# An X-ray - infrared study of AGN unification and selection

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Brightman & Nandra, 2011, MNRAS, 413, 1206

Brightman & Nandra, 2011, MNRAS, in press (arXiv:1103.2181)

# Outline

- Introduction
  motivation & background
- New X-ray spectral models for heavily obscured sources
- X-ray spectral analysis and optical line ratio diagnostics of 12 micron selected galaxies
- Results
- Conclusions

# Introduction

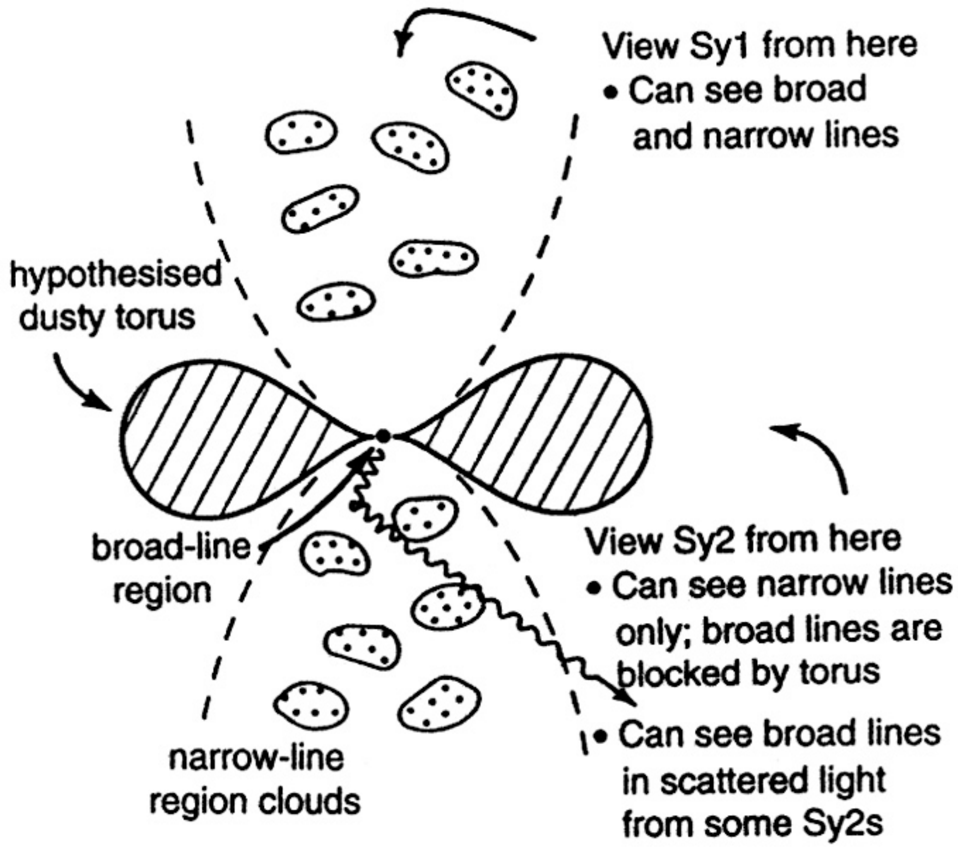
## Aims

To test the AGN unification scheme and investigate AGN selection methods using a well selected sample of local galaxies using X-ray and optical spectroscopy.

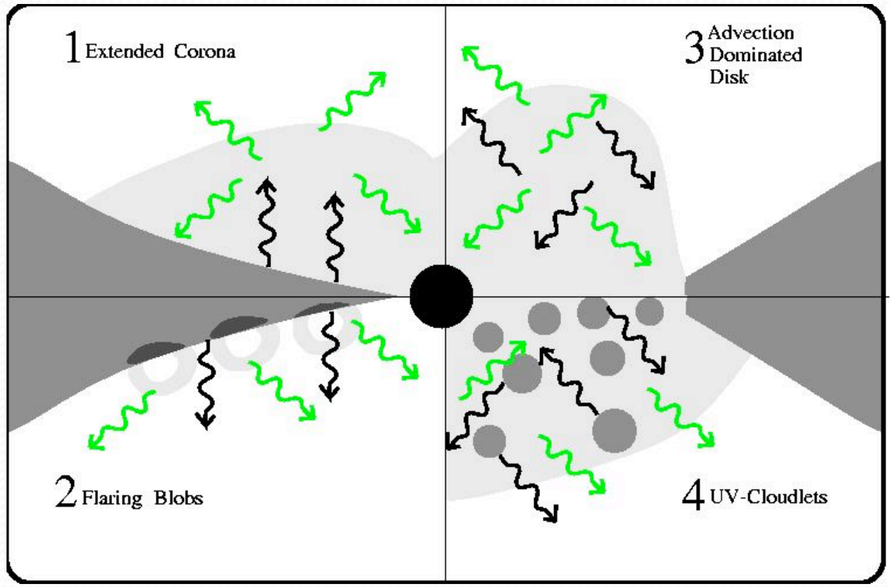
Galaxy sample: IRAS 12 micron galaxy sample (12MGS) of Rush, Spinoglio & Malkan (1993)

Telescope: XMM-Newton

# Introduction: Active Galactic Nuclei




Taken from nedwww.ipac.caltech.edu

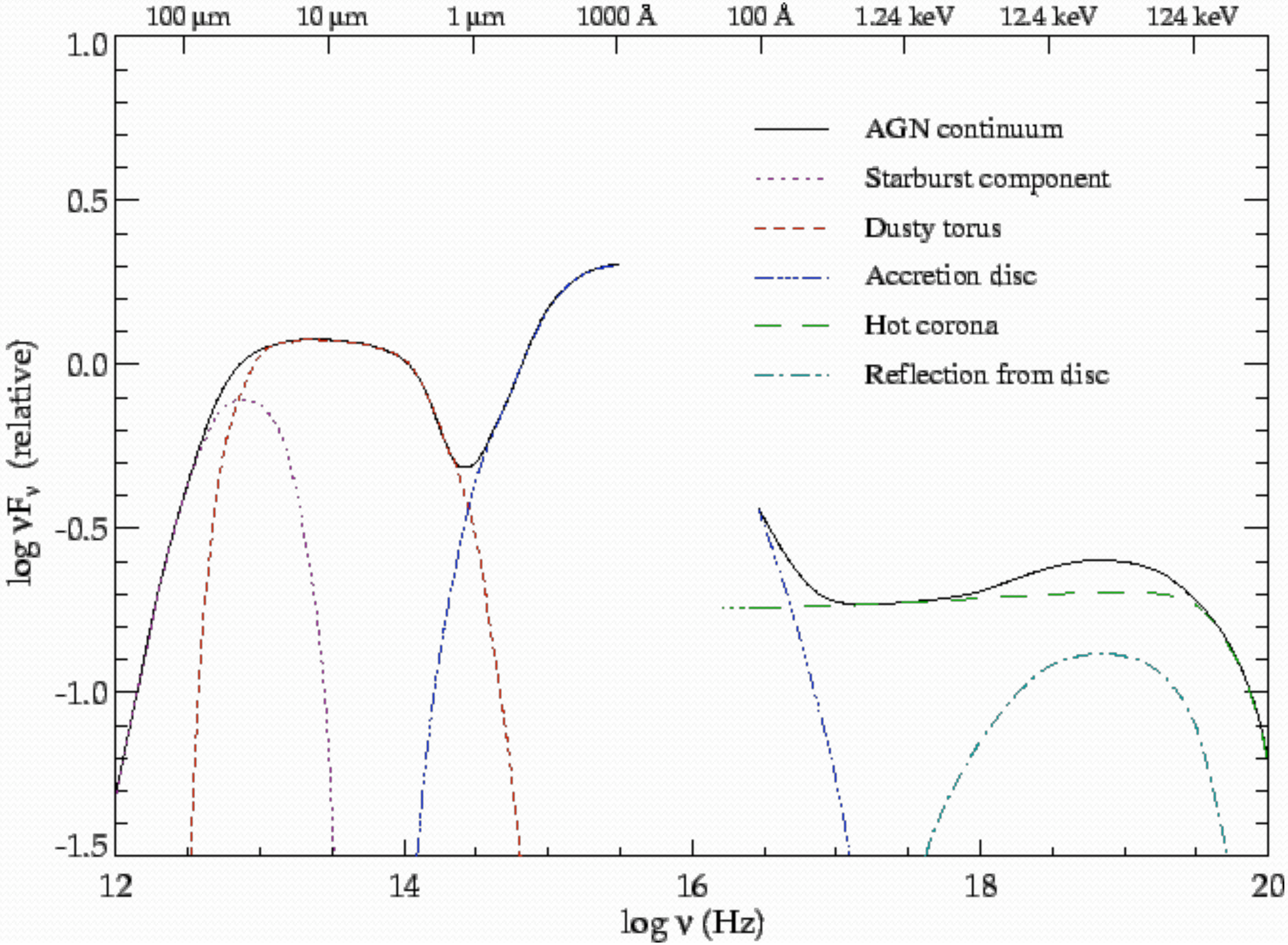



Taken from Haardt+97

- AGN unification supported by the discovery of polarised broad lines in Sy2s (Antonucci & Miller 1985)

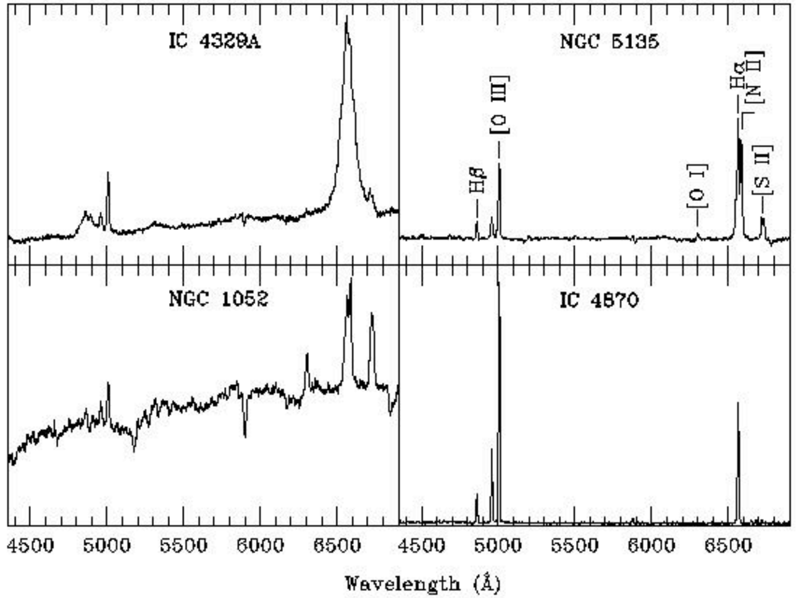
- Accretion disk emits thermally, peaking in UV
- Hot corona inverse-Compton scatters these photons up to X-ray energies

