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SPECTROSCOPIC OBSERVATIONS OF OBJECTS IDENTIFIED WITH RADIO SOURCES

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ABSTRACT

Results of a spectroscopic survey of radio source identifications are reported. Redshifts have been determined for 20 quasars and seven radio galaxies. A large proportion of identifications with neutral-colored stellar objects appear to have continuous spectra of the BL Lacertae type. Thus while very high-redshift QSOs will turn up in such a sample, their frequency is probably fairly rare.

Subject headings: galaxies — quasi-stellar sources or objects — radio sources — redshifts

I. INTRODUCTION

The purpose of this paper is to report spectroscopic observations of a variety of objects identified with radio sources and, where possible, to give redshifts. The identifications, which include both galaxies and stellar objects, have come from a number of radio source lists. Our attention has, however, been concentrated on sources from the Molonglo survey (Hoskins *et al.* 1972; Hoskins *et al.* 1973; Baldwin *et al.* 1973; Hazard and Murdoch 1973), and on sources for which accurate radio and optical positions have been obtained at the Royal Radar Establishment (Browne, Crowther, and Adgie 1973; Adgie *et al.* 1973). In the latter category we have been especially interested in studying objects of neutral color in order to see how much color selection influences the redshifts of QSOs. In particular, we wished to ascertain whether many high-redshift objects such as 0642+44 (OH 471) (Carswell and Strittmatter 1973) have been missed because the optical depth in the Lyman continuum results in a deficiency of violet radiation. For this reason we have also observed many of the QSOs from the Parkes $\pm 4°$ survey for which Bolton and Wall (1970) and Wall, Shimmins, and Merkelijn (1971) found no ultraviolet excess but whose position agrees to within $\pm 2''$ with the optical identification (Browne and McEwan 1972). Much of this work has been done in collaboration with the group at the Lick Observatory, and some overlap has therefore occurred (cf. Baldwin *et al.* 1973).

II. THE OBSERVATIONS

All the observations reported here have been made with the Cassegrain spectrograph and RCA-33063 two-stage image-tube system at the Steward Observatory 2.2-meter telescope. The spectral survey was made at a reciprocal dispersion of 240 Å mm^{-1} and with a useful spectral range of 3200–5700 Å. Kodak IIaO emulsion was used throughout. Acquisition of faint objects was greatly facilitated through use of an integrating TV system which views an approximately $2' \times 2'$ area at the slit. This system uses an intensified SEC TV camera to integrate the low-light-level slit image. The integrated picture is then recorded on a silicon-target storage tube for continuous monitor display until the next camera integration is complete. Typically, 4 seconds of integration is sufficient to detect the nightsky background.

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III. RESULTS

Our results for QSOs are listed in table 1, in which column (1) contains the coordinate designation and name (if any), and column (2) the identification reference. Columns (3) and (4) contain wavelengths of measured lines, and a qualitative description of their strength and breadth. In columns (5) and (6) we list, where possible, the suggested line identifications and the corresponding individual redshifts. The adopted redshift $\langle z \rangle$ is given in column (7). In table 2 we list similar data for galaxies, the columns in this case containing the coordinate designation, identification reference, measured features, and adopted redshift, respectively. We have also included redshifts for two bright galaxies close to QSOs listed in table 1. A number of suggested identifications with stellar objects in fact turned out to be normal stars, and these are listed in table 3. Others listed in table 4 appear to have continuous spectra at our dispersion but may possibly have very weak or diffuse lines. These are described as "continuous" (C) or "inconclusive" (I), depending on our subjective degree of confidence that no lines are present. The term "UV deficit" means that relative to normal QSOs the ultraviolet continuum is weak. This is probably due to a continuum slope that is steeper than for the typical QSO. Sometimes, however, the deficit seems to begin rather sharply, in which case the term "UV cutoff" is used. Two objects —namely, 0529+07 (OG 050) and 0808+019—could not be assigned to any of the above categories. Their spectra are described in the following section.

