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WHAT IS THE DIFFERENCE BETWEEN RADIO-LOUD AND RADIO-QUIET QUASI-STELLAR OBJECTS?

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ABSTRACT

Direct images have been obtained with the Canada-France-Hawaii Telescope of a sample of low-redshift, high-luminosity, radio-quiet QSOs, whose redshift and luminosity distribution matches that of a radio-loud sample previously discussed. We present measures of the nuclear and host galaxy luminosities and colors, and a morphological discussion of the host galaxies. We compare five samples of radio-loud and radio-quiet QSOs from the same telescope which enable us to compare the effects of radio activity, redshift, nuclear luminosity, and detector quality on these properties. We find that radio-quiet QSOs reside in galaxies which are smaller, fainter, and redder than the host galaxies of radio-loud QSOs. These properties are generally consistent with the suggestion that radio-quiet QSOs live in spiral-type galaxies and radio-loud QSOs live in more elliptical-type galaxies. We find significantly less evidence for tidal interactions among the radio-quiet objects, although they appear to live in somewhat richer environments in terms of nearby companions. We present a general discussion of QSO host galaxy properties and puzzles.

Subject headings: galaxies: interactions — galaxies: photometry — galaxies: structure — quasars — radio sources: galaxies

I. INTRODUCTION AND OBSERVATIONS

Hutchings (1987) has studied the morphology of two samples of radio-loud quasars (RLQs) and radio galaxies (RGs) which were matched in redshift, radio spectral index, and radio luminosity. The sample in that program consisted of ~25 of each group, and the data were deep *B* and *R* broad-band images obtained at the prime focus of the Canada-France-Hawaii Telescope with an RCA CCD. A very high fraction of these (high radio luminosity) objects were found to be galaxies in tidal interaction. The host galaxies of the two classes of object were found to have a number of similarities (moderate to high luminosity, elliptical morphology, large physical size), but also some significant differences (mean luminosities and colors). It is not clear whether these differences are due to initial differences in the galaxies or are a result of the different levels of nuclear activity in their present state. It appears that the present states of the host galaxies are profoundly disturbed both by the nuclear activity and the tidal events which appear to have preceded that. The study of the radio-loud samples indicated a very high fraction of tidally interacting systems, so that it would seem reasonable to assume that *all* luminous radio sources are tidally interacting (those that were undetected being awkardly oriented or otherwise more difficult to detect).

In an earlier study of both radio-loud and radio-quiet quasars (RQQs), Hutchings, Crampton, and Campbell (1984, hereafter HCC) found lower fractions of interacting objects, with image-tube data which were not as good as the CCD data. In that study, the radio-quiet objects appeared to be systematically different from the radio-loud objects, but the samples were not well matched. The 1984 study tended to select objects for ease of observation; the optically selected QSOs generally had lower redshift and luminosity than the radio-selected ones. The present work was therefore undertaken to study the morphological properties of radio-quiet QSOs, using a sample of RQQs which matches the radio-loud CCD samples of RLQs and RGs in optical properties and in data quality.

A sample of RQQs was chosen to match the radio-loud samples of Hutchings (1987), with the same distribution in the redshift/(*v*) magnitude plane. The final sample consisted of 23 objects (four more were attempted but did not result in usable data), compared with the radio-loud samples of 25 RGs and 27 RLQs. The members of the radio-quiet sample are listed in Table 1 while Figure 1 shows the redshift-magnitude distributions for the sample, as well as for other previously published samples which we will compare. The observations were made in *B* and *R* band at the prime focus of the Canada-France-Hawaii Telescope in 1987 July and 1988 January. The detector was the RCA2 CCD, with on-chip 2 × 2 binning to produce 0″.41 sided pixels, as was the case for the radio-loud data. The image resolution was always in the range 0″.7–1″.3 FWHM, which also matches well the radio-loud data. Photometric calibration was provided by observations of standard fields. The weather was clear for all observations except one, which was done through some thin cloud. Data reductions were performed as in Hutchings (1987) and the same measurements were made on the QSOs. Table 1 summarizes the objects observed, the measurements made, and the principal morphological comments.

[1] Guest Observer, Canada France Hawaii telescope, which is operated by CNRS of France, NRC of Canada, and the University of Hawaii.

