Ionized Ultraviolet and Soft-X-ray Absorption in the Low Redshift Active Galactic Nucleus PG1126–041

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ABSTRACT

We present here the analysis of ultraviolet spectra from IUE and an X-ray spectrum from ROSAT PSPC observations of the X-ray weak, far-infrared loud AGN, PG 1126–041 (Mrk 1298). The first UV spectra taken in June 1992, simultaneously with ROSAT, show strong absorption lines of NV, CIV and SiIV, extending over a velocity range from $-1000$ to $-5000$ km s$^{-1}$ with respect to the corresponding line centre. Our analysis shows that the Broad Emission Line Region (BELR) is, at least partially, covered by the material causing these absorption lines. In the IUE spectrum taken in Jan. 1995, the continuum was a factor of two brighter and the UV absorption lines are found to be considerably weaker than in 1992, but only little variation in the emission line fluxes is found. With UV spectral indices of $\alpha_{uv} \approx 1.82$ and 1.46 for the 1992 and 1995 data, the far UV spectrum is steep. Based on the emission line ratios and the broad band spectral energy distribution, we argue that the steepness of the UV spectrum is unlikely to be due to reddening.

The soft X-ray emission in the ROSAT band is weak. A simple power-law model yields a very poor fit with a UV-to-X-ray spectral index $\alpha_{ux} = 2.32$. Highly ionized (warm) absorption is suggested by the ROSAT data. After correcting for a warm absorber, the optical to X-ray spectral slope is close to the average of $\alpha_{ux} \approx 1.67$ for radio quiet quasars.

From photoionization calculations we find: (1) A single zone absorption model cannot explain simultaneously the UV absorption lines and the ionized X-ray absorption if metal abundances are solar. Furthermore, in order to be consistent with the equivalent width of the observed Ly$\alpha$ absorption line, the turbulent velocity of the warm absorber must be less than 190 km s$^{-1}$, which imposes serious constraints on a disk wind model. (2) The UV absorption lines and their variability cannot be explained by a single zone model with solar abundances and the large variability in the absorption lines suggest that CIV and NV absorption lines are not severely saturated. (3) The absorption of the ionizing continuum by warm material strongly affects the emission line spectrum.

Key words: galaxies:individual (PG1126–041) – galaxies: Seyfert – quasars: absorption line: emission line – X-rays: galaxies

1 INTRODUCTION

About 10% of radio quiet luminous quasars (QSOs) exhibit Broad Absorption Lines (BAL) in the highly ionized resonant UV lines, such as NV, SiIV and CIV (Turnshek 1984, Weymann, 1995). Approximately 5–15% of these also show low ionization BAL such as MgII, AlIII (Weymann et al. 1991, Hartig & Baldwin 1990, Boroson & Meyers 1992, Voit, Weyman & Korista 1993). The BALs are displaced to shorter wavelengths with velocities of up to 0.1c relative to their corresponding emission line peaks. This indicates the presence of partially ionized gas outflows at enormous velocities from the central nucleus in these objects. The BAL
QSOs are either a unique type of objects or normal QSOs viewed under special geometrical conditions. Evidence in support of the latter interpretation includes the small covering factor inferred from the line profile modeling (Hamann et al. 1993) and the similarity in the emission line spectra between BAL and non-BAL objects (Weymann et al. 1991). New spectro-polarimetric observations reveal that the BAL region shows a disk-like structure and that the BAL clouds are mixed with dust which, at least in some objects, effectively blocks part of the light from the innermost nucleus (Glenn, Schmidt & Foltz 1994, Goodrich & Miller 1995, Cohen et al. 1995, Hines & Wills 1995).

Blue-shifted, low velocity absorption lines are usually found in the IUE spectra of ~15% of less luminous, low redshift, Seyfert galaxies. Variations of these absorption lines imply that they are also produced close to the nucleus, as are the BAL clouds (Stocke et al. 1994 and references therein). These absorption lines might represent the low velocity counterpart of the BAL phenomenon in the less luminous Seyfert nuclei. Stocke et al. (1994) proposed that the low velocities are the consequence of the comparatively low total power of Seyfert galaxies.

The UV spectrum of BAL QSOs has been extensively studied, while the X-ray spectra of these objects -potentially important to clarify a number of questions- have been poorly investigated. The unresolved absorption troughs in the UV may contain partially saturated lines, which can easily escape the detection in a moderate resolution spectrum. This is not a problem for the X-ray continuum, because the X-ray absorption is sensitive to the total absorbing column density in the BAL region. Part of the absorbing material might be highly ionized and produces only very weak absorption in the UV but much stronger absorption in X-rays.

