State transition of the new black hole transient XTE J1650−500

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Abstract

We present results on the temporal properties of the state transition from the soft to hard state in the new black hole transient XTE J1650−500. After MJD 52232, the power law index hardened, rms amplitude of the power spectrum increased significantly, and QPOs were observed. We also found enhanced lags during the transition as observed in Cyg X-1. The enhanced lags may be due to the presence of a larger Comptonizing area of the base of a jet, but another possibility is also discussed. We also show the correlation between the peak frequencies of the fit components, which is consistent with previous reports of such correlations for various kinds of X-ray binaries.

1 Introduction

The Soft X-ray Transient XTE J1650−500 was first detected by the All-Sky Monitor on board the *Rossi X-ray Timing Explorer (RXTE)* in 2001 September (Remillard, 2001). The optical and radio counterparts were identified (Castro-Tirado et al., 2001; Groot et al., 2001). Pointed X-ray observations by *RXTE* show strong low frequency QPOs and band limited timing noise while *Chandra* revealed ionized iron absorption lines (Miller et al., 2002). The source flux started to decay 45 days after the beginning of the outburst, and a state transition to the hard state occurred. During the hard state, additional radio measurements were made and an inverted spectrum indicative of a compact jet was observed. Both the X-ray spectra, and the temporal properties are similar to the known Galactic black hole candidates (BHC), but the mass function has yet to be measured.

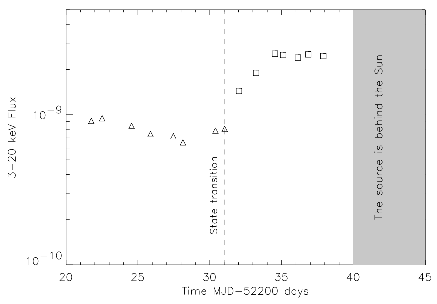

FIGURE 1: A portion of the X-ray (PCA) light curve for the 2001 outburst decay from XTE J1650−500. Observations represented with empty boxes are the ones discussed in this poster, and they are numerated from the first one after the dashed line.

Until MJD 52230 the X-ray energy spectrum was typical of a soft state black hole spectrum. On MJD 52232, both the energy spectrum and the power spectrum showed significant changes indicating that a transition to the hard state had begun. The power law index hardened to 2.5, the RMS amplitude jumped to 17% (Obs 1), and a weak QPO appeared at 8.71 Hz in Obs 2. Between Obs 3 and 7 the energy spectrum and the power spectrum showed characteristics of a typical hard state with the energy spectrum having a hard power law with index of ∼1.9, and the power spectrum showing strong band limited noise with QPOs (see Figs. 2 and 3).

2 Analysis

For each observation, we computed the power spectra and cross spectra using IDL programs developed at the University of Tübingen for three energy bands, 2 – 6 keV, 6 – 15 keV, and 15 – 30 keV and for the combined 2 – 30 keV band. We fit our power spectra with Lorentzians L_i where subscript i denotes each Lorentzian component in the fit, and smaller i correspond to smaller frequencies. We used the peak frequencies to characterize the Lorentzians:

$$\nu_i \;=\; f_i\,\left(\frac{\Delta_i^2}{4\,f_i^2}+1\right)^{1/2} \qquad (1)$$

where Δ_i is the full-width-half-maximum and f_i is the resonance frequency. In Fig. 2, we plot the power spectra in the form of PSD × frequency and overplot the Lorentzians fits. In this figure, the Lorentzians peak at ν_i.

We also used the cross-spectral elements of the Fourier transform to obtain information about the system. We obtained the average time lags (Fourier-frequency-dependent measure of the time delay between two concurrent time series (Miyamoto & Kitamoto, 1989; Nowak et al., 1999)) and the coherence function (Fourier-frequency-dependent measure of the degree of linear correlation between two concurrent time series, in this case light curves measured simultaneously in two energy bands (Nowak et al., 1999)) and plot them in Fig. 4.

3 Results

Except for Obs 1, each observation requires at least two broad Lorentzians to fit the continuum, and a narrow QPO. Obs 4 is an exception where the second peaked component is less narrow, but still quoted as a QPO to be consistent. The peak frequencies of all the components shift to lower values (Fig. 2a) and the overall rms amplitude increases (Fig. 2b) as the transition occurs. This shift in the frequency could be due to the inner disk radius retreating as discussed in Kalemci et al. (2001).

The temporal properties of XTE J1650−500 during the transition to the hard state are very similar to what has been observed for other BHCs, but especially to the failed state transitions of Cyg X-1 (Pottschmidt et al., 2002). The X-ray time lags in 1 – 10 Hz frequency range are enhanced and mean coherence is low during the state transition compared to the following observations, just as in Cyg X-1. The peak frequencies of L_1 and L_2 are significantly enhanced and L_3 is absent during the state transition, again very similar to what has been observed in Cyg X-1.

