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EXTENDED RADIO SOURCES AND ELLIPTICAL GALAXIES. III. OPTICAL POSITIONS FOR GALAXY CENTERS

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ABSTRACT

Optical positions generally accurate to $\lesssim 0.4$ arcsec are given for the centers of 87 elliptical and S0 galaxies identified with radio sources that have been mapped with the NRAO interferometer and the VLA. Fifty identifications are based on coincidence between a small-diameter component in the radio structure and the optical center of a galaxy; the remaining identifications are examined in light of a number of reliability criteria formulated in paper I (Bridle and Fomalont 1978).

I. INTRODUCTION

This paper is the third of a series reporting studies of ~500 radio sources which in 1973 were considered to be associated with elliptical or S0 galaxies. The primary aim of the series is to study how the gross features of extended radio galaxies are related (a) to their orientations relative to their parent optical objects and (b) to the current activity of the galaxies as evidenced by radio emission within their optical boundaries. Paper I (Bridle and Fomalont 1978) discussed the optical identifications of 48 extended sources containing small-diameter radio components and formulated several criteria for the reliability of identifications of elliptical galaxies with extended radio structures. This paper describes measurements of optical positions for the centers of 87 elliptical and S0 galaxies identifiable with radio sources that have been mapped either with the NRAO 4-element interferometer at 2.7 and 8.1 GHz or with antennas from the Very Large Array at 4.9 GHz (Fomalont and Bridle 1978a; paper II). Section II outlines the optical measuring procedure; Section III gives the new optical positions (Table I). Section IV discusses the reliability of the identifications in the light of the criteria established in paper I.

II. OPTICAL POSITION MEASUREMENTS

The selection of the source sample studied in this series of papers was described in paper I. The subset whose optical positions are the subject of this paper have either (a) small-diameter radio components which can assist the optical identification or (b) bifurcated radio structures which can be identified with a bright galaxy near the radio centroid. The objects whose optical positions have been measured were selected by the following procedure. The positions of the principal components in the radio structure observed at NRAO or at the VLA were first located on the *Palomar Sky Atlas* prints with an accuracy of ~5 arcsec using transparent overlays drawn to mean print scales of 67.38 arcsec/mm in X and 66.78 arcsec/mm in Y. The positions of stars from the Smithsonian Astrophysical Observatory Catalogue served as fiducial markers on these overlays. The optical objects selected for subsequent position determination were those apparently lying near radio components or near the centroids of the radio structures. Precise positions of these objects were obtained by measuring the (X–Y) coordinates of their images on the *Sky Atlas* prints relative to those of reference stars from the AGK3 Catalogue (Dieckvoss *et al.* 1975).

The (X–Y) coordinates were measured with a Gaertner two-coordinate cathetometer with a nominal screw resolution of one micron and a working area of 75 mm by 75 mm. The measuring and reduction procedures have been described in detail by Bridle and Goodson (1977); the main features are as follows,

(a) we measure between six and eight AGK3 stars in each field, selected by faintness, low quoted proper motion, and even distribution around the identification candidates.

(b) standard coordinates obtained from the Schmidt equations (Dixon 1962) are adjusted to fit the measured (X–Y) positions of the reference stars using Schlesinger's method (Schlesinger 1911; Schlesinger 1926).

(c) the internal consistency of the adopted AGK3 reference frame is monitored in two ways—first by reducing the position of each AGK3 reference star relative to the others and comparing the result with its AGK3 position and second by withholding the AGK3 star closest to the identification candidate from all determinations of the frame, so that the agreement between our estimate of its position and its AGK3 position can be used to test the final reliability of the reference frame near the candidate itself.

(d) four independent measurements are made of each reference star and each unknown object, to monitor the effects of random setting errors; rms setting residuals are found to be ~2 microns when the cathetometer is used at 10× linear magnification.

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TABLE I. Optical positions of radio galaxy centers.

