Contribution of Compton Thick AGNs to the X-ray Background

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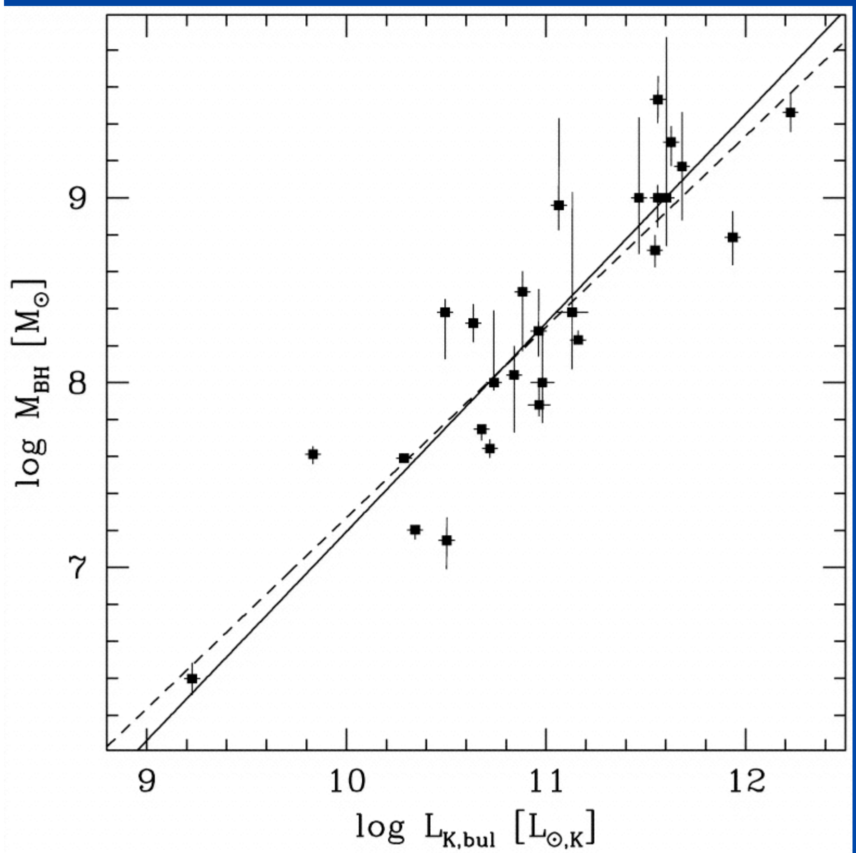
I. Introduction

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-evoluton" scenario.

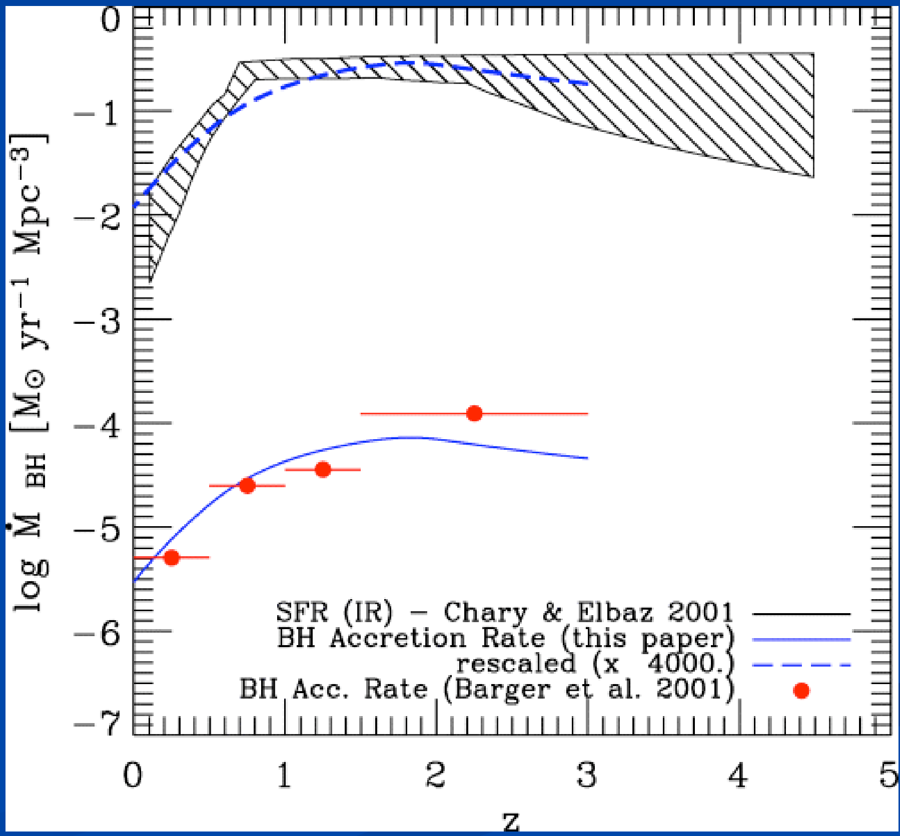
Co-evolution of galaxy and super massive black holes in galactic centers

