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A CLOSE PAIR OF RADIO-EMITTING QUASI-STELLAR OBJECTS

Frazer N. Owen
National Radio Astronomy Observatory,[1] Charlottesville, Virginia

Beverley J. Wills and D. Wills
McDonald Observatory and Department of Astronomy, University of Texas, Austin
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ABSTRACT

We report observations of a pair of QSOs, both associated with compact, flat-spectrum radio sources, and separated by only 33″. Their redshifts are different (0.678, 2.296). VLBI measurements of their relative proper motion could help to distinguish between cosmological and "local" QSO hypotheses.

Subject headings: quasars — radio sources: general

I. INTRODUCTION

A number of pairs of QSOs, separated by <1′–2′, and with different redshifts, are now known (Stockton 1972; Wampler *et al.* 1973; Bolton *et al.* 1976; Wills, Wills, and Uomoto 1980). In each of these cases, at least one member of the pair is not a detected radio source. Here we report the discovery of a pair of QSOs that are both compact radio sources, and thus allow a search to be made for changes in their angular separation (33″), using VLBI techniques.[2]

II. RADIO AND OPTICAL OBSERVATIONS

The objects were found during observations at 2695 and 8085 MHz with the NRAO interferometer, by Owen, Porcas, and Neff (1978), who measured the structures of QSO candidates in the Jodrell Bank 966 MHz survey (Cohen *et al.* 1977). The source 1038+528 (=OL 564) was found to consist of two compact components, with flat spectra between 2695 and 8085 MHz. One is coincident with the ~17.5 mag blue stellar object (BSO) suggested by Cohen *et al.* (1977) as the optical identification, and the other is coincident with a ~18.5 mag BSO 33″ Nf (the fainter BSO was also mentioned by Cohen *et al.* [1977], presumably as an alternative optical identification to what they considered to be a single radio source). Observations made at 4886 MHz with 10 antennas of the VLA in 1978 April are shown in Figure 1, which also shows the optical positions of the two BSOs, measured with the UTRAO laser measuring machine described by Ghigo (1977); the radio-optical position agreement is $\lesssim 0\farcs3$ for both objects. In addition to the two unresolved ($<0\farcs2$) radio sources, there are extended (~5″) regions of emission, whose relation to the former is not clear at present. The radio data are summarized in Table 1, and a finding chart for the two BSOs is given in Figure 2 (Plate L1).

A photographic spectrogram of the brighter object had already been obtained at McDonald Observatory by Walsh, Wills, and Wills (1979) during the course of observations of QSO candidates in the Jodrell Bank survey. Spectra of both objects were obtained later at McDonald using an intensified dissector scanner (IDS) and a self-scanned Digicon on the 2.7 m and 2.1 m reflectors, respectively (except that the fainter object was observed only with the IDS). The spectra are shown in Figure 3, and the optical data are described in Tables 2 and 3. Although only one strong emission line is seen in the spectrum of the brighter object, support for its identification with Mg II λ2798 comes from the existence of broad emission features near rest wavelengths of 2600, 2950, and 3200 Å, identified as blended Fe II multiplets that are commonly seen in other QSOs (Wills, Netzer, Uomoto, and Wills 1980). In addition, there may be narrower emission lines of [Ne V] and [Ne III] (λλ3426, 3869). We therefore assume the redshift of the brighter QSO to be $z = 0.678$. The fainter object shows emission lines of Lα, N V, C IV, and C III] (λλ1216, 1240, 1549, 1909) at $z = 2.296$. Neither object shows any obvious spectroscopic anomalies when compared with other QSOs of similar redshift.

III. PROBABILITY OF PHYSICAL ASSOCIATION

As in earlier cases of QSO pairs with different redshifts, the probability of a physical association can be assessed only via statistical arguments. The present pair would probably not have been found had they not been radio sources, so this fact has to be included in the calculations. Without making assumptions that are artificially close to the observed properties, we may estimate the probability of finding a QSO brighter than 19.5 mag within 1′ of a given point in the sky (in this case, the position of the brighter QSO). Assuming a

[1] The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation.

