RELATIVISTIC IRON K EMISSION AND ABSORPTION IN THE SEYFERT 1.9 GALAXY MCG −5-23-16

V. Braito,1,2 J. N. Reeves,1,2,3 G. C. Dewangan,4 I. George,1,5 R. E. Griffiths,4 A. Markowitz,1,2 K. Nandra,6 D. Porquet,7 A. Ptak,1,2 T. J. Turner,1,5 T. Yaqoob,1,2 and K. Weaver1

Received 2007 March 7; accepted 2007 July 19

ABSTRACT

We present the results of the simultaneous deep XMM-Newton and Chandra observations of the bright Seyfert 1.9 galaxy MCG −5-23-16, which is thought to have one of the best known examples of a relativistically broadened iron Kα line. The time-averaged spectral analysis shows that the iron K-shell complex is best modeled with an unresolved narrow emission component (FWHM < 5000 km s−1, EW ~ 60 eV) plus a broad component. This latter component has FWHM ~ 44,000 km s−1 and EW ~ 50 eV. Its profile is well described by an emission line originating from an accretion disk viewed with an inclination angle ~40°, with the emission arising from within a few tens of gravitational radii of the central black hole. The time-resolved spectral analysis of the XMM-Newton EPIC pn spectrum shows that both the narrow and broad components of the Fe K emission line appear to be constant in time within the errors. We detected a narrow sporadic absorption line at 7.7 keV, which appears to be variable on a timescale of 20 ks. If associated with Fe xxvi Lyo, this absorption is indicative of a possibly variable, high-ionization, high-velocity outflow. The variability of this absorption feature appears to rule out a local (z = 0) origin. The analysis of the XMM-Newton RGS spectrum reveals that the soft X-ray emission of MCG −5-23-16 is likely dominated by several emission lines superimposed on an unabsorbed scattered power-law continuum. The lack of strong Fe L-shell emission, together with the detection of a strong forbidden line in the O vi triplet, is consistent with a scenario in which the soft X-ray emission lines are produced in a plasma photoionized by the nuclear emission.

Subject headings: galaxies: active — galaxies: individual (MCG −5-23-16) — galaxies: Seyfert — X-rays: galaxies

Online material: color figures

1. INTRODUCTION

One of the key issues in high-energy research on active galactic nuclei (AGNs) is the study of the 6.4 keV iron Kα emission line profile, which can provide fundamental diagnostics of the physical and dynamical conditions of AGN central engines. The fluorescent Fe Kα emission line is a prominent and ubiquitous feature in the X-ray spectra of AGNs, and it is believed to be produced in the innermost regions of the AGN, such as the broad-line region (BLR), the circumnuclear obscuring torus, and/or the accretion disk. The profile of the line itself provides direct information on the region from which it originates. If the Fe Kα emission line is produced far from the nucleus, e.g., in the putative torus, its profile is expected to be narrow, while if the line originates in the innermost part of the accretion flow, a broad and asymmetric profile is predicted as a result of the special and general relativistic effects, such as Doppler shifts, gravitational redshift, and light bending (see Fabian et al. 2000; Reynolds & Nowak 2003 for a review). In the latter case, the shape of the profile itself could be used to derive information on the nature of the black hole and accretion disk system.

The observations with the Advanced Satellite for Cosmology and Astrophysics (ASCA) of relativistically broadened iron Fe Kα emission lines in AGNs (Nandra et al. 1997), in particular the detection of a broad and skewed profile in the long ASCA observation of MCG −06-30-15 (Tanaka et al. 1995), were considered the first evidence that at least some line emission originates in the inner part of the accretion disk close to the central black hole. However, the scenario emerging from XMM-Newton and Chandra observations of AGNs appears to be more complex. Indeed, these observations have shown that only a handful of objects show the presence of the relativistically broadened line, while the narrow Fe emission line at 6.4 keV is a ubiquitous feature in many type I AGNs (see Bianchi et al. 2004; Reeves et al. 2004; Yaqoob & Padmanabhan 2004). Furthermore, the broad component appears to be in general weaker than what was expected given the initial ASCA results, and in some cases it may be absent (e.g., NGC 4151: Schurch et al. 2003). These observations have also shown that the interpretation of the Fe profiles can be strongly dependent on the modeling of the underlying continuum, which can be complicated by the presence of complex absorption (e.g., NGC 3783: Reeves et al. 2004; NGC 3516: Turner et al. 2005) and reflection components (see Reeves et al. 2007 and references therein). Furthermore, red- and blueshifted Fe absorption lines, associated with the presence of infalling or outflowing matter in the proximity of the black hole, have been detected in the X-ray spectra of QSOs and Seyfert galaxies (see Cappi 2006 and references therein). These absorption and emission features, together with the complexity of modeling the underlying continuum, make the study of the Fe line profiles more complex and thus feasible only for the brightest objects.
In this framework, MCG –5-23-16 represents one of the best and more robust examples of a relativistically broadened Fe line. MCG –5-23-16 is a nearby (z = 0.008486) Seyfert 1.9 galaxy, with a typical 2–10 keV flux of $\sim 8 \times 10^{-11}$ ergs cm$^{-2}$ s$^{-1}$, making it one of the X-ray–brightest Seyfert galaxies. Previous X-ray observations showed that the X-ray emission of MCG –5-23-16 resembles the classical spectrum of a Compton-thin (i.e., $N_{\text{H}} < 10^{24}$ cm$^{-2}$) Seyfert 2 galaxy, with a soft excess below 1 keV and a column density $N_{\text{H}} \sim 10^{22}$ cm$^{-2}$ (Dewangan et al. 2003; Balestra et al. 2004). Higher energy observations (i.e., above 10 keV) performed with the Rossi X-Ray Timing Explorer (RXTE; Weaver et al. 1998; Mattson & Weaver 2004) and BeppoSAX (Perola et al. 2002; Risaliti 2002) detected a Compton reflection component, which was interpreted as reprocessed emission from the distant molecular torus. A strong broad Fe Kα line was first detected with ASCA (Weaver et al. 1997, 1998), with an equivalent width EW $\sim$ 200 eV, which could be modeled with a broad relativistic line profile ($i \sim 50^\circ$, where $i$ is the disk inclination angle) plus a narrow core at 6.4 keV (equivalent width EW $\sim$ 60 eV). The presence of both these components has been subsequently confirmed with Chandra and XMM-Newton observations. In particular, a narrow iron line component at $\sim$6.4 keV has been clearly revealed with the Chandra observation; the intensity of this narrow core (EW $\sim$ 90 eV; Weaver 2001) was found to be in good agreement with the ASCA results. Meanwhile, two short XMM-Newton observations, whose summed exposure time was $\sim$25 ks, confirmed the presence of an underlying broad component with EW $\sim$ 100 eV (Dewangan et al. 2003; Balestra et al. 2004). However, the relatively short exposure time of the past XMM-Newton observations did not allow the above authors to put strong constraints on the geometry of the emission region. Indeed, neither the inner disk radius nor the inclination angle could be accurately derived using only the XMM-Newton data.

In this paper we present an analysis of the iron K line profile and variability from simultaneous deep XMM-Newton (130 ks) and Chandra (50 ks) observations of MCG –5-23-16; the analysis and results of the simultaneous deep Suzaku (~100 ks) observation are described in Reeves et al. (2007). The XMM-Newton and Chandra observations and data reduction are described in § 2. In § 3 we present the modeling of the time-averaged XMM-Newton EPIC and RGS spectra and the results of the spectral fits of the simultaneous Chandra HETG spectra. In § 4 we report the results obtained with time-resolved spectral analysis, aimed to assess the possible variability of the iron K emission line during the long observation and to investigate the relation (or lack of) between the Fe emission line intensity and the flux of the underlying X-ray continuum. In § 5, we also discuss the appearance of a sporadic absorption feature at 7.7 keV (rest frame) that is indicative of a possibly variable, high-velocity ($v \sim 0.1c$) outflow. The results are discussed and summarized in § 5.

2. OBSERVATIONS AND DATA REDUCTION

In 2005 December, MCG –5-23-16 was observed simultaneously with many different X-ray observatories: Suzaku, XMM-Newton, Chandra, and RXTE; in Table 1 we report the log of the different observations. In this paper we concentrate on the XMM-Newton and Chandra observations, while the Suzaku and RXTE observations and results are described in detail by Reeves et al. (2007).

2.1. XMM-Newton

MCG –5-23-16 was observed with XMM-Newton on 2005 December 8 for a total exposure time of about 130 ks (see Table 1). The pn, MOS1, and MOS2 cameras had the medium filter applied; the MOS1 and MOS2 were operating in Small-Window mode, while the pn was in Large-Window mode. The XMM-Newton data have been processed and cleaned using the Science Analysis Software (SAS ver. 6.5) and analyzed using standard software packages (FTOOLS ver. 6.1 and XSPEC ver. 11.3). In order to define the threshold to filter for high-background time intervals, we extracted the 10–12 keV light curves and filtered out the data when the light curve is $2 \sigma$ above its mean. This screening yielded net exposure times (which also includes a dead-time correction) of 96, 101, and 103 ks for the pn, MOS1, and MOS2, respectively. For the scientific analysis, we concentrated on the EPIC pn data, which have the highest signal-to-noise ratio (S/N), and we used the MOS1 and MOS2 data to check for consistency. Taking into account the brightness of the source (the 2–10 keV count rates are 7.9, 2.7, and 2.8 counts s$^{-1}$ for the pn, MOS1, and MOS2, respectively), we ran the SAS task epatplot to check for possible pileup, and we found that both in the pn and MOS detectors the pileup fraction is below 1%. However, since we have good photon statistics, when analyzing the time-averaged pn spectrum, we decided to use only the pattern 0 data (corresponding to single events), which are better calibrated, and we considered the pattern 0-4 (single and doubles) when we extract spectra with lower exposure times for the time-variability study.
The EPIC pn source spectrum was extracted using a circular region of 37′′, and background data were extracted using two circular regions with an identical radius (37″) centered at ~4′′ from the source. EPIC MOS1 and MOS2 data were extracted using a source extraction region of 27″ and two background regions with identical size (27″) selected on the nearby CCDs. Response matrices and ancillary response files at the source position have been created using the SAS tasks arfgen and rmfgen. Background-subtracted data were then binned to have at least 50 counts in each energy bin. The Reflection Grating Spectrometer (RGS; den Herder et al. 2001) data have been reduced using the standard SAS task rgsproc and the most recent calibration files; the total exposure times are ~97 ks for both RGS1 and RGS2. The RGS1 and RGS2 spectra were binned at the resolution of the instrument (Δλ ≈ 0.1 Å).

