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ON THE REDSHIFT–APPARENT SIZE DIAGRAM OF DOUBLE RADIO SOURCES

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ABSTRACT

We review the data on the angular sizes of double radio sources. A list of 540 Fanaroff-Riley type II double sources is collected from literature, and it is used for a critical discussion of previous work based on smaller samples. We find that results from all previous samples agree well with each other and with our new sample, if the discussion is limited only to well-defined two-sided ("classical") doubles. Different results which have appeared in literature are traced to different sample definitions of double radio sources. In addition, we find that the behavior of high radio power quasars and radio galaxies is different from low radio power radio galaxies which, if unnoticed, leads to contradicting conclusions. The main conclusions, relevant to all samples studied, are the following:

1. There is a positive correlation between the true radio source size and radio power among low-luminosity radio galaxies. This may be partly explained through sample selection effects.
2. There is a negative correlation between radio size and power among high luminosity radio galaxies and all quasars. It follows the constant total energy envelope closely.
3. There is no significant difference between the radio sizes of radio galaxies and quasars of the same luminosity. However, it is possible that real differences in the radio sizes of the two populations are hidden by selection effects in our sample.
4. The angular size–redshift diagram shows a deficiency of large radio sources at high redshifts which is fully explained by the above-mentioned negative correlation without need for cosmic evolution of radio source size. However, the possibility of some cosmic evolution is not totally ruled out by the data.

Subject headings: cosmology: observations — quasars: general — radio continuum: galaxies

1. INTRODUCTION

In studies of the large-scale geometry of the universe, standard rods play an important role. Among the most promising standard rods are the largest double radio sources (Miley 1971). The first appearance of the largest angular size (LAS)–redshift (z) diagram was in striking accordance with the static Euclidean model of the universe (Kellerman 1972), while the standard Friedmann models required additional assumptions, such as cosmological evolution of the standard rod (Miley 1971; Strom 1973; van der Kruit 1973; Wardle & Miley 1974; Swarup 1975; Kapahi 1975) or an inverse correlation between the radio source size and its absolute luminosity (Jackson 1973; Richter 1973). In some samples the LAS-z diagram was also in agreement with the standard Friedmann models without any additional corrections (Reinhardt 1972; Hewish, Readhead, & Duffett-Smith 1974).

It has become increasingly obvious in recent years that the LAS-z diagram lacks large sources according to the Friedmann cosmologies but agrees with the Euclidean model (Swarup, Sinha, & Hilldrup 1984; Barthel & Miley 1988). The explanations for the deviation from the Friedmann models still vary. Various authors have pointed out that the assumption of cosmological evolution is unnecessary (Hooley, Longair, & Riley 1978; Wills 1979; Masson 1980; Downes 1982; Macklin 1982; Fielden et al. 1983), while others consider it significant in their data (Katgert-Merkelijn, Lari, & Padrielli 1980; Kapahi & Subrahmanya 1982; Eales 1985; Oort et al. 1987b; Barthel & Miley 1988). The problem has been the close connection of redshift and intrinsic luminosity in most samples. In this paper we assemble a new large sample from literature in order to separate the different parameters.

2. THE SAMPLE

The data on 540 double radio sources (267 radio galaxies and 273 quasars) are listed in Table 1. Since one of the main parameters of study is the linear size, we do not include the Fanaroff-Riley (1974) type I sources, where the components fade away gradually toward their outer edges, and the observed size depends on instrumental factors. An example of the excluded sources is Centaurus A. On the other hand, Fanaroff-Riley (1974) type II sources have a well-defined largest size since the brightness maxima lie (by definition) close to the extremeties of the source structure. In cosmological studies the Fanaroff-Riley type I sources would anyhow play a minor role since they are intrinsically weak and are not usually observed at high redshift.

The radio morphology was determined on the basis of published radio maps. In the few cases where maps were not available the classification and the angular size in the original paper were used. Only those showing FR II–like double structure were selected into the sample. Unlike many earlier studies, we exclude poorly resolved sources of unknown FR type, compact complex radio sources and one-sided doubles. However, due to the uncertainties in the optical position, the classification is somewhat uncertain for sources with small ($\simeq 1''$) angular size, and some one-sided double sources may have entered the sample.

The first and second columns of Table 1 give the name(s) of the source. The third column gives the spectroscopically mea-

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TABLE 1

DOUBLE RADIO SOURCE DATA

IAU name	other name	z	LAS arcsec	size kpc	log L erg sec^{-1}	α	id	refs.
0003-003	3C2	1.037	5.0	55.2	45.3	0.74	Q	72,126
0003+15	4C15.01	0.450	31.5	240.1	43.9	0.78	Q	13,34,95
0006+014	-	1.302	16.5	194.6	44.4	0.77	Q	81
0007+12	4C12.03	0.157	160.0	588.3	43.3	0.78	G	34,80,111
0007+33	4C33.01	0.743	79.0	770.3	44.2	0.71	Q	34,114
0013+79	3C6.1	0.840	26.0	266.3	45.1	0.89	G	72,80,112
0017+154	3C9	2.012	12.5	161.7	46.2	1.02	Q	72,141
0017+257	4C25.01	0.284	47.0	268.8	43.4	0.50	Q	13,34,62
0018-19	-	0.095	252.0	608.0	42.5	0.69	G	30,34,129
0031+391	3C13	1.351	28.0	333.3	45.5	1.08	G	66,72,136
0032+423	4C42.01	1.588	4.5	55.6	44.9	1.00	Q	11,34
0033+079	4C08.04	1.578	3.3	40.7	44.9	0.80	Q	11,13,34
0033+098	4C09.01	1.918	8.0	102.6	45.3	0.62	Q	34,81
0033+18	3C14	1.469	24.0	291.6	45.6	0.91	Q	66,72
0035+130	3C16	0.405	60.0	430.3	44.2	0.94	G	72,119,136
0038-019	4C-02.04	1.690	20.0	250.5	45.5	0.80	Q	11,13,34
0038+32	3C19	0.482	9.6	76.0	44.5	0.75	G	66,72,136
0040+514	3C20	0.350	53.0	347.6	44.7	0.82	G	66,72,136
0041+119	4C11.06	0.228	45.0	220.3	43.0	0.88	Q	34,62,81
0042+101	-	0.583	59.0	515.3	43.4	0.80	Q	13,62
0044+030	-	0.624	11.7	105.6	43.7	0.90	Q	13,64
0046-067	4C-06.04	2.063	8.4	109.1	45.6	1.06	Q	11,34
0048+50	3C22	0.937	24.0	255.9	45.1	0.89	G	66,72,136
0052+682	3C27	0.184	46.0	191.7	43.9	0.78	G	59,72,113,136
0053+26	3C28	0.195	38.0	165.5	43.6	1.22	G	50,72,136
0055+300	N315	0.017	3100.0	1493.7	41.5	0.48	G	18,19,128
0059+14	4C14.03	0.188	41.0	173.7	43.2	0.66	G	34,80
0106+013	4C01.02	2.107	6.8	88.6	46.0	0.00	Q	13,34,100
0106+13	3C33	0.060	249.0	398.1	43.2	0.74	G	12,72
0106+729	3C33.1	0.181	216.0	888.5	43.5	0.94	G	66,72,136
0107+315	3C34	0.689	48.0	453.1	44.7	0.98	G	66,72,136
0109+176	4C17.09	2.157	13.0	170.0	45.3	0.84	Q	11,34,47
0109+49	3C35	0.067	672.0	1188.1	42.5	0.78	G	72,136,148
0110+297	4C29.02	0.363	76.2	511.4	43.5	0.68	Q	34,95
0114-47	-	0.146	580.0	2011.1	43.5	0.60	G	30,128,129
0115+027	4C02.04	0.672	13.1	122.3	44.6	0.90	Q	13,34,127
0118+034	4C03.02	0.765	44.2	436.2	44.6	0.93	Q	34,62,142
0119-046	4C-04.04	1.948	3.6	46.3	45.6	0.60	Q	34,101
0123+32	3C41	0.795	23.1	231.5	45.0	0.68	G	72,84,111,136
0125+28	3C42	0.395	28.0	197.8	44.2	0.86	G	66,72,136
0127+233	3C43	1.459	2.8	34.0	45.6	0.71	Q	72,101
0130+242	4C24.02	0.457	54.6	419.7	43.8	0.83	Q	34,95
0131-36	N612	0.029	852.0	688.1	42.3	0.60	G	37,40
0132+37	3C46	0.437	163.0	1221.8	44.2	0.95	G	55,72
0133+207	3C47	0.425	68.0	501.6	44.6	0.94	Q	72,95
0136+397	4C39.04	0.211	341.0	1576.6	43.5	1.13	G	55,71,128,60
0137+012	4C01.04	0.260	27.0	145.2	43.4	0.60	Q	13,34,62
0138+138	3C49	0.621	1.0	9.0	44.6	0.81	G	44,72,136
0142+26	4C26.04	0.371	36.0	244.9	43.4	0.80	G	13,34,56
0145+531	3C52	0.285	66.0	378.3	44.0	0.71	G	72,113,136

TABLE 1—*Continued*

IAU name	other name	z	LAS arcsec	size kpc	log L erg sec^{-1}	α	id	refs.
0146+35	N679	0.016	260.0	118.1	40.2	1.70	G	7,116
0152+435	3C54	0.827	52.0	529.4	44.9	0.90	G	13,34,84,136
0154+286	3C55	0.240	64.0	325.2	43.9	0.93	G	66,72,136,138
0156-252	-	2.016	6.6	85.4	45.5	1.05	G	93
0157+393B	4C39.05	0.072	156.0	294.3	42.0	0.85	G	13,34,152
0158+293	4C29.05	0.148	58.0	203.3	42.9	0.79	G	34,55,71
0159-117	3C57	0.669	15.4	143.5	44.8	0.62	Q	34,64
0203-209	-	1.258	12.1	141.4	44.8	1.13	G	93
0204+29	4C29.06	0.109	199.0	540.6	42.8	0.58	G	34,55,71
0210+860	3C61.1	0.186	184.0	773.0	43.9	0.95	G	16,72,136
0211-47	-	0.220	336.0	1602.5	43.4	0.83	G	31,128,129
0212+171	-	0.472	39.0	305.2	43.7	0.50	Q	13,62
0214+108	4C10.06	0.408	119.0	857.1	43.9	0.85	Q	34,95
0217+417	-	1.430	61.0	736.4	44.8	0.94	Q	13,152
0220+39	3C65	1.176	17.4	199.5	45.4	1.02	G	72,84,136
0221+276	3C67	0.310	2.5	15.2	43.9	0.83	G	72,109
0222-008	4C-00.12	0.687	13.4	126.3	44.4	0.79	Q	34,35,62
0225-014	4C-01.11	2.037	16.0	207.3	45.4	0.75	Q	11,34,35
0229+341	3C68.1	1.238	46.0	535.1	45.4	0.86	Q	66,72
0231+313	3C68.2	1.575	22.3	275.2	45.8	1.35	G	53,72,112
0232-042	4C-04.06	1.436	13.1	158.3	45.3	0.83	Q	34,62,124
0232-025	4C-02.12	1.322	6.3	74.6	45.0	0.75	Q	34,62,95
0234+589	3C69	0.458	47.7	367.1	44.6	1.01	G	59,72,112,136
0237+053	-	0.694	3.8	36.0	43.8	0.72	Q	81
0238-084	N1052	0.005	22.0	3.2	40.2	0.30	G	130,162,163
0238+100	-	1.816	17.0	215.9	45.2	1.00	Q	11,13
0240-00	3C71	0.003	13.0	1.1	40.1	0.71	G	72,136,160
0256+13	4C13.17C	0.080	120.0	248.8	42.2	0.90	G	13,34,131
0300-004	4C-00.14	0.693	8.2	77.6	44.4	0.70	Q	13,34,64
0307+169	3C79	0.256	87.0	462.9	44.1	0.98	G	72,135,136
0307+444	4C44.07	1.165	4.3	49.2	45.0	0.53	Q	13,34,127
0309+390	4C39.11	0.161	50.0	187.6	43.2	0.70	G	1,34
0313+344	4C34.13	1.156	24.0	273.8	44.8	0.94	Q	34,71
0316-257	-	3.130	6.7	91.7	46.2	1.13	G	93
0317-023	4C-02.15	2.092	2.6	33.8	45.3	0.64	Q	34,81
0320-37	ForA	0.006	1980.0	342.3	42.0	0.51	G	39,76
0325+02	3C88	0.030	200.0	166.9	42.1	0.69	G	12,72
0326+39	-	0.024	340.0	228.9	41.4	0.60	G	13,38
0340+048	3C93	0.357	34.0	225.8	44.2	0.85	Q	64,72
0349-278	-	0.066	370.0	645.3	43.0	0.87	G	12,51,154
0349-146	3C95	0.616	114.0	1022.4	45.1	1.19	Q	34,95
0350-073	3C94	0.962	42.5	457.2	45.2	0.90	Q	34,143
0352+123	4C12.17	1.616	7.5	93.1	45.5	1.00	Q	11,13,34
0353+027	4C02.11	0.602	16.5	146.4	44.1	0.90	Q	34,81
0354+202	-	1.728	21.0	264.2	44.9	1.00	Q	13,101
0356+101	3C98	0.031	300.0	258.3	42.6	0.62	G	12,66,72
0358+00	3C99	0.426	4.5	33.2	44.2	0.66	G	72,90,136
0404+03	3C105	0.089	309.0	704.1	43.1	0.72	G	12,72
0404+429	3C103	0.331	97.0	614.0	44.3	0.95	G	72,113
0409+229	4C22.08	1.215	5.0	57.9	45.2	0.50	Q	13,34,101

