Investigation of AGN evolution with eROSITA

Yoshihiro Ueda
Kyoto University

Outline

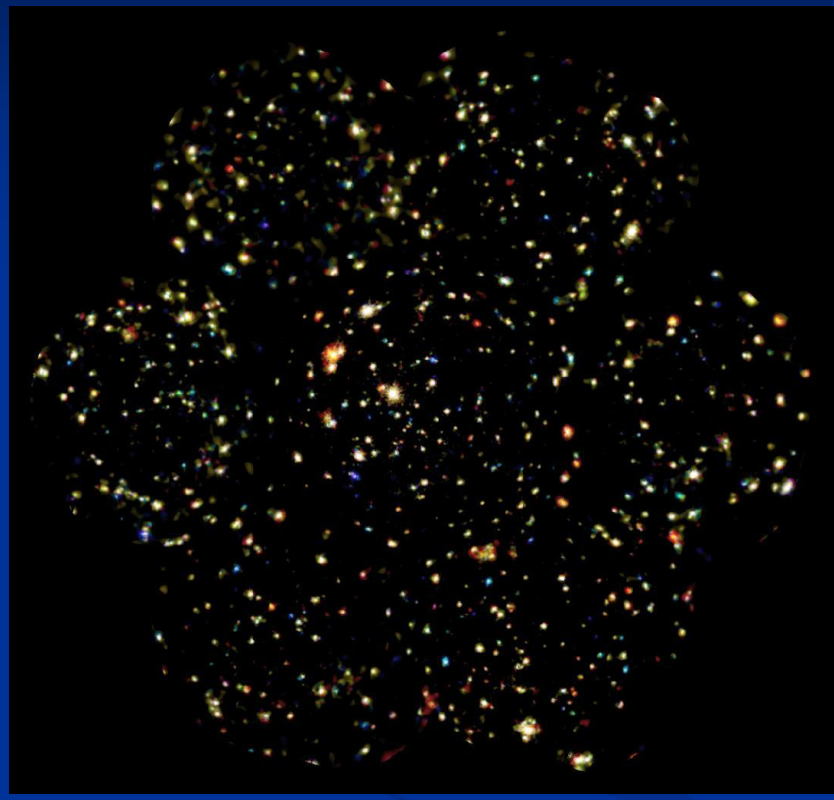
1. Why X-rays?
2. Present Status of AGN evolution from X-ray surveys
3. Remaining Issues
4. eROSITA prospects

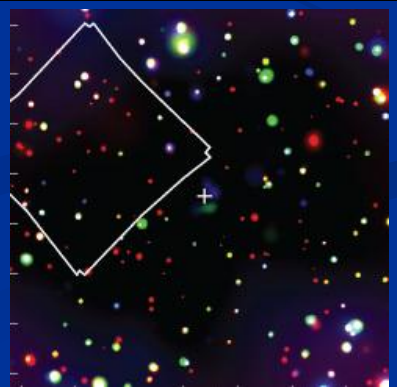
Importance of "X-ray" Surveys of AGNs

- To fully understand the growth history of SMBHs: the main goal of X-ray surveys
- For this *Complete* detection of AGNs with different types (type1 and type2) is required over a wide *L*-*z* range

- Now almost all of the XRB below 8 keV is resolved, mostly into Compton-thin AGNs (N_H < 10^{24} cm^2) with ~10^4 deg^{-2}
- X-ray surveys are the most sensitive among those at any wavelengths

SXDS U+08





CDFS
Xue+ 11

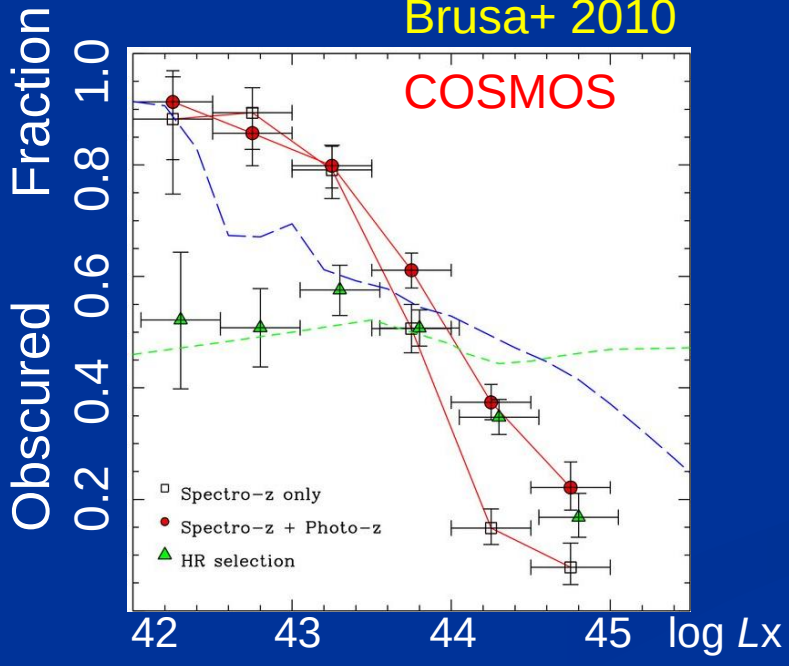
X-ray vs longer wavelengths

The majority of AGNs are obscured by gas and dust

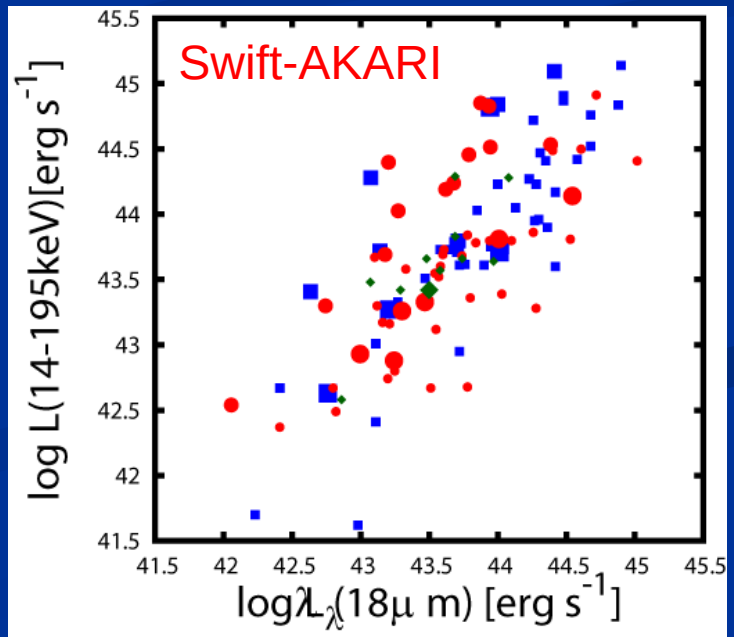
The obscured fraction increases with decreasing luminosity

- Merits of using X-rays
  - Strong penetrating power against obscuration at high E
  - No contamination from stars (c.f. in the mid infrared band separation from star bursts are sometimes difficult.)
- Demerits: expensive, not easy to perform "wide and deep" surveys: but *eROSITA* can do !

Brusa+ 2010



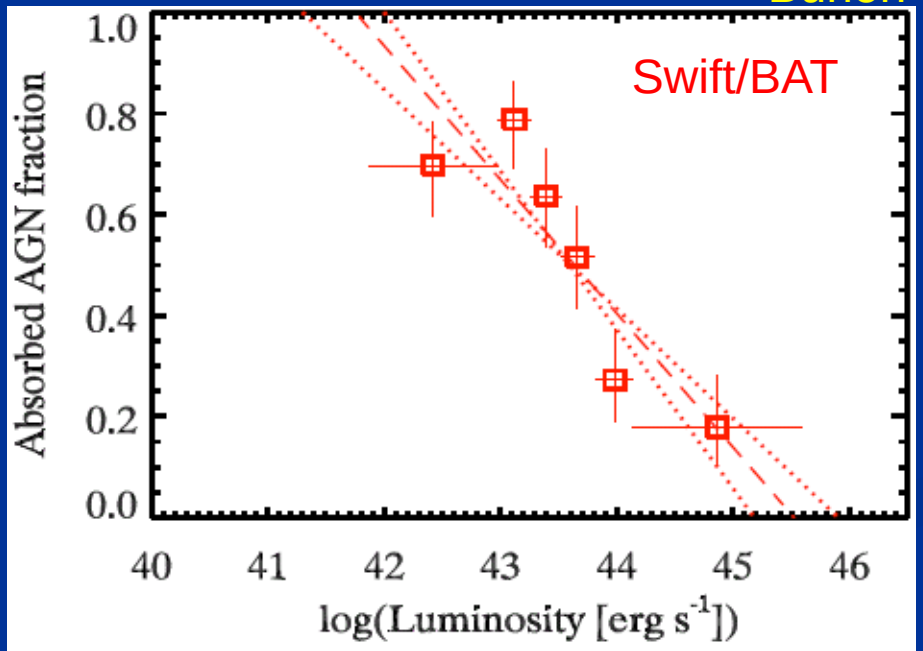
Ichikawa+12, Gandhi+09

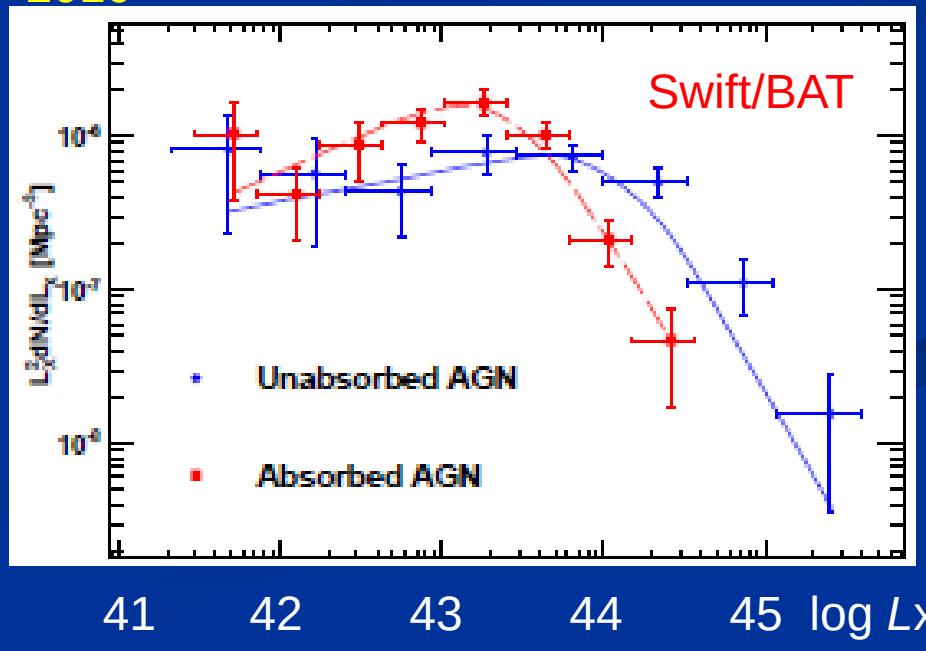


AGNs in the local universe

- The basis of cosmological models as their "end-point"
- Hard X-ray all sky surveys (E>10 keV) with Swift/BAT and INTEGRAL provide least biased samples, except for heavily Compton-thick AGNs, with excellent efficiencies (eg, Tueller+09, Beckmann+09, Burlon+10)
- MIR selection is also useful (eg, Brightman & Nandra +11)
- Luminosity functions of type-1 and type-2 AGNs different when separately plotted because of absorbed fraction dependence on Lx

