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Is the 'disappearance' of low-frequency QPOs in the power spectra a general phenomenon for Disk-Jet symbiosis?

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Abstract. One of the best possible ways to look for disk-Jet symbiosis in galactic Black Holes is to study the correlation between X-ray and radio emissions. Beyond this study, is there any alternative way to trace the symbiosis? To answer, we investigated the X-ray features of few black hole candidates based on the archival data of PCA/RXTE. We found evidences of 'disappearance' of QPOs in the power density spectra and subsequent spectral softening of the energy spectra during the radio flares (i.e., 'transient' jets). We delve deep into the nature of the accretion dynamics to understand the disk-jet symbiosis.

Keywords : X-rays: binaries – methods: data analysis – black hole physics – radiation mechanisms: general

1. Introduction

Most of the Galactic Black Hole (GBH) sources are observed to be outbursting in nature and these sources also have Jet emissions, which are observed as Radio flares. It is inferred that during Jet ejections, there is an absence of QPO which implies that the inner part of the disk (i.e., 'hot' corona) gets disrupted and evacuated, and subsequently the source spectra softens implying the X-ray emission to be mostly from the disk (Feroci et al. 2001; Vadawale et al. 2001; Nandi et al. 2001; Fender et al. 2009; Miller-Jones et al. 2012).

2. Observation and analysis

We analysed the public archival data obtained from HEASARC database of the RXTE Satellite to study the temporal and spectral evolution of the BH sources during the

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radio flares. The standard procedure for PCA and HEXTE data reduction was employed using the FTOOLS package HEASOFT v 6.11. For timing analysis, we used PCA science data of Binned mode and Event mode. Energy dependent study of the power density spectra (PDS) as well as the phase lags were performed using GHATS v 1.0.1[1]. Spectral data were extracted using Standard2 data product in the energy range of 3 - 20 keV (using PCU2 only). High energy spectral data of 20 - 150 keV were also extracted using the HEXTE data for whichever cluster (A/B) carried out the observations. Broadband spectral modelling was done in the energy range of 3 - 150 keV using a thermal *diskbb* component, a non-thermal component *powerlaw/highecut* modified by the interstellar absorption *phabs*.

3. Results

3.1 XTE J1859+226

During the 1999 outburst of XTE J1859+226 (top panel of Fig. 1), multiple Radio flares (see Brocksopp et al. 2002; Fender et al. 2009) have been detected (middle panel of Fig. 1). From the spectral and temporal properties of the source during these flares, we observed that during the first flare (F1), there is a partial 'disappearance' of QPO in 2 - 5 keV and 13 - 25 keV energy bands. During the flares F2, F3, F4 and F5, we observed a complete absence of QPO in power spectra over 2 - 25 keV energy band (see Radhika & Nandi 2013 for details). We also observed that during all these flares when the QPO is absent, the thermal flux increases compared to the hard X-ray flux and the spectra gets soften. It was observed that during the flare the total rms of the PDS reduces and phase lag studies showed that there was no lag observed between the soft (2 - 6 keV) and hard (6 - 25 keV) energy bands. 'Spectro-temporal' signatures suggest the possible presence of another flare F6, which was probably not reported due to lack of continuous radio observations. We observed that during F1, F2, F3, when the QPO was observed before the flares, it was of type C/C* (see Wijinads et al. 1999; Casella et al. 2004 for details on types of QPOs) and when it 're-appeared' after the flare it was of type B. We observed a type B/C* QPO before the flare and a type C* QPOs after the flare, respectively for the flares F4/F5 (Radhika & Nandi 2013).

