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REDSHIFTS OF SOUTHERN RADIO SOURCES

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ABSTRACT

Redshifts derived from observations with the image-tube dissector scanner on the 4 m Anglo-Australian Telescope are reported for 23 objects associated with southern radio sources. Included are redshifts for two QSO pairs with component separations of about 1′, one QSO–galaxy pair where the QSO lies within twice the galaxy's radius, and one QSO with no ultraviolet excess. Absorption lines were found in the spectra of five QSOs.

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

I. INTRODUCTION

The work reported here is part of a program designed to provide comprehensive optical and radio data for southern QSOs selected from the Parkes 2700 MHz radio surveys. Our primary aim is to examine the properties of QSOs found in short-wavelength radio surveys for comparison with the QSOs from the longer-wavelength surveys.

For the Parkes sources, two main criteria are being used to establish the optical identifications. Where radio positions of moderate accuracy ($\sim 10''$) are available, the identification is based upon an ultraviolet excess as shown by two-color photography (cf. Shimmins *et al.* 1971). Radio positions of high accuracy ($\leq 2''$) are being measured with the NRAO three-element interferometer; and where these are available, the identifications are based on radio-optical position coincidence, without reference to color or morphology. These two approaches will allow an assessment of the effects of color selection in QSO identification.

II. THE OBSERVATIONS

The image-tube dissector scanner (Robinson and Wampler 1972) at the f/15 focus of the Anglo-Australian Telescope (Wampler 1975) was used to obtain spectrum scans covering the wavelength range 3500–6100 Å with a resolution of 7 Å. Scans of 30 objects were obtained on the nights of 1975 September 7, 8, 9, and 10 while the seeing disk was 3″ or less.

The 23 objects for which redshifts have been determined are given in Table 1. In the case of the QSO pairs, the QSO on the radio position is designated by /R and the other QSO in the pair is designated /2. In the case of the QSO–galaxy pairs, the QSO on the radio position is designated by /Q and the galaxy by /G. The positions in Table 1 are accurate to about 6″ except for those sources with positions given to 0″.1 where the accuracy is better than 1″. The magnitudes in Table 1 are from the blue image on the two-color plates or from the Palomar Sky Survey prints. Optical variables are indicated by parentheses. The radio flux densities are from the New Parkes Catalogue (Bolton 1975). The line measurements and identifications used to determine the redshifts are given in Table 2. The line-to-continuum ratio is the ratio of the peak line intensity to the continuum at the center. The line width is the full width at half-maximum intensity.

In addition to the QSOs for which we have determined redshifts, four other objects can be classified as probable QSOs on the basis of color and positional agreement. These are 0047+023 with a probable line at λ6008 and 0422−380 with a probable line at λ4690. The two other objects have apparently continuous spectra with no emission lines. These are 0118−272 and 1953−325/Q.

Three objects that we observed are clearly stars. These are the object suggested as the identification for 0045−000 by Balonek, Condon, and Jauncey (1976), the blue object that they noted just south of the QSO 0044+030, and the object south of the QSO 0035−39.

a) Notes on Individual Objects

0046−315.—Observations at low dispersion covering the wavelength range 4200–7400 Å were obtained in November. The lines of C IV λ1549 and C III] λ1909 were seen at λ5765 and λ7115, respectively. The line-to-continuum ratio for Lα had increased to 2.51, and the object was fainter in November by about 1 mag.

