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# Observations At Astronomical Observatory Belogradchik with the CCD Camera ST-8

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The purpose of this paper is to make calibrations of the new CCD ST-8 camera attached to the 60-cm telescope at Astronomical Observatory Belogradchik. We describe the equipment, the camera, available filters, limits to the observations and workability for astronomical observations.

## 1. Equipment

### *1.1. Telescope and camera*

Astronomical observatory Belogradchik is situated in the vicinities of the town of Belogradchik, in the north-west site of Bulgaria. The coordinates of the observatory are longitude east $01^h30^m12^s$; latitude +42°37' 35"; altitude 610 m. A 60-cm Zeiss reflector (Kassegrain 600/7500) is mounted at the observatory [1], and since 1997 CCD observations are fulfilled. The camera in use is SBIG ST-8 model, equipped with KAF1600 chip. The chip is 16 bit, 1530×1020 pixels, with possibilities to bin if necessary 2 × 2 and 3 × 3. The linear dimensions are 13.8×9.2 mm (9x9 μm pixel). CCD spectral sensitivity reaches maximum at 6750 Å, and drops to the half of it at approximately 4500 Å and 7500 Å. A Peltier element supports the chip temperature 25-30 degrees below the ambient temperature. The field in the main focus is 6.4×4.2 arcmin, scale without binning 27.5"/mm, 0.25"/pixel. The mechanics of the telescope allows exposures of 100-200 sec without need of guiding depending on the position of the telescope. The program *ccdops* operates the camera. According the manual readout noise is $15e^-$/pixel and gain $2.3e^-$/ADU. More information about ST-8 camera and other SBIG models can be found at *www.sbig.com*.

### *1.2. Noises and linearity*

Noises are predominantly due to photon shot noise from the object and background, readout noise and dark signal noise. Noises from flat fielding can be neglected. Photon noises depend only on the level of the signal (as a square root), i.e. it is necessary to increase the exposure time to reduce the noises. To explore the influence of dark noise and readout noise we analyzed about 100 dark frames, obtained with different exposure times (0 ÷ 120 sec) and chip temperatures (-6 ÷ -42 °C). The results can be summarized as following:

1. Readout noise is approximately ±10 ADU ($1\sigma$) and is almost independent of exposure time or temperature. Readout noises do not differ significantly from the Gaussian distribution. Dark noise can be neglected compared to readout noise for temperatures below -10 °C and exposure times less than 100 - 200 sec (this is the normal condition in practice) - it is less than 1-2 ADU. When sky background level is above 300 - 400 ADU (photon noise is about 20), readout noise can be neglected and frames could be added without increasing

significantly the overall noise in comparison with a single, long-exposure frame. Readout noise dominate when the background is under 50 that is for short exposures in B band.

2. The influence of cosmic particles is not important at this altitude (~ 600 m).
3. Analysis shows that the camera is linearly sensitive up to level of 60,000 ADU - within 1-2%, and below 0.2% for levels between 50 and 5,000. For exposure times under 1 sec, photometry can be made with errors not less than 5%.

### *1.3. Filters*

Observations are made with Schott standard filters B, V, $R_c$, $I_c$, the system is Johnson-Cousins - glass combinations are shown in Table 1.

| | |
|---|---|
| B | 1BG12 + 1BG39 |
| V | 1GG11 + 1BG39 |
| R | 2OG570 + 2KG3 |
| I | 3RG9 |

Table 1

Transmissions of the filters as a functions of wavelength are shown on Figure 1. The combination filter-camera provide a signal (in counts) for a star $10^m$ at zenith for different filters and 1 sec esposure as shown in Table 2.

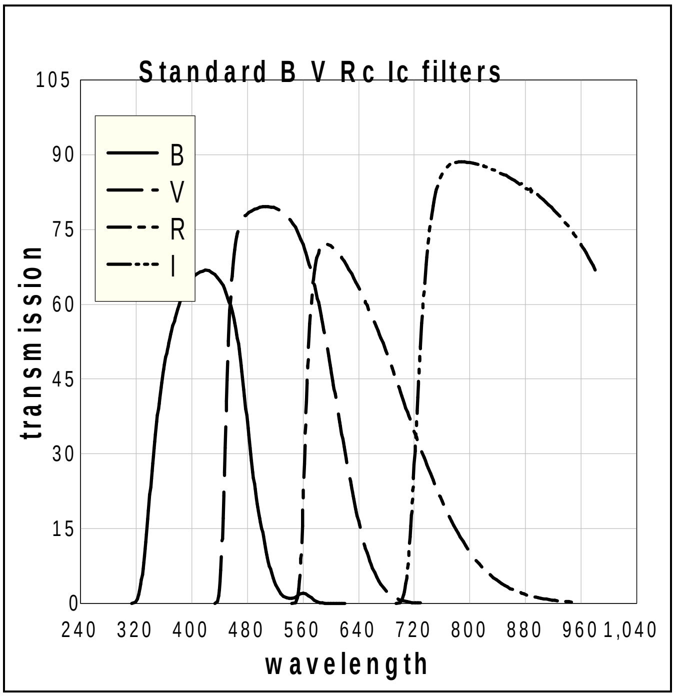


Figure 1

| B | V | R | I |
|---|---|---|---|
| 4000 | 16500 | 12000 | 10000 |

Table 2

## 2. Atmospheric conditions

The seeing at the location of the observatory is normally between 2 and 2.5 arcsec and practically is always under 3 arcsec. Sky background is relatively high because of the city proximity. Star magnitudes per square arcsec of the background for different filters are shown in Table 3. The magnitudes are for a clear night and with no moon light.

| B | V | R | I |
|---|---|---|---|
| 21.7 | 21.8 | 21.3 | 19.8 |

Table 3

Noises (object photon noise, sky background photon noise, readout noise, dark signal noise, etc.) limit the star photometry accuracy. Signal to noise ratio of a star defines the errors of the photometry of the object.

