PHOTOMETRIC BEHAVIOR OF 67P/CG SPECTRAL PARAMETERS AS INFERRED FROM PRE-LANDING DATA.

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Introduction: The Visible and Infrared Thermal Imaging Spectrometer (VIRTIS) [1] onboard the ESA Rosetta spacecraft has been mapping the surface of comet 67P/Churyumov-Gerasimenko since August 2014.

VIRTIS is composed of two optical heads, i.e. VIRTIS-H, a high resolution spectrometer working in the near-infrared range (1.9-5.1 µm), and VIRTIS-M, a mapping spectrometer working in the visible 0.2-1 mm) and infrared (1-5 µm) spectral range.

The first data of VIRTIS revealed a very dark nucleus and the presence of opaque materials associated with organic macromolecular materials [2].

Photometric correction is a fundamental process of data analysis, since it is aimed at removing the trends of reflectance with incidence, emission and phase angles, which can lead to a misinterpretation of data. Moreover, the retrieval of phase curves allows evaluating physical and optical properties of the surface, such as grain size, roughness and role of single and multiple scattering (e.g. [3], [4], [5]).

In this work we study the photometric behavior of spectral descriptors characterizing the visible and IR (thermally removed[6]) spectra of 67P/CG, such as reflectance at different wavelengths (0.55 µm, 0.75 µm, 1.2 µm, 1.7 µm, 2.0 µm, 2.8 µm, 4.0 µm), depth and center of the 3.2 µm band (due to organics) [2], depth and center of the 2.0 µm band, due to exposed water ice [7], infrared and visible spectral slope. Moreover, we study the photometric behavior of these parameters for the four different macro-regions of the comet (i.e. head, body, neck and bottom) and for different Local Solar Times (i.e. from 24 to 6, 6 to 12, 12 to 18, 18 to 24h LST).

The analysis is performed on pre-landing data, i.e. data acquired when the comet was far from perihelion and hence cometary activity, if present, was low.

Method: In order to correct the reflectance, we apply the photometric empirical model already developed to correct the VIR data of Vesta [3] and Ceres. The first step of this method consists in identifying the disk function more suitable to remove the influence of topography effects (i.e. due to incidence and emission angles). This disk function is then used to obtain the equigonal albedo, which still depends on the phase angle. In order to remove the phase influence, we define reflectance families by means of a statistical analysis: the aim is to obtain phase functions for brighter and darker regions of the comet. However, in all the cases analysed so far, we do not observe changes in phase functions between dark and bright regions.

Due to the albedo homogeneity observed across the 67P/CG surface, the photometric behavior of the other parameters considered in this study is inferred as average behavior of each parameter with incidence, emission and phase angle, respectively.

Results: ***Reflectance.*** Among the tested disk functions (i.e. Lambert, Lommel-Seeliger, Akimov), the Akimov one is the only one which removes the influence of incidence and emission angles (Figure 1). The phase functions obtained at the seven wavelengths are similar, even if slight differences are observed.

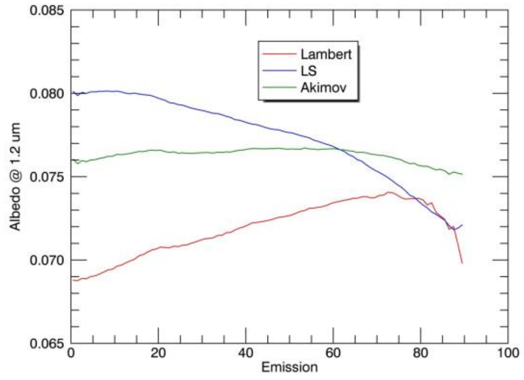

Figure 1. Equigonal albedo at 1.2 µm obtained by applying three different disk functions as a function of emission angle (expressed in degrees).

