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The evolution of X-ray-selected narrow-emission-line galaxies

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ABSTRACT

We examine the cosmological evolution of X-ray-selected narrow-emission-line galaxies (NELGs), using a sample of 35 such objects identified in the combined *ROSAT* UK Deep Survey and RIXOS. This sample is entirely independent of those previously used to investigate the X-ray evolution of NELGs.

We detect evolution which is at a similar rate to the evolution found in the optical luminosity function of blue galaxies. The lack of high-redshift ($z > 0.6$) NELGs detected in X-ray surveys, and the small, well-defined number of X-ray sources which are not optically identified indicate that the evolution of NELGs is probably not the same as the X-ray evolution of QSOs: NELG evolution is slower than the evolution of QSOs and/or ends at a lower redshift.

Key words: surveys – galaxies: active – galaxies: evolution – quasars: general – cosmology: observations – X-rays: galaxies.

1 INTRODUCTION

Narrow-emission-line galaxies (NELGs) show only emission lines with FWHM < 1000 km s^{-1} in their optical spectra; they are a heterogeneous group, probably including starburst, H II region like, LINER and Seyfert 2 galaxies. It has recently been discovered that NELGs constitute a large proportion (> 50 per cent) of faint field galaxies (Tresse et al. 1996), and are a major contributor to the X-ray source population at faint fluxes (McHardy et al. 1997). It has also been determined that the optical luminosity function of faint blue galaxies, many of which are NELGs, is increasing between $z = 0$ and 1 (Lilly et al. 1995; Ellis et al. 1996).

Recent investigations of X-ray-selected NELG evolution (Boyle et al. 1995; Griffiths et al. 1996) have used combinations of the *Einstein* Extended Medium Sensitivity Survey (EMSS) (Stocke et al. 1991) NELG sample and NELGs discovered in deeper *ROSAT* surveys: the Cambridge–Cambridge *ROSAT* Serendipity Survey (CRSS) (Boyle et al. 1995) and the deep *ROSAT* survey described in Boyle et al. (1994). These studies have indicated that the NELG X-ray luminosity function is evolving rapidly with redshift, at a rate similar to the evolution rate of QSOs. Evolution analysis of the subclasses of NELGs, e.g., the Seyfert 2 and starburst galaxies, is currently impossible because of the small sample sizes and the difficulty of assigning NELGs to the individual classes.

We test the results of Boyle et al. (1995) and Griffiths et al. (1996) using a sample of NELGs drawn exclusively from two *ROSAT* surveys, namely the *ROSAT* International X-ray Optical Survey (RIXOS) and the UK Deep Survey. The sample of NELGs studied here is completely independent of those used by Boyle et al. (1995) and Griffiths et al. (1996). The latter two samples have objects in common, and hence are not independent of each other. Throughout this paper we have assumed $H_0 = 50$ km s^{-1} Mpc^{-1}; results obtained using values of $q_0 = 0$ and 0.5 are differentiated in the text.

2 RIXOS AND THE UK DEEP SURVEY

RIXOS covers 20 deg^2, the majority of which is identified to a flux of 3×10^{-14} erg s^{-1} cm^{-2} (0.5–2 keV); it contains 17 identified NELGs and is fully described in Mason et al. (1997). The *ROSAT* UK Deep Survey covers a much smaller area of sky, 0.16 deg^2, but to a much lower flux limit, 2×10^{-15} erg s^{-1} cm^{-2} (0.5–2 keV), and contains 18 NELGs. Full details of both the X-ray and the optical observations of the *ROSAT* UK Deep Survey are given in McHardy et al. (1997).

Both surveys have a high level of spectroscopic completeness: at their respective limiting fluxes 93 per cent of RIXOS sources are identified, while 85 per cent of the *ROSAT* UK Deep Survey sources are identified. High completeness is essential, since NELGs represent only a small proportion of the total source population at high fluxes, and are among the most difficult sources to identify due to the paucity of unambiguous features in their optical spectra. The 7 per cent of sources that are unidentified in RIXOS corresponds to 23 sources; this is a very significant number when compared to the 17 NELGs in RIXOS. It is therefore possible, though unlikely, that RIXOS is systematically underpopulated by NELGs. This is not as great a problem for the UK Deep Survey, where only 11 sources remain unidentified compared to 18 NELGs. For the UK Deep Survey, an important source of systematic error may be chance association of the X-ray positions with faint galaxies. As explained in McHardy et al. (1997), the expected number of chance coincidences with NELGs at any redshift and $R<21$ mag is ~ 1.5. The NELG identifications in the UK Deep Survey are very secure: only two of the 18 NELGs have $R>21$ mag, and both of these are at sufficiently large redshifts ($z=0.58$ and 0.60) that they are unlikely to be random coincidences between X-ray sources and optical galaxies. All but one of the RIXOS NELGs have $R<20$ mag; again the faint NELG has a relatively high redshift ($z=0.43$). Sky areas, corrected for spectroscopic incompleteness, can be found in Page et al. (1996) for RIXOS, and in Jones et al. (1997) for the *ROSAT* UK Deep Survey.

