A new CCD camera at the 60-cm telescope of the Belogradchik Astronomical Observatory

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Abstract. We present the new CCD camera FLI PL-9000 attached to the 60-cm telescope at the Belogradchik Astronomical Observatory. We describe its specifications, present some tests results, and give some precautions to the observers.

Key words: Instrumentation: detectors

Нова CCD камера към 60-см телескоп на Астрономическата Обсерватория Белоградчик

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Представена е новата CCD камера FLI PL-9000, монтирана на 60-см телескоп на Астрономическата Обсерватория Белогрдчик. Описани са нейните спецификации, представени са резултати от някои тестове и са дадени препоръки към наблюдателите.

INTRODUCTION

At the end of the year 2008 the Belogradchik Astronomical Observatory employed the usage of a new CCD camera. This is a high-quantum efficiency front illuminated CCD chip FLI PL-9000 by the Finger Lakes Instrumentation. It is attached to the 60-cm Cassegrain telescope, and comes to replace the old CCD ST-8. It is provided with a wheel with standard Johnson-Bessel filters set.

The camera was set up and started operating almost immediately in observational campaigns. It produced a reasonable scientific output. Studying some of the frames that we have collected so far, and also performing specific tests, we decided to describe in detail the behavior of the camera, to check some of its specifications, and study the conditions under which it can perform best.

In this paper we present tests concerning biases, dark frames, flat fields, residual bulk images (RBI) effect, limiting magnitudes, color coefficients, and give some precautions concerning the usage of FLI PL-9000 with the 60-cm telescope at Belogradchik AO.

CAMERA SPECIFICATIONS

The FLI PL-9000 camera specifications and chip quantum efficiency are given in the FLI website (www.flicamera.com). For clarity, we also present these specifications in Tab. 1 and 2. Fig. 1 shows a picture of the camera, attached to the telescope. The pixel size is 12 μm which gives with our telescope a scale of 0.330 $''/px$ with binning 1×1; 0.670 $''/px$ with binning 2×2; and 1.0 $''/px$

with binning 3×3. In all cases the field of view is $\approx 17 \times 17'$. The gain is set to 1 e^-/ADU and there is no option to change it. The camera chip can be cooled down to 60°C below the ambient temperature.

Fig. 1. CCD FLI PL-9000 at the 60-cm telescope at Belogradchik AO

TESTS

We performed a number of tests mostly using the typically used binning (2×2, 3×3) and camera chip temperature interval (-20°C – -40°C). These tests are the following:

Biases and readout noises

Bias frames are relatively stable being on average 2046 ADU for binning 2×2, and 2163 ADU for binning 3×3. No significant camera temperature dependence of the mean bias level was found for the temperature range -20°C – -40°C. The typical CCD chip temperature used is around -30°C. As seen

Table 1. CCD and chip sensor specifications according to the manufacturer

CCD:	KAF-09000
Digital Resolution:	16-bit
Maximum Download Speed:	8 MHz
Typical System Noise:	9 e^- RMS at 1 MHz
Typical Maximum Cooling:	60°C below the ambient temperature
Typical Dark Current:	$<$ 0.05 e^-/pixel/sec (-40°C)
Temperature Stability:	0.1°C
Operating Environment:	-30°C - 45°C; 10% - 90% Relative Humidity
Nonlinearity:	$<$ 1%
Sensor Manufacturer:	Kodak
Array Size:	3056 × 3056
CCD Type:	Front Illuminated
Pixel Size:	12 μm
Mega Pixels:	9.3
Sensor Diagonal:	51.9
Linear Full Well:	110,000 e^-
Anti-blooming:	300×
Peak Quantum Efficiency:	0.68

Table 2. Chip quantum efficiency

4000Å	5000Å	5200-6200Å	6700-8300Å	9500Å
45%	55%	65%	55 - 45%	15%

in Fig. 2, there is a small decrease of the mean bias level of about 4-5 ADUs shortly after the camera has been cooled down. The effect is practically the same in the Normal and Fast read-out mode. One should avoid using the first few biases immediately after cooling down the camera. By comparing different bias frames we measured the readout noise, which was 12.5 ADU rms with binning 2×2, and 15.5 ADU rms with binning 3×3. These values are close to the value cited in the Tab. 1.

Dark frames

Fig. 2 shows dark mean level for Normal and Fast read-out speed. The tests were running for approximately 6 hours, a few minutes after the camera has been switched on and cooled down to -20°C. The mean level of the dark frames decreases exponentially. This effect is much stronger in the Fast read-out mode (140-150 ADUs) than in Normal mode (10-12 ADUs). In all cases dark frames should be taken shortly before or after the scientific exposures to ensure a correct dark frame subtraction.