TABLE 1

DATA AND MEASURES

Name	m_R[a]	z	Morphology[b]	Size (Kpc)	b/a	R[c] $L_{n/g}$	R[c] $-M_n$	R[c] $-M_g$	R[c] Sc.L	B[c] $L_{n/g}$	B[c] $-M_n$	B[c] $-M_g$	B[c] Sc.L	$(B-R)_0$ Nuc	$(B-R)_0$ Gal	Sep[d] (kpc)
0038+327...	17.3	0.20	I, T, G?, N2, Sp	36	...	0.24	19.9	21.7	4.8	0.52	19.1	20.7	4.4	0.8	1.0	6, 37
0046+112...	16.9	0.28	G	32	0.78	5.3	22.7	21.2	4.6	23	22.4	20.2	4.9:	0.3	1.0	...
0052+251...	15.5	0.16	I?, N23	45	...	2.4	22.6	21.9	4.7	3.0	22.3	21.8	3.7	0.3	0.1	8, 12, 27
0111+388...	17.1	0.23	I?, off-center	25	0.68	1.9	21.7	21.3	3.3	7.3	21.3	20.2	3.6	0.4	1.1	19, 24
0923+201...	15.2	0.19	I?, G	27	...	U	23.7	<19	...	U	23.0	<19	...	0.7	...	24, 26, 35
0953+414...	14.5	0.24	I??, S, T?, G?	59	...	>50	24.9	<21	...	68	24.3	20.9	12:	0.6	<0.3	21
1012+008...	15.3	0.19	I!, N234, G	46	...	4	23.4	22.1	≥4.1	10	22.8	20.8	≥2.8	0.6	1.3	8, 15
1444+407...	16.0)	0.27	S?, off-center	23	...	50:	23.6	19.7	...	...	...	...	...	...	...	...
1543+489...	16.1	0.40	I?, T	50	...	70	24.6	20.4	10:	>100	24.0	<21	10:	0.6	>−0.3	20
1549+203...	16.6	0.25	I?, T?, G	30	...	59	22.9	18.8	7.8	130	22.3	18.2	...	0.6	0.6	43
1553+113...	14.5	0.36	S, T?	50:	...	100	25.9	20.9	...	U	25.2	<21	...	0.7	...	...
1612+266...	16.7	0.40	I?, G	≤14	...	U	24.0	<19	...	U	23.4	<19	...	0.6	...	33, 53
1628+380...	17.1	0.39	I?, G	≤14	...	U	23.5	<19	...	U	22.8	<19	...	0.7	...	19
1803+676...	15.9	0.14	I?, G	22	0.83	6.5	22.1	20.2	3.7	27	21.8	18.8	4.4	0.3	1.3	18, 20
1821+643...	14.2	0.30	G	≤65	...	U	25.7	<20	...	U	25.2	<21	...	0.5	...	30, 30
2112+059...	15.8	0.47	off-center	45	0.77	16	25.1	22.6	9.1	30	24.5	22.8	...	0.6	−0.2	...
2141+040...	17.1	0.46	I?, T, G	32	...	60	23.9	19.9	...	U	23.5	<20	...	0.4	>−0.1	31, 37
2154−210...	18.6	0.41	G	24	0.76	13	22.0	19.6	3.8	U	21.6	<18	...	0.4	>0.9	20
2157−180...	18.2	0.38	G, T?	<20	...	30	22.3	19.0	2.7:	U	22.0	<18	...	0.3	>0.7	38
2200−179...	18.3	0.34	I?, T?, G	27	...	5	21.7	20.4	...	U	21.5	<18	...	0.2	>2:	12
2215−037...	16.9	0.24	E?	50	0.77	2.5	22.1	21.4	5.4	8.2	21.7	20.5	4.9	0.4	0.9	34
2233+134...	16.0	0.33	G?	<40	...	U	24.1	<19	...	U	23.5	<20	...	0.6	...	11, 14
2344+184...	16.8[e]	0.14	Bar (Sp)	30	0.80	0.1	18.8	21.4	1.7	0.1	17.2	20.3	2.5	1.6	1.1	59

NOTE.—Colons denote values that are less certain.