3.2 XTE J1748−288

For the 1998 outburst of XTE J1748−288, we observed complete absence of QPO around 24 hrs before the peak flare (marked as F) of 600 mJy at 1.4 GHz (see left side of Fig. 2). We also observed decrease in total rms of the PDS, absence of phase lag and subsequent increase in soft flux which was also implied by the steepening of the spectral index (see right side of Fig. 2), during the flare. The QPOs observed before

[1]http://www.brera.inaf.it/utenti/belloni/GHATS_Package/Home.html

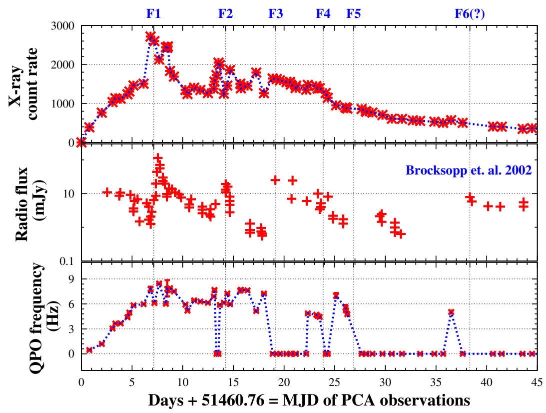

Figure 1. Variation of X-ray flux, Radio flux and QPO frequency for the BH source XTE J1859+226 (1999 outburst).

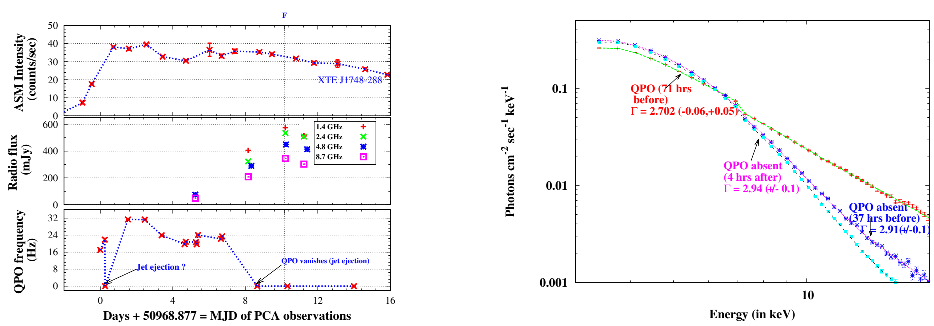

Figure 2. Left side plot shows variation of X-ray intensity, Radio flux and QPO frequency observed for the BH source XTE J1748−288 (1998 outburst). Right side plot shows spectral softening during the radio flare.

the ejection event was found to be of type C. Absence of QPO and spectral softening (early phase of the outburst, when source transit from hard to soft-intermediate state), suggests presence of another possible ejection, although there was no radio observation (see Radhika et al. 2013a).

3.3 H 1743−322

During the 2009 outburst of H 1743−322, we observed that the QPO frequency increases from 0.91 Hz (MJD 54980.39) to 3.58 Hz (MJD 54984.37). The next observation (on MJD 54987.26) showed absence of QPOs (see right side of Fig. 3) and spectral softening was observed around 46 hrs before the peak Radio flare (primary ejection) of 12.8 mJy bm^{-1} at 8.4 GHz (see also Miller-Jones et al. 2012). We also

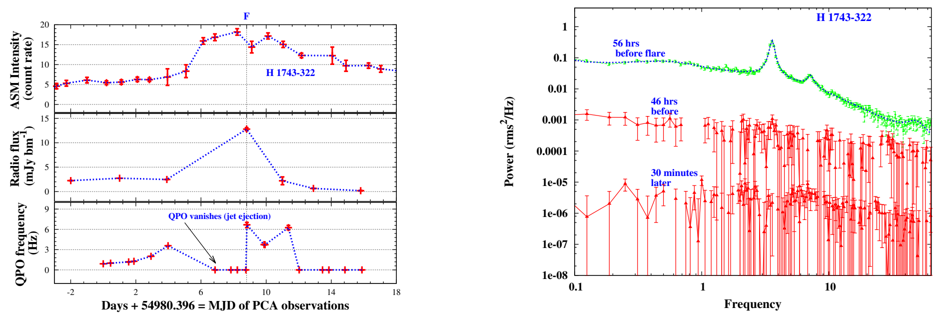

Figure 3. On the left side, we show variation of X-ray intensity, Radio flux and evolution of QPO frequencies, observed for the BH source H 1743−322 (2009 outburst). The evolution of the PDS (right side of the figure) showing the absence of QPOs during the flare.

noted that before the flare, the QPO observed was of type C, whereas after the flare QPO was of type B. Complete absence of QPO and spectral softening was noted after 3 days of QPO re-appearance. Spectral analysis also suggest that the primary ejection could have triggered during the transition from hard to soft-intermediate state of 2009 outburst (Radhika et al. 2013b).

