Nordic Optical Telescope

ALFOSC CCD Detector Controller
Test report

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1 Introduction

This document provides a status report on the new detector controller delivered by the NBI for the ALFOSC CCD used at the Nordic Optical Telescope (NOT). The requirements for the controller and the accompanying data acquisition system were provided in "Detector Controller User Requirements" (Thomas Augusteijn & Graham Cox, November 2007) and in "Data Acquisition System – Requirements and Development Plan" (Jacob Clasen & Thomas Augusteijn, September 2008).

The report details the performance of the controller both in relation to its properties in such measures as, e.g., read-out noise and linearity with the ALFOSC CCD, and in its operations through software. This report is intended as basis for a comparison with the user requirements to define what is needed for final acceptance of the detector controller and associated software for use with the ALFOSC CCD.

2 Properties

The new detector controller provides 4 different speeds (113, 200, 400 and 800 kpix/sec), where the 200 kpix/sec speed was specifically defined in the user requirements. Most of the tests and results given below refer to those obtained with the 200 kpix/sec speed using amplifier A which we have adopted for the moment as the standard readout speed.

2.1 Gain

Various gain tests were made using the beta-light installed in FASU. This illuminate a small area in the center of the CCD more or less uniformly. Set of series of exposures with a range of exposure times using the beta-light were done with the 200 kpix/sec readout speed with both amplifiers and very similar results were obtained with both amplifiers during different tests. The gain is derived from the relation between the variance as a function of intensity. The most noticeable thing is the clear dependence of the derived gain on the range in intensity covered. The same effect is also found when calculating the gain from sets of 2 exposures using the LEDs inside the dewar. The illumination across the CCD is very non-uniform and different intensity levels were sampled by both using different sets of exposures and by using different areas in a given set. These measurements are probably somewhat less precise as the illumination is very non-uniform, but the results are very similar to the tests with the beta-light and as shown in Fig. 1 illustrates the effect very well.

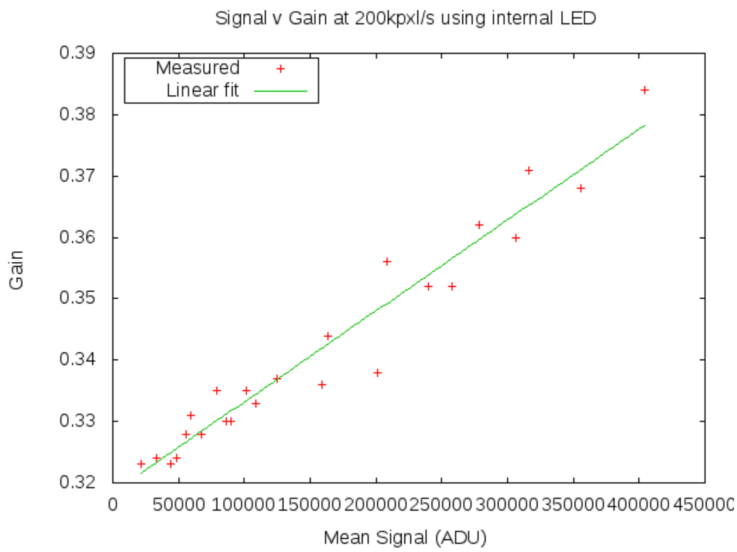

Figure 1: Gain measurements as determine from sets of 2 exposures using the LED inside the dewar as a function of intensity. The drawn line is a linear fit to the data.

Some tests with the beta-light were also made with the 400 kpix/sec readout speed with similar results as for gain values and variation in gain as a function of intensity.

This does raise the question which gain value to use. Tests using the beta-light with the old controller were made on the 20th of June. These tests we consider the baseline for comparison to the new controller. A gain value of 0.749 e-/ADU was obtained using the high gain setting and amplifier A for data ranging up to 32 343 ADU (24 225 e-). With the new controller the very same test was repeated on the 23rd of June using the 200 kpix/sec readout speed and amplifier A. A gain value of 0.322 e-/ADU was obtained for data ranging up to 69 979 ADU (22 533 e-).