BH mass vs Stellar mass @z=0



e.g., Marconi & Hunt 03

Star forming history vs accretion history

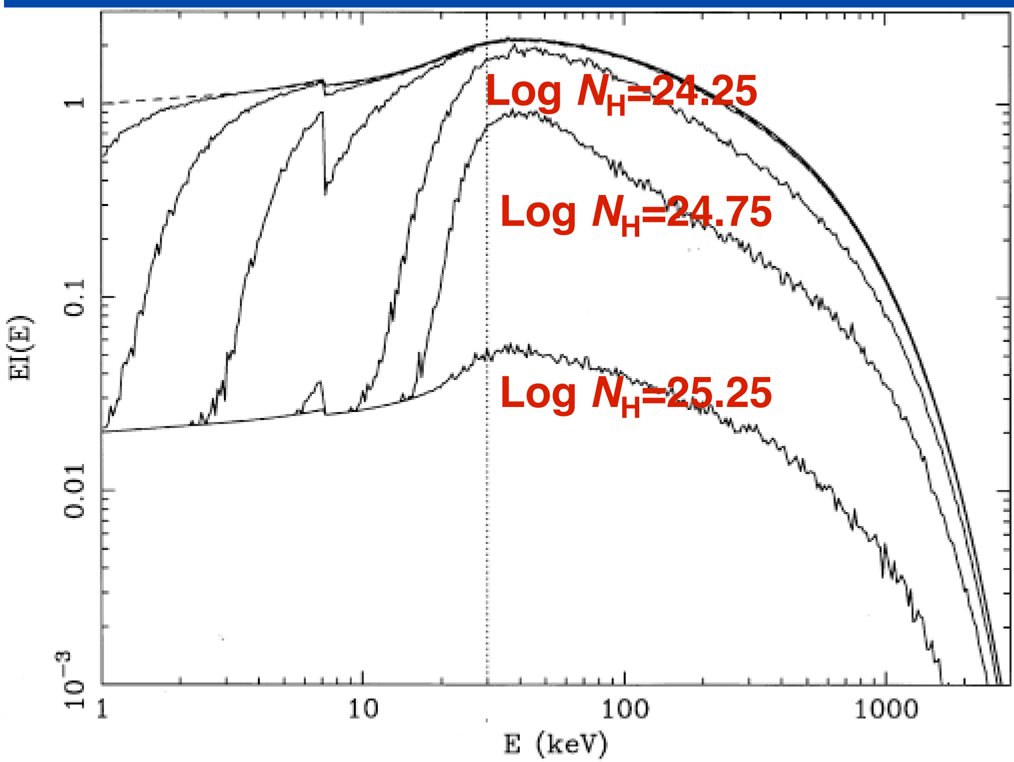


Marconi+ 04

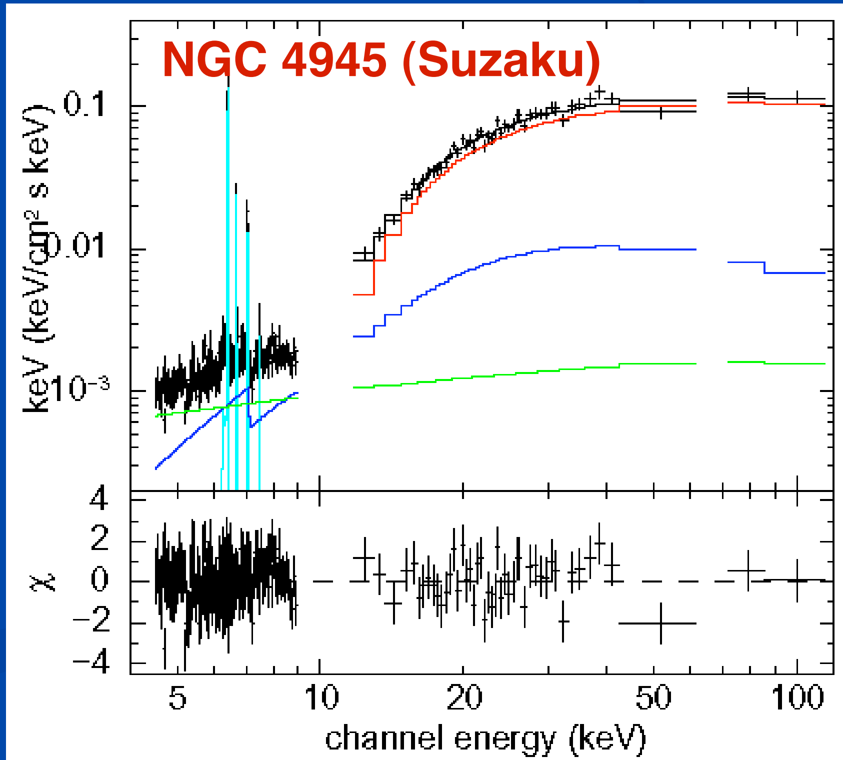
X-ray Spectra of Heavily Obscured AGNs

- 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 exeeds ~10^{25} cm^{-2} .

Wilman & Fabian (1999)



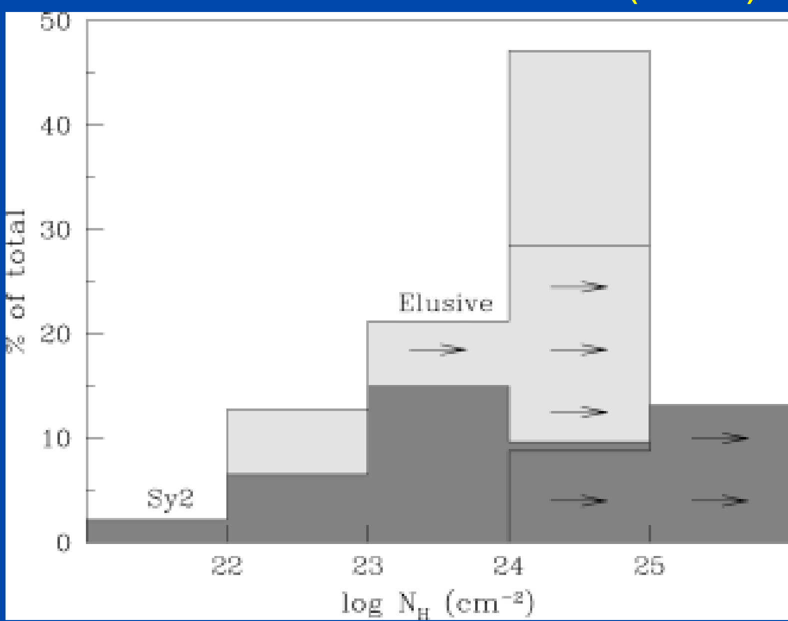
Itoh, T.+ (2008)



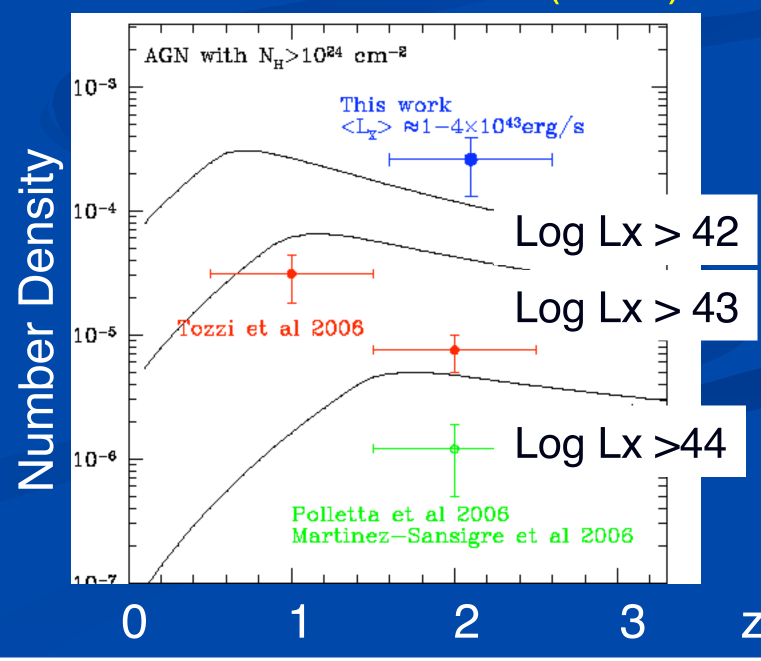
Evidence for Compton thick AGNs

- 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

Maiolino+ (2003)



Daddi+ (2007)

