Detection of Nonthermal Optical Flashes with 10^{-3}–10^{-1} s Duration from Some LMXBs

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1 Introduction

In order to study very rapid optical variability of astrophysical objects on time scales between 10^{-7} s and 10^2 s (Shvartsman 1977), at SAO the *MANIA* (Multichannel Analysis of Nanosecond Intensity Alterations) experiment is being used. A special photometric registration system and software has been developed (Beskin et al. 1982' Plokhotnichenko 1983, Zhuravkov et al. 1994).

One of the applications of these tools is the detection of radiation from accreted or ejected plasma near compact objects. A choice between two models of accretion onto compact objects in binary systems – hydrodynamic flow or magnetc flaring (Shakura & Sunyaev 1973, Pustil'nik & Shvartsman 1974) has not yet been made. Recent optical and X-ray observations of X-ray binaries provide information on their (fast) variability, their nonthermal radio emission, generation of very high energy particles, and nonthermal processes in rapid optical flares (Bartolini et al. 1994, Beskin et al. 1994). However, the data are not fully described by classical hydrodynamical models.

Within the context of hydrodynamical models, optical flares have a thermal origin. Thus, their brightness temperatures should not exceed 10^7–10^8 K (Lipunov 1987). On the other hand, in the magnetic flare model optical radiation is generated, independent of the X-ray emission, by dissipation of magnetic fields and the interaction of electrons with these fields near "blobs" in the accretion structure (Pustil'nik 1975, Beskin & Minarini, in prep.). These processes could yield nonthermal optical flares with brightness temperatures $> 10^8$–10^9 K on time scales of 10^{-6}–10^{-2} s.

Low-mass X-ray binaries (LMXBs) are the most useful systems for studies of the accretion processes in the optical range, because the normal component is faint enough to allow observations of optical emission from the accreting plasma.

2 Observational Results

We present some results of our study of very short events from some selected LMXBs: A0620–00, MXB1735–44 and Nova Per 1992 (GRO J0422+32).

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A0620–00 and MXB1735-44 were observed in 1986 with the *MANIA* system on the 6 m telescope of SAO RAS and in 1991 on with the 2.15 m telescope of CASLEO (Argentina) (Shvartsman et al. 1989, Beskin et al. 1994). Nova Per 1992 was simultaneously observed in different pairs of color bands (*UB, BV, VR*) in 1992-94 with the 6 m telescope.

A0620–00. During observations of A0620–00 (without filter in one of the sets) on '986 November 13, five particularly short flashes were detected. The first two had durations of 3 and 5 ms and their rise times were 1–2 ms. The remaining events lasted ~ 0.4–0.5 ms with rise times of about 0.1 ms (Fig. 1).

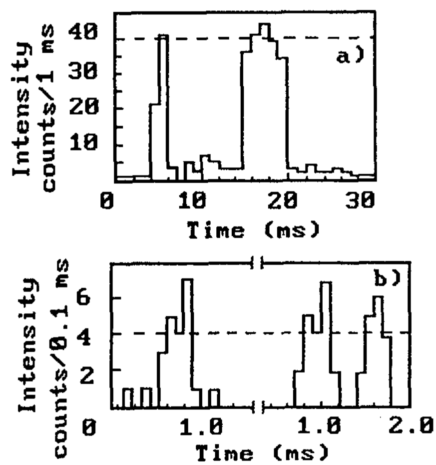

Fig. 1. Ultrashort flares of A0620–00 (Feb. 13, 1986).

MXB 1735-44. During the observations of MXB 1735–44 two flares with durations of ~ 0.25 s were detected (see Fig. 2).

To study the fine structure of these events their detailed light curves were analyzed with the "splash method" (Beskin et al. 1994). These primary light curves, $I(t)$, were smoothed with a rectangular temporal window. The forward edges of both flares had very steep gradients, lasting about 0.05 – 0.06 s.

We used these two curves to construct the so called "normalized discrepancies": $\delta I(t) = \Delta I(t)/(D[\Delta I(t)]^{1/2})$, where $\Delta I(t) = I(t) - < I(t) >$ is the difference between the original and the smoothed light curve, and $D[\Delta I(t)]$ is the dispersion of this discrepancy calculated under the assumption that the data are due to a Poisson process of variable intensity. In calculating $D[\Delta I(t)]$ we took into account that $I(t)$ and $< I(t) >$ are correlated. If there is no fine time structure, $\delta I(t)$ must be close to a normal distribution with zero mean and unit dispersion. This was verified with the standard χ^2 test, and we found that the hypothesis of a normal distribution has to be rejected (at a confidence level of 95% to 99.5%). In other words, both flares have a fine structure on time scales of 5–10 ms.

