MiARD

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Deliverable Report

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Table of Contents:

Summary

This deliverable consists of datasets summarising the results from numerical models of the outgassing of the comet 67P/Churyumov-Gerasimenko. The datasets are available for download from the project website at http://www.miard.eu/homepage/publications/- A summary of how the datasets were obtained, some example images, and a description of the dataset is provided in this report.

Details (scientific and technological achievements)

A full description of the physics and numerical approaches included in the modelling work can be found in the publications by Marschall et al. We repeat here a summary of the approach to modelling the gas outflow (also found in the MiARD project deliverable report D2.4 “Mapping of gas sources back onto the shape model”), together with a summary of how the dust outflow is modelled.

The model

A schematic of the forward modelling approach we have set up to study the inner gas and dust coma of comet 67P is shown in Figure 1. The SHAP4S shape model was used for the calculations (the SHAP 7 model became available too late, and the extra detail of the surface shape is not needed). The results shown here have been calculated for comparison with data gathered in September 2014, when the comet was at a heliocentric distance of 3.4 AU and a sub-solar latitude of 42.6°.

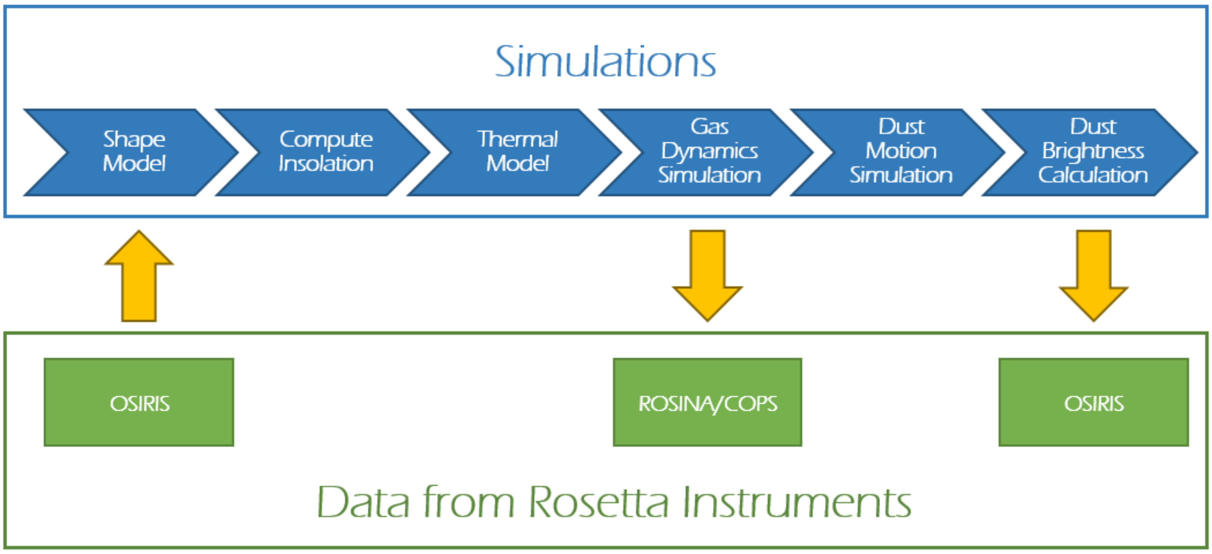

Figure 1: Forward modeling and interactions of Rosetta data sets (as used in Marschall et al., 2016 & 2017

From the shape model and orientation of the comet, we calculate the angle of incidence of the sunlight onto the surface taking into account self-shadowing. The resulting solar flux is used as an input to calculate the sublimation rate and surface temperature of each surface element.

The simple thermal model used initially assumes a pure ice surface, and has a heat balance including the incident radiation, thermal emission and sublimation but neglecting thermal conductivity. The surface temperatures and sublimation rates are then used in our Direct Simulation Monte Carlo (DSMC) software code to calculate the flow field of the water molecules from the comet's surface into 3D space. The resulting local number density of the gas can then be directly compared to measurements made by the ROSINA/COPS instrument on the Rosetta spacecraft. A comparison of the predicted values of the model and the data show that the model over estimates the number densities by roughly two orders of magnitude if a pure ice surface is assumed. This clearly indicates that the assumption that the entire surface of the comet is pure ice is not true (from images of the comet we do not expect this assumption to be true). We introduce a physically motivated parameter with a value between 0 and 1 - a scaling factor of the production rate at the surface which we call the effective active fraction (EAF), to obtain a better fit between the model and observations. An EAF of unity represents a pure ice surface and an EAF of zero represents an ice-free surface (i.e. no outgassing).

