Rovers and Lasers: The Autonomous, Non-destructive Search for Life in Lava Tubes

Alberto Ruiz, Brett Berger, Xin Huang, Phuong Nguyen, Sean Messenger, Jingbin Yang, Samuel Yim, Shreyasha Paudel, Leonardo Huerta, Jesus Villegas, Willie Zuniga, Gregory Lyzenga, Christopher Clark, Michael Storrie-Lombardi

Harvey Mudd College, 301 Platt Blvd. Claremont, CA 91711

Overview

Life, both microbial and human, requires protection from ionizing radiation. On the Moon and Mars, sites devoid of a protective atmosphere and magnetic field, shielding can be provided by 3 meters of ice, rock, or soil. Lava tubes offer such protection, have been identified on both the Moon and Mars, and are accessible via skylights for robotic and human exploration. These tubes have been proposed as both potential habitats for extant or ancient life, and also as optimal sites for human colonization. Unfortunately, robotic exploration of lava tubes is problematic. The tube walls that provides effective shielding from radiation, also interferes with the electromagnetic radiation necessary for communication with Mission Control.

We report here on work conducted at Harvey Mudd College by undergraduate students to build the optical science probes and the cooperative, autonomous rovers necessary to map and search for life in the radiation-shielded lava tubes of Mars. This project will serve as a proof of concept for autonomous rovers navigating and searching for life in the lave tubes of Mars.

Field Site

The field test site is a series of lava tubes at Pisgah Crater in the Mojave Desert. The tubes are 2-4 feet high, the floor is covered with fine silica sand, and there is significant rocky debris.

Figure 1. Pisgah Crater, located in the Mojave Desert, is home to various lava tubes

Navigation and Localization

Robots exploring Mars' shielded lava tubes cannot communicate with Earth, making autonomous navigation critical. The DrRobot Jaguar Lite platform uses odometry corrected with a two-robot detection algorithm, to localize itself in the rugged lava tube site. It is capable of accurately navigating to and marking sites of interest, as well as plotting a 3-D point cloud map of lava tube with laser scan data.

