Ultraluminous X-ray Sources in the Interacting Galaxy System NGC 4490 and NGC 4485

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Abstract

We report the X-ray study of five brightest ultraluminous X-ray sources (ULXs) in the interacting galaxy system NGC 4490 and NGC 4485 using the archived data from three *Chandra* and one *XMM-Newton* observations. To investigate spectral variations of these ULXs, we plotted their disk luminosities against the innermost disk temperatures estimated via the multi-color disk model. We found that the observed spectral variations are classified into two types; one indicating a power-law relation between the luminosity and the innermost disk temperature and the other without such a relation. The latter type shows flux changes more than an order. We discuss spectral state changes for individual sources.

Key words: accretion, accretion disks — black hole physics — X-rays: binaries

1. Introduction

Ultraluminous X-ray sources (ULXs) are off-nuclear point-like sources detected in the X-ray bandpass with luminosities of $>10^{39-41}$ ergs s^{-1} (Fabbiano 2006). A possible interpretation is that ULXs are black holes (BHs) with a mass comparable to or slightly larger than that of Galactic BHs (GBHs) of $<40\ M_\odot$ (Ebisawa et al. 2003), and that the super-Eddington luminosity is interpreted as a consequence of ULXs being in the slim-disk (SD) state (Abramowitz et al. 1988) rather than in the standard disk state (Shakura, & Sunyaev 1973). An alternative interpretation is that ULXs are BHs with a mass of 100–1000 $M_\odot$ shining at sub-Eddington luminosities (Miller, & Colbert 2004).

Some ULXs are known to show transitions between the two states called the power-law (PL) like state and the curved spectrum state (Kubota et al. 2001). Previous studies (e.g. Kubota et al. 2002) proposed that the two states correspond to the two high accretion states of GBHs, which are so-called the "very high state" and the "apparent standard state", respectively. An observational test of this hypothesis is to examine the similarities and differences in the state transitions, including their frequencies and time scales of transitions.

ULXs in interacting galaxy systems at 5–10 Mpc are fainter in flux than those in nearby galaxies (<5 Mpc). However, the density of ULX per galaxy is much higher, enabling us to monitor a large number of ULXs simultaneously. Thus, the NGC 4490 and NGC 4485 system (hereafter NGC 4490/85) at ∼8 Mpc, which hosts eight ULXs, is a suitable target to study long-term variation of multiple ULXs at a time. Previous X-ray studies (Roberts et al. 2002; Fridriksson et al. 2008) presented the long-term variation in flux and color in some ULXs. We apply physical models and discuss the nature of spectral variations.

2. Analysis and Results

We analyzed the ULXs in NGC 4490/85 using all the archived data sets of *Chandra* and *XMM-Newton*. We labeled the three *Chandra* and the one *XMM-Newton* observations as C1-3 and X1, respectively.

Eight ULXs are known in NGC 4490/85 (ULX-1–8). Among them, we focus on the sources with the maximum counts more than 1000 per observation, which are practically bright enough for our spectral analysis. Five sources are thus selected; ULX-2, 3, 4, 6, and 8.

We applied a PL model and a multi-color disk (MCD) model, which are commonly used for the continuum emission of GBH binaries or ULXs. In addition, we used a SD model calculated by Kawaguchi (2003). All the models yielded acceptable fits for all the data sets. Gladstone, & Roberts (2009) derived similar results using the same data sets, and also discussed state transitions with the PL and the MCD model.

In order to investigate the spectral variations of the five ULXs, we examined parameters derived from the MCD model, the innermost disk temperature $T_{\rm in}$ and the disk luminosity $L_{\rm X}$. We constructed a plot of $L_{\rm X}$

