

## DETECTION OF LIGHT ELEMENTS ON THE MOON SURFACE USING COMBINED TECHNIQUES.

I. Uwarowa<sup>1</sup>, P. Porizka<sup>2</sup> and J. Kaiser<sup>3</sup>, <sup>1</sup> Lightigo Space srl, 9 avenue des Hauts Fourneaux, L-4362 Esch-sur-Alzette, Luxembourg, [uwarowa@lightigo-space.com](mailto:uwarowa@lightigo-space.com), CEITEC - Central European Institute of Technology, Purkyňova 123, 612 00 Brno, Czechia, [inna.uwarowa@ceitec.vutbr.cz](mailto:inna.uwarowa@ceitec.vutbr.cz) <sup>2</sup> CEITEC - Central European Institute of Technology, Purkyňova 123, 612 00 Brno, Czechia, [pavel.porizka@ceitec.vutbr.cz](mailto:pavel.porizka@ceitec.vutbr.cz), <sup>3</sup> CEITEC - Central European Institute of Technology, Purkyňova 123, 612 00 Brno, Czechia, [jozef.kaiser@ceitec.vutbr.cz](mailto:jozef.kaiser@ceitec.vutbr.cz).

**Introduction:** Leading space industries and companies prioritize Moon and Mars exploration, with scientific instrumentation playing a crucial role in the preparation phase. Advanced analytical tools will be essential for characterizing and utilizing planetary resources, paving the way for a sustainable lunar presence.

Detecting the full spectrum of elements on the Moon requires leveraging the strengths of different instruments and optimizing their combined use. The challenge of detecting light elements—such as helium, hydrogen, oxygen, carbon, nitrogen, sodium, and potassium—can be addressed through laser-ablation-based techniques, including Laser-Induced Breakdown Spectroscopy (LIBS) and Laser Ablation Mass Spectrometry (LAMS).

Traditional LIBS analyzes laser-induced plasma radiation to detect individual elements, while LAMS takes advantage of the lunar vacuum to enable direct mass spectrometry, allowing for speciation and isotopic analysis (e.g., distinguishing helium isotopes).

**Detection requirements:** Scientific and commercial lunar exploration missions have differing requirements for element detection. Depending on the mission's objectives, it may sometimes be sufficient to detect the presence of an element and quantify its abundance. In other cases, distinguishing between isotopes is crucial.

Commercial missions focused on regolith beneficiation primarily target the detection of hydrogen and oxygen. In contrast, scientific missions often require isotope differentiation, such as measuring the deuterium-to-protium ratio to understand its origins. Certain commercial applications may also necessitate isotope identification - for example, in helium-3 detection, where merely confirming the presence of helium is insufficient.

**Methodology:** Laser-Induced Breakdown Spectroscopy (LIBS) is widely recognized for its advantages across multiple industries and applications on Earth. It has also been successfully deployed in space, including on the surfaces of the Moon and Mars.

LIBS addresses the challenge of in-situ geological surveys of celestial bodies by providing detailed elemental composition analysis. It is particularly effective in detecting light elements [1]. As a remote sensing

technique, LIBS enables elemental analysis with minimal sample preparation, making it an ideal choice for space exploration.

Laboratory studies have demonstrated the capability of LIBS to detect hydrogen isotopes, as shown in Figure 1 [2]. However, measurements conducted under vacuum conditions, simulating the lunar environment (Figure 2), indicate that while LIBS can detect elemental presence, it does not provide a detailed breakdown of isotopic composition.

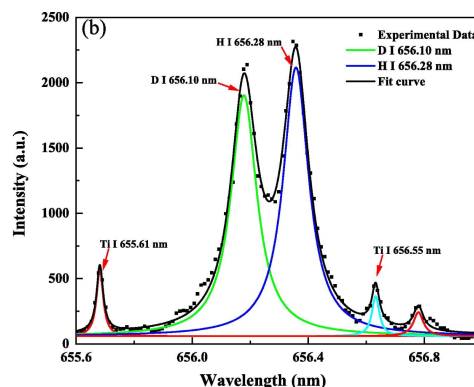


Figure 1 Detected Hydrogen isotopes [2]

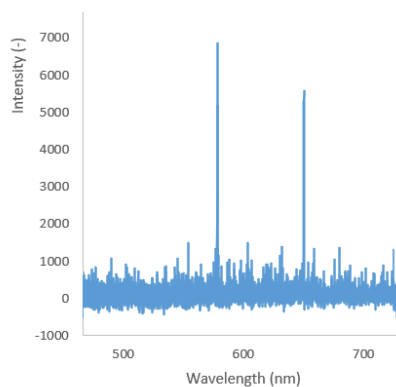


Figure 2 Regolith simulant tested under vacuum conditions.

The primary factor reducing sensitivity and resolution is the vacuum environment and the way plasma expands within it. However, this effect can be leveraged by integrating mass spectrometry to enhance isotope recognition precision.

In low-pressure conditions, laser ablation produces rapidly expanding particles, allowing them to reach the detector at sufficient velocity for Orbitrap system analysis. Distinguishing helium-3 from helium-4 is particularly challenging due to their minimal mass difference, requiring highly sensitive techniques.

Currently, Time-of-Flight Mass Spectrometry (TOF-MS) and Resonance Ionization Mass Spectrometry (RIMS) are being explored for light element detection. Both methods utilize an ionization source—such as laser ablation, which is also a fundamental component of LIBS instruments.

**Conclusions:** Introducing an instrument with a single laser source for ionization and dual outputs to expand the spectral range and enhance detection sensitivity for selected elements offers significant benefits for In-Situ Resource Utilization (ISRU) missions.

Optimizing instrument performance to balance high data quality with cost efficiency focuses on reducing mass, power consumption, and development time. A comparison of commercial lunar exploration vehicles provides preliminary design requirements, enabling the development of a plug-and-play solution for commercial availability.

#### References:

- [1] H. Saeidfirozeh et al., “Laser-induced breakdown spectroscopy in space applications: Review and prospects,” Dec. 01, 2024, Elsevier B.V. doi: 10.1016/j.trac.2024.117991.
- [2] Y. Xing et al., “Quantitative analysis of hydrogen isotopes in hydrogen storage material using laser-induced breakdown spectroscopy,” Nuclear Materials and Energy, vol. 31, Jun. 2022, doi: 10.1016/j.nme.2022.101204. [2] Author E. F. et al. (1997) *Meteoritics & Planet. Sci.*, 32, A74. [3] Author G. H. (1996) *LPS XXVII*, 1344–1345.

**Acknowledgement:** We gratefully acknowledge the support by ESRIC Start-Up Support Programme and Czech Science Foundation (25-18588L).