The two surveys are complementary in providing a sample of X-ray-selected NELGs covering a wide range of redshift–luminosity parameter space as shown in Fig. 1. The X-ray spectra of the NELGs detected in RIXOS and the UK Deep Survey have been fitted with power laws of the form $F_\nu \propto \nu^{-\alpha_X}$. The mean slope found for the UK Deep Survey NELGs is $\alpha_X \sim 0.5$ (Romero-Colmenero et al. 1996), while the mean slope found for the RIXOS NELGs is $\alpha_X \sim 1$ (Mittaz et al. 1997).

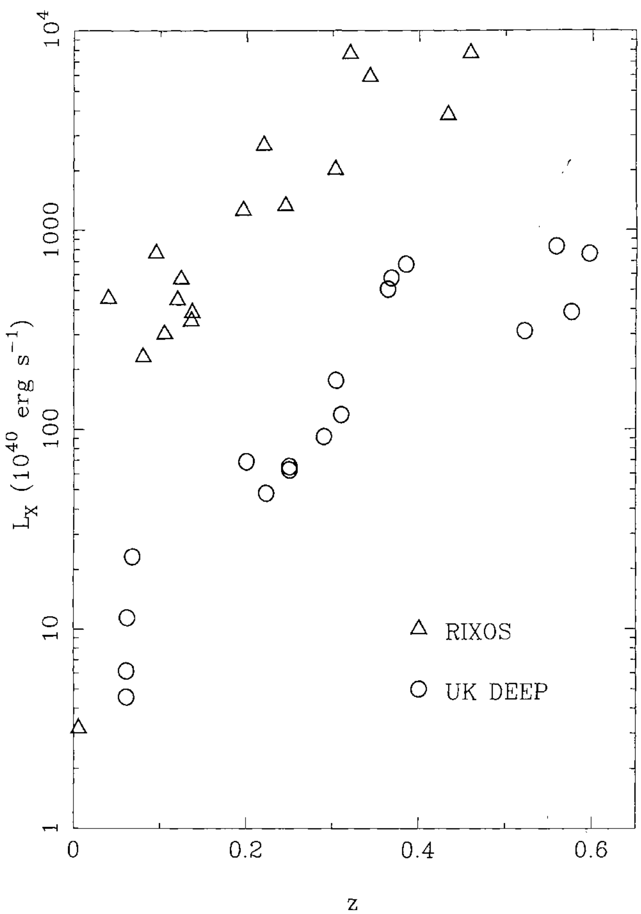

Figure 1. Redshift–luminosity distribution for RIXOS and UK Deep Survey NELGs, assuming $q_0=0$.

3 DETECTION OF EVOLUTION

3.1 $\langle V_e/V_a \rangle$ testing

We have used the $\langle V_e/V_a \rangle$ test described by Avni & Bahcall (1980) to test for evolution in our NELG sample. For each object the ratio of the survey volume enclosed by the object (V_e) to the survey volume available to the object (V_a) is calculated. A mean ratio, $\langle V_e/V_a \rangle$, which is significantly larger than 0.5 implies that evolution is taking place. When testing the RIXOS and UK Deep Survey NELG samples separately, spectral slopes of $\alpha_X=1$ and 0.5 respectively have been used. The combined sample of RIXOS + UK Deep Survey NELGs has been tested once with each spectral index, and once with spectral slopes of $\alpha_X=1$ and 0.5 for the RIXOS and UK Deep NELGs respectively. A deceleration parameter of $q_0=0$ has been used; for $q_0=0.5$, $\langle V_e/V_a \rangle$ is different by no more than 0.01.

The results of the test are shown in Table 1; errors given are 68 per cent without brackets, and 95 per cent within brackets. Only the combined RIXOS + UK Deep Survey sample has sufficient coverage of parameter space to detect evolution; $\langle V_e/V_a \rangle$ is greater than 0.5 with 99 per cent confidence, hence evolution is detected at the 99 per cent confidence level.

