A NEW SAMPLE OF BURIED ACTIVE GALACTIC NUCLEI SELECTED FROM THE SECOND XMM-NEWTON SERENDIPITOUS SOURCE CATALOGUE

KAZUHISA NOGUCHI, YUICHI TERASHIMA, AND HISAMITSU AWAKI
Department of Physics, Ehime University, Matsuyama, Ehime 790-8577, Japan
Received 2008 December 17; accepted 2009 September 18; published 2009 October 12

ABSTRACT

We present the results of X-ray spectral analysis of 22 active galactic nuclei (AGNs) with a small scattering fraction selected from the Second XMM-Newton Serendipitous Source Catalogue using hardness ratios. They are candidates of buried AGNs, since a scattering fraction, which is a fraction of scattered emission by the circumbinary photoionized gas with respect to direct emission, can be used to estimate the size of the opening part of an obscuring torus. Their X-ray spectra are modeled by a combination of a power law with a photon index of 1.5–2 absorbed by a column density of $\sim 10^{23–24}$ cm$^{-2}$, an unabsorbed power law, narrow Gaussian lines, and some additional soft components. We find that scattering fractions of 20 among 22 objects are less than a typical value ($\sim 3\%$) for Seyfert 2s observed so far. In particular, those of eight objects are smaller than 0.5%, which are in the range for buried AGNs found in recent hard X-ray surveys. Moreover, [O iii] $\lambda$5007 luminosities at given X-ray luminosities for some objects are smaller than those for Seyfert 2s previously known. This fact could be interpreted as a smaller size of optical narrow emission-line regions produced in the opening direction of the obscuring torus. These results indicate that they are strong candidates for the AGN buried in a very geometrically thick torus.

Key words: galaxies: active – galaxies: Seyfert – X-rays: galaxies
Online-only material: color figures

1. INTRODUCTION

It is widely accepted that the cosmic X-ray background (CXB) is produced by the integrated emission of faint extragalactic pointlike sources (Brandt & Hasinger 2005). XMM-Newton and Chandra resolved 80%–100% of the CXB at $< 2$ keV, while the resolved fraction of the CXB at hard X-rays (8–12 keV) decreased to only $\approx 50\%$ (Worsley et al. 2005). Various observations indicate that a large fraction of active galactic nuclei (AGNs) is hidden by a large amount of cold material (e.g., Awaki et al. 1991; Comastri 2004). According to population synthesis models of the CXB (Comastri et al. 1995; Ueda et al. 2003; Gilli et al. 2007), the peak intensity of the CXB spectrum at 30 keV can be explained by considering contribution of hidden AGNs. Such a population is yet to be understood, because the direct emission from the nucleus is absorbed by surrounding cold gas and is hard to be fully explored with X-ray observations below 10 keV. Hard X-ray surveys performed with Swift/BAT (15–200 keV; Markwardt et al. 2005; Tueller et al. 2008) and INTEGRAL (10–100 keV; Bassani et al. 2006; Beckmann et al. 2006; Sazonov et al. 2007) are suitable for unveiling such a type of AGNs with much less selection biases than surveys at lower energies. In fact, AGNs buried in a large amount of matter have been discovered by Suzaku follow up observations of a sample selected by the Swift/BAT survey (Ueda et al. 2007).

In a unified model of an AGN (e.g., Antonucci 1993), torus-like gas is surrounding a supermassive black hole (SMBH), and photoionized gas is created in the opening part of the torus by radiation from the nucleus. If an AGN is observed from the torus side, absorbed direct emission and scattered light by the photoionized gas will be observed in an X-ray spectrum. The fraction of scattered light to direct emission (scattering fraction) can be used to estimate the opening angle of the torus. The fractions for AGNs found by Ueda et al. (2007) are extremely small ($< 0.5\%$), whereas a typical value is $\sim 3\%$ (Turner et al. 1997; Bianchi & Guainazzi 2007). Furthermore, Winter et al. (2008) found a similar type of AGNs by XMM-Newton observations of Swift/BAT selected AGNs. They would be buried in a geometrically thick torus with a very small opening angle assuming that the scattering fraction reflects the solid angle of the opening part of the torus. In an early stage of the evolution of galaxies and their central black holes, a large amount of gas responsible for active star formation may be closely related to obscuration of the nucleus. Therefore, AGNs almost fully covered by an absorber are an important class of objects in studying evolution of AGNs and their hosts. Moreover, they might be significant contributors to the CXB at hard X-rays. Testing a selection technique to find such AGNs and understanding the properties of the population are of significant interest for exploring these issues.

We search for buried AGNs with a scattering fraction of 0.5% or less using the Second XMM-Newton Serendipitous Source Catalogue (2XMM) and the archival data of XMM-Newton. We selected candidate sources from the catalogue using hardness ratios (HRs) and scattering fractions calculated by analyzing spectra obtained with XMM-Newton. The selection method of candidate sources is described in Section 2. Our results of spectral analysis are presented in Section 3 and their characteristics are discussed in Section 4. Section 5 summarizes our conclusions. We adopt $(H_0, \Omega_m, \Omega_{\Lambda}) = (70$ km s$^{-1}$ Mpc$^{-1}$, 0.3, 0.7) throughout this paper.

2. SELECTION OF CANDIDATES FOR A BURIED AGN

Our sample was selected from the 2XMM Catalogue that has been assembled by the XMM-Newton Survey Science Centre (Watson et al. 2009). This catalogue contains 246897 X-ray source detections. The median flux in the full energy band (0.2–12 keV) is $\sim 2.5 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$ and about 20% of the sources have total fluxes below $1 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$.

We used HR3 and HR4 among some HRs defined in the 2XMM Catalogue to select candidates of buried AGNs. These
HRs are defined as

\[
HR3 = \frac{CR(2.0–4.5 \text{ keV}) - CR(1.0–2.0 \text{ keV})}{CR(2.0–4.5 \text{ keV}) + CR(1.0–2.0 \text{ keV})}
\]

and

\[
HR4 = \frac{CR(4.5–12 \text{ keV}) - CR(2.0–4.5 \text{ keV})}{CR(4.5–12 \text{ keV}) + CR(2.0–4.5 \text{ keV})},
\]

where \(CR(1.0–2.0 \text{ keV})\), \(CR(2.0–4.5 \text{ keV})\), and \(CR(4.5–12 \text{ keV})\) are count rates in the 1.0–2.0, 2.0–4.5, and 4.5–12 keV bands, respectively. The values of HR given in the 2XMM Catalogue were calculated using count rates measured by the emldetect task in the XMM-Newton Science Analysis System (SAS). If direct emission from an AGN is absorbed by cold material with \(N_{\text{H}} \sim 10^{23} \text{ cm}^{-2}\), \(CR(1.0–2.0 \text{ keV})\) and \(CR(2.0–4.5 \text{ keV})\) are dominated by the soft component such as scattered emission and absorbed direct emission, respectively. In the case of \(N_{\text{H}} \sim 10^{24} \text{ cm}^{-2}\), \(CR(2.0–4.5 \text{ keV})\) and \(CR(4.5–12 \text{ keV})\) are dominated by the soft component and direct emission, respectively. Therefore, HR3 and HR4 can be used to efficiently select objects with \(N_{\text{H}} \sim 10^{23} \text{ cm}^{-2}\) and \(10^{24} \text{ cm}^{-2}\), respectively.

