

THE HUBBLE SPACE TELESCOPE QUASAR ABSORPTION LINE KEY PROJECT. VI. PROPERTIES OF THE METAL-RICH SYSTEMS¹

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ABSTRACT

We present an analysis of the properties of a sample of 18 metal-rich, low-redshift $z_{\text{abs}} \ll z_{\text{em}}$ absorbers seen in low- and medium-resolution spectra obtained for the Quasar Absorption Line Key Project with the *Hubble Space Telescope* Faint Object Spectrograph. For most of the C IV and Lyman-limit systems, observations in the optical wavelength range of the expected associated Mg II absorption are available. As at high redshift ($z \sim 2$), there are two subclasses of absorbers which are characterized by the presence or absence of Mg II absorption. However, some low-redshift Mg II and Fe II absorptions originate from regions optically thin to UV ionizing photons and thus, at low redshift, the low-ionization systems do not always trace high opacities, as is the case at high redshift. This implies that the mean ionization state of metal-rich, optically thin absorbing clouds falls with decreasing redshift, which is consistent with the hypothesis that the gas is photoionized by the metagalactic UV background radiation field.

Two main constraints are derived from the analysis of the Lyman-limit sample, assuming photoionization models are valid. First, a low opacity to ionizing photons ($\tau_{\text{LL}} \lesssim 1$), as observed for several Mg II–Fe II systems at $z \sim 0.5$, sets limits on the ionization level of hydrogen, thus on the total hydrogen column density and the heavy element abundances, $[Z/H] \sim -0.5$ to -0.3 . Second, the dimensions of individual Mg II clouds are smaller than at high redshift by a factor 3–10.

At $z \gtrsim 0.6$, the O VI absorption doublet is detected in four of the five $z_{\text{abs}} \ll z_{\text{em}}$ systems for which the O VI wavelength range has been observed, whereas the associated N V doublet is detected in only two cases. This suggests that the presence of a high-ionization O VI phase is a general property of $z \sim 0.6$ –1 absorption systems, as is also probably the case at high redshift. These O VI absorbers can be ionized by the UV metagalactic field if their density is low, $n_{\text{H}} \lesssim 3 \times 10^{-4} \text{ cm}^{-3}$. The O VI phase would then be a homogeneous region of large extent, $r \gtrsim 50 \text{ kpc}$.

A detailed photoionization model of the $z_{\text{abs}} = 0.791$ absorber toward PKS 2145+06 confirms the properties derived from the Mg II, C IV, O VI, and Lyman-limit samples. The galaxy causing this extensive metal-line absorption system has been identified, and its possible contribution to the UV ionizing flux does not substantially modify the value of the derived parameters. The heavy element abundances are about half the solar values. The O VI region has a density about 20 times lower than the Mg II clouds and a size of $\sim 70 \text{ kpc}$. Alternatively, the high-ionization phase could be collisionally ionized and trace gas associated with a possible group of galaxies at the absorber redshift.

Subject headings: cosmology: observations — galaxies: evolution — quasars: absorption lines

1. INTRODUCTION

The population of sharp metal-rich absorption systems detected in quasar spectra have been extensively studied since the late 1970s (see, e.g., Weymann et al. 1979; Young, Sargent, & Boksenberg 1982). This population can be used to probe the physical properties of intervening metal-rich gaseous clouds and to estimate the metagalactic UV flux (Sargent et al. 1979; Bergeron & Stasińska 1986). Whereas the majority of these studies have been made for C IV absorption systems at redshifts of 2–3, identification of the objects causing metal-rich absorption systems has mainly been achieved for lower redshift Mg II absorption systems in the redshift interval $0.15 \lesssim z_{\text{abs}} \lesssim 1.1$. These Mg II systems are identified with extended galactic gaseous envelopes with radii around $70 h_{50}^{-1} \text{ kpc}$ (h_{50} is the Hubble constant in units of $50 \text{ km s}^{-1} \text{ Mpc}^{-1}$, and we assume $q_0 = 0$) associated with bright galaxies of luminosity $L > 0.2L^*$ (Yanny, York, & Williams 1990; Bergeron & Boissé 1991; Bergeron, Cristiani, & Shaver, 1992; Steidel 1993).

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To derive the evolution with redshift of the properties of intervening metal-rich absorbers and the metagalactic UV field, it is necessary to determine the level of ionization and opacity to UV ionizing photons of low-redshift absorption systems. Detailed spectroscopic data on quasar absorption line systems could not be obtained with the *IUE* satellite. The needed information is now being provided by the *Hubble Space Telescope* (*HST*) quasar absorption-line survey (Bahcall et al. 1993, 1994, hereafter Papers I and VII). Combining results from quasar absorption-line studies (ionization state, kinematics) with the observed properties of the absorbing galaxies (size of the gaseous envelope, stellar luminosity, morphology, star formation activity) should place constraints on the nature and the strength of the ionization source(s) and yield information on the total column density and heavy element abundances of the absorbing galactic envelopes.

At redshifts $z_{\text{abs}} \sim 2$, the population of metal-rich absorbers comprises two subclasses characterized by the presence or absence of low-ionization species (C II, Mg II, Fe II). Assuming that these absorbers are photoionized by the UV metagalactic field, Bergeron & Stasińska (1986) and Wolfe (1986) have shown that the difference between these two subclasses of absorption systems (C IV only or mixed systems) mainly arises from an opacity effect and not from a large range in gas density. The phase which contains singly ionized ions has a large optical depth at the Lyman limit (i.e., H I column density of at least $3 \times 10^{17} \text{ cm}^{-2}$) and the opacity increases with increasing rest equivalent width ratio $w_r(\text{Fe II } \lambda 2382)/w_r(\text{Mg II } \lambda 2796)$. It is also observed that stronger Mg II (or C IV) systems have a larger equivalent width ratio $w_r(\text{Mg II})/w_r(\text{C IV})$, as first pointed out by Boissé & Bergeron (1985), and confirmed by Lanzetta, Turnshek, & Wolfe (1987). The completed *HST* absorption-line survey will determine the fraction of C IV-only systems at low redshift and how the fraction evolves with redshift. In the $z_{\text{abs}} \sim 1.3$ –2 sample of Lanzetta et al. (1987), the fraction of C IV systems with associated Mg II absorption is roughly one-half. From a larger Mg II absorption survey down to an equivalent width limit $w_{r,\text{lim}}(\text{Mg II } \lambda 2796) = 0.3 \text{ \AA}$, Steidel & Sargent (1992) have found that, in the redshift range 1.2–2.2, 73% of the systems have only C IV absorption and that there is just one case (1%) with Mg II detected but not C IV.

The ionization level and opacity to ionizing photons of the absorbers can be derived using photoionization models and column density measurements, including $N(\text{H I})$ obtained from observations of the Lyman discontinuity or the Lyman series. These physical properties are determined mainly by the ionization parameter $U = n_e/n_{\text{H}}$, where n_e is the number density of incident ionizing photons and n_{H} is the total density of hydrogen (see, e.g., Bergeron & Stasińska 1986). They depend on the assumed spectral shape of the ionizing radiation field but are quite insensitive to the heavy element abundances when these are lower than the solar values. Determination of the gas density and the characteristic size of the clouds then requires an estimate of the intensity of the UV metagalactic flux. Analysis of the proximity effect indicates that the average ionizing intensity at the hydrogen Lyman limit equals $J_{\nu_0} \simeq 10^{-21 \pm 0.5} \text{ ergs s}^{-1} \text{ cm}^{-2} \text{ sr}^{-1} \text{ Hz}^{-1}$ over the redshift range $1.8 \leq z \leq 3.5$ (Bajtlik, Duncan, & Ostriker 1988; Lu, Wolfe, & Turnshek 1991). However, lower values have been derived from photoionization models of self-gravitating spheres for metal-rich systems (Petitjean, Bergeron, & Puget 1992) and from a reanalysis of the proximity effect (Espey 1993). Given the range of ionization parameters found for Mg II systems and

using the above value of the metagalactic UV flux leads to a density in the range 10^{-1} to 10^{-2} cm^{-3} for Mg II or Lyman-limit systems at $z \sim 2$ –3 and sizes (thickness along the line of sight) of 0.2–20 kpc (Bergeron & Stasińska 1986; Steidel 1990; Petitjean, Bergeron, & Puget 1992). For optically thin C IV clouds, the gas densities are lower and the cloud sizes are larger than those of optically thick absorbers. Up to Lyman-limit opacities of order unity, the inferred cloud size is roughly proportional to $N(\text{H I})J_{\nu_0}n_{\text{H}}^{-1}$.

