The Mars 2020 SuperCam Microphone to constrain rock hardness and LIBS crater volume.

B. Chide[1,2], S. Maurice[2], B. Bousquet[3], X. Jacob[4], D. Mimoun[1], N. Murdoch[1], A. Cousin[2], G. David[2], J. Lasue[2], P-Y. Meslin[2] and R.C. Wiens[5], [1]Institut Supérieur de l'Aéronautique et de l'Espace (ISAE-SUPAERO), Toulouse, France, [2]Institut de Recherche en Astrophysique et Planétologie (IRAP), Toulouse, France, [3]Centre Lasers Intenses et Applications (CELIA), Talence, France. [4] Institut de Mécanique des Fluides de Toulouse (IMFT), Toulouse, France. [5]Los Alamos National Laboratory (LANL), Los Alamos, United States.
[baptiste.chide@isae-supaero.fr]

Introduction: As part of the Mars2020/SuperCam instrument suite, the Mars Microphone will record sounds from the surface of Mars in the audible range (100 Hz to 10 kHz). It will support the Laser-Induced Breakdown Spectroscopy (LIBS) investigation by recording LIBS shock-waves at distances up to 4 m [1].

The LIBS technique is already used daily on Mars with ChemCam, onboard the Mars Science Laboratory rover, that can fire up to 150 laser shots at the same location to probe rocks at depth [2]. However, it is impossible to directly measure the depth of these laser pits. This knowledge would be valuable as it would help to decipher a variation of the LIBS signal due to chemical target stratification with depth, as encountered during a depth profile [3].

Recording the LIBS shock-wave has been shown to be an efficient tool to study the ablation process as it carries information about the laser-matter coupling [4]. In addition to this, some correlation can be established between the shock-wave velocity, the physical matrix effects [5], and the hardness of targeted samples [6]. Furthermore, as the laser penetrates at depth into the sample, a modification of the shock-wave propagation geometry is seen; this change in the acoustic signal can be used as an indicator of the LIBS pit growth [7].

Recently, a detailed experimental study [8] was conducted under ambient atmosphere, and led to a quantitative relationship between the LIBS acoustic shock-wave, the rock hardness and the ablated volume: the shot-to-shot LIBS acoustic signal decrease is shallower for harder targets, and acoustic energy is linearly correlated with the volume of the LIBS pit. These initial results confirmed how promising acoustic data for LIBS investigation are, and demonstrated the science potential of listening to laser sparks at remote distances on Mars.

Although sound propagation [9] and the laser ablation process [10] differ significantly at low CO_2 pressure relative to ambient pressure, comparison to the Mars Microphone test campaign [11] suggests that the trends observed at ambient pressure are transposable to Mars. The aim of this study is to calibrate for the first time, the LIBS acoustic signal with regard to rock hardness and LIBS pit volume under a simulated Mars atmosphere.

Method: The ChemCam laboratory setup at IRAP, Toulouse uses a chamber filled with 7 mbar of a simulated Martian atmosphere and equipped with a SuperCam Mars Microphone, from the same batch as the flight model, without any additional amplification stage. Four homogeneous samples were prepared and selected to test the influence of basic rock properties with regards to LIBS acoustic signal (see Fig. 1): a piece of solid calcium-sulfate plaster, a pressed pellet of JSC Martian soil simulant [12], a rectangular block of black marble and a piece of magnetite. Series of LIBS pits with different total numbers of shots (5, 15, 30, 90, 150 and 300) were made; each experimental condition was repeated 3 times. The morphologies of each crater made on the targets were analyzed with a non-contact 3D surface profiler. Target hardness was estimated with a Micro Vickers Hardness Tester. As indicated in Fig. 1, Vickers hardnesses (H_V) varies over a wide range of values.

For each laser shot, the propagation of the LIBS shock-wave (compression and rarefaction phase) is recorded. The integral of the square values of the time series signal during the compression phase (hereinafter referred as the "acoustic energy") was computed for each single shot.

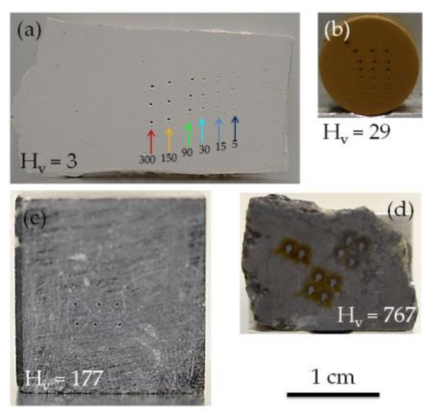

Figure 1 - Targets analyzed: (a) calcium-sulfate plaster, (b) JSC Mars simulant powder compacted by 3 tons of pressure, (c) black marble and (d) magnetite. The six craters (x3) resulting from an increasing number of shots are annotated by colored arrows on the plaster target.

