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PG 1700+518: A LOW-REDSHIFT, BROAD ABSORPTION LINE QSO[1]

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ABSTRACT

We present the first high-resolution optical spectra and lower resolution ultraviolet spectra of PG 1700+518, the only known broad absorption line (BAL) QSO at low redshift ($z_{\rm em} = 0.288$). The outstanding feature of the optical spectrum is a strong, broad Mg II absorption trough, detached from the Mg II emission line and indicative of ejection velocities of between 7000 and 18,000 km $\rm s^{-1}$. We also detect narrow (FWHM = 350 km $\rm s^{-1}$) Mg II absorption lines at $z_{\rm abs} = 0.2698$, which are probably related to the mass ejection phenomenon. From consideration of these optical and ultraviolet data we conclude that the emission-line spectrum of PG 1700+518 is similar to that of other low-redshift QSOs. However, we find some obvious differences from typical *BAL* QSOs, most notably in the unusually low level of ionization of both emission-line and broad absorption line gas. There are several indications in the spectrum that the BAL gas may not cover the emission-line region, as seen from Earth. The absence of He I $\lambda3889$ provides an important observational difference between the BAL gas and the material producing the blueshifted absorption lines seen in the nuclei of some Seyfert 1 galaxies. The implications of these findings for current interpretations of the BAL phenomenon are briefly discussed.

Subject headings: galaxies: nuclei — galaxies: redshifts — quasars

I. INTRODUCTION

A small proportion of QSOs show broad absorption lines (BAL), or "troughs," indicative of outflowing material with velocities which can reach a significant fraction of the velocity of light (0.1–0.2c). Recently, this class of QSOs has attracted an increasing amount of interest, partly in response to the realization (Hazard *et al.* 1984) that the BAL QSOs may constitute between 3% and 10% of all bright ($V < 18$) QSOs in the redshift range $2.2 < z < 2.4$ (where they are most easily recognized on objective prism plates). Since the covering factor of the outflowing gas producing the broad absorption lines is probably less than 10% (Junkkarinen 1983), this may imply that a significant fraction of all QSOs may be "intrinsic" BAL QSOs. Two observational features are characteristic of BAL QSOs and have influenced significantly current ideas of the nature of these objects. First, all known BAL QSOs are at $z_{\rm em} > 2$ (with the exception of PG 0946+301 [$z_{\rm em} = 1.216$] which has recently been recognised as a BAL QSO by Wilkes 1985). Second, they generally exhibit a high degree of ionization, both in the emission lines and, principally, in the gas producing the broad absorption lines. In particular, the latter rarely shows in C II $\lambda1334$, and only one case has been reported so far of a strong Mg II $\lambda\lambda2795, 2802$ trough (He *et al.* 1984).

In view of this, the discovery by Wampler (1985) that PG 1700+518, a bright ($B = 15.43$), low-redshift ($z_{\rm em} = 0.292$) QSO from the Schmidt and Green (1983) survey, shows broad Mg II absorption is remarkable indeed. Here we present the first high-resolution (1.2 Å FWHM) observations of the optical spectrum of PG 1700+518, together with lower resolution (~ 7 Å FWHM) ultraviolet spectra which are the first *IUE* images of a BAL QSO.

II. OBSERVATIONS AND DATA REDUCTION

The optical observations were obtained on 1984 May 28, May 29, June 2, and June 4 with the new 2.5 m Isaac Newton Telescope (INT) at the Observatorio del Roque de los Muchachos on the island of La Palma, Spain. The 235 mm focal length camera of the Cassegrain intermediate dispersion spectrograph (IDS) was used with the image photon counting system (IPCS) as the detector. With 1200 lines $\rm mm^{-1}$ gratings we recorded ~ 1050 Å wide portions of the spectrum in 2000 wavelength bins, at a dispersion of ~ 35 Å $\rm mm^{-1}$ and a resolution of 1.2 Å FWHM. Each object exposure was bracketed by emission-line spectra from a comparison Cu-Ar hollow cathode lamp, providing a wavelength scale and a measure of the spectral resolution. After correction for atmospheric extinction, the extracted spectra were flux-calibrated by reference to spectra of standard stars; we estimate this calibration to be accurate to no more than ~ 30%, because the spectrograph slit was comparable to the FWHM of the seeing disk. Figure 1 shows the final merged spectrum between 3200 and 7000 Å, binned in 2 Å wide channels so as to display to best advantage the broad spectral features. The blue end of the spectrum, including the Mg II emission line and absorption trough, is reproduced in the original bin size (0.5 Å) in Figure 2.

