The contribution of AGN to the X–ray background: the effect of iron features

R. Gilli\textsuperscript{a,b}, A. Comastri\textsuperscript{c}, G. Brunetti\textsuperscript{d,b}, G. Setti\textsuperscript{d,b}

\textsuperscript{a}Dipartimento di Astronomia, Università di Firenze, Largo E. Fermi 5, I–50125 Firenze, Italy
\textsuperscript{b}Istituto di Radioastronomia del CNR, Via Gobetti 101, I–40129 Bologna, Italy
\textsuperscript{c}Osservatorio Astronomico di Bologna, Via Ranzani 1, I–40127 Bologna, Italy
\textsuperscript{d}Dipartimento di Astronomia, Università di Bologna, Via Ranzani 1, I–40127 Bologna, Italy

Abstract

The contribution of the iron emission line, commonly detected in the X–ray spectra of Seyfert (Sey) galaxies, to the cosmic X–ray background (XRB) spectrum is evaluated in the framework of the XRB synthesis models based on AGN unification schemes. To derive the mean line properties, we have carried out a search in the literature covering a sample of about 70 AGN. When adopting line parameters in agreement with the observations, it turns out that the maximum contribution of the iron line to the XRB is less than 7% at a few keV. This is still below the present uncertainties in the XRB spectrum measurements.

Key words: X–rays: galaxies, galaxies: Seyfert, cosmology: diffuse radiation

PACS: : 98.70.Qy, 98.54.Cm, 98.70.Vc

1 Introduction

The observations performed by the HEAO–1, ROSAT and ASCA satellites have allowed a good description of the X–ray background spectrum over a wide energy range from 0.1 to \( \sim 400 \) keV. The intensity above \( \sim 1 \) keV has an extragalactic origin, resulting from the summed emission of unresolved sources over all cosmic epochs. The recent ROSAT deep survey in the Lockman hole has shown that in the soft 0.5–2.0 keV band nearly 70% of the XRB is already resolved into discrete sources at a limiting flux of \( \sim 10^{-15} \) erg cm\(^{-2}\) s\(^{-1}\) (Hasinger et al. 1998). The resolved fraction in the 2–10 keV band is much lower: from a medium sensitivity survey with the ASCA GIS about 27% of...
the XRB measured by HEAO–1 (Gruber 1992) has been resolved at a limiting flux of \( \sim 6 \times 10^{-14} \) erg cm\(^{-2}\) s\(^{-1}\) (Cagnoni, Della Ceca & Maccacaro 1998). While nearly 80% of the ROSAT sources have been optically identified as active galactic nuclei (AGN; Schmidt et al. 1998), the optical counterparts of the ASCA sample are not fully available yet.

On the other hand it is well known that the 2–20 keV XRB spectrum, well approximated by a flat power law with energy spectral index \( \alpha \sim 0.4 \), cannot be simply reproduced by the emission of quasars and Sey 1 galaxies, which have steeper (\( \alpha \sim 0.8 – 0.9 \)) hard X-ray spectra (Comastri et al. 1992; Nandra & Pounds 1994). This apparent contradiction, known as the “spectral paradox” (Boldt 1987), has been circumvented by Setti & Woltjer (1989) who demonstrated that the main characteristics of the XRB could be reproduced by summing the contributions from unabsorbed (type 1) and absorbed (type 2) AGN according to the population ratios predicted by the unification models (Antonucci & Miller 1985; Barthel 1989). Comastri et al. (1995) have since worked out a detailed model which provides a good fit to the XRB in the broad 3–100 keV band and is consistent with all known X-ray properties of AGN classes (see also Madau et al. 1994). Other AGN models of the XRB do not meet observed constraints on the X-ray spectra and/or source counts (see Setti & Comastri 1996 for a review).

However, it has been pointed out (Matt & Fabian 1994) that strong iron features, such as the line at \( \sim 6.4 \) keV and related absorption edge commonly found in Seyferts spectra (Nandra & Pounds 1994), may lead AGN synthesis models to predict a detectable feature in the XRB spectrum at a few keV. Since recent ASCA observations (Gendreau et al. 1995) have shown that the 1.7–10 keV XRB spectral shape is rather smooth and featureless, apart from a narrow bump at \( \sim 2 \) keV due to the gold edge in the instrumental response, Di Matteo & Fabian (1997) have proposed that a new and as yet undetected population of advection-dominated sources with flat X-ray spectra is required to fit the XRB spectrum.

In order to further investigate whether the iron structure in the XRB spectral profile should have been detected, we have reconsidered the AGN synthesis model of the XRB described by Comastri et al. (1995) adding the iron lines to the input spectra.

Throughout this paper the values \( q_0 = 0 \) and \( H_0 = 50 \) km s\(^{-1}\) Mpc\(^{-1}\) have been assumed.
The iron line

The X-ray spectra of Seyfert galaxies commonly show radiation excesses in the 5–7 keV band with respect to a power law continuum. These are usually interpreted as Kα iron emission lines from regions reprocessing the nuclear radiation.

The iron line properties strongly depend on the geometry and dynamics of the reprocessing medium. From the energy of the line peak $E_{K\alpha}$, the width $\sigma_{K\alpha}$ and the equivalent width $W_{K\alpha}$, it is possible to identify the emission line regions. In most cases it is found that $E_{K\alpha} \simeq 6.4$ keV, in agreement with fluorescence emission from iron in the ionization range Fe i–Fe xvi, which is thought to be distributed into a cold ($T < 10^6$ K) accretion disc as well as into a surrounding molecular dusty torus.

Since the disc and torus components may contribute differently to the observed properties, the profiles and intensities of the iron lines are expected to be complex, depending also on the inclination with respect to the line of sight.

The properties of the iron line emitted by a cold accretion disc have been calculated in a number of papers (George & Fabian 1991; Matt et al. 1991). When relativistic effects are considered (Matt et al. 1992), the calculated line profile is broad ($\sigma_{K\alpha} \geq 0.2$ keV), asymmetric and double horned, with a Doppler boosted blue horn. The line equivalent width is predicted to be at most $\sim 200$ eV. Broad asymmetric line profiles have been detected by ASCA in several Sey 1 galaxies (Tanaka et al. 1995; Mushotzky et al. 1995; Nandra et al. 1997a) in agreement with relativistic disc models.

Ghisellini, Haardt & Matt (1994) have performed a quantitative analysis of the fluorescence line emission from a specific torus configuration under the assumption that the disc and the torus are coplanar. In the case of type 1 AGN, viewed along lines of sight free from obscuration, the iron line emitted by a dense torus ($N_H > 5 \times 10^{23}$ cm$^{-2}$) may contribute substantially to the overall line strength (up to $W_{K\alpha} \sim 90$ eV). On the other hand, since in type 2 AGN the radiation from the central source is intercepted by the torus, the equivalent width of the torus iron line may become very large (up to a few keV) for tori that are optically thick to Compton scattering (equatorial $N_H >$ a few $\times 10^{24}$ cm$^{-2}$). It is important to note that the iron line emitted by the torus should have roughly a narrow ($\sigma_{K\alpha} \leq 0.1$ keV) gaussian profile. The iron line equivalent widths and profiles of several Sey 2s are in good agreement with the torus picture (Smith & Done 1996; Weaver et al. 1996). Very strong iron lines associated to flat reflection continua are found in a dozen of type 2 objects, most likely Compton thick AGN (Maiolino et al. 1998 and references therein).