The total hydrogen column density inferred from the UV absorption lines is of the order ~10^{20} cm^{-2}, which is not high enough to produce significant X-ray absorption, however there exists some evidence for large X-ray absorption in BAL objects. The X-ray emission of BAL objects in the ROSAT band is generally extremely weak. Only very few objects have been detected in soft X-rays (Green & Mathur 1996, Wang, Brinkmann & Bergeron 1996), with a broad band spectral index of \( \alpha = 2.19 \) for all of them. This suggests that the X-ray emission of BAL QSOs is either intrinsically weak or suppressed by absorption. The similarity in the emission line spectra of BAL and non-BAL QSOs, and the detection of large X-ray absorption in two relative bright BAL QSOs (Green & Mathur 1996, Mathur, Elvis & Singh 1996) suggests that absorption is common in these objects. Some recent BAL models predict the presence of significant X-ray absorption. To overcome the confinement problem (c.f. Weymann 1995) in radioactive emission models for BAL QSO’s, Murray et al. (1995) suggested that the BAL gas is shielded by a very large column density (10^{23}\ldots 10^{24} cm^{-2}) of highly ionized gas, which absorbs the soft X-ray photons but not the ultraviolet photons. Murray & Chiang (1996) further extended these results to Seyfert galaxies and radio-loud objects. Absorbing column densities of a few times 10^{22} cm^{-2} are predicted for Seyfert galaxies and radio-loud quasars. Although this model explains nicely the soft X-ray deficit in BAL QSOs, verification of this theory is largely dependent on the detection of the warm absorbing gas. The existence of thick absorber has been claimed for a few BAL QSOs, it has however not been demonstrated that the gas is highly ionized, as is essential for the validity of this theory. It should be noted that most low redshift Seyfert galaxies with UV absorption lines do not show heavily absorbed X-ray spectra, i.e., steep optical to X-ray spectrum, although about 50% of these objects do show some warm absorber associated features (Reynolds 1996).

In this paper, we report the result of the detailed analysis of the ultraviolet and X-ray spectrum of the high redshift BAL QSO analogue, PG1126–041 (Mrk 1298) which is a high luminosity Seyfert 1 galaxy (M_{r} = -22.8, only slightly fainter than a typical quasar) with weak X-ray emission (\( \alpha_{ox} = 2.05 \)). Strong UV absorption, extending to a maximum velocity of about ~5000 km s^{-1}, in CIV, NV and SiIV are present in the low resolution IUE spectra. The ROSAT PSPC spectrum shows strongly ionized absorption with a column density \( \geq 4 \times 10^{22} cm^{-2} \).

2 THE ULTRAVIOLET SPECTRUM

Two short-wavelength and one long wavelength spectrum were obtained with IUE in June 1992 and one short wavelength spectrum in January 1995. The spectra were retrieved from the IUE archive and were processed with the IUE NEWSIPS software, which also corrects thermal and temporal degradation of the camera sensitivity. They have been corrected for Galactic reddening, which has been estimated from the Galactic Hydrogen column density 4.4 \times 10^{20} cm^{-2} (Dickey & Lockman 1990) with a conversion factor 5.5 \times 10^{-2} cm^{-2} (Diplas & Savage 1993). All line and continuum measurements reported in this paper are based on the spectra corrected for the corresponding reddening of E(B-V) = 0.08.

In Fig. 1 we show the combined SWP and LW spectra of 1992. Emission and absorption lines are marked in the figure. The strong NV, CIV and SiIV absorption lines, at the short wavelength side of the emission lines, are pronounced. The short wavelength spectrum taken in 1995 (SWP3285) shows an increase in the continuum flux by a factor two (see Table 1), much weaker absorption lines (Table 2), and little variation in the emission lines.

Figure 2 shows details of the emission and absorption line profiles at both epochs. The 1992-spectrum is normalized to match the local continuum of the 1995 data for each line. Firstly, we notice that CIV emission line peaks to the red side of the line position in the object’s rest frame (z=0.060), unlike the Lyα line, which peaks at zero velocity. This difference is most likely due to the strong absorption in CIV. Secondly, in the 1992 spectrum, the CIV and NV absorption troughs are deeper than the local continuum, suggesting partial coverage of the absorbing material of the emission line region. In 1995, the absorption lines are much weaker and an additional large velocity CIV absorption line is indicated.

As the emission lines are relatively narrow, the continuum, which can normally only be defined with difficulty in BAL QSOs, can be reliably estimated from the pseudo-line free windows. The continuum over the full SWP region is modeled with a single power law. Emission lines are fitted by multiple Gaussians: Lyα and CIV are modeled with two Gaussians with the relative central wavelengths and widths...
for each component fixed; NV 1240, SiIV+OIV], HeII, CII] and MgII are fitted with one Gaussian and their central wavelengths are fixed at the observed wavelengths.

