Laser Induced Breakdown Spectroscopy (LIBS) spot size at Stand-off distances with ChemCam. S. Maurice[1], A. Cousin[1], R. Wiens[2], O. Gasnault[1], L. Parès[1], O. Forni[1], P.-Y. Meslin[1], S. Clegg[2] and the ChemCam team, [1]Institut de Recherche en Astrophysique et Planétologie, Observatoire Midi-Pyrénées, CNRS - Université (31400 Toulouse, France; sylvestre.maurice@irap.omp.eu); [2]Los Alamos National Laboratory, New Mexico.

Introduction. The ChemCam instrument [1,2] onboard the Mars Science Laboratory (MSL) mission [3], on its way to Gale crater, carries the first Laser-Induced Breakdown Spectroscopy (LIBS) experiment. At distances from 1.5 to 7 m from the rover mast, the LIBS technique will permit active remote interrogation of rocks and soils, through dust layers and almost 1 mm into rocks, and far deeper into soils. The elemental compositions are expected within ±10% relative accuracies [4,5]. The purpose of this paper is to define the ChemCam spot size as a function of distance to the target. From a technical point of view, the spot size is related to the laser irradiance on the target, therefore to the intensity of the LIBS plasma. From a scientific point of view, the spot size needs to be compared to the size of pure mineral phases and grains in natural targets [6]. This has implications on the capability of ChemCam to return the bulk composition of a geological target and the measurement strategy [7, 8].

Estimate of the LIBS spot size. In the literature [9] the LIBS spot size is usually defined by the minimum diffraction radius:

$$r \approx 2\frac{\lambda R}{\pi D}M^2 \qquad \text{(Eq. 1)}$$

λ is the laser wavelength (1067 nm), *D* the beam expansion diameter (90 mm), *R* the distance to the target. M^2 is the beam propagation factor (ranging from 1.5 to 2.5 on ChemCam); a perfect Gaussian beam yields 1 [10]. Thus, the irradiance decreases as R^2 because of the linear increase of the laser spot diameter. According to this equation, ChemCam spot diameter should be ~45 µm at 1.5 m and ~200 µm at 7 m.

The reality is different. The ChemCam telescope has a central obscuration which blocks 40% of the laser energy. Tensions on the reflective surfaces, especially the primary mirror, create interferences within the coherent laser beam. Interferences and various aberrations (such as astigmatism) modify the distribution of the laser energy within the Airy pattern on the target: the intensity of the central peak is reduced; more energy is being rejected into outer rings; the minima move away from the center. There is no analytical solution for such a complex system and at present time no numerical solution. It is qualitatively known that the spot radius is much larger than the diffraction limit. It must be measured directly.

On the other hand, the size of LIBS craters depends on the efficiency of the laser coupling with the target, which itself depends on the texture, albedo – opacity, roughness, grain size, etc. It is therefore variable from target to target. Spot size variations with distance have been observed by the ChemCam team on a graphite pellet, figure 1 of [11], but no accurate measurements were performed.

Measurement of the LIBS spot size. This study reports on some quantitative measurements of the ChemCam spot size, using the instrument setup in Toulouse, France. The Engineering and Qualification Model (EQM) at IRAP is an exact duplicate of the Mast-unit portion of the flight instrument. It contains the laser and the telescope, which generate the LIBS plasma. Samples are placed at various distances from the telescope, in a chamber simulating the Martian atmosphere (composition and pressure) or at ambient conditions. See [12] for details on the experimental setup.

Black anodized Al plates are used for targets, placed perpendicularly to the laser beam. The telescope is commanded to focus. Then bursts of *N* shots at 10 Hz are performed at different distances with the laser at full power. When in focus, the laser beam removes the oxidation layer and the shiny surface of the aluminum appears. The spot size is imaged through a binocular microscope (Fig. 1). The exposed surface is calculated and converted into the diameter of a circle, having the same area. In reality, the laser spot is not a circle, but close to a square, due to the form of the emission crystal in the laser.