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TABLE 1

Radio Sources with Redshifts

Parkes source number	R.A. (1950.0) h m s	Dec. (1950.0) ° ' "	Optical type	mag	Redshift z	Radio flux density 2700 MHz (Jy†)	5000 MHz (Jy†)	Finding chart reference
0035-39	00 36 02.3	-39 16 13	QSO	16.5	0.592	0.85	0.44	2
0044+030	00 44 31.36	+03 03 32.9	QSO	16	0.624	0.09		5
0046-315	00 46 57.9	-31 32 48	QSO	(16.5)	2.721	0.15		2
0047-579	00 47 48.3	-57 54 48	QSO	18.5	1.797	1.96	2.19	4
0054-006	00 54 43.42	-00 40 45.1	QSO	18	2.795	0.11		5
0208-512	02 08 56.9	-51 15 08	QSO	17.5	1.003	3.56	3.21	4
0222+000	02 22 34.25	+00 03 36.7	QSO	18	0.523	0.14		6
0234-301	02 34 22.0	-30 06 52	QSO	18	2.102	0.42	0.52	2
0254-334/R	02 54 39.6	-33 27 20	QSO	(17)	1.915	0.37	0.53	2
0254-334/2	02 54 44.8	-33 27 24	QSO	16	1.849	radio quiet		2
0402-362	04 02 02.2	-36 13 16	QSO	16	1.417	1.04	(1.5)	1
0537-441	05 37 20.5	-44 06 40	QSO	(15.5)	0.894	3.84	(3.96)	1
1953-325/G	19 53 51.0	-32 34 27	Galaxy	15	0.018	radio quiet		2
2020-370/G	20 20 30.7	-37 04 49	Galaxy	15	0.027	radio quiet		1
2020-370/Q	20 20 31.99	-37 05 02.8	QSO	17.5	1.048	0.45	0.39	1
2024-217	20 24 09.1	-21 46 16	QSO	19	0.463	0.59	0.43	3
2044-168	20 44 30.72	-16 50 08.2	QSO	17	1.946	0.77	0.80	3
2143-156/R	21 43 38.81	-15 39 36.7	QSO	17.5	0.700	1.11	0.82	3
2143-156/2	21 43 44.4	-15 41 05	QSO	18.5	2.055	radio quiet		3
2208-137	22 08 42.7	-13 42 59	QSO	17	0.392	0.71	0.53	3
2246-309	22 46 32.5	-30 55 00	QSO	17	1.307	0.29		2
2255-282	22 55 22.32	-28 14 25.7	QSO	17	0.926	1.38	1.73	3
2335-18	23 35 19.8	-18 09 09	QSO	17.5	1.441	0.69	0.59	7

† 1 Jy (Jansky) = 10^{-26} Wm^{-2} Hz^{-1}.

Finding chart references: (1) - Peterson and Bolton (1972); (2) - Peterson and Bolton (1973); (3) - Peterson et al. (1973); (4) - Savage (1975); (5) - Balonek et al. (1976); (6) - Bolton and Wall (1970); (7) - Bolton and Ekers (1967).

0047−579.—Both the Lα λ1216 and the C IV λ1549 lines are asymmetric due to blue shifted absorption with strong wings extending to the short-wavelength side of the absorption line core. The radio source is variable at 2700 MHz.

0054−006.—Both Lα and C IV have asymmetric profiles from absorption features on their short-wavelength sides.

0222+000.—Observations at low dispersion covering the wavelength range 4200–7400 Å were obtained in November. The possibility that the strong line at λ4260 is Lα instead of Mg II is ruled out by the absence of C IV and C III], and identification of the line with Mg II is supported by possible lines at λλ5216 and 5898 which may be due to [Ne V] and [Ne III], respectively.

0234−301.—There is an absorption dip 260 Å to the short-wavelength side of the Lα emission line.

0254−334/2.—The lines of N V λ1240 and C IV λ4401 are asymmetric due to redshifted absorption from several components with strong wings to the short-wavelength side of the absorption cores. This object has a rich absorption spectrum and deserves further study.

0537−441.—This object is a violent optical variable (Peterson and Bolton 1972). No lines were found on previously obtained image-tube spectra.

2143−156/R.—The strong line at λ4757 could be either Mg II or Lα. Prior observations by Wills and Wills (see Wills 1974) yielded a single line at λ4765 ± 20. Further observations in the red are required in order to confirm the redshift.

2143−156/2.—Prior observations by Wills and Wills (see Wills 1974) gave a redshift of $z = 2.07$.

2044−168.—The Lα λ1216 and C IV λ1549 emission lines have absorption counterparts blueshifted by 2000 km s^{-1}.

2208−137.—The strong line at λ3896 could be either Mg II or Lα. Further observations in the red to confirm the redshift are required.

