GLOBAL DISTRIBUTION OF POSSIBLE LAVA TUBES FROM NEAR-SURFACE TO A HUNDRED METER DEPTH ON THE MOON. T. Kaku[1,2], J. Haruyama[2], W. Miyake[1], A. Kumamoto[3], K. Ishiyama[2], T. Nishibori[2], T. Iwata[2], S. T. Crites[2], T. Michikami[4], Y. Yokota[2,5], T. Ohno[1,2], R. Sood[6], H. J. Melosh[7,8], L. Chappaz[9], and K.C. Howell[7]. [1]Department of Mechanical Engineering, Graduate School of Engineering, Tokai University (4-1-1 Kitakaname, Hiratsuka, Kanagawa 259-1292, Japan), 7bemm027_at_mail.u-tokai.ac.jp (change "_at_" to @), [2]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, [3]Department of Geophysics, Graduate School of Science, Tohoku University, [4]Faculty of Engineering, Kindai University, [5]Faculty of Science, Kochi University, [6]Department of Aerospace Engineering and Mechanics, College of Engineering, The University of Alabama, Tuscaloosa, AL, USA, [7]School of Aeronautics and Astronautics, Purdue University, West Lafayette, IN, USA, [8]Department of Earth, Atmospheric, and Planetary Science, Purdue University, West Lafayette, IN, USA, [9]AstroLabs, Pasadena, CA, USA.

Introduction: Lunar lava tubes are important from various science perspectives and provide potential sites for future lunar base construction.[1-4] Since the insides of lava tubes are shielded from cosmic radiation, particle implantation, and micro-meteorite bombardment, they are expected to have preserved original lava compositions, textures, and even volatiles that can tell us the evolutionary history of the Moon. The radiation and meteorite bombardment that disturbs the geologic record on the surface of the Moon also makes it a harsh place for humans and instruments. Thus, the inside of an intact lava tube could be one of the most scientifically interesting and safest places on the Moon from an exploration perspective.

Lava tubes form beneath the surface of a cooled lava flow, thermally insulating the lava within the tube, allowing it to be transported for long distances. Theoretical studies indicate that lava flowing in a tube can travel significantly further than analogous channel-fed or surface lava flows. [5]

Techniques based on gradiometry and cross correlation were utilized to isolate the target signal of mass deficits from GRAIL gravity data, Chappaz et al. (2017)[6] detected several locations of horizontally extended mass deficits. One of the mass deficits is in an area containing the rille A at Marius Hills in which a skylight hole has previously been discovered.[7] Kaku et al. (2017)[8] investigated radar data from the Lunar Radar Sounder (LRS) onboard SELENE (Kaguya) for the mass deficit area and found a distinctive two-peaked radar echo pattern, suggesting the existence of a subsurface intact lava tube.

The LRS, an active radar sounder, was installed on SELENE. The operation frequency of the LRS is 4–6 MHz (around 60 m wavelength), and transmission power is 800 W. Subsurface structures at depths of a few hundred meters to a few kilometers have been investigated using LRS data.[9-11]

In this paper, we examine the LRS echo data reflected from a few tens to a few hundred meters' depth in mare regions.

Results: Figure 1 shows the results that mark locations corresponding to the characteristic features of two-peak echo patterns similar to those found near the Marius Hills Hole.[8] The background of the figure is an image from the Terrain Camera (TC) onboard SELENE. The colors of the circular points denote the power difference between the two echo peaks (ΔPrb): the first echo peak is from the nadir surface and the second echo peak is from the ceiling or floor of a subsurface cave such as a lava tube. Some candidate sites for the presence of a cave exhibit strong second echo peaks; the lower the ΔPrb value (for instance, in regions of orange to red and purple colors in Figure 1), the more likely the presence of a subsurface cavity. The candidate sites are observed globally in the mare region.

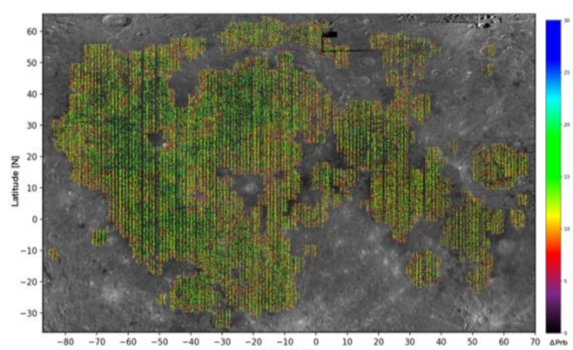

Figure 1: Locations presenting the characteristic features of two-peak echo patterns which suggest the existence of caves or lava tubes in the shallow subsurface (a few tens to a few hundred meters' depth) in the mare region.