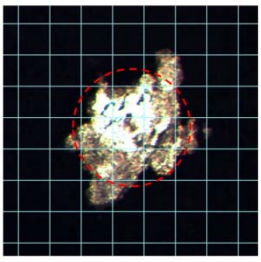

Fig 1. LIBS spot at 2.45 m. The aluminum is exposed where the laser has removed the oxidation layer. In red, the calculated circle with the same surface is shown. The grid mesh is 100 x 100 µm.

When setting up this experiment, we have observed:

- Similar spot sizes and forms are obtained in Terrestrial and Martian conditions, even though the plasma is brighter under Martian atmospheric conditions [e.g. 13].
- The spot size is independent of the number of shots for *N* smaller than ~200. Beyond that, the quality of the coupling decreases and the crater rims move outward slightly [14]. Finally, *N* = 10 was chosen for the measurements described below.
- A few measurements were done at both full and reduced power of the laser at 3.5 m. No spot size difference could be observed.

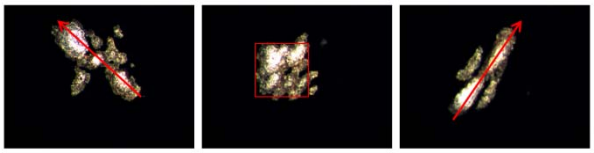

Fig 2. Series of LIBS spots at 5.6 m. The left image is out of focus (10 cm beyond the best focus); the telescope astigmatism points to the left. The right image is also out of focus (10 cm past the best focus); the astigmatism is pointing to the right. The image at the center corresponds to the best focus. The best focus is less than 1 cm away from the focus returned by the autofocus.

- With these measurements, the best focus position found visually (most compact spot size) could be compared to the autofocus position [1]. Both solutions are within the ±0.5% of the distance, i.e. within the requirements. When out of focus, the spot shape reveals the telescope astigmatism (Figure 2), which is slightly larger on the ground model than on the flight model.
- Observations with the microscope also reveal a dark halo of re-deposition around the LIBS spot. It is larger under ambient pressure (twice the size of the LIBS spot) than under Mars pressure.

Conclusions. The LIBS spot size at the best focus position is given in Figure 3. It ranges from 360 µm at 1.5 m to 550 µm at 7 m. As expected it is larger than predicted by simple diffractive geometry (Eq. 1), especially at short distances. It is a linear function of the distance to the target, with a slope of 34.6 µm/m, which is very similar to that of Eq. 1, 30 µm/m for $M^2 = 2$.

As shown in Figures 1 and 2, the spot shape at best focus is close to a square. The approximation by a circular spot size tends to mis-estimate the actual size of the LIBS spot by ±40 microns.

Aluminum couples very well with the ChemCam laser. The threshold to remove the dark oxidation seems to be low, lower than the 1 GW/cm^2 value which produces stoechiometric plasma [15]. Only a fraction of the area within the LIBS spot, where the intensity is larger (for instance, the saturated area in Figure 1) will produce a significant plasma. Hence, we estimate that the current study yields an upper value of the true area which is sampled by the laboratory instrument. The actual flight model of ChemCam must have comparable performances.

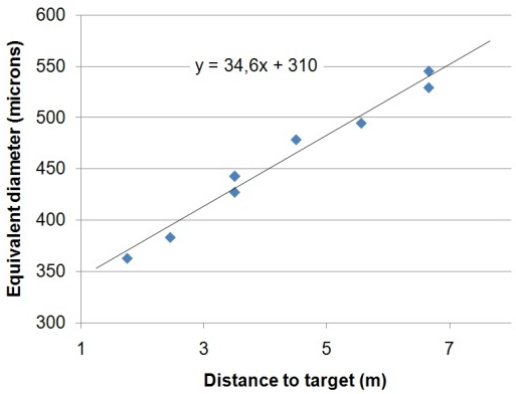

Fig 3. LIBS spot size as a function of the distance to the target: measurements (symbols) and linear trend.

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