THE ASTRONOMICAL JOURNAL VOLUME 83, NUMBER 11 NOVEMBER 1978

STRUCTURES OF 18 RADIO SOURCES WITH PECULIAR OPTICAL FEATURES

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Received 27 June 1978; revised 28 August 1978

ABSTRACT

Radio positions, angular structure data, and polarizations were measured with the NRAO interferometer at 3.71 and 11.1 cm for 18 sources whose optical identifications seem to have jets, wisps, or close companions. Optical positions were measured with the University of Texas measuring machine. In five cases, alignment within 10° in position angle of the optical and the radio major axes was found. The quasar PHL 1093 (0137+012) may be similar to 3C273. There is a compact, flat-spectrum source at the quasar position and an extended, steep-spectrum component at the end of the optical jet.

I. INTRODUCTION

There are at present a few known cases of a quasar or galaxy with a jet detectable in both the optical and radio regions. About ten additional cases are known to have only radio jets (Van Breugel and Miley 1977). Such jets are widely believed to be related to the presence of the double radio sources that accompany the objects. They have been interpreted in terms of the beam model (e.g., Blandford and Rees 1974) and the gravitational slingshot model (Saslaw, Valtonen, and Aarseth 1974). Either model needs to explain why a jet is invisible in many cases, for example, Cygnus A. Gathering a larger sample of objects showing possible jets may help to find which properties of radio galaxies lead to the formation of jets.

Some evidence for optical objects associated with radio lobes has been found by Saslaw, Tyson, and Crane (1978) and by Simkin (1978). Although these optical objects are very faint ($m \gtrsim 23$), it is possible that a few such objects are bright enough to appear on the Palomar Observatory Sky Survey (PSS) plates but have been hitherto overlooked. Therefore, I have also included objects with close optical companions in the observations.

In the course of studying large numbers of optical photographs of radio source identifications one notices that occasionally an optical identification has a wisp, jet, or close companion. A group of 18 such objects was gathered from several lists of identifications. The lists used were those by Schilizzi (1975), Wills (1976), Cohen *et al.* (1977), Callahan (1977), and Ghigo (1977). No attempt was made to insure that all cases of jets, wisps, or close companions occurring in these lists were included. Nor did the authors of these lists insure that all such phenomena were reported. Thus the group of objects studied here is not statistically complete.

The radio observations described in Sec. II were made with the National Radio Astronomy Observatory (NRAO) interferometer. Since only a few baselines were used, the aperture synthesis is incomplete. Thus the radio observations were sensitive only to relatively compact regions. Extended regions (>25″ at 11 cm or >8″ at 3.7 cm), if present, would have been missed.

Optical positions were taken from the literature where available. Most were also measured with the University of Texas measuring machine on PSS plates.

Results and comments about each source are in Sec. III. In Sec. IV, we discuss the significance of the similarities of radio and optical morphology that were found.

II. OBSERVATIONS AND RESULTS

The sources were observed in April 1977 at 2695 MHz and 8085 MHz with the NRAO interferometer using baselines of 900 m, 1800 m, 2700 m, and 35 km. The interferometer has been described by Hogg *et al.* (1969) and its receivers by Coe (1973). The use of the 35-km baseline has been described by Wade and Johnston (1977) and by Fomalont and Sramek (1975). The number of 15-min scans made on each source ranged from 4 to 49. The scans were spaced fairly evenly over the available hour angle range. The position and flux density calibrators are listed in Table I.

A map of each source was made by doing a Fourier transform of the visibility data using standard programs available at NRAO. From the maps, initial estimates of position, angular size, and flux density were made. From these estimates a least-squares fit of one or more elliptical Gaussian components was made to the visibility data. The component positions, flux densities, and half-power diameters are given in Table II. Table II also gives optical identifications, many of which are based on positions measured on the PSS plates with the University of Texas plate measuring machine by E. Pumphrey (private communication).

The errors quoted in Table II for positions and flux densities are the quadratic sums of the errors found by the least-squares fit (a measure of system noise) and the

TABLE I. Position and flux density calibrators.

Name	RA(1950.0)	Dec. (1950.0)	Flux density (2695 MHz) (Jy)	Flux density (8085 MHz) (Jy)
PKS 0106+01	$01^h06^m04\overset{s}{.}518$	$01° 19'00\overset{''}{.}47$		
3C48	01 34 49.827	32 54 20.63	9.0	3.3
CTA 21	03 16 09.145	16 17 40.70		
NRAO140	03 33 22.405	32 08 36.73		
OJ+287	08 51 57.249	20 17 58.57		
DA267	09 23 55.319	39 15 23.65		
PKS 1116+12	11 16 20.760	12 51 06.70		
3C287	13 28 15.940	25 24 37.25	4.6	2.2
3C286	13 28 49.653	30 45 58.79	10.2	5.2
OQ+208	14 04 45.615	28 41 29.35		
DA406	16 11 47.916	34 20 19.89		
3C345	16 41 17.608	39 54 10.88		
3C395	19 01 02.311	31 55 14.00		
CTA102	22 30 07.804	11 28 22.97		

calibration errors, which are $0\overset{''}{.}15$ in position and 1.5% and 4.5% in flux density at 2695 and 8085 MHz, respectively. Errors given for angular sizes and position angles are simply the uncertainties in the least-squares fits.

The phases of the 35-km baseline data were too unstable to provide any useful position information. However, these data were useable for estimates of angular sizes at 11 cm for 0137+012, 1215+643, and 1625+213.

Polarizations were measured and calibrated as described by Conway and Kronberg (1969). The polarization calibrators are listed in Table III. Calibration errors of 7% and 10% at 2695 and 8085 MHz, respectively, were added in quadrature to the noise-based errors in the Stokes parameters. All sources with polarized flux in excess of twice the combined errors are listed in Table IV, which gives the degree of polarization (M) and the position angle (chi). There seems to be no correlation between the polarization properties and the occurrence of radio-optical alignment.

In Fig. 1 we present maps for five sources with more than one component in which alignment of radio and optical structures may be present. The side lobes in the maps have been removed by the CLEAN algorithm (Högbom 1974). Figures 2 and 3 are diagrams of 0033+079 and 1538+082 in which radio-optical alignment may also be present. Figure 4 shows the optical fields of four of the most interesting objects.

Explanation of Table II

Column 1. Source name. Alternate names are given in Sec. III.

Column 2. Number of 15-min scans made on this source. The noise level reached in one 15-min scan is about 8 mJy at 2695 MHz and about 10 mJy at 8085 MHz.