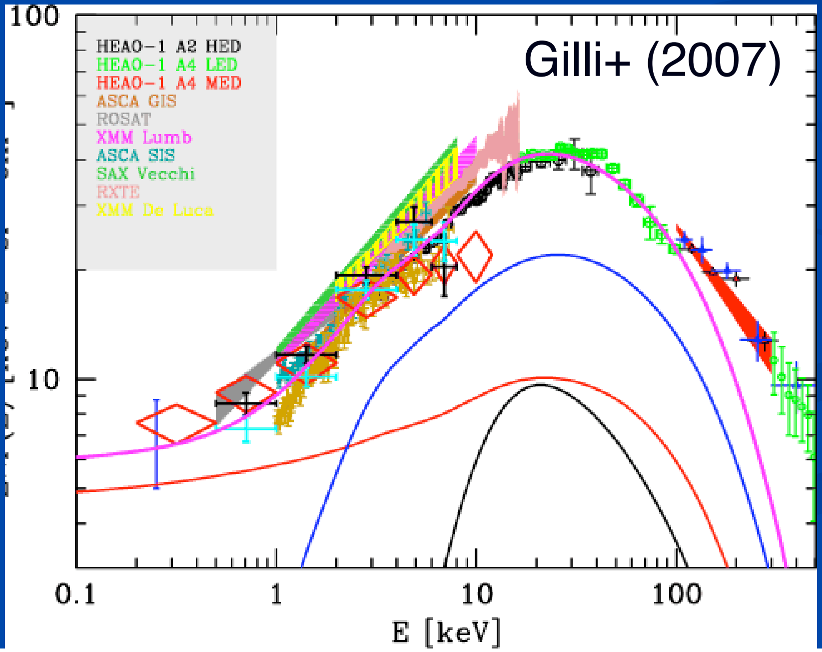


A big remaining issue: the number density of Compton thick AGNs

- 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



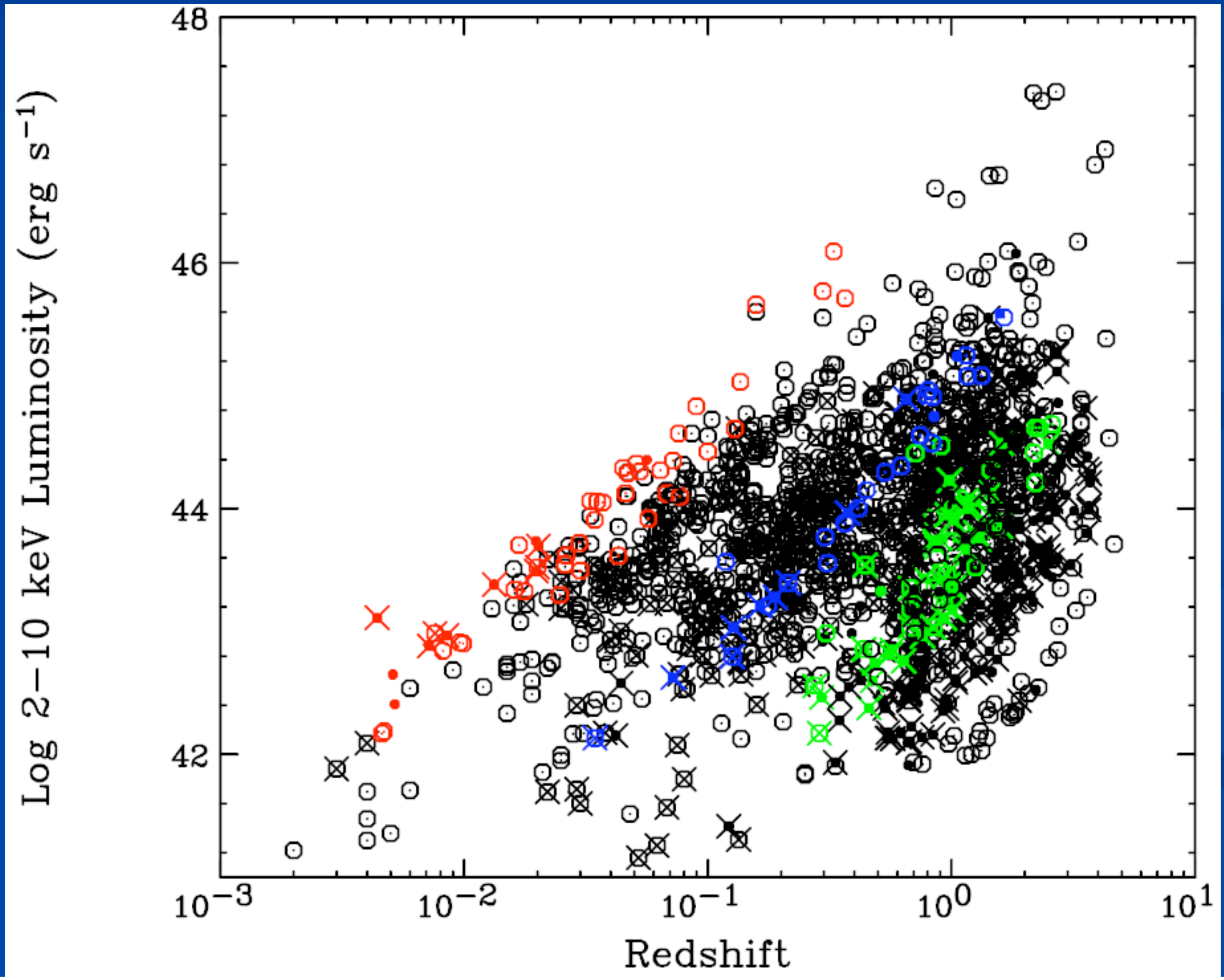
(1) Ultimate XLF of *Compton thin* AGNs

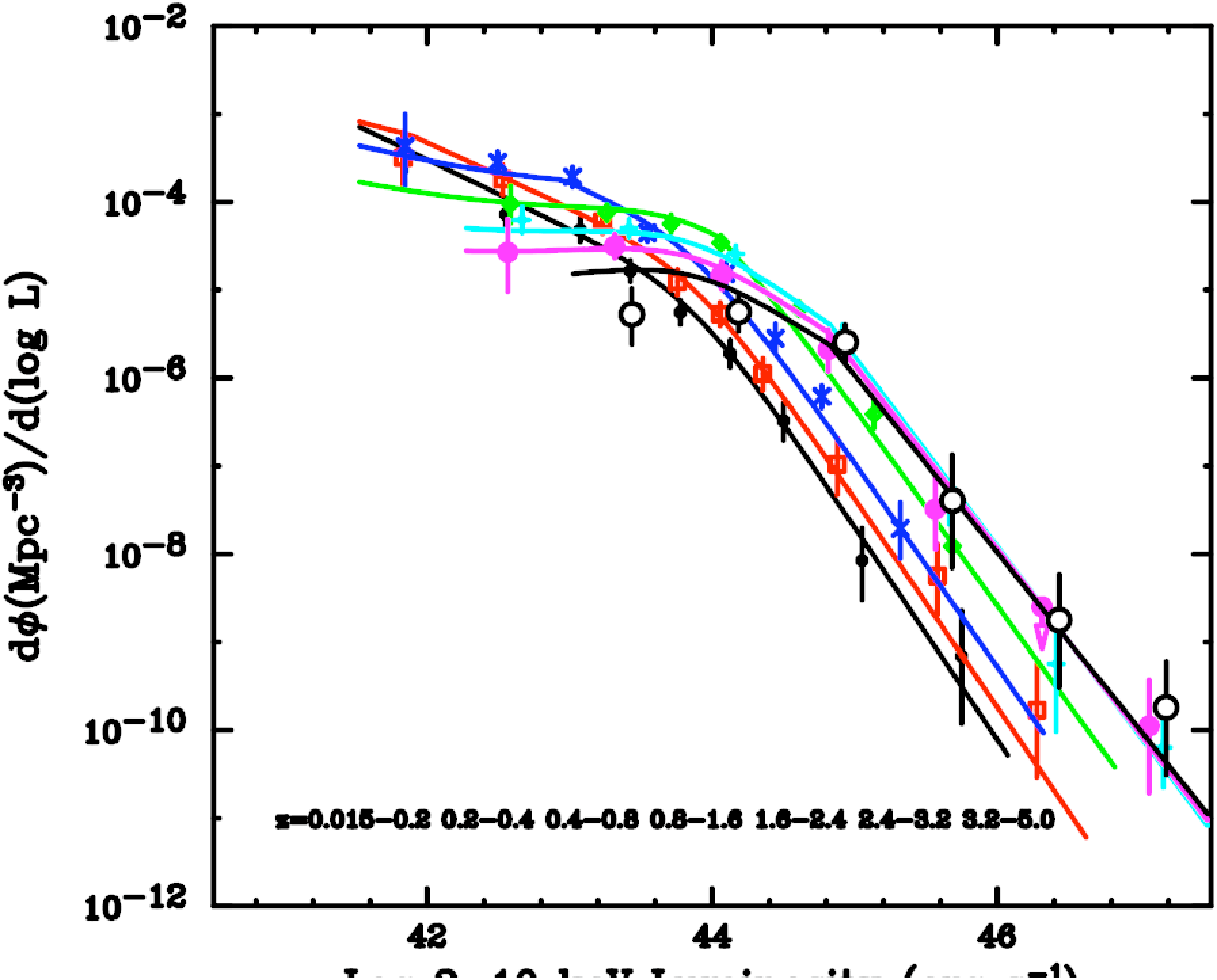
YU, Hasinger, Miyaji+ (2008)

- 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	1.7×10^{-11}
ASCA MSS/LSS	125	1×10^{-13}
HELLAS2XMM	89	1.5×10^{-14}
XMM LH	84	5×10^{-15}
CLASXS, CDFN/S	208	1.1×10^{-15}
ROSAT/XMM/Chandra	1048	1.1×10^{-16}

