SCIENTIFIC OPPORTUNITIES IN HERACLES ENABLED BY THE GATEWAY.

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Introduction:

With consensus building in the space community about the relevance of the Moon and its orbital environment for the next steps in space exploration, concrete steps are undertaken to implement the needed infrastructure: the Gateway is in transition from concept to project phase and the lunar surface has shifted into the focus of study teams worldwide who want to utilise the Gateway as a staging location. Key questions to be addressed are: What are the technical challenges of such an undertaking, and what are the respective opportunities for scientific investigations offered by it?

The common goals and objectives of space exploration are frequently coordinated and evolved by participating agencies of the International Space Exploration Coordination Group (ISECG) – a forum representing 15 agencies. A high-level roadmap of exploration missions and capabilities is one of the products of ISECG. This global exploration roadmap (GER), in its current version [1], reflects a common human exploration strategy. From the GER a clear roadmap of exploration from the current capabilities LEO via the Gateway to lunar surface missions that enable missions to the Martian vicinity and continue to the surface of Mars.

The international community recognises that lunar surface exploration represents a significant utilisation case for the Gateway. The Gagteway will be placed on one of the family of libration orbits in the Earth-Moon system [e.g. 2]. Due to its strategic location, access and communication to the polar and far side locations on the Moon's surface will become available.

For the lunar surface, the GER foresees [11] a stepwise approach of increasing capability starting with automated missions aiming to close strategic knowledge gaps by the end of this decade, advancing to human assisted sample return in the mid-2020s, and culminating in the return of human explorers to the lunar surface towards the end of the 2020s. The main subject of the present and an accompanying [10] paper is a description of the two latter mission scenarios, attempting to engage in an open exchange with the community on how to make use of the scientific opportunities presented by them.

Human Assisted Sample Return:

Recognising the significant challenges of human lunar return, the ISECG has devised an affordable and feasible approach to flight-demonstrate critical components of the human lunar exploration architecture. The international mission study "Human-Enabled Robotic Architecture and Capability for Lunar Exploration and Science" (HERACLES) was initiated in late 2017 by a Letter of Intent signed by the Canadian Space Agency (CSA), the European Space Agency (ESA), and the Japan Aeronautic Exploration Agency (JAXA). It has conceptualised a mission scenario using a sub-scale landing vehicle, rover, and ascent vehicle [3,12]: The lander operates for two and a half lunar cycles (day-night-day-night-day) while the rover demonstrates mobility collecting samples. The ascend vehicle then returns the samples to the Gateway – much as the human-rated ascender will return humans to the same location. Recognising the capabilities of human operators [4], it is planned to enable tele-operations of the rover on the surface by crew from the Gateway as well as from a control centre on Earth. After 15 kg of samples will have returned to the Earth inside the crew vehicle, the rover continues its demonstration of long-duration and long-distance planetary surface mobility - tele-operated from the ground and relying on time-tagged commands. A tentative definition of a one-year surface traverse in given in [5].

Results of the HERACLES mission study indicate a high efficiency of this approach in reducing the development and operational risk for human lunar exploration and an affordable expenditure of resources.

Human Lunar Exploration:

A concept of human lunar exploration that addresses the objectives of scientific knowledge gain, advancement of in-situ resource utilisation, and preparing human missions to Mars has been advanced by ISECG [11] based on strategic principles of affordability, exploration value, international cooperation, capability evolution, human-robotic partnership, and robustness. In its current version the human lunar architecture calls for five mobility-based missions allowing exploration of far side and polar locations within an exploration zone of approximately 100 km radius each.

Technical Challenges:

Lunar surface exploration benefits from the availability of data and experience from the Apollo programme [6]. However, increased mission duration, mobility requirements, and a changed level of risk acceptance by stakeholders lead to a number of technical challenges. The lunar surface environment requires mechanisms to be resilient against dust, withstanding temperature fluctuations and hard vacuum. Radiation poses challenging conditions for complex data handling equipment and humans. However, on the Moon it is with <1mSv/0.3mGy per day more benign by a factor ~3 than on the martian surface.

Operational risk is dominated by space transportation, i.e. reliability of the propulsion system and its associated control system. There are mission phases in orbit insertion, descent, ascent, and rendezvous that require flight-demonstrated systems before humans are accepted on board. On the surface, the crew will critically rely on the functioning of their habitat and surface mobility, both of which have seen only short-term demonstration in the frame of the historic Apollo missions. There are a number of technologies and components that are considered in the frame of human lunar exploration and thus require flight proving in the frame of a demonstrator mission: main engines, guidance, navigation, and control (GNC), hazard detection and avoidance (HDA), attitude and orbit control system (AOCS), generation of electrical and thermal power for life support, and drive trains for locomotion.

Scientific Opportunities:

In space exploration, scientific investigations address strategic knowledge gaps and provide enabling information for future missions, but also benefit from the opportunities of new capabilities. The ongoing process of regular review and update of scientific goals and objectives has the motivation to make maximum use of opportunies if and when they arise. For the case of lunar exploration, prominent, internationally recognised reference documents have been released by the National Research Council [7], the Lunar Exploration Analysis Group [8], and the ISECG [9].

Mastering the technical and operational challenges of lunar exploration requires capabilities that naturally open opportunities for sample return and in-situ investigations that potentially address many of the top-priority investigations [7,8,9]. The need to reduce the risk of operating in the less known locations in the lunar polar regions and on the far side means that new, previously unexplored regions will become available for science [6]. In particular, the one-year traverse of the tele-operated demonstration rover will provide imaging data, (limited) opportunities for in-situ payloads. The samples taken during the lander mission represent the most significant opportunity for laboratory analyses after the return of more than 380 kg of lunar samples in the frame of the Apollo programme. While the missions are primarily for demonstration purposes, scientific objectives will be developed for each mission with input from the scientific community, and scientifically-informed operations activities for selection of samples will be developed in order to address these objectives. In particular the survival of robotic and human systems in lunar night conditions and the lunar dust environment pose significant, yet surmountable engineering challenges.

In the human exploration phase, the capabilities of a scientifically-trained crew to intuitively characterise and document a geologic context and to make serendi-tous discoveries as proven in the Apollo programme will create potential of scientific discovery beyond current capabilities. It is expected that hundreds of kilogrammes of samples are returned in the frame of the five missions currently conceptualised. Also, deployment of in-situ instrumentation with an accumulated mass in the same order will become available. Investigations in the frame of in-situ resources will create opportunities for understanding the evolution and origin of volatile materials in the Solar System.

Summary:

The communities addressing lunar geology, solar system physics, astrophysics, life sciences, and technology research are called to contribute ideas for instrument payloads, sample analysis, and technology demonstration in the frame of mission scenarios conceptualised in the frame of the GER. Opportunities exist in the near term to shape possible programmatic implementation of these concepts by international space agencies.

References:

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