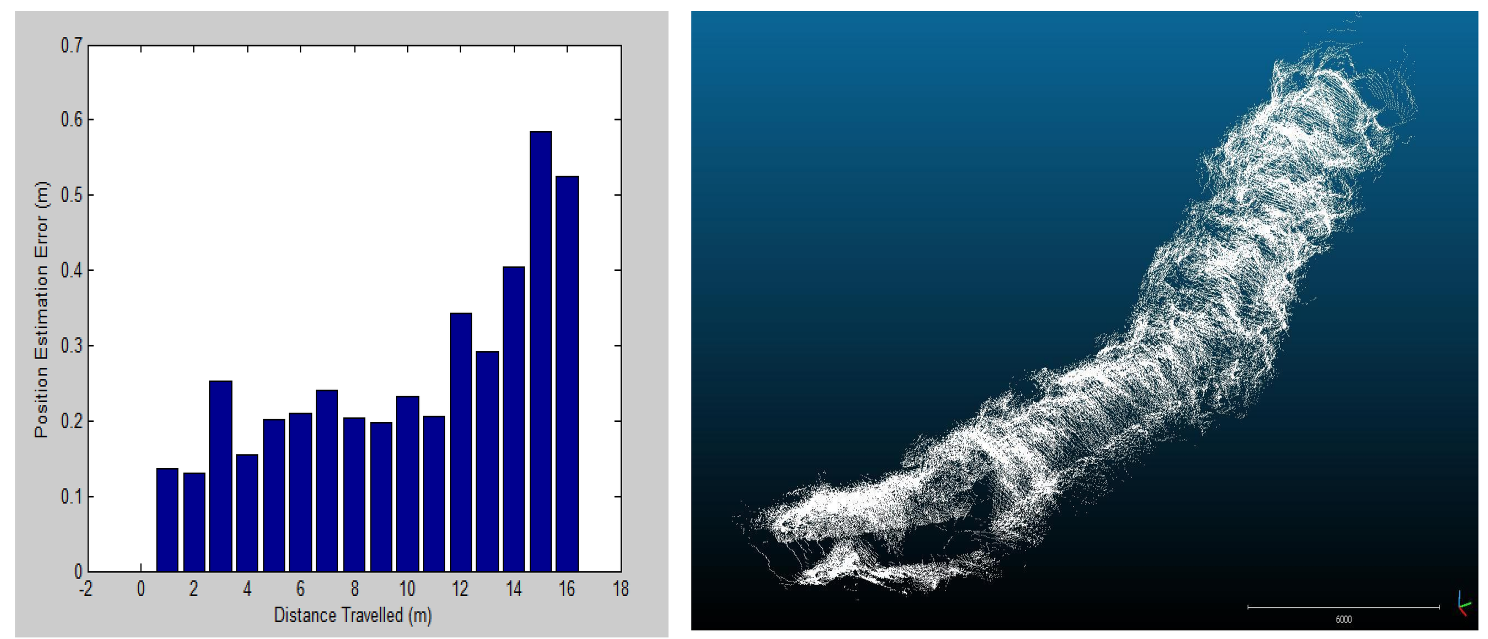

Figure 2. Left: Localization error of the mapping robot as a function of distance travelled. Right: 3-D point cloud map (in mm) of lava tube in the Mojave Desert. The point cloud is made up of 212,400 points.

Science Package

To identify and characterize putative scientific targets within the lava tube environment a system of modular science packages capable of non-contact and non-destructive probing of the tube walls were designed. These packages use reflectance and fluorescence imaging along with fluorescence and Raman spectra to identify and characterize targets of interest (TOI).

