X-RAY ABSORPTION IN RADIO-QUIET QSOS

W.N. Brandt,[1] S.C. Gallagher,[1] A. Laor[2] and Beverley J. Wills[3]

1) Department of Astronomy & Astrophysics, 525 Davey Lab, The Pennsylvania State University, University Park, Pennsylvania 16802 USA
2) Physics Department, Technion, Haifa 32000 Israel
3) Department of Astronomy, University of Texas at Austin, Austin, Texas 78712 USA

ABSTRACT Major flows of ionized gas are thought to be present in the nuclei of most luminous QSOs, and absorption by these flows often has a significant effect upon the observed X-ray continuum from the black hole region. We briefly discuss X-ray studies of this gas and attempts to determine its geometry, dynamics, and ionization physics. Our focus is on X-ray warm absorber QSOs, Broad Absorption Line QSOs, and soft X-ray weak QSOs. We also discuss some prospects for further study with the next generation of X-ray observatories.

KEYWORDS: QSOs: absorption — QSOs: general — galaxies: active — X-rays: galaxies.

1. INTRODUCTION

X-ray absorption studies of active galaxies are proving to be one of the most powerful ways of probing material in the immediate vicinity of supermassive black holes. Rapid X-ray variability suggests that the nuclear X-ray source is the most compact emitter of continuum radiation, and it thus provides a point-like and luminous ‘flashlight’ right at the heart of the active galaxy. Because X-rays are highly penetrating, X-ray spectra can be used to probe column densities over the wide range 10^{19}–10^{25} cm^{-2}. X-ray absorption is produced by the innermost electrons of metals, and it provides a probe of matter in nearly all forms (i.e., neutral gas, ionized gas, molecular gas and dust).

Here we shall briefly review several types of X-ray absorption seen in luminous, radio-quiet QSOs. We will discuss X-ray warm absorber QSOs, Broad Absorption Line QSOs, and soft X-ray weak QSOs. We will also discuss some future prospects for radio-quiet QSO X-ray absorption studies. Due to lack of space, we will not be able to cover the important red QSO and type 2 QSO debates or the exciting recent results on X-ray absorption in radio-loud QSOs.

2. X-RAY WARM ABSORBERS IN RADIO-QUIET QSOS

Warm absorption by ionized nuclear gas is familiar from the lower-luminosity Seyfert 1 galaxies where it has been intensively studied (e.g., Reynolds 1997; George et al.

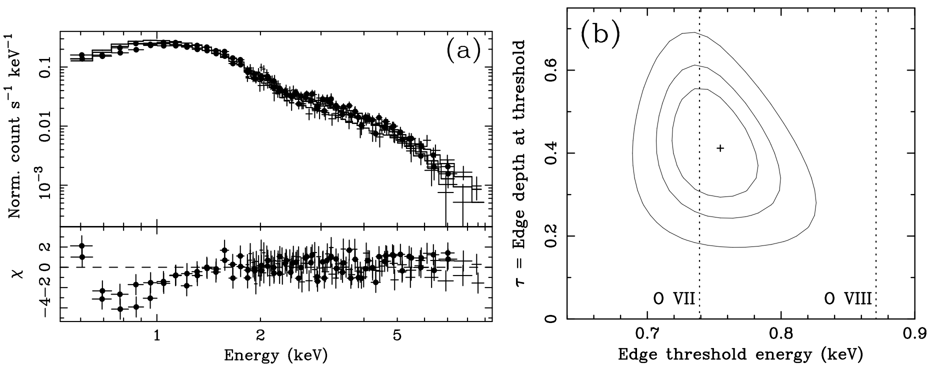

FIGURE 1. (a) *ASCA* SIS (solid dots) and GIS (plain crosses) observed-frame spectra of the warm absorber QSO IRAS 13349+2438 (z = 0.107). A power-law model has been fit to the 2–9 keV data and extrapolated back to show the deviations at low energies. The ordinate for the lower panel (labeled χ) shows the fit residuals in terms of σ with error bars of size one. Note the systematic absorption residuals at low energies due to ionized oxygen. (b) Confidence contours for the edge parameters. Contour levels are for 68.3, 90.0 and 99.0% confidence. The fitted edge energy has been corrected for cosmological redshift. From Brandt et al. (1997).

