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1343.4+2640: A CLOSE QUASAR PAIR

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ABSTRACT

Two quasars of virtually identical redshift separated by 9″.5 have been discovered on a CFHT grens plate. Subsequent spectroscopy reveals substantial differences in their spectral line strengths which appear to be incompatible with a gravitational lens hypothesis. Furthermore, deep CCD images of the field do not show any indication of a lensing galaxy or extended Lyα emission. It is likely that these quasars are a physically related pair, possibly residing in a cluster of galaxies at $z = 2.03$.

Subject headings: gravitational lenses — quasars

I. INTRODUCTION

Two quasar candidates with apparently similar spectra and separated by only $\sim 10''$ were discovered with the blue "grens" on the CFHT during the course of a large survey for faint quasars. Since these represent a very good gravitational lens candidate, and interest in lenses is high due to the potential cosmological information which can be derived from their study (see, e.g., Canizares 1986), further spectroscopic observations of the two quasars were obtained.

The two objects were first recognized as quasars on a grens plate, although they had independently been selected as "blue objects" in a survey by Richter, Richter, and Schnell (1968) who referred to them as IV 26 and IV 27. Their photographic photometry gave $B = 20.23$, $U-B = -1.23$ for the westernmost object, IV 26, and $B = 20.18$, $U-B = -1.17$ for IV 27. However, the latter object is ~ 0.4 mag brighter on both the grens plate and on the Palomar Sky Survey prints (see Fig. 1), suggesting possible variability. The 1950 coordinates of the two objects were determined to an estimated accuracy of $\pm 1''$ from astrometry of 14 surrounding SAO stars on a glass copy of the Palomar Sky Survey to be

A: (IV 26) $13^h43^m24^s.7$ $+26°40'06''$

B: (IV 27) $13^h43^m25^s.4$ $+26°40'05''$ (brighter) .

Spectra of both quasars obtained in 1986 July with the CFHT revealed that the redshifts were indeed very similar. Subsequent MMT observations in 1987 February, covering a wider wavelength interval, confirm that the quasars have identical redshifts but differ substantially in line strengths, making it difficult to explain them with the lens hypothesis. Deep direct images obtained at the Lowell Observatory in 1987 April and May show no evidence of a potential lensing galaxy, nor any evidence of bright galaxies at the redshift of the quasars. This quasar pair appears to be similar to the pair associated with PKS 1145−076 subsequently discovered by Meylan *et al.* (1987).

II. SPECTROSCOPY

a) Observations

Observations were obtained (by P. H. and E. K.) at CFHT with a double-density RCA CCD on the Herzberg spectrograph. The resolution was 2.4 Å per pixel and the spectra covered the wavelength region $\sim$4000–6000 Å, with the short wavelength cutoff limited by the spectrograph optics and CCD response. Only one 1800 s integration was obtained through a long 2″ wide slit on each quasar. The MMT observations were made (by A. C.) with the blue sensitive photon-counting spectrograph and a grating which gave ~ 7 Å resolution over the wavelength region 3000–8000 Å. Three 1200 s integrations on each quasar were made through each of the two 2″ × 3″ apertures. Unfortunately, the seeing at the MMT was poor and the transparency variable, so accurate flux calibration of the spectra is not possible. The CFHT observations were reduced with the IRAF software package and the MMT observations with IRS. Particular attention was paid to get as accurate wavelength calibration as possible. The largest source of error in the positions of the lines is due to the asymmetries and structure in the line profiles.