Results: Recording the acoustic signal of the LIBS shock-wave shows that only the amplitude of the signal decreases as a function of the number of shots during a depth profile, while the acoustic waveform remains the same. On the one hand, this decay rate depends on the nature of the target and on the second hand, it can be linked to the depth of the LIBS pits.

Inferring rock hardness. For the four analyzed targets, the acoustic energy decreases exponentially with the number of laser shots (see Fig. 2). The decay rate of the acoustic energy is controlled by the target hardness: the softer the target, the steeper the slope. This decrease is attributed to different rates of growth of the LIBS crater: the softer the target is, the faster and the deeper the laser ablates the material. However, a shock-wave generated inside a crater at depth results from a downgraded laser-matter interaction compared with laser-surface interaction. Therefore less vaporized material is available to push against the background gas, resulting in a less energetic shock front.

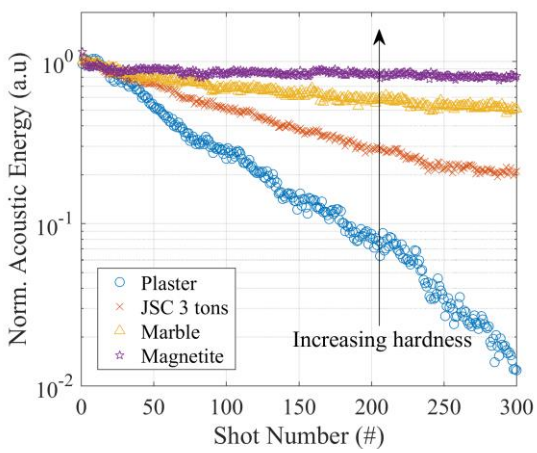

Figure 2 - Variations of the acoustic energy during a series of 300 consecutive shots at the same location for the 4 analyzed targets.

Extracting LIBS pit volume. To verify the previous assumption, acoustic data have to be compared with crater morphologies. Fig. 3 synthetizes the relationship between the acoustic energy and the crater volume; for a given crater, it links the volume of the crater with the acoustic energy of the last shot of the raster that produced the crater. A linear decrease of the acoustic energy with crater volume can be noticed. Remarkably, this decrease is independent of the target hardness. As the laser-to-target distance is fixed, the volume is linearly linked with the crater depth. This relationship means that the recording of the acoustic energy can be used to monitor the LIBS crater volume reached after a given number of shots.

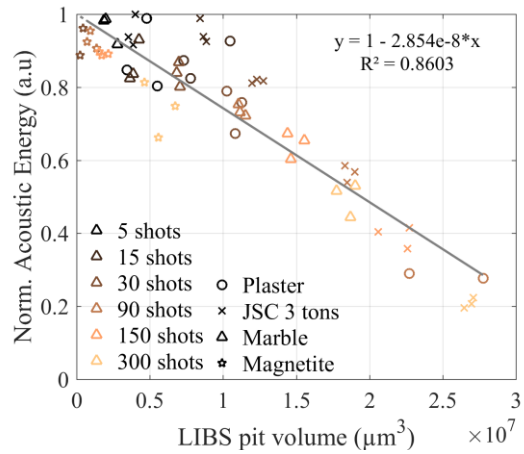

Figure 3 - Normalized acoustic energy at the bottom of the LIBS pit (i.e. last shot acoustic energy) as a function of the cavity volume.

Conclusion: Recording the acoustic signal of the LIBS shock-wave under a simulated Martian atmosphere shows that the Mars Microphone will add valuable information to document the LIBS SuperCam targets on Mars:

- The decay rate of the acoustic energy along a depth profile is indicative of the target hardness.
- The acoustic energy can be used as a tool to monitor the ablated volume, and thus, the depth, regardless of the physical properties the target. This piece of information not provided by the analysis of the LIBS spectra and useful to study the thickness of coatings and alteration layers of targets.

This study confirms that the trends observed under ambient conditions [8] are applicable to Mars atmospheric pressure. It also suggests the need for further calibrations of the Mars Microphone with more geological samples.

References: [1] Maurice S. et al. (2016), LPSC XLVII, Abstract #3044. [2] Maurice S. et al. (2012) Space Sci. Rev. 170. [3] Lanza N.L. et al. (2016), Geophys. Res. Lett 43. [4] Jeong S.H. et al. (1999), J. Phys. D : Appl. Phys 32. [5] Krasniker R. et al, (2001), Spectrochimica Acta B 56. [6] Abdel-Salam Z. et al. (2007), Spectrochimica Acta B 62. [7] Grad L. and Mozina J. (1993), Appl. Surf. Sci 69. [8] Chide B. et al. (2019, submitted), Spectrochimica Acta B. [9] Bass H.E. and Chambers J. P (2001) J. Acoust. Soc. Am. 109. [10] Knight A. K. et al. (2000) Appl. Spectr. 54. [11] Murdoch N. et al. (2018) Planetary and Space Science. [12] Allen C.C. et al. (1998) LPSC XXIX.