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Comet simulation experiments – a simplified approach

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Abstract

Rosetta and other cometary missions have returned data that are interpreted based on predictions of theoretical models and the results of laboratory experiments (e.g. [1]). Our work supports Rosetta's observations by investigating the influence of insolation on the hardening process of the near-surface layers and the change in surface morphology. Our sample consists of pure, porous H_2O ice and carbon black particles. The final results of our experiments suggest that translucence of the near-surface ice is an important factor in the process of subsurface hardening. Our experiments also produced large, low-density dust aggregates from pure carbon particles on the sample surface.

1. Introduction

Our knowledge about the physical processes of comets is based on data from several space missions (most recently ROSETTA), the predictions of theoretical models and the results of laboratory experiments.
A number of comet simulation experiments performed in the past (e.g. KOSI [2]) have deepened our understanding of the physics that drives cometary activity and alters cometary nuclei. Although those experiments improved the understanding of the physics and morphology of cometary analogue materials, for most of them the set-up was quite complex and made it difficult to analyse the results in a quantitative manner.
In order to avoid these difficulties we decided to start a series of experiments using samples that only contain two components – H_2O ice and carbon particles (carbon black).

2. Experiments

To investigate the influence of subsurface solar light absorption by dust, we added varying quantities of carbon particles to samples of porous ice (0.02% to 0.5% per weight). The samples were irradiated for 18 hours, temperature and hardness profile were measured and the change of the surface structure was recorded.

All experiments were performed in the same way: a cylindrical container consisting of two Perspex halves fixed on a cooled base plate inside an environmental chamber was filled with the sample material. The sample with an initial height h_0 was cooled down to -100°C, while the chamber was de-pressurised. After the temperature gradient inside the sample had stabilised, the samples were irradiated using a solar simulator with an AM0 filter and the temperature profile inside the sample was measured. Additionally, a time lapse record of the morphology of the sample during the irradiation phase was obtained using a set of commercial off-the-shelf webcams.

2.1 Hardness measurements

To measure the hardness, the sample was cut in halves. The hardness profile along the vertical axis was measured using the method described by [3].
After the samples were cooled in a depressurized surrounding and irradiated each of the samples got significantly harder with a soft layer including the surface, a harder layer beneath and a softer one closer to the bottom of the sample. For samples with up to 0.2%−0.3% carbon the hardness of a subsurface layer at 3–6 cm depth increases. Samples with a higher carbon content than 0.3% show less increase in mechanical hardness.

2.2 Surface structure

The irradiation process has changed the surface significantly. During de-pressurisation a thin, homogeneous layer of carbon black accumulates on top of the sample, at that time the surface is darker than the original material. Figure 1 shows the sample surface at the beginning of the irradiation phase (left) and after 18 hours of irradiation (right).

Figure 1: Change of the surface structure after 18 hours of irradiation. Sample includes 0.5% carbon black. T_0=173K, h_0 = 15cm.

Significant changes of the sample surface can already be observed within the first few minutes of the irradiation phase. Carbon particles are emitted immediately after irradiation has started. Within the first minute this affects only small particles.

For the following few minutes, the sample surface brightens as patches of carbon particles are lifted. After some time (10 to 40 minutes, depending on the amount of carbon added) agglomerates can be seen to accrete. The more carbon black is added, the sooner the sample surface reaches maximum brightness.

Our experiments also produced large, low-density dust aggregates composed of pure carbon particles. These aggregates can reach heights of up to 5 mm if carbon content is as high as 0.5%.

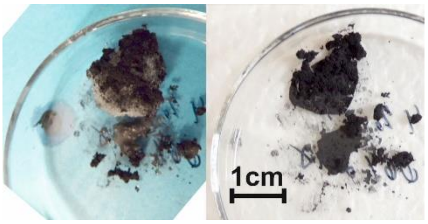

Figure 2: Images from agglomerates built up during an experiment with a 0.4% sample. Left: image taken after the agglomerate was taken of the surface. Right: same agglomerate after drying.

Samples of those surface agglomerates were collected after some of the experiments. Their structure showed remarkable mechanical strength: the carbon particles still stuck together and the agglomerates kept their shape when taken of the surface and allowed to dry (see Figure 2).

3. Summary and Conclusions

All samples were hardened considerably by exposure to solar light.

The samples reach a maximum hardness if the carbon content is 0.2% to 0.3%. No explicit hard layer can be identified if the carbon amount is higher or equal 0.4%.

The hardest layer can be found 3 - 7cm below the surface where the sample temperature is ~ 204K ±1.8K.

Particle emission starts immediately after the sample is exposed to insolation and conglomerates of carbon black built on the surface. The sample surface stays active until irradiation stops.

The evolution of the sample critically depends on where the solar energy is absorbed: at or below the surface.

We were able to produce a low-albedo dust mantle with active surface regions from an ice-dust mixture with an extremely low proportion of dust within a short period of time. This suggests caution when quantifying the bulk ratio of ice to refractory components of a real comet nucleus from remote observations alone.

The dramatic surface hardening by insolation combined with the drastic change in surface structure (even if only a marginal amount of carbon particles are added to the ice sample) suggests that cometary models should treat the nucleus surface as an interactive transitional zone to better represent cometary processes.

Acknowledgements

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