NEAR-IR REFLECTANCE SPECTROSCOPY IN A LAVA TUBE CAVE FROM A ROBOTIC PLATFORM.

K. Uckert[1], N. J. Chanover[1], D. G. Voelz[2], X. Xiao[2], R. Hull[2], P. J. Boston[3], A. Parness[4], N. Abcouwer[4], A. Willig[4], and C. Fuller[4]; [1]Astronomy Department, New Mexico State University, Box 30001/MSC 4500, Las Cruces, NM 88003, [2]Klipsch School of Electrical and Computer Engineering, New Mexico State University, Box 30001/MSC 3-O, Las Cruces, NM 88003, [3]Earth and Environmental Sciences Department, New Mexico Institute of Mining and Technology, Socorro, NM 87801, [4]Extreme Environment Robotics Group, Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109

Introduction: Lava tube caves on Earth serve as valuable analogs for similar structures on other solar system bodies such as the Moon and Mars. Due to the protection they offer from the constant bombardment of cosmic rays, energetic particles, and ionizing radiation from the Sun, particularly on bodies that lack a protective magnetic field, these subsurface environments may offer refugia, providing habitable conditions over a long time scale [1, 2]. Hence, planetary caves are desirable sites for future robotic exploration efforts aimed at the detection of biosignatures resulting from extinct or extant life [3-5].

The robotic exploration of planetary caves should include the abiliy to analyze sites that traditional rovers cannot access, i.e. the walls or overhangs, as these locations are often rich with interesting formations and deposits. A rock climbing robot equipped with a suite of remote sensing instruments designed to address habitability and biomarker detection is ideally suited for this task. Here, we describe a pilot effort to integrate a near-infrared point spectrometer developed for operation on a robotic platform with the LEMUR rock climbing robot.

Field Site Description: We selected Big Skylight Cave and Four Windows Cave in the El Malpais National Monument in New Mexico for our first field tests because they offer a wide range of rock features and orientations for testing the LEMUR robot. These caves and the surrounding volcanic terrain have been frequently used as a planetary analog site [4, 6, 7], and the microbially precipitated mineral deposits and biovermiculation patterns present at these field sites may contain unique NIR spectral signatures that could be identified as biomarkers. The field tests of LEMUR and PASA at the El Malpais National Monument were conducted from September 10-18, 2015.

Technology Description:

NIR Reflectance Spectrometer. We employed the Portable AOTF Spectrometer for Astrobiology (PASA), which is a point spectrometer that operates between 1.6-3.6 µm and uses an acousto-optic tunable filter (AOTF) as the wavelength selecting element [8]. This instrument has been used in several caves, including Fort Stanton Cave (Lincoln County, NM), El Malpais National Monument lava tubes (Grants, NM), and Cueva de Villa Luz in Tabasco, Mexico, to acquire NIR reflectance spectra of various deposits, speleothem formations, microbial colonies, and biofilms [9-10]. PASA was modified from previous prototypes for mounting on the LEMUR robot by making it more lightweight, operable through a 10 m cable bundle, increasing the focus length, and using a higher power lamp to improve the signal-to-noise ratio for the darker basaltic rock typical of a lava tube cave. Figure 1 illustrates the light path through the optical components of PASA. A photograph of PASA mounted on the body of LEMUR in the field is presented in Figure 2.

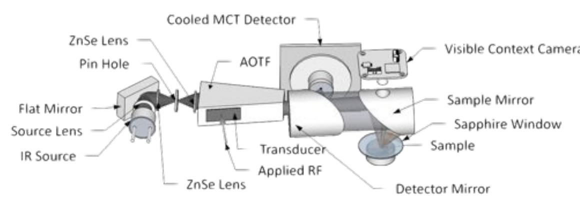

Figure 1: The light path through the optical components of PASA. The optical axis of the visible context camera passes through an aperture in the first off-axis parabolic mirror.

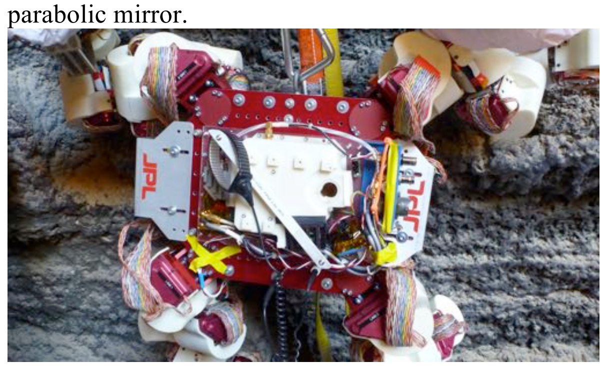

Figure 2: PASA (white housing) mounted onto LEMUR in the Four Windows Cave.

Rock climbing Robot. The LEMUR rock climbing robot is a limbed system with 7 degrees of freedom (joints) per limb and 4 limbs. Each joint within the limb is exactly the same, and joints are arranged in a serial manner such that there are no collocated degrees of freedom. The robot uses microspine grippers as end effectors to anchor itself to the floor, walls, and ceilings of caves and cliff faces. Microspine grippers use hundreds of sharp hooks that catch small bumps, pits, and other rough spots on a rock surface. The robot grips the rock by squeezing all of these hooks towards the center of the gripper. Compliance in the independent microspines allows the hooks to conform to the arbitrary roughness of the rock and also distributes the load amongst the hooks that have found a grip. Typically only 10 percent of a grippers hooks need to engage to create a strong anchor. A previous version of the robot with much more limited mobility is described in [11].

