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Optical/Infrared properties of Be stars in X-ray Binary systems

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Abstract: Be/X-ray binaries, consisting of a Be star and a compact object (neutron star), form the largest subclass of High Mass X-ray Binaries. The orbit of the compact object around the Be star is wide and highly eccentric. Neutron stars in the Be/X-ray binaries are generally quiescent in X-ray emission. Transient X-ray outbursts seen in these objects are thought to be due to the interaction between the compact object and the circumstellar disk of the Be star at the periastron passage. Optical/infrared observations of the companion Be star during these outbursts show that the increase in the X-ray intensity of the neutron star is coupled with the decrease in the optical/infrared flux of the companion star. Apart from the change in optical/infrared flux, dramatic changes in the Be star emission line profiles are also seen during X-ray outbursts. Observational evidences of changes in the emission line profiles and optical/infrared continuum flux along with associated X-ray outbursts from the neutron stars in several Be/X-ray binaries are presented in this paper.

1 Introduction

X-ray binaries are among the brightest X-ray sources in the sky and dominated the focus of research in X-ray astronomy. These systems, consisting of a compact accreting object such as a neutron star, a stellar-mass black hole or a white dwarf and an optical companion rotating around the common center of mass, are sites of some of the highest energy phenomena in the local universe. The compact objects emit radiation through mass accretion from the optical companion star. If the optical companion is a low mass ($\sim$1 $M_\odot$) star, then the mass accretion from the companion star to the compact object takes place through the Roche lobe overflow. The accreting gas from the companion gets trapped in the strong gravitational field of the compact object and forms an in-spiraling accretion disk around it. The accreted matter looses its gravitational potential energy - a part of which is emitted as X-ray radiation. If the companion star is a massive ($\geq$10 $M_\odot$) star of O-B spectral type, then mass accretion takes place through the capture of stellar wind of the optical companion.

1.1 Low Mass and High Mass X-ray Binaries

Depending on the mass of the optical companion star, X-ray binaries are conventionally classified into two categories such as (i) Low Mass X-ray Binaries (LMXBs) and (ii) High Mass X-ray Binaries (HMXBs). The optical companions in LMXB systems are generally of spectral type A to M with

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mass below 3 $M_\odot$. Due to its lower mass, the companion star evolves slowly and can take $\sim$2.2 Gyr to enter its giant phase. The lifetimes of LMXBs are typically $\sim 10^7$ - 10^9 yr. The X-ray emission from these LMXB systems often dominates the optical and ultraviolet (UV) emission from the binary companion. The ratio between the X-ray and optical luminosities (L_x/L_{opt}) is typically in the range of 100-1000. The orbital period of these binary systems is in the range of $\sim$12 minutes, as in case of 4U 1820-30, to several months.

HMXBs consist of either a neutron star or a black hole which accretes matter from the optical companion star with mass $\geq$10 $M_\odot$. In these binary systems, the companion star is generally a massive and early-type (O or B-type) star which dominates the optical/UV radiation. Due to its strong gravity, the massive primary star evolves very quickly and explodes in a supernova. As the evolution process is much faster, the lifetimes of the HMXBs are short and are in the range of 10^5–10^7 yr. The HMXBs are generally in eccentric orbits and are not close enough for the optical companion star to fill its Roche lobe. The massive optical star has a substantial stellar wind through which it looses mass up to as high as 10^{-5} $M_\odot$ yr^{-1}. The compact object in the binary system captures a significant fraction of the stellar wind which is sufficient to power the X-ray source. The material accreted from the stellar wind of the companion forms a common envelope through which angular momentum gets transferred to the compact object. The HMXBs are young and population I objects and are concentrated in the Galactic plane. LMXBs, in contrast, tend to be population II objects and their spatial distribution shows no preference for the Galactic plane. The compact object in LMXBs and HMXBs can be a black hole or a neutron star whose identification is based on the determination of its mass. A few of the LMXBs and a large number of HMXBs are known to be X-ray pulsars with neutron star as the compact object.

