**INITIAL MULTISPECTRAL IMAGING RESULTS FROM THE MARS SCIENCE LABORATORY MASTCAM INVESTIGATION AT THE GALE CRATER FIELD SITE.** J.F. Bell III[1], A. Godber[1], M.S. Rice[2], A.A. Fraeman[3], B.L. Ehlmann[2], W. Goetz[4], C.J. Hardgrove[5], D.E. Harker[5], J.R. Johnson[6], K.M. Kinch[7], M.T. Lemmon[8], S McNair[5], S. Le Mouélic[9], M.B. Madsen[7], M.C. Malin[5] and the MSL Science Team; [1]School of Earth & Space Exp., Arizona State Univ., Tempe AZ (Jim.Bell@asu.edu); [2]Caltech, Pasadena CA; [3]Washington Univ., St. Louis MO; [4]Max-Planck-Inst. für Sonnensystemforschung, Katlenburg-Lindau, Germany; [5]Malin Space Science Systems, Inc., San Diego CA; [6]JHU/APL, Laurel MD; [7]Niels Bohr Inst., Copenhagen Univ., CPH, Denmark; [8]Texas A&M Univ., College Station TX; [9]Laboratoire de Planétologie et Géodynamique, CNRS, Nantes, France.

**Summary:** The Mars Science Laboratory (MSL) rover "Curiosity" Mastcam imaging investigation [1,2] has been acquiring RGB and narrowband 445 to 1013 nm multispectral "science filter" images of the missions' Gale crater field site since landing in August 2012. As of MSL Sol 100 (15 Nov. 2012), ~40 Mastcam multispectral sequences have been run on ground and sky targets. These observations have been calibrated to radiance using pre-flight calibration coefficients, and to radiance factor (I/F) using associated observations of the Mastcam calibration target. Mastcam 13-color (including Bayer RGB) I/F "spectra" of materials at the site so far are consistent with typical nanophase ferric oxide-bearing airfall dust coating most rock and soil surfaces. Some low albedo rock and sand surfaces show spectra consistent with the presence of weak pyroxene and/or olivine "1 micron" absorptions, as in many basaltic materials. No clear evidence was found in these early observations for the presence of other diagnostic absorption features, such as those from hydrated minerals, many of which should be detectable in Mastcam's longest-wavelength filters [3,4].

**Mastcam Multispectral Imaging.** The Mastcam imaging system [1] is a pair of CCD cameras mounted on the rover's mast about 2 m above the surface and capable of obtaining high resolution visible to short-wave near-IR (VIS-NIR) images. The left Mastcam (M-34) has a 34-mm focal length, a 0.22 mrad/pixel image scale, and a 18.4°x15° field of view (FOV) over the 1600x1200 pixels of its Kodak KAI-2020 interline transfer CCD. The right Mastcam (M-100) uses a similar CCD and has a 100-mm focal length, a 0.074 mrad/pixel image scale, and a FOV of 6.3°x5.1°.

Each Mastcam obtains images through a Bayer pattern of RGB filters and telecentric microlenses bonded onto the CCD [2] and also through an 8-position filter wheel that provides the ability to obtain additional narrowband images through visible, near-IR, and solar neutral denstity filters (Table 1).

**Mastcam Radiometric Calibration.** The early mission Mastcam data calibration pipeline uses pre-flight calibration measurements to subtract the small "electronic shutter smear" component and small bias and dark current signal from unprocessed Mastcam images [*e.g.,* 5] and to correct for pixel-to-pixel nonuniformities on the array ("flatfield correction"). Images corrected for these effects are normalized by exposure time and converted to radiance (*e.g.,* W/m$^2$/nm/sr) using pre-flight observations of a NIST-calibrated integrating sphere. Observations of a uniform region of the sky on sols 36-38 are being used to refine further the flatfield calibration of these measurements.