The *IUE* data consist of two low-resolution (~ 7 Å) SWP images (SWP 23672 and SWP 23691) obtained, respectively,

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[1] This paper is based on optical data obtained with the Isaac Newton Telescope and ultraviolet data obtained with the *International Ultraviolet Explorer* satellite. The INT is operated on the island of La Palma by the Royal Greenwich Observatory at the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofisica de Canarias.

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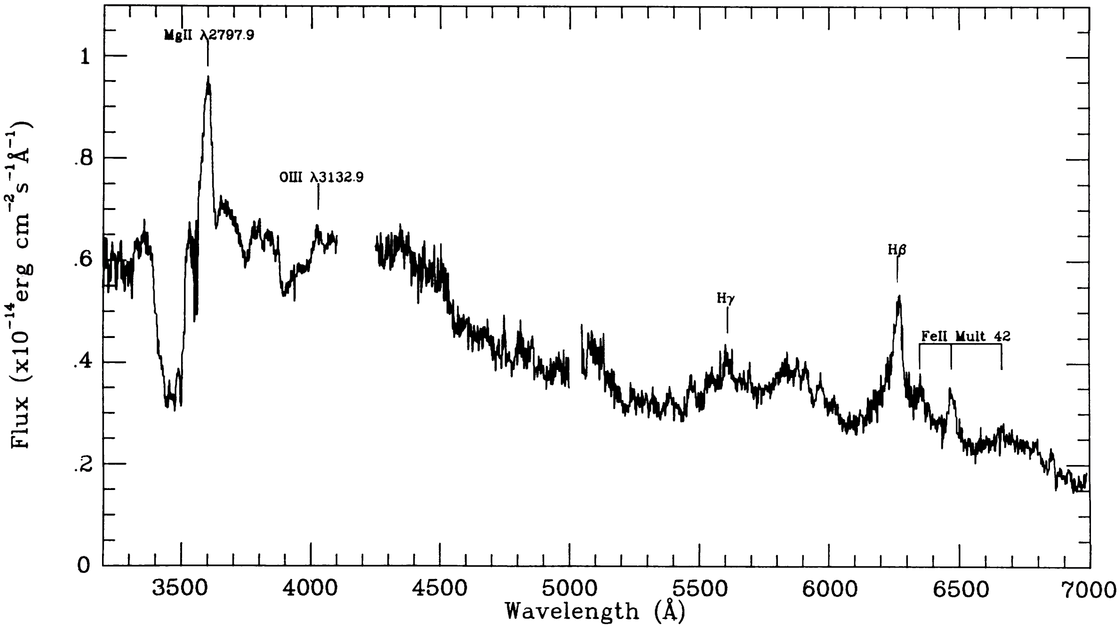

FIG. 1.—Optical spectrum of PG 1700+518 sampled every 2 Å. The spectrum was recorded in four wavelength intervals, each spanning ~ 1050 Å, and leaving two small gaps (near 4200 and 5000 Å) where no data were obtained. The integration time in the 3200–4100 Å region was 9000 s, 4–6 times greater than in the rest of the spectrum; this accounts for the superior signal-to-noise ratio of the data at these wavelengths.

on 1984 August 11 and August 15 with integration times of 403 and 410 minutes. The summed spectrum, covering the wavelength region 1250–1975 Å, is reproduced in Figure 3.

III. DESCRIPTION AND MEASUREMENTS OF THE SPECTRUM OF PG 1700+518

a) *Emission Lines*

The emission line spectrum of PG 1700+518 is not unusual for a low-redshift QSO. The most prominent emission lines are indicated in Figure 1 and listed in Table 1A, together with their central wavelengths and corresponding redshifts. From these measurements we deduce a mean emission redshift $z_{\rm em} = 0.288 \pm 0.002$. In addition, there is evidence for a number of low contrast features which are likely to be mainly unresolved blends of Fe II lines, as shown most recently by the models of Wills, Netzer, and Wills (1985). The only Fe II lines which we resolve are λ4924 and λ5018 from multiplet 42. On the basis of the observed strengths and widths of these lines, it appears that these models can account, at least qualitatively, for the most prominent structure in the spectrum. In particular, we point out the following:

