Reinvestigation of the relation between the state transition and the mass accretion rate in black hole candidates

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Abstract

State transitions observed in black hole candidates (BHCs) are thought to result from changes in the mass accretion rate. To estimate the distance to 6 BHCs discovered by MAXI, we verify the luminosity and mass-accretion-rate relation that the X-ray luminosity at the high/soft-state (HSS) to low/hard-state (LHS) transition is 1-4% of the Eddington luminosity, $L_{\rm Edd}$ (e.g., Maccarone 2003). We also reinvestigate two empirical relations in outburst, pointed out by Yu et al. (2007), that the LHS peak flux at the beginning of an outburst is nearly proportional to the time since the flux peak in the previous outburst, and that the following HSS peak flux is nearly proportional to the LHS peak flux. Using MAXI/GSC and Swift/BAT data of GX 339-4, we confirmed the constancy (0.01-0.03$L_{\rm Edd}$) of the X-ray luminosity at the HSS-to-LHS transition. The other two relations, however, could not be confirmed in MAXI/GSC, RXTE/ASM, and Swift/BAT data of GX 339-4 and H 1743-322.

Key words: accretion, accretion disks — stars: black hole candidates: individual (GX 339-4, H 1743-322)

1. Introduction

MAXI discovered 6 black hole candidates (BHCs), but the distance to these new sources has not been known yet. To estimate the distance, we reexamined the relation that the luminosity at the state transition from the high/soft state (HSS) to the low/hard state (LHS) is 1-4% of the Eddington luminosity (Maccarone 2003) or 0.1-10% of the Eddington luminosity (Dunn et al. 2010).

We also investigated the following two empirical relations with the mass accretion; the nearly proportional relation between the LHS peak flux and the time since the LHS peak in an previous outburst, and the proportional relation between the LHS and HSS peak fluxes in the outburst (Yu et al. 2007).

2. Observations and Data Reduction

To reexamine these relations, we analyzed GX 339-4 and H 1743-322. The distance and the mass of GX 339-4 we used are 6 kpc and 5.8 $M_\odot$, respectively (Hynes et al. 2004).

2.1. Reevaluation of light curves

In order to determine more reliable time at the state transition, we reevaluated MAXI light curves. Even if the scanning observation terminated, for instance, to protect the detectors, the lack of the background region is not taken into account in the public data, resulting in fake brightening. On the other hand, in the on-demand data, such data are excluded in the default configuration. To solve these problems, we used the image fit method that took into account the point spread function of the detectors (Morii et al. 2016). As a result, we obtained more continuous and more reliable light curves, especially for data of H 1743-322 near the Galactic center, influenced by X-ray emission from the Galactic plane (Fig. 1).

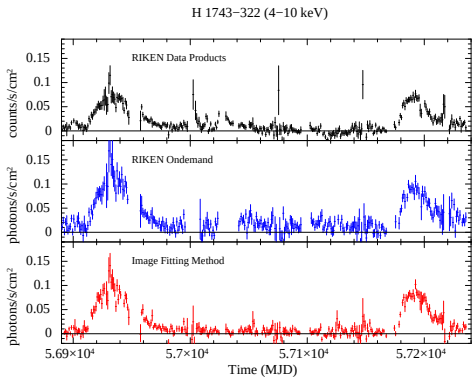


Fig. 1: Light curves of H 1743-322 (2015/02/05-08/04) (from the top, Riken public data, Riken on-demand data, and image fitting method data)

2.2. Determination of the time at the state transition

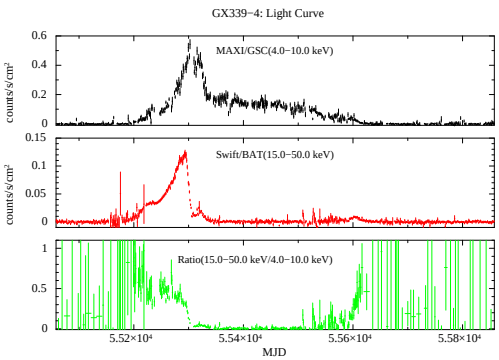
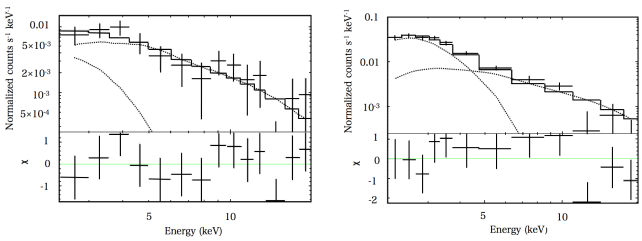