TABLE 1

QSOs

Name	Ref.	Lines	Character	ID	Z	<Z>	Comments
0038-019	1	3278	Sm	Lα	1.696	1.690	Lα affected by atmospheric cut-off
		3780:	Ww	SiIV 1397	1.670:		
		4154	Sw	CIV 1549	1.682		
		4413	Ww	HeII 1640	1.691		
		5133	Ww	CIII] 1909	1.689		
0105-008	2	3673	Sw	CIV 1549	1.371	1.369	Alternative redshift z = 0.316 - see notes
		3885	MSmw	HeII 1640	1.369		
		4175	Mw	?			Possibly [NIII] 1750?
		4405	Ww	?			Probably NS
		4518	Mm	CIII] 1909	1.367		
0109+35	3	4053	Sw				
(GC)		4279?	Ww				
0240-06	3	3466	Mw	CIV 1549	1.238	1.238	
(GC)		4325	Sw	CIII] 1909	1.238		
		4548	Ww				
0310+01	4	4645	Mm	MgII 2798	0.660	0.660	
		5690:	Wm	Ne[V] 3426	0.661		
0458-02	2	3995	Sw	Lα	2.285	2.286	Continuum disappears shortward of Lα
			Ww	SiIV 1397			
		5091	Mw	CIV 1549	2.287		
0642+44	5,6	4548	Mw	OVI 1033	3.403	3.402	Continuum vanishes shortward of 4000A,
(OH471)		5351	Sw	Lα	3.400		cf., Carswell and Strittmatter (1973)
		5460	Ww	NV 1240	3.403		
0723-00	6	4197	Ms	[OII] 3727	0.126	0.127	Probably an N system; included here
(OI-039)		5646	Ms	[OIII] 5007	0.128		because of stellar image (ref. 4);
							[OIII] 4959 and Hβ are present but
							are confused by night sky 5460 and 5577
0736-06	3	3553	Sw	Lα	1.921	~1.9	Strong absorption in Lα and CIV. 4042
(OI-061)		3594	Mw	NV 1240	1.898		may be confused by night sky.
		4042:	MWm	SiIV 1397	(1.893)		
		4486	Sw	CIV 1549	1.896		
		4761	Wm	HeII 1640	1.903		
		5551	Mm	CIII] 1909	1.907		
0827+24	7	3701	Sw				
0844+31	8	3453	Sw	Lα	1.839	1.834	
(4C31.32)		3957	WMmw	SiIV 1397	1.832		
		4383	Smw	CIV 1549	1.830		
1126+101	9	3555	Wm	OIV] 1406	1.528	1.515	Probably confused with NS
		3897	Sw	CIV 1549	1.516		Absorption lines present
		4800	Mw	CIII] 1909	1.514		
1253+104	10,11	3477	Mw	CIII] 1909	0.821	0.824	
		5111	Mw	MgII 2798	0.827		
1323+037	9	3822	Mm				Probably night sky
		3907	Wm				
		5628	Wm				
		5692	vWm				
1435+17.2	10	3838	WMms				
		5793	Wm				
1442+117	10,11	3492	Mw	CIII] 1909	0.829	0.852:	3492 confused by night sky, cf. Baldwin
		4580	vW	[OII] 2470:	0.854:		et al. who noted a feature at 5187A.
		5180	Mw	MgII 2798	0.851		
GC1633+38	12	3424	MSm	Lα	1.815	1.814	Absorption lines present
(4C38.41)		3493	Wm	NV 1240	1.816		
		4356	MSm	CIV 1549	1.812		
1656+05.3	9	3908:	vWw				
(OS094)	6,13	5270	Mm				Baldwin et al. noted a feature at 5275A.

