THE ASTROPHYSICAL JOURNAL, 288:481–486, 1985 January 15

STATISTICS OF EMISSION-LINE GALAXIES IN RICH CLUSTERS

ALAN DRESSLER, IAN B. THOMPSON, AND STEPHEN A. SHECTMAN
Mount Wilson and Las Campanas Observatories of the Carnegie Institution of Washington
Received 1984 May 31; accepted 1984 July 26

ABSTRACT

We tabulate and analyze the emission-line characteristics of a sample of 1095 galaxies in rich clusters and 173 field galaxies for which Dressler and Shectman (1985) have obtained spectra. We find, in agreement with earlier studies, that the emission-line frequency is much higher in field galaxies than in cluster galaxies. Relatively strong emission is found in the central regions of 31% of the field galaxies, but in only 7% of the cluster galaxies. The difference in the distribution of morphological types can only partially explain this effect; much of the difference must be attributed to environmental influences.

Active galactic nuclei (AGNs) occur at a frequency of ~5% in the field sample but only ~1% in the cluster sample, the same ratio as found for the emission-line galaxies. The average frequency is an order of magnitude lower than that found for the distant 3C 295 cluster by Dressler and Gunn (1983), but some nearby clusters may also have an unusually high AGN fraction.

Subject headings: galaxies: clustering — galaxies: nuclei — galaxies: Seyfert

I. INTRODUCTION

Osterbrock (1960) was the first to point out that the frequency of emission lines is lower in cluster galaxies than field galaxies. Gisler (1978) assembled an inhomogeneous sample of ~1300 galaxies which gave quantitative verification of this effect.

Dressler and Shectman (1985) have obtained moderate resolution spectra for 1268 galaxies in the fields of 14 rich clusters cataloged by Dressler (1980). These data provide a sample which is homogeneous in selection criteria, absolute magnitude, and spectral quality.

This paper presents the results from the Dressler/Shectman (1985) sample for the frequency of emission-line galaxies as a function of environment, and, in particular, the occurrence of active galactic nuclei (AGNs) in and out of clusters.

II. THE DATA

The spectra of 1268 galaxies in the fields of the rich clusters A548, A754, A1631, A1644, A1656, A1736, A1983, A2151, DC 0003−50, DC 0247−31, DC 0428−53, DC 0559−40, DC 0608−33, and DC 2048−52 were obtained as described in Dressler and Shectman (1985). Most of these were observed with the Reticon spectrograph of the du Pont 2.5 m telescope at Cerro Las Campanas, Chile. About 100 spectra were obtained with the Reticon detector on the Cassegrain Double Spectrograph of the Hale 5 m telescope on Palomar Mountain. All observations were made with a 4″ × 4″ aperture, which roughly corresponds to a 5 × 5 kpc box ($H_0 = 50$ km s^{-1} Mpc^{-1}) at the average redshift ($z \sim 0.04$) of the sample. The spectra cover ~3500–6500 Å at a resolution of ~5 Å FWHM, and have a typical signal-to-noise ratio of 10 at 5000 Å.

In the present study, emission-line galaxies are defined as those in which the equivalent width of the [O II] doublet (λ3727), $W_{[\rm O\,II]}$, is greater than about 3 Å. The typical spectrum of such an emission-line galaxy shows weaker Hβ and weaker still (or absent) [O III] $\lambda\lambda$5007, 4959. The entire sample includes 1095 galaxies that are cluster members (as evaluated from the velocity histograms of Dressler and Shectman 1985), of which 78 had [O II] emission with an equivalent width $\gtrsim 3$ Å. In contrast, 53 of the 173 interloping field galaxies in the sample had [O II] emission of this strength.

