A MISSION CONCEPT FOR LAVA TUBE EXPLORATION ON MARS AND MOON – THE DLR SCOUT ROVER.
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Introduction: Caves are among the least explored and pristine terrestrial environments of our planet. On other planetary bodies they pose a great potential for planetary sciences. Lava caves form when lava conduits are drained and remain partially empty. They are probably the most important type of extraterrestrial caves [1]. From an astrobiological perspective, on the one hand they might be candidate astronaut shelters, due to their natural protection from radiation and therefore increased human habitability. On the other hand, caves might even shelter traces of extinct or present life on Mars.

Even though pit craters on Mars [2] and Moon [3] have been known for quite some time, only few orbital missions investigated these objects in further detail [4]. Some of these gathered proof for continuations of lava tubes below these so called "skylights" [4]. However, most of nowadays mobile robotic systems are still not capable of entering and traversing such a cave system.

Thus, we propose a mission concept centered on the DLR Scout rover, a novel and inherently robust cave exploration rover, based on rimless wheels [5].

Mission Overview: The goal of the mission is to enter a martian or lunar skylight in order to check for cave continuations and placement of a sensor suite. A camera will also be used in order to deliver visible light images for context. With a combination of the navigation suite and communication modules, the cave passages will also be surveyed in order to produce a map, as is tradition in terrestrial speleology.

From a technical point of view, the mission is planned to be as simple as possible. Thus, it is planned to discard rope access systems and to focus on sufficient robustness of the rover system. This allows for dropping into smaller skylights (10-20m depth) or larger ones, partially filled with regolith.

Figure 1 illustrates an overview of the mission sequence which is designed to be "one way", i.e. the rover is going into the cave but never out again. It allows to take a higher risk of going beyond obstacles that are not reversible and to omit the need for a recharging system for the rover once it is in the cave. Thus, the mission inside the cave will last as long as the battery runtime. As the scout rover is a small, lightweight system, several such rovers may be part of one mission to increase the exploration impact and science return.

In order to access an entrance of a lava tube there are several options to be considered: having a bigger main rover that is delivering one or more Scouts from the landing module to the entrance, or having the Scout equipped with solar panels to make the approach on its own. The first option is favorable as system complexity of the Scout is reduced, while the second option is preferred for rough terrain during the approach.

The Scout rover is based on rimless wheels [5] and uses a modular design concept. It consists of a main module, housing the control hardware, a set of actuators and batteries, while the auxiliary modules house a set of actuators each and offer space for up to 6kg of payload. As a baseline, three modules with six wheels are used. Compliant elements in the spokes and as "vertebrae"

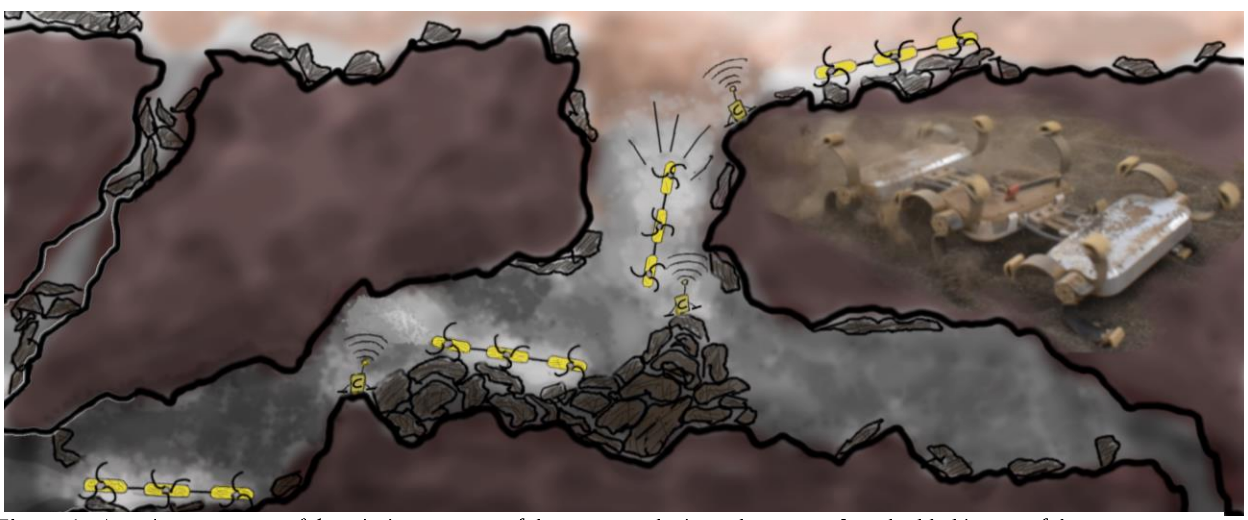

Figure 1*: Artist's impression of the mission concept of the rover exploring a lava cave & embedded image of the rover*