2.2. Chandra

Chandra observed MCG – 5-23-16 with the ACIS-S with two relatively short exposures for a total of 50 ks (see Table 1). For this study the Chandra observations were made with the High-Energy Transmission Grating (HETG; Markert et al. 1994) in the focal plane of the High Resolution Mirror Assembly. The Chandra HETG consists of two grating assemblies, a High-Energy Grating (HEG) and a Medium-Energy Grating (MEG); the HEG affords the best spectral resolution in the ~6–7 keV Fe K band currently available (~39 eV, or 1860 km s⁻¹ FWHM at 6.4 keV). The MEG spectral resolution is only half that of the HEG. The HEG also has higher effective area in the Fe K band. The HEG and MEG energy bands are ~0.9–10 keV and ~0.4–8 keV, respectively, although the effective area falls off rapidly with energy near both ends of each bandpass.

The Chandra data were reprocessed with CIAO version 3.2.18 and CALDB version 3.0.1. Spectral redistribution matrices (rmf files) were made with the CIAO tool mkgrmf for each arm (−1 and +1) for the first-order data of each of the gratings, HEG and MEG. Telescope effective area files were made with the CIAO script fullgarf, which drives the CIAO tool mkgarf. Again, separate files were made for each arm of each grating for the first order. The effective areas were corrected for the time-dependent low-energy degradation of the ACIS CCDs using the option available in the mkgarf tool in the stated version of the CIAO and CALDB distribution. Events were extracted from the −1 and +1 arms of the HEG and MEG using strips of width ±3.6″ in the cross-dispersion direction. Light curves and spectra were made from these events, and the spectral fitting described below was performed on first-order spectra combined from the −1 and +1 orders (using response files combined with appropriate weighting), keeping the HEG and MEG spectra separate. The background was not subtracted, as it is negligible in the energy ranges of interest. Examination of the image of the entire detector and cross-dispersion profiles confirmed that there were no nearby sources contaminating the data.

In the following, unless otherwise stated, fit parameters are quoted in the rest frame of the source, and errors are at the 90% confidence level for one interesting parameter (Δχ² = 2.71). Abundances were set to those of Wilms et al. (2000).

3. SPECTRAL ANALYSIS

3.1. The XMM-Newton 0.3–10 keV Continuum

To characterize the X-ray continuum of MCG – 5-23-16, we first fitted the 2–10 keV pn data with a redshifted power-law model, modified by Galactic ($N_H = 8 \times 10^{20} \text{cm}^{-2}$;Dickey & Lockman 1990) and local absorption. For this initial fit, we ignored the 5.0–7.5 keV band, where the Fe Kα emission is expected. This model yielded an acceptable fit ($\chi^2$/dof = 1066.3/987) with $\Gamma \sim 1.65$ and $N_H \sim 1.3 \times 10^{22} \text{cm}^{-2}$. However, the extrapolation of this model to the whole 0.5–10 keV band did not provide a good fit ($\chi^2$/dof = 6024.2/1794). Indeed, it left strong residuals in the soft ($E < 1 \text{keV}$) band and, as expected, at the energy of the Fe Kα emission line. Furthermore, it was not clear whether the relatively flat photon index was intrinsic or indicative of the presence of emission due to Compton reflection. To illustrate this, in Figure 1 we show the ratio of the pn data to an absorbed power-law model fitted over the 2–10 keV energy band (ignoring the 5.0–7.5 keV band), with the photon index fixed to the best-fit value, $\Gamma = 1.82$, derived with detailed modeling of the XMM-Newton and Suzaku broadband spectra (see § 3.3).

In order to model the soft X-ray emission, we added to this model a soft power-law component absorbed only by the Galactic column density. The photon index of this soft component was found to be steep, $\Gamma = 3.13 ± 0.10$, and even at the CCD resolution of the pn instrument, the power-law model left linelike residuals (see Fig. 2; black data points). In particular, an emission line is required by the data ($\Delta \chi^2 = 37$) at 0.92 ± 0.02 keV with a flux of $1.2 \times 10^{-5}$ photons cm⁻² s⁻¹. This emission line and the steep power-law continuum are confirmed by the MOS1 and MOS2 data (see Fig. 2, red and green data points, respectively) and also by the simultaneous Suzaku observation (Reeves et al. 2007). This model gives a 2–10 keV observed flux of ~8.2 × 10⁻¹¹ ergs cm⁻² s⁻¹ and an observed luminosity of ~1.3 × 10³⁴ ergs s⁻¹.

This model is still too simple to describe the overall emission of MCG – 5-23-16, because it does not account for the line emission seen in the RGS spectra (see below). However, it demonstrates that scattering of the nuclear power-law continuum is a plausible explanation for the soft X-ray continuum spectrum.

3.2. The RGS Spectra: Soft X-Ray Spectrum Dominated by Emission Lines

In order to investigate whether the apparent steep soft X-ray photon index could be due to the presence of emission lines that are unresolved at the pn CCD resolution, we analyzed the RGS data. Indeed, thanks to the long exposure (~100 ks), the RGS1...
and RGS2 spectra have enough statistics to attempt a spectral analysis (a total of \( \sim 17,500 \) net counts between RGS1 and RGS2). The first inspection of the RGS data reveals the presence of several soft X-ray emission lines, as well as the energy cutoff at \( \sim 1 \) keV due to the rest-frame absorption. We then rebinned the RGS spectra in X-ray emission lines, as well as the energy cutoff at 0.5 keV. The data below 1 keV still required a contribution from the scattered power-law component of the AGN baseline model, which has \( F_{0.5-2}\ 	ext{keV} \sim 2.1 \times 10^{-13} \text{ergs cm}^{-2} \text{s}^{-1} \). Allowing the photon index of this soft power law to vary, we found that it was no longer unusually steep (\( \Gamma \sim 2.1 \)). Although not well constrained, the abundances for N, O, and Ne required with this model are found to be low, \( Z \sim 0.2 \ Z_\odot \), \( Z_\odot \sim 0.2 \ Z_\odot \), \( Z_{\text{Ne}} \sim 0.4 \ Z_\odot \). In particular, iron is found to be underabundant, with only an upper limit of 0.2 \( Z_\odot \). This is due to the lack of Fe L-shell emission lines and is at odds with the flux measured for the Fe K\( \alpha \) emission line (see § 3.3; Table 3). Furthermore, this value is also in contrast with the Fe abundance measured with the neutral iron edge from the reflection component in the simultaneous Suzaku data (\( Z_{\text{Fe}} = 0.4 \pm 0.1 \ Z_\odot \) at the 90\% confidence level; Reeves et al. 2007).

We then fitted the RGS spectra by adding to the AGN baseline continuum model several unresolved emission lines, fixing both the soft and the hard power-law photon indices to the value found for the AGN primary power-law component (\( \Gamma = 1.82 \); see § 3.3). To account for the excess of counts below 1 keV, five lines are required (\( \Delta \gamma = 70 \); their fluxes are listed in Table 2, together with their EWs, which range from \( \sim 10 \) eV (N \( \text{vii} \)) to \( \sim 46 \) eV (O \( \text{vii} \)). The most likely identifications are \( 2 \rightarrow 1 \) emission lines from H\( \text{viii} \) and He-like O, Ne, and N (see Fig. 3).

We tentatively allowed the line widths to vary and found the O \( \text{vii} \) H\( \alpha \), the O \( \text{vii} \) radiative recombination continuum (RRC), and the Ne \( \text{ix} \) H\( \alpha \) lines to be marginally resolved, while the N \( \text{vii} \) Ly\( \alpha \) and the O \( \text{viii} \) Ly\( \alpha \) lines are unresolved. Although a quantitative measure is beyond the statistics of the present data, from the width of the O \( \text{vii} \) RRC feature (\( \Delta \gamma > 0.739 \) keV) we derived an upper limit of \( k_B T < 24 \) eV on the recombining electron temperature. It is worth noting that this low value indicates that the soft X-ray emission originates in a photoionized, rather than in a collisionally ionized, plasma (Liedahl & Paerels 1996; Liedahl 1999). Taking into account the brightness of the O \( \text{viii} \) and the N \( \text{vii} \) Ly\( \alpha \) line, this photoionized material should also produce RRC.

