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Radio properties of spiral galaxies in high-density groups

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ABSTRACT

Radio-continuum observations with the Very Large Array (VLA) of 133 spiral galaxies in 68 Hickson Compact Groups are used to investigate possible enhancement of the effects of interactions among galaxies in such high-density groups. In most of the 56 HCG spirals that were detected the radio radiation is confined to slightly extended nuclear regions suggestive of starburst activity. It is found that the total radio radiation from compact group spirals is significantly lower than from a comparison sample of isolated spirals. However, the radio radiation from the nuclear regions is more than 10 times that from comparable regions in the comparison sample. This effect is more dominant in late-type spirals than it is in early-type spirals. The observations are interpreted in a scenario, suggested by numerical simulation studies by a number of authors, in which galaxy interactions are shown to cause both massive inflows of gas towards the centres of galaxies and outflows from the outer regions. The resultant star formation activity at the centre leads to the formation of supernovae and the subsequent radio radiation. On the other hand, the outflow from the outer regions may be expected to remove the gas and magnetic fields from the disc, resulting in reduced disc radio emission. Observations of gaseous and molecular line distributions may be expected to provide kinematic information for modelling of specific interacting systems.

Key words: galaxies: clusters: general – galaxies: interactions – galaxies: nuclei – galaxies: spiral – galaxies: starburst – radio continuum: galaxies.

1 INTRODUCTION

The radio-continuum radiation from isolated spiral galaxies has been extensively studied by a number of investigators in order to understand the various physical processes that contribute to the observed emission and the variety of different components that comprise the total emission. These studies have been reviewed by Hummel (1981a), who carried out a systematic study of an optically selected sample of 280 spiral galaxies at a frequency of 1415 MHz with the Westerbork Radio Telescope. His results clearly demonstrated the dominance of the non-thermal component in the radio radiation from the discs of spiral galaxies and the dependence of the radio radiation on the optical luminosity and the morphological type of the galaxies concerned. More recently multiwavelength studies of spiral galaxies have been reviewed in the proceedings of the workshop on the 'The Interpretation of Modern Synthesis Observation of Spiral Galaxies' (Duric & Crane 1991). These studies have shown that, in a number of galaxies, in addition to the non-thermal continuum radiation from the discs of these galaxies there are also significant contributions from sources in the galactic nuclei (van der Hulst 1991). One of the important issues raised in the course of these investigations is the influenceof neighbours in the generation of radio as well as other radiations from a particular galaxy. There have been several previous investigations of the possible effect of interactions on the radio continuum properties of galaxies (Burke & Miley 1973; Allen et al. 1973; Wright 1974a,b; Sulentic 1976; Stocke 1978). These earlier studies had suggested that gravitational interactions among galaxies have some influence on the radio-continuum radiation from double and multiple systems.

Hummel (1981b) made a statistical comparison of radio radiation from a sample of isolated spiral galaxies with that from a sample of multiple systems, and found that the radio power of the central sources in double galaxies is on average a factor of 2.5 higher than the radio power of the central sources in isolated galaxies, after correction for their absolute magnitude differences, while the ratio of the radio power of the disc components was at most a factor of 1.5. A more recent investigation of a complete sample of isolated and interacting galaxies by Hummel et al. (1990) also suggests an enhancement of the nuclear sources in the interacting systems compared to isolated systems. The large-scale effects of interactions in producing starburst phenomena as well as the ultraluminous *IRAS* galaxies have been reviewed by Kennicutt (1990), and the effects of interactions on nuclear activity and star formation have been reviewed by Heckman (1990). If, as these studies suggest, the radio radiation (as well as radiation at other wavelengths) from the nuclei of interacting spirals is enhanced as a result of interactions, then we may expect this effect to be particularly dominant in the case of galaxies in very high-density groups, such as the Hickson Compact Groups (HCG) (Hickson 1982, 1993), in which multiple interactions could have taken place over the Hubble time. In order to investigate this question in some detail, I have carried out a systematic study of the radio properties of all galaxies in a sample of 68 groups from the Hickson catalogue. In an earlier paper (Menon 1992), I discussed the possible influence of interactions on the statistical properties of the total radio radiation from galaxies of different morphologies. This paper is a discussion of the data and interpretation of the observations of 133 spiral galaxies that are members of the above groups, as well as a comparison of their properties with those of a sample of isolated spiral galaxies.

2 OBSERVATIONS

The basic sample of 68 groups consisted of all groups north of declination −20° from Hickson's (1982) Catalogue of Compact Groups (HCG) that have a minimum number of four galaxies with concordant redshifts, and that satisfy Hickson's criteria of compactness and isolation. The optical data for these galaxies are from Hickson, Kindl & Auman (1989) and Hickson (1993). The morphological distribution of the 133 spirals based on the classification given in Hickson, Kindl & Auman is given in Table 1. The observations were carried out with the VLA in various configurations at 1.4 and 4.9 GHz over the period 1984–1991. All the data were processed using the AIPS data processing package of NRAO. The initial low-resolution survey at 1.4 GHz in the C configuration of the VLA (Menon & Hickson 1985) was carried out in the snapshot mode, and the detection sensitivity varied considerably from field to field due to confusing sources in the primary beam. Hence I have assumed a conservative value of 1 mJy for the upper limit for the flux density of those galaxies observed but not detected in the C configuration. Many of the fields were re-observed in the B configuration with much longer integration times, and the detection limits in such cases were at least a factor of 3 better than the above limit of 1 mJy. This is the case for 58 of the 68 groups in the present programme. These different upper limits are incorporated into the statistical treatment of the data discussed later in the paper. A total of 47 galaxies were detected above 1 mJy and nine below that limit.

