Calibration of the MSL RMI and MAHLI Cameras

Abstract #1099

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ChemCam Remote Microscopic Imager (RMI) Calibration

- Panchromatic RMI uses same 110-mm diameter f/4 telescope as Laser-Induced Breakdown Spectroscopy (LIBS) portion of ChemCam instrument [2]
- Focus position can be adjusted automatically or manually at distances of 1.2 m to infinity [Le Mouélic *et al.*, this conf.]
- ChemCam calibration target includes titanium plate with black paint along two edges to allow inflight measurement of the modulation transfer function (MTF) of the camera [3]
- Sky observations after landing allow measurements of flat-field response and monitoring of possible changes due to dust contamination of ChemCam optical window

Flat field calibration: 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 initially 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. The images are taken near sunset to avoid direct illumination of the RMI optics by the Sun. Such zenith sky flats can be acquired at all 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. 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, especially for images focused close to the camera. Zenith sky flats have been acquired at 2, 4, 6, 20, and infinity focus positions.

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. This 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 Figure 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. Comparison of zenith sky flats taken on Sol 32 and 612 shows differences of only 1%, possibly due to contamination. In any case, the precision of flat field correction using inflight data is no worse than 2%, more likely 1%.

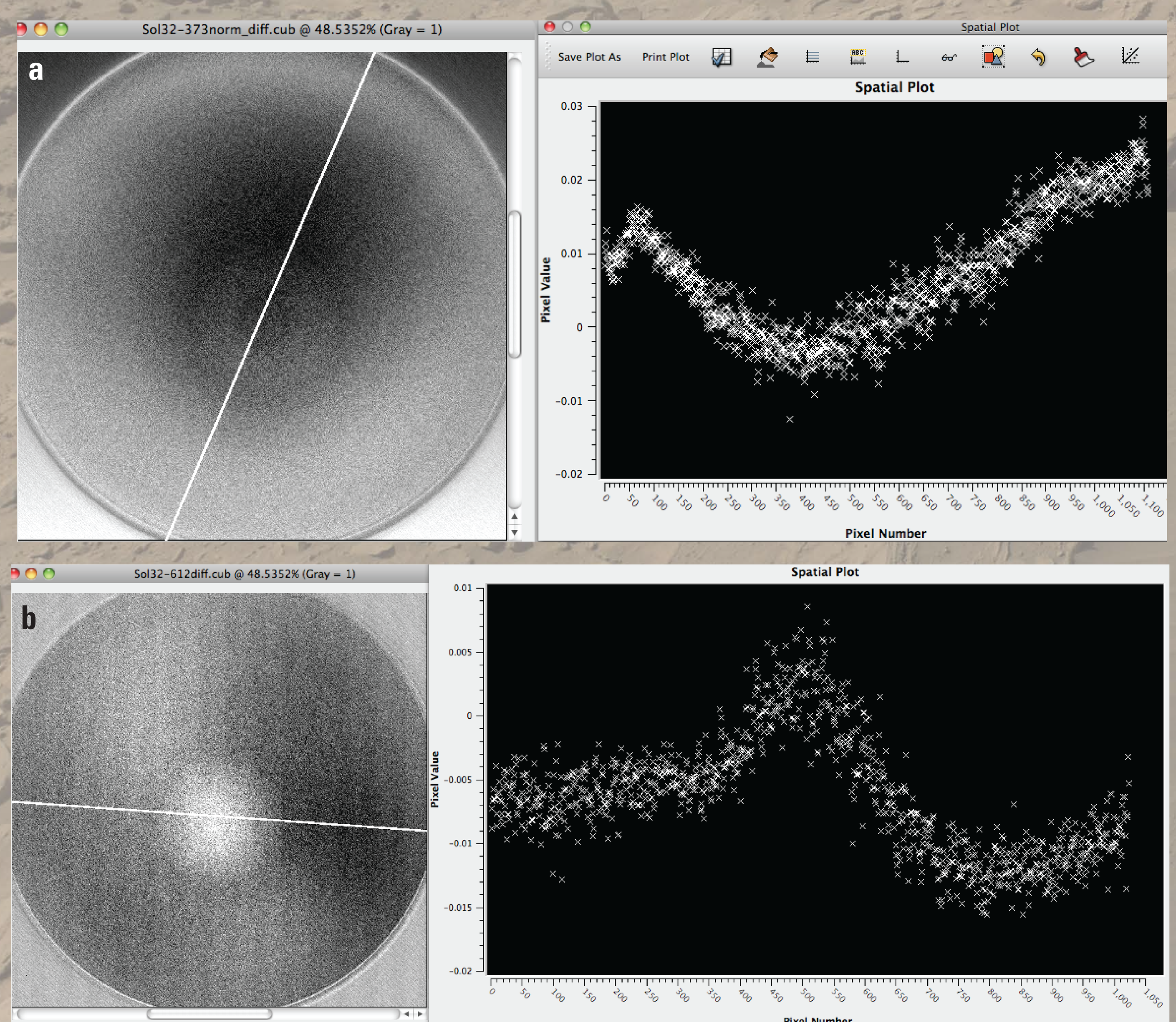


Figure 1 (a) Difference between dark-corrected RMI sky flats acquired at 2 m focus distance using two different methods. Image shows normalized average of Sol 32 zenith sky flats minus normalized, sky gradient-corrected Sol 373 sky flat. Diagonal white line shows location of profile in plot at right. Brightness variations in corners (not illuminted) show magnitude of sky gradient correction. Plot shows differences of up to 2%, perhaps partly due to errors in sky gradient correction or inflight dust contamination of optics.
(b) Difference between dark-corrected zenith sky flats acquired at 2 m focus distance on Sols 32 and 612. Diagonal white line shows location of profile in plot at right. Difference of up to 1% may be due to dust contamination of optics.

Resolution calibration: The resolution of a camera is often specified in terms of the magnitude of the optical transfer function (Fourier transform of the point/edge spread function), or modulation transfer function (MTF). To measure the inflight MTF of the RMI, subframes of images of the black edge of the ChemCam titanium calibration target were analyzed using the otf1 program written by Jean Lorre (JPL). An example of one of the RMI images analyzed is shown in Figure 2, and some of the results plotted in Figure 3. Dust or sand on the calibration target (Fig. 2) likely decreases the apparent MTF derived from these images, so resolution is probably better than shown here. MTF varies with focus position as expected, and more complete analysis of these images should provide useful constraints on the resolution of the RMI as a function of focus position.