1998). Warm absorbers imprint moderately strong edges (e.g., O VII and O VIII) on the continuum, but this absorption is not so strong that it completely extinguishes the soft X-ray flux. Assuming photoionization equilibrium, the column density and ionization parameter of the ionized gas can be obtained via X-ray spectral fitting.

To our knowledge, only five luminous radio-quiet QSOs have been shown to have X-ray warm absorbers: MR 2251–178 (e.g., Halpern 1984; Pan, Stewart & Pounds 1990; Reeves et al. 1997), IRAS 13349+2438 (Brandt, Fabian & Pounds 1996; Brandt et al. 1997; Siebert, Komossa & Brinkmann 1999; see Figure 1), PG 1114+445 (Laor et al. 1994; George et al. 1997), IRAS 17020+4544 (e.g., Leighly et al. 1997), and IRAS 12397+3333 (e.g., Grupe et al. 1998). It has been difficult to perform detailed studies of the warm absorbers in these QSOs due to limited photon statistics, but the basic physical properties of their warm absorbers appear similar to those seen in Seyfert 1s. Edges from O VII and O VIII seem to be the strongest spectral features, and column densities of $\approx 10^{21}$–10^{23} cm^{-2} and ionization parameters of $\xi \approx$ 20–160 erg cm s^{-1} are inferred. In three cases (IRAS 12397+3333, IRAS 13349+2438 and IRAS 17020+4544), the warm absorber probably contains dust which causes significant reddening of the optical continuum. Dust will not be rapidly sputtered at warm absorber temperatures (the gas temperature is $\sim 10^5$ K for a photoionized warm absorber), and it will not be sublimated if the warm absorber is located outside the Broad Line Region (BLR). Two of the QSOs with X-ray warm absorbers (as well as most of the Seyfert 1 galaxies; Crenshaw et al. 1999) show UV absorption lines (PG 1114+445: Mathur, Wilkes & Elvis 1998; MR 2251–

178: Mathur et al., in preparation), and it has been argued that the X-ray and UV absorption arise in the same gas. While there is still debate over the extent to which the X-ray and UV absorbers can be unified, they are likely to have qualitatively similar dynamics. The UV absorbing gas is measured to be outflowing from the nucleus at speeds of several hundred km s^{-1}.

The incidence of warm absorbers in luminous, radio-quiet QSOs is difficult to address at present (e.g., George et al. 1999). Warm absorbers are detected in $\gtrsim 50\%$ of Seyfert 1s, while a much smaller percentage of radio-quiet QSOs have *detected* warm absorbers. However, the X-ray spectra of most radio-quiet QSOs have significantly lower signal-to-noise than those of Seyfert 1s, and cosmological redshifting also moves the main warm absorber edges down to regions of low effective area and often poor calibration. Seyfert-like warm absorbers could be lurking undetected in the noisy X-ray spectra of many radio-quiet QSOs, and the only clear conclusion that can be drawn at present is that better data are needed (although Laor et al. 1997 suggest that warm absorbers are relatively rare in radio-quiet QSOs based upon *ROSAT* PSPC data).

3. BROAD ABSORPTION LINE (BAL) QSOS

Luminous radio-quiet QSOs show another type of absorption that is not familiar from Seyfert 1s: UV Broad Absorption Lines (BALs) that are created in an outflowing 'wind' with velocities up to $\sim 0.1c$. BALs have been intensively studied in the UV for many years, and it is likely that most QSOs create BAL outflows (e.g., Weymann 1997). The BAL region is thought to be major part of the nuclear environment with a covering factor of 10–50% (e.g., Goodrich 1997; Krolik & Voit 1998), and the BAL phenomenon may be fundamentally connected to the QSO 'radio volume control' (e.g., Weymann 1997). In addition, BAL outflows may clear gas from QSO host galaxies and thereby affect star formation and QSO fueling over long timescales (e.g., Fabian 1999).

Ideally, one would like to use X-rays to study the absorption properties, nuclear geometries, and continuum shapes of BAL QSOs. X-ray absorption studies would constrain the column density, ionization state, abundances, and covering factor of the BAL gas, and the nuclear geometry could be constrained using the iron Kα line and X-ray variability. Regarding the continuum shape, it is important to establish that, underneath their absorption, BAL QSOs emit like normal radio-quiet QSOs.

