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Dust Impact Monitor (SESAME-DIM) on-board Rosetta/Philae: Aerogel as comet analog material

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ABSTRACT

On 12 November 2014, during the descent of the Rosetta lander Philae to the surface of comet 67P/Churyumov–Gerasimenko the Dust Impact Monitor (DIM) on board Philae recorded an impact of a cometary dust impact of a cometary dust particle at 2.4 km from the comet surface (5 km from the nucleus' barycentre). In this work, we report further experiments that support the identification of this particle. We use aerogel as a comet analog material to characterise the properties of this particle. Our experiments show that this particle has a radius of 0.9 mm, a low density of 0.25 g/cm^3 and a high porosity close to 90%. The particle likely moved at near 4 m/s with respect to the comet.

1. Introduction

The Dust Impact Monitor (DIM) was an instrument of SESAME (Surface Electric Sounding and Acoustic Monitoring Experiment, (Seidensticker et al., 2007)) on board the Rosetta Lander Philae. DIM consisted of a piezoelectric detector with the shape of a $\sim$7 cm side cube (Fig. 1) and a dedicated board within the SESAME electronics. DIM's goal was to measure the flux of millimetric dust particles that move close to the surface of comet 67P/Churyumov–Gerasimenko (ahead, simply 67P).

On 12 November 2014, Philae was separated from Rosetta. During the descent of Philae to the surface of comet 67P, the DIM instrument recorded only one actual impact -among many false signals- of one cometary grain on its Y-side when Philae was at 2.4 km from the comet surface or 5 km from the comet barycentre (Krüger et al., 2015; Hirn et al., 2016; Podolak et al., 2016). The detected dust particle produced an impact signal (we will call this the detection signal) with a voltage of 2.45 mV and a contact time equal to 61 μs (we will call these the detection signal values). From the many DIM calibration experiments that we had performed with different materials with a large range of mechanical properties (Flandes et al., 2013, 2014), we knew that a combination of a small voltage amplitude signal and a large contact time implies a very low density material. In particular, this conclusion was derived from experiments done with particles of aerogel.

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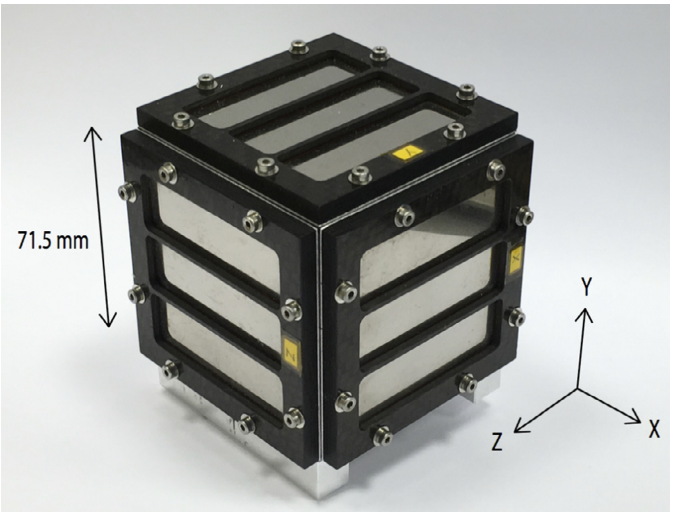

Fig. 1. The Dust Impact Monitor (DIM) sensor.

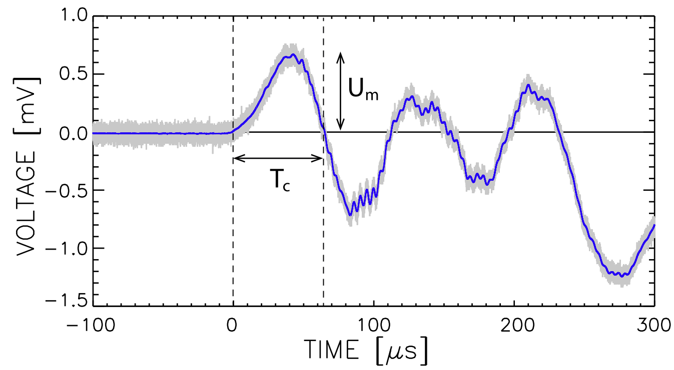

Fig. 2. Example of an actual signal generated by the impact of a *spherical* aerogel particle (radius of 1.5 mm) at ≈1 m/s on the Y side of the spare DIM sensor. The thin curve shows the smoothed signal and the gray curve shows the raw signal. In this case, $U_m = 0.68$ mV and $T_c = 63$ μs. The arrows are added to show how the voltage amplitude and contact time are derived.