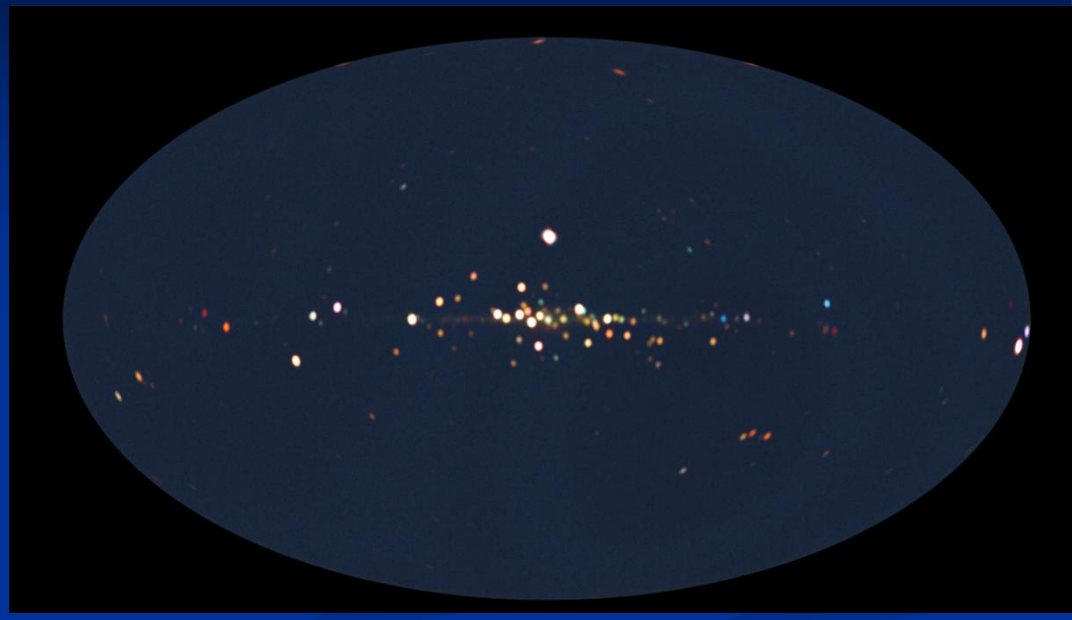
Burlon+ 2010

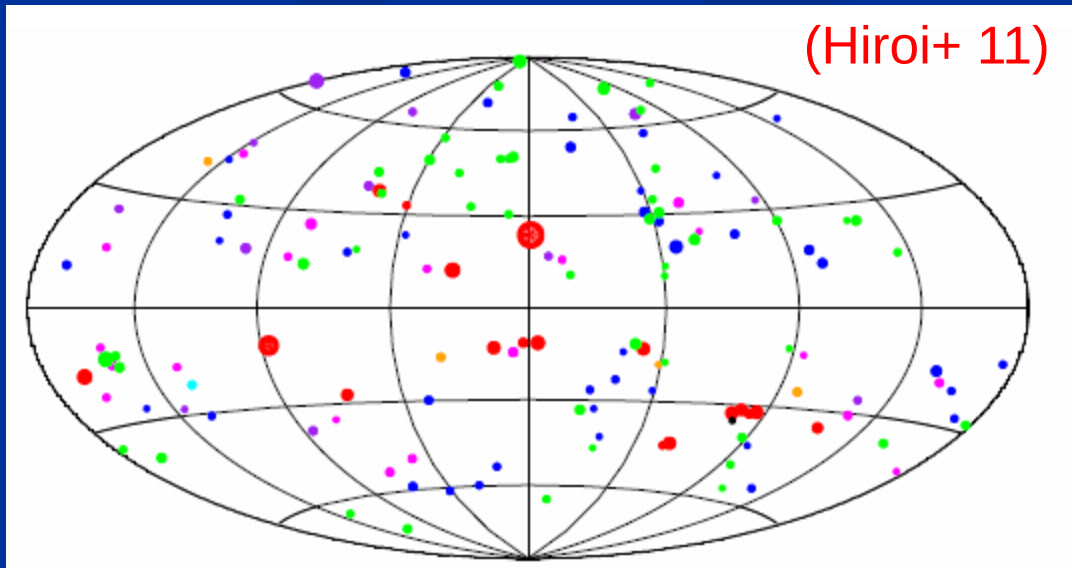




MAXI Extragalactic Survey

- The Monitor of All X-ray Sky Image (MAXI) mission on the ISS is working well to monitor transient objects (Matsuoka+ 09)
- The first 7 month data of the MAXI has provided an unbiased X-ray catalog in the 4-10 keV band at high |b| with better sensitivities than HEAO-1 and RXTE (Hiroi+ 11)
- Contains 143 sources includes 51 AGNs and 48 clusters: ID completeness >99%

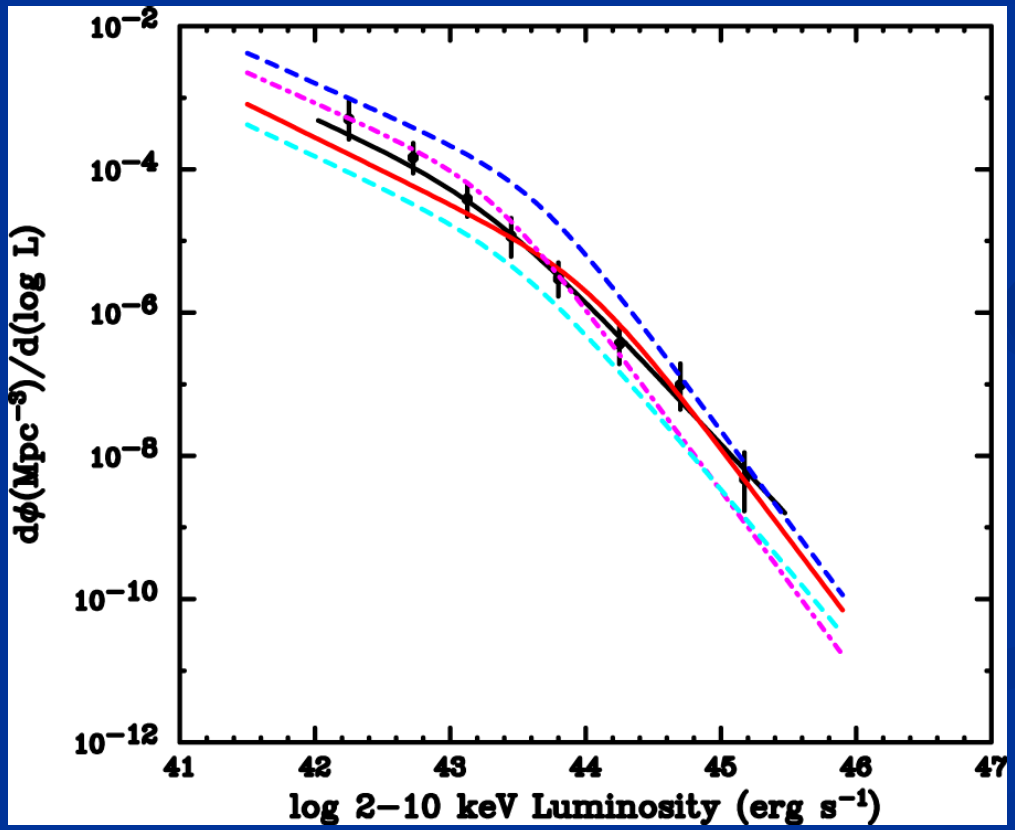




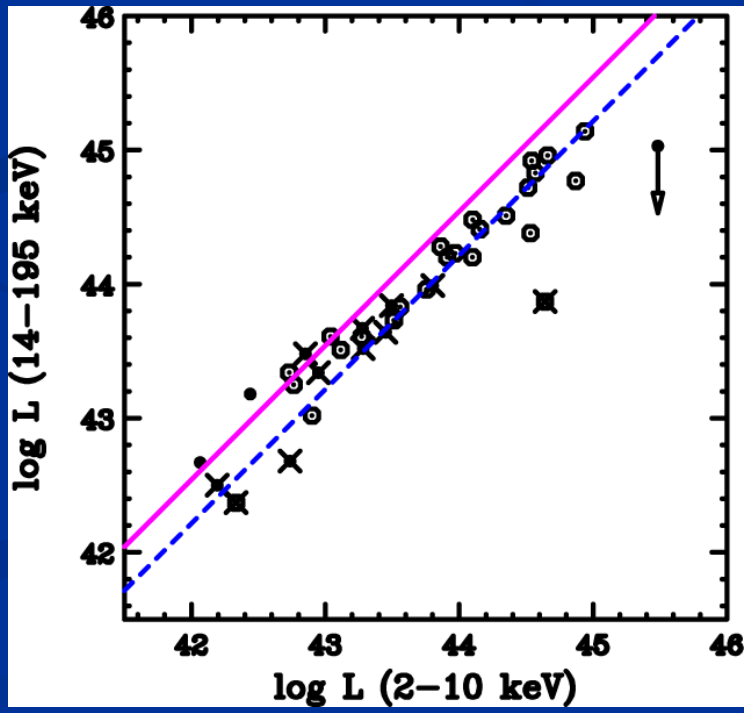
(Hiroi+ 11)

2-10 keV local AGN luminosity function

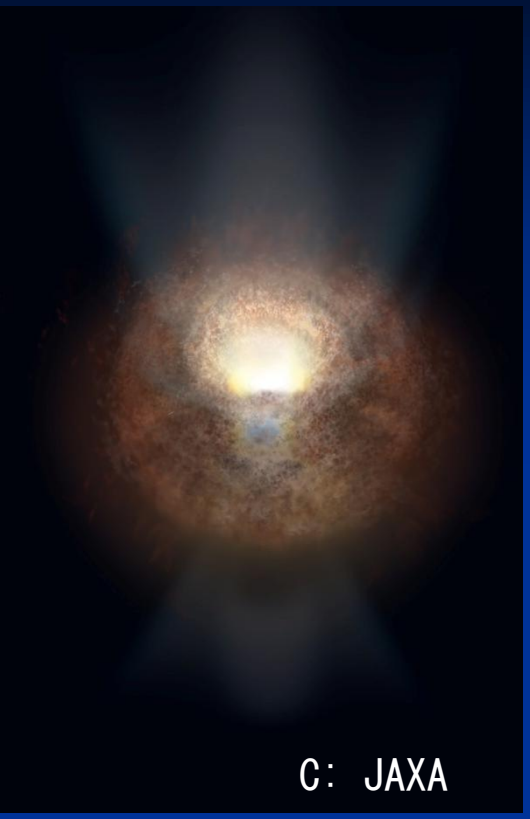
- Apparent discrepancy of HEAO-1/RXTE results from the luminosity function determined above 10 keV
- It can be solved by considering the luminosity dependence (or type dependence) of the broad band X-ray spectra



