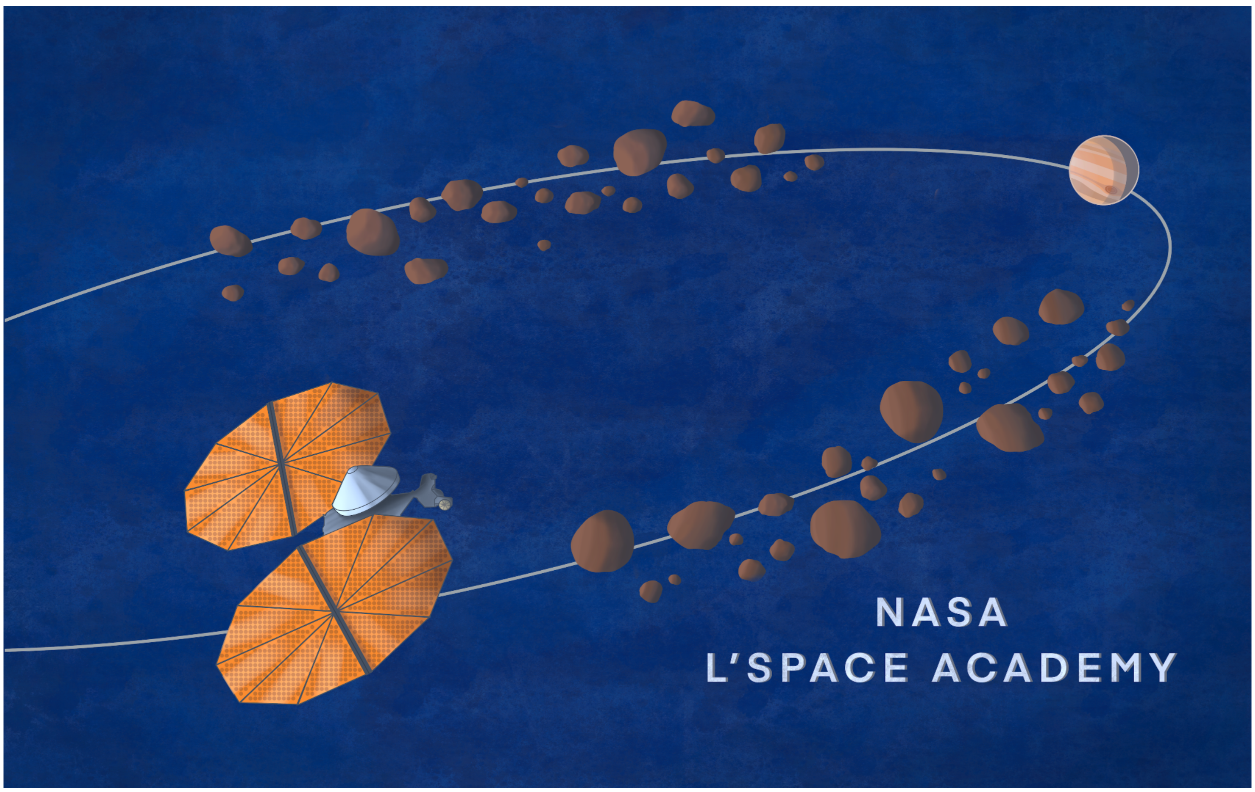
L’SPACE MCA Mission Concept Requirements Review