Columns 3 and 4. Right ascension and declination, epoch 1950.0, with errors. For each component, the position given is the mean of the 2695 and 8085 MHz best-fit positions, weighted by signal to noise. Centroid positions, indicated by "C" in column 5, are the means of the 2695 MHz component positions, weighted by 2695 MHz flux density.

Column 5. Component number. "C" means the centroid position. "12C" means the centroid of components 1 and 2. When one component at 2695 MHz is seen as two at 8085 MHz, the two 8085 MHz components are designated "1A" and "1B."

Column 6. If several objects are in the optical field they are indicated as A, B, C, etc., corresponding to the same designation in the figures and the notes.

Column 7. Approximate magnitude from the PSS prints and type of object: G = galaxy, Q = quasar, ST = star, NSO = neutral-color stellar object, RO = reddish object, ? = faint object.

Columns 8 and 9. Optical minus radio position (α, δ) in arcseconds. The offset is with respect to the radio positions given in the same line of the table.

Column 10. The reference to the optical position is given at the end of the table.

Column 11. Component flux density in mJy ($=10^{-29}$ W m^{-2} Hz^{-1}) at 2695 MHz, with error.

Column 12. 2695-MHz component size. If this is a single component, this is the Gaussian half width along the major axis of the best fit, in arcseconds. If the component is also resolved along its minor axis, both major and minor axis lengths are quoted, e.g., $10'' \times 4''$. If a centroid is indicated in column 5, this is the distance between the centers of the two components. Upper limits represent 2σ.

Column 13. Position angle (measured from north through east) of the 2695-MHz component.

Columns 14–16. 8085-MHz component flux density, size, and position angle.

III. NOTES ON INDIVIDUAL OBJECTS

0033+079 (4C+08.04, OB+056). The quasar has a redshift $z = 1.578$ (Wills and Wills 1976). The associated faint wisp, visible on the finding chart of Wills

TABLE II. Observed radio source parameters.

SOURCE (1)	N (2)	RA(1950.0) (3)	DEC(1950.0) (4)	COMP (5)	IDENT. (6)	(7)	(8)	(9)	REF (10)	S(2695) (11)	θ(2695) (12)	PA(2695) (13)	S(8085) (14)	θ(8085) (15)	PA(8085) (16)
0033+079	23	$00^h 33^m 40^s.97(0^s.02)$	$07^\circ 58' 32''.9(0''.3)$	1		$18^m.5$ Q	$-0''.4$	$+1''.0$	1	179(7)	$3''.0(0''.3)$	$72^\circ(21^\circ)$	68(11)	$2''.8(0''.5)$	$88^\circ(16^\circ)$
0051+336	20	00 51 38.11(0.02)	33 37 23.6(0.3)	1	A	16. ST	+2.1	-2.9	4	75(5)	3.4(1.0)	5(25)	21(6)	<6	
		37.82(0.04)	17.4(0.5)	2						34(8)	4.5(1.3)	62(54)			
		39.12(0.02)	19.7(0.5)	3	B	19. G	+0.2	-1.0	4	39(5)	4.7(1.9)	168(20)	25(6)	<6	
0103+062	30	01 03 19.95(0.02)	06 12 07.0(0.3)	1		17.NSO	+6.3	+8.1	1	113(6)	<3		27(4)	<3	
		22.90(0.03)	19.9(0.6)	2						30(3)	<20				
		20.56(0.02)	09.7(0.3)	C							45.9(0.4)	74(1)			
0137+012 (PHL1093)	49	01 37 22.87(0.02)	01 16 35.2(0.3)	1		17. Q	-0.8	+0.4	4	279(12)	≤ 0.3 *		253(16)	<4	
		23.18(0.02)	45.9(0.3)	2						430(15)	5.9(0.5)	97(10)	100(17)	6.2(1.0)	133(5)
		23.05(0.02)	42.0(0.3)	C							11.3(0.4)	26(2)			
0805+270	24	08 05 01.60(0.03)	27 01 35.4(0.6)	1						78(9)	10 X 4	0(7)			
		02.17(0.04)	17.1(0.8)	2						44(7)	5.7(1.4)	31(21)			
		01.80(0.02)	28.8(0.5)	C		18.5 G	-1.5	+1.0	4		19.8(0.9)	157(2)			
0805+269	24	08 05 34.28(0.02)	26 55 24.3(0.3)	1		19.5 G	+1.1	+1.5	4	168(11)					
0817+307	20	08 17 25.69(0.06)	30 44 14.7(1.0)	1	B	19. G	-1.4	+3.4	1	37(7)	10 X 4	156(19)			
		26.30(0.16)	21.5(1.1)	2						28(10)	11.3(3.6)	67(14)			
		25.95(0.08)	17.6(0.7)	12C	A	19. G	-0.8	+1.1	1		10.4(1.9)	49(10)			
		26.86(0.11)	51.1(0.6)	3	C	18. G	-10.6	-5.4	1	103(14)	20 X 8	96(8)			
0824+294 (3C200)	11	08 24 21.22(0.02)	29 28 46.6(0.3)	1						517(22)	6 X 3	9(7)	69(15)	1.8(0.7)	13(34)
		21.37(0.02)	40.4(0.3)	2		20. G	+0.5	-0.2	1				45(10)	<8	
		21.63(0.02)	33.3(0.3)	3						573(29)	13 X 4	160(3)	119(35)	11.4(3.7)	160(5)
1028+526	5	10 28 36.44(0.02)	52 41 01.1(0.3)	1		17. G	+0.8	-0.3	2	65(27)	<16		76(11)	<2	
1031+114	17	10 31 26.34(0.02)	11 28 01.9(0.3)	1						523(20)	5.3(0.4)	79(10)			
		26.27(0.02)	01.3(0.2)	1A									42(5)	2.3(0.7)	105(15)
		26.52(0.03)	03.2(0.4)	1B									34(8)	<5	
		10 31 13.55(0.05)	11 28 28.8(1.1)	2		16. G	+14.3	-32.2	4	86(17)	10 X 3	176(13)	20(7)	4.2(1.8)	93(19)
1131+213	7	11 31 20.21(0.02)	21 22 11.7(0.4)	1		16. G	-0.8	+0.8	4	368(28)	9 X 2	164(8)			
		20.18(0.02)	13.5(0.3)	1A									91(11)	2 X 1	143(17)
		20.27(0.02)	06.6(0.3)	1B									62(13)	2.4(0.7)	34(46)
1151+295	14	11 51 37.86(0.02)	29 32 55.3(0.3)	1						556(19)	9 X 3	147(3)	94(11)	1.8(0.6)	163(34)
		38.33(0.02)	40.7(0.3)	2	C	20.RO	+2.8	+0.3	1	311(20)	9 X 2	140(4)	79(14)	2 X 2	
		38.05(0.02)	49.8(0.3)	C	A	19. G	+0.6	+1.2	1		15.2(0.3)	157(1)			
1215+643	10	12 15 17.76(0.03)	64 23 48.6(0.2)	1		17. Q	-4.5	-2.4	2	384(25)	0.9(0.3)*	131(8)	144(20)	<2	
1405+258	4	14 05 59.48(0.05)	25 48 08.8(0.4)	1		18. G	+1.1	0.0	1	374(39)	10 X 4	101(12)	71(29)	4.9(2.8)	128(12)
1414+110 (3C296)	4	14 14 26.34(0.02)	11 02 18.9(0.3)	1		12.5 G	+1.0	-1.1	3	38(11)	<15		62(13)	<6	
1529+357 (3C320)	20	15 29 29.08(0.02)	35 43 47.0(0.2)	1						447(15)	4 X 3	79(18)	111(12)	2 X 2	
		30.26(0.02)	49.7(0.2)	2						466(13)	3 X 2	55(16)	146(12)	3 X 2	147(50)
		29.68(0.02)	48.4(0.2)	C		18. G	-0.3	+0.4	4		14.4(0.1)	80(1)			
1538+082	7	15 38 03.15(0.02)	08 14 43.2(0.3)	1		16. G	+5.8	-0.6	4	362(41)	8.7(1.5)	88(12)	89(12)	1.9(0.8)	94(34)
1625+213	6	16 25 22.39(0.02)	21 19 01.4(0.2)	1		20. ?	-2.6	-0.6	4	480(13)	≤ 0.4 *		106(12)	1.1(0.6)	15(47)
1658+148	20	16 58 22.74(0.02)	14 52 45.4(0.2)	1						462(17)	3.7(0.7)	172(9)	144(9)	3.1(0.5)	155(6)
		22.13(0.02)	53 25.4(0.3)	2						264(17)	7.9(1.2)	169(6)	69(13)	3.6(0.8)	8(8)
		22.53(0.02)	52 59.8(0.2)	C	A	18.5 G	-5.2	+7.9	1		40.7(0.3)	168(1)			
					B	20. ?	-2.3	+0.1	1						

