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Study of Quasi Periodic Oscillations in Lmxb Pulsar 4U 1323-619

Astronomy

KEYWORDS : accretion, X-ray pulsar, binary system

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ABSTRACT

we reported the detection of a 0.3162 Hz QPO for the first time in the transient pulsar 4U 1323-619. These newly detected QPOs were present more frequently in decline phase of outbursts as compare to the rising phase. However, there are only very few cases of accretion-powered X-ray pulsar such as SMC X-1 (Wojdowski et al. 1998), Her X-1, 4U 1626-67, LMC X-4 (see Table 1 of Shirakawa & Lai 2002) and 4U 0115+63 where multiple QPOs are seen. Another unique thing we detected in this work is the presence of multiple QPOs simultaneously in the same observation at three occasions.

INTRODUCTION

LMXB 4U 1323–619 exhibits X-ray bursts and irregular intensity dips that repeat every 2.94 hr. The source was first detected by Uhuru and Ariel V (Forman et al. 1978) and the dips and bursts were discovered using EXOSAT (van der Klis et al. 1985). During the dips, which typically last for 30% of the orbital cycle, the 1–8 keV intensity varied irregularly with a minimum of ~50% of the average value outside of the dips. The presence of periodic dips and the absence of X-ray eclipses indicated that the source is also viewed at i =60–80° (Frank et al. 1987). The dip recurrence interval is not so precisely known, with the best measurement being that of Baluci´ska-Church et al. (1999) of 2.94(2) hr. The source exhibited ~1 Hz QPOs which had been attributed to a disk instability (Jonker et al. 1999). The BeppoSAX 1.0–150 keV spectrum of the LMXB 4U 1323–619 persistent emission could be modeled by a cutoff power-law with Γ = 1.48± 0.01 and E cut = 44.1 +5.1 keV together with a blackbody with kT = 1.77± 0.25 keV–4.4 (Baluci´ska-Church et al. 1999).

OBSERVATION AND DATA REDUCTION

RXTE was launched on 1995 December 31 with the main objective of timing studies of celestial X-ray sources. Not only the objective is so far well achieved by RXTE but continued its mission in orbit for the period much more than expected. It made great contributions towards the understanding of high energy astrophysics by means of its unrivaled timing resolution

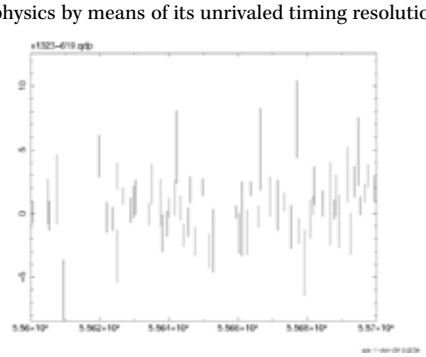

Figure 1 :RXTE/ASM one-day averaged light curve of the transient pulsar 4U 1323-619 in 1.5–12 keV energy range from 1996 January 5 (MJD 55600) to 2011 December 31 (MJD 55700). RXTE/PCA observation during 2011 outburst were analyzed to investigate the QPO features in the pulsar.

We have used the RXTE observations of transient LMXB pulsar 4U 1323-619 during one of its outbursts. RXTE, which is recently decommissioned, had three sets of major instruments as discussed in chapter 2 of this thesis. The all sky monitor (ASM) was sensitive in 1.5-12 keV energy range (Levine et. al. 1996). The PCA, which was consisting of five Xenon filled proportional counter detectors, was sensitive in 2-60 keV energy range. The effective area, energy resolution and time resolution of PCA were ~ 6500 cm^{2} at 6 keV, ≤ 18% at 6 keV and 1 μs, respectively. A detailed description of the PCA instrument can be found in Jahoda et al. (1996). The third instrument, High Energy Timing Experiment (HEXTE) was operating in 15-250 keV energy range (Rothschild et al. 1998).

The RXTE/ASM light curve of 4U 1323-619 from 1996 January to 2011 December is shown in Figure 1. During 2011 outburst, the pulsar was monitored only nine times and hence the data were used in our present analysis.

For our timing analysis, we used data from all PCA observations during the 2011 outburst (as shown in Figure 2). In this work, we analyzed a total of 9 publicly available RXTE/PCA observations . In this work, we used PCA data from these observations to study the evolution of QPO.

