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Tests of commercial colour CMOS cameras for astronomical applications

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We present some results of testing commercial colour CMOS cameras for astronomical applications. Colour CMOS sensors allow to perform photometry in three filters simultaneously that gives a great advantage compared with monochrome CCD detectors. The Bayer BGR colour system realized in colour CMOS sensors is close to the astronomical Johnson BVR system. The basic camera characteristics: read noise (e^-/pix), thermal noise (e^-/pix/sec) and electronic gain (e^-/ADU) for the commercial digital camera Canon 5D MarkIII are presented. We give the same characteristics for the scientific high performance cooled CCD camera system ALTA E47. Comparing results for tests of Canon 5D MarkIII and CCD ALTA E47 show that present-day commercial colour CMOS cameras can seriously compete with the scientific CCD cameras in deep astronomical imaging.

Key words: detectors, observations

INTRODUCTION

The CCD has dominated in astronomical imaging for more than two decades. The leading type of sensor produced by Sony provides a readout noise of 5 to 6 electrons.

The electron multiplying CCD camera (EMCCD) was introduced to the scientific market in 2000 and represents a significant leap forward in combining ultra-sensitivity with speed. It can be considered as the current gold standard for low-light imaging. The EMCCD is capable to detect a single photon at fast frame rates.

In late 2010-th imaging cameras that are based on a new 5.5 megapixel scientific CMOS (sCMOS) sensor were introduced into the scientific market by Andor. sCMOS technology is based on a new generation of CMOS design and process technology. The sCMOS device can provide down to 1 electron RMS read noise, without amplification [1, 2].

Commercial colour CMOS cameras were presented for astronomical applications in the early 2000-th. DSLRs, as a CANON 5D type, can operate at very low light levels at room temperature. Thus images provided by Canon 1D Mark II camera demonstrate that when multiple frames are combined, less than one photon per pixel per frame, can be accumulated to show essential image details[1].

All this proves that the commercial CMOS cameras can be successfully used for deep astronomical imaging on a par with professional CCDs.

Our photometric measurements with colour CMOS cameras coupled to small telescopes (11–30 inch) reveal that the precision of about 0.01 mag can be achieved for stars up to $m_V \sim 14$. In video mode stars up to $m_V \sim 10$ can be shot at 24 frames per second [3].

RESULTS OF MEASUREMENTS

The electronic gain, the readout noise as well as the thermal noise (dark current) are the basic camera characteristics for deep astronomical imaging.

As shown on Christian Buil's[2] and Roger Clark's[1] web pages, we can compute two of these characteristics taking images of a white screen (or a successive flat-field image) and the offset (bias) shot. The electronic gain G can be evaluated as

$$\mathrm{G} = \frac{\mathrm{signal} - \mathrm{bias}}{\sigma^2}\,[\mathrm{electrons/ADU}],$$

where signal and bias are the mean intensities of the flat-field and bias images, σ^2 is the sum of variances (squares of standard deviations) of the offset and flat-field images, ADU is the analog-to-digital unit.

An additional noise component occurs due to the dark current, which is a function of the sensor temperature and the exposure time. The value of the dark current of Canon 5D MarkIII was measured at 23° C for 30 second exposure time at ISO 200. Read

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[1]Clark R. N. 'Night and Low Light Photography with Digital Cameras', http://www.clarkvision.com/articles/night.and.low.light.photography

[2]http://www.astrosurf.com/buil/50d/test.htm

Table 1: Opto-electronic parameters of the commercial colour CMOS camera Canon 5D MarkIII and professional ALTA E47 for comparison.

Camera	ALTA E47	Canon 5D MarkIII
Image format	2048×2048 pixels	5760×3840 pixels
Pixel size	13.5 microns	6.4 microns
Imaging Area	27.6×27.6 mm	36×24 mm
Electronic gain	—	3.97 electrons/ADU
Readout noise	9 electrons RMS	1.72 electrons
Dark Current	< 1 e$^-$/pixel/sec (-25 C)	< 0.2 e$^-$/sec/pixel ($+23°$ C)
Dynamic	16; 12-bit	14-bit
Peak QE (550 nm)	90 %	~ 30 %
Full Well	100K electrons	$\sim$ 30K electrons
Price	€: 27000,00	€: $\sim$3000,00

only noise (RON) is a product of the gain and the standard deviation of the offset image:

$$\mathrm{RON} = \mathrm{G} \times \sigma_{bias} \,[\text{electrons}].$$

For the DSRL images, the ISO setup was 200. Images were computed using the green channel.

The method of transfer curve evaluation on flat-field images was used to calculate the camera gain and read noise[3]. The curve $\sigma^2 = f(I)$ for various values of intensity I is called the transfer curve. The inverse of the slope is the camera gain G. The variance at the origin gives the square of the camera noise in ADU. Example for the Canon 5D MarkIII is presented in Fig. 1.

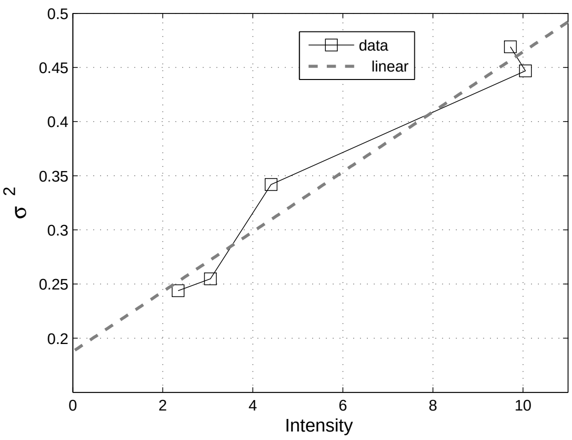

Fig. 1: The transfer curve of the EOS 5D MarkIII (200 ISO) – G = 3.97 electrons / ADU – RON = 1.72 electrons.

For short exposures the read noise dominates in the signal-to-noise ratio. For long exposures the thermal noise (dark current) becomes a primary factor since the thermal noise increases with exposure time.

The read noise for the Canon 5D MarkIII camera was measured at 1.72 electrons (Table 1). This is a similar quantity to that reported for many commercial CMOS cameras at ISO 200.

The dark currents were measured at $< 0.2\,\mathrm{e}^-$/pixel/sec at 23° C for Canon 5D MarkIII. Electronic gain was evaluated at 3.97 electrons/ADU (Table 1).

As shown on Roger Clark's web page for the EOS Canon 1D Mark II camera Quantum Efficiency (QE) is found to be 38% through the green passband. This is a very similar number to that reported for some other CMOS detectors. At the same time the peak QE (550 nm) for ALTA E47 is slightly better than 90%.

Comparing these results to tests of Canon 5D MarkIII and ALTA E47 we can conclude that current commercial CMOS cameras can compete with the specialized CCD cameras in many aspects of astronomical imaging.

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[3] `http://www.astrosurf.com/buil/20d/20dvs10d.htm`