*Angular size estimated from 35-km baseline data.

References to optical positions

	Reference	Accuracy
1	Ghigo (1977)	0".6
2	Cohen *et al.* (1977)	0".5
3	Callahan (1977)	1".3
4	Bozyan and Pumphrey (private communication)	0".6

TABLE III. Polarization calibrators.

Name	2695 MHz M (%)	2695 MHz chi (deg)	8085 MHz M (%)	8085 MHz chi (deg)
3C48	1.7	71	5.2	−67
3C147	0.01	0	1.0	−16
3C286	9.9	34	11.0	33
3C287	4.0	−67	4.1	−9

(1976), extends about 8″ from the center of the quasar image. (See Figs. 2 and 4.) It starts at a position angle (PA) of about 70° and curls to the north past 5″ from the center. The NRAO data at both frequencies show that the radio source is extended about 3″ in PA ≈80°. The radio PA is close to that of the nearer part of the wisp. The 1″ position difference between the radio and optical positions is probably due to optical measurement errors.

0051+336 (OB+387,B2,GC1). Optical positions and finding charts were published by Condon, Balonek, and Jauncey (1975), and by Fanti and Padrielli (1977), the latter of whom determined radio structure in agreement with the present NRAO data. Condon, Balonek, and Jauncey noted "jet-like protrusion following," but this seems to be a separate object of 19–20 mag. The placement of radio components 1 and 3, with separation of 13″ at PA = 106°, is quite similar to that of objects A and B (11″ at PA = 101°), but the 16-mag object (A) has a stellar spectrum (D. Wills, private communication), thus is not related to the radio source. Component 3 is within 0.″8 of object B, so it is quite likely to be the correct identification for this component, and perhaps for all the components, although components 1 and 2 could be an independent double source.

0103+062 (4C+06.06, OC+006, PKS). The optical position and finding chart were published by Ghigo (1977). On the red PSS plate, diffuse emission (PA ≈ 35°) extends about 10″ NW from the 17-m stellar object. (See Figs. 1 and 4.) On the blue plate, the emission extends 20″ in PA ≈50°. The object could be a galaxy with an off-center, compact nucleus. In any case, the optical major axis is not in line with the radio double at PA = 74°. Nevertheless, it may be significant that the optical major axis points directly to radio component 1. The stellar object is somewhat displaced from the line joining the radio components, suggesting that this might be a wide-angle head–tail source.

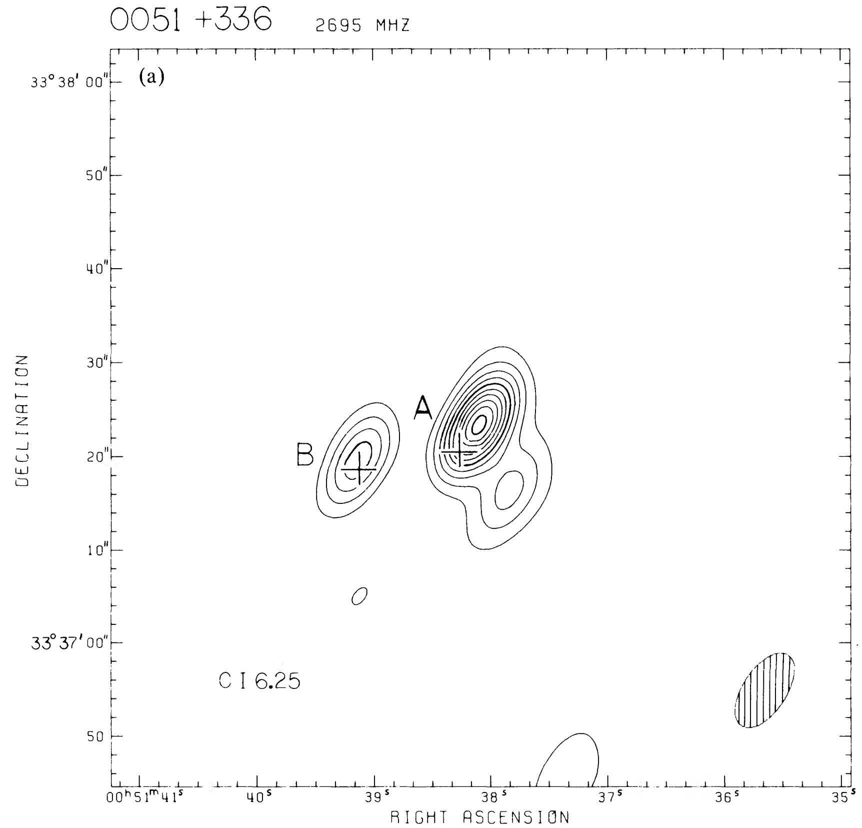
0137+012 (4C+01.04, PHL1093, OC+062). The identification and finding charts are given in Scheuer and Wills (1966), Bolton and Wall (1970), and Radivich and Kraus (1971). An optical position is given by Barbieri *et al.* (1972). Macdonald and Miley (1971) found this to be an 11″ double at PA = 26° (20°) at 2695 MHz, with which the present data are in agreement. The quasar (z = 0.262, Baldwin 1975) is identified with component 1. McEwan, Browne, and Crowther (1975) note that this object has a "possible jet on both prints in PA about 30°." I find that on the red plate, it is about 10″ long, comparable to the radio component separation. (See Figs. 1 and 4.) On the blue plate, the jet is about twice as long and at a PA of about 45°. This source was observed at NRAO in April and December 1977 with the 900–1800–2700-m configuration and in April 1978 with the 600–1200–1800-m configuration. Component 1 is ≲0.″3 and has a flat spectrum. At the end of the jet is component 2, which has a steep spectrum and is extended about 6″. The existence of a compact source centered on the quasar and an extended, steep-spectrum source near the end of an optical jet suggests that this source may be similar to 3C273. (See the map of 3C273 by Conway and Stannard 1975.) Recent Westerbork observations (Miley and Hartsuijker 1978) suggest that there might be a weak component to the west.

