THE ASTROPHYSICAL JOURNAL, 206:364–369, 1976 June 1

REDSHIFTS OF FORTY-THREE RADIO SOURCES

MARIE-HELENE ULRICH*
Department of Astronomy, University of Texas
Received 1975 September 5

ABSTRACT

New redshifts are given for eight QSOs, 25 radio galaxies including five having head-tail radio structures, and three radio-quiet galaxies in the Coma Cluster.

Subject headings: galaxies: redshifts — quasars — radio sources: general

I. INTRODUCTION

In this paper we present redshift measurements of the optical counterparts of 43 radio sources and three radio-quiet galaxies in the Coma cluster. Eleven of the radio galaxies are optical identifications of individual radio sources lying in the direction of the Coma cluster (Abell 1656) and the Hercules cluster (Abell 2147 and 2151) (ref. Abell 1958). Eight sources are newly observed quasi-stellar objects. The other 24 sources are radio galaxies from various radio surveys.

These incidental results of various projects on radio sources are published now because they may be useful to workers investigating the properties of individual sources. We have included our results for galaxies in the Coma cluster for which radial velocities have already been given by other authors, because independent measurements are necessary for assessing the accuracy with which radial velocities of galaxies are measured, and this is particularly relevant for galaxies in clusters.

II. EQUIPMENT, OBSERVATIONS, AND MEASURES

The observations were made with the 2.7 m telescope at McDonald Observatory and the 2.1 m telescope at Kitt Peak National Observatory (KPN0). All the KPN0 spectra were obtained with a two-stage image intensifier and a 600 l mm^{-1} grating giving a dispersion of 127 Å mm^{-1} and a wavelength resolution of 5 Å. Most of the spectra obtained at McDonald Observatory were taken with the ultraviolet image-tube spectrograph (UVITS) using a two-stage image intensifier with transfer-lens output and a 300 l mm^{-1} grating giving a dispersion of 240 Å mm^{-1} and a resolution of 13 Å; a few spectra were taken with a three-stage intensifier at the same dispersion and a resolution of about 18 Å.

Each spectrum was measured twice, once with the two-coordinate Mann measuring machine at the University of California, San Diego, and a second time with the one-dimension Grant profile comparator at KPNO in Tucson. The velocities are usually measured from the K and H absorption lines of Ca II. It has been assumed that the wavelengths of the Ca II absorption lines are the same as in the solar spectrum, i.e., 3933.68 and 3968.49 Å for the K and H lines, respectively. No systematic difference was found between the velocities obtained from the K line and from the H line.

In general we find that the discrepancy between the values of the velocities obtained from two different spectra of the same galaxy or from two measurements of the same spectrum is smaller than the discrepancy between the values obtained separately from the H line and from the K line. We attribute this to the contamination of the galaxy spectrum by the spectrum of the airglow, and conclude that it is the major source of inaccuracy in the measurement of the velocity using the H and K absorption lines. The airglow contribution is particularly bothersome when observing galaxies which are of relatively low surface brightness and/or have velocities such that the H and K lines fall in the range 3900–4500 Å where the airglow spectrum is very rich. Accurate measurements of the velocities of large numbers of galaxies, as is required for investigating the velocity dispersion in clusters, will have to be obtained using devices with which sky subtraction can easily be performed. Other absorption features like the G or Mg I *b* bands or the Na I D doublet may yield more accurate velocity measurements, but we have not yet investigated this point.

When examining our plates one can see on either side of the galaxy spectrum the night-sky features which often modify the profiles of the absorption lines of the galaxy spectrum. However, in the reduction of the measures, the same weight is applied to the K and H lines except in the case of a few KPNO spectra, where one of the mercury lines at 4046 or 4358 Å falls in an absorption line. A systematic error of -30 km s^{-1} was found for the KPNO spectra taken in the spring of 1974, and a correction was applied accordingly; no systematic error was found in the data obtained at McDonald Observatory. We estimate the accuracy of our velocity measurements of a number n of galaxies by assuming that the K and H lines should give the same result, and by calculating the quantity $\sigma^2 = [\sum(\Delta V/2)^2]/n$ for the n galaxies considered, ΔV being the difference of the velocities obtained from the K

