A SPACE TELESCOPE IMAGING SPECTROGRAPH SURVEY FOR O VI ABSORPTION SYSTEMS AT 0.12 < z ≲ 0.5. II. PHYSICAL CONDITIONS OF THE IONIZED GAS

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ABSTRACT

We present a complete catalog of 27 O vi absorbers at low redshift (0.12 < z < 0.5) from a blind survey of 16 QSO echelle spectra in the Hubble Space Telescope Imaging Spectrograph data archive. These absorbers are identified based on matching line profiles and the expected doublet ratio between the λ1031, 1037 transitions. Subsequent searches are carried out to identify their associated transitions. Here we present all relevant absorption properties. By considering absorption components of different species that are well aligned in velocity space, we derive gas temperatures and nonthermal broadening values, bnt. We show that in all 16 cases considered the observed line width is dominated by nonthermal motion and that gas temperatures are well below those expected for O5+ in collisional ionization equilibrium. This result reaffirms previous findings from studies of individual lines of sight but are at odds with expectations for a WHIM origin. At least half of the absorbers can be explained by a simple photoionization model. In addition, in some absorbers we find evidence for large variation in gas density/metallicity across components in individual absorbers. Comparisons of multiple associated metal species further show that under the assumption of the gas being photoionized by the metagalactic background radiation field, the absorbing clouds have gas densities nH < −2.9 and sizes L > 1 kpc. Finally, we compare our absorber selection with the results of other independent studies.

Subject headings: cosmology: observations — intergalactic medium — quasars: absorption lines

Online material: color figures

1. INTRODUCTION

One of the current key questions in observational cosmology is the location of the missing baryons. The total baryon content of the universe is well constrained, with various measurements in relatively good agreement (e.g., Burles et al. 2001; Spergel et al. 2003; O’Meara et al. 2006). In the high-redshift universe, the Lyα forest dominates the baryon census (Rauch et al. 1997), but in the present-day universe, only one-third of the baryons have been identified in known components (Fukugita & Peebles 2004). Cosmological simulations indicate that up to 50% of the baryons exist in a warm-hot intergalactic medium (WHIM), in which gas is shock-heated to ≲105–107 K by the accretion onto large-scale filamentary structures, and remains hot owing to the low gas density and inefficient cooling (Cen & Ostriker 1999, 2006; Davé et al. 2001). This gas is a result of accretion onto large-scale filamentary structures, where cooling is inefficient due to the low densities, and (in some models) the operation of large scale winds that shock-heat outflowing gas to ≲106 K (e.g., Cen & Ostriker 2006). It is therefore important to identify this gas and constrain its contribution to the baryon fraction.

At the temperature range in question (log T = 5.0–7.0), the best observational window for this hot gas is X-ray absorption lines (e.g., O vii Kα, O viii Kα, and Ne ix Kα; Gnat & Sterberg 2007), but the resolutions of current X-ray spectrographs (e.g., Chandra and XMM-Newton) are an order of magnitude too coarse to be useful, and the sensitivities are more than an order of magnitude too low (e.g., Fang et al. 2006). The best tool currently available, therefore, is UV absorption spectroscopy. The O vi doublet (1031.9261, 1037.617 Å) offers the best hot gas tracer for a number of reasons: the transition has a large oscillator strength; oxygen is relatively common; the abundance of the O5+ ion peaks in collisional ionization equilibrium (CIE) at log T ≈ 5.2; the transitions occur longward of the Lyman limit; and absorption can be detected down to limiting column densities log N ≈ 13.5 (Wλ = 30 mÅ) with current instruments such as the Space Telescope Imaging Spectrograph.

If the absorption lines of an element are resolved and unsaturated, we can measure directly the column density (N) and Doppler parameter (b) of the absorbing gas by Voigt profile fitting. The Doppler parameter is an oft-used measure of the temperature of the gas, through the well-known relation b2 = bT2 + 2kT/m, where bT accounts for nonthermal broadening of the line due to, e.g., turbulence. The column density, meanwhile, may be used in conjunction with the path length to derive the contribution to the cosmological mass density of the O5+ ions, ΩO5+ (see Thom & Chen 2008, hereafter Paper I).

In the optical band, ground-based high-resolution (echelle) spectra have made O vi detection possible at 2.3 ≤ z ≤ 3 (e.g., Norris et al. 1983; Carswell et al. 2002; Simcoe et al. 2002). The lower limit is set by the plummeting transmissivity of the atmosphere to UV photons below ∼3500 Å, while the upper limit is set by confusion with the Lyα forest. In the high-redshift regime, O5+ is predominantly photoionized by the UV background radiation field, much the same as the Lyα clouds (Carswell et al. 2002; Gnat & Sterberg 2007). In cases where multiple transitions of the same species are available, a curve-of-growth analysis can also be used.

1 Based in part on observations with the NASA/ESA Hubble Space Telescope, obtained at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS5–26555.

2 It also has an ionization fraction greater than 10−2 up to log T ≈ 5.7; see e.g., Gnat & Sterberg (2007).

3 In cases where multiple transitions of the same species are available, a curve-of-growth analysis can also be used.
Simcoe et al. (2004). To push to lower redshifts, space-based UV spectographs are required. Using near-UV spectra from the Faint Object Spectrograph on board HST, Burles & Tyler (1996) identified 12 O \textsc{vi} doublets with $W_r(1031) > 0.21$ Å in the range $0.5 \leq z \leq 2$ and derived a cosmological mass density $\Omega_{\mathrm{OVI}}h^2 \geq 7 \times 10^{-8}$, providing the first constraint on the mass density of this highly ionized gas.

In the low-redshift universe ($z \leq 0.5$), the O \textsc{vi} doublet transition remains in the far-UV ($\lambda_{\text{obs}} \lesssim 1600$ Å). The terminated Far Ultraviolet Spectroscopic Explorer (FUSE; Moos et al. 2000) could probe O \textsc{vi} absorption out to $z \sim 0.15$ with good signal-to-noise, but at a resolution of only $\sim 20$ km s$^{-1}$ (e.g., Danforth & Shull 2005). This compares poorly with the thermal line width of O \textsc{vi} ($\sim 3$ km s$^{-1}$ at $T = 4.0$ and $\sim 10$ km s$^{-1}$ at $T = 5.0$). The (currently suspended) Space Telescope Imaging Spectrograph (STIS; Woodgate et al. 1998) on board the Hubble Space Telescope (HST) offers a resolution of $\sim 6$–7 km s$^{-1}$, and its data are useful for studies of O \textsc{vi} absorption at slightly higher redshifts than FUSE ($0.12 < z < 0.5$).

Early work on O \textsc{vi} absorption in the low-$z$ universe typically concentrated on single lines of sight, due to the paucity of data. Single-sight line or single-absorber analyses have been conducted on the various lines of sight, beginning with the QSO H1821+643 (Tripp et al. 1998, 2000, 2001; Oegerle et al. 2000). As more data become available, further sight lines were analyzed: PG 0953+415 (Savage et al. 2002), PG 1259+593 (Richter et al. 2004), PG 1116+215 (Sembach et al. 2004), PG 1209+030 (Cooksey et al. 2008). Now, with a database of UV data available, statistical approaches have become possible (Danforth & Shull 2005, 2008; Danforth et al. 2006; Thom & Chen 2008; Tripp et al. 2008).

This is the second in a series of papers reporting the results of our search for O \textsc{vi} absorption systems in the STIS E140M archive. Unlike other searches, we employ a blind search for O \textsc{vi} doublets, which is independent of a priori knowledge of the presence of other transitions such as Ly$\alpha$. In Paper I we reported results on the statistics of the O \textsc{vi} absorbers. The major results were (1) a measurement of the number of absorbers per unit redshift, $dN/W \geq 30$ mÅ$/dz = 10.4 \pm 2.2$; (2) a measurement of the cosmological mass density of the O$^{5+}$ gas, $\Omega_{\mathrm{OVI}}h = (1.7 \pm 0.3) \times 10^{-7}$; (3) $<5\%$ of O \textsc{vi} absorbers originate in underdense regions that do not show a significant trace of H$\beta$; (4) H I column densities of O \textsc{vi} absorbers span more than 5 orders of magnitude, and a moderate correlation exists between $N$(H$\beta$) and $N$(O \textsc{vi}); and (5) the number density of O \textsc{vi} absorbers along a given line of sight appears to be inversely correlated with the number density of H$\beta$ absorbers. In this paper we present our catalog of O \textsc{vi} absorbers on which the results of Paper I are based. We also address the physical conditions of the O$^{5+}$ bearing gas. The nature of the IGM, the O \textsc{vi} absorbers in particular, and their relation to the WHIM is an area that has seen much recent progress. At least two other groups have contemporaneously reported results of similar analyses. We refer the interested reader to the works of Tripp et al. (2008) and Danforth & Shull (2008). Specifically, see § 4 of Tripp et al. (2008) for comments on the differences between both works.

We recall the description of our search and selection technique from Paper I in § 2, presenting the full table of absorbers. We discuss individual lines of sight, and present the measured quantities for each system, in § 3. In § 4 we discuss those systems reported in Table 1.

| QSO     | $z_{\text{QSO}}$ | $z_{\text{min}}$ | $z_{\text{max}}^a$ | $\xi_{\text{exp}}$ | PID |
|---------|-----------------|-----------------|-----------------|-----------------|-----|
| 3C 249.1 | 0.3115          | 0.1222          | 0.2885          | 68776           | 9184|
| 3C 273   | 0.1580          | 0.1144          | 0.1417          | 18671           | 8017|
| 3C 351.0 | 0.3719          | 0.1309          | 0.3483          | 73198           | 8015|
| HE 0226–4110 | 0.4950       | 0.1154          | 0.4707          | 43777           | 9184|
| HS 0624+6907 | 0.3700       | 0.1222          | 0.3464          | 61950           | 9184|
| H1821–643 | 0.2970          | 0.1144          | 0.2741          | 50932           | 8165|
| PG 0953+415 | 0.2390       | 0.1144          | 0.2163          | 24478           | 7747|
| PG 1116+215 | 0.1765       | 0.1144          | 0.1536          | 39836           | 8165/8097|
| PG 1216+069 | 0.3313       | 0.1309          | 0.3078          | 69804           | 9184|
| PG 1259+593 | 0.4778        | 0.1144          | 0.4533          | 95760           | 8695|
| PG 1444+407 | 0.2673        | 0.1222          | 0.2442          | 48624           | 9184|
| PHL 1811 | 0.1917          | 0.1144          | 0.1690          | 33919           | 9418|
| PKS 0312–77 | 0.2230        | 0.1241          | 0.1999          | 37908           | 8651|
| PKS 0405–12 | 0.5726        | 0.1241          | 0.5478          | 27208           | 7576|
| PKS 1302–102 | 0.2784        | 0.1183          | 0.2558          | 22119           | 8306|
| Ton 28 | 0.3297          | 0.1231          | 0.3059          | 48401           | 9184|

Notes.—This summary of STIS echelle lines of sight is taken from Paper I. It is repeated here for completeness.

* The maximum redshift is defined for O \textsc{vi} absorbers at velocity separation $>5000$ km s$^{-1}$ from the background QSO, but the line search is conducted through the emission redshift of the QSO. In this paper we do not consider system inside this $5000$ km s$^{-1}$ limit.

Tripp et al. (2008) that are not accepted by our selection criteria. The physical properties of the ionized gas selected via O \textsc{vi} absorption are discussed in § 5. Section 6 contains a summary and concluding remarks.

2. DATA AND CATALOG

2.1. STIS Data

Our data were drawn from the STIS data archive. The data and search technique are described in Paper I (see in particular § 2.1 for details). For completeness, we repeat parts of that description here. We chose all data with sufficient signal-to-noise ratio ($S/N \geq 5$ per pixel) and resolution, as to be able to detect weak ($W_r > 30$ mÅ) O \textsc{vi} absorbers. This selection yielded 16 lines of sight with STIS E140M data. Table 1 describes these lines of sight.

O \textsc{vi} absorbers were selected on the basis of the equivalent width ratio of the doublet lines alone. In order not to bias our search by the presence of other transitions, we do not consider other associated lines until a later stage. This differs from the traditional technique, which relies on a priori knowledge of absorber positions (usually from Ly$\alpha$) and then searches for possibly associated species. We began our search by Hanning smoothing the spectra and identifying all deviations $>1.5$ $\sigma$ from the continuum level. A Gaussian profile was fit to each feature, with the width restricted to $6$ km s$^{-1} < \sigma < 300$ km s$^{-1}$, where the lower limit is taken from the spectrograph resolution, and the upper limit from consideration of the line width distribution of known O \textsc{vi} systems (e.g., Heckman et al. 2002; Danforth & Shull 2005). An equivalent width was determined by directly integrating the data, with integration limits determined from the Gaussian width. All features with $<2$ $\sigma$ significance were rejected.

We consider each feature a putative O \textsc{vi} $\lambda$1031 line and fit a doublet absorption model to the data to determine whether...
the spectrum is consistent with the presence of both O\textsc{vi} \lambda\lambda 1031, 1037 lines. The doublet model requires both transitions to have the same line width and have a line strength ratio of 2:1 (i.e., the ratio of the oscillator strength–wavelength product, $f_{\lambda}$, for the two transitions). Each system was also visually inspected to determine whether the spectrum is consistent with the presence of a doublet. We accepted candidates if (1) the O\textsc{vi} \lambda 1031 member has $>$3 $\sigma$ significance and (2) the ratio of rest-frame line strengths $R_{O\textsc{vi}} = W_{1037}/W_{1031}$ lies between 1 $-$ $\sigma_{R_{O\textsc{vi}}}$ and $2 + 2 \sigma_{R_{O\textsc{vi}}}$. Finally, we visually identified other species associated with each absorber, typically searching for transitions of the ions H$^0$, Si$^+$, S$^+$, O$^{+}$, Ne$^{+}$, and Ne$^{++}$. The vpfit$^6$ software was used to fit Voigt profiles to all components of all detected species in each absorber. The vpfit software convolves the Voigt profile with a Gaussian line-spread function (LSF) whose width is set by the instrument resolution. The STIS LSF has significant broad wings in some configurations. We have tested that this difference does not affect our measurements of $N$ and $b$ (i.e., the differences are much smaller than the error in the measured values). The number, position, and initial values for the absorption components were assessed initially by eye. We performed a minimum-$\chi^2$ analysis that includes multiple components; new components were added and fit iteratively until either the normalized $\chi^2$ did not decrease, or the newly added component became ill-constrained (error bars for the best-fit parameters were greater than the best-fit values) by the data. For O\textsc{vi} and H$^1$, this process is typically facilitated by the presence of multiple transitions. Section 3 has details of the component structure for each absorber. The fits were used to evaluate the total column density for each absorber and are given in Table 2. Fit results for the individual components that comprise each absorber are given in Tables 3–17. In our fitting, we employed the latest version of the standard atomic data distributed with vpfit$^6$. These data are primarily from the compilation of Morton (2003) with some more recent updates included.

