Data in the Dark: *In-Situ* Augmented Reality Data Visualization of Ultraviolet-Induced Fluorescence at Mauna Loa Lava Tube Analog Field Site.

Z. R. Morse[1,2], S. P. Scheidt[3,2], B.P. Theiling[2], and C. Achilles[2]. [1]Howard University, 2400 6th St NW, Washington, DC 20059; [2]NASA Goddard Space Flight Center, 8800 Greenbelt Rd, Greenbelt, MD 20771; [3]University of Maryland, College Park, MD 20742. zachary.r.morse@nasa.gov

Introduction: In September 2022 the Ultraviolet and Augmented Reality (UVAR) team collected data as part of the Goddard Instrument Field Team (GIFT) Hawaiian Volcanoes and Caves (HVAC) field deployment. This field investigation involved observations inside and on the surface above a basaltic lava tube located on the north slope of the Mauna Loa volcano on the island of Hawaii as an analog to similar geologic features observed on the Moon [1-3] and Mars [4]. The primary objective of the UVAR team was to collect a sequence of long-exposure Ultraviolet-Induced Fluorescence (UVIF) images at several points along the lava tube interior. This process including the camera and lighting systems used, are detailed in Scheidt et al. [5]. Here we discuss the methodology for using Augmented Reality (AR) to visualize the resulting 360° UV fluorescence images *in-situ,* after the data was collected and processed.

AR Data Visualization: AR data visualization is the process of overlaying digital assets or data points within the real-world field of view of a digital display. We achieved this using a 2022 iPad Pro with integrated camera and LiDAR sensor paired with a custom AR software application built using the Unity game engine [6] and Vuforia AR software development kit [7]. The AR visualization technique we employed uses a digital model of the environment to position and visualize digital data overlays in the location where the information was collected. For this work, we used a separate Leica BLK360 portable LiDAR scanner to collect high resolution 3D point clouds of the lava tube interior adequate for science investigations of morphology.

LiDAR Scanning: We collected a sequence of scans by translating The BLK360 to different data collection stations along the 150m traversable length of the lava tube interior. We collected 16 LiDAR scans totaling ~176 million 3D points between the entrance skylight down slope navigable space (Fig. 1). Three LiDAR scans were co-located with the exact tripod positions of 360°-view UV fluorescence images or photospheres [5]. These LiDAR data enabled the AR software to recognize the real-world morphology of the lava tube interior surfaces. In post-processing, we precisely overlaid the UV photospheres in the correct location and orientation within the tube so that AR visualization is exactly aligned to the real-world view. When a user is stands in the same location where the LiDAR and UVIF data were collected, processed data products, sample locations, and analysis results can be viewed as 1:1 scale AR assets, projected, directly into the real world space through a digital display.

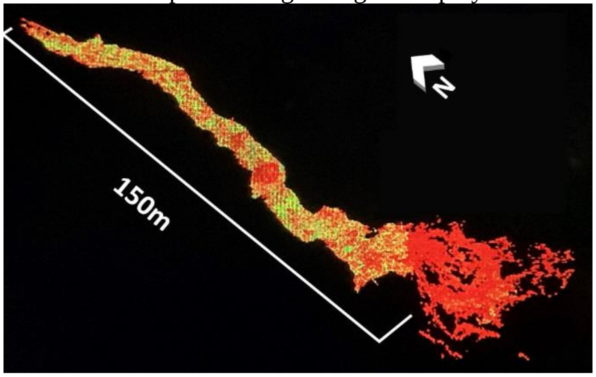

Fig. 1. LiDAR point cloud of lava tube field site. Points colorized based on intensity – Red = High Green = Low.

Creating a Deployable Field Application: LiDAR scan data were co-registered and combined into a single contiguous 3D AR target. The iPad localizes itself using real-time data from its built-in camera and LiDAR sensor to compare observed *in-situ* morphology to this pre-scanned digital AR model target. The AR model target was generated through several steps. First, CloudCompare [8], an open-source 3D point cloud and mesh processing software, was used to calculate 3D point orientations (normals) and link neighboring points into an accurate series of polygons, or mesh, representing the lava tube interior. This mesh was then imported into the Vuforia Target Generator software, a custom AR model target generator, in order to prepare the scale and resolution of the model for linking AR assets. Finally, the resulting Vuforia model target was imported into the Unity 3D game engine. This creates an executable, stand-alone 3D environment for use on the iPad Pro. Data from UV photospheres, thermal scans, and point measurements from geochemistry science teams were accurately aligned to the 3D AR target model (Fig. 2). The Unity project was saved and compiled into an application for our iPad Pro, for real-time in-situ use during the field deployment.