| Energy (keV) | Flux \( \times 10^{-5} \text{ photons cm}^{-2} \text{s}^{-1} \) | ID | EW (eV) | \( \Delta \gamma \) | \( E_{\text{lab}} \) (keV) |
|-------------|-----------------|-----|--------|---------|-----------------|
| 0.499 \( ^{+0.001} \) \( ^{-0.001} \) | \( 6.6 \times 10^{-39} \) \( ^{+0.39} \) \( ^{-0.26} \) | N \( \text{vii} \) Ly\( \alpha \) | 10 \( ^{+5} \) \( ^{-5} \) | 14.3 | 0.500 |
| 0.564 \( ^{+0.002} \) \( ^{-0.002} \) | \( 2.3 \times 10^{-37} \) \( ^{+0.2} \) \( ^{-0.16} \) | O \( \text{vii} \) He\( \alpha \) | 46.5 \( ^{+26.3} \) \( ^{-29.7} \) | 22.5 | 0.561 (f), 0.569 (i), 0.574 (r) |
| 0.653 \( ^{+0.007} \) \( ^{-0.007} \) | \( 0.6 \times 10^{-36} \) \( ^{+0.13} \) \( ^{-0.11} \) | O \( \text{viii} \) Ly\( \alpha \) | 14.7 \( ^{+0.9} \) \( ^{-1.2} \) | 15.4 | 0.654 |
| 0.732 \( ^{+0.001} \) \( ^{-0.001} \) | \( 0.5 \times 10^{-36} \) \( ^{+0.3} \) \( ^{-0.3} \) | O \( \text{vii} \) RRC | 15.7 \( ^{+11.0} \) \( ^{-10.0} \) | 7.0 | >0.739 |
| 0.903 \( ^{+0.020} \) \( ^{-0.020} \) | \( 0.4 \times 10^{-36} \) \( ^{+0.28} \) \( ^{-0.28} \) | Ne \( \text{ix} \) H\( \alpha \) | 15.9 \( ^{+0.10} \) \( ^{-0.10} \) | 10.4 | 0.905 (f), 0.915 (i), 0.922 (r) |

Notes.—The model of underlying AGN continuum has been parametrized according to the best-fit model obtained with the analysis of the pn spectrum (§ 3). The \( \Gamma \) of the soft power law is tied to the hard power-law component and fixed to the best-fit value (\( \Gamma = 1.82 \)). The energy of each line is quoted in the rest frame. Fluxes and possible identifications are reported in col. (2) and (3), respectively. The EWs are reported in col. (4), and they are calculated against the soft power-law component. In col. (5) the improvement of fit is shown using the C-statistic; the value for the model with no lines is \( C = 455.7 \) for 358 PHA bins. In col. (6) we report the theoretical value for the transition energies.
features from these ions. Neither the O\(\text{viii}\) \((E > 0.871\) keV\) or the N\(\text{vii}\) \((E > 0.667\) keV\) RRC features are clearly detected in the RGS spectra. However, the upper limits on the fluxes of both these features are fairly high \((5.9 \times 10^{-8} \text{ and } 3.8 \times 10^{-8} \text{ photons cm}^{-2} \text{ s}^{-1} \text{ for the O\(\text{viii}\) and N\(\text{vii}\) RRC features, respectively).}\) In particular, at the energy of the O\(\text{viii}\) RRC feature the continuum of MCG \(-5\)-23-16 shows a steep rise due to the emergence of the absorbed power-law component, which also complicates a correct deblending of the Ne\(\text{ix}\) H\(\alpha\) triplet (see below).

The O\(\text{vii}\) H\(\alpha\) and the Ne\(\text{ix}\) H\(\alpha\) lines are both triplets, which cannot be resolved into their forbidden and resonance components with the present statistics. However, it is worth noting that for both the O\(\text{vii}\) H\(\alpha\) and the Ne\(\text{ix}\) H\(\alpha\) lines the energy centroids are close to the energy of the rest-frame forbidden line (see Table 2). This suggests a major contribution from forbidden lines in each of the triplets with respect to the resonance lines.

In the case of Ne\(\text{ix}\) H\(\alpha\), its line energy is close to the low-energy photoelectric cutoff present in the MCG \(-5\)-23-16 spectrum due to the local absorption \((N_H \sim 10^{22} \text{ cm}^{-2})\). Furthermore, the energy is also close to the O\(\text{vii}\) RRC feature \((\sim 0.871\) keV\) and to the Fe\(\text{xviii}\)–Fe\(\text{XIX}\) 3d–2p blend \((0.853–0.926\) keV\). We then included in the model three more Gaussian lines to account for the O\(\text{vii}\) RRC feature and for the decomposition of the Ne\(\text{ix}\) H\(\alpha\) triplet.\(^{10}\) The fit did not statistically improve, and we cannot derive any quantitative information on the ratio between the intensity of the forbidden and resonance line. In the case of the O\(\text{vii}\) H\(\alpha\), we measured a width of \(\sigma = 4.6^{+8.5}_{-3.5}\) eV, which is probably due to the presence of the intercombination and resonance component. In order to confirm that the detected emission is dominated by the forbidden line, we then added two lines and kept the line energies frozen for the forbidden \((0.561\) keV\), the intercombination \((0.569\) keV\) \), and the resonance \((0.574\) keV) line. The measured ratio between the flux of the forbidden and resonance lines (for the latter we use the 90\% upper limit) is \(\gtrsim 1.6\), which again is evidence of a strong contribution from a photoionized plasma (Porquet & Dubau 2000). Furthermore, with this model we found that the width of the forbidden line is now unresolved \((\sigma < 4.7\) eV\). Finally, an inspection of the values of the centroid energies of the detected lines (see Table 2) shows that there are no strong shifts between the theoretical and observed values. The measured shifts of these lines give a value of \(\lesssim 1\) eV (which, for example, for the O\(\text{vii}\) Ly\(\alpha\) corresponds to a velocity \(\lesssim 500\) km s\(^{-1}\)).

In order to test whether these lines can be explained with emission from optically thin gas photoionized by the AGN, we replaced the unresolved emission lines with a grid of photoionized emission models generated by xstar (Bautista & Kallman 2001), which assumes a \(\Gamma \sim 2\) illuminating continuum and a turbulence velocity \(\sigma_t = 100\) km s\(^{-1}\). We found that the RGS data are well explained with this model with an ionization parameter \(\log \xi = 1.29^{+0.11}_{-0.09}\) (see § 3.2).

FIG. 3.—Left: XMM-Newton RGS1 and RGS2 spectra in the 0.4–1.3 keV energy range. The underlying AGN continuum model is composed of an absorbed power law plus a scattered soft power-law component \((\Gamma = 1.82\)\). Several emission lines are clearly detected. The possible identifications of the five brightest lines are also shown. Above \(\sim 0.9\) keV, a steep rise of the continuum is evident, due to the emergence of the absorbed power-law component. Right: Best-fit photoionized plasma model (in the 0.4–1.3 keV), which includes a xstar component with an ionization parameter \(\log \xi = 1.29^{+0.11}_{-0.09}\) (see § 3.2).

\(^{10}\) The energy of the forbidden \((0.905\) keV\), the intercombination \((0.915\) keV\), and the resonance \((0.922\) keV\) components were fixed.
photons from the zero-order of both observations. We created a point-source function (PSF) using the MARX\textsuperscript{11} Chandra simulator. We then fit a model to the Chandra image consisting of a constant component, to account for the background, and two Gaussian components with the centroid positions tied together, to account for both nuclear and extranuclear emission. The model was convolved with the PSF and then compared to the data using the Cash statistic. Initially the image was fit with \( \sigma_x = \sigma_y \), i.e., circular Gaussian models. This gave \( \sigma = 0.39^{+0.23}_{-0.15} \) arcsec for the nuclear component and \( \sigma = 1.57^{+0.78}_{-0.31} \) arcsec for the extranuclear component. The count rates for the two components were \( 1.4 \times 10^{-3} \) and \( 1.2 \times 10^{-3} \) counts s\(^{-1}\). Note that some fraction of these extents is likely due to residual error in the aspect solution, which would effectively increase the PSF. Unfortunately, there are no other on-axis point sources bright enough in the field to check this. Allowing the extranuclear component to be elliptical did not improve the fit significantly; however, it reduced \( C \) by 7.2 for two additional parameters (the additional \( \theta \) parameter and the rotation angle), which is significant at the 2 \( \sigma \) level. It is likely, however, that this asymmetry may be due to aspect errors. As a consistency check, we fitted the zero-order image from the 2000 Chandra observation with the same model. In this case, allowing for ellipticity in either component did not improve the fit significantly. In this fit, the best-fitting parameters were \( \sigma = 0.56^{+0.09}_{-0.12} \) arcsec for the nuclear component and \( \sigma = 2.2^{+0.5}_{-0.6} \) arcsec for the extranuclear component, which is consistent within the errors. This is indicative that around half of the soft X-ray emission is due to the central pointlike source and half to an extended component. Assuming the current cosmology \( H_0 = 71 \text{ km s}^{-1} \text{ Mpc}^{-1} \), \( \Omega_m = 0.73 \), and \( \Omega_m = 0.27 \), the soft X-ray emission of this latter component originates within \( \sim 0.7 \) kpc; this value is in agreement with a possible association with the NLR; indeed, this extension is comparable to the extension of the [O iii] \( \lambda 5007 \) derived with HST data (Ferruit et al. 2000).

