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Studying lunar Irregular Mare Patches and lava tubes with the Lunar Geology Orbiter

Sam Poppe[1], **Petr Broz**[2], Kimberly Sofge[3], Akos Kereszturi[4], Anna Losiak[5], Ernst Hauber[6], Martin Divoký[7], Tomáš Kohout[8,9,10], Henrik Hargitai[11], Roman Bohovic[12], Jaan Viru[13], Mihkel Pajusalu[14], Leonardo Carrer[15], Lorenzo Bruzzone[16], Ricardo Gomes[3], Johannes Peace[3], Quazi Saimoon Islam[14], Francesco Sauro[17], and Benjamin Fernando[18]

[1]Centrum Badań Kosmicznych Polskiej Akademii Nauk (CBK PAN), Bartycka 18A, 00-716 Warszawa, Poland
[2]Institute of Geophysics of the Czech Academy of Sciences, Boční II/1401, Prague 14000, Czech Republic
[3]TRL Space Systems, Plynárenská 499/1, 602 00, Brno, Czech Republic
[4]Research Centre for Astronomy and Earth Sciences, Konkoly Thege Miklos Astronomical Institute, HUN-REN, Budapest, Hungary
[5]Institute of Geological Sciences, Polish Academy of Sciences, Wrocław, Poland
[6]Institute of Planetary Research, German Aerospace Center (DLR), Berlin, German
[7]HiLASE Center, Institute of Physics, Czech Academy of Sciences (IOP CAS), Prague, Czech Republic
[8]Department of Geosciences and Geography, University of Helsinki, Finland
[9]Institute of Geology of the Czech Republic, Prague, Czech Republic
[10]School of Electrical Engineering, Aalto University, Otaniemi, Finland
[11]ELTE - Eötvös Loránd University, Budapest, Hungary
[12]World From Space, Brno, Czechia
[13]CrystalSpace OÜ, Tartu, Estonia
[14]Tartu Observatory, University of Tartu, Estonia
[15]Department of Engineering and Computer Science (DISI), University of Trento, Trento, Italy
[16]Department of Information Engineering and Computer Science, University of Trento, Trento, Italy
[17]ESA Topical Team Planetary Caves, Miles Beyond for ESA, Italy
[18]Department of Earth and Planetary Sciences, Johns Hopkins University, Baltimore, United States

INTRODUCTION

A better understanding of lunar geology is critical both scientifically and practically for exploring and settling the Moon in the next decades. Improving our knowledge about the formation and evolution of the Moon helps us 1) to understand the geology of Earth and other terrestrial bodies in the Solar System, and 2) to prepare for in-situ utilisation of lunar resources. Irregular mare patches (IMPs), as well as lava tubes, pits and caves are such lunar geological phenomena that offer progress with both tasks. Even though multiple IMPs were found on the surface of the Moon, their age and formation processes remain enigmatic. Furthermore, many pits have been detected in various lunar geological settings, but it remains uncertain whether any of these openings could lead to extended cave conduits underground. The proposed Lunar Geology Orbiter LUGO aims primarily to reveal the formation ages and mechanisms of IMPs, and secondarily to identify the distribution and dimensions of lava tubes for future exploration.

WHY IRREGULAR MARE PATCHES?

Controversy surrounds the formation age of IMPs because very few impact craters are present at their surface. Whereas one scenario assumes that IMPs consist of compact igneous rocks and thus are relatively young (>100 My), another scenario assumes the existence of old (<3 Gy) but highly vesicular lava foams [1, 2]. The general shape of IMPs and their rugged landform characteristics are well known, but available Digital Terrain Models do not allow unambiguous determination of the properties of the material(s) in which the observed impact craters were formed. It is hence still impossible to distinguish between two possible scenarios for the formation of IMPs [1]. Recently, analysis of hyperspectral data revealed that darker deposits surrounding some IMPs as well as the IMP surfaces themselves contain little to no glassy material, and are barely distinguishable mineralogically from the surrounding mare material [3]. Despite these discoveries, it remains unclear how IMPs originated and what their actual age is, with far-reaching consequences for understanding the thermal evolution of small planetary bodies. For example, young age of IMPs might suggest that we could still expect volcanic eruptions on the Moon.

WHY LUNAR LAVA TUBES?

Lava tubes are underground voids that can be tens of kilometers long and tens of meters wide and are formed when the solidified roof of a lava flow remains after lava supply ends and the lava channel is drained out. Even if the detection of subsurface lava tunnels on the Moon is currently difficult [4], their existence is suggested by the presence of lunar pits, or skylights, which are collapsed features on the lunar surface with near-vertical walls. However, there is still no clear confirmation of continuations of lava tunnels from these potential entrances, and no map of their distribution exists yet. Detection of lava tubes by LUGO would enable us to evaluate their basic characteristics (size, length, depth) as well as the potential for subsurface habitat utilization in the future, where future crews would be shielded from micrometeorites and cosmic radiation [5]. The identification of lava tube dimensions and morphology together with surface observations and composition of the lava would enable estimating the effusion rate, viscosity and related temperature of lunar lava under lower specific gravity.

LUGO payloads

To achieve the objectives of LUGO, the orbiter would collect targeted imagery and topographic data of the lunar surface and subsurface at a very high resolution from a highly eccentric orbit by a quartet of payloads: a ground penetrating radar (GPR), a LiDAR, a hyperspectral camera, and a narrow-angle camera (NAC). Combining such measurements would allow to characterise: a) the regolith thickness over IMPs' and surrounding units and hence reveal whether IMPs were formed recently or in the distant past, b) the properties of the material forming IMPs and hence to find out if they are formed by lava foams or lava flows, c) variations in their spectral compositions across the lunar surface, d) boulder density and distribution estimates as a proxy of regolith maturity, e) nature of the subsurface volcanic feeder system to IMPs. Furthermore, these payloads will allow to compare the subsurface detection of lava tubes as voids (with the GPR) with morphological indicators at the lunar surface (with the stereo-capability of the NAC). The proposed payloads could also allow unprecedented investigations of secondary geological targets such as floor-fractured craters and lunar domes. Future investigations could assess if an end-of-mission impact on an IMP target could provide critical information regarding the lithological properties of IMPs. The LUGO mission concept could provide a feasible way to explore these unknown aspects and could be adapted to fit funding and logistical restrictions. A LUGO mission would provide efficient synergies with already planned lunar missions, and will serve as a blueprint for future repeated observation missions that will help uncover the relation between the geological characteristics and structures at the lunar surface and the geological architecture of the shallow lunar crust.

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