X-RAY EVIDENCE FOR MULTIPLE ABSORBING STRUCTURES IN SEYFERT NUCLEI

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ABSTRACT

We have discovered a correlation between the X-ray absorbing column densities within Seyfert galaxies and the relative alignment between the central engines and their host galactic disks. This correlation carries several implications for Seyfert unification models. (1) In addition to small-scale circumnuclear absorbers, there are absorbing systems associated with the host galactic plane that are capable of obscuring the broad line region emission. (2) The misalignment between the central engine axis and that of the host galaxy arises on intermediate scales between these absorbers. (3) The small-scale absorbers have systematically higher column densities and may be universally Compton-thick.

Key words: galaxies: active, galaxies: Seyferts.

1. THE DUAL-ABSORBER MODEL

Seyfert galaxies are generally subdivided into two spectroscopic classifications: type 1's have extremely broad permitted emission lines, less broad forbidden lines, and strong non-thermal continua, while type 2 Seyferts exhibit only the narrow forbidden lines. Unification models assert that all Seyferts are intrinsically similar but have different appearances in different directions. The canonical model invokes a parsec-scale torus that hides the innermost, energetic regions from some lines of sight. Observers with an unimpeded view of the central region see a Seyfert 1 and those with line-of-sight obscuration see a type 2. To hide the central continuum source and the broad line region (BLR), the screen must have $N_{\rm H} > 10^{21}$ cm^{-2} to attenuate soft X-rays and be dusty to effectively staunch IR/optical/UV continuum.

The distribution of host galaxy inclinations (i) amongst Seyfert types indicates that a model consisting of a single torus is incomplete. If such a torus is the universal source of obscuration, then one of two scenarios are expected: either it is aligned with the host galactic plane, causing Seyfert 1's to be found in face-on hosts and Seyfert 2's in edge-on galaxies, or it is misaligned with the galaxy, in which case there would be no correlation between Seyfert types and i. Neither is the case. Several studies have instead established that type 2 Seyferts are found with any i while type 1's are not found in edge-on galaxies (e.g., Maiolino & Rieke, 1995). The distribution of Seyfert 2's suggests an obscuring medium that is misaligned with the host galaxy, but the dearth of edge-on Seyfert 1 hosts indicates that there is always sufficient material in the galactic plane to hide the broad line region.

The distribution of i values can be explained with the introduction of a second absorber (Fig. 1). In this model, the small-scale "nuclear absorber" or NA (presumably the torus although other models are possible, e.g., Elvis, 2000) is randomly oriented with respect to the host galaxy; the second absorber lies at larger scales and is aligned with the galactic plane, hence the "galactic absorber" or GA. Such a model has been proposed by numerous authors (e.g., McLeod & Rieke, 1995; Maiolino & Rieke, 1995; Kinney et al., 2000). Several lines of evidence suggest an absorbing medium on 100 pc scales, including: missing edge-on Seyferts of any type from optical, UV and soft X-ray selected surveys suggesting a large-scale absorber that covers much of the narrow line region (NLR; McLeod & Rieke, 1995); IR reprocessing by dust (Granato et al., 1997); and direct imaging of dust lanes on few-hundred pc scales (Malkan et al., 1998; Pogge & Martini, 2002). The relative alignment of the absorbers is an important parameter of this model. When the absorbers are misaligned, the shadow of the NA covers less of the GA and the combined covering fraction of the absorbers increases. Seyfert 1's should tend to be in well-aligned systems and Seyfert 2's attenuated by the GA and not the NA should prefer poorly-aligned ones.

The two absorbers should differ in their mean column densities. A significant fraction of Seyfert 2 galaxies exhibit Compton thick absorption ($N_{\rm H} > 10^{24}$ cm^{-2}). To provide marginally Compton-thick absorption over a covering fraction f requires $10^9 M_\odot f (r_{100\ {\rm pc}})^2$; a reasonable quantity for the NA but an excessive amount for the GA. Dynamical mass measurements of some nearby

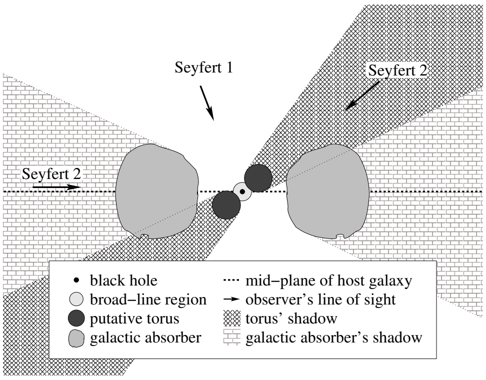

Figure 1. The dual absorber framework. One absorber lies near the nucleus and may be identified with the putative torus, while the other is on much larger scales and is aligned with the host galactic plane. A type 2 Seyfert is observed if either lies along the line of sight to the BLR.

