THE ASTROPHYSICAL JOURNAL, 393:90–97, 1992 July 1

THE SPATIAL DISTRIBUTION OF ACTIVE GALACTIC NUCLEI. I. THE DENSITY OF SEYFERT GALAXIES AND LINERS

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Received 1990 September 4; accepted 1992 January 7

ABSTRACT

We define and use a "complete" sample of 25 Seyfert 1 and 23 Seyfert 2 galaxies within the spatial bounds and magnitude limit of the CfA Redshift Survey. The spatial density of Seyfert galaxies is calculated; classical Seyfert galaxies comprise 1.3% of all galaxies at integrated absolute magnitude −20.0. This result is in substantial agreement with our previous estimates based on considerably more incomplete samples. The fraction of galaxies that are active galactic nuclei (AGNs) rises steeply with absolute magnitude. Three of the five galaxies in the CfA survey (2399 galaxies total) more luminous than $M_B = -21.5$ are AGNs ($H_0 = 100$ km s^{-1} Mpc^{-1}); the two most luminous galaxies in the CfA survey are both Seyfert 1 galaxies. The integrated space density of Seyfert 2 galaxies is found to be approximately twice as large as the space density of Seyfert 1 galaxies.

We also attempt to measure the spatial density of other types of "active" galactic nuclei—in particular LINERs, but find severe selection effects in our optically selected sample of such objects.

Subject headings: galaxies: active — galaxies: Seyfert

1. INTRODUCTION

Over the last two decades research on active galactic nuclei (AGNs) has become one of the most popular fields in astronomy. Despite the number of publications dealing with these objects, many fundamental questions concerning their origin, central energy generation mechanisms and their relation to "normal" galaxies are still unanswered. Even worse, the field is still plagued by many misconceptions.

The particular problem we will address in this paper is the absolute volume density of common types of AGNs and the relative fraction of field galaxies that are AGNs. These results are of interest not only to understand the origin of such objects but also their evolution and their position in cosmology (e.g., their contributions to the X-ray background and their use as possible tracers of galaxy distributions).

To date, over a dozen papers have been written on the optical luminosity function of Seyfert galaxies alone (Sargent 1972; Huchra & Sargent 1973; Notni & Richter 1972; Arakelian 1974, 1977; Terebizh 1980; Meurs & Wilson 1984; Wasilewski 1983; Weedman 1977; Bohuski, Fairall, & Weedman 1978; Veron 1979; Osterbrock & Dahari 1983; Cheng et al. 1985; Marshall 1985, 1987, etc.) and several on their X-ray luminosity function (Tananbaum et al. 1978; Elvis et al. 1978; Reichert & Shafer 1984; Maccacaro, Gioia, & Stocke 1984, etc.). All of the optical analyses suffer from major selection effects that can seriously limit their usefulness. For example, the majority of these studies depend on samples from objective-prism surveys (Markarian 1967; Markarian & Lipovetskii 1976, and references therein; MacAlpine et al. 1978, and references therein). These are known to have biases associated with color (UV excess), contrast of emission lines to the continuum (Salzer 1989), and redshift (the IIIa-J effect—Bohuski et al. 1978), as well as simple incompleteness (Huchra, Wyatt, & Davis 1982, hereafter HWD). Also, Seyfert 2 galaxies are harder to find than Seyfert 1 galaxies; contrast between nucleus and parent galaxy is very important. Last, as has been repeatedly pointed out by Osterbrock (e.g., Osterbrock & Dahari 1983), many objects are mistakenly classified as AGNs based on low-dispersion spectroscopy.

Some early workers artificially enlarged the numbers of objects in their samples by increasing the limiting magnitude. To correct for the incompleteness in samples constructed this way, they modify the differential number of objects in their samples to achieve a mean V/V_m of 0.5 (e.g., Huchra & Sargent 1973; Terebizh 1980; Meurs & Wilson 1984). This is somewhat effective, but depends critically on the assumption that the redshift distribution of missing objects can be estimated from the observed sample. This assumption is incorrect when the missing objects are systematically the faintest in the sample.

One obvious but difficult solution to these dilemmas is to use a spectroscopically complete sample. The most important step in classification of an object as an AGN is intermediate-dispersion spectroscopy. Fortunately such a sample can indeed be constructed. The CfA Redshift Survey (Davis, Huchra, & Latham 1983; Huchra et al. 1983) is a magnitude-limited sample of ~2400 galaxies with essentially complete spectroscopic information. A partial list of new AGNs discovered in this survey has already been published (HWD).

A second paper (Burg & Huchra 1992) will discuss the spatial distribution—in particular, the three-dimensional correlation function, for Seyfert galaxies relative to that of normal galaxies.

2. THE SAMPLE

The sample we use here is derived from the CfA Redshift Survey which consists of all 2399 galaxies in the merged

Zwicky-Nilson catalog (Zwicky et al. 1961–1966; Nilson 1973) that satisfy the following criteria:

$$m_{\mathrm{Zw}} \leq 14.5\ ,$$

and either

$$\delta \geq 0° \quad \text{and} \quad b_{\mathrm{II}} \geq 40°\ ,$$

or

$$\delta \geq -2.5° \quad \text{and} \quad b_{\mathrm{II}} \leq -30°\ .$$

(Note that m_{Zw} is essentially the same as m_{pg}). Optical spectroscopy covering the range 4600–7000 Å is now available for over 98.5% of this sample from the CfA survey. The remaining galaxies are either the brightest objects in the survey which generally have been well observed spectroscopically by many observers, or low surface brightness dwarf galaxies, like the companions to the Milky Way, for which it is difficult to obtain optical spectra because they do not have identifiable nuclei (and are thus *extremely* unlikely to be AGNs).