We have attempted to determine the effect that likely systematic errors may have on the test, as follows. If 10 of the 23 unidentified sources in RIXOS are NELGs, and assuming that they have similar redshifts and luminosities to the 17 which are identified, our RIXOS NELG sample is about 30 per cent incomplete. We simulate this case by reducing the effective sky area of RIXOS by 30 per cent at 3×10^{-14} erg s^{-1} cm^{-2}, the faintest flux limit in RIXOS, remembering that the unidentified fraction increases as the flux limit becomes fainter.

We quantify the importance of the expected chance NELG identifications in the UK Deep Survey by removing the four optically faintest NELGs which, because of the rapidly increasing surface density of galaxies towards fainter magnitudes, are statistically the most likely to be chance associations.

We also consider a third possible systematic error, namely an optical selection effect caused by the spectroscopic wavelength range used to classify X-ray sources in both RIXOS and the UK Deep Survey. At wavelengths longer than 8000 Å, the identification spectra become increasingly noisy. AGN with a broad component to Hα but

Table 1. Results of $\langle V_e/V_a \rangle$ tests. Errors quoted are 68 per cent (95 per cent) confidence, computed using the method of Avni & Bahcall (1980)

sample	number of NELGs	α_X	$\langle V_e/V_a \rangle$
RIXOS	17	1.0	0.45 ± 0.07 (± 0.13)
UK Deep	18	0.5	0.62 ± 0.07 (± 0.14)
UK Deep + RIXOS	35	1.0	0.66 ± 0.05 (± 0.10)
UK Deep + RIXOS	35	0.5	0.65 ± 0.05 (± 0.10)
UK Deep + RIXOS[a]	35	0.5/1.0	0.66 ± 0.05 (± 0.10)
UK Deep + RIXOS[b]	35	0.5	0.62 ± 0.05 (± 0.10)
UK Deep[c] + RIXOS	31	0.5	0.60 ± 0.05 (± 0.10)
UK Deep + RIXOS, $0 < z < 0.23$	17	0.5	0.58 ± 0.07 (± 0.14)
UK Deep + RIXOS, $0.23 < z < 0.6$	18	0.5	0.61 ± 0.07 (± 0.14)

[a] $\alpha_X = 1.0$ for RIXOS NELGs and $\alpha_X = 0.5$ for UK Deep Survey NELGs.
[b] RIXOS effective sky area at 3×10^{-14} ergs^{-1} cm^{-2} reduced by 30 per cent.
[c] Four optically faintest NELGs assumed to be chance associations.

narrow Hβ, will be classified as AGN on the basis of the broad Hα at $z < 0.2$. At $z > 0.2$ a broad base to Hα becomes difficult to distinguish from the noise, and thus AGN with broad Hα but narrow Hβ may be classified as NELGs. At $z > 0.37$, Hα is redshifted completely out of the range of the identification spectra. It is therefore probable that the number of broad Hα AGN that are classified as NELGs increases with redshift at $z > 0.2$, imitating the evolution that we are searching for. We investigate this effect by splitting our sample of NELGS between those with $z < 0.23$ and those with $z > 0.23$; this splits our sample when the observed wavelength of Hα is just beyond 8000 Å. There are approximately equal numbers of NELGs in our sample with $z < 0.23$ and $z > 0.23$, as seen in Fig. 1, allowing a $\langle V_e/V_a \rangle$ test to be performed in both intervals.

It is seen in Table 1 that all of these systematic effects reduce the detection significance of evolution, but, except when the sample is split by redshift, the evolution is still significant at the 95 per cent confidence level. When the sample is split by redshift, $\langle V_e/V_a \rangle$ is greater than 0.5 in *both* redshift ranges, proving that the apparent evolution cannot be (entirely) due to the spectroscopic selection effect discussed above. Hence it is unlikely that the evolution can be explained by selection effects in the RIXOS and UK Deep Survey NELG samples.

3.2 The NELG X-ray luminosity function

The luminosity, ϕ, is defined as the number of objects per unit comoving volume per unit luminosity interval or, equivalently,

$$\phi(L,z) = \frac{d^2N}{dV\,dL}(L,z),$$

where the dependence of ϕ on z is the evolution of the NELG population with cosmic epoch.

In Fig. 2 we show the X-ray luminosity function of the RIXOS + UK Deep Survey NELG sample. It has been constructed in two redshift ranges, $0 < z < 0.23$ and $0.23 < z < 0.6$, using the $1/V_a$ method of Avni & Bahcall (1980), assuming $q_0 = 0$. As discussed earlier, there are approximately equal numbers of NELGs with $z > 0.23$ and $z < 0.23$ in our sample. Evolution is apparent between the two redshift ranges: ϕ is larger in the higher redshift bin at all luminosities. In Fig. 2, evolution of the luminosity of NELGs corresponds to a displacement of ϕ along a line with slope -1, while evolution of the space density of NELGs corresponds to a vertical displacement of ϕ. Either form of evolution could describe the change in ϕ between the two redshift ranges; the shape of the luminosity function is not well enough determined to distinguish between them.