In a few objects, mainly Sey 2 galaxies, the iron emission is due to a combi-
nation of neutral Kα at 6.4 keV plus lines from highly ionized iron (Fe xxv, Fe xxvi) at 6.68 keV and 6.96 keV (Ueno et al. 1994; Turner et al. 1997a,b). These lines are thought to be produced in a ‘warm mirror’ (Matt, Brandt & Fabian 1996), which may also be responsible for the scattering of the broad optical lines observed in polarized light in type 2 objects.

The iron lines (as well as the reflection humps above ~ 10 keV) are not a common feature of the quasars spectra (Lawson & Turner 1997). Iwasawa & Taniguchi (1993) have suggested that an ‘X–ray Baldwin effect’ may hold, whereby the equivalent width of the lines decreases with increasing luminosity. This has been confirmed by Nandra et al. (1997b), who also find a change in the line profile with luminosity and propose a model where the accretion disc becomes more ionized as a function of the accretion rate.

In order to estimate the mean properties of the iron line we have collected literature data based on ASCA and GINGA measurements. We have also included recent data from BeppoSAX observations of several Sey 2 galaxies (Salvati et al. 1997; Maiolino et al. 1998). The sample consists of 29 Sey 1 galaxies, 36 Sey 2s and 6 Narrow Emission Line Galaxies (NELGs). Among the AGN in the sample, 58 objects have been observed by ASCA and 41 by GINGA, with 34 objects in both samples. The $W_{K\alpha}$ and $N_H$ values for the AGN in our samples are shown in Table 1.

2.1 ASCA data

Most of the ASCA data are taken from the samples of Nandra et al. (1997a), Reynolds (1997) and Turner et al. (1997a), plus other sources analyzed in various papers. The AGN have been divided into two classes: type 1 objects, grouping Sey 1.0–1.2–1.5, and type 2 objects, grouping Sey 1.8–1.9–2.0 as well as NELGs because of their substantial intrinsic absorption. Furthermore, we have subdivided type 2s into Compton thin and Compton thick AGN. The average line parameters derived from the sample are reported in Table 2. In this and in the following Tables the mean $W_{K\alpha}$ values are calculated without considering those objects where only upper limits are available (see Table 1). We note here that the derived mean values are generally consistent with the median values within 20%. Whenever dealing with good statistical samples, we have estimated the mean and the intrinsic dispersion of the parent population with the Maximum Likelihood algorithm (henceforth ML, Maccacaro et al. 1988), assuming a gaussian intrinsic distribution of the parameters. Confidence intervals are given at the 68% confidence level for one interesting parameter.

For both type 1 and type 2 objects the average energy of the line peak is close to 6.4 keV, as expected from emission by fluorescent cold iron. Since ASCA
Table 1
Line equivalent widths and column densities for the ASCA and GINGA samples

| Name            | ASCA | GINGA |
|-----------------|------|-------|
|                 | $W_{K\alpha}$ (eV) | $\log[N_H]$ (cm$^{-2}$) | Ref. | $W_{K\alpha}$ (eV) | $\log[N_H]$ (cm$^{-2}$) | Ref. |
| NGC 3227        | 206 ± 22 | 20.98 ± 0.04 | 1,2 | 150 ± 30 | 21.32$^{+0.15}_{-0.24}$ | 3   |
| NGC 3516        | 126 ± 18 | < 19.90    | 1,2 | 110 ± 90 | 22.76$^{+0.03}_{-0.04}$ | 3   |
| NGC 3783        | 132 ± 18 | 20.66$^{+0.04}_{-0.05}$ | 1,2 | 180 ± 40 | 22.34 ± 0.03      | 3   |
| NGC 4051        | 400$^{+97}_{-78}$ | < 19.78    | 2   | 230 ± 30 | < 21.70            | 4   |
| NGC 4151        | 307$^{+148}_{-88}$ | 23.05$^{+0.08}_{-0.07}$ | 5   | 160 ± 20 | 23.05$^{+0.03}_{-0.02}$ | 4   |
| NGC 4593        | 164 ± 35 | 20.30$^{+0.06}_{-0.10}$ | 1,2 | 154 ± 27 | < 21.30            | 3,4 |
| NGC 5548        | 244 ± 34 | < 19.30    | 1,2 | 112 ± 13 | < 21.2             | 3,4 |
| NGC 6814        | 430$^{+479}_{-182}$ | < 20.76    | 2   |        |                   |     |
| NGC 7213        |        |        |     | 130 ± 40 | 21.46$^{+0.16}_{-0.26}$ | 3   |
| NGC 7469        | 147 ± 30 | < 19.60   | 2,6 | 98 ± 70  | < 21.11            | 3,7 |
| Mrk 290         | 448 ± 56 | < 19.78   | 2,8 |        |                   |     |
| Mrk 335         | 167 ± 56 | < 19.95   | 1,2 | 155 ± 70 | < 21.62            | 3,9 |
| Mrk 509         | 210$^{+190}_{-130}$ | 20.32$^{+0.06}_{-0.07}$ | 1,2 | 60 ± 30  | < 20.78            | 3,4 |
| Mrk 766         | 115 ± 24 | < 20.28   | 1,10|        |                   |     |
| Mrk 841         | 130 ± 52 | < 21.00   | 1,2 | 447 ± 184 | 21.73$^{+0.34}_{-1.26}$ | 3   |
| Mrk 1040        | 550$^{+159}_{-162}$ | 21.56$^{+0.05}_{-0.07}$ | 11  |        |                   |     |
| 3C 111          | 40 − 195 | 21.81 ± 0.01 | 12  | < 80    | 22.26 ± 0.05      | 3   |
| 3C 120          | 399$^{+81}_{-74}$ | 21.22 ± 0.01 | 13  |        |                   |     |
| 3C 382          | 900$^{+632}_{-188}$ | 20.04$^{+0.21}_{-0.26}$ | 2   | 200 ± 60 | < 21.79            | 3,4 |
| 3C 390.3        | 251 ± 40 | 20.86 ± 0.04 | 2,14| 43 ± 20  | < 20.90            | 3,4 |
| 3C 445          | 268$^{+165}_{-162}$ | 22.76$^{+0.19}_{-0.16}$ | 15  |        |                   |     |
| MCG−2−58−22     | 320 ± 60 | < 20.56   | 1,2,16| 150 ± 50 | < 21.89            | 3   |
| MCG−6−30−15     | 338 ± 64 | 20.23 ± 0.05 | 1,17| 135 ± 14 | 21.66$^{+0.07}_{-0.08}$ | 3,18 |
| IRAS 15091−2107 | 190 ± 40 | < 22.00   | 4   |        |                   |     |
| ESO 141−G55     | 140 ± 42 | 20.72$^{+0.07}_{-0.06}$ | 2   |        |                   |     |
| IC 4329A        | 132 ± 18 | 21.49 ± 0.01 | 1,2,19| 110 ± 20 | 21.68$^{+0.04}_{-0.05}$ | 3   |
| Fairall 9       | 369 ± 54 | 20.08$^{+0.15}_{-0.18}$ | 1,2 | 120 ± 70 | < 21.15            | 3   |
| Akn 120         | 100 ± 50 | < 21.40   | 3,9 |        |                   |     |
| H2106−099       |        | < 180     | 3   |        |                   |     |
Table 1  
-Continued

