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Enceladus Icy Jet Analyzer (ENIJA) : Search for life with a high resolution TOF-MS for in situ characterization of high dust density regions

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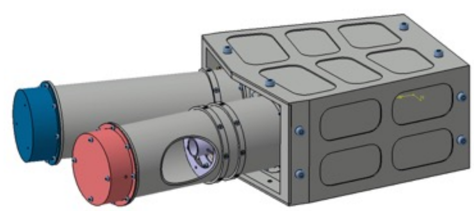
Abstract

ENIJA was developed to search for the prebiotic molecules and biogenic key compounds like amino acids in the plumes of Saturn's moon Enceladus. ENIJA records time-of-flight mass spectra in the range between 1 and 2000 u produced by high-velocity impacts of individual grains onto a metal target. The spectrometer has a measurement mode for cations or anions formed upon impact, with concurrent determination of the mass of the detected grains. Detection of elemental and molecular species over such a wide mass range permits clear characterization of particle chemistry, simultaneously covering individual ions like H^+, C^-, O^- and complex organics with masses of many hundred u. ENIJA is sensitive to water ice, minerals, metals, organic particles, and mixtures of these components. The instrument is based on the principle of impact ionization and optimized for the analysis of high dust fluxes and number densities as typically occur during Enceladus plume crossings or in cometary comae. The mass resolution is m/dm > 970 for typical plume particles in the size range 0.01 to 100 µm. The instrument mass and peak power is 3.5 kg and 14.2 W, respectively. The instrument is part of the model payload for the mission „Enceladus Life Finder" (ELF).

1. Scientific Performance

The core of the Enceladus Icy Jet Analyzer (ENIJA) is a time-of-flight mass spectrometer for the compositional analysis of submicron and micron-sized dust particles. Most of the ice particles in Enceladus' plume have been shown to be direct samples of subsurface waters. In contrast, the plume gas probably reflects a mixture of outgassing from water and ice. To get a meaningful picture of Enceladus' geochemical and astrobiological potential both emitted phases, solid and gas, have to be analyzed.



The high mass resolution enables a clear separation of isotopes for all singly charged elements. Multiply charged ions (e.g. Mg^{2+}, O^{2-}) are not expected for dust impact velocities below 20 kms^{-1}. Cluster ions with higher masses will be abundant species since they preferably form at impact velocities below 10 kms^{-1}. This was shown by the Cosmic Dust Analyzer (CDA) onboard Cassini, with which measurements of plume particles showed that salt bearing icy particle impacts generate molecular clusters like $(H_2O)_nNa^+$, $(NaOH)_nNa^+$, $(NaCl)_nNa^+$, or $(Na_2CO_3)_nNa^+$. These sequences actually revealed the quantitative composition of their liquid sources. Although CDA was by no means optimized for high fluxes of dust and gas in Enceladus' plume, it achieved outstanding results by adaptable instrument operation. In contrast, the ENIJA instrument will be optimized for Enceladus plume measurements. With 5 times lower instrument mass it provides an improved spectrum mass resolution (factor 40), maximum flux (factor 100), sensitivity (factor 100), and spatial resolution (factor 50). The high spatial resolution of ENIJA is based on its high rate operational mode (up to 50 spectra are recorded per second) and accurate impact time information (1/256 s). An Enceladus flyby speed of about 5 km s^{-1} therefore provides a spatial accuracy of less than 20 m, allowing precise determination of compositional profiles along the spacecraft trajectory.

Impact ionization is used as the basic physical principle to characterize individual dust particles. This process is well understood and shows an unsurpassed sensitivity for compounds embedded in a water ice matrix. As has been demonstrated by CDA, salts and other minerals can be identified at ppb level. All organic compounds can be quantified at 10 ppm and below (see lab spectrum above). It could be demonstrated that some polar organic species, like many amino acids, can be quantified down to 1 ppb.

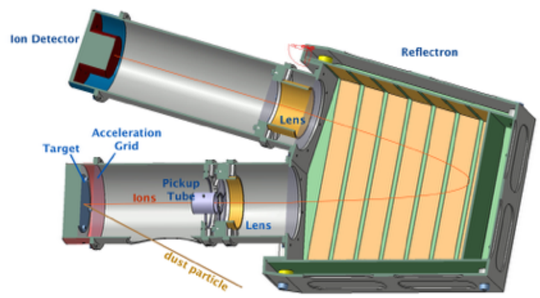
Due to its small target area (smaller capacitance) and better electrical screening, ice particles as small as 0.1 µm (at an impact speed of 5 km s^{-1}) can be analyzed. As this detection threshold scales with impact speed, faster impacts, such as from silica stream particles originating from Enceladus, can be investigated down to the nanometer scale. An optional independent ENIJA subsystem running parallel to the spectrometer during Enceladus encounters is the "High Flux detector" (HFD). It measures fluxes up to 10^8 s^{-1} m^{-2}. This instrument will map the dynamical profile (number density, ejection speeds, and size distribution) of Enceladus' ice jets.

2. Instrument Description

The main system of ENIJA is a reflectron-based impact-ionization time-of-flight mass spectrometer for the detection of individual hypervelocity dust impacts. Major improvements with respect to former dust spectrometers like PIA (Giotto), CIDA (Stardust) or CDA (Cassini) are: a lower weight, a higher mass resolution, a higher impact recording rate, an iridium target with efficient target heating, an instrument cover (CIDA had no instrument cover), and improved background noise.

The reflectron has a depth of 170 mm and the angle between the arms is 20 degrees. The instrument is composed of one reflectron with potential rings and two drift tubes. One tube contains the impact target and the second contains the ion detector. Dust particles enter the target section via an aperture. The aperture is sealed before launch and during cruise phase with a cover which protects the instrument from contamination.

A hypervelocity particle impact generates an impact plasma and the electrical potential of 2000 V between target and acceleration grid separates the



plasma charges. In the positive measurement mode electrons are collected at the iridium target plate whereas the cations are accelerated towards the reflectron drift tube. In negative mode, anions are accelerated. The reflectron corrects the ion energy distribution and increases the mass resolution. Depending on the density of the dust environment the sensitive area of the impact target can be switched between 0.8 cm^2 and 12,5 cm^2, respectively. The ions are collected at the ion detector where a mass spectrum is recorded. Up to 50 full spectra can be recorded per second, each spectrum representing the composition of an individual dust particle. The instrument is controlled by a radiation hardened FPGA and the instrument memory buffers 2048 complete spectra.

The High Flux Detector is a special operational mode with a continuous read-out of the induction channel 3 in order to derive gap-less stochastic impact statistics. Impact times are determined within 4 µs and ion yields are recorded for particle mass determination. This subsystem provides unique information about very high impact rates (up to 10^5 s^{-1}) and allows for accurate noise analysis.

A to-scale laboratory model of a ENIJA was built and tested at the dust accelerator in Heidelberg. Time-of-flight mass spectra were recorded using mineral and organic projectiles.