

CHEMCAM DATA PROCESSING: DARK SPECTRA AND THEIR ROLE IN THE DETECTION OF HYDROGEN. S. Schröder¹, P.-Y. Meslin¹, O. Gasnault¹, A. Cousin¹, S. Maurice¹, J. Lasue¹, O. Forni¹, R.C. Wiens², and the MSL Science Team. ¹ Institut de Recherche en Astrophysique et Planétologie (IRAP), Toulouse, France. ² Los Alamos National Laboratory, NM, USA. [susanne.schroder@irap.omp.eu].

Introduction: The ChemCam instrument [1, 2] on board NASA's Mars Science Laboratory (MSL) combines a Laser-Induced Breakdown Spectroscopy (LIBS) instrument with a Remote Micro-Imager (RMI), providing elemental analysis of soils and rocks together with pre- and post-LIBS context images of the target. One of the main advantages of LIBS is its ability to detect light elements such as hydrogen, which can indicate the presence of water and is a key element in terms of habitability. With ChemCam on Mars, hydrogen is observed in essentially all targets, with usually less intense signal in the rocks than in the soils [3, 4]. Moreover, a hydrated dust layer covers to a greater or lesser extent all the targets on Mars, which can be seen from the single shot analysis by ChemCam [5, 6]. The ChemCam LIBS raw data are processed by subtracting a so-called dark spectrum measured from the same location and for the same integration time as the active LIBS spectrum but without lasing. The dark spectrum accounts for reflected sunlight on the martian target as well as pattern noise and counts due to thermal dark current. In particular a strong hydrogen absorption line (H_{α} at 656.5 nm) is detected in the dark spectra due to the Fraunhofer lines in the solar spectrum. At this wavelength also the most intense and only detectable H emission line from the laser-induced plasma is found in the LIBS spectra. The measurement of an appropriate dark spectrum is therefore essential for the detection of hydrogen by ChemCam and is discussed in this work.

Dark Spectra: In Fig. 1 the mean LIBS spectrum of 30 shots of a fine grained martian soil informally named *Crestaurum* is displayed (red) together with the associated dark spectrum (black) as well as their difference spectrum (green). The H line is partly superimposed by a carbon line that is present in all the LIBS data due to a partial breakdown of the CO_2 dominated atmosphere on Mars.

Similar to a passive spectrum, the dark spectrum depends highly on the target type and solar irradiation properties and can be measured either prior to or after the LIBS analysis (DS1 or DS2, respectively). The dark spectra of ChemCam are usually recorded after the active LIBS measurement. In order to investigate the suitability of this default data processing for the H detection, special observation sequences were run on selected targets.

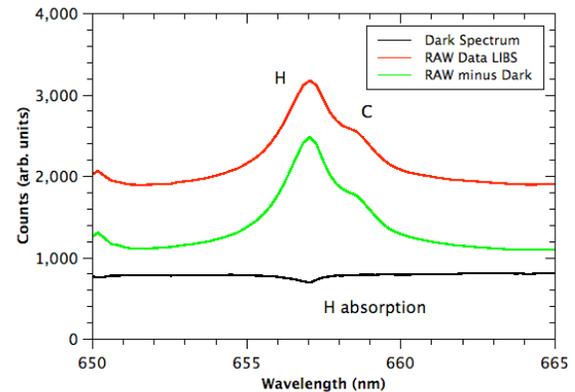


Figure 1: LIBS raw data (red) together with dark spectrum (black) in the wavelength range including the H line. The remaining offset in the difference spectrum (green) is due to continuous emission of the plasma.

Analysis and Discussion: Dark spectra obtained on different sols and of various targets were compared with regard to the solar hydrogen absorption line. Although the dark spectra vary a lot due to the target diversity, the ratio of the dark spectra intensity to the H absorption line depths is characteristic for the solar spectrum and was found to be very stable in the ChemCam dark spectra measured before LIBS (i.e. no crater) with a value of approximately 2.79 (slope of linear fit, see Fig. 2).

A special sequence for the investigation of the dark spectra with laser shot number was run on Sol 271. Dark spectra were taken on a fine grained soil informally named *Sutton Inlier*, which was disturbed and freshly exposed when the rover was driving over a rock. 16 dark spectra were measured, taken before starting, after each of 5 single shots, 5 times at intervals of 5 shots, 3 times at intervals of 10 shots, and then twice after intervals of 20 shots. Thus, in total 100 laser shots were fired on the same position, resulting in a small crater of a few mm in depth. Also, an RMI was taken every time, resulting in a sequence of 16 images, which documents the crater evolution [7]. Due to the reddish martian surface, the obtained dark spectra are most intense in the red wavelength region where the H line is located (cf. ChemCam passive spectra discussed in [8]), shown enlarged in Fig. 3. The dark spectra become less intense with increasing shot number and