Pulsars are thought to be rotating neutron stars with strong magnetic fields of approximately about 10^{12} to 10^{13} Gauss. Pulsars are believed to form when a massive star undergoes a supernova explosion and compresses its core as it blows off its outer layers, or when a white dwarf accretes enough material to cross the Chandrasekhar limit and gravitationally collapse into a neutron star. The pulsation attribute comes from the rapid rotation of the neutron star whose magnetic axis and spin axis are not co-aligned. As material is funnelled onto the magnetic poles of the star, energy from this accreted matter is released in the form of X-rays. Cen X-3 was the first X-ray pulsar discovered with a pulse period of 4.8 s in a binary system with a high mass companion. The orbital period of the binary was estimated to be $\sim$50 hours (Giacconi et al. 1971). Most of the pulsars have a high mass stellar companion. In addition to pulsations, the pulsars can emit occasional flashes of X-rays known as X-ray bursts.

1.2 Be/X-ray Binaries

HMXBs are known to be strong X-ray emitters and appear as the brightest X-ray sources in the sky. The Be/X-ray binaries form the largest ($\sim$67%) subclass of the HMXBs. The compact object in a Be/X-ray binary is generally a neutron star whereas the companion is a B or O-type star that shows emission lines in its optical/infrared (IR) spectra. The neutron star in these systems is typically in a wide orbit with moderate eccentricity with an orbital period in the range of 16-400 days. These objects are characterized by their transient nature. For a brief review of the properties of HMXB transients, we refer to Paul & Naik (2011). The neutron stars in the Be/X-ray binary systems are found to be accretion powered X-ray pulsars, except for a very few cases such as LS I+61303 (Massi et al. 2004). The Be stars in these systems show spectral lines such as hydrogen (Balmer and Paschen series) lines in emission (Porter & Rivinius 2003). Apart from the hydrogen emission lines, these stars occasionally show He and Fe lines in emission (Hanuschik 1996). These stars show an IR excess i.e. an excess amount of IR emission compared to the continuum emission from an absorption-line B star of same spectral type. The observed IR excess and emission lines in the optical/IR spectra of Be stars are attributed to the presence of a gaseous equatorial circumstellar disk. The phenomena involved in the formation of the circumstellar disk still remain highly debated. It is widely accepted that Be stars are fast rotators spinning at $\sim$200 km s^{-1} or more (i.e. between 0.5 to 0.9 of their critical velocity) and that they have a strong stellar wind with high mass loss rate. Circumstellar disks around the Be stars are formed from the equatorially ejected material from the fast-spinning central star.

In Be/X-ray binary systems, the neutron star (pulsar), while orbiting around the common center of mass, spends most of the time away from the circumstellar disk of the companion star. A schematic diagram of a Be/X-ray binary system is shown in Fig. 1. During the periastron passage, the pulsar passes through/closest to the circumstellar disk of the Be star and accretes a significant amount of matter because of its strong gravity. At the periastron passage, the abrupt accretion of a huge amount of matter onto the pulsar results in strong outbursts (Okazaki & Negueruela 2001) during which X-ray emission from the pulsar can be transiently enhanced by a factor more than $\sim$10. Optical/IR observations of the companion Be star during these outbursts showed that the increase in the X-ray intensity of the pulsar is coupled with the decrease in the optical/IR flux of the companion star. Along with the change in observed optical/IR flux, there are several occasions when extreme changes in the emission line profiles have been detected in the optical/IR spectra of Be stars. Therefore, for a detailed and thorough understanding of the evolution of these systems, a multi-wavelength program of observations (in optical, IR, and X-ray wavebands) are required. Using the IR and optical observations of these objects, the physical conditions of matter in the Be circumstellar disk from which the neutron star accretes, can be determined. In combination with the X-ray timing and spectral observations, we can get a clear picture of the accretion process in these systems. In the following sections, the X-ray properties of the pulsar during Type I outbursts and related changes observed in optical/IR wavebands in Be/X-ray binaries are briefly discussed.

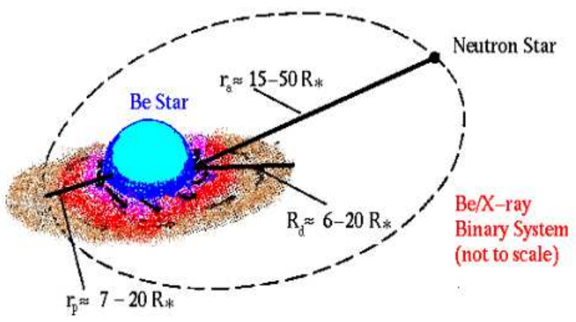

Figure 1: A schematic diagram representing a Be/X-ray binary system is shown here. The compact object in the binary system is a neutron star whereas the companion is a Be star with a huge equatorial circumstellar disk around it. During the periastron passage, X-ray outbursts occur because of the abrupt increase in the mass accretion from the circumstellar disk of the Be star.

