Timing Studies and QPO Detection for Be/X-Ray Binary System V~0332+53

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Abstract— We report the discovery of a quasi-periodic oscillation (QPO) at ~0.45 Hz in the Be/X-ray binary pulsar V~0332+53 using data from the RXTE observatory. The observations used in the present work were carried out during the X-ray outbursts in 2010 January. The 0.45 Hz QPO in V~0332+53 was detected in two Rossi Explorer Timing Experiment (RXTE) Proportional Counter Array (PCA). However, this QPO was rarely detected during other one outburst during year 2005. Though QPOs at ~0.05 Hz and 0.22 Hz were reported earlier in the pulsar, the ~0.45 Hz QPO was detected for the first time in this pulsar. We discuss our results in the context of current QPO detected during outburst of year 2010 of the pulsar in this paper.

Index Terms— X-rays: stars - neutron, binary system, pulsars - stars: individual - V~0332+53.

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1 Introduction

X-ray binaries are calssified in to two types : (1) Low mass X-ray binary (LMXRB) and (2) High mass X-ray binary (HMXRB). This classification depends on the mass of the binary companion. The HMXRBs contain massive and early type (O or B type) companion star. These systems are further classified in to two types :(1) Be/X-ray binaries and (2) super-giant X-ray binaries on the basis of type of companion star. The Be/X-ray bi-naries represent the largest subclass of HMXRBs. Most of the HMXRBs are transient sources that are usually quiescent and occasionally become X-ray bright for few days to tens or hundreds of days. For a detailed description on HMXRBs, refer to Paul & Naik (2011).

HMXB transient source V0332+53 (X 0331+53) was discovered during a bright outburst in July 1973 with the Vela 5B observatory (Terrell & Priedhorsky 1984). The source V 0332+53 was extensively studied in three new outbursts: in 1983 by Tanaka et al. (1983) with EXOSAT, in 1989 by Makishima et al. (1990a) with Ginga and the last one in 2004/2005 by Zhang et al. (2005) and Kreykenbohm et al. (2005) with RXTE and INTEGRAL.

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The first measured pulse period is 4.375 sec with a 34 days orbital period (Stella et al. 1985). Takeshima (1994) studied the QPOs from V0332+53. For detailed description on variable QPOs, refer to Mukherjee et al. (2006). In this paper we report the discovery of a new QPO based on the RXTE observations of V0332+53 during the outburst of year 2010.

2 Observations and Data Reduction

RXTE was launched on 1995 December 31 with the main objective of timing studies of celestial X-ray sources. It made great contributions to our understanding of high energy astrophysics by means of its unrivaled timing resolution. We have used the RXTE observations of transient Be/X-ray binary pulsar V0332+53 during one of its both types of outbursts. RXTE, which is now decommissioned (2012 Januay 5), had three sets of major instruments. 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 s, respectively. A detailed description of the PCA instrument can be found in paper by Jahoda (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 V0332+53 from 1996 February to 2012 January is shown in figure 1. During above duration i.e. entire life time of the RXTE observatory, only one major outburst was detected in the pulsar. We used the data of 2010 outburst, was used in our present analysis.

For our timing analysis, we used data from all the PCA observations during the 2010 (as marked in figure 1). There were a total of 8 RXTE/PCA observations during outburst of year 2010. We used PCA data from above observations to study the

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evolution of QPO in this pulsar. Standard 1 mode data with a time resolution of 0.125 s were used in the present analysis. Data reduction was carried out by using the software package FTOOLS whereas data analysis was done by using the HEAsoft package (version 6.12).

Observation detail with date, Modified Julian Days (MJD), duration of observation, exposure of observation, the PCUs on during the observation and averaged light curve counts with error are shown in table 1. Using the standard 1 mode PCA data, we extracted light curves with a time resolution of 0.125 s from all the RXTE pointed observations during the 2010. We generated power-density spectrum (PDS) from each of the light curves by using the FTOOLs package. The resulting PDS were normalized such that their integral gives the squared rms fractional variability. All the PDS were then examined for the presence/absence of QPOs in a wide frequency range (8 mHz to 8 Hz). We found that the 4.37 s regular pulsations of the pulsar and its harmonics were present in the PDS obtained for all the PCA observations. Apart from these pulsations and corresponding harmonics, the PDS from some RXTE/PCA observations during the outburst of the pulsar were featureless. The 0.45 Hz QPO in the transient pulsar V0332+53 are detected for the first time here though the QPOs of 0.223 Hz and 0.049 Hz were reported earlier.

