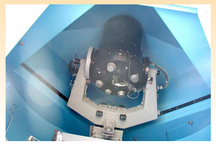

Investigation of the Photometric and Spectroscopic Variations in Be/X-Ray Binaries

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1. OBSERVATIONS and SOURCES

In this study, we present the results of the long-term optical monitoring of the selected Be stars in Be/X-ray binary systems. Using the the archival RXTE/ASM data the analogies between the X-ray and optical light curves have been investigated. We also present the Hα observations of these systems to point out their relation with the optical brightness variations.

The optical monitoring of the sources between 2004-2011 were performed by Robotic Optical Transient Search Experiment (ROTSEIIId – *http://www.rotse.net*) which has an aperture of 45 cm. The system operates without filters and has a wide pass-band which peaks at 5500 Å.

The optical spectroscopic observations were made by the medium resolution spectrometer TFOSC, mounted on the focal plane of The Russian-Turkish 1.5 m Telescope (RTT150); and the grism G8 which has an average dispersion of $\sim$1.1 Å pixel^{-1} in the wavelength range 3850-6850 Å.

The long-term X-ray light curves of the sources have been obtained from the RXTE/ASM archieve. We used the daily averaged ASM/C-band data (5-12 keV) for the source SAX J2103.5+4545 while the weekly averaged ASM/Sum-band (1.5-12 keV) data were used for the rest of the sources.

Source Name	Spec. Type	m_V	$P_{orb.}$ (d)	P_{spin} (s)	e	$Lx_{max.}$ (erg s^{-1})	d (kpc)
4U0115+634 (V635 Cas)	B0.2 Ve	15.1	24.3	3.6	0.34	3.0×10^{37}	7-8
V0332+53 (BQ Cam)	O8-9 Ve	15.7	34.3	4.4	0.3	$> 10^{38}$	7
IGR J06074+2205	B0.5 Ve	12.3	-	-	-	5.6×10^{35}	-
GRO J2058+42	O9.5-B0 IV-Ve	14.9	55.03	198	-	2.0×10^{36}	9
SAX J2103.5+4545	B0 Ve	14.2	12.68	358.6	0.4	$\sim 3.0 \times 10^{36}$	4.4
SAX J2239.3+6116	B0-2 III-Ve	15.1	262.6	1247	-	$\sim 2.3 \times 10^{36}$	6.5

2. RESULTS

- **4U0115+634 (V635 Cas):** The optical outbursts of the system occur in pairs. However these outbursts are not always accompanied by the X-ray outbursts, one of them is clearly missing (Reig et al. 2007). The X-ray activity in 2004 seems to appear about $\sim$180 days after the onset of the optical outburst. The sharp decrease in the brightness can be explained as the transfer of the material from the decretion disk to the compact companion (Baykal et al. 2005). The following X-ray outburst in 2008 occurs after the optical brightening and fading episodes. The Hα evolution of V635 Cas confirms the disk build-up and loss phases. The system has been undergoing a new X-ray activity since May 2011 (Drave et al. 2011).
- **V0332+53 (BQ Cam):** The hard X-ray transient source V0332+53 shows both typeII and typeI outbursts. The X-ray outburts usually coincide with the enhancement in the optical magnitude. Although the system reaches its max. brightness in the beginning of 2010, no X-ray activity has been reported so far.
- **IGR J06074+2205:** The system is one of the Be/X-ray binaries discovered by INTEGRAL in the last decade. The X-ray activity of IGR J06074+2205 was detected during the public observations of the Crab region in 2003 (Chevenez et al. 2004). The Hα profiles show V/R variations. When the system is in optically quite state the Hα line is seen in absorption.
- **GRO J2058+42:** The Hα evolution of the source is compatible with the optical variation during 2006-2008.The system shows a small typeI outburst on May 20, 2008 while the EW of Hα continues to increase. The V/R variations which have been observed after the outburst are the indicators of the perturbations in the disk. The optical and X-ray light curves of GRO J2058+42 do not show any correlation.
- **SAX J2103.5+4545:** The relation between the optical and X-ray light curves is seen explicitly. After the X-ray outburst of the system in 2007, the decretion disk becomes weaker and roughly 1 year later has been completely dispersed. The typical disk formation/dissipation time for SAX J2103.5+4545 is about 2 yr (Reig et al., 2010a).
- **SAX J2239.3+6116:** Altough the optical magnitude of SAX J2239.3+6116 tends to increase in the long-term trend, the X-ray intensity of the source does not show a similar variation.

The sources which are investigated in this work mainly tend to show three different types of variations in their optical light curves;

- **Long-Term Variations:** Depending on the size and the density of the decretion disk, such variations can be irregular (brightenings up to $\sim$1.3 mag.). They last 3-5 years (e.g., V65 Cas, GRO J2058+42, IGR J06074+2205, SAX J2103.5+4545).
- **Mid-Term Variations:** They are either seen as embedded into the long-term variations (e.g., SAX J2239.3+61) or identified clearly with a period of 50-100 days accompanied by 0.1-0.3 mag. differences.
- **Short-Term Variations:** Either the stellar rotation or the NRPs can be the responsible mechanisms. The timescale of these type of variations change in the range of days and hours (e.g., GRO J2058+42, BQ Cam).

