The X-ray spectral properties of X-ray selected AGN: ROSAT spectra of EMSS AGN

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ABSTRACT

Using a sample of 63 AGNs extracted from the Einstein Extended Medium Sensitivity Survey (EMSS), we study the X-ray spectral properties of X-ray selected AGN in the 0.1 – 2.4 keV ROSAT band. These objects are all the EMSS AGN detected with more than 300 net counts in ROSAT PSPC images available from the public archive (as of May 31, 1995). A Kolmogorov-Smirnov test on the redshift and luminosity distributions shows that this subsample is representative of the whole EMSS sample.

For the 21 sources detected with less than 600 net counts we characterize the spectrum only with the hardness ratio technique. For the other 42 sources we obtain a detailed spectral analysis fitting the data with two different power-law models: one with \( N_H \) fixed at the Galactic value and one with \( N_H \) as a free parameter. Eight sources (\( \sim 20 \) per cent) show a significant deviation from a power-law absorbed by Galactic \( N_H \), indicating soft excess (five sources) or excess absorption (three sources). These eight sources are analyzed and discussed separately and are excluded from the sample used to study the mean X-ray spectral properties of the EMSS sources.

A Maximum-Likelihood analysis is used to find the mean power-law spectral index \( \langle \alpha_x \rangle \) and the intrinsic dispersion \( \sigma_p \). We find \( \langle \alpha_x \rangle =1.42 \) with \( \sigma_p=0.44 \). This value is significantly steeper (\( \Delta \alpha \sim 0.4 \)) than the mean Einstein/IPC spectral index obtained applying the ML analysis on the whole sample of EMSS AGN. This result shows that the soft excess already noted in optically selected AGN is present also in X-ray selected AGN. The relatively high value obtained for the intrinsic dispersion confirms that in the soft band AGN are characterized by a variety of spectral indices and the increase with respect to the results obtained from the analysis of Einstein data (\( \Delta \sigma_p \sim 0.16 \)) suggests a further broadening of the spectral index distribution as one moves to softer energies. A comparison between the mean spectral index of Radio-quiet and Radio-loud subsamples shows that the mean index of the RL sample is flatter than that of RQ, both in the IPC (\( \Delta \alpha \sim 0.3 \)) and in the PSPC (\( \Delta \alpha \sim 0.4 \)) data. This suggests that the additional X-ray component in RL AGN dominates the X-ray emission of RL AGN over almost two decades of energy (\( \sim 0.1 – 10 \) keV). Finally, we find no significant correlation between the spectral index \( \alpha_x \) and other physical parameters such redshift, optical and X-ray luminosity.

Key words: galaxies:active – galaxies:nuclei – quasars:general – X-ray: galaxies

1 INTRODUCTION

The X-ray spectra of AGN have been studied extensively over the last decade using a variety of instruments aboard different satellites (see, among others, Petre et al. 1984, Reichert et al. 1985, Wilkes and Elvis 1987, Canizares and White 1989, Turner and Pounds 1989, Comastri et al. 1992, Williams et al. 1992, see also Malaguti et al. (1994) for a catalog of all the X-ray spectra of AGN published from the early 70’s to the end of 1992).

These studies indicate that the X-ray emission above 1–2 keV is well described by a power-law with a spectral slope \( \alpha_x \sim 0.5 (f_\nu \propto \nu^{-\alpha_x}) \) for radio-loud (RL) objects and \( \alpha_x \sim 1.0 \) for radio-quiet (RQ) objects. Below 1 keV an excess emission relative to the flux predicted by an extrapolation of the hard X-ray power-law is observed (Wilkes and Elvis
Ported an average energy spectral index (HR). Possible, by means of the analysis of their Hardness Ratio (HR).

Recent work (Wilkes and Elvis 1987, Kruper et al. 1990) has improved the ROSAT satellite (Trümper, 1983) to allow us to extend the spectral analysis of the EMSS AGN used, while in section 3 we describe the method of analysis. We report and discuss the results in section 4 and 5 respectively, while in section 6 the conclusions and a summary are presented. Throughout the paper a Hubble constant of $H_0 = 50\, \text{km}\, \text{s}^{-1}\, \text{Mpc}^{-1}$ and a deceleration parameter $q_0 = 0$ are assumed.

2 THE SAMPLE

We searched in the ROSAT archive for ROSAT (PSPC) images containing pointed or “serendipitous” observations of EMSS AGN. The first selection criterion used is an off-axis angle $\theta$ (the distance between the source and the center of the PSPC field) smaller than 50 arcmin. We find data for 203 different EMSS AGN. Because our aim is a detailed study of the X-ray spectral properties, we then selected only those sources detected with more than 300 measured net counts. For sources observed more than once, we retain only the observation where the object is detected with the highest number of net counts. We find 63 EMSS AGN satisfying the above criteria; they are listed in Table 1 which is organized as follows: source name, followed by redshift, the two point spectral index between radio and optical band ($\alpha_{\text{o}},$ from Stocke et al. 1991), the extraction radius $r$ (arcmin) calculated as described in section 3, the off-axis angle $\theta$ (arcmin), the net counts detected in the 0.1–2.4 keV band within the $r$ radius circle with the relative error computed as the square root of the total (source + background) observed counts, and the sequence number of the ROSAT observations. Sources for which “normalized” net counts have been computed (see Section 3 for details) are indicated with an asterisk.

Five of these 63 objects are radio-loud objects on the basis of the standard radio to optical spectral index criterion ($\alpha_{\text{o}} \geq 0.35$).

A Kolmogorov-Smirnov (KS) test shows that the redshift, X-ray and optical luminosity distributions of the 63 EMSS AGN discussed in the present paper are not significantly different (at a confidence level greater than 90 per cent) from the distributions of the whole EMSS AGN sample. Moreover we have checked whether the requirement that the sources have more than 300 net counts could introduce a bias in the spectral index distribution due to the fact that steeper spectrum sources could have higher ROSAT count rates. We have searched for a possible correlation between net counts and spectral indices but we found no evidence for it.

We are therefore confident that, although in our analysis we used only $\sim 15$ per cent of the EMSS AGN, the results obtained are representative of the whole sample. We can then compare the mean ROSAT/PSPC spectral properties of the subsample of 63 objects with the mean Einstein/IPC spectral properties of the whole sample, taking advantage of the large size of the latter.

3 DATA ANALYSIS

For each source we fit the X-ray image with a two-dimensional gaussian to determine its centroid. Subsequently we extract the total counts in the 0.1–2.4 keV band using a circle centered on the source centroid. To optimize the signal to noise ratio the extraction radius $r$ is chosen to be the distance from the centroid at which the radial profile of the point source meets the background level. All the extraction radii lay in the range $2.0' \leq r \leq 5.0'$.

The background counts are estimated in an annulus centered on the source with inner radius $r + 1'$ and outer radius $r + 3'$. When other sources are detected within the background region, they are removed using a cutting circle with a radius chosen to contain at least 95 per cent of
the source counts (Turner and George 1992). For the 11 sources detected near other sources or near the window support structure, an azimuthal sector centered on the source position is excluded from the circle used for the counts extraction (and from the annulus used for the background determination) to avoid contamination or shadowing. The net counts thus obtained are used for the spectral analysis. The X-ray flux of these sources, however, is determined normalizing the net counts to a full circle, assuming that the source net counts are azimuthally uniformly distributed. Thus, for example, when we exclude a 90° azimuthal sector, the normalized net counts (and relative error) are obtained multiplying the measured counts (and error) by 360/(360−90).