1. There is a weak emission feature between ~ 3320 and 3390 Å (2580 and 2630 Å in the rest frame), merging with the blue edge of the Mg II trough, which is a blend of many weak Fe II lines, including the resonance lines of UV 1 (λλ2586, 2599).
2. Weak Fe II lines, including UV 62 and 63, probably account for the asymmetric blue wing of the Mg II emission line.
3. Fe II blends can also explain the structure seen longward of Mg II, which includes the commonly observed feature at ~ 2950 Å (Grandi and Phillips 1978).

Point (2) above may be the reason that the two strongest emission lines (Mg II and Hβ) give slightly different redshifts.

b) *Absorption Lines*

The outstanding feature in Figures 1 and 2 is the strong Mg II trough (total equivalent width in the observed frame $W_\lambda^{\rm OBS} = 46$ Å), which extends from ~ 3515 Å to ~ 3386 Å, implying outflow velocities of between ~ 7000 and ~ 18,000 km s^{-1} relative to the emission-line clouds (see Table 1B). These limits may be underestimates because of possible blending with Fe II emission, as explained above (points 1 and 2). The shape of the Mg II trough fits well the defining criteria of class III set out by Weymann and Foltz (1983) in their attempt at classifying BAL QSOs on the basis of the appearance of the C IV absorption troughs. In objects of type III, of which Q1246−057 is the prototype (Boksenberg *et al.* 1978), the troughs are well detached from the emission peak and show some structure, as indeed is the case here. However, the structure at the bottom of the Mg II trough (see Fig. 2) cannot be easily attributed to partly resolved absorption components, as it may appear at first sight. In particular, it is difficult to interpret the feature centered at 3500 Å as a narrow Mg II absorption component, since we find no evidence of the corresponding absorption due to the other member of the doublet. Rather, we consider it more likely that this is a gap between weak Fe II emission lines superposed on the broad Mg II absorption, and that the intrinsic shape of the trough consists of a very steep red edge, a flat bottom, and a gentler rise to the blue. The main evidence in support of this interpretation is the good agreement between the structure seen at the bottom of the trough and the positions of the strongest Fe II lines in this region (indicated by tick marks in Fig. 2), predicted by the models of Wills, Netzer, and Wills