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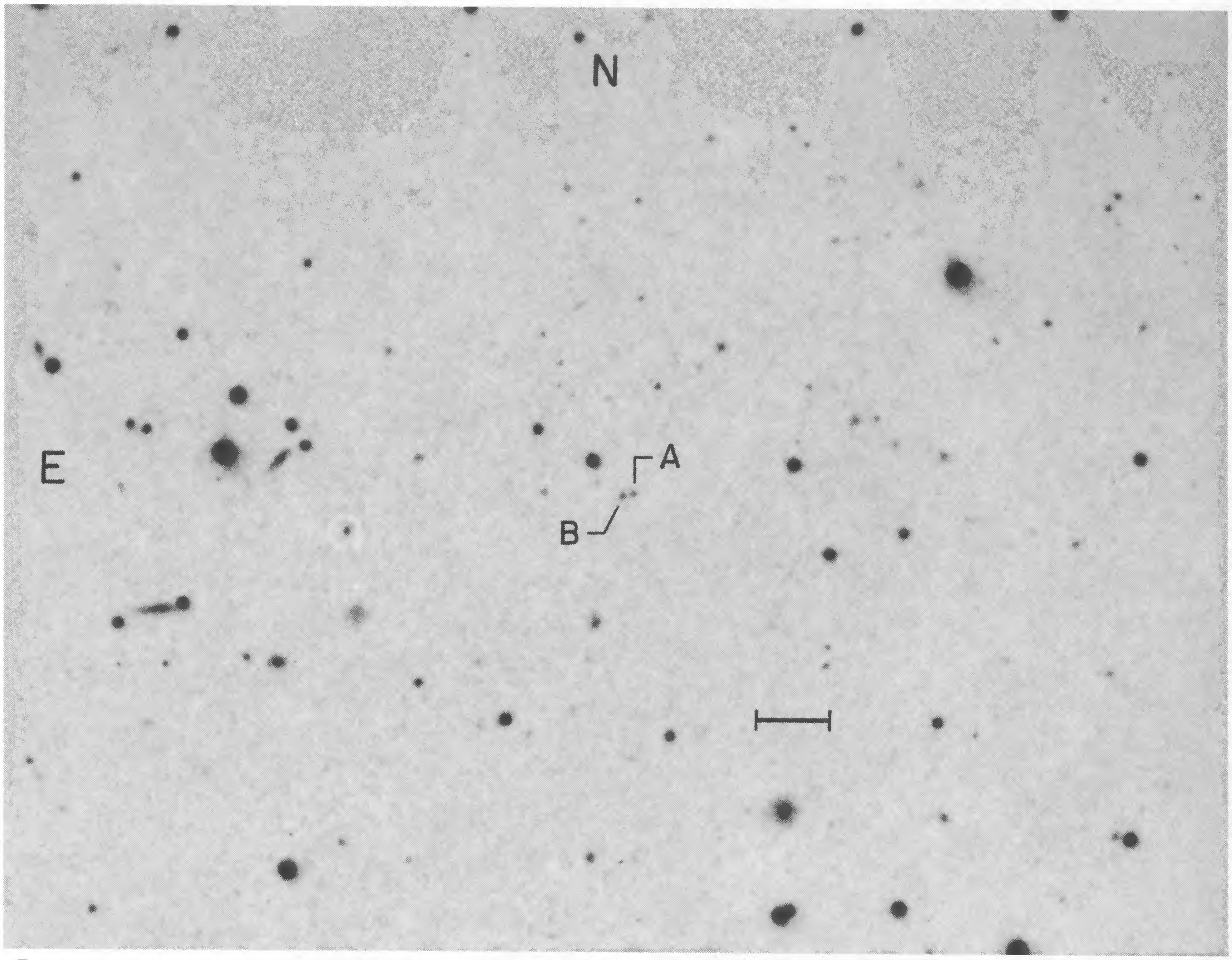

FIG. 1.—Identification chart of 1343.4 + 2640A and B from a blue copy of the Palomar Sky Survey. North is at the top, east to the left. The length of the bar is 1′.

b) Spectra, Redshifts, and Equivalent Widths of Emission Lines

The summed spectra of the two quasars as observed with the MMT are shown in Figure. 2. Although the redshifts are nearly identical, it is obvious that the emission-line strengths differ greatly between the two objects. Lyα is much stronger compared to all other lines in the spectrum of object B than in A; N V, λ1240, and He II, λ1640, are visible in A but not in B. Based on the spectral appearance and the differing relative emission-line strengths, it is unlikely that images A and B are two images of the same quasar.