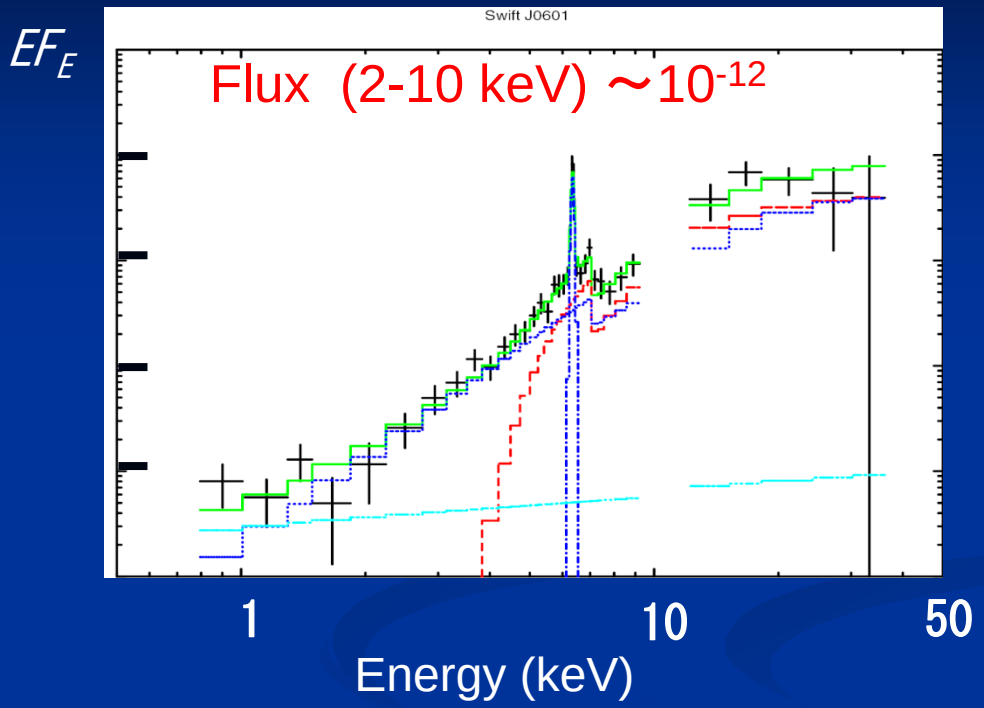
U+11

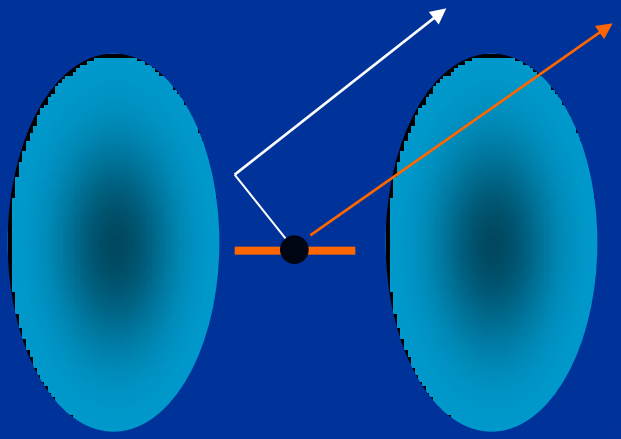


Suzaku Follow-up of Swift/BAT AGNs



Swift J0601 U+ 07





Very weak scattering compont

``New Type'': Obscured by geometrically thick torus

(see Comastri+09 for *INTEGRAL* sources)

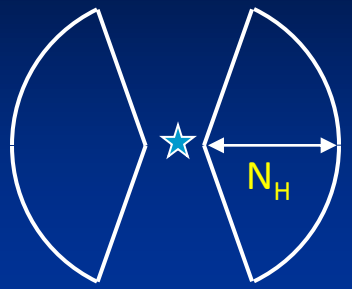
Extremely large N_H if viewd from edge-on

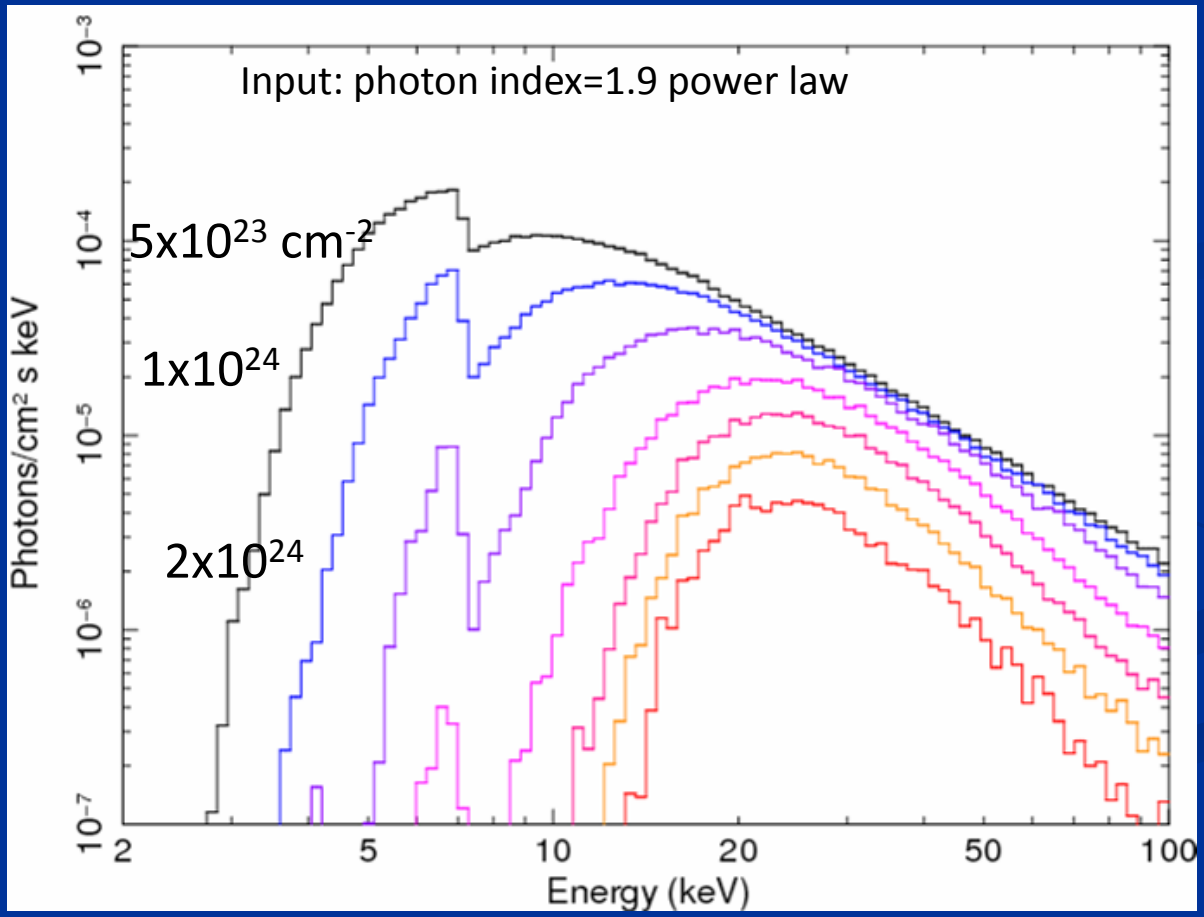
Many buried AGN predicted

Hard X-ray Spectra of Very Compton-thick AGNs

Monte-Carlo prediction

(eg, Ikeda+09; Wilman & Fabian 99)



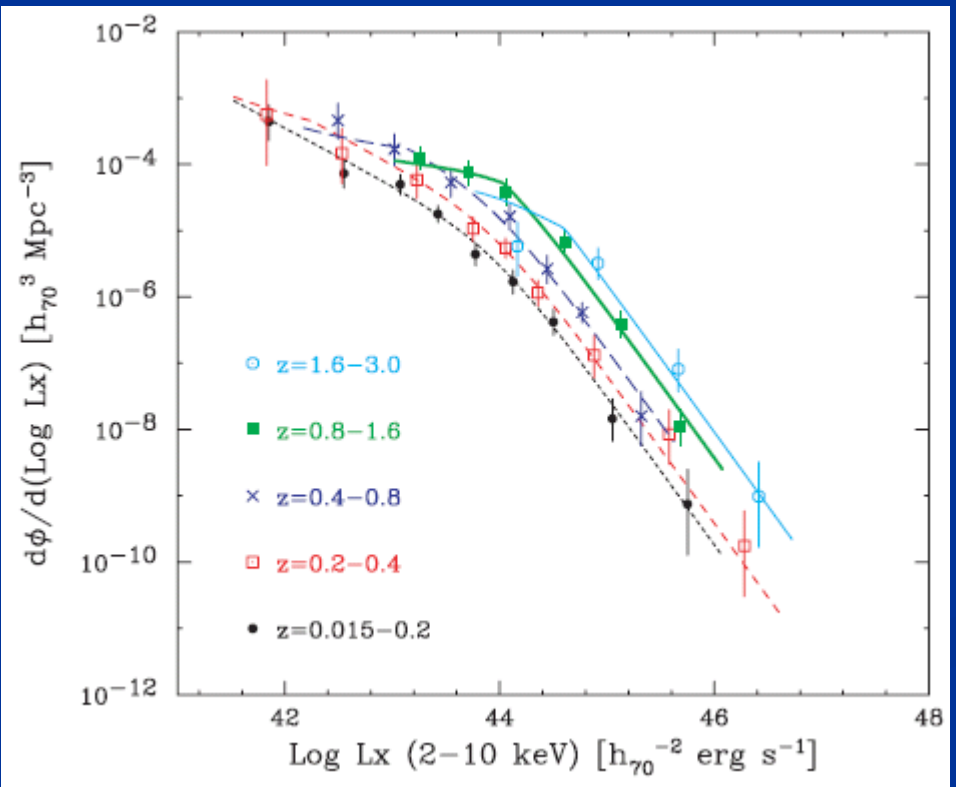


$4x10^{24}$
$6x10^{24}$
$8x10^{24}$
$1x10^{25}$

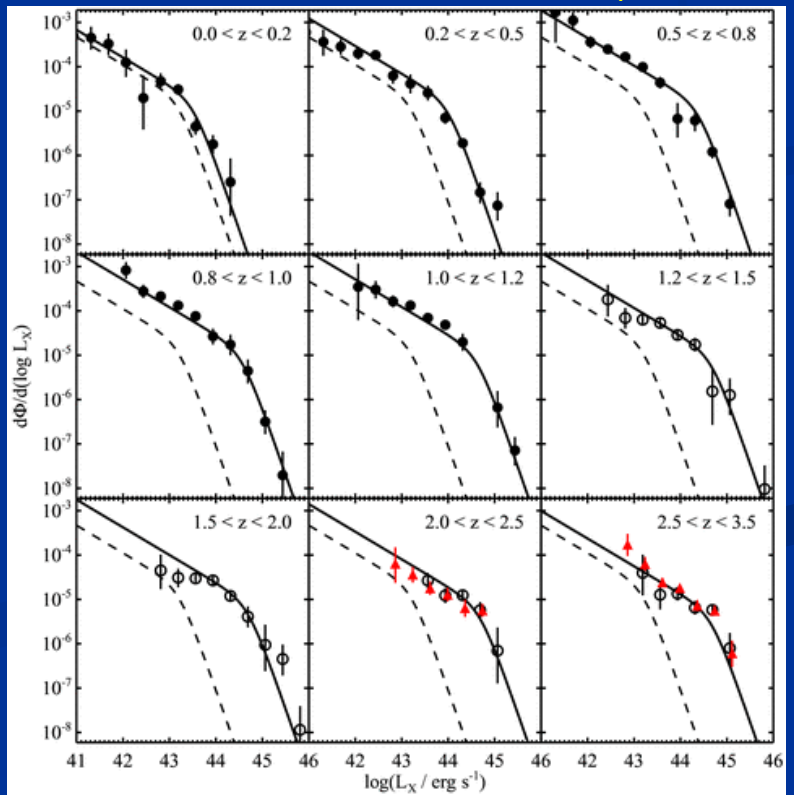
The evolution of LF of *Compton thin* AGNs

