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Normal galaxies, f_X/f_O, L_X: A *Chandra* and *XMM-Newton* study of southern fields

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Abstract: We cross-correlated the *Chandra* XASSIST and *XMM-Newton* Serendipitous Source Catalogue with the 2df Galaxy Redshift Survey. We aimed to identify the most X-ray luminous ($L_X > 10^{42}$ erg s^{-1}) galaxies whose X-ray emission is not dominated by an AGN but by stellar processes ('normal' galaxies, NGs) as well as to test the criterion log f_X / f_{opt} < -2 for separating AGN from NGs. We found 20 2dfGRS galaxies within 3" of a *Chandra* source, and 18 galaxies within 6" of an *XMM-Newton* source. Using emission-line intensity ratios, we classified six 2dfGRS spectra as H II nuclei, and two spectra as possible H II nuclei. The rest of the objects are absorption line galaxies and AGN, including LINERS. No luminous NGs have been found but eight NGs (five H II and three absorption galaxies) have log f_X / f_{opt} > -2 . We performed a similar search in two samples from the literature. In the first sample, which comprises only star-forming galaxies, all galaxies have $L_X < 10^{42}$ erg s^{-1} and log f_X / f_{opt} < -2 . In the second, which comprises all galaxy types, there are four galaxies with log f_X / f_{opt} > -2 and $L_X < 10^{42}$ erg s^{-1} , of which two are massive ellipticals and two non-ellipticals. Thirteen galaxies have log f_X/f_{opt} > -2 and $L_X > 10^{42}$ erg s^{-1} , of which one is a mixed starburst/Seyfert 2 and the rest massive ellipticals. On the whole, the log f_X / f_{opt} < -2 criterion primarily selects against bright, massive elliptical NGs.

Introduction

'Normal' (non-AGN dominated) galaxies (NGs) usually have weak X-ray luminosity, $L_X < 10^{42}$ erg s^{-1} (Moran et al. 1999, Zezas et al. 1998). Before the *Chandra* and *XMM-Newton* era, X-ray studies of NGs were only possible for **local** objects (< 100 Mpc). Further, these galaxies were **optically** selected.

The first X-ray selected sample of NGs was obtained with the Chandra Deep Fields (CDFs, Alexander et al. 2003, Giacconi et al. 2002) at a median redshift $z \sim 0.3$, since *Chandra* reaches very low flux limits, f(0.5-2keV) < 10-16 erg s^{-1}cm^{-2}.
In the CDF-North Hornschemeier et al. (2003) found 43 NG candidates with X-ray to optical flux ratios log (f_X / f_{opt}) < -2 . In both CDFs Norman et al. (2004) found more than 100 NG candidates, some with log (f_X / f_{opt}) > -2 . Georgakakis et al. (2003, 2004a) have identified NGs with log (f_X / f_{opt}) ~ -2 . Further, Georgakakis et al (2004b) and Georgantopoulos et al. (2005) applied the log (f_X / f_{opt}) < -2 criterion to select NGs from *XMM-Newton* and CDF data to obtain the first local X-ray luminosity function of NGs (**Fig. 1**).

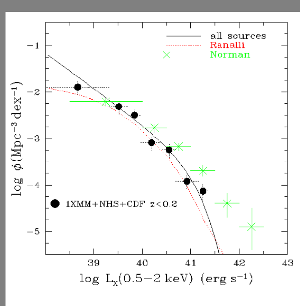

Fig. 1 X-ray luminosity functions (Georgantopoulos et al. 2005).
Filled circles: NGs selected by Georgantopoulos et al.
Crosses: Norman et al. 2004
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In Fig. 1 there is good agreement between Georgantopoulos et al. and Norman et al. at the faint end. However, the discrepancy at the bright end could mean that the log (f_X / f_{opt}) < -2 criterion selects against luminous starbursts and massive ellipticals although luminosity evolution is another possibility. In this work we address this issue. Our aims were:

1. To search for luminous (log L_X > 42) star-forming galaxies.
2. To test the criterion log (f_X / f_{opt}) < -2 for separating NGs from AGN.

2dFGRS data

We used optical spectroscopic data from the 2 degree field galaxy redshift survey (2dfGRS, Colless et al. 2003, 2001) . Its depth (b_J=19.45) allow detection of galaxies up to log (f_X / f_{opt}) ~ 1 for f_X ~ few x 10^{-14} erg cm^{-2} s^{-1}.

