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OBSERVATIONS OF FOUR FAINT QUASARS SURROUNDING THE TOLOLO 1037−271/1038−272 QUASAR PAIR[1]

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ABSTRACT

We have observed four faint quasar candidates surrounding the wide quasar pair Tololo 1037−271/1038−272 with the aim of searching for absorption due to the intervening supercluster proposed to explain the strong correlated absorption seen between $z = 1.95$ and $z = 2.15$ in these two objects. We report a potential positive detection in the case of Tol 1035−276, located at $z_{\rm em} = 2.15$, 39′ ($D_\perp \approx 10h^{-1}$ Mpc) southwest of the pair. Both the emission redshift of this object and two of the absorption systems seen in its spectrum match corresponding systems in Tol 1037−271/1038−272 to an accuracy well within the velocity splitting of $\Delta v \approx \pm 5000$ km s^{-1} expected from the Hubble expansion at the large angular separation. In contrast, no correlated absorption is detected at a larger separation in the spectrum of Tol 1033−269 located at $z_{\rm em} = 2.42$, 62′ ($D_\perp \approx 15h^{-1}$ Mpc) west of the pair. This may indicate that the intervening supercluster has an elongated shape with its largest dimension aligned with the line of sight.

We also present low-resolution spectra of the two fainter quasars Tol 1038−271 and 1036−272 located, respectively, 5′.6 ($D_\perp \approx 1.4h^{-1}$ Mpc) north of 1038−272 and 12′ ($D_\perp \approx 3.0h^{-1}$ Mpc) southwest of 1037−271. At $z_{\rm em} = 1.91$, Tol 1038−271 is located at the extreme near side of the supercluster. We confirm the presence of strong absorption in Si IV, C IV, and Al III at $z_{\rm abs} = 1.89$ in this object, a system that is probably related to the weaker fifth $z_{\rm abs} = 1.90$ common absorption pair seen in Tol 1037−271/1038−272. Conversely, Tol 1036−272 lies far behind the supercluster at $z_{\rm em} = 3.09$, so that the spectral region of interest is lost in the Lyman-alpha forest.

Subject headings: galaxies: clustering — quasars

I. INTRODUCTION

The quasars Tol 1037−271 ($z_{\rm em} = 2.18$) and Tol 1038−272 ($z_{\rm em} = 2.32$) are the two brightest objects out of a list of 23 faint candidate quasars found from deep objective prism plates of a 2.1 deg^2 region of the sky by Bohuski and Weedman (1979). In a recent paper Jakobsen *et al.* (1986) compared the intermediate-resolution spectra of these two objects, and pointed out the remarkable similarity of their absorption spectra. Tol 1037−271 and 1038−272 both show four individual or tight groupings of strong metal-line absorption systems that match within 2000 km s^{-1} at the redshifts $z_{\rm abs} = 1.96$, 2.02, 2.08, and 2.14. Subsequent higher resolution and higher S/N ratio observations carried out recently by Cristiani, Danziger, and Shaver (1987), Robertson (1987), and Sargent and Steidel (1987) have confirmed this result, and revealed the existence of a fifth weaker correlated pair of systems at $z_{\rm abs} = 1.90$.

Because the large 17′.9 angular distance between Tol 1037−271 and 1038−272 corresponds to a linear distance of $\sim 4.4h^{-1}$ Mpc, Jakobsen *et al.* (1986) proposed that a possible interpretation is that the material giving rise to the common absorption in these quasars is associated with a massive intervening supercluster at $z \approx 2$. In this case the span in absorption redshift from $z = 1.96$ to $z = 2.14$ along the line of sight would indicate that the intervening supercluster has a total size of the order $\sim 33h^{-1}$ Mpc, corresponding to an angular distance of about 2°. Hence there is good justification for attempting to observe the fainter surrounding quasar candidates from the Bohuski and Weedman (1979) list in order to search for correlated absorption in other objects due to the hypothetical supercluster.

In this paper we present intermediate-resolution spectra of two of these quasar candidates: Tol 1033−269, and 1035−276; and low-resolution spectra of two others: 1036−272, and 1038−271. Of these, the last object was also observed by Sargent and Steidel (1987) who also presented preliminary spectra of two additional candidates from the Bohuski and Weedman (1979) list: 1032−277 and 1037−277. Sargent and Steidel (1987) determined the redshift of the latter object to be $z_{\rm em} = 1.89$, but were unable to measure the redshift of Tol 1032−277. The location of these objects with respect to the original 1037−271/1038−272 pair is shown in Figure 1.

II. OBSERVATIONS

a) Intermediate-Resolution Data

The quasar candidates Tol 1035−276 and 1033−269 (numbers 16 and 7 of the Bohuski and Weedman 1979 list) were observed on 1987 January 27–28 with the Boller & Chivens spectrograph mounted on the 2.2 m telescope at ESO La Silla. A 600 groove mm^{-1} grating was used in the second order covering the 3400–5600 spectral range at 114 Å mm^{-1}. The detector was a dual channel Reticon Photon Counting System (Christensen *et al.* 1986). A set of 2″ × 2″ entrance

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[1] Based on observations obtained at the European Southern Observatory, La Silla.