TABLE 1—Continued

Name	Ref.	Lines	Character	ID	z	<z>	Comments
1954+51	6	3466	MSm	CIV 1549	1.237	1.230:	Strong absorption at 3400Å
(OV591)		(3650)	Ww	(HeII 1640)			
		4255	MSw	CIII] 1909	1.229		
2136+14	6	4165	VSw	Lγ	2.425	2.429	
(OX161)		4260	Mw	NV 1240	2.435		
		4820:	Ww	SiIV 1397			Possibly confused with night sky
		5302	Mm	CIV 1549	2.428		
2141+17	6	3403	Ww	MgII 2798	0.216	0.213	HeII 3202, [NeV] 3346, [NeIII] 3869,
(OX169)		4155	vWw	[NeV] 3426	0.213		possibly also present but very weak.
		5251	Wm	Hγ	0.210		
		5296	Wm	[OIII] 4363	0.214		
		5890	Ww	Hβ	0.212:		
2142+10	11	3828	W	[OII] 2470	0.550	0.550::	Only 4337 is definite. The redshift
		3892	Ww	MgVII 2513	0.549		is therefore very uncertain.
		4054	MWm	MgVII 2632	0.539		
		4337	Smw	MgII 2798	0.550		
GC2200+31	7,8	3630	Sw	MgII 2798	0.297	0.297	
(4C31.63		5324	Ww	Hδ	0.298		
		5632	Ww	Hγ	0.297		
		6313	Mw	Hβ	0.298		
		6483	Mm	[OIII] 5007	0.295		
2256+017	2	3780	Mw	OVI 1033	2.659	2.663	3780 line may be blend of Lβ and
		4459	Sw	Lα	2.667		OVI 1033.
		4540	Ww	NV 1240	2.661		
		5134	Ww	SiIV 1397	~2.66		
		5673	Sw	CIV 1549	2.662		
2346+38	3	3150	Sm	CIV 1549	1.034	1.032	
		3880	Mw	CIII] 1909	1.032		
		5680	Mw	MgII 2798	1.030		

1. Browne and McEwan (1973)
2. Browne and McEwan (1972)
3. Adgie et al. (1973)
4. Browne (1973)
5. Gearhart et al. (1972)
6. Browne et al. (1973)
7. Johnson (1973)
8. Olsen (1970)
9. Hoskins et al. (1972)
10. Hazard and Murdoch (1973)
11. Baldwin et al. (1973)
12. Pauliny-Toth et al. (1973)
13. Gent et al. (1973)

TABLE 2

GALAXIES

Name	Ref.	Spectrum	z
0038−019			
(nearby galaxy).....	1	H, K, G, Hβ, Hγ, Hε, H6, H7	0.017
0818+47			
(3C197.1).....	2	3727 em, H, K	0.128
1138+117			
(NGC 3810).....	3	3727, Hγ, Hβ, Hα, em, H, K	0.003
1253+104			
(nearby galaxy).....	4	H, K, Hγ, Hβ	0.055
1303+114.....	4	H, K	0.086
1450+173.....	3	H, K, G	0.040
1453+120.....	4	H, K, G	0.032
1601+173.....	4	H, K, G	0.034
1644+118.....	4	3727 em, H, K, G	0.085

REFERENCES.—(1) Browne and McEwan 1973; (2) Wyndham 1966; (3) Hoskins *et al.* 1972; (4) Hazard and Murdoch 1973.

TABLE 3

STARS

Name	Identification	Spectrum	Name	Identification	Spectrum
0012+13			1031+56*		
(4C 13.01)	1	H, K, Balmer	(OL 553)	4	H, K, G, Mg I *b*
0043+40			2022+54		
(5C 3.150)	2	H, K, Balmer	(OW 538).....	4, 5, 6	H, K, G, Mg I *b*
0045+42					
(5C 3.181)	2	H, K, Balmer	2218+106.....	7	H, K, Balmer
0118−00*.....	3	H, K, Balmer	2244+119.....	7	H, K, G, Mg I *b*
0837+03*					
(OJ 063).....	4	H, K, Balmer	2244−00.....	3, 8	H, K, G, Mg I *b*, Na D

IDENTIFICATION.—(1) Munro 1972; identification Carswell. (2) Parkes and Penston 1973. (3) Browne 1973. (4) Radivich and Kraus 1971. (5) Browne *et al.* 1973. (6) Gearhart *et al.* 1972. (7) Hazard and Murdoch 1973. (8) Wall *et al.* 1971.

* According to Adgie *et al.* (1973) these identifications are not confirmed by their more accurate position determinations.

Further comments on individual objects follow.

0024+34.—Our attention was first drawn to the existence of the sharp feature at 4962A by Dr. J. Wampler who has also made observations of this object.

0038−019.—This Parkes 2700 MHz survey radio source was originally identified by Merkelijn and Wall (1970) with a 15th-magnitude spiral galaxy, but more accurate positional work by Browne and McEwan (1973) resulted in the present QSO identification. The redshift of the galaxy is given in table 2.

0105−008.—The spectrum presents some difficulty in interpretation, as two redshifts seem possible. The preferred value is 1.369 as listed in table 1. The feature at 3673 is, however, strongly distorted by the nightsky emission between 3615 and 3662 and could be centered somewhat further to the red. In that event it would be preferable to associate the features at 3673, 3885, 4405, and 4518 Å, respectively with Mg II λ2798, ([Mg V] λ2931 and [Ne V] λ2971), [Ne V] λ3346, [Ne V] λ3426. The corresponding redshifts are 0.313, 0.316:, 0.316, and 0.318, respectively.