Name	R.A. (1950)	Dec (1950)	Plate	m_v	Size	Type (offset)	Refs	Notes
0043+201 3C21	00^h 43^m 50^s.73 0.03	+20° 11′ 41″.8 0.7	E	15.8	8x8	S(1.1)	Bri78 MSB68	1
0053+261 3CR28	00 53 09.12 0.03	+26 08 23.4 0.4	O	18.0	6x6	C(6.0)	unpub Wyn66	2
0104+321 3CR31	01 04 39.10 0.03	+32 08 43.3 0.4	O	12.0	24x18	S(1.7)	Bri78 Wyn66	3,4
0109+492 3CR35	01 09 04.94 0.04	+49 12 40.1 0.4	O	15.6	9x6	S(0.6)	Bri78 Wyn66	
0116+319 4C31.04	01 16 47.25 0.03	+31 55 06.4 0.6	O	14.7	12x12	S(0.6)	Els76 Col75	5
0136+397 4C39.04	01 36 33.58 0.03	+39 41 51.2 0.7	O	19.0	4x4	S(0.3)	Fom78a Fom78a	6
0158+293 4C29.05	01 58 43.49 0.04	+29 19 16.0 0.4	O	16.9	8x5	S(1.6)	Fom78a Win69	1
0206+355 4C35.03	02 06 39.30 0.03	+35 33 41.3 0.4	O	14.0	24x12	S(0.9)	Bri78 Ols70	7
0309+390 4C39.11	03 09 12.60 0.03	+39 05 15.6 0.5	O	16.7	6x5	S(1.1)	Bri78 Ada77	1
0331+391 B20331+39	03 31 00.94 0.05	+39 11 23.5 0.4	O	13.3	12x12	S(0.2)	Bri78 Col75	
0349+212 4C21.13	03 49 45.19 0.04	+21 17 16.2 0.4	E	16.9	10x9	S(0.4)	Bri78 Mer68	
0531+194 PKO531+19	05 31 47.35 0.03	+19 25 24.0 0.4	E	17.6	9x7	S(0.8)	Els76 Cla66	
0623+264 3C160	06 23 48.27 0.07	+26 25 09.5 0.4	O	18.3	3x3	S(1.4)	Bri78 Mer68	
0632+263 4C26.23	06 32 29.60 0.03	+26 19 06.4 0.4	B	14.6	15x15	S(1.1)	Fom78a MSB68	1
0642+214 3CR166	06 42 24.66 0.03	+21 25 02.2 0.5	B	19.4	5x5	S(0.0)	Bri78 Wyn66	1,3
0649+485 4C48.18	06 49 00.41 0.05	+48 35 09.5 0.4	O	17.0	9x6	C(2.8)	unpub Bai68	
0652+426 4C42.22	06 52 37.09 0.06	+42 40 58.7 1.2	O	15.0	9x7	S(0.2)	Bri78 Wil72	
0658+232 4C23.18	06 58 27.58 0.02	+23 17 45.1 0.4	O	16.7	6x3	C(21.9)	unpub MSB68	

(e) reference stars are rejected when rejection significantly reduces the residuals between the computed and the AGK3 positions for all other reference stars in the field.

The external errors in optical positions for faint images measured with this system were examined in detail by Bridle and Goodson (1977), who compared their positions for 33 QSOs with other accurate optical and radio positions for the same objects. They concluded that the standard errors in QSO positions measured using these procedures are ~0.3 arcsec along the X screw of the cathetometer and ~0.36 arcsec along the Y screw. This accuracy is only slightly worse than that claimed for measurements from *Palomar Sky Survey plates* by Wills (1978), who also used AGK3 reference stars and an over-determined set of reference-star measurements which allowed rejection of reference-star candidates.

We adopt 0.3 arcsec on the X screw and 0.4 arcsec on

TABLE I. Optical positions of radio galaxy centers. (Continued).

Name	R.A. (1950)	Dec (1950)	Plate	m_v	Size	Type (offset)	Refs	Notes
0702+749 3CR173.1	07 02 47.61 0.09	+74 54 16.7 0.4	E	18.9	3x3	C(8.9)	unpub Wyn66	
0712+534 OI521.2	07 12 42.10 0.03	+53 28 31.0 0.4	O	18.9	10x9	S(0.7)	Bri78 Wil73	1,3
0714+286 4C28.18	07 14 48.03 0.03	+28 40 35.9 0.4	O	16.2	9x6	S(0.5)	Bri78 Wil72	9
0755+379 NRAO276	07 55 09.07 0.03	+37 55 20.9 0.4	O	13.5	15x12	S(0.0)	Bri78 Win69	1,5
0802+243 3CR192	08 02 35.50 0.02	+24 18 26.4 0.4	E	15.2	12x12	C(4.9)	unpub Wyn66	1,5,8
0818+472 3CR197.1	08 18 00.91 0.03	+47 12 12.0 0.6	O	17.0	6x3	C(12.6)	unpub Wyn66	2,10
0832+347 B20832+34	08 32 05.46 0.03	+34 44 24.4 0.4	O	17.6	6x6	C(2.1)	unpub Gru72	
0836+299 B20836+29B	08 36 59.05 0.04	+29 59 42.2 0.6	O	15.0	24x15	C(18.5)	unpub Col75	11
0840+299 B20840+29	08 40 07.00 0.04	+29 54 53.7 0.3	E	19.3	3x3	C(1.9)	unpub Gru72	12
0844+540 4C54.17	08 44 10.49 0.04	+54 03 39.0 0.5	O	13.9	15x15	C(15.3)	unpub Wil74	
0844+319 B20844+31B	08 44 54.30 0.03	+31 58 13.4 0.4	B	14.2	21x15	S(0.6)	Bri78 Ols70	3
0915+320 B20915+32	09 15 58.53 0.03	+32 04 20.8 0.4	O	15.1	9x8	S(1.1)	Fom78b Fom78b	1
0917+458 3CR219	09 17 50.68 0.03	+45 51 42.9 0.4	O	17.3	5x4	S(0.7)	Bri78 Mal63	13,14
0936+361 3CR223	09 36 50.87 0.06	+36 07 35.0 0.5	O	17.4	3x3	S(1.0)	Fom78a Wyn66	2,15
0938+399 3CR223.1	09 38 18.23 0.03	+39 58 22.3 0.5	O	16.2	9x7	C(1.6)	unpub Wyn66	2
1000+201 PK1000+20	10 00 11.33 0.02	+20 06 24.2 0.5	O	17.1	3x3	C(13.4)	unpub Mer68	16
1003+351 3CR236	10 03 05.37 0.03	+35 08 48.1 0.2	B	16.2	8x6	S(0.2)	Bri78 Wyn66	17
1040+317 B21041+31A	10 40 31.18 0.05	+31 46 51.1 0.7	O	15.0	10x10	S(0.8)	Bri78 Col75	18

the Y screw as minimum errors in single position measurements made with this system. Larger errors may arise in measurements of individual galaxy centers for the following reasons.

