A Deep ROSAT Survey X: X-ray Luminous Narrow Emission Line Galaxies

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ABSTRACT

X-ray luminous narrow emission-line galaxies (NELG) have been previously identified and proposed as an important class of extragalactic X-ray source, with a potentially significant contribution to the total extragalactic X-ray flux at energies below ~ 10 keV. In order to investigate and clarify this possibility, we have used a sample of NELG found in 5 deep ROSAT fields and similar samples belonging to the Cambridge-Cambridge ROSAT Serendipity Survey and to the Einstein Observatory Extended Medium Sensitivity Survey sample. We have been able to study their X-ray properties, to derive their number-flux relationship, to investigate their cosmological evolution and to derive a preliminary X-ray luminosity function (XLF) for this class of objects.

We have compared the above mentioned properties to those exhibited by soft X-ray selected Broad Line AGN (BLAGN) and/or normal galaxies. The principal results of this investigation are as follows: a) for a given optical luminosity, the typical X-ray luminosity of NELGs is about one or two orders of magnitude higher than that of normal galaxies; b) the ratio of the surface density of NELGs compared with BLAGN increases from ~ 0.04 at $f_x \approx 6 \times 10^{-13}$ ergs cm$^{-2}$ sec$^{-1}$ to ~ 0.1 at $f_x \approx 10^{-14}$ ergs cm$^{-2}$ sec$^{-1}$, suggesting that the surface density of NL galaxies might be very close to that of BLAGN at $f_x \approx 10^{-15}$ ergs cm$^{-2}$ sec$^{-1}$; c) we find that these objects are described by a cosmological evolution rate similar to that of soft X-ray selected BLAGN; d) the de-evolved ($z = 0$) XLF of NELGs in the luminosity range $10^{41} - 5 \times 10^{43}$ ergs sec$^{-1}$ is steeper than the BLAGN ($z = 0$) XLF in the same luminosity interval. Their spatial density is significantly lower than the spatial density of X-ray selected BLAGN at $L_x(z = 0) \approx 5 \times 10^{43}$ ergs sec$^{-1}$, but this difference decreases at lower luminosities such that at $L_x(z = 0) \leq 10^{42}$ ergs sec$^{-1}$ the spatial density of NELGs is very close to that of BLAGN. The implications of these results for the contribution of this class of objects to the cosmic X-ray background are discussed.

Key words: X-rays: general – galaxies: active – galaxies:Seyfert – galaxies:starburst – X-ray:galaxies – cosmology

1 INTRODUCTION

The well established classes of extragalactic X-ray source comprise (i) group and clusters of galaxies, (ii) active galactic nuclei (AGN) and (iii) “normal” galaxies. For a review of these topics, see de Zotti et al. (1995) and papers in Barcons and Fabian (1992). One fork of the high-luminosity end of the “normal” galaxy luminosity function comprises the “starburst” galaxies. At least one example of an X-ray emitting irregular starburst galaxy has been known for two decades, viz. M82 (catalogued in the UHURU and ARIEL V sky surveys). The relative importance of the class of objects typified by M82 has, however, been unclear. Although a handful of “narrow-line” galaxies were identified from the early SAS-3 and HEAO-A3 data (e.g. Schnopper et al, 1978, Griffiths et al 1979), it later became clear that these were predominantly Seyfert 2 galaxies. The suggestion that there might be a class of X-ray luminous “starburst” galaxies was first made by Weedman (1986), based on Einstein observations of a small number of optically selected peculiar or irregular galaxies (Fabbiano, Feigelson and Zamorani 1982) for which IRAS fluxes were later obtained. An observed correlation between X-ray and infrared luminosities of an expanded sample of “starburst” galaxies led several authors
X-ray “background” (XRB) at the level of several tens of percent at 2 keV, and perhaps a similar contribution up to at least 10 or even 20 keV.

There were two possibilities summarized by GP90; (i) X-ray emission from luminous infrared galaxies presumably powered by central or distributed starburst activity, and (ii) X-ray emission from blue, star-forming galaxies of the kind contributing to the faint blue number counts. The latter category includes dwarf galaxies with low metallicity (e.g. NGC 5408 – Stewart et al. (1982), and low-metallicity starburst regions within spiral or irregular galaxies. Although there is probably a considerable overlap between the galaxies in these two broad categories, it may be important to try to separate their optical or infrared properties in terms of correlations with X-ray emission. In order to confirm the predictions of the Einstein/IRAS galaxy correlation, Fruscione and Griffiths (1991) and Fruscione, Griffiths and Mackenty (1993) performed low resolution optical spectroscopy (in the range 3500 – 7300 Å) of galaxies selected from the Einstein Observatory Extended Medium Sensitivity Survey (EMSS – see Gioia et al. 1990, Stocke et al. 1991) to establish the existence of X-ray luminous starburst galaxies, and found 6 sources.

In order to investigate and clarify the nature of sources near the ROSAT deep survey limit, we have performed independent ~ 30 – 60 ks ROSAT deep X-ray surveys of 5 fields, which had previously been surveyed for UV-excess quasars by Boyle et al. (1990). About ten X-ray sources in each field were immediately identifiable with UV-excess quasars, and the classification and properties of the remaining sources have been pursued via optical spectroscopy of the corresponding candidate counterparts. At the flux limit (0.5 - 2.0 keV) of ~ 4 × 10^{-15} ergs cm^{-2} sec^{-1} our optical spectroscopy has shown that the majority of these sources are BLAIR at a mean redshift of z ~ 1.5 (Shanks et al., 1991; Boyle et al., 1993;1994), with an important minor-

The above arguments suggest the existence of at least one new population contributing substantially to the soft XRB (Georgantopoulos et al 1995), and from our deep survey observations we explore the possibility that this new population could be comprised of X-ray luminous galaxies. This suggestion has been supported by the detection of a strong (> 5σ) signal below 10^7 in the cross-correlation function of the < 4σ X-ray background fluctuations with B < 23 galaxies (Roche, et al., 1995). These considerations have thus led us to investigate the non-BLAGN counterparts to the ROSAT deep survey sources, and, in particular, the NELG content. An investigation of the properties of NELGs may provide a useful constraint on their cosmological evolution. Unfortunately, with the spectroscopic data at our disposal we can not classify our NELGs as starburst-like or Seyfert 2 like objects using the standard line ratio tests of Veilleux and Osterbrock (1987). Based on high resolution, high signal-to-noise optical spectroscopy of similar objects found in the Cambridge-Cambridge ROSAT Serendipity Survey (CRSS) sample (Boyle et al 1995a,b) and in the EMSS sample (see below) we can conjecture that our NELGs are a mix of starburst, Seyfert II and composite galaxies.

