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Simulation of TOF spectra from cosmic ice particles in the Laboratory by IR-FL-MALDI

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Abstract

TOF-mass spectra of Cassini's Cosmic Dust Analyser (CDA) identify three types of ice-grain-populations in Saturns E-Ring and the plumes emerging from the south pole of Enceladus [1]. With the help of an experimental setup presented here the composition of most emitted ice grains was found to be salt-rich. This supports the hypothesis of a sub-surface reservoir of liquid water being in connection with a rocky core [2]. Our experiment using an infrared laser to disperse a watersolution-microbeam showed the ability to simulate impact spectra of ice grains with high accuracy [3],[4]. The setup will now be exclusively used for a systematic simulation of ice spectra with varying impact energy and composition. Besides the chemical 'reconstruction' of Enceladus ice grains the preparation for compositional analysis of ejecta from icy worlds (e.g the Galileian moons or comets) are the main objectives.

1. Introduction

Three compositional types of ice-grain-populations have been identified in CDA-mass spectra of the plumes ejected from fractures called "tiger-stripes" at the south-pole of Enceladus [4]. CDA-spectra acquired during the close flyby E5 suggest that salt-rich ice grains make up 99 % of the total mass-output of the plumes. Hence the hypothesis of a sub-surface reservoir of liquid water under the icy surface was strongly supported [5]. The composition of the salt-rich ice grains was inferred using an experimental setup to simulate the CDA-spectra [1],[4]. The setup invented by the Abel group in Göttingen (now Leipzig) was initially used for the laser induced, destruction-free release of large organic molecules from the liquid phase [2],[3]. Here we present an advanced version of this experiment which is solely dedicated to detailed simulations of ice-grain-spectra. A variety of impact-energies and compositions will be used to establish a database upon which mass-spectra of ice-grains can be interpreted. Space instrumentation analyzing icy ejecta on future missions, such as a dust-detector onboard the "Laplace"-mission to Jupiter, can be calibrated.

2. Experimental setup

A mix of water and a solute is vertically injected into a vacuum chamber (p= $5{\cdot}10^{-5}$ mbar) through a quartz-microjet-nozzle forming a liquid microbeam of about 10 µm in diameter. The beam is excited by a pulsed infrared laser at λ=2850 nm, which is the OH-stretch vibration of bulk water (Fig.1 d). The energy-density in the laser focus can be adjusted to simulate different impact-energies of ice grains on the CDA. The liquid beam is placed about 1 cm in front of the skimmer-opening (1,5 mm) of a TOF-mass-spectrometer, so desorbed ionized clusters can enter the MS. A pulsed 4-6 kV ion optic accelerates the clusters into the drift-tube of the MS. The delay time of the pulse (5-30 µs) cuts off slow ions. Thus only ions within a small window of the initial velocity-distribution are allowed to pass in order to minimize the error resulting from variations in initial speed. A reflectron further reduces uncertainties caused by varying initial kinetic energies. The experimental setup is described in detail in [2] and [3].

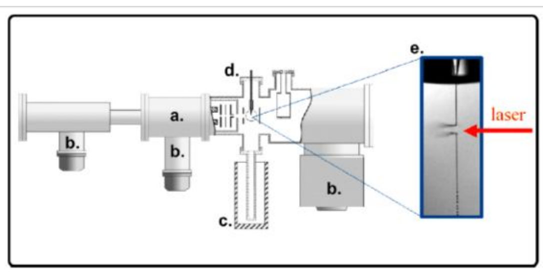

Fig 1: Exp. setup. a) MS b) Turbopumps c) Cryotrap d) Beam site e) Beam irradiated by laser [6].

3. Mechanism of desorption and charge-dispersion

The ultrafast (~7 ns) deposition of the laser-energy causes a shockwave to ablate small-sized, mostly single-charged ion-water-clusters - such as $H^+(H_2O)_n$, $Na^+(H_2O)_n$ - into the vacuum (Fig 1 e). Typical initial cluster-speeds reach several kilometers per second [1]. Even for higher salt-concentrations exceeding $2 \cdot 10^{-3}$M coulomb-forces between ions and an enhanced ion flux during ablation keep inequalities in cation- and anion-numbers within each cluster limited, causing single charge for most clusters [7].

4. Measured spectra

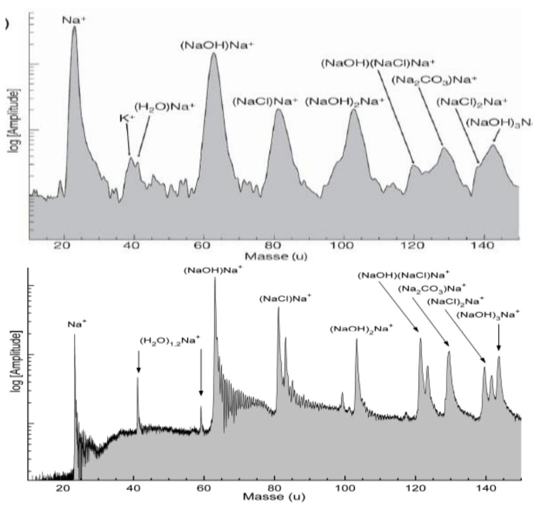

Fig 2: Salt-rich ice grain spectrum taken by Cassini (upper part) and experimental spectrum using 0,2 mol/kg NaCl and 0,1 mol/kg $NaHCO_3$(lower part)[4].

Initial measurements have been carried out to simulate different salt contents in a water matrix. Experimental spectra of low concentrated NaCl with a Na/H_2O ratio of 10^{-8} - 10^{-5} showed peaks of water clusters $H^+(H_2O)_{n=2-8}$ as well as $Na^+(H_2O)_{n=2-6}$, whereas spectra of a solution with a higher content of NaCl and additional $NaHCO_3$ and with a Na/H_2O ratio of exceeding 10^{-3} in contrast showed no H_2O-clusters but instead were dominated by (NaOH)-, (NaCl)- (Na_2CO_3)-clusters such as $(NaOH)_{n=1-3}Na^+$, $(NaCl)_{n=1-2}Na^+$,$(NaOH)(NaCl)Na^+$ and$(Na_2CO_3)Na^+$. These spectra matched very well the Cassini-CDA-spectra of salt-poor and salt-rich ice-grains from Saturns E-ring and Enceladus (Fig 2). The minimum energy-density to get mass-spectra was about $2 \cdot 10^8$ W/cm^2, above 10^9 W/cm^2 first plasma-events occurred, cluster-signals decreased, whereas peaks of small water-fragments increased. Energy-densities exceeding $1{,}8 \cdot 10^9$ W/cm^2 produced only fragmented ions such as HO^+, H_3O^+ H_2O^+ and even O^{2+} , which are typical indicators for plasma[1],[4].

5. Summary and Conclusions

A systematic spectral database for cosmic ice particles with various energies and compositions will be acquired with the presented IR-FL-MALDI-experiment. This will establish a better understanding of all kinds of TOF spectra over a wide range of encounter speeds and possible organic and inorganic compounds embedded in the ice matrix. Moreover it will allow improvements in the design of space instrumentation for future missions, such as an ejecta analyzer for “Laplace” to Jupiter’s icy moons.

6. Acknowledgements

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