In particular:

- The phase functions of the four 67P/CG macro-regions are similar (Figure 2) at all the analysed wavelengths;
- The steepness of phase functions is slightly larger in the nocturnal local times: the slope between 20° and 60° of the phase curve calculated for 24-6 LST is on average 4% larger than the slope of the curve obtained for 6-12 LST. This might be related to the non-

negligible activity (i.e. ice sublimation) observed even on pre-landing data [8].

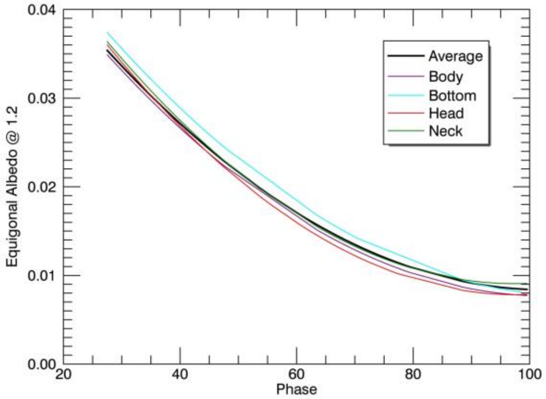

Figure 2. Phase functions at 1.2 μm for the four different macro-regions of the comet.

The phase curve slope of 67P is however much lower with respect to other comets (Figure 3). The interpretation of this result is in progress.

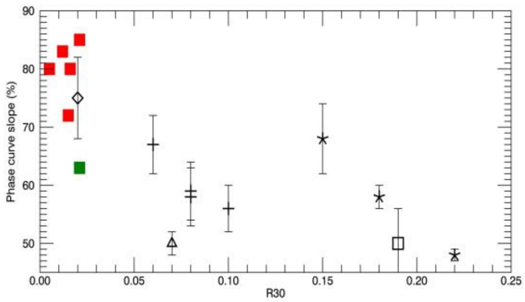

Figure 3. Slope of the phase curve between 20° and 60° as a function of reflectance at 30° phase (R30). The green square corresponds to 67P/CG, the red squares to other comets visited so far by space missions, the "plus" signs to S-type asteroids, the triangle to Lutetia, the open square to Steins and the three asterisks to Vesta bright, intermediate e dark terrains (see [9] for details)

3.2 μm band. Two different behaviors of depth and center of the 3.2 μm band are observed. For "diurnal" LST (i.e. 6-12 and 12-18), the depth increases at increasing emission angle. For "nocturnal" LST (i.e. 24-6 and 18-24), band depth is on average larger, band center shorter, and the band depth trend with emission angle is no longer observed. The band deepening and center shift could be explained by the formation of water ice [7] which affects this band. The ice formation during the night may be at the origin of the different band depth behavior with emission at diurnal and nocturnal LST, respectively.

The band center slightly moves with incidence angle toward longer wavelengths (i.e. shift of 1 VIRTIS band, about 10 nm). This could be ascribed: a) to a real shift due to a temperature change, as observed in other minor bodies (e.g. [3]); b) residuals of the removal of the thermal contribution.

2.0 μm band. This band is observed in few cases. The general behavior is a deepening at increasing incidence angle. However, we ascribe this behavior not to a photometric effect, but to the fact that larger incidence angles correspond to terrains less exposed to Solar illumination, where water ice is more easily formed.

Visible and infrared spectral slope. The trend of the visible (0.55-0.75 μm) and infrared (1.2-2.0 μm) spectral slopes with phase describes the phase reddening. We found that the phase reddening is larger in the visible ($3.8\cdot10^{-4}$ deg^{-1}) than in the infrared ($1.53\cdot10^{-4}$ deg^{-1}) and slightly larger in the nocturnal LST. This might be due to the contribution of water ice to the phase reddening [7].

Conclusions: 67P/CG is photometrically uniform, even if slight differences in the photometric behavior of spectral parameters are observed. This behavior could be due to a non-negligible cometary activity present on the dayside even during pre-landing observations and/or to water ice formation on the nightside. These results could be confirmed by extension of this study following phases of the mission.

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