| Name                | $W_{K\alpha}$(eV) | ASCA $\log[N_H]$ (cm$^{-2}$) | Ref. | GINGA $W_{K\alpha}$(eV) | $\log[N_H]$ (cm$^{-2}$) | Ref. |
|---------------------|-------------------|-------------------------------|------|--------------------------|--------------------------|------|
| NGC 526A           | 175$^{+62}_{-53}$ | 22.18$^{+0.03}_{-0.05}$      | 20   | 212$ \pm 87$             | 22.05$^{+0.42}_{-0.18}$  | 3,21 |
| NGC 1667           | $< 3000$          | $< 22.51$                     | 20   | $< 390$                  | $< 23.00$                | 22   |
| NGC 1672           | $< 1600$          | $< 22.48$                     | 23   | $< 150$                  | $< 22.50$                | 22   |
| NGC 1808           | 336$^{+453}_{-336}$ | $< 22.96$                  | 20   |                          |                          |      |
| NGC 2110           | 206$^{+108}_{-66}$ | 22.45$ \pm 0.03$            | 20   | 154$ \pm 26$             | 22.38$^{+0.04}_{-0.11}$  | 3,21 |
| NGC 2992           | 555$ \pm 60$     | 21.84$^{+0.11}_{-0.08}$      | 2,20,24 | 328$ \pm 42$             | 22.21$^{+0.10}_{-0.28}$  | 3,21 |
| NGC 3281           | 751$^{+232}_{-162}$ | 23.90$^{+0.06}_{-0.05}$      | 25   |                          |                          |      |
| NGC 4258           | 250$ \pm 61$     | 23.18$^{+0.03}_{-0.04}$      | 26   |                          |                          |      |
| NGC 4388           | 487$ \pm 48$     | 23.58$^{+0.02}_{-0.03}$      | 23,27|                          |                          |      |
| NGC 4507           | 152$ \pm 22$     | 23.57$ \pm 0.02$            | 20,23,28 | 469$ \pm 43$             | 23.61$^{+0.08}_{-0.06}$  | 21,22|
| NGC 5252           | 98$ \pm 38$      | 22.64$ \pm 0.03$            | 20,29|                          |                          |      |
| NGC 5506           |                   |                               |      | 196$ \pm 12$             | 22.54$ \pm 0.02$         | 3,21 |
| NGC 5674           |                   |                               |      | $< 140$                  | 22.84$^{+0.09}_{-0.12}$  | 21   |
| NGC 6251           | 228$^{+219}_{-188}$ | 21.09$^{+0.11}_{-0.14}$      | 20   |                          |                          |      |
| NGC 7172           | 72$ \pm 16$      | 22.90$ \pm 0.01$            | 20,23| 71$ \pm 18$              | 23.05$ \pm 0.02$         | 3,21,22|
| NGC 7314           | 550$ \pm 174$    | 22.06$^{+0.02}_{-0.06}$      | 20,30| 104$ \pm 37$             | 21.74$^{+0.09}_{-0.11}$  | 3,21 |
| NGC 7319           | 624$^{+137}_{-159}$ | 23.52$^{+0.10}_{-0.22}$      | 23   |                          |                          |      |
| NGC 7582           | 281$^{+210}_{-153}$ | 22.87$^{+0.08}_{-0.06}$      | 20   |                          |                          |      |
| Mrk 3              | 862$^{+283}_{-183}$ | 23.67$ \pm 0.06$            | 31,32| 550$ \pm 67$             | 23.85$ \pm 0.03$         | 21,22|
| Mrk 348            |                   |                               |      | 177$ \pm 49$             | 23.03$ \pm 0.08$         | 21,22|
| Mrk 463E           | 429$^{+349}_{-320}$ | $< 22.85$                    | 20,23|                          |                          |      |
| Mrk 477            | 490$^{+152}_{-121}$ | $< 23.21$                    | 23   |                          |                          |      |
| Mrk 1210           | 830$^{+272}_{-224}$ | 23.08$^{+0.15}_{-0.22}$      | 23   |                          |                          |      |
| MCG–5-23-16        | 455$^{+194}_{-131}$ | 22.20$^{+0.02}_{-0.02}$      | 20   | 336$ \pm 31$             | 22.25$^{+0.04}_{-0.05}$  | 3,21 |
| IRAS 04575–7537    | 158$^{+28}_{-29}$ | 22.09$ \pm 0.01$            | 33   | 260$^{+69}_{-66}$        | 22.07$^{+0.21}_{-0.10}$  | 21   |
| IRAS 18325–5926    | 580$^{+240}_{-150}$ | 22.12$ \pm 0.04$            | 34   | 198$ \pm 33$             | 22.21$^{+0.10}_{-0.05}$  | 21,22|
| IRAS 20460+1925    | 260$^{+88}_{-83}$ | 22.40$^{+0.04}_{-0.03}$      | 35   |                          |                          |      |
| ESO 103–G35        | 505$^{+265}_{-192}$ | 23.20$^{+0.88}_{-0.68}$      | 20   | 370$ \pm 55$             | 23.38$ \pm 0.03$         | 21   |
| IC 5063            | 80$^{+30}_{-25}$  | 23.38$ \pm 0.02$            | 23   | 272$ \pm 57$             | 23.37$^{+0.03}_{-0.03}$  | 21,36|
| PKS B1319–164      | 327$^{+74}_{-64}$ | 23.61$ \pm 0.03$            | 23   |                          |                          |      |
Table 1
-Continued

| Name          | ASCA          | GINGA         |
|---------------|---------------|---------------|
|               | $W_{K\alpha}$ (eV) | log[$N_H$ (cm$^{-2}$)] | Ref. | $W_{K\alpha}$ (eV) | log[$N_H$ (cm$^{-2}$)] | Ref. |
|---------------|---------------|---------------|-----|-----------------|----------------------|-----|
| NGC 1068      | $1321 \pm 226$ | $> 24.18$     | 20.37 | $2350^{+933}_{-442}$ | $> 24.18$ | 21 |
| NGC 4945      | $1450^{+530}_{-420}$ | $> 24.18$     | 20  | $1500 \pm 182$  | $24.76^{+0.02}_{-0.03}$ | 38 |
| NGC 4968      | $1180^{+4420}_{-827}$ | $> 24.18$     | 20  |                |                      |     |
| NGC 5135      | $4690^{+1580}_{-1460}$ | $> 24.18$     | 20  |                |                      |     |
| NGC 6240      | $1580 \pm 230$  | $> 24.18$     | 20.39 |                |                      |     |
| CIRCINUS      | $2310^{+73}_{-158}$ | $> 24.18$     | 40  |                |                      |     |

Errors are 68% confidence limits. For the objects with more than one reference the quoted values derive from weighted means.