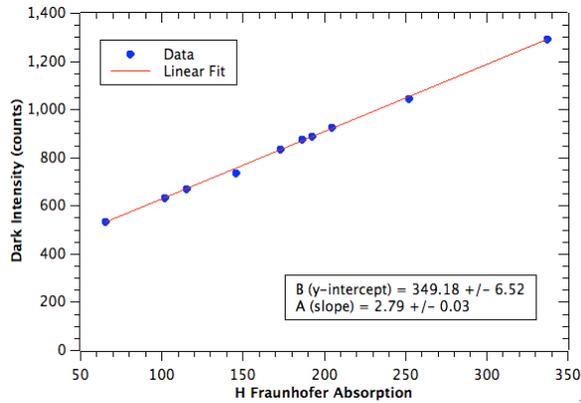


Figure 2: Shown is the ratio of the dark spectrum intensity close to the hydrogen Fraunhofer line at 656.5 nm to the depth of this absorption line as obtained within the first 20 sols on Mars. The targets were quite heterogeneous, including rocks and soils in 2.7 to 6 m from the instrument.

with increasing crater depth. Moreover, the first shots result in greater intensity changes than the later shots. The dark spectra recorded after the first 2-3 shots are more similar to the dark spectrum measured after 30 or 50 shots than to the dark spectrum measured before (DS1), suggesting that the dark spectrum measured after (DS2) matches better the majority of single shot data from standard observations of ChemCam. The dark spectra at the end of this sequence vary a bit in intensity, which can be explained by soil slipping back into the crater and partly refilling it. The ratio of the first dark spectrum taken before to those taken later show the spectral feature of the H absorption line (not shown here) and also other features of the solar spectrum. This can be explained by differences in the reflection and emission spectra of the soil before and with the created crater after LIBS. Moreover, the bigger the difference in intensity between DS1 and DS2, the more intense are the absorption features, which are still visible in their ratio. Thus, targets already in a shadowed region or irradiated with diffuse light (e.g. observed with low solar incidence angle) are less affected than targets exposed to direct sunlight.

From another sequence of this soil it was found that it depends on the crater area, i.e. the relative fraction of the instrument field of view that is changed from a relatively high-albedo surface to a shadowed crater with more diffuse emission. As a consequence, in cases where a large crater is produced in a soil in direct sunlight, the ratio of DS1 to DS2 is not flat across the wavelength region that includes the H absorption line, and whether the dark is measured before or after the laser is fired affects the H emission line intensity in the difference spectra. Recording the DS2 as default therefore can lead to an underestimation of the H emission

line in the first single-shot difference spectra. Similar studies on rocks showed no change in the H absorption line, suggesting that for the investigation of H in rocks it is of minor importance, whether a DS1 or DS2 is measured.

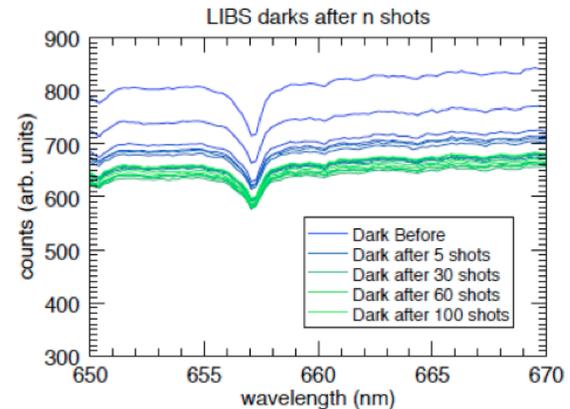


Figure 3: 16 dark spectra of a fine grained martian soil on Sol 271 taken before, after 5 single shots, after 5 times 5 shots, after 3 times 10 shots, and after 2 times 20 shots, each. Shown is the wavelength region including the H absorption line. The legend just names the spectra at these intervals. The dark spectra get darker with shot number and the first shots result in greater change in intensity than the later.

Results: The investigations demonstrate that it is of minor importance for the detection of the H emission in the ChemCam LIBS data whether a DS1 or DS2 is measured, as long as irradiation properties in the field of view of the instrument are not changed significantly by the laser shots. Conversely, the use of a DS1 or DS2 mainly affects soil targets and has the most impact on the detection of the hydrogen line, when a relatively large, shadowed crater is produced in an otherwise bright region. For the standard data acquisition of ChemCam, which involves measuring a DS2 at each position, the hydrogen signal of the first 3-5 single-shot spectra can be underestimated. This is more relevant for targets close to the rover and soil investigations with a high number of laser shots.

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References: [1] Maurice et al., *Space Science Reviews*, Vol 170, Issue 1-4, pp. 95-166, 2012. [2] Wiens et al., *Space Science Reviews*, Vol 170, Issue 1-4, pp. 167-227, 2012. [3] Schröder et al., *EPSC*, #120, 2013. [4] Cousin et al., *Icarus*, submitted, 2013. [5] Meslin et al., *Science* 341, 2013. [6] Lasue et al., *this meeting*, 2014. [7] Le Mouélic et al., *Icarus*, submitted, 2013. [8] Johnson et al., *Icarus*, submitted, 2013.