Black Holes from Stars to Galaxies – Across the Range of Masses
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Observational evidence for intermediate-mass black holes: ultra-luminous X-ray sources

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Abstract. Incorporating early data from the *Suzaku* satellite launched in July 2005, properties of Ultra-Luminous compact X-ray sources (ULXs) were studied in close comparison with those of Galactic and Magellanic black-hole binaries. Based on an analogy between these two types of X-ray sources, ULXs showing power-law type spectra are considered to host Comptonized accretion disks, while those with multicolor-disk type spectra are interpreted to harbor "slim" disks. The analogy also suggests that ULXs are radiating near their Eddington limits, and hence their central black holes are significantly more massive than the ordinary stellar-mass black holes contained in Galactic and Magellanic black-hole binaries. In this sense, ULXs can be regarded as intermediate-mass black holes.

Keywords. Accretion, accretion disks – black hole physics – galaxies: spiral – X-rays: binaries

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1. Introduction

X-ray images of nearby spiral galaxies, obtained with the *Einstein Observatory*, revealed very luminous point-like X-ray sources in their arm regions (e.g., Fabbiano 1989). Their X-ray luminosity reaches $10^{39.5-40.5}$ erg s^{-1}, corresponding to the Eddington limits, $L_{\rm E}$, for 20–200 $M_\odot$ objects. Their nature has long remained a big mystery, because such objects are absent in the local-group galaxies (with a possible exception of M33 X-8) including the Milky Way, and because none of them have optical/radio counterparts.

A breakthrough in the study of these enigmatic objects has been brought about by *ASCA*; Corbert & Mushotzky (1999) and Makishima *et al.* (2000) found that the 0.5–10 keV spectra of the most luminous of these objects resemble those of Galactic black-hole binaries (BHBs). This, together with their high luminosity, led Makishima *et al.* (2000) to name them Ultra-Luminous compact X-ray sources (ULXs), and to propose that they are binaries involving black holes (BHs) which are significantly more massive than ordinary stellar-mass BHs, to be called intermediate-mass black holes (IMBHs). If so, ULXs will provide a long-sought missing link between stellar-mass BHs and active galactic nuclei.

The *ASCA* view has been greatly expanded by *Chandra* and *XMM-Newton*. Nevertheless, the nature of ULXs has remained controversial, since the formation of such IMBHs cannot easily be explained by the contemporary scenario of stellar evolution. As a result, alternative explanations for ULXs have been proposed: that they are BHBs with "ordinary" masses (e.g., $\lesssim 20\ M_\odot$) under very high accretion rates, and their high luminosity is due either to strong X-ray beaming toward us (e.g., King 2002), or to genuine super-Eddington emission (e.g., Begelman 2002). To tell whether ULXs really host IMBHs or not is one of the most important issues of the current BH study.

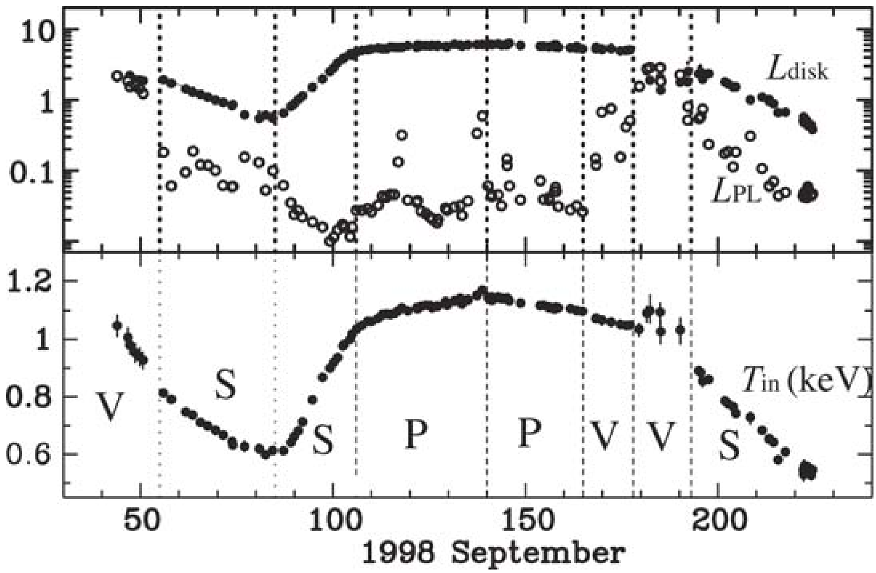

Figure 1. Spectral parameters of XTE 1550−564, obtained by fitting the *RXTE* PCA spectra with an MCD plus power-law model (Kubota & Makishima 2004). (*top*) The bolometric MCD luminosity (upper trace), and the 1–100 keV power-law luminosity (lower trace), both in the unit of 10^{38} ergs s^{-1}. (*bottom*) The innermost disk temperature T_{in} in keV. "S", "V", and "P" specify the High/Soft state, the Very-High state, and the Slim-Disk states, respectively.

