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RADIO SOURCES IN DENSE GROUPS

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ABSTRACT

In order to investigate effects of galaxy environment on radio emission, we have observed 88 compact groups of galaxies, with densities as high as 10^6 galaxies Mpc^{-3}, at a wavelength of 18 cm at the VLA. Forty-one sources were found above a flux limit of 1.5 mJy, with roughly equal frequency in all galaxy types. Elliptical galaxies with detectable radio emission are almost always the first-ranked galaxies in optical luminosity. They are less luminous than typical rich cluster radio galaxies, are coincident with the optical nucleus, and do not show extended structure. Radio sources occurring in spiral galaxies show no strong preference for optical rank. We argue that this is strong evidence that the galaxy environment on large scales plays a crucial role in the development and fueling of nuclear radio sources.

Subject headings: galaxies: clustering — galaxies: structure — radio sources: galaxies

I. INTRODUCTION

It has long been recognized that galactic radio emission may be strongly influenced by environmental factors (Miley 1980). Radio surveys of field galaxies (Stocke 1978; Adams, Jensen, and Stocke 1980) and cluster galaxies (Owen 1974; Leir and van den Bergh 1977) show a correlation between the occurrence of radio emission and the local space density of galaxies. A possible explanation is that galactic interactions affect the supply of gas to the radio source through such mechanisms as ram-pressure sweeping (Gisler 1976) and mergers (Hausman and Ostriker 1978). Alternatively, the gas supply may result from primordial infall (Gunn and Gott 1972) and be determined more by initial conditions than by interactions.

Compact groups of galaxies are systems of small total mass but very high galaxy space density and short dynamical times (Hickson, Richstone, and Turner 1977). They would thus be expected to suffer the same dynamical effects (perhaps to a greater degree) as rich clusters but may differ in both gas density and initial conditions. Recently Hickson (1982) undertook a survey of Palomar Observatory Sky Survey (POSS) prints for groups satisfying three selection criteria of population, isolation, and mean surface brightness. The catalog and several aspects of the structure of these groups are discussed by Hickson (1982) and Hickson *et al.* (1984). We have surveyed the 88 groups in the above sample north of declination −19° for continuum radiation at 20 or 18 cm in order to study the nature and frequency of occurrence of radio sources in this environment. This paper discusses the observations, the optical morphology of the radio groups, and possible interpretations of the results. The detailed structures and luminosity function will be reported in subsequent papers.

II. OBSERVATIONS AND DATA ANALYSIS

Most of the observations discussed in this paper were made at a frequency of 1635 MHz in the C-configuration of the Very Large Array (VLA) of the National Radio Astronomy Observatory[1] (NRAO) in 1983 April. Groups which were definitely found to contain sources and groups with poor data were reobserved in the B-configuration in 1984 January. The C-configuration observations were made in the snapshot mode of the VLA with a bandwidth of 50 MHz and an integration time of 6 minutes for each group. The integration time for B-configuration observations varied from 30 to 10 minutes and also utilized all four intermediate frequency passbands. The calibration and mapping procedures used the standard NRAO programs available at the VLA. Flux densities and positions were measured from the CLEANed maps using the AIPS task IMEAN over a rectangular box set by eye around the sources. More accurate values will be available from the higher resolution data which are being obtained. The flux density calibration was done using 3C 286 as the primary calibrator, and a number of VLA calibrator sources were observed every 30 minutes or so. Positions of all sources detected within the optical boundaries of the groups were compared with the optical positions of the member galaxies determined from the POSS prints using the Mann measuring engine at the VLA. The radio positions have an intrinsic accuracy of about 1″. However, the extended and overexposed nature of the POSS images caused significant errors in estimating the optical positions of the galaxy nuclei. Positions of the radio sources and optical minus radio position differences are listed in Table 1. Median separations are given in Table 2 for elliptical, lenticular, and spiral galaxies separately. The deviations are within the measurement errors for the elliptical galaxies. The larger errors for the spiral galaxies may be due to the greater difficulty in determining the optical center of a spiral, as well as to possible real differences in positions of the optical center and the associated radio source. The significance of these differences can be determined only after analysis of optical images from CCD observations being obtained by one of us (P. H.) with the 3.6 m Canada-France-Hawaii Telescope.