Due to the low spectral resolution of IUE, the detailed structure of the absorption lines can hardly be resolved. Therefore we modeled each broad absorption line with one Gaussian, applied to both the continuum and the emission line.

The best fit parameters are derived by minimizing $\chi^2$, taking into account the NEWSIPS errors. The fit is done using the SPECFIT package developed by G. Kriss within the distribution of STSDAS. Finally, the whole wavelength range of the SWP camera from 1290Å to 1930Å is simultaneously fitted, allowing a reliable determination of both the continuum shape and the flux. The initial values were estimated by fitting each line separately over a 150˚A window centered on the observed emission line peak. Only two strong absorption lines, NV and CIV, were included in this first step. The weaker absorption lines in SiIV and Lyα are then added after a reasonable fit is achieved. The centre and width of the absorption lines in velocity space are locked to those of the CIV absorption line. To avoid finding a local minimum, a ‘simplex’ search is used throughout the fitting process.

Since a single power law continuum cannot be defined over the full LWP band, due to contamination by UV FeII and Balmer continuum emission, we applied only local continuum fits, for CII] and MgII, over a window width of 300 Å centred on the observed wavelength of each line. The fit over the profile of the MgII line yields a line width 2430 km s$^{-1}$, similar to that of the Hβ line, allowing for the separation of the doublet nature of MgII and the resolution of LWP camera. No MgII absorption line is visible.

The final fit over the SWP band is shown in Fig 3. The best fit parameters for the continuum are listed in Table 1 for the emission lines and the continuum, and in Table 2 for the absorption lines. The emission line flux is the sum of the individual components. The errors given in Table 1 and Table 2 are purely statistical at the 1σ level. Since there exists no evidence for short time-scale UV variations in Seyfert galaxies of comparable luminosity, the difference between the two spectra taken in 1992 can be regarded as an indicator for the errors introduced by the measurements and the calibration. The central velocity (−1900 km s$^{-1}$) and width (3000 km s$^{-1}$) for the absorption lines from the different measurements are in good agreement. The equivalent widths of NV, SiIV, and CIV absorption lines as well as the fluxes of the Lyα, NV, SiIV+OIV], and CIV emission lines from the two spectra in 1992 are also within their statistical errors. The HeII fluxes differ by a factor of two, but the HeII line is badly blended with OIII]λ1663, and forms a very broad feature, and the line flux depends critically on the exact value of the continuum placement. In the 1992 spectra a Lyα absorption line is required for spectrum SWP44823, but not for the other (SWP 44822).

Assuming optically thin conditions, column densities for the absorbing ions can be estimated from the above equivalent widths: $W_\lambda/\lambda = \pi c^2/(m_e c^2) N g \lambda f \approx 8.85 \times 10^{-13} N g \lambda f$, where $\lambda$ and $f$ are the wavelength and oscillator strength of the corresponding absorption lines, $N$ is the column density of the absorbing ion and $g$ is the effective statistical weight for the ground level of the corresponding ion (Spitzer 1978). ($g\lambda f$) values were taken from Korista et al. (1991). If individual optically thick absorption lines are present or the absorbing material only partially covers the continuum or emission line region, the column densities derived represent lower limits. These column densities are given in Table 2 under $N_{1992}$.

The overall continuum in the SWP band is steep with a spectral index $\alpha \approx 1.5 - 1.8 (F_\nu \propto \nu^{-\alpha})$ similar to that seen in some low ionization BAL QSOs. If the intrinsic UV continuum of PG1126–041 is similar to other QSOs (Francis et al. 1991), significant intrinsic reddening is required (see the discussion for PG0043+039 by Turnshek et al. 1994). However, the cold $N_H$ column density derived from the X-ray analysis cannot provide sufficient reddening if the dust-to-gas ratio and the properties of the dust are Galactic. Moreover, the Galactic 2200Å absorption feature which is usually seen in similarly reddened objects, is weak.

### 3 THE ROSAT X-RAY SPECTRUM

The ROSAT observation of PG 1126-041 was made overlapping in time with the IUE observation in 1992 with an exposure time of ≈ 20 ks, and can be considered to be simultaneous. The methods used in the X-ray spectral analysis, including source and background extraction, dead-time and vignetting correction, and spectral fitting are similar to those described in Wang, Brinkmann & Bergeron (1996). Independent analysis using EXSAS (WY) and XSELECT plus XSPEC(TW) gives essentially the same results. The results presented here in Table 3, are those obtained from XSELECT. All errors quoted, are at 2.7σ level for each single parameter of interest.