Table 1. Morphological distribution of HCG spirals.

Hubble Type	Type Code	Number
Sa,SBa	3	23
Sab,SBab	4	6
Sb, SBb	5	17
Sbc, SBbc	6	10
Sc, SBc	7	32
Scd, SBcd	8	11
Sd, SBd	9	12
Sdm, SBdm	10	4
Sm, SBm	11	3
Im, IBm	12	12
cI	13	3

Since one of the main motivations for the present study is to compare the properties of galaxies in high-density groups with galaxies in more isolated regions, it is important to choose a proper comparison sample. For this purpose I have chosen the same comparison sample as the 'control sample' that was used by Hummel et al. (1987), leaving out the S0 galaxies from their sample. The selection criteria for this isolated spiral sample (ISPL) are described in Keel et al. (1985). The final comparison sample consisted of 85 galaxies. The radio data for that sample were taken from the Condon (1987) and Hummel et al. (1987). The flux density data of Condon (1987) refers to the integrated total emission from the galaxies, while Hummel et al. (1987) give both the flux density from a region covering roughly the inner 10 arcsec and the flux density from the inner < 1 arcsec wherever it is clearly seen above the more extended emission. Since practically all the galaxies in the comparison sample have dimensions greater than 1 arcmin, the radio emission from the inner 10 arcsec really refers to the central regions of these galaxies as pointed out by Hummel et al. (1990). The angular diameter data given in Hickson et al. (1989) show that 90 per cent of the galaxies in the present sample have angular diameters less than 80 arcsec with a median value of 22 arcsec. The C-configuration maps were convolved with a beam size of 20×20 arcsec^2. The largest angular size (*LAS*) in arcsec that could be imaged can be estimated using the relationship between *LAS* and the smallest projected baseline (*SPB*) in wavelengths. Using a conservative criterion of 80 per cent of peak visibility, this relationship can be written as $LAS = 45\,500/(SPB)$ (Bridle 1989). Since the smallest baseline used in the present survey is about 63 m, the *LAS* turns out to be 260 arcsec. This value is far larger than the angular size of any galaxy in the present survey. Hence the flux densities measured from the images obtained in the C array may be expected to be very close to the true total flux densities to within 10 per cent accuracy. The synthesized beam sizes for the B configuration ranged from 6.5 to about 4 arcsec. Some of the stronger sources were also observed in the A-array configuration at 20 cm with an angular resolution of about 1.5 arcsec.

Comparison of the integrated densities determined from the C-array and B-array observations shows that, in 46 out of the 56 detected galaxies, the observed total flux density could be attributed to a central component. In the galaxies 40c and 67c there is evidence for extended disc emission in addition to a central component. In the galaxy 47a nearly 80 per cent of the radio emission is confined to a spiral arm that has conspicuous starburst activity, while the rest of the emission is in an extended disc component with no detectable central component. In 44a the radio emission consists of a dominant central component and a triple background source, all of whose components lie within the optical boundaries of the galaxy. In the other six cases the total emission arises from a marginally resolved central component, suggesting structure in the central emission. Preliminary and incomplete observations at 5 GHz suggest that all the detected galaxies have non-thermal spectra ranging in spectral indices from 0.6 to 0.8. More detailed observations are being planned. The structures of these sources are discussed elsewhere (Menon 1995, in preparation).

Table 2 contains a list of the detected galaxies and their total flux densities, as well as that attributed to a central component. The positions correspond to that of the central component determined from the low-resolution measurement and in general coincide with the optical position to within the errors of both the optical and radio positions, which are of the order of 3 arcsec. In those cases where the sources have been clearly resolved, the flux densities of the central components and the extended components have been separately determined for the statistical discussions below. The luminosities and linear dimensions discussed in this paper are based on a value of $H_0 = 100$ km s^{-1} Mpc^{-1} and $q_0 = 0.5$. At the distances of the comparison sample the linear dimensions of the inner 10 arcsec range from 1.3 to 0.04 kpc. In the case of the HCG sample a beamwidth of 5 arcsec corresponds to linear sizes of 4.1 to 0.32 kpc. Since the median optical size of the HCG sample is about 22 arcsec, it is clear that for the vast majority of the radio-loud HCG galaxies the radiation is mainly from the central regions of those galaxies.

3 ANALYSIS AND DISCUSSION

It is known, from earlier studies by Auriemma et al. (1977), Hummel (1981a,b), Gavazzi & Jaffe (1986) and Hummel et

Table 2. Radio positions and flux densities of HCG spirals at 1.4 GHz.