In addition, this part of the sky has been well observed by Markarian and coworkers as well as other AGN hunters. The objects in this sample have been classified as in HWD; our classification is basically a spectroscopic one based on the presence of emission lines indicative of nonthermal (nonstellar) activity. Galaxy spectra are classified by visual inspection of plots (cf. the examples in HWD). Objects whose classification was in doubt have been reobserved with higher signal-to-noise ratio (S/N) and/or at higher dispersion. Note that one such object in HWD, NGC 7672, is actually a narrow emission-line galaxy, not a Seyfert 2. This object, however, is fainter than the complete sample magnitude limit. We have not attempted to "subclassify" the Seyfert galaxies into fractions between 1 and 2; any object with an easily visible broad permitted line component (the exact criteria will depend on velocity-width, contrast, and the S/N of the spectrum) was classified as a type 1. Additional information on classification can be found in Osterbrock (1987).

The CfA sample is limited by magnitude. The Zwicky catalog is magnitude-limited to 1 mag fainter than our survey. The Nilson catalog is diameter-limited and adds only one new galaxy (an elliptical that Zwicky missed!) to the merged catalog limited at $m_b = 14.5$. Less than 0.1% of the galaxies in the sample have redshifts that would place the Hα line out of our spectral range; the spectra of those galaxies have been examined and show no evidence of nonthermal activity.

Our catalog of AGNs is given in Table 1. The coordinates (cols. [2] and [3]) come from Clements (1981, 1983; and private communication), from the Zwicky catalog or the Second Reference Catalog or from Edelson's radio positions (Edelson 1987). The magnitude (col. [4]) is in the uncorrected $B(0)$–Zw system (Huchra 1976), which is sufficiently accurate ($\sim$0.3 mag rms) for our purposes. The velocities (col. [5]) are heliocentric *cz* (the IAU standard). The *UBV* photometry (cols. [7], [8], and [9]) comes from the master catalog of Cruz-Gonzalez (1985) and various compilations by Longo & de Vaucouleurs (1983, 1985). The quoted photometry represents the smallest aperture, accurate photometry available. For the well-observed objects this usually means 10″ or 15″, but for the more recently identified, bright galaxies the only photometry available has been done in larger apertures (see, e.g., Longo & de Vaucouleurs 1983).

We have included in this list four objects classified as AGNs in addition to ordinary Seyfert galaxies and low-ionization nuclear emission-line regions (LINER). These are Mrk 421 which is a bright BL Lacertae–type galaxy, the two intermediate-strength X-ray galaxies, NGC 3862 and NGC 4156, discussed by Elvis et al. (1981), and the only quasar inside the survey boundaries brighter than 14.5 mag—3C 273. The presence of these last objects has no significant effect on either the general form of the luminosity function or on the mean averaged luminosity density of AGNs. We will not discuss them further. The quasar 3C 273 is far removed from the normal range of parameters for all the other objects in this sample. We include it, however, because it *does* satisfy the selection criteria of equations (1)–(3), and we think it acts as an important example of the difficulties of defining a complete sample of AGNs. Note also that this area has been well surveyed for other bright ($m < 16$) QSOs by Schmidt & Green (1983). We should note that early versions of our list did not include NGC 4395 which was discovered to be a Seyfert 1 galaxy by Filippenko & Sargent (1989). This was one of the few objects we did not have a spectrum for.

It is important to point out that this sample is primarily magnitude-limited. Very few extragalactic objects have been found that are brighter than 14.5 and yet are not in Zwicky's lists. For example, all of the PG objects (Schmidt & Green 1983) satisfying our criteria were already in the sample except for 3C 273. The sample is neither redshift-limited nor diameter-limited. In addition, almost all of the objects classified as Seyferts have strong, well-observed emission lines.

Most of the LINERs in this sample were identified in the original survey of Heckman (1980) or in the more recent surveys of Stauffer (1982) and Keel (1983). As we will discuss later, relatively high S/N spectra are needed to detect these objects, thus there is a bias against their discovery by the CfA survey.

The present sample contains 26 Seyfert 1 galaxies, 23 Seyfert 2 galaxies, 33 LINERs, one QSO, which can be spectroscopically considered equivalent to a Seyfert 1 galaxy, and three other objects. A major fraction of the Seyfert galaxies (24% of the Seyfert 1 and 43% of the Seyfert 2) are *spectroscopically* discovered objects uncovered in the CfA survey (HWD). A detailed discussion of the radio properties of this sample can be found in Edelson (1987).

3. COMPLETENESS: THE V/V_m TEST

The first question we want to ask about our sample is whether or not it is biased. Schmidt (1968) applied a technique called the V/V_m test to determine if samples of objects had uniform distributions in space. This test can also be used to test for sample completeness if it is known that objects *are* more or less uniformly distributed (e.g., Huchra & Sargent 1973). For the Seyfert galaxies in our sample we expect that cosmological effects (evolution) are negligible—the highest redshifts are only a few tenths—and local clustering is also insignificant—the CfA Redshift Survey limit for luminous galaxies (and Seyferts are generally luminous, cf. Huchra & Sargent 1973, and below) reaches to over 100 Mpc ($H_0 = 100$ km s^{-1} Mpc^{-1}) and covers a large area of the sky. Table 2 shows the V/V_m for our samples of Seyfert 1 galaxies, Seyfert 2 galaxies, and LINERs as a function of limiting magnitude. The Seyfert samples have mean V/V_m values of $\sim$0.5, the expectation value for a complete, approximately uniform sample. Other groups, using

