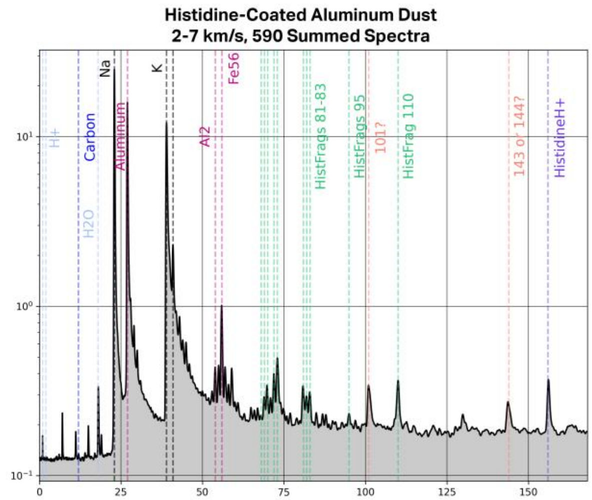
HYPERVELOCITY IMPACT IONIZATION OF AMINO-ACID-LADEN DUST: FIRST DIRECT MEASUREMENTS AND IMPLICATIONS FOR INSTRUMENT CAPABILITIES AND PREBIOTIC CHEMISTRY. Z. Ulibarri[1] (zulibarri@cornell.edu), L. H. Yeo[2,3], H. L. McLain[2,3,4], A. C. Doner[5], J. D. Fontanese[6], S. Kempf[5,6], M. Horányi[5,6], T. Munsat[5], E. M. Petro[1], and Z. Sternovsky[6]. [1]Sibley School of Mechanical and Aerospace Engineering, Cornell University, [2]University of Maryland, [3]NASA Goddard Space Flight Center, [4]Center for Research and Exploration in Space Science and Technology, [5]Department of Physics, University of Colorado, Boulder. [6]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder.

Introduction: Assessing the organic inventory of objects and dust populations throughout the solar system is of high scientific priority because organics are required for habitability and the existence of life as we know it **[1]**. Where life may exist, the distribution, abundance, and stability of organics directly limit the scale and productivity of potential biological systems **[2]**. Amino acids are of particular importance due to their fundamental role in terrestrial biology, and abiotic inventories of amino acids (e.g., the Murchison Meteorite **[3]**) show a dramatically increased prevalence of the simplest amino acids relative to the more complex ones. As such, the relative abundance of amino acids may be used as a biosignature in some cases **[4,5,6]**.

While large-scale impactors are well-established as mechanisms for delivering organic material to planetary surfaces **[7]**, the role of continuous bombardment by interplanetary dust particles (IDPs) for organic deposition remains less well-constrained. IDPs represent a persistent flux of material across the solar system, with particles ranging from nanometers to hundreds of micrometers constantly impacting airless bodies and planetary atmospheres at velocities of up to tens of km/s **[8]**. Understanding the efficiency with which amino acids and other organic molecules survive hypervelocity impacts and remain chemically viable and available is critical for understanding the dynamic effects of IDP gardening of prebiotic material throughout the solar system.

Further, impact ionization mass spectrometers (I2MS) provide unique *in-situ* molecular and/or elemental composition datasets on flyby spacecraft by analyzing cosmic dust grains. Through impact at hypervelocity (>~3 km/s), kinetic energy vaporizes the dust grain and ionizes some or all of its contents for analysis by time-of-flight (TOF) mass spectrometry (MS). Higher velocities increase molecular fragmentation, eventually resulting in purely elemental mass spectra at very high velocity, from which isotopic information can be gathered in some cases.