### 2.2. A Catalog of Random O\textsc{vi} Absorbers at $0.12 < z < 0.50$

The final catalog of O\textsc{vi} doublet systems is given in Table 2. The table lists the line of sight and redshift of the absorber, typically the redshift of the strongest O\textsc{vi} component (cols. [1] and [2]). Rest-frame equivalent widths ($W_\nu$), and errors ($\sigma_{W_\nu}$), are reported in units of mA (cols. [3]–[6]), for both lines of the O\textsc{vi} doublet. The ratio of equivalent widths, $R_{O\textsc{vi}}$, and associated error are listed in columns (7) and (8). Finally, columns (9) and (10) give the total O\textsc{vi} column density for the absorber, which is the sum of the individual components. Individual component fitting results are given in § 3.

### 3. Individual Lines of Sight

For each absorber in the following subsections, we present the results of our profile fitting in the associated figures and tables. Spectra are unbinned, and profile fits are overlayed as solid lines. The error spectrum is plotted as a solid line at the bottom of each panel, also unbinned. The dot-dashed lines indicate the continuum and zero flux levels. Component positions are marked above

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**TABLE 2**

**Summary of O\textsc{vi} Absorbers**

| QSO  | $z_{\text{abs}}$ | $W_\nu$ (1031) | $\sigma_{W_\nu}(1031)$ | $W_\nu$ (1037) | $\sigma_{W_\nu}(1037)$ | $R_{O\textsc{vi}}$ | $\sigma_{R_{O\textsc{vi}}}$ | $N_{O\textsc{vi}}$ | $\sigma_{N_{O\textsc{vi}}}$ |
|------|-----------------|----------------|------------------------|----------------|------------------------|----------------|------------------------|----------------|------------------------|
| 3C 249.1    | 0.24676        | 72.1           | 9.0                    | 31.0           | 9.0                    | 2.33           | 0.74                    | 13.9           | 0.1                    |
| 3C 273     | 0.12003        | 22.4           | 5.6                    | 21.5           | 5.6                    | 1.04           | 0.38                    | 13.5           | 0.1                    |
| 3C 351.0    | 0.31659        | 232.5          | 13.8                   | 139.8          | 13.8                   | 1.66           | 0.19                    | 14.4           | 0.1                    |
| H1821+643   | 0.22498        | 162.2          | 6.7                    | 108.5          | 6.7                    | 1.49           | 0.11                    | 14.3           | 0.0                    |
| H1821+643   | 0.22638        | 29.8           | 3.9                    | 19.7           | 3.9                    | 1.51           | 0.36                    | 13.5           | 0.1                    |
| H1821+643   | 0.24532        | 53.9           | 4.9                    | 36.0           | 4.9                    | 1.50           | 0.25                    | 13.7           | 0.1                    |
| H1821+643   | 0.26666        | 44.2           | 4.0                    | 23.7           | 4.0                    | 1.86           | 0.36                    | 13.6           | 0.1                    |
| HE 0226−4110 | 0.20702      | 165.3          | 8.9                    | 106.5          | 8.9                    | 1.55           | 0.15                    | 14.4           | 0.1                    |
| HE 0226−4110 | 0.32639      | 43.0           | 8.0                    | 15.8           | 8.0                    | 2.72           | 1.47                    | 13.6           | 0.2                    |
| HE 0226−4110 | 0.34034      | 62.1           | 6.6                    | 41.5           | 6.6                    | 1.50           | 0.29                    | 13.9           | 0.1                    |
| HE 0226−4110 | 0.35529      | 45.5           | 7.8                    | 11.5           | 7.8                    | 3.96           | 2.77                    | 13.6           | 0.2                    |
| HS 0624+6907 | 0.31796       | 43.7           | 6.0                    | 26.9           | 6.0                    | 1.62           | 0.43                    | 13.7           | 0.1                    |
| HS 0624+6907 | 0.33984       | 27.1           | 8.3                    | 22.5           | 8.3                    | 1.20           | 0.58                    | 13.4           | 0.3                    |
| HS 0624+6907 | 0.14232       | 121.2          | 22.3                   | 89.1           | 22.3                   | 1.36           | 0.42                    | 14.2           | 0.1                    |
| HS 0624+6907 | 0.13846       | 75.7           | 16.0                   | 38.0           | 16.0                   | 1.99           | 0.94                    | 13.9           | 0.1                    |
| PKS 0405−12 | 0.20702       | 26.4           | 5.6                    | 16.9           | 5.6                    | 1.56           | 0.61                    | 13.4           | 0.2                    |
| PKS 0405−12 | 0.21950       | 98.9           | 7.6                    | 21.1           | 7.6                    | 4.68           | 1.73                    | 13.9           | 0.1                    |
| PKS 0405−12 | 0.25981       | 77.0           | 8.3                    | 34.1           | 8.3                    | 2.26           | 0.60                    | 13.9           | 0.1                    |
| PKS 0405−12 | 0.15786       | 63.5           | 13.2                   | 39.2           | 13.2                   | 1.62           | 0.64                    | 13.9           | 0.2                    |
| PKS 0405−12 | 0.20275       | 655.3          | 20.1                   | 336.5          | 20.1                   | 1.95           | 0.13                    | 15.0           | 0.2                    |
| PKS 0405−12 | 0.16697       | 360.7          | 41.4                   | 236.7          | 41.4                   | 1.52           | 0.32                    | 14.7           | 0.1                    |
| PKS 1022−102 | 0.23740       | 25.6           | 7.0                    | 18.1           | 7.0                    | 1.41           | 0.67                    | 13.4           | 0.2                    |

Notes.—Redshift of absorbers is generally the position of the strongest component. Equivalent widths are rest-frame mÅ. Column densities are total column density for absorber, taken from component fitting. See individual systems for details.

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$^6$ See http://www.ast.cam.ac.uk/~rfc/vpfit.html.
3.1. 3C 249.1

The QSO 3C 249.1 lies at \( z_{\text{qso}} = 0.3115 \), and we searched for O vi absorption along the line of sight from \( 0.122 < z_{\text{abs}} < 0.2885 \). We identify a single O vi doublet system along this line of sight.

\[ z_{\text{abs}} = 0.24676 \] (Fig. 1; Table 3).—This system shows a clear detection of both O vi lines, strong Ly\( \alpha \), \( \beta \), and tentative Si iii \( \lambda 1206 \). The O vi \( \lambda 1037 \) line shows warm pixels on the very edges of the line wings, which do not affect our line fits. The blue wing of the Ly\( \beta \) line partially blends with another strong line, which we tentatively identify as Ly\( \alpha \) at \( z = 0.0517 \). We cannot check this assignment, as the corresponding Ly\( \gamma \) line for this putative assignment is below our wavelength range. In the unblended region, the model fit to the data is good. The Ly\( \gamma \) line is on the edge of the Galactic Ly\( \alpha \) trough and was excluded from our fits. The Si iii line is very weak and offset from the O vi and H i absorption (\( \Delta v = 11 \pm 3 \) km s\(^{-1} \)); its identification is thus uncertain. With the well-aligned O vi and H i components, we derive \( b_{\text{hm}} = 26.1 \) km s\(^{-1} \) and log \( T = 4.7 \); see § 5.2 for details.

3.2. 3C 273

The STIS data for 3C 273 (\( z_{\text{qso}} = 0.1583 \)) are of excellent quality but offer only a short path length over which to detect O vi doublet systems (\( 0.1144 < z_{\text{abs}} < 0.1417 \)). The lowest redshift absorber in our sample, at \( z_{\text{abs}} = 0.12003 \) is detected along this line of sight.

\[ z_{\text{abs}} = 0.12003 \] (Fig. 2; Table 4).—This narrow, weak, single-component absorber is the lowest redshift absorber in our sample and is detectable at such a low wavelength (\( \lambda_{\text{abs}} = 1156 \) Å) only due to the high-quality data for the 3C 273 sight line. For both O vi lines, while noisy, the data show corresponding profiles, and the model fits are satisfactory for both lines. The line strengths from direct integration of the data are mismatched (the equivalent width ratio is \( \sim 1.0 \pm 0.4 \)), but neither line can be weak Ly\( \alpha \) (the system is blueward of the Galactic Ly\( \alpha \) line). Of the H i lines, only Ly\( \alpha \) is present in our data at such low redshifts, and the line is unsaturated and well fit by a single component. Due to the simple structure, we are able to derive \( b_{\text{hm}} = 6.6 \) km s\(^{-1} \) and the gas temperature, log \( T = 4.5 \); see § 5.2 for details.

3.3. 3C 351.0

3C 351.0 lies at \( z_{\text{qso}} = 0.3716 \), giving a usable path length for detecting O vi systems \( 0.1309 < z_{\text{abs}} < 0.3483 \). We detect only a single O vi doublet along this line of sight.

\[ z_{\text{abs}} = 0.31659 \] (Fig. 3; Table 5).—This system shows a complex structure, with three well-defined O vi components present, and corresponding H i profiles. The Ly\( \alpha \) line is saturated, but the Ly\( \beta \) line shows three components that are well aligned with the O vi. The weak Ly\( \gamma \) line is noisier and less well fit by this H i model; the Ly\( \delta \) line is contaminated by Galactic S ii \( \lambda 1250 \) absorption. No C iii \( \lambda 977 \) is observed; the strong, putative C iii \( \lambda 977 \)

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**TABLE 3**

| Ion      | \( z_{\text{comp}} \) | \( v \) (km s\(^{-1} \)) | \( \sigma_v \) (km s\(^{-1} \)) | \( b \) (km s\(^{-1} \)) | \( \sigma_b \) (km s\(^{-1} \)) | \( \log N \) (cm\(^{-2} \)) | \( \sigma_{\log N} \) (cm\(^{-2} \)) | Flag |
|----------|----------------------|--------------------------|--------------------------|--------------------------|--------------------------|-----------------|--------------------------|------|
| O vi     | 0.24676              | 0                        | 0                        | 27.0                     | 3.2                      | 13.9            | 0.1                      |      |
| H i      | 0.24676              | 0                        | 1                        | 38.2                     | 1.4                      | 14.4            | 0.1                      |      |
| Si iii   | 0.24681              | 11                       | 3                        | 9.9                      | 5.6                      | 12.1            | 0.2                      | Z    |

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Fig. 1.—3C 249.1, \( z = 0.24676 \). O vi and strong H i are detected in this system. Ly\( \beta \) is blended with what we tentatively assign as Ly\( \alpha \) line at \( z = 0.0517 \). There is a weak and uncertain feature that may be Si iii \( \lambda 1206 \). [See the electronic edition of the Supplement for a color version of this figure.]
The H1821+643 (zabs = 0.297) line has been studied extensively in terms of intervening absorbers. Tripp et al. (1998) used GHRS and galaxy redshifts to study the Lyα absorbers. Tripp et al. (2000) followed up with STIS observations, focusing on O vi absorption, complemented by Oegerle et al. (2000) with FUSE observations. The STIS data allow us to search for O vi absorbers between 0.144 < zabs < 0.2741. We uncover four absorbers at zabs = 0.22496, 0.22638, 0.24532, 0.26656.

zabs = 0.22496 (Fig. 4; Table 6).—This absorber and the next (H1821+643; zabs = 0.22638) are separated by only ~350 km s^{-1}, but the two absorbers appear to be physically distinct systems (as opposed to components of the same absorption system). The O vi absorption consists of a broad, strong component, with a very weak, narrow component on the red edge. The associated Lyα, β lines are strongly saturated, while the Lyγ, δ lines show some saturation. Three separate H i components are included in the fit, but N(H i) is a lower limit; the two strong components are saturated in the three lowest-order Lyman lines, while the Lyδ line is very noisy. The C iii 4297 profile is similarly complex, with several possible weak components evident around the three main, strong components (at least two of which show signs of saturation). There are three well defined but unsaturated Si iii 13106 components corresponding to the strong C iii 4297 absorption lines. The v = 0 km s^{-1} component of Si iii and the v = -6 km s^{-1} C iii absorption component, while aligned with the main O vi absorption, cannot arise in the same gas phase, since, e.g., b_{Si iii} ≪ b_{O vi}, and we require 0.8 < b_{Si iii}/b_{O vi} < 1.0. These limits are discussed in more detail in § 5.2. At least two weak Si iv 14106 components are also present, which align with the two strongest C iii components but are too weak to be detected in the weaker Si iv 14102 doublet transition.

zabs = 0.22638 (Fig. 5; Table 6).—The weak absorber at z = 0.22638 is separated from the strong system at z = 0.22496 by only ~350 km s^{-1}. The O vi doublet is well fit by a weak, narrow, single-component absorption profile. Lyα absorption at v = -53 km s^{-1} shows a similar single-component profile. There is some evidence of weak C iii 4297 at the same velocity as the Lyα, but we could not obtain a satisfactory fit, and better quality data are needed to confirm this claim.

zabs = 0.24532 (Fig. 6; Table 6).—There are two weak O vi components in this system, with a single weak, broad H i component. There is possible N v present, corresponding the redmost O vi component, but the weak N v 1242 line is totally obscured by Galactic C iv 1548, and we regard this identification as uncertain.

zabs = 0.26656 (Fig. 7; Table 6).—This absorber is relatively simple, with well-aligned, single-component O vi and H i lines. The O vi and H i line centroids differ by only 4 km s^{-1}, and the good alignment permits us to derive gas temperature and nonthermal broadening of log T = 4.9 and b_{abs} = 24.4 km s^{-1}, respectively. Section 5.2 has the details of this derivation.