The Dream Team #33



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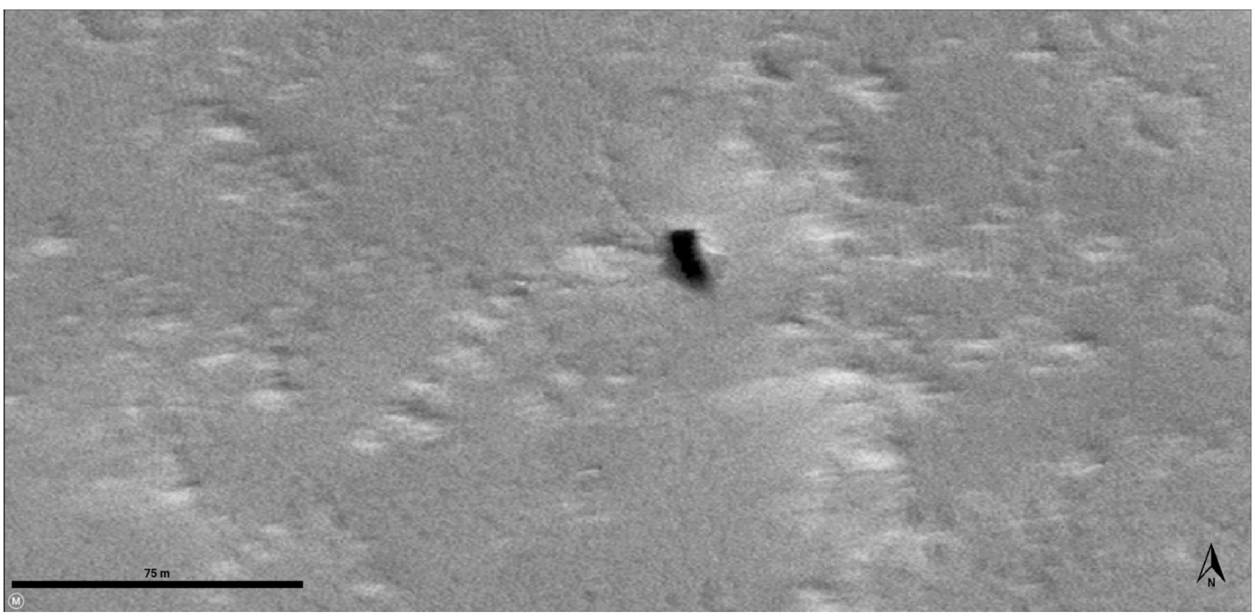
1. Mission Concept

The purpose of this mission is to further human understanding of the Martian cave environment using an uncrewed robot. It shall gather data inside a Martian cave to provide greater information pertaining to the topics of astrobiology, especially whether life could have existed in the past and if life can exist in the future. Scientists will understand the Martian cave environment by investigating the rocks inside the caves. It will search for signs of water ice by observing minerals within the cave such as (TBR) through imagery and spectroscopy. During this time, the robot will also investigate patterns in methane concentration, radiation flux, temperature, and pressure to determine if the cave is safe for human exploration within the cave.

A rock-climbing robot similar to NASA's Lemur 3 (JPL, 2011) will descend and traverse the Martian cave network with a camera to analyze cave structure. The robot will be attached to a base station on the primary payload and lowered into the cave via a tether that provides both power and communications. An ideal cave candidate for this mission would be CC0068, a cave in the northern Tharsis region. This cave has a high potential for seasonal or permanent hoarfrost formation (Schörghofer, 2021), and is part of a lava tube network. The criteria for mission success is furthering the scientific understanding of the role that Martian cave microclimates have in fostering past or present Martian life, with a secondary goal of establishing the potential for future human exploration.



Picture of CC0068, northern Tharsis region, snipped from JMARS (HiRISE)

2. Requirements

This mission shall explore the Martian cave environment in an effort to better understand the viability of Martian caves as a place where either past or present Martian life, or future human life, could exist and flourish.

- The combined vehicle will have a mass less than 50 kg, a volume less than 1.5 meters cubed, and not exceed $300 million in cost.
- The vehicle will be capable of lowering itself into the cave; Once at the base of the cave, it will be capable of traveling in cavernous terrain to scientific places of interest.
- The vehicle shall have a camera system capable of visible, infrared, and LIDAR imagery; a spectrometer for both solids and gasses, a barometer; a thermometer; and a radiation particle detector.
- The tether shall be capable of providing both data communications and power from the base station to the robot, and must be (TBD) long.
- The system shall be maintained within allowable operating temperatures (TBD) for all environmental conditions experienced in the Martian cave.
- The system shall comply with all applicable planetary protection regulations.
- The system shall have sufficient power to operate for (TBD) years.

