Expected Performances of the ChemCam Instrument for the Mars Science Laboratory (MSL) Rover

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Overview: ChemCam is an active remote sensing instrument to investigate details of the Martian geochemistry [1,2] using the Laser Induced Breakdown Spectroscopy (LIBS) technique [3-6] and micro-imaging, to be flown on the Mars Science Laboratory (MSL) rover scheduled for launch in 2009.

The first end-to-end model has been assembled and used to validate the functional capabilities of the instrument. We exploit these technical tests to derive expected science performances of the ChemCam instrument aboard MSL. Four distinct areas have been investigated: the ability to create a plasma and subsequently to collect light onto spectrographs, the imaging performances, and the auto-focus capabilities.

Warning: The reader should consider these results as representative of the ChemCam development model only. Technical updates for the flight model are expected. Furthermore, current tests have been performed at room temperature under terrestrial atmosphere and performance under the reduced Martian atmosphere will be significantly enhanced.

LIBS plasma: Thalès Laser, France, has developed for ChemCam a miniaturized solid state laser with high beam quality ($M^2 < 3$), short pulse duration (< 8 ns), large operating range (40 °C) without thermal control, and energy above 30 mJ. The laser beam is focused by a mirror of 100 mm diameter (see [2] for details).

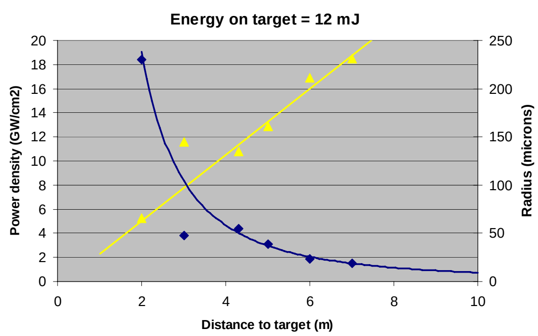

Fig. 1: LIBS spot size (triangles, right scale) and power density (diamonds, left scale) as a function of distance to the target.

With a camera, we have imaged the laser beam focused at various distances, for an output laser energy of 25 mJ. We model the focused laser beam as a circle which contains 12 mJ and the radius of this circle yields the spot size used to calculate the power density on the target.

As shown in Figure 1, the spot radius thus determined is linear with distance, as expected, with the exception of one point for which the camera was out of focus. The radii range from ~50 to 300 µm for analysis distances from 2 to 9 m. A mean power density of 1 GW/cm^2 is known to be a lower threshold for the formation of a useful LIBS plasma [3]. Figure 1 shows that the ChemCam instrument can operate up to 9 m, which agrees with the science requirements of the MSL mission.

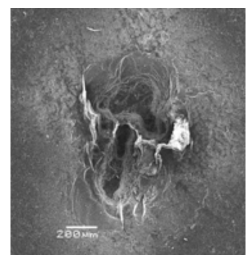

Fig. 2: San Carlos olivine after 300 laser shots.

At 6.4 m, we targeted a single crystal San Carlos (AZ) olivine (~Fo90). Figure 2 shows a photomicrograph of the laser pit. The deepest spots have radii ~250 µm, in accordance with results of Fig. 1. For this material, the overall pattern of interaction (mostly mechanical fractures) appears larger by a factor ~2 than the true total spot size.

LIBS spectra: The telescope collects plasma light and redirects it through a single 300 µm core diameter optic fiber towards alternatively three slightly modified Ocean Optics, Inc. HR2000 spectrographs [7]. Many spectra have been obtained on standard powders, pure metals, sand and rocks.

Figure 3 is a combined spectrum from 240 nm to 900 nm of the San Carlos Olivine, obtained for 3 series of 30 shots (10 Hz) at 6.4 m with the three spectrometers. A blind reconnaissance of elemental composition has identified: Mg, Ca, O, Si, Fe, Na, H, H_2. The sodium is a known trace of human contamination, that gradually disappears when alteration layers are removed with the laser shot number increase. Atomic and molecular hydrogen results from the plasma interaction with the terrestrial atmosphere.

Other elements are indeed constituents of the olivine. Conversely, all elements of the San Carlos Olivine have been detected, except for the minor element Ni (0.44% of NiO [8]). No attempt has been made so far to be quantitative for this first series of tests.

