Studying a comet: two years of results from VIRTIS spectrometer on board of ROSETTA spacecraft

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When the Rosetta spacecraft approached the comet 67P/Churyumov-Gerasimenko (hereafter 67P/CG) in August 2014, the Visible, Infrared and Thermal Imaging Spectrometer (VIRTIS) [1] began a mapping campaign to provide direct measurements of the surface composition of the nucleus. The VIRTIS instrument is composed of two channels: VIRTIS-H, a high resolution cross-dispersed spectrometer working in the spectral range between 2 and 5 μm and VIRTIS-M, an imaging grating spectrometer based on a Shafer-Offner telecentric optical design. The task of VIRTIS-M is the mapping of the comet, in particular its nucleus, in the spectral range from 0.25 to 5.1 μm at moderate spectral resolution (1.8 nm/band for wavelengths below 1 μm and 9.7 nm/band above 1 μm) [1].

From the first data collected by this instrument, the surface of the comet was found to be very homogeneous. All the macro-regions (the 'neck', the 'head' and the 'body' regions) have very similar spectra : a very low albedo (0.052 $\pm$ 0.013), a broad spectral feature centered at about 3.2 μm, and two different spectral slopes in the visible and infrared [2,3] (Fig. 1). From the thermal part of the VIRTIS radiance spectrum, it was possible to calculate the surface temperature of the comet ranging between 180 and 220 K [4].

A notable result of the first data of VIRTIS was the absence of pure water ice absorption bands in the spectra, indicating an upper limit of about 1% on the water ice abundance at the resolution of about 15-30 m/pixel [2]. Subsequent observations of the 'neck' region with a better resolution have showed a change of the band around 3.2 μm for spectra corresponding to pixels in the shadow and in the next illuminated region [5] (Fig. 2). As showed in Fig. 2, the spectra display progressive 3-μm band weakening as the region move into illumination. The spectra showing the strong 3-μm band indicate the presence of water ice in addition to the organic material present on the comet surface. Such observations suggest that the presence of ice is not constant but it depends on the thermophysical condition of the surface corresponding to a cyclic sublimation–condensation process of the water during each comet rotation [5].

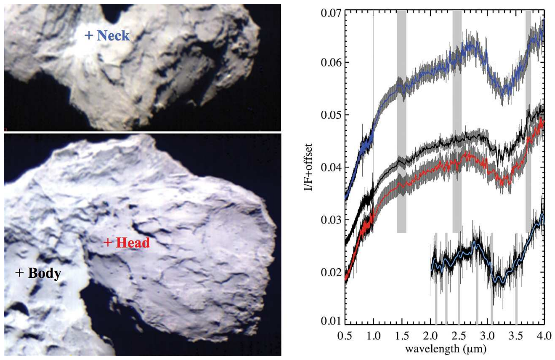

Figure 1. Left: Two RGB images of the nucleus of the comet 67P/CG showing the 'neck', the 'head' and the 'body' regions. Right: Reflectance spectra of the three regions in the range 0.5 – 4.0 μm taken by the VIRTIS-M (blue, black, and red curves with error bars) and a spectrum of VIRTIS-H (light blue curve with error bars) in the spectral region between 2.0 and 4.0 μm. The spectra were scaled for clarity. The vertical light gray bars indicate the instrumental bridging zones and order sorting filters gaps [2].

Even though on the surface of the comet 67P/CG the absence of large regions of exposed water ice was evident from the first data acquired [2], the analysis of VIRTIS spectra registered in the period from September to November 2014 has suggested the presence of a significant amount of water ice in two areas, in the so called Imhotep region [6]. The data reveal two different popu-

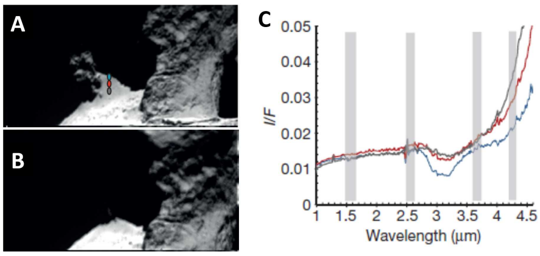

Figure 2. A and B: VIRTIS images at 0.7 μm of the 'neck' region. The data are separated by $\sim$ 12 h. The coloured dots in A indicate the pixels from whic the spectra in C are taken. C: Spectra from A going from illuminated pixels to shadow (grey, red and blue curves). The vertical light gray bars indicate the instrumental bridging zones and order sorting filters gaps (figure modified by [5]).

lations of grains: one is several tens of micrometers in diameter, while the other is much larger, around 2 mm (Fig. 3).