3.4. H1821+643
The H1821+643 (zabs = 0.297) line has been studied extensively in terms of intervening absorbers. Tripp et al. (1998) used GHRS and galaxy redshifts to study the Lyα absorbers. Tripp et al. (2000) followed up with STIS observations, focusing on O vi absorption, complemented by Oegerle et al. (2000) with FUSE observations. The STIS data allow us to search for O vi absorbers between 0.144 < zabs < 0.2741. We uncover four absorbers at zabs = 0.22496, 0.22638, 0.24532, 0.26656.

zabs = 0.22496 (Fig. 4; Table 6).—This absorber and the next (H1821+643; zabs = 0.22638) are separated by only ~350 km s^{-1}, but the two absorbers appear to be physically distinct systems (as opposed to components of the same absorption system). The O vi absorption consists of a broad, strong component, with a very weak, narrow component on the red edge. The associated Lyα, β lines are strongly saturated, while the Lyγ, δ lines show some saturation. Three separate H i components are included in the fit, but N(H i) is a lower limit; the two strong components are saturated in the three lowest-order Lyman lines, while the Lyδ line is very noisy. The C iii 4297 profile is similarly complex, with several possible weak components evident around the three main, strong components (at least two of which show signs of saturation). There are three well defined but unsaturated Si iii 13106 components corresponding to the strong C iii 4297 absorption lines. The v = 0 km s^{-1} component of Si iii and the v = -6 km s^{-1} C iii absorption component, while aligned with the main O vi absorption, cannot arise in the same gas phase, since, e.g., b_{Si iii} ≪ b_{O vi}, and we require 0.8 < b_{Si iii}/b_{O vi} < 1.0. These limits are discussed in more detail in § 5.2. At least two weak Si iv 14106 components are also present, which align with the two strongest C iii components but are too weak to be detected in the weaker Si iv 14102 doublet transition.

zabs = 0.22638 (Fig. 5; Table 6).—The weak absorber at z = 0.22638 is separated from the strong system at z = 0.22496 by only ~350 km s^{-1}. The O vi doublet is well fit by a weak, narrow, single-component absorption profile. Lyα absorption at v = -53 km s^{-1} shows a similar single-component profile. There is some evidence of weak C iii 4297 at the same velocity as the Lyα, but we could not obtain a satisfactory fit, and better quality data are needed to confirm this claim.

zabs = 0.24532 (Fig. 6; Table 6).—There are two weak O vi components in this system, with a single weak, broad H i component. There is possible N v present, corresponding the redmost O vi component, but the weak N v 1242 line is totally obscured by Galactic C iv 1548, and we regard this identification as uncertain.

zabs = 0.26656 (Fig. 7; Table 6).—This absorber is relatively simple, with well-aligned, single-component O vi and H i lines. The O vi and H i line centroids differ by only 4 km s^{-1}, and the good alignment permits us to derive gas temperature and nonthermal broadening of log T = 4.9 and b_{abs} = 24.4 km s^{-1}, respectively. Section 5.2 has the details of this derivation.

3.5. HE 0226–4110
The STIS spectrum of HE 0226–4110, at zabs = 0.495, allows us to search for intervening O vi absorbers in the interval 0.1154 < zabs < 0.4707. We identified O vi doublets at zabs = 0.20702, 0.326390, 0.34034, 0.35525. This line of sight has also been studied by Savage et al. (2005), who focused on the zabs = 0.20702 system, and Lehner et al. (2006), who studied the full path length using STIS and FUSE data.

zabs = 0.20702 (Fig. 8; Table 7).—The strong absorber at zabs = 0.20702 has associated H i, C iii 4297, Si iii 13106 and N v. The O vi 1037 transition differs from the single-component structure seen in O vi 1031, which is probably a result of bad pixels in the O vi 1037 region. We measure only a lower limit on

### TABLE 4

| Ion         | v       | \(\sigma_v\)  | \(\sigma_b\)  | \(\log N\) | \(\sigma_{\log N}\) | Flag |
|-------------|---------|---------------|---------------|-----------|---------------------|------|
| O vi        | 0.12003 | 0             | 1             | 8.6       | 2.5                 | 0.1  |
| H i         | 0.12004 | 3             | 0             | 23.2      | 0.6                 | 0.1  |
|             |         |               |               |           |                     |      |
| z = 0.12003 |         |               |               |           |                     |      |
$N(H\ i)$; the Ly$\alpha$ and Ly$\beta$ transitions are saturated, while the Ly$\gamma$ line is contaminated by hot pixels. Si$\ iii$ $\lambda 1037$ has two components blueward of the fiducial O$\ vi$ position, which roughly correspond to the saturated C$\ iii$ $\lambda 977$ line. The N$\ v$ lines are weak, and uncertain. (Savage et al. 2005) detected Ne$\ viii$ aligned with the O$\ vi$ absorption in FUSE data. They show this system is likely collisionally ionized, which is consistent with the single broad component in O$\ vi$ that we observe.

$z_{\text{abs}} = 0.32639$ (Fig. 9; Table 7).—We tentatively identify an O$\ vi$ doublet at $z_{\text{abs}} = 0.32639$ as the only system in our sample that shows no sign of H$\ i$ absorption. Both O$\ vi$ lines are well fit by a single doublet model, while the position of any putative Ly$\alpha$ line is in the redmost portion of the STIS wavelength coverage, making the data noisier than the O$\ vi$ region, as can be seen in Figure 9. Fixing the redshift and expected Doppler parameter from the O$\ vi$ profile, we set an upper limit on the H$\ i$ column density $N(H\ i) < 12.5$. No other transitions are present in this system. We note that Lehner et al. (2006) do not report identifications for either lines (see, e.g., their Fig. 3). We also note that the O$\ vii$ $\lambda 1037$ line is detected at low significance (only 2 $\sigma$) and emphasize that caution is required interpreting this system as H$\ i$ free. We suggest that further observations would be very valuable to confirm this system and whether it is H$\ i$ free.

$z_{\text{abs}} = 0.34034$ (Fig. 10; Table 7).—The O$\ vi$ $\lambda 1037$ line in this system is contaminated by an unidentified metal line at $v = -26 \text{ km s}^{-1}$, which is excluded from the fit. The Ly$\alpha$ line aligns well with the O$\ vi$ absorption but is in a poor-quality region of the spectrum, and the agreement between the Ly$\alpha$ and Ly$\beta$ profiles is poor. A weak, narrow C$\ iii$ $\lambda 977$ line is also detected, which aligns well with the O$\ vi$ and main H$\ i$ component. The Doppler parameter of the C$\ iii$ line, $b_{\text{C$\ iii$}}$, is significantly smaller than that of the O$\ vi$ component. This may be explained in several ways: the C$\ iii$ line is not real—possible but unlikely, given its precise alignment with the O$\ vi$ and H$\ i$ positions; the O$\ vi$ Doppler width is overestimated, either by unresolved components or due to noise in the profile; finally, the O$\ vi$ and C$\ iii$ absorption may arise in physically distinct gas clouds. For the well-aligned O$\ vi$ and H$\ i$ components, we calculate log $T = 4.0$ and $b_{\text{H$\ i$}} = 16.5 \text{ km s}^{-1}$. Section 5.2 has the details of this calculation.

$z_{\text{abs}} = 0.35525$ (Fig. 11; Table 7).—There is only weak O$\ vi$ and H$\ i$ at $z_{\text{abs}} = 0.35525$, with both transitions precisely aligned. The O$\ vi$ $\lambda 1031$ line shows a weak contaminating component or feature, although it is too weak to be detected in the O$\ vi$ $\lambda 1037$ transition if it is real. We fit this component as a contaminating H$\ i$ line, and the resulting model is a good fit to both O$\ vi$ transitions. As with the $z = 0.34034$ system, the Ly$\alpha$ profile is quite noisy, but the H$\ i$ $\lambda \lambda 1215, 1025$ regions are fit to within the noise. The resulting H$\ i$ position is closely matched to the O$\ vi$ redshift. Using this close match, we derive gas temperature log $T = 4.3$ and nonthermal broadening $b_{\text{nt}} = 22.2 \text{ km s}^{-1}$; see § 5.2.

3.6. HS 0624+6907

The QSO HS 0624+6907 at $z_{\text{qso}} = 0.370$ offers a path length for O$\ vi$ absorption $0.1222 < z_{\text{abs}} < 0.3464$. We detect two O$\ vi$ absorbers, at $z_{\text{abs}} = 0.31796, 0.33984$.

$z_{\text{abs}} = 0.31796$ (Fig. 12; Table 8).—This absorber is seen in only three lines: O$\ vi$ $\lambda \lambda 1031, 1037$, and Ly$\alpha$; Ly$\beta$ is not present. The Ly$\alpha$ and O$\ vi$ positions are offset ($15 \pm 5 \text{ km s}^{-1}$). The O$\ vi$ $\lambda 1031$ line shows evidence of some warm or noisy pixels.

$z_{\text{abs}} = 0.33984$ (Fig. 13; Table 8).—The significance of the O$\ vi$ in this system is very weak. It meets our formal definition of a significant O$\ vi$ $\lambda 1031$ line, and an O$\ vi$ $\lambda 1037$ profile that is consistent with the O$\ vi$ $\lambda 1031$ transition. We thus accept this system, noting that the O$\ vi$ doublet is uncertain. Other transitions are
clearly present, with strong \( \text{H} \) \( \text{I} \), and possibly weak \( \text{N} \) \( \text{V} \). The \( \text{LyC} \) line is saturated, and the fit is suboptimal in the red wing, but good fits are possible to the \( \text{LyB} \), \( \text{LyC} \), and \( \text{LyD} \) lines. The \( \text{LyB} \) profile is partly blended with another line, whose identification is uncertain—if this contaminant is \( \text{LyA} \), the expected \( \text{LyB} \) line is at a low enough wavelength that it would not be detected in the noisy STIS data. The blended portion of the spectrum is excluded from our fits. There is a very weak, broad line at the expected position of \( \text{N} \) \( \text{V} \) \( \lambda 1238 \), but it is too weak to be confirmed in the \( \text{N} \) \( \text{V} \) \( \lambda 1242 \) transition.

### 3.7. \text{PG 0953+415}

Along the line of sight to \text{PG 0953+415} \( (z_{\text{qso}} = 0.239) \), we can detect \( \text{O} \) \( \text{VI} \) absorption in the range \( 0.1144 < z_{\text{abs}} < 0.2163 \). A

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**TABLE 5**

\text{O VI Absorber Measurements along the Line of Sight toward 3C 351.0}

| Ion | \( z_{\text{comp}} \) | \( v \) (\( \text{km} \text{s}^{-1} \)) | \( \sigma_v \) (\( \text{km} \text{s}^{-1} \)) | \( \sigma_b \) (\( \text{km} \text{s}^{-1} \)) | \( \log N \) log (\( \text{cm}^{-2} \)) | \( \sigma_{\log N} \) log (\( \text{cm}^{-2} \)) | Flag |
|-----|---------------------|------------------|----------------|----------------|----------------|----------------|-----|
| \( \text{O} \) \( \text{VI} \) | 0.31635 | -53 | 4 | 21.1 | 5.5 | 13.7 | 0.2 | ... |
| \( \text{O} \) \( \text{VI} \) | 0.31657 | -3 | 2 | 23.3 | 4.4 | 14.0 | 0.1 | ... |
| \( \text{O} \) \( \text{VI} \) | 0.31686 | 62 | 3 | 30.9 | 4.7 | 14.0 | 0.1 | ... |
| \( \text{H} \) \( \text{I} \) | 0.31333 | -58 | 5 | 37.8 | 4.8 | 14.4 | 0.1 | ... |
| \( \text{H} \) \( \text{I} \) | 0.31660 | 2 | 2 | 26.9 | 3.8 | 14.6 | 0.1 | ... |
| \( \text{H} \) \( \text{I} \) | 0.31686 | 62 | 5 | 23.3 | 5.8 | 13.8 | 0.1 | ... |

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**Fig. 4**—H1821+643, \( z = 0.22496 \). A strong main \( \text{O} \) \( \text{VI} \) absorption component and a weaker, offset component are both obvious in this system. \( \text{LyA} \) is heavily saturated, but higher order Lyman lines are available. Strong \( \text{C} \) \( \text{III} \) and \( \text{Si} \) \( \text{III} \) can also be seen. [See the electronic edition of the Supplement for a color version of this figure.]
single system is detected, at $z_{abs} = 0.14232$, which has been previously discussed by Tripp & Savage (2000).

$z_{abs} = 0.14232$ (Fig. 14; Table 9).—This strong O vi absorber falls in a noisy part of the STIS spectrum of PG 0953+415. The O vi $\lambda 1037$ line is stronger than expected, based on the O vi $\lambda 1031$ line strength, but this may be due to noise in the spectrum. Ly$\alpha$ is present and well aligned with the O vi, but we are unable to obtain the gas temperature, log $T$, and $b_{gas}$, since $b_{O\,vi} > b_{H\,i}$; see § 5.2 for further discussion. Due to noise in the Ly$\beta$ portion of the spectrum, and blending of the Ly$\beta$ profile with the QSO host H i $\lambda 2494$ line at $z = 0.2335$, we fit only the zero-velocity H i component. There is a hint of C iv $\lambda 1334$, but it is very weak and uncertain. This system has been discussed by Tripp & Savage (2000).

### 3.8. PG 1116+215

The PG 1116+215 ($z_{qso} = 0.1765$) sight line has a single O vi absorber detected at $z_{abs} = 0.13847$ from the available path length between 0.1144 < $z_{abs}$ < 0.1536.

$z_{abs} = 0.13847$ (Fig. 15; Table 10).—Previously analyzed by Sembach et al. (2004) this absorber has noisy O vi due to the low STIS efficiency at the observed wavelength ($\lambda_{O\,vi\,1031} = 1174.8$ Å). Strong, saturated H i absorption is observed. Well-aligned metal lines of Si ii, Si iii, Si iv, C ii, N ii, and possibly N v, are all observed. The Ly$\alpha$, $\beta$ lines in our STIS data are heavily saturated, and we cannot simultaneously provide a good fit to both H i lines. Using a curve-of-growth analysis and the weak Lyman limit, Sembach et al. (2004) measured $\log N(H\,i) ~ 16.2$ for this absorber. They also concluded that photoionization models at a single ionization parameter, or collisionally ionization models at a single temperature, cannot explain all the metal lines observed.

### 3.9. PG 1216+069

The STIS data for PG 1216+069 ($z_{qso} = 0.3313$) allow us to search for O vi doublets in the range 0.1309 < $z_{abs}$ < 0.3078. We detect only a single intervening O vi absorber, at $z_{abs} = 0.28232$.

$z_{abs} = 0.28232$ (Fig. 16; Table 11).—The only O vi system we detect toward PG 1216+069, this absorber has very weak O vi absorption, along with very strong, saturated, multicomponent H i, allowing us to set only a lower limit on $\log N(H\,i)$. We also detect saturated C iii $\lambda 977$, and strong Si iii $\lambda 1026$. In the C iii region, we fit only the zero velocity component. Other components may be bona fide C iii associated with the blue H i component, but this is not clear. Precise knowledge of the H i component positions would be valuable for determining this.

### 3.10. PG 1259+593

The good quality STIS data for the line of sight PG 1259+593 ($z_{qso} = 0.4778$) allow us to search for weak absorbers over a large...
path length $0.1144 < z_{\text{qso}} < 0.4533$. We detect two O vi systems at $z_{\text{abs}} = 0.21950, 0.25981$. This sight line has also been studied by Richter et al. (2004).

$z_{\text{abs}} = 0.21950$ (Fig. 17; Table 12).—This absorber contains two principle O vi components, both of which are well resolved. The blue component suffers from several bad pixels, which were excluded from the fitting regions. The H i components are aligned with the O vi, although the stronger component is saturated even in the noisy, higher order H i $\lambda 949$ transition. The blue edge of the Ly$\beta$ profile blends with Galactic S ii $\lambda 1250$ but does not affect our fitting. We detect weak Si in $\lambda 1206$ and saturated C iv $\lambda 977$, both aligned with the zero velocity O vi component. Richter et al. (2004), who studied all the systems on this sight line, measured log $N$(H i) = 15.2.

