High Temporal Resolution Multimode Panoramic Photospectropolarimeter

V. L. Plokhotnichenko[1], G. M. Beskin[1,2], S. V. Karpov[1,2,3], S. V. Moiseev[1], V. S. Shergin[1], E. P. Gorodovoy[1], A. G. Gutaev[1], D. A. Badin[4], V. G. de-Boer[5], A. V. Solin[6], A. A. Solin[6], Z. V. Lyubetskaya[1], A. P. Lyubetsky[1], V. V. Pavlova[1] and S. S. Moiseev[7]

[1] Special Astrophysical Observatory, Russian Academy of Sciences, Nizhny Arkhyz, Russia,
[2] Kazan Federal University, Kazan, Russia
[3] CEICO, Institute of Physics, Czech Academy of Sciences, Prague, Czech Republic
[4] Sternberg Astronomical Institute, Lomonosov Moscow State University, Moscow, Russia
[5] A. F. Ioffe Physical-Technical Institute, Russian Academy of Sciences, St. Petersburg, Russia
[6] Institute for Nuclear Problems, Belarussian State University, Minsk, Belarus
[7] Moiseev Individual Enterprise, Taganrog, Russia

Abstract. A modern version of the hardware-software complex of the MANIA experiment for searching and studying the brightness variability of astrophysical objects with a time resolution of 10^{-6} s is described. The basis of the complex is the Multimode Panoramic Photospectropolarimeter (MPPP) of the BTA primary focus, which allows observations in several remotely set modes – photometric, polarimetric, spectral. Two photodetectors (PD) based on coordinate-sensitive detectors (CSD) with S-20 ("blue") and GaAs ("red") cathodes and an EMCCD camera are used to record radiation in a field of view with a diameter of $1'$or in several separate platforms (diaphragms) with sizes $0 - -10'' \times 10'', \times 60''$. The data acquisition system from the PD based on two chronometric devices "Quantochron 4-48" determines with a time resolution of 1μs and encodes the moments of registration of individual photons, accumulating sequences of these codes with additional photometric, polarization, spectral information about events in long-term memory. The EMCCD camera, on the other hand, registers and saves a series of video frames with a temporal resolution of up to 0.1s. Some results of BTA observations of non-stationary objects of different types are presented.

Keywords: instrumentation: detectors

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1 Introduction

The multimode panoramic photometer-polarimeter (MPPP) described in articles Plokhotnichenko et al. (2003); Karpov & Beskin (2007); Plokhotnichenko et al. (2008, 2009) has shown its effectiveness in solving high temporal resolution astronomy (HTRA) problems during a 20-year observation cycle (key 2008). It is used for scheduled BTA observations and significant astrophysical results were obtained. In particular, a change in the shape of the main pulse of the pulsar in the Crab Nebula was detected Karpov et al. (2007); observations of flare stars are regularly carried out, in which polarization of microflares was found in the red dwarf UV Ceti against the background of a giant flare Beskin et al. (2017); in a 200-second time interval, a unimodal periodic emission of a millisecond pulsar was detected Beskin et al. (2018); Karpov et al. (2019).

2 Optical-Mechanical Scheme

MPPP consists of (Fig. 1a):

- a focal platform (I) with a mirror-slit unit for observing the operational field and an input lens for the collimator of the radiation of the investigated sky area;
- a unit of optical blocks (II) with a linear polarization analyzer at the input of the optical beam (Oliva 1997);
- devices (III) for remote installation of five optical units in the working position;
- two photodetectors (IV, V) based on CSD (Debur et al. 2003, 2009; Plokhotnichenko et al. 2020a) with two chronometric devices "Quantochron 4-48" (Plokhotnichenko et al. 2020b), accumulating the arrays of codes corresponding to the registered quanta with a time resolution of 30 ns;
- EMCCD cameras (VI) with a registration system that allows you to take up to 10 frames/s. The structure of the observation complex is shown in Fig. 1b.