We do not have a direct explanation for the ∼7.5% drop in the number of detected electrons as beyond the changes to the dewar vessel and the mounting of the CCD (e.g., the entrance window did not change) the set-up was precisely the same, and alignment issues are not expected to give such a large change. Part of the difference might be explained by the observed variation in gain factor with intensity. No indication of a similar drop in sensitivity is observed in the photometric zero-point of ALFOSC derived from observations of standard stars. In any case, we will use the above derived gain factor in the comparison between the old and new controller.

2.2 Non-linearity

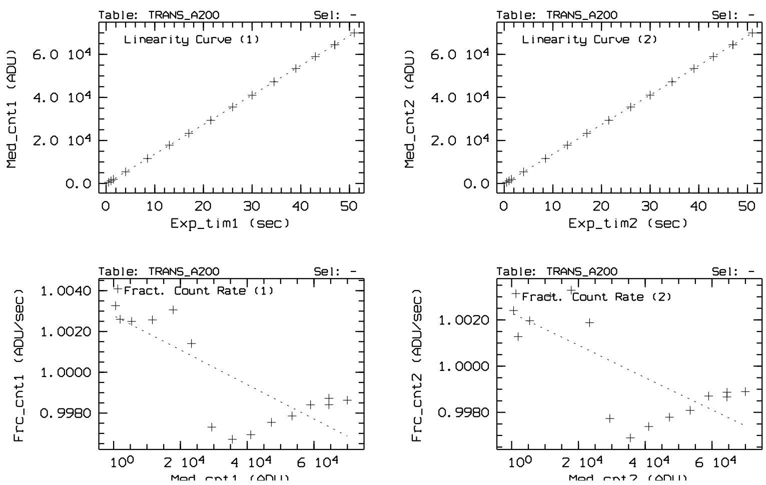

Figure 2: Results of tests with the 200 kpix/sec readout speed and amplifier A using the beta-light. The top curves show the relation between exposure time and count rate for each of the set of 2 exposures that is taken for each exposure time. The bottom curve shows the fractional count rate for the same data, where variations above and below zero indicate deviations in linearity. The range covered here is similar to tests made with the old controller and shows similar level of variations.

The same beta-light tests as described above were used. In Fig. 2 (bottom plots) we show the fractional count (the counts per second normalized on the average) as a function of intensity (total counts) using the 200 kpix/sec readout speed and amplifier A taken on the 23rd of June. In the test 2 exposures are taken for each exposure time, and the pairs of exposures are taken alternating between a series of increasing and decreasing exposure times so any drift in the overall count rate would generate a separation of the measurements at a given intensity level. The plots show a rather smooth variation with maximum deviations of +0.4% and -0.3%. Very similar results were obtained with amplifier B and the variation in the fractional count rate are of the same size as that observed with the old controller.

With the new controller one can go to significantly higher intensity levels in ADU, and more extensive tests were made. In these tests it was found that non-linearity effects become dominant above intensity levels of 375 000–400 000 ADU (∼140 000 e-, consistent with the typical peak charge storage given in the E2V data sheet) for both amplifiers and readout speeds of 200 and 400 kpix/sec (other readout speeds have not been investigated in such detail). In Fig. 3 (bottom plots) we show the fractional count as a function of intensity (total counts) using the 200 kpix/sec readout speed and amplifier B taken on the 28th of June. Again, the variation is smooth with a range in values similar to the test shown in Fig. 2. In fact, all the tests with the different amplifiers and readout speed described here all show very similar variations in fractional count rates as a function of intensity, with a similar size drop to lower values around an intensity of 30 000–40 000 ADU slowing rising again up to an intensity of ∼250 000 ADU before going down again. This seems to indicate that the non-linearity behaviour can be modelled and corrected to levels below 0.1%.

