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# ‘Spectro-temporal’ characteristics and disk-jet connection of the outbursting black hole source XTE J1859+226

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**Abstract**

We re-investigated the ‘spectro-temporal’ behavior of the source XTE J1859+226 in X-rays during its outburst phase in 1999, by analysing the RXTE PCA/HEXTE data in 2–150 keV spectral band. Detailed analysis shows that the source evolves through different spectral states during its entire outburst as indicated by the variation in the spectral and temporal characteristics. Although the evolution pattern of the outburst followed the typical q-shaped profile, we observed an absence of ‘canonical’ soft state and a weak presence of ‘secondary’ emission during the decay phase of the outburst. The broad-band spectra, modeled with high energy cutoff, shows that the fold-energy increases monotonically in the hard and hard-intermediate states followed by a random variation in the soft-intermediate state. We attempted to estimate the mass of the source based on the evolution of Quasi-Periodic Oscillation (QPO) frequencies during rising phase modeled with the propagating oscillatory shock solution, and from the correlation of photon index and QPO frequency. It is also observed that during multiple ejections (observed as radio flares) the QPO frequencies are not present in the power spectra and there is an absence of lag in the soft to hard photons. The disk flux increases along with a decrease in the high energy flux, implying the soft nature of the spectrum. These results are the ‘possible’ indication that the inner part of the disk (*i.e., Comptonized corona*), which could be responsible for the generation of QPO and for the non-thermal Comptonized component of the spectrum, is disrupted and the matter gets evacuated in the form of jet. We attempted to explain the complex behavior of ‘spectro-temporal’ properties of the source during the entire outburst and the nature of the disk-jet connection before, during and after the ejection events in the context of two different types of accreting flow material, in presence of magnetic field.


*Keywords:* Black holes; Accretion disks; Radiation hydrodynamics; X-ray sources; Stars: Individual (XTE J1859+226); Disk-Jet connection

## 1. Introduction

Galactic Black Hole (BH) sources are interesting objects to study as these sources are observed only in binaries and the process of accretion gets very complex as the disk evolves with time, especially when the sources undergo outbursts and jet ejections take place. Some of the BH binaries show persistent emission (e.g. Cyg X-1) along with aperiodic X-ray variability (e.g. GRS 1915+105), over more than a period of decade. Some BH sources show outbursting behavior for shorter duration varying from few days to months, and are called as outbursting BH sources or transients (e.g. GX 339-4, XTE J1118+480, XTE J1748-288, H 1742-322, GRO J1655-40). The outbursting BH sources show different types of intensity variations (i.e., outburst profile) over different period of time (McClintock and Remilard, 2006). Some of the sources after being quiescent for a long time, show a sudden

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increase in the intensity level, and attain a maximum intensity within few days and then decay back slowly to quiescence (H 1743-322, A 0620-00, 4U 1543-47). Their light curves have a ‘Fast Rise and Exponential Decay (FRED)’ profile. Some sources have a slow rise to the peak and decay slowly to the quiescence (GX 339-4, XTE J1752-223) and their light curve profile is termed as ‘Slow Rise Slow Decay (SRSD)’. During this whole phenomena, outbursting sources show different spectral and timing variabilities and exhibit different spectral states like *Hard, Hard-intermediate, Soft-intermediate, Soft state* (Homan and Belloni, 2005; Belloni, 2010) and in some cases a *Very high state* also (Miyamoto et al., 1991; Remilard, 1999), in their Hardness-Intensity diagram (HID).

It is also observed that in outbursting BH sources, strong jets are emitted which are seen in radio observations (Fender et al., 2004), during the transition from hard-intermediate to soft-intermediate state in the rising phase (e.g. H 1743-322, Miller-Jones et al. (2012)) and in the declining phase when the source transits from soft-intermediate to hard state (e.g. XTE J1752-223, Yang et al. (2010)). Quasi-simultaneous multiwavelength observations of sources like GX 339-4 (Cadolle et al., 2011), XTE J1748-288 (Brocksopp et al., 2007), H 1743-322 (Miller-Jones et al., 2012), strongly suggests that the radio flares emitted are associated with the disk emission. It has been reported from the study of GRS 1915+105 that, during the jet ejections, QPOs are not observed as well as the Comptonized component gets suppressed (Vadawale et al., 2001). This implies that the ‘hot’ Comptonized corona gets disrupted and evacuated, and the source spectra softens, suggesting that the X-ray emission is mostly from the disk (Feroci et al., 1999; Vadawale et al., 2001; Nandi et al., 2001; Chakrabarti et al., 2002; Miller-Jones et al., 2012).

