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Extragalactic Sources with One-sided Radio Structure

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Abstract. A list has been compiled of 49 extragalactic sources, most of them identified with quasars, that appear to have a one-sided (D2 type) radio structure characterized by a single outer component displaced from a compact central (nuclear) component coincident with the optical object. The observed properties of a subsample of 28 D2 quasars that have an overall angular size larger than 5 arcsec are briefly discussed and compared with those of normal (D1 type) double quasars. It is found that the central components in most D2 sources account for more than half the total flux density at high frequencies in contrast to the D1 quasars which generally have less than 20 per cent of their total flux density in a central component. This makes it very unlikely that D2 sources are just those D1s in which there is a large intrinsic difference in the flux densities or separations of the two outer components. The observed properties of D2 sources are easier to understand in the relativistic beaming interpretation in which their axes are inclined at smaller angles with the line of sight compared to D1 sources.

Key words: quasars and radio galaxies—double radio sources—asymmetric structure—relativistic beaming

1. Introduction

A vast majority of powerful extragalactic radio sources either have a double structure with the two radio lobes more or less symmetrically placed on either side of the optical object or have only a compact structure ($\lesssim$ 1 arcsec) coincident with the optical object. Observations of double sources with high sensitivity often show up an additional weak and compact central component at the position of the optical identification. In recent years a number of radio sources have, however, been found to consist of a single radio lobe displaced from a compact central component. Such sources are now often referred to as D2 type doubles (after Miley 1971) in contrast to the classical doubles (with or without central components) being referred to as of

D1 type. Most D2 sources are identified with quasars; 3C 273, the first to have shown a one-sided radio structure (Hazard, Mackey and Shimmins 1963), is the standard example of this type. It is not clear if such sources result from one-sided ejections from galactic nuclei or whether they are double sources in which for some reason (intrinsic or extrinsic to the source) one of the outer components remains invisible to us. Three kinds of explanations in the latter category have been suggested.

(a) *Projection effects*. If the axis defined by the outer components does not pass through the nuclear component, then, for some directions of view the superposition of components can make a source appear to consist of only 2 components, one of them coincident with the optical object.

(b) *Intrinsic asymmetries.* Due to intrinsic asymmetry in the brightness or linear displacement of the two outer components, a source can appear to be of the D2 type if one component is either too weak to be detected by the observing instrument or too close to the nuclear component to be resolved by the instrument.

(c) *Relativistic beaming.* If the outer components are moving out at relativistic speeds, a large apparent asymmetry can arise in the observed flux densities provided the source axis makes a small angle with the line of sight.

The phenomena of apparent faster-than-light expansion (*e.g*. Cohen *et al.* 1977) and of the considerable bending of radio structure close to the nucleus (Readhead *et al*. 1978), observed by VLBI techniques in the cores of a few compact and D2 type sources have also been explained by the relativistic beaming of radio waves from narrow jets aimed close to our line of sight (Readhead *et al*. 1978; Scheuer and Readhead 1979; Cohen *et al*. 1979; Blandford and Königl 1979). Observations of a larger sample of D2 sources are clearly needed to test the beaming model and to understand the asymmetry in such sources. The purpose of this paper is to compile a list of radio sources that appear to belong to the D2 category. The list of 49 such sources found, most of them identified with quasars, is presented in Section 2. The fairly common occurrence of D2 structures implies that their explanation in terms of chance superposition of components in non-collinear double sources can be discarded because it predicts that most double sources should depart strongly from collinearity, contrary to observations.

Thirty three of the 49 sources have an overall angular size >5 arcsec and are probably free from serious selection effects. The observed properties of the 28 quasars in this sample are briefly discussed in Section 3 and compared with those of D1 quasars. The comparison leads us to rule out intrinsic asymmetries as a general explanation for the D2 phenomenon and to provide some support to the beaming hypothesis.

For brevity we shall henceforth refer to the central components as CCs and to the outer components as OCs.

2. List of D2 sources

Brightness distributions across hundreds of radio sources, determined with a variety of telescopes at several different observing frequencies have been reported in the literature. We have considered a radio source to be of the D2 type if it consists of one component coincident with an optical object and one or more secondary components located on one side of the optical identification. Since the observations span a wide range in sensitivity and angular resolution, any list of D2 sources compiled from the literature is unlikely to be homogeneous and free from various observational selection effects. In order to restrict the number of doubtful entries in the list and to be fairly objective in our selection we have adopted the following procedure.

(1) We have generally used only the observations made with aperture synthesis telescopes (mainly the Cambridge 5-km telescope, the Westerbork synthesis array, the NRAO 3-lement interferometer and the Very Large Array) or by the lunar occultation technique (mainly using the Ooty Radio Telescope). Most of the synthesis observations have been made at cm wavelengths (frequencies near 1·4, 2·7, 5 and 8 GHz) with angular resolutions ranging between about 1 and 20 arcsec. The lunar occultation observations at 327 MHz have similar angular resolutions.

