PHOTOMETRIC CALIBRATION OF CaSSIS IMAGES. A. Pommerol[1], M. Read[1], N. Thomas[1], A. S. McEwen[2], G. Cremonese[3] and the CaSSIS Team. [1]Physikalisches Institute, University of Bern, Switzerland (antoine.pommerol@space.unibe.ch), [2]LPL, University of Arizona, USA, [3]Osservatorio Astronomico di Padova, Italy.

Introduction: The Colour and Stereo Surface Imaging System (CaSSIS [1]) of ExoMars Trace Gas Orbiter has already collected more than 5000 images to date - many of high quality. The instrument uses a push-frame approach for color imaging. This presents both a challenge and an advantage for the calibration as the production of good quality color images requires an excellent photometric calibration of the data. This allows us to reach very high accuracy in the calibration by correcting efficiently for stray light and variations of the detector bias. Such corrections are particularly crucial for imaging the Martian surface at low illumination conditions, which is permitted by the high sensitivity of the instrument. Due to the non-sun-synchronous orbit of the TGO spacecraft, we are able to observe the Martian surface over a range in local times, including early morning and late afternoon.

Imaging principle: CaSSIS consists of a 4-mirrors telescope with a 880-mm focal length mounted on a rotation platform for stereo imaging and a 2k CMOS detector covered by a fused silica window onto which 4 broad bandpass color filters have been deposited. The acquisition of images is synchronized with the ground-track velocity so that an image can be assembled from generally 30-40 slightly overlapping “framelets” taken through one to four of the color filters.

Calibration procedure: The first classical steps of the photometric calibration are 1) a bias subtraction, 2) a flatfield division, 3) a conversion from DN to I/F units and 4) an interpolation of dead pixels.

1) The detector bias (offset) is obtained by averaging several observations acquired over the night-side of Mars. The dark current generated by the CaSSIS detector is negligible so no correction is needed.

2) The flatfield is obtained by averaging as many valid observations as possible to blur the actual signal from Mars and reveal subtle pixel-to-pixel variations of the detector sensitivity. Correctly filtering the dataset to avoid saturation or corrupted data is the most crucial aspect of this process. The push-frame approach provides a significant advantage as many acquisitions of the same area of the detector are used for each image.

3) The absolute radiometric calibration (i.e. the conversion of DN to I/F) is performed using a radiometric model of the instrument validated by pre-flight laboratory measurements [2]. This calibration has yet to beconfirmed in flight but is planned for upcoming observations of Jupiter and/or reference stars.

4) Ten bad pixels were identified statistically by looking for outliers to the images histograms across the entire dataset and are replaced by values interpolated from neighbor pixels.

Analysis of the first set of images indicated that some images are affected by a low and variable amount of external stray light (see Fig. 1 left for an example: the amount of stray light here varies between 1 and 2% of the signal depending on the filter).

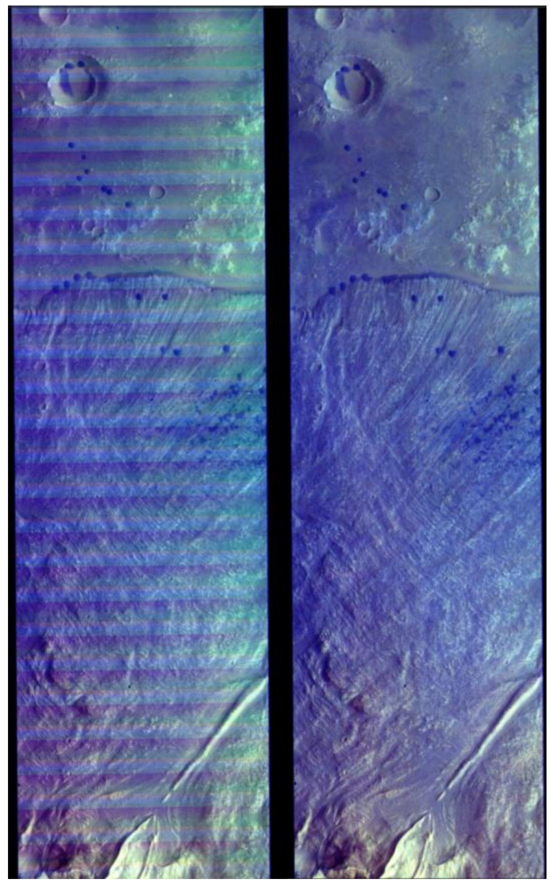

Figure 1: Comparison of the same CaSSIS colour image (Blunck crater, 323°E, 27.5°S) before (left) and after (right) correction of the stray light and variable detector bias. The image was taken early in the morning with local solar time 07:01 and incidence angle: 77.5°. The color image is a RGB composite made out of the RED, PAN and BLU filters, respectively. Image: MY34_002084_210_2

