

The Be/X-ray binary system V 0332+53: A Short Review

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Be/X-ray binary systems provide an excellent opportunity to study the physics around neutron stars through the study of the behaviour of matter around them. Intermediate and low-luminosity type outbursts are interesting because they provide relatively clean environments around neutron stars. In these conditions the physics of the magnetosphere around the neutron star can be better studied without being very disturbed by other phenomena regarding the transfer of matter between the two components of the Be/X-ray binary system. A recent study presents the optical long-term evolution of the Be/X-ray binary V 0332+53 and the X-ray emission mainly during the intermediate-luminosity outburst in 2008. In this paper we comment on the context of these observations and on the properties that can be derived through their analysis.

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1. Introduction

Accreting X-ray pulsars are binary systems composed of a donor star and an accreting neutron star (NS). In High Mass X-Ray Binary (HMXB) systems the optical companion could be either a massive early-type supergiant (supergiant systems) or an O,B main sequence or giant star (Be/X-ray binary; BeXB). Among the most remarkable signatures found in BeXBs are the detection of IR excess and emission-line features in their optical spectra produced in a disc-like outflow around the Be star. Historically, their outbursts have been divided into two classes. Type I (or normal) outbursts normally peak at or close to periastron passage of the NS ($L_X \leq 10^{37}$ erg s⁻¹). Type II (or giant) outbursts reach luminosities of the order of the Eddington luminosity ($L_X \sim 10^{38}$ erg s⁻¹; [1]), with no preferred orbital phase. Also there are some “intermediate”-luminosity states, referring to any X-ray outburst that does not comply with the aforementioned properties, thus have $L_X \sim 10^{37}$ - 10^{38} erg s⁻¹ ([2]).

1.1 V 0332+53

The recurrent hard X-ray transient V 0332+53 was detected with the Vela 5B observatory in 1973 during its giant outburst, reaching a peak intensity of ≈ 1.6 Crab in the 3–12 keV energy band [3]. The optical companion of the system, BQ Cam [4] is an O8-9 type main sequence star at a distance of ≈ 7 kpc [5]. It has been widely observed both in optical and IR wavelengths since its identification. The optical spectrum is characterised by the highly variable emissions of H_α , H_β and H_γ in addition to the He I lines. The photometric data show an IR excess [6, 7, 8, 9].

1.2 On the optical and X-ray emission

Optical (spectroscopic and photometric) observations of BeXBs give us important information on the physics of the processes occurring in the outer envelope of the Be star. These stars are usually fast rotating and expel material into their surroundings in the form of a “decretion” disc surrounding them. The optical properties observed from these systems are dominated by the emission from this disc and its interaction with the accretion disc surrounding the NS via mass-transfer. In the case of V 0332+53 the latter is the less massive component of the binary system and spends most of its time in quiescence, when it is far away from the Be star. When it approaches the Be star during its orbit, then an X-ray outburst takes place (although there are BeXBs that show X-ray outbursts near the apastron passages of the NS). The X-ray emission results from the interaction of matter with the magnetosphere of the NS. This creates a very rich (and currently not totally understood) phenomenology in the X-ray emission from these sources.

2. History of the outbursts

After its discovery in 1973 the system had passed a ten-year X-ray quiescent phase when 4.4 s pulsations were detected with Tenma and EXOSAT satellites [10]. These X-ray activities, a series of Type I outbursts, lasted about three months separated by the orbital period (34.25 d) of the system. During these outbursts, rapid random fluctuations in the X-ray emission in addition to the pulse-profile variations were also reported [9]. The system underwent another outburst, classified

as Type II, in 1989 which led to the discovery of a cyclotron resonant scattering feature (CRSF) at 28.5 keV and two Quasi Periodic Oscillations (QPOs) centred at 0.051 Hz and 0.22 Hz [11, 12, 13].

The brightening in optical/IR light-curves is usually accompanied with the X-ray outburst phases as in the case of the giant 2004 outburst of the system. [14] predicted this outburst based on the optical brightening of the source in the optical/IR band. During the outburst, three additional CRSFs at 27, 51 and 74 keV were detected in *Rossi X-ray Timing Explorer (RXTE)* observations [15] and confirmed with subsequent *INTEGRAL* data [16]. [17] showed that the energy of these features is linearly anti-correlated with the luminosity of the source indicating different X-ray states. The following X-ray activities of the system occurred in 2008, 2009 and 2010 with relatively weak peak fluxes [18, 19, 20]. The system was in X-ray quiescence until 2015 June 18, when the Be companion probably reached its maximum optical brightness after renewing activity in 2012 [21].

A recent study of giant outbursts from V 0332+53 ([22]) at different luminosities has provided crucial insights into the most frequent states of this source. These states are the low and high-luminosity ones. In Fig. 1 we can see the existence of two separate regimes (the diagonal branch - DB - and the horizontal branch - HB -). As from [22] they are separated by a critical luminosity ($L_{\text{crit}} \approx 1 - 4 \times 10^{37} \text{ erg s}^{-1}$, which corresponds to a *RXTE*/PCU2 rate of $\approx 800 \text{ c s}^{-1}$ in Fig. 1). Both regimes are clearly well-populated by X-ray observations whilst observations around the critical luminosity are scarce. This critical luminosity coincides with the so-called intermediate-luminosity state.

