Active galaxy 4U 1344-60: did the relativistic line disappear?

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ABSTRACT

Context. X-ray bright active galactic nuclei represent a unique astrophysical laboratory for studying accretion physics around supermassive black holes.

Aims. 4U 1344-60 is a bright Seyfert galaxy which revealed relativistic reflection features in the archival XMM-Newton observation.

Methods. We present the spectroscopic results of new data obtained with the Suzaku satellite and compare them with the previous XMM-Newton observation.

Results. The X-ray continuum of 4U 1344-60 can be well described by a power-law component with the photon index $\Gamma \approx 1.7$ modified by a fully and partially covering local absorbers. We measured a substantial decrease of the fraction of the partially absorbed radiation from around 45% in the XMM-Newton observation to less than 10% in the Suzaku observation while the power-law slope remains constant within uncertainties. The iron line in the Suzaku spectrum is relatively narrow, $\sigma = (0.08 \pm 0.02)$ keV, without any suggestion for relativistic broadening. Regarding this, we interpret the iron line in the archival XMM-Newton spectrum as a narrow line of the same width plus an additional red-shifted emission around 6.1 keV.

Conclusions. No evidence of the relativistic reflection is present in the Suzaku spectra. The detected red-shifted iron line during the XMM-Newton observation could be a temporary feature either due to locally enhanced emission or decreased ionisation in the innermost accretion flow.

Key words. Galaxies: active – Galaxies: Seyfert – Galaxies: individual: 4U 1344-60

1. Introduction

Bright active galaxies provide a good opportunity to probe accretion physics in the strong gravity regime and to reveal the basic parameters of the accreting black hole (see e.g. Reynolds & Nowak 2003). In particular, the black hole angular momentum can be constrained from the relativistic features in the spectra originating in the closest neighbourhood to the black hole. Suitable tools for this purpose are the high-throughput X-ray detectors on space missions such as XMM-Newton (Jansen et al. 2001) and Suzaku (Mitsuda et al. 2007) whose data analysis we are presenting in this paper.

A sizeable sample of active galactic nuclei (AGNs) with relativistically broadened iron lines was studied by Guainazzi et al. (2006) and later by de La Calle Pérez et al. (2010). Different samples of Seyfert galaxies observed by the XMM-Newton satellite were also examined by Nandra et al. (2007), Brenneman & Reynolds (2009), and Bhavani & Nandra (2011). Broad iron lines in quasars were studied by Jiménez-Bailón et al. (2005). All groups concluded that X-ray spectra of a substantial fraction of AGNs possess a relativistically broadened iron line. The fraction increases with longer-exposed observations providing better statistics for spectroscopic studies.

4U 1344-60, the subject of the study discussed in this paper, is a bright (about 2 millicrabs) and nearby source but it has not been intensively studied so far due to its low Galactic latitude ($|\beta|=1.5^\circ$). Although its X-ray spectrum is heavily absorbed by the Galactic interstellar matter ($N_H \approx 1 \times 10^{22}$ cm$^{-2}$) it has clearly revealed an emission excess in the broadened red wing of the iron line in a previous XMM-Newton observation (Piconcelli et al. 2006).

4U 1344-60 was discovered for the first time by the X-ray satellite Uhuru. In the XMM-Newton observation of Centaurus B, 4U 1344-60 appeared at the edge of the field (Obs.ID: 0092140101). Piconcelli et al. (2006) studied the EPIC-pn spectrum together with the optical observations of the source. The optical spectrum allowed for a classification of the source as an active galaxy of an intermediate type. The cosmological redshift was derived to be $z = 0.012 \pm 0.002$. Its flux, $F_{\text{XMM}}^{\text{2-10 keV}} = 3.6 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$, makes it one of the brightest AGN in the hard X-ray sky. The luminosity, $L_{\text{XMM}}^{\text{2-10 keV}} = 1.5 \times 10^{43}$ erg/s, is typical for Seyfert galaxies. 4U 1344-60 was observed by Integral (Bird et al. 2010) with its hard X-ray flux $F_{\text{Integral}}^{\text{20-40 keV}} = (3.18 \pm 0.08) \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$ and $F_{\text{Integral}}^{\text{40-100 keV}} = (4.1 \pm 0.2) \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$. It was also detected in the Swift-BAT survey with $F_{\text{Swift-BAT}}^{\text{15-150 keV}} \approx (9.0 \pm 0.3) \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$ (Busoniano et al. 2010).