The *HST* medium and low spectral resolution samples will be used in this paper to study the ionization level, opacity to UV ionizing photons, and heavy element abundances of the absorbing clouds at $z_{\text{abs}} \sim 0.5$ and their evolution with redshift. The results of this analysis are strongly dependent on the assumed UV ionizing flux. It is unclear whether at $z \sim 2$ –3, forming galaxies or quasars are the main source of the metagalactic UV field (Bechtold et al. 1987; Steidel & Sargent 1989; Miralda-Escudé & Ostriker 1990; Madau 1991). Even for an ionizing radiation field dominated by quasar-like spectra, intervening absorption alters the metagalactic UV flux. At high redshift, the high density per unit redshift of absorption systems should cause a fairly sharp break at the He II discontinuity at $\lambda = 228 \text{ \AA}$. At $z < 2$, as the density of the absorbers decreases with decreasing redshift, the mean opacity of the universe should also decrease and the He II break should become broader and less pronounced. If most of the sources which contribute to the background UV field are at $z \gtrsim 2$, the intensity of the metagalactic flux at the Lyman edge is then expected to decrease with decreasing redshift as $(1+z)^{3+\alpha}$ for $z < 2$, where α is the power-law index of the ionizing radiation flux $J_{\nu_0} \propto \nu^{-\alpha}$. The estimated range of the ionizing radiation flux from quasars and AGNs at $z \sim 0.5$ is $J_{\nu_0}(z=0.5) = (2\text{--}8) \times 10^{-23} \text{ ergs s}^{-1} \text{ cm}^{-2} \text{ sr}^{-1} \text{ Hz}^{-1}$ (Miralda-Escudé & Ostriker 1990; Madau 1992). From a tentative detection of the proximity effect at low redshift, $z \lesssim 1$, Kulkarni & Fall (1993) have estimated that at $z \simeq 0.5$ the mean ionizing intensity at the Lyman edge is $J_{\nu_0}(z=0.5) \simeq 6 \times 10^{-24} \text{ ergs s}^{-1} \text{ cm}^{-2} \text{ sr}^{-1} \text{ Hz}^{-1}$. However, the uncertainties are large and the 1σ upper limit $J_{\nu_0}(z=0.5) \simeq 4 \times 10^{-23} \text{ ergs s}^{-1} \text{ cm}^{-2} \text{ sr}^{-1} \text{ Hz}^{-1}$ is within the range of the above estimates of the metagalactic flux. The H α surface brightness of high-velocity, neutral hydrogen Galactic clouds place important constraints on the UV metagalactic ionizing flux which is found to be less than $F_{\text{LC}}(z=0) \leq 2 \times 10^5 \text{ photons cm}^{-2} \text{ s}^{-1}$ (Kutyrev & Reynolds 1989) or $F_{\text{LC}}(z=0) < 6 \times 10^4 \text{ photons cm}^{-2} \text{ s}^{-1}$ (Songaila, Bryant, & Cowie 1989). Assuming that the low-redshift Ly α absorption systems detected toward 3C 273 are produced by gas ionized by the UV metagalactic radiation field at large radii in the disks of galaxies leads to similar values of $F_{\text{LC}}(z=0) \simeq (5.2\text{--}26) \times 10^4 \text{ photons cm}^{-2} \text{ s}^{-1}$ or $J_{\nu_0}(z=0) \simeq (4\text{--}20) \times 10^{-23} \text{ ergs s}^{-1} \text{ cm}^{-2} \text{ sr}^{-1} \text{ Hz}^{-1}$ (Maloney 1992). In the rest of this paper, we shall adopt $J_{\nu_0}(z_{\text{abs}}) = J_{\nu_0}(z=2) \times [(1+z_{\text{abs}})/3]^{3+\alpha}$ with $J_{\nu_0}(z=2) \simeq 1 \times 10^{-21} \text{ ergs s}^{-1} \text{ cm}^{-2} \text{ sr}^{-1} \text{ Hz}^{-1}$ and $\alpha = 1$.

At $z \lesssim 1$, the source of ionization in galactic halos may well be the combined flux from star formation in the disk of the galaxy and the metagalactic field. The dominant ionizing field would then be a function of the radial distance from the galaxy center. For identified Mg II absorbers at $z_{\text{abs}} \sim 0.5$, the impact parameter is often large ($\gtrsim 50 h_{50}^{-1} \text{ kpc}$) and the main contribution to the UV radiation field is expected to arise from the UV background. The ionization level of the lower redshift absorbers is then expected to decrease with decreasing redshift,

except if the gas density in the halo strongly evolves with redshift.

Photoionization models also constrain the heavy element abundances of the $z_{\text{abs}} \sim 0.5$ absorption systems observed in the *HST* and optical ranges. Determination of the abundances requires an accurate estimate of $N(\text{H I})$ and observation of a large number of ionization stages. One of the main uncertainties comes from the evaluation of the $\text{H I}/\text{H}$ ionic ratio, which is a function of the ionization level of the heavy elements and the spectral shape of the ionizing radiation flux. This ionic ratio is better determined when the low ionization ions are the dominant species. The best cases are the damped $\text{Ly}\alpha$ systems [$N(\text{H I}) > 10^{20} \text{ cm}^{-2}$] for which $\text{H I}/\text{H}$ is very close to unity. The damped $\text{Ly}\alpha$ absorbers are usually assumed to arise in protogalactic disks (Wolfe et al. 1986; Wolfe 1988) of abundances between 4×10^{-3} and 1 times the solar values (Turnshek et al. 1989). From a survey of Zn II and Cr II absorptions in high-redshift damped systems, Pettini et al. (1994) have derived abundances typically of one-tenth the solar values and a range $-1.5 \leq [\text{Zn II}/\text{H I}] \leq 0.0$. For Lyman-limit systems, Steidel (1990) found that at $z \sim 3$ the heavy element abundances are within the broad range $-3.0 \leq [Z/\text{H}] \leq -1.5$, whereas Bergeron & Stasińska (1986) and Petitjean, Bergeron, & Puget (1992) have derived somewhat larger values covering the range $-2.0 \leq [Z/\text{H}] \leq -0.5$ at $z \sim 2.5$.

The implications that are derived from a comparison between the subclasses of metal-rich absorption systems at low and high redshifts are outlined in § 2. The constraints on the ionization level and the gas opacity at the Lyman edge implied by the *HST* results on Lyman-limit systems are discussed in § 3. The nature of the ionization source of the $\text{N V}-\text{O VI}$ phase is discussed in § 4. A detailed photoionization model of the various column densities in the $z = 0.791$ system arising in the absorbing galactic halo toward PKS 2145+06 is presented in § 5. The main results are summarized in § 6.

2. LOW- AND HIGH-REDSHIFT METAL-RICH ABSORPTION SYSTEMS

There are 18 metal-rich systems with $z_{\text{abs}} < z_{\text{em}}$ and displaced by more than 5000 km s^{-1} from the emission redshift detected toward 10 quasars in the higher spectral resolution ($R = 1300$) sample presented in Papers I and VII. Their redshifts cover the range 0.11–1.04. The rest equivalent widths, w_r , of the absorption lines of these systems are given in Table 1. There are observations in the optical range of the expected Mg II doublets associated with 13 *HST* C IV absorptions. There is an additional system listed in Table 1 ($z_{\text{abs}} = 0.6694$ toward PG 1634+706) with no detected C IV absorption associated with the Mg II system. For the *HST* data, the equivalent width upper limits have a 4.5 significance level (see definition in Paper I), and, for the optical data, they are 4 or 5 σ upper limits (see references in Table 1).

To investigate a possible evolution with redshift of the mean ionization state of metal-rich systems, one can compare the relative number of C IV and Mg II systems in the *HST* and higher redshift samples. The surveys involved have different equivalent width limits, and selecting low-redshift absorption systems with $w_r \geq 0.30 \text{ \AA}$ for the strongest line of both the C IV and Mg II doublets lead to small samples. Only a crude estimate of the number per unit redshift of low-redshift C IV systems could be made from the small *HST* sample described in Paper I. However, there is already preliminary evidence that

the incidence of C IV absorption starts to fall with decreasing redshift at $z < 1.3$. The number density per unit redshift of C IV systems is $dN/dz = 0.87 \pm 0.43$ to a rest equivalent width limit of $w_{r,\text{lim}}(\text{C IV } \lambda 1548) \geq 0.3 \text{ \AA}$ at a mean redshift $\langle z \rangle = 0.3$. At higher redshift $\langle z \rangle = 1.5$ and for the same detection limit, $dN(\text{C IV})/dz = 1.76 \pm 0.33$ (Sargent, Boksenberg, & Steidel 1988a). From a Mg II survey in the wavelength range 3100–3950 $\text{\AA}$, Boissé et al. (1992) have derived a value of $dN/dz = 0.75 \pm 0.35$ to a rest equivalent width limit $w_{r,\text{lim}}(\text{Mg II } \lambda 2796) = 0.3 \text{ \AA}$ at a redshift $\langle z \rangle = 0.284$. Combining their sample with that of Steidel & Sargent (1992) does not change the value of dN/dz and slightly raises the mean redshift to $\langle z \rangle = 0.314$. At $\langle z \rangle = 1.5$, the number of Mg II systems down to $w_r = 0.3 \text{ \AA}$ is $dN(\text{Mg II})/dz = 1.10 \pm 0.17$ (Steidel & Sargent 1992). The ratio of the number of C IV to Mg II systems is $r = 1.60 \pm 0.57$ at $z = 1.5$ and $r = 1.16 \pm 0.78$ at $z = 0.3$. The errors are too big to draw any conclusion and analysis of the completed *HST* absorption line survey is needed to investigate the existence of an evolution in the relative number of C IV and Mg II systems.

An alternative approach to ascertain the evolution of the absorber ionization state is to characterize the absorption systems by their equivalent width ratio $w_r(\text{C IV } \lambda 1548)/w_r(\text{Mg II } \lambda 2796) \equiv \text{C IV}/\text{Mg II}$. Systems with detected C IV doublets (and also possibly Mg II) and $\text{C IV}/\text{Mg II} > 1$ are defined as high ionization level (H) systems, and systems with detected Mg II doublets (and also possibly C IV) and $\text{C IV}/\text{Mg II} \leq 1$ are defined as low ionization level (L) systems. For the *HST* sample, this excludes one C IV system, for which the Mg II detection threshold is higher than $w_r(\text{C IV } \lambda 1548)$, but no Mg II system. In the high-redshift sample of 105 systems presented by Steidel & Sargent (1992, Table 6), the 24 C IV doublets excluded by the above restrictions are weak [$\langle w_r(\text{C IV } \lambda 1548) \rangle = 0.17 \text{ \AA}$]. For both samples, the number and mean w_r of the H and L systems are given in Table 2. We see that L systems constitute 38% of the $\langle z_{\text{abs}} \rangle = 0.53$ sample, whereas their fraction comprises only 17% of the $\langle z_{\text{abs}} \rangle = 1.70$ sample. Although the *HST* sample is small, this clearly suggests an evolution in the ionization state of metal-rich systems. Nevertheless, the fraction of high-ionization systems remains high at low redshift. As the metagalactic UV radiation flux is about one order of magnitude lower at $z \sim 0.5$ than at $z \sim 1.7$ (Miralda-Escudé & Ostriker 1990; Madau 1992; Kulkarni & Fall 1993), this suggests that, if the gas is photoionized by the UV background, the mean gas density of the high ionization systems falls with decreasing redshift.

