THE POPULATION OF WEAK Mg II ABSORBERS. I. A SURVEY OF 26 QSO HIRES/KECK SPECTRA¹,²

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ABSTRACT

We present a search for "weak" Mg II absorbers [those with \( W_r(2796) < 0.3 \) Å] in the HIRES/Keck spectra of 26 QSOs. We found 30, of which 23 are newly discovered. The spectra are 80\% complete to \( W_r(2796) = 0.02 \) Å and have a cumulative redshift path of \( \sim 17.2 \) for the redshift range \( 0.4 \le z \le 1.4 \). The number of absorbers per unit redshift, \( dN/dz \), is seen to increase as the equivalent width threshold is decreased; we obtained \( dN/dz = 1.74 \pm 0.10 \) for our 0.02 \( W_r(2796) < 0.3 \) Å sample. The equivalent width distribution follows a power law, \( N(W) \propto W^{-\delta} \), with \( \delta \sim 1.0 \); there is no turnover down to \( W_r(2796) = 0.02 \) Å at \( \langle z \rangle = 0.9 \). Weak absorbers comprise at least 65\% of the total Mg II absorption population, which outnumber Lyman limit systems (LLSs) by a factor of 3.8 \pm 1.1; the majority of weak Mg II absorbers must arise in sub-LLS environments. Tentatively, we predict that \( \sim 5\% \) of the Ly\( \alpha \) forest clouds with \( W_r(\text{Ly}\alpha) \geq 0.1 \) Å will have detectable Mg II absorption to \( W_r(\text{Mg}\ II) = 0.02 \) Å and that this is primarily a high-metallicity selection effect ([Z/Z\( _\odot \)] \geq -1). This implies that Mg II absorbing structures figure prominently as tracers of sub-LLS environments where gas has been processed by stars. We compare the number density of \( W_r(2796) \geq 0.02 \) Å absorbers with that of both high and low surface brightness galaxies and find a fiducial absorber size of \( 35 h^{-1} - 63 h^{-1} \) kpc, depending upon the assumed galaxy population and their absorption properties. The individual absorbing "clouds" have \( W_r(2796) \leq 0.15 \) Å, and their narrow (often unresolved) line widths imply temperatures of \( \sim 25,000 \) K. We measured \( W_r(1548) \) from C IV in Faint Object Spectrograph/Hubble Space Telescope archival spectra and, based upon comparisons with Fe II, found a range of ionization conditions (low, high, and multiphase) in absorbers selected by weak Mg II.

Subject headings: galaxies: evolution — galaxies: ISM — quasars: absorption lines

1. INTRODUCTION

We present a survey for "weak" Mg II \( \lambda \lambda 2796, 2803 \) absorption in the spectra of QSOs obtained with the HIRES spectrograph (Vogt et al. 1994) on the Keck I Telescope. There have been several Mg II surveys over the previous decade (Lanzetta, Turnshek, & Wolfe 1987, hereafter LTW; Tytler et al. 1987, hereafter TBSYK; Caulet 1989; Petitjean & Bergeron 1990, hereafter PB90; Sargent, Steidel, & Boksenberg 1988b, hereafter SSB; Steidel & Sargent 1992, hereafter SS92). These surveys were complete to a rest frame Mg II \( \lambda 2796 \) equivalent width, \( W_r(2796) \), of 0.3 Å and above. The more comprehensive work of SS92 yielded solid statistics on the equivalent width distribution, redshift number density, large-scale velocity clustering, and evolution over the redshift range \( 0.3 \leq z \leq 2.2 \), for which the Mg II doublet can be observed with ground-based telescopes.

The shape of the \( W_r(2796) \) distribution function at smaller equivalent widths has important implications for our understanding of cosmic chemical evolution and its connection to star-producing environments. At \( 0.3 \leq z \leq 1.0 \), Mg II absorption with \( W_r(2796) \geq 0.3 \) Å has been found to arise within \( \sim 40 h^{-1} \) kpc of normal galaxies (Bergeron & Boisse 1991; Steidel, Dickinson, & Persson 1994). These galaxies exhibit a wide range of colors, from late-type spirals to the reddest ellipticals (though more luminous galaxies are redder), and have \( L_K \) and \( L_R \) luminosity functions consistent with the local luminosity function (types later than Sd are absent). It has been concluded that a wide range of morphological types are contributing to the Mg II–absorbing gas cross section, except that isolated low-mass (\( L_K \leq 0.06L_\odot \)) “faint blue galaxies” are not (Steidel et al. 1994). A rapid cutoff in the equivalent width distribution would imply that this observed sample of galaxies provides a complete picture of the star-forming environments that give rise to Mg II–absorbing gas. Currently, that picture is one in which the galaxy population selected by Mg II absorption is stable, showing very little cosmological evolution from \( z \sim 1 \) (but see Lilly et al. 1995).

If, on the other hand, the number of Mg II absorbers per unit redshift continues to rise for decreasing \( W_r(2796) \), it would be implied that surveys complete to 0.3 Å have unveiled only a small portion of the population of metal-line systems selected by Mg II absorption. Churchill & Le Brun (1998) have discussed this possibility, based upon the discovery of two near-solar to supersolar metallicity Mg II absorbers.

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⁶ Throughout this paper we use \( q_0 = 0.05 \) and express physical sizes in terms of \( h = H_0/100 \).
absorbers in the Ly α forest of PKS 0454+039. As such, our current picture of the relationship between Mg II absorbing gas and star-forming environments may require some modification. Perhaps the observed $L_\text{Ly}\alpha \sim 0.06L_\text{K}^2$ cutoff in the luminosity function of Mg II absorption–selected galaxies or the cutoff at $\sim 40 \ h^{-1} \ kpc$ of Mg II absorption around these galaxies does not apply for $W_{\alpha}(2796) < 0.3 \ Å$. Alternatively, perhaps another population of star-forming objects that preferentially give rise to weaker Mg II absorption is implied. Or perhaps both a slight modification to the current picture of Mg II–absorbing galaxies and the incorporation of another population of objects would be implied.

Measuring the statistical absorption properties of the weakest Mg II absorbers is a first step toward verifying or casting new light on such speculations.

For $W_{\alpha}(2796) < 0.3 \ Å$, PB90 and SS92 inferred a cutoff in the Mg II equivalent width distribution, the number of absorbers per unit redshift per unit equivalent width. However, the completeness of their data below 0.3 Å dropped rapidly. Their conclusions necessarily have been based upon a comparison of the number of Mg II absorbers detected with $W_{\alpha}(2796) < 0.3 \ Å$, corrected for completeness, to the number of these absorbers predicted by extrapolating the equivalent width distribution. Measurements of the equivalent width distribution, however, were somewhat inconclusive; the data were adequately described either by a power-law distribution with slope $\delta = 2.0$ (TBSYK) or $\delta = 1.6$ (SS92), or by an exponential with a characteristic equivalent width of $W_{\alpha}(2796) = 0.66 \ Å$ (SS92; LTW). Womble (1995) and Tripp, Lu, & Savage (1997) have tentatively concluded that the equivalent width distribution continues to rise below 0.3 Å.

The HIRES/Keck spectra obtained for the thesis of Churchill (1997) provide duplicate redshift coverage of 26 of the 103 QSO sight lines studied by SS92. The spectra are 80% complete to $W_{\alpha}^{\text{min}}(2796) = 0.02 \ Å$, and provide an opportunity to investigate directly whether in fact there is a paucity of Mg II absorbers with $W_{\alpha}(2796) < 0.3 \ Å$ and to measure the shape of the distribution of equivalent widths well below 0.3 Å. Archival Faint Object Spectrograph (FOS) spectra from the Hubble Space Telescope (HST) cover the C IV $\lambda\lambda 1548, 1550$ doublet, which is a useful indicator of the ionization conditions. For systems with redshifts greater than $\sim 1.2$, ground-based spectra (taken from the literature) cover C IV.

The acquisition of the data and their reduction and analysis are described in § 2. In § 3 we present our adopted sample of weak Mg II systems. In § 4 we compute the redshift path density, determine the shape of the equivalent width distribution, examine the clustering, and discuss the general absorption properties of weak Mg II absorbers. We present the results from a FOS/HST survey and from a literature search for associated C IV and discuss the ionization conditions and constraints on the absorption cross sections in § 5. Our main results are summarized in § 6.

2. OBSERVATIONS AND DATA ANALYSIS

2.1. The Sample of QSO Spectra

A full description of the HIRES data acquisition is given in Churchill (1997) and in Churchill, Vogt, & Charlton (1999b, hereafter CVC99). In short, 26 QSO spectra ($R = 45,000$) were obtained with the HIRES spectrometer (Vogt et al. 1994) on the Keck I Telescope. The QSOs and their emission redshifts, the UT date of the observations, the summed exposure times, and the approximate wavelength coverage are presented in Table 1. The spectra comprise a biased sample of QSO sight lines with “strong” Mg II absorbers. However, the QSO lines of sight are unbiased for Mg II systems with $W_{\alpha}(2796) < 0.3 \ Å$, since nothing is known a priori about the presence of these “weak” Mg II systems.

It is possible that weak systems are preferentially found in sight lines along which strong systems are present, in which case these QSO spectra would not comprise an unbiased sample. We return to this point in § 4.3. Because of the echelle format, each spectrum has breaks in wavelength coverage redward of 5100 Å. The gaps in redshift coverage begin at $z \sim 0.83$ and become more pronounced toward higher redshifts (see Fig. 1). The FOS/HST data have either been collected from the HST archive (in collaboration with S. Kirhakos, B. Jannuzi, and D. Schneider) or are from the QSO Absorption Line Key Project (Bahcall et al. 1996; Jannuzi et al. 1998).

2.2. The HIRES/Keck Data

The raw data frames were bias-corrected, flat-fielded, cosmic-ray–cleaned, combined, and scattered-light–corrected, using the standard IRAF packages following the techniques described in Churchill (1995). The individual spectra were extracted using the optimal extraction algorithms provided in the noao.twodspec.apextract package. The wavelength calibration was done interactively using the eidentify task of the noao.imred.echelle package. We have not resampled the data by linearizing the wavelength as a function of pixel along the dispersion direction. The continuum fits, based upon the formalism of Sembach & Savage (1992), were obtained by minimizing $\chi^2$ between the flux values and a smooth function, usually a Legendre polynomial. For the detection of weak unresolved features, it is critical that the measured uncertainty in each resolution element accurately reflects the continuum noise. Therefore, for each echelle order, we enforced a unity $\chi^2$ between the smooth fitted continuum model and the spectrum by scaling the uncertainty spectrum (output by apextract) by a single “optimizing” multiplicative factor, $f$. To obtain $f$, we root solved the function $1 - \chi^2$, where $\chi^2 = V_{\text{fit}}/V_{\text{true}}$, and $V_{\text{fit}}$ and $V_{\text{true}}$ are the variance in the continuum fit and the uncertainty spectrum, respectively. The process required an automated iterative convergence algorithm in order to objectively mask absorption features from the fit.

For the objective identification of unresolved absorption (and emission) features, we have used the formalism presented by Schneider et al. (1993). The resulting equivalent width uncertainty spectra provide the observed equivalent width detection threshold as a function of wavelength. The $5 \sigma$ rest-frame equivalent width limits of the 22796 transition are shown in Figure 1 as a function of redshift. Where there is no redshift coverage (interorder gaps), we have arbitrarily set the limiting equivalent width to zero.

Only a single exposure of Q0002+051 was obtained, so that removing cosmic rays, especially from the sky, was problematic. As a consequence, the zero level of the spec-
trum is uncertain by \( \sim 10\% \) and the measured equivalent widths may be biased by this probable zero-point offset, which varied from echelle order to echelle order. This uncertainty has not been included in the error estimate of the quoted equivalent widths. In Q1548 + 092, the Ly\( \alpha \) forest compromises all transitions of metal-line systems that lie blueward of the Ly\( \alpha \) feature. We have not searched for Mg\( \II \) doublets in this spectrum below 2803.5 Å.

2.3. The FOS/HST Data

We searched for C IV \( \lambda \lambda 1548, 1550 \) doublets at the redshifts of weak Mg\( \II \) absorbers in FOS/HST spectra (\( R = 1300 \)). These spectra were originally collected for a companion paper (Churchill, Vogt, & Charlton 1999a; Paper II). The archival data have been retrieved and reduced in collaboration with S. Kirhakos, B. Jannuzi, and D. Schneider using the techniques and software of the HST QSO Absorption Line Key Project. The remaining spectra, which were originally obtained for the HST Key Project, have been kindly provided by our collaborators in fully reduced form. In Table 1 we reference the available spectra and the grating that covered C IV. For details of the data reduction see Schneider et al. (1993), Bahcall et al. (1996), and Jannuzi et al. (1998).