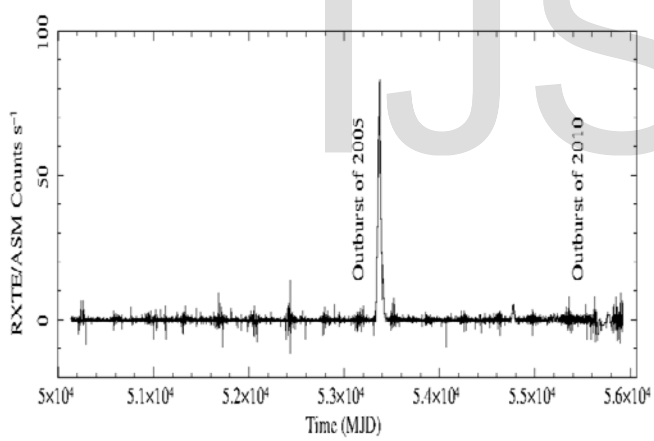

Figure 1 ASM one-day averaged light curve of the transient pulsar V0332+53 in 1.5-12 keV energy range from 1996 February 20 (MJD 50133) to 2012 January 1 (MJD 55927). During entire observing period of RXTE, only one major outburst was detected in the ASM light curve. RXTE/PCA observations during 2010 outburst were analyzed to investigate the QPO features in the pulsar.

One-day averaged 1.5-12.0 keV RXTE/ASM light curves of the pulsar during the 2010 outburst is shown in figure 2. In the figure 2, the day of RXTE observations are marked with vertical lines and the observation in which the QPO was detected is indicated with plus (+) mark. Out of a total of 8 RXTE observations, we found the presence of QPO in 1 observation. The log of observations is given in Table 1. Figure 3 and figure 4 (extended part of PDS) show QPO during 2010 outburst observation 95032-14-02-00.

Table 1 presents log of observations of V0332+53 during X-ray outburst of year 2010

S.No.	Observation Id	Observation Date	MJD	Duration	Exposure time	Average Count rate of light curve
1	95032-14-01-00	2010-01-06	55202	3959	1191	311.82±0.82
2	95032-14-01-01	2010-01-07	55203	11342	5867	291.18±0.38
3	95032-14-02-00	2010-01-08	55204	20691	11212	217.88±0.18
4	95032-14-02-02	2010-01-09	55205	17176	9441	199.27±0.27
5	95032-14-02-01	2010-01-11	55207	6433	3274	151.49±0.39
6	95032-14-02-03	2010-01-12	55208	9508	4467	54.56±0.18
7	95032-14-02-04	2010-01-13	55209	3697	1614	76.70±0.36
8	95032-14-03-00	2010-01-15	55211	4257	2118	25.62±0.18

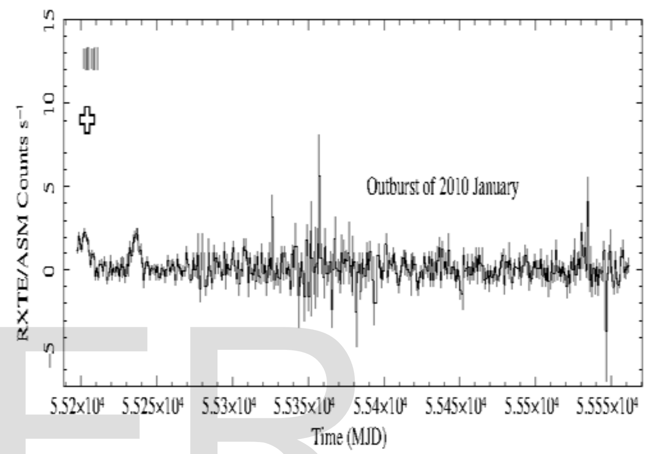

Figure 2 One-day averaged RXTE/ASM light curve of the transient Be/X-ray binary pulsar V0332+53 during 2010. The vertical lines at the top of the figure indicate the RXTE/PCA pointed observations of the pulsar whereas the positive sign indicate the observation when the QPO was detected in the PCA data.

3 Results and Discussion

Due to the motion of the inhomogeneously distributed matter in the inner part of the accretion disk, results to evolution of QPOs in accretion powered X-ray binary pulsars. Useful information on the radius of the inner accretion disk and the interaction between the neutron star accretion disk can be found from detection of QPOs. According to Psaltis [25] the QPO frequency detected in accretion powered X-ray pulsars falls in the range of 1 mHz to 40 Hz. QPO features are detected more in transient sources compared to the persistent ones In accretion powered X-ray binary pulsars. In most of the transient Be/X-ray 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 of 2000 and 2002 outbursts whereas it appeared at the end of the 2001 outburst [24].

