VOILA: LASER-INDUCED BREAKDOWN SPECTROSCOPY (LIBS) FOR THE DETECTION OF VOLATILES IN THE LUNAR POLAR REGION.

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Introduction: The Moon has recently come into the focus of attention of international space agencies again. Concepts for the establishment of a long-term human presence on the Moon have been proposed, such as the Moon Village concept championed by ESA and NASA's lunar outpost concepts as part of the Artemis program. One reason for this renewed interest in the Moon was the discovery of water ice in the lunar polar regions by the Chandrayaan-1 mission [1]. Water and other volatiles 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 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]. One proposed payload is VOILA (Volatiles Identification by Laser Analysis), a LIBS instrument developed by OHB System AG (OHB), Laser Zentrum Hannover (LZH), and the German Aerospace Center (DLR). LIBS (laser-induced breakdown spectroscopy) is a 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 Curiosity of NASA's Mars Science Laboratory mission [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], but the lander crashed onto the lunar surface during descent in September 2019.

Here, we demonstrate the potential of LIBS for the detection of volatiles on the lunar surface. We show preliminary feasibility studies as well as first results of the VOILA demonstration model.

Experimental Setups: The VOILA demonstration model will employ a pulsed laser developed by LZH with a pulse energy of at least 15 mJ at a wavelength of 1030 nm. Samples will be placed onto a nitrogen-cooled sample stage inside a simulation chamber for ambient pressures down to 0.1 Pa. This should be sufficiently low to simulate lunar near-vacuum conditions, since no changes of the LIBS signals have been observed at pressures below 1 Pa [4, 8]. LIBS spectra will be measured with several miniature spectrometers (Avantes AvaSpec-Mini) in order to achieve a broad spectral coverage.

The preliminary feasibility studies shown here were made with two LIBS setups at DLR Berlin. One uses an echelle spectrometer (LTB Aryelle Butterfly) with a spectral coverage from 270 nm to 850 nm. The second setup is used to measure spatial distributions of plasma emissions. Both use ICCDs (Andor iStar) for time gating and Q-switched Nd:YAG lasers (Continuum Inlite / Quantel Viron) at 1064 nm with pulse durations of about 6 ns. Simulation chambers were used to reduce the ambient pressure to about 0.1 Pa.

Samples: Lunar regolith simulants such as NU-LHT-2M, BP-1, and Exolith LMS-1 and LHS-1 are analyzed in this study. They were either pressed into pellets or used as loose material in order to emulate the density of the regolith dust on the lunar surface. The loose regolith was filled into a beaker up to a height of about 10 mm. Additionally, pressed pellets of varying hydrogen concentration were mixed from basalt and gypsum ($CaSO_4 \cdot 2H_2O$) in order to investigate the feasibility of hydrogen quantification.

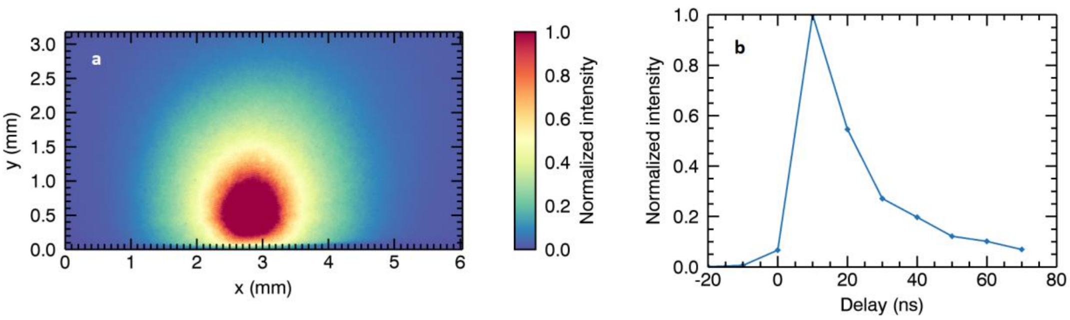

Figure 1: LIBS plasma of a pressed pellet of NU-LHT-2M at 0.1 Pa for a pulse energy of 22 mJ. a) Side view at 10 ns delay with a 10 ns gate. b) Time evolution of the total intensity. Measurements were made in steps of 10 ns with a gate of 10 ns.

