

Compact Cryogenic Environment Instrumentation and Experiment for the Lunar Surface as Analogue for Planet and Exoplanet Surface Processes

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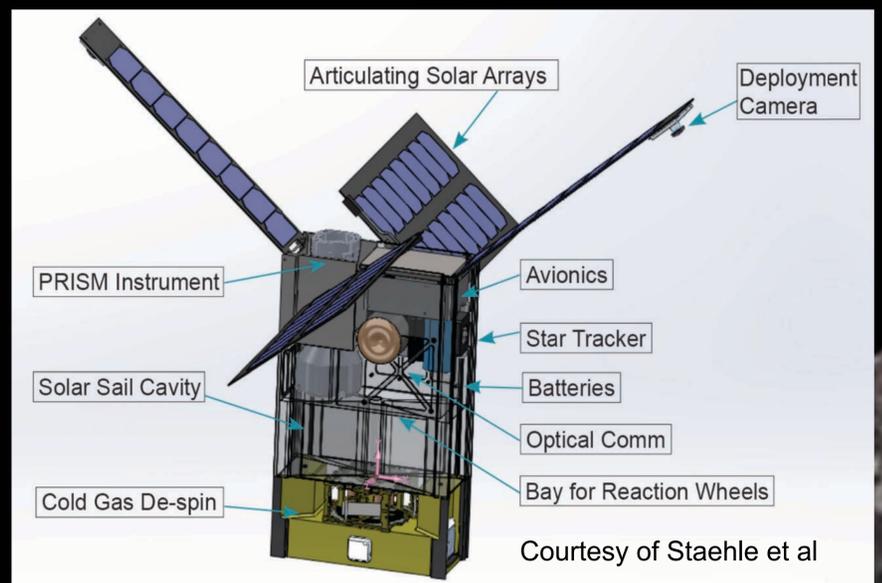
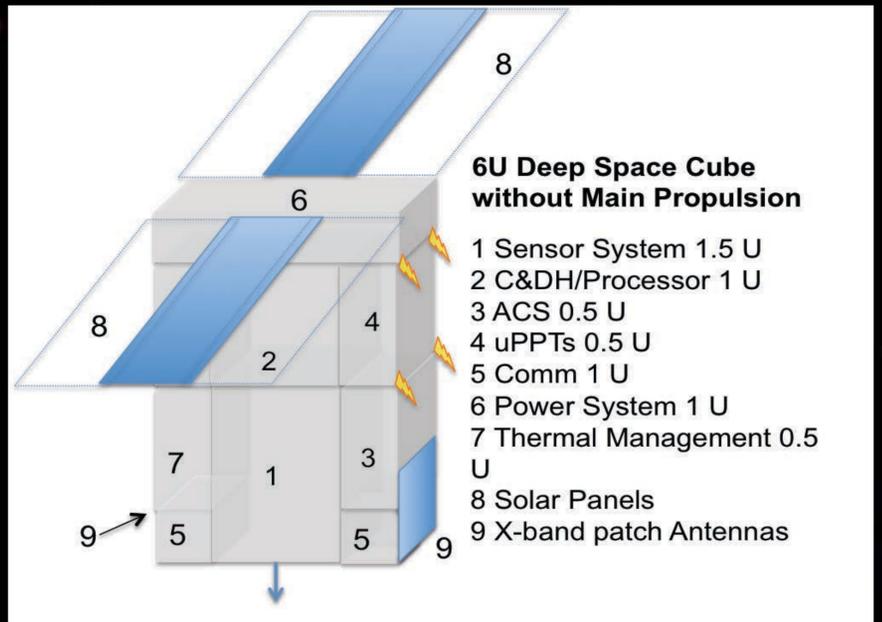
Context: Recent discoveries have led to an understanding that planets orbit most stars, that planets and not stars are the most common body in the universe, and that understanding solid body formation and modification processes is a key to understanding cosmic processes: the new cosmology. The indications that volatiles, including water and simple organics and their ices, are unexpectedly present on Mercury and the Moon, especially at their poles, implies that processes involving volatiles are playing important roles in surface processes and potentially in regolith and planetary formation themselves. The interaction of such simple volatiles with dust and charged particles, as well as radiation and fields, are influencing processes ranging from space weathering to accretion to biological precursor formation. Due to its long diurnal cycle and rugged terrain near the poles, the lunar polar regions, and potentially the subsurface in collapsed lava tubes and pits, are analogues for many, if not most, cosmic environments, which are atmosphereless bodies. This not only makes the Moon an exciting destination in its own right, but the Lunar polar regions a Rosetta Stone for cryogenic chemistry and physics throughout the solar system and beyond, and a testbed for technologies needed to support exploration of the entire solar system.