By tuning the EAF of the surface, the fits to the data can be improved significantly. If one assumes that the entire surface has the same potential for activity i.e. that the EAF is a global constant, then we find that the EAF takes a value of the order of 1% as shown in Marschall et al. 2016. This assumption provides a first order fit to the ROSINA/COPS data but does not reproduce the daily gas density variations very well. As a next step, we assume that different regions have a different potential for activity and thus define the EAF for each region individually. The definition of the regions is that of El Maary et al. 2015 (i.e. independent of any outgassing considerations). Although we constrained these regional EAF values using ROSINA/COPS data from between August and October 2014, see Figure 1, we have also tested the same activity maps with data obtained later in the mission up until the equinox in May 2015 and have found that the relative activity of the different regions seems stable (Marschall et al. in prep.).

However, as shown in Marschall et al. 2017, the regional values of the EAF that are obtained by this approach are not a unique solution. For example, restricting activity on a finer scale to areas of high gravitational slopes (i.e. cliffs) with additional contributions from the Hapi region can produce an equally good fit to the data. It is important to note that the comparison of the model to ROSINA/COPS data cannot alone differentiate between such solutions. Despite the lack of uniqueness for solutions to the outgassing model, our overall conclusions are robust. The highest potential for activity is in the Hapi region, but other regions, including Imhotep and Hatmehit (both also with smooth terrains), are much less active in comparison.

To compute the dust distribution we insert dust particles into the gas flow and track them through space taking into account the gas drag force and the comet's gravity. By tracking millions of test particles in this way we can calculate the local dust densities and velocity within our domain.

3D gas distribution

We present here some visualisations of the 3D distribution of the H_2O coma of comet 67P for the two different outgassing models cosidered: i) the simple, purely insolation-driven model and ii) a more refined inhomogeneous model (maps from which are shown in MiARD deliverable D2.4 “Mapping of gas sources back onto the shape model”), which has been shown to fit well with ROSINA and OSIRIS data. All results shown here assume the position of the Sun and comet in mid-September 2014, when the comet was at a heliocentric distance of 3.4 AU and a sub-solar latitude of 42.6°. The sub-solar longitude has been chosen to be 310°.

All the gas values have been calculated up to a distance of 10 km from the nucleus centre and are given in the dataset on a Cartesian grid with a resolution of 200m. The scalar field of gas number density can be viewed using a number of standard visualization tools (including the freely

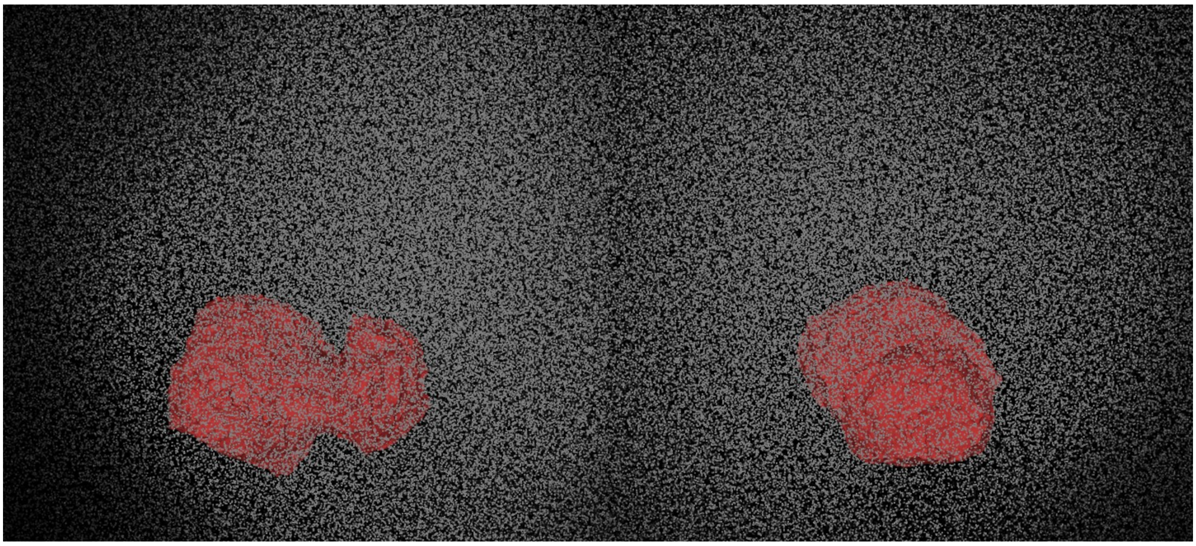

Figure 2: A visualization of the number density of the gas for the purely insolation-driven model.

available Paraview software), but the state-of-the-art for (direct) volume rendering does not always give satisfactory results. The project team has therefore developed an alternative approach for visualization in which the local number density is represented by pseudoparticles which have an opacity related to the number density[1]. This approach is used in all of the figures shown here.

