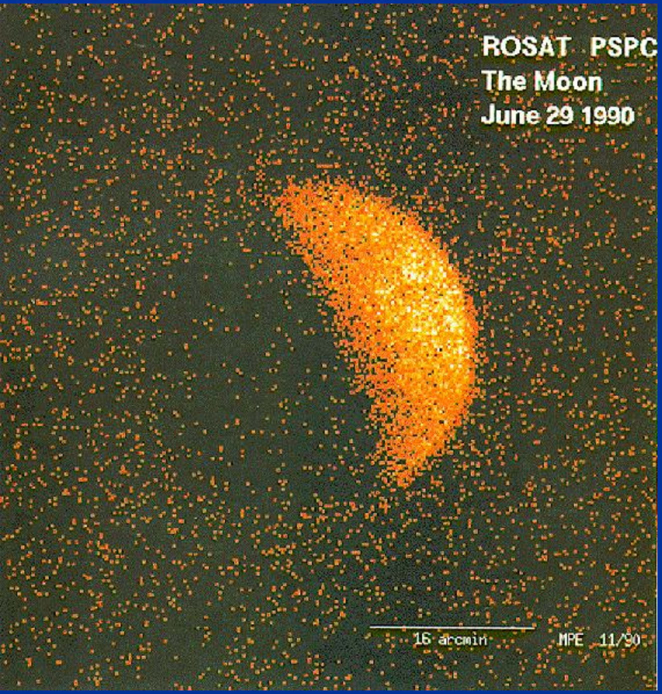
Cosmological Evolution of X-ray Selected AGNs and Synthesis of the X-ray Background

Yoshihiro Ueda

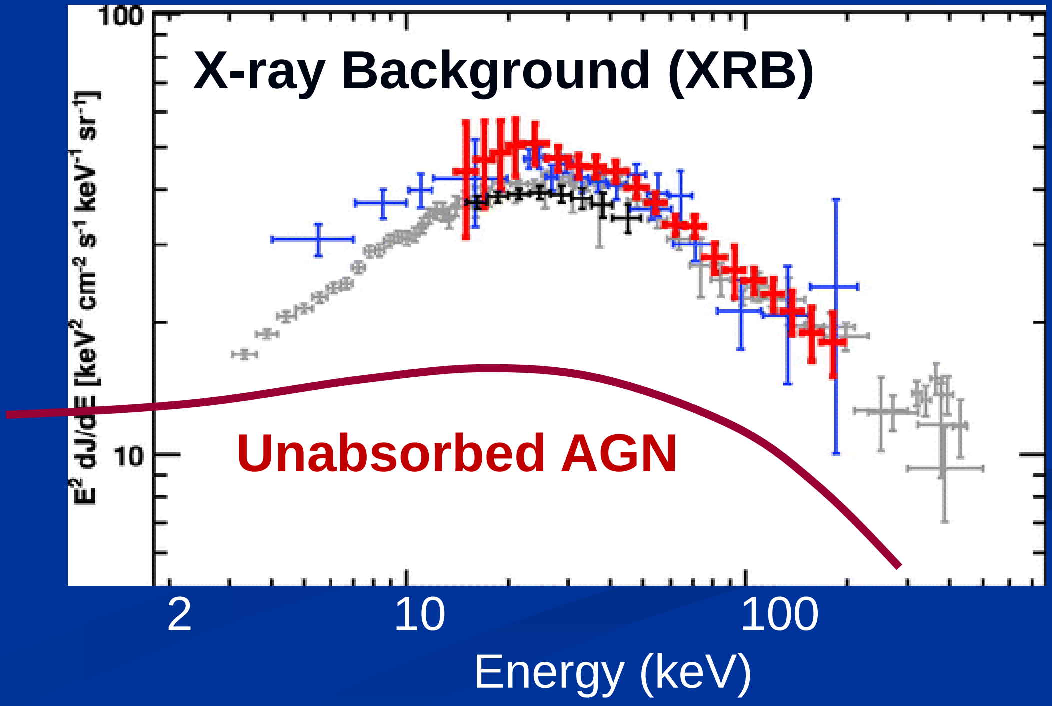
Kyoto University

The X-Ray Background (XRB or CXB)

- The XRB is the integrated eission from all the AGNs in the universe, telling us the growth history of supermassive black holes.
- The energy density peaks at ~30 keV
- The shape of the XRB indicates that *most of the AGNs are obscured.*
- The 2-10 keV band is much better than 0.5-2 keV, but above 10 keV is the best energy band to detect obscured AGNs including Compton thick (CT) ones (log N_H >24), whose contribution is yet uncertain.

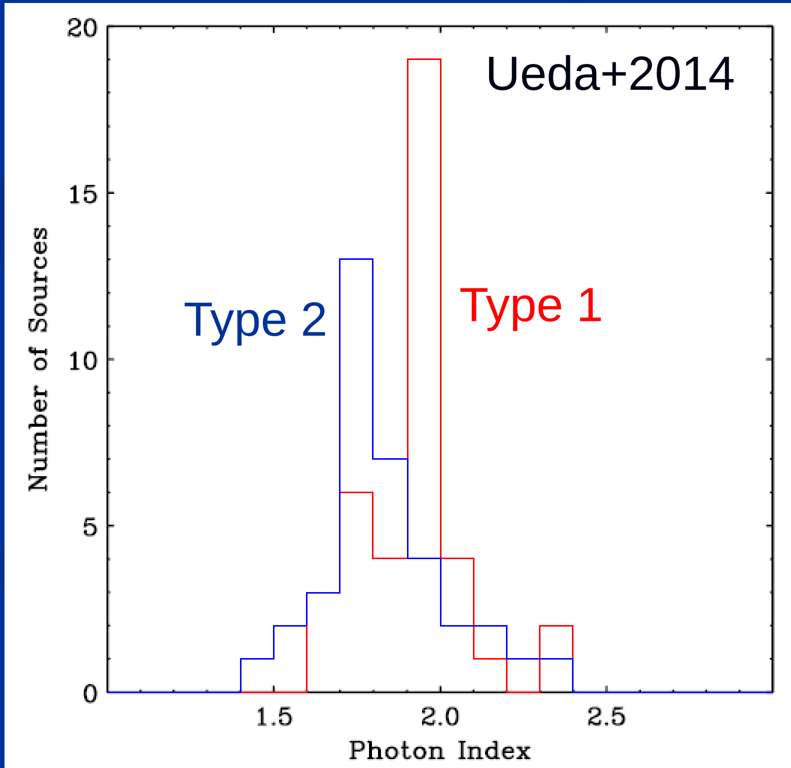


Ajello+ 08



How the XRB constrains the obscuration properties of AGNs?

