Emergence of a Broad-Absorption-Line Outflow in the Narrow-line Seyfert 1 Galaxy WPVS 007

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ABSTRACT

We report results from a 2003 FUSE observation, and reanalysis of a 1996 HST observation of the unusual X-ray transient Narrow-line Seyfert 1 galaxy WPVS 007. The HST FOS spectrum revealed mini-BALs with $V_{\text{max}} \sim 900$ km s$^{-1}$ and $FWHM \sim 550$ km s$^{-1}$. The FUSE spectrum showed that an additional BAL outflow with $V_{\text{max}} \sim 6000$ km s$^{-1}$ and $FWHM \sim 3400$ km s$^{-1}$ had appeared. WPVS 007 is a low-luminosity object in which such a high velocity outflow is
not expected; therefore, it is an outlier on the $M_V/V_{\max}$ relationship. Template spectral fitting produced effective ionic columns, and a \textit{Cloudy} analysis showed that the presence of P V required a high ionization parameter $\log(U) \geq 0$ and high column density $\log(N_H) \geq 23$ for input SED with nominal $\alpha_{\text{ox}} = -1.28$. A recent long \textit{Swift} observation revealed the first hard X-ray detection, and intrinsic $\alpha_{\text{ox}} \approx -1.9$. The X-ray weak SED required a lower column density ($\log(N_H) \geq 22.2$, or $\log(N_H) \geq 21.6$ for $Z = 5$, suggesting possibly that BALQSOs with P V have intrinsically X-ray weak continua. In either case, the large columns and velocities could be problematic for radiative acceleration. The absorbed X-ray weak continuum can account for the \textit{Swift} X-ray spectrum. The origin of the dramatic BAL variability is not known; however, the low luminosity implies a small size scale such that development of a BAL outflow that covered the source would have been feasible between the two observations.

\textit{Subject headings:} quasars: absorption lines, quasars: individual ([WPV85] 007)

1. Introduction

Active galaxies, the most luminous persistently-emitting objects in the Universe, are powered by mass accretion onto a supermassive black hole. But gas not only falls into the black hole, it can also be blown out of the central engine in powerful winds, as indicated by the blue-shifted emission and absorption lines observed in the rest-frame UV spectra. Outflows are likely to be an essential part of the AGN phenomenon because they can carry away angular momentum and thus facilitate accretion through the disk. Winds are important probes of the chemical abundances in AGN, which appear to be elevated (Hamann & Ferland 1999). They can distribute chemically-enriched gas through the intergalactic medium (Cavaliere et al. 2002). They may carry kinetic energy to the host galaxy, influencing its evolution, and contributing to the coevolution of black holes and galaxies implied by the observed correlation between the black hole and bulge masses (e.g., Scannapieco & Oh 2004).

Unfortunately, the nature and origin of AGN outflows remain largely mysterious. Blueshifted absorption lines are the most easily identifiable evidence for outflows. The absorption lines

\footnote{Based on observations made with the NASA-CNES-CSA Far-Ultraviolet Spectroscopic Explorer. FUSE is operated for NASA by Johns Hopkins University under NASA contract NAS5-32985.}
forming in AGN winds are divided into three categories based on line widths: broad absorption lines (BALs; FWHM $\sim 10,000$ km s$^{-1}$), narrow absorption lines (NALs; FWHM $\sim < 500$ km s$^{-1}$), and intermediate mini-broad absorption lines (mini-BALs). The relationship between these types of outflows is not well understood, although it appears that BAL outflows are seen only in luminous quasars (e.g., Laor & Brandt 2002), with narrower lines observed in less luminous objects. It is widely believed that the outflows arise from the accretion disk, but the point of origin and acceleration mechanism(s) are not understood (e.g., Proga 2007). In addition, BAL flows are associated with X-ray weakness (e.g., Gallagher et al. 2006), suggesting absorption of the X-ray continuum by very high columns approaching $10^{23}$ cm$^{-2}$, that, if also outflowing, strongly constrain acceleration mechanisms.

There is a strong need to measure basic parameters of the flows, but it is difficult. The velocity of the BAL is measured directly from the absorption line profile, but the amount of matter and kinetic energy in the outflow is difficult to constrain. Lines are saturated, although not black, implying that the absorbing material only partially covers the source. The geometry and radial extent of the flows are not known. The density is difficult to constrain because most lines arise from permitted transitions and are not very density dependent.

Line variability provides a valuable tool for studying the absorbing gas. For example, variation in absorption-line apparent optical depths can sometimes be attributed to differences in ionization, and the variability time scale can be used to place lower limits on the electron density. This information can then be used to constrain the distance from the nucleus (e.g., Narayanan et al. 2004). But variations appear to be small in general; mini-BALs become stronger or weaker, and portions of BAL profiles become stronger or weaker. The lack of dramatic variability indicates that the flows are stable and long term.

WPVS 007 is a low-luminosity Seyfert 1 galaxy ($\alpha_{2000}=00 39 15.2; \delta_{2000} = -51 17 02; z = 0.02882, M_V = -18.8$), that is known to exhibit rather peculiar behavior. During the ROSAT All Sky Survey (RASS), it was a bright X-ray source, although it was observed to have the softest spectrum ever found in an AGN (inferred $\alpha = -7.3$ for $F_E \propto E^\alpha$ Grupe et al. 1995). Subsequent observations have found the object to be consistently X-ray weak (Grupe et al. 1995, 2007, 2008), and the origin of the X-ray weakness is not known. Recently, a Swift observation revealed the first detection of this object in hard X-rays ($> 2$ keV). Although the number of photons observed were small, the data suggest that the source is partially covered by an absorber with $N_H \sim 10^{23}$ cm$^{-2}$ (Grupe et al. 2008).

The UV observations presented in this paper provide a possible explanation of the X-ray transience through the observation of dramatic variability in the absorption line properties between an archival HST spectrum from an observation in 1996 (discussed in §2) in which the
object displays mini-BALs with a maximum velocity of about $900\text{ km s}^{-1}$ and $FWHM \sim 550\text{ km s}^{-1}$, and a FUSE spectrum from an observation in 2003 (§3) in which the object was found to have developed broad absorption lines with $V_{\text{max}} \sim 6,000\text{ km s}^{-1}$ $FWHM \sim 3400\text{ km s}^{-1}$ in addition to the mini-BAL. This transformation is the most dramatic ever seen in a active galaxy, and we postulate that the changing absorption observed in the UV is responsible for the transient X-ray behavior. We analyze the results using Cloudy models (§4). A summary of the paper is given in §5. Unless otherwise specified, we assume $H_0 = 73\text{ km s}^{-1}\text{ Mpc}^{-1}$, $\Omega_M = 0.27$, and a flat universe.

2. HST Observations

The HST observations were conducted 1996 July 30. The HST spectra are more than 10 years old, and the data have appeared in the literature several times. Goodrich (2000) shows the spectrum in the region of Ly$\alpha$ and comments on the absorption. Crenshaw et al. (1999) include the data in a study of absorption lines in Seyfert 1 galaxies. They report absorption lines from Ly$\alpha$, N V, Si IV, and C IV. Constantin & Shields (2003) analyze some of the properties of the UV spectra of NLS1s, and construct a composite NLS1 spectrum of all publically available HST spectra of NLS1s at the time of writing, including WPVS 007. Kuraszkiewicz et al. (2004) analyze all active galaxies observed with the HST FOS after the COSTAR correction optics had been put in place. They perform an automated spectral fitting over a broad band pass and present extensive tables of results. However, while this object is included in their paper, their tables do not include information on the high-ionization lines at wavelengths from Ly$\alpha$ to He II $\lambda 1640$. Dunn et al. (2006) present light curves from IUE and HST observations of Seyfert galaxies. They find evidence that WPVS 007 varied among four epochs of observation, becoming faintest in the HST observation. Finally, Grupe et al. (2007) present Swift photometry $^2$, showing that WPVS 007 has brightened since the HST observation.

Since none of the previously published results present the information we need to do the required analysis of the absorption lines, we extract the spectra from the archive and perform the measurements ourselves.

$^2$The central wavelengths of the Swift filters are as follows: $v$ 5468 Å; $b$ 4392 Å; $u$ 3465 Å; $uvw1$ 2600Å; $uvw2$ 2246 Å; $uw2$ 1928Å (Poole et al. 2008)
2.1. Preliminary Analysis

The spectra were extracted from the HST Data “Online” website for Legacy instruments including the FOS. These are final calibration data products, so no recalibration was necessary. The observation log is presented in Table 1.

We first verify the wavelength calibration of the spectra by measuring the wavelengths of Galactic absorption lines. We used Si II λ1260.3, C II λ1334.5, Al III λ1670.8, Fe II lines at 2344.2, 2382.8, 2586.6, and 2600.2Å, and Mg II λλ2796.4, 2803.5 (note that vacuum wavelengths are used, as appropriate for the HST data). These lines showed that the spectral segments obtained using the G130H, G190H, and G270H gratings were consistent with no anomalous wavelength shifts. There were no convenient Galactic absorption lines available to examine the spectra obtained with the G400H and G570H gratings; since we find no anomalous redshifts or flux offsets (see below) we assume that these spectra are also free of wavelength shifts.

We next merge the spectra starting with the short wavelengths. We examined overlapping regions for flux offsets and found no evidence for any. The final signal-to-noise ratio of the continuum varies from ∼ 3.7 at wavelengths shortward of 1600Å (observed frame), to 22 in near 2700Å, and falling to ∼ 9 around 6600Å. We smooth the spectra using a three-point scheme in which the center point is weighted three times the adjacent points. We correct for the Galactic reddening of $E(B – V) = 0.012$ mag (Schegel et al. 1998) using the Cardelli et al. (1989) reddening curve. Finally, we shift the spectrum into the rest frame, adopting the NASA/IPAC Extragalactic Database redshift value of 0.02882.

2.2. Continuum Shape and Reddening

The HST spectrum is relatively blue longward of ∼ 2700Å, but becomes significantly redder shortward of that value. We show the spectrum in Fig. 1 overlaid on two comparison spectra. The first comparison spectrum is a mean of HST spectra of two NLS1s that were chosen as follows. As discussed in Leighly & Moore (2004), there is significant range of UV emission-line properties among NLS1s. Since the mini-BALs absorb out most of the emission lines in WVPS 007, we sought objects that were similar in the line bases and UV continua. We found that the WVPS 007 spectrum most closely resembled that of Mrk 493, which had HST FOS spectra stretching from ∼ 1160Å to 6818Å (observed frame), and Mrk 335, which had HST FOS spectra stretching from ∼ 1160Å to 3300Å (observed frame). These

3http://archive.stsci.edu/hstonline/
two spectra were very similar to one another in slope and emission lines in the overlapping region. These spectra were processed in the same way as discussed above, and then uniformly resampled on a logarithmically-binned wavelength scale that matched the original binning approximately. They were then rescaled to match in flux and averaged over the common-wavelength region. The second comparison spectrum is the FBQS radioquiet composite spectrum (Brotherton et al. 2001). The composite spectrum has a very similar continuum shape as the Mrk 493–Mrk 335 average. In the following, we implicitly assume that the unreddened WPVS 007 spectrum has the same shape as the Mrk 493–Mrk 335 average. This assumption is to some extent justified based on the similarity between the composite spectrum and the Mrk 493–Mrk 335 average.

Fig. 1 shows clearly that WPVS 007 is reddened in comparison with the NLS1 mean spectrum and the composite spectrum. The reddening curve appears to be very unusual, however. WPVS 007 and the comparison spectra have essentially the same spectra longward of $\sim 2700\AA$, which means that there is either no attenuation in the optical bands, or that there is no wavelength dependence in the attenuation. We develop the reddening curve as follows. We remove Galactic absorption lines and then coarsely rebin the WPVS 007 spectrum and the Mrk 493/Mrk 335 average. We remove regions of prominent emission lines and compute the ratio. The ratio was then fit with a spline model. The ratio appears to be approximately flat shortward of $\sim 1500\AA$. The ratio appears to have some structure longward of $\sim 3000\AA$, but it is clear that is caused by higher equivalent-width optical Fe II in WPVS 007, so it was assumed to be 1 longward of $\sim 2700\AA$. Since the ratio is flat in the optical band, we cannot define a reddening curve in the standard way, relative to $E(B-V)$, as has been done for other AGN by e.g., Crenshaw et al. (2001) and Crenshaw et al. (2002). Instead, we define it relative to 2000Å, and assume that the optical bands are not attenuated at all. The extinction curve from the spectra, the spline fit and the SMC reddening curve (Prévat et al. 1984) are shown in Fig. 2. The extinction curve in WPVS 007 is unusually steep between 2700Å and 1700Å.

2.3. Absorption Lines and Profile Analysis

The HST spectrum reveals high-ionization absorption lines. Fig. 3 shows the WVPS 007 spectrum between 1185 and 1595Å in comparison with the average Mrk 335–Mrk 493 spectrum. The presence of these absorption lines was previously noted by Crenshaw et al. (1999).

The N V absorption lines are clearly resolved, and we begin our analysis there. Preliminary examination of the lines shows that the absorbing gas must occult both the line-emitting gas and the continuum-emission region since the absorption lines are deeper than the con-
We analyze the absorption profile as follows. The mean Mrk 335–Mrk 493 spectrum was resampled on the wavelength scale of the WPVS 007 spectrum and the ratio of the WPVS 007 spectrum and the average spectrum was made. Assuming that the average Mrk 335–Mrk 493 spectrum is a good representation of the unabsorbed WPVS 007 spectrum, and that the absorption covers both the line emission region and the continuum emission region, this ratio $R$ should be 1 outside of the range of the absorption lines, and should be less than one in the region of the absorption lines. The region of the NV absorption lines was isolated, and the effective optical depths ($\tau = -\ln R$) for the two NV lines were computed. The effective optical depth profiles for the two lines were essentially indistinguishable implying that absorption is saturated but not black. This is commonly understood to be the consequence of a velocity-dependent covering fraction. Since the effective optical depth profiles were indistinguishable, they could be averaged to produce a mini-BAL template (Fig. 4). The HST mini-BAL has an approximate maximum velocity of $V_{\text{max}} \sim 900 \text{ km s}^{-1}$ and approximate FWHM of $\sim 550 \text{ km s}^{-1}$.

