**ILLUMINATING THE INVISIBLE: A PLANETARY EXPLORATION STRATEGY IN A LAVA TUBE AT MAUNA LOA, HAWAII: ULTRAVIOLET-INDUCED FLUORESCENCE IMAGING.** S. P. Scheidt[1,2], Z. Morse[3], D.M. Bower[1,2], C. Achilles[2], and B.P. Theiling[2]. [1]University of Maryland, CP, Department of Astronomy, Center for Research and Exploration in Space Science & Technology II, College Park, MD 20742. [2]NASA Goddard Space Flight Center, Greenbelt, MD 20771; [3]Howard University, Washington, DC 20059. (stephen.scheidt@nasa.gov)

**Introduction:** Lava tubes on both the Moon [1-3] and Mars [4] are of interest for planetary exploration, operations, volcanology [5] and resource utilization (i.e., key volatiles) [6]. These locations are potential habitable environments in our solar system, possibly for human habitation [7,8]. The basaltic mineralogy of Hawaiian volcanic deposits is similar on Mars [8,9], and lava tubes at Mauna Loa are an ideal location for analogue studies [10,11] to understand environmental conditions, biologic activity, and mineral alteration processes [12,13,14].

A lava tube is a dark GPS-denied environment, therefore navigation and relocating sampling sites efficiently is challenging without light, maps and localization. Measurement and sampling locations will likely rely on a light source in the visible spectrum or systematic spacing intervals inside an extraterrestrial lava tube. Although these techniques result in very accurate identification, could important spatial pattern information be “invisible?” Time is likely to be short during an extravehicular activity, potentially reducing the number of possible samples and measurements using handheld in-situ instrumentation. Exploration methods would benefit from a map showing compositional or spectral data of the lava tube interior.

Ultraviolet-induced fluorescence (UVIF) imaging techniques differ from laser-based instrument methods, and have a variety of industrial, research and planetary exploration applications [15,16]. On the surface of Mars, rover instruments such as SHERLOC [17] on Perseverance and MAHLI [18] on Curiosity utilize fluorescence properties for material identification.

**Objective:** A new UVIF system was designed, built and tested for imaging lava tube interiors and caves. The purpose of the instrument is to produce spatially referenced spectral image data related to mineral composition and biomarkers that fluoresce in the dark. Our goal is to integrate the data into an augmented reality (AR) guidance and visualization system in the field [19]. Also see [20] this session.

**Field Site**: A lava tube near the HI-SEAS habitat on the north flank of Mauna Loa was accessible through a skylight of a geologically young (< 200 years old) lava flow at 2430 m elevation. Several types of UV-fluorescent minerals and materials [21] are discoverable in the Mauna Loa lava tube from Raman, LIBS, and XRF spectroscopy instruments [11]. Signs of aqueous alteration that produced secondary minerals are abundant on the inside of the lava tube. Handheld in-situ instruments identified mainly Na-, Ca- sulfates, and minor Mg-sulfates, carbonates, and amorphous material in the secondary precipitates coating the lava tube; basaltic minerals including plagioclase, pyroxene, olivine, and Fe-oxides were also identified. Organic fluorescent molecules, such as microbial pigments, amino acids, and fatty acids were also identified. Most materials identified with the handheld instruments were fluorescent, except for the basalts and associated pyroxene and olivine minerals.

**Methods:** The UVIF system is composed of three main parts: a custom-built UV LED light source panel, a high-sensitivity color astrophotography camera, and a specialized panoramic tripod head for precise 360° pointing. The UV light source was designed to illuminate the lava tube wall interiors to fill the camera’s field of view. The camera features a cooled sensor, native 16-bit data output, 80% peak quantum efficiency, and ultra-low noise that allow high quality image data collection in the low light environment. Although exposure of 0.01 mW/cm² of UV irradiance (λ = 365 nm, FWHM = 10 nm, Fig. 1) is sufficient for material to fluoresce, the active UV light source evenly floods the field of view, typically exposing targets to between 0.6 and 0.3 mW/cm$^2$ at distances expected inside the lava tube (Fig. 1). Color information from fluorescent materials is recorded in the dark. Reflectance images from a visible light source were collected separately. A small handheld tablet was used to control the camera, and cooperation between two persons allowed manual operation of the software, camera, and tripod to complete each survey station. Data were previewed and interactively explored for quality.

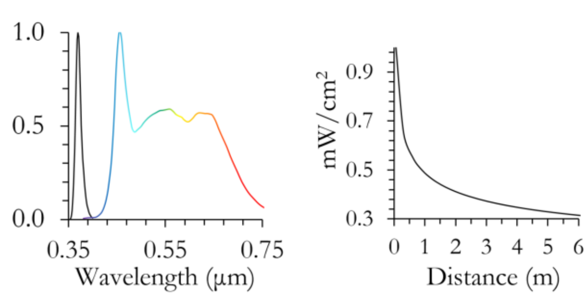


*Figure 1. (left) Spectra of UV (black) and visible (color) LED light sources for low light photography. (right) UV irradiance vs. distance.*