(a) a poor distribution of reference stars may degrade the accuracy with which the AGK3 reference frame can be interpolated to the candidate object, especially when the object lies near a *Sky Atlas* print boundary.

(b) the setting of microscope crosshairs at the geometrical center of a large diffuse elliptical image containing brightness gradients involves a more complex judgement than does measurement of a quasi-stellar image.

(c) galaxy images may be asymmetric, so that judgement of the geometrical center is still more subjective.

TABLE I. Optical positions of radio galaxy centers. (Continued).

Name	R.A. (1950)	Dec(1950)	Plate	m_V	Size	Type(offset)	Refs	Notes
1102+304	11 02 39.68	+30 25 53.0	O	15.0	10x9	C(0.5)	unpub	1
B21102+30A	0.03	0.4					Col75	
1108+411	11 08 53.42	+41 06 43.2	O	15.0	10x9	S(1.5)	Rud77	19
4C41.23	0.03	0.4					Wil76	
1113+295	11 13 53.59	+29 31 40.3	O	14.7	15x12	S(0.4)	Bri78	1,20
4C29.41B	0.03	0.3					Ols70	
1115+315	11 15 52.50	+31 31 42.4	E	18.5	6x6	C(7.8)	unpub	1,21
B21115+31B	0.03	0.5					Gru72	
1123+203	11 23 21.20	+20 22 25.3	O	16.3	7x6	S(1.1)	Bri78	22
PK1123+20B	0.02	1.3					Mer68	
1131+213	11 31 20.13	+21 22 13.1	O	16.1	8x8	C(16.3)	unpub	
4C21.32	0.03	0.6					MSB68	
1140+217	11 40 21.31	+21 45 50.7	O	16.7	8x7	S(1.4)	Bri78	23
PK1140+21	0.04	0.5					Bri78	
1151+295	11 51 37.97	+29 32 50.1	O	19.4	3x3	C(4.9)	unpub	24
B21151+29	0.04	0.5					Ols70	
1158+318	11 58 24.94	+31 50 03.9	E	20.0	4x4	C(7.6)	unpub	2
3CR268.2	0.05	0.4					Gru72	
1204+225	12 04 00.22	+22 32 19.2	O	14.7	12x12	C(7.9)	unpub	23,25
PK1204+22	0.03	0.3					MSB68	
1243+336	12 43 16.67	+33 40 51.1	O	16.8	6x3	C(3.3)	unpub	1
B21243+33	0.03	0.4					Win69	
1250+291	12 50 11.35	+29 08 07.4	O	17.9	6x6	C(4.3)	unpub	
5C4.6	0.05	0.3					Bar72	
1251+278	12 51 46.25	+27 53 49.2	O	15.9	6x6	S(0.7)	Goo79	26,27
3CR277.3	0.02	0.3					Gri63	
1257+282	12 57 10.95	+28 13 42.5	O	12.7	20x20	C(20.9)	unpub	5
5C4.85	0.02	0.3					Col75	
1313+072	13 13 45.97	+07 18 35.6	O	14.9	10x8	S(0.5)	Fom78a	1
PK1313+07	0.02	0.4					Cla66	
1316+299	13 16 43.17	+29 54 20.0	O	15.7	10x10	S(0.6)	Bri78	28
B21316+29	0.03	0.3					Ols70	
1319+428	13 19 05.22	+42 50 55.7	O	15.7	14x8	S(1.0)	Fom78a	
3CR285	0.04	0.3					Wyn66	
1322+366	13 22 35.34	+36 38 18.9	O	13.2	20x15	S(0.3)	Bri78	3
B21322+36B	0.02	0.3					Ols70	

We have evaluated the potentially subjective aspects of measuring the centers of large or complex images by comparing positions measured independently by several observers for the same objects. Among the present authors, differences in judgement of the centers of large images appear not to degrade the consistency of measurement significantly up to image diameters of 30 arcsec (~0.5 mm).

In assigning errors to our quoted positions for individual galaxies, we first obtain the internal errors in the AGK3 reference frame near the galaxy from the measurement of the "test" AGK3 star; if this error is larger than our standard errors of 0.3 and 0.4 arcsec in the appropriate coordinate, the larger error is assigned to the measurement of the galaxy position. This procedure may occasionally overestimate the error in our frame if the

TABLE I. Optical positions of radio galaxy centers. (Continued).