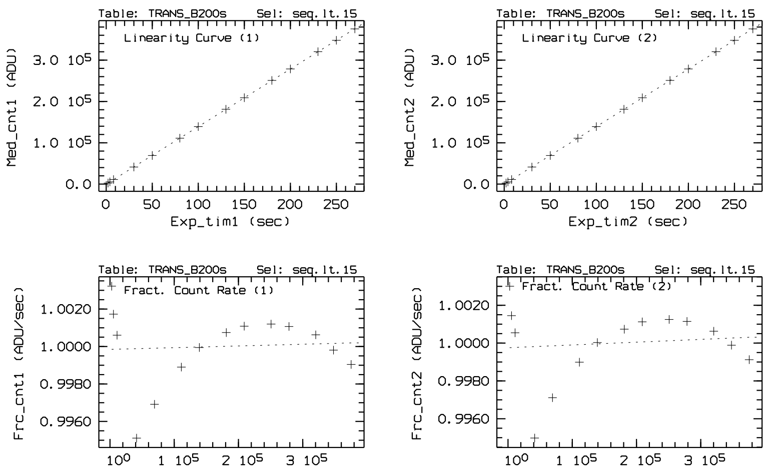

Figure 3: The same as Fig. 2, but showing the results of tests with the 200 kpix/sec readout speed and amplifier B using the beta-light. The intensity goes up a factor 5 higher than in Fig. 2. In the range where the intensity overlaps the behaviour is the same in both plots.

In general, the observed level of non-linearity is similar to that obtained with the old controller over a similar range in intensity, but also up to the peak charge storage of ∼140 000 e- of the CCD.

2.3 Read-out Noise

Regular tests have been taking sets of 5 bias images using the 4 different readout speeds and the two amplifiers. These data were taken using a script. Due to a still not understood problem, changing the readout speed to 800 kpix/sec affects the data produced by the controller which affect all the data taken with this speed using amplifier A.

Table 1: Read out noise as measured for the different readout speeds and amplifier.

Speed kpix/sec	Amp.	Lowest ADU	Lowest e-	Average ADU	Average e-
113	A	10.5	3.4	11.2	3.6
	B	10.1	3.3	10.5	3.4
200	A	12.0	3.9	12.2	3.9
	B	12.1	3.9	12.2	3.9
400	A	17.0	5.5	17.2	5.5
	B	17.8	5.7	18.0	5.8
800	A	...	...	...	...
	B	30.5	9.8	30.6	9.9

What is seen in general is an increased level of noise in the first few test, most markedly for the lowest readout speeds, while the latest test show lower and more stable values of the noise (see also Sect. 2.4). In Table 1 we have listed for each of the readout speeds and amplifier the lowest value of the noise measured, and the average of the latest and lowest tests to give some indication of the stability of the noise. For comparison, a noise of 4.75 ADU (3.56 e-) was measured using the high gain and amplifier A during the tests made on the 20th of June (see above).

From Table 1 it can be seen that the new controller performs significantly better providing the same readout noise as with the old controller with double the speed. The user requirements specified a readout noise of 3.5e- for the 200 kpix/sec readout speed. This level of readout noise is not reached but we note that the noise at this speed (and at the 113 kpix/sec speed) is slightly lower than what is specified by the manufacturer of the CCD.

2.4 Pick-up noise

With the controller mounted on the instrument we have on various occasions observed pick-up noise that appears as a regular pattern of pixels with a value on average $\sim$60 ADU ($\sim$20 e-) lower than the overall average. The distance between the affected pixels is directly proportional to the readout speed, being $\sim$9, 15 and 30 pixels for a readout speed of 113, 200 and 400 kpix/sec, respectively (the pick-up noise is not discernible when using the 800 kpix/sec speed).

From a frequency analysis of the raw pixel data the fundamental frequency of the noise is 13.28KHz (assuming the readout speeds of 200 and 400 kpix/sec are precise). There is no obvious explanation for this frequency.

Tests were done with ALFOSC off the telescope with the power for the CCD controller taken from either the telescope or a wall socket. Also the mains earth was disconnected for some tests. In addition, measurements were made with the dewar removed from the instrument and with the dewar mounted but deliberately electrically connected - note the normal situation is the dewar is electrically isolated from the instrument when mounted. For all these situations the pick-up noise was seen.

