BAT AGN Survey -XMM Suzaku follow-up Progress Report- or 15 things I learned this year or are we breaking any paradigms yet?

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Y. Ueda and Y. Terashima

- The Swift BAT (Burst and Transient Telescope) has been observing the whole sky in the 15-200 keV band for ~22 months
- With follow-up x-ray, optical and IR observations- this is a progress report
- **The 'first' unbiased survey of AGN in the local universe- no selection effects due to obscuration, galaxy properties or optical or radio properties.**
- **These data allow a direct comparison of selection effects for AGN across the electromagnetic spectrum since the majority of the objects are *close and bright***

Large (~ now ~425) *all sky* unbiased sample of low redshift (z_{median}=0.025)AGN

Blazars over wide z range

Uniform selection criteria

Objects are **bright and easily studied in all wavelength bands**

Rare objects (e.g. type II QSOs, very high z Blazars)

Flux limit ~1-3x10^{-11} ergs/cm^2/sec 15-200 kev (~1 mC)

Why is the BAT survey for AGN Important?

- *All previous AGN surveys were biased*-
  - Most AGN are 'obscured' in the UV/optical
  - IR properties show wide scatter wrt x-ray properties
- BAT survey should be unbiased wrt obscuration
- Much larger sample than HEAO-1 (and Integral)-1st sensitive all sky hard x-ray survey in 28 years !
- Wide time coverage -
- Good angular accuracy
- Spectra

BAT data first large unbiased sample of

• host galaxy properties

• relation of optical spectral properties to intrinsic luminosity

•Direct comparison with z~1 Chandra and XMM surveys

•Lots of targets for SUZAKU FOLLOW-UPS

•* Distribution of N(H) values

•* Luminosity function

•* Log N-Log S

•True nature of objects (Suzaku and XMM)

*necessary for modeling x-ray background

The Local Census of Active Galaxies-aka Radiating Massive Black Holes

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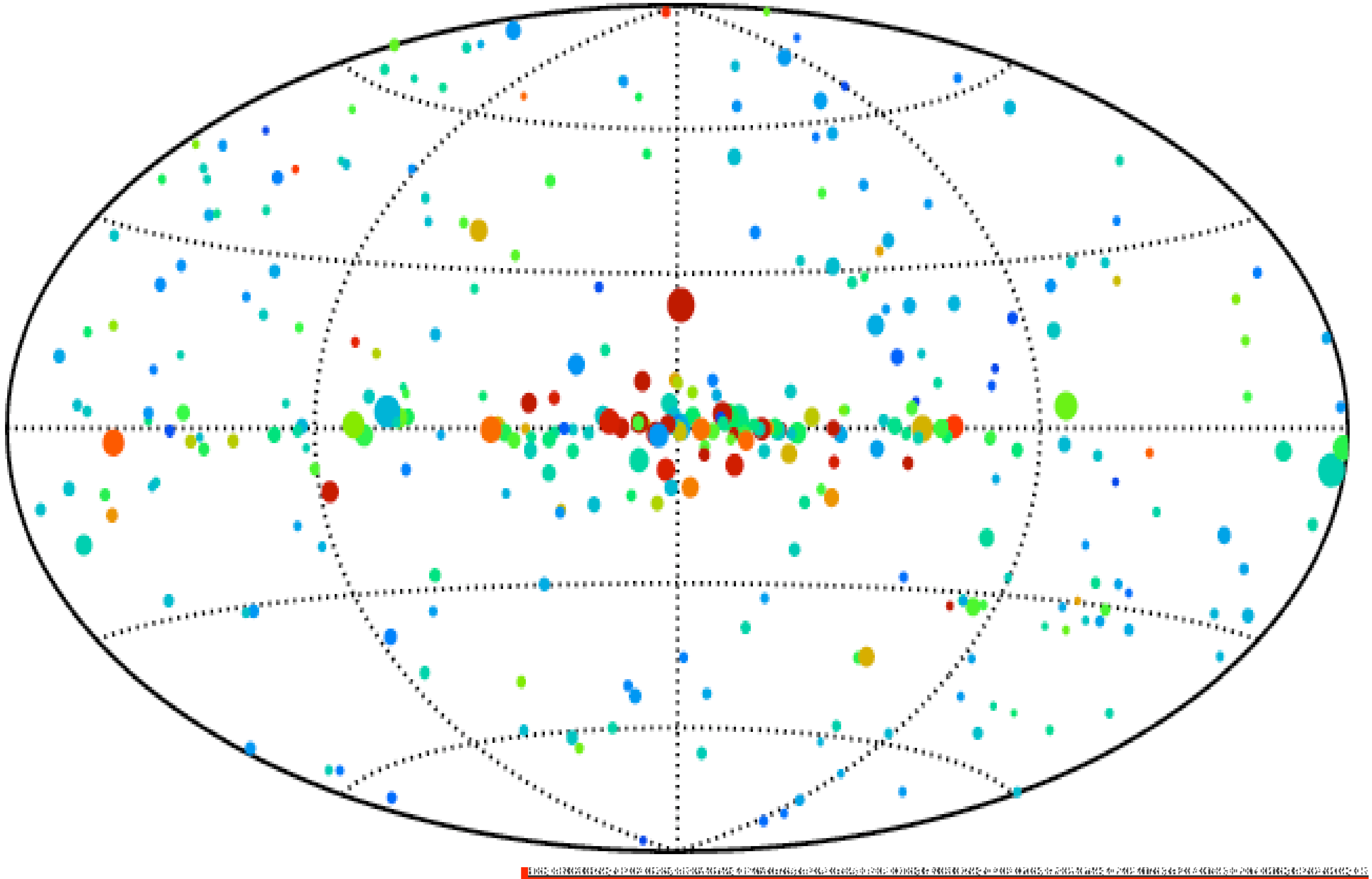