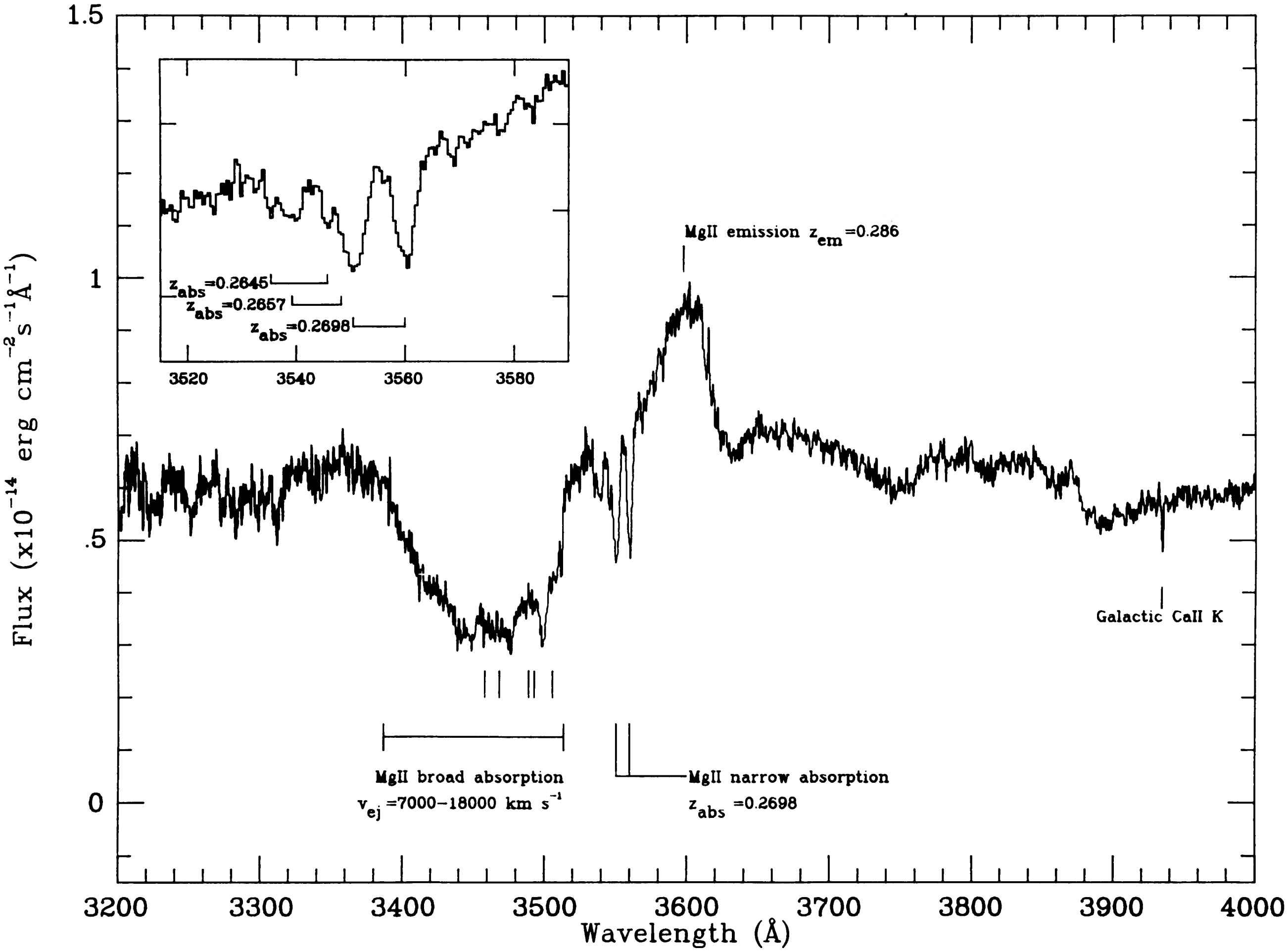

FIG. 2.—The short wavelength end of the optical spectrum of PG 1700+518 is shown in the original bin size of 0.5 Å. The resolution of these data (2.5 channels = 1.2 Å FWHM), is well demonstrated by the narrow profile of the interstellar Ca II K line (λ3933.663) formed in foreground gas in the disk and halo of our Galaxy. The unlabeled vertical ticks below the Mg II broad absorption trough mark the expected wavelengths of the strongest Fe II emission lines in this region at the average emission redshift $z = 0.288$. The inset shows on an expanded scale a small portion of the spectrum, encompassing the narrow Mg II absorption lines. Three separate Mg II doublets can be identified in our data.

(1985). Furthermore, the strength of these Fe II features is qualitatively in good agreement with those of other Fe II multiplets in the spectrum, suggesting that the Fe II emission has not been significantly reduced by the Mg II trough. If this interpretation is correct, it leads to the important conclusion that the outflowing gas only partially covers, if at all, the emission-line region, as viewed from Earth.

We see no evidence of broad absorption in the Fe II resonance lines (UV 1) shortward of 3265 Å, corresponding to the sharp red edge of the Mg II trough. A possible explanation for this is that the ionization level in the BAL gas is too high to give a significant fraction of singly ionized iron. More importantly, there is no indication of broad absorption from the metastable 2 ^3S level of He I at λ3888.646; a conservative upper limit $W_\lambda(\lambda3889) \leq 18$ Å (≤ 14 Å in the rest frame) is obtained from an estimated optical depth of less than 0.1 over the entire velocity range of the Mg II trough. This implies that in the BAL gas the product $n_{\rm He^+} n_e R$ (where R is the thickness of the absorbing region along the line of sight) is significantly smaller than in the outflowing gas in the nuclei of some Seyfert 1 galaxies, such as NGC 4151 and Mrk 231, where He I λ3889 absorption is strong (Anderson 1974; Boksenberg *et al.* 1977). Until this observational difference is understood, it is premature to assume that the two phenomena are closely related, and that the physical properties deduced for the broad absorption line gas in the Seyfert galaxies also apply to BAL QSOs (e.g., Rudy, Foltz, and Stocke 1985; Schmidt and Miller 1985). A search for [O III] λλ4959, 5007 *emission* from the BAL gas could also, in principle, provide a measure of the gas density. However, the relevant wavelength interval includes Hβ and Fe II (multiplet 42) emission at $z_{\rm em} = 0.288$; only by modeling these lines will it be possible, if at all, to deduce a useful limit to the strength of [O III] emission.

