IN-FLIGHT CALIBRATION OF THE MSL REMOTE MICROSCOPIC IMAGER.

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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), which was designed as a context imager, not a photometric instrument [2,3]. The camera includes CCD detectors and focusable optics. ChemCam is mounted on MSL's remote sensing mast (RSM) [1].

ChemCam RMI Calibration: The panchromatic RMI uses the same 110-mm diameter 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 [4]. 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 inflight 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.

MTF performance. A series of RMI images at various focus positions of the edge of the titanium plate were acquired on Sol 352 in order to measure the in-flight MTF performance. The best-focused image from this series (as determined by this analysis) is shown in Figure 1 (top), with the subarea extracted for analysis indicated. This and other images from the series were processed using the USGS Integrated Software for Imagers and Spectrometers (ISIS) version 3 [5] to extract data that were analyzed using the JPL Multimission Image Processing Laboratory program "otf1." The results are shown in the bottom part of Figure 1: The MTF at half the Nyquist frequency (17.8 cycles/mm) is 0.04. The Gaussian fit of the best-focused MTF is poor, but was used to conservatively estimate an upper bound of 5 pixels line spread. These results are consistent with independent analyses of the same dataset, which yielded slightly lower MTF values and a line spread of about 4.4 pixels. Dust is visible on the calibration target (Fig. 1), which reduces the contrast across the measured edge, so the MTF results reported here are considered to be lower limits. Additional data processing and analysis are underway to better determine the MTF behavior.

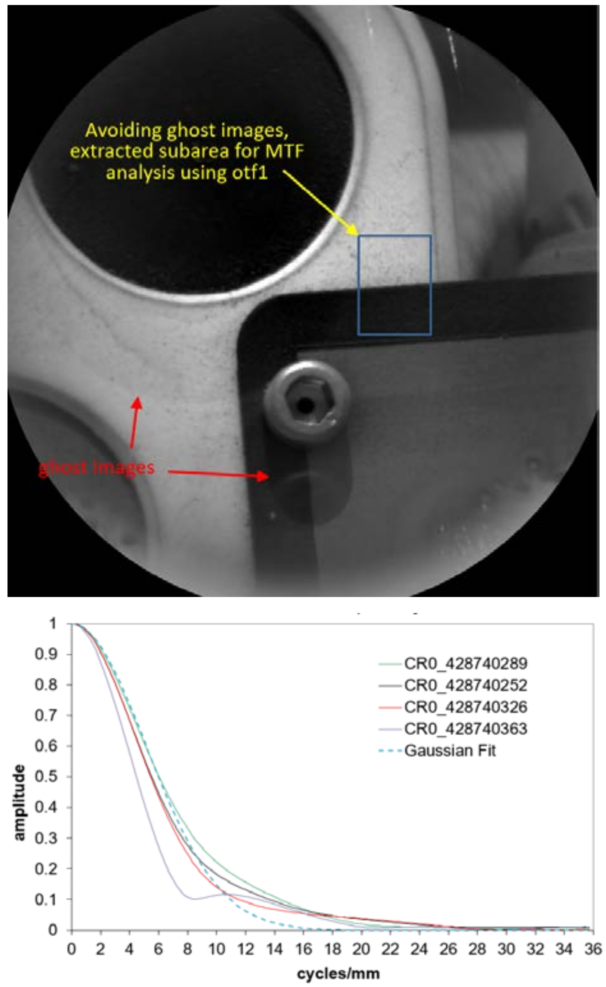

Figure 1. (top) Sol 352 RMI image CR0_428740289 of the ChemCam calibration target, including the Ti plate at lower right. Blue box shows where image data across the edge of the Ti plate were extracted for MTF analysis. (bottom) MTF of images taken at various focus positions and Gaussian fit of MTF of best-focused image.

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 on Sols 32, 612, 617, 618, 620, 627, 820, 1238, and 1497, 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 (after correcting for dark current) 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 small across the small field of view (20 mrad) of the RMI. Early analysis of RMI sky flats showed significant differences relative to pre-flight flat fields, so additional sky flats were acquired at focus settings of 1.2 (minimum), 2, 4, 6, 20 meters, and infinity, which were processed as described above and normalized to the average of the central 100x100 pixels.

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 dark-corrected images are then used to model the gradient in sky brightness and remove it from the central image. Again, the resulting image is normalized to the average of the central 100x100 pixels.

