A Far-Ultraviolet Spectroscopic Survey of Low-Redshift AGN

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Abstract. Using the Far Ultraviolet Spectroscopic Explorer (FUSE) we have obtained 87 spectra of 57 low-redshift ($z < 0.15$) active galactic nuclei (AGN). This sample comprises 53 Type 1 AGN and 4 Type 2. All the Type 1 objects show broad [O\textsc{vi}] emission; two of the Type 2s show narrow [O\textsc{vi}] emission. In addition to [O\textsc{vi}], we also identify emission lines due to [C\textsc{iii}]\,$\lambda\lambda977, 991$, [S\textsc{iv}]$\lambda\lambda1062, 1072$, and [He\textsc{ii}]$\lambda1085$ in many of the Type-1 AGN. Of the Type 1 objects, 30 show intrinsic absorption by the [O\textsc{vi}]$\lambda\lambda1032, 1038$ doublet. Most of these intrinsic absorption systems show multiple components with intrinsic widths of 100 km s$^{-1}$ spread over a blue-shifted velocity range of less than 1000 km s$^{-1}$. Galaxies in our sample with existing X-ray or longer wavelength UV observations also show [C\textsc{iv}] absorption and evidence of a soft X-ray warm absorber. In some cases, a UV absorption component has physical properties similar to the X-ray absorbing gas, but in others there is no clear physical correspondence between the UV and X-ray absorbing components. Models in which a thermally driven wind evaporates material from the obscuring torus naturally produce such inhomogeneous flows.

1. Introduction

Roughly 50% of all Seyfert galaxies show UV absorption lines, most commonly seen in [C\textsc{iv}] and [Ly\alpha] (Crenshaw et al. 1999). X-ray “warm absorbers” are equally common in Seyferts (Reynolds 1997; George et al. 1998). All instances of X-ray absorption also exhibit UV absorption (Crenshaw et al. 1999). While Mathur et al. (1994) and Mathur, Wilkes, & Elvis (1995) have suggested that the same gas gives rise to both the X-ray and UV absorption, the spectral complexity of the UV and X-ray absorbers indicates that a wide range of physical conditions are present. Multiple kinematic components with differing physical conditions are seen in both the UV (Crenshaw et al. 1999; Kriss et al. 2000b) and in the X-ray (Reynolds 1997; Kriss et al. 1996; Kaspi et al. 2001).

The short wavelength response (912–1187 Å) of the Far Ultraviolet Spectroscopic Explorer (FUSE) (Moos et al. 2000) enables us to make high-resolution spectral measurements ($R \sim 20,000$) of the high-ionization ion [O\textsc{vi}] and the high-order Lyman lines of neutral hydrogen. The [O\textsc{vi}] doublet is a crucial link for establishing a connection between the higher ionization absorption edges seen in the X-ray and the lower ionization absorption lines seen in earlier UV observations. The high-order Lyman lines provide a better constraint on the total neutral hydrogen column density than [Ly\alpha] alone. Lower ionization species such as [C\textsc{iii}] and [N\textsc{iii}] also have strong resonance lines in the FUSE band, and these often are useful for setting constraints on the ionization level of any detected absorption. The Lyman and Werner bands of molecular hydrogen also fall in the FUSE band, and we have searched for intrinsic H$_2$ absorption that may be associated with the obscuring torus.
We have been conducting a survey of the \( \sim 100 \) brightest AGN using FUSE. As of November 1, 2002, we have observed a total of 87; of these, 57 have \( z < 0.15 \), so that the O\textsc{vi} doublet is visible in the FUSE band.