A preliminary summary of these former experiments was given in the appendices B and C of Krüger et al. (2015). The current paper presents a complete and detailed description of these experiments.

Our work focuses on demonstrating that the signal recorded by DIM during descent corresponds to an actual comet dust particle with high porosity. One of our hypotheses is that aerogel is a material whose low bulk density and Young's modulus could be considered close to those of porous dust particles ejected from the comet and therefore we use it as a reference material for the analysis of the properties of the cometary dust particle that impacted the DIM sensor (Krüger et al., 2015).

In Section 2 we give some details of the theory behind DIM. In Section 3, we give some details about the type of signals we have obtained with DIM. In Section 4 we show an analysis of the aerogel used in our experiments. In Section 5, we describe our experiments in detail and in Section 6 we analyse and discuss our results in the context of the DIM detection.

2. Operation principles of DIM

The DIM cube has three of its faces covered with sets of three parallel piezoelectric plates (or PZTs) of equal size (50 mm × 16 mm). DIM has a total effective detection area of ≈70 cm^2. Each impact of a particle onto a PZT of DIM produces an electric signal from which its maximum voltage amplitude, U_m, and the duration of this peak or contact time, T_c (see Fig. 2) can be written as function of the radius, R, and the impact speed, v, of the particle, given its mechanical properties, like its density and its Young's modulus, by means of the Hertz impact theory (Seidensticker et al., 2007; Flandes et al., 2013). From this approach, U_m, and T_c are indirectly connected to the mass of the dust particle.

Let us take one of the sensor's PZTs as target and a given dust particle as projectile. Let the PZT have the following mechanical properties: Young's modulus E, Poisson ratio μ, piezo-electric constant d_{33} and capacitance C. We suppose that the particle is a sphere with radius R, density ρ, Young's modulus E_0 and Poisson ratio μ_0. When the particle impacts the sensor with a certain velocity v, it generates a damped quasi-sinusoidal pulse whose maximum peak amplitude, U_m, and the time this peak rises above the detection threshold that corresponds to the contact time interval, T_c, can be related to the particle properties through the following two equations:

$$T_c = 5.09 \left(\frac{R^5 \rho^2}{v E_r^2} \right)^{1/5} \tag{1}$$

and

$$U_m = \frac{3.03\, d_{33}\, E_r^{0.4}\, \rho^{0.6}\, R^2\, v^{1.2}}{C} \tag{2}$$

where E_r is the combined reduced modulus of the PZT sensor and the impinging particle (Flandes et al., 2013).

We highlight that only the amplified input voltage (or U_{out}) and T_c values are recorded by the DIM electronics. U_m needs to be derived from the U_{out} value using the known amplifier's transfer function (Krüger et al., 2015).

3. Signal analysis

In our introduction it was mentioned that the dust detection happened among many other signals that, in the end, were identified as false signals. False signals could be considered artefacts, probably caused by interferences or cross-talk occurring at the beginning of the execution in the measurement electronics (Krüger et al., 2015). These false signals fall into two groups. One group can be characterised by very short contact times ($T_c < 2.0\,\mu$s) and amplitudes in the range between 0.17 mV and 0.58 mV. The other group is concentrated at $T_c \approx 3.4\,\mu$s with an amplitude of 0.86 mV. Measurement data obtained with the DIM flight instrument on board Philae, as well as with the Ground Reference Model (GRM, which is a replica of the instruments and the electronics on board) during ground tests, showed that false signals appear at the very beginning of the execution of the measurements with typical rates between 30 s^{-1} and 110 s^{-1}. These signals cluster in similar ranges in the case of the flight instrument and the GRM data.

To some extent, the many calibration impact experiments that we had performed helped us with the discrimination of the different signals (Flandes et al., 2013, 2014). In our impact experiments we used spherical particles (with radius ≈1 mm) of several materials with a wide range of mechanical properties, mainly compact particles of steel ($\rho = 7.80$ g/cm^3), ruby ($\rho = 3.90$ g/cm^3), borosilicate glass ($\rho = 2.20$ g/cm^3) and water ice ($\rho = 0.92$ g/cm^3); and porous particles of low density polyethylene ($\rho = 0.92$ g/cm^3) (For details about these experiments, we refer the reader to Flandes et al., 2013, 2014). In the first place, these experiments demonstrated that the performance of the sensor closely matched the expected theoretical behaviour, that is shown in Figs. 3 (compact