A survey of hard spectrum ROSAT sources – II. Optical identification of hard sources

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ABSTRACT
We have surveyed 188 ROSAT Position Sensitive Proportional Counter (PSPC) fields for X-ray sources with hard spectra (α < 0.5); such sources must be major contributors to the X-ray background at faint fluxes. In this paper we present optical identifications for 62 of these sources: 28 active galactic nuclei (AGN) which show broad lines in their optical spectra (BLAGN), 13 narrow emission line galaxies (NELGs), five galaxies with no visible emission lines, eight clusters and eight Galactic stars.

The BLAGN, NELGs and galaxies have similar distributions of X-ray flux and spectra. Their ROSAT spectra are consistent with their being AGN obscured by columns of 20.5 < log(N_H/cm^2) < 23. The hard spectrum BLAGN have a distribution of X-ray to optical ratios which is similar to that found for AGN from soft X-ray surveys. However, a relatively large proportion (15 per cent) of the BLAGN, NELGs and galaxies are radio loud. This could be because the radio jets in these objects produce intrinsically hard X-ray emission, or if their hardness is caused by absorption, it could be because radio-loud objects are more X-ray luminous than radio-quiet objects. The eight hard sources identified as clusters of galaxies are the brightest, and softest group of sources and hence clusters are unlikely to be an important component of the hard, faint population.

We propose that BLAGN are likely to constitute a significant fraction of the faint, hard, 0.5–2 keV population and could be important to reproducing the shape of the X-ray background, because they are the most numerous type of object in our sample (comprising almost half the identified sources), and because all our high redshift (z > 1) identified hard sources have broad lines.

Key words: surveys – galaxies: active – X-rays: galaxies – X-rays: galaxies: clusters.

1 INTRODUCTION
The origin of most of the X-ray emission in the Universe is still unknown because the sources that produce most of the >2 keV X-ray background (XRB) are still to be resolved. ROSAT surveys have succeeded in resolving ~80 per cent of the 1–2 keV XRB into individual sources (Hasinger et al. 1998), and optical identification and X-ray spectroscopy has been possible for brighter sources which produce ~40 per cent of the 1–2 keV background. The majority of these sources are broad line active galactic nuclei (hereafter BLAGN), and narrow emission line galaxies (hereafter NELGs, McHardy et al. 1998). Schmidt et al. (1998) argued that the NELGs are also AGN, but with low luminosity or obscured broad line regions. On an average, faint NELGs have harder X-ray spectra (f_\nu \propto \nu^{-\alpha}) with \alpha \sim 0.5, Almaini et al. 1996, Romero Colmenero et al. 1996) than the broad line AGN which have mean \alpha \sim 1 (Ciliegi et al. 1997, Mittaz et al. 1999).

Despite the success of ROSAT surveys, the XRB cannot be synthesized by extrapolating the observed source populations to faint fluxes, because the resultant spectrum would be softer than that of the background; this discrepancy is present for all energy bands between 0.5 and 40 keV. This means that at faint fluxes there must be a population of sources with spectra that are harder than that of the background. According to leading models, these hard sources (e.g. Fabian 1999; Gilli, Risaliti & Salvati 1999) are obscured AGN. However, the physical nature and observational appearance of the XRB producing population is not yet known, and is the subject of some debate. For example, Gilli et al. (1999) examined a model intended to reproduce the XRB, by extrapolating the X-ray emission of the present epoch AGN to high redshift, using the observed soft X-ray luminosity function. In contrast, the model of Fabian (1999) has a large fraction of the
XRB due to a population of high redshift, heavily obscured, growing AGN, which are different to anything observed in the local Universe.

In Page, Mittaz & Carrera (2000, hereafter Paper I), we presented a catalogue of 147 serendipitous ROSAT sources which have spectra harder than that of the XRB. These sources have a steep $N(S)$ relation down to the sensitivity limit of our survey ($\sim 10^{-14}$ erg cm$^{-2}$ s$^{-1}$), and are therefore likely to be the bright tail of the population of hard sources that dominate the source counts at faint fluxes. As such, they could offer us a preview of the faint, hard and dominant X-ray source population. We have therefore undertaken a programme of optical and infrared observations of our ROSAT hard source sample to find out what these sources are. In this paper we present the hard source identifications obtained from our optical (spectroscopic) campaign together with those found in existing catalogues. Section 2 gives details of our method and observations, the results of which are given in Section 3. These results are discussed in the context of the absorbed AGN and the XRB in Section 4. Finally, we present our conclusions in Section 5.