The possible connections between AGN and starburst nuclei have been discussed by Norman and Scoville (1988), Heckman (1991), Williams and Perry (1994), Filipenko (1992) and others. It has been demonstrated that in some nearby objects such as NGC1068 (Wilson et al. 1992), NGC 2992 (Elvis et al. 1992), NGC1672, and NGC1566, composite nuclear regions have been found where there is evidence of both starburst and Seyfert 2 activity. Using infrared observations, Maiolino et al. (1995) have pointed out that Seyfert 2 nuclei tend to lie in galaxies experiencing enhanced star-forming activity (unlike Seyfert 1 nuclei, which lie in galaxies with normal or slightly enhanced nuclear star formation). We note that a population of narrow-line Seyfert 1 galaxies with soft X-ray spectra has been identified using the ROSAT all-sky survey data (Boller, Brandt and Fink 1995), but these have extremely large FeII/Hβ ratios and are spectroscopically different from the objects discussed here.

With the close connection between nuclear starbursts and Seyfert 2 nuclei, it may be appropriate to consider them for the present purposes as a joint sample, in the absence of clear observational evidence for separation of these populations. In this vein, Boyle et al., (1995a) used a combined sample of 43 objects composed of (a) 12 Narrow Emission Line Galaxies found at f_x (0.5 - 2.0 keV) > 2 × 10^{-14} ergs cm^{-2} sec^{-1} in the CRSS and (b) 31 “ambiguous” EMSS sources. The combined sample was used to constraint the cosmological evolution of starbursts/Seyfert II galaxies. In this paper we have been able to make two major improvements over the work of Boyle et al. First, we increase the number of NELGs found in the ROSAT deep surveys at faint fluxes (f_x (0.5 - 2.0 keV) ≥ 4 × 10^{-15} ergs cm^{-2} sec^{-1}) by about 60%. Our flux limit is almost a factor 5 fainter than the CRSS flux limit. Second, using spectroscopic observations of 15 EMSS “ambiguous” sources, along with other data from the literature, we have been able to substantially improve our knowledge of the NELGs in the EMSS.

This paper is organized as follows: in section II we present and discuss our working data set. Having spectroscopically identified ~ 75% of the ROSAT sources in our fields, we also discuss the distribution of these sources in the (f_x/f_B) – f_B plane. As previously noted by Gioia et
al. (1984) and Stocke et al. (1991), this information is extremely useful in programmes of spectroscopic identification of faint X-ray sources. We also report new spectroscopic results on 15 “ambiguous” sources belonging to the EMSS sample. In section III we derive the X-ray number-flux relationship of NELG and compare it with the BLAGN Log $N(> S)$ - Log $S$ obtained from the combined EMSS-ROSAT sample. We also compare the derived Log $N(> S)$ - Log $S$ with the predictions of GP90 which were based on an infrared sample of starburst galaxies and on the measured relation between infrared and X-ray luminosity. In section IV we investigate the cosmological evolution of the NELG, derive an X-ray luminosity function for this class of objects and discuss their contribution to the soft X-ray background. Finally in section V we present our summary and conclusions.

A Hubble constant of $50 \text{ km s}^{-1}$ and a Friedmann universe with a deceleration parameter $q_0 = 0$ are assumed throughout.

2 THE DATA

2.1 Our ROSAT Sample of Narrow Line Galaxies

Our X-ray sample is based on 5 deep exposures taken with the Position Sensitive Proportional Counter (PSPC; Pfeffermann et al., 1986) onboard the ROSAT satellite (Truemper 1983). These fields were previously surveyed spectroscopically for QSOs as part of the Durham UVX QSO survey by Boyle et al. (1990). The names, field centres and exposure times for each PSPC field are reported in Table 1 of Boyle et al. (1994). Full details of the X-ray and optical observations are presented elsewhere (Boyle et al. (1994), Georgantopoulos et al. (1995); Shanks et al., in preparation) and thus only brief details will be given here.

One hundred and ninety four sources were detected above the $5\sigma$ detection threshold in the (0.5-2.0) keV energy band down to a limiting flux of $\sim 4 \times 10^{-15}$ ergs cm$^{-2}$ sec$^{-1}$. The (0.5 - 2.0) keV energy band was preferred over the broad band energy band (0.1-2.4 keV) in order to minimize any contribution from Galactic emission which can dominate below 0.5 keV. Furthermore, due to the rapid increase in the size of the point spread function with off-axis angle, the detection analysis was limited to the inner 18 arcmin of the field centre in each PSPC image. The total area surveyed at the $5\sigma$ limit is therefore 1.41 deg$^2$. The X-ray flux limit depends on the exposure time, on the galactic $N_H$ in the direction of each field and on the position of the sources with respect to the centre of the field. The sky coverage and the procedure adopted to compute it are reported in Boyle et al., 1994. Conversion factors appropriate for a power-law spectrum with energy spectral index of $\alpha_X = 1$ and for the galactic $N_H$ in the direction of each field were used for the conversion between counts and flux (see Georgantopoulos et al., 1995 for details). This conversion factor is accurate to $\pm 10\%$ for all the energy spectral indices in the range $0.5 < \alpha_X < 1.5$ for the low Galactic $N_H$ values along the line of sight of the used fields.

X-ray astrometric corrections were applied by using the optical positions of the known 10-12 Durham UVX AGN detected by ROSAT in each field. The search was made for the optical counterparts of the other X-ray sources detected out to a radius of $\sim 20''$ of the transformed X-ray position. Optical spectroscopy for these counterparts was performed by using the automated fibre-optic system (AUTOFIB) and the Low-Dispersion Survey Spectrograph (LDSS) at the Anglo-Australian Telescope (AAT). Amongst the sources so far identified, there are 107 BLAGN, 7 early-type galaxies, 12 NELG, 1 cluster of galaxies and 12 stars (Georgantopoulos et al 1995). Of the 49 sources with no optical identification, in 30 cases the spectra were too poor to permit a reliable identification.

As previously noted by Stocke et al. (1983) and subsequent works, the X-ray to visual flux ratio is a powerful tool in the process of optical identification of X-ray sources. We have identified $\sim 75\%$ of the 194 X-ray sources found in our fields and are now in a position to study the log($f_X/f_B$) distribution of the various source classes.