TABLE 1—*Continued*

IAU name	other name	z	LAS arcsec	size kpc	log L erg sec^{-1}	α	id	refs.
0410+110	3C109	0.306	96.0	577.2	44.2	0.75	G	12,72
0411+14	4C14.11	0.206	88.0	399.6	43.5	0.70	G	13,34,108,111
0415+379	3C111	0.049	275.0	364.7	43.1	0.68	G	66,72,82,136
0417+17	3C114	0.815	52.0	526.4	44.7	0.92	G	72,139
0433+293	3C123	0.218	23.0	109.0	44.9	0.79	G	72,118,136
0446-208	-	1.896	51.0	652.9	45.0	0.83	Q	15,101
0453+224	3C132	0.214	23.0	107.5	43.7	0.86	G	66,72,136
0459+25	3C133	0.278	11.8	66.5	44.2	0.73	G	66,72,136
0503-286	MSH05-22	0.038	2040.0	2131.2	42.3	1.10	G	128,140
0511+00	3C135	0.127	84.0	259.7	43.3	0.80	G	51,72,136
0512+249	3C136.1	0.064	415.0	703.8	42.7	0.67	G	72,82,113
0518-45	PicA	0.034	432.0	406.1	43.3	1.02	G	26,76
0534-201	-	0.995	11.4	124.1	44.0	0.00	Q	64,155
0553-205	-	1.544	5.0	61.4	44.4	0.73	Q	101,155
0557-168	-	1.240	21.0	244.4	45.1	1.15	Q	63,101
0605+48	3C153	0.277	6.5	36.5	44.0	0.82	G	72,85,112
0610+26	3C154	0.580	50.0	435.6	44.9	0.71	Q	72,113,136
0618-37	-	0.032	90.0	79.9	42.0	0.62	G	40,76
0634-20	-	0.056	920.0	1380.6	43.0	0.77	G	12,40
0640+23	3C165	0.296	87.0	511.6	44.0	0.98	G	72,82,113
0642+214	3C166	0.245	45.0	232.1	43.8	0.67	G	72,113,133,136
0659+253	3C172	0.520	122.0	1005.7	44.6	0.89	G	65,72,138
0702+74	3C173.1	0.292	60.0	349.6	44.0	0.92	G	66,72,136
0704+384	4C38.20	0.579	20.6	179.3	44.2	0.91	Q	34,95
0708+32	-	0.067	8.0	14.1	41.3	1.18	G	13,43,46
0710+118	3C175	0.768	48.0	474.5	45.0	1.02	Q	66,72
0712+534	4C53.16	0.064	31.0	52.6	42.3	0.60	G	13,17,34,105
0719+670	4C67.13	0.131	31.0	98.3	42.6	0.60	G	13,34,123
0722+30	-	0.019	29.0	15.6	40.2	0.62	G	13,45,46
0723+679	3C179	0.846	15.0	154.0	45.0	0.52	Q	76,102
0725+147	3C181	1.382	5.9	70.6	45.6	0.89	Q	72,112
0726+431	4C43.14	1.072	19.2	214.1	44.5	0.90	Q	13,34,62
0730+257	4C25.21	2.686	7.2	96.9	45.8	0.80	Q	34,62
0730+659	-	1.937	20.0	257.0	44.5	0.80	Q	11
0731+653	-	3.035	31.0	422.9	44.7	0.10	Q	13,100
0733+705	3C184	0.994	4.4	47.9	45.2	1.00	G	66,72,136
0734+803	3C184.1	0.118	179.0	520.2	43.2	0.76	G	72,96,136
0736-019	3C185	1.033	8.5	93.7	45.0	0.80	Q	13,34,62
0738+336	-	0.364	124.0	833.6	43.4	0.77	G	34,88,105
0740+380	3C186	1.063	1.6	17.8	45.3	1.08	Q	24,72
0742+02	3C187	0.350	128.0	839.6	43.9	1.00	G	51,72,136
0742+318	4C31.30	0.462	115.0	889.5	44.2	0.45	Q	9,34,42
0744+559	DA240	0.036	2040.0	2024.8	42.3	0.77	G	80,120,128,144
0745+521	-	0.063	101.0	168.8	41.8	0.68	G	13,34,123
0752+258	OI287	0.446	14.0	106.2	43.7	0.95	Q	146
0755+379	4C37.21	0.041	138.0	154.9	42.1	0.59	G	32,71
0758+120	-	2.660	10.0	134.5	45.1	0.80	Q	11
0758+143	3C190	1.195	4.0	46.1	45.5	0.86	Q	72,109
0759+341	-	2.440	14.0	186.3	44.9	0.80	Q	13,100
0802+103	3C191	1.956	4.5	57.9	46.0	1.00	Q	11,72

TABLE 1—*Continued*

IAU name	other name	z	LAS arcsec	size kpc	log L erg sec^{-1}	α	id	refs.
0802+241	3C192	0.060	190.0	303.8	42.8	0.70	G	66,72,136
0805+578	4C57.15	0.438	26.0	195.1	43.8	0.90	Q	13,34,64
0806+42	3C194	1.184	14.2	163.1	45.3	0.89	G	72,106,112,139
0808+289	-	1.910	60.0	769.1	44.5	0.66	Q	41,121
0809+483	3C196	0.871	5.0	51.9	45.8	0.88	Q	72,85,112
0810+327	-	0.842	26.0	266.5	44.1	0.54	Q	41,121
0811+388	4C38.23	0.132	29.0	92.6	42.5	0.93	G	13,34,152
0814+227	4C22.20	0.980	22.0	238.2	44.8	0.80	Q	13,34,70,94
0818+472	3C197.1	0.130	14.0	44.1	43.1	0.67	G	72,117,136
0819-30	-	0.086	246.0	543.9	42.8	0.68	G	30,129,154
0819+061	3C198	0.082	198.0	419.7	42.6	1.05	G	51,72,136
0821+447	4C44.17	0.904	26.0	273.7	44.6	0.90	Q	13,34,102
0821+621	4CP62.12B	0.542	45.0	379.0	44.1	0.20	Q	13,34,102
0822+34A	4C34.28A	0.406	18.0	129.3	43.5	0.80	G	3,4,5,13
0823+37	4C38.25	0.207	42.0	191.4	42.9	1.00	G	3,4,5,13,34
0824+29	3C200	0.458	24.0	184.7	44.4	0.89	G	55,72
0827+193	4C19.30	0.658	24.0	221.9	44.0	0.90	Q	13,34,64
0828+324	4C32.25	0.051	320.0	440.4	41.8	0.51	G	13,34,46
0831+101	-	1.760	29.0	366.2	44.8	0.80	Q	11,13
0831+557	-	0.241	12.0	61.2	44.2	0.21	G	34,76,156
0833+654	3C204	1.112	36.0	405.9	45.2	1.04	Q	72,95,102
0835+580	3C205	1.534	16.0	196.3	45.7	0.94	Q	72,95,102
0836+195	4C19.31	1.691	31.2	390.8	45.2	0.92	Q	34,124
0836+290	-	0.079	345.0	707.4	42.2	0.62	G	13,32,46,147
0836+299	4C29.30	0.065	64.0	110.1	42.0	0.65	G	27,45,53
0837-120	3C206	0.198	169.0	744.8	43.5	0.80	Q	95
0838+133	3C207	0.684	8.4	79.0	44.9	0.52	Q	72,112
0838+325	4C32.26	0.068	9.5	17.0	42.0	0.70	G	13,22,34,46,87,161
0839+616	4C61.19	0.862	26.0	268.9	44.7	0.90	Q	13,34,102
0844+31	4C31.32	0.068	270.0	483.8	42.3	0.78	G	13,27,34,46,88
0846+100	4C09.31	0.366	54.0	364.2	43.5	0.87	Q	34,54,95
0847+37	4C37.25	0.407	33.0	237.3	43.7	0.50	G	3,4,5,13,34
0850+140	3C208	1.110	11.0	124.0	45.5	1.15	Q	66,72
0850+581	4C58.17	1.322	15.2	179.9	45.2	0.16	Q	10,34,76
0854+39A	-	0.528	164.0	1362.7	43.7	1.00	G	3,4,5,13
0855+143	3C212	1.048	9.0	99.6	45.3	0.84	Q	66,72
0855+28	3C210	1.169	18.0	206.0	45.2	0.96	G	72,139
0856+170	4C17.46	1.449	10.3	124.7	45.1	0.90	Q	13,34,143
0857+39	-	0.229	24.0	117.9	42.9	0.80	G	3,4,5,13
0901+285	-	1.121	25.0	282.6	44.0	0.54	Q	41,121
0901+474	-	0.170	9.0	35.3	42.6	0.90	G	13,123
0903+169	3C215	0.411	43.0	311.1	44.2	1.00	Q	62,72
0905+38	3C217	0.898	11.0	115.5	45.0	1.09	G	69,72,136
0906+546	4C54.18	0.625	49.0	442.5	44.1	0.80	Q	13,34,102
0908+376	-	0.104	39.0	101.8	42.3	0.56	G	13,43,46,87
0913-025	4C-02.38	1.203	16.4	189.2	44.8	0.79	Q	34,81
0917+449	-	2.180	19.0	248.8	45.6	0.20	Q	13,100
0917+455	3C219	0.174	160.0	638.2	43.9	0.93	G	33,72,136
0922+149	4C14.31	0.896	41.1	431.2	44.7	1.10	Q	34,142
0923+392	4C39.25	0.699	4.0	38.0	45.2	-0.20	Q	13,34,74

TABLE 1—*Continued*

IAU name	other name	z	LAS arcsec	size kpc	log L erg sec^{-1}	α	id	refs.
0924+30	IC2476	0.027	720.0	543.0	41.2	1.20	G	13,29,38
0926+117	4C11.32	1.754	7.0	88.3	45.2	0.90	Q	11,34
0926+79	3C220.1	0.610	26.0	232.1	44.7	1.10	G	23,72,77,136
0927+362	3C220.2	1.157	8.0	91.3	45.1	0.85	Q	66,72
0928+312	-	1.310	21.0	248.0	44.5	1.02	Q	41,121
0931+836	3C220.3	0.680	7.4	69.4	44.8	1.15	G	66,72,136
0932+022	4C02.27	0.659	44.8	414.6	44.2	0.78	Q	34,124
0936+361	3C223	0.137	290.0	954.5	43.3	0.73	G	12,72
0937+391	4C39.27	0.618	52.0	467.1	44.2	1.00	Q	13,34,89
0938+119	-	3.190	7.0	95.9	45.3	0.40	Q	13,100
0938+399	3C223.1	0.108	117.0	315.4	42.8	0.60	G	55,72
0939+139	3C225.0	0.580	4.9	42.7	44.9	0.90	G	13,34,53,136
0941+100	3C226	0.823	35.0	355.6	45.0	1.01	G	66,72,136
0945+07	3C227	0.086	215.0	475.3	43.2	0.82	G	12,72
0945+73	4C73.08	0.058	780.0	1208.9	42.5	0.85	G	34,91,128
0947+14	3C228	0.552	45.0	382.5	44.8	0.83	G	66,72,136
0952+097	4C09.35	0.298	12.5	73.8	43.2	0.80	Q	13,34,62
0952+357	4C35.21	1.241	18.0	209.5	44.8	1.00	Q	3,4,13,34
0957+003	4C00.34	0.907	31.4	330.9	44.8	0.84	Q	34,62,142
0958+290	3C234	0.185	110.0	460.2	43.9	0.95	G	72,82,136
1001+226	4C22.26	0.974	67.0	723.9	44.6	0.90	Q	13,34,137
1003+26	-	0.117	6.0	17.3	41.9	1.32	G	43,45,46
1003+351	3C236	0.099	2400.0	6001.4	43.0	0.70	G	8,72,128
1004+130	4C13.41	0.241	115.0	586.1	43.4	0.72	Q	34,81,95
1005+077	3C237	0.877	1.4	14.6	45.3	0.84	G	44,72,136
1005+282	-	0.148	240.0	841.4	41.9	0.82	G	13,32,46
1007+417	4C41.21	0.611	32.0	285.9	44.4	0.68	Q	34,124
1008+46	3C239	1.781	11.2	141.7	45.9	1.15	G	72,112,136
1011+280	4C28.25	0.899	14.0	147.1	44.4	0.65	Q	34,41,121
1012+022	4C02.30	1.374	8.4	100.4	45.0	0.84	Q	34,81
1012+488	4C48.28	0.385	109.0	758.3	43.5	0.70	Q	13,34,62
1014+397	4C39.30	0.106	137.0	363.4	42.5	1.10	G	13,34,55
1015+277	4C27.21	0.469	21.0	163.8	44.0	0.80	Q	34,41,121
1017+487	4C48.29A	0.053	306.0	436.4	42.1	0.56	G	13,21,34
1019+222	3C241	1.617	0.9	11.2	45.7	1.14	G	44,72,136
1019+39B	4C39.31	0.921	7.0	74.2	44.4	0.84	G	3,4,5,34
1022+194	4C19.34	0.828	11.5	117.1	44.5	0.30	Q	13,34,64
1023+067	3C243	1.699	13.0	163.0	45.9	1.20	Q	11,34
1030+581	3C244.1	0.428	53.0	392.6	44.5	0.94	G	66,72,136
1038+528	-	0.677	37.0	346.5	44.0	0.10	Q	13,104
1040+123	3C245	1.029	7.1	78.1	45.3	0.67	Q	72,78
1046+053	4C05.46	1.115	8.8	99.3	44.6	0.80	Q	13,34,62
1047+096	4C09.37	0.786	21.1	210.5	44.2	0.98	Q	34,124
1048-090	3C246	0.344	83.0	538.5	44.0	0.84	Q	95
1048+240	4C24.23	1.274	15.0	175.9	44.8	1.00	Q	13,34,112
1049+616	4C61.20	0.422	2.5	18.4	43.9	0.80	Q	13,34,103
1056+431	3C247	0.749	13.0	127.2	45.0	0.88	G	66,72,136
1058+110	4C10.30	0.423	31.0	228.1	43.8	0.80	Q	13,34,95
1100+772	3C249.1	0.311	21.0	127.6	44.0	0.79	Q	72,95
1102+30	-	0.072	170.0	320.8	41.8	0.72	G	13,32