Emission lines in these galaxies can arise in nuclear H II regions or be the result of an active nucleus with a source of shock heating or photoionization. Although active nuclei can be separated unambiguously from central H II regions using various ratios of emission lines, as shown by Baldwin, Phillips, and Terlevich (1981), most of the required lines are too weak to be seen in the present data. Therefore, we follow the approach used by Heckman (1980*a*, *b*), which uses the [O II], [O III], and Hβ lines alone to identify probable cases of active nuclei. All spectra in which $W_{[\rm O\,III]} \gtrsim W_{[\rm O\,II]}$ *or* $W_{\rm H\beta} \gtrsim W_{[\rm O\,II]}$, *and* $W_{[\rm O\,III]} \gtrsim W_{\rm H\beta}$ have been attributed to AGNs. The latter "high-excitation" condition is also found in H II regions with low metal abundance, but the galaxies in the present sample are all very luminous and thus are not likely to have low metal abundance in their nuclear regions.

Application of these criteria yielded 22 AGNs in the sample, 13 in clusters and nine among the field galaxies. Their positions, morphological types, and magnitudes are listed in Table 1. An approximate description of the emission-line characteristics is given in Table 2. Of the 13 cluster AGNs, seven are strong cases (very high excitation) including two Seyfert 1's, recognizable by their broad hydrogen lines. Of the nine field AGNs, six are strong cases, including one Seyfert 1. Examples of strong cases of cluster and field AGNs are shown in Figure 1. Except for the three Seyfert 1's, all of the strong and most of the weak cases are likely to be Seyfert 2's. The emission lines usually have widths of FWHM ~ 500 km s^{-1}, typical of Seyfert 2 galaxies. No obvious cases of low-ionization nuclear emission-line regions ("Liners") (Heckman 1980*a*) were found; [O I] λ6300 was not strong in any of the 22 spectra.

The distribution of galaxy properties for the emission and AGN subsets are compared with the whole field and cluster samples in Figures 2, 3, and 4. The morphological types, bulge sizes, and absolute magnitudes plotted have been taken or derived from the data of Dressler (1980).

The morphological-type distribution (Fig. 2) shows that the cluster galaxies are usually earlier type galaxies (E and S0 galaxies) than the field galaxies, and that the emission and

TABLE 1

BASIC DATA FOR GALAXIES WITH ACTIVE NUCLEI

Object		R.A. (1950)	Decl. (1950)	Type[a]	m[a]	b[a]	e[a]	cz	M[b]	Membership[c]
A548	104.....	05h43m50s.6	−25°43′08″	Sa	16	6	4	13580	−21	Y
A1631	18.....	12 50 21.0	−15 30 16	Sbc	14	3	1	14950	−23	Y
A1644	83.....	12 53 07.3	−17 03 50	S	16	−2	7	5567	−19	N
	118.....	12 52 42.2	−16 49 33	S0p	15	7	4	3995	−20	N
A1736	14.....	13 20 59.0	−27 23 55	U	15	−2	−2	2337	−18	N
A1983	83.....	14 50 52.4	+17 07 25	Sab	15	3	7	13588	−22	Y
A2151	28.....	16 03 52.0	+17 35 38	Sa	15	5		10699	−22	Y
	61.....	16 03 00.8	+17 50 35	S0	15	3	7	9432	−22	Y
0003−50	66.....	00 03 10.9	−50 23 35	S0	14	10	4	10027	−23	Y
0247−33	19.....	02 47 35.4	−31 24 35	S0	14	10	4	8716	−22	Y:
0428−53	53.....	04 32 36.7	−53 52 57	Sb	15	4	7	11824	−22	Y
	77.....	04 29 30.8	−53 43 20	Ep	14	10	0	11994	−23	Y
	94.....	04 30 50.8	−53 36 10	E	16	5	1	12741	−21	Y
0559−40	2.....	05 57 13.9	−40 38 57	Sa	15	5	2	18951	−23	N
	25.....	06 02 26.9	−40 05 13	Sa	14	6	4	4917	−21	N
	107.....	06 01 05.6	−39 29 47	S	15	4	7	13570	−22	Y
	115.....	05 59 04.9	−39 19 08	I	15	−1	−2	24899	−23	N
0608−33	89.....	06 09 38.1	−33 26 13	Sa	16	4	4	15272	−21	N
	117.....	06 09 51.1	−33 03 20	SBb	15	2	2	23426	−23	N
2048−52	56.....	20 51 38.4	−53 04 08	Ep	16	6	2	20851	−22	N
	178.....	20 49 08.3	−52 21 05	Sb	13	4	3	14407	−24	Y

[a] Type, *m* (apparent *V*-magnitude), *b* (bulge size), and *e* (ellipticity) given as in Dressler 1980.