The sensitivity and detection limits of the survey were estimated by the following procedure. In the field of each observed group the rms noise was measured in a region of the map devoid of any obvious sources. These values ranged from 0.3 to 0.4 mJy for the C-configuration data and from 0.15 to 0.2 mJy for the longer integration B-configuration data. However, in

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TABLE 1

DATA ON RADIO SOURCES IN COMPACT GROUPS

GALAXY		GROUP	RADIO POSITION (1950)		SEPARATION		S		log P	
No. (1)	Type (2)	TYPE (3)	R.A. (4)	Decl. (5)	(arcsec) (6)	m (7)	(mJy) (8)	M (9)	(W Hz^{-1}) (10)	R (11)
15d	E	EIII	$02^{\rm h}05^{\rm m}02\overset{\rm s}{.}52$	$01°56'37\overset{''}{.}70$	0.72	13.7	3.99	−18.6	21.40	1.84
27b	S	SIII	04 16 57.51	−11 49 17.10	0.84	15.3	0.64	−18.1	21.07	1.69
28b	L	SI	04 24 57.51	−10 26 11.50	0.44	15.0	3.21	−18.5	21.79	2.27
31a	S	SII	04 59 09.09	−04 19 51.05	11.54	14.3	13.03	−16.9	21.49	2.59
34a	E	EI	05 19 04.31	06 38 27.26	2.99	13.1	4.71	−19.8	21.71	1.67
34c	S	EI	05 19 07.53	06 38 05.60	2.92	15.4	0.46	−17.5	20.70	1.58
34b	S	EI	05 19 08.25	06 37 47.60	5.37	14.8	6.06	−18.1	21.82	2.46
37d	E	SI	09 10 34.21	30 13 20.74	3.95	14.8	0.89	−17.5	20.75	1.63
37a	L	SI	09 10 39.25	30 11 59.61	7.58	12.1	20.54	−20.2	22.12	1.91
37b	S	SI	09 10 33.34	30 12 24.14	4.93	12.8	2.45	−19.5	21.19	1.27
40a	E	EII	09 36 22.99	−04 37 21.39	0.46	12.5	5.56	−19.7	21.51	1.51
40c	L	EII	09 36 23.07	−04 37 60.99	5.99	13.2	10.30	−19.0	21.78	2.05
40b	L	EII	09 36 24.14	−04 38 12.00	12.42	13.1	3.12	−19.1	21.26	1.49
40d	L	EII	09 36 25.23	−04 36 39.40	0.45	13.9	5.95	−18.3	21.54	2.09
44a	S	SII	10 15 20.26	22 04 57.60	5.93	10.0	7.29	−18.9	20.34	0.62
46a	L	EIII	10 19 24.29	18 05 25.99	1.64	13.8	2.45	−18.8	21.33	1.67
47a	S	SI	10 23 05.39	13 58 12.46	9.08	12.9	8.44	−20.1	22.02	1.85
47b	L	SI	10 23 08.11	13 58 55.66	2.14	14.5	0.73	−18.5	20.96	1.42
51c	L	EII	11 19 51.24	24 33 12.58	2.49	13.3	18.40	−19.3	22.21	2.34
