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'Q' factors in Galactic Black Hole Sources – A case study of 1999 outburst of XTE J1859+226

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Abstract. The outburst profile of Galactic Black Hole (GBH) sources follow a typical Q-diagram in the hardness-intensity (HI) plane. The evolution of Quasi-Periodic Oscillation (QPO) frequencies, QPO-rms and ejection of transient-jets are associated with different and distinct branches of HI diagram. The *Q-diagram*, *QPO evolution*, *transient-jet* etc. are termed as *'Q' factors* of GBH sources. In this work, we outline the framework to understand these observational features from a single paradigm of accretion disk model and attempt to model the outburst properties of XTE J1859+226 BH source for its 1999 outburst as a representative case.

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

1. Introduction

Most of the GBH sources undergo outburst phases that are of typically Fast Rise Slow Decay (FRSD) and Slow Rise Slow Decay (SRSD) in nature. The outburst profiles follow a symbolic pattern of Q-shape in the HI plane displayed as log-log plot (Homan and Belloni 2005; Nandi et al., 2012). It has been observed that the evolution of low frequency QPOs (i.e, in general C-type QPOs) is associated with hard and hard-intermediate states of Q-diagram. In general, transient-jets (i.e, transient radio flare) are observed while the source transits from hard-intermediate state to soft-intermediate state (Fender et al. 2009) with 'signature' of absence of QPO (Feroci et al. 1999; Vadawale et al. 2001; Nandi et al., 2013; Radhika and Nandi 2014), or, with

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the presence of A/B-type QPOs. The transient jets and QPOs are suppressed in soft state (Fender et al. 2009), while the source spectra are dominated by thermal emission. In the subsequent sections, we present the observation and modelling schemes in order to understand the observed ‘Q’ factors of outbursting BH sources considering a test case scenario for the 1999 outburst of XTE J1859+226.

2. Observation, analysis and model

2.1 The 1999 outburst of XTE J1859+226

The BH source XTE J1859+226 went into outburst phase during 1999 and it was first discovered with All Sky Monitor (ASM) on-board Rossi X-ray Timing Explorer (RXTE). The source was continuously monitored with RXTE for several months following a typical FRED like outburst profile. At the same time, multiple radio flares (i.e, transient jets) were detected (Brocksopp et al. 2002) that makes the source more complex to understand its observed properties (Casella et al. 2004; Radhika and Nandi 2014). We re- analysed the temporal and spectral data (energy band of 3 - 150 keV) from the entire outburst period (observations span over of around 166 days) using PCA and HEXTE instruments on-board RXTE. Details of the data reduction, analysis and phenomenological modeling are given in Radhika and Nandi 2014.

2.2 Model: A Hybrid Disk-Jet Model

We invoke a Hybrid Disk-Jet Model (HDJM) to understand the observed properties (i.e, ‘Q’ factors) in GBH sources. The model is based on Two Component Advective Flow (Chakrabarti and Titarchuk 1995) where a Keplerian disk in the equatorial plane sandwiched by the sub-Keplerian flows. The shocked and compressed sub-Keplerian flow forms a ‘hot’ Compton cloud around the vicinity of the black hole which is responsible for the generation of QPOs, as well as, the outflows from the disk (Das et al. 2014). In the context of HDJM, we attempt to understand the dynamical properties associated with the various branches of Q-diagram of XTE J1859+226 considering variable outflow, transient ejection, QPO evolution, broadband energy spectrum etc. (Nandi et al. 2001; Chattopadhyay and Das 2004; Mandal and Chakrabarti 2010; Kumar et. al. 2014; Das et al. 2014; Iyer et al., 2015; Vyas et al. 2015).