The positions and equivalent widths (in the rest frame) of all emission features visible were measured and the results for the MMT spectra are listed in Table 1. The equivalent widths confirm the apparent line strength differences. In particular, Lyα is twice as strong in B as in A, whereas all other lines are about twice as strong in A. The line positions were measured both by cursor settings and by fitting parabolae to interactively selected portions of the line profiles on the individual spectra and on the average spectra of each object. The errors in measurement range from $\sim \pm 2$ Å for Lyα to $\sim \pm 10$ Å for the weaker lines. The redshifts are obviously most easily determined from Lyα. The MMT observations give $z = 2.0312 \pm 0.003$ for A and $z = 2.0313 \pm 0.002$ for B based on the sharp peaks of Lyα. The value derived for A could be affected by violet absorption since Lyα is slightly asymmetric. However, such an effect, if present, is small since the other lines (Si IV, C IV, C III]) in A give $z = 2.0296 \pm 0.0004$. If the latter value is assumed to be the best value of the redshift of A, the

TABLE 1

WAVELENGTHS AND EQUIVALENT WIDTHS OF EMISSION FEATURES

	A		B	
FEATURE	Wavelength (Å)	EW (Å)	Wavelength (Å)	EW (Å)
Lyα	3684.2	80	3684.5	180
N V	...	25	...	...
Si IV	4242.4	9	4213	6
C IV	4693.2	50	4692.0	12
He	5015	12	...	...
C III]	5782.6	44	5763	22

Rest-frame equivalent widths are given.

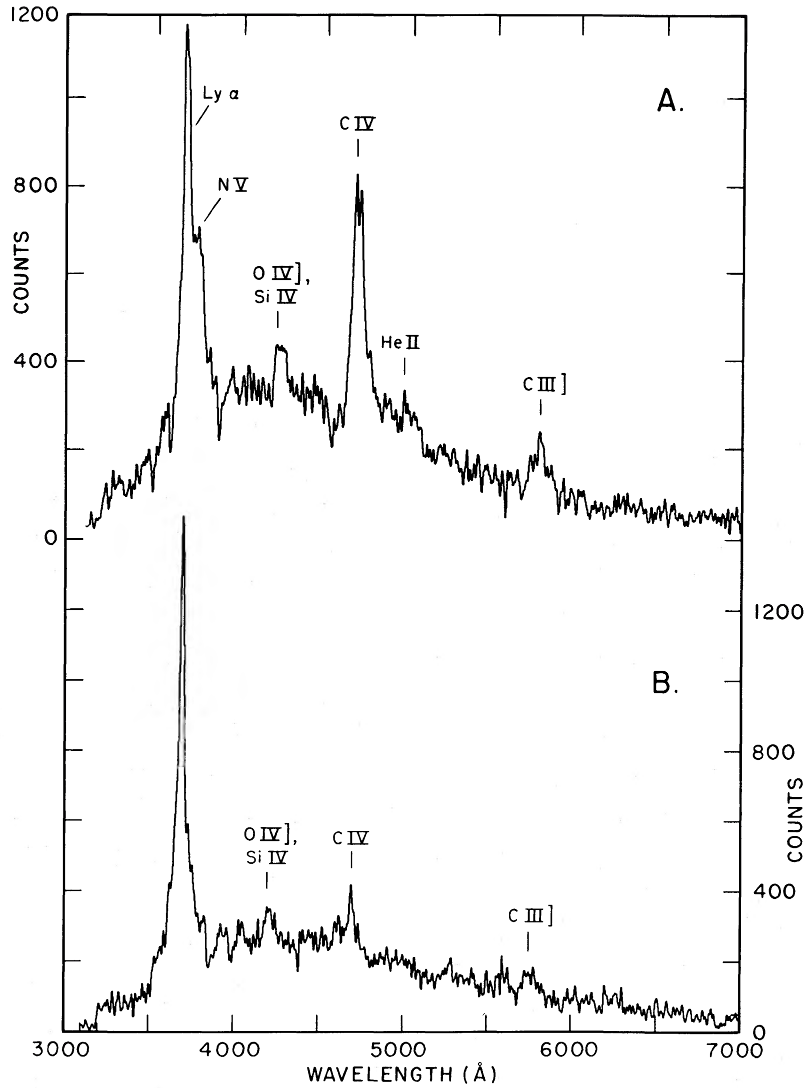

FIG. 2.—Spectra of the two quasars obtained with the MMT. The strongest emission lines are identified.

difference $\Delta z(A - B) = -0.0016$. This is in good agreement with the difference in redshift derived from the C IV lines in the two quasars: $\Delta z = -0.0008$. The mean redshift difference, $\Delta z = -0.0012$, is smaller than our measurement errors. The CFHT observations, although less accurate, confirm these results; measures of the C IV and C III] lines give $z = 2.028 \pm 0.002$ for A and 2.030 ± 0.005 for quasar B. We conclude that the quasars have nearly identical redshifts of 2.030. We estimate that the maximum redshift difference that our observations allow is ~ 0.009.