Figure 2 (a) shows an LRS image obtained along a north-south observation track at 35.75-36.00°N, 313.235°E, south of Rima Sharp and west of Rima Mairan. Figure 2 (b) is an enlarged figure of the LRS image in Figure 2 (a). Here we set the dielectric constant (ε) to that of vacuum, which is 1, to calculate an upper limit for the depth. The first echo peak is from the surface, and the second peak is likely from the subsurface boundary. Location P_0 (35.892°N, 313.235°E) in Figure 2 presents typical characteristic features of radar echo signals with two peaks similar to those found near the Marius Hills Hole. Furthermore, the first strong echo seems to form an arch from south towards north along the observation track at location P_0 in Figure 2, which likely indicates an arch-shaped roof structure that is often seen for typical terrestrial lava tubes.

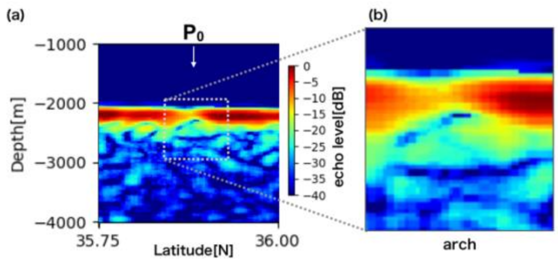

Figure 2: LRS image obtained along the north-south observation tracks at 35.75-36.00°N, 313.235°E south of Rima Sharp and west of Rima Mairan. The color indicates echo level (dB). An arch shape of 1,500 meters' width can be seen in the center of the figure, suggesting the existence of a wide lava tube.

Figure 3 shows the results in a region (52-55°N, 310-315°E) in Mare Frigoris and marks locations corresponding to the characteristic features of two-peak echo patterns, the same as those found near the Marius Hills Hole.[8] The colors of the circular points denote the power difference between the two echo peaks (ΔPrb): the first echo peak is from the nadir surface and the second echo peak is from a ceiling or floor of a subsurface cave such as a lava tube. Some sites are candidates for the presence of a cave exhibit strong second echo peaks; the lower the ΔPrb value, the more likely the presence of a subsurface cave.

We observe a set of closely spaced locations of second echo peaks across three observation tracks, indicated by a white arrow in Figure 3, suggesting an elongate cave or a lava tube lying in an east-west direction.

Conclusions: We investigated the LRS data to detect subsurface intact lava tubes from a few tens of meters to a few hundred meters' depth for the mare region. Several locations exhibit the characteristic double-peak echo patterns that were seen near the Marius Hills Hole. These locations are potential candidate sites for the presence of underground lava tubes or cavernous voids.

Our in-depth study of a few locations indicates that there likely exist lava tubes a few hundred meters wide with an arch-shaped roof structure such as those seen at Rima Mairan, and are probably a few kilometers in length (for instance, the candidate sites at Mare Frigoris).

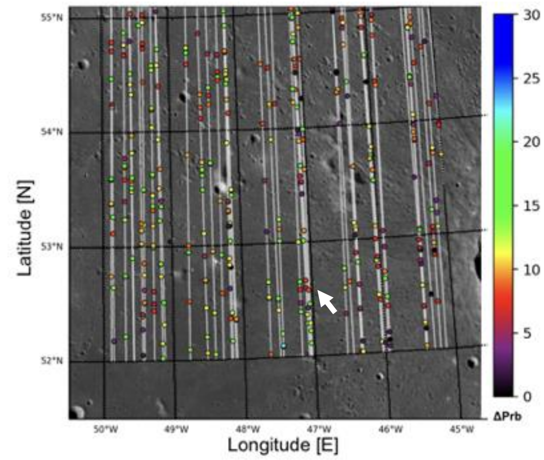

Figure 3: Locations presenting the characteristic two-peaks echo patterns which suggest the existence of caves or lava tubes at Mare Frigoris (52-55°N, 310-315°E). The white arrow indicates a set of close locations of two-peak echo patterns. These likely imply the existence of an elongate lava tube. The background of the figure is an image from the Wide Angle Camera (WAC) on the Lunar Reconnaissance Orbiter (LRO).

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