The mean equivalent widths of the detected C IV and Mg II lines are not well defined because the different samples have a variety of equivalent width limits. However, it should be noted that, for L systems, the Mg II absorption is much stronger at higher redshift (see Table 2), whereas, for H systems, the average strength of the C IV absorption is roughly the same for the low- and high-redshift samples. There is a strong correlation between the total Mg II equivalent width and the number of subsystems down to scales of 50 km s^{-1} (Petitjean & Bergeron 1990); hence the decrease in the strength of Mg II systems at low redshift may suggest that clustering of these systems on scales smaller than $\sim 200\text{--}300 \text{ km s}^{-1}$ is not as strong at low as at high redshift. It could also indicate an evolution in other physical properties of Mg II absorbers such as the gas density and/or the column densities. However, the latter is an unlikely alternative. Indeed, the Mg II doublet ratio does not show any strong evolution with redshift: its mean

TABLE 1
IONIZATION LEVEL OF $z_{\text{abs}} \leq z_{\text{em}}$ METAL-RICH SYSTEMS^a

z_{abs}	$w_{\text{r}}(\text{Ly}\alpha)$ (Å)	$w_{\text{r}}(\text{C II})$ $\lambda 1334$ (Å)	$w_{\text{r}}(\text{C III})$ $\lambda 977$ (Å)	$w_{\text{r}}(\text{C IV})$ $\lambda \lambda 1548, 1550$ (Å)	$w_{\text{r}}(\text{N V})$ $\lambda \lambda 1238, 1242$ (Å)	$w_{\text{r}}(\text{O VI})$ $\lambda \lambda 1031, 1037$ (Å)	$w_{\text{r}}(\text{Si II})$ $\lambda 1260$ (Å)	$w_{\text{r}}(\text{Si IV})$ $\lambda \lambda 1393, 1402$ (Å)	$w_{\text{r}}(\text{Mg II})$ $\lambda \lambda 2796, 2803$ (Å)	$w_{\text{r}}(\text{Fe II})$ $\lambda \lambda 2382, 2600$ (Å)	References (optical)
PKS 0044+030: $z_{\text{em}} = 0.624$											
0.2456.....	...	<0.40	...	0.62, 0.43	...	...	...	<0.39, <0.39	<0.15, <0.15	<0.32, <0.32	1
0.4493.....	0.61	<0.20	...	0.25, 0.20	<0.34, <0.34	...	<0.34	<0.16, <0.16	<0.30, <0.30	<0.18, <0.16	1, 2
PKS 0122-00: $z_{\text{em}} = 1.070$											
0.3989.....	1.85	<0.37	...	1.59, 1.01	<0.65, <0.65	...	<0.46	0.76, <0.33	...	...	
0.9531.....	1.25	<0.29	0.63	0.96, 0.88	<0.33, <0.33	1.08, 0.56	<0.27	<0.29, <0.29	...	...	
0.9667.....	0.94	<0.29	0.57	0.37, <0.35	<0.27, <0.27	0.42, 0.32	<0.27	<0.29, <0.29	...	...	
3C 95: $z_{\text{em}} = 0.614$											
0.3566.....	0.94	<0.21	...	0.66, 0.52	<0.30, <0.30	...	<0.23	0.52, <0.20	<0.40, <0.40	<0.29, ...	3
3C 263: $z_{\text{em}} = 0.652$											
0.1164.....	...	...	...	<0.32, <0.32	...	...	...	...	0.50, 0.53	<0.20, <0.40	
TON 153: $z_{\text{em}} = 1.022$											
0.2891.....	...	<0.27	...	0.45, 0.34	...	...	<0.76	<0.20, <0.20	0.33, 0.31	...	4
0.6606.....	1.48	0.23	0.72	<0.21, <0.21	<0.10, <0.10	<0.19, <0.19	0.43	<0.22, <0.22	0.49, 0.33	0.42, 0.17	4
PG 1352+0.11: $z_{\text{em}} = 1.121$											
0.5258.....	2.62	0.57	...	0.71, 0.47	<0.19, <0.19	...	0.77	0.47, 0.47	...	...	
0.6677.....	0.94	0.43	0.59	1.37, 1.12	0.31, 0.20	0.72, 0.29	0.57	0.80, 0.65	...	...	
PG 1634+706: $z_{\text{em}} = 1.334$											
0.6694.....	...	...	...	<0.07, <0.07	...	...	...	<0.09, <0.09	0.29, 0.15	<0.12, <0.10	4
0.9060.....	0.49	0.05	...	0.17, 0.13	0.37, 0.28	...	<0.06	<0.06, <0.06	<0.15, <0.15	<0.20, <0.20	4
0.9908.....	1.10	0.38	...	0.30, 0.21	<0.07, <0.07	...	0.25	0.32, 0.17	0.58, 0.42	<0.20, <0.20	4
1.0417.....	1.42	0.10	...	0.16, 0.15	<0.06, <0.06	...	<0.06	0.26, 0.13	<0.15, <0.15	<0.20, <0.20	4
3C 351: $z_{\text{em}} = 0.371$											
0.2216.....	0.93	<0.45	...	0.43, 0.30	<0.17, <0.17	<0.29 ^b , <0.25	0.29	0.56, <0.27	0.45, 0.27	0.38, <0.33	1
PKS 2145+06: $z_{\text{em}} = 0.990$											
0.7913.....	1.22	<0.22	0.84	1.13, 0.89	0.29, 0.23	0.82, 0.47	<0.17 ^c	0.41, 0.30	0.61, 0.46	<0.17, <0.12	2, 5
3C 454.3: $z_{\text{em}} = 0.859$											
0.1538.....	...	...	...	0.97, 0.49	...	...	...	...	<0.36, <0.36	<0.36, <0.36	1
0.3906.....	0.66	<0.31	...	0.40, <0.24	<0.43, <0.43	...	<0.35	<0.30, <0.30	<0.15, <0.15	...	

^a The equivalent width upper limits for the absorption lines in the *HST* range are at the 4.5 significance level.

^b Could be present but blended with the Galactic Si II $\lambda 1260$ absorption line.

^c Could be present but blended with the line at $\lambda_{\text{obs}} 2258.32$ identified with Ly α at $z = 0.8577$.

REFERENCES:—(1) Boissé et al. 1992 (5 σ); (2) Sargent, Steidel, & Boksenberg 1988b (5 σ); (3) Tytler et al. 1987 (4 σ); (4) Steidel & Sargent 1992 (5 σ); (5) Pettitjean & Bergeron 1990 (4 σ).

TABLE 2
CHARACTERISTICS OF C IV AND Mg II ABSORPTION SYSTEMS^a

Sample	$\langle z_{\text{abs}} \rangle$	Number of Systems	Class	$w_r(\text{C IV})$ $w_r(\text{Mg II})$	$\left\langle \frac{w_r(\text{C IV})}{w_r(\text{Mg II})} \right\rangle$	$w_r(\text{C IV})$	$\langle w_r(\text{C IV}) \rangle$	$w_r(\text{Mg II})$	$\langle w_r(\text{Mg II}) \rangle$
HST	0.53	13		0.24–4.13					
		5 ^b	L	0.24–1.00	<0.43			0.29–0.58	0.46
		2 ^c	L	0.52–1.00	0.74	0.30–0.43	0.37	0.45–0.58	0.52
		8 ^d	H	1.00–4.13	>2.09	0.16–1.13	0.57		
		2 ^c	H	1.00–1.85	1.61	0.45–1.13	0.79	0.33–0.61	0.47
SS92	1.70	81		0.10–9.67					
		14 ^b	L	0.10–1.00	<0.44			0.49–7.37	1.98
		13 ^c	L	0.10–1.00	0.46	0.08–2.19	0.83	0.49–7.37	2.05
		67 ^d	H	1.00–9.67	>2.76	0.10–2.07	0.61		
		14 ^c	H	1.00–3.36	2.02	0.37–1.68	1.05	0.11–1.33	0.60

^a The equivalent widths are in Å and refer to the strongest line of the Mg II or C IV doublets.

^b Systems with detected Mg II absorption.

^c Systems with detected Mg II and C IV absorptions.

^d Systems with detected C IV absorption.

value is 1.41 and 1.37 at $z \sim 0.5$ and 1.7, respectively. Consequently, the optical depths and also, probably, the column densities of individual Mg II subsystems, do not substantially vary with redshift.

3. THE LOW-REDSHIFT LYMAN-LIMIT SAMPLE AND THE UV BACKGROUND FLUX

We now investigate the constraints which can be derived from the Lyman-limit sample. Among the 29 quasars in the low spectral resolution ($R = 180$) survey described in Paper I, there are five objects also observed at higher spectral resolution ($R = 1300$) having metal-rich systems with $z_{\text{abs}} \ll z_{\text{em}}$ (Papers I and VII). The quasars listed in Table 3 have either Lyman-limit systems detected by a sharp discontinuity in their continuum spectra and/or C IV or Mg II absorption systems with Lyman limits in the observed wavelength range. Of the latter, two are of high ionization with $\text{C IV}/\text{Mg II} > 2.5$ ($z_{\text{abs}} = 0.4493$ toward PKS 0044+030 and $z_{\text{abs}} = 0.3908$ toward 4C 454.3). The quasar continua do not show any break at the Lyman edges of these systems, and the upper limit on their optical depth τ_{LL} can be estimated by measuring the 1σ rms of the continuum each side of the Lyman edge. This gives a conservative upper limit; for both systems we get $\tau_{\text{LL}} < 0.5$.

