CHEMCAM FLIGHT MODEL CALIBRATION. S.M. Clegg[1], J. Lasue[1,2], O. Forni[2], S. Bender[1], R.C. Wiens[1], S. Maurice[2], B. Barraclough[1], D. Blaney[3], A. Cousin[2], L. DeFlores[3], D. Delapp[1], M.D. Dyar[4], C. Fabre[5], O. Gasnault[2], N. Lanza[1,6], R.V. Morris[7], T. Nelson[1], H. Newsom[6], A. Ollila[6], R. Perez[8], V. Sautter[9], D.T. Vaniman[1], [1] Los Alamos National Laboratory, Los Alamos, NM 87545, USA, sclegg@lanl.gov, [2]Institute pour Recherche en Astrophysique et Planetologie, Toulouse, France, [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA, [4]Mount Holyoke College, South Hadley, MA, USA, [5]Nancy Université, Vandoeuvre les Nancy, France, [6]University of New Mexico, Albuquerque, NM, USA, [7]Kennedy Space Center, Houston, TX, USA, [8]Centre National d'Etude Spatialle, Toulouse, France, [9]Musee Nationale d'Histoire Naturelle, Paris, France.

Introduction: ChemCam is an integrated Remote Laser-Induced Breakdown Spectrometer (LIBS) and a Remote Micro-Imager (RMI) on the Mars Science Laboratory Rover, *Curiosity*[1,2]. The LIBS instrument was designed to determine the elemental composition of samples 1.5 to 7.0 m from the rover mast while the RMI will record context images of the samples probed. Extracting quantitative elemental compositions from LIBS spectra requires instrument calibration and multivariate analysis (MVA) models. In this paper, the LIBS calibration experiments completed prior to delivery and integration into MSL are described, including elemental accuracy, precision, and minimum detection limits as a function of distance.

Experimental: ChemCam employs a focused 1067 nm Nd:KGW laser to ablate material from samples, generating an expanding plasma containing electronically excited atomic species. These excited species relax to lower electronic states and emit light at wavelengths indicative of the species present in the sample. Some of this emission is collected with a telescope and recorded with one or more dispersive spectrometers. The ChemCam laser will deposit 8 – 14 mJ/pulse on the target and focus to a distance-dependent 200 – 500 μm FWHM laser spot size.

The ChemCam Flight Model (FM) was calibrated from a thermal- and vacuum- (TVAC) regulated environment at 0°C and 7 Torr CO_2 to simulate Mars surface conditions. Samples were placed in a separate vacuum chamber maintained at 25°C and 7 Torr CO_2. The vacuum chamber was positioned 1.56, 3.0, 5.0, and 7.0 m from the outer optical window of the ChemCam telescope. Each of the calibration samples was probed with 50 laser shots in four separate locations, producing 200 spectra per sample at each distance.

Samples: Table 1 lists the 28 standards used to calibrate the FM unit from the TVAC chamber prior to delivery and integration into MSL. Spectra of all samples were recorded at the 1.56 m and 3 m standoff distances except macusanite and shergottite were not measured at 3 m. A smaller set of 19 standards was probed from a 5 and 7m standoff distance. Pieces of the eight fabricated or naturally-occurring calibration targets and the titanium spectral calibration target included in the onboard instrument suite are shown in bold in Table 1. Many of these samples have been probed with LIBS under simulated ChemCam conditions and reported as references in Table 1. More details regarding the geologic characterization and LIBS analysis can be found in those references.

Table 1. Calibration Samples

Sample	Description	Distances (m)	Ref.
AGV-2	andesite	1.56, 3, 5, 7	3, 4
BE-N	basalt	1.56, 3, 5, 7	4
BHVO-2	basalt	1.56, 3, 5, 7	3, 4
BIR-1	basalt	1.56, 3, 5, 7	3, 4
BK-2	basalt	1.56, 3, 5, 7	4
BT-2	basalt	1.56, 3, 5, 7	
GBW07105	basalt	1.56, 3, 5, 7	3, 4
Green River	shale	1.56, 3, 5, 7	
JA-2	andesite	1.56, 3, 5, 7	
JA-3	andesite	1.56, 3, 5, 7	
JB-2	basalt	1.56, 3, 5, 7	
JB-3	basalt	1.56, 3, 5, 7	
JDo-1	dolomite	1.56, 3, 5, 7	
KGa-Med-S	ceramic	1.56, 3, 5, 7	6
NAu2-Hi-S	ceramic	1.56, 3, 5, 7	6
NAu2-Lo-S	ceramic	1.56, 3, 5, 7	6
NAu2-Med-S	ceramic	1.56, 3, 5, 7	6
STSD-1	stream sediment	1.56, 3, 5, 7	
Ti	metal	1.56, 3, 5, 7	
cystine		1.56, 3	
graphite	slab	1.56, 3	
MHC2319	melanterite	1.56, 3	
NBS688	basalt	1.56, 3	
norite	glass	1.56, 3	5
picrite	glass	1.56, 3	5
ultramafic	rock	1.56, 3	
macusanite	glass	1.56	5
shergottite	glass	1.56	5

Bold = replicas of on-board calibration targets.

Results: Figure 1 shows four LIBS spectra at different distances following the data processing sequence described below. Each spectrum is the average of the 200 spectra recorded on each sample at a given distance. Spectra were also normalized and offset to show the emission lines present. Similar spectra were recorded for each sample and distance listed in Table 1.

