Compton-Thick AGN: The Hidden Side of Supermassive Black Hole Accretion

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ABSTRACT

Most of the AGN in the local Universe are obscured. Studies of the X-ray background suggest that there may be a significant population of heavily obscured, Compton-thick AGN, but the exact number is unknown. The relative number of Compton-thick AGN can be estimated by studying samples of obscured AGN that are selected based on emission that is unaffected by the column density of the obscuring medium. We report on 3 such samples here and demonstrate that most of these objects show signatures of potentially Compton-thick obscuration in their observed X-ray emission. This is true for both local, moderate luminosity AGN (Seyferts) and more distant, higher luminosity AGN (quasars). For the subset of sources with high signal-to-noise, we fit their X-ray spectra using physically motivated models to derive realistic estimates on the line-of-sight and global column densities. We find that more than half of these objects (11/19) have heavy to Compton-thick obscuration.

KEY WORDS: galaxies: active, galaxies: Seyfert, quasars: general, X-rays: general

1. Introduction

Active galactic nuclei (AGN) are powered by accretion onto a supermassive black hole (SMBH). Direct view of the central engine is obscured in ∼75% of AGN in the local Universe (e.g. Comastri 2004, Treister et al. 2004). When the column density of the obscuration in these Type 2 AGN exceeds the inverse of the cross-section for Thompson scattering (N_H > 1.25 × 10^{24} cm^{-2}), the source is considered “Compton-thick.”

Studies of the X-ray background (XRB), the integrated emission of discrete point sources (largely AGN), indicate that a significant fraction of SMBH growth is hidden behind Compton-thick obscuration (e.g., Treister & Urry, 2005). The summed emission of unobscured (Type 1) and moderately obscured AGN under-predicts the peak of the XRB at 30 keV, which has been interpreted as evidence for a Compton-thick population as numerous as their Compton-thin counterparts (Gilli et al. 2007). However, Treister et al. (2009) demonstrated that parameters used to model the XRB are degenerate, and by fixing the local Compton-thick population to the number identified by hard X-ray selection (>10 keV) with INTEGRAL and Swift, the XRB can be adequately modeled with a factor of 4 fewer Compton-thick AGN than previously assumed.

Though the fraction of Compton-thick AGN can not be constrained through modeling the XRB, it seems clear that this population likely represents a significant fraction of growing SMBHs and is currently undersampled. Additionally, hard X-ray selection may not fully reveal the most hidden black holes. Comparison of hard X-ray flux with other tracers of intrinsic AGN power show that even this hard X-ray emission, which is most likely to punch through the obscuring medium, is weaker in Type 2 AGN than Type 1 AGN in the local Universe (LaMassa et al. 2010, Weaver et al. 2010). Recently, NuSTAR, which is sensitive from 3-50 keV, targeted 3 obscured AGN that have bright [OIII] 5007 Å emission, but 2 of these objects are not detected and 1 is marginally detected (Lansbury et al. 2014): though bright at other wavelengths, the hard X-ray emission is heavily suppressed.

2. Finding Hidden Black Holes

Though hard X-ray surveys have been fruitful in selecting AGN samples, it is important to supplement such surveys with objects identified via other mechanisms to obtain the most comprehensive view of SMBH growth. Selecting AGN based on emission that probes the intrinsic AGN power is ideal for a representative sampling (see LaMassa et al. 2010 and Diamond-Stanic et al. 2009 for a review). Such intrinsic AGN flux proxies include emission lines that form in the narrow line region, which is located hundreds of parsecs above and below the cir-
cumnuclear obscuration, and are primarily ionized by the AGN continuum. Often used emission line fluxes include the optical [OIII] 5007 Å (Bassani et al. 1999) and [NeV] 3426 Å (Gilli et al. 2010) lines and the mid-infrared [OIV] 26 μm (Meléndez et al. 2008) and [NeV] 14.32 μm (Goulding & Alexander 2009) lines. Mid-infrared emission from the obscuring medium is another inherent AGN flux proxy, where optical and ultraviolet photons from the accretion disk are absorbed by the circumnuclear dust and re-radiated, making up ~20% of the bolometric luminosity in both obscured and unobscured AGN (Spinoglio & Malkan 1989, Buchanan et al. 2006).