[2] Walsh, Carswell, and Weymann (1979) have recently discovered a very close (6″) pair of QSOs with essentially identical redshifts. Both are radio sources (Pooley *et al.* 1979; Roberts Greenfield, and Burke 1979), and may be gravitational lens images of a single object.

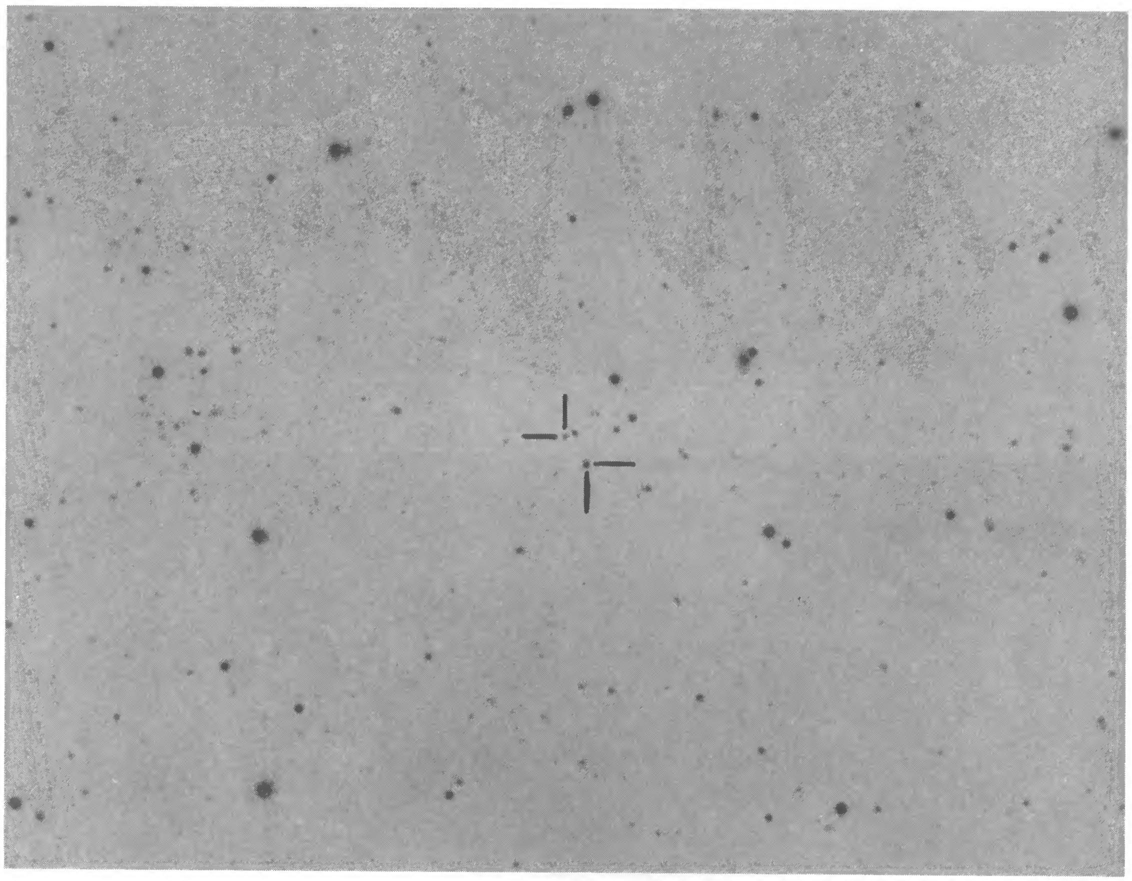

FIG. 2.—Finding chart for the two QSOs associated with the radio source 1038+528. North is at the top and east to the left. The separation of the two objects is 33″.5. The chart is from the *E* (red) print of the Palomar Sky Survey (copyright by the National Geographic Society-Palomar Observatory Sky Survey. Reproduction permission granted by the Hale Observatories.)

