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Rosetta Lander – Philae on Comet 67P/Churyumov-Gerasimenko

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Rosetta is a Cornerstone Mission of the ESA Horizon 2000 programme. In August 2014 it reached comet 67P/Churyumov-Gerasimenko after a 10 year cruise. Both its nucleus and coma have been studied with its orbiter payload of eleven PI instruments, allowing the selection of a landing site for Philae. The landing on the comet nucleus successfully took place on November 12th 2014.

Philae touched the comet surface seven hours after ejection from the orbiter. After several bounces it came to rest and continued to send scientific data to Earth. All ten instruments of its payload have been operated at least once. Due to the fact that the Lander could not be anchored, the originally planned first scientific sequence had to be modified. Philae went into hibernation on November 15th, after its primary battery ran out of energy. Re-activation of the Lander is expected in spring/summer 2015 (before the conference) when CG is closer to the sun and the solar generator of Philae will provide more power.

The presentation will give an overview of the activities of Philae on the comet, including a status report on the re-activation after hibernation.

Rosetta is an ESA mission with contributions from its member states and NASA. Rosetta's Philae lander is provided by a consortium led by DLR, MPS, CNES and ASI with additional contributions from Hungary, UK, Finland, Ireland and Austria.

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The low strength of 67P: evidence for a primordial nucleus?

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Abstract

Rosetta is orbiting comet 67P/Churyumov-Gerasimenko since August 2014. The OSIRIS camera [1] onboard this spacecraft has acquired hundreds of images of the nucleus surface, with a spatial resolution down to the decimeter scale [2]. The images reveal a complex nucleus surface made of smooth and hummocky terrains, covered partially or entirely by dust or exposing a consolidated material, pits, cliffs and fractures from the hundred meter scale to the decimeter scale [3]. The nature and origin of these terrains and geomorphological features are far from being understood but remain of paramount importance to better constrain the formation and evolution scenario of the nucleus of 67P and comets in general.

This study focuses on the link between the nucleus gravitational slopes and surface morphology, to provide constraints on the nature of the cometary material and its mechanical properties in particular (tensile strength, shear strength and compressive strength). The derived strengths can also be used to constrain the origin of the nucleus of 67P.

We derive a low tensile strength for the nucleus, typically from a few tens to a few hundreds Pa [4]. Our results tend to favour a formation of comets by pebble accretion in a region of higher concentration of particles like a vortice [5, 6, 7], which implies a gentle formation process by accretion at low velocity on the order of 1 m s^{-1} or less. On the contrary, the hierarchical accretion model with velocities up to 50 m s^{-1} for particles larger than 1 m [8], or the collisional scenario between two large bodies of tens of km or more with an internal compression by gravity larger than 10 kPa [9], although not excluded, are less favored. This points towards a primordial nucleus, which might have not been strongly affected by collisions since its formation.

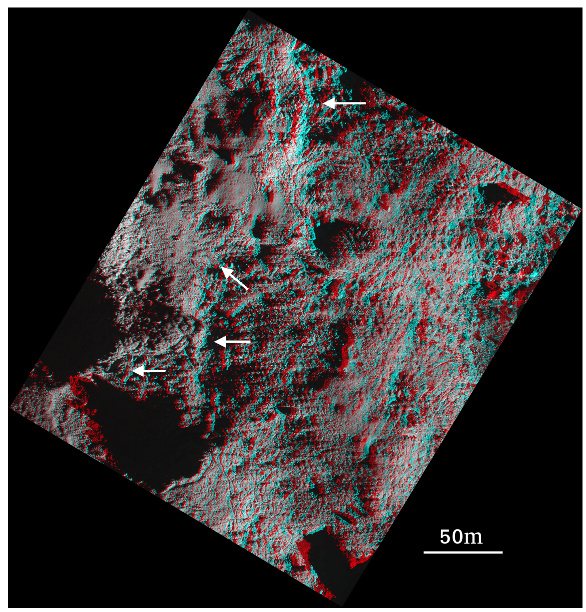

Figure 1: Red/blue anaglyph of overhangs (white arrows) at a high spatial resolution of 18 cm per pixel, in the Maftet region. Image NAC_2014-10-19T13.18.55.

Acknowledgements

OSIRIS was built by a consortium of the Max-Planck-Institut für Sonnensystemforschung, Katlenburg-Lindau, Germany; CISAS University of Padova, Italy; the Laboratoire d'Astrophysique de Marseille, France; the Instituto de Astrofísica de Andalucia, CSIC, Granada, Spain; the Research and Scientific Support Department of the ESA, Noordwijk, Netherlands; the Instituto Nacional de Técnica Aeroespacial, Madrid, Spain; the Universidad Politéchnica de Madrid, Spain; the Department of Physics and Astronomy of Uppsala University, Sweden; and the Institut für Datentechnik und Kommunikationsnetze der Technischen Universität Braunschweig, Germany. The support of the national funding agencies of Germany (DLR), France (CNES), Italy (ASI), Spain (MEC), Sweden (SNSB), and the ESA Technical Directorate is gratefully acknowledged. We thank the Rosetta Science Operations Centre and the Rosetta Mission Operations Centre for the successful rendezvous with comet 67P/Churyumov-Gerasimenko.

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The ROSETTA PHILAE Lander damping mechanism as probe for the Comet soil strength.

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Abstract

The ROSETTA Lander is equipped with an one axis damping mechanism to dissipate kinetic energy during the touch down. This damping is necessary to avoid damages to the Lander by a hard landing shock and more important to avoid re-bouncing from ground with high velocity. The damping mechanism works best for perpendicular impact, which means the velocity vector is parallel to the damper axis and all three feet touch the ground at the same time. That is usually not the case. Part of the impact energy can be transferred into rotational energy at ground contact if the impact is not perpendicular. This energy will lift up the Lander from the ground if the harpoons and the hold down thruster fail, as happen in mission.

The damping mechanism itself is an electrical generator, driven by a spindle inside a telescopic tube. This tube was extended in mission for landing by 200mm. A maximum damping length of 140mm would be usually required to compensate a landing velocity of 1m/s, if the impact happens perpendicular on hard ground.

After landing the potentiometer of the telescopic tube reading shows a total damping length of only 42,5mm.

The damping mechanism and the overall mechanical behavior of the Lander at touch down are well tested and characterized and transferred to a multi-body computer model. The incoming and outgoing flightpath of PHILAE allow via computer-simulation the reconstruction of the touch down. It turns out, that the outgoing flight direction is dominated by the local ground slope and that the damping length is strongly dependent on the soil strength. Damping of soft comet ground must be included to fit the damping length measured. Scenario variations of the various feet contact with different local surface features (stone or regolith) and of different soil models finally lead to a restricted range for the soil strength at the touch down area.

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Churyumov-Gerasimenko comet core: bifurcation of debris

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All cosmic bodies are under an action of forces origin of which is due to the bodies' movements in non-circular keplerian orbits. Periodical changes of accelerations cause warping bodies inertia-gravity waves; rotations distribute these warpings into four interfering ortho- and diagonal directions [1-4]. Lengths and amplitudes of the waves are inversely proportion to orbital frequencies of bodies: smaller frequency larger waves and, vice versa, larger frequency smaller waves [1-2]. An etalon may be Earth: 1/1year frequency- πR/2 waves (πR/4 or a half wave tectonic granule), or the Sun's photosphere: 1/1 month frequency – πR/60 granulation. The Ch-G comet 6.6 years – 2398 days, 57552 hours - orbiting period (1/57552 hours fr.) gives 1.65 πR tectonic granule – too large to observe directly. But modulations by this small frequency the much higher rotation frequency of the comet (1/12.5 hours) gives two side frequencies (division and multiplication of the higher fr. by the lower one): 1/4604 and 1/719400. To them correspond two granule sizes: πR/4604 & πR/719400 (R=~ 2500-2000m) or 1.70-1.36 & 0.011-0.009 m. Rosetta 'images reveal penetrating comet's body geometrically regular lattice with spacing about a few meters. Its more accurate dimension can be measured at a block of ~ 5 meters across (Fig. 5, 6) where stripes width is about 1-2 meters and a granule, consequently, is about 1- 2 meters across. The smaller (finer) modulated centimeter fragment size is presented in numerous "deluvial" covers in local depressions (Fig. 1-3, 5). The coarser meter size spherical (polyhedron) boulders also are ubiquitous (Fig.1-6). It is important that only calculated two fragment sizes prevail amidst derbies released from outcrops appeared as 3D " wafer cakes". This debris size splitting (bifurcation) is one of the strongest confirmations of the wave nature of celestial bodies deformation by external orbital forces.

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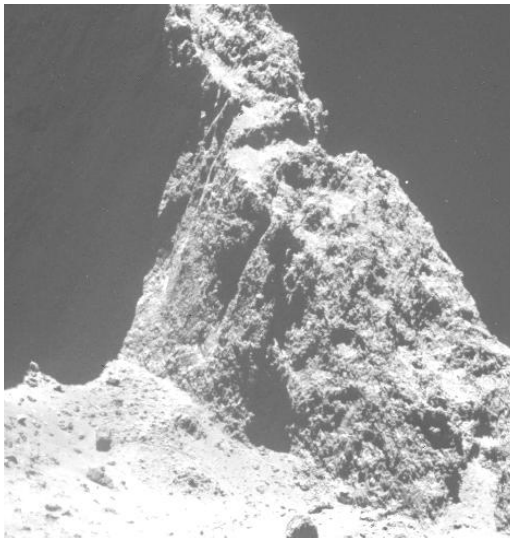
Fig.1. Outcrop at the Ch-G comet. AP_rosetta_comet_mission_2_jtm_141111_16x9_992.jpg
Fig.2. Spherical (polyhedron) fragments moving down slope along with finer debris ESA_Rosetta_NAVCAM_141010_D.jpg
Fig. 3. Ch-G rock. NAVCAM_top_10_at_10_km_5.jpg
Fig. 4. Portion of Fig. 3. Crossing stripes with ready to detach meter size spherical fragments
Fig. 5. Comet_from_40_metres.jpg. The block is 5m in size. Credit: ESA/Rosetta/Philae/ROLIS/DLR
Fig. 6. The block of Fig. 5. ~5m across. Stripes & spheroids ~ 1m wide.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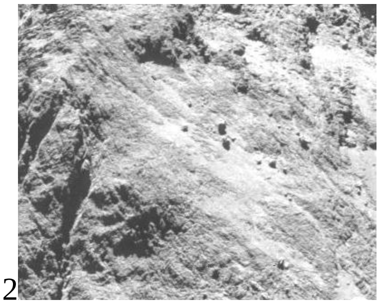
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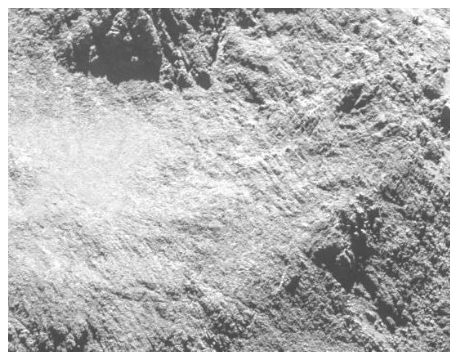
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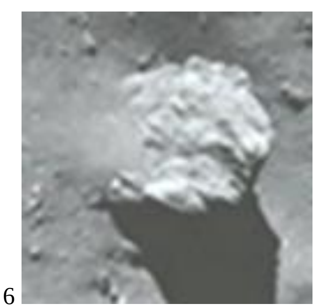
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TRANSIENT WATER ICE ON COMET 67P/CHURYMOV-GERASIMENKO

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Introduction: The Visible InfraRed Thermal Imaging Spectrometer, VIRTIS [1] onboard ESA's Rosetta mission started to observe the nucleus of the 67P/Churyumov-Gerasimenko in August 2014. The instrument is composed by two units. VIRTIS-M, the mapping unit of the instrument, relies on a Shafer-Offner optical design and performs imaging spectroscopy in the 0.25-5.1 µm spectral range across 864 channels resulting in a spectral sampling of 1.8 nm/band for wavelengths below 1 µm and 9.7 nm/band between 1-5 µm. The instrument has a 3.7 deg FOV and uses 256 samples with an IFOV of 250 µrad [1]. VIRTIS-H is the high spectral resolution unit, operating between 2-5 µm and it is mainly devoted to the coma study.

Data: Comet 67P/Churyumov-Gerasimenko was observed to be moderately active very far from the perihelion by Rosetta mission, that collected high spatial and spectral resolution data of the comet from VIRTIS [1]. Here we analize the VIRTIS data acquired in the period August-September 2014 (3.6-3.3 AU from the Sun), with a ground spatial resolution varying between 7.5-25 m/pixel, and covering a spectral range of 0.35-5.0 µm.

Results: The first reflectance spectra, taken in different areas over the illuminated regions of the comet's nucleus, show the presence of a broad absorption band at 2.9-3.6 µm, attributed to organic compounds [2]. The same spectra showed the absence of pure water ice absorption bands, indicating an upper limit of about 1% on the water ice abundance at that resolution [2]. Those early data were acquired with a resolution of about 15-30 m/pixel.

In the following observations, VIRTIS acquired data of the "neck" region with a better spatial resolution. In some specific areas of the neck, VIRTIS observed spectral variations moving from the illuminated pixels to the shadowed areas, with a progressive change of the band around 3-µm. This feature shows a clear shape change with a broadening, a shift towards shorter wavelengths and a strong increase of the depth. The characteristics of the spectra showing the stronger 3-µm band indicate the presence of water ice in addition to the organic material present on the comet surface.

Fig.1 shows the region of the neck where the ice signature has been observed, and fig. 2 shows the two spectra taken from the same region, one very close to the shadow and one on the well illuminated area.

The two spectra show a clear difference in the 3-µm spectral range (fig.2). The strong 3-µm ice band is clearly present in all the pixels located at the border of the shadow and it progressevly disappears going far from the shadow. The same regions has been seen at different comet rotations and the same phenomenon has been observed: a stronger 3-µm ice band close to the shadows.

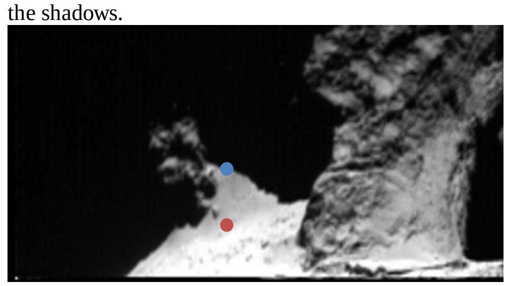

Fig.1. VIRTIS monochromatic image at 0.7-µm of the neck region of 67P. The colored dots indicate the zones from which the spectra in Fig.2 are taken.

The analysis done indicates that the maximum quantity of ice is found very close to the shadows in all the observations, even if the pixels in shadows are different in each image. The observations suggest that the ice is not constant but it depends on the thermo-physical condition of the comet surface. The spectra show also different thermal emissions: the spectra with stronger 3-µm band are also charcterized by smaller thermal emissions. A clear anti-correlation trend of ice abundance with temperature is seen in this region of the neck, suggesting that the water ice feature is present only when the temperature is low enough to permit the stability of water ice on comet surface. Thus, we are looking at a process that implies sublimation and condensation of water going from illuminated to not illuminated points.

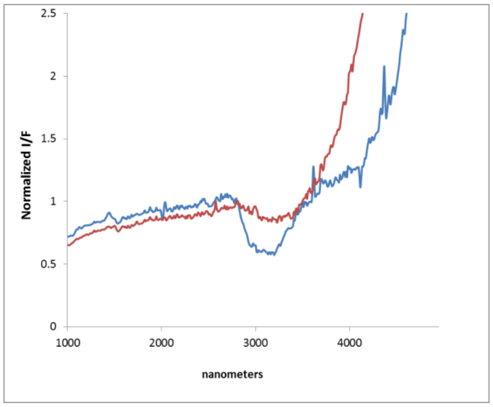

Fig.2 Two spectra taken from the region in fig.1. The red and the blue spectra correspond, respectevely, to the red and blue spots in fig.1.

Two possible mechanisms for the condensation of water ice in the comet unilluminated area can be considered: the condensation of coma material (emitted gas and icy grains) onto cold spots on the nucleus [3] or condensation in the colder external layers of gas coming from subsurface sources [4,5]. Both the mechanisms can be responsible for the phenomenon we see.

Conclusion: Ice has been observed on other cometary surfaces [6] as patches of pure ice mixed with the non-ice component of the surface. In case of comet 9P/Tempel 1, these ice patches were not directly linked with the comet gas activity and the main sources of gases were indicated in the comet interior. On comet 67P, VIRTIS observes surface ice mixed with a non-ice organic rich component, in a region were the localized water activity occurs [7]. Moreover, the ice signature is variable with time and illumination conditions suggesting a cyclic process of sublimation-condensation of water ice on the comet surface.

The cyclic replenishment of ice, due to the light/dark changes, in the first comet layers can be the key for the strong local activity seen from the comet neck.

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Circular depressions on 67P/Churyumov-Gerasimenko observed by the OSIRIS instrument

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Abstract

Since it close encounter with comet 67P/Churyumov-Gerasimenko (67P) in August 2014, the OSIRIS instrument [1] on-board the Rosetta Spacecraft has imaged the surface of the nucleus with unprecedented resolution. From its global morphology description, numerous circular depressions of different sizes and shapes have been observed [2, 3]. Few of these circular depressions, also called pits, have shown sign of activity with the detection of faint jet-like features originated most likely from their walls [4]. The mechanism responsible for the formation of these morphological features is not yet well understood, although different hypotheses have been raised such as the collapse of a ceiling above internal voids [4]. These voids could either be due to primordial structure of the comet's interior, or they could have been created with subsequent evolution of the nucleus. In both case, these features provide important constrains on the formation and evolution of cometary nucleus. Follow-up observations of the OSIRIS instrument should both confirm the nature of the activity (i.e., sporadic vs. regular) and the number of active depressions.

In this analysis, we provide a thorough identification and description of the circular depressions on the surface of the comet nucleus. These circular depressions exhibit different shapes, from pits to alcoves, with sizes varying from tens to hundred of meters, and ultimately with different texture on their walls (i.e., with fractures and polygons, or not). The accumulation of boulders at the bottom of some of these depressions indicates that whatever is creating these features, they are changing and evolving significantly trough time. These variations may reflect different formation mechanisms, or/and time of formation and evolution, and also probably internal heterogeneities below the comet's surface.

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Are fractured cliffs the major source of cometary dust jets ? Evidence from Rosetta at 67P

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Abstract

Dust jets, i.e. fuzzy collimated streams of cometary material arising from the nucleus, have been observed in-situ on all comets since the Giotto mission 30 years ago. Yet their formation mechanism remains unknown. Several solutions have been proposed, from localized physical mechanisms on the surface/subsurface (see review in [1]) to purely dynamical processes involving the focusing of gas flows by the local topography [2]. While the latter seems to be responsible for the larger features, high resolution imagery has shown that broad streams are composed of many smaller features (a few meters wide) that connect directly to the nucleus surface. We show here observational evidence that jets of comet 67P arise from fractured cliffs and describe the physical processes involved, which may explain jet-like activity on all comets.

Sources of fine jets on 67P

The OSIRIS cameras on board ESA's Rosetta give us for the first time the possibility to image these features at a spatial scale better than 30 cm/px, and to monitor their evolution over many months. We summarized here our findings for the epoch August 2014 (3.6 AU) to March 2015 (2.0 AU), when only the Northern hemisphere of comet 67P was illuminated.

Using many images of jets, taken from different angles, we triangulated the position of their footprints on the nucleus. We observed a strong correlation between active sources and sub-solar latitude. Large scale jets sources (a few tens of meters diameter) have been steadily migrating southward since August 2014, always remaining in a latitude band centered on the sub-solar point. This type of activity also seems to start and stop with the terminator crossing the area; the switch on/off time uncertainty is given by our imaging cadence of one observation every 20min. We interpret this as jets being solely driven by solar illumination, with no sub-surface heat source involved.

Jet sources are not evenly distributed within the active latitude band. Detailed inversion of the smallest features shows a clear correlation between jets and fractured cliffs. We do not detect activity arising from smooth surfaces. This is particularly striking in Seth and Ma'at regions where we unambiguously linked dust jets to the fractured walls of active pits and cliffs (Fig. 1) [3].

These active walls show similar morphologic features independently of their location on the nucleus. They are fractured and present signs of ongoing erosion. Large debris fields can be observed below the cliffs, interpreted as blocks falling down from the wall. Cliffs upper edges display mass wasting features, with the upper dust layer seemingly flowing down as the edge of the cliff collapses (Fig. 2). These granular flows expose underneath fractured terrains, indicating that cracks propagates inwards and not only on the surface.

Jet formation and surface evolution

We interpret this morphology as a the signature of a multi steps activity mechanism:

1. Cliffs are first fractured by mechanical or thermal processes [4]

2. Fractures propagate into a matrix of dust and ices

3. Cracks allow the diurnal heat wave to penetrate deeper into the surface, reaching volatiles otherwise insulated

4. Cracks act as nozzles, effectively accelerating and focusing the gas flows to the level needed to lift off dust particles seen in the jets

5. The combination of continued cracking and expanding gas flows weakens the structural in-

tegrity of the cliff, leading to collapse of the wall and mass wasting on the cliff table

6. The cliff continues to retreat until all volatiles are exhausted.

A general mechanism

The process described above is supported by observational evidence on comet 67P, for instance the continued degradation of the cliffs and expansion of granular flows. We believe, however, that it is much more general and apply to all comets. Other authors have linked jest to ragged surfaces on comets 81P/Wild 2 [5], 9P/Tempel 1 [6], and 103P/Hartley 2 [7], but lacked the spatial resolution to describe the smallest jets. Because these regions are very similar to 67P on the large scale (cliffs, pits, no activity from smooth areas) we suspect that their jet activity and surface evolution is driven by the same processes as on 67P.

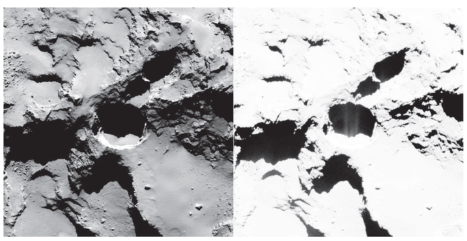

Figure 1: Tiny jets arising from the fractured edge of a 200 m diameter pit.

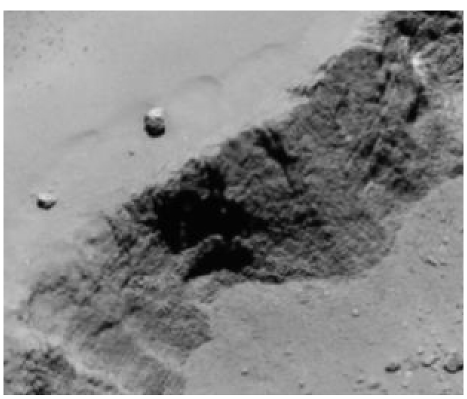

Figure 2: Wall collapse and mass wasting features on an active cliff.

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Colors of active regions on comet 67P

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Abstract

The OSIRIS (Optical, Spectroscopic, and Infrared Remote Imaging System) scientific imager (Keller et al. 2007) is successfully delivering images of comet 67P/Churyumov-Gerasimenko from its both wide angle camera (WAC) and narrow angle camera (NAC) since ESA's spacecraft Rosetta's arrival to the comet. Both cameras are equipped with filters covering the wavelength range of about 200 nm to 1000 nm. The comet nucleus is mapped with different combination of the filters in resolutions up to 15 cm/px. Besides the determination of the surface morphology in great details (Thomas et al. 2015), such high resolution images provided us a mean to unambiguously link some activity in the coma to a series of pits on the nucleus surface (Vincent et al. 2015).

Introduction

Comet 67P's spectrum globally displays a red slope (Sierks et al. 2015) although we see slope variations in smaller scales (Fornasier et al. 2015). The spectrophotometric properties of the comet 67P is investigated in details and three groups of terrains are identified by Fornasier et al. (2015) as low spectral slope, average spectral slope and high spectral slope groups. High spectral slope group describes various parts of the comet surface and the entire Apis region. Defined low spectral slope group hosts the Hapi region, which was showing the most activity at the arrival to the comet and the Seth region, where we see jets rising from the pits. Average spectral slope group includes the Ma'at region, which also hosts active pits. This work focuses on the color variations inside and in the vicinity of those active pits.

Data and Methods

OSIRIS NAC images of the regions Seth and Ma'at with their active pits, and the Hapi are studied. Images taken in various filters are co-registered, Lommel-Seeliger photometric correction is applied and multi-spectral data sets are generated by using USGS ISIS3 (Integrated Software for Imagers and Spectrometers, `http://isis.astrogeology.usgs.gov/index.html`, (Anderson et al. 2004)) software. Photometric angles are extracted from the 8 m resolution 3D shape of the comet (Preusker et al. 2015), using SPICE kernels (`http://naif.jpl.nasa.gov/naif/index.html`) for the orientation of it for the observing conditions. With the help of spectral slopes and the color composites generated by coding images taken in various filters as RGB channels (see Fig. 1 for an example), region of interests (ROIs) are defined for each multi-spectral data set.

Results

By comparing spectral slopes, color ratios of these ROIs, and using spectral parameters described in Oklay et al. (2015), we find that all regions can be classified in 3 main categories:

1. Regions of low spectral slopes correlate with sources of activity.

2. Regions of high spectral slopes correlate with inactive surfaces.

3. Regions of intermediate spectral slopes correspond to either surfaces partially covered by material ejected from active spots or inactive areas peppered with small bright spots, which are currently interpreted as minor ice deposits (Pommerol et al. 2015).

We will present the details of this classification, and how we use it to reliably detect potential active areas on the nucleus.

Figure 1: Stretched RGB image of Seth pits and the Hapi region taken on 22 August 2014 around 01:42 UT. The images taken with filters centered at 989.3 nm, 701.2 nm and 480.7 nm coded to RGB channels respectively.

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Compositional maps of 67P/CG nucleus after perihelion passage by VIRTIS-M aboard Rosetta

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Abstract

Comet 67P/Churyumov-Gerasimenko undergoes periherm transit at 1.2 AU in August 2015. During this passage the illumination conditions above the south hemisphere of the nucleus rapidly improve becoming optimal for the retrieval of the surface properties by VIRTIS-M [1] onboard Rosetta. A similar mapping of the surface at about 12.5 m/pixel and at solar phases below 40 deg has been already performed during the Philae prelanding phase (August-September 2014, heliocentric distance 3.6 AU) allowing us to build compositional maps of the entire north hemisphere and equatorial regions down to latitudes -50 deg on a limited part of the Hapi, or the comet's neck, region [2]. One year after this first mapping campaign the illumination geometry becomes favorable to complete the coverage above the South polar region. Since comet's activity is rapidly increasing and the Rosetta spacecraft cannot orbit on low trajectories like during the prelanding phase, the south hemisphere maps shall be reasonably observed by VIRTIS-M with a spatial resolution of about 25 m/pixel. Global scale data have shown that the nucleus' double-lobe surface is characterized by morphologically different units [3] uniformly covered by a very dark, low-albedo, dehydrated organic-rich material [4]. Compositional properties across the different regions of the nucleus are mapped by measuring visible and infrared spectral slopes, calculated on the best linear fit to the reflectance spectra between 0.5-0.8 µm and 1-2.5 µm, respectively. As pre-landing data have clearly shown, spectral slopes are highly diagnostic to identify active areas, like in the Hapi area [5], and exposed water ice deposits where the spectra appear less red. As heliocentric distance decreases and diurnal temperatures increase, the 3-5 µm spectral range becomes affected by thermal emission from the surface [6]. This emission is overlapping with the 3 µm feature previously observed by VIRTIS during the pre-landing period making more difficult to retrieve the distribution of the organic material. A summary of the spectral characteristics observed on the south hemisphere region during the perihelion passage is given. Activity-driven spectral changes observed before and after perihelion passage on some specific areas of the surface are discussed.

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Surface compositional variation on the comet 67P/Churyumov-Gerasimenko by OSIRIS data

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Abstract

Since the Rosetta mission arrived at the comet 67P/Churyumov-Gerasimenko (67/P C-G) on July 2014, the comet nucleus has been mapped by both OSIRIS (Optical, Spectroscopic, and Infrared Remote Imaging System, [1]) NAC (Narrow Angle Camera) and WAC (Wide Angle Camera) acquiring a huge quantity of surface's images at different wavelength bands, under variable illumination conditions and spatial resolution, and producing the most detailed maps at the highest spatial resolution of a comet nucleus surface.

67/P C-G's nucleus shows an irregular bi-lobed shape of complex morphology with terrains showing intricate features [2, 3] and a heterogeneity surface at different scales.

1. Introduction

The Narrow Angle Camera (NAC) was designed to study the nucleus with eleven large band filters at different wavelengths from the ultraviolet (269 nm) to the near-infrared (989 nm), while the Wide Angle Camera (WAC) is devoted to the study of gaseous species in the coma with a set of eleven narrow band filters ranging from the ultraviolet to visible.

The OSIRIS imaging system has been the first instrument with the capability to map a comet surface at high resolution with its filters and reached a maximum resolution of 11 cm during the closest fly by on February 14, 2015 at a distance of ~ 6 km from the nucleus surface.

Our analysis is carried out on images obtained with different filters at close sequences. Due to the time necessary to switch filters and acquire new images, the images of a colour series are taken at intervals of about 15 seconds. As during this time the comet rotates and the spacecraft moves onto its trajectory, the co-registered images acquired through the different filters are corrected by illumination [4] and the reflectance spectro-photometry and spectral map are extracted.

2. Results

Global colour images of the nucleus reveal a generally dark surface with geometric albedo of 6.5±0.2% at 649 nm and surface albedo variations up to ~ 30% [4].

The images taken at beginning of August when the spacecraft was at about 100 km from the comet at different rotational phases were analysed and the spectral slope were computed for each pixel of the surface in the 535-882 nm range [4].
Three groups of terrains have been identified based on the spectral slopes: i) group 1 with low spectral slope (comprise between 11 and 14%/(100 nm) and higher albedo. This group includes Hathor, Hapi, Babi, partial Seth regions and a portion of the Ma'at region ; ii) group 2 with average spectral slope (between 14 and 18%/(100 nm) and including Anuket, Serqet, regions and partially Ma'at, Ash ; iii) group 3 with high spectral slope (above 18%/(100

nm) which includes Apis region, Hatmehit depression (small lobe) and partially several other regions. The three groups are distributed everywhere in the nucleus, with no evident distinction between the small and large lobe. Spectral variations have been also observed by the VIRTIS imaging spectrometer in the visible and near-infrared (up to 5 μm) range [5].

To better investigate the surface colour variations, we analyse the same images [4] with the G-mode multivariate statistics [6]. The G-mode method is a unsupervised statistical classification method that allows the user to obtain an automatic clustering of a statistical sample of homogeneous taxonomic groups with no a priori grouping criteria and taking into account the instrumental errors in measuring each variable. The method also gives indications of the relative importance of the variables in separating the groups [6, 7, 8] and allows to investigate the existence of the finer structures on the samples. G-mode statistics were applied to the images taken on August 6 at a phase angle of 50° with a surface resolution of about 2m/px. The G-mode were applied on the images corrected by illumination conditions derived by SPG shape model [9] using 7 NAC filters from 480 nm (Blue filter) to 989 nm (IR filter).

Local variations are also present at small scale with higher or lower albedo value and clear differences of spectral-photometry properties. The variations are connected with surface composition and rugosity characteristics. Pommerol et al. [10] reported over one hundred meter-sized bright spots in different regions. The bright spots are clustered or isolated, but in general at low insolation. Their albedo is much higher and the spectra are significantly bluer than surrounding area. These observations are associated to the presence of H_2O ice [10] and confirmed by VIRTIS [11]. Spectral photometric variations are found in many different regions and also on the portion of the red Imhotep region observed during the closest fly-by of 14 February 2015. It's well known that spectral slope can change also with the refractory particle size, but the detected variation is not always associated to the surface morphology.

The surface of comet 67P/C-G is highly complex. Both comet lobes show evidence of regions of the surface covered by different layers of dust. These dusty areas are present on many regions of the nucleus surface including areas with evidence of transport of materials [12] for which detailed spectro-photometric analysis is needed.

3. Conclusion

The heterogeneity of the nucleus is evident from the spectro-photometric properties. Compositional interpretation is difficult on the basis of only photometric filters in the NAC NUV-IR range, due to the limited spectral range and to the fact that the comet surface is composed by an overlap of different components, but we detect a clear evidence of the compositional variability.

The majority of the surface shows a red visible spectral slope which can be associated to the presence of organic components confirmed also by the detection of the broad absorption feature at 3.2 μm band detected by VIRTIS [5, 13, 14] with random bluer areas plus the large region of Hapi where a presence of exposed H_2O ice has been invoked.
The results obtained by OSIRIS data will be presented and compared with those of VIRTIS.

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The use of 3D shape models of Rosetta targets for morphological studies

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Abstract

New 3D reconstruction techniques have been developed during the last decade to retrieve the global and/or local topography of small solar system bodies from visible images. These techniques can be separated into two categories: the so-called "photoclinometric" and the so-called "photogrammetric" techniques. Two implementations of the photoclinometric technique are available: the SPC technique (StereoPhotoClinometry) which combines sparse stereo with a classical clinometry algorithm[1] and a more recent method called MSPCD (Multi-Resolution Stereo-PhotoClinometry by Deformation) which proceeds by iterative deformation of a triangular mesh in a multi-resolution scheme[2], using stereo points as a guide during the deformation[3].

Our study is based on the 3D shape models of the asteroid Lutetia and of the comet 67P/Churyumov-Gerasimenko retrieved by the SPC and MSPCD methods. More specifically, we describe how the models produced by these two techniques can contribute to detailed and quantitative studies of the morphological properties of small bodies through three test cases shortly described below.

• Measurement of crater depth and depth-to-diameter distribution. We show that the reconstruction techniques can lead to systematic differences in the measurement of crater depth. This will be illustrated by a set of craters[4] identified in the Achaia region at the surface of the asteroid 21 Lutetia.

• Calculation of the volume of large boulders at the surface of comet 67P/C-G. We show how the reconstruction technique affects significantly the volume determination of a large boulder named Cheops in the Imhotep region.

• Measurement of gravitational slopes. We discuss the differences between the gravitational slope distributions in Seth obtained with the SPC and MSPCD models[5].

Since no ground control points are available on small bodies, we use the comparison of high-resolution images with the corresponding synthetic images generated with the models[6] to assess their ability to retrieve detailed topographic features at the surface of 67P/C-G and Lutetia.

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One year at 67P: evolution of the coma composition measured by ROSINA

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Abstract

Since August 2014, when Rosetta arrived in the vicinity of 67P/C-G the Rosetta Orbiter Spectrometer for Ion and Neutral Analysis (ROSINA) instrument [1] is monitoring the volatile composition in the coma. While the coma had already a very rich chemical inventory at 3.5 AU from the Sun, it was also recognized that the coma composition is heterogeneous [2]. In this paper we report on the evolution of the coma composition from 3.5 AU up to perihelion. Up to May 2015 the northern part of the comet was the summer hemisphere getting most of the illumination. Water was by far the dominant species. The southern hemisphere, which was poorly illuminated at that time, showed a lot of very volatile species like e.g. CO, CO_2, and C_2H_6. This changed during May. Since end of May the southern hemisphere is experiencing the highest solar input on the comet. We will discuss compositional differences in the coma attributed to this change.