III. DISCUSSION

a) QSO Pairs

Eleven candidate QSO pairs, consisting of an ultraviolet-excess object on the position of a flat-spectrum radio source and (within a radius of about 1′) a second ultraviolet-excess object, and two candidate QSO–galaxy pairs, consisting of a galaxy and (within twice the galaxy's radius) an ultraviolet-excess object on the position of a flat spectrum radio source, have been found on two-color (blue and ultraviolet) plates (Peterson and Bolton 1972, 1973; Peterson, Bolton, and Shimmins 1973; Peterson, Bolton, and Savage 1976).

Both pairs of these ultraviolet-excess objects that we examined are confirmed as QSO pairs. There appears to be no obvious relationship between the redshifts of the two QSOs in each pair. The redshift difference for the 0254−334 pair is 0.066 while for 2143−156 it is 1.355. This brings the total confirmed number of close QSO pairs to six (Wampler *et al.* 1973; Stockton 1972; Wills 1974; Browne, Savage, and Bolton 1975).

A preliminary estimate of the statistical significance of pairs, based upon the surface density of ultraviolet-

TABLE 2

Line Measurements and Identifications

Parkes source number	Redshift z	Observed wavelength λ_o	Identifications	Emitted wavelength λ_e	$\lambda_o/(1+z)$	Line to continuum ratio	Line width $\Delta\lambda$
0035-39	0.592	4447	Mg II	2798	2793	1.55	84
		5945	[O II]	3727	3734	1.59	28
0044+030	0.624	4544	Mg II	2798	2799	1.51	94
		6050	[O II]	3727	3726	1.26	39
0046-315	2.721	4523	Ly-α	1216	1216	1.61	43
		4615	N V	1240	1240	1.16	38
		5202	Si IV]	1397	1398	1.09	28
0047-579	1.797	3896	Si IV]	1397	1393	2.47	63
		4332	C IV	1549	1549	1.58	50
		4632	He II	1640	1656	1.10	63
		"	O III]	1664	"	"	"
		5336	C III]	1909	1908	1.18	100
0054-006	2.795	4606	Ly-α	1216	1214	3.01	150
		5888	C IV	1549	1552	2.54	45
0208-512	1.003	3816	C III]	1909	1905	1.39	71
		5617	Mg II	2798	2804	1.28	73
0222+000	0.523	4260	Mg II	2798	2798	1.62	63
		4339	[A IV]	2854	2850	1.32	38
0234-301	2.102	3788	Ly-α	1216	1221	3.03	85
		3841	N V	1240	1238	2.11	60
		4344	Si IV]	1397	1400	1.34	74
		"	O IV]	1406	"	"	"
		4793	C IV	1549	1545	1.84	98
0254-334/R	1.915	3545	Ly-α	1216	1216	5.04	75
		3595	N V	1240	1233	3.13	48
		4516	C IV	1549	1549	3.52	53
0254-334/2	1.849	3531	N V	1240	1239	1.84	141
		4401	C IV	1549	1545	1.84	114
		5457	C III]	1909	1915	1.43	223
0402-362	1.417	3749	C IV	1549	1551	1.55	64
		4607	C III]	1909	1906	1.10	80
0537-441	0.894	3617	C III]	1909	1909	1.85	29
		5300	Mg II	2798	2798	1.63	39
1953-325/G	0.018	4004	K Ca II	3934	3932	0.52	15
		4041	H Ca II	3968	3968	0.61	19
		4383	G CH	4304	4304	0.77	15
		4949	H-β	4861	4859	0.86	26
		5274	Mg I	5175	5179	0.78	31
		6003	D Na I	5892	5894	0.79	10
2020-370/G	0.027	3830	[O II]	3727	3728	2.32	19
		4994	H-β	4861	4860	2.30	10
2020-370/Q	1.048	3908	C III]	1909	1908	1.50	78
		5735	Mg II	2798	2800	1.61	73
2024-217	0.463	4093	Mg II	2798	2798	2.76	75
		4160	[A IV]	2854	2843	1.93	33
		5011	[Ne V]	3426	3425	1.56	45
		5453	[O II]	3727	3728	2.07	31
2044-168	1.946	3589	Ly-α	1216	1218	3.90	41
		4556	C IV	1549	1546	2.35	73
2143-156/R	0.700	4757	Mg II	2798	2798	1.64	64
2143-156/2	2.055	3718	Ly-α	1216	1217	3.00	95
		4727	C IV	1549	1547	2.43	75
2208-137	0.392	3896	Mg II	2798	2798	1.54	85
2246-309	1.307	3577	C IV	1549	1550	2.86	125
		4398	C III]	1909	1907	1.77	80
2255-282	0.926	3675	C III]	1909	1909	1.52	75
		5389	Mg II	2798	2799	1.71	63
2335-18	1.441	3772	C IV	1549	1545	1.24	91
		4632	C III]	1909	1913	1.35	56

