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MAIRIE DE TOULOUSE

Diurnal and Annual Variation of CO

Emission from 67P/Churyumov-Gerasimenko

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ABSTRACT

We will report both the diurnal and the annual variation of the CO emission measured with Alice, the ultraviolet spectrometer on Rosetta, at comet 67P/Churyumov-Gerasimenko. We make use of the Deep Volatile Abundance Campaigns (Deep VACs), during which the boresight of the spacecraft was fixed to monitor the sunward limb (and the tailward limb when the field of view was sufficiently large) over one or more successive rotations of the nucleus. The slit of the Alice spectrograph was always aligned sunward-tailward and passing over the center of the nucleus during these VACs. Averaging the sunward and tailward release provides a crude estimate of the global activity, while monitoring the sunward release provides a means of determining the nuclear regions that dominate the release of CO. Ratios of the 1-0, 0-0, and 0-1 allow discrimination of fluorescence by CO from the dissociation or CO2 into CO. The validity of averaging sunward and tailward can be checked in some cases by using observations offset perpendicular to the slit of Alice. Integrating over the diurnal variation allows an estimate of the total release per rotation. Regular Deep VACs from before the southern vernal equinox until after the southern autumnal equinox allow us to directly estimate the total release of CO by the comet during an orbital period, since the CO is largely undetectable in our early observations and only intermittently detectable near the end of our observations suggesting only a minor contribution from the unobserved portion of the orbit.

Dynamics of decimetre-sized aggregates in the coma of 67P/Churyumov-Gerasimenko

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ABSTRACT

The OSIRIS camera system on board Rosetta observed individual decimetre-sized aggregates released from confined areas on the nucleus on various occasions. Starting from one particular observation obtained on 2016, January 6, we discuss the motion of these aggregates under the influence of gravity, gas drag, rocket force induced by asymmetric sublimation of ice due to a temperature gradient across an aggregate's surface, and torques on a rotating, aspherical aggregate embedded in a gas flow.

Following the motion of individual aggregates through an image sequence of about 2h, we measure the projected velocities and accelerations of the aggregates. We find that approximately 50% of the aggregates are accelerated away from the nucleus, and 50% towards it, and likewise to either lateral direction. The measured accelerations are up to one order of magnitude stronger than local gravity, and seem to have significantly influenced the aggregates' motion during the approximately half hour between their release from the surface and our observations, which is suggested between the correlation between acceleration and velocity.

We analyse the gas flow and its coupling to the aggregates using the Direct Simulation Monte Carlo (DSMC) method to find out whether gas drag alone can explain the observed velocity and acceleration or whether the rocket effect is needed in addition, which provides an estimate of the aggregates' ice content. We also address the question if the aggregates received an initial kick upon leaving the surface, providing constraints to the mechanism of their ejection.

Comets in the Young Solar System: First Results from Hybrid Plasma Modelling

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Abstract

The observations of the Rosetta mission and, in particular, of the Rosetta Plasma Consortium (RPC) have provided lengthy in-situ observations of a cometary plasma environment. Building on results of the Rosetta mission, we have taken recent astronomical findings on the evolution of the Sun and the solar wind and employed them to provide the first iteration of an early solar system cometary plasma model.

We investigate a 67P-like comet at three heliocentric distances (corresponding to the orbital distances of Venus, Earth and Mars) and at solar system age of approximately 100 Gy, using EK Draconis as a solar proxy. The strong inferred EUV flux, along with strong solar wind and low solar constant provide harsh conditions for the coma, creating plasma environments considerably smaller than with contemporary conditions. We discuss the differences between modern and young solar system cometary plasma environments, present the first results of the modelling and provide discussion on the planned developments to modelling the young solar system comets.

What did Rosetta tell us about the formation of Jupiter ?

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ABSTRACT

We review our knowledge on the link between the chemical composition of comets and Jupiter in the pre-Rosetta era (with Halley) and summarize the questions this mission left us with. We then show how the chemical composition measurements in comet 67P/C-G answered many of these questions and shed new lights on the origin of Jupiter and ther other giant planets. We use a global formation model based on pebbles accretion (a mechanism than gained further acceptance after Rosetta measurements) and includes chemistry of disk to link the chemical composition of Jupiter to that of the disk and Rosetta.

Highlights of the Rosetta mission from the Rosetta orbiter spectrometer for Ion and Neutral Analysis (ROSINA)

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ABSTRACT

In this talk I will review the main results from the ROSINA mass spectrometers during the two years at the comet. Some of them were expected, even so they are first detections, like N2 and Argon. Some of them were expected, but surprising like a high D/H in water and some of them were unexpected like O2 and glycine. While N2 and Argon confirmed the cold formation temperatures of comets, the high D/H not only put doubts to a cometary origin of terrestrial water, but also made clear that the distinct formation regions of the different dynamical classes of comets cannot be

upheld. Like Argon, Krypton and Xenon were assumed to be in the cometary ice, but it was nevertheless surprising that ROSINA measured 5 out of 6 Krypton isotopes and 7 out of 9 Xenon isotopes. Analysis is ongoing, but the impact of those measurements on the history of solar system formation and the Earth-comet connection will be huge. The abundance of complex hydrocarbons, alcohols, sulfur bearing species and PAH's links comets to the presolar cloud. Cometary ice may have at least partly survived the collapse of the cloud and the accretion of comets, a fact, which was heavily debated before. To be able to monitor the comet over a large part of its orbit around the Sun gives invaluable clues on the mechanisms which drive cometary activity and therefore on the interior structure of the comet. The many new detections and the conclusions which can be drawn from ROSINA results show that in situ mass spectrometry is a very powerful tool in cometary and planetary science.

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Europlanet H2020 Planetary Space Weather Services for Cometary Science

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ABSTRACT

Under Horizon 2020, the Europlanet 2020 Research Infrastructure (EPN2020-RI) will include an entirely new Virtual Access Service "Planetary Space Weather Services" (PSWS) that will extend the concepts of space weather and space situational awareness to other planets in our Solar System and in particular to spacecraft that voyage through it. Five entirely new 'toolkits' accessible to the research community and to industrial partners planning for space missions will be made available: a general planetary space weather toolkit, as well as three toolkits dedicated to the following key planetary environments: Mars (in support ExoMars), comets (building on the expected success of the ESA Rosetta mission), and outer planets (in preparation for the ESA JUICE mission to be launched in 2022). We will describe here all the developments related to cometary science in the framework of the programme. Europlanet 2020 RI has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 654208.

Radiogenic Volcanism of Primordial Comet Interiors

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ABSTRACT

In this work, a possible physical mechanism for eruptions and volcanism in primordial comet interiors is proposed. Due to the motion of a solidification front, radiogenic particles could be more likely to be ejected than to be engulfed by the front, and, as a result, a mechanism by which radiogenic particles accumulate may be developed. If the rate of accumulation due to this mechanism is greater than the rate of natural radioactive decay, then an increase in the concentration of radiogenic material in the molten core will result in a continuous temperature rise. For small comets, the boiling point of the innermost region could be reached, and subsequent cometary eruptions cannot be ruled out. Using a simplified physical geometrical model, analytical expressions for the probability of volcanism are derived.

The possibility of volcanic activity in primordial comets could be of importance in determining the final morphology displayed by such comets, e.g. in the formation of cometary lobes, and even more importantly by providing a mechanism for the ejection of cometary material without the need for external sources, e.g. solar heating or collisions, as required in current panspermia theory.

Cometary dust composition and its variation as seen by COSIMA over nearly two years of the Rosetta mission

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ABSTRACT

The COSIMA instrument is a Time-Of-Flight Secondary Ion Mass Spectrometer collecting and analysing *in situ* cometary dust particles in the vicinity of comet 67P/Churyumov-Gerasimenko. The mass resolution of COSIMA (1400 at full width half maximum at m/z=100) allows in most cases to resolve elements from organic molecular ions.

Mass spectra of the cometary particles have been acquired since August 2014. The elemental composition and variation of the dust particles over nearly two years will be presented. The link between the cometary carbon content and the interplanetary dust particles will be particularly emphasized.

Relations among TNOs, comets, and asteroids

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Asteroids, comets, and transneptunian objects (TNOs) show different observational characteristics due to their history and evolution, but as primitive leftover building blocks of the Solar System formation, they offer an un-rivalled record of the chemical mixture from which the Solar System and its planets formed some 4.6 billion years ago.

The study of the small bodies that orbit the Sun beyond Neptune has completely changed our view of the Solar System. In the last decade, a huge quantity of data has been obtained by large ground-based telescopes and by space missions. Various surface compounds have been detected, including ices of water, methane, nitrogen, methanol, ethane, and ammonia. An overview for all available surface properties on TNOs and Centaurs will be presented analysing the ice content with respect to their physical and dynamical characteristics and their analogy to cometary nuclei.

Primitive dark asteroids following the taxonomical C, P, and D types have wide distribution in the Solar System from NEAs to Trojan population with the composition partly similar to comets. Recent discoveries of asteroids with cometary-like activity and asteroids with the presence of water ice are new arguments in favour of a compositional continuum of these objects, as the evidence shown by the Stardust sample return mission. Some meteorites such as the primitive chondrite Orgueil, might also directly originate from comets.

Mass-loading of the solar wind around 67P/CG as seen by the Rosetta Plasma Consortium Ion Composition Analyzer (RPC-ICA)

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ABSTRACT

The Rosetta Plasma Consortium (RPC) has been observing the plasma environment in the vicinity of the comet 67P/Churyumov-Gerasimenko for the last two years. We focus here on how the solar wind (SW) flow is affected by its interaction with the partially ionized coma, using data from the Ion Composition Analyzer (RPC-ICA).

At large heliocentric distances (*i.e.* low nucleus activity), the entire coma is permeated by the SW, and plasma boundaries such as bow shock or ionopause are not yet formed. Mass-loading (initially, neutral particles being ionized within an undisturbed plasma flow) is the main mechanism through which the coma affects the SW. Observations show that the SW deflection from the comet-Sun line is controlled by the convective electric field, as expected for mass-loading[1]. For heliocentric distances larger than 2.2 AU, deflection of the observed SW from the comet-Sun line remains bellow 90°, while its deceleration is very low: it is efficiently deflected but doesn't lose much energy[2].

When the nucleus draws closer to the Sun, activity keeps increasing, and the effects of this denser and larger coma on the SW flow become accordingly larger. Proton velocity distributions become much more complex than the previous beam-like distribution, exhibiting parts of the proton population with a main sunward velocity component (*i.e.* deflection reaching almost 180°). The deceleration remains fairly low, the speed stays above 75% of the expected upstream speed.

During this period, no obvious signature of a bow shock is observed, and the SW is reaching the vicinity of the nucleus. In agreement with these observations – complex velocity distributions with limited loss of energy, protons observed close to the nucleus – we propose the following interpretation: the SW gyrates in the coma, with a gyro-radius only function of the radius (distance to the nucleus).

Even closer to the Sun, the SW is not observed at the spacecraft position anymore. A SW free region has been created.

The SW then re-appears after perihelion, when the comet moves away from the Sun. We rewind the same scenario as described above, with a noticeable time-lag indicating a possible asymmetry in the nucleus activity along the inbound and outbound legs of the comet orbit around the Sun.

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[1]Behar et al., GRL 2016

[2]Behar et al., A&A 2016

A simple model of the solar wind flow around 67P/CG based on the Rosetta Plasma Consortium Ion Composition Analyzer (RPC-ICA) observations

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ABSTRACT

For the last two years, the Rosetta Plasma Consortium-Ion Composition Analyzer (RPC-ICA) has been measuring ion distributions in the plasma environment of the comet 67P/Churyumov-Gerasimenko. Spanning heliocentric distances from 3.65 to 1.24 AU, it has been following in particular the effect of the partially ionized coma on the solar wind (SW) flow.

Initially, the SW flow was observed almost undisturbed, with a slight deflection from the comet-Sun line due to mass-loading (*i.e.* neutral particles being ionized within an undisturbed plasma flow). As heliocentric distances decrease, the nucleus activity increases and this denser and larger coma has larger effects on the SW. At first, only the deflection increases, with little to no deceleration. The SW proton velocity distribution is beam-like.

Later on, when this deflection nears 90°, more complex proton velocity distributions are observed, exhibiting parts of the proton population with a main sunward velocity component (*i.e.* deflection reaching almost 180°). However, these distributions are still characterized by a limited loss of energy.

In order to account for these distributions, we introduce a simplistic model of the solar wind flow in the coma. In this 2D model, test-particles experience a single force, always normal to their velocity, with a magnitude proportional to $1/r^2$ (r the radius, or distance to the nucleus). These particles have no influence on each other. This 2D dynamics can be seen as test-particles gyrating in a magnetic field normal to the plane of motion, with an amplitude profile in α/r^2. We show that the resulting curvature of the trajectories is also a function of $1/r^2$.

In agreement with the observations, this model results in an arbitrarily large deflection from the upstream velocity direction depending only on the factor of proportionality α. The energy is conserved, as with the magnetic force. We also show very convincing agreements with results from much more complex simulations of an hybrid model, which validate the relevance and the interest of this simplistic model.

The main result of this simple model is that already in the low activity case, complex velocity distribution are seen close to the nucleus. As soon as the SW is locally deflected, one has to expect distorted velocity distribution, not exactly at the same position than where the largest deflection occurs.

The obvious interest of this model is its extreme cheapness compared to hybrid or MHD models, which makes it an interesting tool to work with, when considering SW flow around a low to medium activity comet.

Atomic Force Microscopy of Cometary Dust:

Results from MIDAS and future prospects

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ABSTRACT

MIDAS, the Microscopic Imaging and Dust Analysis System, is an atomic force microscopic (AFM) carried on-board the Rosetta orbiter. Comprising a sample collection and handling system and AFM, MIDAS collected particles in the coma during passive exposures and scanned them by rastering a sharp tip over the surface, yielding 3D topography. The science goals of MIDAS include characterisation of the micro-structure and texture of cometary dust, its shape size and morphology. Additional imaging modes included phase imaging (related to the elastic properties of the sample) and magnetic force microscopy (to detect and map magnetic inclusions).

The instrument was proposed less than a decade after the development of the first AFM in 1986, and long before the underpinning theory was completely developed. The key result expected from MIDAS as written in the proposal was the “size and texture of individual cometary particles and their building blocks in the range 4 nm to 5 µm.”

The observed dust size distribution at 67P, poorly constrained by remote observations for the smallest particles, was nevertheless used to plan exposures and estimate dust collections. For several months after arrival, scans showed no evidence of dust particle collection. Eventually, in November 2014, dust was first collected and found to be much larger than expected, causing instrumental problems. After this time, dust was sporadically collected until February 2016 when MIDAS was exposing during a large outburst, resulting in a large dust collection that resulted in the majority of the well-imaged dust.

The key results show a diverse morphology of cometary dust at the smallest scale, with particles observed at all scales appearing to be aggregates of smaller particles and having a hierarchical nature. The latest results and conclusions will be presented, including how MIDAS results fit into the framework of cometary science. Finally, if and how such an instrument could be flown on future missions will be discussed.

The new Planetary Science Archive (PSA): Exploration and discovery of scientific datasets from the Rosetta mission

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The Planetary Science Archive (PSA) is the European Space Agency's (ESA) repository of science data from all planetary science and exploration missions. The PSA provides access to scientific datasets through various interfaces at http://archives.esac.esa.int/psa. All datasets are scientifically peer-reviewed by independent scientists, and are compliant with the Planetary Data System (PDS) standards.

The PSA is currently implementing a number of significant improvements, mostly driven by the evolution of the PDS standard, and the growing need for better interfaces and advanced applications to support science exploitation.

The newly designed PSA will enhance the user experience and will significantly reduce the complexity for users to find their data promoting one-click access to the scientific datasets with more specialised views when needed. This includes a better integration with Planetary GIS analysis tools and Planetary interoperability services (search and retrieve data, supporting e.g. PDAP, EPN-TAP). It will be also up-to-date with versions 3 and 4 of the PDS standards, as PDS4 will be used for ESA's ExoMars and upcoming BepiColombo missions. Users will have direct access to documentation, information and tools that are relevant to the scientific use of the dataset, including ancillary datasets, Software Interface Specification (SIS) documents, and any tools/help that the PSA team can provide. A login mechanism will provide additional functionalities to the users to aid / ease their searches (e.g. saving queries, managing default views).

Modelling of the Plasma Environment Surrounding 67p: What Is the Effect of the Convective Electric Field on Ion Density Profiles?

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ABSTRACT

By following comet 67P/Churyumov-Gerasimenko along its orbit, Rosetta during its cruise is offering us the unique opportunity to understand the complex evolution of the comet with its environment. Although the coma is not bounded at the surface, its photo-ionisation by solar extreme ultraviolet radiation is creating a complex plasma environment, which is interacting with and influenced by the solar wind.

In particular, electrons and water ions, such as H_2O^+, are produced from the photo-ionisation of sublimated water molecules. As the newborn electrons are more energetic than ions, they escape faster and an ambipolar should be set up to ensure the quasi-neutrality between ions and electrons. Furthermore, since the comet bathes inside the solar wind, these new ions are affected by the Lorentz force: it includes the effect of the convective electric field which can be described by the ideal Ohm's law of the solar wind. This force may affect strongly the dynamic of new ions and electrons and thus their density profiles around the comet.

We present our first results on the ionospheric density profiles for ions with a kinetic and collisionless approach.

The heliocentric and time variation of the release of molecules by 67P/Churyumov-Gerasimenko as seen by MIRO

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ABSTRACT

During the two years around the Aug. 2015 perihelion, the MIRO instrument on board the Rosetta spacecraft has been regularly mapping the emission of 8 molecular lines around 560 GHz (H_2O and its isotopes, CO, NH_3 and CH_3OH) in the inner coma of comet 67P/Churyumov-Gerasimenko. We have used those observations to estimate the mean outgassing rates as a function of time in 2014-2016 and heliocentric distance (r_h=1.2-3.6 AU). The peak outgassing rate of water (~10^{28} molec./s), based on maps of $H_2{}^{18}O$ was reached slightly after perihelion. We have also measured the evolution of the abundances relative to water of CO, CH_3OH and NH_3. The abundances of CH_3OH and CO significantly increased around and after perihelion time when most of the outgassing was coming from the illuminated southern pole. We have also retrieved the 3-D outgassing patterns, which enabled us to track the location of the bulk of outgassing for each molecule.

The inventory of molecular abundances in comets from mm/submm molecular surveys

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ABSTRACT

Since 1997, beginning with the great comet Hale-Bopp, submm/mm radio techniques have proven to be very efficient in detecting a large number of parent molecules in cometary comae. Current mm detectors, especially at the IRAM telescopes, are now over 20 times more efficient for spectroscopic surveys. The recent apparitions of several bright comets (especially C/2009 P1 (Garradd), C/2012 F6 (Lemmon), C/2012 S1 (ISON), C/2013 R1 (Lovejoy), C/2014 Q2 (Lovejoy) and C/2013 US_{10} (Catalina)) have enabled the detection of all molecules previously observed in comet Hale-Bopp, as well as new Complex Organic Molecules (COMs) such as ethanol and glycolaldehyde. Sensitive upper limits on the abundance relative to water of additional COMs and other molecules of interest observed in comet 67P by the ROSINA instrument on Rosetta, like phosphine, were also obtained and will be presented.

The formation of comet 67P - lessons learnt by Rosetta

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ABSTRACT

Before Rosetta, several competing models of the formation of planetesimals had been published. With the help of the outstanding data of the various Rosetta instruments, we now are able to constrain the formation of the nucleus of comet 67P/Churyumov-Gerasimenko: in its current form, comet 67P must have formed by a gentle gravitational collapse of cm-sized dust aggregates ("pebbles"). Only this model can simultaneously explain the measured porosity, tensile strength, size distribution of emitted dust particles, thermal inertia, temperature profiles, and increase in water production rate with decreasing heliocentric distance, respectively.

I will review the empirical evidence from the Rosetta instruments, describe the formation model and its consequences for the constitution of the nucleus of comet 67P, and develop a thermophysical activity model for the activity of comet Churyumov-Gerasimenko.

Although the formation process of comet 67P has been clarified, it is still unclear whether it was formed as a km-sized body in the solar-nebula phase or in a later catastrophic collision of a larger precursor. This will also be discussed during the presentation.

Seasonal evolution of comet 67P activity from Rosetta/VIRTIS-H observations

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ABSTRACT

Spectroscopic infrared observations of the coma of 67P/Churyumov-Gerasimenko were carried out with the VIRTIS-H instrument onboard Rosetta. Vibrational bands of H_2O, CO_2, $^{13}CO_2$, OCS, and CH4 were detected, from which column densities and abundance ratios were measured. The data set show that seasons play an important role in the activity of the comet. We report here on data obtained from July 2015 to the end of the Rosetta mission. Raster maps obtained from July to November 2015 show prominent CO_2 and H_2O outgassing from the southern regions. The abundance ratios relative to water strongly increased 6 days after perihelion, reaching 32%, 0.5%, and 0.2% for CO_2, CH_4, and OCS, respectively. This is interpreted as resulting from the ablation of devolatilized surface layers in the southern hemisphere, and the subsequent exposure of non-differentiated volatile-rich material to solar heat. Comparison with data obtained pre-equinox suggests that the low CO_2/H_2O values measured above the illuminated northern hemisphere during pre-equinox are characteristics of outgassing from differentiated, dust-covered regions. Unexpectedly, the CO_2 outgassing remained high long after perihelion. A strong pre/post perihelion asymmetry in CO_2 activity is observed on both the southern and northern hemispheres. The large CO_2/H_2O ratio measured around perihelion indicates that 67P is a CO_2-rich comet.

Physical reactions in the inner coma of 67P between 3 AU before and after its perihelion.

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ABSTRACT

Rosetta explored a regime not accessible before: the inner coma of a low-activity comet at a large range of heliocentric distances. The Wide Angle Camera (WAC) of the OSIRIS instrument on board the *Rosetta* spacecraft is equipped with several narrowband filters that are centered on the emission lines and bands of various molecules and ions. These filters allow us to image fragment species that are relatively bright and that have been used for numerous comet studies from Earth, such as OH, CN, OI, NH, and NH_2.

Surprisingly, we found that outside 2 AU pre-perihelion, the light imaged with the filters was dominated by emission from plasma interactions with the neutral gas, most likely dissociative electron impact excitation (Bodewits et al. 2016). Closer to perihelion, higher gas densities reduced electron temperatures in the inner coma and photo-processes drove much if not most of the emission from the comet. Our observations allowed us to study changes in the physical environment of the inner coma with respect to heliocentric distance and at a broad range of activity levels, and Rosetta's excursions as far as 1000 km from the surface allowed us to study different regions of the coma. In this contribution, we will summarize the results of our OSIRIS observations from approximately 3 AU before to 3 AU after perihelion.

Comet Nucleus : Sublimation of Multicomponent Ices

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ABSTRACT

The sublimation and condensation are key processes to get insight in volatiles history and in solar system physical chemistry. These processes play a prime role in planetary science. In comets and in order to link the observed gases production rates to the real ices composition, one have to be as accurate as possible. Sublimation and Condensation are two intimately bounded phenomena, they are widely regarded as a facets of one and only one process which is a first order phase transition mechanism. In this work, we will distinguish between sublimation of pur and multicomponent ices. Sublimation and Condensation of pur ices is a process during which chemical composition hold constant. This have been widely investigated and both theoretically and experimentally. In contrast, systems undergoing chemical composition changes in the vapor phase have not received the same effort. We will highlight misunderstandings and emphasize the improvement. We will draw heavily on the review work of N. Fray & B Schmitt about sublimation of ices of astrophysical interest to address this issue and propose a suitable description to handle multicomponent sublimation process in comets. We will show, where and how our work improve the modeling of this processes. We will address different cases H2 O : CO, H2 O : O2 and H2O : CO : O2 or CO2 systems. The assumptions, approximations and limitations are shown explicitly and finally we discuss the astrophysical implications of this work in the models simulating comet activity.

The Spatial Profile of Cometary Suprathermal Electrons

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Rosetta's observations of 67P/Churyumov-Gerasimenko have highlighted the dynamic nature of a comet's plasma environment. In this work, we study the suprathermal electrons excited in the coma. Broiles et al. [2016; in review] have found some evidence that Landau damping of lower hybrid waves is responsible for heating these electrons. The evidence for lower hybrid wave heating in the coma is strong, but further questions remain. For example, what generates the lower hybrid waves? Are these waves present throughout the coma, or are certain regions preferentially heated? In this analysis we focus on the energetic electrons observed by RPC/IES and discuss their heating mechanisms. We determine how the energetic electron fluxes vary with distance from the comet. This work further constrains the physical conditions responsible for lower hybrid wave heating of cometary electrons, and tell us more about this poorly understood phenomenon.

What can White Dwarf Pollution by infalling Debris tell us about Solar and exo-Comets?

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ABSTRACT

There is extensive evidence that most star type,s from young through Main Sequence and post-Main Sequence to compact objects experience infall of rocky and icy conglomerate debris left over from earlier proto-planetary or disrupted planetary eras.

In the very high gravity of White Dwarf stars, heavy element species should sink under the surface of the predominantly hydrogen body of the star. Consequently the metallicity seen in many WD spectra must be due to ongoing infall of high metallicity debris. Understanding the mechanisms and locations of deposition of such debris as a function of stellar and infaller parameters is important to understanding histories of planetary systems and origins of the debris.

