above) and after (below) the photometric correction.

In addition, the retrieval of phase functions revealed a steeper decrease of reflectance at increasing phase in dark regions and a flatter one in bright terrains. This is in agreement with a more important role played by multiple scattering in bright regions, where incident light is more redistributed at all the phase angles, resulting in a decrease of the phase slope.

The analysis on Lutetia has been instead performed on Rosetta-VIRTIS data [6]. In this case, the same phase function has been obtained for all the reflectance families, leading to the conclusion that Lutetia is an homogeneous body [7].

4. Application to Venus

The empirical model has been applied on VIRTIS-Venus Express data [8], considering the I_λ vs cos e scatterplot (Limb Darkening Functions), where I_λ is the radiance thermally emitted at the wavelength λ. Four wavelength have been considered, relative to emission originating from different atmospheric heights. In this case the families empirically defined correspond to different optical depth conditions [9].

We obtained that the Limb Darkening Functions are steeper at near-equatorial latitudes and flatter poleward of 50°. This has been ascribed to a cloud opacity increase at high latitudes (confirmed also by a radiance decrease), since the larger density of scattering centres redistributes the radiation at all the emission angles [9].

5. Results expected for Churyumvov-Gerasimenko

According to ground-based observations [10], Churyumov-Gerasimenko presents a very dark nucleus. Therefore we should expect very steep phase functions (due to negligible role of multiple scattering), with phase function variations mostly related to change of physical properties (e.g. roughness, grain size) rather than optical ones. The analysis will allow to reveal if Churyumov-Gerasimenko is more similar to Tempel 1, Wild 2, Hartley 2 (phase functions almost constant across the whole surface) or to Borrelly (where phase function variations are larger).

Finally, since cometary activity can be highlighted by exposed ice [11], having a larger albedo and coarser grains (i.e. steeper phase slope), we could detect a reflectance family corresponding to an active region.

References

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