- The Luminosity Function of AGNs is the most important quantity to describe their cosmological evolution
- The Luminosity Dependent Density Evolution (LDDE) found by Miyaji+00 in the soft band (type-1 AGNs) and Ueda+03 in the hard band (type1+type2 AGNs) is confirmed in many works e.g., Hasinger+05, La Franca+05, Silverman+08, Ebrero+09, Yencho+09
- The Luminosity and Density Evolution (LADE) is proposed by Aird+10

U+03, LDDE



Aird+ 10, LADE



Most up-to-date luminosity function

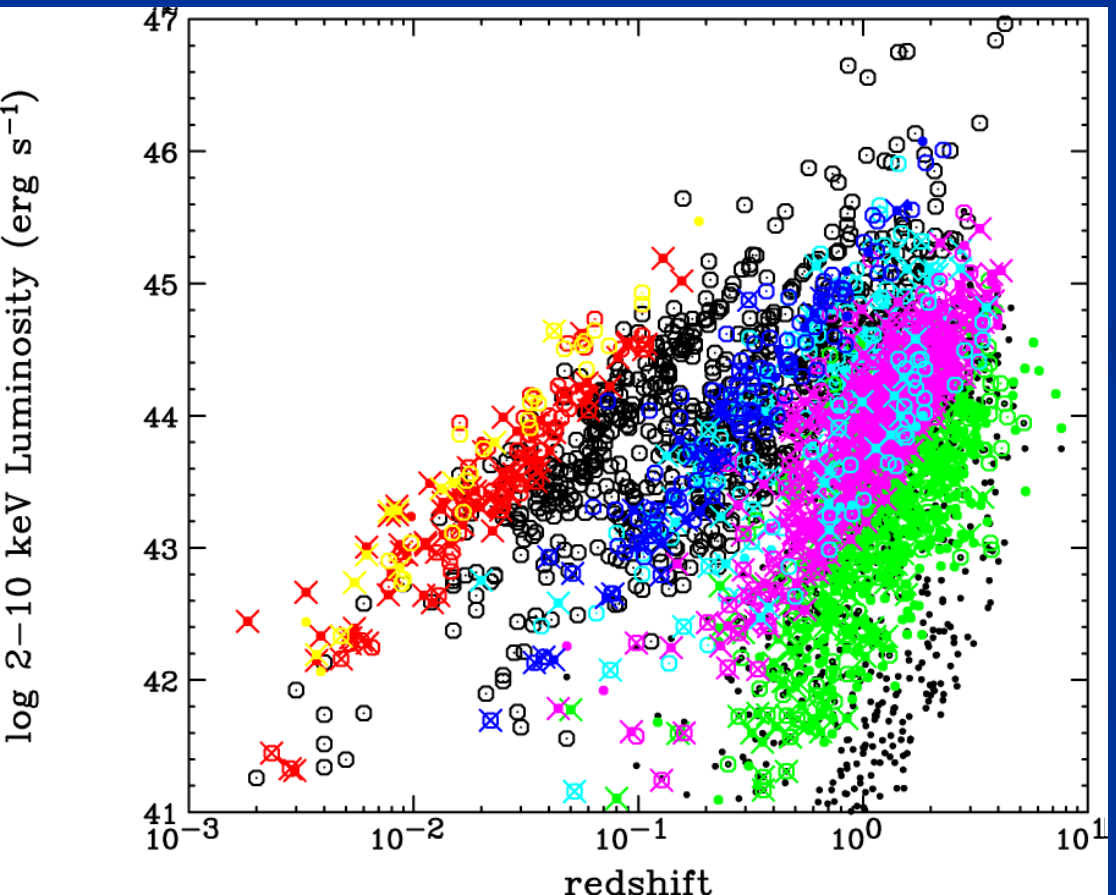
- Aims: best constrain the rest-frame 2-10 keV LF of all Compton thin AGNs using all the heritage of X-ray surveys with various depth, width, and energy bands (both >2 keV and <2 keV) performed up to date

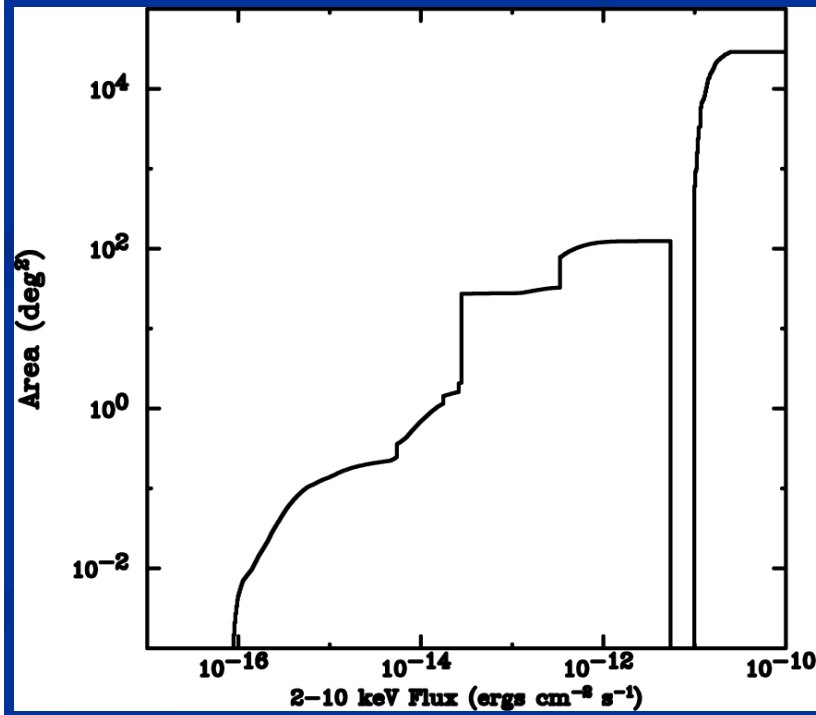
- Utilize only samples with high identification completeness (total >97%)
- *Unbinned maximum likelihood method* applied to the list of count rate and redshift by considering each "survey response".
- The LF is coupled with the absorption function, both are simultaneously constrained from the fit.

Hard band sample (1770 objects)

- Swift/BAT 9-month and MAXI 7-month
- ASCA (AMSS+ALSS)
- XMM (HBS + Hellas2XMM + Lockman Hole + SXDS)
- Chandra (CDFN 2Ms+ CDFS 4Ms+ CLASXS)

- + soft band sample (2339 objects) including ROSAT samples

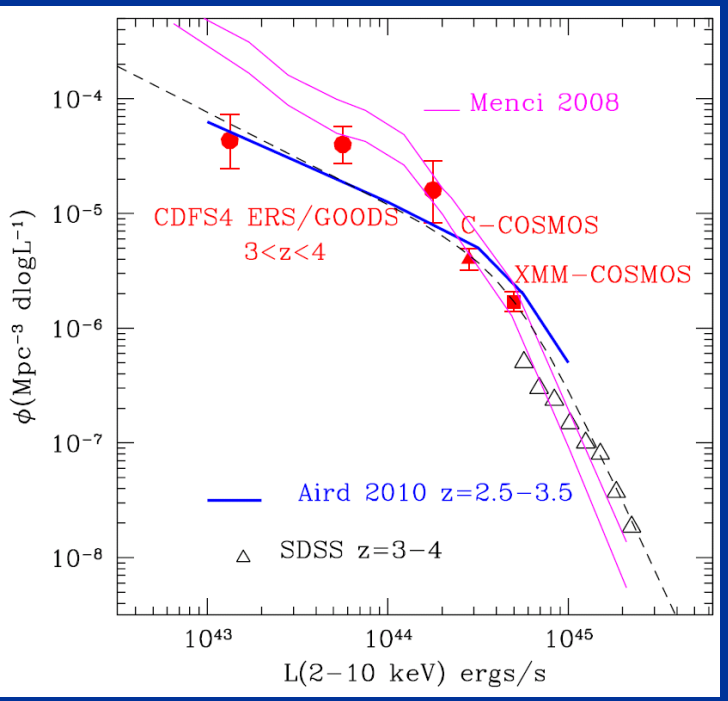


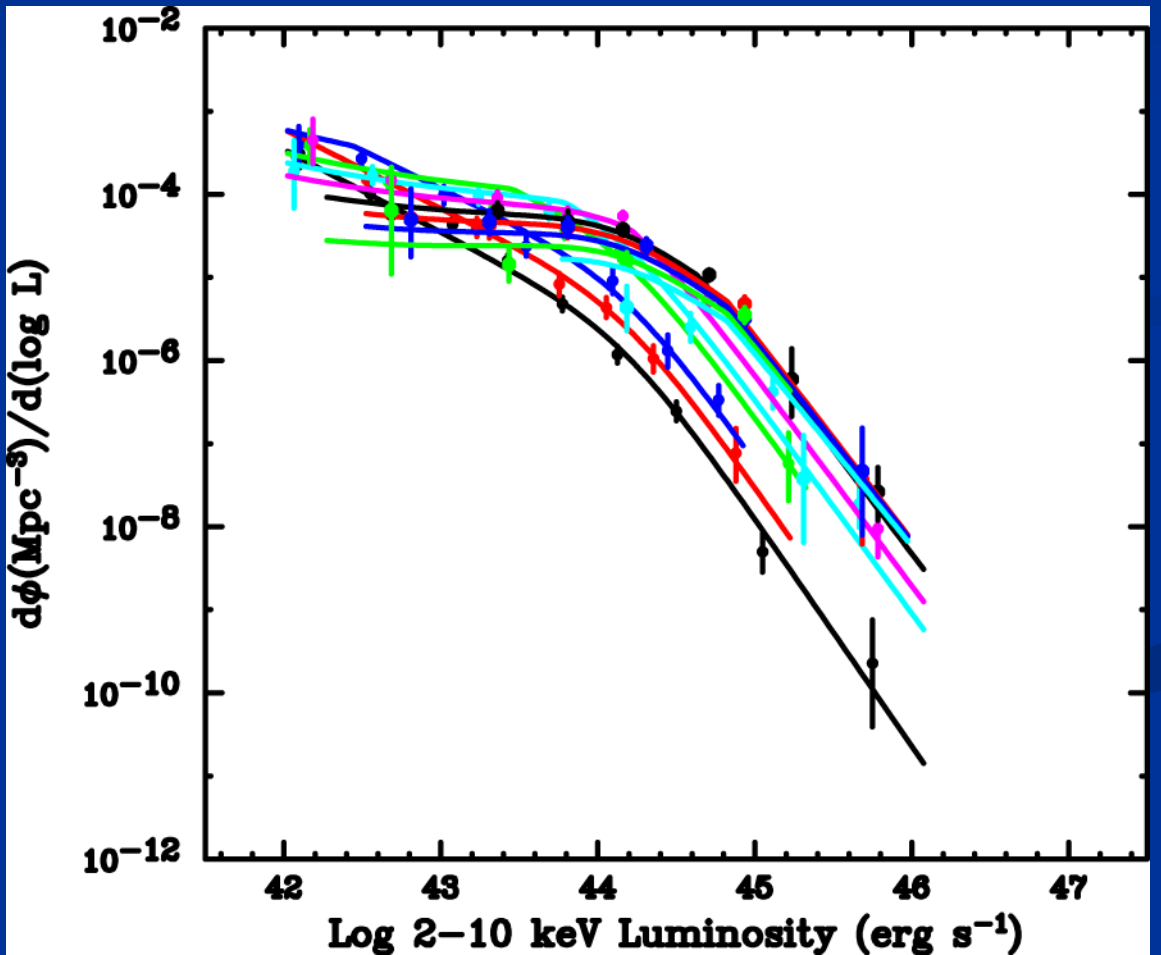


Results: 2-10 keV X-ray AGN LF

- LDDE preferred (flatter low-Lx slope at z>1)
- Effects by incompleteness and possible errors in photo-z must be further examined, however.