* Visiting Astronomer at Kitt Peak National Observatory which is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

TABLE 1

QUASI-STELLAR OBJECTS

Name (1)	Coordinates (2)		m (3)	z (4)	Observed Emission Lines (Wavelengths in Å) (5)	Ident. (6)
B2 0810+32.......	$08^h10^m57^s$	+32°46′39″	18.0	0.842	3515 (C III 1909), 5151 (Mg II 2798)	a
B2 1204+28.......	12 04 55	+28 11 42	18.1	2.177	3872 (Lα 1216), 4420 (Si IV 1397), 4912 (C IV 1549)	a
B2 1340+29.......	13 40 42	+28 59 12	16.5	0.905	3633 (C III 1909), 5336 (Mg II 2798)	a
B2 1351+31.......	13 51 51	+31 53 44	17.4	1.326	3603 (C IV 1549), 4425 (C III 1909), 6544 (Mg II 2798)	a
B2 1353+30.......	13 53 26	+30 38 51	18.2	1.018	3847 (C III 1909), 5662 (Mg II 2798)	a
B2 1435+31.......	14 35 31	+31 31 58	18.0	1.366	3665 (C IV 1549), 4518 (C III 1909)	a
NRAO 0742+33...	07 42 47	+33 20 55	17.7	0.610?	4507 (Mg II 2798)	b
NRAO 1555+33...	15 55 33	+33 13 25	18.3	0.942	3708 (C III 1909), 5437 (Mg II 2798)	b

and H lines. The value of σ depends on the equipment which was used for observing these n galaxies. The K and H lines were measured on 19 McDonald spectra and on 10 KPNO spectra. The values of σ for these two groups of measurements are 113 and 66 km s^{-1}, respectively. These values represent the error due to the airglow spectrum, which is the major cause of inaccuracy. After making allowances for additional smaller errors, we estimate that the measurements of the velocities of the galaxies in Tables 2 and 3 are accurate within ± 200 km s^{-1}. The accuracy is higher for the brightest galaxies like those in the Coma and Hercules clusters, because their velocities are measured on relatively short-exposure spectra. For the five galaxies in Coma for which the velocities were also measured by Tifft and Tarenghi (1975), the mean difference between the velocities measured by Tifft and Tarenghi and by us is 50 km s^{-1}.

III. RESULTS

The results of the redshift measurements are summarized in Table 1 for the quasi-stellar objects, in Table 2 for the galaxies in the directions of the clusters A1656, A2147, and A2151, and in Table 3 for the other radio galaxies. In Table 3 the radio sources are grouped according to the various projects of radio observations during which the radio positions which are listed were measured. All the optical identifications except those of the 11 radio sources at the bottom of Table 3 were made from arcsec radio positions measured with the NRAO interferometer, the Cambridge One-Mile telescope, or the Westerbork Synthesis Radio Telescope (WSRT), and are considered certain.

For the 11 radio sources at the bottom of Table 3, the standard error in the radio postitions combined with the densities of galaxies of about 16th magnitude