2. Information from black hole binaries

2.1. *The transient source XTE 1550−564*

To understand ULXs which are though to involve BHs under high accretion rates, we may take lessons from BHBs (e.g., Remillard & McClintock 2006), including in particular transient sources (Tanaka & Shibazaki 1996) because of their large luminosity changes. An important role in our study has been played by the transient BHB, XTE 1550−564 (Kubota & Makishima 2004), which contains a BH of $8.4 - 11.2\ M_{\odot}$ (Orosz *et al.* 2002).

Figure 1 shows evolution of spectral parameters of XTE 1550−564 in an extended outburst. These were obtained by analyzing a large number of pointing data taken with the *RXTE* PCA, with a conventional model consisting of an MCD (multi-color disk) component and a PL (Kubota & Makishima 2004); as widely known, the MCD model (Mitsuda *et al.* 1984, Makishima *et al.* 1986) describes X-ray spectra emergent from standard accretion disks around BHs. As the luminosity varied by an order of magnitude, the source experienced three characteristic states, specified as "S", "V", and "P".

2.2. *Four spectral states*

Figure 2 exemplifies the PCA spectra of XTE 1550−564 for the above three states, all fitted with a conventional MCD plus power-law model. Thus, the state "S" is characterized by a canonical High/Soft (=standard-disk) state spectrum, with a luminosity of 5–40% of L_{E}. Assuming an inclination of $i \sim 70°$ (Orosz *et al.* 2002), the obtained inner disk radius $r_{in} \sim 60$ km (Kubota & Makishima 2004) agrees, within $\sim 20\%$, with $3R_{S}$ (R_{S} being the Schwarzschild radius) predicted by the optically measured BH mass quoted above. Therefore, the state "S" can be securely identified with the High/Soft state.

Figure 3 is so-called luminosity-temperature diagram of accreting black holes (Makishima *et al.* 2000), where their innermost disk temperature T_{in}, derived with the

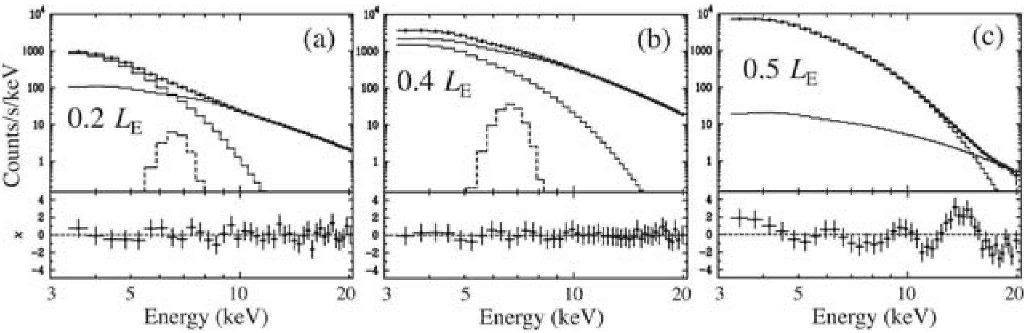

Figure 2. Response-inclusive PCA spectra of XTE 1550−565, in the three spectral states specified in Fig.1. An approximate 1–20 keV luminosity is also indicated in the unit of L_E. (a) High/Soft state ("S"). (b) Very-High state ("V"). (c) Slim-Disk state ("P").