ROSAT observations found BAL QSOs to be very weak in the soft X-ray band with few X-ray detections (e.g., Kopko, Turnshek & Espey 1994; Green & Mathur 1996, hereafter GM96). This was an important and surprising result since, if BAL QSOs indeed have normal underlying X-ray continua, large neutral column densities of $\gtrsim 4 \times 10^{22}$ cm^{-2} are required to extinguish the X-ray emission. Ionization of the absorbing gas led to even larger required column densities. The *ROSAT* column densities were at least an order of magnitude larger than those inferred from UV data. Subsequently, it was realized that the UV absorption lines are severely saturated (e.g., Hamann 1998), leading to much larger inferred UV column densities.

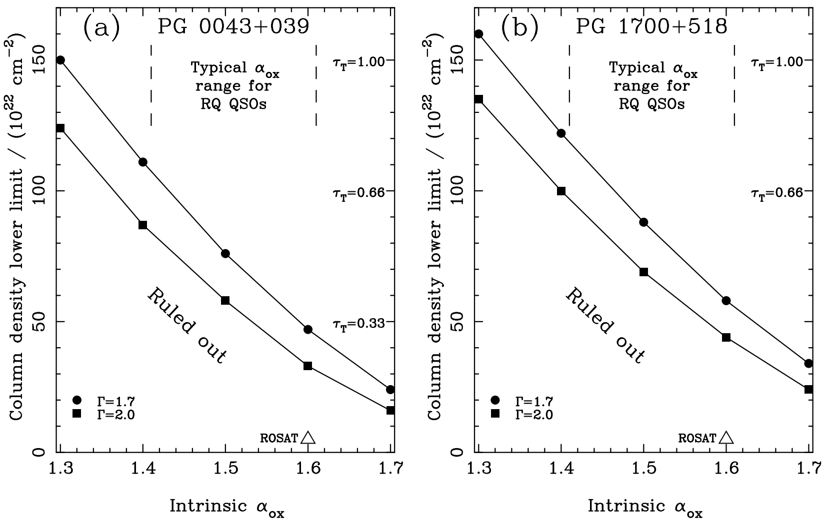

FIGURE 2. Column density lower limits for (a) PG 0043+039 and (b) PG 1700+518 derived using our *ASCA* SIS0 data. We show the inferred column density lower limit as a function of the intrinsic (i.e., absorption-corrected) value of $\alpha_{\rm ox}$ (the slope of a nominal power law connecting the rest-frame flux density at 2500 Å to that at 2 keV). The square data points are for an X-ray photon index of $\Gamma = 2.0$, and the circular dots are for an X-ray photon index of $\Gamma = 1.7$. The open triangle at $\alpha_{\rm ox} = 1.6$ illustrates the typical BAL QSO column density lower limit found by GM96 based on *ROSAT* data. The numbers along the right-hand sides of the panels show the Thomson optical depth of the corresponding column density; note that our inferred column densities are within a factor of ≈ 3 of being optically thick to Thomson scattering. The column density lower limits shown in this plot are for absorption by neutral gas with solar abundances. In reality, the absorbing gas is probably ionized, and this can significantly raise the required column density. We have made similar plots to those above using $\alpha_{\rm ix}$ (between 1.69 μm and 2 keV), and we find similarly large column densities are required. From Gallagher et al. (1999).

These column densities are then consistent with the X-ray data.

Hard X-rays are much more penetrating than soft X-rays, and if BAL QSOs are absorbed by column densities of a few times 10^{22} cm^{-2} they should be much brighter above 2 keV than below this energy. Using *ASCA*, Mathur, Elvis & Singh (1995) detected the famous BAL QSO PHL 5200 ($z = 1.98$) and claimed to measure a large column density for this object via spectral fitting. Our independent analysis of these data confirms the detection, but the claim for a large column density in this object is not reliable at present due to extremely limited photon statistics (Gallagher et al. 1999). The nearby BAL QSO Mrk 231 ($z = 0.042$) has also been studied by *ASCA* (Iwasawa 1999; Turner 1999) and appears to show absorption with a column density of $\gtrsim 2 \times 10^{22}$ cm^{-2}, although precise constraints are difficult due to the complex X-ray spectrum of this object (e.g., there appears to be a significant starburst contribution in X-rays).

