Performance of the CHIRON CCD detector with the Torrent controller

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1 Introduction

CHIRON echelle spectrometer has a cryogenically cooled CCD detector. It was deployed in March 2011 with the Monsoon Orange controller as a temporary solution. On February 14, 2012, the new Torrent controller was installed. This document reports the performance of this new detector+controller combination. To our knowledge, this is the first astronomical instrument that uses Torrent.

The detector is a CCD device CCD231-84-0-XXX from *e2v*, 4096x4112 pixels of 15 μm size. It has a gradient coating in the line direction for optimum sensitivity in a wide spectral range.

The readout is performed through four amplifiers. The binning and region-of-interest modes work (however, simultaneous ROI and binning do not work). Two readout speeds, normal and fast, are implemented (pixel rate 129 kHz and ??). A summary of the detector performance in normal and fast readout modes is given in Table 1.

Table 1: Readout modes summary for four quadrants

Mode, binning	Readout time, s	Lower-left (0) RON, el	Lower-left (0) Gain el/ADU	Lower-right (1) RON el	Lower-right (1) Gain el/ADU	Upper-left (2) RON, el	Upper-left (2) Gain el/ADU	Upper-right (3) RON el	Upper-right (3) Gain el/ADU
Normal, 1x1	38	5.4	1.30	5.5	1.250	5.4	1.264	5.7	1.257
Fast, 1x1	18?	12.8	5.684	19.0	5.454	11.3	5.520	12.2	5.470

In CHIRON, most observations are done with 3x1 and 4x4 binning in the full-frame normal mode, with readout time of 18 s and 5 s respectively. The fast readout mode is not used so far.

2 Readout noise

Signal fluctuations in bias frames contain regular periodic components which dominate the total variance. The bias frames have characteristic “fringes” (Fig. 2) which differ from one image to another in the normal mode and thus cannot be removed by subtracting the median bias. Quantitative analysis has been done on the real data of March 25, 2012 using the IDL program `noise1.pro` which subtracts the mean line from each line of the bias frame and averages the power spectra of all lines. The power spectra of the noise signal in the two quadrants of the same frame are shown in Fig. 3. This

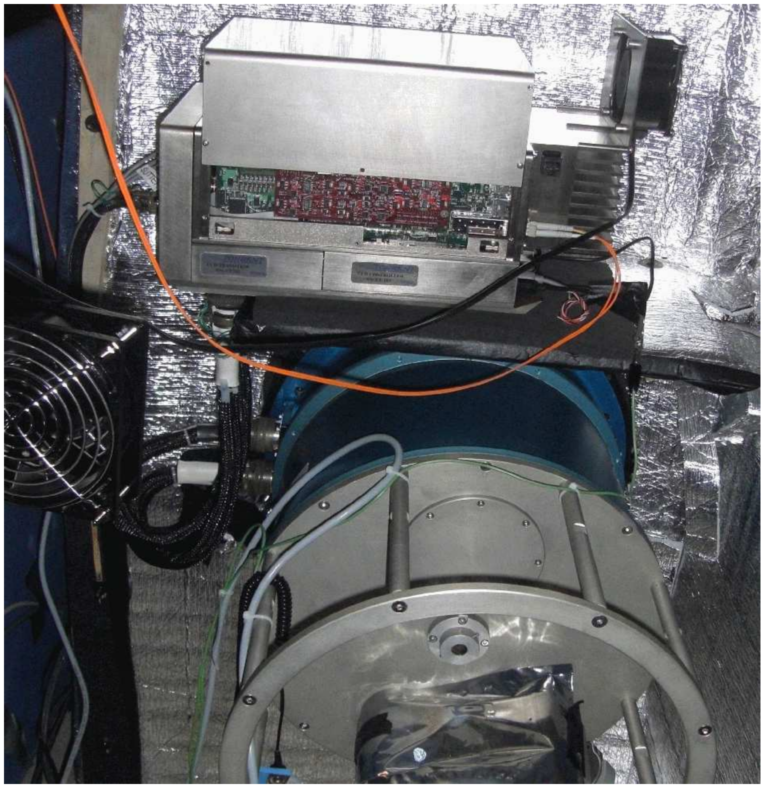

Figure 1: Torrent controller is installed on a small shelf above the CCD dewar and connected to it by two 40-cm cables. The controller is half-opened and air-cooled to prevent power supply failures caused by overheating.

