New Bulgarian-Ukrainian Universal Photometer of the Belogradchik Astronomical Observatory

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Abstract

The new Bulgarian–Ukrainian Universal Photometer (BUP) was designed in the Laboratory of the Institute of Astronomy, Bulgarian Academy of Sciences and at the Main Astronomical Observatory, National Academy of Sciences of Ukraine. The photometer has a modular structure. It can be used both for single-channel photoelectric photometry and for CCD photometry. The photoelectric photometer is based on a EMI 9789 QA photomultiplier cooled by a two-cascade Peltier. For CCD photometry a SBIG ST-8 CCD camera is used. The main components of the photometer are: photometer head, control and counting module, photon registering module, CCD camera, personal computer and software. The photometer is capable of working with the 60cm Cassegrain telescope at Belogradchik Observatory and with the 2m RCC telescope at the National Astronomical Observatory – Rozhen. It is suitable for observing variable stars, galaxies, stellar clusters, asteroids. Some first observations carried out with BUP attached to the 60cm telescope at Belogradchik Observatory and to the 2m telescope at NAO-Rozhen are presented.

Introduction

The Belogradchik Astronomical Observatory (BO) of the Institute of Astronomy, Bulgarian Academy of Sciences, is situated in the North-Western part of Bulgaria. The coordinates of the Observatory are: latitude $+43^0 37'35"$ and 1h 30m 42s eastern longitude. The altitude is 630m. There are two telescopes – a 60cm Cassegrain built by Carl Zeiss and a 36,5cm Schmidt–Cassegrain by Celestron. The 60cm Cassegrain (600/7500) telescope (Antov, Konstantinova-Antova, 1995) was equipped with a single-channel electrophotometer without a cooling system and without an offset for guiding. In 1997 the telescope was also equipped with SBIG ST-8 CCD camera.

Since 1990 at Belogradchik Observatory has began research of fast brightness variations in chromospherically active stars, cataclysmic, symbiotic stars and asteroids. This kind of research requires patrol observations with short integration times of several hours duration. In 1995 a cooperative program has been started with the participation of the Institute of Astronomy (BO and NAO-Rozhen, Bulgaria), the Main Astronomical Observatory, the International Center for Astronomical, Medical and Ecological Research, NAS (Ukraine), the Crimean astrophysical Observatory (Crimea – Ukraine), and Stephanion Observatory (Greece). This project includes high-speed photometric observations of short-duration and low-amplitude stellar variability (Zhilyaev et al.,2000).

BUP consists of separate modules in order to be easily reconfigured for electrophotometric or CCD observations. A major advantage over the old photometric system is the cooling system, which decreases the dark current level significantly. Another benefit of the instrument is the offset, which allows guiding during observations. This makes possible longer CCD exposures and continuous patrol photoelectric observations that need not be interrupted to center the object in the diaphragm.

1 BUP Configuration

The main components of BUP are: photometer head, control and counting module, photon registering module, CCD camera (SBIG ST-8), personal computer and software. The photometer is used for electrophotometric and CCD observations.

The opto-mechanical photometer head as well as the control and counting module were manufactured in the Laboratory of the Institute of Astronomy. The photon registering module with two-cascade Peltier cooling system was designed in the Main Astronomical Observatory, Ukraine. The different modules are separate parts of the photometer and are easily mountable. This allows fast change between both detectors – the electrophotometer and the CCD camera.

1.1 The photometer head

This is an opto-mechanical module containing several parts: Offset, Diaphragm wheel and Filter wheel.

1.1.1 The Offset

The offset makes possible the guiding of a star. The field of view of the offset with the 60cm telescope is 20' and the faintest star suitable for guiding is about 13.5^m. As for now the guiding is made by hand, but there are plans for building a CCD based auto guiding system.

The guiding allows long exposures with the CCD camera and long patrol electrophotometric observations. There is no need to unmount the Offset when the electrophotometer and CCD camera are changed. When the diaphragm wheel, the filter wheel, the photon registering module and the control and counting module are attached to the offset, BUP can operate as an electrophotometer (Figure 1). For CCD observations the filter wheel and the CCD camera are attached to the offset (Figure 2).