(2) We have only considered the sources that are optically identified and for which the accurate optical positions (~l arcsec accuracy or better) are known. Apart from excluding ' empty field ' sources, the necessary requirement of an optical identification can discriminate against D2 sources that have very weak or no detected CCs. Such sources would show a genuine displacement between the true optical identification and the observed radio position and could therefore be wrongly considered as unidentified. This possibility has been discussed in Section 3.2 where we have argued that D2 sources in which the CCs contribute only a small fraction of the total flux density at high frequencies are likely to be quite rare.

(3) Although the spectral indices of most CCs in Dl sources and of the few well known D2 sources are known to be relatively flat (α<0·5, with the definition $S \propto \nu^{-\alpha}$), it is important not to introduce a bias in the sample with regard to spectral information. We have therefore considered a restricted sample of D2 sources that have an LAS (largest angular size; in the present case the separation between the CC and the OC)>5 arcsec. The criterion of agreement in the radio and optical positions (both generally known to an accuracy of ~1 arcsec or better) of the CCs alone has been used in this sample to make the D2 classification, regardless of any available spectral information. For sources with LAS<5 arcsec, positional coincidence alone may not be sufficient in most cases and we have therefore imposed a restriction that the suspected CC be known to have a flat spectral index (α<0·5). Only the restricted sample with LAS>5 arcsec has been used for the purpose of a statistical investigation of the properties of D_2 sources.

(4) We do not include the well known head-tail sources which are generally found in clusters of galaxies and have a one-sided radio structure.

The list of 33 sources with LAS>5 arcsec that satisfy the above criteria and the 16 sources with LAS<5 arcsec is presented in Table 1 which is arranged as follows:

Columns 1 *and* 2. The source name in coordinate designation and one alternate name or the catalogue in which the source appears.

Column 3. Optical identification;Q = QSO; G=galaxy; BSO=blue stellar object and RO = red object.

Columns 4 *and* 5. The redshift and a coded reference for it, or the approximate magnitude and reference to the optical identification if redshift is not known. The references are given at the foot of the Table.

Columns 6 *and* 7. The observed LAS and the corresponding linear size (calculated for q_0 =0·5, H_o =50 km s $^{-1}$ Mpc $^{-1}$).

Table 1. Radio sources with one-sided (D2 type) structure.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Source	Other name	Optical Identification			LAS (arcsec)	Lin size (kpc)	Ref to radio structure	Spect indices		f_c	Notes
		Type	z	Ref				α_c	α_e		
0003−003	3C 2	Q	1·037	1	6	51	PW, J80	0·7	0·9	0·63	*
0051+291	4C 29·01	Q	1·828	1	2·7	23	PW, RP	0·1	0·7	0·63	
0115+027	4C 02·04	Q	0·672	1	9	71	MH			0·58	
0241+622	4U	Q	0·044	1	3·8	5	TSMB	−0·2	0·7	0·92	*
0309+411	S4	G	m = 18	2	87		K79	−0·2			
0409+229	4C 22·08	Q	12·13	1	3·4	29	PW, SN				*
0615+578	4C 57·12	BSO	m = 18	3	6·6		OPN	1·1		(0·8)	*
0740+380	3C 186	Q	1·063	1	100	857	S80, RP, HC	1·0	0·8	0.9	*
0742+376	4C 37·19	BSO	m = 20	4	56		KLP			(0·34)	
0814+201	OTL	RO	m = 20	5	12		SG				*
0821+394	4C 39·23	Q	1·216	1	24	207	K80, PW, SN	0·1		0·85	
0836+195	4C 19·31	Q	1·691	1	18	152	JPR, MH			0·31	
0836+710	4C 71·07	Q	m = 16·5	6	1·5		PFJ	0·4	1·7		
0919+218	4C 21·25	Q	1·421	1	6	52	PW	0·6	1·0	0·41	
0932+022	4C 02·27	Q	0·659	1	38	298	MH, BHSS	0·5	0·9	0·51	
0945+408	4C 40·24	Q	1·252	1	4.1	35	PFJ	0·2	0·7	0·9	
1012+232	4C 23·24	Q	0·565	1	11·2	84	PW	−0·3	1·0	0·92	
1040+123	3C 245	Q	1·029	1	4·6	39	JPR, L72	0·6	0·9	0·72	*
1047+096	4C 09·37	Q	0·786	1	71	582	MH	0·9	1·1	0.81	
1055+201	4C 20·24	Q	1·110	1	23	198	MH	<0		0·42	*
1055+018	4C 01·28	Q	0·890	1	1·5	13	SGV	0·1			*
1132+303	4C 30·22	Q	0·614	1	7·8	60	PW	0·8	1·2	0·50	
1136−135	PKS	Q	0·554	1	9	67	MH			0·69	
1203+109	4C 10·34	Q	1·088	1	10	86	MH			0·94	
1222+216	4C 21·35	Q	0·435	1	10·1	68	PW	0·5	0·9	0·78	
1226+023	3C 273	Q	0·158	1	21	75	MH, PFJ	−0·3	0·8	0·93	
1320+29	B2	BSO	m = 20·5	7	52		F77, F79	0·3	0·9	(0·53)	*
1347+539	4C 53·28	BSO	m = 17	3	31·3		OPN	0·0		(>0·9)	