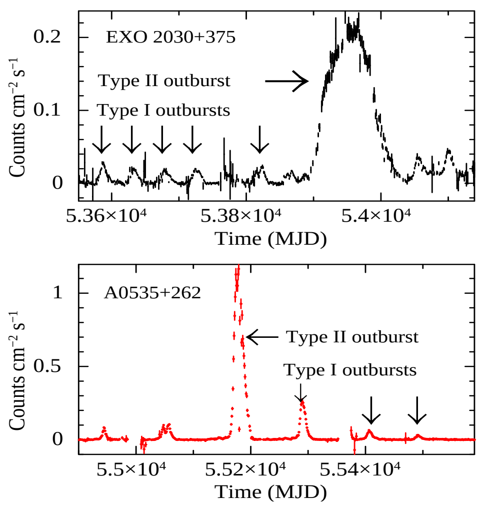

Figure 2: The outburst profiles of the Be/X-ray binary pulsars EXO 2030+375 (top) and A0535+262 (bottom) are shown in the 15-50 keV energy band, as observed by Swift/BAT. Type I and Type II X-ray outbursts seen in these pulsars are marked in both panels.

Neutron stars in Be/X-ray binary systems are generally quiescent and show periodic normal (Type I) X-ray outbursts that coincide with its periastron passage and giant (Type II) X-ray outbursts which are extremely rare and do not show any clear orbital dependence (Negueruela et al. 1998).

The normal Type I outbursts, which last for days to weeks, are characterized by a lower luminosity ($\sim 10^{36-37}$ erg s^{-1}) and are connected with the periastron passages of the neutron stars. The persistent low-luminosity below 10^{36} erg s^{-1} between these Type I X-ray outbursts is understood to be due to the low mass accretion rates or the onset of the propeller effects in the neutron stars (pulsars). This makes the pulsars barely observable during the quiescent phase with the available X-ray observatories. These pulsars are generally observed during X-ray outbursts and termed as Be/X-ray transients. Almost all Be/X-ray binaries show Type I outbursts. Some systems, such as EXO 2030+375 and A0535+262 show Type I outbursts during almost every periastron passage whereas in some other cases like 4U 0115+63 and V0332+53, these outbursts are very rare. Type II outbursts, also known as giant outbursts, are characterized by high luminosities ($\geq 10^{37}$ erg s^{-1}; Negueruela et al. 1998). These outbursts last for several weeks to months. These outbursts are very rare and the recurrence time is more than several years to decades. Type II outbursts are usually preceded by an activity in the Be star that enhances the properties of the emission lines. Fig. 2 shows the occurrence of Type I and Type II X-ray outbursts in the 15-50 keV Swift/BAT light curves of the Be/X-ray binary pulsar EXO 2030+375 (top) and A0535+262 (bottom).

1.3 Infrared/Optical observations of the Be/X-ray binaries

During the periastron passage of the neutron star in Be/X-ray binary systems, the circumstellar disk of the companion Be star is most affected. As the neutron star approaches periastron, the enormously strong gravity of the neutron star causes partial truncation or evacuation of the Be circumstellar disk. This evacuated matter from the circumstellar disk contributes towards the enhancement of the X-ray intensity from the neutron star giving rise to Type I X-ray outbursts. As the circumstellar disk contributes towards the IR and optical continuum emission, the effect of periastron passage of the neutron star is expected to be pronounced in these bands. Apart from affecting the continuum emission, the periastron passage of the neutron star also influences the observed emission lines in the optical/IR spectrum of the Be star. During X-ray outbursts in these systems, there are many occasions when extreme changes in the Be star emission line profiles along with the changes in the optical/IR flux have been reported. A striking episode of circumstellar disk loss and subsequent formation of a new disk has been reported in the A0535+252/HDE 245770 Be/X-ray binary system (Haigh et al. 1999). During this circumstellar disk loss episode, the Br γ emission line was detected in absorption along with a significant decrease in the strength of He I line at 2.058 μm. IR spectroscopy of the companion star HDE 245770 obtained over 1992-1995 showed significant variability, implying changes in the circumstellar disk (Clark et al. 1998). A decrease in the flux of the Paschen series lines, the strength of the H_α line and the optical continuum emission were seen between 1993 December and 1994 September. These changes were attributed to the reduction in the emission measure of the Be disk. Though the emission lines from the companion star are affected during the X-ray outbursts from the neutron star in Be/X-ray binary systems, there are instances when only a reduction in the optical/IR continuum flux without any changes in the emission line profiles has been observed. The observed changes in the optical/IR continuum flux and emission line profiles from the companion Be star are found to be associated with the intensity of X-ray outbursts from the neutron star which depend on the quantity of mass evacuated from the Be circumstellar disk.

