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Sublimation of water ice with organic volatiles, comet 67P/Churyumov-Gerasimenko.

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Abstract

Evolution of the surfaces of cometary nuclei is determined by the sublimation of ice. The rate of sublimation is commonly calculated using the simple Hertz-Knudsen formula. It is inaccurate because it assumes equilibrium distribution of the velocities of molecules. The Hertz-Knudsen formula can be corrected by a temperature dependent sublimation coefficient α_s (e.g. [1, 2, 3]). It was found, that the sublimation coefficient of a frozen spring water is different than that of pure H_2O ice [3]. The cometary nuclei contain H_2O ice with admixtures [4, 5]. The temperature dependence of the sublimation coefficient may significantly affect evolution of cometary nuclei, including the sublimation driven erosion of the surface.

The temperature dependence of the sublimation coefficient of H_2O ice with admixtures, and its influence on the evolution of comet 67P/Churyumov-Gerasimenko will be presented.

1. Introduction

Investigations of comets indicate, that they contain many organics, also volatile, were detected [4, 5]. Laboratory investigations dealing with selected admixtures C_3H_6O (acetone), and CH_3OH (methanol) show that the sublimation coefficient is sensitive to very small concentrations of admixtures [6].

For investigation of comets it is important to know to what extent the temperature dependent sublimation coefficient affects the calculated sublimation rate of ice, ether exposed, or covered by a dust mantle. Performed were example simulations dealing with the recession of the surface in the region Hatmehit on the nucleus of comet 67P/Churyumov-Gerasimenko. The model is and extended version of these described in [7, 8].

Below are described the basic features of the model.

The model nucleus is layered. At the top is a layer composed of agglomerates of dust particles. The dust has thermal conductivity λ_{dm}, and the specific heat depending on the temperature. Beneath the dust mantle is a layer composed of agglomerates of crystalline H_2O ice and dust. In the interior of the nucleus H_2O ice is in amorphous form. The particles of H_2O ice are mantled by CO ice.

Boundary conditions are at the surface and at the largest considered depth i.e. at the bottom of the numerical grid. At the surface the temperature is determined by the energy balance taking into account among other variable illumination, which is calculated in 3D.

The thermal conductivity of the dust mantle is temperature dependent.

The ice-dust material strengthens due to the vapor diffusion from the surface source (Kelvin effect), and the volume diffusion form the boundary source.

Porosity of the ice-dust material evolves due to sublimation/condensation of vapor, as well as due to sintering of ice grains.

2. Results

Calculation of the sublimation rate using uncorrected Hertz-Knudsen equation is equivalent to the assumption $\alpha_s = 1$ at any temperature. Experiments indicate, that $\alpha_s(T > 235\ K) \sim 0.15$. This result is valid both for pure H_2O ice [1, 2, 3, 6], and for ice with acetone, or methanol [6]. At small temperatures the sublimation coefficient significantly depends on the presence of admixtures. When the admixture is acetone and the mass fraction $f = 0.005$ $\alpha_s(215K) \sim 0.46$ instead of ~ 0.18 for pure water ice; when $f = 0.01$ $\alpha_s(215K) \sim 0.74$; when $f = 0.02$ $\alpha_s(215K) \sim 0.78$ [6]. If we assume, that the classical approach $\alpha_s(T) = 1$ is acceptable when $\alpha_s(T) > 0.9$ the uncorrected Hertz-Knudsen equation can be used at: $T < 200$ K in the case of pure water ice, and $T < 210$ K, when ice contains acetone and its mass fraction is 0.01 [6].

The temperature dependent sublimation coefficient of H_2O ice with admixtures affects the energy balance at the interface between the dust mantle and the underlying ice-dust material. Decrease of the sublimation coefficient leads to an increase of the local temperature. This results in an enhancement of the heat flux conducted to the rich in CO interior of the nucleus, and in some enhancement of the emission of CO molecules.

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