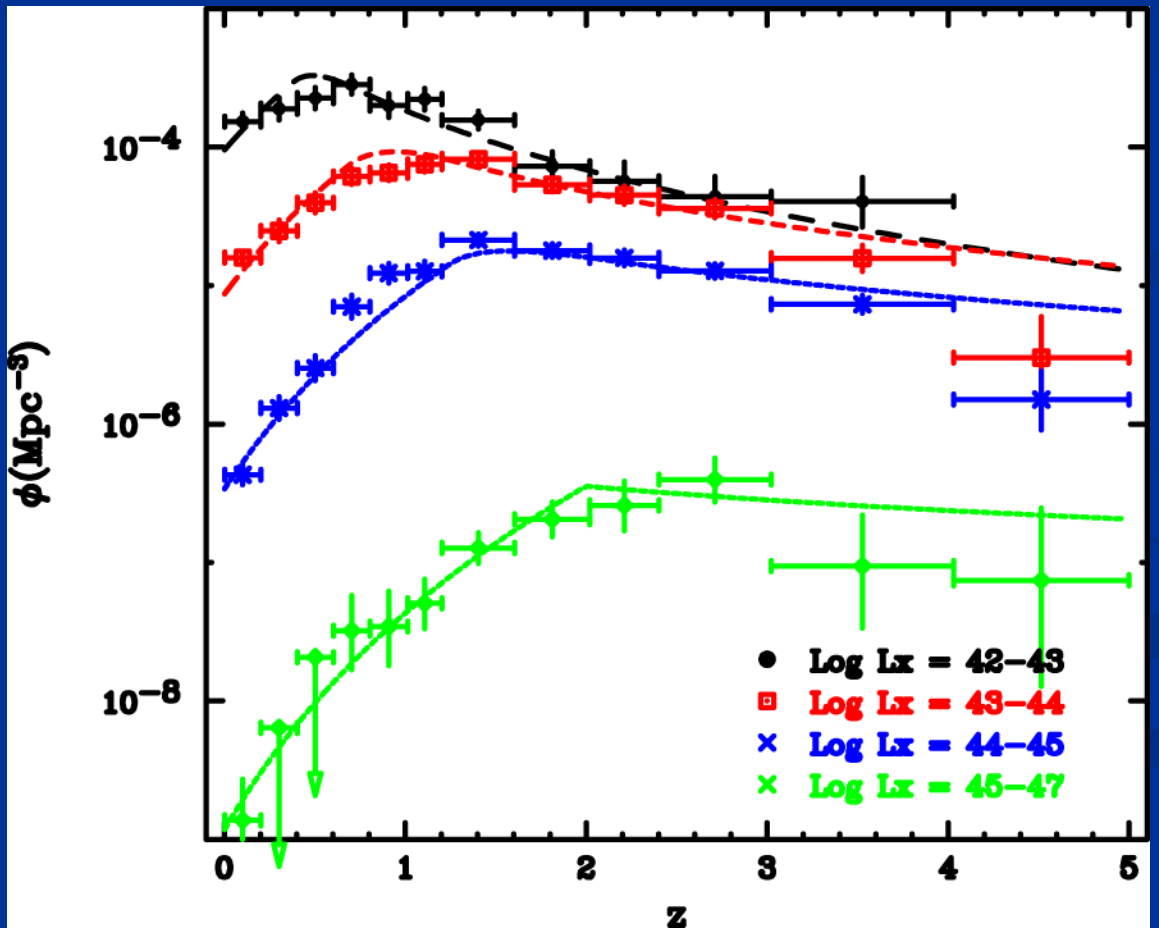
Fiore+ 11





Number density evolution

- AGNs with lower Lx have the number density peak at lower redshift: “Down sizing” or “anti hierarchical evolution” confirmed.
- Decay toward higher z is observed

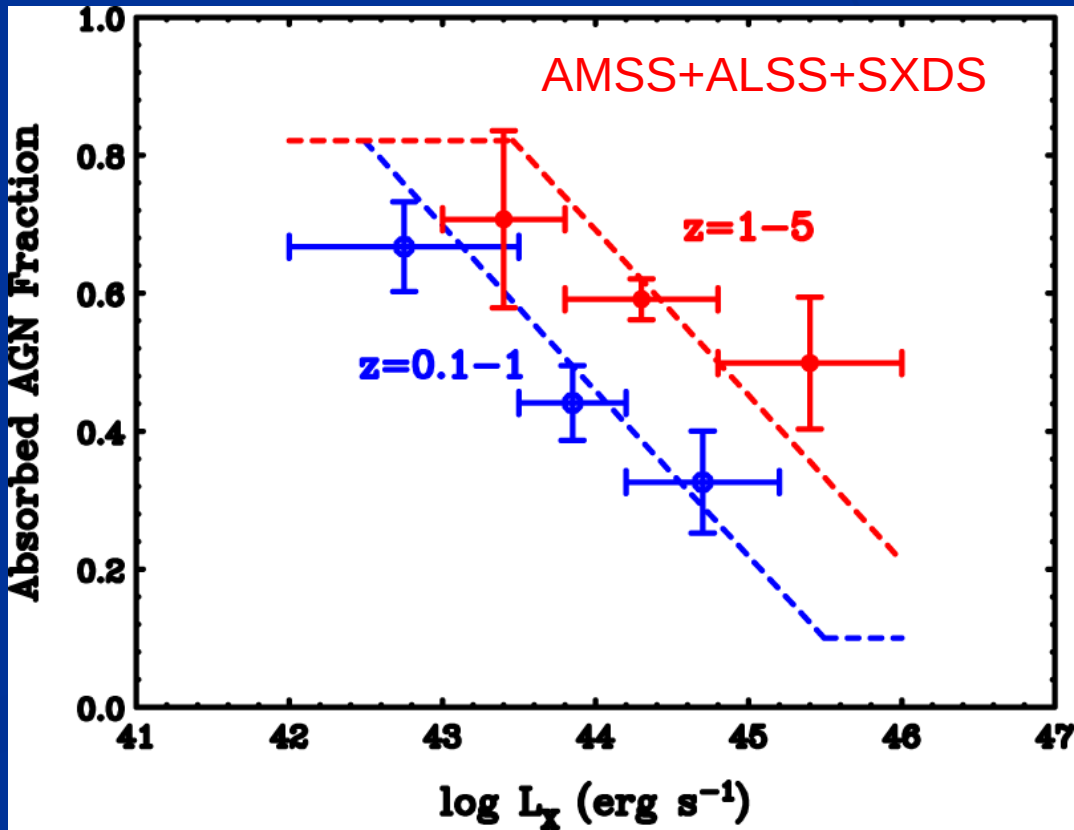


Absorbed fraction (Compton thin AGNs)

- This tells us the “averaged” opening angle of the torus of AGNs at a given epoch.
- Type-1 and type-2 objects are not necessalily the same population with different viewing angles, probably in different evolutional stage (eg, Page+04)

The absorbed AGN fraction increases with redshift as ~$(1+z)^{0.6\text{-}0.7}$ by keeping the known anti-correlation with the luminosity.

The trend reported by La Franca+05, Treister+07, Hasinger 08 is confirmed.



Major remaining issues in AGN evolution

1. Evolution of high-z (z>5) AGNs

   (skipped here, see Warren's talk)

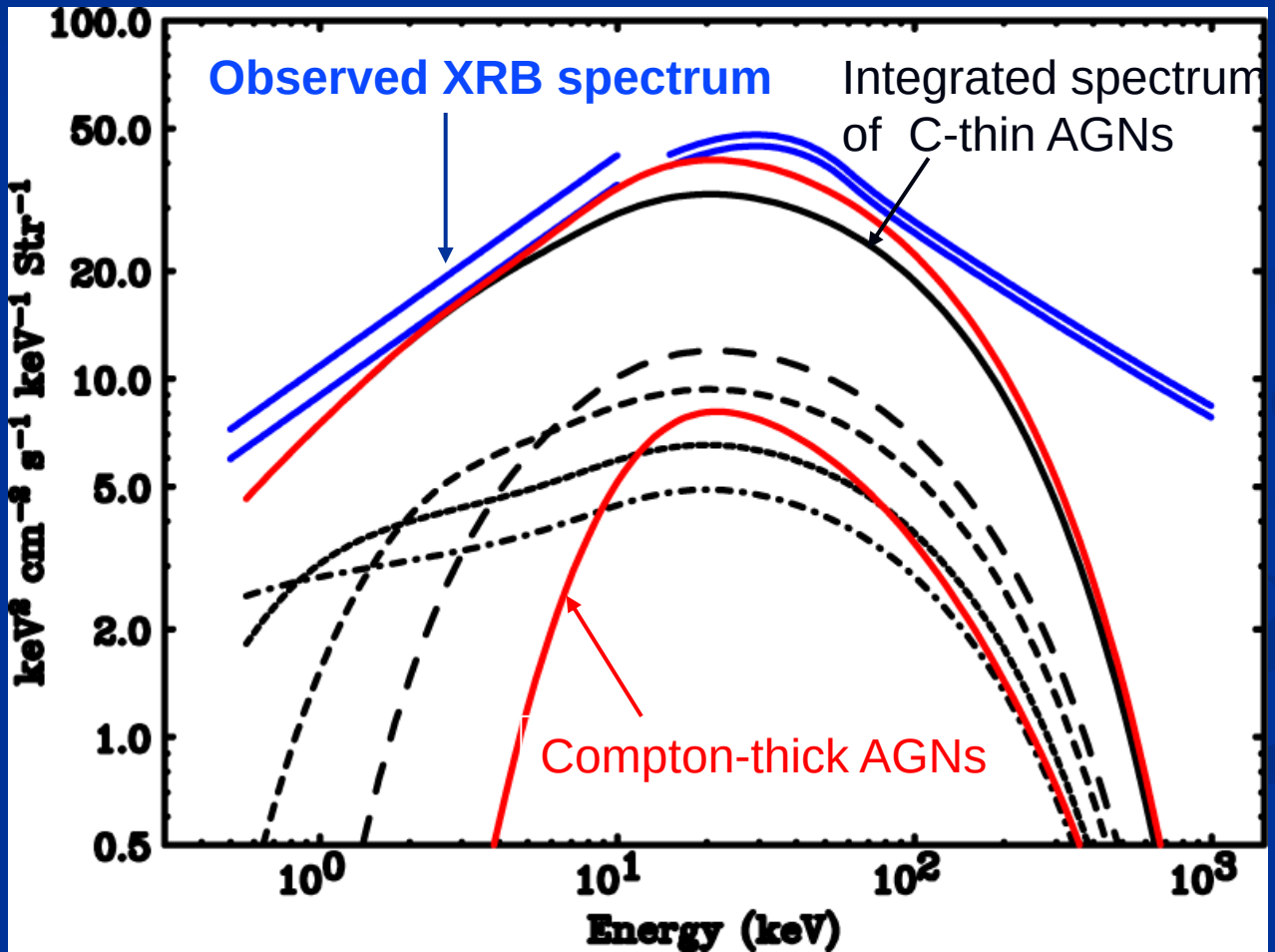
2. Evolution of Compton thick AGNs

   (see also Comastri's talk)