As shown in Figure 2, differences between the two methods of removing the variations in sky brightness are less than 3%, perhaps caused by small differences in focus position (which are known to affect flat field response) or sky brightness curvature. Brightness variations in the corners of the images (not illuminated) in Figure 2 show the magnitude of sky gradient correction. The difference between zenith flat fields acquired on Sols 32 and 612 (not shown) is ±2%, indicating that the precision of flat field correction of RMI data is of this order. RMI sky flats continue to be acquired in order to detect changes in response.

Absolute radiometric accuracy. Pre-flight calibration data and in-flight observations of ChemCam's calibration target and stars are being analyzed to determine the absolute radiometric response of the RMI. In addition, nearly-simultaneous Right Mastcam [6] and RMI images of the Martian sky have been acquired and are planned in order to compare radiometric calibration. Results of these studies will be summarized at the conference and used to reprocess raw data as appropriate to improve radiometric calibration accuracy.

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] Le Mouélic, S. *et al*. (2015) *Icarus 249,* 93-107. [5] Anderson, J. *et al*. (2004) *LPS XXXV,* abstract #2039. [6] Malin, M. C. *et al.* (2017) *Earth & Space Sci*., doi:10.1002/2016EA000252.

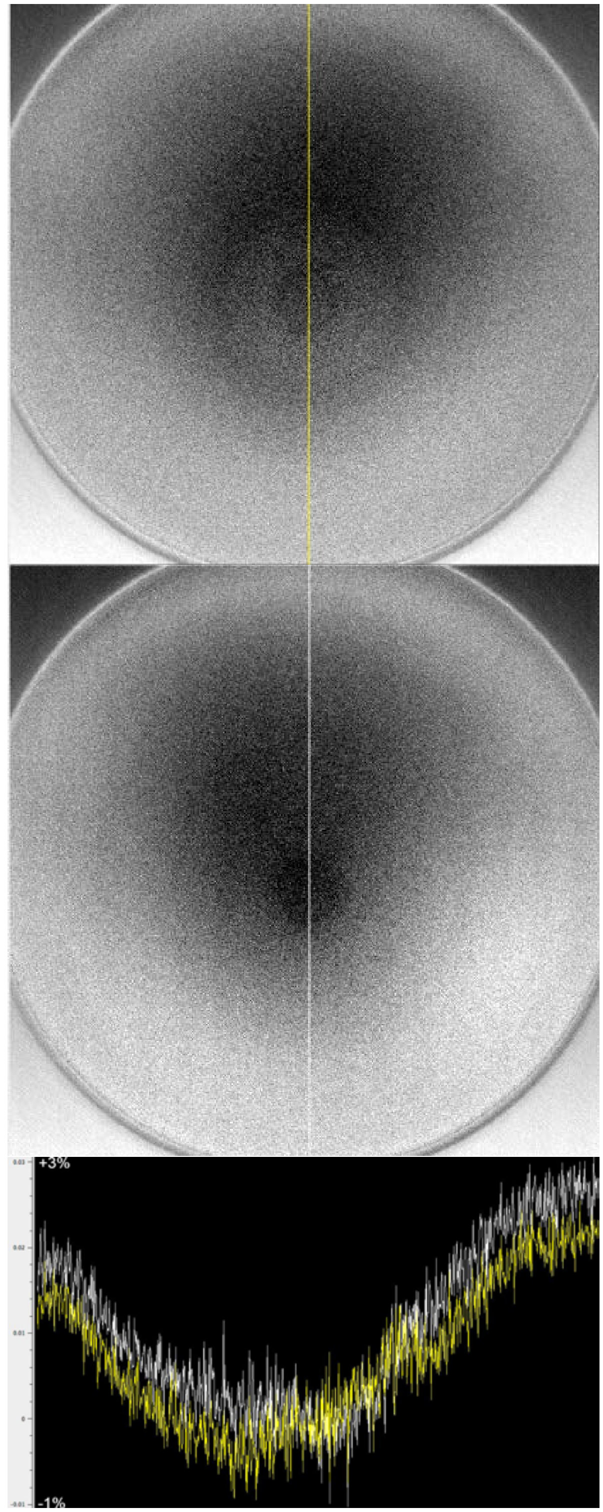

Figure 2. Difference between dark-corrected RMI sky flats acquired at 2 m focus using different methods. (top) Normalized average of Sol 32 sky flats minus normalized, sky gradient-corrected Sol 373 sky flat. Yellow line corresponds to profile plotted below. (middle) Normalized average of Sol 612 sky flats minus normalized, sky gradient-corrected Sol 373 sky flat. White line corresponds to profile plotted below. (bottom) Plot showing overall differences of up to 3% (ordinate range is -1 to +3%), but curves are identical to within 1%, indicating only minor changes in dust contamination of the RMI optics.