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PAIRED QUASARS NEAR NGC 2639: EVIDENCE FOR QUASARS IN SUPERCLUSTERS?

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ABSTRACT

Arp found 10 quasars near a low-redshift galaxy 27′ SSE of NGC 2639. Six of the quasars can be grouped into three redshift pairs which align across the anonymous galaxy. The large number of quasars and pairings could show an association with the low-redshift galaxy, or, alternatively, might be due to superclusters seen along the line of sight. We tested the latter hypothesis by using deep, red-sensitive Lick 3 m prime focus plates to search for a supercluster associated with the $z = 0.3$ quasar pair. The plates show extended nebulosity associated with the quasar U10 ($\theta \sim 7''$, or 20 kpc at $z = 0.3$) and a richness class 1, Bautz-Morgan type III cluster 4′ NW of U10. A spectrum of one the cluster's brightest galaxies gives $z = 0.34$, suggesting that the cluster and quasar are unassociated. We obtained spectra of eight of the quasars and find that (i) two of the quasars have very strong absorption shortward of Lyα, and (ii) two of Arp's redshifts (including one which Arp considered uncertain) are incorrect. Our redshifts break two of the redshift pairs, including the pair at $z = 0.3$. We use the redshift distribution of optically selected quasars to argue that the third pair has no statistical significance, and conclude that there is no basis for associating the quasars with the low-redshift anonymous galaxy. The disappearance of the redshift pairs vitiates the possibility of testing the paired-quasars-in-superclusters hypothesis in the NGC 2639 field.

Subject headings: cosmology — galaxies: clusters of — galaxies: redshifts — quasars

I. INTRODUCTION

Arp (1979, 1980) has found quasars with similar redshifts which appear to be paired across low-redshift galaxies. One of the most striking examples of this phenomenon is 10 quasars which appear near a small, high surface brightness galaxy ($v_{\langle obs \rangle} = 1680$ km s^{-1}, Arp 1980) that is located 27′ SSE of NGC 2639 ($v_{\langle obs \rangle} = 3005$ km s^{-1}, de Vaucouleurs *et al.* 1976). Arp (1980) found that eight of the 10 quasars can be grouped into pairs with similar redshifts. Three of the pairs straddle the small galaxy. Two of the straddling pairs, U7/U10 and U3/U15, appear to have redshifts (0.303/0.305 and 1.522/1.525, respectively) which are identical within Arp's measuring errors. Arp concludes that the pairings are evidence for an association between the high-redshift quasars and the small, low-redshift galaxy.

Oort, Arp, and de Ruiter (1981) suggested an alternative hypothesis to explain the close redshift pairs. They propose that the two closest pairs are in superclusters at the cosmological distances implied by the quasars' redshifts. The apparent separations of the quasars ($7h^{-1}$ and 13.4 h^{-1} Mpc; $h = H_0/100$ km s^{-1} Mpc^{-1}) and the small velocity differences, 428 km s^{-1} and 167 km s^{-1}) are compatible with superclusters' observed sizes and velocity dispersions (Gregory and Thompson 1978; Tarenghi *et al.* 1979; Gregory, Thompson and Tifft 1981; Ford *et al.* 1981).

The low-redshift quasar pair U7/U10 (0.303/0.305) is close enough to allow detection of any associated clusters of galaxies on deep red photographs. Consequently, we decided to test the supercluster hypothesis by searching for faint clusters which might comprise a supercluster at $z \sim 0.3$.

In § II*a* we describe a photographic survey which revealed nebulosity around the quasar U10 and a faint rich cluster of galaxies 4′ NW of U10. In § II*b* we present spectroscopy of six of the 10 quasars and show that two of Arp's redshifts must be revised. We also describe the spectra of four faint galaxy candidates in the rich cluster. In § III we discuss the consequences of our observations for Arp's suggestion that the quasars are associated with a low-redshift galaxy near NGC 2639. We then consider the hypothesis that the paired quasars are in superclusters. We end with a discussion of the cluster's redshift, the possible association of U10 and the cluster, and the significance of U10's nebulosity.

