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THE QUASAR PAIR TOLOLO 1037 – 27 AND 1038 – 27: EVIDENCE FOR CORRELATED ABSORPTION ON MEGAPARSEC SCALES[1]

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ABSTRACT

We present medium-resolution observations of the absorption-line spectrum of the quasar Tol 1038 – 27 ($z = 2.32$) and point out its remarkable similarity to that of the nearby quasar Tol 1037 – 27 ($z = 2.18$). Both objects display a broad C IV system centered near $z = 2.08$ in addition to three neighboring C IV systems that coincide in redshift in the two quasars to within 2000 km s^{-1}. At an angular separation of 17'.9, the projected distance between the lines of sight to the two objects is of the order ~ 4 Mpc, the largest distance over which correlated absorption in quasar spectra has been reported to date. Our favored interpretation of these observations therefore involves a massive intervening supercluster.

Subject headings: galaxies: clustering — quasars

I. INTRODUCTION

Unique information on the physical size of the material giving rise to quasar absorption lines can be derived from the study of correlated absorption in close quasar pairs. Such studies have indicated that the characteristic dimensions of the absorbing regions of the Lyman-α forest systems are of the order of ~ 10 kpc (Foltz *et al.* 1984), whereas the metallic line systems appear to be considerably larger. To date, common absorption has been seen in the C IV doublet at velocity splittings much less than 1000 km s^{-1} at separations corresponding to distances of up to about ~ 400 kpc (Shaver, Boksenberg, and Robertson 1982; Shaver and Robertson 1983), and a few candidate cases for correlated absorption at larger velocity splittings and angular distances approaching megaparsec scales are also known (Sargent, Young, and Schneider 1982; Robertson and Shaver 1983).

The purpose of this *Letter* is to draw attention to the highly unusual absorption spectra of the two quasars Tol 1037 – 27 and Tol 1038 – 27. These are the two brightest objects out of a list of 23 faint candidate quasars found from deep objective prism plates by Bohuski and Weedman (1979). The magnitudes and redshifts of 1037 – 27 and 1038 – 27 are, respectively, $B = 17.4$, $z = 2.18$ and $B = 17.8$, $z = 2.32$. At an angular separation of 17'.9, these two objects constitute a relatively wide quasar pair.

II. OBSERVATIONS

a) *Tol 1038 – 27*

The spectrum of Tol 1038 – 27 displayed in the upper frame of Figure 1 is a composite of data obtained on 1985 February 11–12 and May 20 with the 2.2 m telescope at ESO La Silla. The instrumentation used was an ESO-supplied Boller and Chivens spectrograph used with the ESA Photon Counting Detector (di Serego Alighieri, Perryman, and Macchetto 1985). The data consist of four 30 minute exposures obtained at a dispersion of 85 Å mm^{-1} and four 25 minute exposures obtained at 45 Å mm^{-1} in the blue. These exposures were individually wavelength-calibrated and forced to a common flux scale before they were co-added. The spectral resolution of the resulting spectrum is ~ 6 Å (FWHM), and the S/N ratio per 1 Å bin is about 5 in the continuum off the emission lines. From the measured peaks of the Lyα, N V 1240, Si IV/O V] 1400, and C IV 1549 emission lines at 4047, 4141, 4644 and 5145 Å, respectively, we obtain an emission redshift for Tol 1038 – 27 of $z = 2.32 \pm 0.01$. This value is in good agreement with that listed by Bohuski and Weedman (1979).

At our modest spectral resolution and S/N ratio, we are only able to study the more outstanding features of the absorption spectrum of Tol 1038 – 27. Our detection limit for narrow absorption lines is about 3 Å in equivalent width. Table 1 contains a list of lines stronger than this limit detected in our spectrum. The listed observed wavelengths should be accurate to within 2–3 Å. The quoted error on the observed equivalent widths reflects the propagation of the photon statistics as well as an estimate of the uncertainty in placing the continuum level (typically 20%).

