LABORATORY TESTS OF THE LARGE AREA MASS ANALYSER

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ABSTRACT

The Large Area Mass Analyser (*LAMA*) discussed in this paper was developed by the Max Planck Institute Nuclear Physics in Heidelberg. This spectrometer is designed to perform elemental analysis of interplanetary dust, interstellar dust or space debris particles in the Earth environment. The instrument consists of a target with a sensitive area of 0.1 m^2 and performs time-of-flight measurements of the impact plasma ions from hypervelocity dust impacts. The device employs a reflectron for the improvement of the mass resolution which has values between 150 and 300. The mass resolution of this spectrometer is better than of any other known instrument with a comparatively large sensitive area. Here we report about the first laboratory tests at the Heidelberg dust accelerator facility using iron particles with speeds up to 35 $\mathrm{km\,s}^{-1}$.

1. INTRODUCTION

Recently, the research field of *Dust Astronomy* was established in order to investigate the properties of interplanetary and interstellar dust [6]. It was shown that we need to learn more about the mass distribution [7] and elemental composition of particles [9, 10] Appropriate techniques were developed in order to address the key questions of *Dust Astronomy* [5] and space missions were proposed which carry a set of dust instrumentation [17, 16]. The payload for a *Dust Astronomy* mission such as DUNE is a dust telescope, which is capable of determining the speed, mass, primary charge, trajectory and elemental composition of individual particles, to high accuracy [13, 15, 16]. An important subsystem of a dust telescope is *LAMA*.

Low fluxes of interstellar and interplanetary dust require a large sensitive area (>0.1 m^2) together with a high mass resolution of the spectrometer ($\frac{m}{\Delta m} > 100$). The time-of-flight spectrometer *LAMA* is based upon impact ionisation and a SIMION 3D study was performed in order to find a geometry and electric field configuration which focuses the ions in space and time onto the ion detector (Fig. 1).

The impact detector consists of a flat annular shaped impact target at +5 kV potential and a grounded acceleration grid mounted 50 mm in front of the target. Potential rings provide a smooth electric field close to the edges. The acceleration distance of 50 mm is several times bigger than the 3 mm for Cassini CDA [14] or the 10 mm of CIDA onboard Stardust [3]. Thereby, the effect of shielding within the impact plasma cloud is reduced since the ion cloud is allowed to expand into a much greater volume before acceleration becomes effective.

A dust impact onto the target generates impact plasma, neutral ions, and ejecta fragments. The ions of the impact plasma are immediately accelerated by the voltage of 5000 volts. The ions pass a field free region and enter the ion reflector which focuses the ion beam onto the central ion detector (Burle two stage multichannel plate with a diameter of 8 cm.). The results shown in this paper refer to the design option *LAMA2*, which has a field free region of 170 mm between the acceleration grid and the reflectron in order to incorporate a trajectory sensor [13].

2. LABORATORY TESTS AND RESULTS

Iron dust particles were used to achieve time-of-flight mass spectra with *LAMA* at the Heidelberg dust accelerator. More than 100 spectra were recorded with a particle speed range between 10 and 30 km s^{-1} and with sizes between 0.1 and 0.5 μm. The targets were a thin silver or gold foil attached to the target plate. The first tests in May 2005 were performed with an uncleaned silver foil purchased from Goodfellow. Later tests used silver foils coated with silver or gold black material which were pro-

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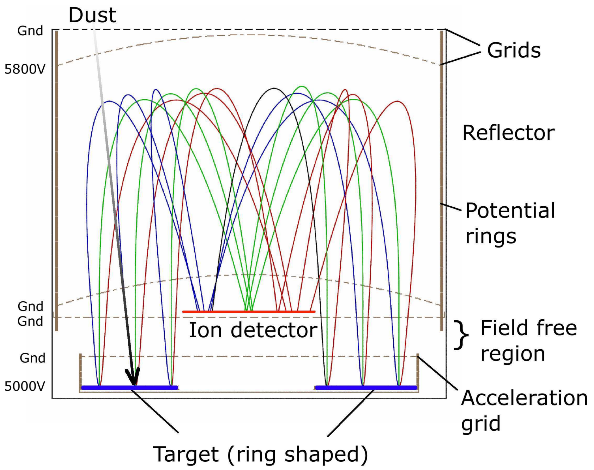