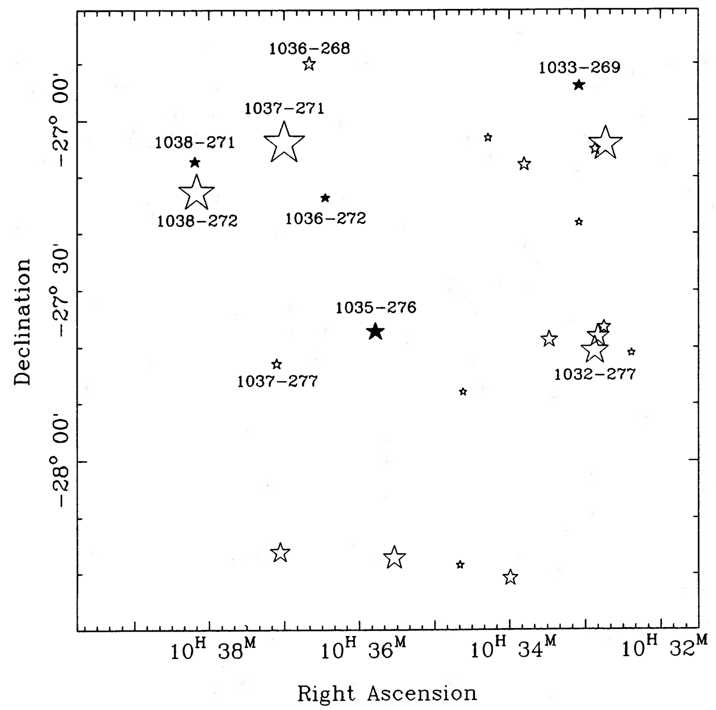

FIG. 1.—Map of the Bohuski and Weedman (1979) deep survey field showing the position of the wide quasar pair Tol 1037−271/1038−272 and the relative locations and apparent magnitudes of the additional 21 faint quasar candidates found. The four quasars observed are identified by filled symbols. All objects mentioned in the text are labeled with their coordinate designations.

apertures was used, resulting in a spectral resolution of ∼6 Å (FWHM).

Tol 1035−276 was observed for a total of 16,800 s but, for reasons beyond our control, Tol 1033−269 was observed for only 7200 s. The spectra were flat-fielded, sky-subtracted, and wavelength-calibrated using standard procedures. An approximate absolute flux scale was established by observing the photometric standard LDS 235B (Oke 1974). The spectra shown in Figures 2 and 3 have been binned to 1 Å and once Hanning (1–2–1) smoothed. Also shown is the 1 σ error per pixel resulting from propagation of the photon statistics.

Three emission lines are visible in our spectrum of Tol 1035−276. These are readily identifiable as Lyα/N v, Si IV/O IV], and C IV, leading to an emission redshift of $z_{\mathrm{em}} = 2.15 \pm 0.01$. The continuum magnitude of Tol 1035−276 is $B = 18.9$. Four emission lines can be identified in our spectrum of Tol 1033−269: O VI, Lyα/N v, Si IV/O IV], and C IV. From these we determine a redshift of $z_{\mathrm{em}} = 2.42 \pm 0.01$. Tol 1033−269 has a continuum magnitude of $B = 19.8$. Our emission redshifts and magnitudes compare reasonably well with the preliminary estimates given by Bohuski and Weedman (1979).

The signal-to-noise ratio of our spectrum of Tol 1035−276 ranges between 7 and 25 per 1 Å pixel. Hence at 6 Å resolution our 3 σ limit for the detection of narrow absorption lines varies between 0.5 and 1.7 Å. The corresponding span in detection limit for our lower S/N ratio spectrum of Tol 1033−269 is $W_\lambda \geq 0.7$–3.5 Å. The absorption lines detected in our spectra of Tol 1035−276 and 1033−269 are listed in Tables 1 and 2. In addition to photon statistics, the quoted errors on the observed equivalent widths also include a 15% contribution due to the uncertainty in placing the continuum level.

We are able to identify three absorption systems in Tol 1035−276. These are indicated in Figure 2. The lowest redshift system at $z_{\mathrm{abs}} = 0.823$ is defined by a resolved Mg II doublet at 5099, 5111 Å in addition to several Fe II lines. The high ionization $z_{\mathrm{abs}} \approx z_{\mathrm{em}}$ system at $z_{\mathrm{abs}} = 2.125$ consists of a resolved C IV doublet at 4839, 4835 Å together with a matching resolved N v doublet at 3870, 3883 Å; Si III at 3770 Å; and, possibly, a weak

TABLE 1

ABSORPTION LINES IN TOL 1035−276

λ(Å)	W_λ(Å)	Identification
3503	3.6 ± 1.0	…
3625	3.2 ± 0.7	Lyα; $z = 1.982$
3673	1.9 ± 0.5	…
3714 3730	7.0 ± 1.2	…
3770 3781	3.0 ± 0.7	Si III; $z = 2.125$
3794 3803	2.2 ± 0.4	Lyα; $z = 2.125$?
3822 3833	4.2 ± 0.7	…
3870	0.8 ± 0.2	N v; $z = 2.125$
3883	1.2 ± 0.2	O I; $z = 1.982$[a]
3932	0.9 ± 0.2	…
3976	0.9 ± 0.3	C II; $z = 1.982$
4039	1.3 ± 0.3	…
4110	0.9 ± 0.2	…
4275	1.0 ± 0.3	Fe II; $z = 0.823$
4344	0.9 ± 0.3	Fe II; $z = 0.823$
4621	1.0 ± 0.3	C IV; $z = 1.982$
4839 4845	2.1 ± 0.4	C IV; $z = 2.125$
5099 5111	3.4 ± 0.7	Mg II; $z = 0.823$

[a] Blended with N v; $z = 2.125$.