I2MS instruments have been critical for understanding the chemical composition of multiple planetary objects, most notably with the Cosmic Dust Analyzer (CDA) on the Cassini spacecraft **[9]**. The CDA was instrumental in the identification and



histidine-bearing aluminum dust grains. These 590 grains were impacted into an IDEX-like I2MS prototype instrument, providing highly realistic flight data analogs across the 2-7 km/s velocity range.

characterization of the Enceladus subsurface ocean **[10,11]** and its ejecta plumes, where it found organic fragment species, perhaps originating from higher mass complex organic parent molecules in the liquid water ocean **[12,13]**. The Interstellar Dust Experiment (IDEX) I2MS launched in 2025 aboard the Interstellar Mapping and Acceleration Probe (IMAP) **[14,15]** spacecraft to measure the flux and composition of interstellar dust (ISD) and IDPs at the L1 Earth-Sun Lagrange point. In addition, the Surface Dust Analyzer (SUDA) I2MS aboard the Europa Clipper flagship mission will study dust grains lofted from Europa, the moon of Jupiter **[16,17]** to determine Europa's surface composition and the composition and activity of any potential extant plumes, specifically by identifying hydrated minerals, salts, and organic compounds **[18,19]**. Finally, the DESTINY+ Dust Analyzer (DDA) will study 3200 Phaethon after launch on the upcoming JAXA DESTINY+ mission **[20]**, and a number of proposed missions or instruments use I2MS technology to provide compositional measurements of planetary objects and dust populations across the solar system **[21,22]**.

Given the importance of measuring amino acids or other organic molecules for planetary exploration, habitability assessments, and astrobiology searches, there thus exists a need to study hypervelocity impact with amino acid-bearing dust. Studies are needed to probe I2MS instruments' ability to detect these species and to assess rates of deposition and survival in IDP and ISD impacts with planetary objects in carefully controlled laboratory settings over a wide range of hypervelocity conditions **[23]**. While dust accelerators can launch particles at relevant velocities and sizes (hundreds of nanometers to a few microns) **[24,25]**, the dust grains must have a conductive outer surface to enable sufficient charging for acceleration. As such, these accelerators typically rely on simple, uncoated metallic dust, such as iron or aluminum. As there has not been any capability of launching dust containing amino acids with these systems, a number of experimental analog **[26,27,28]** and modeling simulations **[29]** have been performed. Mikula *et al.* have studied polypyrrole-coated anthracene at hypervelocity as an analog for polycyclic aromatic hydrocarbons **[30]**. Burke *et al.* have developed a method to accelerate electrosprayed ice grains to 4.2 km/s **[31]**, and other ice grain accelerators are coming online **[32,33]**. However, none of these have accelerated amino acid-laden dust to higher velocities, and none have accelerated amino acid-laden dust at non-ice temperatures to any velocity.

Here we present results from the first study of hypervelocity dust impacts with amino acid-bearing dust grains from 1 to ~30 km/s (although the vast majority of measured particles is below 6 km/s). Two mixtures of aluminum dust with diameters ranging from hundreds of nanometers up to a few µm were coated with single amino acids, with one being coated with a thin layer of histidine and the other with arginine. The dust samples were accelerated at room temperature at the IMPACT dust accelerator **[24]** at the University of Colorado at Boulder and studied with a prototype IDEX-like I2MS instrument **[33]**.

Initial Results: Fig. 1 shows 590 summed I2MS spectra from 2 to 7 km/s impacts of histidine-laden aluminum dust. The intact parent molecule, Histidine$^+$, is shown at the far right in purple, while characteristic fragments are highlighted in green. Similar results were obtained for arginine. These results illustrate that both the parent and the diagnostic fragment molecules survive these hypervelocity impact conditions and remain detectable.

While there is only sparse data beyond 5 km/s as of yet, intact, unambiguous detection of histidine is observed in *individual* spectra up to at least 6.8 km/s, and similarly intact arginine is observed in individual spectra up to at least 5.1 km/s. These should not be taken to be well-defined upper bounds due to the limited data at these and higher velocities, but they illustrate clear survivability for these species at these velocities, and it underscores the ability of I2MS to study organics with flyby spacecraft and to probe organic hypervelocity survivability in the laboratory.

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