TABLE 1

BRIGHT ACTIVE GALACTIC NUCLEI

Name (1)	R.A. (1950) (2)	Decl. (3)	m_b (4)	V_H (5)	Type[a] (6)	V (7)	$B-V$ (8)	$U-B$ (9)
Mrk 334	00h00m35s.6	21°40′54″	14.40	6605	2	14.42	0.13	0.31
Mrk 335	00 03 45.2	19 55 29	14.00	7757	1	13.85	0.41	−.70
A0048+29	00 48 53.1	29 07 46	14.50	10763	1			
I ZW 1	00 50 57.9	12 25 18	14.30	18116	1	14.07	0.36	−.80
Mrk 993	01 22 42.7	31 52 36	14.00	4625	2	13.43	1.04	0.23
Mrk 573	01 41 22.9	02 05 57	14.00	5178	2	13.64	0.97	0.09
0152+06	01 52 44.7	06 22 02	14.50	5208	2			
NGC 863	02 12 00.5	−0 59 58	14.00	7891	1	13.94	0.56	−.80
NGC 1068	02 40 07.0	−0 13 31	10.30	1109	2	10.44	1.00	−.01
NGC 1144	02 52 38.9	−0 23 07	13.20	8641	2	14.41	1.01	0.22
NGC 2768	09 07 45.0	60 14 30	11.48	1363	L	11.90	1.04	0.54
NGC 2841	09 18 34.6	51 11 18	10.27	637	L	10.45	0.99	0.50
NGC 2911	09 31 05.4	10 22 36	13.82	3254	L	13.92	1.20	0.80
NGC 3031	09 51 30.0	69 18 18	8.15	−44	L	10.34	1.04	0.60
NGC 3080	09 57 14.2	13 17 03	14.50	10602	1	15.07	0.72	−.23
NGC 3079	09 58 34.8	55 55 24	11.20	1114	L	13.26	0.94	0.50
NGC 3185	10 14 53.4	21 56 18	13.23	1237	L			
NGC 3227	10 20 46.8	20 07 07	12.20	1152	2	13.52	0.82	−.11
NGC 3362	10 42 15.2	06 51 35	13.60	8318	2			
A1058+45	10 58 42.5	45 55 22	14.10	8778	2			
Mrk 421	11 01 40.6	38 28 43	14.00	9230	B	13.50	0.51	−.55
NGC 3516	11 03 22.8	72 50 20	12.30	2540	1	12.60	0.63	−.30
NGC 3642	11 19 25.2	59 21 00	11.96	1584	L	12.71	0.78	
NGC 3786	11 37 04.9	32 11 11	13.50	2737	1	13.74	0.88	0.20
NGC 3862	11 42 29.6	19 53 02	14.00	6462	X	14.15	1.05	0.46
NGC 3898	11 46 36.0	56 21 48	11.60	1158	L	11.83	0.96	0.54
NGC 3921	11 48 28.2	55 21 24	13.40	5895	L	13.35	0.79	0.39
NGC 3982	11 53 53.0	55 24 18	12.45	1188	2			
NGC 3998	11 55 20.9	55 43 55	11.79	1047	L	11.70	0.98	0.58
NGC 4036	11 58 53.4	62 10 30	11.87	1401	L	11.20	1.01	0.58
NGC 4051	12 00 36.1	44 48 44	11.50	674	1	12.64	0.80	0.05
NGC 4111	12 04 31.8	43 20 42	12.08	794	L	11.22	0.90	0.48
NGC 4151	12 08 00.4	39 41 02	11.20	970	1	11.91	0.58	−.57
NGC 4156	12 08 18.2	39 45 03	14.28	6766	X	13.77	0.89	0.07
NGC 4192	12 11 15.6	15 10 48	11.00	−110	L	11.21	0.92	0.48
NGC 4235	12 14 36.6	07 18 06	12.86	2300	1	12.27	0.99	1.40
NGC 4253	12 15 55.2	30 05 18	13.70	3836	1	13.55	0.72	0.06
NGC 4258	12 16 29.4	47 35 00	9.19	449	L	11.65	0.78	0.30
NGC 4278	12 17 36.0	29 33 36	11.20	635	L	11.26	0.95	0.53
NGC 4303	12 19 21.6	04 45 06	10.90	1585	L	12.88	0.78	0.19
Mrk 205	12 19 33.5	75 35 15	14.50	20978	1	13.24	0.40	−.94
NGC 4388	12 23 14.4	12 56 18	12.20	2535	2	12.78	0.82	0.08
NGC 4395	12 23 18.0	33 49 00	10.84	318	1	13.13	0.57	−.18
NGC 4419	12 24 25.2	15 19 24	12.23	−182	L	11.71	0.93	0.39
NGC 4438	12 25 13.6	13 17 07	12.00	1020	L	12.09	0.93	0.59
NGC 4450	12 25 58.2	17 21 42	11.29	1957	L	13.19	1.01	0.62
3CR 273	12 26 33.4	02 19 42	13.10	47352	1	12.86	0.21	−.85
NGC 4486	12 28 17.4	12 40 06	10.30	1265	L	12.05	1.00	0.64
NGC 4501	12 29 27.6	14 41 42	10.49	2270	L	12.20	1.05	0.65
NGC 4569	12 34 18.6	13 26 24	10.58	−245	L	11.69	0.83	0.17
NGC 4579	12 35 12.0	12 05 34	11.50	1486	L	11.72	0.97	0.50
Mrk 231	12 54 05.4	57 08 40	14.10	12287	1	13.85	0.85	0.14
NGC 4826	12 54 16.8	21 57 06	9.60	414	L	9.62	0.86	0.36
NGC 5005	13 08 37.2	37 19 24	10.85	1022	L	10.39	0.89	0.40
NGC 5033	13 11 09.2	36 51 30	11.00	892	1	11.09	0.82	0.27
NGC 5194	13 27 45.6	47 27 18	9.03	474	L	12.89	0.84	0.11
NGC 5195	13 27 52.2	47 31 48	10.94	558	L	12.30	1.21	0.73
Mrk 789	13 29 55.4	11 21 44	14.50	9318	1	14.68	0.57	−.18
1335+39	13 35 28.4	39 24 31	14.20	6023	2			
NGC 5252	13 35 44.4	04 47 47	14.50	6926	2	14.21	1.00	0.34

