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Study of HMXB EXO2030+375 by RXTE Satellite.

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ABSTRACT:

We report the results of timing analysis of X-ray pulsar EXO2030+375. The observations were made using Rossi X-ray Timing Explorer Space Satellite. In EXO2030+375 the pulse profile is double peaked for all the energy range. Study of pulse period with time shows that the pulse period is maximum at the peak of outburst. At this point the QPO (Quasi Periodic Oscillation) frequency is also maximum.

KEY WORDS: X-ray Pulsar, accretion disc, QPO

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INTRODUCTION:

High mass X-ray binaries (HMXBs) were among the very first bright X-ray sources detected and optically identified in the 1970s, comprising of a orbiting compact object around a massive OB class star. The compact object should be either a neutron star (NS) or black hole and is a strong X-ray emitter from the gravitational energy of accretion of matter of the OB companion. The HMXBs, conventionally, can be further divided into two subgroups: those in which Be star is primary (Be/X-ray binary) and those in which the primary star is a super giant (SG/X-ray binary) [1,2].

The majority of the known high mass X-ray binaries are Be/X-ray systems (BeXRBs), especially those in the Magellanic Clouds[3]. In Be systems, the compact object is a neutron star and is typically in a wide, moderately eccentric orbit, and it spends little time in close proximity to the dense circumstellar disk surrounding the Be companion [4,5]. No Be star system with black hole has been found yet[6]. X-ray outbursts are expected when the compact object passes through the Be-star disk, and accretes the low-velocity and high-density wind around the Be star. Thus system collectively termed as Be/X-ray transients. Their X-ray spectra are usually hard. The hard X-ray spectrum, along with the transience, is an important characteristic of the Be/X-ray binaries[7].

In the second group of HMXB systems, the compact star orbits around a super giant early-type star, through deep highly supersonic wind[8]. The X-ray luminosity is either powered by the strong stellar wind of the optical companion or roche-lobe overflow. In a wind fed system, accretion from the stellar wind results in a persistent X-ray luminosity of 10^{35} -10^{36} erg s^{-1}, while in Roche-lobe overflow system, matter flows via the inner Lagrangian point to an accretion disc. A much higher X-ray luminosity ~ 10^{38} erg s^{-1} is produced[9].

Quasi-periodic oscillations (QPOs) observed in X-ray binaries are generally thought to be related to the rotation of the inner accretion disk. In the case of black hole candidates and low magnetic field neutron star sources, when the accretion disk can reach very close to the compact object, the rotation of the in homogeneities or hot blobs of material in the inner disk are reflected in the light curve as QPOs. However, the disk is interrupted at a large distance by the strong magnetic field of the neutron star, and the inner transition zone of the disk, which is at a large distance from the neutron star, the X-ray pulsar does not emit X-rays. Hence, in X-ray pulsars, QPO are believed to be rare.

SOURCE

EXO2030+375 is a member of massive X-ray binaries known as Be/X-ray binary systems. The Be/X-ray binary systems contain a neutron star accreting material from a Be companion. These systems show two types of X-ray outburst. Type I, also known as periodic outburst which are thought to occur either when the neutron star physically impinges the circumsteller envelope of the Be star, during periastron passage or when the neutron star accretes material in the form of an enhanced stellar wind. In type I outburst L_{max}/L_{min} is typically ~ 10-100. In type II or irregular outbursts occur unpredictably and do not correlate with any orbital phase. Type II outbursts are believed to be related to the photospheric activity of the Be star. In this type of outburst the ratio L_{max}/L_{min} is ~ 100-1000. EXO2030+375 is a pulsar which belongs to the class of high mass X-ray binaries (HMXB). It was discovered by the EXOSAT satellite in 1985 May when the source underwent a gaint outburst [10]. In May 1985, the X-ray luminosity was of the order of 10^{38} erg s^{-1}, close to the Eddington luminosity for accretion on to a neutron star. Over the period of 3 month, 1985 May 19-August 25, the X-ray flux decreased by about two orders of magnitude from $L_x \sim 10^{38}$ erg s^{-1} to $L_x \sim 10^{36}$ erg s^{-1}. In October 1985, the source turned on, showing quasi periodic flare event 3.96 h[11].