To understand the changes in the optical/IR properties of the companion Be star and the X-ray emission from the neutron star in the Be/X-ray binaries at various orbital phases, an extensive monitoring program of a sample of such systems is being carried out by using the 1.2-m telescope of Physical Research Laboratory at Mnt. Abu, Rajasthan, India. Near-IR (NIR) photometric and spectroscopic monitoring of a few systems have been carried out at several epochs. Results obtained from a few such systems, specifically A0535+262/HDE 245770, X Per/HD 24534, and EXO 2030+375 are described here in the following sections.

2 Observations and Data Reduction

NIR spectroscopic and photometric observations in the J, H, and K bands of the Be/X-ray binary systems A0535+262/HDE 245770, X Per/HD 24534, and EXO 2030+375 were carried out by using the 1.2-m telescope of the Physical Research Laboratory at Mt. Abu. Photometric and spectroscopic observations of the above sample of Be/X-ray binaries were obtained at a resolution of $\sim$1000 by using a NIR imager/spectrometer with a 256$\times$256 HgCdTe [Near-Infrared Camera Multi-Object Spectrograph 3 (NICMOS3)] array and Near-Infrared Camera/Spectrograph (NICS) equipped with a 1024$\times$1024 HgCdTe Hawaii array. Spectral calibration was done by using the OH sky lines that are registered with the stellar spectra. Spectra were recorded with the star dithered to two positions along the slit. Sometimes, multiple spectra were also recorded at both the positions to improve the signal-to-noise ratio (SNR). The co-added spectra in each of the dithered positions were subtracted from each other to remove the contributions from the sky and atmosphere. The resulting spectra from these subtracted images were extracted by using IRAF[1] tasks. Wavelength calibration was done by using a combination of OH sky lines and telluric lines that are registered with the stellar spectra. Telluric lines were removed from the source spectra by taking ratios between the source spectra and spectra of the standard stars. The ratioed spectra were then multiplied by a blackbody curve corresponding to the effective temperature of the standard stars to yield the final source spectra. Photometric observations of the Be stars were carried out on several nights in photometric sky conditions using the NICMOS3 & NICS arrays in the imaging mode. Several frames in each of the three J, H and K bands were obtained in four dithered positions, typically offset by 30 arcsec from each other, with exposure times ranging from 0.4 to 100 s depending on the brightness of the stars. The sky frames were generated by median combining the average of each set of dithered frames and subsequently subtracted from the frames of the stars. Nearby field stars, observed at similar airmass as the stars, were used as standard stars for the photometric observations. Aperture photometry was done using the *apphot* task in *IRAF*.

3 Analysis & Results

3.1 A0535+262/HDE 245770

The neutron star in the A0535+262/HDE 245770 is a 103 s X-ray pulsar discovered by Ariel 5 during a large outburst in 1975 (Coe et al. 1975). The binary companion HDE 245770 is an O9.7-B0 IIIe star in a relatively wide eccentric orbit ($e = 0.47$) with an orbital period of $\sim$111 days and at a distance of $\sim$2 kpc (Finger et al. 1996). The pulsar shows regular outbursts with the orbital periodicity. Occasional giant X-ray outbursts are also observed when the object becomes even brighter than the Crab (Naik et al. 2008 and references therein). Extensive photometric and spectroscopic studies in the UV, optical and IR bands show the variable nature of the optical companion of the pulsar (Haigh et al. 2004). IR spectroscopy of the companion Be star HDE 245770 obtained over 1992-1995 showed significant variability, implying changes in the size of the Be circumstellar disk (Clark et al. 1998). A decrease in the flux of Paschen series lines, the strength of the H_α line and the optical continuum emission were seen between 1993 December and 1994 September. These changes were attributed to the reduction in the emission measure of the Be disk. A striking episode of circumstellar disk loss and the subsequent formation of a new inner disk in the Be binary system A0535+262/HDE 245770 have been reported earlier (Haigh et al. 1999). The Brγ emission line, which was earlier seen in