Selecting AGN based on emission that is relatively unaffected by the column density of the obscuring medium then provides a representative sampling of the relative number of Compton-thick AGN to the global population. Following up such samples with X-ray observations reveals the amount of obscuration present. Clues of heavy obscuration include a low observed 2-10 keV X-ray luminosity when compared with the intrinsic AGN luminosity. In heavily obscured to Compton-thick AGN, X-ray emission is suppressed due to the effects of photoelectric absorption and Compton-scattering, which can scatter X-ray photons out of the line-of-sight or to lower energies where they are subsequently absorbed. The ratio of $L_{2-10\text{keV}}$ to the intrinsic AGN luminosity is therefore an order of magnitude or more lower than unabsorbed AGN in heavily obscured systems. Another trademark of potential Compton-thick obscuration is a large Fe Kα equivalent width value: as this emission feature is produced in the reflection spectrum and is measured against a depressed transmitted continuum, an EW exceeding 1 keV is a sign of Compton-thick absorption. In sources with a high signal-to-noise X-ray spectrum, we can use physically motivated models to estimate both the line-of-sight and global column densities ($N_{\text{H,Z}}$ and $N_{\text{H,S}}$, respectively), as well as investigate the geometry of the X-ray reprocessor.

3. How Obscured are Obscured AGN?

We report on the results of X-ray campaigns to study AGN samples selected based on their intrinsic AGN luminosity. Simple absorbed or double absorbed power laws were fitted to X-ray spectra to measure the observed 2-10 keV flux which was then compared to the inherent AGN flux. When an Fe Kα line was present, this feature was fitted with a Gaussian component and the EW was then calculated.

3.1. Local Universe

Seyfert 2 galaxies (Sy2s) are local ($z < 0.15$), moderate luminosity AGN. In LaMassa et al. (2009), we selected a flux-limited [OIII] 5007 Å Sy2 sample from the Sloan Digital Sky Survey (SDSS) and were awarded *Chandra* time to observe 17 out of 20 of these objects. We analyzed a mid-infrared, 12μm IRAS selected sample (Spinoglio & Malkan, 1989) in LaMassa et al. (2011), utilizing archival *Chandra* and/or *XMM-Newton* observations for 28 of the 31 Sy2s; 4 of these objects varied among multiple X-ray observations.

As reported in LaMassa et al. (2011) and shown in Figure 1, a majority of Sy2s had normalized 2-10 keV X-ray fluxes an order of magnitude or more lower than unabsorbed Sy1s, regardless of how the sample was selected or the intrinsic AGN flux proxy used to normalize the observed X-ray flux ([OIII], [OIV] and mid-infrared). The anti-correlation between $F_{2-10\text{keV}}/F_{\text{intrinsic}}$ and the Fe Kα EW (i.e., the low normalized X-ray fluxes were consistent with high EW values) indicates that obscuration is attenuating the X-ray emission, rather than these sources being intrinsically X-ray weak (Figure 2). Additionally, both the normalized X-ray fluxes and Fe Kα EWs show a continuum of values rather than a bi-modal distribution of implied Compton-thick and Compton-thin sub-populations.

3.2. Intermediate Universe

Jia et al. (2013) analyzed the X-ray observations of Type 2 quasars (i.e., luminous AGN where $L_{\text{bolometric}} > 10^{45}$ erg s$^{-1}$) which were also selected from SDSS based on their [OIII] luminosities (Reyes et al. 2008). Of the 887 Type 2 quasars from the Reyes et al. (2008) sample, 71 had *Chandra* and/or *XMM-Newton* archival data. Similar to the results reported in the Sy2 analysis, Jia et al. (2013) found that most Type 2 quasars had X-ray emission suppressed relative to [OIII] emission when compared with unabsorbed Sy1s from the Heckman et al. (2005) sample. The Fe Kα EW was also statistically significantly anti-correlated with $L_{2-10\text{keV}}/L_{\text{[OIII]}}$.