2.1 The intermediate-luminosity outburst in 2008

A multi-wavelength study of V 0332+53 mostly during the recent events initiated in 2008 has been recently performed ([2]). For this purpose we used archived *Swift*-XRT and *RXTE* pointed observations carried out in 2008, as well as one *Suzaku* observation from 2010 and survey data from different space-borne telescopes and covering intermediate and low-luminosity events. In addition, we used optical/IR data from our dedicated campaign involving several ground-based astronomical observatories (Fig. 2 shows a zoom of the optical and X-ray light curve covering such time). This provides us a unique opportunity to undertake studies of X-ray outbursts of intermediate-low X-ray luminosities. The former is a regime very scarcely explored in V 0332+53, one of the BeXBs with strongest magnetic field already known.

3. Discussion and conclusions

Here we present a hint of the optical long-term evolution of the BeXB V 0332+53 and the X-ray emission mainly during the intermediate-luminosity outburst in 2008. Most of the characteristics found are alike those found in giant outbursts. Nevertheless, some particular points do not coincide which the aforementioned outbursts, e. g.:

- The presence of QPOs at a frequency close to the pulse of the NS during the lowest luminosities.
- A positive correlation of the energy of the CRSF line with luminosity.

We refer to [2] for a report on the details and discussion of these (and other) results obtained.

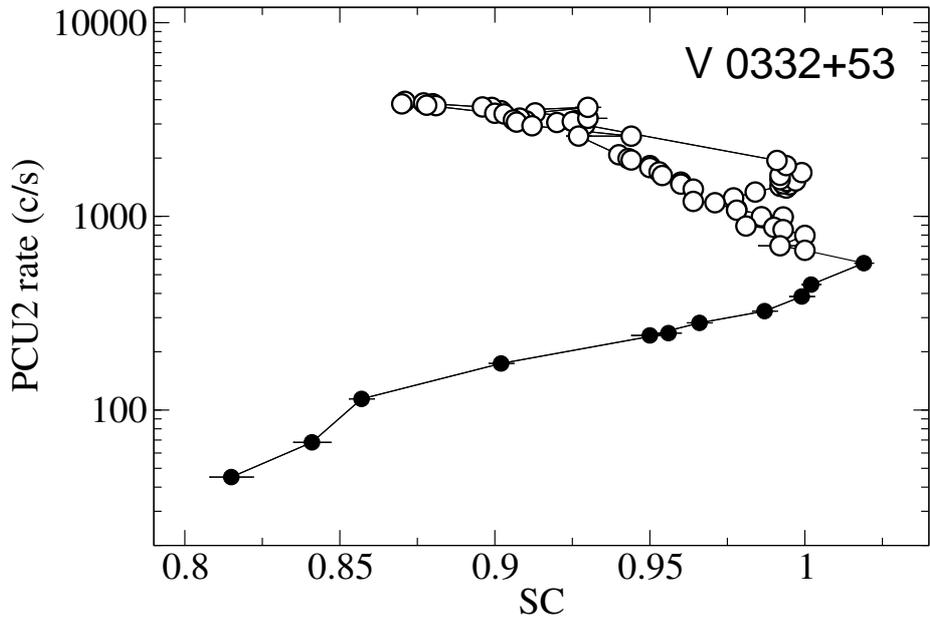


Figure 1: Hardness (soft colour)-intensity diagram. The soft colour was defined as the ratio 7-10 keV / 4-7 keV. The count rate was obtained for the 4-30 keV energy band. Open circles designate points in the DB, while filled circles correspond to the HB. A logarithmic scale is used for the count rate. Figure from [22].

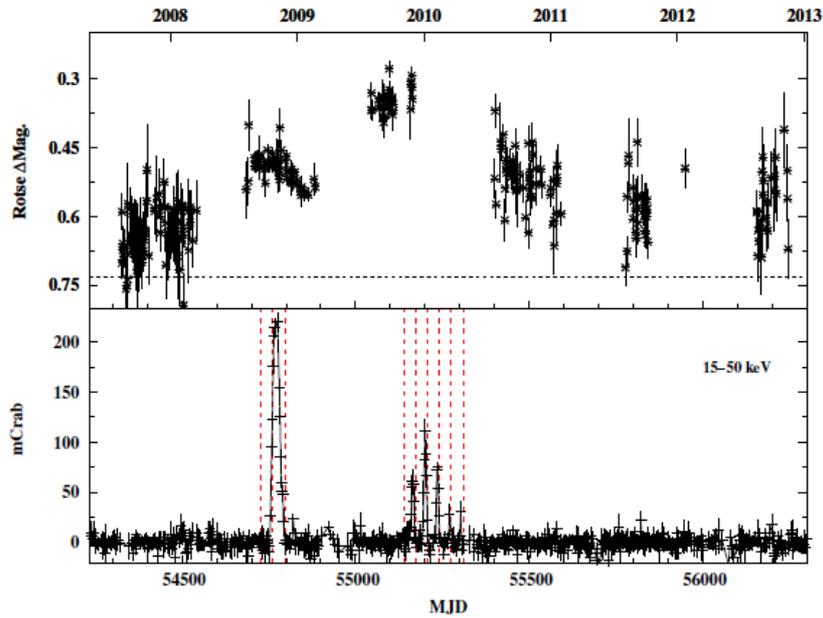


Figure 2: Comparison of Swift/BAT light curve (15-50 keV) with a bin size equal to 2 d with the ROTSEIII (optical) magnitudes of V 0332+53, for the time interval MJD 54275-56300. The horizontal black dashed line in the ROTSE panel denotes quiescent differential magnitude of V 0332+53 whereas the vertical red dashed lines in the X-ray panel represent the times of the periastron passages of the NS. Figure adapted from [2].

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