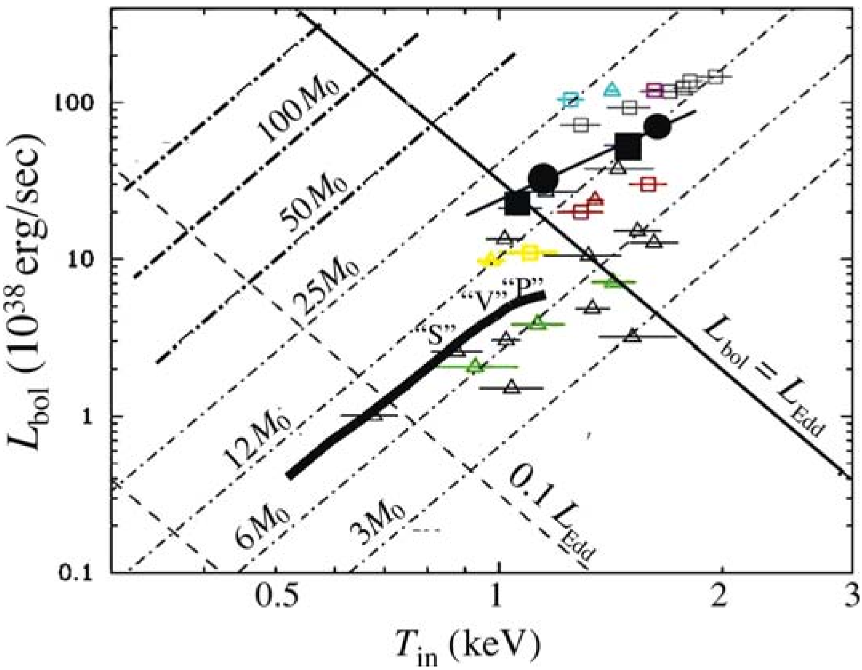

Figure 3. A luminosity-temperature diagram of accreting black holes (Makishima *et al.* 2000), where results on some CS-type ULXs are plotted. The family of dash-dotted lines show loci of standard accretion disks seen at an inclination of $i = 60°$, assuming non-rotating BHs with $r_{in} = 3R_S$. The thick solid line represents the results on XTE 1550−564 (Kubota & Makishima 2004). The filled squares and filled circles indicate NGC 1313 X-2, observed with *ASCA* (Makishima *et al.* 2000) and *Suzaku* (§ 4.3), respectively.

conventional MCD fit, are plotted against their bolometric disk luminosity L_{disk}. While XTE 1550−564 is in the state "S", its locus is indeed seen to follow the $L_{disk} \propto T_{in}^4$ relation (Makishima *et al.* 2000), drawing a straight section of the thick solid line.

When the source brightens to $\sim 0.4L_E$, there appears the state "V", which is identified with the previously reported Very-High state (Miyamoto *et al.* 1991) or the *anomalous regime* (Kubota & Makishima 2004). The fitted PL component dominates the whole energy range, so the overall spectrum assumes a power-law shape with a weak soft excess (Fig. 2b). Although the conventional fit yields unphysical values of T_{in} and r_{in}, these

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anomalies can be removed by assuming that the disk emission is Comptonized by a hot electron cloud to form the dominant hard tail (Kubota, Makishima & Ebisawa 2001, Kubota & Makishima 2004, Kobayashi *et al.* 2003). When the MCD parameters are corrected for the Comptonization effects, the data points on Fig. 3 still align on the same straight section of the thick solid line as the "S" state data points (Kubota & Makishima 2004). Therefore, we presume that a (nearly) standard disk is still present.

The state "P" is characterized by the highest and strongly saturated disk luminosity at $\sim 0.5 L_{\rm E}$ (Fig. 1). The hard tail diminishes so that the spectrum resumes a thermal shape, but the disk temperature clearly becomes higher than in the High/Soft state (Fig. 2a,c). The canonical $L_{\rm disk} \propto T_{\rm in}^4$ relation no longer holds, as evidenced by the nearly constant $L_{\rm disk}$ as $T_{\rm in}$ changes. As a result, the slope of its locus on Fig. 3 becomes significantly flatter than in the state "S". These properties are explained (Kubota & Makishima 2004, Abe *et al.* 2005) by assuming that the standard accretion disk has changed into an optically-thick advection-dominated accretion disk, called a "slim" disk (Abramowicz *et al.* 1988, Watarai & Mineshige 2001), which is theoretically predicted to appear under very high accretion rates. We therefore call the state "P" the Slim-Disk state.

2.3. *Eddington limits*

From the above considerations, we presume that an accreting BH takes four characteristic spectral states; the Slim-Disk state ("P"), the Very-High state ("V"), the High/Soft state ("S"), and the Low/Hard state, in the decreasing order of the mass accretion rate. A fact of essential importance seen in Fig. 1 is that the luminosity of XTE 1550−565 saturates very strongly at $\sim 0.5 L_{\rm E}$, even in the most luminous Slim-Disk state. This can be ascribed to the radiation inefficiency of a slim disk.

A genuine super-Eddington luminosity of XTE 1550−565 was realized only for a short while (a few days), accompanied by radio flares (Orosz *et al.* 2002) at day ~ 5 in Fig. 1 (outside the plot). Similarly, super-Eddington luminosities from other Galactic BHBs are observed usually as short episodes (e.g, Wijnands & van der Klis 2000), e.g., at the beginning of outbursts, rather than a sustained (e.g., $>$ a few days) steady state. These episodes may be transient phenomena, accompanied by unstable mass ejections.

3. Properties of ULXs

3.1. *Two spectral types of ULXs*

ULXs typically show two spectral types. One is to be called convex-spectrum (CS) type, in which their 1–10 keV spectra exhibit featureless convex shapes. The other is power-law (PL) type, wherein the spectra approximately take power-law shapes. As shown in Fig. 4, some ULXs make transitions between these two types (Kubota *et al.* 2001, La Parola *et al.* 2001), with factor 1.5–3 higher luminosity in the CS-type state. Thus, the two types of ULXs are thought to be the same class of objects in different spectral states.

