ESA SYSNOVA LUNAR CAVES CHALLENGE: IDEAS AND TECHNOLOGIES FOR A MISSION TO LUNAR CAVES.

L. Bessone[1], I. Carnelli[1], M. Fontaine[1], F. Sauro[2]. [1]Directorate of Human and Robotics Exploration, European Astronaut Centre (EAC) - European Space Agency (Linder Höhe, D-51147 Cologne, Germany; loredana.bessone@esa.int), [2]Geological and Environmental Sciences, Italian Institute of Speleology - Bologna University

Introduction: Recent years have seen a rapid expansion of international participation in lunar exploration. The Moon has become a focal point for many governmental and private organisations in the areas of technology development, scientific research, human exploration and public engagement. While the surface of the Moon has been documented with high resolution cameras by several satellite missions, very little is known about the presence and nature of lunar subsurface cavities.

In several areas of the lunar Maria, planetary geologists have identified peculiar pits that appear to be related to the collapse of cavities. For example, in Marius Hills a pit on the bottom of a shallow rille has been interpreted as the partial collapse of a lava tube roof with a visible cavern below the overhanging ceiling [1, 2]. Gravity measurements by the mission GRAIL have also revealed the probable presence of linear subsurface voids along sinuous rilles [3], while the Lunar Radar Sounder on board of the satellite Kaguya [4] has detected the presence of potential voids located between 70 to 140 meters below the surface in the Marius Hill region. Studies on the structural stability of lunar lava tubes in 1/6 g that take into account the strength characteristic of Maria basalts, have shown that these types of cavities could theoretically reach dimensions of more than 2 km wide and 600 m deep, with a roof less than 20 meters thick [5]. The exploration and mapping of lava caves could provide new data on the formation of plateau basalts on the Moon, providing access to vertical sections of lava flows. Caves formed by lava flow conduits could also provide long-term shelter for human habitats shielded by cosmic radiation and micrometeorite impacts on the Moon. In addition to the protection offered by these caves, they may also provide access to several resources, including volatiles and possibly water ice trapped in cave regolith. To explore these environments further, space agencies have already started to discuss possible mission scenarios and evaluate the necessary technology required to achieve them. In the view of the Artemis and Gateway missions, and the general new-found interest in returning to the Moon, the European Space Agency has also started to develop technologies and seek ideas for future lunar caves mission scenarios. In order to start a discussion in Europe on the topic involving academia and industrial partners, in August 2019 European Space Agency opened a campaign called the Sysnova Lunar Caves Challenge through its Open Space Innovation Platform, soliciting novel ideas to address detecting, mapping and exploring caves on the Moon. These new system studies are used by ESA either as a precursor for technology development, or to assess the feasibility of systems for space.

Mission Scenario: The campaign examined mission concepts based on single rover/robot designs, or on a distributed system of robotic/rover systems operating together to meet mission objectives. In both system architectures, the proposals had to operate under the following assumptions and constraints: 1) a robotic/rover system shall be landed on the lunar surface in the proximity of the Marius Hill skylight; 2) each robotic/rover system landed on the surface must fit within the physical constraints required by existing and planned launch and transportation systems; 3) the cave detection system from the surface must be able to identify a void in basaltic material.at a depth of between 30 to 150 meters, measuring between 100 to 1000 m on its longest axis; 4) the robotic/rover system, or part of it, must be able to access pits to a depth of at least 50m. This includes overcoming vertical or overhanging walls and unstable pit rims; 5) the robotic/rover system accessing the cave from the bottom of the pit must be able to progress at least 200 meters further inside; 6) the communication of data must be possible from a minimum depth of 50 meters to the surface

Results of Sysnova Lunar Cave challenge: A total of 34 ideas were submitted to the call, of which 22 were found eligible for evaluation. An Evaluation Board composed of planetary geologists, volcanologists, robotic and system engineers and mission planners then thoroughly assessed the submissions, with eight being selected as promising and a more thorough proposal requested. In May 2020, five of the selected proposals were funded in order to develop the proposed concepts further within a 6 month period. The resulting concept analyses will support ESA's technology roadmaps and will inform ESA's strategy for future missions, and promising concepts will be developed within ESA's Concurrent Design Facility (CDF) in early 2021.