Low-redshift Mg II systems are of particular interest, since at high redshift the presence of low-ionization ions is an indicator of large optical depths at the Lyman edge (see § 1). In the Lyman-limit sample (see Table 3), there are four systems for which Mg II absorption is detected in optical spectra, and for a fifth system there is an associated C II absorption. The values of the optical depths given in Table 3 differ from those listed in Paper I (Table 10), since they are derived using a more conservative approach. The fluxes below and above the Lyman edge, $F(\lambda_-)$ and $F(\lambda_+)$, are mean values within rest wavelength intervals of 30 Å each side of the observed discontinuity, excluding a zone of $\Delta\lambda_r = \pm 10 \text{ Å}$ from the midpoint (λ_{LL}) of the discontinuity. Absorption by the higher members of the Lyman series results in a drop redward of the redshifted Lyman edge at z_{abs} , and z_{LL} as derived from λ_{LL} is thus an upper limit of the true redshift z_{abs} of the Lyman-limit absorption system. The latter could differ from z_{LL} by up to 0.01 or about $\Delta\lambda_r \simeq 10 \text{ Å}$.

The best physical constraints derived from the HST Lyman-limit sample are given by an optically thin system with associated Mg II and Fe II absorptions ($z_{\text{abs}} = 0.6213$ in PG 1338+416). Similar constraints on the ionizing parameter U and opacities of Mg II absorbers are also derived from the two mixed ionization systems with $\tau_{\text{LL}} \simeq 1$ ($z_{\text{abs}} = 0.4563$ in PKS 1354+19 and $z_{\text{abs}} = 0.4416$ in 4C 06.41).

TABLE 3
OPTICAL DEPTHS OF LYMAN-LIMIT SYSTEMS

Quasar	z_{em}	z_{LLS}	τ_{912}	τ_{min}	τ_{max}	$z_{\text{abs}}(\text{C II})$	$z_{\text{abs}}(\text{C IV})$	$z_{\text{abs}}(\text{Mg II})$	$w_r(\text{Mg II})^a$
PKS 0044+030	0.624		0	0	0.50	...	0.4493	...	...
4C 19.34	0.828	0.542	1.10	0.17	2.46	...	...	...	...
4C 06.41	1.270	0.457	1.22	0.55	2.24	...	...	0.4416	0.66
PKS 1055+20	1.110	1.046	2.28	1.69	3.22	...	...	...	...
PG 1206+459	1.158	0.937	0.63	0.22	1.09	...	...	...	...
MC 1215+113	1.396	1.110	0.65	0.20	1.16	...	...	...	...
		1.276	0.40	0.10	0.77	...	...	...	...
TON 153	1.022	0.670	4.58	3.07	>10	0.6606	...	0.6596	0.49
PG 1338+416	1.219		0	0	0.50	...	...	0.6213	0.31
PG 1352+011	1.121	0.684	5.78	2.58	>10	0.6677	0.6677	...	...
PKS 1354+19	0.720	0.465	1.16 ^b	0.19 ^b	2.55 ^b	...	...	0.4563	0.89
PKS 1424-11	0.805	0.663	1.88	1.14	>10	...	...	...	...
4C 454.3	0.859		0	0	0.50	...	0.3908	...	...

^a The Mg II equivalent widths are in Å and refer to the strongest line of the doublet.

^b For $F(\lambda_-)$, we have used the combined window 1242–1272 Å and 1312–1332 Å.

3.1. The $z_{\text{abs}} = 0.6213$ System toward PG 1338+416

On the assumption of photoionization, the presence of C IV and Mg II (or C II) absorption lines in $z \sim 2$ systems implies the existence of two phases and a range of ionization parameters $2 \times 10^{-4} \lesssim U \lesssim 2 \times 10^{-2}$ (Bergeron & Stasińska 1986). The C IV absorption arises in a phase optically thin to UV ionizing photons in which several ions of the same element can coexist. In this phase, Fe is more highly ionized than Mg since the ionization potential of Mg III is higher than that of Fe V (and also of C IV). For $U = 1 \times 10^{-3}$ and a power-law spectrum $J_\nu \propto \nu^{-\alpha}$ with $\alpha \simeq 1$, the dominant ions in the optically thin phase are Mg III–Mg IV and Fe IV–Fe V–Fe VI. Consequently, at $z \sim 2$, absorption by singly ionized elements arises in a phase optically thick to UV ionizing photons, and the presence of Fe II absorption implies large H I column densities in excess of 10^{18} cm^{-2} . The lack of any discontinuity at the Lyman edge of the $z_{\text{abs}} = 0.6213$ system (Steidel & Sargent 1992) toward PG 1338+416 implies $\tau_{\text{LL}} < 0.5$ or $N(\text{H I}) < 8 \times 10^{16} \text{ cm}^{-2}$. The Mg II doublet ratio is very close to 2, and the derived column density is $N(\text{Mg II}) = 7.6 \times 10^{12} \text{ cm}^{-2}$. If we also assume that the Fe II $\lambda 2382$ absorption is optically thin, we get $N(\text{Fe II}) = 9.7 \times 10^{12} \text{ cm}^{-2}$. In a region optically thin to ionizing radiation, a ratio $N(\text{Mg II})/N(\text{Fe II}) \simeq 1$ requires very low values of the ionization parameter, at most $U \simeq 1 \times 10^{-4}$. For $U \leq 1 \times 10^{-4}$, the ionic ratio H II/H I is at most 30. Consequently, the total hydrogen column density is limited, $N(\text{H}) < 3 \times 10^{18} \text{ cm}^{-2}$. Even if we assume that Mg and Fe are entirely in the form of singly ionized ions, this inevitably implies high heavy element abundances. Adopting $N(\text{H I}) = 5 \times 10^{16} \text{ cm}^{-2}$ ($\tau_{\text{LL}} = 0.3$), a strict lower limit on the heavy element abundances is then $[Z/\text{H}] > -0.7$, whereas the value obtained from photoionization models with $U = 1 \times 10^{-4}$ ($\text{Mg II}/\text{Mg} \simeq \text{Fe II}/\text{Fe} \simeq 0.4$) is $[Z/\text{H}] \simeq -0.3$. This result is very insensitive to the spectral shape of the ionizing flux. Using lower values of U would lead to higher values of the heavy element abundances. There are arguments for gas depletions of refractory elements substantially less severe than in Galactic interstellar clouds based on the relative abundances of Zn, Cr in high-redshift, damped Ly α systems (Pettini et al. 1994). This should also be the case for the $z_{\text{abs}} = 0.6213$ system toward PG 1338+416, since adopting the depletion factors derived for the Galactic diffuse interstellar medium (de Boer, Jura, & Shull 1987) would lead to an abundance ratio Fe/Mg of ~ 10 , i.e., one order of magnitude larger than the solar value.

Other physical parameters of the $z_{\text{abs}} = 0.6213$ absorbing cloud, such as its density and size (thickness along the line of sight), can be estimated if the intensity of the ionizing flux is known. Since there is no identification of the galaxy causing the Mg II–Fe II absorption, the distance of the absorbing cloud to the galaxy center is unknown. Although the ionizing radiation from the galaxy could also contribute to the UV flux incident on the absorbing cloud, we assume that the metagalactic UV radiation field gives the main contribution. The ionizing UV flux is then $J_{\nu 0}(z_{\text{abs}} = 0.62) \simeq 8.5 \times 10^{-23} \text{ ergs s}^{-1} \text{ cm}^{-2} \text{ sr}^{-1} \text{ Hz}^{-1}$ (see § 1) which combined with $U = 1 \times 10^{-4}$ leads to a gas density $n_{\text{H}} = 1.5 \times 10^{-2} \text{ cm}^{-3}$, a total column density $N(\text{H}) = 1.5 \times 10^{18} \text{ cm}^{-2}$ and a very small cloud size $l = 30 \text{ pc}$. As l is roughly proportional to $N(\text{H I})J_{\nu 0}(z_{\text{abs}})n_{\text{H}}^{-2} \propto N(\text{H I})Un_{\text{H}}^{-1}$, larger sizes could be obtained if the constraint on U was relaxed. This would be the case if the detected Fe II absorption was assumed to only be an upper limit. The limit on the ionization parameter would then be $U \leq 4 \times 10^{-4}$ and the cloud size could be about 15 times larger, or $l \simeq$

0.5 kpc. For a given value of the ionization parameter, lower intensities of the metagalactic UV flux, than adopted above, also lead to larger cloud sizes.

3.2. The $\tau_{\text{LL}} \sim 1$ Mg II Absorption Systems

The physical parameters of marginally optically thick ($\tau_{\text{LL}} \simeq 1$) Mg II systems are very sensitive to the value of the ionization parameter which is strongly constrained by the presence or absence of Fe II absorption. As for optically thin absorbers the lowest values of U , and hence the smallest cloud sizes, will be obtained for those absorption systems with the lowest optical depth in H I and with detected Fe II absorption.