[1] http://iraf.noao.edu/

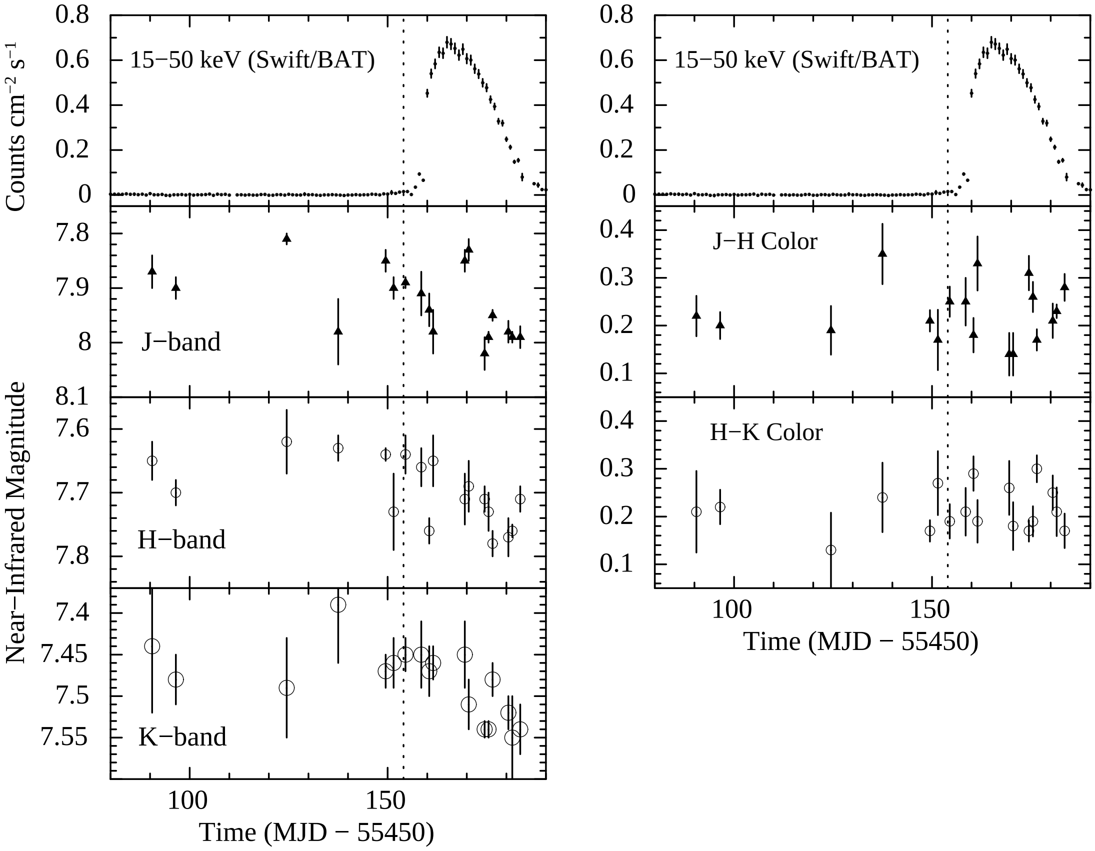

Figure 3: The Swift/BAT X-ray light curve (top) and the NIR JHK light curves of the Be star in A0535+262/HDE 245770, covering the X-ray outburst in 2011 February-March are shown in the left panels. The middle and bottom panels on the right show the J-H and H-K colors of the companion Be star. This figure is taken from Naik et al. (2012).

emission, had gone into absorption, as detected on 1998 November 10. Along with the change in the Brγ line (from emission to absorption), the HeI line at 2.058 μm was also detected in emission with a significantly reduced intensity. During this particular disk-loss phase, the Hα emission line was also found to be absent. The disk-loss phase in the Be star HDE 245770 has, however, not been seen again. Considering the above reported results, we attempted to investigate the association of X-ray emission from the neutron star and optical/NIR emission from the Be circumstellar disk. We monitored the system at X-ray quiescent and outburst phases of the binary system which spanned over four orbital cycles. It should be noted that such contemporaneous IR coverage of the giant X-ray outburst had not been undertaken earlier.

