OUTFLOWS VS. CLOUDS IN AGN
INTRINSIC ABSORBERS

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Abstract.
We discuss the crucial role of a dynamical picture in the analysis of AGN intrinsic absorbers data. High quality FUSE data of Mrk 279 are used to demonstrate that the line of sight covering fraction is a strong function of velocity. In Mrk 279, as well as in most cases where the data is of high enough quality, the shape of the absorption troughs is mainly determined by the velocity-dependent covering fraction. We argue that the traditional “cloud” picture of AGN outflows is hard pressed to account for the velocity-dependent covering fraction, as well as for the highly super-thermal width of the troughs and the detached trough phenomenon. A disk outflow picture naturally explains these features and furthermore, is using the simplest reservoir for the outflowing material: The accretion disk around the black hole. Accounting for velocity dependent covering can drastically increase the inferred ionic column density of the analyzed trough, an increase which is amplified in the total column density and ionization parameter solution for the AGN outflow trough.

1. Introduction
AGN outflows are evident by resonance line absorption troughs, which are blueshifted with respect to the systemic redshift of their emission counterparts. In Seyfert galaxies, velocities of several hundred km s$^{-1}$ (Crenshaw et al. 1999; Kriss et al. 2000) are observed in both UV resonance lines (e.g., C$\text{IV}$ $\lambda\lambda$1548.20,1550.77, N$\text{V}$ $\lambda\lambda$1238.82,1242.80, O$\text{VI}$ $\lambda\lambda$1031.93,1037.62 and Ly$\alpha$), as well as in X-ray resonance lines (Kaastra et al. 2000; Kaspi et al. 2000). Similar outflows (often with significantly higher velocities) are seen in quasars (Weymann et al. 1991; Korista, Voit, Morris, & Weymann 1993; Arav et al. 2001a). Reliable measurement of the absorption column densities in the troughs are crucial for determining the ionization equilibrium and abundances of the outflows, and the relationship between the UV and the ionized X-ray absorbers.

In the last few years our group (Arav 1997; Arav et al. 1999a; Arav et al. 1999b; de Kool et al. 2001; Arav et al. 2001a) and others (Barlow 1997, Telfer et al. 1998, Churchill et al. 1999, Ganguly et al. 1999) have shown that in quasar outflows most lines are saturated even when not black. We have also shown that in many cases the shapes of the troughs are almost entirely due to changes in the line of sight covering as a function of velocity, rather than to differences in optical depth (Arav et al. 1999b; de Kool et al. 2001; Arav et al. 2001b). Gabel et al. (2003) show the same effect in the outflow troughs of NGC 3783. As a consequence, the column densities inferred from the depths of the troughs are only lower limits.
Figure 1. In the bottom panel we show the $C(v)$ solution for the O\textsc{vi} troughs in Mrk 279. The straight lines below the trough are our attempt to attach a single covering factor to each of the troughs (covering fraction values are read from the right axis). It is clear that the shape of trough A is dominated by $C(v)$. The top panel shows three solutions for the optical depth: Apparent $\tau$, which is derived from the residual intensity of the blue doublet component assuming full coverage (i.e., the ISM and IGM case); a solution (dashed line) assuming a constant covering (shown at the bottom of troughs A and B); and the real $\tau$ using the $C(v)$ curve shown on the bottom panel.

2. The importance of $C(v)$: O\textsc{vi} troughs in Mrk 279

Mrk 279 was observed by FUSE for a combined 92 ksec on December 1999 and January 2000. The source was in a high state, rivaling the highest UV flux state of any Seyfert outflow target. Several factors combined to make these data arguably the highest quality FUSE observation of an AGN outflow: Non-blending of the O\textsc{vi} trough, the length of exposure at a very high flux level, very low Galactic column along the sight-line, and insignificant narrow emission line. In figure 1 we show the O\textsc{vi} doublet data, covering fraction solution and three different extractions of the optical depth. We find that the shape of trough A is almost exclusively determined by $C(v)$. This feature manifests itself in the $\tau(v)$ solution. The column density extracted from the real solution is four times larger than the one we obtain from a simple inversion of the blue doublet-component data. Moreover the real column density is three times larger than the one we extract using a constant covering fraction for this outflow component. We also observe that the shape of $\tau(v)$ is very different if we assume a constant covering fraction instead of the actual $\tau(v)$. Underestimating ionic column densities by a factor of a few can translate to a much larger discrepancy in the solution for the ionization parameter ($U$) and total Hydrogen column density ($N_H$) of the outflow component. As shown in Arav (2001b) a five fold change in inferred ionic column density can result in a 10 times higher $U$ and a 100 times higher $N_H$. 
3. Clouds vs. Dynamical Disk Outflows

The “cloud” picture of absorption features associated with AGN outflows was developed from the traditional ISM absorber model: A concentration of gas with thermal velocity distribution. Since the width of the outflow absorption troughs were found to be 10–1000 times the expected thermal width, a “turbulent” velocity broadening was invoked. We point out that this “turbulent” broadening is problematic since it suggests internal motions with large Mach numbers which should result in shocks and the destruction of the absorption ionic species. In addition, once it was realized that many of the troughs are saturated but not black, a partial geometrical covering of the emission source was invoked, as illustrated in the top part of figure 2. The main problem with this picture is its inability to explain the velocity dependence of the covering fraction. A cloud sitting in front of an emission source should have a velocity independent covering fraction. Furthermore, the cloud picture is hard pressed to explain the observed detached troughs where the absorption starts from non-zero velocity.

We advocate the dynamical outflow scenario shown on the bottom of figure 2. As we show below, this model naturally explains the strong velocity dependence of the covering fraction, the detached trough phenomenon and the highly super-thermal width of the trough. All these attributes are connected to invoking the simplest reservoir for the outflowing material: The accretion disk around the black hole. This scenario fits well with the global AGN atmosphere model of Elvis (2000).
In figure 3 we illustrate how an accelerating outflow can produce an absorption trough whose shape is totally determined by $C(v)$. We make two plausible assumptions: 1) The flow is at a small angle to the line of sight (i.e. the flow is not purely radial). 2) The flow is accelerating as it crosses the cylinder of sight, which contains all the lines of sights from the continuum source to the observer. For simplicity we also assume a 2-D geometry where the velocity is constant perpendicular to the velocity vector. A covering fraction dominated absorption trough is produced for a fully opaque flow in a given resonance line (e.g., Lyα). Prior to the flow reaching point a it does not intersect the cylinder of sight, therefore we do not see any absorption at $v < v_a$. This scenario gives a natural explanation to the widely observed phenomenon of detached troughs. As the flow continues to accelerate, it gradually covers a larger fraction of the cylinder of sight. For example, at point M the flow covers roughly one third of the cylinder of sight with material moving at $v_M$. Even if the resonance line opacity is very large at $v_M$ the absorption trough only dips to 1/3 below the continuum flux. $C(v)$ gradually increases until $v_b$, at which point a maximum coverage has been reached. The maximum coverage can be smaller than one in cases where there is an additional extended emission source (e.g., the broad emission line region). At $v_c$ the flow reaches the last point of maximum coverage and thereafter the coverage decreases gradually. **A fully opaque outflow produces an absorption trough purely from velocity dependent covering factor.**

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