TABLE 1—*Continued*

Name (1)	R.A. (1950) (2)	Decl. (3)	m_b (4)	V_H (5)	Type[a] (6)	V (7)	$B-V$ (8)	$U-B$ (9)
NGC 5256	13 36 14.7	48 31 53	14.10	8239	2	13.42	0.77	0.06
NGC 5283	13 39 41.2	67 55 36	14.30	2697	2	14.05	0.92	0.31
NGC 5273	13 39 55.1	35 54 21	12.71	1089	1	13.24	0.83	0.16
Mrk 461	13 45 04.4	34 23 57	14.50	4894	2			
NGC 5347	13 51 05.4	33 44 00	13.18	2335	2	12.70	0.76	0.04
Mrk 279	13 51 52.5	69 33 16	14.50	9129	1	14.46	0.69	−.45
NGC 5371	13 53 39.0	40 42 24	11.59	2561	L	12.63	0.98	0.52
NGC 5548	14 15 43.7	25 21 59	13.10	4981	1	13.76	0.48	−.71
NGC 5675	14 30 36.4	36 31 19	14.00	3973	L			
NGC 5674	14 31 22.5	05 40 38	13.70	7442	2			
Mrk 817	14 34 57.9	59 00 39	14.30	9430	1	13.86	0.31	−.57
NGC 5695	14 35 19.7	36 47 02	13.90	4209	2	13.60	0.95	0.28
Mrk 841	15 01 36.3	10 37 56	14.00	10921	1		0.68	−.89
NGC 5899	15 13 14.4	42 14 00	12.79	2554	L	12.08	0.80	0.26
NGC 5929	15 24 18.9	41 50 41	14.00	2504	2	13.40	0.98	0.23
NGC 5940	15 28 51.3	07 37 38	14.30	10160	1	14.90	0.66	−.20
NGC 6104	16 14 40.1	35 49 50	14.10	8397	1			
2237+07	22 37 46.5	07 47 34	14.30	7487	1			
NGC 7469	23 00 44.5	08 36 18	13.13	4790	1	13.10	0.48	−.75
NGC 7479	23 02 26.4	12 03 06	11.93	2392	L	13.10	0.96	0.44
Mrk 530	23 16 22.6	−0 01 39	14.40	8691	1	14.01	0.72	−.21
I 1481	23 16 52.6	05 37 57	14.50	6118	L			
NGC 7674	23 25 24.4	08 30 13	13.60	8662	2	13.67	0.76	−.03
NGC 7682	23 26 30.7	03 15 28	14.30	5107	2	13.46	0.94	
NGC 7743	23 41 48.6	09 39 18	12.50	1658	L	13.85	0.94	0.30

[a] Type 1 = Seyfert 1; 2 = Seyfert 2; X = weak-lined X-ray source; L = LINER; B = BL Lacertae object.

NOTES.—Mrk 334 = IV Zw 1; NGC 863 = Mrk 590; NGC 3031 = M81; NGC 3080 = Mrk 1243; NGC 3227 = VV 209; NGC 3786 = Mrk 744 = Turner 39A; NGC 3862 = 3C 264; NGC 3921 = Mrk 430 = I Zw 28; NGC 4253 = Mrk 766; NGC 4388 = Arp 120; NGC 4486 = M87; NGC 5194 = M51 = VV 1 = Arp 85; NGC 5195 = M51 = VV 1 = Arp 85; Mrk 789 = VIII Zw 323; NGC 5256 = Mrk 266 = I Zw 67; NGC 5283 = Mrk 270; NGC 5695 = Mrk 686; NGC 5929 = Arp 90 = I Zw 112 = Turner 126A; NGC 7603 = Mrk 530; NGC 7674 = Mrk 533 = VV 343.

earlier versions of our list, find that there is evidence for incompleteness, at the 2–3 σ level, for low-luminosity objects (Persic et al. 1989). We feel that the small number of statistics and the sizable systematic problem due to density homogeneities at redshifts of order 1000 km s^{-1}, which affects only low-luminosity sources, does not allow for a strong conclusion. The sample is thus treated to be complete.

The LINER sample, on the other hand, contains almost no galaxies fainter than 13th mag, and appears to be complete only to 11.5 or 12.0. This disappointing result is not unexpected. LINERs can be recognized only by unusual emission line ratios, in particular, the presence of strong OI 6300 Å emission, and this can be detected only in high S/N spectra. More importantly, the contrast problem is significant. The nuclei of this type of galaxy do not contribute significantly to the total galaxy luminosity. Observations of galaxies at larger redshifts with fixed slit sizes (the Redshift Survey slits are a fixed 3".2 in width) contain larger and larger fractions of the surrounding galaxy. We thus might expect to find only nearby LINERs and those higher redshift objects with lower luminosity parent galaxies or very high luminosity nuclei. In the calculation of the space density below, we must cut the sample of LINERs at 12th mag. Even then, the sample suffers from incompleteness.