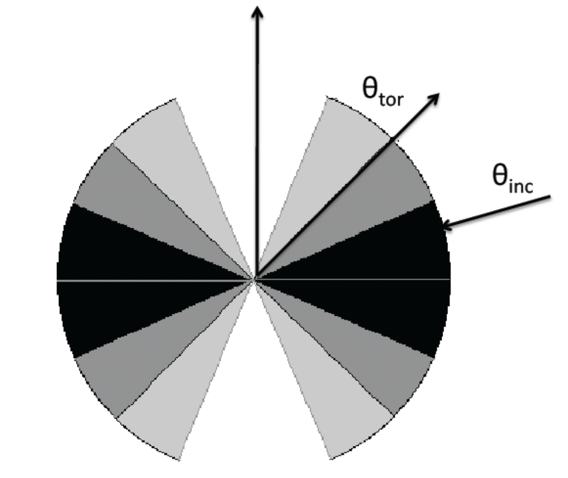
- The XRB spectrum just gives only an boundary condition
  - It is easy to construct a "population synthesis model" as there are many free (poorly constrained) parameters
- Key elements
  - Comoving space number density (L_X, z) or Luminosity Function
  - Absorption Distribution Function or N_H Function including CT AGNs
  - X-ray broad band spectra including
    - photon index distribution (Ricci's talk)
    - reflection components from the "torus" and accretion disc



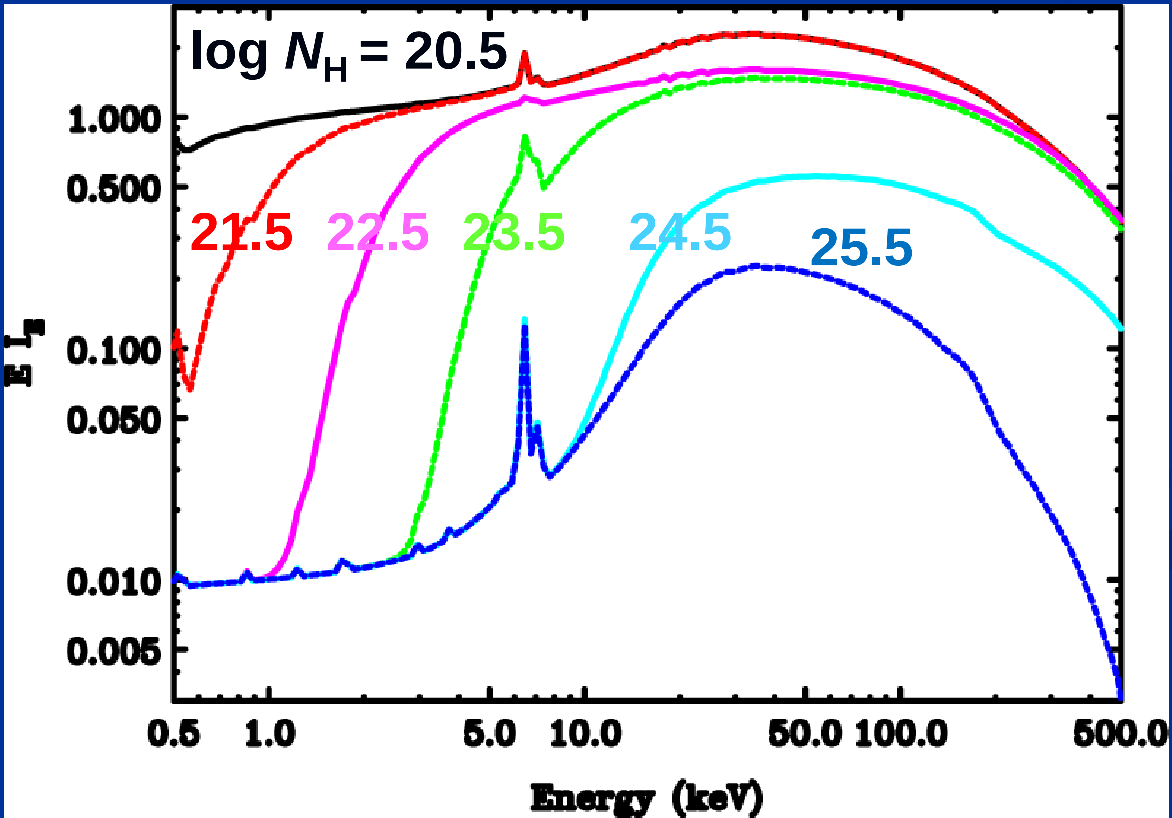
Effect of Obscuration

- X-ray spectra become "hard" by photoelectric absorption
- Even hard X-rays above10 keV are suppressed when heavily Compton thick (N_H > a few 10^{24} cm^{-2})
- CT AGNs show complex spectra (reflection dominant below 10 keV): *need physically self-consitent spectral models !*

