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Energy transfer into the surface layer of 67P/Churyumov-Gerasimenko: constraints on the thermophysical properties from MIRO observations.

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Abstract

The thermophysical properties of the surface layer of comets remain surprisingly difficult to assess. The near-absence of pure water ice on the surface implies an ice-free porous dust layer covering a more volatile-rich interior. This hypothesis presents conceptually significant difficulties. These include understanding how dust particles are released from the comet and how heat is transferred to the subsurface despite the measured (extremely) low thermal inertia.

Our model is designed to place constraints on the thermal, chemical, and structural properties of the surface layer and to establish mechanisms for mass (both volatile and non-volatile) loss as a consequence of these properties. We seek to establish and constrain models of these layers using multiple datasets from the MIRO instrument on board the Rosetta spacecraft.

1. Introduction

The Microwave Instrument for the Rosetta Orbiter (MIRO) performs observations of the nucleus of 67P/Churyumov-Gerasimenko in the millimeter-wave continuum starting from July 2014. The analysis of data obtained at wavelengths of 0.5mm and 1.6mm during August and September 2014 showed that the observed brightness temperatures strongly depend on the diurnal and the seasonal variations of solar illumination. The notable diurnal variations have been detected for the millimeter-wave channel that may be interpreted as the thermal emission from within the region of variable temperature. It means that thermal emission arises at depths of the same order of magnitude as the thermal skin depth. Gulkis et al. (2015) has shown that the observational data are quantitatively consistent with a very low thermal inertia values (~5-30 J K^{-1} m^{-2} $s^{-1/2}$). Such a low thermal inertia clearly shows that the surface region has a high porosity. The effective thermal conductivity of the non-volatile porous layer is a key term in the thermal inertia: only its variations can significantly affect the value of inertia. The resulting estimates suggest that the effective thermal conductivity of the medium is hundreds of times smaller than a typical bulk thermal conductivity. Thus, in addition to the high porosity one should assume that the cometary surface layer is composed of agglomerates which contain micron size particles. Both of these assumptions are supported by the results obtained in other experiments. Dust grains from about ten to several hundred micron in size have been detected and collected by GIADA [2] and COSIMA [3]. The dust grains appeared to be weakly bound, fluffy agglomerates with high porosity.

First qualitative analyses of the data and the first reasoned estimation of thermophysical properties of the uppermost region of the cometary nucleus were obtained using a simple thermal model. However, Schloerb et al (2015 submitted to A&A) noticed that these properties varied not only with the cometocentric position (which may indicate the nucleus inhomogeneity), but also with the depth. They found that the thermal inertia values best fitting the observations of the different channels differ considerably.

These results have motivated us to construct a more detail microscopic model describing energy transfer into the uppermost surface layer in order to get constraints on the thermophysical properties from MIRO observations.

2. Model

MIRO gives us brightness temperatures measured at two unknown depths. Even without detailed information about the dielectric properties of the medium we can get some information about the thermophysical properties of the surface layer. The general approach was presented in [5]. The skin depth of the heat wave is very small, resulting in a cometary surface layer which reacts extremely fast to changes in irradiance, so that activity becomes a strongly local property of a surface area. One can therefore expect that the observable effects reflect the distinctions in physical and chemical properties of the nucleus and its inherent heterogeneities.

Recently we suggested a new thermophysical model for cometary nuclei based upon the assumption that comets formed through gravitational instability of an ensemble of dust and ice aggregates [6]. Under this condition, the transport processes as well as the tensile strength of the ice-free outer dust layer were derived. We use available laboratory data of the gas permeability and the thermal conductivity of ice-free porous dust beds. Although this gives our approach a semi-empirical character, we believe that coupling the model to laboratory results puts it on a solid base and is a strong point of our model.

If the characteristic time scales for gas diffusion and heat conduction are smaller than the characteristic time of irradiation changes, the stationary approach to the energy transfer can be applied. In this case in order to evaluate the resulting gas flow and the resulting gas pressure above the sublimating layer one has only to consider energy balances on the top and on the bottom of the refractive porous layer [7]. Thus we get a system of nonlinear equations for temperatures on the surface and on the sublimating front. This system can be effectively solved for the most general case when an effective conductivity is a nonlinear function of temperature. Applying the balance equations for the energy flux at the boundaries of the dust layer one can obtain a similar system of equations for the case when the incoming energy is absorbed in the volume (a so called solid state greenhouse effect) and the thermal radiation is emitted from a non-isothermal porous layer.

A porous refractive layer greatly reduces the effective production for all regimes of gas diffusion (from Knudsen diffusion to a continuous flow). For the collisionless gas flow (Knudsen regime) we use an empirical experimental formula [6]. Three conductivity mechanisms are included into the model: conductivity through a solid medium, conductivity via the thermal emission, and conductivity via the gas diffusion. The detailed description of the model is presented in [7].

3. Conclusions

Based on computer simulations we evaluate the effective thermal inertia of a porous dust medium as a function of its microphysical characteristics. We demonstrate that sublimating ice works as an effective cooler, which decreases the media temperature above the sublimating region. Thus, adding ice to the model we change the general temperature distribution within the surface layer of comet. The ice existence can be recognized in the analysis of MIRO observations. Note that we don't assume that deeper MIRO measurements are related to an icy region, it is enough to assume that such an icy region exists close to the surface. We also accurately evaluate the gas diffusion through the porous dust crust and the effective sublimation rate.

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