A deep ROSAT survey – XII. The X-ray spectra of faint ROSAT sources

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ABSTRACT
Optical spectroscopy has enabled us to identify the optical counterparts to over 200 faint X-ray sources to a flux limit of $S(0.5-2\,\text{keV}) = 4 \times 10^{-15}\,\text{erg s}^{-1}\text{cm}^{-2}$ on five deep ROSAT fields. Here we present a spectral analysis of all the X-ray sources to investigate claims that the average source spectra harden at faint X-ray flux. From a hardness ratio analysis we confirm that the average spectra from 0.5 to 2 keV harden from an equivalent photon index of $\Gamma = 2.2$ at $S(0.5-2\,\text{keV}) = 1 \times 10^{-13}\,\text{erg s}^{-1}\text{cm}^{-2}$ to $\Gamma \approx 1.7$ below $1 \times 10^{-14}\,\text{erg s}^{-1}\text{cm}^{-2}$. These spectral changes are due to the emergence of an unidentified source population rather than the class of X-ray QSOs already identified. The 128 QSOs detected so far show no evidence for spectral hardening over this energy range and retain a mean photon index of $\Gamma = 2.2$. Recent work suggests that many of the remaining unidentified sources are X-ray-luminous galaxies. Taking a subset identified as the most likely galaxy candidates we find that these show significantly harder spectra than QSOs. The emission-line galaxies in particular show spectra more consistent with the residual X-ray background, with $\Gamma = 1.51 \pm 0.1$ from 0.1 to 2 keV. Individually the galaxies appear to be a mixture of absorbed and unabsorbed X-ray sources. Combined with recent cross-correlation results and work on the source number count distribution, these results suggest that we may be uncovering the missing hard component of the cosmic X-ray background.

Key words: galaxies: active – quasars: general – diffuse radiation – X-rays: galaxies – X-rays: general.

1 INTRODUCTION
We are conducting a survey to understand the nature of the faint X-ray sources identified on deep (21 – 49 ks) ROSAT PSPC exposures. So far we have identified over 100 QSOs from five ROSAT fields and shown that QSOs make up at least ~ 30 per cent of the X-ray background (XRB) at 1 keV (Shanks et al. 1991). However, studies of the QSO X-ray luminosity function (Boyle et al. 1994) and the number count distribution (Georgantopoulos et al. 1996) suggest that the known QSO population is unlikely to form more than 50 per cent of the total XRB flux. QSOs also show relatively steep X-ray spectra with indices of $\Gamma = 2.2 \pm 0.1$ while the extragalactic XRB from 1 to 10 keV has a flatter power-law index of $\Gamma = 1.4$ (Gendreau et al. 1995). This suggests that we need a new, faint source population with a flatter X-ray spectrum to account for the remainder of the background radiation.

From these deep ROSAT exposures it is also beginning to emerge that many of the remaining X-ray sources are associated with faint galaxies. These appear to be a mixture of absorption and emission-line galaxies with optical spectra and redshifts typical of the galaxy population, but the implied X-ray luminosities are 10 – 100 times higher than those of similar galaxies locally (Roche et al. 1995a; Boyle et al. 1995a; Griffiths et al. 1995; Carballo et al. 1995; McHardy et al. 1995). The nature of the X-ray emission mechanism in these galaxies is still not clear, but recent work at brighter flux limits (Boyle et al. 1995b) suggests that some may be Seyfert 2 or starburst galaxies. The clearest evidence that faint galaxies are significant contributors to the XRB has come

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from the spatial cross-correlation of XRB fluctuations and faint $B < 23$ galaxies (Roche et al. 1995a). This statistical method avoids the source confusion problem that prevents faint galaxies from being associated with X-ray sources. The amplitude of the cross-correlation implies that $B < 23$ galaxies directly contribute some 17 ± 2 per cent of the XRB at 1 keV. Integrating the implied local X-ray volume emissivity to faint magnitudes and high redshifts suggests that the remainder of the soft XRB can be explained by faint galaxies (Roche et al. 1995a; Almaini 1996). Their potential contribution to the hard XRB depends critically on their X-ray spectra.