Purpose: Here, we discuss and compare several concepts proposed and at various stages of development for study of lunar polar regions, especially potential cold traps in polar craters and the subsurface, using compact systems and the current status of technologies needed to support such exploration. A particular concern is power storage under the extremely cold conditions at or near the lunar poles. The costs for orbiters, impactors, or landers, even for developing the first 'prototype' lunar CubeSats, would be between one and two orders of magnitude less than Discovery Class missions.

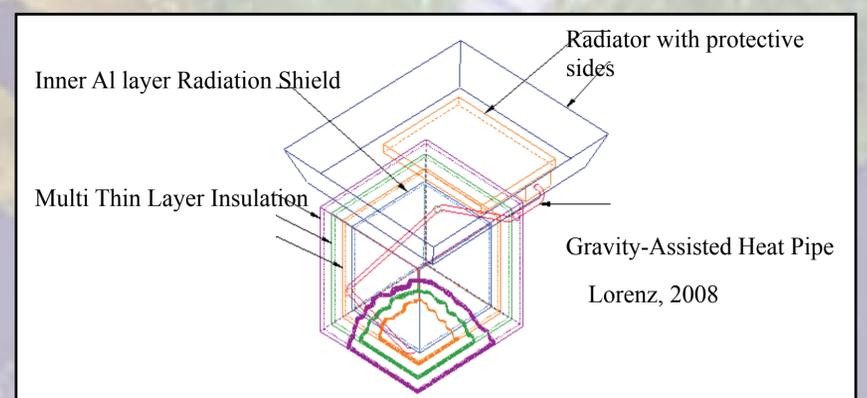
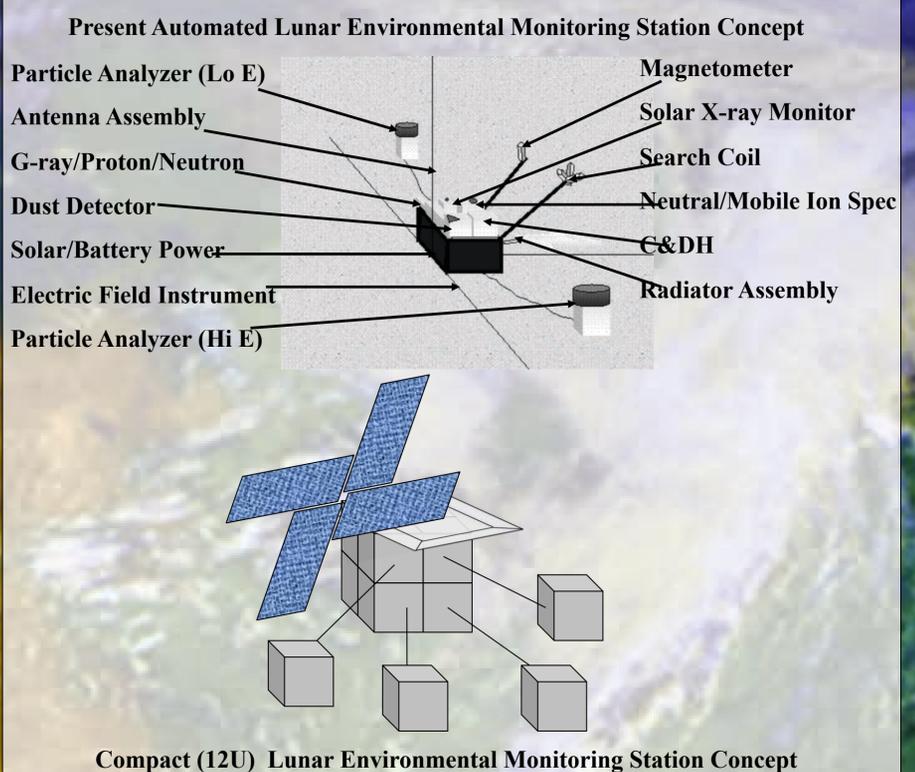
Study Concepts: The systematic distribution of water and other volatiles globally and in the polar regions can be determined systematically as a function of latitude as well as time of day, regolith composition and age, using cubesat technology in extremely compact orbiters. Proposed studies include LWaDi (Lunar Water Distribution) orbiter with an extremely compact broadband IR spectrometer with microcryocooler over the course of about six months [1]. Lunar Flashlight [2], another 6U orbital cubesat concept, search for ice deposits in permanently shadowed craters by reflecting 50 kW of sunlight off a sail, also being used for propulsion, in a 1 degree beam to the lunar surface, and then using an onboard Near IR spectrometer to take measurements in 3 bands associated with water ice. The latter concept is riskier, requiring sail deployment and accurate pointing, as well as the presence of an ice layer at the surface. The results could be negative, but would have enormous impact in confirming the presence of cold traps if ice were found. The challenges for compact orbiters include more accurate pointing, communication with greater bandwidth, and greater radiation hardness of components than previous generation CubeSats required. All of these technologies now exist or are under development.