3.3. The Iron K Band

We then considered the hard X-ray emission of MCG –5-23-16, using the dual power-law continuum as described above and only the Gaussian emission line at \( \sim 0.9 \) keV. In Figure 4 we show the residuals left by the absorbed power-law model (with \( \Gamma = 1.65 \)) at the energy of Fe K\( \alpha \) band. These residuals clearly reveal the presence of a strong narrow core at the expected energy of the Fe K\( \alpha \) (6.4 keV) and broad wings, which extend from \( \sim 5.7 \) to \( \sim 7 \) keV. The pn data also show a narrow emission line at \( \sim 7 \) keV, due to Fe K\( \beta \), and a drop at 7.1 keV, probably due to a reflection edge. The presence of this latter component was already suggested by the previous short XMM-Newton observations (Dewangan et al. 2003); however, the short exposure of these observations, together with the lack of any simultaneous observation above 10 keV, did not allow the authors to put strong constraints on this feature. We adopted the best-fit model obtained by Reeves et al. (2007) from the simultaneous Suzaku observation for the underlying continuum in order to derive the Fe K\( \alpha \) emission line properties. Indeed, Suzaku’s broadband energy range (0.4–100 keV) allowed these authors to measure the amount of Compton reflection and thus better constrain the continuum in the 2–10 keV energy band. This model is composed of a primary absorbed power-law component with an exponential cutoff at high energies (>200 keV) and a component due to reflection from neutral material (the PEXRAV model in XSPEC; Magdziarz & Zdziarski 1995). The parameters of this reflection component are the reflection fraction, which is defined by the subtending solid angle of the reflector \( R = \Omega/2\pi \approx 1.1 \), an inclination angle \( \theta = 45^\circ \), and an abundance \( Z = 0.4 \) Z\(_{\odot} \). When fitting this model to the pn data, we kept the values of \( Z \), \( R \), and the cutoff energy fixed, since they cannot be determined using the lower energy bandpass of XMM-Newton. After including the reflection component, the residuals no longer show the deep edge at 7.1 keV, which is well modeled with the reflection component (see Fig. 5a). With this model we found that the primary power-law component has a photon index \( \Gamma = 1.82 \pm 0.01 \), absorbed by a neutral column density of \( N_H = (1.49 \pm 0.01) \times 10^{22} \) cm\(^{-2}\). To model the Fe line, we first added narrow Gaussian lines at the energies of Fe K\( \alpha \) and Fe K\( \beta \). For this latter line, we kept the energy fixed at 7.06 keV and fixed its flux to be 12% of the Fe K\( \alpha \) flux. This model clearly leaves an excess of counts at the energy of the 6.4 keV Fe K\( \alpha \) line (see Fig. 5b), which can be accounted for by including a

\textsuperscript{11} See http://space.mit.edu/CXC/MARX.
In order to measure the parameters (i.e., strength and profile) of the broad component, we first derived the width and flux of the narrow core using the simultaneous Chandra observations. We combined the Chandra ±1 MEG and HEG first-order spectra of the combined spectra were rebinned at the maximum spectral resolution of the instruments (Δλ = 0.012 and 0.023 Å for HEG and MEG, respectively), and the spectral fit was minimized with the C-statistic (Cash 1979). We then adopted the Suzaku best-fit model for the underlying 2–8 keV continuum. Thanks to the high resolution of the MEG and HEG instruments, the Chandra HETG residuals clearly reveal the presence of a narrow core at 6.4 keV (see Fig. 6), which is best modeled with a Gaussian line. Although the fit did not statistically improve, we added a second Gaussian line. We also added a Compton shoulder at 6.3 keV, with its normalization set to 20% of the Fe Kα flux (Matt 2002); the fit improved with a good agreement with the upper limit measured with a previous Chandra observation of MCG −5-23-16 (Balestra et al. 2004).

### 3.3.2. The Broad Fe Line

We then adopted the Chandra upper limit on the width of the narrow core for the XMM-Newton fits. The broad component was first modeled adding a second Gaussian line. We also added a Compton shoulder at 6.3 keV, with its normalization set to 20% of the Fe Kα flux (Matt 2002); the fit improved with a good agreement with the upper limit measured with a previous Chandra observation of MCG −5-23-16 (Balestra et al. 2004).

### Table 3

**Results of the Fit for the Mean Spectrum and the Low- and High-Flux States**

| Parameter | Mean | High | Low |
|-----------|------|------|-----|
| Continuum |      |      |     |
| Γ         | 1.82 ± 0.01 | 1.84 ± 0.01 | 1.81 ± 0.01 |
| N_Y         | 1.49 ± 0.01 | 1.50 ± 0.02 | 1.49 ± 0.02 |
| Flux       | 8.16 | 8.84 | 7.39 |
| Narrow Gaussian |      |      |     |
| E          | 6.42 ± 0.01 | 6.41 ± 0.02 | 6.40 ± 0.02 |
| EW         | 61.0 ± 3.3 | 48.1 ± 18 | 81.7 ± 15 |
| N_Y         | 5.4 ± 0.6 | 4.6 ± 1.2 | 6.5 ± 1.2 |
| Broad Gaussian |      |      |     |
| E          | 6.4 ± 0.01 | 6.4 ± 0.01 | 6.4 ± 0.01 |
| σ          | 0.35 ± 0.1 | 0.35 ± 0.13 | 0.37 ± 0.22 |
| EW         | 64.1 ± 19 | 61.7 ± 20 | 75.1 ± 12 |
| N_Y         | 5.9 ± 1.5 | 5.9 ± 2.6 | 6.3 ± 2.6 |
| Diskline |      |      |     |
| R_m         | 48 ± 62 | ... | ... |
| i          | 41 ± 29 | ... | ... |
| EW         | 53 ± 13 | ... | ... |
| N_Y         | 4.6 ± 1.2 | ... | ... |

Notes.—The line energies are expressed in units of keV, while their widths σ and EWs are in eV. The disk radial emissivity has been fixed to q = 3.

- Column density in units of 10²² cm⁻².
- The 2–10 keV flux in units of 10⁻¹¹ ergs cm⁻² s⁻¹.
- Normalization of the Fe line in units of 10⁻² photons cm⁻² s⁻¹.
- The parameter has been kept fixed.

Δχ² = 44 for three additional parameters (χ² = 1932 for 1785 degrees of freedom [dof]). The broad Gaussian component (E = 6.22 ± 0.01 keV) has an EW of 66 ± 19 eV and a width of σ = 0.42 ± 0.14 keV, which corresponds to a velocity of σ_v = 20,000 km s⁻¹ (FWHM = 40,000 km s⁻¹). The broad Gaussian component (E = 6.22 ± 0.01 keV) has an EW of 66 ± 19 eV and a width of σ = 0.42 ± 0.14 keV, which corresponds to a velocity of σ_v = 20,000 km s⁻¹ (FWHM = 40,000 km s⁻¹).

We then tested a relativistic disk-line model (DISKLIN in XSPEC; Fabian et al. 1989); this code models a line profile from an accretion disk around a Schwarzschild black hole. The main parameters of this model are the inner and outer radii of the emitting region on the disk and its inclination. The disk radial emissivity is assumed to be a power law, in the form of r⁻q. For the fit, we fixed the outer radius to be 400R_g (with R_g = GM/c²) and the emissivity q = 3. Finally, we assumed the line to be from neutral Fe Kα. From a statistical point of view, this fit gives a similar result to the model with a broad Gaussian line (χ² = 1928 for 1785 dof); however, the high velocity inferred from the width of the Gaussian line is indicative that the line must be produced close to the central black hole; i.e., within 100R_g, and thus inside the broad-line region. With this model, we find that the inner radius R_in = 48 ± 62 R_g and the inclination angle is i = 41 ± 29 deg, while the EWs of the broad and narrow components are EW_broad = 53 ± 14 eV and EW_narrow = 64 ± 16 eV, respectively. If the constraint on the disk emissivity is relaxed and a flatter emissivity is assumed (q = 2), then a disk inner radius of 6R_g is allowed by the present data. The ratio between the data and this best-fit model is shown in the bottom panel of Figure 5; an absorption line near 8 keV is the only residual. Adding an absorption line to our best-fit model improved the fit (Δχ² = 20 for two additional parameters, [EW] = 30 eV, E = 7.9 keV). Figure 7 shows the resulting EPIC pn spectrum and the best model components are shown. The parameters derived...
for the disk-line did not change significantly; the main difference is a slight reduction in its EW, which became now 46\pm13 eV. Taking into account that this absorption feature is indicative of the presence of an ionized absorber (see §4.1 and 5.3), we tested whether the presence of a more complex absorber could mimic the profile of the detected broad component. We found that the inclusion of two layers of absorption, characterized by a high (log $\xi = 3.7$) and low (log $\xi = 2$) ionization level, did not impact the detection of the broad component and its parameters.

4. VARIABILITY OF THE IRON LINE AND CONTINUUM

During the XMM-Newton observation, the 2–10 keV flux of MCG $-$5-23-16 varied from $\sim7 \times 10^{-11}$ to $\sim9 \times 10^{-11}$ ergs cm$^{-2}$ s$^{-1}$. In order to investigate the possible variability of the line properties and continuum shape, we first tested whether there was any clear difference between the spectra extracted when the source was in relatively higher and lower flux states. We extracted spectra using a 2–10 keV threshold of $<4.6$ counts s$^{-1}$ ($F_{2-10\text{keV}} \sim 7.4 \times 10^{-11}$ ergs cm$^{-2}$ s$^{-1}$) and $>5.5$ counts s$^{-1}$ ($F_{2-10\text{keV}} \gtrsim 8.8 \times 10^{-11}$ ergs cm$^{-2}$ s$^{-1}$). We then fitted both spectra with the previous best-fit model, replacing the disk-line with a broad Gaussian. We found no evidence of variability in either the broad or the narrow component; indeed, their normalizations are consistent within the errors (see Table 3). Furthermore, the width of the broad line is constant. In order to confirm that the line is not strongly variable, we checked the difference spectrum, obtained by subtracting the low- from the high-state data. The difference spectrum can be modeled with an absorbed power law with photon index $\Gamma = 1.80 \pm 0.09$; no strong residuals are left either in the soft band or in the iron K band.