In this paper we investigate the X-ray spectra of all the sources identified on five deep ROSAT fields. Recent work by Carballo et al. (1995) has suggested that X-ray-luminous galaxies show harder spectra than QSOs. Other deeper surveys (Hasinger et al. 1993; Vikhlinin et al. 1995) have revealed the possibility that the mean spectra of the source population may harden as we go to fainter X-ray fluxes, perhaps indicating that we are beginning to identify the missing faint sources required to explain the remainder of the X-ray background. In this paper we attempt to identify the type of source responsible for this trend. In Section 2 we present our data set and the data reduction techniques and in Section 3 we use model-independent hardness ratios to investigate the X-ray spectra of the QSOs and other source types. In Section 4 we repeat this analysis with full spectral fitting followed by our conclusions and a discussion in Section 5.

2 OBSERVATIONAL DATA

2.1 The sample

Here we use five deep (21–49 ks) pointed observations with the ROSAT PSPC with optical identifications from the X-ray source catalogue of Shanks et al. (in preparation). These are well-studied optical fields selected from the ultraviolet excess (UVX) survey of Boyle, Jones & Shanks (1991). Our analysis is restricted to the central 18-arcmin radius of the ROSAT pointings to maximize the sensitivity of our observations since the point spread function of the PSPC rapidly increases beyond the central 20-arcmin radius. Due to the considerable contamination from both the galactic background and solar scattered X-rays below 0.5 keV (Snowden & Freyberg 1993) we optimize the sensitivity of source detection by concentrating on the 0.5–2.0 keV data.

Full details of the X-ray source detections and optical spectroscopic identifications will be given elsewhere (Shanks et al., in preparation) and so only brief details will be given below. Sources were identified using the standard PSS algorithm within the ASTERIX data processing package, which detects peaks above a certain threshold and matches the expected PSF to the background fluctuations to determine whether the source is real. In this way, 356 X-ray sources were detected above a 4σ significance and 197 sources were detected above 5σ in the 0.5–2.0 keV band over five ROSAT fields. Optical counterparts to these X-ray sources were identified from COSMOS and APM measurements of J- and U-band UK Schmidt plates. Astrometric transforms between ROSAT X-ray and COSMOS/APM co-ordinates were set up using the Durham/AAT UVX QSOs detected by ROSAT on each field. Low-resolution (12 Å) optical spectra were then obtained for the nearest optical counterpart to each X-ray source using the AUTOFIB multi-object system at the Anglo-Australian Telescope. A summary of the optical identifications of the 4σ sources is given in Table 1. Note that this is considerably less complete than the identifications of the smaller list of 5σ sources given in Georgantopoulos et al. (1996) since in this work we are attempting to probe fainter flux limits. Of the 257 sources for which optical identifications were attempted, 128 were identified as QSOs and Seyfert 1 galaxies which directly account for ~30 per cent of the total XRB at 1 keV (Shanks et al. 1991). Less than 10 per cent of the sources were found to be galactic late-type stars. Of the remaining positive identifications, 10 continuum objects and the emission from a galaxy cluster were also detected (Roche et al. 1995b). However, as can be seen from Table 1, a large fraction of the sources remain unidentified or unobserved (both hereafter referred to as the ‘unidentified’ sources). In many cases, observing limitations prevented the object from being observed or the S/N in the optical spectra was too poor to allow a reliable identification. Interestingly, however, ~100 of these unidentified X-ray sources appeared to be associated with faint, ‘normal’ galaxies on photographic plates and for 38 of these sources the optical counterpart was firmly identified as a galaxy by spectroscopy. However, due to the high sky density of galaxies at faint magnitudes (~10000 deg−2 at B < 23, Metcalfe et al. 1991) and the ~25 arcsec FWHM X-ray error circle, many of these will be chance coincidences. A reliable estimate of the contribution of faint galaxies to the XRB can only be determined statistically (see Roche et al. 1995a). For the galaxies at brighter limiting magnitudes the confusion problem becomes less pronounced. We therefore identify a sample of ‘probable’ galaxy candidates with B < 21.5 for which the optical counterpart lies within 20 arcsec of the X-ray source. This optical magnitude represents the limit of reliable galaxy identification on a UK Schmidt plate. Cross-correlating COSMOS and APM galaxy catalogues to the same magnitude limit with the unidentified X-ray sources, we estimate that ~6 of this restricted sample will be spurious identifications. 15 of these galaxies were identified with narrow emission-line features and 8 were identified as absorption-line galaxies. The sample used by Griffiths et al. (1996) is taken from the 5σ subset of these galaxies. Further details of the properties of these sources are given in Table 5 (later) and in Shanks et al. (in preparation).