3.4 GRO J1655−40

During the 2005 outburst of GRO J1655−40, we observed an evolution of QPO frequency from 1 to 6 Hz (see bottom panel on left side of Fig. 4), followed by an absence of QPOs for almost 6 days. During the observation where the QPO was not present in the PDS, the ratio of soft to hard flux increased and the outburst evolved from hard to soft-intermediate state. But since there is no Radio observation available, the time of possible ejection (as a radio flare) is not known. Around 6 days later (after the 1st X-ray peak of the 2005 outburst), we observed QPOs of 14 Hz in the power spectra around 48 hrs before a peak flare of 6 mJy (see middle panel of left side figure). The observation 29 hrs before the flare showed absence of QPO. QPO re-appeared around 10 hrs after the flare (power spectral evolution is shown in right side of the figure). During this phase, we observed a decrease in total rms of PDS, absence of phase lag and increase in soft flux (3 - 20 keV) over hard X-ray flux (20 - 150 keV). The QPO observed before and after the ejection was possibly of type C*/C (high Q-factor with less rms).

3.5 Other BH sources

Absence of QPOs during a flare event (i.e., transient Jets) has been already observed for the BH source GRS 1915+105 (Vadawale et al. 2001; Feroci et al. 2001). We have extended our study to few more BH sources (eg. XTE J1752−223, XTE J1550−564, GX 339−4, MAXI J1836−194). Temporal analysis of these sources showed that

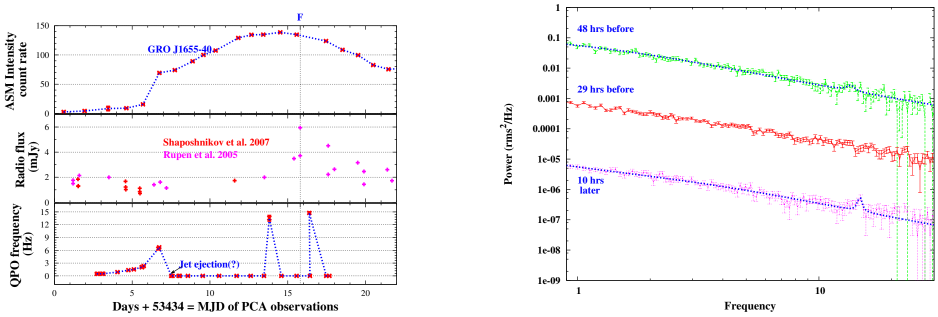

Figure 4. The variation of X-ray intensity, Radio flux and QPO frequencies observed for the BH source GRO J1655−40 (2005 outburst) is shown on the left side, while the evolution of power spectra during the peak flare is shown on the right side.

whenever a Radio flare occurs, QPOs 'disappear' along with reduction of total rms (see also Fender et al. 2009) of the power spectra. Absence of phase lag for soft to hard photons was also observed during the flares. Spectral analysis showed that there was an increase in thermal flux whenever a QPO was absent during the radio flare. Detailed spectro-temporal analysis (during radio flares) of all the sources will be presented elsewhere (Radhika et al. 2013b).