0805+270 (OJ+209, B2). The tentative identification with a 19-mag stellar object 16″ north having a wisp extending towards the radio source was based on the Ghigo and Owen (1973) position, which the present NRAO data show to be a lobeshift. Thus the tentative identification was incorrect. The correct identification, a 19-mag probable galaxy, does not have any obvious optical peculiarities and lies close to the 2695-MHz centroid of the radio emission. Zwicky cluster 0805.1+2658 (type VD, medium compact) is 3.′6 SE.

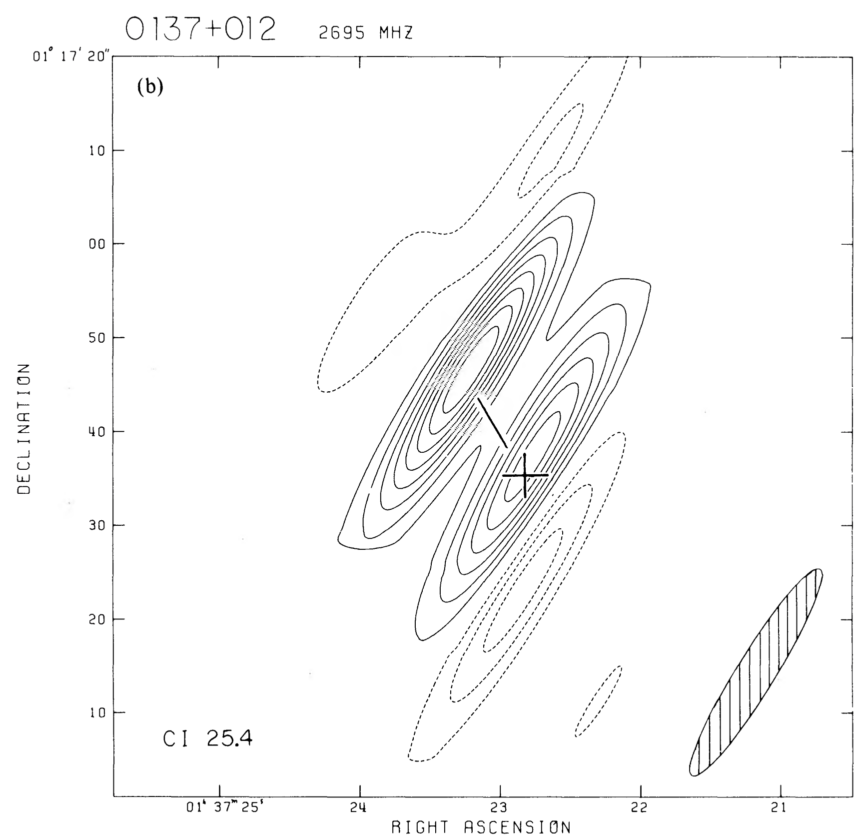
0805+269 (GC3, OJ+209, B2). This source was not intended to be observed in this project, but it is near the edge of the interferometer field of view for 0805+270, so it is included here. It occurs in the 5000-MHz survey by Pauliny-Toth and Kellermann (1972). OJ+209 may

TABLE IV. Sources with detectable polarization.

Name	Comp.	2695 MHz M (%)	2695 MHz chi (deg)	8085 MHz M (%)	8085 MHz chi (deg)
0033+079	1	2.3(1.1)	11(14)		
0051+336	1	4.9(2.4)	144(14)		
0103+062	1	3.4(1.2)	25(10)		
0824+294	1	7.5(1.4)	28(6)		
0824+294	3	6.2(1.4)	32(9)		
1031+114	1	5.3(0.9)	165(4)		
1215+643	1	3.1(0.7)	31(6)	5.3(2.5)	31(14)
1405+258	1	6.5(2.1)	10(11)		
1538+082	1	7.8(1.9)	142(5)		
1658+148	1	5.0(0.8)	116(5)	4.2(2.1)	61(15)
1658+148	2	3.1(1.3)	45(14)		