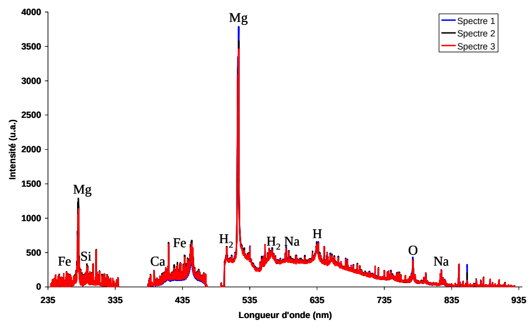

Fig. 3: Spectrum of San Carlos Olivine tested at 6.4 m distance obtained with 3 series of 30 shots and 3 spectrometers.

By varying the telescope to sample distance, we have shown that the line intensity varies by 10% within ± 0.3% of best focus and by 50% within ±1% of best focus. This measures the LIBS depth of field.

Micro-imaging capability: The heart of the imaging capability is the flight qualified CCD and its associated electronics which were developed for ESA projects. For these tests a 100% reflecting mirror diverges the telescope light to the CCD, whereas a broad band dichroic is expected for future models.

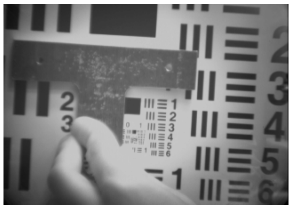

Fig 4: USAF target at 8 m distance, with an Al sample punctured by many LIBS shots.

For the field of view, we obtain 20 mrad, which corresponds to a 10 cm target at 5 m. The illumination across this field drops by a factor 2 from the center to the edges. USAF standard targets (Figure 4) have been used to determine the instrument resolution, in units of cycle/mm in the object space. Depending on the distance, the resolution translates to 55 – 85 µrad, or in terms of smallest object you can resolve: 200 µm at 2 m distance and 600 µm at 10 m distance. Finally the depth of field for imaging was estimated to be ~ 0.6 % of the distance to the target.

Auto-focus capability: The MSL rover will point ChemCam in azimuth and elevation toward the target of interest, and shall provide a target distance with accuracy ±5 %. Considering the LIBS and imaging depth of field, an autonomous acquisition of focus has been developed using a continuous wavelength laser.

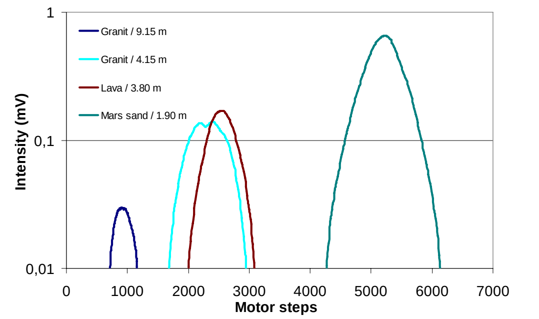

Fig 5: Autofocus curves for granite and lava rocks, as well as sand at different distances. Curves are symmetric around the best focus.

Hardware and software processes have been tested for numerous non-ideal targets (Figure 5). Results show that ±0.5 % precision around the best focus can be obtained, in agreement with LIBS and imaging requirements.

Conclusions: First performance results of ChemCam, as a laboratory setup, are in accordance with what was proposed to the MSL mission. LIBS spectra shall be obtained from 1 to 9 m for data analysis of elemental composition. The imaging capability does of ChemCam a micro-imager at remote distances.

Acknowlegments: The ChemCam development is being supported by science co-Is and collaborators (see authors lists of [1], [2], [9]) plus many engineers and technicians. Specifically in France: B. Dubois, M. Bouyé, L. Parès, J. Platzer, H. Valentin, T. Gharsa, M. Dupieux, A. Cros, J.-J. Thocaven, H. Seran, R. Pérez, J.-L. Espaignol, Q.-M. Lee, D. Lullier, N. Raimbault, B. Faure, E. Durand, M. Lescure, M. Berthé, F. Durantel, P. Cais, B. Quertier, E. Condé, A. Martin, L. Rouby, A. Gaboriaud, Y. Parot, G. Orttner, P. Pujol, P. Couderc.

References: [1] Wiens et al. (2005), *LPSC 36th*, #1580. [2] Maurice et al. (2005), *LPSC 36th*, #1735. [3] Cremers (1987) *Appl. Spectrsoc.*, 41, 1042. [4] Knight et al. (2000), *Appl. Spectrosc.*, 54, 331. [5] Brennetot et al. (2003) *Appl. Spectrosc.*, 57, 744. [6] Sallé et al. (2005) *Spectro. Acta*, 60, 479. [7] Sallé et al. (2005) *Spectro. Acta*, 60, 805. [8] Galoisy et al. (1995) *Americ. Mineral.* 80, 1089. [9] Wiens at al. (2007) *LPSC 38th*, this issue.