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REDSHIFTS OF SOUTHERN RADIO SOURCES. IV.

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ABSTRACT

We present the results of further low-dispersion spectroscopic observations using the Anglo-Australian 4 m telescope for 32 objects identified with Parkes radio sources. Included are redshifts for 26 QSOs and one radio galaxy. Three of the QSOs have redshifts in excess of 2.5 and one of these has a redshift of 3.1. Two other QSOs probably have low-redshift ($z < 1.0$) absorption systems.

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

I. INTRODUCTION

We present further observations from a continuing program designed to provide comprehensive optical and radio data for southern QSOs selected from the Parkes 2700 MHz survey. As this is a high-frequency radio survey, it contains an unusually large number of flat-spectrum ($\alpha > -0.5$, where $S_\nu \propto \nu^\alpha$) radio sources, relative to surveys made at lower frequencies.

A flat radio spectrum for a source almost always indicates a compact nature and, if accurate radio positions ($<2''$) are obtained, such sources can be identified with optical objects, normally QSOs, with a high degree of confidence.

The general aims of our program have been described in earlier papers (Peterson *et al.* 1976; Wright *et al.* 1977; Jauncey *et al.* 1978; hereafter Papers I, II, and III, respectively). In particular, we now have near completion a complete sample of strong, flat-spectrum radio sources located between declinations $-30°$ and $-4°$ for which accurate ($<2''$) positions have been measured by using the NRAO three-element interferometer (Condon, Hicks, and Jauncey 1977). Such a sample is likely to be the first that can be *completely* identified optically.

II. OBSERVATIONS

Most of the observations were made on the nights of 1978 February 11, 12, and 13 with the Image Photon-Counting System (Boksenberg 1972) and the RGO spectrograph at the f/8 Cassegrain focus of the 4 m Anglo-Australian telescope (AAT). The spectral scans covered the wavelength region from approximately 3200 Å to 7000 Å with a resolution of about 7 Å.

A small number of scans were also acquired on the night of 1978 March 14 using the Image Dissector Scanner (Robinson and Wampler 1972) on the Boller and Chivens spectrograph at the f/15 Cassegrain focus of the AAT. This system is now equipped with a blue-sensitive tube (unlike the system for the observations described in Papers II and III), and the wavelength region covered at reasonable efficiency was again approximately 3200 Å to 7000 Å but with a slightly lower resolution of about 10 Å.

The 27 objects for which redshifts could be determined are given in Table 1. The positions (generally optical) normally have a standard error of 1″ except where a smaller number of significant figures indicates positions accurate only to about 6″. The identifications given are those suggested by the original authors (not ourselves). We would now classify all the objects in Table 1 as QSOs with the exception of PKS 0959−443, which we suggest (see note) is a compact galaxy.

The abbreviations used in the identification column are: BSO, blue stellar object (as determined from comparison of the Palomar prints); QSO, a quasi-stellar object with confirmed ultraviolet excess; Q?, a suggested QSO but without confirmed ultraviolet excess; RG, red galaxy; BG, blue galaxy. Throughout both this table and Table 2, properties which are uncertain or values of relatively low accuracy are given in parentheses.

The magnitudes given, again from the original references, are blue or photographic magnitudes and have a standard error of approximately 0.5 mag. We