It would be most straightforward to consider the CS-type and PL-type ULXs to be analogous to BHBs in the High/Soft and Low/Hard states, respectively. Then, the ULX transitions such as seen in Fig. 4 would be identified with those of BHBs between these two classical states (Kubota *et al.* 2001). However, if so, these ULXs would be inferred to be emitting at a few percent of $L_{\rm E}$ (a typical transition luminosity of BHBs; Remillard & McClintock 2006), and hence their true Eddington limit would have to be $\sim 10^{41}$ erg s^{-1} (Tsunoda *et al.* 2007). Added to this difficulty, other problems (see below) argue against the above simple-minded state assignments.

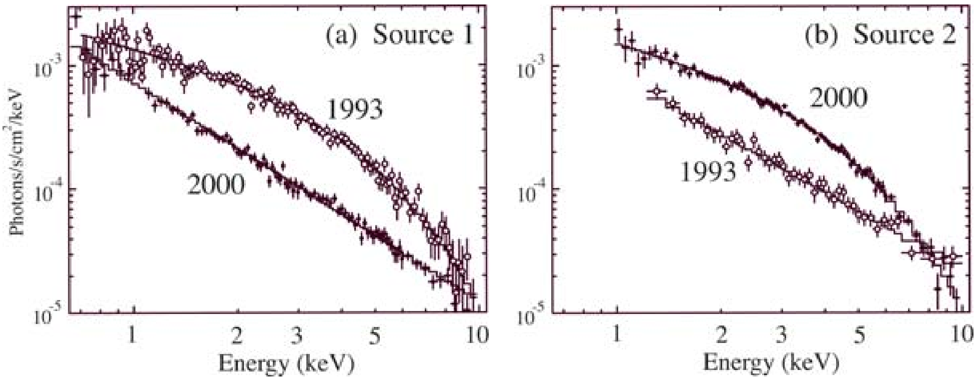

Figure 4. Response-removed spectral of two ULXs (X-1 and X-2) in IC 342 observed with *ASCA* (Kubota *et al.* 2001), revealing transitions between the CS and PL states.

3.2. *CS-type ULXs*

Spectra of CS-type ULXs are reminiscent of those of BHBs in the High/Soft state. In fact, the low-luminosity end of the CS-type ULX population may be confused with the high-luminosity end of the BHB population (Tanaka *et al.* 2005). However, compared with BHBs in the High/Soft state, the majority of CS-type ULXs exhibit a marked anomaly; their values of $T_{\rm in}$, typically 1.3–1.8 keV, are too high for their luminosity (Makishima *et al.* 2000), to presume that they host sub-Eddington standard disks with $r_{\rm in} = 3R_{\rm S}$. This problem is visualized in Fig. 3, where CS-type ULXs are seen to fall mostly on the super-Eddington region.

The problem could be solved if BHs in these ULXs are rapidly spinning (Makishima *et al.* 2000); then, $r_{\rm in}$ would decrease down to $0.5R_{\rm S}$. However, due to relativistic effects, $T_{\rm in}$ will not increase as much as hoped, so that the problem of too high $T_{\rm in}$ would not be solved unless the disk inclination is very high (Ebisawa *et al.* 2003). Furthermore, there remains another problem, that their values of $r_{\rm in}$ apparently varies roughly as $r_{\rm in} \propto T_{\rm in}$ (Mizuno *et al.* 2001), whereas that of a High/Soft state BHB stays constant at $\sim 3R_{\rm S}$ (the last stable orbit). As a result, the loci of ULXs on Fig. 3 show a flatter slope than the canonical ones, just in the same way as XTE 1550−564 in the state "P" .

A most promising explanation for these apparent anomalies of the CS-type ULXs is to assign the state "P" (§ 2.2) to them, namely to assume that they host slim disks rather than standard disks. This can explain (Watarai *et al.* 2001, Mizuno *et al.* 2001, Tsunoda *et al.* 2007) both their too high values of $T_{\rm in}$, and their deviation from the $L_{\rm disk} \propto T_{\rm in}^4$ relation in Fig. 3 .

If CS-type ULXs in fact harbor slim disks, we can no longer determine their BH masses reliably from the observed spectra (particularly $r_{\rm in}$), since a slim disk would no longer be sharply truncated at $3R_{\rm S}$, and the color hardening factor under such a condition is un-calibrated. Instead, we may get a crude estimate of the BH mass by equating the observed luminosity with $L_{\rm E}$. This is based on the empirical knowledge from BHBs in § 2.3, rather than any rigorous belief in the Eddington limit. Thus, we consider that CS-type ULXs involve BHs with masses several tens to a few hundreds $M_\odot$.

3.3. *PL-type ULXs*

Compared with the photon index of of ~ 1.7 which is typical of BHBs in the Low/Hard state, the spectral slopes of PL-type ULXs scatter more, e.g., $1.5 \sim 2.8$. In addition, their spectra often show high-energy turn-over (Kubota, Done & Makishima 2002, Dewangan *et al.* 2005), in energies of 5–10 keV which is much lower than the thermal cutoff (at

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$\sim$ 100 keV) observed from Low/Hard-state BHBs. Together with the problem associated with the transition luminosity (§ 3.1), these make it difficult to explain PL-type ULXs in terms of the Low/Hard state.

