THE VOILA INSTRUMENT: LASER-INDUCED BREAKDOWN SPECTROSCOPY AT THE LUNAR SOUTH POLE. D. S. Vogt[1], S. Schröder[1], H.-W. Hübers[1,2], L. Richter[3], M. Deiml[3], P. Wessels[4], J. Neumann[4], [1]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Berlin, Germany, david.vogt@dlr.de, [2]Humboldt-Universität zu Berlin, Berlin, Germany, [3]OHB System AG, Weßling, Germany, [4]Laser Zentrum Hannover e.V., Hannover, Germany.

Introduction: The lunar south pole is of great interest for upcoming lunar exploration endeavors due to the detection of large reservoirs of water ice in the pole's permanently shadowed regions [1]. Water is an important resource for life support on future Moon bases and for potential applications as propellants for spacecraft. In-situ resource utilization (ISRU) is therefore considered vital to reduce the costs of a sustained presence on the Moon and to support the future human exploration of the solar system [2]. An important scientific goal for future robotic missions to the Moon is therefore the scouting of available water resources with payloads that are sensitive to signals of traces of water on the lunar surface.

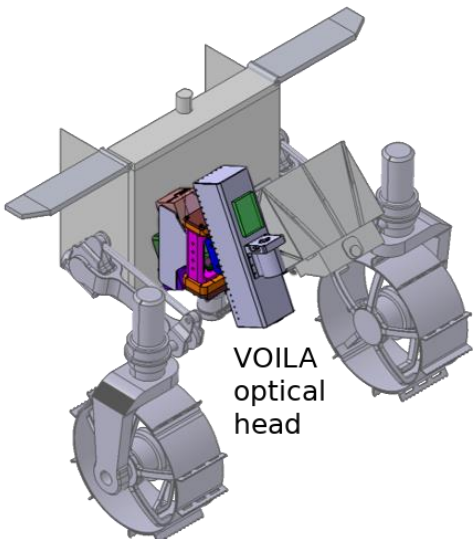

Figure 1: CAD model of the accommodation of the VOILA optical head at the front of the LUVMI-X rover.

VOILA on LUVMI-X: 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 water and other volatiles in the lunar polar region on a small, lightweight rover [3]. One of the proposed instruments is VOILA (Volatiles Identification by Laser Analysis), which uses LIBS (laser-induced breakdown spectroscopy) to analyze the elemental composition of the lunar surface. LIBS uses a pulsed laser to ablate material from an investigated target, which forms a bright plasma plume that can be analyzed spectroscopically to gain an emission spectrum of atomic and ionic emission lines of the elements in the targeted surface. The technique only requires optical access to its target and allows for quick measurements within a few seconds, making it well-suited for analyses of multiple targets in proximity to the rover [4]. LIBS has been first used in space by ChemCam on NASA's Mars Science Laboratory mission [5, 6] and will also be employed on Mars by SuperCam on NASA's Mars 2020 mission and by the Mars Surface Compound Detector on China's Tianwen-1 mission, both of which will arrive on Mars in 2021 [7, 8]. The first LIBS instrument on the Moon was supposed to operate on board the Pragyan rover of India's Chandrayaan-2 mission [9], but the lander failed to achieve a soft landing in September 2019.

Fig. 1 shows a CAD model of the optical head of VOILA mounted at the front of the LUVMI-X rover's body. The optical head includes the LIBS laser and a focusing mechanism to achieve working distances from 300 mm to 500 mm. It can be rotated along one axis in order to aim at different targets on the lunar surface in front of the rover. The light collected from the laser-induced plasma is coupled into a fiber that guides it into the spectrometer in the rover body. The spectrometer then records the spectrum in the wavelength range from 350 nm to 790 nm, which includes the H emission lines at 486.1 nm and 656.3 nm as well as the emission lines of major rock-forming elements such as Ca, Mg, Si, Fe, Al, and O.

