FEASIBILITY OF CAPTURING ORGANIC ICE PARTICLES IN HYPERVELOCITY TRANSITS OF ENCELADUS PLUMES.
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Introduction: Studying the organic history, habitability and potential for, or presence of, extinct or extant life on any solar system body is an exciting quest. However, this work must be performed with high capability instruments and with appropriate caution to prevent planetary contamination. Instruments that can capture materials from plumes, clouds, comae or ejecta and perform sensitive analysis for organic molecules advantageously avoid the technical and planetary protection problems of a surface lander.

The Cassini mission revealed a number of distinct, narrow geysers [1] venting from four prominent and warm fractures in Enceladus' south polar region that make Enceladus an extremely interesting target for non-contact analysis. These geysers form a giant plume that extends thousands of kilometers into space and is responsible for Saturn's E ring [2]. Cassini data [e.g. 3], and ground-based telescope analysis of Saturn's E ring [4] suggests that the largest particles near the surface of Enceladus are frozen droplets of salty liquid water and that vapor in the plumes include trace amounts of ammonia and light organic compounds [5]. Various sources of evidence indicate a sub-ice-surface liquid water ocean, with salinity similar to oceans on Earth, that is in contact with a rocky core [6]. Additionally, analysis of E ring particles [7] indicates hydrothermal sources at the ocean-core boundary, similar to the hydrothermal vents at Lost City [8]. The presence and accessibility of the salty liquid ocean and geothermal activity on Enceladus make it a most promising place to conduct further, in-depth astrobiological investigations using a remote, *in situ* analysis technique to probe for organic molecules indicative of extraterrestrial life.

One concept for remote analysis of Enceladus involves flying an instrument through a plume at high velocity to capture particles for *in situ* organic analysis as proposed by the Enceladus Organic Analyzer or EOA [9]. Hypervelocity impact experiments indicate that varying amounts of projectile residue are deposited in the impact crater depending on the encounter velocity and physical properties of the projectile and target [10]. Typically, only traces of organic compounds are present in the sample, meaning it is important to select an encounter velocity and capture surface that provide maximum capture efficiency. Many organic compounds, particularly amino acids, are sensitive to capture effects and can decompose when exposed to shock or heating [11]. Therefore, it is also necessary to consider organic survival in the capture process.

Hypervelocity Impact Experiments: A series of twelve experiments were conducted using the light gas gun (LGG) at the University of Kent with the objective of answering two fundamental questions: (1) what is the optimal capture surface material at different encounter velocities between ~0.5 km s^{-1} and ~3.0 km s^{-1}, and (2) do organics survive the impact?

Target (Capture Surface): The capture surface materials were chosen to provide a compliant impact surface that captured the particle and reduced shock and thermal destruction of the organic materials in the projectile. Additionally, the material had to permit fabrication in a variety of configurations and thicknesses, suitable for flight instrument deployment. Finally, it had to be readily cleaned to very low levels of organic contamination and easily washed to extract captured particle residue for analysis. Thus, soft inert metals (Ag, Al, Au, Cu and In) were chosen for test.

During each impact experiment, the target was fabricated out of five thin metal foils (Ag, Al, Au, Cu and In) in a grid configuration. This design acted as a control, allowing the cloud of projectiles to impact under nominally the same velocity and conditions.

Projectiles (Plume Analog): The projectiles were chosen to provide a comparable analog for Enceladus' plume ice particles (i.e. micron-sized, similar melting point and mechanical properties). The majority of the plume's mass, at an altitude of 50 km, resides in particles with a diameter of 2–6 µm [12, 13]. Thus, spherical monodisperse poly(methylmethacrylate) (PMMA) projectiles with diameters of ~2, ~4 and ~6 µm were chosen. Additional ~10 µm projectiles were included to extend the dataset.

Crater Analysis: A sample of craters on each target material were analyzed by SEM-EDX, utilizing a Bruker Quad-Flat EDX detector. The crater sizes were measured on SE images and related to projectile size to provide calibration for later ice shots. C and O element maps were used to quantify shot PMMA captured in the craters.

PMMA residue in one crater was compared to unshot PMMA using Raman spectroscopy, to measure any modification of the bonding and to detect pyrolytic processes.

Results: Our results indicate that both speed and target properties influence the capture efficiency of the particles. The effect that different encounter velocities have on the capture efficiency of a material are demonstrated in Figure 1, where ~10 µm projectiles impacted In foils at velocities of ~1.0 and ~2.2 km s^{-1}, respectively. At low velocity a depression with very little PMMA residue is observed indicating that the particle quasi-elastically bounces off the target material with very little capture consistent with recent modeling [14]. At 2.2 km s^{-1} significant PMMA residue is observed in the crater with a smooth appearance perhaps indicative of melting.

