DISTINGUISHING CAVES FROM NON-CAVE ANOMALIES USING THERMAL INFRARED: LESSONS FOR THE MOON AND MARS. J. J. Wynne[1,2], T. N. Titus[3], M. D. Jhabvala[4], G. E. Cushing[3], N. A. Cabrol[1,5], and E. A. Grin[1,5]. [1]SETI Carl Sagan Center, 515 N. Whisman Road, Mountain View, CA 94043 (jut.wynne@nau.edu); [2]Merriam-Powell Center for Environmental Research, Department of Biological Sciences, Northern Arizona University, Box 6077, Flagstaff, AZ 86011; [3]U.S. Geological Survey, Astrogeology Branch, 2255 North Gemini Dr., Flagstaff, AZ 86001; [4]NASA Goddard Space Flight Center, Instrument Systems and Technology Division, Code 550, Greenbelt, MD 20771; [5]NASA Ames Research Center, Space Science Division, MS 245-3, Moffett Field, CA 94035.

Overview: Caves on Earth are often microclimates which contain evidence of extant life. On other solar system bodies, such as Mars, these features may be excellent places to search for extinct/ extant lifeforms. For the Moon and Mars, caves may also provide protection or habitats for future human exploration.

The Earth-Mars Cave Detection Project has entered its fourth year; Phase 2 of this effort has launched its first year. Our research to date has demonstrated the viability of the thermal detection of caves on Earth [1-3] and Mars [4,5], as well as provided theoretical justification for lunar cave detection [1]. On Earth, caves are detectable when differences in thermal radiance between cave entrance and surface are greatest [1-3]. On Mars, features associated with speleogenesis [e.g. 6,10,11] and actual cave-like features [e.g. 4,5] have been confirmed. While no cave entrances have been observed on the Moon, sinuous rills (features largely accepted as lava channels), collapsed lava tubes and collapse pit features [6-9], have been identified.

While these efforts have improved our understanding of cave thermal behavior [e.g. 1-5], we have yet to address how cave thermal behavior may influence cave detection using thermal infrared (TIR) imaging. One of the most critical concerns facing remote sensing of caves is how to differentiate a cave from a false positive (non-cave anomaly) [1]. Before NASA will target caves on the Moon or Mars as potential sites for robotic exploration, a high level of certainty must be obtained that the feature of interest is indeed a cave.

Importance of Martian Caves: (A) Caves may be important in detecting evidence of extraterrestrial life because they offer protection from inhospitable surface conditions [1-5]. (B) A manned mission to Mars will require access to significant H_2O deposits for drinking water, oxygen and hydrogen fuel. If water deposits exist, caves may provide the best access to these resources [12]. (C) Future human exploration and possible establishment of a permanent settlement on Mars will require construction of living areas sheltered from harsh surface conditions. Caves with a protective rock ceiling would provide an ideal environment where these shelters may be built [13].

Importance of Lunar Caves: These features may be valuable as potential shelters for human habitation [14-15] because this buffered environment could protect astronauts from the inhospitable lunar surface.

Objective: This work aims to improve our understanding of thermal signature strength as it relates to differentiating caves from non-cave anomalies in the TIR.

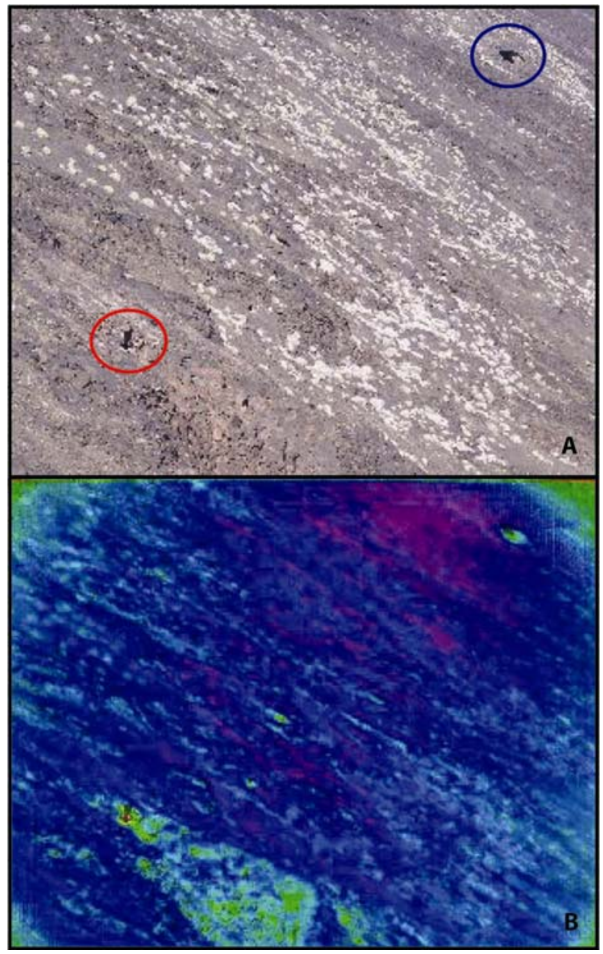

Fig. 1: Pisgah lava beds, Mojave Desert, CA. [A] Color visible image containing cave entrance (red circle) and anomaly (blue circle). [B] IR image acquired at 0510 hr overlaid on the visible image. Cave entrance appears as a warmer feature.