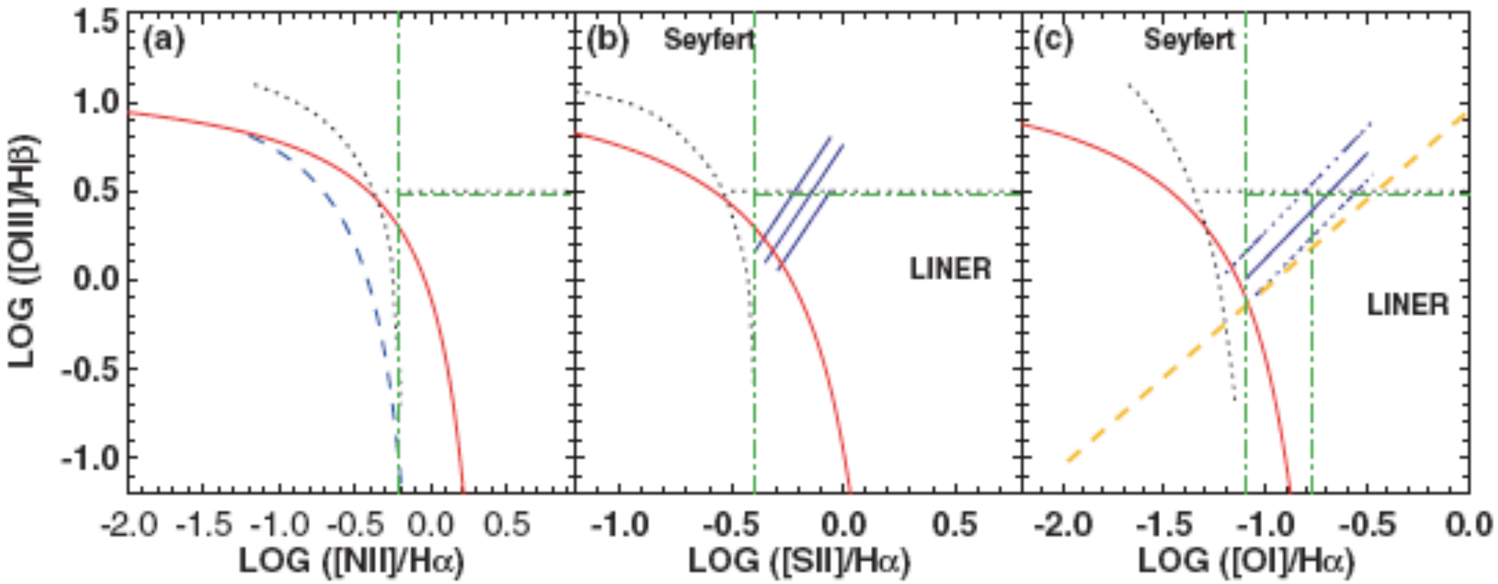
# AGN Spectral Energy Distribution



# AGN Selection

- optical line ratio diagnostics are the most widely used methods for identifying AGN activity.
- Baldwin, Phillips and Terlevich (BPT) 1981 scheme is commonly used.
- Most recently Kewley+2006 presented the following method:



# Introduction

Why 12 microns?

- Corresponds to peak of torus dust emission in AGN (Rowan-Robinson & Crawford 1989)
- Is isotropic (Nenkova+2008)
- Is relatively unbiased against absorption (Horst+ 2008)
- Representative – all active galaxies emit a constant fraction of their bolometric flux in the 12 micron band (Spinoglio+ 1995)
- The IRAS 12 micron galaxy sample (12MGS, Rush, Malkan & Spinoglio 1993) contains a large fraction of AGN and has coverage at all wavelengths.

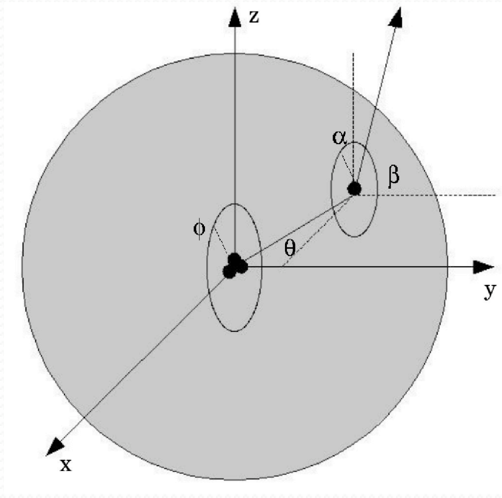
  893 galaxies, 13% AGN fraction, $z<0.1$, $F_{\nu}(12\mu m)>0.22$ Jy

# Monte-Carlo modelling of X-ray reprocessing

- Absorption along the line of sight is often seen in the X-ray spectra of AGN, the column density ($N_H$) of which is sometimes measured to be in excess of $10^{23}$ cm$^{-2}$, especially in Seyfert 2 galaxies.
- At $N_H = 1.5 \times 10^{24}$ cm$^{-2}$, $\tau_e = 1$ (Compton thick) ➔ Compton scattering by electrons becomes increasingly important.
- At these high $N_H$, the calculations for modelling the transmission spectrum become non-linear due to multiple scatterings so models describing simple attenuation of the spectrum by absorption and scattering become invalid.
- Monte-Carlo methods are ideal for this purpose.
- New models by Murphy & Yaqoob (2009) and Ikeda+ (2009) do this for toroidal geometries
- Results presented here for both spherical and toroidal geometries.

# Monte-Carlo simulations

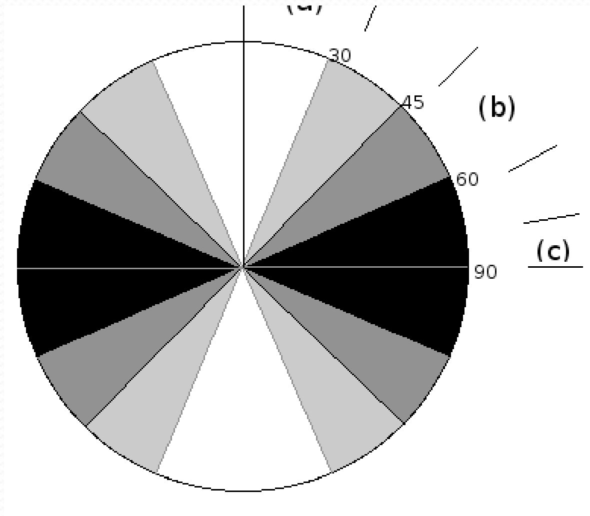
- An isotropic point source of X-rays
- Fɣ = $E^{-\Gamma}$ input spectrum
- Monte-Carlo simulations of *Compton scattering*, *photo-electric absorption* and *iron Kα fluorescence*
- Interaction probabilities calculated from cross-sections, σ(E)
- Models include fluorescent emission lines: Fe Kα (6.4 keV), Fe Kβ (7.1 keV) + Kα lines from several other elements



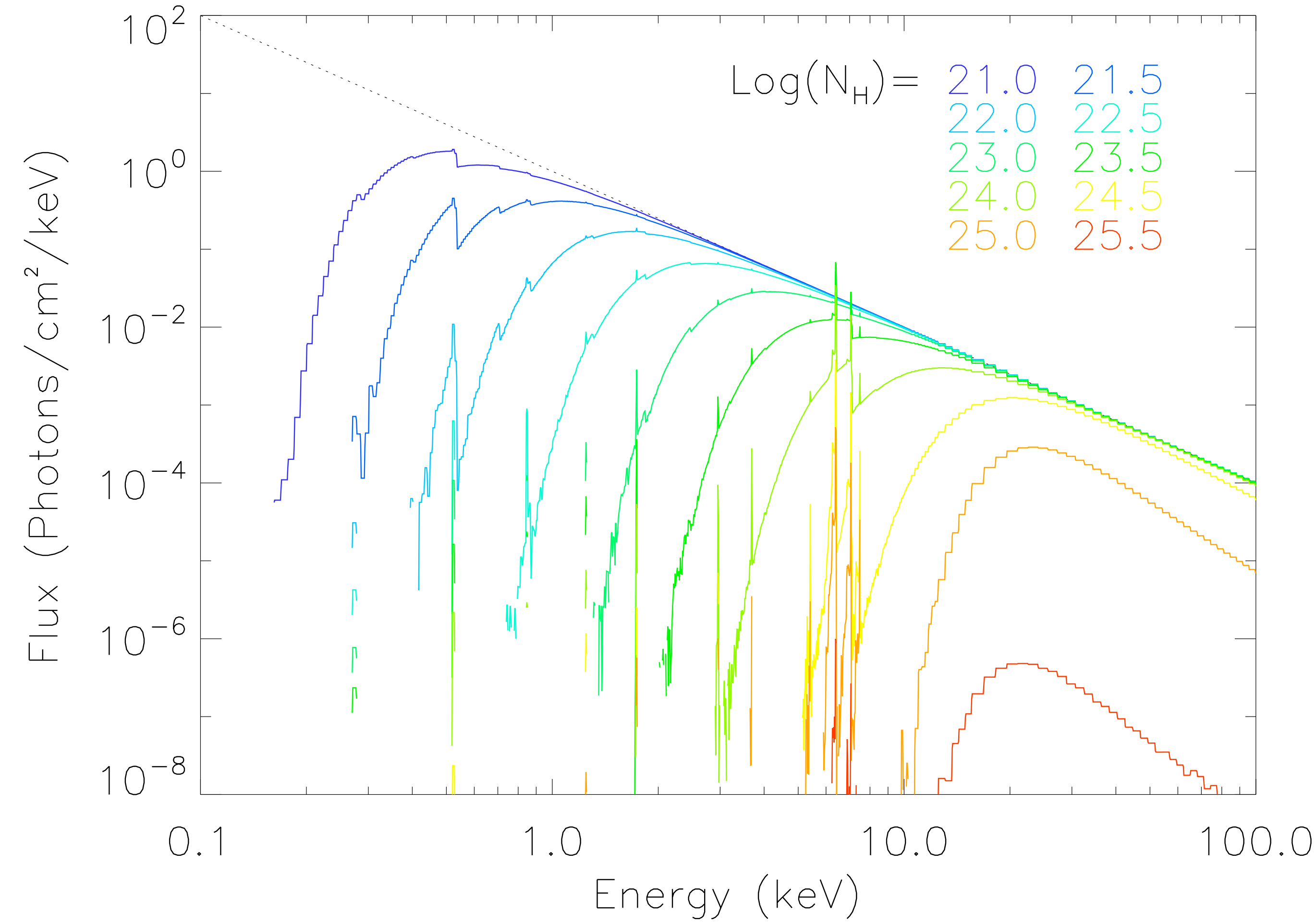

- $10^{20} \leq N_H \leq 10^{26}$ cm$^{-2}$
- $1 \leq \Gamma \leq 3$
- 0.1 ≤ iron abundance ≤ 10 solar abund.
- 0.1 ≤ elemental abundance ≤ 10 solar abund.