In addition to the broad trough, we also identify *narrow* Mg II absorption, with three doublets at $z_{\rm abs} = 0.2645, 0.2657$, and 0.2698 (see inset in Fig. 2 and Table 1B). We consider it likely that this gas is related to the BAL phenomenon, rather than to the quiescent interstellar medium of an intervening galaxy, for three principal reasons. First, low-redshift Mg II systems are rarely detected, while BAL QSOs are known to

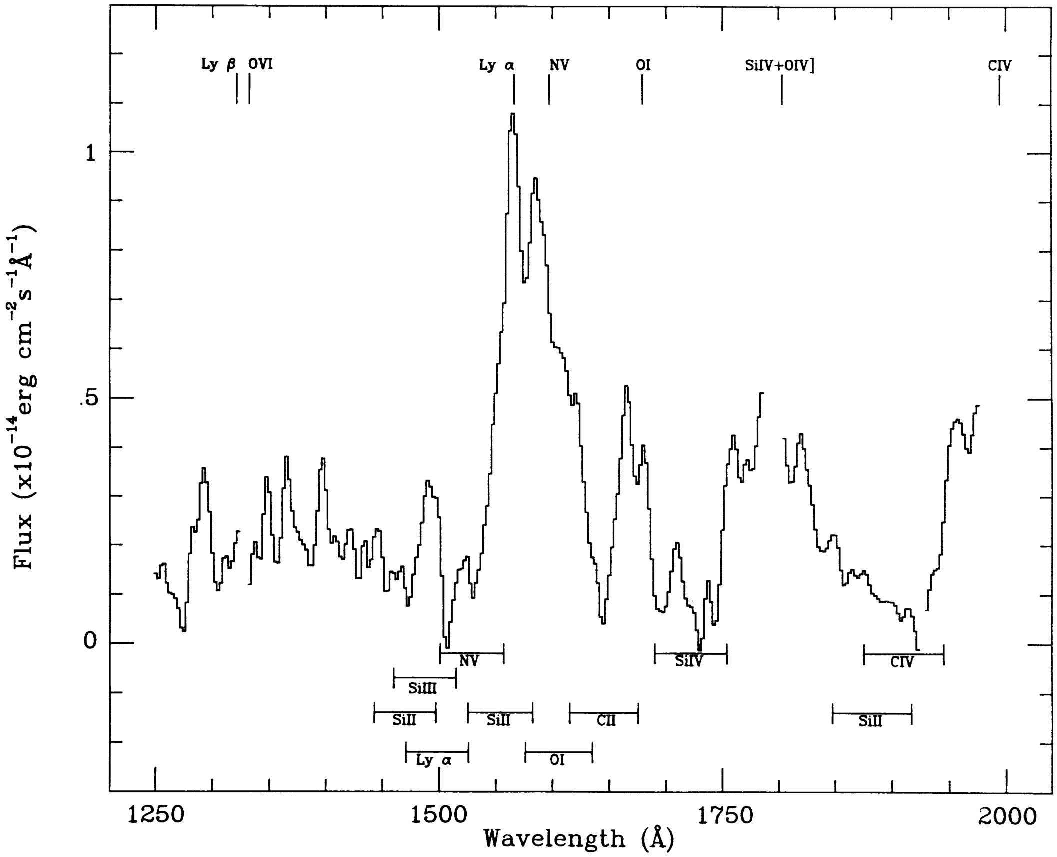

FIG. 3.—Far-ultraviolet spectrum of PG 1700+518. The expected positions of the most prominent emission lines at a redshift $z_{\rm em} = 0.288$ (measured from the optical spectrum) are indicated by tick marks at the top of the figure. Also given, at the bottom of the figure, are the wavelength ranges covered by the strongest UV absorption lines, if they extend over the same velocity interval as the Mg II trough.