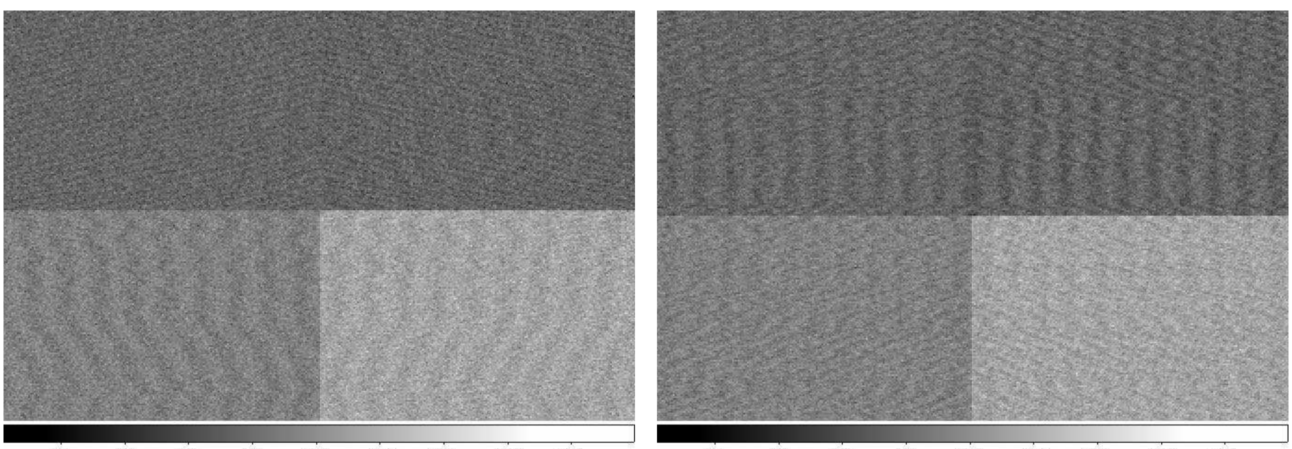

Figure 2: Central fragments of bias frames with binning 3x1 (left, `chi120325.1049.fits`) and 4x4 (right, `chi120325.1058.fits`) in the normal readout mode.

program also calculates the “noise floor” by taking the lowest 25% of power-spectrum values and assuming white noise of this magnitude for all frequencies. This estimates the noise performance without periodic pickup. The result for the bias frame `chi120325.1048.fits` is listed below.

	Q0	Q1	Q2	Q3
Total, ADU	3.83	4.07	3.95	4.21
Floor, ADU	2.41	2.58	2.44	2.54

For the quadrant 0 (lower-left), the pickup component contributes 60% of the total power. Without the pickup, the rms noise is 2.41 ADU or 3.1 el. The readout noise listed in Table 1 includes the pickup.

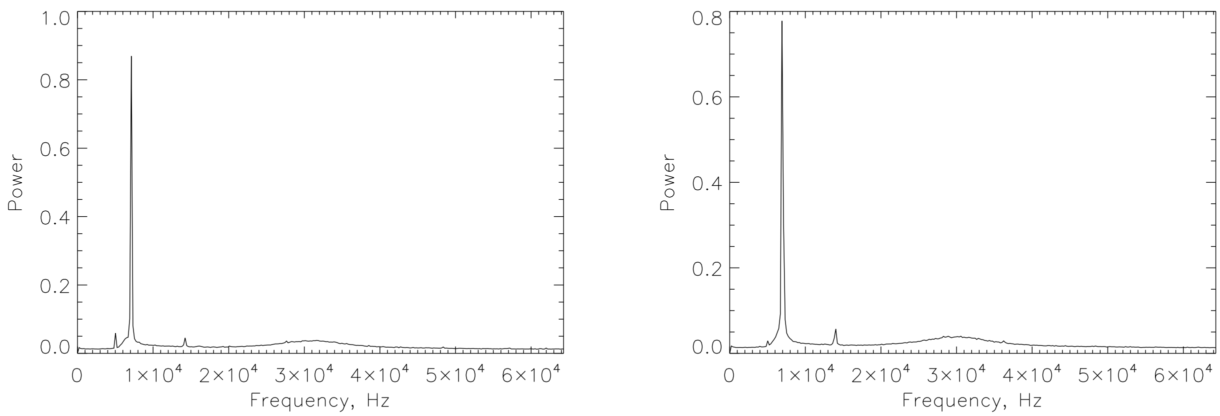

Figure 3: Power spectra of readout noise in quadrants 0 (left) and 2 (right) of the bias frame `chi120325.104.fits`, assuming pixel frequency of 129 kHz.

In the fast mode, however, part of the periodic signal is reproducible from one frame to another (Fig. 4). Subtraction of the median bias can improve the noise. For example, for the quadrant 0 we can get 9.9 el instead of 12.8 el listed in Table 1.