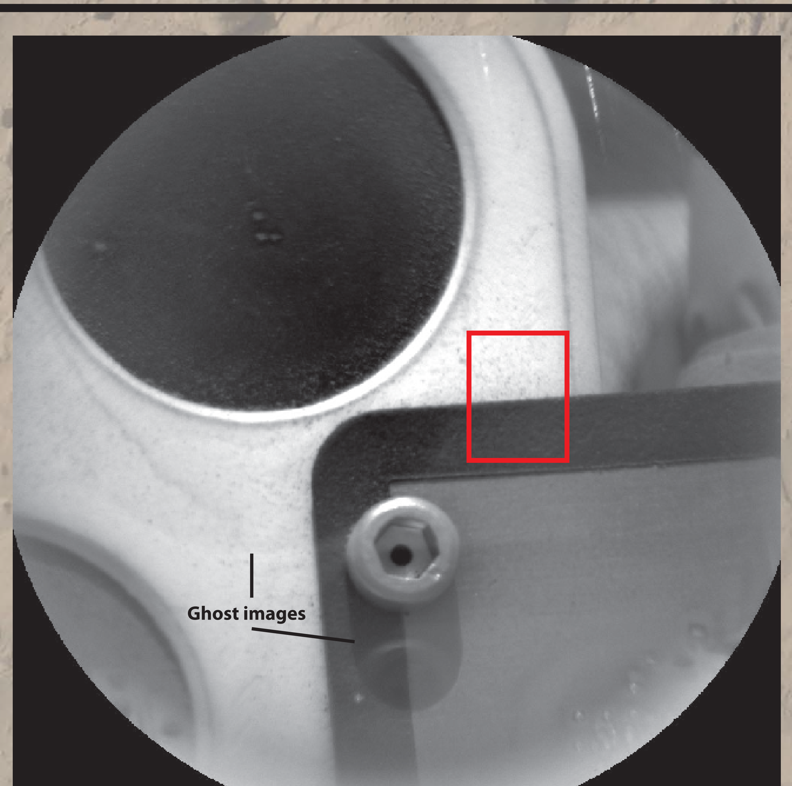


Figure 2 RMI image CR0_428740289, acquired on Sol 352 with illumination from top. Ti calibration plate at lower right has been painted black along edges for high-contrast edge against white background. Red box indicates subframe extracted for MTF analysis, avoiding ghost images.