For the four sources (MS0439.7−4319, MS0919.3+5133, MS1059.0+7302, MS1408.1+2617) detected near the window support structure we included a systematic error of 10% in the X-ray flux by adding it in quadrature to the statistical error. Sources for which normalized net counts have been computed are indicated in Table 1.

For all sources we have computed the energy spectral index $\alpha$ of the power-law using the hardness ratio $HR$ and fixing $N_H$ at the Galactic value. The hardness ratio $HR$ is defined as $HR = (H−S)/(H+S)$ where $S$ is the number of net counts detected in the 0.11−0.43 keV band and $H$ is the number of net counts detected in the 0.5−2.02 keV band (see Appendix A in Ciliegi et al. 1996 for a full description of the ROSAT hardness ratio technique). Following Hasinger (1992), before computing the hardness ratio, we have corrected the net counts of each source for the energy dependence of the Point Spread Function (PSF). Of the 63 sources, 42 are detected with more than 600 net counts. For these sources a more detailed spectral analysis is possible. We have thus considered 31 of the 34 energy channels from the MPE Standard Analysis Software System (SASS) pipeline processing excluding the first two channels (<0.1 keV) and the last channel (>2.4 keV) because the response of the instrument is not well-defined at the extremes of the energy range. The spectrum is then binned to obtain at least 20 net counts and a signal to noise ratio $S/N \geq 3$ in each bin so that the $\chi^2$ statistic could be applied. Finally we make two different power-law fits: (1) with $N_H$ fixed at the Galactic value and (2) with $N_H$ as free parameter. Model fits are carried out using the XSPEC software package, and the best fit model parameters are obtained by $\chi^2$ minimization. Following Fiore et al. (1994), we have used the 1992 March response matrix for observations made before October 1991 and the 1993 January response matrix for observations made after October 1991.

4 RESULTS

The results of the spectral fits are given in Table 2. For each source we report the results of the hardness ratio analysis (columns 2 and 3) and of the detailed spectral analysis (columns 4−9). The table is organized as follows:

- **Column 1:** Source name. Radio-loud AGN are indicated with “R”.
- **Column 2:** Hardness Ratio ($HR$).
- **Column 3:** Energy spectral index $\alpha_{HR}$ obtained from the $HR$, fixing $N_H = N_H^{Gal}$.
- **Column 4:** Best fitting spectral slope $\alpha_s$ for fit 1 (first row) and for fit 2 (second row).
- **Column 5:** $N_H^{Gal}$ used for fit 1 (first row) and the best fitting $N_H$ for fit 2 (second row).
- **Column 6:** $\chi^2$ of the fit ($\chi^2_{FIT}$) and the number of degrees of freedom (dof) for fit 1 (first row) and fit 2 (second row).
- **Column 7:** Probability for $\chi^2 > \chi^2_{FIT}$.
- **Column 8:** F-test probability (Bevington and Robinson 1992) that the reduction in $\chi^2_{FIT}$ with the addition of $N_H$ as a free parameter is not statistically significant ($P(F > F_{FIT})$).
- **Column 9:** X-ray flux in the 0.1−2.4 keV band obtained using the fit 1 parameters or, for sources with less than 600 net counts, using $\alpha_{HR}$ and Galactic $N_H$. Flux errors are computed from photon-counting statistics only (i.e. without taking into account the error on the spectral slope and on $N_H$).

The errors represent the 68 per cent confidence intervals for a single interesting parameter when $N_H$ is fixed, and for two interesting parameters when both the X-ray energy spectral index $\alpha_s$ and $N_H$ are free to vary.

A comparison of fit 1 and 2 allows us to determine whether there is evidence for a significant intrinsic excess absorption or excess emission relative to a single power law model plus Galactic absorption. As shown in Table 2, in eight of the 42 objects for which we have enough net counts to allow a spectral fit, there are significant deviations from a simple power-law plus Galactic absorption (i.e. $P(F > F_{FIT}) < 0.01$). These eight sources, that will be separately discussed in § 5.1, represent about 20 per cent of the sources with more than 600 net counts.

Finally, we have used these 42 sources to test the reliability of the hardness ratio technique by comparing the spectral indices $\alpha_{HR}$ derived from the hardness ratio with those derived from the detailed spectral analysis (fit 1: $N_H$ fixed at the Galactic value). The result is illustrated in Figure 1. The slope derived by the two method are very well correlated through a wide range of values ($\alpha_s \sim 0.4−2.2$). For $\alpha_s > 2.2$ (3 objects) the slopes obtained from the hardness ratio are lower ($\Delta \alpha \sim 0.2$) than those obtained from the detailed spectral analysis. This same difference was evident also in the results of the X-ray spectral analysis of the CRSS AGN sample (Ciliegi et al. 1996). Since all the EMSS AGNs analyzed solely with the HR show an energy spectral index $\alpha_s < 2.1$ (see Table 2) we are confident that can safely combine the results obtained with the two techniques. Of course one should keep in mind that the hardness ratio technique is not able to recognize those sources showing a significant deviation from a power-law model plus Galactic absorption, since its application rests on the assumption of the knowledge of the spectral form. However, on the basis of the results obtained from the detailed analysis of the 42 sources detected with more than 600 net counts we expect that this assumption (i.e. X-ray spectra well fitted by a simple power-law plus Galactic absorption) may not be appropriate only for ~20 per cent of the 21 sources analyzed with this technique (i.e. ~ 4 sources).

We have therefore removed the 8 sources that show significant deviations from a single power-law model plus Galactic absorption to obtain a sample of 55 AGN which we use in the following. Given the small number of objects for
which the HR results may be unreliable (<8 per cent of the whole sample of 55 objects) the results obtained should not be strongly affected by their possible inclusion.

5 DISCUSSION

5.1 Sources with a significant deviation from a simple power-law plus Galactic absorption

As discussed above, eight sources show a significant deviation from a simple power-law fit plus Galactic absorption. Five of these sources show a best fit value of \(N_H\) lower than the Galactic value, indicating an excess of soft emission relative to a single power-law fit with \(N_H=N_{H,\text{Gal}}\), while the other three sources show excess absorption (\(N_H>N_{H,\text{Gal}}\)). For only two of these eight sources (MS1215.9+3005 and MS1747.2+6837) there are ROSAT/PSPC spectra already published in the literature (Molendi and Maccacaro 1994, Brandt et al. 1994). For the other six sources we plot in Figure 2 a two dimensional contour plot for a single power-law model with spectral slope \(\alpha_s\) and equivalent hydrogen absorbing column density \(N_H\). Below we briefly discuss each of these sources in turn.

**MS0104.2+3153** This X-ray sources is a QSO-Galaxy pair discovered as a serendipitous source in the EMSS. Based upon the IPC data (52 net counts, Gioia et al. 1990) the true identity of MS0104.2+3153 was ambiguous due to the presence in the error circle (\(\sim 40\)″) of a radio-quiet broad absorption line (BAL) QSO (z=2.027) only 10″ away from a giant elliptical galaxy (z=0.111) at the center of a compact group of galaxies (Stocke et al. 1984). Successively, this source was observed with the Channel Multiplier Array (CMA) aboard the EXOSAT satellite (Gioia et al. 1986). Since no X-ray source was apparent in the deep (160 ksec) EXOSAT observation, Gioia et al. (1986) concluded that the X-ray source is variable and thus that the QSO is the strongest candidate for the optical identification of MS0104.2+3153 excluding any contribution to the X-ray flux from the giant elliptical galaxy or from the cluster of galaxy. Moreover, Gioia et al. (1986) concluded that the EXOSAT CMA data implied a substantial decrease in the X-ray luminosity of this object, unless its soft X-ray spectrum is unusually and extremely flat (\(\alpha_s<0.2\)) or this object exhibits a significant amount of intrinsic absorption (\(N_H>2\times10^{21}\) cm\(^{-2}\); quite possible for a BAL QSO).