Residuals in the energy range, where emission features by iron line are expected, were formerly analysed by Piconcelli et al. (2006) in the XMM-Newton observation. A model consisting of the power-law continuum plus a narrow unresolved Gaussian line gave an unacceptable fit. If the line profile was allowed to be distorted by relativistic effects the fit was significantly improved. The inner disc radius was found to be within 10 gravitational radii ($r_g \equiv \frac{M}{c^2}$). The outer one was larger than

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90 r_g with a fixed radial emissivity index q = 2.5. The inclination of the disk was found to be around 20 degrees. The equivalent width of the line was about 400 eV.

4U 1344-60 also exhibited a complex absorption in the X-ray spectrum. Piconcelli et al. (2006) suggested the presence of a partially covering absorber to explain a remarkably flat power law describing the data. A combined analysis of the XMM-Newton and Integral observation was later done by Panessa et al. (2008), who concluded that the spectrum is affected by one fully and two partially covering absorbers with substantial column densities ($N_H^1 \approx 5 \times 10^{22}$ cm$^{-2}$, and $N_H^2 \approx 4 \times 10^{23}$ cm$^{-2}$) and covering fractions around 50%.

In this paper, we present new spectroscopic results of the recent observation of 4U 1344-60 obtained with the Suzaku satellite. We compare them with the archival XMM-Newton data, which we re-analysed. The paper is organised as follows. Sect. 2 describes the data reduction of the Suzaku XIS and HXD/PIN, and also the re-analysis of the XMM-Newton data. The basic timing and spectral properties of the Suzaku observation are presented in Sect. 3. We compare the spectral results from the Suzaku observation with the archival XMM-Newton data in Sect. 4. The achieved results are discussed in Sect. 5 and the main conclusions are drawn in Sect. 6. The timing and spectral analysis of Centaurus B is presented in the Appendix A, as well as the estimate of its contribution to the 4U 1344-60 HXD/PIN spectrum.

2. Data reduction and analysis

4U 1344-60 was observed by the Suzaku satellite on January 2011 (obs. ID 705058010) for the total exposure of 100 ks. The observation was performed using XIS-nominal position. It was accompanied by a short 10 ks observation pointed to the radio-galaxy Centaurus B (obs. ID 705059010), which is a neighbouring source on the X-ray sky. Due to its proximity, the HXD/PIN spectrum of 4U 1344-60 is likely to be contaminated. The short observation of Centaurus B was performed to measure its flux and spectral properties below 10 keV with the XIS detectors, in order to estimate its contribution to the HXD/PIN spectrum of 4U 1344-60. This observation strategy was possible only thanks to the very low short-time variability of the Centaurus B and its simple power-law shaped X-ray spectrum, as was suggested from the previous observations by the ASCA and XMM-Newton satellites (see Appendix).

We used the Heasoft package version 6.11. for the data reduction and also for the subsequent spectral and timing analysis. The data were processed standardly following the Suzaku Data Reduction Guide for all XIS detectors, we combined both 3x3 and 5x5 modes to extract the event files. The source spectra of 4U 1344-60 and Centaurus B were obtained from a circle around the centre of the point spread function with the radius of 260 arcsec. We defined the background extraction region as an annulus around the source circle with the outer radius of 360 arcsec to avoid any contamination from the calibration source. We created the related response matrices and ancillary response files using the tools xisrmfgen and xissimarfgen. The HXD/PIN spectra were reduced with the tool hxdpinxbrs. The tuned background files were used for modelling the non X-ray background. The standard method was used to account for cosmic X-ray background as described in the Suzaku Data Reduction Guide.

Cross-normalisation between the Suzaku detectors were fixed to 1 for XIS 0, free for XIS 1 and XIS 3, and fixed to 1.16 for HXD/PIN. Fits were performed in the 1-10 keV and 15-60 keV energy ranges for the XIS and HXD/PIN, respectively. The data below 1 keV were not included due to large Galactic absorption. The XIS 1 data in the energy range 1.6-2.3 keV were ignored due to calibration uncertainties. We used C-statistics (Cash 1979) for fitting the (unbinned) data, which employs the appropriate Poisson distribution of count fluctuations. However, we express the goodness of the fit also with the more familiar $\chi^2$ statistics. Only for this purpose, we binned the spectra to contain at least 30 counts per bin because the Gaussian smooth distribution of count fluctuations is good only for a sufficient number of counts.