The $z_{\text{abs}} = 0.4563$ system toward PKS 1354+19 ($\tau_{\text{LL}} = 1.2$) has a strong Mg II absorption, $w_r(\text{Mg II } \lambda 2796) = 0.89 \text{ \AA}$, with a doublet ratio close to unity. The Fe II $\lambda 2600$ absorption is unambiguously detected with $w_r(\text{Fe II } \lambda 2600)/w_r(\text{Mg II } \lambda 2796) = 0.35$ (Weymann et al. 1979; Steidel & Sargent 1992). These values lead to $N(\text{Mg II}) > 4 \times 10^{13} \text{ cm}^{-2}$ and $N(\text{Fe II}) = 2.6 \times 10^{13} \text{ cm}^{-2}$ (assuming that the Fe II line is optically thin). The Mg II absorption alone does not severely constrain the ionization parameter. Indeed, for $N(\text{H I}) \simeq 2 \times 10^{17} \text{ cm}^{-2}$, the ratio Mg II/Mg is roughly proportional to H I/H over a large range of U (10^{-4} to 3×10^{-3}), so that $N(\text{Mg II})$ is nearly constant. The ratio $w_r(\text{Fe II } \lambda 2600)/w_r(\text{Mg II } \lambda 2796)$ and the strength of the Fe II absorption lead to values of U in the range $(2\text{--}5) \times 10^{-4}$. For $U = 2 \times 10^{-4}$, the Mg II/Mg and Fe II/Fe ionic ratios are both equal to ~ 0.3 , whereas the H I/H ratio is roughly 10 times smaller. The high column densities of Mg II and Fe II imply large abundances $[Z/\text{H}] \sim -0.3$. For lower values of U , the inferred total hydrogen column density decreases proportionally to U , while the ionic fractions Mg II/Mg and Fe II/Fe vary at most by a factor of 2. Consequently, very low ionization parameters ($U \simeq 3 \times 10^{-5}$), which are marginally compatible with the observed column densities, would imply heavy element abundances higher than solar. For $U = 2 \times 10^{-4}$ and $J_{\nu 0}(z_{\text{abs}} = 0.46) \simeq 6 \times 10^{-23} \text{ ergs s}^{-1} \text{ cm}^{-2} \text{ sr}^{-1} \text{ Hz}^{-1}$, the gas density is $n_{\text{H}} = 6 \times 10^{-3} \text{ cm}^{-3}$ and the cloud size is $l = 0.3 \text{ kpc}$ with $l \propto U^2$.

The $z_{\text{abs}} = 0.4416$ system toward 4C 06.41 (Weymann et al. 1979; Steidel & Sargent 1992) is also marginally optically thick, $\tau_{\text{LL}} = 1.2$, with a saturated Mg II doublet but no Fe II absorption. We derive $N(\text{Mg II}) > 3 \times 10^{13} \text{ cm}^{-2}$, leading to abundances similar to those inferred for the absorber toward PKS 1354+19. The lack of Fe II absorption implies larger values of U in the range (3×10^{-4}) to (3×10^{-3}) , indicating larger cloud sizes. Adopting an intermediate value of $U \simeq 10^{-3}$, we obtain $n_{\text{H}} = 1 \times 10^{-3} \text{ cm}^{-3}$ and $l = 6 \text{ kpc}$. The galaxy causing the $z_{\text{abs}} = 0.4416$ absorption has been identified, and its center is at a projected radial distance of $70 h_{50}^{-1} \text{ kpc}$ from the quasar sightline (Bergeron & Boissé 1991).

In summary, analysis of the Lyman-limit survey data shows that (1) the mean ionization level of mixed absorption systems decreases with decreasing redshift with, at low redshift, Mg II and Fe II ions present in some cases in optically thin ($\tau_{\text{LL}} < 1$) clouds; and (2) the heavy element abundances of the absorbers are fairly high, around 0.2–0.5 solar. These results are fairly insensitive to the assumed strength and spectral shape of the UV ionizing radiation field.

4. THE HIGH-IONIZATION PHASE

Among *HST* higher resolution samples of Papers I and VII, four of the five $0.5 < z_{\text{abs}} \ll z_{\text{em}}$ systems, with observations in the rest wavelength range $\lambda\lambda 1031\text{--}1037$, exhibit O VI absorp-

tion (see Table 1), of which two ($z_{\text{abs}} = 0.6677$ toward PG 1352+011 and $z_{\text{abs}} = 0.7913$ toward PKS 2145+06) have an associated N v absorption. The mean equivalent width ratio $w_r(\text{O VI } \lambda 1031)/w_r(\text{N v } \lambda 1238)$ of the latter equals 2.58, and the lower limits on this ratio for the other two O VI systems are 1.55 and 3.27. If the gas is photoionized, a significant amount of N v and O VI can only be produced for high values of the ionization parameter, $U \gtrsim 10^{-2}$; thus the gas must be tenuous (Bergeron & Stansinska 1986; Petitjean et al. 1992). Adopting the evolution of J_{ν_0} given in § 1, we find $J_{\nu_0}(z_{\text{abs}} \sim 0.7) \simeq 1.0 \times 10^{-22} \text{ ergs s}^{-1} \text{ cm}^{-2} \text{ sr}^{-1} \text{ Hz}^{-1}$, leading to a gas density $n_{\text{H}} \lesssim 3 \times 10^{-4} \text{ cm}^{-3}$ for the N v–O VI optically thin region. The detection of associated C II or Mg II absorption for the two N v–O VI systems, together with moderate opacities at the Lyman limit (see Table 2 and § 5.1) imply values of the ionization parameter in the low-ionization phase in the range (1×10^{-4}) to (3×10^{-3}) . Consequently, if UV photoionization is the dominant process, two phases of radically different density must be present.

In high-redshift intervening gas, O VI but not N v has been detected in a composite spectrum formed of 73 C IV systems, and the column density ratio $N(\text{O VI})/N(\text{N v})$ could suggest collisional ionization (Lu & Savage 1993). A different conclusion has been reached by Reimers et al. (1992) from the analysis of the ionic column densities of individual absorption systems, within the redshift range 1.15–2.43, toward H1700+6416. In particular those authors have found that photoionization models correctly predict the column density ratios $N(\text{O III}):N(\text{O IV}):N(\text{O V})$. The inferred N/C abundance ratio is usually at the cosmic value, whereas the O/C abundance ratio is enhanced in all the high-redshift systems detected toward this quasar. The observational result obtained by Lu & Savage (1993) may thus be possibly interpreted as an abundance effect rather than a difference in ionization processes. In the halo of the Galaxy, N v is thought to trace hot ($T \sim 2 \times 10^5 \text{ K}$) collisionally ionized gas, whereas Al III should be a tracer of photoionized gas, C IV and Si IV probably being produced in both media (Sembach & Savage 1992). The recent detection of Galactic O VI absorption on the line of sight to 3C 273 with $N(\text{O VI}) > 3 \times 10^{14} \text{ cm}^{-2}$ seems to confirm the existence of a high-temperature Galactic halo (Davidsen et al. 1991, 1994). No single model satisfactorily reproduces all the Galactic observations. In particular, photoionization models fail to produce enough N v and the predicted C IV/Si IV ratio is higher than the observed one (Bregman & Harrington 1986).

For the two N v–O VI absorbers at $z \sim 0.7$, the C IV and N v column densities derived using the doublet ratio method are $N(\text{C IV}) \sim 1 \times 10^{15} \text{ cm}^{-2}$ and $N(\text{N v}) \sim 3 \times 10^{14} \text{ cm}^{-2}$, i.e., about 10 times larger than the typical column densities observed through the Galactic halo, whereas, at least in one system (see § 5.1), $N(\text{Si IV})$ ($\sim 1 \times 10^{14} \text{ cm}^{-2}$) is of the same order of magnitude as in the Galactic halo (Sembach & Savage 1992). Since at $z = 0.7$, the intensity of the UV metagalactic flux is estimated to be about 10 times larger than at $z \simeq 0$, photoionization by the UV metagalactic field could be the dominant process in galactic halos at $z \gtrsim 0.7$, and O VI absorption should then be fairly common at high and intermediate redshifts. This model predicts that the O VI column density and the ratios $N(\text{O VI})/N(\text{N v})$ and $N(\text{O VI})/N(\text{C IV})$ decrease with decreasing redshift.

Alternatively, as for Galactic fountain models, an overpressurized gas heated by supernovae occurring in the galactic disk can flow into the halo and then cool while falling back

toward the disk. These models have mainly been applied to the Galaxy (Houck & Bregman 1990; Shapiro & Benjamin 1991), thus for a much higher density and a much smaller scale height of the hot phase than observed in intermediate-redshift absorbers. For the $z_{\text{abs}} = 0.7913$ absorber toward PKS 2145+06, the projected distance between the galaxy center and the quasar sightline is $55 h_{50}^{-1} \text{ kpc}$ (Bergeron & Boissé 1991), i.e., about two orders of magnitude larger than observed in the Galaxy. Furthermore, as pointed out by Shapiro & Benjamin (1991) ionization parameters as large as $U \gtrsim 10^{-2}$, as required for quasar absorption-line systems, cannot be achieved in self-ionized fountain flows.

Finally, it is possible that the O VI phase could be hot intra-group gas. The presence of a group, a cluster or a supercluster of galaxies might be revealed by multiple absorption systems spanning a velocity range up to about 1000–2000 km s^{-1} around z_{abs} of the O VI absorption systems. There are indeed highly clustered clumps of Ly α lines, close in redshift space to about half of the extensive metal-line systems (Paper VII). However, the latter do not always have associated O VI absorption. There are also some observational evidences suggesting that Ly α absorption systems are not distributed at random with respect to galaxies (Morris et al. 1993) and that they could arise in very extended halos (with radii up to at least $320 h_{50}^{-1} \text{ kpc}$) of luminous galaxies (Lanzetta et al. 1994). We have checked for the existence of Ly α systems close to z_{abs} of the O VI systems described in Papers I and VII. One O VI system is accompanied by highly clustered neighboring clumps of Ly α lines within 1000 km s^{-1} and another one is within 1700 km s^{-1} of a Ly α system. The two remaining O VI absorption are detected toward the same quasar, and they are within 2000 km s^{-1} of each other. Consequently, there is not a clear correlation between highly clustered Ly α lines and high-ionization metal-line systems.