A variety of compact impactor concepts that would allow an understanding of the interaction of charged particles, radiation, fields, and volatiles have been proposed [3,4]. A low energy ion analyzer, ULF electric field/plasma density instrument, and UV spectrometer package on a sequential string of impacts would provide in situ measurements of volatile distribution field disruption, and differential charging resulting from an impact event. Time resolved measurements on ejecta angle, velocity, and spectra of materials generated from a near-terminator or limb kinetic impactor(s) with compact X-ray, IR, and/or UV spectrometer packages could, when compared with experimental and theoretical models, constrain material composition, distribution, and underlying structure. Special challenges here are accurate spatial and temporal targeting.

We developed a design concept for an ALSEP-like stand-alone lunar surface instrument packages without dependence on radioisotope-based batteries. 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) of which over half 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/insulating materials and gravity-assisted heat pipe. Using existing cubesat technology with the same design concept for the fields and particles instruments, we are studying a 12U concept for such stations with 4-5U for payload.



Reduction in mass and power for LEMS as new concepts are used				
Design Regime	Conventional Electronics	Cold Electronics	New Packaging Concept	Compact 12U concept
Operational Limit C	-10	-40	-40	-40
Survival Limit C	-20	-50	-50	-50
Battery Mass kg	240	120	30	5
Remaining Mass kg	260	260	70	10
Total Mass kg	500	380	100	15
Minimum Power W	50	30	10	10



Potential Instrument Payload Status				
Type	Performance	Resources	Status	Heritage
X-ray	Remote (or in situ if active source) major to minor element (fluorescence) and mineral (diffraction) identification and abundance to tens of nm depth. Radiation Background; with in situ X-ray source, rapid character assessment	3.5kg, 2.5U, 5W	Solid state collimated compact XRS. TRL 6 concepts for in situ sample characterization combined XRF/XRD	DCIXS. Work needed to make XRF/XRD system (MICA, CMIST) coffee cup rather than coffee can size (Marshall et al, Gendreau et al, Clark et al)
γ-ray	Target remote (or in situ if active source) major or even minor to trace (if radioactive) elemental Abundance to tens of cm depth. Neutron and proton background constraints. H abundance, neutron and proton background	<5kg, 5U, <10W,	Mid-TRL Concepts for compact GRS and NS components	3-5 1U cube modules w/in decade for combined γ-ray/neutron spectrometer (larger U with source) Parsons et al
neutron	Target remote (or in situ if active source) neutron flux impacted by H abundance to 1 meter depth. With in situ neutron source, overall composition-dependent albedo	<5kg, 5U, <10W,	Mid-TRL Concepts for compact GRS and NS components	DAN on MSL. 3-5 1U cube modules w/in decade for combined γ-ray/neutron spectrometer (larger U with source) Parsons et al
Imaging spectrometers (visible/NIR)	Photo Interpretation (albedo, geomorphology, color, texture), mineralogy (primarily Fe-bearing), soil maturity	<2kg, ~2U, 5W	Work underway to fly prototype with facilitating microcryocooler to increase sensitivity. mid-TRL	UCIS JPL
IR (near to mid)	mineralogy (from Fe-bearing to mineral signatures in mid-IR), volatile (water and simple molecule) components	<2kg, 1.5U, 5W	1-4 micron broadband IR compact high spectral resolution, broadband IR workhorse with critical microcryocooler under development. Need funding to advance TRL faster.	LWaDi GSFC, mini TES
UV	Atmosphere/exosphere species, from fraunhofer lines	3kg, 4U, 3W	Unaware of work to make compact version for deep space.	MASCS on MESSENGER
Longwave	Physical component and surface characterization	2.5kg, 5W, 4U (IR), 16kg, 25W (SAR)	thermal, radio, need work on microsizing components. Work is underway on microsizing TES further	Mini-TES on MERs, mini-SAR
fields	Magnetic and gravity fields, interior characterization	<1kg, <1U, <2W. Boom improves.	Many groups working on compact magnetometers and compact transponders/transceivers/software radios	e.g., CINEMA magnetometer; INSPIRE transponder
Mass spectrometry (MS) (molecular component)	Mass spectrometry (MS) passive sampling of ambient volatiles (neutrals, ions) by mass. 'active' source (e.g. heating) to release from solid or liquid for sampling (e.g., laser induced breakdown (LIBS) MS).	MS <2 kg, <2U, 5-10W; LIBS 2 kg, 2U, 5-10W	Chip-scale MEMS MS under development. Mini-libS under development.	MEMS MS Cheung et al, 2010; Garcia et al, 2010 in IEEE journal microelectromechanical systems; mini-LIBS Barraclough, Waugh 2010
Energetic particle analyzer	Electrons, ions spatial and energy distribution	3kg, 4-5U, 2W, 30 eV – 30 KeV	State of art. MEMs based multi-cube module concepts under development.	Amptek ESA series
Dust detectors, Characterize cosmic dust on spacecraft	High energy ionic particles providing greater understanding of solar, galactic, and extragalactic processes and impacting space weather, atmospheres, and magnetospheres.	0.5 kg, 2U, 5W	Dustbuster novel compact time of flight concept	Dustbuster, Austin et al, 2010
Cosmic Ray Detectors	High energy ionic particles providing greater understanding of solar, galactic, and extragalactic processes and impacting space weather, atmospheres, and magnetospheres.	1 kg, 1U, <1W	Full field of view State of art Cherenkov/LET detector characterizing direction, energy, mass, and speed of particle in 1 to 1000 MeV/amu range.	CFIDS, Wrbanek et al, 2013