TABLE 2

V/V_m TEST

	SEYFERT 1		SEYFERT 2		LINERS	
$m_{\lim}$	V/V_m	n	V/V_m	n	V/V_m	n
14.5.....	0.46 ± 0.06	26	0.47 ± 0.06	23	0.08 ± 0.05	33
14.0.....	0.35 ± 0.08	14	0.48 ± 0.08	13	0.11 ± 0.05	32
13.5.....	0.31 ± 0.09	10	0.29 ± 0.12	6	0.11 ± 0.05	30
13.0.....	0.29 ± 0.11	7	0.27 ± 0.14	4	0.14 ± 0.06	28
12.5.....	0.26 ± 0.13	5	0.54 ± 0.14	4	0.23 ± 0.06	27
12.0.....	0.30 ± 0.14	4	0.09 ± 0.29	1	0.35 ± 0.06	24
11.5.....	...	...	...	...	0.38 ± 0.07	17
11.0.....	...	...	...	...	0.44 ± 0.08	12

4. INTEGRATED VERSUS NUCLEAR MAGNITUDES

There has been considerable debate on the use of nuclear magnitudes versus integrated magnitudes in the computation of the Seyfert luminosity function. Veron (1979), in particular, has stressed that the relevant quantity for both the computation of the AGN contribution to the X-ray background and the comparison of the Seyfert to quasar luminosity function is the nuclear magnitude. Unfortunately, there is to date no sample of objects selected by nuclear magnitudes, and none is likely to exist on reasonable time scales.

In addition, the definition of "nuclear" magnitude is complicated. Veron used magnitudes determined in small apertures,

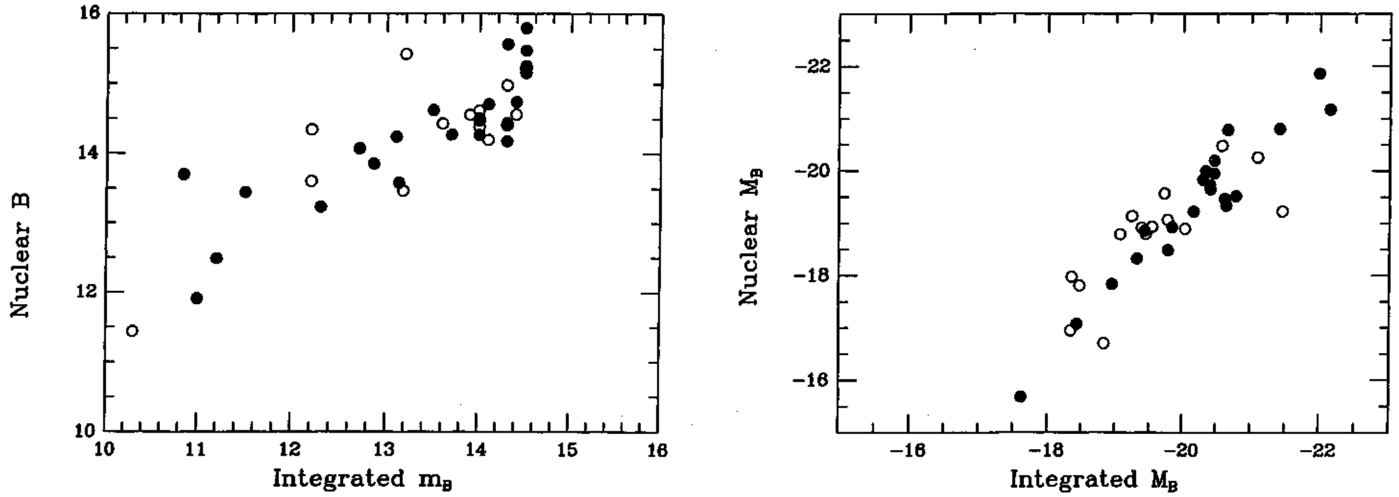

FIG. 1a FIG. 1b

FIG. 1.—(*a*) Apparent integrated *B* magnitudes [in the *B*(0)–Zwicky system] vs. small-aperture *B* magnitudes. Seyfert 1 galaxies are filled circles and Seyfert 2 galaxies are open circles. (*b*) The same except now plotted as absolute magnitudes.

but this estimates the contribution of the surrounding galaxy in a redshift-dependent manner. Ideally, one would want to measure only the contribution of the nonthermal source—remove the stellar component from disk, bulge, and even the nucleus. This is possible in the optical only for the nearest objects or those objects where the nuclear source is so dominant that errors in the determination of the underlying galaxy component are irrelevant. In any case, optical techniques for identifying nonthermal sources in large numbers of galaxies are applied only to "integrated" magnitude-limited samples. To make matters worse, Seyfert galaxies are not very strong radio sources, and Seyfert 2 galaxies are generally weak X-ray sources, so surveys at other wavelengths also yield a mixed bag of objects.

The sample of galaxies analyzed here is apparently bright, and almost all have optical broad-band photometry. The best we can do at the moment is contrast the small-aperture photometry to the integrated magnitudes (as Veron did). Figure 1 is a plot of integrated *B*(0)–Zw magnitude versus the *B* magnitude from the smallest available aperture (Table 1). There is no significant departure from a linear relation, although there is a constant offset of about 1 mag, with a large amount of scatter. It is unlikely that use of small-aperture magnitudes will significantly change the shape or normalization (integrated number of objects per unit volume) of the derived luminosity function. It is thus still useful (although probably not optimal) to calculate such quantities as the X-ray to optical luminosity of Seyfert galaxies in terms of their integrated optical luminosities. Programs are underway (e.g., Edelson 1987; M. Elvis et al., private communication) to determine the nonthermal nuclear luminosities for the galaxies in this sample. Edelson (1987) has shown that the radio luminosity is well correlated with the *integrated* optical luminosity of the parent galaxy but with a slope steeper than unity.