[b] M = absolute V-magnitude with $H_0 = 50\ \mathrm{km\ s^{-1}\ Mpc^{-1}}$.

[c] Cluster (Y) or field (N) galaxy.

AGN subsets are weighted more toward later types (Sa, Sb, Sc, Sd, I) than their respective field and cluster parent distributions. The AGN galaxies are typically S0, Sa, or Sb galaxies, as noted by Simkin, Su, and Schwarz (1980), but there are three elliptical galaxies in the present sample, including a Seyfert 1. It is perhaps significant that two of these were classified as "E peculiar" by Dressler (1980) before the spectra were obtained. These AGNs in ellipticals may simply be the result of misclassification of early-type disk galaxies at relatively high redshift, but higher resolution images are needed to confirm this.

The absolute-magnitude distribution (Fig. 3) shows that the whole sample is weighted toward luminous galaxies (most of the galaxies are brighter than the characteristic magnitude M^*), and that the emission and AGN subsets are quite representative of the parent distributions. As one expects, the larger volume sampled for brighter galaxies weights the sample of contaminating field galaxies to higher luminosities relative to the cluster sample.

The distribution of bulge sizes (Fig. 4) shows that the Dressler/Shectman (1985) sample is biased toward the large

TABLE 2

APPROXIMATE EQUIVALENT WIDTHS[a] OF EMISSION LINES IN AGNs

Object		[O II] λ3727	[Ne III] λ3870	Hγ λ4340	Hβ λ4861	[O III] λ5007	Comments
A548	104.....	3	1	1	2	3	
A1631	18.....	3	2	0	0	3	
A1644	83.....	3	1	0	1	3	lines unresolved
	118.....	3	1	1	2	3	lines unresolved
A1736	14.....	3	2	1	2	3	
	49.....	3	2	1	1	3	
A1983	83.....	2	0	0	0	2	lines unresolved
A2151	28.....	2	0	0	0	2	lines unresolved
0003−50	66.....	1	0	2	3	2	Seyfert 1
0247−33	19.....	3	1	1	3	3	
0428−53	53.....	2	0	0	1	2	
	77.....	1	1	3	3	2	Seyfert 1
	94.....	2	1	1	2	3	
0559−40	2.....	2	0	3	3	3	
	25.....	3	1	2	3	3	
	107.....	3	0	0	0	3	lines unresolved
	115.....	3	1	2	3	3	
0608−33	89.....	3	1	1	2	3	
	117.....	2	1	0	1	3	
2048−52	56.....	3	0	0	2	3	
	178.....	1	0	0	0	2	

[a] Key: 0 = absent; 1 = weak, 0–10 Å; 2 = intermediate, 10–20 Å; 3 = strong, > 20 Å.

