PROCEEDINGS OF SCIENCE

Low/hard state of microquasars at low luminosities

Tolga Dinçer[*] **and Emrah Kalemci**
Sabancı University, Orhanlı-Tuzla, Istanbul, TURKEY
E-mail: `tdincer@su.sabanciuniv.edu`
E-mail: `ekalemci@sabanciuniv.edu`

John A. Tomsick

SSL, UC Berkeley & CASS, UC San Diego, CA, USA

Michelle Buxton

Yale University, New Haven, USA

Galactic black hole transients (GBHTs) spend most of their time in the low/hard spectral state during the outburst decay. This state exhibits a hard X-ray spectrum with X-ray flux correlating with both the radio and the infrared flux. As the luminosity declines, the spectra of the GBHTs got harder. However, for a few sources at very low luminosity levels a softening of the spectrum has been observed. In this work we discuss the evolution of GBHTs at the very lowest luminosity levels using *RXTE* data and discuss the behavior of the X-ray spectrum, as well as the reported correlations.

VII Microquasar Workshop: Microquasars and Beyond
September 1-5 2008
Foca, Izmir, Turkey

---

[*] Speaker.

1. Introduction

According to X-ray spectral and temporal properties of GBHTs, their outburst evolution is characterized with various X-ray spectral states (see [18] for a review). One of those, the low/hard state, mostly governs the outburst rise and decay even though a few exceptions (e.g., SWIFT 1753.5-0127) have been observed. When the X-ray activity stops significantly, the source enters to quiescent state. X-ray spectrum in the low/hard state is usually modelled using a power law component which is thought to be related to Comptonization of cold photons in a hot plasma, synchrotron emission coming from outflow of matter through a jet, or an advective dominated flow, all having a total contribution of at least 80% or more and a weak thermal component associated with the emission coming from the inner hot accretion disk. The quiescent state resembles the low/hard state in terms of spectral and temporal properties at low luminosity levels [22].

Multiwavelegth observations of low/hard state have provided a better understanding of the nature of GBHTs. On one hand, in radio, jets are sometimes spatially resolved and the radio activity is also related to launch of jets. Global radio/X-ray correlations have been established [4, 8]. On the other hand, in infrared where the contribution of the emission could originate from the companion star, from jet or from reprocessing of X-rays, an X-ray/Optical-IR has also suggested [20]. But, lately some exceptions have been observed against to X-ray/radio and X-ray/OIR correlations [2, 3].

The general picture of the evolution of outburst decay of black holes has been summarized in [14]. This work points out that towards the end of the decay, a softening of the spectrum is possible. Besides, softening of the spectrum has been observed in quiescent state of black holes with imaging instruments [5, 6]. In this work, we will focus on the decay evolution of GBHTs at the very lowest luminosity levels using *RXTE* data and discuss the behavior of the X-ray spectrum, as well as the reported correlations.

2. Observations and Data Analysis

In this work, we analyzed *RXTE* and *SMARTS* monitoring observations to study the long term outburst decay evolution of GBHTs in the low/hard state. For some sources, we used readily available informations from the literature. In order to see whether the sources in our sample exhibit a softening during the decay, we reanalyzed some of the *RXTE* data with great care to take out the diffuse Galactic ridge emission.

We used 3-25 keV band of the PCA instrument, and added 0.8% up to 7 keV, and 0.4% above 7 keV as systematic error. Since we deal with the lowest fluxes, diffuse Galactic ridge emission becomes significant. In order to model the ridge emission we used simultaneous observations of imaging instruments, quiescent state observations or the literature [19]. In addition, infrared and radio data were gathered.

X-ray spectral fitting of each observation is made using a common model consisting of interstellar absorption, a multicolor disk black body, a smeared edge [7], a power law, a narrow Gauss line to model iron line, and a second power law to model ridge emission if necessary.

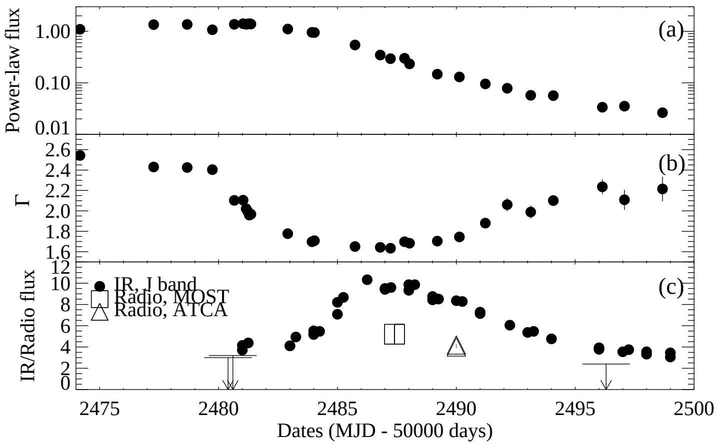

Figure 1: 2002 outburst decay of XTE J1543-47 replotted from Kalemci et al. 2005; the evolution of (a) the power law flux in 3-25 keV band in units of 10^{-9} ergs cm^{-2} s^{-1}, (b) the photon index, (c) the J-band infrared fluxes from Buxton et al. 2004 along with radio fluxes from our observations (triangles) and Park et al. 2004. (upper limits and square)