3. ‘Q’ factors: Q-diagram, QPO evolution, Transient-Jet

3.1 Q-diagram of XTE J1859+226

The Q-diagram is generated using flux estimated in the energy band of 3-20 keV, 3-6 keV and 6-20 keV. This is done by modelling the spectra with a phenomenological model (*diskbb* + *po*) using spectral data from the entire outburst. In Fig. 1 (left panel), we present the Q-diagrams where red color indicates the result estimated using spectral modelling and blue color represent the result obtained based on photon counts. Note that there is a difference in hardness variation (in X-axis), whereas flux is multiplied by 100 time just for the comparison purpose (in Y-axis). We model the energy

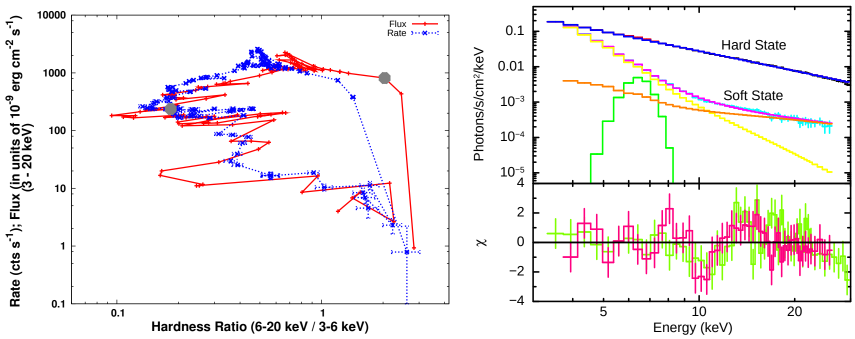

Figure 1. Left Panel: Q-diagram of 1999 outburst of XTE J1859+226 over-plotted using flux (modelling the energy spectra–red) and photon counts (total counts using temporal data–blue). Flux and photon counts are calculated in the energy band of 3-20 keV, whereas HR is the ratio of 6-20 keV and 3-6 keV flux and photon counts respectively. Flux based Q-diagram is multiplied by 100 along the Y-axis just for the purpose of comparison. Right Panel: TCAF based spectral modeling of Hard and Soft states (corresponding spectral data points are marked in HI plane–grey).

spectra following the two component advective flow (TCAF) model, recently incorporated in *XSPEC* (see Iyer et al., 2015) to estimate the fluxes in order to reproduce the Q-diagram as well as spectral modelling. Two such modelled spectra are shown in Fig. 1 (right panel) for hard and soft states. The corresponding representation of both cases in Q-diagram are marked in grey (left panel of Fig. 1). Details of this modelling will be presented elsewhere (Nandi et al. 2015 in preparation).

3.2 QPO Evolution

In general, QPO frequency increases in rising phase and decrease in declining phase of the outbursting BH sources. The evolution of QPO frequencies is modelled with the propagating oscillatory shock (POS) embedded in TCAF (Chakrabarti and Titarchuk 1995; Nandi et al., 2012; Iyer et al., 2015). In XTE J1859+226, the QPO frequencies are observed to evolve from 0.46 Hz to 5.97 Hz (C-type QPOs during hard and hard-intermediate states) that we model with POS in order to calculate the variation of shock location and compression ratio and finally estimate the mass of the source (Nandi et al. 2015 in preparation). It has also been observed that QPO rms decreases as the QPO frequency increases during the rising phase of the outburst. Preliminary results are already presented in Radhika and Nandi 2014.

3.3 Transient-Jet

The relativistic 'transient' jets are observed as a radio flare, while the source transits from the hard-intermediate state to soft-intermediate state (Brocksopp et al. 2002; Radhika and Nandi 2014). During ejection, we observe the 'signature' of absence of QPO, drop in QPO rms along with the softening of the X-ray energy spectra (Radhika and Nandi 2014). We attempt to model the jet ejection mechanism by incorporating the stochastic magnetic fields in the disk (Nandi et al. 2001) in addition to the modelling of the broadband energy spectrum (Nandi et al. 2015 in preparation).

4. Conclusion and discussion

In this work, we define the 'Q' factors in GBH sources. Towards this, an effort is given to model the observed properties in BH sources, especially in the context of the 1999 outburst of XTE J1859+226. The energy spectra could be well explained with the TCAF model. It has been noted that the toroidal magnetic field strength increases as the source transits from hard to intermediate states and possibly triggers the jet ejection. This endeavor helps us in understanding and diagnosing the disk-jet symbiosis in other BH sources too.

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