Low Frequency QPOs from the Black Hole Candidate XTE J1550-564 in the 2-120 keV Range

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1 Introduction

The Soft X-ray transient XTE J1550-564 shows rapid X-ray variability and a hard energy spectrum very similar to that of the known Galactic black hole candidates (Cui et al., 1999). The power density spectra show low (0.08 - 18 Hz) and high frequency (~ 200 Hz) quasi periodic oscillations (QPOs).

XTE J1550-564 has been studied extensively at lower energies (3-15 keV) with the PCA instrument on RXTE (Sobzcak et al., 2000b,a; Cui et al., 1999). We focus on the HEXTE instrument on RXTE which has a bandpass of 13-200 keV. We developed a technique to correct for the dead-time effects in HEXTE power spectrum. We have been able to detect or obtain useful upper limits for the amplitude of QPOs in the 60-120 keV range where PCA has negligible effective area. Also, having a real background measurement (as HEXTE gives by rocking) instead of estimating background from a model (as is used for PCA) is advantageous, since we are interested in the amplitudes of the PSD (power spectral density) features.

The goal of this study is to test the dead-time correction technique and to use the resulting power spectra to find correlations between energy, QPO strength and frequency for XTE J1550-564. These relations may have important implications for the accretion disk geometry and temperature profile of the corona.

2 Observations and Analysis

We have analyzed HEXTE data from the first 15 observations of the rise of the 1998 outburst (see Fig. 1) since this is where QPOs varied over a wide range of frequencies. For each observation, we extracted light curves in the 13-30 keV, 30-60 keV and 60-120 keV energy bands with 2 ms time resolution using Cluster A of HEXTE. We then FFTed 32 s time intervals and averaged resulting power spectra for each observation. The dead-time effects were corrected as explained in the next section. The PSDs were fitted with a broken power law and Lorentzians representing the continuum and the fundamental QPO and a harmonic. (see Fig. 3). We obtained upper limits for the rms amplitude of the fundamental QPO in 60-120 keV band for observations without a clear detection of the QPO. We have used values from Sobzcak et al. (2000b) for 2-13 keV range. For the first five observations, we also used Cluster B light curves to obtain longer time segments than the rocking period of 32 s. This provided more low frequency bins.

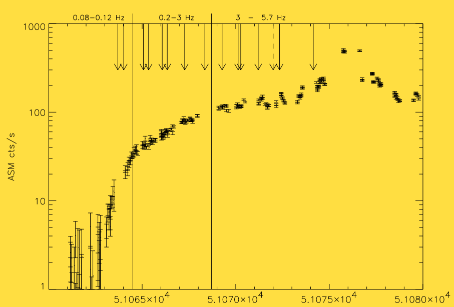
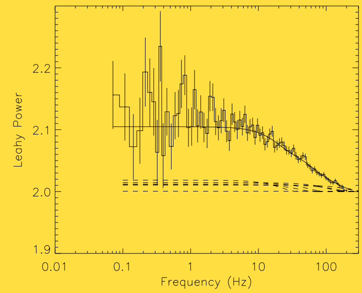


FIGURE 1: ASM light curve of XTE J1550-564 during its 1998 outburst. The arrows represent the times of observations. The solid vertical lines divide the outburst into three stages with different range of QPO frequencies indicated at the top of the figure. The observation shown with the dashed arrow has a QPO with 2.6 Hz central frequency.

3 Dead-time correction to HEXTE power spectra

High energy particles leaving more than 20 MeV in the HEXTE detectors cause them to be non-operational for at least 2.5 ms. The rate of these particles is ~ 100 cts/s, and, including the contribution from lower energy particles, the cumulative dead-time effect can be as high as 35%. This has a dramatic effect on the Fourier transform of the time series (see Fig. 2). The dead-time depends on the energy loss in the scintillation crystals. We devised a dead-time correction formula for the HEXTE and were able to fit the Leahy normalized background power spectrum. The formula is given below. $\mathrm{R_x}$ is the X-ray rate per detector and $\mathrm{R_p(i)}$ is the rate of particles which cause a dead-time of $\tau(\mathrm{i})$.

$$\mathrm{P(f)} = 2 + 2\,\mathrm{R_x} \sum_{\mathrm{i}} \mathrm{R_p(i)} \frac{\mathrm{Sin}^2(\pi\,\tau(\mathrm{i})\,\mathrm{f})}{\pi^2(\mathrm{i})\,\mathrm{f}^2}$$



Fit Parameters

R_p (cts/s)	55.	22.	19.	7.6	4.6	1.9	0.96	0.36
τ (ms)	2.5	4	5	7	10	14	25	35

FIGURE 2: Leahy normalized power spectrum of a blank sky observation by HEXTE Cluster A. The 0.1 Leahy power excess from the nominal level of 2 is due to dead-time effects. The solid line is the fit to data by the function given in the text and with the parameters seen above. The dashed lines correspond to contribution from each term from the fit parameters.