TORUS, additional parameters:

- viewing angle
- opening angle

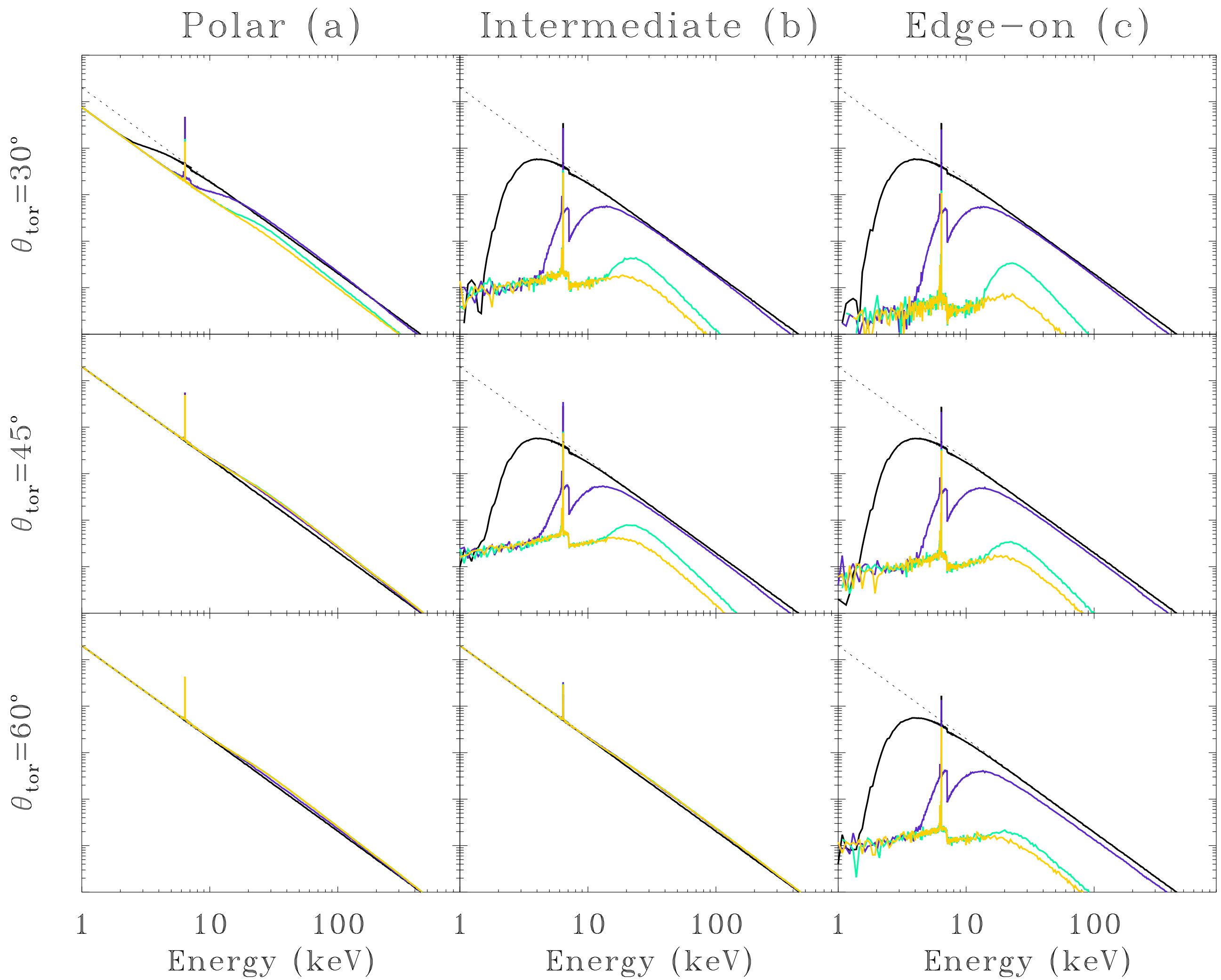


# Sphere: spectra




✧ At extreme $N_H$, even 10-100 keV emission is very suppressed
✧ However, Fe Kα emission can still be observed in 2-10 keV band

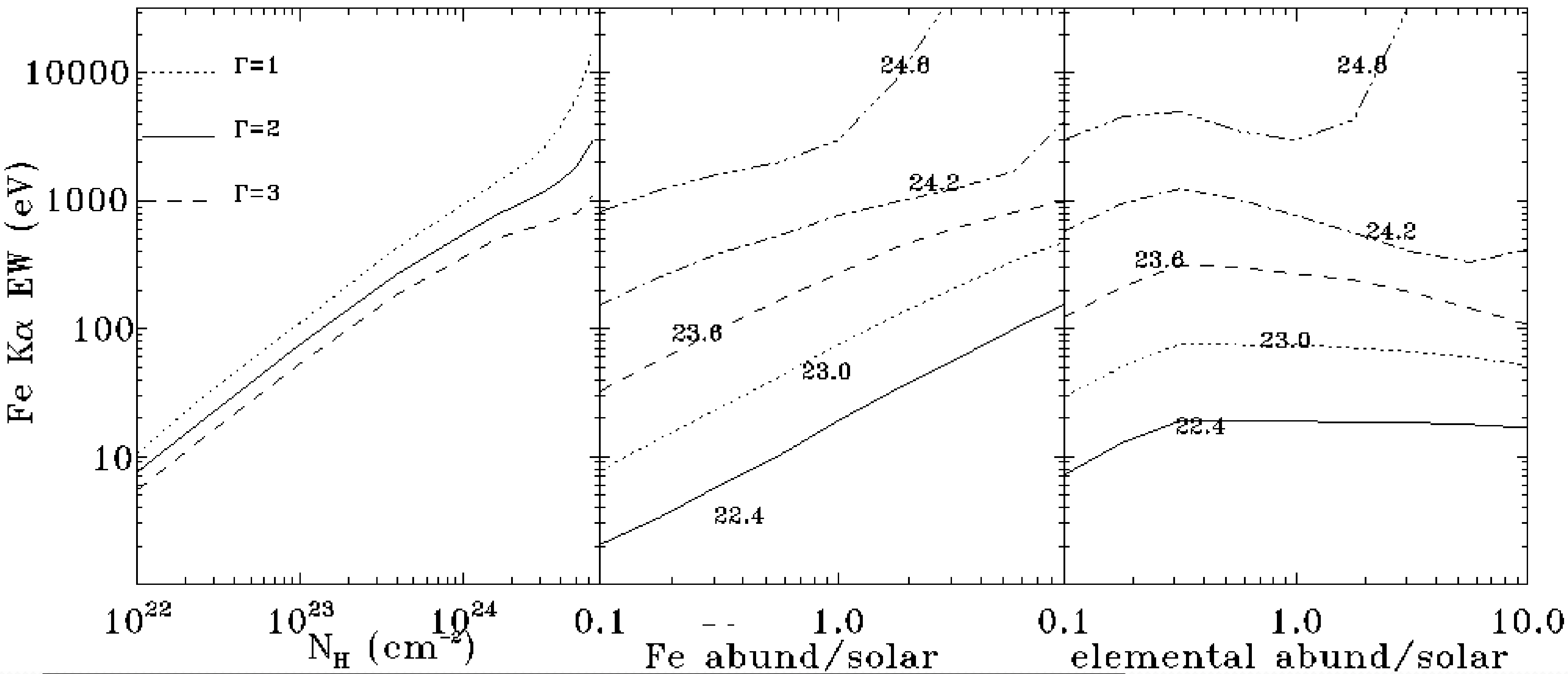
# Torus: spectra




✧ At extreme $N_H$ , torus emission becomes reflection-like
✧ Emission below 10 keV is still observable

# Iron Kα Equivalent Width Predictions

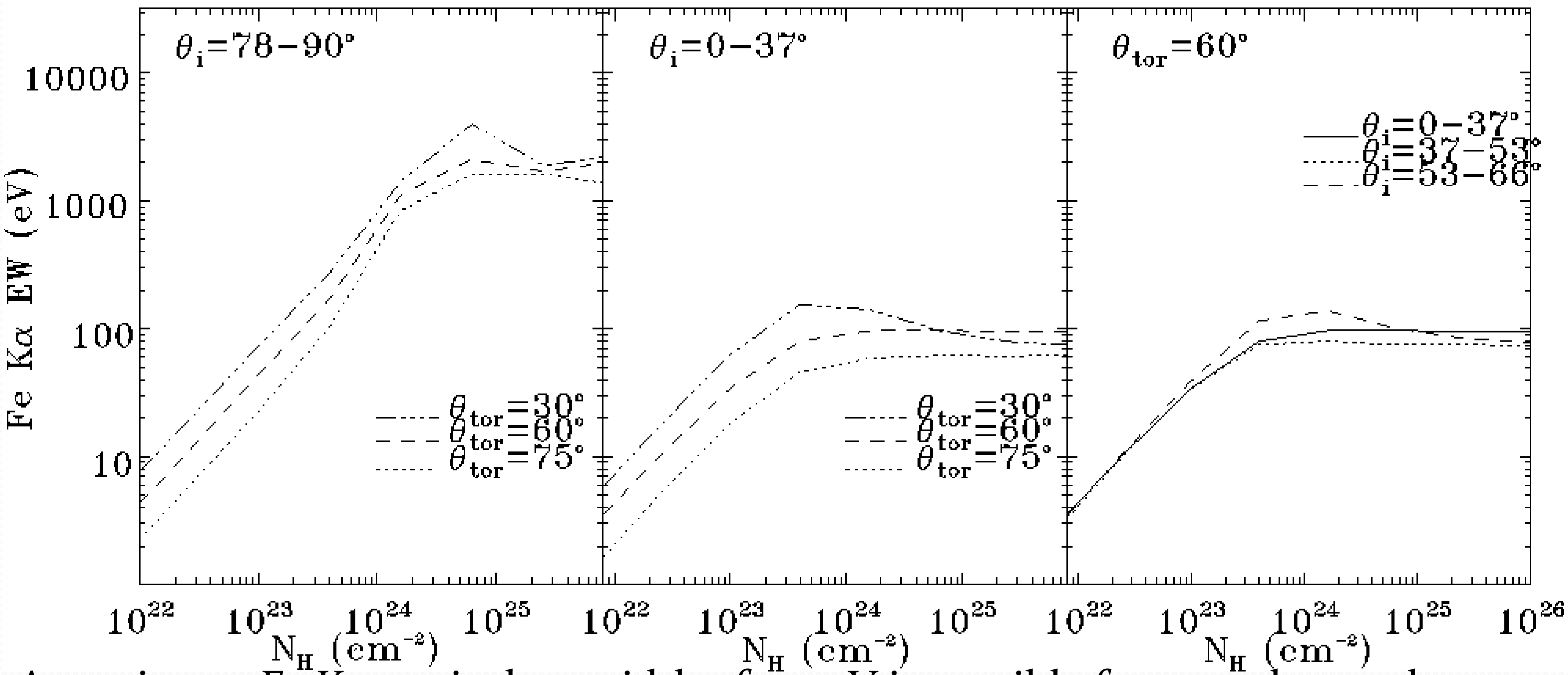
Spherical geometry




✧ Fe Kα line EW heavily dependent on $N_H$ and iron abundance.