4. Revealing Details of the X-ray Reprocessor with Physically Motivated models

The analysis summarized above demonstrates that a significant fraction of obscured AGN, both locally and beyond and over a range of moderate to high bolometric luminosities, are heavily obscured. However, accurately measuring the column density requires models that correctly treat the physics of photoelectric absorption and Compton scattering. These processes imprint signatures on the observed X-ray spectrum that can be interpreted using physically motivated models that have become available the past several years: the MYTorus model (Murphy & Yaqoob, 2009) and the spherical and toroidal model from Brightman & Nandra (2011). These models self-consistently treat the transmitted, Compton-scattered and fluorescent Fe Kα line emission in the X-ray reprocessor. The MYTorus model also allows a global column density ($N_{\text{H,S}}$) to be measured indepen-
Fig. 1. Distribution of $L_{2-10\text{keV}}$ normalized by (a) $L_{[\text{OIII}]}$, (b) $L_{[\text{OIV}]}$ and (c) $L_{\text{MIR}}$ for the [OIII]-selected (red) and 12 µm-selected (blue: non X-ray variable, cyan: X-ray variable) Sy2 samples. The grey shaded region shows the average values for Sy1s from (a) Heckman et al. (2005), (b) Diamond-Stanic et al. (2009) and (c) Gandhi et al. (2009). Most Sy2s, regardless of sample, have weak observed X-ray emission compared with the unabsorbed AGN population. (Figure from LaMassa et al. 2011.)

In LaMassa et al. (2014), we fitted the X-ray spectra of the [OIII]-selected Sy2 and Type 2 quasars with these self-consistent models. Nineteen objects in total had high enough signal-to-noise for these models (9 Sy2s and 10 QSO2s). The Compton-thick fraction estimated from this modeling is therefore a lower limit for the total sample. Indeed, the remaining 8 Sy2s have signatures of heavy to Compton-thick obscuration based on their normalized X-ray luminosities and/or Fe Kα EWs; about half of the remaining Type 2 quasars have inferred $N_H$ values from Monte-Carlo simulations that are Compton-thick (see Jia et al. 2013 for details).

Though these sources represent the X-ray brightest Sy2s, more than half have estimated column densities that are heavily obscured to Compton-thick (see Table 1). One object, Mrk 0609, has no evidence of X-ray absorption, though its optical classification seems to have shifted from a Sy 1.8 (e.g., Osterbrock 1981) to a Sy2 (Trippe et al. 2010); this may be a changing-look AGN or a naked Sy2 candidate. Four objects have significantly different global from line-of-sight column densities.

With reliable estimates of the obscuring column density, we calculated intrinsic 2-10 keV X-ray luminosities ($L_{X,\text{in}}$). When normalizing this by the [OIII] luminosity, we found that $\log (L_{X,\text{in}}/L_{[\text{OIII}]}) = 1.54 \pm 0.49$ dex, which is essentially identical to the value found for Sy1 galaxies (1.59 ±0.48 dex, Heckman et al. 2005). Thus, the intrinsic AGN luminosity estimated from the [OIII] emission is consistent with that calculated from the intrinsic 2-10 keV luminosity.

References
Fig. 2. Fe Kα EW as a function of the 2-10 keV luminosity normalized by (a) $L_{\text{[OIII]}}$, (b) $L_{\text{[OIV]}}$, and (c) $L_{\text{MIR}}$ for the [OIII]-selected (red triangles) and 12μm-selected (blue diamond: non X-ray variable, cyan diamond: X-ray variable) Sy2s. The significant anti-correlation indicates that the relative X-ray weakness is due to obscuration. A continuum of $L_{2-10\text{keV}}/L_{\text{intrinsic}}$ values and Fe Kα EWs is also apparent, suggesting that AGN do not segregate into distinct Compton-thick and Compton-thin populations. (Figure from LaMassa et al. 2011.)

Table 1. $N_H$ Summary from Physically Motivated Modeling

<table>
<thead>
<tr>
<th>How Obscured?</th>
<th>$N_H$ range cm$^{-2}$</th>
<th>Number of sources$^\dagger$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unabsorbed</td>
<td>$&lt; 10^{21}$</td>
<td>1</td>
</tr>
<tr>
<td>Mild</td>
<td>$10^{21} - 10^{22}$</td>
<td>2</td>
</tr>
<tr>
<td>Moderate</td>
<td>$10^{22} - 10^{23}$</td>
<td>5</td>
</tr>
<tr>
<td>Heavy</td>
<td>$10^{23} - 10^{24}$</td>
<td>6</td>
</tr>
<tr>
<td>Compton-thick</td>
<td>$&gt; 1.25 \times 10^{24}$</td>
<td>5</td>
</tr>
</tbody>
</table>

$^\dagger$19 sources total.

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