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SPLITTING OF C IV LINES IN A QSO ABSORPTION-LINE SYSTEM[1]

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ABSTRACT

The C IV doublet in the $z = 1.795$ absorption-line system in the QSO B2 1225+317 has been observed with the Multiple Mirror Telescope echelle spectrograph at a resolution of 10 km s^{-1}. The profile of C IV, previously known to contain at least three velocity components, is shown to consist of at least eleven. Individual components have Doppler width upper limits of 6.4–13.2 km s^{-1}. These low upper limits plus a study of published profile shapes for several other species suggest that the observed gas is not in an equilibrium state of collisional ionization, and that electron temperatures are 35,000 K or lower. The width of the aggregate profile (~ 500 km s^{-1}) is larger by a factor of 5 than any C IV or Si IV profile observed through the halo of our Galaxy, while individual components are narrower than those in the Galaxy. Thus, intervening galaxies with halos similar to that of our own Galaxy, even if occurring in groups, may not explain this QSO absorption-line system.

Subject headings: galaxies: general — galaxies: redshifts — quasars

I. INTRODUCTION

Many QSOs have strong absorption lines with $z_{abs} < z_{em}$, where z_{em} is the QSO redshift (Weymann *et al.* 1981). These are often attributed to absorption in large halos around intervening galaxies (Bahcall and Spitzer 1969; York 1982*a*). Detailed tests of this suggestion are difficult because they require high-resolution spectroscopic analysis of gas in halos of nearby galaxies and in the QSO systems. Spectra at 30 km s^{-1} resolution (R) of gas that may be in the halo of our Galaxy have been obtained only recently, using the *International Ultraviolet Explorer* (*IUE*) satellite (Savage and de Boer 1981; York *et al.* 1982, 1983, 1984). Spectra of QSO absorption systems with $R \sim 40$ km s^{-1} have been published for some 10 QSOs (see, e.g., Sargent *et al.* 1979; Sargent *et al.* 1980, hereafter SYBT). Recently, Pettini *et al.* (1983) have published $R = 20$ km s^{-1} spectra of the C IV doublets in the BL Lac object 0215+015. Resolution as high as 10 km s^{-1} has been obtained with the Multiple Mirror Telescope (MMT) echelle spectrograph, but published data cover only a narrow region in the Lyα forest of PHL 957 (Chaffee *et al.* 1983). More results are in preparation.

The importance of the high-resolution data is that they allow physical tests of several hypotheses and analogies that have been drawn with respect to galactic halos. This *Letter* describes $R = 10$ km s^{-1} observations of B2 1225+317 in an effort to determine the temperature and ionization mechanism of the gas in which the C IV absorption lines arise. Section II describes the observations, while § III contains a discussion of the results.

[1]The observations reported in this *Letter* were obtained at the Multiple Mirror Telescope Observatory, a joint facility of the Smithsonian Institution and the University of Arizona.

II. DATA

The MMT echelle spectrograph (Chaffee 1974) was used on the nights of 1983 March 15, 16, and 17 to observe C IV and Al III doublets in the $z = 1.795$ absorption system of B2 1225+317, a QSO with $z_{em} = 2.2$, $V \sim 15.9$. The intensified Reticon detector (Latham 1982) has a quantum efficiency of about 9% at 4300 Å. The spectrograph/telescope/detector system, which gives $R = 10$ km s^{-1}, is described in detail by Chaffee *et al.* (1983). The results described here consist of 8 hours of integration on March 16, using a 1″ entrance slit, covering the region 4310–4349 Å for C IV, and 4 hours on March 17, covering 5170–5220 Å for Al III. Every 20 minutes, the exposure was stopped and a wavelength calibration made. The resulting 20 minute accumulations were divided by a white-light spectrum, wavelength corrected for flexure-induced and thermal shifts, dark subtracted, and co-added. The observations were taken during the dark of the Moon so no sky subtraction was necessary.

The doublet pattern in many separate C IV components is apparent in Figure 1; the individual lines are listed in Table 1. Noise in the plot can be judged by eye. Photon or dark noise appears at the highest frequency, whereas apparent noise caused by weak absorption lines appears at lower frequency (one optical resolution element of 10 km s^{-1} is covered by 6 pixels).