Independent of one's views on integrated versus nuclear magnitudes, it is still possible to address the questions: (1) What fraction of galaxies as a function of galaxy absolute magnitude are AGNs, (2) What is the integrated volume density of Seyfert galaxies, and thus (3) What is the contribution of such objects to the X-ray background?

5. SPACE DENSITIES

The calculation of the luminosity function is relatively straightforward. Our overall goal is comparison with the luminosity function of "normal" galaxies, so the most important consideration is uniform treatment of our samples of AGNs and field galaxies. We can use the parent sample from the CfA Redshift Survey to derive the field luminosity function.

We correct our sample for the effects of a Virgocentric flow (more for the faint end of the field function than anything else, see Aaronson et al. 1982) with an infall velocity of 300 km s^{-1}. We assume a Hubble parameter of 100 km s^{-1} Mpc^{-1}, and *do not* correct for galactic absorption. Our sample is mostly at high galactic latitude, and if Sandage's (1973) prescription for galactic absorption correction is nearly correct, as most new observations seem to indicate (e.g., the *IRAS* results on high-latitude dust—Low et al. 1984; Knude 1986), then the overall correction to the luminosity density will be less than 10% (Felten 1977). This follows because the Sandage (1973) absorption correction is zero above $|b^{II}| = 50°$, and the CfA sample is primarily above $|b^{II}| = 40°$. We note once again that the magnitudes used are on the *B*(0)–Zwicky system. A small correction has been applied to the search volume to correct for the tendency of galaxies to cluster. This correction is essentially dividing through by the integral of the correlation function to correct for the tendency for galaxies to cluster around our own and has no significant effect on the space density in the luminosity range covered by the Seyfert and LINER samples. More complete details of the analysis can be found in Appendix A.

There are two simple techniques for the determination of differential luminosity functions from complete samples. One is simply binning the sample by absolute magnitude, counting the number of objects per bin, and calculating the mean search volume at the center of the absolute magnitude bin. The second is to use the V/V_m technique as described by Huchra & Sargent (1973). Both have been described in detail by Felten (1977) and have essentially the same statistical efficiency, but the V/V_m technique is slightly less susceptible to bias due to small number statistics and placement of objects in the absolute magnitude bins. The results of these analyses are presented in Table 3 and in Figures 2 and 3. The space density of

TABLE 3

SPACE DENSITY

Bin	Seyfert 1 + 2 log ϕ	n	Seyfert 1 log ϕ	n	Seyfert 2 log ϕ	n	LINERs log	n	Field log ϕ
−17.5 to −18.0	−3.83	1	−3.83	1	...	0	−2.08	2	−1.71
−18.0 to −18.5	−3.69	4	−4.32	1	−3.81	3	−2.71	1	−1.87
−18.5 to −19.0	−4.08	3	−4.63	1	−4.23	2	−2.88	1	−2.02
−19.0 to −19.5	−3.90	8	−4.57	2	−4.00	6	−2.60	5	−2.23
−19.5 to −20.0	−4.32	6	−4.84	2	−4.48	4	−2.61	9	−2.43
−20.0 to −20.5	−4.46	9	−4.54	8	−5.27	1	−3.23	4	−2.85
−20.5 to −21.0	−4.65	10	−4.87	6	−5.05	4	−4.25	1	−3.54
−21.0 to −21.5	−5.29	5	−5.74	2	−5.48	3	...	...	−4.38
−21.5 to −22.0	−6.45	1	−6.45	1	...	...	...	...	−5.88
−22.0 to −22.5	−6.54	1	−6.54	1	...	...	...	...	−6.54
Total V/V_m............	0.46 ± 0.04		0.46 ± 0.06		0.47 ± 0.06		0.35 ± 0.06[a]		
Luminosity Function Parameters									
M^*	−20.14		−20.57		...		−19.08		−19.46
α	−1.34		−1.54		...		−0.76		−1.34
ϕ^*	1.5^{-4}		4.5^{-5}		3.9^{-5}		1.1^{-2}		1.6^{-2}
$\Phi(M_B \leq -18)$[b]	...		7.8^{-5}		1.8^{-4}				

[a] Based on a $m_{\rm lim}$ of 12.0.
[b] Integrated number density of galaxies more luminous than −18.

LINERs has been computed from the sample limited to 12th mag. The two techniques give the same results (as they should).

Schechter functions (Schechter 1976) have been fitted to the luminosity functions, and their parameters are also given in Table 3. We advise caution in the use of these parameters, especially for the AGNs samples. There is a very large covariance between the derived value of α, the slope of the luminosity function at the low-luminosity end, and the high-luminosity cutoff parameter, M^* (Schechter 1976). More importantly, we observe *no* AGNs in faint galaxies. Very, very few Seyfert nuclei are observed in galaxies fainter than $M_B \sim -18$, either in the present sample or in much larger (but incomplete) samples of several hundred AGNs (Veron-Cetty and Veron 1985; Huchra 1991).

