Science Goals and Objectives for Canadian Robotic Exploration of the Moon Enabled by the Deep Space Gateway. M. Bourassa[1], G. R. Osinski[1], M. Cross[1], P. Hill[1], D. King[1], Z. Morse[1], E. Pilles[1], G. Tolometti[1], L. L. Tornabene[1], and M. Zanetti[1]. [1]Western University (1151 Richmond St, London, ON, Canada). Email: mbouras@uwo.ca.

Introduction: The Moon is the focus of renewed interest by the world's space agencies, and there are major fundamental science drivers for lunar surface robotic and human missions. Returning to the surface of the Moon is critical as exploration and return of lunar samples are vital to answering outstanding lunar science and terrestrial planet questions and addressing the formation of our solar system and early evolution of the Earth-Moon system. The proximity of the Moon makes robotics and in-situ human exploration of the surface of the Moon a high priority topic in the context of exploration beyond low Earth orbit. A key driver of lunar surface exploration is to have human presence in the cis-Lunar space on the Deep Space Gateway (DSG).

Mission Concept: Human Enabled Robotic Architecture and Capability for Lunar Exploration and Science (HERACLES) is an international mission concept to prepare for human exploration of the Moon [1]. An early component of HERACLES involves landing a rover on the lunar surface as part of a demonstrator/precursor mission. This Precursor to Human and Scientific Rover (PHASR) mission is a technical demonstrator and focuses on robotic lunar sample return to Earth using the DSG architecture. As a demonstration of the Canadian commitment to joining the international community's exploration of the lunar surface, we are conducting a science maturation study for PHASR based on the HERACLES and DSG architecture. The goal of PHASR is to land on the lunar far side (tentatively Schrödinger Basin) and cache samples over a 70-day period. The samples would then be transferred to the ascent module which would rendezvous with the DSG and return to Earth. The rover would continue with follow-up science there-after. The purpose of the SMS contract is to mature the preliminary science requirements of PHASR by developing the science investigation, creating a science plan for Canadian scientific contributions to the PHASR mission, and preparing an analogue science mission scenario. The preliminary science goals for PHASR have been divided into four broad categories with each goal consisting of multiple specific objectives to describe the mission investigation. The goals are: lunar chronology, impact cratering, volcanics, and preparing for human return to the Moon.

Lunar Chronology: Presently, the absolute ages of lunar rocks are constrained based on studies of Apollo and Luna samples and lunar meteorites. To constrain the early bombardment history of the solar system, characterize the lunar crust, and constrain the thermal evolution of the Moon, returning lunar sample to the Earth is essential. This goal can be achieved by completing the following objectives:

- Acquire chemical data and return samples of:
  - Clast-poor impact melt rock produced by the Schrödinger impact event for isotopic analysis in order to determine the age of the Schrödinger Basin, better approximate the end of the Late Heavy Bombardment period in the early solar system.
  - Ejected impact melt rock from SPA Basin for isotopic analysis in order to determine a date of the oldest lunar impact structure and its implications for the Late Heavy Bombardment. A sample from the SPA basin also provides the opportunity to examine the lower-crust, or even upper-mantle, compositions of the Moon and the timing of mantle processes.
  - Peak ring material (anorthosite, norite, troctolite) to characterize the lunar crust, date the formation of the target material, and better understand peak-ring basin formation.
  - Exotic material from secondary craters for age dating to help constrain the ages of large impacts (e.g., from SPA and Orientale basins, Antoniadi Crater) in order to improve the accuracy of age dating via crater counts.

Impact Cratering: A fundamental geological process on all planetary bodies, impact cratering is the most important process on the Moon, affecting its surface, crust, and possibly even the mantle [2]. Acquiring samples and in-situ measurements from Schrödinger Basin impactites would provide insight into peak ring basin formation, impact melting, and short metamorphic processes, as well as help to understand the provenance of uplifted and excavated lunar crustal materials. The specific objectives of this science goal for PHASR are to:

- Acquire chemical/mineralogical data and return samples of:
  - Impact material (i.e., impactites) along a multi-km traverse within Schrödinger Basin in order to sample a wide range of crater-forming events and to investigate the extent of lateral mixing within the lunar regolith.
  - Peak ring material from Schrödinger Basin in order to understand peak-ring formation and determine the depth of origin material that is uplifted and exposed with the peak-ring.