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Acknowledgements

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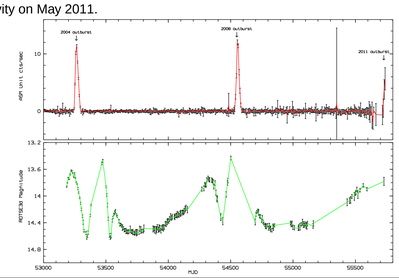
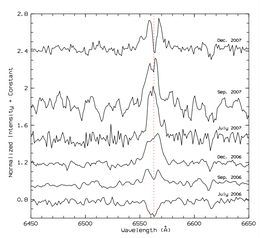
V635 Cas

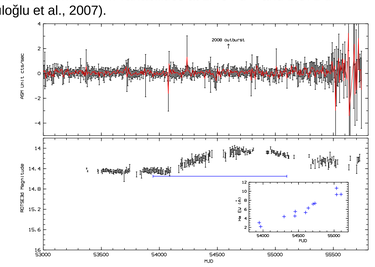
The optical outbursts which are seen in pairs can occur even after the X-ray outbursts (Oct. 2008) The brightness variation between the quiscent and active states is at the order of $\sim$1.3 mag. The time scale of the loss and build up stage of the decretion disk is $\sim$3-5 yr (Negueruela & Okazaki 2001). The enhancement in the optical magnitude has turned out to be an X-ray activity on May 2011.

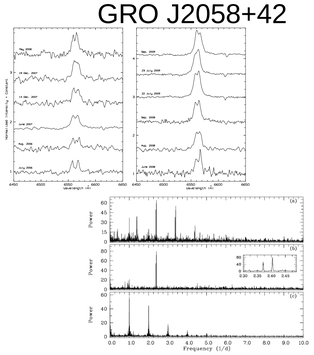




GRO J2058+42

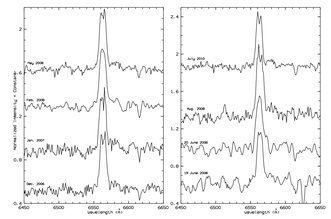
The optical and X-ray light curves of the source do not show a significant correlation. However the measurements of the Hα line over nearly $\sim$3 yr are compatible with the optical variations. The frequency analysis of the optical light curves of the Be star results in two short-term variabilities at 2.404 d^{-1} and 2.371 d^{-1} (Kızıloğlu et al., 2007).

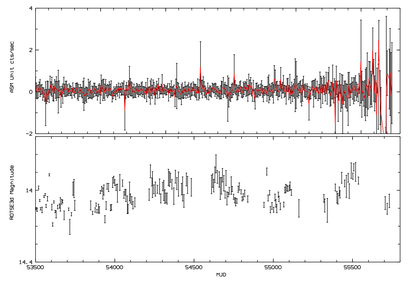




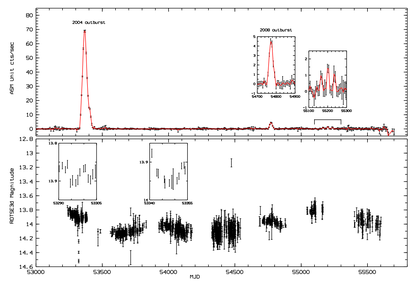
SAX J2239.3+6116

The system shows reccurrent $\sim$0.3 mag. brightness variations in the time interval of 100-200 days. The Hα lines are always seen in emission.

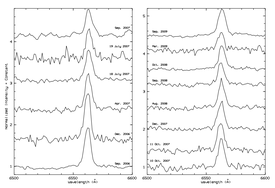




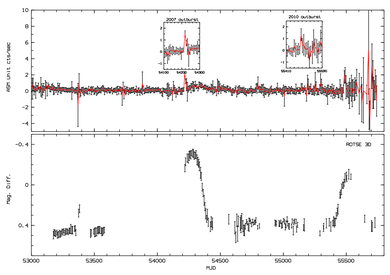
BQ CAM

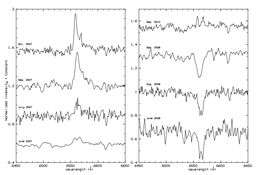


Observed rapid low-amplitude variability on time scales of a few days is typical for this source (Goranskij 2001). It shows a nearly sinusoidal variation with an amplitude of $\sim$0.02 mag. in the time interval MJD 55290-55355 (Baykal et al.,2005).



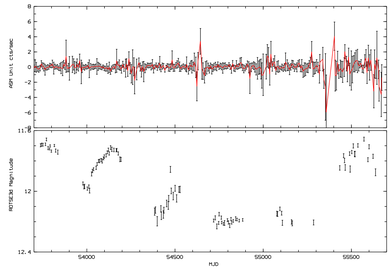
SAX J2103.5+4545

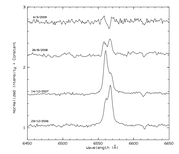




The decretion disk of the Be star is formed in $\sim$2 years (Reig et al., 2010a). The X-ray behaviour of the compact companion can be characterised by faint and bright states. The Hα profiles which are seen after the X-ray in 2007 have a quite complex structure. The system shows weak Hα emission while it reaches its max. optical brightness. In addition the EWs observed about four months after the X-ray outburst are larger than its previous values (Kızıloğlu et al., 2009).

IGR J06074+2205





The asymmetric Hα line shapes are thought to occur due to the global changes in the decretion disk of the Be star(Reig et al., 2010b). The Hα line has been seen to change from a double-peaked emission to an absorption profile indicating the loss of the equatorial disk. The optical brightness of the source shows mid-term magnitude varitaions at the order of $\sim$0.3 mag.