OWEN *et al.* (*see* page L57)

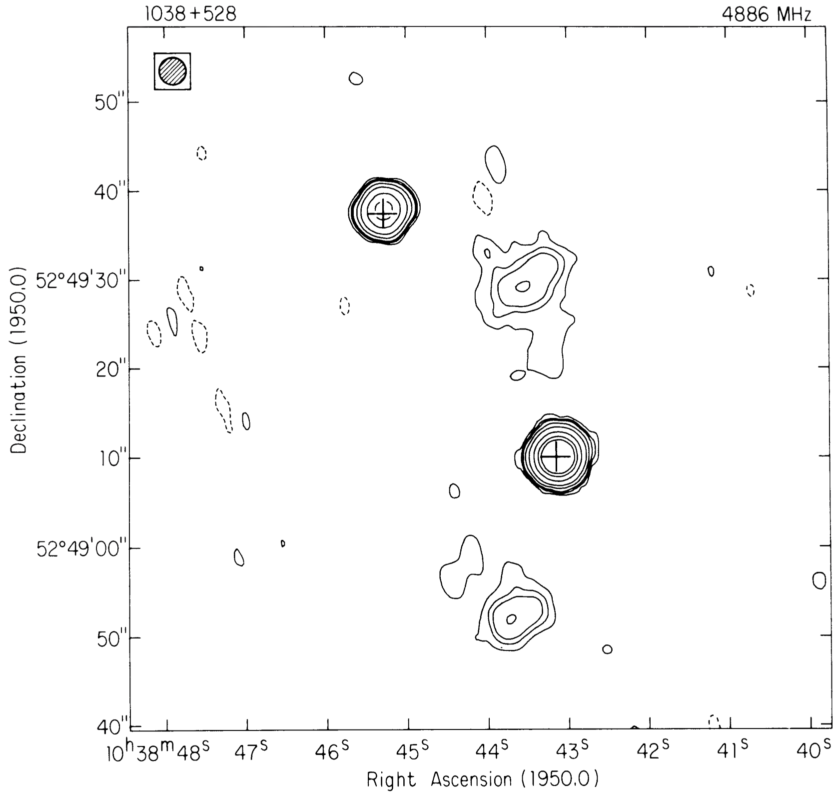

FIG. 1.—VLA map of 1038+528 at 4886 MHz. Components A and D are saturated in order to display the extended components B and C. Contour intervals are 1.58 × (90, 60, 30, 12, 6, 3, 2, and 1) × 10^{-29} W m^{-2} Hz^{-1} per clean beam area. The clean beam is the shaded circle in the upper left-hand corner of the figure. Crosses show the optical positions of the QSOs.

TABLE 1

RADIO DATA FOR 1038+528

COM-PONENT	POSITION		FLUX DENSITY			STRUCTURE	
	R.A.(1950.0)	decl.(1950.0)	S_{2695}	S_{4886}	S_{8085}	Angular Size(″)	Position Angle
A.......	$10^h38^m43^s.14(0^s.01)$	+52°49′10″.1(0″.1)	435(23)	416(20)	655(39)	<0.2	...
B.......	10 38 43.52(0.02)	52 49 29.3(0.2)	74(15)	39(3)	...	7(2)×4(1)	126°(10°)
C.......	10 38 43.68(0.03)	52 48 52.5(0.3)	37(8)	26(2)	...	5(1)×3(1)	122°(10°)
D......	10 38 45.27(0.01)	52 49 37.5(0.1)	154(12)	136(8)	119(36)	<0.2	...

NOTES.—The rms errors are given in parentheses. Flux densities S are subscripted with the frequency in MHz.