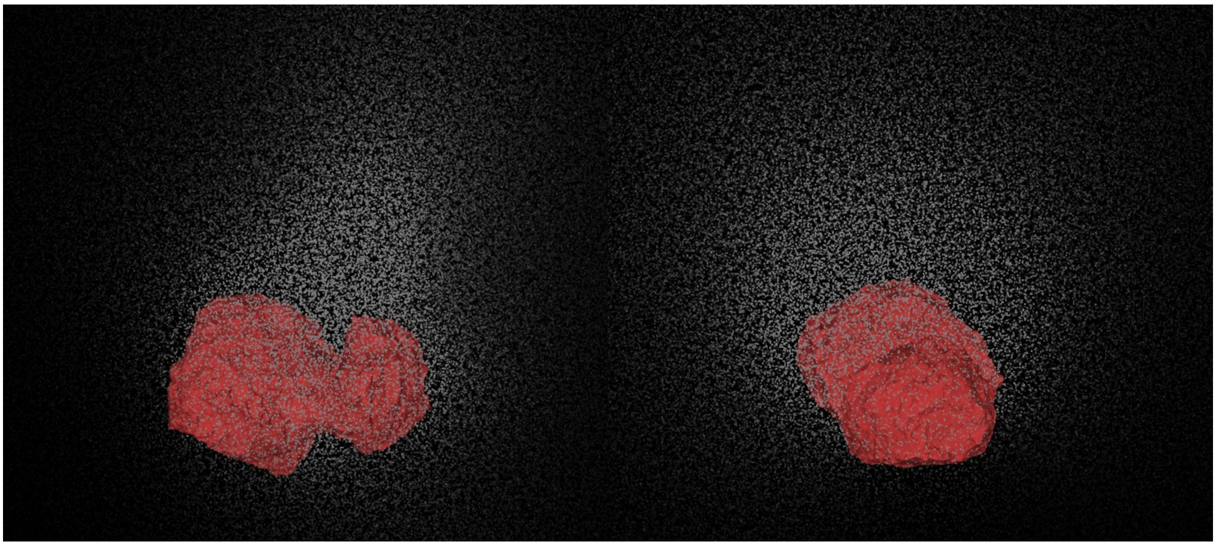

Figure 3: Similar to Figure 2, but showing the distribution of gas for the purely inhomogeneous model assumptions.

3D dust distribution

In this section we present a visualisation of the 3D distribution of the dust coma, for the gas flow fields calculated from the two sets of assumptions presented above. For each gas flow field, we show the dust distribution for three different dust sizes: 1.6 μm, 16 μm, and 160 μm (assuming a dust to gas mass ratio of unity - the gas density comes form the model). All dust values have been calculated up to a distance of 10 km from the nucleus centre and are given in the dataset on a Cartesian grid with a resolution of 200m.

1The program to do this may in future be released by the project - software licences are being checked.

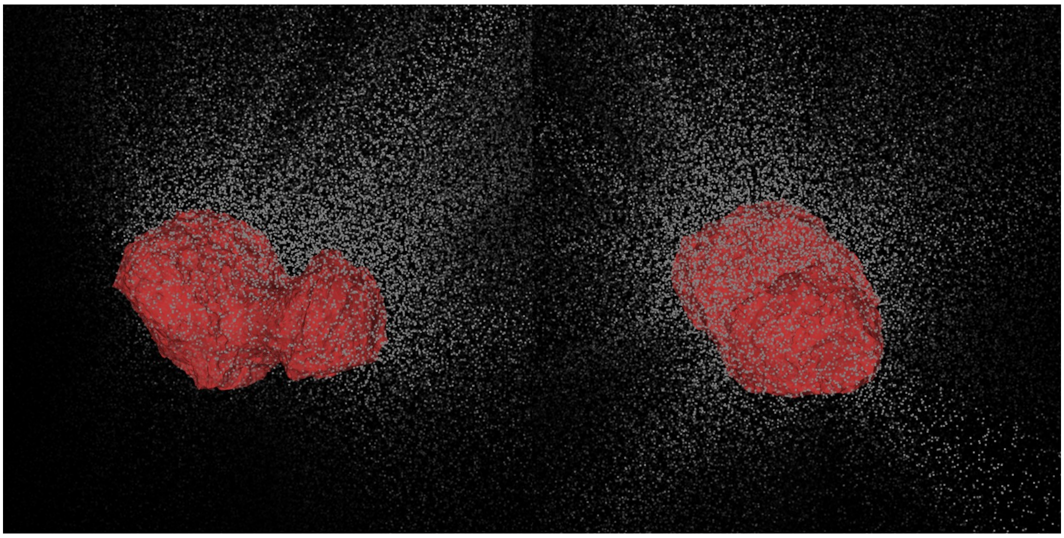

Figure 4: Dust particle distribution for particle size 160 µm and the purely insolation-driven model.