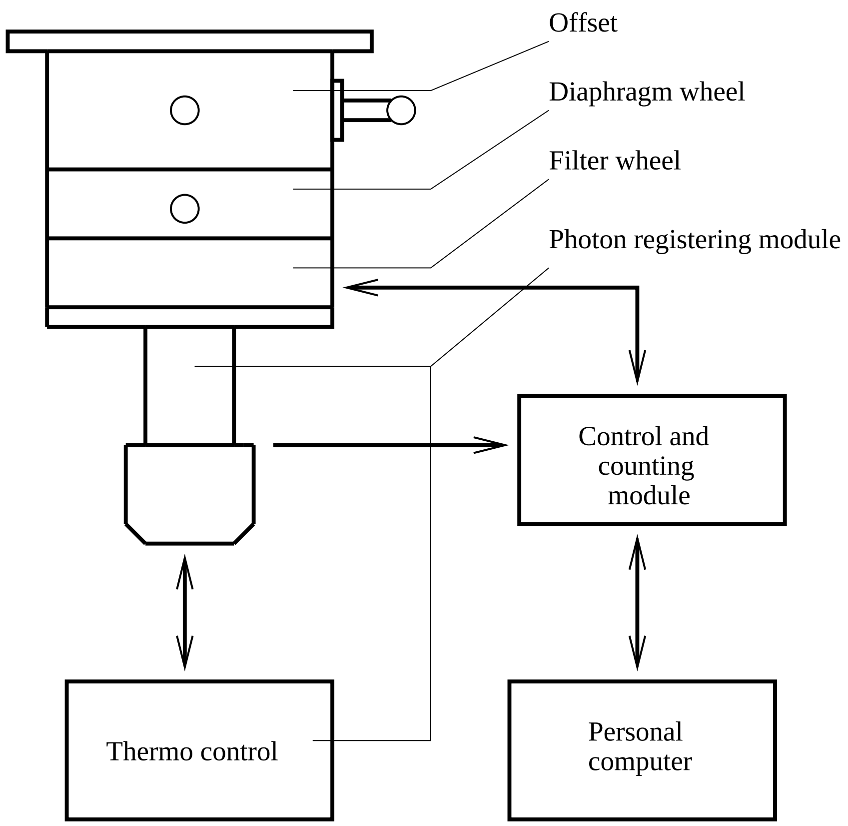

Figure 1: BUP configured as an electrophotometer.

1.1.2 The diaphragm wheel

The diaphragm wheel is not used for CCD observations. It has 8 places, where 6 diaphragms are mounted (Table 1). The diaphragm wheel operation is still manual.

Table 1: Diaphragm sizes.

Linear size [mm]	0.5	1.1	1.6	2	3.2	5
Angular size ["]	13.8"	30.36"	44.16"	55.2"	88.32"	138"

There is a luminophore in one of the places for calibration and testing of the equipment.

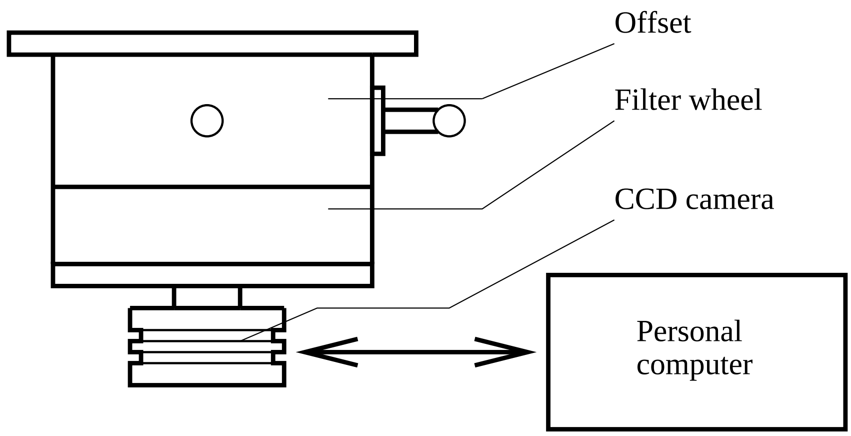

Figure 2: BUP Configured for CCD observations.

1.1.3 The filter wheel

The filter wheel is rotated by a stepper motor, driven by the Control and counting module. There are three different filter revolvers that allow usage of different photometric systems. Each of them has five filter places with a diameter of 45 mm.