Recently, we have been performing an exploratory BAL QSO survey using *ASCA* and *BeppoSAX* (Gallagher et al. 1999; Gallagher et al., in preparation). We chose these satellites because they provide access to penetrating 2–10 keV X-rays. We performed moderate-length ($\approx$ 20–30 ks) exploratory observations to learn about the basic X-ray properties of as many BAL QSOs as possible without being too heavily invested in the uncertain results from any one object. Our goals were to define the 2–10 keV properties (e.g., fluxes) of the class, to discover good objects for follow-up studies with *Chandra* and *XMM*, and to set absorption, geometry and continuum constraints (to the greatest extent possible with exploratory observations). We proposed many of the optically brightest BAL QSOs known since the optical and X-ray fluxes are generally correlated for QSOs. Most of our objects should have been easily detected if they have normal QSO X-ray continua absorbed by column densities of several times 10^{22} cm^{-2}. We focused on bona-fide BAL QSOs (no mini-BALs; see §3.1 of Weymann et al. 1991), and we also tried to sample a few objects with extreme properties (e.g., optical continuum polarization) to look for correlations.

We have performed new *ASCA* and *BeppoSAX* observations for 8 BAL QSOs in total, and we have also analyzed the archival data for 4 BAL QSOs. Our objects have $z = 0.042$–3.505 and $B = 14.5$–18.5; PHL 5200 ($B = 18.5$) is the optically faintest member of our sample. We detect 5 of our 12 BAL QSOs, with our most distant and most luminous detected BAL QSO being CSO 755 ($z = 2.88$, $M_{\rm V} = -27.4$; Brandt et al. 1999). Our detection fraction is higher than in soft X-rays, consistent with the idea that heavy absorption is present in these objects. However, we find that BAL QSOs are still generally faint 2–10 keV sources, and several of them are strikingly faint. For example, we did not detect the optically bright BAL QSOs PG 0043+039 ($B = 15.9$, $z = 0.384$, 24 ks *ASCA* exposure) and PG 1700+518 ($B = 15.4$, $z = 0.292$, 21 ks *ASCA* exposure). If these objects have normal underlying X-ray continua, then large neutral column densities of $\gtrsim 5 \times 10^{23}$ cm^{-2} are needed to explain their X-ray non-detections (see Figure 2). Because of our access to more penetrating X-rays, our column density lower limits for some objects are about an order of magnitude larger than those set by *ROSAT*. Ionization of the absorbing gas raises our required column densities to the point where they are almost 'Compton-thick' ($N_{\rm H} \gtrsim 1.5 \times 10^{24}$ cm^{-2}; compare with Murray et al. 1995). These large column densities increase the inferred mass outflow rate and kinetic luminosity. If the X-ray absorption arises in gas at $\gtrsim 3 \times 10^{16}$ cm that is outflowing with a significant fraction of the terminal velocity measured from the UV BALs, one derives extremely large mass outflow rates ($\dot{M}_{\rm outflow} \gtrsim 5$ M$_\odot$ yr^{-1}) and kinetic luminosities ($L_{\rm kinetic} \gtrsim L_{\rm ionizing}$). While such powerful winds are perhaps not impossible, the mass outflow rate and kinetic luminosity can be reduced if much of the X-ray absorption occurs at velocities significantly smaller than the BAL terminal velocity. Note that the X-ray and UV absorbers in BAL QSOs have not yet been shown to be identical, and the X-ray and UV light paths may differ.

Our exploratory observations demonstrate that it is risky to attempt long X-ray spectroscopic observations of BAL QSOs that do not have established X-ray fluxes, and we find that optical flux is *not* a good predictor of X-ray flux for BAL QSOs. We fail to detect some of our optically brightest objects, while some of our optically faintest are clearly detected. We have empirically searched for other predictors of X-ray brightness, and while the data are limited there is a tentative connection between high optical continuum polarization and X-ray brightness (see Brandt et al. 1999 for details). Such a connection could be physically understood if the direct lines of sight into the X-ray nuclei of BAL QSOs are usually blocked by Compton-thick matter, and we can only see X-rays when there is substantial electron scattering in the nuclear environment by a 'mirror' of moderate Thomson depth. Further studies of uniform, well-defined BAL QSO samples are needed to avoid biases and check this potential connection better. It can also be checked with detailed X-ray studies of highly polarized BAL QSOs. Iron Kα lines with large equivalent widths could be formed if most of the X-ray flux is scattered, and one would also not expect rapid ($\lesssim 1$ day) X-ray variability.