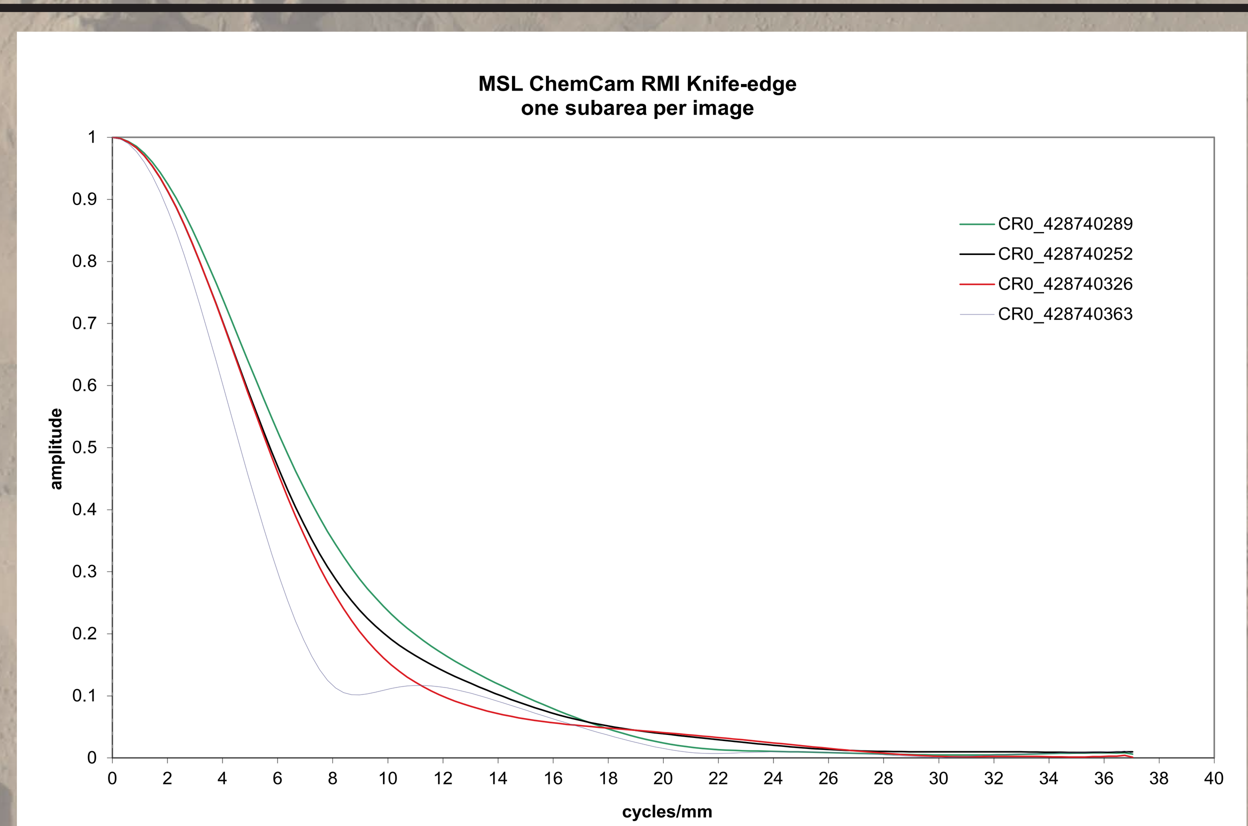