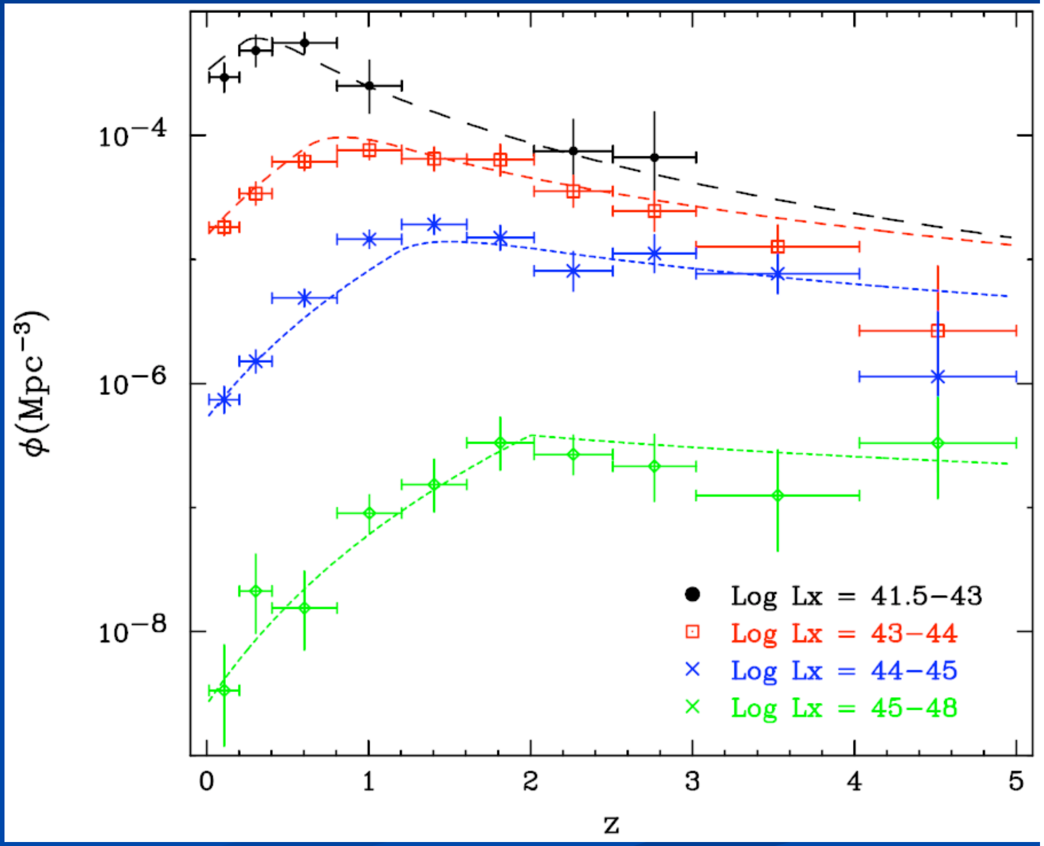




10−2
10−4
10−6
10−8
10−10
10−12
dφ(Mpc−3)/d(log L)
42
44
46
z=0.015−0.2 0.2−0.4 0.4−0.8 0.8−1.6 1.6−2.4 2.4−3.2 3.2−5.0

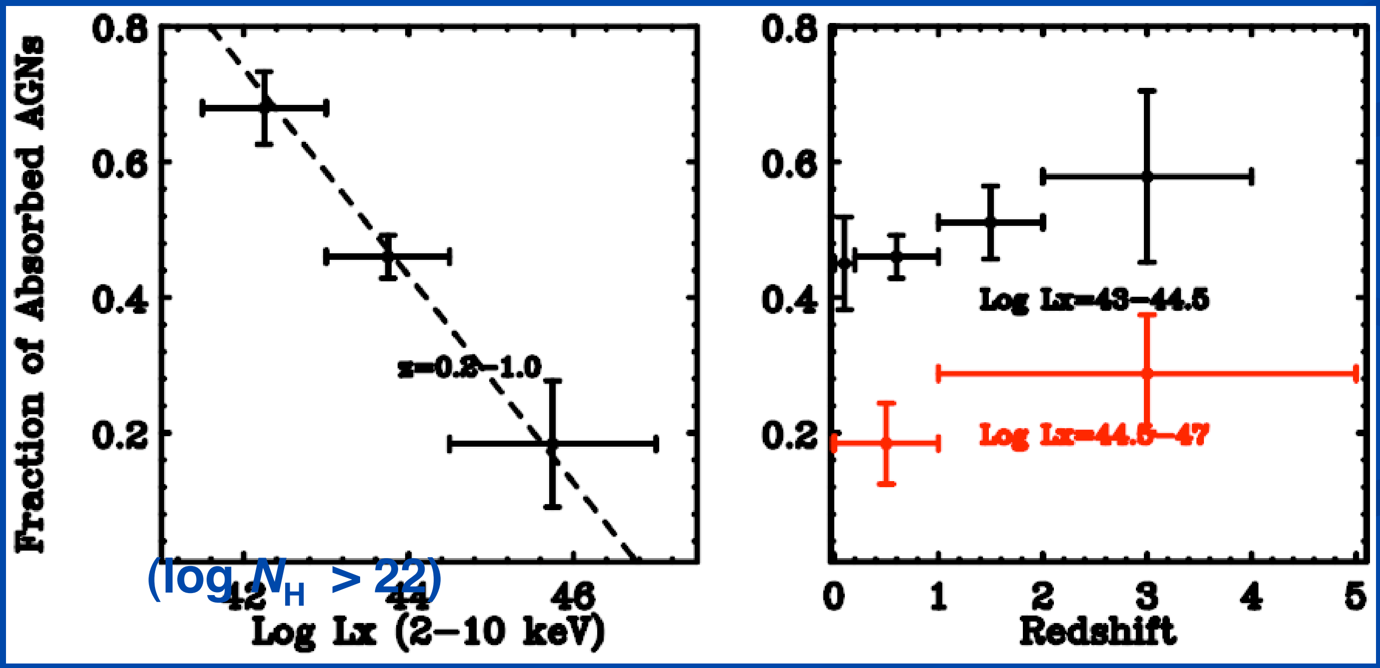
The AGN number density as a function of redshift

- 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~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: *Fx*(2-10 keV) > 3e-15 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?



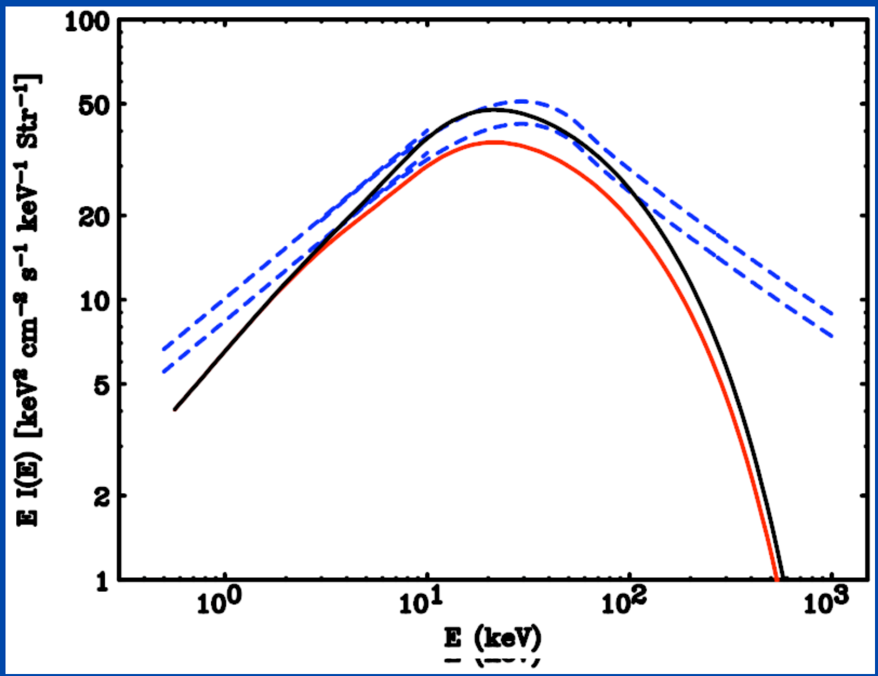
(1)+(2) → Population Synthesis Model

- 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

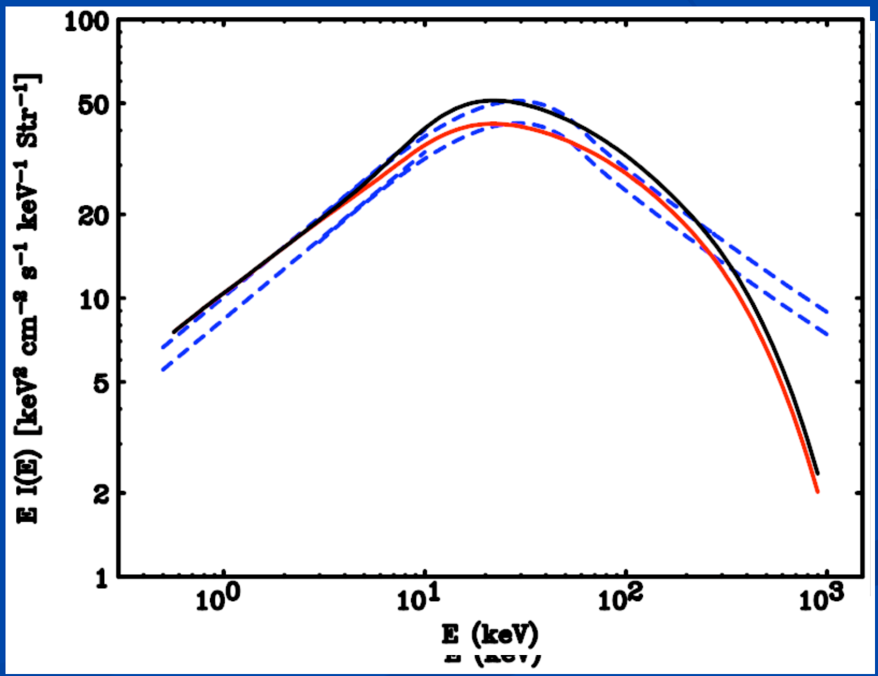
Predicted XRB spectrum

- The XRB intensity at 10 keV is ~10 % lower than the previous model, which did not utilize the CDFS sample