On the basis of the absorption lines listed in Table 1, we have been able to identify four strong redshift systems in Tol 1038 – 27. These are indicated in Figure 1. The broad absorption troughs in N V, Si IV, and C IV that define the dominant $z = 2.08$ system all have relatively sharp edges which confine the absorption to a full intrinsic velocity width of ~ 3000 km s^{-1}. Although the absorption troughs appear to be contiguous at our modest resolution, we suspect that they actually consist of several narrow components. In fact, the predicted region of Lyα absorption for this system contains a sharp-edged blend of narrow lines which we identify as a weak Lyα trough. One of the members of this blend matches with

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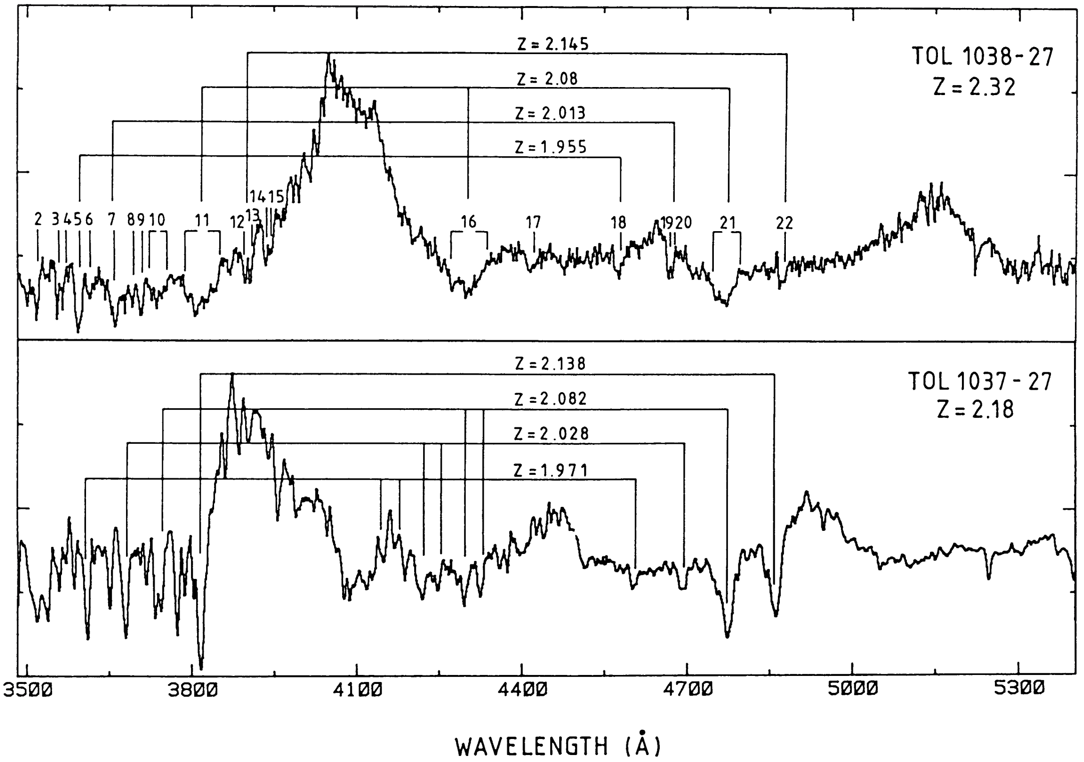

FIG. 1.—Spectra of the quasars Tol 1038−27 and 1037−27 at ~ 6 Å resolution. The three emission lines seen in both spectra are, respectively, Lyα/N V, Si IV/O V], and C IV. Absorption lines in 1038−27 are marked as in Table 1. The identified absorption systems listed in Table 2 are also indicated.

TABLE 1

STRONG ABSORPTION LINES IN TOL 1038−27

Number	λ (Å)	W_λ (Å)	Identification
1	3464	4.6 ± 1.4	Lyα; $z = 1.85$?
2	3517	4.6 ± 1.4	Si II; $z = 1.955$?
3	3554	6.9 ± 1.8	...
4	3564		Si III; $z = 1.955$
5	3593	11.9 ± 2.6	Lyα; $z = 1.955$
6[a]	3613	3.2 ± 1.3	...
7	3661	9.6 ± 2.2	Lyα; $z = 2.013$
8	3692	3.7 ± 1.3	...
9	3707	5.6 ± 1.6	...
10[b]	3716–3757	11.5 ± 2.6	Lyα; trough
11[c]	3786–3848	29.4 ± 6.1	N V; trough
12	3896	7.1 ± 1.8	N V; $z = 2.145$
13	3906		
14	3934	6.3 ± 1.7	...
15	3942		C II; $z = 1.955$?
16[d]	4262–4334	23.2 ± 4.9	Si IV; trough
17	4417	3.7 ± 1.3	C IV; $z = 1.85$?
18	4577	5.5 ± 1.6	C IV; $z = 1.955$
19	4665	4.6 ± 1.4	C IV; $z = 2.013$
20	4672		
21	4740–4790	20.5 ± 4.3	C IV; trough
22	4874	4.2 ± 1.4	C IV; $z = 2.145$

[a] Blend.
[b] Components at 3727, 3736, 3745, and 3753 Å.
[c] Components at 3794, 3808, and 3828 Å.
[d] Components at 4272 and 4296 Å.

depressions seen in the Si IV doublet trough corresponding to a subcomponent at $z = 2.065$. The $z = 2.013$ and $z = 1.955$ systems appear to be classical metal line systems consisting of a C IV doublet and a matching strong Lyα line. The identification of the $z = 2.145$ system is mainly based upon the nearly resolved C IV doublet seen longward of the C IV trough and the resolved N V doublet seen longward of the N V trough. The intrinsic properties of these four systems are summarized in Table 2.

