EPSC Abstracts
Vol. 12, EPSC2018-865, 2018
European Planetary Science Congress 2018

Organic features in the spectrum of 67P/ Churyumov-Gerasimenko from the improved calibration of VIRTIS-M-IR

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1. Introduction

The VIRTIS spectra of 67P/CG in the region between 2.9 and 3.5µm display a wide absorption band, which has been associated to the presence of organic compounds [1, 2]. However, several instrumental effects have hindered, so far, the detailed interpretation of the molecules and compounds contributing to this band. In this work we revised the in-flight calibration of the VIRTIS-M-IR instrument onboard Rosetta spacecraft [3, 4] with the aim to improve: a) the detection of low-contrast spectral features and b) the radiometric accuracy. This updated calibration involves all 432 spectral channels (λ) and 256 spatial samples. It includes: 1) the removal of artifacts associated to calibration residuals and/or incomplete flat field correction; 2) the reduction of the non-poissonian noise introduced by the readout electronics of the instrument; 3) a newer version of the radiometric calibration using stellar sources. Furthermore, we have modeled the thermal emission to remove the nucleus contribution at wavelengths in excess of 3.0 µm and we have also modeled and removed, by means of the Hapke [5] model, the contribution of water ice absorption to isolate the organic features within the spectral region 2.9 – 3.5 µm. These spectral features have been compared with laboratory measurements and observations of diffuse interstellar medium to provide indications on the relative contribution of the Aromatic and Aliphatic components.

2. Artifacts Removal

Spectral artifacts, caused by calibration residuals, are superimposed on the real spectral features preventing the detection of small features. A comparison of the 67P/CG and 21 Lutetia spectra revealed that these artifacts are ubiquitous and they depend linearly on the signal level. In order to remove these effects, for each spatial sample we take into account an average signal of the comet nucleus acquired during the first mapping phase of the Rosetta mission in August-September 2014, and of the Lutetia asteroid. Spectra are processed sample (s) by sample to trace the variability of the artifacts across the focal plane. The ratio between 67P/CG and 21 Lutetia spectra allows removing all the spectral artifacts while keeping information of the ratio of the real features. Assuming the spectrum of Lutetia is devoid of small (few spectral channels-wide) real features, we model it with a polynomial interpolation representing the absolute reference, which is then used to isolate an artefact-removed spectrum of 67P (see Eq. 1):

1)
$$\frac{\frac{I}{F}(\lambda,s)_{67P/CG}}{\frac{I}{F}(\lambda,s)_{Lutetia}} \cdot \frac{I}{F}(\lambda,s)^{interp}_{Lutetia} = \frac{I}{F}(\lambda,s)^{AR}_{67P/CG}$$

3. Reduction of the noise

The average spectrum of the comet, cleaned from artifacts, still presents a source of non-poissonian noise introduced by the electronics of the instrument. Due to the detector's architecture, the even spectral channels response is affected by the temperature of the instrument, which introduces spurious offset along the wavelengths especially at low fluxes. Thus, we replaced the even channels by an average of the contiguous odd spectral channels.

4. Absolute calibration with star observations

Both VIRTIS-Rosetta and VIMS-Cassini observed stars during the cruise phase of the mission. This gives the possibility to compare the flux observed by both instruments to perform an inter-calibration. In particular, we compared two acquisitions of Arcturus performed by VIRTIS-M-IR with six observations performed by VIMS onboard Cassini [6]. The ratio of the average fluxes observed by the two instruments provides a correction factor as a function of the wavelength, which can be applied over the whole VIRTIS-M dataset.

5. Modeling: thermal emission and water ice removal

Thermal emission is subtracted from the average 67P spectrum as discussed in [7].

Previous works [8, 9, 10] showed that the surface of the comet presents spatial and temporal variations of the band depth and shape of the absorption at 2.9-3.5 µm due to variation of water ice content. Following this argument, we can reasonably expect that the entire nucleus surface contains a small amount of water ice, in depths accessible to VIRTIS. By means of Hapke model [5] and using the optical constants of [11, 12] we inferred an anhydrous spectral albedo of the comet removing from the average spectrum of the nucleus a modeled spectrum of 1.8% (p_w) of water ice, with a grain diameter of 0.6 microns, according to equation (2).

2) $(\text{Anhydrous } 67P)_\lambda = (67P)_\lambda - p_w\,(\text{water ice})_\lambda\,/(1.-p_w)$

When water ice is removed additional small spectral features stand out, which are discussed below.

6. Interpretation of the spectral features

The elaboration of the average spectrum of the comet by means of the improved calibration and the modeling resulted in a revised shape of the whole spectrum and the isolation of spectral features, which can be attributed to specific organic materials. In particular we identified small features centered at: 3.28 µm, which are consistent with aromatic C-H stretching; 3.38, 3.42, 3.48 µm which can be attributed to aliphatic (CH_3 asymmetric, CH_2 asymmetric, and CH_3 symmetric stretching, respectively) [13], previously reported in [14]; other small features are present at 2.85, 3.0, 3.1 µm. They can be attributed to C-H overtones, OH-stretches, and/or N-H stretching, according to spectral comparison with analog materials. Finally, the organic features on the spectrum of the comet present similarities with observations of interstellar diffuse material [15], with Ceres [16] and Saturn rings [17]. Their significance in the framework of the comet origin and evolution will be discussed.

Acknowledgements

We thank the following institutions and agencies for support of this work: Italian Space Agency (ASI, Italy) Centre National d'Etudes Spatiales (CNES, France), DLR (Germany). This work takes advantage of the collaboration of the ISSI international team "Comet 67P/Churyumov-Gerasimenko Surface Composition as a Playground for Radiative Transfer Modeling and Laboratory Measurements", number 397.

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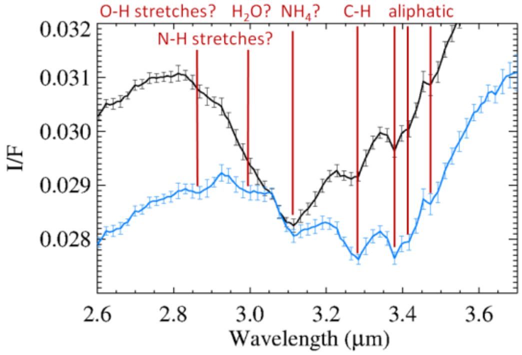

Figure 1. Black line: average spectrum of 67P after the new calibration process, and thermal removal. Blue line: 67P spectrum after water ice removal. Error bars indicate the uncertainties of the calibration.