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Technical Note

GOME Instrument Performance Monitoring by using LED Measurements

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Table Of Content

1.0 Introduction 5

2.0 ESRIN QA Tools and Data Set 6

3.0 Pixel-to-Pixel Gain Algorithm Description 7

4.0 Analysis of Pixel-to-Pixel Gain Data 8

5.0 Analysis of the Saturation Data 16

6.0 Analysis of the Polarisation Measurement Devices.....24

8.0 Annex A 25

Acronyms and Abbreviations

BU	Binary Unit
DLR	Deutsche Forschungsanstalt fuer Luft- und Raumfahrt
ERGO	Extended Rascals for GOME
ERS	European Remote Sensing Satellite
ESA	European Space Agency
ESRIN	European Space Research Institute
GOME	Global Ozone Monitoring Experiment
LED	Light Emitting Diode
PMD	Polarisation Measurement Device
PPG	Pixel to Pixel Gain
QA	Quality Assurance
SRON	Space Research Organisation of The Netherlands
TPD	Technisch Physische Dienst

List of Figures:

FIGURE 1. LED Calibration Spectra for Band 1A for an integration time of 3 seconds.....8
FIGURE 2. Fitted continuum to the LED Calibration Spectra of the band 1A and 1B (Integration time 3s) (1B has not been shown here because it only includes a few pixels) 8
FIGURE 3. Pixel-to-pixel Gain of band 1A calculated from the fitted curve and the actual readings.8
FIGURE 4. LED Calibration Spectra for band 2B for an integration time of 3seconds.....9
FIGURE 5. Fitted continuum to the LED Calibration Spectra of the band 2B (Integration time 3s) (2A has not been considered as it only includes few pixels).....9
FIGURE 6. Pixel-to-pixel Gain for band 2B for an integration time of 3s.....9
FIGURE 7. LED Calibration Spectra for band 3 for an integration time of 3s.....10
FIGURE 8. Fitted continuum to the LED Calibration Spectra of band 3.....10
FIGURE 9. Pixel-to-pixel Gain for band 3.....10
FIGURE 10. LED Calibration Spectra for band 4 for an integration time of 3s.....11
FIGURE 11. Fitted continuum to the LED Calibration Spectra of band 4.....11
FIGURE 12. Pixel-to-pixel Gain for band 4.....11
FIGURE 13. Difference of the PGG between the 28/07/95 and the 04/02/96 for each channel. The difference is not any larger than +/- 0.0005 BU.....13
FIGURE 14. Difference of the PPG between the 28/07/95 and the 28/07/96 for each channel. The difference is not any larger than +/- 0.0005 BU.....13
FIGURE 15. Difference of the PPG between the 28/07/95 and the 28/01/97 for each channel. The difference is not any larger than +/- 0.0005 BU.....14
FIGURE 16. Difference of the PPG between the 28/07/95 and the 28/07/97 for each channel. The difference is not any larger than +/- 0.0005 BU apart for some pixels at the edge of the detector array.....14
FIGURE 17. Difference of the PPG between the 28/07/95 and the 28/12/97 for each channel. The difference is not any larger than +/- 0.0005 BU.....15
FIGURE 18. LED Calibration Spectra for band 1a in saturation mode (24 seconds).....16
FIGURE 19. LED Calibration Spectra for band 2b in saturation mode.....16
FIGURE 20. LED Calibration Spectra for band 3 in saturation mode.....17
FIGURE 21. LED Calibration Spectra for band 4 in saturation mode.....17
FIGURE 22. Differences in LED Calibration Spectra in band 1a.....19
FIGURE 23. Differences in LED Calibration Spectra in band 2b.....19
FIGURE 24. Differences in LED Calibration Spectra in band 3.....20
FIGURE 25. Differences in LED Calibration Spectra in band 4.....20
FIGURE 26. Polarisation Measurement Devices trend from 28/07/95 to 28/12/97.....22
FIGURE 27. Trend in signal of LED Measurements on the detector 4.....23

1.0 Introduction

GOME was launched on ERS-2 in April 1995 and has been continuously operational since then. It is a scanning nadir-viewing spectrometer, with its primary scientific objective being to retrieve total column ozone globally. To calculate these total column ozone, it measures the radiance from the Earth's atmosphere and surface as well as the irradiance.

The 4 detectors are a linear array of silicon with 1024 pixels of size $25\mu m$ (in dispersion direction) by 2.5 mm (in the along slit direction). They are of type RETICON RL_1024_SRU. In principle, each pixel of the array can be addressed individually; in GOME, however, only the detectors of channel 1 and 2 are split into 2 virtual bands which can have different integration times and readout cycles. The physical dimensions of the detector are 42.7mm * 15mm * 1.9mm, with the light sensitive area being 25.6*2.5mm. This area is covered by a $3\mu m$ thick SiO_2 protectic layer.

The sensitivity of the pixels is determined regularly (the 28th of each month) using in-flight data obtained with LED exposure. The extracted calibration parameter are collected into a complete calibration data base over the entire lifetime of the GOME sensor at ESRIN. A LED source is a monochromatic light, not very stable by nature and change of 30% of light output due to temperature and ageing shall be considered normal!

This is why the LEDs are in the first place used to determine pixel-to-pixel variations and its stability within each detector array.

As technical clarification: The 1. LED driver circuit has in series the LEDs of channel 1,2 and 3. The 2nd driver has in series the LEDs of channel 4 and the PMDs. Therefore the LED measurements for channel 4 can be correlated to the PMD LED measurements.

2.0 ESRIN QA Tools and Data Set

This investigation was mainly done using a tool called ERGO produced under ESA contract by Dornier and SRON. This software is designed to provide quality assurance measures about GOME.

Each month, generally the 28th, a set of calibration files are generated. They contain extra information about the instrument. Among these are the measurements of PPG obtained using an algorithm described in Section 3.0 on page 7.

The data set consists of 5 monthly calibration files regularly spaced in time: we took as reference data set, the measurements performed during the 28/07/95 (orbit 1410 - 1414) and data after every six months (depending on availability). Appendix A gives the details about the orbits chosen.

3.0 Algorithm Description

The algorithms used for the calculation of the PPG are summarised in the following.

The pixel-to-pixel gain is determined from LED calibration measurements, by calculating the difference from a smoothly varying continuum.

Determining the shape of the continuum is the fundamental problem.

TPD uses a 3rd order polynomial fit through the measured LED signals (after substraction of dark signal) as the continuum. Some structure with an amplitude of up to 2% due to reflections of the LEDs on the lens mounting are still noticeable. The determination of the PPG from this polynomial will therefore give systematic errors of up to 2%.

Instead, SRON calculated the continuum as a smoothed spectrum, ignoring outliers (e.g, dead pixels, saturated pixels). Good results can be achieved with a triangular profile of *n_smooth* = 30 pixels half-basewidth.

The generic algorithm is:

Main input: Set of LED calibration raw measurement signals

Processing:

1. Average all the LED calibration spectra.
2. Correct for dark signal.
3. Calculate the continuum level.

   Replace each dead pixel by an approximation.

   Convolve the spectra with a triangular kernel. The signal array has been extended with its mirror image of *n_smooth/2* on each side not to loose any information.
4. Calculate the PPG by dividing the measured values by the continuum.

4.0 Analysis of Pixel-to-Pixel Gain Data

For the same measurement of incident light, different pixel of the detector arrays have different responses. This pixel-to-pixel variation is assessed by illuminating the detector arrays by a LED which is basically monochromatic and illuminates the detector directly, i.e. not through any dispersing element. The monitored detector signal is then a superposition of a smoothly varying signal, caused by the LED characteristics, and a rapidly changing structure, the pixel-to-pixel variation or also called pixel response non-uniformity. After substracting the smooth contribution by applying a polynomial fit to the measured curve, the pixel-to-pixel variation is left.

