Contribution of Compton Thick AGNs to the X-ray Background

Yoshihiro Ueda
(Kyoto University)
I. Introduction

Obscured Growth of SMBHs

- Nearly every present-day galaxy contains a BH in its centre with a mass proportional to the spheroid mass, indicating a tight link between the BH and star formation: *SMBH is a key ingredient of the universe*

- Most AGNs are “obscured” (cannot always be distinguished or recognized in other wavelengths). Hard X-ray observations are the most straightforward approach to detect this population with least selection biases.

- In fact, massive star forming galaxies contain rapidly growing BHs heavily obscured by dust (submilimeter galaxies at z~2, Alexander et al. 2005; ULIRGs at z~0, Imanishi et al. 2006). This is consistent with the “co-evolution” scenario.
Co-evolution of galaxy and super massive black holes in galactic centers

BH mass vs Stellar mass @ z=0

e.g., Marconi & Hunt 03

Star forming history vs accretion history

Marconi+ 04
X-ray Spectra of Heavily Obscured AGNs

- Compton thick AGNs show complex spectra as a function of column density.
- Reflection/scattered component can be detected below 10 keV, but only limited information can be drawn there (e.g., intrinsic luminosity).
- We can detect them at $E > 30$ keV as long as $N_H$ does not exceed $10^{25}$ cm$^{-2}$.

Wilman & Fabian (1999)  
Evidence for Compton thick AGNs

- In the local universe the number density of Compton thick AGNs may be comparable to or even larger than Compton thin AGNs (e.g., Risaliti+1999, Maiolino+ 2003)
  - X-ray follow-up of [OIII] or infrared selected galaxies
- At higher redshifts, little is known about the number density of Compton thick AGNs.
  - There may be a huge number of CT AGNs in star-forming galaxies at z~2 below Chandra flux limit (Daddi+ 2007) as one interpretation from the Chandra stacking analysis.
A big remaining issue: the number density of Compton thick AGNs

- Question: what is the contribution of C thick AGNs to the growth of SMBH?
  - Answer: we don’t know yet

- Indirect approach: from the XRB
  - estimate from the missing flux of the XRB at ~30 keV

- Direct approach: detect them!
  - The first results come from recent all sky, hard X-ray ($E>10$ keV) surveys (Swift/BAT, INTEGRAL)
  - A major theme of next generation X-ray astronomy ($NuSTAR, NeXT, Simbol-X, XEUS$)
II. Evolution of Compton thin AGNs

- Sensitive surveys below 10 keV, currently available, can provide us with a complete picture of “Compton thin” AGN (log $N_H<$24) in the universe.

- It is critical to establish the cosmological evolution of “Compton thin” AGNs, in order to evaluate the role of "Compton thick" AGNs.

Gilli+ (2007)
(1) Ultimate XLF of *Compton thin* AGNs

YU, Hasinger, Miyaji+ (2008)

- The X-ray Luminosity Function (XLF), the co-moving spatial number density of AGNs, is the basis of any AGN evolution model (previous work: YU+03, La Franca+05, Barger+05)

- Best constrain the rest-frame 2-10 keV LF of all *Compton thin* AGNs using all the heritage of X-ray surveys with various depth, width, and energy bands performed up to date.

- Utilize only samples with high identification completeness (>90%)
Sample: 1603 detections

- HEAO-1 49 $1.7 \times 10^{-11}$
- ASCA MSS/LSS 125 $1 \times 10^{-13}$
- HELLAS2XMM 89 $1.5 \times 10^{-14}$
- XMM LH 84 $5 \times 10^{-15}$
- CLASXS, CDFN/S 208 $1.1 \times 10^{-15}$
- ROSAT/XMM/Chandra 1048 $1.1 \times 10^{-16}$
The latest rest-frame 2-10 keV XLF of all Compton-thin AGNs, showing the "LDDE" behavior.
The AGN number density as a function of redshift

- Luminous AGNs have a density peak earlier in the cosmic time than less luminous AGNs.
- “Down-sizing” / “anti-hierarchical”: more massive BHs formed earlier, by assuming \( L \sim M \).
- SMBH accretion history is similar to star forming rate (e.g., Cowie+ 1996, Kodama+ 2004), consistent with the “co-evolution” scenario.
(2) Fraction of Absorbed AGNs

- Our present analysis: $F_x(2-10\text{ keV}) > 3e^{-15}\text{ cgs}$
  - Swift/BAT 3 months Catalog (Markwardt+ 2005)
  - ASCA LSS/MSS
  - CLASXS
  - XMM Hard Bright Sample (Caccianiga+ 04)
  - XMM Lockman Hole 800 ks (Hasinger+01, Matteos+05)
  - CDFS + XMM 400 ks (Giacconi+02, Streblyanska+08)

- Redshift dependence is not significant, but plausible: if true indicative of higher fraction of Compton thick AGNs at early universe?
(1)+(2) → Population Synthesis Model

- Given the luminosity function and absorption function determined below 10 keV, we predict contribution of Compton-thin AGNs to the background above 10 keV with an assumption of a broad band spectrum extrapolated above 10 keV.

- The missing background is then attributed to Compton thick AGNs assuming the same evolution as Compton thin ones.
The XRB intensity at 10 keV is ~10% lower than the previous model, which did not utilize the CDFS sample.