Table 1. Summary of optical identifications to 4σ X-ray sources from five deep ROSAT fields.

| Source Type | Number |
|-------------|--------|
| QSOs | 128 |
| Seyfert 1 | 27 |
| Continuum | 1 |
| Clusters | (Unidentified) | 96 |
| Probable galaxies | (Unidentified) | 89 |
| Total | 356 |
2.2 Obtaining X-ray spectra

For each source the X-ray counts used to determine fluxes, hardness ratios and spectra were obtained using a circle that encloses 90 per cent of the source photons. The radius of this circle varies with energy and the off-axis angle (Hasinger et al. 1992). Data from periods of high particle background were excluded from the analysis, excluding approximately 10 per cent of the data when the Master Veto Rate was above 170 count s\(^{-1}\) (Plucinsky et al. 1993). Due to the faint nature of many of these sources, considerable care was taken in choosing an area for background subtraction. Possible problems include irregularities in the galactic background or contamination from solar scattered X-rays. However, after the subtraction of sources the residual background levels were found to remain constant over the 18-arcmin central region and no significant gradient was apparent on any field. Circular areas of 4- to 6-arcmin radius were then chosen from source-free regions to perform the background subtraction, correcting for the vignetting between source and background boxes.

3 HARDNESS RATIOS

3.1 QSOs and unidentified sources

Since the majority of our sources have fewer than 100 total counts in the ROSAT band, detailed spectral fitting is not possible. We therefore derive model-independent hardness ratios to compare the spectral properties of these sources. By forming a 'soft' energy band (S) from the 0.5 - 1 keV flux and a 'hard' band (H) from the 1 - 2 keV flux we define the hardness ratio as

\[
HR = \frac{H - S}{H + S}
\]  

As explained above, our sample was initially selected by excluding the data below 0.5 keV to allow a higher efficiency in source detection. We therefore ignore the very soft flux in the first instance and define our hardness ratios from 0.5 to 2 keV in order to characterize the source population fairly without a preferential selection of hard sources.

To test for possible systematic biases that might arise due to the combined energy and radial dependence of the PSF, the entire sample was split into sources lying within a 10-arcmin radius from the centre of the PSPC and those lying beyond. No trend in hardness ratios with off-axis angle was apparent at any flux, as verified by a Kolmogorov–Smirnov test on the data. Another potential problem in analysing mean hardness ratios would be an artificial skewness in the distribution at faint X-ray flux. If the instrument is more sensitive in either the H or S band, individual hardness ratios may be skewed towards +1 or -1 as the flux tends to zero and becomes dominated by noise. To overcome this, we will plot hardness ratios of the stacked spectra in each flux bin. However, the similarity of these distributions to those obtained with mean hardness ratios suggests that this problem does not significantly affect our data.

Removing the known galactic stars, BL Lac candidates and the cluster emission\(\dagger\), we plot the stacked hardness ratios for the other 313 X-ray sources in Fig. 1, binned as a function of flux. These results show a hardening of the mean source spectra with decreasing flux, as previously suggested by Hasinger et al. (1993) and Vikhlinin et al. (1995).