3. Results

3.1 4U 1543-47

The details of long term multiwavelength coverage and analysis of 2002 outburst decay of the source can be found in [13]. The Galactic ridge emission was modelled using the description introduced by [19]. Figure 1 shows the evolution of spectral parameters along J-band IR and radio flux that belongs to intermediate state and low/hard state. As the flux drops, photon index decreases and infrared and radio activity show up. In other words there is no response to IR reflaring in the X-ray flux. When the photon index reaches its hardest value, IR emission peaks (see Fig. 1 in [1]). Afterwards, the decrease in X-ray flux and IR magnitude is accompanied with an increase in photon index.

3.2 GRO J1655-40

The long term multiwavelength coverage of 2005 outburst decay of the source is published in [14] excluding the lowest flux analysis. We analyzed the very end of the outburst decay taking into account the ridge emission. The Galactic ridge emission was modelled using simultaneous `RXTE` and `SWIFT` observations when the source was faint [10]. Figure 2 shows the evolution of spectral parameters along J band IR magnitude and radio flux right after the radio activity begins. In the low/hard state while the X-ray flux and IR magnitude are dropping, the photon index gradually increases. No response were observed in both X-rays and IR as opposed to radio activity.

3.3 GX 339-4

GX 339-4 has recently become active again and Figure 3.3 shows the long term evolution of spectral parameters and J band IR magnitude in the low/hard state. The Galactic ridge emission was modelled using a simultaneous *RXTE* and *CHANDRA* observations when the source was faint [9]. During the decay, while photon index is fluctuating, a rebrightening in X-rays have been observed.

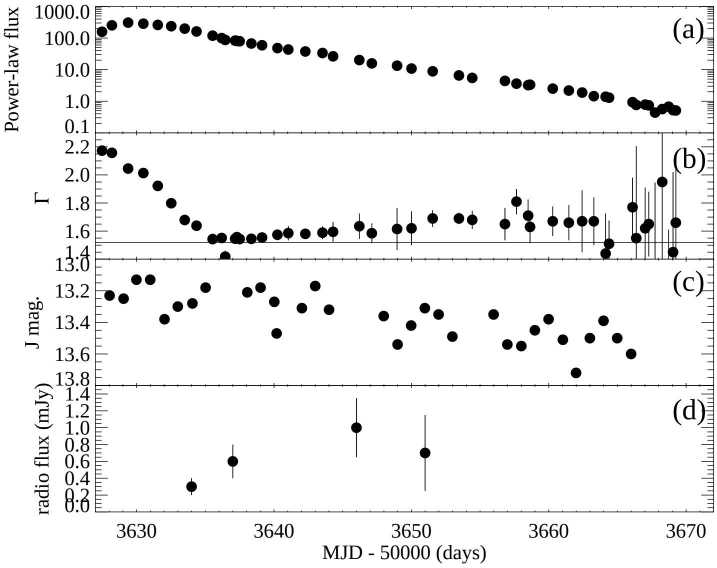

Figure 2: 2005 outburst decay of GRO J1655-40; the evolution of (a) the power law flux in 3-25 keV band in units of 10^{-11} ergs cm^{-2} s^{-1}, (b) the photon index, (c) the J-band magnitude, (d) the radio flux

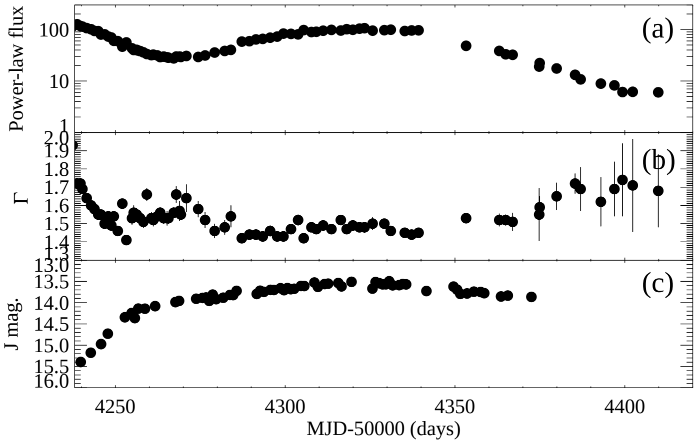

Figure 3: 2007 outburst decay of GX 339-4; the evolution of (a) the power law flux in 3-25 keV band in units of 10^{-9} ergs cm^{-2} s^{-1} , (b) the photon index, (c) the J-band magnitude

The IR magnitude starts to increase before the X-ray rebrightening. Towards the end of the decay the photon index increases.

