Suzaku observation of transient black hole binary XTE J1752−223

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Abstract

Triggered by MAXI team, we carried out a Suzaku observation of XTE J1752-223 at high/soft state. The source was so bright ($>$ 100 mCrab) that we carefully estimated and removed the effect of event pileup at the CCD image peak. Removing the pileup events fallen within $2'.5$ from image peak at least, we extracted the pileup-free X-ray spectra to evaluate with a multi-color disk emission model. The derived disk temperature and inner disk radius were $T_{\rm in} = 0.517 \pm 0.008$ keV and $R_{\rm in}(D/10\ {\rm kpc})^{-1}\sqrt{\cos\theta} = 129.6^{+7.9}_{-6.9}$ km, respectively. Assuming the source as a Schwarzschild black hole at a distance of 3.5 kpc, the derived value of the inner disk implies that the black hole mass is $M{\sim}8.59^{+0.44}_{-0.38}$ $(\sqrt{\cos\theta/\cos 60^\circ})^{-1}$ $M_\odot$, which is reasonable for an ordinary stellar mass black hole binary.

Key words: accretion, accretion disks – black hole physics – stars: individual (XTE J1752−223) – X-rays

1. Introduction

The black hole (BH) candidate XTE J1752−223 was discovered on October 23, 2009 with RXTE/PCA (Markwardt et al. 2009) and its whole picture of the outburst was continuously observed with MAXI. During this occasion the source varies from low/hard state through high/soft state to low/hard state again (Nakahira et al. 2010). Other X-ray satellites, Swift and XMM-Newton, also observed XTE J1752−223, but the BH mass, distance and inclination angle were not well determined.

The observation of Suzaku (Mitsuda et al. 2007) was performed on February 24, 2010 triggered by MAXI team. According to the MAXI's light curve, the state was high/soft at the observation. It is believed that the soft component is well described with the multi-color black body model (MCD model; Mitsuda et al. 1984, Makishima et al. 1986). In this paper we evaluate the Suzaku spectrum to obtain parameters of accretion disk with MCD model and estimate the BH mass.

2. Observation and Data Reduction

2.1. Observation and Data Reduction

Suzaku ovservation of XTE J1752−223 was performed from 2010 Feburuary 24 04:58:00 to Feburuary 25 04:27:24. The X-ray CCD cameras (X-ray Imaging Spectrometer; XIS, Koyama et al. 2007) onboard Suzaku were operated with "burst" and "window" options. The burst time, the window size and the editing mode were "0.3 sec, 1/4 window and 2×2" for both XIS0 and XIS3. The Hard X-ray Detector (HXD; Takahashi et al. 2007) was performed at normal mode. The observation was operated in "HXD nominal position".

Source events were extracted from a rectangle of $8'.6 \times 4'.5$ tracing 1/4 window for XIS0,3. Since the source was bright ($>$ 100 mCrab), we masked the image peak with a circle to avoid the pileup effect whose radius is estimated in §2.2. The HXD-PIN detected the events up to ∼50 keV while the HXD-GSO was not able to detect the events significantly.

2.2. Pileup Estimation

We estimated the pileup affected region by comparing the spectra extracted with various masks.We fitted the $3'.5$ masked spectrum with a MCD model using 1.2–4 keV band spectrum, and evaluated the ratio between the 0–$3'.0$ masked spectra and the MCD model derived above. The result of XIS3 is shown in Fig.2. We see significant deviation in the ratios with masks whose radii are less than $3'.0$.

In order to verify the sameness of the spectra whose radius $> 2'.5$, we performed simultaneous fit with the

$3'.5$ masked spectrum. Possible uncertainty of ancillary response files (arfs) is compensated with a free constant factor in the fitting. The sameness of the spectral shape was estimated by null hypothesis probability (NHP) derived by the fitting with a MCD model using 1.2–4 keV band spectrum. Figure 3 shows the NHP for each radius of the mask 0–$3'.0$. From Fig.3 we found that the shapes of the spectra with masks whose radii is $< 2'.5$ (for XIS0) and $< 3'.0$ (for XIS3) are different from $3'.5$ masked spectrum with NHP of $< 10\%$. Thus we should exclude within $2'.5$ (for XIS0) and within $3'.0$ (for XIS3) from the image peak to avoid pileup effect.

