ADVANCING TO LUNAR LAVA TUBE SENSING: A NEW RADAR PERSPECTIVE OF PHILOLAUS SKYLIGHT CANDIDATES.

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Lunar Lava Tube Sensing: As part of establishing future lunar base, large conduit-shaped tunnels could provide substantial access to the subsurface in the form of lava tubes. The emergence of such structures initially arises from the low-viscous and thermally insulated lava flowing underneath the evolved sub-crustal thickened roof [1]. However, the extinction of volcanism ceases the flow, thereby cooling the rocks of surrounding walls and forming the corresponding tunnels. The prominent existence of such subsurface tubes comes from the exposure of collapsed roof segment, revealed by an open circular depression called skylight [2]. In particular, these sites prove to be significant for supporting large-scale in-situ operations in the subsequent lunar base development. This further demonstrates the capability of subsurface cavities for identifying volatiles while behaving as cold traps. Moreover, the harmful solar insolation and enhanced proportion of galactic cosmic rays could be avoided in such stable lava tube environments. This becomes even more intriguing for polar regions due to the evident understanding of potential volatiles in the permanently shadowed regoliths.

Recently, the remote search for these interpreted volcanic post-flow features has expanded by utilizing very high resolution imageries of LRO NAC camera [3]-[5]. However, the subsurface penetration capabilities of radar signal could strengthen the investigation, thereby chiefly contributing to the lava tube sensing paradigm. In this study, an attempt is made to incorporate the backscattering information of the LRO MiniRF for delineating the possible reserves of lava tube candidates. This preliminary effort is validated near the Philolaus skylights.

Philolaus Lava Tube Skylights: The discovery of water-ice in the polar regions has initiated a quest for identifying probable subsurface ingress to the lunar interior [6]-[7]. This leads to the recognition of skylight candidates in the impact melt deposits of the Philolaus crater [4]. The propinquity of these sites from the North pole signifies the potential availability of life sustaining ingredients, thereby showcasing their importance in the subsequent ISRU exploration. This further signals toward planning rover missions for envisaging the regolith dynamics of the prospective candidates. The location of these skylights is emplaced by young impact melt deposits in the northeastern end with prominence of several sinuous rilles. In Fig. 2, the skylights are encircled in red while tubes are traced in white dashed line.

Observations: A preliminary analysis of MiniRF data for retrieving polarimetric information from the potential sites is carried out. In this, both radar backscatter and circular polarization ratio (CPR) images are evaluated to reveal the probable buried structures. Upon performing m-χ decomposition modeling of the regolith, it is observed that the accumulated crater fill melt deposits of the northeastern floor are characterized by diverse scattering mechanisms. Particularly, the enhanced proportions of dissecting sinuous rilles in the floor are easily identifiable by mixed scattering mechanisms, due to multiple interaction of EM wave with the rille floor, wall and surrounding elevated terrain (Fig. 1). However, several segments of the entire trail exhibit anisotropic behavior with increased random depolarization. This may attribute to the presence of water-ice in such regions of regolith. Moreover, the results from CPR are indicative of higher values, thereby supporting the decomposition results (Fig. 1).

It is also observed that the backscattering powers tend to vary throughout these winding channels with significant variations in the same-sense circular polarization (SC) values. This is suggestive of the lava tube existence, which would have collapsed in certain sections along with occasional intact/partially collapsed geometry. Evidently, the regolith of the uncollapsed lava tubes represent higher SC response, thereby indicating the identical polarization of the received backscattered field to the transmitted. This can also be seen in the opposite-sense circular polarization (OC) image where the prominent undulating upper regolith of the lava tube describes the opposite polarization state of beam, thereby signifying more anisotropic backscattering (Fig. 1).

The immediate surroundings of the skylights, oriented along the buried lava tube trail, are clearly exhibiting the Bragg scattering power, which is indicative of their rimless geometry. However, there are certain other similar skylight-like subsurface features in the vicinity of the lava tube. Owing to the location of these features near the pole, the inside temperature are supposedly low (< 25 K), suggestive of volatile-enriched regolith. This is also reflected in the m-χ image with enhanced volume scattering around the lava tube. These patterns are majorly extracted from very small circular features, possibly skylights. Also, the roof of the lava tube exhibits significant volume scattering powers, attributing to the possible presence of water-ice. In order to reconfirm this, SC, OC and CPR images are used along with the NAC images to understand the detailed regolith dynamics of the region surrounding lava tubes.