XMM-Newton observations

We cross-correlated archival observations from the 1XMM-Serendipitous Source Catalogue with the 2dfGRS and obtained 18 X-ray/optical pairs within a 6" matching radius.

Chandra observations

We cross-correlated observations from the XASSIST catalogue (http://www.xassist.org) with the 2dfGRS and obtained 20 X-ray/optical pairs within a 3" matching radius.

Calculations

For each source we calculated L_X , f_X (Γ=1.8) as well as hardness ratios HR=(H-S)/(H+S), (H hard band counts, S soft band counts). We calculated log(f_X/f_{opt}) using the relation of Stocke et al. 1991 log (f_X / f_{opt}) = log f_X (0.3 – 3.5 keV) + 0.4V + 5.37 and B-V from Fukugita et al. 1995. We estimate the areas searched to obtain our correlation samples to be ~8.2 and ~5.8 square degrees for *XMM* and *Chandra*, respectively. We used H_0=72 km s^{-1}Mpc^{-1} and the 'conconrdance' cosmological model.

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Diagnostic emission-line ratios were our primary classification criterion.
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The 2dFGRS fiber spectra cannot be reliably flux-calibrated, so we were very conservative in classifying galaxies using this criterion. If not enough lines were available, the classification, if suggested at all, is only tentative. If this criterion was unusable, we also looked for *broad emission lines* and *high* N_H , both indicative of an AGN. LINERS were classifiedby means of the line intensity ratio criteria for [O II] 3727, [O III] 5007 and [O I] 6300 by Heckman (1980).

We thus classified 6 spectra as H II nuclei, and 2 spectra as possible H II nuclei as shown in the tables below. The rest of the objects are absorption line galaxies, AGN and LINERS: see **Tables 1 and 2**.

We complemented our results with data from the literature (Zezas 2001, Fabbiano et al. 1992, see **Fig. 2** and **Table 3**). The correlation apparent in Fig. 2 is to be expected from the relation $L_X \sim L_B^{1.8}$ (Fabbiano et al. 1992). Incompleteness is important for the region between 41 and 42 in log L_X (see Table 3).

Table 1. The *XMM-Newton/2dFGRS* correlation sample. Shown from left to right are sample identification number, *2dFGRS* database name, right ascension and declination for the X-ray source, offset between X-ray and optical source, b_J magnitude from *2dFGRS*, X-ray flux, redshift from *2dFGRS*, logarithm of X-ray luminosity, logarithmic X-ray-to-optical flux ratio, hardness ratio and error, and, in the last column, galaxy type. For this column the following abbreviations hold: A: absorption line galaxy; F: featureless; G: group; H II: H II nucleus. A question mark indicates that a classification is not possible. Question marks after a classification indicate a high degree of uncertainty.