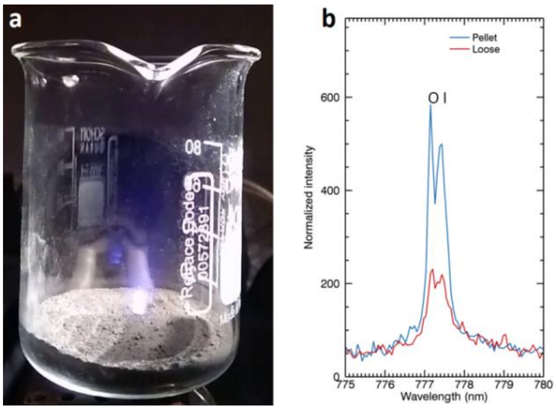

Figure 2: a) Plasma formation for loose LMS-1 regolith simulant at a pulse energy of 15 mJ. b) Spectra of O lines at 777 nm for pressed and loose LMS-1 samples (15 mJ/pulse).

Results: Plasma emissions at 0.1 Pa atmospheric pressure are still very intense (Figure 1a). The plasma plume is several millimeters large and has a circular shape. The plasma has a short lifetime of less than 100 ns (Figure 1b), so that time gating for specific spectral features is not feasible. Laser energies as low as 5 mJ/pulse produced spectra with clear lines of the major elements in the regolith in the case of pressed samples. For loose regolith measurements (Figure 2a), the ablation process is less efficient. The signal-to-noise ratio was reduced and higher laser energies of about 15 mJ/pulse were needed to produce spectra that could be analyzed (Figure 2b).

In order to analyze the low-intensity H signal in the basalt/gypsum samples, 450 individual spectra were averaged for each sample. In order to reduce the influence of atmospheric hydrogen adsorption, 5 laser shots were made at each position before measuring. In the averaged spectra, the H line at 656.3 nm can be detected clearly even for the lowest H concentration of 0.17 wt% (Figure 3a). A clear correlation of the measured H line intensities with the H concentration in the samples can be observed (Figure 3b).

Conclusion: Our initial experiments show that LIBS can be employed at low pressures and that high signal intensities can be obtained even in loose regolith. The pulse energy of about 15 mJ is achievable by the VOILA laser prototype developed by LZH. The detection and quantification of hydrogen is promising, but adsorption from the atmosphere needs to be controlled in the lab experiments. Low-temperature measurements of frozen regolith mixed with water ice should be done to 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 this symposium.

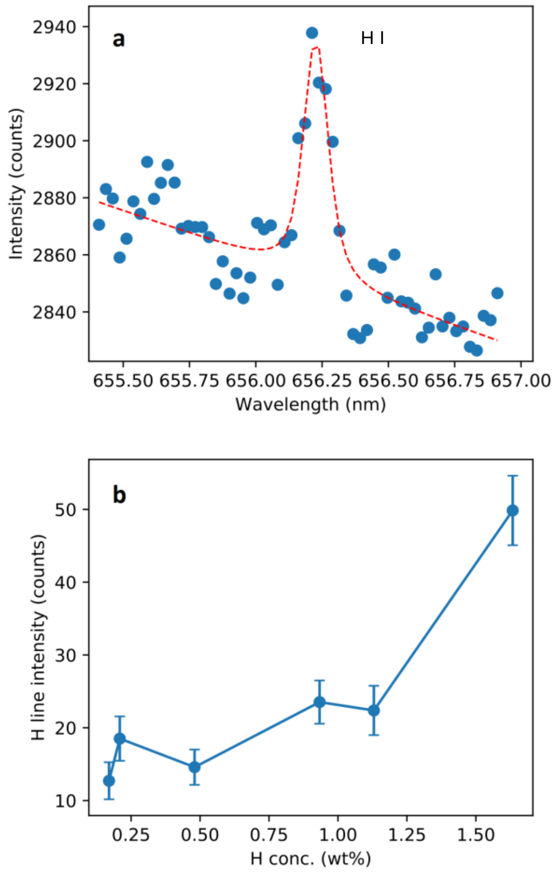

Figure 3: a) Spectrum (blue dots) and Voigt fit (red dashed line) of the H line at 656.3 nm for a 13:1 basalt/gypsum mixture (0.17 wt% H). b) Fitted intensities of the H line obtained from averaged spectra for all basalt/gypsum mixtures. All measurements were made with a laser energy of 15 mJ/pulse.

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