# Iron Kα Equivalent Width Predictions

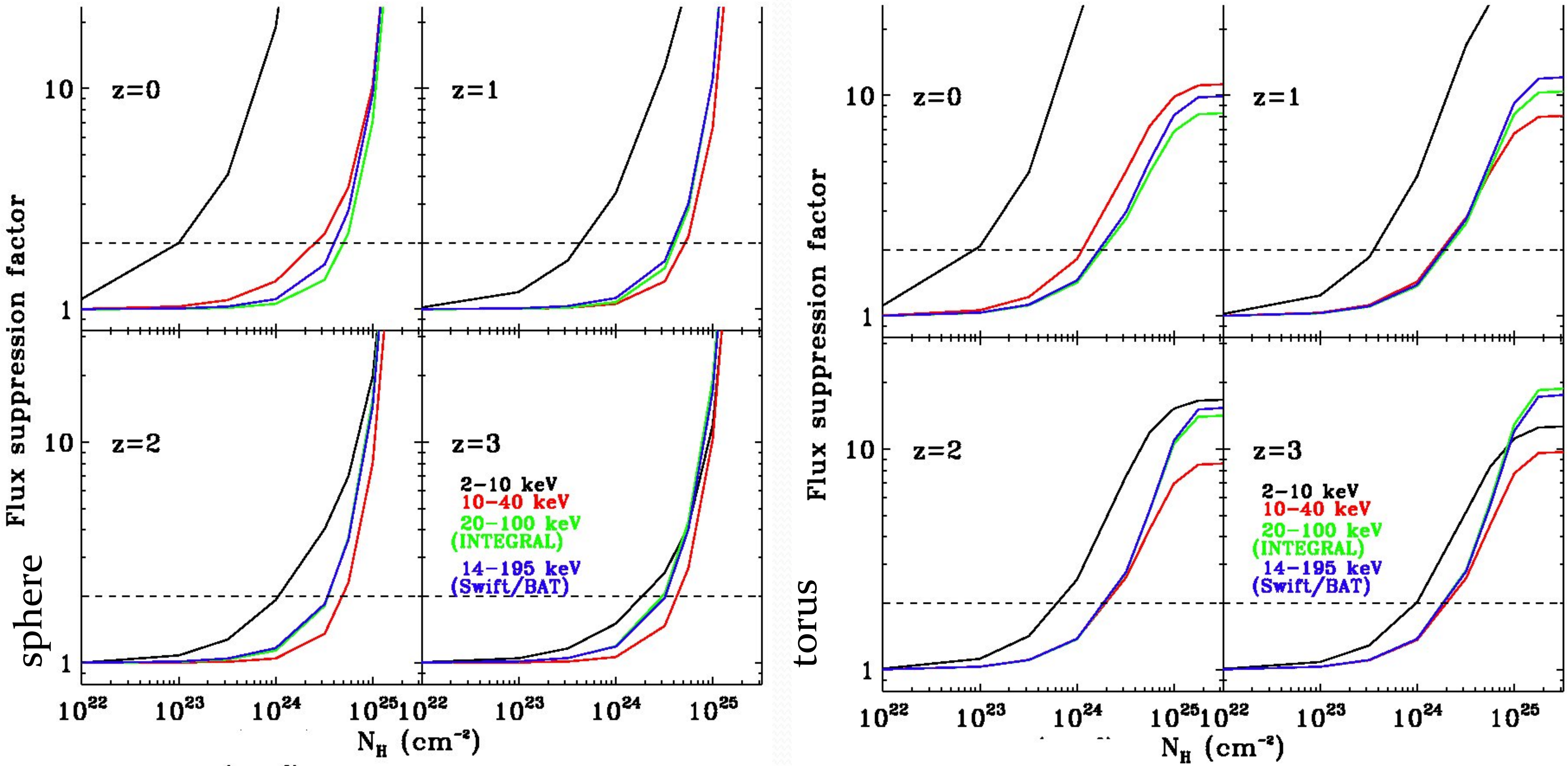
Toroidal geometry




➔ A maximum Fe Kα equivalent width of 150 eV is possible from unobscured sightlines

➔ Sources with values higher than this are likely to be heavily obscured

# Flux suppression factors




➔In all X-ray bands and at all redshifts, for both geometries, emitted flux is suppressed by at least a factor of 10 for $N_H > 10^{25}$ $cm^{-2}$

➔This may explain biases seen in hard X-ray surveys against Compton thick AGN (e.g. Beckman+ 2009)

# X-ray Spectral Analysis

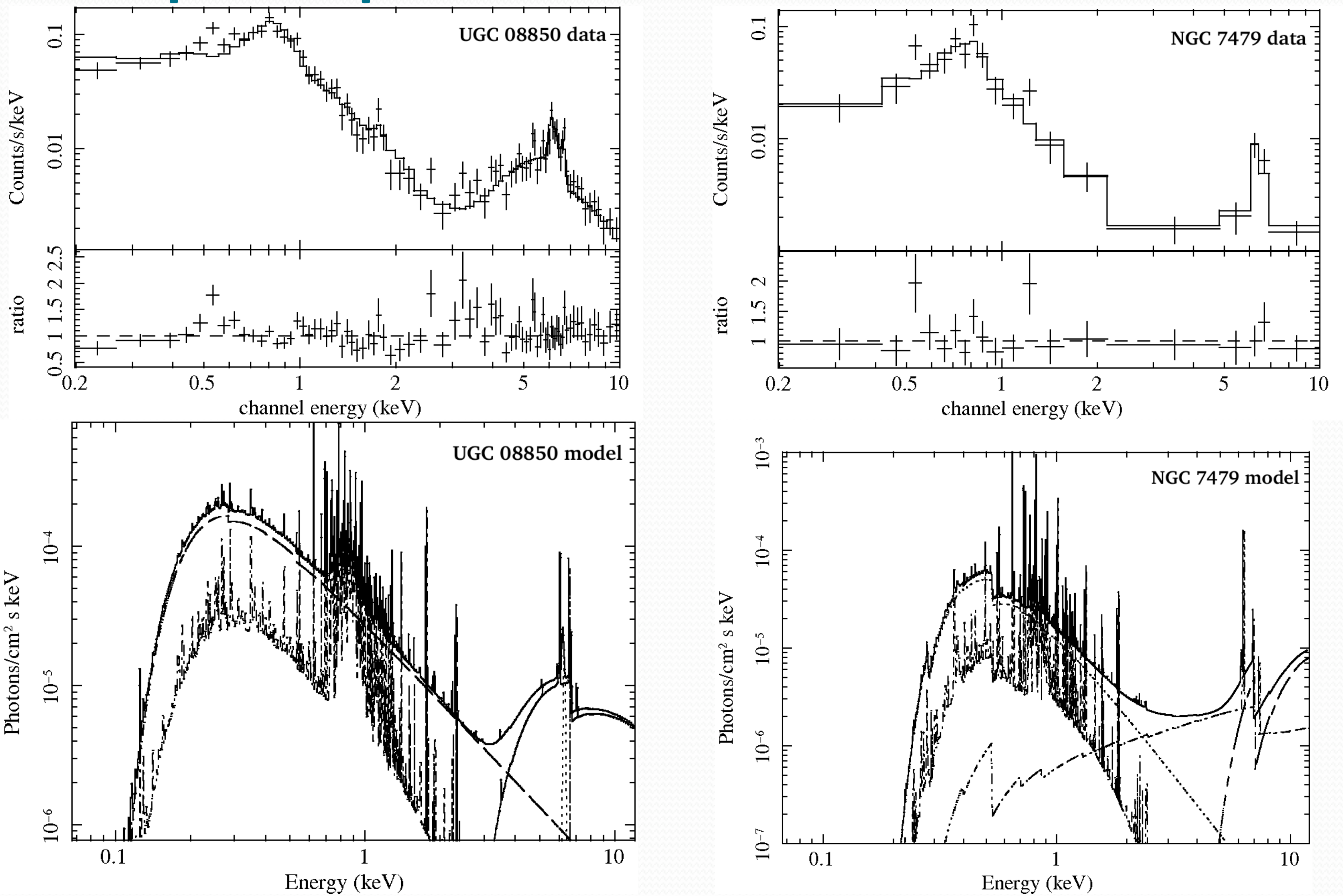
## Sample selection

- All galaxies of the 12MGS with XMM-Newton observation (as of Dec 2008) for which a meaningful spectrum is produced having filtered for flares and background is subtracted.
- 126 galaxies in total.
- X-ray subsample conserves parent sample optical type proportions

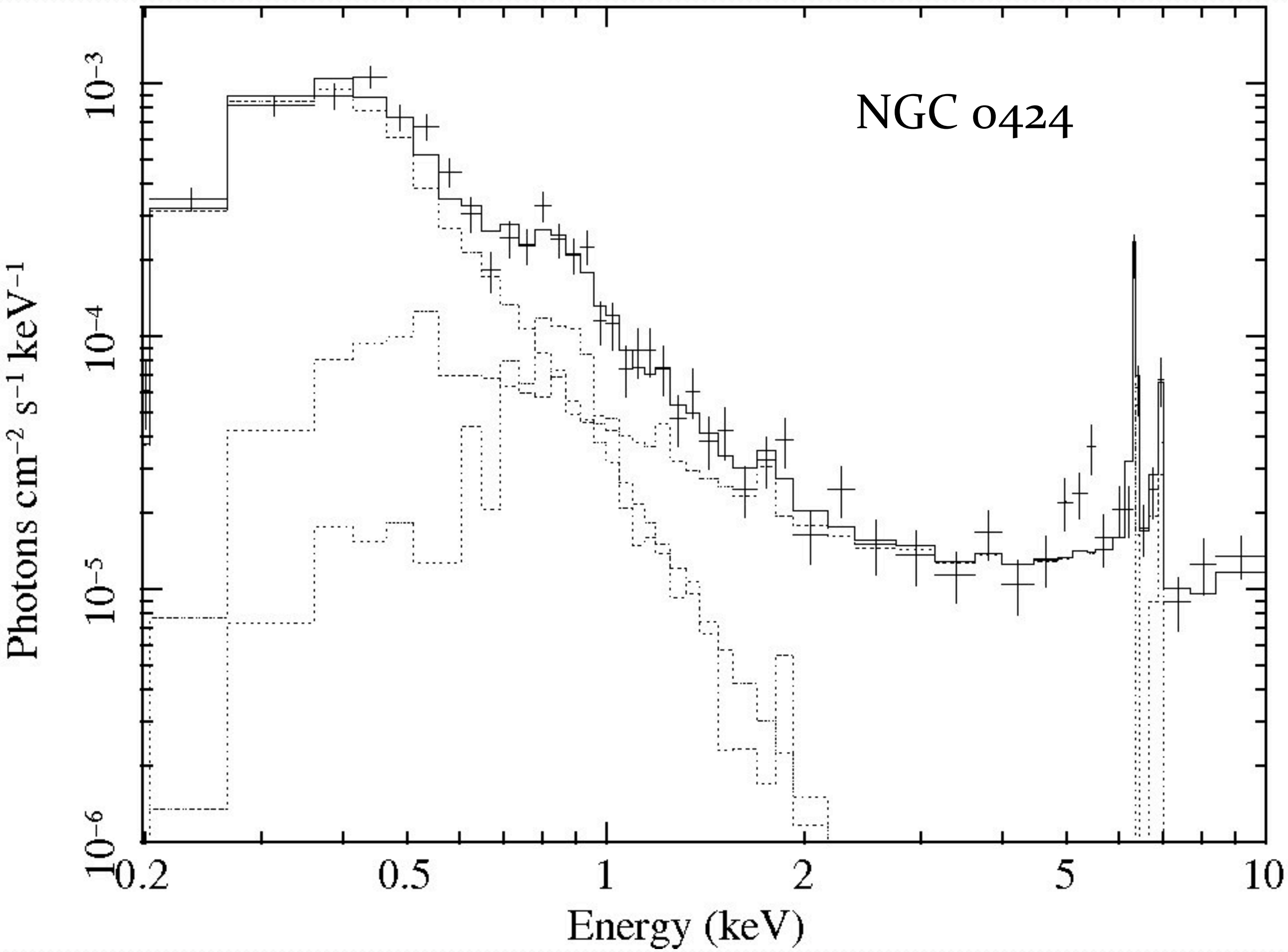
## Spectral fitting

- $\chi^2$ fitting to background subtracted spectra with at least 20 counts per bin.
- Fit to 0.2-10 keV spectrum with a power-law model, adding absorption, reflection and/or heavily obscured transmission (new model!) if required. ($\Delta\chi^2$ constraints)
- Also including thermal plasma, scattered power-law or soft excess components if required