2.4. Doublet Searching

The search for Mg\( \II \) doublets involved the following steps. First, a complete list of 5 \( \sigma \) features were objectively defined in each HIRE S spectrum. To locate candidate Mg\( \II \) doublets, we then tested the features one by one, starting at the smallest wavelength feature and moving toward larger wavelengths. We assumed each feature was a candidate doublet when the detection significance was roughly equal to or greater than 5 \( \sigma \). The scan is performed about 50 Å both sides of the expected location of the Mg\( \II \) feature. Then the \( \lambda 2796 \) line with observed central wavelength was used to determine the equivalent width and its uncertainty were measured in an aperture with the same full width at the continuum as that of the candidate \( \lambda 2796 \) feature. These quantities were measured using the formalism of Sembach & Savage (1992). The pair was designated as a candidate doublet when the \( \lambda 2796 \) detection significance was roughly equal to or greater than half that of the \( \lambda 2796 \) feature (given by the ratio of the \( f_2 \) and the doublet ratio (DR) was consistent with 1 \( \leq \) DR \( \leq 2 \) within the 1 \( \sigma \) uncertainties.

We also employed a quantitative measure of the chance that the candidate \( \lambda 2803 \) transition could be a random feature or a transition from another system along the QSO sight line. A "false alarm" probability is computed by scanning the spectrum pixel by pixel (also with an aperture given by the full width at the continuum of the candidate \( \lambda 2796 \) feature). The scan is performed about 50 Å to both sides of

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**TABLE 1**

| OBJECT | \( z_{em} \) | HIRES Spectra | FOS Spectra |
|--------|--------------|---------------|-------------|
|        |              | Date (UT) | Exp (s) | \( \lambda \) Range (Å) | Source | Grating |
| -----  | -------------|-----------|--------|----------------|--------|---------|
| 0002 + 051 | 1.899 | 1994 Jul 05 | 2700 | 3655.7–6079.0 | KP | 270H |
| 0058 + 019 | 1.959 | 1996 Jul 18 | 3000 | 3766.2–5791.3 | ... | ... |
| 0117 + 212 | 1.491 | 1995 Jan 23 | 5400 | 4317.7–6775.1 | KP | 270H |
| 0420 – 014 | 0.915 | 1995 Jan 23 | 3600 | 3810.5–6304.9 | ... | ... |
| 0450 – 132 | 2.253 | 1995 Jan 24 | 5400 | 3986.5–6424.5 | ... | ... |
| 0454 + 036 | 1.345 | 1995 Jan 22 | 4500 | 3765.8–6198.9 | AR | 270H |
| 0454 – 220 | 0.534 | 1995 Jan 24 | 5400 | 3765.8–6198.9 | AR | 270H |
| 0823 + 223 | ... | 1995 Jan 24 | 3600 | 3977.8–6411.8 | AR | 270H |
| 0958 + 551 | 1.755 | 1995 Jan 23 | 3600 | 5400.0–7830.0 | KP | 270H |
| 1148 + 384 | 1.299 | 1995 Jan 24 | 5400 | 3986.5–6424.5 | ... | ... |
| 1206 + 456 | 1.155 | 1995 Jan 23 | 3600 | 3810.5–6304.9 | KP | 270H |
| 1213 – 003 | 2.691 | 1995 Jan 24 | 5200 | 5008.1–7356.7 | ... | ... |
| 1222 + 228 | 2.040 | 1995 Jan 23 | 3600 | 3810.5–6304.9 | AR | 270H |
| 1225 + 317 | 2.219 | 1995 Jan 24 | 2400 | 5737.5–8194.7 | ... | ... |
| 1241 + 174 | 1.282 | 1995 Jan 22 | 3600 | 3765.8–6198.9 | KP | 270H |
| 1248 + 401 | 1.032 | 1995 Jan 22 | 4200 | 3765.8–6198.9 | KP | 270H |
| 1254 + 044 | 1.018 | 1995 Jan 22 | 3600 | 3765.8–6198.9 | KP | 270H |
| 1317 + 274 | 1.014 | 1995 Jan 23 | 3600 | 3810.5–6304.9 | AR | 270H |
| 1329 + 412 | 1.937 | 1996 Jul 18 | 6300 | 3766.2–5791.3 | AR | 270H |
| 1354 + 193 | 0.719 | 1995 Jan 22 | 3600 | 3765.8–6198.9 | KP | 270H |
| 1421 + 331 | 1.906 | 1995 Jan 23 | 3600 | 3818.6–6316.9 | ... | ... |
| 1548 + 092 | 2.749 | 1996 Jul 19 | 3600 | 3766.2–5791.3 | ... | ... |
| 1622 + 235 | 0.927 | 1994 Jul 04 | 16200 | 3726.9–6191.0 | AR | 270H |
| 1634 + 704 | 1.335 | 1994 Jul 04 | 2700 | 3723.3–6185.7 | AR | 270H |
| 2128 – 123 | 0.501 | 1996 Jul 19 | 3900 | 3766.2–5791.3 | KP | 270H |
| 2145 + 064 | 0.999 | 1996 Jul 18 | 4500 | 3766.2–5791.3 | AR | 270H |

**Note:** AR denotes FOS spectrum taken from the HST archive, and KP denotes FOS spectrum obtained from the Key Project.

\( a \) Total exposure time is sum of combined frames.

\( b \) Above 5100 Å there are small gaps in the wavelength coverage.
the candidate $\lambda 2803$ feature. This corresponds to a total redshift window of $\Delta z \sim 0.02$, or $\pm 3000$ km s$^{-1}$ about the feature. The false alarm probability is simply the fraction of pixels with detected features (both emission and absorption) having a significance level greater than or equal to the candidate $\lambda 2803$ feature. The detection levels of the $\lambda 2803$ transitions for all included doublets were greater than $4.5 \sigma$.

Most bona fide Mg II doublets have false alarm probabilities of $P_{fa} \leq 10^{-6}$. The largest false alarm probability, for S24 in Q1213−003 at $z = 1.1277$, was $P_{fa} \sim 0.009$. We are quite certain that our adopted sample is not contaminated by false Mg II systems.

In addition to the above constraints, a nearest neighbor velocity separation greater than 500 km s$^{-1}$ was enforced.

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**Fig. 1a**

Survey sensitivity, given as the 5 $\sigma W_{r(2796)}$, is shown as a function of redshift. Breaks in the echelle spectral coverage, where there is no possibility of detecting a Mg II doublet in a given redshift range, are arbitrarily assigned $W_{r(2796)} = 0$.

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**Fig. 1b**
The velocity filter was applied so that small equivalent width, high-velocity components in strong systems would not be included in the sample. The 500 km s\textsuperscript{-1} separation criterion resulted in our dropping only a single potential weak Mg II absorber from our sample in Q1206+456 (see “system A” in Churchill & Charlton 1998).

The search for C IV in the FOS/HST spectra was performed in an identical fashion as for the Mg II doublets, except that the objective line list was relaxed to 3 \( \sigma \) detections.\textsuperscript{10} We visually inspected each spectrum to determine whether a candidate C IV doublet (at the redshift of a weak Mg II system) was real or a blend of Ly\( \alpha \) lines. If real, we measured \( W_r(1548) \) using the same techniques used for the HIRES data. If not, we measured the 3 \( \sigma \) equivalent width limit. We verified our results with the literature when possible, but all quoted C IV equivalent widths and limits are based upon our measurements in order to maintain uniformity.

3. THE DOUBLET SAMPLE

Our adopted sample includes 30 systems and is presented in Table 2. Tabulated are the system number, the absorption redshift, the QSO spectrum in which it was detected, the velocity width in km s\textsuperscript{-1} of the \( \lambda 2796 \) transition, and the Mg II doublet ratio. The last column contains the cumulative redshift path, \( Z_i(W_r, DR) \), which is the total redshift path over which the tabulated system could have been detected in this survey (see eq. [2]). The velocity widths, \( \omega_v \), are measured directly from the flux values according to

\[
\omega_v^2 = \int_{-\infty}^{+\infty} \tau(v)(\Delta v)^2 dv \int_{-\infty}^{+\infty} \tau(v) dv ,
\]

where \( \tau(v) = \ln(I_v/I_\odot) \) is the apparent optical depth (Savage & Sembach 1991), \( I_I(v) \) is the continuum flux at velocity \( v \), \( I_\odot(v) \) is the measured flux at \( v \), \( \Delta v = v - \langle v \rangle \), and \( \langle v \rangle \) is the velocity centroid of the absorption profile. The \( \omega_v \) are mathematically equivalent to the Gaussian width of a normal distribution.

In Table 3 we present the properties of each system, including the transition identity, the observed wavelength, and the rest-frame equivalent width or its 3 \( \sigma \) upper limit. The equivalent widths and their uncertainties are computed using the methods of Sembach & Savage (1992). For all Mg II systems, we searched the HIRES spectrum for other transitions with the significance level relaxed to 3 \( \sigma \). Because the Fe II and Mg I \( \lambda 2853 \) transitions are the strongest and most commonly found in Mg II absorbers, we have presented their limits. Other transitions are included in Table 3 when they have been detected. The data are shown in Figure 2. Features marked with an asterisk either are members of other systems or are unidentified.

3.1. Discussion of Systems

3.1.1. S1 (Q1421 + 331; \( z_{abs} = 0.45642 \))

There is no previous report of S1. No Fe II transitions were captured by the CCD. Mg I was not detected. A FOS/HST spectrum of this QSO was not available. There is no galaxy candidate (C. Steidel 1998, private communication).

3.1.2. S2 (Q1329 + 412; \( z_{abs} = 0.50079 \))

S2 was reported as a “probable” Mg II doublet by SSB. This system is associated with a bluish low-mass galaxy with \( z = 0.52149 \) at an impact parameter of \( \approx 5 \) h\textsuperscript{-1} kpc (C. Steidel 1998, private communication). The signal-to-noise ratio of the HIRES spectrum is fairly low, and only the Mg II doublet was detected. C IV was not detected in the FOS/HST spectrum.

3.1.3. S3 (Q1354 + 193; \( z_{abs} = 0.52149 \))

There is no previous report of S3. Although Fe II and Mg I were captured by the CCD, only the Mg II doublet was detected. C IV was not detected in the FOS/HST spectrum (see also Jannuzi et al. 1998). This QSO field has about five galaxies at \( z \approx 0.5 \), which are part of a foreground cluster (C. Steidel 1998, private communication).

3.1.4. S4 (Q1229 + 412; \( z_{abs} = 0.55020 \))

There is no previous report of S4. Although Fe II and Mg I were captured by the CCD, only the Mg II doublet was detected. However, Fe II \( \lambda 2600 \) may be present at the 2.7 \( \sigma \) level. A C IV detection was ambiguous in the FOS/HST spectrum (see also Impey et al. 1996); we conservatively quote a nonrestrictive limit. There is no galaxy candidate (C. Steidel 1998, private communication).

\textsuperscript{10} We acknowledge A. Dobrzycki, who kindly assisted us in a preliminary search for C IV doublets in the FOS/HST spectra of Dobrzycki et al. (1998).
3.1.5. S5 (Q1241 + 174; \( z_{\text{abs}} = 0.55844 \))

There is no previous report of S5. Although Fe II and Mg II were captured by the CCD, only the Mg II doublet was detected. C IV was tentatively detected in the FOS/HST spectrum; however, the \( \lambda5184 \) line may be Ly\( \alpha \) (Jannuzi et al. 1998). There is no galaxy candidate (C. Steidel 1996, private communication).

3.1.6. S6 (Q0002 + 051; \( z_{\text{abs}} = 0.59149 \))

S6 is known to be associated with a red \( \approx 1.3L^* \) galaxy with impact parameter \( \approx 24 h^{-1} \) kpc (Churchill, Steidel, & Vogt 1996). Although multiple Fe II transitions were captured by the CCD, none were detected. If Mg II is present, it was detected only at the 2 \( \sigma \) significance level. The equivalent widths may be biased by a zero-point uncertainty, which has not been included in the error measurement. C IV was not detected in the FOS/HST spectrum (see also Jannuzi et al. 1998).

3.1.7. S7 (Q0454 + 036; \( z_{\text{abs}} = 0.64283 \))

S7 was studied by Churchill & Le Brun (1998) and has no detectable C IV in the FOS/HST spectrum. There is no galaxy at this redshift in this well-studied field. Here we also report a 3.3 \( \sigma \) detection of Fe II \( \lambda2587 \). Mg I was not detected.

3.1.8. S8 (Q0823 – 223; \( z_{\text{abs}} = 0.70547 \))

There is no previous report of S8. Although Fe II and Mg I were captured by the CCD, only the Mg II doublet was detected. C IV was not detected in the FOS/HST spectrum.