The equivalent widths values measured by ASCA derive from broad line fits. Type 1 AGN collect objects with optical spectrum from Sey 1.0 to 1.5; Type 2 AGN collect Seyferts from 1.8 to 2.0 and NELGs.

References. – (1) Nandra et al. 1997a; (2) Reynolds 1997; (3) Nandra & Pounds 1994; (4) Awaki et al. 1991; (5) Yaqoob et al. 1995; (6) Guainazzi et al. 1994; (7) Piro et al. 1990; (8) Turner et al. 1996; (9) Iwasawa & Taniguchi 1993; (10) Leighly et al. 1996; (11) Reynolds et al. 1995; (12) Reynolds et al. 1998; (13) Grandi et al. 1997; (14) Eracleous et al. 1996; (15) Sambruna et al. 1998; (16) Weaver et al. 1995; (17) Tanaka et al. 1995; (18) Awaki 1991; (19) Cappi et al. 1996a; (20) Turner et al. 1997a; (21) Smith & Done 1996; (22) Awaki & Koyama 1993; (23) Ueno 1997; (24) Weaver et al. 1996; (25) Bassani et al. 1998; (26) Makishima et al. 1994; (27) Iwasawa et al. 1997; (28) Comastri et al. 1998; (29) Cappi et al. 1996b; (30) Yaqoob et al. 1996; (31) Iwasawa et al. 1994; (32) Griffiths et al. 1998; (33) Vignali et al. 1998; (34) Iwasawa et al. 1996; (35) Ogasaka et al. 1997; (36) Koyama et al. 1992; (37) Ueno et al. 1994; (38) Iwasawa et al. 1993; (39) Iwasawa & Comastri 1998; (40) Matt et al. 1996; (41) Maiolino et al. 1998; (42) Malaguti et al. 1998.
Table 2
Mean iron line parameters from the ASCA and the GINGA samples.

| AGN type | Sample   | Mean iron line parameters |
|----------|----------|---------------------------|
|          |          | $E_{K\alpha}$ (keV)       | $\sigma_{K\alpha}$ (keV) | $W_{K\alpha}$ (eV) |
|          |          | $m^a$ $ML^b$              | $m$ $ML$               | $m$ $ML$               |
| type 1   | ASCA     | $6.36 \pm 0.13^{(23)}$    | $6.36_{-0.02}^{+0.03}$ | $0.51 \pm 0.37^{(20)}$ | $0.40 \pm 0.05$ | $287 \pm 180^{(24)}$ | $229 \pm 23$ |
|          | GINGA    | $6.50 \pm 0.30^{(16)}$    | $6.38_{-0.05}^{+0.04}$ |                                                    |
| type 2   | ASCA     | $6.28 \pm 0.32^{(22)}$    | $6.38_{-0.01}^{+0.02}$ | $0.34 \pm 0.27^{(14)}$ | $0.27 \pm 0.06$ | $390 \pm 231^{(24)}$ | $322 \pm 43$ |
|          | GINGA    | $6.45 \pm 0.18^{(11)}$    | $6.46 \pm 0.04$         |                                                    |
| Compton  | ASCA     | $6.40 \pm 0.11^{(5)}$     | $0.20 \pm 0.07^{(4)}$   |                                                    |
| thick    | BeppoSAX |                                                   | $2089 \pm 1334^{(6)}$  |
|          |          |                                                    | $2543 \pm 2583^{(6)}$  |

Errors are 68% confidence limits. The number of objects are in small brackets.

$a$ Mean and standard deviation.

$b$ Maximum Likelihood estimate.

has good spectral resolution ($\Delta E = 120$ eV at 6 keV) the line profile can be carefully fitted allowing a precise measure of the line width. Type 1 objects show broad lines with a ML mean $\langle \sigma_{K\alpha} \rangle = 0.40 \pm 0.05$ keV in agreement with the value quoted by Nandra et al. (1997a), suggesting that the iron emission is dominated by the relativistic accretion disc component. Compton thin type 2 objects have a ML mean width $\langle \sigma_{K\alpha} \rangle = 0.27 \pm 0.06$ keV, mostly due to the broad lines of NELGs, suggesting that a disc line component may still be significant (Weaver & Reynolds 1998).

Two opposite effects are relevant in the ASCA measurements of the iron line equivalent widths: good energy resolution allows a careful fit to the line flux above the underlying continuum, but the limited energy band covered by the satellite (0.5–10 keV) and especially the low effective area above 7 keV prevent a detailed modeling of the continuum. The $W_{K\alpha}$ measurements spread is clearly visible in Fig. 1, where it is also evident that type 1 and 2 AGN are divided into two groups according to their X–ray absorption, the dividing column density being $N_H \sim 10^{21.5–22}$ cm$^{-2}$.

If Compton thick AGN are taken into account, a correlation between $W_{K\alpha}$ and $N_H$ may be recognized for type 2 objects. Nevertheless, the data dispersion is very high and a selection effect may be present, the strongest lines being more easily detected. This trend is predicted by theoretical models (Ghisellini
et al. 1994; Awaki 1991) whereby, given the average inclination of type 2 objects with respect to the line of sight, the observed line intensity produced by reflection and transmission in the torus increases with equatorial $N_H$, while the continuum flux is reduced, leading to an enhancement of the equivalent width at the highest column densities. If Compton thick AGN are not considered, there is still some evidence of this correlation in the last $N_H$ bin (see also Table 4), but the number of objects is small and the sample incomplete.

The mean equivalent widths of type 1s and 2s, estimated with the ML method, are $\langle W_{K\alpha} \rangle = 229 \pm 23$ eV and $\langle W_{K\alpha} \rangle = 322 \pm 43$ eV, respectively. The ML average value quoted by Nandra et al. (1997a) for their type 1s sample is $160 \pm 30$ eV (lines fitted with broad gaussians), which is lower than our result, but consistent with it within $2\sigma$. The average ML equivalent width in the sample of Turner et al. (1997a), which however includes several Compton thick objects, is $\langle W_{K\alpha} \rangle = 452^{+184}_{-144}$ eV, statistically consistent with our estimate.