# Example spectra



# Results What can we determine from the torus model?

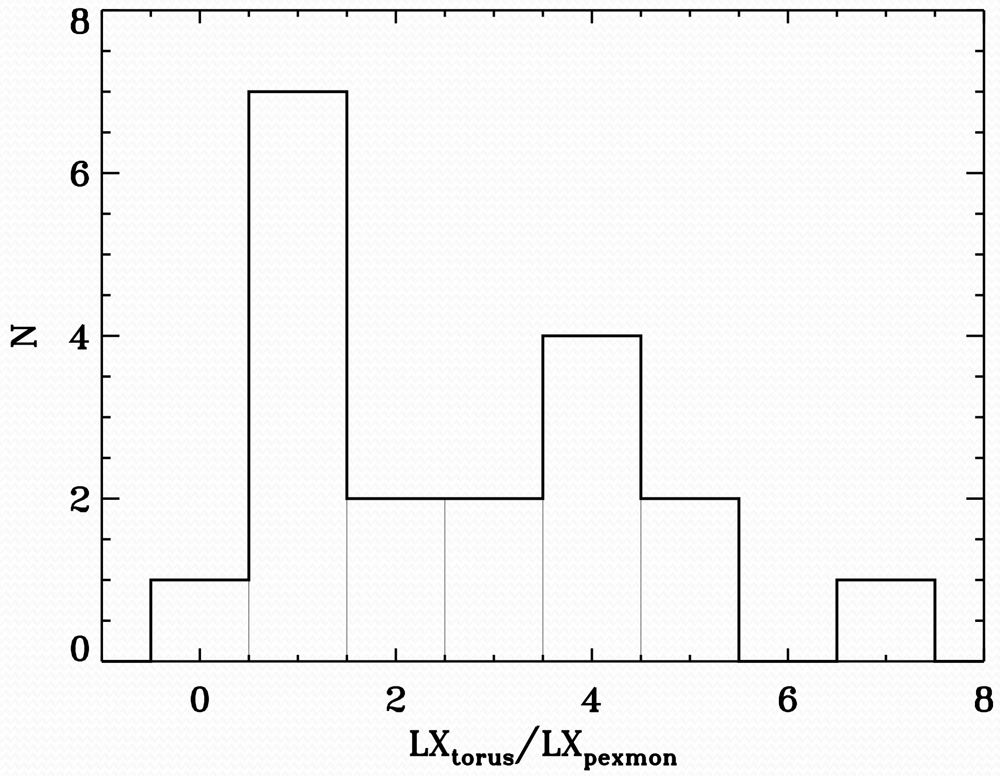



🡐We fitted our new 'torus' model to 19 'reflection dominated' spectra to see if we could constrain the torus opening angle or viewing angle.

🡐 However, neither parameter could be constrained with the data available

- Eguchi+11 have used model of Ikeda+09 to fit broadband Suzaku spectra

# Results What can we determine from the torus model?




➔The intrinsic source luminosity is underestimated by a factor of up to 7 when using slab geometries rather than toroidal geometries

➔ Also found by Murphy & Yaqoob (2009) with their torus model

# Conclusions

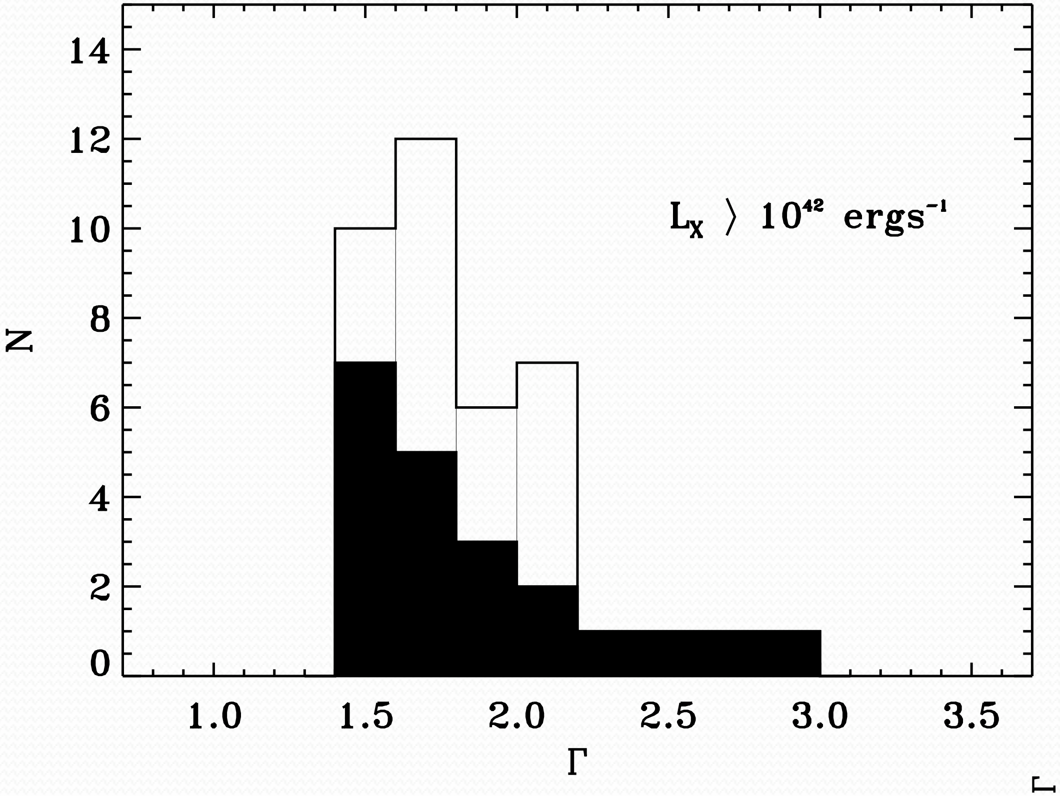
## From the X-ray models:

- For torus distributions a maximum Fe Kα EW of ~ 150 eV is possible for unobscured sightlines. For EW>150 eV, $N_H > 10^{23}$ cm$^{-2}$

- for $N_H = 10^{25}$ cm$^{-2}$ , flux suppression in all X-ray bands and at all redshifts is >10 - important for considering the biases present against hard X-ray selected, heavily obscured AGN.

- using spectral models based on slab geometries (e.g. pexrav) will underestimate the intrinsic $L_X$ with respect to toroidal geometries by up to 7, as also found by Murphy & Yaqoob (2009).

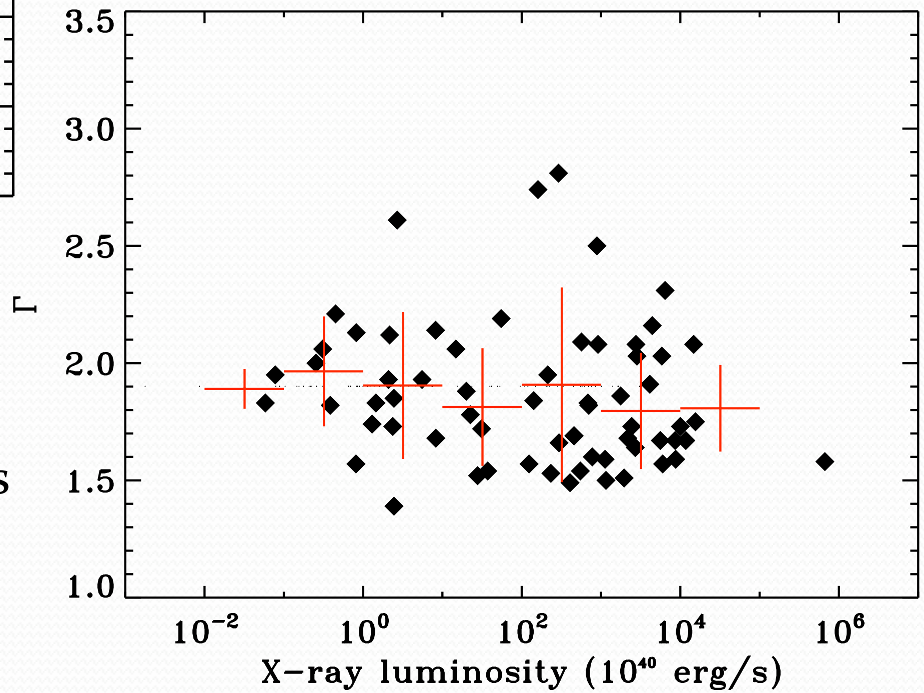
# Results Properties of the primary emission




- ← unobscured AGN
  $<\Gamma>= 1.84^{+0.12}_{-0.14}$  $\sigma_\Gamma = 0.32^{+0.11}_{-0.08}$
- ← obscured AGN
  $<\Gamma>= 1.90^{+0.16}_{-0.14}$  $\sigma_\Gamma = 0.38^{+0.13}_{-0.07}$

← Populations are statistically indistinguishable (K-S test)