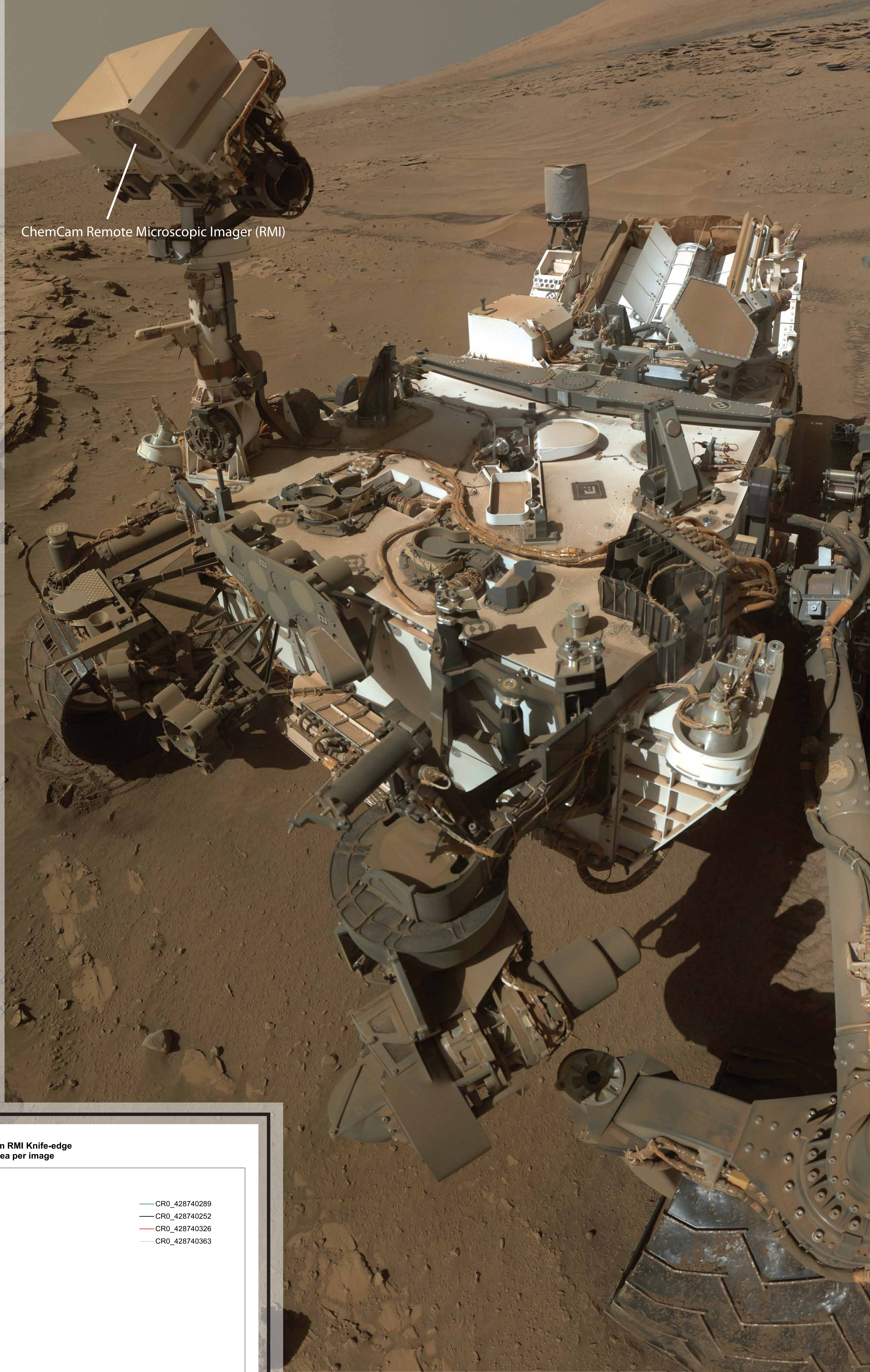