Req #	Requirement	Rationale	Parent Req	Child Req	Verification method	Relevant Subsystem
SYS.01	Determine the percent abundance of water ice within the Martian cave.	Science goal 1 for the mission.	STM		Science Review	All
SYS.02	System shall collect data on atmospheric samples within the cave.	Science goal 2 for the mission.	STM		Science Review	All
SYS.03	Determine the viability of human habititation in the radiation environment within the Martian caves.	Science goal 3 for the mission.	STM		Science Review	All
SYS.05	System shall send and receive data to Earth ground station.	Necessary for both remote operations, and for sending instrument data.	Customer		Demonstration	Communications
FUN.01	System shall be capable of recording and storing data.	It is necessary to store data before radio transmission to Earth.	None		Analysis and Modeling	Instruments
FUN.02	System shall have sufficient power to operate for TBD duration.	System needs power for operations, communication, and instruments.	None		Demonstration	Electrical
PER.01	System shall be able to withstand thermal environment of a Martian cave for TBD duration.	The mission needs to be able to survive the extreme environments on the surface and within the Martian caves.	None		Demonstration	Electrical
PER.02	System shall have the ability to manuever into, and around the cave.	Probe must enter cave, and manuever to points of scientific interest.	None		Demonstration	Motion
CON.01	System will not exceed a mass of 50kg.	Defined by primary payload's targeted mass.	None		Inspection	All
CON.01	System will not exceed a volume of 1.5 cubic meters.	This requirement was given by the customer	None		Inspection	Structural

Mission Requirements Spreadsheet

3. Science Traceability Matrix

Science Goals	Science Objectives	Science Measurement Requirements: Physical Parameters	Science Measurement Requirements: Observables	Instrument Performance Requirements		Predicted Instrument Performance	Instrument	Mission Requirements
Do Martian caves present a location where life could have existed in the past, and do they present a viable location for future human exploration?	Determine the percent abundance of water ice within the Martian caves	Identify presence of permanent or seasonal water ice formation	Detect temperature of cave roof	Visible Range:	TBR	TBR	MASTCAM-Z by MSL (Bell, et al)	System shall collect imagery from within Martian cave
			Detect Hoarforst formation	Field of View:	TBR	TBR		
			Detect fallen ice crystals					
		Identify minerals such as calcium carbonate, calcium sulfate, and sodium chloride	Detect concentrations of carobates, sulfates, and chloride materials	TBR	TBR	TBR	Planetary Instrument for X-ray Lithochemistry by Mars 2020 (Alwood, et al)	System shall collect spectrographic data on rocks within the cave
		Identify the water gas at various depths	Detect concentrations of water gas in ppbv	Sensitivity:	TBR	Methane 2 ppb; Water 2ppm	Tunable Laser Spectrometer by MSL (Grecious, et al)	System shall collect spectrographic data on atmospheric samples
	Determine the percent abundance of organic materials	Identify key elements for life (nitrogen, phosphorous, sulfur, oxygen and carbon)	Detect materials within the 2 - 535 Dalton range	TBR	TBR	TBR	TBR	
	Determine the atmospheric patterns in methane concentration within the Martian caves	Identify the methane gas concentration at various depths	Detect concentrations of methane gas in ppbv	Isotopes:	TBR	13C/12C in methane; 13C/12C in CO_2; 18O/16O in CO_2; 17O/16O in CO_2;	Tunable Laser Spectrometer by MSL (Grecious, et al)	
				Isotope Precision:	TBR	Typically < 10 per mil		
		Measure atmospheric properties within the cave	Collect atmospheric pressure and temperature data	TBR	TBR	TBR	TBR	System shall measure atmospheric pressure and temperature within the cave
	Determine the viability of human exploration in the radiation environment within the Martian caves	Measure all high-energy radiation such as protons, energetic ions of various elements, neutrons, and gamma rays	Detect dose rate from 180 to 225 micrgrays per day	Charged Particle Energy Differential Flux Range:	TBR	95 MeV/nuc - 450 MeV/nuc	Radiation Assessment Detector (RAD), by MSL (Hassler, et al)	System shall measure the radiological environment inside the cave
				Neutral Particle Energy Differential Flux Range:	TBR	8 MeV - 100 MeV		
				Dynamic Range:	TBR	0.2 keV/um - 1000 keV/um		
				Observation Rate:	TBR	15 min/hr		
				Field of View:	TBR	36.7deg		
				Max Count Rate:	TBR	5000 events/sec		

