ACOUSTIC RECORDING OF LIBS ANALYSES IN PREPARATION FOR MARS 2020  S. Maurice1, X. Jacob2, L. Couvert3, D. Mimoun2, R. C. Wiens2, W. Rapin1, A. Cousin1, O. Forni1, O. Gasnault1, J. Lasue1, P.-Y. Meslin1.

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Introduction. As part of the NASA Mars 2020 payload, the SuperCam instrument suite will include a microphone to support the Laser Induced Breakdown Spectroscopy (LIBS) investigation of soils and rocks on Mars [1,2]. The primary purpose of LIBS is to investigate at remote distances the elemental composition of Mars, thanks to a pulsed laser (15 mJ, 5 nsec) and the spectral analysis of the plasma that is created when the laser beam is focused to achieve >1 GW/cm² irradiance. The ablation also generates a very sharp pressure wave (the “LIBS shock wave”), which accelerates supersonically for a few hundred nsec. Because it is so sharp (usec), the acoustic wave is broad band and contains no effective spectral information. However its overall intensity is proportional to the mass of ablated materials [3] and will reveal some unique physical properties (this study) of the targets probed with LIBS.

While this study gives results at ambient pressure, the ultimate purpose is to calibrate the laser impacts sounds on various rocks for future studies supporting the SuperCam Mars microphone. The ChemCam [4] Engineering Qualification Model in Toulouse, France, is used in this study to generate the plasma and to collect LIBS spectra. An external, remotely located microphone and its suite of ground support equipment is added for this study. Samples are in open air, at 1.80 m from ChemCam telescope and 50 cm from the microphone.

Acoustic data. We use a 1/2” microphone from Brüel & Kjær (B&K, type 4165) with a sensitivity of 51.9 mV/Pa, a band pass 2.6 Hz – 20 kHz, and a dynamical range from 20 to 140 dB. The low signal-to-noise preamplifier is also from B&K (type 2669). The microphone sensitivity is calibrated for 1 Pa at 1 kHz, which corresponds to 94 dB. An oscilloscope records the signal at 5 MHz.

Acoustic data are time series recordings in volts and converted to Pa. For each laser shot, the RMS acoustic pressure P is calculated from the quadratic sum of the signal amplitude in Pa, and turned to Sound Pressure Level (SPL) in dB: \( L_p = 20 \log_{10} \left( \frac{P}{P_0} \right) \) with

\[
P = \sqrt{\frac{1}{T} \sum \text{Amplitude}^2 \Delta t} \quad \text{in Pa.}
\]

\( P_0 = 20 \mu \text{Pa} \) is the reference sound pressure. \( \Delta t \) is the duration of the signal.

LIBS data. The laser unit is maintained at a controlled temperature of -10°C in a climate chamber. The laser beam (14 mJ, 5 nsec) exits the chamber horizontally and is directed vertically downward by a mirror at 45°. This mirror is adjustable to be able to move the LIBS spot on the target. The laser spot size on target is ~300 µm. The spectrometers are at room temperature. They record LIBS spectra from 240 nm to 900 nm, with a gap around 345 nm. For this very particular study, we use the RMS spectral intensity in dB: \( I_{LIBS} = 20 \log_{10} \left( \frac{I}{I_0} \right) \) with

\[
I = \sqrt{\frac{1}{\lambda_{max} - \lambda_{min}} \sum \text{Intensity}^2 \Delta \lambda} \quad \text{in counts.}
\]

\( \Delta \lambda \) is the resolution in nm, \( \lambda_{max} = 905 \) nm, the upper bound of the VNIR spectrometer, \( \lambda_{min} = 240 \) nm, the lower band of the UV spectrometer.

Samples and variables. Several targets have been selected for their shape and size, surface roughness, and hardness (Mohs scale). For this study, none of these targets are certified or even pure. The hardness value is approximate: (i) Talc (clay mineral composed of hydrated magnesium silicate; hardness 1), coarse surface. (ii) Calcite (calcium carbonate; hardness 3), powder, coarse and smooth surfaces. (iii) Marble (metamorphic rock composed of recrystallized carbonate minerals, most commonly calcite or dolomite; hardness 3 – 4), plates of different sizes. (iv) Dolomite (calcium magnesium carbonate; hardness 3.5 – 4), coarse and smooth surfaces. (v) Basalt (fine-grained igneous rock; hardness ~6), coarse and smooth surfaces. (vi) Mars soil simulant [5]: pressed powders at 2 tons, 3 t, 4 t, 6 t, 8 t, 10 t, and 15 t. The samples have been placed on foam or directly on the concrete floor. Once we verified that this had no effect, they were placed directly on the foam.

On each target, one or several bursts of 10 (or 150 shots) are acquired at 3 Hz. For each laser shot, a LIBS spectrum is obtained together with an acoustic recording. The only other variable is the focus quality of the laser beam, which was systematically varied around the best focus position.

Results. The intensity of the acoustic signal is independent of the sample orientation with regards to the laser beam. This is important for further in-situ measurements. On the contrary, it depends on the target roughness that has to do with the plasma generation efficiency by the laser.
The intensity is plotted (Fig. 1) as a function of the pressure applied to JSC pressed powders: as shown the more compact the target, the higher the acoustic level.

Fig. 1: Acoustic signal for different pressed powders.

The intensity decreases with the number of laser shots (Fig. 2). The starting point is higher for larger hardness, but we cannot exclude that to be biased by the focus quality. More important is the slope, that is indeed related to the target hardness. On (soft) calcite, the dispersion is also larger than on the other targets.

Fig. 2: Acoustic signal for different targets as a function of the shot index in series of 150 shots.

Fig. 3: Acoustic signal for two long series of laser shots on 2 t and 15 t pressed powders.

Performing many laser shots is a way to penetrate deeper into the samples [4]. However, after several tens of laser shots, the rate of penetration levels off [8] because of the conical shape of the LIBS pits, the amorphisation of their slopes, and also the confinement of the plasma itself. This study shows that the intensity of the acoustic signal decreases during depth profiles, following a slope that depends on target hardness.

These initial results show how useful a recording of the shock wave during LIBS acquisition will tell us about the target hardness and other mechanical properties that are otherwise unknown at remote distances. This information will certainly help the interpretation of LIBS signals, specially for volatile elements such as H.

**Discussion.** There is not an extensive literature on the systematic study of LIBS-induced pressure wave, or the experiments only apply to very specific conditions [6,7]. It is known to be proportional to the amount of ablated material [3]. In addition, the efficiency of the coupling, a major contribution to the ablated mass, is related to the plasma temperature, which itself is proportional to the Vickers hardness. This study seems to close the loop, showing that the acoustic signal is proportional to the target hardness.