GLOBETROTTER: A NEW MISSION CONCEPT FOR LUNAR POLAR AND PIT/CAVE EXPLORATION.

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Summary: GlobeTrotter is a concept for a universal all-terrain soft-walled robotic hopper for rapid, robust, and low-cost exploration of the surface and subsurface of the Moon, Mars, Phobos, Deimos, and other small bodies. We present here GlobeTrotter lunar science mission concepts to explore the polar regions and pits/caves in support of Artemis astronaut missions to the Moon.

Motivation: To date, less than 0.002% of the 38 million km^2 of the Moon's area has been explored from the surface. Vast tracks of lunar highlands and maria, including discrete regions and features such as impact basins and craters, volcanic centers, lunar rilles, lunar pits and caves, and the permanently shadowed regions (PSRs) of the lunar poles, remain unexplored from the surface. The maria are topographically benign at large scales (hm to km) but can present significant roughness at small scales (m to dm), *e.g.* large boulder fields [1]. The highlands present slopes at hm scales that commonly exceed 15^o-20^o and may reach angle of repose at 32^o-35^o [2]. Their surface roughness at small scales may replicate that at larger scales [1]. The youngest large impact craters on the Moon present even steeper slopes and rougher terrain [3]. The lunar poles, where H_2O ice-rich terrains occur and where NASA aims to land astronauts by 2024 (at the Lunar South Pole) are in rough and steep-sloped highland terrain.

Lunar polar terrains also present significant diversity in terms of relationship between the 3D distribution of H_2O ice and physical conditions prevailing at the surface and in the subsurface. Moye & Lee [4] show that the lunar polar terrains may be divided into different classes based on combinations of the following key factors: a) whether or not they present detectable H at the surface or within the top 1 m of the regolith, b) whether or not they are located in PSRs, and c) whether or not thermodynamic models predict that H_2O ice would be stable within the top few meters of the subsurface. This classification is useful not only to help understand the origin, evolution, and 3D distribution of volatiles at the lunar poles, but it may also serve as tool for planning future exploration missions to the Moon. For instance, as the various classes of lunar polar terrain are typically separated over distance scales of 10 to several 10s of km, exploration at that scale is required in order to adequately sample the full range of terrain classes [4].

Thus, robust *in-situ* robotic precursors capable of rapidly scouting out large areas of the lunar surface over ranges of 10s of km in the polar regions, including into and out of the cold, dark, and often steep and rough interiors of PSRs, are needed.

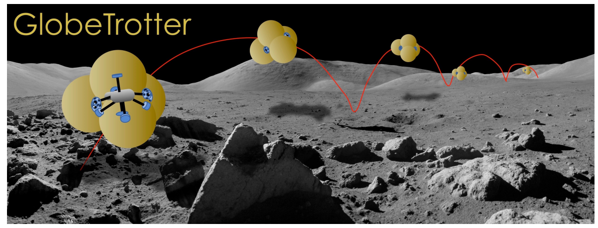

Figure 1. GlobeTrotter on the Moon.

Meanwhile, lunar pits and caves, which will also attract robotic and human explorers for science and exploration as they may offer unique geological insights into the lunar subsurface, shelter, and potential resources present specific exploration challenges [5-8]. Candidate lava tube skylights reported at high latitude on the Moon, in Philolaus Crater (72°N) 500 km from the lunar North Pole, are particularly intriguing, as they would be cold enough to cold-trap H_2O ice [5-9].

Conventional pit/cave exploration concepts such as robotic rovers, walkers, danglers and direct landers present the significant risk of having to interact intimately with poorly known, likely very rough terrain, as well as limited dwell times in cold, dark, solar-power- and comms-denied caves. Drones have been proposed [7], but the gas thrusters needed for lunar drones would likely stir up significant dust. A more robust robotic scout insensitive to terrain roughness and capable of entering, exploring, and exiting any pit/cave without stirring up significant dust during entry is needed.

GlobeTrotter: GlobeTrotter is a soft-walled robotic vehicle that can rapidly and robustly explore vast areas of the Moon via "leaps and bounds" **(Fig.1)**, tolerant to terrain roughness, able to use gravity and slopes to its advantage, and capable of low risk pit/cave ingress and egress. The concept emphasizes aerial coverage (range) and access to extreme terrain (trafficability), including deep cavities, while offering a variety of science mission focus options (mission versatility). We present below three lunar polar science mission concepts: 1) An extended traverse at Idel'son Crater to investigate several classes of lunar polar terrain as defined in [4]; 2) A mission to Shackleton Crater at the lunar South Pole to explore the Shackleton PSR all the way to the bottom of the crater; 3) A mission to a high latitude pit/cave to search for and study potential cold-trapped H_2O ice. Beyond lunar polar science, GlobeTrotter could, at high latitudes, keep pace with the shifting lunar terminator and investigate other lunar processes such as charged dust transport. The above missions may be designed as their own science-driven missions, and/or serve as precursors to Artemis Program astronaut missions.

Mission to Idel'son Crater. Idel'son Crater (D~28km), at 84.2°S, 115.8°E, lies on the far side of the Moon, just behind the southern lunar limb, in an area periodically in direct view of the Earth due to libration. The crater and vicinity offer access to several distinct and important lunar polar terrain classes (Class 1, 3, 4 and 8 in the classification system of [4]) within a surface traverse of a few tens of km in range **(Fig. 2).**

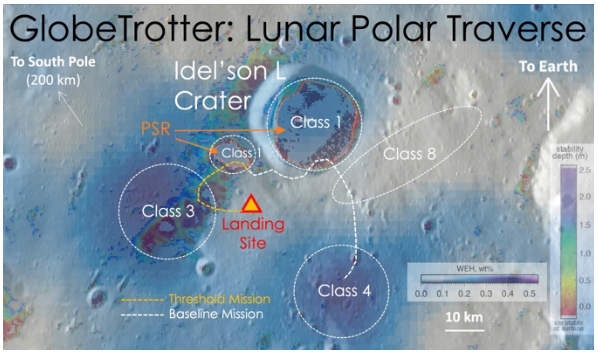

Figure 2: GlobeTrotter Lunar Polar Traverse at Idel'son Crater. GT would examine H-rich regions inside PSRs (Class 1) and outside PSRs, in the latter case both where H_2O ice is expected to be stable in the shallow subsurface (Class 3) and not (Class 4). (Base map adapted from [4]).