4. SOFT X-RAY WEAK (SXW) QSOS

BAL QSOs are generally weak in the soft X-ray band, presumably due to heavy X-ray absorption. One can also address the converse questions: Do all Soft X-ray Weak QSOs (SXW QSOs) suffer from absorption? Do all SXW QSOs have BALs? Alternative possible causes of soft X-ray weakness include unusual intrinsic spectral energy distributions (SEDs) and extreme X-ray or optical variability (e.g., changes in $\alpha_{\rm ox}$ over time). The presence of QSOs with relatively weak soft X-ray emission was recognized at least as early as the mid-1980s, with some observed to be $\gtrsim 20$ times weaker than expected given their optical fluxes (e.g., Elvis & Fabbiano 1984; Avni & Tananbaum 1986; Elvis 1992). For example, Avni & Tananbaum (1986) discussed a 'skew tail' towards soft X-ray weak objects for the $\alpha_{\rm ox}$ distribution of the PG QSOs. Many new SXW QSOs were found in *ROSAT* samples (e.g., Laor et al. 1997; Yuan et al. 1998), and *ROSAT* was also able to place significantly tighter constraints upon $\alpha_{\rm ox}$. This sparked further detailed studies of these objects (e.g., Wang et al. 1999; Wills, Brandt & Laor 1999), and we have recently completed the first systematic study of a well-defined SXW QSO sample (Brandt, Laor & Wills 1999). Our goals for this study were (1) to determine the origin of soft X-ray weakness in general, (2) to discover relations between SXW QSOs, BAL QSOs, and X-ray warm absorber QSOs, and (3) to search for correlations between soft X-ray weakness and other interesting observables.

We selected all SXW QSOs from the Boroson & Green (1992, hereafter BG92) sample of 87 $z < 0.5$ PG QSOs. The BG92 sample is well defined and representative of the optically selected QSO population, and there is already a large amount of high-quality and uniform data available for it. We computed our own $\alpha_{\rm ox}$ values for the BG92 objects using data mainly from *ROSAT* but also from *ASCA* and *Einstein* as needed, and our resulting $\alpha_{\rm ox}$ values were substantially more complete