- While their contribution to the XRB is minor, it affects our understanding of the accretion history onto SMBH e.g., accretion mode (Treister+11)
- Key objects in rapid growth phase of SMBHs (Hopkins+06)
- Important targets in next generation X-ray astronomy (*NuSTAR, Astro-H*, *eROSITA*)

The constraint from the XRB

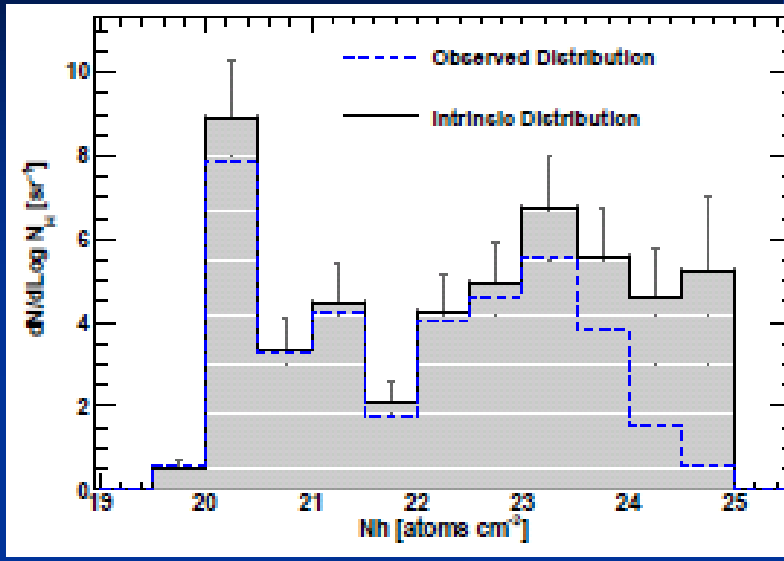
- Although the absolute intensity of the XRB at 30 keV seems to be settled (eg, Ajello+ 09), it is hard to accurately constain the minor population whose contribution to the XRB is <10%
- The fraction of Compton thick AGNs is coupled with the reflection strength of Compton thin AGNs (assumed to be Ω=π for both type-1 and type-2 AGNs here)



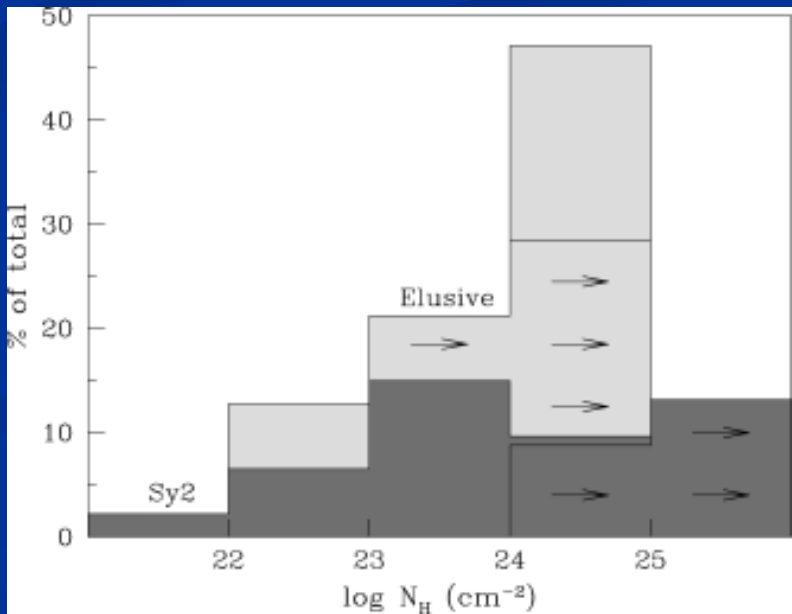
Compton thick AGNs in the local universe

- Even hard X-ray surveys above 10 keV have bias against absorption if Compton thick
- Intrinsic CT AGN fraction is ~20%
- Follow-up observations of [O III] selected or IR selected galaxies suggest even a larger fraction (Risaliti+99, Maiolino+03)
- These heavily CT AGNs can be detected by *eROSITA* surveys as those with reflection dominated spectra

Burlon+11



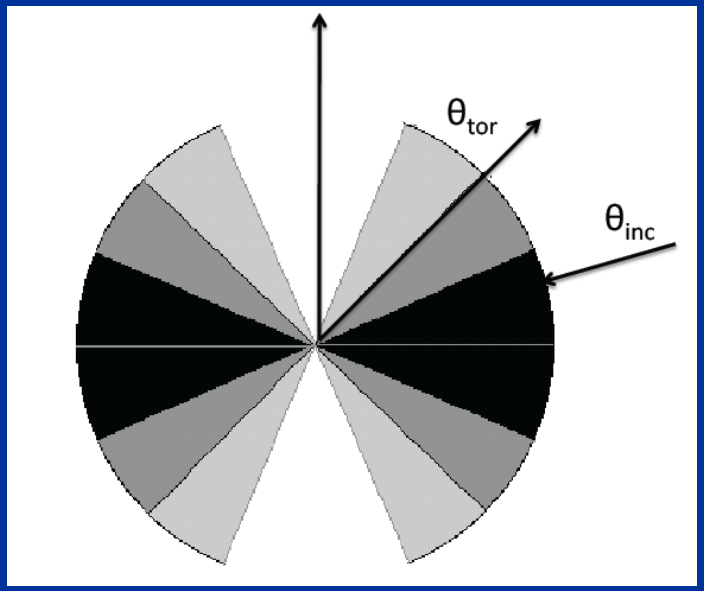
Maiolino+03

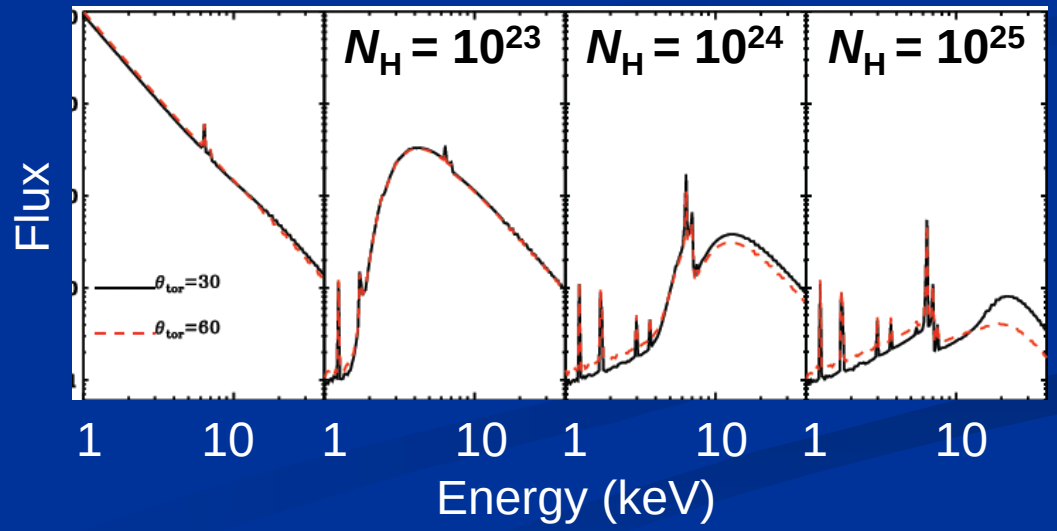


Compton thick AGNs at high z
(1) X-ray selection (Brightman&Ueda, submitted)

- The spectra of CT AGNs are complex
- Systematic application of Monte Carlo based "torus model" to the spectra of CDFS X-ray sources
- Determine the best fit torus geometry for each AGN for obscured objects

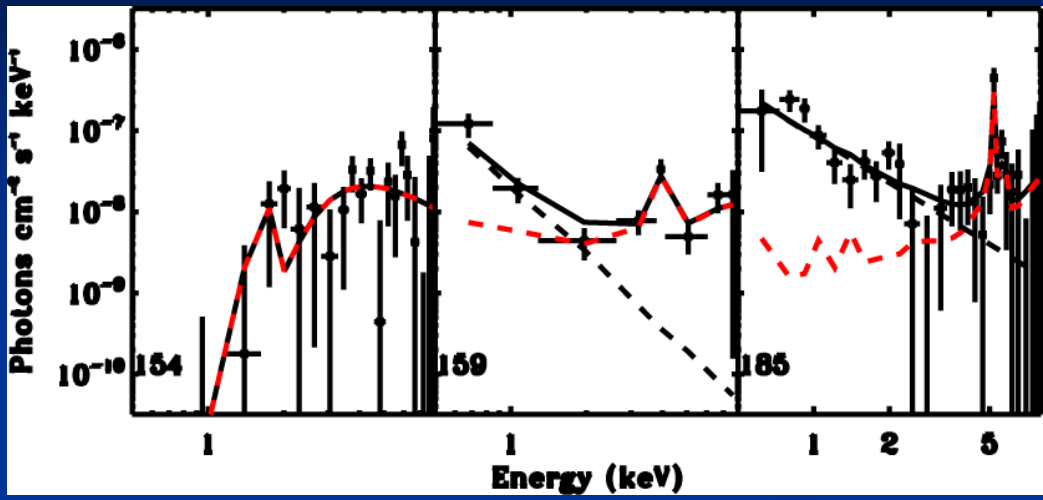
Simulated Spectra by Brightman&Nandra+11 model

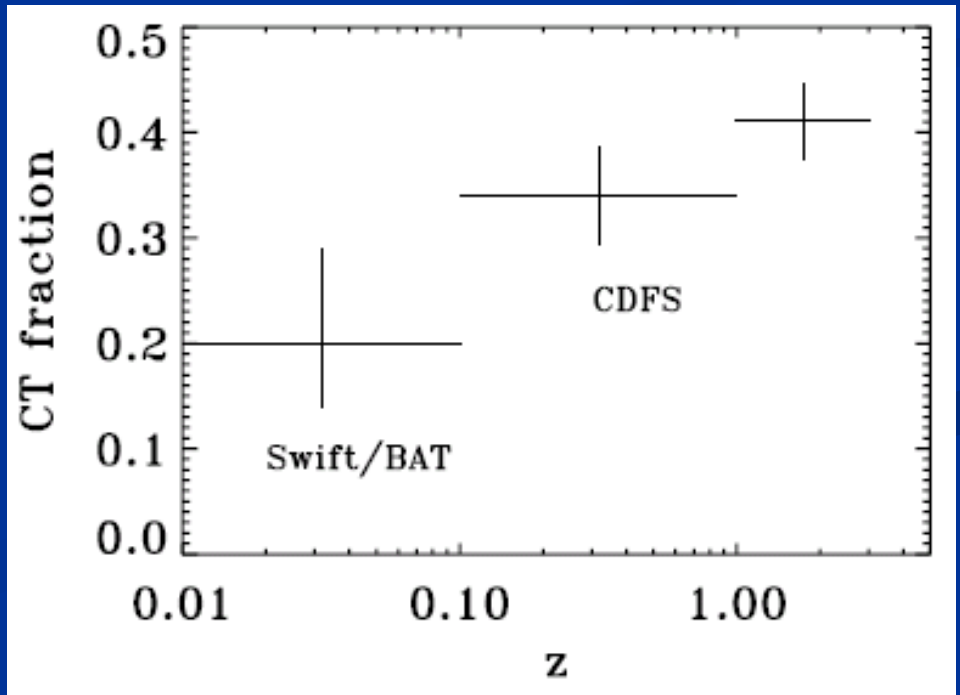




Compton thick AGNs at high z
(1) X-ray selection (Brightman&Ueda, submitted)

- ~40 CT AGN candidates
- Even though it is difficult to firmly identify individual CT AGNs with limited photon statstics, we can constrain the “CT fraction” in the total AGNs by correcting for incompleteness from comparison with simulation.
- CT AGN fraction increases from 20% (z~0) to 40% (z~2), consistent with the evolution of absorbed fraction.