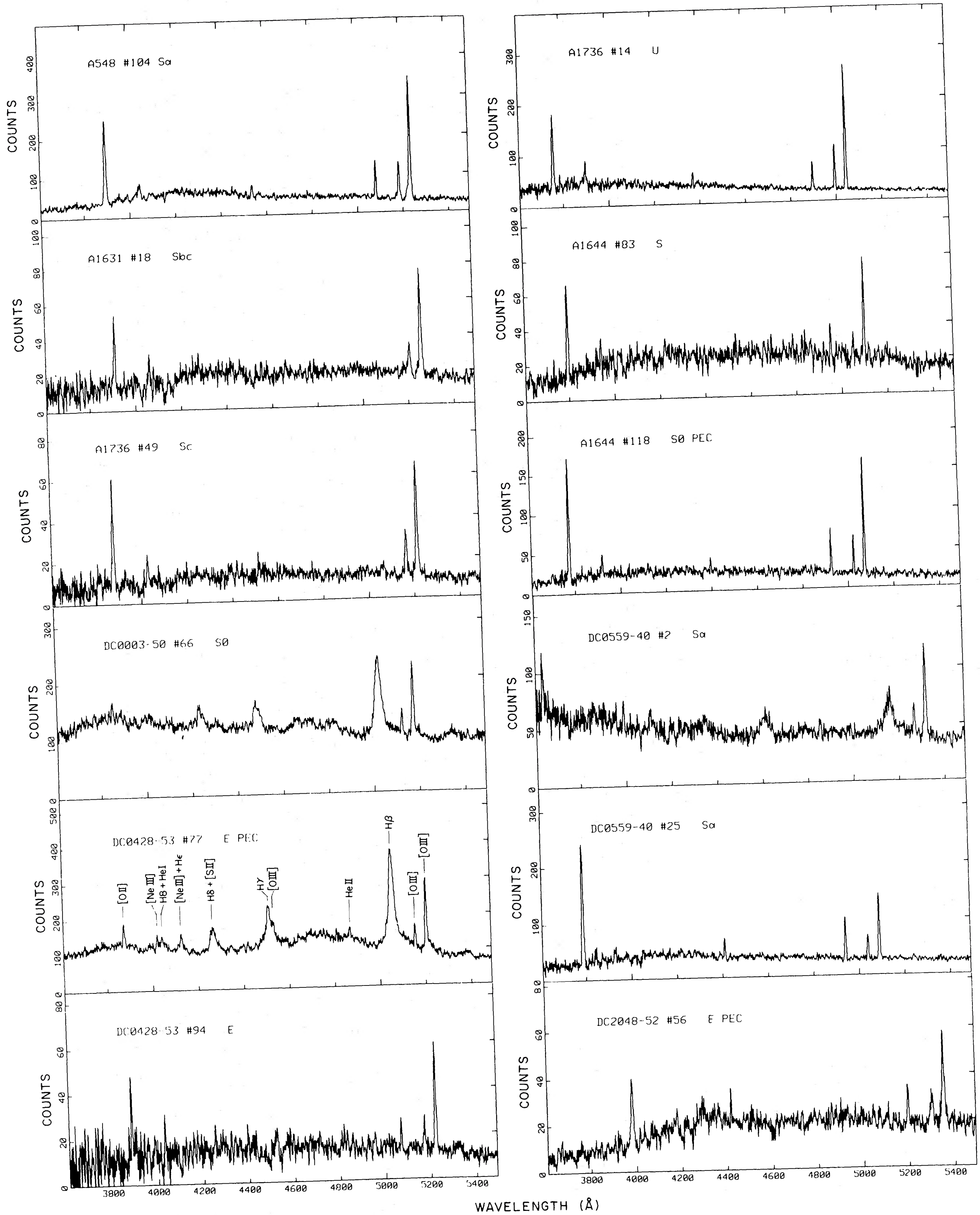

FIG. 1.—Spectra of the strongest cases of AGN spectra from the sample of emission-line galaxies. The spectra in the left-hand panel are cluster members; the right-hand panel shows spectra of field AGNs. Most of the lines that can be seen in spectra of this quality are identified in the spectrum of the Seyfert 1 galaxy DC 0248 − 53 77.