Throughout this paper we define the power law spectral index $\alpha$ such that $f_{\nu} \propto \nu^{-\alpha}$.

2 OPTICAL IDENTIFICATION

2.1 Strategy

To produce a systematic and efficient optical identification programme, we divided the hard X-ray sources into two groups depending on the ease of optical identification. Sources which had one or two plausible candidates present in the Cambridge Automated Plate Measuring (APM) Machine data and/or the Digital Sky Survey (DSS) were considered suitable for optical spectroscopy, and make up the ‘spectroscopic sample’, while sources with either no or more than two plausible candidates, were considered unsuitable for spectroscopy and became the ‘imaging sample’. There are 103 sources in the spectroscopic sample and 44 sources in the imaging sample. This paper will deal only with identified sources from the spectroscopic sample (except for two sources, RX J005812.20–274217.8 and RX J101112.05+554451.3, which are fainter than our spectroscopic sample limit but have catalogue identifications). The properties of sources in the imaging sample, and their relationship with the spectroscopic sample sources, will be discussed briefly in Section 3.2 and in more detail in Carrera et al. (in preparation) where we will present the results of our optical and infrared imaging. The three data sources for the identification process were spectra taken on the William Herschel Telescope (WHT) and the European Southern Observatory 3.6-m Telescope (ESO 3.6), and data bases of existing catalogues. The optical spectra will be presented in Mittaz et al. (in preparation) along with a full description of the observations and data reduction.

Catalogue identifications were obtained by searching the NASA Extragalactic Database (NED) and SIMBAD around all the ROSAT hard source positions (not just the spectroscopic sample). One further source (RX J043420.48–082136.7) was identified from a WHT spectrum taken during the RIXOS programme, but was not part of the full RIXOS sample presented in Mason et al. (2000).

3 RESULTS

Table 1 contains the list of optical identifications. We have categorized our sources as follows. X-ray sources with an optical counterpart which is a Galactic star, of any type, have been classified as stars, and X-ray sources which are clusters of galaxies have been classified as clusters. X-ray sources with an extragalactic optical counterpart which has one or more broad emission lines, or a broad component ($>2000$ km s$^{-1}$) to an emission line, is classified as a BL AGN. X-ray sources with galaxy optical counterparts showing narrow emission lines ($<2000$ km s$^{-1}$) but no broad emission lines are classified as NELGs. Note that none of the narrow line objects in this survey would be classified as narrow line Seyfert 1s (e.g. by the criteria given in Goodrich 1989). Galaxies with no discernable emission lines were classified as galaxies. The numbers of objects in each category, and their mean properties are given in Table 2. The sample is dominated by extragalactic sources, and of these over half are BL AGN.

The distributions of offsets between the X-ray positions and the optical counterparts for the different classes of hard sources are shown in Fig. 1. The mean offsets for each source type are given in Table 2, and are 6–7 arcsec for all source types except for the Galactic stars, which have a mean offset of 12 arcsec and a flat distribution of offsets (Fig. 1). This suggests that the ‘star’ identifications are less secure than the others.

We have systematically checked the redshifts of the extragalactic hard sources for similarity to the redshifts of the targets of the Position Sensitive Proportional Counter (PSPC) observations in which they were detected. Only two sources, RX J111926.34+210646.1 and RX J120403.79+280711.2, both clusters of galaxies, have redshifts similar to the observational targets.

3.1 X-ray slopes and fluxes

The fitted X-ray spectral slopes and fluxes for the different types of sources are shown in Fig. 2, and their mean slopes and fluxes are given in Table 2. A noticeable feature of Fig. 2 is that the clusters of galaxies are concentrated towards the top right-hand (soft spectrum, high flux) corner compared to the other sources. This trend is confirmed by a two-dimensional Kolmogorov Smirnov (2DKS) test (Fasano & Franceschini 1987): the cluster distribution of $(\alpha, S)$ is different from that of any (or all) of the other source types with confidence $>99$ per cent. Because they are not particularly hard, and because they are predominantly bright and therefore do not have as steep an $N(S)$ relation as the rest of the hard sources, the clusters are unlikely to be important contributors to the faint hard source population.

Note that the very hard mean spectral index of the Galactic stars (see Table 2) is due to the three objects with best-fitting values of $\alpha < -1$, two of which (RX J112056.87+132726.2 with best fit $\alpha = -1.65$ and RX J133146.37+111420.4 with best fit $\alpha = -1.472$) are unlikely to be correct identifications (see Section 3.6). The other three types of sources (BL AGN, NELGs and galaxies) have distributions of $(\alpha, S)$ which are indistinguishable from one another according to the 2DKS test; any (or all) of them could be significant contributors to the faint, hard population.