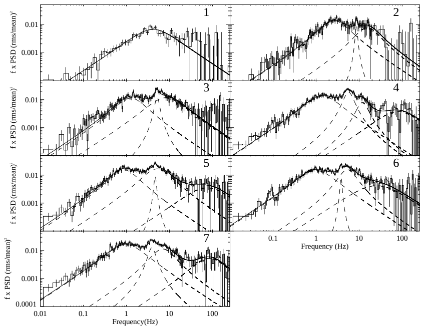

FIGURE 2: Lorentzian fits to all observations. The solid line is the overall fit and the dashed lines are individual components.

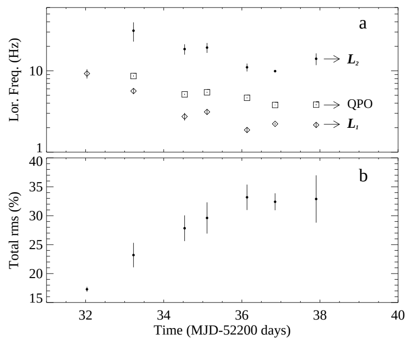

FIGURE 3: Lorentzian fit parameters: (a) Peak frequencies of the Lorentzians and the resonance frequencies of the QPOs, (b) total rms amplitude.

4 Discussion

During the transition, the average time lags are enhanced compared to the following observations as shown in Fig. 4. For Cyg X-1, the mean time lags have similar values during the hard state and the soft state, but they are enhanced only during the failed state transitions. This suggests that the time lags are not related to the size of the corona, since it is believed that the state transitions are related to the geometrical change of the corona and inner disk radius. Pottschmidt et al. (2000) suggested that the appearance of an outflow during the state transition, which creates additional Comptonizing area at its base, increases the time lags. For XTE J1650−500, an optically thick outflow is present after the state transition is complete (Corbel, private communication), however there is no radio observation during the time we observed the enhanced lags which would strengthen the jet base argument.

The lack of enhanced lags after Obs 2 could also be due to different components acting over the same frequency range. Nowak (2000) discussed the case that the overall measured time lag may be a composite of time lags inherent to each individual PSD component. Although the individual time lags can be fairly large, the composite lag might be small. Over 1 – 10 Hz range, as seen in Fig. 2, Obs 1 has only L_1, and Obs 2 is dominated by L_1, and L_2 contributes little. Moreover the QPO, which is also within the frequency range is weak. For the remaining observations, significant part of L_2 moves in this frequency range and the QPOs are strong. Similar behavior is also observed in Cyg X-1 (Pottschmidt et al., 2002).

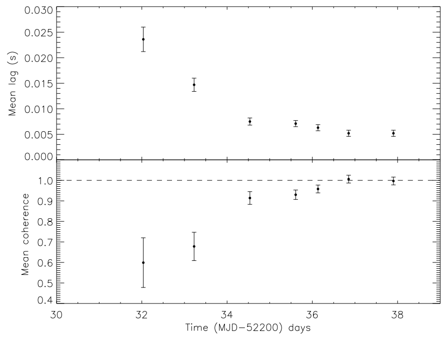

FIGURE 4: Mean lags and coherence. Mean is taken in the frequency band of 1–10 Hz where the measurements are well above the noise level. The energy bands are 2–6 keV and 6–15 keV. The lags are enhanced for Obs 1 and 2. The dashed line is the unity coherence.

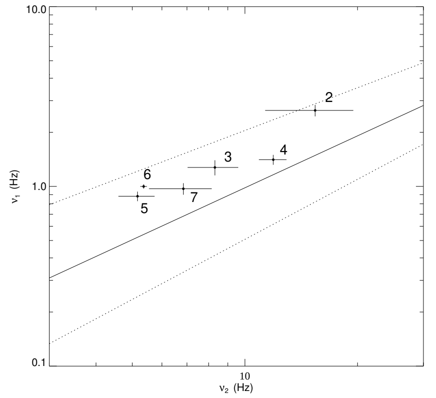

FIGURE 5: The correlation between the peak frequencies of L_1 and L_2. The solid lines box the area where this correlation is valid for other sources, taken from Psaltis, Belloni & van der Klis (1999).

Various papers address the correlations between certain fit parameters of the power spectrum for X-ray binaries and show that these correlations exist for decades of frequency range (Wijnands & van der Klis, 1999; Psaltis, Belloni & van der Klis, 1999). One of them is the correlation between the narrow QPO frequency and the frequency of a peaked Lorentzian component that occurs at frequencies higher than the QPOs (Psaltis, Belloni & van der Klis, 1999). In our case, the correlation between L_1 and L_2 is consistent with the correlation reported in Psaltis, Belloni & van der Klis (1999) as shown in Fig. 5. These correlations imply that same kind of variability occurs in both neutron star and black hole systems which constrains strongly the theoretical models of formation of variability. The same correlation between L_1 and L_2 is also seen for Cyg X-1, adding one more to the similarities list.

References

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