TABLE 1—*Continued*

IAU name	other name	z	LAS arcsec	size kpc	log L erg sec^{-1}	α	id	refs.
1103-006	4C-00.43	0.426	21.0	155.1	43.9	0.60	Q	13,34,62
1104+167	4C16.30	0.634	40.0	363.6	44.3	0.40	Q	13,34,62
1107+036	-	0.963	63.0	678.0	44.4	1.00	Q	13,98
1107+379	4C37.29	0.346	82.0	534.0	43.9	0.80	G	13,34,55
1108+35	3C252	1.105	60.0	675.2	45.2	1.12	G	66,72,136,138
1109+437	4C43.21	1.680	53.0	663.1	45.5	0.90	Q	13,34,152
1111+408	3C254	0.734	13.2	128.0	45.0	1.01	Q	62,72,102
1113+295	4C29.41	0.049	78.0	103.4	42.1	0.64	G	34,71,97
1118+128	4C12.40	0.685	21.7	204.3	44.0	0.90	Q	13,34,62
1130+106	4C10.33	0.540	3.1	26.1	44.1	0.70	Q	13,34,62
1130+34	4C34.35	0.512	78.0	637.8	43.7	0.80	G	3,4,5,13,34
1136-135	-	0.557	15.8	134.9	44.8	0.70	Q	76,127
1137+660	3C263	0.646	44.2	405.3	44.8	0.82	Q	72,112
1140+22	3C263.1	0.366	5.8	39.1	44.3	1.03	G	66,72,136
1141+374	4C37.32	0.115	270.0	767.7	42.7	0.94	G	34,46,71
1141+466	4C46.23	0.162	8.2	30.9	42.8	1.10	G	13,34,123
1142+318	3C265	0.811	78.0	788.0	45.1	1.10	G	66,72,136
1143+500	3C266	1.275	4.3	50.4	45.4	1.17	G	66,72,136
1146-11	-	0.117	192.0	554.0	42.9	0.96	G	30,34,129
1146+111	-	0.863	16.4	169.7	43.9	0.90	Q	13,62
1147+130	3C267	1.140	38.0	431.7	45.4	0.94	G	66,72,136
1148+36A	4C36.19	0.141	27.0	91.0	42.6	1.00	G	3,4,13,34
1148+387	4C38.31	1.303	7.8	92.0	45.0	0.88	Q	34,62,71
1148+477	4C47.33	0.867	20.0	207.3	44.6	1.10	Q	13,34,102
1150+497	4C49.22	0.334	16.0	101.9	43.8	0.60	Q	13,34,102
1151+295	4C29.44	0.329	22.0	138.7	43.8	0.90	G	13,34,55
1151+456	4C45.23	0.192	62.0	266.9	43.1	0.60	G	13,34,152
1152+659	4C65.13	1.199	57.0	657.1	44.8	1.00	Q	13,34,103
1156+631	4C63.15	0.594	58.0	511.2	44.2	0.90	Q	13,34,103
1157+118	-	0.731	24.9	241.1	43.8	0.90	Q	13,62
1157+73	3C268.1	0.970	46.0	496.3	45.5	0.69	G	66,72,136
1158+318	3C268.2	0.362	93.0	623.0	44.0	0.97	G	72,139
1159-036	-	1.102	41.0	461.0	44.7	1.12	Q	35
1203+645	3C268.3	0.371	1.3	8.8	44.2	0.85	G	72,109
1204+34	-	0.079	62.0	127.1	42.0	0.60	G	13,46,107
1205+392	4C39.35	0.243	24.0	123.1	43.2	0.90	G	13,34,152
1206+439	3C268.4	1.400	9.8	117.7	45.5	0.95	Q	62,72
1207+38	-	0.790	27.0	269.9	44.1	0.90	G	3,4,5,13
1208+322	-	0.388	82.0	573.2	43.4	0.89	Q	41,121
1209+74	4C74.17.1	0.107	480.0	1283.5	42.4	0.85	G	13,34,149
1213+422	4C42.34	0.120	303.0	893.1	42.3	0.73	G	13,21,20,34
1213+538	4C53.24	1.065	33.0	367.2	45.2	0.80	Q	13,34,66,102
1214+106	-	1.884	27.0	345.2	44.9	0.90	Q	11,13
1214+348	-	2.647	7.4	99.5	45.2	0.80	Q	13,100
1215+643	4C64.15	1.288	9.5	111.7	44.9	0.70	Q	13,34,103
1216+060	3C270	0.007	498.0	100.3	41.4	0.57	G	52,72,136
1217+023	-	0.240	110.0	559.0	43.4	0.36	Q	13,34,47,99
1218+339	3C270.1	1.519	12.0	146.9	45.7	0.89	Q	66,72
1220+373	-	0.489	36.0	287.2	43.6	0.90	Q	3,4,5,13
1221+186	4C18.34	1.401	23.0	276.3	44.8	0.90	Q	13,34,95

TABLE 1—*Continued*

IAU name	other name	z	LAS arcsec	size kpc	log L erg sec^{-1}	α	id	refs.
1221+42	3C272	0.944	59.0	630.6	45.0	1.02	G	66,72,139
1222+216	4C21.35	0.435	16.8	125.6	44.2	0.40	Q	13,34,62
1223+252	4C25.40	0.268	67.0	368.1	43.0	0.90	Q	34,54,95
1225+26	-	0.064	63.0	106.8	41.2	0.79	G	13,43
1226+105	-	2.296	5.8	76.5	45.8	1.00	Q	11
1227+08	N4472	0.003	150.0	13.0	38.9	0.70	G	13,36,105
1229-021	4C-02.55	1.038	18.0	198.6	45.1	0.41	Q	34,62,76
1232-249	-	0.355	86.0	569.2	44.1	0.96	Q	95
1232+21	3C274.1	0.422	150.0	1102.0	44.4	1.03	G	72,139
1233+108	-	0.665	101.0	938.4	43.7	0.70	Q	13,64
1241+166	3C275.1	0.557	14.0	119.5	44.7	0.88	Q	66,72
1244+324	4C32.41	0.949	24.0	257.0	44.4	0.92	Q	34,41,121
1245+189	-	0.723	8.7	83.9	44.0	0.67	Q	81
1247+450	4C45.26	0.799	18.0	180.8	44.3	0.80	Q	13,34,102,152
1248+305	4C30.25	1.061	29.0	322.3	44.6	0.85	Q	34,41,121
1249+50	3C277	0.414	139.0	1009.8	44.0	1.00	G	72,139
1250+568	3C277.1	0.321	1.5	9.3	44.0	0.64	Q	72,109
1251+159	3C277.2	0.766	55.0	543.1	44.9	0.92	G	72,110,136,138
1251+27	3C277.3	0.086	32.0	70.7	42.9	0.65	G	72,136,151
1253+104	-	0.824	23.8	241.9	44.2	0.80	Q	13,62
1254+47	3C280	0.996	12.9	140.4	45.5	0.86	G	72,112,136
1258+404	3C280.1	1.659	19.8	247.1	45.8	1.09	Q	62,72
1301+382	4C38.35	0.470	28.0	218.6	43.8	0.81	G	3,4,5,34,71
1308+182	4C18.36	1.677	10.3	128.8	45.1	0.89	Q	11,34,81,143
1308+27	3C284	0.239	180.0	912.0	43.7	0.82	G	55,72
1311-270	-	2.195	19.0	249.1	45.6	0.90	Q	11
1317+520	4C52.27	1.060	29.3	325.5	44.9	0.50	Q	13,34,62
1318+113	4C11.45	2.171	5.8	75.9	45.9	0.80	Q	11,34
1319+425	3C285	0.079	134.0	274.7	42.7	0.75	G	72,82,136
1319+647	4C68.14	0.230	74.0	364.6	43.2	0.80	G	13,21,34
1322+366	4C36.24	0.018	53.0	27.0	41.0	0.46	G	27,34,46
1323+655	4C65.15	1.618	7.8	96.8	45.1	0.80	Q	11,13,34
1330+022	-	0.216	117.0	550.5	43.5	0.59	G	34,35
1331-09	-	0.081	774.0	1622.7	42.8	0.90	G	34,129
1332+552	4C55.27	1.249	76.0	886.2	44.8	1.00	Q	13,34,58,95
1333-33	IC4296	0.012	2100.0	719.5	41.3	0.62	G	73,76,129
1333+412	4C41.26	0.189	12.0	51.0	43.1	0.90	G	13,34,123
1335-061	4C-06.35	0.625	11.1	100.2	44.8	0.80	Q	34,62,86
1340+606	3C288.1	0.961	6.7	72.1	45.0	0.99	Q	72,103,112
1343+500	3C289	0.967	10.0	107.8	45.1	1.00	G	66,72,136
1345+584	4C58.27	2.039	13.0	168.5	45.4	0.80	Q	11,34
1347+28	-	0.072	54.0	101.9	41.6	0.70	G	13,43,46,107
1349+647	3C292	0.710	133.0	1272.0	44.7	0.70	G	71,136
1350+31	3C293	0.045	216.0	264.6	42.4	0.69	G	72,82,136
1351+267	-	0.310	190.0	1152.3	43.0	0.80	Q	41,121
1351+318	-	1.326	12.0	142.2	44.5	0.76	Q	41,121
1354+195	4C19.44	0.720	43.7	420.5	44.8	0.65	Q	34,124
1354+258	-	2.032	12.0	155.4	44.9	0.70	Q	11
1356+581	4C58.29	1.371	45.0	537.7	44.9	1.00	Q	13,34,103,102
1357+27	4C27.27	0.155	46.0	167.4	42.6	0.83	G	34,56

TABLE 1—*Continued*

IAU name	other name	z	LAS arcsec	size kpc	log L erg sec^{-1}	α	id	refs.
1357+28	-	0.063	139.0	232.4	41.6	0.80	G	13,43,46
1358-11	A1836	0.037	294.0	299.5	42.0	0.70	G	6,30,129
1400+162	4C16.39	0.245	17.0	87.7	43.3	0.60	Q	13,34,61
1404+34	3C294	1.779	15.0	189.8	45.8	1.14	G	72,139
1409+52	3C295	0.461	4.3	33.2	45.2	0.90	G	12,72
1415+172	-	0.821	7.9	80.2	44.2	0.54	Q	81
1416+067	3C298	1.436	2.0	24.2	46.2	1.10	Q	72,109
1416+159	-	1.472	27.1	329.4	44.6	0.80	Q	13,62
1416+36	N5557	0.011	1218.0	383.1	39.7	0.75	G	48
1420+198	3C300	0.270	100.0	552.3	44.0	0.91	G	72,82,136
1420+326	-	0.685	31.0	291.9	44.1	0.20	Q	13,64
1422+202	4C20.33	0.871	11.0	114.2	44.8	0.90	Q	13,34,125
1422+26	-	0.037	140.0	142.6	41.6	0.74	G	27,46
1423+243	4C24.31	0.649	20.5	188.4	44.5	0.80	Q	13,34,62
1425+267	-	0.362	240.0	1607.8	43.2	0.79	Q	41,121
1429+160	-	1.005	167.0	1823.4	44.0	0.80	Q	13,62
1433+177	4C17.59	1.203	9.7	111.9	45.0	0.70	Q	34,62,81,127
1435+172	-	1.470	21.0	255.2	44.7	0.90	Q	13,62
1435+248	4C24.32	1.010	5.5	60.2	44.6	0.80	Q	13,34,62
1435+315	-	1.366	24.0	286.5	44.3	0.25	Q	41,121
1441+26	-	0.062	230.0	378.9	41.5	0.79	G	13,43,46
1441+52	3C303	0.141	32.0	107.8	43.2	0.74	G	72,75,136
1442+117	-	0.852	15.0	154.5	44.1	0.50	Q	13,62
1446+20	3C304	0.254	14.0	74.1	43.7	0.90	G	13,34,112
1447+771	3C305.1	1.132	2.7	30.6	45.3	0.92	G	72,109,136
1451+097	4C09.52	0.632	23.0	208.8	44.2	0.70	Q	13,34,95
1452+16	3C306	0.046	228.0	285.1	42.2	0.68	G	13,28,34,129
1453-109	-	0.938	41.0	437.2	45.3	0.79	Q	76,95
1455+280	4C28.38	0.141	213.0	717.9	42.7	0.75	G	13,34,46
1455+348	-	2.732	4.8	64.8	45.2	0.60	Q	13,100
1458+718	3C309.1	0.905	2.1	22.1	45.5	0.57	Q	72,136,150
1502+26	3C310	0.054	210.0	304.7	42.9	1.29	G	72,82,136
1508+08	3C313	0.461	130.0	1004.3	44.7	1.00	G	12,13,34
1509+158	4C15.45	0.828	9.1	92.7	44.6	0.70	Q	13,34,64
1511+103	-	1.546	33.0	405.6	44.7	0.90	Q	11,13
1512+30	-	0.093	22.0	52.1	41.5	0.75	G	13,34,46
1512+370	4C37.43	0.371	61.0	414.9	43.7	0.78	Q	34,87,95
1517+176	-	1.390	17.9	214.6	44.4	0.70	Q	13,62
1522+155	-	0.628	20.0	181.0	44.0	0.10	Q	13,64,132
1522+546	3C319	0.192	105.0	452.0	43.6	1.02	G	72,82,136
1524+101	4C10.43	1.358	10.0	119.2	44.8	0.58	Q	34,47
1525+290	-	0.065	23.0	39.6	41.4	0.73	G	27,45,46
1528+29	-	0.084	235.0	508.8	41.7	0.90	G	13,43,46
1529+24	3C321	0.096	290.0	706.0	43.0	0.83	G	12,72
1529+357	3C320	0.342	18.0	116.4	43.9	0.96	G	55,72
1530+137	4C13.55	0.771	11.7	115.8	44.5	0.75	Q	14,34,62,158
1533+557	3C322	1.681	33.0	412.9	45.7	1.08	G	72,139
1539+343	4C34.42	0.402	63.0	449.8	43.7	0.90	G	13,34,55
1540+110	-	0.992	37.4	406.6	44.4	0.90	Q	13,62
1540+180	4C18.43	1.662	5.9	73.7	45.1	0.60	Q	11,34