HCG No	Type	R.A. (1950)	Dec (1950)	Stotal (mJy)	Scentre (mJy)
1a	7	$00^h23^m29^s.578$	$+25^\circ26'46''.0$	01.58	1.58
7a	5	$00^h36^m39^s.510$	$+00^\circ35'23''.2$	12.85	12.85
10c	7	$01^h23^m28^s.294$	$+34^\circ29'40''.2$	02.47	02.43
13a	4	$01^h29^m50^s.414$	$-08^\circ07'01''.4$	01.26	01.26
15a	3	$02^h05^m17^s.942$	$+01^\circ55'49''.7$	01.09	01.09
16a	4	$02^h06^m57^s.216$	$-10^\circ22'19''.0$	33.18	33.18
16b	4	$02^h06^m53^s.488$	$-10\circ22'09.''.0$	02.62	02.62
16c	12	$02^h07^m11^s.245$	$-10^\circ22'56''.0$	78.29	78.29
16d	7	$02^h07^m15^s.381$	$-10^\circ25'10''.0$	30.91	30.91
19b	8	$02^h40^m17^s.990$	$-12^\circ38'25''.3$	02.08	02.08
23a	4	$03^h04^m30^s.371$	$-09^\circ44'10''.6$	00.89	00.89
23b	7	$03^h04^m43^s.900$	$-09^\circ47'03''.6$	08.01	08.01
23d	9	$03^h04^m29^s.760$	$-09^\circ49'12''.6$	03.18	03.18
25a	7	$03^h18^m10^s.401$	$-01^\circ17'23''.7$	04.70	02.63
26a	8	$03^h19^m33^s.989$	$-13^\circ49'41''.9$	10.52	10.52
33c	9	$05^h07^m49^s.836$	$+17^\circ57'33''.0$	04.58	04.58
34b	9	$05^h19^m08^s.344$	$+06^\circ37'45''.6$	06.03	05.72
34c	9	$05^h19^m07^s.337$	$+06^\circ38'02''.6$	00.85	00.85
37b	6	$09^h10^m33^s.371$	$+30^\circ12'24''.5$	01.55	00.57
37d	10	$09^h10^m34^s.167$	$+30^\circ13'21''.1$	00.76	00.76
40c	6	$09^h36^m23^s.146$	$-04^\circ38'02''.8$	06.03	03.11
40d	3	$09^h36^m25^s.233$	$-04^\circ36'38''.8$	06.39	03.69
43a	5	$10^h08^m46^s.033$	$+00^\circ13'26''.7$	00.95	00.95
43b	8	$10^h08^m33^s.833$	$+00^\circ12'15''.7$	01.06	01.06
44a	3	$10^h15^m20^s.154$	$+22^\circ04'58''.0$	04.77	00.98
44c	7	$10^h15^m52^s.748$	$+22^\circ56'18''.5$	02.45	02.45
44d	9	$10^h15^m03^s.634$	$+22^\circ08'08''.0$	02.95	02.95
45a	32	$10^h15^m22^s.060$	$+22^\circ04'16''.0$	02.41	02.41
47a	5	$10^h23^m05^s.527$	$+13^\circ58'22''.0$	12.25	00.31
49a	8	$10^h53^m23^s.596$	$+67^\circ27'08''.2$	00.68	00.68
49b	9	$10^h53^m20^s.641$	$+67^\circ27'50''.2$	01.70	01.70
57d	7	$11^h35^m18^s.671$	$+22^\circ15'41''.8$	05.09	05.09
58a	5	$11^h39^m36^s.314$	$+10^\circ33'18''.5$	20.71	20.71
58b	4	$11^h39^m48^s.069$	$+10^\circ32'40''.0$	01.46	01.46
59a	3	$11^h45^m52^s.956$	$+13^\circ00'18''.5$	09.02	09.02
67b	7	$13^h46^m22^s.004$	$-06^\circ56'48''.1$	06.70	03.36
67c	8	$13^h46^m35^s.141$	$-06^\circ57'39''.8$	13.49	13.49
68c	6	$13^h51^m14^s.695$	$+40^\circ36'32''.9$	02.10	02.10
69a	7	$13^h53^m11^s.070$	$+25^\circ19'04''.1$	03.13	00.60
69b	5	$13^h53^m15^s.659$	$+25^\circ17'38''.9$	04.71	06.60
70d	7	$14^h01^m58^s.631$	$+33^\circ35'05''.7$	00.28	00.28
70e	6	$14^h01^m54^s.630$	$+33^\circ33'34''.7$	00.13	00.13
75b	5	$15^h19^m17^s.194$	$+21^\circ22'14''.3$	03.10	03.10
80a	9	$15^h58^m50^s.620$	$+65^\circ22'21''.6$	20.62	20.42
81a	7	$16^h15^m53^s.592$	$+12^\circ55'26''.1$	03.13	01.93
82c	12	$16^h26^m26^s.536$	$+32^\circ55'12''.0$	08.33	05.10
88a	5	$20^h49^m56^s.624$	$-05^\circ54'02''.2$	00.90	00.90
92c	7	$22^h36^m46^s.082$	$+33^\circ42'59''.9$	24.74	19.99
92d	7	$10^h15^m22^s.060$	$22^\circ04'16''.0$	00.80	00.80
93b	9	$23^h12^m48^s.182$	$+18^\circ46'02''.0$	10.92	05.07
95b	8	$23^h17^m02^s.026$	$+09^\circ13'17''.0$	03.86	03.86
95c	11	$23^h16^m59^s.339$	$+09^\circ13'45''.5$	06.06	06.43
96a	7	$23^h25^m24^s.402$	$+08^\circ30'12''.6$	200.1	192.4
96c	3	$23^h25^m26^s.513$	$+08^\circ30'26''.1$	04.80	04.80
100a	5	$23^h58^m45^s.894$	$+12^\circ49'56''.4$	09.17	05.93
100b	11	$23^h58^m52^s.108$	$+12^\circ50'04''.1$	01.04	01.04