Discussion of Data Analysis: A nominal ChemCam investigation from MSL will involve recording 50 laser shots per sample location as well as 50 dark spectra where the laser is not fired. All spectra resulting from the 50 laser shots or the sum or average of these

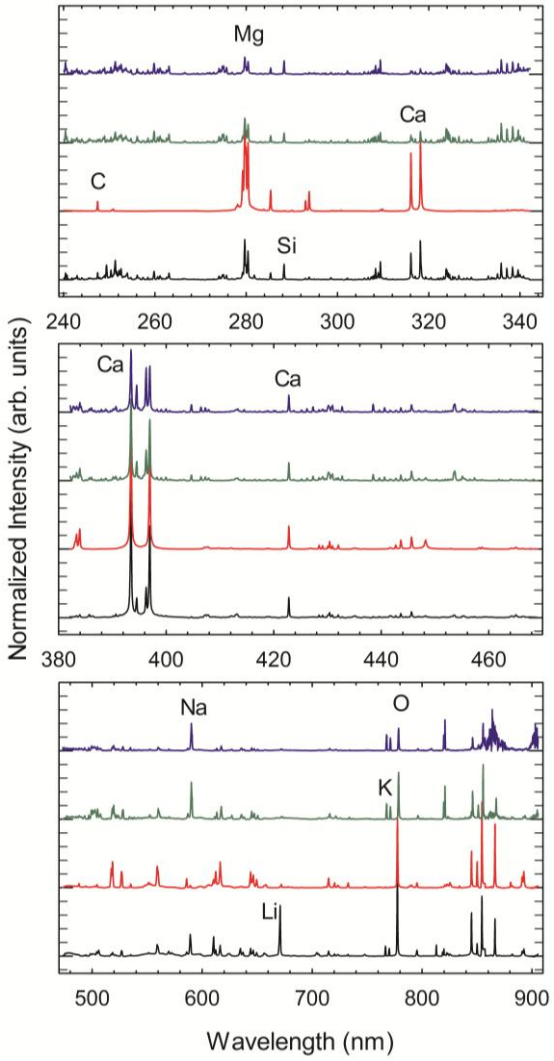

Figure 1: ChemCam FM LIBS spectra of the KGa calibration target at 1.56m (black), JDo-1 at 3m (red), BHVO-2 at 5m (green) and AGV-2 at 7m (blue). Spectra were normalized to total integrated intensity and offset to simplify comparisons.

50 laser shots could be returned. TVAC calibration experiments will be used to calibrate the FM observations and this database will eventually be supplemented with verified MSL observations.

Processing ChemCam data begins with subtracting a dark spectrum from the LIBS spectra to remove any fixed pattern noise or ambient baseline. Spectra are then denoised relative to the observed SNR and spectrally recalibrated to account for spectrometer temperature changes. MVA routines used to quantitatively analyze the LIBS spectra require a constant set of wavelengths so the calibrated spectra are resampled into a common set of wavelength pixels. The Bremsstrahlung continuum is removed, resulting in a flat baseline as required for distance corrections. The instrument response function is applied to the spectra, resulting in spectral intensities that are calibrated photons/DN in the FOV. Spectra in Figure 1 were processed using these steps and were then normalized to more easily compare the spectral features. Finally, resulting spectra are corrected for variable distance geometery, producing an object space per shot "radiance" by dividing the photon count by the plasma area (cm^2), collection solid angle (sr), and spectral bin width (nm).

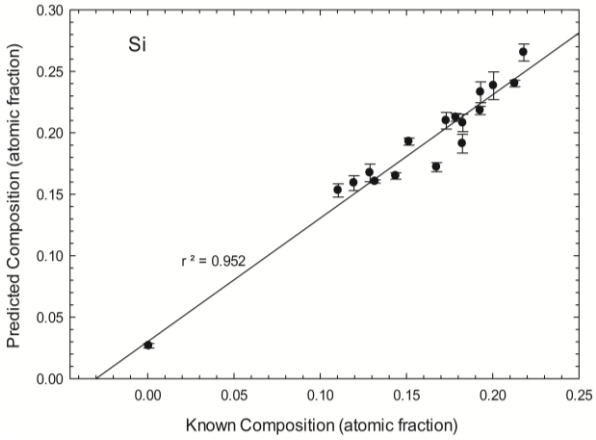

Figure 2: Si validation plot where the known composition is plotted against the LIBS PLS observed composition.

The resulting distance-independent library and Mars spectra are used in several MVA routines developed for ChemCam data processing. Independent Components Analysis (ICA) will be used to classify samples and determine sample rock type. Sammon's Map is a variant of Principal Components Analysis that will spectrally cluster new ChemCam observations with TVAC and Mars library spectra [7]. Finally, Partial Least Squares (PLS) analysis will be used to determine quantitative elemental compositions [3]. Figure 2 contains a Si validation plot for the 7 m data where the known composition is plot against the PLS determined composition. Following the preprocessing and distance corrections discussed above, the 3 m LIBS spectra were used to generate a PLS2 model. The distance independent 7 m elemental compositions were then calculated from the 3 m model.

References: [1] Wiens etal. Space Sci Rev. submitted 2012, [2] Maurice etal. Space Sci Rev. submitted 2012, [3] Clegg et al. Spectro Acta B, 64, 79, 2009, [4] Tucker et al. Chem Geo, 277, 137, 2010, [5] Fabre et al. Spectro Acta B, 66, 280, 2011, [6] Vaniman etal. Space Sci Rev. submitted 2012. [7] Lasue et al. Anal Bioanal Chem, 400, 3247-3260, 2011.

Acknowledgements: The authors gratefully acknowledge the NASA Mars Science Laboratory Program and CNES for funding this work.