Data Reduction Report

Jun 16, 2020

Contents

1 Final Light curve

The plot below shows the final light curve built with the default aperture.

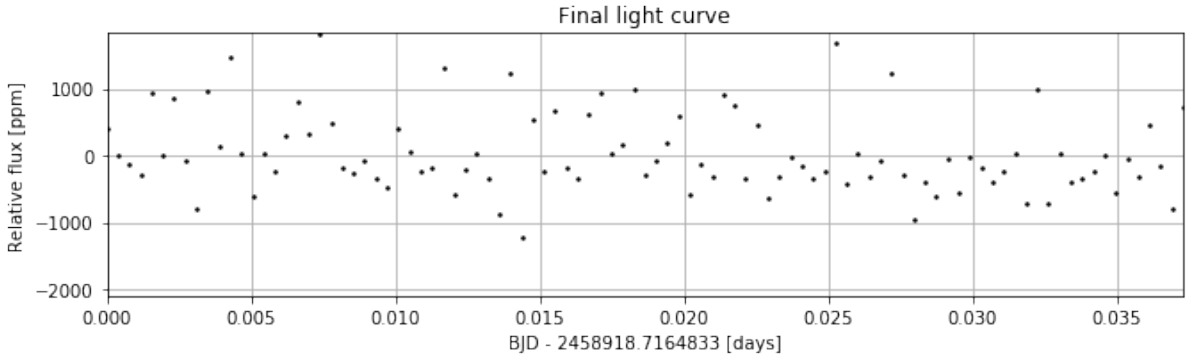

Figure 1: Final light curve of the observation corresponding to the DEFAULT aperture size. Only non-flagged points are shown.

1.1 Observation and processing summary

DPR run info	
Processing date	2020-06-16 08:46
Pipeline Version	cn01t-20200615T224519

TARGET	
Name	Pollux
Teff [K]	4620.0
CHEOPS mag	0.74
GAIA G mag	N/A

PROGRAM	
PI	Andrea FORTIER
PI ID	5572
Observation ID	1015985
Visit Number	1
Program Type	30
Program ID	50
Request ID	1

Observation info	
Start [UTC]	2020-03-10 05:05
End [UTC]	2020-03-10 06:00
Duration [hrs]	0.91
Number of frames	99
Number of flagged frames	2
Integration time [s]	0.6
Repetition Period [s]	1.1
# Exposures x exp. time [s]	30 x 0.0 s
Imagettes available	Yes
Number of coadded imagettes	990.0
Stacking order of imagettes	3.0

Photometry info	
Aperture shape	Circular
Default radius [pix]	25.0
Optimal radius [pix]	32.0

Table 1. Summary of the observation and DRP run.

1.2 Noise curves and metrics

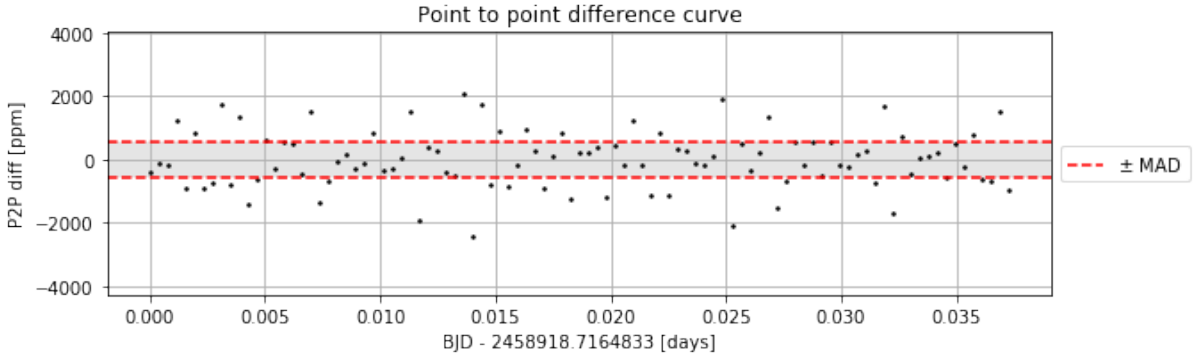

Figure 2. Difference between two consecutive points of the final light curve. Shaded area between dashed lines represents the median absolute deviation of the points (MAD).

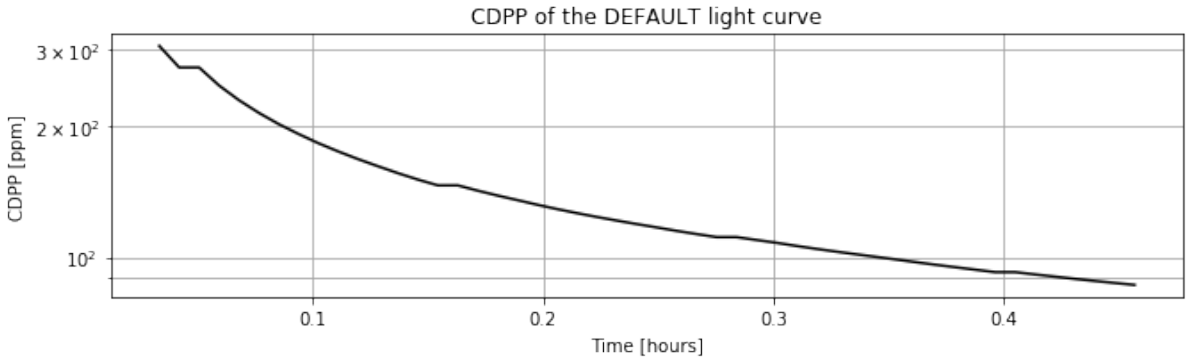

Figure 3. Combined Differential Photometric Precision (CDPP) estimation of the DEFAULT light curve. Only non-flagged points were considered for the CDPP estimation, therefore it might differ from the values recorded in the light curve headers where all the points were considered for the calculus. CDPP is estimated as in the DRP paper: Hoyer et al. (2020).

Light Curve Metrics	
Robust mean flux [e]	4.5553e+08
RMS [ppm]	375
MAD [ppm]	261
CDPP 3h [ppm]	61
CDPP 6h [ppm]	0

Table 2. Metrics of the DEFAULT light curve using only non-flagged points. The CDPP of 3 and 6 hours (if apply) are given in the last two rows of the table.

1.3 Pipeline status

Technical summary of the DR pipeline run. For details please check the log files.

		Skipped modules
Modules ID	ADU_CONV	DARK

DR Section	# Errors	# Warnings
Calibration	0	0
Correction	0	0
Photometry	0	0

Table 3. Number of errors and warnings present in the log files of each section of the DRP. For detailed information please refer to the log files of the DRP.

2 Summary of the processing stages

DR Stage	Units	Mean	RMS
Bias	ADU/frame	5.63e+02	1.14e-13
RON	ADU/frame	7.30e+00	2.66e-15
Dark current	e-/pix/s	4.00e-02	6.94e-18
Gain	e-/ADU	1.96e+00	2.22e-16
Smear	e-/pix/s	4.95e+03	1.20e+02
Background	e-/pix/s	3.02e+04	1.40e+02

Table 4. Description of the quantities used for calibrating and correcting the data.

DRP step	RMS [ppm]	CDPP [ppm]
raw	141.9	14.5
Bias	141.9	14.5
ADU to e-	155.6	15.9
Linearization	159.2	16.2
Dark	159.2	16.2
Flatfield	157.4	16.1
Bad pixels	526.8	53.8
Smear	527.1	53.8
Background	594.7	60.7

Table 5. Evolution of the dispersion of the derived light curve after each step of the data processing. The RMS and CDPP (3 hours) are calculated with the non-flagged points of the light curves.

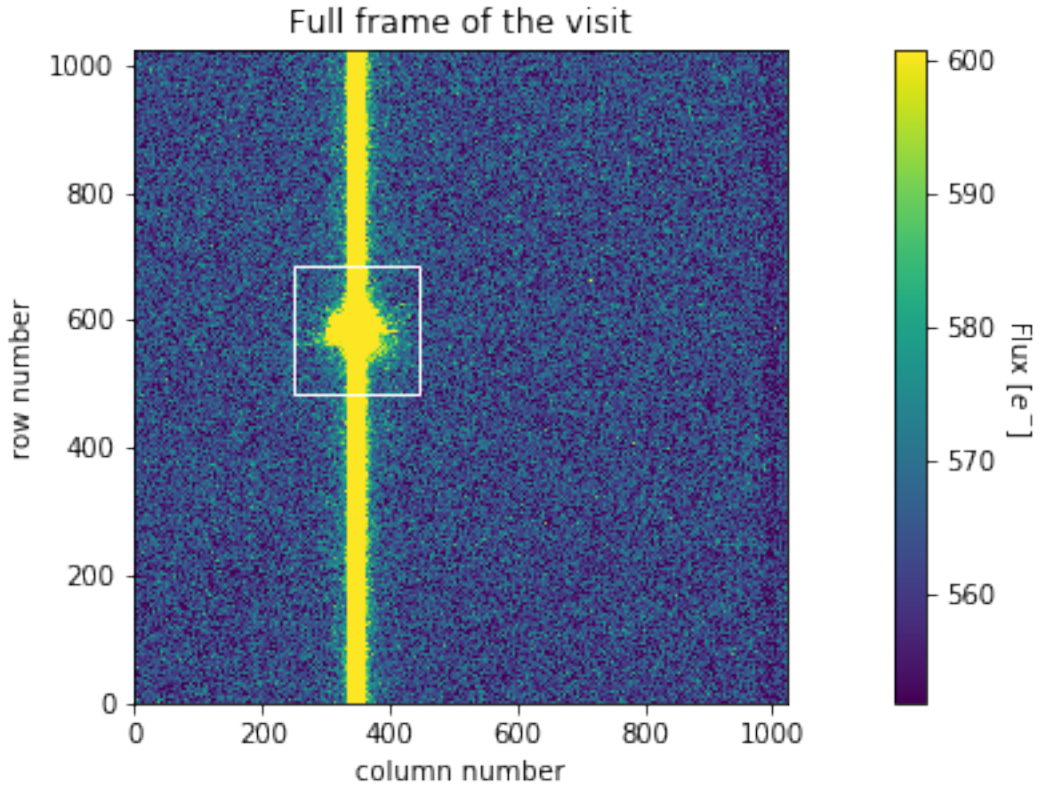

Figure 4. Field of view of the full (1024x1024 pix) CCD. The white square represents the location and size of the subarray window.