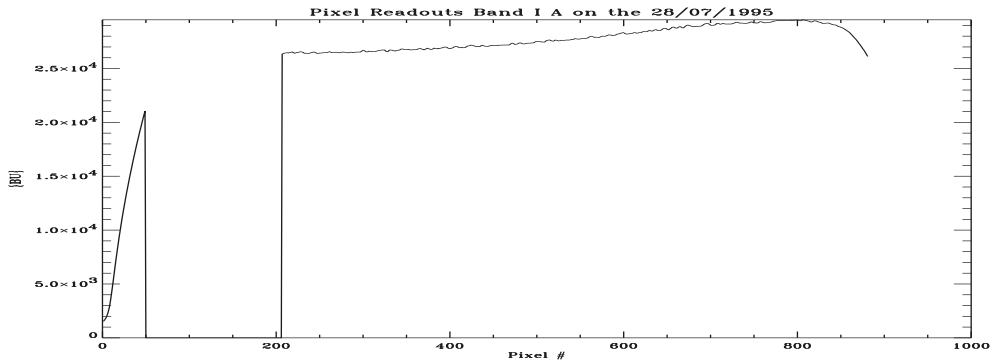

FIGURE 1. LED Calibration Spectra for Band 1A for an integration time of 3 seconds.

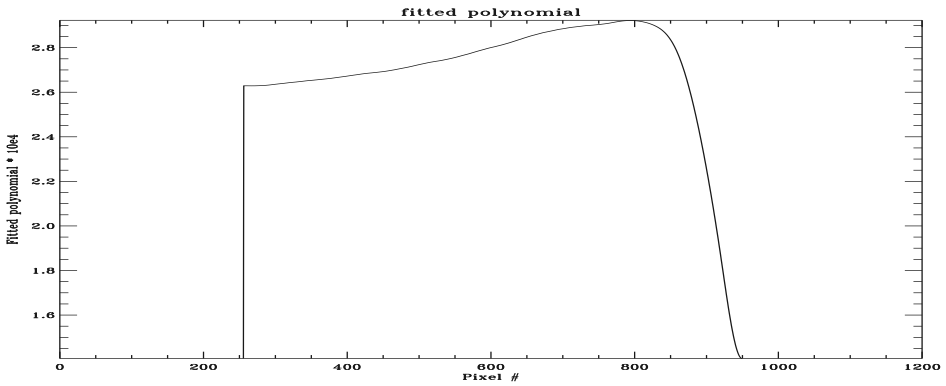

FIGURE 2. Fitted continuum to the LED Calibration Spectra of the band 1A and 1B (Integration time 3s) (1B has not been shown here because it only includes a few pixels of no interest for us).

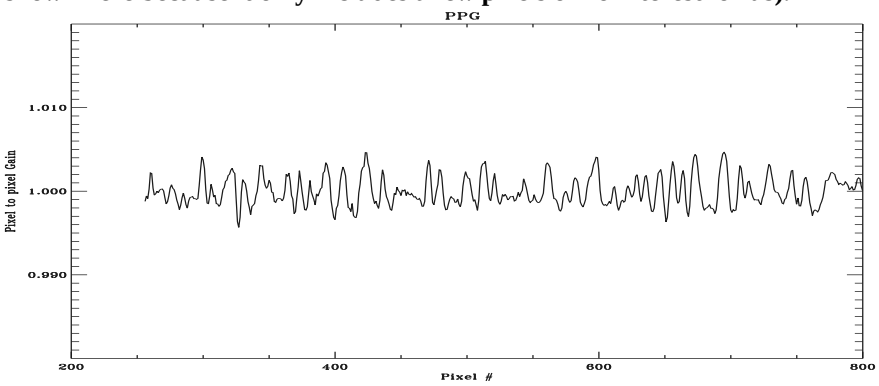

FIGURE 3. Pixel-to-pixel Gain of band 1A calculated from the fitted curve and the actual readings.

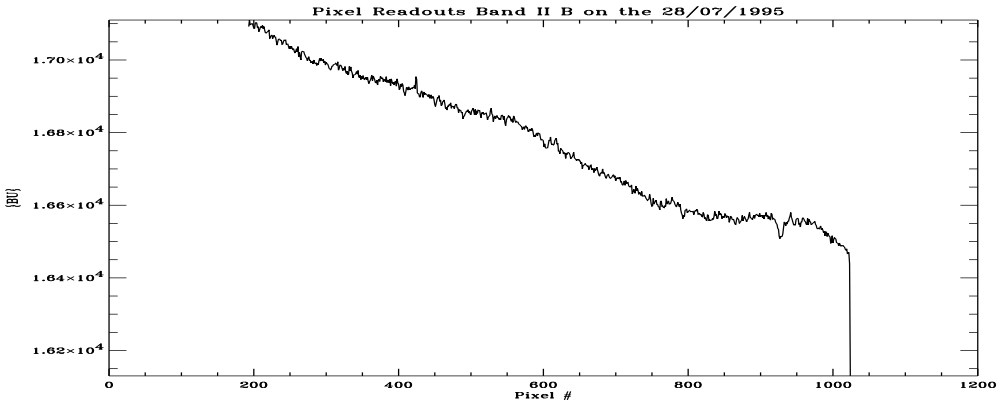

FIGURE 4. LED Calibration Spectra for band 2B for an integration time of 3seconds.

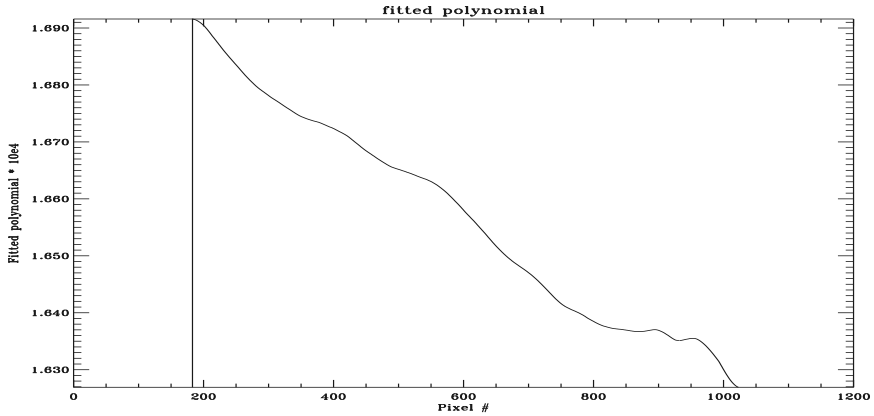

FIGURE 5. Fitted continuum to the LED Calibration Spectra of the band 2B (Integration time 3s) (2A has not been considered as it only includes few pixels).

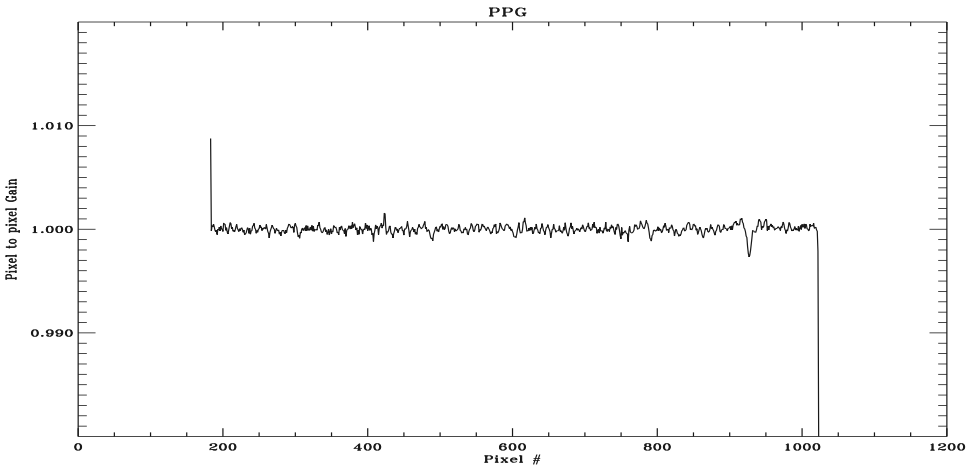

FIGURE 6. Pixel-to-pixel Gain for band 2B for an integration time of 3s.

