Emission Lines in Active Galaxies: New Methods and Techniques
ASP Conference Series, Vol. 113, 1997
B.M. Peterson, F.-Z. Cheng, and A.S. Wilson (eds.)

Associated Absorption at Low and High Redshift

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Abstract. Combining information on absorbing material in AGN from X-ray and the UV creates a powerful investigative tool. Here we give examples from both low and high redshift.

1. Introduction

At low redshift, we have found that the ionized ('warm') X-ray absorbers and the associated UV absorbers in two radio-loud quasars were due to the same material: an X-ray quiet quasar 3C 351 (Mathur et al. 1994) and a red quasar 3C 212 (Elvis et al. 1994, Mathur 1994). In both cases, the absorber is situated outside the broad emission-line region (BELR), is outflowing, and is highly ionized. This delineates a new nuclear component in lobe-dominated, radio-loud quasars. Could the same component explain all the X-ray and UV absorption in AGN seen over the past 20 years and more (Anderson 1974, Ulrich 1988)?

We have recently tested this generalization using the best studied of all AGN, NGC 5548. We applied the same photoionization modeling method (Mathur et al. 1994) to the X-ray and UV absorbers in NGC 5548 to determine whether consistent values for the abundances of all the observed ions could be obtained. In NGC 5548, the model must meet two extra requirements: it must not lead to a density for the absorber in conflict with its recombination time, and the distance of the absorber from the continuum source must not conflict with the well-determined BELR size.

At high redshifts, X-ray absorption and rest-frame UV absorption have been found together in a number of radio-loud quasars. The low-energy X-ray cut-offs in these objects are likely to be due to their environment. The absorption seen in the high-z quasars may be similar to the low-z 'X/UV' absorption, but on a larger scale.

2. Testing the X/UV Models with NGC 5548

ASCA observations confirm the presence of an ionized absorber in NGC 5548 with equivalent $N(\mathrm{H}) = 3.8 \times 10^{21}\,\mathrm{cm}^{-2}$ (Fabian et al. 1994a), and resolving the O VII and O VIII absorption edges. An Fe-K edge is not detected ($\tau_{\mathrm{Fe-K}} \leq 0.1$). *HST* finds blueshifted UV absorption lines (Korista et al. 1995). The C IV and

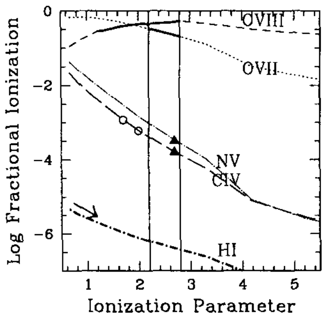

Figure 1. Ionization fractions of O VII, O VIII, C IV, N V, and H I as a function of U. The thick lines mark the observed ranges for O VII and O VIII (*ASCA*). Triangle: *HST* values for C IV and N V; o: *IUE* range. The *HST* range for H I is large, represented by the thick curve. Arrow: *HUT* upper limit. The vertical lines define the best fit model parameter: $2.2 < U < 2.8$.

N V doublets, and an associated Lyα absorption line ($N(\text{H I}) \geq 4 \times 10^{13}\,\text{cm}^{-2}$) are all clearly seen in the mean FOS spectrum.

We searched (using CLOUDY, Ferland 1991) for a photoionized absorber satisfying both X-ray and UV constraints. Figure 1 shows the ionization fractions of O VII and O VIII as a function of ionization parameter U. We used the de-reddened continuum for NGC 5548 and assumed solar abundances (Grevesse & Andres 1989) and density $n = 10^7$ atoms cm^{-3}. The *ASCA* constraints on the fractional ionization of O VII and O VIII (Fig. 1, thick lines) allow only a narrow range of U, $2.2 < U < 2.8$.

In the mean *HST* spectrum, the C IV doublet ratio is 3.8 ± 0.2, putting them off the linear portion of the curve of growth. A consistent solution for all three ions, C IV, N V, and H I is obtained for $b = 40\,\text{km}\,\text{s}^{-1}$, with only a small tolerance for both UV and X-ray constraints to be met (see Mathur et al. 1995 for the details of the model). The matching of the five ion abundances leads us to conclude that the UV and X-ray absorbers in NGC 5548 are one and the same.

An additional test of the model is now available. The *HST* Lyα H I column density is highly uncertain, $13 < \log N(\text{H I}) < 18$, while the model values are tightly constrained, from 15.2 to 15.4. Mathur et al. (1995) noted that a Lyman-edge absorption would be observed if $\log N(\text{H I}) > 16.3$, and would be detectable by *HUT*. In the event *HUT* did not find a Lyman edge (Kriss et al. 1996), implying $\log N(\text{H I}) \lesssim 16.3$, close to our best fit value. This strengthens our X/UV model. O VI absorption would provide another strong test. Unfortunately the *HUT* spectrum seems to have low S/N in O VI, although the O VI absorption doublets may be present.

