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

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## Abstract

We describe the RZC model developed to predict the gas environment of the comet 67P (it was used for estimation of the aerodynamic forces on the Rosetta lander in November 2014) and the results of adjustment of this model to the observational data obtained by the Rosetta probe before landing.

Also, we present the results of our attempts to fit the dust coma images obtained by the Optical, Spectroscopic, and Infrared Remote Imaging System (OSIRIS).

## 1. Introduction

On November 12, 2014 the ESA Rosetta probe deposited the Philae lander on the nucleus of the comet 67P located at 3.00 AU from the Sun. Within the Rosetta project, the responsibility of the aerodynamic and gravitational force assessments on the lander was delegated to the French National Space Center CNES, who delegated the assessment of the gas outflow structure to a so-called "RZC" team gathering the three of present authors.

The RZC model includes two differing tools: (1) a set of gasdynamic/gaskinetic codes to compute the vacuum outflow of a rarefied gas mixture from a central, highly anisotropic and rotating source; (2) a specially developed code to derive the central source parameters from data on the nucleus provided by the observations from the orbiter probe.

Ideally speaking, the optimization of the gas model would have resulted from a succession of predictions of the local gas parameters along optimal probe trajectories, as well as of the gas parameters inside the field-of-view of the remote sensing instruments, followed by comparison with the in-situ sampling and remote sensing instrument data. This turned out however impossible for many reasons. Instead, preset trajectories and instrument view directions were defined which then may not have been optimal for adjusting the model parameters. Therefore we are limiting our efforts to fitting the Rosetta Orbiter Spectrometer for Ion and Neutral Analysis (ROSINA). Also, since cometary dust has been shown to be an accurate tracer of the gas flow discontinuities, we made attempts to fit the dust coma images of the Optical, Spectroscopic, and Infrared Remote Imaging System (OSIRIS).

## 2. The model

The observational nucleus data for the model were (a) a nucleus rotation model, and (b) a nucleus surface shape model. From the latter we constructed an "effective surface model" to be used by the gas code. This procedure evidently erases small-scale details but also creates a surface slightly different from the "real" one, having, for instance a different shadow pattern under oblique solar illumination.

The gas production model assumes that the less volatile molecules of $H_2O$ are produced from the surface of the nucleus by sublimation of surface ice inclusions and the more volatile molecules (CO and $CO_2$) are produced by diffusion to the surface after having been sublimated at variable depths inside the nucleus. The emission has two components one is modulated by the Sun, while the other is permanent. In addition, we introduce position dependent factors $f_{H2O}$, $f_{CO}$, $f_{CO2}$ of surface inhomogeneity (separately for each gas species) which linearly adjust surface fluxes.

A multi-species 3D+t gas solver is based on: (1) gas-dynamic approach – the numerical integration of the Euler/Navier–Stokes equations combined with a locally plane-parallel solution of the collisional Boltzmann equation for the nonequilibrium near-surface Knudsen layer (BE-NSE) [1]; and (2) kinetic approach - the direct simulation Monte–Carlo (DSMC) method. Since the radial size of the region of interest is usually less than 150 km we use quasi-steady approximation for the gas simulations. For the dust coma we use the stochastic approach - the Dust Monte-Carlo (DMC) [2]. We assume that dust grains are spherical moving under influence of three forces: the nucleus gravitational force, gas coma aerodynamic force, and solar radiation pressure force, and consider the full mass range of ejectable grains. The dust grains move slower than the gas, therefor for the dust coma we perform fully time dependent simulations. At each surface point, the dust mass flux (of a given size) is proportional to the gas mass flux. This proportion may be variable over the surface.

## 3. The adjustment of the gas production

The adjustment of the model to the in-situ observational data is separated on two consecutive stages. On the first stage we adjust the integral parameters: the total production rates and the proportion of solar modulated and permanent diffusion. On the second stage we adjust the distribution of surface inhomogeneity factors. From positions of the orbiter we traceback the flowlines down to the corresponding surface elements. For the surface elements we collect statistics on the ratio of measured and simulated density and composition. The currently used factors $f_{H2O}$, $f_{CO}$, $f_{CO2}$ are corrected (multiplied) by the averaged ratio. Since variation of the flux affect the flow in general it is necessary to repeat iteratively simulations for the whole rotational period with the new flux distribution. The observational data are limited and some of the surface elements may have no data, for them we apply the algorithm of flooding from adjacent cells.

## 4. Comparison with the dust coma images

To compare the outcome of the dust models to OSIRIS images have generated synthetic column densities from the outcomes of the dust simulations. The light scattered by the dust towards the pixel of the WAC/NAC camera is computed by using Mie theory for spherical particles. The total flux scattered back by the coma on each pixel is finally reduced taking properly into account the efficiency of the CCD and optics. For the dust particles we adopt an average density of 800 kg/m$^3$ and a composition typical of organic material modelling interstellar dust under the assumption that such material is also representative of cometary dust. The synthetic images are compared to observations via direct comparison with 2D images or using polar plots. These last ones are obtained by fixing a given radial distance *R* from the center of the comet and comparing the flux computed along the circle of radius *R* surrounding the comet for both the observed and synthetic image.

## 5. Results

We have tried to best fit the data acquired in August-November 2014 by the pressure gauge COPS on the orbiter. Fig.1 shows an example of surface inhomogeneity distribution after adjustment.

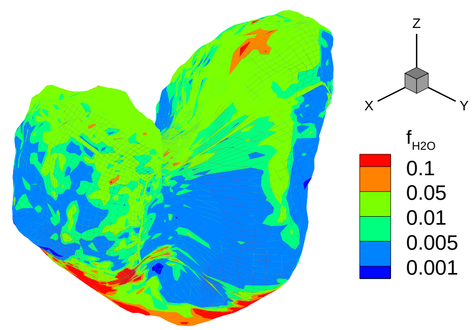


Figure 1: $f_{H2O}$ distribution over the surface.

## References

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