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67P/Churyumov-Gerasimenko - Global, regional, and local shape of a comet's nucleus from stereo-photogrammetry

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Abstract

We applied stereo-photogrammetric methods to more than 200 OSIRIS NAC images of comet 67P/Churyumov-Gerasimenko (67P/C-G) that have been acquired from onboard the Rosetta spacecraft in August/September 2014. From this high-resolution SPG shape model at 2 m lateral sampling and a typical vertical accuracy at the decimeter scale, we present global three-dimensional views of the nucleus, as well as various regional and local close-ups of some prominent areas of this unique body.

1. Introduction

Stereo-photogrammetric (SPG) methods have been used for the derivation of highly accurate three-dimensional representations of the surfaces of planets, satellites, asteroids, and now also for the very irregular nucleus of comet 67P/C-G [1] using images from the SHAP4S image sequence (~1 m image resolution) of the OSIRIS NAC camera [2,3] onboard the Rosetta spacecraft.

2. The shape of comet 67P/C-G

67P-C-G's nucleus provides a great variety of different morphological units and regions [4,5]. On a global scale, the entire body consists of three main entities, the big lobe, a small lobe, and a connecting concavity, the neck region. Besides a global view (Fig. 1), exemplary views of different prominent areas and features are displayed in Figs. 2-4. Names for morphological units of 67P/C-G are defined in [4].

Because of the illumination conditions in Aug/Sep 2014, the SPG SHAP4S shape model is limited to the northern hemisphere and low southern latitudes. Within 2015, we expect to extend the coverage of the shape model by the stereo-photogrammetric analysis of OSIRIS images of the imaging season in 2015 and to provide additional views of the currently unknown southern hemisphere. Finally, the integration of high-resolution OSIRIS NAC image data of up to a few decimeters per pixel will allow for local shape representations for specific regions at meter scale lateral resolution.

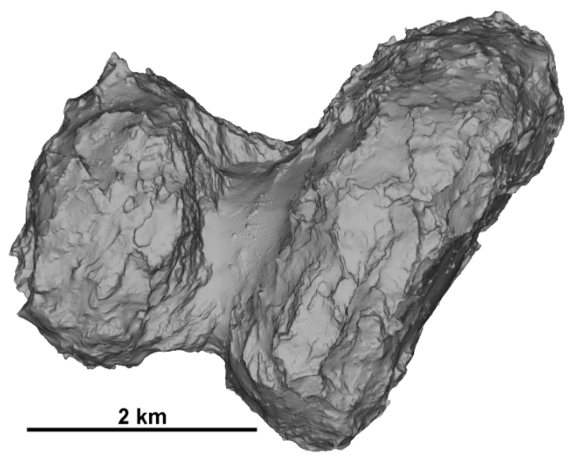

Figure 1: Global view of the SPG SHAP4S shape model of C-G [1].

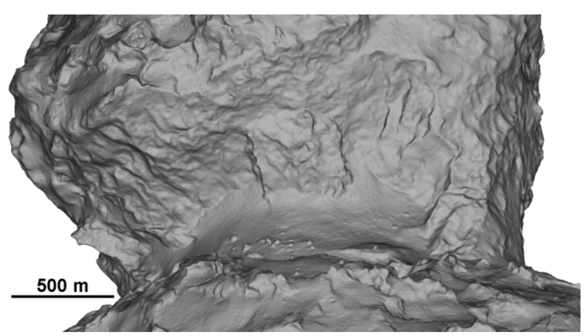

Figure 2: View of the cliff-like Hathor feature on the small lobe at the boundary to the Hapi region on the neck.

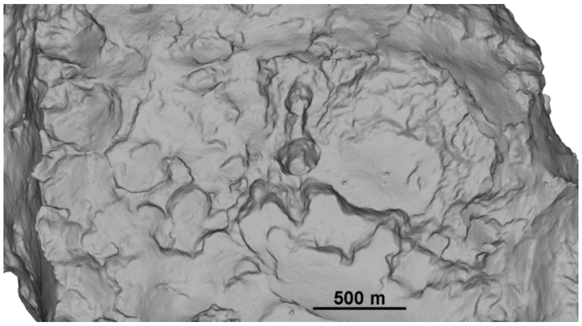

Figure 3: Pit-like structure in the Seth region on the big lobe (at the center of this figure, ~200 m in diameter) [6].

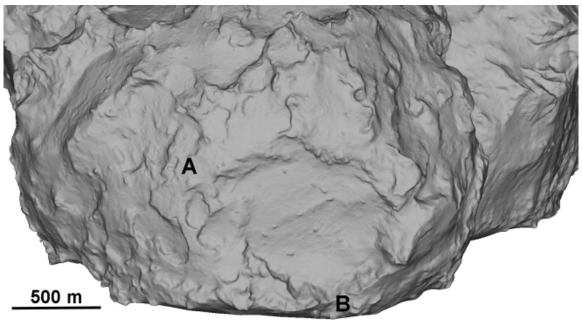

Figure 4: The Hatmehit depression on the small lobe. ‘A’ marks the first touchdown site Agilkia of the Philae lander, ‘B’ marks Philae’s final landing site Abydos [7].

Acknowledgements

OSIRIS was built by a consortium of the Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany, CISAS - University of Padova, Italy, the Laboratoire d’Astrophysique de Marseille, France, the Instituto de Astrofísica de Andalucia, CSIC, Granada, Spain, the Research and Scientific Support Department of the European Space Agency, Noordwijk, The Netherlands, the Instituto Nacional de Técnica Aeroespacial, Madrid, Spain, the Universidad Politéchnica de Madrid, Spain, the Department of Physics and Astronomy of Uppsala University, Sweden, and the Institut für Datentechnik und Kommunikationsnetze der Technischen Universität Braunschweig, Germany. The support of the national funding agencies of Germany (DLR), France (CNES), Italy (ASI), Spain (MEC), Sweden (SNSB), and the ESA Technical Directorate is gratefully acknowledged.

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EPSC Abstracts
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Polarisation Properties of Low-Frequency Waves in the Inner Coma of Comet 67P/Churyumov-Gerasimenko

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Abstract

Since its arrival at comet 67P/Churyumov-Gerasimenko in August 2014 the magnetometer experiment, as part of the Rosetta Plasma Consortium (RPC), onboard the Rosetta spacecraft has been detecting low-frequency waves in the cometary plasma environment. These waves are present in the frequency range of 10-100 mHz with a mean value of 40 mHz. In order to understand the properties of the waves, detailed information on their polarisation dependent on external parameters such as background magnetic field, ion density and distance to the comet is required. In this study the magnetometer data is treated to a Minimum Variance Analysis of three-minute intervals over the entire escort phase of Rosetta. This analysis is the basis of a detailed investigation of temporal and spatial variations in the direction of propagation and polarisation of the wave. This mission also offers the unique opportunity to measure these waves at two points at the same time. The ROMAP instrument onboard the lander Philae measured the same wave activity as RPC, which allows to study the correlation between these two instruments. It is found that the propagation direction is dependent on the position of the measurement in relation to the comet and that it is fluctuating heavily. Only a long term study reveals two prominent directions of propagation in the terminator plane of the comet.

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Characterization of the Subsurface of 67P/Churyumov-Gerasimenko's Abydos Site

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Abstract

We investigate the structure of the subsurface of the Abydos site using a cometary nucleus model with parameters adapted to comet 67P/Churyumov-Gerasimenko and the Abydos landing site. We aim to compare the production rates derived from our model with those of the main molecules measured by Ptolemy. This will allow us to retrieve the depths at which the different molecules still exist in solid form.

1. Introduction

On November 12, 2014, *Rosetta*'s descent module *Philae* landed on the Abydos site of comet 67P/Churyumov-Gerasimenko (67P). Among the instruments onboard *Philae*, the Ptolemy mass spectrometer performed the analysis of several samples collected from the surface and atmosphere of the comet. Here we investigate the structure of the subsurface of the Abydos site. To do so, we employ a cometary nucleus model with an updated set of thermodynamic parameters relevant for 67P. Appropriate parameterization of the illumination at the Abydos site is also used. The comparison of the production rates derived from our model with those of the main molecules measured by Ptolemy should allow us to place important constraints on the structure (layering and composition) of the subsurface of *Philae*'s landing site.

2. Model and Parameters

We used the one-dimensional cometary nucleus model developed by [1]. The model considers an initially homogeneous sphere composed of a predefined porous mixture of ices and dust in specified proportions. It describes heat transmission, gas diffusion, sublimation/recondensation of volatiles within the nucleus, water ice phase transition, dust release, and mantle formation. This model takes into account all phase changes of water ice known in a cometary nucleus: amorphous ice, crystalline ice and clathrates. In the present study, we assumed that the nucleus is made of crystalline ices (H_2O, CO and CO_2) mixed with dust. Based on the recent *Rosetta* ROSINA observations [2], we also assumed CO/H_2O = 0.13 and CO_2/H_2O = 0.08 in the nucleus. Other key parameters have been derived from recent 67P studies: the dust/ice mass ratio is now assumed to be 4 [3], instead of being set typically to ~1, and the porosity of the nucleus is now 65% [4].

3. Results and Conclusions

Figure 1 represents the evolution of the ratio between CO and CO_2 that outgas throughout the surface of the Abydos site as a function of the orbital evolution of 67P. After the first orbital evolution, the outgassing rates of the different molecules follow the same trend at Abydos, irrespective of the considered period. The CO/CO_2 ratio varies over several orders of magnitude, depending on the comet's position on its orbit. The outgassing of CO_2 is more important when 67P arrives at perihelion, but the trend reverses once perihelion is reached and the outgassing of CO becomes dominant (peaks that can be seen at perihelion are induced by diurnal changes of insulation, which are significant at this period of the orbit). The next step of our study will consist in comparing our results with the production rates of molecules measured by Ptolemy at the Abydos landing site. By doing so, this will allow us to retrieve the depths at which the different molecules still exist in solid form.

4. Figures

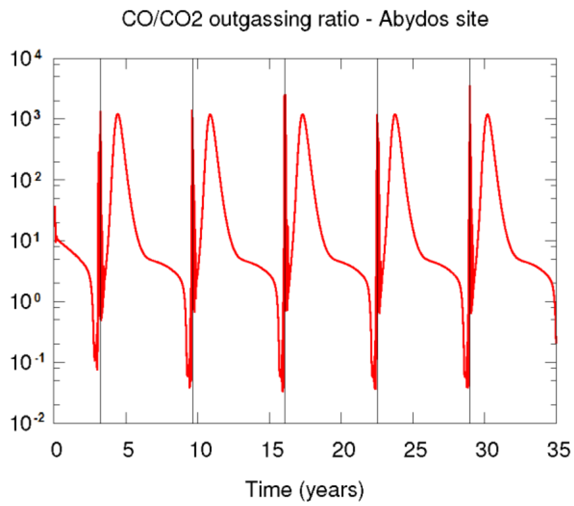

Figure 1: Evolution of the CO/CO_2 ratio at the Abydos landing site during 35 years of orbital evolution. Vertical lines correspond to the passages of the comet 67P at perihelion.

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EPSC Abstracts
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OSIRIS observations of metre-size bright exposures of H_2O ice at the surface of comet 67P/C-G.

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1. Metre-size bright spots

Since the beginning of Rosetta's orbital observations, over a hundred small bright spots [1] have been identified in images returned by its OSIRIS NAC camera, in all types of morphological regions on the nucleus.

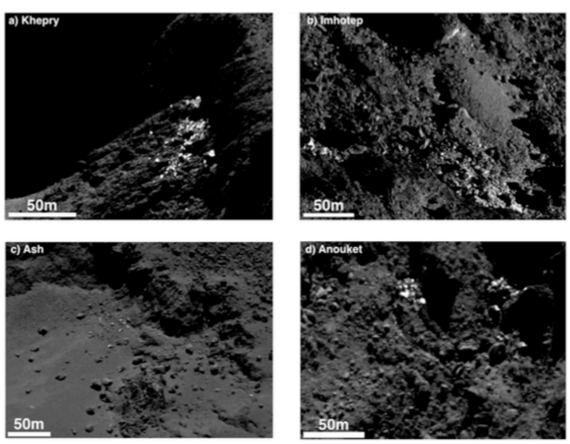

Figure 1: Example of clusters of bright spots in four different regions of the nucleus.

Bright spots are found as clusters of several tens of individuals in the vicinity of cliffs, or isolated without clear structural relation to the surrounding terrain. They are however mostly observed in the areas of the nucleus currently receiving the lowest amount of insolation and some of the best examples appear completely surrounded by shadows (Fig. 1).

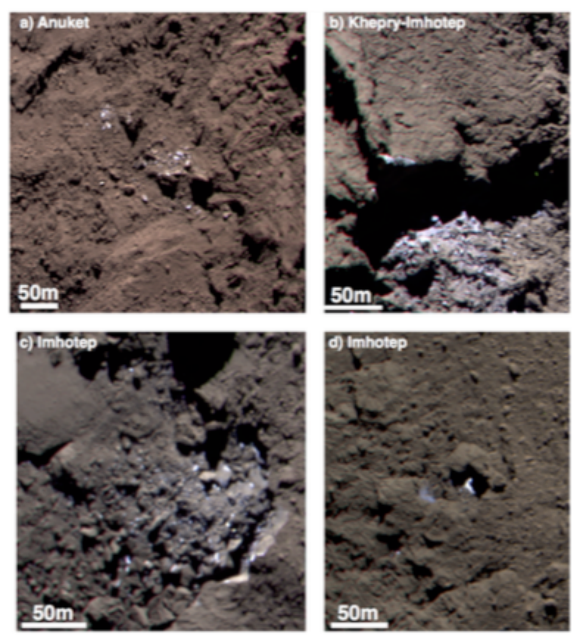

Figure 2: False-color RGB images assembled from frames acquired by OSIRIS in the near-infrared, visible and near-ultraviolet, respectively.

Their typical sizes are of the order of a few metres and they are often observed at the surfaces of boulders of larger dimension.

The brightness of these spots is up to ten times the average brightness of the surrounding terrain, reaching reflectance factor in the range of 0.10-0.15, and multi-spectral analyses show a significantly bluer spectrum over the 0.3-1µm range (Fig. 2) than the rest of the surface of the nucleus, which displays a steeper red slope [2]. Comparisons of images taken in September and November 2014 under similar illumination conditions do not show any significant change of these features

2. Laboratory experiments

Analysis of the results of past and present laboratory experiments with H_2O-ice/dust mixtures provide interesting insights about the nature and origin of the bright spots. In particular, recent sublimation experiments conducted at the University of Bern [3,4] reproduce the spectro-photometric variability observed at the surface of the nucleus by sequences of formation and ejection of a mantle of refractory organic-rich dust at the surface of the icy material.

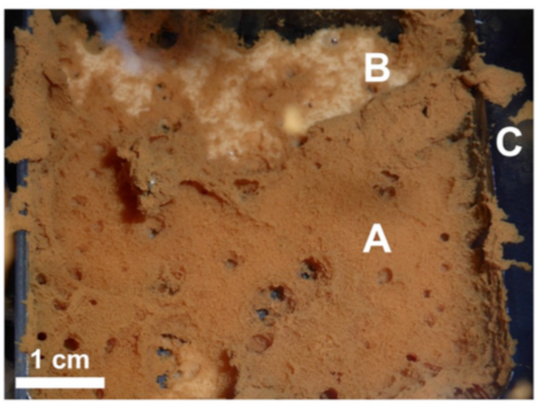

Figure 3: Picture of the surface of a sample initially prepared as a mixture of fine-grained water ice and tholins. After exposure to low temperature and pressure conditions for tens of hours, a surficial mm-thick very porous layer of tholins has formed (A). cm-size chunks of this mantle are regularly ejected (C), exposing the underlying brighter and less red ice-rich material (B).

The formation of hardened layers of ice by sintering/re-condensation below the uppermost dust layer can also have strong implications for both the photometric and mechanical properties of the

3. Interpretation and discussion

Based on the comparison between OSIRIS observations and laboratory results, our favoured interpretation of the observed features is that the bright spots are exposures of dusty water ice, resulting from the removal of the uppermost layer of refractory dust that covers the rest of the nucleus. Some of the observations of clusters of bright spots (Fig. 2b for example) are indicative of a formation process, which involves the breakage and collapse of brittle layers of ice to form fields of large boulders, some of them showing bright spots on part of their surface. Some of the isolated spots observed elsewhere on the nucleus might as well have been formed by similar processes and then have been transported over large distances by multiple bounces. These surface exposures of water ice must be more recent than the last passage at perihelion, as they would rapidly sublimate at short heliocentric distance. The hypothesis formulated here will thus easily be tested as the comet approaches the Sun, by checking if and how fast the bright spots vanish and disappear. The VIRTIS imaging spectrometer on-board Rosetta should also be able to detect the water ice spectral signatures over the largest of these bright areas.

Acknowledgements

OSIRIS was built by a consortium of the Max-Planck- Institut für Sonnensystemforschung, Göttingen, Germany, CISAS–University of Padova, Italy, the Laboratoire d'Astrophysique de Marseille, France, the Instituto de Astrofísica de Andalucia, CSIC, Granada, Spain, the Research and Scientific Support Department of the European Space Agency, Noordwijk, We thank the national funding agencies of Germany (DLR), France (CNES), Italy (ASI), Spain (MEC), Sweden (SNSB), and the ESA Technical Directorate

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Study of the photometric properties of the comet 67P/Churyumov-Gerasimenko with the OSIRIS instrument of the Rosetta spacecraft

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Abstract

The ROSETTA mission is the cornerstone mission of the European Space Agency devoted to the study of the minor bodies of the Solar System. Its primary objective is to perform an extensive study of the comet 67P/Churyumov-Gerasimenko (hereafter 67P/CG). Launched on the 2^{nd} of March 2004, the spacecraft overflew the asteroids 2837 Steins in 2008 and 21 Lutetia in 2010. Since its encounter with 67P/CG in July 2014, the spacecraft has been escorting the nucleus thus allowing to study it with cameras, spectrometers, dust analysers and radio science experiments. The spacecraft will continue its escort at least until December 2015.
We present the results on the photometric properties of the nucleus derived from disk-averaged and disk-resolved images of the OSIRIS instrument acquired in 2014-2015 including the close fly-by data acquired on the $14^{\rm th}$ of February 2015.

1. Introduction

After 10 years of flight and a cumulative travelled distance of 6.4 billions kilometers, the Rosetta spacecraft reached the comet 67P/CG in July 2014 and has been escorting it ever since. The scientific camera system (OSIRIS), one of the 11 instruments onboard the orbiter, has been presented in [1].
OSIRIS is constituted by the Narrow Angle Camera (NAC) and the Wide Angle Camera (WAC). The NAC has a 2°x2° field-of-view and an angular resolution 18.6 μrad/px. Its filters are optimised for the study of the mineralogical properties of the nucleus. The WAC has a 12°x12° field-of-view and an angular resolution of 101 μrad/px, its filters are optimised for the study of the gaseous species of the coma.

2. Observations and data reduction

The OSIRIS instrument has mapped the 67P/CG nucleus in the 250-1000 nm wavelength domain at different phase angles (ranging between 1° and 90°) with a resolution that went below 1 m/px for the NAC. We analysed sequences of images taken over the period of July-August 2014, as well as high-resolution images acquired during the close fly-by of February 2015. From the 2014's images, we produced the disk-integrated photometry in eight different filters covering the 325-990nm together with the disk-resolved photometry with the orange filter (centred at 649 nm), covering the 1.3° to 54° phase angle range. Those sequences were taken specifically for the hyperspectral mapping of the nucleus with a resolution up to 2.1 m/px. The details of this dataset was presented in [2]. The images were treated with the OSIRIS standard pipeline, converted into I/F radiance and then corrected for illumination conditions using the Lommel-Seeliger disk law. We registered images according to their respective sequences and performed disk-averaged and disk-resolved photometric analysis using Hapke modelling [3,4,5].
On the $14^{\rm th}$ of February 2015, the Rosetta probe performed a close fly-by of a part of the Ash region [6]. The probe dived straight down from an altitude of 50 km just after midnight, reached the point of closest-encounter at a altitude of approximately 6 km around 12:40, and climbed up towards an altitude of 254 km three days later before adopting a new attitude. This imply that in between the beginning of the close fly-by and the point of closest encounter, the resolution of the NAC varies between 1.5 and 0.11 m/px and the WAC's varies between 7.9 and 0.59 m/px. Furthermore, we considered a set of 158 images

that were taken with the NAC and 67 with the WAC between 02:30 and 20:05 of the 14^{th} of February and covering a phase angle domain ranging between 80.2° and less than 1°. At the time of writing, we concentrated this analysis mainly on a subset of 70 NAC images that were taken between 12:00 and 13:10 with different filters. The most repeated sequence of filters used during the flyby includes the 480 nm, 649 nm and 743 nm filters.
Those images will permit to study some of the surface properties of the comet to a degree of precision never achieved before.

3. Results and perspectives

The Hapke modelling obtained from the disk-averaged reflectance in 8 filters yields a low single-scattering value ranging from 0.028 to 0.066 in the 325-1000 nm wavelength domain and an asymmetry factor (g_λ) around -0.40, indicating light backscattering. The data shows a strong opposition effect. Hapke modelling of disk-resolved images confirm the strong opposition effect and the dark surface with a single scattering albedo of 0.042. We find a porosity value reaching 87% for the upper surface layer of 67P/CG's nucleus. As reported in [2], this value is higher than those found by laboratory experiments, though recent works evoke fractal aggregates as the best analogues of cometary dust. Surfaces composed of such material have porosity ranging from 80% to 90%, which would be in agreement with our fit of the Hapke 2012 model. Furthermore, we do not see clear wavelength dependence of g_λ, B_0 and h_s parameters, implying that the shadow-hiding effect must be the main cause of the opposition surge. The geometric albedo at different wavelengths derived from Hapke modelling perfectly matches the comet spectrophotometry behaviour.
The Hapke modelling gave parameters for 67P/CG that are compatible with previously studied comets such as Hartley 2, Tempel 1 and Wild 2 [7,8,9].
The derived geometric albedo at 649nm is 0.065 ± 0.02, which implies that the surface of 67P/CG is dark in absolute terms. It is however one of the brightest among the other cometary nuclei investigated by space missions [7,8,9]. The nucleus shows colour and albedo variations across the surface: Hapi is about 16% brighter than the mean albedo over the surface, while the Apis and Seth regions are about 8-10% darker. The analysis revealed also a strong phase reddening for the nucleus for both disk-averaged and disk-resolved data, with the disk-averaged spectral slope for instance increasing from 11 to 16% per 100 nm in the 1.3° to 54° phase angle range.
At the time of writing, we have performed spectrophotometry analysis on different surface regions for the close fly-by data of February 2015, and we are working on the phase functions in three filters. The opposition effect is clearly visible on the mapped surface. The results of this analysis will be presented.

Acknowledgements

OSIRIS was built by a consortium of the Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany, CISAS–University of Padova, Italy, the Laboratoire d'Astrophysique de Marseille, France, the Instituto de Astrofísica de Andalucia, CSIC, Granada, Spain, the Scientific Support Office of the European Space Agency, Noordwijk, The Netherlands, the Instituto Nacional de Técnica Aeroespacial, Madrid, Spain, the Universidad Politéchnica de Madrid, Spain, the Department of Physics and Astronomy of Uppsala University, Sweden, and the Institut für Datentechnik und Kommunikationsnetze der Technischen Universität Braunschweig, Germany. The support of the national funding agencies of Germany (DLR), France (CNES), Italy (ASI), Spain (MEC), Sweden (SNSB), and the ESA Technical Directorate is gratefully acknowledged.

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Millimeter and submillimeter observations of comet 67P/C-G with the MIRO instrument

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Abstract

The Microwave Instrument on the Rosetta Orbiter (MIRO) [3] makes submillimeter- and millimeter-wavelength observations of the nucleus and coma of the target comet of the Rosetta mission (Comet 67P/Churyumov-Gerasimenko). By making broadband continuum measurements at two wavelengths (approximately 0.5 and 1.6 mm), MIRO probes the thermal and dielectric properties of the nucleus subsurface. High-resolution spectroscopic measurements of 8 molecular lines in the submillimeter (H_2O, $H_2{}^{17}O$, $H_2{}^{18}O$, CO, NH_3, and three lines of CH_3OH) constrain the abundance, velocity, and temperature of gases in the coma. These measurements allow MIRO to study the nucleus and coma as a coupled system.

Upon arrival at the comet (August 2014) measurements by MIRO [4] and other instruments quickly determined that the upper ~10 cm of the nucleus generally have thermal properties consistent with very porous, dusty material, but that there is ice within the upper few cm at least in some regions. It was also found that gas emission from the nucleus varies with location and time.

More recently, we have begun to study in detail the time and spatial variability of the nucleus [2, 6] and coma [1, 5]. This presentation will provide an overview of the MIRO instrument, our data sets, and provide a high-level discussion of what we are learning about the upper meter of the nucleus' surface and the distribution and transport of water.

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EPSC Abstracts
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Neutral Na in comet tails: a chemical story

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Abstract

The origin of the neutral sodium comet tail discovered in comet Hale-Bopp in 1997 is still a matter of discussion. Here we propose a scenario which is based on chemical grounds. The starting point is the chemical trapping of the Na+ ion in the refractory material during the condensation phase of the protosolar nebula, followed by its incorporation in the building blocks of the comets parent bodies. In the next step, the Na^+ ions are washed out of the refractory material by the water formed by the melting of the ice due to the heat released in the radioactive decay of short period elements. When the water freezes again, the Na+ ion looses its positive charge to evolve progressively toward a neutral atom when approaching the surface of the ice. As shown by high-level numerical simulations based on first principle periodic density functional theory (DFT) to describe the solid structure of the ice, it is a neutral Na that is ejected with the sublimation of the ice top layer

1. Introduction

The presence of sodium D line emission has been confirmed in a large number of comets close to perihelion over the past century. Observations of comet C/1995O1 Hale-Bopp during the spring of 1997 led to the discovery of a new tail connected with the sodium D line emission. This neutral sodium gas tail is entirely different from the previously known ion and dust tails, and its associated source is unclear. It has been proposed that this third type of tail is shaped by radiation pressure due to resonance fluorescence of Na atoms [1]. Further possibilities were considered regarding the origin of this tail, then rejected, as photo-sputtering and/or ion sputtering of non-volatile dust grains [2]. Instead, it was proposed that the driving force would be the collisional interaction between the cometary dust coma of micron-sized particles and the very small grains [2].

Here, a completely different scenario built upon chemical grounds is proposed.

2. A three steps scenario

To obtain the solid and gaseous composition of the disk, we use the HSC chemistry package [3], based on the Gibbs energy minimization method. The equilibrium compositions of Na-bearing compounds forming over a wide range of temperatures in the protosolar nebula are represented on Figure 1. Whatever the disk's temperature, these Na-bearing compounds are all refractory materials below 900K.

It is generally admitted that comets are formed by accretion from solids consisting in a mixture of ice and rocks. At early epochs after accretion, the interior of comets has been subject to heating due to the radiogenic decay of short-lived nuclides ^{26}Al and ^{60}Fe. Despite the fact that specific results on the early heating of comets by radioactive isotopes alone still require detailed investigations on comet formation processes and timescales, so far all models are consistent with a potential occurrence of liquid water inside comets, for a given set of realistic initial parameters.

The evolution of the central temperature of 30km-radius bodies calculated, as a function of time after

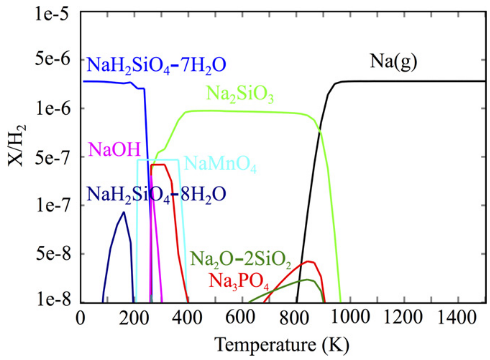

Figure 1: Equilibrium Na/H_2 abundances.

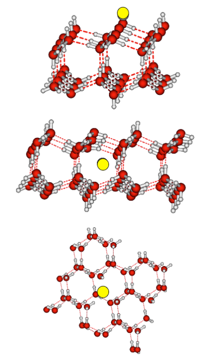

Figure 2: The path of Na, from bulk to surface.

formation, is obtained by numerical simulations based on the model of Guilbert-Lepoutre [4]. It shows the melting of the ice in the nucleus, allowing the transfer of Na^+ from refractory compounds to liquid water, with an electronic charge q=1.

The last step, i.e. the transformation of Na^+ into a neutral atom when released from the sublimating cometary ice can be followed by means of high level numerical simulations based on first principle periodic density functional theory (DFT) to describe the solid structure of the ice. We used a periodic representation of solid water in the form of apolar hexagonal ice composed of bi-layers of water molecules. It is computationally justified because only apolar structures can generate slabs that are, at the same time, stable, reproduce the bulk properties, with a balanced distribution of hydrogen and oxygen sites at their surfaces. Practically, the Vienna ab initio simulation package (VASP) was used to carry out all the calculations [5]. The generalized gradient approximation (GGA) was used for geometry optimization and calculation of adsorption energies on the ice, including the Grimme correction to take care of the long-range van der Waals interactions. A plane-wave expansion of the basis set is used, coupled to projector augmented wave ultrasoft pseudo-potentials for the atomic cores.

In the ice, the periodic structure of the crystal imposes strong geometrical constraints leading to stable structures without counterpart in the liquid phase or in micro clusters. This evolution can be followed on Figure 2.

Bottom : Substituted to H_2O molecule in the crystal, Na (q=+0.82) is stabilized by ~ 22-25 kcal/mol that is stronger than the ice cohesion. *Middle :* Encapsulated in a void in the crystal, Na (q=+0.86) is stabilized by ~ 12 kcal/mol which is about one half of the ice cohesion. *Top :* On the surface, a quasi-neutral Na (q=+0.20) is attached by ~ 14 to 17 kcal/mol, i.e., by a bonding energy close to that of ~14 kcal/mol with which a single H_2O is attached to the ice surface.

3. Summary

Our scenario [6] is based upon chemical grounds. It is shown that the Na^+ ions, originally trapped in the refractory materials, then washed out during the hydration phase, loose their positive charge to evolve progressively into neutral Na with their migration towards the surface of the cometary ices with which they are ejected.

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Water Ortho-to-Para Ratio in Comet 67P/Churyumov-Gerasimenko from VIRTIS/Rosetta Observations

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Abstract

The ν_3 vibrational band of H_2O at 2.67 µm was observed with the high spectral-resolution channel of the Visible InfraRed Thermal Imaging Spectrometer (VIRTIS-H) onboard Rosetta. The spectral resolution is adequate to resolve the rovibrational structure of the band. High signal-to-noise ratios allow us to measure both the rotational temperature and the ortho-para ratio of water (OPR) in comet 67P/C-G. The measured OPR value will be presented and compared to measurements obtained in other comets from ground-based and space telescopes.

1. Introduction

Molecules with H atoms at symmetrical positions may exist in different nuclear-spin species, e.g. ortho and para species for molecules with two H atoms. The ortho-para ratio (OPR) of water has been measured in several comets from high and medium resolution spectroscopy in the infrared [2, 6, 7]. Most measurements indicate a spin temperature within 25–35 K, though some comets exhibit higher spin temperatures, corresponding to an equilibrated OPR. No relationship was found between the spin temperature and the comet dynamical origin, or with the heliocentric distance at which the comets were observed, and their volatile composition. Un-equilibrated spin temperatures might be related to the temperature environment of the species in the nucleus or even before, i.e., they could indicate that molecules formed at ~30 K or were last processed at about 30 K [2]. However, quantum mechanics calculations show that the inter-conversion between para and ortho H_2O states is very fast inside the ice [3], so that the actual spin temperatures measured in cometary atmospheres might depend both on the ice temperature and of the evaporation history of the ice. Thermal desorption might be more efficient for para-water than for ortho-water according to [8]. Experiments show that thermal desorption could clear the memory of the OPR stabilized at low ice temperature (see review of [9]).

2. VIRTIS-H observations

Since July 2014, the Visual IR Thermal Imaging Spectrometer (VIRTIS) onboard the ESA's Rosetta spacecraft has intensively observed comet 67P/ Churyumov-Gerasimenko [4]. VIRTIS is composed of two channels, –M for mapping and –H for high resolution, working in the 0.25-5 µm and 2-5 µm wavelength domains, respectively [5]. Limb observations were carried out to obtain spectra of the coma, and to detect fluorescence emissions of gas phase species. The ν_3 vibrational band of H_2O at 2.67 µm was detected in mid-October 2014 using VIRTIS-H, and is observed regularly since then [1] including from VIRTIS-M [3].

A sample VIRTIS-H spectrum of the water band acquired when the water production rate was typically 10^{26} mol/s is shown in Fig. 1. This spectrum is an average of the observations acquired from December 2014 to January 2015 and has a signal-to-noise on the band area larger 100 [1]. Similar SNRs were obtained in March 2015 for typical total integration times of 3-4 h due to the increasing activity of the comet and increased fluorescence emission related to closer distance to the Sun.

3. Ortho/para ratio

Determining the OPR from the VIRTIS-H spectrum requires modelling the fluorescence emission of the water ν_3 band, following, e.g., [6, 7] who determined the OPR in comets C/1995 O1 (Hale-Bopp) and 103P/Hartley 2 from observations with the Infrared Space Observatory of the same water band with similar spectral resolution as VIRTIS-H. Weak water bands present rovibrational lines blended with ν_3 lines (Fig. 1), and their contribution requires to be considered for best accuracy in the OPR determination. A model considering the optical thickness of the ν_3 water lines is used for analysing observations obtained near perihelion. The OPR inferred value and possible variations in the coma will be presented and compared to values measured in other comets.

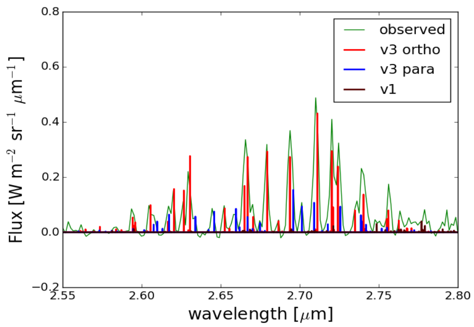

Figure 1: VIRTIS-H spectrum of the 2.7 µm band of water (green). Data from 4 December 2014 to 24 January 2015. A fluorescence spectrum with infinite spectral resolution is shown with ortho and para lines in red and blue, respectively. This range presents also lines of the water ν_1 band (black) and of water hot bands.

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Seasonal temperature effects on comet 67P/Churyumov-Gerasimenko as inferred from Rosetta/VIRTIS

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Abstract

The Visible InfraRed Thermal Imaging Spectrometer (VIRTIS) [1] on board the orbiter of the ESA Rosetta mission operates in the spectral range 0.25-5.1 μm. VIRTIS is continually used to map and investigate the surface composition of the comet nucleus in its uppermost layer within a depth of a few tens of microns [2,3,4]. Moreover, the temperature of these surface layers can be mapped utilizing VIRTIS' long wavelength spectral measurements. To do this, the VIRTIS team uses a Bayesian approach to nonlinear inversion [5], which was already adopted in the past for other small bodies [2,5]. The superficial layer sampled by VIRTIS is significantly different from the much thicker layers sampled by the Microwave Instrument for the Rosetta Orbiter (MIRO) [6]. Furthermore, VIRTIS is not sensitive to physical temperatures on the nightside of the comet, where the signal is considerably low. Typically, 170 K is the minimum surface temperature that can be measured while preserving small formal errors (<1 K on retrieved temperatures). Temperatures below ~170 K have increasingly lower accuracy, and should be carefully interpreted.