If the absorption lines are saturated, and if the Mrk 335–Mrk 493 mean spectrum is an accurate representation of the unabsorbed WVPS 007 spectrum, we should be able to apply the mini-BAL template to the Mrk 335–Mrk 493 mean spectrum in the region of C IV and Ly$\alpha$, and reproduce the observed WPVS 007 spectrum in those regions. Fig. 5 shows that the absorption lines in the WPVS 007 spectrum are well reproduced, although not without some adjustments: The Ly$\alpha$ region was rescaled by a multiplicative factor of 1.1, and the C IV region was scaled by a multiplicative factor of 0.8, and an additive factor of $0.05 \times 10^{-14} \text{ erg s}^{-1} \text{ cm}^{-2} \text{ Å}^{-1}$. The fact that these scale factors are necessary imply that the absorption lines are consistent with being optically thick and with having the same velocity profile to the extent that the continuum is 5% different, and the emission lines are 10–20% different in flux in WPVS 007 compared with the Mrk 335–Mrk 493 mean spectrum. The Ly$\alpha$ line, however, has a red excess near the peak of the line. This could be a narrow-line-region component of Ly$\alpha$, in which case it is rather redshifted from the NED redshift value. It is perhaps more likely that the Ly$\alpha$ has a more peaked profile than the mean of Mrk 335 and Mrk 493.

To obtain quantitative measures of the absorption line profile parameters, we next fit the spectrum using IRAF Specfit. Specfit allows template continuum, and for that we use the mean Mrk 493–Mrk 335 spectrum. For the absorption lines, we use the template developed from the NV line and shown in Fig. 4. We fix the template wavelengths (in Specfit treated as a redshift) to the rest wavelengths for each line, and allow the scale factors to be free in the spectra fitting. The results are given in Table 2, which includes
also the FUSE spectral fitting results discussed in §3.5. The first column of Table 2 lists the line, the second column gives the vacuum wavelength, the third column is the scale factor of the template including the uncertainty from the spectral fitting, the fourth column is the template used with the exception of the alternative deblending of the FUSE spectrum as discussed in §3.5.4, and the fifth column is the estimate of the lower limit of the column density obtained by integrating over the line profile (Eq. 9, Savage & Sembach 1991). The uncertainties in the column densities are proportional to the uncertainties in the scale factors in the fitting, and thus they give only an estimate of the statistical uncertainty. Atomic data were taken preferentially from NIST\textsuperscript{4}, as well as from The Atomic Line List v2.04\textsuperscript{5} and Morton (1991).

### 3. FUSE Observation

The observing log for the FUSE observation is given in Table 1. The exposure times are split into “day” and “night” exposures. During the day exposures, the satellite is over the portion of the earth in which the earth is lit by the sun. Background from scattered light is somewhat higher during the day exposures, and emission from airglow is stronger. The LIF detectors have larger effective area, and we used both the day and night data from them. The SIC detectors have significantly lower effective area, and as WPVS 007 is a somewhat faint AGN, we used only night data from them. Hence, the exposure times reported in Table 1 are shorter for the SIC spectra compared with the LIF spectra.

The FUSE data were processed with a modified version of the CalFUSE pipeline version 3.1.8. The modifications involved a reduction of background intensity using a PHA selection. The details are given in Appendix A. The resulting spectra were then merged and smoothed, and the details of that process are given in Appendix B. The resulting spectrum is shown in the top panel of Fig. 6. Identified Galactic absorption lines are labeled below the plot, and prominent restframe absorption lines in this bandpass are labeled above the plot, regardless of whether they are identified or not. A plausible unabsorbed continuum using the HST quasar composite spectrum (Zheng et al. 1997) is included on the graph.

The spectrum clearly shows the presence of broad absorption lines in both high-ionization lines such as O \textsc{vi} $\lambda\lambda$1031.9, 1037.6 and low-ionization lines such as C \textsc{iii} $\lambda$997. There are a few features that are seen immediately, and they are confirmed by the detailed analysis

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\textsuperscript{4}http://www.physics.nist.gov/PhysRefData/ASD/index.html

\textsuperscript{5}http://www.pa.uky.edu/~peter/atomic
below. P V λλ1118, 1128 is present. This line from the rather low-abundance element phosphorus has been shown to be characteristic of absorption-line gas with high column density (Hamann 1998). The 1128Å component is clearly deeper than the 1118Å component, suggesting that the lines are perhaps not completely saturated and thus the optical depth is not extremely high. O VI absorption is dominated by a broad and deep trough, but narrow absorption lines similar to the mini-BALs seen in the HST spectra are observed in both the O VI doublets and also in Lyβ. The mini-BALs are not apparent in the P V troughs.

Before we perform a quantitative analysis of the absorption lines in WPVS 007, we qualitatively compare our spectrum with the HST spectrum of a BALQSO LBQS 1212+1445, also shown in Fig. 6. At a redshift of z = 1.6245, the HST STIS G230L bandpass samples the restframe 600–1200 Å band. This comparison is useful because the 10,811-second-exposure HST spectrum has considerably better signal-to-noise ratio than our FUSE spectrum. It also has a rather similar BAL structure. Thus, the lines are easier to identify and measure. In LBQS 1212+1445, we see many of the same lines as in WPVS 007. The P V BALs are clearly present, and the 1118Å component is clearly deeper than the 1128Å suggesting again that the line is not completely saturated. The velocity profile has a larger $v_{\text{min}}$ but perhaps the same $v_{\text{max}}$ for P V. Minibals are present in O VI in both objects, and are also clearly present in C III and N III in LBQS 1212+1445.

### 3.1. P V Analysis

Analysis of broad absorption lines is very complicated. If the lines are overlapping, the continuum may be difficult to identify. The absorption lines themselves may be blended. The opacity of a line depends on velocity, there may be partial covering that may also depend on velocity, and these cannot be diagnosed directly because of blending. In the case of very high signal-to-noise spectra and unblended lines, these factors may be robustly deconvolved (e.g., Arav et al. 2007), but that is not generally the case.

As noted in §3.2, P V λλ1117.98, 1128.01 is clearly seen in the FUSE spectrum. Phosphorus has much lower solar abundance than other elements such as carbon, nitrogen and oxygen that commonly produce BALs (e.g., P/C = 0.00093, Grevesse et al. 2007). Therefore, even if those lines are clearly saturated and partially covering the source, it is possible that the P V will not be completely saturated. Moreover, if the P V line is in a somewhat isolated part of the spectrum, and it may not be subject to severe blending. In fact, the doublet ratio (1118Å component divided by the 1128 Å component) is 2.03, and visual examination of the region suggests that the 1118Å component may have a larger effective optical depth than the 1128Å line. Therefore we first analyze the P V line with the intention
of developing an effective absorption line template from this feature that can be used for the other absorption lines.

Fig. 7 shows an expanded version of the region of the FUSE spectrum near P V, after three Galactic absorption lines marked in Fig. 6 have been modeled out. For the continuum, we use a spline fit to the HST FOS composite spectrum, initially scaling by a factor of 0.7 (the level shown in Fig. 6). We assume that that P V is solely responsible for the absorption between 1095 and 1127Å. Then, the termination of the absorption at 1095 Å implies that the maximum velocity is 6179 km s$^{-1}$. The 10Å separation between the P V doublet components corresponds to 2678 km s; this is large compared with the maximum velocity. This means that the absorption between 1118 and 1128Å, corresponding to the velocity profile between zero and $-2678$ km s$^{-1}$ originates solely from the 1128Å component. Likewise, for the assumed maximum velocity of 6179 km s$^{-1}$, the region between 1095 and 1104.8 Å originates solely from the 1118Å component. This band corresponds to the velocities between 3555 and 6178 km s$^{-1}$. There is an overlap of the absorption troughs from the two doublet components only between 2678 and 3555 km s$^{-1}$. This is sampled in two parts of the spectrum, between 1114.7 and 1118.0Å, which corresponds to the overlap of the 2678 and 3555 km s$^{-1}$ section of the 1128Å profile with the zero to 854 km s$^{-1}$ for the 1118Å component, and between 1104.8 and 1108.1Å, which corresponds to the overlap between the 2678 and 3555 km s$^{-1}$ section of the 1118Å component with the 5338 to 6178 km s$^{-1}$ section of the 1128Å component.

Thus our strategy to produce the effective optical depth profile is as follows. We generate the effective optical depth by dividing the spectrum by the continuum and taking the logarithm ($\tau_{eff} = -\ln R$). We construct the profile in the 0–2678 km s$^{-1}$ band using the 1128Å component, and the profile in the 3555–6178 km s$^{-1}$ using the 1118Å component. Then, the two estimates for the 2678–3555 km s$^{-1}$ are generated from the overlap regions by subtracting the known component from the effective optical depth. The overlap region is then the mean of these two estimates. To test the resulting template, we apply it to the continuum to generate the spectrum.

The two uncertainties in this procedure are the ratio of the effective taus of the two lines and the placement of the continuum. Specifically, we assume that the derived optical depth profile corresponds to the 1128Å component, and the 1118Å component is related by a ratio, to be determined. Initially, we assume that the ratio is the ratio of the $gf_{ik}$ for the two lines, or 2.03, appropriate if the real optical depths of the absorption lines are optically thin. The result is shown as the dashed dark grey line in Fig. 7. By definition, the simulated spectrum models the profile well in the low and high velocity regions of the feature that are created by either the 1118 or the 1128Å component by itself. However, in the overlap region, the synthetic spectrum clearly shows stronger absorption than in the observed spectrum.
The are several different possible origins for the discrepancy between the synthetic spectrum and the observed spectrum. First, the absorption line could be partially saturated so that the ratio between the effective optical depths of the 1118 component and the 1128 component is less than 2.03 and approaches 1. Alternatively, the continuum level could be lower than assigned. A continuum offset seems unlikely, though, as we set the continuum level at the point where the sharp low-velocity drop on the 1128Å component occurs. One factor is ruled out, however: partial covering by itself, and without saturation could not create this discrepancy, as that would only make the zero flux point higher (i.e., subtracting off the partial covering). It is worth repeating that given the poor statistics of the spectrum, we are assuming that there is no velocity dependence in the saturation or partial covering; physically, there may be, but the spectrum is not good enough to be able to determine whether there is or not.

Since the ratio of the effective taus of 2.03 is ruled out, we determine a best fitting ratio as follows. We define a figure of merit (fom), which is the sum of the absolute value of the difference between the simulated spectrum and the observed spectrum in the overlap region. Simulated spectra are generated using a range of effective tau ratios between 2.03 and 1. The fom is a shallow apparently parabolic function of the ratio with a minimum of 1.35. The simulated spectrum using this best fitting effective tau ratio is shown by the light grey line in Fig. 7. The fit is not perfect, being too shallow for shorter wavelengths and too deep for longer wavelength in the overlap region, but it is clearly better than the fit for a ratio of 2.03. Another possibility is that the effective tau ratio varies as a function of velocity, with a lower ratio (approaching 1) for low velocities and a higher ratio for high velocities. Since the fom has no statistical significance, we estimate the uncertainty on this value by examining at the residuals and determining the point at which the simulated spectrum clearly does not fit the data, yielding a conservative range of 1.15–1.55.

The constraints on reasonable placement of the continuum are fairly tight. The absorption decreases sharply at low velocity, and thus the continuum cannot reasonably be placed very far below the position where this joins the continuum. Likewise, unless we do not see the continuum at all in this object, we cannot place the continuum much higher. We examine the cases in which the continuum was set to be about 4% higher and lower than the original value; this range seemed consistent with the constraints above. The results are very similar. A higher continuum yields a higher maximum velocity and perhaps a slightly better fit for longer wavelengths in the overlap region. A lower continuum yields a lower maximum velocity and a notably worse fit at longer wavelengths in the overlap region. The best fom was obtained for the original continuum level, but the differences are not large. Therefore, we use the optical depth profile obtained using the original continuum level, with an inferred ratio of the effective optical depths of the 1118Å component to the 1128Å component of 1.35;
the effective optical depth profile plot is shown in Fig. 4. The profile has an approximate maximum velocity of $V_{\text{max}} \sim 6000 \text{ km s}^{-1}$, and an approximate FWHM of $\sim 3400 \text{ km s}^{-1}$.

3.2. MiniBAL Analysis

The *FUSE* spectrum of WPVS 007 has mini-BALs as well as BALs. These can clearly be seen on O VI and Ly$\beta$, and they can also be seen on N III and C III. They are not seen on Si IV or P V. They are distinguished from the BALs by their distinctive shape, most clearly seen on O VI but also because they have a lower-velocity onset than the BALs, as shown in Fig. 8. In this section we analyze the mini-BALs in the region of Ly$\beta$ and O VI in order to produce a template for fitting the other ones.

The mini-BALs are superimposed on the BALs, and thus their profiles are difficult to analyze. To define a pseudocontinuum, we isolate the region of the spectrum between 1020 and 1038 Å, and remove the regions of the spectrum containing the mini-BALs from Ly$\beta$, and O VI $\lambda\lambda1031.9, 1037.6$. We then fit the remainder with a model intended to parameterize the pseudocontinuum. We find that a lorentzian line model plus a constant works well. Next, we need to find the effective optical depths, generally done by dividing the continuum by the data, and then taking the logarithm. The problem with that procedure for these data is that the spectrum in the region of the mini-BALs dips below zero. This is, of course, not physical, and may be a consequence of residual background subtraction problems, although we note that Fig. 17 shows that the errors are sufficiently large that the data are consistent with zero in the region of the mini-BALs. Therefore, to obtain the template, we add 0.1 to both the continuum model and the spectrum before taking the logarithm. The result is encouraging, as it shows three effective optical depth profiles that are very similar in shape and depth, although the O VI $\lambda1032$ component has slightly larger optical depth. The similarity in profiles indicate that the lines are saturated. We resample the Ly$\beta$ and O VI $\lambda1038$ components to the wavelengths of the O VI $\lambda1032$ component, and compute the mean profile. The result, as a function of velocity, is shown in Fig. 4 in comparison with the mini-BAL template developed from N V in the *HST* spectra, and the *FUSE* BAL profile developed in §3.3. *FUSE* mini-BAL template has approximately the same maximum effective optical depth as the *HST* mini-BAL; however, this is a lower limit as we had to add a constant to the spectrum in order to compute the effective optical depth. The *FUSE* mini-BAL seems to perhaps have a sharper onset, a little lower maximum velocity ($\sim 800 \text{ km s}^{-1}$) and a little smaller FWHM ($\sim 470 \text{ km s}^{-1}$), compared with the *HST* mini-BAL, perhaps indicating evolution of this component.
3.3. Modeling the FUSE Spectrum

Now that we have developed templates for the BAL (discussed in §3.3) and the mini-BAL (discussed in §3.4), we can apply the templates to the remainder of the FUSE spectrum, with the aim of determining which lines are present and what their effective optical depths are. As for the HST spectrum, we use IRAF Specfit to fit the spectra. We use the HST composite continuum (Zheng et al. 1997) with the normalization fixed at the level shown in Fig. 6 for the continuum. We use the two templates derived in §3.3 and 3.4, fixing the wavelength (treated in Specfit as a redshift) to correspond to the rest wavelengths of the absorption lines investigated, allowing only the scale factor (effectively, the optical depth) to be free. We discuss three regions of the spectrum separately: the P V/S IV region between 1037.5 and 1135 Å, the O VI region between 991 and 1135 Å, and the C III/N III/P IV region shortward of 991 Å.