Downloaded data from archival site was raw data and therefore for analysis, data reduction was carried out by using the software package FTOOLS where as real data analysis was done by using the HEAsoft package (ver 6.11). Using the standard 1 mode PCA data, we extracted light curves in 2-60 keV energy range with time resolution of 0.125 s from all the RXTE pointed observations during the 2011 outbursts. While extracting the source light curves, we found that different number of PCUs were on during different dates of observations. Corresponding background light curves were created by using the modeled background event data (as provided by the instrument team). Data from all available PCUs were used in our analysis. Power-density spectra (PDS) were generated from each of the light curves obtained from the RXTE observations of the pulsar during 2011 outbursts by using the FTOOLs package powspec. To detect the presence/absence of QPO, PDS were created for small segments of duration 512 s and averaged over the total number of available segments in the individual light curves. The PDS were normalized to subtract the white noise level. These

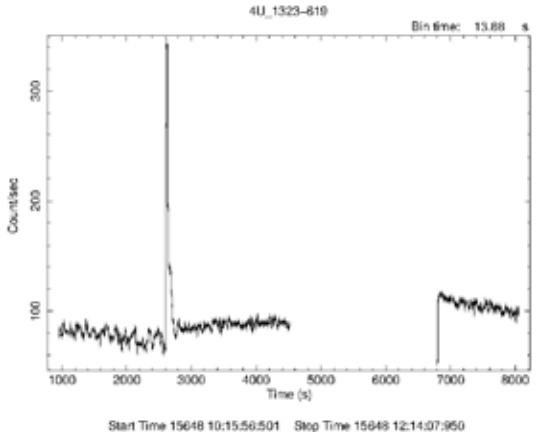

Figure 2 Light curve of 4u 1323-619 during 2011 March 28.

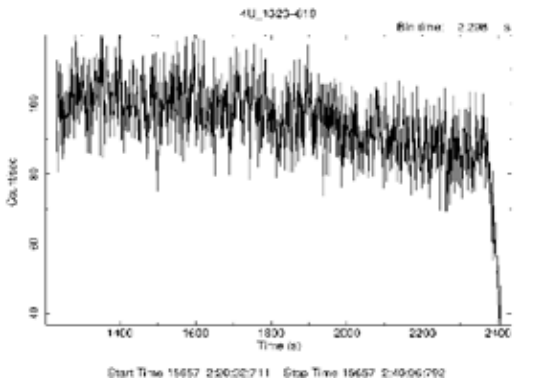

Figure 3 Light curve of 4u 1323-619 during 2011 April 06.

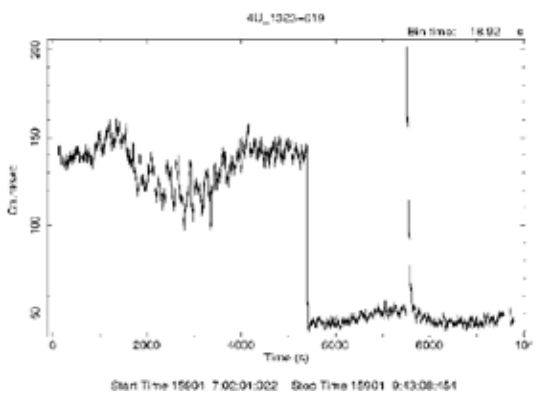

Figure 4 Light curve of 4u 1323-619 during 2011 December 06.

normalized PDS were used to estimate the squared rms fractional variability by integrating over a certain frequency range. All the PDS were then examined for the presence/absence of QPOs in a wide frequency range (~1 mHz to ~1 Hz).

We found that the regular pulsations of the pulsar and its harmonics were present in the PDS obtained from all the RXTE/PCA observations. Apart from these pulsations and corresponding harmonics, the PDS from 8 RXTE/PCA observations during the three outbursts of the pulsar were featureless. To estimate the frequency of the QPO, we fitted the PDS (2011 March 28 observations) with two continuum components such as a power law and a Gaussian. Peaks corresponding to the spin frequency of the pulsar and its harmonics were ignored while fitting the PDS continuum. The fit clearly showed the presence of a Gaussian feature at 0.3162 Hz (shown in Figures 5 & 6). This QPO in the transient pulsar 4U 1323-619 is detected for the first time.

We obtained the ratio of the amplitude and uncertainty of the Gaussian component.It may be noted that the exposure of individual RXTE/PCA observations were not very large (poor signal-to-noise ratio) which enhanced the error in the Gaussian component and degraded the significance level of the QPO feature. However, the feature can be clearly seen in the PDS as shown in one of the observations (Figure 5).