c) Absorption Lines

The absorption lines (see Table 2) due to intervening material along the line of sight are substantially different between the two objects. The signal-to-noise ratio in our MMT spectra is only ~ 10 for A and ~ 15 for B, so no detailed comparison can be made. Nevertheless, the correlation between even the strongest features is poor (see Fig. 3). The Lyα profiles of the quasars are more symmetrical than those we have observed in most quasars of comparable redshift. The Lyα profile of A shows some signs of violet absorption, but the presence of strong N V makes quantitative assessment difficult. The differences in the absorption features present in the two spectra is evidence in this case that they cannot be produced in intervening superclusters, as suggested by Oort (1981), since the lines of sight to the the two quasars should pass through the same superclusters. The absorption features must arise in

TABLE 2

WAVELENGTHS AND EQUIVALENT WIDTHS OF ABSORPTION FEATURES

A		B	
Wavelength	EW (Å)	Wavelength	EW (Å)
3354	20	3868	14
3489	11	3989	10
3596	6	4381	6
3897	8		
4542	10		

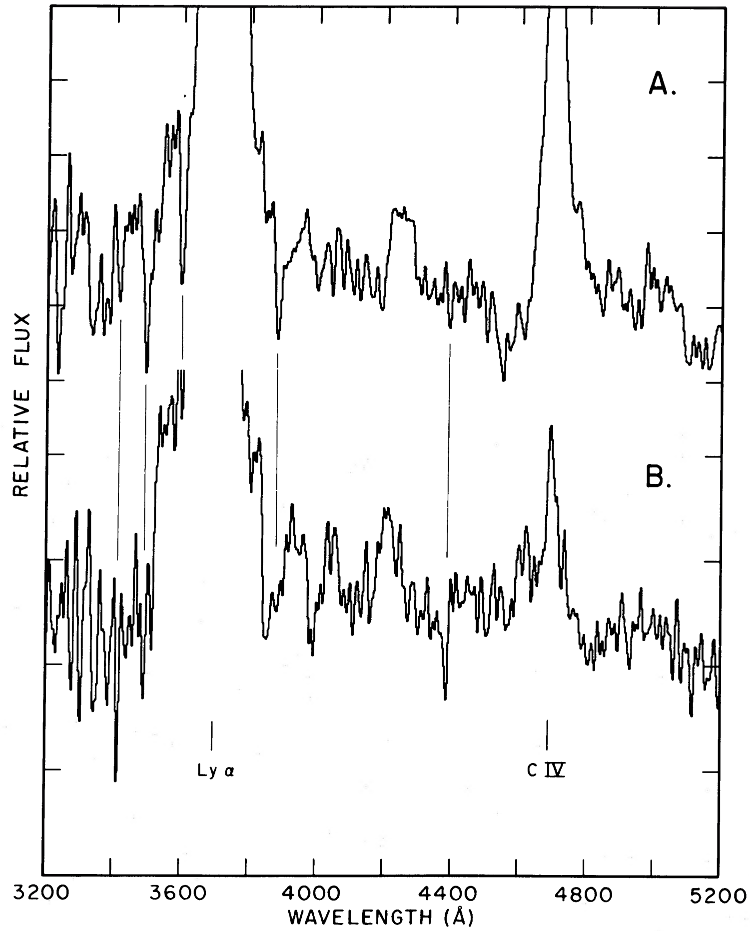

FIG. 3.—Portions of the MMT spectra of the two quasars enlarged to display possible absorption features. The vertical lines are drawn to assist in the comparison of the two spectra. The emission lines of Lyα and C IV are identified for reference.

individual galaxies along the line of sight. Observations with higher wavelength resolution to further compare the absorbing material along the two lines of sight would be of considerable interest.

The spectrum of quasar A also shows broader absorption lines of C IV and Lyα (Fig. 2) near the emission-line redshift which presumably originate close to the quasar itself. Since these do not appear in quasar B, this is additional evidence that the two quasars are not just lensed images of the same object.

