Hyperspectral Mineral Mapping of the Lunar Surface

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Introduction: Artemis III will provide the first opportunity for in-situ direct human information gathering to support NASA's long-term sustainability goals. Collecting samples is essential, but very limited due to return mass constraints. In lieu of a physical sample, a suite of human operated instruments that can characterize surface content is essential to maximize the value of the early missions. To understand the evolutionary history of the lunar surface it is critical to accurately map the distribution and abundance of distinct mineral types and to determine their chemical, mineral and physical properties. Spectral observations of the lunar surface from orbit in the visible and near infra-red (VNIR) have provided important information on the mineralogical record of the lunar surface, with orbital-based VNIR maps indicating the signatures and proportions of distinct minerals, e.g. pyroxene, plagioclase and olivine, across a diversity of lunar regolith and compilations of observations across a range of terrain (e.g. crater floors, walls, rims and peaks as well as ejecta rich regions) have been able to provide some stratigraphic information on the lunar crust [1-3]. However, hyperspectral imaging from orbit is limited by poor spatial resolution and, as a consequence, their signals may be dominated by surficial weathering and dust distributions, as has been shown recently on Mars [4]. Surface-based hyperspectral data from the Chang'E rovers [5,6] in the VNIR wavelength range have demonstrated significant departures from the expectations inferred from space. Specifically, the Visible Near Infrared Spectrometer (VNIS) on Chang'E-3 found that in-situ spectra of an undisturbed region near the landing site indicated a surface that is significantly less mature (i.e., less affected by space weathering) than was inferred for the same region by orbiting spectral imagers [5]. Subsequent observations by Chang'E-4 determined lunar mineral compositions from regolith near that landing site that were consistent with orbital spectra confirming the potential origin of the surface material as a nearby crater, and, more interestingly, the mineralogy of a rock that indicated a different origin [6]. These results stress the importance of detailed hyperspectral field work on the lunar surface. The Chang'E results were limited to a small number of sites close to the landing stage and performed robotically. While they provided key comparisons between lander-blasted and pristine regolith, as well as direct comparison with remotely sensed observations, they only provided limited direct spectral characterization of boulders and only within a limited range of terrain.

Motivation: The need for detailed field measurements to provide ground truth in support of remotely sensed observations is a high priority science objective of the Artemis III mission [7]. Additionally, the ability to make observations in several distinct sites from a range of angles and under a range of lighting conditions is ideally suited to astronaut operation. To achieve the highest quality science within the various constraints of the Artemis mission, the astronauts need to be provided with the necessary tools and instrumentation to make optimum use of their limited time on the lunar surface. The ability to perform on-site spectral characterization over large areas and across a diverse array of lunar terrain is a critical approach that will provide a versatile and powerful means to examine samples in-situ, optimizing the selection of samples to be return for detailed analyses on the Earth.

Research Challenge: The Chang'E in-situ mineralogical studies have shown the versatility of reflectance hyperspectral observations in the VNIR range. Portable snapshot hyperspectral imaging is a powerful tool for identifying and characterizing a wide range of lunar terrain in-situ and under a wide range of conditions (lighting, viewing angles, resolutions). The VNIR wavelength range (400 - 2400nm) in particular contains a wealth of mineralogically important information, providing knowledge on the origin, relative age evolution and weathering of the lunar surface. For example, the ability to determine compositional information of rocks, e.g. relative proportions by volume of pyroxene, olivine, or plagioclase, can be critical in identifying the source region of the initial impact yielding a better picture of the large-scale quantitative variations in lunar terrain. The challenge is to provide portable, robust, low-resource instrument suite [8, 9] that can yield high fidelity in-situ measurements at a number of sites accessible to the landing crew under a wide range of observing conditions in order to provide more detailed classification of rock and regolith composition, ground-truth for remote sensing observations and foundational information for subsequent sample-return selection and analyses. Compact snapshot hyperspectral imagers allow us to meet this challenge by providing the ability to observe a large-area mineralogical scene with high spatial and spectral resolution while meeting the low-resource (mass, power, volume) demands of a lunar mission.

Additional Hyperspectral Utility in Support of Artemis Strategic Objectives: It is worth noting that a human mission to the surface of the Moon will be highly constrained given the time-pressure to complete a wide range of scientific experiments both for understanding the Moon and for paving the way for a sustainable human presence in and around the Moon and on to Mars. A hyperspectral imaging system can potentially be reconfigured to perform additional science functions such as monitoring and characterizing ISRU processes (outgassing analysis, water/ice contaminants etc.), be used to assist in crew health monitoring, e.g. fundus camera observations of the retina for assessing low-gravity impact on astronaut vision, and provide important pre-cursor astronaut training and scientific approaches for application to Mars surface operations.

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