AN EXCESS SIGNAL IN THE TAIL OF THE PSF OBSERVED IN THE PANCAM R7 FILTER ON BOARD THE MARS EXPLORATION ROVERS: CHARACTERISATION AND CORRECTION Simone J. Jakobsen[1], Kjartan M. Kinch[1], Morten B. Madsen[1], James F. Bell III[2], Danika Wellington[2], Austin Godber[2]. [1]Niels Bohr Institute, University of Copenhagen, Øster Voldgade 5-7, 1350 Copenhagen K, Denmark; (simonejj@nbi.ku.dk), [2]School of Earth and Space Exploration, Arizona State University

Introduction: The Panoramic Camera (Pancam) is a stereoscopic, multispectral camera system mounted on the masts of the Mars Exploration Rovers, Spirit (MER A) and Opportunity (MER B) [1].

During preflight standalone calibration activities in 2002, a discrepancy was noted between reflectance spectra extracted from Pancam images of the calibration target (caltarget), to equivalent spectra obtained with a spectrometer. In the longest wavelength filter (R7 at 1009 nm), the Pancam observed lower contrast between dark and bright caltarget regions, than expected. At the time, this was thought to be due to partial transparency of caltarget materials at longer wavelengths [1]. However, the effect is observed not only in caltarget images, but is also seen in-flight, in images of Martian terrain. The effect is typically small enough to be within the stated uncertainty of the Pancam system (10% absolute, 3% filter-to-filter)[2]. But, in specific cases the effect may be dramatic: for instance very dark shadows can show an artificial increase of a factor of $\sim$2 in radiance in the R7 filter, relative to the neighbouring filter (R6 at 934 nm).

Here, we describe the observed effect, propose an explanation of its physical origin, and construct a method to correct for it.

Characterising the effect: In order to determine the nature of the R7 filter effect, we made use of simple images of a broad spectrum light source on a dark background obtained during preflight calibration. We selected an image in each filter in order to use them as a means to compare the throughput. By using these images as estimates of the point spread function (PSF), we could directly compare the shape of the PSF between filters, by assuming that the distribution of the light incident on the filters is approximately the same.

The raw images were calibrated according to the usual MER calibration procedure described in [2]. The source area within 260 pixels from the source center were normalized and radial profiles were calculated over the same area by finding the average radiance per pixel in each bin, with the bins defined as 130 concentric annuli, each with a width of 2 pixels. The resulting radial profiles were used as estimates of the PSF in each filter (see Figure 1).

Comparing the light distribution in the different filters for the right eye of Pancam (filters R2 at 754 nm, R3 at 803 nm, R4 at 864 nm, R5 at 904 nm, and R6 at 934 nm) showed us that the shape is more or less the same for all five filters. Only the R7 filter showed a visibly different distribution with a higher contribution in the tail region, as seen in Figure 1.

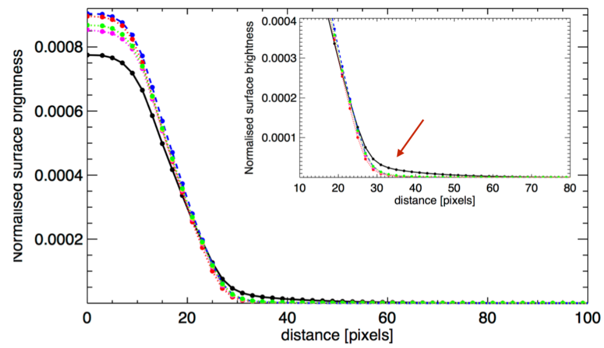

Figure 1: The figure shows the radial profiles used as estimates of the PSF in the different filters. The coloured curves correspond to filters R2-R6, the black curve is the R7 filter profile. The inset shows a zoom-in on the tail part of the distribution.

Unlike the R2-R6 filters, the Pancam R7 filter is a long-pass filter, relying on the rapidly declining sensitivity of the CCD itself to provide the long-wavelength cutoff. In contrast, in the conceptually similar Mastcam system on Mars Science Laboratory (MSL) all filters are bandpass filters [3]. Since the described effect is only observed on MER, not on MSL, this leads us to believe that the effect arises from light at wavelengths very close to the edge of the silicon band gap at 1100 nm, beyond the cutoff of the longest-wavelength filter on the MSL Mastcam.

The hypothesis: We propose that at the longest wavelengths, we get additional reflection from the backside of the CCD. Figure 2 shows how we expect some of the light hitting a pixel to be transmitted through the bulk silicon of the CCD and part of it being backscattered and registered in neighbouring pixels, ultimately resulting in a more broad distribution of the light than should be expected.

We expect the scattering to be Lambertian as a good estimate, and the amount of the radiation reaching the pixel layer to be dependent on the absorption depth in silicon at the wavelength dominating the effect. This makes it possible for us to limit the number of parameters needed in our model.