TABLE 1

SURVEY PLATES OF FIELDS NEAR NGC 2639

Plate Number	U.T. Date	Telescope	Emulsion	Exposure Time (min)	Right Ascension (1975.0)	Declination (1975.0)	Remarks
ED 2827 ...	1981 Feb 4	Lick 3 m	Baked IIIa-F	180	8^h47^m0	49°32′	a
ED 2829 ...	1981 Feb 5	Lick 3 m	Baked IIIa-F	360	8 40.7	50 03	b
CD 3118 ...	1981 Apr 3	Crossley	Flashed 098-04	65	8 44.3	49 49	c
CD 3119 ...	1981 Apr 4	Crossley	Flashed 098-04	150	8 44.3	49 49	
CD 3121 ...	1981 Apr 5	Crossley	Flashed 098-04	150	8 44.3	50 10	

[a] Because the plates were slow, the exposure was very light.
[b] The seeing was approximately 1″ for the first $3\frac{1}{2}$ hours; thereafter, it was 2″–3″.
[c] Exposure interrupted by fog.

II. OBSERVATIONS

a) Photographic Survey

Fields near NGC 2639 were photographed at the prime foci of the Shane 3 m telescope and the Crossley 0.9 m telescope through an OG 570 filter. Pertinent information about the plates is summarized in Table 1. The right ascensions and declinations of the plate centers are listed in the last two columns of the table. Because there is at present no provision for nitrogen or forming gas baking at Lick Observatory, the IIIa-F plates were baked in air for 10.5 hours at 50° C. The baked plates were very slow and required an inordinately long exposure to reach the sky at the f/5 prime focus of the 3 m telescope.

Figure 1 (Plate 6) is a high-contrast enlargement of a region of the prime focus plate ED 2829. The plate has a red limiting magnitude which is considerably deeper than the Palomar Observatory Sky Survey (POSS) E print. A rich cluster of galaxies, which does not show on the POSS E print, is located 1′.9 west and 3′.6 north of the quasar U10. The cluster of galaxies is also discernible in Arp's Figure 1 and on his original 48 inch Schmidt IIIa-J plate which he kindly loaned to us. We measured the size and richness of the cluster by comparing our IIIa-F plate to Arp's IIIa-J plate and counting all galaxies in the field whose $J - F$ colors are comparable to those of the central galaxies. Although this technique fails to detect any cluster galaxies with active star formation, it greatly increases the cluster's apparent contrast by eliminating foreground galaxies. These filtered galaxy counts show a Bautz-Morgan type III cluster (Bautz and Morgan 1970) extending over an angular size of ~ 6′ on the sky. By combining the galaxy counts with a Schechter luminosity function (Schechter 1976), we estimated the Abell richness class (Abell 1958) to be approximately 1. These properties are summarized in Table 2.

The quasar U10 lies at the southeast corner of Figure 1. On the original plate the quasar has a dominant stellar image and a faint associated nebulosity extending 6″.8 ($20h^{-1}$ kpc at $z = 0.3$; $q_0 = 0.0$) at a 53° position angle. U10's image is very similar to that of a faint spiral galaxy which appears 140″ to the NW. Romanishin (1983) has analyzed KPNO 2.1 m telescope video camera pictures of U10 and concludes that the light distribution is well represented by the superposition of a bright stellar nucleus and the almost edge-on disk of an underlying Sab galaxy with an exponential scale length of $\sim 1.8h^{-1}$ kpc. He found that the observed image profile is inconsistent with the smeared image of a point source and an underlying elliptical galaxy.

TABLE 2

PROPERTIES OF GALAXY CLUSTER 0839+50

R.A. (1950.0)	$8^h38^m44^s.1$
Decl. (1950.0)	50°12′24″
Abell richness class	1
Bautz-Morgan type	III
Radius (″)...............	~ 400
Redshift (z)	0.34

We obtained spectra of the galaxies which are marked in Figure 1. The positions of those galaxies are listed in Table 3. The positions of the 10 quasars are listed in Table 4. The coordinates were derived by using a multiple linear regression to transform two-screw Grant comparator x, y measurements from plate ED 2829 and Arp's Schmidt plate to a standard coordinate system defined by SAO stars on the plates. The accuracy of the positions is approximately 1″ in x and in y.

b) Spectrophotometric Observations of Quasars and Galaxies near NGC 2639

We used the Lick Image Tube Scanner (ITS; Robinson and Wampler 1972a, b) to make spectrophotometric observations of the quasars U1, U7, U8, U10, U14, and U15 and four candidate galaxies in the faint cluster near U10. Two of the galaxy candidates were also observed with the Intensified Image Dissector Scanner (IIDS) on the Mayall 4 m telescope. Our spectroscopic observations are summarized in Table 5. The Lick 600 lines