53a	S	SI	11 26 13.36	21 04 29.79	15.30	12.2	7.90	−19.9	21.62	1.54
56b	S	SIII	11 29 55.28	53 13 34.48	3.33	13.5	32.96	−19.1	22.46	2.68
58a	S	SIII	11 39 36.37	10 33 14.90	3.61	13.5	20.42	−18.6	22.03	2.47
60c	L	EII	12 00 33.83	51 57 47.37	2.19	15.2	14.12	−19.3	22.83	2.99
60a[a]	E	EII	12 00 34.08	51 57 12.98	1.54	14.4	55.25	−20.1	23.43	3.26
61c	S	EIII	12 09 59.08	29 26 45.99	1.74	11.8	35.66	−19.3	21.86	2.03
62a	E	EIII	12 50 29.54	−08 55 57.47	3.25	12.4	0.70	−18.8	20.22	0.57
67c	S	EIII	13 46 35.06	−06 57 39.80	1.56	14.5	11.40	−18.0	21.93	2.62
68c	S	EII	13 51 14.64	40 36 32.74	2.07	11.0	6.41	−19.0	20.69	0.97
68a	E	EII	13 51 19.70	40 31 42.95	1.33	10.5	36.60	−19.5	21.45	1.52
68b	E	EII	13 51 19.75	40 32 53.15	0.67	11.0	1.25	−19.0	19.98	0.26
69b	S	SII	13 53 15.60	25 17 38.94	1.31	13.8	3.98	−19.7	21.61	1.60
71b	S	SI	14 08 46.00	25 45 15.20	0.94	14.5	5.40	−18.4	21.80	2.29
73a	S	SI	15 00 29.05	23 31 45.50	6.94	13.0	0.40	−18.9	20.24	0.56
74a	E	EII	15 17 10.53	21 04 35.42	2.72	12.9	13.50	−20.6	22.42	2.05
77a	L	EIII	15 47 05.96	21 58 15.02	5.38	14.8	117.66	−18.4	23.24	3.75
79a	E	EIII	15 56 59.24	20 53 43.50	4.91	12.6	5.90	−18.6	21.14	1.57
81a	L	EIII	16 15 53.62	12 55 26.49	1.09	14.5	3.20	−19.4	21.97	2.07
82c	S	EII	16 26 26.60	32 55 12.77	2.15	13.9	7.73	−19.4	22.08	2.21
84a	L	EIII	16 46 44.02	77 55 39.37	0.61	13.5	24.54	−19.5	22.97	3.03
85a	E	EIII	18 51 22.37	73 17 25.37	2.85	13.6	10.69	−19.8	22.29	2.23
92c	S	SII	22 33 46.05	33 42 59.55	4.10	13.2	23.87	−18.9	22.10	2.42
93a	E	EIII	23 12 46.85	18 41 18.98	0.74	12.0	49.57	−19.6	22.24	2.26
93b	S	EIII	23 12 48.10	18 46 00.00	7.61	12.0	4.82	−19.6	21.22	1.24
94a	E	EI	23 14 44.08	18 26 05.33	1.47	13.1	24.50	−20.5	22.70	2.39
95d	S	EIII	23 16 59.34	09 13 44.71	0.68	14.1	5.07	−19.3	21.97	2.11
95b	S	EIII	23 17 01.96	09 13 15.91	1.19	13.2	3.67	−20.2	21.83	1.60
96a	S	SII	23 25 24.43	08 30 12.63	3.72	12.0	196.08	−20.8	23.30	2.85
100a	S	SI	23 58 46.25	12 49 58.00	1.42	12.1	31.97	−19.7	22.10	2.10