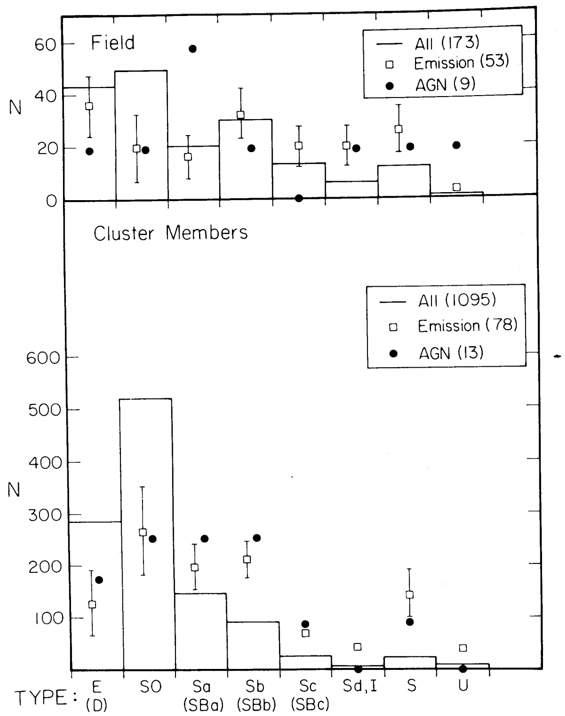

FIG. 2

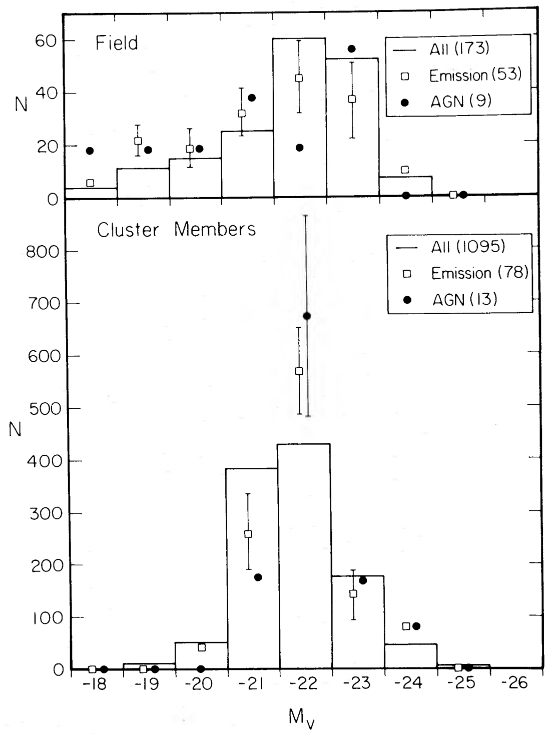

FIG. 3

FIG. 2.—The distribution of morphological types for the total, emission-line, and AGN samples, separated into field and cluster galaxies. Morphological types have been taken from the Dressler (1980) catalog. The plotted values for the emission-line and AGN subsets of the field and cluster samples have been normalized to the total number of galaxies in each sample. The cluster sample contains a larger fraction of early-type galaxies than the field sample, as expected, and for both samples emission is more common in the later Hubble types.

FIG. 3.—The distribution of absolute V-magnitude for the total, emission-line, and AGN samples, separated into field and cluster galaxies. The data for the emission-line and AGN subsets have been normalized as in Fig. 2. The samples are biased toward luminous galaxies, particularly the field sample because of the V/V_{max} effect. There is no significant difference in the distribution of absolute magnitudes for the three samples.

bulge end of the Dressler (1980) catalog, because of the relative ease of obtaining redshifts for these galaxies. Since the frequency of emission-line galaxies rises for small bulge systems, the incidence of emission-line galaxies will be somewhat higher for a sample limited by *total* magnitude, but this correction should be less than 20% on the basis of the number of small bulge systems in both the field and the cluster samples. A marginally significant bimodality of the distribution of AGN bulge sizes suggests that AGNs are found preferentially in galaxies with small but significant bulges, and in very large bulges.

None of the AGNs are to be found in the catalog of radio sources compiled by Dixon (1970).