[a] As measured from data. Mean spread from catalog values ~0.3 mag. A parenthesis denotes catalog value.

[b] I = interacting; T = tidal tail; G = group of galaxies; N = extra nuclei; Sp = spiral characteristics; E = elliptical characteristics.

[c] U = unresolved; Sc.L is *e*-folding radius in kiloparsecs.

[d] Projected distance on sky of companion.

[e] Much fainter than published value of 15.9: our $m_b = 18.5$.

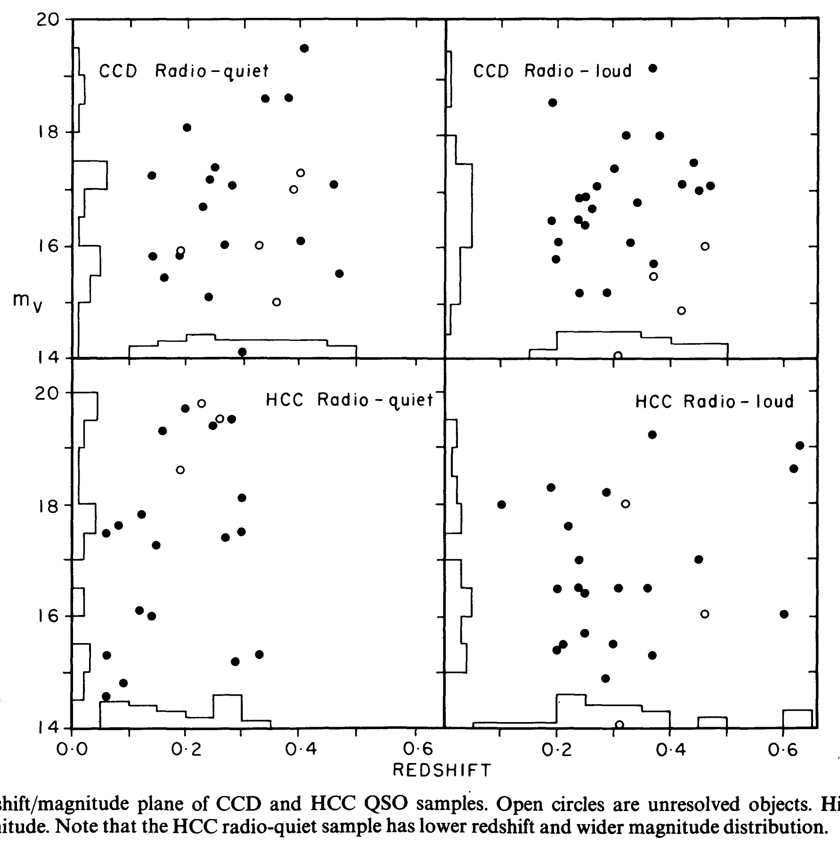

FIG. 1.—Distributions in redshift/magnitude plane of CCD and HCC QSO samples. Open circles are unresolved objects. Histograms along axes show the distributions in redshift and magnitude. Note that the HCC radio-quiet sample has lower redshift and wider magnitude distribution.

TABLE 2

MEAN QUANTITIES OF SAMPLES

QUANTITY	CCD DATA			HCC DATA	
	Radio-quiet	Radio QSO	Radio-Galaxy	Radio-quiet	Radio QSO
Sample size	23	27	25	23	26
m_v mean	16.8	16.7	18.5	17.6	16.8
m_v range	14.1–19.5	14.0–19.2	15.5–20.7	14.6–19.8	14.0–19.2
z mean	0.3	0.3	0.3	0.2	0.3
z range	0.14–0.47	0.19–0.47	0.10–0.48	0.06–0.33	0.10–0.63
$-M_{nuc}$ R	23.3 ± 1.4	23.3 ± 1.3	...	21.0 ± 1.9	23.2 ± 1.8
$-M_{gal}$ R	20.7 ± 1.1	22.0 ± 1.2	21.1 ± 1.0	20.6 ± 1.7	21.8 ± 1.7
L_n/L_g R median	20	7	...	2	4
L_n/L_g B median	25	16	...	5	12
$(B-R)_0$ nuc	0.50 ± 0.16	0.0 ± 0.25	...	(0.3 ± 0.2)	(0.5 ± 0.5)
$(B-R)$ gal	0.94 ± 0.36	0.29 ± 0.51	0.68 ± 0.6	(0.7 ± 0.3)	(0.8 ± 0.5)
Size (Kpc)	34	38	42	23 ± 10	26 ± 8
Scale L (kpc) R	4.1	5.0	3.8	2.0	2.6
Scale L (kpc) B	4.2	5.6	3.6	2.9	3.5:
Interacting	9%	32%	60%	5%	8%
Probable interacting	57%	≥68%	84%	17%	46%
Companion galaxy	74%	67%	84%	30%	54%
Companion Sep (kpc)	24 ± 13	24 ± 12	15 ± 8	16 ± 9	14 ± 7
Galaxy group	60%	33%	36%	19%	35%
Tidal tail	13%	25%	28%	22%	8%
Unresolved B, R	17%	11%	...	13%	12%
Unresolved B	26%	15%	...	...	...
Spiral morphology	4%–21%	0%–7%	0%–28%	43%–67%	4%–12%