TABLE 3

Galaxy Positions and Redshifts

Object	R.A. (1950.0)	Decl. (1950.0)	z	Notes
Galaxy 1	$8^h38^m34\overset{s}{.}86$	50°12′15.4″	0.185	
"Galaxy" 2	8 38 43.39	50 12 18.8	0.0	a
Galaxy 3	8 38 44.05	50 12 24.2	0.344	
Galaxy 4	8 38 55.41	50 13 01.4	...	b
Arp's anonymous galaxy	8 40 31.96	49 58 30.8	0.0056	c

[a] This is a foreground star.
[b] The spectrum does not have the characteristic shape of an early type galaxy.
[c] The redshift is from Arp 1980.

TABLE 4

Coordinates of Quasars in the NGC 2639 Field

Quasar	R.A. (1950.0)	Decl. (1950.0)
U1	$8^h40^m40\overset{s}{.}89$	49°55′37.4″
U2	8 40 46.62	49 55 29.7
U3	8 40 55.50	49 59 55.9
U4	8 40 09.65	49 54 13.0
U5	8 41 38.12	49 50 48.2
U7	8 42 21.85	49 49 23.9
U8	8 40 00.03	50 10 00.3
U10	8 38 55.81	50 08 50.4
U14	8 41 09.71	49 34 47.5
U15	8 37 34.00	49 43 56.1

TABLE 5

Spectroscopic Observations of Quasars and Galaxies Near NGC 2639

Object	U.T. Date (mo-day-yr)	Integration Time (min)	Grating/Image Tube (lines/mm)/(Red or Green)	$\lambda_{central}$ (Å)
		Lick Observatory 3 m Telescope, ITS		
QSO U7.......	2-06-81	48	600/R	5600
	4-06-81	40	300/G	5380
QSO U8.......	4-07-81	40	300/G	5380
	4-08-81	32	600/G	4380
QSO U10......	2-06-81	32	600/R	5600
QSO U14......	4-07-81	32	300/G	5380
QSO U1.......	11-19-81	32	300/R	5837
QSO U15......	11-19-81	56	300/R	5837
Galaxy 1	2-06-81	32	600/R	5230
"Galaxy" 2 ...	2-06-81	40	600/R	5230
Galaxy 3	4-06-81	112	600/G	5080
	4-08-81	96	600/G	5080
Galaxy 4	4-09-81	80	600/G	5590
		Kitt Peak 4 m Telescope, IIDS		
Galaxy 3	10-24-81	56	500	5834
	10-25-81	56	500	5834
Galaxy 4	10-26-81	56	500	5834