We present a simple analytic formulation allowing easy theoretical determination of which debris destruction mechanism (sublimation, tidal fragmentation or 'impact") should dominate, and at what distance, as a function of infaller size and of two size-scale coefficients, one measuring sublimation rate and the other tidal fragmentation resistance. These coefficients are simple products of powers of stellar parameters (mass, radius, effective temperature) and infaller parameters (density, latent heat, tensile strength). We present results of this approach to WD cometary and rocky debris infall and discuss how they extend to solar and general stellar cases of infalling cometary and rocky debris.

Why are Comets so Dark?

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ABSTRACT

The elusive low-albedo material in the outer Solar System has been considered one of the key vectors for the influx of prebiotic material onto the terrestrial planets. During the past three decades, exploration of the area beyond the asteroid belt has shown the ubiquity of this material. In a region dominated by volatiles, low-albedo material appears on many moons of the outer planets, including the leading side of Iapetus, some areas of the Uranian moons, and the surface of Titan. Dark dust dominates the rings of Uranus and the surface of comets. The nature and evolution of this material, and its relationship to interstellar dust, is one of the key questions in planetary and cometary science.

Detailed analysis of the spectra and albedo of dark material by spacecraft including *Cassini* and *New Horizons* shows that the dark material is diverse, covering a wide range of compositions. Some is neutral-colored in the visible part of the spectrum, such as that found on Phoebe, while some is very red, such as that on the surfaces of D-type asteroids or the dark side of Iapetus. The different types of low-albedo material may reflect both compositional diversity, including contamination by volatiles or darkening agents, and divergent alteration histories. The key question is whether a particular sub-type of low albedo material is pristine, an unprocessed accumulation of interstellar dust; or an end product of polymerization and photolysis into ever more complex materials.

Comets are among the lowest albedo objects, with albedos in the 0.02-0.06 range, a characteristic they share with only a small number of objects, including the leading hemisphere of Iapetus, Titan, and the lowest-albedo C-type asteroids. Observations by the WISE and NEOWISE cameras, which can measure the sizes of comets to unprecedented accuracy, show that comets have consistently low albedos[1]. The first quantitative measurement of low-albedo material in the Kuiper Belt, from which comets such as 67P/Churyumov-Gerasimenko come, shows that even this material is not as dark as that found on comets[2].

What is the factor that makes cometary dust so dark? Results from both *Stardust*[3] and more recently *Rosetta*[4] show that cometary surfaces contain prebiotic molecules, including the amino acid glycine. Other very low albedo objects have similarly been connected to complex organic molecules: in the case of Iapetus, PAHs have been detected[5], and Titan's surface is believed to be covered with hydrocarbons that are produced in its haze layer and fall down onto its surface[6].

The presence of organic molecules, including complex ones, could be the unique characteristic of the very darkest material. The remaining question is whether this material is pristine, heralding from the very earliest periods of collapse from an interstellar cloud, or processed by ultraviolet radiation and, in the case of comets, concomitant devolatizing as successive solar passages are made.

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Dust grains in the coma of 67P/Churyumov-Gerasimenko – link with surface properties and cometary activity

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The imaging spectrometer VIRTIS and the dust analyzer GIADA, onboard Rosetta, made an extensive observation of the dust particles in the coma of the comet 67P/Churyumov-Gerasimenko. From the analysis of GIADA data, two different kind of particles have been revealed, compact and fluffy with different compositions and dynamical properties. Compact particles are characterized by densities of about 10^3 kg/m^3, while fluffy particles have an almost fractal nature, with densities less than 1 kg/m^3.

In this work we present the initial results of a model linking the dust flux distribution, as obtained from a theoretical thermal nucleus model, with a model describing the dynamics of aspherical grains in the coma. The results are discussed in the context of the latest observations from VIRTIS and GIADA instruments.

The 2D nucleus thermal model, when applied to the real shape of the comet, provides the size distribution and physical properties of the emitted grains at different times and location on the surface. The thermal model can simulate grains of various size distribution, composition and physical properties. This information is used as an input for the dust dynamical model that follows the emitted particles in the coma. The main source of heating is the solar illumination. In the dust dynamical model, the grain trajectory of emitted particles remains in a plane perpendicular to the rotational axis and the direction of illumination is taken to be in the same plane (i.e. does not cause transversal forces). The dust particles are assumed to be isothermal convex bodies and temperature changes only induce modest changes in the aerodynamic force (twice higher temperature changes aerodynamic force less than ~30%). This study reviews the theoretical values at which temperature difference starts to play a role on the dynamics. We discuss to what extent the particle's temperature affects the terminal velocities of the dust grains in the 67P coma in dependence on their mass and temperature constrained by the observations.

67P/Churyumov-Gerasimenko's evolving interaction with the solar wind observed by the Rosetta Plasma Consortium

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ABSTRACT

Whilst earlier cometary-encounter missions have observed the plasma environment of a comet at some specific point along its orbital path, the unique feature of the Rosetta mission was to accompany the comet from its relatively inactive state, at a heliocentric distance close to 4 AU, through maximum activity close to perihelion at 1.2 AU, and even beyond as activity declined post-perihelion. The Rosetta Plasma Consortium (RPC) – a suite of plasma detectors comprising ion/electron sensors, an ion composition analyser, magnetometers and Langmuir & mutual-impedance probes – was designed to measure the evolving coma's composition, structure, and interaction with the solar-wind from the first initial traces of activity through to operation in the relatively dense ionosphere at perihelion. RPC's observations of the comet began with water-ions born of solar photo-ionisation at a heliocentric distance of 3.6 AU. At this time, the tenuous coma was fully pervaded by the solar-wind. Decreasing heliocentric distance increased both the sublimation of volatiles and the photo-ionisation rate. Enhanced plasma densities caused a deflection of the solar-wind, draping the magnetic field around the nucleus, enhancing the strength of the magnetic field to levels not previously measured in interplanetary space, and eventually excluding the solar-wind ions entirely. Low-frequency waves were observed (the 'singing comet') and whilst the magnetic field can reach regions deep inside the inner-coma, from which the solar-wind ions are excluded, a diamagnetic cavity was repeatedly observed at remarkably large distances from the nucleus. Excursions to the day-side and night-side complemented a thorough inventory of the near-nucleus environment, and revealed plasma boundaries together with an observation of the environment's compression under the influence of a passing coronal mass ejection. The instruments of the RPC had been optimised for measurement in this dusty plasma environment, requiring a high dynamic range whilst being constrained by resources of mass, power and telemetry. The measurements and performance of the RPC during the whole of the Rosetta mission, supported by extensive simulations, provide an input for the scientific and technical preparation of future cometary missions.

The astrochemical protostellar-comet link

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ABSTRACT

The first phases of the formation of a Solar-like planetary system are featured by a rich chemistry, which is started at the very beginning of evolution of its primordial condensation. Two major and important aspects characterise this phase: the molecular super-deuteration phenomenon and the synthesis of relatively complex organic molecules.

In this presentation, I will review the observations and the theory that allow to link these aspects to the comet volatile composition, and I will discuss what we have and what remains to be understood.

2D-photochemical model for forbidden oxygen line emission for comets 1P/Halley and 67P/ Churyumov-Gerasimenko

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A 2D-photochemical model has been developed to calculate the production and loss mechanisms of the O(^{1}S) and O(^{1}D) states, which are responsible for the emission lines at 577.7 nm (green line), 630 nm, and 636.4 nm (red-doublet), for comets 1P/Halley and 67P/Churyumov-Gerasimenko. The presence of O_2 within cometary atmospheres, measured in-situ by the Rosetta and GIOTTO missions, necessitates a revision of the previously used photochemical models. Indeed, the photodissociation of molecular oxygen also leads to a significant production of oxygen in those excited electronic states, previously attributed to photodissociation of H_2O, CO and CO_2. A 2D approach has been investigated to correctly model the solar UV flux absorption. While the green to red-doublet ratio is not affected by the solar UV flux absorption, red-doublet and green lines emissions are, however, overestimated by a factor of 2 in the 1D model compared to the 2D model for very active comets such as 1P/Halley. Even when assuming spherical symmetry of the neutral gas coma, the phase angle of the observation introduces asymmetries in the measured emission line ratios. Our 2D model can be used to produce emission maps for direct comparison to ground and/or in-situ observations. To show these capabilities we consider two observation angles that might be useful for better constraining the abundance of CO_2 in cometary atmospheres.

Probing the interior of 67P/Churyumov-Gerasimenko

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ABSTRACT

Since the arrival at comet 67P during the summer of 2014, the cameras onboard the Rosetta's main spacecraft (OSIRIS and NAVCAM) and Philae lander (ROLIS and CIVA) have been studying the nucleus surface. They revealed at the surface and inside the walls of the deep pits linked to the comet's activity several-meters scale repeating structures, thus providing hints about the internal structure of the nucleus, and suggesting that primordial 'cometesimals' may be objects around 3m in size.

The CONSERT (Comet Nucleus Sounding Experiment by Radiowave Transmission) experiment is the only instrument that was designed to specifically sound the interior of the nucleus and provide information on the nucleus internal structure. The work presented here is based on the CONSERT data collected during the First Science Sequence (FSS) and marginally during Philae's Separation Descent and Landing (SDL) for comparison. The smaller lobe of the nucleus in the vicinity of Abydos has been actually sounded by CONSERT's electromagnetic waves at 90 MHz with a spatial resolution around 10 m. The measured propagation time during FSS constrains a very low bulk dielectric permittivity value for the cometary material, which confirms the high porosity of the nucleus. The sharp shape of the received signals suggests that the signal suffered weak diffusion through the sounded part of the smaller lobe of 67P, which is thus fairly homogeneous on a spatial scale of tens of meters.

Here, we present further results on the variation of the CONSERT's signal shape transmitted through the small lobe of the nucleus. For a more accurate analysis and interpretation of the data, we split the FSS data into two distinct sets: one corresponding to soundings performed West of Philae and the second one for those acquired East of Philae to investigate potential differences. Tentative interpretation in terms of nucleus internal structure based on propagation simulations performed in non-homogeneous nucleus numerical models will be presented.

VIRTIS observations of the nucleus of 67P/Churyumov-Gerasimenko at low phase angle

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On 9-10 of April 2016, the Rosetta orbiter completed a close flyby around the nucleus of 67P/Churyumov-Gerasimenko, when the comet was at heliocentric distance of 2.76 AU, along the outbound leg of its orbit around the Sun. This allowed the VIRTIS-M imaging spectrometer to observe the surface of 67P at visible wavelengths (0.2-1 μm) in the 0.93°-89.7° phase angle range with a spatial resolution ranging from 7 to 46 m/pix, resulting in a total of 105 hyperspectral images. Previous observations of the comet at low phase angle were acquired by VIRTIS-M during the approach phase on July 2014 (3.7 AU), with pixel resolution varying from 450 to 3200 m/pix, preventing disk-resolved imaging. The April 2016 observations fill this gap, allowing us to constrain the spectrophotometric properties of the surface at higher spatial resolution in the opposition surge geometry, therefore investigating both the 'shadow hiding' and 'coherent backscattering' opposition effect. Extrapolation to 0° phase angle of the reflectance measured during the flyby at latitude between -10° and 30° indicates a surface normal albedo of 0.06 at 0.55 μm. This result is close to the previous average value derived by Ciarniello et al. (2015) from a full-disk analysis giving 0.062+/-0.002 (3.7 AU, inbound orbit). Subsequent measurements by Filacchione et al. (2016) and Ciarniello et al. (submitted), derived from pre-perihelion observations at lower heliocentric distances, revealed a progressive enrichment of water ice abundance on the nucleus, in northern hemisphere regions, with a consequent brightening of the surface. The measured normal albedo derived from the 9-10 April 2016 dataset seems to indicate that during the post-perihelion phase the northern hemisphere has returned to albedo values compatible to the ones measured during the inbound part of the orbit, when the comet was at 3.7 AU from the Sun. This could be an indication that the northern hemisphere has been either covered by dust emitted by the southern hemisphere during the very active perihelion phase, or that dehydration of the upper surface layers has taken place.

Cometary plasma boundaries

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ABSTRACT

Cometary flyby missions provided the first in-situ observations of plasma boundaries. These provided confirmation of anticipated boundaries such as the bow shock and diamagnetic cavity boundary (contact surface). In addition, unexpected boundaries were found including the magnetic pileup boundary, an ion pileup boundary, tail current sheet(s) and a 'mystery' boundary. Here, we review the observations and our understanding of the physics of cometary plasma boundaries, providing context for the Rosetta results.

Modeling Comet Activity:
Connecting In Situ and Remote Sensing Measurements

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ABSTRACT

This talk will review progress in modeling the activity of comet 67P/Churyumov-Gerasimenko by combining both in situ and remote sensing Rosetta spacecraft measurements and using a 3D kinetic model of the coma. Even a state-of-the-art spacecraft such as Rosetta, with 11 orbiter instrument packages and 12 lander instrument packages, which is capable of a wide range of in situ gas, dust and plasma measurements and a wide wavelength range of remote sensing and imaging instruments, cannot be in more than two places (including the lander) at the same time. The coma around a comet is a complex three-dimensional spatial structure that also changes continuously in the fourth dimension, time. In situ instruments can capture detailed information at a series of single locations at a series of times. Remote sensing instruments can capture a "snap shot" of integrated information along up to a 2D array of lines-of-sight, obtained within a reasonably short exposure time. Because remote sensing and in situ instruments are co-located on the spacecraft, they are usually giving information about different regions at different times. Models of the coma are therefore needed in order to provide both a physics-based context to the measurements and to help to fill in the gaps of the limited dimensional coverage of the measurements. In this presentation we show how kinetic simulations link Rosetta in situ measurements and remote sensing observations to form a consistent picture of the neutral gas coma of comet 67P/Churyumov-Gerasimenko and the activity from the surface.

Comets and Astrobiology, (re)assessment for comet 67P after ROSETTA

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Comets are commonly regarded as objects with a prime astrobiological importance. They are reservoirs of a large amount of material considered as necessary for the origin of life: water and organic molecules. While the measurement of the D/H ratio in the water of comet 67P established in the early stages of the mission that comets such as 67P are probably not a source of water on Earth, the nature and amount of the organic content of comet 67P is progressively revealed through the complementary measurements of ROSINA, COSAC, PTOLEMY and COSIMA instrument. The detection of glycine and phosphorous atoms in the atmosphere of the comet have demonstrated the presence of so called “prebiotic” ingredients. However, it takes certainly much more than this to feed the chemical evolution toward the origin of life on a planet.

The part that comets could have played in the origin of life on Earth will be discussed with regard to the inventory of organic matter detected by Rosetta instruments in comet 67P, and in the light of recent advances in prebiotic chemistry.

Large Scale Morphological Changes in the Hapi Region on Comet 67P/Churyumov-Gerasimenko

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ABSTRACT

The Hapi region is located on the northern hemisphere of comet 67P/C-G at the neck that joins the two lobes of the nucleus. It primarily consists of granular material that is unresolved at 0.35 m/pixel resolution and that forms a smooth surface with small slopes with respect to local gravity. The OSIRIS cameras on the ESA spacecraft Rosetta observed Hapi regularly since its rendezvous with the comet in August 2014. No changes were seen during the first five months in orbit but on December 30, 2014, two spots appeared in Hapi. Over the course of two months they grew gradually into a 110 by 70 meter shallow depression with a depth of about 0.5 meters. We use OSIRIS observations to characterize the morphology and spectrophotometry of the region. We use measurements of the thermal emission of the comet by the MIRO millimeter and submillimeter radiometer in combination with thermophysical modeling to characterize the surface temperature, near surface temperature gradient, and thermal inertia of the region. The formation mechanism of the depression is discussed in view of these empirical data.

New Light on Ceres: Dawn Results

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ABSTRACT

In early 2015, Dawn arrived at Ceres after its 7.5-year journey. It had orbited and mapped the basaltic asteroid Vesta before arriving at its final target, the innermost dwarf planet[1]. Dawn found a very dark, cratered surface punctuated by small extremely bright spots[2]. Ceres surface has many craters but it is missing the largest expected craters and is gravitationally relaxed at lowest orders, implying a mechanically strong thick crust with a weaker deep interior[3,4]. Ceres' surface composition is dominated by dark carbon-rich minerals, phyllosilicates, ammoniated clays, and carbonates[5,6]. The distribution of the observed species across the surface indicates that Ceres underwent to widespread alteration processes[6]. The composition of the brightest areas is mostly consistent with a large amount of carbonate, implying recent hydrothermal activity [7]. Moreover, the minerals constituent this bright material have been also found in the Enceladus plume[8] reinforcing the link with the outer solar system

Water ice has also been observed in fresh craters[9] and elemental composition is consistent with an increasing H content toward high latitudes[10], indicating an increasing content of water ice in the immediate subsurface. Several morphological evidences, like flat crater floors, flows of material across the surface, isolated mountains, point to the importance of volatile-driven activity on Ceres that likely involves brine-driven cryovolcanism.

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Temporal variation in dust environment as measured by GIADA

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GIADA (Grain Impact Analyzer and Dust Accumulator) on-board the Rosetta spacecraft [1] 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. The combination of the measurements performed by these 3 subsystems provides: the number, the mass, the momentum and the velocity distribution of dust grains emitted from the cometary nucleus. Since July 2014 GIADA monitored continuously comet 67P dust environment. GIADA sampled the typical non-volatile composition of the pebbles that formed all planetesimals [2]. The acquired results allowed us to describe 67P coma dust spatial distribution, the dust mass size distribution, and to define the dust particle speeds range, from 0.3 to 35 ms^{-1} [3, 4, 5, 6]. We distinguished different type of particles populating 67P coma: compact particles having a bulk density of $(1.9 \pm 1.1)\times10^3$ kg m^{-3} [6] and fluffy porous aggregates with a density < 1 kg m^{-3} [7].
In the present work, thanks to the high sampling resolution time guaranteed by GIADA, we describe short and long dust emission time periodicity. We study how these periodicities change while comet 67P proceeds along the orbit. In addition, we analysed in terms of particle speeds, masses and periodicity the data acquired when GIADA detected the so called outburst events during perihelion and in February, May and July 2016. This was done to show possible differences between "normal" cometary activity and these peculiar and short lasting (about 3 hours each) phenomena.

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Hydrogen Halides In The Coma Of 67P

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We report the first-ever in situ detection of hydrogen halides in a comet atmosphere. The main halogen-bearing compounds detected by Rosetta/ROSINA in the coma of 67P/Churyumov-Gerasimenko are HF, HCl and HBr. The hydrogen halide abundances are not linearly proportional to the water abundance. Moreover, an increase of the halogen-to-oxygen ratios was found as a function of distance from the nucleus, suggesting that hydrogen halides have a distributed source. Bulk halogen-to-oxygen ratios have been derived from measurements taken at nucleus distances where release from this distributed source could be considered to be complete. Isotopic ratios for $^{37}Cl/^{35}Cl$ and $^{81}Br/^{79}Br$ have been obtained and match solar values within 2σ error margins. All these observations point to an origin of the hydrogen halides in molecular cloud chemistry, a freeze-out of halide-bearing material on dust grains, and a subsequent incorporation into comets as the cloud condensed and the solar system formed.

Dynamic assembly of cometary ices in protoplanetary disk midplanes

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ABSTRACT

Protoplanetary disk midplanes harbor the largest reservoir of icy dust grains that will be incorporated into planetary embryos and comets. The chemical content of these midplane ices originates in the prestellar phase and is shaped during the dynamic transport towards the disk upon the onset of collapse, as shown by means of a sophisticated physicochemical model [Drozdovskaya et al. 2014, 2016a]. In this talk, results for two protoplanetary disks, one grown predominantly via viscous spreading and another via pure infall, will be shown. The models predict that the amount of CO_2 can increase during infall via the grain-surface reaction of OH with CO, which is enhanced by photodissociation of H_2O ice. Complex organic ices can be produced at abundances as high as a few % of H_2O ice at large disc radii (R > 30 AU) at the expense of CH_3OH ice, meaning that current Class II disc models may be underestimating the complex organic content. These simulations immediately imply that planet population synthesis models may underestimate the amount of CO_2 and overestimate CH_3OH ices in planetesimals by disregarding chemical processing between the cloud and disc phases. The model results are used to derive the C/O and C/N ratios as a function of radius in midplanes of embedded disks and are predicted to differ between the gas and solid phases. The two ice ratios show little variation beyond the inner 10 AU and both are nearly solar in the case of pure infall, but both are sub-solar when viscous spreading dominates. These models highlight the importance of dynamics and chemistry in the embedded phase of star and planet formation for the chemical budget of comets and planetary building blocks.

About the O_2/H_2O abundances ratios observed in comet 67P/ Churyumov-Gerasimenko

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ABSTRACT

The detection of molecular oxygen in the coma of comet 67P/Churyumov-Gerasimenko with never anticipated O_2/H_2O abundances ratios in the range 1-10% raises troubling questions. More precisely, where and how O_2 has been formed and how this molecule could have survived in the cometary environment until it was observed.

After an elimination process of the plausible causes it was proposed that the radiolysis of icy grains in low-density environments such as the pre-solar cloud or low-density regions of the proto-solar nebula (PSN) leads to the production of large amounts of molecular O_2. The aim of this presentation is to show the mechanism at work from the irradiation step to the liberation of the molecule together with the environing water ices.

Contrary to UV photons whose effect is limited to the topmost layers of the ice mantles, irradiation by energetic particles is known to make latent tracks deep in the bulk of the ices. The damaging effect of the irradiation results in the formation of radicals (O, H and OH) that recombine to give H_2, H_2O and O_2, eventually. H_2 diffuses easily to the gas phase; H_2O reconstructs the ice lattice locally, closing the tracks and forming cavities inside which, O_2 remains trapped.

Hereafter we focus on the situation of O_2 inside the bulk of the ice and its stability in such environment. To this end we rely on numerical simulations based on first principle periodic density functional theory (DFT). We find that molecular oxygen is a guest species perfectly stable within the host lattice, with a ratio of one O_2 to 20-30 H_2O according to the size of the cavity; hence the correlation observed between the sublimations of O_2 and H_2O. Even more interesting is the fact that O_2 dimers are equally stable. The possibility of having both, the monomer as well as the dimer, trapped in the cavities strengthens the interpretation of the variations of the proportion O_2/H_2O observed to vary within the 1- 10% limits.

Amino Acids in the Solar System

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ABSTRACT

The organic contents of meteorites and comets reflect early solar system chemistry, as well as the physical and chemical processes that have occurred in the past 4.5 billion years. Among the most well-studied of the organic compounds present in these extraterrestrial materials are amino acids. Amino acids have been detected in a variety of meteorites, as well as in materials collected from NASA's Stardust mission to Comet Wild-2 [1,2]; recently, observations by the ROSINA mass spectrometer also identified glycine in the coma of 67P/Churyumov-Gerasimenko [3].

Amino acids are of particular interest to astrobiology and astrochemistry research for several reasons: (1) they are essential to life on Earth; (2) they are a structurally diverse group of compounds; and (3) some of them possess large enantiomeric excesses of extraterrestrial origin. We have examined the abundances, structural distributions, stable isotopic ratios, and enantiomeric compositions of amino acids in meteorites from all eight carbonaceous chondrite groups (CI, CM, CR, CO, CV, CK, CH, and CB), as well as representatives of other meteorite classes and materials from comet Wild-2. These studies show a wide diversity in the amino acids present across these samples. This diversity highlights the potential roles of parent body processes and composition on the organic content of these bodies, as well as the potential for a variety of formation mechanisms and organic reservoirs in the solar system. In addition, the observed large L-enantiomeric excesses of some proteinogenic amino acids in certain meteorites (up to ~60%) may be relevant to understanding the origin of homochirality in life on Earth, although the potential mechanisms leading to these enantiomeric excesses are currently poorly understood.

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Analyses of cometary dust: from space to the laboratory

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ABSTRACT

Comets are among the best remnants of the matter used to form the solar system in its current architecture. Primitive meteorites originate from asteroids. They are rocks containing a small amount of carbonaceous matter (less than 5 wt%). The most carbon-rich meteorites have suffered various extent of aqueous alteration, which is evidence for the presence of ices at the time of their accretion in their parent asteroids. Comets are made of ices and organics mixed with some amount of minerals.

Ultracarbonaceous Antarctic Micrometeorites (UCAMMs) are dust particles recovered from snow in the central regions of Antarctica. They are most probably of cometary origin; they are dominated by a nitrogen-rich disorganised organic matter (atomic N/C ratios up to 0.2) showing extreme D/H ratios (Duprat *et al.* 2010). The UCAMMs contain a small (but variable from one particle to another) amount of mineral inclusions embedded in the organic matter (Dobrică *et al.* 2012). There are (at least) two carbonaceous phases in UCAMMs, one that is N-rich, the other one showing an atomic N/C ratio $< 0.05\%$ (Engrand *et al.* 2015). The N-rich organic matter could have been formed by Galactic cosmic ray irradiation of ices at the surface of small icy bodies in the outer regions of the solar system (Dartois *et al.* 2013; Augé *et al.* 2016). The N-poor organic matter of UCAMMs is associated with the minerals and has a composition compatible with that of the organic matter found in the primitive meteorites. In the context of the Rosetta results on the composition of dust from 67P/Churyumov-Gerasimenko, we will present the implications of these results for the formation of cometary dust, and the possible connexions with the mineral and organic compounds found in meteorites.