Name	R.A.(1950)	Dec(1950)	Plate	m_V	Size	Type(offset)	Refs	Notes
1325+321 4C32.44	13 25 13.29 0.03	+32 06 57.9 0.4	E	18.0	4x4	C(2.7)	unpub Gru72	
1336+391 3CR288	13 36 38.59 0.04	+39 06 21.8 0.4	E	18.3	9x6	C(13.0)	unpub Wyn66	29
1340+053 PK1340+05	13 40 12.47 0.02	+05 19 37.7 0.4	O	16.3	6x5	S(0.2)	Goo79 Cla66	30
1346+268 4C26.42	13 46 33.98 0.03	+26 50 27.8 0.4	E	14.6	12x12	S(0.4)	Bri78 Ols70	
1350+316 3CR293	13 50 03.20 0.03	+31 41 33.8 0.6	O	14.1	20x13	S(0.9)	Bri78 Col75	31
1405+258 PK1405+25	14 05 59.55 0.03	+25 48 08.2 0.4	B	17.7	6x6	S(0.3)	Goo79 MSB68	32
1424+344 B21424+34	14 24 52.88 0.09	+34 25 24.7 0.4	O	16.2	12x12	C(5.7)	unpub Gru72	33
1446+206 3C304	14 46 33.12 0.05	+20 37 58.4 0.4	E	19.4	4x4	C(18.0)	unpub Ols70	34
1452+166 3C306	14 52 00.63 0.02	+16 36 34.2 0.5	E	18.4	3x3	S(0.4)	Bri78 Bri78	1,35
1502+262 3CR310	15 02 46.92 0.02	+26 12 35.1 0.7	O	16.2	8x8	S(0.6)	Bri78 Gri63	1,4,13,36
1511+263 3CR315	15 11 30.82 0.02	+26 18 40.3 0.5	O	16.4	5x5	S(0.5)	Bri78 Gri63	1,13,37
1529+357 3CR320	15 29 29.73 0.03	+35 43 48.6 0.4	E	19.2	6x6	C(4.5)	unpub Wyn66	
1547+309 B21547+30	15 47 12.01 0.02	+30 56 21.5 0.6	O	17.3	6x6	S(0.6)	Goo79 Gru72	38
1553+245 B21553+24	15 53 56.21 0.04	+24 35 32.9 0.4	O	14.9	12x9	S(0.4)	Bri78 Col75	
1557+708 4C70.18	15 57 41.25 0.08	+70 49 49.8 0.4	O	12.8	27x22	S(1.4)	Bri78 Bri78	
1602+178 PK1602+178	16 02 53.93 0.03	+17 51 53.4 0.4	O	13.5	14x7	C(11.7)	unpub Shi75	
1602+240 4C24.36	16 02 48.91 0.03	+24 04 03.7 0.4	O	12.8	25x17	C(9.0)	unpub MSB68	39
1615+324 3CR332	16 15 46.99 0.03	+32 29 50.3 0.4	O	16.9	6x3	S(0.3)	Ril75 Gru72	1,2,5,40

random errors in our measurements and in the AGK3 measurement of the test star "conspire." In most cases, however, the discrepancy between our estimate of the test star position and its position in AGK3 is consistent with a ~0.2 arcsec standard error in AGK3 and a ~0.35 arcsec standard error in our measurements, as demonstrated by Bridle and Goodson (1977, Fig. 2). For large or asymmetric galaxy images, we estimate the final error from the scatter among several observers' measures of the system, as well as by the above procedures, and adopt whichever estimated error is greater.

III. OPTICAL POSITIONS FOR 87 RADIO GALAXIES

Table I gives optical positions for 87 galaxies which we believe to be associated with radio sources on the basis

TABLE I. Optical positions of radio galaxy centers. (Continued).

Name	R.A. (1950)	Dec(1950)	Plate	m_V	Size	Type(offset)	Refs	Notes
1641+173 3CR346	16 41 34.54 0.03	+17 21 20.8 0.4	O	17.2	5x4	S(1.4)	Goo79 Cla66	41
1658+302 B21658+30	16 58 48.97 0.02	+30 12 33.2 0.4	O	14.3	17x17	S(0.6)	Bri78 Gru72	1,42
1717+228 PK1717+22	17 17 02.75 0.03	+22 48 09.0 0.3	O	18.3	3x3	C(32.5)	unpub Ols70	43
1743+666 WK386	17 43 57.59 0.06	+66 39 23.9 0.3	E	18.9	6x3	C(10.4)	unpub	
1744+557 4CT55.33.1	17 44 00.58 0.03	+55 43 25.0 0.4	O	13.5	15x12	S(0.4)	Bri78 Bri78	
1759+211 4C21.51	17 59 40.50 0.03	+21 09 25.1 0.7	O	16.0	5x5	S(0.9)	Bri78 Haz70	1,44
1833+326 3CR382	18 33 11.99 0.02	+32 39 17.9 0.4	O	14.6	12x9	S(0.3)	Bri78 Wyn66	1,5,45
1834+196 PK1834+19	18 34 29.47 0.03	+19 41 09.9 0.4	O	13.4	30x20	S(1.6)	Bri78 Wes69	3
1845+797 3CR390.3	18 45 37.64 0.11	+79 43 06.1 0.4	O	15.9	9x9	S(0.9)	Bri78 Wyn66	
1939+605 3CR401	19 39 38.81 0.03	+60 34 33.5 0.4	E	19.1	9x3	C(11.5)	unpub Wyn66	46
2229+391 3CR449	22 29 07.67 0.02	+39 06 03.9 0.4	O	13.4	17x15	S(1.1)	Bri78 Wyn66	1,4,47
2234+386 WK458	22 34 34.08 0.05	+38 37 42.6 0.4	O	15.8	8x7	S(0.3)	Bri78 Win69	
2254+354 B22254+35	22 54 23.18 0.03	+35 25 24.1 0.4	O	16.8	5x5	C(25.4)	unpub Ols70	1
2335+267 3CR465	23 35 58.94 0.06	+26 45 16.4 0.4	O	13.4	18x18	S(0.5)	Bri78 Gri63	1,48
2357+004 PK2357+00	23 57 25.00 0.04	+00 25 24.5 0.4	O	15.2	9x7	S(1.5)	Fom78a Cla66	1,49