In figure 1 we show the X-ray to optical flux ratios for all classes of X-ray sources found in our ROSAT deep surveys:
panel (a) - QSOs; panel (b) - NELGs, Early-type Galaxies and Stars. The relation

\[ \log [f_x(0.5 - 2.0 \text{keV})/f_B] = \log [f_x(0.5 - 2.0 \text{keV})] + B_J/2.5 + 5.5 \]

has been adapted from the original relation

\[ \log [f_x(0.3 - 3.5 \text{keV})/f_V] = \log [f_x(0.3 - 3.5 \text{keV})] + V/2.5 + 5.37 \]

given in Maccacaro et al. (1988) assuming a power-law X-ray spectral model with energy index \( \alpha_x = 1.0 \) and an optical colour-index (B-V) \( =0.3 \). The two dotted lines in figure 1 indicate the range of log \( \log [f_x(0.5 - 2.0 \text{keV})] \) comprising \( \sim 70\% \) of the sources identified with BLAGNs in the EMSS, while the two dashed lines indicate the range of log \( \log [f_x(0.3 - 3.5 \text{keV})] \) comprising \( \sim 70\% \) of the sources identified with Galaxies. The X-ray to optical flux ratio of our sample of BLAGN is in very good agreement with the same ratio for the BLAGN in the EMSS, i.e. the two dotted lines include \( \sim 70\% \) of the BLAGN in our sample. Since our BLAGN sample has a higher mean redshift (\( < z > \sim 1.5 \)) than those in the EMSS sample (\( < z > \sim 0.4 \)), this figure clearly shows that the X-ray to optical properties of X-ray selected BLAGN do not change very much with \( z \). This is consistent with the results obtained for optically selected BLAGN (Avni and Tananbaum, 1986; Wilkes et al., 1994). The NELGs and early-type galaxies from our sample occupy a part of the \( f_x/f_B \) diagram located between those parts occupied by BLAGN and normal galaxies, although there are 4 NELGs (three belonging to the “restricted” ROSAT sample defined below) which lie within the AGN locus and which are therefore suspected of AGN activity. The X-ray and optical properties of the 12 NELGs belonging to our sample are reported in Table 1; the optical spectra are presented in figure 2. A more detailed discussion of their optical properties is presented in Griffiths et al. (1995).

In order to reduce the problem of field contamination, we have selected and used in the following analysis a subsample of NELGs (hereafter the “restricted” sample), defined to have an offset between the X-ray and optical positions less than \( 20^\prime \), together with a magnitude limit of \( B_J < 21.5 \). This “restricted” sample consists of the 7 NELGs annotated with a “C” in column 13 of Table 1.

We have addressed the problem of the contamination from the field galaxies in this “restricted” sample in the following way. In the error circles of the X-ray sources with spectroscopically identified QSOs, we have recorded the angular distance from the X-ray centroid to the nearest non-stellar objects having apparent magnitude less than B. The distribution of the recorded objects, as a function of the distance, has then been normalized to the 75 X-ray source fields which do not contain identified QSOs or stars, and this distribution has been compared with the similar distribution for the galaxies spectroscopically identified in the survey. We have thus estimated that about 2 sources with \( B < 21.5 \) are expected by chance to be the nearest neighbours of these 75 X-ray sources, at distances less than 20 arcsec. If we bear in mind that galaxies with emission lines are about 20% of the field galaxy population, we expect less than one object to be a chance galaxy in our “restricted” sample of NL objects.

### 2.2 Previous Samples of X-ray Selected Narrow Line Galaxies

The CRSS (Boyle et al., 1995a) is a study of serendipitous X-ray sources in 20 PSPC fields at high galactic latitude (\( |b| > 30^\circ \)). In order to simplify the optical identification process, the X-ray source detection in each field was limited to a flux level \( f_x (0.5 - 2 \text{ keV}) > 2 \times 10^{-14} \text{ ergs cm}^{-2} \text{ sec}^{-1} \). About 90% of the 123 x-ray sources in the sample were spectroscopically identified and amongst them there were 10 NELGs (we have excluded from the original sample of 12 NELGs reported in Boyle et al. (1995a) the two objects (CRSS1413.3+4405 and CRSS1415.0+4402) now classified as Seyfert 1.5 in Boyle et al. (1995b). High resolution, high signal-to-noise optical spectroscopy allowed these authors to classify the NELGs as starburst-like or Seyfert 2 galaxies, with approximately equal numbers. This sample of NELGs is important for our purposes because it fills the gap between those found in our ROSAT deep surveys (\( f_x (0.5 - 2 \text{ keV}) \geq 3 \times 10^{-15} \text{ ergs cm}^{-2} \text{ sec}^{-1} \)) and those in the EMSS (\( f_x (0.3 - 3.5 \text{ keV}) \geq 1 \times 10^{-13} \text{ ergs cm}^{-2} \text{ sec}^{-1} \)).

The Einstein Observatory EMSS (Gioia et al., 1990; Stocke et al., 1991; Maccacaro et al., 1994) contains several examples of NELGs (having emission lines with FWHM < 1000 km s\(^{-1}\)). As shown by Fruscione and Griffiths (1991) and Fruscione, Griffiths and Mackenty (1993) these objects can generally be found amongst the EMSS X-ray sources associated with galaxies with “ambiguous” classification, with spectral properties which were either unclear or at the borderline between those of AGN and normal/starburst galaxies. The ambiguous EMSS X-ray sources which satisfy the above requirements are listed in Tables 8 and 10 of Stocke et al. (1991), numbering 36 objects in total. However, in many cases the entries in these tables are simply due to insufficient signal to noise ratio at \( H_\alpha \) or \( H_\beta \) to determine unambiguously if a broad-line component is present. As explicitly reported by Stocke et al., higher resolution and higher signal-to-noise spectra would clarify whether weak broad-line components are present in many of these objects.

In an attempt to investigate the presence of “starburst” galaxies in the EMSS sample we have taken optical spectra of 15 EMSS NELG candidates and have used the ratios of selected emission lines to classify the observed galaxies. The observations were made during 3 nights in February and October 1991 at the Steward Observatory 2.3m telescope, equipped with a Boller and Chivens spectrograph, and 2 nights in October 1991 at the Multi Mirror Telescope Observatory 4.45m equivalent telescope plus “Red” spectrograph. The detector was in both cases a Texas Instruments 800 x 800 pixel CCD. We took \( \sim 10 \) Å-resolution spectra and oriented the slit along the major axis of the galaxies covering a total spectral range of \( \approx 4500 – 8200 \) Å. We reduced the data using standard IRAF packages and measured the flux and the width of selected emission lines from the extracted 1-d spectra using the task “splot”. We used the option of fitting a single Gaussian profile or else deblending multiple Gaussians (e.g. in the case of H\(_\alpha\) and [NII]). The flux and FWHM are calculated by this task for the fitted Gaussian profiles above the continuum level. We estimated an average 20-30% uncertainty in the flux level. We computed the redshift of each source by measuring the centroid of a gaussian centered on the [O III]\( \lambda 5007 \) or H\(_\alpha\) emission line. In
all cases the redshift corresponds to the redshift reported in Stocke et al., confirming the identification.

The spectra of the 15 observed EMSS objects are shown in figure 3. We considered both the broadening of the line profiles and the line-ratio diagnostics in the classification of the objects. Lines with FWHM \( \gtrsim 1000 \text{ km sec}^{-1} \) were considered an indication of a broad line region, i.e. indicative of a BLAGN. The line-ratio diagnostics described in Veilleux and Osterbrock (1987) were used to discriminate between HII and Sy2 types: however, in some cases, the comparison of different line-ratio gives a different classification, or the position in the diagnostic diagrams is ambiguous (see e.g. Fig. 3 in Fruscione and Griffiths 1991). In these cases the objects were classified as borderline HII/Sy2. The emission line properties and classification for the observed objects, along with the emission line properties and classification for other “ambiguous” EMSS sources from the literature, are reported in Table 2. The (0.3-3.5) keV X-ray fluxes, redshifts and V magnitudes reported in Table 2 were taken from Stocke et al. (1991). X-ray fluxes were corrected for galactic absorption and were computed assuming a power law spectral model with energy index \( \alpha_x = 1 \).

