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VOILA on LUVMI-X: Volatiles Detection in the Lunar Polar Region with Laser-Induced Breakdown Spectroscopy

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Introduction

With the confirmation of water ice in the lunar polar regions [1], the Moon has recently come into the focus of attention of international space agencies again. Volatiles, specifically water and hydrogen, are important resources both for life support and for potential applications as fuels and propellants for spacecraft. In-situ resource utilization (ISRU) of volatiles could significantly reduce the costs of a sustained presence on the Moon and could be beneficial for the future human deep space exploration of the solar system [2]. The detection of volatiles is therefore an important scientific goal for future robotic missions to the Moon.

The LUVMI-X project (Lunar Volatiles Mobile Instrumentation – Extended) is developing an initial system design as well as payload and mobility breadboards for the detection of volatiles in the lunar polar region on a small, lightweight rover [3]. The LUVMI-X rover is shown in Figure 1. One proposed scientific payload is VOILA (Volatiles Identification by Laser Ablation), which is jointly developed by OHB System AG (OHB), Laser Zentrum Hannover (LZH), and the German Aerospace Center's Institute of Optical Sensor Systems (DLR-OS). VOILA will use laser-induced breakdown spectroscopy (LIBS) to analyze the elemental composition of the lunar surface, with a special focus on detecting and quantifying hydrogen and oxygen as indicators for water.

LIBS is a versatile technique that requires only optical access to its target [4]. A LIBS spectrum is obtained within seconds, making it well-suited for quick analyses of multiple targets in proximity to the rover. LIBS was first used in space by the ChemCam instrument on board NASA's Curiosity rover on Mars [5, 6]. The first LIBS instrument on the Moon was supposed to operate on board the Pragyan rover of India's Chandrayaan-2 mission [7]. However, the Chandrayaan-2 lander failed a soft landing in September 2019.

Here, we present a summary of the VOILA instrument design and its intended capabilities for volatiles detection at the lunar south pole.

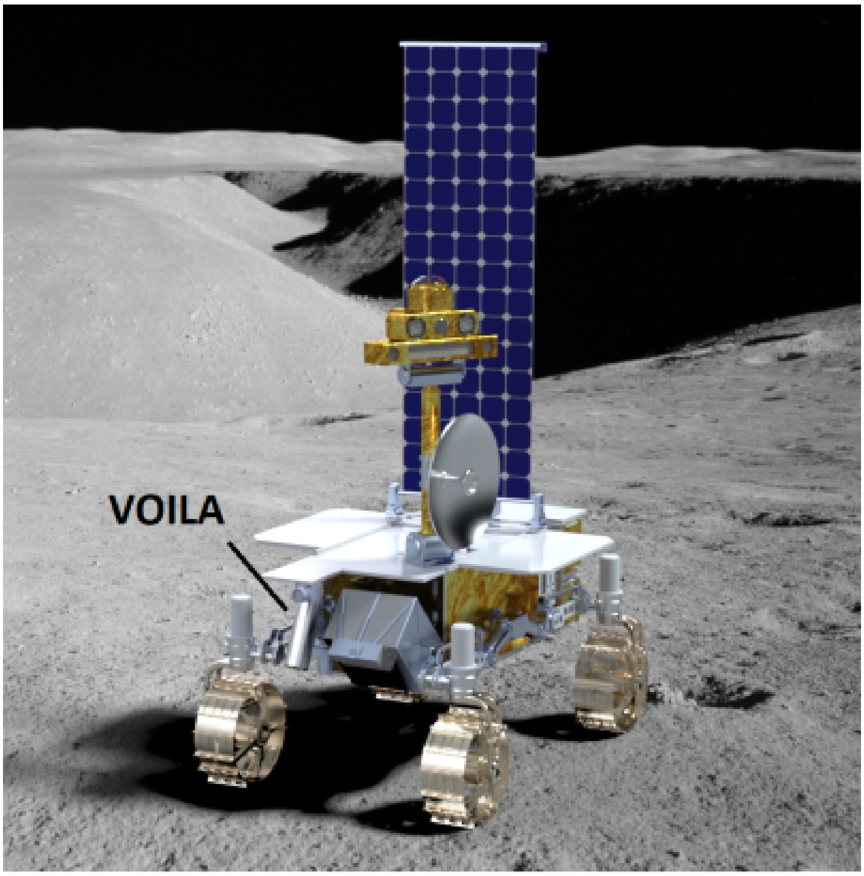

Figure 1: Concept art showing the LUVMI-X rover on the Moon. The optical head of VOILA can be seen mounted at the front of the rover body. (Credit: Space Applications Services)