3.1.9. S9 (Q0058 + 019; \( z_{\text{abs}} = 0.72518 \))

There is no previous report of S9. Relatively strong Mg I was detected. There is a 3 \( \sigma \) detection of Fe II \( \lambda2600 \), which we present in Table 3, but this detection is insecure. A FOS/HST spectrum of this QSO was not available. There is no galaxy candidate, although there is a galaxy at \( z \approx 0.68 \) (C. Steidel 1998, private communication).

3.1.10. S10 (Q0117 + 212; \( z_{\text{abs}} = 0.72907 \))

S10, a multicomponent system, is associated with a red and massive \( \approx 3.7L^* \) galaxy at an impact parameter of \( \approx 36 h^{-1} \) kpc (Churchill, et al. 1996). The absorption at \( v \approx -120 \) km s\(^{-1} \) near the \( \lambda2830 \) transition is a Ti II transition from a damped Ly\( \alpha \) absorber at \( z_{\text{abs}} = 0.5764 \). Also, Fe II \( \lambda2600 \) is nearly blended with Mg I from this damped Ly\( \alpha \) absorber. Fe II has been detected in four of the five Mg II components, and Mg I was detected in the strongest one. C IV was not detected in the FOS/HST spectrum (see also Jannuzi et al. 1998).

3.1.11. S11 (Q1548 + 093; \( z_{\text{abs}} = 0.77065 \))

SSB reported a weak, but unambiguous, Mg II absorbing system at \( z_{\text{abs}} = 0.7708 \). This system is associated with a reddish low-mass galaxy with \( \approx 0.1L^* \) at an impact parameter of \( \approx 23 h^{-1} \) kpc (C. Steidel 1998, private communication). Although the HIRES spectrum is noisy, both Fe II and Mg I were detected. A FOS/HST spectrum of this QSO was not available.
### Table 3

| Ion and Transition | $\lambda_{abs}$ (Å) | $\Delta\lambda$ (Å) | EW (Å) |
|--------------------|---------------------|---------------------|---------|
| **S1: Q1421 + 331; $z_{abs} = 0.45642$** |                    |                     |         |
| Mg II 2796        | 4072.649            | 0.179 ± 0.019       |         |
| Mg II 2803        | 4083.105            | 0.155 ± 0.020       |         |
| Mg I 2853         | 4155.100            | < 0.004             |         |
| **S2: Q1329 + 412; $z_{abs} = 0.50079$** |                    |                     |         |
| Fe II 2587        | 3882.008            | < 0.092             |         |
| Fe II 2600        | 3902.303            | < 0.100             |         |
| Mg II 2796        | 4196.726            | 0.258 ± 0.035       |         |
| Mg II 2803        | 4207.500            | 0.194 ± 0.054       |         |
| Mg I 2853         | 4281.688            | < 0.038             |         |
| **S3: Q1354 + 193; $z_{abs} = 0.52149$** |                    |                     |         |
| Fe II 2587        | 3935.583            | < 0.016             |         |
| Fe II 2600        | 3956.158            | < 0.012             |         |
| Mg II 2796        | 4254.644            | 0.030 ± 0.007       |         |
| Mg II 2803        | 4265.567            | 0.023 ± 0.010       |         |
| Mg I 2853         | 4340.779            | < 0.007             |         |
| **S4: Q1222 + 228; $z_{abs} = 0.55020$** |                    |                     |         |
| Fe II 2587        | 4009.830            | < 0.011             |         |
| Fe II 2600        | 4030.793            | < 0.009             |         |
| Mg II 2796        | 4334.910            | 0.080 ± 0.014       |         |
| Mg II 2803        | 4346.039            | 0.061 ± 0.013       |         |
| Mg I 2853         | 4422.670            | < 0.008             |         |
| **S5: Q1241 + 174; $z_{abs} = 0.55844$** |                    |                     |         |
| Fe II 2587        | 4031.147            | ...                 |         |
| Fe II 2600        | 4052.221            | < 0.012             |         |
| Mg II 2796        | 4357.955            | 0.135 ± 0.014       |         |
| Mg II 2803        | 4369.143            | 0.066 ± 0.019       |         |
| Mg I 2853         | 4446.182            | < 0.008             |         |
| **S6: Q0002 + 051; $z_{abs} = 0.59149$** |                    |                     |         |
| Fe II 2344        | 3730.781            | < 0.026             |         |
| Fe II 2374        | 3778.919            | < 0.032             |         |
| Fe II 2383        | 3792.135            | < 0.020             |         |
| Fe II 2587        | 4116.615            | < 0.014             |         |
| Fe II 2600        | 4138.136            | < 0.012             |         |
| Mg II 2796        | 4450.352            | 0.103 ± 0.008       |         |
| Mg II 2803        | 4461.778            | 0.064 ± 0.011       |         |
| Mg I 2853         | 4540.449            | < 0.010             |         |
| **S7: Q0454 + 036; $z_{abs} = 0.64283$** |                    |                     |         |
| Fe II 2344        | 3851.138            | < 0.031             |         |
| Fe II 2374        | 3900.829            | < 0.019             |         |
| Fe II 2383        | 3914.471            | 0.029 ± 0.005       |         |
| Fe II 2587        | 4249.418            | 0.014 ± 0.004       |         |
| Fe II 2600        | 4271.634            | 0.037 ± 0.014       |         |
| Mg II 2796        | 4593.923            | 0.118 ± 0.008       |         |
| Mg II 2803        | 4605.716            | 0.081 ± 0.009       |         |
| Mg I 2853         | 4686.926            | < 0.005             |         |
| **S8: Q0823 – 223; $z_{abs} = 0.70547$** |                    |                     |         |
| Fe II 2344        | 3997.991            | < 0.019             |         |
| Fe II 2374        | 4049.577            | < 0.016             |         |
| Fe II 2383        | 4063.739            | < 0.017             |         |
| Fe II 2587        | 4411.459            | < 0.008             |         |
| Fe II 2600        | 4434.522            | < 0.008             |         |
| Mg II 2796        | 4769.100            | 0.092 ± 0.007       |         |
| Mg II 2803        | 4781.344            | 0.044 ± 0.011       |         |
| Mg I 2853         | 4865.650            | < 0.005             |         |
## TABLE 3—Continued

| Ion and Transition | \( \lambda_{abs} \) (Å) | EW, (Å) |
|-------------------|-----------------|--------|
| S16: Q1241 + 174; |                  |        |
| Fe n 22344        |                 |        |
| Fe n 22374        |                 |        |
| Fe n 22383        |                 |        |
| Fe n 22587        |                 |        |
| Fe n 22600        |                 |        |
| Mg n 22796        |                 |        |
| Mg n 22803        |                 |        |
| Mg 1 2853         |                 |        |
| S17: Q1634 + 706; |                  |        |
| Fe n 22344        |                 |        |
| Fe n 22374        |                 |        |
| Fe n 22383        |                 |        |
| Fe n 22587        |                 |        |
| Fe n 22600        |                 |        |
| Mg n 22796        |                 |        |
| Mg n 22803        |                 |        |
| Mg 1 2853         |                 |        |
| S18: Q0454 + 036; |                  |        |
| Fe n 22344        |                 |        |
| Fe n 22374        |                 |        |
| Fe n 22383        |                 |        |
| Fe n 22587        |                 |        |
| Fe n 22600        |                 |        |
| Mg n 22796        |                 |        |
| Mg n 22803        |                 |        |
| Mg 1 2853         |                 |        |
| S19: Q1206 + 456; |                  |        |
| Fe n 22344        |                 |        |
| Fe n 22374        |                 |        |
| Fe n 22383        |                 |        |
| Fe n 22587        |                 |        |
| Fe n 22600        |                 |        |
| Mg n 22796        |                 |        |
| Mg n 22803        |                 |        |
| Mg 1 2853         |                 |        |
| S20: Q0002 + 051; |                  |        |
| Fe n 22344        |                 |        |
| Fe n 22374        |                 |        |
| Fe n 22383        |                 |        |
| Fe n 22587        |                 |        |
| Fe n 22600        |                 |        |
| Mg n 22796        |                 |        |
| Mg n 22803        |                 |        |
| Mg 1 2853         |                 |        |
| S21: Q1329 + 412; |                  |        |
| Fe n 22344        |                 |        |
| Fe n 22374        |                 |        |
| Fe n 22383        |                 |        |
| Fe n 22587        |                 |        |
| Fe n 22600        |                 |        |
| Mg n 22796        |                 |        |
| Mg n 22803        |                 |        |
| Mg 1 2853         |                 |        |
| S22: Q1329 + 412; |                  |        |
| Fe n 22344        |                 |        |
| Fe n 22374        |                 |        |
| Fe n 22383        |                 |        |

## TABLE 3—Continued

| Ion and Transition | \( \lambda_{abs} \) (Å) | EW, (Å) |
|-------------------|-----------------|--------|
| Fe n 22344        |                 |        |
| Fe n 22374        |                 |        |
| Fe n 22383        |                 |        |
| Fe n 22587        |                 |        |
| Fe n 22600        |                 |        |
| Mg n 22796        |                 |        |
| Mg n 22803        |                 |        |
| Mg 1 2853         |                 |        |
| S23: Q1634 + 706; |                  |        |
| Fe n 22344        |                 |        |
| Fe n 22374        |                 |        |
| Fe n 22383        |                 |        |
| Fe n 22587        |                 |        |
| Fe n 22600        |                 |        |
| Mg n 22796        |                 |        |
| Mg n 22803        |                 |        |
| Mg 1 2853         |                 |        |
| S24: Q1213 + 033; |                  |        |
| Fe n 22344        |                 |        |
| Fe n 22374        |                 |        |
| Fe n 22383        |                 |        |
| Fe n 22587        |                 |        |
| Fe n 22600        |                 |        |
| Mg n 22796        |                 |        |
| Mg n 22803        |                 |        |
| Mg 1 2853         |                 |        |
| S25: Q0958 + 551; |                  |        |
| Fe n 22344        |                 |        |
| Fe n 22374        |                 |        |
| Fe n 22383        |                 |        |
| Fe n 22587        |                 |        |
| Fe n 22600        |                 |        |
| Mg n 22796        |                 |        |
| Mg n 22803        |                 |        |
| Mg 1 2853         |                 |        |
| S26: Q0450 + 132; |                  |        |
| Fe n 22344        |                 |        |
| Fe n 22374        |                 |        |
| Fe n 22383        |                 |        |
| Fe n 22587        |                 |        |
| Fe n 22600        |                 |        |
| Mg n 22796        |                 |        |
| Mg n 22803        |                 |        |
| Mg 1 2853         |                 |        |
| S27: Q0450 + 132; |                  |        |
| Fe n 22344        |                 |        |
| Fe n 22374        |                 |        |
| Fe n 22383        |                 |        |
| Fe n 22587        |                 |        |
| Fe n 22600        |                 |        |
| Mg n 22796        |                 |        |
| Mg n 22803        |                 |        |
| Mg 1 2853         |                 |        |
| S28: Q0958 + 551; |                  |        |
| Fe n 22344        |                 |        |
| Fe n 22374        |                 |        |
| Fe n 22383        |                 |        |
| Fe n 22587        |                 |        |
| Fe n 22600        |                 |        |
| Mg n 22796        |                 |        |
| Mg n 22803        |                 |        |
| Mg 1 2853         |                 |        |
| S29: Q0117 + 212; |                  |        |
| Fe n 22344        |                 |        |
| Fe n 22374        |                 |        |
| Fe n 22383        |                 |        |
| Fe n 22587        |                 |        |

Al m 1855        | 4135.015 | 0.042 ± 0.009 |
Al m 1863        | 4153.092 | 0.010 ± 0.005 |
Fe n 22344       | 5226.367 | 0.015 ± 0.014 |
Fe n 22383       | 5312.315 | 0.037 ± 0.010 |
Fe n 22587       | 5766.872 | 0.007 ± 0.007 |
Fe n 22600       | 5797.020 | 0.039 ± 0.017 |
Mg n 22796       | 6234.397 | 0.135 ± 0.010 |
Mg n 22803       | 6250.402 | 0.105 ± 0.010 |
Mg 1 2853        | 6360.612 | 0.007 ± 0.007 |
Al m 1863        | 4331.013 | 0.016 ± 0.004 |
Fe n 22344       | 5450.307 | 0.006 ± 0.002 |
Fe n 22374       | 5520.632 | 0.017 ± 0.007 |
Fe n 22383       | 5539.938 | 0.030 ± 0.010 |
Fe n 22587       | 6013.972 | 0.010 ± 0.005 |
| Ion and Transition | $\lambda_{abs}$ | EW, ($\lambda$) |
|--------------------|---------------|----------------|
| Fe II $\lambda2600$  | 6045.412      | 0.026 ± 0.009 |
| Mg II $\lambda2796$ | 6051.530      | 0.291 ± 0.009 |
| Mg II $\lambda2803$ | 6518.221      | 0.180 ± 0.011 |
| Mg II $\lambda2853$ | 6633.153      | 0.005 ± 0.002 |

$S30$: $Q0117+212$: $z_{abs} = 1.34297$

$Al III \lambda1855$ | 4345.600 | 0.031 ± 0.003 |
$Al III \lambda1863$ | 4364.461 | 0.022 ± 0.003 |
$Fe II \lambda2344$ | 5492.421 | 0.018 ± 0.005 |
$Fe II \lambda2374$ | 5563.289 | <0.014 |
$Fe II \lambda2383$ | 5582.745 | 0.029 ± 0.004 |
$Fe II \lambda2587$ | 6060.441 | 0.012 ± 0.005 |
$Mg II \lambda2796$ | 6051.530 | ... |
$Mg II \lambda2803$ | 6568.586 | 0.153 ± 0.008 |
$Mg II \lambda2853$ | 6684.406 | <0.010 |

3.1.12. $S12 (Q1634 + 706; z_{abs} = 0.81816)$

There is no previous report of S12. The Mg II is very weak, with $W_r(2796) = 0.03$ Å. There is no detection of Mg I, where the signal-to-noise ratio is quite high, or of Fe II. C IV was not detected in the FOS/HST spectrum (see also Bahcall et al. 1996).

