Towards A Complete Census of Compton-thick AGN and N_H Distribution in the Local Universe.

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1. ABSTRACT

We present an updated census of Compton-thick AGN (CTAGN) population in the local universe using a volume-limited sample of mid-IR selected AGN complete to D=15Mpc. 20% of the sample has been identified as bona fide CTAGN from current X-ray studies. Further CT candidates are then identified using mid-IR:X-ray and optical [OIII]λ5007:X-ray diagnostics. Based on these analyses, we find that 25-45% of the AGN in our sample are CT. However due to lack of data, we believe that this fraction could also be as high as 70%. Of the three diagnostics used, we find that the mid-IR approach provides the most unbiased method to identify CTAGN as it yields the highest CTAGN fraction within the sample. Finally, we estimate the intrinsic N_H distribution of the AGN population in the local universe. This work provides a well-defined local benchmark for AGN obscuration studies.

2. INTRODUCTION

Compton-thick AGN (CTAGN) are defined by AGN that are obscured by the circumnuclear torus (absorbing material) with a column density greater than the inverse Thomson scattering constant, σ_T, i.e. $N_H > 10^{24}$ cm^{-2}. The X-ray spectra of these sources show a broad bump peaking at around 20-30 keV with a steep decline below and above this energy due to photoelectric absorption and Compton-down scattering respectively. In the 2-10 keV band, this is approximated by a flat power law ($\Gamma \lesssim 1$). At such high column density, the direct X-ray emission from the AGN below 10 keV is totally blocked by the obscuring material, and the observed X-ray flux arising from the photons scattered or reflected at the back-side of the torus is just a few percent of the total energy output. Their X-ray spectra also show a strong Iron Kα fluorescence line at ~6.4keV with EW > 1 keV.

Many studies have shown that CTAGN provide important contribution to the cosmic X-ray background spectrum (10-25% at 30keV; e.g. Gilli et al. 07). Since they are very weak in X-rays, this indicates that their population should be fairly numerous. In fact according to Matt et al. 00, of the three AGN that we know within D < 4 Mpc, two are CT. This corresponds to a fraction of 75% of the AGN population! However, to date only 20 bona fide CTAGN are identified at D < 200 Mpc (Goulding et al. 12), which accounts for <<1% of the expected AGN population within this volume. This tells us that we don't have a complete census of their population beyond 4 Mpc. Therefore, a representative AGN sample is needed in order to constrain their population, starting at the local universe.

3. IDENTIFYING COMPTON-THICK CANDIDATES

Mid-IR AGN sample within D < 15 Mpc from A. D. Goulding & D. M. Alexander (2009) was used as the parent sample for this work. Three other known AGN within D < 15 Mpc were then added to complete the sample.

CTAGN can be identified via several methods:

1. X-ray
   - N_H measurements, strong Iron Kα line (EW > 1 keV) and flat photon index ($\Gamma \lesssim 1$) below 10 keV.
   - Advantages: - Traces the intrinsic continuum directly. - Direct measurement of N_H values.
   - Disadvantage: - Misses heavily CTAGN ($N_H > 10^{25}$ cm^{-2}).

2. Optical
   - $F_{2\text{-}10keV} / F_{[OIII],corr} < 1$ (Bassani et al. 99)
   - Advantage: - Traces ionized gas in the narrow line region which extends beyond the torus.
   - Disadvantage: - Narrow line region can be obscured by the host galaxy.

3. Mid-IR
   - $F_{2\text{-}10keV} / F_{12\mu m} < 0.04$
   - Advantage: - Most of the absorbed radiation is re-emitted in Mid-IR by the torus.
   - Diasdvantage: - Contamination by the host galaxy.

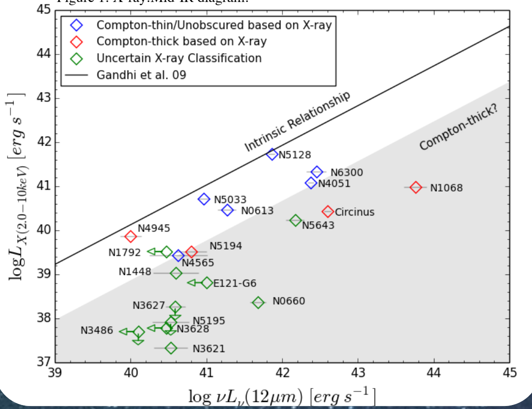
We first looked into literatures for published N_H values for the sources from current X-ray studies. However, only about half of them have high signal-to-noise X-ray spectroscopic data available, which allows accurate N_H measurements to be done.