4 PARAMETRIZING THE EVOLUTION

As discussed in the previous section, there are not sufficient NELGs in our sample to distinguish between luminosity evolution and density evolution. However, we parametrize the evolution as pure luminosity evolution (PLE) to compare our results to those of previous researchers, and to compare the X-ray evolution of NELGs to that of broad-line AGN. In PLE it is assumed that the space density of NELGs remains constant, but the luminosity of each NELG evolves. We consider a power-law PLE model of the form

$$L(z) = L_0 \times (1+z)^C,$$

which is used by Boyle et al. (1995) and Griffiths et al. (1996), and is widely used to model the evolution of broad-line AGN.

4.1 $\langle V_e/V_a \rangle$

We have used the $\langle V_e/V_a \rangle$ test to find acceptable evolution parameters, as described by Maccacaro et al. (1983). This method has the advantage of requiring no assumptions about the shape of the luminosity function, and is the method used by Griffiths et al. (1996). Throughout we have assumed a spectral index of $\alpha_X = 0.5$; adopting $\alpha_X = 1.0$, as do Boyle et al. (1995) and Griffiths et al. (1996), simply increases the evolution parameter C by 0.5. The values of C obtained from $\langle V_e/V_a \rangle$ testing are listed in Table 2. The evolution is only constrained when the RIXOS + UK Deep Survey sample is not split by survey or redshift. We have imposed two different upper limits to the redshift over which the test is carried out: performing the test over the very large redshift interval $0 < z < 3$ results in a reduced evolution rate compared to that obtained for $0 < z < 1$. We have identified only NELGs with $z < 0.6$; imposing a limit of $z = 1$ is therefore justified. It is seen from the CFRS (Lilly et al. 1995) that identification of NELGs is possible to $z = 1$; at $z > 1$ the optical faintness of NELGs may make them particularly difficult to identify. However, obtaining evolution parameters using the larger redshift limit of $z = 3$ does illustrate that the results obtained for $z < 1$ cannot be reliably extrapolated to higher redshifts when calculating the contribution of NELGs to the X-ray background. The evolution rates obtained here for $0 < z < 3$ and $q_0 = 0$ are consistent with those found by Griffiths et al. (1996) using $\langle V_e/V_a \rangle$ over the same range (remembering that 0.5 must be subtracted from the values obtained by Griffiths et al. before comparison, because of the different values of α_X). The errors quoted by Griffiths et al., for a sample of similar size to that used here, are extremely small. The sample of NELGs used by Griffiths et al. is drawn from three surveys (the EMSS, the CRSS, and the deep survey described in Boyle et al. 1994), which in total contain a very large number of unidentified sources (> 50). In addition, the evolution analysis of Griffiths et al. relies on a conversion from *Einstein* to *ROSAT* fluxes, which may not be well determined (see Page et al. 1996), particularly given the lack of detailed knowledge of NELG X-ray spectra. It is also possible that the EMSS is systematically lacking bright, nearby NELGs, because they were observation targets and therefore excluded from the EMSS; 142 of the IPC images used for the EMSS were targeted on galaxies (Gioia et al. 1990). Thus the potential for systematic error is considerably larger in the sample of Griffiths et al. than in this work. We suggest that the realistic uncertainty on the evolution of