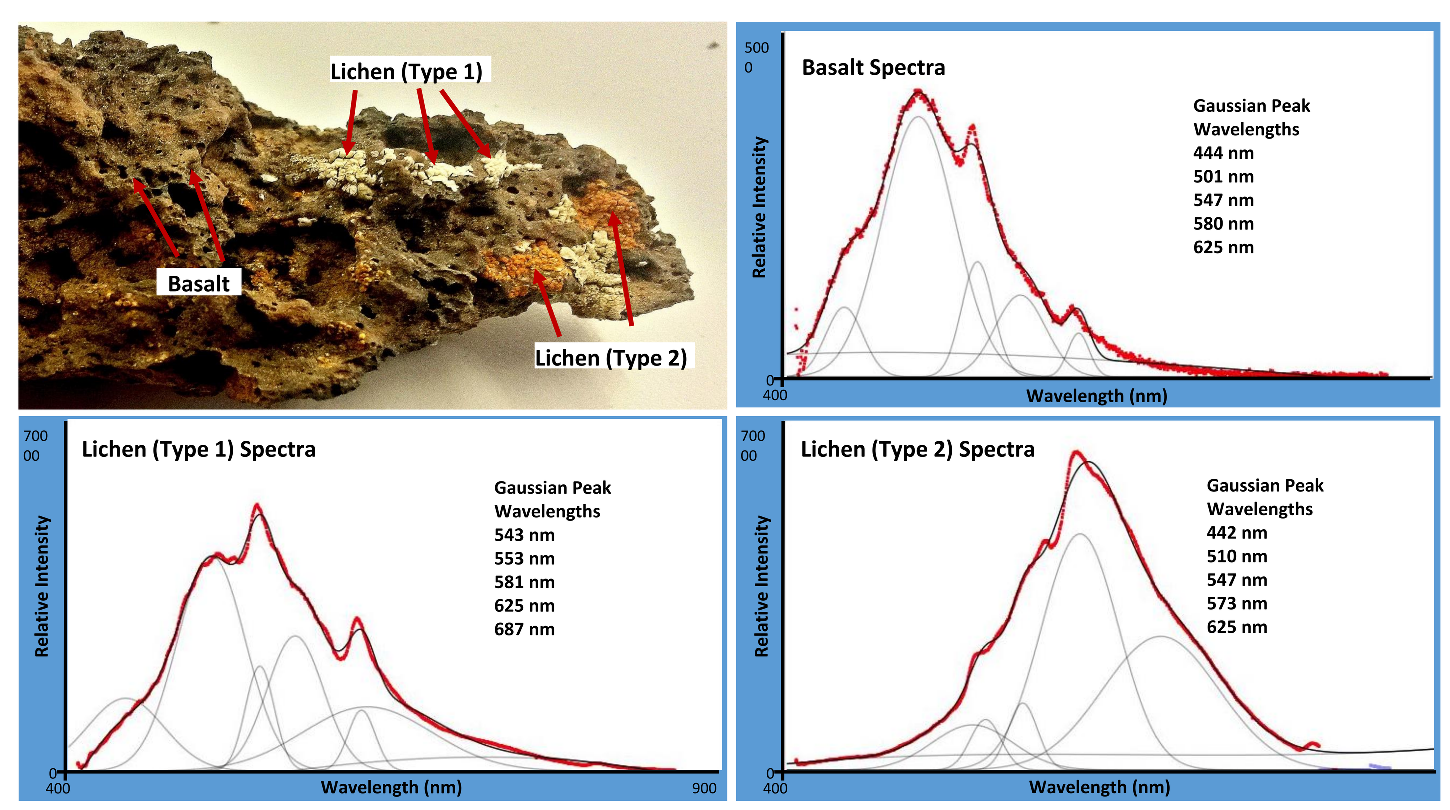

Figure 3. A basalt sample from Pisgah crater exhibits two different types of lichen, an organism known to live in extreme environments. Using 405 nm excitation reveals distinct fluorescence spectra of the basalt and two lichen populations. Gaussian deconvolution allows the characterization of each fluorescence curve.

The first package, named Pandora, is an imager and spectrometer capable of taking both fluorescence and reflectance data at a 1m distance using a 405 nm laser diode, white LED, and two CCD detectors. The second package, currently under design, uses either a 405 nm or 532 nm excitation source and is capable of achieving higher spectral resolution with a high signal collection efficiency for the purpose of Raman spectra acquisition. The 405 nm source provides high Raman scattering signal output while producing strong absorption on the porphyrin family of organic molecules. The 532nm excitation is widely used in spectroscopy and minimizes the background fluorescence, allowing for the ready comparison with existing Raman spectra.

Field Tests and Results

During field trials the rover successfully navigated a 100 foot long tube. It detected multiple fluorescing artifacts on the walls and the ceiling, marked their location, and then demonstrated the ability to return to those targets of interest with a ±2 cm accuracy. With Pandora mounted on the rover, reflectance and fluorescence images and spectra were acquired from a TOI at a 1m distance as shown in Figure 4.