Since AGN are the main contributors to the total source flux at brighter limits (e.g. Shanks et al. 1991), there have been suggestions that an evolution in AGN X-ray spectra may be responsible for the trend in hardness ratios. A hardening of QSO spectra towards higher redshift has been postulated, due to either a change in the actual intrinsic spectrum (Morisawa et al. 1990) or the effect of intervening absorption from damped Ly\(\alpha\) systems (Vikhlinin et al. 1995). In Fig. 2(a) we plot the individual hardness ratios, separating QSOs from the other, mostly unidentified sources. The dominant feature on this diagram is the large spread in hardness ratios towards fainter fluxes due to counting statistics. We therefore bin these hardness ratios according to flux, and Fig. 2(b) displays the hardness ratios for the stacked spectra in four flux bins.

Several features are immediately apparent from these distributions. They show that the unidentified sources have harder X-ray spectra than QSOs, regardless of source intensity. A Kolmogorov–Smirnov test yields a > 99.9 per cent probability that the two distributions shown in Fig. 2(a) do not arise from the same parent population. This is consistent with the errors on the stacked spectra shown in Fig. 2(b). Secondly, the QSOs show no evidence for spectral hardening with decreasing flux, indicating that the change in mean source spectra is due to the emergence of another population from within the unidentified sources with a harder spectrum than QSOs. Given the incomplete spectroscopic identification in our survey, the unidentified population almost certainly contains some contribution from steep-spectrum QSOs. The mean spectrum of the remaining population may therefore be even harder than indicated in Fig. 2. It is also worth noting that the total spectrum of the unidentified sources hardens below \(1 \times 10^{-14}\) erg s\(^{-1}\)cm\(^{-2}\). This may in part be due to a decreasing fractional contaminati-

\(\dagger\) Note that replacing these sources has a negligible effect on any of the results presented here.

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tion by unidentified QSOs, but it is interesting to note that this behaviour is predicted by models which explain the residual XRB using a population of sources with curved X-ray spectra (Boyle 1996). The increased contribution from high-redshift objects would produce a steep log N–log S relationship for the unidentified population and harden the mean spectra at faint fluxes.

In Figs 3(a) and 3(b) we also plot QSO hardness ratios as function of redshift. This also illustrates the lack of spectral evolution in our QSO sample from 0.5 to 2 keV, suggesting that broad-line AGN are unlikely to account for the missing hard component of the cosmic XRB. Interestingly, however, in the softer band below 0.5 keV (where the cosmic X-ray background is dominated by galactic emission) there does appear to be evidence for a change in QSO spectra with redshift. In this band it is now widely accepted (see Mushotzky, Done & Pounds 1993) that the spectra of QSOs have a significant contribution from a soft excess component, generally believed to be thermal emission from an accretion disc. Using the same sample of QSOs in an independent analysis, Stewart et al. (1994) find evidence for a hardening in the spectra of QSOs with redshift in this softer band which has been attributed to changes in the thermal blackbody component. This evolution is due in part to a redshifting of the soft excess component out of the ROSAT passband for higher redshift QSOs, but there also appears to be evidence for a change in the temperature and normalization of this component. However, we are concerned here with the extragalactic X-ray background above 0.5 keV and in this band there is no evidence for any QSO spectral evolution.

Figure 2. (a) Individual 0.5–2 keV hardness ratios as a function of flux for QSOs (unfilled circles) and unidentified X-ray sources and galaxies (filled triangles). For clarity, the appropriate 1σ errors are displayed for only a representative selection of sources. In (b) we plot hardness ratios for stacked spectra binned according to flux, as in Fig. 1, but separating the QSOs from the unidentified sources and galaxies. Note the change in scale compared with (a).