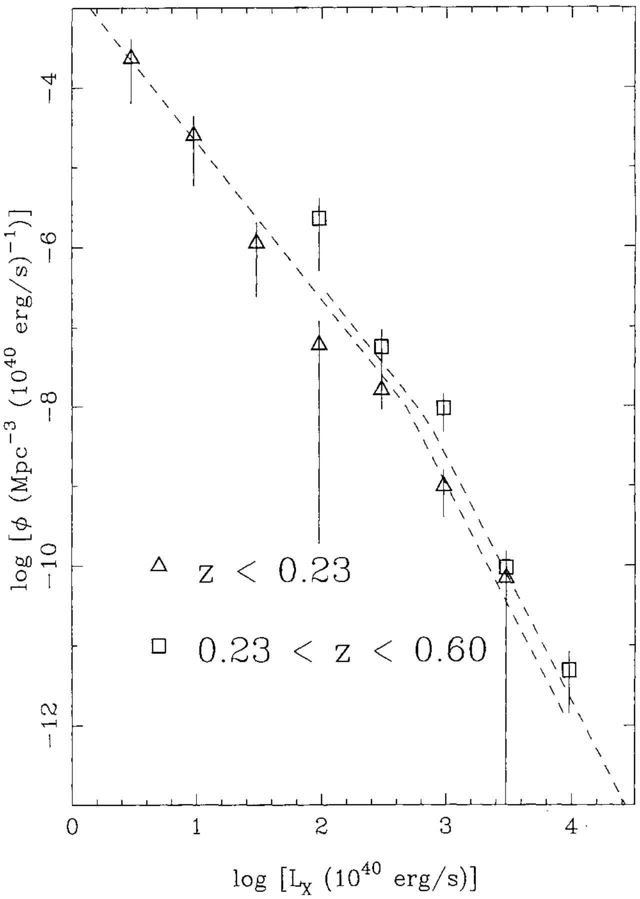

Figure 2. Binned $1/V_a$ NELG X-ray luminosity in two redshift shells, assuming $q_0 = 0$ (symbols) and a model luminosity function in the same redshift shells (dashed line, see Section 4.2).

Table 2. Evolution rates and luminosity functions fitted with maximum likelihood and $\langle V_e/V_a \rangle$ tests. A spectral index of $\alpha_X = 0.5$ has been assumed. Errors quoted are 68 per cent (95 per cent) for one interesting parameter.

sample	fitting range	q_0	C $\langle V_e/V_a \rangle$	C max likelihood	γ_1	γ_2	L_{break}[a]	K_1[b]	I_{XRB}[c]
RIXOS + UK Deep	$0 < z < 1$	0.5	$3.4^{+0.3}_{-0.7}(^{+0.4}_{-1.8})$	$1.9^{+0.9}_{-0.6}(^{+1.5}_{-1.0})$	$2.0^{+0.2}_{-0.2}(^{+0.3}_{-0.3})$	$3.0^{+0.3}_{-0.2}(^{+1.1}_{-0.5})$	$2.5^{+0.2}_{-0.2}(^{+0.7}_{-0.3})$	1.7	3.2
RIXOS + UK Deep	$0 < z < 3$	0.5	$2.4^{+0.3}_{-0.4}(^{+0.7}_{-1.1})$	$0.8^{+0.6}_{-0.3}(^{+0.7}_{-0.4})$	$1.9^{+0.2}_{-0.2}(^{+0.3}_{-0.3})$	$3.1^{+0.3}_{-0.3}(^{+0.6}_{-0.5})$	$2.6^{+0.2}_{-0.1}(^{+0.6}_{-0.3})$	1.4	2.6
RIXOS + UK Deep	$0 < z < 1$	0	$3.6^{+0.9}_{-1.1}(^{+2.0}_{-2.0})$	$1.8^{+0.8}_{-0.5}(^{+1.4}_{-0.9})$	$2.0^{+0.2}_{-0.2}(^{+0.3}_{-0.3})$	$3.1^{+0.3}_{-0.2}(^{+0.9}_{-0.4})$	$2.5^{+0.2}_{-0.2}(^{+0.6}_{-0.3})$	1.5	4.4
RIXOS + UK Deep	$0 < z < 3$	0	$2.6^{+0.5}_{-0.6}(^{+0.9}_{-1.3})$	$1.0^{+0.6}_{-0.4}(^{+0.8}_{-0.5})$	$2.0^{+0.2}_{-0.2}(^{+0.3}_{-0.3})$	$3.2^{+0.2}_{-0.3}(^{+0.6}_{-0.5})$	$2.7^{+0.2}_{-0.2}(^{+0.4}_{-0.4})$	1.5	3.5
RIXOS[d]+ UK Deep	$0 < z < 1$	0	$2.7^{+1.0}_{-0.8}(^{+1.7}_{-1.8})$	$1.6^{+0.6}_{-0.6}(^{+1.2}_{-0.7})$	$2.0^{+0.2}_{-0.2}(^{+0.3}_{-0.3})$	$3.0^{+0.3}_{-0.3}(^{+1.0}_{-0.5})$	$2.6^{+0.2}_{-0.1}(^{+0.7}_{-0.4})$	1.9	5.0
RIXOS + UK Deep[e]	$0 < z < 1$	0	$2.7^{+1.3}_{-1.0}(^{+2.6}_{-2.3})$	$1.5^{+0.6}_{-0.6}(^{+1.5}_{-0.7})$	$2.0^{+0.2}_{-0.2}(^{+0.3}_{-0.3})$	$3.1^{+0.2}_{-0.3}(^{+1.0}_{-0.5})$	$2.6^{+0.2}_{-0.2}(^{+0.7}_{-0.3})$	1.7	3.9

[a] L_{break} in units of 10^{40} erg s^{-1}.
[b] K_1 in units of 10^{-3} $(10^{40}$ erg s$^{-1})^{(\gamma_1 - 1)}$ Mpc^{-3}.