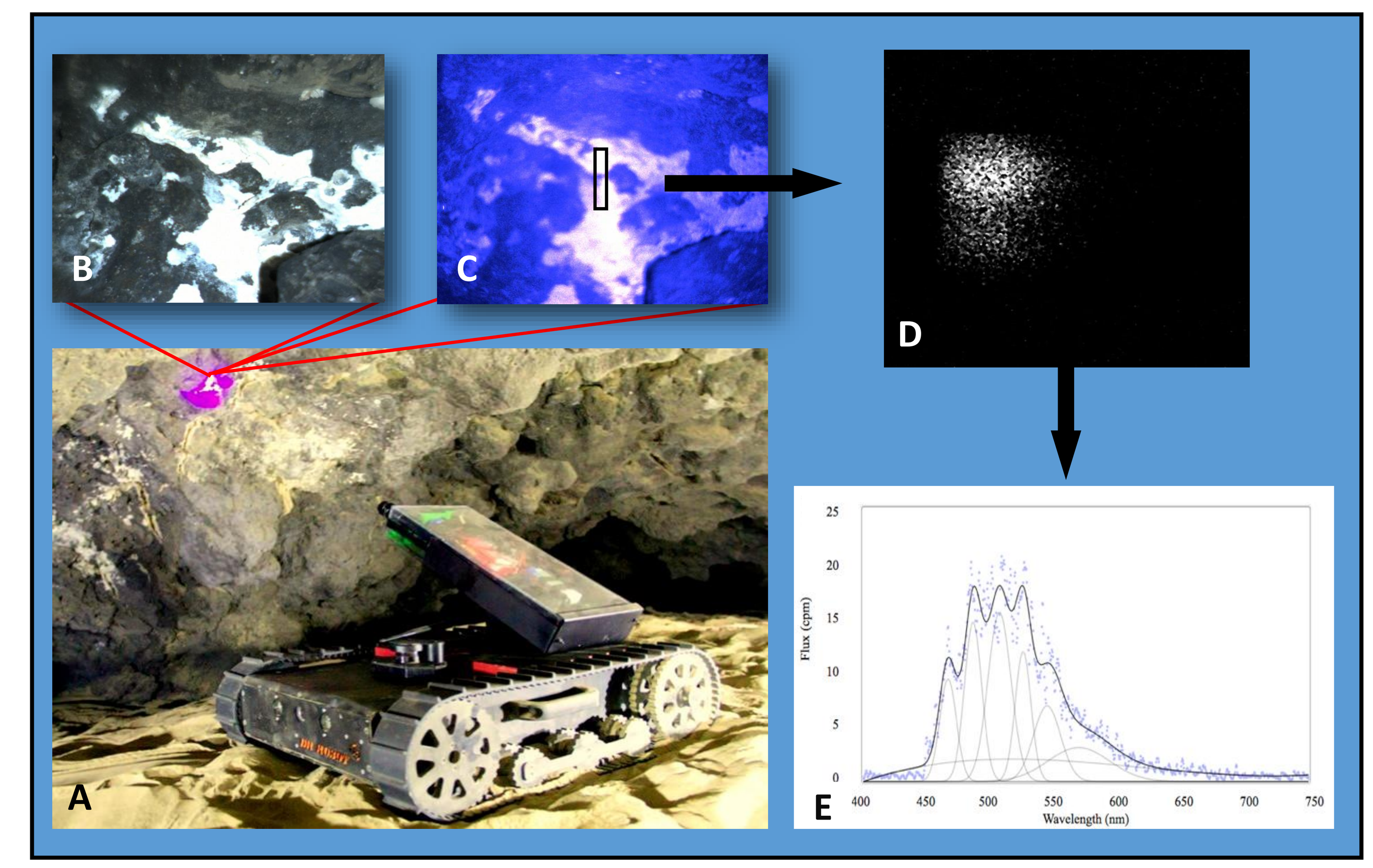

Figure 4. A) Jaguar rover, mounted with the Pandora scientific package, pointed at a TOI on the lava tube walls B) Reflectance image of target C) Fluorescence image of target D) CCD fluorescence spectral output of a thin section of the fluorescence image E) Integrated fluorescence spectra best modeled by Gaussian deconvolution.

The reflectance image (Fig. 4b) identifies a complex system of white material that is easily differentiated from the rest of the lava matrix. Fluorescence images (Fig. 4c) reveal a strong white fluorescence signature. Spectra of this signature (Fig. 4e) is best modeled by three Gaussians with center wavelengths of 470.7 nm, 501.6 nm, and 531.4 nm. The spectra signatures can be attributed to either mineral or porphyrin structures. Raman spectra is needed to distinguish between these mineral and biological contributions.

Future Work

This summer, the team plans to finish the design and deploy the second science package to collect Raman spectra of targets of interests on the lava tube walls. This requires the construction of a robotic arm for the placement of the device within millimeters of potential targets. Furthermore, simultaneous localization and mapping, cooperation between rovers equipped with different science packages, and image recognition of targets of interests are on their way to implementation. By integrating all these elements a system of cooperative and autonomous rovers for the purpose of lava tube exploration can be achieved.

Acknowledgements

We gratefully acknowledge the Rose Hills Foundation, the Baker Foundation, the Sherman Fairchild Foundation, Edmund Optics Higher Education Grant Program, and the Shanahan Endowed Student-Directed Projects Fund.