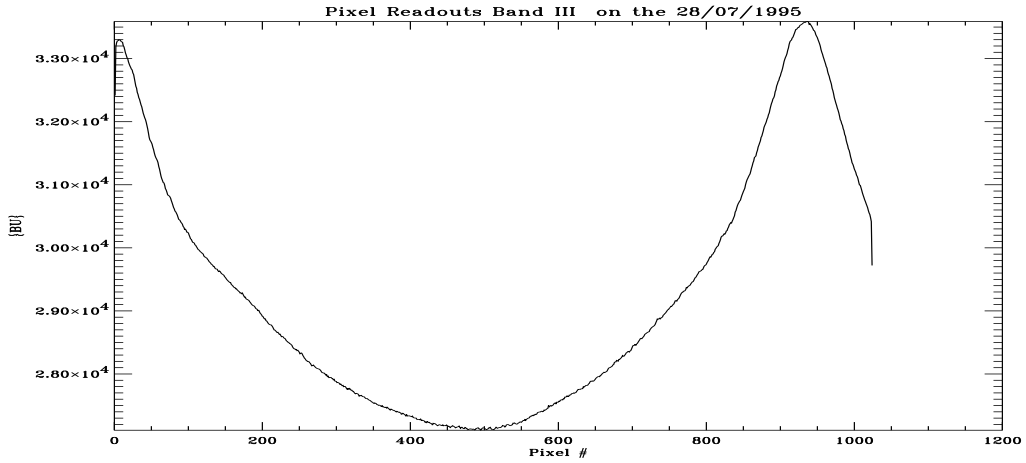

FIGURE 7. LED Calibration Spectra for band 3 for an integration time of 3s.

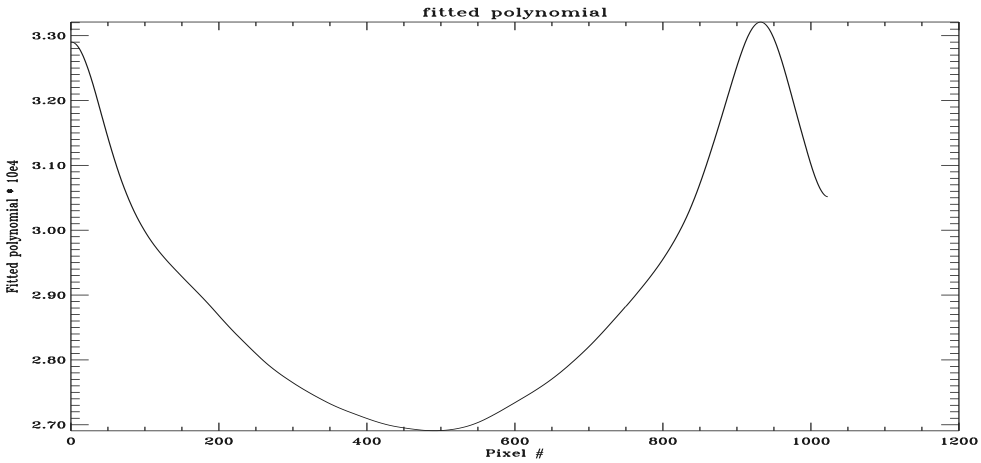

FIGURE 8. Fitted continuum to the LED Calibration Spectra of band 3.

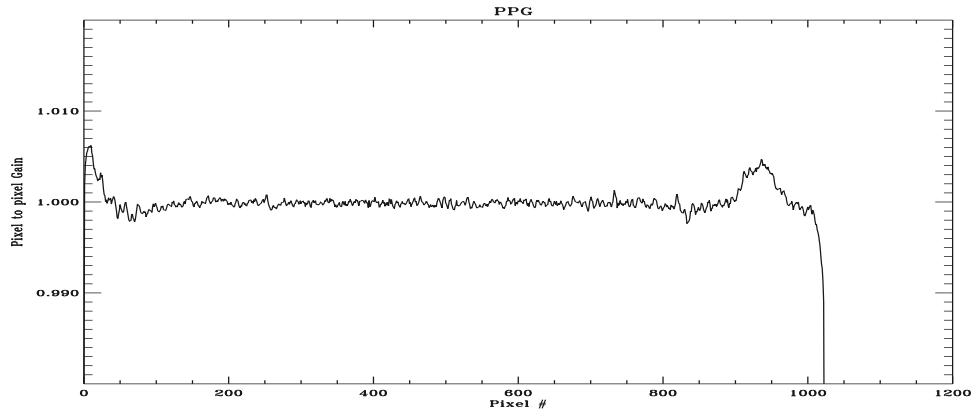

FIGURE 9. Pixel-to-pixel Gain for band 3.

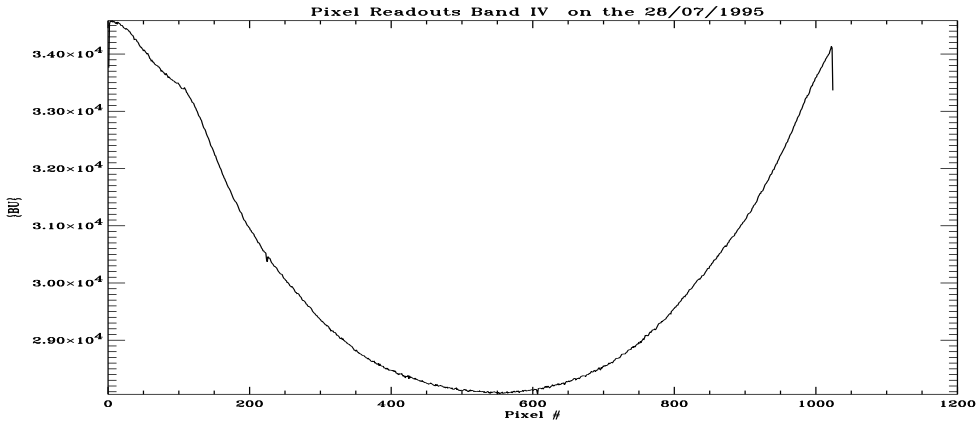

FIGURE 10. LED Calibration Spectra for band 4 for an integration time of 3s.

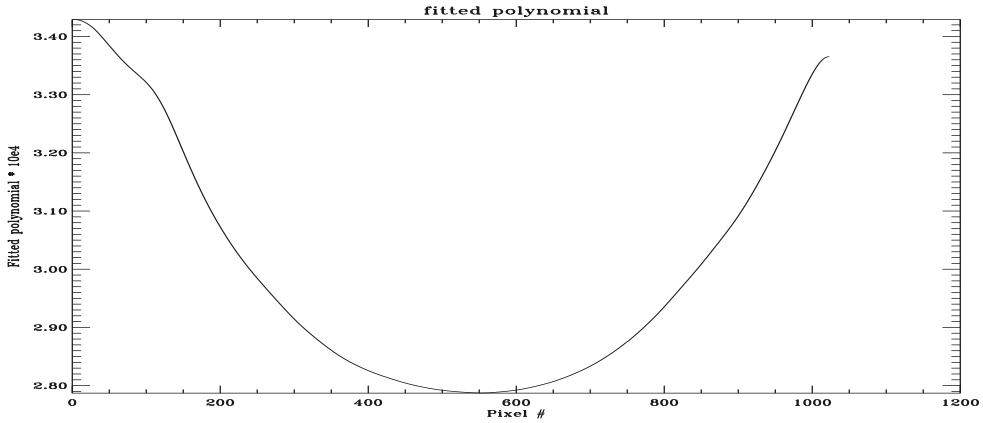

FIGURE 11. Fitted continuum to the LED Calibration Spectra of band 4.

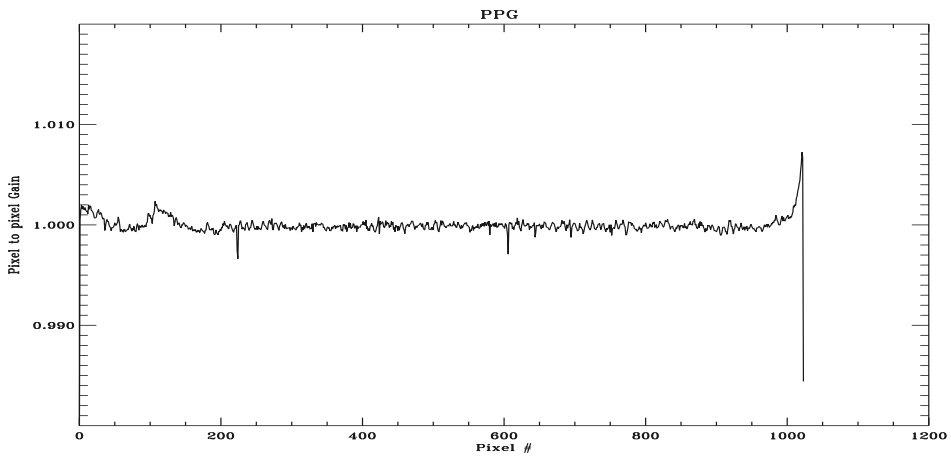

FIGURE 12. Pixel-to-pixel Gain for band 4.