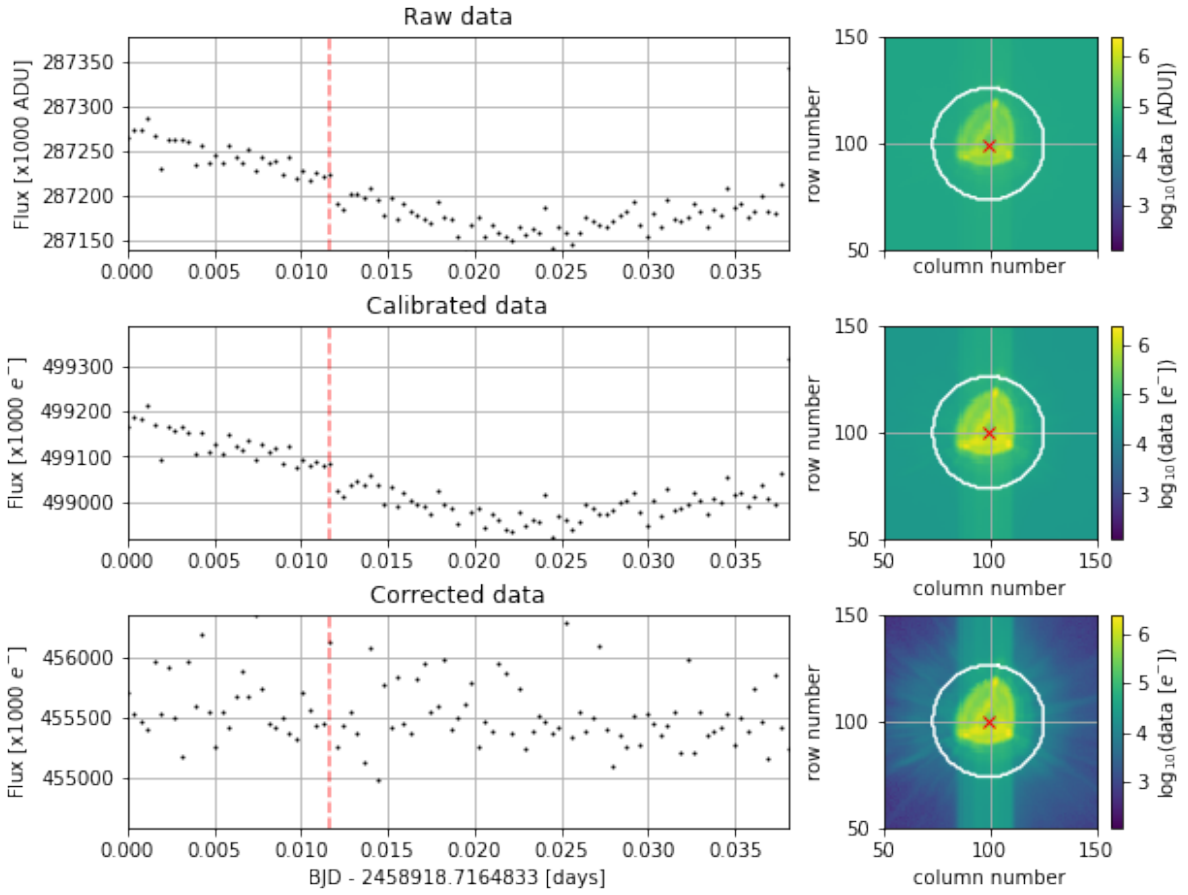

Figure 5. From top to bottom, raw, calibrated, and corrected data. Left: derived light curves after each of the main processing stages. Right: data snapshots of the corresponding processing level. The white circle and the red cross represent the DEFAULT photometric aperture and the estimated centroid, respectively. All points are shown including the flagged points but outliers are clipped for better visualization. The vertical dashed line in the left panel represents the corresponding time of the image shown at the right.

3 Processing summary

The following subsections present the relevant figures and derived light curves of each data processing step. In addition, a measure of the dispersion of the target's light curve before and after each step is given.

3.1 Bias correction

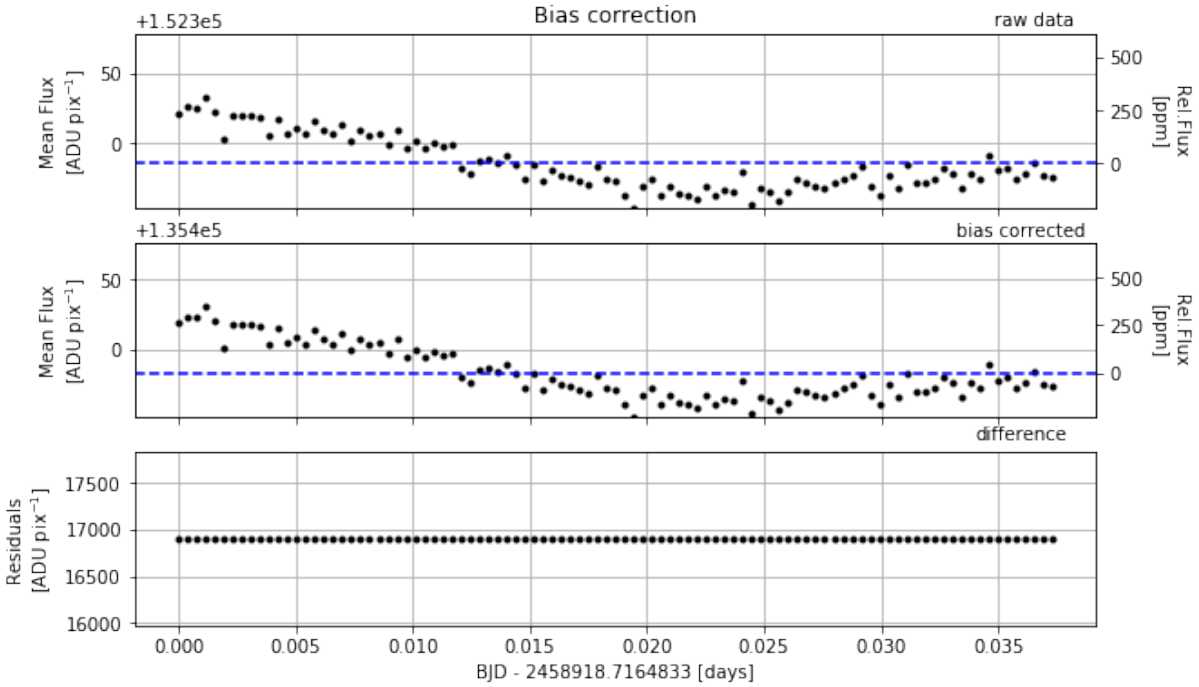

Figure 6. Light curves before (top) and after (middle) bias correction. The bottom plot shows the residuals after correction. The mean of the applied bias is 16902.0 [ADU pix^{-1}] and its dispersion is σ=0.0 [ADU pix $^{-1}$].

	p2p rms [ADU]	diff
before	36225.0	
after	36225.0	0.0

Table 6: dispersion calculated over all the non-flagged points of the derived light curves before and after bias correction.