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TABLE 1—*Continued*

IAU name	other name	z	LAS arcsec	size kpc	log L erg sec^{-1}	α	id	refs.
1540+60	3C323	0.679	26.0	243.8	44.6	1.06	G	72,139
1545+210	3C323.1	0.264	70.5	383.3	43.8	0.79	Q	72,142
1547+21	3C324	1.206	10.0	115.5	45.5	1.05	G	66,72,136
1548+114	4C11.50	0.436	50.0	374.3	43.9	0.50	Q	13,34,47
1549+202	3C326	0.090	1170.0	2692.2	42.9	0.88	G	72,80,128,159
1549+62	3C325	0.860	16.0	165.3	45.1	1.03	G	66,72,136
1554-203	-	1.945	23.0	295.7	44.8	0.80	Q	11
1555+332	-	0.942	34.0	363.1	43.9	0.39	Q	47
1559+021	3C327	0.104	270.0	704.5	43.4	0.84	G	12,72
1602-63	-	0.059	438.0	689.6	43.0	1.25	G	26,30,129
1602-001	4C-00.63	1.625	25.0	310.6	45.4	0.80	Q	11,34
1602+014	3C327.1	0.463	16.0	123.9	44.6	1.01	G	12,72
1606+180	4C18.47	0.346	13.3	86.6	43.5	0.90	Q	13,34,62
1606+289	4C28.40	1.989	30.0	387.2	45.5	1.08	Q	34,71,117
1608+113	-	0.457	12.0	92.3	43.6	0.89	Q	81
1609+31	-	0.094	25.0	59.8	41.5	0.52	G	13,34,43,45,46
1609+66	3C330	0.550	56.0	475.1	44.9	0.81	G	66,72,136
1610-608	-	0.017	552.0	266.0	42.8	1.15	G	30,129
1613+27	-	0.065	31.0	53.3	41.5	0.40	G	13,43,45,46
1615+325	3C332	0.152	91.0	326.0	43.2	0.83	G	46,72
1618+177	3C334	0.555	46.0	392.1	44.5	0.97	Q	62,72
1620+356	4C35.41	1.473	22.0	267.5	44.9	1.00	Q	13,34,62
1622+158	4C15.55	1.406	8.1	97.4	45.2	0.90	Q	13,34,62
1622+238	3C336	0.927	21.7	230.5	45.1	0.93	Q	72,112
1623+173	-	0.552	32.0	272.0	43.8	0.80	Q	13,34,64
1626+277	3C341	0.448	82.0	623.4	44.3	1.00	G	55,72
1627+23	3C340	0.775	47.0	466.3	44.8	0.88	G	66,72,136
1627+44	3C337	0.635	43.0	391.2	44.7	0.91	G	66,72,136
1628+363	4C36.28	1.254	16.2	189.1	44.9	0.84	Q	34,62,87
1634+176	-	1.897	6.8	87.1	45.3	0.90	Q	11,13,143
1634+269	3C342	0.561	39.0	334.2	44.3	0.87	Q	34,71,95
1637+626	3C343.1	0.750	0.4	3.9	44.9	0.99	G	44,72,136
1637+826	N6251	0.023	3070.0	1983.8	41.7	0.64	G	80,128,153
1638+398	-	1.660	8.0	99.8	45.2	-0.10	Q	13,74,76
1642+690	4C69.21	0.751	10.0	97.9	44.7	0.10	Q	13,34,74
1643+27	-	0.102	145.0	372.1	41.6	0.92	G	32,43,45
1648+05	3C348	0.154	115.0	416.3	44.7	1.03	G	51,72,136
1658+302	4C30.31	0.035	144.0	139.2	41.4	0.66	G	13,32,34,46,49
1658+470	3C349	0.205	82.0	371.0	43.7	0.77	G	66,72,136
1658+575	4C57.29	2.173	5.4	70.7	45.5	1.10	Q	11,13,34
1700+180	4C17.73	1.424	9.6	115.8	44.8	0.88	Q	34,62,81
1704+608	3C351	0.371	58.0	394.5	44.2	0.74	Q	72,95
1707+344	4C34.45	0.080	48.0	99.5	42.2	0.90	G	13,34,55
1709+46	3C352	0.806	10.0	100.8	44.9	1.05	G	66,72,136
1713+641	-	0.078	26.0	52.7	41.7	0.50	G	13,123
1717-00	3C353	0.030	230.0	191.9	43.2	0.72	G	12,72
1721+343	4C34.47	0.206	440.0	1998.1	43.4	0.59	Q	9,34,68,71
1723+510	3C356	1.079	75.0	837.9	45.2	0.99	G	66,72,136
1726+318	3C357	0.167	107.0	413.2	43.4	0.77	G	46,72
1732+160	4C16.49	1.880	15.2	194.3	45.9	0.98	Q	11,34,80

TABLE 1—*Continued*

IAU name	other name	z	LAS arcsec	size kpc	log L erg sec^{-1}	α	id	refs.
1732+655	4C65.21	0.856	22.0	226.9	44.5	0.90	Q	13,34,102
1736+32	-	0.074	44.0	85.1	41.6	0.76	G	43,45,107
1739+184	4C18.51	0.186	212.0	890.7	43.1	0.80	Q	13,34,142
1741+279	4C27.38	0.372	9.2	62.7	43.6	0.67	Q	13,34,62,127
1802+110	3C368	1.132	7.9	89.6	45.4	1.30	G	25,72,136
1807+279	4C27.41	1.760	8.5	107.3	45.2	0.50	Q	13,34,101
1816+475	4C47.48	2.225	6.3	82.8	45.6	1.00	Q	11,13,34
1819+228	4C22.47	0.628	22.0	199.1	44.4	1.00	Q	13,34,62
1825+741	3C379.1	0.256	76.0	404.4	43.6	0.74	G	57,72,136
1827+32	-	0.066	440.0	767.4	41.6	0.75	G	13,43,46,106
1827+387	-	1.080	2.3	25.7	44.4	0.70	Q	13,101
1828+487	3C380	0.692	7.5	70.9	45.6	0.57	Q	72,103,157
1830+285	4C28.45	0.594	28.2	248.6	44.5	0.37	Q	62,76
1832+427	3C381	0.161	69.0	258.9	43.5	0.76	G	72,117,136
1833+32	3C382	0.058	170.0	263.5	42.7	0.74	G	72,107,136
1842+453	3C388	0.091	31.0	72.0	43.2	0.88	G	72,112,136
1845+794	3C390.3	0.056	213.0	319.6	43.1	0.78	G	57,72,136
1857+566	4C56.28	1.595	30.0	371.3	45.4	1.10	Q	11,34
1924+507	4C50.47	1.098	18.0	202.2	44.7	0.50	Q	13,34,102
1928+738	4C73.18	0.302	40.0	238.4	44.2	0.00	Q	13,34,74
1939+60	3C401	0.201	19.0	84.7	43.8	0.90	G	66,72,136
1949+02	3C403	0.059	97.0	152.7	42.7	0.80	G	12,72
1951+498	-	0.466	13.0	101.0	43.7	0.70	Q	13,102
1954+513	-	1.220	18.0	208.5	45.2	0.20	Q	74,76
1957+403	3C405	0.057	122.0	186.1	45.2	1.09	G	2,72,113
2005-044	3C407	0.589	20.0	175.6	44.5	1.01	Q	34,64
2019+098	3C411	0.467	31.8	247.4	44.5	0.94	G	72,134,136
2025-218	-	2.630	4.0	53.7	45.8	1.09	G	93
2025+117	-	1.920	9.0	115.5	44.9	1.00	Q	13,101
2028-293	-	0.503	4.9	39.7	43.8	1.01	G	93
2040-26	-	0.039	186.0	199.1	42.1	0.73	G	40,51,105
2058-13	-	0.030	288.0	240.3	41.6	0.81	G	129,154
2104-242	-	2.491	21.6	288.2	46.1	1.32	G	93
2104+76	3C427.1	0.572	23.1	199.9	44.9	1.07	G	72,112,136
2112+172	4C17.86	0.878	6.0	62.5	44.4	0.90	Q	13,34,64
2117+603	3C430	0.054	85.0	123.3	42.9	0.68	G	72,135,136
2120+15	3C434	0.322	12.0	74.6	43.6	0.85	G	72,112
2120+168	3C432	1.805	13.4	170.0	45.9	1.07	Q	72,143
2126+073A	3C435A	0.461	14.0	108.2	44.0	0.89	G	92
2126+073B	3C435B	0.865	46.0	476.4	44.7	0.89	G	92
2131+175	4C17.87	1.215	32.4	374.9	44.7	0.87	Q	34,81
2135-147	-	0.200	150.0	666.2	43.7	0.74	Q	51,76,95
2141+279	3C436	0.215	104.0	487.6	43.8	0.90	G	72,117,136
2145+15	3C437	1.480	36.0	438.2	45.7	0.92	G	72,139
2146-133	-	1.800	3.7	46.9	45.9	0.90	Q	11
2150+053	4C05.81	1.979	17.0	219.2	45.7	1.10	Q	11,34
2153+37	3C438	0.290	19.0	110.2	44.4	1.13	G	66,72,136
2158+101	4C10.67	1.725	1.2	15.1	45.2	0.80	Q	13,34,101
2201+315	4C31.63	0.297	80.0	471.5	44.1	0.00	Q	34,76,99
2203+292	3C441	0.708	32.6	311.4	44.8	0.78	G	72,84,111,136

TABLE 1—*Continued*

IAU name	other name	z	LAS arcsec	size kpc	log L erg sec^{-1}	α	id	refs.
2209+080	4C08.64	0.484	10.5	83.3	44.2	0.70	Q	13,34,62
2209+152	-	1.502	15.0	183.2	44.9	0.90	Q	11,13
2211-17	3C444	0.153	83.0	298.9	43.9	1.12	G	34,35,51,76
2222+051	4C05.84	2.323	3.0	39.7	45.9	0.90	Q	11,34
2223+210	-	1.959	5.5	70.8	45.8	0.50	Q	13,101
2226-224	-	0.280	10.6	60.0	43.2	0.92	G	93
2230+114	4C11.69	1.037	2.4	26.5	45.3	0.30	Q	13,34,101
2236+35	-	0.028	47.0	36.7	41.0	0.58	G	27,45
2243+392	3C452	0.081	250.0	524.1	43.4	0.90	G	67,72,117,136
2244+366	4C36.47	0.082	17.0	36.0	42.6	0.80	G	13,34,55
2247-248	-	1.634	13.2	164.2	45.0	0.95	G	93
2248+192	4C19.74	1.806	6.0	76.1	45.6	1.10	Q	11,34
2249+185	3C454	1.757	1.0	12.6	45.8	0.76	Q	72,101
2251+113	4C11.72	0.323	9.8	61.1	43.8	0.79	Q	34,47,62,95
2251+134	4C13.85	0.673	6.7	62.6	44.6	0.61	Q	34,127
2252+129	3C455	0.543	3.2	27.0	44.6	0.90	Q	66,72
2303-052	4C-05.95	1.139	10.0	113.6	44.9	0.81	Q	34,62
2303-253	-	0.740	18.8	183.0	44.5	1.12	G	93
2303+391	4C39.72	0.206	170.0	772.0	43.1	0.77	G	13,34,122
2308+098	4C09.72	0.432	82.0	610.6	43.7	0.76	Q	34,95,143
2309+184	3C457	0.428	190.0	1407.3	44.3	1.01	G	80,111
2310+05	3C458	0.290	161.0	933.8	44.0	0.81	G	51,72,136
2314-116	-	0.549	37.0	313.6	43.9	0.84	Q	64
2314+038	3C459	0.220	8.2	39.1	43.9	0.91	G	72,136,145
2318+23	3C460	0.268	7.2	39.6	43.7	1.07	G	72,79,136
2322+110	-	1.965	6.0	77.3	45.0	0.70	Q	13,101
2322+27	4C27.51	0.319	104.0	642.7	43.4	0.91	G	34,56
2325+269	4C27.52	0.875	7.4	77.0	44.8	0.84	Q	34,127
2325+293	4C29.68	1.015	51.0	558.7	44.9	0.98	Q	34,71,95
2332+489	-	1.534	39.0	478.6	45.2	0.90	Q	11,13
2333+019	-	1.871	30.0	383.1	44.9	0.60	Q	13,101
2338+042	4C04.81	2.594	2.7	36.2	46.2	1.01	Q	11,34,81
2345+18	3C467	0.632	32.0	290.5	44.5	1.00	G	13,34,112
2347+30	-	0.390	36.0	252.4	43.4	0.80	G	13,56
2349+327	4C32.69	0.659	66.0	610.7	44.3	0.80	Q	13,34,115
2352+796	3C469.1	1.336	74.0	878.4	45.5	1.04	G	72,84,136
2353+283	4C28.59	0.731	9.7	93.9	44.3	0.70	Q	13,62
2354+144	4C14.85	1.810	11.0	139.6	45.5	0.80	Q	11,13,34
2354+471	4C47.63	0.046	258.0	322.6	42.0	0.72	G	13,34,152
2356+438	3C470	1.653	24.0	299.3	45.7	0.97	G	72,83,117

References.—(1) Adams and Rudnick 1977; (2) Alexander et al. 1984; (3) Allington-Smith 1982; (4) Allington-Smith et al. 1982; (5) Allington-Smith et al. 1985; (6) Andernach et al. 1980; (7) Ballarati et al. 1983; (8) Barthel et al. 1985a; (9) Barthel et al. 1985b; (10) Barthel et al. 1986; (11) Barthel et al. 1988; (12) Baum et al. 1988; (13) Becker et al. 1991; (14) Binette et al. 1981; (15) Blades et al. 1981; (16) Branson et al. 1972; (17) Bridle & Fomalont 1978; (18) Bridle et al. 1976; (19) Bridle et al. 1979; (20) Burns 1978; (21) Burns & Gregory 1982; (22) Burns & Owen 1979; (23) Burns et al. 1984; (24) Cawthorne et al. 1986; (25) Chambers et al. 1988; (26) Christiansen et al. 1977; (27) Colla et al. 1975b; (28) Condon & Broderick 1988; (29) Cordey 1987; (30) Danziger & Goss 1983; (31) Danziger et al. 1978; (32) de Ruiter et al. 1986; (33) De Young et al. 1979; (34) Dixon 1970; (35) Downes et al. 1986; (36) Ekers & Kotanyi 1978; (37) Ekers et al. 1978; (38) Ekers et al. 1981; (39) Ekers et al. 1983; (40) Ekers et al. 1989; (41) Fanti et al. 1975; (42) Fanti et al. 1977; (43) Fanti et al. 1978; (44) Fanti et al. 1985; (45) Fanti et al. 1986; (46) Fanti et al. 1987; (47) Feigelson et al. 1984; (48) Feretti & Giovannini 1980; (49) Feretti et al. 1983; (50) Feretti et al. 1984; (51) Fomalont 1971; (52) Fomalont et al. 1980; (53) Giovannini et al. 1988; (54) Gower & Hutchings 1984; (55) Gregorini et al. 1988; (56) Grueff et al. 1981; (57) Hargrave & McEllin 1975; (58) Hewitt & Burbidge 1987; (59) Hiltner & Röser 1991; (60) Hine 1979; (61) Hintzen & Owen 1981; (62) Hintzen et al. 1983; (63) Hunstead et al. 1978; (64) Hutchings et al. 1988; (65) Jenkins &

sured redshift z. The redshifts for quasars are from Hewitt & Burbidge (1987) with a few exceptions. For 3C galaxies the redshifts are mainly from Spinrad et al. (1985) and Strom et al. (1990) and for the rest of the galaxies from various references listed in the last column. The largest angular size LAS (the fourth column) is measured between the outer hot spots. The true linear size (the fifth column) is calculated in the $H_0 = 50$ km s^{-1} Mpc^{-1}, $q_0 = 0.0$ cosmology. Linear size is obtained from the apparent angular size by multiplying the latter by the (angular diameter) distance d_A:

$$d_A = \frac{c}{2H_0}\left[1 - \frac{1}{(1+z)^2}\right], \quad q_0 = 0.0$$

$$d_A = \frac{2c}{H_0(1+z)}\left[1 - \frac{1}{\sqrt{1+z}}\right], \quad q_0 = 0.5 \qquad (1)$$

$$d_A = \frac{c}{H_0}\ln(1+z), \qquad \text{tired light}$$

(Sandage 1988). The symbols c (=speed of light), H_0 (=the Hubble constant), and q_0 (=deceleration parameter) have their usual meanings. Besides the usual Friedmann models, we also study a static universe where the redshift results from an (unexplained) tired light effect.