[a] Central component only.

practice these values are not applicable uniformly across all maps because of sporadic interference and other instrumental effects. In order to establish a uniform detection limit for all groups for the determination of the luminosity function, a conservative value of 1.5 mJy will be used as the upper limit for the undetected galaxies. It may be possible to improve the limits by further editing and processing of the data.

The basic data on all detected sources are given in Table 1. Column (1) gives the Hickson catalog number, col. (2) the galaxy type, col. (3) the group type, cols. (4) and (5) the radio position, col. (6) the optical minus radio separation, col. (7) the estimated red magnitude, col. (8) the 20 cm flux density in mJy, col. (9) the absolute red magnitude, col. (10) the 20 cm radio luminosity in W Hz^{-1}, and col. (11) the ratio of radio to optical luminosity. Absolute magnitudes and radio luminosities were derived assuming a Friedmann cosmology with $q_0 = \sigma_0 = 0.5$ and $H_0 = 100$ km s^{-1} Mpc^{-1}. The ratio R of the radio and optical luminosities is defined as $R = S$ dex $[0.4(m - 12.5)]$, where S is the total flux density at 20 cm in mJy and m is the red magnitude from column (7).

III. DISCUSSION

Most radio sources are located within 3″ of the optical nucleus. This is consistent with the expected errors in estimating and measuring the optical center on the overexposed sky survey images. There is, however, a correlation of optical minus radio offset with galaxy type, as can be seen from the median offset for each galaxy type as listed in Table 2. The offsets are smallest for elliptical galaxies and are significantly

TABLE 2

STATISTICS OF RADIO SOURCES IN COMPACT GROUPS

Galaxy Type	N	Median Separation (arcsec)	$\langle\mu_G\rangle$	σ	$\Delta\langle\mu_G\rangle/\sigma_d$
E	10	1.54	22.67	1.53	1.29
L	11	2.34	22.47	1.08	2.43
S	20	3.33	22.85	1.17	1.60
All types	33	...	22.77	1.25	2.18
Nonradio groups ...	67	...	23.31	0.96	...

larger for spiral galaxies. This may be the result of more uncertain optical positions or an extranuclear component of the radio emission in these galaxies. Higher resolution radio observations and the current CCD imaging program should resolve this question.

The probability that the detected sources are background sources not associated with the groups is very small. Table 3 lists the number of background sources expected to occur by chance at various distances from the nuclei for three flux limits. The numbers were computed from Bridle (1982). At most one or two of the sources could be unrelated to the groups.

The distribution of morphological types among the detected galaxies is compared with the distribution for all group galaxies in Figure 1. There is no significant difference between the two populations, indicating that the probability of radio emission above our detection limit is not a strong function of galaxy type. However, when we examine which galaxies in individual groups show radio emission, differences are found. As shown in Figure 2, almost all elliptical radio galaxies are first-ranked in the group in optical luminosity. Only the brightest elliptical galaxies have radio sources, and no group has more than one elliptical radio galaxy. This is in sharp contrast to the optical result (Hickson 1982) that the rank distribution of elliptical galaxies in the groups is similar to that of nonelliptical galaxies, and that there is no excess of elliptical types among the first-ranked galaxies. This result is highly significant; the probability that the distribution in Figure 2 is due to chance is 3×10^{-5}. This effect is not found in spiral radio galaxies, which show equal preference for all but the faintest galaxies. The distribution for lenticular galaxies appears to be intermediate, but caution is warranted here. Faint lenticulars are hard to distinguish from faint spirals, and it is very likely that some may be misclassified spirals. If this is so, true lenticular galaxies may more closely resemble elliptical galaxies in their radio properties. More accurate classifications should soon be available when the (two-color) CCD imaging is complete.

The distribution of radio luminosities at 20 cm is shown in Figure 3. Of all the detected galaxies, only one has an extended structure beyond the optical dimensions of the associated

TABLE 3

EXPECTED NUMBER OF BACKGROUND SOURCES[a]

FLUX LIMIT (mJy)	RADIUS FROM NUCLEUS 1″	5″	10″
1.5..............	2.4×10^{-2}	6.1×10^{-1}	2.4
1.0..............	3.5×10^{-2}	8.8×10^{-1}	3.5
0.5..............	6.6×10^{-2}	1.6	6.6

[a] Total number for the 404 galaxies observed.