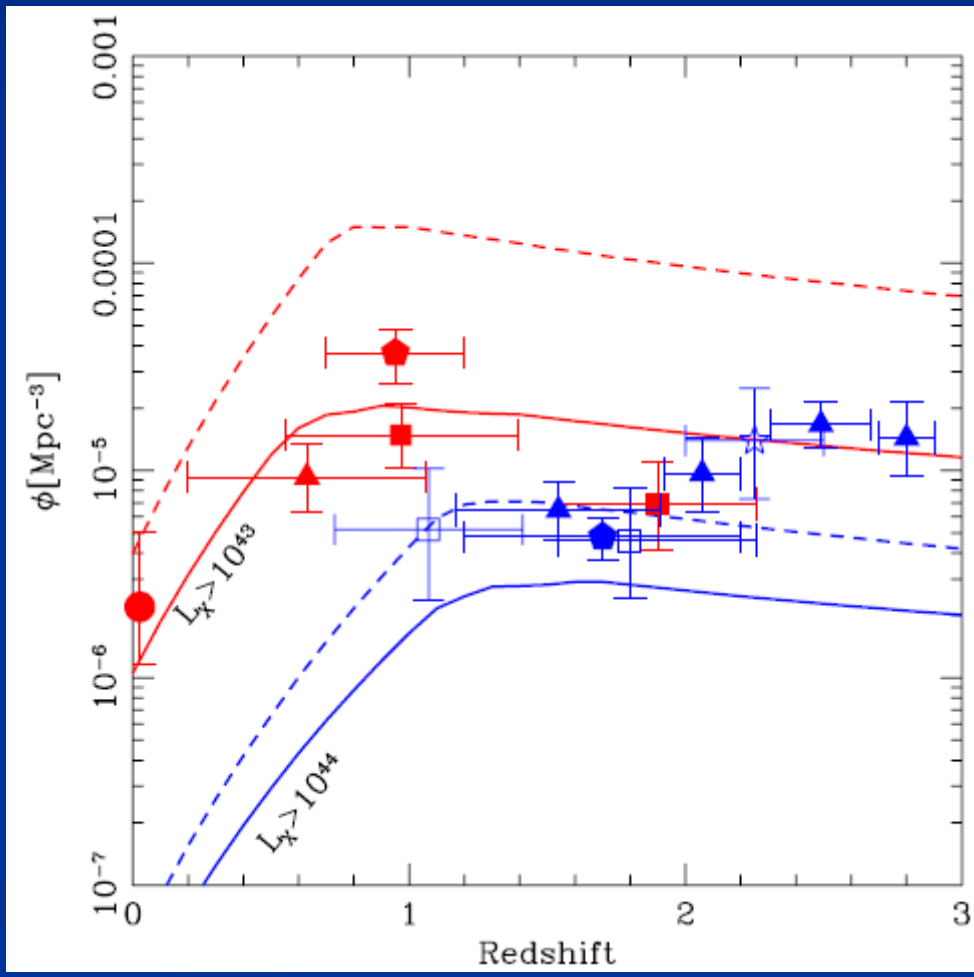




Compton thick AGNs at high z
(2) MIR selection (eg, Daddi+07, Fiore+08, Treister+09)

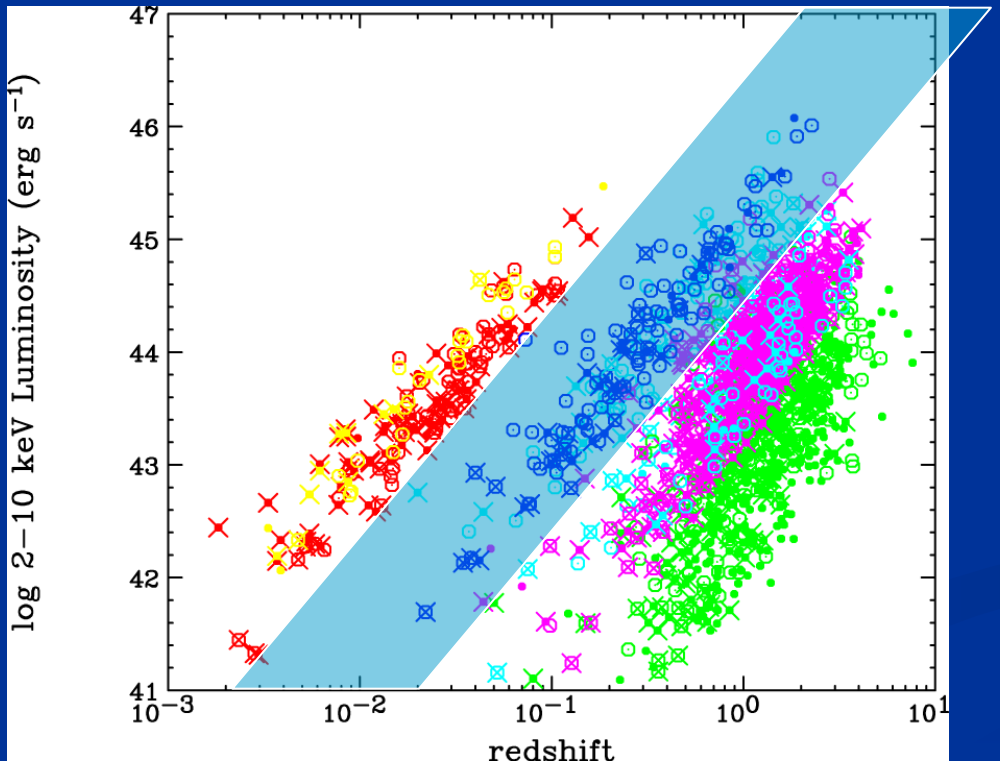
- Larger fraction of X-ray undetected “heavily CT” AGNs is suggested from stacking analysis of MIR excess galaxies, although derived number density depends on assumptions.
- If restricted to X-ray detected AGNs, the CT fraction becomes moderate (Georegeantopolous+11)
- CT QSOs may be the pre-phase before unobscured QSOs? (Treister+10)

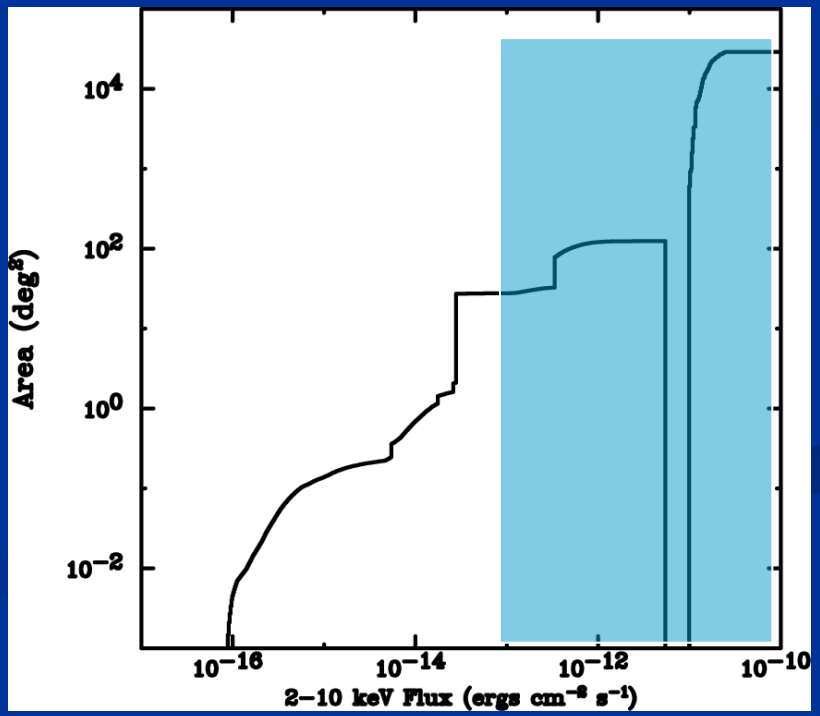
Treister+ 09



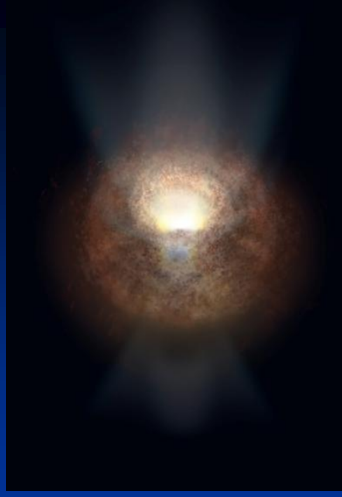
Prospects for eROSITA

- Establish the statistical properties of AGNs in the present "survey flux gap" in the 2-10 keV band at 10^{-11}~10^{-12} cgs
  - XMM Slew Survey (Saxton+ 08) is also important .
  - Systematic survey of reflection dominant CT AGNs in the local universe (hard X-ray imaging surveys are too narrow)
- Detect *rare* objects
  - luminous QSOs (Lx>$10^{45.5}$ erg s^{-1}) , rapidly growing BHs, transient AGNs





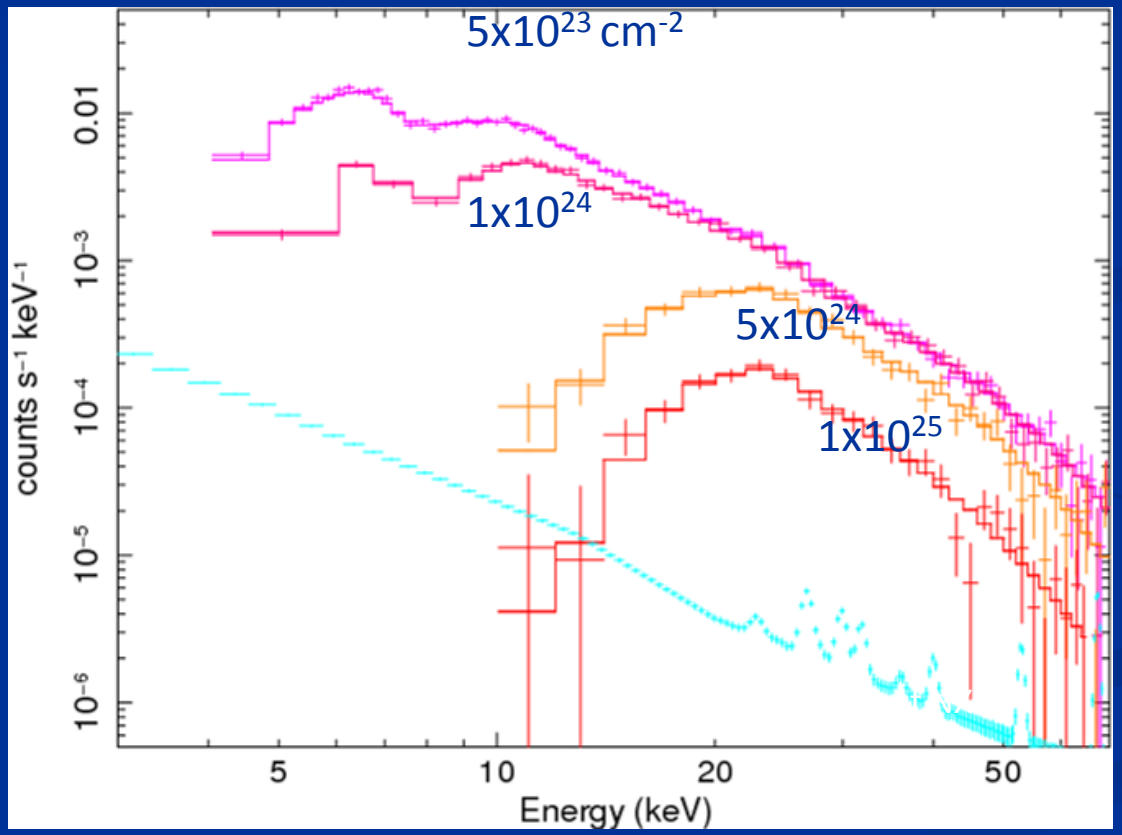
NuSTAR/Astro-H can detect VERY Compton-thick AGN



NEW type AGN: Swift J0601: N_H~1x10^{24} cm^{-2}; F2-10(intrinsic) = 1x10^{-11} cgs

Assumption: log N_H = 25 if viewed from edge-on

photon index1.9; No reflection component.



