EXOMOON – A DISCOVERY AND SCOUT MISSION CAPABILITIES EXPANSION CONCEPT. R. C. Elphic[1], J. D. Weinberg[2], R. Dissly[2], J. Evanyo[2], D. H. Crider[3], G. T. Delory[4], D. J. Lawrence[5], P. G. Lucey[6], T. Fong[7], J. L. Heldmann[1], R. Vondrak[8], K. Zacny[9], I. Yachbes[9]. [1]Planetary Systems Branch, NASA Ames Research Center, MS 245-3, Moffett Field, CA, 94035-1000, [2]Ball Aerospace & Technologies Corp., PO Box 1062, Boulder, CO 80306-1062. [3]Catholic University of America, 106 Driftwood Dr, Gibsonville, NC 27249-0000, [4]Space Sciences Lab, University of California, 7 Gauss Way, Berkeley, CA 94720-7450, [5]Johns Hopkins University Applied Physics Laboratory, MP3-E104, 11100 Johns Hopkins Road, Laurel, MD 20723, [6]Hawaii Institute of Geophysics & Planetology, University of Hawaii, 1680 East-West Road, Honolulu, HI 96822, [7]Intelligent Robotics Group, MS 269-3, NASA Ames Research Center, Moffett Field, CA, 94035-1000, [8]Solar System Exploration Division, Code 690, NASA Goddard Space Flight Center, Greenbelt, Maryland 20771, [9]Honeybee Robotics, 460 W. 34th Street New York, NY 10001.

Summary: This paper describes a Discovery class landed mission concept for the in-situ investigation of volatiles in the lunar polar cold traps. This mission is enabled by the use of the Advanced Stirling Radioisotope Generators (ASRG), currently in development by NASA.[1] A NASA grant has recently been awarded to study this mission concept through a new program element in Appendix C.26 of the Research Opportunities in Space and Earth Sciences (ROSES) program, entitled “Discovery and Scout Mission Capabilities Expansion”.

Background: One of the key priority questions asked by the NASA Solar System Exploration Roadmap is “*How did the Solar System evolve to its current diverse state?... how [do] processes that shape planetary bodies operate and interact?*”.[2] The Earth’s Moon offers a unique laboratory to conduct investigations to help answer these questions. In an attempt to answer “*Twelve Key Scientific Questions that Underpin the Overall Exploration Strategy*,” the NRC Decadal Survey has placed a high priority on the investigation of the history of volatile materials, especially water, across the solar system as well as the global mechanisms that affect their evolution on planetary bodies. [3] The NRC Report, *The Scientific Context for Exploration of the Moon*, took this one step further by recommending that a high priority investigation should be to “*Characterize the volatile compounds of polar regions on an airless body and determine their importance for the history of volatiles in the solar system”*.[4] The Decadal Survey suggests a Lunar Discovery-class mission aimed at addressing these questions through the “*Investigation of polar volatiles to verify deposits (character, mineralogy, composition, extent, depth), to determine sources (solar wind, cometary, meteorite) and history (recent versus ancient), and to understand processes of volatile migration and deposition on airless bodies*”.[3]

Science Investigation: The lunar polar environment is completely unlike any other visited by human or robotic missions; we know almost nothing about it. The Moon’s low orbital obliquity has likely remained essentially unchanged for the past two billion years, and consequently locations of permanent shadow exist near the poles. These permanently shadowed regions (PSRs) can trap volatile species for very long times. Assessing cold-trapped volatiles at the Moon’s poles will help us understand the sources and processes by which exogenic water and other species have contributed to the terrestrial planets’ volatile inventory over the history of the solar system – a contribution that could well have influenced the development of biology on Earth.

If ice exists on the Moon, observations indicate that it is buried, patchy, and/or not very pure.[5] While orbital radar data from Clementine may be indicative of ice deposits on the Moon, [6] they are inconclusive regarding the contents of the cold traps because similar signals are found in locations where ice is not expected [7] and may be due to blocky regolith. [5] The Lunar Prospector Neutron Spectrometer (LPNS) detected a signature over the lunar poles consistent with enhanced hydrogen concentration. [8] This hydrogen enhancement may indicate preferred retention of solar wind hydrogen, water ice, or hydrates. The LPNS data suggest that the hydrogen enhancements are buried under ~10 cm of dry regolith. [9] However, the spatial resolution of the LPNS data is too coarse to resolve the likely scale size of volatile deposits. Elphic et al. have used image reconstruction techniques and models of permanent shadow to refine the spatial resolution and find that concentrations may be at least 1 wt. % water-equivalent hydrogen. [10] But much higher concentrations, albeit limited in spatial extent, are also permitted by the data.

The scientific questions concerning lunar polar cold traps are many and far-reaching: Can the lunar poles be used as a natural laboratory for physical processes, such as the interactions of silicates and ices, surface-atmosphere effects, and the influences of energetic particles and photons on sequestered volatile deposits? Is the moon an analog for conditions in interstellar space that may be a nursery for organic molecules or for the surfaces of tidally locked exoplanets? It is also important to understand sources and sinks in the current epoch: What are the directions, compositions and magnitudes of fluxes in and out of the polar cold traps? What are the sources, how do they vary in time and relate to the plasmas in the vicinity of Earth and Moon, and to episodic impacts associated with meteoroid streams such as the Leonids?

The study of the Moon's poles offers a pristine test case that has the potential to provide a view of the flux of inner solar system volatiles over the life of the cold traps – perhaps as far back as two billion years. It is also possible, however, that the surface environment of the lunar poles may be too dynamic to provide an interpretable record. Since so little is known about what volatiles may exist in the lunar polar cold traps, a landed mission of exploration and discovery will immediately provide completely new and potentially revolutionary knowledge about this exotic locale. Any resulting data will be scientifically compelling and stands to greatly increase our understanding of volatiles and global processes on planetary bodies.

Mission Study: A Discovery class mission aimed at addressing the above science questions must land within striking distance of permanent shadow in order to access the cold traps themselves. Non-nuclear power systems considered for robotic lunar exploration would require one-time use of batteries (severely limiting mission lifetime), or periodic return to sunlight for recharging (increasing risk of mission loss if the mobile element cannot reach sunlight). Fortunately, Advanced Stirling Radioisotope Generators (ASRGs) make extended operations within permanent shadow plausible.

This paper describes key considerations for development of a Discovery class mission to a lunar polar cold trap. Included are outlines of four trade studies: Mission Science Definition, Surface Mobility, Payload Definition and Accommodation and Mission Design Study. Each study critically examines the capabilities enabled by the use of ASRG primary power supplies.

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