In previous papers, we have provided a thorough description of surface temperature maps and thermal properties of comet 67P/Churyumov-Gerasimenko as derived from infrared data acquired by Rosetta/VIRTIS in the early Mapping phase carried out in August and September 2014 [e.g., 7,8]. We divided those maps into intervals of true local solar time and we evaluated, for the available coverage, the average daily temperatures. In addition, we studied correlations between temperature and albedo at different wavelengths, and derived diurnal temperature profiles for several local sites, representative of as many macro-regions of the comet [e.g., 8].

In this new work, we focus on effects determined by the season and the heliocentric distance. Due to the low thermal inertia of the nucleus surface material, the surface temperature is essentially dominated by the instantaneous value of the solar incidence angle. Small values of this angle result in high surface temperatures, but, due to comet 67P's obliquity, for each location the smallest achievable value of insolation angle depends on the season. During 2014, VIRTIS' visible and infrared measurements covered only the northern regions of the cometary surface and the equatorial belt became gradually unveiled, while the southern region is going to be revealed from 2015 onwards.

In addition, the heliocentric distance strongly affects the surface temperature. This is a larger effect in comets than in asteroids, due to the wide range of heliocentric distance values spanned by comets. However, on the basis of temperature data returned by the VIR instrument onboard Dawn, it was possible to discern the effect of the heliocentric distance also in the large asteroid Vesta [5].

When Rosetta started its global mapping observation campaign, i.e. in early August 2014, the heliocentric distance of comet 67P was ~3.6 AU, while it decreased to 3.0 AU on 11 November 2014, to 2.0 AU on 27 March 2015, and the perihelion passage is expected on 13 August 2015 at 1.24 AU from the Sun. By relating surface temperatures as measured by VIRTIS to three variables: solar incidence angle, true local solar time and heliocentric distance, for a given location on the surface (chosen particularly in the equatorial region, which experienced different seasons), we aim to separate the relative contributions due to season and to the heliocentric distance.

These results are unprecedented for a comet, given the unique ability of Rosetta to closely observe a cometary nucleus over a long period of time. In principle, such work may deepen the knowledge of the thermal properties of the cometary nuclei. However, the increase in activity on a global scale that accompanies the perihelion passage implies to consider other effects such as sublimation and changes in the surface composition and roughness.

The inference of seasonal changes in thermophysical properties is clearly an ambitious goal for the future, but this work poses a first constraint in this regard.

Acknowledgements

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Comet 67P/Churyumov-Gerasimenko: Activity and Non-Gravitational Forces

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Abstract

The long term observations during the Rosetta rendezvous and a resulting detailed shape model enable us to calculate the reaction forces caused by sublimation in detail. We use a shape model with > 10^5 facets to simulate the distributed forces and calculate their exerted torques. These torques influence the angular momentum and hence the spin rate of the nucleus. The model can also be applied to calculate the non-gravitational forces influencing the orbital motion.

1. Introduction

Comet 67P/Churyumov-Gerasimenko has been investigated during the rendezvous with ESA's Rosetta spacecraft. Unprecedented, detailed, observations over many months revealed details of the nucleus and its activity starting at a heliocentric distance of 3.7 AU while the comet approached its perihelion in August 2015. Early observations revealed that the rotation period had changed from its last perihelion passage in 2009 [7]. Detailed shape models derived from observation by the OSIRIS cameras [3] along with thermal modeling make it possible to calculate the diurnal activity of the facets [4] while the comet flies along its orbit. [5] determined the torques on the nucleus, exerted by the facets depending of the geometric position, orientation and characteristics of their activity.

2. Model

In order to study the effect of sublimation-induced reaction on the comet's motion, we model the sublimation process as reported in [4]. Basically, 67P is described as a polyhedron with triangular facets, for which we adopted the SHAP4 shape model by Preusker et al (2015), down sampled to approximately 108,000 facets. We assume that sublimation is driven by solar energy input (direct, reflected and re-emitted), and that, due to the low thermal inertia of the cometary material [2], local thermal equilibrium is reached very rapidly with respect to the typical times of changes in illumination. Under those assumptions, the equilibrium temperature of the surface, or of a sublimating sub-surface layer, depends only on the instantaneous solar energy input, and not on the insolation history. For the purpose of this study we use a 2-layer thermal model [8], where a porous, refractory dust layer is superposed to a sublimating water ice/dust layer [4]. The properties of the body are assumed to be constant across the surface, and a net torque arises as a consequence of varying illumination over an irregular body. The net torque due to sublimation can be written as

$$\boldsymbol{T_i} = -\sum_i \frac{dm_i}{dt} \boldsymbol{r_i} \times \boldsymbol{v_i}$$

where v_i is a vector describing the gas ejection velocity, with orientation parallel to the facet's normal, r_i is the vector from the center of mass to the center of the facet and the index *i* runs over all facets. The term dm_i/dt is the mass sublimation rate, whereas $-v_i\, dm_i/dt$ is the reaction force for facet *i*.

2.1 Changes of the Angular Momentum

The net torque will cause a change in the angular momentum $\boldsymbol{L}$ according to

$$\boldsymbol{T} = \frac{d\boldsymbol{L}}{dt}$$

Often, the resulting motion will be an excited rotation with precession of the spin axis. The full rotation can be modelled by integrating the Euler equations of motion. As a first step [5] considered the rotation axis to be stable and adopted a simplified approach and considered only the z component of the torque, which mainly contributes to the change in the spin rate, according to

$$T_z = \frac{dL_z}{dt} = I\frac{d\omega}{dt}$$

with I being the largest moment of inertia and ω the spin rate. The inertia axes and moments, body volume and mass are computed by using the method by [1]. We will report about the recent evolution of the rotation period.

2.2 Changes of the Orbital Motion

Rather than considering the effects of the torques on the rotation we can calculate the forces acting on the motion of the nucleus. We will compare our results with the traditional approach to calculate the non-gravitational forces based on the well known empirical formula [6].

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Ground-based observations of 67P/Churyumov-Gerasimenko

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Abstract

I will described the campaign of observations from ground-based (and Earth orbiting) telescopes that supports the Rosetta mission. Rosetta gets closer to the nucleus than any previous mission, and returns wonderfully detailed measurements from the heart of the comet, but at the cost of not seeing the large scale coma and tails. The ground-based campaign fills in the missing part of the picture, studying the comet at ∼1000km resolution, and following how the overall activity of the comet varies. These data provide context information for Rosetta, so changes in the inner coma seen by the spacecraft can be correlated with the phenomena observable in comets. This not only helps to complete our understanding of the activity of 67P, but also allows us to compare it with other comets that are only observed from the ground, and in that way extend the results of the Rosetta mission to the wider population.

The ground-based campaign includes observations with nearly all major facilities world-wide. In 2014 the majority of data came from the ESO VLT, as the comet was still relatively faint and in Southern skies, but as it returns to visibility from Earth in 2015 it will be considerably brighter, approaching its perihelion in August, and at Northern declinations. I will show results from the 2014 campaign, including visible wavelength photometry and spectroscopy, and the latest results from early 2015 observations. I will also describe the varied observations that will be included in the campaign post-perihelion, and how all of these results fit around what we are learning about 67P from Rosetta.

Figure 1: The comet in 2014, in R band images from the ESO VLT, taken in February, May, July and October, showing the evolution of the coma as the comet became active.

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Temporal variability of 67P/Churyumov-Gerasimenko nucleus spectral properties from VIRTIS-M onboard Rosetta

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Abstract

We investigate the variability, on both diurnal and seasonal scale, of the spectral properties of the nucleus of comet 67P/Churyumov-Geresimenko as observed by the VIRTIS-M imaging spectrometer onboard the Rosetta spacecraft. The spectrum is described by means of spectral indicators: visible and infrared slopes, band areas and band positions.

1. Introduction

Launched on 2 March 2004, the Rosetta spacecraft arrived to comet 67P/Churyumov-Gerasimenko (CG) on 6 August 2014 at a heliocentric distance of 3.5 AU and started escorting the comet until the perihelion passage (13 August 2015 at 1.24 AU) and beyond. Seasonal and heliocentric distance variations modify the illumination conditions on the surface affecting the cometary activity on long-term scale. Furthermore, diurnal variations are induced by nucleus rotation with a period of 12.4 h [1]. All these effects can modify the surface composition along its physical properties and thereby the spectral shape of the nucleus.

VIRTIS-M [2] is an imaging spectrometer onboard Rosetta spacecraft. It extensively observed CG nucleus in the overall 0.25-5.1 µm range, producing millions of spectra. This allowed us to observe the same regions on the surface multiple times and to monitor temporal variations both on diurnal and seasonal scale.

2. Method

The monitoring of the surface properties is performed by means of spectral indicators aimed at characterizing the most significative regions of the spectrum. In particular, spectral slopes in the visible range (0.55-0.80 µm) and in the infrared range (1-2.5 µm) are computed [3]. Along with these quantities, the band area of the organics feature at 3.2 µm [4] is calculated as well as the position of its minimum. These spectral indicators can give us clues on the temporal variability of water ice on the comet surface since both visible and infrared slopes are affected by water ice content, as well as the region around 3 µm where water ice absorption feature occurs [5].

Together with changes in composition also the observation geometry can affect the spectral shape through phase reddening. In order to disentangle the two effects the analysis is performed on photometrically reduced data, following the approach of [6].

Main findings for selected regions of the nucleus will be discussed.

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The role of numerical models in data analysis for the Rosetta mission

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Abstract

The Rosetta mission will have collected data for over a year by September 2015, ranging over a wide range of heliocentric distances, latitudes, longitudes and local times. However, both remote sensing and in situ instruments capture very specific features of the cometary system in their respective measurements. Numerical models can help, for example, link these in situ and remote sensing observations which, in turn, inform the numerical models by constraining them. The end result is that much more information is obtained from the mission than possible with observations alone. Here we use simulation outputs from a 3D DSMC, and a 3D hydrodynamic code to link results between different instruments on the Rosetta spacecraft.

1 Models

We present model results for the coma of 67P from two different codes. Both including a detailed shape model of the comet nucleus and realistic illumination conditions. AMPS, which is a Direct Simulation Monte Carlo (DSMC) code, simulates a large but discrete set of particles that are ejected at each surface element of the shape model according to realistic boundary conditions. The code then simulates interactions of the gas molecules based on gaskinetic effects. Macroscopic properties of the coma are obtained by sampling of a subset of particles in different cells within the computational domain. BATS-R-US is a hydrodynamic code that approximates the cometary coma as a fluid, and solves the Euler equations on a 3D block adaptive Cartesian grid. Both codes can be run on multiple CPUs to handle the high computational demands of full 3D models.

2 Method

BATS-R-US and AMPS both produce physical quantities such as number density, bulk velocities and gas temperatures within a three dimensional simulation box. From the SPICE toolkit we can compute exact instrument pointings and the position of Rosetta relative to the comet. By interpolation we are able to reproduce results of both, local measurements or line of sight integrations through the coma, which allows for a comparison between in situ and remote sensing instruments. We provide a sophisticated web interface to these tools to different teams within the Rosetta mission. The generic implementation and the integration of SPICE kernels make these tools extendable to simulations of other missions.

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Activity as a driver for cliff collapse on comet 67P/Churyumov-Gerasimenko

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Abstract

ESA's Rosetta spacecraft is orbiting its target comet 67P/Churyumov-Gerasimenko since August 2014. OSIRIS (Optical, Spectroscopic, and Infrared Remote Imaging System) [1], the scientific camera system onboard, has since then been acquiring images of the comet's nucleus revealing a large variety of surface features and geomorphologically diverse regions [2, 3, 4]. Among these features are cliff structures that show fractures and an accumulation of debris at the bottom, suggestive of continuous mass wasting [5]. Vincent *et al.* [6, 7] suggest that continuous cracking and subsequent removal of volatiles through activity destabelize the cliff to a point where the front of the cliff breaks off. We present here a model aiming to derive physical parameters from the observed collapse features.

1. Introduction

The OSIRIS images allow us to analyze the structure of the surface of 67P in high resolution of up to 10 cm/px. Figures 1 and 2 shows a cliff with an accumulation of debris at its foot. In addition to a fractured wall and accumulated debris, the blanket of dust covering the upper table of the cliff shows indications of mass wasting towards the cliff edge. The OSIRIS images serve to constrain parameters that help to understand the cliff's condition:

- the degree of fracturing constrains the mechanical stability of the wall
- the amount of debris that is accumulating at the foot gives a lower limit for the former volume of the cliff
- the mass wasting at the top edge constrains the thickness of the dust layer and its mechanical properties

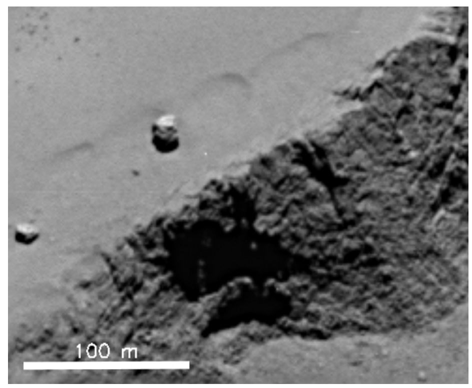

Figure 1: An example of a cliff with fractures and debris accumulated at the foot.

2. Mapping cliffs

Using images taken in September and October 2014 we map the global distribution of cliffs over the entire nucleus and compare the spatial distribution of cliffs with the maps of active sources by Vincent *et al.*

3. Modeling of cliff collapse

Assuming that volatiles act to strengthen the cliffs through their larger cohesiveness, their removal by activity should subsequently lead to structural weakening of the cliff wall resulting in a collapse of parts of the cliff. We aim to estimated the depth to which the volatiles have to receed before the wall becomes instable through a simple two-dimensional model that describes the cliff as a dust-ice-mixture with different dust-to-ice ratios. Fractures are introduced to additionally weaken the material locally. We assume material strengths as deduced by Groussin *et al.* [8].

Additionally, we conduct some descrete element modelling computer simulations using the open source code ESyS-Particle [9] to corroborate the findings from the theoretical modelling. We simulated a small slice of a cliff (50x15x25 meters; height, width, depth)

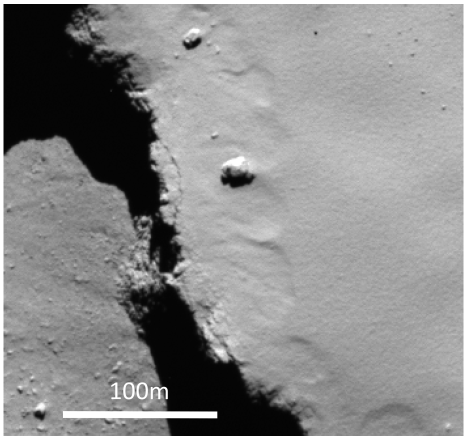

Figure 2: A top view of the same cliff as in figure 1 emphasizing the mass wasting present near the edge of the cliff.

made up of spherical boulders. The size distribution of the boulders was varied in the centimeter to meter range constrained by the size of the fragments found at the foot of the cliffs. Each individual simulated boulder consists of either a dust-ice mixture or pure dust. The strength of the cohesive bonds between boulders is stronger for those boulders containing ice, thus giving these parts of the cliff a higher strength. Starting from the front of the slice, the dust-ice boulders are replaced by pure dust one until such a point where the cliff becomes unstable. Additionally, the influence of cracks (both their number and their depth) is investigated by selectively removing boulders from the cliff in a predefined cross cut.

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3D DSMC Modeling of the Coma of Comet 67P/Churyumov-Gerasimenko Observed by the VIRTIS and ROSINA instruments

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1. Introduction

Since its rendez-vous with comet 67P/Chruryumov-Gerasimenko (CG), the Rosetta spacecraft has provided invaluable information contributing to our understanding of the cometary environment. On board, the VIRTIS and ROSINA instruments can both measure gas parameters in the rarefied cometary atmosphere, the coma, and provide complementary results with remote sensing and in-situ measurements, respectively.

The use of a numerical model is a way to correlate the information provided by both VIRTIS and ROSINA to fully understand the volatile environment of comet CG. To describe the entire coma including the regions where collisions cannot maintain the flow in a fluid regime, the use of a kinetic method is necessary. Here, the Direct Simulation Monte-Carlo (DSMC) approach is applied to the cometary coma to solve the Boltzmann equation [1] using the Adaptive Mesh Particle Simulator (AMPS) code [2], [3], [4], [5], and then compared with VIRTIS and ROSINA data.

2. Description of the model

During its journey in the Solar System, as the comet gets within a few astronomical units of the Sun, solar heating liberates gases and dust from its icy nucleus forming the coma. The model boundary conditions are then based on the local solar illumination. The complex shape of the nucleus of comet CG, here based on SHAP5 from the OSIRIS team, requires taking into account self-shadowing. The temperature at the inner boundary is based on the thermophysical model from [6], [7], [8], while the gas flux is constrained by ROSINA measurements and driven by the angle between the normal of each surface element with the solar direction. This model was shown to have a good agreement with both ROSINA [9] and VIRTIS-H [10] data. Progress comparing the model with VIRTIS and ROSINA data is described. This comparison provides a better global understanding of the gas coma of comet CG.

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ROSINA would not give such outstanding results without the work of the many engineers, technicians, and scientists involved in the mission, in the Rosetta spacecraft, and in the ROSINA instrument team over the last 20 years whose contributions are gratefully acknowledged.

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Outer solar system formation: first lessons learnt from Rosetta/ROSINA

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Abstract

Comet 67P/Churyumov-Gerasimenko (67P) is a Jupiter Family comet targeted by the Rosetta mission for in-situ analysis of cometary material and properties. The ROSINA (Rosetta Orbiter Sensor for Ion and Neutral Analysis) instrument on board of the Rosetta spacecraft has been analyzing the composition of gases emitted from 67P since August, 2014 [1]. Here we review the different molecular and isotopic measurements that have been performed by ROSINA over the last few months. We discuss the implications of these measurements for deriving some clues on the formation conditions of the outer solar system. For example, the comparison between the N_2/CO and Ar/CO ratios measured in 67P [2,3] places important constraints on the structural properties of the icy grains from which the comet was agglomerated. Also, the high D/H ratio measured in 67P, about 3 times higher than the standard SMOW value [4], matches chemical models that predict a monotonic radial increase of the deuterium enrichment profile [5,6] and implies that the comet formed at a higher heliocentric distance than JFCs and OCCs with lower D/H ratios, in agreement with recent dynamical models of the outer solar system [7]. If the low N_2/CO ratio measured in 67P [2] is typical of that of planetesimals formed in the outer solar system, this implies that the compositions of Jupiter and Saturn cannot be explained solely via the accretion of these solids during their formation.

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Photometric study of comet 67P/Churyumov-Gerasimenko as seen by VIRTIS-H onboard Rosetta

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Abstract

In this study we present an analysis of the large dataset from H channel of VIRTIS (Visible Infrared Thermal Imaging Spectrometer) onboard ESA's Rosetta spacecraft. We focus on photometric properties of the nucleus since there are many different observation geometries and illumination conditions available. Variations of the signal with phase are reproduced with a Lommel-Seeliger model. This allows to retrieve phase function and then, by fitting the data, the single scattering albedo and asymmetry parameter for every wavelength.

1. Introduction

Since 6 August 2014, VIRTIS allows us to study comet 67P/Churyumov-Gerasimenko with two different channels ([1]): VIRTIS-M and VIRTIS-H. The first one is an imaging spectrometer working from 0.25 to 5.1µm and covering a large field of view. The second one is a point spectrometer covering the range from 1.9 to 5.0µm with a higher spectroscopic resolution. Both have already observed the comet 67P/CG under many different illumination conditions and observation geometries (e.g. between 0 and 110° phase angle). This allows us to perform a photometric study and to potentially monitor changes of the physical properties of the nucleus. In order to do that and to compare these results with [2] we work on the dataset of VIRTIS-H acquired from August 2014 to March 2015.

2. Model

Firstly, comet 67P/CG is very dark ([3]) so we assume multiple scattering can be neglected on the surface. Secondly we investigated phase angles larger than 20° which permits to neglect the opposition effect (OE) ([4]). Based on these two assumptions the signal is expected to follow the Lommel-Seeliger model:

$$I/F(i,e,g) = \frac{w}{4}\frac{\mu_0}{\mu_0+\mu}p(g)$$

$$\mu_0 = cos(i)$$

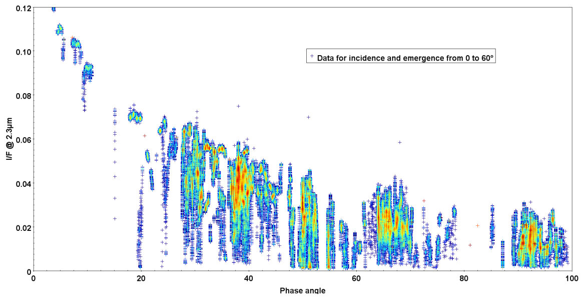
$$\mu = cos(e)$$

$$p(g) = \frac{1-b^2}{(1+2bcos(g)+b^2)^{3/2}}$$

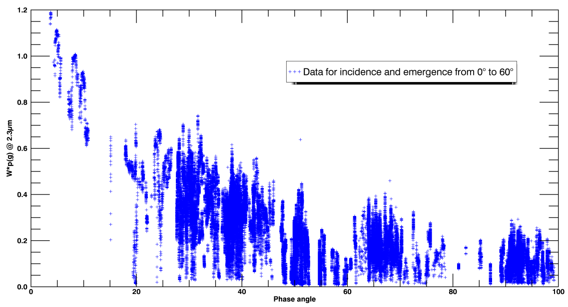
where i, e and g are respectively the incidence, emergence and phase angles for the measured reflectance I/F. w is the single scattering albedo (SSA) and b the asymmetry parameter. $p(g)$ is the phase function which is represented by a one-lobe Henyey-Greenstein function ([5]).

3. Data analysis and method

The available data are calibrated in radiance $(W/m^2/sr/\mu m)$. In order to use them according to the model previously described, we convert every pixel in reflectance (I/F, represented in figure 1a) which removes any variations due to the heliocentric distance. We then use the Lommel-Seeliger model to remove angular dependencies and to obtain the product $w * p(g)$. We choose to exclude data where incidence and emergence angle are greater than 60° in order to remove illumination or viewing conditions as well as roughness effects. These angles are computed from the center of each pixels, based on the shape model 5 of Osiris. The result is displayed in figure1b where the number of pixels is larger than 90.000. We will then study the behavior of w and b along the wavelength, up to $3.0\mu m$ where thermal emission becomes noticeable. The values of w and b obtained by fitting the average I/F will be compared with values retrieved by VIRTIS-M [2] and with values measured on other comets ([6, 7, 8]).



(a)



(b)

Figure 1: (1a) Density plot of reflectance (I/F) for 10 channels aroud 2.3µm for all data from August 2014 to March 2015. (1b) Product of the Single Scattering Albedo (SSA) by phase function (p(g) where g is the phase angle). The plots are relative to observations obtained at incidence and emission angles lower than 60°.

4. Future works

Owing to the shape of the nucleus and small scale relief, roughness may deeply affect the reflectance and will be investigated further. As Rosetta continues its mission, the dataset will enlarge in the coming months. With 67P/CG passage at perihelion in August 2015, the activity in the coma will increase drastically. Surface properties may exhibit significant changes as the surface becomes warmer and more active. Possible changes in photometric parameters will be monitored and reported.

Acknowledgements

The authors would like to thank the following institutions and agencies, which supported this work: Italian Space Agency (ASI-Italy), Centre National d' Etudes Spatiales (CNES, France), Deutsches Zentrum für Luft und Raumfahrt (DLR, Germany), National Aeronautic and Space Administration (NASA-USA) Rosetta Program, Science and Technology Facilities Council (UK). VIRTIS has been built by a consortium, which includes 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 VIRTIS instrument development has been funded and managed by ASI, with contributions from Observatoire de Paris financed by CNES, and from DLR. The authors wish to thank the Rosetta Science Ground Segment and the Rosetta Mission Operations Centre for their fantastic support throughout these early phases of the mission.

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EPSC Abstracts
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Sub-Surface Properties of Comet 67P/Churyumov-Gerasimenko Derived from Combined Thermal and Spectroscopic Data from the MIRO Instrument

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Abstract

The Microwave Instrument on the Rosetta Orbiter (MIRO) [1] measures a) thermal emission from the nucleus of comet 67P/Churyumov-Gerasimenko in two continuum bands (centered near 190 GHz and 562 GHz), and b) eight molecular emission and absorption lines (of $H_2{}^{16}O$, $H_2{}^{17}O$, $H_2{}^{18}O$, CH_3OH, NH_3, and CO) in the 562 GHz band with a spectral resolution of 44 kHz. Average thermal and dielectric properties of the nucleus have been derived from the continuum measurements in Ref. 2, 3 and 4, and coma properties were obtained in Ref. 2, 5 and 6.

The reference publications relied on thermal models of the sub-surface regions of the nucleus for the analysis of continuum data, and on models of the coma density, gas velocity, and temperature, and on radiative transfer calculations for the analysis of the molecular lines. These two types of analyses were mostly conducted without explicit consideration for the coupling that exists between the thermal models and gas production models. Consequently, gas production rates derived from the spectral data analysis are not necessarily consistent with the temperature profiles obtained from the continuum data analysis, where sublimation of ices was not included. We will present results from a unified analysis of the continuum emission and the molecular lines for a set of observations in 2015, including two flybys with closest approach to the nucleus smaller than 10 km.

Our analysis constrains the physical properties of the sub-surface material of the nucleus, such as its porosity, ice-to-dust ratio, thickness of the dust layer, and dust grain size, by using a thermal model for porous materials similar to the one described in Ref. 7, including sublimation of ice, and a combination of simple hydrodynamic and gas kinetic models to compute the resulting properties of the gas column probed with MIRO. Non-local thermal equilibrium radiative transfer calculations yield the spectral line shapes. As part of the analysis of the sub-surface nucleus materials, we will compare the model parameters used in the independent thermal and spectral, and combined model approaches.

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Analysis of dust in the coma of comet 67P using VIRTIS-M observations

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Abstract

We present a preliminary overview of the analysis on the dust spectrophotometry in the inner coma of comet 67/P that was obtained during the escort phase (started on December 2014) with the imaging spectrometer VIRTIS-M onboard the Rosetta mission [1]. The morphology and behavior of the dust coma has been monitored by VIRTIS–M from the arrival at the comet (~August 2014) throughout the early escort phase. The data reveal intricate details and numerous radial jets coming from different regions on the surface. On March 15, 2015, VIRTIS-M performed a set of 22 coma observations, each about 23 minutes in duration and offset from the nucleus by about 1 km. The 22 observations lasted about 12 hours and thus covered a complete rotation of the comet.

The maps of the dust distribution in the coma reveal three major structures: a roughly uniform background dusty coma, several enhanced radiance jet features and a region that shows a thermal radiation component between 3.5 and 5.0 µm. (Figure 1 and Figure 2) The jets features can be traced back to several region of the comet, neck, body and head.

We shall analyse the three major structures to provide the basis to understand coma composition and properties and the relation between gas and dust. We will discuss the morphology of the background coma, the jet and the enhanced thermal radiation. We will also examine correlations between the water vapor column density and the coma/jet /thermal radiation intensity. For the thermal radiation component there are several explanations, viz: stray instrumental scattered light or instrumental ghosts from heated part of the nucleus, or thermal radiation emanating from the nucleus and scattered by the dust in closest proximity or a region of small particles in the coma heated by solar radiation.

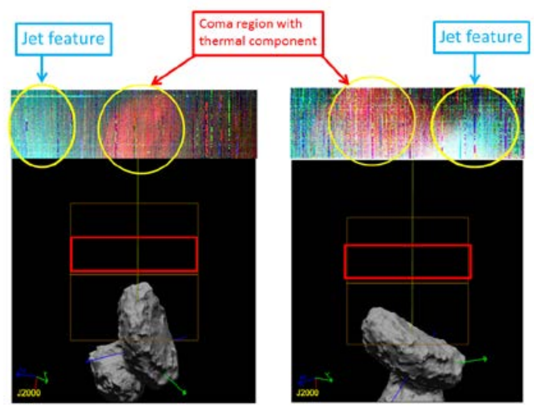

Figure 1: This figure shows two VIRTIS-M cube images (above) taken on March 15th at 2.11 AU and images of the Rosetta 3dtool below. The 3dtool shows the position of the comet with respect to the VIRTIS-M FOV (yellow square). The VIRTIS-M images start at the horizontal yellow line and extend about 2 km up. The figure shows the main structures in the coma: jet feature and the coma region with the thermal component.

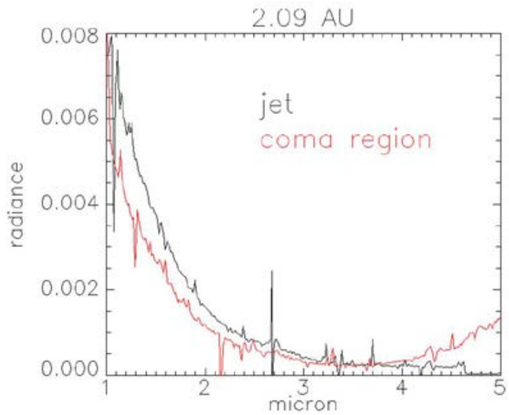

Figure 2: Example of VIRTIS-M spectral profiles in the IR channel. The black curve is a spectrum for the jet feature and the red curve is a spectrum of the region showing thermal emission. The figure shows that in the range between 3.5-5 µm the jet has a flat spectrum while the red curve shows a definite thermal signature.

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Four-fluid MHD Simulations of the Plasma and Neutral Gas Environment of Comet Churyumov-Gerasimenko Near Perihelion

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Abstract

We develop a 3-D four fluid model to study the plasma environment of comet Churyumov-Gerasimenko (CG), which is the target of the Rosetta mission. Our model is based on BATS-R-US within the SWMF (Space Weather Modeling Framework) that solves the governing multifluid MHD equations and and the Euler equations for the neutral gas fluid. These equations describe the behavior and interactions of the cometary heavy ions, the solar wind protons, the electrons, and the neutrals. This model incorporates mass loading processes, including photo and electron impact ionization, furthermore taken into account are charge exchange, dissociative ion-electron recombination, as well as collisional interactions between different fluids. We simulate the near nucleus plasma and neutral gas environment with a realistic shape model of CG near perihelion and compare our simulation results with Rosetta observations.

1 Introduction

The neutral and plasma environment is critical in understanding comet CG. Rubin et al. (2014) developed a multi-fluid plasma model and compared their simulation results with a hybrid simulation and showed that the multi-fluid plasma code can represent some distinct features from the hybrid simulation. However, their code applies a spherically symmetric neutral background from the analytical Haser model, which is only a crude approximation. Moreover, recent observations showed that comet CG has an irregular shape, which will likely influence the near body neutral and plasma distribution.

To understand the neutral gas and plasma interactions along with the irregular shape, we develop the first 3D multi-fluid neutral gas + plasma code, based on BATS-R-US within SWMF, with arbitrary shape.

2 Model Philosophy

Hydrodynamic equations for cometary neutral gas are provided in Equation 1:

$$\begin{aligned}
&\frac{\partial \rho_n}{\partial t} + \nabla\cdot(\rho_n \mathbf{u_n}) = \frac{\delta \rho_n}{\delta t}\\
&\frac{\partial \rho_n \mathbf{u_n}}{\partial t} + \nabla\cdot(\rho_n \mathbf{u_n}\mathbf{u_n} + p_n \mathrm{I}) = \frac{\delta \rho_n \mathbf{u_n}}{\delta t}\\
&\frac{\partial p_n}{\partial t} + \nabla\cdot(p_n \mathbf{u_n}) + (\gamma-1)p_n(\nabla\cdot\mathbf{u_n}) = \frac{\delta p_n}{\delta t}
\end{aligned} \tag{1}$$

while MHD equations for cometary heavy ions (subscript s), solar wind protons (subscript s) and electrons (subscript e) are shown in Equation 2:

$$\begin{aligned}
&\frac{\partial \rho_s}{\partial t} + \nabla\cdot(\rho_s \mathbf{u_s}) = \frac{\delta \rho_s}{\delta t}\\
&\frac{\partial \rho_s \mathbf{u_s}}{\partial t} + \nabla\cdot(\rho_s \mathbf{u_s}\mathbf{u_s} + p_s \mathrm{I})\\
&\qquad - Z_s e\frac{\rho_s}{m_s}(\mathbf{E} + \mathbf{u_s}\times\mathbf{B}) = \frac{\delta \rho_s \mathbf{u_s}}{\delta t}\\
&\frac{\partial p_s}{\partial t} + \nabla\cdot(p_s \mathbf{u_s}) + (\gamma-1)p_s(\nabla\cdot\mathbf{u_s}) = \frac{\delta p_s}{\delta t}\\
&\frac{\partial p_e}{\partial t} + \nabla\cdot(p_e \mathbf{u_s}) + (\gamma-1)p_e(\nabla\cdot\mathbf{u_e}) = \frac{\delta p_e}{\delta t}\\
&\frac{\partial B}{\partial t} = -\nabla\times\mathbf{E}\\
&\mathbf{E} = -\mathbf{u}_+\times\mathbf{B} - \frac{1}{n_e e}\nabla p_e
\end{aligned} \tag{2}$$

u_+ in Equation 2 is the charge averaged ion velocity and it can be expressed as $u_+ = \frac{\sum_{s=ions} Z_s n_s \mathbf{u_s}}{n_e}$. All the source terms for neutral gas and plasma fluids are incorporated in the right hand side of both Equation 1 and 2. The neutral gas fluid and the plasma fluids are coupled together. We specify the inner boundary at the comet surface and the outer boundary at the edge of the simulation domain.

Acknowledgements

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Temperature and reflectance derivation from VIRTIS-H observations of 67P

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Abstract

A specific thermal emission model is applied to observations of 67P/Churyumov-Gerasimenko surface by the high-resolution channel of VIRTIS. Signal inversion provides both an effective surface temperature (averaged inside the FoV) and a reflectance spectrum corrected from thermal emission. Details of the organic material band at 3.2 µm [1] and longer wavelengths can then be studied at resolution R ~ 1500-3000 with increased contrast and accuracy.

1. Introduction

We use a basic radiance model in which reflectance and emissivity are related through a photometric function, and a single temperature is used for each pixel – this actually represents an average of sub-pixel temperatures weighted by area and black body radiance, and is therefore usually slightly less than the highest temperature present in the pixel. However, inversions of such models are known to be numerically instable. A regularization scheme is used here.

2. Radiance model

The method is adapted from that described in [2]. Radiance reads:

$$L(\lambda) = r_F(i,e,\varphi)\ \frac{E_s(\lambda)}{\pi R^2} + B_\lambda\ \varepsilon(e)$$

where B_λ is the black body radiance at the effective surface temperature T, $\frac{E_s(\lambda)}{R^2}$ is the solar irradiance at the target distance R, $r_F(\lambda)$ and $\varepsilon(\lambda)$ are the radiance factor and the directional emissivity of the surface at the same wavelength.

In a particulate medium at thermal equilibrium, directional emissivity is related to hemispherical-directional reflectance at each wavelength by Kirchhoff's law:

$$\varepsilon(e) = 1 - r_{hd}(e) = 1 - \int_{2\pi} r_F\ d\Omega_i$$

where reflectance is integrated over incidence angles in the free half-space. This strongly depends on the phase function of the material. If the photometric function can be assumed Lambertian (a reasonable assumption for bright materials) Kirchhoff's law simply reads:

$$\varepsilon(e) = 1 - r_F / (\cos i)$$

This quantity does not depend on incidence in the Lambertian case, and emission is isotropic. For dark materials such as the 67P surface, the Lommel-Seeliger model is however a better assumption. In this case, a similar, more complicated formulation of Kirchhoff's law can be derived, where emissivity is no longer isotropic. The photometric functions used in the present formulation mostly account for the influence of sub-pixel roughness, which is often modeled using a "beaming factor" [e.g., 3].