Brightman&Nandra+11



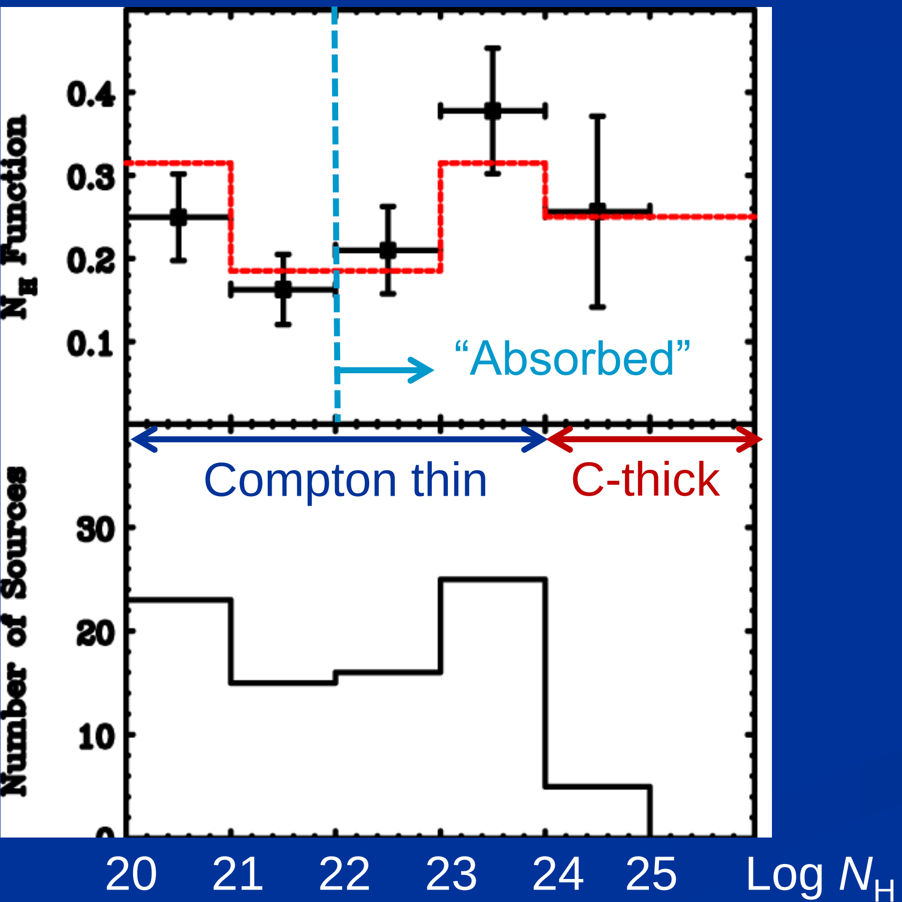
Ueda+14



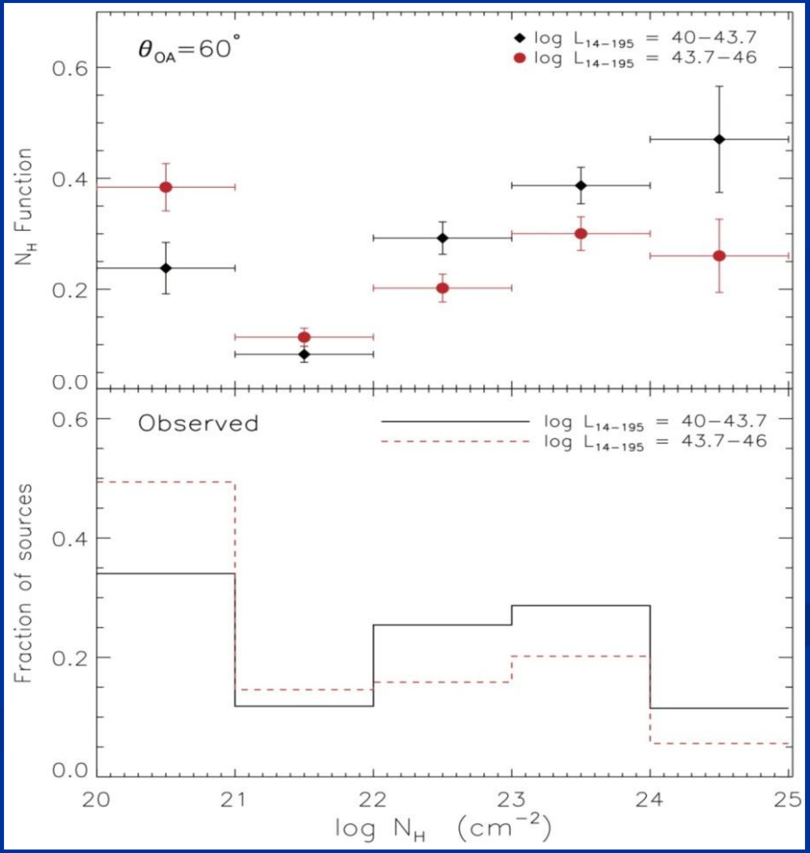
Absorption distribution in the local universe

- Swift/BAT, INTEGRAL with follow-up by Suzaku and other observatories: absorbed AGNs dominant
- Intrinsic CT AGN fraction in total AGNs is ~30% (cf. observed ~6-8%) if N_H function is extrapolated to $N_H = 10^{26}$ cm^{-2}

Swift/BAT 9-month (Ueda+ 14)

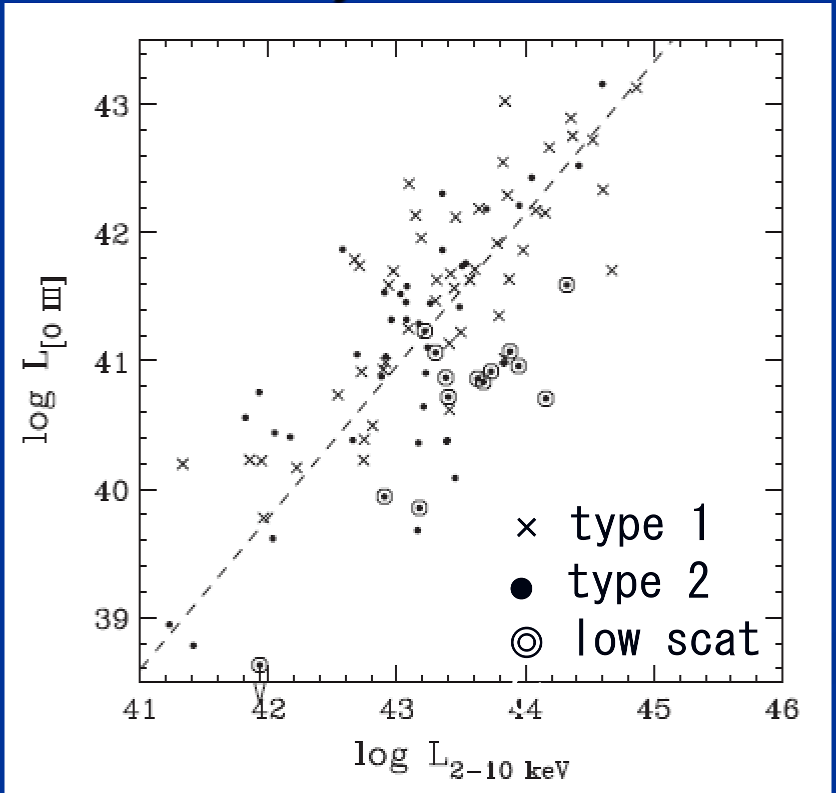


Swift/BAT 70-month (RIcci+, submitted)

