MAXI/GSC observation of X-ray outbursts from Be/X-ray binary pulsars

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Abstract

MAXI/GSC has been monitoring the X-ray activities of Be/X-ray binary pulsars for 7 years since the MAXI operation started. During this period, over the hundred outbursts were observed, and 50 Atels were issued based on the MAXI/GSC observation data. So far, two types of the X-ray outbursts (normal and giant) have been observed. The observations of the consecutive X-ray outbursts from A 0535+26 and GX 304-1 found the systematic shift of the outburst peaks. This systematic shift can be explained by the precessed Be disk model. Comparing with the previous results, we find that these outburst phase shift rate might depend on the orbital parameters.

Key words: pulsars: individual(A0535+26,GX304-1,GRO J1008-57) — X-rays: binaries

1. Introduction

Be/X-ray binary pulsar (BeXBP; Reig 2011 and references therein) composed of an O or B type main sequence star with Balmar emission lines (Be star) and a highly magnetized ($\geq 10^{12}$ gauss) neutron star orbiting an eccentric system is a representative subgroup of the X-ray transients. This source occassionally or regularly exhibit a X-ray outburst lasting for a few days to months, due to the mass accretion from a circumstellar disk around Be star. The class of the X-ray outbursts are generally divided into two types regarding the orbital phase and its luminosity. A normal (type-I) outburst takes place at or near periastron and its peak luminosity distributes in a narrow range of 10^{36-37} erg s^{-1}. This outburst is generally repeated by the orbital period. Whereas a giant (type-II) outburst exhibits a large X-ray luminosity ($\geq 10^{37}$ erg s^{-1}) at its peak and their orbital phases out of the periastron (Priedhorsky & Terrell 1983; Reig 2011).

So far, several all-sky X-ray monitor instruments have been observing the X-ray activities of BeXBPs. From 2009 August, Monitor of All-sky X-ray Image (MAXI;Matsuoka et al. 2009) onboard Internatioal Space Station had started its operation, and the monitor data are archived via web page. Thanks to the high sensitivity of GSC and continuous observations, a lot of X-ray outbursts have been observed and their data are systematically catalogued in the data base. In this paper, we introduce a brief observational results, about peculiar periodicity of X-ray outbursts from BeXBPs. We will report the analysis results of the BeXBP outbursts with the past/present all-sky monitor data, centering on MAXI data.

2. MAXI/GSC observation of X-ray ouburssts

So far, over 100 outbursts from BeXBPs have been observed by MAXI/GSC. Figure 1 shows the representative light curves of BeXBPs. We have issued some reports to Astronomer's Telegram and MAXI Mailing List about these detected events. In the cases of GX 304-1 and GRO J1008-57, the detection of the onset of the giant outbursts were reoprted on 2010 August (Mihara et al. 2010) and 2012 November (Nakajima et al. 2012), and its alert information led to the discovery of cyclotron lines by the Suzaku ToO observations (Yamamoto et al. 2011; Yamamoto et al. 2014). In addition to the above urgent followup observations, we also issued some reports about the ordinary or extraordinay X-ray outburst behavior of BeXBPs. In the following, we focus on the peculiar outburst periodicity.

3. Outburst Periodicity

Based on the MAXI/GSC data, we have reported some peculiar outburst periodicity. Usually, the normal outburst recurs synchronized with its orbital period. However, the representative BeXBP, A 0535+26 and GX 304–1, exhibited the consecutive X-ray outbursts which were not repeated by the orbital period.