For comparison Fig. 2 also shows the unidentified sources. Unidentified objects in the spectroscopic sample are found with similar spectral slopes and fluxes when compared to the identified sources (except the clusters which are softer and brighter). The sources in the imaging sample are more concentrated towards faint fluxes and comprise of most of the faintest ($S \sim 10^{-14}$ erg cm$^{-2}$ s$^{-1}$) hard sources.
### Table 1. Hard source optical counterparts.

| Source             | Optical position RA | Dec.     | Origin       | Type  | $z$ | Cat name | Notes                           |
|--------------------|---------------------|----------|--------------|-------|-----|----------|---------------------------------|
| RX J010044.43-362638.0 | 00 11 44.54 | -36 26 39.0 | ESO 3.6 | BLAGN | 0.900 |                      |                                 |
| RX J004651.98-204329.0 | 00 46 51.83 | -20 43 28.6 | cat        | BLAGN | 0.380 | [HB89] 0044-209 |                                 |
| RX J005734.78-272827.4 | 00 57 34.94 | -27 28 28.0 | ESO 3.6 | BLAGN | 2.185 |                      |                                 |
| RX J005736.81-273055.9 | 00 57 36.75 | -27 30 04.6 | cat        | NELG  | 0.213 | GSPG 4X:069 |                                 |
| RX J005746.75-273000.8 | 00 57 46.83 | -27 30 00.9 | cat        | galaxy | 0.019 | ESO 411-034 |                                |
| RX J005801.64-275038.6 | 00 58 01.32 | -27 53 10.2 | ESO 3.6 | NELG  | 0.416 | GSPG 4X:091 |                                |
| RX J142712.47-182258.3 | 14 27 12.94 | -18 22 58.3 | cat        | ESO 3.6 | 0.336 |                      |                                 |
| RX J14159.22-543037.0 | 14 15 49.91 | -54 30 39.6 | cat        | ESO 3.6 | 0.168 |                      |                                 |
| RX J163308.57 | 16 33 08.57 |                      |                      |        |     |                      |                                 |
| RX J163054.25 | 16 30 54.25 |                      |                      |        |     |                      |                                 |
| RX J133146.37 | 13 31 46.37 |                      |                      |        |     |                      |                                 |
| RX J124913.86 | 12 49 13.86 |                      |                      |        |     |                      |                                 |
| RX J114621.27 | 11 46 21.27 |                      |                      |        |     |                      |                                 |
| RX J110008.53 | 11 00 08.53 |                      |                      |        |     |                      |                                 |
| RX J101120.05 | 10 11 20.05 |                      |                      |        |     |                      |                                 |
| RX J005756.99 | 00 57 56.99 |                      |                      |        |     |                      |                                 |
| RX J052839.93 | 05 28 39.93 |                      |                      |        |     |                      |                                 |
| RX J085340.52 | 08 53 40.52 |                      |                      |        |     |                      |                                 |
| RX J090518.27 | 09 05 18.27 |                      |                      |        |     |                      |                                 |
| RX J034119.02 | 03 41 19.02 |                      |                      |        |     |                      |                                 |
| RX J034520.48 | 03 45 20.48 |                      |                      |        |     |                      |                                 |
| RX J035559.27 | 03 55 59.27 |                      |                      |        |     |                      |                                 |
| RX J052839.93 | 05 28 39.93 |                      |                      |        |     |                      |                                 |
| RX J091908.27 | 09 19 08.27 |                      |                      |        |     |                      |                                 |
| RX J094414.51 | 09 44 14.51 |                      |                      |        |     |                      |                                 |
| RX J095340.67 | 09 53 40.67 |                      |                      |        |     |                      |                                 |
| RX J110008.53 | 11 00 08.53 |                      |                      |        |     |                      |                                 |
| RX J110123.17 | 11 01 23.17 |                      |                      |        |     |                      |                                 |
| RX J101147.48 | 10 11 47.48 |                      |                      |        |     |                      |                                 |
| RX J110008.53 | 11 00 08.53 |                      |                      |        |     |                      |                                 |
| RX J104648.27 | 10 46 48.27 |                      |                      |        |     |                      |                                 |
| RX J104723.37 | 10 47 23.37 |                      |                      |        |     |                      |                                 |
| RX J110742.05 | 11 07 42.05 |                      |                      |        |     |                      |                                 |
| RX J111750.51 | 11 17 50.51 |                      |                      |        |     |                      |                                 |
| RX J111926.34 | 11 19 26.34 |                      |                      |        |     |                      |                                 |
| RX J111942.16 | 11 19 42.16 |                      |                      |        |     |                      |                                 |
| RX J112056.87 | 11 20 56.87 |                      |                      |        |     |                      |                                 |
| RX J124913.86 | 12 49 13.86 |                      |                      |        |     |                      |                                 |
| RX J131635.62 | 13 16 35.62 |                      |                      |        |     |                      |                                 |
| RX J133146.37 | 13 31 46.37 |                      |                      |        |     |                      |                                 |
| RX J133147.00 | 13 31 47.00 |                      |                      |        |     |                      |                                 |
| RX J135152.51 | 13 51 52.51 |                      |                      |        |     |                      |                                 |
| RX J135505.69 | 13 55 05.69 |                      |                      |        |     |                      |                                 |
| RX J140134.94 | 14 01 34.94 |                      |                      |        |     |                      |                                 |
| RX J140416.61 | 14 04 16.61 |                      |                      |        |     |                      |                                 |
| RX J142754.71 | 14 27 54.71 |                      |                      |        |     |                      |                                 |
| RX J163054.25 | 16 30 54.25 |                      |                      |        |     |                      |                                 |
| RX J160308.57 | 16 03 08.57 |                      |                      |        |     |                      |                                 |
| RX J170123.32 | 17 01 23.32 |                      |                      |        |     |                      |                                 |
| RX J204640.48 | 20 46 40.48 |                      |                      |        |     |                      |                                 |
| RX J204716.74 | 20 47 16.74 |                      |                      |        |     |                      |                                 |
| RX J213807.61 | 21 38 07.61 |                      |                      |        |     |                      |                                 |
| RX J223619.89 | 22 36 19.89 |                      |                      |        |     |                      |                                 |
| RX J235113.89 | 23 51 13.89 |                      |                      |        |     |                      |                                 |