3.2 Gain correction

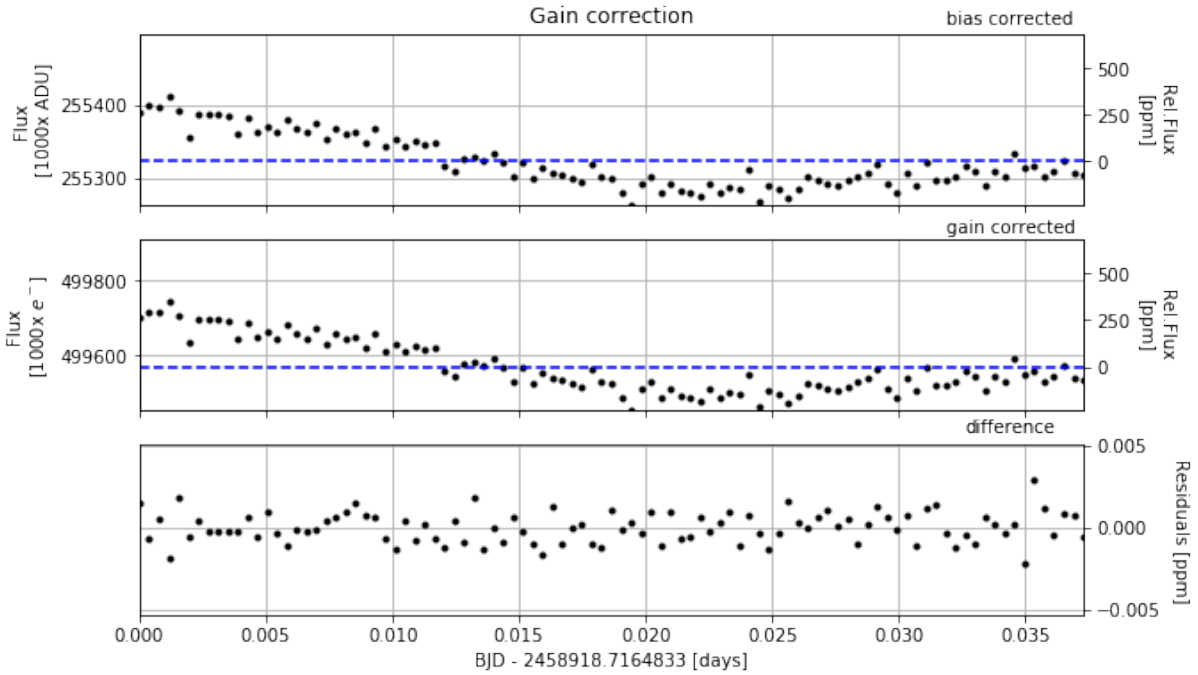

Figure 7. Light curves before (top) and after (middle) gain correction. Difference of the normalized light curves is shown at the bottom. The dispersion of these residuals is σ=0.0009 [ppm].

	p2p rms [ppm]	diff
before	141.9	
after	141.9	0.0

Table 7: dispersion calculated over all the non-flagged points of the derived light curves before and after gain correction.

3.3 Non-linearity correction

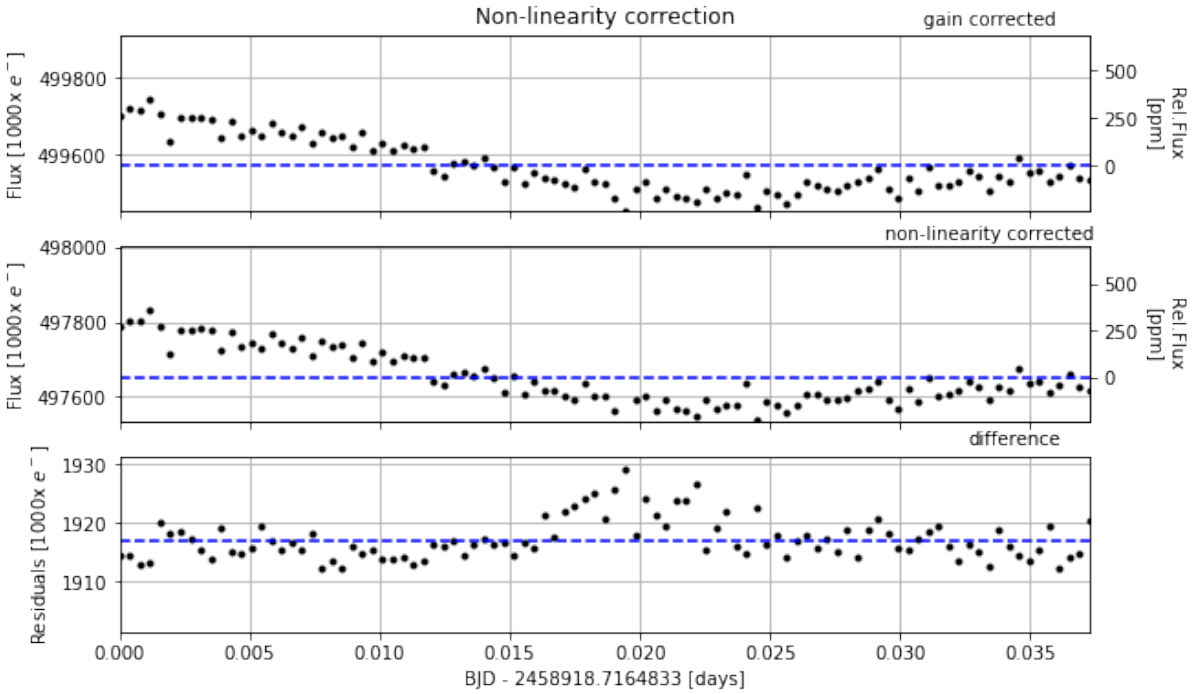

Figure 8. Light curves before (top) and after (middle) non-linearity correction. The difference of these light curves is shown in the bottom panel. The dispersion of the residuals is σ=3467.59 [e^-].

	p2p rms [e]	diff
before	70878.7	
after	72511.5	1632.745

Table 8: dispersion of all non-flagged points of the derived light curves before and after non-linearity correction.

3.4 Dark current correction

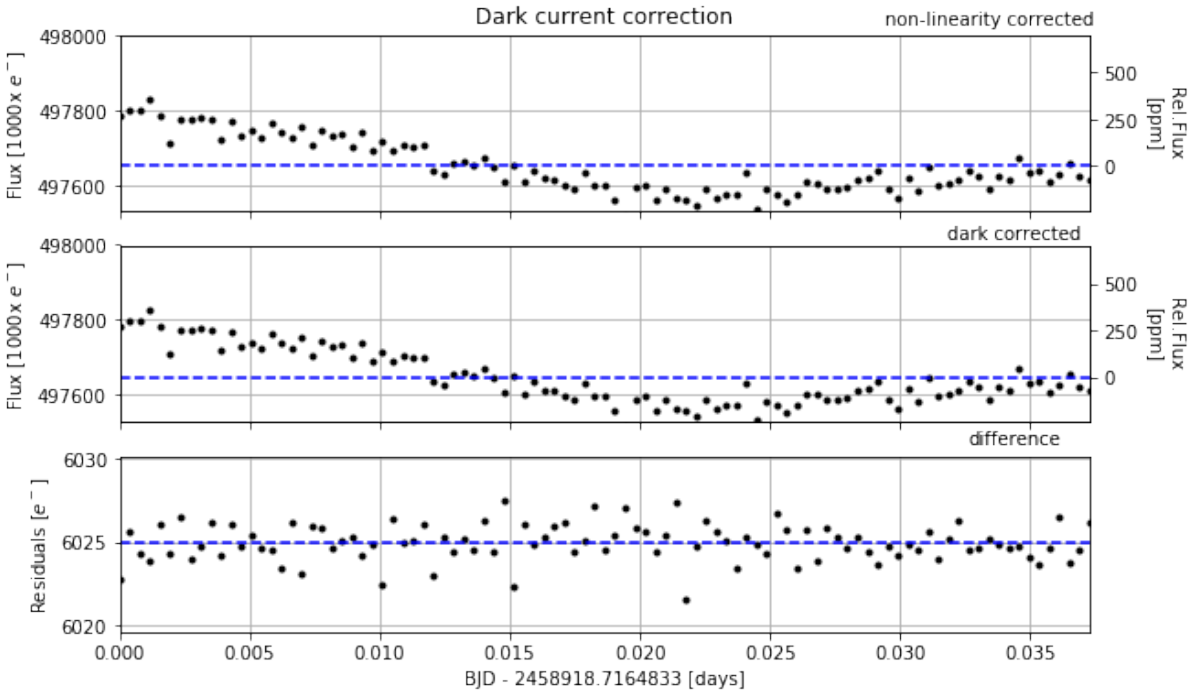

Figure 9. Light curves before (top) and after (middle) dark current correction. The difference of these light curves is shown in the bottom panel. The dispersion of the residuals is σ=7.23 [ppm].

	p2p rms [e]	diff
before	70878.7	
after	72511.6	1632.88

Table 9: dispersion of all non-flagged points of the derived light curves before and after dark correction.

3.5 Flat field correction

Based on the provided temperature of the target, target_teff=4620.0 [K], the flat field correction was performed using the extension of the reference file corresponding to the temperature: 4590.0 [K].