Results: Using the QWIP (Quantum Well Photodetector) camera, we collected thermal imagery of the Pisgah lava beds, Mojave Desert, CA (**Fig. 1**). Imagery was collected every 10 m over ~24 hrs, 07-08 April 2008 (122 images captured). Within the field of view are two features, a cave and tunnel (i.e., anomaly). Using all 122 images, we ran a Principal Components Analysis (PCA) to investigate for potential differences between our cave and non-cave anomalies.

For the dataset presented, our results suggest PCA was a useful tool in discerning a cave from an anomaly. Scatter plot (**Fig. 2**) shows a clear separation between these two features. Plotting Eigenfunction weight against time of day (**Fig. 3**), we observe the cave as most discernable from the anomaly between ~0500-1000hr and ~1300-1400hr.

Discussion: While the results presented are encouraging, our findings represent only one example. Thermal signal strength of the entrance, and thus detectability, is likely driven by volume, horizontal length, depth from surface, percentage of rock obstructing entrance, slope, aspect, topographic roughness, and geologic substrate [1,3]. We suggest these factors will also influence signal strength of non-cave anomalies. We had the luxury of a large dataset containing data points over a diel window (122 images). Imagery captured via a satellite platform for a lunar or martian mission would be limited and may represent only a couple of data points. Additional work is required to better understand and discern thermal signatures associated with cave entrances and anomalies.

Because detectability of caves on the Earth, Moon and Mars is likely driven by conduction, locating caves on these planetary bodies is possible [1]. Unlike on Earth, groundtruthing potential cave targets on the Moon and Mars is not possible without considerable expense. As Phase 2 in the Atacama and Mojave Deserts continue, we will improve both our cave detection capabilities and our ability to distinguish caves from non-cave anomalies. The analytical tools developed and lessons learned from terrestrial applications will ultimately be used for interpreting and evaluating exploration targets on the Moon and Mars.

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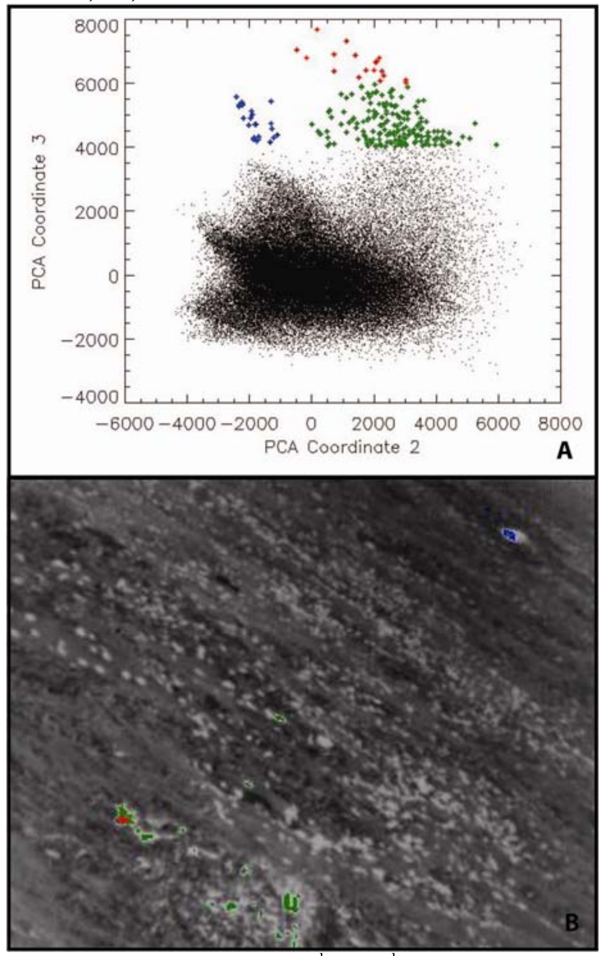

Fig. 2: [A] Scatter plot of the 2nd and 3rd principle components. Output can be used to differentiate between the cave (red), non-cave anomaly (blue), and high thermal inertia basalt (green). [B] Visible image with 3rd principle component output overlaid; colors match those used in A.

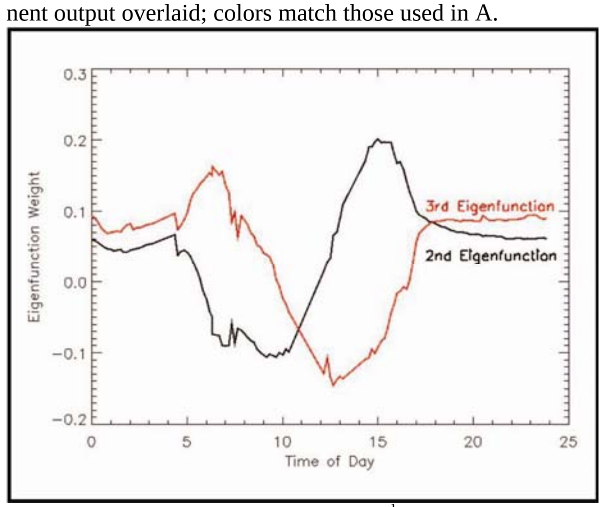

Fig. 3: Cave entrance has a strong 3rd Eigenfunction, suggesting warm temperatures at dawn and cool temperatures in afternoon. The 2nd Eigenfunction is phase-shifted, allowing the differentiation between cave and anomaly.