III. DIRECT IMAGING

a) Observations

CCD imaging observations of the 1343+2640 field were obtained under photometric conditions on the nights of 1987 April 21 and May 4 using the AT&T Bell Laboratories RCA CCD camera on the Lowell Observatory 1.1 m telescope. A 2 : 1 focal reduction camera and on-chip 2 × 2 pixel binning gave a field of 9ʹ.0 × 7ʹ.2 and an image scale of 2ʺ.7 per pixel at an effective focal ratio of f/4. Six exposures were obtained in each of four filters: J (0.36–0.53 μm), B (0.38–0.46 μm), R (0.58–0.72 μm), and I (0.78–0.93 μm), where the quoted range of filter/CCD response is the full width at half-maximum. Total integration times were 80 minutes in J, 100 minutes in B, and 30 minutes in both R and I. In order for the telescope to reach its quantum limit for imaging, the image on the CCD was randomly moved 30ʺ between exposures in each filter by moving the telescope so that systematics such as bad pixels, fringing, or radiation events could be eliminated. During the image processing, reconstructed median filtered images were formed from the cleaned disregistered images to produce sky-noise limited images of size 6ʹ × 8ʹ in each filter of the 1343+2640 field. Images of standard stars were also obtained in each filter to provide absolute photometric calibration.

b) Results

A composite of our $BJRI$ observations of the 1343+2640 field with a total integration time of 240 minutes is shown in Figure 4. The quasars A and B are indicated as well as two other potentially interesting objects, C and D. The 1 σ limiting surface brightness of the data in Figure 4 is approximately 28.6 magnitudes arcsec^{-2}. Our imaging results are presented in Table 3. For objects A, B, and C, the error in the J magnitude is 0.02; in $B-J$ and $J-R$, it is 0.05; and in $R-I$, it is 0.07. The errors in the magnitudes and colors of object D are ∼0.5 mag. The two quasars have similar magnitude in B and J but quasar B is significantly brighter in both R and I (in 1987 April–May). As noted above, photographic observations circa 1965 (Richter, and Schnell 1968) indicated that $B = 20.23$ for quasar