Instrument Design

With an expected mass of about 3 kg, VOILA is designed to be more lightweight than the ChemCam instrument, but heavier and slightly more complex than the LIBS instrument designed for the Chandrayaan-2 mission. It will include an optical head with a focusing mechanism designed for working distances between 30 cm and 50 cm, which allows for compensation of uneven terrain or different rover configurations. The optical head is mounted at the front of the rover body and can rotate horizontally to select multiple targets of interest at each rover location.

VOILA uses an actively Q-switched pulsed Yb:YAG laser developed by LZH with a pulse energy of at least 15 mJ at a wavelength of 1030 nm to ablate sample material, generating a laser-induced plasma that can be spectrally analyzed. The VOILA spectrometer will have a wavelength range from 350 nm to 790 nm at a spectral resolution of about 0.5 nm, thereby covering atomic and ionic emission lines of the major rock forming elements (O, Si, Al, Fe, Mg, Ca, Na, K, Ti) and of hydrogen.

LIBS measurements with VOILA are intended for the analysis of the topmost lunar surface layers. Simple depth profiling within millimeters could be achieved by repeated ablation of the same location on the surface. A single shot is expected to produce a crater of several millimeters depth due to the force of the outgoing shockwave in the regolith.

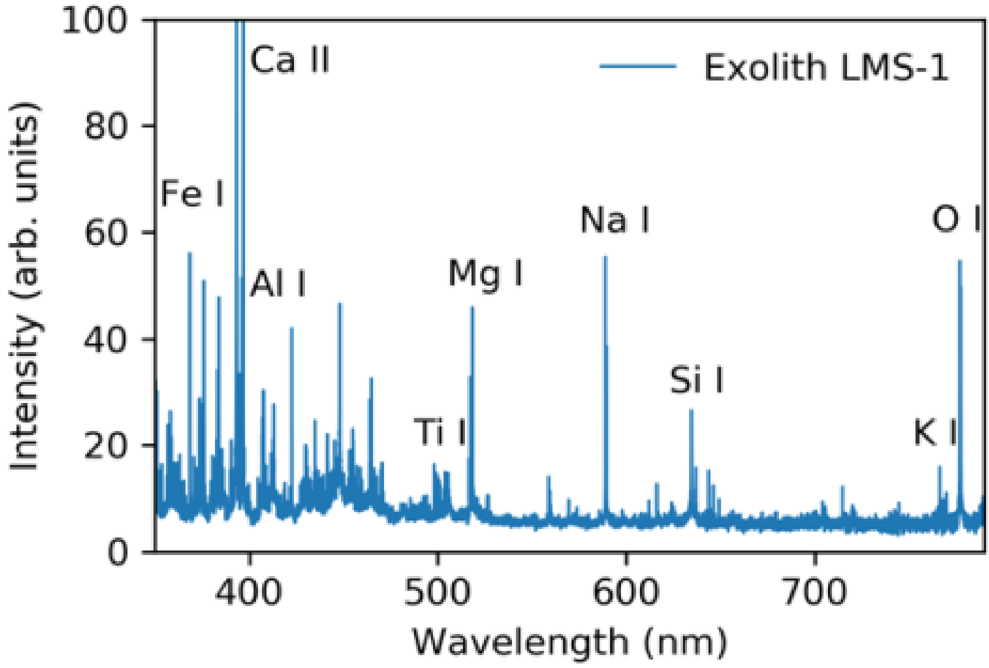

Figure 2: LIBS spectrum of regolith simulant Exolith LMS-1 measured at 0.1 Pa with a Nd:YAG laser (1064 nm, 15 mJ/pulse). Intense signals of all major rock forming elements can be observed.