4. Possible physical scenario

Several attempts have been made until now to understand the phenomenon of outflows (Kumar & Chattopadhyay 2013) and disk-jet coupling in BH binaries (Meier & Nakamura 2004; Fender et al. 2009). But none of these studies have discussed the disk-jet coupling in the context of QPO 'disappearance' and subsequent spectral softening. We attempted to understand the disk-jet connection (Vadawale et al. 2001; Nandi et al. 2001) in the outbursting sources based on the Two Component Advective Flow (TCAF) in the presence of magnetic field. According to TCAF (Chakrabarti & Titarchuk 1995), there are two types of flow viz, Keplerian and sub-Keplerian. The sub-Keplerian halo matter forms the Compton cloud (i.e., CENtrifugal pressure supported BOundary Layer (CENBOL)) during the shocked-accretion phase. Due to oscillation of the shock, the CENBOL (i.e., also the store house of 'hot' electron source) surface may oscillate resulting in QPOs.

A sudden occurrence of a radio flare can occur in the presence of magnetic field in the disk. According to the magnetised-TCAF (Nandi et al. 2001), matter can anchor large stochastic magnetic fields during the phase of accretion of matter from the companion. When the flux tube enters into the 'hot' Compton cloud of temperature $\sim 10^9 K$, it collapses catastrophically due to magnetic tension (i.e., the strongest force in the 'hot' plasma within the CENBOL) and evacuates the inner part of the disk producing Jets. As a result, CENBOL gets disrupted and hence its oscillation ceases,

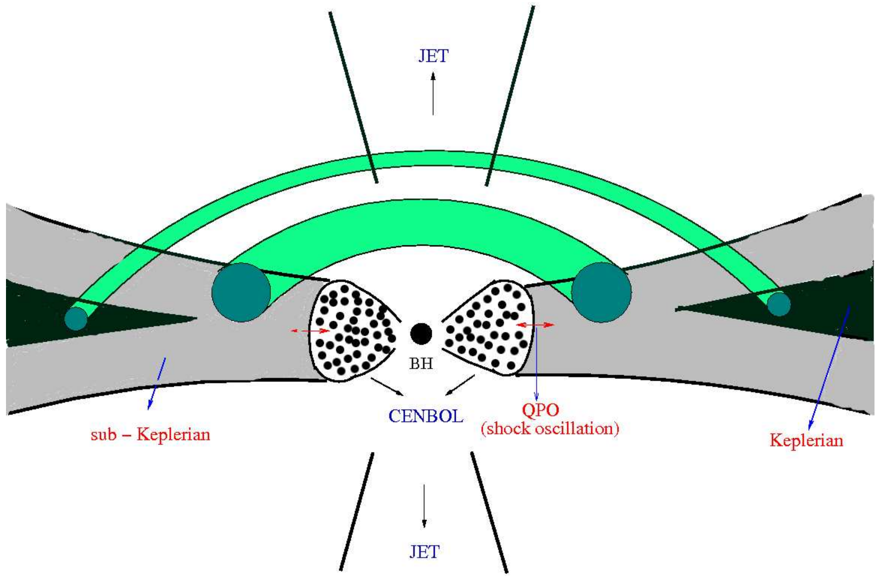

Figure 5. Magnetised-TCAF model, showing Keplerian and sub-Keplerian components of flow along with magnetic flux tubes, which are responsible for disrupting the inner-part of the disk (i.e., CENBOL (Chakrabarti & Titarchuk 1995)). Adopted from Radhika & Nandi 2013.

resulting in absence of QPO. As matter gets evacuated from the CENBOL in the form of Jets, the energy spectra will be dominated by thermal emission.

5. Conclusion and discussion

In order to verify the conjecture of ‘disappearance’ of QPO during the Jet ejections (i.e., radio flares), we investigated the X-ray properties of several BH sources. Our analysis seems to suggest that there is an absence of QPO, absence of soft/hard lags, decrease in total rms of the power spectra, when an ejection occurs. The spectral evolution also implies the softening of the spectra during the ejections. Based on the magnetized-TCAF model, we can understand that the absence of QPO and spectral softening implies the disruption of inner-part of the disk in the presence of magnetic field. The re-appearance time scale of QPOs (~ hour to day) implies the time taken by the sub-Keplerian matter to form inner-part of the disk (i.e., the CENBOL).

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