As a second test to assess the possible variability of the Fe emission complex, we divided the XMM-Newton observation into five intervals with a duration of 20 ks each; for the fit we tied all model parameters except the normalization of the primary power-law component. This model gives a statistically acceptable fit for all five spectra. Figure 8 shows the 5.5–8.5 keV residuals to this model for all five intervals; no strong deviations from the model are required at the energy of the iron K$\alpha$ line. We then allowed the normalizations of the narrow and broad components to vary freely. Figures 9a and 9b show the fluxes of the narrow and broad components, respectively. There is no evidence of variability during the present observation; furthermore, the fluxes of both components are consistent within the errors with the values measured in the previous XMM-Newton and Chandra observations (Dewangan et al. 2003; Balestra et al. 2004). This lack of variability can be explained by taking into account that MCG $-$5-23-16 is not highly variable on either short or relatively long timescales; indeed, the source has remained at a similar flux level [$\sim 7 \times 10^{-11}$ ergs cm$^{-2}$ s$^{-1}$] for the last 10 years.

The most striking feature that appears to be variable during the XMM-Newton observation is a possible absorption line at $\sim7.7$ keV ($E \sim 7.66$ keV, observer frame). This feature is present in the average EPIC pn spectrum, but as shown in Figure 8, it is
strongest in the third spectrum (40 ks after the beginning of the XMM-Newton observation). To illustrate this, in Figure 9c we compare the intensity of this absorption feature during the five intervals. For this purpose, we modeled the absorption with an inverted Gaussian line and fixed the energy to the best-fit value found with the spectral analysis of the third interval ($E \sim 7.7$ keV, $|\lambda| = 3.2 \times 10^{-5}$ photons cm$^{-2}$ s$^{-1}$, EW = 52 ± 15 eV). The line is clearly variable, and it appears to be strongest during the interval with the slightly higher 2–10 keV flux (see Fig. 9d), while it is barely detected in the other four spectra.

4.1. A Variable Absorption Feature at 7.7 keV

4.1.1. Epic pn Background and Calibration Checks

Before attempting any further modeling, we performed several tests to exclude that the 7.7 keV absorption feature is due to inappropriate background, binning, or pattern selection. The EPIC pn background near this energy range presents two instrumental lines due to Cu (8.05 keV) and Ni (7.48 keV) Kr emission lines, and an inadequate background selection could in principle cause spurious absorption features. However, several arguments exclude this possibility. First of all, the net count rate ($\sim 2.56$ counts s$^{-1}$) of MCG 5-23-16 in the 5–10 keV band is $\sim 300$ times greater than the background ($\sim 8 \times 10^{-3}$ counts s$^{-1}$). Second, the sporadic nature of the feature is indicative that the feature cannot be an artifact of the background or calibration of the EPIC pn. Finally, there was no background flaring activity during this time interval. We conclude that the feature is not due to instrumental or external background.

In order to exclude the possibility that the 7.7 keV feature is due to a binning effect, we rebinned the pn data of the third interval with a constant energy binning of 80 eV. This choice corresponds to about half of the energy resolution of the EPIC pn camera in this energy range (FWHM $\sim 150$ eV at 6.4 keV; see Ehle et al. 2006). As shown in Figure 10, the residuals left by the time-averaged best-fit model confirm the presence of the feature, thus excluding the possibility that it is an artifact of the choice of the binning.

To exclude a pattern selection effect we then compared the pn spectra extracted with the pattern 0-4 and pattern 0 selection criteria. Although the latter has 30% fewer counts, we found no significant difference in the absorption-line parameters ($\Delta \chi^2 = 26$ for 2 dof; $E \sim 7.7$ keV, EW $\sim 60$ eV). Finally, the presence of an absorption feature is confirmed by the MOS1 and MOS2 spectra extracted in the same time interval. Because of the lower photon statistic, the significance of the absorption line is lower in these spectra; however, both the flux and the energy of the feature are consistent ($|\lambda| = (2.2 \pm 1.8) \times 10^{-5}$ photons cm$^{-2}$ s$^{-1}$, $E = 7.4 \pm 0.2$ keV, $\Delta \chi^2 = 6$; see Table 4) with the values found with the pn data. Furthermore, the presence of the absorption feature is confirmed by the simultaneous Suzaku observation; indeed, a weak absorption feature is present in the time-averaged spectrum (see Fig. 6c in Reeves et al. 2007). The absorption line is weaker than in the XMM-Newton observation, which could be explained if we take into account the apparent sporadic nature of the feature, with a dilution effect due to the longer duration time ($\sim 220$ ks) of the Suzaku observation in the Earth orbit. Although the absorption line is not well constrained in the time-averaged Suzaku spectrum, the energy of the line at 7.8 ± 0.1 keV is coincident with the XMM-Newton data, while the flux of the line is weaker $|\lambda| = (1.8 \pm 0.9) \times 10^{-5}$ photons cm$^{-2}$ s$^{-1}$ (see Table 4).

4.1.2. Modeling the Absorption Feature of the Third Segment

We first fitted the absorption feature, adding a Gaussian-shaped absorption line and keeping its width fixed to $\sigma = 0.1$ keV. The addition of this line improved the fit with a $\Delta \chi^2 = 33$ for two additional parameters ($\chi^2$/dof = 1451/1505). The line energy is 7.72 ± 0.06 keV with an $|\lambda| = 52 \pm 15$ eV ($|\lambda| = (3.2 \pm 0.9) \times 10^{-5}$ photons cm$^{-2}$ s$^{-1}$). Leaving the width of the line free did not improve the fit significantly ($\Delta \chi^2 = 5$ for one additional parameter). With this fit, we find $\sigma = 0.2 \pm 0.1$ keV, EW = 78 ± 29 eV, and an energy consistent with the previous best fit ($E = 7.71 \pm 0.08$ keV). In Figure 11 we show the confidence contour plot of the line parameters (rest-frame energy and intensity), with the line width left free to vary. We also attempted to fit the absorption feature, replacing the Gaussian line with an edge due to K-shell absorption from partially ionized iron. This model gives a best-fit energy of 7.33$^{+0.22}_{-0.13}$ keV and an optical depth of $\tau = 0.09 \pm 0.03$. The fit is statistically acceptable; however, it is worse than the Gaussian absorption model ($\chi^2$/dof = 1465/1505, which

Unfortunately, the Chandra observations do not overlap with this segment of the XMM-Newton spectrum. However, two possible weak absorption features appear to be present at the rest-frame energy of about 7.3 and 7.4 keV (see Fig. 6), suggesting possible variability of the absorber, although the statistical significance of these features is low.

---

12 See http://xmm.vilspa.esa.es/external/xmm_user_support/documentation/uhb/XMM_UHB.html.

13 Unfortunately, the Chandra observations do not overlap with this segment of the XMM-Newton spectrum. However, two possible weak absorption features appear to be present at the rest-frame energy of about 7.3 and 7.4 keV (see Fig. 6), suggesting possible variability of the absorber, although the statistical significance of these features is low.
corresponds to a $\Delta \chi^2 = 14$, worse compared to the absorption line, and more importantly, it is unsuccessful at modeling the residuals at 7.7 keV.

4.1.3. The Significance of the Detection of the Absorption Line

By applying the standard two-parameter $F$-test to the drop in $\chi^2$ of 33 for the addition of an inverted Gaussian at 7.71 keV, we found a null hypothesis probability for adding this extra component of $\sim 4 \times 10^{-8}$. However, as discussed by Protassov et al. (2002), the $F$-test applied in this way could overestimate the true significance of the detected absorption line. In particular, the $F$-test does not take into account the number of bins within which the line is searched, as well as the range of energy where the line might be expected (see Porquet et al. 2004).

To assess the significance of the detection, we then performed Monte Carlo simulations, as described in Porquet et al. (2004) and in Markowitz et al. (2006), for a similar case of a blueshifted Fe Kα absorption line detected in the XMM-Newton observation of IC 4329a. We assumed as our null hypothesis model the best-fit model with no absorption feature, and we simulated 1000 spectra with the photon statistics expected for a 20 ks exposure. Each simulated spectrum was then fitted with the null hypothesis model to obtain a $\chi^2$ value, and we systematically searched for an absorption line over the 4–9 keV energy range, stepping the energy centroid of the Gaussian in increments of 0.1 keV and refitting at each step. We then obtained for each simulated spectrum a minimum $\chi^2$ and created a distribution of 1000 simulated values of the $\Delta \chi^2$ (compared to the null hypothesis model), which was used to construct a cumulative frequency distribution of the $\Delta \chi^2$ expected for a blind line search in the 4–9 keV range. Not a single fake spectrum had a $|\Delta \chi^2| \geq 33$; thus, the inferred probability that the null hypothesis model was correct is <0.1%. Taking into account the number of intervals into which the observation had been split (5), we derive that the line detection is significant at >99.5%.

Finally, we performed a similar Monte Carlo simulation to test the statistical significance of the absorption feature in the MOS spectra. For simplicity, we ran the simulation on MOS1 only, and we found that in this case, the significance is only ~61%, mainly due to the lower S/N of the MOS spectra at this energy. However, the fact that the absorption feature is detected by the pn, both MOS cameras, and Suzaku suggests that the feature is likely real and not an artifact.

4.1.4. The Ionized Absorber Model

As already discussed with X-ray spectroscopic observation of several other Seyfert galaxies (e.g., MCG –6-30-15, Young et al. 2005; NGC 3783, Reeves et al. 2004; Mrk 509, Dadina et al. 2005; Mrk 335, Longinotti et al. 2007; E1821+643, Yaqoob & Serlemitsos 2005; IC 4329a, Markowitz et al. 2006) and QSOs (e.g., PG 1211+143, Pounds et al. 2003; PDS 456, Reeves et al. 2003; APM 08279+5255, Chartas et al. 2002; PG 1115+08, Chartas et al. 2003), a likely candidate for the 7.7 keV feature is blueshifted K-shell absorption due to He- or H-like iron. In particular, if we assume that the line is due to H-like iron (Fe xxv Lyα at 6.97 keV), the observed blueshift suggests that the absorber is outflowing with a velocity of the order of 0.1c.