Fig. 1. XIS0, XIS 1, XIS 3, and HXD/PIN (all background subtracted) light curves in the 0.5 – 10 keV, or 15 – 60 keV energy range, respectively. The time bin size is 4096 s.

Fig. 2. XIS0 (background subtracted) light curves in different spectral bands: 0.5 – 2 keV (upper panel), and 2 – 10 keV (middle panel). Their ratio is plotted in the bottom panel. The time bin size is 4096 s.

1. http://heasarc.nasa.gov/heasoft/
2. http://heasarc.nasa.gov/docs/suzaku/analysis/abc/
The time-averaged spectra of 4U 1344-60 is background-dominated with the 27% of

The only clear residuals from this simple model are around 10 keV spectra (see Figure 2).

The 15-60 keV flux of 4U 1344-60 is approximately 8 × 10⁻¹² erg cm⁻² s⁻¹ while the estimated flux from the XIS spectra of Cen B is only 8 × 10⁻¹² erg cm⁻² s⁻¹, i.e. one order of magnitude lower.

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Fig. 5. Comparison of Suzaku and XMM-Newton data residuals. Up: data residuals from the identical underlying model consisting of an absorbed power law and a Gaussian line. Bottom: data residuals from the final model containing an additional absorber with different covering fraction and slightly different slope of the power law for the XMM-Newton and the Suzaku observation. The front-illuminated spectra of XIS0 and XIS3 are jointly shown by black data points, the back-illuminated XIS1 are red, and the EPIC-pn data are blue and emphasised by small circles. The data are binned for plotting purposes only.

Table 1. Spectral analysis of 4U 1344-60 - the model parameters.

| model component | parameter | flat power-law model | 'part. cov.' model | complex model 'fix' | complex model 'free' |
|-----------------|-----------|----------------------|--------------------|---------------------|----------------------|
|                 |           | Suzaku | XMM | Suzaku | XMM | Suzaku | XMM | Suzaku | XMM | Suzaku | XMM | Suzaku |
| local absorption | $\eta_{\text{I,full}}$ [$10^{22}$ cm$^{-2}$] | 0.86$^{+0.07}_{-0.06}$ | 0.93 $\pm$ 0.02 | 0.92 $\pm$ 0.02 | 0.95 $\pm$ 0.02 | 0.98 $\pm$ 0.02 |
|                 | $\eta_{\text{I,part}}$ [$10^{22}$ cm$^{-2}$] | ... | 7.5$^{+1.3}_{-1.2}$ | 9.3$^{+1.3}_{-1.2}$ | 8.2 $\pm$ 1.5 |
|                 | cov. fraction [%] | ... | 44$^{+15}_{-13}$ | 6 $\pm$ 3 | 50 $\pm$ 3 | 5 $\pm$ 3 | 41$^{+15}_{-13}$ | 10 $\pm$ 6 |
| power law       | $\Gamma$ | 1.26$^{+0.04}_{-0.02}$ | 1.68$^{+0.02}_{-0.01}$ | 1.66$ \pm$ 0.09 | 1.72$ \pm$ 0.02 | 1.72$^{+0.03}_{-0.02}$ | 1.68$^{+0.08}_{-0.09}$ | 1.83 $\pm$ 0.06 |
| reflection       | $R$ | ... | 0.48 $\pm$ 0.05 | 2 $\pm$ 1 |
|                 | $E_{\text{fold}}$ | ... | ... | 100 (f) | 200 $\pm$ 100 |
|                 | $i$ [deg] | ... | ... | 45 (f) | 85 $\pm$ 6 |
|                 | $N_{\text{abs}}$ [$10^{-22}$] | 5.7$^{+0.3}_{-0.4}$ | 10.9 $\pm$ 0.2 | 7.1 $\pm$ 0.4 | 11.0 $\pm$ 0.3 | 7.6$^{+0.7}_{-0.6}$ | 11.2 $\pm$ 0.2 | 7.5 $\pm$ 0.5 | 12.2 $\pm$ 0.6 |
| Gaussian line   | $E_{\text{rest}}$ [keV] | 6.26$^{+0.08}_{-0.07}$ | 6.40 $\pm$ 0.01 | 6.29$^{+0.06}_{-0.07}$ | 6.40 $\pm$ 0.01 | ... | ... |
|                 | $\sigma$ [keV] | 0.23$^{+0.09}_{-0.08}$ | 0.08$^{+0.02}_{-0.01}$ | 0.21$^{+0.06}_{-0.07}$ | 0.08 $\pm$ 0.02 | ... | ... |
|                 | $N_{\text{line}}$ [$10^{-3}$] | 10 $\pm$ 3 | 4.7$^{+0.6}_{-0.4}$ | 9 $\pm$ 3 | 4.7$^{+0.5}_{-0.6}$ | ... | ... |
| fit goodness    | $C/\nu$ | 9543/9110 | 9484/9108 | 9477/9114 | 9460/9111 |