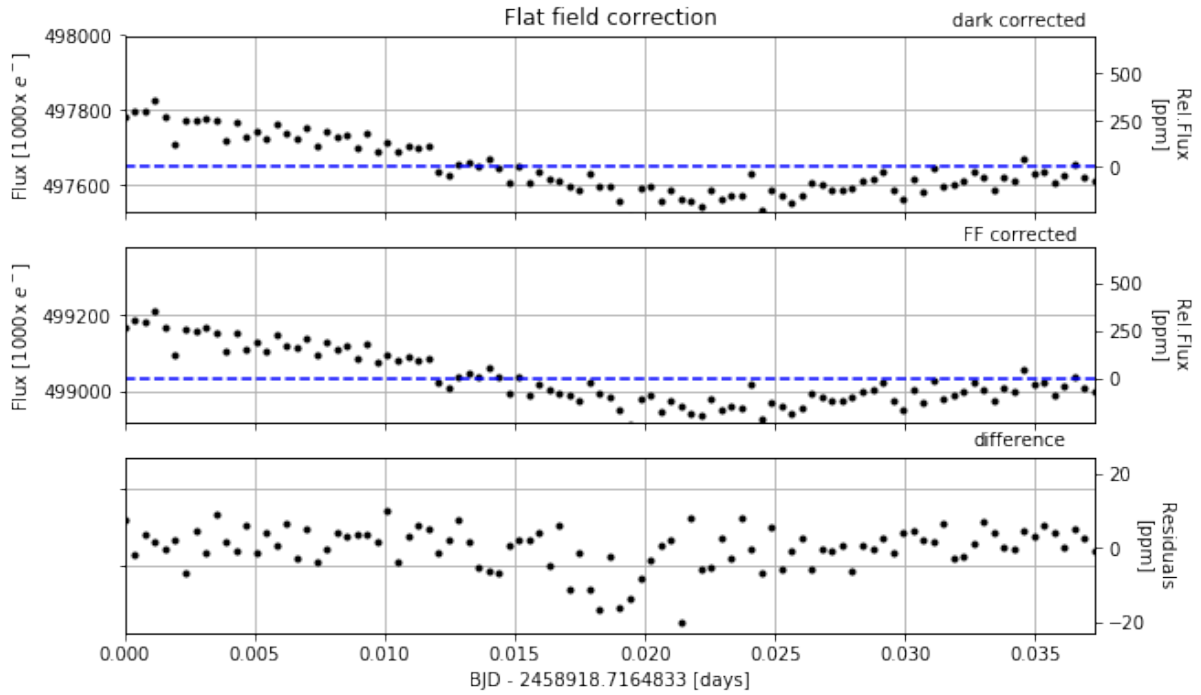

Figure 10. Light curves before (top) and after (middle) flat field correction. The difference between these light curves is shown in the bottom panel. The dispersion of the residuals is σ=5.38 [ppm].

	p2p rms [ppm]	diff
before	159.2	
after	157.4	-1.76

Table 10: dispersion of all the non-flagged points of the derived light curves before and after flat field correction.

3.6 Bad pixels correction

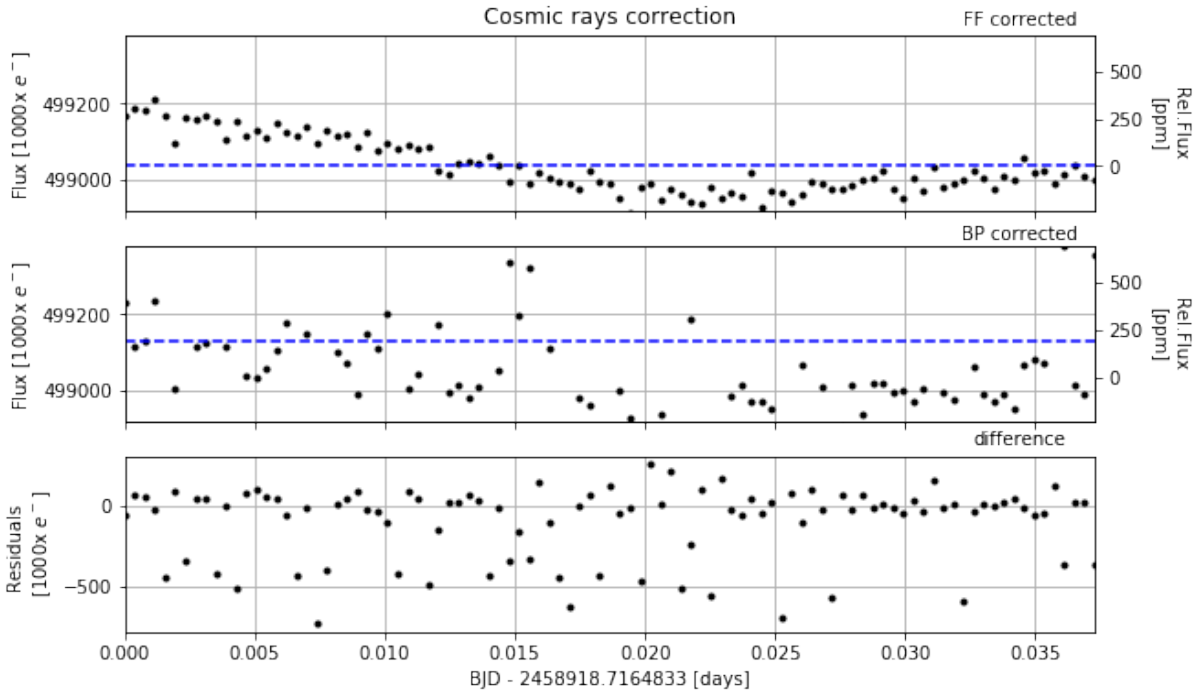

Figure 11. Light curves before (top) and after (middle) cosmic rays correction. The residuals are shown at the bottom. The mean value of the correction is m=-98008.31 [e^-]. Only non-flagged points are shown in the plot.

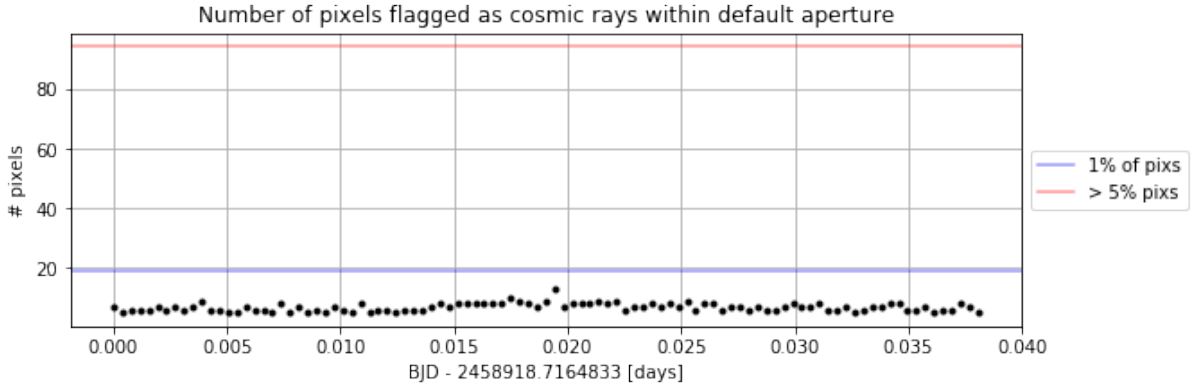

Figure 12. Number of pixels within the aperture affected by cosmic rays on each exposure. Blue line represents the 1% of the total number of pixels in the aperture. Points on the red line, when present, correspond to exposures with at least 5% of pixels affected by cosmic rays hits within the aperture. If present, vertical lines indicate the frames with more than 5% of the total number of pixels affected by cosmic rays (typically a good indicator of SAA crossings).

	p2p rms [ppm]	diff
before	157.4	
after	526.8	369.42

Table 11: dispersion of all the non-flagged points of the derived light curves before and after cosmic rays correction.

3.7 Smear correction

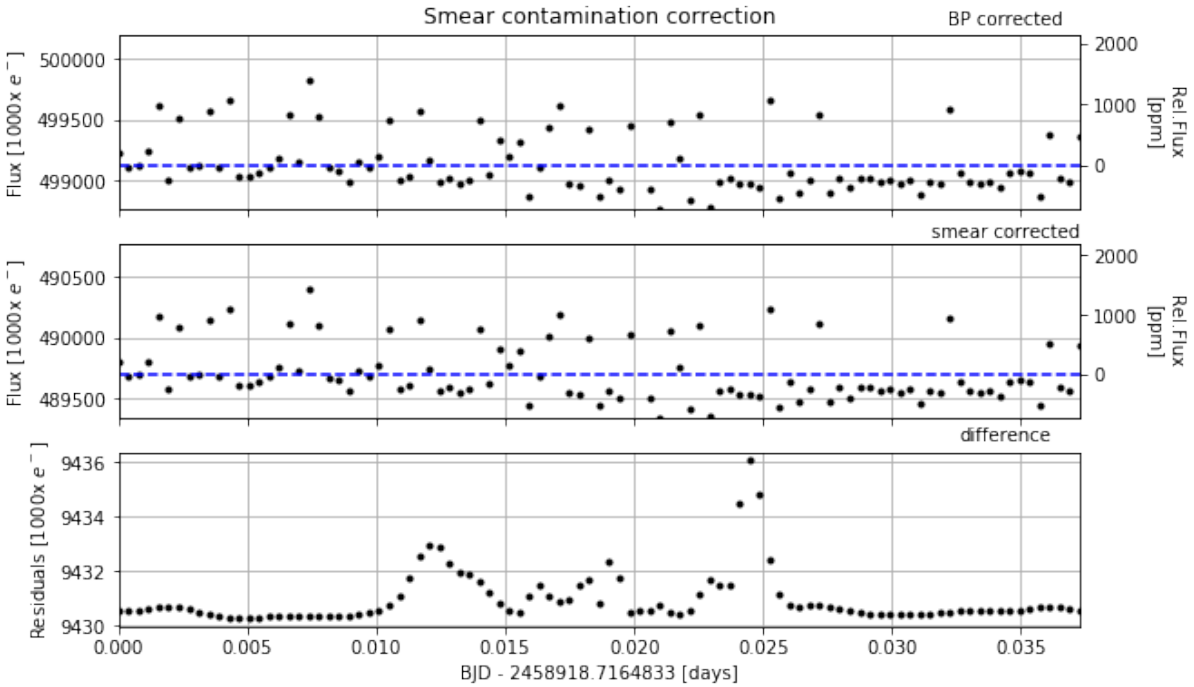

Figure 13. Light curves before (top) and after (middle) correction for smear contamination. The difference of the light curves is shown in the bottom panel.

	p2p rms [ppm]	diff
before	526.8	
after	527.1	0.22

Table 12: dispersion of all the non-flagged points of the derived light curves before and after smear correction.