Short summaries of the funded studies

Rover-based system for scouting and mapping lava tubes using gravimetric surveying. This project, from Canadensys and the Queens University of Ontario pro

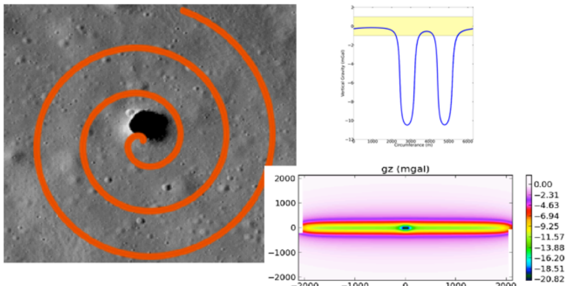

Figure 1. Example of planned path and expected signals for the detection of lava tubes on the Moon using gravimetry.

poses to first scout out prospective lunar pits using a small lunar-surface rover mission that would measure the gravitational field around pits to search for the presence of lava tubes (Fig. 1). This information would be used to plan a more advanced mission that can enter tubes via pits.

*A tethered micro-rover for safe semi-autonomous exploration of lava tubes***.** Carried out by the DFKI Robotics Innovation Center together with the Robotics Group of the University of Bremen, this investigation aims to find al solution for accessing and mapping a lunar lava tube with a semi-autonomous rover. The concept involves entering a lava tube using a tether system that also provides communication and energy. When the bottom is reached, the tether spool is deployed and serves as a recharging station and communications relay for the battery-operated rover.

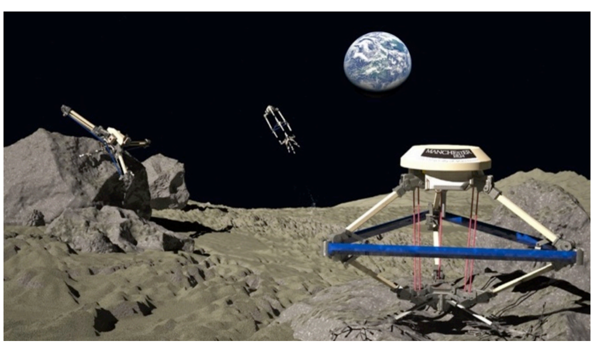

Figure 2. Hoppers could be used to scout pit rims, pit walls and explore the cave overcoming obstacles like boulders or deep steps.

Bio-inspired hopping rovers for lunar caves exploration. Inspired by biology, this study is led by the University of Manchester investigates a network of low-cost, low-mass agile hopping rovers that can vault and bounce in complex terrain (Fig. 2). Each rover would be able to operate independently while also communicating with nearby rovers to share navigation and mapping data, using a range of complementary sensing packages, which could be deployed across the rover network.

Robotic crane for wireless power and data transmission between surface and cave. This study by the Universities of Oviedo and Vigo in Spain investigates a system composed of a unit on the Moon's surface equipped with a solar panel large enough to supply energy to itself as well as to charge the batteries of robots operating inside the cave. The surface unit would send power wirelessly to the robots in the cave using a crane that enters the cave and deploys a wireless 'charging head'.

Descent and autonomous exploration in lava underground structures. Developed by a consortium led by the University of Würzburg, this mission concept aims to explore and characterise the entrance and initial part of lunar lava tubes using a compact, tightly integrated spherical robotic device (Fig. 3). This device would have a complementary payload set and autonomous capabilities, and specifically aims to identify and characterise potential resources for future ESA exploration missions, whilst also studying the local subsurface environment and its geological and compositional structure. The sphere will house laser scanners, cameras and supporting equipment, and will be lowered into the skylight to explore the entrance and nearby caverns and pipes. Lidar systems will produce the primary exploration output of the mission by generating 3D models of the environment..

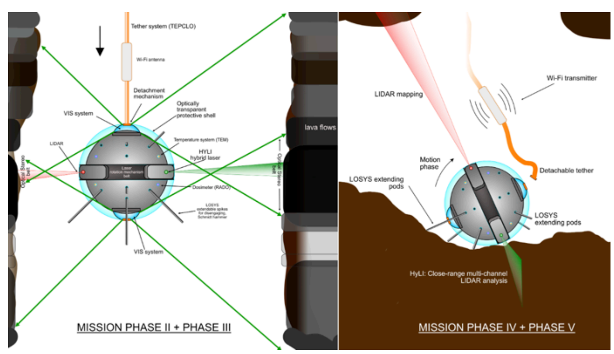

Figure 3. The Daedalus sphere designed by Würzburg Universiy.

References: [1] Wagner, R.V. and M.S. Robinson, (2014) Icarus, 237: p. 52-60. [2] Haruyama, J., et al., (2009) Geophysical Research Letters, 36 (21).[3] Chappaz, L., et al. (2017) Geophysical Research Letters,. 44(1): p. 105-112. [4] Kaku, T., et al., (2017) Geophysical Research Letters, **44**(20). [5] Blair, D.M., et al., 2017, Icarus, **282**: p. 47-55.