The sixth column gives the radio luminosity L in the frequency interval 10 MHz–10 GHz. The luminosity was calculated on the basis of available flux measurements. For 3C sources, the flux densities at 178 MHz and 5 GHz were mainly taken from Kellerman et al. (1969). For the rest of the sources most of the flux densities at 178 MHz and 5 GHz are from Dixon (1970) and Becker et al. (1991), respectively. When no information at 178 MHz or 5 GHz was available, the flux density was estimated using published measurements at nearby frequencies. The expression used in calculating the luminosity is

$$L = \frac{Ka}{1-\alpha}\left[(10^{10})^{1-\alpha} - (10^7)^{1-\alpha}\right] \text{ ergs}, \qquad (2)$$

where $\alpha \neq 1$, and

$$K = 1.20 \times 10^{27} d_A^2 (1+z)^{3+\alpha}$$

$$a = \frac{S_{178}}{(178 \times 10^6)^{-\alpha}},$$

and where S_{178} is the source flux at 178 MHz in janskys (either observed or extrapolated from low-frequency measurements). The spectral index α was calculated between 178 MHz and 5 GHz using the flux values found in literature ($S \propto \upsilon^{-\alpha}$). For comparison, the seventh column gives the spectral index at the high-frequency end of the spectral range, as reported in literature. The eighth column specifies the type of central object, either a galaxy (G) or a quasar (Q). References to literature are given in the last column.

3. POWER VERSUS SIZE

It has been noticed by several authors that powerful radio quasars tend to be smaller in size than weak radio quasars (Richter 1971; Wardle & Potash 1977; Stannard & Neal 1977; Masson 1980). It has also been pointed out that in weak radio galaxies the opposite tendency appears to hold: the source size increases with radio luminosity (Colla et al. 1975a; Birkinshaw et al. 1978; Gavazzi & Perola 1978; Miley 1980). The latter effect is at least partially a selection effect: for practical reasons most radio source samples have an upper limit for the angular size of the source which is included in the sample. This limitation becomes important for the nearby faint radio galaxies for which intrinsically large radio doubles may have been missed (Colla et al. 1975a; Baldwin 1982; Leahy & Williams 1984). A corresponding selection effect affects also the upper left part of the power-size diagram: there absolutely bright small sources are likely to be missed (Baldwin 1982).

The power-size anticorrelation for all but the faintest sources shows up in many different samples. It was noticed in the 3CR 166 source sample (Jenkins, Pooley, & Riley 1977) by Baldwin (1982). The study by Leahy & Williams (1984), based on the 3CR sample of Laing, Riley, & Longair (1983), indicates an anticorrelation for log $P_{178} > 25$, while an opposite correlation holds for faint sources. A similar feature is noticeable in the work of Ekers et al. (1981): at the upper end of the luminosity function, an anticorrelation is seen, while at the lower end a direct correlation in the outer envelope is observed (Ekers & Kotanyi 1987). The latter effect is more or less what one expects from the observational selection of missing large faint sources in the double source samples.

We show the dependence of the linear size (lin) distribution on the redshift and the absolute power in our sample in Figures 1 and 2. In Figure 1 radio galaxies are grouped in intervals of log L and redshift z. There is no obvious change of

References to Table 2—*Continued*

Scheuer 1976; (66) Jenkins et al. 1977; (67) Jägers 1987; (68) Jägers et al. 1982; (69) Kapahi 1981; (70) Kapahi et al. 1973; (71) Katgert-Merkelijn et al. 1980; (72) Kellerman et al. 1969; (73) Killeen et al. 1986; (74) Kollgard et al. 1990; (75) Kronberg & Strom 1977; (76) Kühr et al. 1981; (77) Kühr et al. 1987; (78) Laing 1981a; (79) Laing 1981b; (80) Laing et al. 1983; (81) Lawrence et al. 1986; (82) Leahy & Williams 1984; (83) Le Fèvre & Hammer 1988; (84) Longair 1975; (85) Lonsdale & Morison 1983; (86) Lyne 1972; (87) Machalski & Condon 1983; (88) Machalski & Condon 1985; (89) Machalski et al. 1982; (90) Mantovani et al. 1990; (91) Mayer 1979; (92) McCarthy et al. 1989; (93) McCarthy et al. 1990; (94) Menon 1976; (95) Miley & Hartsuijker 1978; (96) Miller 1985; (97) Morganti et al. 1987; (98) Murdoch et al. 1983; (99) Neff & Brown 1984; (100) Neff & Hutchings 1990; (101) Neff et al. 1989; (102) Owen & Puschell 1984; (103) Owen et al. 1978; (104) Owen et al. 1980; (105) Palumbo et al. 1982; (106) Parma et al. 1985; (107) Parma et al. 1986; (108) Peacock & Wall 1982; (109) Pearson et al. 1985; (110) Pedelty et al. 1989; (111) Perryman et al. 1984; (112) Pooley & Henbest 1974; (113) Pooley et al. 1987; (114) Potash & Wardle 1979; (115) Potash & Wardle 1980; (116) Righetti et al. 1988; (117) Riley & Pooley 1975; (118) Riley & Pooley 1978; (119) Riley et al. 1980; (120) Roger et al. 1973; (121) Rogora et al. 1986; (122) Rudnick & Adams 1979; (123) Rudnick & Owen 1977; (124) Saikia et al. 1984; (125) Saikia et al. 1986; (126) Saikia et al. 1987; (127) Saikia et al. 1989; (128) Saripalli et al. 1986; (129) Schilizzi & McAdam 1975; (130) Slee & Higgins 1975; (131) Slingo 1974; (132) Smith et al. 1977; (133) Spangler & Bridle 1982; (134) Spangler & Pogge 1984; (135) Spangler et al. 1984; (136) Spinrad et al. 1985; (137) Stannard & Neal 1977; (138) Strom & Conway 1985; (139) Strom et al. 1990; (140) Subrahmanya & Hunstead 1986; (141) Swarup et al. 1982; (142) Swarup et al. 1984; (143) Swarup et al. 1986; (144) Tsien 1982; (145) Ulvestad 1985; (146) Ulvestad & Antonucci 1988; (147) Valentijn 1979; (148) van Breugel & Jägers 1982; (149) van Breugel & Willis 1981; (150) van Breugel et al. 1984; (151) van Breugel et al. 1985; (152) Vigotti et al. 1989; (153) Waggett et al. 1977; (154) Wall & Cole 1973; (155) White et al. 1980; (156) Whyborn et al. 1985; (157) Wilkinson et al. 1991; (158) Wills & Lynds 1978; (159) Willis & Strom 1978; (160) Wilson & Ulvestad 1987; (161) Wirth et al. 1982; (162) Wrobel 1984; (163) Wrobel & Heeschen 1984.

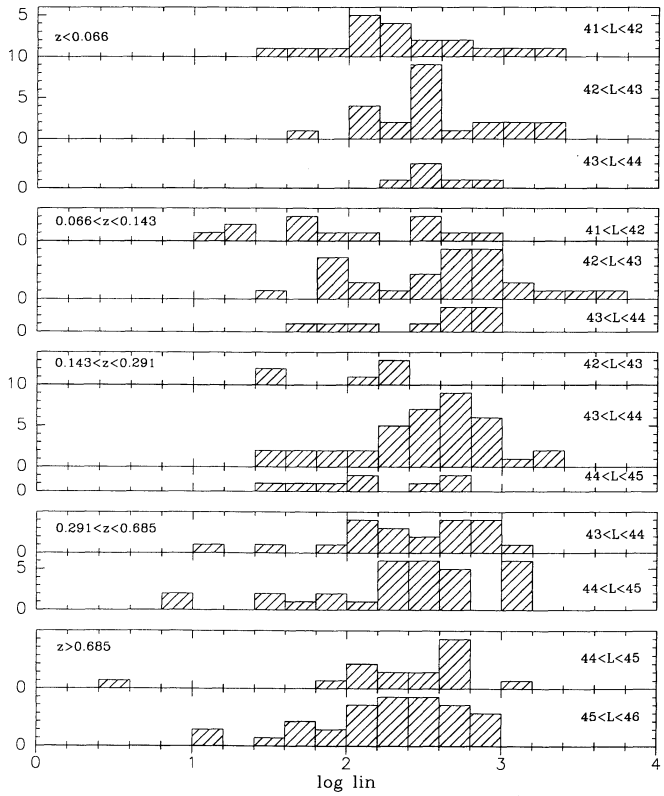

FIG. 1.—The distribution of linear sizes (lin) of double radio galaxies in different redshift (z) and log luminosity (L in ergs s^{-1}) bins ($q_0 = 0.0$).

the size distribution with redshift. This may be best seen by looking at the luminosity ranges $43 < \log L < 44$ and $44 < \log L < 45$, where significant amount of data exist over a wide span of redshifts. However, there may be a positive correlation of linear size with luminosity at low redshifts and a reverse trend at high redshifts. It appears as if the power-size correlation changes from positive to negative when the power goes over $\log L \cong 43$.

The corresponding diagram for quasars (Fig. 2) shows exactly the same behavior. There is a clear decrease of linear size with power at all redshifts. The quasar sample does not extend below $\log L = 43$, and thus we do not know if the trend would be reversed at lower power as in the case of radio galaxies. The independence of source size on redshift can now be clearly seen at two intervals of power: $44 < \log L < 45$ and $45 < \log L < 46$ which are well represented in all or nearly all redshift groups. These results are summarized in Figure 3 where the median values of the distributions are shown both for galaxies and quasars. The symbols in Figure 3 correspond to the lower limit of the luminosity bin.

To be more quantitative, we have searched for correlations of the type

$$\log \text{lin} = b_0 + b_1 \log (1 + z) + b_2 \log L . \qquad (3)$$

The coefficients b_0, b_1, b_2 and their significance were calculated for radio galaxies and quasars separately. We have also studied correlations of the form

$$\log \text{lin} = a_0 + a_1 \log L . \qquad (4)$$

The results are summarized in Table 2. Calculations have been carried out for different cosmological models as well as for several samples. These are indicated in column (1). Column (2) tells the number of sources in the sample. Column (3) gives the values of the correlation coefficients in equation (3), and column (4), their statistical significance. The corresponding values for equation (4) are given in columns (5) and (6).

In the quasar sample the correlation of the size with redshift is never very significant (below 3 σ level). On the other hand, the correlation of the size with luminosity is as a rule more significant than the correlation of the size with redshift. The luminosity correlation is generally above the 3 σ significance level when considered by itself.

We note also that while the linear size in the $q_0 = 0.0$ sample very clearly does not depend on redshift, the situation is not equally clear in the tired light (TL) model and the $q_0 = 0.5$ Friedmann model. The latter situation is somewhat expected: transformation from $q_0 = 0.0$ model to $q_0 = 0.5$ model is strongly redshift dependent (eq. [1]). Thus if $q_0 = 0.0$ model has no redshift dependence, $q_0 = 0.5$ model is bound to show some correlation. The linear size in the tired light model apparently is almost equally sensitive to redshift and luminosity.

When we move over to radio galaxies, there appears a very strong positive correlation between linear size and luminosity at low luminosities, $\log L \leq 43$. The inverse correlation at high luminosities $\log L > 43$, on the other hand, is not as clear as with quasars. Shifting the luminosity division up to, say, $\log L > 43.5$ would bring up the correlation somewhat closer

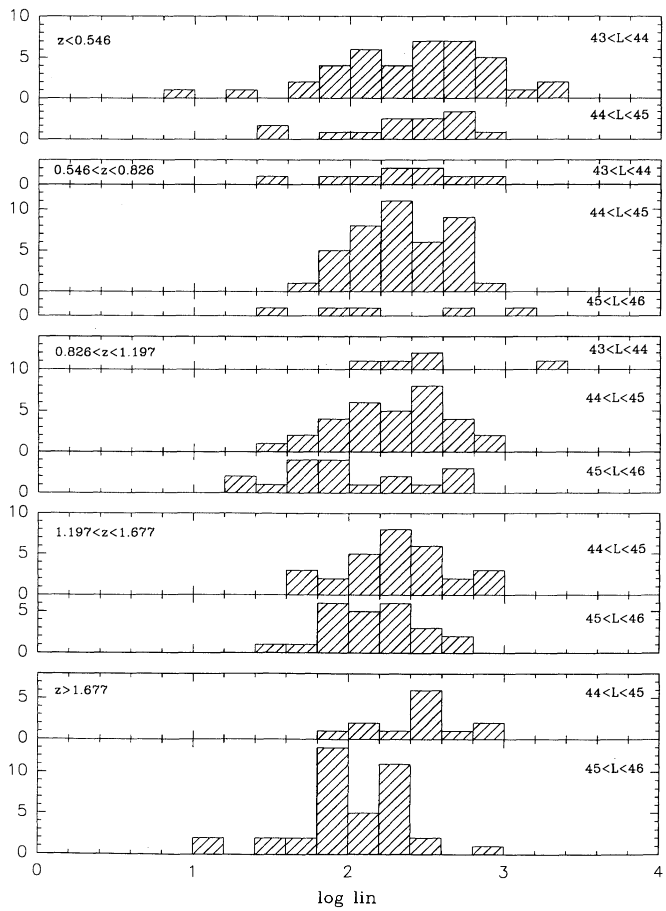

FIG. 2.—The distribution of linear sizes (lin) of double radio quasars in different redshift (z) and log luminosity (L in ergs s^{-1}) bins ($q_0 = 0.0$).