#### 2.3 The unidentified sources

We now briefly consider the question: how fair a subsample, of the whole ROSAT hard source sample, are the identified sources? Starting with the spectroscopic sample, candidates were chosen for identification on our WHT and European Southern Observatory (ESO) 3.6-m observing runs without any regard to their optical magnitudes and morphologies, (except to exclude sources with an existing catalogue identification) and are hence an unbiased subsample of the spectroscopic sample. The catalogue identifications,
although including a few optically bright galaxies, are mostly from the previous flux limited X-ray surveys. They therefore tend to have higher X-ray fluxes than the spectroscopic sample as a whole, but are otherwise a fair subsample. This means that except for a bias towards higher X-ray fluxes, the identified sources are a fair subsample of the spectroscopic sample.

The spectroscopic sample is a significant fraction of the whole ROSAT hard source sample (103 of 147 sources), but it cannot be considered a fair subsample because it excludes the optically faint sources which form the imaging sample. Without spectroscopically identifying the imaging sample (which is currently impractical) it is not possible to determine whether the imaging sample is actually made up of the same mix of sources as the spectroscopic sample or not. However we can examine whether it is possible, by assuming that similar types of sources will have similar X-ray to optical flux ratios. Fig. 3 shows the X-ray flux against the APM red (E or R) magnitude for the identified sources with the available APM data. BLAGN, NELGs and galaxies are found with similar ranges of X-ray to optical ratios. The optical counterparts to the imaging sample sources are presumed to be fainter than the plate limit, which we take to be 20.5 and 21.0 for sources with the APM data available for E and R plates, respectively. The imaging sample sources are plotted in Fig. 3 with these lower limits except for the two sources RX J031956.76–663938.5 and RX J101031.05+503458.6, which are in the imaging sample because there are too many potential counterparts for practical spectroscopic follow up. The dashed line corresponds to an X-ray to optical ratio which is similar to that of RX J111750.51+075712.8, which has the highest X-ray to optical ratio of the identified spectroscopic sample sources excluding the clusters. Only six of the imaging sample sources lie above the dashed line, and therefore definitely have X-ray to optical flux ratios different to those of the identified sources. Therefore the limits on the X-ray to optical ratios are consistent with the identified sources being the same type of objects as those that constitute almost the whole ROSAT hard source sample.