Johnson UBV system is used with the electrophotometer (Table 2).

Table 2: Johnson UBV filter system.

System	Type
U	2UG1 + 1BG39
B	1GG385 + 1BG12 + 1BG23
V	2GG495

The instrumental u,b,v magnitudes and the standard Johnson U,B,V system magnitudes are related in the following way:

$$\Delta V = \Delta v - 0.15(b - v)$$
$$\Delta(B - V) = 1.11\Delta(b - v) \quad \text{(for 2000)}$$
$$\Delta(U - B) = 0.96\Delta(u - b)$$

The coefficients are determined using standard stars in the stellar cluster Pleiades.

The Johnson–Cousins photometric system BVRI is used with the CCD camera (Table 3). The transformation equations from instrumental to standard magnitudes for this system are derived as follows (Bachev et al., 1999):

$$B = b + 0.510(b - v) - 0.37X + 17.74$$
$$V = v + 0.065(b - v) - 0.21X + 20.66$$
$$V = v + 0.074(v - r) - 0.21X + 20.81$$
$$R = r + 0.064(v - r) - 0.08X + 20.48$$

$$R = r + 0.032(r - i) - 0.07X + 20.48$$
$$I = i + 0.190(r - i) - 0.08X + 20.16,$$

where b, v, r and i are instrumental magnitudes, B, V, R and I are standard magnitudes, $X = \sec Z$ – the air mass and Z is the zenith distance.

Table 3: Johnson–Cousins BVRI photometric system.

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

1.2 Control and counting module

This module is used only in conjunction with the photon registering module when configured as an electrophotometer. It is used for filter setting, photon counting, and has real time clock with high resolution (0.01 s). This device has on board memory for storing the measured values. Prior to storing this values are marked with the time of the measurement start, the identifier of the measurement type (comparison star, sky background, variable star etc.), and the identifier of the filter used. The device is controlled by the personal computer. The shortest integration time is 0.01s. The block diagram of the module is presented in Figure 3. The control and counting module is still under development and currently the old system is used (Antov, Konstantinova-Antova, 1995).

A short description of all units of the module is presented below:

1.2.1 Counter

The counter provides for the counting of the incoming pulses. This is a 24-bit counter. The counting is driven by the Programmable timer.

1.2.2 Programmable timer

This unit generates programmed time intervals from 0.01s to 120s, and the error of the 1s interval is less than 10^{-4}s.

1.2.3 Real time clock

The unit is used for marking the measured values with the real time stamp. The resolution is 0.01s, which makes possible marking even measurements with the shortest integration time.

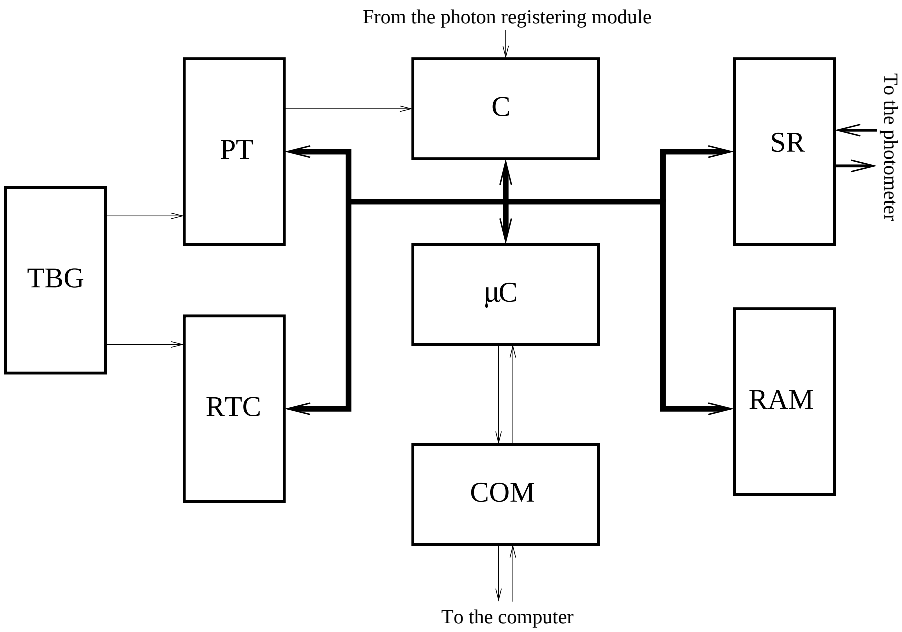

Figure 3: Block diagram of the Control and counting module.
C – counter, PT – programmable timer, RTC – real time clock, SR – status registers, RAM – random access memory, COM – communication unit, TBG – time base generator, μC - controller.

