OPERATIONAL STRATEGIES FOR THE CHEMCAM LIBS EXPERIMENT ON MSL H.E. Newsom[1], D. Blaney[2], R.C. Wiens[3], S. Clegg[3], N. Lanza[3], D. Vaniman[3] S. Maurice[4], O. Gasnault[4], P. King[5], N. Bridges[6], M.D. Dyar[7], N. Melikechi[8], J.G. Blank[9], A. Cousin[4], A. Ollila[1,4], A. Baxter[1], A. Vasavada[2], N. Mangold[10], S. Le Mouelic[10] and the ChemCam Team, [1]Inst. of Meteoritics, Univ. of New Mexico, Albuquerque, NM 87131, (newsom@unm.edu); [2]Jet Propulsion Lab., Pasadena, CA; [3]Los Alamos National Lab., Los Alamos, NM; [4]Inst. Rec. Astrophys. Planét., Toulouse, France; [5]Res. School Earth Sci., Australian Nat. Univ.; [6]Dept. Astronomy, Mt. Holyoke College, South Hadley, MA; [7]Applied Physics Lab., Laurel, MD; [8]Optical Science Center for Applied Res., Delaware State U., Dover DE; [9]BAER Institute, Moffett Field CA; [10]Univ. de Nantes, France.

Introduction: ChemCam is a pair of instruments on the Mars Science Laboratory (MSL) rover that will land in August 2012 (**Fig. 1**). ChemCam includes a Laser-Induced Breakdown Spectrometer (LIBS) and a Remote Micro-Imager (RMI) with 90 µrad resolution (0.9 mm features at a distance of 10 m, or 180 µm features just in front of the rover) [1,2]. LIBS yields the elemental composition of a sample via spectral analysis of atomic and ionic lines emitted by plasma generated by laser pulses size (~300 µm diameter) that ablate a few hundred nanograms of the target. The plasma emits characteristic light through various emission and recombination processes [3,4]. ChemCam can fire multiple laser pulses at the same point to get better statistics on a single location, or to get a depth profile. Rasters or line scans can also be obtained by analyzing multiple points. The pointing accuracy of the Mast containing the laser and telescope is better than ±5 mrad absolute and up to ±0.2 mrad relative (i.e., between points of a line scan or raster).

Figure 1. Artist's conception of the ChemCam instrument in operation, courtesy NASA, PIA14760.

The large operational flexibility of ChemCam offers a number of analytical strategies for different geochemical and geological situations, ranging from routine analysis of soil and rock targets to statistical sampling of fine-grain layered sedimentary rocks and coarse-grain igneous and conglomerate sedimentary rocks. For these heterogeneous targets, the variability of ChemCam data might signal the need to use the Alpha Proton X-ray Spectrometer (APXS) for bulk geochemical analysis of targets (<1.7 cm diameter). For high value targets, ChemCam will enhance the value of APXS bulk characterization by determining in all three dimensions the heterogeneity of the target. Additional strategies are planned to ensure analysis of small veins from hydrothermally altered basement materials or spatially variable features, such as alteration rinds. To simplify the daily science planning effort we have broken down the unique capabilities of ChemCam into a series of analysis types described below.

ChemCam operational constraints and capabilities: In general, an individual "target" selected for analysis by MSL instruments will consist of geologic materials encompassed within a single RMI image (e.g., **Fig. 2**) that is suitable for analysis by ChemCam (and the APXS and MAHLI imager on the arm if close enough). For a given target, the ChemCam laser can target multiple points through small movements of the mast bearing the ChemCam telescope.

Routine use of the ChemCam instrument involves several steps. Optical focusing of the telescope on a target is always the first step, with subsequent RMI imaging and LIBS analyses. Target analysis can include acquisition of integrated spectra from multiple laser shots, and follow-up imaging of the resulting laser pit(s). The mast can be slewed between points, allowing for the acquisition of a line or grid of analysis points with or without re-focusing, and depth profiling can be performed [5]. The constraints on using these ChemCam capabilities come mainly from the time needed for cooling of the focal plane arrays and heating of the lasers prior to use (~ 15 min), focusing at the target (maximum of 2 min per focus), and the amount of data acquired from the RMI and spectra. Duration of individual RMI-LIBS-RMI observations including data processing lasts ~6.5 min with the LIBS analyses lasting ~ 1 min. The combination of the constraints and capabilities leads to the following operational strategies ranging from single spot observations on targets to rasters and linescans of points on targets.

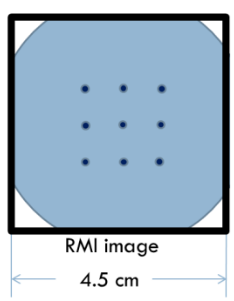

Figure 2 Schematic geometry for a Recon Grid analysis with nine points 1 cm (5 mrad) apart at 2 m range. Spacing to as little as 400 µm between points is possible. Pre- and post-LIBS RMI images are co-registered with the central analysis point.