al. (1988), that the radio power P of galaxies is proportional to the optical luminosity and that the relationship is of the form $P \propto L_B^\alpha$ where L_B is the blue luminosity. The value of the exponent α for spiral galaxies has been estimated by the above authors to range between 0.8 and 1.1 for different samples. In order to estimate the value of α for the sample under investigation, I have divided the sample into three absolute magnitude intervals each containing 18, 19 and 19 detections, respectively, and computed the fractional luminosity functions utilizing the methods of survival analysis as discussed by Feigelson & Nelson (1985). In these methods both the detections and upper limits are taken into account and the detection limits can vary from different objects, as is the case in the present study. The fractional luminosity functions computed by this procedure for the three optical luminosity intervals are shown in Fig. 1. The values of the mean radio powers and the optical luminosities obtained from the above functions were used (Menon 1992) to derive a value 0.8 ± 0.32 for the exponent α for spiral galaxies of the present sample, and this value is comparable to the values found by the other authors. The dependence of the radio power on the optical luminosity can also be seen by using the distance-independent radio R, defined as $R = S \times \mathrm{dex}[0.4(B_{\mathrm{TC}} - 12.5)]$, where S is the flux density at 1.4 GHz in mJy and B_{TC} is the corrected blue magnitude from Hickson et al. (1989), and computing the fractional ratio function $F(\geqslant R)$ by the procedures of survival analysis. The three functions are shown in Fig. 2, and it confirms that the radio and optical luminosities are strongly correlated. It is clear from Fig. 1 that the radio sources associated with these galaxies are indeed from the low end of the radio luminosity function.

The present data can also be used to study the effects of the environment on the radio properties of the spirals in dense groups as compared to isolated systems. The mean absolute magnitudes of the two samples differ by about 0.45 mag, the ISPL sample being the brighter of the two. Hence, on the basis of the relationship between the radio and optical luminosities determined earlier, the radio luminosities of the isolated sample may be expected to be about 1.5 times those of the HCG sample. The fractional luminosity functions and the fractional ratio functions of the total radiation from the two samples are shown in Figs 3 and 4. The median radio luminosity of the ISPL sample is about 5 times greater than that of the HCG sample, while the median value of the ratio R is about 3 times greater for the ISPL sample. Hence it would appear that, statistically, the HCG galaxies have lower radio luminosity for a given optical luminosity. This result is in sharp contrast to the results of Gavazzi & Contursi (1994), who found that the radio luminosity of galaxies in the cluster A1367 is greater than that of a sample of isolated galaxies. Gavazzi (1993) suggests that this higher luminosity of the cluster galaxies might be due to the amplification of the magnetic fields by ram pressure effects. Since the radio emission from the HCG spirals is mostly from the nuclear regions, it appears that the effects of low-velocity interactions in the compact groups are phenomenologically quite different from those occurring in the high-velocity dispersion cluster systems.

The earlier studies of Hummel (1981a) suggested that the radio emissivity of the disc and the central sources in spirals both depend on the morphological type of the galaxy. The HCG sample contains galaxies of a wide range of morphological types, and the morphological classification has been carried out on a consistent basis using the CCD iamges of the galaxies taken with the Canada–France–Hawaii 3.6-m telescope (Hickson et al. 1989; Hickson 1993). The classification system is that defined in the Hubble Atlas of Galaxies (Sandage 1961). A similar classification was available for practically all the galaxies of the isolated galaxy sample in the Revised Shapley–Ames Catalogue (Sandage & Tammann 1981). Hence the data can be used to study the morphological dependence of the radio properties. Hickson et al. (1989) assigned a numerical code for their morphological classification, and, on the basis of this code, I divided the HCG sample into two subsamples corresponding to morphological types Sa–Sb and Sbc–Scd, which include 76 per cent of the HCG

