EPSC Abstracts
Vol. 12, EPSC2018-256, 2018
European Planetary Science Congress 2018

New constraints on the chemical composition and outgassing of 67P/Churyumov-Gerasimenko

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Abstract

Constraining the composition and the internal structure of the cometary nuclei of 67P/Churyumov-Gerasimenko (hereafter 67P) is challenging as we mainly dispose of remote measurements. The ROSINA/DFMS mass spectrometer has measured the production rates of various species in the coma of 67P. Results display strong variations of volatile abundances [1]. Several studies proposed that the complex shape of the nucleus and the large tilt of the rotation axis of 67P would imply large seasonal effects driving the species outgassing [2,3] while others suggested that the diversity of surface morphologies of 67P results from non-uniform sub-surface composition [4,5]. Here we brings some constraints on the composition and internal structure of the nucleus of comet 67P by comparing the data provided by the ROSINA/DFMS instrument and a thermochemical numerical model designed to depict the evolution of the stratigraphy of cometary nuclei.

1. Data and comet nucleus numerical modelling

The production rates of the species coming out from the nucleus have been investigated via a numerical model depicted in [6]. This model is designed to compute the thermal and chemical evolution of a single spot at a given cometary latitude on the surface of the nucleus along the comet's orbit around the Sun. The nucleus is considered to be a porous sphere with an initially defined radius R and made of a mixture of ices and dust in specified proportions. The model solves the conservation of energy and conservation of mass equations via the finite volume method, in spherical coordinates and in one dimension along the radial axis. Errors in the mass conservation do not exceed 0.1% for the global error and 1% for the local error (at a given time t).

Our model outputs are compared with the ROSINA/DFMS data, which correspond to the bulk composition of the coma. We focus on H_2O, CO and CO_2, namely the three major species detected in the coma [1,7]. As the data were collected at different sub-spacecraft latitudes and distances from the nucleus, following the spacecraft orbit, we ran simulations for different latitudes explored by the spacecraft and extracted the results at the corresponding epochs. We performed numerical simulation for latitudes between 60°S to 60°N, with a 10 ± 2° increment. We used the characteristic properties of 67P as input of the model. The nucleus is considered as a mixture of dust and crystalline ice. The initial abundances of the three studied species were modified until we found the best combination to fit the measurements. The dust mantle thickness at the surface is a parameter that has also been varied.

2. Results

Our simulations match fairly well the CO/CO_2 ratio measured by ROSINA/DFMS at different epochs of the comet orbital evolution (Fig. 1). At epochs before perihelion (*i.e.*13th August 2015), the data are fitted with the same initial configuration, *i.e.* a CO/CO_2 abundance ratio of ~0.6 and a dust mantle of 5 mm (composed of silicates) corresponding to the top layer of the nucleus. This latter modifies the thermal inertia and the heat wave propagation. The initial conditions differ at epochs after perihelion. The fits are satisfied assuming i) an initial CO/CO_2 ratio of ~0.1 and ii) the absence of a dust mantle. Agreements of CO/H_2O and CO_2/H_2O ratios with those measured by the ROSINA/DFMS instrument are less striking than the previous ones (Fig. 1). The global trend is reproduced but the order of magnitude sometimes differs. This could be explained by the fact that H_2O outgassing present larger variation than CO and CO_2 over time and is sensitive to the complex topography of the nucleus, redistribution of dust containing H_2O ice and/or the presence of active areas at the surface of 67P [8,9].

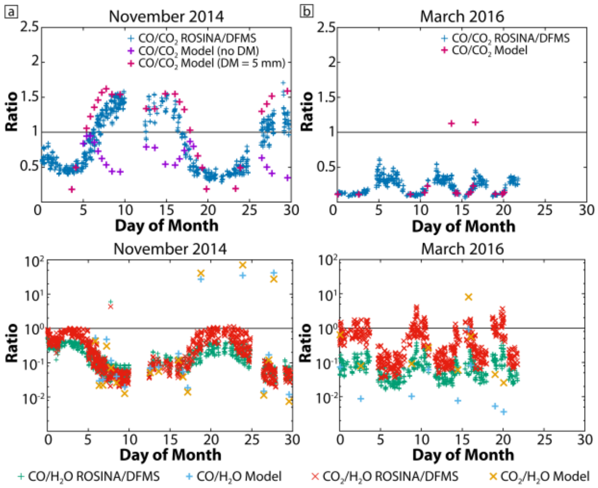

Figure 1: Comparison of the CO/CO_2 (top) and CO/H_2O and CO_2/H_2O (bottom) ratios computed by the model (pink, blue and orange crosses respectively) with the data measured by ROSINA/DFMS (blue, green and red crosses respectively) for (a) before perihelion (November 2014, initial molar abundance: 90% H_2O, 4% CO and 6% CO_2) and (b) after perihelion (March 2015, initial molar abundance: 90% H_2O, 1% CO and 9% CO_2). Results obtained with no initial dust mantle (DM) are also show in (a, top) (purple crosses).

3. Conclusion

Our study suggests that the nucleus volatiles composition is likely to be dominated by H_2O ice with a relative molar abundance ratio of CO/CO_2 ranging between 0.1 and 0.6. As we fit the data at different times and latitudes for a given composition for pre-perihelion data and another composition for post-perihelion data, 67P's nucleus is thought to be rather homogenous. Still, it results that a heterogeneous coma, as it has been observed for 67P by ROSINA/DFMS, does not necessary result from heterogeneous composition of the nucleus. Therefore the outgassing seems to be mainly insolation-driven leading to an internal structure defined by the sublimation front of each ice. Further investigations need to be performed to provide hints on the absolute H_2O abundance, the influence of the dust mantle and the dichotomy between the CO/CO_2 ratios needed to match the measurements before and after perihelion.

Acknowledgements

This project has received funding from the European Unions Horizon 2020 research and innovation programme under grant agreement No 686709 (MiARD project, www.miard.eu). This work was supported by the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract number 16.0008-2. The opinions expressed and arguments employed herein do not necessarily reflect the official view of the Swiss Government.

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