$z_{\text{abs}} = 0.25981$ (Fig. 18; Table 12).—The multicomponent absorber at $z = 0.25981$ has two main O vi components: a narrow component at $-44$ km s$^{-1}$ separation from the broad zero-velocity component. The best-fit H i profile has two components, well aligned with the O vi components. We discount the reality of a putative weak Si in $\lambda 1206$ transition at $+40$ km s$^{-1}$. We attempted to derive log $T$ and $b_{\text{nt}}$ for both components ($\S$ 5.2) but were only successful only for the O vi/H i pair at $-44$ km s$^{-1}$. The zero-velocity O vi/H i component pair has $b_{\text{O vi}} > b_{\text{H i}}$, and is discussed further in $\S$ 5.2. For the component at $v = -44$ km s$^{-1}$, we measure $b_{\text{nt}} = 13.9$ km s$^{-1}$ and log $T = 4.5$.

3.11. PHL 1811

The PHL 1811 ($z_{\text{qso}} = 0.1917$) sight line contains a single O vi absorber at $z_{\text{abs}} = 0.15786$ in the available range $0.1144 < z_{\text{abs}} < 0.1690$. Jenkins et al. (2005) have studied this sight line, focusing on the LLS at $z_{\text{abs}} = 0.0809$. 

Fig. 5.—H1821+643, $z = 0.22638$. This system comprises weak O vi absorption, and very broad H i absorption offset from the O vi by $-53$ km s$^{-1}$. This absorber is only $-350$ km s$^{-1}$ from the system at $z = 0.22496$. [See the electronic edition of the Supplement for a color version of this figure.]

Fig. 6.—H1821+643, $z = 0.24532$. Two weak O vi components and a corresponding very weak H i absorber are seen in this system. N v $\lambda 1238$ is possibly present, but the N v $\lambda 1242$ line is lost in the Galactic C iv $\lambda 1548$ line. [See the electronic edition of the Supplement for a color version of this figure.]
3.12. PKS 0312−77

The data for the PKS 0312−77 ($z_{\text{qso}} = 0.223$) allow a path length for our doublet search $0.1241 < z_{\text{abs}} < 0.1999$. We detect the strongest O vi absorber in our survey in these data, at $z_{\text{abs}} = 0.20275$, which is part of a partial LLS.

$z_{\text{abs}} = 0.20275$ (Fig. 20; Table 14).—The STIS spectrum of the sight line toward PKS 0312−77 was obtained under proposal id 8651 (PI: Kobulnicky). This line of sight contains the strongest O vi absorber of our entire sample: a partial Lyman-limit system at $z_{\text{abs}} = 0.20275$ with $15.9 < \log N(\text{H} \ i) < 18.4$, which is confirmed by a brief inspection of a FUSE spectrum. This system has two groups of components, each having a complex structure. The main component group has strong, broad O vi absorption and covers the range $-100 \text{ km s}^{-1} \leq v \leq 100 \text{ km s}^{-1}$, while the weaker group shows evidence of weak O vi ($-300 \text{ km s}^{-1} \leq v \leq -100 \text{ km s}^{-1}$).

Fitting for this absorber was complicated by the fact that many components are saturated, particularly in stronger transitions such as Ly$\alpha$, Ly$\beta$, C iii $\lambda \lambda 977$, and Si iii $\lambda 1206$. In general, we used weaker, low ion transitions (typically N ii and C ii) to fix the redshifts of the components (excluding O vi), and initialized fits with fixed redshift, and initial b-value and column density guided by weaker absorbers. Degeneracies and poorly constrained parameters naturally result from fitting saturated absorbers; these are indicated by large formal parameter errors, and the fit values are typically indicative of lower limits only.

For the main component group, we fit each species separately. Five components were first identified from low-ion transitions C ii $\lambda 1306$, N ii $\lambda 1308$, and Si ii $\lambda \lambda 1193, 1260$, all of which show the same structure. These redshifts were fixed, and fits were performed. The O vi line, while probably requiring more than one component for the measured breadth, shows little evidence of individual component structure, and a single component provided adequate fits. Only three H i transitions are present in the STIS data, all of which are strongly saturated, resulting in mostly $N(\text{H} \ i)$ lower limits. Si ii transitions are well fit, except for Si ii $\lambda 1190$, which shows possible contamination from Galactic C r'.

PKS 0405−12

PKS 0405−12 ($z_{\text{qso}} = 0.5723$) is the highest redshift QSO in our sample, allowing a path length to search for O vi absorbers $0.1241 < z_{\text{abs}} < 0.5478$. We detect four O vi systems, at $z_{\text{abs}} = 0.15597, 0.18291, 0.36333, 0.49514$. This line of sight has also been studied previously by Chen & Prochaska (2000) and Prochaska et al. (2004, 2006).

$z_{\text{abs}} = 0.16697$ (Fig. 22; Table 15).—The PKS 0405−12 sight line has been studied by Prochaska et al. (2004) and the partial Lyman-limit system at $z = 0.167$ by Chen & Prochaska (2000).
The system has strong, saturated H\textsc{i}, and two O\textsc{vi} components—one broad and strong; one weak and narrow. Prochaska et al. (2004) estimate \( \log N(\text{H}\textsc{i}) = 16.45 \) from an analysis of the flux decrement shortward of the 912 Å Lyman limit in FUSE data for this sight line.

The STIS data exhibit strong lines of Si\textsc{ii}, Si\textsc{iii}, Si\textsc{iv}, C\textsc{ii}, N\textsc{ii}, and O\textsc{i}, some of which appear saturated. In general, the low ion transitions are well aligned, and details are given in Table 15.

Due to the heavily saturated H\textsc{i} lines, only the weak O\textsc{vi} feature at 110 km s\(^{-1}\) can be matched well with H\textsc{i} absorption components, and the resulting parameters \( b_\text{abs} = 7.0 \) km s\(^{-1}\) and \( \log T = 3.7 \) are derived in § 5.2.

\( z_{\text{abs}} = 0.18291 \) (Fig. 23; Table 15).—The absorber at \( z_{\text{abs}} = 0.18291 \) consists of two separate components, separated by \( \sim 90 \) km s\(^{-1}\), both of which are reported in Prochaska et al. (2004). In our STIS data, we have only the Ly\( \alpha \) line corresponding to these absorbers (Ly\( \beta \) blends into the Galactic Ly\( \alpha \) trough), which is heavily saturated. We thus derive only lower limits to \( \log N(\text{H}\textsc{i}) \), consistent with Prochaska et al. (2004). The two O\textsc{vi} components are also well fit, despite the O\textsc{vi} \( \lambda 1031 \) line appearing on the red edge of the Galactic Ly\( \alpha \) absorption.

\( z_{\text{abs}} = 0.36333 \) (Fig. 24; Table 15).—This system has a well-fit O\textsc{vi} doublet and corresponding noisy H\textsc{i} profile. Ly\( \alpha \) is the only H\textsc{i} transition we detect, but it is marred by hot pixels in the data, so our resulting measurements are uncertain. Further, the Ly\( \gamma \) line lies very close to the Galactic C\textsc{i} \( \lambda 1656 \), blending with the fine-structure C\textsc{i} \( \lambda 1657.38 \) line. Lacking the detection of Ly\( \beta \), we cannot obtain reliable \( \log N(\text{H}\textsc{i}) \). We also detect weak C\textsc{iii}.

\( z_{\text{abs}} = 0.49514 \) (Fig. 25; Table 15).—Prochaska et al. (2004) present a brief analysis of the absorber at \( z_{\text{abs}} = 0.49514 \). At such a high redshift, the Ly\( \alpha \) line is redshifted out of the STIS bandpass, and the Ly\( \beta \) and Ly\( \gamma \) transitions are weak and noisy. Both O\textsc{vi} lines are contaminated by hot pixels. In the region of the O\textsc{vi} \( \lambda 1037 \) line, Galactic C\textsc{iv} \( \lambda 1538 \) falls at \( \sim -90 \) km s\(^{-1}\). Inspection of the C\textsc{iv} \( \lambda 1542 \) line shows that it does not significantly affect the O\textsc{vi} line. C\textsc{iii} is detected at \( v = 0 \) km s\(^{-1}\), as are offset O\textsc{iii} \( \lambda 832 \) and O\textsc{iv} \( \lambda 787 \). Both the O\textsc{iii} and O\textsc{iv} transitions also show a component at \( \sim 90 \) km s\(^{-1}\). While there is no associated H\textsc{i} with these components at \( v = 90 \) km s\(^{-1}\), the exact alignment of both transitions argues that the absorption is real (as opposed to, say, weak H\textsc{i}). Due the noise in the data, we could...
not obtain an acceptable fit to the H\textsc{i} lines and we were forced to fix the H\textsc{i} Doppler parameter. Higher quality data would be very valuable for this system, both to obtain an accurate H\textsc{i} column density and confirm the assumed Doppler parameter for H\textsc{i}.

3.14. PKS 1302–102

We searched the STIS data for PKS 1302–102 (\(z_{\text{spec}} = 0.2784\)) for O\textsc{vi} absorbers in the range 0.1183 < \(z_{\text{abs}}\) < 0.2558, detecting two close absorbers at \(z_{\text{abs}} = 0.22565, 0.22744\). This sight line has also been studied by Cooksey et al. (2008).

\(z_{\text{abs}} = 0.22565\) (Fig. 26; Table 16).—As with the H1821+643 absorber pair, these absorbers at \(z_{\text{abs}} = 0.22565\) and \(z_{\text{abs}} = 0.22744\) along the PKS 1302–102 sight line are separated by only \(\Delta v = 440\) km s\(^{-1}\). Also similar to the previous example, this absorber pair consists of a strong and weak system, with the weaker system at a slightly higher redshift (although in this case, the difference is far less dramatic). The system at \(z_{\text{abs}} = 0.22565\) consists of two well-defined O\textsc{vi} components separated by 28 km s\(^{-1}\). Both O\textsc{vi} components have matching H\textsc{i} absorption, detected primarily in Ly\alpha. The two strong lines at the expected positions of the N \textsc{v} doublet are obviously unrelated Ly\alpha absorbers. The temperature and nonthermal broadening can be determined for only the \(v = 0\) km s\(^{-1}\) component (log \(T = 4.4\); \(b_{\text{int}} = 12.5\) km s\(^{-1}\)), since the H\textsc{i} position for the component at \(v = -28\) km s\(^{-1}\) has been fixed to that of O\textsc{vi} in our fitting; see § 5.2 for details.

\(z_{\text{abs}} = 0.22744\) (Fig. 27; Table 16).—The weaker of the two close O\textsc{vi} absorbers toward PKS 1302–102, this system has only very weak transitions of O\textsc{vi} \(\lambda 1031, 1037\) and Ly\alpha. The O\textsc{vi} \(\lambda 1031\) line is close to, but unaffected by, a strong Ly\alpha absorption line at \(z = 0.4224\). Both species are well aligned and suitable for temperature analysis in § 5.2. We derive log \(T = 4.2\) and \(b_{\text{int}} = 10.7\) km s\(^{-1}\).

3.15. Ton 28

The Ton 28 (\(z_{\text{spec}} = 0.3297\)) line of sight hosts only one O\textsc{vi} absorber at \(z_{\text{abs}} = 0.27340\) in the available path length 0.1231 < \(z_{\text{abs}} < 0.3059\).

\(z_{\text{abs}} = 0.27340\) (Fig. 28; Table 17).—The system toward Ton 28 contains strong H\textsc{i} absorption, and only weak O\textsc{vi}. The O\textsc{vi} \(\lambda 1031\) line is detected at >3 \(\sigma\) significance, while the O\textsc{vi} \(\lambda 1037\) is only \(\sim 2.5\) \(\sigma\). The Ly\textsc{\alpha} absorption line is saturated and blended with Galactic C \textsc{iv} \(\lambda 1548\). Comparison of the Galactic C \textsc{iv} \(\lambda 1548\) and \(\lambda 1550\) lines shows that the full Ly\alpha profile is blended, not just the red wing (which is apparent in Fig. 28). The Ly\beta and Ly\gamma lines allow us to obtain a good H\textsc{i} fit, and we include the C \textsc{iv} absorption component that is obvious in the Ly\alpha wing. The discrepancy between the Ly\alpha data and fit profile is can be ascribed to the C \textsc{iv} blending. No other associated transitions are detected. The alignment of the H\textsc{i} and O\textsc{vi} positions makes this system useful for our temperature analysis in § 5.2. We have derived log \(T = 4.5\) and \(b_{\text{int}} = 20.2\).

4. COMPARISON WITH OTHER WORK

As noted in § 1, two similar contemporaneous studies have been conducted by other groups (Tripp et al. 2008; Danforth & Shull 2008). While differences exist in the selection of O\textsc{vi} systems in the different samples, there is typically good agreement in measured quantities for common systems. Here we specifically address systems reported by Tripp et al. (2008) that are not accepted by our selection criteria. In general, this is a difference between performing a blind search for the O\textsc{vi} doublet and looking for one of the doublet lines in previously identified systems (e.g., Ly\alpha absorbers). This associated Ly\alpha technique accepts cases in which one or other of the O\textsc{vi} doublet lines is masked by strong absorption from ISM or IGM lines at a different redshift. Other
systems simply fall outside our wavelength range or are identified in different data (e.g., the O\textsc{vi} doublet is identified in FUSE spectra).

We only consider absorbers from the Tripp et al. (2008) compilation that are within our wavelength range but not recovered in our search. Table 18 summarizes these systems, and we comment on each system below. The O\textsc{vi} $\lambda$1031 (top) and $\lambda$1037 (bottom) spectral regions for each system are shown in Figures 29 and 30. Note that Danforth & Shull (2008) have also recently conducted a similar survey using both STIS and FUSE data. Finally, where our sample has common systems with the samples of Tripp et al. (2008) and Danforth & Shull (2008) we see no marked differences in the measured total column densities, or the component b-values and column densities where similar component structures are fitted.

4.1. 3C 351.0

$z = 0.21811$.—This system shows broad absorption at the expected position of both O\textsc{vi} doublet members but is rejected because acceptable fits could not be obtained; the line strengths of the putative doublet members are inconsistent at the 3–4 $\sigma$ level, with O\textsc{vi} $\lambda$1037 stronger than O\textsc{vi} $\lambda$1031. There is a putative Ly$\alpha$ absorber at this redshift, but its velocity is inconsistent with the O\textsc{vi} position ($\Delta v \sim 50$ km s$^{-1}$). C iii is obscured by Galactic Si ii $\lambda$1190 and no Si iii is detectable. It is possible that the O\textsc{vi} $\lambda$1037 line in this system is a broad Ly$\alpha$ absorber (see e.g., Sembach et al. 2004). We concur with Tripp et al. (2008) that higher S/N observations would be very valuable to firmly establish the nature of this system.