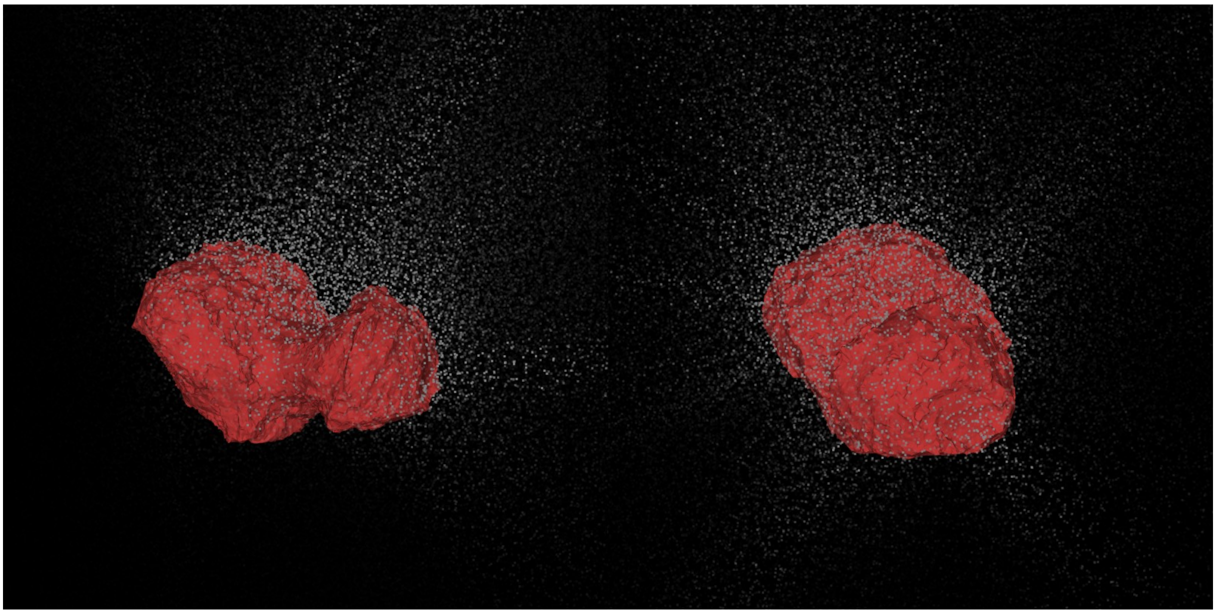

Figure 5: Figure 4: Dust particles distribution for particle size 160 µm and the inhomogeneous model.

The dataset

The delivered dataset consists of a number of space separated ASCII files with seven columns of data. These seven columns (x, y, z, number density, u, v, w) are:

- *x,y,z* spatial coordinates in metres from centre of comet (Cheops reference frame)
- the number density of the gas or dust (m^{-3})
- *u, v, w* the x,y,z components of the velocity vector (m/s)

There are eight files in total (plus a readme.txt), these are: for each model (inhomogeneous or purely insolation driven) there is one file for the gas number density and velocity, and one file for each dust particle size. The filenames are self-explanatory.

The data can be downloaded from the MiARD project website az http://www.miard.eu/homepage/publications/

Deviations from the DoA

N/A

Conclusions, expected impact and use of deliverable, outlook

The images in this report are just to provide an idea of what the datasets contain. The detailed data will be useful to those seeking to correlate observational data with models and physical explanations of the activity of the comet.

References

R Marschall et al. (2016) Modelling observations of the inner gas and dust coma of comet 67P/Churyumov-Gerasimenko using ROSINA/COPS and OSIRIS data: First results *Astronomy & Astrophysics* **589** A90

R Marschall et al. (2017) Cliffs versus plains: Can ROSINA/COPS and OSIRIS data of comet 67P/Churyumov-Gerasimenko in autumn 2014 constrain inhomogeneous outgassing?, *Astronomy & Astrophysics* **605** A112