1.2.4 Status registers

This unit consists of three 4-bit registers. Two of them are read-only and one is write-only. The read-only registers contain data for the identifier of the current filter and the type of the measurement (comparison star, sky background, variable star etc.). The setting of the appropriate filter by the filter wheel is done by writing its identifier in the write-only register.

1.2.5 Random access memory

It is used for storing the marked measurements before uploading them to the personal computer. They are uploaded on computer-generated request via the communication unit.

1.2.6 Communication unit

All commands to the device and the data are transferred to and from the personal computer by this unit. It organizes RS-232 serial interface.

1.2.7 Time base generator

The time base generator is used for generating clock ticks of the Controller, time base for the programmable timer and real time clock. The time base generator produces accurate and stable ticks. The accuracy of the measurements depends on this unit.

1.2.8 Controller

The controller commands all other units of the device and is based on Atmel 89C51 microcontroller. It programmes the programmable timer, reads and sets the real-time clock, reads the current status of the counter, reads and writes in the status registers and the on-board memory. This unit provides the data transfer between the personal computer and the control and counting module. Since the device is computer-driven, the controller also interprets and executes the commands received from the computer.

1.3 Photon registering module

The photon registering module is based on EMI 9789 QA photomultiplier (PMT). The PMT is mounted in the air-tight, thermo-isolated steal cylinder in order to be protected from moisture, magnetic and electric influences. The full block diagram is illustrated on Figure 4.

1.3.1 High voltage

The high voltage generator supplies the anode of the photomultiplier with stable voltage from 1000V to 2000V with resolution of 0.1V. The time instability of the high voltage is less than 1V per 12 hours of work.

1.3.2 Amplifier-discriminator

The output of the PMT is amplified by the amplifier-discriminator to $4 \pm 0.5V$ (compatible with TTL levels). The pulse width is $t_p = 40ns$.

1.3.3 Cooling system

The PMT is cooled by two-cascade Peltier cooler. The PMT temperature can be regulated in the interval from the environment temperature T_0 to $T_0 - 40^0C$. The temperature instability after 30min operation is $< 0.1^0C$.

1.3.4 PMT Protection

There is a light protection system for the PMT. The system is activated when the photon rate reaches the value of 2 400 000 photons per second. Also there is a hand-driven shutter protecting the PMT when not in operation.

1.3.5 Control panel

Th control panels of the module have indication of PMT photo-cathode temperature, high voltage value, low voltage supply for the amplifier-discriminator and PMT overload. Control panels are used for temperature, HV and discrimination level regulation and monitoring.