A more plausible interpretation is to regard PL-type ULXs as in the Very-High state. Actually, the mild spectral turn-over found with these ULXs is also observed from BHBs in the Very-High state (e.g., Kobayashi *et al.* 2003), though at considerably higher energies (several tens keV). In addition, the spectral slopes of PL-type ULXs are similar to those of BHBs in the Very-High state, 2.0 to 3.0 in photon index. The higher luminosity of a ULX in the CS state than in the PL state is also consistent with the luminosity differences between the Slim-Disk and Very-High states of BHBs (Fig. 2). We hence conclude that PL-type ULXs is in the Very-High state, so that their power-law like continua result from unsaturated Comptonization of disk photons by a hot electron cloud. The high-energy spectral curvature can be attributed to the electron temperature.

As another similarity to BHBs in Very-High state, PL-type ULXs often show a weak soft excess above the dominant power-law. The excess has been interpreted (e.g., Miller *et al.* 2003) as the emission from a cool ($T_{\rm in} \sim 0.1$ keV) standard accretion disk, of which $r_{\rm in}$ corresponds to $3R_{\rm S}$ of a $\sim 10^3$ $M_\odot$ BH (e.g., Miller *et al.* 2003). Although this has been taken as evidence for genuine IMBHs, the disk parameters are derived with a conventional MCD fit without considering the possible Comptonized effects. Therefore, we should not use face values from the MCD modeling of the soft excess. Instead, our new state assignment implies that PL-type ULXs are radiating at $\sim L_{\rm E}$, and hence the required BH mass reduces typically to $\sim 10^2$ $M_\odot$.

In some cases, however, the soft excess may be interpreted indeed as emission from a standard disk. One such candidate is the low-luminosity ($\sim 5 \times 10^{39}$ erg s^{-1}) state of Holmberg II X-1 (Dewangan *et al.* 2004); this could be a source excursion from the Very-High state into the High/Soft state. If this luminosity is identified with 0.5 $L_{\rm E}$ after XTE 1550$-$564, a BH mass of ~ 60 $M_\odot$ is indicated.

3.4. *Other properties of ULXs*

A fair fraction of ULXs are surrounded by optical line-emitting nebulae (Pakull & Mirioni 2003), each several hundred parsecs in radius and several hundreds $M_\odot$ in mass. The lines are likely to be excited by the central ULXs themselves. The required excitation luminosity is estimated to amount to $\sim 10^{40}$ erg s^{-1}, assuming an isotropic radiation. This argues against the beaming interpretation of ULXs, because the excitation flux would become insufficient if the X-ray radiation were beamed toward us. The detections of slow quasi-periodic oscillations from some ULXs (Strohmayer & Mushotzky 2003, Dewangan *et al.* 2006) also point to significantly higher BH masses than in ordinary BHBs.

4. ***Suzaku*** **observations of ULXs**

4.1. *The **Suzaku** satellite*

The fifth Japanese cosmic X-ray satellite *Suzaku* (*Astro-E2*; Mitsida *et al.* 2007) was launched on 2005 July 10. It carries onboard X-ray CCD cameras called the X-ray Imaging Spectrometer (XIS; Koyama *et al.* 2007), placed at the focal plane of the X-ray Telescopes (XRT), and the Hard X-ray Detector (HXD; Takahashi *et al.* 2007, Kokubun *et al.* 2007). Unfortunately, the X-ray micro-calorimeter (XRS) stopped its function before the start of observations. Although the HXD is providing useful upper limits on the 10–50 keV emission from a few ULXs, here we concentrate on the XIS results.

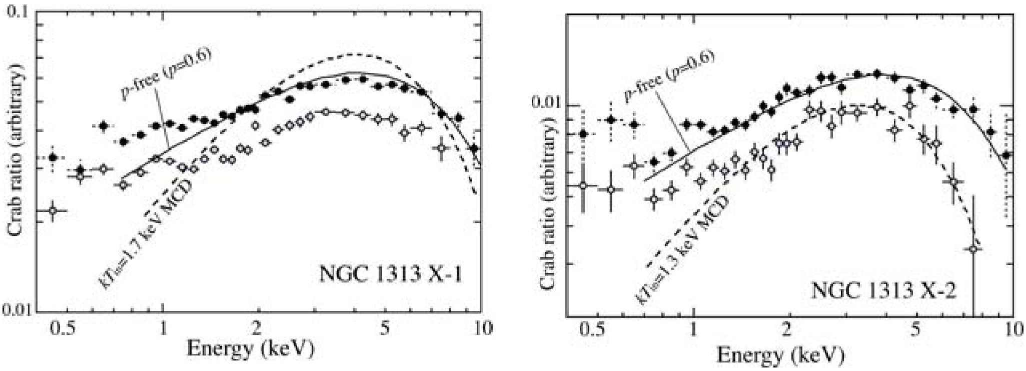

Figure 5. *Suzaku* XIS spectra (sum of the three FI sensors) of NGC 1313 X-1 (*left*) and X-2 (*right*), shown as ratios to the Crab Nebula spectrum. Filled and open circles indicate brighter and fainter phases of each source, respectively. Predictions by an MCD model (dashed curve) and a p-free model with $p = 0.6$ (solid curve) are illustrated.