  - Impact-melt material exposed by selected craters along a multi-kilometer traverse to assess composition of the melt and to seek out evidence of sheet melt differentiation.
- Investigate shock effects in lunar materials (i.e., plagioclase, pyroxene) and determine the shock level of rocks and minerals through Schrödinger Basin.
- Characterize the geology of secondary craters.

Volcanics: Volcanism is one of the most important geologic processes on the Moon [3]. To better understand of the overall history of lunar volcanism and its relation to the thermal and compositional evolution of the Moon, PHASR will acquire samples and in-situ measurements of mare and pyroclastic volcanic deposits from Schrödinger Basin. To address the goal of studying lunar volcanism via the PHASR mission, the following objectives were defined:

- Acquire chemical/mineralogical data and return samples of:
  - Mare deposits to determine their composition, mantle source depths, the age of some of the potentially oldest mare samples.
  - Pyroclastic deposits to provide information on the depth of the magma ocean and the character of the lunar mantle, as well as the nature of the mare basalt source regions on the lunar far side.
  - Volcanic material along a multi-km traverse within Schrödinger Basin.

Prepare for Human return to the Moon: In addition to the fundamental science being addressed, PHASR, is a precursor for human activity on lunar surface. As such, PHASR will also analyze the topographic, radiation, and temperature environments within Schrödinger Basin. This will involve completing the following objectives:

- Measure the radiation environment to prepare for the return of humans to the lunar surface.
- Measure the surface temperature variations across several day/night transitions.
- Create detailed outcrop-scale geologic and terrain maps in preparation for human return to Schrödinger Basin and future navigation and landing logistics.

Current Status: At the time of this workshop, the SMS will be at its mid-term point. The science goals and objectives have been defined, as well as the list of science payloads to be used on the PHASR rover. The science investigation which includes detailing a traverse plan within Schrödinger Basin and to create a traceability matrix for the payloads will have been completed. A draft of the analogue mission science scenario document will also be complete.

Deep Space Gateway Requirements: To enable the PHASR mission as part of HERACLES, the DSG architecture would require a system in place to robotically capture the ascent vehicle after take-off from the lunar surface and a mechanism to transfer the sample container from the ascent vehicle to the DSG. Constant communications with PHASR is also paramount to the success of the mission and to maximize the ability to operate the rover over the 70-day primary mission phase. As such, utilizing the communication system of the DSG to permit an Earth-based ground control team to communicate with PHASR would be required. This communication setup could be made possible if the DSG were to be placed in a halo orbit around lunar L2 to allow for constant line-of-sight with the lunar far side and the Earth. The aforementioned traverse plan could also utilize real-time driving opportunities for the rover supported by astronauts on the DSG wherever possible. This would be made possible by a small mission control system setup within the DSG.

Conclusion: The results of this study will help ensure that Canada is poised to be a major contributor to the international effort to explore the lunar surface. The DSG can play a major role in that exploration effort. In addition to the science opportunities possible on-board the habitat, its close proximity and communications access to the far side of the Moon is an instrumental part of HERACLES architecture which would facilitate a lunar rover mission to collect and return samples from Schrödinger Basin.

Acknowledgements: The authors are very grateful to the CSA team, Vicky H., Tim. H., Martin P., and James D., among others for their support of the science maturation contract. The SMS contract was awarded by the Canadian Space Agency to mature and validate the preliminary science requirements for a precursor rover (PHASR) for the HERACLES lunar demonstration mission concept and a preliminary science scenario. The HERACLES mission concept, enabled by the Deep Space Gateway, is being jointly studied by ESA, CSA, and JAXA and includes the objective of demonstrating technologies in preparation for the human exploration of the Moon and Mars, while robotically returning lunar samples to the Earth and performing in-situ investigations on the surface. The baseline HERACLES science scenario is anticipated to be developed through an international Science Definition Study exercise.

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