show a statistical excess of narrow C IV systems within the velocity range of the broad absorption troughs (Young, Sargent, and Boksenberg 1982). These "narrow" lines are in fact typically a few hundred km s^{-1} wide, as seen here. Second, the fact that we do not detect Fe II λλ2586, 2599 at $z_{\rm abs} = 0.2698$ indicates that this gas is more highly ionized (or of different chemical composition, which we consider unlikely) than the interstellar medium in galactic halos (e.g., Savage and de Boer 1981; Blades *et al.* 1985). Third, and most importantly, it appears that the covering factor of the emission-line region by the *narrow* Mg II absorption may also be less than unity. This is suggested by the fact that the residual intensity in the cores of the lines of the strongest of the three Mg II doublets ($z_{\rm abs} = 0.2698$) is large (~ 0.65), whereas the doublet ratio [$W_\lambda(\lambda 2795)/W_\lambda(\lambda 2802) \leq 1.28$] indicates that the lines are approaching saturation. These two contradictory observations cannot be easily reconciled, since the line profiles are resolved (the instrumental broadening is only 100 km s^{-1} FWHM, whereas the lines have FWHM ≈ 350 km s^{-1}).

c) The Ultraviolet Spectrum

It is immediately obvious from Figure 3 that the ultraviolet spectrum of PG 1700+518 is a complex blend of emission and absorption features. This blending makes it particularly difficult to identify any continuum windows in the spectrum, although we suspect that the underlying continuum level lies between 0.2 and 0.3×10^{-14} ergs cm^{-2} s^{-1} Å^{-1}. For this reason, we limit ourselves to qualitative remarks on the most important spectral features evident in Figure 3, rather than attempting measurements which would be inherently very uncertain. At the top of Figure 3 we have indicated the positions of the most prominent emission features which at $z_{\rm em} = 0.288$ would be redshifted into the wavelength range of the SWP camera. Clearly, Lyman-α and N V λ1240.1 emission can be recognized in Figure 3. O I λ1303.5 and the Si IV + O IV blend at λ1399.7 are also probably present, while Lyman-β and O VI λ1033.8 are not detected. At 1995 Å C IV λ1549.1 is just outside our range. The small differences between the predicted and apparent central wavelengths of N V and O I may be due to the superposition of broad absorption features, as discussed below.

Also indicated in Figure 3 are the wavelength ranges covered by the strongest UV absorption lines, if they extend over the same velocity interval as the broad Mg II trough. Although blending does complicate the interpretation, the following points emerge. Steep red edges to the C IV and Si IV troughs are indeed present at the expected wavelengths; the blue extent of the former is probably increased by overlapping Si II λ1526.7 absorption. Conversely, a steep red edge cannot be readily recognised in N V; instead Lyman-α emission is seen

TABLE 1

MEASUREMENTS OF THE OPTICAL SPECTRUM OF PG 1700+518

A. EMISSION LINES

Central Wavelength[a] (Å)	Identification	$z_{\rm em}$[a]	Comments
6468.76	Fe II λ5018.434	0.2886	Multiplet 42
6349.21	Fe II λ4923.921	0.2891	
6262.92	Hβ (λ4861.332)	0.2880	
5604.48	Hγ (λ4340.468)	0.2909	
4028.54	O III λ3132.86	0.2855	Bowen fluorescence (Multiplet 12)
3597.93	Mg II λ2797.9	0.2856	
$\bar{z}_{\rm em}$[a]		0.288 ± 0.002	

B. ABSORPTION LINES

Wavelength[a] (Å)	$W_\lambda^{\rm obs}$ (Å)	Identification	$z_{\rm abs}$[a]	v (km s^{-1})	Comments
3513.8–3386.7	45.8	Mg II λ2797.9	0.2555–0.2101	7090–18115[b]	Mg II trough
3535.37	···	Mg II λ2795.528	0.2643	4950[b]	Narrow Mg II absorption
3545.75	···	Mg II λ2802.704	0.2647		
3539.22	···	Mg II λ2795.528	0.2657	4675[b]	
3550.45	1.79	Mg II λ2795.528	0.2697	3710[b]	
3559.95	1.40	Mg II λ2802.704	0.2698		
3934.39	0.20	Ca II λ3933.663	−0.000098	−12[c]	Galactic ISM

[a] Vacuum heliocentric.

[b] Ejection velocity relative to Mg II emission-line region.