In the selection process, we required sources to satisfy the following conditions: (1) count rate for EPIC-pn in 0.2–12 keV > 0.05 counts s\(^{-1}\), (2) high Galactic latitude (\(|b| > 20^\circ\)), and (3) error of HRs < 0.2 at a 90\% confidence level. The errors of HRs shown in the 2XMM Catalogue were derived from count rates measured by the SAS task emldetect. 4627 sources among 246897 satisfied these criteria.

We simulated AGN spectra in XSPEC (version 11.2) to calculate HRs expected for an object with a low scattering fraction, using the response function of the EPIC-pn. The spectral model assumed in the simulation is a combination of absorbed and unabsorbed power laws, which correspond to direct and scattered components, respectively. We fixed the photon indices of both power-law components at 1.9, which is a typical value of Seyfert 2 galaxies (e.g., Smith & Done 1996). The scattering fraction is defined as a ratio between the normalizations of the two power laws. We simulated spectra for scattering fractions of 10, 5, 3, 1, and 0.5\%, and log \(N_{\text{H}}\) from 20.5 to 24.5 \(\text{cm}^{-2}\) at a logarithmic step of 0.1. The expected HRs are shown in Figure 1 as solid and dashed lines. The five solid lines represent the scattering fractions of 10, 5, 3, 1, and 0.5\% from inside to outside. The three dashed lines correspond to objects with log \(N_{\text{H}}\) = 23, 23.5, and 24 from lower right to upper left. 4627 sources among 246897 satisfied these criteria. In order to select buried AGNs with a scattering fraction of < 0.5\% as many as possible, we selected 23 objects located upper right of the line for a scattering fraction of 1\% since there are uncertainties in HR values and all the spectra may not be explained by the simple model defined above. The 23 candidates are plotted with circles in Figure 1.

![Figure 1. Distribution of HR for the 2XMM Catalogue sources (Crosses). These are satisfied all conditions; count rate in 0.2–12 keV > 0.05 counts s\(^{-1}\), \(|b| > 20^\circ\), and HR error < 0.2. Our sample is shown by circles. Solid lines show the HRs expected for the scattering fraction of 10, 5, 3, 1, and 0.5\% from inside to outside. Dashed lines correspond to log \(N_{\text{H}}\) of 23, 23.5, and 24 cm\(^{-2}\) from lower right to upper left.](image)

(Kalberla et al. 2005) using the nh tool at the NASA’s High Energy Astrophysics Science Archive Research Center, XMM-Newton results of some of the objects in our sample have been published. References for the AGN type are also shown in Table 1. Since 2XMM J234349.7–151700 is a star, we excluded it from our sample for spectral analysis in Section 3.

3. DATA REDUCTION AND ANALYSIS

In order to calculate accurate values of the scattering fraction for our sample, we analyzed their X-ray spectra obtained with EPIC-pn. The data were reduced with the SAS version 7.1. We created calibrated photon event files for the EPIC-pn camera from the observation data files (ODF). The ancillary response files and detector response matrices were generated using the arfgen and rmfgen tasks, respectively. X-ray events corresponding to patterns 0–4 were selected from the event files. We extracted source spectra from circular regions with a radius in a range 10'–40', depending on the brightness of the source. Background spectra were taken from a region near the target. Time intervals with very high background rates were identified in light curves above 10 keV and discarded. We fit spectra of the sample in the 0.4–10 keV range with various models by using XSPEC version 11.2. All spectra except one were binned so that each spectral bin contains more than 20 counts per bin to enable usage of the \(\chi^2\) fit statistics. Since the total number of counts for one object, 2MASX J12544196–3019224, is small, the same way of binning resulting is very small number of bins. We therefore used C-statistic (Cash 1979) to fit the unbinned spectrum of this object. The quoted errors correspond to a 90\% confidence level for one interesting parameter (i.e., \(\Delta \chi^2 \text{ or } \Delta C = 2.71\)).

3.1. Baseline Model

We fitted spectra of the 22 sources with a model consisting of two power laws and a narrow Gaussian line to account
for an Fe K emission at 6.4 keV, all modified by Galactic absorption using phabs in XSPEC. An absorption by cold matter at the redshift of the source (zphabs in XSPEC) was added to the Gaussian and one of the power laws. We assumed that the photon indices of both power laws are same. Hereafter, we fixed the inclination angle of the reflector at 60° which is determined by an Fe–K absorption feature, and obtained an improved fit ($\chi^2$/dof = 1.27(170)). We added a second Gaussian component in order to account for this feature, and obtained an improved fit ($\chi^2$/dof = 1.18(168)).

First, we added an optically thin plasma model (mekal model in XSPEC; Mewe et al. 1985; Kaastra 1992; Liedahl et al. 1995) to the baseline model. The abundance was fixed at 0.5 solar, where the solar abundance table by Anders & Grevesse (1989) was assumed. If the temperature of the plasma was not constrained, the value was fixed at 0.65 keV, which is typically observed in Seyfert 2 (e.g., Guainazzi et al. 2005b). Spectra of six objects (NGC 1142, 3C 98, IC 2461, NGC 4138, NGC 4939, and NGC 7172) were fitted acceptably with this model. In the spectrum of NGC 7172, excess emission at around 1.7 keV was seen in this model fit ($\chi^2$/dof = 1.14(15)). The high-energy cutoff of the incident power law at 300 keV, and assumed solar abundances (Anders & Grevesse 1989) were used in this model. We added a second Gaussian component in order to account for this feature, and obtained an improved fit ($\chi^2$/dof = 1.18(168)).

Soft excess seen in the spectrum of IC 4995 was modeled by adding a second mekal component ($\chi^2$/dof = 1.14(15)). The best-fit temperatures of the two mekal components are $kT \approx 0.08$ and $\approx 0.5$ keV, respectively.

Next, we added a Compton reflection model (pexrav in XSPEC; Magdziarz & Zdziarski 1995) to the baseline model. We fixed the inclination angle of the reflector at 60° (0° corresponds to face-on), the high-energy cutoff of the incident power law at 300 keV, and assumed solar abundances (Anders & Grevesse 1989). The pexrav model was used in such a way that it produces reflected emission only (relr parameter was
part of the spectrum. A Gaussian to express the Compton shapes that were not reproduced by the models explained NGC 4507, we introduced the following model components. spectrum of Mrk 348. In order to represent the spectrum of 6.9 keV. This model provided an acceptable fit to the baseline model. The photon indices of all the power-law components were assumed to be the same. Moreover, to represent two absorption-line-like features seen at 6.6 keV, we used this model component.

