A COMPACT, LOW-POWER PLANETARY IMAGER FOR RADIOMETRIC LWIR AND REMOTE THERMAL IMAGING. R.N. Schindhelm[1], D. Osterman[1], M. Veto[1], [1]Ball Aerospace

Introduction: Ball Aerospace has developed a low size, weight and power instrument for radiometrically calibrated imaging in multiple Long Wave Infrared (LWIR) bands. The instrument is called the Compact Infrared Radiometer in Space (CIRiS) and has potential planetary applications for minerology, surface thermal mapping, heat flux measurement, detection of trace gases and particulates, and other atmospheric phenomena. CIRiS includes a versatile on-board calibration system that supports a range of modes optimized for different conditions, e.g., thermal mapping of terrain that is hot, cryogenic, or a combination of the two. CIRiS provides three calibration views: to deep space, to a source at the instrument temperature, and to a heated source with selectable temperature above that of the instrument. A multi-element filter over the FPA enables multi-spectral operation, including pushbroom scanning of the instrument field of view (FOV) in the different bands over the same planetary surface area. The present CIRiS implementation has three discrete bands in the range from 7.5 um to 13.75 um and an F/1.8 transmissive optical system with 9 deg x 12 deg FOV. A modular architecture facilitates changes to the filter and optical parameters. Ball has designed additional CIRiS optical systems for specific planetary missions. CIRiS has been integrated to a 6U CubeSat spacecraft for LEO and has completed calibration and thermal testing in a thermal-vacuum chamber. Demonstration is planned for 2019 in low earth orbit.

Instrument Overview: CIRiS is a successor of the Ball Experimental Sea Surface Temperature Radiometer (BESST) which has been demonstrated in numerous aircraft and UAV campaigns [1,2]. The 18 x 19 x 9 cm^3 instrument envelope is compatible with the size, weight and power requirements of a 6U Cubesat spacecraft (Fig. 1) and the need for thermal insulation space between the instrument and spacecraft walls. CIRiS has a modular structure that facilitates the replacement or modification of subsystems including each of the two calibration sources, the FPA, optics and scene-select motor.

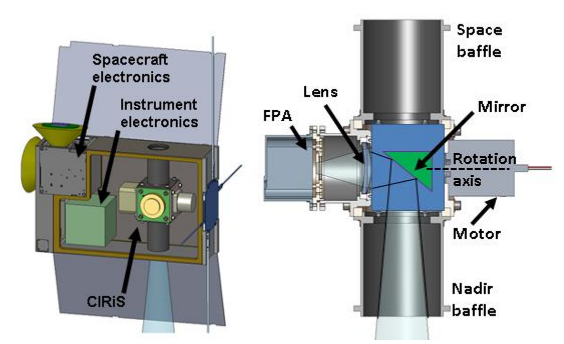

Figure 1: Left – The CIRiS instrument integrated in the 6U spacecraft. Right – The scene select mechanism rotates the FPA field of view in four directions.

Key to the architecture is a fold mirror that rotates the FOV of an uncooled microbolometer FPA in four directions. This enables the FPA to selectively view the object of interest in the nadir direction, deep space in the zenith direction or either of two on-board calibration sources (Fig.1). Incoming rays strike the mirror at the same fixed angles of incidence, which eliminates polarization changes. One carbon nanotube source is in thermal contact with the instrument structure while the other has thermal control for temperatures up to 20 °C above the instrument's ambient temperature.

The uncooled microbolometer FPA views external scenes through an infrared transmitting window. A three-element butcher block filter is mounted over the window, defining spectral bandpasses on three rectangular regions of the array. Pushbroom scanning over the object of interest translates the scene sequentially across the FOV of each rectangular array segment with its own bandpass. CIRiS employs a commercial infrared detection "engine" combining an uncooled microbolometer FPA and read-out electronics. The CIRiS baseline selection is a unit with 640 x 480 format and 12 um pixels. The FPA consists of a vanadium-oxide based pixel array monolithically fabricated on a silicon Read Out Integrated Circuit (ROIC) chip. The ROIC implements signal processing up to, and including, A to D conversion. Under funding from another program Ball Aerospace is qualifying the radiation performance of two commercial uncooled infrared FPA models that are candidates for CIRiS and other missions. The FPA and electronics require 3.5 W, and heating for temperature stabilization is estimated at 4 – 6 W.