II. RESULTS AND MEASURES

The major purpose of these observations is in the comparison of properties of the different types of QSOs. The three samples—radio galaxies, radio-loud quasars, and radio-quiet QSOs—have the same distributions of redshift (see Fig. 1). The RLQs and the RQQs have the same distribution of optical luminosity. The RLQs and the RGs have the same distribution of radio properties. It is also instructive to compare the results of HCC, which have different quality data from the new results, as they reveal what measured properties are dependent on the data quality. The HCC samples of interest are the radio and optically selected ones. (We omit the X-ray–selected ones as it appears that X-ray selection is not an important parameter, and that group contains both radio-loud and radio-quiet objects, subject to X-ray selection effects.) The HCC radio sample matches the new quasar samples well in redshift and optical luminosity, and matches the radio luminosity distribution of the radio-loud quasars quite well. (There are 11 RLQs—and 2 RQQs—in common.) Thus in this comparison we have a good way of seeing what properties are data dependent. The HCC optical sample is different in having lower redshift and luminosity than the new sample, and so allows an assessment of the effects of these parameters. In Table 2, therefore, we give a summary of the main properties of objects in all five samples. Some of the properties listed here were not published in the original papers. The sample objects are listed in Hutchings (1987) and HCC.

Before discussing the results, we summarize the morphological evidence in these data which we regard as indicative of tidal interactions. The principal criterion is the presence of two (or more) mutually resolved and extended centers of light, which have overlapping, asymmetrical, or connecting luminosity not consistent with simple isophotal overlap of galaxies of normal symmetry. This includes extensions which are oriented away from a companion galaxy, interpreted as tidal tails, as seen in nearby interacting galaxies, and in numerical models. Supportive evidence is (1) redness of such tails (old stars) and blueness of connecting or inner luminosity (star-formation); (2) similarity of luminosity scale lengths, consistent with galaxies at the same redshift. These phenomena are well illustrated in the pictures and isophotes published for the radio sample by Hutchings, Johnson, and Pyke (1988).

a) Data-dependent Quantities

We discuss first the differences between the HCC and new radio quasar results, as these should reflect only things which depend on the difference between the image tube/photographic and CCD detectors. First, the derived absolute magnitudes of the host galaxies and the nuclei, after separation, are very similar. Therefore, the procedure we use is data independent. We find the same fraction of unresolved objects (8%[HCC] and 11%[CCD]), and the same fraction to have detected companions (54% and 67%), and to have groups of companions (35% and 33%). Thus these numbers seem robust. The differences are found in the measured azimuthal exponential scale lengths of the host galaxy luminosity (3.5 kpc[HCC] vs. 5.6 kpc[CCD] or about a factor 2), and the fractions of objects seen to be interacting or to have tidal tails (16%[HCC] vs. 57%[CCD]) or factors of order 3, although the "probably interacting" fractions are less different (46% vs. ≥68%). These may all be attributed to the CCD data reaching to fainter limits. Since these morphological properties are of major importance in assessing the connection between tidal events and nuclear activity, we stress the need to observe to as faint a limit as possible. The signs of tidal interaction are often faint, and the interacting companions are often (usually) faint. There is one other difference, which is not statistically significant but consistent with the same cause: the lower separation of the quasar and interacting companion seen in the image tube (HCC) data is likely to be an observational effect because the more distant companions are fainter and harder to detect. This could mean that these fainter companions are not connected with the quasar event at all, or that there has been some time-dependent fading of the companion as it moves away from the quasar. We note that the HCC radio-quiet sample also has smaller mean separation than any of the CCD data, consistent with the above explanation. With these instrumental sensitivities in mind, we now proceed to compare the radio-quiet and radio-loud quasars.

