CALIBRATION OF THE MSL RMI AND MAHLI CAMERAS. K. E. Herkenhoff[1] O. Gasnault[2], K. Edgett[3], M. Lemmon[4], S. LeMouélic[5], Y. Langevin[6], E. M. Lee[1], R. Sucharski[1], M. Rosiek[1], S. Bender[7], J. R. Johnson[8], N. Bridges[8], S. McNair[3], J. Maki[9], R. L. Kirk[1], S. Maurice[2] and R. Wiens[7], [1]USGS Astrogeology Science Center (2255 N. Gemini Dr., Flagstaff, AZ 86001; kherkenhoff@usg.gov), [2]IRAP, Toulouse, France, [3]MSSS, San Diego, CA, [4]Texas A&M University. [5]CNRS, Université de Nantes, France, [6]IAS, Orsay, France, [7]LANL, Los Alamos, NM, [8]APL, Laurel, MD, [9]Caltech/JPL, Pasadena, CA.

Introduction: The science payload on the Mars Science Laboratory (MSL) rover [1] includes 17 cameras, all of which were calibrated before launch in November 2011. Since landing in August 2012, in-flight camera calibration data have been acquired to verify instrument performance and to update calibration as necessary. Here we focus on inflight calibration of the ChemCam Remote Microscopic Imager (RMI) [2,3] and the Mars Hand-Lens Imager (MAHLI) [4] through Sol 595. Both camera designs include CCD detectors and focusable optics. ChemCam is mounted on MSL's remote sensing mast (RSM) and MAHLI is mounted on the instrument arm turret [1].

ChemCam RMI Calibration: The panchromatic RMI uses the same 110-mm diameter f/4 telescope as the ChemCam Laser-Induced Breakdown Spectroscopy (LIBS) portion of the instrument to image the surface and atmosphere of Mars at distances of 1.2 m to infinity [5]. Focus position can be adjusted automatically or set manually. The value of inflight RMI calibration observations was recognized well before launch: The ChemCam calibration target includes a titanium plate that was painted black along two edges to allow in-flight measurement of the modulation transfer function (MTF) of the camera [3]. RMI observations of the sky were planned early in the mission to allow measurements of flat-field response and to monitor possible changes in response due to dust contamination of the ChemCam optical window.

Flat field response. The response of the RMI to a flat field measures both the pixel-to-pixel variations in CCD sensitivity and variations in optical throughput across the field of view. The martian sky approximates a flat field (uniform brightness/radiance across the camera's field of view), but is not expected to be flat enough to provide accurate calibration data. Therefore, two methods for removing the effects of variations in Mars sky brightness have been used to measure RMI flat field response. The first, used only on Sol 32, is to point the RMI straight up in the RSM frame, take an image of the sky, rotate the camera 180 degrees in azimuth, and take another image of the same patch of sky. Averaging these two images effectively corrects for the gradient in sky brightness, but curvature (second spatial derivative) of sky brightness variations is not precisely removed. However, the curvature in sky brightness is expected to be insignificant across the small field of view (20 mrad) of the RMI.

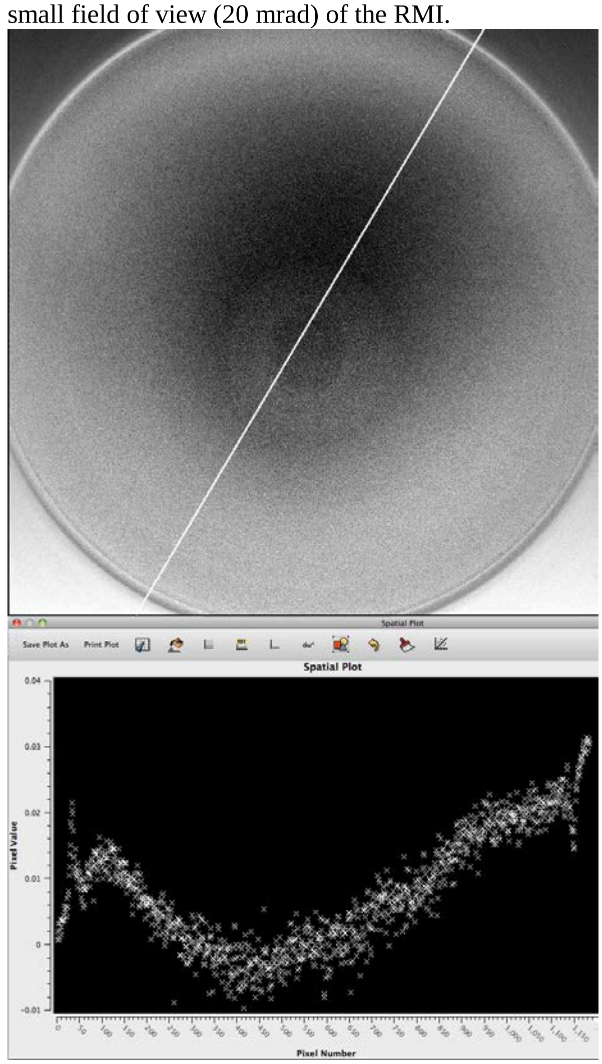

Figure 1. Difference between dark-corrected RMI sky flats acquired at 2 m focus distance using two different methods. (top) Normalized average of Sol 32 sky flats minus normalized, sky gradient-corrected Sol 373 sky flat. Diagonal white line shows location of plot below. Brightness variations in corners (not illuminted) show magnitude of sky gradient correction. (bottom) Plot showing differences of up to 2%.

