THE *LUNAR VERTEX* CAMERA ARRAY. Brett W. Denevi[1], Heather M. Meyer[1], Giuseppe Pasqualino[2], William F. Ames[1], Scott A. Cooper[1], Ann L. Cox[1], Alexandra R. Dupont[1], James P. Mastandrea[1], Krista McCord[2], Alexandra V. Ocasio Milanes[1], Howard W. Taylor[1], Calley L. Tinsman[1], and David T. Blewett[1], [1]Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA, [2]Redwire Space, Littleton, CO 80127, USA.

Introduction: *Lunar Vertex* [1] is a suite of instruments and rover, selected through NASA's first Payloads and Research Investigations on the Surface of the Moon (PRISM) call, that will be used to explore and characterize the Reiner Gamma swirl in Oceanus Procellarum (landing site at 7.585°N, 301.275°E [2]). The *Lunar Vertex* payload includes the Vertex Camera Array (VCA), which will provide 360° imaging from the Commercial Lunar Payloads Services (CLPS) lander built and operated by Intuitive Machines.

Science Objectives: VCA objectives are focused on contributing to the *Lunar Vertex* goal of testing hypotheses for the origin of lunar swirls (other goals [1] are related to the origin of the magnetic anomaly and structure of the mini-magnetosphere). VCA images will be used to characterize the landing site geology and to understand the physical properties of the lunar regolith in the region affected by the impinging rocket plume (the "blast zone", estimated to extend up to ~50 m from the lander), the pristine swirl surface outside of the blast zone, and within wheel tracks left by the rover as it crosses both terrains. VCA will collect a suite of images every 3.75° change in solar incidence angle (every seven hours) throughout the mission, providing a photometric data set from which the physical properties of the regolith can be assessed via radiative transfer modeling (e.g., 3–5). The photometric properties of lunar swirls are distinct from those of fresh impact craters [5–9], and have been suggested to indicate swirl formation by a recent or ongoing process, such as a comet impact or unusual dust motion/sorting e.g., [6,10–12]; together with the Rover Multispectral Microscope [13], VCA will help to test this hypothesis.

Instrument Characteristics: VCA is being built by Redwire Space of Littleton, Co. and consists of three clusters of three cameras (Fig. 1) fixed on the lander for 360° panoramic coverage. Each camera has a vertical field-of-view (FOV) of 40.8° and a horizontal FOV of 55.6°, leaving ~15° of overlap with each adjacent camera. The camera clusters are each mounted on a tilting wedge angled 10° downward from the horizontal, so that the FOV extends from ~5 m from the lander to the horizon. The ruggedized optics are from Edmund Optics (see Table 1 for characteristics). VCA makes use of Sony IMX214 detectors, which are backside illuminated CMOS sensors with Bayer pattern (red, green, and blue) filters. The 3120 × 4208 active pixels yield an IFOV of 224 μrad (Table 1).

Fig. 1. VCA engineering model, showing a single cluster of three cameras. VCA is being built by Redwire Space and consists of three clusters positioned around the lander for 360° coverage. The camera housing is 3.1 × 3.26 inches at its base.

Each camera cluster is 0.25 kg, with a peak power of ~10 W during boot up, an idle power of 1.8 W, and a power draw of 2.2 W during imaging/download. There is a single Micro-D connector per cluster, with one RS-422 for commanding and data transfer and one 28 V channel. Images can be read out as RAW10 or JPEG (adjustable quality) format, and are saved to camera on-board storage for compression using the embedded Linux operating system prior to transfer to the lander for downlink. After lossless compression, the data volume of each RAW10 image (with its associated meta data file) is estimated to be 9.05 MB. The meta data file contents include commanded parameters (e.g., exposure time, image format, ISO) and information such as sensor number, time, and temperature.

Calibration: The calibration plan for VCA is driven by the science objectives and associated requirements. Context imaging necessitates a geometric calibration to characterize alignment, magnification, and distortion such that knowledge of feature locations in detector space can be translated into relative or absolute distances. Checkerboard target measurements will be used to determine magnification, and scene images will be used to confirm the relative alignment of the cameras to each other and to the spacecraft. Laboratory images of a grid target will enable measurements of camera distortion. Commercial software from Imatest will be used to calculate the magnitude and direction of distortion across the FOV for each camera, and a simple

equation will describe distortion in a camera model. We are currently working to adapt APL's Small Body Mapping Tool [14] for projection, mosaicking, and analysis of VCA images (and landed image processing in general).