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TABLE 1

OBJECTS WITH REDSHIFTS

Name PKS	R.A. (1950)	Decl. (1950)	I.D.*	m_{pg}	z	S_{2700} (Jy)	S_{5000} (Jy)	Observing Session	Finding Chart Ref.
0406−127....	$04^h06^m45^s.42$	−12°46′40″.9	BSO	18.5	1.563	0.59	0.61	Feb	A
0414−189....	04 14 23.32	−18 58 26.2	(B)SO	18.5	(0.402)	1.18	1.31	Feb	A
0435−300....	04 35 38.97	−30 00 02.6	BSO	17.5	1.328	0.75	0.50	Feb	B
0454−22.....	04 54 02.2	−22 03 56	Q?	17.0	0.534	1.36	0.90	Feb	C
0522−611....	05 22 00.49	−61 10 41.2	QSO	18.5	1.400	0.71	0.67	Mar	D
0537−286....	05 37 56.90	−28 41 26.8	R(G)	20.0	3.11	0.74	0.99	Feb	A
0537−158....	05 37 17.34	−15 52 08.0	BSO	18.0	0.947	0.63	0.61	Feb	A
0606−223....	06 06 53.42	−22 19 47.2	(B) (SO)	20.0	1.926	1.00	1.36	Feb	B
0845−051....	08 45 29.55	−05 09 26.7	BSO	19.0	1.242	0.49	0.40	Feb	A
0902−256....	09 02 40.83	−25 40 50.9	BSO	19.0	1.635	0.50	0.47	Feb	A
0915−213....	09 15 10.34	−21 18 54.6	BSO	18.5	0.847	0.59	0.54	Feb	B
0919−260....	09 19 16.67	−26 05 53.5	BSO	19.0	2.300	1.15	1.28	Feb	A
0959−443....	09 59 58.91	−44 23 25.1	QSO	17.0	0.021	0.87	0.83	Feb	E
1004+141....	10 04 59.80	+14 11 10.4	B(SO)	18.0	2.713	0.77	0.72	Feb	F
1032−199....	10 32 37.33	−19 55 59.3	BSO	19.0	2.198	1.10	1.15	Feb	A
1148−171....	11 48 30.45	−17 07 19.9	B(G)	19.0	1.751	0.60	0.50	Feb	A
1156−221....	11 56 37.77	−22 11 55.0	BSO	19.5	0.565	0.71	0.78	Mar	A
1200−051....	12 00 00.63	−05 11 24.1	BSO	18.0	0.381	0.50	0.46	Feb	A
1203−26.....	12 02 58.63	−26 17 18.2	BSO	19.5	0.790	1.34	0.99	Feb	A
1232−249....	12 32 59.4	−24 55 46	QSO	17.2	0.356	1.10	0.61	Mar	G
1243−072....	12 43 28.8	−07 14 24	QSO	18.0	(0.267)	0.79	1.11	Feb	A
1403−085....	14 03 21.88	−08 33 56.8	BSO	19.0	1.763	0.71	0.58	Feb	H
1405−287....	14 05 56.26	−28 46 08.4	BSO	19.0	0.575	0.34	0.29	Mar	B
1430−178....	14 30 10.56	−17 48 23.2	BSO	19.5	2.331	1.00	0.93	Mar	H
1502+106....	15 02 00.20	+10 41 16.8	BSO	18.5	(0.567)	1.74	2.04	Mar	I
1542+042....	15 42 29.80	+04 17 06.2	BSO	18.0	2.182	0.53	0.47	Mar	J
1556−245....	15 56 41.22	−24 34 11.3	BSO	19.0	2.813	0.69	0.54	Mar	B

* The identification given is that originally proposed. We would now class all these objects as QSOs, with the exception of PKS 0959−443, which we believe to be a compact galaxy (see note).

REFERENCES.—[A] Bolton *et al.* 1975; [B] Condon *et al.* 1977; [C] Merkelijn 1969; [D] Savage *et al.* 1976; [E] Peterson and Bolton 1972; [F] Shimmins *et al.* 1975; [G] Bolton and Ekers 1966; [H] Peterson *et al.* 1973; [I] Blake 1970; [J] Jauncey and Hazard 1970.

