THE CHEMICAL EFFECTS OF HYPERVELOCITY IMPACT: IMPLICATIONS FOR OCEAN WORLDS PLUME SAMPLING SCHEMES.
S.E. Burke[1], M.E.C. Miller[1], R.E. Continetti[1], K. Hanold[1], S.E. Waller[2], A. Jaramillo-Botero[3], R.P. Hodyss[2], M.J. Malaska[2], A.E. Hofmann[2], B. Abel[4], F. Postberg[5], J.I. Lunine[6], and M.L. Cable[2], [1]University of California, San Diego, [2]NASA Jet Propulsion Laboratory, California Institute of Technology, [3]California Institute of Technology, [4]Universität Leipzig, [5]Freie Universität Berlin, [6]Cornell University

Background and Motivation: Plume flythrough sampling is a powerful method for exploring ocean worlds, as demonstrated by the advancement of knowledge about Enceladus as a result of the plume sampling of the Cassini mission. The Cosmic Dust Analyzer (CDA) on board the spacecraft utilized impact induced ionization time-of-flight mass spectrometry (TOFMS) to characterize the icy particles from the plume of Enceladus. The results of this data suggested the presence of both low- and high-mass organic species in the grains [1,2]. This, along with evidence for a global liquid water ocean and hydrothermal activity, makes the Ocean World Enceladus a key target for astrobiology investigations [3]. Advancements in plume sampling instrumentation would provide sufficient resolution and sensitivity to identify biosignatures in the plume grains. An improved instrument called the Enceladus Ice Analyzer (ENIA) has been proposed for a future exploratory mission [4]. Like the CDA, the ENIA is a mass spectrometer that uses impact-induced ionization. This is a useful ionization method for flyby missions because it allows for ionization as well as particle break-up to expose entrained molecules [4]. However, one significant concern is the potential for molecular fragmentation of the entrained organics, particularly at hypervelocity (>3 km/s) impact speeds. The potential velocity thresholds at which entrained organics fragment will have important implications for the ideal flyby velocity of a future mission to Enceladus and for the validation of flyby mass spectrometry. The objective of our work is to investigate ice grain and entrained molecule fragmentation upon hypervelocity impact in a laboratory setting.

Experimental Methods: The study of impact behavior and post-impact character for Enceladean plume materials will be performed with the Aerosol Impact Spectrometer (AIS) at UC San Diego (*Fig 1)* [5].

Instrumentation. The AIS has the unique capability to perform single-particle analysis of impact behavior and post-impact character. The AIS generates particles analogous in size and composition to those observed by the Cassini mission via electrospray ionization. Individual, energy-selected grains are characterized with charge detection mass spectrometry and then are accelerated with a 41-element linear accelerator, designed to reach relevant hypervelocity speeds (up to 5 km/s). The accelerated ice grain is then impacted onto a metal target and the post-impact behavior can be analyzed. One detection method is the Tapered Image Charge Detector (TICD) [6], which is useful for lower velocity impact behavior (i.e. sticking, bouncing, fragmentation) measurements. Chemical effects of hypervelocity impact can be studied with another detection method: a post-impact fragment time-of-flight mass spectrometer (see *Fig. 1* insert).

Samples. This laboratory study will investigate the materials that were previously identified in the Enceladean plume by the CDA. These include pure water ice grains, ice grains containing organics, and ice grains containing significant salt concentrations [7]. Both the TICD and the post-impact fragment TOFMS are used to study pure water ice grain impacts. For the organic-containing ice grains, first a library of mass spectra for single-solute solutions will be collected. The solutes to be tested have been selected based on computational modeling of the fragmentation velocity thresholds [8]. They include arginine, lysine, aspartic acid, palmitic acid, and the short peptide Gly-Pro-Glu. The spectra of these individual species will be analyzed as a function of impact velocity in order to validate molecular fragmentation thresholds. Next, the mass spectra of mixtures of organics will be measured. These mixtures are designed to represent abiotic and biotic concentration distributions [9]. The mass spectra will be compared in order to determine the impact velocity range at which abiotic and biotic mixtures can be distinguished with post-impact TOFMS. Finally, mass spectra of salt-rich ice grains will be collected and the effect of salts on the mass spectrometric measurements of organics will be investigated.