In Table 4 we present the *limit magnitudes* obtained by aperture photometry for a star object for different filters and assumed photometrical errors.

| ± Δ m | B | V | R | I |
|---|---|---|---|---|
| 0.01 | 13.4 | 14.4 | 14.2 | 13.5 |
| 0.03 | 14.8 | 15.8 | 15.6 | 14.7 |
| 0.1 | 16.4 | 17.2 | 16.9 | 16.1 |
| 0.3 | 17.7 | 18.4 | 18.1 | 17.3 |

Table 4

These values are for good atmospheric conditions, for a zenith star and 100 sec exposure. One may increase them about $0.5^m$ by doubling the exposure time. Magnitudes in Table 4 are theoretically obtained without taking into account dark signal and flat field errors, so they may be overestimated by $0.2\text{-}0.3^m$. Stars, determined with $0.3^m$ errors are quite faint and it is difficult to distinguish them well because of the noise on the image.

## 3. Calibration

To calibrate our photometrical system, i.e. to transform the instrumental star magnitudes to standard ones, we observed and measured standard stars. Transformation equations are proposed to be as following:

$$\boldsymbol{B-b} = \alpha_b \boldsymbol{(b-v)} + \beta_b \boldsymbol{X} + \gamma_b$$
$$\boldsymbol{V-v} = \alpha_v \boldsymbol{(b-v)} + \beta_v \boldsymbol{X} + \gamma_v$$
$$\boldsymbol{R-r} = \alpha_r \boldsymbol{(v-r)} + \beta_r \boldsymbol{X} + \gamma_r$$
$$\boldsymbol{I-i} = \alpha_i \boldsymbol{(r-i)} + \beta_i \boldsymbol{X} + \gamma_i$$

where *b, v, r, i* are instrumental magnitudes, *B, V, R, I* - standard magnitudes, *X* is the atmosphere mass ($X$=sec($z$), $z$ is the zenith distance) and α, β, γ - reduction coefficients. For the calibration we used the open cluster M67, where most of the stars are measured by several authors [2]. Calculated coefficients are shown in Table 5. Coefficients β and especially γ are variable and depend on the atmospheric conditions during the night. Ordinary β ~0.05-0.3 and it also depends on the wavelength.

As one can see from Table 5, coefficient α for B-filter is significantly high (these coefficients are expected to be close to zero), that makes B-photometry unreliable. The error of coefficient γ is minimal for CCD-photometry - here approximately $0.02^m$.

| Coeff. | α | ±α | ±γ |
|---|---|---|---|
| **B** | 0.58 | 0.02 | 0.02 |
| **V** | 0.09 | 0.01 | 0.02 |
| $\mathbf{R_c}$ | 0.06 | 0.02 | 0.02 |
| $\mathbf{I_c}$ | 0.20 | 0.02 | 0.025 |

Table 5

## 4.Observations

Specific conditions and equipment of Astronomical Observatory Belogradchik are good for a few types of observations:

### *4.1 Secondary standards*

To calibrate a photometric system it is convenient to use standard clusters with many standard stars in the field, instead of single standard stars. Most of the standard stars in clusters, used frequently for calibration of the instrumental system are too faint for small telescopes, so we obtained magnitudes of brighter secondary standards in some fields. We observed two well known standard clusters - M92 and NGC 7790 [3]. B, V, R and I magnitudes for about 50 selected stars in these clusters have been calculated. Errors of the photometry are approximately $\pm$ 0.02-0.04$^m$, and are maximal for B-band ($\pm$ 0.05$^m$).

### *4.2 AGN*

A lot of our observational time has been spent to examine the physics of active galactic nuclei (AGN). We studied variability (quasars, BL Lac, Seyfert galaxies) and surface brightness (near Seyferts) of selected AGN. First interesting results for Mkn 279, Mkn 315, Akn 564, Mkn 501, HS 1946+765, etc. have been obtained. Monitoring is continuing.

### *4.3 Galaxies*

A program for surface photometry of near-by galaxies is carried on the observatory. Edge-on bulge-peanut galaxies with total magnitudes approximately 12-13$^m$ are observed in order to understand their physics.

### *4.4 Close binaries*

A symbiotic variable KR Aur has been thoroughly explored. This object had recently a deep minimum (18-19$^m$) which lasted unexpectedly long time (more than one year). Monitoring is continuing.

### *4.5 Open clusters*

There are several open clusters in our Galaxy, which are suspected to be double. (The one surely known double cluster is h, $\chi$ Per). We intend to obtain H-R diagrams for these clusters to prove or disprove this.

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