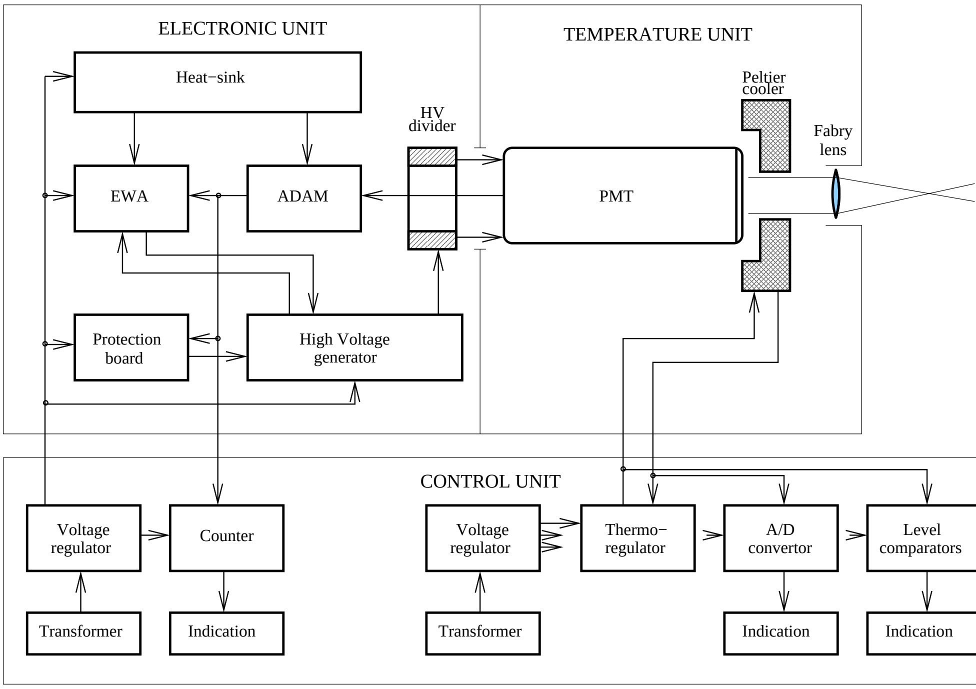

Figure 4: Block diagram of the Photon registering module.
EWA – control panel, ADAM – amplifier-discriminator module, PMT – photomultiplier.

1.4 CCD camera

The ST-8 CCD camera is a standard module produced by Santa Barbara Instrument Group (*http://www.sbig.com*). The CCD chip is Kodak KAF-1602E with 1.5 million pixels array (1530x1020). The pixel size is 9x9 microns. The chip is Peltier cooled with $\Delta t = -25^0 C$. The Analog to Digital converter is 16-bit. The camera is controlled by the computer through the parallel printer port.

1.5 Personal computer and software

The personal computer is a generic IBM PC compatible one running MS DOS. It is used for controlling all other modules, for observational data storage and data processing.

At present the software package "Electrophotometer control"(EP) is used, running under DOS. The results of the measurements are presented graphically on the screen as well as most of the necessary information about the running observations (object being observed, current filter etc) in real time. EP calculates the hour angle, the altitude and azimuth and the air mass of the observed object. It is capable of working with a control panel, mounted on the telescope, and the results can be monitored on the second screen placed under the dome of the telescope. The output data of the EP can be processed with the APR package (Kirov et al., 1991).

The new control and counting module is not compatible with the EP software. That is why a new software is being developed running under Linux operating system.

2 First results

Since August, 2000 BUP operates at Belogradchik Observatory and observations are carried out by using the photometer attached to the 60 cm telescope. One of the aims of BUP is the high-speed electrophotometric monitoring of chromospherically active stars, cataclysmic variables, symbiotic stars, asteroids etc.

Figure 5 presents the result of the stability test of the equipment received by observations of the non-variable star HD 185958 (U=6.26^m) with integration time of 1s. The observations were carried out in U-filter of the Johnson UBV system in August 24/25, 2000 at Belogradchik Observatory. Δu is the difference (in instrumental magnitudes) in the brightness values of HD185958 and the standard star HD 185758.

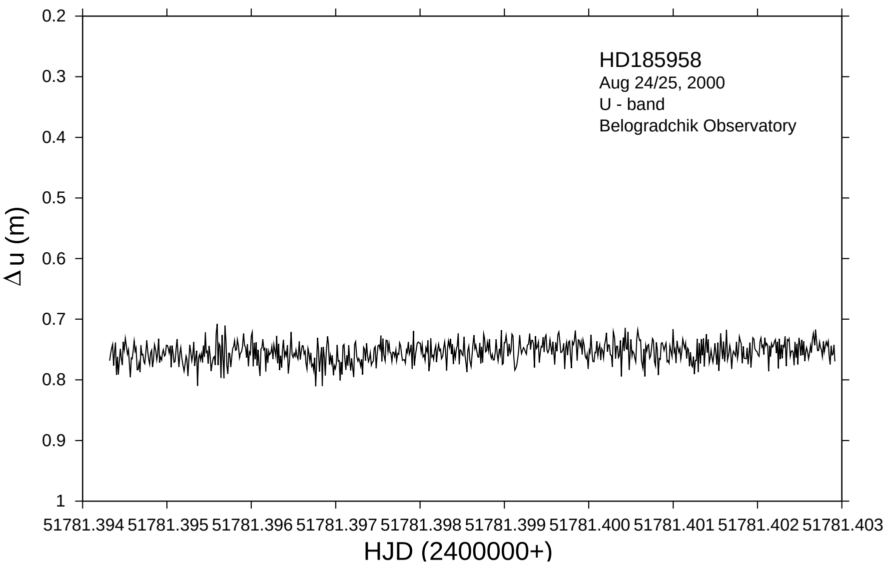

Figure 5: Photometry of the non-variable star HD 185958 with the 60cm telescope. The integration time is 1s.