← Supports AGN unification

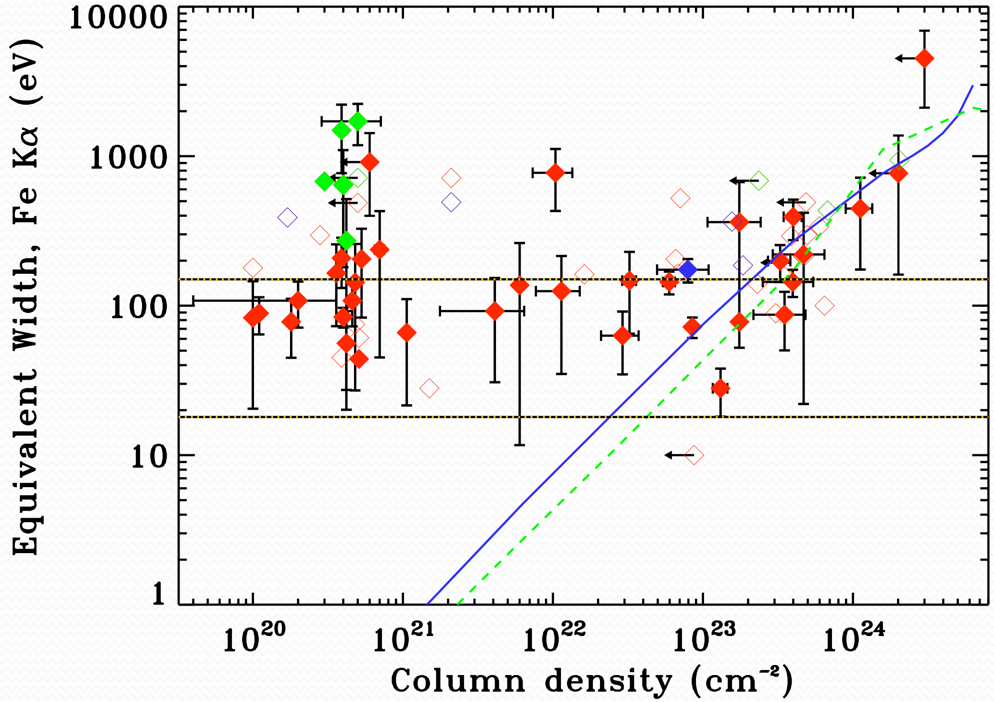


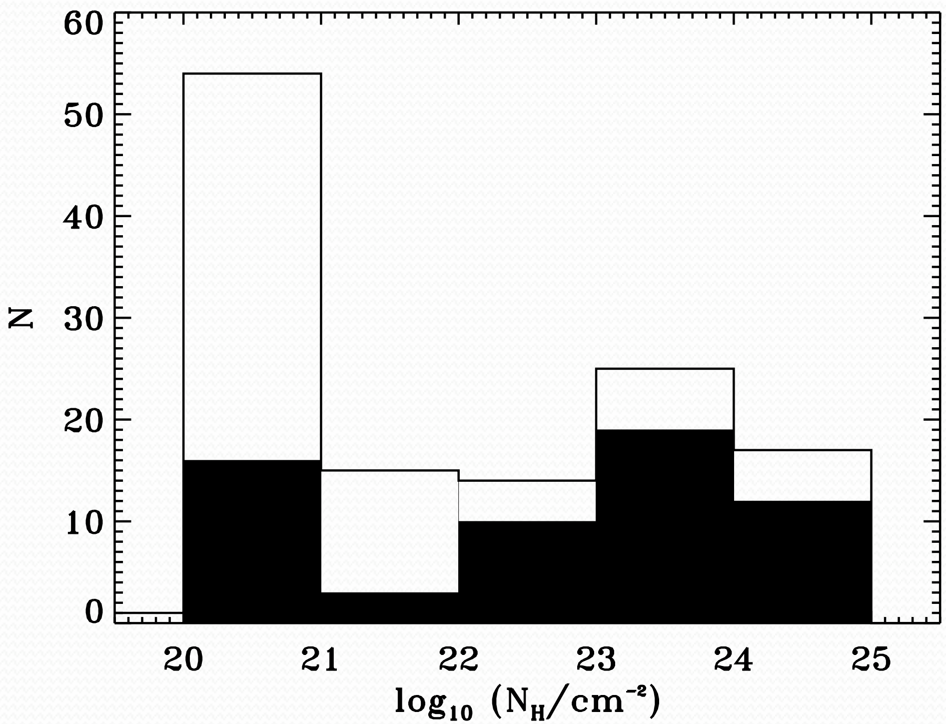

➔ $<\Gamma>$ is consistent with previous works (e.g. Nandra & Pounds 1997), but $\sigma_\Gamma$ is larger (c.f. 0.15). Important for XRB sysnthesis models

➔ We find there to be no dependence of Γ on $L_{X,}$ supporting findings of George+ (2000)

# Results Properties of absorption

➔ Fe Kα EW is a key indicator of obscuration
➔ Calculations show unobscured sources cannot have EW>150 eV, therefore high EW source should be heavily obscured, e.g. NGC 3690



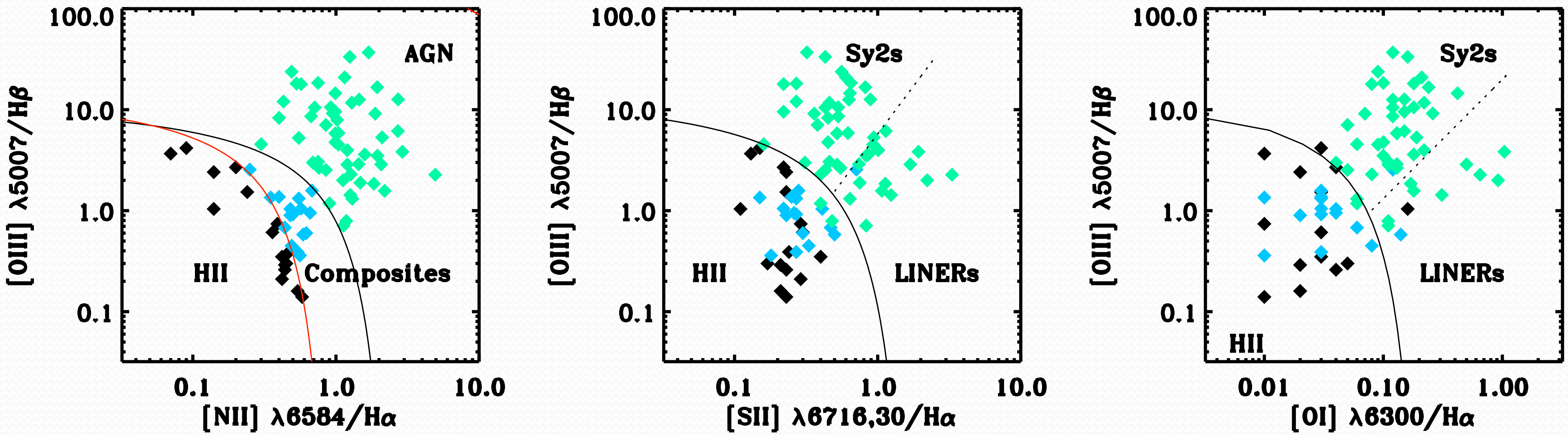

🡐 $L_X > 10^{42}$ ergs $s^{-1}$ AGN exhibit heavy absorption in a higher fraction of sources than lower luminosity sources
🡐 AGN Compton thick fraction is 18 ± 5 %, higher than hard X-ray selected samples (<10 %)

# Results BPT activity classification

➔ Optical line ratios compiled from the literature for XMM-Newton subsample

➔ BPT diagnostics carried out using Kewley, et al (2006) classification scheme. Classes narrow line galaxies into star forming, LINER, Seyfert 2 or 'composite' class.

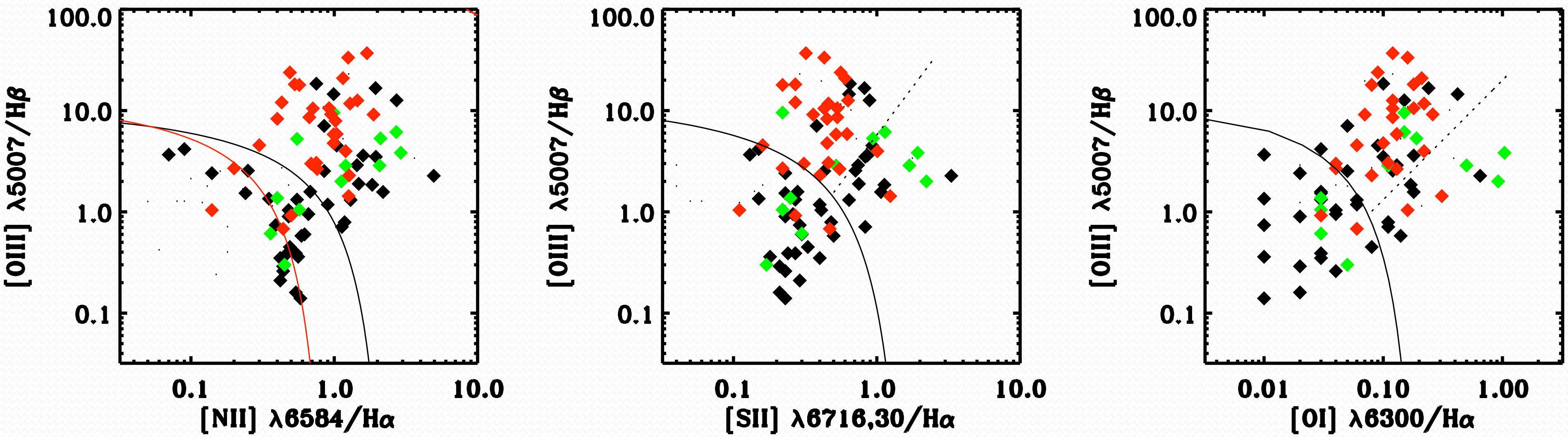
➔ Broad line classification also taken from literature, giving 'strict' Sy 1s, and intermediate type Sy 1.2, 1.5, 1.8 and 1.9.



# Results BPT activity classification

➔ We compare the optical line diagnostics with X-ray indications for AGN power ($L_X$>$10^{42}$ ergs/s or $N_H$>$10^{23}$ $cm^{-2}$)

➔ 40% LINERs exhibit AGN power from X-rays
➔ 17 % of composites exhibit AGN power from X-rays
➔ 0% HII galaxies exhibit AGN power.



# Results

## Luminosity characteristics

Significant differences (c.l.>90%) observed between:

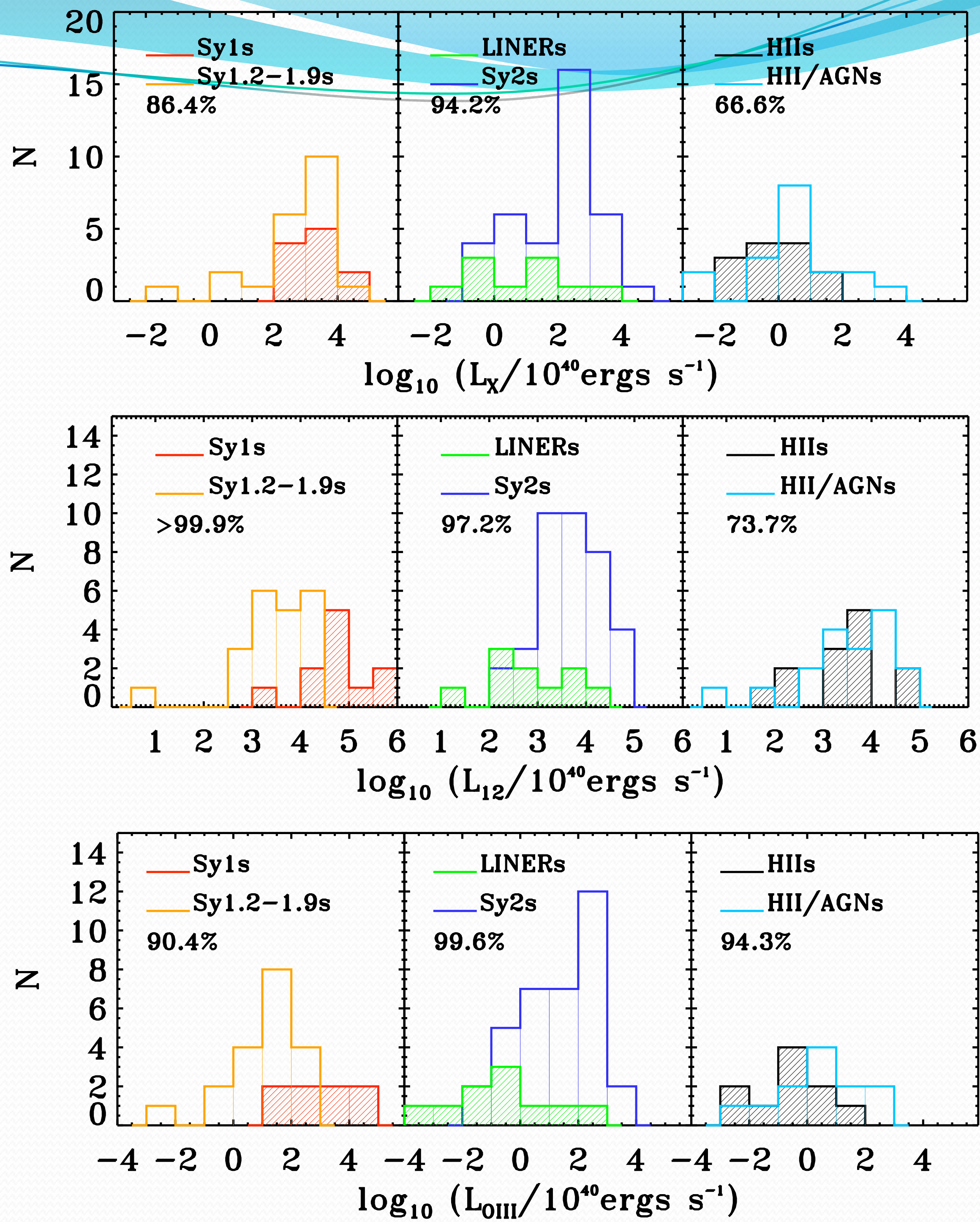
➔ Sy 1s and Sy2s at all wavelengths

➔ Sy 2s and LINERs at all wavelengths

➔Sy 1s and Sy 1.2-1.9s in 12 micron and and [OIII] luminosities

➔ HII and HII/AGN composite galaxies in [OIII] luminosity

➔ All wavebands have been corrected for reddening/absorption, so luminosity differences are intrinsic