However, also in some of the tests the pick-up noise is intermittent and it appears to be absent lately.

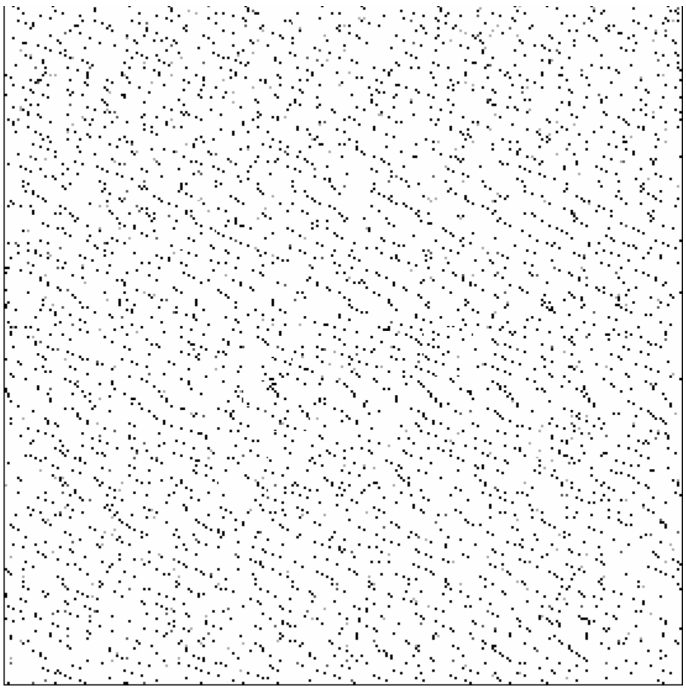

Figure 4: The pattern of pick-up noise observed on some occasions. The pick-up noise manifests itself as a regular pattern proportional to the readout speed which have a value on average ∼60 ADU (∼20 e-) lower than the overall average. Here an example is shown for the 200 kpix/sec readout speed where the low pixels appear every ∼15 pixel.

2.5 Charge transfer efficiency

To estimate the CTE flat field images were used where the signal in the first over-scan pixel is compared with the last illuminated pixel (after correction for the average in the last part of the over-scan). As the CCD image is slightly vignetted at the top it is actually not straightforward to measure the vertical CTE using this method.

Looking at data using the readout speeds we find consistent results for all speeds giving a horizontal CTE of 0.9999957 using amplifier A which is slightly better than the typical value specified by the manufacturer.

In general the data obtained has not shown a fundamental problem with the CTE, but we had occasional problems (see Sect. 2.8.1).

2.6 Cross-talk

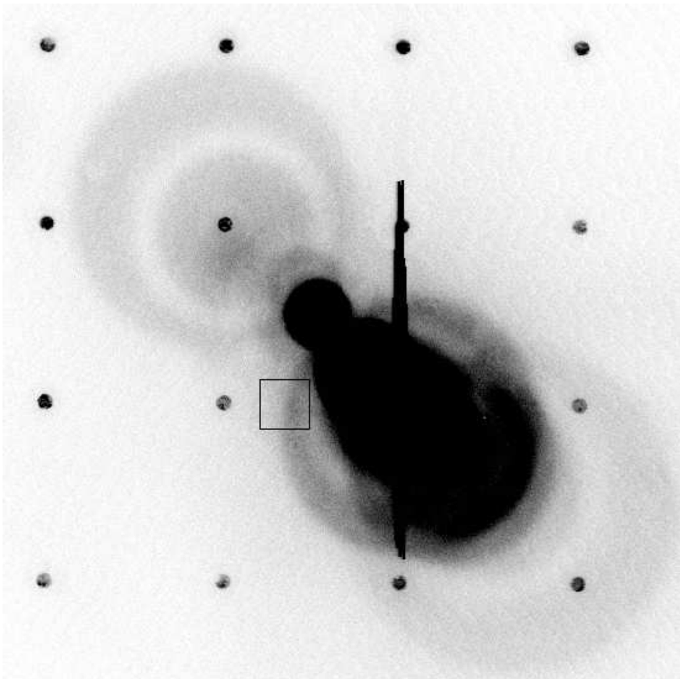

Figure 5: A heavily over-expose image of a pinhole using the AB readout mode. The square is centered on the pixels readout through amplifier A that coincide with the pixels centered on the pinhole readout through amplifier B.