Laboratory Studies

Preliminary LIBS studies in near-vacuum (0.1 Pa of air) were made with the high-resolution LIBS setup at DLR-OS to determine the VOILA instrument requirements. Figure 2 shows a LIBS spectrum of lunar regolith simulant Exolith LMS-1 in which all major rock forming elements could be observed within 350 nm to 790 nm. A laser energy of 15 mJ/pulse was found to produce a very intense plasma when focused to a spot of 300 µm diameter. For a basalt/gypsum mixture with a water concentration of about 1.5 wt%, the H I line at 656.3 nm was successfully detected, see Figure 3. The signal to noise ratio is about 4.3 for this line, indicating that even lower concentrations can be detected. Furthermore, the high-resolution echelle spectrometer used for the measurements has a low throughput that will be exceeded by the VOILA instrument itself.

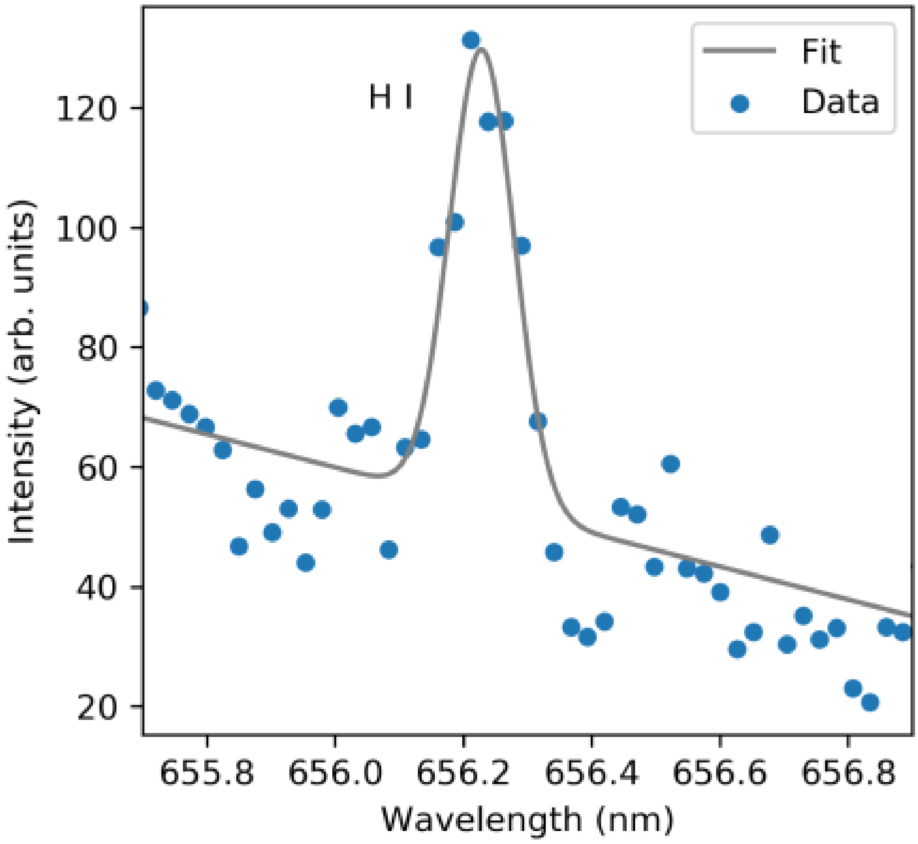

Figure 3: H I line at 656.3 nm in the LIBS spectrum of a basalt/gypsum mixture with 1.5 wt% H_2O (15 mJ/pulse, 1064 nm). The signal to noise ratio of about 4.3 is achieved with a low-throughput spectrometer.

Conclusion

VOILA is a new LIBS instrument for the detection of volatiles at the lunar south pole. Initial experiments show that LIBS can be employed at low pressures and that clear signals of all major rock-forming elements and of hydrogen can be obtained in the specified spectral range of VOILA. The pulse energy of VOILA is at least 15 mJ, which is achievable by the laser prototype developed by LZH. The successful detection of hydrogen is promising, but the instrument should also be qualified with measurements of real water ice at low concentrations. Future studies should also investigate whether water ice can be distinguished from other hydrogen and oxygen sources. New results obtained with the VOILA demonstration setup developed by OHB, LZH and DLR will be presented at the conference.

Acknowledgments

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