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THE ABSORPTION-LINE SPECTRUM OF Q0453−423

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ABSTRACT

The optically selected QSO Q0453−423 (z_{em} = 2.659) is shown to have a rich absorption-line spectrum. At least two redshift systems are shown to be present, with z_{abs} = 1.1492 and 2.2754, and there is evidence for other absorption redshifts at very high velocities relative to the QSO. The spectrum provides another example of the C IV doublet in absorption falling in the Si IV emission feature.

Subject headings: galaxies: redshifts — quasars

I. INTRODUCTION

The Cerro Tololo objective-prism survey for emission-line objects at high galactic latitudes (Smith 1975) has yielded a number of bright, high-redshift QSOs (Smith 1976). These form a sample based on uniform selection criteria, and a study of their emission-line spectra at low (~16 Å) resolution has already been presented (Osmer and Smith 1976). Since high-redshift QSOs almost invariably show rich absorption-line spectra, we have undertaken a systematic program of observations at higher resolution to study the absorption-line systems in each of these objects. The eventual aim of this program, which is in progress, is to obtain statistical information on the distribution of absorption redshifts. The purpose of this paper is to draw attention to one interesting object from the sample, the 18th mag QSO Q0453−423, which has a number of absorption redshifts at considerably less than the emission redshift of 2.659.

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II. THE OBSERVATIONAL MATERIAL

Q0453−423 is an 18th mag QSO with redshift z_{em} = 2.66 at position

$$\alpha_{1950} = 04^h53^m48^s.0 \pm 0.4\,,$$

$$\delta_{1950} = -42°21'00'' \pm 4\,.$$

A finding chart has been published by Smith (1976).

Spectroscopic observations were obtained using the image-tube scanner system (Robinson and Wampler 1972), at the fast Cassegrain spectrograph of the Anglo-Australian 3.9 m telescope. Three scans were obtained, the details of which are given in Table 1. The resolution quoted in the table refers to that at the center of the wavelength range, and is degraded somewhat near the ends. Also, the scanner response is reduced at ultraviolet wavelengths, and so only strong features are measurable there. The spectrum of Q0453−423 obtained from joining the two higher resolution scans at 5060 Å is shown in Figure 1. Because of clouds a standard star was not observed at the same wavelength setting as the 1975 December

TABLE 1
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Date (UT)	Wavelength Region (Å)	Resolution (FWHM)	Integration Time (min)	Comments
1975 December 3.68	4200–6200	4.5	80	Standard star not observed at same wavelength setting
1976 February 29.44	3700–5100	4.5	64	Seeing ≤1″, some cloud during last 30 min
1976 April 6.41	3800–7400	9	48	

TABLE 2

EMISSION LINES

Wavelength (Å)	Identification	z
3790:	O VI 1034	2.665:
4452	Lα 1216	2.661
4529	N V 1240	2.652
4770:	O I 1305	2.655:
5110:	Si IV 1397	2.658:
5663	C IV 1549	2.656
7001	C III] 1909	2.667

observations, so the flux scale is not reliable in the λλ5060–6200 region in this figure.

Wavelengths and identifications for the emission lines in the observed region are given in Table 2. Lα, N V λ1240, Si IV λ1397, C IV λ1549, and C III] λ1909 are clearly present at a mean redshift of 2.659, in good agreement with the value of 2.661 determined by Osmer and Smith (1976). Si IV λ1397 is weak and strongly affected by absorption features, so the wavelength given is approximate and has not been used in the redshift determination. The wavelength of the Lα emission peak is clearly little affected by absorption, as evidenced by the good internal agreement between the redshifts obtained from the individual features. There is a probable emission line at about 3790 Å corresponding to O VI λ1034 (the signal-to-noise ratio is poor in this region because of the reduced scanner response in the ultraviolet), and we also find a weak feature at 4771 Å which could be identified with O I λ1305. Both of these lines have also been noted by Osmer and Smith (1976).

As is usual with bright, high-redshift QSOs there are numerous absorption lines in the spectrum. Air wavelengths and observed frame equivalent widths for the absorption lines obtained from our observations are listed in Table 3. Only lines that we regard as being definitely present have been listed; a number of possible but not definite features have been omitted.