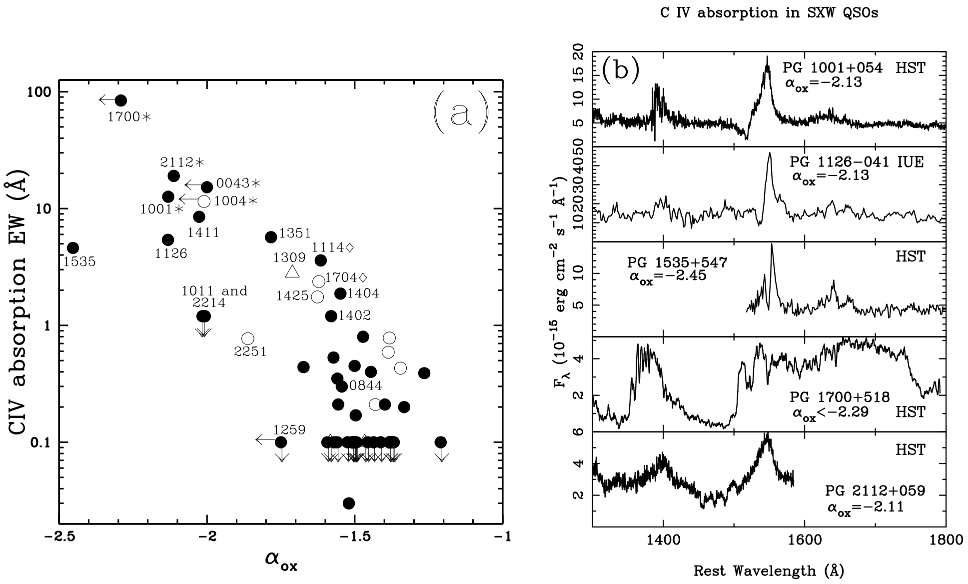

FIGURE 3. (a) Plot of $\alpha_{\rm ox}$ versus C IV $\lambda1549$ absorption-line EW (in the rest frame) for the BG92 QSOs with UV coverage. Following BG92, solid dots are radio-quiet QSOs, open triangles are core-dominated radio-loud QSOs, and open circles are lobe-dominated radio-loud QSOs. SXW QSOs (those QSOs with $\alpha_{\rm ox} \leq -2$) and other interesting QSOs are labeled by the right ascension part of their name. An asterisk to the right of an object's name indicates that it is a BAL QSO or probable BAL QSO, and a diamond indicates that it is known to have an X-ray warm absorber. (b) UV spectra of the regions of the broad C IV emission line for some of the SXW QSOs. Note the strong, blueshifted C IV absorption. From Brandt, Laor & Wills (1999).

and constraining than those previously available (especially for the SXW QSOs). We used $\alpha_{\rm ox} \leq -2$ as our criterion for soft X-ray weakness (note in this section we take $\alpha_{\rm ox}$ to be a *negative* quantity). Thus, given their optical fluxes, our SXW QSOs were ≥ 25 times weaker than 'usual' in soft X-rays. We found 10 SXW QSOs with $\alpha_{\rm ox} \leq -2$, and thus SXW QSOs appear to comprise $\approx 11\%$ of the optically selected QSO population. Nine of our SXW QSOs are radio-quiet, and one is radio-loud.

We compared the continuum and line properties of our 10 SXW QSOs to those of the other 77 BG92 non-SXW QSOs using nonparametric tests. The properties compared included those listed in Tables 1 and 2 of BG92 as well as the optical continuum polarization, the optical continuum slope, and the radio structure. We also compared the C IV $\lambda1549$ absorption-line properties for the 55 QSOs from BG92 that have high-quality UV coverage in this spectral region. All C IV measurements were made by B. J. Wills with particular effort toward ensuring consistency and uniformity. We found that the SXW QSOs and non-SXW QSOs have consistent distributions of $M_{\rm V}$, z, radio loudness (R), optical continuum slope, optical continuum polarization, and Hβ FWHM. In addition, they have consistent EW distributions of Hβ, He II and Fe II. SXW QSOs were found to have significantly lower [O III] luminosities than those of non-SXW QSOs; low [O III] luminosities have similarly been noted for low-ionization BAL QSOs (e.g., Turnshek et al. 1997). Since [O III] emission is likely to be a reasonably isotropic property for radio-quiet PG QSOs (e.g., Kuraszkiewicz et al. 1999), this result is significant as it suggests there may be an *intrinsic* difference between SXW QSOs and non-SXW QSOs (see Brandt, Laor & Wills 1999). In addition, SXW QSOs appear to have 'peaky' Hβ line profiles and large Hβ line shifts (either to the blue or the red relative to the rest frame defined by [O III]).

The most striking difference between the SXW QSOs and non-SXW QSOs is their UV absorption. SXW QSOs show greatly enhanced C IV absorption (see Figure 3). We find blueshifted C IV absorption with EW $>$ 4.5 Å in 8 of our 10 SXW QSOs, while only 1 of 45 non-SXW QSOs had EW $>$ 4.5 Å. The two SXW QSOs without clear UV absorption, 1011–040 and 2214+139, have UV spectra of only limited quality. Given that UV and X-ray absorption have a high probability of joint occurrence in Seyfert galaxies and QSOs, we consider Figure 3 to be evidence that absorption is the primary cause of soft X-ray weakness in QSOs. Only one of our SXW QSOs, 1411+442, has a broad-band X-ray spectrum at present, and it indeed shows evidence for strong X-ray absorption with $N_{\rm H} \gtrsim 10^{23}$ cm^{-2} (Brinkmann et al. 1999). We can argue against unusual SEDs as the primary cause of soft X-ray weakness by noting that our SXW QSOs have normal Hβ, He II and Fe II EWs (see Korista, Ferland & Baldwin 1997). We also do not find general evidence for strong $\alpha_{\rm ox}$ variability when we compare our $\alpha_{\rm ox}$ values with the limited historical data available. The fact that we find no evidence for QSOs with intrinsically weak soft X-ray emission underscores the universality of QSO X-ray production.