Heavily over-exposed images were taken with the halogen internal flat field lamp of a pinhole plate reading out both amplifiers using the AB mode. Independent of the exposure level no significant emission was detected. This is illustrated in Fig. 5 which shows the area close to the center of the CCD with the heavily overexposed image of the pinhole which is on the right side of the CCD readout through amplifier B. The area inside the square to the left is centered on the place corresponding to the pixels that are readout through amplifier A together with the heavily over-exposed pixels and which might be affected by cross-talk between the two channel.

Beyond light caused by reflections in the instrument, no additional emission is detected in the square. The regular small dots present in the image are due to the fact that the plate actually contains a whole grid of pinholes that are taped-off but which because of the very high level of illumination still let through a small amount of light. Although it is hard to give precise numbers, we conclude that any crosstalk between the channels is below 1:100 000.

2.7 Remnants

Examination of data taken after heavily over-exposed images did not show any remnants.

2.8 Bias images

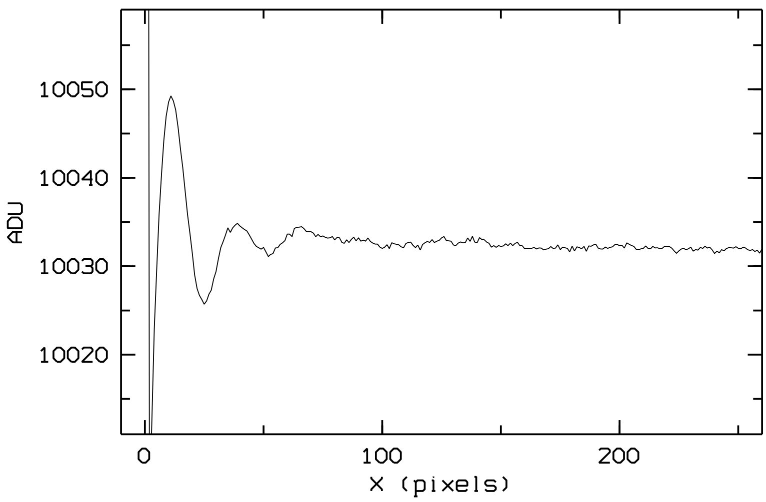

Figure 6: Average in the serial (X-) direction of a bias image readout with the 200 kpix/sec readout speed and amplifier A.

In general the bias images are flat and stable both in count level as well as shape (but see Sect. 2.8.1). One of the most marked things is a well defined oscillation in the level at the beginning of each line. This is illustrated in Fig. 6, where the average in the serial (X-) direction of a bias image readout with the 200 kpix/sec readout speed and amplifier A is shown. This behaviour can be seen as stripes in the image. The pattern appears to be related with the start of readout of each line and seems to have a fixed time scale for all readouts, leading to the oscillations extending over a larger range for high readout speeds (e.g., for a readout speed of 800 kpix/sec the oscillations are extended 4 times further in the serial direction then shown in Fig. 6). Note that the amplitude decreases rapidly and for all readout speeds the amplitude gets quickly below the level of the readout noise (see Table 1).

A more detailed comparison of the overall shape of bias images show them to be very stable over time-scales as long as a few months, with variations in the shape (including the oscillations)