In order to represent the spectra of the remaining seven sources, both mekal and pexrav were added to the baseline model. The spectra of 3C 33 and ESO 383–G18 were explained by this model. If the absorption column for the reflection component was left free, the spectra of ESO 103–G035 and NGC 7319 were reproduced. If two mekal components ($kT \approx 0.2$ and $\approx 0.8$ keV) and absorbed pexrav were introduced, the spectrum of NGC 4388 was explained.

Mrk 348 and NGC 4507 show more complex X-ray spectral shapes that were not reproduced by the models explained above. In the fit of the spectrum of Mrk 348, we added two mekal components and the third absorbed power law to the baseline model. The photon indices of all the power-law components were assumed to be the same. Moreover, two Gaussians with negative normalization were also added to represent two absorption-line-like features seen at 6.6 keV and 6.9 keV. This model provided an acceptable fit to the spectrum of Mrk 348. In order to represent the spectrum of NGC 4507, we introduced the following model components. We used nine Gaussians instead of mekal to model the soft part of the spectrum. A Gaussian to express the Compton shoulder (CS; see Matt 2002) was also added at 6.32 keV with a fixed width of $\sigma = 40$ eV as in Matt et al. (2004). An absorbed pexrav component was also added, where the absorption column density for pexrav was assumed to be independent of that for the absorbed power-law component. The combination of the baseline model and these additional components reproduced the spectrum.

The results of the fits are summarized in Tables 3–5. Table 6 shows the best-fit models for our sample. The photon indices were distributed between $\sim 1.5$ and $2.0$. This is consistent with a range of photon indices observed in Seyfert 2s (e.g., Smith & Done 1996). The obtained $N_H$ were in the range of $\sim 10^{23–24}$ cm$^{-2}$. The spectra along with the best-fit model are shown in Figure 2.

### 3.3. Fluxes and Luminosities

The X-ray fluxes calculated using the best-fit model are summarized in Table 7. Columns 2 and 3 are observed fluxes in 0.5–2 keV and 2–10 keV bands, respectively. Columns 4 and 5 are observed fluxes for the power-law components in the 0.5–2 keV and 2–10 keV bands, respectively. Columns 6 and 7 are absorption corrected fluxes for the power-law components in the 0.5–2 keV and 2–10 keV bands, respectively. Columns 8 and 9 are observed and absorption corrected fluxes in the 0.5–2 keV band, respectively, for the power law with only Galactic absorption. Columns 10 and 11 are observed and absorption corrected fluxes, respectively, for the mekal component in the...
0.5–2 keV band. We calculated intrinsic luminosities of the absorbed power-law component in the 2–10 keV band as shown in Table 8, Column 2. Most of the objects have luminosities in the range of Seyferts \((10^{41–44} \text{ erg s}^{-1})\). The intrinsic 0.5–2 keV luminosities for all the components except for the heavily absorbed power law were also calculated and tabulated in Table 8, Column 3.

4. DISCUSSION

4.1. The Origin of the Soft X-ray Emission

Since various spectral components presumably contribute to the soft X-ray emission in obscured AGNs, understanding the origin of the soft emission is of importance to derive true scattering fractions. One of the possible origins is the circumnuclear
gas photoionized and photoexcited by AGN emission. The soft X-ray emission is also produced through Thomson scattering of the primary radiation by free electrons in the ionized gas. High-resolution spectra of some Seyfert 2 galaxies obtained with Chandra or XMM-Newton have shown that emission from a photoionized or photoexcited plasma is dominant in soft X-rays (e.g., Sako et al. 2000; Kinkhabwala et al. 2002). Another possibility is the contribution of thermal emission from a collisionally ionized plasma, which is heated by shocks induced by AGN outflows (King 2005) or intense star formation. For example, a high-resolution image of NGC 4945 with Chandra suggested that the soft X-rays are mostly dominated by thermal radiation from a starburst region (Schurch et al. 2002).

Far-infrared (FIR) luminosities are often used to estimate the contribution of starburst since star-forming activity is much
[43x126]more effective than the AGN in powering the FIR emission. A tight linear relation between the soft X-ray and the FIR luminosity is known for starburst and normal galaxies (e.g., David et al. 1992; Ranalli et al. 2003). Thus, the FIR luminosity can be used to determine the contribution of starburst to the soft X-ray. The FIR luminosities of our sample were calculated using the formula defined in Helou et al. (1985), based on flux densities at 60 μm and 100 μm. Infrared fluxes (60 μm and 100 μm) measured with Infrared Astronomical Satellite (IRAS) for 12 objects were taken from the NED. IRAS fluxes for the rest of the 10 objects are not available. The soft X-ray luminosities were calculated from fluxes in 0.5–2 keV corrected for absorption given in Table 7, Columns 9 and 11, except for NGC 4507 and NGC 7172. For calculations of the soft X-ray luminosities of NGC 4507 and NGC 7172, absorption corrected fluxes of the Gaussians in 0.5–2 keV (NGC 4507: 27.6 × 10^{-14} erg cm^{-2} s^{-1},
NGC 7070A

Figure 2. (Continued)

