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A study on the long term periodicities among the X-ray binaries: Two new superorbital periods

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Long term behaviours of a few selected X-ray binaries are studied on the basis of RXTE/ASM archive covering a period of ∼13 years of continuous X-ray data. Two new superorbital periods seem to be revealed for the GX354-0 and X Persei systems as 8.7 years and 345 days, respectively. Although the X Persei system has two strongest peaks in its power density spectrum at 15.7 years and at 345 days, the latter is much more plausible. The GX354-0 system also has few additional periodicities appeared in different time intervals.

1 Introduction

It has long been known that X-ray binaries have periodicities longer than their orbital periods, which are called superorbital periods or third periods. These periodicities are detected especially in X-rays. The underlying physical process is proposed to be precessional motion of a warped accretion disk (Petterson 1977), a hypothetical third body (Chou & Grindlay 2001) or precession of the neutron star's magnetic axis (Trümper et al. 1986).

In the context of observational studies up to now, the long term behaviours of X-ray binaries (XRBs) can be interpreted in terms of a few sub-classes: (i) Quasi-periodicities or multi-periodicities appeared as different periods in distinct time intervals, e.g., Cyg X-2 (Paul, Kitamoto & Makino 2000), GX354-0 (Kong, Charles & Kuulkers 1998), LMC X-3 (Wen et al. 2006), 1820–303/Sgr X-4 (Chou & Grindlay 2001), 1705–440 (Benlloch et al. 2001). This kind of temporary periodicities looks very common in XRBs. (ii) Regular changes or sudden jumps in superorbital periods by time, e.g., SMC X-1 (Clarkson et al. 2003; Wojdowski et al. 1998), Cyg X-1 (Javier 2008; Kemp et al. 1983; Brocksopp et al. 1999; Pooley, Fender & Brocksopp 1999). (iii) Unexpected state transitions, e.g., Cyg X-1 (Pottschmidt et al. 2000), Cyg X-3 (Smale & Lochner 1992), 1905+005/Aql X-1 (Benlloch et al. 2001) and Cir X-1 (Clarkson, Charles & Onyett 2004). (iv) Steady periodicities, e.g., Her X-1, LMC X-4, SS433 (Wen et al. 2006), 0114+650 (Farrell, Sood & ONeill 2006). However, some clues of decaying superorbital periods in the systems Her X-1 and LMC X-4 were reported by Still & Boyd (2004), and Paul & Kitamoto (2002). Although some systems may display a mixture of features above, the superorbital variability in each system is unique.

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A recent systematic research for long term periodicities of 458 sources observed by RXTE/ASM instrument is given by Wen et al. (2006). Some references for the detailed physical interpretations of these superorbital periods can be found in Raichur & Paul (2008).

In this paper, the preliminary results of the long term timing analysis of a random sample of 29 X-ray binaries, which is about 10% of the total number, are presented by constructing the power density spectra (PDS), which is the result of ∼13 years of ASM data registered in 1.3–12 keV band.

2 Observational data

The ASM detector on board RXTE provides an opportunity to observe the entire sky continuously in X-rays with a flux sensivity of 20–100 mcrab and a time resolution of 90 s dwells. The targets are monitored daily in three energy bands, i.e., 1.3–3.0, 3.0–4.8 and 4.8–12 keV. A detailed description of the ASM instrument, as well as its calibration and data reduction process, was given by Levine et al. (1996).

The full energy bands of light curves of randomly selected XRBs as 1 dwell were taken through the anonymous archive of MIT (URL: http://space.mit.edu/XTE/asmlc/ASM.html). The coverage of mostly uninterrupted daily data is about 12.5 years in between 1996 January and 2008 August except for the GX354-0 and X Per systems for which the coverage is more than 13 years.

Some physical parameters of the systems concerned in the study were gathered from Guseinov et al. (2000) and Liu, van Paradijs & van den Heuvel (2006, 2007).

3 Data analysis and results

Discrete Fourier transform (DFT) (Deeming 1975) is a preferable algorithm to detect periodicities in unevenly sampled data in time domain and can be used for searching long scale variabilities. The full energy range (1.3–12 keV) ASM light curves of selected XRBs in the form of 90 s dwells are set to be input values for the Period04 package which works on the basis of a revised algorithm of DFT (Kurtz 1985) and produces powers in frequency domain. Considerable powers over the sensivity limit produced by the DFT algorithm for each system are checked for long term periodicities in the low frequency region ($f < 0.1$ d^{-1}). The most prominent peaks relative to the sensivity limit in the power spectra are taken and folded light curves are constructed accordingly. Therefore, any considerable peak in the frequency region is tested by the folded light curves to see periodicity in time domain. Any evident periodicity appeared in the power spectra but not clear in the folded light curve is rejected, which may be due to artificial periods such as 96 m, 1 d, ∼50 d, 1 yr and their probable harmonics or may be due to sensitivity limit of ASM detector that makes it impossible to identify the periodicity in time domain.