In order to obtain a more physical representation of the absorber, we replaced the Gaussian line with a model composed of a grid of photoionized absorbers generated by the xstar photoionization code (Bautista & Kallman 2001). For the absorber, we assumed a one-zone photoionization model with half-solar abundances and a turbulence velocity of 1000 km s$^{-1}$. The free parameters of this model are the column density ($N_H$), the outflowing velocity of the absorber ($v_{out}$), and the ionization parameter ($\xi = L/nr^2$, where $L$ is the ionizing luminosity, $n$ is the electron density, and $r$ is the absorber distance). To reproduce the absorption feature, a column density of $\sim 8 \times 10^{22}$ cm$^{-2}$ and an ionization state characterized by log $\xi = 3.7^{+0.2}_{-0.3}$ ergs cm$^{-1}$ are required with an outflow velocity of $(0.09 \pm 0.01)c$ ($\sim 30,000$ km s$^{-1}$). A plot of this best-fit model is shown in Figure 12 (model A). The column density is not well constrained, and we can place only a lower limit of $>2 \times 10^{22}$ cm$^{-2}$. At this ionization level, the Fe K-shell absorption is indeed mainly due to Fe xxvi and is consistent with absorption from highly ionized iron outflowing at $\sim 0.1c$ with respect to systemic.

A lower velocity outflow could in principle be obtained assuming that the feature is due to a Fe xxiv 1s–3p line at 7.78 keV. This is illustrated in Figure 12 (model B), which illustrates an xstar model with a column density of $N_H = 10^{23}$ cm$^{-2}$, an ionization parameter of log $\xi = 3.0$ ergs cm$^{-1}$, and no velocity shift. The absorption line at 7.8 keV indeed corresponds to the above Fe xxvi 1 → 3 transition. However, in this ionization regime (log $\xi \sim 2.5–3.0$), we would expect to detect an absorption trough at 6.5–6.7 keV due to a blend of the 1 → 2 transitions of Fe xvii–Fexxxv, but this is not observed in the MOS and XMM-Newton spectra. In particular, at this lower ionization, we would expect to see the strong absorption due to the Fe xxiv 1s–2p absorption line at 6.67 keV, and for log $\xi = 3.0$ ergs cm$^{-1}$ (as illustrated in the figure), we would also expect to see an even deeper absorption feature at 6.7 keV due to the Fe xxv resonant absorption. Furthermore, in this ionization regime (log $\xi \sim 2.5–3.0$), several strong absorption lines from iron L-shell (2 → 3) transitions, as well as He- and H-like Si/S K-shell lines are expected near 1–2 keV, which are not observed in either the XMM-Newton, Suzaku, or Chandra HETG spectra. Therefore this lower velocity solution appears to be ruled out.

Finally, it is possible to have a low-ionization K/β absorption line without strong Kα absorption from the same species. This scenario is shown in Figure 12 (model C) for an absorber with a column density of $N_H = 10^{23}$ cm$^{-2}$ and an ionization parameter of log $\xi = 1.5$ ergs cm$^{-1}$. Indeed, at this ionization state the dominant species is iron less ionized than Fe xv; the L shell is full and cannot produce the 1s–2p absorption between 6.4 and 7.0 keV. However, there is an absorption line from 7.1 to 7.2 keV due to 1 → 3 transitions from Fe less ionized than Fe xvii. In this scenario, a blueshift of $\sim 0.08c$ would still be required to model
the absorption line at 7.7 keV in the spectrum. Furthermore, the column density required to model the EW of the Kβ absorption feature is $N_{\text{H}} \gg 10^{23}$ cm$^{-2}$, which would introduce too much continuum (bound–free) absorption below 6 keV, inconsistent with the pn data. Therefore we conclude that the fast (0.1c) high-ionization outflow is the most likely model to account for the absorption feature at 7.7 keV. Moreover, when we compare the 2–10 keV continuum and the neutral $N_{\text{H}}$ measured during the third interval with the other intervals and with the average spectrum, we do not find any statistically significant difference ($\Delta N_{\text{H}} < 10^{21}$ cm$^{-2}$), which rules out the possible presence of a variable neutral and/or low-ionization absorber.

5. DISCUSSION AND CONCLUSIONS

We have presented the results from XMM-Newton and Chandra observations of MCG−5−23−16, which are part of a simultaneous campaign conducted in 2005 December, also comprising Suzaku and RXTE observations. The 0.5–10 keV continuum of MCG−5−23−16 resembles at first order the canonical X-ray emission expected from a Compton-thin Seyfert 2 galaxy: an absorbed ($N_{\text{H}} = 1.5 \times 10^{22}$ cm$^{-2}$) power-law component ($\Gamma = 1.82$), which emerges at energy $\geq 1$ keV, and a steep soft excess, which is well fitted by a power-law component plus several emission lines from O, Ne, and N. The XMM-Newton observation of MCG−5−23−16 confirms the presence of the Fe Kα emission complex, which is well described by a narrow Fe Kα emission line superimposed on a relativistically broadened component. The simultaneous Suzaku observation provided us with an accurate description of the underlying continuum, which allowed us to perform detailed modeling of the Fe K emission line complex. Finally, due to the sufficiently long duration, the XMM-Newton RGS spectra have enough photon statistics to investigate the origin of the soft X-ray emission.

5.1. The Origin of the Soft X-Ray Emission

The analysis of the EPIC pn and MOS spectra of MCG−5−23−16 revealed the presence, below 1 keV, of a soft excess with respect to the primary nuclear emission. This soft excess can be well fitted by adding an unabsorbed power-law component to the primary AGN emission; the photon index of this power law is found to be steeper ($\Gamma \sim 3.1$) than the primary AGN component ($\Gamma \sim 1.8$), and even at the EPIC CCD resolution an emission line is detected around 0.9 keV.

A soft excess below 1 keV is not unusual in obscured Seyfert galaxies such as MCG−5−23−16 (see Bianchi et al. 2006 and references therein), and it has been already suggested that it could be due to a superimposition of scattered emission into the line of sight by ionized gas plus several emission lines from highly ionized (He- and H-like) elements (e.g., Mrk 3, Sako et al. 2000; Pounds & Page 2005; Bianchi et al. 2005; Circinus, Sambruna et al. 2001; NGC 1068, Kinkhabwala et al. 2002; Ogle et al. 2003; Brinkman et al. 2002; NGC 4507, Matt et al. 2004). Key diagnostics to understanding the origin of this X-ray emission when a high-resolution spectrum is available are the detection of RRC transitions, the detection of enhanced K-shell emission lines from H- and He-like ions, the detection of Fe L-shell emission, and the ratio between the forbidden and the recombination transition in the He-like triplets.

This long XMM-Newton observation has provided for the first time RGS spectra for MCG−5−23−16 with sufficient photon statistics to perform a detailed modeling of the soft X-ray emission, allowing for the first time the detection of the O vi RRC feature in this object. The width of this emission line indicates that the recombining electron temperature is a few eV ($kT < 24$ eV). This is suggestive that the emitting plasma is photoionized, rather than
collisionally ionized (Liedahl & Paerels 1996). This is also indicative that the soft X-ray emission is probably dominated by scattering of the primary AGN emission, rather than due to emission from hot gas in the host galaxy, e.g., from starburst activity. Our analysis of the RGS spectra of MCG –5-23-16 confirms the detection of the O vii and O viii lines previously reported by Guainazzi & Bianchi 2007, and the line fluxes are in agreement with the measurement obtained with the analysis of these previous short XMM-Newton observations of MCG –5-23-16. We cannot exclude on statistical grounds the possible presence of emission due to a collisionally ionized plasma. Indeed, the spectra can be modeled equally well by replacing these emission lines with a multitemperature thermal model, which represents the emission due to a collisionally ionized plasma. However, the AGN model (scattered power-law component plus several photoionized emission lines) is preferred because of the low ion abundance obtained (Z < 0.2 Z⊙) in the thermal model, which reflects the lack of a strong Fe L-shell emission with respect to the fluxes of the oxygen lines. We therefore conclude that the most likely origin of the soft X-ray emission is a plasma photoionized by the AGN. This plasma must be located outside the Compton-thin absorber and, as already suggested for other Seyfert 2 galaxies, it could be coincident with the NLR.

5.2. The Fe Kα Emission Complex

This deep XMM-Newton observation of MCG –5-23-16 confirms the presence of broad and narrow iron Kα emission lines, which were reported since the first ASCA observation (Weaver et al. 1997). The Chandra HETG spectrum clearly reveals a narrow line at EKα = 6.40 ± 0.02 keV with a FWHM < 5000 km s⁻¹ and a flux of (5.6 ± 0.7) × 10⁻⁵ photons cm⁻² s⁻¹. The intensity of this component is found to be constant within the errors during this observation and also when comparing with the previous observation ([ION] = 4.5 × 10⁻⁵ photons cm⁻² s⁻¹; Balestra et al. 2004; ION = (6.5 ± 2.7) × 10⁻⁵ photons cm⁻² s⁻¹; Weaver et al. 1997). The constancy in flux of this line, together with the limits on the width obtained with Chandra, are suggestive of an origin from distant matter, such as the putative torus. Indeed, the upper limit on the FWHM corresponds to a distance from the central black hole greater than 10⁴Rg.

