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SUBSURFACE CHARACTERIZATION OF 67P/CHURYUMOV-GERASIMENKO'S ABYDOS SITE

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Abstract. We investigate the subsurface structure of comet 67P/Churyumov-Gerasimenko at the landing site of Rosetta's descent module Philae. We use a cometary nucleus model with an optimized parametrization and assume an initial composition derived from Rosetta/ROSINA measurements. We compare the CO and CO_2 outgassing rates derived from our model with those measured *in situ* by the Ptolemy experiment aboard the Philae module on November 12, 2014. We find results that allow us to place two main constraints on the subsurface structure of this region: a low CO/CO_2 molar ratio is needed in the nucleus, and the dust/ice mass ratio is higher at Abydos than in the rest of the nucleus. These specific constraints on Abydos support the statement of an important heterogeneity in 67P/Churyumov-Gerasimenko's nucleus.

Keywords: comets: individual (67P/Churyumov-Gerasimenko), solid state: volatile, methods: numerical

1 Introduction

On November 12, 2014, Rosetta's descent module Philae landed on the Abydos site of comet 67P/Churyumov-Gerasimenko (67P). Among the instruments onboard Philae, the Ptolemy mass spectrometer performed the analysis of several samples collected from the surface and atmosphere of the comet (Morse et al. 2015), with the detection of H_2O, CO and CO_2 giving a value of 0.07 ± 0.04 for the CO/CO_2 molar ratio. This value is substantially different from the production rates measured in 67P's coma by the ROSINA double mass spectrometer aboard the Rosetta spacecraft. Thus we investigate the structure of the subsurface of the Abydos site. To do so, we employ a cometary nucleus model with an updated set of thermodynamic parameters relevant for 67P, assuming that the composition of the solid phase located beneath the landing site initially corresponds to the value in the coma. Thus, we selected the measurements performed by ROSINA on August 7, 2014 (the spacecraft's closest flyby date of the Abydos region), giving a CO/CO_2 molar ratio of 1.62 ± 1.34 (Hässig et al. 2015). The comparison of the production rates derived from our model with those measured by Ptolemy allows us to place important constraints on the structure (layering and composition) of the subsurface of Philae's landing site.

2 The cometary nucleus model

The one-dimensional cometary nucleus model used in this work is the one depicted in Marboeuf et al. (2012). This model considers an initially homogeneous sphere composed of a predefined porous mixture of ices and dust in specified proportions. It describes heat transmission, gas diffusion, sublimation/recondensation of volatiles within the nucleus, water ice phase transition, dust release, and dust mantle formation. Using a 3D geometric

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model developed by Jorda et al. (2014), we determine orbital parameters of comet 67P as well as we correctly reproduce the illumination conditions at Abydos (see Table 1). Porosity and dust/ice mass ratio in the cometary material have been chosen to match the value of the nucleus' density determined by Jorda et al. (2014) (510 ± 20 kg/m^3).

In addition to water ice and dust, the solid phase of our model includes CO and CO_2 whose abundances, inferred from the ROSINA observations of August 7, 2014, are $CO/H_2O = 0.13 \pm 0.07$ and $CO_2/H_2O = 0.08 \pm 0.05$ (Hässig et al. 2015). In this model, water ice is fully crystalline, making it impossible to trap volatile molecules. Thus, CO and CO_2 are crystallized in the pores of the matrix beside water ice.