1350+316	3C 293	G	0·045	8	85	103	ARP	0·7	0·7	0·83	*
1354+195	4C 19·44	Q	0·720	1	15	120	MH			0·84	*
1415+463	4C 46·29	Q	1·552	1	12·7	108	OPN, K80	0·0		0·82	*
1419+31	B2	BSO	m = 20	7	128		F77, F79	−0·1	1·6	(0·77)	
1433+177	4C 17·59	Q	1·203	1	4·6	40	W79	0·2	0·9	0·47	
1509+158	4C 15·45	Q	0·828	1	8·2	68	W79	0·8	1·1	0·56	
1547+309	4C 30·29	G	0·111	9	11	30	CBV, KLP	1·0	1·1	0·68	
1636+473	4C 47·44	BSO	m = 18·5	6	18		K80	<0		(0·76)	*
1637+574	OS 562	Q	0·745	1	8·8	71	OPN	0·0		0·92	
1641+399	3C 345	Q	0·595	1	2·8	21	PJ, DSC	0·0	1·0	0·97	
1642+690	4C 69·21	Q	m = 19	3	4		PFJ	−0·7	1·3		
1729+501	4C 50·43	Q	1·111	1	20·8	179	OPN		0·9	0·09	
1741+279	4C 27·38	Q	0·372	1	4	25	PW	0·4	0·7	0·57	
1800+440	OU 401	Q	0·660	1	2·6	20	OPN, K80	−0·4			
1807+698	3C 371	G	0·050	8	3·3	4	PJ	−0·2	1·1	0·96	
1828+487	3C 380	Q	0·692	1	1·2	10	S77				*
1842+681	JB	BSO	m = 18	3	2·8		OPN	−0·4			
2037+511	3C 418	Q	1·686	1	1·6	14	PJ	0·2	1·2	0·94	
2041−149	OTL	RO	m = 20·5	10	28		SGV				*
2251+158	3C 454·3	Q	0.859	1	5·4	45	DSC	0.0	1.0	0·9	*
2251+134	4C 13·85	Q	0·673	1	6·6	52	W79	0·3	0·6	0·75	

References to redshift or optical identification:

1. Hewitt and Burbidge (1980)
2. Kapahi (1979)
3. Cohen *et al.* (1977)
4. Katgert-Merkelijn *et al.* (1980)
5. Subrahmanya and Gopal-Krishna (1979)
6. Kühr (Personal communication)
7. Fanti *et al.* (1975)
8. Sandage (1966)
9. Sargent (1973)
10. Singal *et al.* (1979)

Additional notes to Table 1.

0003—003 (*3C 2*): The one-sided structure of this source was first pointed out by Lyne (1972) from a lunar occultation at 408 MHz. A recent occultation observation at 327 MHz, (Joshi 1980) with the Ooty Radio Telescope has enabled the strip brightness distributions along and perpendicular to the source axis to be determined with a resolution of 0·6 arcsec. These show the outer component which accounts for ~ 30 per cent of the total flux density to have a narrow jet-like structure extending to ~ 6 arcsec from the CC in PA 196°. The CC itself consists of two compact components (< 1 arcsec) with a separation of~ l·2 arcsec along the source axis. The stronger of the two accounts for ~ 60 per cent of the total source flux density and lies at the extreme and opposite the jet. The location of the two with respect to the optical nucleus is, however, unclear. All the observed components appear to have normal spectral indices.

0241+622: This low redshift quasar is identified with the X-ray source 4U 0241 + 61 (Apparao *et al,* 1978).

0409+229: A model fit at 2·7 GHz (Potash and Wardle 1979) shows a single component of size 3·4 ± 0·7 arcsec. From the observed flux densities at 2·7 and 8·1 GHz and a position difference of ~ 1 arcsec at the two frequencies, Potash and Wardle conclude that the source is almost certainly a D2 double whose components have different spectral indices.

0615+578: The stronger component lies 1·7 arcsec from the optical position and has a steep spectral index (α= 1·1) between 2·7 and 8·1 GHz (Owen, Porcas and Neff 1978). There is therefore some doubt about its being the CC.

0740+380 (*3C 186*): Recent VLA observations at λ=6 cm (Schilizzi, Personal communication) show that the CC could itself be double with a separation of ~ 1·5 arcsec along the source axis. The OC which is ~ 100 arcsec away is therefore likely to be physically associated with the source. The total spectrum of the source is straight (α ~ 1) except for a kink around 20 MHz (Veron, Veron and Witzel 1974), which could arise from synchrotron self absorption in one of the two components near the quasar.

0814+201: Structure based on lunar occulation at 327 MHz (Subrahmanya and Gopal-Krishna 1979). The two components have roughly equal flux density. Spectra of individual components are not known; the total spectral index is ~ 0·4 between 327 MHz and 2·7 GHz.

1040+123 (*3C 245*): Lunar occulations at 408 and 240 MHz (Lyne 1972) indicate that the CC may consist of two components with a separation of ~ 1·5 arcsec. The outer of the two then has α= 1·2 and the inner α = 0·4 between 240 MHz and 2·7 GHz. The spectral indices given in columns 9 and 10 are from Lyne (1972) for the total flux density from the CC.

1055+201: The total spectrum is flat at high frequencies (Kuhr *et al*. 1979) implying that the CC must have α< 0 near 5 GHz.