The presence of two Compton-thick X-ray reprocessors responsible for the two components of the iron line, suggested since the ASCA observation (Weaver et al. 1997), is confirmed with this deep XMM-Newton observation and with the deep Suzaku observation (Reeves et al. 2007). The geometry inferred for MCG –5-23-16 with this latter observation is discussed in detail in Reeves et al. (2007). To summarize, one plausible scenario is that we are seeing MCG –5-23-16 through the Compton-thin edge of the putative torus, which is Compton-thick at the plane of the accretion disk. This is in agreement with the inclination 4 (i = 41.2 ± 23) deg of the accretion disk derived by modeling the broad-line component with a relativistic line profile. The column density of 1.5 × 10²² cm⁻² measured using the low-energy cutoff is thus associated with the thinner absorbing material, e.g., encountered viewing through the edge of the torus. We found no evidence of variability of the column density of this absorber within this long observation, and also no strong variability is found when comparing the column densities measured with the previous observations performed with BeppoSAX (Risaliti 2002), ASCA (Weaver et al. 1997), XMM-Newton, and Chandra (Dewangan et al. 2003; Balestra et al. 2004). This result implies that the absorber is probably far from the central black hole, and there is no evidence that this absorber is clumpy, as suggested for other Seyfert 2 galaxies (Risaliti et al. 2002).

This deep XMM-Newton observation confirms the presence of a relativistically broadened iron Kα line; the width derived from modeling this component with a Gaussian profile corresponds to a FWHM ~ 40,000 km s⁻¹ and is suggestive of an origin in the accretion disk. The profile of this component is nearly symmetric and can be modeled equally well with a broad Gaussian or a relativistic profile; in the latter case, the derived inner radius is about (20–40)Rg. Since the advent of XMM-Newton and Chandra, one of the most debated issues in the study of the broad iron Kα lines has been the fraction of AGNs that clearly show the presence of a broad component (Nandra et al. 2006; Guainazzi et al. 2006). Several authors have discussed the robustness of the detection in some objects of a broad iron line (e.g., NGC 3516, Turner et al. 2005; NGC 3783, Reeves et al. 2004). This controversy emerged when observations characterized by high photon statistics showed the ambiguity of modeling the iron Kα line when complex absorption is present (Pounds et al. 2003, 2004). Indeed, a high column density warm absorber can produce curvature in the spectrum at the energy of the iron Kα line that mimics the profile of a relativistically broadened emission line. The detection of the absorption feature at ~7.8 keV shows that a high column density variable absorber (a high-velocity, highly ionized outflow) is also present in MCG –5-23-16; this could in principle give rise to ambiguity in the interpretation of the broad component. However, in the case of MCG –5-23-16, the availability of a simultaneous observation with Suzaku above 10 keV allowed us to tightly constrain the underlying X-ray continuum and to rule out the interpretation of the broad line as due to unmodeled complex absorption. Indeed, the residuals left at the energy of the iron Kα line, when we take into account the amount of reflection detected with Suzaku, cannot be explained by the effect of complex absorption. Furthermore, once the absorber responsible for the feature detected at ~7.8 keV is accounted for, either in the time-averaged spectrum or in the third segment of the XMM-Newton observation, a broad line is still required by the data, which has a similar EW and FWHM. Note that the ionization parameter of the absorber is required to be high and does not introduce additional spectral curvature below 6 keV, which hence does not impact the broad iron line modeling.

The remaining open questions about the origin of the broad line in MCG –5-23-16 are the relatively large inner radius derived for the accretion disk and its lack of variability. The former can be explained with several scenarios: the disk could be truncated or missing below 20Rg, or the inner part of the accretion disk could be so highly ionized that the iron is fully ionized. However, it worth noting that, as shown by Reeves et al. (2007), assuming a flat emissivity (q = 2), an inner radius of about 6Rg (in the case of a Schwarzschild black hole) cannot be statistically ruled out.

The second open issue is the lack of variability of the iron emission line, both on short and long timescales. Indeed, the flux of the broad component is found to be consistent with being constant when using the short-term time-resolved spectroscopy performed within this deep observation and when comparing our result with the long-term flux history presented in Balestra et al. (2004). The strength of the broad component appears to be lower during this observation with respect to the value reported since the first ASCA observation (EW ~ 200 eV; Weaver et al. 1997); however, when we take into account the larger errors on the early ASCA measurements, we cannot exclude the line being constant.
In MCG $-5\,23\text{-}16$ this lack of variability of the iron emission line is not so striking as in MCG $-6\,30\text{-}15$ (Miniutti et al. 2007; Vaughan & Fabian 2004), due to the low level of variability of the intrinsic continuum (30\%–40\%, compared to a factor of 2–3 in the case of MCG $-6\,30\text{-}15$).

5.3. The Blue-shifted Absorption Line: A Possible High-Velocity, Ionized Variable Outflow

Perhaps the most interesting result of this long XMM-Newton observation has been the discovery of a possibly variable absorption line from ionized iron. The feature appears to be transient, with a timescale of about 20 ks, and it is detected at an observed energy of about 7.66 keV (corresponding to a rest-frame energy of 7.72 keV). As shown, the most plausible association of this feature is with K-shell absorption from H-like iron, which is blueshifted by $\sim 0.1c$. Indeed, modeling this absorption feature with xstar (Bautista & Kallman 2001) requires a column density of about $8 \times 10^{22}$ cm$^{-2}$ and a high-ionization parameter ($\log \xi = 3.7 \pm 0.3$ erg cm$^{-s}$), which implies that the absorption is due to a blueshifted $1 \rightarrow 2$ transition of Fe xxvi ($E = 6.97$ keV). The velocity of the absorbing material is found to be $v = (0.09 \pm 0.01)c$.

In the last few years, red- and blueshifted absorption lines associated with the presence of highly ionized gas in- and/or outflowing at relativistic velocities have been reported for several AGNs (E1821+643: Yaqoob & Serlemitsos 2005; Mrk 509: Dadina et al. 2005; NGC 3516: Nandra et al. 1999; Turner et al. 2005; Mrk 335: Longinotti et al. 2007). These absorption lines are found in Seyfert galaxies (NGC 3783, Reeves et al. 2004; IC 4392a, Markowitz et al. 2006; NGC 1365, Risaliti et al. 2005; Ark 564, Papadakis et al. 2007). However, as well as in quasars (PG 1211+143, Pounds et al. 2003; PDS 456, Reeves et al. 2003) and in broad absorption line (BAL) QSOs (APM 08279+5255, Chartas et al. 2002; PG 1115+080, Chartas et al. 2003). These absorption systems can also be variable on different timescales, in their ionization state and column density, with the most extreme cases being NGC 1365 (Risaliti et al. 2005) and Mrk 509 (Dadina et al. 2005). From the analysis of the different intervals in which we split the observation, we can infer that it is unlikely that the variability of the absorber in MCG $-5\,23\text{-}16$ is due to a change in the ionization state of the outflowing material; otherwise, we would detect signatures of this absorber in all the spectral slices. A more likely scenario is a change in column density of this absorber.

The present data suggest that we are seeing a transient absorber, which could be associated with a cloud that sporadically obscures the central source. This cloud could be the signature of a clumpy absorber located close to the central X-ray source or of matter ejected sporadically. Different models have been proposed to explain the powerful outflows detected with the recent XMM-Newton and Chandra observations; in particular, transient red- and blue-shifted absorption lines are predicted in several theoretical models of failed disk winds (Proga et al. 2000; King & Pounds 2003) or an aborted jet (Ghisellini et al. 2004). The picture emerging is that these features can provide a direct probe of the dynamics and kinematics of the innermost central regions of AGNs. For the absorber detected in MCG $-5\,23\text{-}16$, the data suggest that this feature appears when the source reaches a relative maximum in the intrinsic 2–10 keV flux. However, monitoring the spectrum on longer timescales would be required to determine whether there is a statistically firm correlation between the presence of the absorber and the source brightness and determine whether any duty cycle is present. Thus, both a scenario in which a clumpy absorber or a variable or failed outflow or jet are possible at present. Finally, it is worth noting that the rapid variability of this absorption feature is indicative of a compact absorber and rules out a possible $z = 0$ origin, e.g., due to the warm intergalactic medium (WHIM) or a local hot bubble, as claimed along the line of sight to other AGNs (McKernan et al. 2004, 2005).

Before deriving an estimate of the location, mass, and energetics associated with the absorber, we performed a consistency check for the $N_H$ value measured with the xstar model and the EW ($\sim 50\, eV$) of the absorption line measured with the Gaussian component. Following the curve of growth for H-like iron (see Fig. 4 of Risaliti et al. 2005), we inferred that the detected EW requires a turbulence velocity greater than 500 km s$^{-1}$; a lower turbulence velocity would imply a Compton-thick absorber and a similar EW of the H-like $K/\beta$ line (due to saturation of the $K/\alpha$ line), which is not detected ($EW < 15\, eV$ at the 90% confidence level). On the other hand, a turbulence velocity greater than 3000 km s$^{-1}$ would produce a broad absorption feature that would be resolved even at the EPIC pn resolution at 8 keV ($\sim 170\, eV$).