For each of theses graphs, when comparing the LED Calibration spectra with the fitted continuum a shift of more or less 150 BU can be observed. This is due to the dark current, i.e. the plots of the actual measurements have not been corrected for dark current.

Secondly, an assessment of the change of the PPG of the detectors was made.

Data analysed: The PPG values calculated from the average of the LED Calibration Spectra gathered over 5 orbits.

Method: PPG_ref: PPG values of the LED Calibration Spectra of the reference date (28/07/95) which corresponds to day 67 after launch

PPG: PPG values of the LED Calibration Spectra of date spaced of 6 months up to now.

For each of the date: (04/02/96 - 28/07/96 - 28/01/97 - 28/07/97 - 28/12/97)

Trend =PPG_ref -PPG

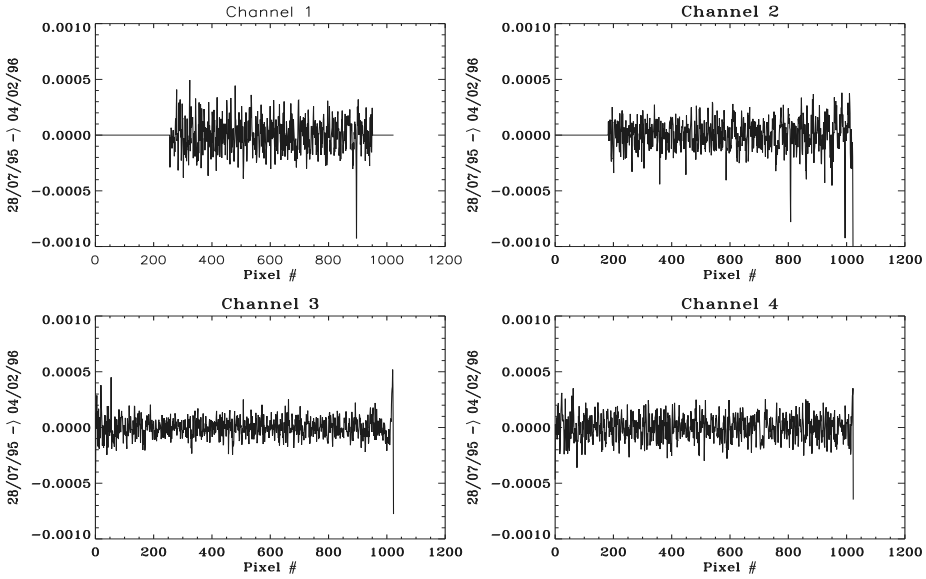

FIGURE 13. Difference of the PGG between the 28/07/95 and the 04/02/96 for each channel. The difference is not any larger than +/- 0.0005 BU.

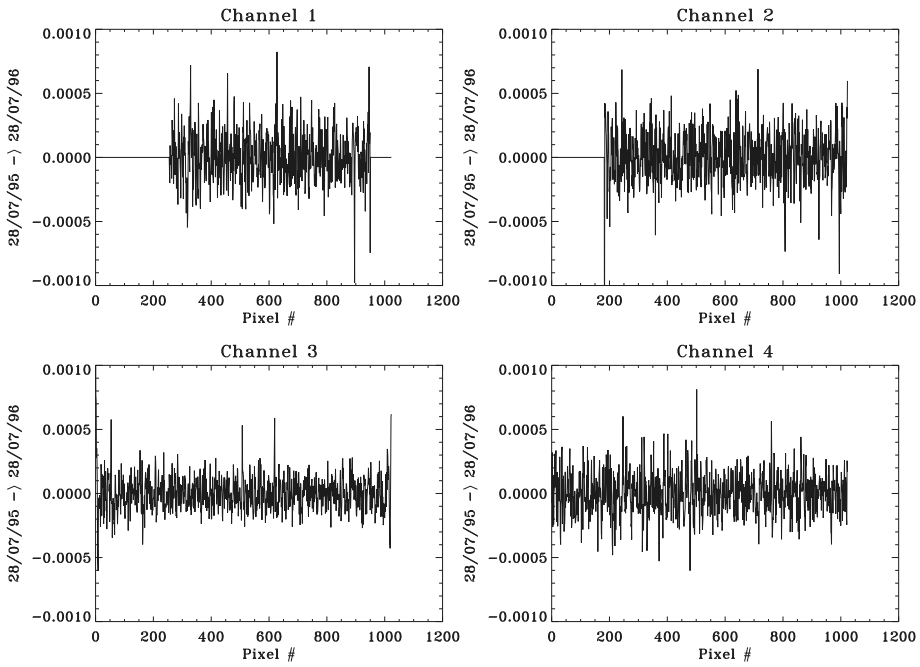

FIGURE 14. Difference of the PPG between the 28/07/95 and the 28/07/96 for each channel. The difference is not any larger than +/- 0.0005 BU.

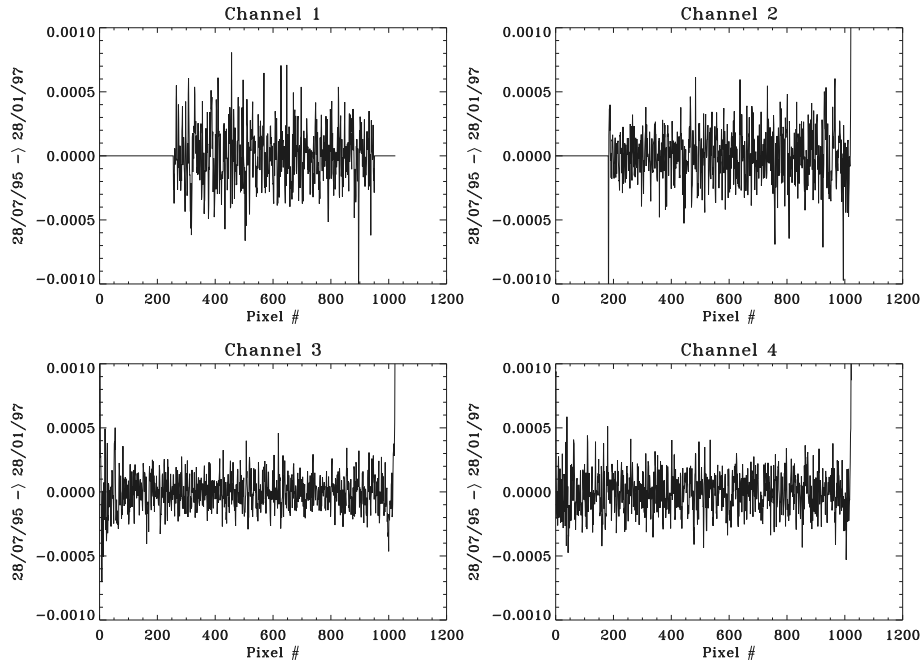

FIGURE 15. Difference of the PPG between the 28/07/95 and the 28/01/97 for each channel. The difference is not any larger than +/- 0.0005 BU.

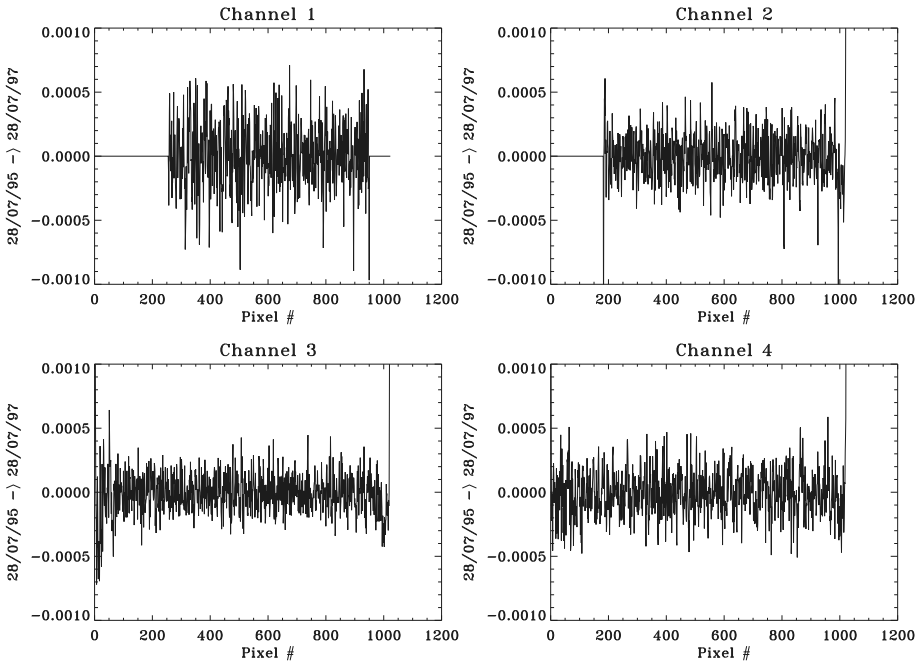

FIGURE 16. Difference of the PPG between the 28/07/95 and the 28/07/97 for each channel. The difference is not any larger than +/- 0.0005 BU apart for some pixels at the edge of the detector array.

