MINERALOGICAL, ELEMENTAL, AND TOMOGRAPHIC RECONNAISSANCE INVESTIGATION FOR CLPS (METRIC).
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Introduction: Geological solids are characterized by their mineral structure, elemental composition, and morphology. The Mineralogical, Elemental, and Tomographic Reconnaissance Investigation for CLPS (METRIC) is an instrument payload that will quantify all three. METRIC comprises a suite of instruments in a lander to perform X-ray diffraction (XRD) for mineral structure, X-ray fluorescence (XRF) for elemental composition, and X-ray Micro Computed Tomography (XCT) for 3D internal micromorphology. The instruments are accompanied by cameras to provide geologic context. The Honeybee Robotics PlanetVac pneumatic sampling and transfer system [1] will be positioned on a lander footpad to deliver sieved regolith to the X-ray instruments for analysis. This payload is envisioned for deployment to the lunar surface on a Commercial Lunar Payload Services (CLPS) lander (Figure 1) but could be carried on a lander or rover to any solid surface in the solar system.

Instrument Suite:

METRIC XRD/F. The XRD/F instrument draws on heritage from the Mars Science Laboratory CheMin instrument [2] and improves upon the design in multiple ways [3]. Like CheMin, Rietveld refinement and full-pattern fitting of METRIC XRD data can identify minerals at a detection limit of ~1 wt.%, quantify their abundances when present at $\geq$3 wt.%, and determine elemental composition of all minerals present at $\geq$5 wt.% from their refined lattice parameters [4,5]. The angular range of the METRIC XRD has been shifted to higher 2θ compared to CheMin to enable detection of elemental iron, making it more relevant for use on the Moon. The most significant improvement to the CheMin design is the production of two X-ray beams to analyze materials for XRD and XRF separately, allowing for quantitative geochemical analysis. Simulations of METRIC XRF data show that the instrument can quantify elements $11 \leq Z \leq 26$ present in abundances >84 μg/g, Zr present in abundances >2 μg/g, La through Lu present in abundances >5 μg/g, and Th present in abundances >3 μg/g. The quantification of rare-earth elements and Th are especially important for lunar deployment and the identification of KREEP components and elucidate their origins.

METRIC XCT. XCT is a non-destructive, high-resolution three-dimensional imaging technique used to analyze the internal features of multiphase materials and to characterize porous granular materials [6,7]. An XCT instrument has never been flown on a planetary mission, so the first deployment of the METRIC XCT will be an important technology demonstration for future missions. The METRIC XCT design utilizes components already developed to high TRL for XRD/F, reducing the cost and schedule risk normally associated with development of a new instrument. Data collected by the breadboard version of METRIC XCT have a 30 μm spatial resolution, allowing for the characterization of grain sizes and shapes as well as vesicle shape, size, and orientation [8]. Crystal morphologies derived from METRIC XCT data complement the bulk mineralogy determined by METRIC XRD and provide a measure of grain size distribution for the different phases.

Context Cameras. Four color cameras positioned on a CLPS lander will provide information on the depth of the regolith samples and geologic context of the landing site. One camera will be positioned on the underside of the lander oriented to the nadir to collect video imagery during the landing and evaluate the extent of regolith removal/disturbance. A second camera will be mounted on the lander leg associated with PlanetVac to collect video imagery during sampling to document and validate the representativeness of the ingested material. A color camera stereo pair will be placed on the lander to collect images from the horizon to near the base of the lander, providing geologic context of the landing site for remote spectroscopy.

Sample Delivery: PlanetVac is integrated to a footpad of the lander and will deliver sieved regolith to the XRD/F and XCT separately. Briefly, high-pressure $N_{2(g)}$ agitates the regolith and blows it through a 1 mm screen. The <1 mm material is transported up the Transfer Tube to two cyclone separators (one for the XRD/F and one for the XCT), where the sample is separated from the gas flow. A screen at the base of each