The Astrophysic Group of the Department of Mathematics and Physics 'E. De Giorgi' of the University of Salento (Lecce) is very active in the work done by the VIRTIS team. It supports the interpretation of the VIRTIS spectra through the spectroscopy study in laboratory of possible analogues minerals of the comet surface. For the spectral analysis we use two different spectrometers operating in two wavelength ranges partially overlapped. The first is a grating spectrometer, Perkin Elmer Lambda 900, covering the range 200 to 2500 nm; the second is a Fast Fourier Spectrometer (FFT), Perkin Elmer Spectrum 2000, spanning the range 2.0–25 μm. Both instruments are equipped with an integrating sphere coated with an appropriate highly reflecting material (Spectralon and Infragold, respectively) in order to obtain the directional-hemispherical reflectance. When necessary, the grain size of each sample can be investigated by mean of a laser diffractometer, Malvern Mastersizer 2000.

Since coals have been recognized for a long time as potential analogs of cometary refractory carbon, we have decided to investigate the spectra of a series of coal samples with a different grade of maturity: two coals from the same mine at Mericourt, one from Escarpelle mine, and one from La Mure mine, France. In Fig. 4A their spectra are shown along with the spectrum of an Amorphous Carbon. All samples display a very low reflectance value in the visible range but only the coals with a very low grade of maturity (i.e. those from Mericourt mine, black and red curve in Fig. 4A) have the 3.2 μm band with sufficiently high

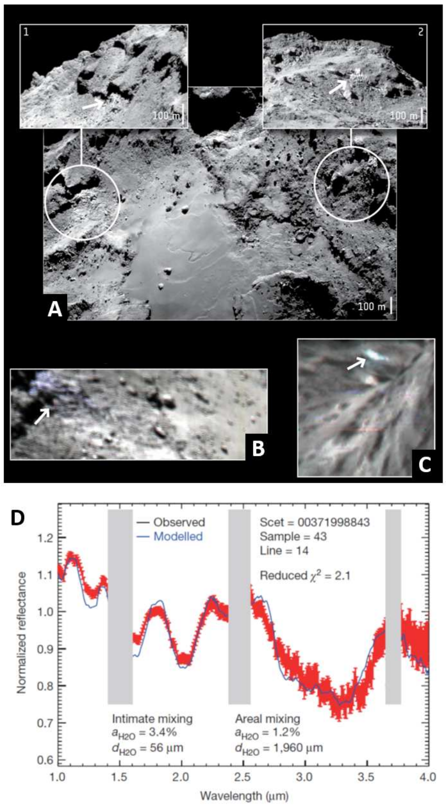

Figure 3. A: Rosetta NAVCAM images of Imhotep region of the two debris falls (magnificated in 1 and 2). B and C: VIRTIS images of the two areas: the blue pixels indicate the presence of the water ice. D: VIRTIS spectrum of one of the water-ice rich area (red curve with error bars) and best-fit synthetic model (blue curve) obtained as a combination of intimate and areal mixing of water ice with dusty grains (figure modified by [6]).

spectral contrast.

For this reason, we have decided to study a coal sample with a very low maturity from the Penn State University Coal Bank and Data Base, PSOC 1532 (provided by E. Quirico). This sample was sieved into six granulometric classes and their spectra are shown in Fig. 4B. It is possible to see that the spectral behavior varies with the grain size; in particular, the mean reflectance value increases as the grain size decreases. The bands at 2.3 μm could be assigned to stretching modes of CH_2 or CH_3 while the feature located at $\sim$2.5 μm may be due to a combination of C-H stretch with C-C stretch. On the other hand, the features centered at 1.4 and 1.9 μm are probably due to molecular water adsorbed by the samples.