Figure 3. (a) Hardness ratios as a function of redshift for the 128 QSOs detected on these fields. (b) shows the stacked hardness ratios when binned according to redshift with 1σ errors representing the rms error on the mean. The dashed line shows the mean QSO hardness ratio.
3.2 X-ray-luminous galaxies

In Section 2 we noted that ~100 of the 185 unidentified sources appear to be associated with faint optical galaxies. The cross-correlation results of Roche et al. (1995a) suggest that many of these are likely to be genuine X-ray sources, but due to the high sky density of 'normal' field galaxies at faint magnitudes there will also be a significant number of chance associations. We therefore selected a restricted sample of the most likely galaxy candidates with brighter optical magnitudes ($B < 21.5$) and lying within 20 arcsec of the X-ray source. In total, 23 galaxies meet this criteria from which we expect only ~ 6 to be spurious identifications (see Section 2.1). The hardness ratios for these X-ray sources and the 128 QSOs are displayed in Fig. 4(a), separating the 15 narrow emission-line galaxies from the 8 absorption-line galaxies. Despite the limited sample and the large errors on individual faint sources, there is clearly evidence that the emission-line galaxies in particular come from a harder population than the QSOs. While the 8 absorption-line galaxies are evenly distributed about the mean hardness ratio for QSOs, 13 of the 15 emission-line galaxies lie formally above this mean value. In Fig. 4(b) we display the hardness ratios for QSOs and emission-line galaxies binned according to flux. A Kolmogorov–Smirnov test yields a 98.6 per cent probability that the hardness ratios associated with the emission-line galaxies and QSOs do not arise from the same parent population. The cumulative distributions are shown in Fig. 5.

4 SPECTRAL FITTING

4.1 Stacked spectra

In Section 3 we used hardness ratios to analyse the X-ray spectra of individual faint sources. In this section we analyse the X-ray spectra in more detail using the full resolution of the PSPC detector by stacking together the spectra of different source types.

Details of the five ROSAT fields used in this analysis are summarized in Table 2. The column densities of galactic hydrogen are very similar on each field, but a mean value weighted...
by exposure times was used if any stacked spectra were obtained from different fields. For the spectral fitting, the response matrix DRM.06 was used for observations made before 1991 October (QSF1 and QSF3) while the matrix DRM.036 was used for observations made after that date (SGP2, SGP3 and GSGP4). Although problems in the calibration of the PSPC (see Turner 1993) can lead to some uncertainties in the spectral fits, we are primarily concerned with broad differences between the spectra of different sources which should be unaffected by these problems.

Using the XSPEC spectral analysis package, we attempt fitting power-law models (modified only by galactic absorption) to the stacked spectra of QSOs, unidentified X-ray sources and the subset of probable galaxies. We emphasize that no particular physical significance should be attributed to these models and we are merely attempting to parametrize the spectral differences between the source types. For comparison with the hardness ratio analysis in Section 3 we also perform the fits using only the 0.5-2 keV data. The results (see Table 3) confirm that the unidentified sources, on average, have a harder spectrum than QSOs. In agreement with the hardness ratio analysis, the subset of probable X-ray-emitting galaxies (emission-line galaxies in particular) appear to have a significantly harder spectrum than QSOs. The raw channel spectra for the QSOs, unidentified sources and the subset of narrow-line X-ray galaxies are displayed in Fig. 6 with the best-fitting power-law models.

Table 3. Results of power-law fits to the stacked spectra from all fields, separated according to QSOs, unidentified sources and the subset of probable galaxies. Fits are performed with the full 0.1-2.0 keV ROSAT band and the restricted 0.5-2.0 keV for comparison with hardness ratios. Values of photoelectric absorption are fixed at the mean galactic value.