### 3.3 Redshifts and luminosities

Fig. 4 shows the redshifts and 0.5–2 keV luminosities for the extragalactic hard sources. Luminosities were calculated from the fitted fluxes, K corrected using the best fit spectral slopes, and assuming $H_0 = 50\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$, $q_0 = 0$. The majority of the BLAGN have higher luminosities and redshifts than the NELGs and galaxies; all the high redshift ($z > 1$) sources are BLAGN. This may imply that either the hard spectrum narrow line sources do not exist at high luminosity/redshift or our spectroscopic sample is not deep enough (in X-ray or optical flux) to find them.

![Figure 1. Histogram of offsets, in bins of 2 arcseconds, between the X-ray positions and optical counterparts for the different classes of identified sources.](https://academic.oup.com/mnras/article-abstract/325/2/575/1158357/3.4-X-ray-optical-radio-flux-ratios)

#### 3.4 X-ray–optical–radio flux ratios

It is common to parametrize the X-ray to optical and optical to radio flux ratios of AGN as $\alpha_{\text{OX}}$ and $\alpha_{\text{OR}}$, where $\alpha_{\text{OX}}$ is the slope of the power law which (in the rest frame of the object) would connect the flux density ($F_\nu$) at 2500 Å with the X-ray flux density at 2 keV, and $\alpha_{\text{OR}}$ is the slope of the power law which would connect the flux density at 2500 Å with the flux density at 5 GHz.

For all sources we have estimated the rest frame 2500 Å flux density using the B photometry (taken from Carrera et al. in preparation) and assuming a power law optical – UV spectrum with slope $\alpha = 0.5$, and using the B magnitude to flux conversion given by Wilkes et al. (1994). The B magnitudes have been corrected for Galactic reddening using the expression for $E(B-V)$ in Bohlin, Savage & Drake (1978) and assuming $A_B = 4E(B-V)$.

To estimate the rest frame 5 GHz fluxes we have searched for potential radio counterparts to our X-ray sources in the catalogues of radio sources in the Very Large Array (VLA) 1.4 GHz FIRST (White et al. 1997) and NRAO VLA Sky Survey (NVSS) (Condon et al. 1998) surveys and the 5 GHz Parkes-MIT-NRAO (PMN, Griffith & Wright 1993) survey. Additionally,
radio images from these surveys were searched by eye to ensure that any of the extended radio sources associated with our X-ray sources were not missed, and to ensure that there were no spurious radio counterparts associated with other extended radio sources. The uncertainty in the radio source position from these three surveys ranges from better than 1 arcsecond (FIRST) to around 10 arcseconds (PMN). The sky density of radio sources is sufficiently low (reaching around 100 deg$^{-2}$ at the 1 mJy completeness limit of FIRST) for it to be unlikely that there are any chance coincidences. Where no suitable radio source appears in a survey catalogue, we have taken the catalogue completeness limit as the upper limit to the radio flux of the X-ray source. We took the best measurement (or upper limit) available from the three surveys and assume a radio spectral slope of $\alpha = 0.7$.

The 2 keV flux density has been estimated from the fitted 0.5–2 keV fluxes assuming an X-ray spectral slope of $\alpha = 0$. We then computed

\[ \alpha_{\text{OX}} = 0.384 \log\left(\frac{f_{\text{OX}}(2500\text{Å})}{f_{\text{OX}}(2\text{keV})}\right) \]

and

\[ \alpha_{\text{OR}} = -0.186 \log\left(\frac{f_{\text{OR}}(2500\text{Å})}{f_{\text{OR}}(5\text{GHz})}\right) \]

$\alpha_{\text{OX}}$ and $\alpha_{\text{OR}}$ are shown in Fig. 5 for all hard sources identified as BLAGN, NELGs and galaxies. The horizontal dashed line marks $\alpha_{\text{OR}} = 0.35$ which is commonly used to differentiate radio loud and radio quiet objects (Zamorani et al. 1981). Seven hard sources (four BLAGN, two galaxies and one NELG) lie above this line, and are therefore radio loud. This is a large radio loud fraction (15±5 per cent where errors are the Poisson 68 per cent confidence interval, Gehrels 1986) of the BLAGN, NELGs and galaxies compared to the fraction found in normal ROSAT surveys without spectral selection, e.g. Ciliegi et al. (1995) found that only two of

**Figure 2.** X-ray spectral slopes and fluxes for the different types of hard sources. For comparison the unidentified sources are shown in the last panel: the spectroscopic sample as filled dots and the imaging sample as crosses (see Section 2 for definitions of the two samples).