3. Inversion method

The above equation can be inverted to provide temperature and spectral reflectance from measurements. In practice, the inversion process is extremely sensitive to the noise and subject to numerical divergences, in particular near the crossover point between solar reflected light and thermal emission. On 67P, this is located between 3 and 5 μm and migrates towards shorter wavelengths as the comet approaches the Sun. A simple inversion therefore results in a correct estimate of temperature but in large spectral oscillations, sometimes with large negative values. It is therefore not applicable to recover a reflectance spectrum to be compared with experimental measurements.

The procedure used here consists in including a continuity constraint, i.e. to minimize the difference in retrieved reflectance between any two consecutive channels. This constraint prevents large oscillations to alter the reflectance spectrum, and acts as a smoothing function. As opposed to the Bayesian methods used for VIRTIS-M [4] no assumption is made on the expected spectrum, which could conceal minor absorptions. A practical drawback is the large increase in computing time (currently a factor of ~20), but it does provide reasonable estimates of spectral reflectance.

4. Application

The method presented here is applied to the inversion of VIRTIS-H / Rosetta observations of the nucleus of 67P and gives satisfying results when applied at a certain distance from the limb (e < 60°). Accuracy is assessed using spectra of similar areas at different temperatures. Reflectance estimates will be compared with laboratory measurements of relevant materials.

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 from 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'études spatiales et d'instrumentation en astrophysique of the Observatoire de Paris, France, and the Institut für Planetenforschung of DLR, Germany. The authors wish to thank the Rosetta Science Ground Segment and the Rosetta Mission Operations Centre for their continuous support. With fond memories of Angioletta Coradini.

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Investigations of 67/P-CG surfaces thermal properties at Southern latitudes and variations with heliocentric distances with VIRTIS/Rosetta

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Abstract

The Visible InfraRed and Thermal Imaging Spectrometer VIRTIS [1] instrument onboard Rosetta (ESA) has been intensively used to map the nucleus spectral and thermal properties of the nucleus comet 67/P-CG [2][3]. Here we report the thermal analysis of surfaces using thermal modeling dedicated to the comet. We focus on variations of thermo-physical properties with time, as long as the comet reaches its perihelion, and on thermal properties of the southern regions that were not illuminated during the last years due to the high obliquity of CG [4].

1. Introduction

Thermal emission of airless planetary surfaces depends on composition, surface roughness, porosity, thermal conductivity but also on the shape of the body. Thermal conduction is usually the most efficient mechanism to transport energy from the surface down the sub-surface. When ice is present at surface or beneath the surface, sublimation affects significantly the thermal contrast between noon and midnight. Because of its eccentricity and its strong obliquity, the comet 67/P-CG experiences strong seasonal variations especially near its south pole which is only illuminated near perihelion. Up to mid 2015, VIRTIS data allowed us to derive the temperatures and the thermal properties of the northern hemisphere [5]. This presentation focuses on the derivation of thermal properties of the southern hemisphere and on their variations in the equatorial regions between 3 AU and perihelion.

2. Thermal properties

We use a quasi-3D approach to model heat transfert by conduction that includes sublimation effects, self-heating and mutual shadowing. We analyze separately the geomorphological regions described by [6]. For each of them, a representative set of temperature measurements is selected randomly and compared directly to the simulated one in order to determine the thermal parameters that best fit the measurements within a given region. For each of the considered geomorphological regions, we aim to derive thermal conductivity that provides information on the physical properties of the surface. We particularly focus on the Southern hemisphere and on the equatorial regions. The southern hemisphere is only heated by the Sun when the comet is close to the perihelion so we expect strong seasonal variations. In particular, water ice that is supposed to be present in this cold should sublimate rapidly as long as the surface is illuminated. Thus, one may detect variations of thermal conduction as long as ice sublimates. We also analyze and model temperatures at equatorial latitudes as those area can be observed at very similar absolute sub-solar latitudes in summer and winter but at very different heliocentric distances. Direct comparisons with models can emphasize variations of thermal properties due to chemical variations of the surface to radiations processes and structural surface modification.

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Cometary dust at the nanometre scale - the MIDAS view after perihelion

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Abstract

The MIDAS instrument on-board the Rosetta orbiter [1] is a unique combination of a dust collection and handling system and a high resolution Atomic Force Microscope (AFM). By building three-dimensional images of the dust particle topography with nano- to micrometre resolution, MIDAS addresses a range of fundamental questions in Solar System and cometary sciences. The greatest number of particles is expected to be collected around perihelion and the initial results of imaging these will be presented.

1. Predicting the dust flux at 67P

The number of dust grains to be collected by MIDAS during the mission was estimated prior to arrival at comet 67P using the GIADA dust environment model [2]. However, extrapolation of the dust size distribution observed from the ground to the size of interest to MIDAS (nanometre to micron sized) required assumptions about the power law index below the limit of such observations.

Because of this the range of expected particle counts was dependant on the model chosen and highly variable, but was always expected to be highest during the initial (bound) orbits and again at perihelion.

2. Dust collection at perihelion

Dust collection in the early months after arrival revealed very few small (sub-micron) particles but several particles much larger than expected (close to or beyond the limit observable with the instrument). This is believed to be partly due to the intrinsic dust distribution, but partly due to the spacecraft environment and charging effects [3].

It is expected that the exposure of the Southern hemisphere of the comet (last sunlit during the previous apparition) and the perihelion passage in August 2015 will together result in a significant increase in the number of particles collected.

The first results obtained from imaging these particles will be presented here and a comparison to pre-perihelion findings made.

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Distribution of H_2O and CO_2 in the inner coma of 67P/CG as observed by VIRTIS-M onboard Rosetta

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VIRTIS (Visible, Infrared and Thermal Imaging Spectrometers) is a dual channel spectrometer; VIRTIS-M (M for Mapper) is a hyper-spectral imager covering a wide spectral range with two detectors: a CCD (VIS) ranging from 0.25 through 1.0 μm and an HgCdTe detector (IR) covering the 1.0 through 5.1 μm region. VIRTIS-M uses a slit and a scan mirror to generate images with spatial resolution of 250 μrad over a FOV of 64 mrad. The second channel is VIRTIS-H (H for High resolution), a point spectrometer with high spectral resolution ($\lambda/\Delta\lambda$=3000@3 μm) in the range 2-5 μm [1].

The VIRTIS instrument has been used to investigate the molecular composition of the coma of 67P/CG by observing resonant fluorescent excitation in the 2 to 5 μm spectral region. The spectrum consists of emission bands superimposed on a background continuum. The strongest features are the bands of H_2O at 2.7 μm and the CO_2 band at 4.27 μm [1]. The high spectral resolution of VIRTIS-H obtains a detailed description of the fluorescent bands, while the mapping capability of VIRTIS-M extends the coverage in the spatial dimension to map and monitor the abundance of water and carbon dioxide in space and time.

We have already reported [2,3,4] some preliminary observations by VIRTIS of H_2O and CO_2 in the coma. In the present work we perform a systematic mapping of the distribution and variability of these molecules using VIRTIS-M measurements of their band areas.

All the spectra were carefully selected to avoid contamination due to nucleus radiance. A median filter is applied on the spatial dimensions of each data cube to minimise the pixel-to-pixel residual variability. This is at the expense of some reduction in the spatial resolution, which is still in the order of few tens of metres and thus adequate for the study of the spatial distribution of the volatiles. Typical spectra are shown in Figure 1.

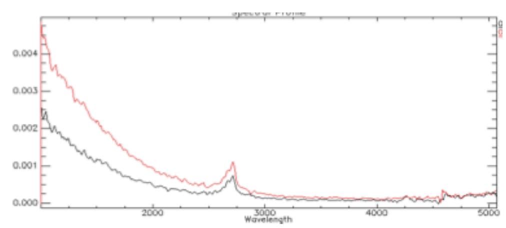

Figure 1: Example of radiance spectra, expressed in $W/m^{-2}\ sr^{-1}\ \mu m^{-1}$, after the spatial filtering process. The black curve is a spectrum of a pixel in the cube 00387393237, while red refers to the same pixel in the cube 00387396837. The water band at 2.7 μm is clearly visible. The CO_2 emission band at 4.27 μm can be seen in the black spectrum

For each of the two molecules we derive the band areas by removing the estimated continuum level from the measured radiance and use the band areas to derive the H_2O and CO_2 molecules column densities, see Figure 2. The two VIRTIS channels perfectly complement each other, VR-M providing the mapping capability and VR-H the high spectral resolution required to fix the absolute abundance scale accurately. The data set used here allows us to study the diurnal evolution of the activity above specific regions of the nucleus surface, including the most active areas, and to analyze the relative abundances of water vapour and carbon dioxide. The presentation will describe the results obtained.

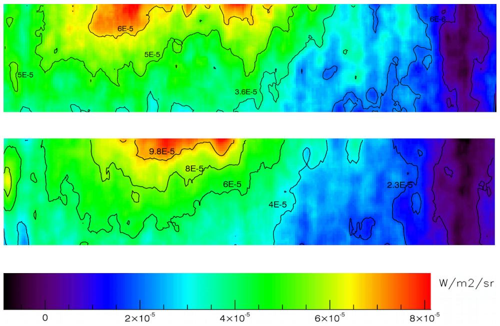

Figure 2: Typical water vapour band area maps derived from two consecutive VIRTIS-M data cubes obtained on 11th April 2015. The frame size is approximately 6.5 by 1.8 km., and the surface of the nucleus is about 1 km above the top of each frame.

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The volatile inventory of comet 67P/Churyumov-Gerasimenko from Rosetta/ROSINA at 3 AU

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Abstract

Comets are believed to be the most pristine bodies in the solar system. The study of their composition can therefore give us important clues about the processes that occurred during the solar system formation. We will report abundances of the major observed species with focus on the hydrocarbons detected by ROSINA/DFMS in the coma of 67P/Churyumov-Gerasimenko in October 2014 at 3 AU.

1. ROSINA experiment

ROSINA consists of a suite of three instruments: a pressure sensor (COPS: COmetary Pressure Sensor) and two mass spectrometers: the Reflectron Time of Flight mass spectrometer (RTOF) and the Double Focusing Mass Spectrometer (DFMS).

For this study, the data have been obtained with the high-resolution mass spectrometer DFMS, a traditional magnetic mass spectrometer that combines an electrostatic analyzer for energy analysis with a magnet for momentum analysis. Its mass resolution is 9000 at FWHM at 28 u/e, which allows to resolve CO from N_2 at m/z= 28 u/e [1].

2. Objective

In October 2014, before lander release, the Rosetta spacecraft trajectory around the nucleus was in the terminator plane at different distances from the nucleus. This study focuses on the parent species detected during the 10 km orbit. The abundance/detection of the different parent species will be presented and compared to the abundance reported for other comets such as 103P/Hartley 2, 1P/Halley, Hale-Bopp, Hyakutake, and also to the composition in the interstellar medium.

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Modelling of the sublimation of icy grains in the coma of comet 67P/Churyumov-Gerasimenko

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Abstract

The ESA (European Space Agency) Rosetta spacecraft was launched on 2 March 2004, to reach comet 67P/Churyumov-Gerasimenko in August 2014. Since March 2014, images of the nucleus and the coma (gas and dust) of the comet have been acquired by the OSIRIS (Optical, Spectroscopic, and Infrared Remote Imaging System) camera system [1] using both, the wide angle camera (WAC) and the narrow angle camera (NAC). The orbiter will be maintained in the vicinity of the comet until perihelion (R_h=1.3 AU) or even until R_h=1.8 AU post-perihelion (December 2015). Nineteen months of uninterrupted, close-up observations of the gas and dust coma will be obtained and will help to characterize the evolution of comet gas and dust activity during its approach to the Sun. Indeed, for the first time, we will follow the development of a comet's coma from a close distance. Also the study of the dust-gas interaction in the coma will highlight the sublimation of icy grains. Even if the sublimation of icy grains is known, it is not yet integrated in a complete dust-gas model.

We are using the Direct Simulation Monte Carlo (DSMC) method to study the gas flow close to the nucleus. The code called PI-DSMC (www.pi-dsmc.com) can simulate millions of molecules for multiple species.When the gas flow is simulated, we inject the dust particle with a zero velocity and we take into account the 3 forces acting on the grains in a cometary environment (drag force, gravity and radiative pressure).

We used the DLL (Dynamic Link Library) model to integrate the sublimation of icy grains in the gas flow and allow studying the effect of the additional gas on the dust particle trajectories. For a quantitative analysis of the sublimation of icy, outflowing grains we will consider an ensemble of grains of various radii with different compositions [2] The evolution of the grains, once they are ejected into the coma, depends on their initial size, their composition and the heliocentric distance (because the temperature of the grain is higher close to the Sun). The grain temperatures will be derived by assuming equilibrium between the energy absorbed from the Sun, the energy re-radiated in the infrared, and the cooling by sublimation. We will use Mie theory [3, 4] to compute the scattering properties of an assumed grain (grain size, shape and composition, including mineralogy and porosity). We follow the evolution of grains until the icy layer sublimates completely. Once ejected in the gas flow, the generated molecules have no preferred direction. First results highlighted that the sublimation has a significant influence on the dust trajectories and generates a gas cloud that moves with the velocity of the icy grains.

Our model can produce artificial images for a wide range of parameters, including outgassing rate, surface temperature, dust properties and sublimation of icy grains. The results of this model will be compared to the images obtained with OSIRIS camera and to the published data from other instruments.

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COSIMA - Dust Particles in the Inner Coma of Comet 67P/Churyumov-Gerasimenko prior to perihelion passage

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Abstract

COSIMA, the COmetary Secondary Ion Mass Analyser, is one of the three scientific in-situ dust instruments onboard the Rosetta spacecraft. Rosetta has been accompanying the comet 67P/Churyumov-Gerasimenko since August 2014 during the journey of the nucleus into the inner solar system. COSIMA has collected several thousands of cometary particles in the inner coma from 10 to hundreds of kilometers off the cometary nucleus. We will discuss the evolution of the inner coma dust particles as observed for the collected, imaged and analyzed cometary particles.

1. The Instrument

The COSIMA instrument is a secondary ion mass spectrometer equipped with a dust collector, an ion gun, and an optical microscope for target characterization. Dust from the near comet environment are collected on a set of targets. Those can be moved to a microscope imager where the positions of the collected grains can be determined. The cometary grains can then be bombarded with a liquid indium ion gun. The resulting secondary ions are extracted into a time-of-flight mass spectrometer and the secondary mass spectra are recorded for science analysis (Figure 1).

2. Grain collection

As shown in Figure 2, a remarkable number of grains (several thousands) have been collected since the beginning of operations in September 2014.

3. Grain Analysis

The grain chemical composition as inferred from secondary mass spectra will be presented and discussed.

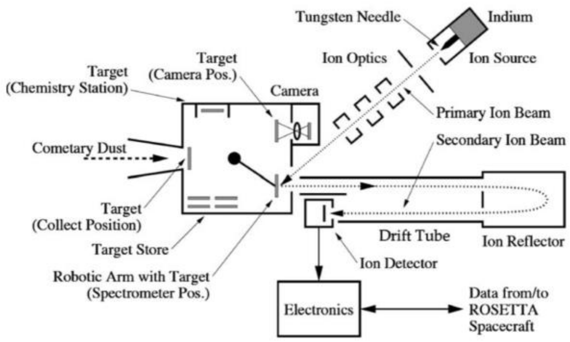

Figure 1: Schematic view of COSIMA from Kissel et al. (2007).

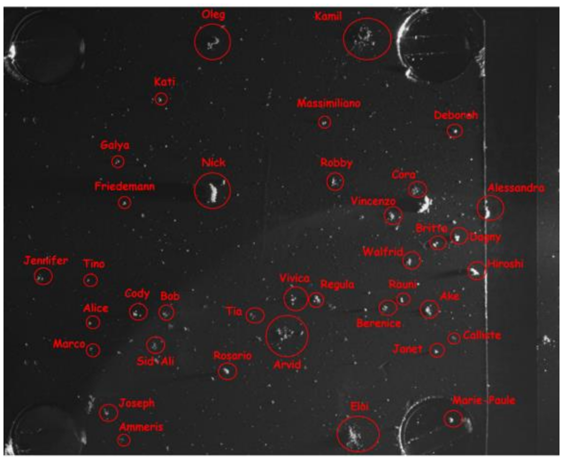

Figure 2: A target plate (1cm across), showing dust grains collected between 11 August and 12 December 2014. Credits: ESA/Rosetta/MPS for COSIMA Team MPS/CSNSM/UNIBW/TUORLA /IWF/IAS/ESA/BUW/MPE/LPC2E/LCM/FMI/UTU/ LISA/UOFC/vH&S.

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Searching for the spectral features of minerals on the surface and in the dust of the comet 67P/Churyumov-Gerasimenko in NIR spectral range of VIRTIS-M data

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Abstract

The main subject of the paper is constraining the composition of the surface and possibly of the dust on the comet 67P/Churyumov-Gerasimenko by means of comparison between the data from the VIRTIS instrument [1] onboard Rosetta and adopted model of the surface of asteroids [9]. As a first step we have taken into account the spectral range 2.0 - 4.0 µm. For our calculations Mie and Hapke's models have been considered.

1. Introduction

There are some observational evidences that the mineralogical composition of the comet 67P/C-G and the asteroid 24Themis can be similar [2,6]. The presence of water ice and organic compounds were detected on both objects [3,2,9]. Pyroxenes are also suggested as important mineral species. Spectra from these astronomical bodies show very similar trends around 3.0µm. Taking into account these facts we started to use as cometary analogs elaborated models of the surface of the asteroid 24Themis [9]. Considering the surface with various kinds and proportion of minerals suggested for the surface of asteroid 24Themis as a starting point for analysing cometary spectra we can expect that several new features will be detectable. The possibility of revealing a feature depends on the abundance of the particular species.

We show in Fig.1 an average VIRTIS-M spectrum (MTP008 I100371997863) from darkest regions of the surface of the Comet 67/P compared with preliminary simulation. The model is an intimate mixture containing 29% pyroxene coated with a 0.045-µm-thick layer of water ice and 71% of amorphous carbon [6,5]. The modelled grain size is about 20µm for all the components. The minimum in the model is shifted in comparison to the VIRTIS data toward smaller wavelength The work is in progress. Simulation will be continued and improved using better spectral resolution of optical constants and new size distribution of grains and new sources of optical data [7,8].

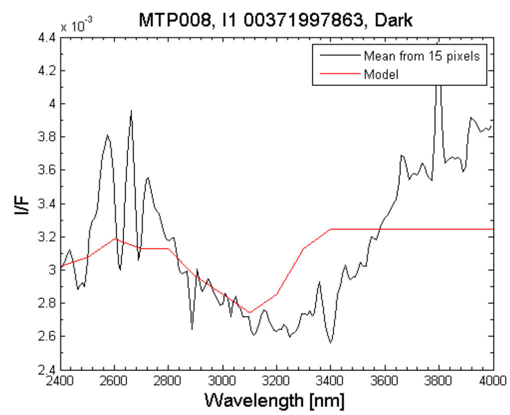

Fig 1.The average spectrum (black) from 15 pixels of darkest region of the surface of the comet 67/P C-G compared with smoothed low spectral resolution model [9]

2. Method

For our analysis the VIRTIS-M data the IDL\ENVI and additional codes written in MATLAB were used. The programs used for modelling the reflectances are Mie (e.g. for particles coated with water ice) and Hapke (for the reflectance of the mixtures).

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Findings from the PP-SESAME experiment on board the Philae/ROSETTA lander on the surface of comet 67P

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Abstract

The Permittivity Probe (PP-SESAME [1]) on-board the Philae Lander of the ROSETTA mission was designed to constrain the complex permittivity of the first 2 meters of the nucleus of comet 67P/Churyumov-Gerasimenko and to monitor its variations with time. Doing so, it is meant to provide unique insight into the composition (and activity if data could have been acquired longer) of the comet. In this paper, we present the analysis of the PP-SESAME measurements acquired during the first science sequence, on November 13, 2014, on the surface of the comet.

1. Introduction

The ROSETTA probe reached its final target last summer: the comet 67P/Churyumov-Gerasimenko. On November 12, 2014, the Philae module landed on the surface of the small body. Among the instruments on board Philae, the Permittivity Probe experiment, which is part of the SESAME package [1], operated both during descent and on the ground. The objective of this experiment is to measure the low frequency complex permittivity, i.e. the dielectric constant and electrical conductivity, of the first two meters of the subsurface of the cometary nucleus. Unfortunately, interferences during the descent and the non-nominal attitude of Philae at the surface made this task more difficult than anticipated. In this paper, we describe the efforts undertaken to understand the data collected by the Permittivity Probe and interpret them in terms of cometary composition.

2. Theory of Mutual Impedance Probes

PP-SESAME is a mutual impedance probe. Its principle is based on the quadrupole array technique which uses a set of transmitters to inject a current in the ground, and measure: i) the magnitude of the induced potential difference ΔV between a pair of receiving electrodes, ii) the magnitude of the injected current I and iii) the phase shift between them [2]. The mutual impedance of the array is the complex ratio $\Delta V/I$ and normalizing it by the mutual impedance in vacuum we can derive both the dielectric constant and the electrical conductivity of the surface down to a depth that is in the order of magnitude of the distance between the receiving electrodes.

3. Determining the complex permittivity with PP-SESAME

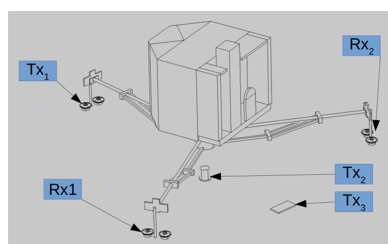

Figure 1: Modelling of PP-SESAME in operation with COMSOL Multiphysics®

PP-SESAME can use 5 electrodes, 3 located on the feet of the Philae lander and 2 mounted with other instruments (see Fig. 1). It operates at very low frequencies, in the range 10 Hz-10 kHz. In practice, in order to derive the complex permittivity from PP-SESAME active measurements, the influence of both the electronic circuit of the instrument and the conducting elements in its close environment (Philae body, harpoons, ice screw...) must be accounted for. The method that allows this has been described before in [3] and [4]. To be applied it requires a good knowledge of the attitude of the Philae lander with respect to the ground.

4. Measurements during descent and on the surface of the comet

During descent PP-SESAME acquired data during four measurement sequences which were mainly devoted to calibration, with the deployed landing gear, away from the Rosetta spacecraft influence and in an environment of known permittivity (i.e. near-vacuum). Unfortunately the measured received potentials during descent were all saturated due to disturbances from another instrument. The transmitted current, however was not and therefore could be measured. On the cometary ground, PP-SESAME performed measurements during four identical sequences, each of them separated by 2 hours, during the night. The amplitude of measured transmitted current on foot $+X$ was very close to that measured during descent indicating no contact with the ground (at least a few cm away) and/or a very low dielectric constant (close to 1). This latter interpretation would be consistent with the high porosity of the nucleus around 80% [5] and the results obtained by the CONSERT radar [6]. The potentials received on feet $+Y$ and $-Y$ were also measured but cannot be used as planned due to many factors. First, the attitude of the lander with regard to the surface is not well known. Second, the measurements were obtained in safe mode before the deployment of two of the transmitting electrodes, therefore PP-SESAME was operating with only 3 electrodes and not in a quadripolar configuration as it should. However, some constraints can be derived from the amplitude of potentials received on the two feet. The potential on $+Y$ is higher than that that on $+Y$ (Fig. 2). This is most probably not an effect of the temperature on the electronics as both feet are at the same temperature at the end of the night and the potential difference is still present. The most likely explanation is the presence of more material around the $+Y$ foot. Accurate simulations of the lander attitude and environment at the surface of the comet, using all available information (camera images, solar panel telemetry…) should confirm this hypothesis and allow us to derive the material electric properties. Furthermore, new laboratory measurements on the electronics of the receiving feet (down to -175°C) have shown that the drop in potential throughout the night (see Fig. 2) can be explained by the effect of temperature on the electronics. We recall that the electrical properties of the surface, and in particular of water ice, are not expected to vary at such low temperature (below -130°C).

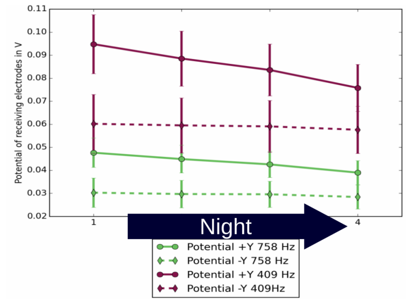

Figure 2: Received potentials on the +Y and -Y feet of the lander as a function of time

5. Summary and Conclusions

In this paper, we present the work done to understand the measurement of the PP-SESAME instrument on the surface of the comet. We will present simulations of the lander and its attitude with respect to the surface and the constraints on the surface properties we are able to derive from these simulations. Future work includes the geo-electrical characterization of materials relevant to the comet's nucleus and analysis of the data collected during a possible long term science sequence.

Acknowledgements

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Water vapor emission mechanism for 67P/Churyumov-Gerasimenko

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Abstract

In this work we study the water vapor emission by the the comet 67P/CG, the target of Rosetta mission. In this work we investigate the physical conditions required to generate short-lived outbursts in cometary nuclei. We applied a thermo-physical model [1, 2, 3] in order to evaluate the temperature of surface and sub-surface layers and the water flux. Cyclic sublimation and water condensation in the sub-surface layers, due to the change of the illumination condition on the surface, is a likely mechanism to explain part of the water outgassing [5].

1. Introduction and The Model

Comet 67P/Churyumov-Gerasimenko is the target of Rosetta, an ESA mission launched on March 2014. Observations from VIRTIS-Rosetta show water ice (whose stability depends on the local illumination condition) on the surface of the comet, which represents a localized source for short-lived outbursts [5].

The “Rome model” we applied [1, 2, 3] uses a quasi-3D approach, in which diurnal and latitudinal temperature variations are calculated by the insulation on the body. The numerical code computes the heat diffusion in the porous cometary material, leading to the water ice phase transition and sublimation of the volatile ices. The gas flux is controlled by a conservation mass equation, according to kinetic theory. The model takes into account the water ice amorphous-crystalline transition with the release of gases trapped in the amorphous ice, if present. A Crank-Nicholson implicit scheme is adopted. The code computes a “ critical radius” representing the largest particle that is likely to leave the comet and compares it to the dust particle characteristics (mass and radius), in order to establish if a dust grain could or not leave the surface (and consequently form a crust). The model accounts for three different diffusion regimes comparing the mean free path and the pore diameters (Knudsen, viscous Stokes and transitional regimes). It assumes the comet as initially composed by a homogeneous mixture of water ice, silicatic and organics dust. The dust grains are distributed in different sizes classes, classes each of ones with their physical and thermal properties.

In Tab.1 we report the main physical parameters of our model.

Albedo	0.06	[4]
Dust (Silicates)/Ice	1.5	
Dust (Organics)/Ice	2.0	
Porosity	0.6	
Initial temperature	163	
Emissivity	0.9	[2]

Table 1: Main adopted physical parameters values in SI units.

2. Results

We study the surface and sub-surface layer temperature and also the water flux emission. In particular we focus on facet n°14083 of the shape (V4) as representative of the “neck” region [5] in order to study the sublimation and re-condensation effect. The facet examined experienced a “sudden shadow” during its regular day-night cycle: this introduces an inversion in the temperature profile vs depth as shown by Figs.1 and 2. We examined the case with and without self-heating, both with an ice’s depth of 1 cm beneath the surface. Self-heating (due to the particular shape of the comet) has the effect to increase of about 10 K the temperature. The inversion of the temperature is present in the first layers of the comet and it is more evident after few minutes from the “sudden shadow”. The thermal evolution of each facets is followed for several rotations at heliocentric distance of VIRTIS observations. In particular, we compare these observations with different theoretical curves, characterized by different ice depth and different initial thermal conductivity of the crust (see Fig.3). We focus on the facets n°120538-120542 of the shape (V5).

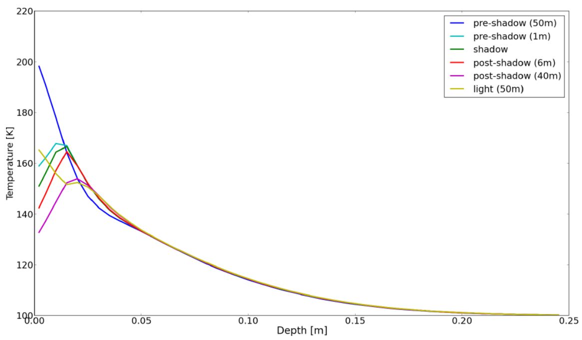

Figure 1: Temperature profile vs depth in case of ice 1cm deep (no self-heating)

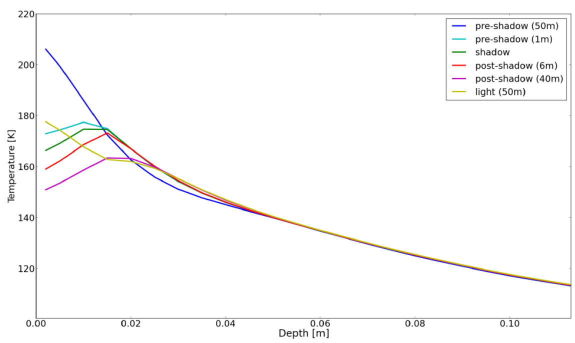

Figure 2: Temperature profile vs depth in case of ice 1cm deep (with self-heating)

3. Summary and Conclusions

Our simulations suggest that short-lived outbursts could be explained by the combined effects of sublimation and re-condensation. Ice that refreezes on subsurface layers due to change of the conditions of illumination on surface, could contribute to the water flux. Self-heating seems to be be required to fit with VIRTIS observations. We also observe that low thermal conductivity values lead to temperature profiles compatible with the observations. Surface roughness could increase the temperature of the comet.

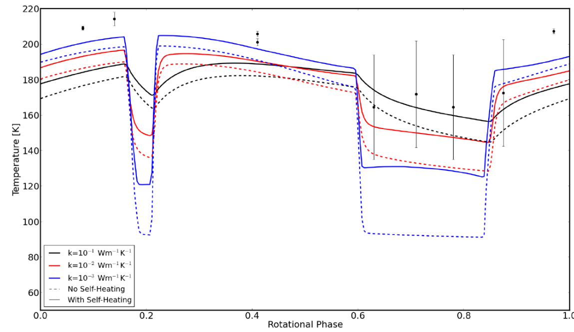

Figure 3: Temperature profile vs rotational phase for different values of thermal conductivity of the crust and with or not the effect of the self-heating. Black dots represent VIRTIS observations.

Acknowledgements

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Observation of Ammonia and Methanol in comet 67P with MIRO onboard Rosetta

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Abstract

The Microwave Instrument on the Rosetta Orbiter (MIRO) [5] makes submillimeter- and millimeter-wavelength observations of the nucleus and coma of the target of the Rosetta mission: comet 67P/Churyumov-Gerasimenko. MIRO is probing both the continuum emission of the nucleus at 0.5 and 1.6 mm wavelength and the gaseous emission via high-resolution spectroscopic measurements of 8 molecular lines in the submillimeter range (H_2O, $H_2^{17}O$, $H_2^{18}O$, CO, NH_3, and three lines of CH_3OH).

Since Rosetta arrived in the vicinity of comet 67P/Churyumov-Gerasimenko in July 2014, MIRO has been observing the coma almost continuously. Water emission at 556.9 GHz has been detected since early June 2014 [6] and the water outgassing of the comet and its spatial distribution has been regularly monitored and mapped [4, 6, 7].

MIRO is also observing the fundamental rotational transition J_K=($1_0 - 0_0$) of ammonia at 572.5 GHz and three lines of methanol: J_K=($3_{-2} - 2_{-1}$E) at 568.6 GHz, ($8_{+1} - 7_0$E) at 553.1 GHz and ($12_{-1} - 11_{-1}$E) at 579.2 GHz. The ammonia line and the lowest energy ($3_{-2} - 2_{-1}$E) methanol line have been detected in absorption against the nucleus of the comet (Fig.1,2) and in emission in the coma since August 2014, when Rosetta was at distances between ≈10 to ≥100 km from the nucleus.

We will present the results of one year of monitoring of the ammonia and methanol emissions. The measured NH_3 and CH_3OH abundances relative to water in comet 67P/Churyumov-Gerasimenko will be compared to remote measurements made in several other comets [1, 2, 3].

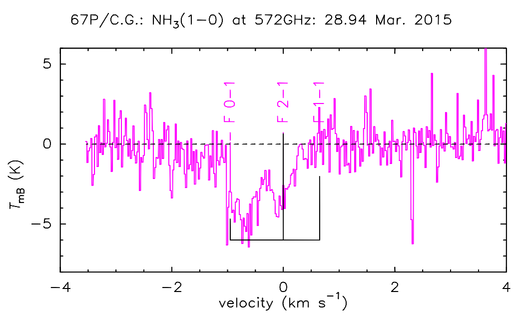

Figure 1: Ammonia detection in absorption against the nucleus of comet 67P on 28 March 2015 with MIRO.

Acknowledgements

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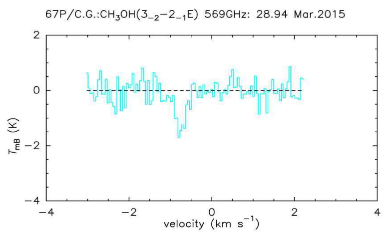

Figure 2: Methanol detection in absorption against the nucleus of comet 67P on 28 March 2015 with MIRO.

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Meter-scale polygons on 67P/Churyumov-Gerasimenko as evidences of near subsurface water ice

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Abstract

Since August 2014, high spatial resolution images of the nucleus of 67P/Churyumov-Gerasimenko have been acquired by the OSIRIS camera on board the Rosetta spacecraft, enabling to identify meter-scale features on the surface. Among them, we identify polygons with a size from 2 to 20 meters. We define the polygons on 67P as high-centered thermal contraction polygons, which further evolve through preferential sublimation along the cracks. This kind of polygons are known on Earth and Mars as evidences of permanent water ice table in the near subsurface [1,2,3].

1. Introduction

Polygons are landforms associated with frozen environment that can be observed on Earth and Mars at high latitudes [1,2]. They formed when the thermal stress of the ground surface exceeds the tensile strength of the frozen ground, forming fractures [3]. This thermal contraction cracking produces episodic fracture expansion, which develops into a polygonal network. This process creates a population of proximal polygons with variable trough depths and sizes from typically a few meters to tens of meters [4].

We present here our detection of putative thermal contraction polygons on the surface of the nucleus of 67P [5], their morphological characteristics (size and shape) and how they are distributed on the nucleus surface.

2. Polygon identification and distribution

Using the morphological criteria defined by [4] and similarities with terrestrial and martian analogs, we identified putative polygons using OSIRIS images with a minimum resolution of 50 cm/px (Fig. 1). Polygons have elevated centers/sloping margins, with a few meters size. These morphologies are typical of sublimation polygons [2,3], which are formed by thermal contraction and evolve by preferential sublimation along the thermal cracks.

We mapped the polygons on the images in order to determine their size distribution, and we located them on the global shape model of the nucleus [6].

3. Results, discussions and conclusions

The global size distribution shows polygons with variable sizes from 2 m to 20 m, with a mean value of 7 m. The size and shape of thermal contraction crack polygons is determined by complex interactions between water ice content, cooling history and other mechanical properties of the soil [3]. Sublimation polygons form in a material that has water ice excess content in the subsurface [3]. [7] use a numerical model related to the martian environment and climate to evaluate the ice content and ice table depth from the polygon size.