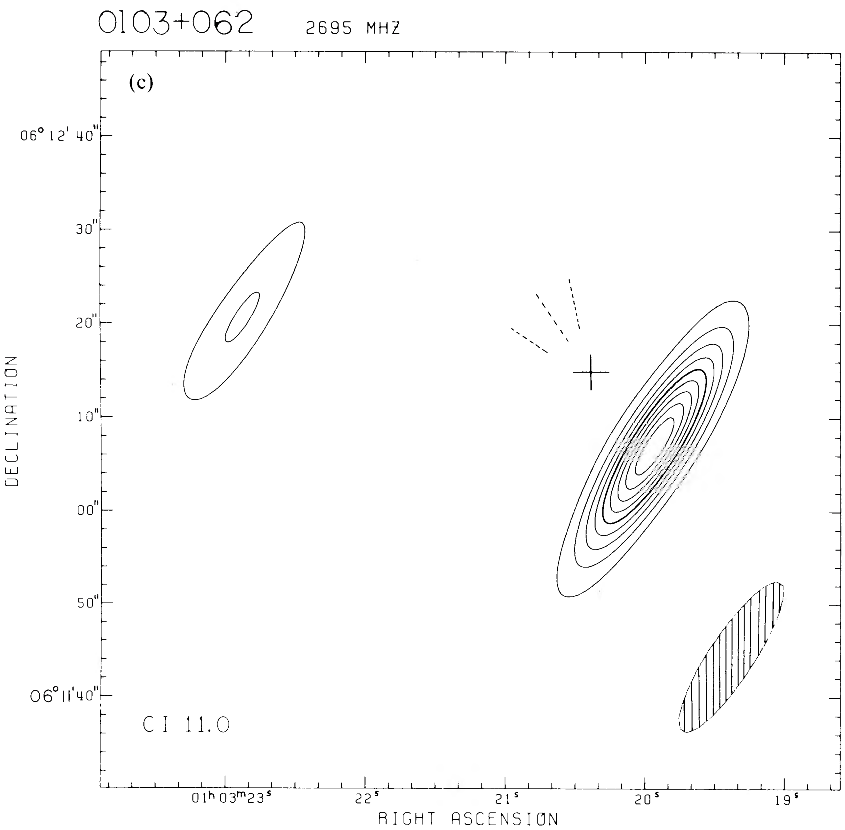


0051 +336 2695 MHZ
(a)
33°38' 00"
50"
40"
30"
20"
10"
33°37' 00"
50
DECLINATION
A
B
CI 6.25
00h51m41s
40s
39s
38s
37s
36s
35s
RIGHT ASCENSION



0137+012 2695 MHZ
(b)
01° 17' 20"
10
00
50
40
30
20
10
DECLINATION
CI 25.4
01h 37m 25s
24
23
22
21
RIGHT ASCENSION

FIG. 1.



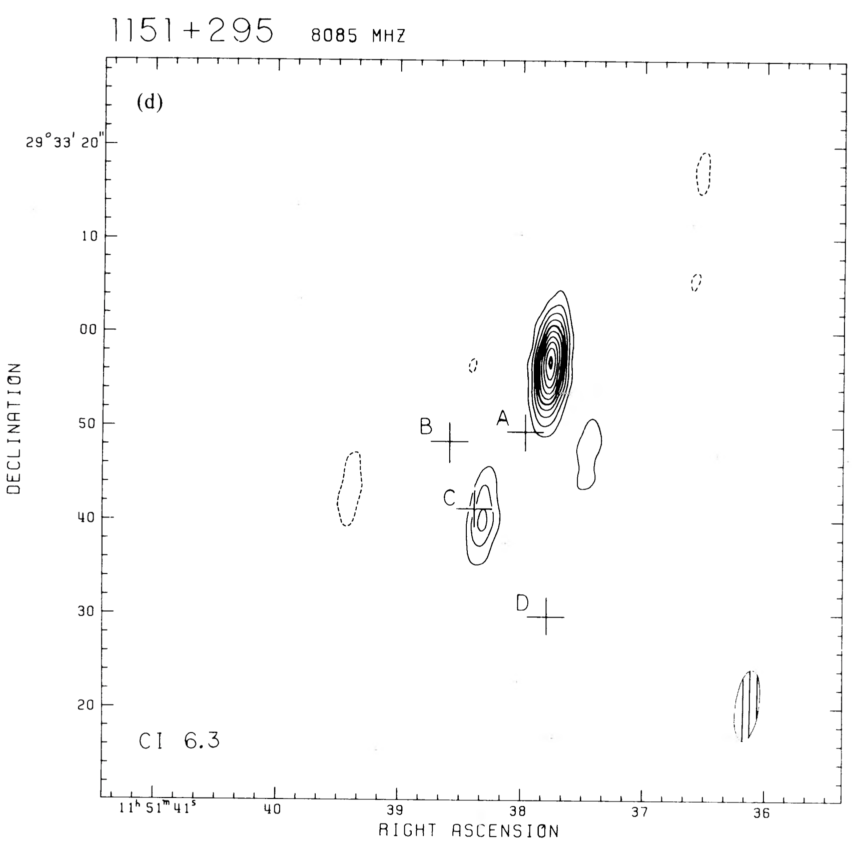


FIG. 1. (continued)

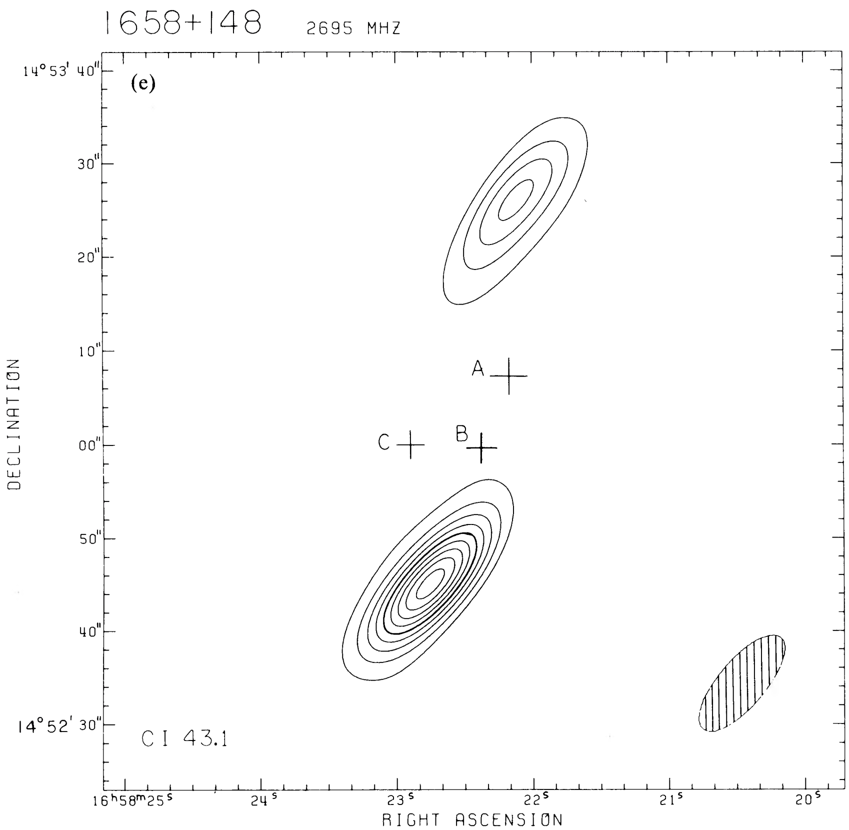


FIG. 1. CLEAN maps of the sources with double or triple structures that may be related to optical structure. The size and orientation of the synthesized beam to half power is shown as the shaded ellipse in the lower right hand corners. The lowest contour level, and the contour interval, in mJy, is labeled CI. The map of 1151+295 is at 8085 MHz. The others are at 2695 MHz. Optical objects are indicated by crosses. The jet in 0137+012 is shown as a line segment. The dotted contours are negative sidelobes not properly removed by CLEAN. The diffuse optical emission in 0103+062 is shown as three dashed lines.

be a blend of this source and 0805+270. No angular size or 8085-MHz data were obtained. The identification is a 19–20-mag galaxy, with a companion galaxy 16″ east, both visible only on the red PSS plate.