Notes. The common parameters for all the fits are the column density of the absorber due to interstellar matter in our Galaxy $\eta_{\text{ISM}} = 1.06 \times 10^{22}$ cm$^{-2}$ (Kalberla et al. 2008), and the cosmological redshift $z = 0.012 \pm 0.002$ (Piconcelli et al. 2006). Solar abundances were assumed in the reflection models. The $N_{\text{abs}}$ parameter is a normalisation factor of the direct component while $N_{\text{line}}$ corresponds to the component affected by the partially covering absorber. They belong to the power-law, or the reflection model by PEXMON, respectively. The sign '(f)' means that the parameter was fixed to that value.
Although this model can satisfactorily explain the XMM-Newton spectrum, the narrow line from the Suzaku spectrum suggests that the reflection originates much further from the central black hole. A major part of the iron-line profile can be indeed explained by the same narrow line as seen in the Suzaku spectrum (see Sect. 4.2 for more discussion). Therefore, we proposed an alternative model explaining the spectral change between the XMM-Newton and Suzaku observation.

4.3. Model with a complex absorber’s variability

Piconcelli et al. (2006) suggested that a partially covering absorption might be responsible for measuring the flat spectral shape in the XMM-Newton spectrum. Employing the model with more complex absorption did not improve the statistical goodness of the fit, but yielded a photon index more similar to the values measured in Seyfert galaxies (e.g. Bianchi et al. 2009). Therefore, we also included the partially covering absorption in our model, first only to the XMM-Newton data. We found the iron-line parameters between the Suzaku and XMM-Newton spectra for the case that the spectral curvature at around 5-6 keV could be explained by partially absorbing clouds, similarly as in spectroscopy studies of different sources by Miller et al. (2008) or Turner et al. (2011).

The photon index of the XMM-Newton spectrum, \( \Gamma = 1.6 \pm 0.1 \), is indeed found to be more consistent with the Suzaku observation. The goodness of the fit is also better than in the previous case with \( C/\nu = 9499/9109 \), or \( \chi^2 = 6408/6216 \approx 1.03 \), respectively. The column density of the fully covering absorption was found to be \( N_{I_{\text{XMM,full}}} = 0.86 \pm 0.11 \times 10^{22} \text{ cm}^{-2} \). The fraction of the partially absorbed power law is 44 ± 12% with the column density \( N_{I_{\text{XMM,part}} = 7.1_{-1.8}^{+2.0}} \times 10^{22} \text{ cm}^{-2} \).

As a next step, we included the partially covering absorption also for the Suzaku data. We simply assumed that only the fraction of the partially covering absorption changed between the times of the two observations (allowing the column densities to vary did not improve the fit significantly). The column density of the fully covering absorption was found to be \( N_{I_{\text{XMM,full}}} = 0.92 \pm 0.02 \times 10^{22} \text{ cm}^{-2} \), the column density of the partial covering \( N_{I_{\text{XMM,part}}} = 7.5_{-1.3}^{+1.7} \times 10^{22} \text{ cm}^{-2} \), and the fraction of the partially absorbed power law 44 ± 15% for the XMM-Newton and 5 ± 3% for the Suzaku spectrum. The fit goodness is \( C/\nu = 9490/9110 \), or \( \chi^2 = 6347/6217 \approx 1.02 \), respectively.

Piconcelli et al. (2006) rejected the model with the partially covering absorber (their “model E”), because it did not explain all the residuals at the iron-line energy band. Indeed, when we unbound the iron-line parameters, we obtained similar results as with the flat-power-law model. The energy of the line is found red-shifted, \( E = 6.3 \pm 0.1 \text{ keV} \), and broadened, \( \sigma = 0.2 \pm 0.1 \text{ keV} \). The equivalent width of the line is \( \text{EW}_{\text{Suzaku}} = 96_{-12} \text{ eV with Suzaku, and} \text{EW}_{\text{XMM}} = 160_{-60} \text{ eV with XMM-Newton.} \) The difference consists in the width of the line. A more detailed look on the iron-line residuals is shown in Fig. 7. The partially-covering absorber does not explain why the iron line is broader and more redshifted in the XMM-Newton spectrum. However, we consider this model further, as it is more consistent with the Suzaku measurements than the flat power-law model.