Figure 1. Schematics of *LAMA* and ion trajectories simulated by the software package SIMION 3D. The initial kinetic energy of the ions was 50 eV.

vided by G. Hornung. Black materials are loosely packed aggregates of nanometre sized metal grains, sticking together by adhesion forces [8]. The black materials with a thickness between 10 and 20 μm were freshly coated and were kept clean before the impact tests.

Both, negative and positive ions were recorded upon the dust impact. For the measurement of negative ions, the target and reflector voltages were reverted. Fig. 2 shows the time-of-flight spectra using an uncleaned silver foil. The dominant peak masses (in dalton) of a typical positive spectrum are 1 (H^+), 12 (C^+), 23 (Na^+), 39 (K^+), 56 (Fe^+), 107 (Ag^+) and 109 (Ag^+).

The bottom plot in Fig. 2 shows a negative mass spectrum of a 140 nm iron grain with a speed of 31 km s^{-1}. Negative spectra are easily identified by the strong leading electron peak. The overall yield of negative spectra is lower than for positive spectra. Furthermore, sodium and potassium lines are absent, and the yield of silver is significantly lower than in the positive spectra. The projectile material iron could not be identified. Abundant lines were identified at the masses 1 (H^-), 12 (C^-), 16 (O^-), 24 (C_2^-), 25 (C_2H), 26 (CN^-, $C_2H_2^-$), 35 (Cl^-), 36 (C_3^-), 48 (C_4^-), 49 (C_4H^-), 107 (Ag^-) and 109 (Ag^-). In contrast, positive spectra of the silver black target shown in Fig. 3 and Fig. 4 reveal a strong hydrogen, iron and silver double peak. Sodium and potassium lines (contaminations) are almost not visible. The negative spectrum shows more lines and is similar to the spectrum of the uncleaned silver surface.
Spectra using a gold black target are shown in Fig. 5 and Fig. 6. The results confirmed the excellent instrument performance and provided sharp mass lines. The positive spectrum shows a clear dominance of the target (gold, 197 amu) and projectile (iron, 56 amu) ions. The negative spectra shows strong lines at the masses 24, 25 and 26 amu which were well resolved.