$z = 0.22111$.—This system is not considered because the O\textsc{vi} $\lambda$1031 position is clearly blended with heavily saturated Galactic Si ii $\lambda$1260 absorption. Ly$\alpha$ and Si iii $\lambda$1206 are present at the expected wavelengths; C iii $\lambda$977 blends with Si ii $\lambda$1193 at $z = 0$.

4.2. H1821+643

$z = 0.12143$.—There is strong Ly$\alpha$ absorption at $\sim -80$ km s$^{-1}$ from the nominal position of this system, but our STIS data are far too noisy to detect O\textsc{vi} absorption (S/N $\approx 2$–3 in this region), which is reported by Tripp et al. (2008) in FUSE data.
The strong absorption at the \( \lambda 1037 \) position for this redshift is Ly\( \delta \) at \( z = 0.225 \) (Tripp et al. 2001).

\[ z = 0.21331. \] —We initially considered this system, but rejected it due to mismatched line strength ratio. The O\( \text{vi} \) \( \lambda 1037 \) line is stronger than the O\( \text{vi} \) \( \lambda 1031 \) line, and the strength ratio is \( R_{\text{O vi}} = 0.77/0.14 \). As noted by Tripp et al. (2000) the region of the O\( \text{vi} \) \( \lambda 1037 \) line contains a strong Galactic S\( \text{ii} \) \( \lambda 1259 \) at a velocity \( v \approx +100 \) km s\(^{-1} \) with respect to the absorber redshift, and a weaker Galactic S\( \text{ii} \) \( \lambda 1259 \) feature at \( \approx +30 \) km s\(^{-1} \). This weaker component partially blends with the putative O\( \text{vi} \) \( \lambda 1037 \) line. The weaker component is also seen in S\( \text{ii} \) \( \lambda 1253 \) and is likely associated with the intermediate-velocity cloud (IVC) in the Milky Way known as the IV arch (Kuntz & Danly 1996).

4.3. HE 0226–4110

\[ z = 0.42670. \] —The data show a strong O\( \text{vi} \) \( \lambda 1031 \) line in this candidate, but there is no corresponding O\( \text{vi} \) \( \lambda 1037 \) line (the \( \lambda 1037 \) position does contain a narrow absorption spike due to noise, which is reflected in the error array). Ly\( \alpha \) is redshifted out of the STIS bandpass, and there is no Ly\( \beta \). Galactic Si\( \text{iv} \) \( \lambda 1393 \) blends with the expected position of C\( \text{iii} \) \( \lambda 977 \), and there is also no Si\( \text{iii} \) \( \lambda 1206 \). We conclude that this system is not real.

4.4. PG 1216+069

\[ z = 0.26768. \] —O\( \text{vi} \) \( \lambda 1037 \) blends with the heavily saturated Ly\( \beta \) line from the absorber at \( z = 0.28232 \), and hence this system cannot meet our criteria for a doublet search.

4.5. PG 1259+593

\[ z = 0.31972. \] —We do not detect the O\( \text{vi} \) \( \lambda 1037 \) line in this system, although there is a single-pixel negative noise spike (which is reflected in the error array). A model based on the putative O\( \text{vi} \) \( \lambda 1031 \) line is not consistent with the data in the \( \lambda 1037 \) region. The red wing of the O\( \text{vi} \) \( \lambda 1037 \) region blends with a weak (~20 m\( \text{A} \)) unidentified line.

4.6. PG 1444+407

\[ z = 0.22032. \] —The O\( \text{vi} \) \( \lambda 1031 \) line blends with Galactic S\( \text{ii} \) \( \lambda 1259 \). The \( z = 0 \) S\( \text{ii} \) \( \lambda 1253 \) transition, confirming its Galactic nature. Shallow, broad Ly\( \alpha \) may be seen, but the O\( \text{vi} \) \( \lambda 1037 \) is very weak and uncertain.

4.7. PHL 1811

\[ z = 0.13240. \] —At the observed wavelength of this system (\( \lambda_{\text{obs}} = 1168.5 \) \( \text{A} \)), the spectrum is quite noisy. We detect a strong O\( \text{vi} \) \( \lambda 1031 \) line, and at higher wavelengths the saturated, offset Ly\( \alpha \) line is easily detected in higher S/N data. We do not, however, see evidence of an O\( \text{vi} \) \( \lambda 1037 \) line, and thus we reject this system.

4.8. PKS 0312−77

\[ z = 0.15890. \] —The data for the PKS 0312−77 sight line are quite noisy, especially in the low-wavelength region about the O\( \text{vi} \) \( \lambda 1031 \) position. We see a well-fit O\( \text{vi} \) \( \lambda 1031 \), but this same profile bears no resemblance to the data in the expected region.
of O vi \lambda 1037. Multicomponent Ly\alpha is also seen, but the lack of O vi \lambda 1037 absorption leads us to reject this system.

z = 0.19827.—As with the lower redshift system described above, we detected Ly\alpha (saturated in this case) and broad O vi \lambda 1031, but no evidence of O vi \lambda 1037. There is no correspondence in the data between O vi \lambda 1031 and O vi \lambda 1037 regions, and the profile fit from the O vi \lambda 1031 region is a poor fit to the O vi \lambda 1037 region.

4.9. PKS 0405—12

z = 0.36156.—Initially detected in our doublet search and published by Prochaska et al. (2004) there is considerable mismatch between the O vi \lambda 1031 and O vi \lambda 1037 regions. Ly\alpha is uncertain, but there may be a weak line in the wing of the strong (N(H i) = 15.1) Ly\alpha line at z = 0.3608. Due to the profile mismatch, we are unable to confirm this system.

4.10. PKS 1302—102

z = 0.19159.—This system is another example that we are unable to confirm due to lack of O vi \lambda 1037 absorption. A line at the position of O vi \lambda 1031 is present, as is saturated Ly\alpha, and possibly Si iii \lambda 1206. Given the strength of the apparent O vi \lambda 1031 line (~62 m\AA), we should expect to detect any O vi \lambda 1037 line, but no significant absorption exists, and the O vi \lambda 1031 profile fit is a poor descriptor of the data in the O vi \lambda 1037 region. The independent work of Cooksey et al. (2008) confirms this result; those authors report Ly\alpha and O vi \lambda 1031 but do not detect O vi \lambda 1037 (see their Table 3).

4.11. Ton 28

z = 0.13783.—A strong line at the position of O vi \lambda 1031 is seen in this absorber, but no corresponding O vi \lambda 1037 is seen. At such low wavelengths, however, this is hardly surprising—our STIS spectra have S/N < 3 per pixel at the position of O vi \lambda 1037. A profile fit to the O vi \lambda 1031 line does not follow the data in the O vi \lambda 1037 region. Ly\alpha is detected as part of a stronger, saturated Ly\alpha system.

5. PHYSICAL PROPERTIES OF IONIZED GAS SELECTED BY O VI ABSORPTION

Having identified a sample of O vi absorbers, and related transitions, we now consider these absorbers in detail. We begin by matching individual absorption components of O vi and H i within an absorber. These components trace physically distinct gas clouds, and we consider first the global properties of these clouds. With the sample of absorption components well-aligned in velocity space, we derive the gas temperature and nonthermal broadening and examine whether the temperatures are consistent with a collisional ionization origin. We also consider the ionization state of the O vii-bearing gas using photoionization models. We close with a brief comment on the lack of O vi-only systems.

5.1. N(O vi) versus N(H i) for Individual Components

To consider any interpretation of the O vii-bearing gas, we must determine whether the different species observed in the absorbers arise from the same gas. It is well established from very high-resolution studies of the ISM that absorbers can be resolved into multiple (even many) individual absorption components (\Delta v < 1 km s\(^{-1}\); e.g., Weyl et al. 1996, 1999). Since these components will trace physically distinct gas clouds, it is at this component level that we must assess the physical nature of the gas. To define well-matched components, we compare the positions of the O vi and H i components in each absorber. The motivation for this matching is to constrain the temperature of the O vii-bearing gas, a subject to which we will return in the following sections. In principle, highly ionized species such as N v would be the ideal candidate to compare to O vi in deriving physical conditions, in particular the gas temperature. N v peaks in CIE at log T = 5.25 (Sutherland & Dopita 1993), and so occupies the same temperature range as O vi. Conversely, H i is orders of magnitude more abundant, and so is much more likely to result in a good component match. We therefore attempt to match all O vi components with corresponding H i components. If the two component positions are equal to within their 2 \sigma positional uncertainties (to a maximum of the STIS resolution: 6–7 km s\(^{-1}\)) we consider them related.

In Figure 31 we plot, for all well-matched components, the O vi column density as a function of the neutral hydrogen column density (cf. Fig. 19 of Tripp et al. 2008). It is not surprising that no points lie in the upper left part of this plot since (1) they would require high metallicity and optimum ionization parameter and (2) we see little evidence of a class of systems lacking (or with weak) H i (see § 5.2). The lower portion of the plot is empty due to a selection effect; in most of the survey, our detection limit is \(N(H) \approx 30 \text{ m}\AA, which corresponds to log \(N(O vi) \gtrsim 13.5\). A range of physical conditions may be used to explain any particular point on this plot, since the ionization parameter and metallicity are degenerate. Nevertheless, it is worthwhile considering the range of conditions that are allowed by the data. In this vein, we have overplotted two sets of model photoionization curves: models for a variable ionization parameter at fixed metallicity and varying metallicity at fixed log \(U\). The dot-dashed line shows our “fiducial” condition of gas at peak ionization parameter and one-tenth solar metallicity. Since N(O vi) peaks for fixed density and metallicity at log \(U = -0.2\), any increase or decrease

### Table 8

| Ion   | z\(_{\text{comp}}\) | v \(_{\text{b}}\) (km s\(^{-1}\)) | \(\sigma_b\) (km s\(^{-1}\)) | log \(N\) (cm\(^{-2}\)) | \(\sigma_{\text{log } N}\) (log (cm\(^{-2}\))) | Flag |
|-------|---------------------|-------------------------------|-------------------------------|------------------------|---------------------------------|------|
| O vi  | 0.31796             | 0.0                           | 2.0                          | 24.0                   | 3.1                             | 13.7 | 0.1 |
| H i   | 0.31789             | -15.0                         | 4.0                          | 35.9                   | 6.5                             | 13.3 | 0.1 |

| Ion   | z\(_{\text{comp}}\) | v \(_{\text{b}}\) (km s\(^{-1}\)) | \(\sigma_b\) (km s\(^{-1}\)) | log \(N\) (cm\(^{-2}\)) | \(\sigma_{\text{log } N}\) (log (cm\(^{-2}\))) | Flag |
|-------|---------------------|-------------------------------|-------------------------------|------------------------|---------------------------------|------|
| O vi  | 0.33978             | 0.0                           | 7.0                          | 34.8                   | 11.6                            | 13.4 | 0.3 |
| H i   | 0.33978             | -14.0                         | 0.0                          | 40.9                   | 9.0                             | 14.5 | 0.1 |
in log $U$ will act to shift this line to the lower right [i.e., $N(\text{H} \text{I})$ will be larger at fixed $N(\text{O} \text{vi})$], an effect that is clear in Figure 32. What, then, of the points above this line? Under the assumption of photoionization equilibrium, we then infer that these systems must have higher metallicity than our canonical one-tenth solar value. The dashed line shows the model curve for $\log U = -1.2$; $[\text{M}/\text{H}] = 1.0$ and hence, at fixed $[\text{M}/\text{H}] = 1.0$, the data allow a range of ionization parameters of $\sim 1$ dex. If we instead consider the variation in the points as solely a function of metallicity at fixed (optimal) ionization parameter, we obtain the bounds delimited by the crosses and squares, and a range of metallicities of $\sim 1.7$ dex.

It is immediately apparent that the data do not follow the same global trend as the model curves shown. Although we cannot determine a zero point for the model curves, due to the degeneracy between metallicity and $\log U$, the trend is nevertheless valid, and we should expect a variety of metallicities and ionization conditions in the absorbers. The scatter in the observations of $N(\text{O} \text{vi})$...
TABLE 9

O VI ABSORBER MEASUREMENTS ALONG THE LINE OF SIGHT TOWARD PG 0953+415

| Ion   | $z_{\text{comp}}$ | $v$ (km s$^{-1}$) | $\sigma_v$ (km s$^{-1}$) | $b$ (km s$^{-1}$) | $\sigma_b$ (km s$^{-1}$) | $\log N$ (log cm$^{-2}$) | $\sigma_{\log N}$ (log cm$^{-2}$) | Flag |
|-------|-------------------|-------------------|--------------------------|-----------------|--------------------------|-------------------------|-------------------------------|------|
| O vi  | 0.14232           | -1                | 3                        | 31.9            | 4.5                      | 14.2                    | 0.1                           | ... |
| H i   | 0.14232           | 1                 | 2                        | 28.7            | 2.2                      | 13.5                    | 0.1                           | ... |
| C ii  | 0.14233           | 2                 | 3                        | 8.3             | 4.6                      | 12.8                    | 0.2                           | Z   |

Fig. 15.—PG 1116+215, $z = 0.13847$. While the O vi transitions in this absorber are quite noisy, we have good data for Ly$\alpha$, both of which are saturated. We cannot obtain satisfactory fits to Ly$\alpha$ and Ly$\beta$, both of which are saturated. Si ii, Si iii, Si iv, N ii, and C ii are all clearly detected, often in multiple transitions (e.g., Si ii is detected in the 1190, 1193, 1260, and 1304 transitions). See the electronic edition of the Supplement for a color version of this figure.
versus \(N(\text{H} \, \text{i})\) can thus be understood as due to scatter in the metallicity and ionization state of the gas.\(^7\)

The case of the 3C 351.0 absorber at \(z = 0.31659\) (open squares) is interesting, since the \(\text{O} \, \text{vi}\) and \(\text{H} \, \text{i}\) clearly separate into three individual components. No other species are detected in the STIS band. If we posit a physical connection, based on the proximity of the components, we might expect similar conditions for each gas cloud. The three components are shown as open squares in Figure 31. It is clear that no single set of ionization and metallicity conditions can explain all the components, yet the temperatures do not admit of a collisional origin (see § 5.2). It is likely we are simply seeing, for a constant flux of ionizing photons, density variations along the line of sight. By contrast, we would require variations of ~1.0 dex to explain the observations by metallicity variations alone.