1055+018: Structure based on lunar occultations at 327 MHz. The two components have a flux density ratio of about 2:1. The source is a radio variable even at metre wavelengths (McAdam 1976) and is known to have a flat spectrum from metre to cm wavelengths (Veron, Veron and Witzel 1974). The stronger component at 327 MHz is almost certainly the CC.

1320+29: There are two OCs on the same side of the CC.

1350+316 (*3C 293*): The central component has been resolved into a close double (separation ~1·5arcsec) at15GHz, in a PA quite different from that of the OC (Argue, Riley and Pooley 1978). All components have normal spectra.

1354+195: Structure based on limited angular resolution comparable to the LAS.

415+463: The model fit at 2·7 GHz (Owen, Porcas and Neff 1978) indicates that there could be two compact components separated by ~ 1·7 arcsec, close to the optical position.

1636+473: The total spectrum (Kühr *et al*. 1979) implies that the CC must have α< 0 near 5 GHz.

1828+487 (*3C 380*): A 15.GHz map in Scott (1977) shows two components separated by 1·2 arcsec in PA — 37°. As the total spectrum is known to be flat at such high frequencies the stronger component is likely to be the CC. There could be an additional extended component or halo at lower frequencies.

2041—149: Structure based on lunar occultations at 327 MHz. The two components have roughly equal flux density. While the CC is not resolved (< 2·5 arcsec) the OC could have a narrow jet like structure.

2251+158 (3C 454·3): The spectral indices given in the table are estimated from the figure in Davis Stannard and Conway (1977).

Column 8. Reference to best available measurements of the radio structure.

ARP	Argue, Riley and Pooley (1978)	MH	Miley and Hartsuijker (1978)
BHSS	Bentley *et al.* (1976)	OPN	Owen, Porcas and Neff (1978)
CBV	Conway, Burn and Vallee (1977)	PFJ	Perley, Foimalont and Johnston (1980)
DSC	Davis, Stannard and Conway (1977)	PJ	Perley and Johnston (1979)
F77	Fanti *et al.* (1977)	PW	Potash and Wardle (1979)
F79	Fanti *et al.* (1979)	RP	Riley and Pooley (1975)
HC	Hiigbom and Carlsson (1974)	S80	Schilizzi, R. T. (Personal Communication)
JPR	Jenkins, Pooley and Riley (1977)	S77	Scott (1977)
J80	Joshi (1980)	SGV	Singal, Gopal-Krishna and Venugopal (1979)
K79	Kapahi (1979)	SN	Stannard and Neal (1977)
K80	Kapahi (1980)	SG	Subrahmanya and Gopal-Krishna (1979)
KLP	Katgert-Merkelijn, Lari and Padrielli (1980)	TSMB	Tzanetakis *et al.* (1978)
L72	Lyne (1972)	W79	Wills (1979)

Columns 9 and 10. The approximate spectral indices, α_c and α_e of the central and outer components respectively, if available. For most of the sources these refer to the frequency range of either 2·7 to 8·1 GHz or 1·4 to 5 GHz.

Column 11. The fraction of the total source flux density contained in the CC referred to a constant frequency of 8 GHz in the frame of reference of the source. For sources with unknown redshift the value is given in parenthesis and refers to the observed frequency of 5 GHz and therefore corresponds to 8 GHz at the source for a redshift of 0·6.

Column 12. Indication of additional notes on some sources at the foot of the table.

While scanning the literature we came across several cases where better observations indicated that a particular source previously considered to be of the D2 type was actually not so. In most of them an additional component on the other side of the optical object had been missed in the earlier observations either because of its low flux density or low surface brightness. It is quite possible that such weaker components exist also for the sources listed in Table 1. The upper limits on the flux densities of such undetected components depend not only on the characteristics of the telescopes used in the observations but also on the size of such components. For unresolved components we estimate that only in 4 or 5 sources with LAS>5 arcsec could the ratio of the flux density of the observed OC to that of the missing OC be < 3. In several cases this ratio is likely to exceed 10.

3. Observed properties and comparison with D1 quasars

Of the 49 sources listed in Table 1 as many as 43 are identified with QSOs (33 confirmed QSOs and 10 BSOs of unknown redshift) and only 4 are identified with galaxies. The remaining two are faint red objects of unknown redshift. It thus appears that QSOs are much more likely to have one-sided radio structure than galaxies. It was pointed out by Riley and Jenkins (1977) that such a difference exists in the 3CR sample even when the comparison is restricted to QSOs and galaxies of comparable total luminosity. Although many more deep galaxy identifications and redshifts have recently become available (*e.g.* Smith and Spinrad 1980) no 3CR galaxy with redshift >0·1 appears to have a D2 structure. Since the D2 quasars generally have dominant CCs (see Section 3·3) the paucity of such structures among galaxies could be related to the fact that their CCs are usually found to be much weaker than those of quasars (Riley and Jenkins 1977; Miley 1980).