b) *Radio-loud and Radio-quiet Comparison*

The radio-quiet QSOs have host galaxies ~ 1.3 mag fainter in R (and 0.6 mag more in B) than the radio quasars. The nuclei have the same values in both groups. Since the nuclei are the dominant luminosity sources, and the samples are matched in magnitude, this is so by selection. The ratio of nuclear to galaxy luminosity (corrected for redshift, seeing, and limiting brightness, as in earlier papers) is higher in the RQQs than in the RLQs by a factor 3 in R and 2 in B: thus, the RQQ host galaxies are redder. The radio galaxies are intermediate between the RLQ galaxies and the RQQ galaxies in luminosity and color. The RQQ nuclei are redder than the RLQ nuclei by 0.5 mag in $B-R$, but this result has a significance of only 2 σ. (The HCC sample has fewer measured colors, and shows no significant difference.) The RQQ galaxy sizes are marginally smaller than the RLQ galaxies, which in turn are smaller than the radio galaxies; the RQQ galaxies are closer to the range of normal galaxy sizes than the galaxies associated with either type of radio source. Luminosity scale lengths of the RQQs are intermediate between the RLQs and the RGs.

In the radio-quiet quasars *a significantly lower fraction of objects show visible tidal interactions or tidal tails* than in either of the radio-loud samples, even if the large number of uncertain cases are included (see Table 1). This is probably the most important difference found in this study between the types of objects. However, a high fraction of the RQQs have a companion object (74%, similar to that found in the radio sources [67% RLQs and 84% RGs]). Also, a larger fraction of the radio-quiet sources (60%) is seen in a group or cluster of galaxies than for the radio sources (33% RLQs, 36% RGs). The separations between the companions and the RQQs are the same as for the RLQs, both are larger than for the RGs.

A higher fraction of RQQs is unresolved, but the difference is not very significant. Finally, we see little or no evidence for spiral structure in any of the objects, although it would often be detectable in the B images were it present.

c) *Redshift and Luminosity Effects*

These may be discussed by comparing the HCC and new (CCD) samples of radio-quiet QSOs, bearing in mind particularly the quantities which are independent of the data type (absolute magnitude, unresolved fraction, and fraction with companions and in groups in particular). The host galaxy luminosities are the same for the two groups, suggesting no strong redshift or nuclear luminosity dependence. However, the nuclear luminosities are higher by close to 2 mag in CCD sample relative to the HCC (image tube) sample, and consequently the ratio of nuclear to host luminosity is different by 5–10 times. The host galaxy colors are similar, as are the nuclear colors. The galaxy size is data dependent, but we note that the difference between the HCC optical and radio samples is in the same ratio and sense as the difference in the new CCD (RQ and RL) samples. Similar remarks apply to the fraction of interactions seen and the luminosity scale lengths. The HCC (lower luminosity) objects have a smaller fraction with companions and groups of companions, which we believe is data independent. Finally, the same fraction is unresolved. Thus the main difference in the high- and low-luminosity (or redshift) RQQs appears to be simply in the nuclear luminosity. However, the original host population may be different in that we find a greater fraction of the low-luminosity (HCC) RQQs have spiral characteristics and a smaller fraction of the low-luminosity RQQs are in groups, relative to the higher luminosity (or higher z) CCD sample. The nearby, low-luminosity HCC RQQs seem to bridge the gap between the CCD sample quasars and Seyfert galaxies.