*Figure 2. Field image showing the UVIF system in operation. The right lava tube wall is directly illuminated by UV showing bright green and blue fluorescence. Photo credit: NASA Expeditions.*

**Results and Discussion:** Three locations inside the lava tube were surveyed generating complete datasets that documented the lava tubes interior walls, floor and ceiling. This included a) UVIF color image data (Fig. 2), b) low-light color photography, c) 3D LiDAR scans of the lava tube (Fig. 3), d) thermal maps, and e) an exterior stereo-derived digital terrain model built from small uncrewed aerial system (sUAS) camera images (Fig. 3). LiDAR data were collected throughout using a Leica BLK360 LiDAR instrument. A control points network of visible and fluorescent targets was established on the interior and exterior of the lava tube. The surfaces and skylights were surveyed by both sUAS and LiDAR to combine surface and subsurface data. Exterior control points were surveyed using a differential GPS system, and these targets were also scanned by both sUAS and LiDAR. This produced a complete georeferenced 3D point cloud model of the lava tube field site. UVIF digital image data were presented to scientists during sampling to compare their visual observations to the unique color patterns otherwise invisible to the unaided eye. This guided sampling of material, and users described the UVIF data as a positive enhancement to sampling procedures that do not have knowledge of UV fluorescence spatial patterns. We successfully demonstrated how the UVIF system could improve in-situ sampling and laser-based handheld instrument measurement by showing unseen spatial patterns.

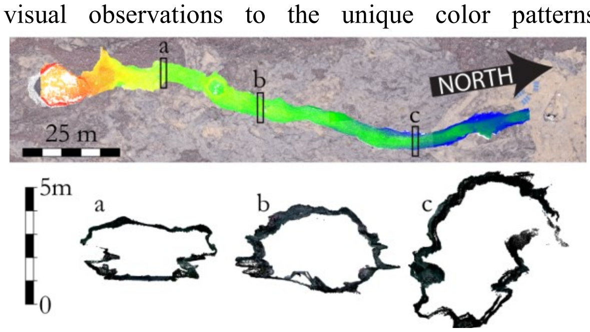


*Figure 3. Combined UAV-generated surface (true color) projected on the DEM and LiDAR point cloud of the lava tube interior. The depths of points range between 0 m at the surface (red) to 25 m below ground (blue). Cross sections of the lava tube (1-meter-wide subsets, transverse to the flow direction) are shown at locations a, b and c.*

**Further Research:** We hope to expand upon the science potential of multiple co-located datasets and collaboration with geochemistry and geophysical instrument teams. Analyze of topography may reveal spatial patterns and correlations between interior and exterior features. Data will be distributed to determine if UV fluorescence patterns aid research of secondary mineral deposits and biological signatures in the lava tube. UVIF data will be validated using laboratory spectra of samples, and image data will be calibrated to assess 3D spatial patterns of composition.

The data collection scheme was designed to enable AR data visualization [20], and therefore the tools and concept operations will be applied to other activities and projects investigating planetary exploration operation strategies. We hope to return after the 2022 Mauna Loa eruption to assess changes in the lava tube or explore new lava tubes with different mineral signatures.

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**References:** [1] Blair, D.M. et al. (2017) *Icarus*, 282, 47-55. [2] Greeley, R. (1971) *The Moon*, 3, 3, 289-314. [3] Haruyama, J. et al. (2009) *Geophys. Res. Lett.*, 36(21). [4] Sauro, F. (2020) *Earth-Sci. Rev.*, 209, 103288. [5] Crown et al. (2022) *J. of Geophys. Res-Planets*, 127, 6, e2022JE007263. [5] Angelis, D.G. et al. (2002) *J. Radiat. Res. 43*, S41-S45. [6] Horz, F. (1985) 405-412. [7] Boston P.J. (2010) *J. Cosmol.*, 12, 3957-3979. [8] Morris, R.V (2000) *J. of Geophys. Res-Planets*, 105(E1), 1757-1817. [9] Minitti, M.E. (2007) *J. of Geophys. Res-Planets*, 112(E5). [10] Bleacher et al. (2017) *LPSC XLVIII*, Abs. 2634. [11] McAdam et al. (2017) *LPSC XLVIII*, Abs. 2600. [12] Bower, D.M. et al. (2022) *AbSciCon, Abs*. 327-04 [13] Brown, G.E. and Calas, G. (2011) *C. R. Geosci.*, 343, 90-112. [14] Bower, D.M. (2020) *AGU Fall Meeting 2020*, #P063-06. [15] Sandak, J. et al. (2020) *Sensors*, 20, 2, 545. [16] Smith, H. D. et al. (2014) *J. Biol. Eng.*, 8,1, 1-14. [17] Bhartia, R. et al. (2021). *Space Sci. Rev*., 217, 4, 1-115. [18] Fisk et al. (2015) *AGU Fall 2015*, # P51E-07. [19] Morse, Z. et al., (2020) *AGU Fall Meeting 2020*, # P063-02. [20] Morse et al., (2023) *LPSC LII*, (this session). [21] Waychunas G. (2014) *Rev. Mineral. Geochem*., 78, 1, 175-217.