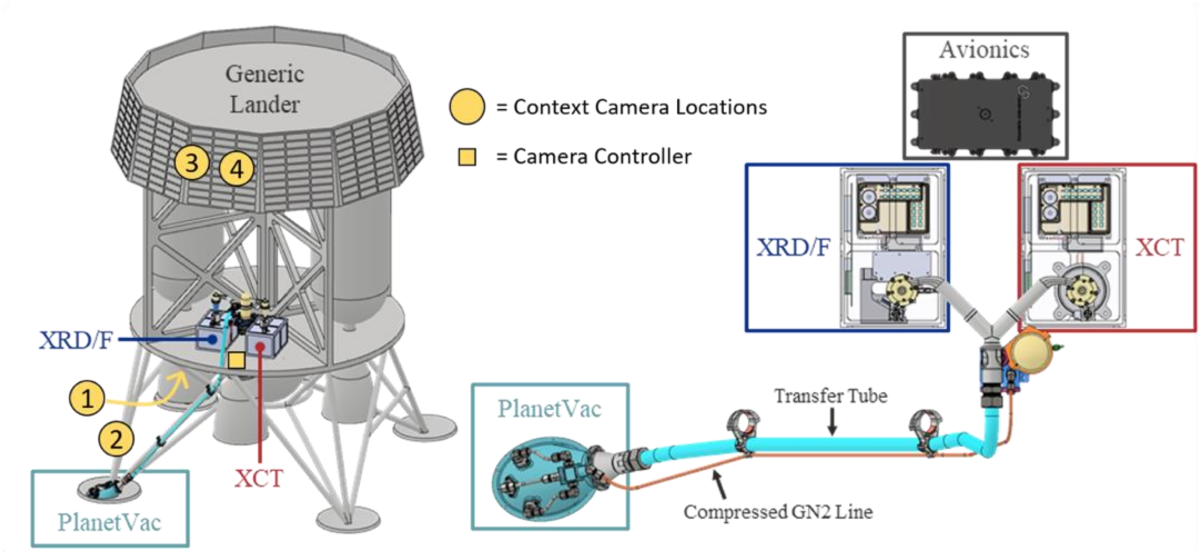

Figure 1. METRIC layout, showing regolith acquisition with PlanetVac, delivery to XRD/F and XCT, and notional camera locations.

cyclone separator sieves the sample (<150 μm for the XRD/F and <750 μm for the XCT), and a small amount of material (<1 g) is dispensed into each instrument's cell/tube.

PlanetVac is an ideal sample delivery system for a lander payload because it doesn't require a complex robotic arm. In other mission scenarios where a robotic arm is a possibility, regolith could be scooped and sieved, or rocks could be drilled and powdered before delivery to the XRD/F and XCT.

Science Questions that can be Addressed with the METRIC Payload: Elemental composition, mineral structure and abundance, and micromorphological features (e.g., grain size and shape) can be used to address a variety of questions related to the origin and evolution of terrestrial planetary bodies. The METRIC payload was submitted to the Payloads and Research Investigations on the Surface of the Moon (PRISM-2) call for deployment at the Gruithuisen Domes, where silica polymorphs and possible hydrous minerals will be readily identified by METRIC. These volcanic features are enriched in SiO_2 based on orbital thermal-infrared data [e.g., 9,10]. Their petrogenesis remains enigmatic, and the domes and other high-silica regions on the Moon are hypothesized to have formed via a variety of mechanisms including fractional crystallization, silicate liquid immiscibility, and/or basaltic underplating [9,10]. Mineralogical and geochemical data from the METRIC payload can be used in thermodynamic models to distinguish between these formation hypotheses. Thermodynamic models using METRIC data can also be used to constrain properties of the magma(s) that formed the domes, including composition, viscosity, and solidus/liquidus conditions. Micromorphological data from the METRIC XCT can provide information on vesicle size and shape to infer volatile content and interpret explosive and effusive volcanic products. METRIC XRD/F can quantify the amount of X-ray amorphous material (i.e., glass), determine its SiO_2 content and its overall elemental composition. This will further constrain the origin and method of emplacement of the material.

Although the METRIC payload is well-suited for addressing the petrogenesis of the Gruithuisen Domes, the payload could be used at other lunar sites and other solid solar system objects to address fundamental science questions. The METRIC payload could analyze regolith from any rocky planetary body (e.g., Mercury, Venus, Mars, asteroids), and the combination of mineralogy, geochemistry, and micromorphology could be used to constrain magma composition and evolution of those bodies. For geologically complex bodies that have multiple sources contributing to the regolith, data could be used identify different components in the regolith using linear least squares mixing models.

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