TABLE 3

ABSORPTION LINES

Wavelength (Å)	E.W. (Å)	Wavelength (Å)	E.W. (Å)
3982.1	5:	4961.3	0.5
4017.1	6:	5037.1	5.0
4128.8	2.9	5069.6	1.9
4186.1	3.6	5077.3	1.4:
4234.4	0.9	5101.3	2.9
4257.7	3.5	5120.2	6.7
4276.6	1.5	5256.7	0.8
4300.6	2.1	5265.3	0.7
4359.1	1.7	5336.1	1.4:
4372.4	1.1	5348.0	1.0
4396.4	2:	5559.8	3.7
4407.9	4:	5589.7	7.2
4421.9	5:	6011.0	10:
4434.1	0.8::	6025.5	9:
4466.5	0.8::	6131.7	1.8:
4565.0	0.6	6874.4	4.2:
4825.4	1.6	6896.8	1.6:
4837.2	1.5	6947.7	5.4:

However, between 4200 and 6000 Å lines of equivalent width >1 Å are unlikely to have been missed unless they either were rather broader than the instrumental resolution or fell in the wings of strong emission lines. A number of weaker absorption lines were found in the well-observed wavelength region from 4400–5000 Å. Comparison of equivalent widths obtained from the overlap regions of each scan indicates that the errors in their values should not exceed about 15% or 0.3 Å, whichever is the larger.

III. ABSORPTION REDSHIFTS

A search for identifications of the absorption lines listed in Table 3 yielded two highly probable redshift systems at $z_{abs} = 1.1492$ and 2.2754. Table 4 lists the lines identified in each system, and in parentheses, the probability that such a system would be found by chance using the high-resolution data (see Coleman *et al.* 1976 for a description of the method used). Of the two systems the $z_{abs} = 1.1492$ redshift is the more certain, since all the expected lines of Fe II and Mg II are present in the observed range with equivalent widths consistent with their *f*-values. Mg I λ2852 is also present in the low-resolution scan. There is no evidence for the presence of Fe II fine-structure lines, and we do not find any of the lines of Mn II that were found in the $z_{abs} = 0.524$ system in AO 0235+164 (Burbidge *et al.* 1976; Rieke *et al.* 1976), nor the Cr I features suggested as possibly present at $z_{abs} = 0.6128$ in PHL 938 (Chan and Burbidge 1971).

The $z_{abs} = 2.2754$ system is based primarily on the identification of the nearly blended pair at 5069.6 and 5077.3 Å with C IV λλ1548.2, 1550.8 and the probable presence of Lα at 3982.1 Å. Si IV λ1393.8 is present on all scans, and there is a possible weak feature at 4595.0 Å which would correspond to Si IV λ1402.8. The presence of Si II in this system is indicated only by Si II λ1260.4, at 4128.8 Å, but since in the observed range the only other candidates have rather lower *f*-values, they would be weaker and could well have been missed. Also, the 4128 Å feature may arise in some other redshift system; it has been tentatively identified with Lα in a possible system at $z_{abs} = 2.3953$.

Ten absorption lines longward of the Lα emission have not been associated with definite redshift systems, but possible systems based on them are given in Table 5. Eight of the lines occur as apparent doublets, and so probably arise from the Mg II and C IV doublets as indicated. The most extreme case arising this way is system 3, with $z_{abs} = 0.7255$ based on the Mg II λλ2795, 2802 doublet alone. On one scan there is weak evidence for Mg I λ2852 and Fe II λ2599 in this system, but this was not confirmed on the second, and so its reality remains in doubt.

A second doublet corresponding to Mg II appears at 5336.1, 5348.0 Å, corresponding to a redshift of 0.9079. Again, no confirmation from other lines is present, though a feature at 4961.3 Å corresponds to Fe II λ2599 in this system. However, there is no sign of any feature at the expected position of Fe II λ2382, so the λ2599 line remains doubtful. Mg I λ2852 is also