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Plasma Density Variations and Waves in the Inner Coma of Comet 67P

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ABSTRACT

The plasma in the inner coma of comet 67P/Churyumov-Gerasimenko, sampled by the instruments of the Rosetta Plasma Consortium (RPC) for two years, has proven to be very dynamic. Stable conditions are rare, with density fluctuations often reaching tens of per cent over short time periods. Spectral analysis of data from the Langmuir probe instrument RPC-LAP typically shows turbulent spectra rather than linear waves, sometimes with enhancements around resonance frequencies like the lower hybrid frequency. Some fluctuations appear as short pulses of higher density plasma while others have more wavelike appearance. We study the density fluctuations themselves with LAP, using other RPC sensors mainly for context, and discuss the characteristics and origin of the variations.

Evolution of 67P/Churyumov-Gerasimenko's FUV Surface Properties through its 2015 Perihelion Passage

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ABSTRACT

Alice, NASA's lightweight and low-power far-ultraviolet (FUV) imaging spectrograph onboard ESA's comet orbiting spacecraft *Rosetta* (Stern *et al*. 2007, *Space Sci. Rev*. 128, 507), has just completed its characterization of the nucleus and coma of the Jupiter family comet 67P/Churyumov-Gerasimenko (C-G). With a spectral range from 700-2050 Å, *Alice* was able to monitor the sunlit surface of C-G in order to establish if there was variability in the FUV reflectivity across the nucleus, determine if there were distinct spectral features associated with various morphological regions, and infer compositional makeup of the comet. Using spatially resolved pre-perihelion data, the FUV phase dependence, albedo, and spectral slope were derived for the nucleus (Feaga *et al.* 2015, *A&A* 583, A27) and were consistent with a homogeneous layer of dust covering the northern hemisphere. During the increase in activity around perihelion and change of seasons on the comet, the *Rosetta* suite of instruments has shown evidence of surface changes, mass movement of material, and transient patches of ice. The FUV properties of the nucleus throughout the perihelion passage inside of 3 AU, including observations during a zero phase flyby and its associated opposition surge and a search for exposed water ice on the surface, will be presented here and compared to the early pre-perihelion characteristics.

Compositional maps of 67P/CG nucleus surface after perihelion passage by Rosetta/VIRTIS

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ABSTRACT

Moving after perihelion passage (August 13th 2015), VIRTIS-M[1] the 0.25-5.0 μm imaging spectrometer on board Rosetta has mapped again the north and equatorial regions of 67P/CG's nucleus with the scope to trace color and composition evolution of the surface. With the loss of the IR channel due to the active cryogenic cooler failure occurred in May 2015, VIRTIS-M has observed only with the VIS channel in the 0.25-1.0 μm spectral range. Despite this limitation, the returned data are valuable in performing a comparison of surface properties between pre and post-perihelion times. Approaching perihelion passage, 67P/CG's nucleus has experienced a general brightening due to the removal of the surficial dust layer caused by the more intense gaseous activity with the consequent exposure of a larger fraction of water ice[2]. Coma observations by VIRTIS during pre-perihelion have shown a correlation between the areas of the nucleus where gaseous activity by water ice sublimation is more intense[3] with the surface brightening caused by dust removal. After having applied data calibration[4] and photometric correction[5], VIRTIS data are projected on the irregularly shaped digital model[6] of 67P/CG with the aim to derive visible albedo and colors maps rendered with a spatial resolution of 0.5×0.5 deg in latitude-longitude, corresponding to a sampling of about 15 m/pixel. Dedicated mapping sequences executed at different heliocentric distances, are employed to follow the dynamical evolution of the surface. Direct comparison between compositional maps obtained at the same heliocentric distances along inbound and outbound orbits allows to evidence the changes occurred on the same areas of the surface. In this context, the first VIRTIS-M maps, obtained in August 2014 at heliocentric distance of 3.4 AU along the inbound orbit with a solar phase angle of about 30-45° are compared with the last ones, taken in June 2016 at 3.2 AU from the Sun on the outbound trajectory at solar phases of about 40-50°. In particular we focus our investigation on the two large Bright Albedo Patches (BAPs) where water ice exposures have been detected before perihelion[7]. The availability of these datasets acquired with unprecedented spatial and spectral resolutions gives us the opportunity to study temporal changes occurring on a comet's nucleus during the perihelion passage.

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The 67P/Churyumov-Gerasimenko nucleus spectroscopic properties and their evolution over time

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ABSTRACT

Comets are primitive small bodies witness of the Solar System formation. Our knowledge on cometary nuclei and on their evolution over time is very limited because they are dark, small, and thus faint objects, spatially unresolved by groundbased telescopes and masked by their atmosphere when they become brighter close to the Sun. Before the Rosetta mission, only 5 cometary nuclei have been directly imaged and investigated by space missions during relatively short fly-bys, catching thus a small fraction of the comet lifetime in its orbit. The Rosetta mission is orbiting around the 67P/Churyumov-Gerasimenko comet since August 2014, and provides the unique opportunity to continuously investigate the 67P nucleus during about 2 years, from large heliocentric distances (about 4 AU) to its perihelion passage (1.24 AU) and beyond.

The OSIRIS cameras and VIRTIS spectrometer have shown that the 67P nucleus has a red spectral behavior with spectral properties similar to those of bare cometary nuclei, of primitive D-type asteroids like the Jupiter Trojans, and of the moderately red Transneptunians population (Sierks et al., 2015, Capaccioni et al., 2015). The surface is globally dominated by dehydrated and organic-rich refractory materials (Capaccioni et al., 2015), and shows some color heterogeneities. Three kind of terrains, from the spectrally bluer and water ice enriched terrains to the redder ones, associated mostly to dusty regions, have been identified by visible spectrophotometry from the first resolved images acquired in July-August 2014 (Fornasier et al., 2015), covering mostly the northern hemisphere of the nucleus. The southern hemisphere has become visible from Rosetta only since March 2015, and it shows a lack of spectrally red regions compared to the northern one, associated to the absence of wide spread smooth or dust covered terrains.

Although water is the dominant volatile observed in the coma, exposed water ice has been detected only in small amounts in different regions of the comet (Pommerol et al., 2015; De Sanctis et al., 2015; Filacchione et al., 2016; Barucci et al. 2016). Thanks to the unprecedented spatial resolution, VIRTIS and OSIRIS instruments have detected the occurrence of water frost close to the morning shadows, putting in evidence the diurnal cycle of water. Seasonal color and spectral variations have also been observed when the comet approached perihelion, indicating that the increasing activity had progressively shed the surface dust, partially showing the underlying ice-rich layer.

I will present an overview of the spectroscopic properties of the 67P nucleus and of their diurnal and seasonal variations over time and heliocentric distance.

Modeling the Major Volatiles in the Coma of Comet 67P/Churyumov-Gerasimenko Constrained by Rosetta Observations

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ABSTRACT

The Rosetta observations provide unprecedented temporal and spatial information about the coma of Comet 67P/Churyumov-Gerasimenko. In particular, the complementary measurements from ROSINA and VIRTIS allow to push forward the state-of-the art in coma modelling. We present the latest results of a full 3D multi-species (H_2O, CO_2, CO, and O_2) Direct Simulation Monte-Carlo model using the Adaptive Mesh Particle Simulator code (Tenishev et al. 2008, 2011, Fougere 2014). The model uses a realistic nucleus shape from the OSIRIS team and takes into account the self-shadowing created by its concavities. The outgassing flux is computed from the local illumination and a surface activity distribution taking into account the non-uniformity of the surface. Progress in incorporating Rosetta measurements from the second half of the mission into our model will be presented. The model/data comparison suggests that the seasonal effects result in the northern hemisphere of 67P's nucleus being more processed with a layered structure while the southern hemisphere constantly exposes new material.

Characterization of the refractory organic matter present in the dust particles of 67P/Churyumov-Gerasimenko.

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ABSTRACT

The Cometary Secondary Ion Mass Analyser (COSIMA), a miniaturized time-of-flight secondary ion mass spectrometer (ToF-SIMS), is one of the dust particle instruments onboard the orbiter of the Rosetta mission that arrived to comet 67P/Churyumov-Gerasimenko in mid-2014. COSIMA analyses the mineral and organic composition of dust grains that are captured on metal targets exposed to space.

The mass spectra acquired by COSIMA show that refractory organic matter is ubiquitous in cometary dust particles. The nature of this carbonaceous material will be discussed. We will highlight its nitrogen to carbon elemental ratio and compare results from the dust particles of 67P to those from other astrophysical objects (carbonaceous chondrites, IDPs, micro-meteorites). This comparison could provide clues on the origin and evolution of the cometary organic matter.

Unexpected and Significant Findings in 67P: the latest news

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ABSTRACT

We review the latest most significant discoveries obtained by the Rosetta spacecraft during the last six months of observations at close distance from the nucleus of comet 67P. We discuss the implications of these observations to models of the nucleus structure and activity, and of the origin of short period comets.

Change of outgassing pattern during the March 2016 equinox as seen by ROSINA/RTOF

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ABSTRACT

Like most other bodies in the Solar System, comet 67P/Churyumov-Gerasimenko (67P/C-G) spins. The spin axis is not normal to the orbital plane, meaning that 67P/C-G has seasons, with two solstices and two equinoxes per orbit. We have been monitoring these seasonal variations in the gas coma with the Reflectron-type Time-Of-Flight mass spectrometer (ROSINA/RTOF) onboard the ESA's Rosetta spacecraft. Rosetta has been following 67P/C-G since its rendezvous in August 2014, from a distance of almost 3.5 AU to the Sun through perihelion at 1.24 AU and away from the Sun again.

We will present the change of outgassing pattern during the March 2016 equinox as seen by ROSINA/RTOF, where the H_2O abundance was dropping rapidly while CO_2 and CO abundances remained high over the southern hemisphere. We will discuss the results in terms of the comet crossing the snowline and thermal inertia of the nucleus.

Properties of Dust Particles in the Comet Environment around the Rosetta Spacecraft

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ABSTRACT

In addition to its payload of scientific instruments, the Rosetta spacecraft is also equipped with a navigation camera (NAVCAM) for operational purposes. NAVCAM images are primarily used by the Flight Dynamics team in the navigation process for determining the position of the spacecraft relative to the comet nucleus. A limited number of images are also acquired as context images for science observations and for calibration purposes.

In the present study we analysed a series of off-nucleus images which were scheduled in July 2015 for characterising the properties of dust particles in the comet environment around the spacecraft. A diffuse background component contains information about unresolved dust particles along the line-of-sight. Larger dust particles appear as individual point sources on the images. Particles which are very close to the camera are out of focus and appear as extended circular features on the images.

From the apparent image sizes of the out-of-focus particles and using the camera aperture and focal length their distances can be determined. They are in the range of metres to a few tens of metres from the spacecraft. Measuring the flux and assuming representative values for the reflectance additionally makes it possible to determine the particle sizes. The resulting estimates are in the order of tenths of millimetres to one millimetre. Finally, for a few objects also their motion on the images and therefore their projected velocities can be derived.

We also investigated the properties of the large number of point-like objects by deriving flux and magnitude histograms. The number of objects detected is much larger than the number of stars expected in the respective field-of-view. Assuming the same typical sizes as determined for the out-of-focus particles, the flux histograms can be transformed into distance histograms. The typical distances derived in this way are in the order of hundred metres to one kilometre. This is the population of dust particles which confused the software of the Rosetta Star Trackers as “false stars” and prevented the spacecraft from flying safe trajectories in the comet vicinity during a considerable period of time.

Rosetta Plasma Consortium data access and analysis facilitated by CDPP tools

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ABSTRACT

The French Plasma Physics Data Centre (CDPP, cdpp.eu) distributes a wide variety of natural plasma physics datasets originating from spacecraft missions or ground-based projects. In this frame, the CDPP provides to the Rosetta Plasma Consortium (RPC), a suite of five different plasma sensors, with the possibility to visualize plasma data acquired by the Rosetta mission through its data analysis tool AMDA. AMDA has been used during the operational phase of the Rosetta mission, facilitating data access between different PI teams, thus allowing a better understanding of single instrument observations in the context of more global observations. These in-situ data are complemented by model data, for instance, a solar wind propagation model or illumination maps of 67P. The CDPP also proposes 3D visualisation tool for planetary / heliospheric environments which helps putting data in context (3dview.cdpp.eu); for instance all comets and asteroids in a given volume and for a given time interval can be searched and displayed. The CDPP tools and recently published RPC scientific results enabled/facilitated through the use of these tools will be presented. The RPC data access is provided through collaboration with Imperial College, London, whose work is supported by UK Space Agency; CDPP is supported by CNES and CNRS.

Understanding the Early Solar System via Synergy between Comets and Protoplanetary Disk Models

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ABSTRACT

Near-infrared spectroscopic observations of native (primary) volatiles sublimating into cometary comae have been performed for over 30 comets. The “mixing ratios” between observed species ($CH_4/C_2H_2/C_2H_6/HCN/NH_3/CO/H_2CO/CH_3OH/H_2O$, etc) vary substantially among the comets sampled to date. However, the identification of distinct taxonomic classes has been challenging, and the cosmogonic significance of the observations has remained elusive. Comets are the end product of a variety of processes, including chemical and dynamical evolution in the protoplanetary disk and possibly thermal evolution during successive perihelion passages. Understanding the relative importance of these processes requires both increasing the sample size of observed comets and a comprehensive synergy with chemical models.

Chemical models and observations suggest that protoplanetary disks are comprised of three distinct regions where the temperatures, processes, and chemical abundances vary. Both the hot disk atmosphere, comprised of atoms and ions, and the warm molecular layer, where ices sublimate and undergo ion-molecule reactions, are above the region where planets formed but can be observed via millimetre and infrared spectroscopy. The cold mid-plane, where ices freeze to dust grains, is where the outer planets and comets formed. Transport processes may have mixed material from the different layers to the planet-forming zone. Recent modelling has incorporated these various processes. However, since protoplanetary disks are optically thick, the mid-plane is generally not observable. A synergy between models and comet observations could thus provide the key to testing models of chemistry in the disk mid-plane and in understanding the principle processes occurring in the early solar system.

We will show how this synergy is being realized via close collaboration between modelling and observations. We will use current state-of-the-art models to address which chemical reaction pathways are expected to dominate the synthesis of cometary compounds, which processes in the protoplanetary disk may have left strong signatures in cometary ices, and determine whether existing models can provide testable predictions for the observed chemical diversity of comets. We will present comparisons between relative abundances for several cometary volatiles and those predicted for the mid-plane of the protoplanetary disk where comets formed. This work is supported by NSF (AAG) and NASA (Astrobiology, Emerging Worlds, PATM, PAST, SSO).

Modelling of the outburst on July 29th , 2015 observed with OSIRIS in the southern hemisphere of comet 67P/Churyumov-Gerasimenko

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ABSTRACT

Images of the nucleus and the coma (gas and dust) of comet 67P/Churyumov- Gerasimenko have been acquired by the OSIRIS (Optical, Spectroscopic, and Infrared Remote Imaging System) cameras system since March 2014 using both the wide angle camera (WAC) and the narrow angle camera (NAC). We are using the NAC camera to study the bright outburst observed on July 29th, 2015 in the southern hemisphere. The NAC camera's wavelength ranges between 250-1000 nm with a combination of 12 filters. The high spatial resolution is needed to localize the source point of the outburst on the surface of the nucleus. At the time of the observations, the heliocentric distance was 1.25AU and the distance between the spacecraft and the comet was 126 km. We aim to understand the physics leading to such outgassing: Is the jet associated to the outbursts controlled by the micro-topography? Or by ice suddenly exposed? We are using the Direct Simulation Monte Carlo (DSMC) method to study the gas flow close to the nucleus. The goal of the DSMC code is to reproduce the opening angle of the jet, and constrain the outgassing ratio between outburst source and local region. The results of this model will be compared to the images obtained with the NAC camera.

A review of the magnetic field at comets

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Abstract

Since the Giotto mission at comet 1P/Halley the influence of the comet's ionosphere on the interplanetary magnetic field has been studied intensely. Several boundaries like the bow shock and the magnetic cavity boundary have been observed at more than one target and allow a study of their dependence on solar wind and outgassing parameters. The Rosetta mission has spent over two years following comet 67P/Churyumov-Gerasimenko on its journey through the solar system. It has for the first time afforded a study of the plasma environment of a weakly outgassing comet. The orbiter magnetometer RPC-MAG and the lander magnetometer ROMAP have detected waves with a frequency of 10-100 mHz, the "singing" of the comet. When the outgassing rate increases the magnetic field is characterized by sharp discontinuities and shows clear signs of draping close to the nucleus. The solar wind parameters heavily impact the plasma environment and is in turn modified by mass-loading. Close to perihelion Rosetta detected multiple signatures of a diamagnetic cavity and high (270nT) magnetic field magnitude regions. The distance of a bow shock or bow wave could be constrained. It was also possible to detect a highly asymmetric tail structure during the low-activity period of the comet. The measurements and conclusions drawn from this mission can pinpoint additional areas of study that may be targeted in future missions.

Two years of Solar Wind and Pickup Ion Measurements at Comet 67P/Churyumov-Gerasimenko

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The Ion and Electron Sensor (IES), as well as other members of the Rosetta Plasma Consortium (RPC) on board the Rosetta spacecraft have been measuring the characteristics of the solar wind almost continuously since arrival at 67P/Churyumov-Gerasimenko (CG) in August 2014. An important process at a comet is the so-called pickup process in which newly ionized atoms or molecules begins gyrating about the interplanetary magnetic field, are carried along with the solar wind and are thus accelerated. Within a month after comet arrival, while Rosetta was <100 km from CG, we began to observe cometary ions that had been picked up and accelerated by the solar wind to ~several hundred eV energy. These ions were in the early phase of pickup and had not yet reached the energy they would after at least one full gyration about the magnetic field. As CG increased its activity the flux and energy of the measured pickup ions increased intermittently while the solar wind appeared intermittently as well. By about the end of April 2015 the solar wind had become very faint until it eventually disappeared from the IES field of view. We then began to see ions at the highest energy levels of IES, >10 keV for a few days then these disappeared but lower energy (~few keV) pickup ions were observed. We observed only pickup ions of very low (~10 eV) to a few keV until early December, when also for a few days ~10 keV ions were observed again. As of early February 2016 the solar wind has reappeared more consistently. We believe that the disappearance of the solar wind in the IES field of view is probably the result of deflection of the solar wind from interaction with the pickup ions. Also, the predicted (but not observed) formation of a bow shock sunward of the CG nucleus would have caused the solar wind flow to be deflected around the nucleus.

Properties of Dust Particles by Polarimetric Observations of Split Comets Revisited using Ground-Truth from Rosetta Experiments

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ABSTRACT

Remote observations of the light scattered by comet 67P/C-G dust (photometry and imaging polarimetry) allowed us to compare their physical properties deduced by simulations, to in-situ observations of the dust particles by Rosetta instruments. The ground-truth obtained from the in-situ observations confirms some of our clues from polarimetry and from laboratory experiments, such as slow moving compact particles before perihelion and fluffy aggregates of submicron grains after. The results obtained from imaging polarimetry observations of two split comets (comet 73P/Schwassmann-Wachmann 3, a Jupiter Family Comet and comet C/1999 S4 LINEAR, an Oort cloud comet) correlate well with the particles structures and sizes deduced for 67P/C-G by Rosetta. The differences in composition between the comets belonging to these two orbital classes remain questionable. The two main B and C fragments of 73P/SW3 were found by other observers to have about the same chemical composition but differences in their optical properties were underlined in the polarization images. A very important variability and evolution in the coma structures was observed during our one-week observations in April-May 2006. The differences in polarization and intensity images suggest different physical properties in the dust cloud that need to be confirmed and could be clues to the previous presence of sub-nuclei formed in not exactly the same regions in the proto-planetary disk. The very high polarization around the largest fragment of comet LINEAR S4, after the complete disruption of the nucleus, may be interpreted by the presence of very large fragmenting particles. The Rosetta results give us an opportunity to revisit these comets observations and confirm (or not) the properties of their dust particles. The results will be compared to other cometary results and tentatively interpreted in terms of internal properties, the dust particles from split comets providing a unique insight into the structure of the cometary nuclei.

Plasma response to a cometary outburst: Rosetta Plasma Consortium observations during comet 67P/Churyumov-Gerasimenko outburst event on 19 February 2016

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ABSTRACT

Cometary outbursts are one of the most spectacular aspects of comet behavior. They are characterized by an abrupt increase in cometary brightness followed by a gradual fall off to the pre-event brightness. Although there are several studies on outburst events, to our knowledge, no detailed analysis on the variation of the cometary plasma environment during an outburst has ever been reported. On 19 February 2016, when comet 67P/Churyumov-Gerasimenko was at a heliocentric distance of 2.4 AU, an outburst event, characterized by two orders of magnitude increase in coma surface brightness, took place. Rosetta was at a distance of 30 km from the comet nucleus, orbiting with a relative speed of 0.17 m/s. The Rosetta Plasma Consortium (RPC) provided in-situ measurements of the cometary plasma, embedded in the solar wind, and the associated magnetic field during this outburst, as the dust and gas expelled from the comet were passing by the spacecraft. While the neutral density (ROSINA/COPS) at the spacecraft position increased by a factor of 1.5, the local plasma density (RPC/MIP) was found to increase by a factor of 3 during the outburst event, driving the spacecraft potential more negative (RPC/LAP). The event was characterized by the energy degradation of energetic (10s of eV) electrons (RPC/IES). In response to the outburst, the local magnetic field exhibited a slight increase in amplitude and a slow rotation (RPC/MAG). A weakening of 10-100 mHz magnetic field fluctuations was also observed during the outburst. The RPC instruments show that the effects of the outburst on the plasma lasted for about 4 hours, from ~1000 UT to 1400 UT. Detailed analyses of the observations made by RPC along with ROSINA/COPS will be presented in the paper.

The Evolution of Water Production of Comet 67P/Churyumov-Gerasimenko Throughout the Rosetta mission: Insights from Modeling and Rosetta data

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ABSTRACT

We present a summary of what we have learned about the water production at 67P/Churyumov-Gerasimenko as a result of observations made by the Rosetta spacecraft as it has followed the comet starting in June 2014 (beyond 3.6AU) through the perihelion passage and outbound until mission end (September 2016). The insights we present have been gained by studying Rosetta data directly as well as through the use of the data to create high fidelity models of the water coma. We will concentrate on insights learned from the ROSINA data, but will present other published Rosetta and ground-based data as well. We will discuss several interesting periods of 67P/CG's passage through the solar system, including: (a) a possible rapid increase of the production rate just before Rosetta rendezvous at 3.6AU (b) the period between 3.6 and 3.0 AU which does not show the expected

dependence on heliocentric distance (c) the dramatic shift of water production from the northern hemisphere to the southern hemisphere during the passage through equinox, and (d) the short interval of approximately six weeks around perihelion.

Cosmochemical implications of CONSERT permittivity characterization of 67P/CG

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ABSTRACT

Analysis of the propagation of the CONSERT signal throughout the small lobe of 67P/CG nucleus permitted to deduce the real part of the permittivity, at a value of 1.27± 0.05 [1]. The first interpretation of this value using the dielectric properties of mixtures of ices (H2O, CO2), dusts and porosity, led to the conclusion that the comet porosity ranges between 75 – 85%. In addition, the dust to ice ratio was found to range between 0.4-2.6 and the permittivity of dust (including 30% of porosity) was determined to be lower than 2.9. This last value corresponds to a permittivity lower than 4 for a material without any porosity.

This paper is intended to refine the dust permittivity estimate by taking into account the updated values of nucleus densities and dust/ice ratio, and to provide further insights into the nature of the constituents of comet 67P/CG. We adopted a systematic approach: determination of the dust permittivity as a function of the Ice / Dust and Vacuum (i.e. porosity) volume fraction and comparison with the permittivity of meteoritic, mineral and organic material from literature and laboratory measurements. Then different composition models of the nuclei corresponding to cosmochemical endmembers of 67P/CG dust are tested. For each of these models the location in the I/D/V diagram is calculated based on available dielectric measurements, and confronted to the locus of 67P/CG. The number of compliant models is small and the cosmochemical implications of each are discussed to conclude on a preferred model [2]. An important fraction of carbonaceous material is required in the dust in order to match CONSERT permittivity observations, establishing that comets represent a massive carbon reservoir.

[1] Kofman et al., Science, 349, 6247, aaa0639, 2015. [2] Herique et al., MNRAS, submitted, 2016.

Ion composition in the coma of 67P – model vs. DFMS comparison

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A multi-species ionospheric model applied to comet 67P has been developed in order to interpret the origin and chemical pathways yielding the ion composition observed by the Rosetta Orbiter Spectrometer for Ion and Neutral Analysis (ROSINA)-Double Focusing Mass Spectrometer (DFMS) near perihelion. This study assesses the impact of minor neutral species detected by DFMS, such as ammonia, formaldehyde, hydrogen sulphide and others. In a gas that is largely dominated by water and its respective ions (H_2O^+ and H_3O^+), the protonated version of these neutral species is efficiently produced in a dense enough environment. This happens in the first few kilometres around comet 67P when it is sufficiently outgassing ($Q>10^{27}$ s^{-1}). Once produced, the terminal ions are lost through transport, therefore their relative abundances decrease with respect to the water ions at larger cometocentric distances.
An ion species inventory is generated and an in-depth data comparison with DFMS is performed in order to verify the validity of the model and the conditions under which its underlying assumptions are valid.

Simulation of the near-surface dust charging and transport on 67P Churyumov-Gerasimenko

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Abstract

The Rosetta spacecraft reached comet 67P/Churyumov-Gerasimenko on August 2014 and was inserted into orbit, on November Philae separated from Rosetta and landed on the comet. After a first touchdown close to the expected landing site, Philae bounced and finally stopped in a more chaotic region after several touchdowns.