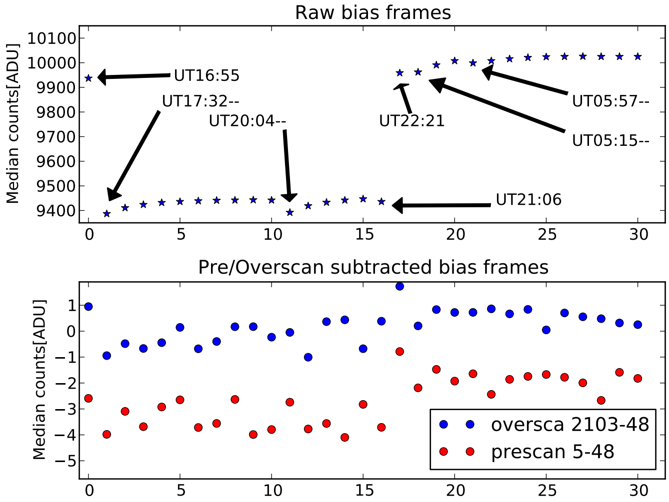

Figure 7: Behaviour of all the bias images taken throughout the night of July 6 using the 200 kpix/sec readout speed and amplifier A. The top panel shows the median count level for each frame, and the bottom panel shows the count level corrected using the pre- and over-scan, respectively.

to be smaller than the readout noise.

The overall bias level is all fairly stable, where it generally varies by a few 10's of ADU from frame to frame. However, we also have seen strong changes of a few 100 ADU. The latter is illustrated in Fig. 7 which shows the median count level (top panel) of all bias images taken throughout the night of July 6. A clear jump occurs in the afternoon and the bias returns to normal levels early in the night after the controller was reset. It is not clear if anything specific happened to the controller when the downward jump occurred in the afternoon but the observations when the bias was at a low level appear to be normal. What can be seen in the bottom panel of Fig. 7 is that the variations in the bias level in all cases are well corrected by using the pre- and (even better) over-scan of the images.

A more typical behaviour of the bias is shown in Fig. 8 which shows the median count level (top panel) for series of bias images taken during the night of July 16. Different series show a similar behaviour in which the count level rises asymptotically as a function of time. In particular, there seems to be an effect in the level rising when the detector is readout often which is likely related to some 'heating-up' effect of the amplifier. Again, as shown in the bottom panel of Fig. 8 the over-scan provides a very good way to correct the bias level.

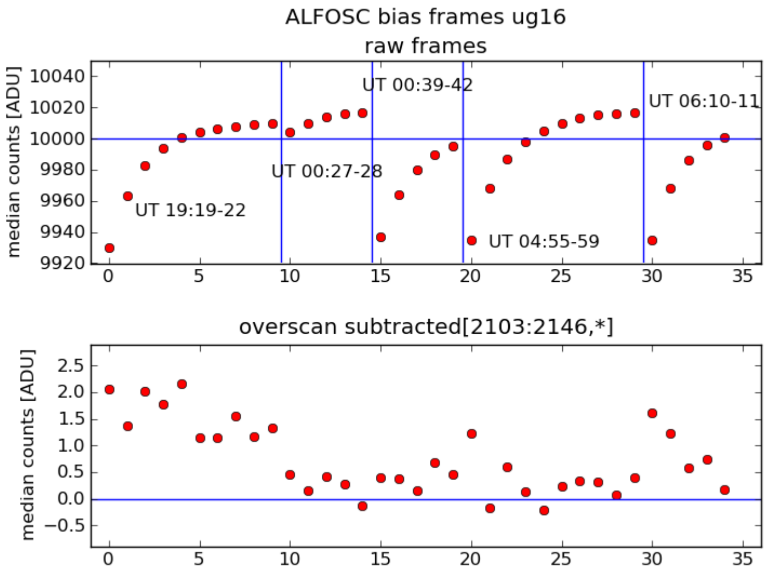

Figure 8: Behaviour of series of bias images taken throughout the night of July 16 using the 200 kpix/sec readout speed and amplifier A. The top panel shows the median count level for each frame, and the bottom panel shows the count level corrected using the over-scan.