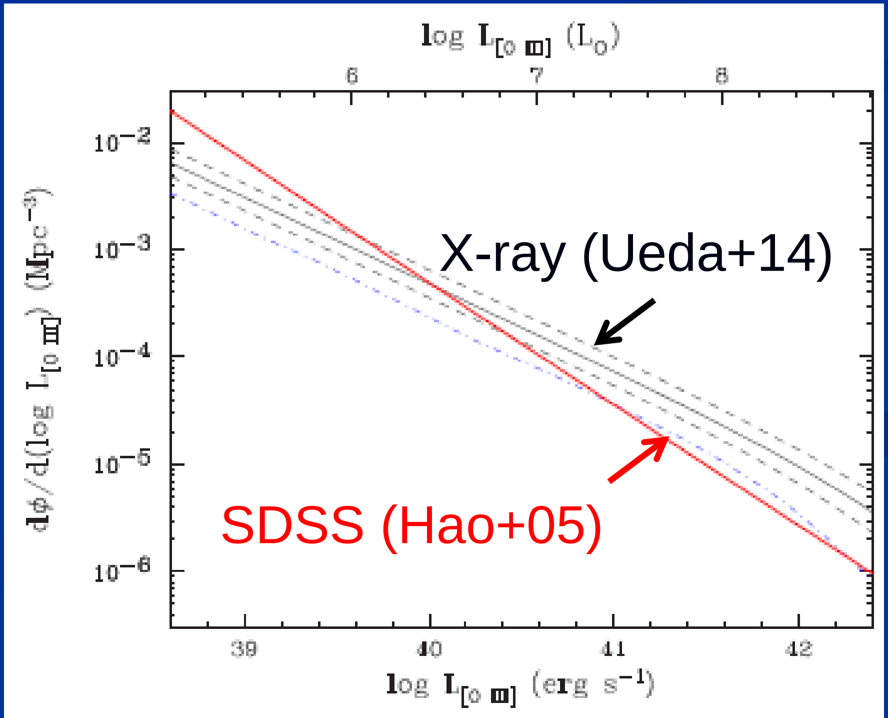


Hard X-ray vs [O III] selections

- Optical spectroscopy of a complete sample of Swift/BAT 9 month AGNs (see also Berney+15, submitted)
- Good correlation but with a large scatter
- AGNs with low X-ray scattering fraction show small $L_{[O\ III]}/L_x$, consistent with some being deeply buried in the torus
- Hard X-rays do not miss many AGNs !!



Ueda+15 submitted

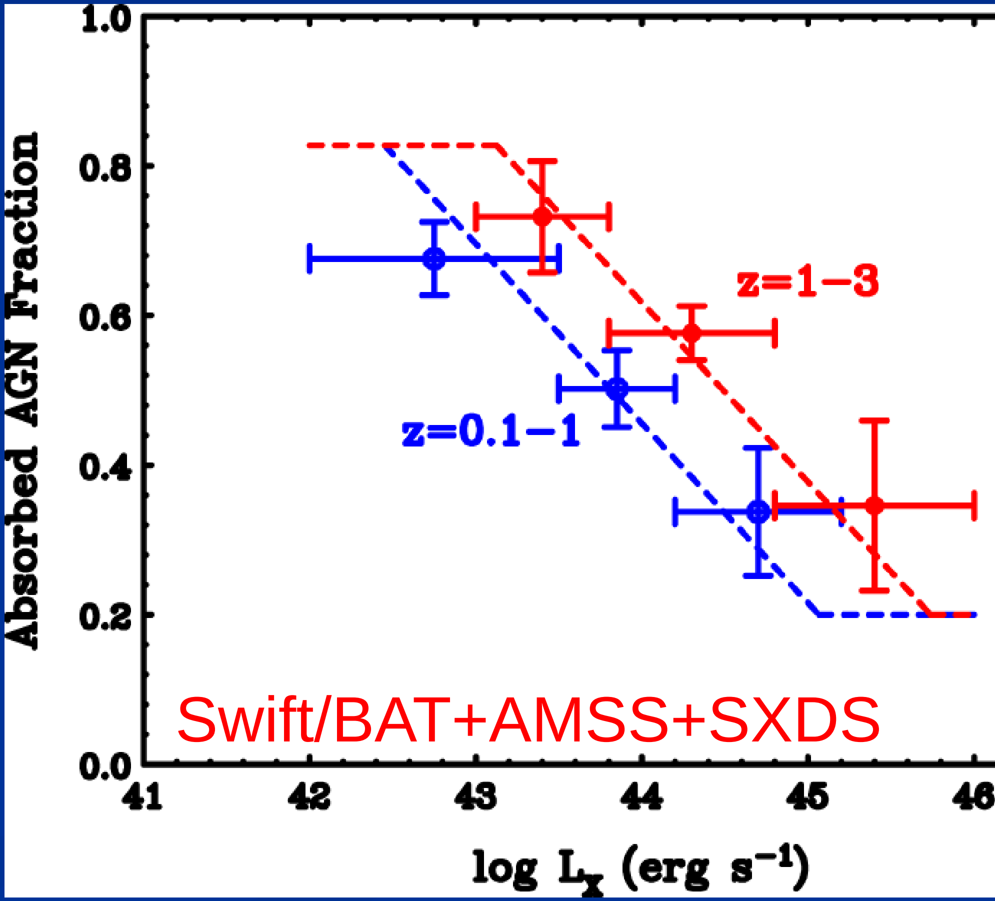


Absorbed Fraction (Compton thin AGN)

"Luminosity and Redshift Dependent Unified Scheme"

- The absorbed AGN fraction increases with redshift as $\sim(1+z)^{0.5\text{-}0.6}$ by keeping the known anti-correlation with the luminosity
- Confirming the evolution trend reported by e.g.,
  La Franca+05, Hasinger 08
  (Hiroi+12, Iwasawa+12
  for high luminosity AGNs)
- Type-1 and type-2 AGNs may be distinct populations in different evolutionary stage of galaxies
  (eg Page+04)