In view of the predominance of QSOs in the D2 sample we shall compare the observed properties of the 22 QSOs and 6 BSOs with LAS> 5 arcsec and listed in Table 1, with a sample of D1 type quasars (Kapahi and Saikia 1981). Although the D1 sample contains all QSOs with known redshift that have been reported in the literature (from aperture synthesis observations at high frequencies) we consider only the 93 sources with LAS> 10 arcsec, because the average minimum separation of an individual from the central object would then be the same in the two samples. Since most of the D1 and D2 sources have been found from the structural determinations of the same samples of QSOs, largely selected from low frequency surveys, there is no significant bias in the two samples with regard to flux density or the distribution of redshifts. It should also be noted that every double quasar in our sample has been classified either as D1 or as D2. As the number of ambiguous cases, mainly in the D2 sample (e.g. 0003—003 and 0615+578), is quite small, this is unlikely to affect the comparisons seriously.

3.1 *Spectral Indices*

The distributions of spectral indices, α_c and α_e, whenever available, for the central and outer components are shown in Fig. 1. While the OCs have a fairly narrow distribution peaked around α_e =0·9 as is well known for D1 sources, the CCs appear to have a much wider distribution extending from —0·4 to about +1. Spectral information regarding the total flux density, extending from about 178 MHz to 10 GHz is available in the literature for about half the sources in the sample. In all such cases for which α_c is flatter than 0·5 the total spectrum is flat or inverted at high frequencies ($\gtrsim$2·7 GHz) and shows a steep component at low frequencies. D2 sources have generally been associated exclusively with this spectral class (*e.g.* Stannard and Neal 1977: Davis, Stannard and Conway 1977).

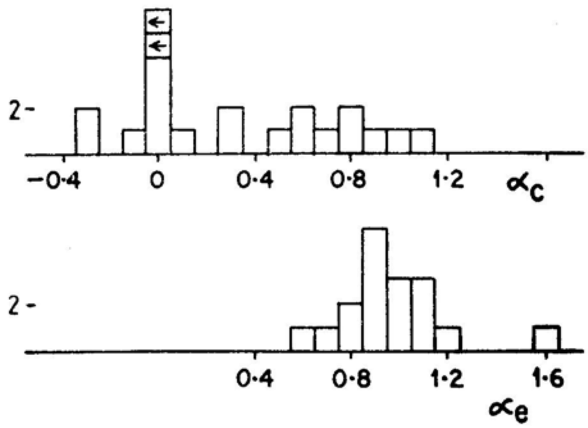

Figure 1. Distributions of spectral indices of the central (α_c) and outer (α_e) components of D2 quasars with LAS > 5 arcsec.

It is not clear how the D2 sources with α_c > 0·5 differ from the well known flat spectrum variety. Although the width of the α_c distribution is quite broad also for the CCs of D1 quasars (Kapahi and Saikia 1981), the fraction of D2 quasars with α_c > 0·5 (~38 per cent) is somewhat larger than the corresponding fraction for D1 quasars (~25 per cent). Values of α_c > 0·5 are unlikely to have been caused by flux variations because in the few cases where spectral information on total emission is available over a wide range of frequencies there is no evidence of any flattening of the spectra at high frequencies as is known to be the case for strongly variable sources. It is possible that the CCs of such sources have compact double structure or are synchrotron self absorbed at low frequencies. The core components of several double radio galaxies are known to have steep spectra and double structure on a scale of a few kpc (Bridle and Fomalont 1978). The CCs of two D2 quasars in our sample (*viz*. 3C 2 and 3C 186) do appear to have a double structure (on a scale of ~10 kpc; $\lesssim$ 1·5 arcsec) but the exact location of the components with respect to the optical nucleus is uncertain. Another possibility is that such CCs consist of both flat and steep spectrum components, *e.g.* core and jet, or core and other OC close together, since in most cases it is found that $\alpha_c < \alpha_e$. As the D2 classification in the latter case would be incorrect we shall keep this possibility in mind in the subsequent discussion.

3.2 *Luminosities of Central and Outer Components*

The distributions of the calculated luminosities at 5 GHz of the CCs and OCs in D1 and D2 sources are shown in Figs 2 and 3 respectively. It is seen that the CCs in D2 quasars tend to be more powerful than those in D1 quasars while the luminosities of

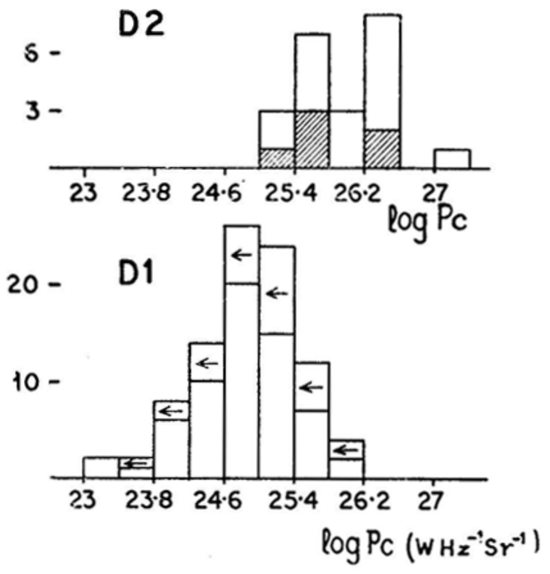

Figure 2. Histograms of the 5 GHz luminosity of the central components of D1 and D2 quasars Upper limits to the luminosities in D1 quasars without detected CCs are indicated by arrows. In this and subsequent figures the shaded portion refers to D2 quasars in which the CCs have a spectral index $\alpha_c > 0·5$.