To test this correction, we analyzed power spectra from one observation in the 15-30 keV range using both HEXTE and PCA (Fig. 3). Without the correction, the PCA and HEXTE power spectra are significantly different. With the dead-time correction good agreement between PCA and HEXTE fit parameters is obtained.

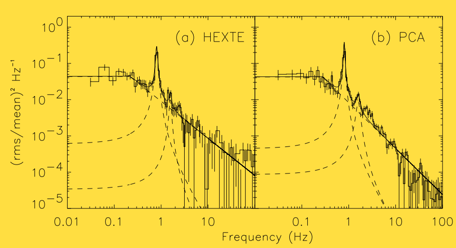


FIGURE 3: XTE J1550-564 power spectrum in the 15-30 keV range. Both HEXTE (Cluster A) and PCA show the fundamental QPO (0.8 Hz) and its harmonic (1.6 Hz). The RMS values of the fundamental are $18.1\% \pm 1.1\%$ and $18.1\% \pm 1.4\%$ respectively.

4 Results

We divided the data into three stages depending on the slope of the ASM light curve. The frequency of QPOs increases with flux, as reported before by Cui et al. (1999). Therefore, these stages also correspond to different QPO frequency bands shown in Fig. 1. The only exception is the observation at MJD 51072, which is shown with a dashed arrow. The QPO for this observation has a central frequency of 2.6 Hz and it is grouped with the 0.2 - 3 Hz QPOs. For each stage, we averaged the amplitudes of the fundamental QPOs for each energy band. The results are plotted in Fig. 4. The amplitudes of the 0.08-0.12 Hz QPOs, occurring at the initial steep rise of the outburst, stay constant with energy. There is an increase of amplitude with energy for 0.2 - 3.0 Hz QPOs. Between 3.0 and 5.7 Hz, the amplitude increases with energy first and then turns over.

5 Discussion

Previous work by Cui et al. (1999) showed that the amplitude increases with increasing energy in the PCA band, for observations after the initial steep rise of the outburst. Adding the HEXTE data from the 60-120 keV range shows that this relation has a turnover (similar to that of GRS 1915+105 reported by Tomsick & Kaaret (2000)) for some stages of the outburst.

The origin of low frequency QPOs in BHCs are not very well understood. There are reports linking the QPO properties to spectral parameters both from the disk and the corona (Sobzcak et al., 2000a; Markwardt, Swank & Taam, 1999). One possibility is that the QPOs are created in the disk and then modified by the corona. In this case, the amplitude versus energy relation might be used to determine temperature profile and the geometry of the corona as suggested by Lehr, Wagoner & Wilms (1999).

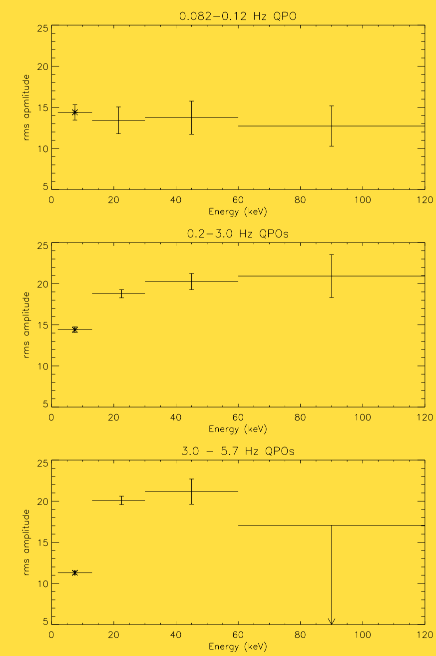


FIGURE 4: Amplitude vs. energy relations of QPOs in different frequency bands shown in Fig. 1. The data points indicated by asterisks ("$*$") are PCA data points obtained from Sobzcak et al. (2000b). The data points with arrows are 95% upper limits. The errors correspond to 95% confidence.

Their simulations assume a plane parallel corona enshrouding the disk with a temperature profile that decreases with radius. They predict a turnover in amplitude vs. energy relation as the QPO frequency decreases. Our results indicate the opposite. If their explanation is correct, then the temperature profile of the corona must evolve rapidly during the rise of the outburst. Another possibility is that the QPO is not created in the disk but in the corona in terms of small oscillations of the electron density as described in Lee & Miller (1998).

Additional temporal studies by HEXTE, by analyzing the QPO profiles (Tomsick & Kaaret, 2000) and/or the power spectra described in this poster along with spectral information at high energies may be very important for testing different models for the origin of QPOs and their interactions with the hot corona.

We are planning to use a Monte Carlo code similar to the one described in Lehr, Wagoner & Wilms (1999). By using the results from these simulations, we expect to obtain more information about what physical processes and what disk-corona orientations and sizes can cause the evolution of the amplitude vs. energy relation observed in this study.

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