Investigating state transition luminosities of Galactic black hole transients in the outburst decay

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Abstract
We have performed a comprehensive spectral and timing analyses of Galactic black hole transients (GBHTs) during outburst decay in order to obtain the distribution of state transition luminosities. Using the archival data of the Rossi X-ray Timing Explorer (RXTE), we have calculated the weighted mean for state transition luminosities of 11 BH sources in 19 different outbursts and for disks and power-law luminosities separately. We also produced histograms of these luminosities in terms of Eddington luminosity fraction (ELF) and fitted them with a Gaussian. Our results show the tightest clustering in bolometric power-law luminosity with a mean logarithmic ELF of -1.70 ± 0.21 during the transition index (as the photon index starts to decrease towards the hard state). We obtained mean logarithmic ELF of 1.80 ± 0.25 during the transition to the hard state (as the photon index reaches the lowest value) and -1.50 ± 0.32 for disk blackbody luminosity (DBB) during the transition to the hard-intermediate state (HIMS).

We discussed the reasons for clustering and possible explanations for sources that show a transition luminosity significantly below or above the general trends.

Introduction
Galactic black hole transients (GBHTs) are systems with a low-mass optical companion which spend most of their time in a faint quiescent state where almost no activity is observed. Occasionally, they undergo sudden and bright X-ray outbursts which usually last from a few weeks to a few months. The spectral and temporal parameters of the source may experience an abrupt variation in some occasions when compared to the general behavior during the outburst cycle. These sudden changes are usually referred to as state transitions.

Although the nature of state transitions have been studied for more than four decades, the physical origin has not been well understood. Knowing what physical processes dominate during a state transition may hold a key to understand the accretion environment and the radiation mechanism during different spectral states.

One way to approach this problem is to quantify the state transition luminosity clustering in transition to the hard state and study the impact of different observables (e.g., inclination, spectral model parameters) in the distribution of state transition luminosities.

Methods
In this study, by using the definitions in Belloni (2010) and Kalemci et al. (2013), we have determined the state transition luminosities of GBHTs in the outburst decay in order to find the reasons for clustering. Taking into account both the spectral and temporal changes have allowed us to more accurately determine the transition times and luminosities compared to earlier works. Furthermore, the disk and power-law luminosities were obtained separately.

We started our analyses while the sources are still in soft state and followed their spectral and timing evolution towards the decay. In this sense, we have excluded extremely outburst. For the sources without a mass measurement we have adopted a general value of 8 ± 1.5 M$_\odot$, based on work of Özel et al. (2010) and Krüger et al. (2012) as well as $k = 2$ kpc. For the sources without a distance measurement based on work of Corral-Santana et al. (2016)

We used both the PCA (3-25 keV) and the HEXTE (15-200 keV) data for the spectral fit. We have mainly fitted our spectra with a combination of a multicolor disk-blackbody, a power law, an absorption model and a smeared edge and added an exponential cut-off if required.

Temporal analyses were applied to each observation in order to extract timing information such as the rms amplitude of variability and the type of the quasi-periodic oscillations (QPO). We computed the PSD from the PCA data using the "Tübingen timing tools" in 3-25 keV energy range.

Conclusion
We calculated the weighted mean of state transition luminosities for 11 GBHT in 19 different outbursts. The luminosities were first weighted by the inverse squares of their standard deviation (Maccarone 2003). However, this weighting method is strongly affected by the anomalously low luminosity outburst of XTE J1550-564

Since the data from a single outburst may cause a large deviation in the weighted means, we have also tried fitting histograms of the state transition luminosities.

With this method, we have obtained a tight clustering during the index transition with a log luminosity and an error of $-1.70 ± 0.21$ (1.99 ± 1.00 ELF) for the power-law. Similarly, in Figure 6, we have found a clustering for the disk emission during the transition to HIMS with a log luminosity and an error of $-1.50 ± 0.32$ (3.16 ± 2.34 ELF).

We have found that only the DBB luminosity correlates with the cosine of the inclination angle whereas PL luminosity showed a flat distribution in almost all state transitions. This would not only highlight an importance of the inclination angle correction in luminosity calculations, but it might also suggest a spherical hole in the middle type geometry for the hot-flow.

References
Belloni T. M., 2010, in Lecture Notes in Physics, Berlin Springer