VOILA laboratory setup: The results shown here were measured with the VOILA demonstration setup at the DLR Berlin, which resembles the VOILA instrument concept as close as possible in order to demonstrate the capabilities of the instrument design. The setup uses a vacuum chamber to reach pressures in the order of 1 mPa (10^{-5} mbar), so that the measurement conditions are sufficiently close to those on the lunar surface [4, 10]. A translation stage inside the vacuum chamber is used to adjust the position of the sample, which can be cooled with liquid nitrogen for LIBS measurements of frozen samples. The breadboard VOILA instrument is mounted above the vacuum chamber with a fixed working distance of 400 mm and employs a laser deliberately developed for VOILA at the Laser Zentrum Hannover e.V. and a fiber-coupled Avantes AvaSpec-Mini spectrometer. The laser

Figure 2: Gypsum sample on the sample stage inside the vacuum chamber before and during LIBS measurements. a) Image before LIBS measurement. b) Laser-induced plasma plume during LIBS measurement. c) False-color image of emission captured with a 656.3 nm bandpass filter.

operates at a wavelength of 1030 nm with a pulse energy of 17 mJ and a pulse duration of 7.8 ns. The spectrometer covers a wavelength range from 350 nm to 910 nm with a spectral resolution of about 0.4 nm.

Experimental results: Fig. 2 shows a gypsum pellet (a), the laser-induced plasma at 3mPa pressure as a true-color image (b), and a false-color image of the emission at 3 mPa measured with a bandpass filter at 656.3 nm (c), which corresponds to the hydrogen emission line and to some continuum emission. The plasma has a bright spot at the ablation zone and lower-intensity emissions above the sample in a conical distribution with a diameter of several millimeters.

For a basalt/gypsum mixture with 6 wt% gypsum, no hydrogen signal was detected with a field of view of 1.8 mm around the plasma center. Instead, the LIBS spectrum showed a strong continuum emission. However, when the LIBS spectrum was measured with a field of view of 5 mm *excluding* the inner 1.8 mm, a weak hydrogen signal is observed, see Fig. 3. This indicates that most of the hydrogen emission comes from the conical plume above the sample, while the bright spot at the plasma surface seen in Fig. 2c is mostly due to continuum emission.

Conclusion: VOILA is a prototype LIBS system jointly developed by OHB System AG, Laser Zentrum Hannover e.V., and DLR, which is being optimized for volatiles detection and geochemical analysis of the surface along the LUVMI-X rover traverse at the lunar south pole. The laboratory setup confirms its capability for hydrogen detection. However, it is likely that the performance can still be increased considerably by improving the optical design and the field of view of the instrument.

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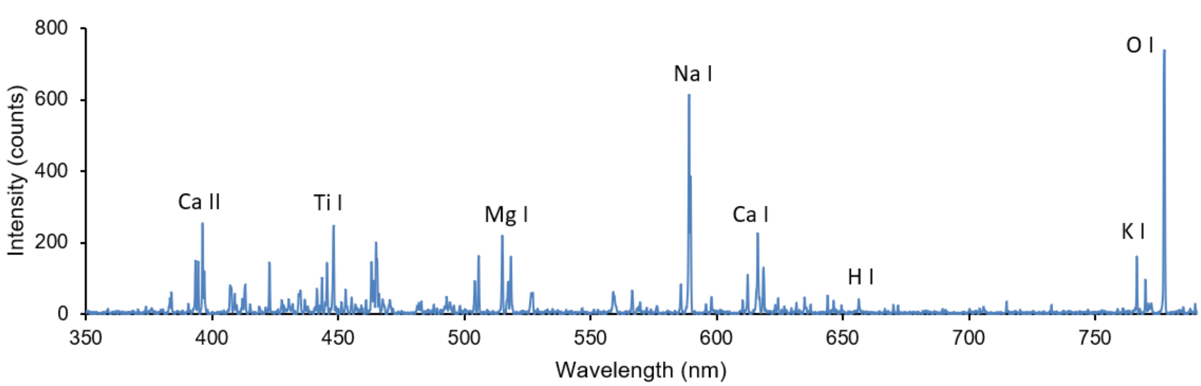

Figure 3: VOILA spectrum of basalt/gypsum mixture measured at 3 mPa pressure. The plasma center was obscured in order to obtain only the spectrum of the plasma perimeter. Emission lines of H and major elements can be observed.