TABLE 2

DETAILS OF INDIVIDUAL SPECTRA

Name PKS	Mean Redshift $\bar{z}$	Observed Wavelength λ_{obs} (Å)	I.D.	Emitted Wavelength λ_{em} (Å)	$\lambda_{obs}/(1+\bar{z})$	z	Line-to-Continuum Ratio (l)	$\Delta\lambda_{1/2}$ (Å)
0406−127......	1.563	3966	C IV	1549	1547	1.560	+0.83	60
		4905	C III]	1909	1914	1.569	+0.51	80
0414−189......	0.402	3916	Mg II	2798	2793	0.400	+1.1	85
		(4124)	[Mg V]	2931	(2942)	(0.407)	+(1.0)	N.R.
		(4800)	[Ne V]	3426	(3424)	(0.401)	+(1.0)	(25)
0435−300......	1.328	3606	C IV	1549	1548	1.328	+0.81	50
		4436	C III]	1909	1905	1.324	+0.35	70
		(6529)	Mg II	2798	2805	(1.33)	+(0.7)	(50)
0454−22.......	0.534	4292	Mg II	2798	2798	0.534	+0.95	100
		(4508)	[Mg V]	2931	(2939)	(0.538)	+(0.1)	(25)
0522−611......	1.400	(3719)	C IV	1549	1550	(1.401)	+(0.6)	(100)
		4575	C III]	1909	1906	1.397	+0.5	180
0537−286......	3.11	4238	Lβ/O VI	(1030)	1031	(3.115)	+0.9	(60)
		5000	Lα	1216	1217	3.112	+1.7	(110)
		(5090)	N V	1240	(1238)	(3.105)	+1.0	(70)
		(6302)	C IV	1549	(1533)	(3.068)	+(1.0)	...
0537−158......	0.947	3719	C III]	1909	1910	0.948	+0.44	60
		5441	Mg II	2798	2795	0.945	+0.44	(90)
0606−223......	1.926	3553	Lα	1216	1214	1.922	+4.0	(30)
		4536	C IV	1549	1550	1.928	+3.4	30
		(5586)	C III]	1909	1909	1.926	+0.7	(80)
0845−051......	1.242	3477	C IV	1549	1551	1.245	+0.67	70
		4275	C III]	1909	1907	1.239	+0.55	90
		(6300)	Mg II	2798	(2810)	(1.252)	+(1.0)	(60)
0902−256......	1.635	4078	C IV	1549	1548	1.633	+0.95	(90)
		5035	C III]	1909	1911	1.638	+0.3	(100)
0915−213......	0.847	3522	C III]	1909	1907	0.845	+1.2	70
		5176	Mg II	2798	2802	0.850	+1.5	70