Flat fields

The combination of chip sensitivity and telescope optics requires the flat field correction to the scientific frames. Due to the relatively large linear field, signs of small vignetting are apparent – the center is about 10% brighter than the periphery. The flat field correction works very well in this case. The standard

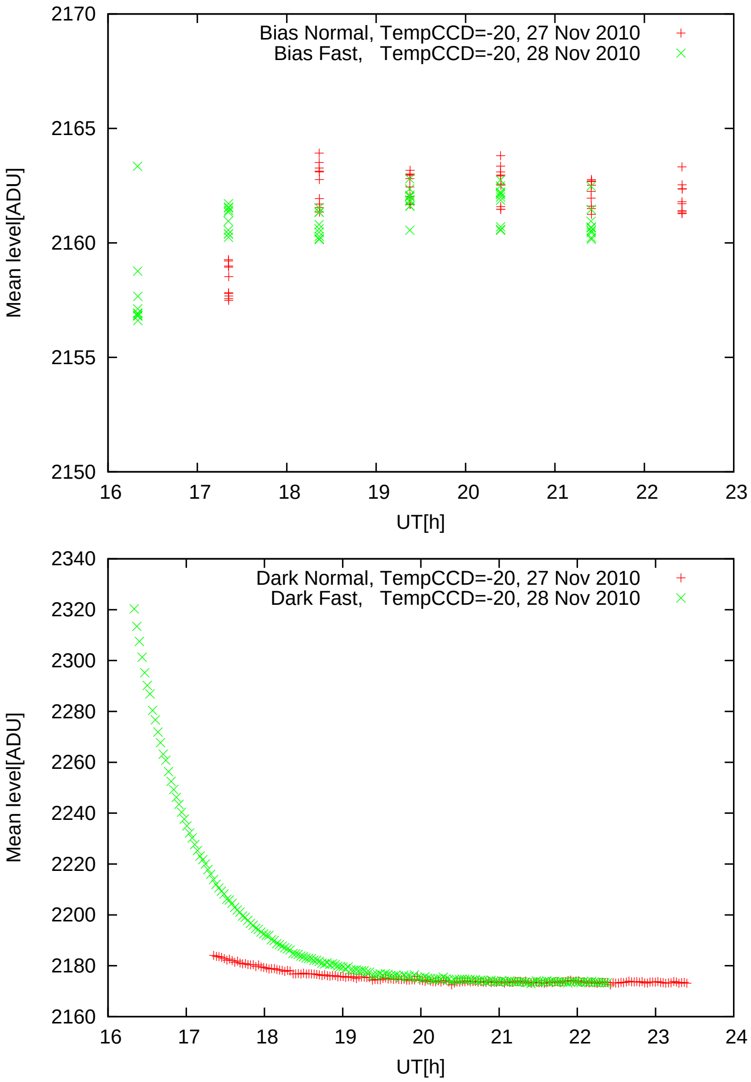

Fig. 2. Biases and dark frames mean level changing with time

deviation for the total flat field frame is about 4%, meaning this will be the average photometric error if no flat field corrections are made. Taking into account the dominating large scale structure of the flat field, this error should be smaller in case of nearby comparison stars. In any case, proper flat field treatment is strongly recommended. In addition, due to the central shutter, flat-field exposures of at least 3 sec are required to eliminate the possible shutter effect and to ensure equal illumination troughout the chip surface.

