PROPOSED MISSION ARCHITECTURE AND TECHNOLOGY REQUIREMENTS FOR ROBOTIC AND HUMAN EXPLORATION OF MARTIAN CAVES. J. J. Wynne[1], C. M. Phillips-Lander[2], and T. N. Titus[3]; [1]Department of Biological Sciences, Merriam-Powell Center for Environmental Research, Northern Arizona University, Flagstaff, AZ, jut.wynne@nau.edu; [2]Space Science & Engineering Division, Southwest Research Institute, San Antonio, TX; and, [3]Astrogeology Science Center, U.S. Geological Survey, Flagstaff, AZ.

Introduction: Since the identification of atypical pit craters in 2007[1], the number of cave-like features resolved on Mars has steadily increased. To date, at least 1,035 features have been cataloged[2]; most of these features occurred within regions identified, via thermal inertia and numerical modeling, as capable of maintaining stable water ice deposits underground[3] (**Fig. 1**). In addition to serving as veritable laboratories to investigate numerous questions related to planetary geology, martian caves: (1) represent one of the best locations to search for evidence of life, (2) may provide access to water ice deposits for human use, and (3) are the safest places for human habitation.

However, beyond their locations and elementary entrance characteristics, we know little about these potential access points to the martian subsurface. How do we identify the most important candidates for astrobiology research versus human use? Importantly, how can we evaluate and rank these features? Moreover, what are the key planning elements to include in robotic and human missions? Here we briefly describe a mission architecture for robotic and human cave missions, while identifying critical lacunas in technologies that must be addressed to make such missions viable, as well as to help ensure mission success.

Mission Architecture: We propose a simplified process to advance martian speleology from a rudimentary understanding to acquiring the data required to evaluate and select the best candidates for astrobiological investigations and human outposts (**Fig. 2**).

I. Remote Detection. ***Development Status (DS):*** Combining thermal and visible imagery is a useful approach for detecting terrestrial[4-6] and martian[1,2,7] cave entrances, while gravimetry has been applied to estimate the subterranean extent of lunar caves[8]. ***Technology Requirements (TR):*** A multispectral approach will be most effective to most accurately identify and examine martian caves of interest; this