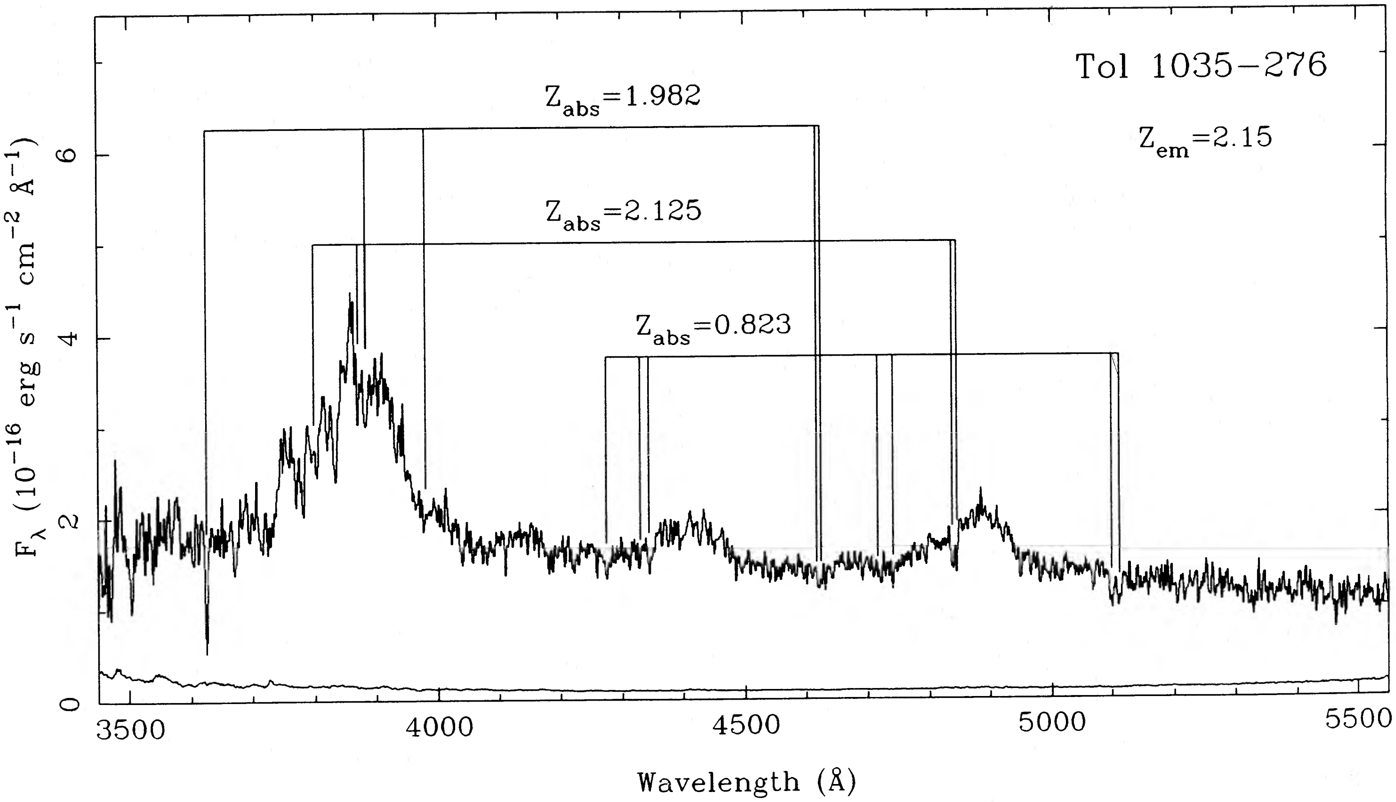

FIG. 2.—The B & C/RPCS spectrum of Tol 1035−276 at ~6 Å resolution. Also shown is the 1 σ error spectrum per 1 Å pixel. The flux scale is approximate, but should be accurate to within 30%. The three identified absorption systems are indicated.