In this paper, we will address the following questions:

- Is there a variability of the polygon shape and size depending on their location on the nucleus (e.g., illumination conditions, local inhomogeneities)?

- What is the ice table depth constrained by the observations?

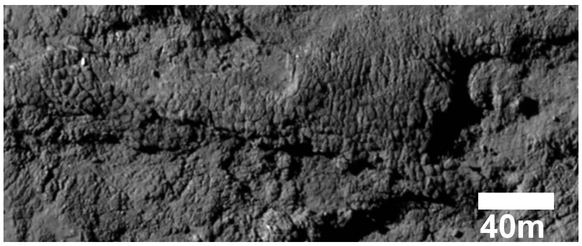

Figure 1: NAC image of the Apis region of 67P showing high-centered polygons [8].

Acknowledgements

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Fractures on comet 67P/Churyumov-Gerasimenko observed by Rosetta/OSIRIS

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Abstract

The OSIRIS experiment onboard the Rosetta spacecraft currently orbiting comet 67P/Churyumov-Gerasimenko has yielded unprecedented views of a comet's nucleus. We present here the first ever observations of meter-scale fractures on the surface of a comet. Some of these fractures form polygonal networks. We present an initial assessment of their morphology, topology, and regional distribution.

1. Introduction

The Rosetta spacecraft was inserted into orbit around comet 67P/Churyumov-Gerasimenko (hereinafter referred to as comet 67P) on Aug 6, 2014. Since then, the comet's nucleus has been extensively imaged and monitored by the Optical, Spectroscopic, and Infrared Remote Imaging System (OSIRIS) [1] at high spatial resolutions reaching ~0.15 m/px. The OSIRIS images have shown the surface of comet 67P to be morphologically complex with several terrain types and numerous intricate features [2,3]. In particular, images of sub-meter resolution, acquired when the spacecraft was orbiting <20 km above the surface have shown that many regions on the comet, especially those composed of consolidated materials [3,4], are fractured forming various patterns. We present these fractures here in detail and give an initial assessment of their morphology, topology and distribution.

2. Fracture settings

Comet 67P has a bi-lobed shape comprising a large lobe connected to a smaller lobe by a short "neck region" [2,3]. A regional assessment of the surface morphology has resulted in the classification of the comet's surface into distinctive regions based on morphological and structural attributes [3,4]. Our initial assessment of the fractures distribution suggests that they are globally present on the surface of the nucleus, particularly in consolidated regions [3], wherever images with high enough spatial resolution are available. These fractures are present in one of four distinctive settings:

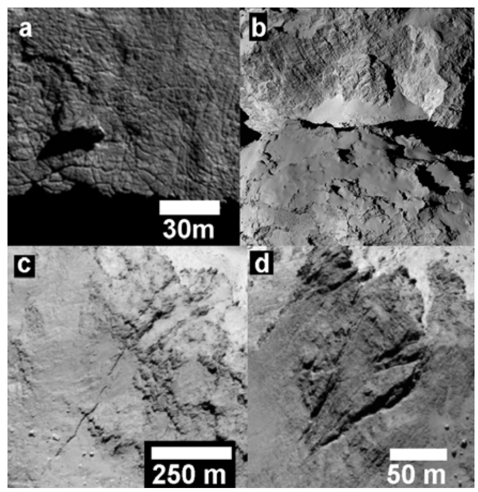

Figure 1. Fractures on the surface of comet 67P. [a] Polygonal patterns in the Apis region. [b] Fractured cliff in the Hathor region. [c] Linear fracture system in the Anuket region close to the neck. [d] The angular fracture system in the Aker region.

2.1. Fracture Networks

This is the most common fracture setting observed on the surface generally on quasi-flat surfaces in variable orientations with respect to the gravitational potential (Fig. 1a). The fractures are generally narrow (sub-meter in width) and resemble mode-I tensile fractures. The fractures create irregular polygonal patterns in many cases. Fractures vary greatly in length from a few meters to ~250 meters in length. Similarly, the angles of intersections of the fractures are variable. However, some locations show orthogonal intersections that are probably indicative of a slowly evolving uniformly stressed system

2.2. Fracture on escarpments

Fractures are similarly observed on the edges of escarpments in a number of regions but are mostly observed in the Seth region in the weakly consolidated units [3,4]. In some locations, the feet of the fracture cliffs are covered by debris deposits, which suggest continuous mass wasting events triggered by the fracturing process

2.3. Fractured boulders

Irregular fractures are observed on a number of large (20–60 m-wide) boulders scattered on the surface of the comet. In some cases, the fractures appear to have pervasively fragmented the boulders, whereas in other cases, they appear to be confined to sharp and polished surfaces, which may represent an erosional sequence where boulders become increasingly fragmented with time.

2.4. Unique/special fracture systems

Apart from the three main fracture settings described above, three unique features are observed on the surface: 1) longitudinal fractures on the cliff of Hathor (Fig. 1b), 2) a ~500 m-long fracture system in the Anuket region (Fig. 1c), and 3) a 200 m-long angular fracture system in the Aker region (Fig. 1d), and. These unique features have already been mentioned briefly in recent publications [e.g., 3].

3. Formation mechanism(s)

The ubiquitous presence of fractures on the surface of the comet's nucleus, in various settings and showing different morphologies suggests numerous formation mechanisms, which include thermal fatigue, orbital-induced stresses (e.g., activity-induced torques or tidal stresses), and possibly seasonal thermal contraction [5]. We plan to present in the meeting a detailed assessment of these mechanisms and their respective roles in creating the observed fractures.

4. Implications

The presence of fractures on a cometary surface is of paramount significance to cometary science and could be a main driver in the surface evolution process and long-term erosion as well as a possible conduit for jet activity [6].

Acknowledgements

OSIRIS was built by a consortium of the Max-Planck-Institut für Sonnensystemforschung, in Göttingen, Germany, CISAS-University of Padova, Italy, the Laboratoire d'Astrophysique de Marseille, France, the Instituto de Astrofísica de Andalucia, CSIC, Granada, Spain, the Research and Scientific Support Department of the European Space Agency, Noordwijk, The Netherlands, the Instituto Nacional de Técnica Aeroespacial, Madrid, Spain, the Universidad Politéchnica de Madrid, Spain, the Department of Physics and Astronomy of Uppsala University, Sweden, and the Institut für Datentechnik und Kommunikationsnetze der Technischen Universität Braunschweig, Germany. The support of the national funding agencies of Germany (DLR), France (CNES), Italy (ASI), Spain (MEC), Sweden (SNSB), and the ESA Technical Directorate is gratefully acknowledged. We thank the ESA teams at ESAC, ESOC and ESTEC for their work in support of the Rosetta mission.

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Geomorphological and Spectrophotometric Study of Philae Landing Site A

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Abstract

On August 6, 2014, the European Space Agency's Rosetta spacecraft started orbiting the Jupiter family comet 67P/Churyumov-Gerasimenko (hereafter 67P). Afterwards, the OSIRIS instrument (Optical, Spectroscopic and Infrared Remote Imaging System [1]), got the highest-resolution-ever images of a cometary nucleus, reaching the unprecedented scale of 50 cm/px. A brief description of OSIRIS early analysis on the nucleus structure and activity of 67P is available in [2]. Despite its small dimensions, ∼4 km diameter, 67P shows a morphological diversity that is still puzzling the cometary community: boulders [3], high-reflectivity particle clusters [4], local fracturing [5], pits [6], as well as dust covered terrains [7], are only few examples that can be found on 67P.

Since the Rosetta arrival, an extremely detailed analysis of 67P surface has been performed to select five different landing sites candidates for the lander Philae. By using the OSIRIS images the comet shape model [8] has been produced to study the slope constraints, as well as the identification and measurements of boulders and production of hazard maps of the landing spots [3]. A final landing site, called Agilkia and located on the smaller lobe of the comet, was announced on October 15, 2014. Here, Philae, on November 12, 2014, made its historic comet touchdown [9].

Despite its unique scientific potential, one of the five finalists, called "site A", was avoided due to higher risks with respect to Agilkia, during both the landing phase and the surface operations. This area is located on the bigger lobe of the comet, on the Seth region [10] facing the Hathor cliff. Site A (Fig. 1) is close to the 'neck' region, i.e. the connecting bridge between the two lobes, where the main dust jet activity has been observed since the Rosetta arrival. This area is the biggest terrace of Seth region, delimited in the upper part by a steep wall showing multiple niches, strata heads and smaller terraces. Moreover, between the 5 finalists, this site has the unique value to provide detailed analysis of the multiple fractures present on its cliff and on the neighboring Hathor.

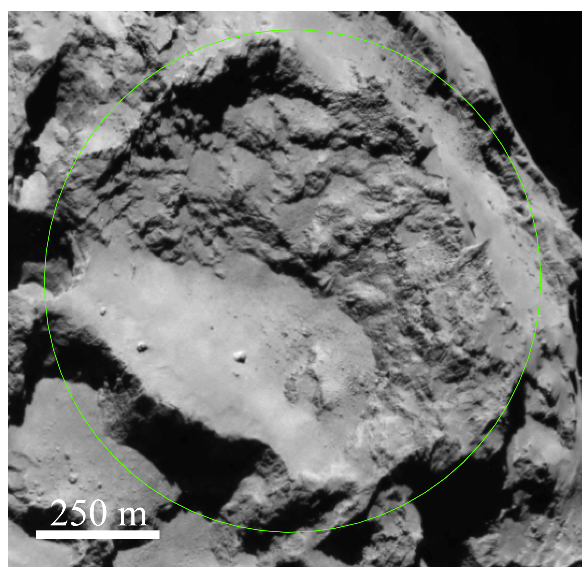

Figure 1: Site A as imaged by the OSIRIS NAC camera on 6 August 2014 at 02:20:12 UT. The distance from the comet center is 117.24 km, the scale is 2.17 m/px.

We here present the geomorphological map coupled with the size-frequency distributions of boulders $\geq$ 2 m located on the different types of terrains here identified, such as outcropping layered terrains, gravitational accumulation deposits, taluses and fine particle deposits. Gravitational slopes, derived through the 67P shape model by assuming uniform density, have been used to characterize and better interpret the various terrains. Moreover, we show the spectrophotometric properties of the area, studied through images taken by OSIRIS NAC with a scale of 50 cm/px. Albedo maps, as well as surface reflectance spectra have been obtained by taking advantage of the shape model and DTM in order to correct for the illumination and observing conditions of the terrain. This multidisciplinary analysis highlights that different types of deposits show different photometric properties.

Acknowledgments

OSIRIS was built by a consortium of the Max-Planck-Institut für Sonnensystemforschung, in Göttingen, Germany, CISAS-University of Padova, Italy, the Laboratoire d'Astrophysique de Marseille, France, the Instituto de Astrofisica de Andalucia, CSIC, Granada, Spain, the Research and Scientific Support Department of the European Space Agency, Noordwijk, The Netherlands, the Instituto Nacional de Tecnica Aeroespacial, Madrid, Spain, the Universidad Politechnica de Madrid, Spain, the Department of Physics and Astronomy of Uppsala University, Sweden, and the Institut für Datentechnik und Kommunikationsnetze der Technischen Universität Braunschweig, Germany. The support of the national funding agencies of Germany (DLR), Italy (ASI), France (CNES), Spain (MEC), Sweden (SNSB), and the ESA Technical Directorate is gratefully acknowledged. We thank the ESA teams at ESAC, ESOC and ESTEC for their work in support of the Rosetta mission.

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Understanding Rosetta's measurements through laboratory experiments

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Abstract

The Rosetta spacecraft the Philae lander provide an unprecedented opportunity to follow the evolution of surface and the growing activity of the comet 67P/Churyumov-Gerasimenko. In this study we will present an explanation of the observed surface features on the comet nucleus, as derived from our laboratory experimental results, such as gas/water ratios, surface features as craters, boulders, active areas and smooth terrains, due to ice sublimation and evolution of gases from the interior of the nucleus.

1. Introduction

Our experimental studies on "cometary" gas laden amorphous ice can explain the direct measurements of the Rosetta spacecraft the Philae lander. The ice grains are ejected together with gas jets from the ice, forming on the surface craters and smooth areas as found in the direct observations. Our experimental results on the gas/water ratios, density, thermal conductivity and mechanical strength are similar with the in situ results of comet 67P/ C-G.

1.1 Surface of the nucleus

The surface of the comet shows complex active processes such as craters, boulders, smooth areas.

In our experiments, upon heating from above, two types of ices were observed with different properties: on the surface -smooth water ice layers – compacted and denser and gas laden ices - very porous.

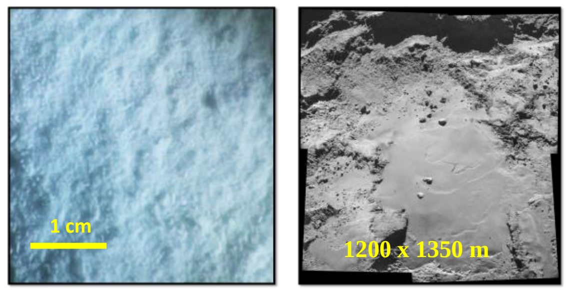

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Figure 1: Ejected ice grains cover the surface forming smooth areas as observed in different regions of the comet [1].

1.2 Cometary Activity

Most of the activity of the nucleus of the comet 67P is coming out from the transition region between the small and the large lobe, where, emanating jets and craters were observed [2]. From our experiments, jets are formed when an underneath pocket of gas explode carrying with it water vapor and ice grains, forming on the surface of the ice holes (craters) and cracks. The micron size distribution fit the Rosetta's direct observation [3].

2. Summary and Conclusions

Our experiment fit the direct observations on the comet 67P/Churyumov-Gerasimenko and the results from pervious missions to different comets. These results can explain also direct observations of the activity of distant comets [4].

Acknowledgements

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Rosetta Science Tracking

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Abstract

In this work, we are presenting an overview over the scientific goals of the Rosetta mission[1] and provide a summary of the completed, on-going and still open objectives in a comprehensive format that outlines the scientific achievements of one of the most ambitious space missions to date.

1. Introduction

Since the wake-up in January 2015, the Rosetta Spacecraft has been following the scientific objectives of its primary mission. Among them are spectacular scientific 'firsts', such as acquiring data from the surface of a cometary nucleus and, for an extended time, monitor the onset of activity and evolution of the cometary activity. But also many smaller and more specialized goals are being pursued by the instrument suites on the landing (Philae) and orbiter (Rosetta) units. By performing diverse measurements, Rosetta is collecting a large number of puzzle pieces that may help to uncover the secrets of cometary formation and evolution , as well as to provide new insights into the history of the solar system as a whole.

By tracking the progress of each of the many different science goals, we build a map of knowledge about the Comet 67/P from the science performed in the primary mission phase of Rosetta and are able to identify any gaps that can or need to be filled during a possible mission extension.

2. How Rosetta science progress is followed

The basis on which we are tracking the progress of Rosetta science is a compilation of the individual science goals, which is maintained in the Rosetta "Master Science Plan". This document identifies unique and ongoing measurement objectives, sorted into scientific focal points, called Discipline groups (DG). The four areas into which the science goals are sorted are:

DG1 = Nucleus composition and properties

DG2 = Coma composition and properties

DG3 = Interrelation between refractory and volatiles

DG4 = Cometary activity and evolution

We collect information on the qualitative and (where applicable) quantitative progress with respect to each science goal per discipline group and then identify for which objectives the mission has collected sufficient or insufficient amount and/or quality of data.

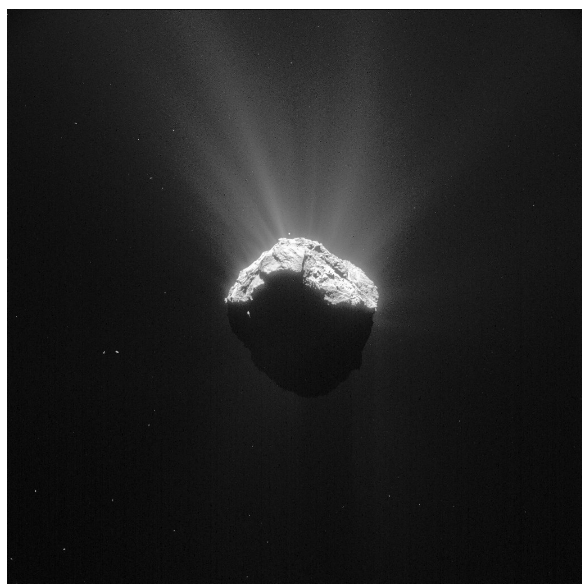

Figure 1: NAVCAM image from April 15.

3. Summary and Conclusions

Tracking the progress of all science goals allows for a comprehensive overview of the achievements of the mission, as well as help identifying in which areas Rosetta needs to enhance data acquisition. The results of the tracking are then fed back into the planning process, allowing to fill potential observational gaps and help to safeguard against scientific objectives not being fulfilled before the end of the mission.

Acknowledgements

This work has been performed in support of the Rosetta Science Working Team. Special thanks go to the many hard working and motivated Scientists and Engineers from the Instrument teams and the Ground Support whose tireless efforts for planning the many demanding instrument operations are the foundation for the success of the Rosetta mission.

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Comet 67P/Churyumov-Gerasimenko: structure of the sub-surface layer

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Abstract

From the operation of the MUPUS thermal probe [1] concluded that the material of the nucleus of 67P/Churyumov–Gerasimenko at the Philae landing site is likely to have a high crushing strength of >4 MPa and a compressive strength of >2 Mps. In this work we consider the derived strength of the material in order to constrain its granulation. For this purpose we performed numerical simulations of the long–term sintering of ice–dust granular mixtures of different granulation, covered by a dust mantle. The dust mantle has a thickness of 0 - 16 cm, and a (pore size and temperature-dependent) thermal conductivity. According to our simulations a hardened layer at least a meter thick forms beneath the dust only when the grains are tens of microns in radius, or smaller. See also [2].

1. Introduction

Comet 67P/Churyumov-Gerasimenko has a long orbital history. We focus our attention on the time span between the last major change of orbit in 1959, when the heliocentric distance at perihelion decreased from more than 3 AU to 1.29 AU, and the 2015 perihelion (8.5 orbital periods) [3]. In this time frame the orbital elements, and orientation of the rotation axis in space, are roughly constant.

Calculations are performed for selected locations on the nucleus, including likely Philae landing region. The physical structure of the surface at Philae's final landing site is currently not known, neither is the exact orientation of Philae. For simplicity, we therefore assume the surface to be horizontal and smooth in this work. If the surface investigated by MUPUS is significantly inclined, and shadowed most of the day, the material should sinter slower than indicated by the presented simulations. Thus, when our simulations predict negligible sintering, the real process should happen even slower.

In our model, the uppermost layer of the nucleus is composed of dust only. It is called the dust mantle. Deeper is a mixture of crystalline H_2O grains and dust. The material underneath the dust is composed either of ice grains with dust cores, or of agglomerates of grains.

The dust grains do not sinter. In the material underneath the dust mantle, the sintering process leads to a depth dependence of the hardness. The rate of sintering of ice grains depends on their sizes. Small ice gains sinter much faster than large ones. Thus, individual ice particles may sinter to form agglomerates much faster than the agglomerates can clump together through sintering. The rate of sintering is significantly depends on the local temperature. Hence, the presence of a thick dust mantle of low thermal conductivity should have significant influence.

The average tensile strength is proportional to the volume fraction of the material, which is (1 - porosity ψ) and the ratio between the grain-to-grain contact areas and the cross sections of the grains, described by the Hertz–factor h.

2. Results

In the figure below we show the thickening of the hardened sub–dust layer for a dust mantle that is 4 cm thick. The hardened layer is considered as the layer where the hertz factor exceeds a threshold value h_{th}, which is 0.33 i.e. approximately the limit of efficiency of the sintering mechanism dominating under considered conditions. The location is at the latitude 15°N. Plotted is the thickness of this hardened layer versus time for cases in which: the grain radius r_g is 1.5 μm, and 15 μm; the radius of pores in the dust layer r_d is 3 μm and 30 μm; the initial Hertz factor h_0 is 0.001 and 0.01; and the initial temperature is 80 K and 40 K. When the material is fine–grained and unconsolidated, the hardened layer thickens to 5 meters within just 2 - 3 orbital periods, depending on the initial tem-

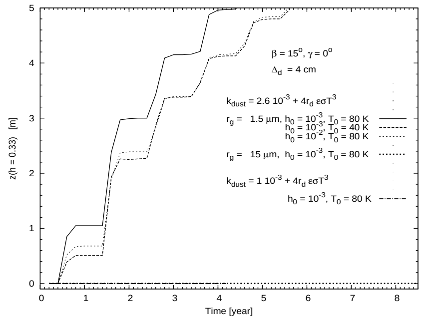

Figure 1:

perature. When the radii of grains and pores are ten times larger, or the initial Hertz factor is hundred times higher, the sintered layer grows only to 2 m thickness during the considered period. When $r_g = 15$ μm, $h_0 = 0.001$ and $k_{dust} = 2.6 \times 10^{-3} + 4r_d\epsilon\sigma T^3$, the layer of $h > 0.33$ does not form in the considered period. When $r_g = 150$ μm, and $k_{dust} = 2.6 \times 10^{-3} + 4r_d\epsilon\sigma T^3$, the Hertz factor increases only to 0.14.

3. Summary and Conclusions

The performed numerical simulations of the long–term sintering of ice–dust granular mixtures of different granulation indicate, that in the Philae landing site a hardened layer at least a meter thick forms beneath the dust. This hardening can only be observed in the models when the ice grains are smaller than a few tens of microns in radius.

Acknowledgments

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Evolution of Cometary Activity at 67P/Churyumov-Gerasimenko as seen by ROSINA/Rosetta

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Abstract

Since nine months the European Space Agency's spacecraft Rosetta, with the Rosetta Orbiter Spectrometer for Ion and Neutral Analysis (ROSINA) onboard, is in the comet escort phase. ROSINA is a suite of three instruments, consisting of the COmetary Pressure Sensor (COPS), the Double Focusing Mass Spectrometer (DFMS), and the Reflectron-type Time-Of-Flight (RTOF) mass spectrometer [1]. The two mass spectrometers measure in situ the neutral and ionized volatile material in the coma of comet 67P/Churyumov-Gerasimenko (67P/C-G). With COPS we are able to derive the total gas density, bulk velocities and temperatures of the coma.

1. ROSINA Characteristics

Due to the high sensitivities of DFMS and RTOF, measurements of very low particle densities are possible. The two mass spectrometers have high dynamic ranges and complement each other with a large mass range (RTOF) and with high mass resolution (DFMS). The results of both of them will allow us to detect heavy organic molecules as well as isotopic ratios of the main cometary species. Synchronized measurements of cometary neutrals with one mass spectrometer and cometary ions with the other mass spectrometer are also possible.

2. Measurements and Results

In this work, we will present the latest ROSINA measurements, i.e. the time from April through September 2015. From mid-May on, the southern hemisphere of comet 67P/C-G starts to become more illuminated by the Sun than the northern hemisphere. We will discuss the evolution in the activity especially from the southern hemisphere and compare these results with our measurements of the northern hemisphere.

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Mass loading of the solar wind near comet 67P at low activity

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Abstract

Analyzing data from the ion sensor RPC-ICA flying on the european spacecraft Rosetta, we study the dynamics of the interaction between the solar wind ions and a partially ionized atmosphere around a comet, further than 2 AU away from the Sun. We give a close picture of this interaction with a first case study, to then consider the whole low activity period through a statistical study, and characterize the time evolution of this dynamics.

1. Overview

The Rosetta mission reached comet 67P/Churyumov-Gerasimenko early August 2014, at a distance of 3.65AU to the Sun as 67P was heading to its perihelion. Data presented here are collected between 3.65 to 2 AU by the Rosetta Plasma Consortium Ion Composition Analyser (RPC-ICA) [2], when the comet was still presenting a low activity case. The atmosphere of 67P at low activity is permeated by the solar wind, the plasma boundaries (bow shock, ionopause) of larger objects such as planet ionosphere are not yet observed. As long as such structures are not formed, mass loading remains the main mechanism through which the comet atmosphere affects the solar wind [4] (Figure 1).

2. Case study

Using data from the 28th of November 2014, we go into details in this dynamics, on a short time scale ($10h$, $192s$ resolution) [1]. We compare flow directions from solar wind and cometary accelerated water ions, and local magnetic field direction, and diagnose the different correlations between those directions. We find that solar wind ion deflection and water ion acceleration is controlled by the convective electric field as expected for mass loading. The solar wind is deflected as depicted in Fig. 1, not flowing around the obstacle. The two flow components orthogonal to the sun line are opposing each other. A surprise is that the accelerated water ions have a dominating component of their flow velocity in the anti-sunward direction: the flow is directed very close to the sun line.

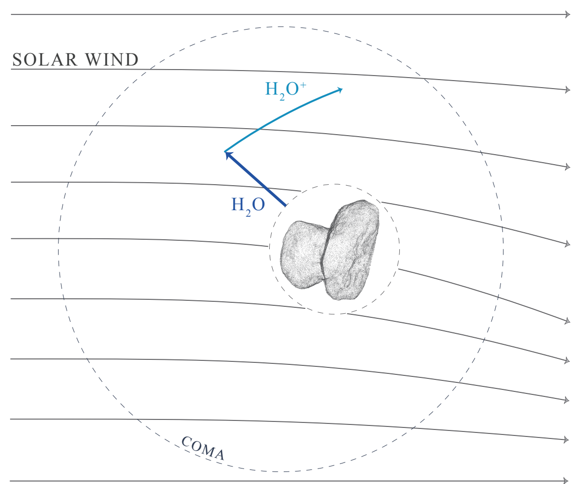

Figure 1: Illustration of the simplified interaction involving mass-loading .

Observations for this case study are made on a $30km$ terminator orbit, at $2.88AU$ away from the sun.

3 Statistical study

We produce statistics about the same interaction over a period of low activity, starting beginning of August 2014. We compute the deflection angle and the energy for solar wind protons and alpha particles, and study the influence of the plasma environment (ion densities, magnetic field amplitude).

Acknowledgements

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this study would be impossible. Sharing data within RPC is made possible by the web-based interface AMDA, developed and made available for RPC use by Centre de Donnees de la Physique des Plasmas (CDPP). This easy and efficient interface has been of a great use for this work.

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Evolution of the ion environment of comet 67P

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Abstract

The Rosetta mission has been designed to rendezvous with and escort comet 67P/Churyumov-Gerasimenko from a heliocentric distance of 3.6 AU, when the comet still has a low activity level, until perihelion passage at 1.25 AU where the comet reaches the maximum of its activity. During the initial low activity stage the solar wind permeates the thin comet atmosphere that has just begun to form from sublimation. Eventually the size and plasma pressure of the ionized atmosphere leads to the formation of plasma boundaries: a magnetosphere is born. Using the Rosetta Plasma Consortium Ion Composition Analyzer, we study the gradual evolution of the comet ion environment as the comet activity increases. Mass loading caused by picked-up comet ions deflect the solar wind. Charge exchange between the solar wind and comet atmosphere gradually increases with comet activity, leading to a situation where a significant fraction of the solar wind has charge-exchanged close to the comet nucleus. Pick up ions created upstream of the comet nucleus are accelerated by the solar wind electric field and are seen with energies up to a few keV as they move back towards the nucleus. Locally produced water ions are seen moving with velocities similar to the neutral outgassing velocity of the order of 1 km/s (10 eV), but with their direction and speed influenced by the solar wind electric field. High charge state solar wind ions (O^{6+}, O^{5+}) are also seen at times. We quantify the ion environment near a low activity comet and show how it depends on the solar wind intensity and the distance to the sun.

1. Introduction

Rosetta is the first mission to visit and follow a low activity comet (Glassmeier et al., 2007). Rosetta carries a plasma instrument suite, the Rosetta Plasma Consortium (RPC, Carr et al. (2007)). We use data from the mass resolving ion spectrometer RPC-ICA (Nilsson et al., 2007). The initial measurements obtained using the RPC-ICA showed the first presence of water ions at a distance of about 100 km from the nucleus, while the comet was at 3.6 AU from the Sun (Nilsson et al., 2015a). These initially observed ions were picked up by the solar wind electric field and moved perpendicular to the solar wind flow. As the spacecraft approached the comet and the comet approached the sun, a significant deflection of the solar wind could be seen, up to about 45° from the anti-sunward direction. It was also shown that the alpha particles of the solar wind were less deflected than the protons (Nilsson et al., 2015a). Single charged helium, He^+ was also observed, resulting from charge exchange between the solar wind He^{2+} and the comet atmosphere. Intermittently accelerated water ions with an energy up to 800 eV were seen coming from the upstream direction.

2. An evolving environment

Observations using RPC-IES data (Burch et al., 2007) confirm the initial picture of the early pick up ion process (Goldstein et al., 2015) as reported in Nilsson et al. (2015a). They could also show how the low energy ion environment is modulated by the comet rotation. Details of the mass loading process have later been studied in more detail (Broiles et al., 2015; Behar et al., 2015).

A description of the evolution of the ion environment around comet 67P from 3.6 to 2.0 AU has been reported by Nilsson et al. (2015b). They show how the water ion flux can typically be divided into a cold population where the neutral gas velocity still has a significant influence on the flow velocity, and an accelerated water ion population coming from the upstream direction. The accelerated water ion population increased by 2 to 4 orders of magnitude from 3.6 AU to 2.0 AU heliocentric distance. Simultaneously the solar wind was deflected and gradually showed more variability and possibly heating. At 2.0 AU heliocentric distance there was still no observation of the formation of any plasma boundaries such as a bow shock or ionopause. The accelerated water ion flux at 2.0 AU sometimes equals that of the solar wind. The cold water ions by far dominate the local plasma density.

3. Conclusions

The solar wind interaction with comet 67P is constantly evolving as the comet activity increases. In the initial phase we can study the effect of mass-loading of the solar wind and the details of solar wind - atmosphere interaction on spatial scales much below a comet pick-up ion gyroradius.

Acknowledgements

Rosetta is a European Space Agency (ESA) mission with contributions from its member states and the National Aeronautics and Space Administration (NASA). Rosetta's Philae lander is provided by a consortium led by DLR, MPS, CNES and ASI. The work on RPC-ICA was funded by the Swedish National Space Board under contracts 108/12 and 112/13.

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Water and carbon dioxide sources on comet 67P nucleus as measured from the VIRTIS-H instrument aboard Rosetta

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Abstract

Using the high spectral-resolution channel of the Visible InfraRed Thermal Imaging Spectrometer (VIRTIS-H) onboard Rosetta, we observed the ν_3 vibrational bands of H_2O and CO_2 at 2.67 and 4.27 µm in comet 67P/Churyumov-Gerasimenko [1]. Observations were undertaken in limb viewing geometry with various line-of-sight (LOS) orientations in the body-fixed frame. A geometry tool is used to characterize the position of the LOS with respect to geomorphologic regions [6] and the illumination properties of these regions. We will present the heliocentric evolution, diurnal variations and distribution of H_2O and CO_2 production. Inhomogeneities in the CO_2/H_2O relative production rates will be discussed.

1. Introduction

Since July 2014, the Visual IR Thermal Imaging Spectrometer (VIRTIS) onboard the ESA's Rosetta spacecraft has intensively observed comet 67P/Churyumov-Gerasimenko. First results were published in [2]. VIRTIS is composed of two channels, –M for mapping and –H for high resolution, working in the 0.25-5 µm and 2-5 µm wavelength domains, respectively [4]. In addition to nucleus mapping observations, limb observations were carried out to obtain spectra of the coma, and to detect fluorescence emissions of gas phase species. The ν_3 vibrational bands of H_2O and CO_2 at 2.67 and 4.27 µm, respectively, were detected in mid-October 2014 using VIRTIS-H, and observed regularly since then [1] including from VIRTIS-M [3].

Outgassing from cometary nuclei involves complex surface and subsurface processes that depend on the physicochemical properties of the cometary material and ice structure, as well as on current and past illumination conditions. Because they are important constituents of cometary ices, water and carbon dioxide are key species to understand cometary activity. In addition, their different volatility allows us to investigate both surface and subsurface outgassing.

2. Results at 2.5-2.9 AU from the Sun

Samples of VIRTIS-H spectra of the H_2O and CO_2 bands are shown in Figs 1 and 2.

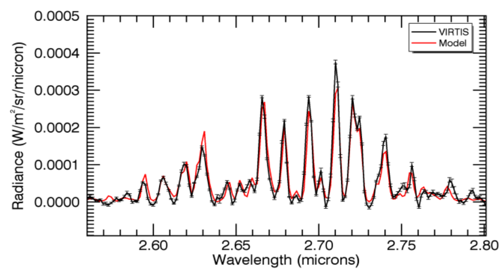

Figure 1: VIRTIS-H spectrum of the 2.7 µm band of water. Data from 4 December 2014 to 24 January 2015. In red, a fluorescence spectrum for a rotational temperature of 102 K (from [1]).

Data obtained in the time frame October 2014 - January 2015 led to the following conclusions [1]:

- Water and CO_2 productions did not evolve much from 2.9 to 2.5 AU during this period.

- High water column densities are observed for LOS above neck regions, suggesting they are the most productive in water vapour.

- Whereas water production is weak from regions with low solar illumination, CO_2 is outgassing from both illuminated and non-illuminated regions at about the same rate, which indicates that CO_2 sublimates at a depth that is below the diurnal skin depth.

- The CO_2/H_2O column density ratio varies in the range 2% to 30%. For regions into sunlight, mean values between 3 and 6% are measured, with the lowest value for regions Seth and Anuket situated in the most central parts of the body and head of the comet, respectively. The lower bound value is likely representative of the CO_2/H_2O production rate ratio from the neck regions.

- An illumination driven model, with an homogeneous surface releasing water, provides an overall agreement to VIRTIS-H data, though some mismatches, especially on the neck, are witnessing the presence of local surface inhomogeneities in water production [5].

- Rotational temperatures of 90-100 K are derived from H_2O and CO_2 averaged spectra

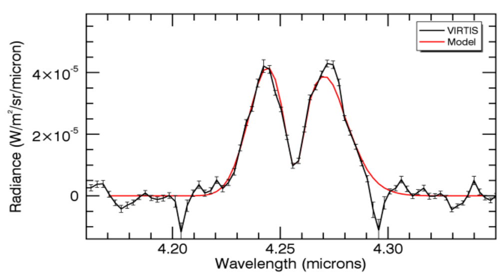

Figure 2 : VIRTIS-H spectrum of CO_2. Data from 4 December 2014 to 24 January 2015. In red, a fluorescence spectrum with a rotational temperature of 90 K (from [1]).

2. Prospects

As the comet approaches the Sun, signals are becoming stronger, allowing us to examine with fine details the outgassing of active regions and diurnal variations. We will also be able to monitor the changes of their production rates globally as 67P/C-G approaches perihelion and for different regions, in particular the southern hemisphere as it is progressively illuminated, thus providing important information to understand the source of the volatile molecules inside the nucleus and potentially retrieve their initial composition and possibly spatial heterogeneity. At the time of writing this abstract, the data have not been acquired.