Although the net counts for the source are only about 320, a single power law with Galactic column fails to produce a reasonable fit ($\chi^2/d.o.f. = 4.00/10$) leaving a deep and broad dip around 0.8 keV (Figure 4). In addition, this fit yields a column density ($N_H \approx 0.5 \times 10^{20} \text{cm}^{-2}$), some 10 times less than the Galactic value, and a very flat spectrum $\Gamma_s \approx 1.48$. When the column density is fixed at the Galactic value, the fit becomes much worse with $\chi^2/d.o.f. = 4.25/11$. In this case the single power law description the UV to X-ray spectral index is 2.3±0.1, much steeper than for typical radio quiet QSOs with a mean value 1.65 (Yuan et al. 1998).

As the photon deficit around 0.8-1.0 keV is a typical signature of warm absorption due to edges, more complicated models were applied. As a first step, a single absorption edge was added to the model. A good fit can be obtained with ($\chi^2/\nu = 1.01/8$, Table 3). However, the edge energy of the best fit at 0.56±0.03 keV does not correspond to any of the more common ion edges. This might be caused by the combination of several edges. To evaluate the results further, we next fitted the spectrum with a warm absorption model using a variable slope power-law ionizing continuum (see Zdziarski et al. 1995). The free parameters are photon index, column density, absorber temperature and ionization parameter ($\xi = L/nR^2$). We have fixed the temperature at 5 $\times$ 10$^4$ K and forced the photon index of ionizing continuum to be the same as the X-ray photon index. The best fit parameters are presented in table 3. The fit is accepted

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at a confidence level of 23% (\(\chi^2/\nu = 1.23/8\), Figure 4). A small amount of excess cold absorption is also required with \(N_e = 2.6^{+1.0}_{-0.9} \times 10^{20}\) cm\(^{-2}\). Figure 5 shows \(\xi\) versus \(N_w\) contours for the warm absorption model. The best fit column density \(N_w = 3.2^{+0.9}_{-0.8} \times 10^{22}\) cm\(^{-2}\) for the absorbing material is within the range typically for Seyfert I galaxies (e.g., Reynolds 1997). However, the ionization parameter is lower than normally found for other Seyfert I galaxies. Using the best fit photon index, the X-ray derived dimensionless ionization parameter \(U_x = (\text{density of ionizing photons in the energy } > 0.1\text{ keV})/(\text{hydrogen density})\) (Netzer 1996) is only 0.086\(^{+0.26}_{-0.10}\) with \(\xi = 55^{+16}_{-12}\). After correcting for the warm absorption, the far UV to X-ray spectral slope becomes \(1.66^{+0.07}_{-0.13}\) which is consistent with the X-ray spectral index \(1.79^{+0.13}_{-0.15}\) and well within the range of the mean value for radio quiet AGNs.

4 DISCUSSION

4.1 Broad Band Continuum and Absorption

In figure 6 we show the Spectral Energy Distribution (SED) of PG 1126-041 from infrared to X-ray energies. The SED peaks around 3000\(\text{Å}\) and is flat in the infrared and optical band. As mentioned in the previous section, the far UV spectrum is steep and consistent with a direct extrapolation of the X-ray spectrum. Barvainis (1993) interpreted the flatness of the infrared to optical spectrum in this object as contamination of stellar light which fills the gap between the spectral bumps. However, the steep UV spectrum cannot be explained in this way since the contribution of stellar light in the far UV is negligible under any reasonable assumption for the stellar population. An alternative method to generate such steep UV spectra is through significant dust absorption. We will show below that this is also an unlikely cause for the steep spectrum.

If the intrinsic UV spectrum of PG1126-041 is similar to other QSOs a reddening of E(B-V) > 0.15 is required. However, the Balmer decrement in this object is normal, with a ratio H\(_\alpha\)/H\(_\beta\) = 2.92 (Miller et al. 1992), very close to that expected for case B recombination, and it is also similar to the mean value of H\(_\alpha\)/H\(_\beta\) = 3.07±0.56 as determined for a sample of bright QSOs with Z< 0.5 by Miller et al. (1992). Using the H\(_\alpha\) flux of 8.92 \(10^{-13}\) erg cm\(^{-2}\) s\(^{-1}\), we find from the Ly\(_\alpha\) flux in Table 1, that for PG1126-041 the ratio Ly\(_\alpha\)/H\(_\alpha\) is between 2.3 and 3.6, for the two epochs of IUE observations in 1992 and 1995. As this is already very close to the photoionization prediction of Ly\(_\alpha\)/H\(_\alpha\) > 4.0, it is clear that reddening can not bring the flux at 1200\(\text{Å}\) up much more than a factor of two at most, arguing against the existence of large reddening affecting the emission lines.