TABLE 2

OPTICAL POSITIONS OF THE QUASI-STELLAR OBJECTS

Object	R.A.(1950.0)	decl.(1950.0)	m_v	Separation
Sp..........	$10^h38^m43^s.13(0^s.03)$	+52°49′10″.4(0″.3)	17.5	33″.45(0″.10)
Nf..........	10 38 45.27(0.03)	52 49 37.6(0.3)	18.5	

NOTES.—The optical positions were measured from the glass plate copies of the Palomar Sky Survey, using AGK3 reference star positions. Each position is the mean of four values, determined from the red and blue plates, and with the plates rotated by 180°. The values in parentheses are rms uncertainties. The angular separation of the objects should be less subject to personal measuring errors than are the individual positions; the four determinations gave separations of 33″.33, 33″.43, 33″.52, and 33″.56.

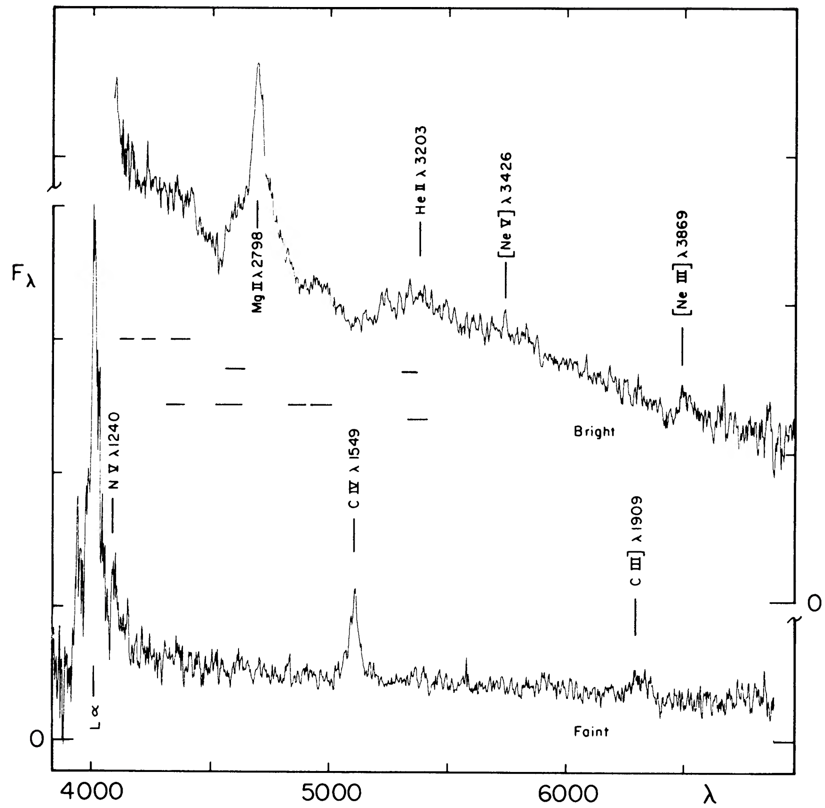

FIG. 3.—Optical spectra of the two QSOs associated with 1038+528. The upper spectrum is that of the brighter object (called "Sp" in Table 2, and coincident with radio component A in Fig. 1 and Table 1). For this object, the horizontal bars indicate the wavelength ranges expected for Fe II multiplets. The FWHM is 8 Å.

Both spectra are composites of more than one scan. The observations were made during cloud and/or poor seeing and are therefore not on an absolute scale. The continuum shape of the brighter object was adjusted to that of the best-calibrated scan. Note the displaced zeros.

surface density of 5 QSOs $\deg^{-2}$ (Wills 1978), this probability is 1 in 230. The probability that the second QSO is a radio source with high-frequency flux density exceeding 50×10^{-29} W m^{-2} Hz^{-1} is perhaps 0.03 (Sramek and Weedman 1978, Tables 2–5), giving a probability of $>10^{-4}$ of finding an unrelated pair of radio-emitting QSOs this close by chance. Since radio structure measurements have certainly been made for more than 100 QSOs, there is at least a 1% chance that a pair similar to 1038+528 should have been found by now.