ID	Name	α_X (J2000)	δ_X (J2000)	δ_{XO} ('')	b_J	$f_X/10^{-14}$ (cgs)	z	log L_X (cgs)	log f_X/f_O	HR	±	Type
1	TGS548Z244	23 56 27.68	−34 35 35.8	0.65	15.52	1.700	0.0479	40.94	−2.09	−1.00	0.11	A
2	TGS549Z357	23 56 10.72	−34 49 42.1	3.20	18.73	1.170	0.2399	42.26	−0.97	−0.74	0.16	F, G
3	TGS617Z146	00 58 18.33	−35 55 48.1	3.12	18.01	0.375	0.0479	40.28	−1.75	−0.57	0.15	H II
4	TGS210Z018	00 55 51.51	−27 26 09.7	3.19	19.12	4.555	0.2125	42.74	−0.22	−0.50	0.24	F
5	TGS327Z003	21 51 06.12	−30 24 27.1	1.72	18.83	2.080	0.1373	42.00	−0.68	−0.77	0.17	A, G
6	TGS063Z133	22 21 51.26	−24 45 30.7	0.98	19.08	2.470	0.0777	41.54	−0.51	−0.26	0.09	AGN
7	TGS120Z043	22 35 32.80	−26 06 05.6	3.83	15.37	0.321	0.0192	39.40	−2.87	−0.62	0.15	H II
8	TGN296Z199	10 44 44.83	−01 20 17.7	1.35	18.73	2.230	0.1846	42.29	−0.69	−0.71	0.04	?
9	TGN295Z042	10 44 19.91	−01 24 26.7	1.97	18.69	0.158	0.0610	40.13	−1.86	−0.37	0.17	H II
10	TGN295Z067	10 43 52.59	−01 17 40.1	2.97	14.69	3.330	0.0262	40.70	−2.13	−0.75	0.03	H II
11	TGN448Z020	11 51 29.69	+01 48 31.7	5.81	18.80	0.211	0.1581	41.13	−1.68	−0.80	0.17	F
12	TGN388Z113	12 29 47.33	+01 54 03.5	1.03	19.04	1.360	0.1577	41.94	−0.78	−0.77	0.11	?
13	TGN387Z032	12 28 58.43	+02 11 27.2	0.14	16.64	0.500	0.0775	40.84	−2.18	−1.00	0.07	A
14	TGN387Z056	12 28 17.84	+02 12 29.3	0.55	18.86	3.850	0.1203	42.16	−0.40	−0.66	0.11	?
15	TGN387Z067	12 28 07.61	+02 02 52.1	0.66	18.48	0.694	0.0903	41.12	−1.30	−0.61	0.19	?
16	TGN266Z089	13 31 39.59	−01 48 26.2	4.79	18.23	0.290	0.0749	40.57	−1.77	−0.26	0.20	H II
17	TGS924Z253	22 52 28.19	−17 49 16.8	0.78	19.24	3.290	0.1331	42.16	−0.31	−0.63	0.05	?
18	TGS924Z246	22 52 31.62	−17 46 32.4	0.60	18.44	0.853	0.0689	40.97	−1.22	−0.43	0.23	H II

Table 2. The *Chandra/2dFGRS* correlation sample. Column details are as in the previous figure.

ID	Name	α_X (J2000)	δ_X (J2000)	δ_{XO} ('')	b_J	$f_X/10^{-14}$ (cgs)	z	log L_X (cgs)	log f_X/f_O	HR	±	Type
1	TGS432Z052	23 58 27.21	−32 41 03.3	0.23	19.20	6.36	0.2394	42.99	−0.50	+0.39	0.04	AGN[1]
2	TGS522Z150	02 57 14.04	−33 18 27.5	0.82	17.93	1.84	0.1093	41.72	−1.54	+0.23	0.11	AGN[1]
3	TGS212Z026	00 58 24.51	−27 29 23.2	0.78	16.83	0.36	0.0977	40.91	−2.70	−0.63	0.24	H II?
4	TGS211Z082	00 56 51.78	−27 28 56.3	1.44	18.90	4.22	0.2144	42.71	−0.80	+0.61	0.11	AGN[1]
5	TGS243Z005	03 32 46.89	−27 42 13.3	2.52	17.53	0.39	0.1028	41.00	−2.38	−0.54	0.12	A
6	TGS407Z114	22 01 36.09	−31 53 23.2	1.63	18.06	1.63	0.0972	41.56	−1.55	+0.24	0.03	AGN[1]
7	TGS132Z150	23 51 39.38	−26 05 02.5	2.90	18.00	9.17	0.2346	43.13	−0.82	−0.61	0.01	LINER
8	TGN163Z121	10 56 50.04	−03 33 42.8	1.10	17.69	0.69	0.0488	40.56	−2.07	−0.56	0.07	A (noisy)
9	TGN163Z123	10 56 48.84	−03 37 25.8	0.73	18.54	0.41	0.1816	41.55	−1.96	−0.78	0.10	A
10	TGN071Z177	12 49 02.23	−05 49 33.8	1.43	18.34	0.60	0.0485	40.50	−1.87	−0.32	0.08	H II?
11	TGN206Z127	14 12 49.69	−03 07 19.7	2.59	18.09	0.94	0.0748	41.08	−1.77	−0.43	0.13	AGN?
12	TGN440Z057	11 23 20.17	+01 38 09.9	1.84	18.66	0.07	0.1259	40.47	−2.66	−0.68	0.25	A
13	TGN382Z123	12 04 27.15	+01 53 46.2	2.69	14.25	3.10	0.0197	40.42	−2.79	−0.80	0.01	A
14	TGN243Z240	11 55 45.38	−01 41 30.3	0.70	19.00	1.79	0.2476	42.48	−1.13	−0.57	0.08	LINER?
15	TGN247Z076	12 16 01.62	−00 37 33.6	0.46	17.70	0.25	0.1214	40.98	−2.50	−1.00	0.24	A
16	TGN318Z209	12 15 53.29	−00 36 06.9	1.71	18.00	0.23	0.1193	40.90	−2.42	−0.39	0.21	A
17	TGN336Z169	13 44 52.88	+00 05 20.4	0.81	17.38	77.8	0.0876	43.14	−0.14	−0.63	0.02	AGN?[2]
18	TGN336Z187	13 44 28.34	+00 01 47.2	0.71	18.12	0.56	0.1351	41.43	−1.98	−1.00	0.48	A
19	TGN275Z203	14 12 34.68	−00 35 00.1	0.49	18.16	30.4	0.1269	43.09	−0.24	−0.74	0.07	AGN?[3]
20	TGS906Z501	23 25 19.74	−12 07 26.2	1.77	15.89	4.94	0.0824	41.89	−1.93	−0.64	0.002	LINER

