CHEMCAM REMOTE MICRO IMAGER PERFORMANCE. O. Gasnault[1], K.E. Herkenhoff[2], S. Le Mouélic[3], R.C. Wiens[4], A Cousin[1], A Williams[5], N.T. Bridges[6], R.B. Anderson[2], Y. Langevin[7], S. Maurice[1], H.E. Newsom[8], P. Pinet[1], W. Rapin[1,9], and B. Gondet[8], [1]Institut de Recherche en Astrophysique et Planétologie (Toulouse, France, ogasnault@irap.omp.eu), [2]USGS (Flagstaff, AZ, USA), [3]LPGN (Nantes, France), [4]LANL (Los Alamos, NM, USA), [5]DPAG (Towson, MD, USA), [6]APL (Laurel, MD, USA), [7]IAS (Paris, France), [8]UNM (Albuquerque, NM, USA), [9]Caltech (Pasadena, CA, USA).

Introduction: In addition to the laser-induced breakdown spectrometer (LIBS), Curiosity rover's ChemCam instrument includes also a Remote Micro-Imager (RMI) [1, 2]. This camera documents the changes induced by the laser shots on the target, and remotely studies the martian rocks and soils at high resolution [3, 4]. As of Sol 1555, a total of 8785 RMI images were taken and downloaded, and roughly 20,000 more images were taken for the autofocus function (see below) but not downloaded. Here we report the performance of this camera.

ChemCam's RMI is an Atmel TH7888A CCD sensor. Once integrated in ChemCam, it has a very fine pixel scale with 19.6 µrad/pixel (1024x1024 panchromatic gray-scale CCD detector). Its small depth-of-field was estimated to be between 1 cm at 2 m and 25 cm at 10 m [2] with a field-of-view of only 20 mrad. The smallest features that can be distinguished are of the order of 0.1 mm at 3 m at best focus [3]. In practice, because the depth-of-field is small and the autofocus is optimized for the small region-of-interest where the laser hits the target, RMI images often have badly focused areas and the resolution is not optimal over the entire image. The photometric response is close to linear over 80% of the dynamic range, after optimization of the gain a few days after landing; Non-linearity near saturation is partly corrected by the ground processing. The image is coded on 10 bits at the sensor level, and transmitted on 16 bits afterward.

Signal-to-noise: Signal-to-noise ratios (SNRs) can be estimated by dividing the average counting rate in the image center (128x128 pixels) with the standard deviation on an equivalent surface in the hidden corners that receive no light (actually the average of the standard deviations in the 4 corners). With a typical target (Windjana drill tailing, Sol 626), we find an SNR of 310 with this approach, or 250 with a simple model of the instrument response. In both cases, it reaches the initial requirement of an SNR of 200 [2].

RMI functions:

Autoexposure. Most images are taken in the autoexposure mode, which was inherited from Rosetta's CIVA camera. It relies on the comparison of pixel intensities in a large region of interest with two thresholds, and multiplicative/divisive time factors of 3, $3^{0.5}$, and $3^{0.25}$. Half of the images taken with that mode have a final exposure time different than the given seed. The resulting exposure times go from 7 to 242 ms, but exposures up to 1 min were obtained at dusk. In a large majority though, the final exposure time varies from 8 to 57 ms, half of the cases being between 13 and 25 ms. Only 1% of the images did not have an optimized exposure time despite the use of this mode.

A good exposure time optimizes the use of the detector dynamic. Most of the time gain 14 of the camera is used, which corresponds to a linear response up to 814 DN when coded on 10 bits, i.e. 1024 DN [3]. In 86% of the images, the maximum counting rate is below this linearity threshold, and this is true for all the images if only 1% of the brightest pixels are ignored. Most of the time, the maximum counting rate is around 670 DN. The autoexposure therefore works pretty well.

Autofocus. Since Sol 983, ChemCam uses the RMI to focus its telescope. A series of images at different focus are taken, and a sharpness criterion (here a Laplacian score) is computed over a small region of interest to find the best focus. A large majority of the RMI autofocus commands returned an optimized focus; other cases were close and probably suffered from a distance seed that was incorrect. A few cases have focus curves that are not understood well with several maxima. The advantage of this new focus algorithm is that it works at all distances.

Compression. RMI images are compressed onboard by the rover computer. Early in the mission, experiments using various types of the onboard ICER compression software [5] were analyzed and used to select optimal compression parameters for RMI images. Various levels of ICER lossy "MINLOSS" (quality 1-7) compression were tested and compared with losslessly-compressed RMI images. This type of quality compression is ideally suited to RMI images, which often include both well-focused and poorly-focused areas. The ICER quality compression preserves sharp features in well-focused parts of the image, while applying more compression to poorly-focused areas. This approach results in variable compression rates among image segments, depending on the amount of information contained in each. Therefore, the image data are compressed to levels that preserve fine detail while minimizing downlink data volume. ICER MINLOSS quality 2 results in negligible loss of information while compressing RMI images to about 2 bits/pixel, and was therefore selected as the default compression quality.