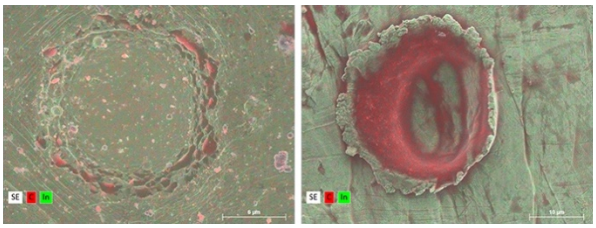

Figure 1. SEM-EDX images of craters in the In target caused by ~10 µm PMMA particle impacts at ~1.0 km s^{-1} (left) and ~2.2 km s^{-1} (right). Carbon (which traces PMMA) is depicted in red.

The effect that different target properties (i.e. ultimate tensile strength) have on the capture efficiency is demonstrated in Figure 2, where ~6 µm particles impacted Al and In foils at a velocity of ~1.0 km s^{-1}. Particle impacts into the harder Al foil produce a dent in the Al foil indicating that it bounced off while at higher velocity more significant penetration and PMMA deposition is observed.

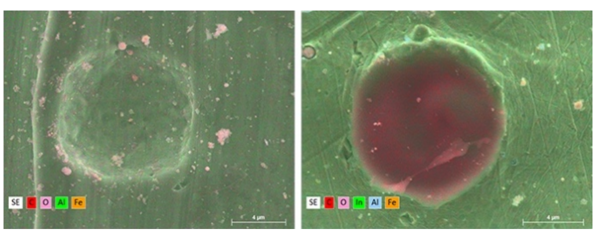

Figure 2. SEM-EDX images of craters in the Al (left) and In (right) target caused by ~6 µm PMMA particle impacts at ~1.0 km s^{-1}. Carbon (which traces PMMA) is depicted in red.

Raman spectroscopy revealed that PMMA does survive the impact relatively chemically intact. Figure 3 shows the Raman spectra of unshot material (**D**) and spectra taken at several points within an impact crater. The appearance of the carbon 'D' and 'G' bands in spectra **B** and **C** at ~1300 and ~1550 cm^{-1} show where the PMMA is starting to decompose into pyrolyzed elemental carbon but the majority of the fingerprint lines are present (including the C-H stretches in the 3000 cm^{-1} region).

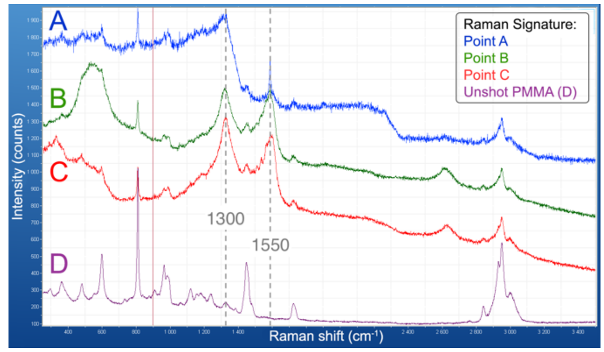

Figure 3. Raman spectra at three different points within a PMMA crater (**A, B, C**) and the Raman spectra of unshot PMMA material (**D**) for comparison. Impact velocity of ~2.2 km s^{-1} with 10 µm projectile.

Discussion & Conclusions: These preliminary results indicate that capture process and efficiency depends considerably on the impact velocity, impact material and target material. (1) Impact velocity: Analysis of the In foils shows that ~10 µm projectiles at low velocity 'bounce off' the target leaving effectively no residue. Between ~1 km s^{-1} and ~2.5 km s^{-1} the capture efficiency increases and peaks at ~2.2 km s^{-1} (~90%). Above ~3 km s^{-1}, the amount of residue rapidly decreases. (2) Impactor size: At ~1.0 km s^{-1} the capture efficiency is greater for smaller projectiles (~6 µm) than larger projectiles (~10 µm). This is demonstrated in Figure 1 (left) and Figure 2 (right), where ~6 µm particles stick in In and ~10 µm projectiles bounce off at the same encounter velocity. (3) Capture material: Capture efficiency scales inversely with the ultimate tensile strength of the material. All things being equal the softer materials tend to be better at capturing particles than the harder materials. *We conclude that soft metals can be used as a plume capture medium that preserves organic content but the optimum material will be a sensitive function of velocity and particle material properties.*

Further analyses are ongoing to investigate the capture efficiency versus projectile size, encounter velocity and material property dependence and to fully quantify the volume of the projectile retained.

References: [1] Porco et al. (2014) *Astron. J.,* 148, 45. [2] Spahn et al. (2006) *Science*, 311, 1416. [3] Postberg et al. (2011) *Nature*, 474, 620. [4] Schneider et al. (2009) *Nature*, 459, 1102. [5] Waite et al. (2009) *Nature*, 460, 487. [6] Postberg et al. (2009) *Nature*, 459, 1098. [7] Hsu et al. (2015) *Nature*, 519, 207. [8] Kelly et al. (2005) *Science*, 307, 1428. [9] Mathies et al. (2017) *Astrobiology*, 17, 902. [10] Wozniakiewicz et al. (2015) *MAPS*, 53, 1066. [11] Kearsley et al. (2017) *P. Eng.* 204, 43. [12] Hedman et al. (2009) *Astron. J.*, 693, 1749. [13] Porco et al. (2017) *Astrobiology*, 17, 876. [14] Golozar et al. (2018) AGU.