0458−02.—Both spectra which have so far been obtained of this object show that the continuum vanishes shortward of Lα but recovers again at ~3500 Å. The deficiency of radiation between these

TABLE 4

CONTINUOUS OR INCONCLUSIVE SPECTRA

Object	ID/mag	No. of Spectra	Comments	Category	Object	ID/mag	No. of Spectra	Comments	Category
0024+34 (OB338)	1 ~18.5	3	A fairly sharp emission appears at 4962Å	I	1147+24.5	2 ~17	1		C
0035+36 (GC)	1 ~18.5	2	Some strengthening near 5577	I	1514+19 (GC)	1 ~18	2	UV cut-off 4000Å. Fainter than on sky survey	I
0048-09.7	2 17.3	3	See Carswell et al. (1973) UV deficit	C	1604+15 (OS108.2)	1 ~18	1		
0133+47 (OC457)	3 ~17.5	2	Possible emission at 5200Å	I	1749+09 (OT081)	1 ~18	2		C
0234+09 (OD058)	1 ~19	2	Fainter than on sky survey UV cut-off at 3800Å	I	1754+15.9	4 ~18.5	1		I
0237+04 (OD062)	3 ~17.5	2	Possible emission at 3775 and 4606Å	I	2003-025 (OW-006)	5 ~19	3	UV deficit shortward of 3500Å: possible features at 3800-4650Å	I
0256+07 (OD094.7)	1 ~19.5	2	Fainter than on sky survey Very weak spectra	I	2121+05 (OX036)	1,6 ~19	3	Possible emission at 4420, 5700Å	I
0743-00 (OI-072)	1 ~17.5	1	Possible feature 4800	I	2207+02	5 ~19	2	UV deficit	C
1057+10	4 ~17.5	1		C	2254+07 (OY091)	1 ~17.3	3	UV deficit	C
					2335+03	7 ~18	2	UV deficit shortward of 3500Å	C

1. Browne et al. (1973)
2. Hoskins et al. (1973)
3. Adgie et al. (1973)
4. Hoskins et al. (1973)
5. Browne and McEwan (1972)
6. Johnson (1973)
7. Browne (1973)

wavelengths probably accounts for the lack of ultraviolet excess noted by Bolton and Wall (1970) and Wall *et al.* (1971). It may be due to extended Lα absorption similar to that seen in Lα, N v, Si iv, and C iv in PHL 5200 (Lynds 1967) and often ascribed to mass outflow. In this case, however, the gas would have to be in a lower ionization state since no broad Si iv or C iv absorption is observed.

0529+07.—Our two spectra of this object, taken untrailed with an open sky decker, are remarkable in that they show sharp emission lines of O ii λ3727, Hδ, Hγ, Hβ, and Hα at rest wavelength and extending at more or less constant intensity across the whole window (~1 arc min). The object identified by Browne *et al.* (1973) appears to have no discrete spectral features. We are led to conjecture that the optical line emission comes from a faint extended H ii region in our own Galaxy and that the radio source is probably of BL Lacertae type and is physically unrelated to the H ii region. In view of the uncertainty, however, we have not included this object in table 4.

0736−06.—Not only does this object have many absorption lines in its spectrum but the continuum intensity declines sharply below Lα. The Lα and C iv emission features in particular seem strongly influenced by absorption, which may account for the poor wavelength agreement. Studies at higher dispersion are clearly required.

0808+019.—Our single spectrogram of this object contains a number of features, many of them unfortunately coinciding approximately with nightsky emission. In an object as bright as 0808+019 their relative strength is rather surprising. Features at ~4600, 4935, and 5400 Å are probably sufficiently broad to be real. The object is probably a QSO. Further spectra of this object are needed to clarify its classification.

0844+31 (4C 31.32).—This source was originally identified with the nearby 13.5-mag galaxy NGC 2402 by Olsen (1970), who also noted the proximity of the 18-mag blue stellar object observed by us. Sargent (1973) gives a redshift of $z = 0.0675$ for NGC 2402.