Field Testing the App: When active, the app uses the iPad's camera and LiDAR sensor to continuously scan the surrounding area, using identified terrain features for localization. When the observed real-world terrain matches the digital model target, the app automatically projects data into the digital field of view.

As a scientist explores the field site with this digital asset, the data are viewed in AR at 1:1 scale in the precise location and orientation where data was collected. The view and data projections adapt as a user moves throughout the lava tube environment and reorients their field of view, including moving closer or farther away from a feature of interest. This enables a field scientist to return to the field site and experience natural first-hand interactions augmented with additional data. This is an enormous optional benefit because field instruments and equipment do not need to be redeployed. The operational and science benefit of the AR system is particularly clear for the visualization of UV fluorescence. The image products require post-processing, significant power resources to collect, and two personnel to perform the field operation. AR visualization of the completed UV photospheres enables the full interaction with the data visualization capability for one individual and one electronic viewing device.

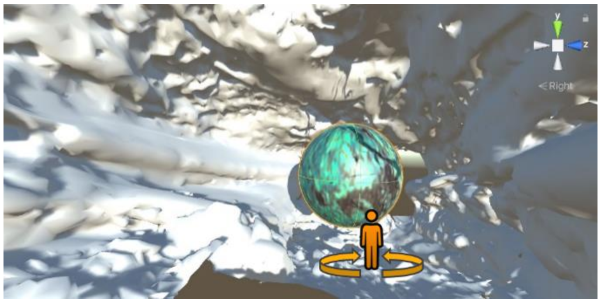

Fig. 2. Screenshot of Unity project with a UVIF photosphere AR asset situated within a 3D model of the lava tube. Human icon shows user position and scale.

Cross-Team Collaboration: The UV fluorescence photospheres revealed clusters of minerals and biologic material on the lava tube walls and ceiling that were not readily apparent in visible light alone. Another team on the field deployment studying the tube as an analog to potential Martian habitats was able to use our iPad visualization to specifically target areas of bright UV fluorescence for ATP analysis (Fig. 3). This collaboration confirmed that some of the areas of high UV fluorescence did exhibit higher ATP levels than background or dark portions of the cave wall when viewed in UV. This unique in-field collaboration was enabled by our data visualization techniques and resulted in additional data collection and insights for the astrobiology work.

Future Work: With the entire length of the lava tube scanned and converted into an AR target, we can theoretically link and visualize any data collected within the tube on this or any previous field expedition. Future work may entail creating an AR database for all archived geologic data linked to the morphology of the tube so that future exploration can easily access and compare datasets. As long as the interior morphology of the lava tube does not change significantly, the model target generated from this work would continue to function indefinitely as a method of connecting collected data to the real-world morphology. Additionally, we may employ this technique at other GIFT field sites. Lava tubes and caves both make ideal candidates for model-based AR data visualization as they tend to be morphologically distinct throughout, and also host relatively well-preserved interior spaces that do not change drastically between field seasons. Similar *in-situ* AR data visualization techniques are also set to be tested during the upcoming Augmented Reality Data Visualization Analog Research Campaign (ARDVARC), a 3-year AR-focused PSTAR project.

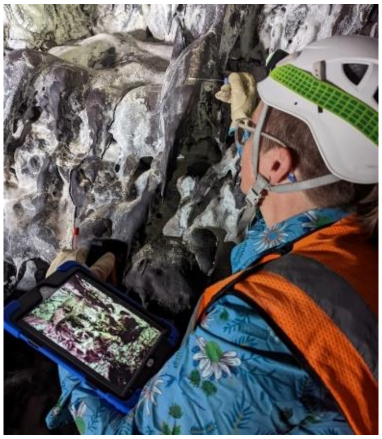

Fig. 3 – Astrobiology team member Bethany Theiling testing for ATP abundance using iPad-based UVIF image to target areas of high fluorescence.

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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] Scheidt, S. P. et al. (2023) LPSC (this conference), [6] https://unity.com (2022) Unity Technologies. [7] https://www.ptc.com/en/products/vuforia (2022) PTC. [8] https://www.danielgm.net/cc/ (2022) CloudCompare.

Additional Information: The poster associated with this abstract will feature an interactive demonstration of the AR data visualization application discussed here. We believe that firsthand interaction with the technique is the best way to share the experience, so please stop by and try it in person.