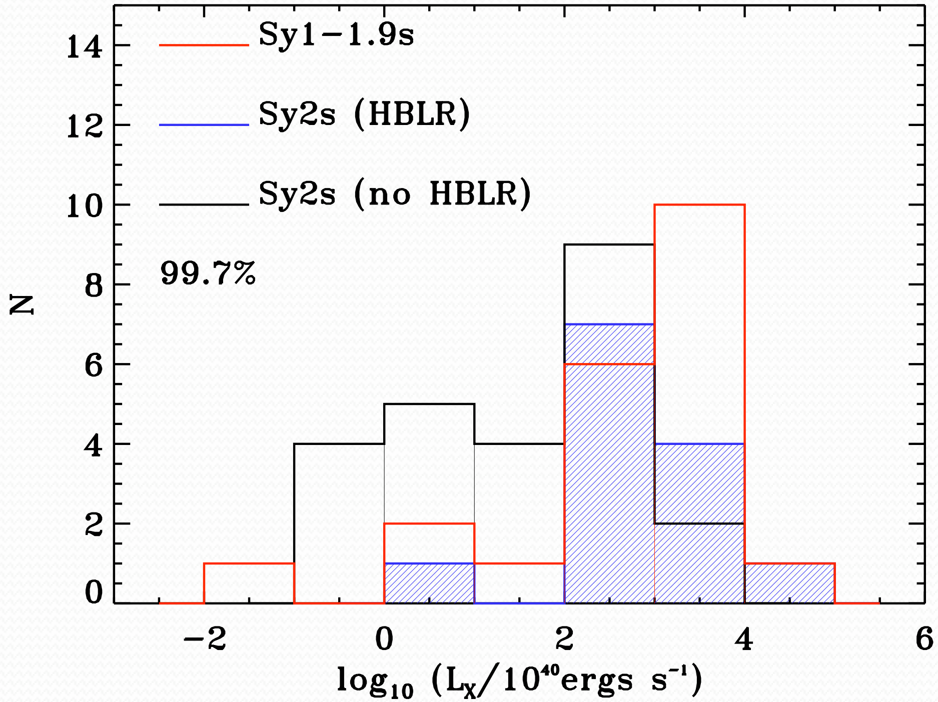
# Results

## Luminosity characteristics

Significant differences observed between:

➔ Sy2s with the detection of a HBLR and Sy2s without the detection of a HBLR. Confirms findings of Tran+2003

➔Suggests some link between the X-ray generation mechanism and the line emitting gas close to the black hole



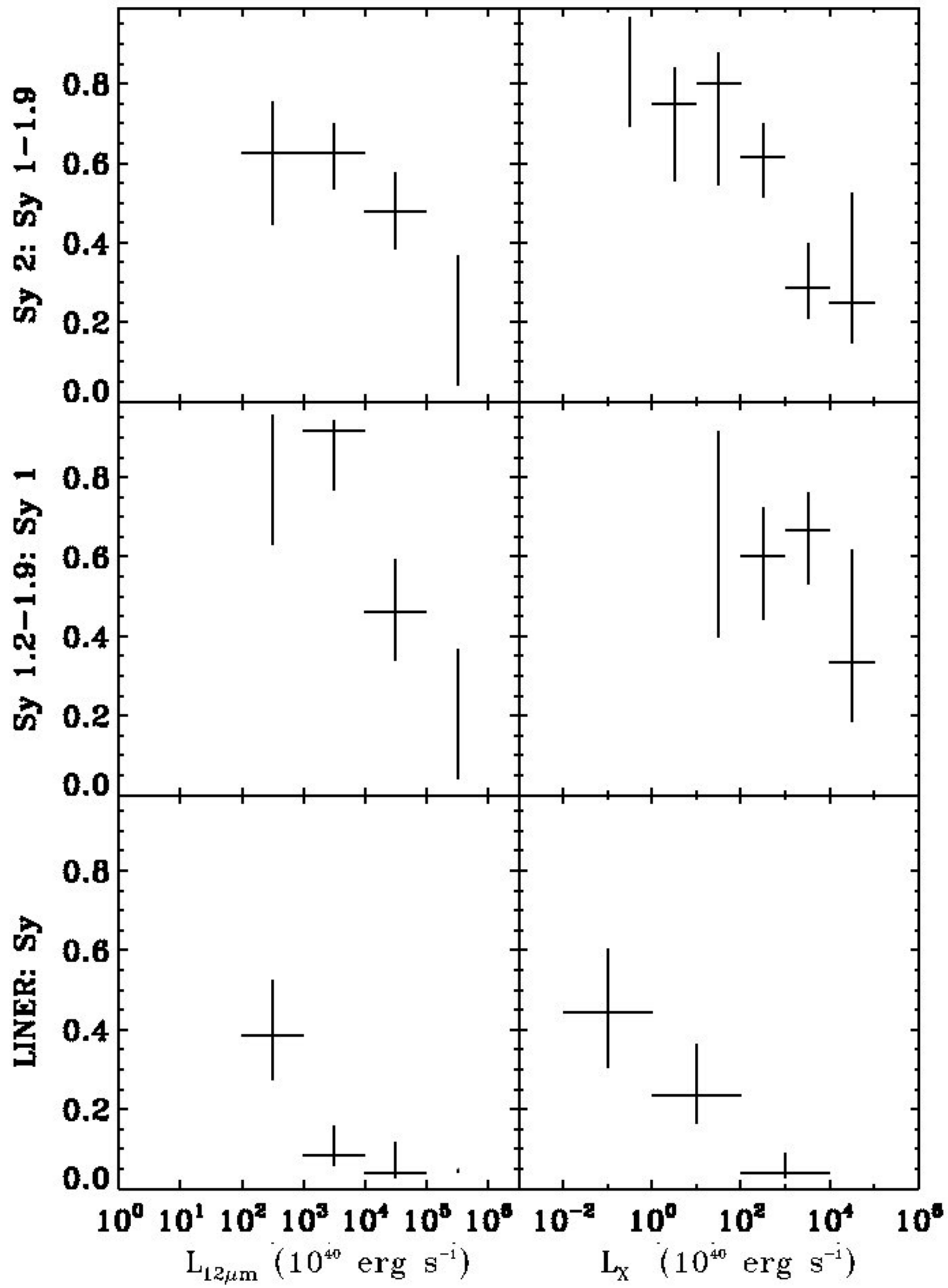
# Results

## Luminosity characteristics

➔ The Sy2 to Sy1 ratio is a function of both 12 micron luminosity

➔ The Sy 1.2-1.9 fraction of Sy 1s is a function of 12 micron luminosity

➔ The LINER fraction of narrow line galaxies is a function of 12 micron and X-ray luminosities.



# Results Properties of absorption

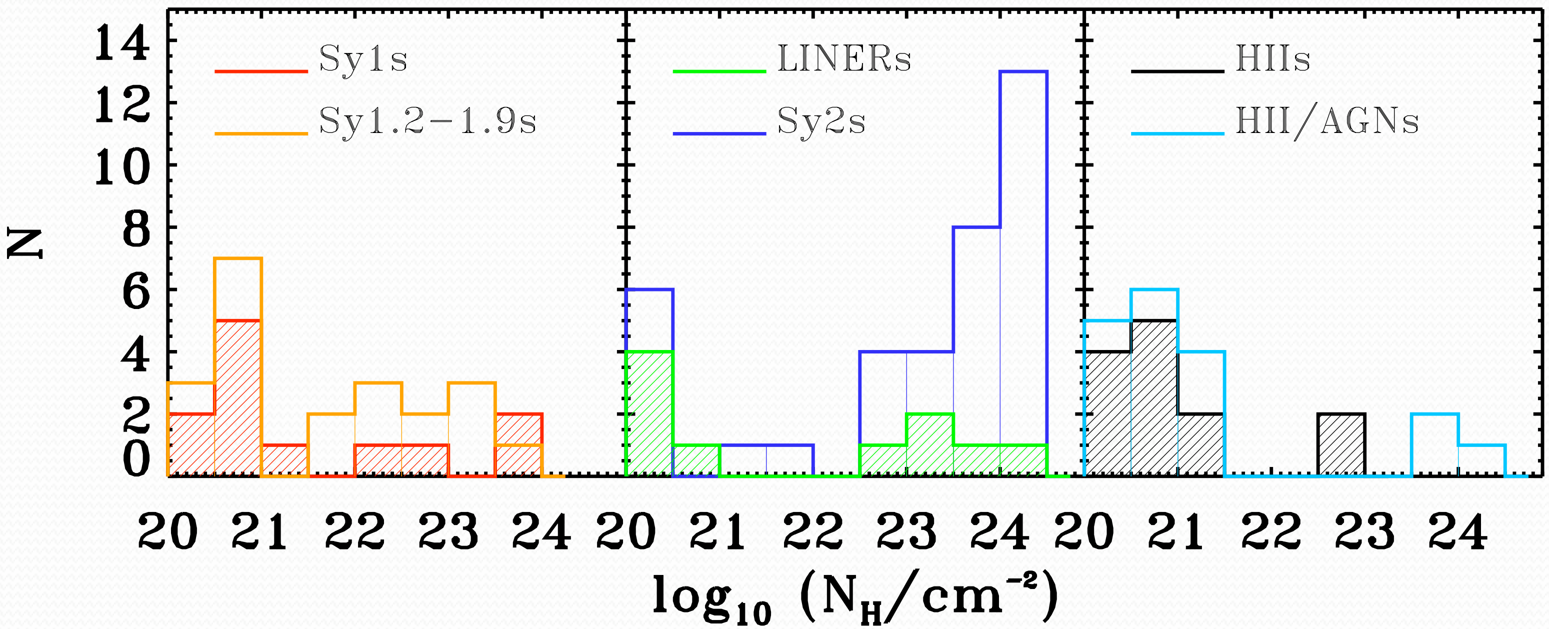
➔Sy 2s show the largest levels of X-ray absorption, and Sy 1s show lower levels as predicted by AGN unification

➔However a significant number (24%) of sources have X-ray absorption which does not correspond to the visibility of the broad lines

➔This is a problem for AGN unification schemes

➔X-ray absorption in Sy1s may be due to dust-less gas within the opening of the torus (BLR?)

