Compact Cryogenic Environment Instrumentation and Experiment for the Lunar Surface as Analogue for Planet and Exoplanet Surface Processes: P.E. Clark[1], W. Farrell[2], R. Cox[3] [1]Catholic University of America@NASA/GSFC, Greenbelt, MD 20771, [2]NASA/GSFC, Greenbelt, MD, [3]Flexure Engineering Inc. (Correspondence email: Pamela.E.Clark@NASA.gov).

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.

Polar 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.

Concepts and Technology Challenges on the Surface: 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].

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.

References: [1] Clark et al (2013), LCW3, Session 2 online at http://lunarcubes.com; [2] Staehle et al (2013), Session 2 online at http://lunarcubes.com; [3] Farrell et al (2013), LCW3, Session 1 online at http://lunarcubes.com; [4] Hermalyn et al (2013), Session 1 online at http://lunarcubes.com; [5] Martin et al (2008) Earth and Space, 1-10; [6] Clark et al (2006) Lunar and Planetary Science 1129.pdf; [7] Austin et al (2004) JGR 109, E07S07; [8] Clark et al, 2011, SPESIF2011, AIP Conference Proc Physics Procedia, 20, 300-318 [9] NASA OCT, http://www.nasa.gov/offices/oct/stp/strg/minogue.html; [10] Smart et al, *J. Electrochem. Soc.*, **157 (12)**, A1361-A1374 (2010); [11] Selvamanickam et al, 2011, IEEE Trans Appl Superconductivity, 21, 3049, [12] Masson and Meinke, 2009, http://www.comsol.com/papers/ 6450; [13] Strasik et al, http://m.iopscience.iop.org/0953-2048/23/3/034021 ?v_ showaffiliations=yes.