

## Focusing a Laser Induced Breakdown Spectroscopy (LIBS) telescope with a Microphone.

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**Introduction:** The SuperCam instrument suite selected for the NASA Mars 2020 rover will include as an add-on, the Mars Microphone [1]. It is designed to record the sounds of shock-waves generated by the supersonic expansion of a laser-induced plasma [2]. Its potential to provide additional information to document the Laser-Induced Breakdown Spectroscopy (LIBS) targets on Mars has already been demonstrated under terrestrial [3] and Mars [4] atmosphere.

The ChemCam instrument onboard the NASA Mars Science Laboratory rover relies on LIBS to study the chemical composition of the Gale crater surface since 2012 [5]. To maximize the laser irradiance level on a target, and simultaneously the amount of collected plasma photons, the telescope is focused on the target by moving the secondary mirror. Different methods have been used so far to determine the best focus:

- On ChemCam, the nominal autofocus capability used a pulsed continuous wave laser (CWL). The light returned from the target was maximized at the telescope's best focus [2]. This capability failed 801 sols after landing [6].
- After the CWL failure, from Sol 801 to Sol 983, ChemCam focus relied on laser focus z-stacking: LIBS signal was collected at different focus planes; the best focus position is selected a posteriori as the position that maximized the LIBS emission spectrum [6].
- After Sol 983, ChemCam has used Remote Micro-Imager (RMI) z-stacking to focus its telescope: images are taken at various focus distances and the onboard algorithm chooses the distance that maximizes sharpness [6,7]. This technique has been working flawlessly since then.

Laboratory LIBS analyses typically use another technique: maximizing the sound intensity from the LIBS spark to rapidly determine the best focus for their setup. On Mars, this very same method might be used in 2020 thanks to the Mars Microphone. In this study we investigate how the laser-induced shock-wave depends on the focus quality.

**Method:** *Acoustic test bench:* The ChemCam instrument replica, at IRAP in Toulouse, is fired inside a homemade anechoic box designed to shield the acoustic signal from the clean room environmental noise and to avoid uncontrolled resonance modes. The entire test bench is under ambient pressure and temperature. This anechoic box is equipped with a SuperCam Mars Microphone, from the same batch as the flight model, without any additional amplification stage (see [3] for detailed description of the test bench).

*Sample preparation:* Seven samples were chosen with respect to their varying physical properties and chemical composition: a piece of solid calcium-sulfate plaster, three pressed pellets of JSC Martian soil simulant with a grain size smaller than 45  $\mu\text{m}$  and compacted at 1 ton, 3 tons and 10 tons, a rectangular block of black marble, a piece of hematite, and a piece of magnetite.

*Experimental procedure:* The depth of field for acoustic data and LIBS spectrum was estimated using a focus stacking ("Z-stack" technique), as described in [7] for the ChemCam Remote Micro Imager. For all the targets, 18 bursts of 30 shots were fired at various distances around the best focus position. The best focus position was determined by the nominal autofocus capability of ChemCam with the CWL. 10 motor steps (corresponding to  $\sim 4$  mm at our working distance of 1.8 m) separate two consecutive focus frames. The impact position of the laser was slightly shifted between each successive burst so that the LIBS pits did not superimpose each other. This avoids any cavity effect either on acoustic or spectral intensity. The 18 craters resulting from 30-shot bursts at various distances around the best focus distance are shown in Fig. 1.

**Results:** For each laser shot, the propagation of the LIBS shock-wave (compression and rarefaction phase) was 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.

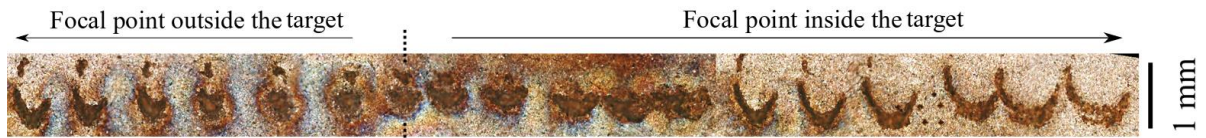


Figure 1 - Microscope images of craters produced with 30 shots at varying focus distances in the 3 ton compacted JSC target. The 7th crater (dashed line) is obtained at best focus. Craters on its left correspond to shorter focus distances and craters on its right to longer focus distances. Each crater focus distance is separated by  $\sim 4$  mm

Fig. 2 shows the evolution of the acoustic energy for different distances around the best focus position. First, the mean acoustic energy is at its maximum around the best focus distance and decreases as we move away from this position. Looking at the acoustic energy variation over 30 shots (black points in Fig. 2) confirms the results presented in [4] that the acoustic energy decreases with the number of the laser shots at the same location (see red line slopes in Fig. 2).