of our measurements. Column 1 gives the source designation on the IAU convention and, below that, a common name from a radio catalogue (nomenclature as in Kesteven and Bridle 1977). Columns 2 and 3 list our measured (epoch 1950.0) right ascension and declination for the galaxy center; below each position is its standard error in seconds of time (R.A.) and arcsec (Dec). Column 4 codifies the color sensitivity of the *Sky Atlas* print from which our measurement was made (*E*–red; *O*–blue; *B*–both, averaged). Column 5 gives an estimate of the apparent visual magnitude of the galaxy, from separate estimates on the *O* and *E* prints made as described by Bridle and Fomalont (1978); these estimates are *not* corrected for galactic extinction. Column 6 gives an estimate of the angular dimensions of the most heavily-exposed part of the galaxy image in arcsec; these estimates are included only to display the significance of offsets between the optical and radio positions (Col. 7), rather than as well-defined intrinsic parameters of the galaxies.

Column 7 codifies the basis for identification of the radio source with the galaxy. Letter *S* denotes that the identification is based on positional coincidence between the center of a galaxy and a *s*mall-diameter radio component (radio "core"), as in papers I and II. In these cases the number in parentheses in Col. 7 is the angular offset in arcsec between the optical and radio core positions (R.A. and Dec offsets combined in quadrature). Letter *C* denotes that the identification is based on approximate coincidence between the center of a galaxy and the *c*entroid of extended bifurcated radio emission, without confirmation by a core radio component, but

