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On understanding multi-instrument Rosetta data of the innermost dust and gas coma of comet 67P/Churyumov-Gerasimenko - results, strengths, and limitations of models

Raphael Marschall (1), Ladislav Rezac (2), David Kappel (3), David Marshall (2), Chin-Chia Su (4), Selina-Barbara Gerig (5), Olga Pinzon (5), Ying Liao (8), Martin Rubin (5), Clémence Herny (5), Paul Hartogh (2), Ekkehard Kührt (3), Stefano Mottola (3), Frank Preusker (3), Frank Scholten (3), Laurent Jorda (6), Panagiotis Theologou (5), Olivier Groussin (6), S Kokou Dadzie (7), Chariton Christou (7), Gabriele Arnold (3), Jong-Shinn Wu (4), Kathrin Altwegg (5), Holger Sierks (3), Rafael Rodrigo (1), Nicolas Thomas (5), OSIRIS, ROSINA, MIRO, and VIRTIS teams

(1) International Space Science Institute, Hallerstrasse 6, CH-3012 Bern, Switzerland, raphael.marschall@issibern.ch, (2) Max-Planck-Institut für Sonnensystemforschung, Justus-von-Liebig-Weg 3, 37077 Göttingen, Germany, (3) DLR, Institut für Planetenforschung (DLR-PF), Rutherfordstraße 2, D-12489 Berlin, Germany, (4) Department of Mechanical Engineering, National Chiao Tung University, 1001 Ta-Hsueh Road, Hsinchu 30010, Taiwan, (5) Physikalisches Institut, University of Bern, Sidlerstrasse 5, CH-3012 Bern, Switzerland, (6) Laboratoire d'Astrophysique de Marseille, UMR 7326, 13388 Marseille, France, (7) Heriot-Watt University, Institute of Mechanical Process and Energy Engineering, EH14 4AS Edinburgh, Scotland, (8) Macau University of Science and Technology

Abstract

Numerical models are powerful tools for understanding the connection between the emitted gas and dust from the surface of comets and the subsequent expansion into space where remote sensing instruments can perform measurements. We will present such a predictive model which can provide synthetic measurements for multiple instruments on board ESA's Rosetta mission to comet 67P/Churyumov-Gerasimenko (hereafter 67P). We will demonstrate why a multi instrument approach is essential and how models can be used to constrain the gas and dust source distribution on the surface.

1 Introduction & problem

From August 2014 to September 2016 ESA's Rosetta spacecraft escorted comet 67P on its journey into the inner solar system and out again. The mission provided, via various instruments for dust and gas measurements, unprecedented data on the nature of cometary activity. The determination of the activity distribution on the surface of a comet is a key goal of Rosetta to investigate the interaction of the comet with the Sun.

As the cometary ice sublimates the gas expands into space and fills the near-nucleus environment. Individual sources of activity have been observed on the surface but it remains uncertain where the bulk of the mass is lost and how the processes that are involved work in detail. There are several reasons for this. First, optical imaging experiment use the dust coma as a proxy for the gas activity. Because the optical depth of the dust is orders of magnitude below 1 in all but a few cases, it is not possible to trace dust filaments back to the source against the backdrop of the illuminated surface. Second, remote sensing instruments detecting gas emission (i.e. infrared and sub-mm spectrometers) may suffer from limited spatial and temporal resolution. In addition, the spectral lines may be optically thick and the line-of-sight direction usually cuts through the inhomogeneous coma (in density or temperature) which further complicates their interpretation considerably. However, as we will show, with good a-priori estimates of coma structures spectral lines can be accurately inverted to provide constraints of the gas coma down to a few hundreds of meters above the surface (e.g. MIRO). The in-situ instruments (e.g. ROSINA or GIADA) must consider possible biases due to the spacecraft position relative to the nucleus and respective illumination conditions on the surface. For instance, the frequent use of terminator orbits by Rosetta introduced a significant problem because the measured local densities were at points remote from what we assume to be the main direction of outflow, namely near the sunward direction. In addition, the possible inhomogeneities of the outgassing at the surface cannot be detected due to the fact that the rapid gas expansion smoothens the coma. Therefore, measurements taken tens of kilometers above the nucleus surface are rather insensitive to emission inhomogeneities at the surface and provide only ambiguous results.

2 Multi-instrument approach

The difficulties described above show the need for predictive models that can reproduce multiple measurements in one self-consistent framework. The starting point of all our models is the SPG shape model SHAP7 [1]. We then use a Direct Simulation Monte Carlo (DSMC)[2] code to model the expanding rarefied gas, and a test particle code [3, 4] to simulate the dynamics of dust particles of different sizes. Each program provides us with the physical properties of the gas/dust coma within 10 km from the nucleus center. This allows the generation of synthetic measurements of multiple Rosetta instruments and compared to the actual measurements. We will present results from our study of diverse Rosetta data sets (including OSIRIS, VIRTIS, MIRO, and ROSINA), constraining the gas emission into the coma and establish whether the data enable us to reach appropriate conclusions on the activity distribution on the nucleus surface. We focus here on the time around May 2015 (equinox). While this period is a few months prior to perihelion, the spacecraft was close to the comet, providing a relatively high spatial resolution of the remote sensing observations such that, in principle, they can be more easily linked with the in-situ measurements.

On the one hand, models can be used to constrain certain properties of the activity such as the emission distribution of the surface. On the other hand, they provide strong constraints on the limits of the interpretations of some of the available datasets. Due to the use of physical models we can test a variety of initial conditions that result in identical predicted measurements. We will present such limitations rooted in the physical dynamical processes of the expanding gas and dust flows from the surface.

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