Acknowledgements

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GIADA characterises 67P/Churyumov-Gerasimenko Dust Environment

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Abstract

GIADA (Grain Impact Analyzer and Dust Accumulator) flying on-board Rosetta is devoted to study the cometary dust environment of 67P/Churiumov-Gerasimenko (hereafter 67P). GIADA is composed of 3 sub-systems: the GDS (Grain Detection System), based on grain detection through light scattering; an IS (Impact Sensor), giving momentum measurement detecting the impact on a sensed plate connected with 5 piezoelectric sensors; the MBS (MicroBalances System), constituted of 5 Quartz Crystal Microbalances (QCMs), giving cumulative deposited dust mass by measuring the variations of the sensors' frequency [1]. The combination of the measurements performed by these 3 subsystems provides: the number, the mass, the momentum and the velocity distribution of dust particlesemitted from the cometary nucleus. No prior in situ dust dynamical measurements at these close distances from the nucleus and starting from such large heliocentric distances are available up to date.

1. Results

We report on the dust spatial distribution in the 67P coma as well as its dynamical and physical properties with the final goal of studying the ejection process and the dust environment evolution. GIADA could disentangle two different types of particles in the 67P coma: compact particles [2] and fluffy porous aggregates of grains of about 0.1 micron in size.[3]. The detections of the first type of particles are mainly concentrated within at latitudes and longitudes such that the spacecraft was in view of the 'neck' of 67P. We registered an increase of the compact particles from 3.36 to 2.43 AU heliocentric distances. The speed of these particles, having masses ranging from 1x10^{-10} to 3.9 x 10^{-7} kg, resulted to vary from 0.3 to 12.2 m s^{-1}. Measuring the particles velocity distribution allowed us to constrain the acceleration region to distances from the nucleus > 30 km. The dynamics of the fluffy aggregates, whose detection is not localized as for the compact particles, is found to be biased by electrostatic interactions with the spacecraft. The electrostatic interaction results in the fragmentation and deceleration of the fluffy aggregates that have speeds < 1 m s^{-1}, i.e. much lower than the compact ones.

The density of the two types of particles was constrained [2,3]. The influence of solar radiation pressure on the nanogram particle fluxes was studied. The results confirm a strong anisotropy in the dust flux: the integrated flux of nanogram particles coming from the Sun direction is about 3 times larger than the flux coming directly from the comet nucleus. The integrated flux of nanogram particles coming from the Sun direction (particles reflected back by the solar radiation pressure), is larger than the flux coming directly from the nucleus. We estimated the ratio of these dust fluxes, sub-solar areas versus terminator areas. taking into account the different flight time of reflected versus direct particles. Since the received dust flux scales accordingly to the square of the dust flight time, we conclude that terminator areas eject a flux of nanogram dust a factor < 15% than the nucleus areas characterized by a sun-zenith angle < 50○.

2. Discussion

Comet 67P showed a quite localized gas activity especially when studying the water vapour emission in the view of the neck region [4,5]. These findings seem to be somehow related with what we find for compact particles emission. Fluffy low density aggregates are highly dispersed over the longitude/latitude map of detections. This could suggest that the emission mechanism for these particles could be different from the emission mechanism of the compact particles. An over-simplified interpretation would lead to a connection between the fluffy aggregates and the CO2 emission. The data show quite a strong dependence of compact particle velocity as a function of particle mass as $v \propto m^{-0.29}$. However, in [2] this was not the case. This could be either connected to the different heliocentric distance at which these measurements were performed, [2] referred to very far (3.4-3.7 AU) heliocentric distances, or to the quite large distance of the spacecraft, i.e. the distance of detected dust particles, from the comet nucleus.

3. Conclusion and Future work

GIADA was able to characterise the coma dust environment of an awakening comet describing the dust spatial distribution and measuring speed and mass of individual particles, for the first time in cometary space exploration. GIADA is continuing monitoring the dust environment while 67P is increasing its activity approaching the perihelion (August 2015). GIADA will improve the dust dynamic characterization and reevaluate the dust to gas ratio determined at high heliocentric distances (from 3.6 to 3.4 AU) [2].

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Spectral modeling in the VNIR range of 67P/Churyumov-Gerasimenko nucleus from VIRTIS-M onboard Rosetta

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Abstract

Topic of this work is the analysis of the surface composition of comet 67P/Churyumov-Gerasimenko using the data obtained by the VIRTIS instrument [1] onboard the Rosetta spacecraft. We have focused on the VNIR spectral range (0.4 - 2.5 µm) which presents a nearly flat spectrum with quite uniform spectral slopes across the entire comet surface. In this work we report about the spectral modeling of CG VIS-IR spectra by means of Hapke's radiative transfer model.

1. Introduction

VIRTIS (Visible, InfraRed and Thermal Imaging Spectrometer) performs high spectral and spatial resolution observations in the VIS (0.25 - 1.0 µm) and IR (1.0 - 5.1 µm) spectral ranges.

The spectra of the comet 67P/Churyumov-Gerasimenko display a red slope over the range 0.5 to 0.8 µm with a coefficient of 5 to 25% kÅ^{-1}. The spectrum shows a change of the slope at ~1.0 µm and displays a more neutral (1.5 to 5% kÅ^{-1}) spectral slope in the range 1.0 to 2.0 µm [2]. The identification of the plausible compounds from these spectra is quite challenging due to the lack of specific absorption features. For this reason we consider the presence of dark refractory materials (like Fe-bearing opaque – sulfides - minerals) which give rise to the very low reflectance observed and have neutral spectra. In addition, plausible components of the complex mixture making up the surface of 67P are the Insoluble Organic Matter (IOM) found in carbonaceous chondrites [3] which display neutral and very dark spectra in the studied spectral region. Furthermore, macromolecular organic solids also contribute to the spectrum as evidenced by the broad absorption band at 2.9 – 3.4 µm [2]. However, none of the typical features of the spectra of the abovementioned compounds are compatible with the spectra of 67P (Fig.1), indicating that a complex mixture is required for reproducing the spectra of the nucleus surface.

Our analysis is performed using the above mentioned compounds as end-members and modeling (intimate as well areal) mixtures taking into consideration also variable grain sizes.

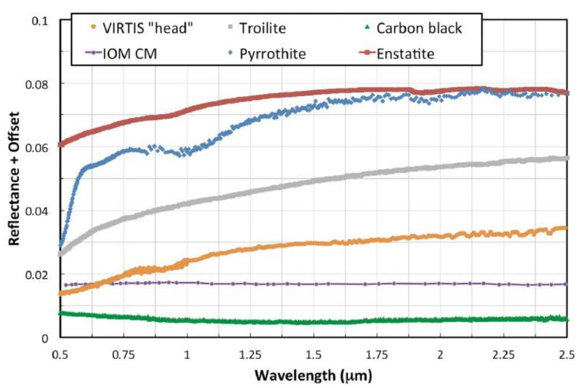

Fig. 1. The spectrum of 67P (yellow), from the "Head" region, in the spectral range 0.5 to 2.5 µm is compared to the spectra of several other compounds. The Murchison IOM is from [3], enstatite spectrum from [4], troilite and carbon black spectra from [5], and pyrrothite spectrum from [6]. For further details see [2].

2. Method

In order to model the measured spectra we have taken into account the Hapke radiative transfer model [7] which allows to infer the composition, the abundances of the end-members and the grain size.

Calibrated spectra are cleaned from spikes and artefacts are removed. The best fit is obtained with a least square optimization algorithm, which can account for multiple end-members, each one characterized by its own optical constants. The latter are mostly obtained by applying the methodology described in [8] to IR spectra reflectance obtained from the RELAB database.

The poissonian noise is calculated by taking into account the total raw signal in photoelectrons. Then the resulting error bars of the reflectance spectra are used to weight the different parts of the spectra during the fitting procedure. For further details on the method see [9].

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'études spatiales et d'instrumentation en astrophysique of the Observatoire de Paris, France, and the Institut für 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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EPSC Abstracts
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On the formation temperature of comet 67P/Churyumov-Gerasimenko

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Abstract

Grand Canonical Monte Carlo simulations are used to reproduce the N_2/CO ratio ranging between 1.7 x 10^{-3} and 1.6 x 10^{-2} observed in situ in the Jupiter family comet 67P/Churyumov-Gerasimenko (67P) by the ROSINA mass spectrometer aboard the Rosetta spacecraft, assuming that this body has been agglomerated from clathrates in the protosolar nebula (PSN). Simulations are done using interatomic potentials for investigating the temperature dependence of the trapping within a multiple-guest clathrate formed from a gas mixture of CO and N_2 in proportions corresponding to those expected for the PSN. By assuming that 67P agglomerated from clathrates, our calculations suggest the cometary grains must have been formed at temperatures ranging between ~31.8 and 69.9 K in the PSN to match the N2/CO ratio measured by the ROSINA mass spectrometer.

1. Introduction

The important deficiency of clathrate equilibrium data at low temperatures implies the use of theoretical approaches to characterize the clathrates. However, the usual thermodynamic approaches such as the usual van der Waals & Platteeuw method are based on simplified intermolecular potentials calibrated on equilibrium measurements performed at higher temperatures. As a consequence, the capabilities of these simple potentials for predicting the composition of clathrates in the outer Solar System could be questionable.
In this work, we aim to reproduce the N_2/CO ratio ranging between 1.7×10^{-3} and 1.6×10^{-2} observed in situ in the Jupiter-family comet 67P by the ROSINA mass spectrometer on board the Rosetta spacecraft [1]. By assuming that 67P has been agglomerated from clathrates, it is possible to derive the temperature range of formation of these crystalline structures in the PSN by means of Grand Canonical Monte Carlo (GCMC) simulations based on elaborated interatomic potentials. These potentials allowed us to investigate the temperature dependence of the trapping within a multiple-guest clathrate formed from a gaseous mixture of CO and N_2 in proportions corresponding to those expected for the PSN.

2. Modeling approach

We assume multiple guest (MG) clathrate formation from a gaseous mixture composed of N_2 and CO with respective mole fractions of 0.129 and 0.871, which correspond in proportions to a plausible protosolar gas phase composition [2].
The MG clathrate composition has been computed along its equilibrium pressure curve, which is in the range of ~5.2×10^{-10}–2.9×10^{-3} bar range when T is varied between ~52 and 100 K, respectively. We have calculated the composition of N_2–CO clathrates via Grand Canonical Monte-carlo (GCMC) simulations for temperatures in the 52–100 K range. All our calculations have been performed in the case of Structure I (SI) clathrates. This choice has been motivated by the fact that CO is the dominating species in the gaseous mixture and is known to form Structure I single guest clathrate [3].
In our system, the considered crystal size consists in 125 cubic unit cells (5×5×5), corresponding to 5,750 water molecules. The dimension of one parameter of the cubic simulation box is set equal to 60.15 Å. Periodic boundary conditions are applied to mimic infinite crystal. The water molecules are modeled using the TIP4P/2005 model [4], allowing them to translate and rotate during the simulation. Models for N_2 and CO molecules are taken from [5] and [6], respectively. One hundred million MC steps were performed including insertion, deletion, translation and rotation of the molecules. Only the last 50 million steps were used to compute the data. The

first 50 million steps have been discarded from the analysis and were only used to equilibrate the system. Below 52K the equilibration time is too long for the GCMC simulation. As a consequence, the CO/N_2 quantities have been evaluated via the Van't Hoff relation [2].

3. Results

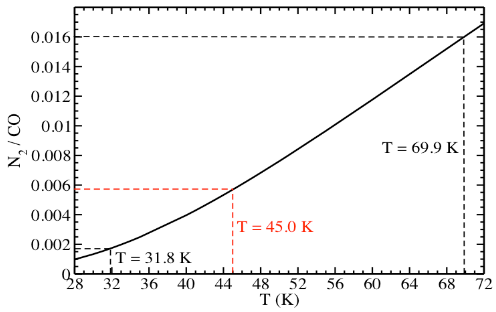

Figure 1: Minimum and maximum N_2/CO ratios measured in 67P and corresponding formation temperatures for the ice grains.

In the temperature range of 20K to 100K, the calculated N_2/CO ratio is significantly lower than the ratio of ~0.15 in the coexisting gas phase. This indicates that the clathrate formation favors the CO entrapping at the expense of N_2. This behavior is related to the difference in entrapping energy between CO and N_2. Indeed, ΔE_{CO} being lower, the entrapping of CO is selectively favored when the temperature decreases.
Figure 1 shows the correspondence between the N_2/CO ratio measured in 67P by the ROSINA instrument and the formation temperature of the ice grains from which the comet agglomerated. Taking into account the strong variation of the N_2/CO measurement between 0.17 to 1.6% depending on the position of the Rosetta spacecraft above the surface of the comet nucleus [7], we find that the ice grains at the origin of 67P formed at temperatures ranging between ~31.8 and 69.9 K in the protosolar nebula, with corresponding equilibrium pressures ranging between 6.0×10^{-19} and 2.1×10^{-6} bar. For the sake of information, the mean N_2/CO ratio of 0.57% corresponding to the averaging of the 138 spectra obtained by [7] is represented on Fig. 1. The corresponding formation temperature of the ice grains is of ~45 K in the PSN, with an equilibrium pressure of 3.3×10^{-12} bar.

4. Summary and Conclusions

The composition of a MG clathrate formed from a gaseous mixture of N_2 and CO in proportions corresponding to those expected for the protosolar nebula (87.1 % for CO and 12.9% for N_2) has been investigated in the 20–100 K temperature range.
The results show that, at thermodynamic conditions relevant to those of the protosolar nebula, CO has a much higher propensity than N_2 to be trapped in clathrates. Assuming that 67P agglomerated from clathrates, our calculations suggest that the cometary grains must have formed at temperatures ranging between ~31.8 and 69.9 K in the protosolar nebula to match the N_2/CO ratio measured by the ROSINA mass spectrometer [7].

Acknowledgements

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Minor species from comet 67P as measured from the VIRTIS-H instrument aboard Rosetta

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Abstract

Since July 2014, the Visual IR Thermal Imaging Spectrometer (VIRTIS) onboard the ESA's Rosetta spacecraft has intensively observed comet 67P/Churyumov-Gerasimenko (67P/C-G). First results were published in [3]. VIRTIS is composed of two channels, –M for mapping and –H for high resolution, working in the 0.25-5 µm and 2-5 µm wavelength domains, respectively [4]. In addition to nucleus mapping observations, limb observations were carried out to obtain spectra of the coma, and to detect fluorescence emissions of gas phase species. H_2O, CO_2, CO and organics have strong vibrational bands in the 2.5-5 µm range. The ν_3 vibrational bands of H_2O and CO_2 at 2.67 and 4.27 µm, respectively, were detected in mid-October 2014 using VIRTIS-H, and observed regularly since then [1,2].

In this contribution, we will present observations of minor species, such as OCS, CO, CH_4, NH_3, CH_3OH. These species have been detected in cometary atmospheres, some of them in comet 67P by other Rosetta instruments. Model simulations show that they should be detected with VIRTIS-H near perihelion. Observations with the VIRTIS instrument will allow us to investigate whether the outgassing distributions of the species and diurnal variations are related to their volatility. Data acquired in the November 2014 to January 2015 period indicate a very low CO abundance relative to water of less than 1.9% (3-sigma), and a CO/CO_2 upper limit of 0.7 (3-sigma), which show that 67P/C-G is CO-poor, as measured for other Jupiter-family comets.

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Typology of dust particles collected by the COSIMA mass spectrometer in the inner coma of 67P/Churyumov Gerasimenko from Rendez-Vous to perihelion.

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Introduction: COSIMA is a TOF/SIMS spectrometer dedicated to the analysis of cometary grains collected in-situ on the the Rosetta orbiter. The grains are collected on targets 10 mm x 10 mm in area exposed by sets of 3 ("target assembly") in front of a funnel providing a 20° x 40° FOV to the outside environment of the spacecraft. 4 target assemblies have been exposed from August 8th 2014 (distant approach phase) to April 29th, 2015 on a weekly basis, except during near comet passages (daily basis). 10 of the 12 targets exposed up to now are covered by "metal black" layers (gold or silver) so as to maximize grain collection efficiency [1], the other two targets being silver foils. The collected grains are detected by a microscope, COSISCOPE, using two LED's at grazing incidence and a 14 µm pixel size (714 pixels across the target). This set up was designed so as not to miss the small particles expected to dominate the distribution of collected dust as well as the imprints resulting from rebounding particles when simulating impacts at speeds of up to 300 m/s as predicted by models of the inner coma [2]. The number and size of collected particles far exceeded expectations, with more than 10000 identified particles, including more than 80 collected dust particles with sizes of 7 pixels (100 µm) or more, making it possible to characterize the diversity of cometary grains collected in-situ at very low velocities in the inner coma of 67P/Churyumov-Gerasimenko. The first results demonstrated that cometary dust close to the nucleus is dominated by fluffy aggregates [3]. At EPSC, we will present the results on the pre-perihelion phase (August 2014 to August 2015).

Dust collection characteristics: The collection rate is extremely irregular, from a few particles on all three targets during a week to more than 2000 particles over a few days. For such a high collection rate period, there are also large variations between targets, as demonstrated by Fig. 1a and Fig. 1b.

These large variations in time and between targets, as well as the spatial correlations observed for the largest collections, demonstrate that most of the observed dust particles during a high collection episode originate from a single large parent particle, which disintegrated close to the spacecraft or within the COSIMA entry funnel. In such cases, fluffy particles dominate the typology. These observations by COSIMA are fully consistent with those of

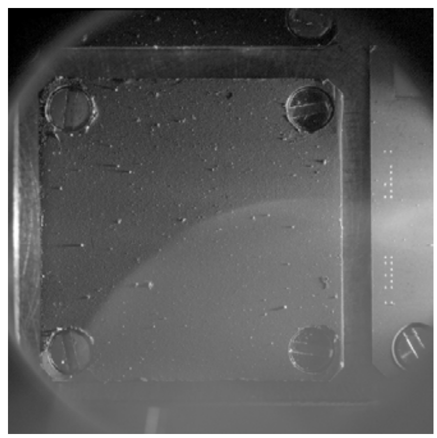

Fig. 1a: Target 3CF after a high collection week, displayed with a log scale. The bright spots indicate grains illuminated from the right)

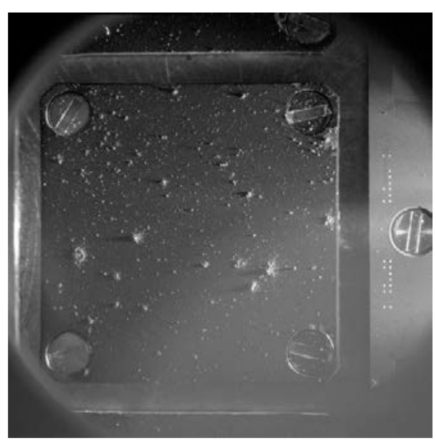

Fig. 1b: Target 2CF after the same week. The number and typology of collected grains markedly differs from that of grains collected on the neighbour target.

GIADA, which detects dust optically and with an impact sensor, a large fraction of the detections having been observed in clusters [4].

Dust typology: it ranges from very weak aggregates which shattered on the target even at the low velocities (1 to 12 m/s) measured by the GIADA instrument [4] to compact particles, some of which have been observed to move on the target from one week to the next while maintaining their shape.

The shattered clusters and more compact rubble piles dominate the dust collection. Examples of the different classes of grains are given in Fig. 2-4

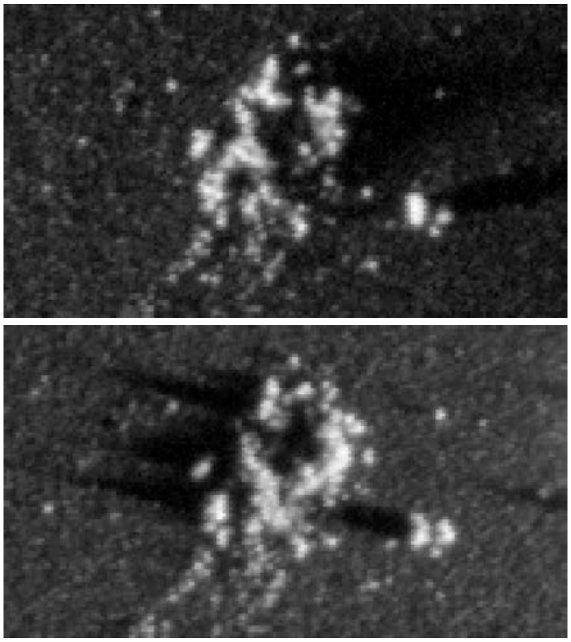

Fig. 2: Kamil (shattered cluster) as seen from the left LED (top) and the right LED (bottom)

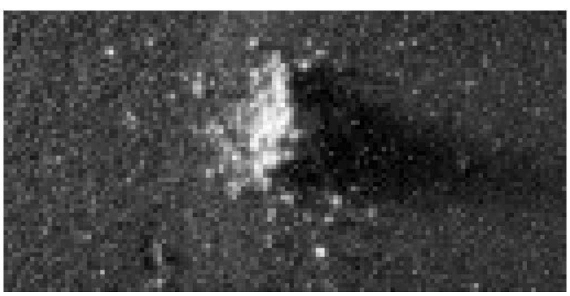

Fig. 3: Eloi (rubble pile), grain selected for reference [3]

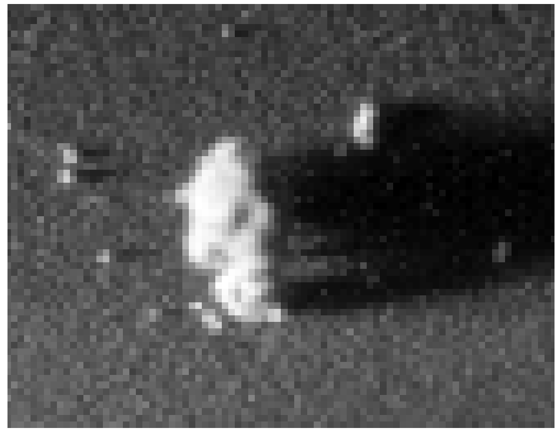

Fig. 3: Nick (compact grain). The shadow from the left LED demonstrates that the grain is not in contact with the target over its full length, as some light gets through.

Variations in typology have already been observed, but the relationship with heliocentric distance and the distance from the comet is not straightforward. Given the low velocity of dust particles, the orientation of the spacecraft with respect to the ram direction is likely to be critical.

Conclusion: Due to the very low collection velocities and the resulting high collection efficiencies of metal black targets, COSIMA/COSISCOPE provides the first optical characterization of an unbiased sampling of dust in the vicinity of an active cometary nucleus. The typology of the collected grains is dominated by aggregates extending to larger scales (100's of µm to millimeters for parent aggregates) the complex structure of IDP's and micrometeorites, in line with hierarchical dust accretion models [5]. A small fraction of compact grains which may be related to Stardust terminal particles [6] is also observed. A possible evolution of the typology of dust particles as the comet gets close to perihelion will likely be related to newly exposed areas after removal of the dust mantle.

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SESAME/CASSE listening to the insertion of the MUPUS PEN at Abydos site, 67P/Churyumov-Gerasimenko

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1. Introduction

SESAME is a suite of three instruments (the *Comet Acoustic Surface Sounding Experiment* CASSE, the *Dust Impact Monitor* DIM, and the electrical *Permittivity Probe* PP) that have sensors and transmitters distributed all over the Philae lander, but share common electronics for commanding and processing. SESAME is conducted by a consortium of DLR, the Max Planck Institute for Solar System Research (Göttingen), and the Finnish Meteorological Institute (Helsinki, [1]).

The Multi-Purpose Sensor MUPUS, run also by DLR, combines a thermal conductivity and heat flow experiment with a mechanical properties experiment associated with the anchoring harpoons of the lander ([2]).

It was recognized early in the preparation of both the SESAME and MUPUS experiments that the hammering mechanism of the latter, which drives the thermal probe into the ground, might as well serve as source of elastic waves for the CASSE experiment. To support the CASSE experiment, the MUPUS flight software provides information on its hammering process in a shared memory of the lander data management system.

CASSE listening to the MUPUS PEN hammer mechanism proved to be the first active seismic experiment conducted on a celestial body other than Earth since the Lunar Seismic Profiling Experiment, which was carried out on the Moon by the Apollo 17 astronauts in 1972 (e.g. [3]).

2. Experiment Setup

The experiment was conducted at the Abydos site on comet 67P/Churyumov-Gerasimenko, which is the place where the Philae lander finally came to rest after repeated bouncing. At the time of writing, the exact location of Abydos on the comet is still unknown, although constrained to an area of a few hundred square meters on the “head” of the comet by the CONSERT instrument ([4]). Contrary to the nominal landing site Agilkia, which is a relatively flat terrain, Abydos shows steep walls at least as tall as the lander itself and partly less than 1 *m* away [5]. Moreover, it is not obvious from existing imagery which direction is “down”, i.e. what the orientation of Philae with respect to local gravity is.

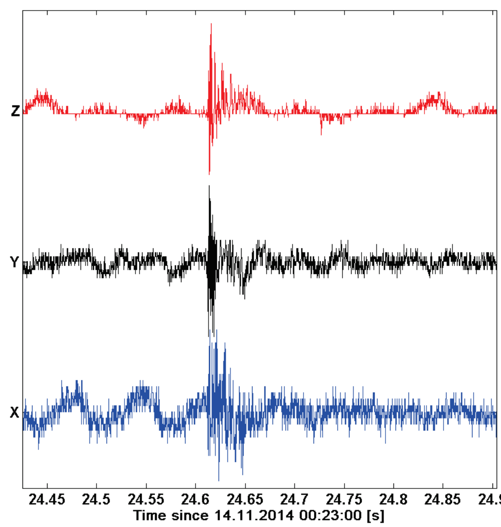

Fig. 1: An early MUPUS hammer stroke as recorded by CASSE on the +Y foot. All channels normalized to unit amplitude individually to emphasize wave train shape. Actual amplitude is of the order of 0.1 m/s^2. Note that in the manufacturer’s nomenclature, the “x” channel is vertical, while “y” and “z” are horizontal, i.e. in the plane of the lander feet.

The MUPUS PEN consists of a glass fiber rod with a metal tip. Its hammering mechanism is accommodated in a cylindrical housing on top of this rod. The working principle is that of a coil gun: a capacitor is short-circuited via a coil, thus generating a magnetic field that accelerates the hammer head onto the rod. Strokes may be executed at four different energy levels which are set automatically in order to penetrate materials of different strength [2].

The receiving sensors of CASSE are piezo electrical accelerometers (Bruel & Kjaer 4506 Ortho-Shear) capable of recording three orthogonal components of acceleration. Three of these sensors are housed in the landing feet of the Philae lander. Two principal operational modes were foreseen to listen to MUPUS: a triggered mode, where a threshold trigger starts storing data from a ring buffer memory as soon as a certain amplitude threshold is exceeded on selected sensor channels, and a listening mode which simply records for a certain amount of time whenever it is commanded.

3. Results

SESAME was active during the MUPUS PEN insertion phase for more than two hours, starting at 14.11.2014, 00:12:07 UTC and ending at 02:28:00 UTC. During this time, 5 listening mode measurements, 14 triggered mode measurements and several soundings using the CASSE piezo transmitters were conducted. Sampling rates ranged from 2 *kHz* to 5 *kHz*, since sampling rate, number of recording channels, and recording duration needed to be traded against each other. A total of 231 time series with durations from 40 *ms* to 15 *s* were recorded during the MUPUS PEN insertion phase. An example is shown in figure 1. All sensors and transmitters are fully functional; the bumpy landing caused no damage whatsoever.

During the first five recordings, all three accelerometers show more or less continuous vibrations at frequencies between 10 *Hz* and 30 *Hz*, that are often much stronger in amplitude than the signals interpreted as actual hammer strokes, although there is evidence that these vibrations are also sustained by the hammering of MUPUS. Since only a few discrete frequencies are observed, we conclude that these vibrations represent eigenmodes of the Philae landing gear, excited via the deployment boom of MUPUS, which was connected to MUPUS during the entire experiment.

The actual hammer strokes of MUPUS are transient, broad-banded signals with decay times of a few tens of milliseconds. Typically the +Y foot received the strongest signals and triggered the recording, although the –Y foot is closer to the nominal position of MUPUS. In one case, the strongest signal was received by the +X foot. Signal quality varies between recordings, but the measurements nevertheless support that all three feet are in contact with the comet. One recording contains signals from two adjacent strokes with a time delay perfectly fitting to the nominal stroke sequence of MUPUS at that time.

4. Discussion and Conclusions

Two pathways for elastic waves must be considered in the evaluation of the presented data: unwanted acoustic crosstalk through the structure of the lander and the desired sounding of the comet subsurface. The presence of (1) low frequency vibrations in only the first few recordings, (2) the changes of relative and absolute signal strength between recordings of hammer strokes, (3) the broad banded frequency content allowing for sharp onsets of the transient signals, as well as (4) the perfectly fitting time delay in the recording containing two strokes all support our interpretation that we do indeed see signals from subsurface sounding rather than crosstalk. Finally, we expect crosstalk signals to arrive synchronously at all feet, while subsurface sounding should reflect differences in path length.

In most cases, time series require careful individual processing to make further evaluation possible. Thus the evaluation and geological interpretation of the data is still ongoing at the time of writing this abstract.

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Coma chemical composition at the Abydos landing site

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Abstract

The Ptolemy instrument, onboard the Rosetta Philae Lander, made measurements of the chemical composition of the coma mid-bounce, just after the non-nominal landing on the surface, and subsequently at the Abydos landing site. This presentation will discuss Ptolemy's operations throughout this 45 hour period and the results obtained.

1. Introduction

Ptolemy is a Gas Chromatograph – Mass Spectrometer onboard Rosetta's Philae Lander [1]. Philae initially landed at the Agilkia landing site on 12th November 2014, bounced and finally came to rest at the Abydos site some 1½ hours later. Ptolemy is primarily designed to analyse volatiles released from solid comet samples collected by the SD2 drill [2] following heating in an oven. However, it can also operate in a "sniff" mode where the local gas environment is analysed directly. Despite the non-optimal landing, the Ptolemy instrument made six measurements of the coma gas at the comet surface over the following 45 hours. These analyses provide ground truth measurements of the coma gas pressure and composition at the Abydos location on the surface of the comet. The concentrations of the main chemical components give insights into the nature of the sublimation regions of the comet.

2. Ptolemy operations

The timeline of measurement made by Ptolemy is shown in Table 1. All analyses were made at the Abydos site, apart from the first measurement, which made 20 minutes after the initial touchdown whilst Philae was mid-bounce. As a consequence of the non-nominal landing, Philae was commanded to execute the pre-programmed Safe Block of measurements. This Safe Block was restricted to measurements that did not require any movement of the Lander or mechanical mechanisms such as the SD2 drill, MUPUS penetrator or APXS. However the Safe Block did include a total of four Ptolemy coma gas measurements, at two hour intervals, during which time the Abydos site passed from illumination into night.

Table 1: Timeline of Ptolemy "sniff" operations after Philae initial touchdown (TD)

Date	Time (UTC)	Ptolemy Temp. (°C)	Comments
12-Nov	15:54	0	20 minutes after TD
13-Nov	06:35	0	Comet day
	08:37	-2	Comet dusk
	10:39	-2	Comet night
	12:41	-4	Comet night
14-Nov	02:54	-17	Comet night
	12:36	-23	Comet night

3. Results

The mass spectra acquired at Abydos had peaks attributed to three main components: water, carbon monoxide and carbon dioxide. Carbon monoxide has an isobaric interference with nitrogen, both with a mass/charge ratio of 28. However, the nitrogen concentration is thought to be a minor component as there was no fragment peak at m/z 14. Furthermore, on the orbiter the ROSINA [3] mass spectrometer, which has sufficient resolving power, has measured a very low N_2/CO ratio of less than 0.01 [4].

The coma gas concentration at Abydos was much lower than the average coma concentration measured by ROSINA. The initial measurement made by Ptolemy in comet day was about a factor of 10 less than that of the average gas concentration and the concentration decreased even further during the comet night.

The measurement at Agilkia had similar CO and CO_2 concentrations relative to the more abundant water. However, there were much higher levels of organic compounds present, which is attributed to the disturbance of the surface layer by the Lander impact.

4. Discussion and future operations

The coma composition at the surface reflects the sub-surface sublimation processes occurring within a localized area. The low coma pressure indicates that Abydos is a low activity region. The ratios of the main components suggest that the more volatile species may already have been depleted at this location.

As the comet approaches perihelion we hope that Philae will survive the hibernation and have sufficient power to begin instrument operations. The Ptolemy "sniff" mode is low power (<5W) and duration (<10 minutes). Also, the mode has been modified to improve the scientific and data return rate. When Philae wakes up the coma will be much more active and the greater solar irradiation will result in sublimation occurring at greater depths. Measuring changes in coma composition will give insights into the subsurface composition and processes occurring on the comet surface.

5. Summary and Conclusions

Ptolemy made measurements of the coma gas composition as it left Agilkia and at the Abydos site of comet 67P/Churymov-Gerasimenko. Results indicate that this is a low activity region depleted of volatiles. Further measurements, made as the comet approaches perihelion would sample the sub-surface at greater depths and give insights into the sublimation processes occurring on the comet.

Acknowledgements

The Ptolemy instrument was built collaboratively by the Open University and RAL Space. Financial support was provided by the Science and Technology Facilities Council (Consolidated Grant ST/L000776/1) and UK Space Agency (Post-launch support ST/K001973/1). We appreciate the efforts of teams of scientists and engineers from many organisations who have made this project successful, including the Lander Control Centre (LCC), Science Operations and Navigation Center (SONC) and the Rosetta Mission Operation Centre (RMOC).

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Rosetta mission status: challenges of flying near a comet

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Abstract

Recent operational events, most likely due to the increased presence of dust near the spacecraft during close flybys of C67P/Churyumov-Gerasimenko in the comet escort phase, have led to a redefinition of the Rosetta mission through the design of new trajectories allowing the spacecraft and its payload to continue flying safely around the comet while augmenting the wealth of scientific data and results that has characterized the beginning of the mission so far. A decision process is being put in place in view of finding the best ways forward operationally so as to recover some capabilities that will allow Rosetta to continue optimising its scientific mission, in both the nominal and expected extended mission intervals.

1. Introduction

The Rosetta nominal mission is in full swing, following successful exit from hibernation in January 2014, the subsequent approach to C67P/Churyumov-Gerasimenko in the Summer of that year, and the astonishing touchdown of its Philae lander on the surface of the comet on 12 November 2014. With gained experience flying near the comet, down to a 10-km bound orbit, the ESA operations teams were confident of remaining very close to the comet through the perihelion passage due to occur this August. However, two very close flybys in early 2015 have demonstrated the difficulties of remaining close to a comet whose activity is on the increase. The following sections describe the events and ongoing activities of the process developed to adapt to the new, evolving situation.

2. The C67P/C-G Escort Phase

Having dropped the Philae lander module in its final resting place of Abydos on the comet's surface, the Rosetta spacecraft has continued to orbit C67P/Churyumov-Gerasimenko through bound orbits until early February 2015, in view of further characterizing the small body. The post-landing operations initiated the so-called Comet Escort Phase, designed for the orbiter spacecraft to follow the comet on its path toward the Sun and back in the course of 2015.

Since 4 February the mission no longer could fly bound orbits around the comet but was designed to fly, until the end of the nominal mission, dedicated trajectory patterns which included a number of flybys at varying distances adapted to the scientific needs of the mission (Figure 1). The first one was the closest flyby to be flown, on 14 February, with the spacecraft passing at 6 km from the comet's surface. The second very close flyby occurred on 28 March.

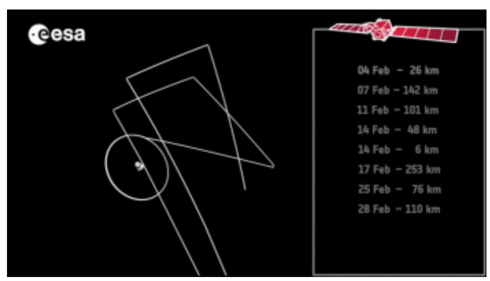

Figure 1. Example of Rosetta's planned flyby trajectories at Comet 67P/C-G. Credit: ESA.