TABLE 2—*Continued*

Name PKS	Mean Redshift $\bar{z}$	Observed Wavelength λ_{obs} (Å)	I.D.	Emitted Wavelength λ_{em} (Å)	$\lambda_{obs}/(1+\bar{z})$	z	Line-to-Continuum Ratio (l)	$\Delta\lambda_{1/2}$ (Å)
0919−260......	2.300	3402	Lβ/O VI	(1030)	1031	2.303	+1.0	(50)
		(4000)	Lα	1216	(1212)	(2.289)	+2.6	50
		4606	Si IV/O IV]	(1400)	1396	2.290	+0.5	(100)
		5110	C IV	1549	1548	2.299	+1.3	80
		(6310)	C III]	1909	1912	(2.305)	+0.5	(50)
0959−443......	0.021	4030A	Ca II H and K	(3950)	3947	(0.02)	...	...
		4394A	G	4303	4304	0.021	−0.3	45
		4962A	Hβ	4861	4860	0.021	−0.1	25
		5275A	Mg I	5170	5167	0.020	−0.2	45
1004+141......	2.713	4514	Lα	1216	1216	2.713	+2.6	(80)
		4610	N V	1240	1242	2.718	+1.0	(50)
		(5750)	C IV	1549	(1549)	2.712	+1.0	(70)
1032−199......	2.198	(3335)	O VI	1035	(1043)	(2.222)	+(1.0)	70
		3886	Lα	1216	1215	2.196	+2.7	60
		(4470)	Si IV/O IV]	(1400)	(1398)	(2.193)	+0.5	...
		4960	C IV	1549	1551	2.202	+1.7	(60)
1148−171......	1.751	3345	Lα	1216	1216	1.751	+1.6	50
		(3870)	Si IV/O IV]	(1400)	1407	(1.764)	+0.7	(50)
		4260	C IV	1549	1549	1.750	+1.5	60
		(5260)	C III]	1909	1912	(1.755)	+0.9	(80)
1156−221......	0.565	4380	Mg II	2798	2799	0.565	+1.0	50
		5833	[O II]	3727	3727	0.565	+2.0	20
1200−051......	0.381	3868	Mg II	2798	2801	0.382	+0.55	25
		5148	[O II]	3727	3728	0.381	+0.80	N.R.
		5992	Hγ	4340	4339	0.381	+1.0	(30)
		6714	Hβ	4861	4862	0.381	+1.5	30
		6910	[O III]	5007	5004	0.380	+2.0	N.R.
1203−26.......	0.790	3421	C III]	1909	1911	0.792	+(4.0)	(60)
		5000	Mg II	2798	2793	0.787	+2.2	80
1232−249......	0.356	(3810)	Mg II	2798	(2810)	(0.362)	+(0.5)	(60)
		4642	[Ne V]	3426	3423	0.355	+0.29	30
		5054	[O II]	3727	3727	0.356	+0.57	25
		5250	[Ne III]	3869	3872	0.357	+0.38	35
		5548	Hδ	4102	4091	0.353	+0.29	(60)
		5882	Hγ	4340	4338	0.355	+0.60	50
		6592	Hβ	4861	4861	0.356	+1.0	(40)
		6728	[O III]	4959	4926	0.357	+2.2	30
		6794	[O III]	5007	5010	0.357	+5.5	30
1243−072......	(0.267)	3540	Mg II	2798	2794	0.265	+1.2	40
		4351	[Ne V]	3426	3434	0.270	+0.3	N.R.
		(4730)	[O II]	3727	(3733)	(0.269)	...	...
1403−085......	1.763	3358	Lα	1216	1215	1.762	+2.0	(60)
		(3871)	Si IV/O IV]	(1400)	(1401)	(1.765)	...	...
		4278	C IV	1549	1548	1.762	+1.9	60
1405−287......	0.575	4408	Mg II	2798	2799	0.575	+0.48	40)
		4520	[Ar IV]	(2860)	2870	(0.580)	+(0.1)	(30)
		5866	[O II]	3727	3724	0.574	+(0.2)	N.R.
1430−178......	2.331	3427	Lβ/O VI	(1030)	1029	(2.327)	+(1.0)	(30)
		4051	Lα	1216	1216	2.331	+2.9	55
		(4650)	Si IV/O IV]	(1400)	(1396)	(2.321)	+0.6	...
		5160	C IV	1549	1549	2.331	+1.6	40
1502+106......	(0.567)	4388	Mg II	2798	2800	0.568	+1.6	90
		5020	He II	3203	3203	0.567	+0.7	30
		5354	[Ne V]	3426	3417	0.563	+1.2	45
1542+042......	2.182	3871	Lα	1216	1217	2.183	+3.4	45
		4196	?	...	1319	...	+1.3	60
		4927	C IV	1549	1548	2.181	+1.5	60
1556−245......	2.813	4636	Lα	1216	1216	2.813	+2.4	80
		(4710)	N V	1240	1235	(2.798)	+1.3	60
		5900	C IV	1549	1547	2.809	+2.2	70

point out however, that flat-spectrum, radio-selected QSOs are frequently optically variable. The radio flux densities at 2700 MHz and 5000 MHz are from the most recent Parkes measurements. The observing session referred to is either 1978 February or 1978 March, as described above.

Measurements of the strengths and widths of the emission lines used to determine the redshifts are given in Table 2. As mentioned above, values given in parentheses are of relatively low accuracy. The line-to-continuum ratio (l) is the excess height of the line above the continuum divided by the height of the continuum and is therefore negative for absorption features. The line width ($\Delta\lambda_{1/2}$) is the full width at half-maximum intensity. The abbreviation N.R. means that the line was not resolved in our spectrum. No values are given where the data are very poor. It should be noted that line-to-continuum ratios and line widths do not provide meaningful data on equivalent widths if the lines are not resolved or have severely non-Gaussian profiles.

In addition to the objects in Tables 1 and 2 for which redshifts could be obtained, the following objects were found to have continuous spectra in that no emission or absorption lines were seen with $|l| > 0.15$; PKS 0346−163, 0823−223, 0829+046, and 0851+202. References to finding charts and flux densities for these objects are found in Condon *et al.*

The object suggested as the identification (Bolton, Shimmins, and Wall 1975) for PKS 0618−252 was found to have a normal stellar-type spectrum with redshift $|z| < 0.005$. It is therefore probably a galactic star misidentified with the radio source.

III. NOTES ON INDIVIDUAL OBJECTS

0414−189.—The redshift is based essentially on only one line and is therefore uncertain. In addition, the line at 3916 Å is broad and asymmetrical, suggesting self-absorption on the short-wavelength side, which is more typical of C IV λ1549. However, we have no evidence for C III] λ1909 at the expected wavelength of about 4825 Å.