We therefore conclude that the observed EW and line width are in broad agreement with the xstar estimate of a column density of about $10^{23}$ cm$^{-2}$, for a turbulence velocity $\sigma = 1000\, km\, s^{-1}$. Using this value for the column density, we can now estimate the maximum distance of this cloud or blob from the central black hole using the relation between the ionization parameter, the density of the absorber, and the illuminating continuum luminosity, $L/\xi = nR^2$, where $L$ is the intrinsic 2–100 keV X-ray luminosity ($5.4 \times 10^{43}$ ergs s$^{-1}$). Assuming then that the thickness of the cloud $\Delta R = N_H/n$ is less than the distance $R$, we find $R < 10^{17}$ cm. A lower limit for the distance of the absorber, assuming it is in the form of an outflow, can be obtained by equating the velocity of the absorbing material to the escape velocity at a given radius $R$ from the central black hole; the derived distance is then $R > 100R_g$. A constraint on the size of this cloud can be placed assuming 20 ks as the characteristic variability timescale, when our line of sight intercepts the absorbing cloud; this gives us $\Delta R \sim 6 \times 10^{13}$ cm, which corresponds to $\sim 10R_g$ for a black hole mass of $5 \times 10^7$ M$_\odot$ (Wandel & Mushotzky 1986). We can then infer a density of $\sim 10^9$ cm$^{-3}$ and, assuming a spherical geometry for the cloud, a mass of about $10^{28}$ g. These are our estimates for the mass and velocity correspond to a kinetic energy $E_{\text{kin}} = 5 \times 10^{46}$ ergs and, using the 20 ks as a characteristic timescale, to a power of $2.5 \times 10^{42}$ ergs s$^{-1}$. This value corresponds to $\sim 10\%$ of the 2–10 keV X-ray luminosity and is thus in agreement with a radiation-driven wind model (Proga & Kallman 2004) or an aborted jet (Ghisellini et al. 2004).

In conclusion, this deep XMM-Newton observation revealed that the soft X-ray emission of MCG $-5\,23\text{-}16$ can be ascribed to material photoionized by the AGN, likely to be located outside the subparsec scale of the absorber and perhaps coincident with the NLR. We confirm the presence of an iron K$\alpha$ emission line complex composed of a narrow and a broad relativistic component. The inclination derived from the disk-line profile ($i \sim 40\,$$^{\circ}$) is in agreement with the orientationally based Unification Scheme of AGNs (Antonucci 1993), the X-ray classification of MCG $-5\,23\text{-}16$ as a Compton-thin Seyfert 2 galaxy (i.e., intermediate between a type 1 AGN and a Compton-thick type 2), and the optical classification as a Seyfert 1.9 galaxy. Finally, we detected a sporadic Fe K absorption feature that could be a signature of a variable high-velocity outflow. This detection adds one more object to the increasing sample of AGNs in which relativistic outflows have been revealed in the X-ray band. The growing evidence of high-velocity outflows in AGNs indicates that they may play an important role in the energetics of AGN central engines.
We would like to thank the anonymous referee for his/her useful comments, which have improved this paper. This paper has made use of observations obtained with XMM-Newton, an ESA science mission with instruments and contributions directly funded by ESA member states and the USA (NASA). Support for this work was provided by the National Aeronautics and Space Administration through Chandra award GO5-6146Z issued by the Chandra X-Ray Observatory Center, which is operated by the Smithsonian Astrophysical Observatory for and on behalf of the National Aeronautics Space Administration under contract NAS8-03060.

REFERENCES

Antonucci, R. 1993, ARA&A, 31, 473
Balestra, I., Bianchi, S., & Matt, G. 2004, A&A, 415, 437
Bautista, M. A., & Kallman, T. R. 2001, ApJS, 134, 139
Bianchi, S., Guainazzi, M., & Chiaberge, M. 2006, A&A, 448, 499
Bianchi, S., Matt, G., Balestra, I., Guainazzi, M., & Perola, G. C. 2004, A&A, 422, 65
Bianchi, S., Miniutti, G., Fabian, A. C., & Iwasawa, K. 2005, MNRAS, 360, 380
Brinkman, A. C., Kastra, J. S., van der Meer, R. L. J., Kinkhabwala, A., Behar, E., Kahn, S. M., Paerels, F. B. S., & Sako, M. 2002, A&A, 396, 761
Cappi, M. 2006, Astron. Nachr., 327, 1012
Cash, W. 1979, ApJ, 228, 939
Chartas, G., Brandt, W. N., & Gallagher, S. C. 2003, ApJ, 595, 85
Chartas, G., Brandt, W. N., Gallagher, S. C., & Garmire, G. P. 2002, ApJ, 579, 169
Dadina, M., Cappi, M., Malaguti, G., Ponti, G., & de Rosa, A. 2005, A&A, 442, 461
den Herder, J. W., et al. 2001, A&A, 365, L7
Dewangan, G. C., Griffiths, R. E., & Schurch, N. J. 2003, ApJ, 592, 52
Dickey, J. M., & Lockman, F. J. 1990, ARA&A, 28, 215
Ehle, M., et al. 2006, XMM-Newton Users’ Handbook, Issue 2.4 (Madrid: XMM-Newton Science Operations Centre), http://xmm.esa.int/external/xmm_user_support/documentation/uhb
Fabian, A. C., Iwasawa, K., Reynolds, C. S., & Young, A. J. 2000, PASP, 112, 1145
Fabian, A. C., Rees, M. J., Stella, L., & White, N. E. 1989, MNRAS, 238, 729
Ferruit, P., Wilson, A. S., & Mulchaey, J. 2000, ApJS, 128, 139
Ghisellini, G., Haardt, F., & Matt, G. 2004, A&A, 413, 535
Guainazzi, M., & Bianchi, S. 2007, MNRAS, 374, 1290
Guainazzi, M., Bianchi, S., & Dovciak, M. 2006, Astron. Nachr., 327, 1032
Iwasawa, K., Wilson, A. S., Fabian, A. C., & Young, A. J. 2003, MNRAS, 345, 369
Kallman, T. R., Liedahl, D., Osterheld, A., Goldstein, W., & Kahn, S. 1996, ApJ, 465, 994
King, A. R., & Pounds, K. A. 2003, MNRAS, 345, 657
Kinkhabwala, A., et al. 2002, ApJ, 575, 732
Liedahl, D. A. 1999, X-Ray Spectroscopy in Astrophysics, ed. J. van Paradijs & J. A. M. Bloeker (Berlin: Springer), 189
Liedahl, D. A., & Paerels, F. 1996, ApJ, 468, L33
Longinotti, A. L., Sim, S. A., Nandra, K., & Cappi, M. 2007, MNRAS, 374, 237
Magdziarz, P., & Zdziarski, A. A. 1995, MNRAS, 273, 837
Markert, T. H., Canizares, C. R., Dewey, D., McGuirk, M., Pak, C. S., & Schattenburg, M. L. 1994, Proc. SPIE, 2280, 168
Markowitz, A., Reeves, J. N., & Braito, V. 2004, ApJ, 646, 783
Matt, G. 2002, MNRAS, 337, 147
Matt, G., Bianchi, S., D’Ammando, F., & Martocchia, A. 2004, A&A, 421, 473
Mattson, B. J., & Weaver, K. A. 2004, ApJ, 601, 771
McKernan, B., Yaqoob, T., & Reynolds, C. S. 2004, ApJ, 617, 232
Mewe, R., Gronenschild, E. H. B. M., & van den Oord, G. H. J. 1985, A&A, 62, 197
Miniutti, G., et al. 2007, PASJ, 59, S315
Nandra, K., George, I. M., Mushotzky, R. F., Turner, T. J., & Yaqoob, T. 1997, ApJ, 477, 602
Papadakis, I. I., Brinkmann, W., Page, M. J., McHardy, I., & Uttley, P. 2007, A&A, 461, 931
Porquet, D., & Dubau, J. 2000, A&AS, 143, 495
Porquet, D., Reeves, J. N., Uttley, P., & Turner, T. J. 2004, A&A, 427, 101
Pounds, K. A., & Page, K. L. 2005, MNRAS, 360, 1123
Pounds, K. A., Reeves, J. N., King, A. R., & Page, K. L. 2004, MNRAS, 350, 10
Pounds, K. A., Reeves, J. N., King, A. R., Page, K. L., O’Brien, P. T., & Turner, M. J. L. 2003, MNRAS, 345, 705
Proga, D., & Kallman, T. R. 2004, ApJ, 616, 688
Proga, D., Stone, J. M., & Kallman, T. R. 2000, ApJ, 543, 686
Protassov, R., van Dyk, D. A., Connors, A., Kashyap, V. L., & Siemiginowska, A. 2002, ApJ, 571, 545
Reeves, J. N., Nandra, K., George, I. M., Pounds, K. A., Turner, T. J., & Yaqoob, T. 2004, ApJ, 602, 648
Reeves, J. N., O’Brien, P. T., & Ward, M. J. 2003, ApJ, 593, L65
Reeves, J. N., et al. 2007, PASJ, 59, S301
Sako, M., Kahn, S. M., Paerels, F., & Liedahl, D. A. 2000, ApJ, 543, L115
Sambruna, R. M., Netzer, H., Kaspi, S., Brandt, W. N., Chartas, G., Garmire, G. P., Nousek, J. A., & Weaver, K. A. 2001, ApJ, 546, L13
Schurch, N. J., Warwick, R. S., Griffiths, R. E., & Sembay, S. 2003, MNRAS, 345, 423
Tanaka, Y., et al. 1995, Nature, 375, 659
Turner, T. J., Kraemer, S. B., George, I. M., Reeves, J. N., & Bottorff, M. C. 2005, ApJ, 618, 155
Vaughan, S., & Fabian, A. C. 2004, MNRAS, 348, 1415
Wandel, A., & Mushotzky, R. F. 1986, ApJ, 306, L61
Weaver, K. A., Krolik, J. H., & Pier, E. A. 1998, ApJ, 498, 213
Weaver, K. A., Yaqoob, T., Mushotzky, R. F., Nousek, J., Hayashi, I., & Koyama, K. 1997, ApJ, 474, 675
Wilms, J., Allen, A., & McCray, R. 2000, ApJ, 542, 914
Yaqoob, T., & Padmanabhan, U. 2004, ApJ, 604, 63
Yaqoob, T., & Serlemitsos, P. 2005, ApJ, 623, 112
Young, A. J., Lee, J. C., Fabian, A. C., Reynolds, C. S., Gibson, R. R., & Canizares, C. R. 2005, ApJ, 631, 733