3. Close Flybys Operational Events

However, during the 14 February flyby, with the spacecraft so close to the comet environment, severe star tracker issues were experienced and the spacecraft was very close to ending up in safe mode.

During the second close flyby performed on 28 March other, worse star tracker (STR) issues were experienced, despite measures taken to address those that had occurred during the first close flyby. Tracking issues started at 50 km from the comet, with tracking fully lost at 23 km. Tracking was recovered on the outbound leg of the flyby on 29 March, at a distance of 75 km from the comet, after around 24 hours with no STRs. But at that time there was a clear indication of High Gain Antenna off-pointing, with the imminent risk of losing contact from the ground. During recovery actions, on-board surveillances checking consistency between STR and gyro measurements triggered twice (due to STR locking on dust particles seen as false stars), the second one of which leading to safe mode.

With no indication of degraded STR optics, and tracked stars being measured with expected magnitude, both STRs behave in the same way and the above issues only seem to appear close to the comet where the number of particles is expected to be much larger. As a result of these operational events, the spacecraft performance in a more active environment is being characterised and mitigation measures explored so as to minimise both likeliness and impact of reoccurrence.

4. Adapting Rosetta's Trajectories

As a result of the safe mode, Rosetta moved onto an 'escape trajectory' taking it approximately 400 km from Comet 67P/C-G. An orbital correction manoeuvre was executed on 1 April to start to bring the spacecraft back again toward the comet, and with a second manoeuvre executed on 4 April, the target distance of 140 km was reached on 8 April.

But as a consequence of the star tracker issues, confidence in flying the spacecraft in the close vicinity of the comet has been damaged, therefore close flybys are not possible for the time being. A path to rebuild confidence and re-establish science operations in the coming weeks, while ensuring the safety of the spacecraft, had to be chosen.

A revised science operations plan was agreed for the months ahead leading to perihelion, using a trajectory scheme of pyramid and terminator arcs starting at around 100 km but with the aim of optimising the distance to the comet over time. The Rosetta Science Ground Segment (RSGS) and Rosetta Mission Operations Centre (RMOC) teams are assessing the optimal trajectories and the pointing capabilities of such trajectories. At the same time, lander communication opportunities have to be reassessed.
Three of these pyramid trajectories (Figure 2) are currently planned up until the end of April. The RMOC operations team will assess the situation each week before deciding to move closer or, if necessary, to move further away again.

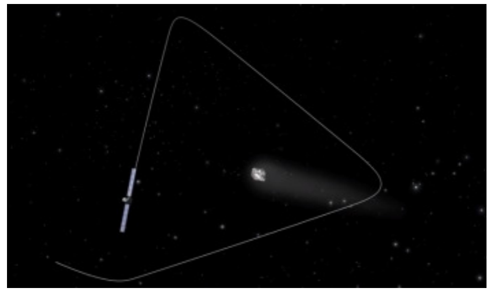

Figure 2: An example of 'pyramid' trajectories close to the comet. Credit: ESA.

Adapting the Rosetta mission to such trajectory schemes may allow flying closer to the comet again in the near future, albeit with significant constraints and limitations required for spacecraft safety in an increasingly active comet environment.

In addition to the above issues, the Rosetta teams have to monitor the state of the spacecraft reaction wheels. One of the reaction wheels actually started displaying increasingly high friction levels early in 2015, which led the RMOC operations team to recommend bringing maximum wheel speeds to lower values. This has been applied and will result in slightly longer spacecraft slew durations, while wheel speeds will be monitored, and will have a small impact on science.

5. Summary and Conclusions

At time of writing, Rosetta continues to recover well from the significant operational problems experienced during the close flybys of 14 February, and over the weekend of the 28th of March that resulted in the spacecraft entering safe mode. The scientific payload is now switched back on again, acquiring invaluable data from the nearby C67P/C-G.

Scientific and operations teams are now dedicating most of their activities toward optimising the already replanned and future science observations and associated spacecraft pointings in connection with newly adapted flight trajectory schemes. As we move forward and closer to perihelion, with a foreseen increase in comet activity, we will analyse what can be further modified and improved in order to maximise science return within the capabilities of the Rosetta spacecraft. Those are the challenges of flying really close to a comet approaching the Sun.

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Photometric correction of VIRTIS spectra of 67P/CG: empirical approach

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Abstract

In this work, a photometric correction, based on the empirical approach already tested successfully on Vesta [1], is applied on VIRTIS data of comet 67P/Churyumov-Gerasimenko. Preliminary results are discussed.

1. Introduction

The Visible, Infrared and Thermal Imaging Spectrometer (VIRTIS) [2] 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 μm) and infrared (1-5 μm) spectral range.
The first data of VIRTIS revealed a very dark nucleus and the presence of opaque minerals associated with organic macromolecular materials [3].
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. [1], [4], [5]).
Different procedures for obtain a photometric correction of VIRTIS data are under development (e.g. [6], [7]).
Here we present the application on VIRTIS-M data of the empirical approach, developed by [1] and already applied on VIR/Dawn data of Vesta [1] and VIRTIS/Rosetta data of Lutetia [8]. The same procedure is currently being applied also on VIR/Dawn data of Ceres [9].

2. Approach

The photometric empirical model is based on a statistical analysis of the whole VIRTIS-M dataset, which in this case includes about 3 million spectra.
It has been applied on calibrated reflectance spectra and can be divided in the following steps:

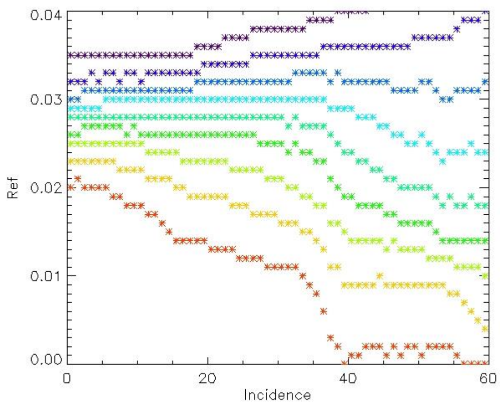
1. Identification of the most adequate disk function *D* and retrieval of equigonal albedo *(I/F)/D* in order to remove the incidence and emission effects
2. Identification of equigonal albedo families in the equigonal albedo vs phase angle scatterplot. A family is defined by equigonal albedo values of 10% (20%, 30% and so on) of brightest pixels at each phase
3. Retrieval of phase function for each equigonal albedo family
4. Correction, i.e. retrieval of the reflectance at standard illumination condition (i.e. 0° or 30° phase).

Some photometric parameters retrieved with this method, such as albedo and slope of the phase curve, can give indication about the spectral class of asteroids ([8], [9]). Therefore, in the CG case, can identify the asteroid spectral class most similar to the comet.

3. Preliminary results and discussion

The Step 1 has been applied by considered different disk functions among those present in literature, such as Lambert, Lommel-Seeliger, Akimov.
The Lambert function is not adequate for describing the photometric properties of the CG surface, since it

introduces spurious correlation of reflectance and incidence angles (Fig. 1 top). Otherwise, the other two functions well correct for the brighter regions of CG. However, even after the application of these disk functions, a residual correlation between reflectance and incidence angle is still observed for darker regions (Fig. 1 bottom) and should be understood.



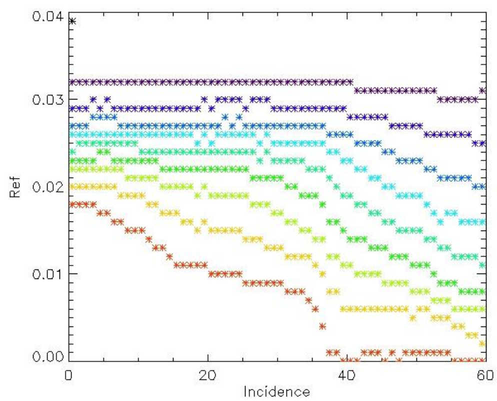


Figure 1. Equigonal albedo at 1.2 μm for different reflectance families (highlighted by different colors), obtained by applying the Lambert (top) and Akimov (bottom) disk function (results obtained for the Lommell-Seeliger disk function are similar to those obtained for Akimov). In the first case an increasing trend with incidence angle is introduced for brighter regions, whereas a residual decreasing trend is still observed for darker region whatever the disk function applied.

The application of Step 2 and Step 3 revealed that the phase functions retrieved for the different families are similar. This suggests a similar photometric behaviour across the whole 67P surface, even in active regions. However, this result should be re-discussed after the comet has passed the perihelion, when a strong increase of cometary activity is expected.

Finally, the photometric parameters describing these preliminary CG phase functions (albedo and phase slope) seem to be similar to those obtained for C-type asteroids. A detailed investigation about this comparison is in progress.

Acknowledgements

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COMPOSITION OF COMET 67P/CHURYUMOV-GERASIMENKO REFRACTORY CRUST AS INFERRED FROM VIRTIS-M/ROSETTA SPECTRO-IMAGER

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Abstract

We report the interpretation of VIRTIS/ROSETTA spectra of comet 67P/CG, based on laboratory data collected on meteorites and series of analogs. We show that the crust is composed by a macromolecular carbonaceous material, mixed with minerals and likely more volatile molecules and possibly ammonium salts.

1. Introduction

The Visible InfraRed Thermal Imaging Spectrometer, VIRTIS [1] onboard ESA's Rosetta orbiter has completed two extensive mapping campaigns of the 67P/Churyumov-Gerasimenko comet nucleus in August-September 2014 [1,2]. Reflectance spectra were collected within the 0.4-5 µm range and reveal a dark surface (normal albedo ~6 %), a positive (red) near-infrared spectral slope, a steeper red visible slope, and a broad feature that peaks at 3.2 µm [1]. Here we address interpretation of these spectra through comparison with experimental data.

2. VIRTIS spectra

A full image-cube, with thermal contribution removed [3] from the MTP06 observing campaign (August 2014) has been analyzed in order to retrieve the general behavior of the surface spectra. The main spectral features of this data set are a single normalized infrared slope, two classes of normalized visible slopes ("neck" and "body") and a 3.2 µm band depth that appears to vary independently of the slopes for the body.

3. Organics and opaque minerals

Dark surfaces of small solar system bodies are often related to the presence of dark refractory organics. Primitive chondrites contain a polyaromatic black solid (1-5 wt%), which is insoluble in common organic solvents and extracted with chemical HF/HCl protocols (IOM, Insoluble Organic Matter). IOM shares similarities with terrestrial type III kerogens and coals, and coal samples have been used as fair analogues in earlier studies [4]. Raman spectroscopic analyses clearly evidenced polyaromatics compounds are present in grains of plausible cometary origin (stratospheric IDPs, Antarctic micrometeorites), but likely with a broader range of chemical compositions than chondritic IOM [5]. Therefore, we selected a series of coal samples from the Penn State University Coal Bank and Data Base covering a wide range of maturities, i.e. a wide range of chemical compositions and degrees of structural order of the polyaromatic structures. The reflectance spectra of these coal samples were collected with the Spectro-Gonio Radiometer at IPAG at normal incidence and 30° emergence.

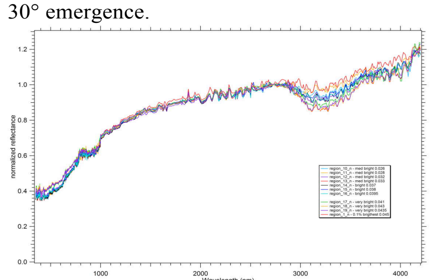

Fig. 1: *representative nucleus surface vis+IR spectra ("neck" and "body") normalized at 2.72 µm with thermal emission removed. High frequency spectral variations are due to noise and calibration artefacts.*

The reflectance spectra strongly depend on maturity and grain size [7,9]. All samples display very low reflectance in the visible range. In contrast, low maturity samples display a rather high reflectance level in the near-infrared range, while mature coals (e.g., anthracite) are spectrally flat and dark over the visible and near-infrared ranges. Mature coals cannot be considered as fair analogues of cometary refractory organics. Mature IOM is recovered in thermally metamorphosed chondrites that experienced high temperatures (> 600 °C) conditions over millions of years. The near-infrared range appears then as a critical range for constraining the nature of the dark components of 67P/CG. Indeed, the reflectance spectra of primitive carbonaceous chondrites and of IOM extracted from Orgueil CI chondrite are basically flat and dark in the visible and near-infrared [6].

A strong effect of grain size is observed. The reflectance level in the near infrared is found to increase upon decreasing grain size, in particular in the case of a lignite whose composition is very close to that of the IOM of the CI Orgueil chondrite. As submicrometric particles are expected in the 67P/CG refractory crust, we infer that grain size cannot account for the high near infrared reflectance. Similar observations have been made on a wide range of terrestrial organics like solid oil bitumens, and that our general conclusions obtained from a series of coals would apply to polyaromatic solids that sample broader range of compositions and polyaromatic structures [7].

Furthermore, dark polyaromatic hydrocarbons that are ubiquitous in cometary and asteroid grains cannot account for the low reflectance of primitive chondrites, and of comet 67P/CG. In fact, the very low reflectance and spectrally flat reflectance spectra of primitive carbonaceous chondrites and of their IOM strongly suggests spectral contribution from opaque minerals such as sulfides and oxides, which cannot be dissolved using HF/HCl protocols. Sulfides (troilite, pyrrhotite, pentlandhite) and Fe-Ni alloys (kamacite, taenite) are ubiquitous in chondrites and cometary grains. They play a key role in the control of the low albedo of carbon-rich cosmomaterials [8,9], and likely for comet 67P/CG. Finally, sulfides can also exhibit red slopes in the visible and might account for the spectral characteristics of the spectra of comet 67P/CG [1].

4. The 3.2 µm band

The broad 3.2 µm band can be assigned to OH, CH, H_2O, NH/NH_2 and NH^{4+} chemical groups, molecules or ions. The contribution of water ice is considered as weak due to the lack of peak at 3.1 µm. Water ice has been marginally detected in area of the nucleus just emerging from shadow [10]. NH/NH_2 do not fit properly the 3.2 µm band, and their ubiquitous presence is also unlikely, as N-rich cometary grains are extremely scarce in collections [11]. The OH chemical groups trapped in minerals or inserted within the network of refractory polyaromatic solids is a possible candidate. OH in proto-serpentines and glasses, which are stable up to 300 °C, are reported in primitive chondrites [12, 13]. However, the peak position of their band lies around 3.1 µm, and the width is smaller than that of the observed 3.2 µm band. In a carbonaceous structure, OH can be present as either alcohol (terminating -OH) or carboxylic groups (-COOH). The carboxylic band is broader than the alcoholic one, due to efficient proton exchange through hydrogen bond. The contribution of carboxylic groups appears thus highly plausible, but contribution of alcoholic OH cannot be rejected. Ions like NH_4^+ could also contribute to the 3.2 µm band. This ion spectrally matches well the 3.2 µm band, and has been found to form along with OCN^- in laboratory experiments [14]. Tosum up, OH and alkyl groups in organics and ammonium salts appear as the most plausible candidates.

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The dust coma of 67P/Churyumov-Gerasimenko as seen by OSIRIS onboard Rosetta

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1. Introduction

The dust coma of 67P was detected and monitored by OSIRIS, the scientific camera onboard Rosetta, since the beginning of the post-hibernation operations in March 2014. A complete description of the coma during the approach phase to the comet was presented in [5], including the detection of a sudden cometary outburst at the end of April 2014. OSIRIS images acquired at the end of the approach (July 2014) and during the escort phase were used to characterize dust particles present in the comet's inner coma ([4], [3], [2], [1]).

2. The comet's dust environment

OSIRIS images, calibrated following the instrument pipeline described in [6], were used to obtain photometric measurements of the unresolved coma and individual dust grains. A large number of individual dust grains have been detected and characterized in terms, for example, of size, colors, orbits [2].

In this study, following a similar way as described in [5] for the first three months of the mission, surface brightness vs. comet distance profiles are used to characterize the comet's dust environment and its evolution with heliocentric distance.

Images acquired with different filters, spanning the wavelength range from 240 nm to 1000 nm, allow us to measure coma colors, their diurnal variations, and changes with heliocentric distance, providing insight into the dust composition.

Montecarlo simulations are used to constrain dust parameters (such as size, size distribution and velocities of the dust particles) by comparing synthetic and observed images.

Additionally, images acquired at phase angles between 0º and 160º allowed us not only to measure the dust phase function in different colors but also to investigate the intimate nature of cometary dust particles by solving the inverse scattering problem.

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Modelling of the inner gas and dust coma of comet 67P/Churyumov-Gerasimenko using ROSINA/COPS and OSIRIS data - First results

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1 Introduction

The physics of the outflow above the surface of comets is somewhat complex. Ice sublimating into vacuum forms a non-equilibrium boundary layer, the "Knudsen layer" (Kn-layer), with a scale height of ~20 mean free paths. If the production rate is low, the Kn-layer becomes infinitely thick and the velocity distribution function (VDF) remains strongly non-Maxwellian. Thus our preferred method for gas dynamics simulations of the coma is Direct Simulation Monte Carlo DSMC. Here we report on the first results of models of the outflow from the Rosetta target, comet 67P/Churyumov-Gerasimenko (C-G). Our aims are to (1) determine the gas flow-field of H_2O and CO_2 in the innermost coma and compare the results to the in-situ measurements of the ROSINA/COPS instrument (2) produce artificial images of the dust brightnesses that can be compared to the OSIRIS cameras. The comparison with ROSINA/COPS and OSIRIS data help to constrain the initial conditions of the simulations and thus yield information on the surface processes.

2 Boundary Conditions

The calculations have been performed using the nucleus shape model "SHAP4S" of [3]. Surface temperatures have been defined using a simple 1-D thermal model (including insolation, shadowing, thermal emission, sublimation initially neglecting conduction) computed for each facet of the shape model. The DSMC program used is PDSC^{++} [2] which is a 3-D implementation based on work by Wu and co-workers. An unstructured grid is used. The simulation domain extends out to 10 km from the centre of the nucleus. Dust particles are assumed to be spherical and at rest on the surface of the nucleus. The procedure is then (1) calculation of a steady state solution for the gas field, (2) dust particle tracking in the gas field to get a dust particle distribution function, (3) scattering of the sun light on the dust particles and (4) line of sight integration to produce dust brightnesses and gas column densities to make predictions for other experiments.

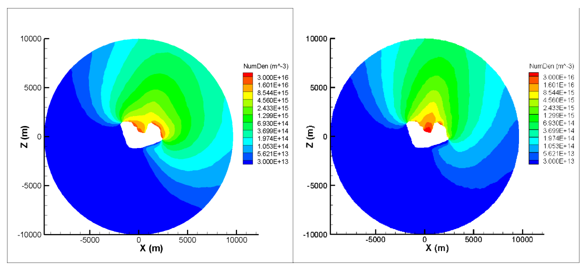

Figure 1: The gas velocity in the x-z plane of the 3D model of outflow from C-G at 3.4 AU. The sun is in the $+x$ direction and a half Maxwellian VDF was used on the comet surface. The axes are given in metres.

3 Gas Simulations

Figure 1 shows the number density of the outflow from C-G simulated at a heliocentric distance of 3.4 AU. A homogeneous (purely insolation driven with a gas production rate of 1.6 kg s^{-1}) and inhomogeneous

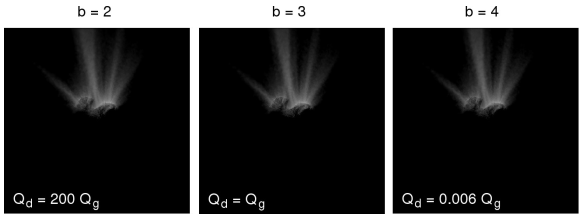

Figure 2: Artificial images composed for the viewing geometry of Rosetta on the $5.9.2014$ at $9{:}20$ UTC for different values of b and Q_d/Q_g. The images are on a log. scale for the radiance in W m^{-2} nm^{-1} sr^{-1} from 10^{-7} to 10^{-4}.

case (increased activity is assumed in the Hapi and Hathor regions of the nucleus resulting in a gas production rate of 2.6 kg s^{-1}) is shown here. The 3D gas results lay the basis for the comparison with the ROSINA/COPS data we have performed.

4 Dust Simulations

To calculate the dust distribution in the coma we assume test particles in the gas field without any back coupling. The motion of the dust is driven by the drag force resulting from the gas flow. We assume a quadratic drag force with a velocity and temperature-dependent drag coefficient. We also take into account the gravitational force of the nucleus on the dust. From the 3D dust density distribution of 40 size bins we perform a line of sight integration.

5 Scattering

For the scattering of the dust, we use Mie theory for spherical particles using the algorithm of [4]. Under the assumption of zero optical depth, the observed radiance can be summed and compared to the expected radiance of a column of dust with a specified size distribution for which we adopt a power law distribution $n(r) \sim r^{-b}$, where n is the number of particles of radius r. Figure 2 shows first results of this calculation for different values b and gas to dust mass ratios Q_d/Q_g.

6 Conclusions

Our DSMC and dust codes have been used to study a variety of models for the gas & dust distributions of comet C-G. The codes use an unstructured grid and can provide global values for gas & dust density, velocity and temperature out to 10 km from the nucleus. Our results can be compared with the in-situ measurements of ROSINA/COPS and the OSIRIS data. The presentation will show the improved quality of the fits using inhomogeneous emission for the August-September 2014 time frame.

Acknowledgements

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Analysis of Opposition effect on 67P/Churyumov-Gerasimenko's nucleus from Rosetta-OSIRIS images

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Abstract

We aim to assess two mechanisms involved in opposition effect phenomenon, i.e. shadow hiding effect (SHOE) and coherent backscattering effect (CBOE), using OSIRIS images taken on the 14th of February 2015.

1. Introduction

Launched in 2004, the Rosetta spacecraft woke up on January 20, 2014 after 10 years in cruise and 30 months of deep space hibernation. OSIRIS, the Optical, Spectroscopic, and Infrared Remote Imaging System [1] is the scientific imaging system onboard Rosetta. It contains two cameras: the Narrow Angle Camera (NAC) and the Wide Angle Camera (WAC) covering the wavelength range of 250 nm to 1000 nm with total of 25 filters. NAC and WAC have been designed as a complementary pair that addresses the study of the nucleus surface such as its morphology [2] or its photometric properties [3] and the investigation of the dynamics of the sublimation processes. During the close flyby (~ 6 km) on the 14th of February 2015 zero phase angle observations were performed and acquire images taken in combination of various filters. These observations allow us to increase our understanding of the sharp spike in the brightness near zero phase angles of atmosphereless bodies. This phenomenon is called opposition effect and is of special interest among photometric studies.

2. Methodology

We apply the Hapke [4] and Shkuratov [5] photometric models since formalism of both models considers the contribution of SHOE and CBOE mechanics in the opposition effect. The main difference between SHOE and CBOE is that SHOE does not vary with wavelength, while the CBOE depends on the wavelength of incidence light.
We evaluate a spectral appearance of CBOE [6] for the regions of the images obtained at phase angles less than 3° using NAC images in three filters F84 (480.7 nm), F82 (649.2 nm) and F88 (743.7 nm). Since the CBOE mechanism is believed to occur due to multiple scattering, we also apply the Minnaert photometric modeling [7] to estimate the contribution of multiple scattering at opposition. In order to extract the intensity and the associated geometric angles for the images, we used the shape model of comet [8] and the SPICE toolkit [9].

Acknowledgements

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Rotational study of 67P/Churyumov-Gerasimenko

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Abstract

The aim of the study is to determine the gravity field and moments of inertia along the principal axes of the comet, the obliquity of the axis of rotation with respect to the mean orbital plane, the precession rate, and the nutation coefficients. We also investigate the role of relevant parameters on the rotation.

1. Introduction

In Sierks et al. (2015) the nucleus structure and activity of comet 67P/Churyumov-Gerasimenko have been investigated based on data of the OSIRIS scientific imaging system on board the Rosetta spacecraft. The authors found no obvious evidence for complex rotation of the comet nucleus and were able to constrain any motion of the spin-axis to $< 0.3^{\circ}$ over 55 days. In this work we predict complex motion of the spin axis of 67P/Churyumov-Gerasimenko over the comet's orbital period of 6.4 years, which is in agreement with the bounds given by Sierks et al. (2015), namely in terms of the precession rate and nutation coefficients of the comet's spin axis based on a rigid body approximation.

2. Methods

The gravity field and moments of inertia are derived from a polyhedron model, which is provided by the OSIRIS and NAVCAM experiments on Rosetta, and assuming constant density and volume of the comet. We calculate the obliquity of 67P with respect to the mean orbit, the precession rate and the nutation coefficients from rigid body theory (Kinoshita 1977).

3. Preliminary results

The 2nd degree denormalized Stokes coefficients turn out to be $C_{20} = -6.74 \times 10^{-2}$, $C_{22} = 2.60 \times 10^{-2}$. These values are consistent with normalized principal moments of inertia $A/MR^2 \simeq 0.13$, $B/MR^2 \simeq 0.23$ for normalized polar moment of inertia c equal $C/MR^2 \simeq 0.25$. The obliquity between the rotation axis and mean orbit normal is $\varepsilon \simeq 52^{\circ}$, the precession rate becomes $d\psi/dt \simeq 24$ ″/y. Oscillations in longitude turn out to be of the order of $\Delta\psi \simeq 1'$, oscillations in obliquity are of the order of $\Delta\varepsilon \simeq 0.5'$. A parametric study of the precession rate in polar moment of inertia c can be found in Figure 1.

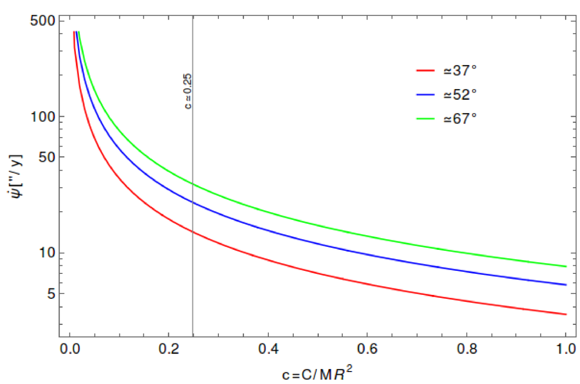

Figure 1: Mean constant precession rate of 67/P for ε=52° with an offset of ±15° for different polar moments of inertia c.

4. Summary and Conclusions

We provide important rotational parameters and a new gravity field solution, based on a rigid body approximation, that allow to validate possible interior structure models of comet 67P/Churyumov-Gerasimenko.

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In-situ investigations of the ionosphere of comet 67P

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Abstract

Since arrival of Rosetta at its target comet 67P/Churyumov-Gerasimenko in August 2014, the plasma environment has been dominated by ionized gas emanating from the comet nucleus rather than by solar wind plasma. This was evident early on from the strong modulation seen with Rosetta's position in a reference frame fixed to the rotating nucleus, with higher plasma densities observed when the spacecraft is above the neck region and when the comet exposes maximum area to the sun. In this respect, Rosetta is inside the comet ionosphere, providing excellent in situ investigation opportunities for the instruments of the Rosetta Plasma Consortium (RPC). In contrast to the often modelled scenario for a very active comet, the Langmuir probe instrument (RPC-LAP) finds electron temperatures mainly in the range of tens of thousand kelvin around this less active comet. This can be attributed to the lower density of neutral gas, meaning little cooling of recently produced electrons. A side effect of this is that the spacecraft charges negatively when within about 100 km from the nucleus. Interesting in itself, this also may point to similar charging for dust grains in the coma, with implications for the detection of the smallest particles and possibly for processes like electrostatic fragmentation. The inner coma also proves to be very dynamic, with large variations not only with latitude and longitude in a comet frame, but also with the solar wind and various wave phenomena.

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Correlation Based analysis of SIMS Data from Meteorite Samples for Comparison with Cometary Grains

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Abstract

We used the reference model of COSIMA, the TOF SIMS on board Rosetta to compare different meteorite samples, using correlation analysis to find references which allows us to characterize the cometary grains and to put them into the context of meteorite data.

1. Introduction

COSIMA is a time-of-flight secondary ion mass spectrometer on board the Rosetta spacecraft and is analysing cometary grains ejected off the nucleus of comet 67P/Churyumov-Gerasimenko since August 2014 [1]. In our effort to understand the composition and the history of these cometary grains, we studied the characteristics of different meteorite samples with the COSIMA reference instruments at the Max Planck Institute for Solar System Research in Göttingen (Germany), with the goal to separate individual compounds and their fragmentation patterns.

2. Method and Meteoritic Samples

Different types of meteoritesamples were prepared in the laboratory. Among these were one ordinary chondrite H4 (Ochansk), one unequilibrated ordinary chondrite H3 (Tieschitz) [3], one carbonaceous chondrite CR (Renazzo) [2], and a Martian shergottite (Tissint) [4]. Grains of sizes up to 100 µm were pressed into a blank gold metal target. The grains were identified with the instrument microscope and positive and negative secondary ion mass spectra were accumulated on different positions on selected grains. The mass spectra are accumulating all secondary ions up to mass 300 with reasonable detection efficiency and a mass resolution of 1400@ 100 u. This mass resolution is sufficient to separate organic (hydrogen rich) molecule peaks from minerals or elemental mass peaks.

The obtained mass spectra were aligned to a reference mass spectrum taken from the same target but pointing the ion beam at the gold substrate instead of at the meteorite samples. This involves the remapping of the time/mass scale for each single spectrum used. The cross calibration is mandatory to get meaningful correlations between time of flight channels across different spectra.

The rebinned spectra were processed with a centred moving average filter with a width of 3 bins and then used to construct a correlation matrix S in which each element r_{ij} is the correlation of the counts in time slot i with the counts in time slot j across a specific sample. Taking an individual column or row of the matrix, yields the correlation of a single time slot with every other time slot. As the time slots translate to specific mass to charge ratios, this method allows to gain information on which elements and molecules are related in the investigated sample.

3. Results

In this abstract, we show the correlation analysis of samples from Tieschitz and Renazzo. Figures 1 and 2 show the Pearson correlations of counts at the time slots, which translates to the mass of $^{56}Fe^{+}$, with the counts across different time/mass ranges for the Tieschitz sample in Figure 1 and the Renazzo sample in Figure 2. To keep the text concise from now on, we just write of “correlation of ion abundance at mass x with masses from range y to z”.

4. Discussion and Conclusions

As can be seen from the figures, there are some subtle and some larger differences between the samples from the H3 chondrite and the CR chondrite. Especially the correlations of $^{56}Fe^{+}$ (mass 55.93 u) with different masses in the 50 u to 80 u range show that iron may be associated with different elements in Tieschitz and in Renazzo. Tieschitz shows some correlation of iron with masses 55 and 71, which might be associated with Mn and MnO, while Renazzo does not show the corresponding correlation peaks.

This single element already shows that the two distinct samples can clearly been distinguished from each other by correlation analysis. This makes us confident in our use of this technique to further characterize the spectra of the cometary dust particles. However, the correlation analysis is just one step to really identify compounds from the samples. Other methods are also needed, e.g., to look at absolute and relative abundance of specific elements, etc. We continue to apply and improve these tools for the use with cometary data.

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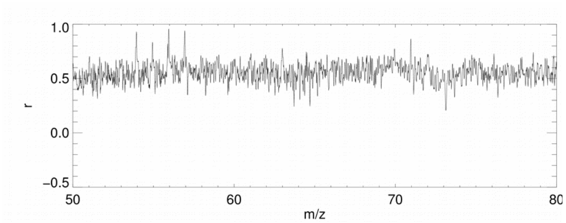

Figure 1: Correlation of ion abundance at mass 55.93 u (iron) with masses between 50 u and 80 u from the Tieschitz sample.

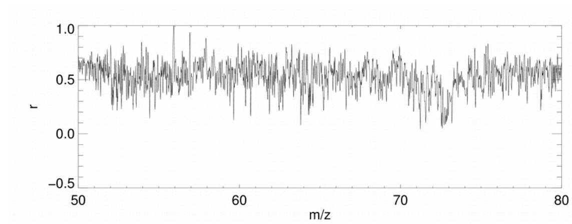

Figure 2: Correlation of ion abundance at mass 55.93 u (iron) with masses between 50 u and 80 u from the Renazzo sample.

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Layering and geological inner structure of 67P Churyomov-Gerasimenko comet nucleus

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Abstract

Context The peculiar bi-lobe shape of 67P Churyumov-Gerasimenko (67P/CG) has soon raised the question if it is the expression of two distinct objects or the result of a well-localized excavation on the nowadays-active region in-between the two lobes. The widespread layering involving most of 67P/CG surface seems to give an unambiguous answer to this topic.

1. Introduction

Surface layering on cometary nuclei has been proposed for 9P/Tempel 1 and, possibly, both for 81P/Wild2 and 19P/Borrelly. Nevertheless the OSIRIS [1] images of 67P/CG comet, provide clear and unquestionable evidences of a layering extent never seen before. In this work we illustrate such evidences showing how such geomorphological features can provide fundamental clues to understand the nucleus inner structure.

2. Methods

We used both the OSIRIS NAC and WAC images acquired from 6 August 2014 up to 17 March 2015 with a spatial scale ranging between 0.5 m/px to 4.5 m/px depending on cometocentric distances and the derived shape models to infer presence, distribution and attitudes of layers throughout the entire comet surface. Layers where interpreted in ARC-GIS environment and their orientations derived from best fit planes reconstructed on the bases of shape models nodes of morphological terraces and cuestas-like features. 3D reconstructions were realized using Mesh-lab and Mat-lab soft-wares.

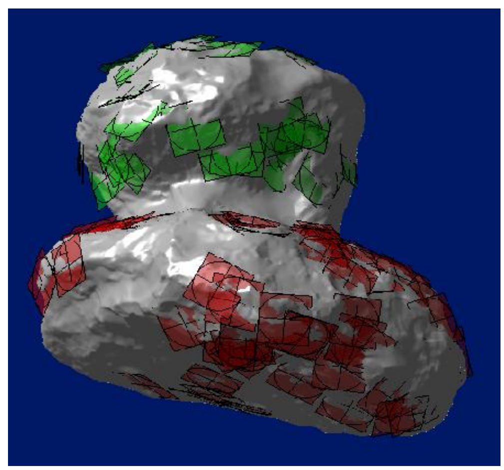

Figure 1: Planes referred to terraces on the 3d model with color depending by the lobe considered.

All the terraces are extracted from the 3D photo clinometric model (3.6M faces at 6m sampling). Best fitting planes are derived from the points clouds defined on the model.

These data allowed us to realize geological sections across the comet in order to infer the subsurface structure of the two lobes. In addition gravity vector fields were calculated for the entire bi-lobe shape body as well as for the two isolated (and reconstructed) lobes.

Stereographic projections are then used to describe statistics of the orientation of planes in the relative reference system [5] of the gravity fields [2,3,4].

This enabled us to evaluate the angular relationship between the gravity vectors and the strata planes at different regions of the comet both considering the entire nucleus or two distinct objects.

2. Results

67P/CG layering form a nearly continuous (up to 150 m thick) envelop of the major lobe (the main body) which is independent for an analogues envelope of the minor lobe (the head). Thus the geo-structural analysis revealed that layers are neither continuous throughout the Hapi valley nor compatible between the two lobes[6]. Gravity vectors are nearly perpendicular to the layers considering the two separated lobes and diverge from perpendicularity considering the entire comet nucleus.

2. Conclusions

All the above mentioned evidences are in favour of 67P/CG being an accreted body of two distinct objects with onion-like layered envelopes formed before their aggregation.