The two on-board CIRiS calibration sources comprise CNT films deposited on circular substrates 1/8 in thick and 2 ½ inches in diameter. Ball has developed CNT sources in a variety of sizes for multiple Internal/Contract Research and Development programs, and extensively characterized performance for space applications. NIST full hemispheric reflectively measurements on samples fabricated for CIRIS show emissivities in the thermal infrared range e > 0.9965. Calibration accuracy benefits two ways from the high emissivity; from reduced uncertainty due to the minute deviation from ideal blackbody emissivity = 1.0, and also from low reflectance < 0.004, which reduces stray light reflection into the FPA during calibration.

The CIRiS optical system was designed to comply with cost and volume requirements. An F/1.8 germanium lens singlet with 36-mm focal length has one aspheric surface, reducing spherical aberration. For Low-Earth Orbit, the optics temperature ranges between 10 °C and 20 °C making athermalization unnecessary. Distortion over the entire FOV is < 1.4 %.

Applications for Planetary Science: Although CIRiS has been designed to achieve objectives in Earth Science, tailoring of the lenses, filters, and FPA could enable radiometric imaging in the thermal infrared across the solar system. The implementation would be the same as in LEO for a flyby or orbiting mission, relying on pushbroom scanning of the FOV. Applications include:

- High resolution (spatial, temperature) surface temperature imaging
- Active thermal phenomena: plumes and plume vents, volcanism
- Subsurface thermal phenomena – tidal heating, ice fracturing, trapped liquid water
- High accuracy radiometric measurement (e.g. global heat flux, cryogenic surface temperatures and flux)
- Thermal Inertia: particle size and compaction, block abundance, regolith properties
- Minerology: surface composition, rock forming materials

A double lens optical solution yields improved off-axis performance (e.g. spatial resolution, distortion). A greater variety of filters can be chosen for different science objectives (e.g. minerology, thermal imaging). For a lander, the instrument could survey the surface by means of a rotation stage mount, enabling rotation of the FOV around the full horizon. This would require an extra 9 W for a few seconds every few minutes to complete the survey.

CIRiS Build and Test: All CIRiS parts have been fabricated, assembled, and integrated into the 6U spacecraft (Fig. 2). Thermal/Vacuum (TVAC) calibration is now complete The CIRiS observing sequence alternates between a Deep Space view, a nadir view, and two on-board calibration targets. TVAC testing is performed with a NIST traceable blackbody source and views to 83 K scene to simulate deep space. The TVAC data is being analyzed for calibration accuracy, including effects of algorithmic processing. Test data viewed through the three CIRiS filters shows repeatability between two viewing positions. Individual filter data shows stability over individual measurements.

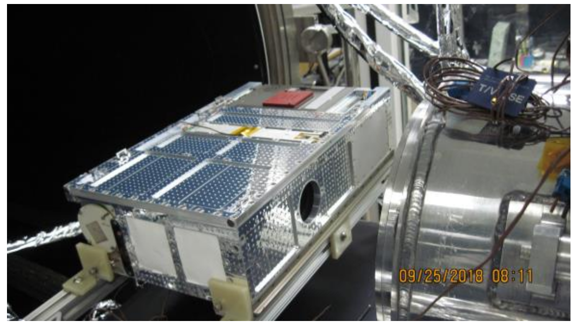

Figure 2: CIRiS is integrated in its 6U spacecraft and has completed test in a thermal vacuum chamber.

References: [1] Emery, W J., Good, W.S., Tandy Jr., W., Izaguirre, M.A. and Minnett P.J., "A Microbolometer Airborne Calibrated Infrared Radiometer: The Ball Experimental Sea Surface Temperature (BESST) Radiometer," IEEE Transactions on Geoscience and Remote Sensing 52, 12, 7775-7781 (2014).
[2] Good,W.S., Warden, R., Kaptchen, P.F., Finch, T., Emery, W. and Giacomini, A., "Absolute airborne thermal SST measurements and satellite data analysis from the deepwater horizon oil spill," in Monitoring and Modeling the Deepwater Horizon Oil Spill: A Record-Breaking Enterprise. Washington, DC, USA: Amer. Geophys. Union, ser. Geophysical Monograph Series 195 (2011).