EXO2030+375 shows variability on all time scales in X-ray emission. It is characterized by 41.7 s pulsations and periodic 46 d Type I outbursts that occur at each periastron passage of the neutron star[12]. The continuous monitoring carried out by the Burst and Transient Source Experiment (BATSE), since its launch allowed the determination of the following orbital parameters[13] : P_{orb}=46.02±0.01d, e=0.36±0.02, $a_x$sini=261±14 light second, ω=223°.5±1°.8 and T_{peri}=JD 2448936.8±0.3 [14,15].

OBSERVATION AND DATA REDUCTION

To perform high resolution time variability studies of the emission from X-ray sources, the RXTE (Rossi X-ray Timing Explorer) satellite was launched on 30 December 1995. In this paper, the data obtained with the Proportional Counter Array (PCA) instrument are used comprising of data from five identical co-aligned gas filled proportional modulus. These units give a collecting area of ~ 6500 cm^2, having an energy resolution of < 18 percent at 6 keV and a time resolution of 1 micro second. There are two volumes in each PCU, the main Xenon volume, the propane veta volume. To prevent the detection of photons with energies lower than 2 keV, each PCU is covered with a thin window of aluminized mylar. There is also a collimator in each PCU for providing the same field of view for all the PCUs (~1°). A detailed description of the proportional counter array instrument can be found in Glasser, Odell & Senfert[16]. The All Sky Monitor (ASM) on board the Rossi X-ray Timing Explorer satellite consists of three wide-angle Scanning Shadow Cameras (SSCs). These cameras are mounted on a rotating drive assembly, which covers ~ 70% of the sky every 1.5 h[17].

In RXTE satellite, data can be packed in up to seven different modes, each mode suitable for a particular purpose. We use standard 1 mode, which provides binned data with a time resolution of

0.125 s but no energy resolution, as all 256 channels are combined into one, to calculate light curve, hardness ratios, pulse periods and pulse profiles[18].

Data reduction was carried out using FTOOLS whereas data analysis was done using the XRONOS and XSPEC packages[19].

RESULTS:

Outburst

During Feb, 2007, EXO2030+375 was observed with the pointed mode instruments of the RXTE satellite.

For the period of Feb 01, to March,11, 2007, the RXTE-ASM light curve of EXO2030+375 with a bin size of one day is shown in figure, which shows that during the RXTE pointed observations the source was in the phase of outburst. From the beginning of the RXTE mission in 1995 to the present data have been used for RXTE-ASM long term light curve of EXO2030+375 and data from 42 pointed observations for RXTE-PCA.

The RXTE-PCA data analyzed here extended for nearly 40 days. These data cover the whole outburst of X-ray emission on 2007, Feb 1 to 2007, March 11. However huge X-ray outburst of 2006 extended over three periodic orbital motions of NS around the Be-star. Reason of this event is still not known, but essentially of great interest for the Astronomers because luminosity is about 14 times greater than 2007 burst.

Light curve

Light curves with bin size 0.125 s were extracted from all the 44 observations, and then Barycenter corrections were applied on them. The background count rates were simulated and subtracted from the Standard -1 light curves. Pulses could be seen in all the individual light curves. For all the observations the combined background subtracted light binned at a pulse period of 41.5 s had an average count rate of ~ 1047 counts s^{-1} over the energy band of 2-60 keV. The intensity of combined light curve increases and then decreases with time.

The 2-60 keV X-ray light curve is generated with a bin size of 41.5 s, same as spin period to remove pulsation related intensity variations. A pulse period of 41.44±.01 seconds within 90 percent confidence interval is found by pulse folding and χ^2 maximization method

From all the 31 observations, Barycenter corrected light curves were extracted with a bin size of 0.125 sec. The background count rates were simulated and subtracted from the Standard-1 light curves. All the individual light curves showed the pulses. The intensity of combined background light curve binned at the pulse period of ~3.61 s increases and then decreases.

