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Seasonal colors cycling on 67P/CG nucleus and coma

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Abstract

Understanding how comets work is one of the more compelling questions to which Rosetta mission is trying to answer to. In this perspective, we investigate the temporal evolution of 67P/CG nucleus surface and dust particles with the scope to quantify the spectral changes occurring at different heliocentric distances, to search for possible correlations among them and to verify their dependence with activity. A quantitative analysis of seasonal color changes occurring in the coma and nucleus of 67P/CG has been conducted by means of a systematic processing of the entire Rosetta-VIRTIS-M-VIS [1] channel dataset. Specific spectral indicators have been separately computed for the coma and the nucleus and then ordered in time-series spanning from January 2015 (in-bound orbit, heliocentric distance 2.55 AU), encompassing perihelion passage (August 2015, 1.24 AU) up to May 2016 (outbound orbit, 2.92 AU).

1. How does the coma changes?

For VIRTIS coma data, spectral analysis is performed considering all pixels inside an annulus defined by tangent altitudes between 1 and 2.5 km above the limb. The following four spectral indicators are computed for each observation: 1) integrated radiance (I) across the VIS spectral range; 2) wavelength of maximum emission of the radiance (λ_{max}); 3) 0.4-0.5 μm I/F spectral slope; 4) 0.5-0.8 μm I/F spectral slope. The *integrated radiance (I)* of the coma emission (dust and gas) is computed by averaging the integral of the spectral radiance in the 0.25-1 μm spectral range on the annulus:

$$I = \frac{\sum_{n=1}^{N} \int_{0.25\mu m}^{1\mu m} R(n,\lambda) d\lambda}{N} \tag{1}$$

where $R(n,\lambda)$ is the spectral radiance measured on the n-th pixel of the annulus at wavelength λ and N is the total number of pixels within the annulus area. The *wavelength of maximum emission of the radiance (λ_{max})* is determined from a 4th degree quadratic fit on the average spectral radiance computed on the annulus $(\sum_{n=1}^{N} R(n,\lambda)/N)$. *Spectral slopes* are computed following the method discussed in [2, 3]. On average, both dust colors and integrated radiance changed significantly approaching the perihelion passage (Fig. 1). The spectral radiance from 67P coma is largely dominated by scattered light from grains at visible wavelengths. Monitoring the integrated intensity in an annulus around the nucleus allows to trace the temporal activity changes as a function of the heliocentric distance. The general trend of the integrated radiance as a function of the heliocentric distance shown in Fig 1 top left panel, is characterized by an asymmetric, or cusp-like, profile similar to the water production rate measured by other Rosetta instruments [4]. The maximum is reached in MTP020, with a delay of less than a month with respect to the perihelion passage (MTP019). Two intense integrated radiance peaks of about 50 W/(m^2 sr), occurred around the perihelion period when the spacecraft was performing dayside excursions orbiting at great distances (up to 1400 km) from the nucleus. The increased optical depth along the line of sight during these two periods and the intense cometary activity (outbursts occurred in September 2015) are the cause of the integrated radiance rapid increment. The wavelength (λ_{max}) of maximum emission increases from about 0.45 μm in January 2015 to 0.55 μm around perihelion to decrease again to 0.45 μm in May 2016 (Fig 1, bottom left panel). A similar trend is observed also on the two spectral slopes (0.4-0.5 and 0.5-0.8 μm) profiles calculated on I/F spectra which show a reddening around perihelion passage (Fig 1, right column panels). All these parameters show how the spectral behavior of the coma is changing with the heliocentric distance, becoming more red towards perihelion.

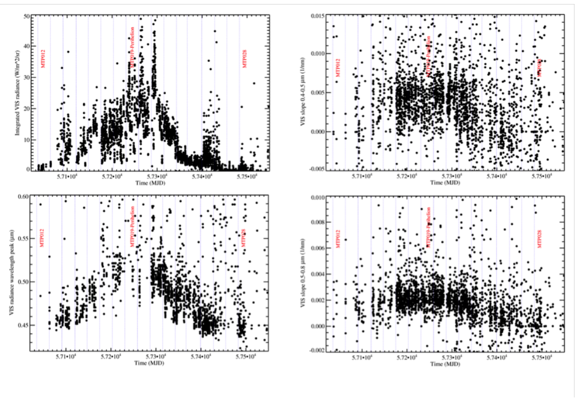

Figure 1: Time-series showing the evolution of coma spectral indicators: integrated radiance (top left panel), λ_{max} (bottom left), 0.4-0.5 μm slope (top right), 0.5-0.8 μm slope (bottom right).

2. How does the nucleus changes?

The color of the nucleus is mainly driven by the abundance of the water ice on the surface regolith [5, 6]. VIRTIS data show that the nucleus surface is progressively becoming bluer while the comet was approaching the sun [2, 3, 7]. The analysis performed on several locations across the nucleus for which a continuous coverage across the entire mission is available (Fig. 2) indicate that the minimum reddening is reached in September 2015, about one month after perihelion. On the next months the reddening increases again returning to pre-perihelion values towards the end of the Rosetta mission

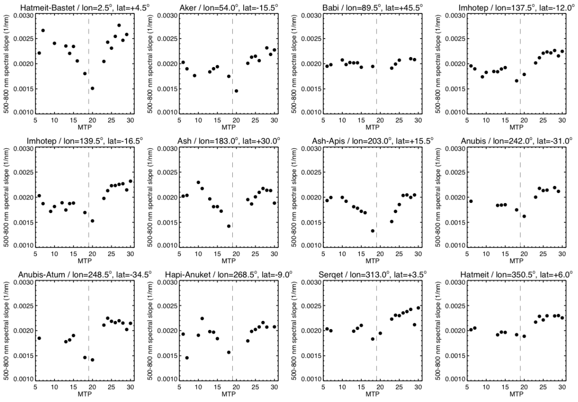

Figure 2: Time-series showing the evolution of visible spectral slope on 12 test equatorial areas. The minimum reddening is observed in MTP020 (September 2015).

3. Summary and Conclusions

By comparing coma and nucleus spectral slopes, two opposite trends with heliocentric distance are observed: while the I/F spectra of the coma becomes more red when the comet approaches perihelion, on 12 equatorial areas of the nucleus, for which we have continuous time-coverage during the entire Rosetta mission, we observe a systematic bluening of the surface, with a reduction of the spectral slope up to 50%. During the pre-perihelion period we interpret the coma color changes as a consequence of the progressive loss of the ice fraction in the dust grains ejected from the nucleus which makes them more red. At the same time the nucleus' surface becomes bluer following the exposure of more pristine subsurface layers and the removal of surface dust caused by the gaseous activity. After perihelion, as soon as activity begins to settle, the progressive accumulation of dehydrated dust on the surface makes it redder again. The study of coma's and surface's color time-series observed by VIRTIS indicate that a similar seasonal cycle is developing during the orbital phase close to the sun.

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