Although the amount of stray light is fairly low, CaSSIS images are constructed by mosaicking framelets, which also makes these effects appear quite prominently as periodic color bands. The source of the stray light is probably a reflection from the illuminated

Martian surface on the backside of a shield protecting the entrance of the telescope. The spatial pattern of this stray light on the detector is remarkably constant whereas its intensity varies from image to image. This property allows us to correct for this problem by deriving a fixed stray light pattern from the statistical analysis of all data. The pattern can then be fitted to the averaged signal in each observation to find the correct intensity to remove (Fig.2).

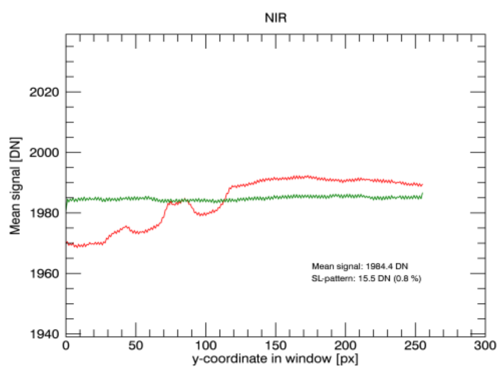

Figure 2: Example of stray light pattern removal for NIR filter. The red curve is the averaged y-profile (over all columns and framelets) before correction. The green curve is the result of the subtraction of the fixed stray light pattern with adjusted intensity. The maximum amount of stray light removed here is 0.8% of the measured signal.

Another prominent artefact is caused by apparent changes in the bias of the detector between acquisitions of the framelets. The method to correct for this issue is to compare the average reflectance within the overlap of successive framelets (Fig. 3). In addition, linear gradients left after the removal of the stray light pattern at the previous step are corrected here. If most of the artefact is removed by a purely subtractive correction (i.e. bias correction only), residuals appear filter-dependent indicating that the sensitivity of the detector might also vary slightly together with its bias. Residuals are in any case much below the estimated signal-to-noise ratio.

Results and discussion: Figure 1 shows the comparison of a CaSSIS color image before and after photometric correction. In this example, the correction has removed automatically all visible artefacts. The image was taken under challenging conditions, at 07:01AM with an incidence angle of 77.5°. To permit observations of the surface under such challenging conditions is a main strength of CaSSIS, and thus the successful correction of the photometric artefacts is crucial for the full scientific exploitation of the instrument capabilities.

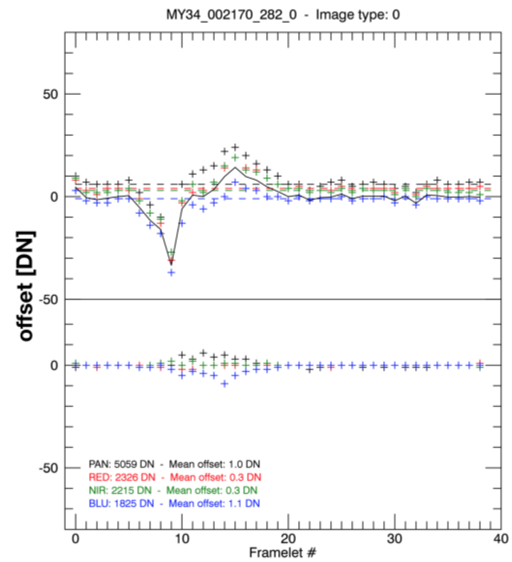

Figure 3: Example of framelet-to-framelet offsets due to the variation of the detector bias and residual stray light gradient (symbols on top). The symbols at the bottom show the results of the correction. Maximum residuals are of the order of 0.2% for PAN and 0.5% for BLU, much below the estimated SNR.

The latest photometric correction procedure removes all artefacts at or below the noise level and permits the scientific use of color data for all images with sufficient signal-to-noise ratio. Calibrated images will regularly be archived into the Planetary Science Archive (https://www.cosmos.esa.int/web/psa/) for distribution to the community. Examples of use of CaSSIS data acquired in low-illumination conditions can be found in [3] where the reflectance and color of dark spots and fans appearing on the seasonal ice cap at the end of the southern winter are studied.

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References: [1] Thomas N. et al. (2017) *Space Sci. Rev., 212,* 1897–1944. [2] Roloff V. et al. (2017) *Space Sci. Rev., 212, 1871-1896*. [3] Cesar et al. (this conference).