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Thermophysical Modelling of Cometary Activity

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1 Introduction

When comets approach the Sun their surface is heated and the volatiles start to sublimate. Due to the evolving gas pressure, dust is ejected from the surface which can be observed as cometary coma, dust tail and trail. However, the physical process of the dust ejection from cometary surfaces driven by the sublimation of volatiles is not understood in detail.

We have developed a full thermophysical model, based on physical concepts derived from theoretical works, laboratory experiments, and Rosetta observations that is able to explain the repetitive dust activity from comet 67P/Churyumov-Gerasimenko's southern hemisphere during perihelion.

2 Comet 67P at Perihelion

Due to its orientation, the southern hemisphere of comet 67/Churyumov-Gerasimenko experienced polar day during perihelion, which led to strong gas and dust emission, also including significant CO_2 outgassing.

Several instruments onboard the Rosetta spacecraft have provided very important measurements of the outgassing and dust ejection rates of comet 67/Churyumov-Gerasimenko during perihelion on 13th of August 2015:

1. H_2O outgassing rate: $250\,\mathrm{kg\,s^{-1}}$ (MIRO; [1]) - $600\,\mathrm{kg\,s^{-1}}$ (ROSINA; [2]).
2. CO_2 outgassing rate: $50\,\mathrm{kg\,s^{-1}}$ (VIRTIS; [3]) - $150\,\mathrm{kg\,s^{-1}}$ (ROSINA; [3]).
3. Integrated dust loss rate: $4400\,\mathrm{kg\,s^{-1}}$ (OSIRIS; [4]).
4. Mass and size of the ejected dust: most mass is lost in $\sim\ 1\,\mathrm{kg}$-sized chunks, which means that the chunks are $\sim\ 12\,\mathrm{cm}$ in size [4].

3 The Thermophysical Model

The thermophysical model solves the 1D-heat-transfer equation for different layers of the cometary surface with the Crank-Nicolson-Method (see Fig. 1). We included different thermal transport processes, gas diffusion and redistribution as well as latent heat of sublimation. The code derives the temperature stratification (see Fig. 2), tracks the ice content (H_2O and CO_2) in each layers, and derives the resulting pressures. These pressures are then compared with the tensile strength of the material. If the gas pressure exceeds the tensile strength, the overlying layers are ejected (see Fig. 3).

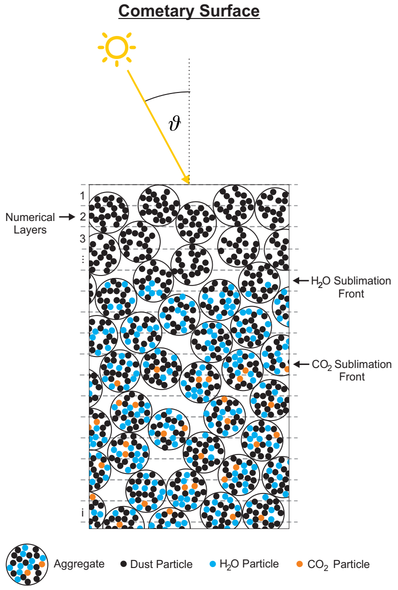

Figure 1: Sketch of the setting used to model the dust activity of comet 67P at perihelion. The surface consists of aggregates which themselves are composed of non-volatile (silicateous dust and organic materials), H_2O-ice, and CO_2-ice particles.

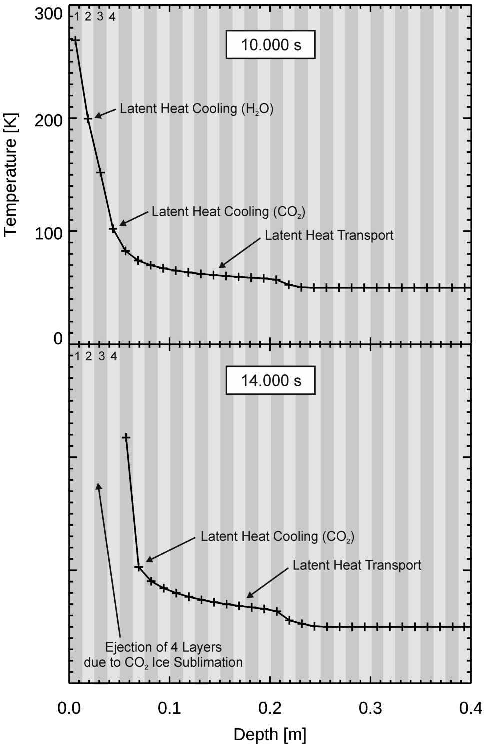

Figure 2: Typical temperature profiles before and after an ejection event. The grey bars are visualizing the numerical layers.

4 Results

The model provides dust, ice and gas loss rates [kg/s] which can be compared with the Rosetta measurements. We have tested different formation scenarios and found that the model is in very good agreement with the Rosetta data if we assume a pebble surface that is created when comets have formed by the gravitational instability scenario.

In this case, the model yields a pebble radius of $5\,\mathrm{mm}$, a dust-to-ice ratio of $5-7$, a tensile strength of $0.3\,\mathrm{Pa}$ and a $\mathrm{CO_2}$ content of $15-25\,\%$.

Furthermore, we found that the pressure build-up by $\mathrm{H_2O}$ ejects small, ice-free chunk, whereas the pressure build up by $\mathrm{CO_2}$ causes the ejection of larger, $\mathrm{H_2O}$ ice-containing chunks. The ice content is $\sim\,80\,\%$ of the initial value but this value also depends on the other input parameters (e.g., on the ice-to-dust ratio).

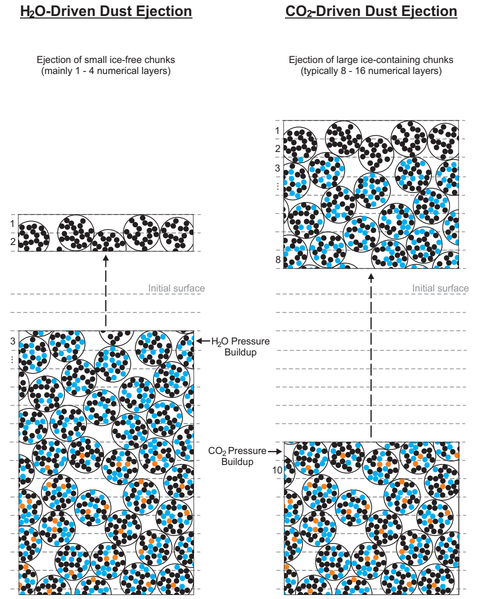

Figure 3: Graphical visualisation of the ejection events. If erosion occurs, the numerical layers above the pressure maximum are removed from the simulation. The pressure build up by $\mathrm{H_2O}$ (left panel) ejects small, ice-free chunk, whereas the pressure build up by $\mathrm{CO_2}$ (right panel) can cause the ejection of larger, $\mathrm{H_2O}$ ice-containing chunks.

Acknowledgements

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