The second approach involves acquiring a 2x2 matrix of sky images, plus a single image in the center of the 34-mrad square matrix. The averages of the central 100x100 pixels of the images are then used to model the gradient in sky brightness and remove it from the central image. The first approach has been used only at the sun-safe focus distance of 2 m, with images acquired near sunset so that the ChemCam optics and window were not directly illuminated by the sun. Such zenith sky flats can be acquired at other focus positions only in rover orientations that prevent the sun from passing within 17 degrees of the ChemCam boresight at any time of day, to avoid instrument damage. Therefore, the second approach has been used to acquire sets of RMI sky flats at 2, 3, 4, 5, 6, 10, 20, 40, and infinity focus positions.

As shown in Fig. 1, differences between the two methods of removing the variations in sky brightness are less than 2%, and may be partly caused by dust contamination. In any case, the precision of flat field correction using inflight data is no worse than 2%.

MAHLI Calibration: The focus range of MAHLI allows in-focus images to be acquired at working distances of 2.1 cm to infinity [4]. Unlike RMI, MAHLI's focal plane assembly includes red, green and blue filtered microlenses on the 7.4-micrometer square CCD pixels, in the common Bayer pattern [4]. RGB color images are typically generated by interpolating pixels across the Bayer pattern, but uninterpolated (greyscale) MAHLI images can also be returned to Earth. Like ChemCam, the value of MAHLI inflight calibration was recognized before launch, and the MSL payload includes a MAHLI calibration target with a bar target derived from the USAF 1951 Resolution Test Chart [4]. MAHLI observations of the sky were planned early in the measurement to allow measurement of flat-field response and to monitor possible changes in response due to dust contamination of the MAHLI optics.

Modulation Transfer Function. Before launch, MAHLI images of a USAF test chart similar to the one included in the onboard MAHLI calibration target were acquired, allowing MTF calibration. An example of these uninterpolated images is shown in Fig. M1. The target was typically illuminated by the MAHLI LEDs [4], often resulting in reflections that complicated the MTF analysis of these images. Black squares and bars on the test chart provide sharp boundaries (all spatial frequencies) for MTF measurements; subframes containing such edges (Fig. 2) were extracted from these images and used with Jean Lorre's "otf1" software at JPL's Mulitimission Image Processing Lab to generate MTF curves as shown in Fig. 3.

Flat field response. An approach similar to the RMI zenith sky flat method has been used to measure the inflight MAHLI flat field response: Pairs of MAHLI images of the sky were taken, separated by a 180-degree rotation about the MAHLI boresight. MAHLI was pointed opposite the sun, about 40 degrees above the horizon for sky flats, because variations in sky brightness are expected to be minimized in that direction. Sky flats were acquired when sunlight would not directly illuminate MAHLI's optics, to eliminate stray light. Again, averaging the two sky flats effectively removes the gradient in sky brightness, but curvature in the sky brightness is not completely removed, and may be significant across the approximately 35–degree MAHLI field of view.

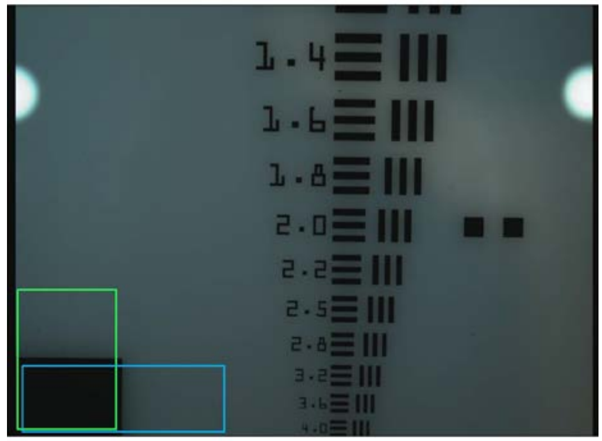

Figure 2. Preflight MAHLI calibration image of USAF test chart. Note reflection of LEDs at upper right and upper left, and more subtle reflection above and right of center. Rectangles at lower left outline subareas extracted for MTF analysis. Numbers denote spatial frequency of bar patterns in cycles/mm.

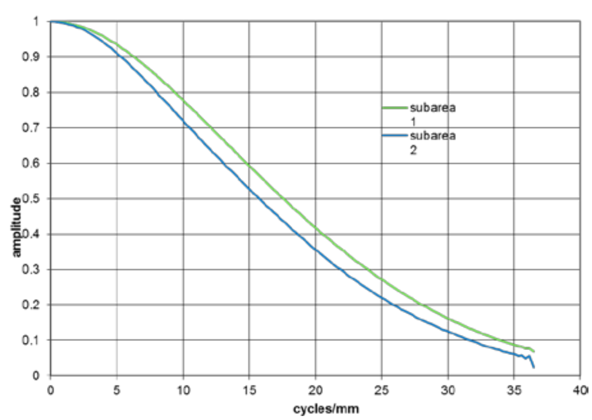

Figure 3. Example modulation transfer function plot for interpolated green pixels. Curve colors correspond to subareas in Fig. 2.

Future Work: Results of inflight calibration analysis will be used to reprocess raw data as appropriate, to improve radiometric accuracy and to better determine image resolution.

References: [1] Grotzinger, J. P. *et al.* (2012) *Space Sci. Rev. 170*, 5–56. [2] Maurice, S. *et al.* (2012) *Space Sci. Rev. 170*, 95-166. [3] Wiens, R. *et al.* (2012) *Space Sci. Rev. 170*, 167–227. [4] Edgett, K. *et al.* (2012) *Space Sci. Rev. 170*, 259-317. [5] LeMouélic, S. *et al*. (2014) *Icarus* (in press).