3.1.13. $S13 \ (Q1421 + 331; z_{abs} = 0.84325)$

There is no previous report of S13. However, Uomoto (1984) reported two unidentified weak lines in his low-resolution spectrum; these two lines correspond to Fe II $\lambda2600$ and $\lambda2374$ at this redshift. This system is very rich in Fe II transitions. Also, Mg I was detected. A FOS/HST spectrum of this QSO was not available.

3.1.14. $S14 \ (Q1248 + 401; z_{abs} = 0.85455)$

There is no previous report of S14, which exhibits multiple components. Fe II was detected only in the strongest Mg II component. C IV was reported by Jannuzi et al. (1998) in the FOS/HST spectrum and is confirmed in our search. There is no galaxy candidate (C. Steidel 1998, private communication).

3.1.15. $S15 \ (Q0002 + 051; z_{abs} = 0.86653)$

There is no previous report of S15. This is the weakest system in our survey, with $W_r(2796) = 0.018$ Å. In Figure 3 we show the detection of this system. Fe II and Mg I were captured by the CCD, but neither was detected. The equivalent widths may be biased by a zero-point uncertainty, which has not been included in the error measurement. C IV was not detected in the FOS/HST spectrum (see also Jannuzi et al. 1998). The Q0002 + 051 field has been studied in detail and there is no galaxy (to roughly 0.2L$_{Mg}$) observed at this redshift within 20' of the QSO (C. Steidel 1998, private communication).

3.1.16. $S16 \ (Q1241 + 174; z_{abs} = 0.89549)$

There is no previous report of S16. Neither Fe II nor Mg I were detected. C IV was not detected in the FOS/HST spectrum (see also Jannuzi et al. 1998). There is no galaxy candidate (C. Steidel 1998, private communication).

3.1.17. $S17 \ (Q1634 + 706; z_{abs} = 0.90555)$

There is no previous report of detected Mg II in S17, though C IV was reported by Bergeron (1994) and Bahcall et al. (1996). Mg I was not detected, where the signal-to-noise ratio is high, nor was Fe II.

3.1.18. $S18 \ (Q0454 + 036; z_{abs} = 0.93150)$

S18 was studied by Churchill & Le Brun (1998), who found no C IV in the FOS/HST spectrum and no galaxy at this redshift. Fe II $\lambda2383$ was detected, and Fe II $\lambda2600$ would likely have been detected, but the region of the spectrum was compromised by the pen mark on the HIRES CCD. There is a tentative detection (2.7 $\sigma$) of Fe II $\lambda2587$. Mg I was not detected.

3.1.19. $S19 \ (Q1206 + 456; z_{abs} = 0.93428)$

S19 was studied by Churchill & Charlton (1998). No Fe II transitions were detected, nor was Mg I. S19 may be a member of a small group of galaxies. Kirhakos et al. (1992) identified 10 galaxies within 100' of the QSO, three of which are within 10'. Thimm (1995) found strong [O II] $\lambda3727$ emission at $z = 0.93$ from one of these galaxies. In the FOS/HST spectrum, C IV and O VI are clearly present (see Jannuzi et al. 1998; Churchill & Charlton 1998).

3.1.20. $S20 \ (Q0002 + 051; z_{abs} = 0.95603)$

There is no previous report of S20. Neither Fe II nor Mg I was detected. The equivalent widths may be biased by a zero-point uncertainty, which has not been included in the error measurement. C IV was detected in the FOS/HST spectrum (see also Jannuzi et al. 1998). The Q0002 + 051 field has been studied in detail, and there is no galaxy (to roughly 0.2L$_{Mg}$) observed at this redshift within 20' of the QSO (C. Steidel 1998, private communication).

3.1.21. $S21 \ (Q1329 + 412; z_{abs} = 0.97387)$

There is no previous report of S21. The $\lambda2803$ transition is near the CCD edge. Fe II was not detected. Mg I may have been detected, but only at the 2.5 $\sigma$ level. A nonrestrictive limit was placed in C IV, which falls in the Lyz forest in the FOS/HST spectrum. There is no galaxy candidate (C. Steidel 1998, private communication).

3.1.22. $S22 \ (Q1329 + 412; z_{abs} = 0.99836)$

There is no previous report of S22. The system has strong Fe II absorption. Mg I was not captured by the CCD. C IV was not detected in the FOS/HST spectrum. There is no galaxy candidate (C. Steidel 1998, private communication).

3.1.23. $S23 \ (Q1634 + 706; z_{abs} = 1.04144)$

There is no previous report of detected Mg II in S23, though C IV was reported by Bergeron et al. (1994) and Bahcall et al. (1996). Even at very high signal-to-noise ratio, neither Fe II nor Mg I was detected.

3.1.24. $S24 \ (Q1213 + 003; z_{abs} = 1.12770)$

There is no previous report of S24. This system had a "false alarm" probability of $P_{fa} = 0.009$, the largest in the
sample. Fe II λ2383 may have been detected at the 3σ level, but there are two nearby 3σ features. We conservatively quote a limit. A ground-based spectrum covering C IV was not found in the literature.

3.1.25. S25 (Q0958+551; z_{abs} = 1.21132)

There is no previous report of S25. Neither Fe II nor Mg I was detected. A ground-based spectrum covering C IV was not found in the literature.

3.1.26. S26 (Q0450−132; z_{abs} = 1.22948)

S26, a multicomponent system, was reported by SS92. The system is strong in Fe II absorption in the strongest Mg II component. The Al III λλ1855, 1863 doublet was detected in the strongest component (see also Petitjean, Rauch, & Carswell 1994). This is the lowest redshift system in which Al III was covered. Mg I was not detected. A ground-based spectrum covering C IV was not found in the literature.
3.1.27. S27 \((Q0450 - 132; z_{\text{abs}} = 1.23244)\)

There is no previous report of S27. The Mg II profiles is in two components. Fe II and Mg I were detected in the narrow component. However, the Mg I detection is ambiguous. A ground-based spectrum covering C IV was not found in the literature.

3.1.28. S28 \((Q0958 + 551; z_{\text{abs}} = 1.27238)\)

There is no previous report of S28. Fe II was detected; however, the \(\Delta 2600\) equivalent width is unphysically large with respect to the more robust \(\Delta 2383\) equivalent width. Mg I was detected but is deemed uncertain. Sargent, Boksenberg, & Steidel (1988a) reported C IV at this redshift.
3.1.29. S29 (Q0117+212; \( z_{\text{abs}} = 1.32500 \))

S29 was reported by SS92. The system is comprised of five distinct components. Fe II was detected in three of the five components. Al III \( \lambda 1863 \) was also detected in three components; Al III \( \lambda 1855 \) was not captured by the CCD. Mg I was detected in the weakest Mg II component, and in this component there is no Al III. C IV absorption was reported by SS92, though the doublet was not resolved. There are candidate galaxies for this system (C. Steidel 1998, private communication).

3.1.30. S30 (Q0117+212; \( z_{\text{abs}} = 1.34297 \))

S30 was also reported by SS92. Only the \( \lambda 2803 \) transition of the Mg II doublet was captured. As such, this system would not have been detected in our unbiased doublet search. It is not a member of our adopted sample, nor was it included in any of the system statistics. The Mg II profile is comprised of four components. Mg I was not detected. Fe II was detected in the dominant, but narrow, Mg II component. Also, Al III was found in this component. C IV was reported by SS92, though the doublet was not resolved. There are candidate galaxies for this system (C. Steidel 1998, private communication).

3.2. Survey Completeness

To evaluate the completeness of the survey as a function of redshift, we have adopted the formalism used by SS92 and LTW, namely, the “redshift path density,” \( g(W, z) \). This function gives the number of sight lines along which a Mg II \( \lambda 2796 \) transition at redshift \( z \) and with rest-frame equivalent
width greater than or equal to $W$ could have been discovered. Because of the high resolution of the spectra, we have slightly modified the computation of the redshift path density to include sensitivity to the Mg II doublet ratio. Thus, we have $g(W, z, DR)$, the number of sight lines along which an Mg II doublet at redshift $z$ with $\lambda 2796$ rest-frame equivalent width greater than or equal to $W$ and with doublet ratio less than $DR$ could have been detected.

The cumulative redshift path length covered by the survey over a given redshift interval is then

$$Z(W, DR) = \int_{z_1}^{z_2} g(W, z, DR) dz,$$

where we have chosen not to integrate over the range $0 \leq z \leq \infty$ because our $g(W, z, DR)$ drops dramatically for $z_1 < 0.4$ and for $z_2 > 1.4$. In Figure 4 we have plotted the cumulative redshift path of the survey as a function of $W_{\text{min}}$ for $DR_{\text{max}} = 1$ (dotted curve) and for $DR_{\text{max}} = 2$ (solid curve). It is apparent that the redshift path, and thus the survey completeness, is not sensitive to the doublet ratio. We are 91% complete at $W_r(2796) = 0.03$ Å (5σ), and 80% complete at $W_r(2796) = 0.02$ Å. For comparison, SS92 were 83% complete at $W_r(2796) = 0.3$ Å.

4. THE STATISTICAL PROPERTIES OF WEAK Mg II ABSORBERS

4.1. Redshift Number Density

Since we are unbiased only for $W_r(2796) < 0.3$ Å, we calculated the number of absorbers per unit redshift, $dN/dz$, for this limited range using the formalism of LTW. From equation (2), we computed the redshift path length, $Z(W, DR)$, over which the $i$th system could have been detected in our survey. The values are presented in Table 2. The number per unit redshift path is simply the sum of the reciprocal of the cumulative redshift path lengths,

$$\frac{dN}{dz} = \sum_i \frac{N_{\text{sys}}}{Z(W_i, DR_i)},$$

(3)
The variance in $dN/dz$ is given by

$$\sigma_{dN/dz}^2 = \sum_{i=1}^{N_{sys}} [Z(W_i, DR_i)]^{-2}.$$  \hspace{1cm} (4)

Over the redshift range $0.4 \leq z \leq 1.4$, we obtained

$$dN/dz = 1.74 \pm 0.11 \text{ for } 0.02 \leq W_r(2796) < 0.3 \text{ Å},$$  \hspace{1cm} (5)

where $\langle z \rangle = 0.9$. In the left panel of Figure 5, we have plotted $dN/dz$ versus redshift for $0.02 \leq W_r(2796) < 0.3$ Å, for three redshift bins, [0.40, 0.74], [0.74, 1.07], and [1.07, 1.40]. The curves represent the no-evolution expectations for $q_0 = 0.5$ (dashed curve) and for $q_0 = 0$ (dotted curve) normalized to $dN/dz = 1.74$ at $z = 0.9$. We have assumed the standard parameterization, $dN/dz = N_0(1 + z)^\gamma$, where $\gamma = 1$ for $q_0 = 0$ and $\gamma = 0.5$ for $q_0 = 0.5$. A formal fit yielded $\gamma = 1.3 \pm 0.9$ and $N_0 = 0.8 \pm 0.4$. The data are not inconsistent with the no-evolution expectations for either $q_0$. In the right panel of Figure 5, we have plotted the mean $dN/dz$ and its uncertainty at $\langle z \rangle = 0.9$ for (1) the $W_r^{min}(2796) = 0.3$ Å MG1 sample of SS92, which has $dN/dz = 0.91 \pm 0.10$; (2) the combined $W_r^{min}(2796) = 0.02$ Å sample, which has $dN/dz = 2.65 \pm 0.15$; and (3), the HST Key Project results for a sample of Lyman limit systems (LLSs), which has $dN/dz = 0.7 \pm 0.2$ over the interval $0.4 \leq z \leq 1.4$ (Stengler-Larrea et al. 1995).