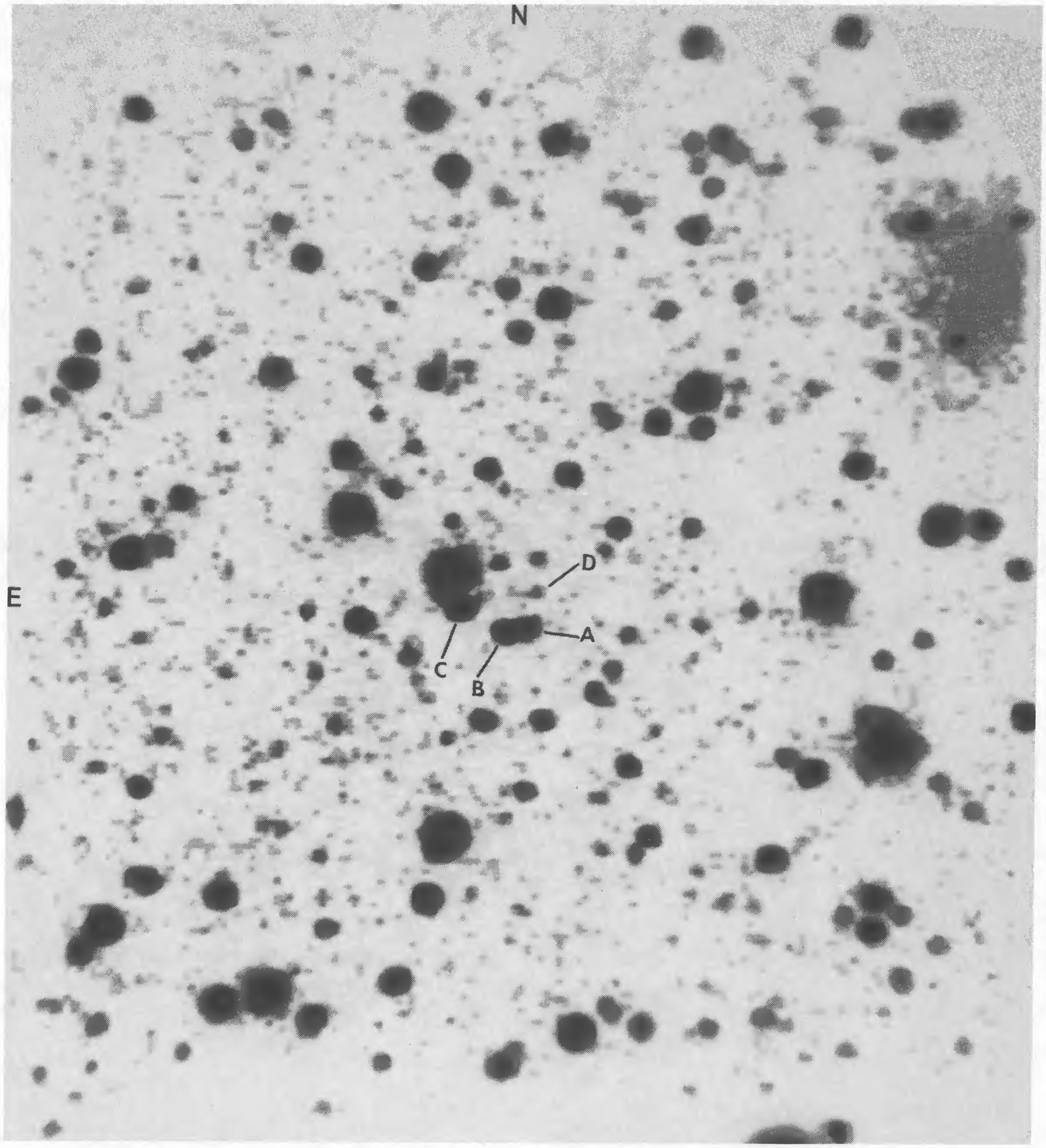

FIG. 4.—Composite of the *BJRI* CCD images of the 1343+2640 field. The total integration time was 4 hr and the limiting surface brightness is ~28.6 mag arcsec^{-2}.

A and $B = 20.18$ for quasar B whereas A was ~0.4 mag fainter than B at the epoch of the Palomar Sky Survey (1950 April 19), during our grens observation (1986 May 4) and also during our spectroscopic observations (1986 July 12 and 1987 February 5). Thus one or both of the QSOs are certainly variable. The ~0.7 mag difference between the 1965 photographic observations and the present data seems too large to be a systematic error in the photometry, so perhaps both are variable.

Our specific interest in imaging this pair was to search for a possible lensing galaxy between the pair and for any extended Lyα emission surrounding the quasars which might be similar to that observed in PKS 1614+051 (Hu and Cowie 1987) or 3C 326.1 (McCarthy *et al.* 1987). None of our sky-limited images shows any detectable objects between the quasar pair.

The observed wavelength of Lyα corresponds closely to the [O II] 3727 Å line in its rest frame. A [O II] 3727 Å filter was available to us, but the FWHM was only 15 Å and we concluded that it would be virtually impossible to obtain sky-

TABLE 3

IMAGING RESULTS

Object	J	$B-J$	$J-R$	$R-I$
A.........	20.51	0.31	0.31	0.29
B.........	20.70	0.19	0.78	0.75
C.........	20.38	0.29	0.92	0.25
D........	23.4:	...	0.9:	0.1:

limited images in that filter for any reasonable integration time. Instead, the fact that the transmission of the B and J filters differs considerably at the observed wavelength of Lyα was used to construct a "Lyα image." Examination of the $B-J$ image shows no obvious structure in Lyα surrounding the QSOs or in the form of a discrete cloud near the QSOs. We find no evidence for extended Lyα emission brighter than about 27 J mag arcsec^{-2} (3 σ). This corresponds to a Lyα luminosity of less than or equal to $8 \times 10^{44} h^{-2}$ ergs s^{-1} in the quasar restframe for $q_0 = 0.5$. This estimate assumes a size scale comparable to the separation of the QSOs.

Examination of Table 3 also reveals that B is significantly redder than A. In both $J-R$ and $R-I$, the difference amounts to approximately 0.5 mag. This color difference could be intrinsic to the QSOs or be the result of more intervening material, such as galaxies, along the line of sight to B than to A. Deep imaging in R and I at a larger scale than used here and careful subtraction of a stellar point spread function may reveal the foreground galaxies responsible for such absorption. As demonstrated by Bahcall, Bahcall, and Schneider (1987), even imaging as deep as ours is not deep enough to reveal the presence of galaxies in an associated cluster at $z = 2.03$, the redshift of the quasars.

