A Truncated Disk of the Black Hole in GX 339-4 Observed with Suzaku

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Abstract

We re-analyzed the Suzaku data of the black hole binary GX 339-4, obtained in 2007 February. We observe an Fe-K emission line in the XIS spectrum, but the data do not require its extremely relativistic broadening claimed by Miller et al. (2008). Furthermore, the disk emission seen in the softest end of the continuum yields $R_{\rm in}/\ R_{\rm g} \sim 11$, assuming a black-hole mass of 7 solar masses and a distance of 8 kpc. Thus, the disk is likely to be truncated at $> 6\ R_{\rm g}$, and hence the Suzaku data can be fully explained in terms of a non-rapidly-spinning black hole (Yamada, Makishima et al. 2009, ApJL, submitted). The above results were obtained using the XIS, HXD-PIN, and HXD-GSO data covering 0.5–300 keV, in which the XIS data were carefully corrected for event pile-up effects and telemetry saturation. The source was found in the "Very High" state, with a 0.5–200 keV luminosity of 3.8×10^{38} erg/s/cm^2. We successfully reproduced the wide-band spectrum as a combination of a power-law with $\Gamma \sim 2.6$, a disk blackbody with $T_{\rm in} \sim 0.7$ keV, a narrow iron line with an $EW \sim 40$ eV, and a reflection with $\Omega/\ 2\ \pi \sim 0.6$. In short, we need a particular caution in quoting a disk penetration down to $\sim R_{\rm g}$.

Key words: workshop: proceedings — individual (GX 339-4) — X-rays: binaries

1. Introduction

X-ray emission from mass-accreting black holes provides valuable probes into general relativity. Such examples include broad Fe-K lines, thought to reflect relativistic effects around BHs. These days, possible broad Fe-K line emitters are found in black hole binaries (BHBs) (Miller et al. 2007), including in particular GX 339−4. This BHB has a binary period of ~ 1.7 day, a mass of $M_{\rm BH} >\sim 6\ M_\odot$ (Hynes et al. 2004), a distance of ~ 8 kpc (Zdziarski et al. 2004), and an inclination of $i \sim 25^\circ$ (Gallo et al. 2004). This BHB brightened up in late 2006 (Swank et al. 2006), and was observed with *Suzaku* in 2007 February. Analyzing the obtained spectra, Miller et al. (2008), identified a broad Fe-K feature, and argued that the object is an extreme Kerr BH with $R_{\rm in} \sim R_{\rm g}$.

We noticed not only that the *Suzaku* XIS data of GX 339−4 suffer heavy photon pile up effects and a telemetry saturation, which MEA08 did not correct for, but also that the broad line is strongly dependent on the chose of the underlying continuum. We hence carefully re-analyzed the same *Suzaku* data, concluding that the disk is truncated at $R_{\rm in}/\ R_{\rm g} \sim 11$.

2. The continuum and the broad iron line

We tentatively fitted XIS0 spectrum from $0 - 4'$ (black one in Figure 1a), by a power-law (PL) plus `diskBB` model, but ignoring the 4–7 keV range. When using the PL photon index of $\Gamma = 2.2$ which is found with the XIS data (appended by Miller 2009), the ratio, shown in red in Figure 1, indeed revealed the broad Fe-K line feature. However, the feature becomes much narrower and weaker, if we employ $\Gamma = 2.44$, shown in blue in Figure 1. Thus, the large Fe-K line width claimed by Miller et al. 2008, in fact, depends on the employed continuum slopes, The slope would not differ by $\Delta\Gamma \sim 0.2$ between the XIS and PIN (suzaku memo-2008-06) and the softer index is preferred by HXD-PIN.

3. A preliminary spectral model fitting

We analyzed the spectra from $> 3'$ to avoid the pile-up distortion. We chose a tentative spectral model consisting of a PL, a reflection associated to it, and a `diskBB`. and a relativistic line model (`diskline`(Fabian et al. 1989). This model was moderately successful ($\chi^2/\nu = 136.1/125$). Figure 2a shows the residuals when

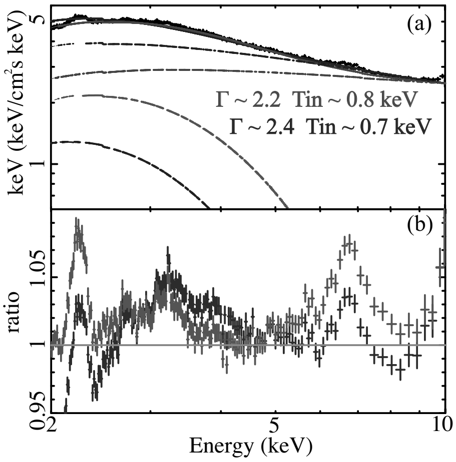

Fig. 1. (a) The uncorrected XIS0 spectrum from the $0' - 4'$ region and different PL+ diskBB models. (b) The spectra divided by the same models as shown in (a).