4.2. *Observations of NGC 1313*

With *Suzaku*, we observed the nearby (3.7 Mpc) Sb galaxy NGC 1313 for 28 ksec on 2005 September 15. From previous X-ray studies (Petre *et al.* 1994, Makishima *et al.* 2000, Mizuno *et al.* 2001, Miller *et al.* 2003, Dewangan *et al.* 2005), this galaxy is known to host three luminous X-ray sources; two ULXs called X-1 and X-2, and SN1978k. During the observation, both X-1 and X-2 varied by $\sim 50\%$, with mild spectral changes.

Figure 5 shows Crab ratios of the spectra of these two ULXs, taken with the *Suzaku* XIS. These are roughly equal to response-removed $\nu F \nu$ forms of the spectra, except in energies below ~ 1.5 keV where the ratios are affected by interstellar absorption. A clear advantage of these *Suzaku* spectra is the very high signal-to-noise ratios in harder energies, thanks to the large effective area of the XRT and a low background of the XIS. Below, we first discuss X-2, and then X-1, after a detailed report by Mizuno *et al.* (2007).

4.3. *NGC 1313 X-2: a CS-type ULX*

This source was detected at a time-averaged 0.4–10 keV luminosity of 6×10^{39} erg s^{-1}. Because its spectra exhibit clearly convex shapes (Fig. 5 right), we confirm that the source was in an CS state like in most of the previous observations. Both the brighter-phase and fainter-phase spectra can be approximated by an MCD model, yielding the two data points (filled circles) in Fig. 3. Thus, the *Suzaku* results are roughly consistent with those from *ASCA* (Makishima *et al.* 2000). As mentioned § 3.2, these data points define a flatter slope (thin solid line) in Fig. 3 than the $L_{\rm disk} \propto T_{\rm in}^4$ relation.

In Fig. 5 (right), the MCD model gives a relatively good fit to the faint-phase spectrum (except below 1.5 keV). However, the model is not fully successful on the brighter-phase spectrum (Mizuno *et al.* 2007), since it is significantly less convex. Instead, a successful fit is obtained using a p-free model with $p = 0.6$, as illustrated in Fig. 5 (right). The p-free model (Hirano *et al.* 1995) generalizes the MCD model, by assuming that the local disk temperature depends on the radius r as $T(r) = T_{\rm in}(r/r_{\rm in})^{-p}$; the case of $p = 0.75$ reduces to the MCD model. The p-free model can approximate theoretical spectra calculated for slim disks (Watarai & Mineshige 2001). Furthermore, it can successfully reproduce the state "P" spectra of XTE 1550−564, and the observed spectra of some other CS-type ULXs (Tsunoda *et al.* 2007). These results support the view (§ 3.2) that X-2 was in the Slim-Disk state during the *Suzaku* observation (Mizuno *et al.* 2007).

4.4. *NGC 1313 X-1: a PL-type ULX*

NGC 1313 X-1 was detected at a 0.4–10 keV luminosity of 2×10^{40} erg s^{-1}, which may be the highest record ever observed from it. Its spectrum (Fig. 5 left) is much less convex than that of X-1, and cannot be represented even by the p-free model with $p = 0.6$. If the spectra were unconstrained above ~ 5 keV, a single PL would be successful; clearly, the object was in the PL state. The Crab ratio also suggests a weak soft excess below ~ 2 keV, as reported previously (Miller *et al.* 2003). Thus, the spectra show a PL-like continuum, a high-energy curvature (Dewangan *et al.* 2005), and a soft excess (Miller *et al.* 2003), all typical ingredients of a Very-High state spectrum. Indeed, the *Suzaku* spectra have been reproduced by a combination of an MCD model and a cutoff power-law (Mizuno *et al.* 2007), the latter emulating the Comptonized disk emission. These results strengthen our interpretation of PL-type ULXs in terms of the Very-High state.