3 Gain and linearity

The gain is determined from the signal fluctuations. Usually a difference or ratio of two uniformly illuminated images is used for the determination of “photon transfer curves”. In CHIRON, the illumination of the CCD by quartz spectra is highly non-uniform. The IDL program `ratio.pro` uses the ratio of two exposures to calculate the gain by grouping pixels with similar illumination. A typical result (Fig. 5) shows a constant gain vs. signal, indicative of good linearity. The gain appears to be stable over one month.

Nearly uniform illumination of the CCD in CHIRON was obtained by installing a red LED near the folding mirror. The LED illuminates a piece of white paper which scatters light into the CCD. Only a small part of the field on the left side is vignetted by the field flattener (Fig. 6). The LED is powered by stabilized current source. It is activated by the shutter signal when the LED cable is plugged in the Torrent instead of the shutter cable.

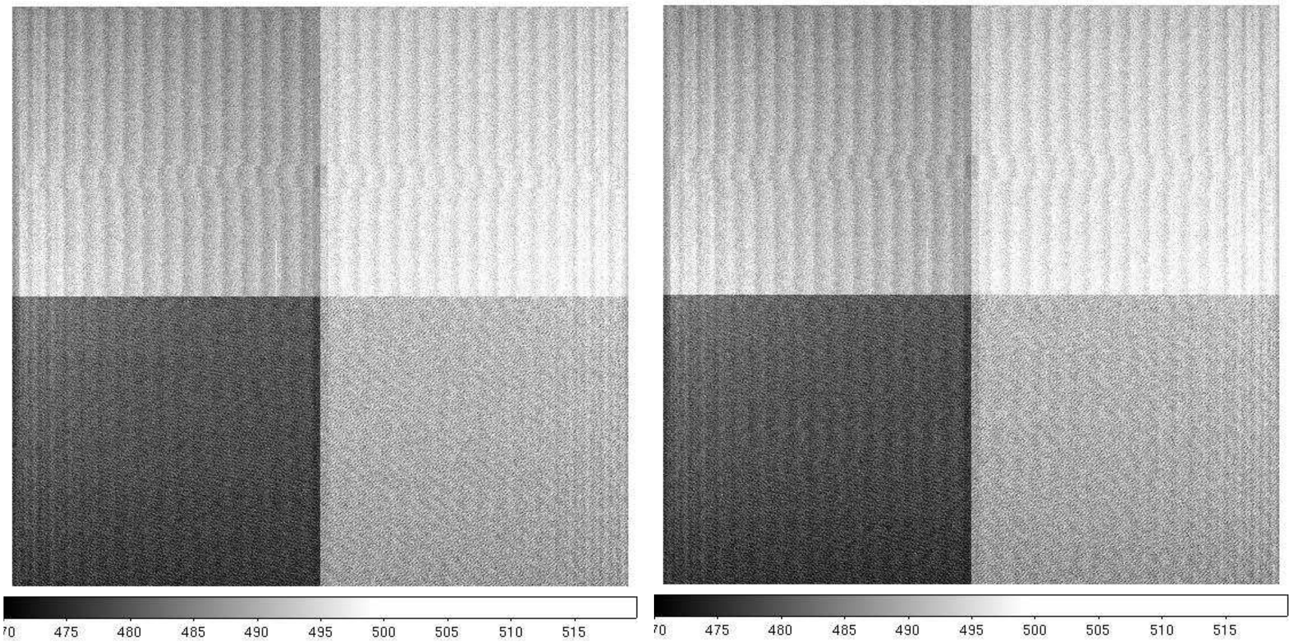

Figure 4: Two full bias frames with 4x4 binning in the fast readout mode.