GX354-0/1728–337 (Low Mass X-ray Binary: LMXB): Any periodicity from this system such as orbital or pulse is not reported until now. Wen et al. (2006) excluded this system in their periodicity search since it has large peaks, even though after their whitening process, distributed randomly through a broad frequency range that correspond to periods of a few several hundreds of days. In the present study, the power spectrum of GX354-0 has the strongest peak at $f = 0.00029$ d^{-1} corresponding to 3485 d of period. Applying a sinusoidal fit to the full energy range of ASM data refines the period to be 3189 days ≈ 8.7 years. When the ASM light curve is folded by this period, it shows a clear sinusoidal variation in full energy range (see Fig. 1). However, the PDS has a few additional peaks with powers higher than the sensivity limit such as 416 d, 324 d, 64 d, 52 d, 182 d, 77 d, and 87 d, in order of power. These periodicities also exhibit periodic features in the folded light curves but lasting only a few cycles in distinct time intervals. Similarly, Kong et al. (1998) revealed a power at ∼72 d in their study of RXTE/ASM data covering only 2 years of period. With this kind of temporary features, the GX354-0 system can be considered to exhibit quasi-periodic behaviour.

X Per/0352+309 (High Mass X-ray Binary: HMXB; $P_{\rm pulse} = 836.8$ s): An orbital period of 250 d was determined by a pulse timing analysis by Delgado-Marti (2001). On the basis of X-ray data, a search for long term periodicities by Wen et al. (2006) showed no evidence about the orbital or superorbital periods of X Persei in their whitening technique applied power spectrum. However, in the present study, more than 13 years of full band ASM data yields the strongest peak at 5747 days ≈ 15.7 years and a second strongest peak at 345 days in the power spectrum. When the light curve is folded by the former to see the variation profile, a variability with time scale of 15.7 yr is clearly seen in all energy bands with an 80% coverage of the full cycle. The light curve folded by the second strong peak, i.e., 345 days, resembles a small amplitude sinusoidal curve (Fig. 2). However, the 15.7 years of variation seems to be state transitions rather than a periodic behaviour.

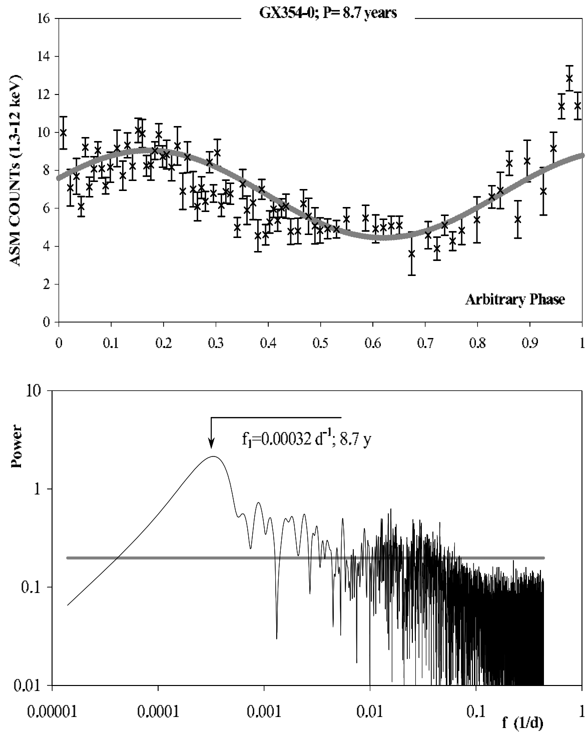

Fig. 1 40-d binned ASM light curve of GX354-0 folded according to 3189 days ≈ 8.7 years of period. More than 13 years of data covers 1.5 cycles. Grey line represents the best fit sine curve (*top panel*). Power spectrum of GX354-0 is shown in the lowest part of frequency ($f < 1$ d^{-1}). A 3σ level is also shown by a horizontal line (*bottom panel*).