We calculated the quality factor Q (QPO central frequency ν/ FWHM (full width at half maximum) of the all three QPOs detected during 2011 outburst and found to be around 3. Conventionally, a local maximum in the PDS is interpreted as a QPO when the quality factor Q is more than 2 (van der Klis 2000). The high value of Q (≥ 2) for the peak at 0.3162 Hz in the PDS of 4U 1323-619 also confirms the feature to be a QPO. Comparisons between the QPO parameters with the flux of the pulsar are given in next section.

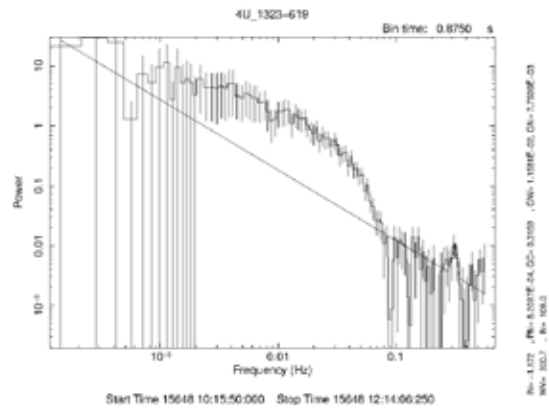

Figure 5:The power density spectrum of 4U 1323-619 obtained from the RXTE/PCA observation on 2011 March 28. The presence of newly detected 0.3159 Hz QPO is clearly seen in the PDS. The pulsations and its harmonics are seen at higher frequencies. The solid line in the figure represents the fitted model comprising of a power-law continuum, a Gaussian function.

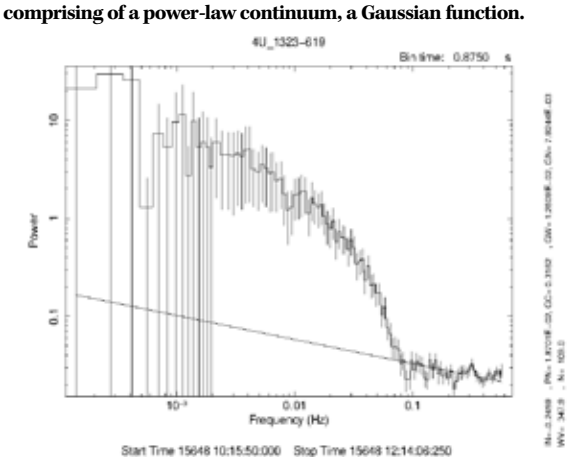

Figure 6: The power density spectrum of 4U 1323-619 obtained from the RXTE/PCA observation on 2011 March 28. The presence of newly detected 0.3162 mHz QPO is clearly seen in the PDS. The pulsations and its harmonics are seen at higher frequencies. The solid line in the figure represents the fitted model comprising of a power-law continuum and a Gaussian function

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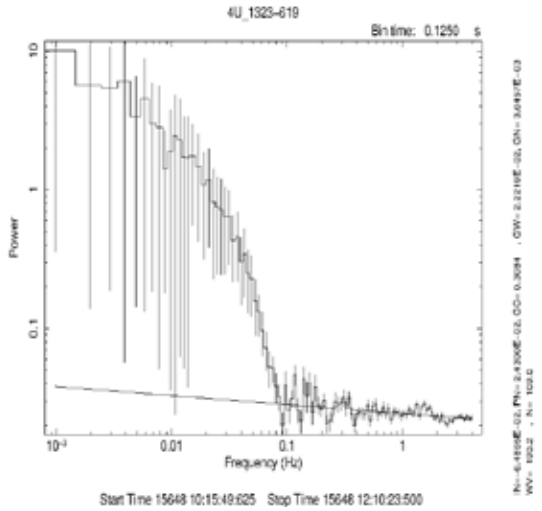

Figure 7: The power density spectra of 4U 1323-619 obtained from the RXTE/PCA observation on 2011 March 28. The presence of newly detected 0.3084 Hz QPO is seen in the PDS. The pulsations are seen at higher frequencies. The solid line in the figure represents the fitted model comprising of a power-law continuum and a Gaussian function.

DISCUSSION

The frequency of the QPOs detected in accretion powered X-ray pulsars generally falls in the range of ~1 mHz to ~40 Hz (Psaltis 2006). Among these binary pulsars, the QPO features are detected more in transient sources compared to the persistent ones. In most of the transient Be/X-ray binary pulsars, the detected QPOs are found to be transient in nature. For example - in case of KS 1947+300, the QPO feature was not seen in the data during 2000 and 2002 outbursts whereas it appeared at the end of the 2001 outburst (James et al. 2010).