Table I. Notes

1. Another optical object is in or near the radio structure; see Table II.
2. Optical position also given by Riley and Pooley (1975).
3. Position quoted is the mean of three measurements by different observers.
4. Optical position also given by Jenkins *et al.* (1977).
5. Position quoted is the mean of two measurements by different observers.
6. Many optical objects are near the radio centroid; see Table II and Fomalont and Bridle (1978a) Fig. 1(a).
7. Position of small-diameter radio component also given by Pooley and Henbest (1974).
8. Optical position also given by Wills *et al.* (1973).
9. Position of small-diameter radio component given by Fomalont and Bridle (1978a).
10. The 8.1-GHz map by Rudnick and Owen (1977) and the 5-GHz map by Riley and Pooley (1975) both show weak extended emission within a few arcsec of our optical position. This might be a weak "extended core" (Bridle and Fomalont 1978) or an emission bridge to the Northern radio lobe.
11. The galaxy has an extensive asymmetric halo extending to the North and to the South-West.
12. The 5-GHz map by Conway *et al.* (1977) shows a "centroidal component" ~3 arcsec North of our optical position.
13. Optical position also given by Griffin (1963).
14. Position of small-diameter radio component also given by Turland (1975).
15. Position of small-diameter radio component also given by Riley and Pooley (1975).
16. Position quoted is for the galaxy identified with the Southern double source in this radio field. Positions for objects in the Northern radio structure are given in Table II.
17. Position quoted is the mean of seven measurements by four different observers.
18. Position is that of the central image of an apparently triple galaxy.
19. Optical position also measured by Wills (1976); this is the North-Western galaxy in her finding chart—the other system lies outside the radio structure.
20. Position of small-diameter radio component also given by Riley (1975).
21. Our 8.1-GHz map shows a possible 17 ± 8 mJy small-diameter component at $11^{h}\,15^{m}\,52^{s}.54 \pm 0^{s}.04$, $31^{\circ}\,31'\,41''.9 \pm 0''.5$. This may be a "radio core" in the proposed identification, but is not separable from the larger-scale emission in our 2.7-GHz map. The object measured is the Northern nucleus of the double system marked by Grueff and Vigotti (1972).
22. The optical object is near the edge of the *Sky Atlas* prints.
23. Position quoted is the mean of two measurements made with the *Sky Atlas* print in different orientations relative to the cathetometer screws.
24. Optical position also given by Wills (1976). A flat-spectrum small-diameter radio component in this structure (Bridle and Fomalont 1978) does not coincide with the proposed identification, which is the most northerly of three galaxies marked by Olsen (1970); see Table II for positions of the other two galaxies.
25. Our 8.1-GHz map shows a 74 ± 17 mJy feature ~6 arcsec in extent centered at $12^{h}\,04^{m}\,00^{s}.11 \pm 0^{s}.09$, $22^{\circ}\,32'\,17''.5 \pm 4''$. This may be an "extended radio core" in the proposed identification, but is not separable from the larger-scale emission in our 2.7-GHz map.
26. Our 8.1-GHz map contains a 16 ± 10 mJy small-diameter component at $12^{h}\,51^{m}\,46^{s}.30 \pm 0^{s}.03$, $27^{\circ}\,53'\,49''.1 \pm 0''.4$. This component is difficult to separate from other fine-scale structure near the source center, but its position agrees with that of the central feature in the 5-GHz map by Pooley and Henbest (1974) and is probably a small-diameter "radio core."
27. On inspection of this system on the Sky Survey plates at the David Dunlap Observatory, AHB and Dr. G. W. Brandie were unable to discern the faint extended envelope of the galaxy sketched by Branson *et al.* (1972). The nearby image whose position is given in Table II appears on both blue-sensitive Sky Survey plates showing this region however, and on a IIIaJ plate of the field obtained with the Palomar 48-in Schmidt by Dr. R. Racine. It is not clear whether this feature is part of the envelope of the identification or whether it is an unrelated background object. It lies near but not on the main ridge of the radio emission South-East of the central feature on the 5-GHz map by Pooley and Henbest (1974).
28. Position quoted is the mean of positions measured from two adjacent *Sky Atlas* print fields.
29. The 5-GHz map by Pooley and Henbest (1974) shows a weak small-diameter radio component at $13^{h}\,36^{m}\,38^{s}.59 \pm 0^{s}.03$, $39^{\circ}\,06'\,22''.2 \pm 0''.5$, in good agreement with our optical position.
30. Our 8.1-GHz data out to 2.7-km baselines can be fitted with a 183 ± 20 mJy small-diameter (<0.5 arcsec) component at $13^{h}\,40^{m}\,12^{s}.46 \pm 0^{s}.02$, $05^{\circ}\,19'\,37''.5 \pm 0''.4$ embedded in larger-scale (~7 arcsec) structure. The separation of this component from fine-scale structure around it may be model-dependent however. At 2.7 GHz the source structure is very complex.
31. Optical position also given by Argue *et al.* (1978).
32. Our 8.1-GHz data show a 44 ± 5 mJy small-diameter (<1 arcsec) component at $14^{h}\,05^{m}\,59^{s}.53 \pm 0^{s}.02$, $25^{\circ}\,48'\,08''.3 \pm 0''.2$, embedded in larger-scale (~4 arcsec) structure. This component was not separated from larger-scale structure (~11 arcsec in extent) at 2.7 GHz, due to the lower resolution of our map at that frequency.
33. The galaxy measured is the brightest object within the error box on the finding chart shown by Grueff and Vigotti (1972).
34. The small-diameter radio component whose position is given by Bridle and Fomalont (1978) does not coincide with the identification, but is fine-scale structure in the North-Western lobe. The optical object suggested as the identification by Hazard *et al.* (1970) is at $14^{h}\,46^{m}\,32^{s}.54 \pm 0^{s}.05$, $20^{\circ}\,37'\,42''.2 \pm 0''.4$, well outside the radio structure; see map in Pooley and Henbest (1974)
35. Position quoted is not for the bright galaxy suggested as the identification by Clarke *et al.* (1966); see Bridle and Fomalont (1978).
36. Position of small-diameter radio component also given by Miley and van der Laan (1973) and by Jenkins *et al.* (1977).
37. Position of small-diameter radio component also given by Northover (1976).
38. The 2.7 and 8.1-GHz maps show a component ~3.5 arcsec in extent at $15^{h}\,47^{m}\,11^{s}.97 \pm 0^{s}.02$, $30^{\circ}\,56'\,21''.7 \pm 0''.2$, which coincides with the optical identification.
39. Position quoted is the mean of four measurements by three different observers. The radio source is entirely within the optical image of the identification.
40. The central component found by Riley and Pooley (1975) is 3.5 by <2 arcsec in extent. The new radio and optical positions disagree with the Véron (1966) optical position by 3.5 arcsec in R.A. and 5.3 arcsec in Dec.
41. The optical position measured by Véron (1966) and plotted on the 5-GHz map by Pooley and Henbest (1974) is 2.4 arcsec later than our optical position in R.A. The optical position measured by Wills (1978) is in excellent agreement with ours, and both positions lie between the peaks of emission on the Pooley and Henbest map. The impression given by this map (Fig. 2 of their paper) that this might be a *narrow* "head-tail" structure is probably incorrect. Our radio data show structure on a variety of scales from 0.4 to ~2 arcsec centered on $16^{h}\,41^{m}\,34^{s}.46 \pm 0^{s}.02$, $17^{\circ}\,21'\,21''.6 \pm 0''.3$; the source may therefore be a "wide-angle-tail" structure with an extended radio core.
42. The identification is the Northern nucleus of the double galaxy marked by Grueff and Vigotti (1972).
43. The source lies within the optical image of the galaxy. It has been mapped at 15 GHz using the VLA and its small radio size (~2 arcsec) accounts for the large percentage offset of radio and optical positions. The identification is not in doubt.
44. The identification is the brightest member of a faint cluster; positions of neighboring galaxies are given in Table II.
45. A galaxy of comparable brightness, possibly a barred spiral, lies immediately South of the North-following radio component and is confused by a stellar object; see Table II for positions.

Table I. Notes

46. Position quoted is for the center of a dumbbell system.
47. Position of small-diameter radio component also given by Jenkins *et al.* (1977).
48. Small-diameter radio component position also given by Miley and van der Laan (1973).
49. Position quoted is for the Eastern (following) nucleus of the dumbbell galaxy marked by Clarke *et al.* (1966) and not for the Western (preceding) nucleus as stated in Fomalont and Bridle (1978a).

Table I. Refs.