Our model is also consistent with the *ASCA* limit on an Fe-K X-ray absorption edge of $\tau < 0.1$, implying $N(\text{Fe XVII}) < 2 \times 10^{18}\,\text{cm}^{-2}$ (for solar abundance). For our best fit model, the dominant stage of iron is Fe XVII. (This is common. Fe XVII dominates over a wider range of U than other ionization

https://doi.org/10.1017/S0252921100040161 Published online by Cambridge University Press

states since it is neon-like and so more stable than other iron ions.) We find $\log f(\mathrm{Fe\,XVII}) = -0.77$, implying $N(\mathrm{Fe\,XVII}) = 3 \times 10^{16}\,\mathrm{cm}^{-2}$, far below the *ASCA* limit.

The absence of an Fe-K absorption edge affects another model. The warm gas above and below the torus that electron-scatters and polarizes light from the BELR into our line of sight in many Seyfert 2 galaxies is a natural candidate for the ionized X-ray absorbers (Krolik & Kriss 1996). In unified schemes, this gas will be seen pole-on in Seyfert 1 galaxies and will cause absorption. Krolik & Kriss (1996) predict an Fe-K or an Fe-L edge of optical depth $\tau \geq 0.1$. The absence of these features in the NGC 5548 *ASCA* spectrum pushes these models to higher U and so lower n_e and larger size. Our X/UV absorber modeling finds smaller column density material at a lower ionization state, and so is due to some other nuclear component.

Netzer (1996) has modeled X-ray absorbers in a similar way to Mathur et al. (1995) but predicts that the UV lines will show $N(\mathrm{N\,V}) > N(\mathrm{C\,IV})$, in contradiction to the observations of NGC 5548, and concludes that two separate absorbers are needed in NGC 5548. However, Netzer uses a continuum with very steep EUV slope. The observed continuum of NGC 5548 instead gives $N(\mathrm{N\,V}) < N(\mathrm{C\,IV})$ (Mathur et al. 1995), as observed. This illustrates the danger of comparing results using differing assumptions.

Our model, together with the reverberation-mapping variability constraints, leads us to understand the physical properties of the absorber. The absorber is highly ionized, has high column density, low density, and is situated outside the C IV-emitting region. The gas is outflowing with a mean velocity of $1200 \pm 200\,\mathrm{km\,s^{-1}}$ (relative to the host, Heckman 1978), and has a corresponding kinetic luminosity of $\sim 10^{43}\,\mathrm{ergs\,s^{-1}}$. A scenario in which the absorbing material comes off a disk, and is accelerated by the radiation pressure of the continuum source may explain the observed properties of the absorber.

We can now generalize our unification of UV and X-ray absorbing outflows from the lobe dominated radio-loud quasars to include radio-quiet Seyfert galaxies. This may also provide a link to the radio-quiet BALQSOs, which show unexpectedly strong X-ray absorption (Mathur, Elvis, & Singh 1996, Green & Mathur 1996). This analogy suggests that the X-ray/UV absorbers in radio-quiet AGN may be viewed close to edge-on, which would be a valuable known parameter if it can be independently supported.

3. Absorption in High-Redshift Quasars

A few *ROSAT* PSPC spectra of high-redshift ($z \approx 3$) quasars showed strong low-energy cut-offs, suggesting strong obscuration (Elvis et al. 1994). A search of the whole PSPC pointed archive (Fiore et al. 1996) has now shown that only radio-loud quasars have X-ray colors suggesting cut-offs; so *low-energy X-ray cut-offs are associated with the quasars*, and not with intervening systems (since those would affect radio-quiet and radio-loud equally). Moreover, among radio-loud quasars those at high redshift are more cut-off than those at low z; so *the X-ray cut-offs show evolution with cosmic epoch.*

Investigating the optical and radio properties of the 11 quasars with *ROSAT* cut-offs (Elvis et al. 1996), we find that *all* have associated absorption lines in their optical/ultraviolet spectra and/or show reddening associated with the quasar. We conclude that *absorption is highly likely to be the cause of the X-ray cut-offs,* too. The implied X-ray column densities are a few$\times 10^{22}$ cm^{-2}.

Also, the higher-redshift quasars are Gigahertz-peaked spectrum source candidates suggesting that the absorbing material is extended on the scale of the radio sources (i.e., pc – kpc).

There are several trends within the sample: going from low to high redshift and luminosity we find a related change from low to high ionization, and from low to high compactness (as indicated by radio size and cut-off frequency). Interestingly, the ionization parameter and column densities are similar to those expected from a large 'cooling flow' ionized by a quasar. Even these pressures are insufficient to thermally confine the radio sources, but ram pressure can slow down their expansion. The suggestive picture that emerges is of radio sources that are both young and frustrated (Fanti 1990) by a high pressure surrounding medium.

Acknowledgments. BJW gratefully acknowledges the financial support of NASA contract NAS8-39073 (ASC) and SM of NASA grant NAGW-4490 (LTSA), and ME of NASA grant NAG5-1356 (*ROSAT*).

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