2.3 Overall Properties of the ROSAT/EMSS sample

The spectroscopic properties of the NL objects in the EMSS sample are similar to those of the NELGs that we have identified here (see Griffiths et al., 1995), as well as those in the CRSS. For the following analysis, we need to define a working sample of X-ray selected NELGs. We have thus taken the 7 objects from the “restricted” ROSAT sample of NELGs (sources annotated with a “C” in Table 1), the 10 NELGs in the CRSS sample and the 15 NELGs in the EMSS sample (sources annotated with a “C” in Table 2). Amongst the 10 NELGs in the CRSS sample there are 5 HII region-like galaxies, 2 Seyfert 2’s, 1 Seyfert 1.8 and 2 objects with ambiguous classification. Amongst the 15 in the EMSS sample there are 6 HII region-like galaxies, 5 Seyfert 2’s, 2 LINERs and 2 objects at the borderline between HII and Seyfert 2 types. We have added the two LINERS to the NELG sample because recent results on optical spectroscopy of luminous infrared galaxies (Veilleux et al., 1995), show that circumnuclear starburst activity is a common feature for this class of objects.

The sky coverage utilized in the present paper is a combination of the EMSS sky coverage (reported in Gioia et al. (1990)), the “ROSAT effective survey area” of our fields (reported in Table 2 of Boyle et al., 1994) and the “ROSAT effective survey area” of the CRSS survey (see Boyle et al., 1995a). The “ROSAT effective survey area” takes into account the spectroscopic incompleteness in the process of identification of the faint sources. The three sky coverages as a function of X-ray flux have been computed assuming a power law spectrum with energy index \( \alpha_x = 1 \). The (0.5 - 2.0) keV X-ray fluxes have been converted into the (0.3 - 3.5) keV energy band (the EMSS energy band) assuming the same spectral index.

In figure 4 we show the distribution of the sample of NELGs in the \( L_B - z \) plane. The ROSAT NELGs (both our sample and the CRSS sample) have X-ray luminosities in excess to ~ 10^{42} \text{ ergs sec}^{-1} and lie in the redshift range ~ 0.1-0.6. Similarly, 12 of the EMSS NELGs have an X-ray luminosity in excess of ~ 10^{42} \text{ ergs sec}^{-1} and the 2 highest redshift EMSS starburst galaxies have a luminosity in excess of ~ 10^{43} \text{ ergs sec}^{-1}. The distribution of NELGs in the \( L_B - L_B \) plane is shown in figure 5. \( L_B \) is the X-ray luminosity in the (0.3-3.5 keV) energy band and \( L_B \) is the optical B luminosity in \( L_B \) (see Canizares, Fabbiano and Trinchieri, 1987 for the definition of \( L_B \)). For the EMSS objects, B magnitudes were computed from the original V magnitudes reported in table 2, assuming B–V = 1.1, 0.8 and 0.3 according to the prescription given in Stocke et al. (1991) (see also the notes to Table 2). Palomar O magnitudes for 8 of the objects in the CRSS sample are reported in Boyle et al., 1995b. For the remaining two objects, CRSS1514.4+5627 and CRSS1605.9+2554, we have only Palomar E magnitudes and they are 20.69 and 20.55, respectively. For the CRSS objects we have used the Palomar O or Palomar E magnitudes. The shaded line in figure 2 encloses the region populated by the normal late-type galaxies observed with the Einstein Observatory (Fabbiano, Kim and Trinchieri, 1992). The optical luminosity of our ROSAT sample ranges between \( L_B \sim 10^{10} L_{\odot} \) (\( M_B \sim -20 \)) to \( L_B \sim 10^{11} L_{\odot} \) (\( M_B \sim -22 \)); this range of optical luminosities is typical of large spiral or elliptical galaxies. However, for a given optical luminosity, the X-ray luminosity of the NELGs is about one to two orders of magnitude higher than the X-ray luminosity of normal late-type galaxies, suggesting a different and/or more efficient X-ray emission mechanism.

3 THE LOG N(>S)-LOG S OF NELGS

In figure 6 we show the Log N(>S)-Log S relationship of our working sample of NELGs (filled circles). This Log N(>S)-Log S has been obtained by folding the total sky coverage with the flux of each source. It is now interesting to compare this Log N(>S)-Log S with the BLAGN Log N(>S)-Log S obtained from the combined EMSS-ROSAT sample. The BLAGN Log N(>S)-Log S is shown in figure 6 as open triangles. There is an apparent increase of the surface density of NELGs with regard to the surface density of BLAN towards lower fluxes. The ratio between NELGs and BLAGN increases from ~ 0.04 at \( f_x \gtrsim 6 \times 10^{-13} \text{ ergs cm}^{-2} \text{ sec}^{-1} \) to ~ 0.1 at \( f_x \gtrsim 10^{-14} \text{ ergs cm}^{-2} \text{ sec}^{-1} \). If this trend is confirmed by better statistics and deeper X-ray surveys (e.g. the AXAF and XMM deep surveys) then the spatial density of NELGs could be very close to the spatial density of BLAN at \( f_x \sim 10^{-15} \text{ ergs cm}^{-2} \text{ sec}^{-1} \) and could produce a re-steepening of the total Log N(>S)-Log S for \( f_x < 10^{-15} \text{ ergs cm}^{-2} \text{ sec}^{-1} \). It is interesting to note that such re-steepening is not inconsistent with the P(D) fluctuations analysis of the deepest ROSAT fields (Georgantopoulos et al. (1993), Hasinger et al. (1993), Barcons et al. (1995)).

We may also compare the Log N(>S)-Log S of X-ray selected NELGs with the predictions of Griffiths and Padovani (1990), which were based on an infrared selected (IRAS) sample of starburst galaxies and on the observed relation between infrared and X-ray luminosities. The prediction shown in figure 6 (dotted line) refers to the case of a cosmological luminosity evolution given by \( L_B(z) \propto e^{C\tau} \) where \( \tau \) is the look-back time and \( C \) is the cosmological evolution
parameter (C=5 for this particular curve). On the assumption that about half of the NELGs are starburst in origin, we found a factor ~ 6 more galaxies with respect to the prediction, suggesting that these objects have higher X-ray luminosities than those predicted by GP90, which were based on the $L_x/L_{IR}$ ratio.

