# CHARACTERIZATION OF AGGLUTINATES PRODUCED BY DUAL LASER SPACE WEATHERING.

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**Introduction:** Agglutinates are the most abundant and the most altered portion of lunar surface material [1-7]. Agglutinates are generally small (<1mm) aggregates of soil grains (e.g., rock, mineral, and even older agglutinates) welded together by impact-melt glass. They are typically irregular in shape, often have branching or dendritic morphologies, and most contain vesicles [2]. The melt glass that welds agglutinates forms when a micrometeorite strikes the regolith. In a mature regolith, agglutinates comprise a significant constituent, making up 25–30% of the soil on average, but can get as high as 60-70% [2]. The abundance of agglutinates is predicted to be greater on Mercury [8, 9] and are believed to form far less on asteroids [10-12]. Because of their difference in physical, chemical, and spectral properties, agglutinates obscure the original composition of rock fragments derived from bedrock in lunar soils [13-21].

Controlled experimental methods are needed to investigate agglutinate formation under many different conditions: e.g., from Mercury to the asteroid belt, from polar to equatorial environments, and with and without the presence of volatiles.

Hence, the dual laser space weathering facility at Washington University in Saint Louis aims to fill knowledge gaps in our understanding of how regolith, under various environmental conditions, responds to the space environment. Various analytical measurements of dual laser-weathered materials (e.g., reflectance spectra, SEM and TEM analyses, and ferromagnetic resonance) will allow the testing of multiple hypotheses that attempt to explain measurable differences in remotely sensed data between polar and equatorial regions.

**Dual Laser Space Weathering Laboratory:** Central to the laser weathering laboratory is a 26-liter, stainless steel, nineteen ports, ultrahigh vacuum chamber (Figure 1). Unique capabilities of the chamber include sample temperature control, volatile dosing, two lasers with different energy deposit pulse lengths, and the ability to measure the reflectance properties of treated materials while under vacuum.

Our experimental setup uses powdered, uncompressed samples (0.2-0.5 g) to represent the physical property of airless bodies. The first trials were conducted with powdered San Carlos Olivine (SCO) and the lunar highlands simulant produced by Exolith lab (LHS-1D). Laser irradiation is performed under vacuum ($10^{-8}$ Torr) using an Osaka combo turbomolecular pumping system.

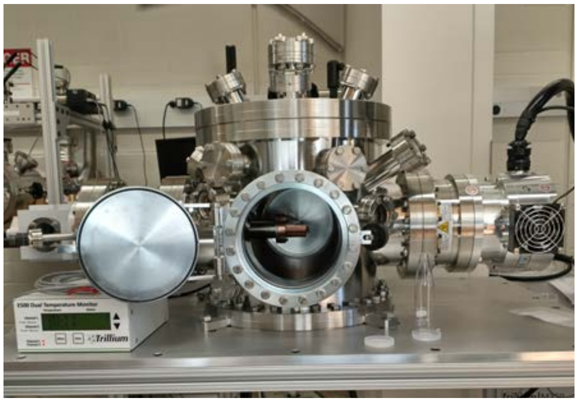

**Fig 1.** UHV stainless steel chamber. The 8” door to the chamber is open showing the sample holder. The holder is attached to a Trillium helium closed looped coldhead with dual temperature readout (left). The Osaka turbomolecular pump is on the right side.

To replicate micrometeorite impacts, we use two Continuum Surelite I-20 Nd:YAG lasers with a fundamental wavelength at 1064 nm, which operate from 1-20 Hz pulse rate. The energy deposition pulse width of the first laser is 6 ns, and for the second laser, the pulse width 100 ns. The purpose of the dual laser system is to recreate the entire thermal event of a micrometeorite impact (particle on the order $1x10^{-12}$ kg). The shorter pulse laser creates vapor, while the more extended pulse laser creates melt and agglutinates. The laser spot size of both lasers is ~300 µm, which deposits incident energy between 5 mJ and 220 mJ per pulse onto the sample, which reproduces impact energies of micrometeorites from Mercury to the asteroid belt.

The shockwave produced by the laser-induced plasma creates a crater that, in turn, gardens the sample. An actuated mirror steers the beam in the X-Y direction. Together, the mirror and gardening yield a uniformly irradiated/weathered powder.