4.4. More complex reflection models

The iron line detected in the XIS spectra implies the presence of the cold reflection component in the spectrum. We used further PEXMON model (Nandra et al. 2007), which combines the re-
Neither the inclination angle nor the origin of the reflection is known in this galaxy. Piconcelli et al. (2006) determined the type of Seyfert 1.5 galaxy from the optical measurements. In terms of the AGN unification scenario by Antonucci (1993), this would correspond to an intermediate value of the inclination, i.e. \( i \approx 45 \) degrees. Therefore we considered two cases: first one with keeping the values of the inclination and the folding energy fixed in the fit (called as “complex fix” in Table I) and second one with those parameters free (“complex free” in Table I or “final” model hereafter).

The fit goodness of the final model is characterised by \( C/\nu = 9460/9111 \), or \( \chi^2 = 6316/6218 \approx 1.02 \), respectively. The final model is plotted in Figure 8 in the \( 1-10 \) keV energy range. It is demonstrated there how the fraction affected by the partially covering absorber decreased between the two observations. The iron and nickel fluorescent lines as well as the iron edge are the properties of non-relativistic cold reflection.

Although the spectrum is described rather satisfactorily by the final model, the residuals at the energy range around 6 keV still persist in the XMM-Newton spectrum. The data/model ratio is shown in the bottom panel of Fig. 5. In order to demonstrate the significance of the remaining residuals, we added a Gaussian line to the final fit. The fit improves by \( \Delta C = 22 \) (or \( \Delta \chi^2 = 23 \), respectively). This is a statistically significant result as the random improvement should be of order of \( \Delta C \approx 6 \) for the three extra parameters added to the model. The energy of the Gaussian line was found to be \( E = 6.15^{+0.12}_{-0.11} \) keV, the width \( \sigma = 0.21^{+0.12}_{-0.11} \) keV, and normalisation factor \( N_{\text{Gauss}} = 5.8^{+1.9}_{-2.1} \times 10^{-5} \). The equivalent width of this feature is \( 90^{+100}_{-40} \) eV. This additional line can be attributed to a redshifted iron line emitted from inner parts of the accretion disc – see Sect. 5.2 for more discussion on this spectral feature.

### 5. Discussion

#### 5.1. Presence of a partially covering absorber

The Suzaku observation of 4U 1344-60 reveals that the spectrum can be characterised by a photon index of the power law \( \Gamma = 1.7 \), which is a typical value for Seyfert galaxies (Bianchi et al. 2009). The different slope of the XMM-Newton spectrum can be explained by a very low photon index (\( \Gamma \lesssim 1.3 \)) or by the presence of a partially covering absorber. A statistically better fit was obtained with the model with the partially covering absorber. Moreover, this model yields flux at high energies more consistent with the measured values by the Integral and Swift satellite, as demonstrated in Table 2.

High-energy flux predicted by different models (flat power law, model with the partially covering absorber, final model) is compared with the values measured by the Integral and Swift satellite. Better agreement is obtained for the scenario with the partially covering absorber (best for the final model). However, this cannot be regarded as a final proof owing to a possible long-term variability between the non-simultaneous observations. Moreover, a low high-energy cut-off in the flat power law would significantly decrease the predicted hard X-ray flux by this model.

An additional fully-covering absorber with \( N_H \approx 10^{22} \) cm\(^{-2} \) along our line of sight to the nucleus of 4U 1344-60 was required by the data. It may be identified with dust lanes or star-forming regions in the innermost host galaxy disc and not associated with the AGN torus (Matt 2000). A very large contamination from the host galaxy has also been claimed by Vasudevan et al. (2010) in order to explain the infrared spectral energy distribution of 4U 1344-60. This scenario is consistent with the intermediate type classification (see e.g. Maiolino & Rieke 1995), which was originally proposed for 4U 1344-60 by Piconcelli et al. (2006).