The ROSAT observation allow us to study in more detail the X-ray emission from this source. Unfortunately, in spite of the improved spatial resolution of the ROSAT/PSPC detector, we are not yet able to confirm, on positional ground, the optical identification of this source. As shown in Figure 2a (see also Table 2) this source has a best fit \(N_H\) value larger than the Galactic value at the 99 per cent confidence level. We fit the absorption excess modelling the data with a power-law plus Galactic absorption plus a second absorption component. We make two different fits, with the additional absorption component fixed at the redshift of the cluster (z=0.111, fit A) and at the redshift of the QSO (z=2.027, fit B). In table 3 we report the results of these spectral models. The PSPC cannot constrain the redshift of the absorbing material, both models give, in fact, a good fit of the data (see Table 3).

The spectral results (models A e B, Table 3) show that the X-ray spectrum of this source is characterized by a very steep spectral index (\(\alpha_s>2.9\)) and by a strong excess absorption relative to the Galactic value (\(N_H>4\times10^{21}\)). Therefore, the non detection with the EXOSAT CMA can not be attributed to an unusually and extremely flat spectrum. However the possibility that the non detection is not due to an X-ray flux variability but to a significant amount of intrinsic absorption can not be excluded.

In conclusion, the ROSAT observation of MS0104.2+3153 does not allow us to obtain a definite identification of the X-ray source.

**MS0132.5−4151** This source shows a best fit value of \(N_H\) lower than the Galactic value at the 99 per cent confidence level (see Figure 2b). We parameterized this soft excess fitting the data with a broken power-law with \(N_H \) fixed at the Galactic value. We find that the spectral index of the soft power-law is poorly constrained while the hard power-law has a spectral index \(\alpha_s=2.21\pm0.65\) (see Table 3). A two component model, consisting of a thermal component (black body, bremsstrahlung or Raymond-Smith dominating the soft part of the spectrum) plus a power-law does not yield a good fit of the data (\(P(\chi^2)<0.01\)).

**MS0144.2−0055** This source shows excess absorption relative to the Galactic value (see Figure 2c). The absorption excess in MS0144.2−0055 can be well parameterized by fitting the data with a power-law plus Galactic absorption plus a second absorption component (\(N_H=1.5^{+0.8}_{-0.7}\times10^{20}\) cm\(^{-2}\)) at the redshift of the source (see Table 3).

**MS0310.4−5543** This source was included in the sample of 53 AGNs which exhibit ultra-soft X-ray excess (Ultra Soft Survey, USS) selected from Einstein IPC sources (Cordova et al. 1992, Puchnarewicz et al. 1992). However, given the few net counts detected by Einstein (\(\sim 40\) net counts) only a limited spectral analysis was possible.

The ROSAT observation (\(\sim 7700\) net counts detected) gives the opportunity to study the X-ray spectrum of this source in more detail. As shown in Figure 2d, the ROSAT data show a soft emission excess relative to a single power-law with \(N_H=N_{H,\text{Gal}}\). We find that the soft excess in this source is well parameterized by fitting the data with a broken power-law with \(N_H\) fixed at the Galactic value. It gives \(\alpha_{\text{SOFT}}=3.89\pm1.09\), \(\alpha_{\text{HARD}}=1.54\pm0.13\), \(E_{\text{break}}=0.25\pm0.13\) keV and \(\chi^2/\text{dof}=23.13/23\) (see Table 3).

**MS0919.9+4543** This source shows excess absorption relative to the Galactic value (see Figure 2e). As for MS0144.2−0055, also for this source the absorption excess can be well parameterized by fitting the data with a power-law including a Galactic absorption plus another absorption component (\(N_H=2.7^{+1.6}_{-1.3}\times10^{20}\) cm\(^{-2}\)) at the redshift of the source (see Table 3).

**MS1215.9+3005** This source is the well know Seyfert 1 galaxy MKN 766. A detailed analysis of the ROSAT observations of this source is reported by Molendi, Maccacaro and Schaeidt (1993) and Molendi and Maccacaro (1994) while the results of the ASCA observation are reported by Leighly et al (1996). Its X-ray spectrum is very complicated, therefore we refer to these works for a detailed discussion of the X-ray properties of this source.
MS1747.2+6837 This is the Seyfert 1 galaxy Kaz 163. The ROSAT/PSPC data of this source were previously analyzed by Brandt et al. (1994). They find that a single power-law model plus galactic absorption is not a good representation of the data since it would imply an \( N_H \) column density lower than Galactic value. However they showed that a broken power-law is a good representation of the spectrum, yielding \( N_H = 5.01^{+1.40}_{-1.37} \times 10^{20} \) cm\(^{-2} \), \( \alpha_{SOFT} = 2.59^{+0.81}_{-1.02} \), \( \alpha_{HARD} = 1.54^{+0.10}_{-0.19} \) with \( \chi^2/\text{dof} = 23.8/28 \).

In our analysis we confirm the results obtained by Brandt et al. (1994). However, since Brandt et al. (1994) showed that there are no indications of excess absorption (\( N_H \sim N_{H,\text{Gal}} \)) in the broken power-law model, we parameterized the soft excess fitting the data with a broken power-law fixing \( N_H \) at the Galactic value. With one less free parameter in the fit, we can better constrain the slopes of the broken power-law. We find \( \alpha_{SOFT} = 2.93 \pm 0.50 \) and \( \alpha_{HARD} = 1.55 \pm 0.09 \) (see Table 3).

MS2340.9—1511 This source shows a best fit value of \( N_H \) lower than the Galactic value, although only at the 68 per cent confidence level (see Figure 2f). Both the two power-law models with \( N_H \) fixed at the Galactic value and with \( N_H \) as a free parameter do not yield a good fit of the data (\( P(\chi^2) \sim 1.5 \times 10^{-8} \) for both fits, see Table 2). We find that the X-ray spectrum of MS2340.9—1511 can be well fitted by a two component model consisting of a thermal component (\( kT=0.52^{\pm0.11} \) keV) based on the model calculations of Raymond and Smith (1977) with abundances fixed at the cosmic value, plus a power-law component (\( \alpha = 2.06 \pm 0.07 \)). In Table 3 we report the results for the Raymond-Smith + power-law fit. Other spectral models used to fit the data (broken power-law, black-body + power-law, bremsstrahlung + power-law) do not yield a good description of the data (\( P(\chi^2) < 0.01 \)).

5.1.1 Warm Absorber

For the four sources that show a best fit value of \( N_H \) lower than Galactic value (MS132.5—4151, MS0310.4—5543, MS1747.2+6837, MS2340.9—1511 — MKN766 is not considered here for the reason stated above) we investigated the possibility that the soft excess could be a signature of an absorption produced not by neutral gas but by partially ionized “warm” material. A signature of such material is a flattening of the spectrum above the oxygen K-edge at \( \sim 1 \) keV, and an excess flux below the edge, at \( \sim 0.25 \) keV, where the ionized lighter elements become transparent. Given the limited spectral resolution of the ROSAT PSPC, warm absorbers could lead to apparent soft excess in the X-ray spectra.