Instrument Technology Challenges: Compact deployable instrument packages in cubesat form factors that can provide in situ measurements on a rover or lander either exist or are under development. Highly desirable is instrumentation that provides high resolution in situ measurements to characterize the environment, rocks, regolith, exosphere, without the need for sample preparation. These would include the IR, visible imaging, UV, and X-ray spectrometers, the latter with compact sources. The next generation combined XRF/XRD instrument now under development could provide mineral and rock 'mapping' and petrological analysis without sample handling [6]. 'Sensors on a chip' are designed to provide specialized measurements of particular volatiles with high degrees of sensitivity [7]. Non-conventional MEMS-concepts for mass spectrometers and other particle analyzers, where large volume optics has previously been required, are currently under development [8]. The biggest challenge is nighttime operation, requiring cold temperature energy storage: batteries. Electronics operating at cryogenic temperatures efficiently already exist [8].

Thermal, Mechanical, Mechanisms Challenges: Thermal and mechanical design must provide a shield from extreme environmental conditions as well as deep space radiation on the lunar surface. Clark and coworkers developed a concept for a passively temperature controlled instrument package operating on a limited duty cycle using JWST G10 material as insulation, a radiator with latitude dependent alignment, and a gravity-assisted heat pipe to greatly reduce heat loss during lunar night. NASA recently developed polymer aerogel (no longer brittle) material would provide even better insulation with even less mass penalty and allow an expanded duty cycle. known. High temperature superconductors could also provide the basis for efficient mechanisms for applications where 'moving parts' are required to operate under cryogenic conditions where minimal power is available, as well as for magnetic shields to protect equipment or crew in deep space radiation environments. Such HTS-based concepts have been designed and tested.

Power Challenges: Designing power systems to operate at cold temperatures is especially challenging. Hibernation has been proposed to provide limited duty cycle operation on the lunar surface [9]. Clark and coworkers developed a concept for a passively temperature controlled instrument package operating on a limited duty cycle [8].

Work done primarily at JPL indicates that Li-based battery technology will allow operation down to -100 degrees C within the next few years [10]. For operating at the extremely cold temperatures in the permanently shadowed areas, down to 25K, we will need high temperature superconductor systems now under development by Selvamanickam, Masson, Beno, Meinke, and others [11, 12,13,14]. High Temperature Superconductor based systems for cooling, power generation, wire for transmission, energy storage and regulation (superconducting magnetic energy storage or flywheel) are currently being developed tested for the large-scale applications for efficient power generation, but we will require the same scales that are normally used in the laboratory. HTS-based technologies, although currently relatively low TRL, would provide optimal solutions for operating at cold temperatures. High temperature superconductors could also provide the basis for efficient mechanisms for applications where 'moving parts' are required to operate under cryogenic conditions where minimal power is available, as well as for magnetic shields to protect equipment or crew in deep space radiation environments. Such HTS-based concepts have been designed and tested.

Applications: The most challenging surface activities which we will ultimately address include measurement and curation of cryogenic samples, robotic rover operation at or near cold traps, combined in situ measurement techniques in lieu of sample handling techniques, and distributed, self-deploying astrophysical observatory networks, such as ROLSS.

Superconductors: improving the generation and delivery of power