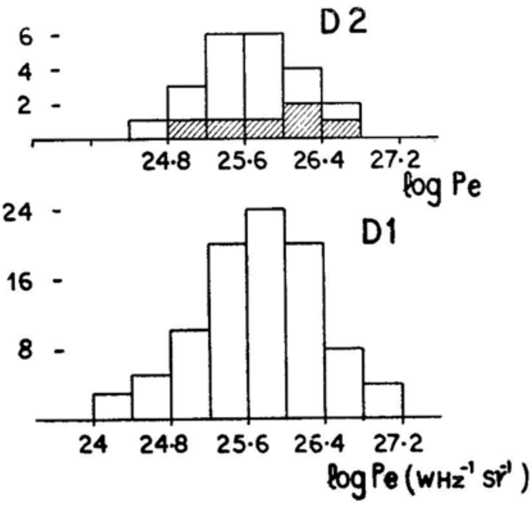

Figure 3. Histograms of the 5 GHz luminosities of the outer components of D1 and D2 quasars.

the OCs do not appear to be significantly different. The difference in the CC luminosities is unlikely to be a result of observational selection effects as quasars of both types have been selected basically from the same flux density limited samples, mostly at low frequencies where the CCs in most sources are unlikely to make a significant contribution to the total flux density.

3.3 *Fractional Flux Density in Central Components*

Because most of the D2 quasars appears to have very prominent CCs, we have calculated the fractional flux density in CCs, f_c ,at a standard frequency of 8 GHz in the rest frame of each source. This choice of frequency should minimize errors due to unknown spectral indices in many cases as the best measurements of flux density are generally available at 2·7 and 5 GHz. We have used the values of α_c and α_e if known. Where these are unknown we have assumed α_c=0·2 and α_e =0·9 which are the median observed values. The resulting distribution of f_c is shown in Fig. 4 together with the corresponding distribution for D1 quasars.

It is clear from Fig. 4 that the f_c distributions for the two types are markedly different. While most of the D1s have f_c <20 per cent, most of the D2s have f_c>50 per cent. It is important to know to what extent the difference can arise from observational selection effects. Two such effects may be important. First, a D2 quasar with very weak or no detectable CC could remain optically unidentified and therefore not be recognized as belonging to this class. Second, due to the larger positional errors for weak CCs a D2 quasar may be misclassified as D1. In order to investigate the former effect we have considered two complete samples of sources from the 4C and 3CR catalogues that appear to be the most suitable for this purpose.

For a sample with S(178 MHz) > 2·5 Jy selected from the 4C catalogue, optical identifications with 69 suspected QSOs were proposed by Olsen (1970), on the basis of positional coincidences. As the radio position errors in this study were of the

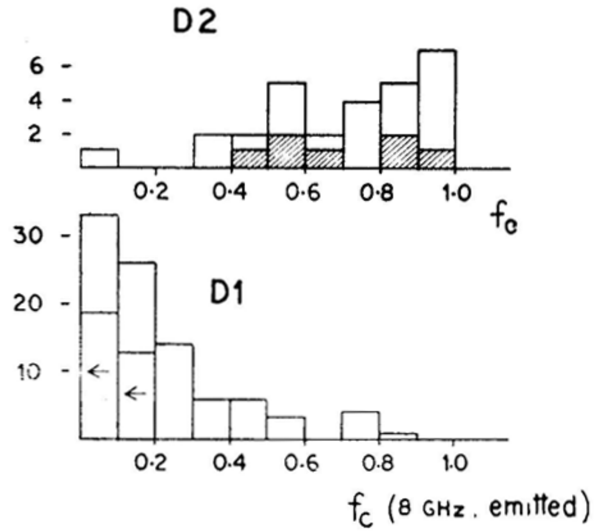

Figure 4. Distributions of the parameter f_c (fractional flux density in the central component) in D1 and D2 quasars. D1 quasars without detected CCs are indicated by upper limits and have been equally distributed in the first two bins.

order of 20 arcsec and the search area was at least ±30 arcsec around the radio position most of the possible D2 quasars would have been considered identified. Spectroscopic observations of the candidates (Schmidt 1974) have confirmed 48 QSO identifications. Of the remaining 21, 17 are stars, 2 have a continuous spectrum and 2 have inconclusive spectra. Brightness distributions (determined with the NRAO 3-element interferometer by Potash and Wardle, 1979) for 46 of the confirmed QSOs for which redshifts are available indicate that 25 are of the D1 type, 6 of the D2 type (included in Table 1) and 15 are classified as single, most of them being unresolved. Nine of the single sources have a spectral index steeper than 0·5 (between 2·7 and 8·1 GHz) but in no case is there any significant difference between the radio and the optical positions (most of which have rms errors of the order of 0·5 arcsec) implying that they cannot be D2 quasars without CCs.