In summary, the O VI absorption traces either the homogeneous phase of a galactic halo, photoionized by the UV metagalactic field, or hot ($10^5 < T < 2 \times 10^6 \text{ K}$) intragroup gas. To resolve this ambiguity requires either to search for a possible group of galaxies at $z_{\text{abs}}(\text{O VI})$ and to determine the velocity dispersion of the group and/or to observe the O VI absorption doublet at high spectral resolution to place constraints on the O VI phase temperature.

5. THE $z_{\text{abs}} = 0.7913$ SYSTEM TOWARD PKS 2145+06

The information available for the $z_{\text{abs}} = 0.7913$ system toward PKS 2145+06 is greater than for any other metal-rich system among the samples presented in Papers I and VII, thus allowing a more detailed modeling of the absorber. A large number of absorption lines from very different ions are detected in the HST spectra (six lines from the Lyman series, the C IV, Si IV, N v, and O VI doublets and single lines from C II, C III, Si II, and Si III), the associated galaxy has been identified (Bergeron & Boissé 1991), and high spectral resolution optical observations of the Mg II doublet are available (Petitjean & Bergeron 1990).

The radial distance between the galaxy center and the quasar sightline is $55 h_{50}^{-1} \text{ kpc}$ (Bergeron & Boissé 1991). The galaxy is bright ($M_r = -21.6$) and shows signs of star formation activity. Thus the ionizing flux escaping from its disk could contribute significantly to the UV radiation flux incident on the absorbing region. The $[\text{O II}] \lambda 3727$ emission flux from the galaxy ($6.6 \times 10^{-17} \text{ ergs cm}^{-2} \text{ s}^{-1}$) corresponds to a total luminosity $L([\text{O II}]) = 3.4 \times 10^{41} \text{ ergs s}^{-1}$. Assuming a ratio

[O II] $\lambda 3727/H\beta \sim 3$, characteristic of the three identified absorbers with observed [O II] $\lambda 3727$ and $H\beta$ wavelength range (Bergeron 1986; Bergeron et al. 1988; Bergeron & Boissé 1991), and following Kennicutt (1983) we derive a total number of ionizing photons absorbed in the disk of the galaxy $N_{\text{Lyman}} \simeq 2.4 \times 10^{53} \text{ s}^{-1}$. It is difficult to evaluate the number of photons actually escaping the galactic disk and eventually reaching the absorbing gas. If a flux similar to that required to ionize the disk escapes the central regions, the number of ionizing photons ($13.6 < h\nu < 54.4 \text{ eV}$) reaching the absorbing cloud would be $F_{\text{Lyman}} = 6.7 \times 10^5 \text{ photons s}^{-1} \text{ cm}^{-2}$. This value is quite insensitive to the values of h_{50} and q_0 and is similar to the estimated metagalactic flux.

5.1. The Column Densities

Unless stated otherwise, the column densities in the absorber are estimated using the atomic data compiled by Morton, York, & Jenkins (1988). From a curve-of-growth analysis of the Lyman series, we can derive the best values for the Doppler parameter b and the column density $N(\text{H I})$. The possible ranges for $N(\text{H I})$ and b , given by the contours of the χ^2 between the observed and theoretical values corresponding to a 99% probability level (for four degrees of freedom), are $1.6 \times 10^{16} \leq N(\text{H I}) \leq 6.3 \times 10^{17} \text{ cm}^{-2}$ and $35 \leq b \leq 63 \text{ km s}^{-1}$. The best fit is obtained for $b = 43 \text{ km s}^{-1}$ and $N(\text{H I}) = 3.2 \times 10^{17} \text{ cm}^{-2}$. The Lyman-limit wavelength region is at the blue end of the G190H *HST* spectrum. The observed continuum is fairly noisy but clearly does not drop to zero intensity at the redshifted Lyman edge $\lambda_{912} = 1633 \text{ \AA}$ (see Fig. 1 of Paper I). The flux $F(\lambda_-)$ can only be measured in a small window, $\Delta\lambda_{\text{obs}} \sim 12 \text{ \AA}$, and the derived opacity is $\tau_{\text{LL}} \simeq 0.5$, or $N(\text{H I}) \simeq 1 \times 10^{17} \text{ cm}^{-2}$, a value well within the range given by the analysis of the Lyman series.

The doublet method can be applied to the C IV, Si IV, N V, and O VI doublets. To obtain the best estimates of the velocity dispersions and the column densities and their associated errors, we use a Monte Carlo method (the corresponding code has been provided by P. Boissé). The equivalent widths for both lines of the doublets are drawn at random from normal populations with means equal to the observed values and standard deviations taken from Paper I. We obtain $N = 1.2^{+1.4}_{-0.3} \times 10^{15}$, $1.1^{+0.8}_{-0.3} \times 10^{14}$, $3.5^{+2}_{-1} \times 10^{14}$, $1.1^{+0.2}_{-0.2} \times 10^{15} \text{ cm}^{-2}$ and $b = 54^{+6}_{-11}$, 38^{+32}_{-6} , 44^{+46}_{-3} , $97^{+10}_{-20} \text{ km s}^{-1}$ for C IV, Si IV, N V, and O VI, respectively. It must be noted that the blue component of the N V doublet is very broad and certainly badly affected by noise. The observations are summarized in Table 4 together with our best guess for the ionic column densities.

It has been shown that even in the presence of several components the doublet ratio method gives a good determination of the total column density provided that some components are not badly saturated; the b value is then related to the number of components and their spread in velocity (Jenkins 1986). The b values determined for C IV, Si IV, and N V are similar and smaller than that derived for O VI. A similar increase in the width of the lines with the ionization level has been noted by Sembach & Savage (1992) in the halo of the Galaxy. The line width is determined by the temperatures and bulk motions of individual clouds and also by the number of components present but not resolved in the *HST* data. Three Mg II components have been detected in this system at higher spectral resolution, $R \sim 10^4$ (Petitjean & Bergeron 1990). The maximum velocity separation between the Mg II components

TABLE 4

LINE PARAMETERS FOR THE $z_{\text{abs}} = 0.7913$ SYSTEM TOWARD PKS 2145+06^{a,b}

SPECIES	LINES	OBSERVATIONS			MODELS	
		w_r ($\text{\AA}$)	N (cm^{-2})	b (km s^{-1})	M1	M2
H I	1215	1.22	1.0(17)	43	1.2(17)	1.3(17)
	1027	0.79				
	972	0.76				
	949	0.68				
	937	0.53				
	930	0.64				
C II	1334	<0.29	<2.2(14)–3.1(14)	50–10	3.5(14)	3.8(14)
C III	977	0.84	3.2(14)–1.6(16)	100–50	3.7(15)	4.6(15)
C IV	1548	1.13	$1.2^{+1.4}_{-0.3}(15)$	54^{+6}_{-11}	1.3(15)	1.5(15)
	1550	0.89				
N III	989	0.46	6.3(14)–1.3(15)	100–50	1.0(15)	1.2(15)
N V	1238	0.29	$3.5^{+2}_{-1}(14)$	44^{+46}_{-3}	2.3(14)	2.3(14)
	1242	0.23				
O VI	1031	0.82	$1.1^{+0.2}_{-0.2}(15)$	97^{+10}_{-20}	1.6(15)	1.6(15)
	1037	0.48				
Mg II	2796	0.57	1.9(13)–2.6(13)	50–10	9.7(12)	1.5(13)
Si II	1260	<0.18	<1.7(13)–2.1(13)	50–10	2.7(13)	3.4(13)
Si III	1206	0.84	7.5(13)–8.1(14)	100–50	1.6(14)	2.1(14)
Si IV	1393	0.41	$1.1^{+0.8}_{-0.3}(14)$	38^{+32}_{-6}	1.0(14)	1.3(14)
	1402	0.30				
S VI	933	<0.4	<1.7(14)–3.1(14)	100–50	7.1(13)	7.9(13)
Fe II	2600	<0.24	<2.2(13)–2.5(13)	50–10	3.1(11)	3.5(11)

^a For singlets and upper limits, the parameters have been computed for two values of b . For $b = 10 \text{ km s}^{-1}$, the lines are considered to be split into three components as observed for Mg II.

^b Numbers in parenthesis are powers of 10.

is $\Delta V = 160 \text{ km s}^{-1}$; accordingly, the velocity spread of all ions should then be at least of this order.

The strong singlet lines C III $\lambda 977$ and Si III $\lambda 1206$ are present in the spectrum with $w_r = 0.84 \text{ \AA}$ for both lines. The C III and Si III column densities cannot be determined without assuming a value for the Doppler parameter b . These two ions are present for a large range of ionizing conditions (see, e.g., Fig. 3 in Petitjean et al. 1992), and thus they could have a larger velocity spread than the Mg II lines. We have therefore computed the column densities for b in the range 50–100 km s^{-1} . We find $7.5 \times 10^{13} < N(\text{Si III}) < 8.1 \times 10^{14} \text{ cm}^{-2}$ and $3.2 \times 10^{14} < N(\text{C III}) < 1.6 \times 10^{16} \text{ cm}^{-2}$.