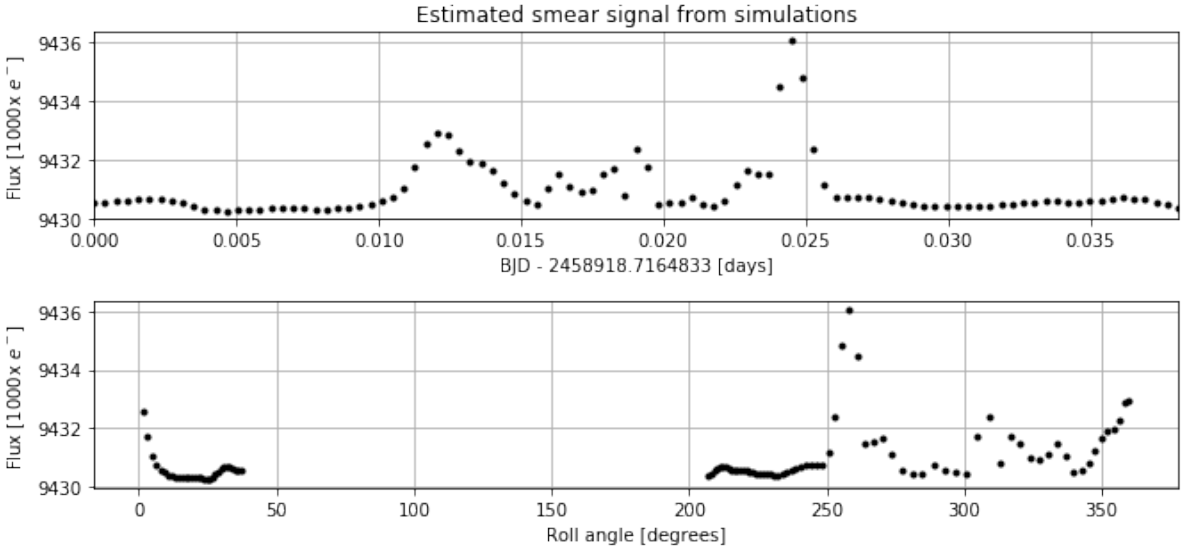

Figure 14. Light curve of the contribution of the smear trails estimated from the simulation of the visit (see section 3.11) as a function of time (top panel) and roll angle (bottom panel).

3.8 Background correction

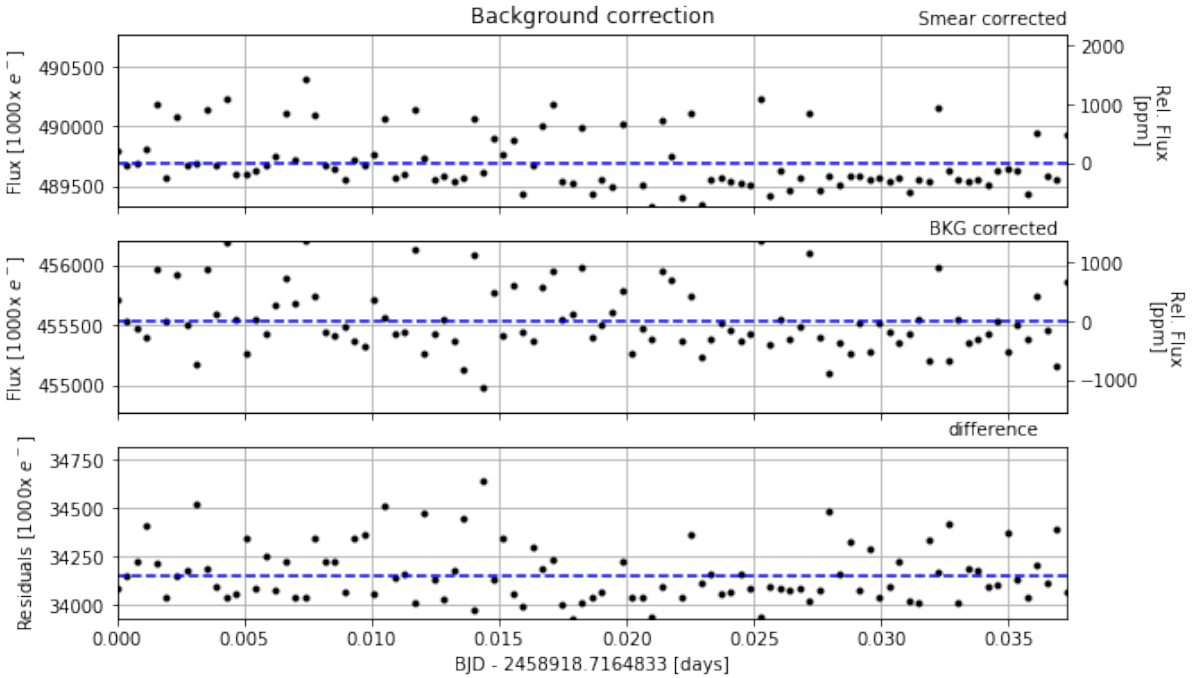

Figure 15. Light curves before (top) and after (middle) background correction. The difference is shown in the bottom panel.

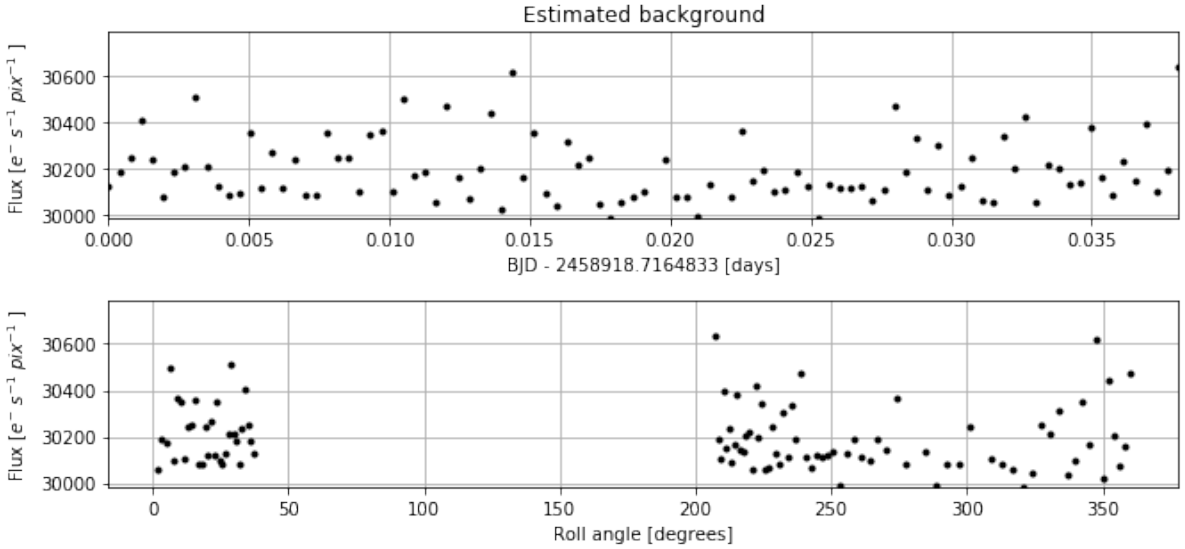

Figure 16. Estimated background signal per image as a function of time (top panel) and roll angle (bottom panel). The points are clipped for better visualization.

	p2p rms [ppm]	diff
before	527.1	
after	594.7	67.6

Table 13: dispersion of all the non-flagged points of the derived light curves before and after background correction.