3.4 XTE J1550-564

In 2000, XTE 1550-564 showed an outburst and a minioutburst in 2001. X-ray spectral analysis of 2000 outburst decay is studied by [21, 12]. We used readily available analysis of Kalemci Ph.D. Thesis (2002). Figure 3.4 belongs to 2000 outburst decay when the source is in the low/hard state. In the beginning of the decay, the photon index drops whereas the H-band magnitude is almost flat. Towards the end of the decay the photon index stays almost flat and H-band IR magnitude increases. X-rays does not respond to flaring in H-band. In 2002 minioutburst, only result that is availble in Figure 3.4 is the smooth increase of the photon index towards the end of the decay.

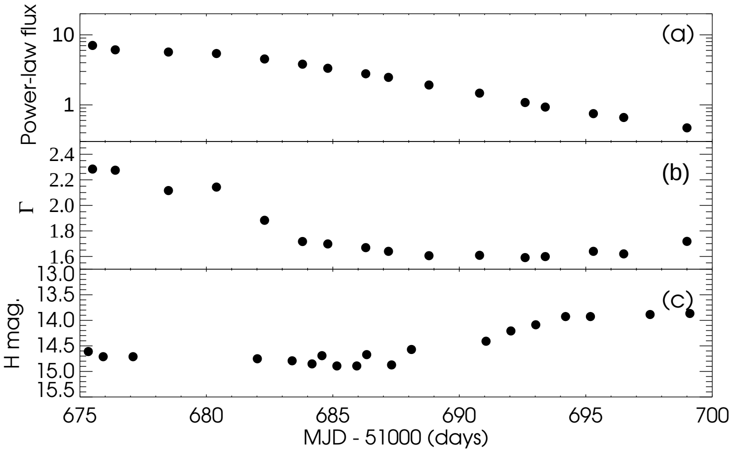

Figure 4: 2000 outburst decay of XTE J1550-564; the evolution of (a) the power law flux in 2.5-20 keV band in units of 10^{-9} ergs cm^{-2} s^{-1} , (b) the photon index, (c) the H-band IR magnitude

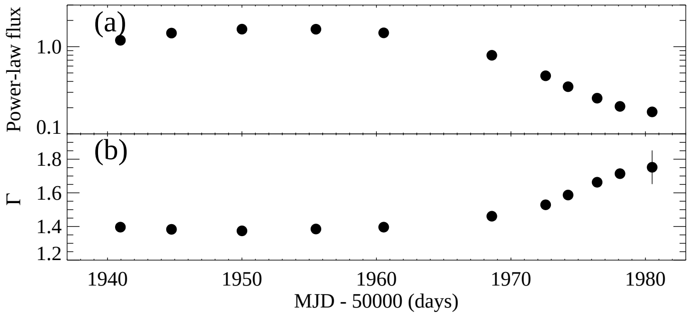

Figure 5: 2001 minioutburst of XTE J1550-564, from Kalemci Ph.D. Thesis, 2002; the evolution of (a) the power law flux in 3-25 keV band in units of 10^{-9} ergs cm^{-2} s^{-1} , (b) the photon index

3.5 SWIFT 1753.5-0127

SWIFT 1753.5-0127 is an interesting black hole which hasn't been observed in any other state than low/hard state during its outbursts. In 2005 July a thermal component was found out during the decay [17]. Figure 3.5, which shows evolution of spectral parameters during 2005 outburst decay, is taken from [17]. This source again shows an increase in the photon index towards the end of the outburst.

3.6 Summary of Results

- Except GRO J1655-40, all sources observed with SMARTS in our sample show a secondary outburst in IR.
- It is possible that the IR emission from the jet of GRO J1655-40 is buried under emission coming from the companion.
- There is no response in the X-ray flux to the increase in the IR emission except GX 339-4.
- There is a softening of the X-ray spectrum for many sources towards the end of the outburst. For some sources the softening starts right after the appearance of the jet.