3.3.1. P V/S IV Region

We first fit the P V region by itself, between 1090 and 1135 Å. The results are given in Table 2. The definitions of the columns were discussed in §2.3. Although we extracted the FUSE BAL template from the 1128 Å line, and thus the scale factor of the FUSE BAL template is by definition 1, the best fit is somewhat less than 1 at 0.89 with statistical error of 0.03. In addition, the template was derived assuming that the optical depth ratio of the 1118 line to the 1128 line is 1.35. But the spectral fitting found a value somewhat less than that of 1.30 ± 0.03. This is probably a consequence of the spectral fitting being able to statistically deconvolve the overlap part better than we could by hand, and the overlap part influencing the optical depth of both components.

We next fit the region between 1037.5 and 1135 Å. This region includes a large absorption feature that can plausibly be identified as S IV. This line is composed of three components. The ground state transition has a wavelength of 1062.7 Å. The other two transitions from this configuration arise from an excited state with \( E_i = 951.43 \, \text{cm}^{-1} \), with wavelengths 1072.96 and 1073.51 Å. The \( g_i f_{ik} \) values for the three transitions are 0.69, 2.09, and 0.23. The later two lines are very close together in wavelength, and we model them with the \( g_i f_{ik} \)-weighted mean wavelength of 1073.07. We obtain an excellent fit, as seen in Fig. 13. In particular, the position of the sharp increase in opacity at low velocity matches the spectrum perfectly for both components, verifying that this feature is indeed S IV.

The undeniable presence of the excited state absorption from S IV is interesting because the energy of the lower level is slightly high. Population of this level requires \( n_e > f_{ki}/A_{ki} \).
Using the NIST values for $f_{ik}$ and $A_{ki}$, we find $n_e > 3.8 \times 10^9$ cm$^{-3}$ for the 1072.962 Å component, and $n_e > 5.8 \times 10^9$ cm$^{-3}$ for the 1073.508 Å component.

3.3.2. The O VI Region

Between 991 and 1037.5 Å there is a very broad absorption feature as well as the mini-BALs originating in O VI and Lyβ that were discussed in §3.4. O VI is at least partially responsible for the broad feature. However, if the O VI components have the same profile as the P V components, and if O VI were the only contribution to this feature, then the high-velocity decrease in opacity should be observed at approximately 1016 Å (the point corresponding to 20% of the maximum opacity of the profile shown in Fig. 6 or 9), rather than stretching to at least 991 Å as observed. This implies that there are several other ions responsible for absorbing the shorter wavelengths. In this section, we investigate this possibility by including absorption from ions that are conceivably present in the gas. Alternatively, the O VI profile could be broader than the P V profile; this would not be surprising if found to be the case as the profiles of high-ionization lines are frequently found to be broader than those of intermediate ionization lines (Junkkarinen et al. 2001). Therefore, we discuss an alternative deblending in §3.5.4.

We approach the problem by modeling the longer wavelength absorption in this feature the FUSE BAL template and the mini-BAL template, first assuming only the presence of O VI, and determining the shortest wavelength to which we could obtain an adequate fit.

Modeling only O VI and the mini-BALs, we find that we can obtain an adequate fit down to 1018 Å, although the fit is not very good between the Lyβ and the O VI λ1032 mini-BAL because the O VI BAL is required to be very deep ($\tau = 4.3$) to model all of the deep absorption present. Decreasing the lower limit of the fitting range further yields larger $\chi^2$ and larger $\tau$ for the O VI λ1032 BAL.

We observe a Lyβ mini-BAL, so it is quite possible that a Lyβ BAL is also present. We add this component, and find a much improved fit around the mini-BALs. We find that the fit is adequate down to 1012 Å; for wavelengths shorter than that, the $\chi^2$ rises precipitously, and the broad Lyβ optical depth becomes very large.

S III has resonance and low-lying excited state transitions in this region of the spectrum. The multiplet consists of six components at 1012.50, 1015.50, 1015.57, 1015.78, 1021.11, and 1021.32 Å, with corresponding lower level energies of 0, 298.7, 298.7, 833.1, and 883.1 cm$^{-1}$, and $g_i f_{ik}$ values of 0.042, 0.042, 0.032, 0.053, 0.053, and 0.158, respectively. We model this feature with three BALs centered at 1012.50, 1015.63, and 1021.27 Å. We obtain a good fit
for wavelengths down to about 1000Å. The results of this fit are given in Table 2. We note that as we add components to the model, the uncertainties on the optical depths increases; for example, the uncertainty on the S III λ1015 component is almost as large as the optical depth. Thus these shorter-wavelength lines cannot really be said to be detected. All we have shown is that their presence is necessary if the entire broad feature between 991 and 1037.5Å is comprised of features with the same profile as P V.

The S III can account for the deepest part of the trough for wavelengths as short as 1000Å; however, shortward of that wavelength, the opacity drops rapidly. If the broad feature between 991 and 1037.5Å is a blend of lines with the same profile as P V, another ion with resonance wavelength around 1000Å must participate in the absorption. We found a P III resonance triplet that will work. The wavelengths are 998.0, 1001.726, and 1003.6Å, with corresponding $gf$ values of 0.223, 0.668, and 0.473. Including these allows a good fit to the shortest wavelength of this feature at 991Å. However, the shortest wavelength component ends up having zero normalization (Table 2), casting some doubt on the robustness of this deblending.

3.3.3. The C III, N III and P IV Region

We finally turn to the region of the spectrum shortward of 991Å that contain C III, N III and P IV. Starting with the region between 955 and 991Å, we see clear evidence for both broad components and mini-BALs for C III and N III, so we begin by adding those lines. The region around N III was fit very well with a BAL and a mini-BAL. In the C III region, the mini-BAL template modeled the region between 972 and 977 angstroms well. However, the feature was too broad to be modeled by the BAL template. Ly$\gamma$ falls in this region at 972.5Å. We see no evidence for a Ly$\gamma$ mini-BAL, so we just add a broad component; it turns out that the data cannot constrain a Ly$\gamma$ BAL and mini-BAL simultaneously, as the signal-to-noise ratio is very low in this region of the spectrum. The Ly$\gamma$ component allows us to extend the fitting region down to 958Å before experiencing a poor fit. We could not find any other transitions in this region that could possibly add to the opacity. This seems to imply that the Ly$\gamma$ or C III absorption profile is broader than the P V profile. However, we caution that the evidence for this inference is rather weak because the signal-to-noise ratio is very low (the spectrum is almost undetected) and because the region not adequately fit by the C III and Ly$\gamma$ absorption is rather narrow, only about 4 angstroms wide.

Finally, we seem to see a P IV mini-BAL and BAL near 950Å, so we add a component for each of those, fitting down to 940Å. The mini-BAL is modeled very well with the template set at the P IV wavelength. The rest wavelength of Ly$\delta$ is only 0.91Å below P IV, so it is
possible that the absorption feature originates in hydrogen instead. However, substituting \( \text{Ly}\delta \) for the P IV mini-BAL gives a much poorer fit (\( \chi^2 = 789 \) for the Ly\( \delta \) mini-BAL, versus \( \chi^2 = 762.5 \) for the P IV mini-BAL), and a wavelength offset between the model and the data is seen. Thus, while the fit is better for the mini-BAL in P IV. This is an odd result, since the mini-BAL is clearly not present in P V and S IV, as discussed above. On the other hand, it is worth reflecting that the signal-to-noise ratio in this region of the spectrum is very low (Fig. 18), and therefore any fit results in this region must be taken with a grain of salt.

For wavelengths shorter than 940Å, there are several ions that could contribute to the opacity. However, the quasar is essentially undetected in this region, so no meaningful constraints on the column densities can be obtained.

We plot the resulting model and the spectrum in Fig. 9. Except for the region between 991 and \( \sim 1000 \)Å in the O VI absorption feature, and the region between 950 and 960Å in the C III/Ly\( \gamma \) absorption feature, the fit is very good. We also plot the individual components of the model in Fig. 9.

\[ \text{3.3.4. Alternative Deblending} \]

Fig. 9 shows that we can very nearly successfully fit the whole FUSE spectrum using the FUSE BAL and mini-BAL templates. In the P V and S IV regions, blending is not severe, and we can be reasonably confident that the deblending is valid. However, since the blending is severe at shorter wavelengths, we cannot be as confident of the results, even though the fit is very good. For example, we deblend the region of the spectrum containing O VI stretching from 990 to 1037Å with lines from four different ions including nine different transitions (and three mini-BALs). It is possible, rather, that the opacity may be dominated by O VI alone. The spectra of other BALQSOs often reveal higher velocities in higher ionization lines (e.g., Junkkarinen et al. 2001), so this possibility is very plausible. Thus, we present an alternative deblending of the blended O VI and C III regions, as follows.

First, for the O VI region, we consider the wavelength range between 990 and 1037Å. We first need to remove the mini-BALs. The most direct way to do this would be to divide the observed spectrum by the mini-BAL template. However, because the opacity of the mini-BALs is so large, this procedure produces an unacceptable amount of noise in the result. Therefore, we start with HST quasar composite spectrum, and convolve it with the FUSE BAL template spectrum for the nine transitions shown in Fig. 9. We then divide the result by the quasar composite to produce the effective optical depth, which is in fact the sum of the opacity for the nine transitions. We next assume that this effective optical depth is
produced solely by O VI. If that were the case, the feature would be badly blended. The O VI transitions are separated by 5.7 Å, while the interval we are considering stretches over 47 Å, for an inferred maximum velocity of about 12,000 km s\(^{-1}\). Therefore, we use a method described in Junkkarinen et al. (1983) in which the feature is described as a single line with an \(f\)-weighted wavelength and an oscillator strength of \(f_1 + f_2\), where \(f_1\) and \(f_2\) are the oscillator strengths for each of the transitions. We then integrated over the effective optical depth in velocity space and obtained a lower limit of the column density as before. The result is given in Table 2, labeled as O VI in the template column.

Moving to shorter wavelengths, we recognize that N III is not blended with other lines in the deblending presented in Fig. 9, but C III is blended with Ly\(\gamma\), and furthermore, the short wavelength end of that feature is not modeled completely using the FUSE BAL and mini-BAL templates. So we assume that the entire region between 953 and 978 Å originates in C III absorption. To create the effective optical depth we follow the same procedure as for O VI: we convolve the HST quasar composite spectrum with the FUSE BAL template in the proportion obtained for C III BAL and Ly\(\gamma\) as shown in Fig. 9, and then divide by the HST composite. Note that this procedure underestimates the possible C III optical depth since the model shown in Fig. 9 does not fully account for the absorption between \(\sim 950\) and \(\sim 960\) Å. The result is given in Table 1, labeled as C III in the template column.

3.3.5. Column Density Lower Limits

Using Eq. 9 in Savage & Sembach (1991), we can integrate over the templates to get estimates of the lower limit of the column densities. Those values are given in the fifth column of Table 2. The uncertainties given are proportional to the uncertainties in the scale factors in the fitting, and thus they provide an estimate of only the statistical uncertainty.

4. Discussion

4.1. Cloudy Models

We would like to determine the physical state of the absorbing gas, and place constraints on other parameters such as the launching radius in order to understand outflows in AGN. While this can be done fairly robustly in some cases where the signal-to-noise ratio is very good and the absorption lines are resolved (e.g., Arav et al. 2007), it is generally difficult because the absorption lines are saturated and partially covering the source. But the situation is a little better for WPVS 007 because we measure P V in the FUSE spectrum, and it
does not seem to be completely saturated, and we find that we can obtain some interesting and useful limits through analysis of the BALs using Cloudy.

4.1.1. Spectral Energy Distribution

In this section we try to constrain the properties of the absorbers by comparing the results of Cloudy models with the column density limits obtained in §3.5.4. Cloudy requires as input a spectral energy distribution (SED). As discussed in §2.2, the UV and FUV spectra are clearly absorbed, and the X-rays are most often not detected, so it is not possible to build an SED directly from the WPVS 007 observations. However, as discussed in §2.2, the emission lines of the NLS1s Mrk 493 and Mrk 335 are very similar to those of WPVS 007, and these objects have roughly similar optical luminosity as WPVS 007 (log($L_{5500}$) = 39.1, 39.4, and 40.2 for WPVS 007, Mrk 493, and Mrk 335, respectively) so as a first approximation, we assume that the intrinsic SEDs are similar. Therefore, we construct a SED for WPVS 007 using data from Mrk 493 and Mrk 335.

Both Mrk 493 and Mrk 335 have been observed by XMM-Newton and therefore simultaneous optical/UV and X-ray data are available. Mrk 493 was observed once. During that observation, only the V-band filter was used. The OM image clearly shows the galaxy as well as the bright central AGN, and it is clear that integration of the flux over the nominal XMM-Newton extraction aperture of 12″ will include a significant amount of galaxy light. Yet we need to use this aperture as that is one that is calibrated for conversion to energy fluxes. So we devise an aperture correction using an observation of the bright quasar PKS 0558–504 observed on 2000-05-24. This object is very luminous, and there is no apparent galaxy emission in the V-band image. Using IRAF, we shifted all the images using the V-band filter to a common centroid and summed. We determined the PSF from the PKS 0558–504 image to be 3.34 pixels. We then extracted the net flux within one FWHM, considering this to be dominated by the AGN, and within 12″, using a background annulus between 14″ and 25″, and derive an aperture correction of 1.35. We extracted the flux from the Mrk 493 image in a region with a radius of one FWHM and also within 12″. We then correct for deadtime and coincidence losses using the instructions in the XMM-Newton Users Handbook. Correcting the flux from the small aperture using the correction factor derived from the PKS 0558–504 observation, we find that about 70% of the flux within the large aperture originates in the galaxy. We also compare the radial profiles from the Mrk 493 and the PKS 0558–504 images, finding that they agree within the size of the small aperture.