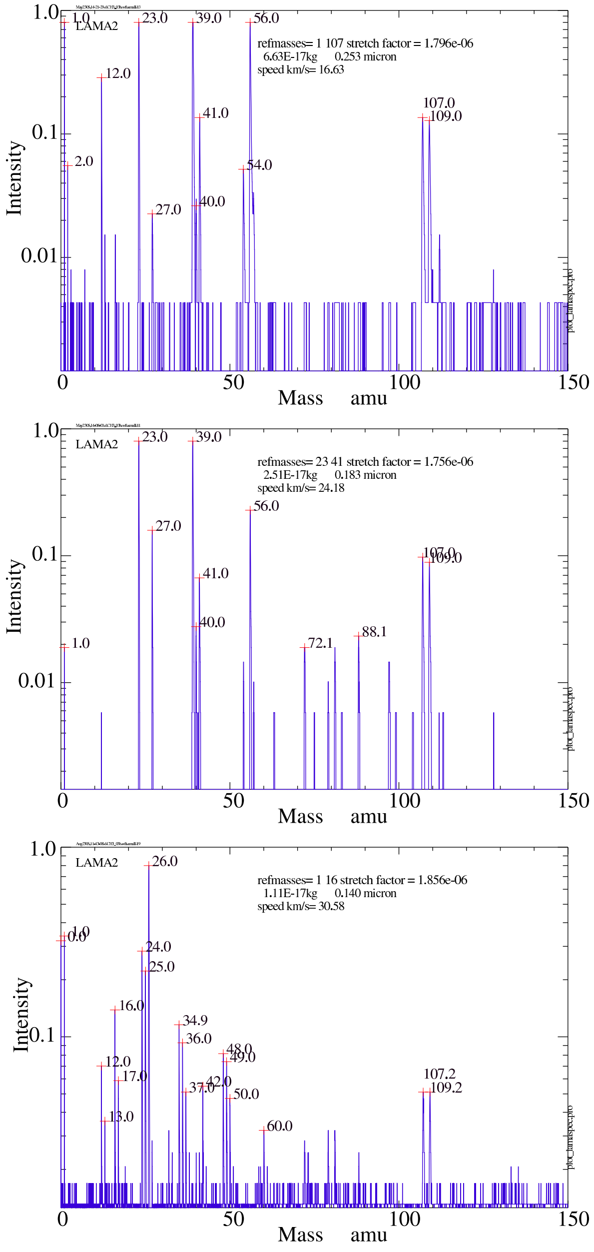

Figure 2. Mass spectra of iron particle impacts onto silver measured with the *LAMA* laboratory model. The silver target foil contains many contaminations due to a limited cleaning procedure. The mass resolution is higher than 100, the two silver isotopes at mass 107 and 109 are clearly separated. The upper two spectra show positive ions species, whereas the bottom plot shows a spectrum of the negative electrons and ions.

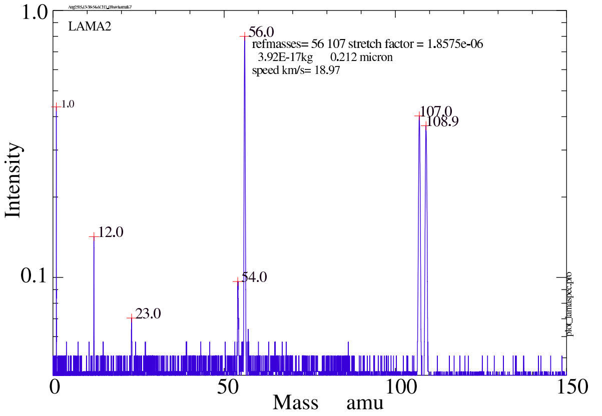

Figure 3. Mass spectra of iron particle impacts onto a silver black target (positive ions).

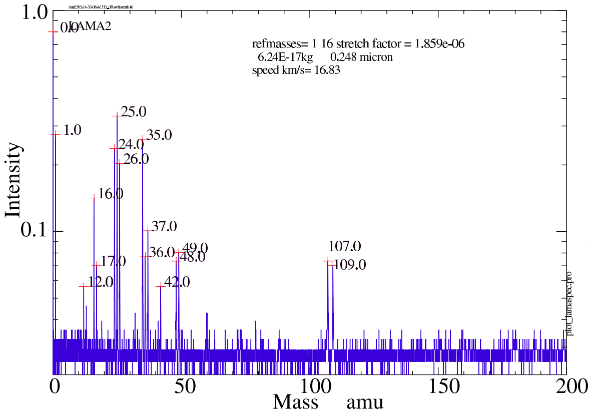

Figure 4. Mass spectra of iron particle impacts onto a silver black target (negative ions).

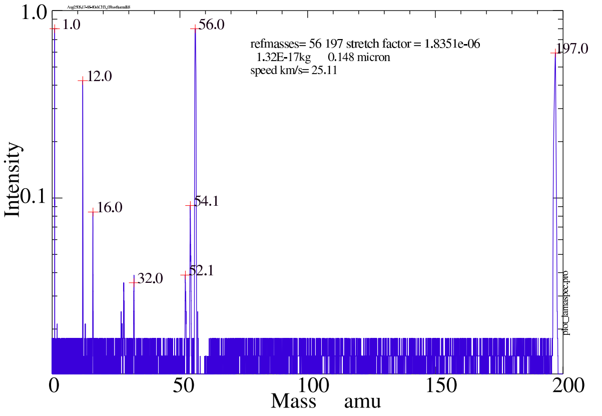

Figure 5. Mass spectra of iron particles onto a gold black target (positive ions).