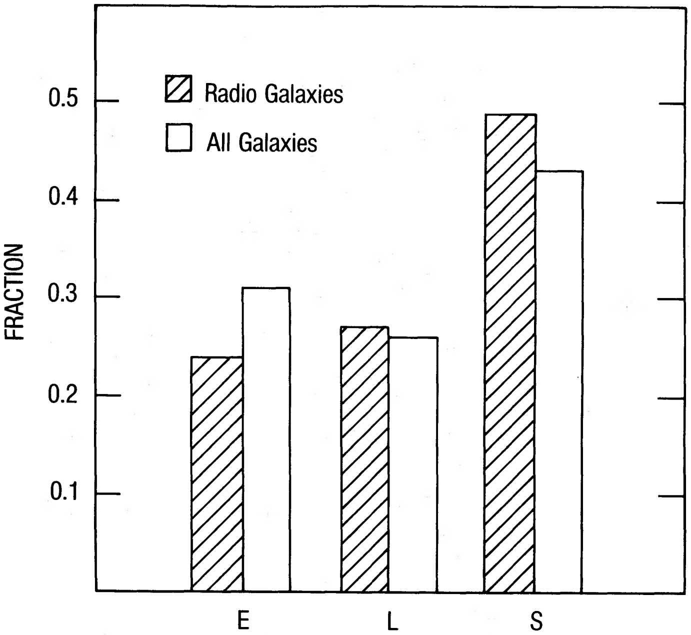

FIG. 1.—The distribution of galaxy morphological types. Shaded bars represent radio galaxies with detected fluxes >1.5 mJy. Open bars represent all group galaxies. The likelihood of radio emission at this level is similar for all galaxy types.

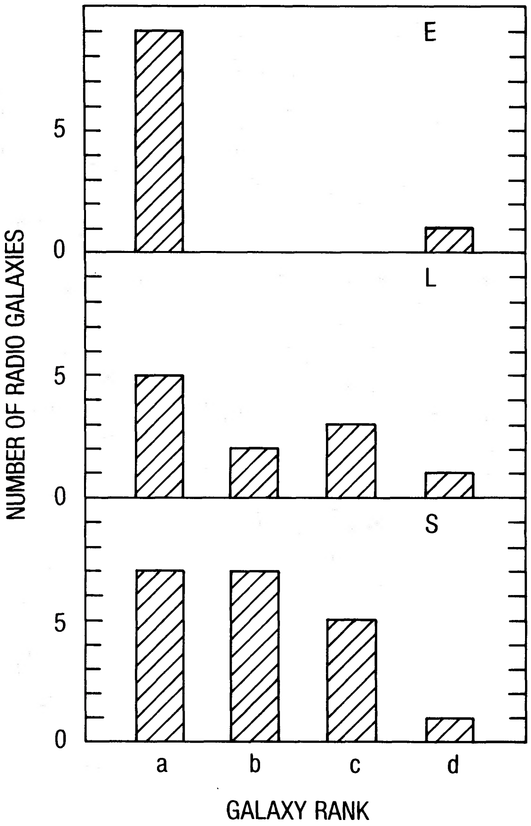

FIG. 2.—Optical rank of the radio galaxies. The distribution of sources with fluxes >1.5 mJy over optical luminosity rank in the host groups is shown. There is a striking preference for elliptical radio galaxies to be first-ranked.

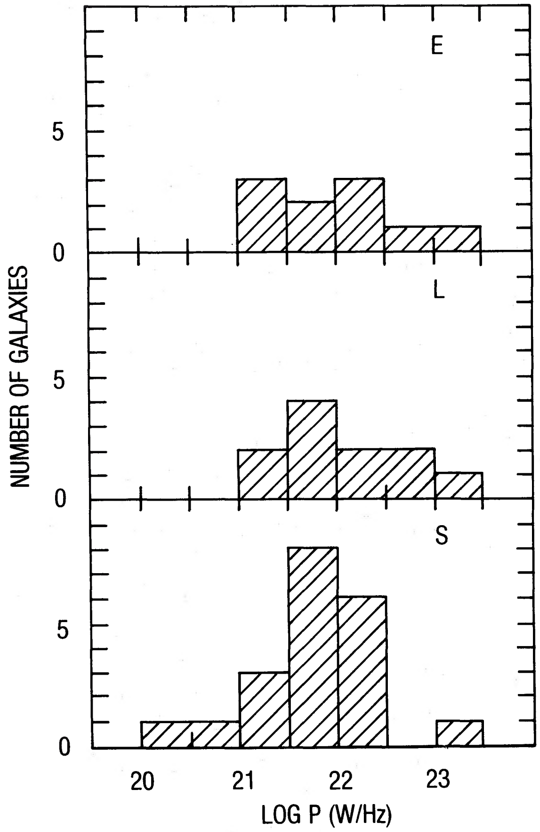

FIG. 3.—The radio luminosity distribution for sources with fluxes > 1.5 mJy. There are no significant differences between the total luminosities of various morphological types.