III. RESULTS

a) The Frequency of Emission-Line Galaxies in Clusters

The primary result of this paper is that, as found by Gisler (1978), the frequency of emission-line galaxies in the field is much higher than in clusters. Gisler's sample consists of 1316 galaxies with $m_p \lesssim 15.7$ and radial velocities $V \lesssim 15{,}000$ km s^{-1} for which there are data in the literature as to the presence of emission lines at a spectral dispersion of less than 500 Å mm^{-1}. Cluster membership was determined from the *Uppsala General Catalogue*. Our present sample is thus much more uniform in selection criteria, spectral quality, and assignment of cluster membership. Since the field sample actually arises serendipitously from the cluster sample, the comparison of field and cluster galaxies is guaranteed to be a fair one.

Emission-line galaxies comprise 31% of the 173 field galaxies in the present sample but only 7% of the 1095 cluster galaxies. Less than half of this factor of 4.4 difference can be attributed to the difference in the distribution of morphological types. The emission-line frequency is a strong function of morphological type in both samples, as shown in Figure 5, and the cluster sample is 73% E and S0 galaxies, as compared with 53% of the field sample. Using the frequency of emission as a function of morphological type for cluster galaxies while forcing the mix of types to match the field distribution results in an increase in the cluster emission-line frequency to 12%. This is still far short of the 31% of the field sample, indicating that the major effect, as shown in Figure 5, is that the emission-line frequency is 2–3 times lower in cluster galaxies at any given morphological type. This means that most of the variation in emission-line frequency must be due to present-day environmental effects, or differences in the galaxies themselves that evolved from early environmental influences.

Similarly, 5% of the field galaxies are classified as AGNs, as compared with only 1% of the cluster sample. This, again, confirms a long-standing opinion that Seyfert galaxies are more rare in rich clusters than in the lower density field. For a similarly small sample of field galaxies that is homogeneous and complete, Keel (1983) also finds a Seyfert frequency of 5%. In the present sample, Seyfert 2's outnumber Seyfert 1's by 6:1, but if only the strong cases are considered, this ratio is halved. It is interesting to note that the frequencies of emission-line galaxies and AGNs go together: the ratio of field to cluster AGNs for the present data is 4.4, exactly the same as the ratio of field to cluster emission-line galaxies.

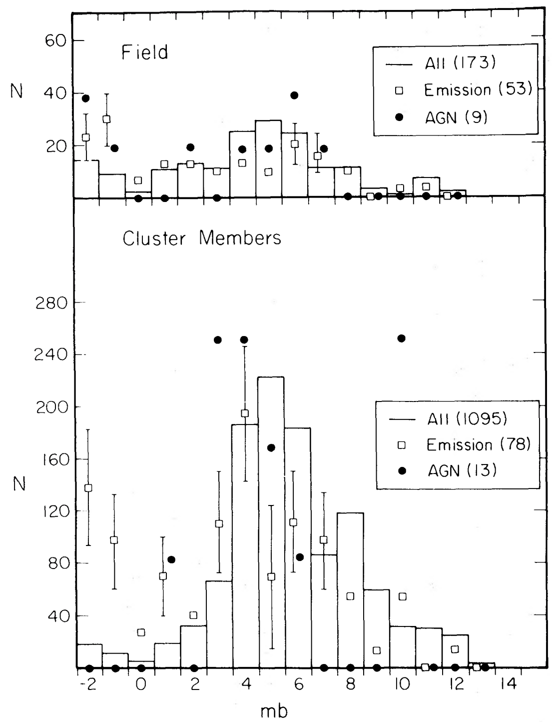

FIG. 4.—The distribution of bulge sizes, *mb*, as determined by Dressler (1980) for the total, emission-line, and AGN samples, separated into field and cluster galaxies. The data for the emission-line and AGN subsets have been normalized as in Fig. 2. Each unit of bulge size is equal to a change of 0.5 mag, with a value of $mb = 6$ corresponding to $V \sim 16$. The only significant difference in the samples is the tendency of small bulge galaxies to have emission lines (usually late-type spirals) and a possible bimodality of the AGN distribution.