A number of models, based on the unification schemes of AGNs, have been recently proposed to explain the origin of the diffuse cosmic X-ray Background. In particular, Comastri et al. (1995) and Madau, Ghisellini and Fabian (1994) have shown that a mixture of unabsorbed AGN (Seyfert 1 galaxies and QSOs) and absorbed AGN (Seyfert 2 galaxies), integrated over the luminosity-redshift plane can account for the cosmic X-ray background from several to ~100 keV. It is thus interesting to compare the predicted surface density of the hypothetical absorbed population with our observed Log N(>S)-Log S. The models of Comastri et al. and Madau, Ghisellini and Fabian predict a surface density of absorbed type 2 AGNs ($N_H > 10^{22}$ cm$^{-2}$) of ~25 deg$^{-2}$ at $f_x(0.3 - 3.5keV) \sim 10^{-14}$ ergs sec$^{-1}$. This prediction is a factor 2 above our observed Log N(>S)-Log S of the total population of NELGs, including Seyfert 2 and starburst galaxies. Owing to the incomplete spectroscopic identification and the small numbers, it may be premature to say if this discrepancy is statistically significant.

Some incompleteness at fluxes fainter than $3 \times 10^{-14}$ ergs cm$^{-2}$ sec$^{-1}$ is also suggested from the shape of the number-counts relationship. The CRSS sample and the EMSS sample have a high rate of optical identification ($\geq 90\%$), while in our sample the identification rate is of the order of 75%. We have therefore corrected, to first order, for the incompleteness following Boyle et al., 1993, but a higher fraction of NL galaxies is probably present amongst the unidentified sources (which are, in the mean, at fainter fluxes) when compared with the identified NL objects as a fraction of the total identified sources. We will discuss this problem and its influence on the cosmological evolution analysis in the next section.

4 THE COSMOLOGICAL EVOLUTION AND X-RAY LUMINOSITY FUNCTION OF NELGS

The $V_x/V_a$ test (Avni and Bahcall, 1980) is a powerful tool for studying the cosmological evolution of any class of objects. If the test is applied to a sample that is known to be complete, then the quantity $V_x/V_a$ has the property of being uniformly distributed between 0 and 1, with a mean value of 0.5 in the absence of cosmological evolution. For our sample of 32 NELGs we find that the hypothesis of a uniform distribution in space is rejected at more than the 99.9% confidence level ($< V_x/V_a > = 0.73 \pm 0.05$).

The evolution can be detected up to a certain redshift limit, where the evaluation of this limit depends on being able to sample the observed luminosity function within different redshift intervals (see e.g., Maccacaro et al., 1991; Boyle et al., 1993 for results on the evolution of the X-ray luminosity function of BLAGN). With a total number of ~30 objects we cannot follow this approach. We have thus applied the $V_x/V_a$ test (see below) over the redshift range 0.0 – 3.0, but the results are essentially unchanged if we restrict the analysis to the redshift range 0.0 – 2.0. In other words, with the data at our disposal, we cannot say if the evolution of these objects “switches off” at $z \sim 3$ or at $z \sim 2$ (as found for optically selected QSOs and X-ray selected BLAGN by Boyle et al., 1991 and Boyle et al., 1993) or at a lower redshift. Better statistics are needed to measure this behaviour, such as those anticipated from the AXAF and/or the XMM deep surveys.

For comparison with other classes of active extragalactic objects, we note that Rowan-Robinson et al. (1993) have tested a range of different evolutionary models (either luminosity evolution and/or density evolution), and have shown that the faint radio source counts can be explained by a population of starburst galaxies undergoing strong luminosity evolution characterised by $L_x(z) \propto (1 + z)^C$. The cosmological evolution rate they found ($C \sim 3.1$ in a q=0=0.5 Friedmann universe) is very close to that found for radio galaxies and quasars (Dunlop and Peacock, 1990), optically selected QSOs (Boyle et al.(1990)) and X-ray selected AGN (Boyle et al., 1994). Furthermore, as shown by Boyle et al. (1990) for optically selected AGN and by Della Ceca et al. (1992) and Boyle et al. (1994) for X-ray selected AGN, a cosmological evolution law characterised by $L_x(z) \propto (1 + z)^C$ provides a better description of the current BLAGN data set.

In order to compare directly our results with those of other authors, we assume a pure luminosity evolution model with the evolutionary form

$$L_x(z) = L_x(0) \times (1 + z)^C$$

where $L_x(0)$ is the de-evolved ($z=0$) X-ray luminosity, $L_x(z)$ is the luminosity at redshift $z$ and $C$ is the cosmological evolution parameter. The best fit $C$ can be determined by finding the value that makes $< V_x/V_a > > 0.5$ and the individual $V_x/V_a$ values uniformly distributed between 0 and 1. The $\sigma$ interval on $C$ corresponds to the values for which $< V_x/V_a >= 0.5 \pm (12N)^{-1/2}$, where $N$ is the number of objects in the sample. The best fit value we have found for the evolution parameter is $C=3.35$ with associated 1\(\sigma\) and 2\(\sigma\) confidence intervals of [3.09-3.57] and [2.72-3.79] respectively.

In order to evaluate how this result is affected by the uncertainty on the exact number of NELGs in the EMSS sample, by the contamination problem in our sample and by the unidentified objects in ours and the CRSS sample we have considered three extreme cases. First of all, we have considered all the objects listed in Table 8 and 10 of Stocke et al. (1991), for which we have no evidence of a broad line component, as possible EMSS NELGs. This sample is then comprised of 24 EMSS objects (we have added to the original EMSS NELG sample the 9 objects annotated with an “E” in table 2) and can be considered as a useful upper limit to the real number of NELGs belonging to the EMSS. The cosmological evolution analysis of these 24 EMSS objects taken together with the 17 ROSAT NELGs (10 CRSS objects plus 7 from our ROSAT deep surveys) gives $< V_x/V_a > = 0.71 \pm 0.05$, still indicating cosmological evolution at the 99.99% confidence level. The best fit evolution parameter is $C=3.15$ with associated 1\(\sigma\) and 2\(\sigma\) confidence intervals of [2.88-3.35] and [2.50-3.54] respectively.

Secondly, in order to evaluate the effect of the contamination problem, we have excluded from the original working sample of 32 NELGs the two NELGs in our ROSAT sample with optical magnitude greater than 21 (GSGP4X:91 and 

...
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These two objects have the highest redshifts in our sample (see Table 1). Analysis of the sample comprised of the remaining 30 objects gives \(<V_c/V_a> = 0.71 \pm 0.05\), still indicating cosmological evolution at the 99.99% confidence level. The best fit cosmological evolution parameter is, in this case, \(C = 3.36\) with associated 1\(\sigma\) and 2\(\sigma\) confidence intervals of [3.06-3.60] and [2.58-3.85] respectively.