The first report by the MAXI/GSC observation of the X-ray outburst from A 0535+26 was issued on 2009 (Sugizaki et al. 2009). The orbital parameters, including the orbital period of 111.1±0.1 day, eccentricity (0.47±0.02) and the epoch of the periastron passage (MJD=53613.0),

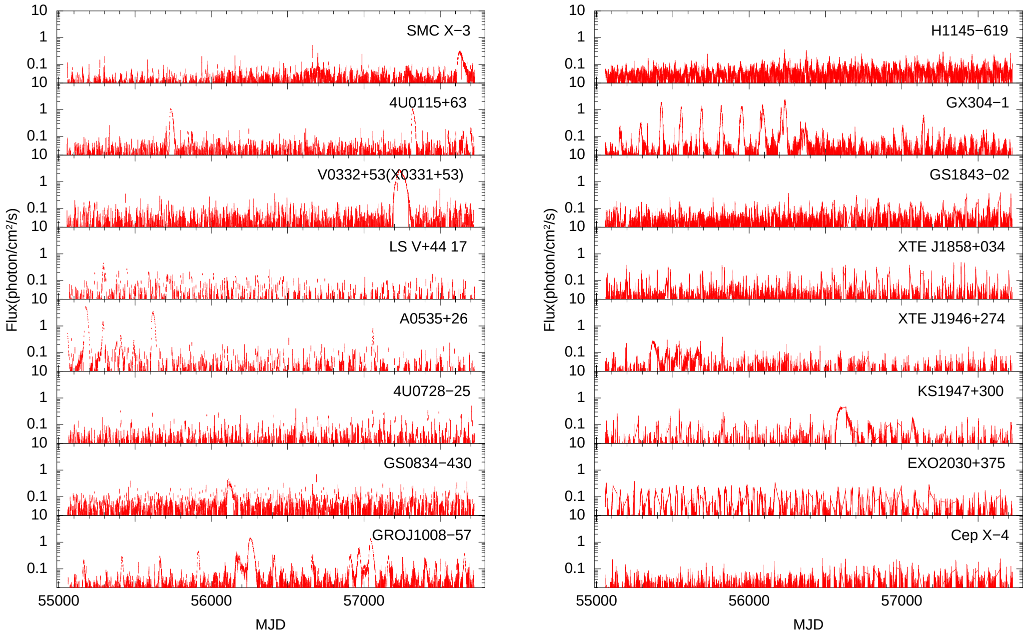

Fig. 1. The 2-20 keV light curves of the representative BeXBPs observed by MAXI/GSC.

were determined by Finger et al. (2006). This source had started a renewed activity from 2008, and the source exhibited quasi-periodic X-ray outbursts. Interestingly, these outburst recurred with the period of 115 days, not the orbital period of 111 days (Nakajima et al. 2014). Thus, the outburst peak phase shifted steadily with the change rate of 3.0×10^{-4} phase d^{-1}. To interpret the outburst phase shift phenomenon, precessed Be disk model was proposed (Moritani et al. 2013 and references therein). According to this model, the Be disk precesse with the period of 8.7 years. This period is comparable to the V/R variation periods of isolated Be stars, ~ 7 yr (Okazaki 1991 and references therein).

Another source which exhibited the outburst phase shift observed by MAXI/GSC is GX 304–1 (Nakajima et al. 2016). This source was reactivated from 2008 after the 30 years quiescent state, and has exhibited the series of normal/giant X-ray outbursts. The systematic outburst phase shifts were observed between 2014 August and 2016 January. Figure 2 shows the normal outbursts light curves of GX 304–1 which were divided into the orbital period of 132.189 day intervals (Sugizaki et al. 2015). During this period, the outburst onset phases shifted steadily from ~ 0.90 orbital phase to 0.02. The phase shift rates of the outburst onset is estimated to be $(2.5 \pm 0.1) \times 10^{-4}$ phase d^{-1}. Thus, it is revealed that the outburst phase shift rates of two sources are comparable.

In addition to the above analysis results obtained by the MAXI/GSC data, we next introduce the other sources which showed the systematic outburst phase shift. There are two BeXBPs, GS 0834–430 and EXO 2030+375, which showed the outburst phase shift in past. In the case of GS 0834–430, the consecutive X-ray outbursts had been observed from 1991 to 1993 by CGRO (Wilson et al. 1997). In this period, the phase shift rate was estimated to be 2.4×10^{-3} phase d^{-1}. On the other hand, EXO 2030+375 exhibited not only the steady shift of the outburst peak phase but also the orbital phase jump in 1996 (Wilson et al. 2002). The previous analysis reported that the phase shift rate was determined to be 1.8×10^{-4} phase d^{-1}. Besides, Laplace et al. (2017) suggested that there is a possible long-term (~ 10 or ~ 20 years) periodicity of the giant outburst due to Kozai-Lidov mechanism in the circumstellar disk around Be star.