In particular, the lander attitude and its position close to a cliff jeopardized its chances to survive. Eventually, the probe received enough power from the sun later in Rosetta's mission and brought new information on the comet surface. Among Philae missions, the Dust Impact Monitor collects dusts. ROSETTA's probe Philae landed on a dust covered soil. This dust may be ejected from the ground through many mechanisms (other than spacecraft landing) : micro-meteorite impacts, electrostatic charging and soil outgassing. In any cases, the dust grains charge electrostatically in the ambient plasma and this charge impacts the dust interaction with the spacecraft, which is itself differentially charged due to its partial exposure to the solar UV light. Using the DUST addition to the Spacecraft-Plasma Interaction Software (SPIS) routinely used to compute the charge state of the spacecraft surfaces, we simulate the electrostatic charging of Philae as well as its dust environment. SPIS-DUST allows one to compute the electrostatic charging of the dust grains on the ground and in the plasma, and to model their ejection and their recollection by the probe. The code dust charging and ejection model was validated against vacuum chamber experiments performed at ONERA for lunar dust stimulant. We simulated one cometary day of the Philae environment at different distances from the sun to observe the variation of the dust collection with Philae's local time.

ROSETTA/COSIMA next to 67P/Churyumov-Gerasimenko: Morphology and Composition of Cometary Dust Particles in the inner Coma

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ABSTRACT

The dust particle instrument COSIMA - COmetary Secondary Ion Mass Analyser - on board ESA's ROSETTA mission collected > 27,000 particles and analyzed > 200 dust particles in the inner coma of Jupiter-family comet 67P/Churyumov-Gerasimenko. COSIMA images and identifies the particles with an optical microscope with a resolution of 14 µm per pixel and analyses their composition with a time-of-flight secondary ion mass spectrometer with a mass resolution of 1400 at half peak maximum at m/z = 100 µ. We will discuss the particle morphologies and the diversity in morphology after impact on the targets of the collected particles and particle fragments pointing towards diverse families of cometary dust particles. The secondary ion mass spectra contain elemental and molecular ions arising from the mineral and organic molecules present on the surface of these particles and the collection metal targets. These in-situ analysis by optical microscopy and mass spectrometry confirm that the comets are among the most primitive objects of the solar system.

Variability of 67P coma major composition as seen by ROSINA RTOF

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ABSTRACT

The environment surrounding the nucleus of comet 67P/Churyumov-Gerasimenko (67P/C-G) has been investigated by the Rosetta space mission over two years starting in August 2014. For that purpose, the ROSINA experiment includes two mass spectrometers to measure the composition of neutrals and ions, and a Comet Pressure Sensor (COPS) to monitor the density and velocity of neutrals in the coma.

The analysis of 67P/C-G's major molecules in the coma during three periods from September 2014 (summer in the northern hemisphere) to February 2016 (end of winter on the northern hemisphere), including periods before and after perihelion show strong variability of the comet's environment in terms of the main volatiles dynamics (H_2O, CO_2, CO) and their ratios. The H_2O sublimation is correlated with the large illuminated areas of the surface, including the active neck region before equinox and moving slowly south after equinox. The CO_2 outgassing is in general smaller than H_2O, and mostly confined to the southern hemisphere. The low abundance of CO_2 from the northern hemisphere during several months before the May 2015 equinox, despite surface temperatures above the sublimation temperature of CO_2, suggests that the upper layers of the northern hemisphere are depleted in this volatile due to the long northern summer period.

The influence of various parameters is investigated in detail, such as the distance of the spacecraft to the comet, the heliocentric distance, the longitude and latitude of the sub-satellite point, the local time, and the phase angle. We compare the data between the spectrometers to confirm the consistency between the ROSINA mass spectrometers. Furthermore, we show that a first order model of the cometary environment based on the DSMC approach successfully reproduces the obtained measurements in the coma of the comet.

Material strength and it influence on cliff stability on 67P/Churyumov-Gerasimenko

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ABSTRACT

The OSIRIS camera system [1] on board ESA's Rosetta spacecraft has been observing comet 67P/Churyumov-Gerasimenko since its arrival in August 2014. Visible on the OSIRIS images are cliff structures with associated rubble fields at their bottom. It is likely that these rubble fields were created during a (partial) collapse of the neighbouring cliff. Several of these rubble fields display individual boulders with different brightness and spectral slope than the rest of the boulders, indicating a varying content of volatiles.

A possible cause for the collapse of cliffs is thermal stresses and heat that intensify the fracturing of possibly pre-fractured walls or form new fractures. This results in sublimation with a progressively eroding cliff. The direct consequence is the occurrence of gravitational events and formation of boulder fields at the foot of the cliffs [2,3]. Both of these processes serve to weaken the structural integrity of the cliff but it is unclear how large the relative contribution of these processes is.

In this study we investigate how the depletion of volatiles and the damage to the cliff structure introduced by cracks will change the integrity and stability of the cliff. We aim to derive limits to the material strength from observed cliffs and cliff collapses and investigate the microphysical parameters governing cliff stability through simulations using the DEM software ESyS Particle [4].

References: [1] Keller, H. U. et al.: OSIRIS The Scientific Camera System Onboard Rosetta, Space Sci. Rev., 128, pp. 433-506, 2007. [2] Vincent, J.-B. et al.: Are fractured cliffs the source of cometary dust jets? Insights from OSIRIS/Rosetta at 67P/Churyumov-Gerasimenko, A&A, 587:A14, 2016 [3] Pajola, M. et al.: Aswan site on comet 67P/Churyumov-Gerasimenko: Morphology, boulder evolution, and spectrophotometry, A&A, accepted [4] https://launchpad.net/esys-particle

Comet 67P/C-G as Seen at Millimeter and Submillimeter Wavelengths by the MIRO Instrument

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ABSTRACT

The Microwave Instrument for the Rosetta Orbiter (MIRO) is a U.S. instrument with French, German, and Taiwanese participation. It is on the European Space Agency's Rosetta spacecraft which, from August 2014 through September 2016, was flying along side comet 67P/Churyumov-Gerasimenko. MIRO is designed to study the nucleus and coma of the comet as a coupled system. It makes broad-band continuum measurements of the thermal emission of the nucleus at 190 and 563 GHz (1.6 and 0.5 mm) which probe the thermal and dielectric properties of the nucleus as a function of depth from ~1 mm to ~10 cm. When looking off the nucleus, continuum emission from dust can be used to constrain the abundance and size distribution of particles. In addition to its continuum channels, MIRO has a high resolution (44 kHz) spectrometer fixed tuned to submillimeter lines of H_2O, $H_2{}^{17}O$, $H_2{}^{18}O$, CO, NH_3, and three CH_3OH transitions, allowing us to determine the abundance, velocity, and temperature of these species in the coma. This presentation will provide an overview of the instrument, discuss results that were in-line with pre-encounter expectations (e.g. the dry, porous nature of the uppermost surface), and some results that were unexpected (e.g. dust outbursts that may not be accompanied by gas outbursts, with particular emphasis on the 19 February 2016 event). We will also discuss the future of submillimeter instruments.

A possible explanation of magnetic field dropouts observed by RPC-MAG in the inner coma of comet 67P/Churyumov-Gerasimenko

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The Rosetta Plasma Consortium MAGnetometer (RPC-MAG) has observed features of diamagnetic cavities in the inner coma region of comet 67P/Churyumov-Gerasimenko at distances from 30km to 400km, which is larger than what has been predicted by numerical simulations of the cometary plasma environment. The physical mechanism behind these large diamagnetic cavities is still unclear. In the present work, we use our newly developed multi-fluid plasma-neutral interaction model (Huang et al. 2016) to investigate this problem. The model solves the governing multi-fluid MHD equations for the cometary and solar wind ions and electrons, and the Euler equations for the neutral gas fluid. We show that a strong local increase of electron pressure is capable to generate the features of the diamagnetic cavities observed by RPC-MAG: the simulation results show that a magnetic field free region is formed and the recovery phase of the magnetic field magnitude is faster than the declining phase, which suggests that the mechanism proposed here based on localized enhancement of electron pressure may provide a possible explanation for the unusually large distance of the observed cavity.

Photometry and spectroscopy of the comet C/2013 X1 PanSTARRS

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ABSTRACT

Comet C/2013 X1 PanSTARRS as a new comet coming from the Oort cloud was bright and interesting object to study during approach to the inner solar system.

In contribution we show some results from two observatories. Groundbased photometry at Skalnaté Pleso (Slovakia) was performed using 0.61-cm *f*/4.3 reflector with CCD SBIG ST-10XME camera and standard Johnson-Cousin BVR filters. There were achieved 17 nights from 2015 Dec. 3 to 2016 Jan. 21. The spectroscopic observations were carried out with the 2-m Zeiss-RCC Telescope of Pik Terskol Observatory operated by the International Center for Astronomical and Medico-Ecological Research (Ukraine, Russia). The Multi Mode Cassegrain spectrometer was used to obtain spectra of moderate spectral resolving power with wavelength coverage from 4140 to 5240 Å. For photometric observation was used broadband filter R.

Using some digital filters we found interesting jet structure and two tails developing in our observing time interval. In spectra can be visible violet system of CN emissions, emissions of C3 and CO+, C2 and NH2. Also we computed a quantity Afrho as a product of the albedo of the dust grains (A) within the coma, a filling factor (f) of the grains within the photometric aperture and the radius (rho) of that aperture projected to the distance of the comet. Our values are in good match with other observers.

During our monitoring of C/2013 X1 an outburst was catched on 2016 Jan. 1. Magnitude increase was about 1 mag. Afrho values during outburst were approx. double as before the event.

From measurements of another astronomers when the comet was not observable from northern hemisphere the brightness of the comet still increased and Afrho was close to pre-outburst values.

Spectroscopy of comet 67P/Churyumov-Gerasimenko at the 6-m telescope of the SAO RAS

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ABSTRACT

We present spectral observations of comet 67P/Churyumov-Gerasimenko performed at the 6-m telescope of the Special Astrophysical Observatory in November and December of 2015 and in April of 2016, on the outbound segment of its orbit between heliocentric distances 1.61 au and 2.72 au.

A focal reducer SCORPIO-2 with the transparent grisms VPHG1200 and VPHG2400 and a long-slit masks with 6.1′×1.0″ and 6.1′×2.0″ dimensions was used. The spectral resolution of spectra was about 5 Å in November, 2015 and April, 2016 and 4 Å in December, 2015 respectively.

CN, C_2, C_3, and NH_2 emissions were identified in the spectra of comet 67P on November 8 and December 9, 2015. Only CN emission was detected in the spectrum on April 4, 2016. The gas production rates of C_2, CN, C_3, and NH_2 were derived using a Haser model. According to the value $\log Q[C_2/CN] = -1.05$, comet 67P corresponds to “depleted” comets.

The spectra are characterized by a high level of continuum during all sets of observations. The dust production rate and color were determined. A normalized gradient of the cometary dust reflectivity in the 3600–7070 Å spectral range amounted to 12.5 %/1000 Å.

Gas and dust activity of comet 67P/Churyumov-Gerasimenko during different appearances will be discussed.

Analysis of the 67P/Churyumov-Gerasimenko dusty environment during the perihelion using aspherical dust dynamical simulations constrained by GIADA measurements.

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ABSTRACT

Comet 67P/Churyumov-Gerasimenko (67P), the target of Rosetta/ESA mission, reached its perihelion (~1.2 AU) on the 13^{th} of August 2015 providing excellent opportunity to study the dust and gas coma evolution during its high activity peak.

During the observational period July – August 2015 the Grain Impact Analyser and Dust Accumulator (GIADA), a dust instrument onboard the Rosetta spacecraft, measured an average dust particle speed of 19 m/s and a maximum one of 34 m/s. In order to study the dynamical properties of the 67P coma dust environment during perihelion, we performed numerical simulations of dust particle motion with the support of GIADA measurements.

We reconstruct candidate trajectories of the particles captured by GIADA taking into account: 1) the grain shape, i.e. spheres and ellipsoids of revolution with different aspect ratios; 2) initial grain orientation and torque. The results of the simulations are compared with the particle masses, geometrical cross sections and terminal velocities determined by GIADA.

We conclude on: 1) how the grain asphericity influences coma dust spatial distribution modeling; 2) to what extend the averaged trajectory of aspherical particles, obtained considering different initial grain orientation on the surface, deviates from the trajectory of a spherical particle with an equivalent mass.

ACKNOWLEDGEMENTS. GIADA was built by a consortium from Italy and Spain under the scientific responsibility of the Università di Napoli "Parthenope", IT, and INAF-Osservatorio Astronomico di Capodimonte, IT, developing a Principal Investigator proposal supported by University of Kent, UK. GIADA is presently managed and operated by the Istituto di Astrofisica e Planetologia Spaziali of INAF, IT. The instrument development for ESA has been managed and funded by the Italian Space Agency ASI, IT, with a financial contribution by MEC, ES. The scientific team includes members from IT, ES, UK, FR, DE, USA. This research was supported by the Italian Space Agency (ASI) within the ASI-INAF agreements I/032/05/0 and I/024/12/0. 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.

From Kuiper Belt to Comet

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ABSTRACT

The Kuiper belt is the likely source of most Jupiter-family comets. In this talk I will discuss the properties of the belt that are relevant to the source and the nature of cometary nuclei. Subjects will include the magnitude of the source population, its location within the Kuiper belt as a whole, the nature of the transport to the terrestrial planet region and the physical and chemical changes initiated in the nucleus by relocation from a cold to a hot place.

Assessing the Primordial Character of Comets and of 67P/Churyumov-Gerasimenko

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ABSTRACT

Meteoritic studies indicate that our solar system formed about 4.6 Gyr ago. But the formation of stars and planetary systems is continuing today. Thus, comets are probably forming in today's nascent planetary systems. At present, research on young stellar objects and their protoplanetary disks is advancing rapidly, as observations with new facilities become available and induce efforts of more detailed modelling. Putting properties derived for comets in our solar system into the context of what we know about today's formation of planetary systems can help to understand the origin of comets in our solar system, in particular when and where they formed. When doing so, we must, however, be aware that, even though the comets of our solar system are believed to be pristine bodies, they may have been altered during the elapsed time since formation. In particular, collisions with other small solar system bodies and solar radiation effects may have altered the comet's properties during the time it spent in the inner solar system.

Most cometary researchers realize that they need to be aware of the present evolution in our knowledge of young stellar objects and the protoplanetary disks surrounding them. But it is difficult to get an overview on the vast literature available on this topic. Therefore in the present contribution a first attempt is made to relate the information on the origin of the solar system as it can be concluded from measurements of comet properties to what we know about nascent planetary systems.

First, the observational evidence from comets is used to characterize selected physical parameters that may have prevailed at the time of their making. Then, we try to associate these results to specific stages of the solar system formation as measured and concluded from observations of young stellar objects and planet forming systems in our galaxy. Wherever possible and available, results of the Rosetta target comet 67P are addressed; however, complementary results obtained from other comets are also included.

The role of comets in planet formation

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ABSTRACT

Planets form in protoplanetary discs around young stars. In the first stages of planet formation dust and ice particles grow to form pebbles and the pebbles concentrate in the turbulent gas. These overdense pebble regions collapse by self-gravity and form planetesimals with a wide range of sizes. Asteroids and comets represent remnant planetesimals from the planet formation epoch in the Solar System that did not become incorporated into the planets. The gravitational collapse model for planetesimal formation predicts that comets are piles of pristine pebbles from the solar protoplanetary disc. I will present the latest theoretical models for the formation of planetesimals and discuss the role of comets in planet formation.

Langmuir Probe and Mutual Impedance Probe Plasma Measurements of Comet 67P in Comparison to Spacecraft-Plasma Interaction Simulations

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ABSTRACT

ESA's comet-chaser Rosetta is monitoring the plasma environment of comet 67P/CG since Summer 2014. Measurements from the Langmuir probes of the Rosetta Plasma Consortium have shown that the spacecraft often reaches negative potentials of around and in excess of -20V, which affect in situ measurement of the plasma environment surrounding the spacecraft. To investigate the performance of the RPC-LAP instrument and the effect of a highly negative spacecraft potential, we simulate the spacecraft-plasma interaction and perform a full Langmuir Probe sweep with SPIS and compare to measurements of RPC-LAP and the Mutual Impedance Probe experiment (RPC-MIP) in comet plasma.

IRRADIATION AND THERMAL ENVIRONMENT OF THE ABYDOS REGION on COMET 67P

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ABSTRACT

Philae's final (and accidental) landing site Abydos is an extremely uneven and rugged terrain, with a correspondingly complex irradiation history which finally controls heat fluxes and energy balance of the region. Based on available Digital Terrain Models derived from images of the cometary surface, we present a three-dimensional thermal model of the region where the Philae lander finally came to rest. Our geometry model consists of nested meshes of a global DTM released by ESA, a local DTM constructed from high resolution OSIRIS images by LAM, and a local DTM constructed from CIVA and ROLIS images provided by LCC. The 3D thermal model is set up in a finite element solver and uses the geometry and irradiation history of the surface as outer boundary condition. Both direct illumination of surface elements and indirect irradiation in the IR range are computed.

The construction of a 3D model turns out to be numerically extremely challenging, in terms of computer memory resources and computation time. This is mainly due to the uneven and rugged nature of the cometary surface, which requires high spatial resolution at many places. We describe these numerical aspects of the model in some detail and show ways to circumvent these difficulties in order to obtain sound numerical results. The main steps in the development of the model environment are the following: First, a fully tree-dimensional radiation field over the global comet surface is calculated. In the region of interest (Abydos) the spatial grid is refined, using the geometry information of the LAM and LCC models. To calculate temperature profiles, a volume grid is constructed, that is again refined in the regions where we want to calculate a temperature profile as a function of depth.

As representative results, we show the evolution of temperature at selected points versus time (e.g. over a rotation period of the comet) and the temperature as a function of depth for selected points in time. The surface temperature is controlled by the surface irradiation as well as by the composition of the surface layer (volatile or non-volatile). Finally we consider the irradiation of the field of view that has been “seen” by the MUPUS Thermal Mapper (TM) sensor and compare our modelling result with what has been derived from measured TM data during the Philae First Science Sequence.

Seasonal back fall of dust on the northern hemisphere of 67P: observational evidence and consequences for the nucleus evolution

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ABSTRACT

Early observations of comet 67P by Rosetta revealed that large parts of the northern hemisphere looked smooth and seemed to be covered by dust layers that originally were considered to be inert. Keller et al. (2015) suggested that the dust cover consists of back fall particles originating from the southern hemisphere. Thermophysical calculations applied to a detailed shape model showed that the water erosion of the southern hemisphere is 3 times higher than on the north side. In the meantime the strong dichotomy of the hemispheres has been confirmed. Large dust particles (18 – 20 cm) are seen to cross the coma with velocities comparable or below the escape speed (Agarwal et al. 2016). High resolution imaging after perihelion reveals a granularity of the back fall particles in a similar range. These particles are large enough to maintain their water ice content but too small for CO_2 or even CO. Philae ROLIS images show wind tails and moats around obstacles, all oriented in a south-north direction, that are well modelled by abrasion by impinging back fall from the south (Mottola et al. 2015). The seasonal transport of surface material from the south to the north is of major influence on the development of the nucleus at its present orbital configuration:

1) In addition to their minor insolation horizontal plains of the northern hemisphere (about 80 %) are covered by the insulating back fall particles. The effective erosion of the northern hemisphere is essential limited to cliffs (with slopes beyond the angle of repose). The erosion on the south is much stronger leading to a distinct dichotomy.
2) The water ice content of the back fall will mostly survive the northern winter, when large parts of the hemisphere are in polar night, and will become active during the following approach of the comet to the sun.
3) H_2O from the back fall dominated the composition measurements by the neutral mass spectrometer ROSINA at the beginning of the Rosetta rendezvous (Fougere et al. 2016) because sublimation activity from the nucleus proper was suppressed by the insulation layer of back fall particles.
4) The liberation of large (water active) particles from the south probably requires stronger activity driven by super volatiles (CO_2 and CO).

We will discuss the observational evidence and the consequences for the evolution of the nucleus of comet 67P.

Constraints for the subsurface structure at the Abydos site on 67P/Churyumov-Gerasimenko resulting from CASSE listening to the MUPUS insertion phase

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ABSTRACT

During the more than 3 hours of the MUPUS PEN insertion phase at Abydos, the Comet Acoustic Surface Sounding Experiment (CASSE), part of SESAME, recorded hammer strokes of MUPUS with all three accelerometers, which are housed in Philae's feet. Stroke times recorded in the MUPUS housekeeping data, the identification of two adjacent strokes in a single recording, and laboratory experiments concerning the properties of sound transmission through Philae's legs and feet foster the identification of the recorded signals as hammer strokes, and as elastic waves transmitted through the comet.

A hammer stroke exerted on a surface dominantly excites surface waves of the Rayleigh type. By comparison of arrival times at the individual feet, we estimate the propagation velocity of these Rayleigh waves to be at least 80 m/s. With the bulk density of 533 ± 6 kg/m^3 as derived from tracking Rosetta (Pätzold et al., Nature, vol. 530, 2016), this velocity translates into a shear modulus of the comet material of at least 3.2 MPa. Shear modulus scales with velocity squared, so when taking into account the formal uncertainties arising from the arrival time inversion, the shear modulus may easily be as large as 10 MPa. This is still low compared to solid rock or monocrystalline ice, but is compatible with highly porous materials.

The recorded signals are only weakly dispersive: Energy at frequencies below approx. 200 Hz arrives slightly later than at higher frequencies. This indicates the presence of a surface layer, to which the above propagation velocity and shear modulus apply, on top of a material with an even lower propagation velocity and shear modulus. The boundary between the two materials is likely more than 20 cm below the surface.

We conclude that the results of CASSE listening to MUPUS support the hypothesis of surficial sintering at least for the Abydos site on 67P/Churyumov-Gerasimenko.

CONSERT bistatic radar on the Rosetta mission: observations and main scientific results.

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ABSTRACT

The internal structure of the nuclei is one of the major unknown in cometary science. The scientific objectives of the Comet Nucleus Sounding Experiment by Radiowave Transmission (CONSERT) aboard the ESA Rosetta spacecraft was to characterize the interior of comet 67P/Churyumov-Gerasimenko nucleus. This was achieved by a series of bi-static soundings between the lander Philae located at the comet's surface and the orbiter Rosetta.

The measurements performed on the 12th-13th of November 2014, during the first science sequence, revealed the internal structure of the small lobe (head) of the comet 67P/ C-G.

We will describe the measurements that explored the interior of the comet, explain the data analyses and present a synthesis of the obtained results, and their interpretation in term of the internal structure and possible composition.

Typology of cometary particles collected by COSIMA during the orbital phase of Rosetta (August 2014 – September 2016)

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ABSTRACT

We will present results on the optical characterization of cometary particles collected by the COSIMA instruments over the full extent of the orbital mission, from August 2014 to the end of the ROSETTA mission in September 2016. The cometary particles collected on "metal black" targets (Hornung et al., 2014) are detected by taking images before and after exposure with a microscope, COSISCOPE, with a resolution of 14 µm / pixel. The targets are illuminated at high incidence (70° – 84°) by two LED's on opposite sides of the targets. Images taken by sampling at 7 µm intervals in X and Y provide an effective spatial resolution of ~ 10 µm. Since rendez-vous, COSISCOPE has detected several 10,000 particles or fragments of particles. Several 100 particles cover an area of more than 10 pixels (40 sub-sampling points), making it possible to characterize their morphology. The typology of particles collected until April 2015 has been presented in Langevin et al. (2016).

A large majority of the collected particles are clusters ranging from connected aggregates to shattered clusters. Other particles are compact, sticking out of the collecting layer. They also exhibit substructure down to the 10 µm resolution of COSISCOPE (no clear evidence for a monocrystalline grain larger than 50 µm has been obtained). During analysis, many compact particles crumbled or exploded under electrostatic stress. While higher than that of cluster particles (a few 100 to a few 1000 Pa, Hornung et al., 2016, PSS, under review), their tensile strength is therefore still low.

During the first 6 months of the mission (August – December 2014), large cluster particles up to 500 µm in size were collected as well as large compact particles up to 400 µm across. No compact particle larger than 200 µm has been collected later on. The period before and close to perihelion (January 2015 – August 2015) has been dominated by a few very large collection events with particles 1 – 2 mm in size breaking up in the entry funnel and spreading hundreds of fragments over the targets. The distribution of fragment sizes differed markedly between collection events, indicating variations in the cohesive strength of the parent particle. After perihelion, the occurrence of such "shower events" decreased, while the proportion of small compact particles (< 100 µm) increased.

Grazing incidence, which was selected for maximizing the detection capability, makes it difficult to determine reflectance properties. However, combining both illuminations, we show that the reflectance of most particles ranges from a few % to 20% (only one large compact particle collected in November 2014 has a reflectance of 35 to 40%), which is consistent with observations at scales of a few mm to several 10 m (CIVA – ROLIS – OSIRIS). The light profiles observed for a large fraction of cluster particles indicate that they are partly translucent, in line with a high porosity.

- K. Hornung et al. (2014) Collecting cometary dust particles on metal blacks with the COSIMA instrument onboard ROSETTA. *Planet. Space Sci.* **103**, pp 309-317.

- Y. Langevin et al. (2016) Typology of dust particles collected by the COSIMA mass spectrometer in the inner coma of 67P/Churyumov Gerasimenko *Icarus*, **271**, p. 76-97.

