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THERMAL MAPS AND PROPERTIES OF COMET 67P AS DERIVED FROM ROSETTA/VIRTIS DATA.

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Introduction: After a 10-year cruise, the Rosetta spacecraft began a close exploration of its main target, comet 67P/Churyumov-Gerasimenko, in July 2014. Since then, the Visible InfraRed Thermal Imaging Spectrometer (VIRTIS) [1] acquired hyperspectral images of the comet's surface with an unprecedented spatial resolution. VIRTIS data are routinely used to map the surface composition and to retrieve surface temperatures on the dayside of the comet.

The thermal behavior of the surface of comet 67P is related to composition and physical properties that provide information about the nature and evolution of those materials.

Here we present temperature maps of comet 67P that were observed by Rosetta under different illumination conditions and different local solar times.

The VIRTIS instrument: VIRTIS is a hyperspectral imaging spectrometer in the overall range 0.25-5.1 µm (VIRTIS-M) and high spectral resolution capabilities (VIRTIS-H) onboard the ESA Rosetta mission [1]. VIRTIS design fully accomplishes Rosetta's scientific objectives at all targets of the mission. The composition of the uppermost layer of the comet's surface down to depths of tens of microns, in terms of water ice, salts, organics and volatiles, can be revealed and mapped by visual and infrared spectroscopy using high spatial resolution imaging, and high spectral resolution to simultaneously improve diagnostic capabilities.

The infrared range longward of 3.5 µm is crucial to reveal the thermal emission of the comet on its dayside, which can be used to map surface temperature across different orbits and local solar times (LST), and therefore constrain thermal properties at different spatial scales (**Fig. 1**).

Data set and analysis: Here we show spatially-resolved temperature maps of comet 67P derived in medium-term planning (MTP) phases carried out in the second half of 2014: MTP006-007-008-009-010-011, in the overall spatial sampling range between 23 m/px and ~2.3 m/px, which has never been achieved before with this technique on a planetary body. Data were acquired under variable phase angles, illumination conditions, and heliocentric distances.

Local-scale features on comet 67P are currently being investigated by the Rosetta team. We focus both on regional maps and on peculiar sites of interest seen at the local scale, with a special emphasis on the actual Philae landing site.

To derive surface temperature, we select the 4.5-5.1 µm range of the infrared spectrum as measured by VIRTIS, and we use a Bayeasian approach to nonlinear inversion [4] that was applied to Rosetta/VIRTIS data obtained during the close flybys of asteroid 21 Lutetia [2,3], as well as to the entire dataset of infrared data acquired by the VIR mapping spectrometer aboard the Dawn spacecraft during its orbital phase at asteroid Vesta in 2011-2012 [4].

The Noise Equivalent Spectral Radiance (NESR) is the rms noise of the in-flight measurements expressed in units of spectral radiance. In the 4.5-5.1 µm range, NESR is dominated by fluctuations of the thermal emission from the spectrometer, which result in a lowest measurable temperature of ~170 K, i.e. no temperature below this threshold can be accurately retrieved from VIRTIS data. This essentially means that VIRTIS cannot measure temperatures on the nightside of comet 67P.

Results: Comet 67P is shown to be everywhere rich in organic materials with little to no water ice visible on the surface [5]. In the range of heliocentric distances from 3.59 to 2.74 AU, daytime surface temperatures are overall comprised in the range between 180 and 220 K, which is incompatible with large exposures of water ice and is consistent with a low-albedo, organics-rich surface [5]. Accuracies down to a few K are achieved in regions of the comet unaffected by shadowing or limb proximity [6]. Maximum temperature values as high as 230 K have been recorded in very few places. The highest values of surface temperature were obtained at the beginning of MTP006, with observations at small phase angles implying that the observed surface has a large predominance of small incidence angles, and local solar times centered around the maximum daily insolation (**Fig. 2**). In all cases, direct correlation with topographic features is observed, i.e. largest temperature values are generally associated with the smallest values of illumination angles, while so far there is no evidence of thermal anomalies, i.e. places of the surface that are intrinsically warmer or cooler than surrounding terrains observed at the same local solar time and under similar solar illumination.