Though the companion Be star HDE 245770 is relatively faint for JHK spectroscopic observations with the 1.2-m telescope, we monitored the source closely during the 2011 February-March giant X-ray outburst to investigate whether any significant changes in the NIR spectra took place at the periastron passage. The JHK light curves of the optical companion, obtained from our photometric observations, are presented in the second, third and fourth panels on the left side of Fig. 3. The Swift/BAT X-ray light curve of the pulsar (in the 15-50 keV energy range) covering the 2011 February-March outburst is also shown in the top panels (left and right sides) to compare the changes in the JHK magnitudes of the companion and the corresponding changes in X-ray intensity of the neutron star. A gradual and systematic change in the JHK magnitudes of the Be companion was seen since the onset of the X-ray outburst (as marked with dotted lines in Fig. 3). A simultaneous increase in the X-ray intensity of the neutron star corroborates the circumstellar disk evacuation/truncation.

The J-H and H-K colors, as shown in the second and third panels at the right side of Figure 3, do not show any systematic variation during the X-ray outburst. NIR spectroscopy of the object showed that the JHK spectra were dominated by the expected emission lines of hydrogen Brackett and Paschen series and HeI lines. During our campaign, the presence of all the hydrogen emission lines in the JHK spectra, along with the absence of any significant change in the continuum of the companion Be star during X-ray quiescent and X-ray outburst phases, suggest that the NIR line emitting regions of the circumstellar disk are not affected during the X-ray outburst. A detailed description of the results obtained from our NIR campaign of the Be/X-ray binary system A0535+262/HDE 245770 can be found at Naik et al. (2012).

3.2 X Per/HD 24534

The Be star X Per/HD 24534 is the optical/IR counterpart of the X-ray pulsar 4U 0352+30. It belongs to the class of Be/X-ray binaries. The orbital period, eccentricity of the orbit and angle of inclination of the binary system are 250 d, 0.11 and 26-33 degrees, respectively (Delgado-Mart et al. 2001). The companion Be star in the binary system was classified to be of B0Ve type with a rotation velocity of 215$\pm$10 km s^{-1} and a distance of 700$\pm$300 pc (Lyubimkov et al. 1997). From optical and IR photometric data spanning over a decade (1987-95), Roche et al. (1997) estimated the spectral type and distance as B0V and 900$\pm$300 pc, respectively, during the disc-less phase. From optical and IR observations during the period 1988-90, Norton et al. (1991) identified the loss of the circumstellar disc of the Be star. This was based on the change of the Hα line profile from emission to absorption, the observed decrease in the IR continuum flux, and the flattening of the IR spectrum. From high-resolution optical spectroscopy and V-band photometry, Clark et al. (2001) identified an episode of complete disc loss during 1988 May to 1989 June, characterized by a reduction in flux of 0.6 mag in the V band and the presence of absorption profiles of Hα and He I 6678 $\AA$ lines.

X Per/HD 24534 was a part of the monitoring programme of the NIR observations of the Be stars in Be/X-ray binary systems to investigate the association of optical/IR emission from the circumstellar disk of the Be star and X-ray emission from the neutron star. As in the case of A0535+262/HDE 245770, photometric and spectroscopic observations of the Be star were carried out at several orbital phases of the binary by using the 1.2-m telescope at Mnt. Abu. The details of the monitoring observations and data analysis are presented in Mathew et al. (2012; 2013). During our NIR observations, the Be star was observed to be prominently bright in the JHK-bands with mean magnitudes of 5.49, 5.33 and 5.06, respectively. NIR JHK spectra of the Be star were found to be dominated by emissions lines of He I and Paschen & Brackett lines of H I. The spectral energy distribution of the star was constructed and found to show an IR excess. Based on the magnitude of the IR excess, the electron density in the disc was estimated and found to be within the range of values expected in Be star discs. A detailed spectral study of our NIR observations revealed that the flux and the equivalent widths of prominent H I and He I emission lines anti-correlate with the source continuum. Such an anti-correlation effect is not commonly observed in Be stars in the optical/IR bands. A possible explanation for this anti-correlation between the continuum flux with both the line flux and equivalent widths could possibly be the presence of a radiatively warped, precessing circumstellar disk around the Be star. During our monitoring observations of the Be star, however, we could not observe any signature of a partial or complete circumstellar disk-loss episode.