*Taken at face value, these numbers imply that weak Mg II absorbers comprise ~65% of the total Mg II absorber population and that the vast majority of them must arise in sub-LLS environments.* We return to this point in § 5.1. The $dN/dz$ of weak Mg II absorbers is roughly 5%–7% of that of the Lyα forest with $W_r(Ly\alpha) \geq 0.1$ Å (Jannuzi et al. 1998). We tentatively suggest that ~5% of $z \leq 1$ “Lyα forest clouds” with $0.1 \leq W_r(Ly\alpha) \leq 1.6$ Å will exhibit Mg II...
absorption to a 5σ $W_r(2796)$ detection limit of 0.02 Å. The two Mg II systems found by Churchill & Le Brun (1998) in a search through 28 forest clouds in the spectrum of PKS 0454 + 039 are consistent with these expectations.

4.2. Equivalent Width Distribution

The distribution function, $n(W)$, is defined as the number of Mg II absorption systems with equivalent width $W$ per unit equivalent width per unit redshift path. It has been customary to parameterize the distribution by either an exponential,

$$n(W)dW = \left( \frac{N^*}{W^*} \right) \exp \left( -\frac{W}{W^*} \right) dW$$

(6)

or a power law,

$$n(W)dW = C W^{-\delta} dW$$

(7)

where $N^*$ and $W^*$ (for the exponential) and $C$ and $\delta$ (for the power law) are parameters obtained by fitting the data. TBSYK fitted the distribution with a power law of $\delta \approx 2$ for a sample with $W^\text{min}_{\text{2796}} = 0.25$ Å and mean redshift $\langle z \rangle \approx 0.5$. For $W^\text{min}_{\text{2796}} = 0.3$ Å systems at $\langle z \rangle \approx 1.6$, LTW fitted the distribution to both an exponential and a power-law distribution (the latter in agreement with TBSYK). LTW concluded that both adequately represented the data, with the exponential distribution slightly favored. SS92 found that $n(W)$ could be parameterized tolerably well either by an exponential, with $N^* \approx 1.5$ and $W^* \approx 0.66$, or by a power law, with $C \approx 0.4$ and $\delta \approx 1.65$. SS92 noted that the exponential underpredicted the number of $W_r(2796) \leq 0.5$ Å systems, whereas the power law underpredicted the

Fig. 3.—S15 Mg II doublet detection (5σ) illustrated from our detection software. S15 is the weakest system in the sample and the (unresolved) profile shapes of the $\lambda 2796$ and 2803 transitions are quite different, with the $\lambda 2803$ profile being broader. This system provides an example of the detection sensitivity of our doublet-searching algorithm. The limiting observed equivalent width on this order is roughly 0.02 Å, which corresponds to 0.011 Å in the rest frame of the $\lambda 2796$ transition at these wavelengths. The top panel shows the spectrum and the uncertainty spectrum. The lower panel shows the equivalent width spectrum (average of zero). Pixels with positive equivalent widths are emission features and those with negative equivalent widths are absorption features. The uncertainty in the equivalent width spectrum is shown at both 1σ (inner) and 5σ (outer) levels. A feature is objectively identified when a pixel has an equivalent width that is larger than the 5σ uncertainty. The vertical dashed lines are to illustrate the locations of the identified features.

where the curves have been normalized at $z = 0.9$ (see text). Right: A comparison of the Mg II $dN/dz$ for different $\lambda 2796$ equivalent width cutoffs with the LLS $dN/dz$. The $W_r(2796) \geq 0.3$ Å number is taken from SS92, and the Lyman limit data are taken from Stengler-Larrea et al. (1995).

Fig. 4.—Redshift path of the survey over the redshift interval $0.4 \leq z \leq 1.4$ vs. the rest frame Mg II $\lambda 2796$ equivalent width threshold for a 5σ detection level. The dotted curve is for unit doublet ratio and the solid curve is for DR = 2.

Fig. 5.—Left: The number of Mg II systems per unit redshift, $dN/dz$, with $0.02 \leq W_r(2796) < 0.3$ Å for three redshift bins over the interval $0.4 \leq z \leq 1.4$. The vertical error bars are the Poisson uncertainties in the $dN/dz$ and the horizontal give the redshift bins. The dotted curve is the no-evolution expectation for $q_0 = 0$ and the dashed curve is for $q_0 = 0.5$, where the curves have been normalized at $z = 0.9$ (see text). Right: A comparison of the Mg II $dN/dz$ for different $\lambda 2796$ equivalent width cutoffs with the LLS $dN/dz$. The $W_r(2796) \geq 0.3$ Å number is taken from SS92, and the Lyman limit data are taken from Stengler-Larrea et al. (1995).
number with "intermediate" equivalent widths, those with 0.7 ≤ \( W_r(2796) \leq 1.3 \) Å.

In Figures 6a and 6b, we present \( n(W) \) for \( W_r(2796) \geq 0.0165 \) Å. We are 70% complete to this equivalent width. Solid triangles are the results from our survey. The data have been binned accounting for the redshift path length over which the equivalent widths could have been detected. The three equivalent width bins are [0.0165, 0.1], [0.1, 0.2], and [0.2, 0.3] Å. Shown as solid circles are the binned equivalent width data from SS92 (see their Fig. 6), which span the range 0.3 ≤ \( W_r(2796) \leq 2.8 \) Å. Figure 6a illustrates the dramatic increase in \( n(W) \) with decreasing equivalent width. There is no turnover or break in the equivalent width distribution for 0.02 ≤ \( W_r(2796) < 0.3 \) Å at \( z = 0.9 \).

The lack of a turnover is further illustrated in Figure 6b, which shows log \( n(W) \) versus log \( W_r(2796) \). The solid curve is a power law with \( \delta = 1.04 \), which was obtained by minimizing the absolute deviation between the curve (eq. [7]) and the binned data. The absolute deviation for the presented fit is 0.07 (in log-log). This fit is also presented in Figure 6a. It would be proper to fit the combined data of this survey and SS92 using the maximum likelihood technique employed by LTW, TBSYK, and SS92. This would require that we invoke the \( g(W, z) \) function of SS92 and reanalyze the SS92 data over the redshift interval 0.4 ≤ \( z \leq 1.4 \). However, with this work, it is our intent to clearly demonstrate the absence of a turnover in the equivalent width distribution at small equivalent widths and to distinguish between the exponential and power-law parameterizations of the distribution. A reanalysis of the SS92 data was not required to demonstrate these points.

Neither equation (6) nor equation (7) accounts for redshift evolution in the distribution. However, such evolution has been observed. TBSYK found evidence for more large equivalent width absorbers at high redshift than at low redshift. PB90 noted that the ratio of "weak" to "strong" absorbers, demarcated by \( W_r(2796) = 0.6 \) Å, increased with decreasing redshift. SS92 measured how the number-density evolution of Mg II systems changed as a function of \( W_r^{\min}(2796) \). As \( W_r^{\min}(2796) \) is increased, evolution becomes pronounced; large equivalent width systems evolve away with time. When \( W_r^{\min}(2796) = 0.3 \) Å is applied, the population of Mg II absorbers is consistent with no-evolution expectations. It appears that the evolution of the strongest systems, those with \( W_r(2796) > 0.6 \) Å, may have strongly biased the SS92 fits to the equivalent width distribution. To emphasize our point, we note that SS92 obtained a significantly steeper power law (\( \delta = 1.65 \)) than the one we quote here (\( \delta = 1.04 \)). This is likely due to the fact that the distribution of SS92 was fitted over the full redshift range 0.2 ≤ \( z \leq 2.2 \), resulting in a bias from the relative paucity of large equivalent width systems at \( z \leq 1.4 \). This is illustrated in Figure 6b, in which we have plotted both the power-law fit (dotted line) and the exponential fit (dash-dotted) from SS92. Note that the \( W_r(2796) \leq 1.3 \) Å data of SS92 also appear to be best described by the \( \delta = 1.04 \) power-law distribution.

In summary, there is no turnover in the equivalent width distribution for \( W_r(2796) < 0.3 \) Å, but there is a strong break above \( W_r(2796) \approx 1.3 \) Å for \( z \leq 1.4 \). The upper limit on the slope for \( W_r(2796) \geq 1.3 \) Å is \( \delta = 2.3 \).
4.3. Clustering and the Issue of a Biased Sample

The spectra used for this study are biased toward strong Mg II absorbers. If the weak Mg II systems tend to cluster around the stronger systems, then it is difficult to argue that the sample of weak systems is unbiased. On the other hand, if they do not cluster about the strong systems, we can conclude that the QSO sight lines are not biased toward an overabundance of weak systems.

We have computed the two-point velocity correlation function, which is presented in Figure 7, where the thick histogram distribution is the cross-correlation function of weak systems with respect to the strong systems. There are no weak systems with velocity separations less than 1000 km s\(^{-1}\) from the strong ones, and there is no apparent signal in the velocity separations. To test whether the weak systems are distributed like a random population with respect to the strong systems, we have computed the relative systems are distributed like a random population with signal in the velocity separations. To test whether the weak systems with velocity separations less than 1000 km s\(^{-1}\) have weak systems with respect to the strong systems. There are no weak systems with velocity separations less than 1000 km s\(^{-1}\) from the strong ones, and there is no apparent signal in the velocity separations. To test whether the weak systems are distributed like a random population with respect to the strong systems, we have computed the relative probability, \(P(\Delta v, \Delta r)\), of detecting a \(\Delta v\) separation from each strong absorption system. Following SS92, we have limited our co-moving velocity difference to \(\Delta v = 60,000\) km s\(^{-1}\) and have normalized the probability integral to the observed number of weak systems. Formally, the observed \(\Delta v\) distribution is not inconsistent with a random distribution; a \(\chi^2\) test on the binned data (1000 km s\(^{-1}\) bins) yielded a probability of 0.18 that the two distributions were drawn from the same parent population.

We examined the redshift clustering of the weak systems with respect to one another and found that it is not inconsistent with a random distribution. The \(\chi^2\) probability was 0.25. These results suggest that the weak systems are statistically consistent with a random cosmological distribution. We conclude that the QSO sight lines surveyed are unbiased for the presence of weak Mg II absorbers.

4.4. Absorption Properties

A more detailed examination of the cloud-to-cloud chemical and ionization conditions will be presented in a companion paper (Paper II). In the HIRES spectra, only Mg I \(\lambda\lambda 2853, 2344, 2374, 2383, 2587, \) and 2600, and the Al I \(\lambda\lambda 1855, 1863\) doublet were detected. In the FOS/HST spectra we have limited our search to C IV and supplemented this with measurements from ground-based observations taken from the literature. The statistics are as follows: 13 of 29 have detected Fe II (either \(\lambda\lambda 2238\) or \(\lambda\lambda 2600\)) and seven of 29 have detected Mg I \(\lambda\lambda 2853\) and each of these also has Fe II, three of four have detected Al II, and nine of 22 have C IV. The 3 \(\sigma\) average equivalent width threshold for Fe II is 0.01 Å for Fe II \(\lambda\lambda 2600\) and 0.008 Å for Mg I \(\lambda\lambda 2383\). The average threshold for Mg I absorption is 0.006 Å, for Al II is 0.01 Å, and for C IV is 0.16 Å.

Plotted in Figure 8 are the rest-frame Mg I \(\lambda 2796\) equivalent widths as a function of redshift. There appears to be no trend in the distribution of weak absorbers with redshift. We have run Spearman-Kendall (SK) nonparametric rank correlation tests to explore whether any correlations are present among the detected absorption properties (limits were not included). We tested redshifts, velocity widths, equivalent widths, and doublet ratios against one another and found no correlations. The most suggestive ranking was an anticorrelation between \(W_r(2796)\) and the Mg II doublet ratio at the 1.4 \(\sigma\) level. As seen in Figure 8, most, if not all, of the individual clouds in these weak absorbers have \(W_r(2796) \leq 0.15\) Å. The three \(W_r(2796) \geq 0.2\) Å systems, S2, S9, and S11, are likely comprised of two or more blended clouds. In the case of S2, the profile clearly has multiple clouds.