Correction method: In order to eventually be able to correct for the effect, we first sought to simulate the effect using our hypothesis. We used the PSF from the

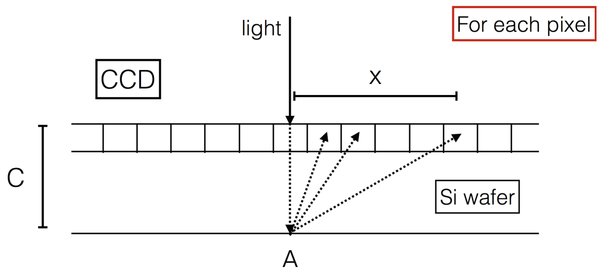

Figure 2: This figure shows how we expect some of the light hitting a single pixel to penetrate through the CCD, get backscattered from the backside of the CCD, and be registered in neighbouring pixels. The model parameter A describes the strength of the effect. X is the distance from the central pixel to the pixel registering the backscattered part of the light. C is the thickness of the CCD.

adjacent filter (the R6 filter), that does not exhibit any excess signal, as a template for how the light should be distributed initially, hereby constructing an algorithm that recreates the effect. In this way it became possible to reproduce the R7 filter image from the template image. This was done by constructing the model:

$$\text{ymod} = A * \exp(-B * \sqrt{C^2 + x^2}) * C/(C^2 + x^2)^{3/2}, \quad (1)$$

where A is a parameter describing the strength of the effect, B is the absorption coefficient in silicon for the dominating wavelength, and C is the thickness of the CCD. ymod is the fraction of the signal in a specific pixel to add to neighbouring pixels at distance x. From this model an algorithm was constructed that simulates the effect described by the model in each pixel, thereby transforming the template image into the R7 filter image using a fitting routine.
In order to correct for the effect, the inverse problem was treated using an iterative process. For each iteration the inverse algorithm using the best fit parameters for the model was applied to the original R7 image by making a guess for the corrected version of the image. The first guess was the R7 image itself. After each iteration, the output image was used as the new guess until the output converged towards the final result.
To test the final version of the correction on more complex and independent data, we made use of caltarget R7 images obtained during the mission. This way we could check whether or not the correction could take care of the contrast issues observed in such images. The algorithm was applied 11 times to be sure to achieve a result that was truly converging.

Results: The fit used to identify the correct form of the model by simulating the effect, gave us a value for the parameter A of 0.182 pixels^2, a value for the parameter B of 0.031 pixels^{-1}, and a value for the parameter C of 25.5 pixels.

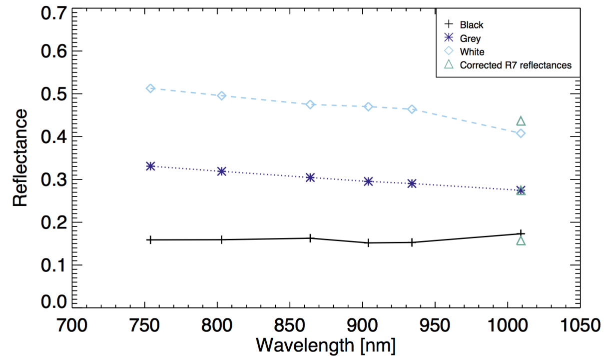

Figure 3: This plot shows the spectra for the white, grey, and black regions of the caltarget including the datapoints obtained from the correction of the R7 filter data, showing an increase in black/white contrast. The spectra have been scaled so that the spectrum representing the grey region matches the spectrum obtained with a spectrometer.

When applying the correction to the caltarget R7 filter image, which was used as an independent dataset, we again observed that the output converged quickly with only minor improvements from iteration # 2 to iteration # 11. The correction increased the black/white contrast in the R7 filter spectrum, bringing it closer to what was expected based on measurements made with a spectrometer (as seen in Figure 3).

Discussion: In order to evaluate our hypothesis for the nature of the effect as posed by the model, we convert the parameter B to a penetration depth giving us a value of $1/0.031\text{pixels}^{-1} * 12$ microns pixels^{-1} = 388 microns, where 12 microns is the physical size of a pixel [1]. This value can be evaluated based on information about penetration depth i silicon. Comparing this to a table of the penetration depth in silicon at different wavelengths, we see that this implies that the dominating wavelength is just above 1080 nm, which fits well with our expectations that the effect is related to wavelengths higher than the MSL cutoff [4]. Converting the value of the C parameter to a thickness of the CCD in microns, we get a value of 25.5 pixels$*$12 microns pixel^{-1} = 306 microns. This fits reasonably well with the value of > 400 microns listed by the manufacturer, given that the parameters are not tightly constrained by the fit.
Further work includes examining the effect on the results when introducing additional wavelengths to the model, as well as introducing the correction on mission images, to determine its performance on actual data.

References: [1] J. F. Bell III, et al. (2003) *JGR* 108(E12):8063. [2] J. F. Bell III, et al. (2006) *JGR* 111(E02S03). [3] J. F. Bell III, et al. (2012) *43rd LPSC*. [4] J. R. Janesick (2001) *SPIE Press*.