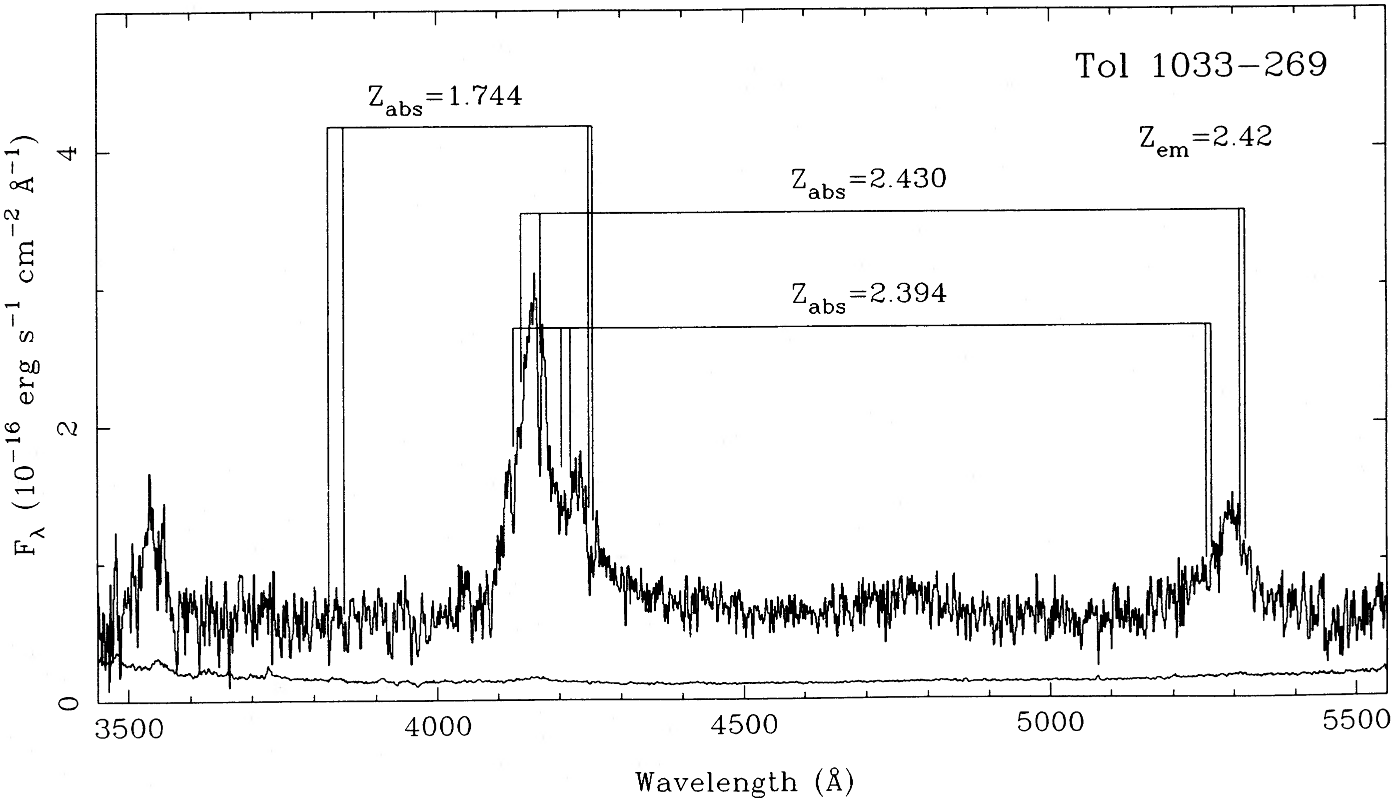

FIG. 3.—As Fig. 2 for Tol 1033−269

TABLE 2

Absorption Lines in Tol 1033−269

λ(Å)	W_λ(Å)	Identification
3825.........	3.1 ± 1.0	Si IV; $z = 1.744$
3848 3854	4.2 ± 1.1	Si IV; $z = 1.744$
3918 3925	4.6 ± 1.0	...
3957.........	2.3 ± 0.8	...
3967.........	3.3 ± 0.8	...
3983.........	4.1 ± 1.0	...
4088.........	2.7 ± 0.7	...
4125.........	1.8 ± 0.4	Lyα; $z = 2.394$
4139.........	0.8 ± 0.3	Si III; $z = 2.430$
4169.........	2.3 ± 0.4	Lyα; $z = 2.430$
4200 4205	1.1 ± 0.4	N V; $z = 2.394$
4212 4217	1.6 ± 0.4	N V; $z = 2.394$
4249 4255	4.3 ± 0.8	C IV; $z = 1.744$
5257.........	2.0 ± 0.7	C IV; $z = 2.394$

Lyα line at 3803 Å. The identification of the low ionization $z_{\rm abs} = 1.982$ system is based on the strong Lyα line at 3625 Å; O I at 3883 Å (blended with N V λ1242 at $z_{\rm abs} = 2.125$); C II at 3976 Å; and a weak unresolved C IV doublet at 4621 Å.

Our spectrum of Tol 1033−269 also reveals three absorption systems. We identify the resolved doublet at 4249, 4255 Å as C IV $z_{\rm abs} = 1.744$, an identification which is further supported by a Si IV doublet in the Lyman-alpha forest at 3825, 3848 Å. The two isolated lines seen on each side of the peak of the Lyα emission line are almost certainly Lyα due to two $z_{\rm abs} \approx z_{\rm em}$ systems at $z_{\rm abs} = 2.394$ and $z_{\rm abs} = 2.430$. The reality of the $z_{\rm abs} = 2.394$ system is supported by a resolved N V doublet at 4205, 4217 Å, and a weak unresolved C IV doublet at 5257 Å. The case for the $z_{\rm abs} = 2.430$ system is somewhat weaker, and is based on a weak Si III line at 4139 Å and a possible weak C IV doublet in the red wing of the C IV emission line. These three systems are marked in Figure 3.

b) Low-Resolution Data

The two very faint quasar candidates Tol 1038−271 and 1036−272 (numbers 23 and 17 in the Bohuski and Weedman 1979 list) were observed on 1987 January 24 and 27 with the ESO 3.6 m telescope at La Silla using the ESO Faint Object Spectrograph and Camera (Buzzoni *et al.* 1986). A 230 Å mm^{-1} grism and 1".5 wide long slit combination was used together with an RCA CCD, providing a resolution of ~15 Å in the 3800–7000 Å range. Because of the faintness of the objects, short direct CCD acquisition images were first taken, from which the offset of the grism entrance slit was determined. We also attempted to observe Tol 1036−268 (candidate number 18, located 14′ north of Tol 1037−271), but were unable to match the position with the finding chart given by Bohuski and Weedman (1979) for this object.

Tol 1038−271 and 1036−272 were both observed for 1200 s. However, the latter object was observed under conditions of extremely high sky background, and hence the signal-to-noise ratio of the data is poor. The obtained spectra were flat-fielded, sky-subtracted, and wavelength- and flux-calibrated in the standard manner. The reduced EFOSC spectra of Tol 1038−271 and 1936−272 are shown in Figure 4.