TABLE 2

VELOCITIES OF GALAXIES IN ABELL 1656, 2147, AND 2151

Radio Source Name (1)	Coordinates (2)		m (3)	V (4)	Lines Used (5)	Cluster Numbers (6)	Notes (7)
... .	$12^h54^m10\overset{s}{.}2$	+28°32′46″	16.0	6945 (M)	Abs. K, H	1656	1
1255+27W1......	12 55 29.7	27 53 13	15.7	20220 (K)	Abs. K, H	...	2
1255+28W3......	12 55 32.9	28 19 54	15.0	8175 (M)	Em. H, [N II], 6584	1656	3
1256+28W4a,b...	12 56 32.9	28 04	16.0	6865 (K)	Abs. K, H	1656	
1256+28W7......	12 56 37.4	28 23 07	15.5	9405 (M)	Em. H, [N II] λ6584	1656	
1257+28W2......	12 57 40.9	28 04 38	15.7	6640 (K)	Abs. K, H	1656	
... .	12 58 14.5	28 17 02	15.9	7020 (K)	Abs. K, H	1656	4
... .	12 58 16.5	28 15 58	15.7	7560 (K)	Abs. K, H	1656	
1559+16W1......	15 59 57	16 09 31	16.0	10135 (K)	Abs. K, H	2147	
1600+16W10.....	16 00 58	16 32 25	15.5	11145 (K)	Abs. K, H	2147	
1601+17W1......	16 01 16	17 20 12	15.2	10150 (M)	Abs. K, H	2151	
1601+16W3......	16 01 21	16 02 18	15.5	32820 (M)	Em. [O II], λ3727	...	5
1601+15W1a,b...	16 01 25	15 55 52	15.5	10185 (K)	Abs. K, H	2147	
1602+17W1......	16 02 11	17 52 40	14.6	12283 (M)	Abs. K, H; Em. [O II] λ3727	2151	6

NOTES ON INDIVIDUAL GALAXIES IN TABLE 2

1. Not a radio source.
2. Radio galaxy behind the Coma Cluster; Tifft and Tarenghi 1975 give $V = 20256$ km s^{-1}.
3. For this galaxy and the next three Tifft and Tarenghi 1975 give V(km s^{-1}) = 8151, 6975, 9491, and 6636 respectively.
4. This galaxy and the next one are not detected radio sources.
5. Radio galaxy behind Abell 2147.
6. Southernmost of a pair of peculiar galaxies; Chincarini and Rood 1972 give $V = 12{,}386$ km s^{-1}.

TABLE 3

REDSHIFTS OF RADIO GALAXIES

Source Name (1)	Coordinates (2)		m (3)	z (4)	Lines Used (5)	Id. (6)	Notes (7)
NRAO 0703+33..	$07^h03^m38^s$	+33°23′18″	16.5	0.0883 (M)	Em. [O III] λλ4959, 5007	b	
NRAO 0933+33..	09 33 06	33 26 42	16.5	0.0760 (M)	Abs. K, H; em. [O II] λ3727	b	
NRAO 1742+33..	17 42 25	33 00 33	16.4	0.0757 (M)	Em. [O II] λ3727	b	
4C 32.52.C.......	16 57 51	32 41 12	16.5	0.0984 (K)	Abs. K, H, G	c	
4C 32.52.A.......	16 57 08	32 34 07	16.8	0.0630 (M)	Abs. K, H; em. [O II] λ3727	c	
3C 465.A–B.......	23 32 32	27 05 39	15.5	0.0606 (M)	Abs. K, H	c	
3C 465.F.........	23 37 30	26 51 25	14.0	0.0314 (M)	Abs. K, H	c	
3C 465.H.........	23 39 28	26 32 13	16.5	0.0944 (K)	Abs. K, H	c	
4C 41.23.........	11 08 54	41 06 45	16.0	0.0737 (M)	Abs. K, H	d	9
4CT 51.29.1.......	12 00 34	51 57 15	16.5	0.0631 (M)	Abs. K, H	d	9
4C 53.37.........	16 38 24	53 52 10	16.5	0.1098 (K)	Abs. K, H	d	9
NB 78.26.........	17 06 19	78 41 53	16.5	0.0586 (K)	Abs. K, H	d	9
4CT 39.49.1.......	17 09 17	39 45 09	16.5	0.0621 (K)	Abs. K, H	d	9
B2 0008+32......	00 08 45	32 00 29	16.5	0.1073 (K)	Abs. K, H	e	
B2 0154+32......	01 54 24	32 00 06	15.5	0.0882 (M)	Abs. K. H; em. [O II] λ3727	e	
B2 0158+29......	01 58 44	29 19 14	15.5	0.1483 (K)	Abs. K, H	e	1
B2 0204+29......	02 04 11	29 16 41	16.0	0.1096 (M)	Em. [O II] λ3727, [O III] λλ4959, 5007	e	2
B2 0226+28......	02 26 45	28 45 21	14.5	0.0467 (M)	Abs. K, H	e	
B2 0327+24......	03 27 33	24 37 33	16.8	0.1070 (K)	Abs. K, H	e	
4CT 15.03.1.......	01 10 26	15 12.8 (R)	...	...	...	f	3, 4
	01 10.3	15 14 (Op)	15.0	0.0445 (M)	Abs. K, H		
4C 06.15.........	02 55 02	06 00.4 (R)	...	...	...	f	3, 5
	02 56.3	06 04 (Op)	15.5	0.0230 (M)	Abs. K, H, G		
4CT 69.05.1.......	03 43 50	69 59.9 (R)	...	...	...	f	3, 6
	03 43.3	70 00 (Op)	14.6	0.0040 (M)	Em. Hα, [N II] λ6584		
4CT 62.29.1.......	17 54 27	62 34.8 (R)	...	...	...	f	3, 7
	17 54.4	62 39 (Op)	14.8	0.0281 (M)	Abs. K, H		
4C 11.71.........	22 47 24	11 20.3 (R)	...	...	...	f	3, 8
	22 47.4	11 20 (Op)	14.4	0.0259 (M)	Abs. K, H		