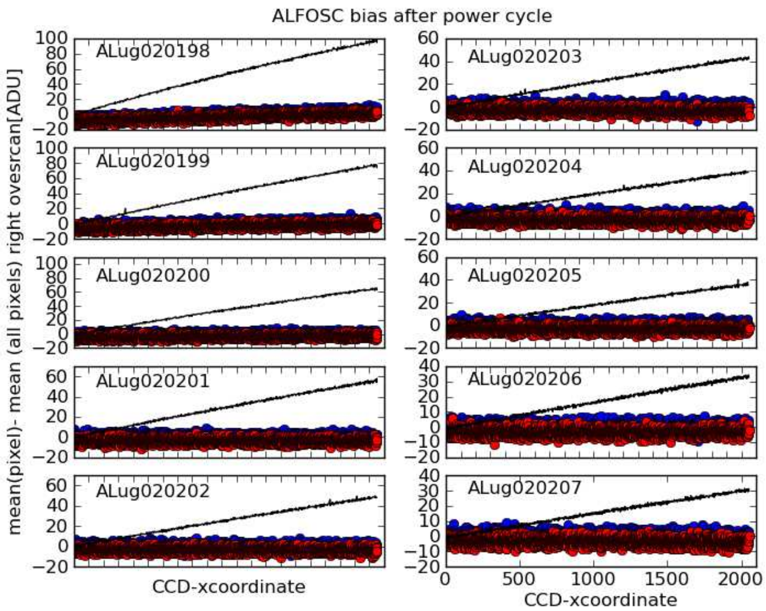

Figure 9: Behaviour of the bias after a controller reset taken at the end of the night of July 2 using the 200 kpix/sec readout speed and amplifier A. Each plot show the average in the parallel (Y-) direction for the pre- (blue) and over-scan (red), and the center of the CCD for a series of bias frames directly following a hard reset of the controller. The series covers in total ∼5 min.

2.8.1 Resetting the controller

A serious issue has been the fairly frequent problems with the horizontal CTE which requires a hard reset of the controller to cure. It appears that these problems are generated by the use of large (>4) binning factors in the serial (X-) direction, but the problem persist in all subsequent data independent of the detector settings used. The main problem is that the bias image is significantly affected directly following a reset, showing a strong slope that only disappears slowly with time. This is illustrated in Fig. 9 which shows the average in the parallel (Y-) direction on the CCD for a series of bias frames taken directly following a hard controller reset. A clear slope is seen which persists during the whole test (covering in total ∼5 min) and which is not corrected by the pre- or over-scan. More extensive tests have shown that it takes around 20 min for the effect to disappear completely.

3 Software

There are various issues with the commands related to operating the detector controller which are listed below:

- '@time 0' is refused by the controller

  This gives rise to the need to command a 2 ms exposure when a bias exposure is needed. The FITS header will, of course, show 2 ms which is not according to specifications. (CCD3 ticket ref.: 16)

- 'ccd3comm' crashes intermittently when '@break' is send to the controller

  This gives rise to the problem that the system needs restarting when an exposure is aborted and this problem occurs. (CCD3 ticket ref.: 45)

- xsize/ysize does not get recalculated when changing xbeg/ybeg

  The controller should recalculate xsize and ysize when xbeg and/or ybeg is changed so the new readout window can not extend beyond xtot/ytot. In the current situation the readout can stall as the actual number of pixels send from the controller can be different from the expected number of pixels. (CCD3 ticket ref.: 115 and 79)

- "Command time out looking for CCD3 program" error.

  This is likely an error that is specific for the ALFOSC/NOT installation as this has never been seen before and cannot be reproduced outside the NOT environment. It is being investigated if this is caused by networking libraries on the host computer in question. (CCD3 ticket ref.: 118)

- Controller reports old 'tima' after '@sint'.

This causes the exposure time progress bar in the graphical status display to jump up just before the exposure begins. Only a cosmetic issue, but annoying. (CCD3 ticket ref.: 83)

- The execution of the sequencer commands 'setup_nnn' sometimes crashes 'ccd3comm'.

  This error was seen on one occasion. The cause is unknown at this time. (CCD3 ticket ref.: 114)

- Order of commands gives different geometry.

  The controller works with pixels referring to the actual binning (1,2,4...) which causes a different order of commands like binning and size to give different results. This is opposed to the old controller (at least the BIAS program) that always refers to 1x binned pixels. Maybe this can be circumvented by the introduction of a 'xend'/'yend' command or script. (CCD3 ticket ref.: 120)