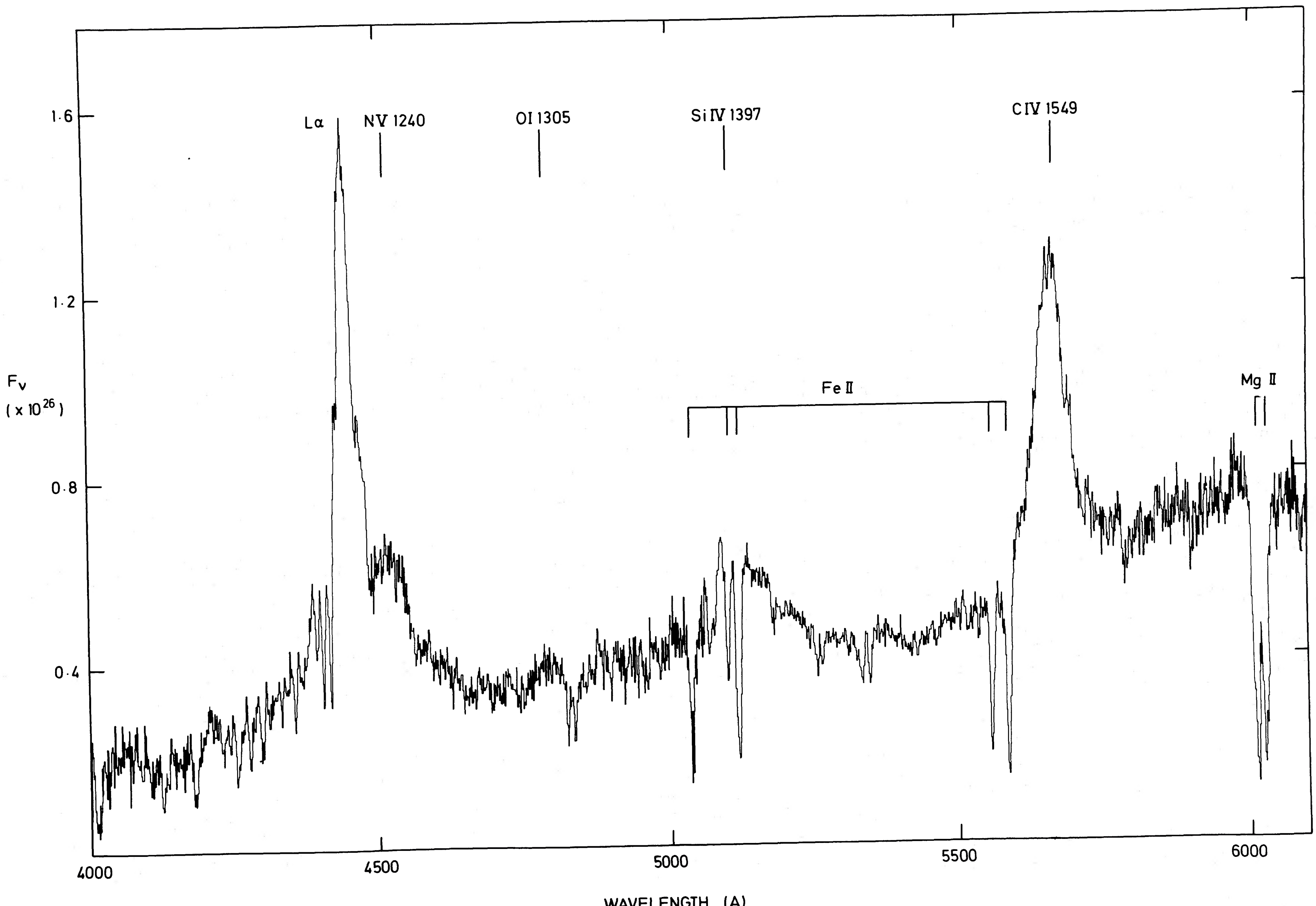

FIG. 1.—The spectrum of Q0453−423 obtained from joining at 5060 Å the two higher resolution scans. The more prominent emission and absorption lines are indicated. The f_ν scale is approximate only.

TABLE 4

PROBABLE ABSORPTION REDSHIFT SYSTEMS

Line	f	λ obs	E.W. (Å) (observed frame)	$1 + z$	Comments
		System 1: $z = 1.1492$ (10^{-5})			
Fe II 2343.5.......	0.11	5037.1	5.0	2.1488	
Fe II 2373.7.......	0.04	5101.3	2.9	2.1484	
Fe II 2382.0.......	0.33	5120.2	6.7	2.1489	
Fe II 2585.9.......	0.06	5559.8	3.7	2.1494	
Fe II 2599.4.......	0.20	5589.7	7.2	2.1497	
Mg II 2795.4......	0.60	6011.0	10.0:	2.1496	
Mg II 2802.7......	0.30	6025.5	9.0:	2.1492	
Mg I 2852.2......	1.90	6131.7	1.8:	2.1492	
		System 2: $z = 2.2754$ (5×10^{-4})			
Lα 1215.7........	0.42	3982.1	5.0:	3.2756	
Si II 1260.4.......	1.20	4128.8	2.9	3.2757	Blend Lα, system 7
C II 1334.5........	0.26	4372.4	1.1	3.2764	
Si IV 1393.8.......	0.54	4565.0	0.6	3.2753	
C IV 1548.2.......	0.19	5069.6	1.9:	3.2745	
C IV 1550.8.......	0.10	5077.3	1.4:	3.2741	

* The redshifts are determined from observed wavelengths measured in air and vacuum rest wavelengths.

absent, but it would probably be considerably weaker than the Mg II lines and therefore would be missed. The pair of lines at 6874.4 and 6896.8 Å can also be identified with Mg II at $z_{abs} = 1.4592$, but again no independent confirmation could be found.

