MOON CADDY: A LUNAR GEOLOGIST'S ROBOTIC ASSISTANT. F. Rehmatullah[1], J. A. Shariff[2], and G. R. Osinski[3], [1]MDA Corporation, 9445 Airport Rd., Brampton, ON, Canada, L6S 4J3, faizan.rehmatullah@mdacorporation.com, [2]MDA Corporation, 9445 Airport Rd., Brampton, ON, Canada, L6S 4J3, jamil.shariff@mdacorporation.com, [3]Institute for Earth and Space Exploration / Department of Earth Sciences, University of Western Ontario, 1151 Richmond St. N., London, ON, Canada, N6A 5B7, gosinski@uwo.ca.

Introduction: Humanity's return to the lunar surface through the Artemis program opens up exciting possibilities to gain scientific knowledge in areas such as geology and geophysics. It also provides the opportunity to develop in situ resource utilization (ISRU) techniques that would aid a sustained human presence on the Moon. A mission architecture combining a human explorer with a roving robotic assistant presents a unique mode for surface exploration. An astronaut geologist can make efficient and informed decisions about target and sample selection. An accompanying rover provides a mobile science laboratory with a suite of instrumentation, along with situational awareness.

Scientific Objectives: The scientific investigations carried out in the mode described above would be to address several main objectives. A first objective is to develop a greater understanding of the chronology of geological processes on the Moon, including the period of Late Heavy Bombardment, and the detailed history of the Moon's thermal evolution [1]. A second objective is gaining further insight into the impact cratering process, for example the formation of peak-ring basins. A third objective is to understand the history of lunar volcanism and its impact on the Moon's mantle composition, evolution, and thermal history. The investigations can be divided into two broad categories: 1) operations involving lunar sample extraction and return, and 2) sensing operations, involving in-situ measurements carried out by active and passive sensing instruments.

Sample-based Operations. Meeting the above objectives requires collection of samples over a wider range of geological sites than were visited by the Apollo and Luna missions. To this end, a mobile robotic platform would include containers for the preservation and transport of samples collected by Artemis astronauts over the course of surveys of previously unvisited landing sites. In keeping with the Artemis mission concept, sample containers and crew would be transported to the Lunar Gateway [2] on an ascent vehicle, where they would then return on the crew vehicle to Earth, where the samples would undergo isotopic and other analyses. However, given the interchangeability of instrumentation on the rover, the potential exists for the future inclusion of an on-board sample-processing module as well.

Sensing Operations. The configuration of mast-mounted and handheld sensing instrumentation on the rover can be altered based on the requirements of a specific mission. An example of a baseline suite of instruments that could meet the aforementioned science objectives is as follows. Spectroscopic instruments on the rover could include a Laser-Induced Breakdown Spectrometer (LIBS), Raman spectrometer, and Alpha Particle X-ray Spectrometer (APXS). Both LIBS (7 m range) and APXS (close range) can quantify the chemical abundances within materials such as impactites. Raman spectroscopy enables quantification of mineral abundances within materials.

Imaging instrumentation should include a Remote Micro Imager (RMI), which would resolve rocks as small as 5 cm × 5 cm at 10 m or better, for the determination of the size, shape, colour, and texture of small rocks and clasts. A panoramic science camera analogous to the PanCam on ExoMars [3] would characterize the broader morphology of a site. A ranging instrument such as LiDAR could, through the generation of a point cloud, resolve features such as small craters and ejecta (with 3 mrad angular resolution), enabling characterization of the geology of the lunar surface.

Design Concept: An example of a rover concept developed to carry out these scientific functions is the Precursor to Human and Scientific Rover (PHASR) shown in Figure 1.

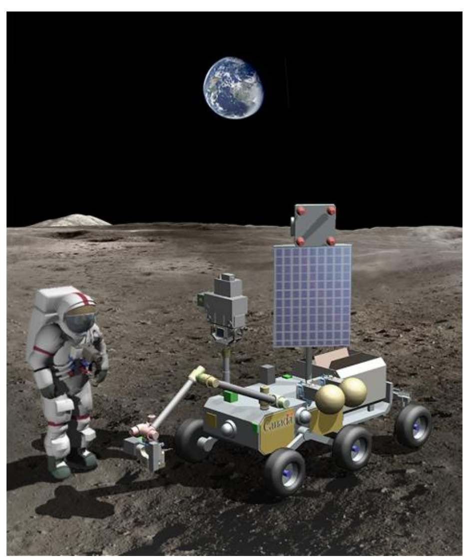

Figure 1: PHASR Design Concept

A team including the authors conducted the Phase 0 concept (MDA) and science maturation (UWO) studies of this rover for the Canadian Space Agency, as part of the HERACLES program [4] [5] [6].