The shape of the luminosity function can also be derived via density-independent techniques (Lynden-Bell 1971; Turner 1979). The above standard techniques for the computation of the luminosity function assume both that its shape does not change with position and that the galaxies are distributed uniformly. The density-independent techniques trade off information about the absolute spatial density in order to relax constraints on the spatial uniformity of the galaxy distribution. We have used a nonparametric density-independent technique to verify the shape of the luminosity function but have found that the small numbers, together with high degree of correlation between bins, did not allow parametric models to be fitted with a high degree of confidence. De Lapparent, Geller, & Huchra (1989) report a Schechter function fitted to the field sample used in this paper utilizing a density-independent approach and found $M^* = -19.3$ and $\alpha \sim -1$.

6. DISCUSSION

The spectroscopic classification of galaxies in a magnitude-limited redshift survey has yielded the most complete list of low-luminosity AGNs to date. In our spectroscopic survey of the 2400 galaxies in the CfA sample, we have found all AGNs discovered with other surveys, and then some. The only systematic problem that limits our ability to classify is the possible existence of extremely faint AGNs buried in bright systems. Note, however, that no other discovery technique has yielded a large population of such systems.

The interpretation of the luminosity function is limited by the small number and by the complications of local large-scale inhomogeneities in the galaxy density distribution—i.e., the Local Supercluster. We stress that the low-luminosity end of the luminosity functions for Seyfert 1, 2, and LINERs are all affected. This may mean that our estimates of the space density of the lowest luminosity objects are overestimates.

The number of AGNs in a blue, magnitude-limited sample of galaxies is small. Only 1% of the galaxies are Seyfert 1 and another 1% are Seyfert 2. A much larger fraction of the most luminous galaxies are AGNs (Table 4). Approximately 20% of the galaxies more luminous than −21 (M_B) are AGNs (Fig. 3). This may be essential in understanding the field galaxy number–magnitude relation at low flux levels. Because the shape of the spectral energy distributions of AGNS is generally

TABLE 4

10 BRIGHTEST GALAXIES IN CFA SURVEY

Name (1)	(m_z)[a] (2)	$(V_{\rm cor})$[b] (3)	(M_B)[c] (4)	Notes (5)
0051+1225	14.00	18078	−22.29	Seyfert 1, I Zw 1
1219+7535	14.50	21413	−22.19	Seyfert 1, Mrk 205
2304+1536	14.00	15043	−21.89	III Zw 93
NGC 3978	13.20	10336	−21.87	
1101+3828	13.10	9196	−21.72	BL Lac, Mrk 421
NGC 5230	12.81	7156	−21.46	
NGC 7620	13.50	9646	−21.42	Mrk 321
1254+5709	14.10	12649	−21.41	Seyfert 1, Mrk 231
NGC 5739	12.47	5967	−21.41	
1107+1302	14.20	12922	−21.36	

[a] $B(0)$–Zwicky magnitude.
[b] Velocity corrected for Virgocentric flow.
[c] Absolute blue magnitude.

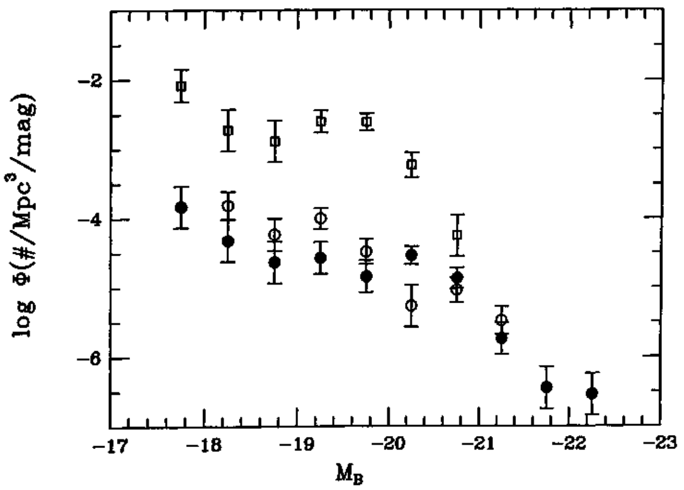

FIG. 2.—Differential luminosity functions of Seyfert 1 (*filled circles*), Seyfert 2 galaxies (*open circles*), and LINERs (*squares*). Error bars represent only the internal statistical error in each magnitude bin. The "hump" in the LINER density at -19.5 almost certainly represents an overestimate of the true density due to the presence of the Local Supercluster.

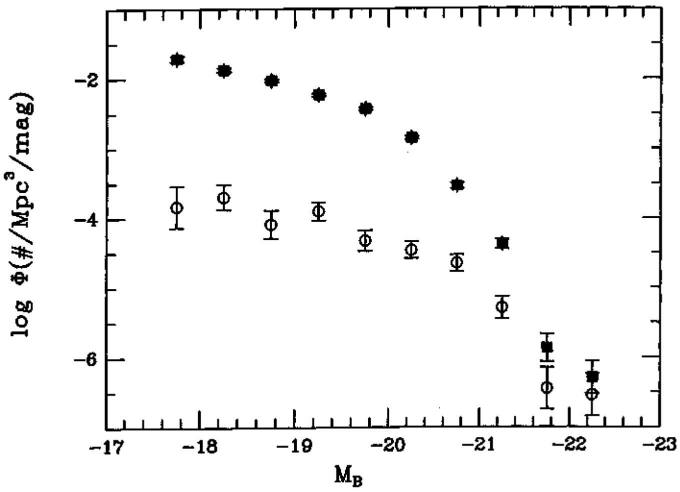

FIG. 3.—Differential luminosity function of all Seyfert galaxies (both 1's and 2's, *open circles*) compared to the luminosity function of field galaxies (*filled circles*) derived from the CfA Redshift Survey.

much flatter than that of normal galaxies, we expect the fraction of AGNs to rise dramatically in fainter, high-redshift galaxy samples (Burg 1987).

