A SIMPLE CAMERA WITH SPECTRAL RESPONSE TAILORED FOR LUNAR ROCK AND SOIL DISCRIMINATION: A TOOL FOR ASTRONAUTS AND ROBOTS. David T. Blewett[1,*] , Charles A. Hibbitts[1], and John Boldt[1]. [1]Space Exploration Sector, Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Rd., Laurel, MD 20723 USA. (*david.blewett@jhuapl.edu).

Introduction: We propose a simple, COTS-based, low-cost multispectral framing camera that will provide a combination of morphology imaging with spectral parameter mapping. Imaging using multiple diagnostic wavelengths selected especially for study of lunar rocks and soils will provide a major increase in the science return compared to traditional RGB cameras. The instrument is ideal for lunar landed missions of any scale: early commercial landers, sample-return landers, robotic rovers, or as a hand-held tool for augmenting geological field work conducted by astronauts.

Optimal Color Filters for Lunar Study: The causes of the Moon's color and spectral variation in the visible to near-infrared (vis-NIR, ~400-2500 nm or 0.4–2.5 μm) are fairly well understood. Lunar minerals, rocks, and soils do not contain sharp absorption bands. According to Hapke's model for the reflectance of a silicate regolith such as the Moon's [1], the reflectance properties in the near-ultraviolet to near-infrared portion of the spectrum are controlled chiefly by three components: (a) opaque minerals such as ilmenite ($FeTiO_3$; titanium content is the basis for classification of lunar volcanic rocks); (b) ferrous iron (Fe^{2+}) in transparent silicate minerals and glasses (variations in iron content are fundamental to understanding the history of the lunar crust and interior), and (c) nanometer-sized particles of metallic iron (nsFe). The nsFe accumulates in materials on the lunar surface in response to exposure to fluxes of solar-wind ions and bombardment by micrometeoroids [e.g., 2] As demonstrated by Lucey and colleagues [3–5], a set of three color filters (at ~415, 750, and 950 nm) enables mapping of the Moon in terms of iron content (FeO), titanium content (TiO_2), and optical maturity (OMAT). Mapping of FeO, TiO_2, and OMAT was achieved from orbit by the *Clementine* multispectral filter-wheel camera (Fig. 1), contributing to numerous studies of various aspects of lunar geology.

A Science Camera for the Lunar Surface: For future assets deployed to the lunar surface (astronauts or robotic landers/rovers), it will be desirable to collect images of the surroundings for geologic context, traverse planning, or sample selection. This is true regardless of the landing target site (polar, mid-latitudes, or equatorial) or specific mission goals. Additional science is enabled if the images provide compositional information on the rocks and soils in the scene. However, spectral imagers (e.g., in the visible/near-infrared or thermal-infrared) such as imaging spectrometers or multispectral filter-wheel cameras, are expensive and resource intensive (mass, power) and due to the nature of their operation, do not lend themselves well to unstable platforms such as vehicles or hand held. A monochrome CCD imager provides morphology imaging, and a red-green-blue (RGB) camera with a Bayer-filter pattern can provide "true color" imaging (that is, the images can be processed to present an appearance similar to what the human eye would see – an approach used on the *Chang'E-3* and *-4* landers and rovers [6]). Unfortunately, the transmission characteristics of standard RGB filters are wide and wavelengths are not optimized, and thus provide only very limited compositional information [7, 8].

We propose a camera that employs a focal-plane array (FPA) with a Bayer-like pattern of filters that are specifically tailored for extraction of maximum information from the reflected visible/near-infrared spectrum of the lunar surface. Thus, our instrument, named the Mahina Color Camera, will provide the capability to construct maps of compositional and space weathering parameters. The camera itself has no moving parts and operates as a framing imager, with no need for scanning to build up an image. This make MahinaCam an ideal choice for any mission to the lunar surface (Fig. 2), by enhancing return of science related to site geology/composition (volcanism, impact mixing), regolith development, space weathering, surface texture and photometric analysis, and movement of surface dust. With the addition of straightforward on-board processing, including machine learning, MahinaCam could offer a means for human or robotic field geologists to perform real-time or autonomous identification of rocks or soils for sampling based on specific target characteristics, as well as flagging anomalous material.

Instrument Development: CCDs with custom, narrow/medium-band filters in a Bayer-like pattern are commercially available, and cameras using this FPA technology have flown in space. The technologies employed to create this type of FPA are well established. For the lunar application, we consider the camera concept as a whole to enter development at TRL 4. In order to raise readiness to TRL 6, needed for proposal to a flight program, the following developments are necessary: (i.) ruggedizing the COTS camera to survive launch and landing environments, (ii.) designing an enclosure to protect the camera from the lunar thermal environment, and (iii.) development of custom flight-ready optics. Camera support electronics do not carry TRL concerns and are likely to be platform specific, and would be developed under an effort separate from that aimed at raising the TRL of the camera itself.