3 Applied Detectors

The light detectors are two coordinate-sensitive detectors of quanta: a "blue" detector with a multialkaline cathode (Debur et al. 2003) and a "red" detector with a GaAs cathode (Debur et al. 2009; Plokhotnichenko et al. 2020a), which have quantum efficiency peaks of 10% and 30% at wavelengths of 400 nm and 500 nm, respectively. These detectors are devices with external photoelectric effect and microchannel multiplication of electron avalanches. The latter are

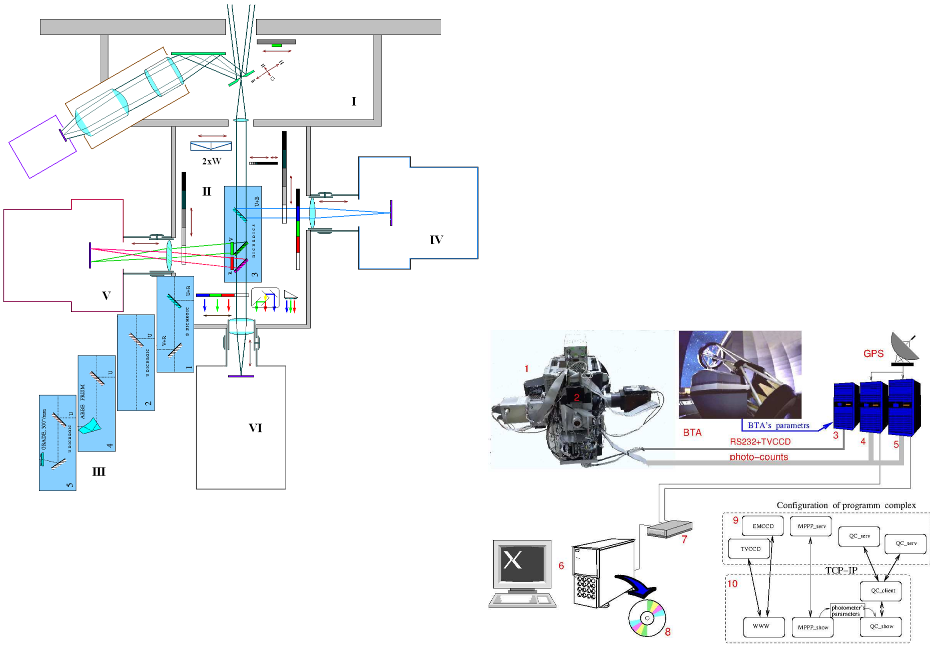


Fig. 1. a. the block diagram of MPPP and b. the structure of the observation complex: 1 – the multimode panoramic automated photospectropolarimeter (MPPP); 2 – the multiplexer of data streams from two PDs, which forms a single sequence from them; 3 – the computer for TV viewing and controlling kinematics; 4, 5 – the computers for receiving data with “Quantochrons 4-48”; 6 – the control computer; 7 – the network switch of a dedicated line; 8 – the accumulated data; 9 – the components of hardware computers; 10 – the software modules of interface computers.

fed to multi-element collectors connected with charge-sensitive amplifiers and analog-to-digital converters that encode the coordinates of the centroids of these avalanches. The working field of the "blue" detector is 15 mm, of the "red" one – 14 mm (more than 60" in the selected scaling of the image), the spatial resolution in the center of the field is 0.05 mm, the temporal resolution (dead time) is 1 μs. The admissible limiting rate of registration of each CSD is 100 000 counts/sec over the entire field and 30 000 counts/sec for a local source. As an additional detector, the MPPP uses an EMCCD camera placed together with BVR optical filters at the end of the device. The video sequence from it is accumulated by a separate computer. Each frame has a capacity of $\sim$ 250 Kb with a maximum continuous reading rate of 14 frames/s. The background of a moonless sky during observations in white light is noticeable above the readout noise level at an exposure of 0.1 s.

4 MPPP Operating Modes

a – the broadband mode, in which the input radiation is divided into two streams in the region of $\sim$ 450 nm, after which the "blue" and "red" components arrive at the corresponding photodetectors;

b – the high-sensitivity mode with an EMCCD camera (Plokhotnichenko et al. 2009), in which sequences of frames in the integral color or BVR bands are accumulated with a temporal resolution of up to 0.1 s, with the simultaneous registration of the radiation reflected by the dichroic mirror in the U-band by the "blue" CSD;

c – the photometric mode with the registration of fluxes of quanta in one of the U or B bands, and in two bands V and R at once;

d – the spectral mode with an Abbe prism, which forms a 5−element resolution spectrum in the slit-free version (for second images), registered by the "red" CSD, while simultaneously registering radiation in the U band with the "blue" CSD;

e – the spectral mode with a diffraction grating that forms a spectrum with 50 resolution elements, with the same (as in item d) use of 2 CSDs.