Texture analysis of IPDs and comparison to 67P dust particles

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ABSTRACT

The Interplanetary Dust Particles (IDPs) are collected in the Earth's stratosphere by NASA aircrafts and curated at the Johnson Space Center. Approximately a third of those samples are determined to be of extra-terrestrial origin (either asteroidal or cometary) based on a composition close to the bulk composition of primitive carbonaceous chondrites (CV3, such as Allende) [1]. Automatic analysis of the particles composition has been shown to improve the classes and classification of the different samples [2]. Studies have shown the close relationship between IDPs and comets based on the fact that meteor shower dust streams are linked to cometary orbits, and that numerical dynamical models of dust indicate most dust particles within 1 au from the Sun to originate from cometary activity.

Since the arrival of the Rosetta international space mission at comet 67P/Churyumov-Gerasimenko, dust detection instruments have been probing the different dust properties over the 2 years of the mission. The GIADA and COSIMA instruments unveiled the existence of two populations of particles with very different properties (one with compact entities and one with agglomerates of many sub-units). The imaging of the COSIMA and MIDAS experiments renders possible the investigation of the agglomerate structure of dust particles with many bulbous sub-units at different size scales (from millimetres down to 100s of nanometres), [3, 4, 5], which is akin to the self-affine similarity found in fractals. Detailed compositional analysis of dust particles by COSIMA is still on-going.

In this work, we use texture analysis of the particles images (e.g. roughness, variograms, fractal dimension) in order to determine classes of IDPs that are relevant to their origin. We then compare the classification scheme to the results obtained from the image analysis of the Rosetta experiments. A simple model of fractal aggregate deformation is also developed to tentatively constrain to the first order the particles properties (e.g. dimension, density, tensile strength) before collection.

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Trapping Mechanism of O_2 in Water Ice as First Measured by Rosetta Spacecraft

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ABSTRACT

One of the most surprising measurements of the Rosetta Orbiter Spectrometer for Ion and Neutral Analysis instrument, ROSINA on the Comet 67P/Churyumov–Gerasimenko was the detection of O_2 along with N_2 and noble gases which were measured for the first time in comets along with water, CO and CO_2. The O_2 high abundance of 1–10% relative to H_2O was calculated, with an average value of 3.80 ± 0.85 (Bieler et al. 2015). The strong correlation of molecular oxygen abundance with water, suggests the formation of O_2 by radiolysis or photolysis of water molecules and trapping it in the amorphous ice together with the other gases while the comet was formed.

In this study we present new experimental results for trapping O_2 with N_2 and Ar in amorphous ice in order to understand the direct measurements of Rosetta spacecraft. Gas mixtures of O_2, N_2, Ar and water vapor were deposited on a 17 cm^2 cold surface at temperatures of 40-60 K, to form a 50 μm thick gas-laden amorphous ice, in a vacuum chamber (Bar-Nun et al. 1987, Laufer et al. 1987). At these temperatures the water ice is amorphous and highly porous, and gases are trapped in the lattice. Upon heating, changes occur in the ice, and all the gases evolve together from it in distinct peaks, related to ice phase transformations and sublimation (Bar-Nun et al. 2013). The trapping efficiencies of gases in the ice is O_2>Ar>N_2, thus explaining the direct observation of gas jets and the high abundance of molecular oxygen in the ROSINA's measurements on the nucleus of comet 67P/C-G.

The discovery of O_2 in comets challenges our understanding of the composition of the volatiles in the outskirts of the young solar system and their delivery to the Earth`s atmosphere.

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Comet 67P Nucleus Water Ice Surface Distributions Retrieved from Rosetta/MIRO Observations

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ABSTRACT

The spatial structure and temporal evolution of the inner coma of Comet 67P have been observed by Microwave Instrument on Rosetta Orbiter (MIRO) since the Rosetta Orbiter has rendezvoused with Comet 67P in August 2014. Among the several cometary gas emission lines that the MIRO spectrometer is tuned to, the water isotopologue $H_2^{18}O$ line is optically thin and is used to probe the inner coma structure as the MIRO beam scans the space near the comet nucleus. The water line area/strength shows clearly that the day side of coma has a lot more gas than the night side of coma and the summer hemisphere side of coma has a lot more gas than the winter hemisphere side of coma. These diurnal and seasonal dependencies strongly suggest that the water gas in the coma is from the sublimation of ice in the nucleus, where its rate greatly depends on the thermal condition of surface and near-surface governed by the sun illumination condition. In addition to the sun illumination condition, the water ice distribution on 67P nucleus affects the inner coma structure. We model the inner coma structures with various ice distributions and compare them with the observations. The comparison undoubtedly shows that the ice is not uniformly distributed on 67P nucleus. The observation favors the model with the ice distributed only in polar caps in both poles. The observation also shows the evidence of temporal evolution of the ice distribution. The southern polar ice cap was less active a few months before the perihelion (August 2015), became more active near the perihelion, and became less active a few months after the perihelion. Note that the ice cap activity change due to the temperature-dependent sublimation rate change is already taken into account, and does not explain the temporal variation of the inner coma structure. This result indicates that there was a change of ice distribution (polar cap size) or ice location near the surface (how deep the dust layer covers the ice).

Linking cometary and zodiacal dust Evidences from the Rosetta mission

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ABSTRACT

Dust particles released from cometary nuclei in filaments, jets, tails and trails contribute to the replenishment of the zodiacal cloud, i.e. the interplanetary dust cloud, which forms a thick disk around the Sun. Micron-sized to millimetre-sized dust particles (depending on their density and initial velocity vector) spiral towards the Sun under Poynting-Robertson effect. Main sources available to ensure the stability of the inner zodiacal cloud are mostly dust particles released by active comets and colliding asteroids.

Before the Rosetta mission, in situ observations from the Giotto spacecraft had suggested the dust particles to be extremely porous and dark. Remote polarimetric observations of comets Halley and Hale-Bopp were successfully modelled with mixtures of minerals and more absorbing organics, consisting both of fluffy aggregates (computed with BCCA or BPCA fractal aggregation models) and compact grains. Meanwhile, from inversion of line-of-sight integrated polarization data, changes in zodiacal dust local properties with solar distance, possibly induced by evaporation processes or collisions, were inferred below 1.5 au. Modelling with mixtures of dust particles suggested that these changes correspond to a progressive disappearance of refractory organics towards the Sun, and that a major proportion of zodiacal dust originates from comets [1].

Rosetta has now established that 67P/Churyumov-Gerasimenko nucleus is extremely porous and less richer in volatile ices than in dust, with many refractory organic compounds already discovered in it. Rosetta has also provided evidence, through GIADA, COSIMA and MIDAS experiments [e.g., 2-4], for a heterogeneous population of dust particles morphologies, with large (10s to 100s μm size-range) fluffy dust of irregular, sub-micron-sized grains, the size distribution and fractal dimension of which was estimated.

These results clearly indicate the likely cometary origin of porous interplanetary dust particles collected in the stratosphere (IDPs) and of ultra-carbonaceous Antarctic micro-meteorites (UCAMMs). The Rosetta ground-truth already provides a missing link for future interpretation of polarimetric observations of comets, and may allow us to speculate about the evolution of the early Earth, with fluffy dust aggregates (more likely to survive atmospheric ablation than compact ones for an equivalent size) enriching the Earth's surface in complex organic compounds, during a heavy bombardment epoch.

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Influence of charge separation on solar wind deflection: electrostatic PIC-modeling of a small comet

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ABSTRACT

Observations by the ICA instrument on board the Rosetta spacecraft show that protons are deflected more than expected as the solar wind interacts with the coma of comet 67P/Churyumov-Gerasimenko. A possible explanation for the large deflection is the electric field generated by the separation of pick-up water ions and electrons. The arising space charge can neither be measured by instruments on board Rosetta nor modelled by conventional hybrid codes. Instead, we utilize an electrostatic particle-in-cell (PIC) model, simulating the solar wind interaction with the comet and its atmosphere. Due to the high computational demands of the PIC code, having to resolve the Debye length of the order of meters, we choose to model a small comet. We study the charge separation between water ions and electrons and its effect on the solar wind proton deflection.

Photometric behavior of 67P spectral parameters and analysis of its diurnal variations

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This work is aimed at inferring the photometric behavior of spectral parameters describing the spectrum of 67P/Churyumov-Gerasimenko, and variations of this behavior among the four comet macro-regions (i.e. head, neck, body, bottom) and with local time (LT, the four LT intervals considered are 0-6, 6-12, 12-18 and 18-24).

The work has been performed on data provided by the VIRTIS imaging spectrometer onboard the ESA Rosetta spacecraft. In particular, only data from pre-landing phase of the mission have been considered in order to have results dependent only on the intrinsic optical/physical properties of the comet nucleus and not on the cometary activity (observed in Escort and Cruise mission phases).

In the following, we summarize the obtained results or each spectral parameter considered:

Reflectance. The radiance factor at six different wavelengths in the visible and infrared range has been extracted, i.e. 0.55, 0.75, 1.2, 2.0, 2.8, 4.0 um. The photometric correction has been performed in two steps: in the first one, the disk function most appropriate to remove the incidence and emission influence has been identified and the equigonal albedo has been retrieved; in the second one, the equigonal albedo behavior with phase has been modelled for all the wavelengths, regions and LT intervals considered. For all the wavelengths considered, the Akimov disk function is the best one to obtain equigonal albedo and the phase function does not show geographical and diurnal variations. However, the phase function steepness is much lower than other comets previously explored by space missions and is instead more similar to S-type asteroids. This may reflect a different composition or physical properties of the 67P surface regolith.

3.2 um band depth. This band is ascribed to organics, but can be modified by the presence of water ice, which can deepen the band and shift the band center shortward. The band depth has been found to be independent on both incidence and phase angles, whereas a linear increase with emission is observed only in the 12-18 LT interval. However, this increase is of order of 1%, which is lower than the noise level, hence has not been investigated further.

3.2 um band center. A longward shift at increasing incidence angle is observed. The shift is larger at diurnal LT (about 20 nm at 12-18 LT) and is absent in the night LT (0-6). The interpretation is that the 3.2 um «dark» carrier show this behavior, and the formation of water ice during the night shortens the band center at high incidence angles and removes the trend. The shift of band center with incidence observed at diurnal LT may be ascribed to a band center dependence on temperature. This could be confirmed by laboratory measurements on possible 67P/CG analogues.

Visible and infrared slope. The behavior of visible (i.e. between 0.55 and 0.75 um) and infrared (i.e. between 1.2 and 1.9 um) with phase angle has been studied in order to analyze the phase reddening. A linear dependence of both slopes with phase angle is observed. The obtained average behavior is in excellent agreement with previous works, based on different methods. Moreover, slopes and phase reddening are usually spatially and temporally constant, but are sligthly lower and higher, respectively, at neck region and at nocturnal LT (0-6 and 18-24). This is consistent with occurrence of ice in the neck region and with diurnal cycle of water.

The role of comets in understanding the evolution of nitrogen in solar system atmospheres

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The origin and evolution of nitrogen in solar system bodies is an important question for understanding processes that took place during the formation of the planets and solar system bodies. The most abundant molecule in the Earth's, Titan's, Pluto's and Triton's atmospheres is molecular nitrogen. The nitrogen isotope ratio, $^{14}N/^{15}N$, is an important tracer of the origin of nitrogen on these solar system bodies. By modeling the evolution of the nitrogen isotope ratio from its primordial value to its current value, we can determine if this nitrogen originated as molecular nitrogen or is derived from ammonia in the protosolar nebula. We evaluate the potential impact of escape and photochemistry on $^{14}N/^{15}N$ in these atmospheres to determine constraints for the origin of nitrogen on these bodies. Cometary observations of nitrogen isotope ratios play a key role in these studies, which will ultimately provide guidance on measurements needed by future a future Ice Giants mission to study Triton and any mission to follow New Horizons and Cassini in exploring Pluto and Titan.

The morphology and growth of cometary dust at the micrometre scale

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ABSTRACT

The properties of pristine cometary dust grant a view into the processes of the early Solar System. In particular, dust agglomeration in the protoplanetary disc can be studied by investigation of the morphology of cometary particles. Carrying three dedicated instruments for dust analysis, Rosetta opened the unique opportunity to obtain ground-truth measurements of cometary particles. One of the instruments was MIDAS (Micro-Imaging Dust Analysis System), an atomic force microscope that collected and imaged dust particles with sizes down to nanometres. The larger particles, tens of micrometres in size, allow a comprehensive investigation of their morphology.

This presentation focusses on the different morphologies of several ten micrometre sized cometary dust particles and interprets them regarding growth processes in the early Solar System. The most important investigated properties are the size and shape of the sub-units as well as the construction of the parent dust particle. Whilst size and shape of the sub-units are used to infer their origin, the construction of the dust particles grants knowledge about their growth and further processing during comet formation. The results will be compared with the findings of the other dust investigating instruments aboard Rosetta. Whilst COSIMA granted a view on the construction of the larger dust particles, GIADA determined their physical properties like density and speed. These data are used to understand how the morphology of dust particles investigated with MIDAS is reflected in the dust one to two orders of magnitudes larger.

Cometary noble gases measured by the Rosetta orbiter spectrometer for Ion and Neutral Analysis (ROSINA): planetary implications

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ABSTRACT

Noble gases are key tracers for the origin(s) and processing of volatile elements in the nascent solar system and in planetary atmospheres. During a dedicated observing period in May 2016, the Double Focusing Mass Spectrometer ROSINA DFMS detected the three noble gases Argon, Krypton and Xenon with most of their isotopes. In this talk we will present the results from this dedicated observing period and discuss the implications for solar system formation scenarios, as well as for the origin of volatile species on inner planets.

High Resolution Optical Spectroscopy of Rosetta Target 67P/Churyumov-Gerasimenko Using Keck HIRES

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Abstract

We present high spectral resolution optical spectroscopy of Rosetta target 67P/Churyumov-Gerasimenko obtained on UT Dec 26 and 27, 2015 using the HIRES instrument on Keck I when the comet was at a heliocentric distance of approximately 2 AU post-perihelion. The spectra cover a spectral range of 3500-10000 Angstroms at a spectral resolution of 67,000. These observations aim to provide high spectral resolution, large projected field of view context for the high spatial resolution and small projected field of view observations obtained from the Rosetta instrument suite. We report detections of CN, NH_2, and [OI] emission. From the [OI]6300 emission we derive a water production rate of approximately 2 x 10^{27} mol/s. Production rates (or upper limits) for other species will be presented and placed in context with recent results from Rosetta. We will also present results pertaining to the [OI]5577 line, which combined with the [OI]6300 emission can be used as a proxy for CO_2. We will compare our results to observations obtained by Rosetta as well as NEOWISE and Spitzer.

Nearly Inactive Long-Period (Manx) Comets and Their Role in Understanding Solar System Formation

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ABSTRACT

Comets and small primitive bodies were witness to the solar system's formative processes. When gas was present in the disk during the first 5 million years, a local chemical signature was imprinted on the planetesimals. The connection to today's solar system relies on how this material was dynamically re-distributed during planet formation. Recent dynamical models are reproducing key characteristics of today's solar system; some of these require significant giant planet migration, while others do not. A key difference between these two classes of models is that the former models expel rocky material from the inner solar system into the Oort cloud while the latter do not. The recent discovery of an object (C/2014 S3 PANSTARRS) on a long-period comet orbit with minimal cometary (volatile-driven) activity that exhibits a surface spectrum consistent with inner solar system rocky (S-type) material (Meech *et al.,* 2016) suggests that it formed in the inner solar system and it provides tests of dynamical models.

The Pan-STARRS1 survey telescope is now the most prolific facility detecting new faint comets and NEOs, and in particular faint nearly inactive comets on long-period orbits (Manxes). We have undertaken a program to characterize the surfaces of a large sample of Manxes in order to test the dynamical models. We now have about a dozen Manxes that have either been observed or are in the queue for observations. Manx C/2013 P2 PANSTARRS, the second Manx to be well characterized, has an extremely red spectrum, more typical of TNOs than comets, but like C/2014 S3 was also minimally active. We will present the status of the observing program and analysis of several of these objects and the implications for solar system formation in the context of what we have learned from missions to short-period comets.

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Dust Particle flux measured in-situ by Rosetta/COSIMA

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ABSTRACT

The COSIMA instrument collects dust particles ejected from the nucleus of 67P/C-G and analyses their composition by Secondary Ion Mass Spectrometry. The particles are collected on metallic plates with a high sticking efficiency and are detected with the internal camera of the instrument, the COSISOPE, which has a resolution of 14 microns x 14 microns.

Since August 2014, almost 30,000 cometary particles and particle fragments have been detected on the COSIMA plates, with a variety of morphologies and sizes. We will describe how the flux of dust and the size distribution of the particles have evolved along the comet journey around the Sun during the two years of the Rosetta mission.

Title: **Disruptive collisions as the origin of 67P/C-G (and small bilobate comets)**

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Abstract.

Images of comets sent by spacecraft have shown us that bilobate shapes seem to be common in the cometary population. This has been most recently evidenced by the images of comet 67P/C-G obtained by the ESA Rosetta mission, which show a low-density elongated body interpreted as a contact binary. The origin of such bilobate comets has been thought to be primordial because it requires the slow accretion of two bodies that become the two main components of the final object. However, slow accretion does not only occur during the primordial phase of the Solar System, but also later during the reaccumulation processes immediately following collisional disruptions of larger bodies. We perform numerical simulations of disruptions of large bodies. We demonstrate that during the ensuing gravitational phase, in which the generated fragments interact under their mutual gravity, aggregates with bi-lobed or elongated shapes form by reaccumulation at speeds that are at or below the range of those assumed in primordial accretion scenarios [1]. The same scenario has been demonstrated to occur in the asteroid belt to explain the origin of asteroid families [2] and has provided insight into the shapes of thus-far observed asteroids such as 25143 Itokawa [3]. Here we show that it is also a more general outcome that applies to disruption events in the outer Solar System. Moreover, we show that high-temperature regions are very localized during the impact process, which solves the problem of the survival of organics and volatiles in the collisional process. The advantage of this scenario for the formation of small bilobate shapes, including 67P/C-G, is that it does not necessitate a primordial origin, as such disruptions can occur at later stages of the Solar System. We note that the bilobate or elongated shapes resulting from the disruption of a large body might further evolve in subsequent smaller-scale collisions [4] and/or a fission-merging cycle [5]. This demonstrates how such comets can be relatively young, consistent with other studies that show that these shapes are unlikely to be formed early on and survive the entire history of the Solar System [6].

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CN and OH emissions in the 67P/Churyumov-Gerasimenko coma with Rosetta/VIRTIS-M spectrometer

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Abstract

Observations with the visible channel of the Visible and InfraRed Thermal Imaging Spectrometer (VIRTIS) on board Rosetta taken when the spacecraft was at a distance of 80-140 km from 67P/Churyumov-Gerasimenko (67P/C-G) allowed the detection of daughter gaseous species in its inner coma.

The detection of the violet doublet emission of CN at 388.3 nm has occurred during the coma monitoring campaign in November-December 2015, when the instrument has operated with long integration times (50 s) necessary to boost the instrumental SNR and detect these faint emissions. Other features, like the C_3 and C_2 signatures around 420-480 nm, might possibly be visible in few cases but with a very low intensity. For this reason, we concentrate our analysis in the spectral region from 250 to 450 nm, where the detector sensitivity allows the positive detection of the above-mentioned CN violet line at 388.3 nm, and the OH doublet emission at 309 nm. The CN emission at 388.3 nm is observed on both the day and night sides of 67P/C-G with a higher intensity on the dayside. In addition, at a preliminary analysis, the hydroxyl doublet emission intensity seems to be comparable to the violet CN line.

The same emissions were also identified in spectra acquired using ground-based facilities, when the comet had just passed the perihelion (Fitzsimmons et al., 2016).

These gaseous species emissions appear well contrasted with respect to the dust broad continuum, preferentially observed on the dayside.

Distribution and variability of the OH and CN band intensities will be discussed with respect to observation parameters.

Title: **How primordial is the structure of comet 67P/C-G (and of comets in general)?**

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Abstract.

Several properties of the comet 67P-CG suggest that it is a primordial planetesimal. On the other hand, the size-frequency distribution (SFD) of the craters detected by the New Horizons missions at the surface of Pluto and Charon, reveal that the SFD of trans-Neptunian objects smaller than 100km in diameter is very similar to that of the asteroid belt. Because the asteroid belt SFD is at collisional equilibrium, this observation suggests that the SFD of the trans-Neptunian population is at collisional equilibrium as well, implying that comet-size bodies should be the product of collisional fragmentation and not primordial objects. To test whether comet 67P-CG could be a (possibly lucky) survivor of the original population, we conducted a series of numerical impact experiments, where an object with the shape and the density of 67P-CG, and material strength varying from 10 to 1,000 Pa, is hit on the "head" by a 100m projectile at different speeds. From these experiments we derive the impact energy required to disrupt the body catastrophically, or destroy its bi-lobed shape, as a function of impact speed. Next, we consider a dynamical model where the original trans-Neptunian disk is dispersed during a phase of temporary dynamical instability of the giant planets, which successfully reproduces the scattered disk and Oort cloud populations inferred from the current fluxes of Jupiter-family and long period comets. We find that, if the dynamical dispersal of the disk occurs late, as in the Late Heavy Bombardment hypothesis, a 67P-CG-like body has a negligible probability to avoid all catastrophic collisions. During this phase, however, the collisional equilibrium SFD measured by the New Horizons mission can be established. Instead, if the dispersal of the disk occurred as soon as gas was removed, a 67P-CG-like body has about a 20% chance to avoid catastrophic collisions. Nevertheless it would still undergo 10s of reshaping collisions. We estimate that, statistically, the last reshaping collision should have happened 250My-1Gy ago, implying that the actual morphology of 67P-CG should be younger than this age.

We will present preliminary simulations showing that a comet with properties similar to 67P/C-G can be produced in both sub-catastrophic and catastrophic collisions.

Laboratory spectral VNIR studies supporting VIRTIS' nucleus surface composition analysis of 67P/CG and prospects for future observations

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ABSTRACT

The Visible and InfraRed Thermal Imaging Spectrometer (VIRTIS) onboard Rosetta provided 0.25-5.2 μm spectra of 67P/CG (Capaccioni et al., 2015) enabling a nucleus surface composition analysis. Thermally and photometrically corrected reflectance spectra display low geometric albedo, different red VIS and IR spectral slopes, and a complex broad absorption band centered at 3.2 μm. The low albedo and the structure of the ubiquitous 3.2 μm band suggest that the cometary surface is homogeneously enriched in refractory organic materials and darkening phases (Capaccioni et al., 2015).

Detailed studies of laboratory analogue materials are necessary to disentangle different interfering factors that influence the appearance of reflectance spectra. Thus, such investigations are indispensable for reliable compositional analysis of remote sensing data. Here we present 0.25-5 μm laboratory reflectance spectra of well-characterized terrestrial hydrocarbon materials (solid oil bitumens, coals) and discuss their relevance as spectral analogues for 67P/CG refractory organics. In addition, the possible contribution of inorganic matter to spectral characteristics of 67P/CG should be understood based on laboratory reflectance measurements. Although a wide range of silicate compositions was found in cometary dust and anhydrous IDPs of presumably cometary origin, Mg-rich crystalline mafic minerals are dominant silicate components. A large fraction of silicate grains are Fe-free pyroxenes and olivines (forsterites) that are not found in terrestrial rocks but can be synthesized in order to provide a basis for laboratory studies and comparison with VIRTIS data. We report the results of the synthesis, analyses, and/or spectral reflectance measurements of Fe-free low-Ca pyroxenes (ortho- and clinoenstatites), forsterites, and a high-Ca pyroxene (diopside). Finally, fine-grained opaque refractory phases (e.g. iron sulfides, Fe-Ni alloys) are likely responsible for the low IR reflectance and low contrast of the 3.2 μm absorption band. Therefore, we present and discuss 0.25–5 μm reflectance spectra of pure Fe-sulfides (troilites, pyrrhotites) and their intimate mixtures with organic and inorganic analogue materials. Based on the reported laboratory data, we discuss the ability of iron sulfides to suppress absorption bands of other cometary refractory components and to affect the spectral slopes and reflectance values of the 67P/CG surface at different wavelengths from the near-UV to the IR. Summarizing these results, we discuss some prospects for future spectral studies.

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First close-up look at a Cometary Surface: the ROLIS Experiment

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ABSTRACT

The ROLIS instrument – the descent and close-up camera onboard Philae – acquired near-field multispectral images of the cometary surface at a resolution better than 1 mm/pixel. During descent, it also captured a sequence of images with a maximum resolution of 1 cm/pixel with the intent of providing context for the close-up imagery and aiding in the identification of the landing site. The malfunction of the Philae anchoring system, however, resulted in a rebound of the lander, which caused the descent images and the close-up images to be acquired at two different locations.

Among the most significant insights provided by ROLIS is the evidence that even at scales of 1cm/pixel the cometary surface at the Agilkia touchdown site appears of granular nature and no fine "dust" deposits are present. Within the region observed by ROLIS (a square of 70 m in size), two well distinct types of terrain are observed: a smooth one and a rough one. The frequency-size distribution of the particles in the smooth terrain is well described by a power law with an index that matches with surprising accuracy the power law distribution observed by the OSIRIS and GIADA instruments for small particles traveling in the coma (Rotundi et al. 2015, Pajola et al. 2016). This observation, together with the identification of aeolian erosion features around a large boulder present in the ROLIS field, reinforces the notion that the regions in the comet's Northern hemisphere are subject to particle airfall, as first proposed by Thomas et al, (2015). The observed aeolian features are explained by abrasion of a pre-existing sandbed as a consequence of particle airfall (Mottola et al., 2015).