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4 A power-law model was used to measure Swift-BAT flux from the 58-month hard X-ray survey data. [http://heasarc.gsfc.nasa.gov/docs/swift/results/b58mon/](http://heasarc.gsfc.nasa.gov/docs/swift/results/b58mon/)
5.2. The iron line in the XMM-Newton observation

Model consisting of a power-law component modified by the fully and partially covering absorber and the narrow iron fluorescent line represents a good simultaneous fit to both, the archival XMM-Newton spectrum, apart from the emission residuals at the moderately redshifted iron line energy band that are entirely related to the XMM-Newton spectrum. Figure 7 shows this energy band for the Suzaku-XIS and XMM-Newton spectrum in detail. Piconcelli et al. (2006) concluded from the XMM-Newton spectrum that the total iron line profile is most likely formed in the innermost accretion disc. However, the line profile measured by Suzaku is much narrower. Therefore, we interpreted the XMM-Newton iron line profile as the narrow component (the same as in the Suzaku spectrum) plus an additional enhanced emission from the innermost accretion disc.

Such an enhanced emission can be explained, e.g., by a temporary irradiation of a part of the accretion disc by a flare, for instance due to a magnetic reconnection in the corona (Czerny et al. 2004; Uzdensky & Goodman 2008). With the energy $E \approx 6.1\,\text{keV}$, it is significantly redshifted when associated to the iron fluorescent line. Therefore, the probable origin is from the innermost accretion disc where the radiation is affected by strong gravitational redshift. A transient emission feature at a similar energy was reported for another Seyfert galaxy NGC 3516 (Turner et al. 2002; Bianchi et al. 2004). Much longer exposure time allowed to trace the temporal evolution of the emission and reveal possible periodicity due to an orbiting spot in the accretion disc (Iwasawa et al. 2004).

We performed several tests using KY model (Dovčiak et al. 2004a) including also non-axisymmetric models (due to the presence of a partially covering absorber). We tried to split the XMM-Newton observation into several parts and look for the change of residuals. We also generated a light curve related only to the redshifted component of the iron line and compared it with the total light curve. However, the insufficient data quality of the short XMM-Newton observation does not allow us to uniquely constrain neither the geometrical structure of the emission region nor its temporal behaviour. It was not possible to distinguish between a “ring-shaped” static emitting region and an orbiting spot. The evidence of such spectral features, however, satisfy the studies of a locally enhanced emission from parts of the accretion disc (Dovčiak et al. 2004a; Goosmann et al. 2007), and will be potentially resolved with future higher resolution X-ray instruments (see e.g. Sochora et al. 2011).

The absence of any relativistic features in the Suzaku spectrum is rather puzzling. Although the 4U 1344-60 observation revealed a complex absorption the Suzaku observation provided us the clearest view on the nucleus. A possible explanation for non-detection of the redshifted iron-line emission could be due to a truncation of the disc at a further radius. A truncated accretion disc was reported for several other sources (see e.g. Matt et al. 2005; Markowitz & Reeves 2009; Svoboda et al. 2010). The physical reason for such a truncation might be due to a very low accretion rate when the accretion flow would be advection dominated and would not form a thin accretion disc (Esin et al. 1997), or due to an over-ionisation of the innermost part of the accretion disc by strong irradiation (Done et al. 2000, Bhayani & Nandra 2011).

The change of the iron line from a relativistically broadened profile to a narrow one as a likely result of the state transition of the source, was reported for a quasar Q0056-363 (Matt et al. 2005). Different photon indices were measured between the two observations but on contrary to our case the flatter index was related to the narrow line detection. An explanation in terms of the disc truncation is therefore unlikely in the case of 4U 1344-60 since it does not suite well in a truncated disc scenario in the hard states of Galactic black hole binaries (Lubiński & Zdziarski 2001; Fender et al. 2004). Moreover, the measured flux during the Suzaku observation is very close to that measured by XMM-Newton. The accretion rate derived from the infrared and X-ray observations is $\dot{M} \approx 0.03\,\text{M}_\odot\,\text{s}^{-1}$ (Vasudevan et al. 2010), which is somewhat typical value for other Seyfert galaxies as well.

Therefore, the ionisation may represent a more plausible explanation. The illuminating flux is a strongly radialy dependent function, especially if the corona is very compact (Matt et al. 1993; Reynolds & Fabian 2008; Svoboda et al. 2012). The innermost disc can be over-ionised owing to the combination of sufficiently high irradiation flux and relatively low density of the accreting material. The ionisation state could, however, locally decrease if the density is locally increased (e.g. due to a shock wave), or if some clouds partly obscure the illuminating source. The latter one could happen during the XMM-Newton observation. As a result, some additional fluorescent emission was detected from the innermost part of the accretion disc.