Mission to Shackleton Crater. Shackleton Crater (D~21 km, z~4 km), at 89.9°S, 0.0°E, is located at the Lunar South Pole. Portions of its rim are exposed to sunlight 80–90% of the time through each lunar orbit, making it an attractive hub for human activities. Exploration of a substantial extent of its known H_2O ice deposits would require traversing far into the PSR of this steep-walled and deep crater, which only a rapid and robust explorer such as GlobeTrotter could do **(Fig.3).**

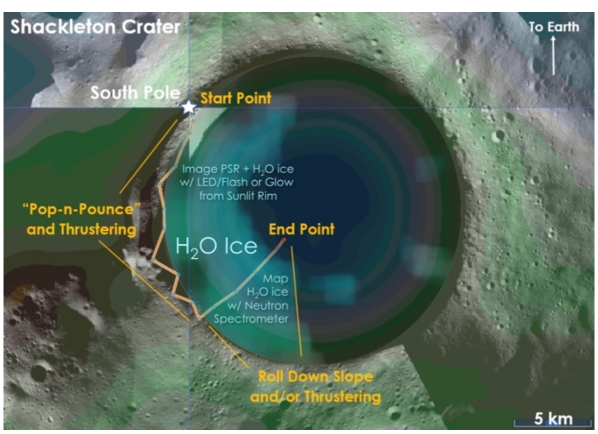

Figure 3: GlobeTrotter Mission to Shackleton Crater. Following a landing at the Lunar South Pole in an area of quasi-continuous insolation, GlobeTrotter would first explore Shackleton's rim, then "dive" into the crater on a 1-way 2-day 10 km traverse to the bottom, investigating H_2O ice deposits at various stops along the way.

Mission to High-Latitude Pit/Cave. The 15-30 m-wide candidate impact melt lava tube skylights on the floor of Philolaus Crater (72.1°N, 32.4°W), if confirmed, would be permanently shadowed and, as the lunar polar PSRs, cold-enough to cold-trap H_2O ice [5,6].

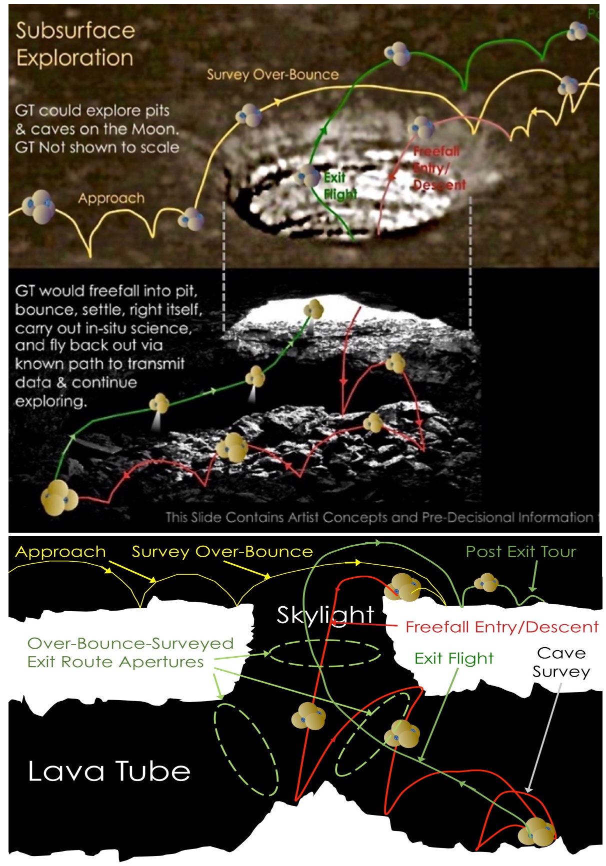

Figure 4: GlobeTrotter Mission to a Lunar Pit/Cave.

Payload: GlobeTrotter's payload may include:
- *Multispectral Imaging System (MIS),* a multidirectional array of multichannel cameras for science (geology, atmosphere), H_2O-ice prospecting, navigation, and hazard avoidance, with LEDs to image shadowed areas.
- *Neutron Detector (ND)* to measure regolith H abundances at 1-10 m resolution for science (geology) and resource prospecting (OH / H_2O ice).
- *Near-Infrared Volatile Spectrometer (NIRVS),* a multichannel spectrometer for mineralogy/volatile studies.
- *Accelerometers* to reconstruct attitude, position, speed *vs* time, and map slope profiles.

References: [1] Rosenburg, M. et al. (2011). *JGR Planets* 116. [2] Krevalsky, M. et al. (2013). *Icarus* 226, 52-66; [3] Kreslavsky, M. & J. Head (2016) *Icarus* 273. [4] Moye, C. & P. Lee (2020). *51st LPSC*, #2594. [5] Lee, P. (2018). *49th LPSC*, #2982. [6] Lee, P. (2018). *6th Europ. Lunar Symp.*, #024. [7] Lee, P. *et al*. (2019) *50th LPSC*, #3118. [8] Lee, P. (2020). *3rd Int'l. Planet. Caves Conf.*, #1066.