EXTRA-TERRESTRIAL LAVA TUBES EXPLORATION

Mission Architecture for Tele-Operated Robotic Exploration of Subsurface Geological Formations on the Moon and Mars

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Master Thesis Presentation
Space Architecture
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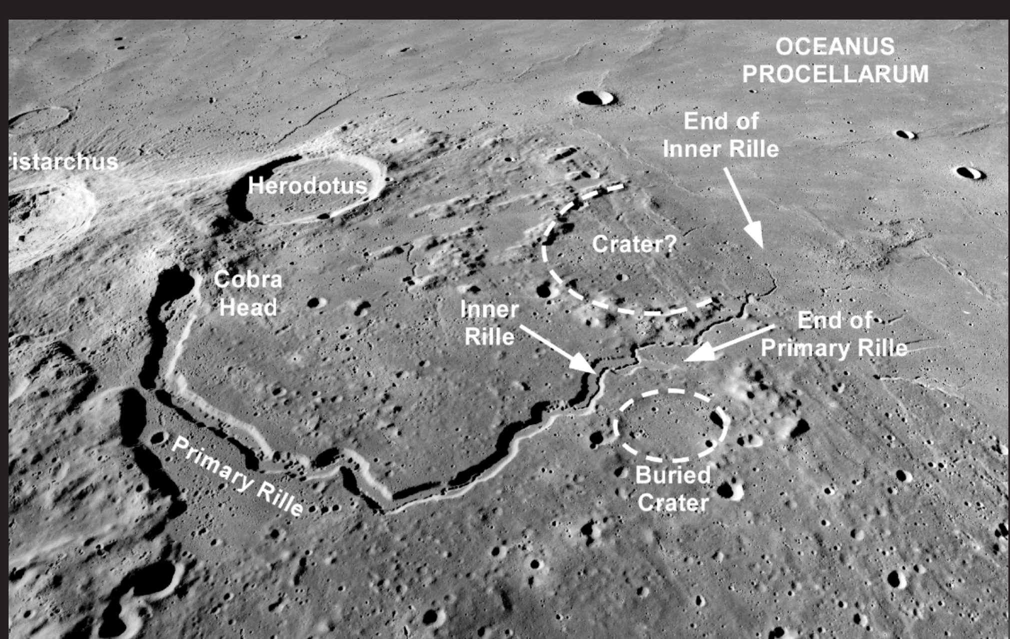
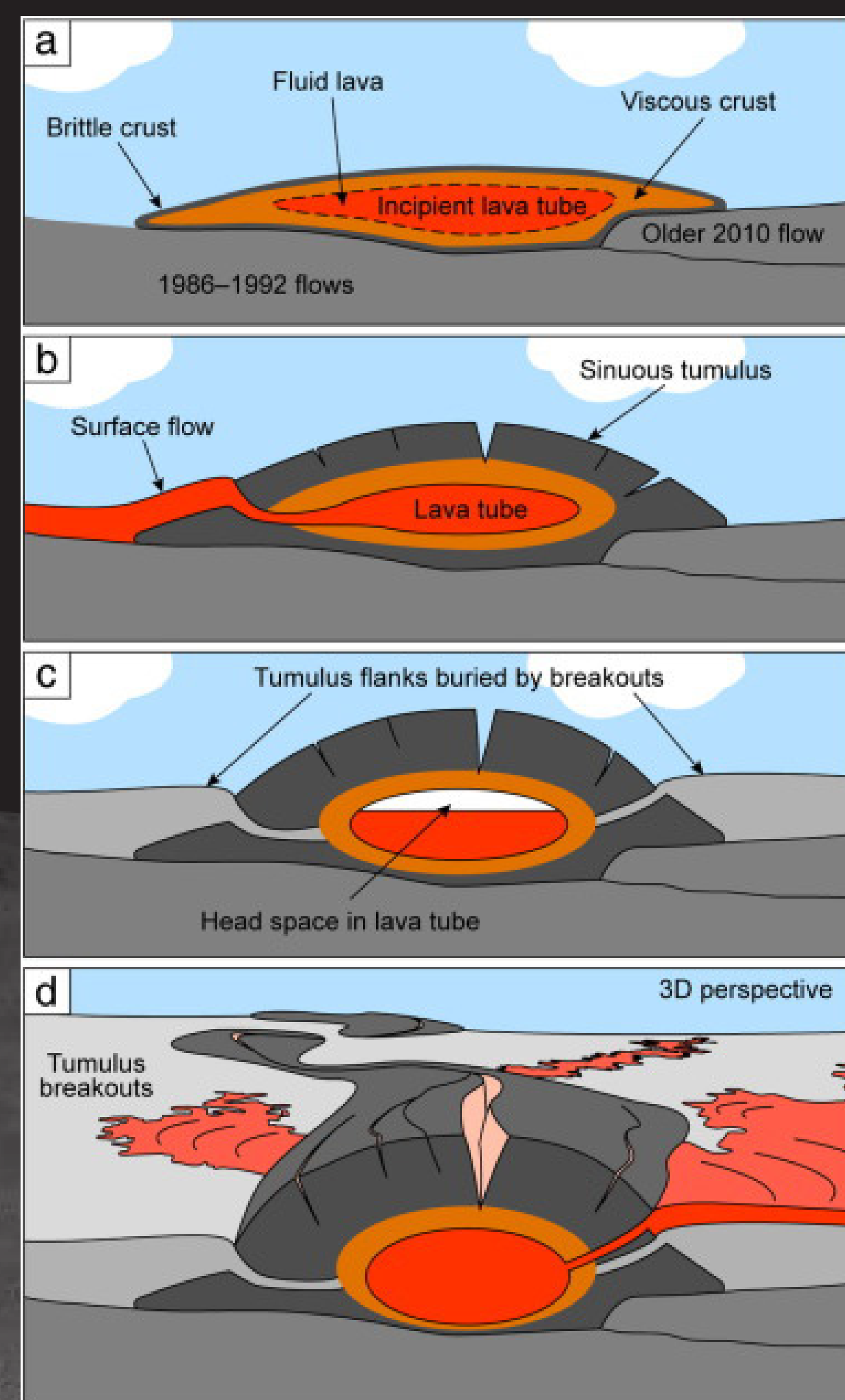
Lunar Lava Tubes