3.9 Centroids estimation

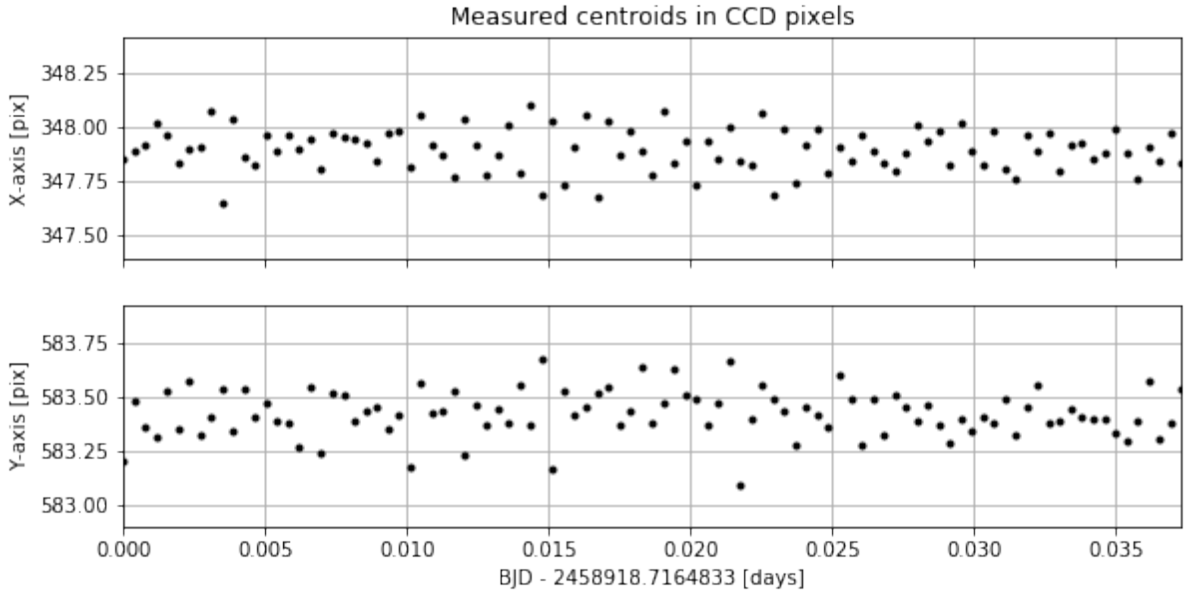

Figure 17. Estimated centroids in the X/Y-axis as a function of time. Pixels are referenced to the corner of the full CCD.

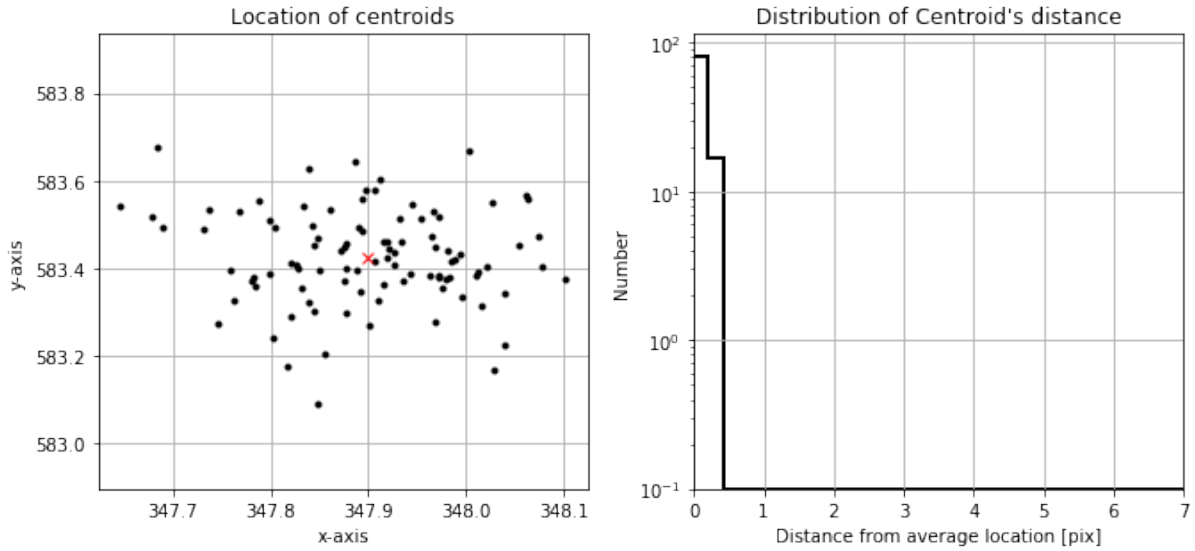

Figure 18. Left: location of the estimated centroids. The red cross represents the average value. Right: distribution of the distance of the centroids to the average estimated centroid.

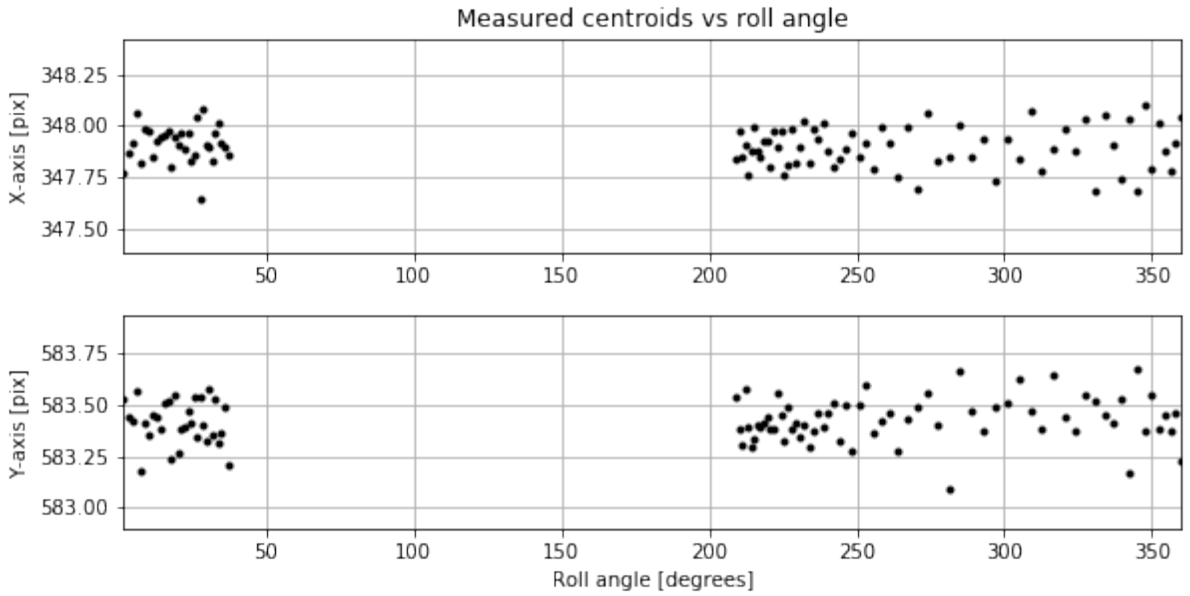

Figure 19. Centroids as a function of the roll angle.

3.10 Flux correlations

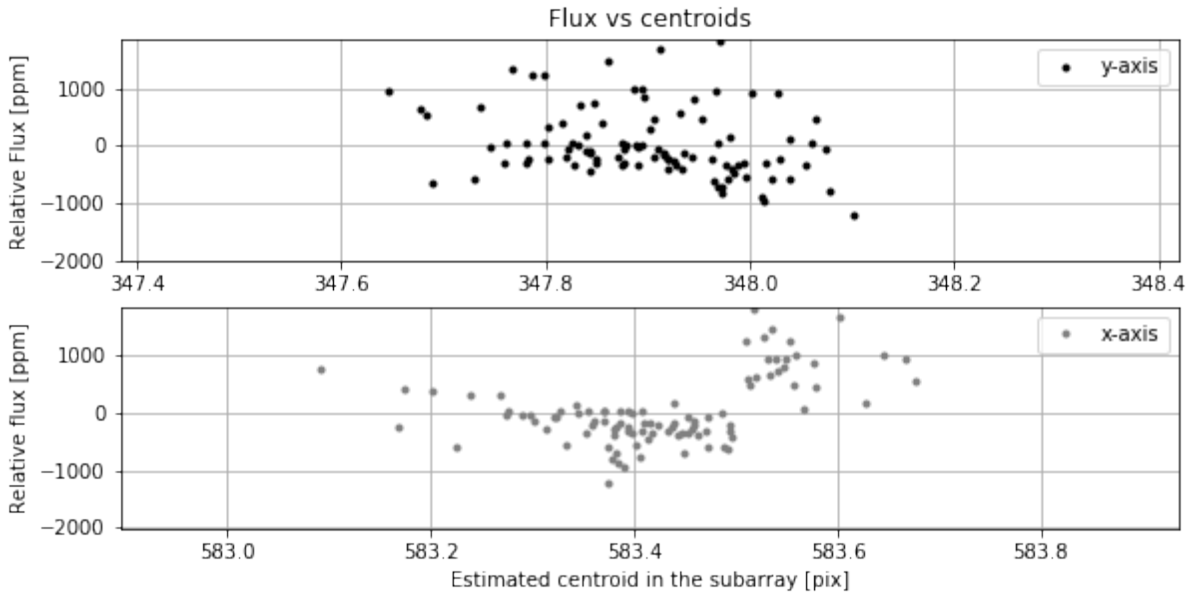

Figure 20. Flux as a function of the estimated centroid in the row (top) and column (bottom) directions. The points are clipped for better visualization.

	max -shift	max +shift	mean shift
Row	347.6	348.1	347.9
Column	583.1	583.7	583.4

Table 14: maximum displacements of the estimated centroids in the row/column directions. The average displacement on each axis is also shown.