As any absorbed UV light must be re-emitted in the infrared band, the infrared luminosity due to the dust emission must be a factor of two larger than the observed luminosity in the UV if the dust covers a large fraction of the nucleus and the reddening is as large as E(B-V)=0.15. The observed integrated infrared flux in the 1-100\(\mu\)m band is \(5.6 \times 10^{-11}\) erg cm\(^{-2}\) s\(^{-1}\), which is similar to the integrated UV flux from 3000\(\text{Å}\) to 100\(\text{Å}\) of 5.7\times 10^{-11} erg cm\(^{-2}\) s\(^{-1}\) for the 1992 data. In addition a significant portion of infrared emission has to originate from the host galaxy. Finally, the shortage of soft X-ray photons would even be more severe if the UV spectrum were highly reddened. With a E(B-V)=0.15 correction applied to the UV spectrum, the UV flux will increase by a factor of four, bringing \(\alpha_{\text{uvx}}\) back to > 2.0, making the object intrinsically very weak in X-rays. Also, the absence of a strong 2200\(\text{Å}\) feature implies that the grains must be different from the standard Galactic composition.

Although we can not completely rule out the possibility of that reddening is responsible for the steep UV spectrum, it requires a number of rather restrictive constraints: 1) the dust covers only a small fraction of the BLR; (2) the grains are not of Galactic composition, (3) the X-ray emission is intrinsically weak. On the other hand, the UV spectrum of an object with UV absorption lines could very well be intrinsically steep. This can be associated for example, with inclination effects. The case of an intrinsically steep spectrum will be discussed in the next section.

4.2 On the Ultraviolet and Ionized X-ray Absorption

We have shown above that, in addition to the highly ionized UV absorption lines of NV, CIV, and SiIV, also strong ionized absorption is detected in the soft X-ray spectrum. Since both the UV and X-ray ionized absorber are photoionized in QSOs (Weymann 1994, Netzer 1993, Ross & Fabian 1993), we will present in this section, photoionization calculations using 90 version CLOUDY (Ferland 1997). The results of these calculations will be used to constrain the physical conditions of the X-ray absorbing material. Solar abundances are assumed throughout although some earlier evidence suggests the existence of a possible heavy element overabundance in the BAL gas (Turnshek 1995).

CLOUDY90 uses a plane parallel slab geometry for the region.

Mathur et al. (1994) have shown that one should use the actually observed SED of an AGN in the application of photoionization codes, rather than a typical quasar SED. Therefore, we take the observed infrared to X-ray spectrum of PG 1126-041 as shown in Figure 6, corrected for Galactic reddening of E(B-V) = 0.08 in the optical and UV and for the ionized absorption in the X-ray band. The EUV spectrum is a linear interpolation from the far UV to the soft X-rays in \(\log(f_v)\) versus \(\log(\nu)\) space.

To predict the UV absorption lines from the parameters of the warm absorber obtained in §3, we have calculated a series of models for gas ionized by the continuum of PG 1126-041. First, the ionization parameter \(\xi\) is converted to a dimensionless \(U = (\text{density of photons at } E> 13.6\text{ eV})/(\text{hydrogen density})\). For \(\alpha_{\text{uvx}} = 1.66\), we find \(U = 0.0427\xi\).

The models cover the parameter range for the warm absorber, indicated by the probability distribution shown in Figure 5 of \(\log(U) = 0.26 - 0.48\), \(\log(N_\text{II}) = 22.38 - 22.61\) and \(n_\text{HI} = 10^9\) cm\(^{-3}\). The resulting predicted logarithmic column densities (in cm\(^{-2}\)) are 16.11\(^{+0.35}_{-0.29}\), 15.23\(^{+0.93}_{-0.95}\), 15.95\(^{+0.61}_{-0.72}\) < 12.00 for the HI, CIV, NV and SiIV respectively. The uncertainties correspond to the minimum and maximum taken for the above parameter range. Although the models reproduce the observed CIV and NV column densities correctly (cf. Table 2), the Ly\(_\alpha\) absorption is far too strong. Under the optically thin assumption, the above HI column den-
sity corresponds to a $W_\lambda (\text{Ly} \alpha) = 72 \text{Å}$, which is a factor of 20 stronger than observed. Since the predicted HI column density is at least a factor of two larger than that of NV, in the optically thick case the $W_\lambda (\text{Ly} \alpha)$ should be similar to that of $W_\lambda (\text{NV})$. Such strong absorption in the Lyα is clearly not present in the data. Also, the model predicts that SiIV absorption should not be observable and $N(\text{NV})/N(CIV) > 2.0$, which would imply either, that NV is partially saturated, or that the abundances of C and N are different from the solar value.