Fiore et al. (1996) have considered a number of warm absorber models and have computed for different values of the spectral index \( \alpha_x \), of the absorption column density \( N_H \) and of the ionization parameter \( U \), the expected ratio of PSPC counts: \( R1 = (1.2—2.4 \text{ keV})/(0.6—1.0 \text{ keV}) \) and \( R2 = (0.6—1.0 \text{ keV})/(0.2—0.4 \text{ keV}) \). They have shown that “warm absorbers” cluster in a well define region of the R1 vs. R2 plane. We have computed the position of the four above mentioned sources in the R1 vs. R2 plane and discovered that all of them fall far away (> 6\sigma) from the “warm absorbers” region (see Figure 3). Therefore we can conclude that absorption by partially ionized “warm” material can be excluded for MS0132.5—4151, MS0310.4—5543, MS1747.2+6837 and MS2340.9—1511.

5.2 Analysis of the power-law spectral index

Within the general assumption that both the measurement errors and the underlying spectral index distributions can be described by a Gaussian, Maccacaro et al. (1988) used the Maximum-Likelihood (ML) analysis (see also Worrall and Wilkes 1990) to obtain the mean spectral index (\( < \alpha_p > \)) and the intrinsic spread in spectral slope (\( \sigma_p \)) of each class of extragalactic objects in the EMSS (we use here the same notation of Maccacaro et al. 1988, where the subscript “p” refers to the parent population). For the AGN sample they found an average spectral index \( < \alpha_p > = 1.03^{+0.05}_{-0.06} \) with an intrinsic dispersion \( \sigma_p = 0.36 \).

In Figure 4 we show the distribution of the EMSS AGN energy spectral indices obtained from our analysis of the ROSAT data. Because a KS test shows that the spectral index distribution of the subsample of EMSS AGN used is not significantly different from a normal distribution (\( > 90 \) per cent confidence level), we used the ML analysis to calculate the mean ROSAT spectral index and the intrinsic dispersion.

Since at the time of the Maccacaro et al. (1988) analysis of the spectral properties of the EMSS AGN there was still a large number (236) of unidentified sources (of which 212 have since been identified) we have also repeated, for a more meaningful comparison, the ML analysis using the IPC data on the current (Maccacaro et al. 1994) EMSS AGN sample.

We have therefore considered 437 AGN (391 RQ and 46 RL) for the ML analysis, excluding 26 sources (23 RQ and 3 RL) for which the hardness ratio is so extreme to make the slope determination meaningless.

Table 4 and Figure 5 give the results of the ML analysis. In Table 4 we report the mean spectral index (\( < \alpha_p > \)) and the intrinsic dispersion (\( \sigma_p \)) obtained with the ML analysis and, for comparison, the weighted mean \( \alpha_{WM} \). Figure 5 shows the 90 per cent confidence contour for two interesting parameters for each data set (\( \text{Einstein}/\text{IPC} \) and ROSAT/PSPC).

A comparison of our IPC results on the whole EMSS AGN sample with the results obtained by Maccacaro et al. (1988), shows that we obtain the same mean spectral index with a small decrease in the intrinsic dispersion (\( \Delta \sigma_p = 0.08 \)). On the other hand, Table 4 and Figure 5 show that the mean IPC spectral index is significantly steeper than the mean IPC spectral index (\( \Delta \alpha \approx 0.4 \)).

A similar discrepancy between IPC and PSPC slopes of AGN has been pointed out also by Laor et al. (1994) and Fiore et al. (1994). This difference is probably due to the “ultra-soft excess” below \( \sim 0.3 \) keV first noted by Wilkes and Elvis (1987) in the IPC X-ray spectra of quasars and interpreted as the high-energy tail of the hot thermal component.

\* Note that the label along X-axis of Figure 7 of Fiore et al. (1993) should read Counts/(0.6—1.0) / Counts/(0.2—0.4) and not Counts/(0.2—0.4) / Counts/(0.6—1.0) (Fiore, private communication)
dominating the UV emission (the big blue bump). Due to the softer ROSAT/PSPC band (∼ 0.1 – 2.4 keV) compared to the Einstein/IPC band (∼ 0.3 – 3.5 keV) the “ultra-soft excess” dominates in the ROSAT spectra and causes a steepening of the X-ray spectra when fitted with a single power-law. However, even if this “ultra-soft component” becomes dominant in the ROSAT band compared to the other components proposed to explain the X-ray emission above 0.5 keV (see Wilkes and Elvis 1987), we expect that its introduction causes a broadening in the spectral index distribution. In fact, because this thermal component comes from the inner accretion disk around the central black hole, different physical and/or geometrical properties of the latter may be responsible of different values of the observed spectral slope, with a consequent broadening of the spectral index distribution. The ML analysis shows (see Table 4 and Figure 5) that the intrinsic spread in the ROSAT spectral slopes is, in fact, greater than the intrinsic spread in the Einstein spectral slopes (Δσp=0.16). To ensure that this difference is not due to the different number of objects used (411 for IPC data and 55 for PSPC data), we repeated the ML analysis using only the IPC spectral indices of the 55 EMSS AGN that we used in our ROSAT analysis. For these sources we find <αp> =1.14 and σp=0.31. The ROSAT spectral indices show a greater intrinsic dispersion (Δσp=0.13) compared to the Einstein spectral indices also for the same data set. We therefore suggest that the difference between the ROSAT and Einstein spectral indices is due to the presence of the “ultra-soft excess” in the ROSAT/PSPC band. However, one should consider the possibility that up to 50% of this difference (i.e. Δα<0.2) may be due to calibration errors in the PSPC and/or IPC instruments. In fact, as suggested by Fiore et al. (1994) (see also Turner 1993), the maximum amplitude of the systematic error due to calibration is ~ 0.2 on the spectral index αx.

Finally, considering only the ROSAT data, our values of the mean spectral index are consistent with previous values obtained for X-ray selected AGN. Using the CRSS sample, Ciliegi et al. (1996) find a mean spectral index <αx> =1.32 (σp=0.33) for the quasar sample and <αx> =1.30 (σp=0.49) for the NLXG sample, whereas there is an intrinsic dispersion present among the ROSAT data (50 RQ). Given the small number (5) of ROSAT RL AGN that we have analyzed, we do not apply the ML analysis to this subsample but we obtain a mean spectral index simply with the weighted mean. Table 4 and Figure 6 give the results of the ML analysis. It is clear that the mean index for the RL sample is flatter than that for RQ, and further that this group of objects shows no intrinsic dispersion, i.e. they are compatible (> 90 per cent confidence level) with a single spectral index, whereas there is an intrinsic dispersion present among the RQ samples (both from Einstein and ROSAT data). The same results were obtained by Lawson et al. (1992) with the EXOSAT data for a sample of 13 RQ and 18 RL quasars.

The flatter and possibly unique X-ray spectral index that we find also for the EMSS RL AGN with the IPC data, strengthen the scheme (Zamorani et al. 1981, Wilkes and Elvis 1987, Shastri 1991, Lawson et al. 1992) in which there is an additional component present in radio-loud objects which produces this single dominant power-law. This could be associated with beaming and jets present in many radio-loud quasar, as recently discussed by Kembhavi (1993) and Ciliegi et al. (1995).

Finally, Table 4 shows that also in the ROSAT data the RL sample shows a flatter spectral index than the RQ sample (Δα30 =0.42). It thus seems that the additional X-ray component in the RL AGN dominates the X-ray spectra of these sources over almost two decades of energy (∼ 0.1–10 keV).