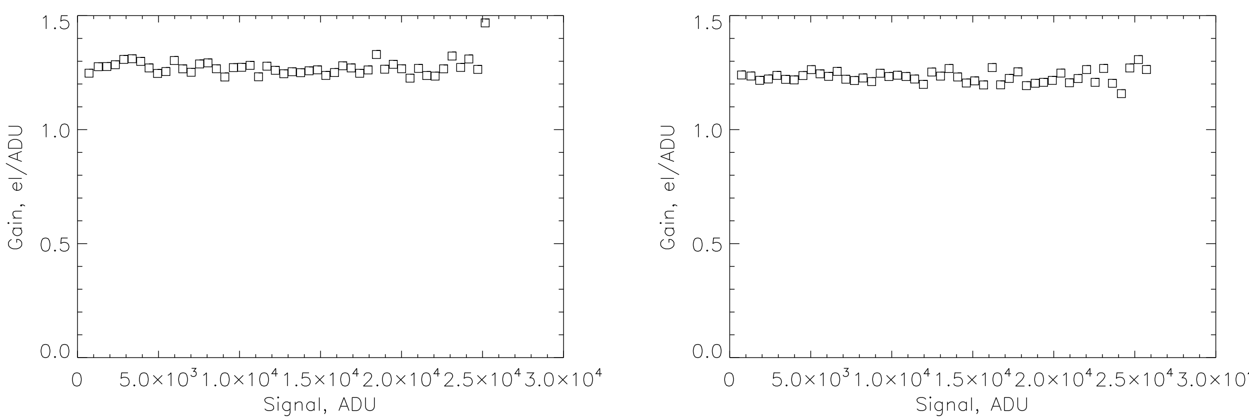

Figure 5: Gain vs. signal level for quadrants 0 (left) and 2 (right) computed from the ratio of two quartz exposures `chi120325.1008.fits` and `chi120325.1009.fits`.

On February 24, 2012, series of LED exposures ranging from 25 ms to 40 s was taken. The program `lin3.pro` selects well-illuminated pixels in each CCD quadrant and computes the ratio of the total flux to exposure time. Figure 7 shows a linear response to better than 0.2% in the normal readout mode, up to the "digital saturation" at 2^{16} ADU. The deviation at low flux could result from the imperfect bias subtraction (the overscan level was subtracted) or the inaccuracy of very short exposure timing. We do not notice effects of LED heating during the exposure. The linearity test with the stabilized

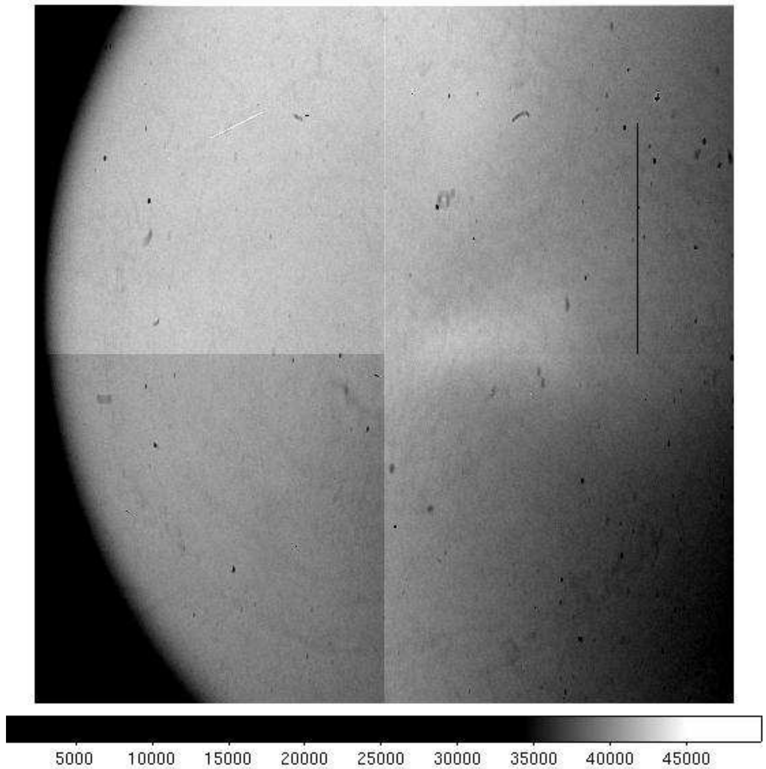

Figure 6: Quasi-uniform illumination by the LED (image `LED0012.fits`, 10s, 4x4 binning, normal mode). The bias and overscan are removed, but the gains are not applied, causing discontinuity between the quadrants.