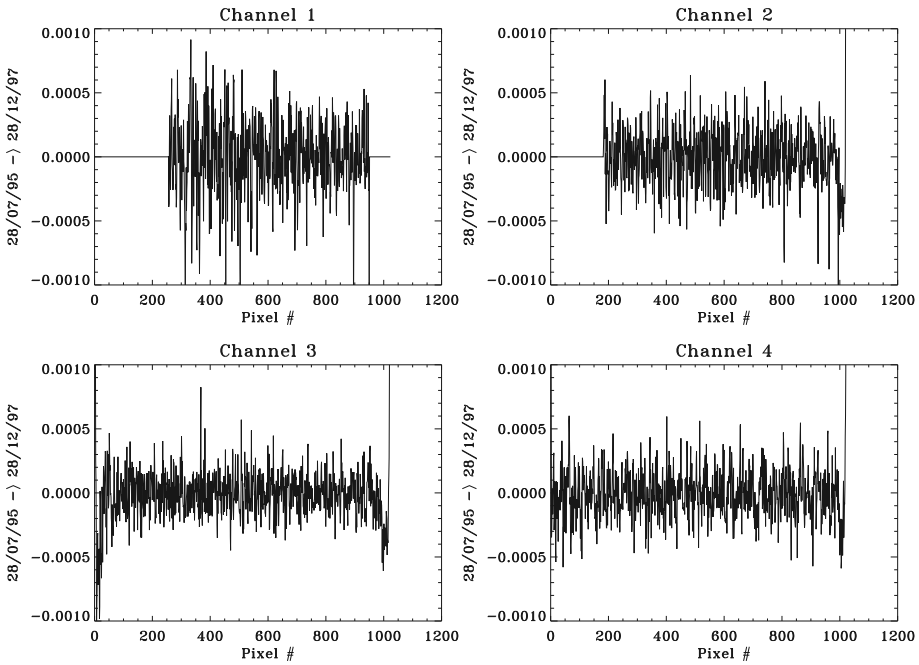

FIGURE 17. Difference of the PPG between the 28/07/95 and the 28/12/97 for each channel. The difference is not any larger than +/- 0.0005 BU

Conclusion:

The analysis shows no significant change of PPG over a period of 2.5 years.

The 5 monthly calibration orbit have been used. The mean of theses 5 orbits was computed, which gave following standard deviation of the PPG:

- 0.015 BU for channel 1,
- 0.0008 BU for channel 2,
- 0.002 BU for channel 3,
- 0.001 BU for channel 4.

5.0 Analysis of the Saturation Data

LED measurements for 24 seconds integration time were used to investigate any changes in the saturation level of the detectors.

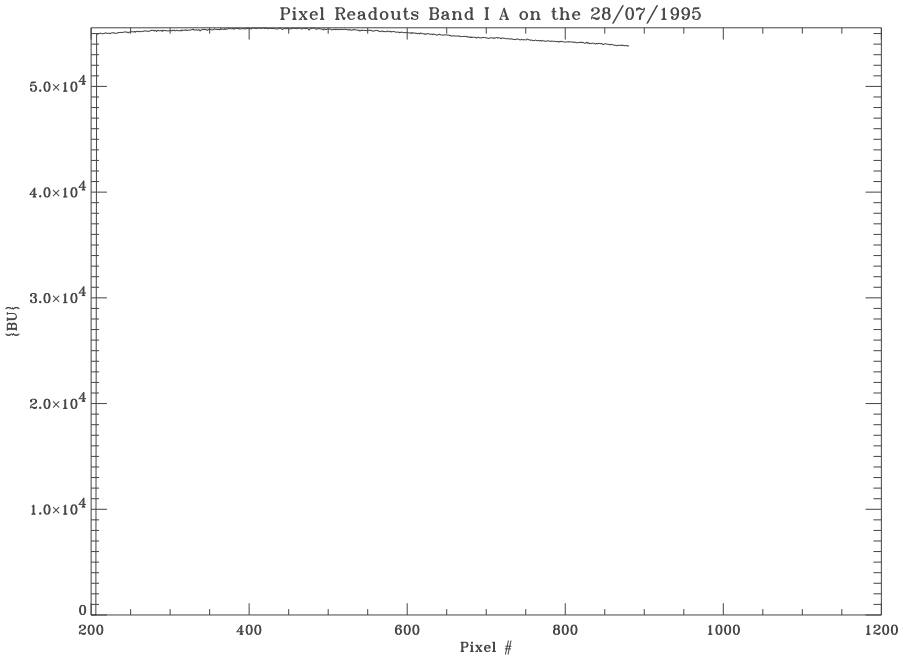

FIGURE 18. LED Calibration Spectra for band 1a in saturation mode (24 seconds).

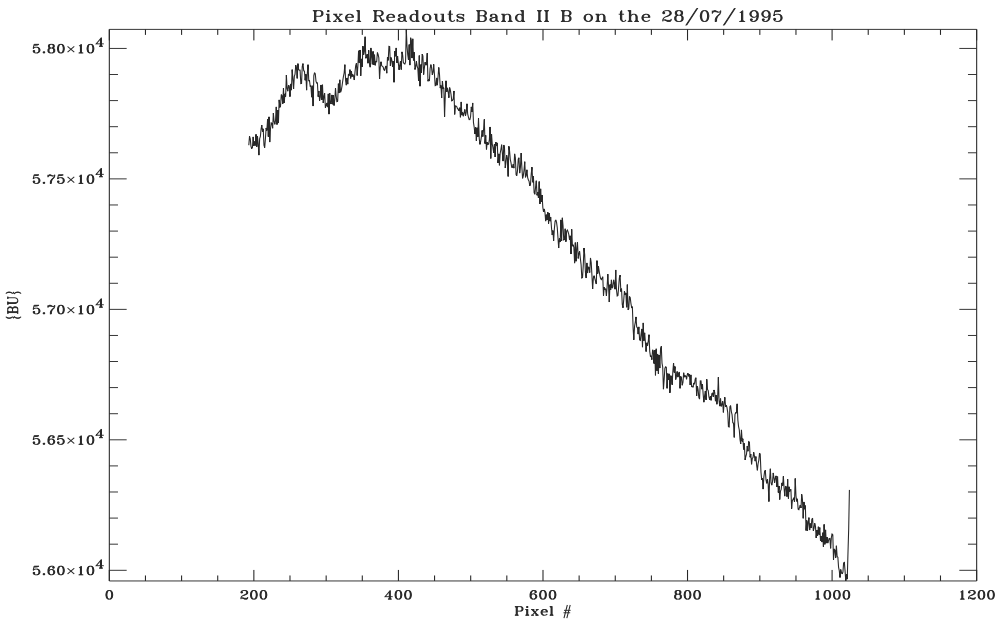

FIGURE 19. LED Calibration Spectra for band 2b in saturation mode.