4. Risks

Martian Cave Exploration Risk Summary

ID	Summary	L	C	Trend	Approach	Risk Statement	Status
1	Robot gets stuck / tips over and is upside down or on its side	3	4	NEW	R	The Robot has to be able to traverse the landscape within the cavern and recover in an unintended orientation. Wheeled rovers are not well suited to navigate through extremely rough terrain or access highly sloped surfaces anticipated to be present in subsurface environments. The method of travel is TBD.	
2	Failure to deliver power to the robot	2	5	NEW	R	Robot has to be able to reliably acquire power source without readily available solar energy in the cavern environment. The inherent risk of the cable spool is entanglement with cavern terrain and weight. Also, since the nature of the cavern interior is unknown, it is impossible to know exactly how much longer the tether would have to be.	
3	Lost in communication	2	4	NEW	R	The method of communication is supported through redundancy. The Robot could transmit scientific findings through an antenna or spool cord linked.	
4	Robot fails to identify obstacle during auto navigation	3	4	NEW	R	Robot has to be able to identify obstacles and navigate around unexplored terrain automatically. This risk is associated with Rover misidentifying obstructions and becoming lodged.	
5	Robot falls into a hole in the cave	3	4	NEW	R	As the Robot is navigating the subsurface terrain, it is possible that it would fall into a hole that is not possible to circumvent through its mode of locomotion. The spooling cord serves as redundancy for recovery in this scenario.	
6	Mechanical failure	2	4	NEW	R	Robot is designed to cross cavern terrain based on cave entrance survey and earth equivalence environment. With uncertain cave formation, this Robot must be built to be sufficiently robust for unforeseen circumstances.	
7	Instrument failure	2	5	NEW	R	The Robot's instrument suite is not redundant; if the instrument is lost, Robot could not perform science with another instrument	
8	Crucial Robot components exceed allowable operating temperatures	3	4	NEW	R	Robot has to be able to withstand TBD temperature gradient from hoarfrost cavern entrance and possible thermal plume beyond the twilight zone. This temperature change will require an active system to keep the components within operating parameters or temperature resistive material that would function under those conditions. Research and mitigate.	
9	Spooling system jams or tether fails	3	5	NEW	R	The spooling system has a possibility of jamming and the tether itself can be prone to tangling. In a cave system, the tether is used as not only a power and communications cable, but also as a life reel for the rover. The uncertainty of the depth of the cave, possible holes, and tangling on rocks makes it likely for failture of the tether system to occur.	

L = Likelyhood (1-5)	LxC Trend	Approach	Criticality
1 = not likely	↓ - Decreasing (improving)	A - accept	HIGH
5 = extremly likely	↑ - increasing (worsening)	M- mitigate	MED
C = Consequence (1-5)	→ - unchanged	W - watch	LOW
1 = low consequence	**NEW** - added this month	R - research	

LIKELIHOOD	1	2	3	4	5
5					
4					
3				1, 4, 5, 8	9
2				3, 6	2, 7
1					

CONSEQUENCES

Criticallity	LxC Trend
HIGH	↓ - Decreasing (improving)
MED	↑ - increasing (worsening)
LOW	→ - unchanged
	NEW - added this month

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