1: Obscured AGN suggested by high N_H value.
2: Suggested by a an Hβ FWHM ~ 2000km s^{-1}.
3: Suggested by a an Hβ FWHM ~ 1500km s^{-1}.

Table 3. NGs with log $f_X/f_O > -2$. Groups of rows separated by horizontal lines correspond to the sample indicated in the first column. *2dFGRS* stands for the combined correlation samples *2dFGRS–XMM-Newton* and *2dFGRS–Chandra*. Each row corresponds to the NG type indicated in the second column. Each of the last three columns gives the fraction of NGs with log $f_X/f_O > -2$ in the log L_X region indicated at the top of the column. Galaxies for which only upper limit information is available have not been taken into account. Empty entries indicate that no NGs of this type have been found. Some galaxy labels are as in tables 2 and 1. For the rest, S stands for spiral, Irr for irregular and E for elliptical.

Sample	NG type	log L_X < 42	41 < log L_X < 42	log $L_X \geq 42$
2dFGRS	H II	4/26		
	H II?	1/26		
	A	2/26	2/10	1/12
Zezas (2001)	any	0	0	0
Fabbiano et al. (1992)	S/H II	1/194	1/75	1/40
	Irr	1/194	1/75	
	E	1/194	1/75	13/40

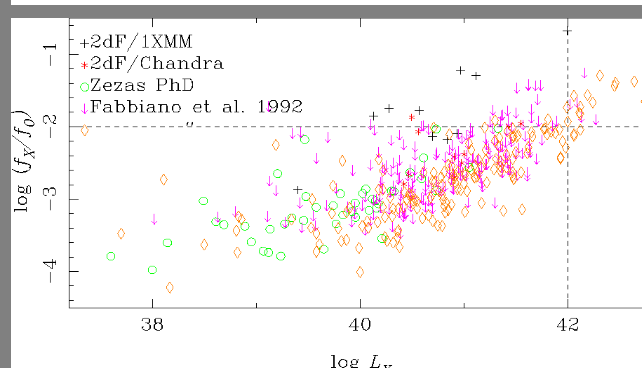

Fig. 2: log f_X/f_{opt} vs. L_X . We plot value from our correlation samples and from the literature. Only non-AGN are plotted. Compare with **Table 3.**

Conclusions

1. We found no luminous NGs in our correlation samples.
2. In our samples, five HII galaxies and three absorption line galaxies have log f_X/f_{opt} > -2.
3. In the Zezas et al. (2001) sample all galaxies have log L_X < 42 and log f_X/f_{opt} < -2.
4. In the Fabbiano et al. (1992) sample there are two non-ellipticals and four ellipticals with log f_X/f_{opt} > -2.
5. The log f_X/f_{opt} < -2 selects against bright, massive ellipticals. Our correlation samples suggest it may also select somewhat against star-forming galaxies. However, better spectra and stellar template subtraction is necessary before a more definitive statement can be made in this respect.