Table 3

| Name       | $N_H$ (10$^{22}$ cm$^{-2}$) | $\Gamma$ | $A_{\text{in}}$ | $E_{\text{line}}$ (keV) | $\sigma$ (eV) | Fe EW (eV) | $A_{\text{ga}}$ | $A_{\text{scat}}$ | $\chi^2$/dof |
|------------|-----------------------------|----------|-----------------|-------------------------|---------------|-------------|----------------|----------------|-------------|
| Mrk 348    | 19.07$^{+0.56}_{-0.52}$    | 1.677$^{+0.021}_{-0.018}$ | 11.89$^{+0.20}_{-0.21}$ | 6.448$^{+0.026}_{-0.032}$ | 5$^{<69}$     | 52$^{+15}_{-12}$ | 2.60$^{+0.86}_{-0.68}$ | 3.41$^{+0.46}_{-0.31}$ | 1.10(137)   |
| 3C 33      | 777$^{+23}_{-21}$          | 2.03$^{+0.14}_{-0.16}$    | 6.3$^{+0.9}_{-2.7}$     | 6.41$^{+0.10}_{-0.03}$    | 55$^{<149}$   | 180$^{+120}_{-2.8}$ | 1.25$^{+0.56}_{-0.62}$ | 1.13(40)     |
| NGC 1142   | 56.5$^{+3.2}_{-1.6}$       | 1.81$^{+0.07}_{-0.03}$    | 5.19$^{+0.26}_{-0.27}$  | 6.41$^{+0.026}_{-0.028}$  | 20$^{<69}$    | 220$^{+60}_{-3.8}$  | 2.84$^{+0.31}_{-0.24}$ | 1.16(90)     |
| IC 2461    | 12.3$^{+1.0}_{-0.6}$       | 1.64$^{+0.07}_{-0.10}$    | 1.11$^{+0.24}_{-0.24}$  | 6.46$^{+0.5}_{-0.7}$      | 0$^{<6}$      | 65$^{+50}_{-0.36}$  | 0.36$^{+0.27}_{-0.28}$ | 0.18$^{+0.10}_{-0.11}$ | 0.88(116)  |
| NGC 4388   | 3.61$^{+0.10}_{-0.06}$     | 1.49$^{+0.05}_{-0.04}$    | 1.40$^{+0.05}_{-0.04}$  | 6.39$^{+0.068}_{-0.066}$  | 10$^{<6}$     | 86$^{+47}_{-45}$    | 1.20$^{+0.43}_{-0.13}$ | 1.17(138)    |
| ESO 506—G027 | 1.14$^{+0.01}_{-0.01}$    | 1.55$^{+0.072}_{-0.03}$   | 6.8$^{+0.3}_{-0.5}$     | 6.41$^{+0.024}_{-0.022}$  | 5$^{<64}$     | 120$^{+160}_{-0.2}$ | 1.7$^{<0.1}_{-1.1}$   | 4.6$^{+0.65}_{-0.61}$ | 1.10(157) |
| NGC 4507   | 4.84$^{+0.31}_{-0.30}$     | 1.50$^{+0.012}_{-0.088}$  | 7.05$^{+0.012}_{-0.017}$ | 6.41$^{+0.013}_{-0.011}$  | 42$^{<68}$    | 220$^{+100}_{-12}$   | 12.0$^{+2.3}_{-1.8}$   | 4.6$^{+0.71}_{-0.65}$ | 1.10(157) |
| ESO 383—G18 | 1.18$^{+0.02}_{-0.01}$    | 1.55$^{+0.072}_{-0.03}$   | 6.8$^{+0.3}_{-0.5}$     | 6.41$^{+0.024}_{-0.022}$  | 5$^{<64}$     | 120$^{+160}_{-0.2}$ | 1.7$^{<0.1}_{-1.1}$   | 4.6$^{+0.65}_{-0.61}$ | 1.10(157) |
| ESO 103—G035 | 2.00$^{+0.06}_{-0.06}$    | 1.92$^{+0.012}_{-0.011}$  | 19.14$^{+0.29}_{-0.28}$ | 6.47$^{+0.026}_{-0.026}$  | 3$^{<63}$     | 66$^{+22}_{-19}$    | 3.6$^{+1.1}_{-1.3}$   | 1.3$^{+0.33}_{-0.35}$ | 1.02(133) |
| IC 4995    | 4.5$^{+2.1}_{-1.9}$       | 1.96$^{+1.6}_{-0.26}$     | 0.45$^{+0.4}_{-0.16}$   | 6.39$^{+0.057}_{-0.062}$  | 0$^{<6}$      | 890$^{+620}_{-40}$  | 1.20$^{<0.5}_{-0.56}$ | 0.99$^{<0.35}_{-0.32}$ | 1.14(15)  |
| NGC 7172   | 7.87$^{+0.071}_{-0.070}$  | 1.66$^{+0.014}_{-0.009}$  | 15.78$^{+0.09}_{-0.09}$ | 6.38$^{+0.020}_{-0.020}$  | 72$^{24}$     | 69$^{+11}_{-1}$     | 5.1$^{<0.74}_{-0.74}$  | 2.81$^{+0.24}_{-0.33}$ | 1.18(168) |
| NGC 7319   | 75.5$^{+6.3}_{-5.7}$      | 1.90$^{+0.12}_{-0.16}$    | 2.70$^{+0.11}_{-0.87}$  | 6.39$^{+0.023}_{-0.023}$  | 54$^{<97}$    | 370$^{+80}_{-0.62}$  | 3.00$^{+0.65}_{-0.62}$ | 1.25$^{+0.20}_{-0.13}$ | 1.13(128) |

Notes. Photon index of the power law with only Galactic absorption was assumed to be the same value as the hard power law absorbed by cold matter at the redshift of the source. (f) indicates the fixed parameter.

a Normalization of the absorbed power law in units of 10$^{-3}$ photons cm$^{-2}$ s$^{-1}$ at 1 keV.

b Normalization of the Gaussian line in units of 10$^{-3}$ photons cm$^{-2}$ s$^{-1}$ in the line.

c Normalization of the less absorbed power law in units of 10$^{-5}$ photons cm$^{-2}$ s$^{-1}$ at 1 keV.
NGC 7172: $1.53 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$), were added to the fluxes given in Table 7, Columns 9 and 11. The calculated FIR and soft X-ray luminosities are shown in Table 8 and the relation between the soft X-ray and the FIR luminosity for our sample is shown in Figure 3. The area surrounded by two solid lines expresses the region for starburst galaxies in Ranalli et al. (2003). About a half of our sample is in the starburst region. This means that the contribution from starburst is likely to be large in the soft X-ray emission of these sources. Therefore, it should be noted that starburst contribution may not be negligible in the soft X-ray emission in calculating scattering fractions in Section 4.2 for about a half of our sample. If starburst significantly contributes to the soft X-ray emission, the level of scattered emission would be much lower than those derived in Section 4.2.

### 4.2. Scattering Fraction

Scattering fractions are often calculated with the following equation:

$$f_{\text{scat}} = \frac{A_{\text{scat}}}{A_{\text{int}}}$$

### Table 4

Spectral Parameters for MEKAL and the Third Power Law in the Complex Models

| Name         | $kT$ (keV) | $A_{\text{int}}$ | $kT$ (keV) | $A_{\text{int}}$ |
|--------------|------------|-------------------|------------|------------------|
| Mrk 348      | 0.68$^{+0.11}_{-0.09}$ | 2.04$^{+0.38}_{-0.28}$ | 0.16$^{+0.015}_{-0.013}$ | 6.0$^{+1.0}_{-1.0}$ |
| 3C 33        | 0.29$^{+0.10}_{-0.09}$ | 2.07$^{+0.40}_{-0.20}$ | ... | ... |
| NGC 1142     | 0.295$^{+0.03}_{-0.043}$ | 3.70$^{+0.07}_{-0.10}$ | ... | ... |
| IC 2641      | 0.65$^{+0.05}_{-0.04}$ | 1.69$^{+0.40}_{-0.20}$ | ... | ... |
| NGC 4138     | 0.265$^{+0.06}_{-0.048}$ | 1.44$^{+0.40}_{-0.20}$ | ... | ... |
| NGC 4388     | 0.78$^{+0.05}_{-0.11}$ | 7.60$^{+0.30}_{-0.30}$ | 0.203$^{+0.05}_{-0.014}$ | 10.9$^{+0.9}_{-0.4}$ |
| NGC 4507     | ... | ... | ... | ... |
| ESO 506–G027 | ... | ... | ... | ... |
| NGC 4939     | 0.65$^{+0.05}_{-0.04}$ | 1.9$^{+0.10}_{-0.10}$ | ... | ... |
| ESO 383–G18 | 0.232$^{+0.030}_{-0.036}$ | 2.77$^{+0.60}_{-0.50}$ | ... | ... |
| IC 4995      | 0.52$^{+0.14}_{-0.13}$ | 2.40$^{+0.55}_{-0.50}$ | 0.081($<0.085$) | 113$^{+21}_{-24}$ |
| NGC 7172     | 0.302$^{+0.07}_{-0.06}$ | 1.30$^{+0.30}_{-0.30}$ | ... | ... |
| NGC 7319     | 0.621$^{+0.054}_{-0.057}$ | 3.51$^{+0.30}_{-0.30}$ | ... | ... |

Notes. (f) indicates the fixed parameter.

### Table 5

Spectral Parameters for Gaussians in the Complex Models

| Name         | $E_{\text{line}}$ (keV) | $\sigma$ (eV) | $A_{\text{gauss}}$ | Identification |
|--------------|--------------------------|---------------|---------------------|----------------|
| Mrk 348      | 6.670$^{+0.045}_{-0.045}$ | 60$^{+111}_{-111}$ | $-2.52^{+0.72}_{-0.60}$ | Fe XXV |
| 7.000$^{+0.035}_{-0.035}$ | 65$^{+67}_{-67}$ | $-1.74^{+0.55}_{-0.45}$ | Fe XXV |
| NGC 7172     | 1.734$^{+0.041}_{-0.041}$ | 77$^{+96}_{-96}$ | $0.57^{+0.20}_{-0.20}$ | Si Kα |
| NGC 4507     | 0.475$^{+0.007}_{-0.007}$ | 10$^{+0}_{-0}$ | $6.0^{+0.75}_{-0.75}$ | O VII Kα |
| ... | ... | ... | ... | ... |
| NGC 1142     | 3C 98 | ESO 103–G035 | IC 4995 | NGC 7172 | NGC 7319 |

Notes. (f) indicates the fixed parameter.

a) Normalization of the Gaussian line in units of $10^{-3}$ photons cm$^{-2}$ s$^{-1}$.  
b) Compton shoulder.

### Table 6

Best-fit Models for Our Sample

| Name | Model$^a$ |
|------|-----------|
| Mrk 348 | BM + two MEKAL + two lines + abs-PL |
| 3C 33  | BM + MEKAL + Ref |
| 2MASX J02281350–0315023 | BM + MEKAL |
| NGC 1142 | BM + MEKAL |
| 3C 98  | BM + MEKAL |
| B2 0857+39 | BM |
| IC 2641 | BM + MEKAL |
| 2MASX J1035255+0044033 | BM |
| MCG +08-21-065 | BM |
| NGC 4074 | BM |
| NGC 4138 | BM + MEKAL |
| NGC 4388 | BM + two MEKAL + abs-Ref |
| NGC 4507 | BM + ten lines + abs-Ref |
| ESO 506–G027 | BM + abs-Ref |
| 2MASX J12544196–3019224 | BM |
| NGC 4939 | BM + MEKAL |
| ESO 383–G18 | BM + MEKAL + Ref |
| ESO 103–G035 | BM + MEKAL + abs-Ref |
| IC 4995 | BM + two MEKAL |
| NGC 7070A | BM |
| NGC 7172 | BM + MEKAL + line |
| NGC 7319 | BM + MEKAL + abs-Ref |

Notes.  
$^a$ BM: Baseline model, PL: power law, MEKAL: thin thermal plasma model (mekal), Ref: cold reflection model (pxevav), abs-PL(or Ref): absorbed PL(or Ref). All components are absorbed by the Galactic absorption.
### Table 7

Flux for the Best-fit Model

| Name | Total Power Law (Observed) | Total Power Law (Observed) | Power Law (Intrinsic) | Power Law (Intrinsic) | MEKAL (Observed) | MEKAL (Intrinsic) |
|------|---------------------------|---------------------------|----------------------|----------------------|-----------------|------------------|
|      | 0.5–2 keV | 2–10 keV | 0.5–2 keV | 2–10 keV | 0.5–2 keV | 2–10 keV | 0.5–2 keV | 2–10 keV | 0.5–2 keV | 2–10 keV |
| Mrk 348 | 12.3 | 27.9 | 8.36 | 28.1 | 32.2 | 60.9 | 6.33 | 7.49 | 3.97 | 5.50 |
| 3C 33 | 6.06 | 2.51 | 2.16 | 1.56 | 12.4 | 13.8 | 2.16 | 2.41 | 1.41 | 1.69 |
| 2MASX J02281350–3015023 | 0.637 | 0.817 | 0.637 | 0.792 | 1.44 | 1.94 | 0.634 | 0.681 | ... | ... |
| NGC 1142 | 7.49 | 3.11 | 5.04 | 2.97 | 11.1 | 17.0 | 5.03 | 6.01 | ... | ... |
| 3C 98 | 3.49 | 2.62 | 2.02 | 2.59 | 2.40 | 4.82 | 1.94 | 2.57 | 1.47 | 2.14 |
| B2 0857+39 | 0.376 | 0.420 | 0.376 | 0.417 | 0.624 | 0.841 | 0.353 | 0.377 | ... | ... |
| IC 2461 | 1.92 | 3.55 | 1.67 | 3.44 | 2.89 | 5.35 | 0.383 | 0.396 | 0.254 | 0.273 |
| 2MASX J10335255+0044033 | 1.10 | 0.557 | 1.10 | 0.557 | 0.918 | 1.24 | 1.10 | 1.28 | ... | ... |
| MCG +08-21-065 | 0.415 | 0.843 | 0.415 | 0.814 | 1.71 | 2.21 | 0.414 | 0.439 | ... | ... |
| NGC 4074 | 6.17 | 2.75 | 6.17 | 2.66 | 4.90 | 6.61 | 6.16 | 6.64 | ... | ... |
| NGC 4138 | 4.77 | 5.44 | 3.58 | 5.37 | 3.32 | 8.30 | 2.56 | 2.65 | 1.19 | 1.28 |
| NGC 4388 | 25.2 | 20.7 | 9.73 | 17.1 | 19.4 | 49.4 | 9.73 | 10.5 | 14.9 | 16.9 |
| NGC 4507 | 36.6 | 12.5 | 18.1 | 10.2 | 15.9 | 39.1 | 18.1 | 21.9 | ... | ... |
| ESO 506-G027 | 2.30 | 4.06 | 2.30 | 2.22 | 15.1 | 34.2 | 2.30 | 2.68 | ... | ... |
| 2MASX J12544196–3019224 | 1.05 | 0.527 | 1.05 | 0.491 | 0.906 | 1.22 | 1.05 | 1.27 | ... | ... |
| NGC 4939 | 7.79 | 3.65 | 5.60 | 3.59 | 6.66 | 8.98 | 5.60 | 6.22 | 2.19 | 2.47 |
| ESO 383-G18 | 5.42 | 6.09 | 2.94 | 5.25 | 4.24 | 11.5 | 2.94 | 3.28 | 1.66 | 2.14 |
| ESO 103-G035 | 5.72 | 23.2 | 2.37 | 20.1 | 41.5 | 54.3 | 2.35 | 2.82 | 2.40 | 2.90 |
| IC 4995 | 6.29 | 0.348 | 1.71 | 0.295 | 0.992 | 1.34 | 1.71 | 1.94 | 4.59 | 5.92 |
| NGC 7070A | 1.43 | 2.17 | 1.43 | 2.16 | 1.63 | 3.99 | 1.39 | 1.50 | ... | ... |
| NGC 7172 | 17.5 | 42.3 | 14.8 | 41.8 | 34.9 | 67.6 | 5.85 | 6.21 | 1.13 | 1.25 |
| NGC 7319 | 5.80 | 1.34 | 2.16 | 0.905 | 5.78 | 7.82 | 2.16 | 2.61 | 3.62 | 4.56 |