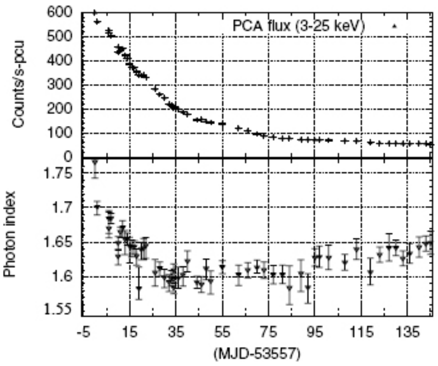

Figure 6: 2005 outburst decay of SWIFT 1753.5-0127, taken from Ramadevi and Seetha 2007; the evolution of (a) PCA count rate in 3-25 keV band, (b) the photon index

4. Discussion

The softening of the X-ray spectrum towards the end of outbursts is detected with *RXTE* for all sources in our sample, except 2000 outburst decay of XTE 1550-564. However, various competing clues obtained from decay evolutions leads to several different explanations for the softening of the spectrum.

The sources, 4U 1543-47, GRO J1655-40, GX 339-4 and XTE 1550-564, observed with SMARTS or in radio show a secondary outburst in IR which is thought to be the indication of a jet launch. For GRO J1655-40 case, the softening starts right after the radio activity although a decrease in IR emission is seen. However, GRO J1655-40 has an early spectral type companion star therefore it is possible that the IR emission is suppressed under emission coming from the companion. This possibility is also confirmed with a broadband spectra fitting using a jet model [15]. For 4U 1543-47, the softening starts at the secondary IR peak. The delay of the softening between two sources indicate that the softening might be influenced by different effects at the same time.

On the other hand, another possibility naturally comes from the characteristic power law component of the hard state spectrum by the Comptonization model. Tuning the parameters which effect the Comptonization can also result a softer spectra. The first possibility natuThe first possibility naturally comes from the characteristic power law component of the hard state spectrum by the Comptonization model.The first possibility naturally comes from the characteristic power law component of the hard state spectrum by the Comptonization model.rally comes from the characteristic power law component of the hard state spectrum by the Comptonization model. The possible explanations of the softening can be summarized as a mixture of the followings; (1) according to standard Comptonization model, shape of the spectrum is determined by Compton y parameter which depends on the electron temperature of the plasma and optical thickness of the medium. A decrease in optical depth due to change in corona size or decrease in mass accretion rate may cause a softer spectra. On the other hand change in coronal temperature may also cause to a softer spectra. (2) An additional soft component could cool the corona and make the spectra softer. And it is possible that this soft comes from the jet. (3) A small fraction of the energy may be transferred into the jet.

References

[1] Buxton, M. M. and Bailyn, C. D., 2004, ApJ, 615, 880

[2] Cadolle Bel M., et al., 2006, ApJ, 659, 549

[3] Chaty, S., *Multi-wavelength observations of the microquasar XTE J1720-318: a transition from high-soft to low-hard state*, in proceedings of *VI Microquasar Workshop*, `PoS(MQW6)014`

[4] Corbel, S., et al., 2003, A&A, 400, 1007

[5] Corbel, S., et al., 2006, ApJ, 636, 971

[6] Corbel, S., et al., 2008, MNRAS, 389, 1697

[7] Ebisawa, K., et al., 1994, PASJ, 46, 375

[8] Gallo, E., Fender, R. P., Pooley, G. G., 2003, MNRAS, 344, 60

[9] Gallo, E., Fender, R., Corbel, S., 2003, ATel, 196, 1

[10] Homan, J., et al., 2005, ATel, 644, 1

[11] Jain, R. K., et al., 2001, 554, 181

[12] Kalemci, E., 2002, *Ph.D. Thesis*, University of California, San Diego

[13] Kalemci, E., et al., 2005, ApJ, 622, 508

[14] Kalemci, E., et al., 2006, *State transitions and jet formation in black hole binaries*, in proceedings of *VI Microquasar Workshop*, `PoS(MQW6)012`

[15] Migliari, S., et al., 2007, ApJ, 670, 610

[16] Park, S. Q., et al., 2004, ApJ, 610, 378

[17] Ramadevi, M. C. and Seetha, S., 2007, MNRAS, 378, 182

[18] Remillard, R. A. and McClintock, J. E., 2006, ARA&A, 44, 49

[19] Revnivtsev, M., 2003, A&A, 410, 865

[20] Russell, D. M., 2006, ApJ, 371, 1334

[21] Tomsick, J. A., et al., 2001, ApJ, 563, 229

[22] Tomsick, J. A., Kalemci, E., Kaaret, P., 2004, ApJ, 601, 439