NOTES ON INDIVIDUAL GALAXIES IN TABLE 3

1. 4C 29.05. Sargent 1973 gives $z = 0.1482$. Finding chart in Olsen 1970.
2. 4C 29.06. Sargent 1973 reports a Seyfert spectrum and gives $z = 0.1090$. Finding chart in Olsen 1970.
3. Top line, radio position (R); bottom line, optical position (Op) from Zwicky, Karpowicz, and Kowal 1965 and Zwicky and Kowal 1968.
4. Double galaxy (Zwicky *et al.* 1965). Brightest member of a cluster, No. 1 on Fig. 1. The other brighter member of the cluster lies 3′ NE of the quoted radio position and has a redshift of 0.0466; No. 2 on Fig. 1.
5. 3C 75. Peterson 1970 gives $z = 0.0230$, from spectra taken by M. Schmidt. Finding chart in Olsen 1970.
6. Spiral galaxy lying 3 arcmin SW of the quoted radio position. Finding chart in Fig. 1.
7. NGC 6512.
8. The declination measured at Parkes is 11°20′.2, and Clarke *et al.* 1966 identified the source with a 14.4 mag elliptical galaxy which is NGC 7385. Tritton 1972 gives $z = 0.0243$ for the galaxy identified by Clarke *et al.* 1966, but probably confused NGC 7385 with NGC 7386 which is 5′ north and 12″ west of NGC 7385. Humason *et al.* 1966 give $z = 0.0240$ for NGC 7386 and $z = 0.0261$ for NGC 7385, in agreement with our measurement. NGC 7385 and NGC 7386 are brightest members of a cluster. The radio source associated with NGC 7385 has a head-tail structure (Schilizzi and Ekers 1975).
9. These five galaxies have head-tail structures and are in the clusters Abell 1190, 1452, 2220, 2256, and 2250, respectively.

causes the proportion of misidentification to be about 10 percent (Caswell and Wills 1967; Colla *et al.* 1972). To avoid ambiguity as to which optical objects we observed, we give in Figure 1 finding charts of the galaxies for which we measured the redshifts and for which finding charts have not previously been published.

The Tables are arranged as follows: Column (1) gives the names of the radio sources; other names are given in the footnotes. Column (2) gives the 1950 coordinates of the peak of the radio sources with an accuracy of 1 to 2 arc seconds. In the few cases where there may be some ambiguity as to which galaxies we observed, finding charts are shown in Figure 1 as explained above. For more accurate radio positions or for a discussion of the precision of the coordinates, the reader is referred to the articles presenting the results of the radio observations. The apparent magnitudes listed in column (3) are taken from the original identification papers or are estimates made by the author from the *National Geographic Society–Palomar Sky Survey* E print. The redshifts or velocities *all with respect to the Sun* are listed in column (4).