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Table 2. Flux of 4U 1344-60 measured by different instruments and predicted values by various models.

| instrument (– model) | flux [10^{-11} \text{erg cm}^{-2} \text{s}^{-1}] |
|----------------------|-----------------------------------------------|
|                      | 2 – 10 keV (observed) | 2 – 10 keV (intrinsic) | 20 – 40 keV | 40 – 100 keV |
| XMM - flat $\Gamma$   | 4.16 ± 0.04            | 4.71 ± 0.04            | 7.7 ± 0.1 (p) | 19.0 ± 0.2 (p) | 26.7 ± 0.3 (p) |
| XMM - part. cov.      | 4.04 ± 0.04            | 5.56 ± 0.04            | 4.3 ± 0.1 (p) | 7.5 ± 0.1 (p) | 11.9 ± 0.2 (p) |
| SUZAKU - part. cov.   | 3.83 ± 0.01            | 4.58 ± 0.02            | 3.29 ± 0.02 | 5.49 ± 0.03 (p) | 8.75 ± 0.05 (p) |
| SUZAKU - final        | 3.38 ± 0.01            | 4.67 ± 0.02            | 3.35 ± 0.02 | 4.09 ± 0.03 (p) | 7.44 ± 0.05 (p) |
| Integral              | ...                     | ...                     | 3.2 ± 0.1$^\text{(a)}$ | 4.1 ± 0.2$^\text{(a)}$ | 6.6$^\text{(b)}$ |
| Swift-BAT             | ...                     | ...                     | 2.7 ± 0.1 | 4.0 ± 0.2 | 6.7 ± 0.3 |

Notes. A sign (p) means that the value was predicted by the model from lower X-ray energies. $^\text{(a)}$ Bird et al. (2010). $^\text{(b)}$ Panessa et al. (2008).
The X-ray continuum spectrum of the Seyfert galaxy 4U 1344-60 is dominated by a power law with a standard value of the photon index $\Gamma \approx 1.7\pm0.1$. A narrow fluorescent line with equivalent width $\approx 100\,\text{eV}$ is an apparent feature in the $XIS$ spectra. The width of the iron line is $\sigma = (0.08 \pm 0.02)\,\text{keV}$, i.e. $\approx 900\,\text{km/s}$ of FWHM, suggesting its origin from a distant matter not affected by relativistic smearing. The outermost parts of an accretion disc, broad line region clouds or torus are possible candidates for the reflector. Its profile is, however, significantly narrower than in the archival $XMM-Newton$ observation.

The spectral shape has also changed between the $XMM-Newton$ and $Suzaku$ observation. We interpret this change as due to the presence of a partially covering absorber. The absorbed fraction of the primary radiation has decreased from around 45\% to less than 10\%. The resulting model is then characterised by the same power law slope. It is also consistent with the flux measured (non-simultaneously) by the $Integral$ and $Swift$ satellite at high X-ray energies. The spectral variability makes 4U 1344-60
an interesting target for further examination within a monitoring programme by an X-ray satellite.

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7. Appendix A

7.1. Timing and spectral properties of Centaurus B from ASCA to Suzaku

Centaurus B is one of the nearest and brightest radio galaxies, at cosmological redshift $z = 0.01215$ and flux density $\approx 250$ Jy at 408 MHz (Jones et al. 2001). It is located only at 13' from 4U 1344-60 on the sky. The proximity of the two sources did not allow us to set an observing configuration in which we can exclude Centaurus B from the HXD detectors. Therefore, we required an accompanying 10 ks observation targeted directly on Cen B to estimate its X-ray flux in HXD/PIN energy range. Here, we present our spectral results from this short Suzaku observation using the XIS detectors together with the analysis of its long-term variability. The data reduction procedure is the same as described in Section 2.

Historically, the flux of Centaurus B was found to be only a factor of a few smaller than 4U 1344-60. The observed flux in the 2-10 keV band was $7.3 \pm 0.2 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$ in the archival ASCA observation (Tashiro et al. 1998), and $5.6 \pm 0.2 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$ in the XMM-Newton observation (see also Tashiro et al. 2005), i.e. around 6 – 7 times fainter than 4U 1344-60. The Integral satellite measured hard X-ray fluxes of $f_{20-40\text{keV}} = (0.76 \pm 0.08) \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$ and $f_{50-100\text{keV}} = (1.1 \pm 0.2) \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$ (Bird et al. 2010), around 4 times less than the 4U 1344-60 fluxes.