an iron line is excluded from this model, while figure 2b shows that from this model, yielding a disk temperature of $T_{\rm in} = 0.72$ keV, a reflector solid angle of $\Omega/2\pi = 0.56$, $\Gamma = 2.64$ for the PL, $E_{\rm c} = 6.95^{+0.48}_{-0.22}$ keV and $R_{\rm Fe} < 12.3 R_{\rm g}$ (down to the model limit at $6R_{\rm g}$). This $R_{\rm in}$ is consistent with either a Schwarzschild BH or a one with significant rotation. However, the derived line equivalent width (EW), 203^{+52}_{-67} eV, is too large as expected from the theoretical estimations (George & Fabian 1991).

The above fit gave a rather high value of $E_{\rm c}$, suggestive of an ionized reprocessor. We hence replaced `pexrav` with `pexriv` and the `diskline` model with a simple narrow Gaussian. Then, as shown in figure 2c, the fit was further improved and became acceptable ($\chi^2/\nu = 120.5/124$), when the iron abundance is 1.6 ± 0.2 times solar. (Fixing this at 1.0 solar resulted in $\chi^2/\nu = 151.9/125$.) The model yielded $\Omega/2\pi = 0.58 \pm 0.04$, and the ionization parameter $\xi = 41.3^{+81}_{-36.5}$. The narrow Gaussian has $E_{\rm c} = 6.83^{+0.17}_{-0.16}$ keV, and an EW of 31 ± 23 eV. The continuum parameters were determined as $T_{\rm in} = 0.67 \pm 0.01$ keV, $R_{\rm in}(\sqrt{\cos i}/\sqrt{\cos 30^\circ}) = (50 \pm 5) d_8$ km after applying the correction factor of 1.18, and $\Gamma = 2.66^{+0.02}_{-0.04}$. The column density of neutral material is 6.2×10^{21} cm^2. The obtained $R_{\rm in}$ is in fact a lower limit, because the PL component is considered to result from thermal Comptonization of soft disk photons by some hot electron clouds (Kubota & Makishima 2004). Since the 0.5–200 keV photon number in the PL component is ~ 4 times larger than that contained in the 0.5–10 keV `diskBB` emission, the estimated radius will increase by a factor of $\sqrt{1+4}$, to $R_{\rm in} \sim 112$ km or ~ 11 $R_{\rm g}$, assuming a black-hole mass of 7 solar masses and a distance of 8 kpc. Figure 2d shows the $\nu F\nu$ spectrum corresponding to the narrow-line solution, in which the detector response was removed. Thus, the disk emission is not a dominant component even in energies below ~ 5 keV.

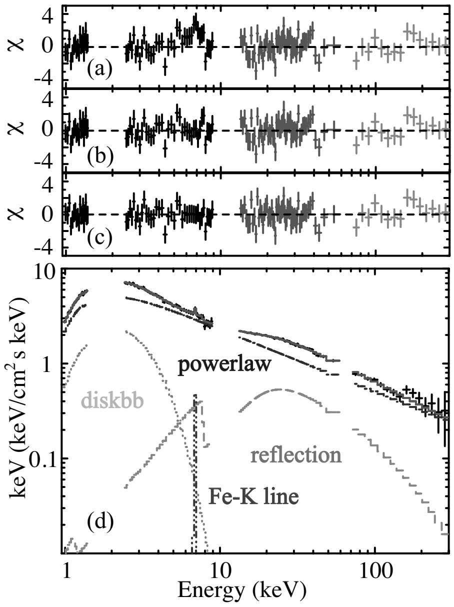

Fig. 2. (a) Residuals from a fit with a diskBB+PL+reflection (neutral) model. (b) Those from a diskBB+PL+reflection (neutral) +diskline model. (c) Residuals from a fit with diskBB, a PL, an ionized reflection, and a narrow Gaussian. (d)A deconvolved $\nu F\nu$ form of the data (black) and the models as shown in (c).

4. Summary

The present value of $R_{\rm in}/\ R_{\rm g} \sim 11$ suggests that the disk gradually retreats as the system evolves from the High/Soft state to deeper Very High states (Kubota & Done 2004; Done & Kubota 2006). As we have shown so far, the *Suzaku* data suggest that the optically-thick accretion disk is truncated at a radius significantly larger than $R_{\rm g}$. Further refinement and examination of the derived spectrum model, as well as comparison with other data of this object, will be reported elsewhere.

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