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Hypervelocity Enceladus Ice Grain Analogue Production with the Aerosol Impact Spectrometer

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Abstract

Ice grains of controlled composition, size, and energy are generated in vacuum to simulate grains found in the plume of Enceladus. Grains are generated with the Aerosol Impact Spectrometer and accelerated to hypervelocities with the ultimate goal of injecting them into the Jet Propulsion Laboratory's Quadrupole Ion Trap Mass Spectrometer for characterization of apparatus response and sensitivity to different high-mass organic species within the ice. The ability of these high-mass organics to survive grain impact and be detected with instrumentation compatible within the constraints of spacecraft payloads will inform future astrobiology measurements and analysis of the Enceladus plume in addition to other potential mission targets.

1. Introduction

Within the plume ejected from the south pole of Enceladus, as studied by the Cassini-Huygens mission, a variety of grain compositions have been observed [1-4] with a subset of those grains containing high-mass complex macromolecular organic species [5]. Characterization of these species in high resolution was not possible with the scientific payload of the Cassini mission, but future missions outfitted with modern scientific equipment would be capable of obtaining more detailed information about these grains. Before any such mission could occur, it is essential that a payload-ready high-mass (>100 amu) resolution spectrometer be qualified and characterized in the laboratory. In-vacuum production of ice grains of known size and composition is possible with the Aerosol Impact Spectrometer (AIS) [6] and can be readily coupled with the high-mass resolution quadrupole ion trap mass spectrometer under development at the Jet Propulsion Laboratory (JPL-QITMS) [7]. This will allow characterization of the JPL-QITMS with laboratory-produced ice grains analogous to those found in the Enceladus plume.

2. Methods

Highly charged water particles are produced and characterized using the same techniques described in [6]. Briefly, a solution of deionized water is sprayed through a custom metal tip electrospray ionization (ESI) source into vacuum via a small (~200 µm) critical orifice. The subsequent particle beam is collimated and focused using an aerodynamic lens. The particle beam is sampled by energy-per-charge using a quadrupole deflector as a filter. Single filtered particles are injected into an electrostatic trap instrumented with an image charge detection electrode at the trap center. The frequency of the repetitive oscillation of the particle within the trap allows the particle mass-charge-ratio to be calculated (Charge Detection Mass Spectrometry), in addition to the absolute charge of the particle from response of the image charge detector. This mass and charge measurement is used in conjunction with the particle's initial velocity (also measured using the image charge detector) to program a multi-stage linear accelerator (LINAC) to accelerate single particles to high velocity ($\geq$ 1 km/s). Additional image charge detection electrodes allow the measurement of the post-acceleration particle velocity prior to injection into the JPL-QITMS. Variation of the composition of the initial solution to include various Enceladus-relevant salts and organics will allow different species to be characterized by the JPL-QITMS.

3. Initial Results

ESI of deionized water has been performed and found to reliably produce highly charged particles between 1-2 µm in size. By repeatedly trapping and mass analyzing single particles, a particle size distribution has been determined for typical operating conditions using the AIS ESI source as shown in Figure 1.

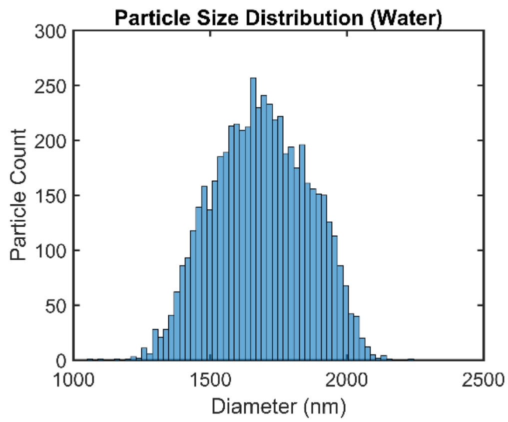

Figure 1: Size distribution of water particles produced with the AIS

Particles are produced with a narrow velocity distribution of ~85 m/s due to initial particle collimation with the aerodynamic lens. All particles are produced with a high amount of positive charge from the ESI source, with a broad distribution: 40k-120k fundamental charges. Ice particle acceleration has been demonstrated with a 12-stage LINAC up to 1 km/s using 10 kV/stage.

4. Summary and Conclusions

The particles produced will be injected into the JPL-QITMS, which is to be mounted to the end of AIS in a vacuum environment of $<10^{-8}$ Torr. Additional image charge detectors immediately before the mass spectrometer will enable measurement of the JPL-QITMS's response to single grain impacts. The mass spectrometer's response to different ice grain compositions and incident velocities will be presented. Velocity is an important factor, as one of the possible configurations for a future Enceladus mission is sampling of the plume at various altitudes during flythroughs, which would typically be at velocities ≥ 1 km/s. We note that the experiments performed here with the JPL-QITMS will be helpful in characterizing organic-laden ice grain impacts at hypervelocity; such information can inform instrument design for many different payload options that might be included on a future mission to the Enceladus plume.

Acknowledgements

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