Two other objects in the vicinity of the QSOs are worth mentioning (see Fig. 4). Object C, which is just visible on the Palomar Sky Survey, is very blue in color and a weak spectrum obtained in 1987 June with the MMT indicates that it is probably an emission line galaxy with $z = 0.09$. Object D, just north of quasar A, is much brighter in R than in J but comparable to R in I. It is likely to be a foreground late-type star or a foreground galaxy with $z \leq 1$.

IV. PHYSICAL SEPARATION

The velocity difference in the rest frame of the two quasars, ΔV, can be computed from the redshift difference, Δz, by

$$\Delta V = c\,\Delta z(1 + z)^{-1} .$$

A difference of $\Delta z = -0.0012$ corresponds to only $\sim$120 km s^{-1}, and $\Delta z = 0.009$ to $\sim$890 km s^{-1}. If the two quasars are both following the Hubble flow, the latter figure gives an upper limit of 5 Mpc for their line-of-sight separation in terms of present epoch coordinates. On the other hand, the maximum velocity difference is comparable to the velocity dispersion of $\sim$400 km s^{-1} (Oort 1983) observed in superclusters; the smaller, measured difference is typical of that observed between galaxies in clusters. It is thus not possible to determine the line-of-sight separation of the quasars from their redshifts.

If it is assumed that two quasars are at the same distance, their linear separation can be determined from their angular separation. This was measured on glass copies of the Palomar Sky Survey to be $9''.5 \pm 0''.2$. For $q_0 = 0.5$, this corresponds to a linear separation of $39h^{-1}$ kpc if $H_0 = 110\ h$ km s^{-1} Mpc^{-1}. Thus, if the quasars are at exactly the same distance, they are very close to each other, and it is probable that they are a physical pair, most likely located in a bound group.

V. CONCLUSIONS

We conclude that 1343.4+2640A and B appear to be a physically bound pair of quasars which may reside in a galaxy association at $z = 2.030$. With two close quasars in a group of galaxies, one might expect other active galaxies to be revealed by narrow-band imaging in the light of Lyα, but no such galaxies were detected in our $B-J$ images. Radio and infrared emission might also be expected from these quasars, but they are in neither the *IRAS* catalog nor Dixon's (1987) radio-source catalog. These quasars are obviously prime examples of possible membership of quasars in superclusters as discussed by Oort, Arp, and de Ruiter (1981), or galaxy associations, as discussed by Bahcall, Bahcall, and Schneider (1986). The latter authors argue that at least three pairs of quasar images previously suggested to be gravitational lenses are more likely to be physical pairs of quasars in galaxy associations and discuss the probability of observing such pairs. The two quasars are not unusual in any way and have typical quasar luminosities, $M \sim -23$ (for $H_0 = 100$ km s^{-1} Mpc^{-1}, $q_0 = 0.5$). The numbers given by Bahcall, Bahcall, and Schneider indicate that the discovery of a small number of such pairs is to be expected, particularly if quasars were more common relative to galaxy associations at $z = 2$ than at present, which is likely. We have thus far surveyed about 10 deg^2 with the blue grens to a limiting magnitude of $m \sim 20.5$. Although follow-up spectroscopy is complete in only 12 fields, or $\sim$6 deg^2, 80% of all candidates are quasars, so all the candidates can be treated as quasars to a first approximation. No other close pairs of identical redshift have been found among the $\sim$1500 candidates. The next closest pair of quasars of identical redshift (1336.5+2804 and 1336.6+2803; Crampton, Cowley, and Hartwick 1987) have a separation of 95 arcsec. (Only low signal-to-noise spectra have been obtained of the members of this pair so it is not known how similar the spectra are.) This frequency of close pairs is consistent with that expected according to the discussion by Bahcall, Bahcall and Schneider.

Despite the spectroscopic observations and the imagery which favor interpretation of the quasars as two separate objects, the gravitational lens hypothesis cannot be completely ruled out. The spectroscopic differences in the broad emission lines could result from minilensing or microlensing under rather fortuitous circumstances (Refsdal 1987; Nemiroff 1987). Optical monitoring of the two images for correlated variability on short time scales or VLA observations for comparison of radio structure could provide stronger constraints on the gravitational lens hypothesis. Deep optical imagery with improved spatial resolution to look for intervening galaxies would also be worthwhile.

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