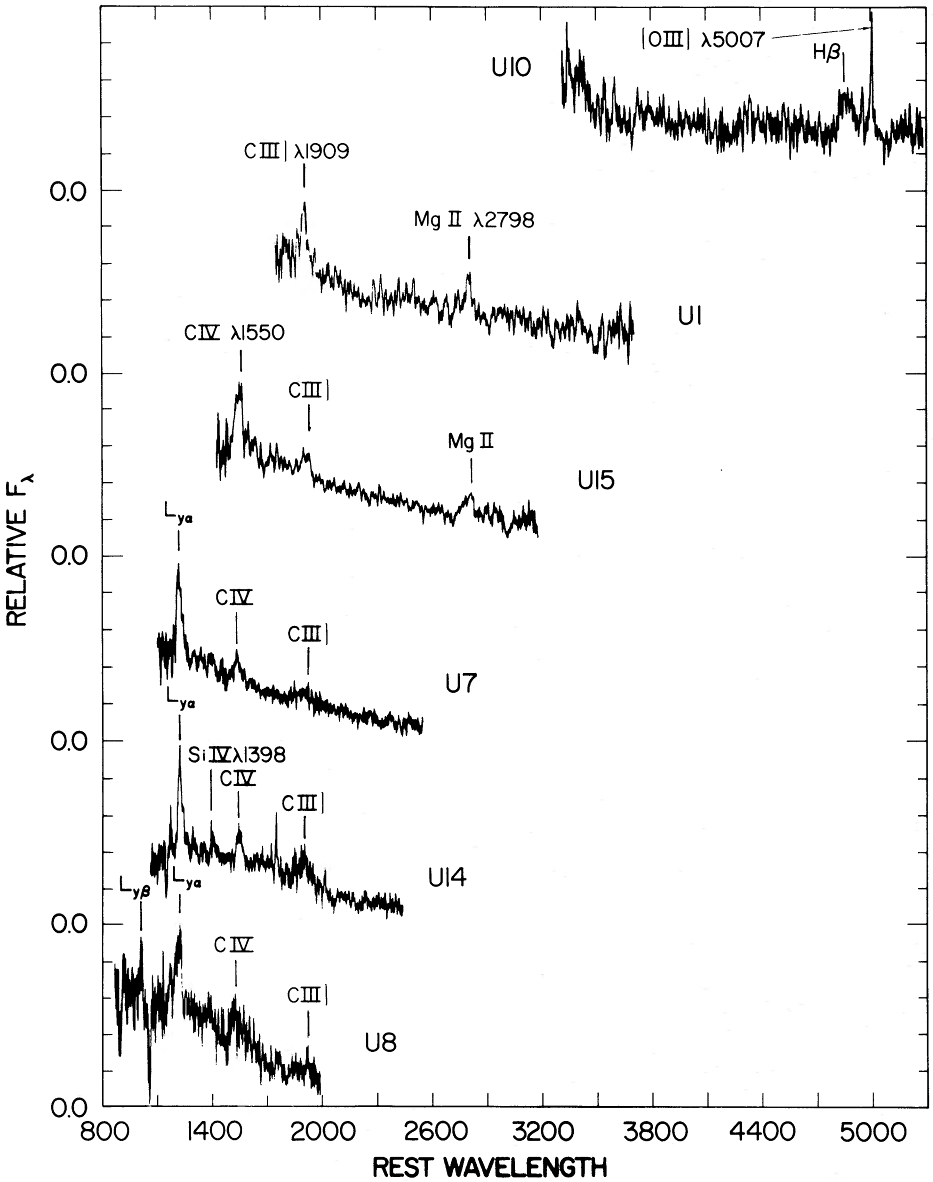

FIG. 2.—ITS spectra of six quasars in the field of NGC 2639. Each quasar has been plotted in its rest frame. The redshift of quasar U7 is almost certainly 2.00, rather than 0.303 as reported by Arp (1980).

mm^{-1} grating is blazed at 5000 Å in the first order and gives a spectral range of 2570 Å with a resolution of 11 Å (FWHM). The 300 lines mm^{-1} grating is blazed at 4230 Å and gives a spectral range of 4530 Å with a spectral resolution of 22 Å. The Lick "red" image tube chain has an S-25 photocathode with high sensitivity at Hα. The "green" image tube chain has higher sensitivity in the blue and green and less in the red than the red image tube chain. The Kitt Peak 500 lines mm^{-1} grating is blazed at 5000 Å in the first order and gives a spectral range of 2120 Å with a spectral resolution of 8 Å. The IIDS's S-20 photocathode has high sensitivity in the blue and green and relatively low sensitivity in the red. We used observations of stars with known flux distributions (Stone 1977; Oke 1974) to reduce the ITS and IIDS scans to relative intensity versus linear wavelength.

i) *Quasars*

Our ITS quasar spectra are shown in Figure 2. To facilitate intercomparison of the spectra, each quasar is plotted in its rest frame. Comparison of the spectra of U7 and U14 shows that the U7 line which Arp (1980) identified as Mg II λ2798 is instead Lyα λ1216. The redshift is almost certainly $z = 2.00$ rather than $z = 0.303$ as measured by Arp.

Arp (private communication) has examined our spectra and agrees that the new redshift is correct. Interestingly, the C IV λ1550 line, which is variable in some quasars, is weak or absent in Arp's spectrum. On the other hand, Si IV λ1398 is relatively strong in Arp's spectrum (Arp 1980) but quite weak in our spectrum (Fig. 2). There is also a 50 angstrom difference between the observed wavelength of C III] λ1909 in Arp's spectrum and our spectrum.

The Lyα profiles of U7 and U8 are similar, and we believe that N V 1240 can be seen on the red wing of both emission lines. Our redshift for U8 is 2.80, a value that differs significantly from Arp's value of 2.03. Comparison of U8's spectrum with the spectra of U7 and U14 shows that the lines which Arp identified as Lyα, C IV, and C III] are instead Lyβ, Lyα, and C IV. Our line identifications and measured redshifts are summarized in Table 6. The redshifts in the last column of Table 6 are subjectively weighted means of the individual lines in each spectrum. The primary uncertainty in the redshifts stems from the problem of estimating the centers of the broad and complex emission line profiles.