Finally, we quote an important argument from Mizuno *et al.* (2007). As seen above, X-1 is about 4 times more luminous than X-2. However, if normalized to their Eddington values, X-1 should be less luminous than X-2, because X-1 is in the Very High state while X-2 in the Slim-Disk state. Then, X-1 must have at least 4 times higher Eddington luminosity, and hence 4 times higher mass, than X-2. Even employing an extreme assumption that X-2 has a rather ordinary stellar mass, e.g., $\sim 10\ M_\odot$ that requires a super-Eddington factor of 4, X-1 is inferred to have at least $\sim 40\ M_\odot$. This indicates that UXLs have a rather broad mass spectrum, making a clear contrast to the ordinary stellar-mass BHs.

5. Conclusions

Based on the close analogy with BHBs under high accretion rates, we conclude that ULXs are close binaries involving IMBHs, in the sense that they are significantly more massive (several tens to a few hundred solar masses) than ordinary stellar BHs. The two spectral types found with them can be assigned to the Very-High state and Slim-Disk state of BHBs.

Acknowledgements

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References

Abe, Y., Fukazawa, Y., Kubota, A., Kasama, D. & Makishima, K. 2005, APSJ, 57, 629
Abramowicz, M. A., Czerny, B., Lasota, J. P. & Szuszkiewicz, E. 1988, ApJ, 332, 646
Begelman, M. 2002, ApJL, 568, L97
Colbert, E. J. M. & Mushotzky, R. F. 1999, ApJ, 519, 89
Dewangan, G. C., Griffiths, R. E. & Rao, A. R. 2005, astro-ph/0511112
Dewangan, G. C., Griffiths, R. E. & Rao, A. R. 2006, ApJL, 641, L125
Dewangan, G. C., Miyaji, T., Griffiths, R. E. & Lehmann, I. 2004, ApJL, 608, L57
Ebisawa, K., Zycki, P., Kubota, A., Mizuno, T. & Watarai, K. 2003, ApJ, 597, 780
Fabbiano, G. 1989, ARA&A, 27, 87
Hannikainen, D., Campbell-Wilson, *et al.* 2001, Astrophys. Space Sci. Suppl., 276, 45
Hirano, A., Kitamoto, S., Yamada, T. T., Mineshige, S. & Fukue, J. 1995, ApJ, 446, 350
King, A. 2002, MNRAS, 335, L13
Kobayashi, Y., Kubota, A., Nakazawa, K. & Takahashi, T. 2003, PASJ, 55, 273
Kokubun, K., Makishima, K., Takahashi, T., Murakami, T., *et al.* 2007, PASJ, 59, in press
Koyama, K., *et al.* 2007, PASJ, 59, in press

