# DAWN-FC

**DAWN - Framing Camera**

# FC2 Out-of-Field Stray Light

DA-FC-MPAE-RP-284
Issue: Draft
Revision: -
15 Dec 2009

Prepared by:
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# Approval Sheet

prepared by: *Stefan Schröder* (signature/date)

approved by: *Holger Sierks* (signature/date)

# Document Change Record

| Iss./Rev. | Date | Pages affected | Description |
|---|---|---|---|
| Draft | | all | first draft |
| | | | |

# Distribution Record

| Holder | | Issue/Revision | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | D | 1 | 2 | | | | | | | |
| Configuration File (Doc) | | | | | | | | | | | |
| MPS | | | | | | | | | | | |
| KMA | Aye | | | | | | | | | | |
| UC | Christensen | | | | | | | | | | |
| RE | Enge | | | | | | | | | | |
| WG | Goetz | | | | | | | | | | |
| PGM | Gutierrez-Marques | | | | | | | | | | |
| HH | Hartwig | | | | | | | | | | |
| HUK | Keller | | | | | | | | | | |
| GK | Koch | | | | | | | | | | |
| WK | Kühne | | | | | | | | | | |
| TM | Maue | | | | | | | | | | |
| AN | Nathues | | | | | | | | | | |
| HP | Perplies | | | | | | | | | | |
| MR | Richards | | | | | | | | | | |
| RS | Schäfer | | | | | | | | | | |
| KS | Schneider | | | | | | | | | | |
| SES | Schröder | | | | | | | | | | |
| ISE | Sebastian | | | | | | | | | | |
| HIS | Sierks | | | | | | | | | | |
| MS | Sperling | | | | | | | | | | |
| ISZ | Szemerey | | | | | | | | | | |
| | | | | | | | | | | | |
| DLR | Carsenty | | | | | | | | | | |
| DLR | Jaumann | | | | | | | | | | |
| DLR | Mottola | | | | | | | | | | |
| IDA | Fiethe | | | | | | | | | | |
| IDA | Michalik | | | | | | | | | | |
| IDA | Bubenhagen | | | | | | | | | | |
| JPL | Miller | | | | | | | | | | |
| JPL | Pavri | | | | | | | | | | |
| OSC | Violet | | | | | | | | | | |
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| **Legend:**<br>A - Approval<br>C - Copy<br>U - Updated Pages | | | | | | | | | | | |

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# 1 General aspects

## 1.1 Scope

We report on the analysis of FC2 in-flight images acquired during a campaign to characterize out-of-field stray light using the Sun as a light source. This continues our efforts to calibrate the FC and characterize its in-flight performance, initiated with the ICO campaign [RD1].

## 1.2 Introduction

The analysis is presented in Section 2. Figures are appended at the end of the text.

## 1.3 Reference Documents

| no. | document name | document number, Iss./Rev. |
|---|---|---|
| RD1 | Framing Camera ICO Report | DA-FC-MPAE- RP-268 |
| RD2 | Calibration Pipeline | DA-FC-MPAE- RP-272 |
| RD3 | FC Optics Specification | DA-FC-MPAE- SP-001 |
| RD4 | Stray Light Analysis Report | DA-FC-KT-AN-0001 |

## 2 Stray Light Analysis

To characterize and quantify the out-of-field stray light contribution the FC2 observed the sky using the Sun as a stray light source. On 31 March 2009 it acquired a series of 1/10/100 sec exposures in all filters with the Sun at off-axis angles ranging from 90.0° to 30.0° with 2.5° decrements. The distance of the spacecraft to the Sun during this campaign was 1.3738 AU.

The images show a distinctive pattern of stray light that increases in strength with decreasing Sun angle. Figure 1 shows what the pattern looks like at its maximum strength through the clear filter. Stray light elevates the signal level over the whole frame, slightly more so in the center, which is more clear in the profiles in Figure 2. Above 50.0° Sun angle stray light is virtually absent; below it the level of stray light increases steadily. There are two angles at which the stray light jumps to higher levels, the first between 52.5° and 50.0° and the second between 40.0° and 37.5° (Figure 3). While these “critical angles” must be associated with structures inside the baffle (e.g. field stops), we are unable to pinpoint their origin.