The general correlation between $\alpha_{\rm ox}$ and C IV absorption EW shown in Figure 1 provides a useful overall view of QSO absorption. Unabsorbed QSOs and BAL QSOs lie at opposite extremes of the correlation, while X-ray warm absorber QSOs and moderate SXW QSOs lie at intermediate positions. We find 4–5 bona-fide BAL QSOs in the BG92 sample; 3 were already known (0043+039, 1700+518 and 2112+059) and 2 are new (1001+054 and probably 1004+130; see Wills, Brandt & Laor 1999 for detailed discussion of 1004+130). If all BAL QSOs are SXW QSOs, then we should have found all the BAL QSOs in the BG92 sample. The incidence of BAL QSOs in the BG92 sample appears to be statistically consistent with the $\approx 11\%$ observed for the LBQS (e.g., Weymann 1997), although this issue could be examined more reliably with complete UV coverage of the BG92 QSOs.

The UV results for our SXW QSOs imply that selection by soft X-ray weakness is an effective ($\sim 80\%$ successful) way to find low-redshift QSOs with strong UV absorption. This is important from a practical point of view because, for bright QSOs, the optical and X-ray flux densities needed to establish soft X-ray weakness can often be obtained from publicly available data. This method has already been exploited in several cases for individual objects (e.g., Fiore et al. 1993; Mathur et al. 1994), and it could be profitably applied to larger QSO samples.

5. SOME FUTURE PROSPECTS

With the next generation of X-ray observatories, it should be possible to find many more X-ray warm absorbers in radio-quiet QSOs or demonstrate that few are present. This will allow study of their basic physical properties as well as a reliable determination of their incidence. Detailed X-ray spectroscopy and modeling should be possible for a few of the X-ray brightest sources, although this will require a significant investment of observation time.

For BAL QSOs, further exploratory observations are needed to look for correlations with optical continuum polarization and other properties. These would be most effective if performed on uniform and well-defined samples. Moderate-quality X-ray spectroscopy should be possible for a few of the X-ray brightest BAL QSOs to study their absorption properties, nuclear geometries, and continuum shapes. For BAL QSOs with enough X-ray flux, the widths and amplitudes of X-ray bound-free edges can constrain the dynamics and metallicity of the absorber. It is also important to study the radio-loud BAL QSOs (e.g., Becker et al. 1999) in X-rays to determine if they follow the same patterns as radio-quiet objects, and deep X-ray surveys over moderate areas may be able to constrain the BAL covering factor (see Krolik & Voit 1998). Studies of SXW QSOs more generally would benefit from a focused X-ray and UV study of a complete sample. The PG SXW QSOs are probably a good starting point, but a larger complete sample would be even better. Intense studies of particularly interesting objects (e.g., 1004+130) are important as well.

Finally, it is crucial to test models that propose to unify the different types of X-ray absorption into a coherent physical picture. Such testing should provide an exciting challenge for even the next generation of X-ray observatories.

ACKNOWLEDGEMENTS

We acknowledge the support of NASA LTSA grant NAG5-8107 and the Alfred P. Sloan Foundation (WNB), NASA grant NAG5-4826 and the Pennsylvania Space Grant Consortium (SCG), the fund for the promotion of research at the Technion (AL), and NASA LTSA grant NAG5-3431 (BJW). We thank C.S. Reynolds for a careful reading and J. Chiang for a helpful discussion.

REFERENCES

Avni, Y., Tananbaum, H. 1986, ApJ, 305, 83
Becker, R.H., et al. 1999, ApJ, in preparation
Boroson, T.A., Green, R.F. 1992, ApJS, 80, 109 (BG92)
Brandt, W.N., Fabian, A.C., Pounds, K.A. 1996, MNRAS, 278, 326
Brandt, W.N., Mathur, S., Reynolds, C.S., Elvis, M. 1997, MNRAS, 292, 407
Brandt, W.N., Laor, A., Wills, B.J. 1999, ApJ, in press (astro-ph/9908016)

Brandt, W.N., Comastri, A., Gallagher, S.C., Sambruna, R.M., Boller, Th., Laor, A. 1999, ApJ, in press (astro-ph/9909284)