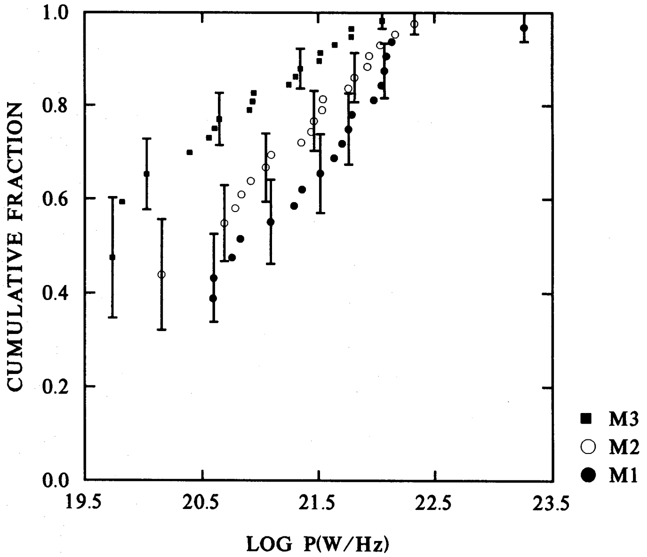

Figure 1. Fractional radio luminosity functions of HCG spirals for three absolute magnitude intervals. The median values of M_B for the three intervals are −18.47, −19.72 and −20.58.

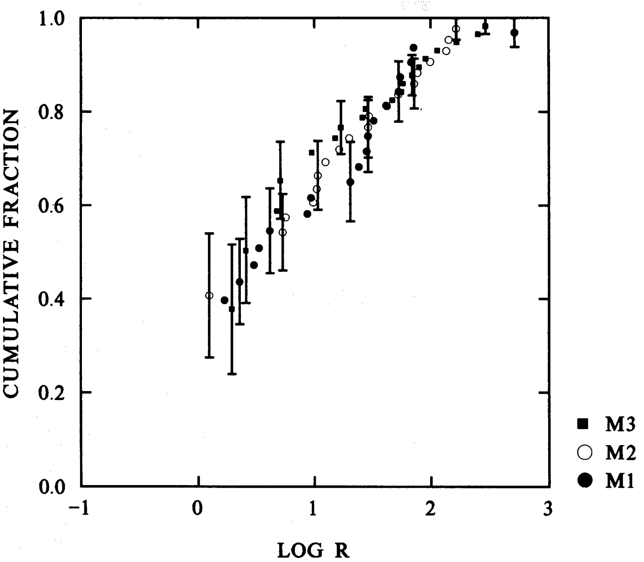

Figure 2. Fractional ratio functions of HCG spirals for the same absolute magnitude intervals as in Fig. 1.

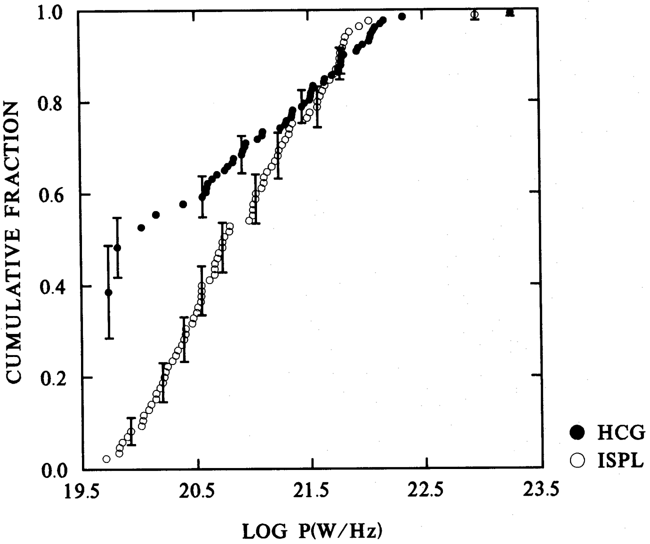

Figure 3. Fractional radio luminosity functions of the total ISPL and HCG samples.

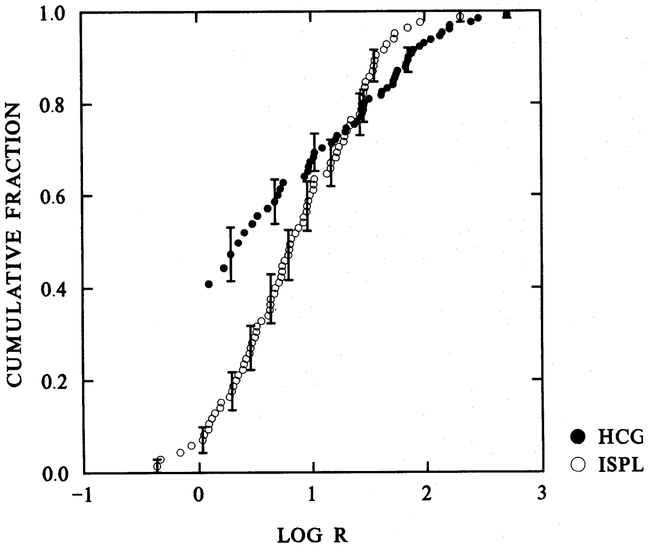

Figure 4. Fractional ratio functions of the total ISPL and HCG samples.

sample and all the galaxies in the ISPL sample. The fractional ratio functions (FRFs) computed for the two subsamples are shown in Figs 5(a) and (b). It is clear that, for both the ISPL and HCG samples, the late-type spirals have higher values of R than do the earlier types. Quantitatively, the median values of R are higher by factors of 2.4 and 5.5, respectively. Furthermore, a comparison of the FRFs for the same morphological types, for the two samples shown in Figs 6(a) and (b), indicates that for the early morphological types the difference between the samples is only marginal, while for the later types the difference is particularly significant. This is confirmed by statistical tests such as the Log Rank test and the Gehan test. For the late spirals, the ratio of the radio to optical luminosities of the ISPL sample is about 3.8 times that of the HCG sample. It should be emphasized that the above comparison is for the total radiation from the two samples.