This work
Γ =1.9, $\Delta\Gamma$ =0.2, Ecut=200 keV



Ueda+ 03
Γ =1.9, no dispersion, Ecut=500 keV



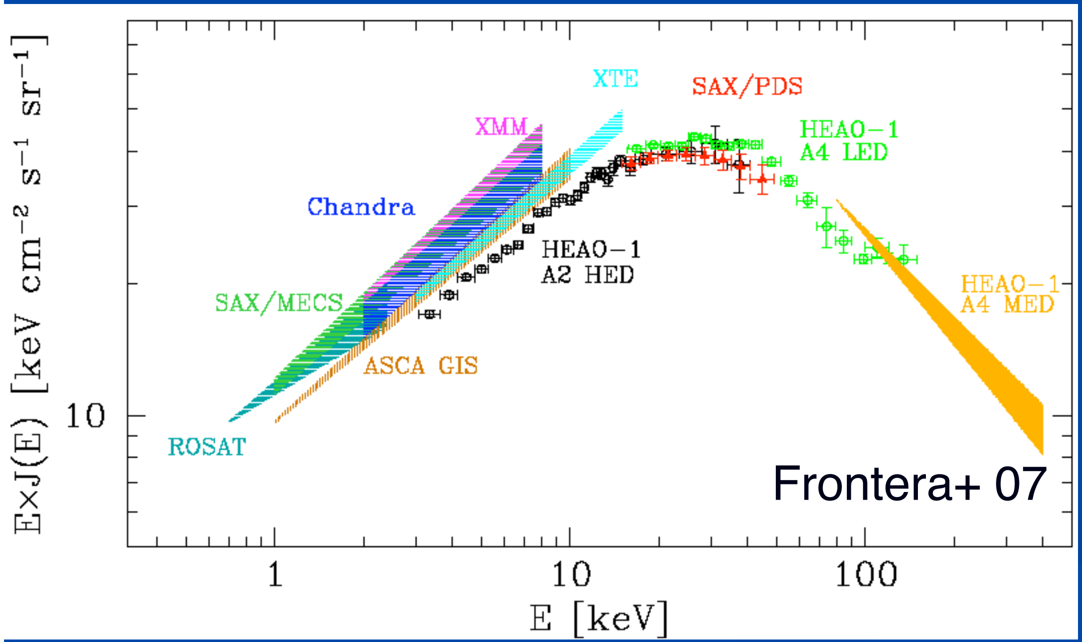
Slightly harder than Gilli+ (2007) because of stronger reflection assumed.

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 reconsile with softer X-ray results by keeping he shape of the 3-50 keV XRB measured by *HEAO-1.*

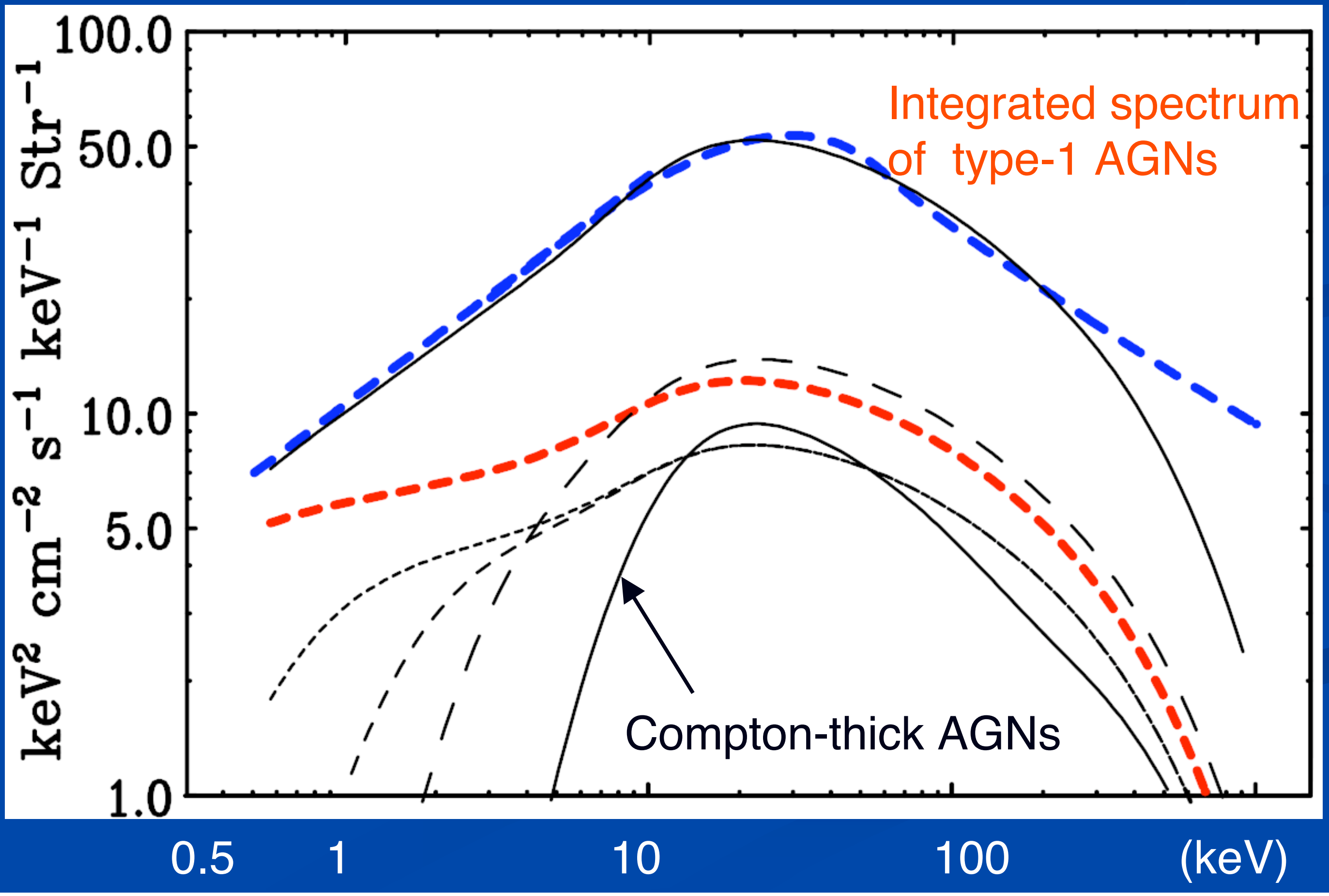


normalized 20-50 keV flux

	XRB	Crab	XRB_cal
HEAO1	1	1	1
INTEGRAL	1.10	1.06	1.04±0.03
BeppoSAX	0.94	0.94	1 (<1.2)

(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 neaby AGNs (especially type-2 AGNs) is crucial. Suzaku observations are important.