3. Analysis

DISKBB is the simplest MCD model and spectrum in the high/soft state well described by sum of DISKBB and power-law (PL) whose photon index of $\Gamma \sim 2$–2.5, in general. We fitted the sum of XIS0 and XIS3 pileup-free spectra with HXD-PIN spectrum with a DISKBB and a PL model. The fit for the entire band spectra was not acceptable (χ^2/dof=174.63/142) due to the structure in 5–7 keV band. In order to forcus the shape of MCD, here we fitted the spectra ignoring 5–7 keV band. The best fit parameters are shown in table 1 and calculated flux was $3.53^{+0.04}_{-0.07}\times10^{-9}$ erg s^{-1}cm^{-2} in 2–10 keV band. The errors were estimated with 90 % confidence range.

4. Discussion

The "disk norm" in table 1 is given by

$$[(R_{\rm in}/1\ {\rm km})/(D/10\ {\rm kpc})]^2 \cos\theta\ ,$$

where $R_{\rm in}$ is "an apparent" inner disk radius, D is distance to the source, and θ is angle of the disk ($\theta = 0$ is face-on). Thus we obtained the apparent inner disk radius of $R_{\rm in}(D/10\ {\rm kpc})^{-1}\sqrt{\cos\theta} = 129.6^{+7.9}_{-6.9}$ km. The "realistic" inner disk radius is given by $\xi\kappa^2 R_{\rm in}$ where κ is spectral hardening factor and the value $\sim$1.7–2.0 (e.g., Shimura & Takahara 1995), and ξ is a correction factor of the order of unity (e.g., Kubota et al. 1998). Here we adopt $D = 3.5$ kpc according to Shaposhnikov et al. (2010), and we also employ $\kappa = 1.7$ and $\xi = 0.412$. Then we obtained the realistic inner disk radius $\xi\kappa^2 R_{\rm in} \sim 76.4^{+3.9}_{-3.4}$ $(\sqrt{\cos\theta/\cos 60^\circ})^{-1}$ km. Assuming $R_{\rm in} = 6R_g$ (i.e. Schwarzschild BH), where R_g is gravitational radius GM/c^2 (G is gravitational constant, M is BH mass, and c is velocity of light), we obtain the BH mass of $M \sim 8.59^{+0.44}_{-0.38}$ $(\sqrt{\cos\theta/\cos 60^\circ})^{-1}$ $M_\odot$, which is reasonable value for an ordinary stellar mass BH binary.

We note that the obtained $T_{\rm in} = 0.517\pm0.008$ keV is slightly lower than that derived by Reis et al. (2010). The discrepancy may be caused by the difference of masked regions to reduce pileup effect. Here we exclude larger region to avoid the effect than that they employed, $30''$ squared region around the peak.

5. Conclusion

We analyzed data of XTE J1752-223 in high/soft state observed with Suzaku. We carefully estimated the pileup affected region and found that region of $2.5'$ and $3.0'$ around image peak should be excluded to avoid the pileup effect for XIS0 and XIS3, respectively. We fitted the derived pileup free spectra with a MCD and a PL model ignoring 5–7 keV band. The model requires an inner disk temperature of 0.517 ± 0.008 keV and inner disk radius of $R_{\rm in}(D/10\ {\rm kpc})^{-1}\sqrt{\cos\theta} = 129^{+7.9}_{-6.9}$ km, which suggest the object should be considered as an ordinary stellar mass Schwarzschild BH at a distance of D = 3.5 kpc.

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Table 1. Best-fit parameters on the DISKBB + PL model

	N_{H} [cm^{-2}]	T_{in} [keV]	disk norm* [10^3]	Γ	PL norm†	χ^2/dof
entire band	0.44±0.04	0.519±0.008	$16.3^{+2.0}_{-1.7}$	2.05±0.11	$0.08^{+0.03}_{-0.02}$	174.63/142
ignore 5–7 keV	0.45±0.04	0.517±0.008	$16.8^{+2.1}_{-1.8}$	1.95±0.11	0.06±0.02	138.84/127

Notes. Errors represents 90% confidence.

* Normalization is defined as $[(R_{\mathrm{in}}/1\ \mathrm{km})/(D/10\ \mathrm{kpc})]^2 \cos\theta$.

† PL normalization at 1 keV in the unit of photons s^{-1} keV^{-1}.