TABLE 1

B2 1225+31 LINE LIST FOR C IV (z = 1.795)

λ Obs. (Å)	W_λ Obs.[a] (mÅ)	b[a] (km s^{-1})	ID[b]	C IV System No.
4324.57	294	8.3	C IV S	1 A
4325.17	581	13.2	C IV S	2 A
4325.65	401	10.2	C IV S	3 A
4326.20	...	...	?	4
4326.67	363	7.0	C IV S	5 A
4327.07	468	8.3	C IV S	6 A
4328.00	442	11.8	C IV S	7 A
4328.90	240	7.9	C IV S	8 A
4329.45[c] ...	207	7.9	C IV S	9 A
4329.68	207	7.9	C IV S	10 A
4330.25	188	6.4	C IV S	11 A
4331.20	161	7.9	C IV S	12 A
4331.75	212	8.3	C IV L	1 B
4332.35	476	13.2	C IV L	2 B
4332.83	306	10.2	C IV L	3 B
4333.85	320	7.0	C IV L	5 B
4334.25	422	8.3	C IV L	6 B
4335.20	328	11.8	C IV L	7 B
4336.10	161	7.9	C IV L	8 B
4336.64	131	7.9	C IV L	9 B
4336.87	131	7.9	C IV L	10 B
4337.44	124	6.4	C IV L	11 B
4338.40	96	7.9	C IV L	12 B

[a] 2 σ formal errors are ±60 mÅ, except for discrepant components discussed in the text. Given these errors in W_λ, formal b values are uncertain by ±2 km s^{-1}.

[b] S = 1548.19 Å; L = 1550.77 Å (vacuum wavelength).

[c] Additional component appears at short-wavelength edge.

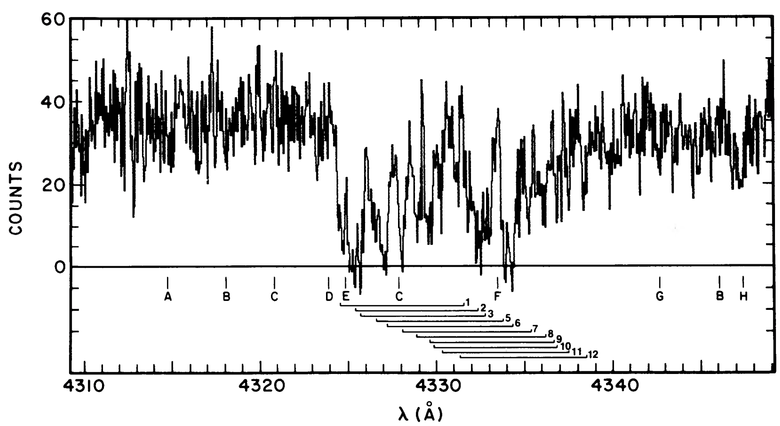

FIG. 1.—Spectrum of the region of z = 1.795 C IV absorption in the quasar B2 1225+317. The velocity components identified in Table 1 are marked and numbered; the letters denote computed locations of possible metal lines corresponding to observed Lyα lines, as listed in Table 2.

Positions of lines of species commonly found in QSO absorption systems at the wavelengths expected for known redshift systems in B2 1225+317 (SYBT) are labeled in Figure 1 and presented in Table 2. From the four systems containing definite lines of heavy elements, only the z = 2.120 system has a line expected in the region 4310–4349 Å: the Si IV λ_{vac}1393.8 line is expected at λ_{air}4347.3. It is probably detected as feature "H" in Figure 1. Many of the "Lyα only" systems listed by SYBT could have lines of Si IV (λ_{vac}1393), Si II (λ_{vac}1526), or C IV (λ_{vac}1548) in this spectral region. Column (2) of Table 2 gives the predicted location of metal lines corresponding to the Lyα lines given in column (4). The locations are marked in Figure 1 by the letter given in column (1). No clear detection of metal lines from the "Lyα only" systems can be reported, although they could, if present, be masked by the C IV absorption near z = 1.795, particularly those labeled C, D, E and F. It is also possible that Fe II and Mg II lines from low-z systems could fall in the observed spectral region.

Data for Al III are of lower quality. We discuss this spectrum later.