### 5.2. Gas Temperature

In the previous discussion, we have assumed that the matched components arise from photoionized gas. Is this assumption justified? Having identified components of two different species that likely arise from the same gas phase, we can use the Doppler parameters to derive an estimate of the gas temperature, which are related through the relation \(b^2 = b_\text{ab}^2 + 2kT/m\), where \(b_\text{ab}\) is the nonthermal component to the Doppler parameter (i.e., turbulence, bulk motion, etc.), and \(k\), \(T\), and \(m\) are the Boltzmann constant, temperature, and atomic mass as usual. The two equations thus determine both the gas temperature and the nonthermal line broadening, and this well-established fact has been used in the past to determine gas temperatures of absorbers (e.g., Chen & Prochaska 2000; Tripp & Savage 2000). It is also clear that, in the absence of a turbulent component, the Doppler parameters will be related through the square root of the ratio of atomic masses. The distribution of \(\text{O} \, \text{vi}\) and \(\text{H} \, \text{i}\) \(b\)-values for well-aligned absorption components is shown in Figure 33. The solid lines bound two limiting cases. At one extreme, for \(b_\text{nt} = 0\), we have simply that \(b_{\text{H}\, \text{i}} = 4b_{\text{O}\, \text{vi}}\). The upper boundary in Figure 33 shows the other limiting case, where \(b_{\text{H}\, \text{i}} = b_{\text{O}\, \text{vi}}\).

Gas in collisional ionization equilibrium with \(T \geq 2 \times 10^5\) implies \(b_{\text{H}\, \text{i}} \gtrsim 60\) km s\(^{-1}\). It is immediately apparent that few of our components satisfy this criteria. Including a nonthermal contribution to the \(b\)-value will further lower the implied temperature (or conversely, increase the implied Doppler parameter). This simple argument indicates that collisional ionization is not the dominant ionization mechanism. It does not, however, rule out collisionally ionized systems, since it is conceivable that weak, collisionally ionized systems may not contain a detectable amount of neutral hydrogen (i.e., by considering only systems with well-aligned \(\text{O} \, \text{vi}/\text{H} \, \text{i}\) components, we may be biased against systems in CIE). To quantify this statement, we examined with Cloudy (ver. 07.02.01) a simple model of gas in collisional ionization at \(T = 5.5\) and one-tenth solar metallicity. For \(\text{O} \, \text{vi}\) column densities in the range \(\log N = 13.5–14.0\) the corresponding \(\text{H} \, \text{i}\) column density is \(\log N \lesssim 13.0\), which will be difficult to detect in our data. We note that, while we see no evidence of a population of \(\text{O} \, \text{vi}\) absorbers lacking \(\text{H} \, \text{i}\) absorption, we certainly see components that are not well matched with \(\text{H} \, \text{i}\).

Table 19 gives the temperature and \(b_\text{nt}\) for the well-matched components defined above. The first three columns identify the absorber and component. The measured \(\text{H} \, \text{i}\) and \(\text{O} \, \text{vi}\) Doppler parameters are recalled here for reference. The derived gas temperature and error are given, along with the nonthermal contribution of the absorption being physically related is not correct for these systems or there are unresolved absorption components.

### Table 10

\begin{table}
\begin{tabular}{|c|c|c|c|c|c|c|c|}
\hline
Ion & \(z_{\text{comp}}\) & \(v\) & \(\sigma_v\) & \(b\) & \(\sigma_b\) & \(\log N\) & \(\sigma_{\log N}\) & Flag \\
\hline
\(\text{O} \, \text{vi}\) & 0.13847 & 6 & 40.5 & 8.7 & 13.9 & 0.1 & ... \\
\(\text{H} \, \text{i}\) & 0.13850 & 0 & 30.0 & 0.6 & 15.0 & ... & L \\
\(\text{C} \, \text{i}\) & 0.13847 & 0 & 11.1 & 0.9 & 13.9 & 0.1 & ... \\
\(\text{N} \, \text{ii}\) & 0.13848 & 2 & 10.7 & 1.4 & 13.7 & 0.1 & ... \\
\(\text{N} \, \text{v}\) & 0.13848 & 2 & 31.3 & 7.6 & 13.0 & 0.1 & ... \\
\(\text{Si} \, \text{ii}\) & 0.13846 & -1 & 6.6 & 0.3 & 12.8 & 0.1 & ... \\
\(\text{Si} \, \text{iii}\) & 0.13848 & 2 & 8.6 & 0.5 & 13.0 & 0.1 & ... \\
\(\text{Si} \, \text{iv}\) & 0.13845 & -4 & 9.5 & 2.2 & 12.7 & ... & ... \\
\hline
\end{tabular}
\end{table}

\(^7\) Other factors such as length scale, and varying redshift will also play a role here.

\(^8\) In which case the component alignment is purely coincidental.
Fig. 16.—PG 1216+069, \( z = 0.28232 \). This system is another instance of very strong, saturated \( \text{H} \) i, strong low ion metal species, but only weak \( \text{O} \) vi. All the Lyman series lines in our spectrum are saturated or are too noisy to be useful. \( \text{C} \) iii at 977 is also saturated. It is not clear whether the absorption to the blue of the central \( \text{C} \) iii component is \( \text{C} \) iii associated with blue \( \text{H} \) i components, or a contaminating line. [See the electronic edition of the Supplement for a color version of this figure.]

### Table 11

| Ion     | \( z_{\text{comp}} \) | \( v \) \( \text{(km s}^{-1} \) | \( \sigma_v \) \( \text{(km s}^{-1} \) | \( b \) \( \text{(km s}^{-1} \) | \( \sigma_b \) \( \text{(km s}^{-1} \) | \( \log N \) \( \text{log (cm}^{-2} \) | \( \sigma_{\log N} \) \( \text{log (cm}^{-2} \) | Flag |
|---------|----------------------|------------------|------------------|------------------|------------------|------------------|------------------|------|
| \( \text{O} \) vi           | 0.28232              | 0                | 12.6             | 2.6              | 13.4             | 0.2              | ...              |      |
| \( \text{H} \) i              | 0.28216              | -38              | 1                | 48.3             | 1.0              | 15.2             | ...              | L    |
| \( \text{H} \) i              | 0.28229              | -8               | 0                | 20.2             | 0.6              | 16.5             | ...              | L    |
| \( \text{C} \) iii             | 0.28228              | -9               | 0                | 10.1             | 1.6              | 14.2             | ...              | L    |
| \( \text{Si} \) iii             | 0.28229              | -6               | 0                | 11.7             | 1.3              | 12.9             | 0.1              | ...  |
In other words, if both absorption components arise from the same gas, then we require that $1/4 < b_{\text{O\,vi}}/b_{\text{H\,i}} < 1$, since $n_{\text{O}} = 16n_{\text{H}}$. The upper limit comes from a state where the $b$-values are dominated entirely by $b_{\text{H}}$ (i.e., $b_{\text{H\,i}} = b_{\text{O\,vi}}$), while the lower limit is the pure thermal case, and the $b$-values are simply related through the square root of the ratio of their respective atomic masses. Similar limits can be trivially written down for all other pairs of species. It is worth emphasizing, at this stage, that these measurements are dependent on several critical factors: (1) the resolution of the spectrograph must be sufficient to resolve the lines in question, reinforcing our decision to rely solely on STIS E140M data with superior resolution (e.g., the FUSE FWHM is $\sim 20-25$ km s$^{-1}$, but our median $b_{\text{O\,vi}}$ is $\sim 21$ km s$^{-1}$); (2) further, the resolution must be sufficient to resolve multiple absorption components and possible blending; (3) the nonthermal contribution to the Doppler parameter must be considered, since it dominates $b_{\text{tot}}$ in most cases. As Table 19 clearly demonstrates, if we do not take this into account, most of our absorbers would be consistent with the coronal temperature range $10^{5}-10^{7}$ K, and we could easily misinterpret these as WHIM absorbers. This point has also been made by Tripp et al. (2008), while Danforth & Shull (2008) derive only upper limits to the temperature using $b_{\text{H\,i}}$.

5.3. Ionization State of O$^{5+}$ Bearing Gas

Before considering the ionization conditions of the O$^{5+}$-bearing gas, we first inspect the results of a typical photoionization model of low-density gas. We use similar models when considering individual systems below, each tailored to the specific conditions of the individual absorber. Figure 32 shows the ionization state for the most commonly observed species as a function of the ionization parameter, $\log U = \log (n_{\gamma}/n_{\text{H\,i}})$, where $n_{\gamma}$ and $n_{\text{H\,i}}$ are the volume densities of ionizing photons ($h\nu > 13.6$ eV) and hydrogen, respectively. The model was calculated for a slab of gas at neutral hydrogen column density $\log N(\text{H\,i}) = 15.0$ and metal abundance one-tenth the solar value. The gas temperature was constrained to be $\log T > 4.0$, although in practice this constraint has little effect.\(^9\) Ionizing radiation comes from an updated version of the Haardt & Madau (1996) spectrum included with Cloudy,\(^10\) at redshift $z = 0.25$ (the median redshift of our sample). Since the spectrum of the UV background is fixed, and the relative intensity is set at a fixed redshift, only changes in the density affect the ionization parameter. Thus, at high densities, there are fewer ionizing photons per atom, and lower ionization states predominate. At lower densities (higher $\log U$), there are more ionizing photons for a given atom, and higher ionization states may be ionized. Inspection of the curves in Figure 33 shows that O vi can be observed over a wide range of conditions, especially if one considers that metallicity may vary over a 1–2 dex range. Thus, unlike with CIE where O vi occupies a very narrow temperature range, simply detecting O vi is not enough to determine the ionization conditions.

The column density ratios predicted by the Cloudy models are not sensitive to the adopted value of $\log N(\text{H\,i})$ in the optically thin regime, although the absolute column densities would obviously be lower for a lower gas column. A comparison between models with solar and one-tenth solar metallicity shows that the column density ratios are unaffected by metallicity effects in the regime $\log U > -4.0$, which corresponds to densities $\log n_{\text{H\,i}} < -1.6$. This is well away from $\log U = -0.2$, where O vi peaks for photoionization models. None of the systems we consider

\(^9\) Collisional ionization is not yet significant at these temperatures.
\(^10\) Cloudy denotes this “HM05.”

Fig. 17.—PG 1259+593, $z = 0.21950$. Multicomponent O vi and H i are both present in this system, with the H i lines saturated. The blue wing of the Ly$\beta$ line blends with Galactic S ii 21250. C iii and Si iii are both detected; C iii is saturated, while the Si iii line is weak. Both species align with the $v = 0$ km s$^{-1}$ component. [See the electronic edition of the Supplement for a color version of this figure.]
fall into this region of parameter space, so the adopted $[\text{M/H}] = -1.0$ for our models should not affect our conclusions.

The detection of multiple metal transitions in an absorber offers a powerful diagnostic of the ionization conditions of the gas, assuming that the metals responsible for the absorption are cospatial. By comparing the column density ratios for well-aligned

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### TABLE 12

| ION | $z_{\text{comp}}$ | $v$ (km s$^{-1}$) | $\sigma_v$ (km s$^{-1}$) | $b$ (km s$^{-1}$) | $\sigma_b$ (km s$^{-1}$) | $\log N (\text{cm}^{-2})$ | $\sigma_{\log N}$ (log cm$^{-2}$) | Flag |
|-----|------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|---|
| O $\text{vi}$ | 0.21934 | -39 | 2 | 18.9 | 3.2 | 13.7 | 0.1 | Z |
| O $\text{vi}$ | 0.21950 | 0 | 1 | 13.6 | 2.5 | 13.6 | 0.1 | ... |
| H $\text{i}$ | 0.21932 | -44 | 31 | 46.0 | 13.6 | 14.0 | 0.5 | ... |
| H $\text{i}$ | 0.21948 | -5 | 1 | 27.5 | 1.6 | 15.1 | ... | L |
| C $\text{iii}$ | 0.21949 | -2 | 0 | 10.8 | 2.0 | 13.7 | ... | L |
| Si $\text{iii}$ | 0.21950 | 0 | 1 | 8.7 | 2.6 | 12.1 | 0.1 | ... |

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$z = 0.25981$

| ION | $z_{\text{comp}}$ | $v$ (km s$^{-1}$) | $\sigma_v$ (km s$^{-1}$) | $b$ (km s$^{-1}$) | $\sigma_b$ (km s$^{-1}$) | $\log N (\text{cm}^{-2})$ | $\sigma_{\log N}$ (log cm$^{-2}$) |
|-----|------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|---|
| O $\text{vi}$ | 0.25962 | -44 | 3 | 15.0 | 3.6 | 13.5 | 0.1 | ... |
| O $\text{vi}$ | 0.25982 | 4 | 6 | 34.2 | 9.6 | 13.6 | 0.1 | ... |
| H $\text{i}$ | 0.25963 | -43 | 7 | 26.6 | 5.0 | 13.6 | 0.2 | ... |
| H $\text{i}$ | 0.25982 | 1 | 6 | 25.3 | 5.3 | 13.5 | 0.2 | ... |

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**PG1259+593** $z = 0.25981$

**PHL1811** $z = 0.15786$

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**Fig. 18.**—PG 1259+593, $z = 0.25981$. This double-component absorber shows only two O $\text{vi}$ and H $\text{i}$ components. [See the electronic edition of the Supplement for a color version of this figure.]

