Wide Range of Low Cost Day and Night Operational Lunar Surface Payloads enabled by High Performance Thermal Components based Packaging

P.E. Clark[1], D.C. Bugby[1], and D. C. Hofmann[1], [1]Jet Propulsion Laboratory/California Institute of Technology, , 4800 Oak Grove Drive, Pasadena, CA 91109, pamela.e.clark@jpl.nasa.gov

Purpose: Credible opportunities for delivery of small payloads to the lunar surface via commercial landers are emerging in the coming decade. Characterization of the highly interactive environment of the lunar surface and subsurface, requires continuous operation. Due to the uniquely extreme lunar surface conditions (high radiation, 2-week <100 K night, 2-week up to 400 K day), radioisotopes have been required for either full day and night operation (Apollo Lunar Surface Experiment Package using RTGs) or day operation and night survival only (all others including Lunakhod, Yutu, proposed commercial designs using RHUs). Compact in situ measurement packages with one or more scientific instruments capable of sustaining stand-alone day/night lunar operation could enable science investigations that heretofore required unaffordable dedicated landers with radioisotopes. Successfully demonstrating the feasibility of such a concept would represent a major breakthrough by enabling studies of the dynamic activities on lunar and other extreme environment solar system surfaces via distributed, lower cost platforms. In situ measurement//monitoring packages of 1 to 3 instruments, deployed on or from landers or rovers, could address high priority science goals and strategic knowledge gaps by providing dynamic measurements of the Moon's environment or interior.

Background: The most challenging problem is creating a thermal design to allow a low-cost, compact (cubesat-scale) package without radioisotopes to, at minimum, survive lunar night, and preferably operate on limited duty cycle during lunar night. This is a particular challenge for small payloads, which have intrinsically higher surface area to volume ratios. A Lunar Geophysical Network (LGN) study indicated a 400:1 thermal switching ratio is required for battery mass viability. Preliminary environmental modeling indicates that the availability of a reverse thermal switch (to maintain a thermal control box) with 1000:1 switching ratio, 10 times better than state of the art MER ratio of 100:1, would be required to allow cubesat-scale package (<20 kg, <2W during lunar night) to survive lunar night. The special parabolic radiator/reflectors required to survive the solar and lunar surface thermal emissions during lunar day have already been demonstrated on the Apollo Lunar Surface Experiment Packages (ALSEPs). Recently, Bugby and coworkers [1] have demonstrated the capability of a reverse thermal switch with a 2500:1 switching ratio which would enable a wide range of low cost instrument packages, including the IR camera and dual magnetometer described here.

Thermal Concept: Two prototype of the crucial thermal switch components were designed, built, and tested. Their basis of operation is the mating/de-mating of parallel (near mirror finish) flat metal surfaces. The physical mechanism causing the motion is the DTE of mid-CTE, high thermal conductivity (k) metallic end-pieces compared to a low-CTE, low k two-piece metal/polymer support beam. The requirements of operation were to be fully ON above 300 K with 1335 N force and fully OFF below 260 K.

Figure 1 DTE Reverse Thermal Switch Prototypes

The thermal switches were designed for seamless integration into box-type instrument enclosures. Each prototype easily slides into a small 25-35 mm circular enclosure opening such that most of the 80-120 mm long thermal switch lies within the enclosure, with 6 mm thick disks visible from the outside.

Testing to raise the TRL of the switches to 6 will be completed by January 2019. In the first test, aerosol freeze-spray was sprayed onto each prototype and measured temperature. Electrically non-conductive polymers in the OFF condition flow path allowed electrical resistance to indicate the ON/OFF transition, which verified the pre-test predictions. The second test (in thermal vacuum) was conducted with a calibrated Q-meter, which demonstrated performance that doubled pre-test ON conductance and was in-line with pre-test OFF conductance predictions. Shock and vibration tests were passed with no degradation in performance. High fidelity environmental testing, involving the simulation of lunar cycles, will be completed in January of 2018.. The two prototypes are illustrated in Figure 1.