NELGs is much larger than the uncertainty given by Griffiths et al.

4.2 Maximum likelihood

We have obtained values for the evolution parameter C also by using a maximum-likelihood test and assuming a two-power-law luminosity function of the form

$$\phi = K_1 L^{-\gamma_1} \qquad L < L_{\rm break},$$

$$\phi = K_2 L^{-\gamma_2} \qquad L > L_{\rm break},$$

where $K_2 = K_1 / L_{\rm break}^{\gamma_1 - \gamma_2}$; this is the method used by Boyle et al. (1995). We have used a de-evolved luminosity interval of $10^{40} < L_0 < 10^{45}$ erg s^{-1}, and have used two redshift ranges, $0 < z < 1$ and $0 < z < 3$, which are those used earlier to determine C using the $\langle V_e / V_a \rangle$ test; again we have used $\alpha_X = 0.5$.

The results of the maximum-likelihood analysis are given in Table 2. Errors quoted are 68 and 95 per cent for one interesting parameter ($\Delta\chi^2 = 1$ and 4 respectively) obtained using the method of Lampton, Margon & Bowyer (1976). The rate of PLE obtained here from maximum-likelihood testing ($C \sim 1$ for $0 < z < 3$) is consistent with, though somewhat lower than, that obtained by Boyle et al. (1995). The parameters are poorly constrained due to the small sample size; the errors on our maximum-likelihood fit parameters are similar to those found by Boyle et al. (1995) for a sample of similar size. Assuming that RIXOS has systematically missed some NELGs, or that some of the UK Deep Survey NELGs are chance coincidences, leads to a lower evolution rate, but this difference is smaller than the statistical error on the evolution parameter C.

We have tested the fitted models in Table 2 for goodness of fit, using the two-dimensional Kolmogorov–Smirnov tests of Peacock (1983) and Fasano & Franceschini (1987); none of the models are rejected at 95 per cent. Our luminosity function parameters are consistent with those of Boyle et al. (1995), given the large uncertainties due to the small sample sizes. Plotted in Fig. 2 as dashed lines are the luminosity functions for $0 < z < 0.23$ and $0.23 < z < 0.60$ obtained from the maximum-likelihood fit in the interval $0 < z < 1$ for $q_0 = 0$. This model is an acceptable representation of the data when compared to the $1/V_a$ binned luminosity function (also shown in Fig. 2), but the model evolution between $0 < z < 0.23$ and $0.23 < z < 0.60$ appears to be slightly underestimated. This is in keeping with the higher evolution rates obtained from $\langle V_e / V_a \rangle$ testing. The reason for the discrepancy is that no NELGs have been detected at $z > 0.6$, which has a significant effect when fitting the luminosity function, but comparatively little effect on the $\langle V_e / V_a \rangle$ test (and none at all on the $1/V_a$ binned luminosity function). The best-fitting evolution parameters obtained from $\langle V_e / V_a \rangle$ for $0 < z < 3$ are inconsistent with those found by maximum likelihood at the 95 per cent level. This discrepancy is indicative that the evolution model is not representative of the data over the full redshift range.

5 DISCUSSION

When considering what evolution models are reasonable for the NELG population over a wide range of redshift (i.e., $0 < z < 3$) and when comparing the NELG evolution to the X-ray evolution of QSOs, we must consider the sources that are not identified. In particular, the number of unidentified sources in the UK Deep Survey, with its low limiting flux and small number (11) of unidentified sources, provides the most realistic constraint to the number of high-redshift NELGs which we could have failed to identify, but which reasonable evolution models predict should be present. Of course, it is possible that some of the Deep Survey sources are misidentified and may, in fact, be high-redshift NELGs. However, the approach we have used is conservative (see McHardy et al. 1997) in that we classify any source as unidentified unless the chance of the optical identification being correct is very high. To estimate the misidentification rate in detail, we must consider each class of X-ray source.