Several of the systems have multiple components. These systems are S10, S14, S26, S27, S29, and S30. The detection of these multiple features is not correlated with the signal-to-noise ratio in the spectra, since they could be detected to \(W_r(2796) = 0.02\) Å in 80% of the systems. Plotted in Figure 9 are the velocity widths, \(\omega_v\), of the full Mg II \(\lambda 2796\) profiles as a function of redshift. The dotted line at \(\omega_v = 2.46\) km s\(^{-1}\), which is the Gaussian width of the instrumental profile, shows the threshold for fully unresolved features. Systems that have been resolved into multiple individual “clouds” are marked with a concentric circle. Note that the

![Figure 7](image7.png)

**Fig. 7.** Two-point velocity cross-correlation function of weak and strong systems. Each bin gives the number of weak systems with velocity separations \(\Delta v\) (km s\(^{-1}\)) from strong systems along the same QSO sight line. The expected number in each bin for a random distribution is given by the thin histogram. There is no evidence that the weak systems cluster in velocity about the strong systems. This implies that the QSO sight lines, though biased for the strong systems, are in fact unbiased for the presence of weak systems.

![Figure 8](image8.png)

**Fig. 8.** Full system rest frame equivalent width of the Mg II \(\lambda 2796\) transition vs. the absorption redshift. There is no evidence of any trend in \(W_r(2796)\) with redshift. There is an indication that most all individual Mg II absorbing clouds likely have \(W_r(2796) \leq 0.15\) Å. Those systems that are comprised of multiple absorption features are marked with a concentric circle; the individual “cloud” \(W_r(2796)\) are \(\sim 0.15\) Å or less. The three remaining systems with \(W_r(2796) \sim 0.25\) Å have relatively poor signal-to-noise ratios; they are likely to be unresolved multiple clouds. See text for discussion.
many single “cloud” systems are unresolved or only marginally resolved. The same holds true for the individual clouds in the multiple cloud systems. The average velocity width, \( \omega_v \), of the individual “clouds” for the full sample is \( \sim 4 \) km s\(^{-1}\), which implies an average temperature of \( \sim 25,000 \) K for thermal broadening. Of the seven systems in which Mg I is detected, three have \( W_r(2796) \leq 0.11 \) Å. Two of the Mg I “clouds” are in multiple-component systems, S10 and S29, and these clouds have \( W_r(2796) = 0.11 \) Å and 0.05 Å, respectively. There does not appear to be a clear threshold for the presence of Mg I with the equivalent width of Mg II down to \( W_r(2796) \sim 0.1 \) Å. It appears that Mg I can survive in sub-LLS environments.

In Figure 10 we present \( W_r(1548) \) versus \( W_r(2796) \) from the data presented in Table 4. Included in this table are the number of absorption components (not Voigt profile components) seen in Mg II absorption, and \( W_r(2796) \), \( W_r(2600) \), and \( W_r(1548) \). Upper limits are denoted with downward arrows. A tentatively suggested ionization condition, either L (low), H (high), or M (multiphase), is given.

**TABLE 4**

| ID   | \( N_e \) | \( W_r(2796) \) (Å) | \( W_r(2600) \) (Å) | \( W_r(1548) \) (Å) | IC\(^a\) | Other References |
|------|----------|----------------------|----------------------|----------------------|--------|------------------|
| S1   | 1        | 0.179 ± 0.019        | ...                  | ...                  | ...    |                  |
| S2   | 1        | 0.258 ± 0.035        | <0.100               | <0.393               | ...    |                  |
| S3   | 1        | 0.030 ± 0.007        | <0.012               | <0.247               | 1      |                  |
| S4\(^c\) | 1    | 0.080 ± 0.014        | <0.009               | <0.645               | 2      |                  |
| S5\(^e\) | 1    | 0.115 ± 0.014        | <0.012               | 0.175 ± 0.055        | H?     | 1                |
| S6   | 1        | 0.103 ± 0.008        | <0.012               | <0.145               | 1      |                  |
| S7   | 1        | 0.118 ± 0.008        | 0.037 ± 0.014        | <0.130               | L      | 3                |
| S8   | 1        | 0.092 ± 0.007        | <0.008               | <0.130               | ...    |                  |
| S9   | 1        | 0.253 ± 0.012        | 0.017 ± 0.005        | ...                  | L?,M?  |                  |
| S10  | 5        | 0.238 ± 0.009        | 0.075 ± 0.016        | <0.088               | L      | 1                |
| S11  | 1        | 0.234 ± 0.024        | 0.101 ± 0.027        | ...                  | L?,M?  |                  |
| S12  | 1        | 0.030 ± 0.018        | <0.008               | <0.034               | L?     | 4                |
| S13  | 1        | 0.086 ± 0.008        | 0.071 ± 0.014        | ...                  | L?,M?  |                  |
| S14  | 6        | 0.235 ± 0.014        | 0.031 ± 0.007        | 0.718 ± 0.600        | M      | 1                |
| S15  | 1        | 0.023 ± 0.008        | <0.010               | <0.110               | ...    |                  |
| S16  | 1        | 0.018 ± 0.005        | <0.005               | <0.093               | ...    |                  |
| S17  | 1        | 0.064 ± 0.004        | <0.005               | 0.169 ± 0.017        | H      | 4, 5             |
| S18\(^c\) | 1    | 0.042 ± 0.005        | 0.022 ± 0.008        | <0.111               | L      | 3                |
| S19  | 1        | 0.049 ± 0.005        | <0.004               | 0.204 ± 0.042        | H      | 1, 6             |
| S20  | 1        | 0.052 ± 0.007        | <0.005               | 0.479 ± 0.040        | H      | 1                |
| S21\(^d\) | 1    | 0.181 ± 0.035        | <0.028               | <0.389               | ...    |                  |
| S22  | 1        | 0.142 ± 0.010        | 0.058 ± 0.017        | <0.119               | L      |                  |
| S23  | 1        | 0.097 ± 0.008        | <0.038               | 0.424 ± 0.018        | H?     | 1, 4, 5          |
| S24  | 1        | 0.036 ± 0.006        | <0.010               | ...                  | ...    |                  |
| S25  | 1        | 0.060 ± 0.007        | <0.006               | ...                  | ...    |                  |
| S26  | 2        | 0.135 ± 0.010        | 0.039 ± 0.017        | ...                  | L?,M?  |                  |
| S27\(^e\) | 2    | 0.101 ± 0.009        | 0.008 ± 0.007        | ...                  | ...    |                  |
| S28  | 1        | 0.081 ± 0.007        | 0.017 ± 0.004        | 0.440 ± 0.030        | M      | 7                |
| S29  | 6        | 0.291 ± 0.011        | 0.026 ± 0.009        | 0.890 ± 0.060        | M      | 8                |
| S30  | 4        | 0.153 ± 0.008        | 0.022 ± 0.004        | 0.670 ± 0.050        | M      | 8                |

\(^a\) Limits are 3 \( \sigma \).

\(^b\) L, H, and M refer to low-, high-, and multiphase ionization conditions. See text for definitions.

\(^e\) Unrestrictive limit due to complex blend in Ly\( \alpha \) forest. Ambiguous case.

\(^d\) C IV \( \lambda 1548 \) transitions could be Ly\( \alpha \) line.

\(^c\) \( W_r(2600) \) scaled from measured \( W_r(2383) \) by ratio of oscillator strengths.

**REFERENCES**—(1) Jannuzi et al. 1998; (2) Impey et al. 1996; (3) Churchill & Le Brun 1998; (4) Bahcall et al. 1996; (5) Bergeron et al. 1994; (6) Churchill & Charlton 1988; (7) Sargent et al. 1988a; (8) Steidel & Sargent 1992.
Based upon photoionization models, the data are designated as low- or multiphase ionization conditions (filled circles), high ionization (open circles), or undetermined (open squares). See text for definitions. Downward arrows give upper limits on the \( W_r(1548) \) two upward arrows are lower limits for an assumed optically thick doublet ratio in unresolved optical data taken from the literature. The dotted line is \( W_r(1548) / W_r(2796) \).

Filled circles are those designated as L or M, open circles as H, and boxes as undetermined ionization conditions. We elaborate on these inferred conditions in § 5.2, where the terms L, H, and M are defined and photoionization models are presented.

In summary, we find that a typical individual Mg II–absorbing cloud is characterized by \( W_r(2796) \leq 0.15 \) \( \AA \) and a temperature of \( \sim 25,000 \) K. The presence or nonpresence of Mg I does not appear to have a threshold dependence upon \( W_r(2796) \) down to 0.1 \( \AA \), and the ionization conditions appear to cover a broad range as inferred from the equivalent width ratios of C IV, Fe II, and Mg II.

5. ON THE NATURE OF WEAK Mg II ABSORBERS

5.1. Comparison with Lyman Limit Systems

A corresponding Lyman limit break is almost always found in UV spectra at the redshift of a strong Mg II absorber (Lanzetta 1988). Thus, the majority of strong Mg II absorbers are believed to arise in LLS environments. We are led to conclude that virtually all weak Mg II absorbers arise in sub-LLS environments, as can be inferred directly from Figure 5 (right panel). The \( dN/dz \) of \( W_{r}^{min}(2796) \) = 0.3 \( \AA \) Mg II absorbers and of LLS absorbers are consistent within uncertainties, with the number density of the strong Mg II absorbers being slightly higher (SS92; Stengler-Larrea et al. 1995). However, for the \( W_{r}^{min}(2796) \) = 0.02 \( \AA \) Mg II absorbers (combined sample of this work and SS92), \( dN/dz = 2.65 \), which is a factor of \( 3.8 \pm 1.1 \) greater than that of the strong Mg II–LLS absorbers.

That weak Mg II systems arise in sub-LLS environments is also consistent with the expectations for photoionized clouds. From preliminary Voigt profile fits, we have found \( 10^{11.8} \leq N(Mg II) \leq 10^{13.2} \) \( \text{cm}^{-2} \) for the individual clouds. We built a grid of photoionization models using CLOUDY (Ferland 1996), where we have assumed a Haardt & Madau (1996) extragalactic UV background spectrum normalized at \( z = 1 \) and a solar abundance pattern with \( [Z/Z_{\odot}] = -1 \) (which can be interpreted as the “gas-phase metallicity,” accounting for possible dust depletion of Mg II). The model clouds are constant-density plane parallel slabs, each defined by its neutral hydrogen column density, \( N(H I) \), and ionization parameter, \( U = n_e/n_H \), where \( n_e \) and \( n_H \) are the number density of photons capable of ionizing hydrogen and the total hydrogen number density, respectively.

![Fig. 10.—\( W_r(1548) \) vs. \( W_r(2796) \). Based upon photoionization models, the data are designated as low- or multiphase ionization conditions (filled circles), high ionization (open circles), or undetermined (open squares). See text for definitions. Downward arrows give upper limits for an assumed optically thick doublet ratio in unresolved optical data taken from the literature. The dotted line is \( W_r(1548) = W_r(2796) \).](image)

![Fig. 11.—Mg II column density vs. total hydrogen column density for a grid of CLOUDY photoionization models, assuming a Haardt & Madau (1996) UV flux at \( z = 1 \). A \( Z = 0.1 Z_{\odot} \) abundance pattern has been assumed. The solid curves are contours of constant \( N(H I) \) and the dotted curves are contours of constant ionization parameter, \( \log U \). The shaded region gives the locus of measured \( N(Mg II) \) for the sample, based upon Voigt profile fits to the data (Paper II). For this abundance pattern, clouds that have \( N(Fe II)/N(Mg II) \sim 1 \) must have low ionization, \( \log U \sim -3.5 \). The arrow shows how the grid would move if the metallicity of the models were decreased by 1 dex.](image)
In conclusion, if the weak Mg~II~ absorbers are photoionized by a Haardt & Madau–like spectrum, then the cloud metallicities are (1) \([Z/Z_\odot] \geq -1\) with \([\alpha/Fe] \sim [\alpha/Fe]_\odot\), or (2) \([Z/Z_\odot] \) slightly below \(-1\) with \([\alpha/Fe] > [\alpha/Fe]_\odot\) by a factor of a few. Such abundance patterns are consistent with those observed in the Galaxy (Lauroesch et al. 1996; Savage & Sembach 1996). The metallicity cannot typically be significantly lower than \([Z/Z_\odot] = -1\), since that would require an implausibly large enhancement of \([\alpha/Fe]\) with respect to the solar ratio.