Our data also show evidence for the existence of a possible fifth metal-line system. Our bluest exposures of Tol 1038−27 show the presence of a moderately strong line at 3464 Å which combined with our marginal detection of a diffuse line at 4417 Å, could be a potential Lyα/C IV pair at a redshift of $z = 1.85$. If we accept these two tentative identifications, then five moderately strong lines in Table 1, all of which lie in the Lyα forest region, remain unidentified. We suspect that some of these are actually Lyα lines belonging to additional weaker undetected metal line systems, since given our detection limit of ~ 3 Å, this density of unidentified lines is 2–3 times larger than that expected due to true Lyα forest systems (Sargent *et al.* 1980; Young, Sargent, and Boksenberg 1982*a*).

b) *Tol 1037−27*

Shortly after we had observed 1038−27 in February, it came to our attention that the neighboring object, 1037−27, had been observed previously in the red (by M. H. U.) with

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TABLE 2

INTRINSIC PROPERTIES OF ABSORPTION SYSTEMS IN TOL 1038-27 AND TOL 1037 − 27

SYSTEM	REST EQUIVALENT WIDTHS (Å)			σV (FWHM)
	Lyα	C IV	N V	(km s^{-1})
1038 − 27:				
$z = 2.145$	< 2?	1.3	2.3	< 500
$z = 2.08^{a}$	3.7	6.7	9.5	~ 1500
$z = 2.013$	3.2	1.5	< 2	< 400
$z = 1.955$	4.0	1.9	< 2	< 750
1037 − 27:				
$z = 2.138^{b}$ ...	5.8	4.2	1.1	~ 1100
$z = 2.082^{c}$ ...	3.4	6.7	< 4?	~ 1500
$z = 2.028$	3.5	1.3	< 2	< 800
$z = 1.971$	2.9	1.0	< 2	< 650

[a] Trough system; component at $z = 2.065$.

[b] Multiple system; C IV and Lyα blended with component at $z = 2.128$.

[c] Multiple system; C IV and Lyα blended with component at $z = 2.070$.

the BC/IDS spectrograph on the ESO 3.6 m in 1983 March. The IDS spectrum of this second object shows that it is remarkably similar to that of nearby 1038 − 27, in that it displays four strong individual or groupings of C IV systems at redshifts very close to the redshifts of the four systems seen in 1038 − 27. This was confirmed by subsequent observations at the ESO 2.2 m in 1985 May during which both quasars were observed in the blue with the BC/PCD. The combined PCD/IDS medium-resolution spectrum of 1037 − 27 has been discussed recently by Ulrich and Perryman (1986) and is reproduced in the lower frame of Figure 1. Table 2 contains a summary of the properties of the absorption systems in Tol 1037 − 27 found by Ulrich and Perryman (1986) and marked in Figure 1. A lower redshift Mg II system at $z = 1.077$ has been omitted from the list since it is not relevant to the discussion here.

III. DISCUSSION

When considered individually, both quasars Tol 1038 − 27 and Tol 1037 − 27 are rather unusual in that they possess very rich absorption spectra. The densities of strong C IV systems seen in both objects is at least 4 times larger than the expected based on the results of Young, Sargent, and Boksenberg (1982*b*) and Bergeron and Boisse (1984). Although both quasars display broad absorption lines in their spectra, their classification as BAL quasars is questionable. Although the spectrum of Tol 1038 − 27 is, at least at our modest resolution, reminiscent of the two detached BAL quasars MCS 141 (Turnshek *et al.* 1980) and 1246 − 057 (Boksenberg, Carswell, and Whelan 1978), the absorption troughs seen in 1038 − 27 are not as broad and are of lower strength than those in the latter two objects. As discussed by Ulrich and Perryman (1986), a similar situation holds for Tol 1037 − 27.