➔ Unabsorbed Sy2s may be missing the broad line region all together.



# Results

## Properties of absorption

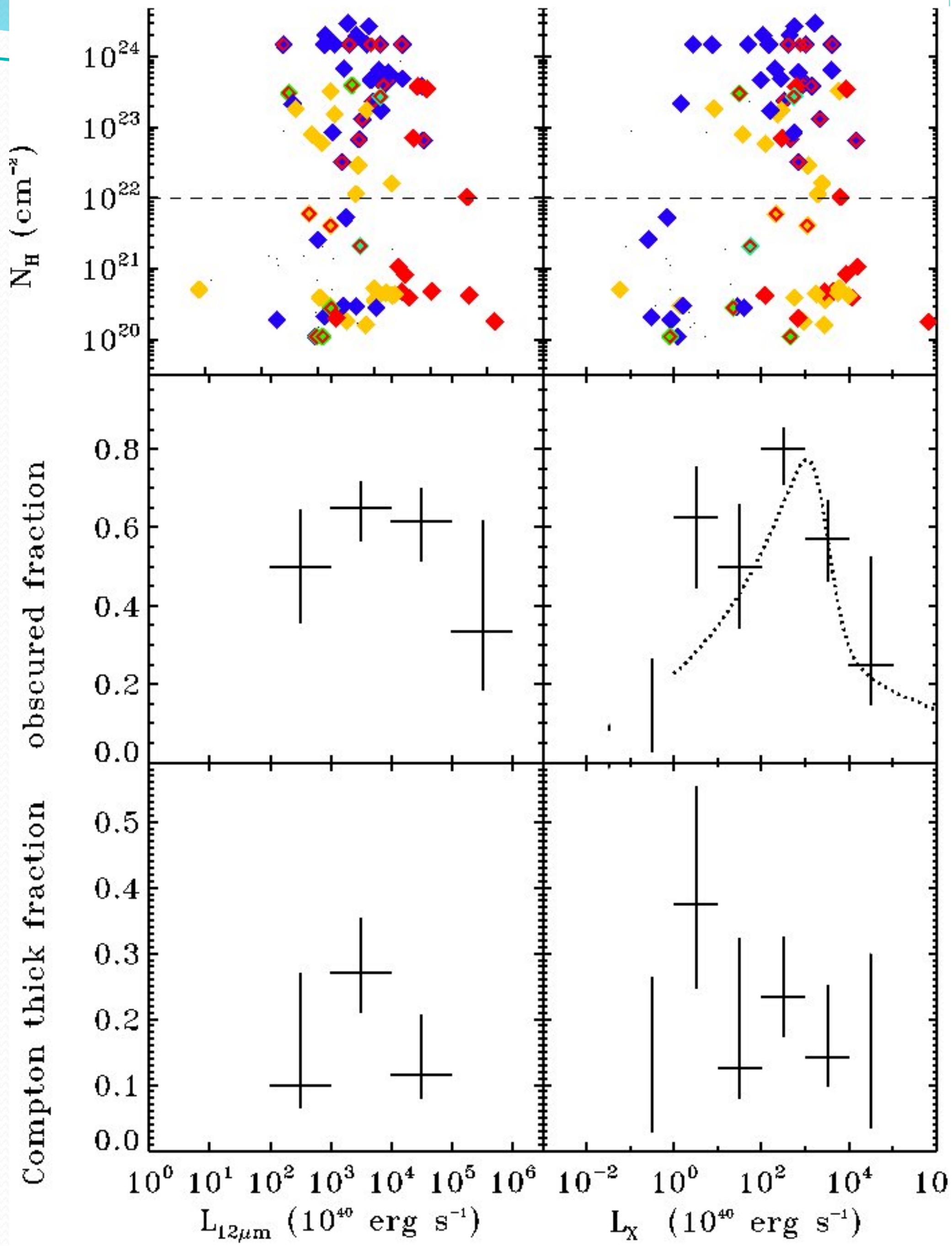
➔Significant variance in the obscured fraction of our sources with $L_X$ detected

➔Decline previously seen above $10^{42}$ ergs $s^{-1}$ (e.g. Ueda+ 2003) for AGN.

➔Decline below $10^{42}$ ergs $s^{-1}$ gaining more evidence (e.g. Burlon+ 2011 Swift/BAT)

➔May support receding torus models (e.g. Lawrence 1991) at high $L_X$, and accretion linked obscuration at low $L_X$ (e.g. Elitzur & Shlosman 2003)

➔ Dependence of absorption on luminosity argues against the simplest unification scenario.



# Impiclations

- The absence of  broad line sources at low X-ray luminosities
- The dependence of broad line strength on 12 micron luminosity (and perhaps dust covering fraction?)
- The dependence of X-ray absorption on X-ray luminosity

➔ Suggests some intrinsic link between X-ray luminosity (and probably accretion rate), the broad line region and the torus

➔ BLR and torus could disappear at low luminosity

# X-ray – IR connection

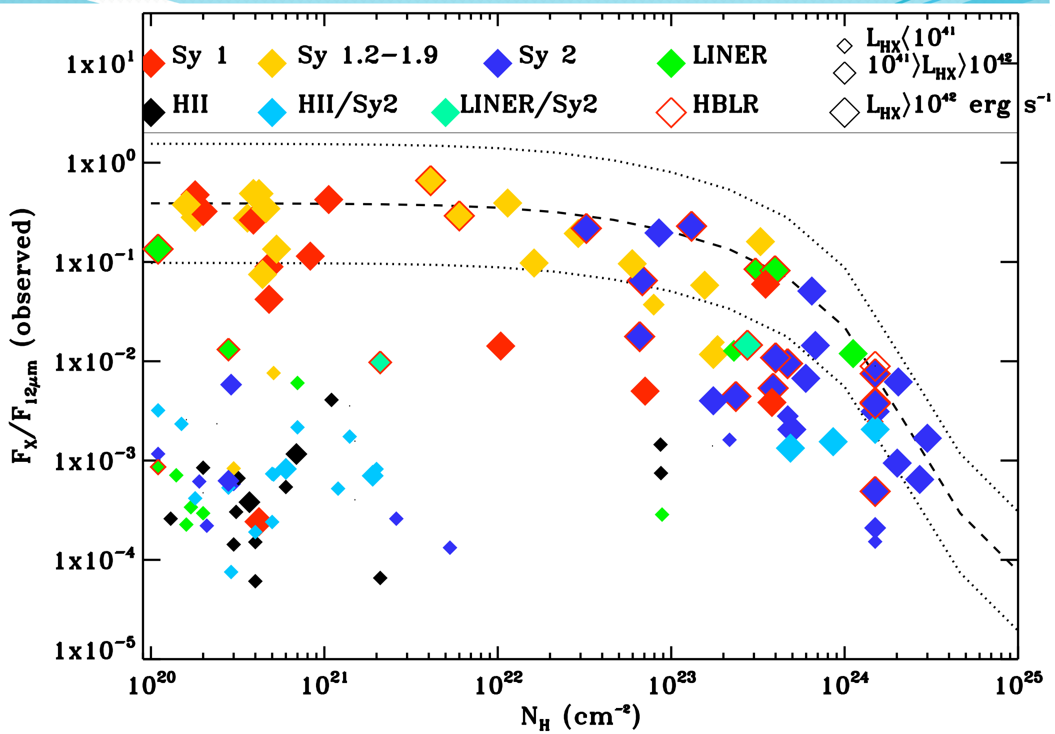
➔IR emission is expected to correlate with X-ray emission due to absorption of the primary radiation by dust which is reradiated in the MIR

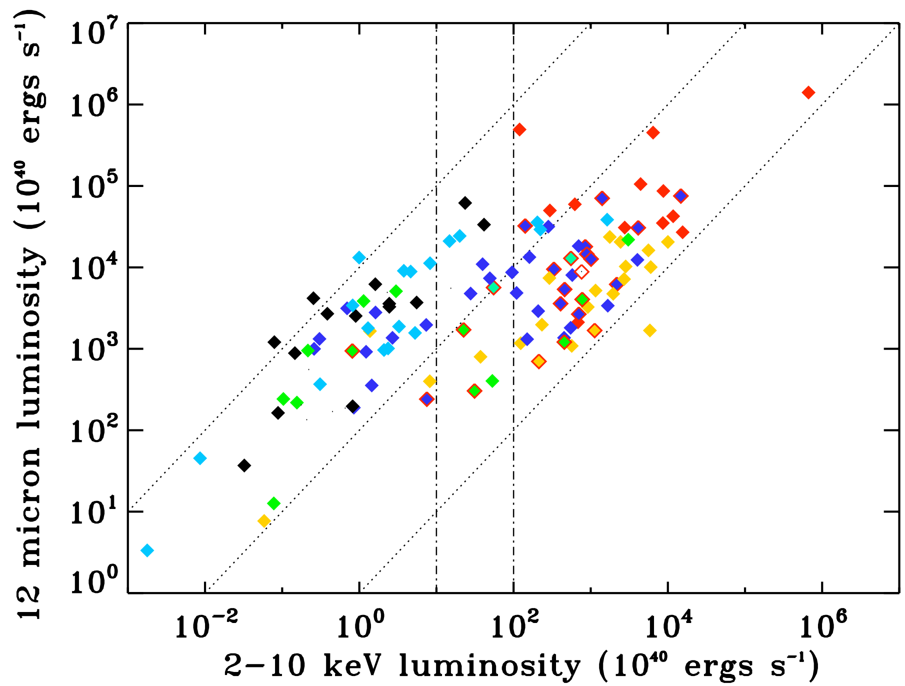
➔For bright unabsorbed AGN, X-ray and IR luminosities correlate well

➔However at lower luminosities and in absorbed sources, MIR emission from the host-galaxy contributes

➔Low $F_X/F_{MIR}$ sources can be both absorbed AGN OR star forming galaxies!

➔ We propose a new X-ray luminosity of $10^{41}$ ergs/s for selecting AGN, which gives only minimal contamination from star forming galaxies.



# Conclusions

## On AGN unification:

- Finding that the X-ray spectral index for obscured and unobscured sources are statistically the same, supports the idea that the central engines in these sources are the same – the cornerstone of unification
- However there appears to be some intrinsic link between X-ray luminosity, the broad line region and the torus, requiring a luminosity dependence modification to the unification scheme

## On AGN selection:

- Compton thick fraction for our X-ray AGN is 18%, which is higher than the hard X-ray selected samples, supporting MIR AGN selection.
- 40% of LINERs and 17 % of composite galaxies exhibit AGN power from X-ray analysis
- AGN can be selected in X-rays using a luminosity of of $10^{41}$ ergs/s, with minimal contamination from star forming sources.
- Low $F_X/F_{MIR}$ sources can be both absorbed AGN OR star forming galaxies!