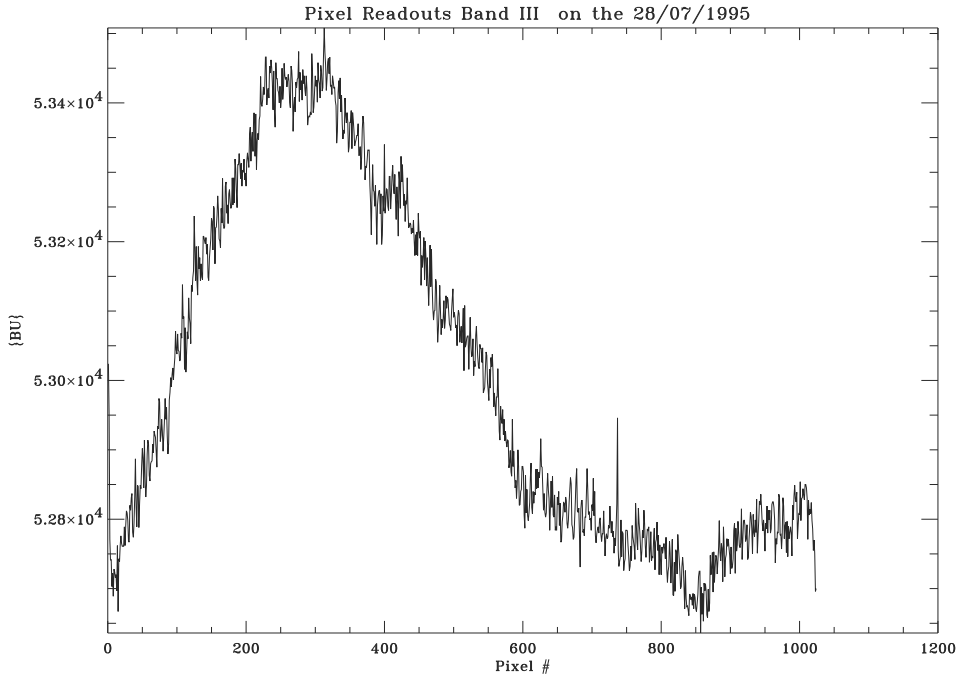

FIGURE 20. LED Calibration Spectra for band 3 in saturation mode.

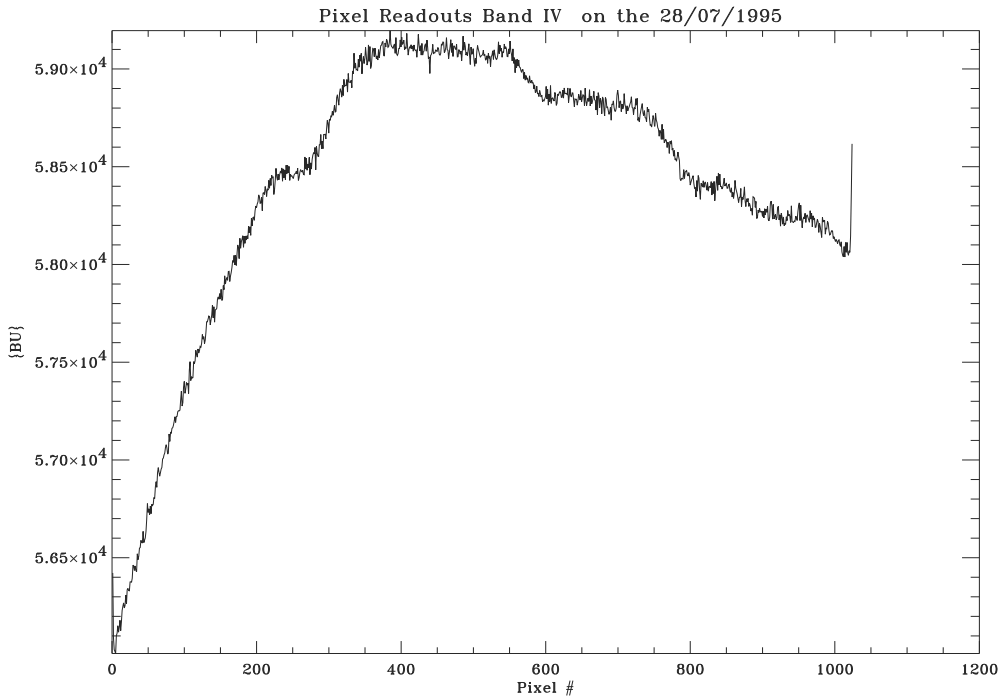

FIGURE 21. LED Calibration Spectra for band 4 in saturation mode.

Trend analysis in saturation mode:

Data analysed: The LED Calibration Spectra in saturation mode. We only use the middle file of each of the 5 monthly calibration orbit.

Method: LED_calib_ref: LED Calibration Spectra in saturation mode of the reference date (28/07/95) which corresponds to day 67 after launch

LED_calib: LED Calibration Spectra in saturation mode of dates spaced of approximately 6 months.

leak_cur: the amount of leakage current corresponding to the date it is subtracted from (see annexe A for values). The fixed pattern noise being constant over time was not taken into account.

For each of the date: (04/02/96 - 28/07/96 - 28/01/97 - 28/07/97 - 28/12/97)

Trend = (LED_calib - leak_cur) - (LED_calib_ref - leak_cur)

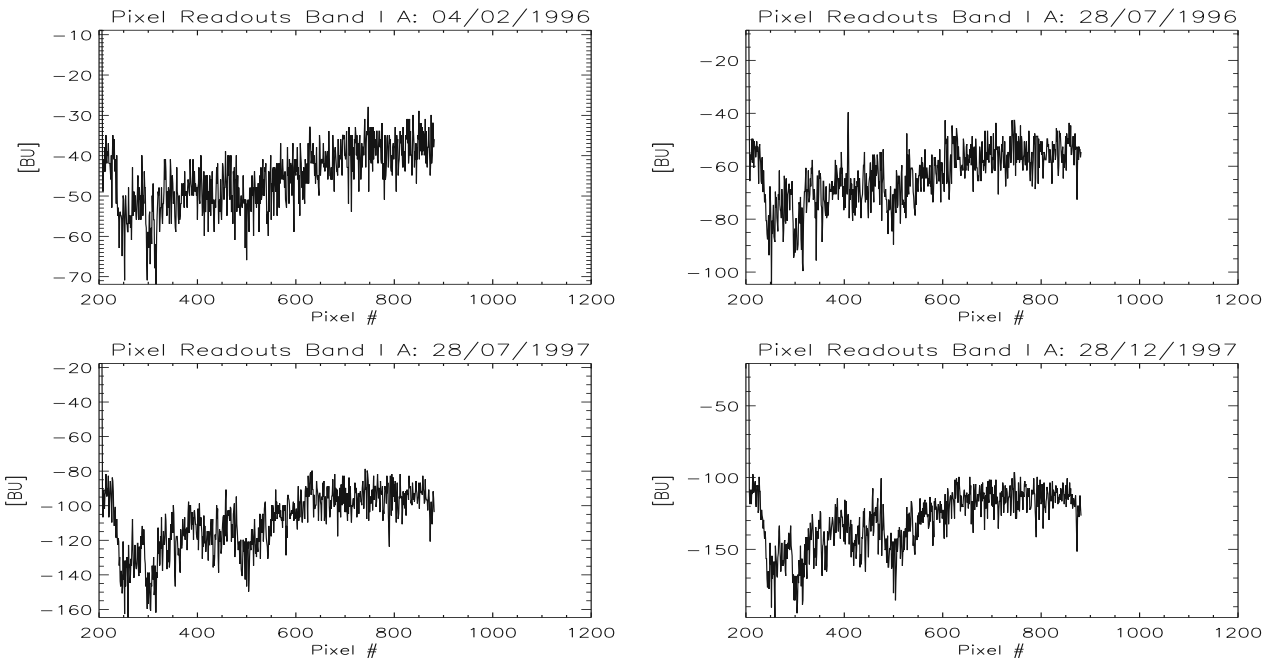

FIGURE 22. Differences in LED Calibration Spectra in band 1a.

