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The sublimation coefficient of water ice: influence on the temperature and outgassing of Comet 67P/C-G.

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Abstract

In most published works dealing with evolution of cometary nuclei, the sublimation rate of ices is calculated with simple Hertz-Knudsen equation. This formulation, derived from the kinetic theory of gases, ignores microphysical processes which determine the sublimation rate. To correctly account for these processes the modified Herz-Knudsen equation must include temperature dependent sublimation coefficient. Including this temperature dependence we find, that the temperature below dust mantle is most sensitive to the value of the sublimation coefficient when the mantle is coarse grained, while the sublimation rate is most affected when the mantle is fine grained. Most importantly, we also find that derivation of the temperature below the dust mantle from the measured water production rate ignoring temperature dependence of the sublimation coefficient can lead to an underestimate of the sub-dust temperature by more than 10 K.

1. Introduction

Model calculations of cometary activity use usually a simple Hertz-Knudsen formula. This formula derived assuming an equilibrium distribution of molecular velocity, ignores all of the information about the microphysical processes determining the actual sublimation rate as well as the growth rate of the ice crystal. These processes need to be separately included in the sublimation coefficient. This problem was investigated by numerous researchers. Unfortunately, theoretical calculation of the sublimation coefficient is very computationally expensive and cannot be used in numerical models of long term evolution of cometary nuclei. For this reason [1] proposed an empirical formula for the temperature dependence of the sublimation coefficient. This formula was based on experimental data on sublimation of clean ice. More recently, based on long series of measurements of the emission of vapour from dust covered ice, [2] proposed new formula for the temperature dependence of sublimation coefficient. Both formulas are in good agreement at temperatures lower than 194 K, and higher than 227 K. In both cases experiments were performed using pure water ice.

Here we address the question in what way evolution of a cometary nucleus depends on the temperature dependent sublimation coefficient. We consider model nucleus having an orbit of Comet 67P/Churumov-Gerasimenko (67P/CG), target comet of the Rosetta mission. We calculate depth and time dependence of the structure and temperature and the outgassing rate for an area located at the equator.

2. Results

The performed numerical simulations show, that the calculated temperature below the dust mantle is sensitive to the value of the sublimation coefficient. The effect is strongest when the nucleus is very coarse grained, while the sublimation rate is most affected when the nucleus is very fine grained.

In Fig. 1 we show plots of the flux of emitted water molecules averaged over rotation period of the comet. This flux significantly depends on the sublimation coefficient for all considered granulations of the material. When $\alpha_s = 1$ the flux is at perihelion an order of magnitude higher than in the case of the $\alpha_s(T)$. The difference of fluxes is not correlated with a significant difference of the sub-dust temperature.

The surface temperature of the dust mantle covering a comet can be derived from the spectroscopic measurements. However, the temperature below the mantle cannot be determined this way. It can be derived from the observed sublimation flux. For this purpose one can invert equation describing the flux of molecules subliming beneath the dust and escaping to space

$$F_s = \alpha_s \frac{r_d(1-v_d)}{\Delta_d \tau^2}\left(\frac{32\mu}{9\pi R_g T}\right)^{0.5} b_1 exp(-b_2/T), \tag{1}$$

The inverted equation will be

$$T \sim \frac{-b_2}{ln(F_s) - ln\left(\frac{r_d(1-v_d)}{\tau^2\Delta_d}\left(\frac{32\mu}{9\pi R_g T}\right)^{0.5} b_1\alpha_s\right)}. \tag{2}$$

When λ_d = 100 mW m^{-1} K^{-1}, $r_d = 0.5$ μm the seasonal maximum of the sublimation flux F_s is 5×10^{-6} kg m^{-2} s^{-1} (α_s = 1), or 7 × 10^{-7} kg m^{-2} s^{-1} (α_s is temperature dependent). When the latter value is substituted to Eq. 2 together with α_s = 1 the resulting temperature is about 240 K instead of about 260 K.

When the temperature dependence of the sublimation coefficient is taken into account, the calculated diurnal amplitude of the temperature oscillations is smaller than in the typical approach, when the sublimation coefficient is equal to unity. Thus, neglecting of the temperature dependence of the sublimation coefficient should affect determination of the thermal inertia from the amplitude of the temperature oscillations.

Acknowledgements

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References

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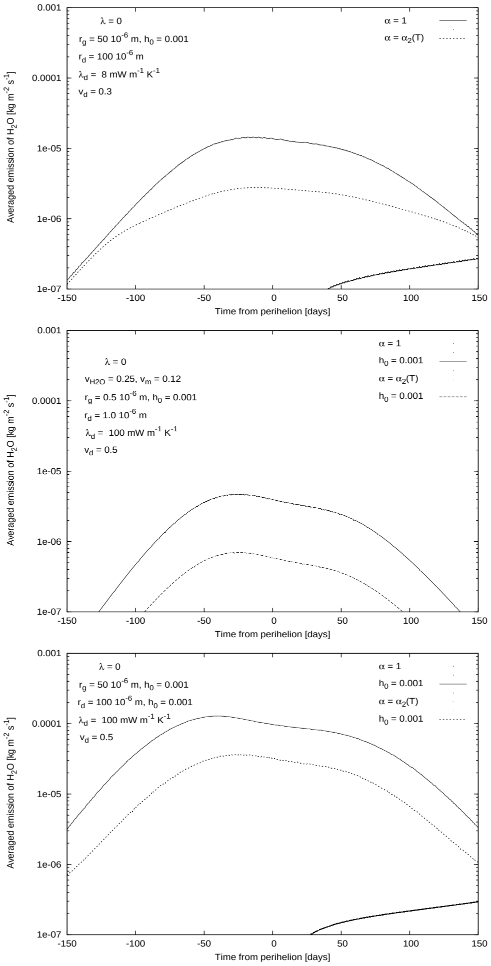

Figure 1: The flux of emitted water molecules averaged over rotation period of the comet.