* First discovered after close examination of images provided by the Viking orbiter
* Lunar Reconnaissance Orbiter images revealed new pits and showed that the Mare Tranquillitatis pit opens into a sub-lunarean void at least 20-meters in extent

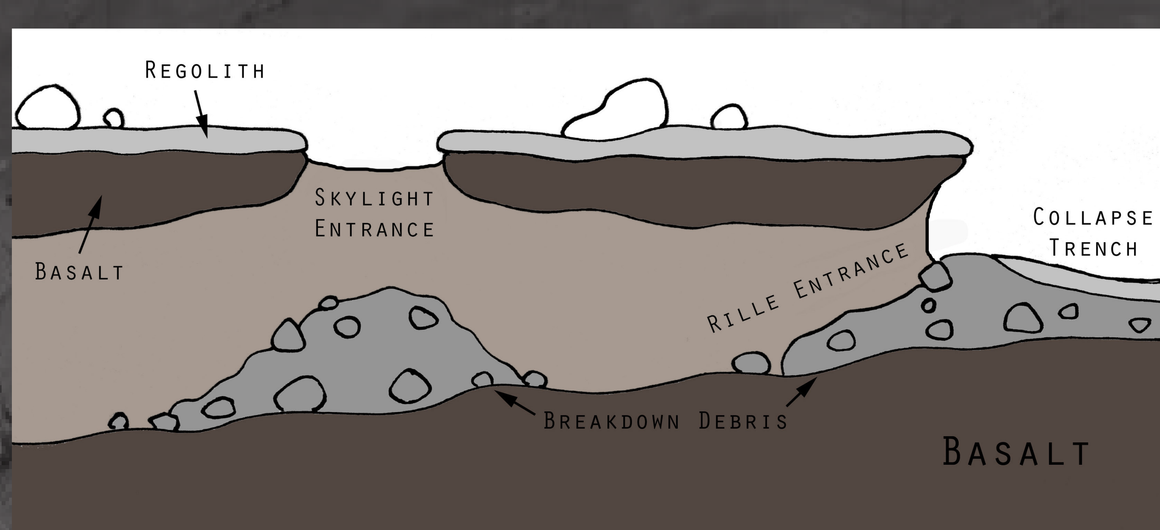


Two ways to Detect
1. Recognizing a long curving conduit or trench known as rille which are believed to be the remains of collapsed lava tubes
2. Observation of caves found on the surface