Thirdly, we have considered the total sky coverage for our sample (reported in Table 2 of Boyle et al., 1994) and for the CRSS sample (Boyle et al., 1995a), on the assumption that no more NELGs were to be found among the unidentified objects. Analysis on our working sample of 32 NELGs then gives \(<V_c/V_a> = 0.72 \pm 0.05\), still indicating cosmological evolution at the 99.99% confidence level. The best fit evolution parameter is, in this case, \(C = 3.16\) with associated 1\(\sigma\) and 2\(\sigma\) confidence intervals of [2.86-3.41] and [2.42-3.62] respectively. However, it may realistically be assumed that more NELGs will be found amongst the unidentified ROSAT sources. This is also suggested from the shape of the number-counts relationship for sources with fluxes \(f(x) \lesssim 4 \times 10^{-14}\) ergs cm\(^{-2}\) sec\(^{-1}\). Since these objects are, in the mean, at the faintest X-ray fluxes their \(V/V_{\text{max}}\) will be higher than the mean \(V/V_{\text{max}}\) of the present sample.

As a consequence, the evolution parameter \(C\) is expected to be (slightly) higher than the value derived here. These results show that, although the statistics are poor (32 objects in total), we have evidence of cosmological evolution of NELGs at a high confidence level.

We briefly mention the different physical scenarios which could be responsible for the evolution of the X-ray properties of NELGs. Under the hypothesis that their X-ray emission derives primarily from massive X-ray binaries (MXRB) Griffiths and Padovani (1990) have pointed out that there may be an inverse correlation between their luminosity and the metallicity of the host galaxy. Since galaxies at high redshift may be poorer in metals than the present-day ones, the implication would be that their X-ray luminosity would be correspondingly higher. Furthermore, the star formation and supernova rates would be higher than those in local galaxies. Starbursting galaxies at moderate to high redshift may thus contain a larger number of MXRBs than our Galaxy. On the other hand, we may be observing an evolving AGN component in these objects. In the latter case, we should perhaps expect the evolution to proceed at a similar rate to that of bona fide or established AGN.

We have also performed a maximum likelihood analysis to obtain a “best fitting” parametric representation of the evolution and luminosity function (see Boyle et al., 1994 for the application of this method). The local \((z=0)\) X-ray luminosity function (XLF) has been described by a power law with two components:

\[
\Phi_x(L_x) = \begin{cases} 
K_1 L_x^{-\gamma_1}, & L_x(z = 0) < L_x^*; \\
K_2 L_x^{-\gamma_2}, & L_x(z = 0) > L_x^*;
\end{cases}
\]

where \(K_1, \gamma_1\) and \(\gamma_2\) represent the normalization, and the faint and bright end slopes of the XLF, respectively. The quantity \(L_x^*\) is the luminosity in the \((0.3-3.5)\) keV energy band expressed in units of \(10^{44}\) erg s\(^{-1}\). The faint-end and bright-end normalizations, \(K_1\) and \(K_2\), are tied together by the requirement of continuity of the XLF at \(L_x^{*44}\), which implies \(K_2 = K_1/L_x^{*44(\gamma_1-\gamma_2)}\).

Due to the small number of objects at our disposal and their limited redshift range, the parameter \(C\) was not well constrained when we tried to fit simultaneously the evolution and the shape of the XLF. We then fixed it at the value obtained using the \(V/V_{\text{max}}\) analysis \((C = 3.35)\) and determined the best fit values for the shape of the XLF. We obtain the following “best-fit” values: \(\gamma_1 = 1.85 \pm 0.25\), \(\gamma_2 = 3.83 \pm 0.20\), \(L_x^* = 10^{42.83 \pm 0.2}\) and \(K_1 = 1.3 \times 10^{-7} Mpc^{-3}(10^{44}\text{ergs}^{-1})^{-1}\). This model was an acceptable fit to the data with a KS probability of greater than 20 per cent, according to the 2D KS-statistic (see Boyle et al. 1994 for details of this test). The derived \(z = 0\) “best fit” XLF is reported in figure 7 as a solid line. The dashed line in figure 6 shows the predicted number-flux relationship for the NELGs, obtained by integrating our best fit model over the luminosity range \(L_x = 10^{40} - 10^{45}\) ergs sec\(^{-1}\) and out to a redshift of 3.

We now compare the de-evolved XLF of the NELG with the de-evolved XLF of BLAGN determined by Boyle et al. (1994) from the combined EMSS - ROSAT sample. The BLAGN XLF (model K of Boyle et al., 1994) is shown in Figure 7 (dashed line). The XLF of NELGs in the luminosity range \(10^{41} - 3 \times 10^{43}\) ergs sec\(^{-1}\) is steeper than the BLAGN XLF in the same luminosity interval. The spatial density of NELGs is significantly lower than the spatial density of BLAGN at \(L_x \sim 5 \times 10^{43}\) ergs sec\(^{-1}\); this difference decreases at lower luminosities and at \(L_x \leq 10^{42}\) ergs sec\(^{-1}\) the spatial density of NELGs is very close to that of BLAGN.

We have compared the spatial density of NELG with the spatial density of BLAGN at \(z = 0\). Given that the two kind of objects show similar cosmological evolution the density ratio NELG/BLAGN at \(L_x(z)\) can be obtained using figure 7 and considering that \(L_x(z) = L_x(z) \times (1+z)^{-C}\).

Having determined the cosmological evolution and the de-evolved XLF of NELGs, starting from X-ray data, we are now in a position to estimate directly their contribution to the cosmic X-ray background. Using the formalism of Maccacaro et al. (1991) with our best fit parameter for the
cosmological evolution ($C = 3.35$) and the estimated XLF at $z = 0$ (figure 7), we have been able to compute the percentage contribution to the 2 keV X-ray background in different bins of luminosities and redshifts. We have used a 2 keV XRB intensity ($I_{XRB}$) equal to $6.14 \text{ keV cm}^{-2} \text{s}^{-1} \text{sr}^{-1} \text{keV}^{-1}$ (Gruber 1992), which is consistent within the calibration uncertainties with the values obtained by Hasinger (1992) from ROSAT PSPC data ($I_{XRB} = 6.61 \text{ keV cm}^{-2} \text{s}^{-1} \text{sr}^{-1} \text{keV}^{-1}$). The results are reported in Table 3. The principal uncertainty in this calculation is the faint end ($L_x \lesssim 2 \times 10^{42} \text{ ergs sec}^{-1}$) slope of the de-evolved XLF. To take account of this uncertainty we have reported in Table 3 the percentage contribution to the 2 keV X-ray background for two extreme cases. The lower limit in Table 3 refers to a faint end slope $\gamma = 1.6$ while the upper limit refers to a faint end slope $\gamma = 2.1$. These values refer to $\pm 1\sigma$ error on $\gamma_1$. NELGs can thus account for $\sim 11 - 36\%$ of the 2 keV X-ray background. The results we have obtained in this analysis thus confirm and strengthen the results obtained by Boyle et al. (1995a). More than 55% of the total NELG contribution at 2 keV comes from objects with $L_x > 10^{41} \text{ ergs sec}^{-1}$, i.e. from objects that we have already seen. About two thirds of the overall contribution comes from objects with $z < 2$.