**Note.** The units of Columns 2, 4, 9, 10, and 11 are $10^{-14}$ erg cm$^{-2}$ s$^{-1}$. The units of Columns 3, 5, 6, and 7 are $10^{-12}$ erg cm$^{-2}$ s$^{-1}$. 

---

No. 1, 2009 NEW SAMPLE OF BURIED AGNs SELECTED FROM THE 2XMM CATALOGUE 463
Figure 3. Comparison between intrinsic luminosity of the soft component in the 0.5–2 keV band and FIR luminosity. The area surrounded by two solid lines is a typical region for starburst galaxies (Ranalli et al. 2003).
(A color version of this figure is available in the online journal.)

Table 8
Hard X-ray, Soft X-ray, Far Infrared, and [O\textsc{iii}] λ5007 Luminosities

| Name         | Hard (erg s\(^{-1}\)) | Soft (erg s\(^{-1}\)) | FIR (erg s\(^{-1}\)) | [O\textsc{iii}] | Reference |
|--------------|----------------------|-----------------------|----------------------|----------------|-----------|
| Mrk 348      | 43.49                | 40.82                 | 43.49                | 41.95          | 1         |
| 3C 33        | 44.07                | 41.55                 | 43.51                | 41.25          | 2         |
| 2MASX J02281350−0315023 | 43.46 | 41.01 | 43.77 | 41.87 | 3 |
| NGC 1142     | 43.51                | 41.25                 | 44.77                | 41.87          | 3         |
| 3C 98        | 43.01                | 41.00                 | 41.91                | 41.91          | 4         |
| B2 0857+39   | 44.12                | 41.77                 | 43.00                | 43.00          | 4         |
| IC 2461      | 41.83                | 38.93                 | 43.62                | 43.62          | 5         |
| 2MASX J10335255+0044033 | 43.75 | 41.77 | 43.62 | 43.62 | 5 |
| MCG +08-21-065 | 42.65 | 39.95 | 43.51 | 39.78 | 6 |
| NGC 4074     | 42.88                | 40.88                 | 43.05                | 43.05          | 7         |
| NGC 4138     | 42.91                | 40.88                 | 38.75                | 38.75          | 8         |
| NGC 4388     | 42.33                | 40.63                 | 44.77                | 44.77          | 1         |
| NGC 4507     | 43.09                | 41.19                 | 43.81                | 43.81          | 1         |
| ESO 506-G027 | 43.69                | 40.58                 | 43.58                | 43.58          | 9         |
| 2MASX J12544196−3019224 | 42.96 | 40.98 | 42.96 | 42.96 | 9 |
| NGC 4939     | 42.33                | 40.31                 | 43.93                | 43.93          | 1         |
| ESO 383-G18  | 42.60                | 40.27                 | 41.43                | 41.43          | 1         |
| ESO 103-G035 | 43.33                | 40.35                 | 43.54                | 43.54          | 1         |
| IC 4995      | 41.88                | 40.66                 | 43.40                | 43.40          | 1         |
| NGC 7070A    | 41.75                | 39.33                 | 42.40                | 42.40          | 7         |
| NGC 7172     | 43.06                | 40.18                | 39.83                | 39.83          | 1         |
| NGC 7319     | 42.95                | 40.92                 | 41.44                | 41.44          | 1         |

Notes. Column 1: Galaxy name. Column 2: logarithm of intrinsic 2–10 keV luminosity. Column 3: logarithm of intrinsic 0.5–2 keV luminosity of soft X-ray components. Column 4: logarithm of far-infrared luminosity. Column 5: logarithm of reddening corrected [O\textsc{iii}] luminosity. Column 6: references for [O\textsc{iii}] luminosity.

References. (1) Bassani et al. 1999; (2) Yee & Oke 1978; (3) Shu et al. 2007; (4) Costero & Osterbrock 1977; (5) Dong et al. 2005; (6) Line flux measurement based on the Sloan Digital Sky Survey data at MPA/JHU (http://www.mpia-garching.mpg.de/SDSS/); Kauffmann et al. 2003; (7) Polletta et al. 1996; (8) Ho et al. 1997; (9) Landi et al. 2007.

where \(A_{\text{int}}\) and \(A_{\text{scat}}\) are the normalization for the power law with large and only Galactic absorption, respectively. The values calculated for our sample are shown in Table 9. Since the origin of soft X-ray emission is not clear as discussed in Section 4.1, we calculated scattering fractions with the equation as follows;

\[
f_{\text{scat}} = \frac{F_{\text{soft}}}{F_{\text{int}}},
\]

\(F_{\text{int}}\) and \(F_{\text{soft}}\) are absorption corrected fluxes in the 0.5–2 keV band for the power law corresponding to the direct emission and all the components except for the direct power law, respectively. This value is regarded as an upper limit on the scattering fraction. The obtained values (Table 9) except for NGC 4507 and IC 4995 are smaller than the value typical for other Seyfert 2s observed so far, which is about 3% (e.g., Turner et al. 1997; Bianchi & Guainazzi 2007). In particular, those of eight sources are less than 0.5%. These are in the range recently found by hard X-ray surveys (Ueda et al. 2007; Winter et al. 2008).