Table 1. Modeling parameters for the nucleus

Parameter	Value	Reference
Rotation period (hr)	12.4	Mottola et al. (2014)
Obliquity (degree)	52.25	
Argument of subsolar meridian at perihelion (degree)	-111	
Co-latitude (degree)	-21	
Initial radius (km)	2.43	
Bolometric albedo (%)	1.5	Fornasier et al. (2015)
Dust/ice ratio	4 ± 2	Rotundi et al. (2014)
Porosity (%)	65 ± 15	Iida et al. (2010)
Density (kg/m^3)	510 ± 20	Jorda et al. (2014)
Thermal inertia (W K^{-1} m^{-2} s$^{1/2}$)	50	Leyrat et al. (2015)
CO/CO_2 initial ratio	1.62 ± 1.34	Hässig et al. (2015)

3 Thermal evolution of the subsurface at Abydos

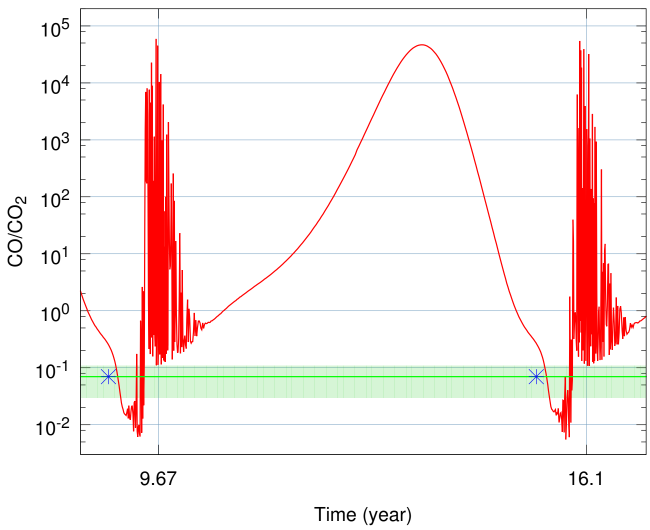

Fig. 1. Evolution of the CO/CO_2 outgassing ratio at Abydos during one orbit. The green line and area represent the Ptolemy central value and its range of uncertainty, respectively. The blue dots correspond to the measurement epoch (November 12, 2014). Vertical lines show the passages at perihelion.

Figure 1 represents the evolution of the CO/CO_2 ratio outgassing throughout the surface of the Abydos site as a function of the orbital evolution of 67P. This process is entirely following the sublimation of CO and CO_2 in the pores of nucleus material, leading to interfaces of sublimation of both species that reach deeper layers in the nucleus, until perihelion is reached and the ablation of the surface erases the progression of these interfaces. Thus, the outgassing rates of both molecules follow the same trend at Abydos during each orbit, irrespective of the considered period. Because the sublimation interface of CO_2 is closer to the surface, its production rate is more sensitive to illumination conditions than CO. The CO/CO_2 ratio thus varies over several orders of magnitude, depending on the comet's position on its orbit. Close to perihelion, this ratio crosses the range of values measured by Ptolemy (0.07 ± 0.04) and reaches a minimum.

A quantitative characterization of our simulation is made possible by measuring the delay taken by the CO/CO_2 ratio to match the value measured by Ptolemy on November 12, 2014 - using the actual measurement epoch as a reference. To improve the results of a simulation, we minimize this time difference by exploring the parameters' ranges of values. This study shows that two quantities have a strong influence on the time difference: the initial CO/CO_2 ratio in the nucleus, and the dust/ice mass ratio. With $CO/CO_2 = 0.46$ and a dust/ice ratio of 6 or higher (because of the suspected heterogeneity of 67P's nucleus), we are able to match Ptolemy's measurement epoch with about 50 days difference, corresponding to less than 2% of error on 67P's cometary year (6.44 terrestrial years).

4 Conclusion

Our model allows us to place constraints on the structure and composition of the comet's subsurface at Abydos: a low initial CO/CO_2 ratio is needed in the composition of the subsurface of Abydos to better match the measure performed by Ptolemy. The minimal value of the range measured by ROSINA in 67P's coma for this quantity is at least needed at Abydos to obtain results under 2% of error. Beside, the dust/ice mass ratio has to be taken in the upper values of the range determined by Rotundi et al. (2014) for 67P. Values even higher for the dust/ice ratio are desirable if we want to improve the time difference to match Ptolemy's data, supporting the hypothesis of a heterogeneous nucleus for 67P.

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