The final doublet at 5256.7, 5265.3 Å corresponds to C IV λλ1548, 1550 at $z_{abs} = 2.3953$. Lα is present in this system at 4128.8 Å, though this line was earlier identified with Si II λ1260 at $z_{abs} = 2.2754$. Si IV λλ1393, 1402 were not found, but they are likely to be weaker than C IV lines.

This leaves two lines above the emission Lα yet

TABLE 5

POSSIBLE ABSORPTION REDSHIFTS

Line	f	λ_{obs}	E.W.	$1 + z$	Comments
		System 3: $z = 0.7255$			
Mg II 2795.4........	0.60	4825.4	1.6	1.7256	
Mg II 2802.7........	0.30	4837.2	1.5:	1.7254	May be too strong
		System 4: $z = 0.9079$			
Fe II 2599.4.........	0.20	4961.3	0.5	1.9081	Blend C IV 1548, system 6
Mg II 2795.4........	0.60	5336.1	1.4:	1.9082	
Mg II 2802.7........	0.30	5348.0	1.0	1.9076	
		System 5: $z = 1.4592$			
Mg II 2795.4........	0.60	6874.4	4.2:	2.4584	
Mg II 2802.7........	0.30	6896.8	1.6:	2.4600	
		System 6: $z = 2.2046$			
C II 1334.4..........	0.26	4276.6	1.5	3.2046	Blend Si II 1260, system 7
Si IV 1393.8.........	0.54	4466.5	0.8::	3.2046	
C IV 1548.2.........	0.19	4961.3	0.5	3.2046	Blend Fe II 2599, system 4
		System 7: $z = 2.3953$			
Lα 1215.7...........	0.42	4128.8	2.9	3.3963	Blend Si II 1260, system 2
Si II 1260.4.........	1.20	4276.6	1.5	3.3930	Blend C II 1334, system 6
C IV 1548.2.........	0.19	5256.7	0.8	3.3954	
C IV 1550.8.........	0.10	5265.3	0.7	3.3953	

unidentified. There is weak support for a system at $z_{abs} = 2.2046$ which identifies the line at 4466.5 Å with Si IV λ1393, though the other two lines in this suggested system are blends with lines from other possible redshifts. No suggested identification was found for the broad feature at 6947.7 Å. Also, a number of features at wavelengths less than 4450 Å have not been identified, but these could well arise from Lα in a number of redshift systems (Lynds 1971).

IV. DISCUSSION

The system at $z_{abs} = 1.1492$ is at an extremely large velocity with respect to the emission-line object with $v/c \approx 0.5$. For well-established absorption systems this is exceeded only by a cloud showing similar Fe II and Mg II lines at $z_{abs} = 0.6127$ in the $z_{em} = 1.95$ QSO PHL 938 (Burbidge, Lynds, and Stockton 1968). Because of its high velocity and possible low ionization, this system in PHL 938 has long been regarded by some as a prime candidate for an intervening galaxy (Bahcall 1971) between us and the QSO. On these grounds presumably the $z_{abs} = 1.1492$ system in Q0453−423 should be similar in origin. It is of interest to compare the cloud forming the system in PHL 938 and that forming the 1.1492 system here. For the PHL 938 cloud, Chan and Burbidge (1971) found a velocity dispersion (b-parameter) of about 50 km s^{-1} and column densities of 9.10^{14} cm^{-2} for Fe II and 3×10^{14} cm^{-2} for Mg II. Using the same method (due to Strömgren 1948), we find from the measured equivalent widths of the Fe II lines in the Q0453−423 cloud a velocity dispersion in the range 105–165 km s^{-1}, with 125 km s^{-1} as our best estimate. The corresponding column density for Fe II is $9(+4, -2) \times 10^{14}$ cm^{-2}, and using the velocity estimate we find that there are about 1.5×10^{15} Mg II ions and 8×10^{12} Mg I per cm^2. These figures should be treated with some caution since they are based on relatively poor equivalent width determinations (for Mg II and Mg I), and there is the possibility, given the high velocity dispersion, that there are a number of clouds, possibly with differing ionization conditions, which add to give the lines we see. Cases of such line splitting have been found, for example, in PKS 0237−23 (Boksenberg and Sargent 1975). The Fe II/Mg II ratio is similar to the solar abundance ratio in the PHL 938 cloud, but for Q0453−423 it is rather lower. It is not clear if this is due to abundance differences, to ionization differences (the ionization potentials of Mg I and Fe I, Mg II, and Fe II are similar, but Mg III ionization requires considerably more energy than Fe III), to our poorly determined magnesium line equivalent widths, or to velocity structure confusing our relative ion abundances. From the absence of the Mn II λ2576.1 line we estimate that N(Mn II)/N(Fe II) < 0.02, which is quite consistent with the solar abundance ratio.

