CubeSat Deployables on the Lunar Surface? P.E. Clark[1,3], J. Didion[2], R. Cox[3], N. Ghafoor[4] [1]IACS, Catholic University of America, Washington, D.C. 20064, [2]NASA/GSFC, Greenbelt Road, Greenbelt, MD 20771, [3]Flexure Engineering, 3518 Fremont Ave. N, #474, Seattle WA 98103, Canadensys Aerospace, 10 Parr Boulevard, Bolton, Ontario L7E 4G9 Canada, Contact Email: clarkp@cua.edu

Science Rationale: Although samples have been collected from the Moon, the 'dynamics' of the lunar environment itself have not been systematically studied. ALSEP packages deployed in the equatorial region during the Apollo era are no longer operational (except for passive retroreflectors), but they certainly gave indications of the nature of the fields and particle environment around the Moon. However, globally (in longitude and latitude) distributed instrument packages taking simultaneous measurements could provide systematic evaluation of the questions that have arisen about the dynamic nature of the lunar environment, the exosphere, dust and volatile transport, charging as a function of exposure to light, solar wind, and plasma, the nature of local and global fields. Particularly important is the capability of taking measurements for at least some portion of lunar night. These measurements should be provided before lunar landed exploration activities planned over the next decade have a significant impact on the environment. Such measurements will provide a much more comprehensive basis for understanding the protection needed for humans and robotic devices spending any length of time on the lunar surface. Because the lunar surface represents the range of conditions on most solar system objects and yet is far closer than other objects, it also represents an ideal technology testbed.

Concept: In support of Project Constellation, we developed a design concept for LEMS (Lunar Environmental Monitoring Station), an ALSEP-like standalone lunar surface instrument packages without dependence on radioisotope-based batteries [1]. An initial conventional attempt to design an environmental monitoring package with a solar/battery based power system led to a package with a unacceptably large mass (500 kg), over half of which was battery mass. We reduced the mass to 100 kg using radiation hard, cold temperature electronics and innovative thermal balance strategies using multi-layer thin reflective/insulting materials and gravity-assisted heat pipe, and were able to achieve a 10% duty cycle during lunar night.

More recently, we explored the use of state of the art ULT/ULP electronics in support of cubesat form factor deployables for use by HEOMD, as well as for GLXP lander deck or lander leg packages.

Application: Here, we revisit this design concept with existing cubesat technology to be used in support of a fields and particles surface monitoring station. Packages based on the cubesat paradigm, standard platform and component with Class D development, acting as 'pathfinders' for environmental networks on the Moon or elsewhere, could be deployed robotically from lunar landers going to widely different latitude and longitude locations. Cubesat systems now being developed for deep space, including C&DH/ processing, communication and solar panel deployables, have components/subsystems capable of operating at colder temperatures and intrinsic radiation hardness.

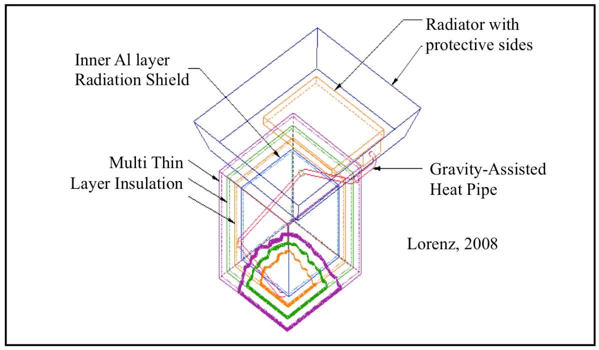

Figure 1: Concept for original LEMS as described in text.

Scalability: How scalable is the thermal design developed for the ALSEP-like LEMS (without RTGs or RHUs) concept for Project Constellation to a cubesat form factor package [2]? A 12U Cubesat would be roughly 1/6 the mass of an ALSEP-like (100 kg versus 15 kg) and, for two to three instruments, require about 1/6 the mass of batteries to support <1/6 of the power requirement (65 W versus <10 W). 2 Cubesat battery packs (2@ 20Ah) should be good for 20W/hour for 2 hours (5W for 8 hours) and require ¾ U volume. A 10% duty cycle over 14 days (32 hours) running at 5W/hour would require 4 times the battery volume (3U). A system requiring 10W/hour could run at a 5% duty cycle. Assuming a passive thermal design, this power level could allow operation of small particle analyzer, electrical field instrument, and UV spectrometer. Based on preliminary work, with state of the art thermal design, a 5 U payload of compact instruments, such as a small particle analyzer, electrical field instrument, and UV spectrometer, could be supported in a 12 U package with cubesat bus and deployables for power generation and communication (4 U), and 3 U for battery volume. With alternative power storage systems under development, a larger payload might be possible.

Challenges and Potential Solutions: Two areas of particular interest are new materials allowing more compact, efficient thermal design and energy storage at lower temperatures. The LEMS thermal design concept

CLASS Science Instruments				
Science Objective	Measurement	Instrument Requirement	Trajectory Requirement	Closure
Nominal (nature of solar wind and SME generated particle interaction with lunar surface as function of lunar, earth, and sun cycles): from ion density range, peak, and variations	charged particle (ion) densities, energies, and spatial distribution as function of time of day and lunar cycle	top hat design, compact DSCOVR, range tens of eV to keVs, FOV 360 x 10 degrees, requiring cubesat high voltage power supply	Nominal: Deploy on surface by robot or human, distribute stations at a variety of longitudes and latitudes around the moon	Nominal: Model for systematics of lunar charged particle, plasma, dust, and exosphere sources, processes, and sinks and the impact of solar activity
Nominal (see above): from electron density range and variations and wave generation indicating field boundary crossing	ULF E-field as a function of time and VLF wave spectra to determine peak emission for determination of electron density as function of time of day and lunar cycle	deployable spring loaded antenna ~1m, VLF pre-amp, and FPGA for digital filtering and analysis, range 0.01 Hz to 100 kHz	Nominal	Nominal
Nominal (see above): from dust density and exospheric species abundance range, peak, and variations	Dust (>10 nm) occultation to determine dust density, exospheric species (K, Na, Si, Al, MG, Ca, Ti, Fe, H2O, others)	Compact LADEE UVS, 230 to 810 nm with 1 nm spectral resolution, FOV ~1 degree	Nominal	nominal

required use of multiple thin, insulating boxes of G10, and a gravity-assisted heat pipe. What technology under development could create a more compact and efficient thermal design? 1) Flexible, lightweight 'smart' materials that would efficiently absorb or release heat as required for lower mass and volume penalty, and that could act as switches to prevent or allow heat flow, and 2) More compact heat pipe technologies, utilizing ionic liquids. In the past, strategies for surviving lunar night have included RTGs, hibernation, and the concept presented for LEMS. What technology under development could create more efficient, lower volume power generation and storage? 1) More efficient, radiation tolerant, compact cubesat deployable solar panels, and 2) Colder operating temperature energy storage technology (depth of charge, number of recharges) (storage, transmission) such as graphene-based supercapacitors linked to produce slower discharge.

References: [1] Clark P.E. et al. (2011) Small cold temperature instrument packages, SPESIF 2011, AIP Conference Proceedings, Physics procedia, 20, 300-307; [2] Clark P.E. et al. (2014) http://lunar-cubes.com/docs/Clarketal%20CLASS%20LCW4%20 left %20and%20right.pdf