In addition to the thermal switches, Ball high performance MLI [2] and kevlar pulley packaging system, both of which have successfully flown in space, would provide even greater performance enhancement in thermal packaging.

Applications (Table): Two instruments with very different requirements, an imaging camera requiring a cryocooler and window and a dual magnetometer with external sensors on booms, provided the basis for requirements and thermal modeling of the generic package concept (Figures 2 and 3) to confirm that all instrument components would remain within acceptable temperature limits (Table).

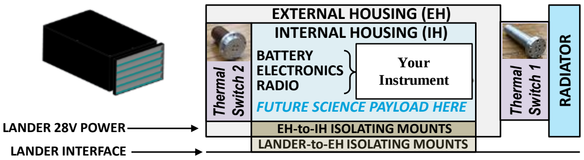

Figure 2 Generic Thermal Package Concept

The Surface Imaging of Lunar Volatiles in the InfraRed (SILVIR), based on a ruggedized version of JPL's EECam (Enhanced Engineering Camera) optics and electronics [3] updated with a JPL cryo-cooled HOTBIRD (High Operating Temperature Barrier InfraRed Detector) focal plane array [4] and filters for selection of water-related absorption bands, would provide snapshots of water-related features as a function of time of day, shadow, and slope, at a given landing site, and thus local 'ground truth' for the orbital observations over many lunar cycles. The SILVIR package would also include instrument electronics, a battery assembly, and the Bugby thermal switch. SILVIR would be most suitable, equipped with a gimbal, for a lander network, but could be used as a water feature 'mapper' on a rover as well. The principal thermal challenge is making sure the battery temperature is within operational limits to operate the cryocooler for at least two hours before the first observation of the day, at dawn.

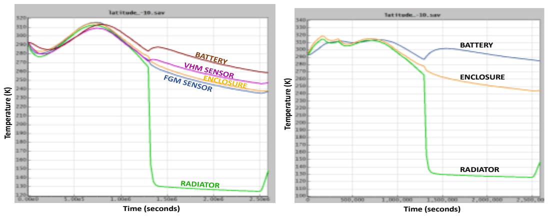

Figure 3 Lunar Cycle Temperature Models for dual magnetometer (left) and IR Camera (right) indicating that components stay within acceptable temperature limits..

The Lunar Interior Magnetic Sounder (LIMS) [5], based on fluxgate and vector helium magnetometers and their associated electronics on short booms, would provide, in conjunction with the orbital ARTEMIS magnetometer, would provide measurements of lunar magnetic induction varying over the course of several lunar cycles (including traverses through the Earth's magnetotail) from which the lunar interior temperature profile could be derived, and models for the origin and formation of the core constrained. The fluxgate magnetometer would be calibrated with the thermally stable vector helium magnetometer. The LIMS package would also include instrument electronics, a battery assembly, and the Bugby thermal switch. LIMS would be most suitable for a lander network. The principal thermal challenges are maintaining the fluxgate magnetometer and battery within operational limits, and vector helium magnetometer within survival limits during lunar night.

Results: Our thermal modeling demonstrates that both packages, representing a range of instrument requirements and incorporating the new thermal switch, should be able to meet their requirements for survival and/or operation during lunar night [1].

Science Investigations Requiring Long Duration	Projected Temp. Range
X-Ray, Broadband IR Spectrometers	263 K – 313 K
Near IR Imager, Compact Camera	
Magnetometer, Seismometer	
Particle Analyzer, Dust Analyzer	

References: [1] Bugby, Clark, and Hofmann (2018), these proceedings; [2] Quest Ball Aerospace. https://www.questthermal.com/sites/default/files/ckfinder/files/QT%20NextGenMLI_flyer_v7.pdf ; [3] McKinney, C. et al (2018) LPSC 2018, 2857.pdf; [4] Ting, D. et al (2011) NASA Tech Briefs, NPO-46477, 16; [5] Clark, Bugby, and Chin (2018) LPSC 2018, 1269.pdf