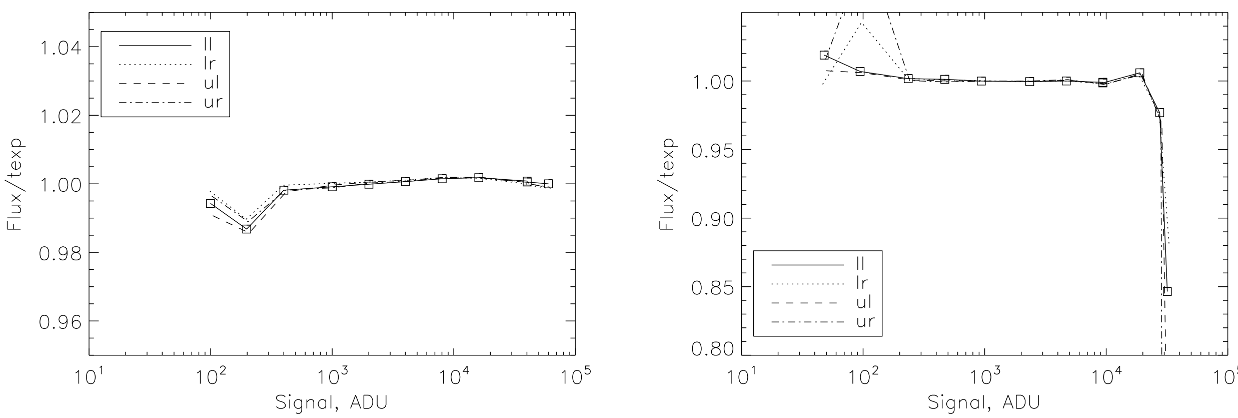

Figure 7: Linearity of the CCD response in the normal (left) and fast (right) readout modes determined with the LED. Curves for all 4 quadrants are plotted.

LED is much more accurate than the photon transfer curves.

In the fast mode, the linearity is also very good up to 20 000 ADU. At 30 000 ADU (or 1.5E5 electrons) the signal saturates and the charge blooming appears. We recommend not to exceed signal levels of 15 000 ADU in the fast mode. The test with LED was repeated on March 27, 2012, and gave similar results.

Images with LED were used to make small adjustment of the gains to reach smooth (invisible) transition between the quadrants. These adjustments of few percent to the gains determined by `ratio.pro` are reflected in the numbers listed in Table 1.

4 Other parameters

The **charge transfer efficiency** was estimated qualitatively by P. Moore[1] during tests in the lab, with a conclusion that "there is no problem".

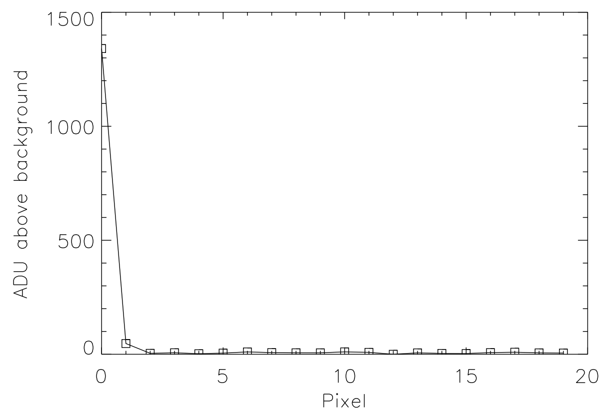

Figure 8: Evaluation of the vertical CTE from the combined trail of cosmic particles. The plot starts at the last bright pixel. Data of February 14, 2012.

The CTE can be evaluated from the cosmic particles in dark exposures. Coordinates of several sharp bright cosmic events in the 300-s dark exposure with 1x1 binning were given to the program `cosmic.pro`, which then combines then in one single trail and calculates the fraction of signal in the first dark pixel. In this instance (Fig. 8) it is 3% after 2600 transfers on average, or a CTE of $1-1.15\,10^{-5}$. Given that cosmic events can have signal spread over several pixels, this is a lower limit, the actual CTE can be better. The horizontal CTE can be roughly evaluated by the residual signal in the first overscan column. In the LED exposure `LED0002` this residual is $\sim$2.5 ADU at the signal level of 40 000 ADU after 512 transfers. The CTE in the line direction is thus excellent.

The histogram of pixel values is always smooth, indicating the absence of preferred signal values. We do not find any periodic noise in the well-exposed images with uniform illumination.

The **cosmetic quality** of the CCD is good, with one dark column (Fig. 6). The sharp dark spots are caused by the dust particles on the CCD surface (the dewar has some internal contamination).

[1] P. Moore. Performance summary for CHIRON Detector. February 14, 2012.

Low-contrast details are produced by dust on the 6 optical surfaces in front of the CCD. The straight white streak in the upper-left quadrant in Fig. 6 is a glitch, it is not present in other images.

The Torrent controller had crushes and other problems after deployment. After software fixes it operates now very reliably. The overheating of the power supply is prevented by the forced air cooling (Fig. 1), it does not cause trouble in regular operation.

5 Conclusions

The CCD detector with the Torrent controller gives scientifically useful data. It has an excellent linearity in the normal readout mode. The pickup component of the readout noise degrades the performance at very low signal levels, compared to the intrinsic CCD noise. The fast readout mode is not used currently because of its increased noise and restricted dynamic range.