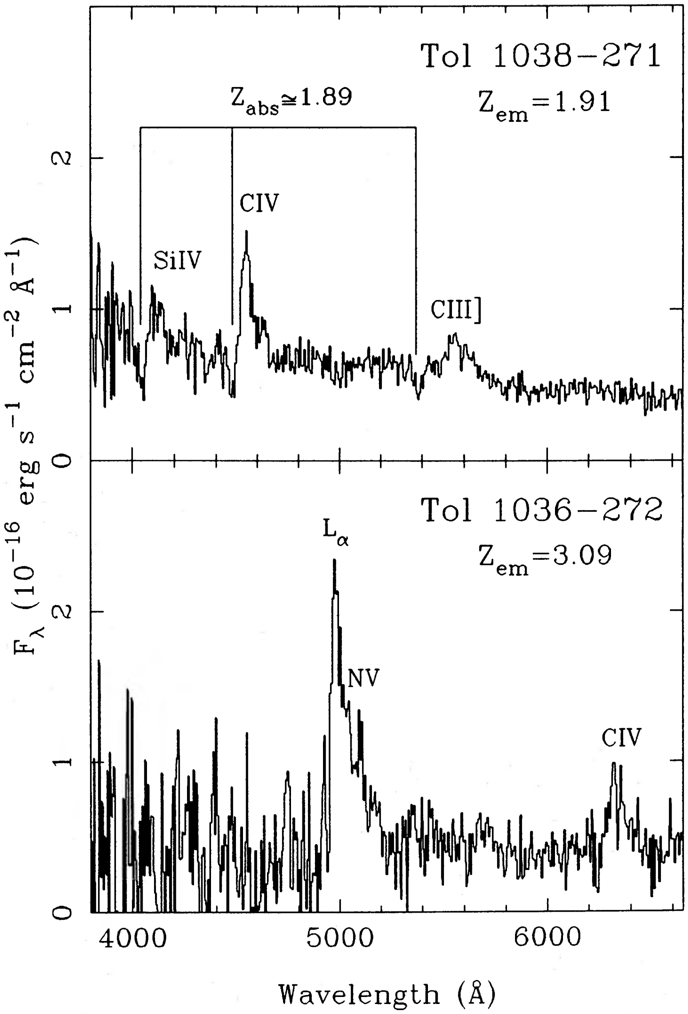

FIG. 4.—EFOSC spectra of Tol 1038−271 and 1036−272 at ~15 Å resolution with the emission-line identifications marked. Also indicated are the strong absorption troughs seen in Si IV, C IV, and Al III in Tol 1038−271 at $z_{\rm abs} = 1.89$.

Tol 1038−272 has $B = 19.9$ and its spectrum displays three emission lines which can be identified as Si IV/O IV], C IV and C III]. The Si IV/O IV] and C IV emission lines are highly distorted by strong absorption in their blue wings; hence, we have determined the redshift of Tol 1038−271, $z_{\rm em} = 1.91 \pm 0.02$, by profile-fitting to the C III] line. This emission redshift is slightly lower than the value of $z_{\rm em} = 1.937 \pm 0.004$ determined by Sargent and Steidel (1987) from the perturbed Lyα, Si IV/O IV], and C IV lines. The strong BAL-like absorption troughs in Si IV and C IV at ~4050 and ~4500 Å, which were also detected by Sargent and Steidel (1987), are in our longer wavelength CCD spectrum accompanied by a matching Al III trough at ~5400 Å. These three absorption features display rather sharp edges that confine the absorption to $z_{\rm abs} = 1.87$–1.91, or to a velocity range of $\Delta v = 4500$ km. The observed equivalent widths of the features are: W_λ(Si IV) = 30 ± 7 Å, W_λ(C IV) = 25 ± 7 Å, and W_λ(Al III) = 20 ± 5 Å.

At $B = 20.3$, Tol 1036−272 is the faintest of the four objects observed. Its EFOSC spectrum reveals that this object is a very high redshift quasar. We have determined a redshift of $z_{\rm em} = 3.09 \pm 0.01$ from the Lyα, N V, and C IV emission lines. The resolution and S/N ratio of our spectrum are too poor to reveal any absorption, although the dense Lyα forest at $z \approx 3$ is clearly visible.

III. DISCUSSION

The motivation behind the observations reported here was to attempt to detect additional correlated absorption systems due to the hypothetical intervening supercluster proposed by Jakobsen *et al.* (1986) to explain the strong correlated absorption seen in Tol 1037−271 and 1038−272. In spite of their large separation of $\theta = 17'.9$, corresponding to $D \approx 4.4h^{-1}$ Mpc at $z \approx 2$, these two objects display four apparently common absorption systems at the redshifts $z_{\rm abs} = 1.971/1.955$, 2.028/2.013, 2.082/2.08, and 2.138/2.145. Of these, the $z_{\rm abs} =$ 2.082 and 2.138 systems in Tol 1037−271 and the $z_{\rm abs} = 2.08$ system in Tol 1038−272 are multiple with subcomponents at, respectively, $z_{\rm abs} = 2.071/2.076/2.082$; 2.128/2.135/2.138 and 2.065/2.077/2.085 (Ulrich and Perryman 1987; Cristiani, Danziger, and Shaver 1987; Robertson 1987; Sargent and Steidel 1987). The correlated absorption systems in Tol 1037−271 and 1038−272 all contain heavy elements and are therefore presumably somehow associated with galaxies. Absorption in N V is widespread among the systems. This implies that the absorbing material is subject to a large ionization parameter, perhaps caused by their proximity to the bright Tol 1037−271 ($M_V \approx -27$, $z_{\rm em} = 2.18$) and/or low gas density.

In addition to the close matches in redshift to within $\Delta v \leq 2000$ km s^{-1}, a second noteworthy feature of the four pairs of groups of absorption systems in Tol 1037−271/1038−272 is their roughly equal spacing of $\Delta z \approx 0.06$. This pattern is manifestly non-Poissonian in nature and is suggestive of a shell-like or sheetlike geometry for the absorbing material, reminiscent of the bubble-like structures revealed by recent deep redshift surveys of galaxies (de Lapparent, Geller, and Huchra 1986). The magnitude of the spacing is remarkably consistent with this interpretation, in that it corresponds to a distance along the line of sight of $D_{\parallel} = (c/H_0)(1+z)^{-5/2}\Delta z \approx 11h^{-1}$ Mpc at $z \approx 2$ ($H_0 = 100h$ km s^{-1} Mpc^{-1} and $q_0 = \frac{1}{2}$ are assumed throughout this paper). Since structures of this size are presumably still participating in the cosmological expansion, this value compares well with the typical bubble diameters of order $D \approx 25$–$50h^{-1}$ Mpc seen today. One possible interpretation of the Tol 1037−271/1038−272 data is therefore that the lines of sight to these quasars happen to intersect a supercluster consisting of three aligned and densely populated galaxy bubbles of size $D \approx 10h^{-1}$ Mpc at $z \approx 2$. A similar interpretation has been proposed by Sargent and Steidel (1987) who argue that a case for a specially oriented elongated structure can also be made on the basis of the sheer richness of the absorption spectra of Tol 1037−271/1038−272 with respect to more typical quasars.