2. Survey Results

Over 50\% (30 of 53) of the low-redshift Type 1 AGN observed using FUSE show detectable O\textsc{vi} absorption, comparable to those Seyferts that show longer-wavelength UV (Crenshaw et al. 1999) or X-ray (Reynolds 1997; George et al. 1998) absorption. None show H\textsc{2} absorption. We see three basic morphologies for O\textsc{vi} absorption lines: (1) **Blend:** multiple O\textsc{vi} absorption components that are blended together. 10 of 30 objects fall in this class, and the spectrum of Mrk 509 is typical (Kriss et al. 2000). (2) **Single:** 13 of 30 objects exhibit single, narrow, isolated O\textsc{vi} absorption lines, as illustrated by the spectrum of Ton S180 (Turner et al. 2001). (3) **Smooth:** The 7 objects here are an extreme expression of the “blend” class, where the O\textsc{vi} absorption is so broad and blended that individual O\textsc{vi} components cannot be identified. NGC 4151 typifies this class (Kriss et al. 1992). Individual O\textsc{vi} absorption components have FWHM of 50–750 km s\(^{-1}\), with most objects having FWHM \(< 100\) km s\(^{-1}\). The multiple components that are typically present are almost always blue shifted, and they span a velocity range of 200–4000 km s\(^{-1}\); half the objects span a range of \(< 1000\) km s\(^{-1}\).

3. Discussion

The multiple kinematic components frequently seen in the UV absorption spectra of AGN clearly show that the absorbing medium is complex, with separate UV and X-ray dominant zones. In some cases, the UV absorption component corresponding to the X-ray warm absorber can be clearly identified (e.g., Mrk 509) (Kriss et al. 2000). In others, however, no UV absorption component shows physical conditions characteristic of those seen in the X-ray absorber (NGC 3516, NGC 5548) (Kriss et al. 1996; Brotherton et al. 2002). One potential geometry for this complex absorbing structure is high-density, low-column UV-absorbing clouds embedded in a low-density, high-ionization medium that dominates the X-ray absorption. This is possibly a wind driven off the obscuring torus (Krill & Kriss 1995, 2001). At the critical ionization parameter for evaporation, there is a broad range of temperatures that can coexist in equilibrium at nearly constant pressure: for this reason, the flow is expected to be strongly inhomogeneous. What would this look like in reality? As a nearby analogy, consider the HST images of the pillars of gas in the Eagle Nebula, M16. These show the wealth of detailed structure in gas evaporated from a molecular cloud by the UV radiation of nearby newly formed stars (Hester et al. 1996). Figure 1 shows what this might look like in an AGN—a dense molecular torus surrounded by blobs, wisps, and filaments of gas at various densities. It is plausible that the multiple UV absorption lines seen in AGN with warm absorbers are caused by high-density blobs of gas embedded in a hotter, more tenuous, surrounding medium, which is itself responsible for the X-ray absorption. Higher density blobs would have lower ionization parameters, and their small size would account for the low overall column densities.

At sight lines close to the surface of the obscuring torus, one might expect to see some absorption due to molecular hydrogen. Given the dominance of Type 1 AGN in our observations so far, the lack of any intrinsic H\textsc{2} absorption is not too surprising since our sight lines are probably far above the obscuring torus. NGC 4151 and NGC 3516 are examples where the inclination may be more favorable since these objects have shown optically thick Lyman limits in the past (Kriss et al. 1992, 1996), but our FUSE observations do not show such high levels of neutral hydrogen. Molecular hydrogen will not survive long in an environment with a strong UV flux, and this probably accounts for the lack of H\textsc{2} absorption.
In summary, we find that O\emissionline{vi} absorption is common in low-redshift (z < 0.15) AGN. 30 of 53 Type 1 AGN with z < 0.15 observed using FUSE show multiple, blended O\emissionline{vi} absorption lines with typical widths of \( \sim 100 \) km s\(^{-1}\) that are blueshifted over a velocity range of \( \sim 1000 \) km s\(^{-1}\). Those galaxies in our sample with existing X-ray or longer wavelength UV observations also show C\emissionline{iv} absorption and evidence of a soft X-ray warm absorber. In some cases, a UV absorption component has physical properties similar to the X-ray absorbing gas, but in others there is no clear physical correspondence between the UV and X-ray absorbing components.

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