If the cloud is close to and photoionized by the QSO and there is no significant absorption by intervening material, then we can determine $n_e R^2$, where n_e is the electron density in the absorbing material and R its distance from the QSO, from our estimate n(Mg II)/n(Mg I) ≈ 200. Assuming that the QSO is at a cosmological distance, a spectral index $\alpha = 1$, and a luminosity of 3.10^{30} ergs s^{-1} Hz^{-1} at the emission Lyman limit, we find $n_e R^2 \approx 10^{48}$ cm^{-1}. We cannot reasonably estimate n_e (the absence of Fe II fine-structure lines could provide an upper limit, but this is quite temperature-sensitive [Wolfe, private communication]), but if $n_e \approx 100$, then $R \approx 30$ kpc. This value is rather higher than usually found from fine-structure line considerations (e.g., Grewing and Strittmatter 1973), but is a reasonable distance for a cloud to have covered at 0.5c in a time not too short compared with estimated lifetimes of QSOs. Similar considerations no doubt apply to the PHL 938 cloud, though there we have no strength for the Mg I line. On the basis of the available data we have clouds in these two QSOs which look consistent with that expected from an intervening galaxy, but find no evidence that this must be the case.

The second highly probable redshift system is at $z_{abs} = 2.2754$, and has the C IV λλ1548, 1550 doublet in absorption falling in the Si IV λ1397 emission line. This coincidence is found in a number of other QSOs—4C 05.34 (Lynds 1971), 1331+170 (Strittmatter *et al.* 1973), PHL 1222 (Williams and Weymann 1976), and probably 4C 19.31 (Carswell *et al.* 1976), and the same $(1 + z_{em})/(1 + z_{abs}) \approx 1.11$ ratio is found in PHL 957 (Lowrance *et al.* 1972) and OQ 172 (Baldwin *et al.* 1974). This ratio has been discussed by Sargent and Boroson (1977, preprint), who conclude that it is more likely to be attributable to line-locking between C IV and Si IV than to Lβ–Lyman edge line-locking. They regard the frequent occurrence of this ratio as marginally significant and having no other obvious explanation than line-locking. The existence and interpretation of preferred ratios and line-locking are controversial. If statistically significant, however, preferred ratios are of importance for solving the problem of where the absorption lines originate.

We also note that the C IV λλ1548, 1550 doublet in the $Z_{abs} = 1.1492$ system falls almost exactly at the emission Lyman limit at 3330 Å. Observations of this UV region are planned to see if there are any features in the emission spectrum there (unlike OQ 172), and to check on the presence of C IV at $z_{abs} = 1.1492$.

Finally, we turn to the less certain line identifications. It is probable that identifications on the basis of doublet ratios alone in regions of the spectrum where only the systems at $z_{abs} = 0.7255$, 0.9079, 1.4592, and 2.3953 occur are not too insecure. Identifications on the basis of the Mg II doublet in particular have been made in 0735+178 (Carswell *et al.* 1974) and Ton 490 (Carswell *et al.* 1976), and of the C IV doublet in PHL 1222 (Williams and Weymann 1976), where these features appear longward of Lα in emission. If our identifications on this basis are correct, then three systems with $z_{abs} < 1.2$ are present in an object with $z_{em} = 2.659$. It is unlikely that many such systems, if they were present, would have been missed in well-observed QSOs with $1.6 < z < 2.8$ since, although spectra of QSOs are normally obtained with coverage of shorter wavelengths at about our resolution, a number do have good coverage over comparable wavelength regions. Indeed, we find only three cases in the literature of $z_{abs} < 1.2$ in such QSOs—the $z_{abs} = 0.6127$ system in PHL 938, and possible systems at $z_{abs} = 0.2548$ in Ton 490 (Carswell *et al.* 1976) and $z_{abs} = 0.744$ in 1331+170 (Strittmatter *et al.* 1973). Three in one object is very unlikely if the number distribution is random, as it would be if intervening galaxies were the seat of the absorption, so despite the extremely high relative velocities, we believe that a source of absorption associated with the QSO cannot be ruled out.

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