0817+307 (4C+30.15, B2, OJ+329). Identification and finding charts were published for this source by Olsen (1970) and Grueff and Vigotti (1972). The radio source was barely detected at 8085 MHz at the 10-mJy level, so no source parameters could be derived at this frequency. The NE member of the galaxy pair (object A in Table II) is close to the centroid of components 1 and 2, and therefore is probably the identification for radio components 1 and 2. Object B may be related to the radio source, since it is only 3.″7 from component 1. Galaxy C is probably unrelated to component 3, being 12″ away.

0824+294 (3C200, 4C+29.29, OJ+240, NRAO293, B2, GC2). Identification and finding charts are given by Wills and Parker (1966) and Wyndham (1966), who notes that the galaxy "appears to have a jet in the SW direction." Structural information has been published by Elsmore and Mackay (1969) and by Jenkins, Pooley, and Riley (1977). The latter group also presents a radio map at 5000 MHz, which is in agreement with the NRAO results. The source is a triple with the central component at the galaxy position. The red PSS plate shows the SW jet mentioned by Wyndham, extending about 10″–15″. It also shows a NW jet of about the same length. Neither optical jet is aligned with the major axis of the radio source. These jets are very faint and may simply be grain patterns. Laing *et al.* (1978) do not see either jet on a 200-in. plate of limiting magnitude 23.5.

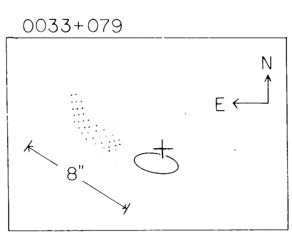


FIG. 2. 0033+079—the ellipse shows the size, to half power, of the Gaussian model fit to the radio source data. The stippled area shows the approximate extent and orientation of the wisp. The cross marks the quasar position. The 1″ offset of the radio source from the quasar is probably mostly due to optical measurement error.

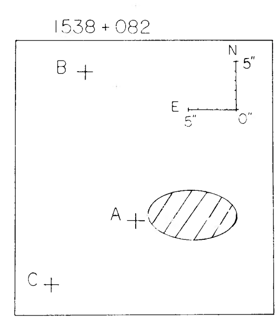


FIG. 3. 1538+082—the ellipse shows the size and PA of the radio source at 2695 MHz. Galaxy positions are marked by crosses.

They note a faint optical extension, which may be a galaxy, about 5″ north. This also does not line up with the radio structure.

1028+526 (4C+52.22, OL+547). Cohen *et al.* (1977) published a position and chart for this 17-mag galaxy. There is a faint companion galaxy 9″ SE at PA about 145°. The radio source is unresolved, with an angular size <3″. The spectrum appears to be very flat between 2695 and 8085 MHz.

1031+114 (4C+11.35, PKS). Caswell and Wills (1967) suggested a 15.2-mag galaxy as the identification. Schilizzi and McAdam (1975) mapped this region at 408 MHz, and Schilizzi (1975) noted that the galaxy had "three jets clearly visible at the western extremity and two faintly discernible at the eastern extremity of the nucleus." The NW radio component seen by Schilizzi and McAdam (1975) is out of the field of view of the NRAO observations. The SE component (component 1) is a 4.″2 double in PA = 64° at 8085 MHz, with 5% polarization at 2695 MHz. One of the galaxy's eastern jets points to component 1, which may be significant, but since it is 174″ east probably isn't. Nothing is visible at