The multispectral close-up images acquired at Abydos, the final landing site, reveal a completely different texture of the terrain. No individual particles are seen down to a resolution of 0.3 mm/pixel. The surface appears cracked, with the cracks occasionally defining plates with typical sizes in the range of decimeters. The edges of the plates have usually a higher reflectance (up to 40% brighter) than the top layer, suggesting the presence of a refractory crust and an underlying softer layer (Schroeder et al. 2016).

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Impact of radiogenic heating on the formation conditions of comet 67P/Churyumov-Gerasimenko

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ABSTRACT

Because of the high fraction of refractory material present in comets, the radiogenic decay of elements can generate enough heat to induce the loss of ultravolatile species such as N_2, Ar or CO if the nuclei accreted early in the protosolar nebula. Here we investigate the influence of this decay heat on the formation conditions of comet 67P/Churyumov-Gerasimenko as a function of its accretion epoch and size of parent body. We consider two possibilities: either, to account its bilobed shape, 67P assembled from two primordial ~1 kilometer-sized planetesimals or it results from the disruption of a bigger parent body. To match the volatile content observed in the coma, we find that 67P/Churyumov-Gerasimenko must have formed several Myr after the protosolar nebula initiation,

independent of i) the size of parent body and ii) the composition of the icy material (amorphous ice, clathrates or cristalline ice). This places stringent conditions on the formation timescales of 67P/Churyumov-Gerasimenko and other comets.

"67P in the Context of a Taxonomic IR Survey of 30 comets: Chemical and Isotopic Signatures, and Their Cosmic Implications"

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ABSTRACT

Strong gradients in temperature and chemistry in the proto-planetary disk, coupled with dynamical dispersion, imply that comets from the Oort Cloud and Kuiper Disk reservoirs should have diverse compositions. Some comet nuclei should contain legacy materials from the natal interstellar cloud core, while others should contain materials that were processed largely within the inner protoplanetary disk. The primary volatiles (ices native to the nucleus) provide excellent metrics that test these hypotheses, and taxonomies based on volatile composition are now beginning to emerge [1-6]. Chemical composition aside, cosmic parameters such as nuclear spin temperatures (e.g., for H_2O, NH_3, CH_4), and enrichment factors for isotopologues (e.g., D/H in water and hydrogen cyanide, $^{14}N/^{15}N$ in CN and HCN) provide important tests for the origin of cometary material and inform us of Earth's cometary (and sometimes interstellar) heritage.

The detailed measurements of volatiles in 67P provide a compelling matrix of results that outline the origin and subsequent history of this cometary nucleus. Their implications for cometary populations in current reservoirs (Oort Cloud, Kuiper Disk), and for planetary system evolution in particular, require consideration within the context of taxonomic databases for many comets – especially those based on measurements of native (primary) volatiles and minerals (chemistry, isotopes, & structure).

I will provide a brief overview of these topics, of the molecular science involved, and of the emerging implications for the origin of Earth's water and its pre-biotic organics. By delivering volatiles to early Earth during the Hadean epoch, comets may well have enabled the origin of life.

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Radial mixing of high- and low-temperature components of comets in the protoplanetary disk

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ABSTRACT

The finding of crystalline materials in the comae of comet 81P/Wild 2 [1, 2] showed large scale mixing of the inner and outer solar materials in the early solar system. Recent our study on the Antarctic micrometeorites [3], which are extremely pristine and which are larger in size giving more general information about size distribution, mixing ratio, and occurrence of high- and low-temperature components in cometary comae compared to IDPs, also showed mixing of high- and low-temperature components in cometary materials. It is thus clear that large scale mixing in the protoplanetary disk is a common feature for the origin of comes.

We have investigated dust transportation in the protoplanetary disk with a newly developed particle-tracking model [4], which describes the movement of individual dust particles that is related to density and temperature of the disk. The model is based on an advection and diffusion equation using the Lagrangean description of fluid dynamics. The unique point of our model is simultaneous application of chemical equilibrium calculation, which enables us to calculate chemical change of the disk due to detailed evaluation of the change of chemical composition of individual dust particles and the spatial and temporal variation of particle numbers. The disk is assumed to be an alha disk, where the viscosity is a parameter, we do not consider accretion to the disk, disk mass is a parameter from 0.1 to 1 of the mass of the Sun, and the dust grain size is 1 micron. Dust particles initially locate at the outer region were basically transported inward due to accretion to the Sun, however a considerable amounts of particles experienced high temperature in the inner region were transported outward due to diffusional turbulence.

The sublimation limit of H2O ice is strictly calculated on the basis of the density (pressure), which varies from ~140K at $P_{tot}=10^{-4}$ Pa to ~200K at $P_{tot}=10^{2}$ Pa. The sublimation limit, which corresponds to “snow line” or “ice line”, stays at ~10AU in the early 10^{4} years, and moves inward to ~2AU after 10^{6} years, but the temperature stays at 152-155 K over the time. The results show that dust particles originated in low temperature (T~10-30K) should accrete to pebble or larger bodies in the outer region where the temperature-pressure condition is below the sublimation limit of ice. If comets were formed within 10^{6} year, the location should have been beyond the Jupiter orbit.

Icy particles are relatively mot abundant at ~30AU in 10^{5} years or later, however, refractory particles that experience high temperature (~1500K) that are observed as fragments of CAIs or chondrules in Wild2 samples are most abundant at several AU in 10^{5} years and ~15 AU in 10^{6} years. Thus, most plausible region would be ~10AU at 10^{5} years to ~~20AU in 10^{6} years.

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Coma features of the comet 67P/C-G in polarimetric context: observations from Rozhen observatory[1]

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ABSTRACT

The imaging polarimetry observations of the comet 67P/Churymov-Gerasimenko were carried out with the 2-m Telescope of National Astronomical Observatory, Rozhen. The polarimetric images were obtained with the two-channel focal reducer equipped with Wollaston prism in the parallel beam, and a polihromatic λ/2 retarder (350-850 nm) placed in the Ritchey-Chretien focal plane. The Wollaston prism is used with a rectangular mask having a FOV projected on the sky 10'x1' arcmin, limited by the retarder size to an usable length of 5' arcmin. For a better S/N ratio a specially designed continuum RX-filter centered at 694 nm was applied. The wide-band RX filter has a blue wing shifted to the redder wavelengths to avoid the brightest water ions emission lines at 614 and 620 nm. The entire focal reducer was rotated at the position angle of the comet in order to align the long side of the rectangular mask along the projected scattering plane of the comet. The sets of observations contain 4 to 8 exposures, with a duration of 200-300 s each. The level of instrumental polarization was accounted for by measurements of unpolarized nearby standard stars obtained immediately before/after the cometary observations.

The main purpose of our observations is to investigate possible relation between morphological structures in the near nucleus coma and features in the spatial distribution of the degree of linear polarization. We present preliminary results from imaging polarimetry observations of the comet 67P/C-G over a various phase-angles (grouped around 17 and 33 deg) obtained after perihelion passage. At the period of observations the heliocentric distance increased from 1.24 to 2.89 AU, and the geocentric distance changed from 1.77 to 2.18 AU. The linear polarisation was measured as a function of aperture diameter. The variations of the average polarisation are clearly visible for the inner coma region (up to $20x10^3$ km) but no strong gradient was present. Our results from the imaging polarimetry show indications for correlation between some phenomena in the inner coma with the jet activity detected from the Rosetta mission.

The presence of faint structures in the inner coma of 67P/C-G is a main characteristic of our continuum observations. We used several image processing techniques to extract these features from the bright surrounding coma. The degree of linear polarization show correlation with the spatial distribution of the intensity features, being, in most of the cases, lower on the place of the features. The relatively higher polarisation in the inner coma could be associated with the daily activity and with some seasonal effects.

Acknowledgements: Authors gratefully acknowledge the grant support of project - Support for Young Scientists-Bulgarian Academy of Sciences, Contract №106.

[1] Based on data collected with the 2m RCC telescope of the Rozhen National Astronomical Observatory.

The Effect of CO_2 on Gas Trapping in Cometary Ices

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ABSTRACT

Water vapor and CO_2 have been detected as the major constituents of the volatiles in the coma of comet 67P/Churyumov-Gerasimenko by ROSINA (Rosetta Orbiter Spectrometer for Ion and Neutral Analysis) (Hassig et al., 2015, Mall et al., 2016) onboard the Rosetta spacecraft. In this paper we describe the experimental results of the influence of trapping CO_2 on the trapping efficiency of other gases such as CH_4, N_2, Ar, Kr, Xe, in cometary ices. In these experiments gas mixtures with CO_2 and water vapor are deposited on a cold surface at temperatures between 25-80 K in a thoroughly evacuated chamber. At these temperatures the water ice formed is amorphous and highly porous, and gases are trapped in the lattice. Upon heating, changes occur in the ice, from the amorphous to the crystalline structure (Bar-Nun et al. 1987, Laufer et al. 1987, Notesco and Bar-Nun 2000). The gases trapped in the ice are released during the structural changes and upon the sublimation of the ice. The trapping efficiency is determined by monitoring the fluxes of the released gases and water vapor during these stages. The experimental results on gas trapping in the ice will be presented and compared with the in-situ Rosetta measurements.

The authors acknowledge support from the Israel Ministry of Science, Technology and Space through the Israel Space Agency.

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Measurements of the Rosetta spacecraft potential and evolution of the cometary plasma environment of 67P

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ABSTRACT

We present and compare measurements of the spacecraft potential ($V_{s/c}$) of ESA's Rosetta spacecraft, currently in orbit around comet 67P/Churyumov-Gerasimenko, by the Langmuir probe (RPC-LAP) and Ion Composition Analyzer (RPC-ICA) instruments. $V_{s/c}$ depends primarily on the thermal flux of electrons in the cometary plasma and has most often been negative due to a high (~5 eV) temperature of the coma photoelectrons. It is generally more negative around perihelion, closer to the nucleus and above the southern (summer) hemisphere, and shows clear diurnal variations predominantly above the northern (winter) hemisphere. This delineates an evolution in cometary activity governed by the combined effects of heliocentric and cometocentric distance and seasonal variations.

LAP only picks up a portion of the full $V_{s/c}$ since the two probes, mounted on booms of 2.2 and 1.6 m length, respectively, are generally inside the potential field of the spacecraft. Comparison to the minimum energy of collected positive ions by ICA shows generally good correspondence between the two instruments, except when local ion production is weak and accelerated ions dominate the flux, and suggests that the portion of $V_{s/c}$ picked up by LAP varies between 0.7 and 0.9. This indicates that a correction factor between about 1.1 and 1.4 should be applied to the LAP measurements to obtain the full $V_{s/c}$.

Temporal variation of long-lived water ice rich features observed on comet 67P/Churyumov-Gerasimenko via OSIRIS NAC multispectral images

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ABSTRACT

Water ice features are detected on the nuclei of comets 9P [1], 103P [2] and 67P [3] via multispectral imaging. Comets 9P and 103P were observed during flybys, which were not suited for studying the lifetimes of the detected water ice deposits. Thanks to the long-term high spatial resolution observations done via OSIRIS NAC on board ESA's Rosetta spacecraft, it is possible to study the temporal evolution of the water ice features observed on comet 67P.

Water ice features are blue in the RGB images generated by using images taken in NUV, visible and NIR wavelengths, they have higher albedo and lower spectral slopes than the average comet surface [3, 4, 5, 6]. More than a hundred of water ice exposures were detected on the northern hemisphere of comet 67P before 2015 [3]. During the observations done from summer 2014 to summer 2016 numerous water ice rich features were disappeared and/or appeared. There are water ice rich features having lifetimes from minutes to months and years [7, 5, 6].

In this study we only concentrate on the water ice rich features having lifetimes of months and years. We investigate the multispectral and morphological changes of these features with their vicinity at different epochs. We quantify the multispectral signatures of their temporal variation. Moreover we investigate the formation/destruction mechanisms of water ice rich features. In many of the water ice rich features, associated activity events i.e. jets and outburst are observed and we discuss this connection via multispectral analysis by additionally considering the morphological changes.

The water ice rich features in the northern hemisphere of comet 67P are mostly located in rough terrains, below overhangs and by cliffs, while the features in the southern hemisphere are mostly located in smooth terrains. The large water ice rich clusters seem to be formed via cliff collapse [3, 7, 8, 9], while the large patches seem to be formed via surface deflation. Multispectral imaging of large debris fields containing water ice at different epochs allow us to calculate material loss on the surface. By calculating the energy input of those features, we will derive the sublimation rate and estimate the thickness of water ice rich features.

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Mass, Density, Internal Structure and Mass Loss of the Nucleus 67P/Churyumov-Gerasimenko

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Cometary nuclei consist mostly of dust and water ice, but the internal structure of a comet nucleus were essentially unknown. Bulk properties such as mass, volume (size and shape), and particularly the density, must be known for constraining its internal structure. The radio science experiment RSI on the Rosetta spacecraft derived the mass and the gravity field of comet 67P/Churyumov-Gerasimenko at distances varying between 100 km and 10 km, and together with the current best estimates of the volume by the OSIRIS camera, the bulk density of the nucleus. A model of the internal structure is derived from the information of two shape models by comparing observed and theoretical gravity coefficients. The comet nucleus appears to be a body of low mass, low density and high porosity. Individual bulk densities of the two lobes were derived by a bimodal gravity field approach which are, however, not very different from the global bulk density. The currently still on-going second gravity field determination will reveal a statistically significant mass loss by the outgassing activity which peaked during the perihelion passage.

COMETS 2016 Abstract

Comparing Regolith Surface Roughness on Comet 67P/CG and Asteroid Vesta: Implications for Radar Observations by the *Rosetta* and *Dawn* Missions

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ABSTRACT

In 2011, the first orbital bistatic radar (BSR) observations of a small body were acquired at grazing incidence during entries and exits from occultation by the *Dawn* spacecraft at Asteroid Vesta. These measurements are used to assess the textural properties of Vesta's surface at decimeter scales and potential volatile occurrence at the surface and shallow subsurface. Characterizing the textural properties of small body surfaces is also important for assessing future landing safety, surface trafficability and for identifying ideal sites for potential sample collection. We observed 16 mid-latitude quasi-specular reflections at Vesta, for which σ^0 was found to range from –12 dB to –20 dB with average decimeter-scale roughness constituted by gently undulating facets with root-mean-square (RMS) slopes that range from 1° to 8° (Figure 1). Vesta's RMS slopes are comparable to the same range observed on the lunar surface over both the heavily cratered highlands and the smooth *maria*. Comparison of the observed distribution of RMS slopes with *Dawn's* observations of hydrogen concentration and surface hydroxyl distribution suggest that regions of low surface roughness with high hydrogen concentration are of primary interest for potential volatile detection.

We now apply the above analysis to constrain Comet 67P's surface roughness from *Rosetta's* BSR observations conducted by the spacecraft's communications antenna. We use power spectrum signal analysis to distinguish surface echoes from the direct signal; measure the area-normalized radar cross section σ^0 of each detectable echo; estimate RMS surface roughness slopes from measured σ^0; and finally we compare 67P's resulting RMS slopes with those of Vesta and the Moon to understand the different textural properties of small bodies' regoliths in support of future radar observations and future landing missions.

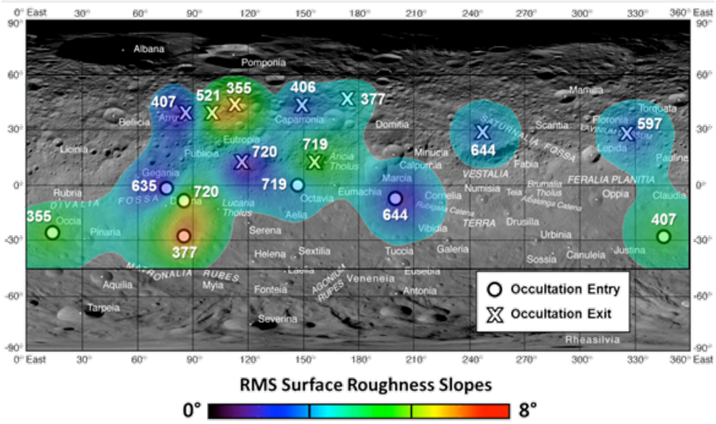

Figure 1. Estimated distribution of decimeter-scale root-mean-square (RMS) surface roughness slopes overlain on an equirectangular projection of Vesta's surface.

Modeling the Dielectric Properties of Comet 67P/CG Based on Observations by *Rosetta's* CONSERT and VIRTIS Instruments

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ABSTRACT

Prior to *Rosetta's* rendezvous with Comet 67P/CG, we established two dielectric models of the comet nucleus to support inversion of *Rosetta's* CONSERT radar data into the hypothesized nucleus geophysical parameters upon which the dielectric constant ε depends. The two models—one assuming a decrease in porosity with depth to the core, the other with decreasing ice fraction toward the core—were developed by combining observations of comets Tempel 1 and Wild 2 with dielectric laboratory measurements on cometary analog material under a range of porosities, temperatures and dust-to-ice ratios (Heggy & Palmer et al., 2012). Laboratory measurements were used to establish empirical formulas that quantify ε as a function of the expected range of geophysical parameters distributed throughout the nucleus.

In this study, we present updated dielectric models (Figure 1) using the latest post-rendezvous observations by *Rosetta* at 67P including: (1) the latest three-dimensional shape model; (2) results from CONSERT, which suggest a bulk ε' of 1.27 ± 0.05 for the "head" of the nucleus; (3) Earth-based radar observations by the Arecibo Observatory, which constrain ε' = 1.9 to 2.1 for the top ~2.5 m of the subsurface; and (4) thermal observations by *Rosetta's* VIRTIS, which is used to constrain near-surface density and surface temperature distribution via thermal inertia modeling as described by Capria et al. (2014) for Asteroid Vesta, and as utilized to model the dielectric properties of Vesta's shallow subsurface by Palmer et al. (2015).

The updated dielectric models will reduce ambiguities associated with inverting the geophysical properties of the nucleus from CONSERT data in terms of potential three-dimensional distributions of porosity, ice fraction and temperature.

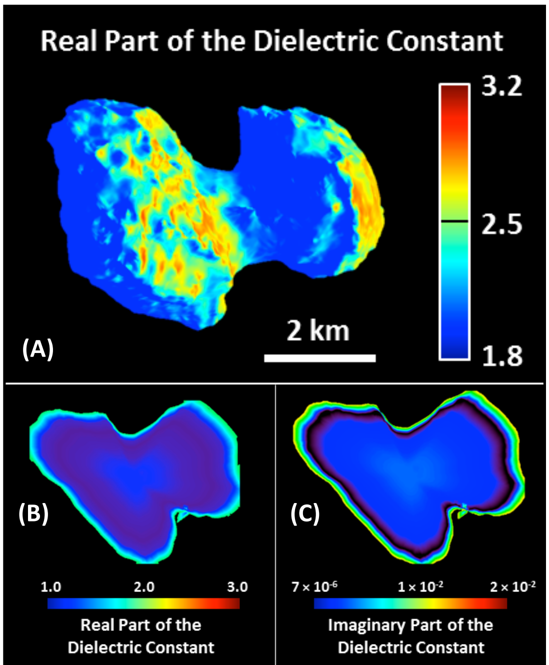

Figure 1. Preliminary updated dielectric models of Comet 67P/CG in the case of: (A) temperature-dependence at the surface under solar illumination from the right, and (B)-(C) decreasing porosity in the comet interior with depth to the core.

New Horizons Results at the Pluto System in Relation to Comets

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ABSTRACT

Starting over two decades ago with the observational confirmation of the Kuiper belt, Pluto was placed in context as the largest, the first discovered, and certainly the most well known of the trans-Neptunian objects (TNOs) in this "Third Zone" of the solar system. Numerical simulations have shown the rich dynamical sculpting of the Kuiper belt and related objects, such as the delivery of transitional Centaurs and Jupiter family comets (JFCs) to the inner zones of the solar system.

Rosetta arrived at the JFC 67P/Churyumov-Garasimenko in August, 2014, beginning a two-year escort of the comet, observing the pre- through post-perihelion changes in its activity cycle, close-up details of its surface and sub-surface, and delivered the Philae lander science packages to the surface.

Soon thereafter, in July 2015, the New Horizons spacecraft flew through the Pluto system consisting of its giant moon - truly a binary companion - Charon, and their four smaller moons. Pluto and its moons are a dynamic, unique, multi-component system, from fully tidally-locked Charon to the other moons exhibiting a wide range of orbit and rotation properties. During the months preceding the closest approach through the days following that, the New Horizons payload obtained unprecedented observations of the surface, atmosphere, and particle environment of Pluto and its moons.

The comparison of 67P and Pluto, distant cousins related through the Kuiper belt, is more a study of contrasts rather than similarities. One obvious difference is the vast difference in size and mass: Pluto and Charon are considerably larger (diameters of 2376 km and 1210 km, respectively) and more massive (by a factor of $\sim 10^9$) than 67P, although Pluto's small moons have sizes (10-50 km) comparable to larger comet nuclei. The densities (1.8 gm/cm^3 for Pluto vs. 0.3-1.0 for typical comets like 67P) are indicative of the differences in their porosity and the rock fraction of their interiors. Pluto's surface is dominated by N_2, CO, and CH_4, with higher hydrocarbons also present, whereas comet 67P's surface is dominated by dust with principal subsurface ices such as H_2O and CO/CO_2. In another contrast, 67P is an escapee of the Kuiper belt, one that has already had many orbits through the inner solar system resulting in thermal processing important and unique to the nature of comets, but which makes it difficult for observations by Rosetta to identify 67P's primordial characteristics. New Horizons' flyby of the Pluto system allowed us to examine a large TNO in situ in the Kuiper belt, far from significant solar processing. However, what we discovered was a world that is still strongly geologically active, even in these far reaches of the solar system. Unlike the case for comets where varying insolation is the dominant energy cycle driver for changes of the comet nucleus, other sources must be driving Pluto's surface and interior changes as implied by New Horizon's observations. Comets typically have atmospheres dominated by H_2O sublimation (and CO/CO_2 at larger distances), whereas Pluto's atmosphere is 90% N_2, and although the escape rate of Pluto's atmosphere (currently ~ 1-5x10^{25} molecules/sec) is comparable to weak comets, the escape processes (Jeans vs. hydrodynamic) and the relationship of the atmosphere to the surface are quite different.

Recently, New Horizons was approved for an extended mission with a flyby of the TNO 2014 MU69 on January 1, 2019, and to study about 20 other TNOs in ways that Earth-based instruments cannot. As a cold, classical TNO at 44 AU and a size of 20-40 km, 2014 MU69 provides a valuable intermediate case relative to Pluto and comets for close study of an outer solar system object.

Modeling comet nuclei, with emphasis on outburst activity

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The main findings of the *Rosetta* mission, as regards the nucleus, revolve around the surprisingly complex and diverse surface structure and the evolving activity pattern. These features, together with the bi-lobate shape of the nucleus (exhibited by other comet nuclei as well) force us to reconsider comet nucleus modeling. Although models have become increasingly sophisticated and comprehensive, the simple geometry used, as demanded by numerical considerations, prevents us from simulating the behavior of any individual comet. . Instead, nucleus models should be used to explain observed phenomena and their typical characteristics in general. They also provide constraints for thermo-physical properties of the nucleus.

Clearly, the source of cometary activity, even if driven by solar radiation, lies in the interior of the nucleus. Models invariably show that the internal structure of the nucleus is stratified and the stratification changes with evolution. Thus, an initially homogeneous composition separates into an outer dust crust and layers composed of dust and different types of ice at lower depths. Sublimation of ices lying at different depths accounts for differentiation in the production rates of volatiles, both in time and in location on the nucleus surface.

Models are capable of simulating the formation of a dust mantle, and show how the presence of such a (thin) mantle may lead - as a result of insolation, combined with rotation of the nucleus - to periodic outbursts of water vapor. Release of volatiles that have been trapped in amorphous ice is shown to result in powerful outbursts and also, in possible sudden depression of surface areas. Evolutionary models show that such activity may occur at large heliocentric distances, both pre- and post-perihelion. Multi-dimensional (e.g., 3-D or quasi 3-D) models show how intrinsic internal inhomogeneity may affect the activity of a nucleus, leading to sporadic outbursts.

Rosetta has presented us with a wealth of puzzles that will challenge comet nucleus modelers for years to come.

Beyond CONSERT: Satellite-Based Radio Tomography for a Small Planetary Object

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ABSTRACT

In this presentation, we focus on mathematical and computational methodology and different radio tomography scenarios applicable for the imaging of a comet nucleus interior. Reconstructing the interior structure is a natural future research direction following the development of the surface reconstruction methods that are currently extensively utilized in the planetary science [1]. In radio tomography, the objective is to reconstruct the target object's internal permittivity distribution. This is an ill-posed and non-linear inverse problem: a slight amount of noise in the data or in the forward simulation can lead to very large estimation errors. Moreover, the permittivity distribution to be recovered is likely to be complex including, e.g., anisotropicity, surface layers and voids.

The first attempt to recover the structure of a comet nucleus interior based on radio-frequency measurements was made in the COmet Nucleus Sounding Experiment by Radiowave Transmission (CONSERT) [2] with Comet P67/Churyumov-Gerasimenko as the target. In CONSERT, the radio signal was transferred between the mothership *Rosetta* and its lander *Philae*. The promising results of the CONSERT [3] show that radio tomography has a great potential as a method of interior imaging. Similar to ordinary georadar applications, the accuracy and reliability of the inversion can be improved, if the coverage of the data can be extended. In planetary science, this is a challenging task due to the many strict limitations related to the space missions. Motivated by these aspects, we have recently investigated potential approaches for gathering and inverting an extended set of radio frequency data [4].