This work:
- $\Gamma = 1.9$, $\Delta \Gamma = 0.2$, $E_{\text{cut}} = 200$ keV

Ueda+ 03:
- $\Gamma = 1.9$, no dispersion, $E_{\text{cut}} = 500$ keV

Slightly harder than Gilli+ (2007) because of stronger reflection assumed.
Issues in Estimating the Number Density of Compton thick AGNs

- The number density of Compton thick AGNs, introduced to reproduce the XRB intensity at 30 keV, is coupled with
  1. The absolute intensity of the XRB (still 10~20% uncertainty)
  2. Assumed broad band spectra, in particular,
     - strength of Compton reflection component
     - dispersion of incident AGN photon indices (Gilli+ 2007)
  3. Affect of cosmic variance in deriving the XLF (at 10% level)
(1) The absolute intensity of the XRB

- INTEGRAL (Sazanov+ 2006) and BeppoSAX PDS (Frontera+ 2007) report an XRB intensity at 30 keV that is consistent within <20% with the HEAO-1 value by Gruber+ (1999)
- Note: the different results often adopt different flux calibration for the Crab Nebula. (let’s define it in the IAU!)
- It seems that 1~1.2 times the Gruber value would be most likely to reconcile with softer X-ray results by keeping he shape of the 3-50 keV XRB measured by HEAO-1.

<table>
<thead>
<tr>
<th></th>
<th>XRB</th>
<th>Crab</th>
<th>XRB_cal</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEAO1</td>
<td>1.10</td>
<td>1.06</td>
<td>1.04±0.03</td>
</tr>
<tr>
<td>INTEGRAL</td>
<td>0.94</td>
<td>0.94</td>
<td>1 (&lt;1.2)</td>
</tr>
<tr>
<td>BeppoSAX</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

normalized 20-50 keV flux
(2) Compton thick AGNs or Compton reflection?

- The fraction of Compton thick AGNs, introduced to reproduce the intensity XRB spectrum at 30 keV, is coupled with the amount of reflection component (assumed to be $\Omega = 2\pi$ for both type-1 and type-2 AGNs).
- Precise study of broad band spectra of nearby AGNs (especially type-2 AGNs) is crucial. Suzaku observations are important.

![Graph showing the integrated spectrum of type-1 AGNs and Compton-thick AGNs](image)
(3) Cosmic Variance: necessity of wide area survey

- Wide and deep continuous surveys, such as CLASXS, COSMOS and SXDS, clearly show the variance of apparent source counts is evident even on an area scale of ~0.2 deg² (Yang+04, Cappelluti+07, YU+07)
- Basic quantities derived from a pencil survey could be affected if we discuss a 10% level of the XRB intensity. This is important to constrain the contribution by yet unresolved populations, such as Compton thick AGNs.
III. The importance of hard X-ray (>10 keV) surveys

**Swift/BAT** 14-195 keV (Markwardt+ 05, Tueller+ 07)
- 126 AGNs (|b|>15 deg, 9 months), 450 AGNs expected from 3 year

**INTEGRAL** 20-100 keV (Bassani+06, Beckmann+06, Sazonov+ 06)
- 127 AGNs

- The most unbiased AGN sample including Compton thick AGNs in the local universe (with $N_H < 10^{24.5}$ cm$^{-2}$)

The aims of *Suzaku* follow-up
- Unveil a new population of AGNs
- Determination of true $N_H$ distribution of local AGNs
- Measurement of the broad band spectrum, especially the Compton reflection component from absorbed AGN
Discovery of “New type”: buried AGNs

- *Swift/BAT* survey + *Suzaku* has started to unveil previously unknown AGNs in the local universe (see Comastri+ 2007 for *INTEGRAL* sources)
- The Suzaku spectra reveal little scattered component (<0.5%), suggesting a small opening angle of the torus - a new type of AGNs buried deeply in a geometrically thick torus. The [O III] luminosity is weak, hence missed in optical surveys (but exceptions: see Mushotzky’s talk)
- Unabsorbed reflection component favors a face-on geometry (i<40 deg) implying a large number of yet unrecognized Compton thick AGNs seen with more edge-on configuration that are hard to be detected even with the currently deepest hard X-ray (E>10 keV) or optical AGN surveys

Swift J0601.9-8636

YU+ (2007)
New Type: Other Examples

- $\log N_H \sim 23.8 \text{ cm}^{-2}$, very small scattering ($S < 0.3\%$) and strong reflection ($R > 1$)
- More in Mushotzky’s talk

---

Eguchi (2008)
Old Type (?) AGNs

- Scattering fraction ($S >\sim 1\%$) + weak reflection (rather common feature for “canonical” Seyfert 2 galaxies?)

Eguchi (2008)
Two types?

Scattering Fraction (%)

Reflection

Old Type

New Type

C: JAXA

C: CXC

0.5
1.0
1.5

0
1
2

Scattering Fraction (%)
The 2-10 keV XLF of Compton-thin AGNs confirms the “down-sizing” nature of BH growth.

While the luminosity dependence of X-ray absorbed-AGN fraction is highly significant, its redshift dependence must be checked by larger samples.

We have not fully understand the XRB origin yet above ~6 keV

From the Suzaku follow-up of Swift/BAT AGNs, we are discovering “new type” of AGNs

- Almost completely buried AGNs in the geometrically-thick torus. Mostly missed in soft X-ray or optical surveys.
- Constitutes a significant fraction of local AGNs

The cosmological evolution of Compton thick AGNs and their contribution of the growth to SMBHs are unknown. Suzaku follow-up of new hard X-ray AGNs has a key role to establish the nature of heavily obscured AGNs.
$N_H$ distribution of AGNs in the local universe

- The Swift/BAT and Integral hard X-ray surveys above 15 keV show that absorbed AGNs are indeed a major population. The fraction of absorbed sources with (log $N_H > 22$) is ~0.5.
- The results of softer-band surveys are consistent with the Swift result after correcting for selection bias against absorbed sources

HEAO1 (2-10 keV)  
Shinozaki+ 2006

RXTE/ASM (3-20 keV)  
Szanov & Revnivtsev 2004

Swift/BAT (15-200 keV)  
Markwardt+ 2005, Tueller+2007