| Energy       | Source Type     | No.  | $\Gamma$ | $\chi^2_{\text{red}}$ |
|--------------|-----------------|------|----------|-----------------------|
| 0.5 - 2.0 keV| QSOs            | 128  | 2.23±0.04| 0.51                  |
|              | Unidentified    | 185  | 1.81±0.06| 0.95                  |
|              | Probable galaxies| 23   | 1.64±0.14| 1.18                  |
|              | (Em. line gal.) | 15   | 1.36±0.18| 1.91                  |
|              | (Abs. line gal.)| 8    | 2.21±0.23| 1.25                  |
| 0.1 - 2.0 keV| QSOs            | 128  | 2.30±0.01| 8.70                  |
|              | Unidentified    | 185  | 1.74±0.03| 3.17                  |
|              | Probable galaxies| 23   | 1.69±0.06| 1.45                  |
|              | (Em. line gal.) | 15   | 1.51±0.09| 1.79                  |
|              | (Abs. line gal.)| 8    | 1.94±0.08| 1.02                  |

Since the 0.5 - 2.0 keV hardness ratios for QSOs remain constant with redshift, this would indicate that we are dealing with a power-law spectrum above 0.5 keV without a significant contribution from a soft excess component.

4.2 Individual galaxy spectra

The stacked spectra for the X-ray-luminous galaxies appear to be significantly flatter than the combined spectra for the QSOs in our survey. While most of the individual sources yield a total of fewer than 40 X-ray photons in the 0.1 - 2.0 keV band, it is important to establish whether the combined spectrum is due to individual spectra that are intrinsically flat (Di Matteo & Fabian 1996) or alternatively a superposition of absorbed X-ray spectra with correspondingly distinct low-energy cutoffs (Comastri et al. 1995; see also Almaini et al. 1995).

In Table 5 we show the results of individual power-law fits (with galactic absorption) to the X-ray spectra of the nine brightest X-ray-emitting galaxies with a 0.5 - 2.0 keV flux $> 1 \times 10^{-14}$ erg s$^{-1}$cm$^{-2}$. Spectral fitting becomes increasingly meaningless for the fainter objects which were therefore stacked before spectral fitting. Alternatively, equivalent photon indices from the hardness ratios in Fig. 4 are given for these fainter galaxies.

A power-law model gives a reasonable fit to seven of the nine brightest galaxies and to the stacked spectra of the fainter galaxies. For two galaxies, however (GSGP4X.091 and GSGP4X.069), simple power-law models do not give an acceptable fit to the data. Both of these are emission-line galaxies and they both show very hard X-ray spectra with $\Gamma < 1$.

GSGP4X.091 For this object, the brightest of the galaxy candidates, a power-law plus galactic absorption model gives a very flat $\Gamma = 0.145$ but is not a good fit to the data ($\chi^2_{\text{red}} = 2.73$). A thermal Raymond–Smith model also gives a very poor fit to the data. The lack of photons at soft energies seems to indicate photoelectric absorption. We therefore try adding an absorbing column at the redshift of the galaxy ($z = 0.416$) and assume an intrinsic power law of $\Gamma = 2.2$ (the mean value for QSOs). This gives a much improved fit with an intrinsic column density of $N_H = 7.5 \pm 1.8 \times 10^{21}$ atom cm$^{-2}$ ($\chi^2_{\text{red}} = 0.97$). The channel spectrum and best-fitting model are
GSGP4X:069 A power law with only galactic absorption gives a very flat $\Gamma = 0.79$, but this is not a good fit to the data ($\chi^2_{\text{red}} = 3.62$). This faint source has only 46 photons from 0.5 to 2.0 keV but nevertheless it also shows evidence for photoelectric absorption at low energies. Repeating the background subtraction with various source-free regions near the source confirms that this is not a systematic effect. Adding an absorbing column at the redshift of the galaxy ($z = 0.213$) and fixing the intrinsic power-law component to $\Gamma = 2.2$ gave a much improved fit to the data ($\chi^2_{\text{red}} = 0.53$) with a rest-frame absorbing column of $N_H = 2.7 \pm 1.9 \times 10^{21} \text{atom cm}^{-2}$. The channel spectrum and best-fitting absorbed model are shown in Fig. 7(b).