Characterizing the photometric properties of the landing site (reflectance values at different times of day and locations across the scene) requires a radiometric calibration so that DN can be converted to radiance or reflectance regardless of the camera settings and state (exposure time, ISO setting, temperature, etc.). Dark images will be collected that span the full range of commandable exposure times (0.01–680 ms) and temperatures experienced during thermal–vacuum testing (–40 to +75° C). Interestingly, the IMX214 sensor performs an on-chip "Optical Black" correction, where a positive or negative offset is always applied to the image so that the mean DN in masked pixels is adjusted to a value of 64. Because the masked pixels are not read out, the value of the shift is not known. However, initial analysis of dark images collected with the engineering model (EM) suggests that even at the hottest temperatures and longest exposure times, shot noise is so low that the true dark current value must be <10 DN and mean signal (after the Optical Black correction) is always within ±0.8 DN of 64.

Linearity, inverse gain, and flat field measurements will be collected using an LED lightbox at ambient temperature and pressure. Linearity and gain are measured with a photon transfer function, where the exposure time is varied across a fixed light level [15]. Initial EM results indicate the gain is ~6 e^-/DN, and full well is ~5500 e^-; nonlinearity is <2 DN. The absolute radiometric response will be determined by using a xenon lamp to illuminate an integrating sphere, and a measurement will be collected of the interior of the integrating sphere with both a calibrated photodiode and with VCA. The calibrated photodiode thus provides information of scene radiance and to be compared with the corresponding DN levels output by the camera. The absolute radiometric response of the VCA detectors is expected to vary with temperature; thermal modeling predicts the detector temperatures will vary from ~0–63° C throughout the surface mission. To understand the change in radiometric responsivity with temperature, integrating sphere measurements will be repeated from ambient to 70°C.

VCA Status: The VCA EM has been delivered to APL and is being used to test calibration and data processing procedures. The Flight Model build is to be completed by February 2023, with calibration completed shortly thereafter.

Table 1. VCA characteristics

Pixel Pitch	1.12 µm
Pixels	4208 × 3120
Spectral	Bayer RGB, IR-Cutoff
Bit Depth	10-bit (RAW10), 8-bit (JPEG)
Aperture	0.89 mm
Focal Length	5 mm
F-Number	f/5.6
FOV	55.6 × 40.8° (single)
IFOV	224 µrad
Power	1.8 W (idle) 2.2 W (imaging/download) 10 W (boot up)
Mass	0.25 kg (per cluster)
Temperature Range	+25 to +70° (operational) –50 to +85°C (survival)

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References: [1] Blewett D.T. et al. (2022) *LPSC* 53, abs. 1131. [2] Blewett D.T. et al. (2023) *LPSC* 54, this meeting. [3] Hapke, B. (2012) *Theory of Reflectance and Emittance Spectroscopy*, Cambridge Univ. Press, New York. [4] Sato H. et al. (2014) *JGR:Planets*, 119, 1775–1805, doi:10.1002/2013JE004580. [5] Kinczyk, M.J. (2022) *AGU Fall Mtg.*, Abs. P25F-2180 [6] Schultz P.H. and Srnka L.J. (1980) *Nature*, 284, 22. [7] Kaydash V. et al. (2009) *Icarus*, 202, 393. [8] Pinet P.C. et al. (2000) *JGR*, 105, 9457. [9] Kreslavsky M.A. and Shkuratov Y.G. (2003) *JGR*, 108, 5015. [10] Bruck Syal M. and Schultz P.H. (2015) *Icarus*, 257, 194. [11] Garrick-Bethell I. et al. (2011) *Icarus*, 212, 480. [12] Pieters C.M. et al. (2014) *LPSC* 45, abs. 1408. [13] Klima R.L. et al. (2023) *LPSC* 54, this meeting. [14] Ernst C.M. et al. (2018), *LPSC* 49, abs. 1043. [15] Janesick J.R. (2007) *Photon Transfer*, SPIE Press, Bellingham, WA.