III. DISCUSSION

In Hutchings (1987) the difference between radio quasars and radio galaxies was discussed; it appeared that the objects are very similar. The parent population of galaxies for both type of objects is probably ellipticals of high (but not the highest) luminosity. Tidal effects in the high luminosity radio sources seem to be ubiquitous, and therefore almost certainly causally related. There are suggestions that the growth of the radio source and the widening separation between the optical components can be traced together. The galaxies are frequently disturbed and have unusually blue colors, indicating strong star-formation which accompanies the central nuclear event. The radio galaxies appear to be in a somewhat stronger (earlier?) state of interaction than the RLQs, judging by their sizes and the distances to their companion(s). The RGs are generally lower luminosity and redder than the RLQ host galaxies, so they may be a parallel phenomenon rather than a different stage of the QSO evolutionary process.

With this background, we now ask how the radio-quiet QSOs differ from the (rarer) radio-loud ones. For objects with the same nuclear luminosity, RQQs live in galaxies which are fainter than either of the radio-source hosts, with galaxy colors which are redder than either. Nuclear colors are also somewhat redder in the RQQs. The RQQ host galaxy sizes are smaller, as are their luminosity scale lengths. Thus, in many ways they seem to be the next step in a progression of host galaxy properties downward in size and extranuclear activity. The RQQs are also less strongly interacting (or maybe some of them are not interacting at all). Is this a later stage or a lower level of interaction altogether? A look at the differences as we go to lower nuclear luminosity is helpful here. We find the host galaxies to be the same in luminosity, color, size, and degree of interaction as we go to lower nuclear luminosity, and, as far as we can tell, the same mean distance to the companions. Mostly, nothing in the host galaxy changes as we go to lower nuclear luminosity. What does change is the detected presence of spiral type features, and possibly the tendency to *have* close companions. We can say little about the type of the host galaxy in the new sample except that they exhibit little structure and they rarely show much eccentricity. There are seven cases where we can measure an axial ratio (i.e., resolved and not obviously disturbed); in these cases the axial ratio values are not distributed like spirals.

It is noteworthy that the host galaxies in the RQQs are redder than the RLQs, because this is not consistent with the properties of normal spirals compared with ellipticals. In Hutchings (1987) it was noted that the radio-loud host galaxies appear to be disturbed ellipticals, and that their extremely blue colors must arise from extensive new star formation. In the case of the RQQs, the redder colors may indicate either less star formation, or more internal reddening due to dust. In this context we note the extremely red colors of many of the IR-bright QSO-like objects (see, e.g., Sanders *et al.* 1988), in which interactions, star-formation, and dust all seem to be important. However, from the general thrust of our discussion, we regard dust as a less likely overall explanation of redness than that of lower star-formation activity.

Before drawing further conclusions from our comparison, an important question to answer is what we *should* expect a galaxy to look like at the redshifts of the sample QSOs. In order to examine this, we looked at images (taken in the same observing runs as the CCD quasar samples) of the Seyfert galaxies NGC 5548, Mrk 573, and Mrk 6, none of which is severely disturbed. The first two have spiral characteristics, and the last one is relatively symmetrical and featureless. We simulate high-redshift data by shrinking the CCD frames by a factor 10 or more. In the shrunken images, the general form of the luminosity law can still be measured, but we note that in these objects the nuclear luminosity is low. The galaxy morphological features can just be distinguished, for effective redshifts up to $\sim$0.2, but we note again that the low nuclear contamination is important. The strong suggestion of this experiment is that we would not expect to detect morphological features or exponential luminosity laws easily for normal spiral type galaxies hosting luminous QSOs at redshifts larger than $\sim$0.25. For lower redshifts and lower nuclear luminosities, we should. This is exactly in accordance with the observations. The reason we are able to make better measures on the radio-loud host galaxies is that they are more luminous and extended objects. Therefore, we suggest that the long-standing expectation that radio-loud quasars live in ellipticals and radio-quiet ones live in spirals, is supported by our data.

Another question we can ask is how detectable interactions may appear at increasing redshifts. We performed the same experiment of image degradation with CFHT images of Mrk 463, Mrk 480, and IC 883, all of which are spectacularly interacting low-redshift galaxies. The images "removed" to redshifts $\sim$0.3 still show the tidal tails and plumes clearly, although the inner structure or double nuclei blend together. The signs of interaction become undetectable first in Mrk 480, which does not have very extended or bright outer structure. Our conclusion from this is that we are able to detect strong tidal events in QSOs easily to redshift 0.4, but that the later stages of a milder interaction will not be detected easily beyond redshift 0.25 in these observations. Thus, the higher detectability of tidal events in the radio-loud objects reflects a real difference between the RL objects and the RQ ones. Whether this difference is in the smaller scale of the host galaxies, is a later stage in a similar event, or is a milder form of interaction, is not easily decided. Because of the similar distribution of companion separations between the samples, we slightly favor the first of these.