When considering the whole ASCA sample, except Compton thick AGN, the average equivalent width is $W_{K\alpha} = 340 \pm 212$ eV for the simple mean and $\langle W_{K\alpha} \rangle = 265 \pm 24$ eV for the ML estimate.
2.2 GINGA data

Most of the data from GINGA are taken from Nandra & Pounds (1994) and Smith & Done (1996) who analyzed a sample of type 1 and type 2 sources, respectively. Since GINGA detectors are not sensitive below $\sim 2$ keV, only an upper limit to the intrinsic absorption of many type 1s can be set. The high absorption revealed in NGC 3516, NGC 3783 and MCG–6-30-15, in disagreement with ASCA data (Table 1), is due to the presence of a warm absorber causing a turnover in the spectra of these sources at the low energy end of the GINGA band that mimics a cold absorption in the GINGA data (e.g., Mathur, Wilkes & Aldcroft 1997).

As for the ASCA data, the mean energy of the line peak $\langle E_{K\alpha} \rangle$ is fully consistent with 6.4 keV (Table 2), but no information is available on the line’s widths due to the poor energy resolution ($\Delta E = 1.2$ keV at 6 keV) of the GINGA instruments, which does not allow a careful sampling of the line profile. Spectral fits have always been obtained by adopting gaussian lines of width 0.1 or 0.05 keV, much narrower than the instrumental response.

The spread in the $W_{K\alpha}$ measurements is lower than in the ASCA sample (Fig. 2). Notice that for the source with $N_H \sim 10^{24.6}$ cm$^{-2}$, namely NGC4945, the detection by GINGA of the nuclear radiation above $\sim 10$ keV, has led to a direct measurements of the torus column density (Iwasawa et al. 1993).
As expected from the theoretical models, $W_{K\alpha}$ and $N_H$ seem to be correlated (Fig. 2). We feel that this conclusion should be taken with due care because, like for the ASCA sample, the number of the most absorbed sources ($N_H > 2 - 3 \times 10^{23} \text{ cm}^{-2}$) is very small and the sample may be biased.

The mean equivalent widths for our GINGA sample are given in Table 2. From the ML analysis $\langle W_{K\alpha} \rangle = 135 \pm 13$ for type 1 AGN, in agreement with the value of $140 \pm 20$ eV quoted by Nandra & Pounds (1994), while for type 2 AGN $\langle W_{K\alpha} \rangle = 259 \pm 35$ eV, which is higher, although statistically consistent, than the value of $200 \pm 40$ eV obtained by Smith & Done (1996).

The mean equivalent width for the whole sample is $W_{K\alpha} = 200 \pm 118$ eV, for the mean and $\langle W_{K\alpha} \rangle = 190 \pm 18$ eV for the ML estimate.

### 2.3 ASCA and GINGA common sample

To evaluate possible effects on the line equivalent width due to the different instruments on board ASCA and GINGA, we consider here only the subsample of objects observed by both satellites. The results are shown in Table 3.

For type 1 objects the average value $\langle W_{K\alpha} \rangle$ derived from ASCA data is significantly higher than that from GINGA, while for type 2 AGN the two values are closer. It is suggested that the discrepancy for type 1 objects could possibly be explained by the different spectral resolutions of the two satellites: when the broad iron lines of type 1 AGN ($\sigma_{K\alpha} \sim 0.4 \text{ keV}$) are fitted with narrow gaussians ($\sigma_{K\alpha} \leq 0.1 \text{ keV}$), as is the case for GINGA fits, it is likely that the

| AGN type | Common Sample | $W_{K\alpha}$(eV) |
|----------|---------------|------------------|
|          | $m^a$         | $ML^b$          |
| type 1   | ASCA          | 267 ± 186$^{(17)}$ | 208 ± 20 |
|          | GINGA         | 154 ± 89$^{(17)}$ | 134 ± 14 |
| type 2   | ASCA          | 363 ± 254$^{(12)}$ | 279 ± 60 |
|          | GINGA         | 300 ± 163$^{(12)}$ | 286 ± 42 |

Errors are 68% confidence limits. The number of objects are in small brackets.

$^a$ Mean and standard deviation.

$^b$ Maximum Likelihood estimate.
flux of the line wings is lost, resulting in an underestimate of the equivalent widths of the lines; on the other hand, this effect should be less important for type 2 AGN, where the narrow line components emitted by the tori make a substantial contribution to the measured line strengths.

As a consequence of the above results and considerations, in our model computations we will only consider $W_{\text{K}\alpha}$ values based on ASCA measurements.

3 The Model

The baseline model adopted to fit the XRB is that described in Comastri et al. (1995), where we have introduced slight changes in the parameter set describing the AGN X–ray luminosity function (XLF) and evolution in order to take into account the recent results obtained by Jones et al. (1997) and Page et al. (1996).

Following Comastri et al. (1995), we assume a pure luminosity evolution $L_x(z) = L_x(0) \times (1 + z)^\beta$, with $\beta = 2.6$ and the XLF of the form:

$$\rho(L, z = 0) = K_1 L_{44}^{-\gamma_1} \text{ for } L_x < L_B$$

$$\rho(L, z = 0) = K_2 L_{44}^{-\gamma_2} \text{ for } L_x > L_B$$

where $L_{44}$ is the source luminosity between 0.3–3.5 keV in units of $10^{44}$ erg s$^{-1}$, $\gamma_1 = 1.7$, $\gamma_2 = 3.4$, while $K_1 = K_2 L_B^{-\gamma_1-\gamma_2}$ and $L_B$ now take the values $6.4 \times 10^{-7}$ Mpc$^{-3}$ ($10^{44}$ erg s$^{-1}$)$^{\gamma_1-1}$ and $8.1 \times 10^{43}$ erg s$^{-1}$, respectively.

The XLF, which spans the luminosity range $10^{42} - 10^{47}$ erg s$^{-1}$, has been assumed to evolve up to $z_{\text{cut}} = 1.8$ and to be constant between $z_{\text{cut}}$ and $z_{\text{max}} = 3$. The input X–ray spectra are those described by Comastri et al. (1995). The absorbed AGN are divided into four bins centered at $\log N_H = 21.5, 22.5, 23.5, 24.5$, to cover the $N_H$ range $10^{21} - 10^{25}$ cm$^{-2}$. Their number densities, which are free parameters of the model, normalized to the density of unabsorbed AGN are respectively: 0.35, 1.30, 2.0, 1.4. The iron lines have been subsequently added in the input spectra.