5.4 Correlation analysis

In this section we describe the search for correlations between αx and other physical parameters, in particular redshift, optical and X-ray luminosity (L2500Å and Lx) and optical to X-ray luminosity ratio (L2500Å/Lx).

The significance of the correlations is tested using the Spearman Rank correlation coefficient rs and the relative probability Pr that an observed correlation could occur by chance for uncorrelated data sets (see Press et al. 1992). A correlation is taken to be significant when Pr ≤ 0.01. A summary of all the correlation coefficients and their significance is given in Table 4, while Figure 7 shows redshift (z), optical luminosity (L2500Å), X-ray luminosity (Lx) and L2500Å/Lx, respectively, as a function of the X-ray energy spectral index αx.

Given the hidden dependence of the normalization at 2 keV on the spectral slope αx obtained from PSPC spectra (see Ulrich and Molendi 1995 for a detailed discussion of this point), we use, in the correlation analysis the broad band (0.1–2.4 keV) X-ray luminosity (Lx) which is much less sensitive to changes in αx. For this reason we do not use the usual two point spectral index α2500Å but instead we use the ratio between the optical (at 2500Å) and broad band X-ray luminosities (L2500Å/Lx).

Table 4 shows that no significant correlations are found. The lack of correlation between αx and z for the EMSS AGN suggests that for these sources the power-law spectrum in the source rest frame extends from the soft (∼ 0.1–2.4 keV) into the hard X-ray band (∼ 0.3 – 7.0 keV for the highest
redshift object). Similar results are obtained for X-ray selected quasars by Ciliegi et al. (1996) and by Puchnarewicz et al. (1996) and for optically selected quasars by Canizares and White (1989) using Einstein/IPC data and by Williams et al. (1992) using Ginga data.

These results appear to be at odd with the result obtained by Schartel et al. (1992). Using the RASS data for 162 strongly-detected optically-selected QSOs Schartel et al. (1992) find a flattening of the spectral slope with increasing redshift from $\alpha_x \sim 1.5$ to $\alpha_x \sim 0.8$ between $z = 0.2$ and $z \sim 2$. The fact that both the EMSS and CRSS sample do not show any correlation between spectral index and redshift strengthen the suspect that the correlation observed in the Schartel et al. 1992 sample is spurious and due to an increasing fraction of RL AGN (that show flatter spectra) at high redshift. In fact, unlike the analysis carried out for the ROSAT spectra of the EMSS and CRSS sample, Schartel et al. (1992) did not make the important distinction between RL and RQ objects. Indeed the Ginga data appear to show a flattening of RL and RQ objects. Indeed the Ginga data appear to show a flattening of the spectral slope with increasing redshift from $\alpha_x \sim 1.5$ to $\alpha_x \sim 0.8$ between $z = 0.2$ and $z \sim 2$. The fact that both the EMSS and CRSS sample do not show any correlation between spectral index and redshift strengthen the suspect that the correlation observed in the Schartel et al. 1992 sample is spurious and due to an increasing fraction of RL AGN (that show flatter spectra) at high redshift. In fact, unlike the analysis carried out for the ROSAT spectra of the EMSS and CRSS sample, Schartel et al. (1992) did not make the important distinction between RL and RQ objects. Indeed the Ginga data appear to show a flattening of $\alpha_x$ with redshift but the correlation disappears when RL and RQ objects are considered separately (Williams et al. 1992).

Finally, the lack of a correlation between $\alpha_x$ and optical and X-ray luminosities is in agreement with the results obtained by Ciliegi et al. (1996) for the CRSS AGN and by Laor et al. (1996) for 23 QSOs of the Bright QSO Survey (BQS).

6 CONCLUSION

Using ROSAT/PSPC observations in the public archive (as of May 31, 1995) we have analyzed the X-ray spectra of 63 EMSS AGN. These objects are all the EMSS AGN detected by ROSAT with more than 300 net counts. A comparison with the whole sample of EMSS AGN shows that this subsample is not significantly different (redshift and luminosities distributions) from the whole EMSS AGN sample. This allows us to compare the PSPC results with the mean IPC spectral properties of the whole EMSS AGN sample. Our major results are the following:

1. Of the 42 sources with more than 600 net counts for which a detailed analysis was possible, eight (~20 per cent) show a significant deviation from a single power-law model plus Galactic absorption. These eight sources were excluded from the sample used to study the mean X-ray spectral properties of the EMSS sources. Five of these sources show a soft emission excess relative to a single power-law fit with $N_H = N_{H_{\text{Gal}}}$ whereas the other three show a significant absorption excess ($N_H > N_{H_{\text{Gal}}}$). Using a color-color diagram developed by Fiore et al. (1993) we can exclude the possibility that the soft emission excess is due to absorption by partially ionized "warm" material.

2. The mean ROSAT/PSPC energy spectral index obtained with the Maximum-Likelihood analysis is $\langle \alpha_p \rangle = 1.42 \pm 0.04$ with an intrinsic dispersion $\sigma_p = 0.44$. This value is in agreement with the ROSAT spectral indices obtained for other X-ray and optically selected AGN, and is significantly steeper ($\Delta \alpha > 0.4$) than the mean Einstein/IPC spectral index obtained on the whole sample of EMSS AGN. Moreover we find a significant increase in the intrinsic dispersion of the ROSAT spectral indices compared to the Einstein data ($\Delta \sigma_p = 0.16$). The steepening of the ROSAT mean spectral index is probably due to the fact that in the ROSAT band (softer than the IPC band) the "ultra-soft excess", already noted in the spectra of many AGN below $\sim 0.3$ keV, becomes dominant. In this scheme, the broadening of the ROSAT spectral index distribution can be explained considering that the slope of the ultra-soft component may differ from object to object, reflecting different physical and/or geometrical properties of the inner accretion disk with which it is associated.

3. The ML analysis of the IPC spectral index for RQ and RL EMSS AGN subsamples shows that the mean index of RL sample is flatter than that of the RQ. Moreover, as already obtained by Lawson et al. (1992) with the EXOSAT data, the RL sample has a 90 per cent confidence contour consistent with zero intrinsic dispersion (i.e compatible with an unique spectral index) whereas there is surely an intrinsic dispersion present in the RQ sample. These results support a scheme where in radio-loud objects there is an additional X-ray component characterized by a single dominant power-law.

4. Although we have ROSAT data for only 5 RL EMSS AGN, we find that also in the ROSAT band the mean index of RL is flatter than that of RQ. This suggests that the additional component in RL AGN dominates the X-ray spectra of RL AGN over almost two decades of energy ($\sim 0.1 - 10$ keV).

5. We found no significant correlation between the spectral index $\alpha_x$ and other physical parameters such redshift, optical and X-ray luminosity and the ratio between optical and X-ray luminosities. Similar results were obtained for other X-ray selected sample of AGN.

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Figure Captions

Figure 1. Comparison between the spectral slope $\alpha$ determined from the source hardness ratio and from a detailed spectral analysis.

Figure 2. Confidence contours (68, 90 and 99 per cent) for the joint determination of the energy spectral index and equivalent hydrogen absorbing column $N_H$, for six of the eight sources that show significant deviation from a simple power-law fit plus Galactic absorption. The vertical line represents the Galactic $N_H$ value (Stark et al. 1992)

Figure 3. Ratio of the counts in the energy intervals 1.2–2.4 keV and 0.6–1.0 keV as a function of the ratio in the intervals 0.6–1.0 keV and 0.2–0.4 keV for $\alpha=0.5$, $N_H=1.2\times10^{22}$ cm$^{-2}$ (crosses); $\alpha=0.7$, $N_H=1.2\times10^{22}$ cm$^{-2}$ (filled squares); $\alpha=0.7$, $N_H=1.5\times10^{22}$ cm$^{-2}$ (open squares) and $\alpha=0.9$, $N_H=1.2\times10^{22}$ cm$^{-2}$ (open circles). In all cases U is varied between 0.1 and 0.2 (adapted from Fiore et al. 1993). The points numbered one to four represent the EMSS AGN with a best fit value of $N_H$ lower than Galactic value.