Other RMI characteristics: .

Vigneting. ChemCam telescope is optimized for LIBS rather than imaging and therefore the imager subsystem has a strong vigneting with an attenuation factor of 3 to 4 between the center and the border of the image. However the flat field response of the instrument can be evaluated in ground and flight calibrations and thus can be corrected during the image ground processing.

In order to quantify possible changes in flat field response during the landed mission, RMI images of the martian sky have been acquired using two techniques to correct for spatial variations in sky brightness: (1) Point the camera at zenith and acquire images with 180-degree rotation between them, and (2) Acquire a 2x2 raster of images around a central RMI image. The images acquired using Technique 1 were averaged and the rasters acquired using Technique 2 were used to model the gradient in sky brightness across the central images and remove it. In both cases, variations in sky brightness that deviate from a simple gradient cause uncertainties in flat field response of up to 3%, but the results using the two techniques are identical to within 1%, suggesting that the response is known to this level of accuracy.

Ground processing. In addition to the flat field correction, which is the strongest correction, the ground pipeline corrects for CCD smearing, subtracts a dark current level based on temperature, averages hot pixels with neighbors, and partially corrects for the non-linearity. All these corrections are based on ground and flight calibrations.

In some circumstances the RMI image quality is affected by stray light, especially if there are bright features within a few degrees of the optical axis (but outside the field-of-view), or when the telescope is focused at very short distances. This is mainly visible in image mosaics, but can be corrected with an additional dark level correction or an additional flat field correction computed on the images themselves. These additional corrections, which are not currently in the default pipeline, give very good results as shown in Fig. 1.

Application examples: In addition to high-resolution documentation of ChemCam laser and passive activities, the RMI images are used in various applications, such as change monitoring of long distances target [6] and grain size analyses at close distances. For example, during the Bagnold Dunes campaign, grains as large as 25.1 mm were identified with the RMI, even though half of the grains have a size smaller than 0.5 mm [7].

Conclusions: The Remote Micro-Imager is still performing well after four years of imaging onboard the rover Curiosity. Its high-resolution for a remote sensing instrument (ChemCam) complement nicely the other cameras of the mission. This concept is being improved for the next generation of instrument, SuperCam, which will be on the Mars2020 rover [8].

References: [1] Wiens et al. (2012) *Space Sci. Rev., 170*, 167-227.. [2] Maurice et al. (2012) *Space Sci. Rev., 170*, 95-166. [3] Langevin et al. (2013) *LPS XLIV*, Abstract #1227. [4] Le Mouélic et al. (2015) *Icarus, 249*, 93-107. [5] Kiely and Klimesh (2003) *Jet Prop. Lab. IPN Progress Report 659*, 42-155. [6] Anderson et al. (2017) *LPS XLVIII*. [7] Cousin et al. (2017) *J. Geophys. Res, submitted*, Geochem. Bagnold Dune Field observed by ChemCam… [8] Virmontois et al. (2016) *LPS XLVII*.

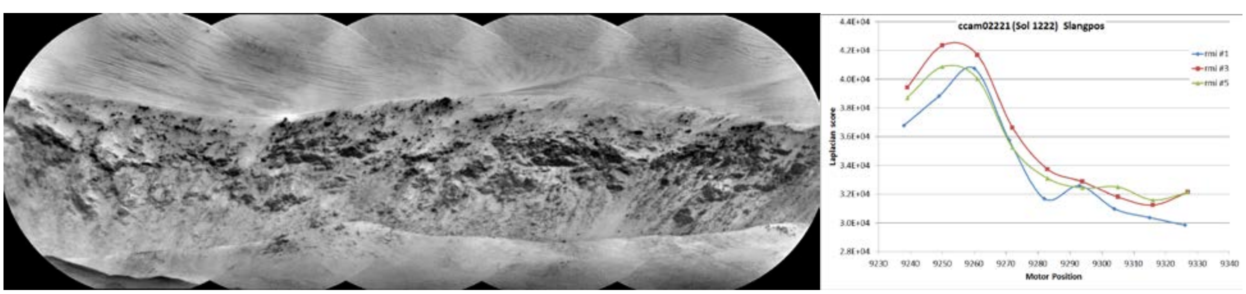

Figure 1: Unamed crater known as target Slangpos photographed by ChemCam from a distance of about 30 km on Sol 1222. For scaling, the crater diameter is about 5 km. The right panel shows the RMI autofocus curves demonstrating the new capability to find the optimal focus around the optical infinity position.