A letter K or M in parentheses indicates spectrographic material obtained at KPNO or McDonald

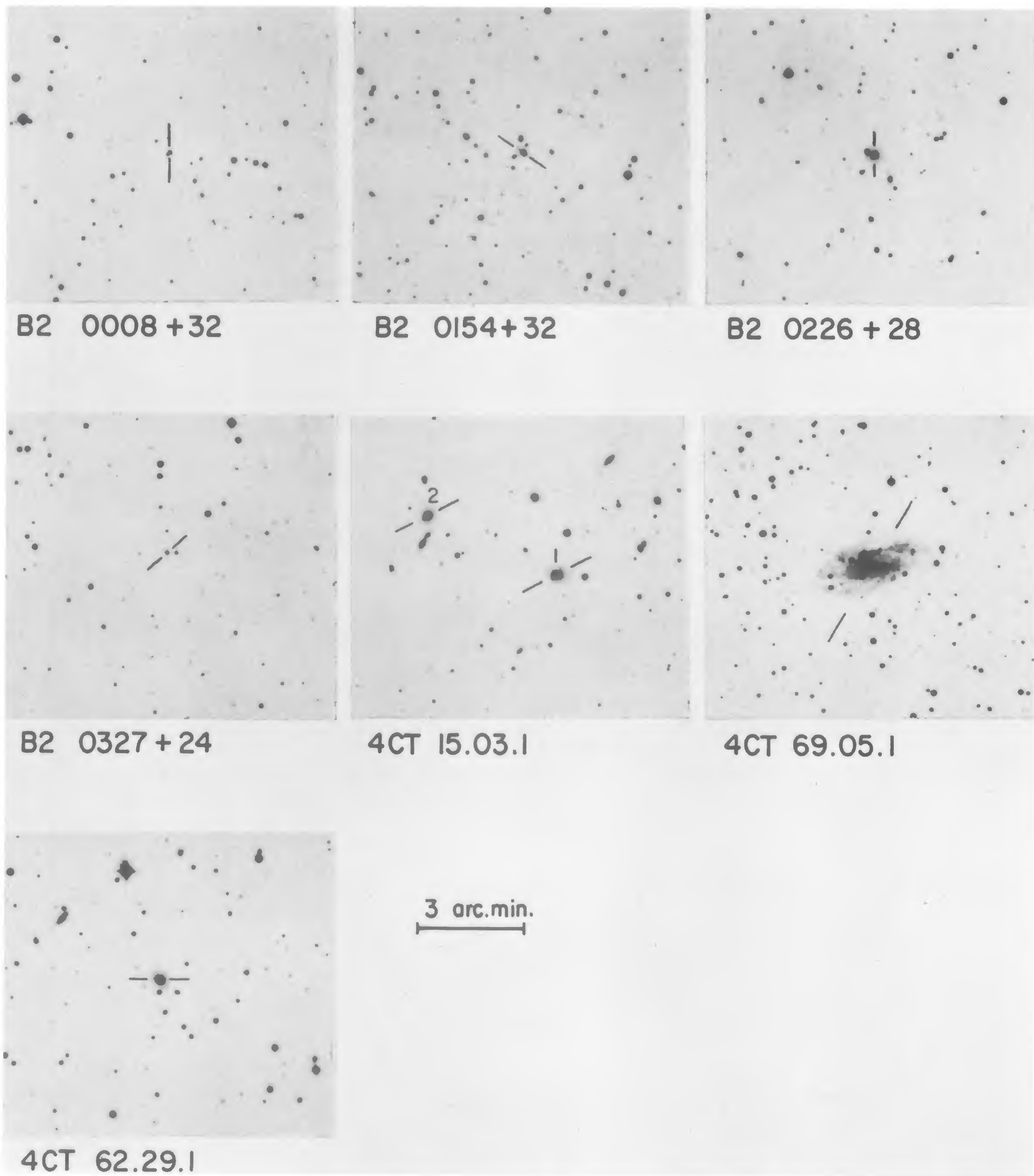

FIG. 1.—Finding charts for the B2- and 4CT-radio-galaxies for which we measured the redshifts, and for which finding charts have not previously been published. The fields are enlargements from the E prints of the Sky Survey. North at the top and east to the left. (© 1957, *National Geographic Society–Palomar Observatory Sky Survey*, permission granted).