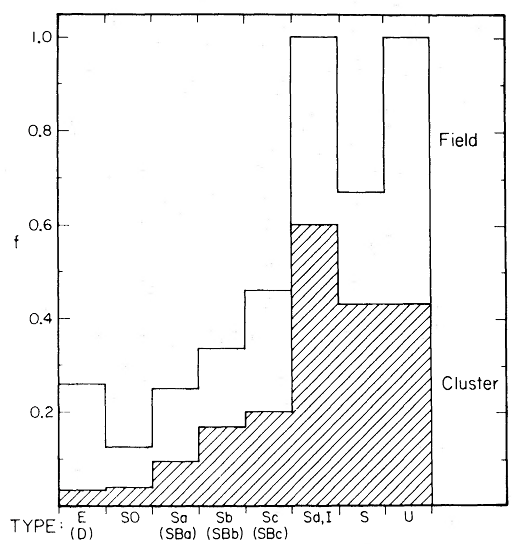

FIG. 5.—The frequency of emission-line galaxies as a function of morphological type for the field and cluster samples. At any given morphological type the incidence of emission lines is 2–3 times lower for cluster galaxies than for field galaxies. This demonstrates that the factor of 4.4 higher frequency of emission-line galaxies in the field sample as compared with the cluster sample is not due primarily to the difference in the morphological-type distributions for the two samples, thus indicating that environment is responsible for the difference.

Finally, it is worth remarking that the emission-line frequencies found in this study are lower, across the board, than those tabulated by Gisler (1978), by a factor ~ 2. This difference is likely to be due to (1) the high average luminosity of the present sample, (2) the dominance of early-type galaxies, and (3) the small aperture, which samples only the central regions of the galaxies.

b) Were Seyferts More Prevalent in the Past?

Osterbrock (1984) has pointed out that, at least for field galaxies, the Seyfert frequency is a strong function of absolute magnitude, such that nearly all very luminous galaxies ($M_B \sim -23$) have active nuclei. Commenting on the three AGNs found in the distant cluster 3C 295 ($z \sim 0.46$) by Dressler and Gunn (1983), Osterbrock (1984) suggests that this frequency of $\sim 10\%$ may not be unusually high compared with present-epoch clusters, since the distant sample is more heavily weighted toward luminous galaxies than any nearby sample. The data presented in this paper demonstrate that this alternative explanation to cosmic evolution is not correct. The cluster sample presented in this paper covers the top three magnitudes of the nearby clusters, which is equivalent to the 3C 295 sample. Even though the absolute magnitude range is equivalent, and the Seyferts detected in both samples are very luminous galaxies, the frequency implied in 3C 295 is roughly an order of magnitude greater than for the present-epoch sample.

The selection criteria for AGNs used in this paper have, in fact, been tailored to correspond to what can be done at higher redshift with lower resolution charge-coupled device (CCD) spectrographs like the PFUEI on the 5 m Hale reflector. If anything, the cluster sample presented here *overestimates* the Seyfert frequency relative to the distant sample because the poorest AGN examples with $W_{[\mathrm{O\,II}]}$ or $W_{[\mathrm{O\,III}]}$ of the order of 5 Å would be hard to detect with the available data for the distant clusters due to (1) poorer signal-to-noise ratio and resolution and (2) the dilution of the emission from the nuclei in the distant sample by a larger contribution of galaxy starlight (the slit covers a larger physical area in the distant sample). These two effects make the difference between the frequency of $\sim 1\%$ for the present-epoch sample and $\sim 10\%$ for the 3C 295 cluster more remarkable.

