JPL R&D FOR DEEP EXTRATERRESTRIAL CAVE EXPLORATION. K. L. Mitchell, L. Kerber, M. J. Malaska, Jet Propulsion Laboratory, California Institute of Technology, Mail Stop 183-601, 4800 Oak Grove Drive, Pasadena, CA 91109, Karl.L.Mitchell@jpl.nasa.gov.

Overview: The discovery of craters indicating the presence of lava tubes on Moon [1,2] and Mars [3] opens up a new frontier for exploration of benefit to both planetary science and human exploration. However, accessing their riches presents a series of technical challenges. A 2014 joint study between Jet Propulsion Laboratory (JPL) and New Mexico Tech (NMT) identified six areas of technological fidelity (see table 1) that would be required to reach a technology readiness level (TRL) of 6 before exploring deep inside an interplanetary cave. Significant advances against these areas have been achieved at JPL both in development of the Moon Diver mission [4] and in a series of individual projects funded both internally and via ROSES R&A programs, including NIAC and PSTAR. Activities continue, with increasing emphasis on demonstrating approaches in terrestrial caves and developing fully integrated resilient semi-autonomous robotic systems for deep cave exploration.

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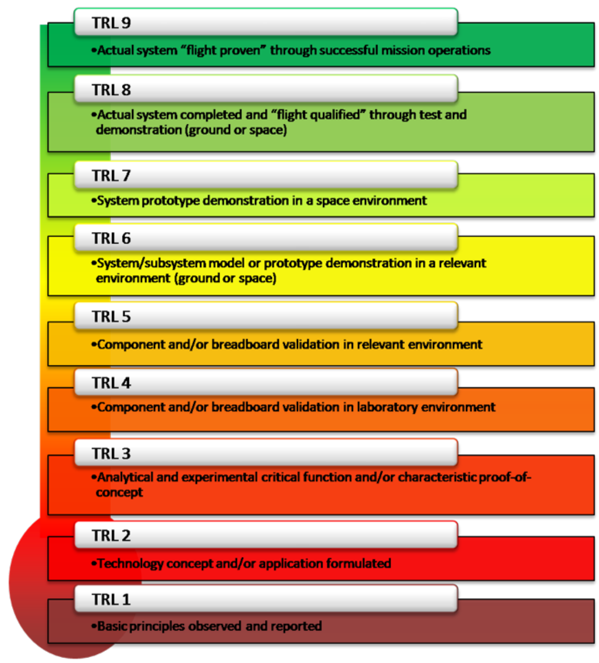

Fig. 1: NASA Technology Readiness Levels. Source: https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html

Table 1: Extraterrestrial cave exploration requires advances in six key areas of technical fidelity.

Area of technical fidelity	Challenges	Potential solutions
Access	Precision landing for limited-range/speed mobility solutions. Descent into a skylight.	Precision landing, large surface rovers carrying smaller devices, wheeled robots with tethers, e.g. Axel [5].
Mobility	Deep cave entry over some unknown, probably rubbly/blocky surfaces.	Wheeled robots (problematic for rubble), hoppers, limbed robots (e.g. LEMUR [6]).
Power	Extended operation without sunlight.	Umbilical (powered tether), MMRTGs [7], beamed energy, reflected sunlight + solar [8], batteries, low power payloads (see instrumentation).
Communications	2-way data transfer for operation and science return without line-of-sight to Earth.	Umbilical (powered tether), wireless relays (e.g. IEEE 802.11), electro- or magneto-quasistatics [9].
Control	Navigation within a previously unmapped environment, automation of complex path planning and mobility activities, intelligent target selection.	Simultaneous autonomous localization, mapping and planning [10], joystick control (Moon-only), hydrid approaches (e.g. Moon Diver).
Instrumentation	Low/no light conditions, limited power, cave-specific conditions/materials.	Ongoing development of numerous instrument classes for planetary exploration (e.g. SHERLOCK [11]).