In order to enable effective inversion in 3D, we have developed a finite element based full waveform imaging technique, which, among other things, enables simulating data for an extensive set of signal transmitter and receiver positions, producing robust inverse estimates, and speeding up of 3D computations via a multigrid method. To evaluate this approach, we have conducted numerical experiments with a multi-satellite system model which is a potential approach for future missions. In these experiments, we explored the sparsity/density of the measurement positions, the number of satellites in the formation, the density of the signal paths, and the detection of voids together with a surface layer, e.g. a dust or ice cover. The results suggest, among other things, that the quality of the inverse estimates will improve along with the number of both transmitter and receiver positions, and that reconstructing a surface layer will be challenging in the case of sparse data.

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The Nature of the Extended Source in the Near-nucleus Outgassing of Comet 17P/Holmes During Its 2007 Outburst

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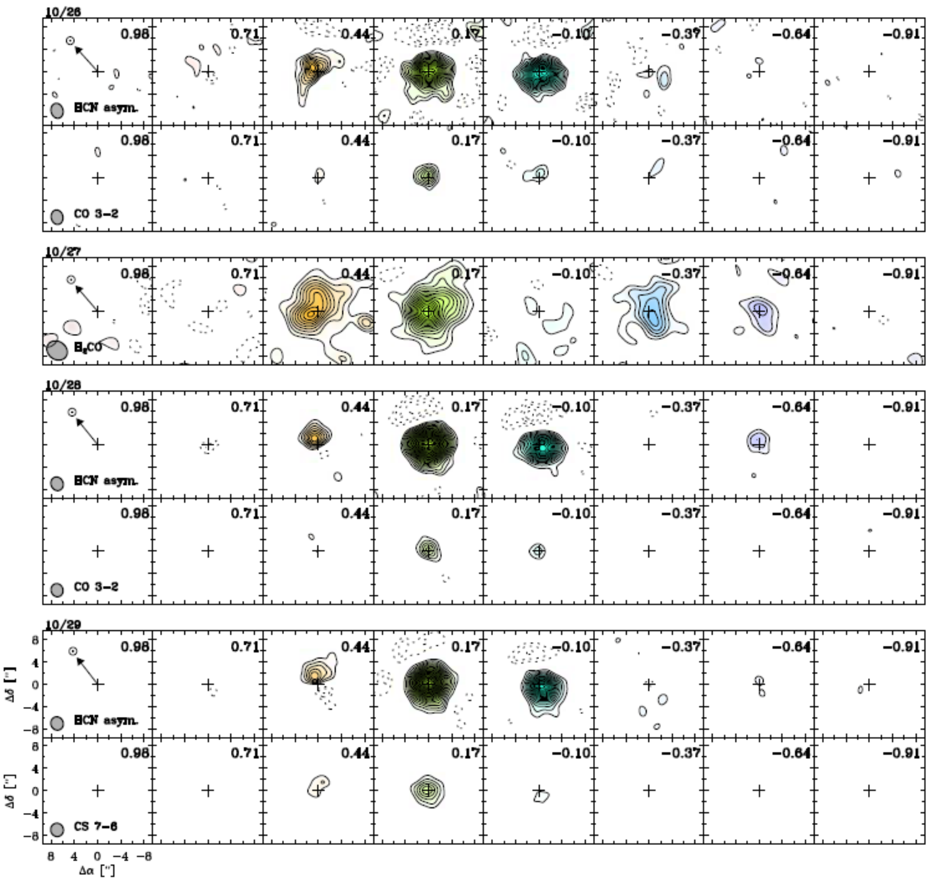
ABSTRACT

We present high angular resolution Submillimeter Array observations of the outbursting Jupiter family comet 17P/Holmes on 2007 October 26-29, achieving a spatial resolution of 2.5", or 3000 km at the comet distance. The observations resulted in detections of the rotational lines CO 3-2, HCN 4-3, CS 7-6 and H_2CO $3_{1,2}$-$2_{1,1}$. From the spectral imaging data, we identify two components in the molecular emission. One component is characterized by a relatively broad line width (~1 km s^{-1} FWHM) exhibiting a symmetric outgassing pattern with respect to the nucleus position. The second component has a narrower line width (<0.5 km s^{-1} FWHM) with the line center red-shifted by 0.2 km s^{-1} (cometocentric frame), as shown in the figure. For 4 continuous days, the emission of CO, H_2CO, and CS shows consistent spatial and velocity shift across the nucleus position, clearly produced in the coma rather than emitted directly from the nucleus - the signature of so called "extended source". We hypothesize that this extended source shown as the narrow-line component in the near-nucleus outgassing originates from the ice grains brought out by jets coming from active regions of the nucleus' surface. We determine much higher CO/HCN ratio in the narrow-line component than in the symmetric broad-line component, reflecting a more pristine volatile composition of nucleus material that is released in the outburst.



The temporal evolution of exposed water ice-rich areas on the surface of 67P/Churyumov-Gerasimenko: spectral analysis.

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ABSTRACT

Water ice-rich patches have been detected on the surface of comet 67P/Churyumov-Gerasimenko by the VIRTIS hyperspectral imager on-board the Rosetta spacecraft, since the orbital insertion in late August 2014. Among those, three icy patches have been selected, and VIRTIS data have been used to analyse their properties and temporal evolution while the comet was moving towards the Sun. We performed an extensive analysis of the spectral parameters, and we applied the Hapke radiative transfer model to retrieve the abundance and grain size of water ice, as well as the mixing modalities of water ice and the ubiquitous dark refractory terrains of the surface.

Study of the spatial distribution of the spectral parameters within the ice-rich patches has revealed that water ice follows different patterns associated to a bimodal distribution of the grains: ~50 µm sized and ~2000 µm sized, respectively in intimate and areal mixture with the dark material.

In all three cases we identified different stages of the evolution of abundance of ice in the selected patches after the first detections at about 3.5 AU heliocentric distance; the spatial extension and intensity of the water ice spectral features reached a maximum after 60-100 days at about 3.0 AU, was followed by an approximately equally timed decrease, and the features were no longer visible when observed again at about ~2.2 AU, before perihelion.

The exposure of deeper layers is consistent with their occurrence in “active” areas where falls or landslides could have caused the occasional exposure of water ice-rich layers.

After the initial exposure of the ice, the activity of the affected area increases thus causing dust removal powered by sublimation, which provides a positive feedback on the exposure itself. The process develops as the solar flux increases, and it reaches a turning point when the exposure rate is outweighed by the sublimation rate, until the complete sublimation of the patch.

It is interesting to note that the behaviour of the analysed patches was very similar with a lifecycle of about 180 days, which can be ascribed to a seasonal cycle. In addition to the observed seasonal cycle we found evidence of short-term variability associated to a diurnal water cycle.

Our analysis, in addition to previous work (Filacchione et al., 2016; Barucci et al., 2016; Ciarniello et al., 2016), indicates that water ice is rather evenly distributed in the subsurface and that no large water ice reservoirs are present.

In situ Study of Organic Molecules in Primitive Meteorites

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ABSTRACT

Carbonaceous chondrites are primitive meteorites rich in organic compounds formed 4.56 Gy ago. During the first stages of the solar system, they accreted millimeter to micrometer-sized grains inherited from the interstellar space, processed in the disk and mixed with other solar system components. Their investigation at fine scale thus provides important clues to understand solar system formation. The matrix of CI, CM and CR primitive carbonaceous chondrites contains abundant hydrated minerals, such as clays, and up to 5 wt.% of organic matter (OM). As OM and water were likely accreted together as ice grains within asteroids and other planetary embryos, their abundance is therefore correlated. After accretion, internal heating due to decay of short-lived radionuclides melted the ice and induced fluid circulation that promoted mineralogical and chemical reactions on the asteroidal parent bodies of these chondrites. This aqueous (or hydrothermal) alteration may have modified some of the chemical and isotopic signatures that the OM could have acquired during it synthesis, hence blurring the record of protosolar conditions.

By combining several sub-micron scale techniques, like TEM (transmission electron microscopy, for textural and mineralogical characterization), NanoSIMS (Nano Secondary Ion Mass Spectrometry for elemental and isotopic imaging), and STXM (scanning transmission X-ray microscopy, providing spatially resolved XANES spectra, X-ray absorption near edge structure, for molecular characterization), we can characterize the nature of the micron-sized organic grains present in the matrices of carbonaceous chondrites (CI, CM and CR chondrites) within their petrographic context. This approach provides compelling data that shed new light on the evolution of OM during the hydrothermal alteration on the parent body and disclose its origin.

We have studied the OM in the Orgueil (CI), Murchison (CM), Paris (CM) and Renazzo (CR) chondrites, which exhibit various degrees of hydrothermal alteration. They show molecular and isotopic heterogeneities (1) that can result from hydrothermal alteration on the asteroidal parent body, or (2) that can indicate that the protosolar disk was heterogeneous in its organic content. In hypothesis (1) a similar organic precursor could have been accreted in all chondrites, and later modified to various degrees related to the intensity of the aqueous alteration. Alternatively, in hypothesis (2), before accretion into asteroids, organic grains could have been influenced by a large array of processes in the different regions of the protosolar disk, and mixed by the active turbulence. Furthermore, an interstellar heritage of some presolar organic grains cannot be excluded. The origin of OM in chondrites remains complex to resolve as a consequence of the likely superimposition of these events.

This presentation will present the main advances arising from the *in situ* investigation of organic matter in carbonaceous chondrites to assess its evolution on the parent asteroid. Such observations will be useful to interpret the Rosetta mission data and offer a model for organic matter evolution in the solar system.

Dust properties in the coma of 67P/Churyumov-Gerasimenko as observed by VIRTIS-M and GIADA

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The Rosetta/ESA spacecraft is studying comet 67P/Churyumov-Gerasimenko from a close distance since August 2014. Onboard the spacecraft the Visual, Infrared and Thermal Imaging Spectrometer (VIRTIS-M), spectral range 0.25 - 5µm, and the dust analyzer Grain Impact Analyser and Dust Accumulator (GIADA) acquired a relevant amount of dust coma measurements. Combining the results of different instruments provides complementary information, in particular VIRTIS-M and GIADA are well suited to characterize and complement coma dust properties.

On 2015 March 28th, Rosetta performed a close flyby with a closest approach distance of 15 km covering latitude and longitude ranges of 40°-60° N and 30°- 90° E, respectively; during the flyby the rate of GIADA dust particle detections was particularly high. GIADA individual dust particle detections allow us to estimate the dust loss rate and to derive the dust size distribution at the sunlit nucleus surface. In the similar timeframe, VIRTIS-M performed observations when the spacecraft was at about 100-130 km from the nucleus, which allowed complete coverage of the surrounding coma at different distances from the nucleus. The two datasets allow combining local coma properties from GIADA to global investigation from VIRTIS. We find that in the inner coma the spectral reflectivity from 0.35 µm to 3.5 µm does not show evident dust absorption features and displays a red slope with a change at around 1 µm. For the sunlit coma, the slope varies between (9±1)% to (12±1)% per 100nm in the range from 0.35 µm to 0.8 µm and from 1 to 2.5 µm the value is (1.7 ± 0.2)% per 100nm.

In this work we present results of a dust scattering model linking the dust spectral reflectivity properties observed by VIRTIS-M to the dust properties inferred by individual GIADA dust particle detections.

Photometry and polarimetry of comet 67P/Churyumov-Gerasimenko at the 6-m telescope of the SAO RAS

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ABSTRACT

We present observations of comet 67P/Churyumov-Gerasimenko carried out at the 6-m telescope of the Special Astrophysical Observatory (Russia) with focal reducer SCORPIO-2 used in the modes of broad-filter photometry and of imaging linear and circular polarimetry. Three sets of post-perihelion observations were made in November and December of 2015 and in April of 2016 covering heliocentric distance of the comet from 1.61 au to 2.72 au and phase angle from 33.2° to 10.4°.

Imaging photometry of the comet was performed in the g-sdss (465/65 nm) and r-sdss (620/60 nm) filters. This allowed us to derive the maps of intensity and color over the coma. After removing the symmetric part of the coma, two bright persistent jets were revealed observed from November 2015 to April 2016. The jets and tail had colors redder than the rest of the coma that may indicate a difference in the properties of dust particles. Color of the coma becomes bluer with increasing distance from the nucleus that suggests an evolution of particle properties.

Linear polarization maps and polarization scans through the coma in various directions, including the direction to the Sun and perpendicularly to it, tail, and two jets, showed a complex structure of the coma with areas of high and low polarization. In November and December, the polarization in near-nucleus area was about 8%, dropped sharply to 2% at the distance 5000 km, and then gradually increased with distance from the nucleus reaching >8% at 40000km. The same trend in the polarization was detected in the jets and the tail. In April, at phase angle about 10°, the negative polarization varied between –0.6% in the near-nucleus area and –4% in the outer coma.

Comparison of polarization and color profiles measured within concentric annuli shows that the innermost area is redder and more polarized than the adjacent coma, the coma becomes bluer with increasing distance from the nucleus, and polarization increases. The radial variations of polarization and color suggest an evolution of particle properties that can be caused by fragmentation of particles and decreasing their size. Note that Jewitt (Aph. J. 2004) obtained similar dependences of polarization and color on the projected distance for comet 2P/Encke. Variations of polarization and color through the coma will be discussed in details.

The Disk-Comet Connection and Comet C/2012 K1 (PanSTARRS)

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ABSTRACT

As some of the first objects to accrete in the solar nebula, comets are among the most primitive remnants from the formation of the solar system. The chemical compositions of cometary nuclei should reflect the makeup of the midplane of the protoplanetary disk where (and when) they formed. Determining the native volatile (i.e., as contained as ices in the nucleus) composition of comets can provide insights into these formation regions and also the formation pathways. Near infrared spectroscopy of fluorescent emission from sublimating volatiles is a powerful tool that can be used to characterize the primary volatile composition of the coma, and by inference the nucleus. To date, the primary volatile composition of about thirty comets have been characterized using near infrared spectroscopy, with the primary output being mixing ratios, or the relative abundances of different primary volatiles.

On 2014 May 22 and 24 we characterized the primary volatile composition of the dynamically new Oort cloud comet C/2012 K1 (PanSTARRS) using the long-slit, high resolution ($\lambda/\Delta\lambda \approx 25{,}000$) infrared echelle spectrograph (NIRSPEC) at the 10 m Keck 2 telescope on Maunakea, HI. We detected fluorescent emission from six primary volatiles (H_2O, HCN, CH_4, C_2H_6, CH_3OH, and CO), and derived upper limits for C_2H_2, NH_3, and H_2CO. We report rotational temperatures, production rates, and mixing ratios (relative to water).

The protoplanetary disks in which comets form can be delineated into three distinct chemical regions: a hot, ionized disk atmosphere, a warm molecular layer, and a cold disk midplane. Most observations of volatiles in disks sample the disk atmosphere or the warm molecular layer. Disk modeling efforts have historically focused on producing gas phase abundances. The cold midplane, where comets form, is optically thick and often not observable. Insights into the structure and composition of disk midplanes can be gleaned from disk models that produce ice phase abundances. The primary volatile compositions of comets can serve as observational constraints for these ice phase models, spurring and assisting their further development.

We will discuss how C/2012 K1 (PanSTARRS) fits in with other comets observed in the near infrared to date, compare the relative abundances of primary volatiles detected in comets with ice phase abundances predicted by state of the art astrochemical disk models, and interpret the results. This work is supported by NSF (PAG) and NASA (Space Grant, Astrobiology, Emerging Worlds, PATM, PAST, SSOP).

Sulfides and refractory organic matter at the surface of 67P/Churyumov-Gerasimenko: evidence from VIRTIS data and laboratory measurements

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ABSTRACT

From Aug. 2014 to Sept. 2016, the Rosetta spacecraft has been orbiting comet 67P/CG and has obtained information on the origin and evolution of comets. The imaging spectrometer VIRTIS collected reflectance spectra of the surface within the range 0.25-5.1 µm that revealed a low single scattering albedo (0.06 @ 0.65 µm) and a homogeneous surface (Capaccioni et al., 2015; Ciarniello et al., 2015). The reflectance spectra are also characterized by red slopes in the visible (0.5-0.8 µm) and in the near infrared (1.0-2.7 µm). These properties have been interpreted to be due to the presence of an organic polyaromatic material mixed with opaque minerals, presumably troilite-like sulfides according to the composition of presumed cometary grains (Quirico et al., 2016).

In order to test this proposition, we have run series of experimental measurements of granular mixtures of an analog of cometary polyaromatic organic matter (an immature coal) and different sulfides (pyrite, pyrrhotite and troilite). Bi-directional reflectance spectra were obtained at IPAG in the range 0.4-4 µm, and under a range of viewing geometries. For the first time we are performing measurements on materials with sub-micrometer grains relevant to what is expected for cometary grains. Produced with a planetary grinder operating on colloidal solutions, these grains were characterized with scanning electron microscopy, X-ray diffraction and an electronic microprobe.

The experiment confirms that the low albedo in the near infrared is controlled by the abundance of pyrrhotite or troilite, while pyrite is not a viable candidate. These sulfides also account very well for the red slopes in the visible and the near infrared ranges. Excellent match with VIRTIS spectra is obtained for coal+pyrrhotite mixtures with a pyrrhotite abundance ranging from 30 to 50 wt%. Although the cometary grains composition include silicates and other organic compounds (see IDPs and Wild2 samples analysis), these results offer another interpretation of the reddish nature of some small bodies' surfaces, which has been interpreted so far as the presence of red organics or the consequence of space weathering. Finally, the suggestion that sulfides are major contributors to 67P dust might be generalized to other cometary nuclei that have similar VNIR spectra, as well as to P & D type asteroids.

Local study of photometric variations at comet 67P/Churyumov-Gerasimenko: a point of view from VIRTIS/Rosetta

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ABSTRACT

From August 2014 to September 2016, the Rosetta spacecraft has been orbiting comet 67P and has obtained information on the origin and evolution of comet. VIRTIS, the Visible, Infrared and Thermal Imaging Spectrometer collected reflectance spectra of the nucleus surface with two different channels: VIRTIS-M and VIRTIS-H. The first one is an imaging spectrometer ranging from 0.25 to 5.1 µm and it covers a large field of view. The second one is a point spectrometer ranging from 1.9 to 5.0 µm with higher spectral resolution. Both channels observed comet 67P under many different illumination conditions and observation geometries (e.g., between 20° to 110° phase angle). VIRTIS spectra revealed a very low single scattering albedo of 0.06 @ 0.65 µm and red slopes in the visible and in the near infrared (Capaccioni et al., 2015; Ciarniello et al., 2015). Thanks to the long duration of the Rosetta mission it is possible to perform a photometric study through time and to monitor potential changes of surface spectral properties (e.g. spectral slope, single scattering albedo) associated with varying activity.

In this context, we defined specific periods of observation and compared them between each other to identify surface changes. Using a Lommel-Seeliger model as a first step, we studied the spatial distribution of the single scattering albedo (SSA) and spectral slope at the local or regional scale. In the period between the end of 2014 and the beginning of 2015, we observe SSA variations which are neither spatially homogeneous nor uniform (i.e., increase and decrease). These changes, observed both in the visible and in the NIR, may be related to different processes such as dust deposit/removal or changes in the ice content in the sub-surface.

We've also used a Hapke model to evaluate the effect of the photometric function on the results. We will also study other periods of observations, in particular around perihelion in August 2015 when the activity was reaching a maximum. VIRTIS-M infrared cryocooler has failed in April 2015 and it is no longer possible to investigate the photometric variations in this wavelength range on large areas. However investigations are still possible with the visible channel.

Properties of cometary dust down to the nanometre scale

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ABSTRACT

Models of the dynamics of small dust grains and their interaction during Solar System formation have a strong dependency on the microscopic properties of the grains. Since comets are believed to have undergone minimal alteration the investigation of cometary dust at the micro- and nanometre scale leads to new insights and constraints on the formation.

So far evidence for the structure and physical properties of cometary dust comes from i) interplanetary dust particles, some of which are believed to come from comets, ii) the (possibly highly modified) dust collected by the Stardust mission and iii) polarimetric observations. The MIDAS (Micro-Imaging Dust Analysis System) instrument on-board Rosetta provides, for the first time, *in-situ* investigation of cometary dust particles down to the nanometre scale.

Here we present a collection of 3D images of diverse cometary dust particles with unprecedented resolution on the micrometre scale. Fragments surrounding these cometary particles in the range of some 10s of micrometres are an indication of their fragile nature. These fragments might be generated during impact with the target, but physical contact during the scanning process is also likely to modify these particles. Furthermore some micrometre and smaller particles have been observed, which seem to be more densely packed. Since little to no fragmentation has been observed at these smallest scales during scanning they seem to be less fragile. Besides the fragile structure, smaller sub-units were detected, which reveal aggregate structure down to some 100s of nanometres. These aggregates show distinct sizes, suggesting a hierarchical growth process.

Reactive collisions of electrons with molecular cations in cometary atmospheres

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ABSTRACT

Dissociative recombination and ro-vibrational transitions – elastic scattering, excitation and de-excitation of molecular cations [1]:

$$AB^+(N^+,v^+) + e^- \rightarrow AB^*, AB^{**} \rightarrow A+B, \;\; AB^+(N^{+\prime},v^{+\prime}) + e^-,$$

(N^+/v^+ standing for rotational/vibrational quantum numbers of the target and AB^*/AB^{**} for electronically singly-/doubly-excited states) play a major role in the kinetics of media of astrophysical interest. In particular, dissociative recombination of molecular cations containing Hydrogen, Carbon, Oxygen and other species occurs in cometary atmospheres [2].

Detailed theoretical studies have been achieved for H_2^+, N_2^+, CO^+, CH^+ [3-5] and for the recently discovered SH^+, HCl^+ and ArH^+ [1]. The accurate state-to-state computed rate-coefficients, which are in good agreement with those measured in storage-ring and plasma-type measurements [1], are available and suitable for use in collisional-radiative kinetic models of various cometary environments.

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Photometry and spectroscopy of comet C/2014 Q2 (Lovejoy)

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ABSTRACT

We present results of the observation of comet C/2014 Q2 (Lovejoy). The comet has been monitored with four different telescopes. Spectral (Echelle and long- slit) and photometric observations of the comet were made in period, when the comet was between heliocentric distances of 1.31 au and 5.14 au.

The photometrical observations were conducted with broadband V and R filters. We derived the *Afρ* parameter and estimated the dust production rate in comet C/2014 Q2 (Lovejoy). The colors and size of the nucleus of the comet were estimated from the images obtained during the late stage at a heliocentric distance of 5.14 au, when the activity had probable ceased.

CN, C_2, and NH_2 emissions were identified in the spectra of comet in December, 2015. The gas production rates of C_2, CN and NH_2 were derived using a Haser model. Gas and dust activity of comet C/2014 Q2 (Lovejoy) during different appearances will be discussed.

Dust Emission around Terminators observed by OSIRIS Sheds Light on the Diurnal Cycle of Activity on 67P/Churyumov-Gerasimenko

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ABSTRACT

The OSIRIS camera on board Rosetta spacecraft has acquired observations of dust emission around both dawn and dusk terminators on the nucleus of comet 67P/Churyumov-Gerasimenko. The high spatial and temporal resolution of these observations makes it possible to investigate how cometary activity occurs on a diurnal basis and, furthermore, how activity is connected with surface and subsurface properties of the nucleus.

Previous analysis on the observations of dust emission beyond dusk terminator has suggested that dust activity is turned off slowly after sunset due to water ice sublimation at a shallow subsurface [1]. On the other hand, observations at the dawn terminator suggest that dust activity can be initiated instantly after sunrise, which implies water sublimation occurring much closer to or even on the nucleus surface. This might be connected to the accumulation of water ice that has been re-condensed on the surface during night [2].

We will study comparatively dust activities at the dawn and dusk terminators and their connection with local topography. We parameterize thermal-physical models to simulate the thermal condition at time of observations. The method of Direct Simulation Monte Carlo (DSMC) is applied for a forward modelling of local gas and dust coma structure to be compared with the observed pattern of dust emission.

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[2] De Sanctis, M. C., Capaccioni, F., Ciarniello, M. et al., 2015, The diurnal cycle of water ice on comet 67P/Churyumov-Gerasimenko, Nature, 525, 500-503.

Comet 67P by Rosetta/OSIRIS

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The paper will give an overview of the latest OSIRIS science and discoveries including the morphology, activity, and surface changes. Implications on the nature of the comet and its mechanisms will be drawn from these. The paper will cover the first interpretations of the unprecedented detail provided by the descent of the orbiter onto the surface of the nucleus of 67P.

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We thank the Rosetta Science Ground Segment at ESAC, the Rosetta Mission Operations Centre at ESOC and the Rosetta Project at ESTEC for their outstanding work enabling the science return of the Rosetta Mission.

Gas production rate of Comet 67P/C-G derived from in situ measurements by the Rosetta plasma instruments

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ABSTRACT

Onboard Rosetta, the Rosetta Plasma Consortium (RPC) instruments are dedicated to the characterisation of the in-situ plasma environment of comet 67P/Churyumov-Gerasimenko (67P/C-G). Here we present a study of two methods to derive some information about the neutral atmosphere of the comet from RPC instruments, namely, the ion spectrometer RPC-ICA and the fluxgate magnetometer RPC-MAG. One such information is the neutral H_2O production rate Q in particles s^{-1}. The first method is based on the ratio of He^+ to He^{2+} fluxes measured by the ion analyser (e.g., Simon Wedlund et al. 2016) while the second relies on the water-group ion cyclotron waves potentially seen in magnetic field measurements (Volwerk et al. 2013). After describing each method, we discuss the pre and post-perihelion datasets in light of the changing activity of comet 67P/C-G. Gas production rates retrieved from the ion spectrometer method are in good agreement with direct measurements of the outgassing rates by the neutral spectrometer ROSINA on Rosetta (Hansen et al. 2016). A search for ion-cyclotron waves in the magnetic field data is also presented.