No lines of Si II and C II are detected. The upper limit on the equivalent width of the Si II $\lambda 1260$ line is $w_r < 0.18 \text{ \AA}$. However, this Si II line, expected at $\lambda 2257.8$, could be blended with the line detected at $\lambda 2258.3$, previously identified as a Ly α line; this would lead to a larger upper limit $w_r(\text{Si II } \lambda 1260) < 0.40 \text{ \AA}$. The more stringent limit is considered in the analysis presented in § 5.2, given the definite absence of Si II $\lambda 1193$. The upper limit on C II $\lambda 1334$ is $w_r < 0.29 \text{ \AA}$, and thus the feature at $\lambda 1855.8$ is too strong to be C II $\lambda 1036$ at $\lambda 1856.3$. However, the C II $\lambda 1334$ absorption is expected at $\lambda 2390.5$, close to the Galactic Fe II $\lambda 2382$ absorption. The latter is not detected, although it should be stronger than the Fe II $\lambda 2344$ Galactic absorption, which is detected with $w_{\text{obs}} = 0.76 \text{ \AA}$. This suggests that the above upper limit for C II $\lambda 1334$ could also be underestimated by about a factor of 2. From the structure of the Mg II doublet, we can infer that the C II and Si II lines should be split into at least three components. We have thus computed upper limits on the column densities for $b = 50 \text{ km s}^{-1}$ and also for $b = 10 \text{ km s}^{-1}$ assuming three components of equal strength. The results are similar in both cases, namely $N(\text{C II}) \lesssim 3 \times 10^{14} \text{ cm}^{-2}$ and $N(\text{Si II}) \lesssim 2 \times 10^{13} \text{ cm}^{-2}$.

We have searched for additional lines which may not have been previously identified. Since the O VI and C III lines are fairly strong, one might expect S VI and N III lines to be present. S VI has a strong doublet at $\lambda\lambda 933, 944$ which is redshifted into a noisy part of the spectrum. Hence we can only derive an upper limit, $w_r(\text{S VI } \lambda 933) < 0.4 \text{ \AA}$, which implies $N(\text{S VI}) < 3.1 \times 10^{14} \text{ cm}^{-2}$. N III has a strong line at $\lambda 989.8$ which is definitely detected at $\lambda 1773.3$, with an observed equivalent width $w_{\text{obs}} = 0.82 \text{ \AA}$. This line is unlikely to be blended with Si II $\lambda 989.9$ at the same redshift, since the latter is expected to be 5.5 times weaker than Si II $\lambda 1193$, which is not detected. Using the recent estimate of the oscillator strength of N III $\lambda 989.8$ (Stafford, Hibbert, & Bell 1993), $f = 0.1208$, we obtain $6.3 \times 10^{14} < N(\text{N III}) < 1.3 \times 10^{15} \text{ cm}^{-2}$.

5.2. Photoionization Models

The large spread in ionization stages observed in the 2145+06 absorber, from Mg II to O VI together with $\tau_{\text{LL}} \simeq 1$, cannot be explained by a photoionization model with a single region of constant density and a quasar-type spectrum radiation flux. The nondetection of Fe II (Petitjean & Bergeron 1990) together with the column density $N(\text{Mg II}) = 2 \times 10^{13} \text{ cm}^{-2}$ imply, as for the $z_{\text{abs}} = 0.4416$ system toward 4C 06.41, values of the ionization parameter U in the Mg II phase in the range (3×10^{-4}) to (3×10^{-3}) . The observed $N(\text{N V})/N(\text{C IV})$ and $N(\text{O VI})/N(\text{C IV})$ ratios can be accounted for only if U is at least equal to $(2-3) \times 10^{-2}$ which, as already pointed out in § 4, suggests that two phases with densities differing by at least a factor of 10 are present. Both phases could then contribute to the observed C IV column density.

To investigate whether the required density difference between the Mg II and O VI phases is consistent with photoionization models, we have modified the detailed photoionization code Nebula (Péquignot, Aldrovandi, & Stasińska 1978; Petitjean, Boisson, & Péquignot 1990). This code computes the ionization structure of a spherical nebula surrounding a central ionizing radiation source. The diffuse ionizing flux produced by recombination in the nebula is computed along 20 outward radial directions. The flux from the diffuse emission is of the same order of magnitude as the flux from the central source when the optical depth is close to unity, thus necessitating a detailed treatment. In the new code, we have added an option to include a diffuse ionizing flux *external* to the nebula to take into account the metagalactic UV radiation field. Starting from a guess for the final optical depth, the code computes the structure of the nebula stepping radially in the outward direction. Then it computes the true diffuse inward ionizing flux which is used in a second iteration. The code converges on the final total optical depth after five to 10 iterations.

If the spherical cloud is optically thin or very optically thick, several iterations are barely needed. The first case can be solved by adding the two ionizing fluxes and the second case by splitting the cloud into two independent zones. However, in the case of intermediate optical depths both external and internal ionizing fluxes are important for the ionization of the central region and have to be taken into account.

5.2.1. Models with No Contribution from the Galaxy

The absorbing cloud is assumed to have an external zone of constant density $n_{\text{H,ex}}$ and extension l_{ex} , surrounding an over-dense inner region of extension l_i . To avoid discontinuities, the density profile in the latter is assumed to vary as $n_{\text{H}} = n_{\text{H,i}} \sin r$. The cloud is ionized from both sides by the metagalactic radiation flux. The evolution of J_{ν_0} is the same as adopted above,

leading to $J_{\nu_0}(z_{\text{abs}} = 0.79) = 1.3 \times 10^{-22} \text{ ergs s}^{-1} \text{ cm}^{-2} \text{ sr}^{-1} \text{ Hz}^{-1}$, but the spectrum is assumed to be flatter, with a power-law index $\alpha = 0.5$, and to have a break at 54.4 eV of a factor of 5 (Madau 1992). The solar abundances are taken from Allen (1973) as H:1., He:8(-2), C:3.3(-4), N:9.1(-5), O:6.6(-4), Ne:7.4(-5), Mg:2.6(-5), Si:3.3(-5), S:3.3(-5), Cl:4(-5), A:4.7(-6), Fe:4.0(-5), and Ca:1.7(-6). There are then five parameters to determine: two densities, $n_{\text{H,ex}}$ and $n_{\text{H,i}}$, two sizes, l_{ex} and l_i , and the heavy element abundances $[Z/H]$ which are assumed to be identical in the two zones.

A first guess of the heavy element abundances can be derived from the best estimates of $N(\text{H I})$ and $N(\text{Mg II})$ together with the upper limits on $N(\text{C II})$ and $N(\text{Si II})$. These four ions are produced only in the higher density region; the contribution of the high-ionization, low-density region to $N(\text{H I})$ is only about 1%, and even less for the column densities of the three singly ionized elements. The optical depth of the inner zone being quite modest, hydrogen is still ionized in its center with a mean ionic fraction $\text{H I}/\text{H} = 3 \times 10^{-3}$ (see Table 5). We can thus write as a first approximation

$$\frac{\alpha_{\text{H}}}{\xi_{\text{H I}}} n_i^2 l_i = N(\text{H I}) \quad (1)$$

and

$$\frac{\alpha_{\text{X}^+} + \beta_r(n_{\text{H I}}/n_i)}{\xi_{\text{X}^+} + \beta_i n_i} \frac{n_{\text{X}^{2+}}}{n_{\text{X}}} Z_{\text{X}} n_i^2 l_i = N(\text{X}^+), \quad (2)$$

where α are the recombination coefficients (radiative and dielectronic), β are the charge exchange reaction coefficients, ξ are the photoionization rates, n are the densities, and Z_{X} is the abundance for element X. The atomic parameters are those adopted by Petitjean, Bergeron, & Puget (1992).

In the conditions prevailing in the inner zone, C, Mg, and Si are mostly in the form of doubly ionized ions. Their ionization states are dominated by radiative recombination and photoionization for Mg II, dielectronic recombination and photoionization for C II and by ionization and recombination charge exchange reactions for Si II. Consequently, combining both equations (1) and (2) for C and Mg we get

$$Z_{\text{X}} = \frac{\xi_{\text{X}^+}}{\xi_{\text{H I}}} \frac{\alpha_{\text{H}}}{\alpha_{\text{X}^+}} \frac{n_{\text{X}}}{n_{\text{X}^{2+}}} \frac{N(\text{X}^+)}{N(\text{H I})}, \quad (3)$$

thus giving an estimate of Z_{X} , if $n_{\text{X}}/n_{\text{X}^{2+}}$ is known. Equation (3) clearly shows that, for a given ionization state, lower Lyman limit opacities imply higher abundances. Using the observed column densities listed in Table 4 and adopting $n_{\text{X}^{2+}}/n_{\text{X}} = \frac{2}{3}$, we obtain $[\text{Mg}/\text{H}] \simeq -0.35$ and $[\text{C}/\text{H}] < -0.1$. The computed heavy element column densities are given in Table 4 (model M1) for $N(\text{H I}) \simeq 1 \times 10^{17} \text{ cm}^{-2}$ and $[Z/H] = -0.3$. The temperature, density and element ionized fractions, at the center of the inner zone and in the external region, are listed in Table 5. The predicted C IV and Si IV column densities are consistent with the values derived from the observations. Both the high-ionization region and the inner region contribute to the C IV absorption, whereas Si IV and doubly ionized element absorptions trace only the inner region. The predicted Si II column density is about twice as large as the observed upper limit. However, the latter might be underestimated (see § 5.1).