The X-ray transient source XTE J1859+226 was first discovered (Wood et al., 1999) with All Sky Monitor (ASM) onboard Rossi X-ray Timing Explorer (RXTE) (Bradt et al., 1993) on Oct 9, 1999. Subsequently, the source was monitored in X-rays with RXTE/PCA (Proportional Counter Array) and CGRO-BATSE (Compton Gamma Ray Observatory – Burst And Transient Source Experiment) for several months (McCollough and Wilson, 1999). The outburst showed the typical FRED profile. Spectral and temporal characteristics confirmed the source as a black hole candidate (Markwardt, 2001). Several observations in optical and radio wavebands confirmed the presence of the counterpart of the source (Garnavich et al., 1999; Pooley and Hjellming, 1999). Spectroscopic studies of the counterpart showed weak emission lines arising from Balmer series of Hydrogen and He II, which is typical for spectra of LMXBs (Wagner et al., 1999). The mass function was estimated to be (4.5 +/– 0.6) $M_\odot$, and an assumed inclination angle of 70° gave a lower mass limit of 5.42 $M_\odot$ (Corral-Santana et al., 2011).

During the 1999 outburst, the source XTE J1859+226 was continuously and extensively monitored in X-rays and in radio, which revealed the X-ray/radio correlations (Brocksopp et al., 2002). The source is observed to exhibit multiple flaring events of five in number. From the study of the spectral evolution in radio, it was found that the jet generation is implied by the production of hard X-rays and also that a correlation exists between soft X-ray and radio ejection during the first flare, while a correlation existed between hard X-ray and radio observation during the other ejections. Casella et al. (2004) studied the temporal properties of the source and found that, the QPOs observed can be classified into three types viz. Type A, B and C. This classification scheme based on the QPO characteristics and phase lag, has been considered as one of the basic formalities to classify the QPOs in Black Hole sources (See also Casella et al. (2005), Motta et al. (2011)). The phase lag difference between different types of QPOs, suggests that the shape of oscillation is different in different energies. But the evolution of low frequency QPOs (C-type) as well as their origin during the initial rising phase of the outburst is still not clear.

In the context of disk-jet symbiosis of black hole sources, Fender et al. (2004), Fender et al. (2009) have provided a unified picture along with the estimation of jet power as a function of X-ray luminosity. Their work also highlighted the occurrence of five radio flares in XTE J1859+226 and suggested that all the flares occur when the source is in a similar spectral state. They found that the rms of the Power density spectra (PDS) reduces during the occurrence of a flare. Rodriguez and Prat (2008) studied the spectral properties of the source during its rising phase and found that the non-thermal flux (2–50 keV) remains constant during the first flare of the source. Markwardt (2001) studied the evolution of the source during the rising phase of the outburst and found that there is a signature of partial absence of the QPO (or Comptonized corona), when the first radio flare occurred.

Dunn et al. (2011a,b) studied the spectral behavior of this source in the context of global study of disk dominated states of several BH sources. Considering a simple phenomenological model (diskbb+powerlaw) for BH spectral study, Dunn et al. (2011a) showed that a large fraction of disk dominated observations of XTE J1859+226 fall below the ‘standard’ Luminosity–Temperature (L–T) relation (see Gierlinski and Done (2004)). Farinelli et al. (2013) has studied the spectral characteristics of the source based on BeppoSAX and RXTE observations, in the context of a bulk motion comptonization model (BMC of XSPEC), and have observed an evolving high energy cut-off component during the hard to soft transition. They have also performed a correlated study between the fraction of Comptonization and the rms variability. But the ‘complex’ evolution of fold energy since the beginning of the outburst along with the evolution of temporal features (QPOs, rms etc.), especially during a radio flare are not explained in detail.

So, in order to have a coherent study of the evolution of temporal and spectral properties of the source (during the entire outburst) as well as the implications on disk