Fig. 2: GX 339-4 (09/08/15-11/08/27) (from the top, MAXI/GSC data 4-10 keV, Swift/BAT data 15-50 keV, and the hardness ratios (BAT/GSC))

By combining MAXI/GSC and Swift/BAT data (http://swift.gsfc.nasa.gov/results/transients/weak/GX-339-4/), we can estimate the time at the state transition more accurately (Fig. 2). We regard the peak-flux time in the Swift/BAT data around the transition, seen in the hardness ratios, as the LHS peak-flux time at the state transition.

3. Analysis

3.1. Is HSS-to-LHS transition luminosity 1-4% of the Eddington luminosity?



(a) 2011/02/06-10 (b) 2015/08/16-20

Fig. 3: Energy spectra during HSS-to-LHS transitions in GX 339-4

We examined two luminosities at the HSS-to-LHS transitions using MAXI/GSC spectra of GX 339-4, and confirmed that both values were in the range of 1-3% of the Eddington luminosity (Fig. 3).

3.2. Is the peak flux of the outburst nearly proportional to the time since the flux peak in the previous outburst?

We analyzed MAXI/GSC and RXTE/ASM data of GX 339-4 over the past 20 years, and MAXI/GSC and Swift/BAT data of H 1743-322 over the past 7 years. We could not confirmed the proportional relation between the LHS peak flux and the time since the peak in the previous outburst (Fig. 4).

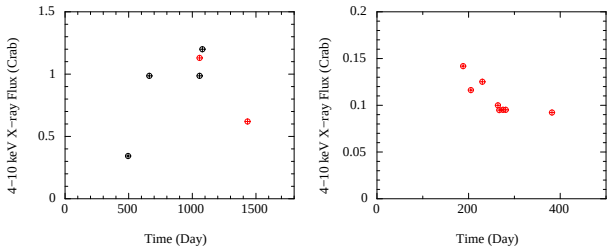


Fig. 4: Peak fluxes in individual outbursts vs. the time intervals from the previous outburst in GX 339-4 (left panel) and H 1743-322 (right panel) (red: MAXI/GSC, black: RXTE/ASM)

3.3. Is the LHS peak flux of the outburst nearly proportional to the HSS peak flux?

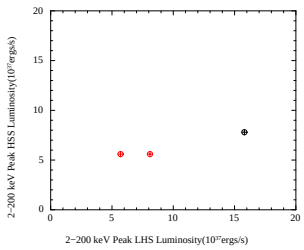


Fig. 5: Relation between LHS peak luminosities and HSS peak luminosities in GX 339-4 (black: in 2011, red: in 2015. The two different luminosities in 2015 are obtained by two acceptable spectral models.)

We used the MAXI/GSC data of GX 339-4. The LH peak fluxes (luminosities) in the two outbursts were different by 1.5-2.0 times, but the HS peak fluxes are nearly same ($\lesssim$1.05) (Fig. 5).

4. Summay/Tasks

We confirmed the constancy of the X-ray luminosity at the HSS-to-LHS transition in GX 339-4 as was expected from a simple accretion disk theory. On the other hand, the two kinds of the linear relations between the LHS and HSS peak-fluxes and the time interval were not confirmed not only in GX 339-4 but in H 1743-322. Finally, we note that out of 9 outbursts in H 1743-322 over the past 7 years, 4 outbursts did not show the state transition. We are investigating the cause of the difference.

Detailed analysis results here will be reported elsewhere.

References

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