Pulse profile

We have folded the energy resolved background subtracted light curves with the pulse period of 41.5 s and generated further pulse profiles for phase averaged spectroscopy in various energy ranges i.e. 2-5 keV, 5-8 keV, 8-12 keV, 12-18 keV, 18-25 keV, 25-35 keV, 35-45 keV, 45-60 keV as shown in figure 3.5. In pulse profiles, the normalized intensity is plotted as a function of pulse phase. For all the eight energy bands the pulse profiles are found likely to be sinusoidal. All pulse profiles of different energy ranges look alike and appear to be independent of energy. The pulse fraction defined as [(Maximum-Minimum)/Maximum] changes from gradually increasing from 42% at 3 keV to 55% at 30 keV. After that pulse fraction decreases to 44% at 40 keV and 49% at 50 keV. The signal to noise ratio decreases after 35 keV because the detection efficiency of PCA is low after that energy. Therefore the soft component of X-ray 2-18 keV, figure 4 exhibits rise in pulse fraction from 42% to 52%

Power density spectra

From 2-60 keV and 0.125 s time resolved light curves power density spectra (PDS) are generated for all the 44 observations. The final PDS for each data is obtained by breaking light curves in segments of length 1024 s. and PDS obtained from each of these segments were averaged. The power spectra were normalized such that their integral gives the squared rms fractional variability and the expected white noise level was subtracted. The 24.13 mHz peak and its harmonics are clearly visible in PDS due to pulsations of EXO2030+375 before 0.20 Hz. The PDS in the frequency range 50 mHz to 4 Hz is fitted with the model consisting of a power law. The QPO is fitted with a Gaussian model component.

The central QPO frequency changes dramatically over the entire X-ray burst of 2007 of the period of 44 days which is very close to orbital period of 46 days of compact NS in EXO2030+375 X-ray binary. Figure 2 shows that ν_{QPO} suddenly jumps from average value of 0.22 Hz to 0.47 Hz during the peak time of X-ray burst at 1.415times10^4 (TJD). However, within 2 days, the value of ν_{QPO} falls back to average value of 0.25 Hz and thereafter for next 10 days it remains same in declining phase of the X-ray burst. This behavior is unique for EXO2030+375 and is difficult to understand.

A critical and dramatic change of ν_{QPO} in figure 2 was probed by investigating the pulse period of X-ray pulsar EXO2030+375 over the entire X-ray burst period of 50 days as shown in figure 2. A graph was plotted between the observed pulse periods and TJD as shown in figure 3.9. It is interesting to record that neutron star spins down smoothly as the X-ray burst increases. Pulse period maximum (spin minimum) synchronizes with the peak time of X-ray burst at $1.415X10^4$ (TJD). Therefore, within 2-3 days time, pulse period decreases to its average minimum value of 41.429 seconds during the declining phase of X-ray outburst. It clearly indicates that when NS passes through circumstellar matter of Be-star accretes huse amount of matter interacting strongly through its surrounding magnetic field and suddenly ejects gained power resulting into the broad high frequency QPO centered at 250 mHz and causing a big X-ray burst. As soon as NS comes out of viscous pressure of circumstellar matter at periastron position, it spins up & ν_{QPO} decreases.

We attempted further to examine QPO power of EXO2030+375 by plotting a graph between QPO area and time (TJD) as shown in figure 3. QPO area represents the rate of change of power emitted in X-ray binary star during the X-ray outburst. The time dependence of QPO area showed a positive slope at the time $1.415 \text{ X } 10^4$ (TJD) when X-ray burst peak was observed. However the trend is not clear during the declining phase of the X-ray burst (i.e. time beyond peak time $1.415 \text{ X } 10^4$ (TJD)) because no QPO were detected. Nevertheless it becomes evident that QPOs are coherent with X-ray outburst maxima, when quite large amount of energy is liberated from the substantial accreted matter near the periastron position of NS in the circunstellar disk of Be star.