Nor X-2/1538–522 (HMXB; $P_{\rm orb} = 3.7$ d; $P_{\rm pulse} = 530$ s), **Sgr X-4/1820–303** (LMXB; $P_{\rm orb} = 0.008$ d), and **Cen X-3/1119–603** (HMXB; $P_{\rm orb} = 2.1$ d; $P_{\rm pulse} = 4.8$ s): A common property of those three XRB systems is to display sliding epoches by time in the folded ASM light curves. Cen X-3 can be characterized by having strong flux variations with transient quasi-periodicity in long time scales (Priedhorsky & Terrell 1983). Chou & Grindlay (2001) reported that 1820–303 could be a triple system. The system's ∼176 days of third period, reported by various authors, see e.g., Priedhorsky & Terrell (1984), Smale & Lochner (1992), can be attributed to the tidal effects of third body. Cen X-3 and Nor X-2 exhibit their orbital periods in the power spectra as the highest peaks meanwhile the other peaks resemble the harmonics of the orbital periods. Although the Sgr X-4 system has some additional peaks in the PDS as a result of its aperiodic nature, the strongest peak corresponds to 172 days that matches its superorbital period previously known. These three X-ray sources follow a common behaviour such a way that the epoches or features

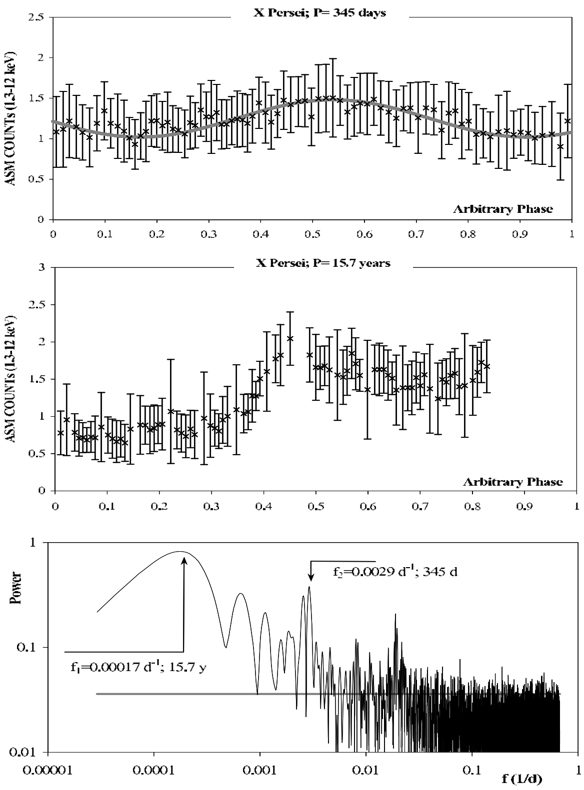

Fig. 2 5-d and 70-d binned ASM light curves of X Persei folded by two distinct periods, i.e., 345 days (*top*) and 15.7 years (*middle*). The middle panel covers only 80 % of the full cycle. The data fallen below the 1σ level from the average are selected to avoid from scattering in the folded light curves. A sinusoidal fit on the 345 days variation is also shown. The power spectrum of X Per below $f < 1\ \mathrm{d}^{-1}$ and the 3σ level are shown in the *bottom panel*.

in the folded light curves change the location by time (see Fig. 3)

Cir X-1/3U1516–56 (LMXB; $P_{\rm orb} = 16.6$ d), **Aql X-1/1908+005** (LMXB; $P_{\rm orb} = 0.8$ d; $P_{\rm pulse} = 0.13$ s), **Cyg X-1/1956+350** (HMXB; $P_{\rm orb} = 5.6$ d), **Cyg X-3/2030+407** (HMXB; $P_{\rm orb} = 0.2$ d): The X-ray light curves of all these systems are affected by unexpected transitions to high or failed states. These powerful transitions produce unrealistic strong peaks in frequency domain. Since the third periodicities are highly distorted by transitions to high/soft states, e.g., Cyg X-1 (Wen et al. 1999; Lachowicz et al. 2006; Özdemir & Demircan 2001) or some systems, e.g., Cir X-1 (Clarkson, Charles & Onyett 2004), have extremely erratic behaviours in high states, truncation of high or failed state transitions may help to find out the third periods more clearly.

4 Conclusions

There are few XRB systems such as Cyg X-2, LMC X-3, 1705–440, GX354-0, Sgr X-4 that exhibit multi periodicities in different time intervals. This kind of nature seems to be the most frequent behaviour among the XRBs. Furthermore, jumps or smooth variations in the superorbital periods are also the case for Cyg X-1 and SMC X-1 systems. Kemp et al. (1983, 1987) concluded that Cyg X-1 had a 294 days of superorbital period from their optical photometry. This period was also confirmed by various authors in X-rays recorded by Vela 5B/ASM (1969–1979) and Ariel V/ASM (1974–1980) (Priedhorsky, Terrell & Holt 1983; Javier 2008). However, by using later radio and X-ray observations including RXTE/ASM, GINGA/ASM, a ~ 150 days of superorbital period was revealed by various authors (Kitamoto et al. 2000; Benlloch et al. 2004; Pooley

