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Collecting cometary dust particles on metal blacks with the COSIMA instrument onboard ROSETTA

Klaus Hornung [a,*], Jochen Kissel [b], Henning Fischer [b], Eva Maria Mellado [a], Oleg Kulikov [a], Martin Hilchenbach [b], Harald Krüger [b], Cecile Engrand [c], Yves Langevin [d], Massimiliano Rossi [a], Franz R. Krueger [e]

[a] *Dept. of Aerospace Engineering, Universität der Bundeswehr München, Werner-Heisenberg-Weg 39, D-85577 Neubiberg, Germany*
[b] *Max Planck Institute for Solar System Research, Justus-von-Liebig-Weg 3, 37077 Göttingen, Germany*
[c] *Centre de Spectrométrie Nucléaire et de Spectrométrie de Masse-CSNSM Bat. 104, 91405 Orsay-Campus, France*
[d] *Institut d'Astrophysique Bat. 121, Faculté des Sciences d'Orsay, 91405 Orsay-Campus, France*
[e] *Messeler Strasse 24, D-64291 Darmstadt-Arheilgen, Germany*

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ABSTRACT

After a brief review of the instrument development and materials selection for collecting cometary dust in the vicinity of comet 67/P Churyumov–Gerasimenko we focus on laboratory verification for the capability of metal black targets to decelerate and capture dust particles (velocities in the order of 100 m/s; sizes of some 10 μm). The results indicate that particles between 10 and 100 μm size can be collected with high probability. Two basic mechanisms of energy dissipation upon impact could be identified: By internal friction within a highly structured dust and within the black's nanostructure. In addition to the actual ROSETTA mission the data presented here might have a more general relevance for future, similar in-situ investigations.

1. Introduction

Ever since the physical and chemical nature of the matter around us has been understood, it is the aim to analyse extraterrestrial materials. Some of these materials like meteorites and micro-meteorites are readily available on ground (e.g. van Ginneken et al., 2012) and have some similarities with cometary dust (e.g. Dobrica et al., 2009); some can be collected in the lower stratosphere (Rietmeijer, 2002) as well as in the upper stratosphere (Della Corte et al., 2012, 2013). The only way, however, to be sure of their parent bodies is to collect them in-situ, as STARDUST (e.g. Brownlee et al., 2006) and HAYABUSA did (Tsuchiyama et al., 2011). Comets and their debris are considered the most interesting objects for 2 main reasons: (1) they formed in the outer region of the solar system and for most of their life they remain far away from the sun, i.e. at low temperatures; (2) Their activities distribute the dust around their nuclei, which can be accessed without landing on them. While we have the most advanced laboratory instrumentation, quite a few compromises have to be accepted for in-situ analysers because of the high cost to get there. The relative speeds between a spacecraft and a comet are of the order of several km/s. For retrograde bodies it can range up to 100 km/s and more. At these speeds the collected sample to be returned to Earth is highly compromised. Slow flyby missions (only a few km/s) or rendezvous missions (delta $v \sim 0$) would be a much better solution to collect unprocessed grains, but much more expensive.

During the run to comet 1/P Halley when 6 spacecraft (ICE, VEGA 1, Susei, VEGA 2, Sakigake, and GIOTTO) got close to it, the composition of Halley's dust has been analysed in-situ for the first time. To the great surprise it turned out that those particles were an intimate mixture of mineral and organic material. The relative speeds have ranged from 68 km/s to 84 km/s, enough to ionize those dust particles upon impact onto a suitable target.

Even before GIOTTO went on its way in 1985, NASA had conceived plans for a rendezvous mission (CRAF). For the analysis of dust this called for another type of instrument, one which would have to produce ions from collected samples of dust by itself (Zscheeg et al., 1992). Among the many options a TOF-SIMS instrument seemed the best feasible solution. It was developed from 1988 onwards to achieve a mass resolution of 10,000 (M/dM, @50% peak), quite an improvement against the 150 for the Halley instruments, and accepted for the NASA-CRAF mission. Unfortunately the CRAF mission got canceled in 1992, and consequently

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* Corresponding author. Tel.: +49 8960042100; fax: +49 60043896.
E-mail address: Klaus.hornung@unibw.de (K. Hornung).

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the instrument development stopped, since there were no other missions on the horizon which would allow low speed dust collection.

Only when ROSETTA started as an ESA cornerstone mission in 1995, there was again a need for a dust analysis instrument. Lacking from laboratory support, COSIMA was designed from the CoMA files as a simplified instrument with a mass resolution of 2000. The dust collection system, however, became more versatile. Finally COSIMA made it on Board of the ROSETTA spacecraft, which was launched in March 2004. During commissioning it sent the first ever SIMS spectra from space. To use a time-of-flight mass spectrometer for secondary ions it is necessary to present the sample under test at the front of the spectrometer. The dust from a comet, however, is widely dispersed, and does not as such appear in the desired location. It is therefore mandatory to provide a collecting surface, which can hold the cometary particle in place, so it can be put in front of the spectrometer through a series of mechanical manipulations. For the original design of CoMA it was considered too risky to manipulate individual targets with the danger to lose one either into space or within the instrument. The targets were attached to a cylinder, which moved up and down while rotating on a fixed screw. This did in turn require a lot of time to get sample on a target to the spectrometer and did also limit what could be exposed for collection during an analysis. For COSIMA, a different solution was adopted (for details see Kissel and COSIMA Team, 2009): Targets with specially prepared surfaces are mounted in groups of three on a target holder. 24 of them are kept in a storage area, which is thermally controlled to stay cold throughout the mission, and are picked by a manipulator to be transported to any of 4 locations, (1) the exposure window, (2) the COSISCOPE position for optical analysis, (3) the analyse/clean position for ion beam exposure, and (4) the heating position, where the collected samples can be heated to some 120 °C. This gives a high degree of freedom for the instrument operation.