If the UV absorption lines are produced by an additional gas component, the weakness of the Lyα absorption line can be used to constrain the turbulent velocity within the absorber. By requiring that the $W_\lambda$ produced by the warm absorber material should not be larger than the observed value, we can derive an upper limit on the turbulent velocity ($b$) of the absorbing material. The curve-of-growth of the Lyα absorption line shown in Figure 7 illustrates that, in order to be consistent with $W_\lambda < 3.4 \text{Å}$, the turbulent velocity within the warm absorber must be less than 190 km s$^{-1}$. This limit is far in excess of the expected thermal velocity of ions. However, a large velocity gradient within the absorber is predicted in some models, which identify the warm absorber with an accretion disk wind. Since warm absorption features are dominated by the absorption edges of metal ions, the required total hydrogen column density will be less if the metal abundances are much higher than the solar value, but this gives only a marginal relaxation of the constraint on the turbulent velocity. For example, if the HI column density is lowered by a factor of 10, i.e. the metal abundances are increased by a factor of 10, the upper limit of $b$ will be increased by a factor of two at most, to 300 km s$^{-1}$ (see Figure 7).

The soft X-ray spectral fit indicates additional absorption due to cold (neutral or low ionized) material, but little constraints on the ionization state can be obtained from the X-ray data. It is likely that part of the UV absorption line is produced by this relatively cold material. It appears that low column, cold material is located outside the warm absorber and the ionizing continuum passes through the warm absorber before striking this material. In this model, we use the above continuum transmitted through the warm absorbing material inferred from the X-ray spectral fitting in the last section. We assume a particle density $n = 10^9$ cm$^{-3}$, and the calculations stop at a column density of $3 \times 10^{20}$ cm$^{-2}$. The column densities for a few UV absorbing ions are shown in figure 7. It is clear that this model still predicts too strong Lyα absorption. For a wide range of ionization parameters, the model predicts $N(HI) \approx N(CIV)$. Therefore, the C and N must be a few times over-abundant in the absorbing material in order to explain the weak Lyα absorption. Moreover, for an ionization parameter range in which $N(CIV) \approx N(\text{NV})$, the SiIV column density is very low, and the observed $W_\lambda$ implies that Si should also have a high abundance. This situation is similar to that found for BAL QSOs (e.g., Junkkarinen, Burbidge & Smith 1987, Hamann 1998).

The change in the absorption equivalent widths between two observations could be due to the fact that either the ionization of the UV absorber is higher in 1995 or, if there is a non-radial velocity component and the structure is not symmetric, the absorber moves out of the line of sight.

Using the scaling law for the BLR size, $R \propto L^{0.5}$, and taking NGC5548 as a calibrator, the BLR size in PG 1126-041 is estimated to be $\sim 10^{22}$ cm. Since the UV absorber is outside of the BLR, the minimal radius can be set to $R_{\text{abs}} > 10^{27}$ cm. If the absorber is an expanding shell of clouds with a radial velocity $v_r = 2000$ km/s (see Table 3), the distance of the absorber to the center has increased by $v_r t \approx 1.5 \times 10^{16}$ cm, which is about 0.1 $R_{\text{abs}}$, from 1992 to 1995. As the absorber is likely in pressure balance with the hot medium, over such small distances the decrease of the pressure should be small. Therefore, the density of the absorber is similar for the two epochs, and we estimate that the ionization parameter in 1995 is about a factor of two higher than in 1992. A factor of two increase in $U$ is also expected if the absorbing material is in steady outflow from the accretion disk. The column density of an ion is proportional to the square of the EW of the absorption line if the line is severely saturated, and proportional to the EW in the optically thin case. As seen in Figure 8, in the range of $N(CIV) \approx N(\text{NV})$, an increase of $u$ by a factor of two will lead to a factor of 2-3 drop in the N V column density and 3-4 in the CIV column density. This suggest that the absorption lines may not be severely saturated in the spectrum obtained in 1992.