Figure 4. Distribution of the energy spectral indices obtained from the analysis of the ROSAT data. The Radio-loud objects are shaded.

Figure 5. 90 per cent confidence contours obtained with the Maximum-Likelihood analysis for the whole EMSS AGN sample with the Einstein/IPC data (dotted line) and for the subsample of 55 EMSS AGN with the ROSAT/PSPC data (solid line) (see §5.2 for more details).

Figure 6. As in Figure 5, for Radio-loud (RL) and Radio-quiet (RQ) AGN separately.

Figure 7. ROSAT X-ray spectral indices for Radio-loud AGN (open squares) and for Radio-loud AGN (filled squares) versus: (a) Redshift, (b) optical luminosity at 2500Å, (c) X-ray broad band (0.1–2.4 keV) luminosity and (d) $L_{2500\AA}/L_x$. 

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TABLE 1: EMSS sources

| SOURCE      | NAME    | z       | $\alpha_{ro}$ | r (t) | $\theta$ (t) | Net Counts (0.1-2.4 keV) | Sequence Number |
|------------|---------|---------|---------------|-------|-------------|--------------------------|----------------|
| SOURCE NAME | $z$ | $\alpha_{ro}$ | $r$ (l) | $\theta$ (l) | Net Counts (0.1-2.4 keV) | Sequence Number |
|-------------|-----|--------------|--------|-------------|--------------------------|-----------------|
| MS1408.1+2617 | 0.072 | < 0.10 | 2.5 | 20.2 | 390± 29* | RP700359 |
| MS1416.3–1257 PG 1416–12 | 0.129 | < 0.01 | 2.0 | 0.1 | 3425± 66 | WP700527 |
| MS1426.5+0130 MKN 1383 | 0.086 | −0.03 | 2.0 | 0.1 | 9697±105 | RP150007 |
| MS1549.8+2022 | 0.250 | < 0.10 | 2.5 | 8.4 | 1535± 66* | WP701213 |
| MS1559.1+3324 | 0.087 | < 0.17 | 4.0 | 27.7 | 2510±102* | RP800003 |
| MS1559.8+4202 | 0.759 | < 0.10 | 3.5 | 24.6 | 342± 32 | RP800103 |
| MS1617.9+1731 MKN 877 | 0.116 | < −0.04 | 2.0 | 0.1 | 1055± 33 | RP700022 |
| MS1640.0+3940 | 0.540 | 0.46 | 3.0 | 18.7 | 421± 35 | RP700870 |
| MS1703.7+2417 | 0.113 | < 0.11 | 3.0 | 18.3 | 430± 27 | RP400118 |
| MS1746.2+6738 | 0.041 | < 0.17 | 5.0 | 49.9 | 324± 24 | WP700650 |
| MS1747.2+6837 Kaz 163 | 0.063 | < −0.01 | 2.0 | 10.6 | 6669± 84 | WP701523 |
| MS1803.6+3940 | 0.136 | < −0.03 | 3.0 | 20.4 | 1255± 39 | WP120013 |
| MS2034.0+0028 PKS | 0.256 | < 0.08 | 2.0 | 1.0 | 529± 28 | WP700547 |
| MS2134.0+0028 PKS | 1.936 | 0.84 | 2.0 | 3.0 | 433± 23 | RP700817 |
| MS2154.5+0107 | 0.220 | < 0.16 | 3.0 | 15.7 | 309± 30 | WP800344 |
| MS2159.5–5713 | 0.083 | 0.46 | 3.0 | 14.3 | 3284± 65 | RP200559 |
| MS2254.9–3712 | 0.039 | 0.03 | 4.0 | 29.1 | 23145±165 | RP600266 |
| MS2255.0–3651 | 0.336 | < 0.14 | 2.0 | 11.3 | 1636± 50 | RP600266 |
| MS2318.2–4220 | 0.212 | < 0.16 | 5.0 | 34.6 | 428± 41 | RP700333 |
| MS2340.9–1511 | 0.137 | < 0.01 | 2.0 | 0.7 | 12051±112 | WP701205 |

