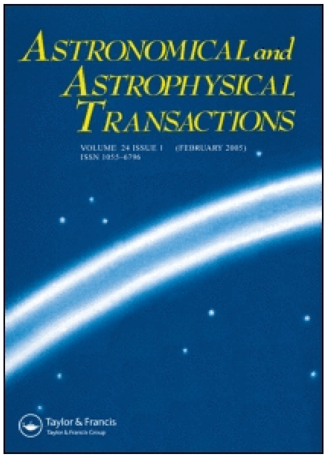


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## Superfast photometry with the MANIA complex

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# SUPERFAST PHOTOMETRY WITH THE MANIA COMPLEX

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We describe the hard/software MANIA complex for carrying out superfast photometry. A new type of time-code converter Quantochron allows us to measure arrival times of photons registered by a photodetector with time resolution up to 20 ns in $2^{16}$ channels (space, colours, polarization, etc.) simultaneously. Special software was developed to investigate variability on a time-scale of $2 \times 10^{-8}$–$10^3$ s by statistical analysis of the time inverval distribution between detected photons and classical light curves. The results of some observations are presented.

KEY WORDS Superfast photometry

## 1 INTRODUCTION

Research into fast optical variability of relativistic and variable objects has been carried out at the Special Astrophysical Observatory of the Russian Academy of Science since 1972 in frames of the MANIA (Multichannel Analysis of Nanosecond Intensity Alterations) experiment. Its goal is to study the energy transformation in strong gravitational and/or magnetic fields which is manifested by very fast optical variability on time-scales from $10^{-7}$ up to $10^3$ s (Shvartsman, 1977). Special hard- and software is used to investigate non-stationary processes on flare stars, pulsars, X-ray binaries, etc.

## 2 THE COMPLEX DESCRIPTION

To study such fast variability a special photometrical hard/software complex was created which consists of:

(1) a photometer (Vikul'ev *et al.*, 1991);

(2) the Quantochron 3–16 — a special time-to-code converter capable of encoding arrival times of each detected photon (Zhuravkov *et al.*, 1992);

(3) special data acquisition and reduction software (Plokhotnichenko, 1983, 1992).

The main characteristics of the Quantochron are:

(1) the rate of data registration with the PC AT 286–486 is up to 370 000 q $s^{-1}$ (in monochannel mode up to 750 000 q $s^{-1}$);

(2) 16-bit registers are used to register the arrival times of photons in $2^{16}$ channels simultaneously;

(3) the accuracy of time measuring is ±20 ns, the dead time is 20 ns; the equipment supports an external synchronization by precise standard time service.

At the present moment a photometer (1,2,4-channels) is used as a detector. Its dead time is $10^{-7}$ s and, therefore, the dead time of the MANIA complex is $10^{-7}$ s as well. Testing and installation of a the coordinate-sensitive detector are being carried out now. Moreover, any device which can provide a registration of individual photons can be used as a detector as well.

## 3 DATA ANALYSIS SOFTWARE

### *3.1 $y_2$-, $d_2$-Function Methods*

While studying variability on a time-scale smaller than the mean interval between photocounts the classical methods for light-curve analysis are not effective due to very small fluxes and, therefore, very large data size. For these purposes a special, so-called $y_2$-function method, was worked out (Shvartsman, 1977).

The $y_2$-function method is intended for variability analyses on time-scales smaller than the mean interval between photocounts. It is based on statistical analysis of the time intervals between photons. The $y_2$-function is defined as:

$$y_2(\tau_i) = \frac{P_0(\tau_i) - P_s(\tau_i)}{P_s(\tau_i)}, \qquad (1)$$

where $P_0(\tau_i)$ is the fraction of intervals of duration from $\tau_i$ to $\tau_{i+1} = 2\tau_i$ in the flux from the object; $P_s(\tau_i)$ is the same for the standard flux.