At the time of the development of the collection strategy, the dust was assumed to come in its majority from the comet radial direction with a deviation of some few degrees. A light baffle, also used as a 4 times concentrator, preclude sun's light entering in the instrument so to keep the temperature as low as possible and to prevent solar UV to modify the collected particles. The main difficulty was, however, to equip targets with a surface that would help the dust to stick to it, even when impacting at some 100 m/s. This is generally difficult since the process has to satisfy both conservation laws for momentum and for energy. For other instruments on CRAF, like e.g. SEMPA or CIDEX, one of us (JK) has made laboratory tests with 'sticky' materials (e.g. silicone grease), unpublished however. From our own experience with the time-of-flight mass-spectrometer CoMA for CRAF we did learn ex-post, that those materials will cover all surfaces by creeping or by sublimation and re-condensation. So all surfaces will be covered, given enough time, like 10 or more years. For COSIMA, however, the silicon in silicone grease would hamper the determination of minerals, while organic greases would interfere with the analysis of cometary organics. The solution was then to use layers of 'metal blacks' i.e. materials of very small grains ($\ll$ 100 nm) forming a very porous structure. Various noble metals were chosen to see whether chemical reactions could be provoked by heating.

Most of this paper deals with tests of the properties of the chosen 'metal blacks' target configurations.

Missions to distant celestial bodies have as a consequence that communications, limited by the speed of light, take more time than a simple operation in a laboratory. In addition there is not

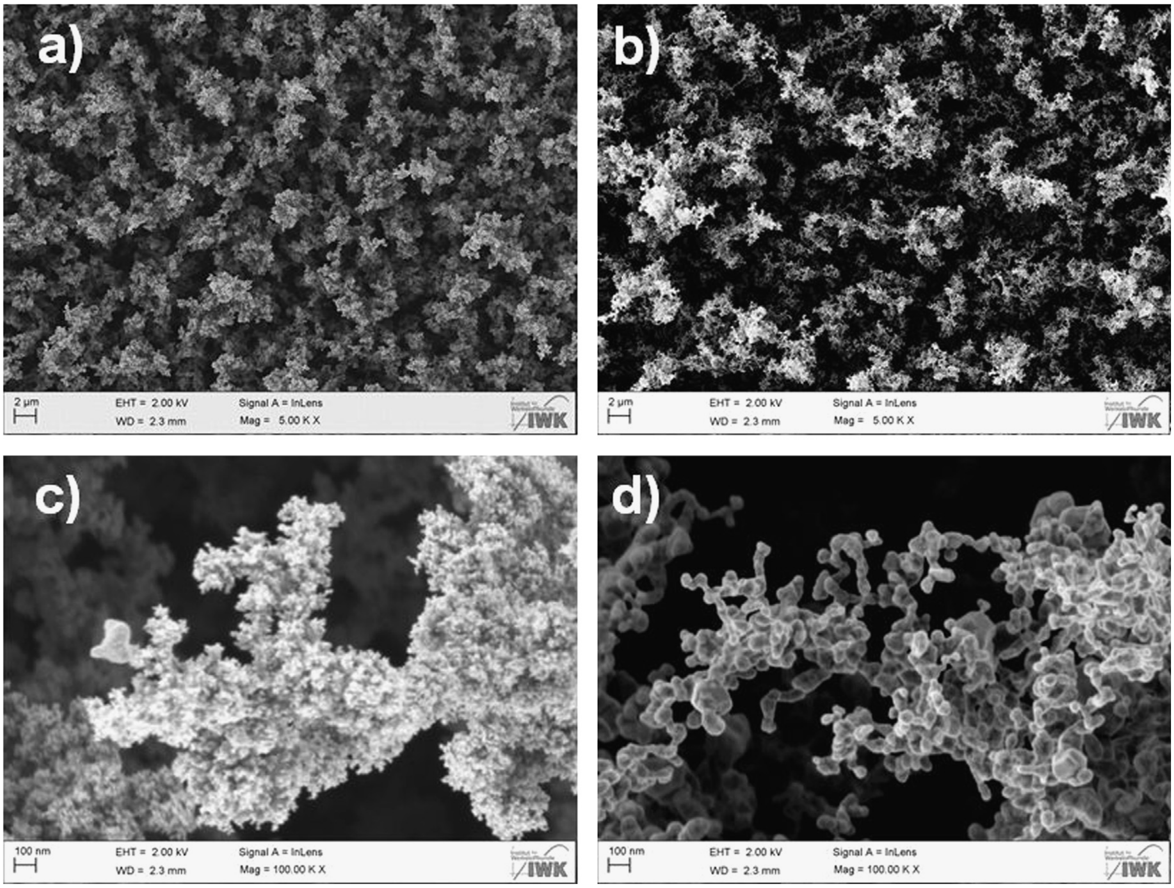

Fig. 1. Vapour deposited blacks: (a) Au, mag. 5000, (b) Ag, mag. 5000, (c) Au mag. 100,000, (d) Ag, mag. 100,000.