In 4U 1323-619, the QPO features were not detected in all of the RXTE observations during 2011 outburst (present work). Transient HMXB pulsars in which QPOs have been detected are EXO 2030+375 (Angelini et al. 1989), 4U 0115+63 (Soong & Swank 1989), V0332+53 (Takeshima et al. 1994), A0535+262 (Finger et al. 1996), SAX J2103.5+4545 (Inam et al. 2004), XTE J1858+034 (Mukherjee et al. 2006), XTE J0111.2-7317 (Kaur et al. 2007), MAXI J1409-619 (Kaur et al. 2010), KS 1947+300 (James et al. 2010), 4U 1901+03 (James et al. 2011), 1A 1118-61 (Devasia et al. 2011a), and GX 301-4 (Devasia et al. 2011b). However, there are only very few cases of accretion-powered X-ray pulsar such as SMC X-1 (Wojdowski et al. 1998), Her X-1, 4U 1626-67, LMC X-4 (see Table 1 of Shirakawa & Lai 2002) and 4U 0115+63 where multiple QPOs are seen. Another unique thing we detected in this work is the presence of multiple QPOs simultaneously in the same observation at three occasions. QPOs in accretion powered X-ray binary pulsars are thought to be due to the motion of the inhomogeneously distributed matter in the inner part of the accretion disk. The detection of QPOs, therefore, provides useful information on the radius of the inner accretion disk and the interaction between accretion disk and the neutron star.

Several models have been proposed to explain the QPO features in the PDS of accretion powered X-ray pulsars. According to the magnetospheric beat frequency model, the observed QPO frequency (ν_{QPO}) represents the beat between the coherent spin frequency of the pulsar (ν_s) and the Keplerian frequency (ν_K) at the inner disk radius i.e. $\nu_{QPO} = \nu_K(\text{rin}) - \nu_s$, at the magnetospheric boundary of the pulsar (Alpar & Shaham, 1985; Lamb et.al. 1985). According to this model, interactions between the neutron star magnetosphere and its accretion disk result in fluctuations in the plasma density at the inner edge of the disk which rotates with the local Keplerian frequency $\nu_K(\text{rin})$. As the magnetic field lines of the neutron star rotate with its spin frequency ν_s, the fluctuation in plasma reappears with a frequency that is the beat frequency as given above. In Keplerian-frequency model, on the other hand, the QPOs arise because of the modulation of the X-rays by inhomogeniously distributed matter in the inner accretion disk at the Keplerian frequency (van der Klis et al. 1987). According to this model, the observed QPO frequency is same as the frequency of the Keplerian motion at the inner accretion disk (i.e. $\nu_{QPO} = \nu_K(\text{rin})$). When the spin frequency of the pulsar is higher than the Keplerian frequency at the inner edge of the accretion disk, mass accretion on to the neutron star is stopped at the magnetospheric boundary by centrifugal inhibition of accretion (Stella, White & Rosner 1986) resulting in the onset of propeller effect. Keplerian-frequency model, therefore, can be applicable only when the QPO frequency is above the neutron star spin frequency, as seen in transient BeXB pulsars such as EXO 2030+375 (Angelini, Stella & Parmar 1989), A0535+262 (Finger et al. 1996), XTE J0111.27317 (Kaur et al. 2007) etc. However, in case of 4U 1323-619, frequency of QPO are found to be less than the spin frequency of the pulsar. Therefore, the Keplerian-frequency model is not suitable to explain the presence of QPO in the transient pulsar 4U 1323-619.

Third model proposed to explain the low-frequency QPO features in strongly magnetized (~10^{12} Gauss) accretion powered X-ray pulsars is the magnetic disk precession model (Shirakawa & Lai 2002). According to this model, the presence of QPOs in binary pulsars is due to the magnetically driven disk warping/precession near the inner edge of the disk at the magnetospheric boundary. The magnetic torque due to interaction of the stellar field and the induced electric current in the disk is responsible for warping and precession of the disk. This model was used to explain the mHz QPO detected in the accretion-powered pulsar 4U 1626-67 along with several others (Shirakawa & Lai 2002). This model was also attempted to explain the QPOs in the transient pulsar 4U 1323-619 in terms of the presence of magnetically driven disk warping/precession around the neutron star.

CONCLUSIONS

We reported the detection of a 0.3162 Hz QPO for the first time in the transient pulsar 4U 1323-619. These newly detected QPOs were present more frequently in decline phase of outbursts as compare to the rising phase (Figures 2, 3, 4).

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