Camera Resource Utilization: Size, weight and power estimates are based on a COTS camera with a custom-designed lens and thermal enclosure.

Size. A COTS camera employing the filter pattern array is ~50 × 50 × 80 mm. The fore-optics are estimated to be 50 mm long, excluding an optional baffle. Addition of a thermal housing would add 10 mm to each side; this excludes any additional camera support electronics.

Mass. The mass of the COTS camera is <400 g. We expect ruggedization (bonding, staking, heatsinking) to increase camera mass to no more than 400 g. The custom optics are estimated at ~200 g. A thermal enclosure (aluminum, MLI, OSR) is estimated as 400 g as an upper bound. In total, the MahinaCam mass is ≤ 1 kg, without any additional camera support electronics.

Power. Nominal power dissipation of the camera is ~5 W and depends on frame rate and the type of communications interface (CameraLink, GigE, etc.). Additional power is required for any camera support electronics and is dependent on the vehicle power and communications interfaces; ~3 W is a ROM estimate.

Cost for Development: The costs for a project to raise the MahinaCam TRL to 6 in a NASA planetary instrument development program (e.g., DALI, MatISSE) are estimated to be ~$1.2M. Additional work would be needed for design of the electronics, specific to the platform hosting the camera.

CONOPS/Astronaut Interaction: Several application scenarios for MahinaCam can be envisioned. These include (i) A low-cost compositional context imager on a stationary lander. The compositional and OMAT maps provided by the camera, merged with the morphology images, could be used to efficiently guide a robotic arm to the samples of the greatest interest. (ii) A panoramic imager on a robotic rover. In this application, MahinaCam would be used in the manner of a traditional RGB camera for traverse planning, hazard identification, and morphological study of the site geology. MahinaCam's lunar-optimized wavelength capability offers the rover science team the added ability to survey the surroundings and identify rocks or soils based on specific compositional or maturity criteria. (iii) A geological survey tool for astronauts, mounted on a tripod or human-driven rover, or hand-held/chest-mounted on the astronaut's spacesuit. On a tripod or human-operated rover, MahinaCam would provide function similar to that on a robotic rover. If used as a hand-held/chest-mounted sensor, MahinaCam could provide real-time compositional maps on a screen or heads-up display. An astronaut might select image modes such as "iron vision" or "anomaly detection".

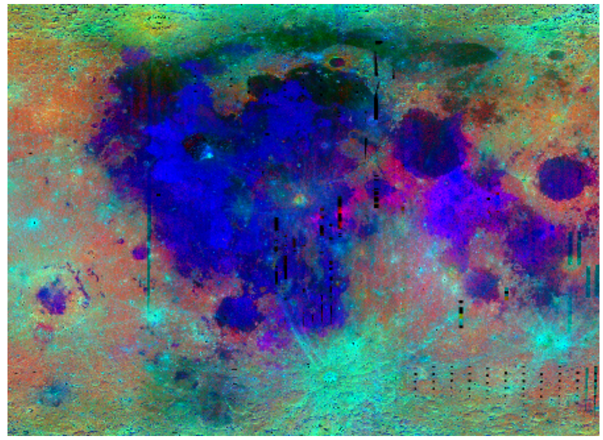

Fig. 1. Image of the nearside constructed from the *Clementine* 950-nm/750-nm ratio in the red channel, 750-nm reflectance in green, and the 415-nm/750-nm ratio in blue. The wide range of color units that are present illustrates the type of information that will be available for mapping any future landing site with MahinaCam.

Fig. 2. *Chang'E-3* rover RGB image. The view shows meter-size boulders in the foreground, and looks across a 450-m diameter crater. Tremendous science return would be realized if the spectral diversity revealed in Fig. 1 was applied to surface scenes like this one. MahinaCam will enable anomalous material to be identified, and allow compositional comparisons of surface material with lithologies excavated from depth. OMAT maps will support detailed study of the way that fresh rock is weathered to mature soil.

References: [1] B. Rava and B. Hapke (1987), *Icarus 71*, 397. [2] B. Hapke (2001), *JGR 106*, 10,039. [3] D. T. Blewett et al. (1997), *JGR 102*, 16,319. [4] P. G. Lucey et al. (2000a), *JGR 105*, 20,297. [5] P. G. Lucey et al. (2000b), *JGR 105*, 20,377. [6] X. Ren et al. (2014), *Res. Astron. Astrophys. 14*, 1557. [7] T. X. Choi et al. (2018), *LPSC 49th*, abstr. no. 1148. [8] T. X. Choi et al. (2019), *LPSC 50th*, abstr. no. 1453.