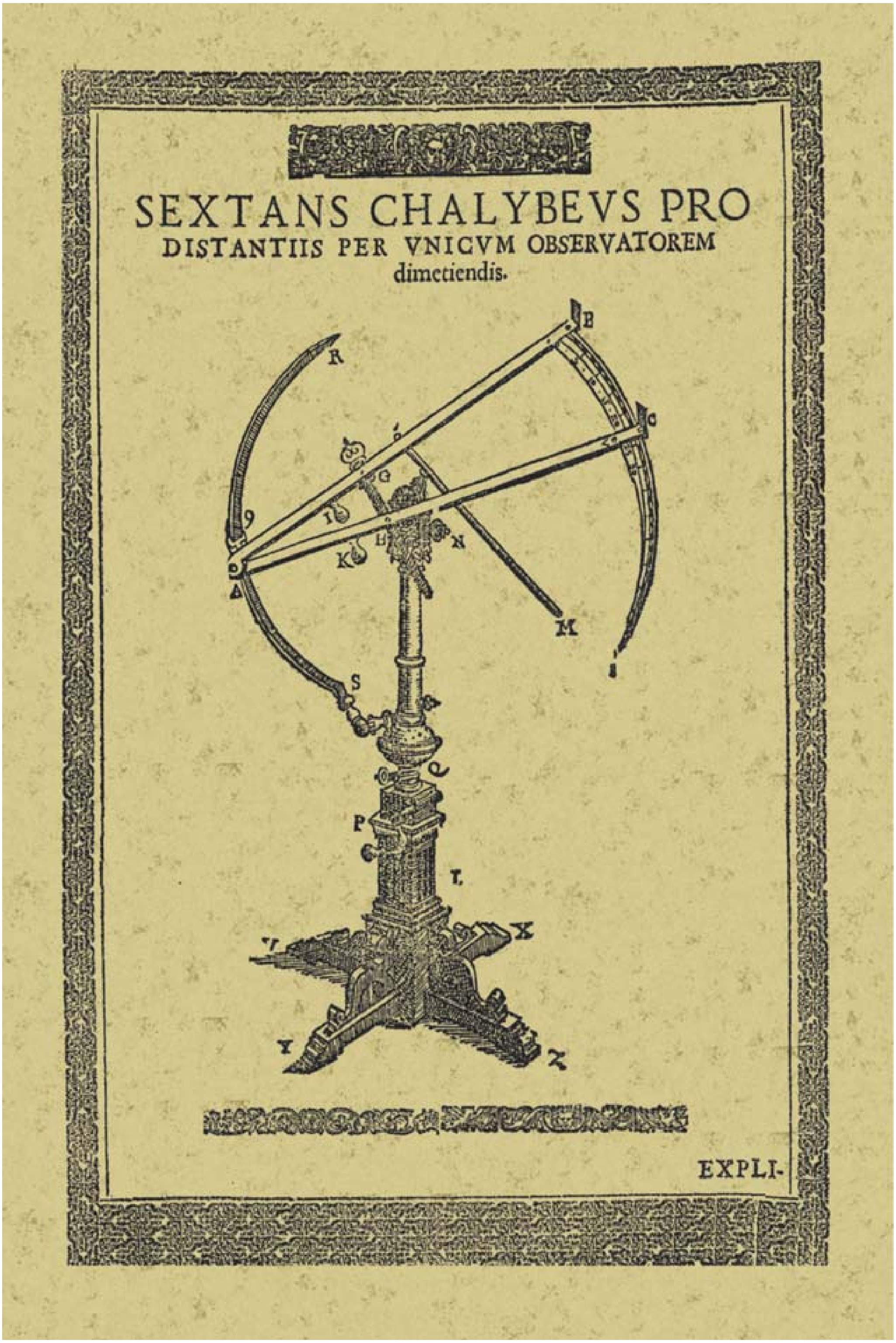
Kubota, A., Done, C. & Makishima, K. 2002, MNRAS, 337, L11
Kubota, A. & Makishima, K. 2004, ApJ, 601, 428
Kubota, A., Makishima, K. & Ebisawa, K. 2001, ApJL, 560, L147
Kubota, A., Mizuno, T., Makishima, K., Fukazawa, Y. *et al.* 2001, ApJL, 547, L119
La Parola, V., Peres, G., Fabbiano, G., Kim, D. & Bocchino, F. 2001, ApJ, 556, 47
Makishima, K., Kubota, A., Mizuno, T., Ohnishi, T., *et al.* 2000, ApJ, 535, 632
Makishima, K., Maejima, Y., Mitsuda, K., Bradt, H., Remillard, R., *et al.* 1986, ApJ, 308, 635
Miller, J. M., Fabbiano, G., Miller, M. C. & Fabian, A. C. 2003, ApJL, 585, L37
Mitsuda, K., *et al.* 2007, PASJ, 59, in press
Mitsuda, K., Inoue, H., Koyama, K., Makishima, K. *et al.* 1984, PASJ, 36, 741
Miyamoto, S., Kimura, K., Kitamoto, S., Dotani, T. & Ebisawa, K. 1991, ApJ, 383, 784
Mizuno, T., Kubota, A. & Makishima, K., 2001, ApJ, 554, 1282
Mizuno, T., Miyawaki, R., Ebisawa, *et al.* 2007, PASJ, **59**, in press (astro-ph/0610185)
Orosz, J. A., Groot, P. J., van der Klis, M., McClintock, J. E. *et al.* 2002, ApJ, 568, 845
Pakull, M. & Mirioni, L. 2003, Revista Mexicana de Astronomia y Astrofisica, 15, 197
Petre, R., Okada, K., Mihara, T., Makishima, K. & Colbert, E. J. M. 1994, PASJ, 46, L115
Remillard, R. A. & McClintock, J. E. 2006, ARA&A, 44, 49
Strohmayer, T. E. & Mushotzky, R. F. 2003, ApJL, 586, L61
Takahashi, T. Abe, K., Endo, M., Endo, Y., Ezoe, Y., *et al.* 2007, PASJ, 59, in press
Tanaka, T., Sugiho, M., Kubota, A., Makishima, K. & Takahashi, T. 2005, PASJ, 57, 507
Tanaka, Y. & Shibazaki, N. 1996, ARA&A, 34, 607
Tsunoda, N., Kubota, A., Namiki, M., *et al.* 2007, PASJ, 59, in press (astro-ph/0610495)
Watarai, K. & Mineshige, S. 2001, PASJ, 53, 915
Watarai, K., Mizuno, T. & Mineshige, K. 2001, ApJL, 549, L77
Wijnands, R., van der Klis, M. 2000, ApJ, 528, L93

Richard Mushotzky: The absence of iron lines is puzzling. What is the nature of Fe K feature in galactic black holes in Very High, slim disc states?

Kazuo Makishima: Honestly, I do not know the answer to this question very well. What I can only say is that these objects do not emit very strong iron lines.

Horacio Dottori: Could you say something on the environment of the intermediate-mass black-hole binaries?

Kazuo Makishima: First of all, these objects generally reside in an environment of active star formation. And secondly, they are often surrounded by huge optical nebulosity, possibly a remnant of the explosion which created the central black hole.



SEXTANS CHALYBEVS PRO
DISTANTIIS PER VNICVM OBSERVATOREM
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EXPLI-