Raster Analysis (Recon Grid): Analysis of interesting targets near the rover will be accomplished on a daily basis, with expectation of as many as 5-20 targets being acquired each sol. The Recon Grid analysis consists of an initial full RMI image after focusing, a grid or raster of 4 or 9 LIBS points within the RMI image, and a post-LIBS RMI image to show the locations of the LIBS pits. An example application is targeting a small 1 cm diameter object just in front of the rover, for which a grid of at least 4 points is needed to ensure at least one analysis of the object, given the ±5 mrad (±1 cm @ 2 m) pointing uncertainty.

Line scan analysis (Recon Line): A common type of analysis will be a line of points within a single RMI image, also using a single focusing procedure (e.g. **Fig. 3**). This analysis can be used to investigate fine-scale sedimentary layering, or to ensure hitting a small vein given the uncertainty in pointing of the mast. Another use would be determining small scale chemical variation across a trench or a fractured rock.

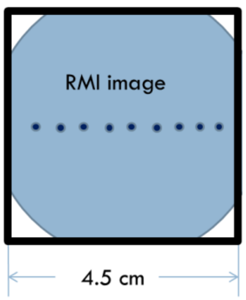

Figure 3 Schematic geometry for a Recon Line analysis with nine points, spaced 5 mm (2.5 mrad) apart at a 2 m range. RMI images are co-registered with the central analysis point.

Depth profile Analysis (Depth): A unique feature of the LIBS technique using ChemCam is the ability to sequentially record groups of integrated spectra as the laser slowly penetrates into a target [1,2,5]. The utility of this procedure for analysis of thin coatings (including dust) will partially replace the capabilities of an abrasion tool that was descoped from the MSL mission. During the depth analysis a preliminary procedure using approximately 1,000 laser shots will be accomplished, with ~15 integrated spectra returned for analysis. The actual depth of penetration will be highly dependent on the physical properties of the target. For example, based on preliminary results, a depth of 1 mm might be reasonable for basalt, but substantially deeper for softer materials that couple well with the laser.

Synergy with APXS Observations (APXS Grid): The Alpha-Particle X-ray Spectrometer (APXS) will provide important chemical information complementary to the ChemCam data which will include high value targets designated for drilling. ChemCam in combination with APXS will provide a broad array of compositional information (particularly for trace elements) and also offer data from multiple points size (~300 µm diameter) within the APXS field of view (< 1.7 cm diameter), thereby providing an indication of the homogeneity of the target. Considering the uncertainty in pointing the mast at a target analyzed by the APXS, a grid analysis with 20 points should routinely result in at least 8 points falling in the APXS field of view area.

Other Analysis: Other types of observations include single point target analysis, analysis of the ChemCam calibration targets, passive spectroscopy, and RMI-only imaging. RMI-only imaging can be used to reconstruct a 3D model of the target using a z-focusing technique.

Statistical sampling strategies for geologic materials: In addition to determining the diversity of chemical compositions in targets, ChemCam data can be used to chemically classify geologic materials by statistical comparison of spectra with a sample set [6-9].

The limitations of ChemCam data for bulk compositional analysis of heterogeneous materials such as coarse grain rocks and conglomerates as a function of the number of LIBS points has been investigated using newly-developed statistical software tools [10, 11]. Such variations may however be used to provide information on the mineralogical composition of targets.

Analysis of sedimentary rocks provides another statistical sampling problem. Sedimentary layering can be present at all scales and a multi-step sampling procedure is needed to determine the compositional variations at a given level of significance. A potential sampling procedure based on the ChemCam range of ~7 m can provide a chemostratigraphic log of a ~10 m section. Visible layers can be directly targeted, but for many thin layers, or in the absence of visible layering (or even using automatic targeting after a drive), a line of evenly spaced targets can be used for statistical sampling. The use of the Recon Line observation normal to the layering can provide sub-sampling of any fine-grain layering at some or all of the target locations. If desired, additional analyses can be acquired to improve the knowledge of the chemical variations, including thin beds of interest.

Conclusions: Analysis modes for ChemCam have been defined to simplify the task of the science theme groups for planning sol to sol activities. Such tools will enhance the ability to sample and characterize the chemical composition of geologic materials in a rigorous statistical fashion. Synergy with other instruments such as the APXS, MAHLI, ChemMin, and SAM can include the ability to assess the fine-scale homogeneity of high value targets picked for drilling.

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References: [1] Wiens R.C. et al. (2012) Subm. to *Spa. Sci. Rev*. [2] Maurice S. et al (2012) Subm. to *Spa. Sci. Rev.* [3] Cremers, D.A. Chinni, R.C. (2009) *Appl. Spectrosc. Rev*. 44, 457 - 506. [4] Winefordner J.D. et al (2004) *J. Anal. At. Spectrom.* 19, 1061-1083. [5] Cousin A., et al. (2011) *Lunar Planet. Sci. LXII*, 1963. [6] Forni, O., et al. (2009). *Lunar Planet. Sci. LXII*, 1523. [7] Lasue, J. et al. (2011) *Analytical and Bioanalytical Chem.* 400, 3247–3260. [8] Clegg, S.M. et al. (2009) *Spectrochimica Acta Part B : Atomic Spectroscopy*, 64(1),:79 – 88. [9] Anderson R.B. et al. (2011) *Icarus* 215, 608-627. [10] McCanta, M.C. et al., this meeting. [11] Dobosh, P.A. et al., this meeting.