Some aspects of the stray light pattern are wavelength dependent. Figure 4 shows that the prominent vertical streak at left shifts leftward with increasing wavelength. In addition, we find that the center is most pronounced in the near-IR (being reddish in the color image). The observed spectrum of the out-of-field stray light is reconstructed in Figure 5. It is essentially the solar spectrum multiplied by the reflectance of the coating on the inside of the baffle. The figure shows that the coating is more reflective than average in the near-IR (>800 nm) and less in the visible (<600 nm), consistent with the reddish color of the center pattern in Figure 4.

We take advantage of the availability of this “extended source” to assess the quality of the flat fields. It is thought that the FC exposures through the color filters are affected by in-field stray light, which increases the signal in the center of images of an extended source by as much as 10% [RD2]. This is clearly seen in the flat field images, which are decidedly non-flat. In Figure 6 we investigate this phenomenon by dividing the F3 stray light image by the F6 image, before and after flat field division. The most obvious consequences of the division are a brightening of the center of the quotient image, a darkening of the corners, and the appearance of several visible dust specks in the center (F3 dust is brighter than average, F6 dust is darker). Since the stray light pattern is wavelength dependent we can, unfortunately, not verify that the brightness changes are due to the in-field stray light issue. The appearance of dust specks in the quotient image implies that these have disappeared from the optics since the flat fields were acquired in the laboratory. Thus, the flat fields correct for light absorbed by dust particles that are no longer present.

Since the images were acquired at three different exposure times (1/10/100 sec) we can test whether the CCD responds linearly to the duration of exposure. Figure 7 compares the charge rates for the three difference exposure times. It can be seen that signal noise decreases with exposure time, as expected for photon noise, and that the 100 sec exposure profile overlies that of the 10 sec exposure. However, the 1 sec exposure profile is slightly offset from the other two. It can be made to fit in with the others by subtracting 0.5 DN. This difference is too large to be attributed to uncertainties in dark current. The most likely explanation is that the estimate for the bias is off by 0.5 DN. We estimate the bias as the mean of the pre-scan image area. The mean ($\mu$) of this area for the 1 sec exposure image is 269.457 DN with a standard deviation ($\sigma$) of 1.142 DN ($n = 12648$). However, the standard error of the mean ($\sigma / \sqrt{n}$) is only 0.010 DN, much smaller than the 0.5 DN offset. This implies that the mean of the pre-scan region is not a perfect estimator for the true bias, and that errors up to 0.5 DN can be expected.

While in-field stray light was found to be a nuisance [RD2], the contribution of out-of-field stray light is very small. The *observed stray light levels are insignificant compared to the expected flux at Vesta* (<13 [DN/sec] versus $10^6$ [DN/sec] for F1). How do these findings compare to the design requirement? The FC optics specifications [RD3] state that the irradiance (in [W $\text{m}^{-2}$]) at the CCD ($E_{\text{det}}$) shall be less than $10^{-9}$ times the irradiance at the baffle entrance ($E_{\text{in}}$) for Sun angles larger than 20°, to be verified at 632.8 [nm]. Ray tracing simulations show that this design requirement has been met [RD4]. Following the verification criterion we verify the requirement by integrating over the pass band of filter F7, which has an effective wavelength of 653 [nm], closest to the wavelength specified [RD2]. The incoming flux $E_{\text{in}}$ in [W $\text{m}^{-2}$] at the baffle entrance is then:

$$E_{in} = \cos\theta \int_{\lambda_i}^{\lambda_f} F_{Sun} d\lambda ,$$

with the wavelength $\lambda$ in [nm], Sun angle $\theta = 30°$, the solar irradiance $F_{\text{Sun}} = 0.83$ [W $\text{nm}^{-1}$ $\text{m}^{-2}$] at 1.37 AU and 653 [nm], and $\lambda_i = 629$ [nm] and $\lambda_f = 671$ [nm] specifying the FWHM of filter F7. The stray light flux $E_{\text{det}}$ in [W $\text{m}^{-2}$] captured by the CCD through F7 is:

$$E_{\text{det}} = 1024^2 \left\langle \frac{n_\gamma}{n_e} \right\rangle \left\langle \frac{n_e}{s} \right\rangle \frac{sE_\gamma}{A} = 1024^2 \frac{gQsE_\gamma}{A} ,$$

with number of photons and electrons per second $n_\gamma$ and $n_e$, the average stray light signal per pixel $s = 1.08$ DN per second, the gain $g = 17.7$ electrons per DN, the energy of a photon $E_\gamma = 3.04\times10^{-19}$ [J] at 653 [nm], the CCD area $A = 2.056\times10^{-4}$ [$\text{m}^2$], and the quantum efficiency $Q = 0.175$ photons per electron at 653 [nm]. With these numbers we calculate $E_{\text{in}} = 30.2$ [W $\text{m}^{-2}$], $E_{\text{det}} = 5.19\times10^{-9}$ [W $\text{m}^{-2}$], and $E_{\text{det}} = 0.17\times10^{-9}\ E_{\text{in}}$. Thus, we have verified from the observations that the *design requirement is met* for Sun angles as low as 30°.