The 3CR complete sample of 166 radio sources (Jenkins, Pooley and Riley 1977) has the best available information both on radio structures as well as on optical identifications. If an unknown D2 quasar without a CC exists in this sample it has to be one of the as yet unidentified sources. After the recent work on optical identifications reaching faint optical magnitudes (Riley, Longair and Gunn 1980, and references therein) there are only 18 sources in the sample that either still remain unidentified or for which the proposed identifications need further confirmation. Sixteen of these sources, however, appear to be classical doubles (LAS>7 arcsec) with nearly equal flux densities in the two components. The remaining 2 sources (3C 241 and 3C 454· 1) are smaller than 2 arcsec and no possible QSO is known to lie within ~ 1 arcmin of the radio positions.

The selection effect associated with larger positional errors of weak CCs is also unlikely to be important because a D2 source with $f_c \leqslant 0{\cdot}2$ would then appear as a D1 with a flux density ratio $\geqslant 4$. In the sample of D1 quasars there are only 6 such sources and in none of them is the D1 classification in doubt because of position errors.

We conclude from the above arguments that selection effects in the data are very unlikely to be responsible for the different distributions of f_c among D1 and D2 quasars.

3.4 *Projected Linear Sizes*

The distribution of projected linear sizes for the twenty two D2 quasars of LAS>5 arcsec with known redshift is shown in Fig. 5 together with the distribution for Dl quasars of LAS> 10 arcsec. Note that in order to compare the distributions directly we have reduced the sizes of Dl quasars by a factor of 2 so that they represent the average projected separation of an individual OC from the optical object. The median sizes for the Dl and D2 samples are about 125 kpc and 75 kpc respectively (if the 6 quasars with α_c > 0·5 are excluded the median size for the D2 sample rises to about 85 kpc), but the formal statistical significance of the difference is only marginal. There is a suggestion in Fig. 5, however, that the shapes of the two distributions could be different. Since many quasars with sizes < 50 kpc would have angular sizes <5 arcsec, which is the limiting value for the two samples it is seen from Fig. 5 that the peak of the distribution for the D2 sample could be lower than 50 kpc unlike that for the Dl sample. Such a possibility is indicated also by the distributions of the observed angular sizes shown in Fig. 6 and is further supported by extending the histograms to sizes upto 2·5 arcsec (note that only D2 quasars with known redshift and α_c< 0 ·5 are included in the LAS range of 2·5 to 5 arcsec). Although Fig. 6 suggests that the typical projected sizes of D2 quasars could be more than 2 times smaller than the corresponding sizes of Dl quasars, the non-homogeneous nature of the samples and the uncertainty in the D2 classification of some sources, particularly those with α_c> 0·5, makes it difficult to assess the significance of the two distributions.

If the comparison of linear sizes is confined to the largest available complete and homogeneous sample of 52 QSOs from the 4C catalogue whose structure has been determined by Potash and Wardle (1979), there are eight D2 quasars of LAS > 2·5 arcsec with a median size of about 55 kpc and 25 D1 quasars of LAS > 5 arcsec with a median size (corresponding to half the LAS) of about 115 kpc.

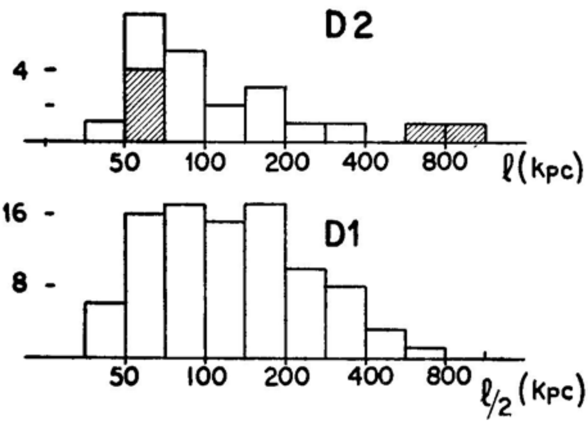

Figure 5. Distributions of projected linear sizes for D1 and D2 quasars.

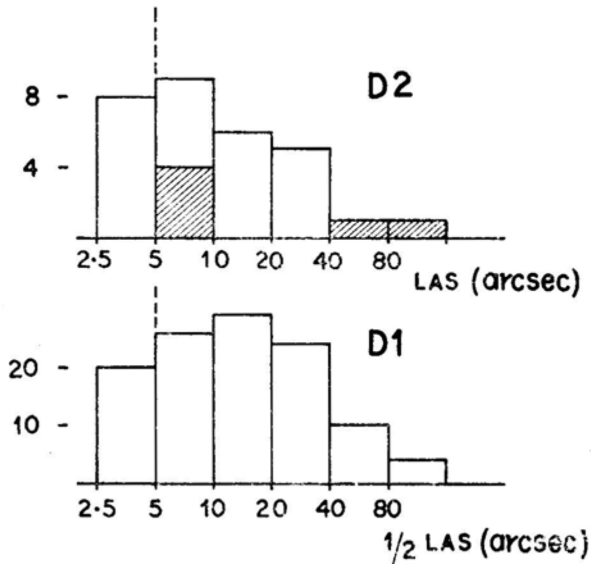

Figure 6. Distributions of the observed angular sizes for D1 and D2 quasars.