1126+101.—Absorption features have been measured at 3394, 3420, and 3896 Å, respectively, but further spectra are required at higher dispersion for a proper analysis of the absorption spectrum.

1253+104.—Baldwin *et al.* (1973) noted a feature at 5111 Å and a possible line at 4482 Å. There are two bright galaxies near the QSO. The redshift of the closer one (separation ~1.″5) is given in table 2.

1323+03.7.—Although only one spectrum of this object is currently available, the three emission lines listed in table 1 seem well established. No redshift could, however, be assigned.

2022+54.—This object was first identified by Radivich and Kraus (1971), and a different identification was suggested by Gearhart *et al.* (1972). Browne *et al.* (1973) confirm the first identification and note that the second is incorrect. Our results refer to the original identification and suggest that it is likewise incorrect.

2142+110.—Baldwin *et al.* (1973) measured a line at 4358 but expressed some doubt as to its reality since it coincided with a nightsky feature.

2200+31.—The emission-line redshift for this source was first given by Tritton, Henblest, and Penston (1973). Our result agrees very well with theirs. Tritton *et al.* (1973) also suggested, however, that absorption lines appeared at 3587, 5574, and 6223 Å and could be identified with Mg ii λ2798, Hγ, and Hβ, respectively. We have therefore obtained several further spectra of this object some at higher dispersion but have been unable to confirm these features.

2256+017.—This object has been observed previously by Baldwin *et al.* (1973) who assigned a provisional redshift $z = 2.663$. Our result confirms this value. The spectrum also contains a number of absorption lines and merits examination at higher dispersion.

III. DISCUSSION

Redshifts have been reported for a total of 20 QSOs and seven radio galaxies. Four further objects have been found to be QSOs, but for various reasons no redshift could be assigned. Ten identifications turned out to have normal stellar spectra while 19 others were found to be continuous or to have at best very weak emission lines in their spectra. The proportion of such "continuous" objects is remarkably high, at least in comparison with most previously published lists. (We note, however, that Baldwin *et al.* 1973 also found a similarly high proportion of "lineless" objects.) In addition, a substantial fraction of the continuum sources appear to have deficient ultraviolet flux compared with QSOs of the same visual brightness. These two results may, however, be connected with selection effects in the original source lists.

The identification list published by Browne and McEwan (1972) was restricted to "blue" objects with no ultraviolet excess. Of the eight objects studied by us or by Baldwin *et al.* (1973), four turned out to be definite QSOs, two are inconclusive, one is continuous, and one is a star. The list of neutral objects published by Browne *et al.* (1973) has produced seven QSOs (OI−039 may be an N system), one star, one H ii region, and 11 continuous or inconclusive spectra. We note, however, that the five BL Lacertae objects studied by Strittmatter *et al.* (1972) appear to have continuous optical spectra of rather steeper slope than is common to QSOs; this probably accounts for their neutral color on the Palomar *Sky Survey* plates. In addition, the sample given by Browne *et al.* (1973) consists mainly of sources with peculiar spectra (flat, peaked, or inverted) and in any case of sources with substantial flux at 2700 MHz at which the accurate Royal Radar Establishment positions were obtained. In these circumstances it is perhaps not surprising that a substantial number of objects like BL Lac should be found.

Following the discovery of the high redshifts of 0642+44 ($z = 3.40$, Carswell and Strittmatter 1973) and 1442+101 ($z = 3.53$, Wampler *et al.* 1973), hopes

ran high that the combination of accurate radio positions and neutral to red stellar identifications should lead to many more high-z objects. Although only a few objects in these lists remain to be observed, no further instances of high-z QSOs have so far been found. Some cases, such as GC 1514+19, seemed promising at first in view of a fairly sharp decrease in the continuum intensity shortward of approximately 4000 Å similar to that which occurs in 0642+44, but no unambiguous emission features could be found. Furthermore, some of the objects were so much fainter than on the *Sky Survey* that we either could not observe them or could obtain only very poor spectrograms. Both 0205−010 (Browne and McEwan 1972) and 0256+07 (OD 094.7) fall into this category, and the presumption must surely be that they are also BL Lacertae objects. In short, while color selection has certainly operated against finding high-z QSOs, particularly those of the 0642+44 type where the Lyman continuum is optically thick, the current evidence suggests that these objects are intrinsically rare and easily confused with BL Lacertae objects.

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