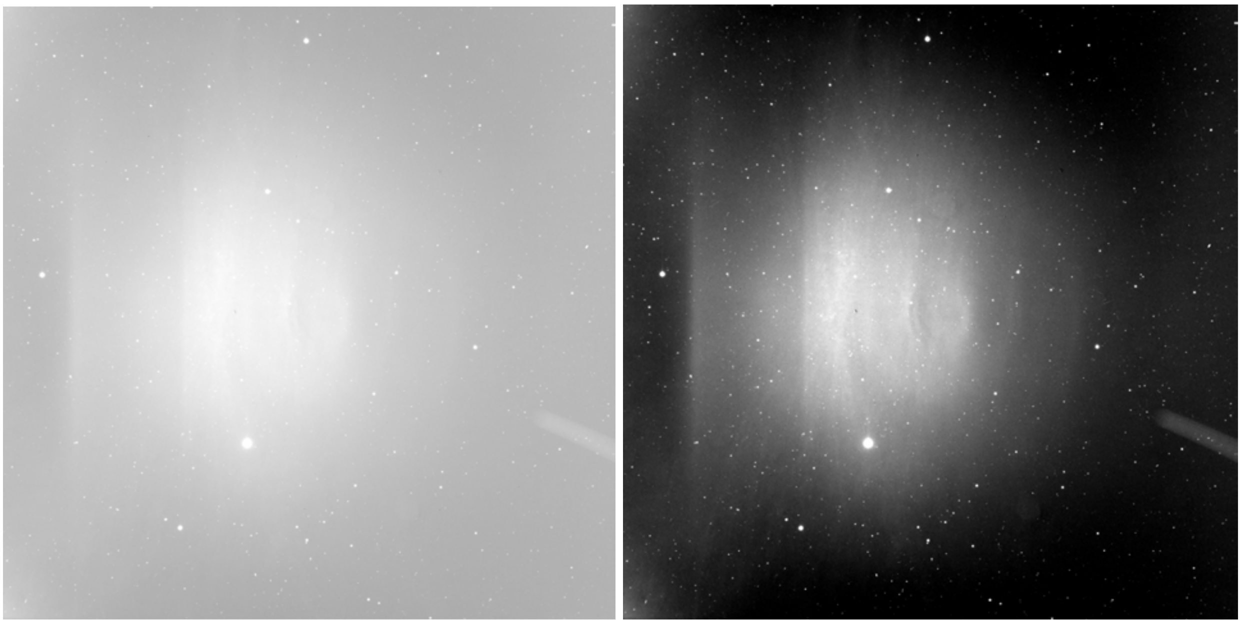

**Figure 1. Calibrated images of stray light recorded through the clear filter (F1) using the Sun as light source at 30° (100 sec exposure). Left: Original stray light image (black means zero intensity). Right: The same image with contrast enhanced to bring out details in the center of the pattern. The brightness scale is linear. Stars are visible in the background, and a streak is visible at lower right.**