[c] Velocity of interstellar Ca II K relative to local standard of rest.

over a significant fraction of the velocity range expected for the N V trough, *contrary to what is normally observed in BAL QSOs* (e.g., Weymann and Foltz 1983). This may be due to an intrinsically low optical depth to N V absorption, reflecting the lower than usual ionization level of the outflowing gas, and/or to a small covering factor of the emission-line region by the BAL gas, as already discussed for Mg II. An independent suggestion of the latter is provided by the lack of a broad C II λ1334.5 trough; overlapping emission is a plausible explanation for the fact that C II absorption apparently extends over a more restricted velocity interval than Mg II.

IV. DISCUSSION

While the relationship of PG 1700+518 to other BAL QSOs has yet to be elucidated, any valid model must from now on obviously account for the existence of low-redshift, low-ionization members of this class of objects. Here we comment briefly on the relevance of PG 1700+518 and its spectral characteristics to current interpretations of the BAL phenomenon.

The smooth absorption troughs seen in some BAL QSOs, most notably PHL 5200, are reminiscent of stellar P Cygni profiles and have led to the suggestion that they may be formed in a continuous outflow of matter from the central source. Recent work (e.g., Drew and Boksenberg 1984) has shown that this class of models, while capable of reproducing the line profiles with a decelerating velocity field, predict a very high ionization level in the outflowing gas. It is difficult to envisage how such QSO wind models can be made to accommodate significant fractions of ion stages as low as Mg^+ and Si^+ with plausible model parameters.

The common absence, or weakness, of broad Mg II absorption in BAL QSOs with "normal" Mg II emission lines, and the fact that the Lyman-α emission line is usually masked by the N V trough, have been used to argue that the BAL gas is located well outside the broad emission line region (see Weymann and Foltz 1983). In the model by Scott, Christiansen, and Weymann (1984) the broad absorption troughs are produced by the effects of a hot thermal wind from the QSO nucleus impinging on "normal" interstellar clouds in the host galaxy, at distances of 1–3 kpc from the continuum source. Evidently, this scenario contrasts with some of the main features of the spectrum of PG 1700+518. In particular, the apparently low covering factor along the line of sight of the broad absorption line gas, and of the narrow Mg II absorption lines, argues in favor of a closer association of the BAL gas with the QSO nucleus.

A recent speculation put forward by Hazard *et al.* (1984) is that the broad absorption troughs are produced in the violent ejection of gas attending the initial turn-on of QSO activity. In such a picture, PG 1700+518 would represent a late stage in the expansion, when the temperature of the dissipating gas has decreased sufficiently for low stages of ionization to appear and the QSO emission-line spectrum more closely resembles that of normal QSOs. Interestingly, this idea would imply that some QSOs are still in the process of formation at recent epochs. However, the model by Hazard *et al.* (1984) suffers from the same difficulties as that of Scott, Christiansen, and Weymann (1984) in the sense that it is not easy to explain in its context the low covering factor of the BAL gas. If this implies that the BAL and the broad *emission* line regions are of comparable dimensions ($R \approx 1$ pc), then the lower limit $N(\mathrm{Mg}^+) \geq 6 \times 10^{14}\ \mathrm{cm}^{-2}$ (derived assuming the Mg II trough to be optically thin) yields, for a solar abundance Mg/H $= 4.0 \times 10^{-5}$ (Ross and Aller 1976), a conservative lower limit to the BAL gas density $n > 5\ \mathrm{cm}^{-3}$. The density is in fact likely to be significantly greater than this, since Mg is mostly in higher ionization stages than Mg^+.

A final point raised by our observations of PG 1700+518 is that low-redshift BAL QSOs may be more common than is generally thought, given the usual weakness, or absence, of Mg II troughs. The only way such objects would be recognized is through observations of their ultraviolet spectra. A recent *IUE* study by Kinney *et al.* (1985) of a sample of 21 low-redshift QSOs has not apparently revealed any new BAL QSOs. However, since the proportion of high-redshift QSOs showing broad absorption lines is estimated to be between 3% and 10% (Hazard *et al.* 1984), the statistics of currently available *IUE* data are insufficient to address the question of a possible redshift evolution in the frequency of the BAL phenomenon.

It is a pleasure to express our gratitude to J. Wampler, who communicated to us, well in advance of publication, his discovery that PG 1700+518 is a BAL QSO; to Linda Smith and especially Dave L. King for their expert assistance with the data reduction; and to Hagai Netzer for stimulating and helpful discussions.

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