The QSOs make up the largest group (32) of Deep Survey X-ray sources. Assuming an average X-ray error circle of $\sim$10-arcsec radius (a pessimistic assumption: see McHardy et al. 1997) and the highest measured surface density of QSOs to date (230 deg^{-2} derived from the UK Deep Survey itself: Jones et al. 1997), we would expect to have less than 0.5 chance coincidences between the X-ray sources and the QSOs, i.e., one can reasonably assume that all of the QSO identifications are correct. Only three objects are identified with Galactic stars; these all have optical to X-ray flux ratios typical of the active stars identified by Stocke et al. (1991); it is unlikely that any of these three sources are misidentified. Six X-ray sources (of which two are extended) have been identified as clusters or groups of galaxies on the basis of an overdensity of close companion galaxies, while 18 X-ray sources have been identified as NELGs. All four clusters/groups that are not associated with extended X-ray emission contain at least one galaxy with $R < 21$ mag. These four clusters/groups are probably the least secure identifications, in that one of the individual galaxies may be the X-ray source. However, the measured redshift for the brightest galaxy is in all cases < 0.6, and hence the clusters/groups are unlikely to be hiding any NELGs with $z > 0.6$ (but could plausibly be hiding $z < 0.6$ NELGs). The expected number of chance coincidences between the (non-QSO) X-ray sources and $R < 21$ galaxies of any spectral type and any redshift is $\sim$3, and hence in total we might expect $\sim$3 misidentifications caused by chance coincidence of X-ray sources and optical candidates.

However, at least five of the sources that are classed as unidentified have likely optical counterparts which are not $z > 0.6$ NELGs. We therefore take 11 as a reasonable upper limit to the number of $z > 0.6$ NELGs which are present, but unidentified, in the UK Deep Survey. Note that the unidentified sources in the RIXOS survey are unlikely to be high-redshift NELGs because of the high limiting flux of RIXOS; if RIXOS has systematically missed any NELGs they are likely to be of low redshift and hence lead to a lower evolution rate (see Section 4.2). This, and the larger number of unidentified sources in RIXOS than in the UK Deep Survey, mean that RIXOS does not provide a useful constraint on the number of high-redshift NELGs (and has not been used as such).

The rapid rates of evolution found from $\langle V_e / V_a \rangle$ cannot reproduce the redshift distribution of our samples, whether the fitting is performed for $0 < z < 3$ or $0 < z < 1$. As a consequence, if the PLE parameters are fixed at the rate obtained from the $\langle V_e/V_a \rangle$ test ($C \geq 2.7$ for $q_0 = 0$) and the luminosity function fitted in the interval $0 < z < 1$ using maximum likelihood, we would expect to have detected four NELGs with $0.6 < z < 1.0$ and nine with $1.0 < z < 3.0$ in the UK Deep Survey. This already formally exceeds the total number of unidentified sources in the UK Deep Survey, and hence optical incompleteness can resolve this discrepancy only if all the unidentified sources are NELGs with $z > 0.6$.

If the unidentified fraction of the UK Deep Survey consists mostly of NELGs with $z > 0.6$, then there must be some *systematic* reason why we could not identify them. This may perhaps be explained by the observed wavelength of Hβ approaching 8000 Å at $z = 0.6$ and the optical faintness of galaxies at $z > 0.6$. This systematic selection effect must also affect RIXOS, the CRSS, and the deep *ROSAT* sample used by Griffiths et al. (1996), none of which contain *any* NELGs with $z > 0.6$.

We have tested our data with the hypothesis that we are systematically unable to identify NELGs with $z > 0.6$ by imposing a limit of $z = 0.6$ on our $\langle V_e/V_a \rangle$ and maximum-likelihood fitting. The resultant evolution rate from $\langle V_e/V_a \rangle$ is unreasonably high, with a 95 per cent lower limit of $C = 3.6$ for $q_0 = 0$ and $C = 3.5$ for $q_0 = 0.5$, which, assuming a two-power-law luminosity function, corresponds to a 95 per cent lower limit of 30 NELGs with $z > 0.6$ being present (but unidentified) in the UK Deep Survey (impossible given that there are only 11 unidentified sources). Maximum-likelihood fitting gives a more modest 95 per cent lower limit to the evolution rate of $C = 2.3$, which would be acceptable at $z > 0.6$ only if almost all the UK Deep Survey unidentified sources are NELGs with $z > 0.6$. This means that under the extreme assumption that all the unidentified Deep Survey sources are $z > 0.6$ NELGs which we were systematically unable to identify, only the lower limit to the PLE rate measured at $z < 0.6$ ($C = 2.3$) provides a self-consistent description of the data.