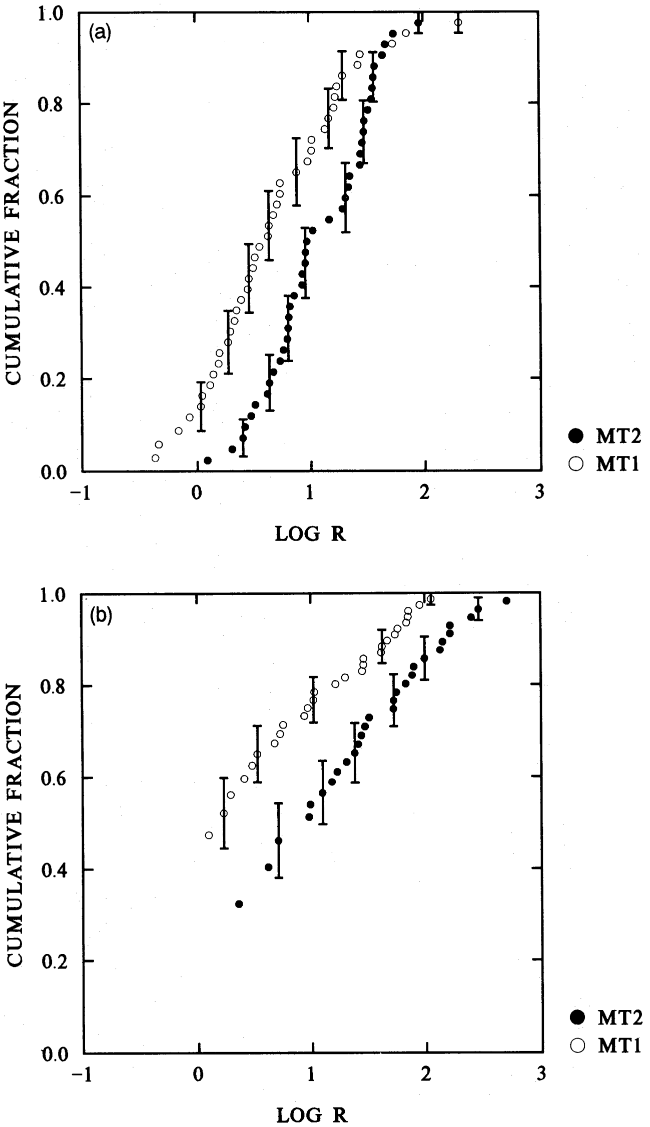

Figure 5. Fractional ratio functions of (a) ISPL spirals, and (b) HCG spirals for early-type (MT1) and late-type (MT2) morphologies.

As pointed out earlier, the radiation from the HCG sample is in most cases from the nuclear regions only, while for the ISPL sample the contribution is mostly from the discs of the galaxies. Hence if we consider the disc emission alone, the HCG sample is significantly deficient compared to the ISPL sample. I shall discuss this difference in detail below.

Since Hummel et al. (1987) have measured the flux densities from the central regions of the ISPL sample, we can compare the radio luminosities of the central regions of both samples. Following the same procedure as before, I have computed the fractional ratio functions using the flux densities from only the central regions of the two samples. Fig. 7(a) refers to the whole samples and Figs 7(b) and (c) refer to the two morphologically divided subsamples. It is clear from Figs 7(a)–(c) that the ratios Rc of the HCG sample are significantly higher than for the ISPL sample. Quantitatively, the median values of Rc are about a factor of 3 higher for the earlier spiral types and a factor of 14 higher for the later spiral types. The results of Stocke (1978) and Hummel