By far the most striking feature of this quasar pair is, however, the remarkable similarity of the two absorption spectra and the close proximity in redshift of the strong systems detected. Not only do the dominant $z = 2.08$ systems in both quasars directly overlap in velocity space, but the redshifts of the three neighboring systems detected in both objects also match to within $\sigma z = 0.02$, or to within a velocity splitting less than ~ 2000 km s^{-1}. The common redshift window for detection of C IV systems in both objects, spanned by the Lya emission line in 1038 − 27 and the C IV emission line in 1037 − 27, has a width of $\Delta z = 0.58$. In view of the fact that the probability of casting four systems at random in each quasar and achieving four matches closer together in redshift than $\sigma z = 0.02$, is of the order $p \approx 4!(\sigma z/\Delta z)^4 = 8 \times 10^{-5}$, we regard it as highly unlikely that the correlated absorption seen in Tol 1038 − 27 and 1037 − 27 could arise by chance. The excess of C IV systems, and the roughly similar ranking of the strengths of the systems seen in both objects further strengthens the case for a common origin for the detected absorption. What makes this interpretation difficult to accept is, of course, the large angular separation between the two objects. In a cosmological model having $H_0 = 100$ km s^{-1} Mpc^{-1} and $q_0 = 1/2$, this separation corresponds to a projected linear distance of 4.4 Mpc, which is considerably larger than the distances over which correlated quasar absorption has been seen to date. If it is assumed that the absorber has a reasonably coherent and homogeneous structure on scales of corresponding to the projected angular separation of the two objects, a minimum mass estimate for the material giving rise to the observed common absorption can be derived from the strengths of the detected lines. Assuming a linear curve of growth, solar abundances, an ionization correction of unity, and a physical size of $D \approx 4.4$ Mpc, we derive a mass of $M \approx 5 \times 10^{11}\ M_{\odot}$ from the observed rest-frame equivalent widths of the C IV lines of the strongest $z = 2.08$ system.

Since the spectra of both objects bear some resemblance to those of BAL quasars, and the broad absorption seen in this class of quasars is believed to be intrinsic and caused by mass-ejection, one possibility is that we are actually witnessing two independent and unrelated cases of quasar mass ejection for which the redshifts of the two sets of systems just happen to coincide. Although, as we have argued above, it is highly unlikely that the observed redshift coincidences could arise by chance under the assumption of a uniform distribution in ejection velocity, it is a curious fact that the absorption-line systems in both 1038 − 27 and 1037 − 27 are remarkably equidistant in the sense that the ratios of $(1 + z)$ between consecutive systems listed in Table 2 in all cases deviate from the average value $R = 1.020$ by less than 1%. Thus if this pattern is actually driven by some form of "line-locking" that operates under the BAL ejection process, then this would dramatically increase the probability of four redshift coincidences occurring by chance, since only a single fortuitous match in ejection velocity would be needed to line up the patterns in the two objects, in spite of their different emission redshifts.

A second and more conventional interpretation of the data involves an intervening supercluster containing several rich clusters of galaxies. In this picture the dominant $z = 2.08$ system seen in both objects represents a dense central con-

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densation in a supercluster in which the neighboring systems are outlying members. Within the cosmological model adopted above, the total redshift range spanned by the four systems indicates a total size of $D \approx 33$ Mpc for any such supercluster at $z = 2.08$. Since superclusters are believed to be still expanding, this inferred size compares reasonably well with typical supercluster diameters of ~ 50–100 Mpc as seen today (Oort 1983). The velocity splittings between the systems seen in the two quasars is also consistent with an expanding supercluster, since the predicted magnitude of the Hubble flow at $z = 2.08$ over a distance of 4.4 Mpc is of the order ~ 2400 km s^{-1}.

In view of the high velocity dispersion of the dominant $z = 2.08$ system, the corresponding cluster would have to be rather massive and therefore presumably very large. This would be consistent with the fact that this system overlaps in velocity space in the two quasars. Furthermore, since the estimate of the minimum gas mass contained in the $z = 2.08$ system derived above is not too far off from the estimates of the gas mass contained in X-ray emitting clusters of galaxies (Forman and Jones 1982), it is possible that we are observing the cluster during some early turbulent gas-stripping phase prior to the heating of the intracluster gas to X-ray temperatures.

Clearly, further observations at higher resolution and S/N ratio are needed in order to establish the true nature of the absorption seen in this highly unusual quasar pair. The original survey list of Bohuski and Weedman (1979) contains several faint quasar candidates of unknown redshift that lie in the general vicinity of Tol 1038 − 27 and 1037 − 27. Spectroscopic observations of these objects would also be highly worthwhile.

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