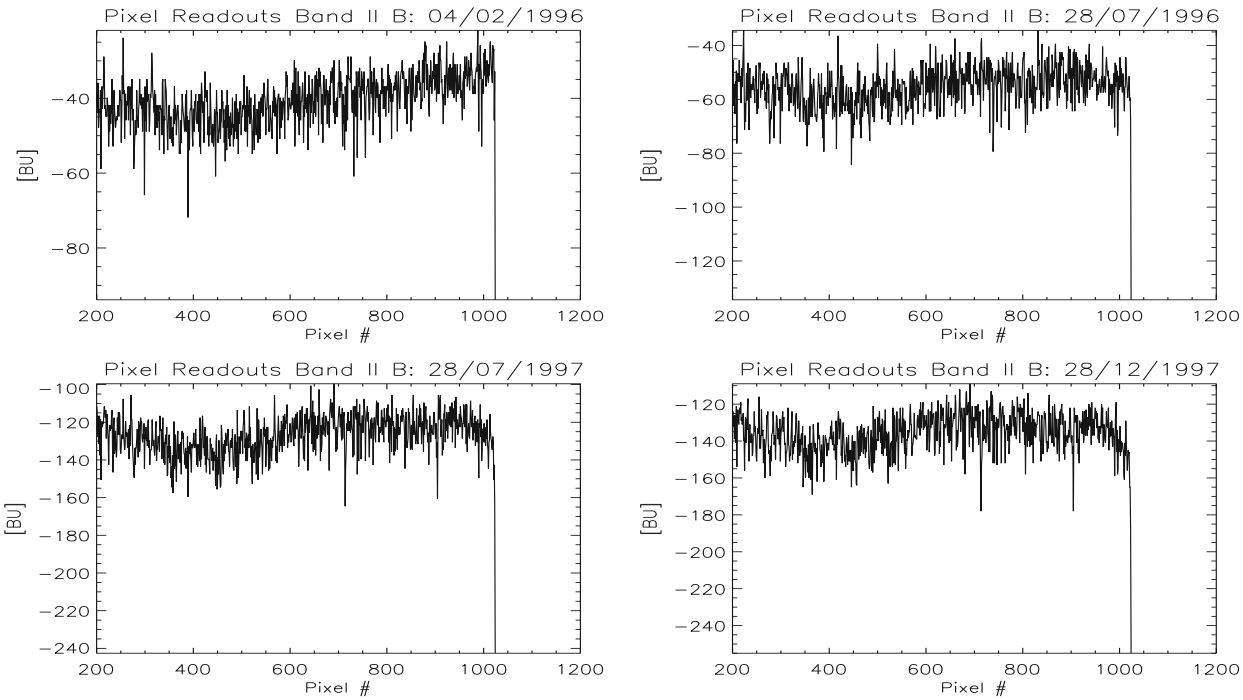

FIGURE 23. Differences in LED Calibration Spectra in band 2b.

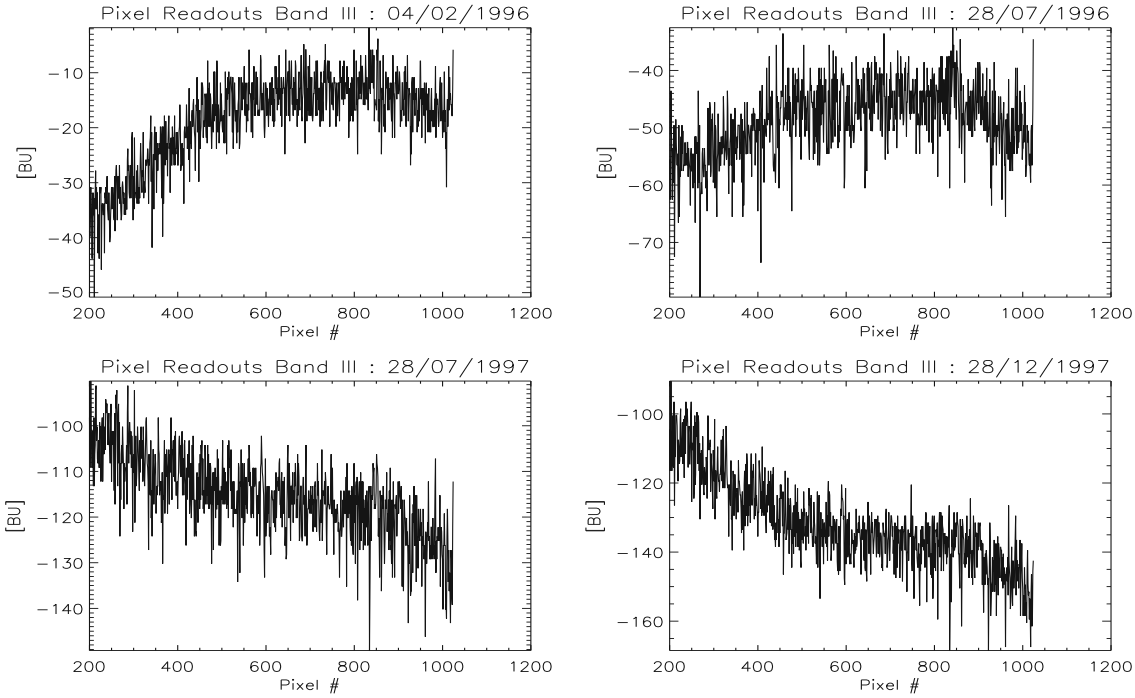

FIGURE 24. Differences in LED Calibration Spectra in band 3.

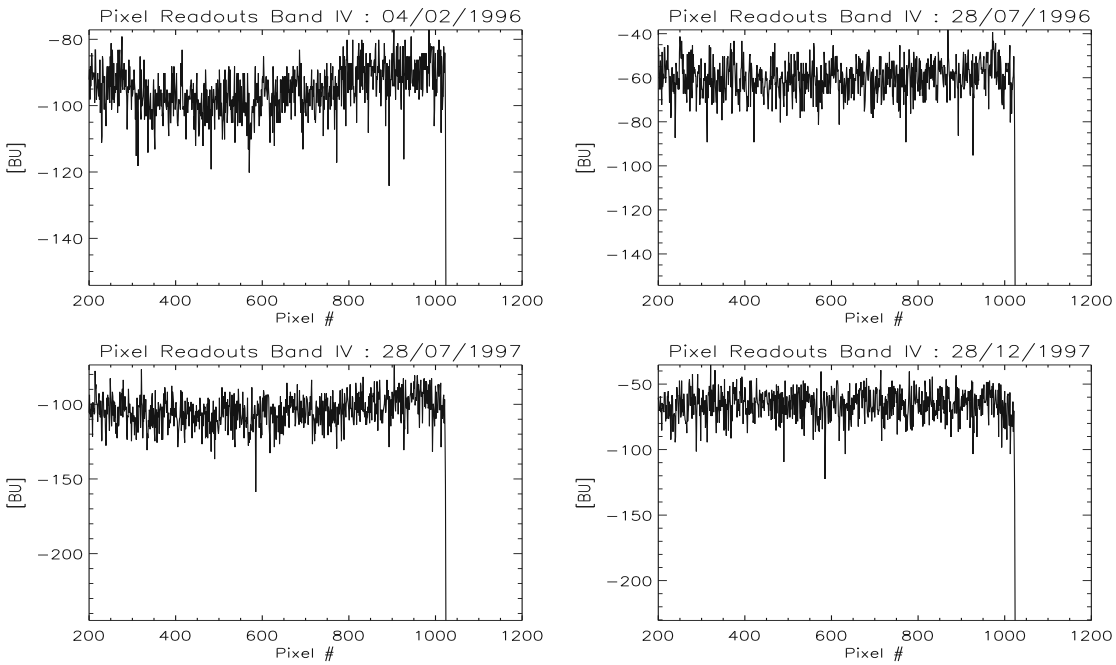

FIGURE 25. Differences in LED Calibration Spectra in band 4.

Conclusion:

In general, saturation measurements are difficult to analyse due to the not known effects on the pre-amplifier and associated electronics.

Differences are:

- Band 1a: about 140 BU over 2.5 years leading to 56 BU/year
- Band 2b: about 140 BU over 2.5 years leading to 56 BU/year
- Band 3: about 130 BU over 2.5 years leading to 52 Bu/year
- Band 4: about 80 BU over 2.5 years leading to 32 BU/year.

Compared to the reference date during the commissioning phase, there is no significant change in the saturation level of the detectors.

6.0 Analysis of the Polarisation Measurement Devices

Set 8 of polarisation measurement devices 1, 2 and 3 was used to monitor a possible degradation of these devices.

Data analysed: PMD measurements of the middle file of each of the 5 monthly calibration orbits.