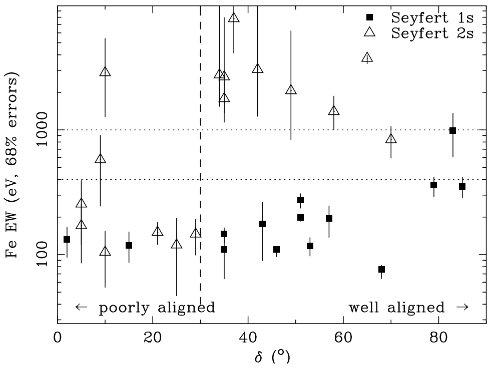

Figure 2. The distribution of the alignment parameter δ amongst the Seyfert classes. Heavily obscured sources are defined as those with Fe EW $>$ 1 keV and modestly obscured sources have EW $<$ 400 eV. The preferences of low-EW Seyfert 2's for low δ values and Seyfert 1's for high values is predicted by the dual-absorber model.

Seyferts can rule out any appreciable Compton-thick covering fraction at $\sim$100 pc scales (e.g., Maiolino et al., 1998). Thus, most if not all Compton thick Seyferts are attenuated by their NA, and typical lines of sight through the GA will have much lower column densities.

To test the dual-absorber model we combine measurements of the line of sight attenuation with geometric constraints on the internal alignment. We divide the Seyferts into three classes: unobscured (optically-defined Seyfert 1's), modestly obscured (Compton-thin Seyfert 2's), and heavily obscured (Compton-thick or nearly so), with the latter two differentiated by X-ray spectroscopy. We assume that these respectively correspond to lines of sight that are unobstructed, intercept only the GA, and intercept the NA. Rather than model $N_{\rm H}$ values, we rely upon the equivalent width (EW) of the Fe Kα line to avoid an ambiguity of models fitted to low S/N data. When the continuum around 6 keV is repressed (if $N_{\rm H} > 10^{23.5}$ cm^{-2}) the EW of the 6.4 keV Fe line skyrockets, providing a robust indicator of heavy obscuration. As an alignment measure, we use published values of δ, the angle between the radio jet and the host galaxy major axis (Kinney et al., 2000): misaligned systems have low values and perfectly aligned ones have $\delta = 90°$.

2. RESULTS FROM THE ASCA SAMPLE

We analyzed all 31 Seyferts with ASCA detections and published δ values, classifying each as heavily, modestly, or not obscured (Fig. 2). We find that (1) modestly obscured Seyfert 2's all have $\delta < 30°$; (2) unobscured systems prefer moderate-to-high δ values ($\delta > 30°$); (3) heavily obscured systems have no strong correlation with δ; and (4) when taken together, systems with modest or no obscuration are uncorrelated with δ. These distributions all agree with the dual-absorber model (points 3 & 4 *should* be independent of δ because they depend only upon whether our line of sight intercepts the NA). A KS test shows the δ distributions of unobscured and modestly obscured Seyferts to differ with 99.8% confidence. The strength of the correlation of modestly obscured sources and δ is surprising; we would expect some misaligned systems to have low δ values due to projection effects.

These observations allow us to make some inferences about Seyfert structures. If the misalignment must be severe before we see GA-only attenuation, then the GA must have a much smaller covering fraction than the NA (contrary to Fig. 1). The fact that we have any correlations with δ means that the radio jet is a reliable indicator of the direction of the NA. Thus, the misalignment between the central engine and the host galaxy must take place on intermediate scales. The NA seldom if ever has a column density below 10^{23} cm^{-2}. Otherwise some fraction of modestly absorbed systems would be observed through the NA and hence shouldn't correlate with δ. The strength of the correlation argues against this but needs to be tested with a larger, more complete sample.

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