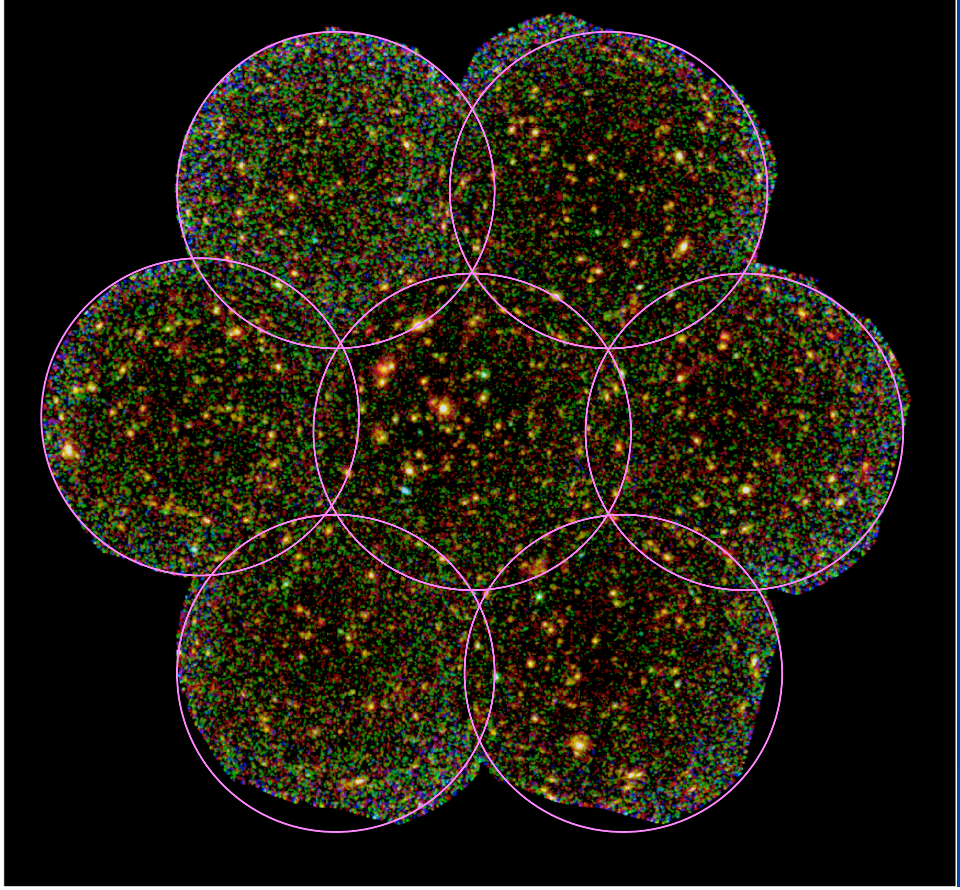


YU+ 2003

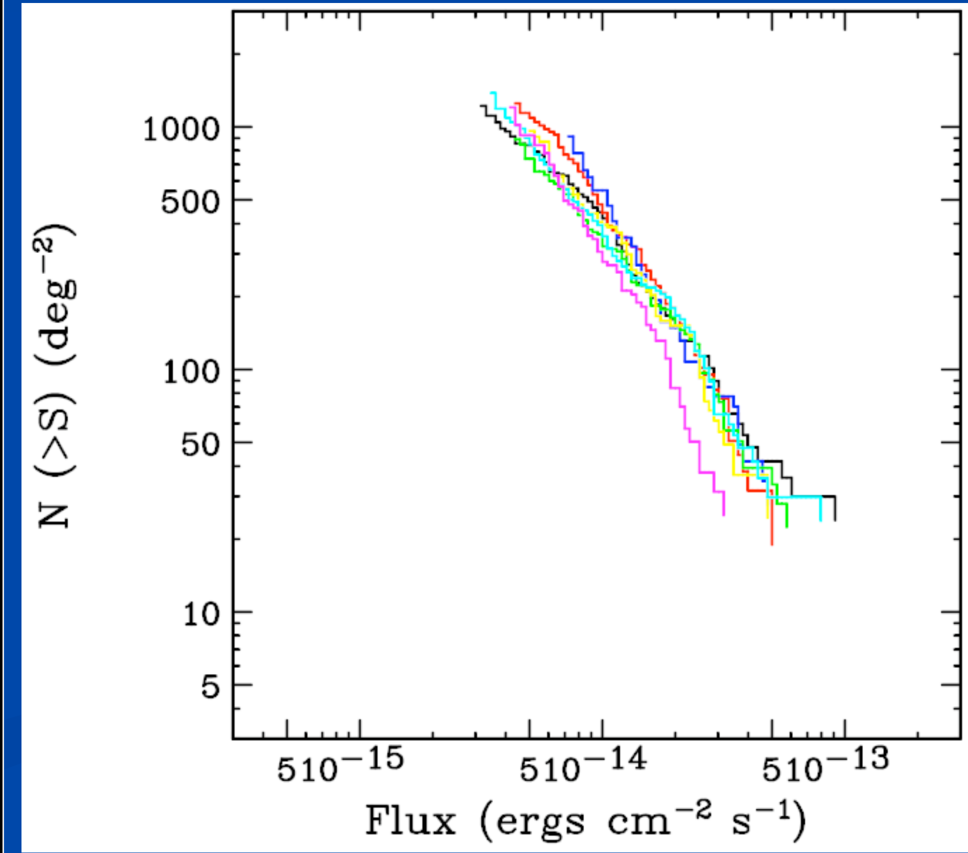
(3) Cosmic Variance: necessity of wide area survey

- 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 deg^2 (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.

Subaru-XMM Newton Deep Survey (SXDS)



YU+, submitted



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})

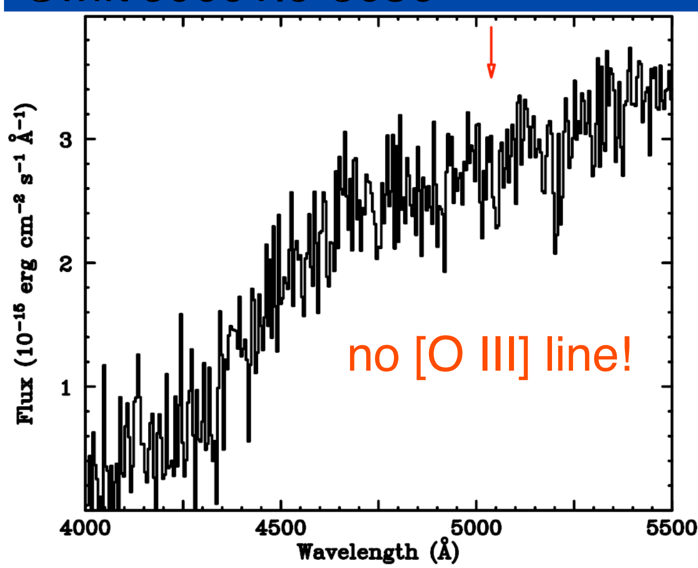
The aims of *Suzaku* follow-up

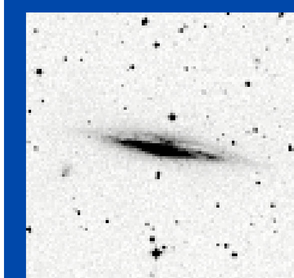
- Unveil a new population of AGNs
- Determination of true N_H distribution of local AGNs
- Measurement of the broad band spectrum, especially the Compton reflection component from absorbed AGN