The scattering fraction can be related to the geometry of the scatterer;

\[
f_{\text{scat}} \sim \frac{\Delta \Omega}{4 \pi},
\]

where \(\Delta \Omega\) and \(\tau\) are the solid angle subtended by the scattering electrons and a scattering optical depth, respectively. Thus, the small scattering fraction indicates that \(\Delta \Omega\) and/or \(\tau\) are small. If \(\tau\) does not differ much from object to object, our sample with a small scattering fraction is strong candidates for AGNs buried in a very geometrically thick torus with a small opening angle.

4.3. Comparison with [O\textsc{iii}] λ5007 Luminosity

[O\textsc{iii}] λ5007 emission is produced in the narrow-line region (NLR), which is considered to exist in the opening direction.
of the torus. Since the X-ray scattering region is also spatially extended along the NLR (Sako et al. 2000; Young et al. 2001; Bianchi et al. 2006), we expect that an AGN buried in a geometrically thick torus with a small opening part should have a fainter \([\text{O} \text{iii}]\) emission luminosity relative to a hard X-ray luminosity compared with classical Seyfert 2 galaxies with a large opening part.

We collected \([\text{O} \text{iii}]\) luminosities for 16 objects in our sample from the literature as shown in Table 8. The \([\text{O} \text{iii}]\) fluxes were corrected for the extinction by using the relation

\[
L_{\text{[OIII]}}^{\text{int}} = L_{\text{[OIII]}}^{\text{obs}} \left( \frac{\text{H} \alpha / \text{H} \beta}{(\text{H} \alpha / \text{H} \beta)_0} \right)^{2.94},
\]

assuming an intrinsic Balmer decrement \((\text{H} \alpha / \text{H} \beta)_0 = 3.0\), where \(L_{\text{[OIII]}}^{\text{obs}}\) and \(\text{H} \alpha / \text{H} \beta\) are an observed \([\text{O} \text{iii}]\) luminosity and a ratio between observed \(\text{H} \alpha\) and \(\text{H} \beta\) line fluxes, respectively (Bassani et al. 1999).

Figure 4 shows the correlation between the intrinsic luminosities in the 2–10 keV band \((L_{\text{2–10}}^{\text{int}})\) and the reddening corrected \([\text{O} \text{iii}]\) line luminosity \((L_{\text{[OIII]}}^{\text{int}})\) for our sample and a large sample of Seyfert 2 compiled by Bassani et al. (1999). From the latter sample, we used objects with \(N_{\text{H}}\) in the range \((0.6–20) \times 10^{23} \text{ cm}^{-2}\), which is the range observed for our sample. Some objects belong to both samples and such objects are regarded as members of our sample. The solid lines in Figure 4 correspond to \(L_{\text{2–10}}^{\text{int}}/L_{\text{[OIII]}}^{\text{int}} = 1, 10, \text{ and } 100\) from bottom to top. The distribution of the \(L_{\text{2–10}}^{\text{int}}/L_{\text{[OIII]}}^{\text{int}}\) ratios for the two samples is shown in Figure 5. The ratios for Bassani’s sample are in the range 1–100, while those for most sources in our sample are > 10. In particular, the ratios for three sources (MCG+08–21–065, NGC 4138, and NGC 7172) are greater than 100.

Netzer et al. (2006) showed that the ratio \(L_{\text{2–10}}^{\text{int}}/L_{\text{[OIII]}}^{\text{int}}\) increases with \(L_{\text{2–10}}^{\text{int}}\) such that

\[
\log \frac{L_{\text{2–10}}^{\text{int}}}{L_{\text{[OIII]}}^{\text{int}}} = (0.38 \pm 0.09) \log L_{\text{2–10}}^{\text{int}} - (15.0 \pm 4.0),
\]

using a sample obtained from Bassani et al. (1999) and supplemented by Turner et al. (1997). Therefore, we compared the distribution of \(L_{\text{2–10}}^{\text{int}}\) between Bassani’s and our samples to examine whether the larger \(L_{\text{2–10}}^{\text{int}}/L_{\text{[OIII]}}^{\text{int}}\) in our sample is explained by this luminosity dependence. The distribution of \(L_{\text{2–10}}^{\text{int}}\) for Bassani’s and our samples is shown in Figure 6 as solid and dashed histograms, respectively. The distribution for our sample is slightly biased toward higher luminosities by \(\log L_{\text{2–10}}^{\text{int}} \sim 0.5\). According to Netzer’s relation, this amount of shift in \(L_{\text{2–10}}^{\text{int}}\) results in an increase of \(L_{\text{2–10}}^{\text{int}}/L_{\text{[OIII]}}^{\text{int}}\) only by a factor of 1.5. We attempted the two-sample Kolmogorov–Smirnov test to examine the difference more quantitatively. The values of \(L_{\text{2–10}}^{\text{int}}/L_{\text{[OIII]}}^{\text{int}}\) were scaled to an assumed reference point \(L_{\text{2–10}}^{\text{int}} = 10^{43} \text{ erg s}^{-1}\) by using Netzer’s relation, which was calculated by

\[
\log \left[ \frac{L_{\text{2–10}}^{\text{int}}}{L_{\text{[OIII]}}^{\text{int}}} \right]_{\text{scaled}} = \log \frac{L_{\text{2–10}}^{\text{int}}}{L_{\text{[OIII]}}^{\text{int}}} - 0.38 \log \left[ \frac{L_{\text{2–10}}^{\text{int}}}{10^{43} \text{ erg s}^{-1}} \right].
\]

The Kolmogorov–Smirnov test showed that the distributions of the scaled \(L_{\text{2–10}}^{\text{int}}/L_{\text{[OIII]}}^{\text{int}}\) for Bassani’s and our samples are drawn from the same parent population with the probability of 9.3%. Thus the difference of \(L_{\text{2–10}}^{\text{int}}/L_{\text{[OIII]}}^{\text{int}}\) between the two samples would not be explained solely by the luminosity dependence.