**Fig. 19.**—PHL 1811, $z = 0.15786$. Both O $\text{vi}$ and H $\text{i}$ in this system are weak. The putative narrow H $\text{i}$ component is not H $\text{i}$, but rather O $\lambda\lambda1302$ in the $z = 0.0809$ Lyman-limit system. We include this line in the fit, detecting only broad, weak H $\text{i}$ that is too weak to be detected in the Ly$\beta$ transition. [See the electronic edition of the Supplement for a color version of this figure.]
Table 13

O VI Absorber Measurements along the Line of Sight toward PHL 1811

| Ion    | $z_{comp}$ | $v$ (km s$^{-1}$) | $\sigma_v$ (km s$^{-1}$) | $b$ (km s$^{-1}$) | $\sigma_b$ (km s$^{-1}$) | log $N$ (log cm$^{-2}$) | $\sigma_{\log N}$ (log cm$^{-2}$) | Flag |
|--------|------------|-------------------|--------------------------|------------------|--------------------------|------------------------|-----------------------------|------|
| O VI   | 0.15786    | 0                 | 5                        | 42.0             | 7.8                      | 13.9                   | 0.2                         | ...  |
| H I    | 0.15785    | -3                | 5                        | 49.9             | 7.1                      | 13.3                   | 0.1                         | ...  |

Fig. 20.—PKS 0312−77, $z = 0.20275$. This Lyman-limit system shows strong, saturated O VI, H I, Si II, Si III, Si IV, and C III. We also see weak N V. We are not able to resolve multiple absorption components in the main O VI absorber, but their presence is strongly suggested by the complicated component structure exhibited in other transitions. [See the electronic edition of the Supplement for a color version of this figure.]
### Table 14

**O vi Absorber Measurements along the Line of Sight toward PKS 0312−77**

| Ion  | $z_{\text{comp}}$ | $v$ (km s$^{-1}$) | $\sigma_v$ (km s$^{-1}$) | $b$ (km s$^{-1}$) | $\sigma_b$ (km s$^{-1}$) | log $N$ | log $\sigma_{\log N}$ | Flag |
|------|-------------------|-------------------|-------------------------|-------------------|-------------------------|--------|------------------------|------|
| O vi | 0.20177           | −243              | 8                       | 80.8              | 13.1                    | 14.1   | 0.1                    | ...  |
| O vi | 0.20276           | 1                 | 1                       | 68.4              | 2.3                     | 14.9   | 0.2                    | ...  |
| H i  | 0.20178           | −241              | 1                       | 14.6              | 1.2                     | 14.7   | 0.1                    | ...  |
| H i  | 0.20192           | −205              | 1                       | 11.8              | 2.7                     | 14.7   | 0.1                    | ...  |
| H i  | 0.20210           | −161              | 1                       | 20.4              | 2.7                     | 14.5   | 0.1                    | ...  |
| H i  | 0.20276           | 1                 | 0                       | 38.2              | 0.4                     | 18.4   | ...                    | U    |
| C ii | 0.20275           | 0                 | 0                       | 5.4               | 2.7                     | 14.4   | ...                    | L    |
| C ii | 0.20288           | 32                | 0                       | 17.3              | 5.6                     | 13.9   | 0.1                    | ...  |
| C ii | 0.20297           | 53                | 0                       | 10.4              | 1.6                     | 14.4   | ...                    | L    |
| C ii | 0.20261           | −35               | 0                       | 19.8              | 5.3                     | 14.5   | ...                    | L    |
| C ii | 0.20254           | −53               | 0                       | 17.3              | 2.0                     | 14.7   | ...                    | L    |
| C ii | 0.20181           | −235              | 1                       | 7.2               | 1.9                     | 13.5   | 0.1                    | ...  |
| C iii| 0.20279           | 8                 | 3                       | 9.8               | 6.1                     | 13.6   | 0.4                    | ...  |
| C iii| 0.20299           | 60                | 2                       | 15.5              | 5.9                     | 14.3   | ...                    | L    |
| C iii| 0.20255           | −50               | 2                       | 17.2              | 7.2                     | 15.6   | ...                    | L    |
| C iii| 0.20319           | 108               | 1                       | 4.1               | 7.2                     | 14.4   | ...                    | L    |
| C iii| 0.20327           | 130               | 2                       | 4.8               | 5.5                     | 13.0   | ...                    | L    |
| C iii| 0.20334           | 147               | 2                       | 6.1               | 5.2                     | 13.1   | 0.3                    | ...  |
| C iv | 0.20212           | −157              | 1                       | 4.9               | 6.7                     | 14.3   | ...                    | L    |
| C iv | 0.20186           | −221              | 2                       | 8.1               | 1.6                     | 16.8   | ...                    | L    |
| N ii | 0.20275           | 0                 | 0                       | 6.8               | 5.5                     | 13.6   | 0.3                    | ...  |
| N ii | 0.20288           | 32                | 0                       | 14.4              | 16.6                    | 13.5   | 0.4                    | ...  |
| N ii | 0.20297           | 53                | 0                       | 9.0               | 3.0                     | 14.2   | ...                    | L    |
| N ii | 0.20261           | −35               | 0                       | 19.4              | 10.4                    | 14.1   | ...                    | L    |
| N ii | 0.20254           | −53               | 0                       | 13.9              | 4.2                     | 14.5   | ...                    | L    |
| N ii | 0.20211           | −160              | 0                       | 35.6              | 6.7                     | 15.2   | ...                    | L    |
| N ii | 0.20193           | −205              | 0                       | 19.1              | 7.6                     | 14.3   | ...                    | L    |
| N v  | 0.20272           | −7                | 9                       | 13.8              | 18.8                    | 13.1   | 0.5                    | ...  |
| N v  | 0.20291           | 41                | 8                       | 27.6              | 13.6                    | 13.5   | 0.2                    | ...  |
| N v  | 0.20262           | −31               | 8                       | 7.9               | 12.1                    | 12.9   | 0.7                    | ...  |
| N v  | 0.20254           | −52               | 3                       | 4.3               | 5.9                     | 12.9   | 0.3                    | ...  |
| N v  | 0.20180           | −236              | 2                       | 7.2               | 3.7                     | 13.2   | 0.2                    | ...  |
| S ii | 0.20266           | −21               | 2                       | 9.0               | 3.1                     | 14.1   | 0.1                    | ...  |
| S ii | 0.20254           | −53               | 2                       | 10.7              | 3.4                     | 14.1   | 0.1                    | ...  |
| S ii | 0.20275           | −1                | 0                       | 10.5              | 1.8                     | 13.1   | 0.1                    | ...  |
| S ii | 0.20291           | 39                | 9                       | 15.3              | 7.4                     | 12.8   | 0.3                    | ...  |
| S ii | 0.20297           | 55                | 0                       | 6.3               | 1.2                     | 13.6   | 0.2                    | ...  |
| S ii | 0.20261           | −33               | 5                       | 10.1              | 3.7                     | 13.8   | 0.3                    | ...  |
| S ii | 0.20254           | −52               | 2                       | 14.2              | 1.2                     | 14.2   | 0.2                    | ...  |
| S iii| 0.20273           | −5                 | 0                       | 30.4              | 2.3                     | 15.7   | ...                    | L    |
| S iii| 0.20194           | −201              | 1                       | 7.9               | 1.8                     | 12.5   | 0.1                    | ...  |
| S iii| 0.20181           | −235              | 0                       | 11.5              | 1.6                     | 12.8   | 0.1                    | ...  |
| S iv | 0.20274           | −1                | 22                      | 56.6              | 14.5                    | 13.7   | 0.2                    | ...  |
| S iv | 0.20295           | 49                | 2                       | 11.1              | 3.9                     | 13.5   | 0.2                    | ...  |
| S iv | 0.20257           | −44               | 2                       | 17.0              | 5.1                     | 14.6   | ...                    | L    |
| S iv | 0.20194           | −201              | 0                       | 15.2              | 4.7                     | 13.2   | 0.1                    | ...  |
| S iv | 0.20181           | −235              | 0                       | 2.6               | 2.3                     | 13.1   | 0.5                    | ...  |

$z = 0.20275$
Fig. 21.—Further transitions of the PKS 0312–77, $z = 0.20275$, system, as for Fig. 20. [See the electronic edition of the Supplement for a color version of this figure.]
Fig. 22.—PKS 0405–12, z = 0.16703. This partial Lyman-limit system has strong O\textsc{vi} and corresponding saturated H\textsc{i}, and low ion metals with a complicated structure. [See the electronic edition of the Supplement for a color version of this figure.]
| Ion   | $z_{\text{comp}}$ | $v$ (km s$^{-1}$) | $\sigma_v$ (km s$^{-1}$) | $b$ (km s$^{-1}$) | $\sigma_b$ (km s$^{-1}$) | $\log N$ (cm$^{-2}$) | $\sigma_{\log N}$ (cm$^{-2}$) | Flag |
|-------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|------|
| O vi  | 0.16660         | $-110$          | 1               | 7.4             | 2.2             | 13.8            | 0.2             | ...  |
| O vi  | 0.16703         | 0               | 3               | 58.7            | 5.1             | 14.7            | 0.1             | ...  |
| H i   | 0.16662         | $-105$          | 1               | 11.5            | 2.2             | 13.5            | 0.1             | ...  |
| H i   | 0.16674         | $-75$           | 3               | 12.8            | 6.8             | 13.1            | 0.2             | ...  |
| H i   | 0.16712         | 23              | 1               | 36.8            | 2.2             | 15.7            | ...             | L    |
| C ii  | 0.16713         | 26              | 0               | 12.2            | 1.3             | 14.3            | ...             | L    |
| C ii  | 0.16699         | $-11$           | 1               | 7.4             | 1.4             | 13.7            | 0.1             | ...  |
| C ii  | 0.16713         | 26              | 1               | 11.2            | 1.3             | 14.2            | ...             | L    |
| O i   | 0.16712         | 22              | 1               | 2.5             | 2.2             | 13.8            | 0.3             | Z    |
| Si ii | 0.16713         | 25              | 0               | 9.4             | 1.0             | 13.3            | 0.1             | ...  |
| Si ii | 0.16697         | $-15$           | 1               | 6.9             | 2.1             | 12.5            | 0.1             | ...  |
| Si iii| 0.16700         | $-7$            | 1               | 13.1            | 2.2             | 12.7            | 0.1             | ...  |
| Si iii| 0.16716         | 32              | 1               | 16.6            | 1.8             | 13.3            | 0.1             | ...  |
| Si iv | 0.16712         | 22              | 2               | 30.5            | 3.5             | 13.4            | 0.1             | ...  |
| O vi  | 0.18256         | $-87$           | 4               | 21.5            | 6.5             | 13.7            | 0.2             | ...  |
| O vi  | 0.18291         | 0               | 2               | 21.4            | 3.8             | 14.0            | 0.2             | ...  |
| H i   | 0.18258         | $-82$           | 4               | 35.3            | 3.1             | 14.5            | ...             | L    |
| H i   | 0.18288         | $-8$            | 5               | 30.9            | 4.6             | 14.2            | ...             | L    |
| O vi  | 0.36334         | 2               | 0               | 8.8             | 1.8             | 13.5            | 0.1             | ...  |
| H i   | 0.36334         | 2               | 0               | 22.8            | 4.1             | 13.6            | 0.1             | Z    |
| C iii | 0.36334         | 2               | 0               | 6.9             | 3.8             | 12.4            | 0.2             | ...  |
| O vi  | 0.49514         | 0               | 1               | 43.8            | 1.9             | 14.5            | 0.1             | ...  |
| H i   | 0.49515         | 2               | 10              | 75.0            | 0.0             | 14.3            | 0.1             | Z    |
| C iii | 0.49507         | $-13$           | 1               | 10.1            | 1.7             | 13.1            | 0.1             | ...  |
| O iii | 0.49499         | $-29$           | 8               | 29.9            | 11.1            | 13.7            | 0.1             | Z    |
| O iii | 0.49558         | 88              | 3               | 9.2             | 4.2             | 13.5            | 0.2             | Z    |
| O iv  | 0.49509         | $-10$           | 6               | 33.0            | 0.0             | 14.5            | 0.1             | Z    |
| O iv  | 0.49556         | 85              | 5               | 6.9             | 5.7             | 13.6            | 0.2             | Z    |
Fig. 23.—PKS 0405–12, z = 0.18291. This system has two strong O\textsc{vi} components separated by some 90 km s\textsuperscript{-1}. The O\textsc{vi} λ1031 data are quite noisy. Both O\textsc{vi} components have corresponding H\textsc{i} absorption, but the Ly\textsc{α} line is heavily saturated and higher order lines are outside the wavelength coverage of our data. No metal absorption is seen. [See the electronic edition of the Supplement for a color version of this figure.]

Fig. 24.—PKS 0405–12, z = 0.36333. This system shows weak O\textsc{vi} with a well-fit doublet. The Ly\textsc{α} line shows contamination from bad pixels and is also possibly blended with Galactic C\textsc{i} λ1657; Ly\textsc{β} is not detected. Weak C\textsc{iii} is also present. [See the electronic edition of the Supplement for a color version of this figure.]

Fig. 25.—PKS 0405–12, z = 0.49514. The highest redshift absorber in our sample, both O\textsc{vi} lines are clearly detected, but both suffer from bad pixels, complicating the fitting. Ly\textsc{α} is redshifted out of our wavelength range, and Ly\textsc{β} shows a very wide profile. Strong C\textsc{iii} is detected, as are O\textsc{iii} and O\textsc{iv}. [See the electronic edition of the Supplement for a color version of this figure.]
transitions with predictions of a model like that in Figure 32, we can place limits on $\log U$; even saturated lines can provide limits in $\log U$. With the ionization parameter determined, we obtain the average volume density of the cloud and using the ionization fraction (from the Cloudy output) we can then calculate a length scale for the cloud. These numbers are, however, dependent on the strength of the UV background ionization field, which is uncertain. When relevant in the following analysis, we give a range of parameters for a range of UV background intensities $J_{\nu,912} = (2-7) \times 10^{-23}$ erg s$^{-1}$ cm$^{-2}$ Hz$^{-1}$ sr$^{-1}$ (Shull et al. 1999; Scott et al. 2002).

We address several systems below. Many of these systems have already been studied in detail in terms of their ionization conditions, characteristic sizes and/or average densities. In these cases, we do not comment unless we have additional information to add, beyond what has been published. The interested reader is encouraged to see the following references for more information: Savage et al. (2005), HE 0226+4110 $z = 0.20702$; Lehner et al. (2006), HE 0226+4110 $z = 0.34034$; Tripp & Savage (2000), PG 0953+12  $z = 0.16703, 0.36333$. Note that all our Cloudy models assume a solar abundance pattern. If there are significant deviations from this pattern (which may be particularly problematic for C or N), then we will deduce incorrect limits. Hence, the more metal transitions we have for a system, the better our results will be.

**TABLE 16**

| Ion | $z_{\text{comp}}$ | $\sigma_v$ (km s$^{-1}$) | $\sigma_b$ (km s$^{-1}$) | $\log N$ (cm$^{-2}$) | $\sigma_{\log N}$ (cm$^{-2}$) | Flag |
|-----|------------------|-----------------|-----------------|----------------|----------------|------|
| $z = 0.22565$ | | | | | |
| O vi | 0.22553 | 28 | 5 | 19.4 | 6.9 | 13.5 | 0.3 | ... |
| H i | 0.22556 | 0 | 2 | 13.4 | 2.8 | 13.7 | 0.1 | ... |
| O vi | 0.22553 | 28 | 0 | 51.6 | 3.7 | 13.9 | 0.1 | ... |
| H i | 0.22565 | -1 | 6 | 23.6 | 10.8 | 13.3 | 0.3 | ... |

| $z = 0.22744$ | | | | | |
| O vi | 0.22744 | 0 | 1 | 11.4 | 2.4 | 13.5 | 0.1 | ... |
| H i | 0.22743 | -1 | 4 | 19.4 | 6.0 | 12.9 | 0.1 | ... |
Ton28  \( z = 0.27340 \)

Fig. 28.—Ton 28, \( z = 0.27340 \). Only very weak \( \text{O} \, \text{vi} \) absorption is seen to correspond with the saturated \( \text{Ly} \alpha \) in this system. \( \text{Ly} \beta \) is present and unsaturated, as is \( \text{Ly} \gamma \). The \( \text{Ly} \alpha \) line is blended with Galactic \( \text{C} \, \text{iv} \) 1548, which we fit simultaneously. [See the electronic edition of the Supplement for a color version of this figure.]