5.2. Comparison with C~IV~ Systems: Ionization Conditions

Sargent et al. (1988a) found \(dN/dz = 1.76 \pm 0.33\) for C~IV~ at \(\langle z \rangle = 1.5\) for a sample complete to \(W_{r_{\text{min}}}^{\text{CIV}} (1548) = 0.3\ \AA\). We note that this value is consistent with the number per unit redshift of the weak Mg~II~ systems at \(\langle z \rangle = 0.9\). Does this imply that the population of systems selected by weak Mg~II~ absorption are, in essence, the same population as selected by the presence of C~IV~ with \(W_{r_{\text{min}}}^{\text{CIV}} (1548) = 0.3\ \AA\)? It is not expected that all weak Mg~II~ systems at \(\langle z \rangle = 0.9\) would have associated C~IV~ with \(W_{r_{\text{min}}}^{\text{CIV}} (1548) \geq 0.3\ \AA\,\text{since the C~IV~ number density is seen to decrease with decreasing redshift for this equivalent width threshold. Berge\-}

Fig. 12.—Photoionization models with \(N(H\ I) = 10^{16.5} \text{ cm}^{-2}\) for solar abundance patterns with \([Z/Z_\odot] = -1\) (left panels) and \([Z/Z_\odot] = 0\) (right panels). The upper panels show the observed column densities as a function of ionization parameter, and the lower panels show the rest frame equivalent widths for \(b = 6 \text{ km s}^{-1}\) for C~IV\ (1548), Mg~II\ (2796), Fe~II\ (2600), Mg~I\ (2853), and Al~III\ (1855). Low and high ionization (L and H, respectively) are defined by the ratio of \(W(\text{C~IV})/W(\text{Mg~II})\).
frame equivalent widths for a Doppler parameter of \( b = 6 \) km s\(^{-1}\), the median velocity width of the individual Mg \( \equiv \) absorption components.\(^{12}\) The models presented have Mg \( \equiv \) 2796 equivalent widths consistent with the observed range for individual components (see Fig. 8). For these sub-LLS clouds, the models show no temperature or ionization structure with cloud depth; the kinetic temperature is the same for all ionization species. For the modeled column densities, Mg \( \equiv \) 2853, Fe \( \equiv \) 2600, and Al \( \equiv \) 1855 are on the linear part of the curve of growth (\( b \)-independent). For Mg \( \equiv \) 2796 and C \( \equiv \) 1548, the value of the \( b \) parameter becomes important for column densities greater than \( \sim 10^{11} \) and \( \sim 10^{13} \) cm\(^{-2}\), respectively. We have neglected thermal scaling of the \( b \) parameters, which would yield slightly elevated C \( \equiv \) equivalent widths.

The demarcation between low- and high-ionization absorbers (L and H, respectively, as marked on Figs. 12c and 12d) is given by the ratio \( W(1548)/W(2796) \), which greater than unity designates high ionization (Bergeron et al. 1994). For these single-phase photoionization models, high-ionization clouds have \( N(\text{Fe} \equiv) < N(\text{Mg} \equiv) \) and \( N(\text{Fe} \equiv) \approx N(\text{C} \equiv) \). For low-ionization gas there is a range of \( N(\text{Fe} \equiv) \) as compared to \( N(\text{C} \equiv) \) and \( N(\text{Mg} \equiv) \). For very low ionization conditions, \( N(\text{Fe} \equiv) \) can be comparable to \( N(\text{Mg} \equiv) \), with both much larger than \( N(\text{C} \equiv) \). We would not expect C \( \equiv \) to be reported in the literature or found in FOS/HST spectra for clouds with \( W(2600)/W(2796) > 0.1 \) (roughly). In fact, for no case in which we have detected Fe \( \equiv \) would we expect a high-ionization single-phase cloud as defined by \( W(1548)/W(2796) \geq 1 \). The point is that the presence of Fe \( \equiv \) absorption at a nonnegligible level is a strong indicator of low-ionization conditions for single-phase clouds. The above arguments remain valid for \( N(\text{H} \equiv) = 10^{17} \) cm\(^{-2}\) cloud models in which some ionization structure is present, resulting in roughly constant \( N(\text{Mg} \equiv) \) as a function of log \( U \), but identical behavior in \( N(\text{Fe} \equiv) \) and \( N(\text{C} \equiv) \).

As seen in Table 4, of the 22 systems for which both C \( \equiv \) and Fe \( \equiv \) were available, four have Fe \( \equiv \) but no C \( \equiv \) (S7, S10, S18, and S22). These are low-ionization systems. Five of 22 systems have C \( \equiv \) but no Fe \( \equiv \) (S5, S17, S19, S20, and S23) to \( W(2600) \approx 0.1 \); these may be high-ionization systems. Four of 22 systems have both C \( \equiv \) and Fe \( \equiv \) (S14, S28, S29, and S30), two of which (S28 and S29) also have Mg \( \equiv \). The simultaneous presence of Fe \( \equiv \) and C \( \equiv \) implies that a single cloud or a single-phase absorption model is not adequate. From this, we speculate that S11, S13, and S26 are either low- or multiphase systems because of their having substantial Fe \( \equiv \), even though we have no information on C \( \equiv \). Overall, it appears that the population of metal-line absorbers selected by weak Mg \( \equiv \) absorption have a range of ionization conditions, possibly including multiphase conditions. In Figure 10 we have illustrated these suggested ionization conditions.

5.3. Evidence for Multiphase Ionization

From Figure 12, we see that it is difficult to obtain \( W(1548) > 0.2 \) Å for single-phase photoionization models with profile widths (i.e., \( b \) parameters) consistent with those observed for individual Mg \( \equiv \) components. This is because of the very flat dependence of \( W(1548) \) on \( N(\text{C} \equiv) \) for the small \( b \) parameters implied by the individual Mg \( \equiv \) components. This upper limit holds for higher \( N(\text{H} \equiv) \) cloud models. The upshot is that \( W(1548) \) is significantly greater than \( \sim 0.2 \) Å in a single-component absorber with \( W(2796) \leq 0.2 \) Å, one of two possibilities can be inferred: Either (1) the absorber has multiple ionization phases, such that the Mg \( \equiv \) arises in a cooler low-ionization region embedded in a higher ionization medium, or (2) additional multiple components (spatially distinct) are observed in C \( \equiv \) but not in Mg \( \equiv \), in which case a high-resolution spectrum of the C \( \equiv \) profile would be required to determine the ionization level of the components seen in Mg \( \equiv \).

Three of the four systems exhibiting both C \( \equiv \) and Fe \( \equiv \) absorption, S14, S29, and S30, have multiple unblended components spread over \( \sim 100 \) km s\(^{-1}\). It is quite plausible that they are multiphase, that low-ionization Mg \( \equiv \) components are embedded in a high-ionization “halo.” Consider S29, which has six components. We estimated \( W(1548) \approx 0.9 \) Å (lower limit) from the unresolved C \( \equiv \) equivalent width reported by SS92. For \( N(\text{H} \equiv) \leq 10^{17} \) cm\(^{-2}\), the C \( \equiv \) equivalent width could be produced as the component sum of high-ionization clouds (near-solar metallicity required), each component contributing \( \sim 0.2 \) Å to the total C \( \equiv \) equivalent width. However, this is unlikely because the Fe \( \equiv \) absorption enforces low-ionization conditions in the phase giving rise to Mg \( \equiv \) absorption. The mean equivalent width of the individual Mg \( \equiv \) 2796 components is 0.05 Å and that of Fe \( \equiv \) 2600 is 0.015 Å. Referring to Figure 12, the mean ratio of \( W(2600)/W(2796) \) is 0.3 for \( W(2796) \approx 0.05 \) Å implies ionization parameters in the range \( -3.5 \leq \log U \leq -4 \); these are low-ionization clouds. Thus, the overall absorption properties of S29 are more consistent with low-ionization Mg \( \equiv \) components embedded in a high-ionization medium or juxtaposed with additional spatially distinct high-ionization components.

5.4. The Physical Sizes of the Absorbers

The measured \( dN/dz \) can be used to constrain their physical sizes, assuming that all absorbers are associated with luminous galaxies (Steidel 1995; Churchill et al. 1996). For a Schechter (1976) function, \( \Phi(L)DL = \Phi^\ast(L/L^\ast)^{p-1} \exp(-L/L^\ast)DL \), there are two important parameters: the faint-end slope, \( \alpha \), and the density of \( L^\ast \) galaxies, \( \Phi^\ast \). Second, a Holmberg (1975) dependence, \( R(L) = R^\ast(L/L^\ast)^p \), of the spatial extent of the absorbing gas on the luminosity of the galaxy is assumed, where \( R^\ast \) is the fiducial size of an \( L^\ast \) galaxy. The product \( \sigma_R \) is given by \( \sigma_R = \pi \int_{L_{\min}}^{L_{\max}} \Phi(L)R^\ast(L)DL \), which simplifies to

\[
\sigma = \pi \Phi^\ast R^\ast \int_{\min}^{\max} (\alpha + 2\beta + 1, L_{\min}/L^\ast) ,
\]

where \( \Gamma \) is the incomplete gamma function, which accounts for the additional assumption of a minimum luminosity, \( L_{\min} \), at which a galaxy will no longer exhibit Mg \( \equiv \) absorption to a well-defined detection level at any impact parameter. Assuming no evolution in the redshift path density of absorbing galaxies, the relation between \( \sigma_R \) and the measured \( dN/dz \) is

\[
dN/dz = \frac{\sigma_R}{H_0} (1+z)(1+2q_0 z)^{-1/2} .
\]
For $W_{\text{min}}(2796) = 0.3$ Å, Steidel (1995) directly measured $\beta = 0.15$ and $R^* = 38 h^{-1}$ kpc for the Holmberg relation and $L_{\text{min}}/L^* \sim 0.06$ for $K$-band luminosities. From this, Steidel et al. (1994) deduced a faint-end slope of $x = -1$ and a number density of $\Phi^* = 0.03 h^3$ Mpc$^{-3}$ for galaxies selected by the presence of Mg II absorption. These values are in good agreement with the values $x = -0.9$ and $\Phi^* = 0.033 h^3$ Mpc$^{-3}$ measured for the Canada-France Redshift Survey (CFRS) sample of galaxies over the similar redshift range of $0.0 \leq z \leq 1.3$ (Lilly et al. 1995). However, it is not entirely clear that the radius-luminosity relationship measured by Steidel (1995) is applicable when the equivalent width detection threshold is lowered to $W_{\text{min}}(2796) = 0.02$ Å. Nor is there a prior reason to assume that the $L_{\text{min}}/L^*$ = 0.06 cutoff should apply for a population of galaxies selected by $W_{\gamma}(2796) < 0.3$ Å absorption. It is possible that low surface brightness (LSB) galaxies contribute to the measured $dN/dz$ of weak Mg II absorbers$^{13}$ (Impey & Bothun 1989; Churchill & Le Brun 1998). At redshift $z \sim 0$, Dalcanton et al. (1997) have measured $\Phi^* = 0.08 h^3$ Mpc$^{-3}$ for LSB galaxies with central surface brightnesses of $23$ mag arcsec$^{-2}$ $\leq \mu_0(V) \leq 25$ mag arcsec$^{-2}$. This is a factor of $\sim 2.5$ higher than the number density of CFRS and Mg II-selected galaxies, which exhibit the Freeman (1970) central surface brightness of $\mu_0(B) = 21.7$ mag arcsec$^{-2}$. Thus, we do not simply assume that the luminosity function of galaxies selected by weak Mg II absorption would have the same number density as that found by Steidel et al. (1994) for strong systems.

For $W_{\gamma}(2796) = 0.02$ Å, we found $dN/dz = 2.71$ at $\langle z \rangle = 0.9$. Writing equation (8) to obtain $R^*$ as a function of $\Phi^*$, $L_{\text{min}}/L^*$, and $\beta$ gives

$$R^* = 79.5 h^{-1} [(\Phi^*/\Phi^*_{\text{CRS}})(2\beta, L_{\text{min}}/L^*)]^{-1/2} \text{kpc}, \quad (10)$$

where it is assumed that the absorbing gas is spherically distributed and has unity covering factor.$^{14}$ For $L_{\text{min}}/L^* = 0.06$, $\beta = 0.15$, and $\Phi^*/\Phi^*_{\text{CRS}}$ $\sim 1$, the inferred $R^*$ is $63 h^{-1}$ kpc. If LSB galaxies have the same absorbing properties as do those observed by Steidel (1995), then the combined galaxy population would have $\Phi^*/\Phi^*_{\text{CRS}} \sim 3$ (Dalcanton et al. 1997), which yields $R^* \sim 35 h^{-1}$ kpc. This is surprisingly consistent with the $R^*$ measured by Steidel (1995) for $W_{\gamma}(2796) > 0.3$ Å absorption-selected galaxies. For $L_{\text{min}}/L^* = 0$, $\beta = 0.15$, and $\Phi^*/\Phi^*_{\text{CRS}}$ $\sim 1$, the inferred size is $R^* = 46 h^{-1}$ kpc. If $\beta = 0$ with $L_{\text{min}}/L^* = 0.06$, then $R^* = 53 h^{-1}$ kpc. If $\beta = 0.4$ (the historically invoked “Holmberg” value), then $R^* = 77 h^{-1}$ kpc.

5.5. Evolution of $n(W)$

If the absorbing gas is photoionized by the extragalactic UV background, then ionization conditions are expected to be higher at higher redshifts. In fact, Bergeron et al. (1994) have found that the ratio of high- to low-ionization metal-line absorbers increases with increasing redshift at a rate that is not inconsistent with a factor of $\sim 5$ increase in the UV background (Kulkarni & Fall 1993). Our observations place no constraint on the evolution of the weak Mg II absorbers over this redshift range.

