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SPECTROSCOPY OF QSO PAIRS

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ABSTRACT

We report spectroscopic observations of objects with ultraviolet excess found within 2′ of radio-detected QSOs. Of six such objects, four are definitely QSOs, and another is very probably a QSO. In the three cases where redshifts have been measured for both members of a pair, they are not the same. The probability of the pairing occurring by chance, given a random distribution of QSOs over the sky, is 10^{-3}, based on current estimates of the surface density of QSOs near 19 mag.

Subject headings: galaxies: redshifts — quasars

I. INTRODUCTION

In the course of a search for optical identifications of radio sources in the Parkes 2700 MHz survey, two of us (J. G. B., B. A. P.) obtained a number of image-tube plates centered on the positions of radio sources with flat radio spectra in the range 2700–5000 MHz. The flat-spectrum sources have a high probability of being quasi-stellar objects (QSOs), and the image-tube plates were taken in two colors approximating the photometric U and B filters so as to confirm the QSOs by their ultraviolet excess (UVX). Results of the search for identifications have been published (Peterson, Bolton, and Shimmins 1973, and references therein); here we are concerned with one intriguing aspect of the observations, namely the appearance of a *second* UVX object on some of the plates. Specifically, eight of 100 fields containing a UVX object near the radio position showed a second UVX object. The plates had typical limiting magnitudes $B \approx 19.0$–19.5 and covered a circular area of 1′.7 radius (unvignetted). Estimates of the surface density of QSOs at this apparent magnitude (§ III) lead us to expect $\lesssim 1$ QSO by chance in the total area, so the observed number (eight) appears highly significant, if the objects are indeed QSOs. The possible significance of these pairs was first mentioned by J. G. B. at IAU Symposium No. 58, at the same time as the announcement of the discovery of a close pair of QSOs by Wampler *et al.* (1973); further mention was made by Wall (1974).

II. SPECTROSCOPIC OBSERVATIONS

The radio-emitting component of each pair is almost certainly a QSO, because of the combination of radio spectrum, positional coincidence ($\lesssim 10''$) of the radio and optical objects, and UVX, but spectroscopic observations of the nonradio components were necessary to establish their nature. The first series of spectroscopic observations was made by two of us (B. J. W. and D. W.) using the McDonald Observatory 2.7 m reflector and equipment described elsewhere (Wills and Wills 1976). Spectrograms were recorded on baked IIa-O or IIIa-J emulsions at a reciprocal dispersion $\sim$240 Å mm^{-1}, and cover a typical spectral range of 3200–6500 Å. Most of the objects have also been observed by J. G. B. and B. A. P. using the image-tube dissector scanner on the 4 m Anglo-Australian telescope.

In Table 1 we summarize our observations so far made of the eight pairs, and give notes on the individual objects. Both components of five pairs appear to be QSOs. For three pairs, redshifts are established for both components and for another there is a redshift for the nonradio component; the radio component of the latter is almost certainly a QSO for the reasons outlined above. Both components of the 1532+016 pair have continuous or weak-lined emission spectra; the $\sim$1″ radio-optical position agreement (Edwards, Kronberg, and Menard 1975) confirms the radio object as a QSO, while the optical variability of the nonradio object suggests that it is also a QSO. In no case are the redshifts of the members of a pair the same; this is also true for the pairs discussed by Stockton (1972) and by Wampler *et al.* (1973).

III. DISCUSSION

There are certainly four, and very probably five, cases out of the six investigated so far from Table 1, where a pair of QSOs is separated by less than 2′ and where the second (nonradio) component has $B \lesssim 19.5$. Even if the two objects not yet investigated turn out to be stars, the result appears to have high statistical significance—the observed number of QSO pairs appears to be significantly greater than the number expected on the basis of a random distribution of QSOs over the

TABLE 1

SPECTROSCOPIC OBSERVATIONS OF QSO PAIRS

Source (1)	Reference to Finding Chart (2)	Separation and Position Angle (3)	Mag. (4)	S_{11} (5)	S_6 (6)	Redshift (7)	Emission Lines (Å) (8)
0254−334	1	0′.9, 100°	(18.5)	0.37	0.53	1.915	3545 (1216), 3595 (1240), 4516 (1549)
Nonradio			(16.5)	...	...	1.849	3531 (1240), 4401 (1549), 5457 (1909)
0602−319	2	1′.4, 105°	18.0	1.89	1.25	0.452	5411 (3727), 5613 (3869), 5766 (3968), 6336 (4363), 7190 (4959), 7272 (5007)
Nonradio			18.0	...	...	...	(star)
1240−294	2	0′.7, 80°	18.0	0.57	0.41	1.133	4060 (1909), 5985 (2798)
Nonradio			19.5	...	...	...	Not yet investigated
1349−439	1	0′.9, 150°	18.5	0.54	0.76	...	Continuous spectrum
Nonradio			17.5	...	...	0.323	5109 (3869), 5264 (3968)
1532+016	1, 3	1′.1, 120°	18.5	1.11	0.92	...	Both objects have continuous spectra
Nonradio			(17.0)	...	...	...	or possible emission
2143−156	2	1′.3, 130°	17.5	1.11	0.82	0.700	4757 (2798)
Nonradio			19.5	...	...	2.055	3718 (1216), 4727 (1549)
2245−328	1	1′.2, 180°	(17.0)	2.01	1.80	...	Neither object has yet been investigated
Nonradio			18.0	...	...	...	
2320−035	1, 4	1′.3, 270°	18.5	0.42	0.39	1.411	3743 (1549), 4593 (1909)
Nonradio			(19.5)	...	...	2.041	3693 (1216), 4258 (1397), 4711 (1549)