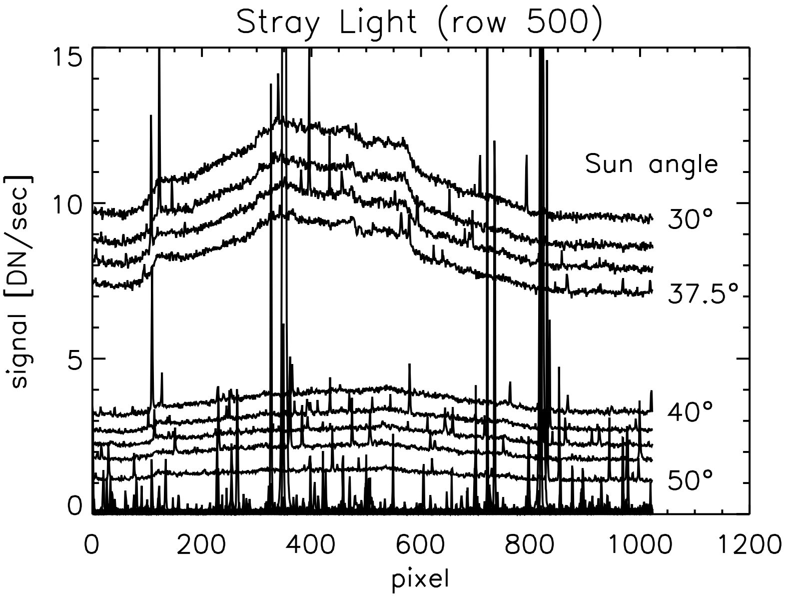

**Figure 2. Stray light profiles representing row 500 in 100 sec clear filter (F1) exposures at different Sun angles.**

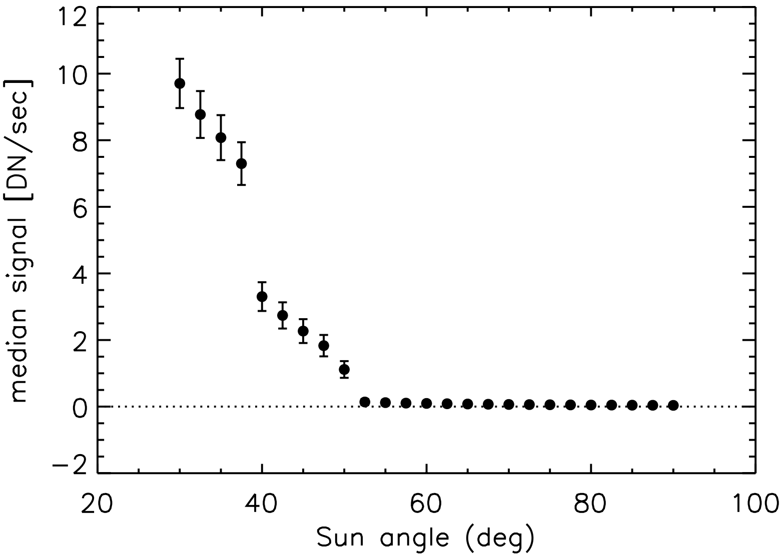

**Figure 3. Stray light contribution expressed as the median of 100 sec clear filter (F1) exposures as a function of Sun angle.**

**Figure 4. Color image of stray light at 30° Sun angle (red: F5, green: F6, blue: F3). Images are 100 sec exposures, contrast enhanced, and not divided by flat fields.**

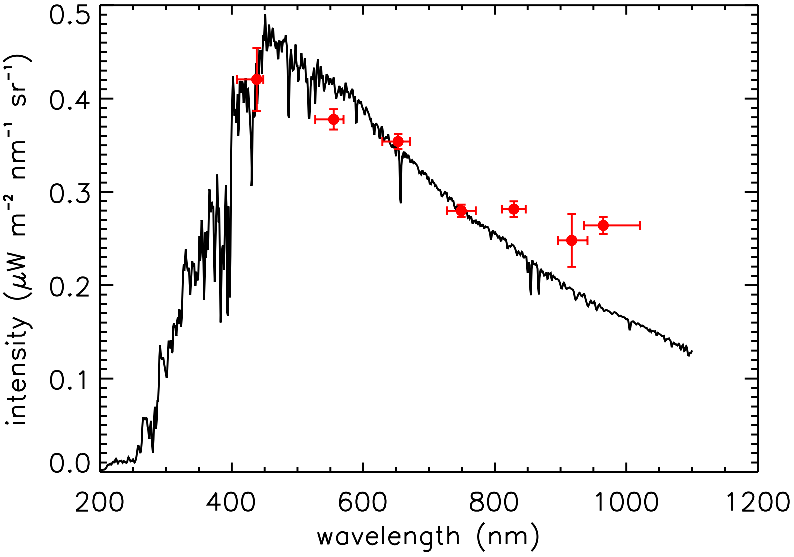

**Figure 5. Stray light spectrum (red data points) calculated as the median of calibrated images with the Sun at 30.0°. A solar spectrum (in black), scaled to the observations, is shown for reference. Images were not divided by flat field.**