III. ANALYSIS

The combined data of Grandi (1979) and Wilkerson *et al.* (1978) (taken with a velocity resolution of ≳ 100 km s^{-1}) for

TABLE 2

OTHER POSSIBLE LINES IN C IV RANGE

Label	$\lambda_{air}{}^{a}$ (Å)	Transition	$\lambda(Ly\alpha)^{b}$
A	4314.79	C IV (λ1550)	3383.4
B	4318.03	Si IV (λ1394)	3767.4
B	4345.96	Si IV (λ1402)	3767.4
C	4320.70	C IV (λ1548)	3393.7
C	4327.93	C IV (λ1550)	3393.7
D	4323.91	Si II (λ1526)	3444.0
E	4324.68	Si IV (λ1394)	3773.2
F	4333.28	Si IV (λ1394)	3780.7
G	4342.62	Si II (λ1526)	3458.9
H	4347.26	Si IV (λ1394)	3792.9
I	4349.40	Si II (λ1526)	3464.3

[a]Corrected to observed wavelength scale by heliocentric velocity shift of 2 km s^{-1}.

[b]Vacuum, heliocentric wavelengths as tabulated by SYBT.

B2 1225+317 show absorption lines at $z = 1.795$, including the ions Si IV, C IV, Si II, Al II, Fe II, and Mg II. The system is therefore very well established.

The C IV data are summarized in Table 1. Voigt profiles were fitted to individual doublets of C IV; in cases where components from different systems overlapped, they were fitted simultaneously. The fits were forced to give consistent column densities and temperatures for both members of each doublet. In most cases, the stronger (λ1548) member gave the best determined value of N(C IV). But for components 5, 6, and 12, the weaker member appeared cleaner, and in fact acceptable fits to the λ1550 lines predicted λ1548 lines too weak to be consistent with the observed features. Component 4 has no corresponding λ1550 feature and is therefore not an obvious C IV absorption. Any values of N and b derived for these four components are evidently uncertain. The noted discrepancies may be caused by photon noise, or contamination from metal line absorption from other redshift systems.

Summed over all velocity components, the total equivalent widths are $W_\lambda(\lambda1548) = 3.5$ Å and $W_\lambda(\lambda1550) = 2.7$ Å, values which agree well with measurements by Grandi (1979: 3.9 and 2.9 Å respectively). In addition to discrepancies mentioned above, it is important to discuss components 2 and 3, which appear blended, as a single broad component at 4325 Å (C IV λ1548) and 4332 Å (C IV λ1550). We tried to fit the data with a single component with large b and found that $b \sim 50$ km s^{-1} is required to fit the line width. This solution was rejected because the only column densities compatible with the profile cores required that damping wings should be seen in our data, but none are apparent.

The profile fits to individual pairs yield the b values ($b = \sqrt{2}\,\sigma$ for a Gaussian profile) given in Table 1. Excluding components 5 and 6 because of problems noted earlier, we find 6.4 km s^{-1} $< b <$ 13.2 km s^{-1}. If individual components are being resolved and they are thermally broadened, 34,000 K $< T <$ 145,000 K. Since the lowest b values are comparable to the resolution, individual components could still be multiple; hence the b value for any one component is an upper limit. We further conclude that the C IV lines are not damped, as could be implied by the large equivalent widths of the narrowest identifiable components found by SYBT.

IV. DISCUSSION

a) *Ionization Mechanism*

Based on lower resolution data, Grandi (1979) derived column densities for C II, C IV; Si II, Si III, Si IV; and Al II and Al III. For all of these elements, he found column densities spread about equally over all ionization stages. From the new data, it is clear that the b values derived from a curve-of-growth analysis represent the overall width of a system of narrow lines and that the b value itself cannot be interpreted to give a kinetic temperature for any one component.

Measurements of a number of lines in this system are given by SYBT, broken into the three apparent components required by the C IV profile (Sargent 1977). Si II, Si III, and Si IV; C II and C IV; and Al II are all detected in the shorter wavelength components. Since collisional ionization at a given temperature results in comparable strengths of Si II, Si III, and Si IV only if several regions along the line of sight with different temperatures are postulated, collisional ionization is unlikely. Moreover, the low b values of components 8–12, for which SYBT have only upper limits for lower ionization species, also demonstrate that the C IV is too cool to be collisionally ionized in equilibrium.