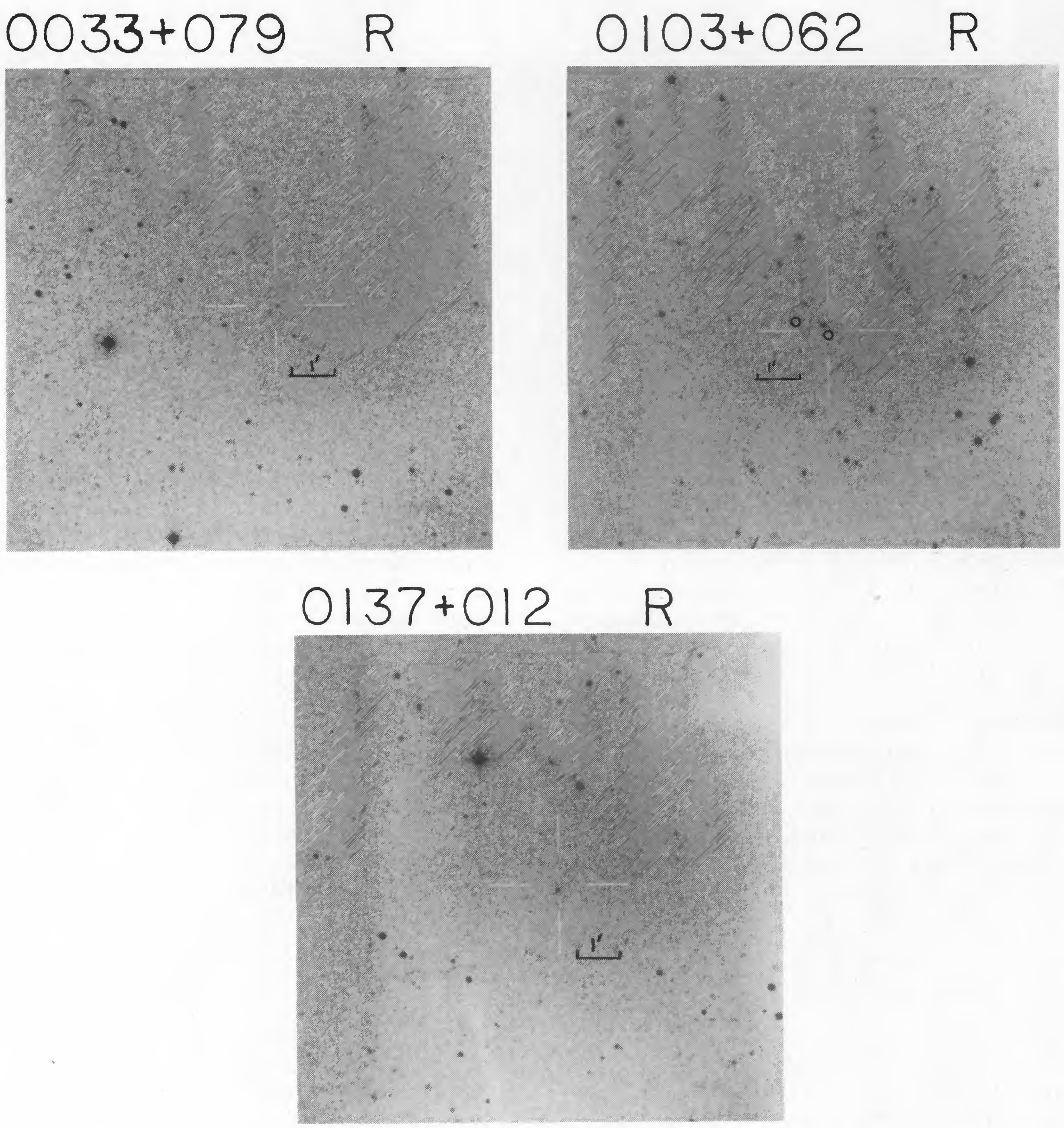


FIG. 4. Four interesting optical fields are shown, reproduced from the PSS copy plates, copyright by the National Geographic Society–Palomar Observatory Sky Survey. Reproduced by permission from the Hale Observatories. Fields marked R are from the red plates. B indicates the blue plates. The circles mark the positions of the radio components for 0103+062 and 1658+148. North is to the top and east is to the left. See Sec. III for a description of these objects.

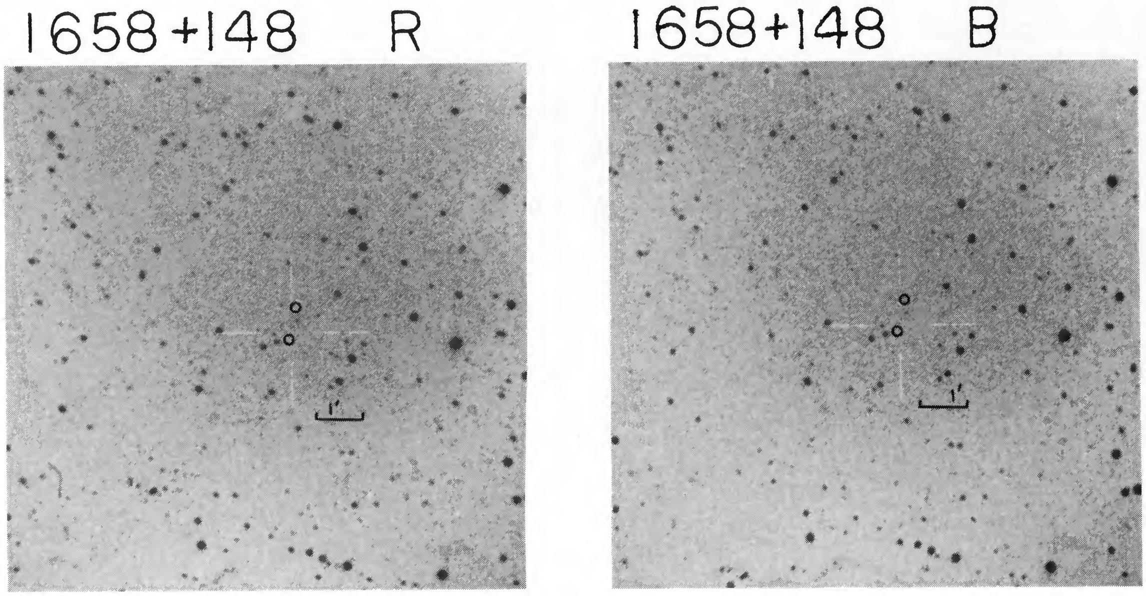


FIG. 4. (continued)

the position of component 1 on the PSS. Radio component 2 is 30″ NW of the galaxy. None of the galaxy's jets points directly toward it.

1131+213 (4C+21.32, OM+252, NRAO377, PKS). Identified with a 16-mag galaxy (Merkelijn, Shimmins, and Bolton 1968). Searle and Bolton (1968) find a redshift of z = 0.066. There is a companion galaxy 10″ NW at PA = 107°. The radio structure is a 7″ double in PA = 170°.

1151+295 (4C+29.44, OM+286, CTD76, B2). Identifications and finding charts have been published by Olsen (1970), Grueff and Vigotti (1972), Hazard, Jauncey, and Backer (1970), and Willson (1972). The source is in Zwicky cluster 1151.6+2934 (type ED, compact). Optical positions for some of the galaxies in this cluster are given by Wills (1976) and Ghigo (1977). Sargent (1973) finds a redshift of z = 0.3292, which presumably refers to the brightest galaxy in the cluster, object D on Fig. 1, about 20″ from the radio centroid. Galaxy A is within 1″.5 of the radio centroid and is therefore the most probable identification. The PA of the line joining galaxies A to C is 148°, close to that of the line joining the radio components (157°), which themselves are extended along the same PA. Galaxy C is only 2″.8 from component 2.

1215+643 (4C+64.15). An identification and finding chart is given by Cohen *et al.* (1977), who quote an uncertain redshift of z = 1.288. There is a jet on the blue PSS print extending about 18″ NW from the center of the quasar image at a PA of about 110°. The angular size, estimated from the 35-km baseline data, is about 0″.9 in PA = 131° (8°). The similarity of the radio PA and that of the jet is interesting, but it is puzzling that the radio source is 5″ NE of the quasar at a PA roughly perpendicular to the radio PA. Thus, this cannot be regarded as a case of alignment.

1405+258 (OQ+210, PKS, B2). This was identified, with a finding chart published, with an elliptical galaxy by Merkelijn, Shimmins, and Bolton (1968). It is probably a member of Zwicky cluster 1406.2+2546 (type ED, open), whose center is 3′.5 to the SE. Two companion galaxies are about 20″ to the NE and SE. A single, steep-spectrum, extended (5″–10″) radio source is seen

1414+110 (3C296, 4C+10.39, OQ+124, NGC5532). The identification with a 13-mag galaxy was noted by, e.g., Pilkington (1964) and Wyndham (1966). [See Véron and Véron (1974) for further references.] The galaxy has a 15-mag companion 33″ SE at PA = 168°, which may be linked to it, as noted by Callahan (1977). Fomalont (1971), observing at 1425 MHz, finds a 208″ double at PA = 37°. In the present observations, these outlying radio lobes are resolved out, but a weak, unresolved central component with an inverted spectrum is found near the nucleus of NGC5532.