galaxy. This is the source 60a, which has a typical structure of a wide-angle head-tail source and extends to almost 70″ (60 kpc), while the optical size of the galaxy is only about 25″. It is interesting that of all the 88 groups surveyed in this program, this group is the only one known to be in an Abell cluster (A1452). As seen in Table 1, this source is also the most powerful in the sample by a considerable factor. The distribution of radio luminosities for all galaxy types is shown in Figure 3. There are no significant differences among the distributions, as is confirmed by Mann-Whitney tests. Although this result differs from those of earlier investigations (see Hummel 1980), this can be accounted for by differences in selection criteria among various samples. The spiral galaxies in our sample have typical distances similar to those of the other galaxy types, so a comparison of the luminosity distributions is meaningful. The luminosity functions for these groups will be discussed in detail in a subsequent paper.

We have examined our data for statistical correlations among various observable parameters of the groups and galaxies. There are no significant correlations between radio and optical fluxes for all galaxy types. However, the likelihood of occurrence of a radio source appears to be a weak function of group density. Table 2 lists the mean surface brightness for all groups containing radio galaxies of a given morphological type, all radio groups, and all nonradio groups. Differences with respect to the nonradio groups are listed in units of the standard deviation of the difference $\sigma_d = (\sigma_1^2/N + \sigma_2^2/N)^{1/2}$. There is a consistent but not strong trend for radio sources to occur preferentially in the more compact groups.

It seems evident that the physical processes causing radio emission in the spiral galaxies are different from those in the ellipticals. In spirals we may be seeing effects of star formation, such as supernova remnants not normally present in ellipticals. Nonnuclear components would account for the greater position offsets observed in these galaxies. From an inspection of the POSS images we find that the radio galaxies contain approximately twice the number of interacting galaxies (as indicated by a close and distorted companion) contained in a random sample from the groups. This hypothesis can be tested by higher resolution radio observations (in progress) to determine the source morphology and optical CCD imaging to assess the degree of interaction and star formation.

The strong preference of radio elliptical galaxies to be first-ranked points to the importance of either mass, or central location of the first-ranked galaxy to the radio emission mechanism. It is perhaps significant that even groups with relatively luminous elliptical galaxies that are second- or third-ranked do not contain radio sources in these galaxies. This would suggest that central location is the important factor and that accretion onto the galaxy may be the dominant process. Further optical observations of these galaxies would be valuable in assessing the causes of activity. Deep CCD images might also reveal cluster background light which would aid in locating the dynamical center.

The conspicuous lack of extended radio emission in the groups is particularly interesting. Either these radio sources do not produce the double radio structure exhibited by galaxies in rich clusters (Miley 1980), or they have not had time to. The latter possibility implies that (1) the groups are young, (2) nuclear radio activity did not occur until the groups reached their present high-density state, and (3) compact groups do not last long. This is consistent with the apparent lack of dynamical evolution in the groups (Hickson 1982) and suggests that the groups that we observe have recently condensed from more extended associations. The short dynamical times derived for compact groups (Hickson, Richstone, and Turner 1977), and the instability to merging shown by numerical simulations of galaxy clusters (White 1979, 1982; Aarseth and Fall 1980; Miller 1983; Quinn 1984), also imply a short lifetime for these groups. If this is the case, it provides further evidence that radio emission in elliptical galaxies in the groups is caused or triggered by the high-density group environment.

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