We found that \([\text{O} \text{iii}]\) luminosities for our sample are intrinsically lower than those of Seyfert 2s studied so far at a given X-ray luminosity, and agree with the above expectation. Although luminosities of optical narrow emission lines are often utilized as a good indicator of an intrinsic luminosity of an AGN and used for constructing the most unbiased samples (e.g., Mulchaey et al. 1994; Heckman 1995; Keel et al. 1994; Heckman et al. 2005), estimation of intrinsic luminosities of an AGN based on \([\text{O} \text{iii}]\) would have large uncertainties and surveys that rely on \([\text{O} \text{iii}]\) emission could be subject to biases against buried AGNs. In order to obtain complete unbiased samples of AGNs, hard X-ray surveys would be imperative.
We searched for AGNs, whose scattered emission is very weak, from the 2XMM Catalogue. In our selection procedure, we calculated HRs expected for an object with a small scattering fraction using a model consisting of absorbed and unabsorbed power laws and 22 sources were selected as candidates from the 2XMM Catalogue. Spectral analysis was conducted using the data observed with XMM-Newton for these 22 sources. Their X-ray spectra are represented by a combination of an absorbed power law with a column density of $\sim 10^{23} - 10^{24}$ cm$^{-2}$, an unabsorbed power law, a narrow Gaussian line for the Fe K emission, and some additional components. The photon indices of the power-law components for 14 objects are in a typical range of 1.9. The distribution of the intrinsic luminosity in the 2–10 keV band for our sample (solid histogram) and the Seyfert 2 sample compiled by Bassani et al. (1999) with $N_{\text{H}}$ in the range of (0.6–20) $\times 10^{23}$ cm$^{-2}$ (dashed histogram).

(A color version of this figure is available in the online journal.)

5. CONCLUSION

We thank an anonymous referee for useful comments that improved the paper. This paper is based on observations obtained with XMM-Newton, an ESA science mission with instruments and contributions directly funded by ESA Member States and the USA (NASA). This research made use of the NASA/IPAC Extragalactic Database, which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. This work is supported by Grants-in-Aid for Scientific Research 2074109 (Y.T.) and 21244017 (H.A.) from the Ministry of Education, Culture, Sports, Science, and Technology of Japan.

Facilities: XMM-Newton

REFERENCES

Anders, E., & Grevesse, N. 1989, Geochim. Cosmochim. Acta, 53, 197
Antonucci, R. 1993, ARA&A, 31, 473
Awaki, H., Koyama, K., Inoue, H., & Halpern, J. 1991, PASJ, 43, 195
Awaki, H., Murakami, H., Ogawa, Y., & Leighly, K. M. 2006, ApJ, 645, 928
Bassani, L., et al. 1999, ApJS, 121, 473
Bassani, L., et al. 2006, ApJ, 636, L65
Beckmann, V., Gehrels, N., Favre, P., Walter, R., Courvoisier, T. J.-L., Petrucci, P.-O., & Malzac, J. 2004, ApJ, 614, 641
Beckmann, V., Gehrels, N., Shadrar, C. R., & Soldi, S. 2006, ApJ, 638, 64
Bianchi, S., & Guainazzi, M. 2007, in AIP Conf. Ser. 924, The Multicolored Landscape of Compact Objects and Their Explosive Origins, ed. T. di Salvo et al. (Melville, NY: AIP), 822
Bianchi, S., Guainazzi, M., & Chiaberge, M. 2006, A&A, 448, 409
Brandt, W. N., & Hasinger, G. 2005, ARA&A, 43, 827
Cappi, M., et al. 2006, A&A, 446, 459
Cash, W. 1979, ApJ, 228, 939
Comastri, A., 2004, in ASSL, Vol. 308, Supermassive Black Holes in the Distant Universe, ed. A. J. Barger (Dordrecht: Kluwer), 245
Comastri, A., Setti, G., Zamorani, G., & Hasinger, G. 1995, A&A, 296, 1
Costero, R., & Osterbrock, D. E. 1977, ApJ, 211, 673
David, L. P., Jones, C., & Forman, W. 1992, ApJ, 388, 82
De Rosa, A., Bassani, L., Ubertini, P., Panessa, F., Malizia, A., Dean, A. J., & Walter, R. 2008, A&A, 483, 749
Dong, X., Zhou, H., Wang, T., Wang, J., Li, C., & Zhou, Y. 2005, ApJ, 620, 629
Evans, D. A., Worrall, D. M., Hardcastle, M. J., Kraft, R. P., & Birkinshaw, M. 2006, ApJ, 642, 96
Fanaroff, B. L., & Riley, M. J. 1974, MNRAS, 167, 31
Foschini, L., et al. 2002, A&A, 392, 817
Gilli, R., Comastri, A., & Hasinger, G. 2007, A&A, 463, 79
Guainazzi, M., & Bianchi, S. 2007, MNRAS, 374, 1290
Guainazzi, M., Fabian, A. C., Iwasawa, K., Matt, G., & Fiore, F. 2005a, MNRAS, 356, 295
Guainazzi, M., Matt, G., & Perola, G. C. 2005b, A&A, 444, 119
Heckman, T. 1995, ApJ, 446, 101
Heckman, T. M., Ptak, A., Hornschemeier, A., & Kauffmann, G. 2005, ApJ, 634, 161
Helou, G., Soifer, B. T., & Rowan-Robinson, M. 1985, ApJ, 298, L7
Ho, L. C., Filippenko, A. V., & Sargent, W. L. W. 1997, ApJS, 112, 315
Isobe, N., Makishima, K., Tashiro, M., & Hong, S. 2005, ApJ, 632, 781
Kaasstra, J. S. 1992, An X-Ray Spectral Code for Optically Thin Plasmas (Internal SRON-Leiden Report, updated version 2.0)
Kalberla, P. M. W., Burton, W. B., Hartmann, D., Arnal, E. M., Bajaja, E., Morras, R., & Pöppel, W. G. L. 2005, A&A, 440, 775
Kauffmann, G., et al. 2003, MNRAS, 346, 1055
Keel, W. C., de Grijs, M. H. K., Miley, G. K., & Zheng, W. 1994, A&A, 283, 791
King, A. 2005, ApJ, 635, 121
Kinkhabwala, A., et al. 2002, ApJ, 575, 732
Kraemer, S. B., Reynolds, S. P., & Pounds, K. A. 2002, ApJ, 575, 892
Kraft, R. P., Birkinshaw, M., Hardcastle, M. J., Evans, D. A., Croston, J. H., Worrall, D. M., & Murray, S. S. 2007, ApJ, 659, 1008
Kraft, R. P., et al. 2007, ApJ, 669, 109
Liedahl, D. A., Osterheld, A. L., & Goldstein, W. H. 1995, ApJ, 438, L115
Magdziarz, P., & Zdziarski, A. A. 1995, MNRAS, 273, 837
Markwardt, C. B., Tueller, J., Skinner, G. K., Gehrels, N., Barthelmy, S. D., & Mushotzky, R. F. 2005, ApJ, 633, L77
Matt, G. 2002, MNRAS, 337, 147
Matt, G., Bianchi, S., D’Ammando, F., & Martocchia, A. 2004, A&A, 421, 473

Figure 6. Distribution of the intrinsic luminosity in the 2–10 keV band for our sample (solid histogram) and the Seyfert 2 sample compiled by Bassani et al. (1999) with $N_{\text{H}}$ in the range of (0.6–20) $\times 10^{23}$ cm$^{-2}$ (dashed histogram).