Formation
Mostly found in terrains composed of basaltic rock
a. Volcanic eruptions cause lava to escape to the surface
b. Top surface of flowing channels gets exposed and it cools faster than the lava a the center and bottom of the stream
c. Upper layer forms a hard crust over the core lava flow
d. Lava on the top cools, solidifies, and creates a solid surface barrier
After volcanic activity all is left behind are empty caves



4 Possible Entrances
1. Rille Entrance
2. Skylight Entrance
3. Hornitos Entrance
4. Artificial Entrance



Mission Context

The mission is set in the context of NASA's Artemis Missions and to fit future plans to colonize and explore the Moon and Mars

Assumptions:
1. For our purpose it is assumed that planetary exploration is already underway
2. A number of self-sustained outposts are already in place
3. Human colonization of the Moon has advanced to a stage that allows expeditions to venture into other regions beyond the safeguard of the first settlements
4. Technologies advancements required to fuel the mission are in place and that expeditionary mobile habitats and research equipment are readily available

Purpose of This Research

* Fuel and motivate future human exploration

* Establish a criteria to characterize and categorize extra-terrestrial lava tubes

* Assess the technologies for teleoperated semi-autonomous research

* Extend human lunar presence, augment exploration capabilities, manipulate assets and resources

* Discover and study lava tubes using remote and in-situ sensors and modeling equipment

* Acquire knowledge and understanding of remote robotic sensing capabilities and situational awareness needed for operations that involve interacting with harsh environments

Why Is Lunar Volcanic Formations Exploration Important?

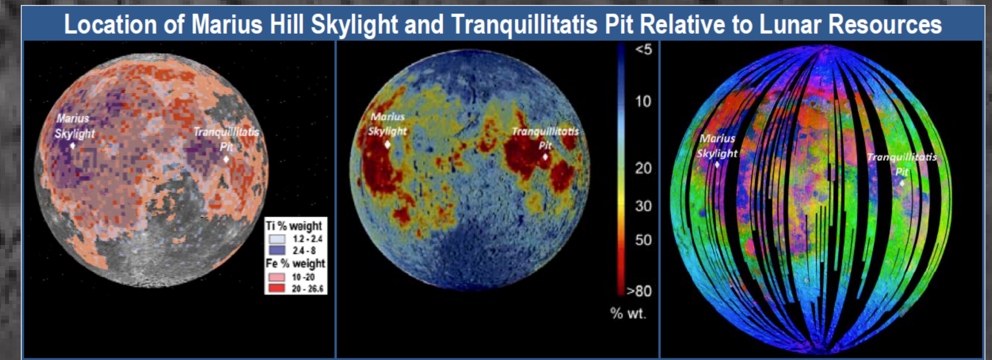
Human endeavor:
* Next frontier in planetary exploration

Habitation:
* Shelter human habitats from pearls such as hazardous radiation, micro-meteorite impacts, extreme temperature changes, and lunar dust mitigation
Resources:

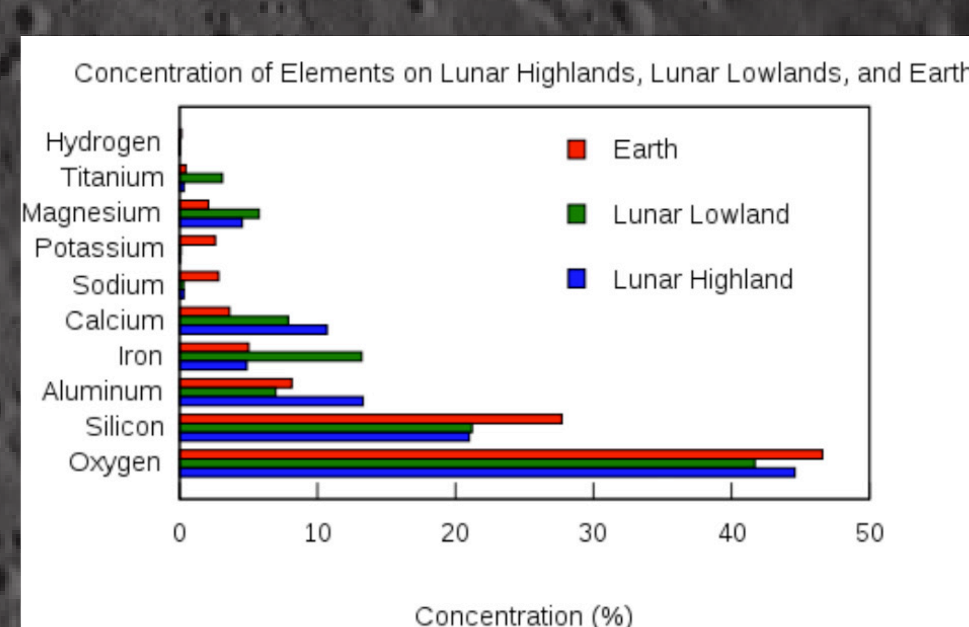
* Lunar skylights are being found all over the Moon's surface and since water ice is abundant on the floors of shadowed polar craters, it is believed that these skylights could also be "cold traps" where stable and accessible ice water could be found

Science:
* Geological treasures hidden in exposed layers of skylights
* Astrobiologists believe lava tubes could have provided a relatively stable environment where life could have taken refuge

Location of Marius Hill Skylight and Tranquillitatis Pit Relative to Lunar Resources



Titanium	Helium-3	Water Extraction
Map showing concentration of iron and titanium in Nearside maria. Iron and titanium are part of the mineral ilmenite ($FeTiO_3$), which has the ability to capture and retain gases, such as hydrogen and helium, from the solar wind. [NASA/USGS/Community College of Baltimore County].	Surface distribution map of Helium-3 implanted by solar wind accumulation in lunar regolith as determined by multi-channel brightness temperature observations from the Chinese satellite, Chang-E 1 (WenZhe, 2010). [Image modified with LTVT LOLA-64 DEM map with Helium-3 overlay, by Maurice Colins, Palmerson North NZ]	Map of water and hydroxyl on the moon from NASA's Moon Mineralogy Mapper (M3), an instrument on the Indian Space Research Organization's Chandrayaan-1 mission. All blue, cyan, magenta and pink areas contain adsorbed water and/or hydroxyl, while red, green, yellow and orange contain little to no water or hydroxyl (Clark, 2010)



Lava Tube Characterization
1. Topography
2. Visual imagery
3. Communications
4. 3D internal mapping of the lava tube cave
5. Soil/regolith composition
6. Bearing capacity
7. Acoustics
8. Temperatures (day, night, extremes)
9. Electromagnetic properties and energy, magnetic field
10. Electrical conductivity, electrostatic charging, Dielectric PermiWvity
11. Lava Tube cave albedo/reflectance
12. Lava Tube cave "air" sample
13. Radiation levels & measurements