6http://heasarc.gsfc.nasa.gov/docs/xmm/uhb/XMMUHB.html
of 3.34 pixels and verifying extended emission from the galaxy at larger radii. Finally, we extract the flux and correct for the sensitivity degradation using the instructions.\(^7\) We then scale the HST spectrum to match the flux point. The X-ray data were analyzed in the usual way and the time-averaged spectrum was fitted with a broken power law between 0.3 and 6 keV.

There were two XMM-Newton observations of Mrk 335. The first was performed 2000 December 25. During this observation, images were obtained using the V, B, U, and UVM2 filters. The host galaxy spectrum is expected to be red and therefore to not contribute significantly to the flux in the UVM2 filter. Therefore, we use the results of the standard OM analysis, and then scaled the HST spectrum to the UVM2 filter flux. The X-ray data were analyzed in the usual way except that pileup was present for the PN instrument and therefore an annular extraction aperture was used. The spectra were fitted with a broken power law. The second observation was performed 2006 January 3. The OM was operated using the UV grism, and the data were processed in the standard way. The HST spectrum was then scaled to the to grism spectrum. The X-ray spectrum was analyzed in the usual way, and fitted to a double broken power law model. Finally, the combined UV and X-ray spectra were sampled in line-free regions to construct SEDs consisting of 10–12 points each.

The three SEDs are very similar. The \(\alpha_{\text{ox}}\) values for the Mrk 493, and first and second Mrk 335 observations were \(-1.33\), \(-1.36\), and \(-1.32\), respectively. These are very close to the value of \(-1.22\) predicted for WPVS 007 based on the 5500 Å luminosity obtained from the HST spectrum and the regression published by Steffen et al. (2006) and their cosmological parameters \((H_0 = 70\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}, \Omega_M = 0.3, \Omega_\Lambda = 0.7)\). Next, we obtain a merged SED. Since the HST spectrum of Mrk 493 extended to the optical band, we started with SED for that object. The Mrk 335 SEDs were rescaled to match the Mrk 493 SED in the near UV. We found that the Mrk 335 points straddled the Mrk 493 points in the X-ray, such that an average would have been very close to the Mrk 493 points. We found that the FUV of the Mrk 335 spectra were very slightly higher than the Mrk 493 points, and appeared to match the optical power law better, so we replaced the three far UV points in the SED with the ones from the scaled Mrk 335 spectrum. We interpolated over the unobservable far UV using a power law between the HST and XMM-Newton PN spectra. We use the Cloudy AGN kirk spectrum at higher and lower frequencies. The final spectrum has \(\alpha_{\text{ox}} = -1.28\).

Recently, (Grupe et al. 2008) report the first detection of hard X-rays in WPVS 007. They find evidence for a partially-covered spectrum, and a plausible deconvolution indicates an intrinsic (i.e., unabsorbed) \(\alpha_{\text{ox}}\) of \(-1.9\). Therefore we also construct a continuum spectrum

\(^7\)http://xmm.vilspa.esa.es/sas/7.0.0/watchout/Evergreen\_tips\_and\_tricks/om\_time\_sensitivity.shtml
with \(\alpha_{\text{ox}} = -1.9\) by simply decreasing the flux of the X-ray and higher energy portion of the SED developed above by a factor of 41.3. The two SEDs are shown in Fig. 10.

4.1.2. Simulations and Results for the BALs

Using the continuum developed above, initially we ran Cloudy models for the \(\alpha_{\text{ox}} = -1.28\) continuum for a range of parameters: ionization parameter \(-3.5 \leq \log(U) \leq 0.5\), \(\Delta \log(U) = 0.25\); density \(8.0 \leq \log(n_H) \leq 12.0\), \(\Delta \log(n) = 0.5\); column density parameter \(\log(N_{H}^{\text{max}})\), defined as \(\log(N_{H}^{\text{max}}) = \log(N_{H}) - \log(U)\), \(21.0 \leq \log(N_{H}^{\text{max}}) \leq 24.0\), \(\Delta \log(N_{H}^{\text{max}}) = 0.1\) for a total of 4,743 simulations. We use \(\log(N_{H}^{\text{max}})\) rather than just \(\log(N_{H})\) because a constant value of \(\log(N_{H}^{\text{max}})\) probes similar depths in terms of the hydrogen ionization front (Leighly 2004; Casebeer, Leighly & Baron 2006; Leighly et al. 2007, e.g.). We used solar metallicity initially.

We followed the approach discussed by Arav et al. (2001) and since used by a number of other investigators. Specifically, we compare our estimates of the column density given in Table 2 with ionic column densities from the Cloudy simulations as a function of ionization parameter and column density. The gas density is a third parameter but in most cases the absorption lines are not dependent on this parameter (e.g., Hamann 1997). We therefore choose \(\log(n) = 10.0\) as the nominal density and extend the simulations above to \(\log(U) = 1.5\), and also run the simulations for the \(\alpha_{\text{ox}} = -1.9\) continuum for this value of the density. Most of the ionic column densities can be extracted from the “column density” output from Cloudy. There is one relevant exception: columns from low-lying excited states of metal ions such as S IV. As discussed above, these should be populated at typical BLR temperatures and sufficiently high densities according to their statistical weights \((2J + 1)\). Thus, the proportion in the ground \((J = 3/2,\) the 1062Å component) and fine structure \((J = 5/2,\) the 1073Å component) states should be 40% and 60% of the column given by the Cloudy output. Interestingly, though, the estimated column densities given in Table 2 show that the proportions of the estimated column density upper limits are 44% and 56%, very close to the expected proportions, and therefore comparing the estimated lower limits with the simulations for both lines would yield indistinguishable results. Thus, for the following analysis, we compare 60% of the Cloudy \(S^{+3}\) column with the observed column of the 1073Å component.

We first examine the results from the \(\alpha_{\text{ox}} = -1.28\) simulations. We first consider the BAL deblending that is shown in Fig. 9 using the columns listed in Table 2. We also measure upper limits on the column density of a multiplet of N II near 1085Å, and one of Fe III near 1126 (Fig. 9) by inserting a FUSE BAL template into the model and increasing
the normalization until the $\chi^2$ increases by 6.63, corresponding to 99% confidence for one parameter of interest. These upper limits are also listed in Table 2. Fig. 11 shows the ionic column contours from Table 2 on the ionization parameter/$N_H^{\text{max}}$ plane for $\log(n) = 10.0$. Ideally, if the lines were not saturated, the contours would converge in one area of the plot, producing best-fitting values of $\log(U)$ and $\log(N_H) - \log(U)$. The presence of P V implies that lines of similar ions of more abundant species are saturated (Hamann 1998), and therefore we do not expect any region of convergence a priori. Interestingly, we do find one in which a majority of the lines converge: for $\log(U) \geq \sim 0.0$, the column densities of a number of the intermediate-ionization ions converge around $\log(N_H) - \log(U) = 23.0$. Notable exceptions are $O^{+5}$ and $H^0$, for which simulations show much higher column density than observed at $\log(U) = 0.0$, $\log(N_H) - \log(U) = 23.0$, and $S^{+2}$ and $P^{+2}$, for which simulations show lower column densities than observed at that point. If the lines are saturated, the observed column densities are lower limits, and therefore the $O^{+5}$ and $H^0$ columns may be consistent with the other lines at $\log(U) = 0.0$, $\log(N_H) - \log(U) = 23.0$, but the $P^{+2}$, and $S^{+2}$ would not be, because the lower limit exceed the simulated column densities at that point.

We note that as expected, there is little dependence on the density for values in the range $9.5 \leq \log(n) \leq 11$. The column densities of $P^{+2}$ are lower at very low densities and increase as the density is increased, but only for the highest values of $\log(N_H^{\text{max}})$. At the highest densities, lower-ionization columns increase, primarily at the highest values of $\log(N_H^{\text{max}})$. In all cases, the differences are small, and we cannot obtain a markedly better agreement with the observations by assuming very high or very low densities.

As discussed in §3.5, while the deblending in terms of the FUSE BAL template presented in Fig. 9 matches the spectrum well, it is possible that the higher-ionization lines have a broader profile, and O VI dominates the region between 990Å and 1037Å, and therefore we presented the alternative deblending in §3.5.4. The alternative deblending does not attribute any measurable opacity to hydrogen, $P^{+2}$, or $S^{+2}$ (since the onset of absorption for these lines cannot be clearly seen in the spectrum), but instead attributes the absorption to $O^{+5}$ between 990Å and 1037Å, and to $C^{+2}$ between 953 and 978Å. Using these alternative fitting results, we generate the contour plot as before (Fig. 11, right side). Now we see that all measured ions and upper limits are consistent near $\log(N_H) - \log(U) = 23.0$ and $\log(U) \geq 0$, except for $O^{+5}$ which is overpredicted.

We perform the same procedure as above for the simulations using the $\alpha_{\text{ox}} = -1.9$ continuum (Fig. 10 middle panel). The results are rather similar in that the columns of the same ions are under- and over-predicted as before. The difference is that the location of the convergence of many ionic columns occurs at a lower value of $N_H^{\text{max}}$. Our nominal
best solution for this continuum is \( \log(U) = 0.0 \) and \( \log(N_H) - \log(U) = 22.0 \). This result can be understood by considering that in gas illuminated by an X-ray-weak continuum, the intermediate-ionization ions are created at smaller column densities, since the X-ray weak continuum is unable to produce the usual higher-ionization ions Leighly et al. (e.g. 2007). Most of the observed absorption lines (except O VI) are from intermediate-ionization ions.

Quasars are often inferred to have enhanced metallicities (e.g., Hamann et al. 2002). The hydrogen column densities derived above are large, and as will be shown in §4.2, challenge outflow models. Inferred hydrogen column densities should be lower if the metallicity is enhanced. We therefore try a \( \alpha_{ox} = -1.9 \) model with \( Z = 5 \) (that includes helium enhanced by a factor 1.29 and nitrogen enhanced by a factor of 25 Hamann et al. 2002). The results are shown in the lower panel of Fig. 11. Here, the intermediate-ionization ions converge for \( \log(U) = 0 \) at \( \log(N_H) - \log(U) = 21.6 \).

Since we expect that partial covering is strongly influencing our analysis, the fact that the data and models converge for many of the ions at particular points in these graphs seems somewhat surprising. This convergence could be coincidental; alternatively, it could really be the case that only O VI and H I are very saturated and the intermediate-ionization ions seen in the FUSE spectrum are not very saturated. We infer an column ratio less than one between the P V lines suggesting that they are not very saturated; however, the analysis assumes a constant covering fraction as a function of velocity, and if that were not the case physically, the column ratios would not mean anything. That is, we do not have two independent measurements of opacity at any velocity in the profile. Nevertheless, the convergence is suggestive, and we use the column densities of convergence at \( \log(U) = 0 \) (specifically, \( \log(N_H) = 23.0, 22.2, \) and \( 21.6 \) for the \( \alpha_{ox} = -1.28 \) set of simulations, the \( \alpha_{ox} = -1.9 \) simulations, and the \( \alpha_{ox} = -1.9 \) and \( Z = 5 \) simulations) for discussion in the rest of the paper. The transmitted continua for these cases are shown in Fig. 10.

Further analysis reveals some interesting facts about these solutions. First, the choice of ionization parameter is driven by \( P^{+4} \); specifically, the ionization parameter must be sufficiently high to produce a sufficient column of \( P^{+4} \) to match the data. This means that the ions seen in the UV spectra are the tip of the ion iceberg, since these ions dominate gas with much lower ionization parameters than \( \log(U) = 0 \). That is, for most elements, most of the atoms are in higher ionization states, including \( C^{+3} \) and \( N^{+4} \), but also much higher ionization states, indicating that most of the opacity is in the extreme UV and soft X-ray band. That this is true can be seen in the absorbed spectra shown in Fig. 10; much of the continuum in the extreme UV and soft X-ray is absorbed by gas with this ionization parameter and column density.

Next, there is somewhat of a selection effect in the observation of the BALs that limits
the range of column densities, and to some extent the physical conditions, that we infer. First, the effective optical depth cannot be too small or the BAL would not be seen. Then, as all of the transitions are permitted, oscillator strengths are all about the same, and this also means that the ions observed are important gas coolants. Thus, the inferred log of the ionic columns have a fairly small dynamic range, from $\sim 15$ to $\sim 16$. Except for phosphorus, the abundances are not very different either. Finally, except for $O^{+6}$, they are all also intermediate-ionization ions, with ionization potentials to create the absorbing ions lying over a relatively narrow range (from $P^{+3}$ at 30.2 eV to $P^{+4}$ at 51.4 eV). This means that we can to some extent expect them all to reach similar column densities at hydrogen column densities where conditions are changing rapidly due to the depletion of continuum photons that can ionize these ions. We demonstrate this phenomenon in Fig. 12, which shows the log of the simulated ionic columns minus the observed as a function of $N_H^{\text{max}}$ for $\log(U) = 0$. For $\alpha_{\text{ox}} = -1.28$, we see that for $\log N_H < \sim 22.9$, the columns of these intermediate ionization ions are much too low, but then there is a strong increase and convergence of ionic columns near the hydrogen ionization front which occurs at about $N_H = 23$. As discussed above, $P^{+4}$ controls the choice of the ionization parameter, and thus the saturated value exceeds the observed by only a small amount, while the other intermediate-ionization ions continue to increase as a function of $\log(N_H) - \log(U)$.