Method: mean_ref_readouts: Mean value of readouts of the reference date (28/07/95) which corresponds to day 67 after launch.

mean_ref_dk_cur: Mean dark current of the reference date

mean_readouts: Mean value of all readouts

mean_dk_cur: Mean dark current

Trend = (mean_readouts - mean_dk_cur) - (mean_ref_readouts - mean_ref_dk_cur)

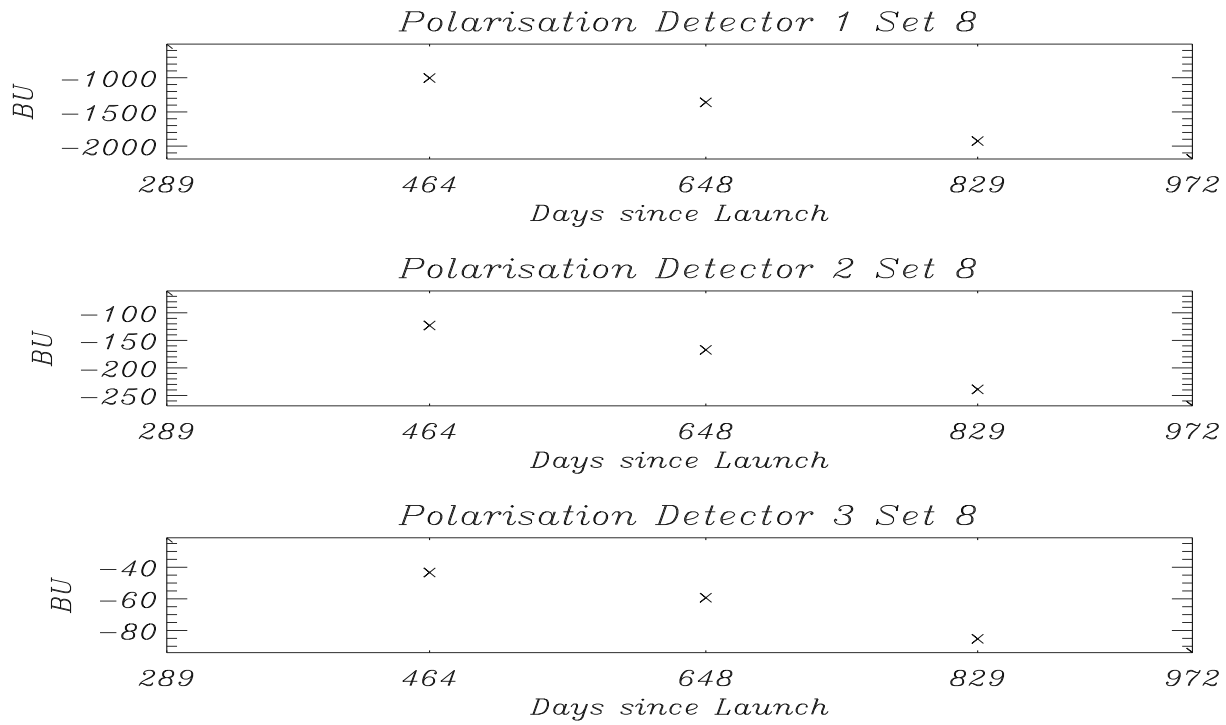

FIGURE 26. Polarisation Measurement Devices trend from 28/07/95 to 28/12/97.

The values are given in annexe A within the tables 1 and 2.

The difference of the LED-PMD measurements dated on the 28/12/97 to the reference data

set chosen at the end of commissioning phase (28/07/95) gives a change in the measured signal of 10% for PMD 1, 9.65% for PMD 2 and 9.04% for PMD 3 over 2.5 years.

To see if this change is caused by LEDs or PMDs degradation, a rough check was done with the LED calibration spectra of channel 4 which has the same driver circuit as the PMD LED.

Data analysed: LED measurements of channel 4 for an integration time of 3s.

Method: mean_ref_readouts: Mean value of readouts of the reference date (28/07/95) which corresponds to day 67 after launch.

ref_lk_cur: Leakage current of the reference date for 3s integration time.

mean_readouts: Mean value of all readouts

lk_cur: Leakage current for 3s integration time.

Trend = (mean_readouts - lk_cur) - (mean_ref_readouts - ref_lk_cur)

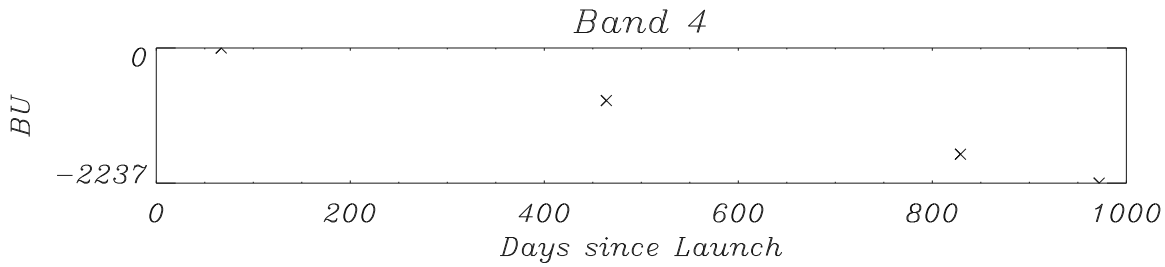

FIGURE 27. Trend in signal of LED Measurements on the detector 4

This difference gives a LED degradation of 7.4% over 2.5 years (considering the mean on the reference date as 100%) which leads to a possible degradation of 2.6% for PMD1, 2.25% for PMD 2 and 1.64% for PMD 3 over 2.5 years. That corresponds to a mean PMD degradation of about 0.9% per year.

7.0 Conclusions

PPG

- No significant changes in the PPG were found over the last 3 years.

SATURATION OF THE DETECTORS:

- The level of saturation changed with time. A shift occurs which is different for each of the 4 channels. The percentage has been calculated considering the difference between the reference data of July 95 and December 97 (100% -> about 50000 BU).

  - Channel 1: 0.27%
  - Channel 2: 0.24%
  - Channel 3: 0.24%
  - Channel 4: 0.12%

- A little but not significant increase of the saturation level can be monitored over a time period of 3 years.

LED PMD SIGNALS

- The PMD LED measurement analysis was performed on request of the ESTEC project.
- We can see an evolution of a bit less than 10% over the instrument lifetime but this does not tell if the degradation comes from the PMDs themselves, the LEDs or optical devices in the optical path.
- Channel 4 LED measurements were used to try to distinguish LED and PMD degradation, which leads to a possible mean PMD degradation of 0.9% per year.

8.0 Annex A

The dates chosen are (monthly calibration sequences):

LED measurements for 3 seconds integration time:

28/07/95: Reference date

04/02/96

28/07/96

28/01/97

28/07/97

28/12/97

LED measurements for 24 seconds integration time:

28/07/95: Reference date

04/02/96

28/07/96

28/07/97

28/12/97

Set 8 PMD trend:

28/07/95: Reference date

04/02/96

28/07/96

28/01/97

28/07/97

28/12/97

Check on LED band4:

28/07/95: Reference date

28/07/96

28/07/97

28/12/97

Values calculated for the PMD analysis.

Table 1: PMD 1, 2 and 3 Set 8 (first 3 months)

date	28/07/95	04/02/96	28/07/96
average Dark current	1314.4 (1) 505.0 (2) 507.9 (3)	1314.6 (1) 506.5 (2) 508.3 (3)	1315.3 (1) 507.1 (2) 508.3 (3)
Average LED read-outs	22763 (1) 3283 (2) 1548 (3)	22255 (1) 3224 (2) 1527 (3)	21760 (1) 3162 (2) 1505 (3)
Difference with reference date	Reference date	-507.7 (1) -60.3 (2) -21.4 (3)	-1003.9 (1) -123.0 (2) -43.3 (3)

Table 2: PMD 1, 2 and 3 Set 8 (last 3 months)

date	28/01/97	28/07/97	28/12/97
average Dark current	1317.4 (1) 512.2 (2) 513.5 (3)	1316.4 (1) 508.4 (2) 508.6 (3)	1299.5 (1) 503.5 (2) 504.7 (3)
Average LED read-outs	21406 (1) 3123.0 (2) 1494.6 (3)	20839 (1) 3047.4 (2) 1462.6 (3)	20559 (1) 3012.6 (2) 1451.0 (3)
Difference with reference date	-1359.7 (1) -167.2 (2) -59.3 (3)	-1926 (1) -239 (2) -85.3 (3)	-2188.7 (1) -268.9 (2) -94.1 (3)

The values of the leakage current used for correction:

TABLE 3. Leakage current in BU/second for each month used.

Band	28/07/95	04/02/96	28/07/96	28/07/97	28/12/97
band 1	2.3	2.6	2.6	3.0	3.1
band 2	2.2	2.3	2.5	2.9	3.0
band 3	2.0	2.1	2.2	2.6	2.7
band 4	2.1	2.3	2.5	2.8	3.0