Do High Frequency QPOs Depend on Phase of Low Frequency QPOs in XTE J1550-564?

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Abstract. We have studied the dependence of the high frequency QPO (∼ 284 Hz) on the phase of the low frequency QPO (∼ 6 Hz) in the black hole X-ray binary XTE J1550-564 in the observations of the Rossi X-ray Timing Explorer (RXTE) performed on MJD 51241. By selecting the local maxima and the local minima in the light curve on the 6 Hz QPO time scale, we have found the corresponding high frequency QPO frequencies are consistent within 1.5 σ. However, the average central QPO frequency of the maxima and the minima is about 2.0 σ lower than the average high frequency QPO frequency obtained in the entire observation. This marginally suggests that the high frequency QPOs probably varies in frequency on short time scales. We briefly discuss these results and their consequences.

1. Introduction

XTE J1550-564 was identified as a Galactic “microquasar” from both X-ray and radio observations. It outbursts have been observed by the Rossi X-ray Timing Explorer (RXTE) for a few times. High frequency QPO with a frequency as high as 285 Hz was observed casually from this source in the outbursts in both 1998-1999 (Remillard et al. 1999; Homan et al. 2001) and 2001 (Miller et al. 2001). X-ray state transitions during the rise and the decay of its outbursts were also observed (see e.g. Homan et al. 2001). On the other hand, superluminal jet production has been observed in radio (Hannikainen et al. 2001).

The high frequency QPOs occur occasionally in the frequency range between 102 Hz and 285 Hz in the 1998-1999 outburst (Remillard et al. 2001; Homan et al. 2001) and the 2000 outburst (Miller et al. 2001). Miller et al. 2001 found that these high frequency QPOs are in fact two QPOs present simultaneously, and with a rough frequency ratio of 2:3. Possible evidence for the harmonic origin of the high frequency QPOs has been found also in other microquasars such as GRO J1566-40 (Remillard et al. 2002; see also papers in this proceedings). If these QPOs are indeed harmonic-related features, the QPO width in frequency can put strong constrains on the range that the high frequency QPO possibly moves. If the QPO frequency is related to the general relativistic frequencies at the inner accretion disk, then the range of the QPO frequency may put constrains on the movement of the inner disk radius.
2. Observations, Data Analysis and Results

RXTE observations of XTE J1550-564 on 4 March 1999 show a strong high frequency QPO (HFQPO) at 284 Hz and a strong low frequency QPO (LFQPO) at $\sim 6$ Hz with its harmonics at $\sim 12$ Hz (see Fig. 12 in Homan et al. 2001). The HFQPO is always stronger in the hard energy band above 6.5 keV (Homan et al. 2001). In the following analysis, we use the entire PCA energy band ($\sim 2$–60 keV) to study the LFQPO and the energy band above 6.5 keV ($6.5$–$60$ keV) to study the HFQPO.

We first select time intervals corresponding to the local maxima and the local minima in the 2–60 keV light curve with a window of 1.25 seconds and a time resolution of 0.03125 seconds. Then we require the local maxima and the local minima to be related to the variation of 2–12 Hz. A total of $\sim 2400$ pairs of local maxima and minima were obtained, corresponding to a coverage of 1/9 of the entire data set ($\sim 3600$ s).

We then calculate the Fourier power spectra corresponding to the local maximal and local minimal intervals and the overall observations in the 6.5–60 keV band. The HFQPOs were studied and compared. The average HFQPO frequency corresponding to the minima is 283.8$\pm$1.7 Hz, while the average HFQPO frequency corresponding to the maxima is 277.6$\pm$3.6 Hz. In the entire observations, the average HFQPO is at 284.9$\pm$0.9 Hz. The frequency difference between that in the maximal and that in the minima is about 1.5 $\sigma$, and the frequency difference between that in the extreme intervals (280.7$\pm$2.0 Hz) and that in the entire observation is about 2 $\sigma$. The average power spectrum corresponding to the maxima is shown in Fig. 1. The 278$\pm$4 Hz QPO, together with its 2:3 harmonic-related QPO at 184$\pm$4 Hz, and a feature which is not significant at 92$\pm$2 Hz are shown.

![Figure 1](image)

*Figure 1.* The average power spectrum corresponding to the maxima selected for the $\sim 6$ Hz QPO pulses.
3. Are High Frequency QPOs Constant?

From the above analysis, we show that within time scales as short as that corresponding to the LFQPOs (e.g. ~ 0.125s), the HFQPO frequency varies at a significance level of 2 $\sigma$. This suggests that the HFQPOs are probably not constant in frequency on short time scales. The QPO frequency movement on short time scales can contribute to part of the HFQPO width observed in each individual observations.

The movement of the HFQPO frequency in the microquasars is also suggested by the HFQPO frequency distribution in XTE J1550-564 and GRO J1655-40 (Remillard et al. 2002). In the histogram of HFQPO frequencies for XTE J1550-564 and GRO J1655-40, the entire width of the HFQPOs or their harmonics is about 50–80 Hz, much larger than the HFQPO width in individual RXTE observations. This suggests that the HFQPO frequency moves also on longer time scales.

4. Discussion

The frequencies of the HFQPO in black hole X-ray binaries are thought to be related to some fundamental frequencies at the innermost orbit around the black hole, e.g. combinations of the azimuthal and radial coordinate frequencies in general relativity (Strohmayer 2001), diskoseismic oscillation frequency (Wagoner 1999) or resonance frequency between the Keplerian and radial coordinate frequencies (Abramowicz & Kluzniak 2001). If this is true, then the movement of the HFQPO frequencies probably suggests that the radius of the innermost orbit vary. An important consequence is that the maximal fundamental HFQPO frequency is the central HFQPO frequency plus its half width, about 25–40 Hz higher than the HFQPO central frequency which was used in constraining the mass and the spin of the central black hole.

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