Two of the quasars, U14 and U8, have strong absorption lines shortward of Lyα. The Lyα line in U8 is very broad (~ 8000 km s^{-1} FWHM in the rest frame) and is split by two absorption lines. The strongest absorption line shortward of Lyα in U8, which we identify as Lyα at $z = 2.37$, has zero intensity in the bottom of the line. This strong line can also be seen very well in Arp's spectrum. We identify an absorption line at 3475 Å as Lyβ in the same system. Table 6 includes a list of the strongest absorption lines in each spectrum. A check

TABLE 6

REDSHIFTS OF QUASARS NEAR NGC 2639

Quasar	Strong Absorption Lines			Emission Lines			Redshift $\langle z_{em} \rangle$ Arp	Redshift $\langle z_{EM} \rangle$ This Paper
	λ_{obs}(Å)	Id.	z_{abs}	λ_{obs} (Å)	Id.	z_{em}		
U1	3987	...	...	4144	C III] 1909	1.171	1.177	1.177
	4037	...	...	6107	Mg II 2798	1.182	...	...
U7	3355	...	...	3659	Lyα 1216	2.010	0.303	2.00
	3430	...	...	3721	N V 1240	1.999	...	...
	3465	...	...	4195	Si IV 1397	2.001	...	...
	3541	...	...	4620	C IV 1550	1.982	...	...
	3595	...	...	5699	C III] 1909	1.986	...	...
	4117	...	...	...	... ...	...	...	...
	4410√	...	...	...	... ...	...	...	...
	4545√	...	...	...	... ...	...	...	...
	4671	...	...	...	... ...	...	...	...
U8	3475√	Lyβ 1026	2.39	...	Lyβ 1026	2.80	2.027	2.80
	3615√	...	...	...	Lyα 1216	2.854	...	...
	3760√	...	...	...	Si IV 1397	2.785	...	...
	3835√	...	...	...	C IV 1550	2.833	...	...
	4055√	...	...	...	... ...	...	...	...
	4092√	Lyα 1216	2.37	...	... ...	...	...	...
	4206√	...	...	...	... ...	...	...	...
	4556√	...	...	...	... ...	...	...	...
	4650√	...	...	...	... ...	...	...	...
	4800√	...	...	...	... ...	...	...	...
	5175√	...	...	...	... ...	...	...	...
U10	4413	...	...	6345	Hβ 4861	0.305	0.305	0.305
	4818	...	...	6468.1	[O III] 4959	0.304	...	...
				6535.1	[O III] 5007	0.305	...	...
U14	3580	Lyα 1216	1.94	3811	Lyα 1216	2.135	2.124	2.132
	3707	...	...	3868	N V 1240	2.118	...	...
	4137	...	...	4393	Si IV 1397	2.143	...	...
	4200	...	...	4829	C IV 1550	2.116	...	...
	4500	...	...	5957	C III] 1909	2.121	...	...
	4687	...	...	...	... ...	...	...	...
	4734	...	...	...	... ...	...	...	...
U15	3662	...	...	3920	C IV 1550	1.530	1.525	1.535
	3725	...	...	4849	C III] 1909	1.540	...	...
	3780	...	...	7105	Mg II 2798	1.540	...	...

NOTE.—A √ means identified in more than one spectrum.

beside the observed wavelength shows that the line was identified in two spectra.

ii) *Galaxies*

Figure 3 reproduces our scans of the candidate cluster members and a high signal-to-noise ratio composite spectrum of four elliptical galaxies. The principal absorption features, and the wavelengths of the strongest city glow and airglow lines, are marked. The characteristic "stair step" shape of E and S0 galaxies is evident in the composite spectrum. The spectra in Figure 3 have been shifted to their rest frames to aid comparison with one another. The redshifts were derived by first reducing the Lick and Kitt Peak scans to linear intensity, adding the spectra, and plotting them as F_λ versus the logarithm of wavelength. We then registered (cross-correlated) the spectra of the program galaxies against the composite template. Reducing the spectra to relative intensity allows us to use the shape of the continuum, as well as the strong absorption lines (H, K, G-band, and Mg I λ5175) to measure the redshift. This is especially helpful when working on the noisy spectrum of a faint galaxy. Using a logarithmic scale removes the wavelength-dependent redshift stretching of the spectrum and allows us to register galaxies with different redshifts against one another.