Candidate Biosignatures: In the El Malpais lava tube caves (NM) and Cueva de Villa Luz (MX), distinctive maze-like microbial mats known as biovermiculations decorate rock surfaces and have been the subject of a number of studies [12-16]. These patterns occur both as living mats and as fossil examples, and we have chosen them as a major focus for testing PASA because they present clear macromorphological evidence of life, while also offering significant challenges in analysis of chemical and mineralogical composition. Characteristic absorption features of common mineral classes and basic organics lie within the 1.6-3.6 µm region probed by PASA, allowing for the identification of the major mineral constituents of a geologic sample [17].

Results: We present NIR reflectance spectra from our integrated field measurements at Big Skylight Cave in Figure 3. The top trace represents the reflectance spectrum of the basalt wall, measured by PASA while mounted to LEMUR gripped to the cave wall. The bottom trace represents a reference spectrum of basalt from the USGS spectral endmember library (limited to 2.7µm). A NIR reflectance spectrum of a biovermiculation mat measured by PASA while detached from LEMUR in Four Windows Cave is presented in Figure 4. Evidence for microbial activity includes the presence of a C-H stretching absorption feature (~3.3µm) and broader hydration features, relative to the basalt host rock.

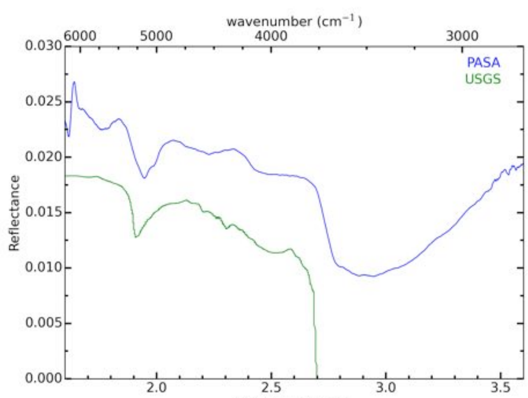

Figure 3: NIR Reflectance spectrum of basalt measured by PASA mounted to LEMUR in Big Skylight Cave (top) compared with USGS basalt reference spectrum (bottom).

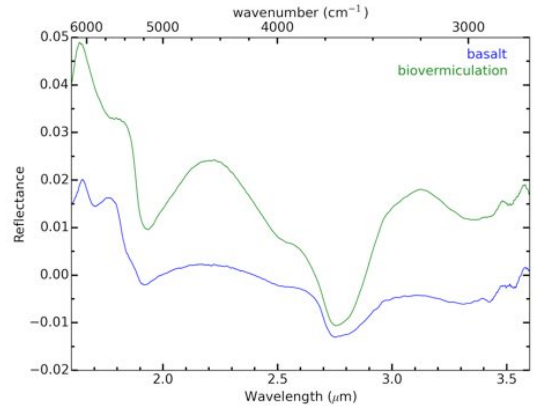

Figure 4: Biovermiculation (top) compared with basalt host rock (bottom) measured by PASA.

References: [1] Boston, P. J. (2010) *J. Cosmol., 12,* 3957–3979. [2] Pavlov, A. A. et al. (2012), *GRL, 39,* L13202. [3] Boston et al. (1992) *Icarus, 95,* 300-308. [4] Boston et al. (2001) *Astrobiology, 1,* 25-55. [5] Leveille, R. J. and Datta, S. (2010) *Planet. Space Sci., 58,* 592-598. [6] Northup, D. E. et al. (2004) *AMCS Bull., 19,* 119-125. [7] Northup, D. E. et al. (2011), *Astrobiology, 11,* 1-18. [8] Tawalbeh et al. (2013), *Opt. Eng., 52*, 063604. [9] Uckert et al. (2015), *46th LPSC #1832*, 2694. [10] Uckert et al. (2015), *Proc. IEEE Aerospace Conf. #2.0709*, 5-12 March 2015, Big Sky, MT. [11] Parness et al. (2013) *J. Field Robotics, 30.6,* 897-915. [12] Boston, P. J. et al. (2009), *Proc. Third IEEE Intl. Conf. Space Miss. Challenges Inform Tech*., 221-226. [13] Schubert K. E. (2010), *Proc. 2010 Intl. Conf. Bioinform. Comput. Biology*, 662-665. [14] Strader, B. et al. (2009), Proc. 2009 *Intl. Conf. Space Miss. Challenges Inform. Tech*., *2,* 503–509. [15] Strader, B. et al. (2010). *Software Tools Algorithms Biol. Syst.* [16] Strader, B. et al. (2011). *Adv. Exp. Med. Biol.*, *696*, 157-70. [17] Pieters, C. M. and Englert, P. A. J. (1993) *Remote Geochemical Analysis: Elemental and Geological Composition*, Cambridge University Press.

Acknowledgements: This work was supported by a NASA Space Technology Research Fellowship (NNX13AL49H). This work was also supported by NASA's Moon and Mars Analog Missions Activities program and Planetary Science and Technology Through Analog Research program.