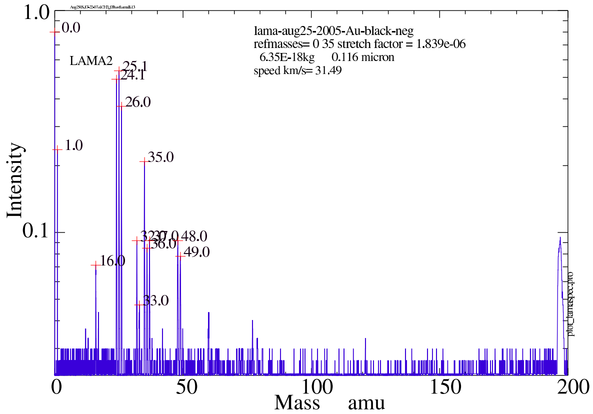

Figure 6. Mass spectra of iron particles onto a gold black target (negative ions).

3. DISCUSSION

High-resolution dust mass analysers that provide elemental composition of dust particles have been flown on the Halley missions [2] and are currently flying on the Stardust mission [3, 4]. Excellent results have been achieved and were published recently in [4] and [1]. However, the mass resolution of these instruments has been low or moderate and their sensitive area has been below than 120 cm^2 (compare Tab. 1).

Table 1. Mass resolution $\frac{m}{\Delta m}$ *of impact ionisation time-of-flight spectrometers. The mass resolution of a mass spectrometer is calculated by the ion mass* m *divided by the corresponding line width* Δm*.*

Mission	Area (cm^2)	$\frac{m}{\Delta m}$	Type
Helios	120	5-20	1m linear drift tube
Cassini	100	20-50	0.2 m linear drift tube
Giotto, VeGa	5	100	1 m reflectron
Stardust	90	100	1 m reflectron
LAMA	1000	>120	1 m reflectron

Here, we present TOF measurements of hypervelocity dust impacts using a spectrometer with a sensitive area of 0.1 m^2 and a mass resolution of 150 or above. Fig. 7 shows the mass resolution $\frac{m}{\Delta m}$ of *LAMA* at a given ion mass m and a peak width Δm at Full Width Half Maximum (FWHM). The ion flight time t is related to m by $t = a \cdot \sqrt{m}$ where a is a constant stretching factor of approximately 1.83×10^{-6} (a is dependent on the spectrometer properties). This spectrometer compensates for the variety of initial ion energies and ion emission angles within the impact plasma. Simulations using the SIMION 3D software package predicted mass resolutions higher than 120 (at m=100 amu) for all target impact locations, ion energies up to 50 eV and emission angles between

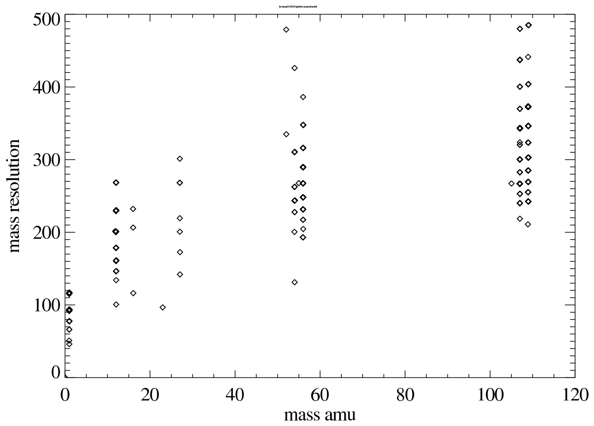

Figure 7. Mass resolution (FWHM) of *LAMA*. Iron particles were shot onto a silver black target and the positive ion peaks were analysed. The mass resolution is high enough to separate the two silver isotopes at 107 amu and 109 amu.

−90° and 90° [11] and [12]. These predictions were confirmed or even exceeded by the laboratory measurements described in this paper.
With the laboratory tests of *LAMA* the technology concept for in-situ measurements of hypervelocity dust impacts on low Earth orbit or interplanetary missions was proven. The large sensitive area of *LAMA* provides the possibility to study, with extremely high resolution, the composition of dusty phenomena like the jovian or saturnian dust streams or the interstellar dust flux in the inner planetary system.

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