* Normalized Net Counts. For this source an azimuthal sector centered on the source position has been excluded from the circle used for the counts extraction (see §3 for more details).
| SOURCE       | HR  | $\alpha_{HR}$ | $\alpha_x$ | $N_H$ | $\chi^2_{FIT}$/dof | $P(\chi^2 > \chi^2_{FIT})$ | $P(F > F_{FIT})$ | $\sigma_F$ |
|--------------|-----|---------------|------------|------|--------------------|--------------------------|------------------|------------|
| MS0017.3+1540 | 0.36±0.04 | 1.42±0.07    | 1.41±0.07  | 4.10 | 18.4/23            | 0.734                    | 10.90±0.44       |            |
| MS0104.2+3153 | 0.90±0.05 | 0.85±0.37    | 0.83±0.15  | 5.60 | 30.8/12            | 0.002                    |                  |            |
| MS0117.2−2837 | −0.78±0.02 | 2.53±0.10    | 2.69±0.10  | 1.70 | 13.3/13            | 0.422                    | 90.01±2.63       |            |
| MS0120.0+0328 | 0.06±0.06 | 1.59±0.09    | 1.57±0.09  | 3.20 |                    |                          | 11.40±0.79       |            |
| MS0132.5−4151 | −0.51±0.04 | 3.56±0.11    | 3.61±0.17  | 5.80 | 25.2/10            | 0.005                    |                  |            |
| MS0144.2−0055 | −0.01±0.03 | 0.99±0.04    | 1.01±0.05  | 1.40 | 21.0/23            | 0.579                    |                  |            |
| MS0204.8+0217 | −0.01±0.06 | 1.70±0.09    | 1.62±0.30  | 2.95±0.82 | 9.9/22          | 0.987                    | 5.4×10⁻⁵        |            |
| MS0232.5−0414 R | 0.13±0.03 | 1.25±0.05    | 1.24±0.04  | 2.50 | 20.6/25            | 0.715                    | 27.33±0.75       |            |
| MS0232.8−0400 | −0.39±0.04 | 2.06±0.05    | 2.02±0.11  | 2.50 | 10.9/13            | 0.617                    | 21.10±1.02       |            |
| MS0244.6−3020 | −0.16±0.05 | 1.41±0.08    | 1.82±0.32  | 2.06±0.70 | 10.6/12          | 0.570                    | 0.530           |            |
| MS0244.8+1928 | 0.76±0.03 | 1.88±0.12    | 1.64±0.10  | 9.30 | 20.0/20            | 0.455                    | 85.70±2.63       |            |
| MS0310.4−5543 | −0.40±0.01 | 1.75±0.02    | 1.72±0.02  | 1.80 | 85.9/25            | 1.3×10⁻⁸                  |                  |            |
| MS0439.7−4319 R | 0.06±0.07 | 1.38±0.10    | 1.31±0.10  | 2.50 | 15.9/14            | 0.322                    | 12.12±1.43       |            |
| MS0719.9+7100 | 0.07±0.06 | 1.65±0.09    | 1.52±0.10  | 3.40 | 9.6/13             | 0.726                    | 14.90±1.07       |            |
| MS0737.0+7436 | 0.22±0.03 | 1.37±0.05    | 1.41±0.05  | 3.30 | 16.6/24            | 0.866                    | 38.13±1.19       |            |
| MS0803.3+7557 | 0.18±0.06 | 1.34±0.09    | 1.65±0.30  | 4.06±0.88 | 14.7/23          | 0.904                    | 0.105           |            |
| MS0828.7+6601 R | 0.59±0.10 | 0.98±0.23    | 1.01±0.15  | 2.70 |                    |                          | 5.69±0.55        |            |
| MS0844.9+1836 | 0.30±0.09 | 1.01±0.15    | 1.77±0.11  | 3.10 |                    |                          | 8.23±0.59        |            |
| SOURCE          | HR   | $\alpha_{HR}$ | $\alpha_{x}$ | $N_H$ ($\times 10^{20}$ cm$^{-2}$) | $\chi_{FIT/dof}^2$ | $P(\chi^2 > \chi_{FIT}^2)$ | $P(\chi^2 > \chi_{FIT}^2)$ | $f^a_x$ |
|----------------|------|---------------|--------------|-----------------------------------|--------------------|---------------------------|---------------------------|--------|
| MS0850.2+1336  | 0.16±0.04 | 1.55±0.06  | 1.53±0.07 | 3.50 | 17.7/22 | 0.724 | 21.59±0.86 |
| MS0919.3+5133  | -0.67±0.02 | 2.04±0.02  | 2.09±0.06 | 1.40 | 18.1/18 | 0.452 | 31.47±1.05 |
| MS0919.9+4543  | -0.61±0.02 | 2.01±0.02  | 2.04±0.06 | 1.50 | 19.0/19 | 0.458 | * |
| MS1018.2+2010  | -0.23±0.05 | 1.72±0.07  | 2.63±0.30 | 2.72±0.67 | 7.3/18 | 0.987 | 4.2×10$^{-5}$ |
| MS1059.0+7302  | 0.28±0.03 | 1.18±0.05  | 1.15±0.04 | 3.00 | 29.6/25 | 0.241 | 64.32±6.64 |
| MS1125+4059    | -0.28±0.02 | 1.59±0.03  | 1.61±0.04 | 1.90 | 15.9/24 | 0.892 | 25.53±0.62 |
| MS1136.5+3413  | -0.38±0.03 | 1.76±0.05  | 1.77±0.08 | 1.90 | 10.6/21 | 0.971 | 93.96±3.47 |
| MS1158.6−0323  | 0.33±0.02 | 0.92±0.03  | 0.96±0.03 | 2.50 | 37.8/29 | 0.127 | 30.80±0.65 |
| MS1200.1−0330  | 0.49±0.04 | 0.63±0.08  | 0.70±0.30 | 2.77±1.08 | 10.8/20 | 0.951 | 6.95±0.40 |
| MS1214.3+3811  | -0.03±0.03 | 1.22±0.04  | 1.26±0.06 | 1.90 | 16.2/29 | 0.973 | 16.20±0.52 |
| MS1215.9+3005  | -0.07±0.01 | 1.16±0.01  | 1.19±0.01 | 1.60 | 368/29 | <0.001 | * |
| MS1219.6+7535  | 0.20±0.01 | 1.38±0.02  | 1.37±0.02 | 3.20 | 30.9/29 | 0.372 | 290.5±3.24 |
| MS1223.5+2522  | -0.69±0.03 | 2.15±0.06  | 2.38±0.09 | 1.60 | 20.6/14 | 0.114 | 20.43±0.82 |
| MS1239.2+3219  | 0.39±0.07 | 0.36±0.11  | 0.44±0.12 | 1.30 | 2.6/13 | 0.999 | 6.25±0.45 |
| MS1248.0−0600  | 0.25±0.08 | 0.89±0.12  | 0.62±0.02 | 1.85±1.50 | 2.3/12 | 0.999 | 0.186 |
| MS1248.7+5706  | -0.24±0.06 | 1.27±0.10  | 1.27±0.12 | 1.30 | 20.6/7 | 0.004 | 8.32±0.68 |
| MS1257.4+3439  | -0.32±0.05 | 1.29±0.08  | 1.19±0.09 | 1.10 | 7.9/11 | 0.720 | 6.81±0.44 |
| MS1306.1−0115  | -0.23±0.07 | 1.48±0.10  | 0.77±0.25 | 0.18±1.24 | 18.6/6 | 0.005 | 0.453 |
| MS1332.1+4138  | -0.78±0.02 | 2.04±0.03  | 2.23±0.11 | 0.90 | 5.0/11 | 0.932 | 12.27±0.48 |
| MS1335.1−3128  | 0.49±0.11 | 1.14±0.21  | 2.36±0.34 | 1.05±0.53 | 4.6/10 | 0.914 | 0.410 |
| MS1342.8+6016  | -0.31±0.05 | 1.64±0.08  | 1.64±0.10 | 1.90 | 6.5/12 | 0.888 | 8.97±0.59 |
| SOURCE                | HR       | $\alpha_{HR}$ | $\alpha_x$ | $N_H$ ($\times 10^{20}$ cm$^{-2}$) | $\chi^2_{FIT}$/dof | $P(\chi^2 > \chi^2_{FIT})$ | $P(F > F_{FIT})$ | $\frac{\sigma^2}{\chi^2}$ |
|----------------------|----------|---------------|-------------|------------------------------------|---------------------|-----------------------------|-------------------|-----------------|
| MS1351.6+005         | 0.01±0.05| 0.76±0.07     | 0.73±0.08   | 1.98±1.00                          | 1.00                | 20.0/18                     | 0.340             | 7.98±0.44       |
| MS1408.1+2617        | −0.18±0.07| 1.27±0.10     |             | 1.50                               |                     |                             |                   | 20.03±2.49      |
| MS1416.3−1257        | 0.80±0.01| 1.04±0.06     | 1.11±0.05   | 6.80                               | 7.52±0.70           | 20.2/26                     | 0.784             | 113.0±2.19      |
| MS1426.5+0130        | −0.03±0.01| 1.54±0.02     | 1.56±0.02   | 2.70                               | 3.09±0.20           | 14.7/20                     | 0.794             | 325.0±3.55      |
| MS1549.8+2022        | 0.18±0.04| 1.66±0.06     | 1.64±0.08   | 3.90                               | 3.76±1.10           | 14.6/19                     | 0.745             | 32.86±1.41      |
| MS1559.1+3324        | −0.01±0.03| 1.36±0.04     | 1.39±0.05   | 2.30                               | 3.14±0.23           | 31.4/23                     | 0.114             | 20.52±0.83      |
| MS1559.8+4202        | −0.69±0.07| 2.06±0.17     | 1.77±0.32   | 3.35±0.90                          | 27.4/22             | 0.197                       | 0.087             | 5.97±0.57       |
| MS1617.9+1731        | 0.46±0.03| 1.36±0.06     | 1.19±0.06   | 4.00                               | 34.1/26             | 0.134                       | 45.96±1.44        |
| MS1640.0+3940 R      | −0.23±0.06| 1.11±0.09     | 1.01±0.21   | 3.65±0.69                          | 32.1/25             | 0.155                       | 0.229             | 9.01±0.76       |
| MS1703.7+2417        | 0.24±0.06| 1.73±0.10     |             | 1.00                               |                     |                             |                   | 22.30±1.43      |
| MS1746.2+6738        | 0.45±0.07| 1.32±0.13     |             | 4.30                               |                     |                             |                   | 69.40±5.12      |
| MS1747.2+6837        | 0.21±0.01| 1.82±0.02     | 1.80±0.02   | 4.50                               | 53.4±0.29           | 25.4/27                     | 0.550             | 3.6×10$^{-5}$    |
| MS1803.6+6738        | 0.48±0.03| 1.39±0.06     | 1.36±0.06   | 4.70                               | 16.0/25             | 0.916                       | 84.89±2.64        |
| MS2034.5−2253        | 0.52±0.05| 1.01±0.11     |             | 4.56±0.87                          | 15.9/24             | 0.891                       | 0.766             | 9.49±0.50       |
| MS2134.0+0028 R      | 0.85±0.04| 0.10±0.20     |             | 4.40                               |                     |                             |                   | 15.70±0.85      |
| MS2154.5+0107        | 0.75±0.10| 1.06±0.34     |             | 6.10                               |                     |                             |                   | 7.14±0.71       |
| MS2159.5−5713        | −0.32±0.02| 1.97±0.03     | 1.97±0.03   | 2.60                               | 20.5/24             | 0.670                       | 61.30±1.22        |
| MS2254.9−3712        | −0.49±0.01| 1.63±0.01     | 1.62±0.01   | 1.20                               | 39.7/29             | 0.090                       | 112.4±0.80        |
| MS2255.0−3651        | −0.43±0.03| 1.53±0.05     | 1.53±0.05   | 1.20                               | 11.6/23             | 0.976                       | 6.35±0.20         |
| MS2318.2−4220        | −0.46±0.06| 1.91±0.11     |             | 0.80±0.37                          | 9.3/22              | 0.991                       | 0.031             | 15.70±1.53      |
| MS2340.9−1511        | −0.46±0.01| 2.03±0.01     | 2.10±0.02   | 2.20                               | 88.7/27             | 1.5×10$^{-8}$               | *                 | 0.523           |