For a given LST, the maximum temperature mainly depends on the solar incidence angle and on surface properties such as thermal inertia and albedo. Since VIRTIS is able to observe the same point of the surface at multiple times under different conditions of solar illumination and LST, it is possible to reconstruct the temperature of that point at different times of the comet's day, thus building diurnal profiles of temperature that are useful to constrain thermal inertia.

The availability of spatially-resolved, accurate temperature observations, significantly spaced out in local solar time, provides clues to the physical structure of such peculiar sites, which complements the compositional investigation based on imaging spectroscopy data collected at shorter wavelengths.

In the thermal images of VIRTIS, a note of great interest is provided by the `neck' of the comet close to the `body', where, because of the concave shape, the `head' casts prominent shadows on some areas experiencing maximum daily insolation. This is a place potentially subject to considerable thermal stresses, and here we evaluate both the spatial thermal gradients and the temporal thermal gradients, providing implications for the surface structure.

Being confined to the dayside, coverage of VIRTIS improves along with the progress of the mission, when, with decreasing sub-solar point's latitude, new zones of the southern hemisphere, now precluded to remote sensing observations, will be gradually uncovered.

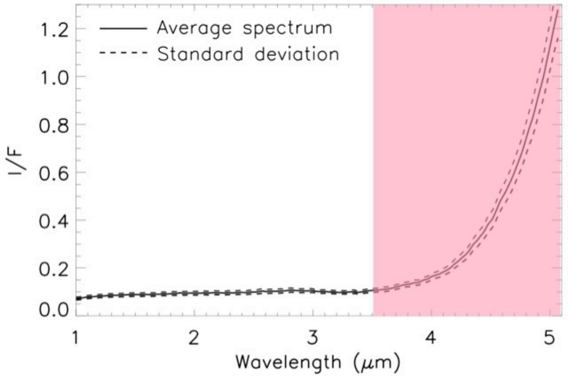

Figure 1. *Average spectrum of comet 67P as measured by VIRTIS-M in the infrared range 1.0-5.1 μm, in units of calibrated radiance factor I/F defined as specific intensity collected by the instrument, divided by the incident solar flux scaled at the heliocentric distance of the target. The thermal emission of the comet is revealed at wavelengths longward of ~3.5 μm (pink box). Dashed lines are 1σ spectra, showing a larger dispersion in the thermal emission range.*

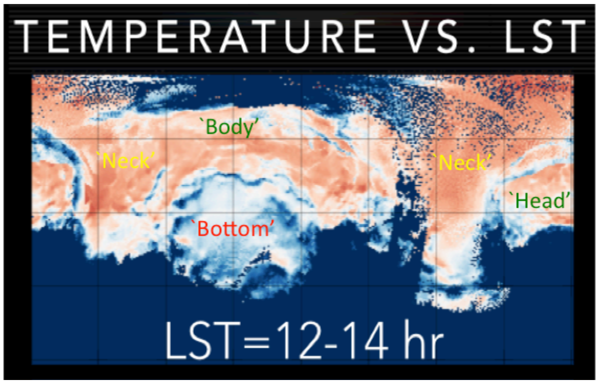

Figure 2. *Global distribution of surface temperatures measured by VIRTIS in the MTP006 session, in simple cylindrical projection. Angular binning of 1°x1° is applied. Only LST between 12 h and 14 h (i.e., those experiencing the maximum daily insolation) are shown. The main comet's features (neck, head, body, bottom) are tagged. The `body' is located at equatorial latitudes and at longitudes between 100°E and 180°E. The `head' is located between about 300°E and 40°E. The region of the `neck' is located at medium-to-high northern latitude and is distorted because of the representation, but is distinguished by higher values of temperature, reaching a maximum of ~220 K (in red). The cold `bottom' of the `body' (in blue) corresponds to a smooth plain where sunlight is grazing for most of the daytime.*

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References: [1] Coradini, A., et al. (2007). *Space Sci. Rev.* 128, 529-559. [2] Coradini, A., et al. (2011). *Science* 334 (6055), 492–494. [3] Keihm, S. et al. (2012). *Icarus* 221, 395-404. [4] Tosi, F., et al. (2014). *Icarus* 240, 36-57. [5] Capaccioni, F., et al. (2015). *Science*, in press. [6] Tosi, F., et al. (2014). *DPS* XLVI, Tucson, 9-14 November 2014.