MOCHII 'L' SPECTROSCOPIC ELECTRON MICROSCOPE: A REMOTE-CONTROLLED LUNAR SURFACE GEOCHEMICAL ANALYZER

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Introduction: The scheduled and imminent return of humans to the Lunar surface with the Artemis missions opens magnificent opportunities to answer key scientific and engineering inquiries. Achieving the mission's science objectives requires a directed strategy and novel technologies that can catalyze understanding of fundamental Lunar processes. Since the return of the Apollo samples, much Lunar regolith morphological and chemical characterization has been done on Earth using scanning electron microscopy (SEM) in concert with energy dispersive X-ray spectroscopy (EDS), which can bridge structure together with underlying physical processes. What if we brought SEM-EDS to the Lunar surface?

Mobile miniature SEM: Over the past decade, coauthors have successfully built, flown, and operated a human spaceflight-certified mobile spectroscopic SEM platform called Mochii [1]. This compact and power-efficient (13 kg, 250 cm tall, 100W) micronanalyzer is currently available to the research community for microgravity research in low Earth Orbit (LEO), as part of part of facility services at the ISS National Laboratory. $\text{Mochii}_{\text{ISS-NL}}$ is a private-public partnership between Voxa, Astromaterials Research and Exploration Science (ARES), and Engineering & Health & Performance Directorates (HEOMD) of NASA Johnson Space Center (JSC). As part of the payload's verification and demonstrations, we conducted *in-situ* analysis on a fragment of the Martian meteorite Allan Hills 84001 (ALH84001, 200) on-orbit [2], and executed *in-situ* analyses of unknown EVA samples during the NEEMO XXIII underwater mission [3].

From this technology heritage on ISS, we are building Mochii 'L', a chamberless portable SEM+EDS for the Lunar surface. This compact (<25kg, <25W) wireless surface experiment station will perform chemical microanalysis and nanoimaging, delivering:

- Real-time geochemical analyses answering urgent and historical scientific inquiries
- Composition-driven selection of new Lunar regolith + traceability of possible sample change (hydration/oxidation) on return to Earth.
- Geochemistry informing future iterative inquiries and ISRU/ISM workflows
- Optional analyses of harvested cores and samples dovetailing with other Artemis experiments
- Continued analysis of staged samples post-crew departure

New Lunar science: Mobile miniature SEM provides the means to characterize previously untouched regions of the Lunar regolith and could deliver new insights into the formation and evolution of the Lunar surface. Even with the >380 kg of returned Apollo rocks and regolith, <10% of the Lunar surface was sampled, biased along equatorial regions. Direct *in-situ* microanalysis on the Lunar surface provides answers such as: **1.** How the solar environment modifies the surface regolith through ion implantation and surface sputtering (informing remote sensing of both the Moon and other airless bodies); **2.** How volatile and chondritic phases including hydrocarbons remobilize and deposit (through ID of extralunar dust impactors and their sources such as meteoritic material and terrestrial debris); **3.** How pyroclastic deposits form and are differentiated (e.g., volcanic glass beads vs. impact-generated glass spherules, through ID of vapor-deposited coatings on the bead surface, and constraining variability of Lunar basalts and assessing volatiles), and **4.** What is the mineralogy and external morphology of Lunar particles *in-situ* in the human respirable size fraction, a prerequisite to ID and mitigate human long-duration Lunar exploration risks.

Mochii L will use our proven ~200mm electron-optical column run at 12kV tripod-mounted under a solar panel shade. It will use a cold field emission source and 4x EDS+backscatter detectors newly enabled by Lunar chamberless operation. The crew simply leaves EVA samples—dust, sediment, rocks—on a 3-axis ~25 cm auto-stage for scientists to remote analyze by iPad over ~1Mbps low commanding downlink.

Lunar *in-situ* SEM+EDS reduces sample return need, analyzes samples in their pristine state, and enables tagging of unique/unusual samples for return to Earth, promising transformative knowledge of the Lunar regolith and accelerating mission science return.

References:

[1] https://www.nasa.gov/mission_pages/station/research/experiments/explorer/Facility.html?#id=7657
[2] Own C. S., et al. (2022) *Microsc. & Micronal, 28 (Suppl. 1).*
[3] Own C. S., et al, (2019) *Microsc. & Microanal.* (https://www.microscopy.org/MandM/2019/program/abstracts/PDP-6.pdf)