H1821+643; \( z = 0.22496 \).—This system was first examined by Tripp et al. (2000), who reported \( N \) for \( \text{O} \, \text{vi} \) absorbers on this sight line but were primarily interested in the cosmological mass density of \( \text{O} \, \text{vi} \) and did not discuss the ionization condition of individual absorbers. As noted in § 3.4, the \( \text{O} \, \text{vi} \) and \( \text{Si} \, \text{iii} \) Doppler parameters for the \( v = 0 \) km s\(^{-1} \) component are inconsistent with a single phase, since \( b_{\text{O} \, \text{vi}} > b_{\text{Si} \, \text{iii}} \) and \( b_{\text{O} \, \text{vi}} > b_{\text{C} \, \text{ii}} \). For this \( v = 0 \) km s\(^{-1} \) component, we also detect weak \( \text{Si} \, \text{iv} \), but no \( \text{H} \, \text{i} \) component are aligned with the \( \text{O} \, \text{vi} \) position. The \( \text{Si} \, \text{iii} \) to \( \text{Si} \, \text{iv} \) column density ratio is consistent with the \( \text{Si} \, \text{ii} \) to \( \text{C} \, \text{iii} \) column density limit, and \( \log U \approx -2.1 \) (log \( N_{\text{H} \, \text{i}} \approx -3.5 \)). The weaker component at \( v \approx 25 \) km s\(^{-1} \) also contains saturated \( \text{C} \, \text{iii} \), \( \text{Si} \, \text{iii} \), and \( \text{Si} \, \text{iv} \). This component also falls within the width of the \( \text{O} \, \text{vi} \) line, but the centroids are significantly different. The nearest \( \text{H} \, \text{i} \) component to this low-ionization gas is at \( v = 15 \) km s\(^{-1} \), and the relation between the two is unclear. For this low-ion \( v \approx 25 \) km s\(^{-1} \) component, \( \text{Si} \, \text{iii} \) and \( \text{Si} \, \text{iv} \) have the same column density, while \( \log N(\text{Si} \, \text{iii})/N(\text{Si} \, \text{iv}) \) is \( \approx 1.0 \) dex, both of which are consistent with \( \log U \approx -1.4 \). There are no obvious matches to the weak \( \text{O} \, \text{vi} \) component at \( v = 60 \) km s\(^{-1} \). The mismatch of the broad \( \text{O} \, \text{vi} \) and low ion Doppler parameters, in addition to the multiple low-ion components falling within the \( \text{O} \, \text{vi} \) absorption range, argues for a core-halo cloud model, with a hot gaseous halo traced by \( \text{O} \, \text{vi} \), surrounding cooler gas traced by lower ionization species.

PG 1216+069; \( z = 0.28232 \).—Tripp et al. (2005) were the first to publish STIS data of PG 1216+069, but they concentrated on the DLA at \( z = 0.00632 \) associated with the NGC 4261 group and do not consider this absorber in detail. We detect \( \text{O} \, \text{vi} \) and saturated \( \text{C} \, \text{iii} \). The \( \text{C} \, \text{iii} \), \( \text{Si} \, \text{iii} \), and \( \text{H} \, \text{i} \) lines are offset from the \( \text{O} \, \text{vi} \) position by \( \Delta v = 6-9 \) km s\(^{-1} \) to the blue, and its association is unclear. We measure \( \log N(\text{C} \, \text{iii})/N(\text{Si} \, \text{iii}) \) $>1.3$, which gives the limit \( \log U > -2.6 \) (log \( N_{\text{H} \, \text{i}} \approx -2.9 \); \( L > 5 \) kpc, where we have folded in the range in \( J_{\odot} \) into the quoted limits).

### Table 17

| Ion   | \( z_{\text{comp}} \) | \( v \) (km s\(^{-1} \)) | \( \sigma_v \) (km s\(^{-1} \)) | \( b \) (km s\(^{-1} \)) | \( \sigma_b \) (km s\(^{-1} \)) | \( \log N \) (cm\(^{-2} \)) | \( \sigma \log N \) (cm\(^{-2} \)) | Flag |
|-------|----------------------|------------------------|-------------------------------|------------------------|-------------------------------|------------------------|-------------------------------|------|
| \( \text{O} \, \text{vi} \) | 0.27340              | 0                      | 3                             | 20.9                   | 4.2                           | 13.4                   | 0.2                           | ... |
| \( \text{H} \, \text{i} \)  | 0.27337              | -8                     | 1                             | 30.2                   | 1.8                           | 14.2                   | 0.1                           | ... |

### Table 18

| QSO (1) | \( z_{\text{abs}} \) (2) | \( N(\text{O} \, \text{vi}) \) (3) | \( N(\text{H} \, \text{i}) \) (4) |
|---------|------------------------|-------------------------------|-------------------------------|
| 3C 249.1 | 0.23641                | 13.99                         | 13.23                         |
| 3C 351.0 | 0.21811                | 13.96                         | 13.50                         |
| 3C 351.0 | 0.22111                | 14.25                         | >14.56                        |
| H1821+643 | 0.12143                | 13.94                         | 14.31                         |
| H1821+643 | 0.21331                | 13.57                         | >14.29                        |
| HE 0226−4110 | 0.42670          | 13.44                         | ...                           |
| PG 1216+069 | 0.26768            | 13.30                         | >14.86                        |
| PG 1259+593 | 0.31972             | 13.92                         | 14.04                         |
| PG 1444+407 | 0.22032             | 13.95                         | 13.63                         |
| PKS 0312−77 | 0.15890            | 13.94                         | 13.90                         |
| PKS 0312−77 | 0.19827             | 13.84                         | >14.26                        |
| PKS 0405−12 | 0.36156             | 14.00                         | >14.14                        |
| PKS 1302−102 | 0.19159            | 13.93                         | >14.17                        |
| Ton 28 | 0.13783                | 13.99                         | >14.37                        |
| Ton 28 | 0.20524                | 13.69                         | 13.20                         |

Notes.—Summary of \( \text{O} \, \text{vi} \) candidates that we do not recover. See text for details on individual systems.

* Tripp et al. (2005) report no \( \text{H} \, \text{i} \) with this system. \( \text{Ly} \alpha \) is redshifted out of the STIS band, and \( \text{Ly} \beta \) is not detected.
Fig. 29.—Spectra of the O\textsc{vi} \lambda 1031 (top) and O\textsc{vi} \lambda 1037 (bottom) spectral regions for absorbers we do not confirm. Blended regions are shown by dotted spectral regions. [See the electronic edition of the Supplement for a color version of this figure.]
PG 1259+593; \( z = 0.21950 \) — Data for the PG 1259+593 sight line were published by Richter et al. (2004), who report the detection of \( \text{O} \, \text{vi} \) in \textit{FUSE} data, in addition to \( \text{O} \, \text{vi}, \text{Si} \, \text{iii}, \) and (saturated) \( \text{C} \, \text{iii} \) metal lines seen in the STIS data. They conclude that the absorber is a multiphase medium, based on the inconsistency of the \( \text{Si} \, \text{iii} \) data with an ionization parameter derived using \( \text{O} \, \text{iii} \) and \( \text{O} \, \text{vi} \). This conclusion is emphasized by our discussion above of the limits placed by the ratio of Doppler parameters. In our STIS data we measure \( b_{\text{O} \, \text{vi}}/b_{\text{Si} \, \text{iii}} = 1.6 \pm 0.6 \), which is inconsistent at the 1 \( \sigma \) level with a single gas phase, since \( m_{\text{O} \, \text{vi}}/m_{\text{Si} \, \text{iii}} = 0.6 \); i.e., for these species to arise from the same gas phase, we must have \( 0.6 < b_{\text{O} \, \text{vi}}/b_{\text{Si} \, \text{iii}} < 1.0 \), irrespective of the relative contributions of \( b_{\text{int}} \) and \( b_{\text{therm}} \).

PKS 0312−77; \( z = 0.20275 \) — While the Lyman-limit system at \( z = 0.20275 \) in the sight line toward PKS 0312−77 shows many metal absorption lines, particularly those of low ions, none can be unambiguously matched with the \( \text{O} \, \text{vi} \) absorption. The main \( \text{O} \, \text{vi} \) absorption component is very broad compared to other ions; even the highly ionized species like \( \text{Si} \, \text{iv} \) and \( \text{N} \, \text{v} \) exhibit a complex multicomponent structure that is seen in the low-ionization species. It is therefore likely that \( \text{O} \, \text{vi} \) arises in a different gas phase or that there are unresolved \( \text{O} \, \text{vi} \) absorption components.

PKS 0405−12; \( z = 0.49514 \) — The highest redshift \( \text{O} \, \text{vi} \) absorber in our survey, this absorber is fit with a single \( \text{O} \, \text{vi} \) component. We detect \( \text{O} \, \text{iii} \) and \( \text{O} \, \text{iv} \) at \( v = 90 \) km s\(^{-1} \), but no associated \( \text{O} \, \text{vi} \) or \( \text{H} \, \text{i} \), and we do not consider this component in detail. At \( v = 10 \) km s\(^{-1} \), the data clearly show \( \text{C} \, \text{iii} \) and \( \text{O} \, \text{iv} \) absorption at \( v = 29 \pm 8 \) km s\(^{-1} \) as too far from the \( \text{O} \, \text{vi} \) centroid. Prochaska et al. (2004) do not provide a full analysis of this system, referring instead to a future paper, which was not forthcoming. From our \( \text{O} \, \text{vi}, \text{O} \, \text{iv} \), and \( \text{C} \, \text{iii} \) measurements, we find \( \log U = -0.8 \) to \( -1.3 \) (\( \log n_{\text{H}} = -4.0 \) to \( -4.5; L \approx 12-140 \) kpc).

5.4. Systems Lacking \( \text{H} \, \text{i} \)

In a survey for \( \text{O} \, \text{vi} \) absorbers, we might expect to find a class of systems that do not contain associated \( \text{H} \, \text{i} \). If large-scale galactic winds and superwinds shock-heat metals to a WHIM phase, they may also ionize hydrogen to a level that is not detectable for weak systems (as in the above discussion on CIE systems). Such hot bubbles may exist even without strong winds (Kawata & Rauch 2007). Since we conduct a blind search for the \( \text{O} \, \text{vi} \) doublet, we should be sensitive to the existence of such systems, down to our detection limit, which is approximately 30 mA with good data (but see Paper I for a better quantification of this, since not all data are of equal quality).

Given the above discussion, it may be somewhat telling that we find no strong evidence for such a class of systems. Our survey contains two systems that we suggest are \( \text{H} \, \text{i} \) free. The \( z = 0.32639 \) absorber toward HE 0226−4110 (Fig. 9) shows no evidence of Ly\( \alpha \) or Ly\( \beta \) absorption, although the Ly\( \alpha \) region is quite noisy. The upper limit on \( N(\text{H} \, \text{i}) \) for this system implies \( \log \left[ N(\text{O} \, \text{vi})/N(\text{H} \, \text{i}) \right] \geq 1.1 \) dex. The \( z = 0.22638 \) system toward

Fig. 30.—Same as Fig. 29, but remaining systems not shown in that figure. [See the electronic edition of the Supplement for a color version of this figure.]

Fig. 31.—Distribution of \( \text{O} \, \text{vi} \) and \( \text{H} \, \text{i} \) column densities for well-aligned absorption components. Full symbols are regular components, while open circles designate components whose alignment is flagged as uncertain.
H1821+643 (Fig. 5) shows a single broad H\textsc{i} component significantly offset ($\Delta v = -53 \pm 2$ km s$^{-1}$) from the O\textsc{vi} position. If we posit that this component could hide a weak, aligned H\textsc{i} component, and attempt to force-fit an H\textsc{i} component aligned with the O\textsc{vi} absorption, we obtain $N$(H\textsc{i}) < 12.3, implying $\log \frac{N(O\textsc{vi})}{N(H\textsc{i})} > 138$ kpc. Such large column density ratios are well outside the bounds of what is found for the well-aligned components ($0.75 < \log \frac{N(O\textsc{vi})}{N(H\textsc{i})} < 0.67$) and imply either strongly enriched gas (supersolar assuming photoionization; see Fig. 31) or that the gas is collisionally ionized. Expanded samples of low-z O\textsc{vi} absorbers will be very valuable for determining the fraction of such systems, and their potential as tracers of hot gas.

6. SUMMARY

We have presented a catalog of O\textsc{vi} absorbers selected from high-resolution $HST$ STIS echelle data. Our selection technique followed a blind search for the O\textsc{vi} doublet feature. Relying solely on the presence of the O\textsc{vi} doublet, and the ratio of doublet line strength, we detect 27 O\textsc{vi} absorption systems, independent of other transitions. The statistics of these absorbers were presented in Paper I. We note that 16 systems reported in a contemporaneous work by Tripp et al. (2008) do not satisfy our selection criteria and therefore are not included in our sample of 27 absorbers. In cases where only one transition is found or the doublet ratio appears to be inconsistent with model expectations, these authors include the presence of other transitions, such as Ly\alpha absorption, for justifying the identifications of O\textsc{vi}.

In our absorbers, it is common to find multiple absorption components in any given system, corresponding to physically distinct gas structures. By matching these absorption components from different species, we can identify different transitions likely due to the same gas. Under this assumption, we can then derive both the temperature of the gas and the nonthermal contribution to the Doppler parameter, $b_{nt}$. This analysis demonstrates that, for well-matched O\textsc{vi}/H\textsc{i} components, gas temperatures are in the range $\log T = 3.7$–5.0, well below the temperature range at which O\textsc{vi} is expected to be found in collisional ionization equilibrium ($\log T = 5.5$). We thus advise caution in identifying the O\textsc{vi} absorbers with the hot WHIM gas that simulations predict will contain a significant fraction of the baryons. Our finding based on all available absorbers in the current $HST$ STIS data archive reaffirms previous findings from studies of individual lines of...
sight. Future generations of X-ray spectrographs are likely to be necessary to solve this question conclusively.

If galactic winds are the dominant source of O \textsc{vi} formation, shock-heating the gas to the WHIM regime, and pushing it out to \sim 1 Mpc from galaxies, we may expect to see this in a variety of ways. A class of H\textsc{i}-free O \textsc{vi} absorbers may arise, as both the hydrogen and oxygen are ionized in strong winds. We see no evidence of a large number of H\textsc{i}-free O \textsc{vi} absorbers, with only two systems present in our survey. Reasoning that the H\textsc{i} absorption will best trace the local overdensity, we compared the velocity difference between our O \textsc{vi} components and the nearest H\textsc{i} component. A wind origin may leave an imprint on the kinematics of the absorbers, manifest as a systematic offset between the H\textsc{i} and O \textsc{vi} positions. We see no such effect (see also comparisons in Paper I), but this test is likely a weak one. Clearly, systematic galaxy redshift surveys around the QSO lines of sight are required to properly address this.

The location of the missing baryons at low redshift is clearly an important issue in modern cosmology and astronomy. The WHIM is a leading candidate reservoir for this mass with simulations and suggesting that it contains as much as 50\% of all z = 0 baryons. While some have claimed that the observations support this view, we argue that caution is required. High-resolution spectra that cover a broad wavelength range are crucial for constraining the ionization, metallicity, and the temperature of the gas involved, and care must be taken to deduce nonthermal broadening mechanisms. If the baryons are to be unambiguously located in the WHIM, further observations are crucial.

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