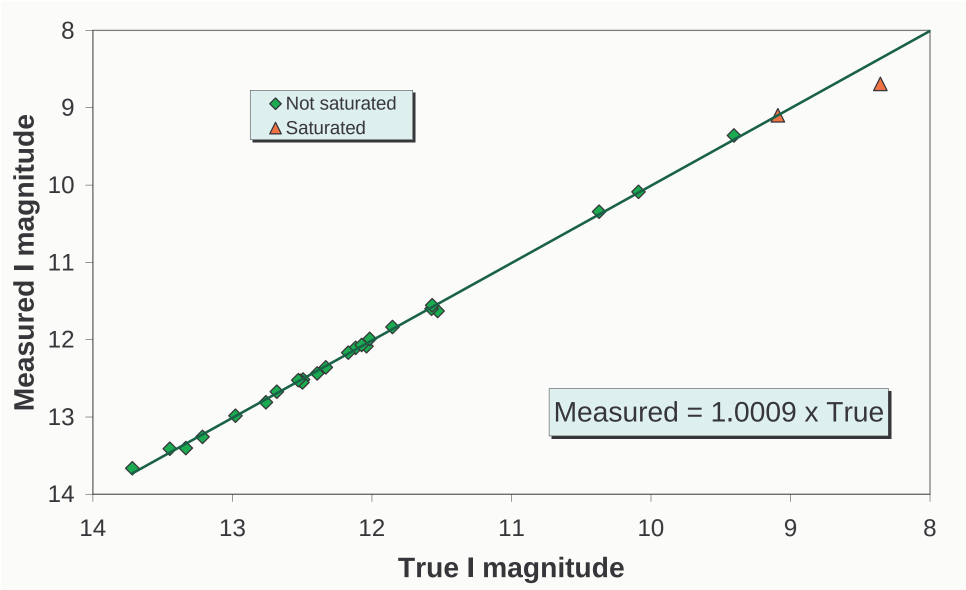

Fig. 3. Comparison between measured and standard magnitudes

Linearity

The chip appears to be linear for the magnitudes of non-saturated stars. Fig. 3 shows an I-band comparison between the measured and the standard magnitudes of stars in the field of $M67$ [Chevalier & Ilovaisky 1991]. We see no significant deviation from the linear slope for any of the bright stars, except for the saturated ones. The slope of the fit (one star is excluded because of saturation) is 1.001 that is consistent with 1 taking into account the photometric errors. Therefore, the response of the chip is linear enough to ensure adequate photometric measurements. To stay on the safe side, observers should avoid exposing objects with peak counts larger than 60 000 ADUs.

Residual bulk images

The presence of Residual bulk images (RBI) for certain types of the new front illuminated CCD chips is a well known problem, and our camera is no exception to this. Soon after its discovering, the Finger Lakes Instrumentation company developed a technique to eliminate RBI effects. This technique is not implemented in our camera, however, and the 'ghosts' are clearly seen. An example of RBI and the bright stars image previously observed is shown on Fig. 4.

The physical interpretation of RBI is described in some detail in [Crisp 2009, Williams 2009]. Shortly, an RBI is a 'ghost' (sometimes it may look like

Table 3. Average counts for a star of 10-th magnitude

U	B	V	R	I	
1300	10700	20500	22800	14300	ADU

a planetary nebula) of a bright area (a bright star in most cases) that was on previous images. These residual images are caused by trapped electrons in the chip by the previous bright object, that need some time to clean up. This time strongly depends on the chip temperature – as the temperature goes down, less electrons are trapped, and faster they will disappear.

However, our study of this effect showed that it does not affect the photometry significantly. When repeated exposures of the same star fields are taken the "ghost" in the next frame appears to be at least 5 magnitudes (6.1 measured once) fainter than the bright star in the previous frame. This means that the photometry may not be affected down to the 0.01 magnitude accuracy level. "Ghosts" intensity slowly diminishes in time, getting fainter with a rate of approximately 1 mag/hour. The "ghost's" intensity is integration time dependent.

Fig. 4 shows an example the RBI effect. The upper part shows a bright star field taken with the telescope without any corrections. The lower part shows a dark frame taken immediately after this image. The 'ghosts' are clearly seen – on the places of the brighter stars there are circles that look like stars. If now the telescope would be pointed to another field, these 'stars' would appear on the frame and would certainly make a confusion with the real stars.

Taking exposures of different star fields, however, should be done with care in order to ensure that no strong "ghost" appears in the next-frame position of a much fainter star of interest. The same is true when a search for new objects in the field is performed.

A certain method to completely eliminate the RBI is to fill up all the pixels to their maximum by a bright light, and then clean them up by taking a few biases immediately afterwards [Williams 2009].

ASTRONOMICAL PERFORMANCE

Light output and limiting magnitudes

The light output (ADUs per second for a 10^m star at the zenith in a clear night) of the CCD FLI PL-9000 with the 60-cm telescope of Belogradchik AO is presented in Tab. 3 for the UBVRI filters. We should however take into account that the mirror coating of the telescope during these measurements was not perfect. Obviously, the output is reasonably good for all bands, except for U. The counts in Tab. 3 are averaged measurements from several clear nights. The photometry was performed in an aperture of $3 \times$ the FWHM.

Based on the light output, the readout noise and the sky brightness, we can calculate the limiting magnitudes needed to achieve a specified photometric accuracy in a frame with given exposure time. We performed direct