GRO J0422+32. Near the maximum of the optical high state ($V < 15^m.5$)

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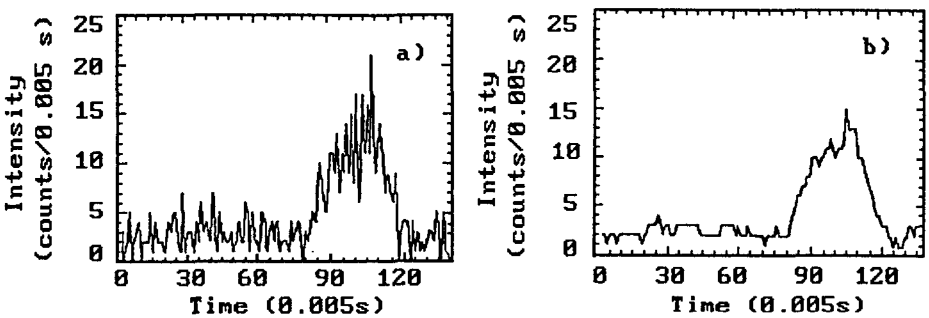

Fig. 2. One of two observed flashes of MXB1735-44: (a) original light curve, (b) smoothed light curve.

the brightness of Nova Per 1992 was irregularly variable in different colour bands on time scales from 4 ms to 200 s with amplitude factors of 0.5–4. The power spectrum of the detected variability was flat in the whole range of frequences from 0.01 to 250 Hz. On time scales from 100 ns to 1 ms variability was probably absent. During the low optical state ($V > 15^m.5$) Nova Per did not show any significant variability on time scales from 100 ns to 10 s. The shortest flares had rising times of 4–40 ms (see Fig.3), which allows us to establish an upper limit of 10^8–10^9 cm on the size of the flare region.

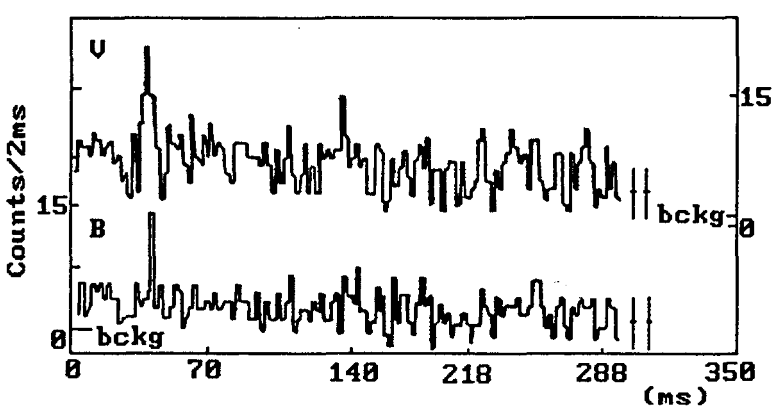

Fig. 3. Flash of Nova Per with a rise time of 4 ms in V (top) and in B (bottom) bands (January 18, 1993).

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3 Interpretation

For all detected events lower limits on the brightness temperatures were estimated with the formula: $T_b = 10^8 \varrho_m t^{-2} f^{-2} D^2$, where t is the duration of the rising front in ms, f is the average frequency of observation (in units of 10^{15} Hz), D is the distance to the source in kpc, and ϱ_m is the source flux in mJy. For the calculation of T_b we assumed the following values; A0620–00: $D \sim 1$ kpc, $B \sim 19^m.3$, $A_v \sim 1^m.2$; for MXB 1735-44: $D \sim 7$ kpc, $B \sim 17\overset{m}{.}2$, $A_v \sim 0\overset{m}{.}8$; for Nova Per: $D \sim 2.4$ kpc (according to Shrader et al. (1992), $B \sim 13\overset{m}{.}9$, $A_v \sim 1\overset{m}{.}2$. We took into account the relation between the intensities of objects, the background, and the effective frequencies of the observations.

Thus, the brigthness temperatures for different flare regions of A0620–00 and MXB 1735–44 exceeded $10^8 - 10^{11}$ K and in the case of Nova Per 1992 it was between 10^8 and 10^9 K. The detected flashes clearly must have a nonthermal origin.

If we would use a thermal mechanism to explain these events, then X-ray fluxes should be very high ($> 10^{39} - 10^{40}$ erg), which is contradicted by the X-ray data obtained almost simultaneously with optical observations.

It is important to mention that for A0620–00 and MXB 1735–44 the detected events were rare, but they were common in the case of GRO J0422+32. This could perhaps be explained with these objects being observed in different states: a quiet state with low accretion rates for A0620–00 and MXB 1735–44, and an active phase with high accretion rates for GRO J0422+32.

Apparently the generation of nonthermal optical flares cannot be explained with the hydrodynamic accretion model. Various mechanisms discussed for the magnetic flaring model provide a better description of the observations.

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