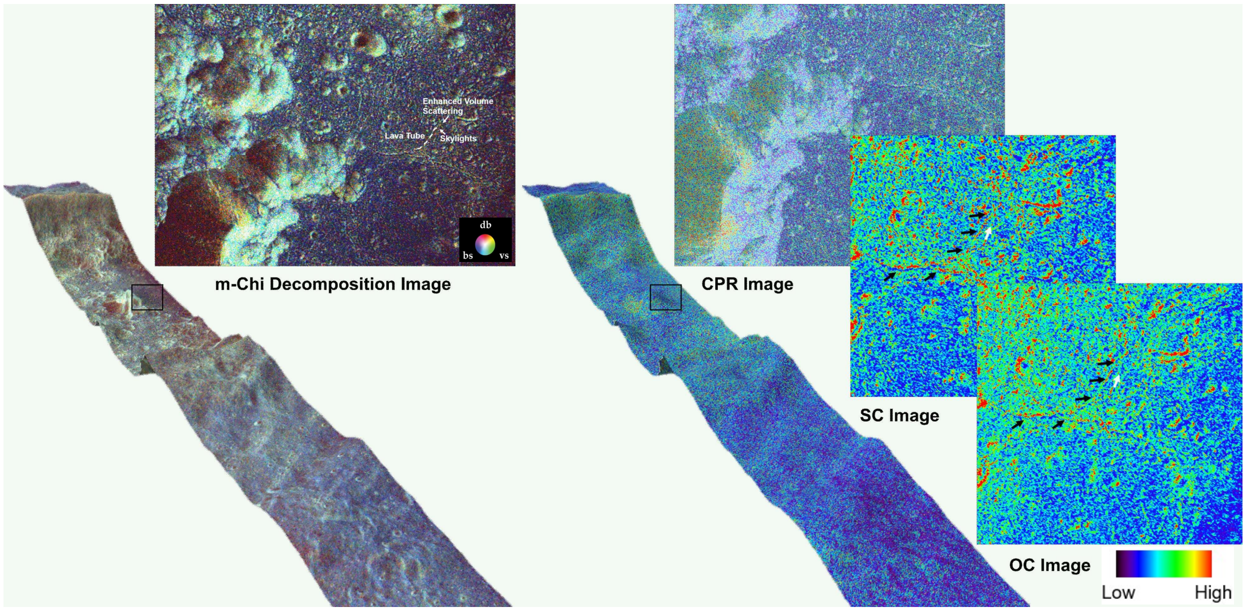

Fig. 1: Radar Perspective of Philoaus crater. The variations in the scattering patterns are observed by m-χ image in conjunction with CPR measurements. White arrow represents the prospective skylight sites while black arrows trace the buried lava tube trail.

While analyzing the very high resolution perspective, it is observed that the contribution of even bounce scattering eventually comes from the microscale roughness in terms of emplaced impact melt deposits (Fig. 2). Such patterns may also be observed due to the different sized regolith grains incorporating higher degree of agglutination. In order to improve the characterization, roll invariant parameters are also implemented based on the eigenvector decomposition of Jones matrix. This, however, provides a higher mean entropy of 0.84 for the entire floor section, thereby reducing the distinguishability of randomness in the scattering patterns. Hence, m-χ decomposition in conjunction with CPR estimates provides efficient quantification of scattering occurrences.

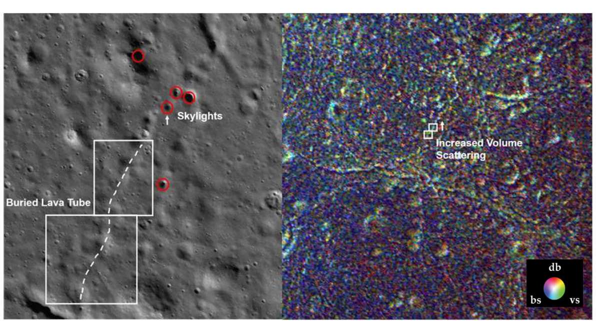

Fig. 2: Comparison with LRO NAC. Increased volume scattering signatures of near lava tube regions.

Conclusion: The importance of this finding expands the scope of hybrid polarimetric radar to identify the scattering characteristics of the potential lava tube features. The observed response of the regolith towards EM wave intensifies the realizable volcanic lava tubes emplaced by young impact melt deposits. The enhanced volume scattering and CPR values following the buried tubular trail proclaims the possible presence of volatiles (mainly water-ice) and hence, strongly recommends for future rover exploration to the Philolaus crater. All the results are in concordance with high resolution analysis and therefore, identifies two more skylights near the buried inclusion suggestive of similar radar backscatter response than others. Although there always exists ambiguities in the model-based decomposition approach, the validation for this needs to be extensively performed by integrating with the spectroscopic data. In addition to this, the higher penetration capabilities of L-band fully polarimetric radar data in the upcoming dual frequency radar instrument onboard Chandrayaan-2 mission could provide further evaluation to this framework. As a future scope, it is planned to retrieve the electrical and geotechnical characteristics of the lava tube candidates by utilizing physics-based theoretical backscattering models along with specific polarimetric signatures.

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