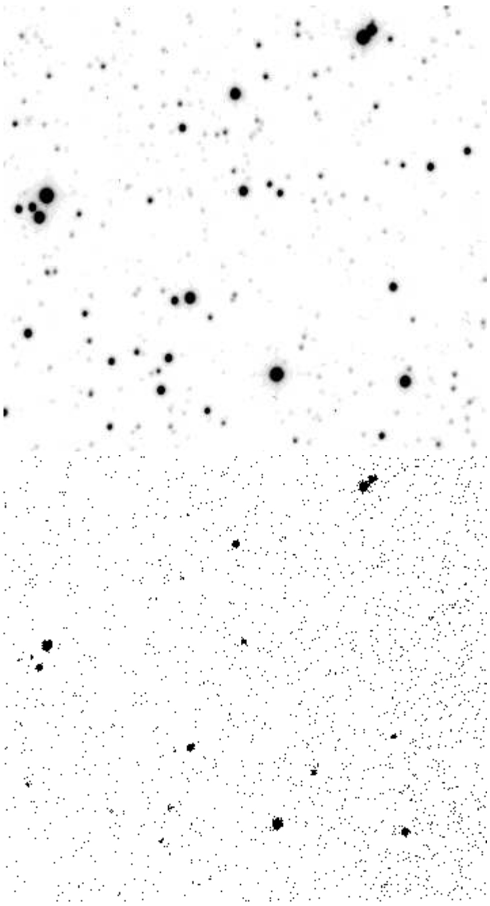

Fig. 4. A bright star field (up) and a dark frame taken immediately after it (down). The effect of RBI is clearly seen as 'ghost stars' on the dark frame (*see text for details*)

measurements, using the field of the quasar 3C 273. The results are summarized in Tab. 4. These are the limiting magnitudes for stars that can be measured in a single 120 sec exposure frame (the typical exposure time used with this telescope) with a specified photometric error ($0^m.01$, $0^m.03$ and $0^m.05$) for the filters UBVRI. They appear to be 1-2 magnitudes brighter than the theoretically calculated under ideal conditions, mostly due to the significant sky background in the vicinity of the nearby town of Belogradchik.

Tab. 4 presents measured limiting magnitudes for three different photometric errors, 120 sec exposures, sensor temperature of -30°C, and typically transparent and bright moonless clear night at Belogradchik AO.

Table 4. Limiting magnitudes for different photometric errors with 120 sec exposures

error	U	B	V	R	I
$0^m.01$	$11^m.9$	$14^m.0$	$14^m.7$	14.7	$14^m.0$
$0^m.03$	$13^m.4$	$15^m.4$	$16^m.0$	15.9	$15^m.2$
$0^m.05$	$14^m.0$	$16^m.0$	$16^m.6$	16.5	$15^m.8$

Table 5. Color coefficients

M1-m1	CC	error	m1-m2	fitting error
B-b	0.37	0.05	b-v	0.05
V-v	-0.06	0.02	b-v	0.02
V-v	-0.10	0.01	v-r	0.02
R-r	-0.13	0.01	v-r	0.03
R-r	-0.12	0.01	r-i	0.03
I-i	0.03	0.02	r-i	0.04

We see that objects as faint as 14^m up to 16^m can be successfully measured in most filters with a relatively good accuracy even without the need of long exposures or frame stacking.

Color coefficients

Based on photometric measurements during several clear nights of the standard stars in the fields of $M67$ [Chevalier & Ilovaisky 1991] and PG 2213−006 [Landolt 1992] we obtained the color coefficients for our photometric system presented in Tab. 5. The table is calculated using equations [Bachev et al. 1999] for transforming the magnitudes into standard system, CC is the Color Coefficient, error is the the Color Coefficient error and fitting error is the standard deviation of the linear fit.

In the table we provide the values only for the color terms, the airmass term depends highly on the atmosphere condition and was studied elsewhere [Bachev et al. 1999]. U-band measurements are not presented because they are often unreliable for low-altitude observatories like Belogradchik AO.

CONCLUSIONS

The new CCD camera FLI PL-9000 attached to the 60-cm telescope at Belogradchik AO appears to perform well and can produce a high-quality scientific output. According to its specifications and the tests we made, it can be used for photometry in the bands B, V, R, and I. This was not the case with the old CCD ST-8 [Bachev et al. 1999], where observations in B-band were unreliable. Limiting magnitudes are in the range 14^m to 16^m depending on the filter, the exposure time, and the desired output error. Observations in U-band with reasonable errors seem to be possible only for brighter objects.

Performing astronomical observations with the camera, observers should take into account the following precautions:

1. Using Fast read-out speed of the CCD chip is not recommended.
2. The operating CCD chip temperature should be in the range -20°C – -40°C. It is be better not to use the first few biases after cooling down the camera.
3. Dark frames should be used with care – they must be taken in the beginning and/or at the end of each observing set.
4. Flat-fields should be taken in the proper way. Evening/morning sky twilight flats should be exposed 3 seconds or more.
5. The observers should take care about the RBI effect. Observing very bright stars will definitely produce 'ghosts'.
6. The chip appears to perform linearly for stars with peak values up to ≈60000. One should avoid exposing objects with peak values higher than that.

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