NOTES

Finding chart references in column (2) are: (1) Peterson and Bolton 1973; (2) Peterson *et al.* 1973; (3) Edwards *et al.* 1975; (4) Browne and McEwan 1972. The position of the nonradio object is given relative to the radio object in column (3). The (B) magnitude estimates in column (4) are from the two-color image-tube plates; values are given in parentheses where the object is known to be variable. Columns (5) and (6) give flux densities (in Jy) of the radio component at 11 cm and 6 cm, respectively. The final column lists the observed wavelengths of emission lines, with rest wavelengths in parentheses (1216 = Lα; 1240 = N v; 1397 = Si IV (1393, 1402); 1549 = C IV; 1909 = C III]; 2798 = Mg II; 3727 = [O II]; 3869, 3968 = [Ne III]; 4363 = [O III]; 4959, 5007 = [O III]). The emission line wavelengths are those measured from the observations with the Anglo-Australian 4 m telescope. Further notes on the objects, including the results obtained at McDonald Observatory, follow:

0254−334.—Results for both objects are also given by Peterson *et al.* (1976). At McDonald, the radio object (which is not visible on the Sky Survey prints) could not be found using a photomultiplier behind a 2″ aperture. The nonradio object showed a strong line peaking near 4418 Å, with two strong absorption lines in the blue wing and more absorption further to the blue. The wavelength of this line given in Table 1 corresponds to the shortward edge of the emission line. The nonradio object was estimated as B = 19 (using counts from the photomultiplier) but could be as much as 1 mag brighter after correction for atmospheric dimming and dispersion. AAT observations show a feature at the expected wavelength of Lα, although it was too far in the ultraviolet to use in the redshift determination. This feature must be too weak to show on the McDonald spectrograms.

0602−319.—The nonradio component shows Hβ, and probably Hγ and Hδ in absorption. The ultraviolet is not very strong.

1532+016.—Both objects were observed only at McDonald. The nonradio object was found to be fainter by ~1 mag than on the Sky Survey prints; some of the spectrograms show an uncertain emission line near 3695 Å.

2143−156.—Results for both objects are also given by Peterson *et al.* (1976). The radio object shows only one emission line. The best McDonald spectrogram, recorded on IIIa-J emulsion, shows none of the expected emission lines which should be present if this line is anything but Mg II λ2798. For the nonradio object the McDonald spectrogram gave wavelengths ~30 Å longward of those given in the table.

2320−035.—Browne *et al.* (1975) give results for both objects, although the listed wavelengths differ slightly. Browne *et al.* mention that the objects differ by 2 mag, but when the objects were observed successively (in 1974 August and in 1974 November) the difference was no more than 1 mag. In 1974 August the nonradio object was found to be $B \approx 19$ (Browne *et al.* report $B \approx 20.6$ in 1975 August).

sky. The expected number of chance pairs cannot be calculated very accurately; it depends on the adopted plate limit, which is not the same on all our image-tube plates (a change of 0.5 mag near B = 19 corresponds to a factor of 2 in the surface density of radio-quiet QSOs). In addition, the surface density of QSOs near 19 mag is not known accurately. Setti and Woltjer (1973) derive densities of 2.1 and 4.3 per square degree at B = 19.0 and 19.5, respectively, based on the survey by Braccesi, Formiggini, and Gandolfi (1970, 1973). Savage (private communication) finds a surface density of five UVX objects per square degree near B = 19–19.5 in two areas near the south galactic pole, but not all of these can be QSOs. Wills and Wills (1976) suggest that the Braccesi, Formiggini, and Gandolfi list may be incomplete, and Wills and Ricklefs (1976) suggest that the incompleteness might be as high as a factor of 5 outside the redshift intervals 0–0.5 and 1.7–2.1. This may not be serious in the present case, if it is a result of selection of radio-quiet QSOs by their UVX, because the objects in the present sample were selected in the same way (and their redshifts are within the intervals mentioned above). Based on the foregoing arguments, our best estimate for the surface density of QSOs down to the limit of our plates is ~3.0 per square degree. The plates cover

100 fields, each with a search area of radius 1′.7. (Images beyond this radius suffer from vignetting.) We thus find the total number of expected chance pairs to be $\sim$0.75. The probability of finding at least four is then about 0.0075, and the probability of finding at least five is about 0.001. Two of the nonradio UVX objects in Table 1 have not yet been observed spectroscopically; if one or both are later found to be QSOs, the final result will be significant at the 10^{-4} or 10^{-5} level, respectively.

Our results on the pairs of QSOs found from radio observations thus suggest that the pairing is statistically significant, unless for some reason our estimate of the surface density of UVX radio-quiet QSOs can be shown to be too small by a factor of $\gtrsim 3$. It is interesting to note that Hawkins and Reddish (1975) have recently found a high degree of clustering, and a preponderance of pairs on a scale $\sim 1'$, in the distribution of blue objects near $B = 21.5$, which may be related to the phenomenon reported here. A search of some two-color Schmidt plates to $B \lesssim 19.5$ by Savage (private communication) suggests that pairing of UVX objects may be present there—the number of pairs found was about 3 times that expected from the actual density of UVX objects. The forthcoming objective prism on the UK 48 inch (1.2 m) Schmidt telescope might also be used to advantage in checking the significance of the pairing in this way.

If the pairing of QSOs with discordant redshifts can be verified, the cosmological origin of QSO redshifts will obviously have to be questioned. An independent search for pairing among QSOs found in high-frequency radio surveys at northern declinations has recently been made by B. J. W. and D. W., and results will be published soon.

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