Various alternative interpretations involving "line locking" and an intrinsic ejected origin for at least some of the Tol 1037−271/1038−272 systems have been discussed by Jakobsen *et al.* (1986), Ulrich and Perryman (1986), Cristiani, Danziger, and Shaver (1987), Robertson (1987), and Sargent and Steidel (1987). Although these authors disagree as to the correct interpretation, the geometry of the situation can be probed further since in the aligned bubble picture one expects to see correlated absorption in other background quasars out to distances from Tol 1037−271 and 1038−272 comparable to the system spacing, or out to $\theta \approx 40'$. If the supercluster is roughly spherical in shape, the correlated absorption could extend out to as much as three times this distance.

In addition to the obvious problem of locating suitable background quasars, a second potential complication for identifying such absorption systems solely on the basis of redshift coincidences is that rather large velocity splittings are expected at these large angular separations, since the expanding structure need not be oriented exactly perpendicular to the line of sight. In a $q_0 = \frac{1}{2}$ cosmological model, the perpendicular distance at redshift z between the sightlines to two quasars separated by the angle θ is (cf. Peebles 1971)

$$D_{\perp} = 2\theta\left(\frac{c}{H_0}\right)(1+z)^{-1}[1-(1+z)^{-1/2}] . \qquad (1)$$

Since the value of the Hubble constant at redshift z is $H(z) = H_0(1+z)^{3/2}$, the expected velocity shift between two absorbers located on two sightlines separated by $D_{\perp}$ and belonging to a comoving structure of size $R \geq D_{\perp}$ is

$$\Delta v = H(z)D_{\perp} \tan\alpha = 2c\theta[(1+z)^{1/2} - 1] \tan\alpha , \qquad (2)$$

where $(-\pi/2) \leq \alpha \leq (\pi/2)$ is the angle between the line-of-sight normal and the line connecting the absorbers on the two sightlines. Thus arbitrarily large velocity shifts are expected if, say, a thin sheet of material is viewed at a small glancing angle ($|\alpha| \approx \pi/2$). On the other hand, in the less extreme case of a spherical, bubble-like geometry we expect $|\alpha| \leq \pi/4$. In the case of Tol 1037−271/1038−272 the expected correlation redshift windows of the four common absorption systems overlap at angular distances $\theta \geq 6'$, resulting in a rather large total window in which possibly correlated absorption can be found. This, in turn, leads to a corresponding increased probability of finding spurious absorption systems within the window. Thus the likelihood of any detected absorption systems being correlated and due to a supercluster must be judged against the probability of finding similar acceptable redshift coincidences by chance, given our knowledge of the average occurrence of absorption systems. In the following we discuss each of the four quasars observed in turn.

a) Tol 1035−276

Tol 1035−276 is located $36'.9$ from Tol 1037−271 and $40'.0$ from Tol 1038−272. At $z_{\rm em} = 2.15$ it lies behind all four common systems seen in that pair. We base our case for a positive detection of the supercluster on three independent redshift coincidences which all occur to an accuracy considerably better than the ±5000 km s^{-1} maximum splitting expected due to the Hubble expansion over the projected distance of $D_{\perp} \approx 10$ Mpc:

1. The absorption system at $z_{\rm abs} = 2.125$ in Tol 1035−276 matches the 2.138/2.145 paired absorption system in Tol 1037−271/1038−272 to within $\Delta v \leq 2000$ km s^{-1}. In addition, this system is a near perfect match to the $z_{\rm abs} = 2.128$ subsystem in Tol 1037−271 ($\Delta v \leq 300$ km s^{-1}). We interpret this system as being associated with an intervening supercluster galaxy.

2. The other high redshift system in Tol 1035−276 at $z_{\rm abs} =$ 1.982 matches the $z_{\rm abs} = 1.971/1.955$ paired absorption system in Tol 1037−271/1038−272 to within $\Delta v \leq 2800$ km s^{-1}. This is consistent with it being due to a second intervening supercluster galaxy.

3. Finally, the emission redshift of Tol 1035−276, $z_{\rm em} =$ 2.15 ± 0.01, lies within $\Delta v \leq 2300$ km s^{-1} of the $z_{\rm abs} =$

2.138/2.145 paired absorption system in Tol 1037−271/1038−272. Hence its host galaxy is very likely a cluster member situated at the far side of the supercluster.

In evaluating the probability of the above redshift coincidences occurring by chance, we adopt a supercluster membership acceptance window of total width $\Delta z = 2.16\text{–}1.94 = 0.22$, which results from the convolution of the $\Delta z_{\text{abs}} = 2.145\text{–}1.955$ range spanned by the absorption in Tol 1037−271/1038−272 and the $\Delta z = \pm 0.05$ Hubble expansion blur.

The probability of the two apparently correlated absorption systems in Tol 1035−276 being spurious can be estimated by comparing with the known average density of metal line absorption systems. According to Young, Sargent, and Boksenberg (1982) and Bergeron and Boissé (1984) there are on the average $dN/dz \leq 2$ metal line systems per unit redshift interval at $z \approx 2$ at a strength above our detection threshold. Under the null hypothesis of no clustering, the occurrences of redshift systems in the acceptance window is a Poisson process with parameter $\lambda = dN/dz\,\Delta z = 0.44$, and the probability of finding two or more systems within the window by chance is therefore of the order $p \approx 7\%$.