3.3 EXO 2030+375

The Be/X-ray binary pulsar EXO 2030+375 was discovered during a giant outburst in 1985 with the EXOSAT observatory (Parmar et al. 1989). Optical and NIR observations identified a B0 Ve star as

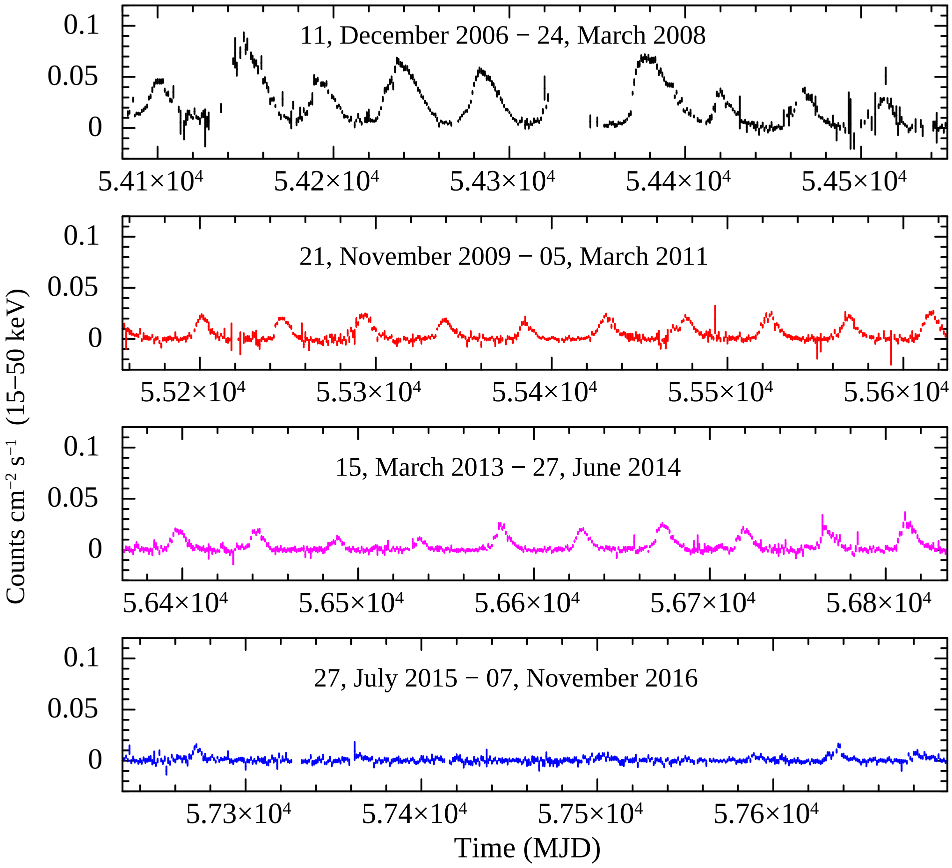

Figure 4: The Swift/BAT X-ray light curve of the Be/X-ray binary pulsar EXO 2030+375 showing Type I outbursts.

the counterpart of EXO 2030+375 (Coe et al. 1988). Using the EXOSAT observations during the giant outburst, the spin and orbital period of the binary pulsar were estimated to be 42 s and 44.3-48.6 days, respectively (Parmar et al. 1989). An extensive monitoring of EXO 2030+375 with both the Burst And Transient Source Experiment (BATSE) of the the space observatory CGRO (Compton Gamma Ray Observatory) and the Rossi X-ray Timing Explorer (RXTE) showed that a normal outburst has been detected for nearly every periastron passage for $\sim$13.5 years (Wilson, Fabregat & Coburn 2005). Using the BATSE observations of a series of consecutive Type I outbursts of the pulsar, Stollberg et al. (1997) derived the orbital parameters of the binary system.

The Be/X-ray binary pulsar EXO 2030+375 consistently shows Type I X-ray outburst at the periastron passage of the neutron star (Naik et al. 2013; Naik & Jaisawal 2015). As described above, these outbursts occur because of the capture of mass from the circumstellar disk of the companion Be star. However, recent follow-up observations of the pulsar showed the absence of these Type I X-ray outbursts from the neutron star (Fig. 4). The absence of such X-ray outbursts suggest the lack of mass accretion by the neutron star from the Be circumstellar disk at the periastron passage. This again puts constraints on the size of the circumstellar disk which can be checked through optical/IR observations of the companion Be star. A detailed investigation of the contribution from the disk (e.g. by studying the IR excess and emission line profiles in the optical/IR spectra) can confirm the disk evolution. Though we attempted to monitor the Be star in the NIR, the star was relatively faint for spectroscopic observations with our 1.2-m telescope. Follow-up observations with better facilities (like the 3.6-m telescope at Devasthal observatory and the upcoming 2.5-m telescope at Mnt. Abu) can confirm the properties of the evolution of the Be circumstellar disk and the associated X-ray emission from the neutron star in Be/X-ray binary pulsars.