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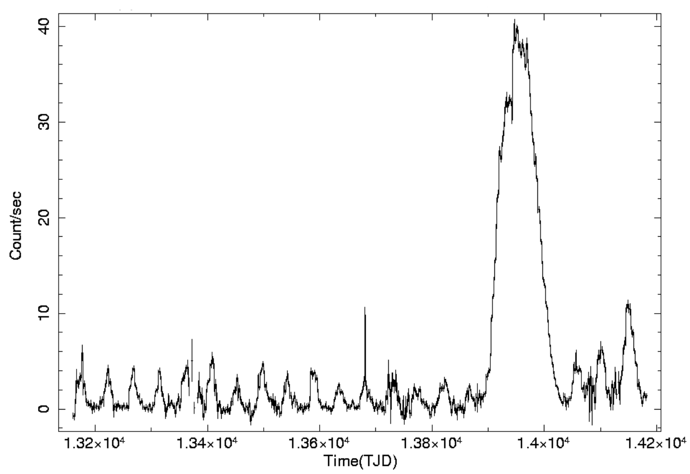

Fig 1 - The section of the RXTE-ASM between the ranges of days $1.32*10^4$ to $1.42*10^4$, shows the regular periodic X-ray outbursts and selected X-ray outburst of the year 2007

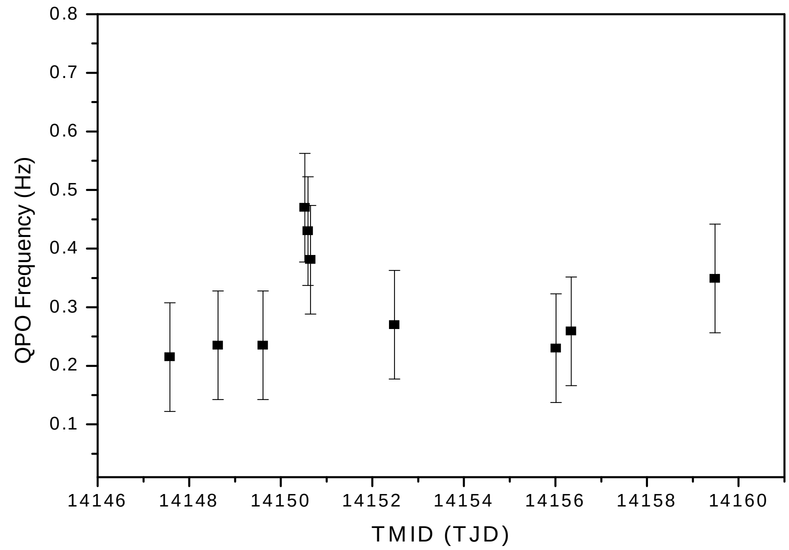

Fig 2 - The QPO frequency is plotted as a function of time

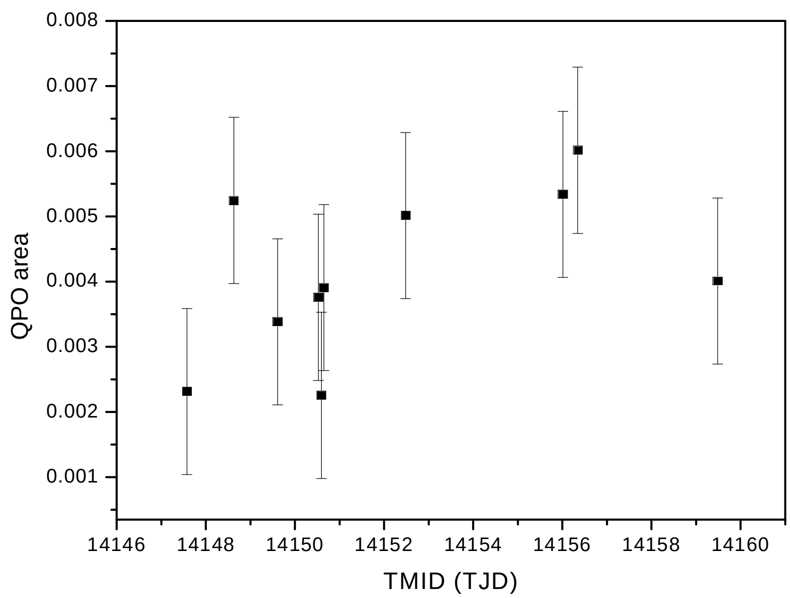

Fig 3 The QPO area as a function of time