The probability of the proximity between the emission redshift of Tol 1035−276 and the $z_{\text{abs}} \approx 2.14$ absorbers in Tol 1037−271/1038−272 being spurious is somewhat higher. The grism search technique used by Bohuski and Weedman (1979) to discover the high-redshift quasars considered here is sensitive to the $1.8 \leq z_{\text{em}} \leq 3.4$ range. However, the distribution in quasar redshift is not uniform over this interval. From the redshift distribution for $19 \leq B \leq 20$ quasars predicted by Schmidt and Green (1983), we estimate that the probability of a random grism-selected quasar falling within the total $\Delta z = 0.22$ redshift acceptance window by chance is of order $p \approx 20\%$.

Although the likelihoods of finding the above coincidences in absorption and emission redshift by chance are rather high when considered individually, these occurrences are independent events under the null hypothesis. Hence the probability that *both* the emission and absorption redshift matches seen in Tol 1035−276 are spurious is $p \leq 2\%$. We stress that this probability is conservative since the redshift matches are in reality much better than the maximum permissible value assumed in our calculation. Furthermore, we note that Foltz *et al.* (1986) have recently provided convincing evidence for the existence of an excess of $z_{\text{abs}} \approx z_{\text{em}}$ absorption systems similar to the $z_{\text{abs}} = 2.125$ system seen in Tol 1035−276. However, consideration of this effect only further strengthens the supercluster interpretation, since $z_{\text{abs}} \approx z_{\text{em}}$ systems are in all likelihood due to absorption by gas associated with clusters in which the quasars are embedded (Sargent, Young, and Boksenberg 1982; Morris *et al.* 1986; Bergeron and Boissé 1986). Moreover, Phillips (1986) has argued that the majority of high-redshift quasars must reside in rich clusters. We conclude that our data is consistent with Tol 1035−276 itself and the material giving rise to the $z_{\text{abs}} = 1.982$ and 2.125 absorption systems in its spectrum being associated with outlying members at $D_\perp \approx 10h^{-1}$ Mpc of a supercluster that also covers Tol 1037−271 and 1038−272.

b) Tol 1033−269

The second quasar observed at intermediate resolution, Tol 1033−269, is located 53′.4 away from Tol 1037−271 and 70′.6 away from Tol 1038−272 and is the most remote of the four objects observed. Although its redshift of $z_{\text{em}} = 2.42$ places it well behind the absorption in Tol 1037−271 and 1038−272, neither of the three probable absorption systems detected at $z_{\text{abs}} = 1.744$, 2.394, and 2.430 can reasonably be associated with the absorption seen between $z_{\text{abs}} \approx 1.95$ and 2.15 in the pair. However, our spectrum of Tol 1033−269 is of modest S/N ratio, so, strictly speaking, this null result only applies to relatively strong C IV systems with rest equivalent widths $W_\lambda^0 \geq 1$ Å. Nonetheless, our results do suggest that, at least in the direction of Tol 1033−269, the intervening supercluster does not extend out to a distance as large as $D_\perp \approx 15h^{-1}$ Mpc from Tol 1037−271 and 1038−272. This, in turn, may imply that the supercluster has its largest dimension oriented along the line of sight, as suggested by Sargent and Steidel (1987).

c) Tol 1038−271

Located 5′.6 north of Tol 1038−272, Tol 1038−271 is the quasar from the Bohuski and Weedman (1979) list nearest to any member of the original pair. Its angular distance from Tol 1037−271 is 16′.3. Unfortunately its redshift of $z_{\text{em}} = 1.91$ places it about 4600 km s^{-1} or ~9 Mpc in front of the bulk of the absorption in Tol 1038−272. This distance is uncomfortably large for inclusion in the supercluster. However, Sargent and Steidel (1987) report the existence of a weaker fifth common absorption system in Tol 1037−271/1038−272 at $z_{\text{abs}} = 1.913/1.893$ which is contained in the strong absorption troughs seen in Tol 1038−271 between the emission redshift and out to $z_{\text{abs}} = 1.87$. As discussed by Sargent and Steidel (1987), this absorption most likely marks a near extension of the supercluster at $z_{\text{abs}} = 1.89$. This interpretation is further supported by the presence of the quasar Tol 1037−277 at $z_{\text{em}} = 1.89$ located 38′.5 ($D_\perp \approx 9.6h^{-1}$ Mpc) to the southwest. If this is indeed the case, it is highly remarkable that this fifth cluster of systems occurs at roughly the same spacing of $\Delta z \approx 0.06$ as seen between the other groupings of systems. Again, this phenomenon is most readily explained by a bubble-like geometry for the location of the absorbers.

d) Tol 1036−272

Tol 1036−272 is located at a distance of 22′.8 from Tol 1038−272 and 12′.1 from Tol 1037−271. Since it lies close to the line connecting Tol 1037−271 and Tol 1035−276, this object ought to also show absorption due to the supercluster if this interpretation of the data is correct. Unfortunately, although at $z_{\text{em}} = 3.09$ Tol 1036−272 is located behind the absorbing gas, its very large redshift places the region of interest in the Lyman-alpha forest. In particular, any C IV absorption in the region of interest between $z_{\text{abs}} = 1.95$ and 2.15 will have to be searched for among the numerous Lyα lines between $z_{\text{abs}} = 2.8$ and 3.0. In view of the faintness of this quasar, and the fact that the Lyα line density at these redshifts is $dN/d\lambda \approx 0.1$ Å^{-1} (Murdoch *et al.* 1986), this task will not prove easy. In any event, our spectrum of Tol 1038−271 is of far too low S/N ratio to justify any search for absorption, and our observations therefore neither confirm nor contradict the intervening supercluster hypothesis.