According to above results, we confirmed that at least 4 BeXBPs exhibit the systematic phase shift of the outbursts. Therefore, the orbital phase shift can be considered as the common phenomenon among the BeXBPs. In the followings, we attempt to compare the results between each source.

According to the previous observations, it is turned out that the outburst phase shift rate of GX 304–1 ($(2.4 \pm 0.10) \times 10^{-4}$ phase d^{-1} for the outburst onset) is same order of the results of EXO 2030+375 (Wilson et al. 2002 ; $(1.8 \pm 0.4) \times 10^{-4}$ phase d^{-1}) and A 0535+26 (Nakajima et al. 2014 ; $(3.03 \pm 0.06) \times 10^{-4}$ phase d^{-1}). Whereas the case of GS 0834–430, it is revealed that its rate (2.4×10^{-3} phase d^{-1}) is significantly higher than the others.

Next, we have searched for a correlation between the orbital phase shift rates and the other orbital/Be-star parameters. The most probable one which relates to the orbital phase shift rates is the orbital eccentricity. Figure 3 shows relation between the eccentricity and the shift rates. In the low eccentric system, the truncation radius of the Be disk is much larger than that of the high eccentric binaries (Okazaki and Negueruela 2001). Thus it might be considered that the tidal effect affects the orbital phase shift rates of the outbursts. However, with the small number of the data, we can not conculde that the eccentricity is a key parameter of the orbital phase shift of the outbursts. Further discussion will be reported in the forthcoming paper.

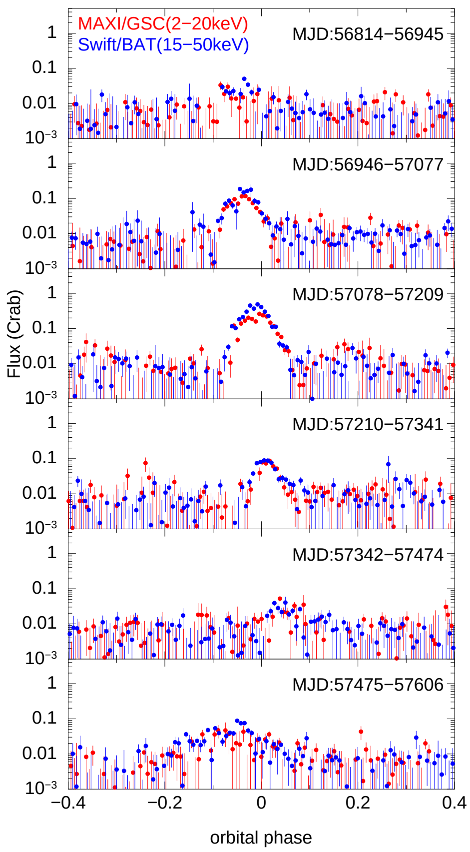

Fig. 2. The light curves of GX 304–1 shown for individual 132.189-d orbital cycles and those fluxes in Crab units. Red marks represent the data obtained by MAXI/GSC, and blue ones are the Swfit/BAT results. The origin of the orbital phase (= 0) corresponds to the periastron passage.

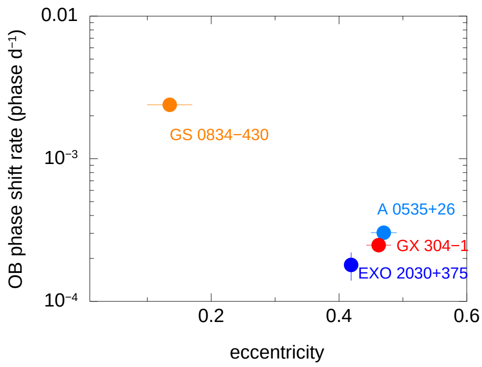

Fig. 3. The relation between eccentricity and outburst phase shift rate.

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