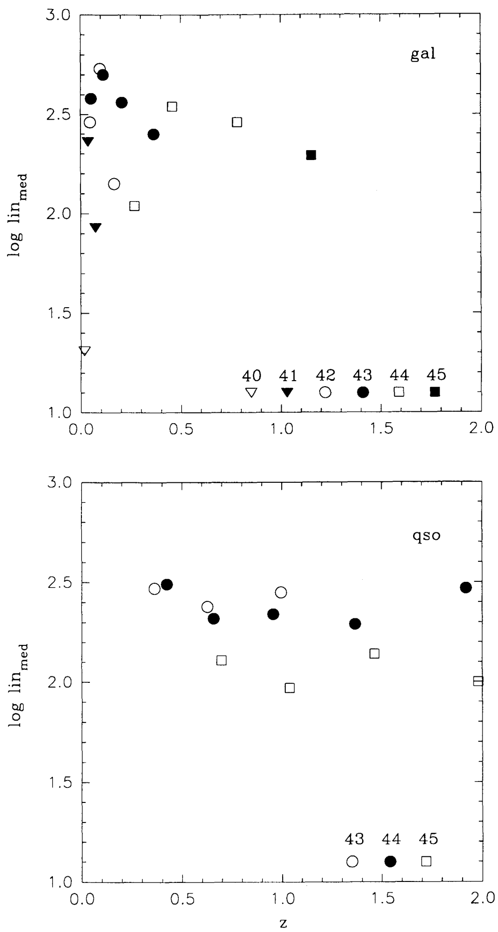

FIG. 3.—The median sizes of double radio galaxies (*upper panel*) and quasars (*lower panel*) in different redshift (z) and luminosity (L) bins ($q_0 = 0.0$). The symbols refer to the lower limit of the luminosity bin with $\Delta \log L = 1.0$.

shifts have been measured. As in all quasar studies, it is difficult to describe how the list of quasar redshifts has developed. We feel that a sample which is limited mostly by the availability of redshifts is a less likely source of biases than a sample defined primarily by radio properties when one is studying correlations between various radio properties.

We have constructed a log (number)–log (flux) diagram for our sample and find, not surprisingly, that our sample is reasonably complete to the flux limit $S_{178} = 10$ Jy. Therefore we performed the correlation studies for this part of the sample separately and report the results in Table 2. We find that the same trends are still there as in the whole sample even though weaker due to a small number of points. Our log (number)–log (flux) diagram shows another break at $S_{178} \cong 2$ Jy, which is close to the 2.5 Jy limit of Hooley et al. (1978). For comparison with earlier results we therefore conducted the correlation studies also for a subsample with $S_{178} > 2.5$ Jy and find the same trends as before.

With an extensive collection of galaxy and quasar linear sizes, we may also ask if there is any difference of true linear size between the two groups. Barthel (1989) studied a relatively small sample of 30 3C radio galaxies and 12 3C quasars and found quasars to be smaller than galaxies by a factor of roughly 2. Barthel (1989) argued that this supports the QSR-RG unification scheme where quasars are beamed toward us and where radio galaxies form the unbeamed parent population. Based on the relative number of galaxies and quasars in his sample, Barthel (1989) calculated that the quasars are aligned toward us with the line of sight within about 44°.4.

We compared the true linear sizes of galaxies and quasars for different subsamples in the $q_0 = 0.0$ model. The null hypothesis that the distributions are the same was tested with the Kolmogorov-Smirnov test. The results are summarized in Table 3. We see that generally the median sizes of radio galaxies tend to be greater than the sizes of quasars by about

to quasars, but its significance level still stays at 80% while the significance of the redshift correlation drops to 2% ($q_0 = 0.0$).

We may ask to what extent these correlations are real and what selection effects may operate to produce spurious correlations. We illustrate the sample selection by Figure 4 where our data points are plotted in the log L–log $(1 + z)$ plane. There is obviously a strong correlation between the two quantities, most of which must to due to selection effects. Only above $\log (1 + z) > 0.1$ and $\log L > 43$ is there a reasonable coverage of points.

In defining a radio source sample, one customarily assigns a minimum flux level at some frequency and tries to be complete in some specified part of the sky. In the present investigation, this type of sample selection is not good since it generally produces a much tighter bunching of points in the log L–log $(1 + z)$ plane than we see in Figure 4 (see, e.g., Kapahi 1988, Fig. 2 for the 3CR sample). Then it becomes very difficult to separate the variation of a third quantity from one or the other.

In the present investigation the radio sources are collected from many samples of different minimum flux densities. This has the advantage of providing good scatter in Figure 4. In this respect this work differs from many previous samples which have been much smaller in size or of more limited use due to use of a flux limit in the sample selection. In fact the limitations of the present sample come mainly from the way optical red-

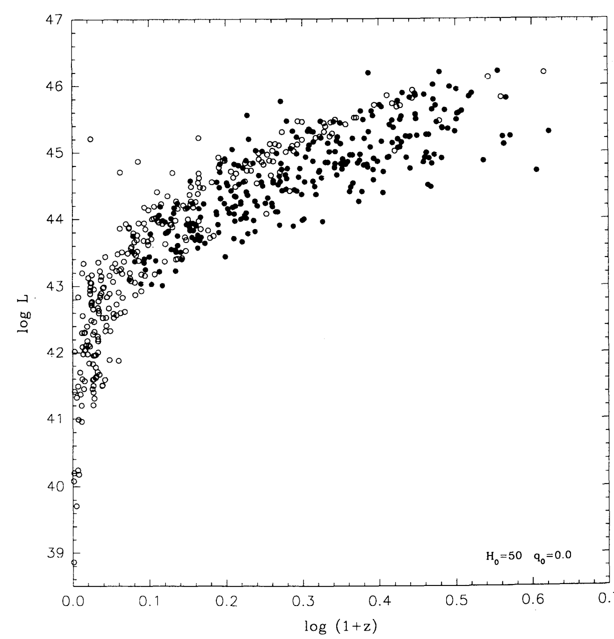

FIG. 4.—Log luminosity (L) vs. log $(1 + z)$ for our sample. Open circles represent galaxies; filled circles, quasars.

TABLE 2

THE CORRELATION COEFFICIENTS

Sample (1)	Number (2)	b_0, b_1, b_2 (3)	Significance (4)	a_0, a_1 (5)	Significance (6)
GAL ($q_0 = 0.0$)	99	−19.0		−14.0	
$\log L < 43$		−9.9	99.14%	0.39	>99.99%
		0.51	>99.99		
GAL ($q_0 = 0.5$)	99	−19.0		−14.0	
$\log L < 43$		−9.9	99.18	0.39	>99.99
		0.51	>99.99		
GAL (TL)	99	−19.0		−14.7	
$\log L < 43$		−8.44	97.70	0.41	>99.99
		0.51	>99.99		
GAL ($q_0 = 0.0$)	168	6.53		7.77	
$\log L \geq 43$		−0.22	25.66	−0.12	99.10
		−0.093	64.96		
GAL ($q_0 = 0.5$)	168	6.28		10.8	
$\log L \geq 43$		−0.75	79.22	−0.19	99.97
		−0.087	62.17		
GAL (TL)	168	6.53		3.59	
$\log L \geq 43$		0.46	61.47	−0.024	32.97
		−0.092	65.94		
QSO ($q_0 = 0.0$)	273	14.1		11.8	
		0.38	78.17	−0.21	>99.99
		−0.27	>99.99		
QSO ($q_0 = 0.5$)	273	13.8		16.1	
		−0.36	83.21	−0.31	>99.99
		−0.26	>99.99		
QSO (TL)	273	14.8		9.29	
		0.86	99.92	−0.15	99.99
		−0.28	>99.99		
GAL ($q_0 = 0.0$)	115	12.6			
$\log L \geq 43$		0.60	42.49	...	...
$S_{178} > 10$ Jy		−0.23	85.93		
GAL ($q_0 = 0.5$)	115	12.3			
$\log L \geq 43$		−0.018	1.55	...	...
$S_{178} > 10$ Jy		−0.22	85.22		
QSO ($q_0 = 0.0$)	51	27.6			
		1.38	65.01	...	...
$S_{178} > 10$ Jy		−0.57	97.39		
QSO ($q_0 = 0.5$)	51	26.7			
		0.32	20.71	...	...
$S_{178} > 10$ Jy		−0.55	97.10		
GAL ($q_0 = 0.0$)	159	5.18		...	
$\log L \geq 43$		−0.40	42.12	...	...
$S_{178} > 2.5$ Jy		−0.062	42.77		
GAL ($q_0 = 0.5$)	159	4.85		...	
$\log L \geq 43$		−0.91	84.46	...	...
$S_{178} > 2.5$ Jy		−0.054	38.36		
QSO ($q_0 = 0.0$)	188	15.7		...	
		0.55	70.28	...	...
$S_{178} > 2.5$ Jy		−0.30	99.93		
QSO ($q_0 = 0.5$)	188	15.3		...	
		−0.23	39.69	...	...
$S_{178} > 2.5$ Jy		−0.29	99.90		

30%, but the significance of this difference is below the 2 σ level. A statistically significant difference is seen only if we consider all sources with no regard to their radio luminosity. However, we have already established that there exists an anticorrelation between luminosity and linear size of double radio sources. Since the quasars in all subsamples lie in the high-luminosity end of the luminosity distribution and the galaxies lie in the low-luminosity end, a difference of linear sizes between the two populations is expected.

This result is in contradiction to Barthel (1989), since his sources came also from a relatively narrow power range $\Delta \log P \cong 1$. The reason for the difference is either simply due to the smallness of the Barthel (1989) sample or may result from selection of sources. The Barthel sample was not restricted to FR II

TABLE 3

COMPARISON BETWEEN GALAXY AND QUASAR LINEAR SIZES

Sample	N_{gal}	N_{qso}	lin_{gal}^{med}	lin_{qso}^{med}	p	$\text{lin}_{gal}^{med}/\text{lin}_{qso}^{med}$
			$S_{178} > 10$ Jy			
All	144	51	329	162	99.69%	2.03
$44.5 < \log L < 45.5$	46	26	232	131	49.54	1.77
$45 < \log L < 46$	31	29	200	128	65.84	1.56
			$S_{178} > 2.5$ Jy			
All	227	188	299	180	>99.99	1.66
$43 < \log L < 44$	67	30	365	291	5.47	1.25
$43.5 < \log L < 44.5$	59	55	299	240	33.63	1.24
$44 < \log L < 45$	53	81	290	209	72.77	1.39
$44.5 < \log L < 45.5$	55	95	232	176	59.66	1.32
			All Data			
All	267	273	267	194	99.93	1.38
$43 < \log L < 44$	74	53	365	272	53.06	1.34
$43.5 < \log L < 44.5$	64	93	295	241	89.48	1.22
$44 < \log L < 45$	54	129	280	226	84.77	1.24
$44.5 < \log L < 45.5$	56	133	219	170	67.96	1.29

double sources, but it contains compact steep spectrum (CSS) and D2 sources. Finally we may refer to Figure 5 where we see that there is no clear difference between the linear sizes of the largest galaxies and the largest quasars of the same redshift interval.

4. ANGULAR SIZE VERSUS REDSHIFT

We plot the apparent largest angular size LAS versus redshift for our sample in Figure 5. For comparison, we show the expected behavior of a standard rod in three cosmological models: Friedmann models with $q_0 = 0.0$ ($\Omega = 0$), $q_0 = 0.5$ ($\Omega = 1$), and a static Euclidean (tired light) model. The line of LAS $\propto z^{-1}$ is also shown and in fact agrees well with the data.

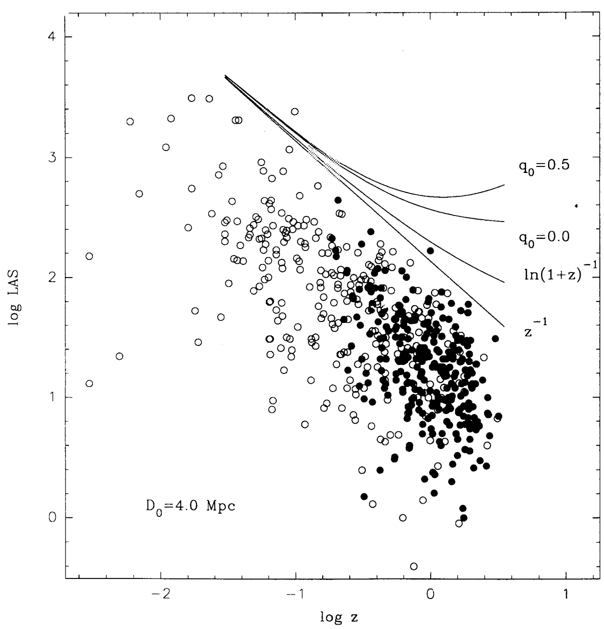

FIG. 5.—The log redshift (z) vs. log apparent size (LAS) diagram for our sample. The behavior of a 4 Mpc rigid rod is indicated in three world models (Friedmann models with $q_0 = 0.0$ and $q_0 = 0.5$ and the tired light model) together with a z^{-1} dependence. Open circles represent galaxies; filled circles, quasars.