Figure 3 RMI modulation transfer function measured across edge of titanium calibration plate (subframe location shown in Fig. 2) in images taken at various focus settings. Frequency given in sensor (focal plane) space.

Background: Mosaic of MAHLI images of MSL rover [1], taken at "Windjana" on Sol 613



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.

Mars Hand Lens Imager (MAHLI) Calibration

- Focus range of MAHLI allows in-focus images to be acquired at working distances of 2.1 cm to infinity [4]
- 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 typically generated by interpolating pixels across Bayer pattern, but uninterpolated (greyscale) MAHLI images can also be acquired
- MAHLI calibration target includes bar target derived from the USAF 1951 Resolution Test Chart [4]

Flat field calibration: 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, 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, especially when focused at infinity. Both uninterpolated and interpolated (RGB) versions of the sky flats are being analyzed; the latter show variations in spatial response in red vs. green/blue channels, as shown in Figure 4. This difference in red flat-field response is not understood, but is evident in all sky flat data analyzed to date.

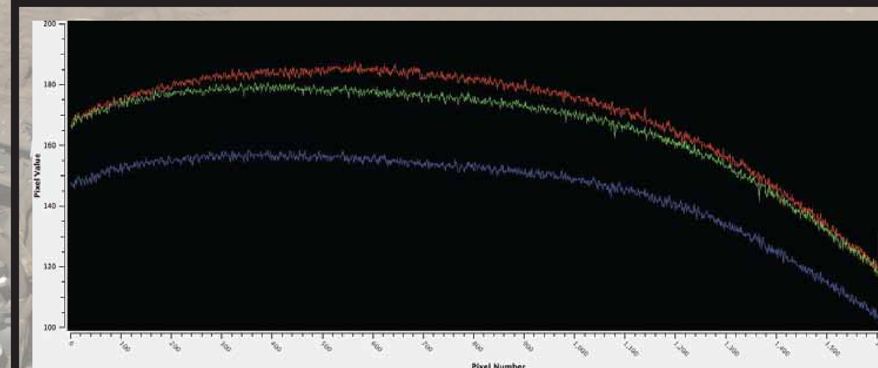


Figure 4 Horizontal (line 601) profiles across MAHLI sky flat acquired on Sol 86. Line color indicates red, green, and blue channels. Note difference in profile shape between red and other channels.

Resolution calibration: 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 an interpolated version of these images is shown in Figure 5. The target was typically illuminated by the MAHLI LEDs [4], often resulting in reflections that complicate 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. 5) were extracted from these images and used with Jean Lorre's "otf1" software at JPL's Mulitimission Image Processing Lab to generate MTF curves (Fig. 6).

