L-CIRiS, AN INSTRUMENT FOR HIGH-SPATIAL RESOLUTION THERMAL INFRARED IMAGING ON THE LUNAR SURFACE.

D. P. Osterman[1], P.O. Hayne[2] T. Kampe[1], G. Reavis[1], R. Warden[1], [1]Ball Aerospace, 1600 Commerce St., Boulder, CO 80301, dosterma@ball.com, [2]University of Colorado, Boulder, Paul.Hayne@Colorado.edu

Introduction: The Lunar Compact Infrared Imaging System (L-CIRiS) is a multispectral imaging radiometer designed for mineralogical and thermophysical measurements on the lunar surface. NASA has selected L-CIRiS for a mission to land within 6 degrees latitude of a lunar pole, with transport to the Moon provided through NASA's Commercial Lunar Payload Services (CLPS) program. From its mounting location on the deck of a lunar lander, L-CIRiS will scan the landscape in four spectral bands, generating images of surface temperature and spectral emissivity. Emissivity images will be further processed to generate high-spatial resolution (< 1 cm) maps of silicate mineral composition. The L-CIRiS design is adapted from the CIRiS instrument, developed and built by Ball Aerospace [1], and launched into low earth orbit on a cubesat spacecraft on December 5, 2019.

Lunar Science and Exploration with L-CIRiS: L-CIRiS will provide in situ context for understanding the Moon's crustal evolution, regolith formation and the processes by which complex thermal environments produce cold-traps for volatiles such as water. Data from L-CIRiS will provide the first-ever view of compositional variations of lunar minerals on the Moon's surface at spatial scales down to < 1 cm. The results will shed light on phenomena contributing to crustal evolution, including large- and small-scale impact events, volcanism, and space weathering [2]. L-CIRiS temperature maps will help quantify the small-scale shadowing that may lead to volatile cold-trapping at the Moon's high latitudes [3,4]. Correlation of L-CIRiS thermal images with those currently and previously acquired from orbit by LRO Diviner will provide critical ground truth to the orbital images. The results will enable the lunar science community to implement new tests of hypotheses regarding the formation and evolution of the Moon. The results will also contribute to future exploration activities by measuring thermal and geotechnical properties of lunar regolith relevant to landers and rovers, thereby supporting the design of safe and effective systems for future robotic and human missions.

L-CIRiS data products Raw data from L-CIRiS will be processed in several steps. Map projection will employ image pairs from the LRO Camera [5]. The final, processed, Level 3 data will include:

1. Christiansen-Feature (7 – 9 um) and multi-band emissivity maps
2. Thermal inertia maps (and the equivalent regolith porosity)
3. Rock abundance maps and rock thermal inertia
4. Specialized products including surface roughness and shadow fraction

Instrument Description: L-CIRiS views the lunar landscape through an optical port with boresight pointed slightly (~ 8°) below the horizon (Fig. 1). The downward tilt results in images whose vertical direction encompasses scene features from the horizon to a foreground at < 4 m distance. An intermediate fixed focus enables good image quality throughout this range. The +/- 180° azimuthal rotation stage rotates the instrument, and its field of view (FOV), in steps of approximately 1°. Panoramic images are created by stitching together the individual images acquired at each rotation step. A filter assembly over the focal plane divides the FOV into four equal vertical fields, each imaging in a different spectral band. Azimuthal rotation therefore simultaneously generates the component images for panoramic composite in all four bands.

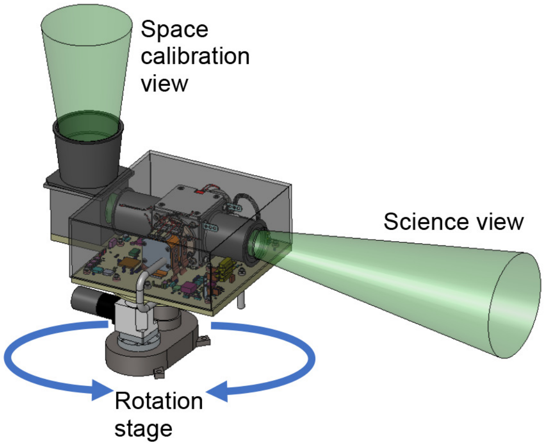

Figure 1. The L-CIRiS instrument will scan the lunar landscape from the deck of a lander.