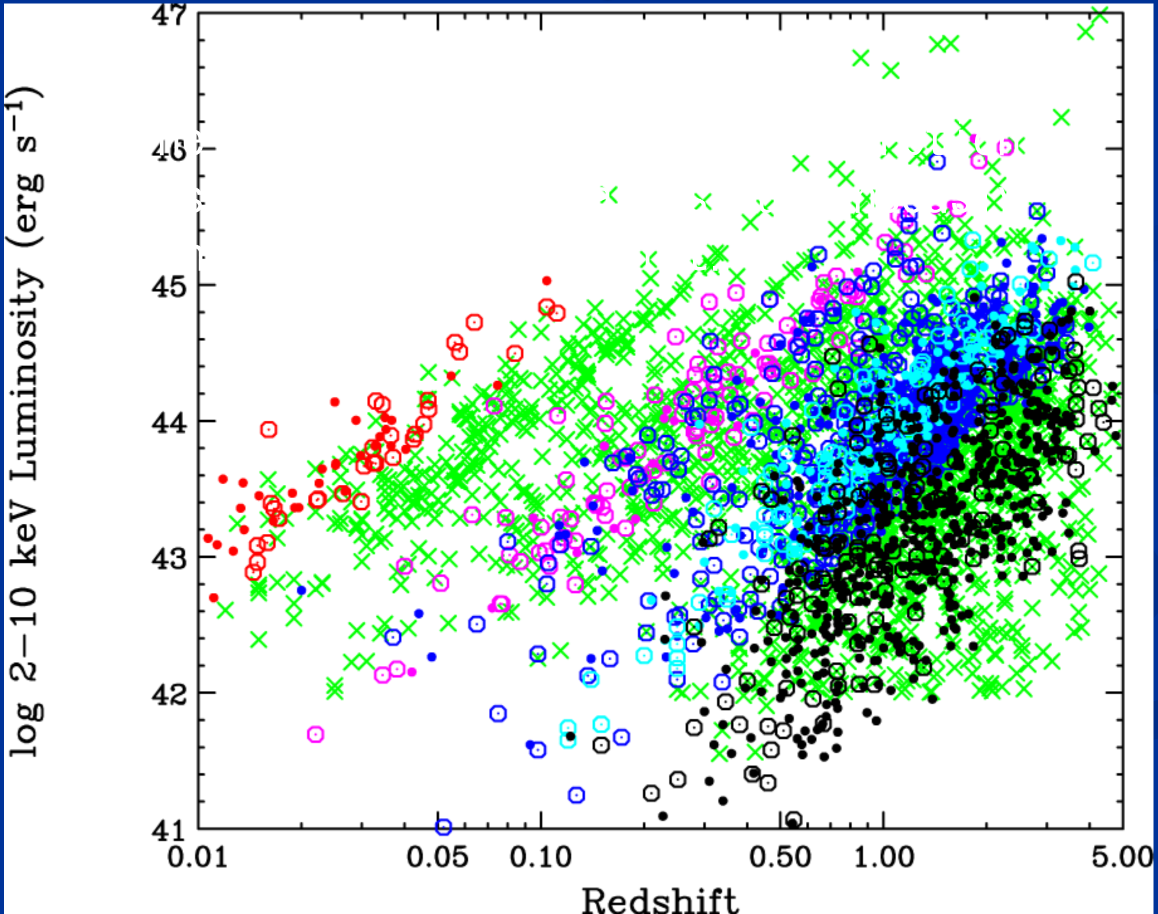
Ueda+ 14



AGN X-ray Luminosity Function (Ueda+14)

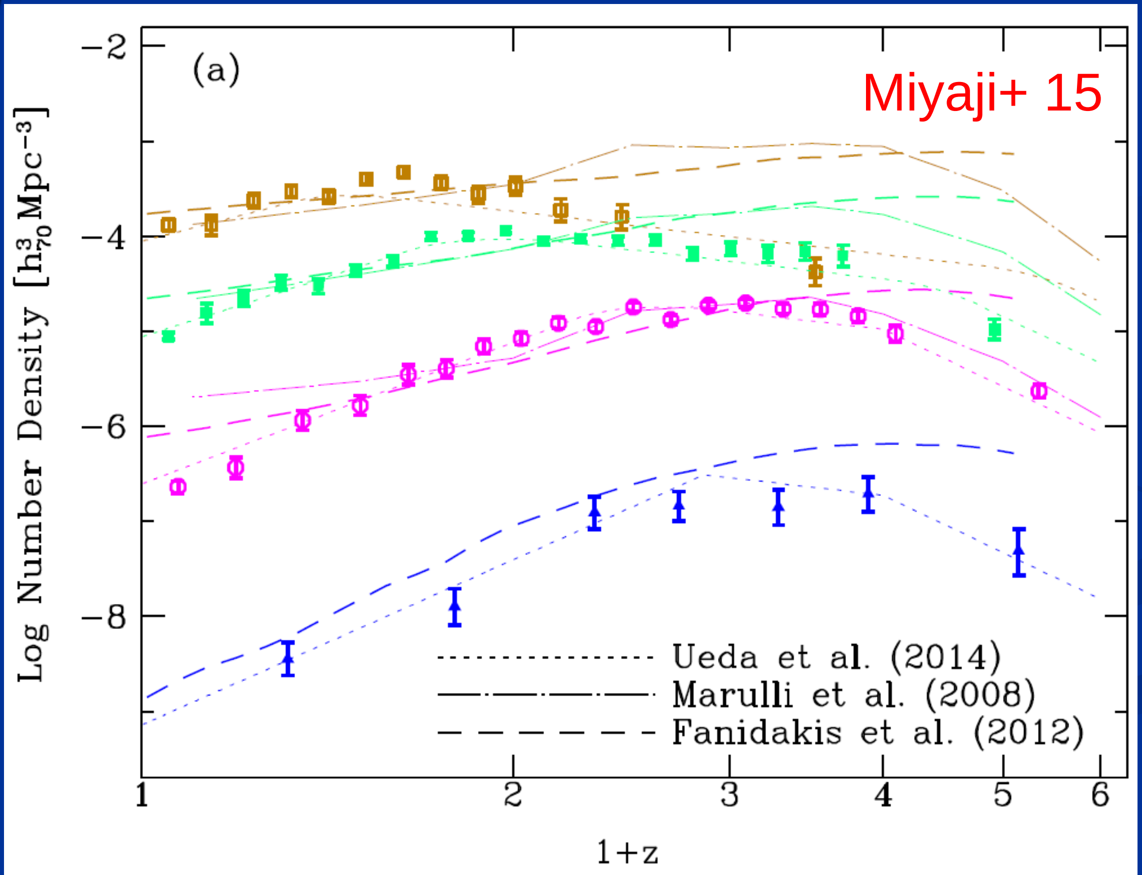
(see also Buchner+15, Miyaji+15, Aird+15)

- "Multi-cone" X-ray surveys with different depth, width, and energy bands. Utilize only samples with high identification completeness (total >97%)
- LF is coupled with the absorption distribution (including CT AGNs), both are simultaneously constrained from the fit.