Photoionization (as postulated, for instance by McKee, Tarter, and Weisheit 1973, and reemphasized by Sargent *et al.* 1979) is a mechanism consistent with data available on the profiles, ionization distribution, and temperatures. Alternately, shock heating can result in gas clouds which are out of ionization equilibrium and which therefore retain a wide distribution of ions even though the gas is relatively cool. It is expected that a model based on photoionization will produce lower b values and smaller velocity differences among ions than will a shock heating model. Therefore, to distinguish between these two possibilities requires measurement of b values and relative velocities of several ions. We attempted to observe the Al III absorption to provide such a distinction. However, in spite of the detection of these lines by Wilkerson *et al.* (1978) [$W_\lambda(1854) = 700$ mÅ $\pm$ 200 mÅ, $W_\lambda(1862) = 500$ mÅ $\pm$ 200 mÅ], we failed to detect any of the various velocity components seen in C IV. Apparently, Al III is distributed among components so each component was below our detection limit. There are also broad unidentified features in the relevant wavelength region which make the continuum hard to define.

b) *Origin of Complex Metal Line Absorption*

It is often suggested that halos of intervening galaxies could cause the QSO absorption systems with $z_{abs} < z_{em}$, such as the one we discuss here. The halo of our Galaxy produces lines of C IV and Si IV, but for lines of the strength reported here, absorption along each line of sight covers $\lesssim 100$ km s^{-1} FWHM (Savage and de Boer 1981; York *et al.* 1983) and the b values are $\gtrsim 20$ km s^{-1}. Theoretically, it is difficult to see how velocity spreads as high as the 500 km s^{-1} seen in this system could arise from a single sight line through the halo of a galaxy (Bregman 1980; Weisheit 1978).

Pettini *et al.* (1983) have found a similar situation for two C IV systems in a temporarily bright BL Lac object, 0215+015. For systems at $z = 1.549$ and 1.649, they found seven and nine components, spread over 300 and 900 km s^{-1}

respectively. They attribute the two multiple narrow-line systems to two separate rich clusters, but point out that the clusters rich enough to produce so many overlapping galaxies in projection are rare (Burbidge *et al.* 1977). The systems may have $z_{abs} - z_{em} \lesssim 0.1c$ (the redshift of the BL Lac object is uncertain), a regime in which very broad troughs of absorption, regarded as being intrinsic to the QSO, may break up into narrow lines. They are thus not able to rule out the intrinsic nature of the complex absorption lines.

Our data would appear to worsen the ambiguity of the origin of complex QSO absorption systems. The $z = 1.795$ complex in B2 1225+317 has an ejection velocity of 41,000 km s^{-1} and shows no evidence for N V lines, but does show W_λ(Mg II) ~ W_λ(C IV). All of these points put the system in the "intervening" category. (Systems physically close to the QSO, with $n_e < 1$ cm^{-3}, would show N V absorption and no Mg II absorption as discussed by Sargent *et al.* 1979; Weymann *et al.* 1979; and York 1982*a*.) Yet the extreme multiplicity ($\gtrsim 11$ components) suggests that the line of sight would need to pass near the center (within 50–100 kpc) of the core of a rare rich cluster, if each galaxy produces only one or two components.

Virtually all QSO metal systems studied before 1982 showed substructure, even at 40 km s^{-1} resolution (Weymann *et al.* 1981). Presumably, the brightest systems with the strongest lines were studied at high resolution. Recent searches have yielded narrow systems (0215+015, Pettini *et al.* 1983; Q0119−046, Sargent, Young, and Boksenberg 1982), but the data suggest the ratio of numbers of systems with velocity spread greater than 200 km s^{-1} to the number of systems with velocity spread less than 100 km s^{-1} will be greater than 1 (York 1982*b*). A larger sample of objects observed at high resolution is required to distinguish between rare lines of sight through clusters of galaxies and evolution in the halo properties of ordinary galaxies.

V. CONCLUSIONS

The $z = 1.795$ absorption-line system in B2 1225+317 is the best studied case of a candidate intervening galaxy. Observed with a resolution of 10 km s^{-1} ($b \sim 6$ km s^{-1}), it splits into at least 11 components. Combining these results with other, low-resolution data, we conclude that all components are consistent with shock heating or photoionization of the gas in which they arise, but that collisional ionization equilibrium does not exist in the gas clouds. Higher resolution could yield still greater numbers of components if this conclusion is correct.

Our analysis suggests that column densities and Doppler widths derived from lower resolution data of any QSO system are subject to numerous obvious errors. Tests of the relationship of halos to QSO lines clearly depend on having accurate statistics for numbers of components and their relative ionization; these tests will apparently only be possible when better high-resolution data are generally available.

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