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Guiding electron to neutral number density ratios in the coma of comet 67P/Churyumov-Gerasimenko throughout the pre-perihelion phase of the Rosetta mission

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Abstract

We combine TIMED/SEE solar EUV spectra [1] with photoionization cross section sets [2] to derive partial photoionization frequencies of H_2O, CO and CO_2, the dominant molecules in the coma of comet 67P/Churyumov-Gerasimenko [3]. The values are in accord with earlier estimates [4] although with some differences regarding the yield of minor product ions. The computed H_2O ionization frequency in the coma of 67P is estimated as a function of time (and heliocentric distance) from August 2014 to August 2015, from the rendezvous of Rosetta with 67P at ~3.6 AU to perihelion at ~1.25 AU. This time-dependent ionization frequency is used together with an adopted radial speed of the cometary neutrals of 650 m/s [5] to generate a guiding electron to neutral number density ratio, $G_{e/N}(r,d)$ as a function of cometocentric distance, r, and heliocentric distance, d. We present a parameterization of $G_{e/N}(r,d)$ and argue that comparisons of observations with $G_{e/N}(r,d)$ is a useful method to gain insights into physical and chemical processes at play in the cometary coma. Minor deviations, by up to a factor of 2 or so, can result from missing ionization processes and by variations in the chemical composition, in the impinging solar EUV irradiation, or in the neutral's outgassing speed profiles. Such effects are accounted for in Ref. [6]. Major deviations, with $G_{e/N}(r,d)$ being significantly higher than ratios observed, can result e.g., from the effect of electric fields accelerating the ion population or, near perihelion, by attenuation of the solar EUV irradiation, by the increased importance of dissociative recombination as a plasma neutralizing mechanism [7] and possibly also, by nanograin charging [8]. Observations by LAP, MIP and ROSINA onboard Rosetta at r=10 km and d=3.2 AU indicate an electron to neutral number density ratio of 1-2x10^{-6} [9]. This is surprisingly well in resemblance with our $G_{e/N}(r=10\text{ km}, d=3.2\text{ AU})$ value of 1.0x10^{-6}. Further comparisons with observations will be presented at the meeting.

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Far-ultraviolet spectroscopy from inside the coma of comet 67P/Churyumov-Gerasimenko with Alice on Rosetta

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Abstract

We present observations of the coma of comet 67P/Churyumov-Gerasimenko made by the *Alice* far-ultraviolet spectrograph on *Rosetta* between January and mid-April 2015. Atomic emissions of hydrogen, oxygen, and carbon are interpreted in terms of dissociative electron excitation of H_2O, CO_2, CO, and O_2, whose relative abundances can be derived from the spectra and which are found to be both spatially and temporally variable.

1. Introduction

The *Alice* far-ultraviolet spectrograph is a lightweight, low-power, imaging spectrograph optimized for *in situ* far-ultraviolet (FUV) spectroscopy of comet 67P. It is designed to obtain spatially-resolved spectra in the 700-2050 Å spectral band with a spectral resolution between 8 and 12 Å for extended sources that fill its field-of-view. The slit is in the shape of a dog bone, 5.5° long, with a width of 0.05° in the central 2.0°, while the ends are 0.10° wide. Each spatial pixel or row along the slit is 0.30° long. Details of the instrument are given in [2]. Measurements of the ultraviolet reflectance properties of the nucleus have been reported in [3].

In our initial paper on the measurement of coma gas emissions [1], we reported on observations made between August and November 2014 that showed multiplets of atomic hydrogen and oxygen concentrated in the first few km above the limb of the comet. From the relative intensities and the presence of the forbidden O I λ1356 multiplet, we identified photoelectron dissociative excitation of H_2O as the source of the observed atomic emissions. The electrons are produced by the photoionization of H_2O. This spectrum is fundamentally different from far-ultraviolet comet spectra observed from Earth orbit, which view the coma on scales of hundreds to thousands of km, in which atomic emissions are due to resonance fluorescence of solar ultraviolet radiation. The spectra also showed weak emission of C I $\lambda\lambda$1561 and 1657 and C II λ1335, which we attributed to electron dissociative excitation of CO_2, whose abundance relative to H_2O was found to be variable.

2. Results and Summary

Beginning in January 2015 we have observed many instances in which the atomic multiplet ratios have differed significantly from those nominally seen and attributed to electron dissociative excitation of H_2O. These were observed in two distinct modes: 1) at distances greater than 80 km from the comet, coma is observed in the wide ends of the spectrograph slit above both sunward and anti-sunward limbs; and 2) in instances when part of the nucleus is in shadow so that emissions are seen along the illuminated line-of-sight to the dark nucleus. The relative atomic line intensities can be used, together with laboratory cross section data, to evaluate the contributions of the various molecular parents to the observed spectra. For example, when C I λ1657 is comparable to H I Lyman-β in brightness this implies a high CO_2 abundance relative to H_2O. Another interesting case is when the brightness of O I λ1356 is comparable to that of O I λ1304 but C I λ1657 is weak, which implies electron impact on O_2 as an important source. The origin of the significant abundance of O_2 near the nucleus remains uncertain.

In addition to the spectral analysis and the relative parent abundance determination, we will discuss the evolution of the coma emissions with time, their spatial extent, and their possible sources relative to the locations on the nucleus near where they are seen. Quantitative analyses will require concurrent information from several other *Rosetta* instruments.

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Apparent and real temporal variability of surface components of 67P/CG nucleus with Rosetta VIRTIS

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Abstract

The surface material of comet nucleus 67P/Churyumov-Gerasimenko contains components with a broad absorption band between 2900 and 3600 nm [1] that was revealed by the Visible and Infrared Thermal Imaging Spectrometer (VIRTIS, [2]) on the Rosetta spacecraft. Absorptions in this range of wavelengths are likely due to C-H and/or O-H chemical groups in various compounds [1, 3, 4]. In this study we investigate the distribution of this absorber across the surface of the comet nucleus, and apparent temporal variability on areas where the absorption band is the strongest.

1. Introduction

Comets are objects that probably contain components that are mostly unaltered since their formation. In addition, they may have contributed in bringing molecules such as H_2O, organics and amino acids at the surface of the planets, satellites and asteroids in the early stages of their formation. Their study is therefore important both to 1) to analyze their processes of formation, which may document the environment at the time of the formation, or even prior to the formation of the solar system, and 2) to clarify their role in the geological and biological evolution of the Earth. Organics are of premium interest, and the nucleus of comet 67P/C-G exhibits a broad and complex absorption band between 2900 and 3600 nm, with some diversity across the surface that may correspond to several types of C-H and/or O-H bonds in a variety of molecules [4]. Our objective is to determine whether apparent variations in absorption band depth in VIRTIS spectra can be indicators of present surface activity, and how much multiple scattering may enhance this effect. Cometary activity involves degasing of water vapor, which may expose materials that is otherwise masked by a top layer of dust. If water ice is present also in the subsurface, it would change the band depth, position and depth of the 2900-3600 nm absorption.

2. Data: All VIRTIS-M IR pre-landing observations

VIRTIS-M (Mapper) measures radiation in the range 0.25-5.1 µm with one detector in the visible (0.25-1. µm) and a second one in the near-infrared (1.-5.1 µm). In this study, we used all observations of the pre-landing phase, between June and December 2014 which represent approximately 10^6 spectra. These observations were designed to study the surface of the comet nucleus in order to choose a site for the lander Philae [5],. Some of these observations have been acquired after the landing. During these six months, the solar distance of the comet decreased from 3.82 and 2.76 astronomical units, resulting in an increase of the thermal emission, affecting increasingly shorter wavelengths. In this study, we focused on locations with a strong and broad absorption feature around 3 µm that were observed several times under various solar incidences, and for which the temperature was low enough to not be affected by thermal emission shorter than 3400 nm.

3. Spectral analysis: Apparent temporal variations in absorption band depth

We first calibrated VIRTIS M IR spectra in I/F (division of the measured radiance by the solar spectrum). In order to compare the variations in absorption band depth, we calculated the average I/F between 1000 and 2600 nm, except within small ranges at the edge of order sorting filter, where scattered light occurs, and we divided each spectrum by its own average I/F. This technique has the advantage of minimizing illumination effects due to the local topography, without using a digital elevation model. Figure 1 illustrates apparent variations in absorption band depth of one location observed multiple times. Its location is shown in Figure 2.

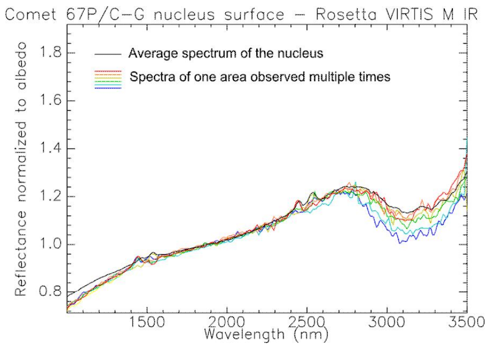

Figure 1:.Spectra of one location at the bottom of the nucleus (showed in Figure 2) where apparent variations as function of time are observed in absorption band depth between 2900 and 3600 nm.

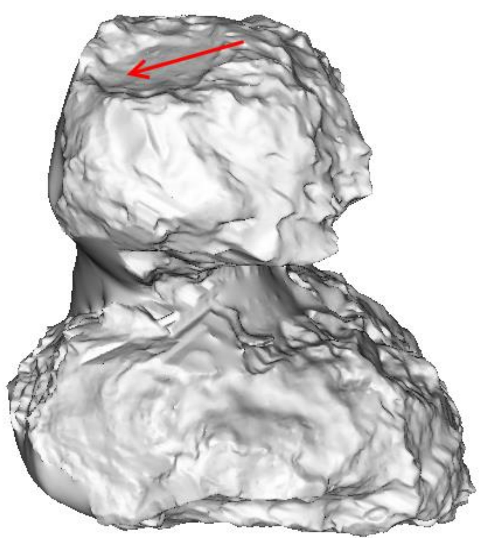

Figure 2: Shaded view of the comet nucleus shape model. The red arrow indicates one location on the head of the comet nucleus where apparent temporal variability has been observed by VIRTIS.

4. Summary and Conclusions

The area presented in this study has a stronger band than the average spectrum of the nucleus (Figure 1). However, given the high solar incidence angle and the rugged topography in the area, these apparent variations may be enhanced by multiple reflections on surrounding terrains. In addition, if the surface regolith is rough, some facets may be illuminated under low incidence angles, which may result in high diversity in surface temperatures within an area observed by one pixel, therefore we cannot exclude possible thermal emission contamination. We will investigate the amplitude of those effects in order to determine how much the observed variations in absorption band depth can be due to temporal variations of the surface material abundance. We will also determine whether this change in absorption band depth can be partially or totally attributed to water.

Acknowledgements

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Identification and Characterization of the landing site of Philae from OSIRIS-NAC Images

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Abstract

On 12 November 2014, Philae rebounded from its first touchdown at the selected Agilka "J" site on the nucleus of Comet 67P/Churyumov–Gerasimenko, an event captured by the Rosetta's OSIRIS narrow-angle camera (NAC [1]). Following two additional bounces, Philae finally landed at the "K" site later named Abydos. Finding its exact location has been a major challenge and could only be indirectly constrained. Thanks to CONSERT measurements, it was finally possible to bound it by an ellipse of approximately 16 x 160 meters. Complementary analyses were performed at CNES-SONC allowing narrowing down the location of Philae to an area of approximately 10 m radius based on illumination conditions and times of contact between Orbiter and Lander during operations. A more precise localization is however hampered by the uncertainties affecting the present 3-dimensional reconstruction (DTM) of the area, presently at the limit of the illuminated part of the nucleus (Figure 1).

Spotting Philae on the images of the nucleus has been even more challenging. The highest resolution images of the region of interest after Philae's landing were obtained by the OSIRIS-NAC in mid-December 2014 at a distance of approximately 20 km, the image scale implying that Philae would at best appear as a few bright pixels. Bright "spots" are however ubiquitous on the surface of the nucleus, from glittering rocks or from local icy patches [2]. After meticulously scanning the region of interest, several candidates were spotted but the ambiguity could only be removed when a pre-landing image of the OSIRIS- NAC collection was identified whose geometric conditions (illumination and viewing) were very similar to one of the post-landing images of 12 December 2014. Although taken at different spatial resolutions, all topographic details match, except for one bright spot present on the post-landing image as shown in Figure 2.

A false detection or an artefact have been ruled out as this candidate was successfully identified on other images taken in mid-December (Figure 2). A local change in the surface is highly unlikely as no activity has been detected on this presently poorly illuminated part of the nucleus. The determined location is remarkably close to that resulting from the indirect constraints, within approximately 10 m, a further validation of the probable detection of Philae. In fact, this solution satisfies all known constraints, taking into account the present uncertainties affecting the DTM.

The Abydos area appears extremely rough with numerous rocks and boulders scattered around, possibly resulting from the local degradation of the rim of the Hatmehit depression. The roughness is confirmed by the large values of the local slopes determined on the present DTM although they are probably underestimated. It is further dramatically illustrated by several anaglyphs constructed from all suitable NAC images of the landing area, thus allowing a stereo view of the local relief.

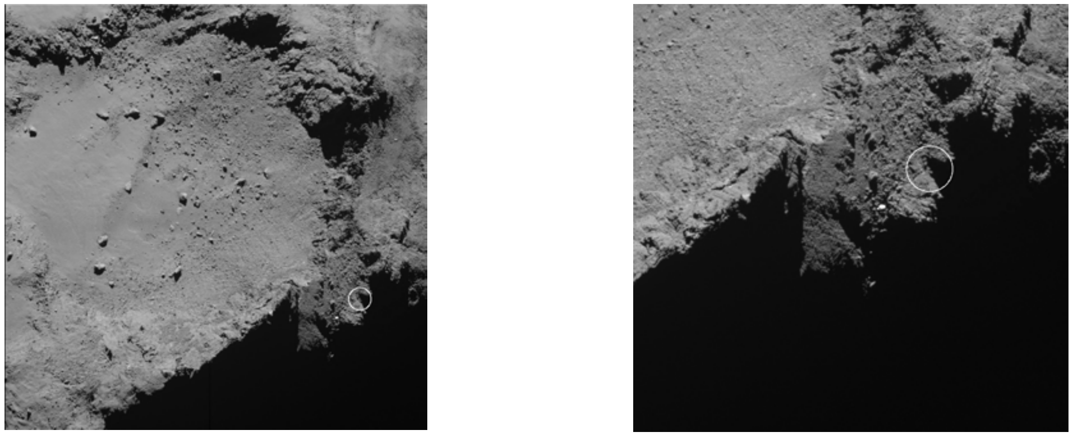

Figure 1: An OSIRIS-NAC image of the small lobe of the nucleus of comet 67P/Churyumov–Gerasimenko showing the large Hatmehit basin and the probable landing zone of Philae best seen on the zoomed sub-image (right panel). The white circles have a diameter of 60 m.

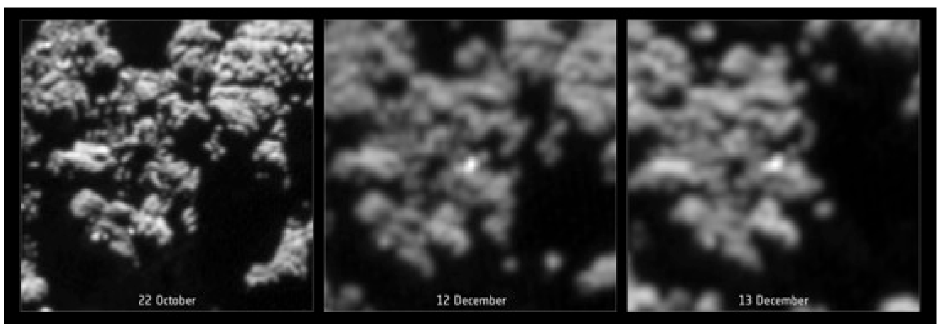

Figure 2: Pre- and post-landing OSIRIS-NAC images illustrating the likely detection of the Philae lander on the surface of the comet. The illumination and viewing conditions, nearly similar on 22 October and 12 December 2014 have already changed on 13 December but still many topographic details can be connected. The original images have been resampled to the same spatial scale. The square images are 20 x 20 m.

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Study of the coma of comet 67P/Churyumov-Gerasimenko based on the ROSINA/RTOF instrument onboard Rosetta

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Abstract

The Rosetta ESA mission investigates the environment of the comet 67P / Churyumov-Gerasimenko since August 2014. Among the experiments onboard the satellite, the ROSINA experiment (Rosetta Orbiter Spectrometer for Ion and Neutral Analysis) includes two mass spectrometers (DFMS and RTOF) to analyze the composition of neutrals and ions, and an instrument (COPS) to monitor the density and velocity of neutrals in the coma [1]. We will here analyze and discuss the data of the ROSINA/RTOF instrument during the comet escort phase. A detailed description of the main volatiles (H_2O, CO_2, CO) dynamics and of the heterogeneities of the coma will be provided.

1. The RTOF instrument

The Reflectron-type Time-Of-Flight (RTOF) mass spectrometer is one of the two mass spectrometers of the ROSINA experiment [2]. It possesses a wide mass range (from 1 amu/e to >300 amu/e) and a high temporal resolution. It was designed to measure cometary neutral gas as well as cometary ions, and is in particular able to detect heavy organic molecules with a very good mass resolution.

2. Results

We will first describe the data analysis process to derive counts/second versus mass/charge spectra from the initial abundance versus time of flight data. The evolution of the abundance of the main volatiles H_2O, CO_2 and CO will then be investigated in detail during the inbound leg of the comet course (until perihelion in August 2015). The heterogeneities of the coma will in particular be investigated on a statistical basis, and the variability of the species abundance will be given as a function of various relevant parameters (distance, phase angle, longitude/latitude, illumination etc.) and compared with the COPS density measurements.

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Search for regional variations of thermal and electrical properties of comet 67P/CG probed by MIRO/Rosetta

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Abstract

The Microwave Instrument for Rosetta Orbiter (MIRO, [1]) on board the Rosetta (ESA) spacecraft observes comet 67P-CG since June 2014. MIRO operates in millimeter and submillimeter wavelengths respectively at 190 GHz (1.56 mm) and 562 GHz (0.5 mm). Both bands provide a broad-band continuum channel for sensing the thermal emission of the nucleus. The submillimeter channel is also coupled to a Chirp Transform Spectrometer (CTS) for spectroscopic analysis of the coma.

Continuum measurements of the nucleus probe the subsurface thermal emission from two different depths. The first analysis of data obtained essentially in the Northern hemisphere [2] [3] have revealed large temperature variations with latitude, as well as distinct diurnal curves, most prominent in the 0.5 mm channel, indicating that the electric penetration depth for this channel is comparable to the diurnal thermal skin depth. Initial modelling of these data have indicated a low surface thermal inertia, in the range 10-30 J K^{-1} $m^{-2}s^{-1/2}$ and probed depths of order 1-4 cm [4].

We here investigate potential spatial variations of thermal and electrical properties by analysing separately the geomorphological regions described by [4]. For each of the 19 regions, we select measurements corresponding to those areas, obtained at different local times and effective latitudes. We model the thermal profiles with depth and the outgoing mm and submm radiation for different values of the thermal inertia and of the ratio of the electrical to the thermal skin depth. We will present the best estimates of thermal inertia and electric/thermal depth ratios for each region selected. Additional information on subsurface temperature gradients may be inferred by using observations at varying emergence angles.

The thermal emission from southern regions has been analysed by [5] during the polar night. By the time the comet reaches perihelion, the South Pole will be fully illuminated, allowing extension of this study to these regions.

Acknowledgements

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Laboratory measurement supporting VIRTIS-M data on 67P/CG

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Abstract

Among the primary goals of the VIRTIS instrument [1] onboard ESA Rosetta mission is to provide the surface composition of the comet 67P/Churyumov-Gerasimenko. The objective of this work is to discuss the needed laboratory measurements on particulate samples supporting the interpretation of the VIRTIS-M spectra.

1. Introduction

Laboratory activity has always been of great importance for the understanding and the interpretation of remote-sensing data. This is also the case of the VIRTIS spectrometer [1] onboard Rosetta mission, currently orbiting the 67P/CG comet.
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].

2. Laboratory facilities

The Astrophysical Laboratory of the University of Salento can rely on two Perkin-Elmer spectrometers covering the spectral range between 0.2 and 25 μm. Both instruments are equipped with Labsphere integrating spheres for measurements of directional-hemispherical reflectance of solid and particulate samples. In addition, a Malvern laser granulometer allows to characterize the grain size distribution of the analyzed sample for a better interpretation of the reflectance spectra.

3. Measurements

Currently, waiting for the perihelion, the work is focused on the composition of the uppermost layer of the cometary surface, in particular the very low albedo and the broad feature centered at 3.2 μm [2]. We have examined some materials, in the range of interest, mainly carbonaceous, with different origin and characteristics. Their spectra are shown in Fig. 1.

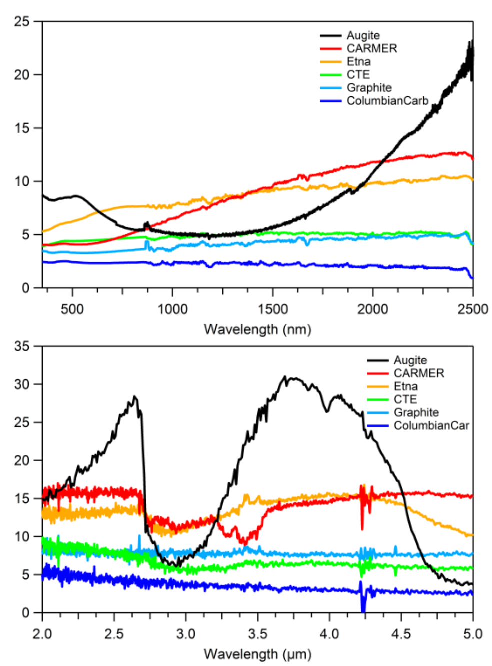

Figure 1: Spectra of several samples analyzed in two different spectral range (350-2500 nm, top panel, and 2.0-5.0 μm, bottom panel): Augite from Harcourt, Ontario; CARMER, carbon from Mericourt mine (Calais, France); Etna, basalt from Etna volcano; CTE, coal tar extracted (Sermide, Italy); pure graphite; pure carbon (ColumbianCar).

The choice of the materials was driven by the need to reproduce the slope in VIS-NIR, the very low albedo and the shallow band at 3.2 μm. We have analyzed three different carbonaceous materials characterized by a low albedo in the whole spectral range (CTE, Graphite and ColumbianCar), a mature carbon (CARMER) showing the slope in VIS-NIR and the feature at 3.2 μm, and two silicate materials: a volcanic basalt (Etna) and a pyroxene (Augite). We are currently analyzing the spectral behaviour of some other materials and, then, we shall characterize their composition and morphology. The objective of the work is trying to fit the observed cometary spectrum focusing on the possibility of a binary mixture of pyroxenes and carbonaceous materials, taking also into account, if possible, the influence of the grain size.

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'études spatiales et d'instrumentation en astrophysique of the Observatoire de Paris, France, and the Institut für 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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CONSERT Radar Investigations of the Shallow Subsurface of Comet 67P, in the Vicinity of the Philae Lander

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Abstract

With receivers and transmitters on-board both Rosetta's main spacecraft and the Philae lander, the CONSERT (Comet Nucleus Sounding Experiment by Radiowave Transmission) bistatic radar has been designed and operated to retrieve information about the internal structure of 67P/Churyumov-Gerasimenko nucleus [1].

CONSERT was successfully operated during the First Science Sequence (FSS) after Philae's landing on the nucleus. While the CONSERT's primary goal is to perform the tomography of the whole nucleus, in this paper, we specifically focus on the local variations in the nucleus shallow subsurface permittivity over depths ranging from tens to hundreds of meters and investigate a possible difference between the Eastern and Western side of the Philae's landing site.

A number of propagation simulations corresponding to the geometrical configurations at grazing angles have been performed for a variety of subsurface permittivity models. The effect of local vertical and horizontal variations of the permittivity values around the landing site as well as comparison with CONSERT's experimental data collected in the same configurations will be presented and discussed. A possible interpretation of the results will be presented

1. The model for the nucleus' shape and subsurface dielectric properties

The nucleus shape model for the simulations is derived from the images of the comet taken by the OSIRIS camera [2]. At CONSERT's 90 MHz frequency, the dielectric properties depend on the porosity, the composition and on the temperature of the nucleus. As a consequence, the data collected by CONSERT should provide information about these parameters values and their spatial variations inside the nucleus. The range of permittivity values we used for this study is based on experimental values available in the literature [3], [4]. These values have been obtained through measurements performed in laboratory on ice/dust mixtures at low temperature and for high porosity values around 70 - 80% commensurate with the information provided by the other instruments of the Rosetta payload.

2. Simulations tool and results

Electromagnetic simulations have been run on these nucleus models to simulate the propagation of the CONSERT waves at 90 MHz between Philae lander and the orbiter. A fast ray tracing method has been used to provide simulated data for a large number of nucleus dielectric constant configurations. It allowed us to study of the effects of the permittivity spatial variations in the shallow subsurface. We considered a variety of possible features such as: a gradient with depth either positive or negative or a random variability of the permittivity. Fig.1 and Fig. 2 illustrate the propagation of the waves from the lander's location. They show how a permittivity gradient in the shallow sub-surface has a potential strong effect on the wave propagation. In both cases, a permittivity gradient taking place within a 50-meters layer below the surface has been considered. Fig. 2 corresponds to a decrease of permittivity with depth while Fig. 2 illustrates the effect of an increase of permittivity with depth.

In this latter case, the rays' curvature clearly show that the refraction prevents the waves transmitted by the lander to propagate towards some given angular directions, which is consistent with the measurement performed by CONSERT during the FSS.

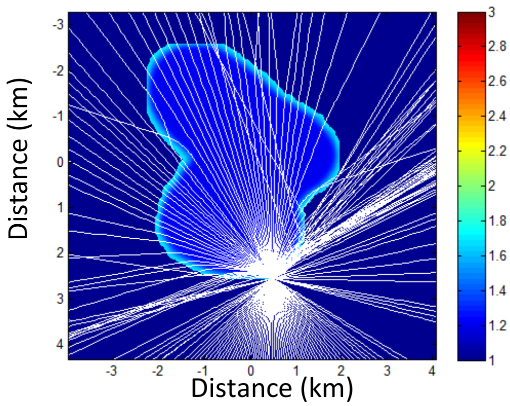

Fig.1: Results of the ray tracing method for a permittivity that decreases with depth. The color indicates the dielectric constant value.

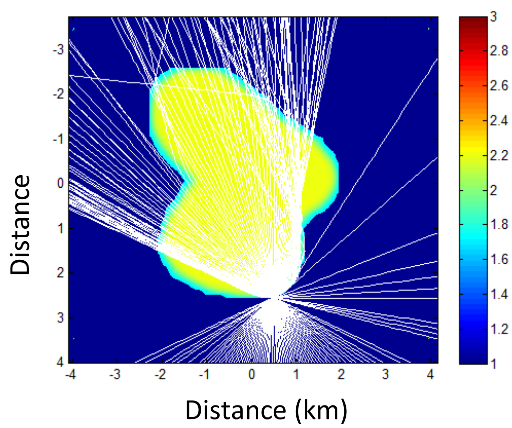

Fig.2: Results of the ray tracing method for a permittivity that increases with depth

3. Conclusions

Comparison between simulated data and experimental data allow us to exclude a situation where the permittivity significantly increases with depth and where the mean permittivity value is larger than 1.3**,** in agreement with a result obtained for an homogenous nucleus [5]

These results can be interpreted in terms of porosity and dust/ice ratio. A preliminary comparison with a model of the subsurface thermal and physical modifications induced by volatiles' sublimation and possible dust crust formation will also be presented.

Acknowledgment

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Icy structures and terrain in comet 67P/Churyumov–Gerasimenko

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Abstract

Rosetta's remarkable images show several indicators of an underlying icy morphology underlying the very black crust. Smooth, planar 'seas' and flat-bottomed craters are features seen also on comet Tempel-1. Surfaces peppered with mega-boulders are like comet Hartley-2. Parallel furrowed terrain appears as a new ice feature. Modelling indicates the 'seas' and crater lakes are refrozen bodies of water overlain with organic-rich debris (sublimation lag) of order 10 cm. The parallel furrows reflect ice fracturing from flexing of the asymmetric and spinning two-lobe body. The mega-boulders are hypothesised to arise from bolide impacts into ice. The outgassing evident at 3.3AU, with surface temperature peaks of 220-230K, implies loosely bound H_2O and/or unconsolidated organic mixtures. Increasing rates of gassing as Rosetta follows comet 67P around its 1.3 AU perihelion will hopefully reveal the activation of possible micro-organisms as well as the nature and prevalence of near-surface ices.

1. Introduction

The old comet model of frozen elementary gases, perhaps combined with H_2O in clathrates and condensed in the early solar system, has not been tenable since the 1986 missions to comet Halley. Comets evidently have high fractions of carbonaceous and mineral solids, and are well-processed bodies, with a geology that reflects their past history and particularly their orbits within the inner solar system. The distinct types of terrain are grouped by Thomas et al [1] into five categories: dust covered terrain, regions exhibiting brittle surface material with pits and circular structures, large-scale depressions, and smooth exposed surfaces. Such features are not consistent with the Whipple dirty snowball model of a comet, with layer by layer peeling off on perihelion passages when solar heating sets in. Rather, comets develop surface crusts that severely restrict gas escape. They also suffer meteorite impact 'weathering.

Comets have long been seen as low-density bodies, 67/P's density of 0.45 (450kg/m^3) constrains the bulk material to have high porosity with its dust component more carbonaceous than mineral. Despite low density, comets are coherent bodies shown by long features and proud-standing mega-boulders. The 'spotty' appearance in Fig.1 comes from 20-50m boulders and their shadows.

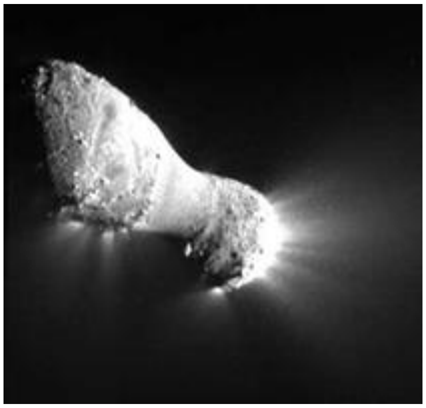

Figure 1 Comet ***Hartley-2*** *NASA News Release 4 Nov.2010:* size ~2km long with 0.4km wide 'neck'. Note the 400m furrow (left end) and a longer sinuous ravine to its left indicating large scale coherence. The neck area of the 2-lobed structure appears devoid of boulders and craters, a property shared with comet 67/P.

Flatbottomed craters and smooth sea-like areas on comet Tempel-1 [2] both indicate bodies of once-molten ice. The main 'tadpole' sea on comet Tempel-1 is a plateau, curving around the nucleus. As on Mars, any ice-covered water body develops sublimation lag as a protective coat. Icy-carbonaceous material outgasses and its residues consolidate under solar radiation into a crust, as discussed earlier in the comet context [3,4].

2. Key Rosetta Images

Comet 67P has a large smooth area like a 'sea' surrounded by an elevated rugged terrain (Fig. 2).

Exposed water would rapidly freeze over and develop a protective regolith, in a new impact crater. But this cometary sea must have been sub-surface from the start [4].

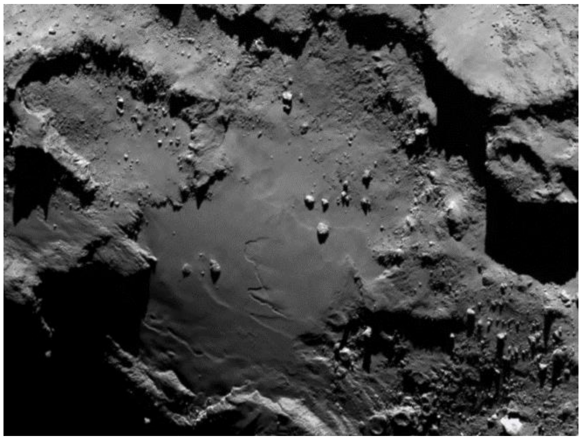

Figure 2 The large planar 600 x 800m Cheops 'sea' located in the Imothep region. It curves away into shadow approaching the terminator at bottom left. The plateau at the top right corner (semi-circular) is a few 100m higher than the sea and appears to have shed debris at the cliff-foot. The cluster of boulders beyond most debris suggests larger fragments roll further over a rigid surface (ESA/Rosetta/MPS for OSIRIS Team).

Fig. 3 shows striking terrain to the right of a largely smooth area, with rocky terrain on both sides. The dark furrows are aligned rather close (20°) to the solar direction and appear metres-deep, so may penetrate the protective crust well into underlying ice. Their position on the 'neck' suggests that the system of cracks and furrows above them are generated by flexing of the two lobes as the comet rotates – as also for comet Hartley-2 (Fig.1). The aligned furrows are reminiscent of cracks on Europa, generated by tidal flexing of that icy satellite, driving ice cracking, creep and convection. Though comet 67P lacks Europa's internal ocean, its furrows would still be sites for active outgassing and jet emissions.

3. Discussion

Rosetta allows us for the first time to watch ice-related changes that relate to comet activity and evolution. Quiescent outgassing such as seen from Comet 67P in July 2014 at 3.9 AU from the Sun is evidence of near-surface icy materials under a weathered crust. More distant episodes of H_2O outgassing from comets, like comet 67P in Nov 2007 at 4.3AU, may be triggered by bigger meteorite impacts; but the low probability of such an event and the observed tendency for repetitive outbursts (eg. of Hale-Bopp at 6.5AU) favour another cause [2]. Chemoautotrophic microorganisms released into the transient lakes laden with organics would rapidly metabolise and replicate, releasing heat that might increase the initial melt volume by a factor of 10-30. Methane or carbon dioxide produced by bacteria as metabolic products can then build up to be eventually released through fissures in the overlying ices or at the lake edges, in the furrows, cracks in ice (sea or craters), bottoms of crater pits, or at the feet of exposed rocks. We argue [2] for consideration of insolation-related biological activity close to the exposed surface of the comet, generally associated with icy features.

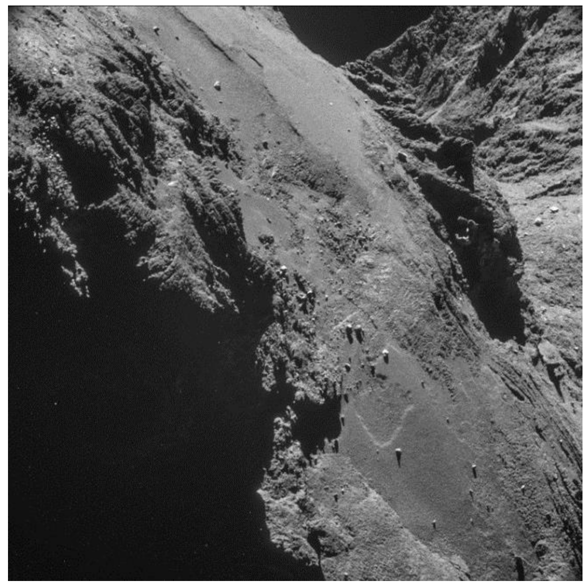

Figure 3 Terrain close to the 'neck' between the two comet lobes (see Fig. 5); the smaller lobe rises in the background. The parallel furrows with 5-10m spacing give the appearance of flexing or compression. (NAVCAM top 10 at 10 km, no. 9 ESA/Rosetta/ NAVCAM – CC BY-SA IGO 3.0; full image size 857m square).

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