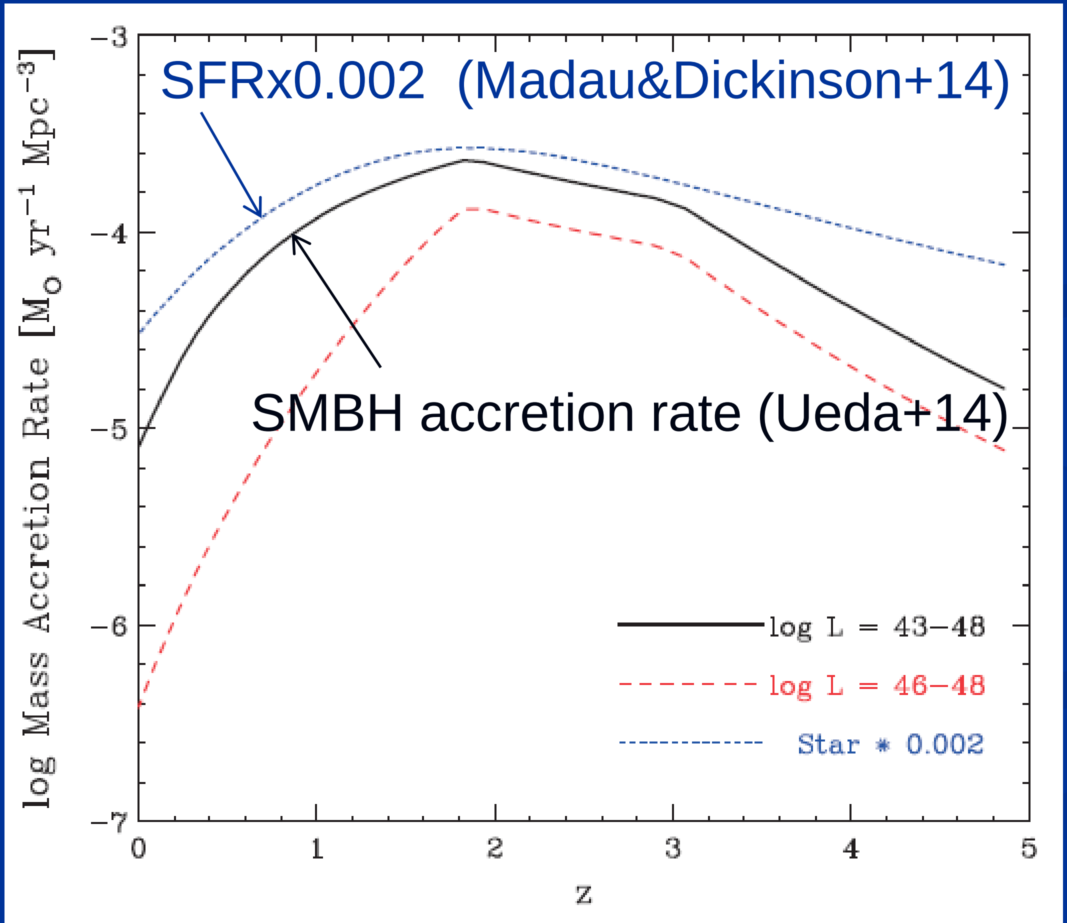
Number density evolution

- AGNs with lower Lx have the number density peak at lower redshift (“Downsizing” or “anti-hierarchical evolution”)
- Theoretical models overpredict the space density at high z and low L_x than observed (or many CT AGN missing there?)
- Two different modes in AGN fueling? (major merger for trigger luminous AGNs + another process for low luminosity AGNs?)



Accretion vs Star Formation History

- The overall history of mass accretion rate onto SMBHs and of star forming rate is similar (with a factor of ~500)
- ~74% of total mass was produced by “obscured” accretion
- Discrepancy at z>3 ? (due to CT AGNs??)