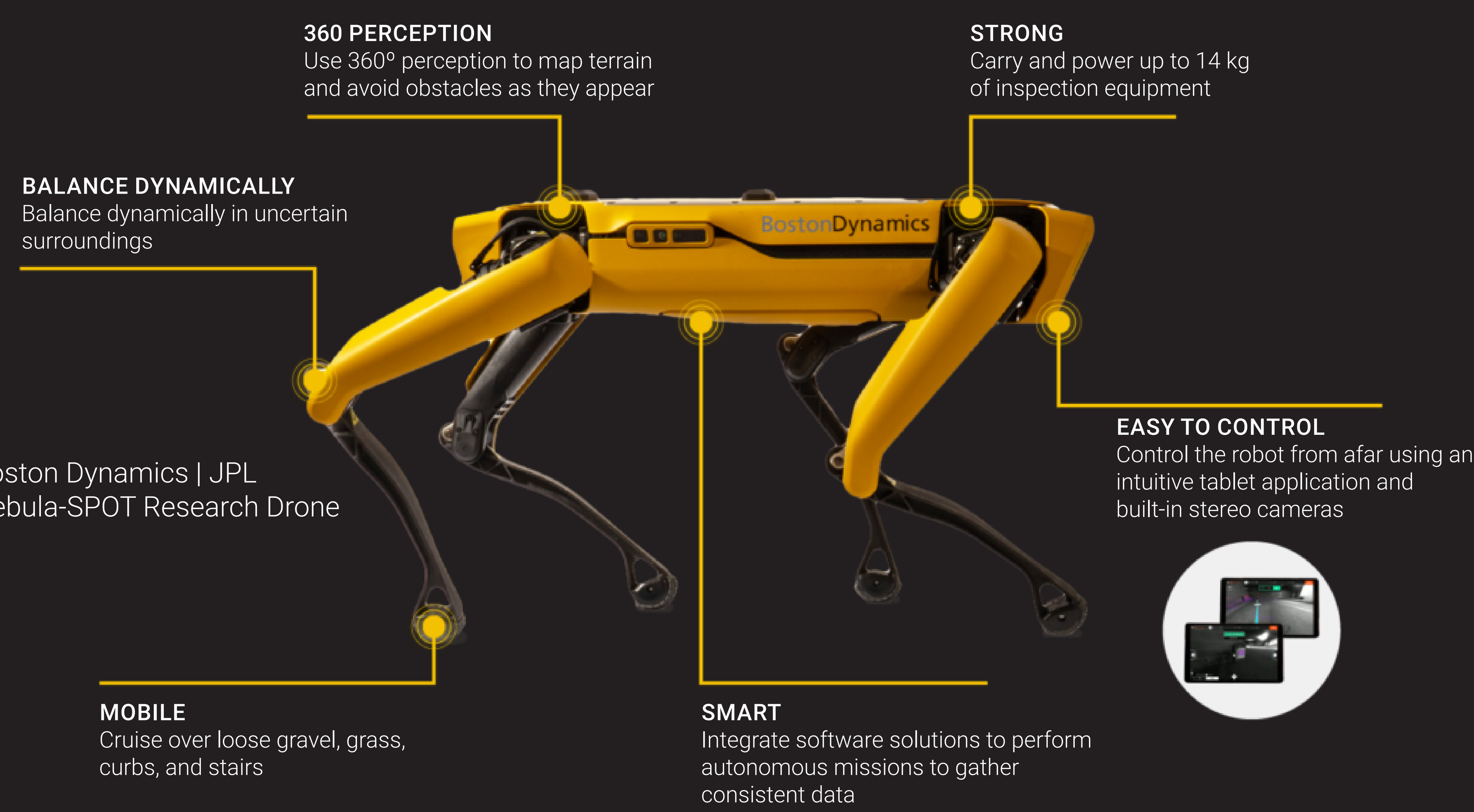
Mission Architecture

Twofold Architecture

1. First phase is the assessment of a lava tube to study its surface characteristics, the environment around the pit, and the resources allocation around the region. Mission is conducted by a semi-autonomous robotic drone equipped with suitable surface surveying instrumentation

2. Second phase of the mission focuses on the lava tube entrance and interior exploration. Exploration and scientific equipment will be delivered and cave introduction and research begins to take place.

