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Observational Properties of X-ray transient source EXO 2030 + 375

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Аннотация. В области созвездия Лебедя находятся три источника излучения высоких энергий, которые уверенно детектируются различными орбитальными обсерваториями. Это Cyg X-1, Cyg X-3 и EXO 2030 + 375. Транзиентный аккрецирующий пульсар EXO 2030 + 375 вместе с его оптическим компаньоном – звездой B0 Ve относится к классу рентгеновских двойных систем с большой массой. Период вращения этого пульсара равен 42 с, а орбитальный – 46 суток.

Используя данные наблюдений RXTE в 2007 г. было зарегистрировано 9 последовательных всплесков, достигнувших уровня 0.08–0.16 Краб в энергетическом диапазоне 1.5–12 кэВ. Было исследовано поведение показателя жесткости и эффективного фотонного индекса в течение всплесков и спадов в терминах абсорбции рентгеновских компонент холодной материей в аккреционном диске. Пиковой рентгеновской светимости источника соответствует умеренная скорость аккреции. Анализ спектра мощности источника показал наличие пика вторичной интенсивности, совпадающего с прохождением апастрона. Наблюдаемое отношение потоков в периастроне и апастроне равно ≈ 7. Наличие двух пиков за орбитальный период может быть объяснено наклоном плоскости орбиты к плоскости аккреционного диска.

OBSERVATIONAL PROPERTIES OF X-RAY TRANSIENT SOURCE EXO 2030 + 375, *by V. Fidelis.* There are three high-energy sources, namely Cyg X-1, Cyg X-3 and EXO 2030 + 375 in Cygnus region that were clearly detected by different orbiting observatories. The transient accreting pulsar EXO 2030 + 375 with its B0 Ve star as optical companion belongs to the class of High Mass X-ray binaries. The spin period of the pulsar is 42 s and orbital one – 46 days.

Using RXTE observations in the 2007 epoch we have detected 9 consecutive outbursts reaching 0.08–0.16 Crab level in the energy range 1.5–12 keV. We investigated the behavior of hardness ratio and effective photon index during outbursts and dips in the terms of absorption of X-ray components by the cold matter in the accretion disk. The accretion rate inferred from the peak luminosity is moderate. The power spectrum of source emission indicates the second intensity peak coincided with apastron passage. The observed periastron/apastron flux ratio equals ≈ 7. The inclination of orbital plane to plane of accretion disk may explain the presence of two peaks in the orbital period.

Key words: Be/X-ray binaries – bursters, transients; X-ray sources – EXO 2030 + 375

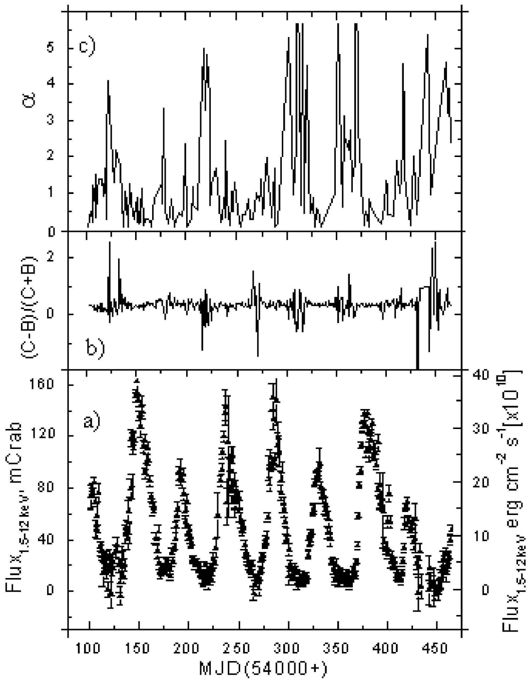

Fig. 1. a) Light curve of EXO 2030 + 375 in the energy range 1.5–12 keV. Time quoted in Modified Julian Dates. The statistical errors are shown. b) Hardness ratio (C-B)/(C+B). c) Photon index (see text). For simplicity the statistical errors on plots b and c do not shown

1 Introduction

Galactic X-ray binaries are among the brightest sources in the X-ray sky. Some of them can be observed only during short episodes of high X-ray luminosity and called transient sources. Observational studies of X-ray binaries may gain our insight into physical processes and emission mechanisms that take place in the vicinity of primary.