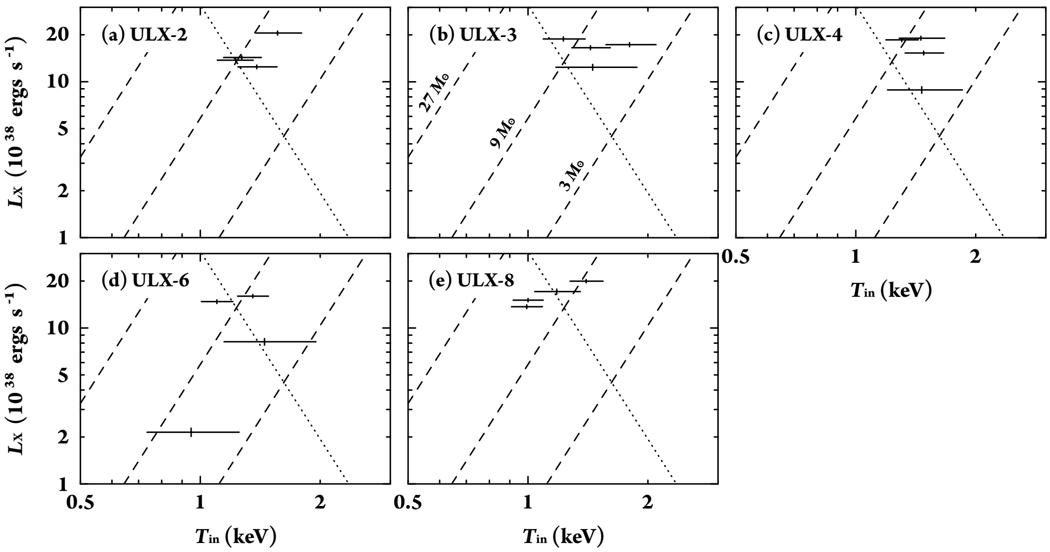

Fig. 1. Plot of X-ray luminosity L_X against the innermost disk temperature T_in based on the MCD fitting results. The dashed lines show the $L_\mathrm{X} \propto {T_\mathrm{in}}^4$ relation with several representative masses, while the dotted line indicates the Eddington luminosities for the standard disk.

against T_in in Figure 1. We confirmed time variations in all the sources. Some sources show a simple correlation between L_X and T_in, while others do not. A simple PL relation is expected as $L_\mathrm{X} \propto {T_\mathrm{in}}^2$ for the SD and as $L_\mathrm{X} \propto {T_\mathrm{in}}^4$ for the standard disk.

We interpret the complex pattern of variation as the mixture of two different origins of time variability — the "intra-state variation", which is in a single state caused presumably by the change in the mass accretion rate, and the "inter-state variation", which takes place between two different states. We consider that the intra-state and the inter-state variation can be distinguished in phenomenological fits by the MCD model. If the variation follows a simple PL relation between L_X and T_in with an index of ~2, as is seen for ULX-8, it is likely that the variation originates from the intra-state variability in the SD state. If the variation does not follow such a PL relation and the flux changes more than an order of magnitude, as is seen for ULX-6, it is likely that the variation originates from the inter-state variability.

3. Discussion

3.1. ULX-8

We speculate that the observed spectral variability is most likely interpreted as the intra-state variability in the SD state based on the two lines of evidence. The first is the correlation in the L_X–T_in plot. The second is the estimated Eddington ratio ($L_\mathrm{X}/L_\mathrm{Edd}$) by the SD model. By fixing the M_BH value among the four observations, the BH mass M_BH is ~37 $M_\odot$ (Table 1). Resultantly, the ratio is 0.28–0.47, which is similar to those of other ULXs in the SD state (Vierdayanti, et al. 2006).

Table 1. Best-fit parameters of the SD model for ULX-8

Data label	Absorption column density (10^{22} cm^{-2})	Accretion rate ($L_\mathrm{Edd}\ c^{-2}$)	L_X (10^{38} ergs s^{-1})
C1	$0.68^{+0.10}_{-0.09}$	12^{+2}_{-1}	21.4 ± 0.8
C2	$0.55^{+0.07}_{-0.06}$	10^{+1}_{-1}	15.5 ± 0.4
C3	$0.68^{+0.06}_{-0.06}$	15^{+2}_{-1}	25.8 ± 0.6
X1	$0.38^{+0.05}_{-0.04}$	11^{+1}_{-1}	18.1 ± 0.6
M_BH ($M_\odot$)			$36.9^{+2.1}_{-1.9}$
Red$-\chi^2$ (d.o.f.)			1.04(143)

3.2. ULX-6

ULX-6 shows the largest flux variation among the five ULXs. There is no M_BH range common among the four observations both for the MCD and the SD fits. This infers that the source did not remain either in the standard or SD states during the four observations. Thus, ULX-6 is considered to have exhibited an inter-state transition.

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