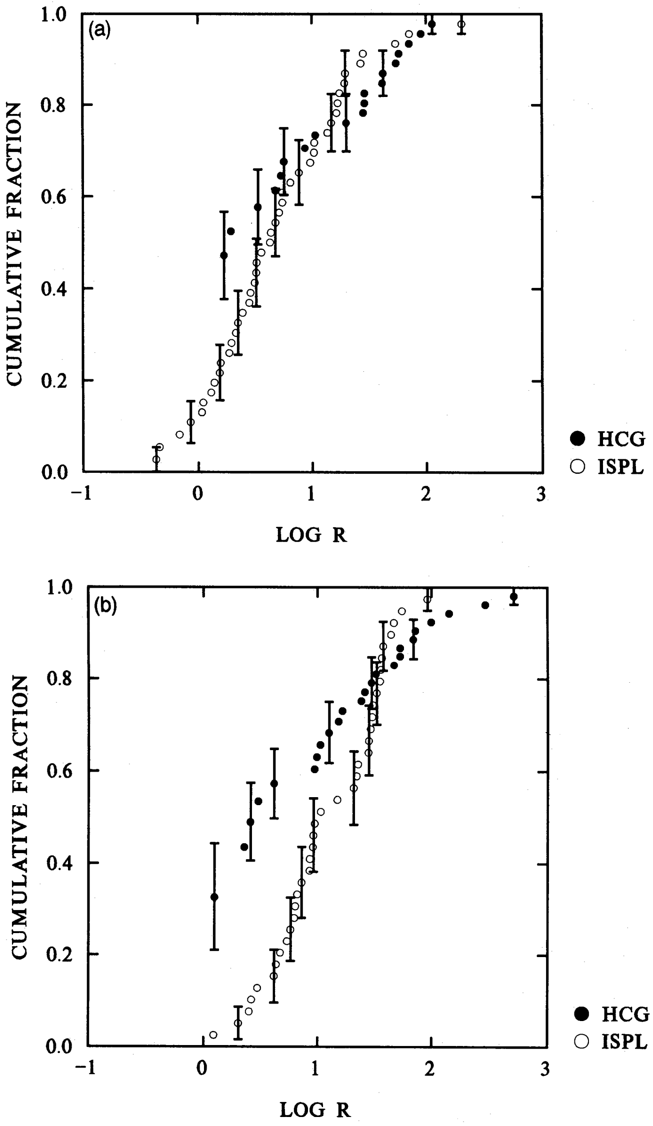

Figure 6. Fractional ratio functions of the (a) early-type spirals, and (b) late-type spirals from the ISPL and HCG samples.

(1981a, b) seemed to suggest that the detection rate of central components tended to increase with decreasing separation of the members of double systems. However, as I have shown in an earlier paper (Menon 1992), and from the results discussed earlier in this paper, the incidence of radio emission in HCG galaxies is a function of several parameters, such as morphology, velocity dispersion of the group and an interaction parameter derived from the luminosity, projected separation, relative velocity of the nearest neighbour, and the time-scale for repeated interactions.

The basic results of this investigation may therefore be summarized as follows. The high-density environment appears to have two principal effects on the radio radiation from spiral galaxies. The total radio emission from the discs of spiral galaxies in the HCG sample is significantly less than that of a comparable sample of isolated galaxies. However, the radio emission from the central regions of the HCG sample galaxies is significantly enhanced compared to the ISPL sample. Furthermore, this enhancement is more for the

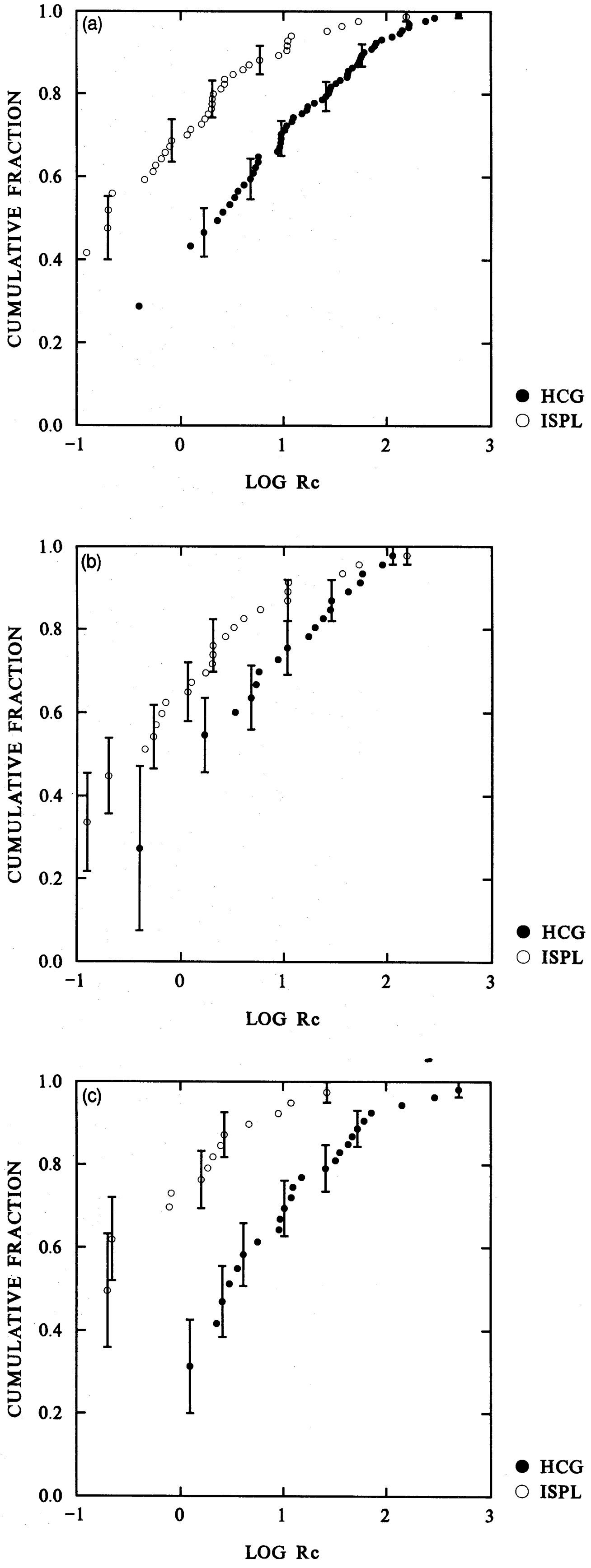

Figure 7. Fractional ratio functions of central sources of (a) all ISPL and HCG samples; (b) all early-type spirals from the ISPL and NCG samples; (c) all late-type spirals from the ISPL and HCG samples.