Extremely absorbed AGN ($N_H > 10^{25}$ cm$^{-2}$) are not expected to contribute significantly to the XRB (Comastri et al. 1995). Indeed, their 2–10 keV luminosity, entirely due to the reflection continuum, is found to be two order of magnitude lower than that of Sey 1s in the same band (Maiolino et al. 1998). However, given their very strong lines, we have included them in our model calculation. We have then assumed as the shape of the XLF of these objects that of type 1 AGN, downshifted in flux by a factor 100, and as their
typical spectrum a pure reflection continuum (e.g. Lightman & White 1988) normalized to reproduce the observed luminosities. The number density of these sources is very uncertain. Preliminary estimates (Maiolino et al. 1998; Risaliti et al. 1998) indicate that the density of Compton thick AGN with $N_H > 10^{25}$ cm$^{-2}$ is 15–20% of the density of all type 2s. If we consider as type 2s the objects with $N_H > 10^{22}$ cm$^{-2}$ (see Fig. 1 and 2), the normalized density of AGN with $N_H > 10^{25}$ cm$^{-2}$ in our model results 0.8. As it will be shown in the next section, the large uncertainty on this value does not have relevant effects in our model.

In agreement with the observed X–ray spectra of quasars, we have not added the iron line in type 1 objects with luminosity above $L_B$.

We have chosen a simple gaussian shape for the line profile, which is sufficiently accurate to estimate the line contribution to the XRB, the most important parameter being the line equivalent width. As a first order approximation, we have added to the objects with $N_H < 10^{24}$ cm$^{-2}$ a line with constant $W_{K\alpha}$, regardless of the amount of intrinsic absorption. In order to maximize the effect produced by the iron line we have performed calculations with $W_{K\alpha} = 390$ eV, which corresponds to the maximum value quoted in Table 2. For the objects with larger $N_H$ we have consistently added a line with $W_{K\alpha}=2$ keV. Calculations have been carried out for both narrow ($\sigma_{K\alpha} = 0.1$ keV) and broad ($\sigma_{K\alpha} = 0.4$ keV) lines. In addition we have run a model by adopting the average $W_{K\alpha}$ values pertaining to the different bins of log$N_H$ as shown in Table 4.

Table 4
Mean equivalent widths per log$N_H$ interval from the ASCA sample.

| log$[N_H$(cm$^{-2}$)] | < 21 | 21.5 | 22.5 | 23.5 | > 24 |
|----------------------|-----|-----|-----|-----|-----|
| $W_{K\alpha}$(eV)    | 280 | 370 | 300 | 470 | 2100 |

4 Results

The model fit to the XRB spectrum is shown in Fig. 3. This is based on the data above 3 keV derived from the HEAO–1 A2 experiment, thus it does not match with the ASCA measurements which have a higher normalization (10 – 15% at 3 keV). However, since the iron signatures are expected in the ASCA band, we will also compare our results with the the Gendreau et al. (1995) data (see below).

The labeled curves represent the contribution of the different absorption classes to the overall XRB, the labels being the logarithm of the hydrogen column density. The curve of unabsorbed objects includes both Sey 1s and quasars.
Fig. 3. The fit to the XRB. The data of larger intensity below 6 keV are from ASCA (Gendreau et al. 1995), while those above 3 keV are a compendium of various experiments including HEAO–1 A2 (Gruber 1992). The various curves represent the contributions of the different classes of sources, the labels being the logarithms of the hydrogen column densities. The curve of unabsorbed sources includes both Sey 1s and quasars. The thick lines between 1.5 – 7 keV represent the additional fluxes due to the iron emission lines for \( W_{K\alpha} = 390 \) eV and \( \sigma_{K\alpha} = 0.1 \) keV.

For each curve the thick line between 1.5 – 7 keV represents the additional flux due to the iron line. Note that for objects with \( \log N_H = 24.5 \) the line excess is undistinguishable from the underlying continuum. This is due to the extremely hard shape of the highly absorbed sources. As expected, the contribution of AGN with \( \log N_H > 25 \) to the XRB is very small: below 4% at about 20 keV and negligible in the 1–7 keV band.

An enlarged view of the relative contribution of the iron line emission with respect to the model without the line is given in Fig. 4. The iron line profile, smeared out by the redshift effects, is relatively smooth: the maximum attained level with respect to the model without the line is less than 7% at \( 6.4/(1 + z_{cut}) \approx 2.3 \) keV for \( W_{K\alpha} = 390 \) eV. Once the \( W_{K\alpha} \) value has been fixed, it is found, as expected, that the only effect produced by a broader line is a smoother profile. When using the \( W_{K\alpha} \) values in Table 4, and adopting \( \sigma_{K\alpha} = 0.4 \) keV when \( \log N_H < 22 \) and \( \sigma_{K\alpha} = 0.1 \) keV when \( \log N_H \geq 22 \), the maximum line contribution is still below 7%.

Matt et al. (1996) have suggested that in Compton thick objects, together with a strong fluorescent iron line at 6.4 keV, another strong iron line at 6.7
keV, produced by resonant scattering in the warm mirror, should be present. Both these lines are predicted to have equivalent widths of a few keV. Indeed, strong emission lines from highly ionized iron with $W_{K\alpha}$ values above 1 keV have been detected in some of the Compton thick objects observed so far, such as NGC 1068 (Ueno et al. 1994) and NGC 2273 (Maiolino et al. 1998). We estimate that a line with $W_{K\alpha} = 5$ keV is sufficiently large to approximate the effects of the iron lines complex of highly absorbed AGN. By performing this test we find that the additional iron flux is less than 1%.

Since we are mainly interested on the effects of the iron feature on the shape of the XRB spectrum we have rescaled the model in order to match the XRB intensity observed by ASCA. The comparison between the rescaled model and the ASCA data is shown in Fig. 5. The data are the same as given by Gendreau et al. (1995) but with a different binning. It should be noted that the model does not reproduce the data below $\sim 2$ keV, because in this spectral region the contribution of sources other than AGN is expected (Comastri et al. 1995). Clearly, the additional flux provided by the iron line is below present uncertainties in the XRB measurements and the dispersion of the data does not allow yet to detect the predicted iron feature. It should also be noted that the relatively deep gold edge in the instrumental response at $\sim 2.2$ keV, which introduces calibration uncertainties around this energy, is very close to the energy where the maximum deviations due to the iron line are expected. Therefore the narrow bump in the observed XRB spectrum around 2 keV has

Fig. 4. The iron line contribution normalized to the XRB model continuum. The curves in Panels a) and b) correspond respectively to $\sigma_{K\alpha} = 0.1$ keV and $\sigma_{K\alpha} = 0.4$ keV for $W_{K\alpha} = 390$ eV.
Fig. 5. The spectrum of the 1–6 keV ASCA XRB (Gendreau et al. 1995) compared with our model with/without the line contribution (upper/lower solid line) for $W_{K\alpha}=390$ eV and $\sigma_{K\alpha}=0.1$ keV. The dotted line is the best power law fit to the XRB.

an instrumental origin and is not produced by the iron line.