We have also checked the results reported in Table 3 as a function of the cosmological evolution parameter(s) used in the calculations. Using values of 2.72 and 3.79 for $C$ (95% confidence interval) and the corresponding “best fit” XLFs, the fraction of the 2 keV XRB intensity accounted for by the NELGs became $\sim 10\%$ and $\sim 26\%$, respectively. The principal uncertainty in the contribution to the XRB is thus the faint end slope of the XLF, rather than the current uncertainty in the evolution parameter.

5 SUMMARY AND CONCLUSIONS

We have used a sample of 7 X-ray emitting NELGs found in 5 deep ROSAT fields together with similar samples from the CRSS (10 objects) and from the Einstein EMSS (15 objects) to investigate and clarify their cosmological properties and evolution. The X-ray luminosities of NELGs range from $10^{41} - 10^{44} \text{ ergs sec}^{-1}$ and, for a given optical luminosity, their X-ray luminosities are about one or two orders of magnitude greater than those observed for typical late type galaxies.

Using these data we have been able to compare the number density of NELGs and BLAGN as a function of flux. This ratio increases from $\sim 0.04$ at $f_x \gtrsim 2 \times 10^{-13} \text{ ergs cm}^{-2} \text{ sec}^{-1} \text{to} \sim 0.1$ at $f_x \gtrsim 10^{-14} \text{ ergs cm}^{-2} \text{ sec}^{-1}$, suggesting that the surface density of NELGs could be very close to that of BLAGN at $f_x \sim 10^{-15} \text{ ergs cm}^{-2} \text{ sec}^{-1}$. We find that NELGs have a similar cosmological evolution rate to BLAGN, but NELGs have a steeper XLF (in the interval $10^{41} - 3 \times 10^{43} \text{ ergs sec}^{-1}$). Their volume density is significantly lower than that of X-ray selected BLAGN at $L_x \sim 5 \times 10^{43} \text{ ergs sec}^{-1}$, but this difference decreases at lower luminosities such that at $L_x \leq 10^{42} \text{ ergs sec}^{-1}$ the volume density of NELG and BLAGN objects is very close. Starting with an X-ray selected sample of objects and having determined their XLF and cosmological evolution, we have been able to directly estimate their contribution to the 2 keV X-ray background. Based on the observed range in the parameter values for the best-fit evolutionary models, these objects can account for $\sim 11 - 36\%$ of the 2 keV X-ray background.

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Narrow Emission Line Galaxies

7 FIGURE CAPTIONS.

Figure 1. The X-ray to optical flux ratio for all classes of X-ray sources found in the ROSAT deep surveys. The two dotted lines in figure 1 indicate the range of $\log [f_x/f_b]$ comprising $\sim 70\%$ of the EMSS BLAGNs, while the two dashed lines indicate the range of $\log [f_x/f_b]$ comprising $\sim 70\%$ of the EMSS normal Galaxies. Panel (a) : QSOs; Panel (b) : Narrow Emission Line Galaxies, Early-type Galaxies and Stars.

Figure 2. Optical spectra of the 12 Narrow Emission Line Galaxies found in our ROSAT fields. See Table 1 for more details.

Figure 3. Optical spectra of the 15 observed EMSS objects. See Table 2 for more details. The objects for which spectra are shown are as follows: filled circles: our ROSAT NL sample; filled squares: HII region-like galaxies in the EMSS; crosses : LINER in the EMSS; open circles : Emission Line Galaxies, Early-type Galaxies, NASA CP-2466, p.351. See text for details. The symbols are as in figure 4.

Figure 4 The X-ray luminosity - redshift distribution for our working sample of NELGs. The symbols are as follows: filled circles: our ROSAT NL sample; filled squares: HII region-like galaxies in the CRSS; open squares: Seyfert 2 like galaxies in the CRSS; filled triangles : HII region-like galaxies in the EMSS; open triangles : Seyfert 2 like galaxies in the EMSS; crosses : LINER in the EMSS; open circles : ambiguous source in the EMSS and in the CRSS samples.

Figure 5. The distribution of the used sample of NELGs in the $L_X - L_B$ plane. The shaded lines enclose the region populated by the normal late-type galaxies observed with the Einstein Observatory (Fabbiano, Kim and Trinchieri, 1992). See text for details. The symbols are as in figure 4.

Figure 6. The X-ray Log $N(> S)$ - Log $S$ of the combined (ROSAT + EMSS) sample of NELGs (filled circles) compared with the BLAGN X-ray Log $N(> S)$ - Log $S$ (open triangles). The dotted line shows the prediction of the X-ray Log $N(> S) - Log S$ of star-forming galaxies based on a sample of infrared selected starburst galaxies. The solid lines represent the EMSS BLAGN Log $N(> S) - Log S$ (best fit and $\pm 1\sigma$ errors on the slope; from Della Ceca et al., 1992). The dashed line represents the prediction on the number-flux relation based on the “best fit” evolution model. See text for details.
to the evolutionary law
\[ L_x(z) = L_x(0) \times (1 + z)^C \]
with C=3.35 (best fit value). Data have been binned with equal logarithmic widths of 0.5; 1σ error bars are determined by the number of objects which contribute to each bin and have been computed using Poisson statistics. The dotted lines represent the XLFs \((z = 0)\) computed using the 95% confidence interval on the cosmological evolution parameter \((C=2.72\) and \(C=3.79)\). The shaded lines represent the model \(K\) of Boyle et al. (1994) for the X-ray luminosity function of X-ray selected BLAGN. The solid line represent the “best fit” two-power law parametric representation of the XLF obtained using the maximum likelihood analysis. See text for details.
Table 1. Narrow Emission Line Galaxies in our deep surveys.

Column 1 gives the X-ray source name, columns 2 and 3 the X-ray field position in degrees measured from the field centre, column 4 the radial distance of the X-ray source from centre in arcmins, column 5 the X-ray flux (erg s$^{-1}$ cm$^{-2}$) (0.5 - 2.0 keV), columns 6 and 7 the celestial coordinates of the X-ray source (equinox 1950.0), column 10 the distance between the X-ray source and optical counterpart in arcsec, column 11 the B mag., column 12 the (U–B) colour, column 13 indicates with a “C” those sources belonging to the “Restricted” ROSAT sample of NELGs (see Section 2.1 for details), column 14 lists the redshifts, and column 15 contains comments. In column 10, “*” indicates that the brighter optical counterpart is listed and that there is also a fainter candidate within the error circle. In the Comment column, W is the equivalent width of the dominant or single narrow line, D is a measure of the “H&K” break (the ratio of continuum strength immediately above and below the CaII H & K features near 4000 Å).