The inner zone has $l_i = 6.7 \text{ kpc}$ and $n_{\text{H,i}} = 5.7 \times 10^{-3} \text{ cm}^{-3}$. The density of the high-ionization region is determined by the N V/O VI ionic ratio and equals $n_{\text{H,ex}} = 2.6 \times 10^{-4} \text{ cm}^{-3}$. As the heavy element abundances in the inner and external zones are assumed to be identical, the extent of the high-ionization region is mainly constrained by the O VI column density and is

TABLE 5
MODEL PARAMETERS FOR THE $z_{\text{abs}} = 0.7913$ SYSTEM TOWARD PKS 2145–06

MODEL	n_{H} (cm^{-3})	T_e (K)	l (kpc)	MEAN IONIZED FRACTION (%)						
				I	II	III	IV	V	VI	VII
M1.....	2.6(–4)	25300	67.8	H	1.3(–2)	100				
				He	5(–4)	4	96			
				C	3(–6)	2(–2)	2	12	54	29
				N	5(–7)	7(–3)	3	22	24	43
				O	3(–7)	3(–3)	2	20	32	26
				Mg	3(–9)	1(–6)	1(–3)	7(–2)	2	13
				Si	6(–8)	9(–5)	2(–3)	1(–2)	5(–1)	6
				Fe	1(–13)	5(–11)	1(–7)	2(–4)	2(–2)	4(–1)
M1.....	5.7(–3)	12450	6.7	H	4.7(–1)	100				
				He	3(–1)	62	38			
				C	1(–2)	8.8	78	12	1	1(–2)
				N	1(–2)	8.3	75	15	1	3(–2)
				O	3(–2)	6.9	81	11	1	9(–1)
				Mg	4(–2)	6.6	69	21	3	5(–1)
				Si	1(–2)	7.6	39	23	25	5
				Fe	2(–4)	8(–2)	3	38	36	18

equal to 68 kpc. The estimated overall size of the Mg II–C IV–O VI absorber (independent of h_{50}) is comparable to the observed projected linear distance ($55 h_{50}^{-1}$ kpc) between the galaxy center and the quasar sightline for $h_{50} \sim 1$ and its mass in gas equals $1.4 \times 10^9 M_{\odot}$.

All the observed column densities of the 2145+06 absorber could be attributed to a small cloud embedded in a large diffuse envelope, both regions being ionized by the metagalactic UV flux. Since the gas density ratio between the two regions is of order 20 whereas their temperatures differ only by a factor of 2, the two phases are far from pressure equilibrium which raises the problem of the nature of the confinement mechanism.

Alternatively, the N V–O VI region could trace a hotter phase with $T = 2 \times 10^5$ K for thermal collisional equilibrium and $N(\text{O VI})/N(\text{N V}) \simeq 3$. This hot gas could be associated with a possible group of galaxies detected by imagery but not confirmed spectroscopically (Bergeron & Boissé 1991). This group comprises at least six galaxies brighter than $M_r = -20$ within $200 h_{50}^{-1}$ kpc (Bergeron, Le Brun, & Boissé 1994). Redshifts of these galaxies should be measured to check whether they are consistent with the estimated temperature of an intragroup gas. A link between the O VI region and the group would also be suggested if the UV background flux was much smaller than our adopted value. For given values of the O VI and N V column densities and the ionization parameter U , the dimension of the high-ionization halo scales as $l_{\text{ex}} \propto J_{\text{v}0}^{-1} \propto n_{\text{H}}^{-1}$. Consequently, if the incident ionizing flux was at least 3 times smaller than the value adopted above, this would lead to a halo dimension of the same order or larger as the size of the group of galaxies possibly associated with the absorbing galaxy.

5.2.2. Models with Contribution from the Galaxy

The case of a significant contribution by the absorbing galaxy to the UV flux ionizing the absorbing cloud is now investigated. If as many ionizing photons escape the galaxy as are absorbed by the observed [O II] $\lambda 3727$ -emitting region, the galactic ionizing flux reaching the absorber is 6.7×10^5 photons $\text{s}^{-1} \text{cm}^{-2}$ (see beginning of § 5). This is close to the contribution from the metagalactic flux of 5.0×10^5 photons $\text{s}^{-1} \text{cm}^{-2}$ (in 4π sr). The galactic UV radiation field is assumed to be dominated by hot stars. Its spectral energy distribution is

then fairly hard between the H I and He II Lyman limit (assumed to follow a power law of index $\alpha = 0.5$) with a break of a factor of 100 at 54.4 eV (see, e.g., Madau 1991).

The solution obtained in § 5.2.1 for the two phase absorbing, spherical cloud can be used as a first guess. In the outer zone of low density, the dominant ions have ionization potentials larger than 54.4 eV. At these energies, the metagalactic field is the main ionization source and the outer high-ionization phase has similar characteristics for both models. In the inner, denser region the dominant species are H I and singly and doubly ionized elements, and the effective ionizing flux is about twice as large as in the previous model. To maintain the H I column density, the gas density $n_{\text{H},i}$ must be increased by a factor smaller than $[(6.7 + 5.0)/5.0]^{0.5} = 1.5$, since the marginally optically thick inner region is not ionized on both sides by the same flux. The column densities for this model M2 are given in the seventh column of Table 4. The main differences between M1 and M2 are the higher optical depth at the He II Lyman limit in M2 (by about 50%) and the increase in the relative fraction, thus column densities (by about 30%), of the ionized species with ionization potential just below 54.4 eV (i.e., C III, N III, Mg II, and Si IV). These differences are not large enough to favor one model over the other. Constraints on the UV metagalactic flux or on the contribution of UV galactic field to the total ionizing flux will be more easily obtained from either lower redshift metal-rich absorbers or from absorbing galaxies with smaller impact parameters.

6. SUMMARY

The results of the analysis of 18 $z_{\text{abs}} \ll z_{\text{em}}$ metal-rich C IV and/or Mg II systems, at a redshift $0.11 \leq z \leq 1.04$, detected in the spectra of 10 quasars observed with the *HST* Faint Object Spectrograph (of which eight have also been observed in the optical range) are as follows:

1. There is an evolution with redshift in the ionization state of the absorbers as defined by their equivalent width ratio $w_r(\text{C IV } \lambda 1548)/w_r(\text{Mg II } \lambda 2796) \equiv \text{C IV/Mg II}$. The fraction of low-ionization systems ($\text{C IV/Mg II} \leq 1$) more than doubles between $\langle z_{\text{abs}} \rangle = 1.70$ and 0.53, reaching 38% at $z = 0.53$.

2. The fraction of strong Mg II systems increases with redshift, as already found by Steidel & Sargent (1992), but the

Mg II mean doublet ratio shows little variation, if any, with redshift. Since the total Mg II equivalent width correlates with the number of subsystems down to scales of 50 km s^{-1} , this suggests that there is less clustering of Mg II systems on scales smaller than 300 km s^{-1} at low than at high redshift.

3. The opacity of Mg II systems to UV-ionizing photons strongly decreases with decreasing redshift, with in some cases at $z \sim 0.5$, $\tau_{\text{LL}} \lesssim 1$. Consequently, the ionization level of the phase optically thin to UV radiation falls with decreasing redshift.

4. On the assumption of UV photoionization, the mean ionization level of hydrogen in $\tau_{\text{LL}} \sim 1$, Mg II systems at $z \sim 0.5$ is $\text{H II}/\text{H I} \lesssim 30$. The derived total hydrogen column densities are $N(\text{H}) \lesssim 10^{19} \text{ cm}^{-2}$ which, together with the observed Mg II column densities, leads to high heavy element abundances, $[Z/\text{H}] \sim -0.5$ to -0.3 , as compared to those inferred at high redshift for damped Ly α systems, $[Z/\text{H}] \sim -1.0$ (Pettini et al. 1994), and Lyman limit systems, $[Z/\text{H}] \sim -2.5$ to -1.0 (Bergeron & Stasińska 1986; Steidel 1990; Petitjean et al. 1992).

5. There is strong O VI absorption at $z \gtrsim 0.6$ in four out of the five systems for which this wavelength range has been observed. In one case the absorber has been identified and the high-ionization region is at a very large radial distance, $r \geq 55 h_{50}^{-1} \text{ kpc}$.

6. At $z \sim 0.6$, the N V–O VI phase could be ionized by the UV metagalactic flux if its density is low, $n_{\text{H}} \sim 3 \times 10^{-4} \text{ cm}^{-3}$. This highly ionized region would then have a dimension of at least 50 kpc to account for the observed O VI column densities. The C IV and Mg II clouds would then be embedded in this homogeneous high-ionization phase. A prediction of this model is that, at $z < 1$, the column density ratios $N(\text{O VI})/$

$N(\text{N V})$, $N(\text{O VI})/N(\text{C IV})$ and especially $N(\text{O VI})/N(\text{Si IV})$ should decrease with decreasing redshift.

7. Alternatively, the O VI phase could be thermally ionized and thus have $T \sim 2 \times 10^5 \text{ K}$. It is not clear whether UV emission from the absorbing galaxy or fountain flows can or not account for the observed O VI column densities. A possible explanation is that the high-ionization phase is intragroup gas. However, at least at $z < 0.8$, groups of bright galaxies associated with the absorbing galaxies are not common (Le Brun et al. 1993).

8. We have performed detailed photoionization modeling for one absorption system for which extensive information is available, including the identification of the absorbing galaxy. This model confirms that, at $z = 0.8$, (1) the estimated UV metagalactic field could ionize both the low- and high-ionization phases; (2) the heavy element abundances in the galactic halo are high, $[Z/\text{H}] \sim -0.3$; (3) the O VI phase is homogeneous, with a density $n_{\text{H}} \sim 3 \times 10^{-4} \text{ cm}^{-3}$, and of large extent ($\sim 70 \text{ kpc}$); (4) the Mg II phase is of intermediate dimension ($\sim 7 \text{ kpc}$) with a density ~ 20 times higher than the N V–O VI region; (5) C IV absorption arises from both phases; and (6) adding a possible contribution of the galaxy to the UV radiation field ($13.6 \leq h\nu \leq 54.4 \text{ eV}$) does not substantially modify the above results.

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