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OBSERVATIONS AT ASTRONOMICAL OBSERVATORY BELOGRADCHIK WITH CCD CAMERA SBIG ST-8

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Abstract. This paper describes observational possibilities with SBIG ST-8 CCD camera at Astronomical Observatory Belogradchik, Institute of Astronomy, Bulgarian Academy of Sciences. We describe the equipment, the camera, available filters, software, limits and workability for astronomical observations.

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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 latitude $+43°37'35''$, longitude east $01^h30^m42^s$, altitude 610 m. A 60 cm Zeiss reflector (Cassegrain 600/7500) is mounted at the observatory [1], and since 1997 CCD observations have been fulfilled. The camera in use is SBIG ST-8 model, equipped with KAF1600 chip. The chip is 16 bits, 1530×1020 pixels, with possibilities to bin if necessary 2×2 and 3×3. The linear dimensions are 13.8×9.2 mm (9×9 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 Peltiér 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. A propeller-type shutter allows exposures longer than 0.1 s. Download time is about 25 s for a 3×3 binned image. The mechanics of the telescope allows exposures of 100–200 s without need of guiding depending on the position of the telescope. According to the manual readout noise is 15 e^-/pixel (6.52 ADU/pixel) and gain is 2.3 e^-/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 s) and chip temperatures (from -6 to $-42\,^\circ$C). The results can be summarized as follows:

1. The readout noise is approximately ± 10 ADU (1σ) and is almost independent of exposure time or temperature. The readout noise does not differ significantly from the Gaussian distribution. The dark noise can be neglected compared to the readout noise for chip temperatures below $-15\,^\circ$C and exposure times less than 100-200 s (normal condition in practice) is less than 1-2 ADU. When sky background level is above 300-400 ADU (the photon noise is about 20), the readout noise can be neglected and frames could be added without the overall noise to increase significantly in comparison with a single, long-exposed frame. The readout noise dominates 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 ($\approx$ 600 m).
3. Analysis shows that the camera is linearly sensitive up to level of 50000 ADU within 1-2 %, and below 0.2 % for levels between 50 and 5000. For exposure times under 1 s 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, and the system is Johnson-Cousins. Glass combinations are shown in Table 1. Transmissions of the filters as functions of wavelength are shown in Fig. 1. The combination filter-camera provides roughly a signal (in counts) for a star 10^m (A0) at zenith for different filters and 1 s exposure as shown in Table 2.

Table 1. Glass combinations of filters

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

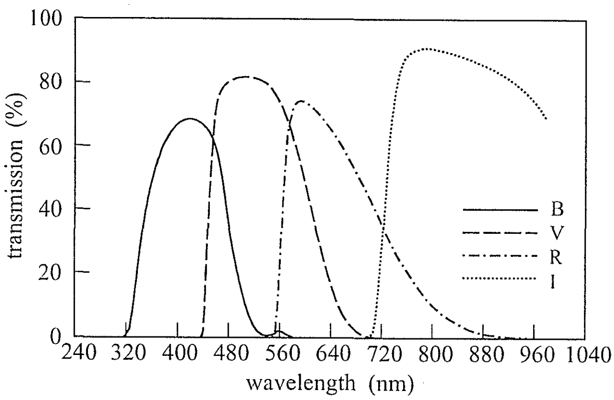

Fig. 1. Transmissions of the standard B, V, R_c and I_c filters as functions of wavelength

Table 2. Signal (counts) for a 10^m star at zenith for different filters, 1 s exposure

B	V	R	I
3200	17800	15400	10500

Table 3. Sky background (magnitudes per square arcsec) for different filters

B	V	R	I
21.7	21.8	21.3	19.8

1.4. Software

1.4.1. *CCDOPS*

The program ccdops operates the camera: it controls the exposures and downloads the frames. Dark subtraction, flat field correction, cleaning warm and cool pixels as well as many other procedures are available. Data is processed in ST8 format (supported by ccdops) and can be converted to FITS if necessary. A big advantage of ccdops is its ability to take auto-darks and auto-grab, e. g. to make automatic exposures by setting exposure time and desired number of images. This makes patrol observations much easier. This program is a part of CCD SBIG ST-8 equipment.

1.4.2. *ASTROBEL*

Positioning of the telescope is done manually by setting hour angle and declination of the object. To calculate these coordinates at the moment of observation we use the program Astrobel that is made by one of us (A. S.). It works under MS Windows environment. Using this program one can locate the telescope position with high precision so that the object of interest appears on the camera chip. This makes the procedure of finding objects easy and quick. Astrobel has been checked for different positions of the telescope. If there are any additional corrections the program has possibility for correction input. One can choose objects directly from a file list and the program will automatically calculate precession, sidereal time, hour angle, air mass, JD and others for the moment of observation. At present the program is under improvement. It is available at the observatory.