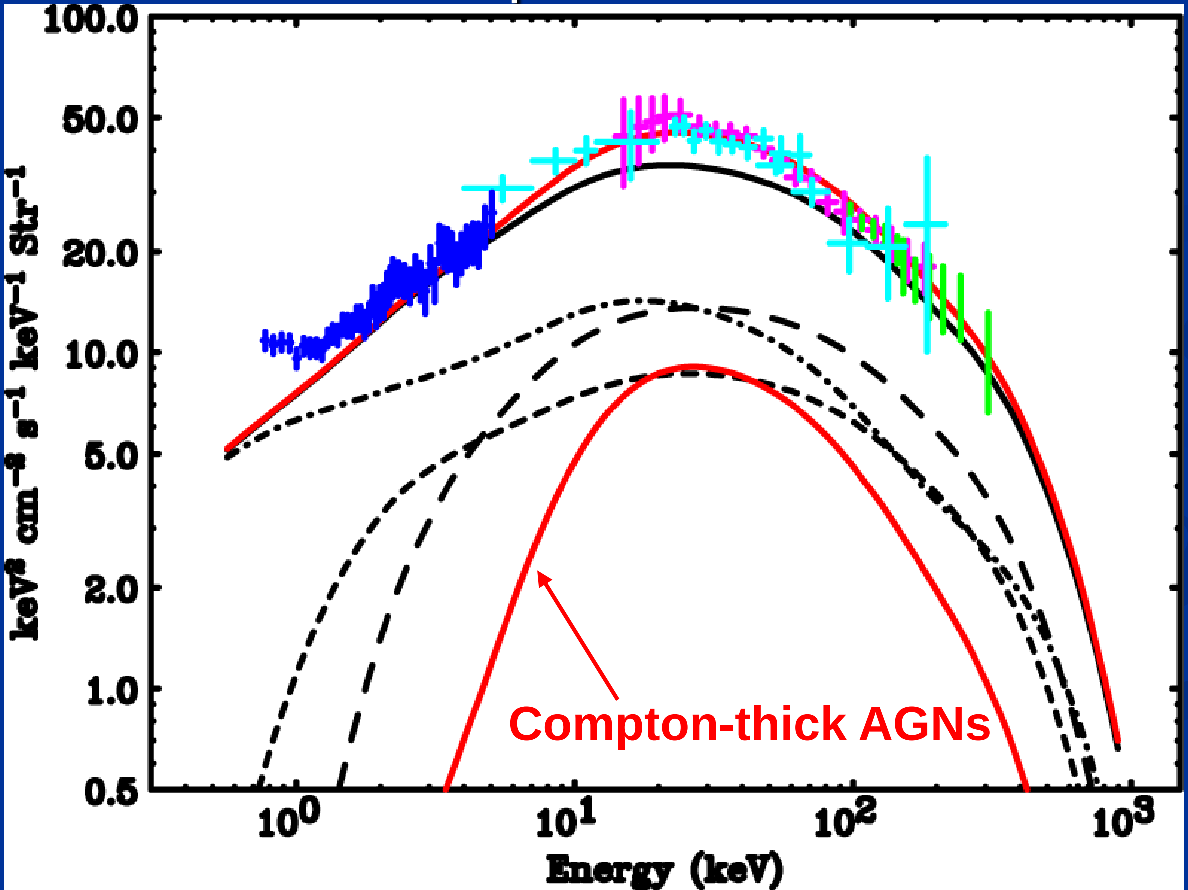


Ueda (2015) PJAB 91, 5

See also Aird+15

Population Synthesis Model of the XRB (Ueda+14)

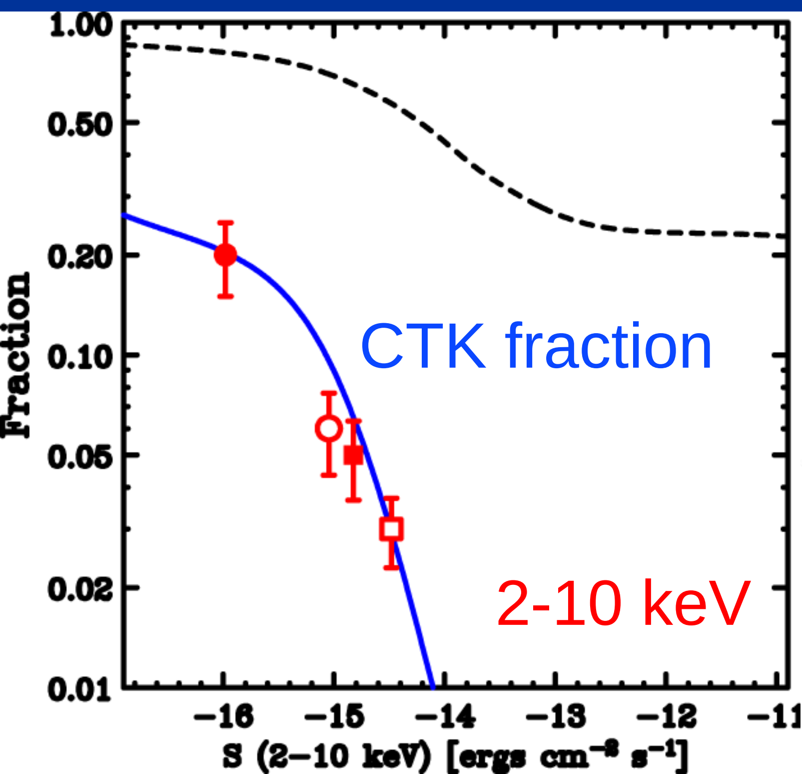
- XRB = (luminosity function) × (absorption distribution)
- Broad-band spectra determined from local AGNs
- To explain the XRB peak intensity at ~30 keV, *the ratio of Compton thick AGN to Compton thin absorbed AGNs must be ~1 (0.5-1.6)* by assuming that they follow the same evolution as Compton thin AGNs



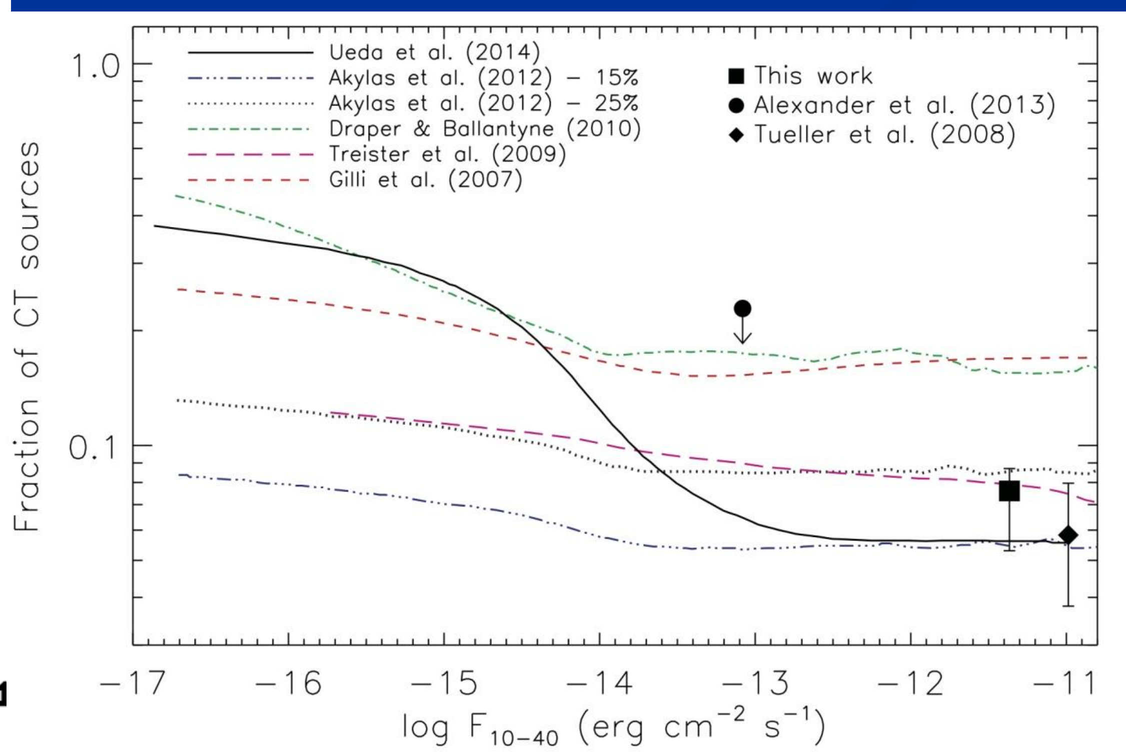
Fraction of Compton thick AGNs

- In the 2-10 keV band, the model prediction is consistent with previous results based on X-ray spectral analysis, including that at the faintest flux (Brightman&Ueda 12)
- At energies above 10 keV, it is also consistent with Swift/BAT and the first NuSTAR results by Alexander+13