**Figure 3.** Optical magnitudes against the X-ray fluxes for the identified sources in the spectroscopic sample (symbols) and the sources in the imaging sample (lower limits). The gradient of the dashed line corresponds to the a constant ratio of the X-ray to optical flux.
the eighty Cambridge–Cambridge ROSAT Serendipity Survey (CRSS) AGN and NELGs (2.5 ± 1.6 per cent) are radio loud. On the other hand, the distribution of $\alpha_{OX}$ of the hard sources is similar to that found in other AGN surveys (e.g. Wilkes et al. 1994; Ciliegi et al. 1995), with the majority of sources having $1 < \alpha_{OX} < 1.8$.

### 3.5 X-ray absorption

The leading hypothesis used to explain the majority of faint hard sources which contribute substantially to the XRB is that they are intrinsically absorbed AGN (e.g. Setti & Woltjer 1989; Fabian & Iwasawa 1999). This is also a likely hypothesis for our hard sources, because the optical spectra and colours of a significant fraction of our BLAGN and NELGs suggest absorption (Carrera, Mittaz & Page 2001; Mittaz et al. 2001). Assuming that our BLAGN, NELGs and galaxies have hard spectra because of absorption, we have estimated their column densities from their three colour ROSAT PSPC spectra. We assume that before absorption they have power law X-ray spectra with energy index $\alpha = 1$ (typical for X-ray selected AGN, e.g. Maccacaro et al. 1988; Mittaz et al. 1999) and we fit their intrinsic cold gas column. The fitting procedure was identical to that described in Paper I, except that the free parameters in the fit are intrinsic column and power law normalization rather than power law slope and normalization. The results of these fits are given in Table 3.

The fitted absorbing columns and luminosities (before absorption) of the BLAGN, NELGs and galaxies are 44.4, 43.2 and 42.2, respectively. We note that the trend in Fig. 6 for the most absorbed sources to have the highest luminosity is probably a selection effect, due to the shifting of the rest frame emitted passband to higher energy with increasing redshift. This means that sources detectable in the PSPC and satisfying our spectral selection criterion (see Paper I) will have larger columns at a higher redshift (and hence at higher luminosity).

### 3.6 Notes on individual sources

**RX J004651.98–204329.0.** The hard ROSAT spectrum of this active galaxy was the subject of Elvis et al. (1997) who proposed that absorption in material associated with NGC247 may be responsible for the spectral hardening.

**RX J005801.64–275308.6.** A second, slightly fainter NELG at J2000 position RA 00 h 58 m 1.69 s Dec. 27 ° 53′ 16″ 0 has the same redshift ($z = 0.086$) as, and is within 10 arcsec of, the NELG identified as the X-ray source.

**RX J013707.63–183846.4.** The star has an unremarkable G-type spectrum, and the X-ray source is coincident with a bright radio source (MRC 0134–188). Hence the star is unlikely to be the correct optical counterpart. The real optical counterpart is too faint to be seen on the Palomar Observatory Sky Survey (POSS).

**RX J031456.58–552006.8.** This radio galaxy has an extended double lobe structure; see Gruppioni, Mignoli & Zamorani (1999).