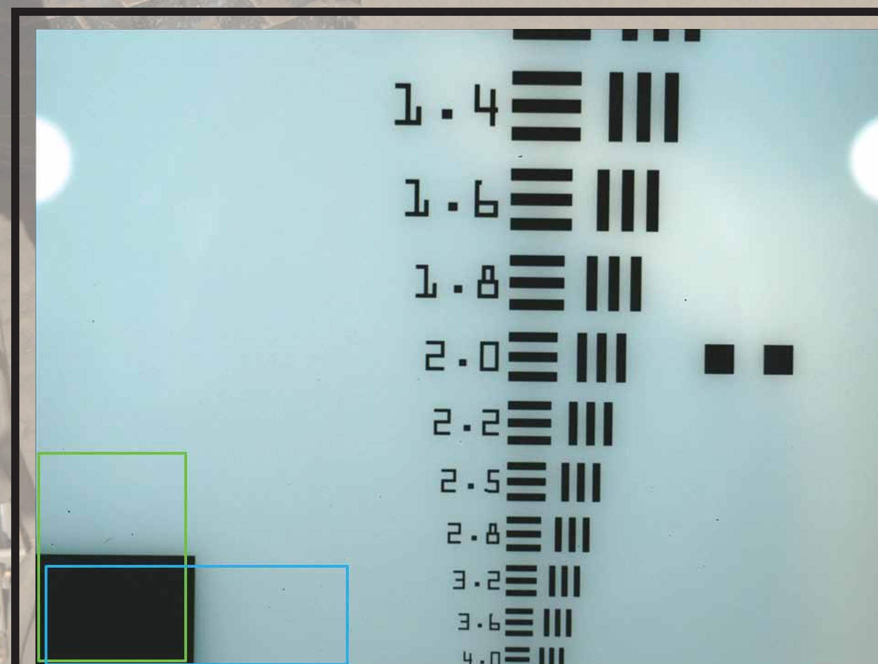


Figure 5 Preflight MAHLI calibration image of USAF test chart. Note reflection of LEDs at upper right and upper left, and more subtle reflection above and right of center. Rectangles at lower left outline subareas extracted for MTF analysis. Numbers denote spatial frequency of bar patterns in cycles/mm.

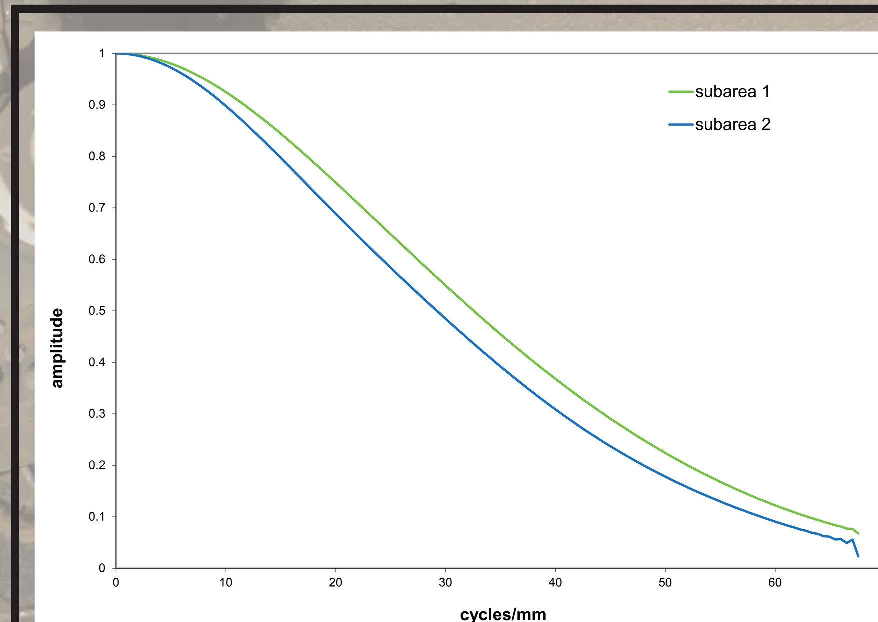


Figure 6 Example modulation transfer function plot for interpolated green pixels; frequency in sensor (focal plane) space. Curve colors correspond to subarea colors in Figure 5.

The difference in MTF between the horizontal and vertical edges is likely due to the architecture of the pixels in the Kodak KAI-2020CM interline-transfer CCD. The active area of each pixel is longer in the vertical direction, consistent with the results shown above. The microlenses bonded to the CCD probably reduce the magnitude of the effect of the pixel layout on horizontal vs. vertical MTF; more study is needed to fully understand these results.