Ada77 Adams and Rudnick 1977
Bai68 Bailey and Pooley 1968
Bar72 Barbieri and Bertola 1972
Bri78 Bridle and Fomalont 1978, paper I
Cla66 Clarke *et al.* 1966
Col75 Colla *et al.* 1975
Els76 Elsmore and Ryle 1976
Fom78a Fomalont and Bridle 1978a, paper II
Fom78b Fomalont and Bridle 1978b
Goo79 This paper, notes to Table 1
Gri63 Griffin 1963
Gru72 Grueff and Vigotti 1972
Haz70 Hazard *et al.* 1970
Mal63 Maltby *et al.* 1963
Mer68 Merkelijn 1968
MSB68 Merkelijn *et al.* 1968
Ols70 Olsen 1970
Ril75 Riley and Pooley 1975
Rud77 Rudnick and Owen 1977
Shi75 Shimmins *et al.* 1975
unpub Centroid position from our (unpublished) NRAO data
Wes69 Westerlund and Wall 1969
Wil72 Willson 1972
Wil73 Wills *et al.* 1973
Wil74 Wills and Wills 1974
Wil76 Wills 1976
Win69 Windram and Kenderdine 1969
Wyn66 Wyndham 1966

following the precepts of paper I, Sec. VI. The centroid positions were calculated from the positions and flux densities of sets of Gaussian components fitted to our radio visibility data. For these sources the number in parentheses is the offset between the optical position and the radio centroid expressed as a percentage of the largest angular size (LAS) of the source.

The LAS is the angular extent between the 10% or the 20% peak brightness contours of the extended structure on the 2.7-GHz maps obtained with the NRAO interferometer (or on the 8.1-GHz maps for sources with LAS $\lesssim$20 arcsec). The reliability of the lower contours and hence the dynamic range and noise level on the map determine the limiting brightness from which we derive the LAS. The LAS is thus a partly subjective measure of the overall extent of the source which may in some cases be defined only to within about 15%–20%. It is nevertheless a useful parameter in the subsequent evaluation of the relative reliability of the identifications (as discussed in Section IV).

Column 8 codifies references to the radio position on which the identification is based (upper row), and to a finding chart for the optical object (lower row). The key to the reference codes follows the Table. Column 9 refers to numbered explanatory notes which also follow the Table. Individual identifications are discussed in Sec. IV below.

Table II gives our positions, approximate apparent magnitudes m_V and brief descriptions for other objects in a number of the fields. These objects are generally other galaxies apparently within the radio contours or near the radio centroids; a few stellar objects which could confuse the interpretation of an identification are also listed, but in general we have not derived positions for stellar objects of neutral color near our fields.

IV. RELIABILITY OF THE IDENTIFICATIONS

Paper I of this series discussed criteria for determining the reliability of identifications of galaxies with extended radio sources. Many of the identifications in Table I that are based on coincidences of radio cores with the centers of elliptical galaxies (letter *S* in Col. 7) were appraised in papers I and II. The new identifications of this kind (0116 + 319, 0531 + 194, 1108 + 411, 1251 + 278, 1340 + 053, 1405 + 258, 1547 + 309, 1615 + 324, and 1641 + 173) are all reliable at the 99% level of confidence under the third criterion of paper I [Sec. IV*b*)], i.e., the radio cores have small *a priori* probabilities of lying in the areas "covered" by the extended radio structures and they coincide within errors with the positions measured for the galaxy centers. In applying this criterion the area "covered" by a source (the search area) is conservatively taken to be the circular area with diameter equal to the LAS of the source.

Most of the identifications for radio sources in Table I *without* detectable small-diameter core components (i.e., those with letter *C* in Col. 7) satisfy both of the following criteria:

(1) the identification is bright enough that there is a

<1% *a priori* probability [based on galaxy counts at high galactic latitudes (Allen 1973)] that the elliptical galaxy is randomly in the area covered by the extended structure, and

(2) there is no other galaxy in the structure whose apparent magnitude is within 2^m of that of the proposed identification (which is always the brightest galaxy in the radio structure).

The identifications which do not satisfy the above reliability criteria divide into two groups;

(1) sources with objects in their radio structures whose apparent magnitudes *are* within 2^m of that of the proposed identification (0802 + 243, 1115 + 315, 1151 + 295, 1243 + 336, 1424 + 344, and 2254 + 354)

(2) sources with faint identifications ($m_V > 18$), so that an object $<2^m$ fainter than the identification *could* be within the radio structure, but would be below the $\sim 20^m$ plate limit (0702 + 749, 0840 + 299, 1158 + 318, 1336 + 391, 1446 + 206, 1529 + 357, 1743 + 666, and 1939 + 605).

Most of these remaining identifications satisfy the secondary criterion which was validated empirically in paper I: the brightest galaxy within 0.15 (LAS) of the centroid of a bifurcated radio structure has a probability $\gtrsim$90% of being the correct identification if its *a priori* probability of being in the radio structure is low (<1%). The only identifications which do not satisfy this criterion are those for the sources 0840 + 299, 1158 + 318,

TABLE II. Positions for other objects in radio fields.