**RX J033402.54–390048.7.** This source is a wide-angle tail radio source in the galaxy cluster Abell 3135. A V, $<16$ magnitude Galactic star is also close to the X-ray source position but is unlikely to be related.
| Source Name | Right Ascension | Declination | X-ray Flux | B Band | A0 | Log Lx | X-ray Column Fit norm |
|-------------|-----------------|-------------|------------|--------|----|--------|----------------------|
| RX J001443.16-362830.0 | 4.19 | 38.34 | 0.12 | 0.08 | <3.50 | 20.38 ± 0.12 | <0.33 |
| RX J000551.78-272602.4 | 4.05 | 37.93 | 0.10 | 0.06 | <3.50 | 20.42 ± 0.10 | <0.33 |
| RX J004857.91-264308.7 | 3.97 | 37.61 | 0.11 | 0.07 | <3.50 | 20.17 ± 0.11 | <0.33 |
| RX J005355.76-270000.0 | 3.87 | 37.66 | 0.09 | 0.06 | <3.50 | 20.02 ± 0.09 | <0.33 |
| RX J005602.02-294134.7 | 3.91 | 37.61 | 0.12 | 0.08 | <3.50 | 20.26 ± 0.12 | <0.33 |
| RX J005620.16-293750.0 | 3.87 | 37.66 | 0.11 | 0.07 | <3.50 | 20.02 ± 0.11 | <0.33 |
| RX J005901.64-275300.0 | 5.09 | 39.00 | 0.13 | 0.09 | <3.50 | 21.03 ± 0.13 | <0.33 |
| RX J005950.65-270000.0 | 3.91 | 37.61 | 0.12 | 0.08 | <3.50 | 20.26 ± 0.12 | <0.33 |
| RX J013721.47-182558.3 | 3.90 | 37.71 | 0.09 | 0.06 | <3.50 | 20.02 ± 0.09 | <0.33 |
| RX J014332.22-240332.4 | 4.05 | 37.93 | 0.10 | 0.06 | <3.50 | 20.42 ± 0.10 | <0.33 |
| RX J015146.42-203500.0 | 3.92 | 37.65 | 0.10 | 0.07 | <3.50 | 20.17 ± 0.10 | <0.33 |
| RX J015641.22-363202.4 | 4.07 | 37.97 | 0.11 | 0.08 | <3.50 | 20.26 ± 0.11 | <0.33 |
| RX J020142.64-153500.0 | 5.09 | 39.00 | 0.13 | 0.09 | <3.50 | 21.03 ± 0.13 | <0.33 |
| RX J021150.08-235300.0 | 4.70 | 38.42 | 0.11 | 0.07 | <3.50 | 20.70 ± 0.11 | <0.33 |
| RX J021437.64-220832.4 | 4.05 | 37.93 | 0.10 | 0.06 | <3.50 | 20.42 ± 0.10 | <0.33 |
| RX J023127.85-235500.0 | 4.70 | 38.42 | 0.11 | 0.07 | <3.50 | 20.70 ± 0.11 | <0.33 |
| RX J024915.86-171832.4 | 4.05 | 37.93 | 0.10 | 0.06 | <3.50 | 20.42 ± 0.10 | <0.33 |
| RX J025044.40-402632.4 | 4.05 | 37.93 | 0.10 | 0.06 | <3.50 | 20.42 ± 0.10 | <0.33 |

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RX J043420.48–082136.7. The identification spectrum of this object was taken on the WHT as part of RIXOS, but the source was not part of the final RIXOS sample and is not included in the final catalogue (Mason et al. 2000).

RX J085340.52+134924.9. This RIXOS identification is uncertain because there is another optical counterpart closer to the centre of the X-ray error circle that was not observed. Note also that the position of the optical counterpart is incorrect in Mason et al. (2000), which should be the same as that in Table 1, i.e. 08°53′41.01″+13°49′19.7″ (J2000).

RX J095340.67+074426.1. The RIXOS identification and redshift of this source are based on a relatively poor optical spectrum and therefore may be incorrect.

RX J101112.05+554451.3. This source was identified as an obscured radio loud AGN by Barcons et al. (1998). It has strong narrow emission lines but $\text{Mg} \, \text{II} A 2798$ is broad, and hence we have classified it as a BL AGN.

RX J101147.48+505002.2. This X-ray source was identified with a NELG having $z = 0.067$ by Carballo et al. (1995), but we identify the source with a BL AGN having $z = 0.079$, which is brighter and closer to the X-ray source. Notably, the $z = 0.079$ BL AGN showed only narrow lines in the optical spectrum of Carballo et al. (1995); the H$\alpha$ line profile appears to have genuinely changed between 1994 and 1998.

RX J111926.34+210646.1. This galaxy cluster and the target of the PSPC observation (PG 1116+215) in which it was found have very similar redshifts (0.1765 and 0.1768, respectively) and therefore this source is not strictly serendipitous.

RX J120506.87+132726.2. The X-ray source is coincident with the symmetric double radio source 87GB 111822.7+134349, and hence the star is unlikely to be the correct identification for the X-ray source.

RX J120403.79+280711.2. This galaxy cluster and the target of the PSPC observation (PG 1202+281) in which it was found have similar redshifts (0.0167 and 0.1653, respectively) and therefore this source may not be strictly serendipitous.

RX J124913.86–055906.2. This broad absorption line quasi-stellar object (BALQSO) was the only bona fide BALQSO in the sample of Green & Mathur (1996) to be detected as a PSPC source.

RX J133146.37+111420.4. This X-ray source is coincident with the radio source 87GB 132918.1+112918, and hence the star is unlikely to be the correct optical counterpart.

RX J142754.71+330007.0. The RIXOS identification and redshift of this source are based on a relatively poor optical spectrum and therefore may be incorrect.