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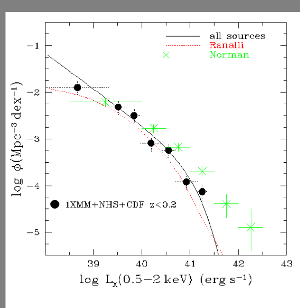

Fig. 1 X-ray luminosity functions (Georgantopoulos et al. 2005).
Filled circles: NGs selected by Georgantopoulos et al.
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8	TGN296Z199	10 44 44.83	−01 20 17.7	1.35	18.73	2.230	0.1846	42.29	−0.69	−0.71	0.04	?
9	TGN295Z042	10 44 19.91	−01 24 26.7	1.97	18.69	0.158	0.0610	40.13	−1.86	−0.37	0.17	H II
10	TGN295Z067	10 43 52.59	−01 17 40.1	2.97	14.69	3.330	0.0262	40.70	−2.13	−0.75	0.03	H II
11	TGN448Z020	11 51 29.69	+01 48 31.7	5.81	18.80	0.211	0.1581	41.13	−1.68	−0.80	0.17	F
12	TGN388Z113	12 29 47.33	+01 54 03.5	1.03	19.04	1.360	0.1577	41.94	−0.78	−0.77	0.11	?
13	TGN387Z032	12 28 58.43	+02 11 27.2	0.14	16.64	0.500	0.0775	40.84	−2.18	−1.00	0.07	A
14	TGN387Z056	12 28 17.84	+02 12 29.3	0.55	18.86	3.850	0.1203	42.16	−0.40	−0.66	0.11	?
15	TGN387Z067	12 28 07.61	+02 02 52.1	0.66	18.48	0.694	0.0903	41.12	−1.30	−0.61	0.19	?
16	TGN266Z089	13 31 39.59	−01 48 26.2	4.79	18.23	0.290	0.0749	40.57	−1.77	−0.26	0.20	H II
17	TGS924Z253	22 52 28.19	−17 49 16.8	0.78	19.24	3.290	0.1331	42.16	−0.31	−0.63	0.05	?
18	TGS924Z246	22 52 31.62	−17 46 32.4	0.60	18.44	0.853	0.0689	40.97	−1.22	−0.43	0.23	H II

Table 2. The *Chandra/2dFGRS* correlation sample. Column details are as in the previous figure.

ID	Name	α_X (J2000)	δ_X (J2000)	δ_{XO} (″)	b_J	$f_X/10^{-14}$ (cgs)	z	$\log L_X$ (cgs)	$\log f_X/f_O$	HR	±	Type
1	TGS432Z052	23 58 27.21	−32 41 03.3	0.23	19.20	6.36	0.2394	42.99	−0.50	+0.39	0.04	AGN[1]
2	TGS522Z150	02 57 14.04	−33 18 27.5	0.82	17.93	1.84	0.1093	41.72	−1.54	+0.23	0.11	AGN[1]
3	TGS212Z026	00 58 24.51	−27 29 23.2	0.78	16.83	0.36	0.0977	40.91	−2.70	−0.63	0.24	H II?
4	TGS211Z082	00 56 51.78	−27 28 56.3	1.44	18.90	4.22	0.2144	42.71	−0.80	+0.61	0.11	AGN[1]
5	TGS243Z005	03 32 46.89	−27 42 13.3	2.52	17.53	0.39	0.1028	41.00	−2.38	−0.54	0.12	A
6	TGS407Z114	22 01 36.09	−31 53 23.2	1.63	18.06	1.63	0.0972	41.56	−1.55	+0.24	0.03	AGN[1]
7	TGS132Z150	23 51 39.38	−26 05 02.5	2.90	18.00	9.17	0.2346	43.13	−0.82	−0.61	0.01	LINER
8	TGN163Z121	10 56 50.04	−03 33 42.8	1.10	17.69	0.69	0.0488	40.56	−2.07	−0.56	0.07	A (noisy)
9	TGN163Z123	10 56 48.84	−03 37 25.8	0.73	18.54	0.41	0.1816	41.55	−1.96	−0.78	0.10	A
10	TGN071Z177	12 49 02.23	−05 49 33.8	1.43	18.34	0.60	0.0485	40.50	−1.87	−0.32	0.08	H II?
11	TGN206Z127	14 12 49.69	−03 07 19.7	2.59	18.09	0.94	0.0748	41.08	−1.77	−0.43	0.13	AGN?
12	TGN440Z057	11 23 20.17	+01 38 09.9	1.84	18.66	0.07	0.1259	40.47	−2.66	−0.68	0.25	A
13	TGN382Z123	12 04 27.15	+01 53 46.2	2.69	14.25	3.10	0.0197	40.42	−2.79	−0.80	0.01	A
14	TGN243Z240	11 55 45.38	−01 41 30.3	0.70	19.00	1.79	0.2476	42.48	−1.13	−0.57	0.08	LINER?
15	TGN247Z076	12 16 01.62	−00 37 33.6	0.46	17.70	0.25	0.1214	40.98	−2.50	−1.00	0.24	A
16	TGN318Z209	12 15 53.29	−00 36 06.9	1.71	18.00	0.23	0.1193	40.90	−2.42	−0.39	0.21	A
17	TGN336Z169	13 44 52.88	+00 05 20.4	0.81	17.38	77.8	0.0876	43.14	−0.14	−0.63	0.02	AGN?[2]
18	TGN336Z187	13 44 28.34	+00 01 47.2	0.71	18.12	0.56	0.1351	41.43	−1.98	−1.00	0.48	A
19	TGN275Z203	14 12 34.68	−00 35 00.1	0.49	18.16	30.4	0.1269	43.09	−0.24	−0.74	0.07	AGN?[3]
20	TGS906Z501	23 25 19.74	−12 07 26.2	1.77	15.89	4.94	0.0824	41.89	−1.93	−0.64	0.002	LINER