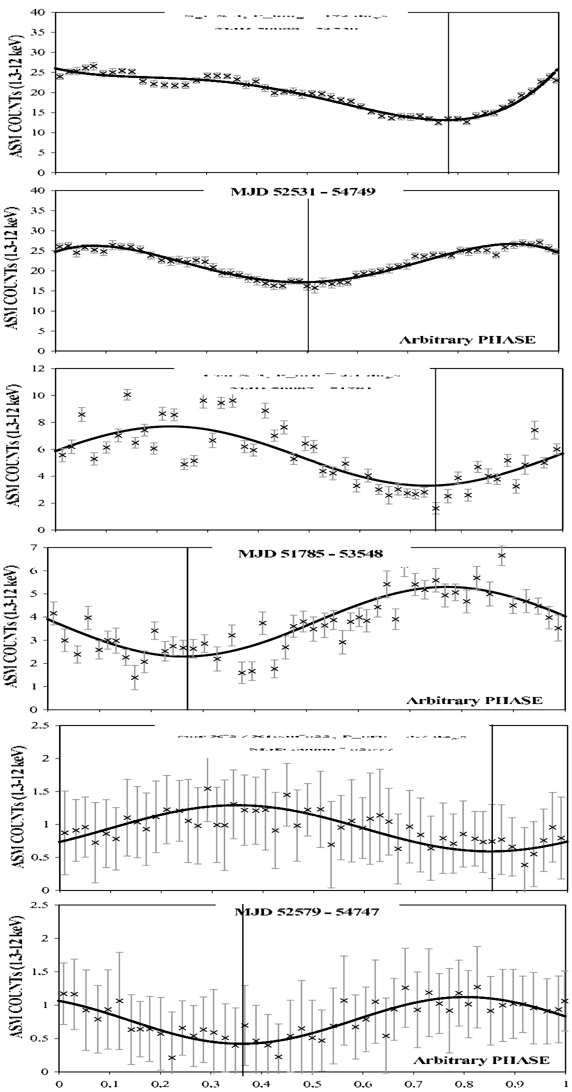

Fig. 3 Sliding epoches in two different time intervals for the Sgr X-4, Cen X-3, and Nor X-2 systems (*from top to bottom*) are shown. Bin sizes for each system are 3 d, 1 h, and 2 h, respectively. Individual graph is constructed accordingly in between time intervals given on the top of each panel. Systematic follows of these features may lead to obtain more sensitive shift ratios of the epoches. Solid curves represent the best fits to the data whereas vertical lines show the centers of dips.

et al. 1999; Brocksopp et al. 1999; Lachowicz et al. 2006; Özdemir & Demircan 2001). In a very recent study of Javier (2008), although a significant peak at 148 days was seen in their RXTE/ASM1 data taken between MJD 50328 and 51444, a third period of 326 days starting at the beginning of 2005 has been reported. The SMC X-1 system is a unique and well-known example that exhibits smoothly changing third period between 40 and 60 days on a time scale of about 1600 d (Clarkson et al. 2003).

Theoretical explanations on superorbital changes basically involve accretion disks and compact objects. Main source of the long term variations is ascribed to any obscuration of the central X-ray source or its reflections originated from the accretion disk that precesses under tidal effects. Tidal effects arisen from the companion star (Katz 1973), warped accretion disk by the intense radiation pressure of the central X-ray source (Petterson 1977), a hypothetical third body (Chou & Grindlay 2001), precession of the magnetic axis of the neutron star (Trümper et al. 1986) are the preliminary models to account for long term variations. Later models, such as tilted and twisted disks by coronal winds (Schandl 1996), warped precessional disks (Wijers & Pringle 1999; Ogilvie & Dubus 2001), could predict variable and chaotic precessional periods. Furthermore, detailed disk warping models by Wijers & Pringle (1999) and Ogilvie & Dubus (2001) point out chaotic disk precessions with unstable long term periodicities which seem to be the most common case in XRBs.

Two systems, GX354-0 and X Per, show strong evidence of long term previously unknown superorbital periods as 8.7 years and 345 days, respectively. The GX354-0 system's 8.7 year periodicity represents a fine sinusoidal curve (Fig. 1) with an increasing amplitude of 0.44, 0.75, and 1.01 count rates through the energy bands of ASM. The folded light curve of X Per according to the 15.7 years of variability (see Fig. 2, middle panel), which is seen as the highest peak in the power spectrum, may indicate its transitions to high and low states. It is seen that the ASM count level of the X Per system increases with the energy through the 15.7 years of cycle. However, more and longer term X-ray data are needed to clarify the nature of this long scale structure.

The Cir X-1 system also shows two strong peaks in its PDS which correspond to 17.5 years and 348 days. However, these periodicities may be connected with its irregular transitions to high state. A similar case can also be seen in Aql X-1.

As a last remark, it is noted that the third or superorbital periodicities are common and should be considered as a phenomenon in XRB studies. Increments in the sensitivity of ASM-type experiments by time will increase the possibility of finding third, perhaps fourth, periodicities in XRBs.

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