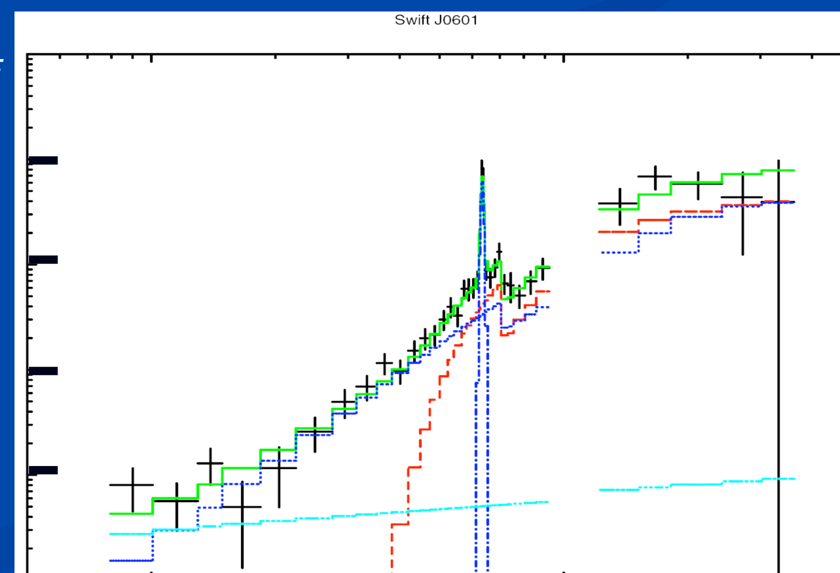
Discovery of "New type": buried AGNs

- *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



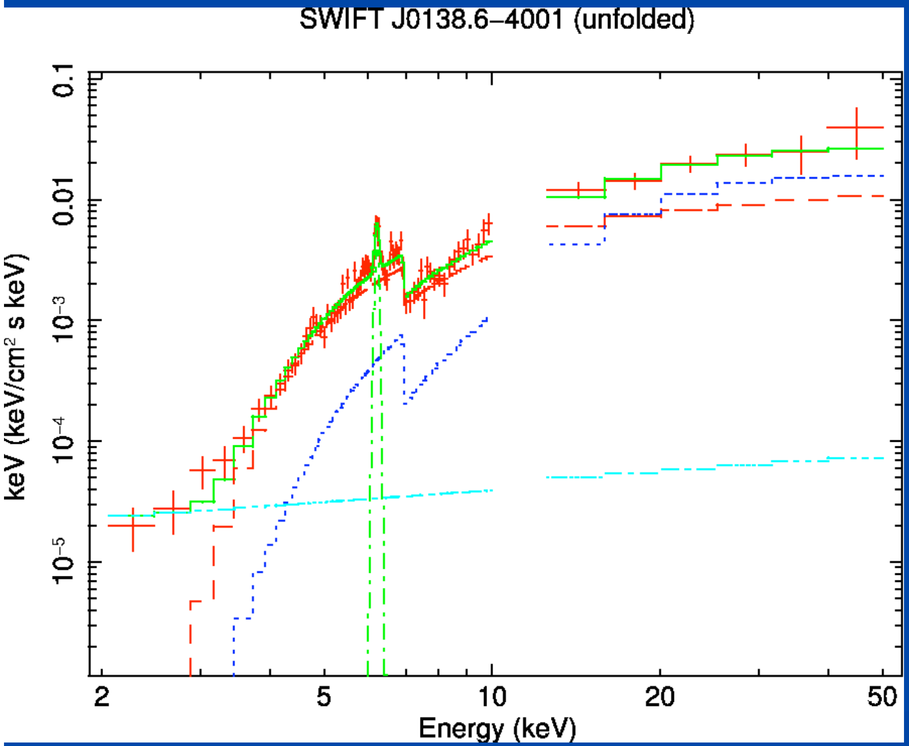


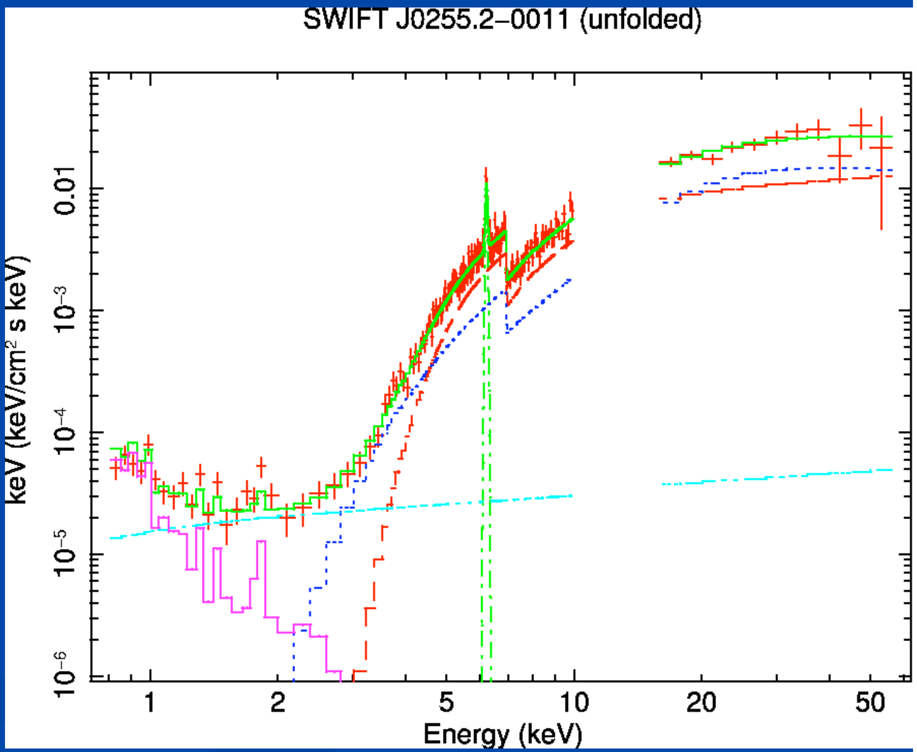


YU+ (2007)

New Type: Other Examples

- Log N_H~23.8 cm^{-2}, very small scattering (S<0.3%) and strong reflection (R>1)
- More in Mushotzky's talk

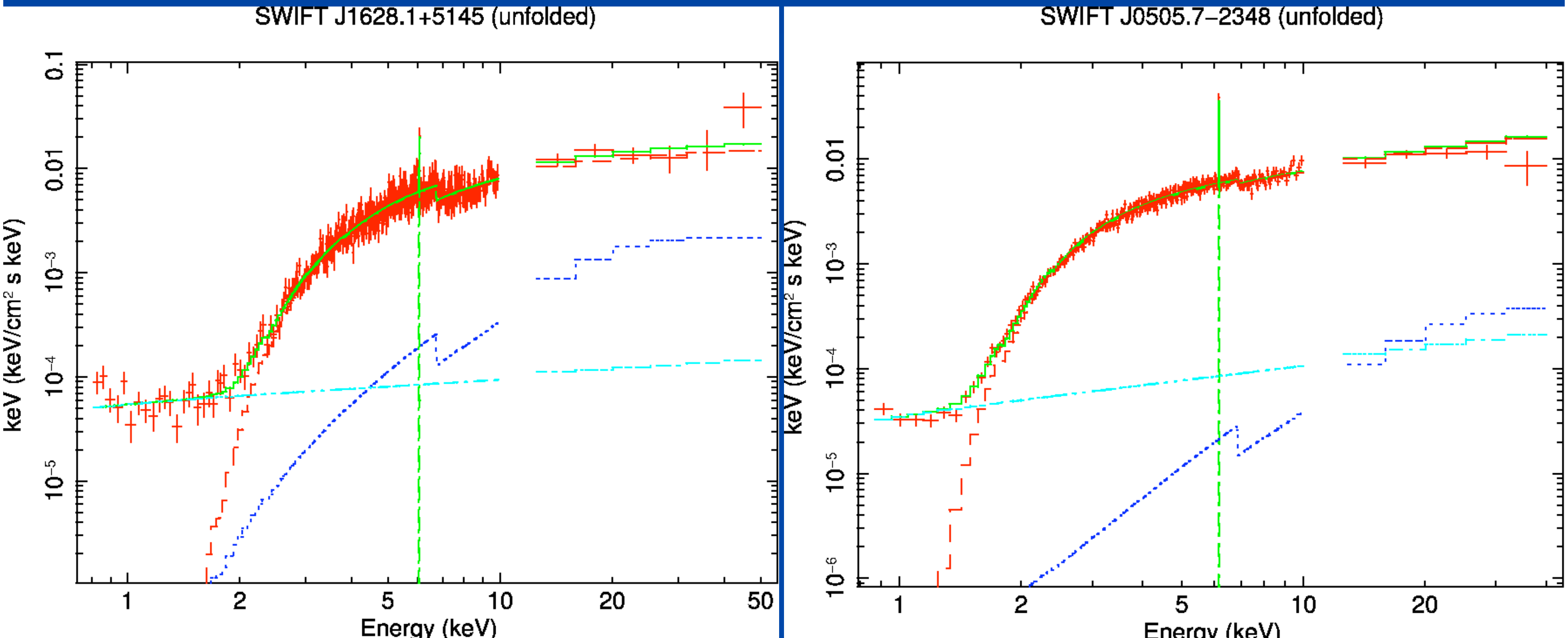




Eguchi (2008)

Old Type (?) AGNs

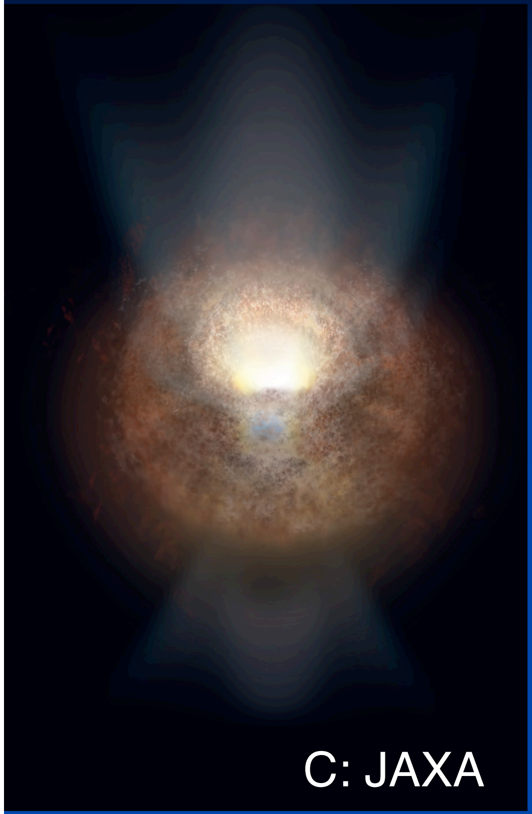
- Scattering fraction (*S* >~1%) + weak reflection (rather common feature for "canonical" Seyfert 2 galaxies?)