This plan targets the pit crater in the Marius Hills region of the Moon, in the Oceanus Procellarum — a vast lunar mare on the western edge of the near side of the Moon Mineral rich region and possible ice-water resources



Boston Dynamics | JPL
Nebula-SPOT Research Drone

MOSEC-XI
Multiporpouse
Lunar Module

LEAP
* Supports a crew of two for a short 30-day mission
* Expandability and interior modularity capabilities

MOSEC XI
* Interior modularity capabilities
* Self-balancing adaptation
* Multi-module connectivity
* Optimal to support command and maintenance operations
Support Types:
* Operations Command Center & Laboratory Module
* Maintenance Facility Module
* Equipment Storage Module
* Habitation & Common Area Modules

LiDAR (Light Detection and Ranging) Scanner
* Riegl vertical line scanner
* Nominal range up to 450 meters
* 360° scanning profiles
* Horizontal point spacing of 4 mm and 7 mm at a distance of 100 meters
* Precision of 3 mm and accuracy of 5 mm
* 308 mm long with a circumference of 180 mm
Ground Penetrating Radar (GPR):
* low 60 and high 500 MHz frequencies
* mass of less than 5.5 kg
* power operating capacity of less than 10 W

VEGA Space Gravimeter
* measures only 9.5 cm x 9.5 cm x 19.3 cm
* mass of 2.1 kg
* power consumption is between 6-11 W
* measuring with an accuracy of 0.3 micro-g RMS error within a 10-minute reading

Lunar Surface Manipulation System (LSMS) - Lunar Crane
* composite materials for its components
* computability for transport
* simple-in-field reconfiguration and repair
* support for teleoperated or automated operations

Ground Penetrating Radar (GPR) & Gravimeter
Capacity to carry the GPR (about 5.5 kg) and the gravimeter (about 2.1 kg) in addition to providing the required power needed for the instrumentation (about 10 W) and the operation of the rover itself

Boston Dynamics SPOT
NASA and the Jet Propulsion Laboratory (JPL) in California are working with these robots to explore caves and optimize the technology for future Moon and Mars cavern exploration. They have proposed the use of three Spot units working as a team carrying different equipment each to complement their functionality

Telepresence
For lava tubes exploration involves a crewed orbiting or near the exploration site and the deployment of robotic surrogates into the pit and tube interior

Advance Technology Concepts
Virtual ReLITY (VR)
AUGMENTED REALITY (AR)
MIXED REALITY (MR)

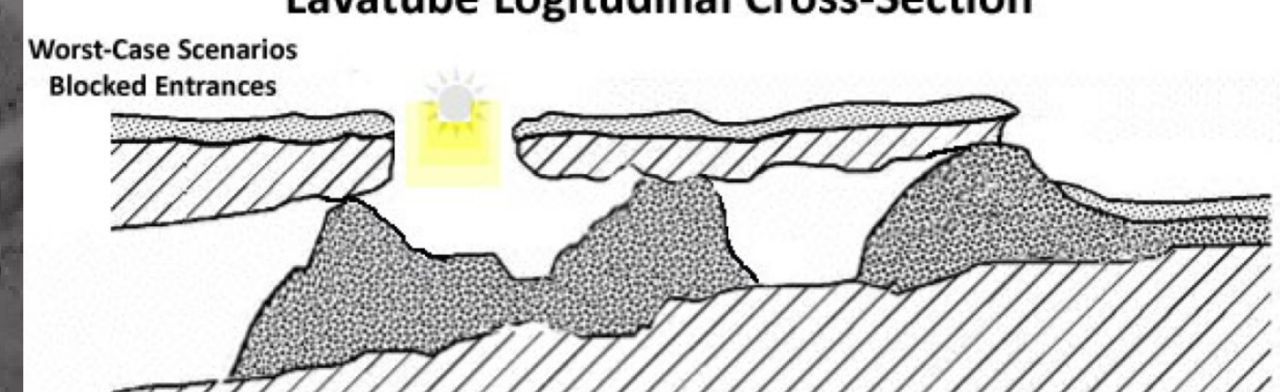
Riegl Vertical
Line Scanner

LEAP Habitat

Challenges
* Human safety
* On-site equipment delivery
* Choosing a valuable site
* Accessing the tube
* In-cave mobility
* Data collection and processing
* Power source
* Communication
* Environmental contamination mitigation
* Mission value must account for mission cost

Biggest concern is the use of propulsive systems and vehicles that could lead to the contamination of the cave's interior and cause irreparable damage to valuable resources and/or scientific data

Lavatube Logitudinal Cross-Section



Proposed Mission Architecture Layout