Stockton and MacKenty (1987) found that $\sim$25% of luminous QSOs have extended [O III]. In their studies the fraction of objects with line emission was found to be somewhat higher for RL objects than for RQ objects, and the [O III] luminosity was found to be higher in the radio-loud sources by an order of magnitude. McCarthy (1988) has done similar work for the 3C radio sources (both quasars and galaxies), and finds that a high fraction of these radio-loud sources have extended emission line gas (and that the fraction of emission line objects increases with redshift). The clumpy and extended nature of the [O III] gas seen in both of these studies suggests that it is tidal in origin and generally illuminated by beamed or partly obscured central sources. These results suggest that the radio-quiet QSOs have less gas or that the illumination is less effective in them; this is not a natural expectation of the spiral/elliptical dichotomy. High-resolution [O III] studies of RQQs would be useful in addressing this question.

Recent or strong interactions have been strongly associated with high IR luminosity (e.g., Sanders *et al.* 1988; Hutchings and Neff 1988). It is therefore of interest to see if there is a difference between the radio-loud and radio-quiet objects in this respect. From the list of QSOs detected by *IRAS* (Neugebauer *et al.* 1986), we find that the same fraction (four of each) have 60 μm detections in our radio-loud and radio-quiet QSO samples. The IR luminosities are similar, but a factor of 3 higher (1 σ difference in the median) in the radio-quiet ones. If IR-bright QSOs are the youngest, then we might expect to find that they are more obviously interacting, or have nearer companions, or have younger (=smaller?) radio structure. The IR-bright objects are 0607−157, 0742+318, 0837−120, 1150+497 in the radio-loud sample, and 0052+251, 1542+489, 1821+643, and 2112+059 in the radio-quiet group. We see no clear distinction of radio or optical properties of these objects that connects them with IR activity. However, these constitute small enough groups that we can hardly draw real conclusions from them. It may well be that there are several different causes of IR luminosity in QSOs. We are investigating a larger sample of IR-bright objects to address this question properly.

Barthel (1988) has proposed that all radio-loud objects are the same, with the quasers being those which are beamed toward us. Many discussions on the structure of Seyfert galaxies, particularly in radio and emission line gas, have indicated that their radiation is beamed, or at least shielded in some directions. It seems likely that QSO radiation is non-isotropic in some significant sense, and that this may well affect the way we see subrgoups of them. However, it also seems unlikely that there is a single unified model for all AGNs, and the scenario of Barthel has some severe problems (implied non-isotropy of NLR and IR emission, IR emission, and the conclusions of Barthel and Miley 1988, based on a biased sample of steep spectrum sources; see also Neff, Hutchings, and Gower 1988). As indicated in Hutchings (1987) and the results reported here, we do not find a unifying scenario relating the types of radio source or the types of QSO. We summarize below our findings and thoughts based on our work.

IV. CONCLUSIONS

1. Radio-quiet QSOs reside in host galaxies which are different from those of radio sources. The RQQs are fainter, smaller, redder, and display less obvious signs of tidal interaction than do the RLQs in the present (matched) samples.

2. The RQQ host galaxies do not have obvious spiral characteristics, but the data are consistent with their being spirals or at least disks. The bright QSO nuclei and the relative invisibility of spiral morphology at high redshift at this resolution may explain the lack of observed spiral structure. Lower redshift and lower nuclear luminosity optical QSOs do have detectable spiral characteristics, with other host galaxy properties being the same.

3. Apart from these, there are no clear global differences between the host galaxy properties: the proportions of objects with extended emission-line gas, or with high IR luminosity are similar for both samples. However, it may be that the radio-

loud QSOs have stronger line emission and the radio-quiet ones weaker IR emission.

4. The details of the tidal effects do not suggest that the radio-loud objects represent a phase in the lifetime of radio-quiet QSOs; rather it appears that they are a different and parallel species.

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