later morphological types than for the earlier types. A similar enhancement of the central emission was also inferred for the far-infrared radiation from the two samples (Menon 1991). The structure and the spectral indices of the radio emission from these central regions suggest that the central regions of most HCG spirals may be undergoing bursts of star formation. Two of the spirals, 92c and 96a, are known to be Seyfert galaxies and have unresolved nuclear components in addition to more extended central emission.

The various possible mechanisms that can initiate activities in the centres of galaxies during encounters have been reviewed by Shlosman (1990). The principal effect of a perturber on the gaseous component of a primary galaxy is to produce tidal forces that force the gas to deviate from the original orbital motions. At the same time, the gravitational potential of the stellar component is perturbed sufficiently to provide additional perturbations on the gaseous component. The consequences of these perturbations will depend on the parameters of the interacting systems, including the geometry of the particular interaction. These processes have been simulated by Noguchi & Ishibashi (1986), Olson & Kwan (1990), Noguchi (1987), Howard et al. (1993), and others. The results of these simulations suggest that during these interactions there is both an inflow of gas into the centre from the central regions and an outflow of gas from the outer regions. The increase in the central gas density due to the inflows can lead to the formation of molecular clouds, an increase in the frequency of cloud collisions and subsequent starburst activity. Such an enhancement of CO emission has been observed in interacting galaxies by Braine & Combes (1993) and Combes et al. (1994). The subsequent starbursts can then lead to the enhancement of the radio radiation. In an earlier investigation (Menon 1991), it was found that the radio and far-infrared radiations from the HCG spirals are strongly correlated, indirectly confirming that both the radiations are originating in the same region. On the other hand, the outflow of gas from the outer parts can be expected to lower the magnetic field intensities there, due to the strong coupling between the gas and the field. The reported deficiency of neutral hydrogen in a number of HCG spirals by Williams & Rood (1987) may be attributed to the gas outflow of the type implied by the above results. This in turn may be the cause of the decrease in the total non-thermal radio radiation from these interacting systems. The greater degree of enhancement of the central component in the case of the later-type spirals can be understood on the basis of the fact that the later-type spirals have larger amounts of gas available in their central regions. Following the formulation of Condon (1992), and assuming that the radiation from the central regions originates in starbursts, we can calculate the star formation rate (SFR) in the centres of these galaxies. For a mean luminosity of 4×10^{20} W Hz^{-1} at 1.4 GHz this rate turns out to be about 0.1 $M_{\odot}$ per year, with a supernova rate of 0.02 per year. Even though this rate is not very large for a whole galaxy, it may be recalled that in the case of HCG spirals the rate refers only to the nuclear regions.

As pointed out by Noguchi (1987), the resultant inflow of gas can continue for an extended period of time, long after the perturber has receded. In the case of the HCG galaxies, as pointed out by Hickson & Rood (1988), the majority of the groups are expected to be bound systems and have crossing times of the order of a few hundred million years. Hence the galaxies are likely to have undergone several interactions among the constituent members in one Hubble time. Keel (1993) has discussed the possible correlations between indicators of nuclear and global star formation, indices of orbital type and the extent of kinematic disturbance. Furthermore, as shown by the numerical simulations of Elmegreen et al. (1991) and Howard et al. (1993), the variation in the orbital parameters and the types of perturbers during different encounters will also have a significant influence in the outcome of the encounter. Hence there is not likely to be a direct correlation between central activity and the distance of the present nearest projected neighbour. Such a lack of correlation between the nearest neighbour distance and activity for the case of the spirals was shown in an earlier investigation (Menon 1992). In order to construct detailed models of interactions for specific systems, we need to obtain kinematic information about the gas and stars in such systems. High-resolution radio observations of neutral and molecular gas, as well as optical observations, are being planned for a number of HCG galaxies. These data may be expected to provide further insights into the effects of interactions among galaxies in dense systems.

There have been a number of suggestions in recent years that galaxy interactions may have played a dominant role in the origin of active galactic nuclei in the early Universe. Even though the present investigation has brought out the importance of nuclear radio emission as a diagnostic of galaxy interactions, it should be emphasized that practically all the radio sources in these galaxies are at the low end of the radio luminosity function, and it is surprising that there are no high-luminosity radio sources in these groups in spite of the high probability of repeated interactions in these systems. It is possible that the physical conditions in the nuclei of galaxies vary with cosmological epoch. With the possibility of obtaining samples of more distant compact groups from automated searches of faint galaxy samples (Pradovani, Iovino & MacGillivray 1994), it is planned to study such distant samples in the near future in order to provide a better understanding of the role of interactions in the origin of active galactic nuclei at earlier epochs.

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