This dual laser method creates agglutinates and spectral properties that are more representative of weathered airless bodies than the short pulsed laser experiments alone [22].

**Analytical Methods:** A Tescan LMH MIRA3 Field Emission-SEM with Energy Dispersive X-ray (EDX) analyzer was used to characterize agglutinates taken from the laser irradiated powdered samples. Agglutinates were embedded in epoxy, which was then polished to reveal the particles in cross section. Backscatter Electron (BSE) images are used to characterize the size and shape of the particles, as well as the percentage of vesicles. The BSE images are converted to binary images to calculate area of vesicle space relative to glass (Figure 2). The EDX system acquires major element compositional maps of particles.

**Results & Findings:** Short-pulsed experiments produce melt and vapor deposits on grains. However, a fundamental limitation of short-pulsed laser experiments is that they cannot produce agglutinitic-like particles or fully melted grains. The dual laser irradiation experiments with SCO and LHS-1D reproduce the internal and external features of lunar agglutinates to some extent. The spherules range in size from 10s $\mu$m to 1 mm. First, the complex surfaces with relatively high surface area. Second, they are mostly glass with some embedded fragments of unmelted material (Fig. 2). Third, they contain ~10% internal vesicles. And fourth, they contain Fe-metal droplets. Agglutinate's size can be up to 500 $\mu$m but most are smaller. Further, the extended pulse laser is able to bulk melt powder clumps and create melt spheres.

Future work will compare and contrast chemistry, and ferromagnetic resonance measurements between dual laser weathered samples and naturally weathered samples. With the ability to conduct spectral analyses of the laser weathered soils without breaking vacuum and while under polar conditions. This capability will allow us to test various observations and conclusions of the lunar regolith based on remote sensing data.

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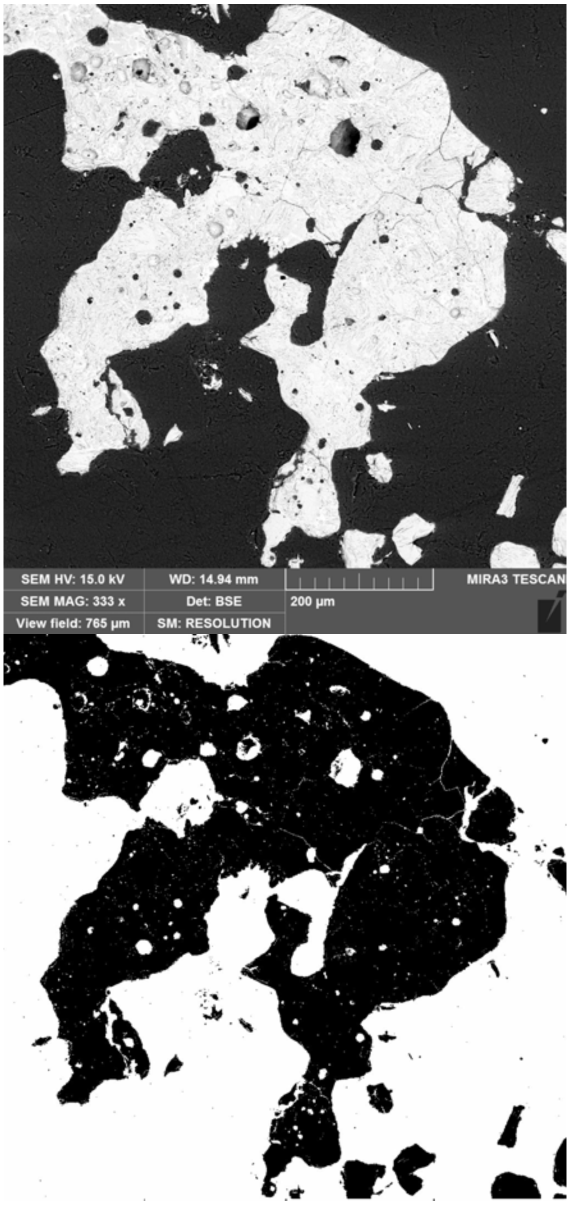

**Fig 2.** (top) SEM BSE image of an agglutinate made from laser weathered San Carlos Olivine. The agglutinate appears to have incorporated material from more than one event. (bottom) Binary image made from BSE for characterizing the shape, size, and vesicle space in the agglutinate.