In 1A~0535+262, the QPO features were not detected in all of the RXTE observations during 2010 and 2011 outbursts (present work). Transient HMXB pulsars from which QPOs have been detected are KS~1947+300 (James et al. 2010), SAX~J2103.5+4545 (Inam et al. 2004), A0535+262 (Finger et al. 1996), V0332+53 (Takeshima et al. 1994), and 4U 0115+63 (Soong et al. 1989), XTE~J1858+034 (Mukherjee et al. 2006), EXO~2030+375 (Angelini et al. 1989), XTE~J0111.2-7317 (Kaur et al. 2007), 4U~1901+03 (James et al. 2011), 1A~1118-61 (Devasia et al. 2011a) and GX~301-4 (Devasia et al. 2011b).

The pulse period of the transient pulsar was found to be 4.376 s. This indicates that neutron star experiences a torque due to the infalling matter under gravity with angular momentum of companion star while entering into circumstellar matter during passage close to periastron position in orbit of Be/ X-ray binary. A prominent QPO feature at 0.45 Hz, fitted with Lorentzian component as shown in figure 1, was detected in the RXTE/PCA observations on 8 January 2010. The pulse profile of the pulsar is found to be single peaked. This QPO frequency is close to the double spin frequency of Newtron Star V0332+53.

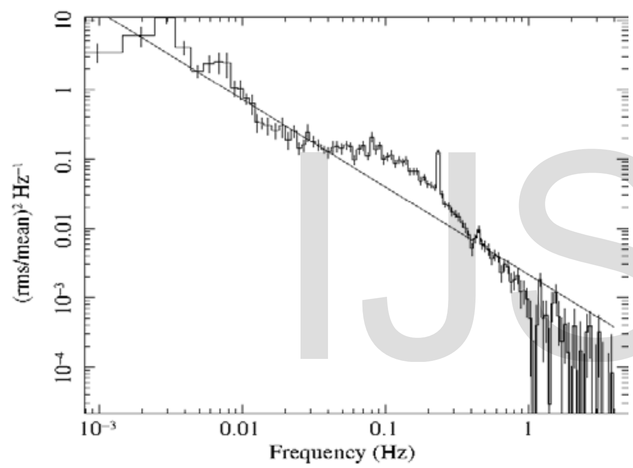

Figure 3 Representative PDS showing QPO for observation ID 95032-14-02-00 of 2010 outburst for V0332+53

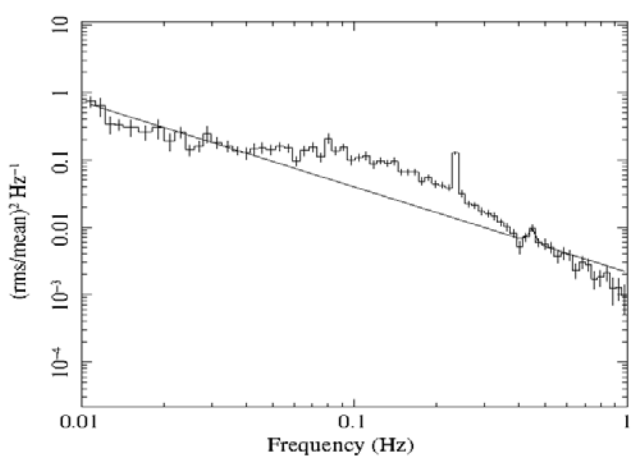

Figure 4 Representative extracted PDS showing QPO for observation ID 95032-14-02-00 of 2010 outburst for V0332+53

In earlier study Jin Lu Qu et al. (2005) have detected two QPOs at 0.223 Hz and 0.049 Hz in which 0.223 Hz match the spin frequency of the Neutron Star and pro-duced near the surface of Neutron Star. The broadening feature in the PDS of QPO justifies the presence of QPO at 0.45 Hz as shown in subset of figure 1. The estimated value of Q factor is 1.4 further confirms the presence of QPO in HMXRB pulsars. Beat frequency model (MBFM) and Keplerian fre- quency model (KFM) are used to explain the basic fea-tures of the QPOs. Both models predict a systematic change of QPO frequency with mass accretion rate or with the flux which are not observed in V0332+53 (Jin Lu Qu et al. 2005).

In our case QPO at 450 mHz does not support MBFM as well as KFM. The alternate model to explain the detected QPO would be the inhomogeneous accretion flow near the surface of the Neutron Star pro- ducing random shots by an arbitrary degree of modu- lation as given by Lazati & Stella (1997) and Burderi (1997). In suggested model the combination of rotation and radiative transfer effect likely to produce a periodic modulation of the shots similar to that of any continuum X-ray emission from the polar cap of the Neutron Star. The new QPO of 450 mHz frequency double of the spinning Neutron Star could be explained within the scenario of this model.

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