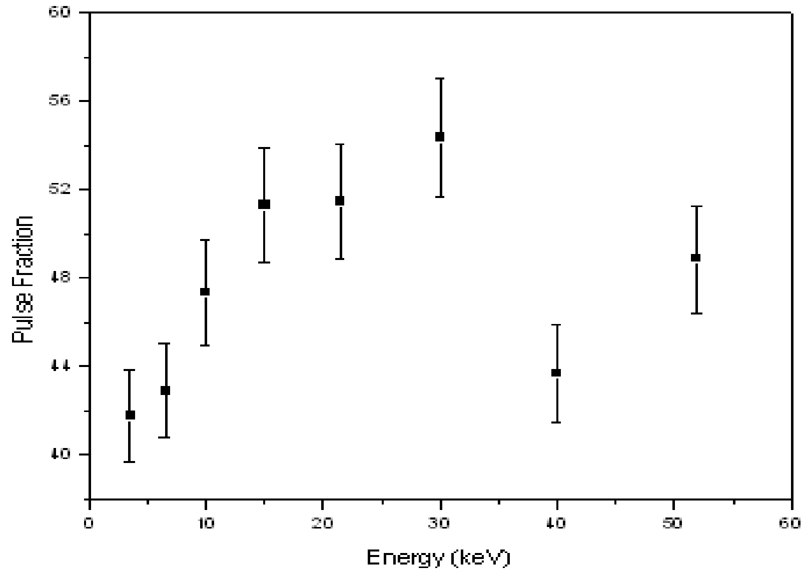

Fig 4 - The pulse fraction is plotted as a function of energy

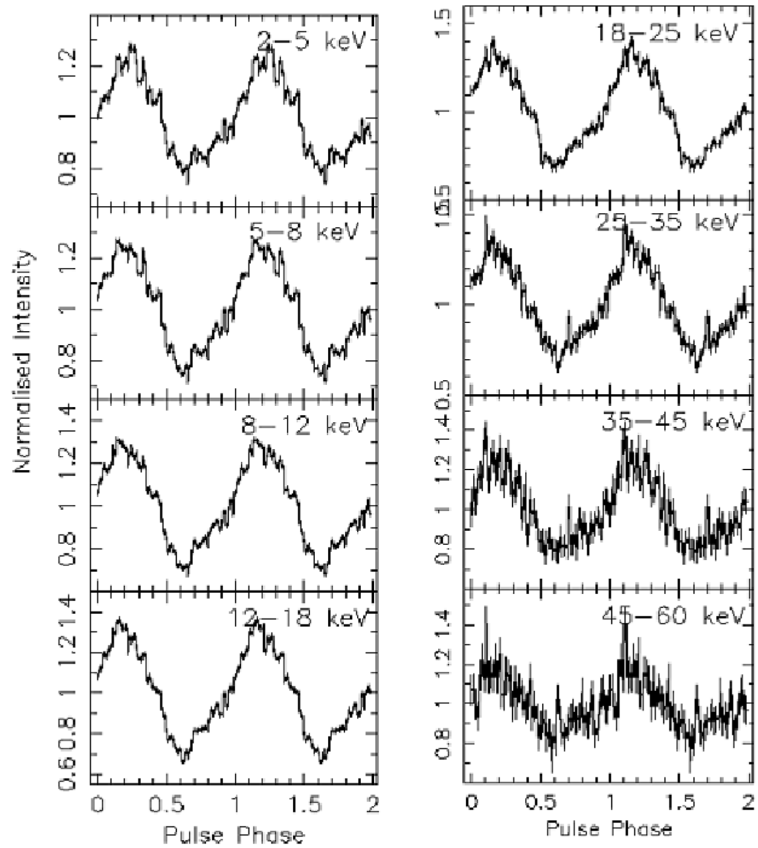

Fig 5 - The nearly sinusoidal pulse profiles of EXO2030+375 folded at a period of 41.445 s are shown (left, from the top) for 2-5 keV(first panel), 5-8 keV(second panel), 8-12 keV(third panel), 12-18 keV(fourth panel). In the right for 18-25 keV(top panel), 25-35 keV(second panel), 35-45 keV(third panel), 45-60 keV(fourth panel)