While only these two galaxies require additional absorption above the galactic value, many of the remaining galaxies fit power-law X-ray spectra significantly flatter than those of QSOs. It would be interesting to determine if these galaxies are intrinsically flat or whether this is also due to obscuration. Unfortunately there are insufficient photons to provide useful constraints on both the power-law index and the rest-frame absorption. Co-adding the fainter spectra does not resolve this ambiguity. Stacking the 14 faintest galaxies with flux $S_{0.5-2 \text{ keV}} < 1 \times 10^{-14} \text{erg s}^{-1}\text{cm}^{-2}$, we obtain a good fit with an unabsorbed power law of index $\Gamma = 1.68 \pm 0.11$ ($\chi^2_{\text{red}} = 0.83$). An equally good fit is obtained with an intrinsic QSO-like power law ($\Gamma = 2.2$) and a low level of additional photoelectric absorption ($N_H \sim 1 \times 10^{21} \text{atom cm}^{-2}$). We conclude that further data are required to differentiate between these possibilities.

5 SUMMARY AND CONCLUSIONS

Using a sample of over 300 X-ray sources detected on five deep (21--49 ks) ROSAT fields, we investigate the X-ray spectra of the source population. Using a hardness ratio analysis, we confirm recent claims that the average source spectra harden towards fainter fluxes from an equivalent photon index of $\Gamma = 2.2$ at $S_{0.5-2 \text{ keV}} = 1 \times 10^{-13} \text{erg s}^{-1}\text{cm}^{-2}$ to $\Gamma \approx 1.7$ below $1 \times 10^{-14} \text{erg s}^{-1}\text{cm}^{-2}$. We then attempt to show the type of source responsible for this trend. So far 128 QSOs have been identified from this survey and these dominate the source counts at X-ray fluxes above $1 \times 10^{-14} \text{erg s}^{-1}\text{cm}^{-2}$. At fainter fluxes the X-ray population remains largely unidentified. We find that the unidentified sources have harder mean X-ray spectra than QSOs, regardless of source intensity. We also show that the QSOs detected so far show no evidence for spectral hardening with decreasing flux, implying that the change in mean spectra is due to the emergence of another source population. Recent work has suggested that many of these are X-ray-luminous galaxies (Roche et al. 1995a; Boyle et al. 1995a; Carballo et al. 1995; McHardy et al. 1995). Taking a subset of 23
Table 4. Results of power-law fits to the stacked spectra from each field, fixing the photoelectric absorption to the galactic values shown in Table 2. The fits are also performed using only the 0.5 - 2.0 keV data.

| Energy   | Field | QSOs  | Unidentified |
|----------|-------|-------|--------------|
|          |       | $\Gamma$ | $\chi^2_{red}$ | $\Gamma$ | $\chi^2_{red}$ |
| 0.5 - 2.0 keV | GSGP4  | 2.13±0.08 | 1.52 | 1.65±0.11 | 1.08 |
|           | SGP2   | 2.16±0.11 | 1.56 | 1.74±0.15 | 1.01 |
|           | SGP3   | 2.38±0.10 | 1.43 | 2.30±0.13 | 0.89 |
|           | QSF1   | 2.19±0.12 | 1.44 | 1.84±0.19 | 0.25 |
|           | QSF3   | 2.44±0.11 | 1.98 | 1.71±0.17 | 1.69 |
| 0.1 - 2.0 keV | GSGP4  | 2.08±0.03 | 5.63 | 1.36±0.07 | 3.83 |
|           | SGP2   | 2.28±0.03 | 4.65 | 1.63±0.07 | 2.37 |
|           | SGP3   | 2.27±0.03 | 3.84 | 2.23±0.04 | 0.96 |
|           | QSF1   | 2.41±0.03 | 2.11 | 1.85±0.09 | 0.30 |
|           | QSF3   | 2.64±0.03 | 1.98 | 1.95±0.07 | 1.68 |