**Table 1. MSL/Mastcam Filter Wavelengths & Bandpasses**

| Left (M-34) | | Right (M-100) | |
|---|---|---|---|
| Filter | $\lambda_{eff}$ ± HWHM (nm) | Filter | $\lambda_{eff}$ ± HWHM (nm) |
| L0[a] | 590 ± 88 | R0[a] | 575 ± 90 |
| L0R | 640 ± 44 | R0R | 638 ± 44 |
| L0G[b] | 554 ± 38 | R0G[b] | 551 ± 39 |
| L0B | 495 ± 37 | R0B | 493 ± 38 |
| L1 | 527 ± 7 | R1 | 527 ± 7 |
| L2 | 445 ± 10 | R2 | 447 ± 10 |
| L3 | 751 ± 10 | R3 | 805 ± 10 |
| L4 | 676 ± 10 | R4 | 908 ± 11 |
| L5 | 867 ± 10 | R5 | 937 ± 11 |
| L6 | 1012 ± 21 | R6 | 1013 ± 21 |
| L7 | 880 ± 10, ND5[c] | R7 | 440 ± 20, ND5[c] |

Notes: [a]Broadband near-IR cut-off filter for Bayer filter RGB imaging. [b]There are two essentiall identical green filters per 2x2 Bayer unit cell [2]. [c]ND5 = $10^{-5}$ neutral density coating for solar imaging.

Mastcam radiance-calibrated images can be rapidly converted to radiance factor (I/F, where I is the measured radiance and $\pi$F is the incident irradiance of sunlight at the top of the martian atmosphere) or estimated Lambert albedo (I/F divided by the cosine of the average solar incidence angle) using calibrated DN to radiance coefficients generated from close-in-time observations of an onboard radiometric calibration target based on the same design as the Mars Exploration Rover Pancam calibration target (Figure 1) [5,6]. The effects of dust accumulation on the Mastcam calibration target are discussed elsewhere [7].

The absolute accuracy of calibrated Mastcam radiance and I/F measurements is presently being assessed by comparison with sky radiance models and with previous and current orbital and surface observations over the same wavelengths. However, the similarity of derived radiances between Mastcam and ChemCam passive spectroscopy observations of the same targets [8], plus the fact that derived I/F values of "classical"

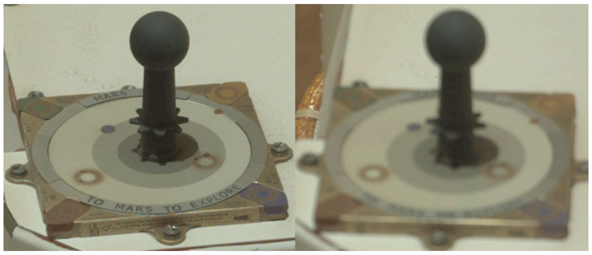

**Figure 1.** Example Mastcam M-34 (left) and M-100 (right) Filter 0 Bayer RGB images of the Mastcam calibration target [5]. The M-100 image spans ~3x more pixels than the M-34 image; the increased image scale adequately offsets the M-100's inability to focus properly at this close range (1.11 m). Red circular features are airfall dust collecting on strong embedded ring magnets [7].

bright dusty surface regions are comparable to those from previous surface missions, imply that the radiometric accuracy of the Mastcam observations (compared to past comparable data) is approx. ±10-20%. JPEG compression (typically to quality 85 or 95) of the raw multispectra data prior to downlink does not appear to significantly degrade the calibration.

**Multispectral Data Sets.** Between MSL mission sols 3 and 100, a total of 89 multiple science filter Mastcam imaging sequences were acquired, covering terrain from Bradbury Landing to the "Rocknest" target region near Glenelg. Surface targets for multispectral imaging were chosen to sample the variety of rocks and soils/dust sampled over the mission so far, with Mastcam multispectral observations often coordinated with ChemCam LIBS compositional and/or passive spectroscopy observations. Seventeen of these observations were designed to measure the photometric properties of the surface over a wide range of phase angles using four science filters in the M-34 camera, and are discussed in detail elsewhere [9]. Eight dedicated Mastcam multispectral sky observations were acquired to characterize the properties of atmospheric aerosols and to create in-flight sky flatfield calibration observations. The remainder include 20 observations of surface rocks and soils, 15 associated observations of the Mastcam calibration target in all the non-solar Mastcam filters, and additional surface or cal target observations in a subset of the science filters (often just the M-100 camera filters) in order to search for evidence of hydration in surface materials [3,4].