We have marked our identifications of absorption features in Figure 3. The spectra of objects 1, 2, and 3 have been shifted to what we consider the best registration against the composite spectrum. The resulting redshifts are listed in Table 3. Each spectrum is discussed in turn in the following paragraphs.

Galaxy 1.—Although H and K are not especially strong, and the G-band is hardly discernible, the overall match of the spectrum with the composite is very good at $z = 0.185$. The spectral region around our identification of Mg I λ5175 is very clean and matches well with the composite spectrum. We believe that the redshift is well determined.

Galaxy 2.—The spectrum shows strong absorption features at 5175 Å and 5890 Å. We think the latter is too strong to have resulted from poor subtraction of the Na D airglow line. We also (belatedly) note that the image of Galaxy 2 looks very stellar on our 3 m plate ED 2829 (cf. Fig. 1). We conclude that Galaxy 2 is a faint, late-type foreground star.

Galaxy 3.—Galaxy 3 does appear to be a galaxy on our deep prime focus plate. The spectrum shown in Figure 3 is the sum of observations obtained at Lick and Kitt Peak. Because the galaxy is very faint, the spectrum is noisy. The light distribution in the spectrum shows that the galaxy is very red; it is in fact redder than an M star. The galaxy's redness is also reflected in the fact that it (and the cluster) are barely discernible on Arp's deep IIIa-J plate. The most distinctive feature in the spectrum is the sudden onset of a rise in the continuum at ~ 5360 Å. There is a relatively strong absorption line shortward of this wavelength. We identify the absorption line and spectral rise as the H and K "break," and derive a redshift $z = 0.344$. We readily acknowledge that the evidence for this redshift isn't overwhelming; however, we believe this is the redshift which is most consistent with the overall shape of the spectrum.

Galaxy 4.—The galaxy appears on the POSS E-print and Arp's IIIa-J plate. It is almost certainly brighter and

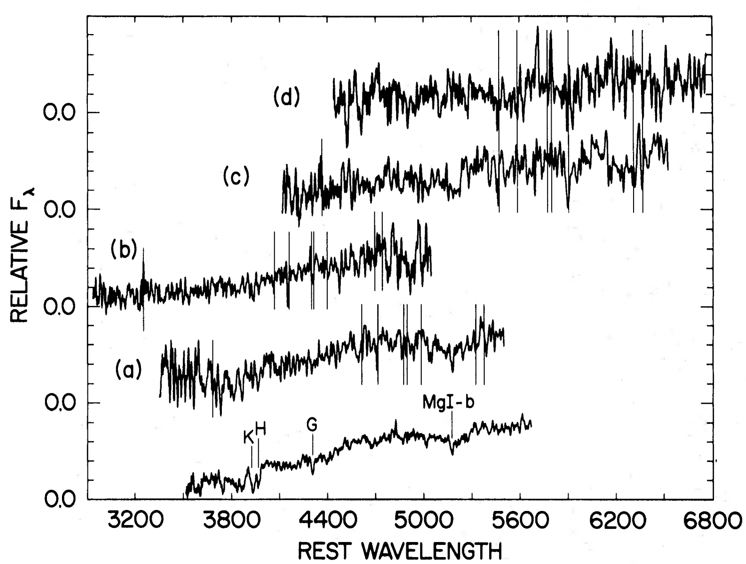

FIG. 3.—Galaxy cluster candidates in the field of U10, compared with a composite spectrum of four elliptical galaxies. Galaxies 1(*a*) and 3(*b*) have been plotted in what we believe is their rest frame. "Galaxy" 2(*c*) is actually a foreground star. Vertical lines through the spectra mark the wavelengths of city glow and airglow lines.

bluer than the cluster galaxies. Because the spectrum of this faint galaxy is noisy, we can say only that its spectrum does not have an early-type galaxy's characteristic shape.