We are interested in particular in the upper envelope of the data points in Figure 5. Its definition is not very clear to the eye since a few isolated points attract undue emphasis. Therefore we prefer to go over to a density contour presentation. The contour presentation was achieved by dividing Figure 5 into a square grid of grid size $\Delta z = 0.2$, $\Delta(\text{LAS}) = 20$, and by counting the number of points in each grid cell. Then contours of equal density were plotted. The result is shown in Figure 6. Now the upper envelope appears well defined out to the redshift where reasonable number of points exist ($z < 2$).

So far no correction due to the power-size anticorrelation has been included. This is done in Figure 7 where we show the LAS-z contour diagram again. We have used the average power-size correlation given in column (5) of Table 2 to correct the linear size of each source to the value it should have at power $\log L = 43$. It means that at high redshifts the correction is as a rule upward. We do not consider the low-redshift end ($z \leq 0.2$) of the LAS-z diagram where the correction could also be in the opposite direction. The crucial assumption here is that the linear size–redshift correlation, if it exists, can be neglected. Under this assumption we may compare the model predictions directly with the contour lines. In case of Figure 7 we observe an excellent agreement with model $q_0 = 0.0$ (solid curve representing a source size of 1100 kpc) and the second level of the contour plot.

In order to get an idea how well the contour lines are defined by the rather sparse sample of high-redshift radio galaxies and quasars, we have performed bootstrap simulations (see, e.g., Bhavsar 1990) to determine error bars for the second contour. The calculations were made for luminosity-corrected data in every three world models and results are displayed in Figures 9–11. Figure 8 shows the results for uncorrected data. The data points in the upper plot of each figure correspond to the second contour level in the contour plots. The error bars were determined in the following manner: In every redshift bin we drew 100 random angular size samples from the original angular size distribution and determined the point where the density reached the second contour level. The error bars in

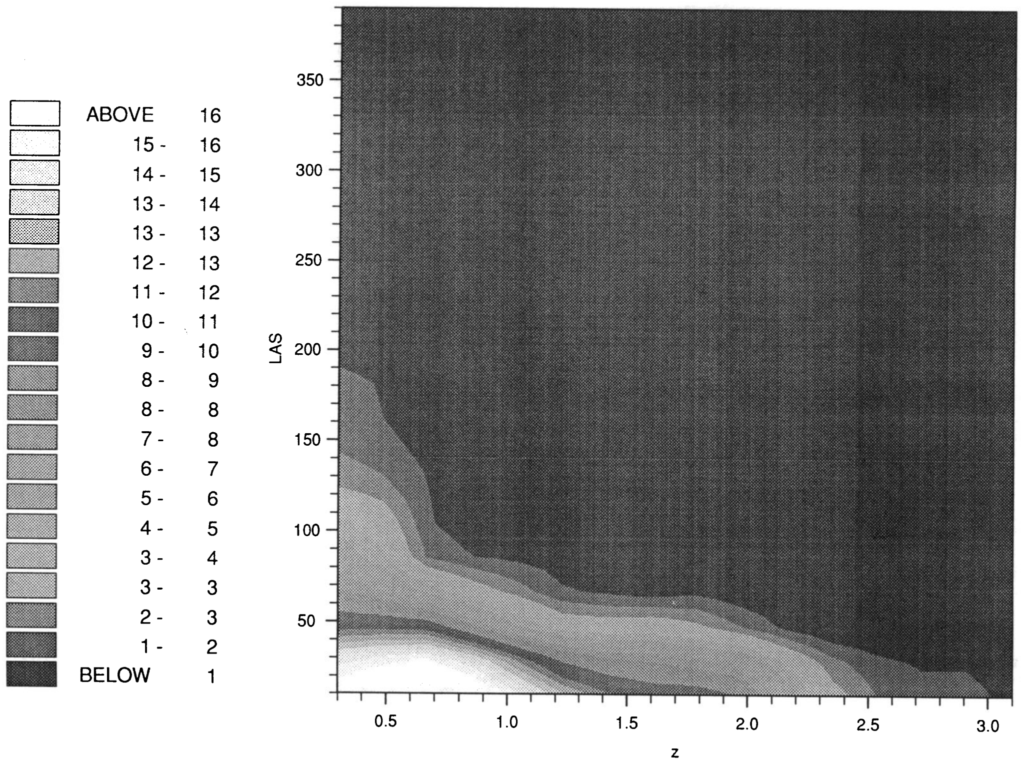

FIG. 6.—The contour representation of the redshift (z) vs. apparent angular size (LAS) diagram. For details, see the text.

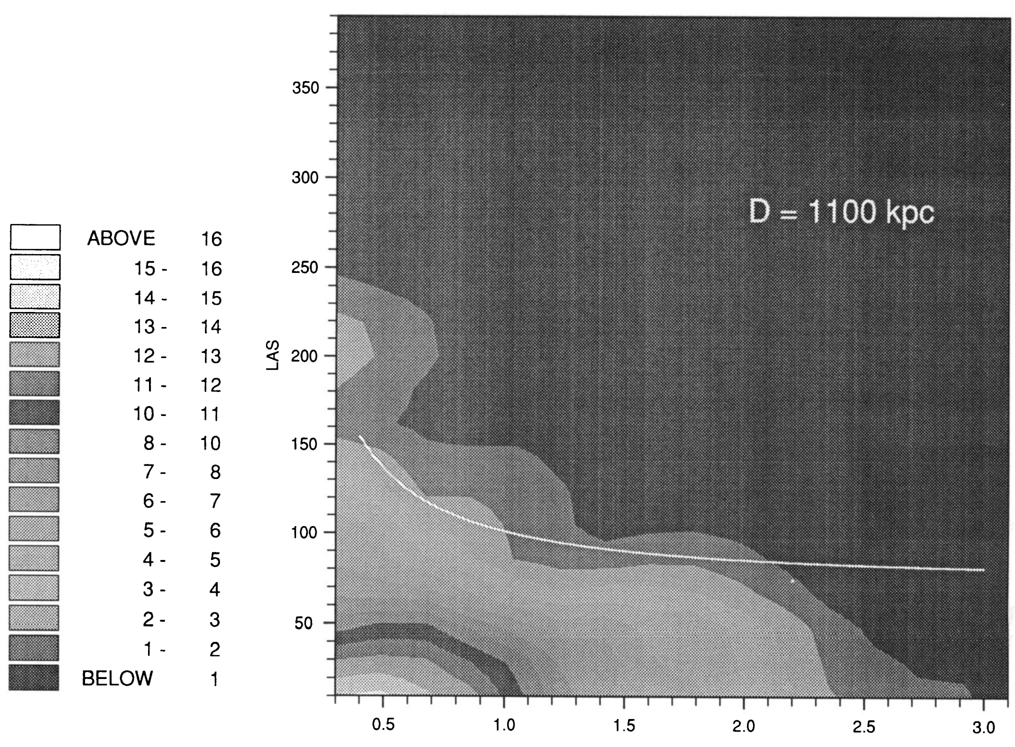

FIG. 7.—The contour representation of the corrected redshift (z) vs. apparent size (LAS) diagram in the $q_0 = 0.0$ model. The behavior of a 1100 kpc rigid rod in this model is indicated.

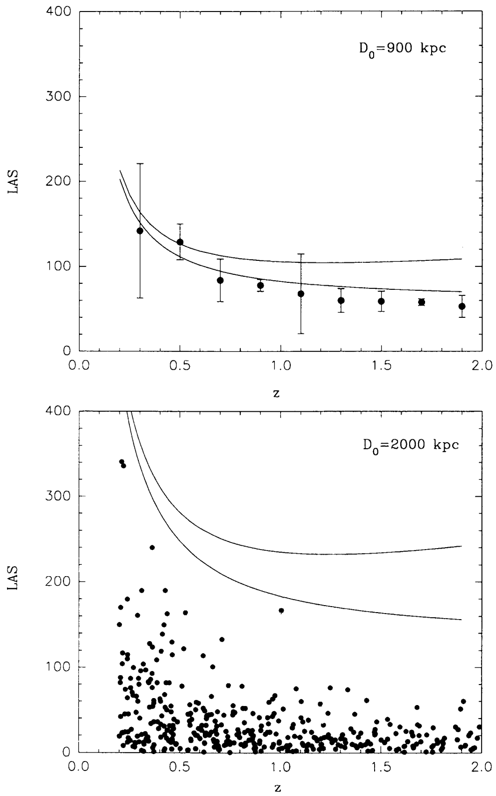

FIG. 8.—The redshift (z) vs. apparent size (LAS) diagram of the uncorrected data in the redshift range $0.2 < z < 2.0$ together with two model curves (*upper curve*, $q_0 = 0.5$; *lower curve*, $q_0 = 0.0$). The data points in the upper panel refer to density = 2 in the contour representation. For the error bars, see text. The points in the lower panel refer to individual double sources.

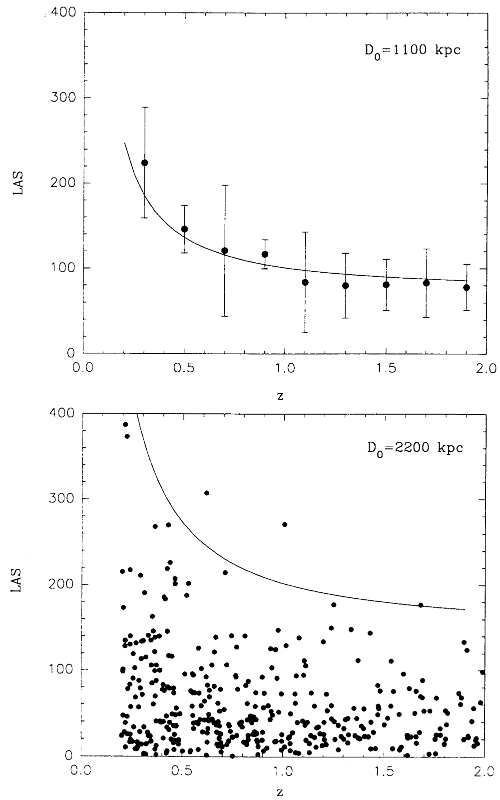

FIG. 9.—The redshift vs. apparent size diagram for corrected data in the Friedmann model $q_0 = 0.0$ together with the appearent size of a standard rod (*solid line*). See legend to Fig. 8.

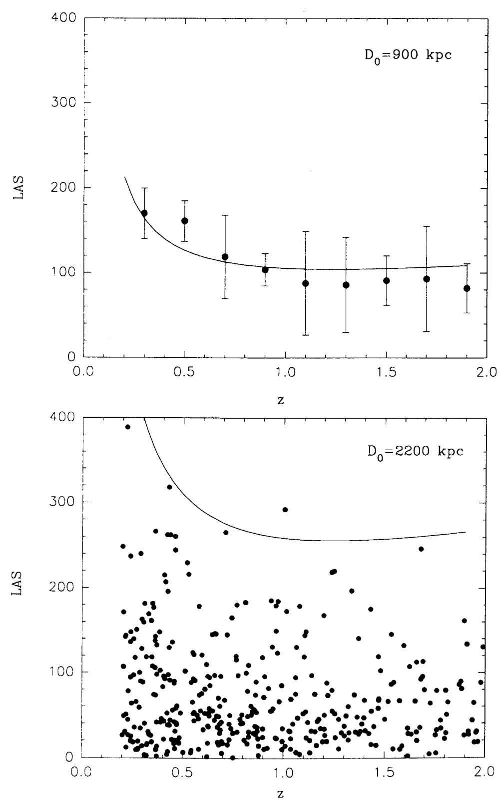

FIG. 10.—The redshift vs. apparent size diagram for corrected data in the Friedmann model $q_0 = 0.5$ together with the apparent size of a standard rod (*solid line*). See legend to Fig. 8.

Figures 8–11 show one standard deviation of this quantity. In the lower plot of Figures 9–11 we show the data points corrected to luminosity $\log L = 43$. We also draw the theoretical redshift–angular size curves for corresponding world models. For Figure 8 the curves are for $q_0 = 0.5$ (*upper curve*) and $q_0 = 0.0$ models.

We notice that the $q_0 = 0.0$ ($\Omega = 0$) model agrees reasonably well with the data even without the luminosity correction. All the models fit nicely with the data after the correction is applied!

5. COMPARISON WITH EARLIER WORK

The angular size of radio sources was first used as a cosmological test by Miley (1971). He used data on 127 quasars and found that radio sources at large redshifts are systematically smaller that what one would expect in standard Friedmann models. For many sources only upper limits of the source size were available. With our more strict sample selection only 72 quasars survive from Miley (1971), and in case of two of the quasars the redshift data has been drastically revised. Thus at present time there is roughly a factor of 4 increase in useful quasar data, if we limit ourselves to the study of well-defined doubles. However, the main conclusions of Miley (1971) are still valid today.

More data were presented by Wardle & Miley (1974) which brought the sample size to 166. Of this sample 94 quasars are qualified to enter our sample. Besides confirming the earlier observational trend, Wardle & Miley (1974) discussed models

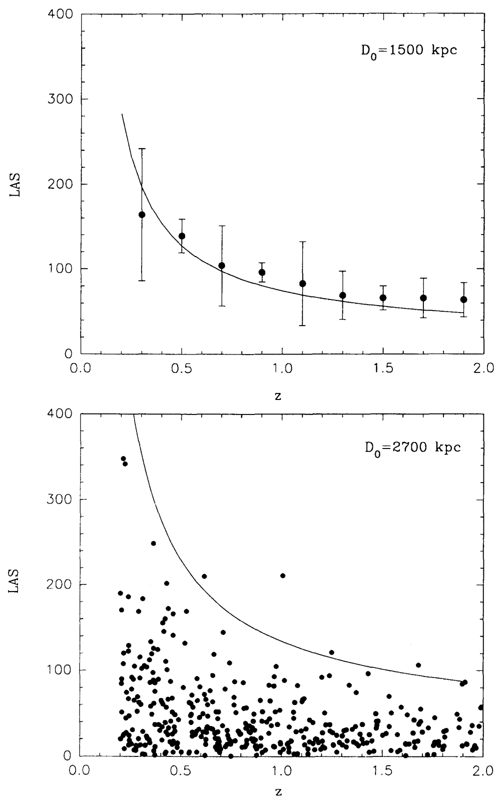

FIG. 11.—The redshift vs. apparent size diagram for corrected data in the tired light model together with the apppearent size of a standard rod (*solid line*). See legend to Fig. 8.