### 4 DISCUSSION

Excluding the clusters, which are unlikely to be an important part of the faint, hard X-ray source population (see Section 3.1), we have identified three types of extragalactic hard sources: BL AgN, NELGs and galaxies. At first sight, the identification content of the sample appears to be similar to that of other PSPC surveys with similar flux limits but without any spectral selection (e.g. BL AGN being the most numerous source). However, in two respects the identification content of this survey is significantly different.

The first difference is that there is a higher proportion of radio loud objects (15% per cent) in this survey (see Section 3.4). There are two possible reasons why this should be so. One is that the intrinsic X-ray emission of radio loud sources may be harder than that of radio quiet sources (Reeves et al. 1997) because the radio loud sources have an additional, hard spectrum X-ray emission component from the inner parts of radio jets. The other possibility is that our radio loud sources are absorbed, and because they are intrinsically more X-ray luminous than radio quiet sources they are numerous in a relatively bright survey of the hard spectrum sources. This would be analogous to the high proportion of (presumably unabsorbed) radio loud sources present in bright soft X-ray surveys (e.g. 11% per cent in the EMSS, Della Ceca et al. 1994) compared to fainter soft X-ray surveys (e.g. 2.5% per cent in the CRSS, Celiegi et al. 1995).

The second difference is that there are nearly half as many NELGs as BL AGN (see Table 1) compared to ratios of ~1:13 NELGs to AGN in RIXOS (Mason et al. 2000) and ~1:6 in the CRSS (Boyle, Wilkes & Elvis 1997). This implies that the fraction of sources with hard spectra is larger in the NELG population than in the BL AGN population. This is consistent with the findings that the NELGs in faint X-ray surveys have, on an average, harder X-ray spectra than BL AGN (Almaini et al. 1996; Romero Colmenero et al. 1996), and with the hypothesis that most X-ray selected NELGs are absorbed AGN (Schmidt et al. 1998; Lehmann et al. 2000).

Hence the hypothesis that most of the sources have hard X-ray spectra, because they are absorbed, could account for both the high radio loud and the NELG content of this survey. It is also consistent with the preliminary analyses of the optical spectra and optical colours of the hard sources (Carrera et al. 2001 and Mittaz et al. 2001).

Related to the absorption hypothesis, an important finding is that the distributions of X-ray spectral slopes and fluxes of the BL AGN, NELGs and galaxies are indistinguishable within the current sample, but the three groups have different ranges of luminosities.

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The galaxies are found at low luminosity while the high luminosities sources are BLAGN (see Figs 4 and 6). The absence of high luminosity, absorbed narrow line AGN has also been noted by Akiyama et al. (2000) in the ASCA Large Sky Survey. These results are consistent with all three source types having the same mechanism for their X-ray spectra (an absorbed active nucleus) but with optical emission line properties which depend on the luminosity. For this reason we point out that the high redshift, high luminosity, absorbed QSOs expected to produce a large fraction of the X-ray background are not necessarily narrow line objects (the proposed `QSO 2s') like Seyfert 2s, their low-luminosity counterparts.

5 CONCLUSIONS

We have performed a survey of ROSAT fields for serendipitous sources with hard spectra (α < 0.5); such sources must be a major contributor to the XRB at faint fluxes. In this paper we have presented optical identifications for 62 of these sources. Almost half (28) of these sources are BLAGN, while 12 are NELGs and five are galaxies without visible emission lines. We have also found eight clusters of galaxies among the hard spectrum sources. However, these are predominantly bright sources and are not particularly hard (their best-fitting spectral indices all lie in the range 0.0 < α < 0.5), and hence clusters are unlikely to be an important component of the hard, faint population.

The hard spectrum BLAGN have a distribution of X-ray to optical ratios which is similar to that found for AGN from other soft X-ray surveys (1 < αOX < 2). However, a relatively large proportion (15 per cent) of the BLAGN, NELGs and galaxies are radio loud. This could be because the radio jets in these objects produce intrinsically hard X-ray emission, or if they are absorbed, it could be because radio loud objects are more X-ray luminous than radio quiet objects.

The BLAGN, NELGs and galaxies have indistinguishable distributions of X-ray flux and spectra, hence any or all may be important to the hard, faint population required to solve the XRB spectral paradox. The majority of the galaxies are low luminosity sources, while the highest luminosity objects, and all the high redshift (z > 1) sources, are BLAGN. Their ROSAT spectra are consistent with their being AGN obscured by columns of 20.5 < log(NH/cm²) < 23. Overall, our data are consistent with the X-ray emission of the BLAGN, NELGs, and the galaxy sources coming from absorbed active nuclei.

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