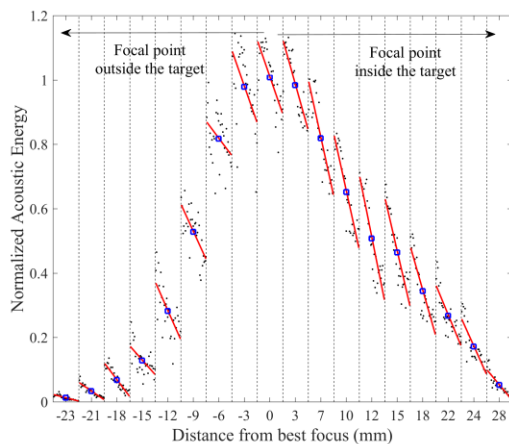


Figure 2 - Evolution of the acoustic energy by bursts of 30 laser shots for different distances from the best focus position for the 10 ton compacted JSC target. For each distance, black points are the measured acoustic energies and the red line is a linear fit over those points to visualize the 30-shot trends as a function of focus. Blue squares represent the mean value of the acoustic energy for each series of 30 shots. Energies are normalized by the mean energy at best focus.

Z-stack analyses were performed on the 7 targets in order to measure the LIBS sound's depth of field and to check whether target physical properties can influence the variation of the acoustic energy with respect to the distance from the best focus position. We define the acoustic depth of field as the distance range over which the acoustic energy intensity is above 50% of its maximal value. The normalized acoustic energies recorded at various focus distances, are plotted in Fig. 3.

For each target, the general behavior is the same as observed in Fig. 2. The sound's depths of field are similar for all the targets. At our working distance ( $\sim 1.8$  m) and for the 7 targets the average acoustic depth of field is  $27 \pm 10$  mm, i.e. 1.5% of the instrument to target distance and seems to be independent from the nature of the target.

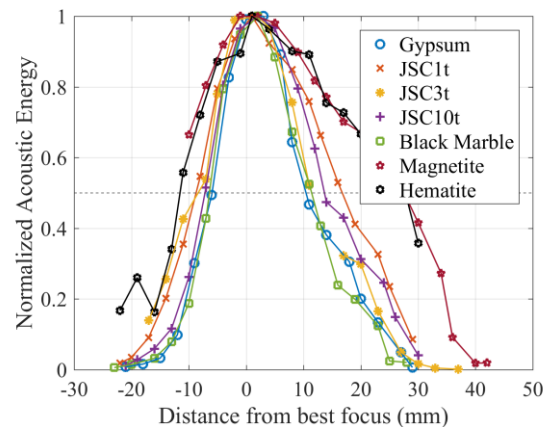


Figure 3 - Normalized acoustic energies at various distances from the best focus for the 7 analyzed targets. Each point is an average over the 30 shots of the raster (i.e. blue points in Fig. 2)

**Conclusion:** As it is commonly inferred by LIBS team, the laser spark sound is louder at best focus. This study demonstrates that it is possible to use acoustic Z-stacks as a focus method for the telescope of a LIBS apparatus. This redundant, but newly quantified way to do a LIBS autofocus will further improve the robustness of the autofocus capability of the SuperCam instrument.

**References:** [1] Maurice S. et al. (2016), LPSC XLVII, Abstract #3044. [2] Miller J.C (1994), Springer. [3] Chide B. et al. (2019, submitted), Spectrochimica Acta B. [4] Chide B et al. (2019), LPSC L, Abstract #1411. [5] Maurice S. et al. (2012) Space Sci. Rev. 170. [6] Peret L. et al. (2016) SpaceOps Conf. [7] Le Mouélic S. (2015)