The standard deviation of random noise fluctuation is $\sigma = 0.01^m$ The data are processed by using the APR package.

The cataclysmic star KR Aur was observed in January 4, 2001 using BUP and ST-8 CCD camera. The exposure time is 180s. Brightness estimates in V,R and I filters, were presented below:

Magnitude	**Date**	**U.T.**
$V = 18.1 \pm 0.2$	5.01.2001	00 09 12
$R = 17.8 \pm 0.2$	4.01.2001	23 45 33
$I = 16.9 \pm 0.1$	4.01.2001	23 41 30

In Figure 6 a flare event, detected on the flare star EV Lac during simultaneous patrol observational campaign for study of small-amplitude stellar variability is presented.

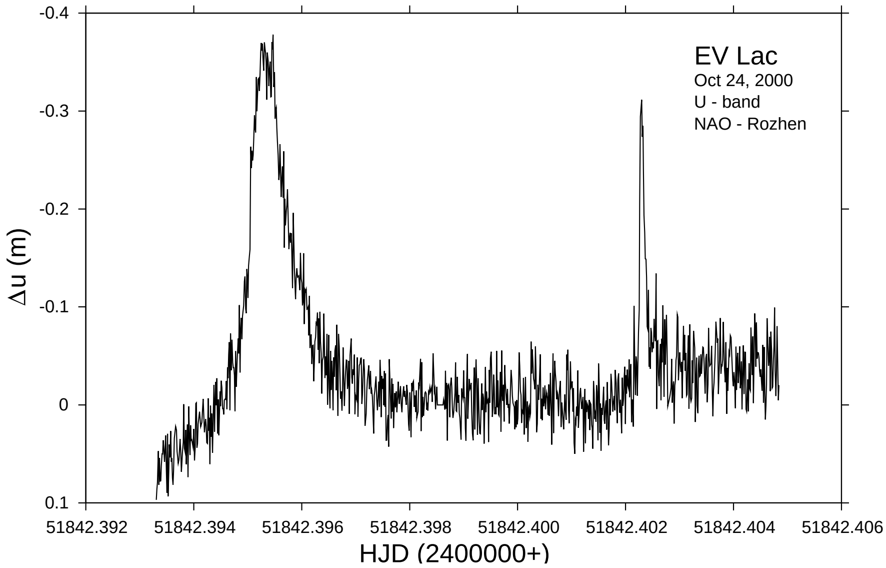

Figure 6: A flare event, observed with the 2m RCC telescope, on the star EV Lac. The integration time is 0.1s.

The event was detected electrophotometrically by using BUP attached to the 2 m RCC telescope at the National Astronomical Observatory – Rozhen in October 24, 2001. The integration time is 0.1s. The standard deviation of random noise fluctuation is $\sigma = 0.02^m$. Δu is the amplitude of the event regarding the quiet state of the star after the substraction of the sky background.

3 Upcoming improvements

There are lots of plans for improving the equipment of the Belogradchik Astronomical Observatory. The most important of them are:

- Building a CCD based auto-guiding system for the 60cm telescope of the Belogradchik Observatory.

- Developing accurate time system based on GPS.

- Creating software for the photometer control, running under Linux operating system.

Summary

BUP is able to work either as electrophotometer or as CCD camera. The accuracy of the electrophotometer mounted on the 60cm telescope is about 0.01^m for a star of 9^m in V band.

The photometer is suitable for observations of variable stars, stellar clusters, active galaxies, asteroids etc. It is designed to be attached to the 60cm Cassegrain telescope at Belogradchik Astronomical Observatory and in the RC focus of the 2m RCC telescope at the National Astronomical Observatory – Rozhen.

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