In principle, it might be that at $z \sim 2$ the Mg II equivalent width distribution exhibits a cutoff at the smallest equivalent widths. It is also expected that the power-law slope of the distribution is flatter for larger equivalent widths at $z \sim 2$ (there are more large $W_{\gamma}(2796)$ absorbers at high redshift) than that measured in this work at $z \sim 1$. This implies a very curious effect in the inferred evolution of Mg II absorption strengths as the minimum equivalent width of the sample covering $0.4 \leq z \leq 2.2$ is continually decreased. It is well established that for $W_{\gamma}(2796) = 0.3$ Å, the population is consistent with no-evolution expectations, and that the lack of evolution is dominated by the lower end of the equivalent width distribution to this $W_{\gamma}(2796)$. When $W_{\gamma}(2796)$ is increased, the evolution becomes pronounced in that the ratio of “large” to “small” $W_{\gamma}(2796)$ absorbers increases with increasing redshift (SS92). Since the UV background is more intense at higher redshifts, one would expect that the presence of Mg II is increasingly dependent upon photon shielding by neutral hydrogen; at $z \sim 2$ (and above), it would be expected that Mg II would not survive in sub-LLS environments (see also discussion in § 7 of SS92). Therefore, as $W_{\gamma}(2796)$ is decreased from $0.3$ Å to $\sim 0.02$ Å for a $0.4 \leq z \leq 2.2$ sample, evolution should again become apparent, this time because of a paucity of weak systems at the higher redshifts. This trend is tentatively suggested by the fact that at $\langle z \rangle = 0.9$ there is a $30\%$ difference between the $dN/dz$ of $W_{\gamma}(2796) = 0.3$ Å absorbers and LLS absorbers, whereas there is only an $8\%$ difference at $\langle z \rangle = 2$ (SS92; Stengler-Larrea et al. 1995).

6. SUMMARY

We searched for weak Mg II $\lambda 2897, 2803$ doublets, those with rest frame equivalent widths $W_{\gamma}(2796) < 0.3$ Å, in HIRES/Keck spectra of 26 QSOs. The QSO sight lines are unbiased for these weak systems. The cumulative redshift path was $Z \sim 17$ over the range $0.4 \leq z \leq 1.4$ and $Z \sim 0.7$ for $1.4 \leq z \leq 1.7$. The survey was complete to $W_{\gamma}(2796) = 0.06$ Å and $80\%$ complete to $W_{\gamma}(2796) = 0.02$ Å, where we have enforced a $5 \sigma$ detection limit. A total of 30 systems were detected, of which 23 were discovered in these spectra. The Mg II $\lambda 2853$ transition was detected in seven of the systems and Fe II, especially the $\lambda 2600$ and/or the $\lambda 2383$ transition, was detected in half of the systems. When Al III $\lambda 1865$, 1863 was covered, we found it in three of four systems. From a literature search and a search we conducted in archival FOS/HST spectra, we detected C IV in nine of 22 covered systems to $3 \sigma$ equivalent width threshold of $0.03$ to $0.3$ Å (rest frame). No systems were found at $1.4 \leq z \leq 1.7$, though this is consistent with expectations when we extrapolate from lower $z$, given that the cumulative redshift path was only $Z \sim 0.7$ over this redshift range. We have combined our sample with the $W_{\gamma}(2796) \geq 0.3$ Å sample MG1 of SS92, taken over the redshift interval $0.4 \leq z \leq 1.4$, and measured the redshift number density and equivalent width distribution of Mg II absorbers with $W_{\gamma}(2796) \geq 0.02$ Å.

Main results from this work include the following:

1. The redshift path density of weak Mg II absorbers was measured to be $dN/dz = 1.74 \pm 0.11$. There is no evidence for evolution in the redshift path density, but the measured
value of $\gamma = 1.3 \pm 0.9$ is not constraining. Incorporating the Mg i sample of SS92 [$W_{\text{min}}^i(2796) = 0.3$ Å], we find that the total number density per unit redshift for systems with $W_{\text{min}}^i(2796) = 0.02$ Å at $\langle z \rangle = 0.9$ is $dN/dz = 2.65 \pm 0.15$. The $dN/dz$ of weak Mg ii absorbers is roughly 5%–7% of that of the Lyx forest with $W_r(\text{Lyx}) \geq 0.1$ Å (Jannuzi et al. 1998). Thus, it is plausible that $\sim 5\%$ of $z \sim 0.9$ “Lyz clouds” will have detectable Mg ii absorption to $W_r(2796) = 0.02$ Å.

2. For $W_{\text{min}}^i(2796) = 0.02$ Å, Mg ii absorbers at $\langle z \rangle = 0.9$ outnumber LLS absorbers by a factor of 3.8 ± 1.1. That the populations of strong Mg ii absorbers and LLS are indistinguishable (Lanzetta 1988) strongly suggests that virtually all of the weak Mg ii systems arise in sub-LLS environments. It is possible that the weak Mg ii systems have high metallicities, whether their ionization conditions are low or high (see Figs. 11 and 12). Photoionization models, using FeI’s CLOUDY, are consistent with this conclusion; many weak Mg ii absorbers probably have $[Z/Z_c] \geq -1$. Lower metallicities require $N(\text{H i})$ above the Lyman limit value, which is not allowed because the ratio of $dN/dz$ of weak Mg ii absorbers to that of LLS absorbers requires that almost all weak Mg ii absorbers have $N(\text{H i})$ near or below the Lyman limit value.

3. The equivalent width distribution was found to follow a power law with slope $\delta \sim 1.0$ down to $W_r(2796) = 0.017$ Å. There is no turnover or break in the equivalent width distribution for $W_r(2796) < 0.3$ Å at $\langle z \rangle = 0.9$. A single power-law slope does not describe the equivalent width distribution over the full redshift range $0.3 \leq z \leq 2.2$. For $z < 1.4$, there is a break (a significantly steeper slope) in the distribution for $W_r(2796) > 1.3$ Å. The upper limit on this slope is $\delta = 2.3$.

4. Most, if not all, of the individual clouds in these weak absorbers have $W_r(2796) \leq 0.15$ Å. Their line widths are narrow, with an average of $\sim 4$ km s$^{-1}$, implying temperatures of $\sim 25,000$ K. The presence of Mg i is not correlated with $W_r(2796)$ or with the Mg ii doublet ratio. In fact, Mg i absorption is present in at least one component having $W_r(2796)$ as small as $0.08$ Å. Statistically, there appears to be no $W_r(2796)$ threshold for the presence of Mg i down to $W_r(2796) \sim 0.1$ Å.

5. The weak Mg ii absorbers may comprise a diverse population, including low-, high-, and multiphase ionization systems. The low-ionization systems would be immediately recognizable by the presence of $W(2600)/W_r(2796) \geq 0.1$. In a single Mg ii component with $b \leq 6$ km s$^{-1}$ and $W_r(2796) < 0.2$ Å, the presence of C iv with $W_r(1548) \geq 0.2$ Å, and especially the simultaneous presence of Fe ii and C iv, may be due to multiphase absorption or additional spatially distinct high-ionization components in which Mg ii has not been detected. In an absorber with $N_c$ components in which the individual components have $b \leq 6$ km s$^{-1}$ and $W_r(2796) < 0.2$ Å, multiphase or additional high-ionization components are likely if the total system C iv equivalent width is larger than $\sim N_c \times 0.2$ Å. Again, this is especially true if the individual Mg ii components have $W_r(2600)/W_r(2796) \geq 0.1$.

6. The velocity clustering of weak Mg ii absorbers around strong ones is consistent with a random distribution; a $\chi^2$ test yielded a probability of 0.18 that clustering was drawn from a random distribution. Furthermore, we examined the redshift clustering of the weak systems with respect to one another and found that the systems are also not inconsistent with a random distribution. The $\chi^2$ probability was 0.25. We conclude that the QSO sight lines surveyed for this work are unbiased for the presence of weak Mg ii absorbers.

7. Assuming the radius-luminosity relationship between gas and galaxies and the cutoff, $L_{\text{min}}$, in the Mg ii absorbing galaxy luminosity function (Steidel 1995), we inferred an $R^*$ for $W_r^m(2796) = 0.02$ Å Mg ii absorbers of $65 ~ h^{-1}$ kpc. If there is no radius-luminosity dependence, then $R^* \approx 55 ~ h^{-1}$ kpc. If there is no luminosity cutoff, then $R^* \approx 45 ~ h^{-1}$ kpc. If LSB galaxies have the same absorbing properties as do the Mg ii–selected galaxies observed by Steidel (1995), then the combined galaxy population would have $R^* \sim 35 ~ h^{-1}$ kpc. It is not inconsistent with the data to suggest that a nonnegligible fraction of the weak Mg ii absorbers are arising in LSB galaxies.

6.1. Objects Selected by Weak Mg ii Absorption

The question remains: what luminous objects could be associated with the large numbers of weak Mg ii systems at $0.4 \leq z \leq 1.4$? Do the galaxies selected by Mg ii absorption with $W_r(2796) \geq 0.3$ Å (Steidel 1995; Steidel et al. 1994) tell the whole story, or do they represent the “tip of the Mg ii iceberg”? Are weak Mg ii absorbers analogous to a bulk of material that lies hidden below the “galactic water line”? That is, are a substantial fraction not directly associated with bright galaxies, but rather associated with intergalactic material or “failed” galaxies? Given that only four of 20 have obvious galaxy counterparts, it is not clear that the surface brightnesses of the star-forming environments associated with weak Mg ii absorbers are above the Freeman (1970) value. It could be that the successful broad band imaging technique for identifying the luminous counterparts of strong Mg ii absorbers in QSO fields will be less effective for locating many of the counterparts associated with weak Mg ii absorbers.

If weak Mg ii absorption arises in the extended regions of Mg ii absorption–selected galaxies, it likely is most often occurring at large impact parameters (a region of $D \geq 40 ~ h^{-1}$ kpc; beyond the well-probed regions within 10" of the QSO). It is possible that some fraction of the Lyx lines seen to arise beyond $\sim 40$ kpc of large extended halos or disks of galaxies (Lanzetta et al. 1995; Le Brun, Bergeron, & Boissier 1996) give rise to weak Mg ii absorption. An alternative possibility is that some fraction of the weak Mg ii population is selecting sub-LLS environments around LSB galaxies or low-luminosity galaxies, those with $L_K < 0.06L_K^*$. That is, some fraction of weak systems could arise in “normal” high surface brightness galaxies (perhaps at greater impact parameters) and some fraction could arise in dwarf or large LSB galaxies.

Conceivably, LSB galaxies could significantly contribute to the weak Mg ii absorption cross section. At the low redshifts studied in this work, most sub-LLS absorbers are thought to be associated with LSB galaxies (Salpeter 1993; Linder 1998). Impey & Bothun (1989), upon reexamining the selection effects and assumptions that go into the calculations of galaxy cross sections from QSO absorbers, found that LSB galaxies are expected to dominate the absorption cross section. If so, why would it be that strong Mg ii absorbers are not associated with LSB galaxies more often than or as often as are normal bright galaxies? And when strong Mg ii absorption is associated with an LSB galaxy, why is it that the absorbers are damped Lyx systems
LSB galaxies typically have H I surface densities a factor of 2 lower than normal high surface brightness galaxies (de Blok, McGaugh, & van der Hulst 1996) and lower metallicities (McGaugh 1994). Further, the inner 15 h⁻¹ kpc of LSB galaxies are found to have N(H I) of a few times 10^{20} cm⁻² (de Blok, McGaugh et al. 1996), i.e., they are damped Lyα absorbers. It could be that some weak Mg II absorbers arise in LSB galaxies at galactocentric distances greater than ~15 h⁻¹ kpc, where the H I environment is sub–Lyman limit and clouds cannot have large Mg II column densities. Thus, it is possible that the strong Mg II (and Fe II) associated with damped Lyα absorbers in LSB galaxies arise in their inner regions, whereas only weak Mg II–absorbing clouds can survive in their outer regions.

Other possibilities include isolated star-forming or post–star-forming dwarf galaxies and/or pregalaxy fragments (Yanny & York 1992), or the remnant material left over from the formation of galaxies and/or small galaxy groups (Bowen, Blades, & Pettini 1995; van Gorkom et al. 1996; Le Brun et al. 1996). Narrowband imaging of emission lines at the absorber redshifts might provide a test for the former scenario, while charting the distribution of galaxies at the absorber redshifts in wide fields (~100°) centered on the QSOs might provide tests for the latter. A more detailed determination of the chemical and ionization conditions and identification of the luminous objects associated selected by weak Mg II absorption is the next logical step toward their further exploration.

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