Ueda+ 14



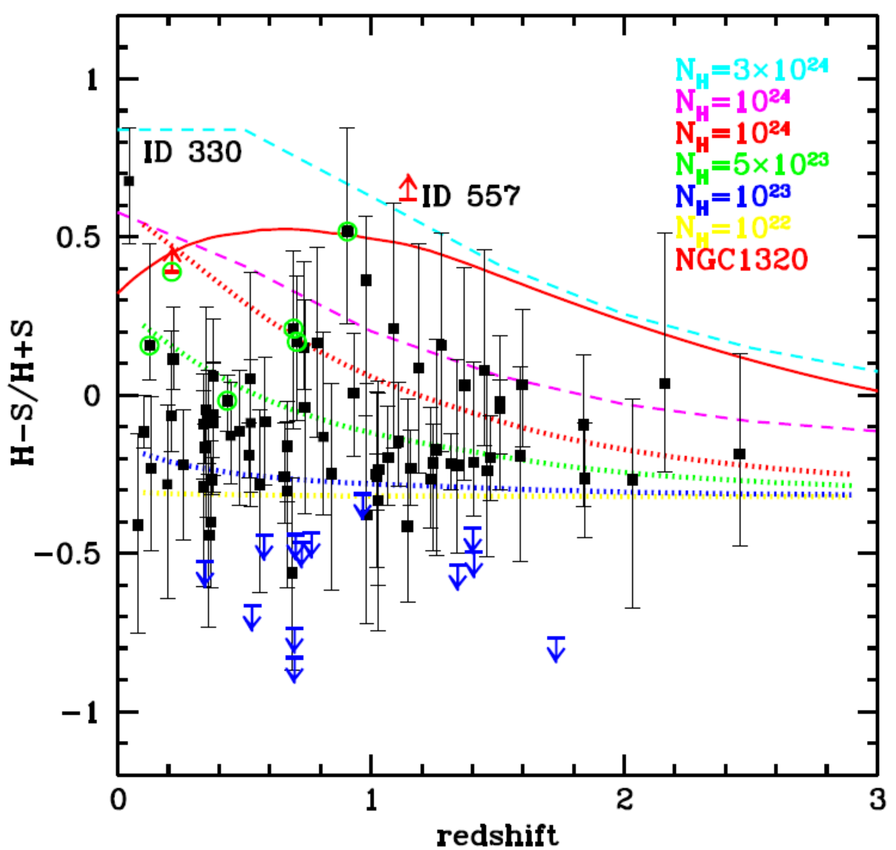
Ricci+15, submitted



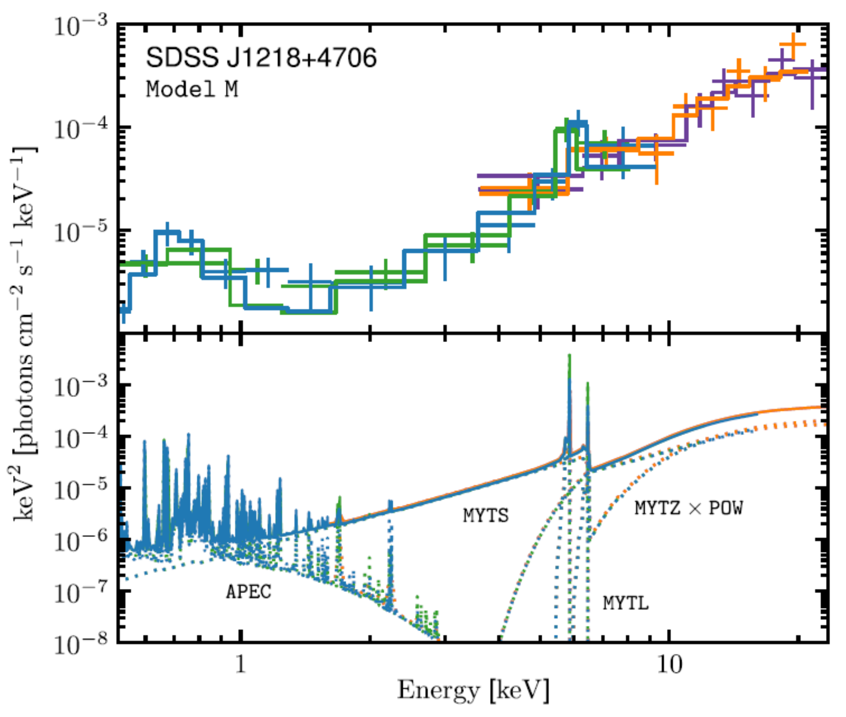
Comparison with latest NuSTAR results

- A Compton thick fraction is estimated to be ~40% at $z<0.5$ (Lansbury+15)
- Observed CT Fraction seems roughly consistent with the prediction by Ueda+14, although it is difficult to identify individual CT AGNs based on hardness ratio alone (this is true for all faint AGNs detected in deep surveys)

COSMOS, Civano+15



SDSS follow-up, Lansbury +15



Summary

1. X-ray observations are a very powerful tool to find AGNs effectively and completely.
2. Obscuration increases toward lower luminosity and higher redshift.
3. AGNs exhibit luminosity dependent density evolution with “downsizing” behavior .
4. Most of theoretical models overpredict the number of LLAGNs at $z>2$
5. Moderate fractions of Compton thick AGN are suggested from the latest XRB model. NuSTAR results seem consistent with the model prediction.