Astro-H HXI
(c: Terashima
& Astro-H team)

100 ksec

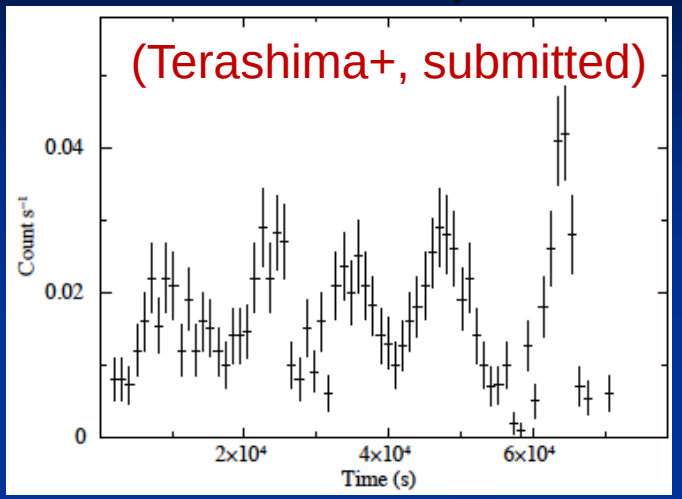
(300 ksec for 1x10^{25})

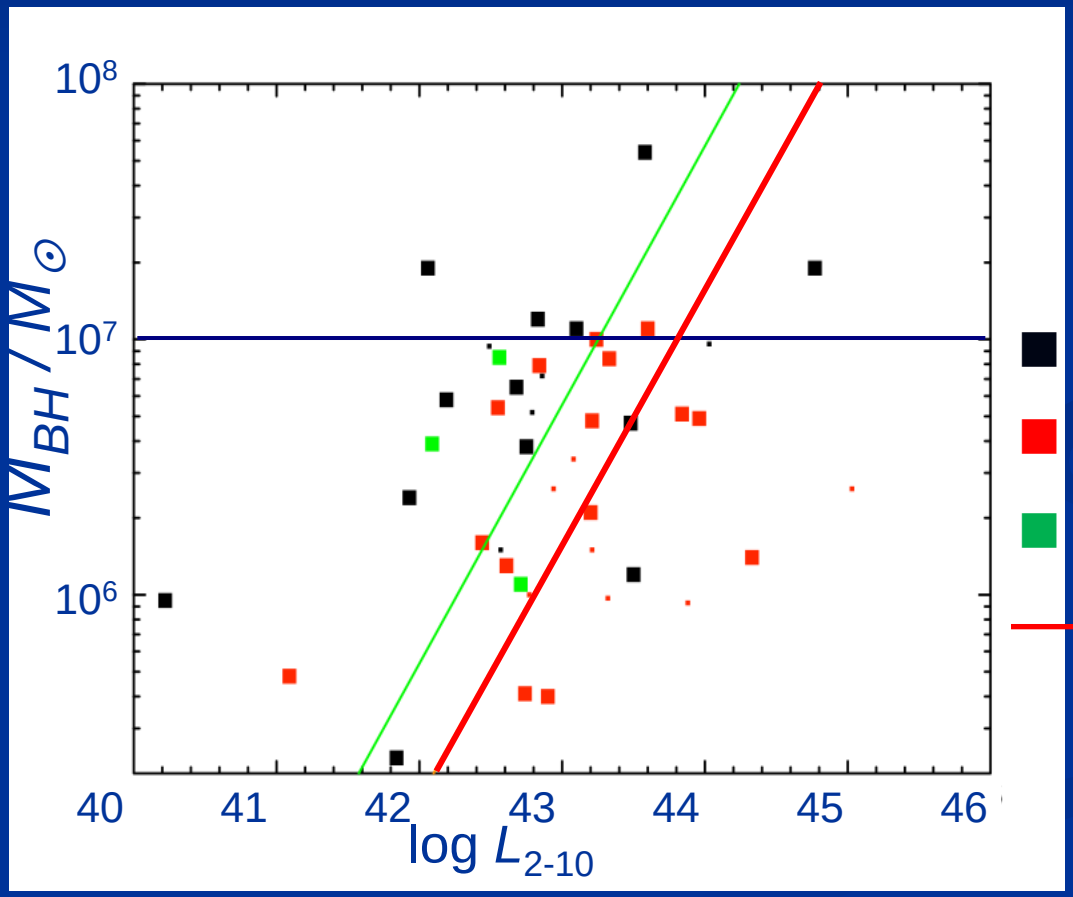
Scattered emission and
Fe line not included.

Buried very Compton thick AGN detectable at >10 keV

Variability Selected AGNs from 2XMM catalog (Kamizasa+ submitted)

- Probability of constant flux $<10^{-5}$
- 40 AGNs out of of $\sim 10^4$ found





Sy1 + Sy2 + QSO

NLSy1

Unclassified AGN

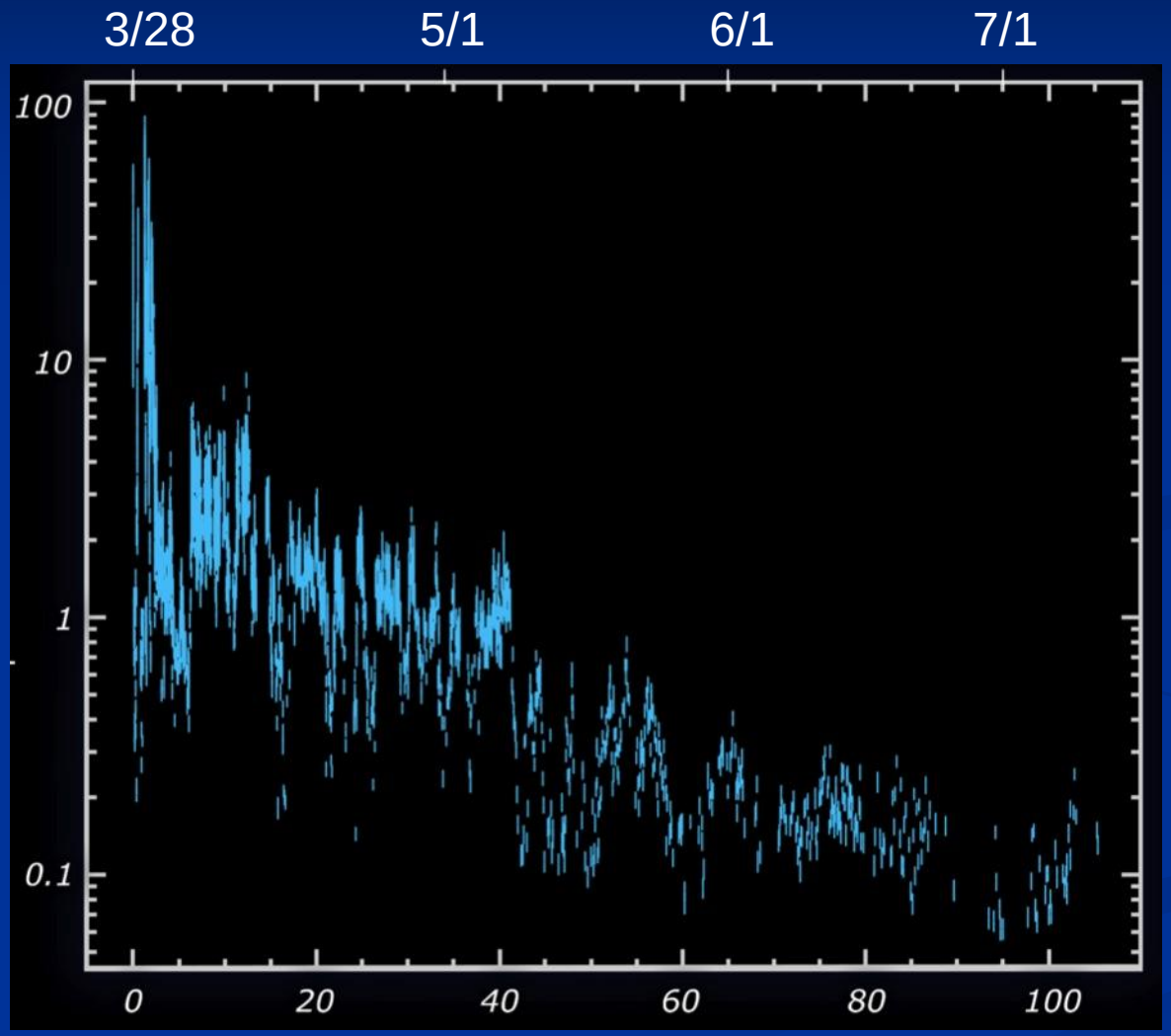
Eddington luminosity

5 objects: $<10^6$ Msolar

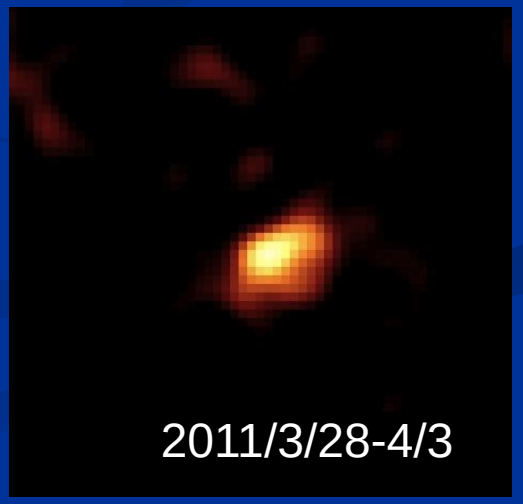
8 objects: SuperEddington

At least > 0.1 % AGNs are super Eddington AGNs

Tidal disruption event onto a SMBH: Swift J1644+57 (Burrows+ 11)



MAXI image



Summary

1. The eROSITA survey will fill the survey flux gap in the 2-10 keV band

2. Very useful to establish the statstical properties of the whole AGN population including heavily Compton thick AGNs

3. Unique chance to detect rare objects e.g., luminous QSOs, rapidly growing SMBHs