Name	R.A. (1950)	Dec (1950)	m_V	Remarks
0043+201	00^{h}43^{m}50^s.74 (0^s.03)	20°11′ 07″.8 (0″.7)	18	galaxy in Southern lobe
0136+397	01 36 33.87 (0.03)	39 41 55.0 (0.7)	20	other nucleus of db
	01 36 32.67 (0.03)	39 41 56.5 (0.4)	18	brightest galaxy in field
0158+293	01 58 43.07 (0.02)	29 19 17.6 (0.4)	17	other nucleus of db
0309+390	03 09 14.23 (0.04)	39 05 22.3 (0.5)	19	galaxy? in Eastern lobe
0632+263	06 32 30.61 (0.03)	26 19 01.9 (0.4)	18	galaxy in field
0642+214	06 42 24.28 (0.04)	21 25 16.9 (0.7)	19	galaxy? in Northern lobe
	06 42 24.46 (0.04)	21 24 39.8 (0.7)	19	galaxy in Southern lobe
0712+534	07 12 44.07 (0.03)	53 28 16.5 (0.3)	16	galaxy near Sf lobe
0755+379	07 55 14.70 (0.06)	37 54 58.6 (0.4)	17	galaxy? near Sf lobe
0802+243	08 02 30.36 (0.02)	24 18 40.3 (0.4)	16	galaxy near Np lobe
0915+320	09 15 57.03 (0.03)	32 03 51.1 (0.4)	16	spiral galaxy in field
1000+201	10 00 11.49 (0.02)	20 08 09.9 (0.5)	19	blue object in N structure
	10 00 12.28 (0.02)	20 08 08.0 (0.5)	19	galaxy? also in N structure
1102+304	11 02 42.58 (0.03)	30 25 58.2 (0.4)	18	galaxy in Eastern lobe
	11 02 37.27 (0.03)	30 25 23.4 (0.4)	19	galaxy? near Western lobe
1113+295	11 13 54.03 (0.03)	29 31 22.2 (0.4)	19	galaxy in field
	11 13 41.65 (0.03)	29 31 30.9 (0.3)	14	identification for 4C29.41A
1115+315	11 15 52.25 (0.03)	31 31 36.2 (0.5)	19	other nucleus of db
	11 15 52.04 (0.03)	31 31 58.6 (0.5)	19	galaxy? in Np lobe
1151+295	11 51 38.42 (0.06)	29 32 42.1 (0.7)	19	galaxy? in field
	11 51 38.59 (0.04)	29 32 48.4 (0.9)	19	galaxy? immediately E of source
1243+336	12 43 17.32 (0.03)	33 40 45.1 (0.4)	17	galaxy? in field
1251+278	12 51 46.54 (0.02)	27 53 43.9 (0.5)	19	blue knot near identification
1313+072	13 13 45.91 (0.02)	07 18 47.1 (0.4)	17	confusing stellar? object
1452+166	14 52 01.25 (0.02)	16 36 49.3 (0.5)	19	galaxy? near identification
1502+262	15 02 48.12 (0.02)	26 12 27.8 (0.7)	16	galaxy in field
	15 02 45.87 (0.02)	26 12 31.8 (0.7)	17	galaxy also in field
1511+263	15 11 30.79 (0.02)	26 18 32.8 (0.5)	17	other nucleus of db

TABLE II. Positions for other objects in radio fields. (Continued).

Name	R.A. (1950)	Dec(1950)	m_V	Remarks
1615+324	16 15 48.04(0.03)	32 29 03.7(0.4)	17	db galaxy near S lobe
1658+302	16 58 48.71(0.03)	30 12 23.8(0.4)	14	confusing stellar? object
1759+211	17 59 40.99(0.03)	21 09 23.0(0.7)	18	galaxy? in field
	17 59 40.74(0.03)	21 09 17.3(0.7)	17	asymmetric blue galaxy
1833+326	18 33 18.33(0.02)	32 39 46.6(0.4)	15	spiral galaxy in Nf lobe
	18 33 17.71(0.02)	32 39 47.7(0.4)	14	star confusing spiral galaxy
2229+391	22 29 08.34(0.02)	39 06 40.3(0.4)	15	galaxy? in field
2254+354	22 54 25.58(0.03)	35 25 26.8(0.4)	17	galaxy near Sf lobe
2335+267	23 35 59.15(0.06)	26 45 30.0(0.4)	14	other nucleus of db
	23 35 48.26(0.06)	26 45 30.0(0.4)	15	galaxy? near Np lobe
2357+004	23 57 24.56(0.04)	00 25 26.3(0.4)	15	other nucleus of db

1446 + 206, and 2254 + 354.

The identifications proposed for the sources 0840 + 299 and 1158 + 318 do not satisfy this criterion as it stands because they have probabilities of 1.2% and 4.8% respectively of being in the entire circular search area defined by the LAS of each source. In both cases however this probability is well below 1% if a more realistic rectangular search area defined by the LAS of the source and the FWHM of the radio components is used. These identifications are therefore relatively secure on the basis of our secondary criterion.

This criterion does not validate the identifications proposed for 1446 + 206 and 2254 + 354 as in both cases the offset between the radio centroid and the optical position is greater than 0.15 (LAS). In 1446 + 206 however the radio components are symmetrically placed around the galaxy and the offset of 0.18 (LAS) between the optical position and the centroid arises from the unusually high (~3:1) ratio of component flux densities at 2.7 GHz. Although we cannot rule out the possibility that the true identification lies near the brighter radio component and is just below the plate limit, we consider this unlikely. The identification for 2254 + 354 lies on the arc of emission defining a C-shaped "wide-angle-tail" radio structure; although a fainter galaxy in the field (Table II) is closer to the centroid of the structure than is the identification, this fainter galaxy is not actually within the radio contours. We therefore consider the identification of 2254 + 354 to be fairly secure on morphological grounds.

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