Role of photoionisation, charge-exchange and electron ionisation on cometary plasma environments: application to 67P/C-G at perihelion

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ABSTRACT

We present a self-consistent 3-D quasi-neutral hybrid model of cometary plasma environment including photoionisation, charge-exchange, electron impact ionisation and electron recombination. Each of these processes may create slow heavy cometary ions, thus adding mass to the flow and removing momentum from the solar wind, resulting in the formation of plasma boundaries such as the bowshock. After describing the model and discussing its inputs and limitations, we study the respective effects of these processes on the formation of the bowshock of comet 67P/Churyumov-Gerasimenko (67P/C-G) in perihelion conditions, i.e., 1.3 AU. Each process is first studied individually and then cumulatively. The boundary to the bowshock is fitted to a paraboloid of revolution in order to quantify how each process is affecting its shape and size when looking at the solar wind ion density, velocity and magnetic field. We then calculate the proportion of cometary H_2O^+ ions arising from each process. Charge-exchange is found to be the process most responsible for the slowing down of the solar wind and the formation of a pileup region, followed by electron impact ionisation and finally photoionisation. Finally, we show how these results can be of use in the interpretation of the Rosetta Plasma Consortium instruments onboard Rosetta, and especially the ion composition analyser (RPC-ICA).

Current Results And Future Prospects For Remote Sensing Of Comets

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ABSTRACT

The ground-based campaign of observations that supported the Rosetta mission provided large-scale context information, total activity measurements, and a way to link mission results to other comets. In addition to its use for the Rosetta mission, this campaign represented one of the most comprehensive sets of observations of a comet as it went from its inactive state, through perihelion, and back to large distance. It is certainly the most detailed characterisation of a typical Jupiter Family Comet (JFC), attracting the level of coverage normally only deployed (for brief periods) for bright Oort cloud comets. Telescopes around the world, and in space, were employed in the campaign, using all possible observational techniques.

The analysis of this large data set continues, but already there are some interesting features: While the overall activity of the comet (as measured by its dust production) varied smoothly and showed a symmetrical pattern around its peak (which occurred a few weeks after perihelion), the production rate of the most easily detected gas species (CN) was highly asymmetric, and is clearly decoupled from dust activity. The large-scale structures within the coma appear long-lived and vary only slowly with the changing seasons on the comet, and match similar structures seen in previous orbits, yet Rosetta revealed many small ‘outbursts’ seen as short-lived ‘jets’ from the surface.

The next steps in comet observation will extend Rosetta results to the wider population. 67P appears to be a fairly typical JFC, but exactly how it compares with its siblings can be better studied by performing similar observations for a wider range of comets – e.g. studying the evolution of dust and gas production rates around the orbit for a significant sample. Various programmes already follow this approach, such as the long-term programme of photometry by Schleicher and colleagues at Lowell or the newer robotic TRAPPIST telescopes, although these efforts are necessarily concentrated on brighter comets and/or those near perihelion. Observations from space can reveal parent gas production rates directly, and provide an important comparison.

In the coming years major new facilities on the ground and in space will become available, such as the E-ELT and JWST, which will offer new opportunities for comet observation. At the same time, we are discovering more ‘end-member’ objects that are significantly different from typical JFCs or Oort cloud comets. Low-activity Main Belt Comets, ‘Manx’ comets in Oort cloud orbits, or near-Sun (SOHO detected) fragments are all interesting low activity regimes, which can be explored with the next generation of telescopes and compared with the more typical JFCs or brighter long period comets that have been studied to date. I will conclude this talk with an outline some questions and some observing opportunities to come in the next years.

Thermal and mechanical properties of 67P as constrained by Philae lander data and how to reconcile these with evidence for low tensile strength on comet nuclei

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ABSTRACT

Data from the MUPUS instrument package on Philae suggest the diurnal temperature at Abydos to vary between 100 K and 130 K and the local thermal inertia to be 85±35 J m^{-2} $K^{-1}s^{-1/2}$. The MUPUS thermal probe did not fully penetrate the near-surface layers suggesting a local uniaxial compressive strength > 2 MPa (1), consistent with the observed failure of the lander ice screws (2). A sintered near-surface micro-porous dust-ice layer with a porosity of 30 to 65% is consistent with the data (3). (We note, however, that organics can also act as binding materials in similar ways to ice-sintering but that these would not be affected by sublimation.) SESAME measurements at Abydos suggest a shear modulus of the top layer of at least 3 MPa. The mechanical response of the landing gear during the unsuccessful landing at Agilkia together with data from SESAME and analysis of the footprint (2) has been interpreted as suggesting that a competent hard layer of unknown thickness and strength there underlies a soft layer. Images taken with the OSIRIS camera show a variety of surface features on 67P (e.g., 4). These range from dusty coverings to brittle boulders, Talus-like structures as well as fractures and depressions. Some of these structures suggest a tensile strength of only a few tens of Pa, consistent with results from other cometary nuclei observations (e.g., 5). We note that OSIRIS and CIVA images suggest brittle behavior of the consolidated but fractured regions on the comets – including Abydos – with clear self-similarity on a wide range of scales. The measured values of compressive strength and shear modulus at Abydos can be reconciled with the inferred low values for tensile strength at 100-meter scales if a brittle rheology is assumed. We suggest that a good part of the morphological variety of surface units on 67P – likely as well as on other cometary nuclei – result from the brittle behavior of a thermally sintered dust/ice mixture while regions covered by ultra-weak dust aggregates and layers result from the sublimation of the ice component (with redistribution of the dust by airfall).

1

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[3] K. Kossacki et al., Icarus **260**, 464 (2015)
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Plasma boundaries round comet 67P

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ABSTRACT

The solar wind interacts with a comet's atmosphere in a similar way as it does with unmagnetized planets like Mars or Venus. Similar plasma boundaries are expected to form as the comet approaches the Sun and the outgassing increases. Spacecraft missions to comets long before Rosetta observed some of these boundaries during their flybys.

A bow shock, where the solar wind flow changes from supersonic to subsonic, was, for example, observed by Giotto at Halley's comet. As the solar wind slows down the interplanetary magnetic field piles up in front of the nucleus forming a magnetic barrier on the sunward side. The magnetic field drapes around the comet forming an induced magnetosphere. A change in composition is sometimes observed close to comets: fluxes of solar wind ions decrease rapidly and are replaced by cometary ions. This boundary, or transition, is referred to as the cometopause. Closer to the nucleus the contact surface encloses a region void of magnetic field, the diamagnetic cavity. The existence of additional, more or less permanent boundaries, has been proposed based on models and observations. However, the comet plasma environment is very variable and the both the existence and the position of the plasma boundaries around a comet may depend on the outgassing rate and the prevailing solar wind conditions.

This presentation reviews the observations of plasma boundaries and transition regions made by the Rosetta Plasma Consortium instruments around comet 67P, and put them in context of earlier in situ measurements. The findings will also be compared to observations of the plasma environments around Mars and Venus.

Short time-scale variation in the ion environment around 67P

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ABSTRACT

The ion environment around the 67P/Churyumov-Gerasimenko is highly varying. To be able to study this a new measurement mode was implemented for the Ion Composition Analyzer (ICA), which is part of the Rosetta Plasma Consortium (RPC). In this mode RPC-ICA observes ions in a plane (2D) with a resolution of 1 s or 4 s. We present measurements made with this mode and discuss how the short time-scale variations depend on, for example, spacecraft potential, distance to the comet and magnetic field direction

Recovery of Comet Nucleus Interior: Hardware Constraints in Future Radio Tomography Applications

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ABSTRACT

Our goal is to advance spaceborne radio tomography for future planetary missions. Tomographic measurements performed by a satellite is an emerging method of planetary science that will be necessary to extend our existing knowledge of solar system. The first mission targeting at recovery of a comet nucleus interior was the Comet Nucleus Sounding Experiment by Radiowave Transmission (CONSERT) [1, 2] which was flown as a part of the *Rosetta* mission to the comet 67P/Churyumov-Gerasimenko. In CONSERT, the measurements of the radio signal between the mothership Rosetta and its lander *Philae* were utilized as the data. Future missions are currently being designed. These aim at an extended coverage of the data and, consequently, more accurate imaging results.

In this study, we focus on developing hardware-level computations and solutions to enable robust inversion of incomplete and noisy radio frequency data under hardware constraints typical for satellite applications. Our aim is to enlighten the effect of the digital waveform signal preprocessing on the inversion results. We use travel-time data, as it is known to yield robust information of the unknown parameter [3], and also as it requires minimal data transfer between the hardware and inversion routines. Data preprocessing on embedded hardware has its limitations, and therefore, we aim to find out how hardware-level evaluation of the travel-time is related to the tomography results. To perform the preprocessing operations, a field programmable gate array (FPGA) chip on a development board was used as a platform for the design.

In the numerical experiments, we compared the integrated and thresholded travel-time (ITT and TTT) approaches via inversion analysis utilizing experimental acoustic waveform data. A 16-bit and 8-bit analog-to-digital (A/D) conversion was tested together with two different threshold criterions and normalization levels. The results show that ITT is invariant with respect to source data bit width reduction in time-domain and the level of thresholding used to locate the signal pulse from recorded audio data. ITT was also found to be more reliable with respect to the normalization of the signal and sparsity of the measurements than TTT. We normalized the 8-bit signal to two different levels to simulate weak receivers, i.e., to decrease signal-to-noise ratio (SNR). This is important, since signals can be weak in some directions. This has been realised in the CONSERT experiment in which the received signal power and quality varied significantly depending on the measurement direction [2]. The stability with respect to the sparsity is important, since it is likely that full data cannot be gathered, such as in the CONSERT.

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Dust distribution in a jet observed by Rosetta VIRTIS-M in a coma of comet 67P/Churyumov-Gerasimenko on April 14, 2015

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ABSTRACT

Dust and gas are two primary components of a cometary coma. Remote sensing and in situ instruments onboard Rosetta have provided an unprecedented opportunity to observe them. Dust images delivered by Rosetta are one of the most important opportunities to characterize the temporal and spatial variability of the dust population in a cometary coma. Analysis of these images will help one to get a better understanding of the relation between gas and dust activity, and size and density of the dust particles.

The main focus of the presented work is a characterization of the location and source rate of a dust jet observed by Rosetta VIRTIS-M on April 14, 2015. This analysis has been performed by means of a coupled kinetic modeling of gas and dust populating the coma, and comparing the calculated dust brightness with that observed by VIRTIS-M. While VIRTIS-M images of the dust coma do not have as high a sensitivity or spatial resolution as the OSIRIS cameras, VIRTIS-M also provides a simultaneous snapshot of the distribution of H_2O and CO_2 gas which are responsible for driving the dust coma expansion. Here we present our estimation of the dust jet source rate, describe the effect of the gas populating the coma on the dust flow, and discuss the dust and gas source distributions on the nucleus surface.

The ionization balance in the innermost coma of 67P

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ABSTRACT

The electron-to-neutral number density ratio, n_e/n_N, is a key to assess the main processes controlling the ionization balance within the coma of 67P. These governing processes change with both the activity and the cometocentric distance. Electron number densities are obtained from in situ measurements by the Mutual Impedance Probe (MIP) and the dual Langmuir probe (LAP), both being subsystems of the Rosetta Plasma Consortium (RPC). Neutral number densities are obtained from measurements by the Comet Pressure Sensor (COPS), a subsystem of the Rosetta Orbiter Spectrometer for Ion and Neutral Analysis (ROSINA). At heliocentric distances of 2.4-3 AU and when within a few tens of km from the nucleus the observed n_e/n_N ratios are typically (and on average) consistent with a collisionally coupled innermost plasma (Odelstad et al., 2015, GRL 42, 10126; Edberg et al., 2015 GRL 42, 4263; Galand et al., 2016 submitted; Vigren et al, 2016 ApJ, in press). At times plasma densities are too high to be explained by plasma production through photoionization only, and electron impact ionization has indeed been shown to be significant from electron spectra acquired by the Ion and Electron Sensor (Galand et al., 2016, submitted). Close to perihelion (1.25 AU) and at a cometocentric distance of ~200 km electron number densities are strongly reduced from values predicted by a collisionally coupled model that also does not account for plasma loss through dissociative recombination. The reduction is so pronounced that its main cause is unlikely to be the non-inclusion of dissociative recombination in the model. From preliminary investigations, combining MIP n_e measurements with ion current measurements by LAP suggests ion flow speeds typically around 5 km s^{-1}, which is significantly higher than the neutral outflow velocity. We are currently seeking to confirm these estimates by independent means.

Coma features, related activity sources, and surface evolution

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ABSTRACT

”Cometary activity” is traditionally summarized as the combination of the sublimation of volatile material and the acceleration of refractory elements leading to a gas and dust coma around the nucleus. In-situ observations have shown that, although correct, this description is not sufficient. Volatiles are scarce on the surface of cometary nuclei, and the activity patterns are far more complex than initially thought.

One example of the problems to solve is to understand how gas and dust can arise from the nucleus as collimated streams, often called ”jets”. ESA's Giotto observed these features for the first time 30 years ago but their formation mechanism remains to be explained. The Rosetta mission provided a continuous monitoring of the nucleus activity at high spatial and temporal resolution. We observed various types of dust and gas release, from narrow jets on a few meters scale to large structures extending 10s of kilometres from the nucleus.

Overall the activity is quite homogeneously distributed, following closely the solar insolation, and repeating itself from one rotation to the other. We find however that some types of surfaces are more prone to create jets than others, reflecting local inhomogeneities in the topography and/or the volatile content. In addition to the typical jets, we also observed many transient events close to perihelion approach: sudden and massive releases of gas and dust for short times which cannot be explained with the standard activity models.

This presentation will review the different types of activity we have observed, their link to surface features, and discuss how Rosetta's datasets challenge the current models.

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Study of the Comets C/2012 S1(Ison) and C/2013 A1(Siding Spring)

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ABSTRACT

The comet C/2012 S1(ISON) was discovered on September 24/2012 by Vitali Nevski and Artyom Novichonok (Rusia) , and though it was expected to be very bright at the end of 2013 and the beginning of 2014, the close encounter with the Sun (November 28th /2013) was devastating; the comet couldn't survive this event. In this work the comet's light curve and the orbital parameters are obtained. We have photographed and studied the comet from the University of Nariño's Observatory (Pasto-Colombia) since January 31st /2013. The brightness' variation of a comet with respect to the heliocentric distance is given by the following equation:

$$m = mo + 2.5 \, n \log (r) + 5 \log (\Delta)$$

m = magnitude as observed from the Earth $\qquad$ m_o = absolute magnitude
r = distance of the comet to the Sun $\qquad$ Δ = distance of the comet to the Earth
n = index of cometary activity

We also obtained the following orbital parameters: eccentricity = 1.000009, orbital inclination = 61.92926 deg, longitude of the ascending node = 295.72536 deg, argument of perihelion = 345.51426 deg, perihelion distance = 0.01249335 A.U. The parameters were calculated based on 22 observations (2013 Jan 31-May 17) with mean residual = 0.387 arcseconds.

The comet called C/2013 A1 (SIDING SPRING) was discovered on January 3/2013 in Australia. In January 28/2014, NASA announced that is preparing for the close encounter that will happen between the comet C/2013 A1 and Mars on October 19-2014. The Mission, called "MAVEN", was inserted in Mars orbit on september 21/2014. The comet passed just 138,000 kilometers far from the surface of Mars. The probability that the comet collided with Mars was small but the dust particles emitted by the comet could cause damage to spacecrafts and probes that are in orbit around that planet. NASA made preparations to take all precautions. We captured images and astrometry data during several days. The pictures of the asteroid were captured with the following equipment: CGE PRO 1400 CELESTRON (f/11 Schmidt-Cassegrain Telescope) and STL-1001 SBIG camera. We obtained the light curve of the body. We calculated the orbital elements and obtained the following orbital parameters (Jan 21 to October 29): Eccentricity = 1.0005849, orbital inclination = 129.04413 deg, longitude of the ascending node = 300.97593 deg, argument of perihelion = 2.42011 deg, perihelion distance = 1.39876996 A.U. The parameters were calculated based on 32 observations with mean residual = 0.309 arcseconds. We also obtained the light curve of the body with our data (January to November/2014). The orbit had a perturbation of 7 minutes, 44 seconds.

Field line draping and current sheets in comet 67P/Churyumov-Gerasimenko's coma

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ABSTRACT

A cometary coma collects the time history of the solar wind magnetic field (IMF). Around the outgassing nucleus a conducting plasma envelope will be created through ionization of the neutrals coming from the comet. Through this layer the IMF cannot freely move, but is hung-up because the magnetic diffusion speed is much slower than the solar wind speed. Changes in IMF direction will therefore be layered in this hang-up region. Rosetta, moving at slow speed through 67P/CG’s coma, measures the magnetic field and observes strong rotations of the field over short (minutes) time scales. These strong rotations have to be accompanied by local current sheets, which should display themselves in the plasma instruments. We will show examples where these rotations are indeed accompanied by an increase in the ion or electron signatures in their respective time-energy spectrograms.

Formation of pebble-pile planetesimals - the internal structure of comets

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ABSTRACT

In the Solar System, asteroids and Kuiper belt objects as well as comets are remnant planetesimals from the time of planet formation. Gravitationally bound planetesimal-mass clouds of pebbles can form in particle overdensities in the protoplanetary disk. Such clouds will inevitably have inelastic collisions between pebbles, lose energy and contract. The contraction leads to an increase in density and collision speeds which, in turn, leads to higher collision rates, faster energy dissipation and a runaway collapse. The internal structure of the resulting planetesimal is heavily dependent on cloud mass, initial pebble sizes and depth inside the planetesimal[1]. Low-mass planetesimals have no/few fragmenting pebble collisions in the collapse phase and end up as porous pebble-piles. In massive clouds, however, pebbles undergo more fragmenting collisions and resulting planetesimals will consist of a mixture of primordial pebbles and smaller fragments. A mixture of particle sizes should lead to better packing capabilities and higher densities. This relationship with higher densities for more massive bodies has been observed for Kuiper belt objects as well as for comets (e.g. 67P/Churyumov Gerasimenko by Rosetta) and for the dwarf planet Pluto by New Horizons. I investigate the internal structure of planetesimals through numerical Monte Carlo simulations of the collapse process.

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Towards synthesis of *in situ* and laboratory observations of cometary materials

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ABSTRACT

Interplanetary dust particles (IDPs), collected in the stratosphere by high-flying aircraft, have been studied in the laboratory since the 1970's. A class of anhydrous IDPs – the so-called chondritic-porous IDPs (CP-IDPs) – are thought to be cometary in origin. CP-IDPs are assemblages of submicron crystalline, partially crystalline, and amorphous fine-grained materials, in association with >1μm crystalline sulfides and silicate rocks. Because they commonly contain relatively high concentrations of pre-solar grains (circumstellar grains that predate the solar system) and strong isotopic anomalies in organic materials, they are thought to be highly primitive, although their relationship to interstellar solids in the protostellar cloud is unclear. CP-IDPs also commonly contain amorphous submicron particles called GEMS (Glass with Embedded Metal and Sulfides). Despite decades of study, GEMS remain enigmatic, and their formation mechanism and formation environment of GEMS is controversial.

In 2006, the Stardust mission brought to terrestrial laboratories the first samples of material from a known small planetary body, the Jupiter-family comet 81P/Wild 2. The decade since the return of Stardust has seen intense laboratory study of Stardust cometary samples, generating a literature of more than 140 peer-reviewed publications,. Stardust also inspired a renewed interest in CP-IDPs. Analyses of both collections are complicated by their own biases and selection effects. For Stardust, the effects of hypervelocity capture in aerogel and aluminum foils must be understood and taken into account, which can include loss of volatile phases, chemical reduction, and mixing with molten aerogel. Heating during atmospheric entry can cause loss of volatiles and oxidation of CP-IDPs; there is a bias against particles with low stratospheric residence times; and the silicone oil capture medium has the potential to contaminate the samples.

Nevertheless, after taking into account these effects, significant, systematic differences are emerging between Wild 2 samples and CP-IDPs. These include: concentration of pre-solar grains, concentration of GEMS, oxidation state of Fe, concentration of condensation products (e.g., enstatite whiskers), concentrations of ``microchondrules" and "micro-CAIs", and others. Key to these observations has been rare and idiosyncratic samples in the Stardust collection, such as Febo and Andromeda, in which fragile, fine-grained material has apparently been partially protected from damage during capture by physical association with and consequent shielding by large (>10μm) robust rocks. It is also becoming clear that the dispersion of properties among CP-IDPs is substantial, with, for example, large variations in concentration of GEMS.

The implications of large systematic differences between CP-IDPs and Wild 2, and significant heterogeneity among samples of both collections, may point not only toward surprising heterogeneity *among* comets, but also toward internal heterogeneity *within* comets. In particular, the systematic difference in Fe oxidation state between CP-IDPs and Wild 2 might be understood if comets are radially inhomogeneous, with a ``late veneer'' of metal-rich material that accreted late in comet formation. This picture may be consistent with *in situ* observations of C-G by Rosetta.

In this talk, I will summarize the state of laboratory study of cometary materials, including materials from 81P/Wild 2 returned by the Stardust mission, and summarize the questions that may be addressed through a synthesis of these observations with *in situ* observations of 67P/C-G by Rosetta. I will focus on emerging laboratory-based analytical techniques (nanoIR, atom probe, and others) that may be brought to bear to answer these questions.

Solar Wind Sputtering of Dust on the Surface of 67P/Churyumov-Gerasimenko

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ABSTRACT

Far away from the Sun, at around 3 AU, the activity of comet 67P/Churyumov-Gerasimenko is low and changes with local time (solar insolation), with location (chemical heterogeneity of the surface), and with season. When the activity is very low because the total cross section of the comet against the Sun is small, the solar wind has direct access to the surface of the comet and causes ion-induced sputtering of surface material, which we observe with the ROSINA experiment on ESA's Rosetta mission. We used the Double Focussing Mass Spectrometer (DFMS) of the ROSINA experiment to search for mass spectrometric evidence of sputtered refractory species in the coma. In high-resolution mode, DFMS can separate some of the mass peaks of sputtered refractory species from the many volatile species still present in the coma.

During the measurements, the locations of solar wind surface access are in the southern hemisphere of the comet (the local winter). Of particular interest is sputtering of dust grains on the surface. We observe global averages over the winter hemisphere of the refractory elements Na, K, Si, and Ca, presumably sputtered from grains residing on the surface. Compared to carbonaceous chondrites, the comet has the same Na abundance, is depleted in Ca, and has an excess of K. In addition, for Si the signal strength is strong enough to compile a coarse compositional map of the winter hemisphere. Most, perhaps all, of the observed variation can be explained by the solar wind being affected by the atmosphere of the comet.

The Forecasting of the Near-Nucleus Gas Coma of Comet 67P Prior to the Descent of PHILAE

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ABSTRACT

The preparation of the PHILAE descent requested an assessment of the gravitational and aerodynamic forces exerted on the lander. We here describe the so-called RZC model developed to predict the near-nucleus gas coma properties responsible for the aerodynamic force. We outline the unusual modelling difficulties resulting, in particular, from the complexity of the nucleus surface on all scales, from the need to infer the surface gas fluxes from the orbiter data, and from the need to perform the whole program within less than three monthes. The RZC model included five differing tools: (1) a 3D+t Eulerian gasdynamic code to compute the vacuum outflow of a rarefied gas mixture from a complex shaped solid source; (2) a 3D+t Navier-Stokes code for the same purpose; (3) an heuristic approach to derive the initial boundary conditions (near-surface gas parameters) for these two codes; (4) a 3D DSMC code to solve the same problem in a gaskinetic approach; and (5) an iterative procedure to adjust the assumed gas production parameters on the nucleus surface to observational data acquired from the orbiter probe. The degree of agreement of the adjusted model with the data in the weeks preceding PHILAE descent is presented and discussed in term of relevance of the approach mentioned above. In so doing, we present not only our pre-descent results, but as well, for the same pre-landing period, results that we could only obtain after this descent.

New insight of chemistry in protoplanetary disks in the age of ALMA

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The composition and structure of cometary nuclei is a fossil record of evolution of materials from natal interstellar clouds to the early solar nebula. Most early studies focused on a comparison of cometary composition with interstellar ices, due to the lack of measurements on chemical abundance within protoplanetary disks. As a result, it is still unclear how much chemical alteration occurs in the disk during the stage where comets are assembled. In this talk, I will review recent ALMA observations of locations of mid-plane snowlines, and new constraints on abundance/distribution of hydrocarbons and complex organic molecules in protoplanetary disks. I will discuss how these observations are linked to disk chemical models which shed light on our understanding of the chemical evolution that occurs within the comet-forming zone. A particularly important chemical aspect from emerging observations is that the growth, settling, and radial drifting of icy particles/planetesimals significantly alters chemical abundances - with the ultimate result of ice enrichment of carbon-bearing molecules prior to and during cometary formation. Finally I will propose some new directions on further observational and chemical modeling efforts to study chemical evolution of cometary materials that is now being revealed by the power of ALMA.