1529+357 (3C320, 4C+35.36, NRAO479, B2). Identified by Wyndham (1966) with an 18-mag red galaxy in a cluster. [See Véron and Véron (1974) for additional references.] There are companion galaxies about 12″ N and 27″ W. Smith, Spinrad, and Smith (1976) find a redshift of z = 0.342 for the identification. Mackay (1969) found the radio source to be extended 17″ in PA = 77°. The present observations show that this object is a 14″.4 double in PA ≈80°, with the galaxy at the 2695-MHz centroid. E. P. Bozyan (private communication), using the McDonald Observatory digital area photometer, notes a jet extending NW.

1538+082 (4C+08.45, OR+063). Identified by Shimmins, Bolton, and Wall (1975) with a 16.5-mag E galaxy in a cluster. Two companion galaxies occur at about 19″ NE and about 16″ SE of the radio source. The proposed identification is 5″.8 E of the radio source (see

Fig. 3). The source is extended along the line joining the galaxy with the radio centroid by an amount comparable to the separation, suggesting that the source is associated with the galaxy.

1625+213 (4C+21.48, PKS). Wills (1967) and Callahan (1977) suggested an identification with a 17-mag BSO 13″ E, which was found to be a star by Lynds and Wills (1968). Hazard, Jauncey, and Backer (1970) suggest a 19.5-mag BSO about 45″ NE of our radio position. Callahan (1977) drew attention to a wisp or jet about 10″ NE of the 17-mag BSO. Since we find the angular size of the source to be $\lesssim 0\farcs4$, none of the previously suggested identifications seems likely. A faint 20–21-mag object 3″ W of the radio source was found on the PSS plates (Pumphrey, private communication), which may be the identification.

1658+148 (4C+14.68, OS+197, GC3). Johnson (1974) gives a finding chart for this object and calls it an empty field. Ghigo (1977) gives optical positions for the galaxy (object A) and the faint companion (object B), which appears on the blue PSS plate (see Figs. 1 and 4). Object C, about 7″ E of B, is visible on the red plate, and is linked to galaxy A by a faint bridge of emission. Objects A and B are at PA = 158°, close to the PA of the double source, 168°. Objects A, B, and radio component 1 are collinear within 1° in PA.

IV. DISCUSSION

Of the 18 objects investigated, two were found to be misidentifications (1625+213 and 0805+270). Of the remaining 16, 7 have apparent wisps or extensions on the PSS plates, and 9 have companions within 20″.

In two cases (0051+336 and 1625+213) a jet or wisp was reported in the literature, but inspection of the Palomar Observatory Sky Survey (PSS) plates showed the jet or wisp was probably a faint neighboring galaxy. Of course, other objects that look like jets or wisps on the PSS may also be discovered to be separate galaxies.

Table V summarizes the results. There are five cases in which the major axis of the optical structure has its position angle (PA) within 10° of that of the radio structure. Two of these cases involve a jet, three involve optical pairs.

In Table V, attention is also drawn to two cases with a different type of alignment. In 0103+062, the line joining the radio and optical centroids is aligned with the optical axis. In 1538+082 the radio optical axis is aligned with the radio major axis.

Let us consider first the objects with wisps or jets. The chance rate of alignment of PAs within 10° is 6% (= 10°/180°). The observed rate, for the objects with jets, is 29% (= 2/7), which is formally significant, but in view of the small numbers, not convincing.

The reality of some of the wisps or jetlike features may be questioned. Inspection of the enlargements of the PSS plates available to the author shows that it is not uncommon for randomly selected objects to have faint tails or jets whose brightness is close to the plate limit. In fact, tails and jets can be found by themselves, unconnected to stellar or galaxy images. Such structures are simply patterns in the PSS plate grains. Objects whose jets are very faint and might simply be grain patterns are 0033+079, 0824+294, 1031+114, and 1215+643. On the other hand, the features in 0103+062 and 0137+012 are probably real because they appear on both the red and blue PSS plates. In all these cases it would be desirable to confirm the existence of these jets and wisps by taking deeper optical photographs.

Turning now to the objects with close companions, the chance alignment rate is higher than 10°/180° since several of the objects are in groups or clusters. For example, an object with two neighbors has a probability of 2 × 10°/180° of aligning with a radio source. The resulting chance alignment rate for the eight cases of close companions within 20″ is 9%, to be compared with the observed rate of 38% (= 3/8). Once again, this may be significant, but is unconvincing due to the small numbers involved.

It should be noted that the alignment in 0051+336 is

TABLE V. Summary of results.

Objects with possible jets	Notes	Objects with companions	Notes	Number of neighbors within 20″
0033+079	1	0051+336	1	1
0103+062	2	0817+307		1
0137+012	1	1028+526		1
0824+294		1131+213		1
1031+114		1151+295	1	3
1215+643		1405+258		2
1529+357		1414+110		0
		1538+082	3	2
		1658+148	1	2

Notes: 1. The optical PA is within 10° of the radio axis.
2. The PA of the radio-optical separation is close to the PA of the optical extension.
3. The PA of the radio-optical separation is within 10° of the radio major axis.

undoubtedly spurious since the stellar object is actually a star, as mentioned in Sec. III.

V. CONCLUSIONS

Six objects with aligned radio and optical structures have been found. The significance of the alignment, on statistical grounds, is marginal. But in view of the rarity of known cases of aligned radio and optical structure and the importance of such cases for testing of theoretical models, close scrutiny of each case is worthwhile.

I would encourage optical observers to take direct photographs of these objects which go two or three magnitudes fainter than the PSS. This will verify whether the optical jets are real and may reveal filaments or bridges of emission connecting close companions which would strengthen the case for significance of their optical–radio alignment.

Robert Potash and Pat Crane gave expert assistance in observing with the NRAO interferometer and in running the reduction programs. NRAO is operated by Associated Universities, Inc., under contract with the National Science Foundation. I also appreciate the work done by E. Pumphrey, who measured optical positions for me at the University of Texas, and I thank E. P. Bozyan, who communicated some results from the University of Texas digital area photometer. I thank J. F. C. Wardle, A. G. Willis, and D. Wills for helpful comments on the manuscript. This work was supported in part by a grant from the National Science Foundation.

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