EPSC Abstracts
Vol. 9, EPSC2014-600, 2014
European Planetary Science Congress 2014

Dust production from gentle surface of cometary nucleus: release and acceleration

Yu. Skorov (1), J. Blum (1), B. Gundlach (1), H.U. Keller (1), V. Reshetnyk (2)
(1) Institut für Geophysik und extraterrestrische Physik, University of Braunschweig, Germany
(2) Taras Shevchenko National University of Kyiv, Ukraine

1. Introduction

Always when we talk about comets, we are talking about their activity. Activity is what makes the comet special objects of our Solar system. Activity appears as the production of gases and dust. Gas production is qualitatively explained by sublimation of ices on or near the surface of a cometary nucleus. The physical processes and conditions that enable the persistent release of dust particles remain the unsolved problems in cometary physics. The enigma of dust release is deeply connected with the strength of cometary material. for the grain ejection the forces attaching the dust particles to the comet nucleus must be overcome by the lifting force caused by the sublimation process. The tensile strength of a homogeneous layer of micron-sized solid particles reaches kPascal. This exceeds by far the total sublimation pressure of cometary ices. This paradox was studied in [1]. Assuming that cometesimals formed by gravitational instability of a cloud of dust and ice aggregates in a gentle environment we presented a consistent model of the formation and removal of a porous dust layer on cometary nuclei, based on the evaluation of the tensile strength and on the energy transfer within an ice-free surface dust layer on top of pure water or carbon dioxide ice. Here we report on some extension of the surface layer model and on a new model of the acceleration of released dust aggregates within a non-equilibrium boundary Knudsen layer – the innermost coma, with a scale length of ~20 mean free paths of gas molecules. The second problem was also already studied in [2], but here an important model extension is presented.

2. Tensile strength and dust release

The complete model description can be found in [1]. The strength evaluation was obtained both from theoretical expectations and from laboratory experiments. The heat transfer model also utilizes results retrieved from laboratory experiments. The major new features of the model include: simulation of an ice-free layer formation (i.e. transient evolution of ice-dust porous mixture); thermal re-emission for an effective conductivity of the dust layer [3]; more realistic simulation of gas diffusion through the hierarchic porous layer.

We found that:

(1) The hierarchic structure of the dust aggregates dramatically reduces the tensile strength of the dust crust formed by such aggregates to a few pascals.

(2)A porous dust crust leads to an increase in the temperature at the iceinterface and, hence, to an increased gas pressure.

(3) It was shown that the gas pressure beneath the ice-free surface layer is a non-monotonic function of the dust layer thickness. For a given absorbed energy the amount of heat supplied to the ice interface decreases with increasing thickness of the layer. This leads to a reduction of the gas pressure. However, the permeability of this layer also decreases with increasing thickness of layer resulting in an increase in pressure.

(4) As a result, the formation and destruction sequence of the dust crust can be repetitive.

(5) The pressure of water ice generally is not sufficient to destroy the dust crust, whereas the pressure of carbon dioxide ice can exceed the tensile strength of the crust even for R> 1 AU.

3. Dust acceleration

Once the binding of the aggregate with the nucleus is destroyed, it falls into the expanding gas flow. Because the grain velocity is much smaller than the gas flow velocity, aggregates are rapidly accelerated due to collisions with molecules. Although the problem of the acceleration of dust particles has to be an integral part of any model of the coma, so far this problem has not received the required attention. In the general case, the problem can be divided into several blocks: (1) modeling of the gas flow, (2) modeling of grains (aggregates), (3) modeling of the interaction of the grain with the gas molecules, (4) modeling of the grain motion under the influence of acting forces (drag force, radiative pressure, nucleus gravity). After the pioneering work of Probstein [4] dozens of papers devoted to this problem have been published. However the theoretical models are usually based on oversimplified assumptions till now. Thus in most cases a motion of *solid spherical* grains by *a Maxwellian gas drag* is simulated, although both observations and modern theory clearly indicate that these model assumptions are not accurate or even wrong. The gas drag force is the dominant force acting on a cometary dust particle close to the nucleus. In general case the drag can be determined by local values of the macroscopic shear velocity and the gas density, the cross section to particle mass ratio and the so-called drag coefficient (see, e.g. [2]). The last parameter depends on a molecular velocity distribution function, particle shape and structure, its temperature and scattering law. In the presented model we take into consideration: (1) a non-equilibrium kinetic character of the rarefied gas flow, (2) a porous complex structure of the lifted dust particles, (3) an appropriate particle size distribution. At the first step we investigate the aerodynamic properties of dust grains (normalized cross section, i.e. the ratio of cross section over volume, and an effective drag coefficient). At the second step we investigate an acceleration of fluffy irregular grains embedded into a rarefied kinetically non-equilibrium gas flow. The available computer models of the boundary layer [2] and a new computational tool simulating the motion of an ensemble of polydisperse porous particles are used. In addition to the gas drag force the gravitational force as well as radiation pressure are included into the model.

4. Conclusions

We developed a thermophysical model for the cometary nucleus, which is based upon the assumption that comets form by gravitational instability of an ensemble of dust and ice aggregates. Under this condition, the tensile strength of the ice-free outer layers of a cometary nucleus was calculated, using the model [5]. Based on available laboratory data on the gas permeability and thermal conductivity of ice-free dust layers, we derived the temperature and pressure at the dust–ice interface. Comparison of the vapor pressure below the dust crust with its tensile strength allows the prediction of dust release from cometary surfaces. We found that pure H2O ice cannot explain the dust emission even at 1 AU, whereas CO2 ice can be major driver for heliocentric distances of $\leq$ 3 AU. Modeling the acceleration of the dust aggregates showed that with increasing porosity of the aggregates the dependence of the normalized cross-section on the aggregate mass is reduced. It means that fluffy big particles can be accelerated as efficiently as small ones. At the same time the free molecular drag coefficient of fluffy aggregates deviates only slightly from the value calculated for a corresponding spherical particle.

References

[1] Skorov, Yu., Blum, J. Dust release and tensile strength of the non-volatile layer of cometary nuclei. Icarus 221, 1–11.2012.

[2] Skorov, Yu., Rickman, H. Gas flow and dust acceleration in a cometary Knudsen layer. Planetary and Space Science, 47, 935-949, 1999.

[3] Gundlach, B., Blum, J. Outgassing of icy bodies in the solar system. Heat transport in dry, porous surface dust layers. Icarus 219, 618–629, 2012.

[4] Probstein R. The dusty gas dynamics of comet heads, in: Problems of Hydrodynamics and Continuum Mechanics, published by the Soc. Industr. Appi. Math., 1968.

[5] Weidling, R. et al. Free collisions in a microgravity many-particle experiment. I. Dust aggregate sticking at low velocities. Icarus 218, 688–700, 2012.