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Applicability of laser ionisation for the test and calibration of in-situ dust instruments

A. Mocker (1,2), Z. Sternovsky (3), E. Grün (2, 3), S. Kempf (3), and R. Srama (1, 2)
(1) Institut für Raumfahrtsysteme, Universiät Stuttgart, Germany (2) Max-Planck-Institut für Kernphysik, Heidelberg, Germany (3) LASP, University of Colorado
(mocker@irs.uni-stuttgart.de / Fax: +49 6221 516 660)

Abstract

In situ measurements, the direct interception and analysis of dust particles by spacecraft-based instrumentation, allows us to gain insights into the dynamical, physical and chemical properties of solar system dust. The methods yielding the highest sensitivity for detection of dust particles in space, rely on impact ionisation. To cover a sufficiently big energy range for the investigation of dust particle impacts and the calibration of impact ionisation instruments, we attempted to complement the particle impact experiments with laser ionisation. Therefore it was necessary to investigate the properties of both processes with respect to their comparability. The findings of this study show that, in general, laser ionisation plasma is not comparable to that generated by hypervelocity particle impacts. However, particular aspects of the the laser ionisation process can be used as a rough substitute for particle impacts, i.e. optimising and testing electronic components for impact ionisation instruments.

1. Introduction

Soon after their introduction in 1962 [1], high-powered pulsed lasers were to be recognised as a flexible and powerful tool for the studying the interaction of intense electromagnetic field with solid bodies [2, 3]. The formation of a hot plasma from the irradiated surface was found to be depending sensitively on laser parameters, such as energy density, as well as the properties of the irradiated material. In general, the resulting ablation plasmas have high ion and electron temperatures and high degrees of ionisation. Due to this, laser set ups were designed to create plasma plumes in order to test and optimise TOF mass spectrometer and other particle impact ionisation instruments or their components [4]. Being a simple method to emit ions from a surface with a higher repetition rate, much less effort and costs and in a wider energy range laser ionisation is regarded as an ideal supplement to a a micro-particle accelerator. Although there have been experimental and subsequent theoretical investigations of the similarity of both ion emitting processes, these studies took place under very specific experimental conditions [5].

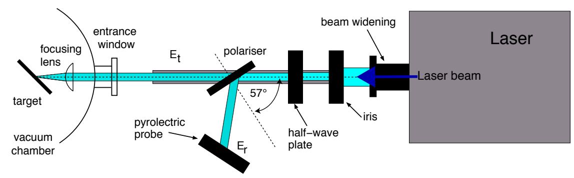

Figure 1: Optical set up of the laser ionisation experiments.

2. Comparability of both processes

Investigation of the comparability of the impact ionisation process and the formation of a plasma cloud due to the irradiance of a solid target follows three guiding themes:

- How reproducible are mass spectra produced by hypervelocity impacts and by laser ablation under similar physical conditions?
- Is laser ablation a useful analogue for the impact ionisation process?
- How deep is our understanding of the impact ionisation process itself?

A program of hypervelocity impact and laser induced ionisation experiments was performed to investigate these questions.

These measurements were conducted with a time-of-flight mass spectrometer designed to provide as comparable as possible impact conditions and optimised to obtain direct information about the process, i.e. the velocity distribution of the generated ions. The laser used in this study is a Nd-YAG solid state laser with a wave length of 355 nm, pulse durations of about 5 ns and a pulse power of up to 200kW. For the laser ionisation measurements, the laser beam was focused to a focal spot of about $10\mu m$ diameter on metal (iron and a copper/silver alloy) as well as silicate targets (gold coated olivine). These materials were chosen to be comparable to the particle impact experiments shots, which had been performed with iron particles as well as with orthopyroxene and olivine dust on metal targets.

3. Measured and compared values

Impact Charge Yield

The charge yields obtained by hypervelocity particle impact ranged between about 5fC and about 0.75pC, whereas for the laser processes charge yields were strongly dependent on the specific laser and target configuration and resulted in ranges from 1fC to about 45pC.

Ion composition and variability of TOF mass spectra

Similar time-of-flight mass spectra can be achieved for only a narrow range of impact parameters. Over this range of impact parameters the resulting spectra are similar with respect to both the appearance of mass lines of certain species and their intensities. Due to the strong variation of the laser ablation process with local surface conditions and the inherent difficulty to control this, it was not possible to determine a fixed setup of the laser to reliably replicate even this limited set of spectra.

Peak Shapes and Line Widths

The shapes of the peaks and the dependence of the line widths on the impact parameters are fundamentally different for impact ionisation and laser processes. Peak shapes of impact ionisation events show a much stronger asymmetry with respect to the preference of faster ions as the laser ablation lines. The lines shapes for laser ionisation corresponds with a Gaussian ion velocity distribution.
Generally laser shots produce narrower, more symmetric lines, implying desorption as the ion formation process.This has major consequences for performance tests and simulations of time-of-flight mass spectrometers with laser set ups. For example, instrument

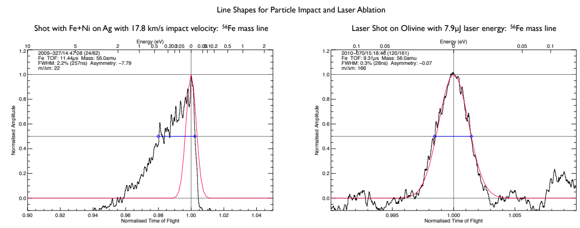

Figure 2: Exemplary line shapes: Iron shots on Ag *(left)* and laser shots on iron *(right)* [6].

mass resolution measurement derived from laser experiments may tend to overestimate the actual instrument performance under hypervelocity impact conditions.

4. Results and Summary

The findings of this study show that, in general, plasma generated by laser ablation or desorption is not comparable to that created by hypervelocity particle impacts. However, particular aspects of the the laser induced ionisation process can be used as a rough substitute for hypervelocity particle impacts: once found and optimised, a particular laser set up can be used to produce many similar impact events at a high repetition rate. This can then be used for optimising and testing detectors, amplifiers and other electronic components for TOF mass spectrometers developed for the investigation of impact ionisation plasmas [6].

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