In summary, we find that we can explain the FUSE spectrum, in particular, the presence of absorption from the low-abundance element phosphorus, with a highly ionized ($\log(U) \geq 0.0$), high column density absorber. Strongly enhanced abundance of phosphorus is not needed because some lines are saturated, although they are not black because partial covering is important. This is essentially the same result found by Hamann (1998) for the quasar PG 1254+047 (see also Hamann et al. 2001). A subtlety explored here is the dependence of the result on the spectral energy distribution. The primary distinction for the X-ray weak $\alpha_{\text{ox}} = -1.9$ simulations is that the column densities of the intermediate-ionization ions are much higher at low values of $N_H$, and thus the simulated columns match the observed at significantly lower values of the column density. As noted above, this occurs because the X-ray-weak continuum is not able to create high-ionization ions, and therefore the gas cools via transitions of intermediate-ionization ions even in front of the helium ionization front (the hydrogen ionization front for the $\alpha_{\text{ox}} = -1.9$ continuum is located beyond $\log(N_H) - \log(U) = 24$). Thus, while the inferred column densities are probably larger than implied by the effective line optical depths, and the outflows are still massive enough to challenge radiative-line driving as the acceleration mechanism (e.g., Hamann et al. 2001, see also §4.2), the situation is not so extreme if the continuum is X-ray weak, because sufficient $P\,V$ can be produced at significantly smaller (factor of 6 for solar abundances, factor of 25 for enhanced abundances) column densities.
4.1.3. Implications for the X-ray Spectra

As discussed in §1, WPVS 007 has peculiar X-ray properties. It was observed to have normal flux during the RASS, but then nearly disappeared from the X-ray sky in many subsequent observations. Could the variable UV absorber be responsible for the X-ray behavior?

As discussed in Grupe et al. (2008), WPVS 007 has been detected recently twice in X-rays: by Chandra, which observed 10 soft photons from the object (also, Vaughan et al. 2004), and more recently by Swift, from which the first hard X-ray detection was made for a total of $35.7^{+6.4}_{-6.7}$ photons. Moreover, the Swift observation suggests a partial-covering spectrum; that is, the spectrum appears to have a soft component, and a separate absorbed hard component (Grupe et al. 2008). As discussed in §4.1.2, the column densities and ionization parameters required to attain sufficient $P^{+4}$ indicate considerable opacity in the extreme UV and soft X-rays, as shown in Fig. 10. We can use those absorbed continua to predict the X-ray count rates, as follows. We first normalize the continuum to the blue optical part of the 1995 HST spectrum, noting that the normalization is somewhat uncertain since the UV emission was observed to change by a factor of 1.5 over the last several years (Grupe et al. 2007, 2008). We convolve the X-ray portion of the continuum with the Galactic column density ($N_H(Gal) = 2.84 \times 10^{20}$ cm$^{-2}$) opacity given analytically by Morrison & McCammon (1983). We fold the result with the ancillary response files (essentially the effective area or quantum efficiency curves) generated for the Chandra and Swift observations. Integrating over the X-ray band pass (taken to be 0.3–10 keV) yields count rates. Finally, multiplying by the effective exposure time (9300 seconds for the Chandra observation, and 85,508 for the Swift observation) yields the number of photons predicted to have been detected. The results are given in Table 3.

These simulations show that, as expected from Fig. 10, the predicted absorbed X-ray flux is much lower than the direct flux. The largest decrease (factors of 31 and 39 for the Chandra and Swift observations) is found for the $\alpha_{ox} = -1.28$ continuum, because that requires the highest column density to attain the required UV line opacity. However, the resulting count rates are much larger than observed: only 10 photons were observed in the Chandra observation, and these absorbed continua predict 454 photons for the absorbed X-ray spectrum. Moreover, as seen in Fig. 10, these would have been hard X-ray photons, while the observed Chandra photons were all soft. The same is true for the Swift observation: the predicted number of photons is 325, while only 35.7 source photons were observed.

The correspondence is much better for the $\alpha_{ox} = -1.9$ models. Again, the predicted absorbed flux is much lower than the direct flux, but by only by factors of 5–8 for the solar metallicity model, and 7–11 for the $Z = 5$ model. This difference is due to the reduction in the lower limit of the column density required to produce the FUV line opacity, as discussed
in §4.1.2. Interestingly, the $Z = 5$ metallicity model requires a smaller column density, yet predicts a lower X-ray flux. This is due to the increased opacity in the soft X-rays from the additional metals. The count rates are still somewhat too high; for example, the predicted Swift spectrum has 70 counts for the $Z = 5$ model, and only 35.7 were observed. But considering the uncertainty on the absolute normalization and the fact that the derived columns are upper limits, the agreement within a factor of two is remarkably good.

Finally, it should be noted that the predicted X-ray spectra shown in the lower two panels of Fig. 10 are hard, absorbed spectra but with a recovery toward soft X-rays that would be able to be fitted by partial covering models. Thus, these models would correspond well to the Swift spectrum (Grupe et al. 2008) but would not explain the Chandra spectrum in which no hard X-rays were observed.

These estimates show that if the intrinsic $\alpha_{\text{ox}}$ is $-1.28$, the gas responsible for the UV absorption lines would have been insufficient to explain the X-ray weakness by absorption in the same gas. However, if the intrinsic $\alpha_{\text{ox}}$ is $-1.9$, as indicated by the Swift spectrum, the same gas could have been responsible for the UV absorption lines, the absorbed component of the X-ray spectrum, and also potentially the X-ray soft excess. There are many caveats, however. The primary one is that the FUSE and Swift observations were separated by four years, and since this is clearly an evolving system, there is no guarantee that the X-ray and far UV spectra were the same as observed. Furthermore, while the idea that the UV and X-ray absorption occur in the same gas is simple and attractive, there is no physical requirement that that be the case, since the X-ray and UV emission are not thought to be produced in the same region of the central engine.

4.1.4. Simulations and Results for the MiniBALs

We next consider the mini-BALs. We combine the results for the HST and FUSE observations, noting that these were not simultaneous and it is possible that the effective optical depths changed between the two observations. Following the same procedure as above, we produce the contour plot shown in Fig. 13, showing again the results for three cases: $\alpha_{\text{ox}} = -1.28$, $\alpha_{\text{ox}} = -1.9$, and $\alpha_{\text{ox}} = -1.9$ with $Z = 5$. An important constraint on the mini-BALs is that we do not detect the mini-BALs in either P$^{+4}$ or S$^{+3}$ (Fig. 8). We obtain upper limits on the mini-BAL columns of these ions by including the mini-BAL template in the spectral-fitting model, and increasing its opacity until the $\chi^2$ increases by 6.63, corresponding to 99% confidence for one parameter of interest. Those values are listed in Table 2.
Considering first the $\alpha_{\text{ox}} = -1.28$ continuum, we find that we obtain a reasonable solution for $\log(U) \geq -0.3$ and a $\log(N_H) - \log(U)$ lower limit of 22.8, corresponding to a $\log(N_H)$ lower limit of 22.5. This solution is consistent with the upper limit on mini-BAL column densities of both P$^{++}$ and S$^{+3}$. This solution indicates that the Ly$\alpha$, C IV and N V absorption lines are strongly saturated.

We next present the results for $\alpha_{\text{ox}} = -1.9$ (middle panel of Fig. 13). We find a rough correspondence for $\log(U) \geq 0.5$ and $\log(N_H) - \log(U)$ lower limit of 22.2 corresponding to a $\log(N_H)$ lower limit of 22.8. Again, Ly$\alpha$, C IV and N V absorption lines are strongly saturated.

Finally, for $\alpha_{\text{ox}} = -1.9$ and $Z = 5$, we find a rough correspondence for $\log(U) \geq 0.5$ and $\log(N_H) - \log(U)$ lower limit of 21.5 corresponding to a $\log(N_H)$ lower limit of 22.0. In this solution, however, the column densities of P$^{++}$ and S$^{+3}$ would exceed the upper limits.

4.2. Luminosity Dependence and Launch Radius

As discussed in the §1, outflows are common in AGN, but their nature differs between high and low luminosity objects. High velocity outflows are generally limited to high luminosity objects, while lower luminosity objects have typical outflow velocities of only $10^3$ km s$^{-1}$. The dependence of absorption on other AGN parameters has been systematically investigated using a sample of low-redshift ($z < 0.5$) quasars with $M_V$ between $\sim -21$ and $\sim -27$ by Brandt et al. (2000) and Laor & Brandt (2002). A primary result of Brandt et al. (2000) is that there exists a significant correlation between $\alpha_{\text{ox}}$ and C IV absorption-line equivalent width, suggesting that the primary cause of X-ray weakness is absorption, with a continuum of absorption columns connecting unabsorbed objects to BALQSOs. In Laor & Brandt (2002) ideas associated with that continuum were further developed; in particular, the question of what makes a soft X-ray weak quasar a BALQSO was addressed. WPVS 007 is soft X-ray weak, and as shown in this paper, it had broad absorption lines during the FUSE observation in 2003. In this section, we compare some of our results with those of Brandt et al. (2000) and Laor & Brandt (2002).

One of the principal results of Laor & Brandt (2002) is that there is a strong dependence of outflow properties on luminosity. Specifically, there are strong positive correlations between the C IV equivalent width and $V_{\text{max}}$, the outflow maximum velocity, with the optical luminosity $M_V$ for soft X-ray weak quasars, and at any luminosity, soft X-ray weak quasars had the largest equivalent widths and maximum velocities. As discussed by Laor & Brandt (2002), this behavior is consistent with outflow scenarios for outflows driven by either dust
or line opacity.

We compare WPVS 007 with the quasar sample from Laor & Brandt (2002) in Fig. 14. The $M_V$ value of $-19.8$ was derived from the dereddened, restframe HST spectrum using $H_0 = 50\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$ and $q_0 = 0.1$ so as to be consistent with the other data. The straight line in that graph shows the best fit to the soft X-ray quiet quasars given by Laor & Brandt (2002); they note that it suggests an upper envelope as would be expected from radiation-driven winds. The filled star labeled WPVS 007 BAL is taken from the FUSE BAL template derived in §3.3. The $V_{\text{max}} = 6179\,\text{km}\,\text{s}^{-1}$ for that absorption line is seen to be a factor of 13 in excess of the value expected if the regression holds for low luminosity objects. We note that most of the data shown in Fig. 14 were derived from C IV absorption lines, and it is not clear that the P V absorption line should have the same profile. However, as shown by Junkkarinen et al. (2001), P V absorption is typically better fit by templates derived from Si IV, and templates from Si IV tend to be narrower than templates from C IV. This evidence, plus the fact that we infer that the O VI absorption profile in WPVS 007 is most likely significantly broader than the P V profile (§3.5.2), indicates that the point shown in Fig. 14 for the BAL may be a lower limit, and the discrepancy between that point and the Laor & Brandt (2002) regression may be even larger. We also plot the $V_{\text{max}}$ for the mini-BALs, where we show the mean of the values for the HST mini-BAL (§2.3) and the FUSE mini-BAL (§3.4). That $V_{\text{max}}$ is very near the Laor & Brandt (2002) regression, indicating the outflow maximum velocity that might be expected for this relatively low-luminosity object.

Such a large maximum velocity in a low luminosity object such as WPVS 007 may cause problems for acceleration models. In a radiative-line-driving scenario, fundamental limits can be placed by simply considering $F = ma$ where the force of the radiative line driving, essentially turning continuum luminosity into wind momentum, is opposed by the force of gravity due to the black hole. The $F = ma$ equation, with the acceleration $a = v(dv/dr)$ integrated to get the terminal velocity, converted to parameters suitable for this situation, is presented as Equation 3 in Hamann (1998) (also, Hamann et al. 2001):

$$V_\infty \approx 9300R_{0.1}^{-1/2}(f_{0.1}L_{46}/N_{22} - 0.1M_8)^{1/2}$$

where $R_{0.1}$ is the launch radius in units of 0.1 pc, $f_{0.1}$ is the fraction of the continuum absorbed by the wind, relative to 10%, $L_{46}$ is the luminosity in terms of $10^{46}\,\text{erg}\,\text{s}^{-1}$, $N_{22}$ is the column density relative to $10^{22}\,\text{cm}^{-2}$, and $M_8$ is the black hole mass in terms of $10^8\,\text{M}_\odot$.

To use the Hamann (1998) equation, we need an estimate of the black hole mass. We estimate the black hole mass using standard methods using the HST spectrum. We model the region including H$\beta$ with a linear continuum, an Fe II template, a Lorentzian profile
for broad Hβ, and two Gaussians for O III constrained to have flux ratios of three to one, equal width, and fixed separation. We also use a Gaussian for the NLR component of Hβ, fixing the flux to be one tenth that of [O III] λ5007 (Cohen 1983; Leighly 1999). The [O III] lines are slightly blueshifted with respect to the peak of Hβ, as is sometimes found in Narrow-line Seyfert 1 galaxies (e.g., Aoki et al. 2005; Bian et al. 2005), and relative to lower-ionization narrow-line region lines, and therefore we fix wavelength of the narrow component of Hβ to match that of broad Hβ. The resulting fit is very good; e.g., substituting a Gaussian for the Lorentzian to model broad Hβ yields a much worse fit. The width of Hβ is measured to be 1190 km s$^{-1}$. We obtain the rest frame flux at 5100 Å from the HST spectrum ($1.1 \times 10^{-14}$ erg s$^{-1}$ cm$^{-2}$ Å$^{-1}$). We compute the broad-line region radius using the regressions found by Bentz et al. (2006) using the flux and a luminosity distance of 126.2 Mpc using their (inferred) cosmological parameters of $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_M = 0.27$, and $\Omega_\Lambda = 0.73$. That is found to be $\log(R_{BLR}) = 1.062$ in units of light-days. Finally, we compute the dispensor of the Hβ line profile obtained after subtracting the other fitted components, and referring to Collin et al. (2006), we use a scale factor of 1.2 to yield a black hole mass of $4.1 \times 10^6 M_\odot$.

We estimate the bolometric luminosity by integrating over the Cloudy continuum spectra discussed in §4.1.1 after they had been normalized to match the rest-frame optical spectrum (recall, as discussed in §2.2, the UV continuum is heavily reddened). These are given in Table 4. We obtain a rough estimate of the fraction of the continuum absorbed in the wind by integrating over the absorbed continuum and comparing with the unabsorbed value. This includes only thermal velocity for the lines, so it provides a lower limit on the fraction of the continuum able to accelerate the wind. These estimates vary from $f_{0.1} = 4.1$ for the $\alpha_{ox} = -1.28$ continuum, from which we infer the highest column density, to $f_{0.1} = 0.67$ for the $\alpha_{ox} = -1.9$, $Z = 1$ case and $f_{0.1} = 0.44$ for the $\alpha_{ox} = -1.9$, $Z = 5$ case, from which we require lower column densities, as discussed in §4.1.2. We emphasize again, though, that only lower limits on the column densities were obtained. Finally, using the opacity profile in Fig. 4, we conservatively estimate a terminal velocity of about 4,000 km s$^{-1}$; that is, we observe measurable opacity to about 6,000 km s$^{-1}$, but the opacity has decreased significantly from the maximum by 4,000 km s$^{-1}$. It should be noted, however, that as discussed in previously in this section, and in §3.5.4, the O VI absorption line may have a much higher terminal velocity, up to 12,000 km s$^{-1}$.

