INVESTIGATING THE POTENTIAL FOR DETECTION OF MARTIAN LAVA TUBES USING SHARAD. N. M. Bardabelias1,2, J. W. Holt1,2, M. S. Christoffersen3, and L. P. Keszthelyi4, 1University of Arizona Department of Geosciences, 2University of Arizona Lunar and Planetary Laboratory, 3USGS Astrogeology Science Center.

Introduction: Lava tubes are tunnel-like structures formed when exposed sections of effusive flows cool while material continues moving internally [1, 2]. These tubes thermally insulate the material flowing through it, allowing subsequent flows to travel long distances before beginning to crystallize [3]. As eruption rate slows, the lava level within the tube can decrease, leaving a hollow tunnel in the solidified flow.

Motivation. For bodies with thin or no atmospheres, lava tubes provide shelter from harsh surface radiation environments, diurnal temperature swings, and micrometeorite bombardment [4]. This is of geologic and astrobiological significance for studies of past habitability or future human exploration: subsurface caverns may preserve biosignatures and/or volatiles which would make lava tubes an ideal exploration candidate for terrestrial bodies.

Lava tubes are difficult to identify in visual remote sensing data as their surface expressions are often the result of collapse - without this collapse, lava tubes are generally indistinct at the surface [1]. Skylights, large pits, and pit chains identified on Mars may indicate a break down in the lava tube breaching the surface, while sinuous rilles observed on the Moon have also been suggested as an expression of tube collapse [5]. For active lava tubes on Earth there are many remote methods of detection include thermal infrared imaging, seismic and electromagnetic sounding, and infrasonics [1, 2]. For inactive lava tubes, the standard method is magnetometry but gravity and s-wave mapping have been successful. Ground penetrating radar (GPR) presents another solution to this problem, as it detects subsurface reflectors through differences in material permittivity and is thus capable of detecting inactive lava tubes [6]. This work hypothesizes that the difference in permittivity between a sufficiently large, evacuated lava tube and its surroundings could lead to a characteristic power echo in radar data. If so, analysis of radargrams can reveal the shape and extent of a single tube or tube network [4].

SHARAD radar system. The Mars Reconnaissance Orbiter (MRO) Shallow Radar (SHARAD) probes the subsurface using a frequency-modulated ('chirped') signal downswept from 25 MHz to 15 MHz. This 10 MHz bandwidth yields a 15-m vertical resolution in free-space, reduced to ~5 m in basaltic rock [7]. Horizontal resolution is 3-6 km cross-track and 1-3 km along-track after focusing [7]. Prior work from the SHARAD science team suggests that, for models of lava tubes under Martian conditions, their instrument may be able to detect these features in the shallow subsurface [7, 8].

Methods: This work uses skylights to identify potential martian lava tubes in SHARAD data. Correlating these skylight locations with radar ground tracks from SHARAD increased the confidence that a subsurface reflection was from a lava tube signal rather than another source.

Martian skylights observed with the Mars Odyssey Thermal Emission Imaging System (THEMIS) [9] Visual Imaging System (VIS) and the Mars Reconnaissance Orbiter (MRO) HiRISE and CTX data [10, 11] are mapped to the USGS Mars Global Cave Candidate Catalog (MGC3), made available by the Planetary Data System (PDS). Of the 1062 candidate cave targets, this work examines only the 354 targets identified in the MGC as potential skylight entrances into lava tubes. All but three of these skylights are within the Tharsis region, with one each in Acidalia Planitia, Elysium Planitia, and Margaritifer Terra. 196 of these skylights are located in the plains west of Pavonis Mons and northwest of Arsia Mons, suggesting either a large number of lava tubes or long lava tubes with multiple collapse features. This region also has dense SHARAD coverage that frequently intersects with the skylights giving a large sample size for this study.

Using the Java Mission-Planning and Analysis for Remote Sensing program (JMARS) [12], this work identified SHARAD ground tracks that cross over or within 5 km adjacent to skylight locations (see Figure 1). Radargrams for these tracks were downloaded from the PDS and off-nadir clutter simulations based on MOLA topography were generated for each file [13]. SHARAD radargrams and skylight locations were then imported into the Geology by SeisWare visualization software for identification of unique subsurface reflectors.

Results & Discussion: No subsurface reflectors seen in the SHARAD radargrams for this region were able to be decisively identified as resulting from lava tubes. This work discovered low-confidence reflectors that were not seen across all of their intersecting SHARAD tracks or did not exhibit the expected parabolic shape of a lava tube ceiling in the radargram. A
number of the latter are linear, flat, subsurface reflectors and can instead be interpreted as signals from interfaces between lava flows.

Given the number of skylights in the region of interest, it is significant that lava tube signals are unable to be identified in SHARAD data. One possibility may be due to the size of the lava tubes. Prior work modeling lava tube cooling rates argues that tubes do not need to be wide in order to be long – a Martian lava tube 1000 kilometers in length may only require a diameter of about 15 meters [3]. This is far below the horizontal resolution, and just at the limit of resolution for SHARAD in free space, which is reduced to about 5-10 meters for typical Martian basalts. However, high resolution imagers at Mars have observed some skylights with a semi-minor axis width of over 100 meters which places a lower limit on the diameter of their parent lava tube, and implying that these may be observable in SHARAD if reflections are sufficiently strong to overcome the noise floor in a given resolution cell.

In order to reconcile these large suggested lava tube diameters with the lack of reflectors seen in SHARAD, we postulate that Martian lava tubes may have ceilings at a shallow (few to ten meters) depth. Most of a lava tube’s radar response should be derived from the subsurface interface with the tube ceiling [14] and they would be undetectable despite their large diameter if the ceiling was within about 10 meters of the surface – approximately the limit of resolution for a low-loss basalt such as those covering the plains around the Tharsis Montes. At this depth or shallower SHARAD’s subsurface resolution would limit the detection of a lava tube ceiling, resulting in the majority of the tube signal being lost within the strong surface echo.

Through further analysis of radar parameters including reflectivity and single-trace analyses, combined with radar wave propagation modeling constrained by observed lava tube depth/size derived from HiRISE digital terrain models, future work aims to ultimately determine whether lava tube detection is plausible with current orbital radar systems at Mars. These results may have implications for RIMFAX operations on the Mars 2020 rover [15], as well as for future orbital GPR at Mars and other terrestrial bodies.

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Figure 1: JMARS software showing a Mars Orbital Laser Altimeter (MOLA) elevation basemap for the Tharsis region, points and labels representing skylight candidates from MGC$^3$ (red), and SHARAD ground tracks (dark blue). The bottom left table displays additional MGC$^3$ data for candidate skylight locations.