IV. SUMMARY AND CONCLUSIONS

We have presented observations of four faint quasar candidates from the Bohuski and Weedman (1979) list that span a range of distances from the Tol 1037−271/1038−272 pair, with an aim toward detecting further correlated absorption due to the hypothetical intervening supercluster proposed by

Jakobsen *et al.* (1986) to explain the remarkable rich absorption seen between $z_{\text{abs}} = 1.95$ and $z_{\text{abs}} = 2.15$ in that wide quasar pair.

We report a potential positive detection at a projected distance of $D_\perp \approx 10h^{-1}$ Mpc in the case of Tol 1035−276. Both the emission redshift of this object ($z_{\text{em}} = 2.15$) and two of the absorption systems seen in its spectrum at $z_{\text{abs}} = 1.982$ and $z_{\text{abs}} = 2.125$ match corresponding systems in Tol 1037−271/1038−272 to an accuracy well within the velocity splitting of $\Delta v = \pm 5000$ km s^{-1} expected from Hubble expansion at the large angular separation. We have argued that the probability of these redshift coincidences being spurious is sufficiently small to warrant a reasonably solid case for confirmation of the intervening supercluster hypothesis.

The positive detection at $D_\perp \approx 10h^{-1}$ Mpc in Tol 1035−276 is, however, contrasted by a null result at the larger distance of $D_\perp \approx 15h^{-1}$ Mpc in Tol 1033−269 ($z_{\text{em}} = 2.42$). Our modest S/N ratio spectrum of this object reveals no C IV absorption in the range of interest at a strength $W_\lambda^0 \geq 1$ Å. This implies that, at least in this direction, the supercluster only extends out to a distance $D_\perp < 15h^{-1}$ Mpc, which should be compared with the extent along the line of sight of $D_\parallel \approx 33\text{–}44h^{-1}$ Mpc spanned by the absorption in Tol 1037−721/1038−272. This is consistent with the suggestion of Sargent and Steidel (1987) that the intervening supercluster is an elongated structure that is viewed along its major axis. The fact that the two absorption systems detected in Tol 1035−276 are apparently associated with the extreme edges of the range of the absorption seen in Tol 1037−271/1038−272, and separated by $D_\parallel \approx 26h^{-1}$ Mpc, may be significant in this context.

We have also presented observations of two fainter quasar candidates located at projected distances of $D_\perp \approx 1.4h^{-1}$ Mpc and $D_\perp \approx 3.0h^{-1}$ Mpc from each member of the pair. Nature has been somewhat capricious in the case of the latter object, Tol 1037−271. Although at $z_{\text{em}} = 3.09$ this quasar does lie behind the supercluster, the spectral region of interest is hidden in the dense Lyman-alpha forest at $z \approx 3$. Conversely the first object, Tol 1038−271, is located at the extreme near side of the supercluster at $z_{\text{abs}} = 1.91$. However, we confirm the detection by Sargent and Steidel (1987) of strong $z_{\text{abs}} \approx z_{\text{em}}$ absorption at $z_{\text{abs}} = 1.89$ in this object. As emphasized by Sargent and Steidel (1987) the redshift coincidence between this system and the fifth fainter common C IV system at $z_{\text{abs}} \approx 1.90$ detected by them in Tol 1037−271/1038−272, provides further support for the intervening supercluster hypothesis, as does the presence of Tol 1037−277 at $z_{\text{em}} = 1.89$.

Finally, we wish to point out that it is possible to argue on statistical grounds that the existence of an absorption system complex as rich as that seen in Tol 1037−271/1038−272 is not too improbable, given our knowledge of the clustering properties of galaxies and the number of quasars surveyed to date. If all absorbers have roughly the same dimensions irrespective of their environment, then the density of absorption systems seen in the Tol 1037−271/1038−272 pair represents about an order of magnitude enhancement over average densities as determined by Young, Sargent, and Boksenberg (1982). Bahcall and Soneira (1984) have shown that the fractional volume of space occupied today by superclusters of size $\sim 100h^{-1}$ Mpc displaying such a high-density enhancement is of the order of 3%. These numbers together imply a line-of-sight spacing of order $\lambda_{\text{cl}} \approx 1$ Gpc for rich superclusters at $z \approx 2$. Thus we expect ~ 10 such rich systems to be intersected by the total path of $\Sigma D_\parallel \approx 10$ Gpc probed by the $n \approx 10^2$ quasars investigated for absorption to date. This probably explains why a system such as Tol 1037−271/1038−272 has not been found in the systematic searches for correlated absorption based on the dozen or so closer ($\theta \leq 6'$) quasar pairs presently known (cf. Robertson *et al.* 1986, and references therein). On the other hand, a number of isolated, nonpaired objects that display complex absorption spectra about as rich as Tol 1037−271 and 1038−272 are known: 0932+501, 1303+308, 1309−056 (Turnshek *et al.* 1984), 0237−233 (Young, Sargent and Boksenberg 1982), 0135−400 (Weyman, Carswell, and Smith 1981), and 1556+335 (Morris *et al* 1986). It is entirely possible that the absorption seen in some of these quasars is similar in nature to that seen in Tol 1037−271 and 1038−272. Clearly, had it not been for the fortuitous proximity of the latter two relatively bright, high-redshift quasars, the significance of the remarkable absorption seen in their spectra would surely have gone unnoticed.

It is evident that spectroscopy of the 17 remaining candidates from the Bohuski and Weedman (1979) list, combined with deep searches for additional quasar candidates, especially north and east of the pair, would be extremely worthwhile undertakings.

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