excess objects, has been reported by Wall (1974), who found the probability of chance to be 1 in 10^3. It remains to be seen how many more of the ultraviolet-excess object pairs are QSO pairs.

Scans were also obtained of the QSO–galaxy pairs associated with the Parkes sources 2020−370 and 1953−325. (See Peterson 1974 for photographs of the fields.) Redshifts were derived for both the QSO and galaxy of the 2020−370 pair and for the galaxy of the 1953−325 pair. No lines could be seen in the spectrum of the QSO associated with 1953−325. In the case of 2020−370, redshifts were obtained for both the galaxy and the QSO.

b) QSOs without an Ultraviolet Excess

There are now three QSOs with redshifts between 2 and 3 that have a flat radio spectrum, but do not have an ultraviolet excess. These are 0458−02, $z = 2.286$, 2256+017, $z = 2.663$ (Strittmatter *et al.* 1974), and 0054−006, $z = 2.795$ (this paper). In each case, the presence of Lα in the B filter band offsets the ultraviolet flux in the continuum and causes the lack of ultraviolet excess. This amply confirms the point made earlier by Bahcall and Sargent (1967) and demonstrates the strong selection against QSOs in this redshift range unless identifications are based on accurate radio and optical positions.

REFERENCES

Bahcall, J. N., and Sargent, W. L. W. 1967, *Ap. J. (Letters)*, **148**, L65.
Balonek, J. J., Condon, J. J., and Jauncey, D. L. 1976, *A.J.*, in press.
Bolton, J. G. 1975, private communication (computer printout available on request).
Bolton, J. G., and Ekers, Jennifer. 1967, *Australian J. Phys.*, **20**, 109.
Bolton, J. G., and Wall, J. V. 1970, *Australian J. Phys.*, **23**, 789.
Browne, I. W. A., Savage, Ann, and Bolton, J. G. 1975, *M.N.R.A.S.*, **173**, 87P.
Peterson, Bruce A. 1974, in *IAU Symposium 58, The Formation and Dynamics of Galaxies*, ed. John R. Shakeshaft (Dordrecht and Boston: Reidel), pp. 221–223.
Peterson, B. A., and Bolton, J. G. 1972, *Ap. Letters*, **10**, 105.
———. 1973, *ibid.*, **13**, 187.
Peterson, B. A., Bolton, J. G., and Savage, Ann. 1976, *Ap. Letters*, in press.
Peterson, B. A., Bolton, J. G., and Shimmins, A. J. 1973, *Ap. Letters*, **15**, 109.
Robinson, L. B., and Wampler, E. J. 1972, *Pub. A.S.P.*, **84**, 161.
Savage, Ann S. 1976, *M.N.R.A.S.*, in press.
Shimmins, A. J., Bolton, J. G., Peterson, B. A., and Wall, J. V. 1971, *Ap. Letters*, **8**, 139.
Stockton, A. N., 1972, *Nature Phys. Sci.*, **238**, 37.
Strittmatter, P. A., Carswell, R. F., Gilbert, G., and Burbidge, E. M. 1974, *Ap. J.*, **190**, 509.
Wall, J. V. 1974, in *Proc. ESO/SRC/CERN Conference on Research Programmes for the New Large Telescope*, ed. A. Reiz (Geneva: ESO/CERN), pp. 267–268.
Wampler, E. J. 1975, *Sky and Tel.*, **50**, 224.
Wampler, E. J., Baldwin, J. A., Burke, W. L., Robinson, L. B., and Hazard, C. 1973, *Nature*, **246**, 203.
Wills, D. 1974, *Observations of QSO Pairs* (a contribution to the December 10 HEAD–AAS discussion at Gainesville, Florida).

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