5 Conclusions

The main conclusion of this work is that the predicted contribution of the fluorescence iron lines to the XRB in the 1.5 – 7 keV energy interval is $\lesssim 5\%$ with a peak intensity $\lesssim 7\%$ at $\sim 2$ keV. Although in our computations we have adopted the specific model of Comastri et al. (1995), this result should essentially hold for those synthesis models of the XRB that are based on the AGN unifications schemes. This estimated contribution of the iron lines is still undetectable within the dispersion of the best available data. Indeed, the uncertainties in the power law fit of the XRB spectrum observed by ASCA are of the order of $\sim 10\%$ (Gendreau et al. 1995). In order to reproduce an iron excess of more than $\sim 10\%$ a mean equivalent width of $W_{K\alpha} \gtrsim 600$ eV for the sources with $N_{H} < 10^{24}$ cm$^{-2}$ should have been adopted, which is inconsistent with the observed average values.

Since in our calculations we have assigned to all Sey nuclei an iron line equivalent width of 390 eV, corresponding to the maximum average value quoted in Table 2, and since not all observed nuclei show detectable iron lines, we
are confident that our result may represent a rather stringent upper limit to any iron line contribution to the XRB. Therefore, the present undetection of iron features in the XRB spectrum does not constitute by itself an argument against the synthesis of the XRB by known classes of AGN. On the contrary, one may argue that the detection of the iron signature would constitute strong evidence in favour of these models, while putting at the same time severe constraints on other classes of as yet undetected AGN which have been recently hypothesized in order to explain the XRB.

In order to observe the predicted iron feature, the dispersion in the XRB data should be reduced by at least 50%. Perhaps, this may be achieved in the near future with the forthcoming X–ray missions. It may be noted that, in principle, from the energy range and profile of the iron feature one could also get relevant information about the values of $z_{\text{max}}$ and $z_{\text{cut}}$ characterizing the evolution of AGN.

Finally, we note that the estimated intensity of the iron feature may partially explain the discrepancy in the normalizations of ASCA and HEAO–1 A2 data. Since the normalization of the XRB from HEAO–1 A2 has been derived from a broad band analysis of the data, one may wonder whether the intensity at the low energy end of the spectrum, where the iron feature is expected, has been somewhat underestimated.

**Acknowledgements**

We thank K. Gendreau for providing the data on the ASCA XRB. AC acknowledges financial support from the Italian Space Agency under contract ARS–96–70. RG acknowledges financial support from the Italian Space Agency under contract ARS–98–116/22.

**References**

[1] Antonucci, R.R.J., Miller, J.S., 1985, ApJ, 297, 621
[2] Awaki, H., 1991, PhD thesis, University of Nagoya
[3] Awaki, H., Koyama, K., Inoue, H., Halpern, J.P., 1991, PASJ, 43, 195
[4] Awaki, H., Koyama, K., 1993, Adv. Space Res., 13, 221
[5] Barthel, P.D., 1989, ApJ, 336, 606
[6] Bassani, L., Dadina, M., Maiolino, R., Salvati, M., Risaliti, G., Della Ceca, R., Matt, G., Zamorani, G., 1998, ApJS, in press
[7] Boldt, E., 1987, Phys. Rep., 146, 215

[8] Boyle, B.J., Griffiths, R.E., Shanks, T., Stewart, G.C., Georgantopoulos, I., 1993, MNRAS, 260, 49

[9] Cagnoni, I., Della Ceca, R., Maccacaro, T., 1998, ApJ, 493, 54

[10] Cappi, M., Mihara, T., Matsuoka, M., Hayashida, K., Weaver, K.A., Otani, C., 1996a, ApJ, 458, 149

[11] Cappi, M., Mihara, T., Matsuoka, M., Brinkmann, W., Prieto, M.A., Palumbo, G.G.C., 1996b, ApJ, 456, 141

[12] Chen, L.-W., Fabian, A.C., Gendreau, K.C., 1997, MNRAS, 285, 449

[13] Comastri, A., Setti, G., Zamorani, G., Elvis, M., Giommi, P., Wilkes, B.J., McDowell, J.C., 1992, ApJ, 384, 62

[14] Comastri, A., Setti, G., Zamorani, G., Hasinger, G., 1995, A&A, 296, 1

[15] Comastri, A., Vignali, C., Cappi, M., Matt, G., Audano R., Awaki, H., Ueno, S., 1998, MNRAS, 295, 443

[16] Di Matteo, T., Fabian, A.C., 1997, MNRAS, 286, 393

[17] Eracleous, M., Halpern, J.P., Livio M., 1996, ApJ, 459, 89

[18] Gendreau, K.C., Mushotzky, R.F., Fabian, A.C. et al., 1995, PASJ, 47, L5

[19] Georgantopoulos, I., Stewart, G.C., Shanks, T., Boyle, B.J., Griffiths, R.E., 1996, MNRAS, 280, 276

[20] George, I.M., Fabian, A.C., 1991, MNRAS, 249, 352

[21] Ghisellini, G., Haardt, F., Matt, G., 1994, MNRAS, 267, 743

[22] Grandi, P., Sambruna, R.M., Maraschi, L., Matt, G., Urry, C.M., Mushotzky, R.F., 1997, ApJ, 487, 636

[23] Griffiths, R.E., Della Ceca, R., Georgantopoulos, I., Boyle, B.J., Stewart, G.C., Shanks, T., Fruscione, A., 1996, MNRAS, 281, 71

[24] Griffiths, R.E., Warwick, R.S., Georgantopoulos, I., Done, C., Smith, D.A., 1998, MNRAS, 298, 1159

[25] Gruber, D.E., 1992, in the Proceedings of “The X-ray background”, eds. X. Barcons & A.C. Fabian A.C. (Cambridge: Cambridge Univ. Press), p. 44

[26] Guainazzi, M., Matsuoka, M., Piro, L., Mihara, T., Yamauchi, M., 1994, ApJ, 436, L35

[27] Hasinger, G., Burg, R., Giacconi, R., Schmidt, M., Trümper, J., Zamorani, G., 1998, A&A, 329, 482