III. DISCUSSION

Arp (1980) argues for the association of high-redshift quasars with an anonymous galaxy 27′ SSE of NGC 2639 because of their high density around the galaxy, their spatial pairing across the galaxy, and their redshift pairing (three pairs) across the galaxy. Our spectrophotometry confirms that the six objects which we observed are quasars, but shows that two of the three redshift pairings are due to incorrect emission line identifications. The mistaken pairings include U7 ($z_{\rm Arp} = 0.303$; $z_{\rm here} = 2.00$) and U10 ($z_{\rm Arp} = 0.305$; $z_{\rm here} = 0.305$), a pair which Arp considered particularly significant because of their nearly identical redshifts and equidistant alignment across the anonymous galaxy.

The remaining pair, U3 ($z_{\langle \rm Arp \rangle} = 1.522$) and U15 ($z_{\langle \rm Arp \rangle} = 1.525$; $z_{\langle \rm here \rangle} = 1.535$), and the quasar U5 ($z_{\langle \rm Arp \rangle} = 1.494$) appear to clump in redshift space. If we suppose that the quasars in this field are randomly distributed in redshift space between $z = 0.0$ and $z = 2.9$, Monte Carlo simulations show that the probability of finding a clump of three quasars within a redshift interval of ± 0.02 is ~ 0.07. This probability increases to ~ 0.13, however, if we adopt the more realistic redshift distribution for UV excess quasars, given by Braccesi *et al.* 1980. Consequently, we conclude that there are no statistically significant redshift pairs or clumps in this field.

Once the redshift pairings disappear, we believe there is no plausible basis for associating the high-redshift quasars with the anonymous galaxy. We also believe there is no basis for Arp's conclusion that the anonymous galaxy ($z = 0.0056$) is a companion of NGC 2639 ($z = 0.010$). Arp (private communication) now agrees that there is no case for associating the anonymous galaxy with NGC 2639.

Our original intent in studying the NGC 2639 field was to test Oort, Arp, and de Ruiter's (1981) intriguing hypothesis that close quasar pairs with similar redshifts are in superclusters. If correct, the hypothesis is very important because "true" paired quasars can then be used to study the evolution of superclusters over most of the age of the universe. Unfortunately, the disappearance of the pairs (especially the low-redshift pair at $z = 0.30$ where a supercluster might be detected) vitiates the possibility of testing the hypothesis in this field. Because of the difficulty of measuring the redshifts of faint quasars with broad emission lines, we think it would be prudent to assess the redshifts of paired quasars and their statistical significance carefully before undertaking programs similar to this one.

Our search for a supercluster at $z = 0.30$ revealed a faint rich cluster of galaxies near the quasar U10 ($z = 0.305$). A foreground cluster, typified by Galaxy 1 ($z = 0.185$; cf. Table 3 and Fig. 1), projects across the faint cluster. When the faint cluster is examined in color-magnitude space by comparing Arp's IIIa-J plate with our IIIa-F plate, foreground galaxies disappear and the apparent contrast of the cluster is greatly increased. Galaxy 3, whose color and magnitude are similar to other cluster members, has a redshift $z = 0.344$. We believe that it is a member of the cluster and that its redshift is relatively well determined. It then follows that U10 is not associated with the cluster in spite of the fact that it projects onto the outer part of the cluster.

U10 clearly shows elongated nebulosity on our IIIa-F plate and on Romanishin's (1983) KPNO 84 inch (2.1 m) telescope video camera photograph. The total extent of the nebulosity ($\sim 7''$) is $\sim 20 h^{-1}$ kpc at $z = 0.3$. Romanishin (1983) has shown that the quasar's image is best represented by the sum of a point source and an exponential disk, which suggests that the quasar is in a disk galaxy.

Hutchings *et al.* (1981) took deep red photographs of 10 quasars with $z < 0.3$ and found that all showed underlying nebulosity. Wyckoff, Wehinger, and Gehren (1981) found that 13 of 15 quasars with $0.1 < z < 0.6$ show nebulosity on deep red plates. Both groups conclude that the underlying nebulae are consistent in sizes and magnitudes with those of underlying galaxies at the redshifts of the quasars. We believe that U10 is another example of such systems. Because U10 is fainter than most of the quasars in the above list, it may be particularly interesting for further investigations of the nature of the underlying nebulosity.

We wish to thank Gene Harlan for his excellent assistance in taking the Crossley plates, and Dr. Edward Wright for providing interesting insights into the statistical significance of "redshift" clumps. We are grateful to Dr. H. Arp for the generous loan of his plate material. Our research was supported by a grant from the UCLA Academic Senate and by NASA contract NAS 5-24463.