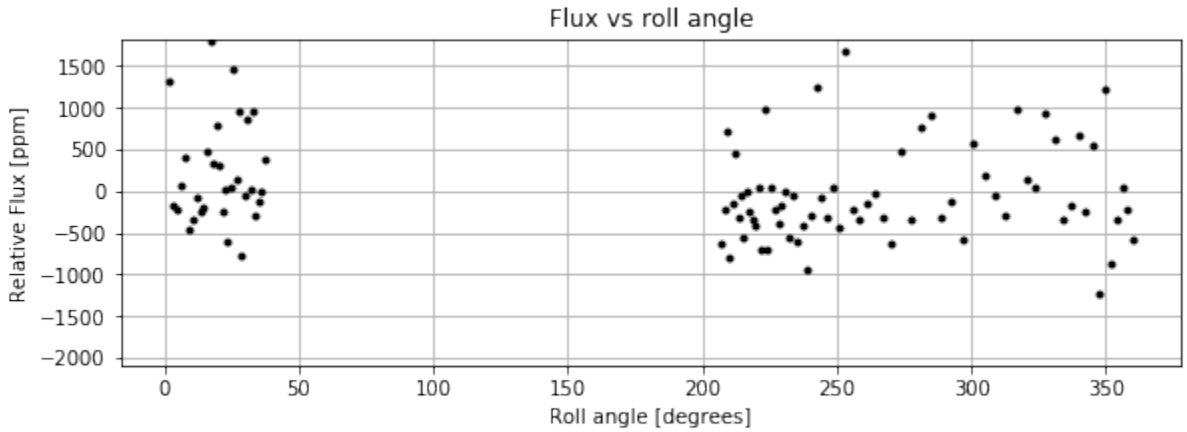

Figure 21. Relative flux as a function of the rotation angle of the exposure. Outliers are clipped for better visualization.

3.11 Contamination Estimation

Based on simulations of the observed Field of View (FoV), the DRP estimates the fraction of flux within the aperture which is induced only by background stars. Figure 22 shows the simulated FoV while Figure 23 shows the light curve (DEFAULT aperture) of the simulated FoV with only the backgrounds stars, i.e., with the target removed.

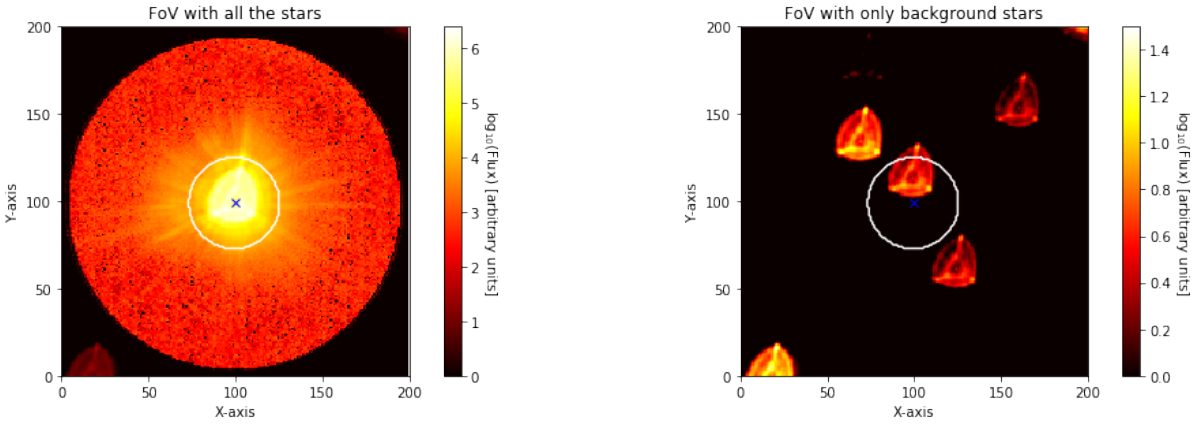

Figure 22. Images of the FoV extracted from the DRP simulations of the observation. Left: all the stars in the FoV are shown (target and background stars). Right: The target has been removed to show only the background stars in the FoV. The white circle and the blue cross represent the default aperture and the target location, respectively.

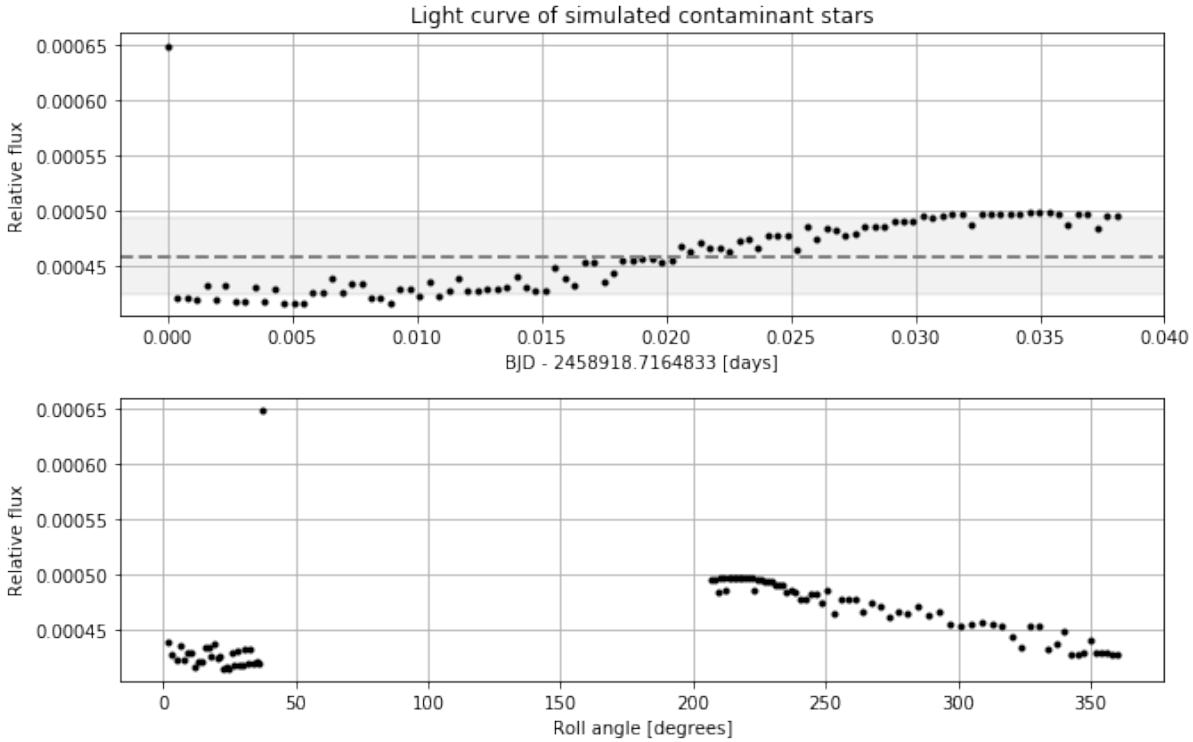

Figure 23. Flux of the simulated contaminant stars in the aperture (black points) as function of time (top panel) and roll angle (bottom panel) relative to the flux of the target. In the top panel, the mean of the contaminant flux (dashed line) and its standard deviation (shaded area) correspond to F_{cont} and σ_{cont} in the noise estimation of the photometry (see following section).

	mean [%]	RMS [%]
bkg stars flux	0.0	0.0

Table 15: Estimated mean and dispertion of the flux of contaminants in the DEFAULT aperture w.r.t the mean flux of the target.

3.12 Aperture Optimization

The optimal radius of the photometric aperture is estimated by using the following expresion:

$$Signal\_to\_Noise = F_{target}/\sqrt{F_{target} + F_{cont} + \sigma^2_{cont} + N_{readout} \times N_{pix} \times RON^2}$$

where:

- F_{target}: median of the simulated flux of the target.
- F_{cont} and σ_{cont}: median and standard deviation of the simulated flux of background stars.
- $N_{readout}$: number of readout per each stacked image.
- N_{pix}: number of pixels in the aperture.
- RON: median read-out-noise of the pixels within the aperture.

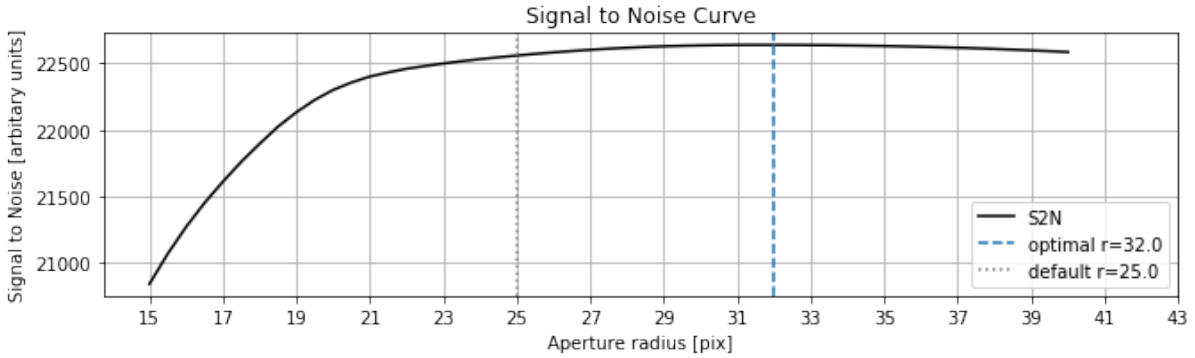

Figure 24. Signal-to-noise as a function of the aperture radius for this observation (see description above). The vertical lines represent the default (dotted-gray) and optimal (dashed-blue) photometric aperture radius.