It is therefore clear that a high rate of evolution ($C > 2.3$) is not consistent with our data set over the whole redshift range $0 < z < 3$. Either the evolution is slower ($C \sim 1$), or the evolution ends at some fairly low redshift ($z < 1$). We propose that the latter is a better representation of our data, given the very high $\langle V_e/V_a \rangle$ evolution rate determined at low redshift. The evolution we observe in our NELG sample is therefore slower and/or over a smaller redshift range than the evolution seen in X-ray-selected broad-line AGN, e.g., for $q_0 = 0$, $C \sim 3.0$ for $0 < z < 1.6$ (Jones et al. 1997), $C \sim 2.9$ for $0 < z < 1.8$ (Page et al. 1996), and $C \sim 3.0$ for $0 < z < 1.9$ (Boyle et al. 1994); with these QSO evolution rates, the number of $z > 0.6$ NELGs expected within the UK Deep Survey exceeds the number of unidentified X-ray sources.

The evolution rate we obtain from maximum-likelihood fitting in the interval $0 < z < 1$ is similar to that seen in the optical luminosity function of *I*-band-selected blue galaxies by Lilly et al. (1995). Lilly et al. report that the change in the luminosity function of blue galaxies is equivalent to a brightening of galaxy luminosities by 1 mag between $0 < z < 0.5$ and $0.5 < z < 0.75$, which corresponds to an evolution parameter $C \sim 2$ in the PLE model fitted here. This is also consistent with the evolution rate $C = 2.5$ found by Boyle et al. (1995), but is somewhat lower than the evolution rate ($C = 3.35$) found by Griffiths et al. (1996).

6 THE NELG CONTRIBUTION TO THE SOFT X-RAY BACKGROUND

The NELG contribution to the 1–2 keV X-ray background has been calculated, for the luminosity function and maximum-likelihood PLE parameters shown in Table 2, in the interval $0 < z < 3$ and $10^{40} < L_0 < 10^{45}$, where L_0 is the de-evolved 0.5–2 keV luminosity in erg s^{-1}. Note that if a lower limit to L_0 were not imposed on the two-power-law luminosity function, then the NELG contribution to the X-ray background would diverge. Where the fitting has been performed in the interval $0 < z < 1$, evolution has been assumed to stop at $z = 1$; where the fitting has been performed in the interval $0 < z < 3$, no limit has been applied to the evolution. A spectral index of $\alpha_X = 0.5$ has been assumed; the X-ray background intensity of each model is shown in Table 2 under the column entitled I_{XRB}. The NELG X-ray background intensities found here are in good agreement with those of Boyle et al. (1995) and Griffiths et al. (1996). Assuming an X-ray background intensity of 1.46×10^{-8} erg s^{-1} cm^{-2} sr^{-1} between 1 and 2 keV (Chen, Fabian & Gendreau 1997), which is in good agreement with the X-ray background intensity determined from the UK Deep Survey field itself, $1.4 \pm 0.1 \times 10^{-8}$ erg s^{-1} cm^{-2} sr^{-1} (Branduardi-Raymont et al. 1994), our model luminosity functions predict that NELGs produce between 15 and 35 per cent of the 1–2 keV X-ray background. We stress that our sample of NELGs is small, that the assumption of PLE may not be correct, and that we have not included the contribution of NELGs with $L < 10^{40}$ erg s^{-1}, because these are not detected in our surveys. For these reasons, the real contribution of NELGs to the X-ray background may lie outside the range given above.

7 CONCLUSIONS

We detect evolution in a sample of NELGs obtained from RIXOS and the *ROSAT* UK Deep Survey with 99 per cent confidence. This sample is independent of the NELG samples for which evolution has been detected previously; selection effects can account for some, but not all, of the evolution. Currently, there are insufficient NELGs to determine what form the evolution takes; luminosity *or* density evolution can account for the change in the luminosity function with redshift. The evolution we see in the X-ray luminosity function of NELGs is of the same order as the evolution of the optical luminosity function of blue galaxies found by Lilly et al. (1995).

Using a power-law pure luminosity evolution model commonly used to parametrize the evolution of broad-line AGN, we find that our data are most consistent with evolution which is slower than that of broad-line AGN ($C \sim 2$) and has stopped by $z = 1$. Maximum-likelihood fitting of this evolution model does not reproduce the very high evolution rate found by Griffiths et al. (1996), but is broadly consistent with the evolution rate found by Boyle et al. (1995). The lack of NELGs found at $z > 0.6$ indicates that their X-ray evolution is not as rapid as that seen in broad-line AGN, unless it is confined to low redshifts ($z < 1$). This means that the evolution of the X-ray-selected NELG luminosity function is probably *not* the same as that of broad-line AGN.

Our fits to the luminosity function and evolution of NELGs suggest that such objects with $L > 10^{40}$ erg s^{-1} contribute between 15 and 35 per cent of the 1–2 keV X-ray background.

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