Brinkmann, W., Wang, T., Matsuoka, M., Yuan, W. 1999, A&A, 345, 43

Crenshaw, D.M., Kraemer, S.B., Boggess, A., Maran, S.P., Mushotzky, R.F., Wu, C. 1999, ApJ, 516, 750

Elvis, M., Fabbiano, G. 1984, ApJ, 280, 91

Elvis, M. 1992, in Frontiers of X-ray Astronomy, ed. Tanaka, Y., Koyama, K. (Universal Acad. Press, Tokyo), p. 567

Fabian, A.C. 1999, MNRAS, in press (astro-ph/9908064)

Fiore, F., Elvis, M., Mathur, S., Wilkes, B.J., McDowell, J.C. 1993, ApJ, 415, 129

Gallagher, S.C., Brandt, W.N., Sambruna, R.M., Mathur, S., Yamasaki, N. 1999, ApJ, 519, 549

George, I.M., et al. 1997, ApJ, 491, 508

George I.M., Turner T.J., Netzer H., Nandra K., Mushotzky R.F., Yaqoob T. 1998, ApJS, 114, 73

George, I.M., et al. 1999, ApJ, in press (astro-ph/9910218)

Goodrich, R.W. 1997, ApJ, 474, 606

Green, P.J., Mathur, S. 1996, ApJ, 462, 637 (GM96)

Grupe, D., Wills, B.J., Wills, D., Beuermann, K. 1998, A&A, 333, 827

Halpern, J.P. 1984, ApJ, 281, 90

Hamann, F. 1998, ApJ, 500, 798

Iwasawa, K. 1999, MNRAS, 302, 96

Kopko, M., Turnshek, D.A., Espey, B.R. 1994, in Multi-Wavelength Continuum Emission of AGN, ed. Courvoisier, T., Blecha, A. (Kluwer, Dordrecht), p. 450

Korista, K., Ferland, G., Baldwin, J. 1997, ApJ, 487, 555

Krolik, J.H., Voit, G.M. 1998, ApJ, 497, L5

Kuraszkiewicz, J., Wilkes, B.J., Brandt, W.N., Vestergaard, M. 1999, ApJ, submitted

Laor, A., Fiore, F., Elvis, M., Wilkes, B.J., McDowell, J.C. 1994, ApJ, 435, 611

Laor, A., Fiore, F., Elvis, M., Wilkes, B.J., McDowell, J.C. 1997, ApJ, 477, 93

Leighly, K.M., Kay, L.E., Wills, B.J., Wills, D., Grupe, D. 1997, ApJ, 489, L25

Mathur, S., Wilkes, B.J., Elvis, M., Fiore, F. 1994, ApJ, 434, 493

Mathur, S., Elvis, M., Singh, K.P. 1995, ApJ, 455, L9

Mathur, S., Wilkes, B.J., Elvis, M. 1998, ApJ, 503, L23

Murray, N., Chiang, J., Grossman, S.A., Voit, G.M. 1995, ApJ, 451, 498

Pan, H.C., Stewart, G.C., Pounds, K.A. 1990, MNRAS, 242, 177

Reeves, J.N., Turner, M.J.L., Ohashi, T., Kii, T. 1997, MNRAS, 292, 468

Reynolds, C.S. 1997, MNRAS, 286, 513

Siebert, J., Komossa, S., Brinkmann, W. 1999, A&A, in press (astro-ph/9909323)

Turner, T.J. 1999, ApJ, 511, 142

Turnshek, D.A., Monier, E.M., Sirola, C.J., Espey, B.R. 1997, ApJ, 476, 40

Wang, T.G., Brinkmann, W., Wamsteker, W., Yuan, W., Wang, J.X. 1999, MNRAS, 307, 821

Weymann, R.J., Morris, S.L., Foltz, C.B., Hewett, P.C. 1991, ApJ, 373, 23

Weymann, R.J. 1997, in Mass Ejection from AGN, ed. Arav, N., Shlosman, I., Weymann, R.J. (ASP Press: San Francisco), p. 3

Wills, B.J., Brandt, W.N., Laor, A. 1999, ApJ, 520, L91

Yuan, W., Brinkmann, W., Siebert, J., Voges, W. 1998, A&A, 330, 108