We then tried to further identify CT candidates within the sample using the mid-IR approach. X-ray fluxes were collected from the literature and archives based on various X-ray observations. X-ray data from high resolution *Chandra* observations were preferred to minimize contamination from other X-ray sources near the nucleus. Mid-IR fluxes at ~12μm were obtained from Asmus et al. (2014) that provides mid-IR data from high-angular resolution observations (≤ 0.4"), minimizing contamination from the host galaxy. For those with no mid-IR high-angular resolution observations, the 12μm emission were estimated from their [NeV]λ14.32μm fluxes (A. Annuar et al. in prep.). The observed 2-10 keV luminosity of the sources were then plotted against their 12μm luminosity, and we defined those that lie >25x below the intrinsic relation by Gandhi et al. (2009) as highly likely to be CT (Rovilos et al. 14).

We also tried to identify CT candidates within the sample using the X-ray:optical diagnostic by Bassani et al. (1999), and the final classification of the sources were made based on all three methods used.

4. X-RAY:MID-IR DIAGRAM

Figure 1: X-ray:Mid-IR diagram.



5. FINAL RESULTS

Table 1: Final Classification.

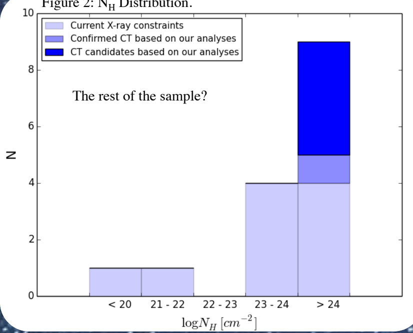
AGN (1)	Optical (2)	MIR (3)	log N_H [cm^{-2}] (X-ray) (4)	Final Classification (5)
Circinus	**CT**	**CT**	**24.6[1]**	**CT**
ESO 121-G6	**?**	**?**	**?**	**?**
NGC 0613	**No**	**No**	**23.6[2]**	**No**
NGC 0660	**CT**	**CT**	**?**	**CT?**
NGC 1068	**CT**	**CT**	**> 25.0[3]**	**CT**
NGC 1448	**?**	**CT**	**?**	**CT?‡**
NGC 1792	**?**	**No**	**?**	**?**
NGC 3486	**CT**	**?**	**?**	**CT?†**
NGC 3621	**No**	**CT**	**?**	**?**
NGC 3627	**CT**	**CT**	**?**	**CT?**
NGC 3628	**No**	**?**	**?**	**?**
NGC 4051	**No**	**No**	**23.3[4]**	**No**
NGC 4565	**No**	**?**	**21.4[5]**	**No**
NGC 4945	**No**	**No**	**24.7[6]**	**CT**
NGC 5033	**No**	**No**	**< 20.9[6]**	**No**
NGC 5128	**No**	**No**	**23.0[7]**	**No**
NGC 5194	**CT**	**CT**	**24.7[8]**	**CT**
NGC 5195	**?**	**CT**	**?**	**?**
NGC 5643	**CT**	**CT**	**?**	**CT***
NGC 6300	**No**	**No**	**23.3[9]**	**No**
%	**35%**	**45%**	**20-25%**	**25-45%**

Notes: Column (1): Name of the sources, (2): Optical diagnostic ('?': lack optical data/X-ray upper limits), (3): Mid-IR diagnostic ('?': those with 12μm upper limits), (4): N_H values from X-ray spectra fittings (N_H values are only given for those with high signal-to-noise X-ray spectroscopic data available, (5): Final classification based on all three diagnostics ('‡': Through private communication with A. D. Goulding, '†': This object has been suggested to be CT based on a flat photon index at 2-10 keV; e.g Cappi et al. 06, '*': This object has been indirectly identified as CT in X-ray based on the presence of strong iron Kα line. However, the N_H value is not well-constrained; e.g. Maiolino et al. 98).

References: (1) Marinucci et al. (2012), (2) Castangia et al. (2013), (3) Matt et al. (2000), (4) Brightman and Nandra (2011), (5) Chiaberge et al. (2006), (6) Diamond-Stanic (2009), (7) Grandi et al. (2003), (8) Fukazawa et al. (2001), (9) Guainazzi (2002).

6. N_H DISTRIBUTION

Figure 2: N_H Distribution.



7. CONCLUSION

In conclusion, the population of CTAGN is very difficult to constrain, even in the nearest universe. So far, we found that 25-45% of our mid-IR selected AGN sample within D < 15 Mpc are CT. This is comparable to what found in the X-ray-selected (~20%; Burlon et al. 11) and optically-selected (~30%; e.g Risaliti et al. 99) AGN sample. However, we can treat this fraction as a lower limit as there are still a lot of the sources in the sample with uncertain classification. If we assume that all the sources with '?' in column (5) of table 1 are CT, this will push up the fraction to as high as 70% of the AGN population! This would agree with what found by Matt et al. (2000) within D < 4 Mpc, and suggest that their population is indeed numerous. In addition, we also found that of the three diagnostics used, the mid-IR approach provides the most unbiased method to identify CTAGN as it yields the highest CTAGN fraction within the sample.

8. REFERENCES

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