The most common type of accreting X-ray pulsar system is Be/X-ray transients, consisting of a pulsar and a main sequence star of spectral class Be (or O) showing Balmer emission lines (Porter and Rivinus, 2003). The spectral feature of these objects is emission lines associated with the equatorial outflow of material from the rapidly rotating Be star that probably forms a quasi-Keplerian disk near this star. X-ray outbursts are produced due to pulsar's interaction with this disk. Be/X-ray binaries are characterized by the giant outbursts with luminosity reaching $L_X \sim 10^{37}$ erg s^{-1} (Klochkov et al., 2007) that equals $\approx 10^4$ times the solar luminosity in optic ($L_\odot = 3.82 * 10^{33}$ erg s^{-1}).

EXO 2030 + 375 is a 42 s transient accreting X-ray pulsar placed at distance 7.1 kpc (Wilson et al., 2002a). It was discovered by EXOSAT during a giant outburst in 1985 (Parmar et al., 1989). The X-ray pulsation in EXO 2030 + 375 like in other X-ray pulsars may be explained by the oblique rotator model where X-ray emission comes from two magnetic poles of a strongly magnetized rotating neutron star, whose rotating axis does not coincide with the magnetic axis (Lamb et al., 1973). During the 1985 giant outburst when the X-ray luminosity of the source reached a value of $L_{1-20keV} \sim 2\ 10^{38}$ erg s^{-1} (Wilson et al., 2002a) the spin period of the pulsar changed dramatically with a spin-up time scale – $P/\dot{P} \approx 30$ yr (Parmar et al., 1989).

Outbursts from this system are regularly monitored with the All Sky Monitor (ASM) on the Rossi X-ray Timing Explore (RXTE), beginning in the 1996 March (Wilson et al., 2002a).

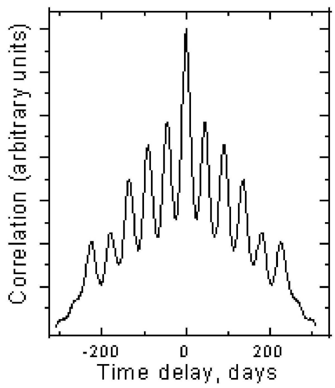

Fig. 2. Cross-correlation analysis of quasi-uninterrupted ASM data shows orbital periodicity ≈ 46 days

2 Observations and data in use

For our analysis we have used ASM archival data taken in the epoch between January 1 and December 31, 2007.

ASM/RXTE consists of three scanning shadow cameras (SSC) attached to a rotating pedestal. Each camera contains a position – sensitive proportional counter, having field of view (FoV) about 6^o and covering ≈ 80 % sky during one revolution, or about 1.5 hours. It accumulates the events in series of ≈ 90 sec "dwells" in which the camera's FoV is fixed on the sky, using three energy channels A: 1.5–3.0 keV, B: 3.0–5.0 keV and C: 5.0–12.0 keV. Each dwell is followed by a 6^o instrument rotation to observe the adjacent patch of the sky. The source counts were produced from difference on-source and background events.

We have used daily averaged ASM data in the sum band 1.5–12 keV. Figure 1a shows consecutive outbursts from object reaching 0.08–0.16 Crab level. Each of these outbursts lasted 7–15 days. Flux estimated in the Crab units (1 Crab unit ≈ 74 ASM counts s^{-1}) (left vertical axis on Fig. 1a).