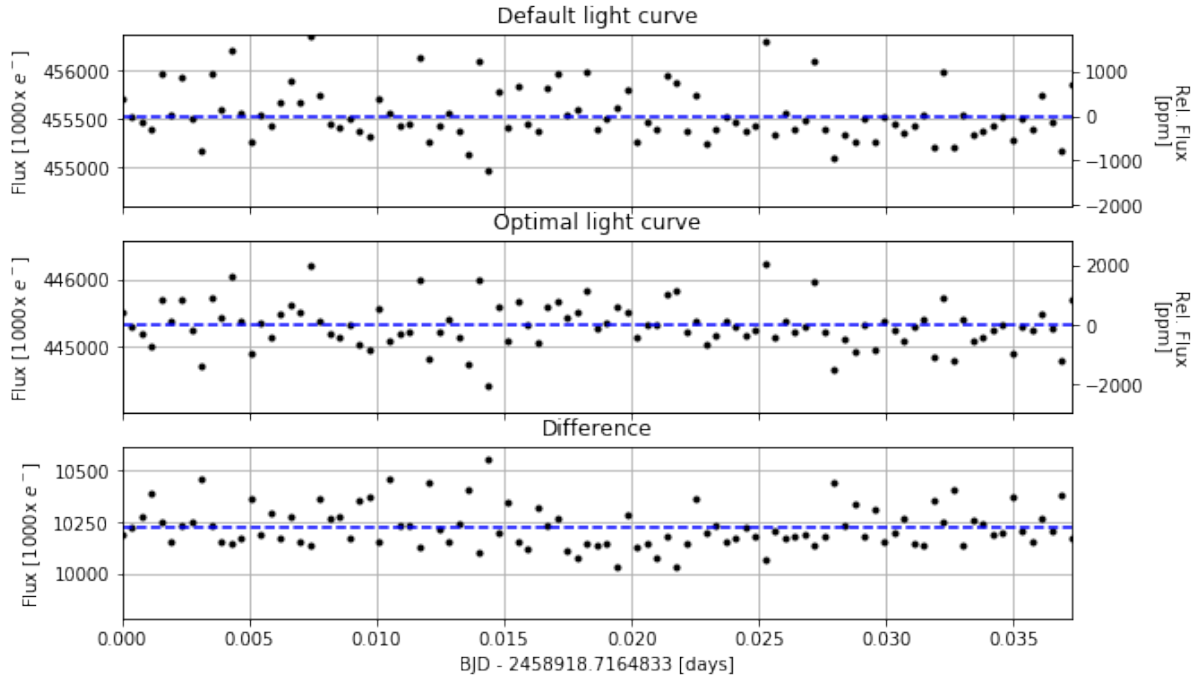

Figure 25. The default and optimal light curves are shown in the top and middle panels, respectively. Bottom plot shows the difference between the two light curves.

	p2p [ppm]	diff [ppm]
default	594.7	
optimal	728.8	134.2

Table 16: dispersion of all non-flagged points of the photometric light curves estimated using the default and optimal aperture radius.

3.13 DRP Light Curves

The DRP produces 4 different light curves for each visit:

- DEFAULT: estimated using the default aperture radius ($r\_default = 25\ pix$).
- OPTIMAL: the aperture radius is automatically set based on SNR (see previous section).
- RINF ($R\_inferior$): using the aperture radius $r = 0.9$x $r\_default$.
- RSUP ($R\_superior$): using the aperture radius $r = 1.2$x $r\_default$.

Each of these light curves are shown in the plots below and their respective metrics are presented in Table 17.

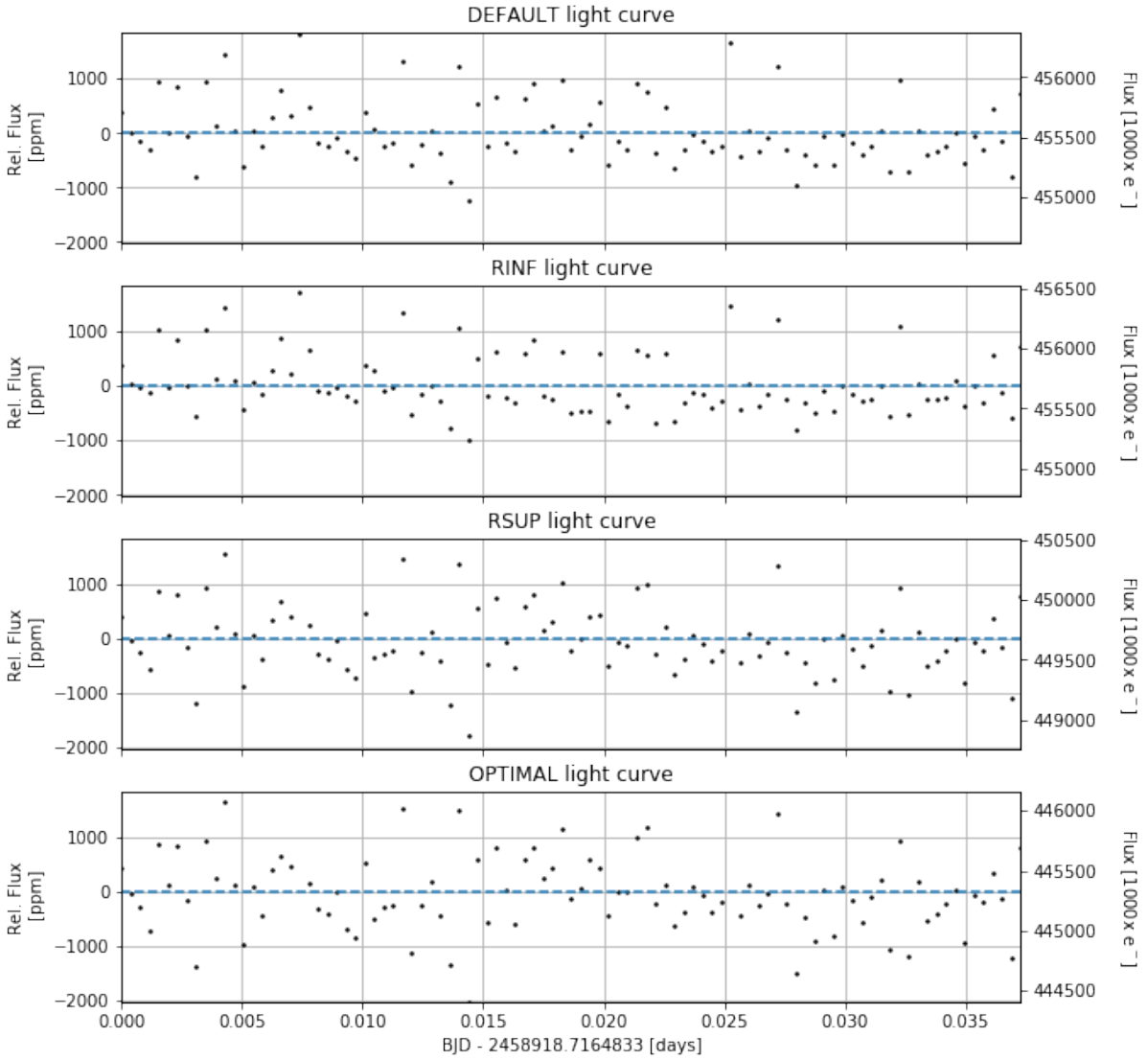

Figure 26. The four light curves produced by the DRP, from top to bottom: DEFAULT, RINF, RSUP, OPTIMAL.

	Radius [pix]	MAD [ppm]	RMS [ppm]	CDPP10m [ppm]	CDPP3h [ppm]
DEFAULT	25.0	261.0	375.0	142.2	60.7
RINF	22.5	251.1	340.7	132.6	57.0
RSUP	30.0	376.1	575.9	164.9	70.2
OPTIMAL	32.0	389.7	645.7	178.5	76.1

Table 17: Metrics for each of the DRP light curves: DEFAULT, OPTIMAL, RINF and RSUP. The values of the aperture radius, the median absolute value (MAD), the point-to-point RMS and the Combined Differential Photometric Precision at 10 minutes (CDPP10m) and 3 hours (CDPP3h) are shown.

3.14 Appendix

Below the code used to flag individual data points in the light curves is shown.
The flag integer is represented as: **|5|4|3|2|1|0|**, where each digit corresponds to:

	Flag name	flag1	flag2	flag3
0	SAA	0: outside	1: inside	–
1	Temperature	0: within range	1: outside range (soft)	2: outside range (hard)
2	Earth Constraints	0: Straylight below threshold	1: Straylight above threshold	9: Earth occultation
3	Moon	0: above threshold	1: below threshold (soft)	2: below threshold (hard)
4	Sun	0: above threshold	1: below threshold (soft)	2: below threshold (hard)
5	Cosmic Rays	0: below threshold	1: $>1\%$ aperture contaminated	2: $>5\%$ image contaminated

Table 18: Code used for event flagging of the light curves data points. Moon and Sun flags correspond to relative angular separation thresholds.