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SUDA: A Dust Mass Spectrometer for Compositional Surface Mapping for a Mission to Europa

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Abstract

We developed a dust mass spectrometer to measure the composition of ballistic dust particles populating the thin exospheres that were detected around each of the Galilean moons. Since these grains are direct samples from the moons' icy surfaces, unique composition data will be obtained that will help to define and constrain the geological activities on and below the moons? surface. The proposed instrument will make a vital contribution to NASA's planned Europa Clipper mission and provide key answers to its main scientific questions about the surface composition, habitability, the icy crust, and exchange processes with the deeper interior of the Jovian icy moon Europa.

The SUrface Dust Aanalyser (SUDA) is a time-of-flight, reflectron-type impact mass spectrometer, optimised for a high mass resolution which only weakly depends on the impact location. The small size ($268 \times 250 \times 171$ mm^3), low mass (< 4 kg) and large sensitive area (220 cm^2) makes the instrument well suited for the challenging demands of the Europa Clipper mission. A full-size prototype SUDA instrument was built in order to demonstrate its performance through calibration experiments at the dust accelerator at NASA's IMPACT institute at Boulder, CO with a variety of cosmochemically relevant dust analogues. The effective mass resolution of m/Δm of 200-250 is achieved for mass range of interest m = 1-250.

1. Dust Exoclouds

The basic idea of compositional mapping [1, 6] is that moons without an atmosphere are ensgulfed in clouds of dust particles released from their surfaces by meteoroid bombardment. The ejecta cloud particles can be detected and their composition analyzed from orbit or during a spacecraft flyby. The ejecta pro-duction process is very efficient: a typical interplanetary 10^{-8} kg micrometeoroid impact on a Jovian moon produces a large number of ejecta particles whith a total mass on the order of a few thousand times of that of the impactor [2]. These ejecta particles move on ballistic trajectories and most of them re-collide with the satellite due to the lower initial speed. As a consequence, an almost isotropic dust exosphere is present around the moon [3, 7].

In 1999, the Galileo dust instrument measured the density profiles of the tenuous dust exospheres around the Galilean satellites Callisto, Ganymede, and Europa [4]. The cloud density decreases asymptotically with radial distance as $r^{-5/2}$, i.e. the cloud extent is only of a few moon radii. However, a spacecraft during a close flyby at Europa will detect a substantial number of ejecta particles. The initial speed of most ejecta particles is smaller than the escape velocity, which in turn is much smaller than the speed of an orbiting spacecraft. The ejecta particles thus hit the dust detector with the velocity of the spacecraft and arrive from the apex direction. The dynamic properties of the particles forming the ejecta cloud are unique and can be clearly distinguished from any other kind of cosmic dust likely to be detected in the vicinity of the satellite.

2. Instrument description

The SUrface Dust Analyser (SUDA) is a reflectron-type, time-of-flight impact mass spectrometer, which has heritage from the Cassini CDA and the Stardust CIDA instruments. The main challenge for the design of a dust mass spectro-meter is to achieve simultaneously a high mass resolution, a sufficiently large sensitive area, and a compact design. The plasma ions produced by the hypervelocity impact may have a broad energy distributions of up to 100 eV, which limits the mass resolution of linear TOF dust spectrometer of reasonable size to about m/Δm = 50. The effect of

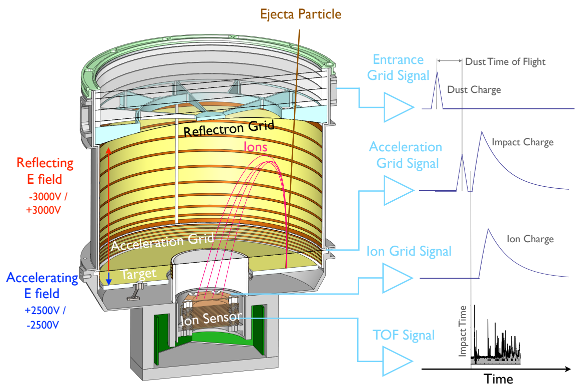

Figure 1: Function principle of the SUDA impact mass spectrometer.

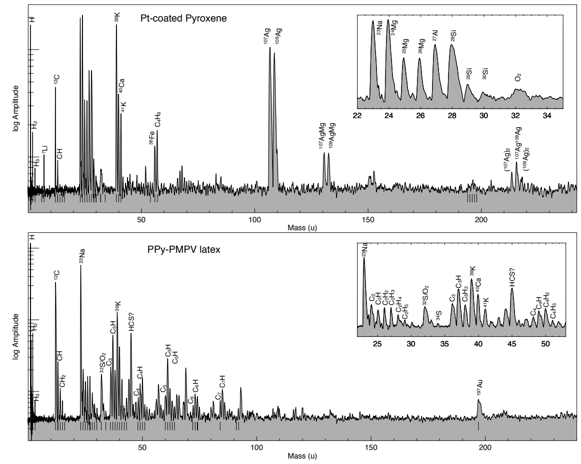

Figure 2: Example spectra of a pyroxene particle impact on a silver target and of a latex particle on a gold target recorded with SUDA.

the initial energy spread on the mass resolution is significantly reduced by employing a so-called reflectron acting as an electrostatic mirror [5]. The ion optics of large area reflectron mass spectrometers can be designed using optimization methods to ensure simultaneously the good spatial and time focus-ing of ions. The combination of a plane target, a set of ring electrodes and an hemispherical reflectron grid yields a good performance instruments (Fig. 1). The instrument size is $268 \times 250 \times 171$ mm^3 and the weight of 5 kg. Dust particles enter the aperture and fly through a set of shielding grids and reflectron grid before impacting on the planar, ring shaped target (Fig. 1). Even a relatively slow dust impact of typically 1.6 km/s generates a sufficient amount amount of atomic and molecular ions for the in-situ mass analysis of the grain?s material. A strong electric field generated by the 2.5 kV bias potential on the target accelerates the ions toward the ions detector, where they are detected in a time-of-flight fashion focusing by the reflectron. The acquisiton of the mass spectra is triggered by the impact generated charge pulse detected by the charge sensitive electronics connected to the target. The retarding field of the reflectron was optimized to achieve the best spatial and time focusing at the ion detector area in the center of the instrument.

3. Instrument Performance

SUDA was tested using the IMPACT 3 MV dust accelerator to simulate hyper-velocity impacts of cosmic dust particles. We performed calibration experiments with powders of orthopyroxene and latex particles. This choice of test particles covers a broad variety of materials representive for cosmic dust grains of planetary, interplanetary, and interstellar origin. The vast majority of the dust impacts were slower than 4 km/s, which is similar to the typical ejecta impact speeds onto a detector during the Europa Clipper flybys at Europa. Fig. 2 shows two typical examples of SUDA impact spectra.

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