Validation. The results obtained with the Aerosol Impact Spectrometer will be compared with concurrent computational modelling by Dr. Jaramillo-Botero at the California Institute of Technology and concurrent analogous laboratory experimentation by Dr. Waller and Dr. Miller at the Jet Propulsion Laboratory. The data can also be compared with the CDA spectra and the work of Dr. Postberg at the Freie Universität Berlin.

Results: Velocity dependent trends of impact behavior have been determined for submicron pure water ice grains with impact velocities below 2 km/s using the TICD. The impact velocity regimes for sticking, bouncing, and fragmentation will be overviewed. The key relevant result is that ice grain break-up (fragmentation) is observed to be the dominant behavior at and above impact velocities of ~600 m/s.

The experimental instrumentation has been shown to be effective at accelerating submicron ice grains to hypervelocity speeds. The post-impact TOFMS has been integrated with the AIS with demonstrated functionality. Preliminary studies of mass spectra of pure water ice grains will be presented along with their correlation to the impact behavior results from the TICD.

Ongoing experimentation with ice grains containing organics will prove vital for informing an ideal flyby velocity and for validating the use of impact-induced ionization as a means of identifying biosignatures at hypervelocity.

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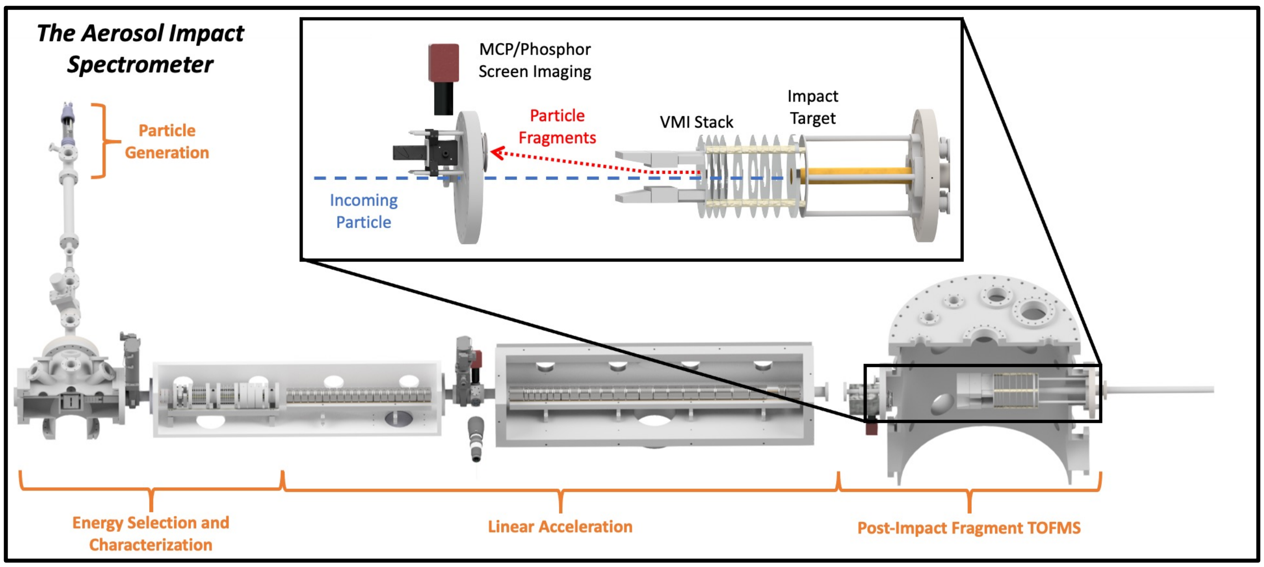

Fig. 1. *Schematic of the Aerosol Impact Spectrometer. Insert: Schematic of the post-impact fragment time-of-flight mass spectrometer.*