The estimate of the launch radii for the $\alpha_{ox} = -1.28$ model, the $\alpha_{ox} = -1.9$ model, and the $Z = 5$ $\alpha_{ox} = -1.9$ model are given in Table 4. For the $\alpha_{ox} = -1.9$, $Z = 1$ model, we obtain a negative radius, which means that the momentum of the absorbed continuum is not sufficient to counteract gravity, and an outflow would not be predicted. The largest outflow radius is found for the $\alpha_{ox} = -1.9$, $Z = 5$ model, of $R_{0.1} = 0.0070$, or $7 \times 10^{-4}$ pc,
or $2.16 \times 10^{15}$ cm. A $4.1 \times 10^6 M\odot$ black hole has a Schwarzschild radius of $R_S = 1.2 \times 10^{12}$, implying that the launch radius is on the order of 1780$R_S$.

The radius of the broad line region was estimated above to be $\log(R_{BLR}) = 1.062$, corresponding to $3 \times 10^{16}$ cm, about 14 times the inferred launch radius. This is a problem for the radiative-line-driving model, since the broad absorption-line region is thought to lie at a larger radius than the broad emission-line region. This may imply that a magnetic component of acceleration is necessary (e.g., Bottorff et al. 1997; Everett 2005).

### 4.3. Absorption Variability in WPVS 007

Variability in broad absorption lines in quasars is common. Usually, changes in optical depth, rather than changes in velocity profile are observed, although recently more dramatic changes have been discovered (e.g., Lundgren et al. 2007; Gibson et al. 2008, and references therein). The BAL in WPVS 007 is distinct in several ways. First, it is one of the very few known cases in which a BAL flow appeared; another possibly similar example was found in the quasar TEX 1726+344. Second, as shown in Fig. 14, it has quite a low luminosity for the maximum velocity of the outflow.

The development of the BAL in WPVS 007 may be associated with its low luminosity. WPVS 007 has a small black hole mass and correspondingly small central engine, and emission and absorption line regions. For example, LBQS 1212+1445, the comparison object shown in Fig. 6, has an outflow with similar velocity, but with $M_V = 27.6$, it is 100 times more luminous, and therefore the emission regions are expected to be 10 times larger.

Currently, we have only two epochs of UV observations of WPVS 007: one with only mini-BALs (the 1996 HST observation), and one with both mini-BALs and BALs (the 2003 FUSE observation. Thus, we can only speculate about the origin of the variability. In other variable objects, the favored explanation is generally a change in covering fraction. Thus, perhaps WPVS 007 always had a BAL outflow, but rotation of the accretion disk (assuming the BAL arises from a disk wind) may have simply rotated it into the field of view. This argument is used to explain variability in quasar-luminosity BALQSOs in Gibson et al. (2008) over 3–6 years, and thus it would certainly be valid for WPVS 007.

Another, perhaps more exciting possibility is that the BAL outflow developed over the time scale of seven years. The observations were separated by $2.22 \times 10^8$ s in the rest frame. If the velocity of the bulk of the outflow was $4,000$ km s$^{-1}$, then it could have covered a distance of $8.9 \times 10^{16}$ cm in the interval between the observations. We estimate the size of the BLR in WPVS 007 to be $3 \times 10^{16}$ cm, and thus there would have been just sufficient
time for the absorbing flow to cover the BLR. In an object 100 times more luminous, such as LBQS 1212+1445, and similar outflow velocity, it would have taken ten times longer, or about 70 years. So WPVS 007 may be unique in that we observed the development of a BAL. Since we can observe such extreme evolution on human time scales, WPVS 007 is an important object for understanding BAL winds physical conditions and driving mechanisms.

The problem with this argument comes if we attribute the variability in X-ray flux also to changing absorption, because WPVS 007 was already known to be X-ray weak by the time of the HST observation.

Clearly, we need more observations to understand what is happening in WPVS 007. These are now even more urgent with the discovery from Swift that the absorption in the X-ray band is apparently changing. A second FUSE observation was approved, and even though WPVS 007, with a declination of −51 was in the region of the sky that could be observed after the loss of the reaction wheels, the observation was never scheduled before the satellite was decommissioned. An observation using HST COS has been approved, along with a contemporaneous Chandra observation, and therefore we still have a chance of observing further absorption evolution of this interesting object.

5. Summary

We present optical and UV observations of the unusual transient AGN WPVS 007. This Narrow-line Seyfert 1 galaxy was observed to be as bright as an average AGN of its luminosity in the ROSAT All Sky Survey, but then nearly disappeared from the X-ray sky in subsequent observation. We present a reanalysis of the 1996 HST optical and UV spectrum, and an analysis of the 2003 FUSE observation. The principle results follow.

• We discovered dramatic variability in the absorption line properties between the HST and FUSE observations. In the HST observation, mini-BALs with \( v_{\text{max}} \sim 900 \text{ km s}^{-1} \) and \( FWHM \sim 550 \text{ km s}^{-1} \) were observed. In the FUSE observation, the mini-BALs were still present, and an additional BAL component with \( v_{\text{max}} \sim 6000 \text{ km s}^{-1} \) and \( FWHM \sim 3400 \text{ km s}^{-1} \) had appeared. While variability of absorption lines in BAL quasars and Seyfert galaxies is frequently seen, it is usually limited to changes in optical depth of the line. The change in absorption described here is the most dramatic ever observed in an AGN.

• Using a template method of analysis, we obtain the effective optical depths of the absorption lines, and derive corresponding ionic column densities for both the BALs
seen in the \textit{FUSE} spectrum, and the mini-BALs seen in both the \textit{HST} and \textit{FUSE} spectra. BALs are thought to be saturated and have potentially velocity-dependent partial covering, so the measured ionic column densities are lower limits. We then use \textit{Cloudy} to try to obtain some information about the physical conditions of the absorbing gas. We use two different continua: one with $\alpha_{\text{ox}} = -1.28$, similar to that of a typical quasar with the same optical luminosity as WPVS 007, and one with $\alpha_{\text{ox}} = -1.9$, corresponding to the inferred value from the recent hard X-ray detection by \textit{Swift} (Grupe et al. 2008). For the BALs, we find that P V constrains the column density and ionization parameter. For the $\alpha_{\text{ox}} = -1.28$ continuum, we find that $\log(U) \geq 0$, and $\log(N_H) \geq 23$. For the $\alpha_{\text{ox}} = -1.9$ continuum, we obtain approximately the same limit on the ionization parameter, but require $\log(N_H) \geq 22.2$. For the $\alpha_{\text{ox}} = -1.28$ continuum and $Z = 5$ metallicity, the column density lower limit becomes $\log(N_H) \geq 21.6$. The inferred column densities are lower for the X-ray weak continuum because intermediate ionization ions are produced at lower column densities in gas illuminated by a soft SED (e.g., Leighly et al. 2007). These large column density estimates are similar to those obtained previously or the P V quasar PG 1254+047 (Hamann 1998). Acceleration of these large column densities challenge radiative-line driving as a mechanism; since the estimated column is lower when the continuum is X-ray weak, and since not all quasars have P V absorption, we speculate that BALQSOs with P V absorption lines are preferentially intrinsically X-ray weak. We obtain similar constraints for the mini-BALs.

- The high ionization parameters and high column densities inferred for the BALs predict X-ray absorption, and it is possible that the X-ray weakness in this object is a consequence of X-ray absorption in the same gas that produces the BALs. For the $\alpha_{\text{ox}} = -1.28$ SED, the X-ray absorption is insufficient to explain the low \textit{Chandra} and \textit{Swift} count rates. However, for the $\alpha_{\text{ox}} = -1.9$ SED, with or without enhanced abundances, the predicted count rates are only slightly higher than observed. The predicted X-ray spectrum for $\alpha_{\text{ox}} = -1.9$ has a heavily absorbed hard component, and a soft component due to reduced opacity resulting from the high ionization parameter. Thus, they resemble the recent \textit{Swift} observation, but cannot explain the \textit{Chandra} observation in which only soft photons were detected (Grupe et al. 2008). The absorption column may have been larger during the \textit{Chandra} observation. Despite the fact that the \textit{FUSE} and \textit{Swift} observations were separated by four years, this consistency supports the idea that the X-ray weakness and the broad absorption lines both result from absorption in the same gas.

- Given the luminosity of the object, an estimate of its black hole mass, the BAL terminal velocity $V_{\text{max}}$, the lower limit on the absorption column, and the fraction of
the bolometric luminosity inferred to be absorbed in the outflow, we can estimate the
launch radius for the outflow using Eq. 3 from Hamann (1998). We find a negative
radius for the $\alpha_{ox} = -1.9$ solar abundance result, indicating that there is insufficient
momentum in the absorbed photons to accelerate the gas to the observed terminal
velocity. The largest launch radius ($2.2 \times 10^{15}$ cm) was obtained from the $\alpha_{ox} = -1.9,
Z = 5$ model, which predicted the lowest estimated column density. However, this
launch radius is a fraction (1/14) of the size of the broad-line region. Since we be-
lieve that the BAL outflows originate at larger radius than the BELR, it appears that
radiative line driving is insufficient to accelerate the outflow, and a form of magnetic
driving may be necessary.

- Broad absorption lines are usually limited to high luminosity quasars. WPVS 007 has a
  uniquely low luminosity compared with other objects with similar $V_{\text{max}}$. It is therefore
  a significant outlier on the $M_V/V_{\text{max}}$ relationship (Fig. 14, Laor & Brandt 2002).

- Given that there are only two epochs of UV spectroscopic observations of WPVS 007,
one without and one with the BAL, it is impossible to determine the nature of the
  absorption variability. It may be a change in covering fraction due to a wind from
  an accretion disk orbiting into the line of sight, as has been suggested to explain
  variability in other BALs (Gibson et al. 2008). But given WPVS 007’s low luminosity,
  quite unusual for an object with BAL $v_{\text{max}} \sim 6000$ km s$^{-1}$, and correspondingly small
  size scales, it is possible that we have observed the development and onset of the
  BAL outflow. An approved HST observation using COS may help us understand the
  variability evolution in this unusual object.

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*Facilities:* FUSE, HST (FOS)

### A. FUSE Data Processing and Background Subtraction

The data were processed with CalFUSE version 3.1.8. The standard procedure circa summer 2006 was followed. First, the “jitter” files were repaired using the command `cf_jitter` and the CalFUSE pipeline was run on the individual segments of the observation. Then, the command `idf_combine` was run to combine the segments, setting the “−c” flag in order to recompute the centroids of the spectral traces in the final intermediate data file (IDF). At the same time, the bad pixel maps were combined using `bpm_combine`. These steps were run for data taken at night alone, and for the combined day-and-night data.

At this point, the data are ready to have the spectrum extracted and calibrated, and the background model constructed and the background subtracted. All of this is done by the CalFUSE script `cf_extract_spectra`. AGN are faint sources for *FUSE*, so a high-quality background subtraction is essential. The data reduction and background subtraction pipeline for *FUSE* has improved dramatically over the years (Dixon et al. 2007). However, the background subtraction algorithms do not fully exploit an important fact: the background has a different PHA (pulse height analyzer) spectrum than the source photons. To illustrate this, we display in Fig. 15 the PHA distributions for the source region and the background region for the LIF1a data. Specifically, we extracted the data from the bow-tie LIF1a extraction region found in the `spex1a009.fit` file given in CalFUSE version 2.4 (the extraction regions are handled differently in CalFUSE 3.1 and greater), and the histogram of PHA is shown as a solid line. The dashed line shows the PHA distribution from background regions of the detector that avoid the apertures and airglow lines, scaled to area of the source aperture, and therefore approximately giving the distribution of background in the source aperture. This background is an estimate for two reasons: 1.) the scattered light is more intense in the aperture, a fact that would increase the estimation of the background; 2.) the regions of the detectors under the apertures have lost sensitivity over the years, a fact that would decrease the estimation of the background. At any rate, it can clearly be seen that the background dominates for PHA channels less than 2 and greater than 20, and we can
reduce the background and therefore increase the statistics of the spectrum by excluding these PHA channels. Note that we are not the first to reduce the background by imposing a PHA restriction (e.g., Brotherton et al. 2002; Casebeer, Leighly & Baron 2006).

The background files provided by the FUSE team have been carefully constructed. Each one is comprised of $\sim 20$ background observations, and they vary stepwise in time to account for periodically imposed gain changes. But they have been constructed for the default PHA range, and although they are scaled in the background modeling process, in principle the shape of the background spectrum should change depending on the PHA range.

We decided therefore to construct our own background images using the following restricted PHA ranges: 1a: 5–20; 1b: 9–22; 2a: 3–14; 2b: 6–20. These were determined as shown in Fig. 15; we plotted background and source regions, and determined the range of PHA in which the source dominates. To construct the background images, first we determined the appropriate background observations from the lists in the headers of the background files produced by the FUSE team. For our observation, there were 24 separate observation IDs that were used in constructing the background images. In general, the background is different during orbital day and orbital night; the scattered background is a little higher in the day, plus there are more and stronger airglow lines, and therefore we construct separate background images for day and night. These various observation segments ranged from 765 seconds to 23345 seconds in duration; we excluded the very lowest exposure observation from the 2a and 2b detectors, therefore we used only 23 files to construct the backgrounds for each of those detectors.

For each detector and each segment, the following processing steps were done. The day and night intermediate data files were extracted using the FUSE IDL program cf_edit, and at the same time the pha restriction was applied. In Calfuse 3.1 and higher, all events are retained in the data files, and bad data (e.g., from flaring or jitter, i.e., when the target is not in the aperture) are marked using flags. We extracted the flag information from the fits files, and then use that information to separate out the good day or night events. An image can be plotted using the good events.

The image of each background file contains airglow lines, with the day image having more lines and more intense lines. We do not want the intense lines in the background, so we exclude regions of the image with strong lines. The flags aid this selection as there is a flag for airglow feature. A mask is made of the excluded regions. Next, the extracted images are added together, day and night separately, weighted by the exposure time and the airglow mask. Regions with a fractional exposure less than 0.3 of the total exposure time are excluded from the background region. The day and night background images are convolved with a gaussian kernel with a FWHM of 15 pixels, and a constant is subtracted.
Finally, the images are output as fits files in the same format as those produced by the FUSE team (indeed with the same headers, with exposure times altered). These files are available online.