Figure 10 shows X-ray light curves from the archival ASCA and XMM-Newton observations. The light curves look stationary with no trend in the flux. We fitted the light curves by polynomial fits, and we found that a constant function represents the best fit. Most of the apparent variability in the light curves is due to Poisson noise whose level is shown by the dashed lines in the plots. These results clearly suggest very low variability and, in particular, no trend in the average flux of Centaurus B on a $\approx 100$ ks time-scale.

The 2-10 keV flux measured with the Suzaku/XIS detectors is $(3.9 \pm 0.2) \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$, which follows a continuous decrease of the flux since the ASCA observation (see Table 3). The extrapolated 15-60 keV flux is then approximately $8 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$, which is one order of magnitude less than 4U 1344-60. Thus, in the hard X-ray regime, the flux of 4U 1344-60 clearly dominates.

Although the X-ray brightness of Centaurus B has decreased by a factor of two from the archival ASCA observation in 1995 to the recent Suzaku observation in 2011 the spectral shape has not changed (see Table 3) and can be characterised by a simple power law with the photon index $\Gamma \approx 1.6$ and local absorption with the column density $N_{	ext{H}} \approx 0.7 \times 10^{22}$ cm$^{-2}$. The Suzaku/XIS spectrum of Centaurus B is shown in Fig. 11. The underlying model is TBABS*ZTBABS*POWERLW in the XSPEC notation with the best-fit values from the Table 3. The statistical goodness of the fit can be characterised by $C/\nu = 177/162$ (or $\chi^2/\nu = 169/162 \approx 1.04$). Some residuals from the model are apparent in the spectrum but they are likely due to a less than perfect subtraction of the background, considering the relatively low flux of Cen B (the fraction of the background flux is around 30%).
Figure 10. Light curve of Centaurus B. **Left:** ASCA (200 ks). **Right:** XMM-Newton (30 ks). Horizontal solid lines represent the average flux. Dashed lines show the 3σ levels where σ is the expected standard deviation due to Poisson noise.

Table 3. Evolution of the X-ray flux and spectral slope of Centaurus B.

|                        | ASCA         | XMM-Newton | SUZAKU |
|------------------------|--------------|------------|--------|
| 2 - 10 keV flux [10^{-12} erg cm^{-2} s^{-1}] | 7.3 ± 0.2a   | 5.6 ± 0.2  | 3.9 ± 0.2 |
| photon index           | 1.64 ± 0.07a | 1.6 ± 0.1  | 1.6 ± 0.2 |
| column densityb        | 1.76 ± 0.11a | 1.7 ± 0.1  | 1.7 ± 0.3 |

(a) Tashiro et al., 98
(b) including Galactic absorption (N_H = 1.06 x 10^{22} cm^{-2})

7.2. Estimate of the contamination of the 4U 1344-60 HXD/PIN spectrum by Centaurus B

Although the high energy flux of Centaurus B is one order of magnitude lower, we considered it for the proper cross-normalisation between XIS and HXD/PIN instruments. We performed a fit of HXD/PIN spectrum of 4U 1344-60 with a single and double power-law model. The second power-law component did not improve the fit at all. However, a slightly flatter photon index was preferred using the single power-law model. This would be an expectable influence of the contamination by a harder Centaurus B spectrum with the photon index Γ ≈ 1.6 ± 0.2. Although the determined error of the photon index from the short Suzaku observation is rather high, the value of 1.6 has been consistently measured since the earliest ASCA observation (see Table 3).

We used the best fit values obtained from the analysis of the XIS spectra of Centaurus B multiplied by a constant between 0 and 1. We fitted the XIS and HXD/PIN spectra simultaneously with the final C-value 7847 with 7505 degrees of freedom, or χ^2_{7847} = 5839/5645, respectively. This means only a marginal improvement with ΔC ≃ 3 (or ΔΓ ≃ 1, respectively) compared to the model without any contamination taken into account. The best-fit value for the constant is c = 0.1^{+0.4}_{-0.1}. Given the fact that the flux of Centaurus B is one order of magnitude weaker than for 4U 1344-60 the contamination is 5% at maximum.