1.4.3. *FITS Imager*

One of us (R. B.) has made a program FITS Imager for reduction and photometry. This program uses MS Windows environment, has user friendly interface and can load, display and correct FITS format images. The program makes relative aperture photometry of stars, pointed by the mouse. The sky background can be automatically subtracted using an annulus just outside the photometry diaphragm. The diaphragm itself can be automatically centred onto the star, finding the location near the pointed one, where the pure signal from the star (the signal from the diaphragm minus the signal from the annulus outside) is maximal. Special attention is paid to patrol observations — the program can find the stars on each frame of the patrol if they are pointed on the first one, despite of possible small displacement of the star positions during the time of the patrol. The result of the photometry can be saved in a file. There are possibilities to make cross sections within the frame. The positions of these cross sections are defined with the mouse and the result can be displayed and saved in a file too. FITS Imager is under improvement. It is available from the author on request.

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 town proximity. Sky background in magnitudes per square arcsec for different filters are shown in Table 3. These magnitudes are for a clear night with no moon light.

Noises (the object photon noise, the sky background photon noise, the read-out noise, the 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 photometric errors.

These values are for good atmospheric conditions, for a zenith star and 100 s exposure. One may increase them with about 0.5^{m} by doubling the exposure time. Magnitudes in Table 4 are theoretically calculated without taking into account dark signal and flat field errors, so these values may be overestimated by 0.2–0.3^{m}.

Table 4. Limit magnitudes obtained by aperture photometry for a star object for different filters and assumed photometric errors, 100 s exposure

$\pm\Delta m$	B	V	R	I
0.01	13.4	14.4	14.2	13.5
0.03	14.8	15.8	15.6	14.7
0.10	16.4	17.2	16.9	16.1

3. Calibration

To calibrate our photometry system, i. e. to transform the instrumental star magnitudes to standard ones, we observed and measured standard stars. Transformation equations are derived as follows:

$$
\begin{aligned}
B &= b + 0.510(b - v) - 0.37X + 18.04 \\
V &= v + 0.065(b - v) - 0.21X + 20.66 \\
V &= v + 0.074(v - r) - 0.21X + 20.81 \\
R &= r + 0.064(v - r) - 0.08X + 20.48 \\
R &= r + 0.032(r - i) - 0.07X + 20.48 \\
I &= i + 0.190(r - i) - 0.08X + 20.16
\end{aligned}
$$

where b, v, r and i are the instrumental magnitudes; B, V, R and I — the standard magnitudes, and X is the air mass ($X = \sec(z)$, z is the zenith distance). For the calibration we used the open cluster M67, where most of the stars are measured by several authors [2]. Transformation coefficients shown are averaged for three measurements. Color coefficient (the first term) is approximately constant because it depends on the filters. Extinction coefficient (the second term) and especially the zero point correction (the last term) depend much on atmospheric conditions and may vary.

As one can see, the color coefficient for B-band is significantly higher than for other filters (these coefficients are expected to be close to zero). This makes the B-band photometry unreliable. The zero point errors of the magnitude scale limit the accuracy of CCD photometry to 0.02^{m}. That means that the equipment is effective mostly for photometry of stars as faint as $14–16^{\mathrm{m}}$, where the noise errors are comparable to the errors of calibration (see Table 4)

4. Observations

Specific conditions and the equipment of Astronomical Observatory Belogradchik provide good conditions for several types of observations.

4.1. Standards

To calibrate a photometry system it is convenient to use standard clusters with many standard stars on the field instead of using single standard stars. As much as most of the standard stars in clusters, used frequently for calibration of the instrumental system, are too faint for small telescopes, we obtained *BVRI* magnitudes of brighter secondary standards in some fields. Some preliminary results are obtained for the fields of NGC 7790 and M92 standard clusters. Errors of the measurements are usually $0.02-0.04^{m}$. The results will be published elsewhere.

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 Lacs, Seyfert galaxies) and surface brightness (Seyferts) of selected AGN. First interesting results for Mkn 279, Mkn 315, Akn 564, Mkn 501, 3C345, HS 1946+7658 and others have been obtained. Monitoring is continuing.

4.3. Galaxies

A program for surface photometry of near-by galaxies is carried on at the observatory. Edge-on galaxies that display box-peanut distortions in their isophotes are to be studied. About 50 galaxies with total magnitudes approximately $12-13^{m}$ are proposed for observation. The galaxy NGC 5610 has been studied in details [3]. The program is continued.

4.4. Close Binaries

A cataclysmic variable KR Aur has been thoroughly investigated. This object has been recently in a deep minimum ($18-19^{m}$) which has lasted unexpectedly long time (more than one year) [4]. 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 and χ Per. We intend to obtain H–R diagrams for these clusters to prove or disprove this. A program for photometry of old open clusters is performed as well.

5. Conclusions

The main conclusion of this work is that available equipment at Belogradchik Observatory including 60 cm telescope, software and ST-8 camera are suitable for CCD photometry in V, R and I bands. Reliable photometry can be made for stellar objects brighter than $16-17^{m}$ and galaxies brighter than $13-14^{m}$.

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