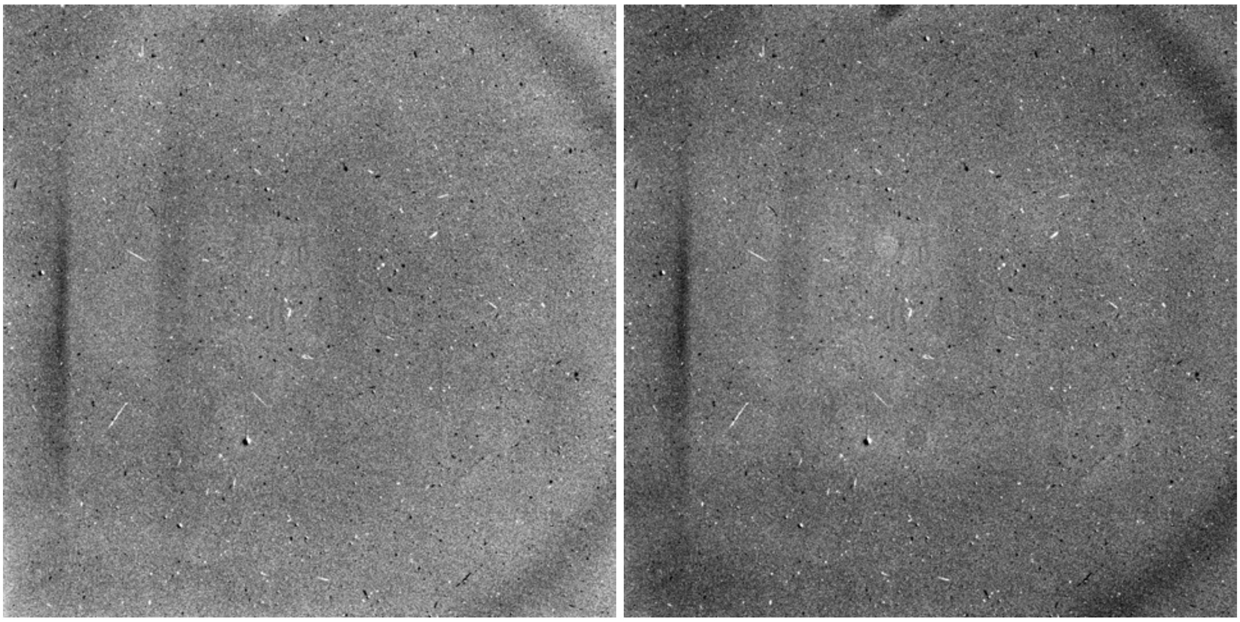

**Figure 6. F3 stray light image divided by an F6 image (100 sec exposures). Left: Before division by flat field. Right: After division by flat field.**

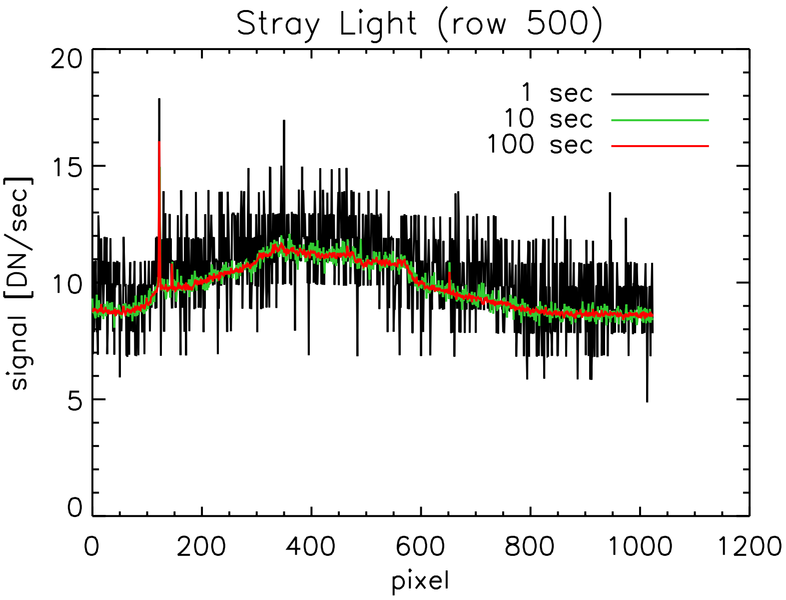

**Figure 7. CCD linearity investigation. Shown is the profile of row 500 of F1 images (exposure times indicated) with the Sun at 30°.**