TABLE 3

OPTICAL FEATURES IN THE TWO QUASI-STELLAR OBJECTS

Object	Emission Lines	Redshift	W_λ
Sp........	4695(Mg II λ2798)	0.678	41
	4959(λ2950)	...	4
Nf........	4002(Lα λ1216)	2.292	93
	4090(N V λ1240)	2.299	16
	5104(C IV λ1549)	2.295	24
	6309:(C III] λ1909)	2.306:	15:

NOTES.—The Sp object is the one identified with radio component A in Fig. 1 and Table 1, the Nf one is component D. Observed wavelengths are in Å, followed by the line identification, the derived redshift, and the rest-frame equivalent width in Å. For the Sp QSO, the redshift is based on the line assumed to be Mg II λ2798. The feature called λ2950 is assumed to be Fe II multiplet UV 60. The C III] line in the Nf object is affected by the night-sky [O I] feature at 6300 Å.

IV. PROPER MOTION

The particular interest of the 1038+528 pair is that their relative proper motion can perhaps be detected by VLBI techniques. The observed proper motion of an object with transverse velocity v_T (km s^{-1}) at the distance given by its cosmological redshift z is

$$7.04 \times 10^{-11}(1 + z)hv_T A^{-1} \quad \text{arcsec yr}^{-1}$$

where Hubble's constant is expressed as $100h$ km s^{-1} Mpc^{-1}, and A is the luminosity distance, which is simply $A = z$ for $q_0 = 1$, or $A = z\ (1 + 0.5z)$ for $q_0 = 0$ (Sandage 1961). Stockton (1978) finds an rms difference of $\sim$400 km s^{-1} between the redshifts of QSOs and associated galaxies, so the expected annual change in the angular separation of the 1038+528 is at least two orders of magnitude smaller than the amount that can be detected using current VLBI techniques ($\sim 10^{-5}$ arcsec, M. Reid, personal communication). An interesting possibility, however, is that one or both of the QSOs may exhibit apparently superluminal expansion, in which case it might be possible to determine whether the components separate symmetrically or not, which could constrain models of the expansion.

If QSOs are closer than their redshifts suggest, the relative proper motion of the 1038+528 pair may be detectable in only a few years. A change of 10^{-5} arcsec will occur after

$$4.7\left(\frac{D}{100\ \mathrm{Mpc}}\right)\left(\frac{1000\ \mathrm{km\ s^{-1}}}{v}\right) \quad \text{years}$$

where v is the projected velocity of separation and D is the distance. The various "local" models of QSOs offer a wide choice of values of D. Associations between QSOs and bright galaxies (e.g., Arp 1977, Table 1) suggest $D < 30$ Mpc, and the lack of coincidence between QSOs and rich Abell clusters suggests $D <$ 50 Mpc (Roberts, O'Dell, and Burbidge 1977). Problems raised by the low radio frequency variability of 3C 454.3 and CTA 102 are reduced if $D <$ 30–100 Mpc (Jones and Burbidge 1973; Burbidge, Jones, and O'Dell 1974), and apparently superluminal expansion in 3C 279 (Cotton *et al.* 1979) can be avoided only if $D <$ 130 Mpc. Finally, distances of up to 200 Mpc have been adumbrated by Burbidge (1977). The value of v is also quite unknown in the "local" models, but could well exceed 1000 km s^{-1}, in which case the relative motion of a pair of QSOs at D = 50 Mpc should become apparent after only $\sim$2 years, unless the proper motion vectors are unfavorably directed.

The QSO distance controversy may have been settled before the 1–100 years needed to detect proper motion of the 1038+528 pair, or to exclude it at a useful level, but an extrapolation of the last 15 years' work is not particularly encouraging, and two first-epoch observations of 1038+528 have already been made (Reid *et al.* 1979).

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Frazer N. Owen: National Radio Astronomy Observatory, Edgemont Road, Charlottesville, VA 22901

Beverley J. Wills and D. Wills: Department of Astronomy, University of Texas, Austin, TX 78712