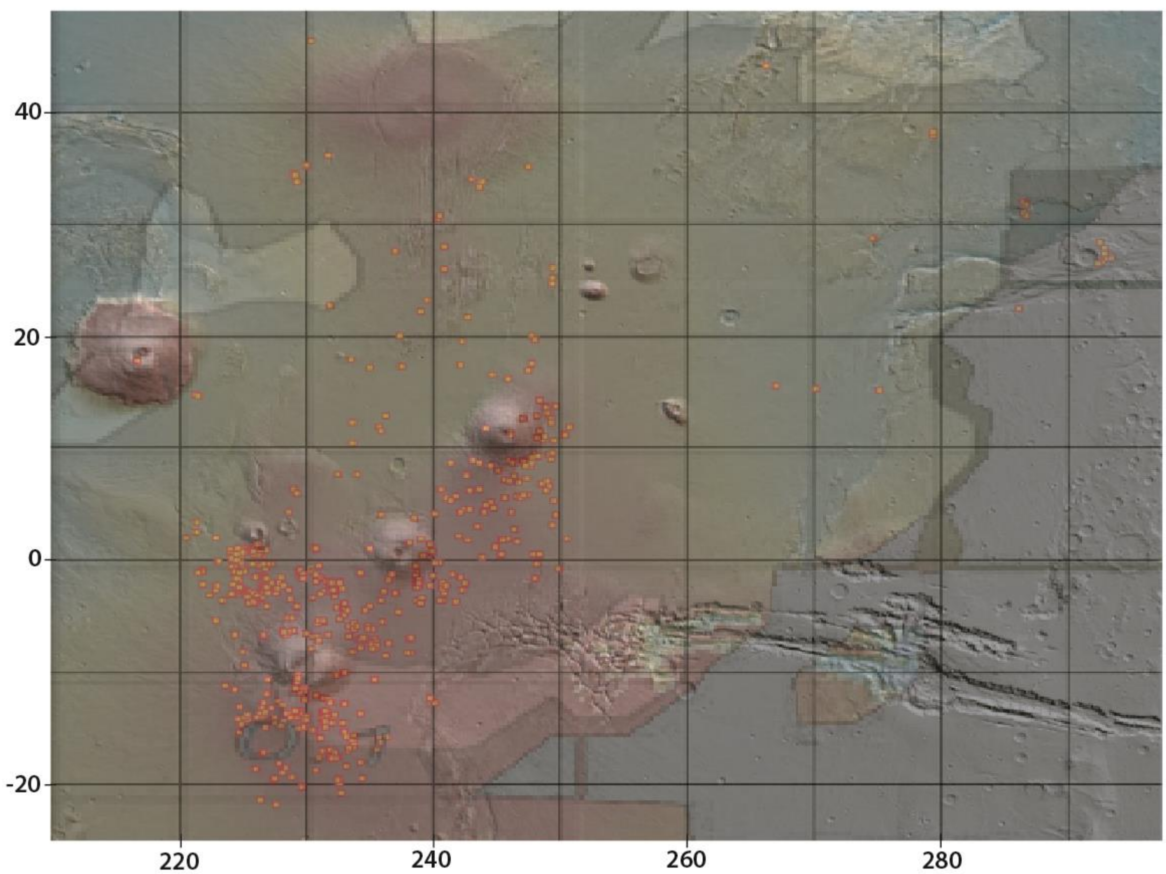

Fig. 1. Global Mars. Map overlay of cave locations (red and yellow dots)[1] primarily in the Tharis Rise (red), which is an area modeled to support water ice within caves[3].

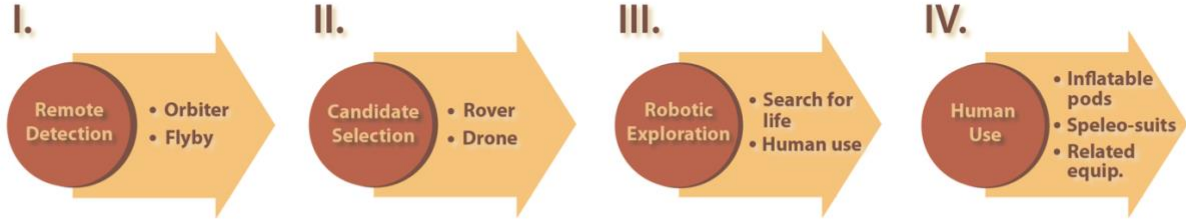

Fig. 2. Proposed architecture for robotic and human exploration missions to martian caves. Development status (DS) and technology requirements (TR), for each of the four steps, are discussed.

should include the addition of LiDAR and gravimetry data. In concert with thermal and visible imagery, LiDAR should be assessed for initial detection analysis, and the limitations of gravimetry need to be evaluated. Once entrances have been confirmed using thermal, visible and LiDAR data, gravimetry may ultimately be applied to differentiate large passages and rooms (conducive to human habitation) from deeper, more expansive caves (those likely to score highest as astrobiology targets).

II. Candidate Selection. In addition to the techniques elucidated in 'step I', these criteria (i.e., characteristics of regolith and local terrain; landing, power, and traversablity considerations for robotics; and, co-location of multiple high priority candidates) may be used to down-select the +1000 caves to a manageable number. Subsequently, either rovers or rotorcraft drone systems could then conduct a more detailed analysis to further pare down the number of suitable candidates. ***DS:*** Rovers currently used in Mars missions may be an effective tool for surveying entrance characteristics. Importantly, the Mars 2020 rover will include a small rotorcraft scout as part of its payload[9]. ***TR:*** Post-Mars 2020, NASA will have 'flight proven' Mars helicopter technology, which could be further refined and used to examine cave entrances.

III. Robotic Exploration. Given that most cave floors are littered with breakdown (cave ceiling material resting on the cave floor), dual-axel rovers will be unsuitable for most cave environments. ***DS:*** Currently, one of the best technologies to overcome this hurdle is the Limbed Excursion Mechanical Utility Robot (LEMUR) 3. Once fully developed, the world's first rock-climbing robot will be able to independently identify the most suitable travel route through a cave's entire 3D interior. This platform may be used to acquire, process, and analyze samples to search for evidence of life, as well as assess the structural stability of cave interiors for human habitation. ***TR:*** Currently, LEMUR 3 is rated at a technical readiness level (TRL) of 6. Substantial advancements (through adequate funding) will be necessary before the LEMUR platform can be elevated to 'flight qualified' status (TRL=8).

IV. Human Use. ***DS:*** Prototypes for inflatable and hybrid inflatable-rigid[10] human habitats are in the proof-of-concept stage and have been successfully tested in computer simulations. Current spacesuit technology, which has been largely unchanged since the Apollo program and is currently used for EVAs on the International Space Station, will be unfit for use underground – due to restricted mobility and the high risk of suit breech. BioSuit technology[11] is a svelte-fitting alternative that offers significant improvements to traditional spacesuits. These suits, and associated donning and doffing technologies, are still at the proof-of-concept stage[12]. To be used in caves, BioSuits must be extremely ruggedized to become puncture and abrasion resistant. Finally, technical climbing and work equipment for conducting science operations in spacesuits does not exist for underground use, nor have there been any studies to inspect the feasibility of such technologies for extraterrestrial cave applications. ***TR:*** All of these technologies need to either be developed and/or evolve from proof-of-concept to 'flight qualified' status (i.e., TRL=8) before we can safely enter, work, and live in the martian subterranean realm.

Conclusion: Through fully developing the analytical techniques and robotic technologies to down-select to the highest priority targets (steps I & II), and ultimately the technologies to support subterranean robotic and human missions (discussed in steps III & IV), then we will be poised to embark upon scientific exploration of the caves on Mars.

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