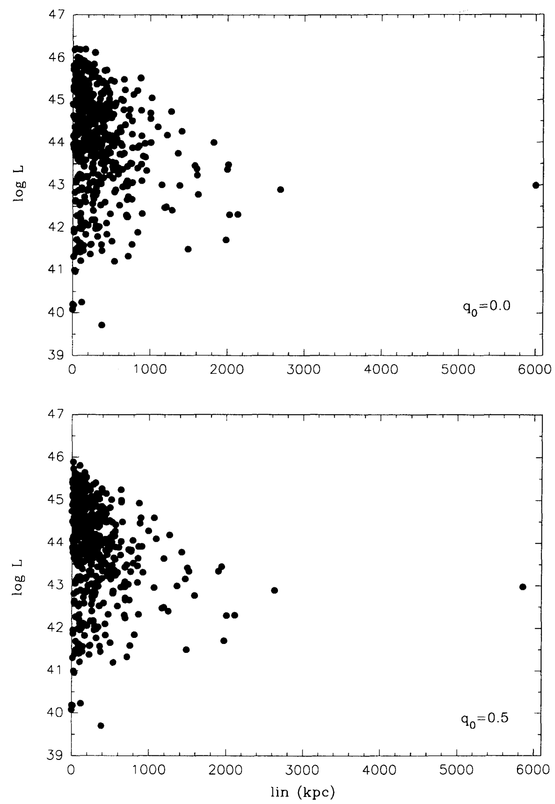

FIG. 12.—Log luminosity (L) vs. linear size (lin), all sources included. Excepting 3C 236 on the far right, a well-defined straight upper envelope is observed. *Upper panel*, $q_0 = 0.0$; *lower panel*, $q_0 = 0.5$.

which could cause the apparent cosmological evolution of the radio source sizes.

As an alternative to cosmological evolution Jackson (1973) proposed a dependence of the linear size on the luminosity of the radio source. He offered a definite model where (1) the radio components are moving away from each other, and (2) the intrinsic radio luminosity of a source diminishes with its age. Using these rather plausible arguments Jackson (1973) demonstrates that the LAS-z diagram is well understood in a Friedmann model of $q_0 = 0.5$ without need for cosmological evolution.

Jackson used a definite relation between the luminosity L and the age t:

$$L = L_0 \exp(-t/t_0) , \quad (5)$$

where L_0 is the luminosity at $t = 0$, and t_0 is a measure of the lifetime of the source. The linear size of the source was obtained from

$$\text{lin} = vt , \quad (6)$$

where v is the velocity of expansion of the source, assumed to be constant. If these relations were true, then radio sources evolve along straight lines in the log L versus lin diagram.

We plot the log L–lin diagram in Figure 12. If Jackson's theory holds, there should be a well-defined straight upper envelope in the diagram, corresponding to the highest expansion speed v, as well as possible steeper straight line structure corresponding to lower expansion speeds. Looking at Figure 12 we find that there is no obvious objection to Jackson's model in our data. Except for 3C 236 (on the far right), there appears a fairly well-defined straight upper edge in the diagram.

Another explanation which has been advanced for the inverse power-size correlation is based on the assumption that there is an upper limit to the total energy of extended steep-spectrum sources. Using the minimum energy condition

$$U_{\text{min}} \propto L^{4/7} V^{3/7} , \quad (6)$$

where V is the source volume, and substituting $V \propto \text{lin}^3$, we obtain

$$\log \text{lin} \propto -\tfrac{4}{9} \log L . \quad (7)$$

This relation is shown in Figure 13 together with our data.

Besides giving a nice fit to the data, this explanation is attractive because it should operate primarily at the high luminosity end. It would explain why the power-size correlation is different among weak and strong sources. The positive correlation among weak sources still remains to be explained, but its existence is not unreasonable (see, e.g., Valtonen 1980).

Hooley et al. (1978) studied a complete sample of 40 3CR quasars and 19 4C quasars of $z > 1.5$. The total of 36 of these remain in our sample. Their results are consistent with the hypothesis that the sizes of brightest quasars do not change with cosmological epoch, even though they noted the smallness of the sample. We have taken a subsample of ours with $S_{178} \geq 2.5$ Jy, which was the flux limit used by Hooley et al. (1978). We now obtain a sample of primarily 3C and 4C quasars with 188 objects. This larger sample confirms the results of Hooley et al. (1978), as Table 2 shows.

The study of Stannard & Neal (1977) included altogether

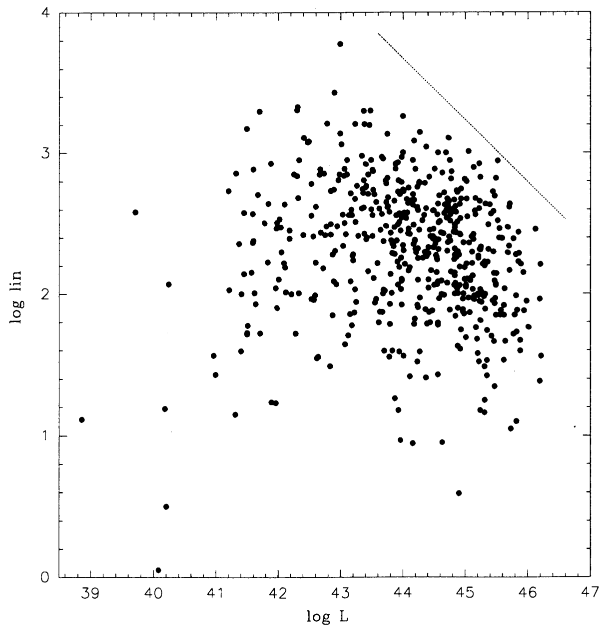

FIG. 13.—The linear size (lin) vs. the luminosity (L) for the whole sample. The dashed line indicates the relation of eqn. (7) ($q_0 = 0.0$).

112 3CR and 4C quasars, out of which 80 are also found in our sample. The flux limit used in this study is also $S_{178} = 2.5$ Jy. Therefore our subsample of $S_{178} \geq 2.5$ Jy may be considered an extension of this work as well. Stannard & Neal (1977) noted that at the same redshift the 4C quasars are 1.3 times bigger in size than 3C quasars. This is exactly what we would expect from our sample considering the difference in the flux limits of the 3C and 4C samples (9 Jy and 2.5 Jy, respectively) and the correlation coefficients in Table 2. We also confirm the Stannard & Neal (1977) result for our equivalent subsample.

Masson (1980) studied a sample of quasars which was essentially a combination of the Hooley et al. (1978) and Stannard & Neal (1977) samples. It has 79 sources in common with ours. Masson finds strong evidence that there is no cosmological evolution of source sizes but an inverse correlation between size and radio power. This is exactly what we also find.

A strong case for redshift rather than luminosity dependence of the linear size has been put forward by Kapahi (1985, 1988), Oort et al. (1987a, b), Barthel & Miley (1988), and Singal (1988). By comparing a strong radio galaxy sample with three different weak galaxy samples, Kapahi concludes that there is a decrease (even though marginal) of source size with redshift between $z \sim 0.1$ and $z \sim 1.0$. However, the three weak samples have altogether only four measured redshifts. It would be very important to try to obtain the actual redshift measurements in order to check the reliability of the redshift estimates which are now based on the magnitudes of the galaxies. With the great uncertainty in distances, it is not at all clear that the four samples of Kapahi (1988) actually possess the same absolute radio luminosity, as was claimed.

Kapahi (1988) as well as Oort et al. (1987a, b) find that the linear size of radio galaxies *increases* with luminosity: log lin = 0.3 L. This is the same result as ours for the fainter radio galaxies. As Oort et al. (1987a) data concentrate at relatively low luminosity levels, it is not surprising that their results agree with ours for the weak radio galaxies.

Whether the strong cosmic evolution of low-luminosity sources proposed by Oort et al. (1987b) exists or not is not relevant to the main problem of this paper since the interesting part of the LAS-z diagram depends on high-luminosity sources. However, we suspect that the power-size correction applied by Oort et al. (1987b) to the linear size data may have been pushed too far toward high luminosities, and thus the evolutionary effects shown in Figure 1 of Oort et al. (1987b) may be excessive.

Barthel & Miley (1988, hereafter BM), studied a sample of 134 quasars and found that the maximum size of quasars depends primarily on redshift, but a possible power-size correlation could not be ruled out either. We performed regression analysis of the BM data in the same manner as we did above with our data. Of the 134 sources in their sample 92 can be found in our sample. The regression results for this part of the sample (BM "good") as well as for the whole sample (BM) are displayed in Table 4. We see that in both cases and both world models we obtain results similar to our results in § 3. On the other hand, if we do a regression of the maximum linear size in a log L–log $(1 + z)$ grid, as BM did, using our data, we find, contrary to BM, that also the maximum linear size of quasars depends strongly on luminosity and not on redshift. Since the results based on the BM sample are so sensitive to the exact method of analysis, we have to consider them rather marginal. If we look at Table 1 in BM, we see that the sample contains many CSS, D2 and compact sources, which were omitted from our sample. As in the case of comparing linear sizes of galaxies and quasars, the different results are probably due to different criteria in selecting the sources.

The only previous study of comparable size and redshift coverage to our sample is the sample of Singal (1988). He has plotted diagrams equivalent to our Figures 1–3 and the diagrams look rather similar. However, the conclusions he draws are different from ours: Singal (1988) finds that the source size

TABLE 4

COMPARISON WITH EARLIER WORK

Sample	Number	b_0, b_1, b_2	Significance
QSO ($q_0 = 0.0$)	303	3.72	
Singal		−0.96	98.39%
		−0.048	51.92
QSO ($q_0 = 0.0$)	239	9.18	
Singal "good"		0.31	57.00
		−0.25	99.98
QSO ($q_0 = 0.5$)	303	3.60	
Singal		−1.49	>99.99
		−0.042	46.86
QSO ($q_0 = 0.5$)	239	9.04	
Singal "good"		−0.40	75.30
		−0.24	99.97
QSO ($q_0 = 0.0$)	134	19.5	
BM		0.86	83.14
		−0.66	>99.99
QSO ($q_0 = 0.0$)	92	13.1	
BM "good"		0.63	79.69
		−0.41	99.98
QSO ($q_0 = 0.5$)	134	19.2	
BM		−0.27	38.01
		−0.65	>99.99
QSO ($q_0 = 0.5$)	92	12.9	
BM "good"		−0.26	45.97
		−0.40	99.98

depends primarily on the redshift and only secondarily on the luminosity. In order to investigate the source of the difference we have carried out statistical tests on Singal's sample using his data.

The total number of quasars in the Singal sample is 303, but the data for many of them are poor: often the morphology is unclear and/or the source sizes are observational upper limits. Only 239 sources in the Singal sample satisfy the criteria used in our work. In Table 4 we show the correlation coefficients found in the original and "good" Singal sample. We see that the "good" part of the Singal sample gives results which are practically identical to ours.

In all QSO samples except in that of Singal the correlation between linear size and power is more significant than the correlation between linear size and redshift. When we consider only the part of Singal's sample which is common with our sample (Singal "good"), then even this one exception is removed. It is apparent that it is the degradation of the sample by spurious data which has caused Singal's anomalous result.

6. DISCUSSION

Our main result is that due to the power-size anticorrelation the lack of very large double sources at large redshift is well understood *without* cosmological evolution. In fact, we do not see any evidence at all for the type of evolution claimed by Barthel & Miley (1988) and Singal (1988). In the light of the more extensive sample and especially with many more high redshifts measured in recent years, we may comment on the earlier papers.

First, there are a number of papers where the linear sizes of the radio sources have been found to increase with radio power (e.g., Gavazzi & Perola 1978). What these studies have in common is that the source sample consists of low redshift, low luminosity radio galaxies. We confirm this result with the new more extensive sample. However, one should not confuse this result with the decrease of linear size with radio power at the high-luminosity end. It is this end of the radio luminosity function that has to be used, for practical reasons, in cosmological studies.

Second, one should be careful in the construction of the source sample. As we have demonstrated in the case of Singal's (1988) sample, the inclusion of poorly resolved sources or galaxies with only estimated redshifts can lead to serious biases. On the other hand, our strict morphological selection can lead to another kind of bias: with increasing redshift we sample the small-size end of the size distribution function more and more poorly. Looking at Figure 5, this would not seem to be a serious problem since the range of angular sizes at any redshift seems to be rather constant. This can be understood because our sample is mainly limited by the lack of optical redshifts, not so much by the lack of structural information. If this bias has any effect on our result at all, it is in the direction of making the power-size anticorrelation appear weaker that it really is. Therefore our main conclusions are not weakened by the possibility of this bias.

Where this bias could be significant is in the comparison of the sizes of radio galaxies and quasars at the same redshift. If the quasars are really end-on radio galaxies as suggested by Barthel (1988), then the quasar sample would be much more heavily cut off from the side of low linear sizes than the galaxy sample. This could make even a real size difference to drop to the low level of significance which is observed in this paper.

Third, one should specify which world model one is using in transforming the observational data into physical parameters. We notice in our sample that the likelihood of cosmological evolution becomes greater if one goes from the $q_0 = 0.0$ Friedmann model either toward the $q_0 = 0.5$ Friedmann model or to the tired light model. The choice of the $q_0 = 0.5$ world model may be one reason why Barthel & Miley (1988) found a strong redshift evolution in radio source sizes. The other reason may be the mixture of source types used: when only "good" double sources in the Barthel & Miley (1988) are used, we obtain an excellent agreement with our sample.

As the error bars in Figures 9–11 demonstrate, the number of high-redshift double radio sources is not yet high enough to tell different world models apart from each other. What would be most needed is a big push to obtain redshifts of all the QSO candidates with known extended radio structure. Even a few hundred such measurements could reduce the error bars considerably. Until such time one should approach with caution the claims which are often made about particular forms linear size evolution with cosmic time (e.g., Subramanian & Swarup 1990).

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