The $d_2$ function method is used for times larger than the mean interval between photons and is an analogue of the variances method. The $d_2$ function is defined as:

$$d_2(\tau_i) = \frac{D_0[n_0(\tau_i)] - D_s[n_s(\tau_i)]}{\{M[n_0(\tau_i)]\}}, \qquad (2)$$

where $D_0[n_0(\tau_i)]$ and $D_s[n_s(\tau_i)]$ are the sample dispersions of the number of photocounts $n_0(\tau_i)$ and $n_s(\tau_i)$ in the window of duration $\tau_i$ of the object and standard flux, respectively, and $M[n_0(\tau_i)]$ is the expectation value of the $n_0(\tau_i)$.

As a standard flux we can use either the flux from a comparison star or the constant Poisson flux with the mean flux equal to the object's flux. It can be shown that there is a connection between the variability parameters (amplitude, filling factor, time, etc.) and the forms of $y_2$- and $d_2$-functions show an increase at times less than the characteristic time of the variability.

If variability is absent we can find the upper limits for the relative power of the variable component with 99.9% probability ($3\sigma$ level) on time-scales from $10^{-8}$ up to $10^3$ s. The limits are calculated based on the dispersion of the $y_2$-, $d_2$-functions of the comparison star. The algorithms of analysis are described in Plokhotnichenko (1983, 1992).

### *3.2 The Fresnel Lense-Like Method (FLL) for Period Search*

The special FLL method for period search was developed (Plokhotnichenko, 1992). In this method we choose a test period and build a set of consecutive light curves with it. We will sum all these light curves afterwards. But due to the difference between the test and the real periods the light curve details will not coinside in phase and they will be spread in the summarized light curve. To avoid this we summarize the light curves taking all possible values of phase shift and get a set of summed light curves finally. Then by means of statistical methods, we find the light curve with the most significant deviation from the noise (poisson) light curve. The period this curve is folded with is the closest to the true one.

### *3.3 Period Fine Fitting and Pulsar Investigation Methods*

These methods are used in the case of a pulsar period known with enough accuracy to build a pulsar light curve with a well-shaped profile. Using data obtained in close moments of time we build a set of light curves. The uncertainties in the period cause the phase shift in each light curve regarding the first one. The value of this shift is calculated by minimization of the squared difference of each couple. We express this phase shift as a function of time, expanding it into a Taylor series. Finally, we calculate the values of pulsar frequency with its two first derivatives which are used to build the pulsar light curve with a high time resolution. This light curve is used afterwards in the search for a fine structure and in investigation of pulsar photometric features.

### *3.4 LCA Package*

To study variability over a wide time range by classical methods (light curves, FFT and correlation analysis) a special software system was created – the Light Curve Analyses (LCA) system for Quantochron data analysis. It was developed under X-Windows for Linux (Unix) systems on the basis of the XView library. It allows us to work with the data in interactive mode.

## 4 SOME RESULTS

(1) Non-thermal optical flares from A0620-00 and MXB1735-44 with durations from $10^{-3}$ to $10^{-1}$ s were detected (Shvartsman *et al.*, 1989b; Beskin *et al.*, 1994).

(2) Fast optical variability of Nova Per 1992 on time-scales from $10^{-2}$ to $10^{2}$ s in the high optical state was revealed (Bartolini *et al.*, 1994).

(3) More then 100 flares during 35 h of monitoring of flare stars with time resolution of $5 \times 10^{-7}$ s were registered and analysed (Shvartsman *et al.*, 1988b).

(4) The light curve of the Crab pulsar with time resolution of $3 \times 10^{-3}$ s was analysed (Shvartsman *et al.*, 1988a).

(5) Forty candidates for single black holes were investigated. The upper limits on the number density of the black holes relative to the one of the normal stars near the Sun were found (Shvartsman *et al.*, 1989a).

## 5 SOME FUTURE PLANS

(1) The new two-head (six-channel) photometer for simultaneous observations of an object and comparison star will be built.

(2) The testing and fitting of the 2D-photometer based on the microchannel plates detector will be finished. Some test observations have been carried out already.

(3) The new Quantochron 3–24 is being developed now with 24-bit storage registers for holding cooordinate information.

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