* Unabsorbed X-ray flux between 0.1-2.4 keV in unit of $10^{-13}$ erg cm$^{-2}$ s$^{-1}$

* This source show a significant deviation from a single power-law plus Galactic absorption (see §5.1). Adequate spectral model and relative X-ray flux are reported in Table 3.
Table 3
Spectral models for the EMSS sources with a significant deviation from a power-law plus Galactic absorption.

### Sources with “soft-excess”

| SOURCE         | Model                    | $\chi^2$/dof | $P(\chi^2 > \chi^2_{FIT})$ | $E_{\text{break}}$ (keV) | $\alpha_{\text{SOFT}}$ | $\alpha_{\text{HARD}}$ | $f^u_x$ |
|----------------|--------------------------|--------------|-----------------------------|--------------------------|-------------------------|------------------------|---------|
| MS0132.5−4151  | Broken power-law         | 10.97/8      | 0.203                       | 0.32±0.10                | 5.00±2.64               | 2.21±0.65              | 350.0±18.23 |
| MS0310.4−5543  | Broken power-law         | 23.13/23     | 0.453                       | 0.25±0.13                | 3.89±1.09               | 1.54±0.13              | 240.6±3.30 |
| MS1747.2+6837  | Broken power-law         | 25.27/26     | 0.504                       | 0.34±0.15                | 2.93±0.50               | 1.55±0.09              | 146.6±1.85 |

| SOURCE         | Model                    | $\chi^2$/dof | $P(\chi^2 > \chi^2_{FIT})$ | $kT$ (keV)   | $\alpha_x$ | $f^u_x$ |
|----------------|--------------------------|--------------|-----------------------------|--------------|------------|---------|
| MS2340.9-1511  | Power-law +              | 28.79/24     | 0.228                       | 0.52±0.11    | 2.06±0.07  | 141.0±1.31 |
|                | Raymond-Smith            |              |                             |              |            |         |

### Sources with “absorption excess”

| SOURCE         | Model                    | $\chi^2$/dof | $P(\chi^2 > \chi^2_{FIT})$ | $N_H$ (×10^{20}cm^{-2}) | $z_{\text{abs}}$ | $\alpha_x$ | $f^u_x$ |
|----------------|--------------------------|--------------|-----------------------------|-------------------------|-----------------|------------|---------|
| MS0104.2+3153  | A : Power-law +           | 11.80/11     | 0.379                       | 47^{+14}_{-30}          | 0.111           | 3.46^{+1.08}_{-1.05} | 5.4±0.30 |
|                | Excess Absorption         |              |                             |                         |                 |            |         |
| MS0104.2+3153  | B : Power-law +           | 12.05/11     | 0.360                       | 394^{+426}_{-258}       | 2.027           | 2.98^{+0.90}_{-0.80} | 5.3±0.30 |
|                | Excess Absorption         |              |                             |                         |                 |            |         |
| MS0144.2−0055  | Power-law +              | 9.86/22      | 0.988                       | 1.5^{+0.8}_{-0.7}      | 0.080           | 1.62^{+0.32}_{-0.30} | 18.7±0.62 |
|                | Excess Absorption         |              |                             |                         |                 |            |         |
| MS0919.9+4543  | Power-law +              | 7.38/18      | 0.987                       | 2.7^{+1.6}_{-1.3}      | 0.293           | 2.70^{+0.40}_{-0.34} | 42.8±1.16 |
|                | Excess Absorption         |              |                             |                         |                 |            |         |

Unabsorbed flux (0.1−2.4 keV) in unit of $10^{-13}$ erg cm$^{-2}$ s$^{-1}$

Unabsorbed (only for Galactic $N_H$) flux (0.1−2.4 keV) in unit of $10^{-13}$ erg cm$^{-2}$ s$^{-1}$
Table 4

Maximum Likelihood analysis and Weighted Mean X-ray spectral index

| Sample            | $< \alpha_p >$ | $\sigma_p$ | $\bar{\alpha}_{WM}$ | Number | Objects |
|-------------------|----------------|-----------|----------------------|--------|---------|
| **Einstein IPC data** |                |           |                      |        |         |
| AGN (RQ + RL)     | 1.02           | 0.28      | 1.05                 | 411    |         |
| AGN RQ            | 1.04           | 0.28      | 1.08                 | 368    |         |
| AGN RL            | 0.81           | 0.11      | 0.78                 | 43     |         |
| **ROSAT PSPC data** |                |           |                      |        |         |
| AGN (RQ + RL)     | 1.42           | 0.44      | 1.58                 | 55     |         |
| AGN RQ            | 1.47           | 0.42      | 1.59                 | 50     |         |
| AGN RL            | 1.17           |           | 1.17                 | 5      |         |
Table 5
Significance of Spearman Rank Correlation Analysis

| Variables Correlated | Rs   | P    | d.o.f |
|----------------------|------|------|-------|
| **AGN Radio Quiet**  |      |      |       |
| $\alpha_x, z$        | 0.281| 0.048| 48    |
| $\alpha_x, L_x$      | 0.324| 0.022| 48    |
| $\alpha_x, L_{2500 \AA}$ | 0.342| 0.015| 48    |
| $\alpha_x, L_{2500 \AA}/L_x$ | −0.213| 0.015| 48    |
| **AGN Radio Loud**   |      |      |       |
| $\alpha_x, z$        | −0.100| 0.870| 3     |
| $\alpha_x, L_x$      | 0.200| 0.750| 3     |
| $\alpha_x, L_{2500 \AA}$ | −0.100| 0.870| 3     |
| $\alpha_x, L_{2500 \AA}/L_x$ | 0.700| 0.190| 3     |