1: Obscured AGN suggested by high N_H value.
2: Suggested by a an Hβ FWHM ~ 2000km s^{-1}.
3: Suggested by a an Hβ FWHM ~ 1500km s^{-1}.

Table 3. NGs with $\log f_X/f_O > -2$. Groups of rows separated by horizontal lines correspond to the sample indicated in the first column. *2dFGRS* stands for the combined correlation samples *2dFGRS–XMM-Newton* and *2dFGRS–Chandra*. Each row corresponds to the NG type indicated in the second column. Each of the last three columns gives the fraction of NGs with $\log f_X/f_O > -2$ in the $\log L_X$ region indicated at the top of the column. Galaxies for which only upper limit information is available have not been taken into account. Empty entries indicate that no NGs of this type have been found. Some galaxy labels are as in tables 2 and 1. For the rest, S stands for spiral, Irr for irregular and E for elliptical.

Sample	NG type	$\log L_X < 42$	$41 < \log L_X < 42$	$\log L_X \geq 42$
2dFGRS	H II	4/26		
	H II?	1/26		
	A	2/26	2/10	1/12
Zezas (2001)	any	0	0	0
Fabbiano et al. (1992)	S/H II	1/194	1/75	1/40
	Irr	1/194	1/75	
	E	1/194	1/75	13/40

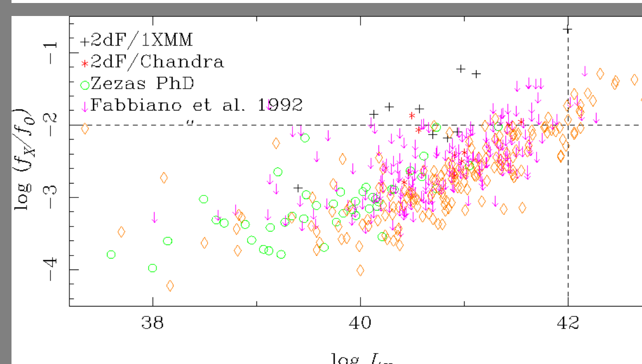

Fig. 2: $\log f_X/f_{opt}$ vs. L_X . We plot value from our correlation samples and from the literature. Only non-AGN are plotted. Compare with **Table 3.**

Conclusions

1. We found no luminous NGs in our correlation samples.
2. In our samples, five HII galaxies and three absorption line galaxies have $\log f_X/f_{opt} > -2$.
3. In the Zezas et al. (2001) sample all galaxies have $\log L_X < 42$ and $\log f_X/f_{opt} < -2$.
4. In the Fabbiano et al. (1992) sample there are two non-ellipticals and four ellipticals with $\log f_X/f_{opt} > -2$.
5. The $\log f_X/f_{opt} < -2$ selects against bright, massive ellipticals. Our correlation samples suggest it may also select somewhat against star-forming galaxies. However, better spectra and stellar template subtraction is necessary before a more definitive statement can be made in this respect.