These background files can be used in two ways. First, they can be directly used in the CalFUSE script `cf_spec_extract` by copying them to the calfiles directory, and changing the BKGD_CAL keyword in the primary header of the IDF file from which the spectrum will be extracted. At the same time, PHALOW and PHAHIGH keywords should be changed to match those of the background files. The scaling factors for the day and night data, plus the constant, can be extracted from the verbose output of `cf_spec_extract`.

Fig. 16 shows the results of our background subtraction compared with the default. To construct these figures, we first determined the y-direction ranges on the image in which the light from the target or scattered emission is not seen, i.e., we avoid the LWRS apertures and mostly the MDRS aperture as well. In addition, regions at the edge of the detector where the background is exceptionally high were also avoided. “Spectra” were constructed by summing the events along the spatial direction, and binning by a factor of 16 in the dispersion direction. These spectra were extracted from the day+night data from WPVS 007 (black lines) and from the modeled background data, using the scale factors obtained from the `cf_spec_extract` output (red lines). It can be readily seen that the background-modeled spectra from our files match the data better. In fact, in the case of the 2b detector, the `cf_spec_extract` modeling appears to have failed for the default data, as the day and night scaling factors were zero, and the background was a constant; the background modeling did not fail for these data for our background files.

While Fig. 16 shows that the PHA-limited backgrounds perform perfectly well in `cf_spec_extract`, there is another way to use these background files. The background spectra were extracted from the WPVS 007 data as above, and day and night background spectra were extracted from the model files over the same background regions. Then, the WPVS 007 background spectra were fit using the IRAF task `Specfit` to a model consisting of the day background spectrum, the night background spectrum, and a constant. Regions where the flux is zero (i.e., beyond the edges of the detector) and regions where strong airglow lines are present were excluded from the fit. The normalizations of the day and night files were constrained to be in proportion to their respective exposure times. Then, the `Specfit` results could be input directly into a modified version of the `cf_spec_extract` program. The result is shown in the right panel as the green line in Fig. 16. It differs only slightly from the result obtained using `cf_spec_extract` directly.

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8http://www.nhn.ou.edu/leighly/FUSE_bkgd
Fig. 17 shows the a comparison of the LIF spectra extracted using the default PHA ranges and cf_spec_extract program with spectra obtained using the restricted PHA range and the new background files scaled using the Specfit fitting described above. We show both the day-and-night spectra in dark grey, and night-only spectra in light grey. The chief utility of the night-only spectra is the identification of airglow lines in the day-and-night spectra. In addition, the less prominent airglow lines are seen only in the day data, so they can be removed by substituting the night-only spectra in those regions. Overall, there is not much difference between the default and the PHA-restricted spectra, even though the background levels are 5–40% lower for the PHA-restricted spectra. There are detailed differences, however. For example, the 1b day-and-night spectra do not agree in normalization with the night-only spectra for the default reduction, while they do for the PHA-restricted reduction. In addition, the failure of the background subtraction for the day-and-night Lif2b data is apparent for the default reduction.

Fig. 18 shows a similar plot for the SIC data. In this case, only the night spectra are shown. The SIC has a much lower effective area (a factor of three) than the LIF, and it is difficult to obtain useful results from these detectors for a faint object like WPVS 007. This can be seen by comparing the spectrum around 1065 Å in the LIF1a spectrum in Fig. 17, and the same region in the SIC1a spectrum. However, the SIC spectra extend to shorter wavelengths; in particular, a feature is clearly detected near 980 Å in both the SIC1b and SIC2a spectra. Again, overall, the differences between the default spectra and the restricted-PHA spectra are small; however, the restricted PHA spectra are slightly less noisy, and approach zero more gracefully (e.g., SIC2a for wavelengths shorter than 960 Å).

B. Merging the FUSE Spectra

The FUSE observation yields eight separate spectra, and we proceed here to merge them. WPVS 007 is a faint object for FUSE and as the SIC telescope/detector systems have effective areas about 1/3 of the LIF, the SIC spectra have rather low signal-to-noise ratios (Fig. 18). Thus, we use those data only for the shortest wavelength ranges where LIF spectra are not available.

The longest wavelengths are sampled by the LIF 1b and LIF 2a. LIF 1b is commonly afflicted by the “worm”, or shadowing of the grid wires on the detector (Sahnow 2002). Our spectra are no exception, as can be seen by the difference in the 1b and 2a spectra longward of $\sim 1140$ Å (Fig. 17). The worm decreases the effective area, decreasing also the signal-to-noise ratio, and therefore we opt to ignore afflicted region. We average the two spectra in overlapping region (1094.25–1137.25 Å), and use the 2a spectrum longward of that. The
errors are computed by propagation in quadrature.

We turn next to the region of the spectrum between 987.5 and 1074.75 Å, which are represented by both the LIF 1a and LIF 2b spectra. The LIF 2b spectrum has generally a poorer signal-to-noise ratio than the LIF 1a spectrum, as seen in Fig. 17, and the question arises, do we enhance or degrade the signal-to-noise ratio of the LIF 1a spectrum by averaging it with the LIF 2b spectrum? We also find that the normalization of the 2b spectrum appears to be about 15% lower than the 1a spectrum. Since at the time of this observation, the pointing was still being determined using the LIF 1a detector, we assume that it has the correct normalization. We examine the mean spectrum and decide to use the mean of the LIF 1a and LIF 2b scaled by a factor of 1.15 between 1011 and 1074.75 Å. The LIF 1a contains useful information longward of the merged region, to \( \sim 1082.5 \) Å, and there is a gap between the coverage of LIF 1a and the coverage of LIF 2b from \( \sim 1082.5 \) to \( \sim 1087 \) Å. In principle, the SIC 2b could be used to fill this gap; however, examination of Fig. 18 shows there is no signal in this region in that spectrum.

Shortward of 1100 Å, we use the LIF 1a, SIC 1b, and SIC 2a spectra, as follows. The LIF 1a nominally extends down to 987.5 Å, but as can be seen in Fig. 17, the signal-to-noise ratio approaches 1 at the shortest wavelengths. The SIC 2a overlaps up to 1005.5 Å, but again, the errors are large at the end of the spectrum. We use Lif 1a alone down to 1002.75 Å, and use the mean of Lif 1a and Sic 2a between 995.5 and 1002.5 Å. Shortward of that, the spectrum is represented by Sic 2a until 992.5 Å, when it is joined by Sic 1b. The uncertainty on the Sic 1b spectrum is very large at the end, so we use the Sic 2a alone down to 987.75 Å. Shortward of that, we use the mean of the Sic 1b and Sic 2a spectra down to 920 Å.

There are several prominent airglow lines remaining in the spectrum. These include the Lyman lines of hydrogen, Ly\( \beta \) at 1025.722 Å, Ly\( \gamma \) at 972.537 Å, and Ly\( \delta \) at 949.743 Å, and O I line near 988 Å. The regions of the spectra in the vicinity of these lines are excised.

Finally, the spectra are modestly smoothed\(^9\), dereddened and shifted to the restframe.

**REFERENCES**


\(^9\)The smoothing function is \(0.2(f(i - 1) + 3f(i) + f(i + 1))\).
Collin, S., Kawaguchi, T., Peterson, B. M., & Vestergaard, M. 2006, å, 456, 75
Goodrich, R. W., 2000, NewAR, 44, 519
ApJS, 77, 119

This preprint was prepared with the AAS L\LaTeX{} macros v5.2.
Table 1. Observing Log

<table>
<thead>
<tr>
<th>Spectrometer</th>
<th>Date</th>
<th>Exposure (seconds)</th>
<th>Bandpass (Å)</th>
<th>Aperture^a</th>
<th>Resolution (Å)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HST FOS (G130H)</td>
<td>1996-07-30</td>
<td>3840</td>
<td>1140–1606</td>
<td>0.86''</td>
<td>2.26</td>
</tr>
<tr>
<td>HST FOS (G190H)</td>
<td>1996-07-30</td>
<td>1500</td>
<td>1590–2312</td>
<td>0.86''</td>
<td>3.16</td>
</tr>
<tr>
<td>HST FOS (G1270H)</td>
<td>1996-07-30</td>
<td>1280</td>
<td>2222–3277</td>
<td>0.86''</td>
<td>4.72</td>
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<tr>
<td>HST FOS (G1400H)</td>
<td>1996-07-30</td>
<td>1000</td>
<td>3235–4781</td>
<td>0.86''</td>
<td>6.94</td>
</tr>
<tr>
<td>HST FOS (G570H)</td>
<td>1996-07-30</td>
<td>630</td>
<td>4569–6818</td>
<td>0.86''</td>
<td>10.06</td>
</tr>
<tr>
<td>FUSE LIF1a</td>
<td>2003-11-06</td>
<td>47354</td>
<td>987.5–1082.5</td>
<td>30''</td>
<td>0.25^b</td>
</tr>
<tr>
<td>FUSE LIF1b</td>
<td>2003-11-06</td>
<td>48054</td>
<td>1094.25–1188.75</td>
<td>30''</td>
<td>0.25^b</td>
</tr>
<tr>
<td>FUSE LIF2a</td>
<td>2003-11-06</td>
<td>48229</td>
<td>1087.0–1181.25</td>
<td>30''</td>
<td>0.25^b</td>
</tr>
<tr>
<td>FUSE LIF2b</td>
<td>2003-11-06</td>
<td>48466</td>
<td>980.0–1074.75</td>
<td>30''</td>
<td>0.25^b</td>
</tr>
<tr>
<td>FUSE SIC1a</td>
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<td>35055</td>
<td>1003.25–1090.5</td>
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<td>0.25^b</td>
</tr>
<tr>
<td>FUSE SIC1b</td>
<td>2003-11-06</td>
<td>35259</td>
<td>904.25–992.5</td>
<td>30''</td>
<td>0.25^b</td>
</tr>
<tr>
<td>FUSE SIC2a</td>
<td>2003-11-06</td>
<td>34982</td>
<td>917.5–1005.5</td>
<td>30''</td>
<td>0.25^b</td>
</tr>
<tr>
<td>FUSE SIC2b</td>
<td>2003-11-06</td>
<td>35010</td>
<td>1016.75–1103.5</td>
<td>30''</td>
<td>0.25^b</td>
</tr>
</tbody>
</table>

^aFor the HST FOS spectra, this refers to the size of the round aperture. For the FUSE spectra, this refers to the size of the LWRS square aperture.

^bThe observed resolution of FUSE using the LWRS aperture is $R = 20,000 \pm 2000$ (The FUSE Observer’s Guide: http://fuse.pha.jhu.edu/support/guide/guide.html). However, the low count rate cannot sample this resolution. Therefore, the resolution refers to the final binsize of the spectra.
Table 2. Estimated Column Densities

<table>
<thead>
<tr>
<th>Ion</th>
<th>Wavelength (Å)</th>
<th>Scale Factor</th>
<th>Template</th>
<th>log(N) (cm⁻²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P IV</td>
<td>950.66</td>
<td>3.08 ± 0.38</td>
<td>P V</td>
<td>15.19 ± 0.05</td>
</tr>
<tr>
<td>P IV</td>
<td>950.66</td>
<td>1.33 ± 0.58</td>
<td><em>FUSE</em> MiniBAL</td>
<td>14.31 ± 0.20</td>
</tr>
<tr>
<td>Lyα&lt;sup&gt;a&lt;/sup&gt;</td>
<td>972.54</td>
<td>2.17 ± 0.31</td>
<td>P V</td>
<td>16.77 ± 0.06</td>
</tr>
<tr>
<td>C III</td>
<td>977.03</td>
<td>2.61 ± 0.37</td>
<td>P V</td>
<td>15.43 ± 0.06</td>
</tr>
<tr>
<td>C III</td>
<td>977.03</td>
<td>1.28 ± 0.23</td>
<td><em>FUSE</em> MiniBAL</td>
<td>14.60 ± 0.08</td>
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<tr>
<td>C III&lt;sup&gt;b&lt;/sup&gt;</td>
<td>977.03</td>
<td>1</td>
<td>C III</td>
<td>15.87</td>
</tr>
<tr>
<td>N III&lt;sup&gt;a&lt;/sup&gt;</td>
<td>990.98</td>
<td>2.38 ± 0.09</td>
<td>P V</td>
<td>15.87 ± 0.02</td>
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<tr>
<td>N III&lt;sup&gt;a&lt;/sup&gt;</td>
<td>990.98</td>
<td>0.88 ± 0.23</td>
<td><em>FUSE</em> MiniBAL</td>
<td>14.93 ± 0.12</td>
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<tr>
<td>P III</td>
<td>998.00</td>
<td>0</td>
<td>P V</td>
<td>0</td>
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<tr>
<td>P III</td>
<td>1001.73</td>
<td>0.59 ± 0.25</td>
<td>P V</td>
<td>15.60 ± 0.19</td>
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<td>P III</td>
<td>1003.60</td>
<td>0.77 ± 0.29</td>
<td>P V</td>
<td>15.72 ± 0.17</td>
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<td>S III</td>
<td>1012.50</td>
<td>1.10 ± 0.34</td>
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<td>16.29 ± 0.14</td>
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<td>S III&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1015.63</td>
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<td>16.35 ± 0.17</td>
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<td>S III&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1021.32</td>
<td>1.28 ± 0.46</td>
<td>P V</td>
<td>16.35 ± 0.16</td>
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<tr>
<td>Lyβ&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1025.72</td>
<td>2.72 ± 0.46</td>
<td>P V</td>
<td>16.55 ± 0.07</td>
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<tr>
<td>Lyβ&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1025.72</td>
<td>3.89 ± 3.0</td>
<td><em>FUSE</em> MiniBAL</td>
<td>16.05 ± 0.44</td>
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<tr>
<td>O VI</td>
<td>1031.91</td>
<td>1.68 ± 0.28</td>
<td>P V</td>
<td>15.97 ± 0.07</td>
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<tr>
<td>O VI</td>
<td>1037.61</td>
<td>2.41 ± 0.15</td>
<td>P V</td>
<td>16.43 ± 0.03</td>
</tr>
<tr>
<td>O VI</td>
<td>1031.91</td>
<td>3.0 ± 1.1</td>
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<td>15.71 ± 0.17</td>
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<tr>
<td>O VI</td>
<td>1037.61</td>
<td>1.99 ± 0.25</td>
<td><em>FUSE</em> MiniBAL</td>
<td>15.83 ± 0.06</td>
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<tr>
<td>O VI&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>S IV&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1073.03</td>
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<td>15.27 ± 0.01</td>
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<td>S IV&lt;sup&gt;a,c&lt;/sup&gt;</td>
<td>1073.03</td>
<td>&lt; 0.046</td>
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<td>&lt; 13.24</td>
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<tr>
<td>N II&lt;sup&gt;a,c&lt;/sup&gt;</td>
<td>1085.12</td>
<td>0.09 ± 0.02</td>
<td>P V</td>
<td>13.77 ± 0.11</td>
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<tr>
<td>P V</td>
<td>1117.98</td>
<td>1.30 ± 0.04</td>
<td>P V</td>
<td>15.29 ± 0.01</td>
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<tr>
<td>P V</td>
<td>1128.01</td>
<td>0.89 ± 0.04</td>
<td>P V</td>
<td>15.43 ± 0.02</td>
</tr>
<tr>
<td>P V&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1128.01</td>
<td>&lt; 0.09</td>
<td><em>FUSE</em> MiniBAL</td>
<td>&lt; 13.95</td>
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<tr>
<td>Fe III&lt;sup&gt;a,c&lt;/sup&gt;</td>
<td>1125.79</td>
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<td>P V</td>
<td>&lt; 13.77</td>
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<tr>
<td>Lyα&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1215.67</td>
<td>0.95 ± 0.05</td>
<td><em>HST</em> MiniBAL</td>
<td>12.31 ± 0.02</td>
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Table 2—Continued