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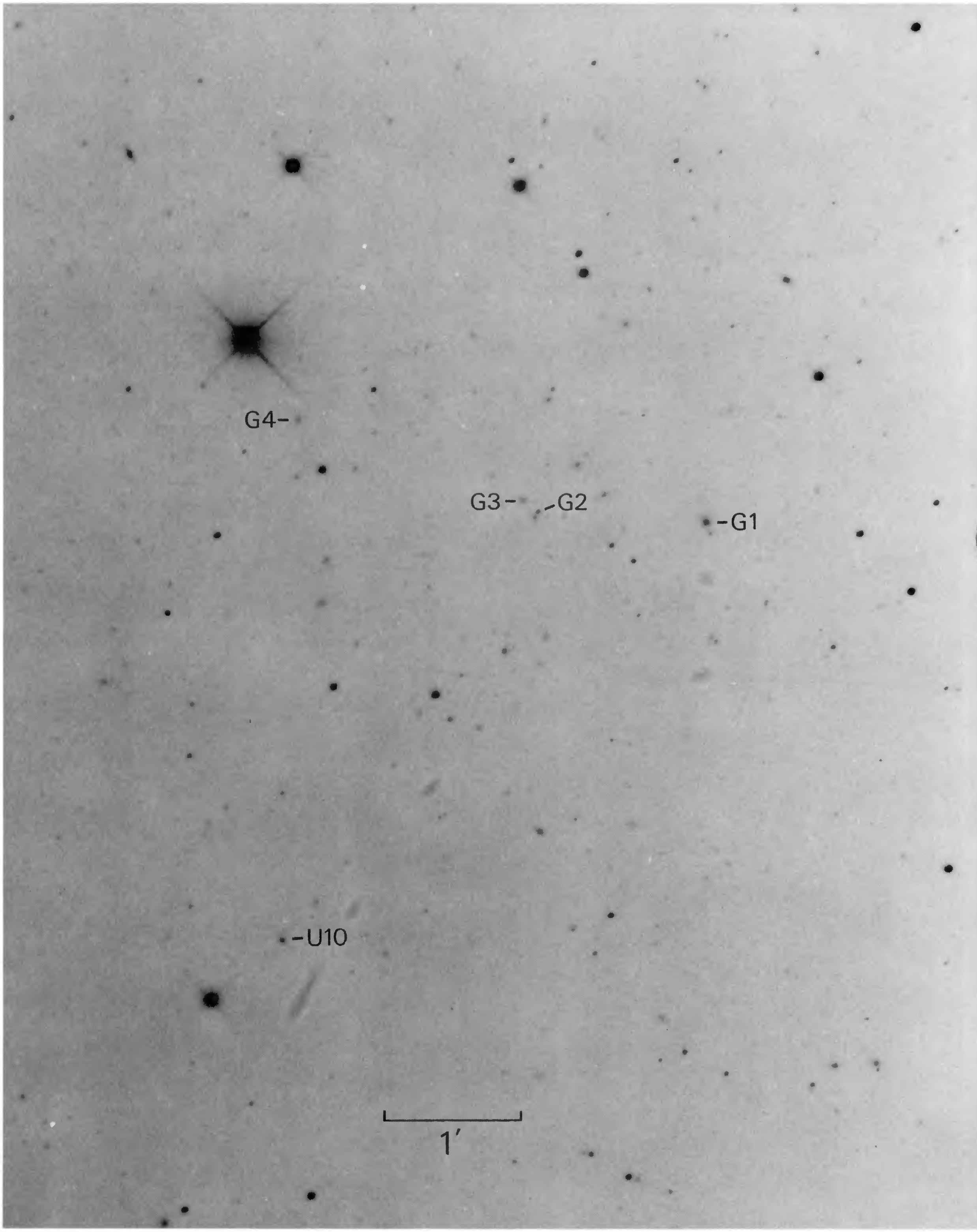

FIG. 1.—The faint galaxy cluster near Arp (1980) QSO U10. North is at the top and east is to the left. Galaxy 3 is believed to be a cluster member and has a redshift of $z = 0.344$. Galaxy 1 is foreground with $z = 0.185$. A faint nebulosity can be seen extending to the NE and SW of the quasar. The shading across the field and the watermarks south of G1 and U10 are reproduction artifacts.

FORD *et al.* (see page 452)