| Name     | X deg | Y deg | rad arcmin | S ergs cm$^{-2}$ s$^{-1}$ | RA (X) H M S | Dec (X) o / ′ / ″ | RA (O) H M S | Dec (O) o / ′ / ″ | Dist arcs. | B mag | U-B mag | Sample z | COMMENTS |
|----------|-------|-------|------------|---------------------------|--------------|-------------------|--------------|-------------------|-------------|-------|---------|----------|----------|
| GSGP4X:24| -0.149| -0.029| 9.1        | 0.429E-14 0 54 23.5 | -27 56 40 0 54 23.2 | -27 56 15 25.3 | 21.41        | 0.226            |            |       |         | (W=20A) |          |
| GSGP4X:48| -0.048| +0.283| 17.2       | 0.300E-13 0 54 51.6 | -27 37 49 0 54 51.8 | -27 38 00 11.3 | 20.37        | 3.17             | C          |       |         | (W=37A) |          |
| GSGP4X:69| +0.029| +0.091| 5.7        | 0.853E-14 0 55 12.2 | -27 49 19 0 55 11.5 | -27 49 17 9.5  | 20.25        | 3.41             | C          |       |         | (W=7A, D=1) |          |
| GSGP4X:72| +0.049| +0.123| 7.9        | 0.465E-14 0 55 17.7 | -27 47 22 0 55 20.4 | -27 47 29 36.5 | 20.14        | 3.87             | C          |       |         | (W=5A, D=1) |          |
| GSGP4X:91| +0.121| -0.242| 16.2       | 0.350E-13 0 55 36.8 | -28 09 15 0 55 36.3 | -28 09 23 10.4 | 21.33        | 0.416            | C          |       |         | (W=18A) |          |
| GSGP4X:94| +0.138| +0.067| 9.2        | 0.650E-14 0 55 42.0 | -27 50 40 0 55 41.9 | -27 50 48 8.1  | 20.22        | 2.84             | C          |       |         | (W=24A) |          |
| GSGP4X:100| +0.158| -0.063| 10.2       | 0.580E-14 0 55 47.3 | -27 58 29 0 55 48.5 | -27 58 23 17.0 | 22.63        | 1.38             | C          |       |         | (W=51A) |          |
| SGP4X:26 | -0.036| +0.098| 6.3        | 0.969E-14 0 52 25.1 | -28 30 16 0 52 27.4 | -28 30 28 32.6 | 19.76        | 0.16             | C          |       |         | (W=42A) |          |
| SGP4X:30 | -0.012| +0.062| 3.8        | 0.666E-14 0 52 31.6 | -28 32 27 0 52 31.8 | -28 32 01 26.1 | 20.87        | 0.077            | (W=23A)   |       |         |          |          |
| QSF1X:33 | -0.069| -0.100| 7.3        | 0.566E-14 3 40 08.5 | -45 10 17 3 40 10.3 | -45 10 20 *19.3 | 19.57        | 0.23             | C          |       |         | (W=60A, QSF1:10) |          |
| QSF1X:36 | -0.066| +0.264| 16.3       | 0.227E-13 3 40 08.3 | -44 48 14 3 40 07.9 | -44 48 24 10.9 | 21.07        | 0.17             | C          |       |         | (W=2A)  |          |
| QSF1X:64 | +0.161| -0.012| 9.7        | 0.852E-14 3 41 26.7 | -45 04 44 3 41 27.6 | -45 04 31 *16.1 | 20.20        | 0.61             | C          |       |         | (W=11A) |          |
Table 2. “Ambiguous” EMSS sources reported in Table 8 and 10 of Stocke et al., 1991

| Name                  | x     | $m_V$          | $f_X$ | $f_r$ | ID  | EMSS | log([OIII]/Hβ) | log([NII]/Hα) | log([SII]/Hα) | log([OI]/Hα) | Class. | Ref     | Sample Comments |
|-----------------------|-------|----------------|-------|-------|-----|------|----------------|---------------|---------------|-------------|--------|---------|-----------------|
| MS0834.0+6517         | 0.019 | 14.16+1.69     | 13.3  | GAL   | 0.26 | -0.56 | -0.44          | -1.54         | HII           | FG91   | C       | Tab.8             |
| MS0942.8+0950         | 0.013 | 15.60 42.31    | <0.6  | AGN   | -0.61 | -0.13 | -0.47          | -1.16         | HII           | This paper | C       | Tab.8             |
| MS1019.0+4836         | 0.062 | 16.93 2.70     | <0.6  | AGN   | 0.38  | -0.23 | -0.55          | -1.40         | HII           | This paper | C       | Tab.8             |
| MS1043.9+1400         | 0.010 | 14.53 3.93     | 19.5  | GAL   | -0.13 | -0.22 | -0.46          | -0.98         | HII           | This paper | C       | Tab.8             |
| MS1047.3+3518         | 0.040 | 15.57 9.21     | 2.6   | AGN   | -0.61 | -0.13 | -0.47          | -1.16         | HII           | This paper | C       | Tab.8             |
| MS1058.5+1003         | 0.028 | 15.47 3.93     | 19.5  | GAL   | -0.13 | -0.22 | -0.46          | -0.98         | HII           | This paper | C       | Tab.8             |
| MS1110.3+2210         | 0.030 | 16.59 5.23     | 1.3   | AGN   | -0.61 | -0.13 | -0.47          | -1.16         | HII           | This paper | C       | Tab.8             |
| MS1111.4+1801         | 0.092 | 16.50 1.02     | <0.6  | AGN   | -0.61 | -0.13 | -0.47          | -1.16         | HII           | This paper | C       | Tab.8             |
| MS1143.6+2040         | 0.023 | 14.00 5.95     | 8.2   | GAL   | -0.61 | -0.13 | -0.47          | -1.16         | HII           | This paper | C       | Tab.8             |
| MS1208.2+3945         | 0.022 | 13.00 3.69     | <0.5  | GAL   | -0.61 | -0.13 | -0.47          | -1.16         | HII           | This paper | C       | Tab.8             |

Note that the EMSS source MS1532.5+0130, classified as an AGN by Stocke et al. (1991), has since been re-classified as a cluster of galaxies (Maccacaro et al. 1994). In column 3 “+” indicates those objects for which we have assumed B–V = 1.1 and “*” indicates those objects for which we have assumed B–V = 0.8. For the other objects, we have taken B–V = 0.3 (see Stocke et al., 1991 for details).
Table 3. Percentage contribution of the NELGs to the 2 keV X-ray Background

| $log(L_x)$ | $z$ | $z$ | $z$ | $z$ |
|------------|-----|-----|-----|-----|
|            | 0.0–1.0 | 1.0–2.0 | 2.0–3.0 | 0.0–3.0 |
| 40–41      | 0.29–4.08 | 0.35–4.90 | 0.39–5.51 | 1.03–14.49 |
| 41–42      | 0.73–3.24 | 0.88–3.89 | 0.99–4.38 | 2.60–11.51 |
| 42–43      | 1.67–2.46 | 2.01–2.95 | 2.27–3.33 | 5.95–8.74 |
| 43–44      | 0.27 | 0.32 | 0.36 | 0.95 |
| 44–47      | < 0.01 | < 0.01 | < 0.01 | < 0.01 |
| 40–47      | 2.96–10.05 | 3.56–12.06 | 4.01–13.58 | 10.53–35.69 |