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A linear TOF mass spectrometer as a tool for the investigation of impact ionisation plasma

A. Mocker (1,2), E. Grün (2, 3), J. K. Hillier (4) , K. Hornung (5), T. Johnson (6), S. Kempf (3), and R. Srama (1, 2)
(1) Institut für Raumfahrtsysteme, Universität Stuttgart, Germany (2) Max-Planck-Institut für Kernphysik, Heidelberg, Germany (3) LASP, University of Colorado, 1234 Innovation Drive, Boulder, CO 80303, USA (4) Universität Heidelberg, Germany (5) Universität der Bundeswehr Neubiberg, München, Germany (6) Dept. of Aeronautics and Astronautics, Stanford University, USA
(mocker@irs.uni-stuttgart.de / Fax: +49 6221 516 660)

Abstract

The generation of charge during impacts provides one of the most sensitive methods for the detection and characterisation of dust particles in space. Linear TOF mass spectrometry offers an opportunity for investigating the thermodynamical properties, e.g. the velocity distribution, of the ions within an impact plasma. Furthermore, the dependence of the plasma properties on the impact parameters were studied at the Heidelberg dust accelerator laboratory. The results imply that the defining parameter of the impact process is either the impact velocity or the energy density.

1. Introduction

Impact physics plays an important role in a variety of field such as investigation of matter at extreme pressures and temperature, shock waves in solid bodies or even solar system research, planetology and cosmic dust research. Impact ionisation is a key part of impact physics, playing an increasingly important role at small scales, i.e. for the impact of micrometer sized dust particles impacting at velocities of some km/s. To relate the dynamical parameters (e.g. mass and velocity) of individual particle impacts with the properties of the resulting plasma, a comprehensive programme of impact experiments under well known experimental conditions for a wide variety of impact parameters is needed. This process involves accelerating dust particles to hypervelocity speeds in the laboratory and the investigation of the resulting plasma with suitable instruments.

The characteristics of the emerging plasma, such as the velocity distribution of the ions, and the ion appearance in the mass spectra can be analysed with a linear TOF mass spectrometer. This provides an opportunity for investigating the thermodynamical properties of the impact plasma leading to a deeper understanding of the process of impact ionisation and the behaviour of matter under extreme conditions.

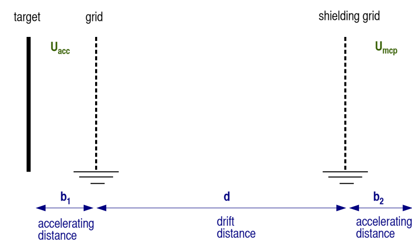

Figure 1: Scheme of the linear BERTA time-of-flight mass spectrometer [2].

2. Experimental Set up

The plasma generated by the hypervelocity impact of a particle is separated by an electrostatic field in its negative and positive components. In the case of a positive acceleration field positive ions are accelerated towards an ion detector and generate a TOF mass spectrum.

For a linear TOF mass spectrometer, the velocity and angular distribution of the ions translate in the broadening of the lines [1]. The shape of a peak is determined by both distributions, complicating the investigation of the underlying processes leading to the form of the line.

To study the the distribution of the ion velocities in direction of the spectrometer axis, the BERTA mass spectrometer (Fig. 1) was designed to filter out the angle distribution of the moving ions. This is obtained by the geometrical set up. The length of the ions' flight path ($0.657\,\mathrm{m}$) and the diameter of the MCP ($\varnothing = 40\,\mathrm{mm}$) lead to an aperture angle of $1.74°$, translating into a space angle $d\Omega \approx 2.90 \cdot 10^{-3}\,\mathrm{sr}$.

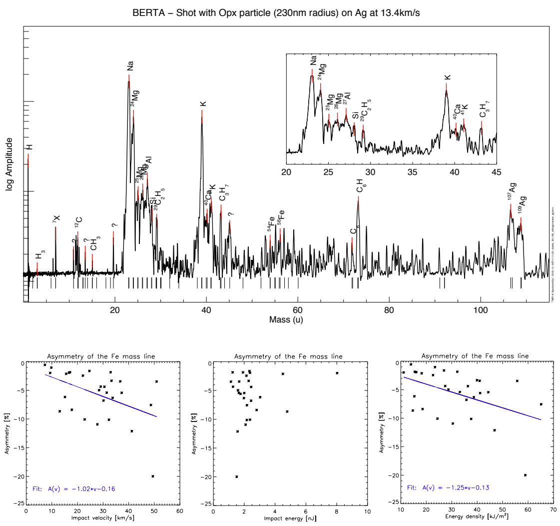

Figure 2: *(above)* A TOF mass spectrum recorded after an impact of a *Opx* particle with 230 nm radius at an impact velocity of 13.4 km s^{-1}. *(bottom)* Asymmetry of the iron line in dependence on the impact velocity, the kinetic energy and the energy density of impacting iron particles.

3. Results

Peak Shapes and Line Widths

The mass lines are highly asymmetric, with a strong preference for fast ions. Due to the unknown spectrometer response function and the unknown distribution ion velocities without further information it impossible to determine whether the observed line shape corresponds to an equilibrium distribution of ion velocities.

The widths of the lines for most of the investigated species show a dependence on the impact velocity and the impact energy density, but no dependence on the impact energy. An exception is the line width of the contamination ions, sodium and potassium, which showed no dependence on any of the impact parameters. Due to the the bias in the accelerated particles' velocities and masses introduced by the functional principle of the dust accelerator, the question, which parameter dominates, could not be answered. Further investigations over a wider range of kinetic energies of the particles are necessary in the future.

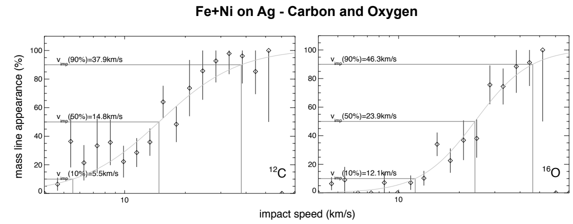

Figure 3: Mass line frequencies for the mass lines of ^{12}C and ^{16}O for *Fe+Ni* particle impacts onto silver in dependence on the impact speed. The data points are be fitted with a Fermi distribution. The error bars represent the Poisson distribution of the measurement and depends therefore on the number of data points obtained in a specific range of the impact parameter in question.

Velocity thresholds for the appearance of ion lines

Using TOF mass spectroscopy to determine the chemical composition of an impacting particle, means to evaluate the ion populations contained in the hot, expanding and evolving vapour plume. Ion formation in a hot, initially dense and expanding plasma is not least affected by the conditions within the cloud [3, 4]. This has of course to be taken into account when it comes to the interpretation of TOF mass spectra. This relation can be used to gain insights and a deeper understanding of the processes in question. The abundance of lines in the spectra and their relative intensities reflect the conditions in the plasma plume and depend on the parameters determining these conditions [5]. Again, the abundance of particular lines is dependent on the impact velocity of the dust particle (Fig. 3). The results of this investigation prove that an in-depth investigation of the speed-dependent line appearance is one of the most promising approaches to develop a more accurate method for determining the impact speed than the rise time method.

References

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