These modes can be used both with a field of view of $1^{\prime}$, and with apertures $0 \div 10'' \times 10''$ or $0 \div 10'' \times 60''$. Polarization, in the form of three Stokes parameters, is determined using a double Wollaston prism. The mirror-slit unit is used for the operation of the viewing camera, and also forms a beam when using the spectral mode.

5 MPPP Control

MPPP control is carried out in an interactive mode, in which, using a stepper motor controller, the units of the device are set to operating positions, while the parameters of electronic components are selected using a graphical interface. This interface shows the scheme of the optical unit installed on the optical axis of the device, the symbols of the keys for influencing its actuators, the parameters of its state, the total light curve of the radiation fluxes received at the CSD with a second time resolution. The names of the observed objects, their coordinates, exposure time and the state of the device are recorded in an electronic journal.

6 Data Acquisition System

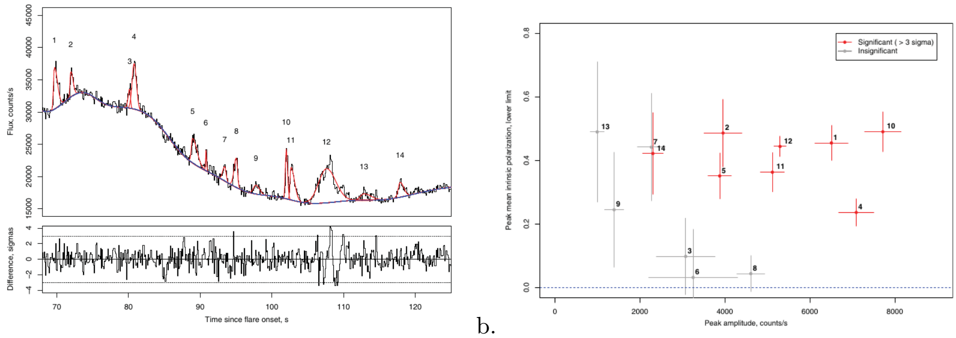
The data acquisition system consists of two identical computers with PCI cards of chronometric devices "Quantochron 4/48" (Plokhotnichenko et al. 2020b) installed in them, recording and storing 64-bit photon codes in the internal random access memory of the FIFO type, as well as a third computer to control the collection process and accumulation of the received information in long-term memory. The first two computers, alternating during second intervals, receive and store the streams, multiplexed by the mixer, of coordinate codes of the photons arriving at the detectors and add to them the codes of the moments of their registration (the time measurement accuracy is 30 ns). These readings are referenced to World Time with the accuracy provided by GPS (0.1 μs). In this case, the accumulation of data occurs during the exposure, limited only by the capacity of disk drives in the computer. The admissible peak data rate is 10^6 cps.

7 Observational Data

Observational data are photon sheets – a series of moments of registration of individual light quanta with their spatial, energy, and polarization characteristics, accumulating in the long-term memory of the computer. They can be processed using various programs, in particular, on the basis of a statistical analysis of the distributions of intervals between quanta, construction and study of light curves with any given window, starting with a microsecond one, construction of correlation functions and power spectra, as well as phasing with a visible period of the pulsar light curves by digital synchronous detection methods. The data received from the EMCCD camera can be processed as video sequences.

8 Some Results

Different versions of MPPP have been used in obtaining observational data for 15 years and a number of astrophysical results have been obtained with them, some of which are shown in Fig. 2 and Fig. 3 (Beskin et al. 2017, 2018; Karpov et al. 2019).



a. b.

Fig. 2. a. Giant UV Ceti flare with subsecond spikes. b. Lower limits of the degree of linear polarization of spikes.

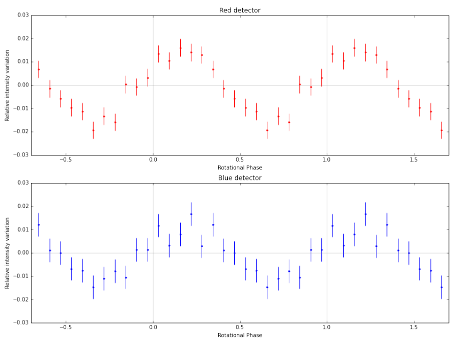


Fig. 3. Phased light curves with a period of 1.69 ms for the pulsar PSR J1023 + 0038 in the red and blue ranges of optical radiation.

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