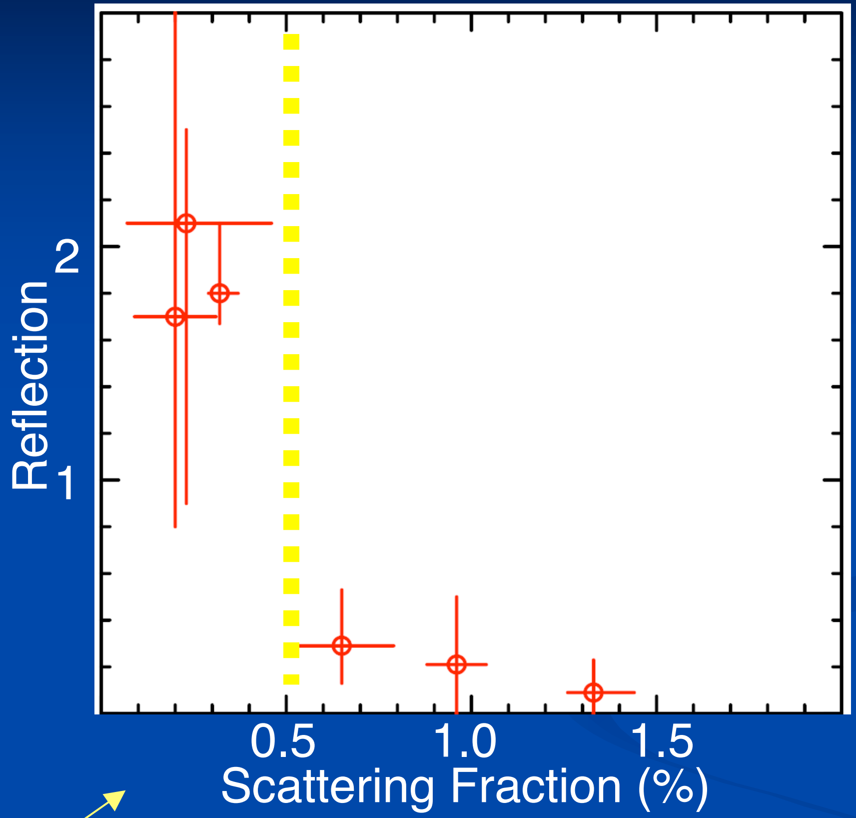


Eguchi (2008)

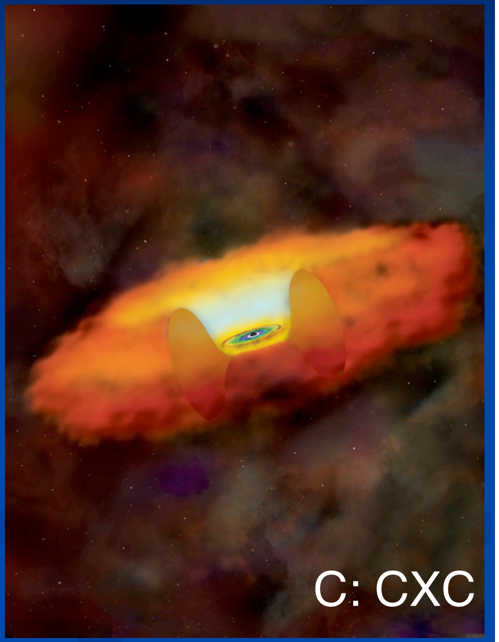
Two types?

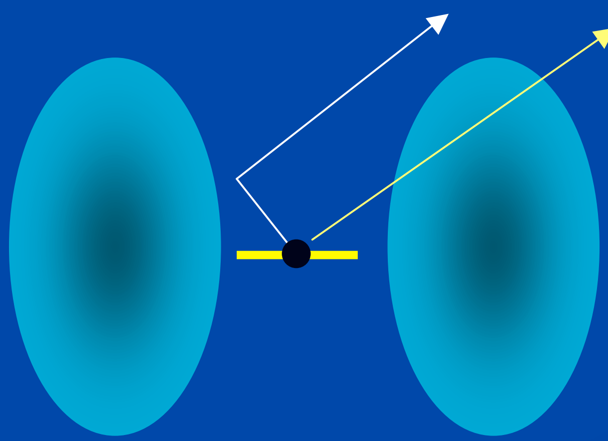
New Type

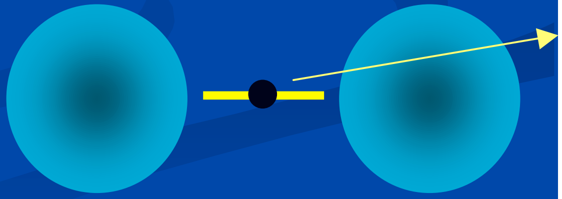




Old Type







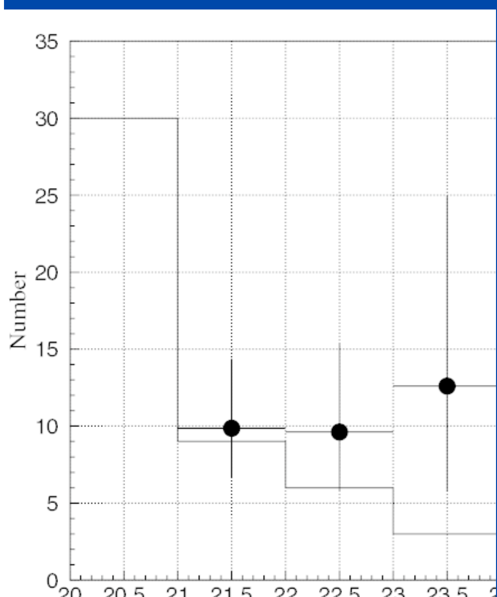
Summary

- 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 burried 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.

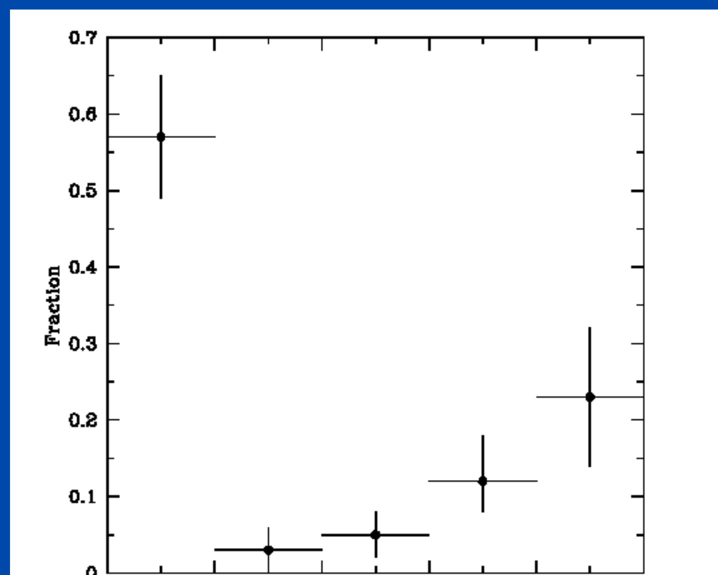
N_H distribution of AGNs in the local universe

- 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