Table 5. Summary of the 23 probable X-ray-emitting galaxies with 0.1-2.0 keV spectral fits for the nine brightest sources and the stacked spectra of the fainter galaxies. The equivalent photon index from a hardness ratio is also quoted for the faintest galaxies. Optical and X-ray coordinates are given in B1950 format. A power-law fit is performed with the photoelectric absorption fixed at the galactic value. The 0.5 - 2 keV flux is given in erg s$^{-1}$cm$^{-2}$. Column 7 gives the offset between X-ray source and optical galaxy in arcseconds. Column 10 gives the $b_j$ magnitude of the galaxy. Note that ~6 of these galaxies will be chance associations with X-ray sources.

| Source    | RA$_x$ | Dec$_x$ | Flux       | $\Gamma$ | $\chi^2_{red}$ | d$_{ox}$ | RA$_o$ | Dec$_o$ | $b_j$ | Em/Abs |
|-----------|--------|---------|------------|-----------|----------------|---------|--------|---------|-------|--------|
| GSGP4X:091| 00 55 36.8 | -28 09 15 | 4.0 x 10$^{-14}$ | 0.14±0.20 | 2.77 | 10.4 | 00 55 36.3 | -28 09 23 | 21.33 | Em    |
| GSGP4X:017| 00 54 08.7 | -27 46 23 | 3.7 x 10$^{-14}$ | 2.25±0.09 | 1.24 | 17.2 | 00 54 08.5 | -27 46 06 | 18.27 | Abs   |
| QSF1X:020 | 03 39 41.5 | -45 21 58 | 1.5 x 10$^{-14}$ | 1.95±0.21 | 0.33 | 14.5 | 03 39 42.5 | -45 21 38 | 20.37 | Em    |
| GSGP4X:048 | 00 51 38.6 | -28 40 46 | 2.5 x 10$^{-14}$ | 1.62±0.18 | 0.64 | 15.0 | 00 51 38.2 | -28 40 32 | 18.78 | Abs   |
| QSF1X:036 | 04 40 08.3 | -44 48 14 | 2.0 x 10$^{-14}$ | 2.90±0.18 | 0.67 | 10.9 | 04 40 07.9 | -44 48 24 | 21.07 | Em    |
| GSGP4X:069 | 00 55 12.2 | -27 49 19 | 1.3 x 10$^{-14}$ | 0.79±0.51 | 3.67 | 9.4  | 00 55 11.5 | -27 49 17 | 20.25 | Em    |
| GSGP4X:064 | 00 55 07.1 | -27 39 30 | 1.2 x 10$^{-14}$ | 1.73±0.35 | 0.65 | 9.5  | 00 55 06.4 | -27 39 32 | 17.84 | Abs   |
| GSGP4X:033 | 00 52 36.3 | -28 54 37 | 1.0 x 10$^{-14}$ | 1.94±0.24 | 0.63 | 17.0 | 00 52 35.2 | -28 54 46 | 18.86 | Em    |

X-ray sources identified as the most likely galaxy candidates, we find that these show a mean spectral index of $\Gamma = 1.69$ from 0.1 to 2 keV, confirming the findings of Carballo et al. (1995). These galaxies consist of 8 absorption-line galaxies and 15 with emission-line features. Hardness ratios suggest that the emission-line galaxies have significantly harder X-ray spectra than QSOs. Stacking the spectra of these faint sources, the absorption-line galaxies yield a spectral index of $\Gamma = 1.51\pm0.09$ while the emission-line galaxies give $\Gamma = 1.69\pm0.08$ further evidence that they may be the missing component of the cosmic XRB.
Figure 7. 0.1–2.4 keV X-ray spectra for the absorbed narrow emission-line galaxies GSGP4X:091 (a) and GSGP4X:069 (b). The models shown are obtained by fixing the intrinsic power law at ζ = 2.2 and allowing the rest-frame absorption to vary.

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