In the light of predictions of the unified model of AGNs (where Seyfert 2 galaxies are obscured Seyfert 1 galaxies, cf. Lawrence 1987; Blandford 1990), a number of authors have examined the relative numbers of Seyfert 1 and 2 galaxies in different samples. Osterbrock & Shaw (1988) examined the Wasilewski sample and estimated that the relative number density of Seyfert 2 to Seyfert 1 galaxies is approximately 8. Salzer (1989), in his analysis of the Michigan Emission Line Survey, finds equal numbers of Seyfert 2 and 1 galaxies in the sample which corresponds to a relative space density of 5. In our blue, magnitude-limited sample, we also find approximately equal numbers of Seyfert 1 and Seyfert 2 galaxies. However, we find, integrating down to an absolute blue integrated magnitude of -18, that the relative space density of Seyfert 2 to 1 galaxies is only 2.3 ± 0.7 (Table 2). From Figure 2, we also note that there is not a strong change in this ratio as a function of luminosity, although there is an apparent dip in the density of Seyfert 2's at -20.

Meurs & Wilson (1984), from a sample of Markarian Seyfert galaxies, find an even higher fraction of Seyfert 1 galaxies. Most of these differences can be explained by the selection techniques used for assembling the different surveys. Objective prism searches that rely on finding emission-line objects will, in general, be more sensitive to sharp emission-line objects for galaxies with lines of similar equivalent width. Thus, when the narrow lines of the Seyfert 2 galaxies are near the limit of spectral resolution for the objective prism, Seyfert 2 galaxies will be more easily selected. UV excess searches, on the other hand, will preferentially select the less reddened Seyfert 1 galaxies. Our sample, based on total blue magnitudes, is much less likely to be intrinsically biased by type, and thus the factor of about 2 between the space densities of the Seyfert 2 and Seyfert 1 galaxies is more likely to be the true ratio.

This paper presents a uniform finding list of apparently bright AGNs that has for a number of years been a useful starting point for detailed investigations.

We would like to thank Yoram Avni, G. de Zotti, Rick Edelson, Alberto Franseschini, Martin Elvis, Herman Marshall, and Richard Mushotzsky for stimulating discussions. Suggestions from the anonymous referee have substantially improved and updated the paper. Typing services again have been generously provided by Fang, Inc.

APPENDIX A

CORRELATION FUNCTION CORRECTION TO THE LF

For both of the two simple methods of deriving the space density of galaxies that have been discussed in this paper—the standard binning techique and the $1/V_m$ technique—one should apply a small correction due to the known existence of the clustering of galaxies. Essentially, we are deriving the mean space density of galaxies but are *not* sampling from a *random* locus in space but rather in shells surrounding a galaxy. Since galaxies cluster, this will cause us to overestimate the density of galaxies when we sample only small volumes around us. This bias is particularly important at low luminosity where, in a magnitude-limited sample, the effective or limiting distance may be much smaller than the correlation length so that a straight application of the above techniques should significantly overestimate the true volume density.

The excess number of galaxies expected because galaxies cluster out to a given radius, r, is

$$\frac{N_{\rm excess}}{N_{\rm mean}} = \frac{N_E}{N_\mu} = \int \xi(r) d^3r \; . \tag{1}$$

If the correlation function, $\xi(r)$ is of the standard form

$$\xi(r) = \left(\frac{r}{r_0}\right)^{-\gamma} \tag{2}$$

(Peebles 1980), and if the correlation function is assumed to be *independent* of luminosity, then the simple integral

$$N_E/N_\mu = 4\pi \int_0^\infty r^{2-\gamma} r_0^\gamma \, dr \tag{3}$$

gives the excess. We can then treat the problem as one of correcting the effective volume searched and modify either V_m of the limiting volume of a given absolute magnitude bin. The "volume" correction factor, C, defined by $V_c = CV_0$, where $V_0 = (4/3)\pi r^3$, becomes

$$C = 1 + \frac{4\pi r_0^\gamma}{3-\gamma} \frac{r^{3-\gamma}}{V_0} . \tag{4}$$

In real samples (including this CfA survey, Davis & Peebles 1983), the correlation function appears to turn over at separations $\sim 2r_0$. If the correlation function steepens to a slope nearer 3.5 at $2r_0$, a more reasonable approximation for the excess is given by

$$N_E/N_\mu = 4\pi \int_0^{2r_0} r^{2-\gamma} r_0^\gamma \, dr + 2^{-\gamma} \int_{2r_0}^\infty 2r_0^{3.5} r^{-1.5} \, dr . \tag{5}$$

In this case, equation (4) is used for $r \leq 2r_0$, and the following equation is used for $r > 2r_0$:

$$C = 1 + \frac{4\pi r_0^\gamma}{3-\gamma} \frac{2r_0^{3-\gamma}}{V_0} - \frac{2^{2-\gamma} r_0^{3.5}[(2r_0)^{-1/2} - r^{-1/2}]}{V_0} . \tag{6}$$

For a sample with a limiting magnitude of 14.5, this correction factor is less than about 30% (or less than ~ 0.1 in log ϕ) for the faintest absolute magnitudes considered in this paper (-17.5) and decreases with luminosity. This is smaller than the sampling statistical errors in the data. Remember that applying this correction will *decrease* the volume density. Note also that this correction is only for very *local* effects; the effects on the determination of the luminosity function caused by large-scale inhomogeneities should be corrected for by using nonparametric estimators of the function's shape and then normalizing to the density determined by a sample that is unaffected by large-scale structure.

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