between the elements allow for terrain adaption and shock absorption. The wheels are coordinated in bionic phase shift schemes to maximize terrain traversability.

With robustness being a design driver, the rover is tested for drops of >1.5m on Earth, spokes can be ripped off if they are stuck in debris and the system can upright itself from sideways positions. Only the most crucial actuators are used in order to reduce single points of failure. Thus steering is done by skidding. Further test campaigns are planned for larger drop heights of up to 10m, while reduced gravity will further increase the survivable drop height on Mars and Moon. Table 1 lists the key characteristics of the rover.

Table 1: *Characteristics of the Scout rover*

Rover mass	~18kg
Payload capacity per aux module	6kg, 5l volume
Maximum speed	~1.7m/s
Max. obstacle height	>400mm
Tested drop height	>1.5m
Battery runtime (single/double)	>5h/10h
Number or modules	2-5

The robustness with respect to impacts makes it a perfect fit for cave exploration, where even intelligent systems will finally be unable to avoid minor incidents like dropping down a shaft or vertical step.

Science: Science is a main driver for the mission and thus an instrument suite to analyze geology and habitability, is considered at first. Following missions might then have a closer look for traces of life on Mars.

Astrobiology and Habitability. If life ever appeared on Mars, its subsurface, and thus lava caves, pose the most habitable conditions. The caves may have provided organisms and their remnants shelter from harmful surface radiation and potentially preserved detectable traces. Field analogue research on Earth has shown the tremendous potential of such environments to sustain unique ecosystems and to contain preserved biogenic or biomineral traces [6-8]. The main characteristics for habitability are the presence of an energy source and a liquid solvent such as water. However, in Martian caves neither the atmospheric conditions, including humidity and temperature nor the presence of key mineral and organics are known and investigated. The latter might serve as nutrients for any kind of life. Consequently, cave exploration might fill these gaps of our knowledge.

Geology. Whereas astrobiology will be the main scientific driver for lava cave exploration, it will be essential to document the geologic context. Beyond visual inspection by a camera, a 3D characterization would be important both for navigation and for information on lava properties, such as drainage rates and rheology. Spectroscopic information on any minerals precipitated by percolating aqueous solutions are required for characterization of the geochemical environment and the assessment of energy sources.

Human Habitability & Mining. Lava caves would provide potentially ideal shelters for future human exploration mission on both Moon and Mars, even more so for a sustained long-term base settlement. Their robotic exploration and characterization are therefore crucial to assess accessibility and safety for future human explorers.

Communication concept: As the concept is designed as a “one way” mission, the rover communication will be relay-based to secure that data can be transmitted to the base station at any time. Therefore the rover has to place relay modules whenever the signal gets too weak or if obstacles would obstruct the connection. The transmission frequencies used will be directly adapted to the cave environment.

The Team is an international, multidisciplinary team including astrobiology, engineering, volcanology and volcanospeleology. Thus, the core team is already well suited for the current conceptual and early prototype stage. For a mission proposal several options are planned: leading a mission proposal with one or several Scout-packages as a major part of the mission, or to be a scientific contribution to a larger mission.

Development timeline: The main goal of the mission concept is to be mission-ready, i.e. TRL 8, by 2030. This ambitious goal together with the target flexibility of the mission (Mars or Moon) are thought to make the package more attractive for a wider variety of institutions and missions. The European large logistics lander [9] will also be a valuable mission opportunity. Development of the rover started in 2016 and yielded a TRL 4 for the locomotion part so far. TRL 5 and 6 are aimed for 2022 and 2026 respectively. Thereby the TRL 5 test is planned within an analog mission in a terrestrial lava tube. In July 2021 the rover will already be part of the ARCHES [10] analog-site mission GEO-II in a multirobot scenario carried out by DLR together with ESA.

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