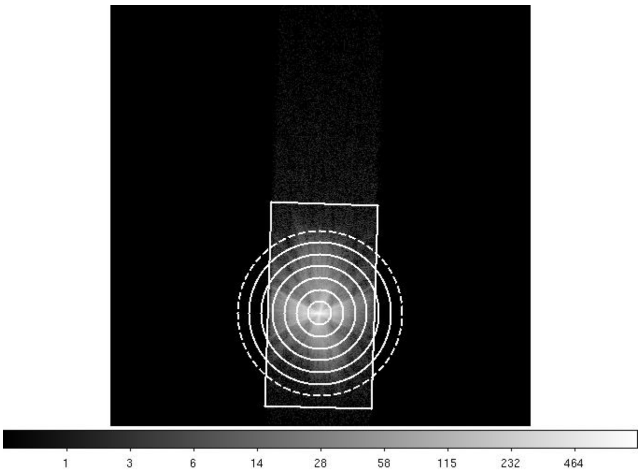

Fig. 1. XIS3 image. Source region (box) and masked region (circle). Radii of masked region change per 0′.5. Outermost radius is 3′.5 (dashed line). Events extracted from the region with 3′.5 masked should be suffered from least pileup effect.

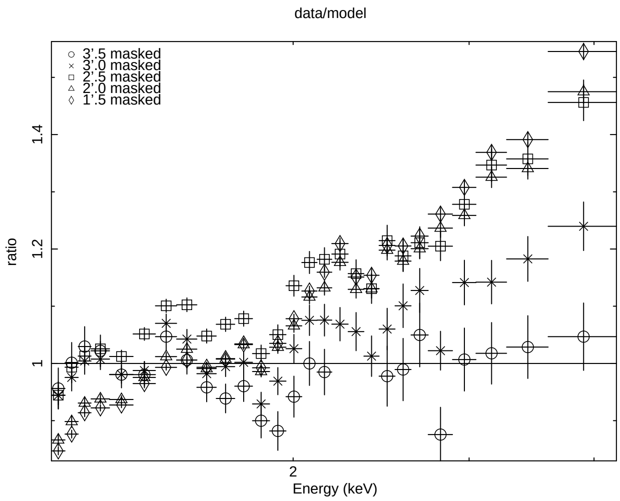

Fig. 2. Ratio each 0–3′.5 masked spectra with the model derived by fitting 3′.5 masked spectrum for XIS3.

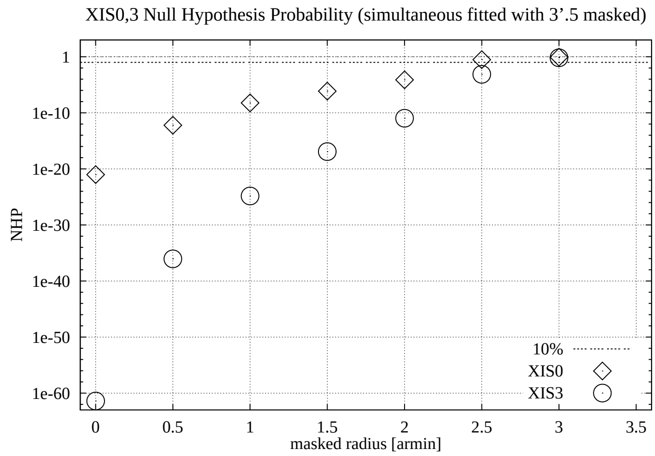

Fig. 3. Null hypothesis probability derived by simultaneous fit of each 0–3′ masked spectra together and 3′.5 masked spectrum.

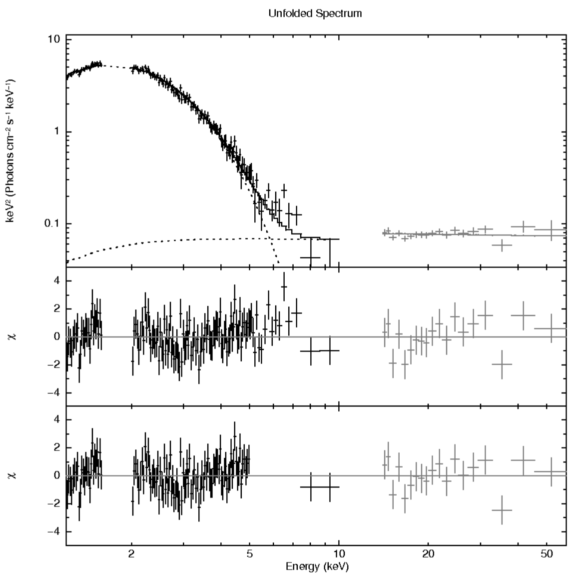

Fig. 4. $\nu F\nu$ spectrum of XTE J1752-223 from the best fit DISKBB plus PL model using the entire band (top panel), residuals between the data and model using the entire band (middle panel), residuals between the data and best fit model ignoring 5–7 band (bottom panel).