With the addition of a human surface-exploration team, the design of the mobile platform can be modified and streamlined, relative to PHASR, in a manner that is dependent on the specific mission concept.

Mission Concepts: We have identified two broad categories of mission concepts, each with advantages and disadvantages.

Stand-alone Launch & Deployment. In this concept, the mobile platform has its own launch, transit, and landing, independent of any crewed mission, much as has been proposed for PHASR. In this concept, the rover will be able to survive a lunar night on its own. It will also have independent on-board power generation, and the capability to communicate with the Earth or the Lunar Gateway. Astronauts can rendezvous with the pre-deployed rover at a designated landing site. An advantage of this concept is that potentially only one instance of the mobile platform is required across multiple Artemis missions. It could further act as a precursor and postcursor source of data. The rover can traverse a cumulative distance of over 600 km over a period of 2 years. Hence, it can travel between any two landing sites within this distance. This mission concept makes minimal use of Artemis infrastructure and resources. It assumes that any landing site suitable for human activity is traversable for the rover.

Integrated Launch & Deployment. In this concept, the mobile platform launches, transits, and lands with the Artemis crew, as a payload. By using the Artemis infrastructure, the demands on the rover can be reduced significantly, since there will be no need to survive lunar night, nor the need for power generation, independent of Artemis resources such as an enclosure to which the rover could dock for charging and environmental protection for night survival. The mass and power of the communications systems on the rover can also be reduced by using the Artemis lander as a communications relay. However, multiple instances of this simplified and less-robust robotic platform would be required across different landings.

In both cases, the rover's robotic manipulator can be removed in favour of the dexterity and speed of the human team members' motor functions, thus reducing cost, mass, and design complexity. The instruments and tools used for contact science can be mounted on the MDA-developed lunar-dust-tolerant interchangeable Dexterous Interface and Tool for Planetary and Deep Space (DIaTPADS). From this interface, tools and instruments can be picked up and placed in contact with the target of interest by astronauts. While traversing to the site of interest, the mass, power, volume, and thermal needs of the instruments will be supported by the rover, thereby reducing the mass of the payloads carried by the astronauts themselves. This feature enables the astronauts to transport and employ sophisticated scientific instruments during exploration activities, increasing the scientific return of the human excursions.

Technical Specifications: As a baseline, relevant specifications from the PHASR concept study are given in Table 1 below.

Table 1: Preliminary specifications for the Mobile Tool Platform and Assistant, based on PHASR

Specification	Value
Mass	330 kg
Average Power	300 W
Volume	1.5 m × 2.5 m × 1.2 m
Range	600 km
Max. Speed	3.6 km/h

Ancillary Functions: A robotic platform could also provide capabilities that improve astronaut safety, and aid in mission planning. For example, an array of guidance sensors mounted on a 2-degree-of-freedom (pan/tilt) sensor mast could provide navigation, route-planning, and hazard-detection capability. Examples of these sensors include an Integrated Vision System (IVS) with stereoscopic cameras and LiDAR. This hardware would also allow the robotic platform to function as a stable and mobile "camera crew", freeing the astronauts to carry out tasks other than mission documentation. In combination with a communications antenna uplink to the Gateway, the visual cameras on the rover could be used to stream footage of humans investigating previously-unexplored regions of the Moon (including the Far side) to Earth in near real time.

Acknowledgments: The authors would like to thank the Canadian Space Agency for the funding and support of the Phase 0 study of PHASR, and of the breadboard development of the DIaTPADS interface.

References: [1] Canadian Space Agency (2009). *6th Canadian Space Exploration Workshop (CSEW6) Report.* [2] Hill, T. R. (2019). *NASA Report KSC-E-DAA-TN65959*. [3] Coates, A. J. et al. (2017) *Astrobiology*, 17, 511-541. [4] Landgraf M. et al. (2015) *LEAG Meeting*, Abstract #2039. [5] Bourassa, M. C. et al. (2019). *50th Lunar & Planetary Sci. Conf.* Abstract #2418. [6] Bourassa, M. C. et al. (2019). *50th Lunar & Planetary Sci. Conf.* Abstract #2886.