However, the data presented here add some support to a model which is an alternative to cosmological evolution, that is, that some special event has occurred in the 3C 295 cluster which triggered the starburst and AGN galaxies (Dressler and Gunn 1983). One of the clusters in the present sample, DC 0428 − 53, has three AGNs by the adopted criteria, the same as have been found in the 3C 295 cluster, and well above the average frequency for nearby clusters. Twelve of the 84 cluster members for which spectra were obtained, or 14%, are emission-line galaxies, twice the average for the nearby cluster sample, and, even more remarkably, none of these are of morphological type Sc, Sd, or I. Thus, DC 0428 − 53 may be an nearby example of a cluster like 3C 295 that has an unusually high degree of activity. The galaxy distribution in DC 0428 − 53 has a well-developed core and is very regular, like 3C 295. The only other cluster of this type in the present sample, DC 2048 − 52, has one AGN (the weakest case in the cluster sample) and a low frequency of emission-line galaxies of only 4%.

Rich regular clusters with a high degree of activity like 3C 295 and DC 0428 − 53 may be rare, and the fact that the 3C 295 cluster was one of the first distant clusters studied may simply be due to the bright radio galaxy 3C 295 that called attention to the cluster. On the other hand, even with the present spectroscopic data, it is not clear whether the three AGNs in DC 0428−53 represent as high a frequency as is seen in the 3C 295 cluster, for it is unknown whether a search for emission-line and AGN galaxies in the 3C 295 cluster as comprehensive and as sensitive as that in DC 0428−53 would have uncovered even more active nuclei, or whether all have already been found. Nearly four times as many galaxies have been studied in DC 0428−53 (although the numbers of blue galaxies alone may not be so different), but because of the dilution of the AGN by galaxy light due to the larger effective aperture, not all three of the AGNs in DC 0428−53 would have been detected in a cluster like 3C 295. Only one, DC 0428−53 77, a Seyfert 1, would certainly have been seen at the distance of 3C 295 with the quality of observations now available.

Therefore, although we can clearly show that the AGN frequency in 3C 295 is much higher than in the average nearby cluster, there remains some doubt as to whether some nearby clusters are also unusually active. This result points up the need for extensive photometry and spectroscopy of nearby cluster galaxies with which to compare the distant sample.

IV. SUMMARY

Spectra for a homogeneous sample of galaxies in the fields of rich clusters show that relatively strong emission is found in 31% of bright field galaxies but in only 7% of comparable cluster galaxies. The difference in frequency is found at each given morphological type, which implies that different population mixes for cluster and field are not alone responsible for the difference between the two samples. This, in turn, suggests some sort of environmental effect is at work.

Galaxies with active nuclei make up 5% of the field sample but only 1% of the cluster sample, again implying an environmental influence. This average frequency of 1% in nearby clusters is an order of magnitude smaller than that found by Dressler and Gunn (1983) for the 3C 295 cluster, but there may be similar nearby clusters that also show an unusually high frequency of AGN galaxies.

The authors thank Mark Phillips and Don Osterbrock for useful discussions and encouragement.

REFERENCES

Baldwin, J. A., Phillips, M. M., and Terlevich, R. 1981, *Pub. A.S.P.*, **93**, 5.
Dixon, R. S. 1970, *Ap. J. Suppl.*, **20**, 1.
Dressler, A. 1980, *Ap. J. Suppl.*, **42**, 565.
Dressler, A., and Gunn, J. E. 1983, *Ap. J.*, **270**, 7.
Dressler, A., and Shectman, S. A. 1985, in preparation.
Gisler, G. R. 1978, *M.N.R.A.S.*, **183**, 633.
Heckman, T. M. 1980*a*, *Astr. Ap.*, **87**, 142.
———. 1980*b*, *Astr. Ap.*, **87**, 152.
Keel, W. C. 1982, *Ap. J. Suppl.*, **52**, 229.
Osterbrock, D. E. 1960, *Ap. J.*, **132**, 325.
———. 1984, *Ap. J. (Letters)*, **280**, L43.
Simkin, S. M., Su, H. J., and Schwarz, M. P. 1980, *Ap. J.*, **237**, 404.

ALAN DRESSLER, IAN B. THOMPSON, and STEPHEN A. SHECTMAN: Mount Wilson and Las Campanas Observatories, 813 Santa Barbara Street, Pasadena, CA 91101-1292