4. Discussion

If the D2 sources are essentially those Dl sources in which the two OCs have large intrinsic ratios of flux density, R_s, or of angular separations from the CC, R_θ, and if the relative strengths of the central and outer components are assumed to be independent of the orientation of the source axis, it is hard to understand the difference in the distributions of f_c shown in Fig. 4, unless there is a strong intrinsic correlation between the luminosity of the CC and the asymmetry in the OCs. No such correlation is however observed in the sample of Dl quasars (Kapahi and Saikia 1981). As most of the CCs in our sample of D2 quasars have luminosities P_{cc}(5 GHz) > 2 X 10^{25} W $Hz^{-1}sr^{-1}$ it is seen from Fig. 2 that less than 20 per cent of the Dl quasars have CCs as bright as this. Furthermore, as only about 15 per cent of the Dl quasars are observed to have a flux ratio R_s > 3, at the most only 3 out of a sample of 100 Dl quasars could be expected to be classified in the D2 category.

A similar argument applies also to the displacement ratio R_θ, since less than 10 per cent of the Dl quasars have R_θ > 2, whereas most of the D2 quasars in our sample (LAS>5 arcsec) must be of this type if the OCs are of comparable flux den sity. It therefore seems very unlikely that the D2 sources represent just the extreme end of a continuous distribution of intrinsic flux density or displacement ratios.

In the relativistic beaming model the apparent strengths of the central and the outer components depend on source orientation due to the strong Doppler enhancement of the flux density of the approaching components for smaller angles of orientation of the source ejection axis. The larger observed values of f_c and of luminosities of the CCs of D2 quasars as compared to those for Dl quasars can both be understood in this model if the bulk velocities of the radiating material near the nuclei are considerably higher than those of the outer components. While velocities $\gtrsim$ 0·9c have been proposed in the jets close to the nuclear source (*e.g.* Scheuer and

Readhead 1979, Blandford and Königl 1979) those in the OCs of double sources have generally inferred, from the observed distributions of the separation ratio R_θ to be $\lesssim$ 0·25c for most sources (Longair and Riley 1979; Katgert-Merkelijn, Lari and Padrielli 1980; Banhatti 1980; and Swarup and Banhatti 1980).

In beam models, if the oppositely directed jets are identical, the apparent flux density ratio is given by

$$R_s = \left\{\frac{1+(v/c)\cos\phi}{1-(v/c)\cos\phi}\right\}^{2+\alpha}$$

where v is the velocity of recession of the OCs, ϕ the orientation angle and α the spectral index. We shall ignore the fact that the two components are seen at slightly different ages due to the difference in light travel times. For velocities of 0·25c, and assuming α=0·9, values of R_s of only about 4 can be obtained for ϕ < 30°. Since many D2 sources are likely to have larger flux density ratios, somewhat larger values of u appear to be required. For v =0·4 for example, R_s can attain values of about 5 to 12 for ϕ < 45°. Furthermore, because of the strong apparent enhancement of the total flux density of a source with decreasing ϕ due to the Doppler boosting in the approaching as compared to the case for ϕ =90°, an increasing number of D2 sources with small values of ϕ can appear in a flux limited sample from the larger population of intrinsically less luminous or more distant sources. The OCs of only a small fraction of all double sources may therefore be required to have v >0·25c in order to explain the D2 phenomenon. The flux density enhancement could also explain the observed distribution of projected linear sizes of D2 quasars which appears to be more concentrated towards smaller sizes as compared to the case for D1 quasars.

5. Conclusion

A search through the literature has resulted in a list of 49 sources that appear, from the existing observations, to have one-sided (D2 type) radio structure. Most of the sources are associated with quasars. The central components, coincident with the optical objects, in several cases appear to have steep spectral indices, α_c>0·5. Better angular resolutions are needed to decide if these could be normal doubles with a large spatial asymmetry.

A comparison of the observed properties of D1 and D2 quasars indicates that unlike the D1 class, the D2 quasars are characterized by strong central components that account for most of their total flux density at high frequencies. This difference in the properties of the 2 types is very unlikely to have been caused by observational selection effects or by the uncertainty in the D2 classification of some sources and appears to rule out the possibility that most D2 sources are a subset of D1 sources with large intrinsic flux density ratios or separation ratios of the two outer components.

The higher relative strengths of the central components observed for the D2 quasars appear, at least qualitatively, to be consistent with the relativistic beaming interpretation in which the axes of such sources are supposed to make small angles with our lines of sight. Although the projected linear sizes of D2 quasars do appear to be generally smaller than those of D1 quasars, suggestive of smaller orientation angles, the evidence cannot at present be considered conclusive because of the heterogeneous nature of the quasar samples and the uncertainty in the D2 classification of several sources, particularly those that have central components of steep spectral indices or for which insufficient spectral information is available.

Observations with higher angular resolution and sensitivity would be quite valuable in understanding the nature of the asymmetry in D2 sources.

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Note added in proof

Recent observations at 6 cm and 2 cm λ of the sources in Table 1 with LAS > 15 arcsec, made with Very Large Array (G. Swarup, personal communication) indicate that three of them (*viz*. 0932+022, 1047+096 and 1354+195) have a triple structure with an additional weak OC on the opposite side of the CC.