**Initial Multispectral Imaging Results.** Calibrated Mastcam I/F spectra (*e.g.,* Figure 2) show overall similarity with previous Mars surface and orbital multispectral imaging observations of relatively dusty surface regions at similar VIS-NIR wavelengths [*e.g.,* 6,10,11]. Specifically, light-toned, reddish airfall dust surfaces show a steep and smooth reflectance increase from 445 nm to 750 nm that has been interpreted as evidence of nanophase ferric ($Fe^{3+}$) oxide material [*e.g.,* 12]. Most darker-toned sand and rock surfaces

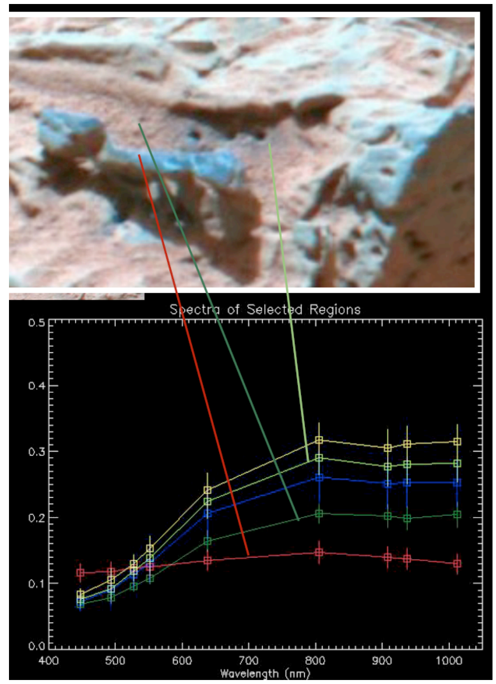


**Figure 2.** Example Mastcam "spectra" of rock and soil units on the sol 72 Rocknest target "Zephyr", sequence mcam00557.

still show dusty, reddish spectral signatures, but some show flatter VIS-NIR spectra (consistent with less ferric-bearing material) and slightly negative near-IR spectral slopes, consistent with the presence of pyroxene and/or olivine in typical basaltic materials. Weak inflections near 530 nm and weak absorption from 800-1000 nm in some light-toned rock surfaces could be evidence for crystalline ferric oxides like hematite or goethite, though these features are as yet within the uncertainty of the calibration at this early stage of the investigation. As of sol 100, measurements of materials from Bradbury landing to Rocknest at the wavelengths most sensitive to certain hydrated minerals (including hydrated sulfates [3,4]) have not revealed evidence for such phases, although it is important to recognize that not all hydrated minerals are detectable at Mastcam wavelengths.

**References:** [1] Malin, M.C. *et al.* (2010) *LPSC 41,* Abs. #1533. [2] Bell III, J.F. *et al.* (2012) *LPSC 43,* Abs. # 2541. [3] Rice, M.S. *et al.* (2010) *Icarus*, *205,* 375-395. [4] Rice, M.S. & J.F. Bell III (2011) *AGU Fall Meeting*, Abs. P22A-02. [5] Bell III, J.F. *et al*. (2003) *JGR, 108*, (E12) 8063. [6] Bell III, J.F. *et al*. (2006) *JGR, 111*, E12S05. [7] Kinch, K.M. *et al.* (2013) *LPSC 44*, Abs. #1061. [8] Johnson, J.R. *et al.* (2013a) *LPSC 44*, Abs. #1372. [9] Johnson, J.R. *et al.* (2013b) *LPSC 44*, Abs. #1374. [10] Bell III, J.F. *et al.* (2008) Chaps. 8 and 13 of *The Martian Surface: Composition, Mineralogy, and Physical Properties* (Cambridge). [11] Farrand, W.H. *et al.* (2008) *Ibid,* Chapter 12. [12] Morris, R.V. *et al.* (1993) *GCA, 57,* 4597.