From an inspection of figs 4A-B, it is evident that the spectra of the materials taken into account do not reproduce very well the spectral characteristics of the 67P/CG, such as the position of the 3.2-μm band as well as the two different spectral slopes in the VIS and IR range. Such occurrence has led us to study three binary mixtures: the first is composed for the 70%Vol. of augite and for the 30%Vol. of a coal from Mericourt mine; the second and the third are composed for the 50%Vol. of an amorphous carbon and for the 50%Vol. of coal PSOC 1532 and a coal from Mericourt mine, respectively. In order to compare the spectra of the produced mixtures with that of the comet 67P/CG, in Fig. 4C, all these spectra, normalized at 2.3 μm, are shown. From this figure, it is evident that the position and the shape of the 3.2-μm band of the spectrum of 67P/CG (black curve in Fig. 4C) is not reproduced by any of the analyzed mixtures. On the other hand, the mixture composed by the coal from Mericourt mine and the amorphous carbon (red curve in Fig. 4C) has the same spectral slope of 67P/CG in the range from 1 to 2.7 μm. In the future, we need to improve our mixtures to better reproduce the 67P/CG VIRTIS spectrum. We will test the effect of changing the percentage and/or the grain size of the components. In addition we will take into account mixtures composed by more than two component.

Acknowledgements: The authors would like to thank ASI - Italy, CNES - France, DLR - Germany, NASA-USA for supporting this research. VIRTIS was built by a consortium formed by Italy, France and Germany, under the scientific responsibility of the Istituto di Astrofisica e Planetologia Spaziali of INAF, Italy, which guides also the scientific operations. The consortium includes also the Laboratoire d'??tudes spatiales et d'instrumentation en astrophysique of the Observatoire de Paris, France, and the Institut f??r Planetenforschung of DLR, Germany. The authors wish to thank the Rosetta Science Ground Segment and the Rosetta Mission Operations Centre for their continuous support.

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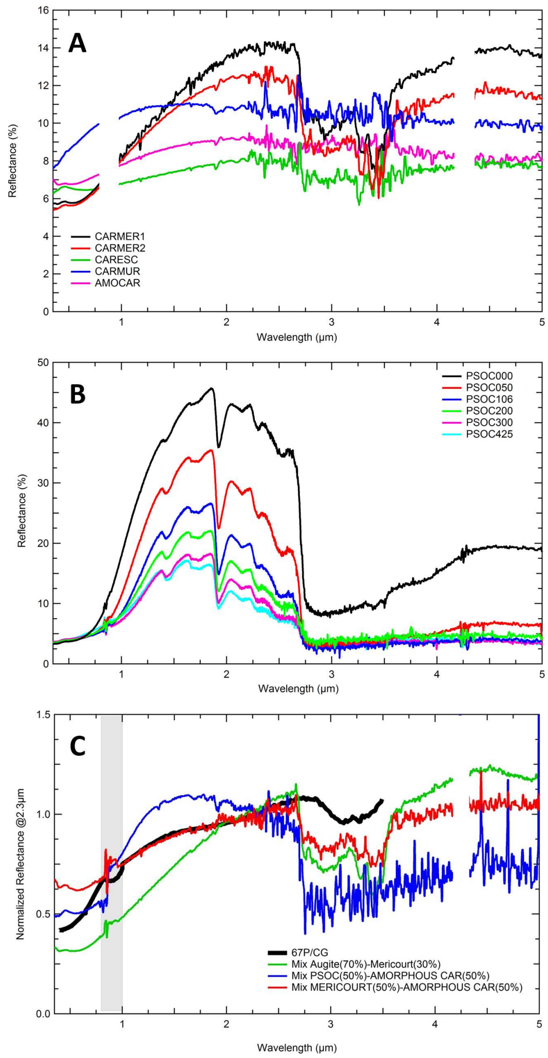

Figure 4. A: Spectra of the analyzed coal samples: an amorphous carbon (AMOCAR), two samples from Mericourt mine (CARMER1 and CARMER2), one from Escarpelle mine (CARESC) and one from La Mure mine (CARMUR). The data around 0.9 μm and 4.2 μm are not shown because of an instrumental artifact. B: Spectra of PSOC 1532 divided in six grain size classes: <50 μm (PSOC000), 50–106 μm (PSOC050), 106–200 μm (PSOC106), 200–300 μm (PSOC200), 300–425 μm, (PSOC300), >425 μm (PSOC425). C:Normalized spectra of the comet 67P/CG (black curve), the mixture composed by 70% of Augite and 30% of coal from Mericourt (green curve), the mixture composed by 50% of PSOC 1532 and 50% of amorphous carbon (blue curve), the mixture composed by 50% of coal from Mericourt and 50% of amorphous carbon (red curve).