<table>
<thead>
<tr>
<th>Ion</th>
<th>Wavelength (Å)</th>
<th>Scale Factor</th>
<th>Template</th>
<th>log(N) (cm(^{-2}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>N V</td>
<td>1238.82</td>
<td>1.07 ± 0.13</td>
<td>(HST) MiniBAL</td>
<td>12.78 ± 0.05</td>
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<tr>
<td>N V</td>
<td>1242.80</td>
<td>0.94 ± 0.11</td>
<td>(HST) MiniBAL</td>
<td>13.02 ± 0.05</td>
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<tr>
<td>C IV</td>
<td>1548.20</td>
<td>1.27 ± 0.10</td>
<td>(HST) MiniBAL</td>
<td>12.67 ± 0.03</td>
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<tr>
<td>C IV</td>
<td>1550.77</td>
<td>1.59 ± 0.09</td>
<td>(HST) MiniBAL</td>
<td>13.05 ± 0.03</td>
</tr>
</tbody>
</table>

\(a\)When the line is comprised of multiplets indistinguishable at the spectral resolution, the column densities were estimated using the sum of the \(f_{12}\) for the multiplets.

\(b\)Column density obtained using the alternative deblending described in §3.5.4.

\(c\)Upper limits on lines that were not observed.
Table 3. Estimated X-ray 0.3–10 keV Count Rates

<table>
<thead>
<tr>
<th>Model</th>
<th>Chandra</th>
<th></th>
<th>Swift</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>direct rate</td>
<td>direct counts$^a$</td>
<td>absorbed rate</td>
<td>absorbed counts$^a$</td>
</tr>
<tr>
<td></td>
<td>direct rate</td>
<td>direct counts$^b$</td>
<td>absorbed rate</td>
<td>absorbed counts$^b$</td>
</tr>
<tr>
<td>$\alpha_{ox} = -1.28; N_H = 23.0$</td>
<td>1.53</td>
<td>14192</td>
<td>0.049</td>
<td>454</td>
</tr>
<tr>
<td>$\alpha_{ox} = -1.9; N_H = 22.2$</td>
<td>0.032</td>
<td>300</td>
<td>0.0061</td>
<td>56</td>
</tr>
<tr>
<td>$\alpha_{ox} = -1.9, Z = 5; N_H = 21.6$</td>
<td>0.032</td>
<td>300</td>
<td>0.0045</td>
<td>41</td>
</tr>
</tbody>
</table>

$^a$The effective exposure of the Chandra observation was 9300 seconds, and 10 net source photons were observed.

$^b$The effective exposure of the Swift observation was 85,508 seconds (Grupe et al. 2008), and 35.7 net source photons were observed.
Table 4. Dynamics Components

<table>
<thead>
<tr>
<th>Model</th>
<th>(L_{46}^a)</th>
<th>(L/L_{Edd}^b)</th>
<th>(F_{0.1}^c)</th>
<th>(N_{22}^d)</th>
<th>(R_{0.1}^e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\alpha_{ox} = -1.28)</td>
<td>0.0114</td>
<td>0.22</td>
<td>4.1</td>
<td>10.0</td>
<td>0.0031</td>
</tr>
<tr>
<td>(\alpha_{ox} = -1.9)</td>
<td>0.0049</td>
<td>0.096</td>
<td>0.67</td>
<td>1.58</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>(\alpha_{ox} = -1.9, Z = 5)</td>
<td>0.0049</td>
<td>0.096</td>
<td>0.44</td>
<td>0.40</td>
<td>0.0070</td>
</tr>
</tbody>
</table>

Note. — We use a black hole mass \(M_8 = 0.041\) estimated from the optical luminosity and the H\(\beta\) line width (Collin et al. 2006). We use a terminal velocity \(V_\infty = 4000\) km s\(^{-1}\) estimated from the effective optical depth shown in Fig. 4.

\(^a\)The bolometric luminosity in units of \(10^{46}\) erg s\(^{-1}\) obtained by integrating over the Cloudy input continua discussed in §4.1.1 after normalizing to the HST spectrum in the optical band.

\(^b\)The ratio of the bolometric luminosity to the the Eddington luminosity obtained using the black hole mass estimate \(M_8 = 0.041\).

\(^c\)The fraction of the continuum absorbed by the wind, estimated by integrating over the absorbed continuum, and divided by 0.1.

\(^d\)The lower limit on the column densities obtained in §4.1.2 in units of \(10^{22}\) cm\(^{-2}\).

\(^e\)The launch radius in units of 0.1 pc estimated using Eq. 3 in Hamann (1998).
Fig. 1.— The *HST* WPVS 007 spectrum (red) overlaid on the mean of the *HST* spectra from two NLS1s Mrk 335 and Mrk 493 (blue) and the FBQS radio-quiet composite spectrum (Brotherton et al. 2001).
Fig. 2.— Reddening curve for WPVS 007. The grey line shows the ratio of the WPVS 007 with the average NLS1 spectrum obtained from Mrk 335 and Mrk 493. The solid black line shows a spline fit to the ratio spectrum. The dashed black line shows the SMC reddening curve (Prévot et al. 1984).
Fig. 3.— The merged HST spectrum from WPVS 007 in comparison with the mean NLS1 spectrum created from the HST spectra of the NLS1s Mrk 335 and Mrk 493. Absorption lines are clearly present on Lyα, N V, and C IV.
Fig. 4.— The extracted optical depths as a function of velocity for the N V mini-BAL, extracted from the HST spectrum (§2.3), the P V BAL, extracted from the FUSE spectrum (§3.3) and the O VI/Lyβ mini-BAL, extracted from the FUSE spectrum (§3.4). Note the difference in onset velocity between the BAL and the mini-BALs. There is some indication that the shape of the mini-BAL changed between the HST and FUSE observations; however, given the uncertainty in continuum placement and background subtraction, those differences may not be significant.
Fig. 5.— Absorption lines in the HST spectrum (red lines) compared with the mean NLS1 spectrum (blue lines). Top: The absorption line template was created from the well-resolved N\textsc{v} absorption lines using the procedure described in §2.3. It was then applied to the mean NLS1 spectrum created from the the HST spectra of Mrk 335 and Mrk 493 (black lines). Assuming that the absorption lines are optically thick and have the same profile for all lines, we apply the template created from the N\textsc{v} absorption lines to the C\textsc{iv} line (middle) and Ly\textsc{a} line (bottom).
Fig. 6.— The merged, smoothed, dereddened, and deredshifted FUSE spectrum of WPVS 007 (black line). For comparison, the scaled HST quasar composite spectrum is shown. Identified Galactic absorption lines are marked below the spectrum. Prominent lines in the bandpass are labeled above the spectrum, regardless of whether or not they are observed. Length of tick marks are proportional to $gf$ for individual multiplets.
Fig. 7.— The analysis of the P V region of the FUSE spectrum. The spectrum is shown by the black line. The continuum, a spline fit to the scaled HST composite spectrum (Zheng et al. 1997), is shown by the dashed black line. The vertical dotted lines delineate the regions of the absorption profile either represented by only the 1118 Å component of P V (left), by only the 1128 Å component of P V (right), and by both (middle). The dashed dark grey line shows the inferred spectrum if the 1118 Å component has 2.03 times the opacity of the 1128 Å component, as would be appropriate if the gas were optically thin. The light grey line shows the results from the best fit ratio of opacities found to be 1.35. See text for details.
Fig. 8.— The \textit{FUSE} spectrum plotted as a function of velocity relative to various absorption line rest wavelengths. The light grey lines show the composite spectrum. The right side shows an expanded view of the low-velocity region. Note the overall similarity between the S IV and the P V profiles; the absorption blueward of O VI is much broader. In addition, the onset of the P V and S IV occurs at higher velocity than the other lines, indicating that the mini-BAL is not present in P V and S IV.
Fig. 9.— The spectral fit derived in §3.5.1, 3.5.2, and 3.5.3. Top panel: the light grey line shows the data, the black line shows the assumed continuum, and the dark grey line shows the model fit comprised of the BAL template created from P V (§3.3) and the mini-BAL template created from O VI and Ly\(\beta\) (§3.4). The fit in the region of S IV, N III is very good and validates the approach. The fit in the region of O VI is good also, but a large number of transitions and ions are needed. As described in §3.5.3, we failed to fit the region between 950 and 958 Å, suggesting that the Ly\(\gamma\) or C III is broader than the P V BAL.
Fig. 10.— Continua used for \textit{Cloudy} modeling (see §4.1.1; light grey) and inferred absorbed spectra (see §4.1.3; black). The inset plots show the X-ray bandpass photon flux units. Top: The continuum inferred using the \textit{HST} and \textit{XMM-Newton} observations of Mrk 335 and Mrk 493; this continuum has $\alpha_{\text{ox}} = -1.28$. The absorbing gas has $\log(U) = 0$, $\log(n) = 10.0$ and $\log(N_H) = 23.0$. Middle: The X-ray weak continuum inferred from the recent \textit{Swift} hard X-ray detection of WPVS 007 (Grupe et al. 2008); $\alpha_{\text{ox}} = -1.9$. The absorbing gas has $\log(U) = 0$, $\log(n) = 10.0$, and $\log(N_H) = 22.2$. Bottom: The X-ray weak continuum again, but absorbed through metal-rich gas ($Z = 5$). The absorbing gas has $\log(U) = 0$, $\log(n) = 10.0$, and $\log(N_H) = 21.6$. 
Fig. 11.— Contours of observed column densities on the \( \log(N_H) - \log(U) \) versus \( \log(U) \) plane for \( \log(n) = 10.0 \). Plots on the left use column densities from the deblending using only the FUSE BAL template (and O VI/Ly/ mini-BAL template) shown in Fig. 9; plots on the right use column densities from the alternative deblending discussed in §3.5.4. The top, middle and bottom panels have the same meaning as in Fig. 10. The line style shows the ionization state: dotted for +5, dot-dot-dot-dash for +4, dot-dash for +3, short dash for +2, long dash for +1, and solid for neutral. Upper limits for lines that are not observed have downward tick marks.
Fig. 12.— Log of the ratio of simulated to observed ionic columns for the right-side figures shown in Fig. 11 for the case of log($U$) = 0. The top, middle and bottom panels have the same meaning as in Fig. 10. The horizontal dotted line shows where the simulated ionic columns match the observed columns.
Fig. 13.— Contours of observed column densities on the log($N_H$) – log($U$) versus log($U$) plane for log($n$) = 10.0 for the mini-BALs. Lines have the same meaning as in Fig. 11.
Fig. 14.— WPVS 007 in comparison with low-redshift quasars presented by Laor & Brandt (2002). This is an adoption of their Fig. 6 and the data was taken from their Table 1. The symbols are taken from their paper with the insubstantial modification that we do not differentiate between objects with data in C IV and objects with data in Lyα, as follows: filled squares are soft X-ray weak quasars (SXWQs), asteristics are non-SXWQs with intermediate absorption (1 Å < EW < 10 Å), open squares are AGN with weak absorption (EW < 1 Å), and arrows are objects with $V_{\text{max}} < 10$ km s$^{-1}$. The solid line is the regression to the SXWQ data presented by Laor & Brandt (2002). In addition, we plot our results from the HST and FUSE observation of WPVS 007. The filled star marked “WPVS 007 BAL” shows the $V_{\text{max}}$ from the FUSE BAL template derivation presented in §3.3. It lies far above the regression, indicating a rather large maximum velocity for its luminosity. The filled star marked “WPVS 007 MiniBAL” shows the mean of the $V_{\text{max}}$ for the HST and FUSE mini-BALs derived in §2.3 and 3.4, respectively. The mini-BAL $V_{\text{max}}$ is more consistent with that expected of an object of WPVS 007’s luminosity.
Fig. 15.— Distribution of PHA from events lying in the source lif1a “bowtie” extraction region (solid line) and background regions scaled to the area of the source region (dashed line).
Fig. 16.— Background spectra were created from the regions of the detectors avoiding the LWRS and MDRS apertures and high background regions near the edges of the detectors. Background spectra were created from the background images over the same background regions. Those background regions were scaled using either the `cf_extract_spectra` output (red lines) or using the results from `Specfit` modeling (green line; see text for details). (a.) the default spectra and pha selection; (b.) the spectra from the new background images created by us using pha selection. The background is lower when the PHA is restricted in range, and the background spectra model the data better.
Fig. 17.— Comparison of LIF spectra extracted using default PHA ranges and background images (left, (a)) with spectra extracted using the restricted PHA range and the new background images (right, (b)). Day-and-night spectra are shown in dark grey, and night-only spectra are shown in light grey. In both cases, the uncertainty is shown as a line below the spectra for clarity. These figures show that overall there is not very much difference between the default and new spectra.
Fig. 18.— Similar to Fig. 17 for the SIC spectra. The left panel (a) shows the spectra extracted using default PHA ranges and background images; the right panel (b) shows the spectra extracted with the restricted PHA range and new background. In both cases, night-only spectra are shown.