4.3 Broad Emission Lines

In order to see if the ionizing continuum illuminating the BELR also passes through the ionized absorption region, we have computed the emission line spectra for two incident ionizing continua, with and without filtered by warm absorption. A typical column density of $10^{23}$ cm$^{-2}$ and a particle density of $10^{10}$ cm$^{-3}$ are adopted. In Figure 9, we plot the ratios of line emissivities (the line flux per unit surface area on the cloud surface) generated by these two input ionizing continua for a wide range of the ionization parameter. The figure shows that the emissivity of most lines is lower if the continuum is absorbed by warm material. This simply reflects the fact that the heating rate decreases due to the absorption of soft X-ray photons by the warm absorber. The drop is particularly large for O VI and NV lines, whose emission strongly depends on the soft X-ray spectrum. For these two lines, the suppression of NV1240 and OVI1032 relative to Lyα is a factor of four and $>-10$ for a typical BLR ionization parameter $U \approx 1$. This supplies a very sensitive test of whether the ionizing continuum passes through the warm absorber before striking the BLR clouds if precise measurement of more emission lines are available. However, OVI is not observed by IUE and the NV emission is sensitive to the abundance as well. Nevertheless, future more sensitive observations will enable us to perform such analyses.

5 CONCLUSION

We have analyzed the UV and X-ray spectra of the X-ray weak AGN PG 1126-041 and found:

1. The UV spectra show strong highly ionized absorption lines in NV, CIV and SiIV, which extend over a velocity range from $-1000$ to more than $-5000$ km s$^{-1}$ from the corresponding emission line center. The absorption column density ratios for metal lines are similar to those found in
BAL QSOs. The equivalent widths of CIV and NV absorption lines have changed by a factor of two over a period of 2.5 yrs.

(2) The UV absorption material covers the broad emission line region at least partially.

(3) Strong ionized absorption has been detected in the soft X-ray spectrum obtained by ROSAT simultaneously with the IUE observation in 1992. After correcting for absorption, the optical to X-ray spectral slope is typical for a radio quiet QSO.

(4) The far UV spectrum is steep with $\alpha_{uv} \simeq 1.82$ and 1.46 for the 1992 and 1995 data, respectively. Based on the emission line ratios and the broad band spectral energy distribution, we argue that the steepness of UV spectrum is not due to intrinsic reddening.

From detailed photoionization calculations, we find: (1) A single zone warm absorber cannot produce the observed equivalent widths of the UV absorption lines if the metal abundances are solar. Furthermore, in order to be consistent with the observed equivalent width of the Ly$\alpha$ absorption line, the turbulent velocity of the warm absorber must be less than 190 km s$^{-1}$, this imposes serious constraints on a disk wind model. (2) The UV absorption lines and their variability cannot be explained by a single zone model with solar abundance, and the large variability in the absorption lines suggest that CIV and NV absorption lines in the 1992 spectrum are not seriously saturated. (3) The presence of a warm absorber strongly affects the ionizing continuum and consequently, has a large impact on the emission line spectrum.

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Table 1. UV continuum and emission line parameters

|            | SWP44822 | SWP44823 | average 1992 | SWP 53285 |
|------------|----------|----------|--------------|-----------|
| **continuum**<sup>a</sup> |          |          |              |           |
| β          | 0.04 ± 0.03 | −0.18 ± 0.02 | −0.12 ± 0.06 | −0.54±0.01 |
| A          | 1.78±0.03 | 2.02±0.02 | 1.90±0.12 | 4.04±0.03 |
| **line flux**<sup>b</sup> |          |          |              |           |
| Lyα        | 211±19   | 208±18   | 210±5       | 317±17    |
| NV         | 73±9     | 64±7     | 69±5        | 67±10     |
| SiIV+OIV   | 40±6     | 37±5     | 39±3        | 51±11     |
| CIV        | 144±19   | 162±14   | 153±9       | 142±10    |
| HeII       | 82±7     | 39±4     | 60±25       | 35±5      |
| CIII       | 51±16    |          |             |           |
| MgII       |          | 29±2     |             |           |

<sup>a</sup> F<sub>λ</sub> = A (λ/1000Å)<sup>β</sup> in units of 10<sup>−14</sup> erg cm<sup>−2</sup> s<sup>−1</sup> Å<sup>−1</sup>.

<sup>b</sup> In units of 10<sup>−14</sup> erg cm<sup>−2</sup> s<sup>−1</sup>.

Table 2. Absorption line parameters

|            | SWP44822 | SWP44823 | 1992 average | N<sub>1992</sub> | SWP 53285 |
|------------|----------|----------|--------------|-----------------|-----------|
| **central velocity and width (km/s)** |          |          |              |                 |           |
| V          | 1826±70  | 1990±70  | 1910±80      | 2200±70         |           |
| σ<sub>a</sub> | 3155±157 | 2875±115 | 3000±150     | 2010±50         |           |
| **equivalent widths (Å)** |          |          |              |                 |           |
| Lyα        | 0.7±0.9  | 2.7±0.7  | 1.7±1.0      | 1.6 10<sup>14</sup> | 3.3±0.5  |
| NV<sub>1240</sub> | 13.9±0.8 | 11.1±0.6 | 12.5±1.4     | 1.6 10<sup>13</sup> | 6.8±0.5  |
| SiIV<sub>1397</sub> | 5.7±1.7  | 6.3±1.3  | 6.0±0.3      | 2.3 10<sup>14</sup> | 0.2±0.4  |
| CIV<sub>1549</sub> | 14.3±1.0 | 15.4±0.7 | 14.9±0.5     | 1.2 10<sup>15</sup> | 5.3±0.7  |

N<sub>1992</sub> is the column density of the ion under optically thin conditions (in units of cm<sup>−2</sup>).