For the purpose of source intensity estimation in absolute units the ASM counting rate was converted into energy fluxes by using the Crab nebula flux of 2.2 $\cdot 10^{-8}$ erg cm^{-2} s^{-1} for the energy interval 1.5–12 keV, i. e. the energy range of ASM (Kirsch et al., 2005). So 1 ASM counts s^{-1} corresponds to $3{\cdot}10^{-10}$ erg cm^{-2} s^{-1}. With this value, the ASM counting rates were converted to energy flaxes (right vertical axis on Figure 1a). So the X-ray peak luminosity of the source in observing period is $L_x \approx 2\times10^{37}$ erg s^{-1}. Assuming that the radiative efficiency of the accretion is ∼ 10 % (L ∼ $0.1\dot{M}c^2$), such L_x corresponds to a mass accretion rate to the neutron star $\dot{M} \sim 2\times10^{17}$ g s^{-1} or $\sim 3.2\times10^{-9}\dot{M}_\odot yr^{-1}$. The uncertainty in this value depends on the system's distance.

Given the differential spectrum approximated by the power law N(E)dE ∼ $E^{-\alpha}$dE, the spectral index α may be evaluated as (Ledden, O'Dell, 1985):

$$\alpha = \frac{lg(S_B/S_C)}{lg(E_C/E_B)}$$

Here S_B and S_C are the spectral fluxes in the energy channels B and C respectively and E_B and E_C – the mean energies of these channels. We have investigated the behavior of the complex hardness ratio of X-ray emission (Fig. 1b) and effective photon index α as the function of time (Fig. 1c).

Only positive values of photon indexes are used. The increasing of hardness ratio during X-ray dips (Fig. 1a and 1b) is the manifestation of low-energy absorption by the cold matter in the accretion disk. During the outbursts 1.5–12 keV X-ray luminosity increases by factors ∼ 4–8, and X-ray spectrum softens considerably. There is seen a clear modulation of the signal at the ∼ 46 day orbital period. Cross-correlation analysis of densely sampled data reveals the recurrence intervals of ≈ 46 days (Fig. 2). This finding close to the 46.03 ± 0.01 days from BATSE observations (Stollberg et al., 1994).

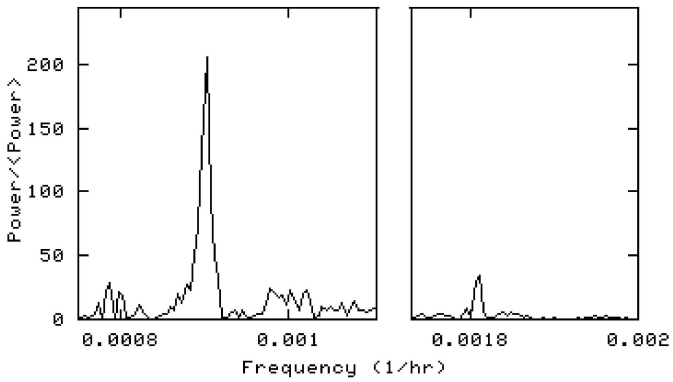

Fig. 3. Power spectrum of EXO 2030 + 375. Power density spectra are created by averaging the light curves into 0.05 day (1 hour 12 min) bins and taking an FFT. The resulting power in each frequency bin is divided by the average power over the whole frequency range. The frequency is plotted in inverse hours

Fig. 3 displays the power spectrum of EXO 2030 + 375. It is obvious that the most emitting X-ray power located near the periastron passage and ≈ 7 times smaller – near the apastron (the closest and furthest points of companion's orbit around the primary).

3 Discussion

So we have presented data on a number of strong outbursts of EXO 2030 + 375 as well as spectral properties of X-ray emission from this source and correlation analysis. Using the source count rates we have obtained the 1.5–12 keV energy flux from EXO 2030 + 375 at the peaks of the X-ray outbursts and inferred the accretion rate on compact object. The spectral analysis has shown the common property to accreting binary system of differential absorption by matter in accretion disk. The power law photon index remains nearly constant for fluxes above $2 \cdot 10^{-9}$ erg cm^{-2} s^{-1} and softens considerably in the dips.

The apastron feature indicates that the orbital inclination angle of B0 Ve star to accretion disk is likely not small. Two outbursts per orbit but not fixed in orbital phase are also seen in another 170^d Be/X-ray binary XTE J1946 + 274 (Wilson et al., 2002b). So two outbursts per orbit phase may be a common property of a misaligned X-ray binary systems.

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