On-board calibration. L-CIRiS implements end-to-end calibration over the entire "photons-to-bits" signal chain, including all optical elements. To calibrate, a scene-select mirror redirects the FOV from the science port to any of three calibration views. In one calibration position the instrument looks to deep space through a mirror (Fig. 1). Two additional sources for calibration are flat-panel substrates coated with carbon nanotube thin-films, with measured emissivity > 0.9965. Calibration with deep space (effectively ~10 K) and the on-board sources, in the range of 270 K to 320 K, bracket most of the scene temperature range near the lunar pole. Operating the on-board sources at different temperatures is useful for characterizing potential response nonuniformity.

Wavelength bands The L-CIRiS spectral band choices (Table 1) include three bands to distinguish compositional differences using the Christiansen feature [6], and one broad band to measure surface temperatures. The preliminary choice for the three mineralogy bands makes them identical to those of LRO Diviner, so that correlation of images acquired by both instruments can be implemented in a common band set.

Band	Wavelength Range (um)	Primary function
1	7.7 to 8.1	Mineralogy
2	8.0 to 8.4	Mineralogy
3	8.3 to 8.9	Mineralogy
4	7.5 to 13.5	Temperature imaging

Table 1. L-CIRiS spectral bands

Instrument performance The intermediate-distance fixed focus of the L CIRIS optical system achieves two goals. For ranges < 5.3 m it attains sub-centimeter spatial resolution, providing lunar thermophysical data at this scale for the first time. Focus at the kilometer range is also good enough for useful image overlap with LRO Diviner images. Diviner pixels have a typical ground sample resolution of 250 meters.

Range (m)	Spatial Resolution (cm)
3.6	0.7
5.3	1.0
10	3.1
100	40
1000	400

Table 2. L-CIRiS spatial resolution as a function of range. Note different units in two columns.

Calculated emissivity precision is < 0.02 for illuminated scene features, enabling identification of silicate minerals. Temperature precision varies from < 10 mK for 300 K targets to < 2 K for 100 K targets.

Size, weight and power Projections for L-CIRiS, based on modifications to the existing CIRiS instrument, are for a volume < 30 cm x 30 cm x 20 cm, mass < 9 kg and average power consumption in science mode < 13 W, inclusive of all components including heater power. L-CIRiS is therefore suitable for future operation on a rover, or transport by an astronaut.

References:

[1] Osterman, D., Hayne, P., Warden, R., Reavis, G., Kampe, T., & Mitchell, S., *Proc. SPIE 11131, CubeSats and SmallSats for Remote Sensing III* https://doi.org/10.1117/12.2531404 (2019) [2] Pieters, C. M., Head, J. W., Sunshine, J. M., Fischer, E. M., Murchie, S. L., Belton, M., ... & Jaumann, R. (1993), *J. Geophys. Res.*, *98*(E9), 17127-17148. [3] Paige, D. A., Siegler, M. A., Zhang, J. A., Hayne, P. O., Foote, E. J., Bennett, K. A., ... & Foote, M. C. (2010), *Science, 330* (6003), 479-482. [4] Hayne, P. O., Greenhagen, B. T., Foote, M. C., Siegler, M. A., Vasavada, A. R., & Paige, D. A. (2010). [5] Laura, J. R., Miller, D., & Paul, M. V., In *Lunar and Planetary Science Conference,* Vol. 43 (2012). [6] Greenhagen, B. T., et al (2010), *Science, 329*(5998), 1507-1509.