[28] Iwasawa, K., Koyama, K., Awaki, H., Kunieda, H., Makishima, K., Tsuru, T., Ohashi, T., Nakai, N., 1993, ApJ, 409, 155
[29] Iwasawa, K., Taniguchi, Y., 1993, ApJ, 413, L15
[30] Iwasawa, K., Koyama, K., Awaki, H., Kunieda, H., Makishima, K., Tsuru, T., Ohashi, T., Nakai, N., 1993, ApJ, 409, 155
[31] Iwasawa, K., Yaqoob, T., Awaki, H., Ogasaka, Y., 1994, PASJ, 46, L167
[32] Iwasawa, K., Fabian, A.C., Mushotzky, R.F., Brandt, W.N., Awaki, H., Kunieda, H., 1996, MNRAS, 279, 837
[33] Iwasawa, K., Fabian, A.C., Ueno, S., Awaki, H., Fukazawa, Y., Matsushita, K., Makishima, K., 1997, MNRAS, 285, 683
[34] Iwasawa, K., Comastri, A., 1998, MNRAS, 297, 1219
[35] Jones, L.R., McHardy, I.M., Merrifield, M.R. et al., 1997, MNRAS, 285, 547
[36] Koyama, K., Awaki, H., Iwasawa, K., Ward, M.J., 1992, ApJ, 399, L129
[37] Krolik, J.H., Madau, P., Życki, P.T., 1994, ApJ, 420, L57
[38] Lawson, A.J., Turner, M.J.L., 1997, MNRAS, 288, 920
[39] Leighly, Y., Karen, M., Mushotzky, R.F., Yaqoob, T., Kunieda, H., Edelson, R., 1996, ApJ, 469, 147
[40] Lightman, A.P., White, T.R., 1988, ApJ, 335, 57
[41] Maccacaro, T., Gioia, I., Wolter, A., Zamorani, G., Stocke, J.T., 1988, ApJ, 326, 680
[42] Madau, P., Ghisellini, G., Fabian, A.C., 1994, MNRAS, 270, L17
[43] Maiolino, R., Salvati, M., Bassani, L., Dadina, M., Della Ceca, R., Matt, G., Risaliti, G., Zamorani, G., 1998, A&A, 338, 781
[44] Malaguti, G., Palumbo, G.G.C., Cappi, M., Comastri, A., Otani, C., Matsuoka, M., Guainazzi, M., Bassani, L., Frontera, F., 1998, A&A, 331, 519
[45] Makishima, K., Fujimoto, R., Ishisaki, Y., et al., 1994, PASJ, 46, L77
[46] Mathur, S., Wilkes, B.J., Aldcroft, T., 1997, ApJ, 478, 182
[47] Matt, G., Perola, G.C., Piro, L., 1991, A&A, 247, 25
[48] Matt, G., Perola, G.C., Piro, L., Stella, L., 1992, A&A, 257, 63 (Erratum in A&A, 263, 453)
[49] Matt, G., Fabian, A.C., 1994, MNRAS, 267, 187
[50] Matt, G., Brandt, W.N., Fabian, A.C., 1996, MNRAS, 280, 823
[51] Matt, G., Fiore, F., Perola, G.C., Piro, L., Fink, H.H., Grandi, P., Matsuoka, M., Oliva, E., Salvati, M., 1996, MNRAS, 281, L69
[52] Mushotzky, R.F., Fabian, A.C., Iwasawa, K., Kunieda, H., Matsuoka, M., Nandra, K., Tanaka, Y., 1995, MNRAS, 272, L9
[53] Nandra, K., Pounds, K.A., 1994, MNRAS, 268, 405

[54] Nandra, K., George, I.M., Mushotzky, R.F., Turner, T.J., Yaqoob, T., 1997a, ApJ, 477, 602

[55] Nandra, K., George, I.M., Mushotzky, R.F., Turner, T.J., Yaqoob, T., 1997b, ApJ, 488, L91

[56] Ogasaka, Y., Inoue, H., Brandt, W.N., Fabian, A.C., Kii, T., Nakagawa, T., Fujimoto, R., Otani, C., 1997, PASJ, 49, 179

[57] Page, M.J., Carrera, F.J., Hasinger, G. et al., 1996, MNRAS, 281, 579

[58] Piro, L., Yamauchi, M., Matsuoka, M., 1990, ApJ, 360, L35

[59] Reynolds, C.S., Fabian, A.C., Inoue, H., 1995, MNRAS, 276, 1311

[60] Reynolds, C.S., 1997, MNRAS, 286, 513

[61] Reynolds, C.S., Iwasawa, K., Crawford, C.S., Fabian, A.C., 1998, MNRAS, 299, 410

[62] Risaliti, G., Bassani, L., Della Ceca, R., Comastri, A., Dadina, M., Gilli, R., Maiolino, R., Matt, G., Salvati, M., Zamorani, G., 1998, Mem. S.A.It, in press

[63] Salvati, M., Bassani, L., Della Ceca, R., Maiolino, R., Zamorani, G., 1997, A&A, 323, L1

[64] Sambruna, R., George, I.M., Mushotzky, R.F., Nandra, K., Turner, T.J., 1998, ApJ, 495, 749

[65] Schmidt, M., Hasinger, G., Gunn, J., Schneider, D., Burg, R., Giacconi, R., Lehmann, I., MacKenty, J., Trümper, J., Zamorani, G., 1998, A&A, 329, 495

[66] Setti, G., Woltjer, L., 1989, A&A, 224, L21

[67] Setti, G., Comastri, A., 1996, IAU Symp. 168, Examining the Big Bang and Diffuse Background Radiations, eds. M. Kafatos and Y. Kondo, (Dodrecht: Kluwer) p.263

[68] Smith, D.A., Done, C., 1996, MNRAS, 280, 355

[69] Tanaka, Y., Nandra, K., Fabian, A.C., et al., 1995, Nature, 375, 659

[70] Turner, T.J., George, I.M., Kallman, T., Yaqoob, T., Życki, P.T., 1996, ApJ, 472, 571

[71] Turner, T.J., George, I.M., Nandra, K., Mushotzky, R.F., 1997a, ApJS, 113, 23

[72] Turner, T.J., George, I.M., Nandra, K., Mushotzky, R.F., 1997b, ApJ, 488, 164

[73] Turner, T.J., George, I.M., Nandra, K., Mushotzky, R.F., 1998, ApJ, 493, 91

[74] Ueno, S., Mushotzky, R.F., Koyama, K., Iwasawa, K., Awaki, H., Hayashi, I., 1994, PASJ, 46, L71
[75] Ueno, S., 1997, PhD thesis, University of Kyoto

[76] Vignali, C., Comastri, A., Stirpe, G.M., Cappi, M., Palumbo, G.G.C., Matsuoka, M., Malaguti, G., Bassani, L., 1998, A&A, 333, 411

[77] Weaver, K.A., Nousek, J., Yaqoob, T., Hayashida, K., Murakami, S., 1995, ApJ, 451, 147

[78] Weaver, K.A., Nousek, J., Yaqoob, T., Mushotzky, R.F., Makino, F., Otani, C., 1996, ApJ, 458, 160

[79] Weaver, K.A., Reynolds, C.S., 1998, ApJ, 503, L39

[80] White, T.R., Lightman, A.P., Zdziarski, A.A., 1988, ApJ, 331, 939

[81] Yaqoob, T., Edelson, R., Weaver, K.A., Warwick, R.S., Mushotzky, R.F., Serlemitsos, P.J., Holt, S.S., 1995, ApJ, 453, L81

[82] Yaqoob, T., Serlemitsos, P.J., Turner, T.J., George, I.M., Nandra K., 1996, ApJ, 470, L27