0454−22.—The signal-to-noise ratio obtained on this object was very good. There is a strong, broadened absorption line at 4123 Å which we identify with the Mg II λλ2796, 2803 doublet and further probable absorption features near 3820, 3510, and 3470 Å which we identify with the normally occurring lines of Fe II λλ2600, 2383, and 2344, respectively. We believe this establishes an absorption system at a redshift of 0.477.

0537−286.—This very high-redshift object was originally identified on the Palomar plates as a red probable galaxy. It has a prominent absorption system containing the Lyman series and a strong Lyman continuum discontinuity, all at a redshift of 2.976. It will be discussed in more detail in a separate paper (Wright *et al.* 1978).

0902−256.—The C IV λ1549 emission line is strongly self-absorbed to the short-wavelength side. It also contains a strong absorption line at about 4120 Å *longward* of the emission line.

0959−443.—The redshift originally given by us (0.84) for this object (Paper II) was incorrect. Our present data, with improved signal-to-noise ratio, show it to possess no emission lines but a strong, galaxy-type absorption system at a redshift of 0.021. The object appears stellar on the ESO B survey plate (size $\lesssim 2''$), and we therefore class it as a very compact galaxy.

1004−141.—A redshift has already been suggested for this object by Wills and Wills (1976) and our value is consistent with theirs. We also confirm their suggestion of a rather unusual profile for the Lα λ1216 line.

1203−26.—Both the C III] λ1909 and Mg II λ2798 lines are unusually strong in this object. In addition, there appear to be several absorption features lying on the short-wavelength side of the Mg II line.

1243−072.—This object contains strong absorption lines at 4023, 3733, and 3710 Å and a weaker line at 3421 Å. These can be identified as Mg II λ2798, Fe II λ2600, Fe II λ2587, and Fe II λ2383, respectively, in a single absorption system at redshift 0.436. This redshift is substantially greater than the suggested emission redshift (0.267) and is thus highly unusual. We therefore considered whether the strong emission line at 3540 Å could be the C IV λ1549 doublet at a redshift of 1.285. However, the line observed at 4351 Å is probably too narrow and has too small an equivalent width to be the C III] λ1909 line at this redshift, and there is also no evidence for a strong Mg II λ2798 line at the predicted wavelength of 6395 Å.

1502+106.—There have been several previous observations of this object in the past: Burbidge and Strittmatter (1972) gave a redshift of 0.572 on the basis of a medium-strength line at 4400 Å as Mg II λ2798 and weaker lines at 5383 and 6238 Å as [Ne V] λ3426 and [Ne III] λ3869, respectively. Smith *et al.* (1977), however, suggested a redshift of 1.833 by identifying the line at 4400 Å as C IV λ1549, the line near 5390 Å as C III] λ1909, and a line near 3444 Å as Lα λ1216. Our own spectrum places the line near 5380 Å at 5354 Å which suggests that it is [Ne V] λ3426 and, taken with our strong line at 4388 Å as Mg II λ2798, gives good wavelength agreement at a redshift of 0.567. This is consistent with the Burbidge and Strittmatter value. Moreover, we see no evidence for a strong line near 3450 Å as Lα λ1216 in the higher-redshift system. There *does*, however, appear to be a continuum level absorption discontinuity just shortward of the strong 4388 Å line which is more typical of the region near Lα in other objects. We therefore considered whether the 4388 Å line could be Lα at a redshift of 2.609. A medium-strength, broad feature in our spectrum near 5600 Å could be C IV λ1549, but then the well-established feature near 5360 Å (seen by all observers), which would occur at a rest wavelength of about 1483 Å, cannot be identified. The absorption shortward of the 4388 Å line may thus be caused by multiple Mg II absorption systems, which would be most unusual in a low-redshift QSO.

We suggest the redshift we give is the most likely, notwithstanding the unusual continuum discontinuity shortward of the Mg II emission line, and thus confirm the original Burbidge and Strittmatter observations.

1542+042.—Our spectrum contains a strong emission line at 4196 Å (1319 Å in the rest frame) which we cannot identify.

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