4 Conclusion

In this paper, we presented the results obtained from our NIR monitoring of the Be/X-ray binary systems A0535+262/HDE 245770, X Per/HD 24534, and EXO 2030+375. The JHK Photometric and spectroscopic monitoring of A0535+262/HDE 245770 during the giant X-ray outburst in 2011 showed a reduction in the NIR flux at the periastron passage of the neutron star. Increase in the X-ray brightness during the outburst at periastron passage was interpreted as due to accretion of evacuated matter from the Be circumstellar disk on to the neutron star. Evacuation of matter, which was contributing to the total NIR emission, caused in reduction of the observed NIR flux from the Be companion star. During our NIR observations of X Per/HD 24534, the star was found to be in a bright state with JHK spectra dominated by emission lines of He I and Paschen and Brackett lines of H I. The IR excess was also detected in the JHK spectra of the Be star. Though, we didnot observe any line disappearing events during our monitoring campaign, change in line equivalent widths and intensities were detected. Results obtained from our photometric observations of EXO 2030+375 were also discussed. NIR monitoring of these Be/X-ray binary pulsars with telescopes of larger aperture can help in understanding the evolution of Be circumstellar disk and its association with the X-ray outbursts.

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References

Clark J. S., Steele I. A., Coe M. J., Roche P. 1998, MNRAS, 297, 657
Clark J. S., Tarasov A. E., Okazaki A. T., Roche P., Lyuty V. M. 2001, A&A, 380, 615
Coe M. J., Carpenter G. F., Engel A. R., Quenby J. J. 1975, Nature, 256, 630
Coe M. J., Payne B. J., Longmore A., Hanson C. G. 1988, MNRAS, 232, 865
Delgado Martí H., Levine A. M., Pfahl E., Rappaport S. A. 2001, ApJ, 546, 455
Finger M. H., Wilson R. B., Harmon B. A. 1996, ApJ, 459, 288
Giacconi R., Gursky H., Kellogg E., Schreier E., Tananbaum H. 1971, ApJL, 167, 67
Haigh N. J., Coe M. J., Fabregat J. 2004, MNRAS, 350, 1457
Haigh N. J., Coe M. J., Steele I. A., Fabregat J. 1999, MNRAS, 310, L21
Hanuschik R. W. 1996, A&A, 308, 170
Lyubimkov L. S., Rostopchin S. I., Roche P., Tarasov A. E. 1997, MNRAS, 286, 549
Massi M., Ribó M., Paredes J. M. et al. 2004, A&AL, 414, 1
Mathew B., Banerjee D. P. K., Naik S., Ashok N. M. 2013, AJ, 145, 158
Mathew B., Banerjee D. P. K., Naik S., Ashok N. M. 2012, MNRAS, 423, 2486
Naik S., Dotani T., Terada Y. et al. 2008, ApJ, 672, 516
Naik S., Mathew B., Banerjee D. P. K., Ashok N. M., Jaiswal R. R. 2012, RAA, 12, 177
Naik S., Maitra C., Jaisawal G. K., Paul B. 2013, ApJ, 764, 158
Naik S., Jaisawal, G. K. 2015, RAA, 15, 537
Negueruela I., Reig P., Coe M. J., Fabregat J. 1998, A&A, 336, 251
Norton A. J., Coe M. J., Estela, A. et al. 1991, MNRAS, 253, 579
Okazaki A. T., Negueruela I. 2001, A&A, 377, 161
Paul B., Naik S. 2011, BASI, 39, 429
Parmar A. N., White N. E., Stella L., Izzo C., Ferri P. 1989, ApJ, 338, 359
Porter J. M., Rivinius T. 2003, PASP, 115, 1153
Roche P., Larionov V., Tarasov A. E. et al. 1997, A&A, 322, 139
Stollberg M. T. 1997, PhD Thesis, Univ. Alabama, 22
Wilson C. A., Fabregat J., Coburn W. 2005, ApJ, 620, 99