Table 3. ROSAT-PSPC spectral fitting

| model | N<sub>0</sub><sup>a</sup> | Γ | N<sub>1 keV</sub><sup>b</sup> | E<sub>edge</sub> or ξ | τ or N<sub>0</sub><sup>a</sup> | χ<sup>2</sup>/ν<sub>red</sub>/dof |
|-------|----------------|---|----------------|-----------------|----------------|----------------|
| PL    | 4.4 (f)      | 3.20 | 0.3                 |                 |                 | 4.72/11          |
| PL    | 0.5          | 1.48 | 0.37                |                 |                 | 4.00/10          |
| Edge  | 5.6<sup>±1.0</sup><sub>−0.9</sub> | 2.2<sup>±0.3</sup>| 2.2±0.3 | 0.56±0.03 | 15.4<sup>(c)</sup> | 1.01/8           |
| WAB   | 7.0<sup>±1.0</sup><sub>−0.9</sub> | 2.8<sup>±1.3</sup>| 6.9±2.5 | 55<sup>±16</sup><sub>−12</sub> | 320<sup>±90</sup><sub>−80</sub> | 1.23/8           |

<sup>a</sup> In units of 10<sup>20</sup> cm<sup>−2</sup>.

<sup>b</sup> In units of 10<sup>−4</sup> cm<sup>−2</sup> s<sup>−1</sup> keV<sup>−1</sup>.

<sup>c</sup> The upper bound of the parameter was 20.
Figure 1. Observed Ultraviolet Spectrum of PG1126−041 processed by NEWSIPS and corrected for Galactic reddening of E(B−V)=0.08 (see text). NEWSIPS errors are plotted as dotted lines. The major emission and absorption lines are indicated. The reality of the second peak in the CIV profile could not be unambiguously established although some structure appears to be present in both 1992 spectra. Upon inspection of the SILO file, it could very well be associated with a camera hotspot on the spectrum in SWP44823.

Figure 2. A detailed view of emission line and the associated absorption line profiles in velocity space. A redshift z=0.060 is adopted. The emission lines do not have their peaks at the same velocity (see also text). The 1992 spectrum is shown as thin line and that of 1995 as thick line. The spectra are normalized to the local continuum level. Note that in 1995, when the continuum level was twice that of 1992 (see also table 1) the absorption lines were considerably weaker.

Figure 3. Fitted SWP spectra of 1992 and 1995 as described in the text.

Figure 4. Fits of the ROSAT soft X-ray spectrum with a single power-law model (dotted line), with an additional absorption edge (dotted-dash line) and with an ionized warm absorption model (dash line). The top panel shows the unfolded spectrum, with the model fits as indicated. The lower panels show the residuals for a single power-law model (PL); with absorption edge (EDGE); and with a warm absorber model (WARM). See text for a detailed description of the models.

Figure 5. 60, 90 and 95 per cent contours (upper limits for two interesting parameters) for the ionization parameter against the column density for the warm absorption model.

Figure 6. Broadband spectral energy distribution of PG1126-041. The UV data have been taken during the ROSAT observation and can be considered as essentially simultaneous. The full line in the X-rays represents the derived input spectrum after correcting the observed X-ray spectrum (also shown) for Galactic absorption and for the presence of a warm absorber (see section 3).

Figure 7. The growth curve for the Lyα absorption line. The solid line corresponds to a column density of HI of 1.3×10^{16} cm^{-2}, the value predicted by the warm absorption model with cosmic abundances, the dashed line for an N(HI)=1.3×10^{15} cm^{-2}, approximating the case of a warm absorption model with metal abundances, a factor of 10 times solar values.

Figure 8. Predicted ion column densities for major ultraviolet absorption ions for a hydrogen column density of 3×10^{20} cm^{-2} (see text for details).

Figure 9. Plot of line emissivity ratios against photoionization parameter for a particle density n_H=10^{10} cm^{-3} and column density N_H=10^{23} cm^{-3}. The I_n is the line intensity calculated assuming that the ionizing continuum passes through the warm absorber before striking the BLR.