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- **A large**
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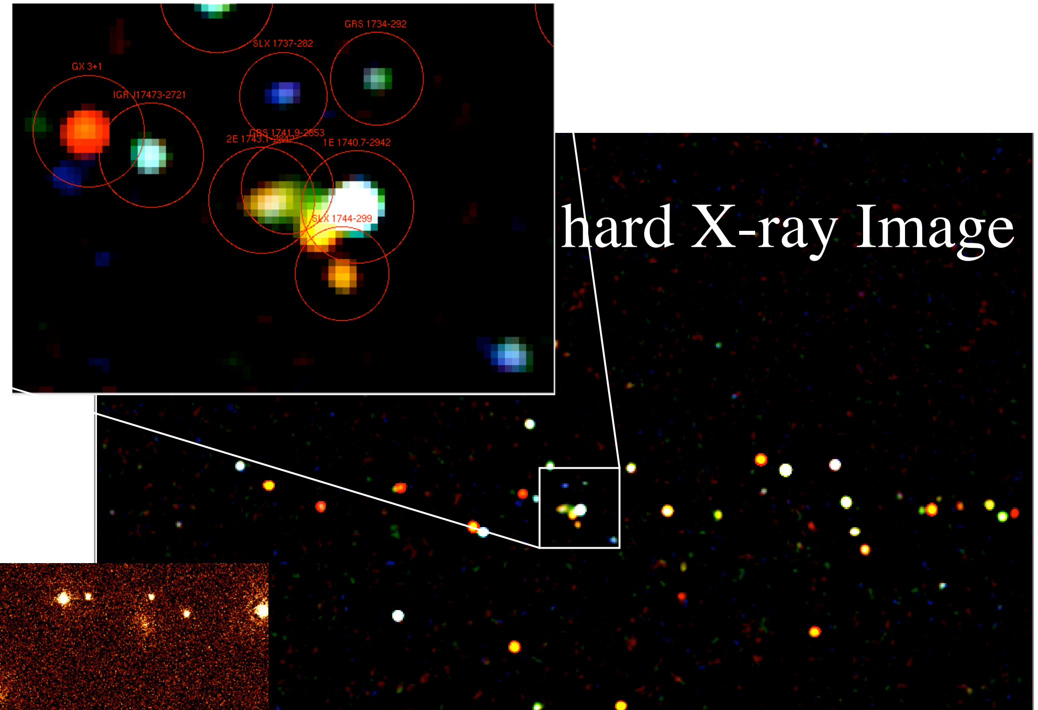
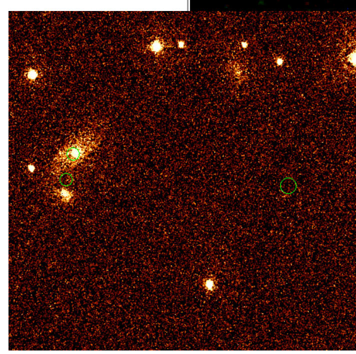
objects which are 'obscured' from view in the optical/
- **UV**

X-ray Color Image (1deg)
of the Chandra Large Area X-ray Survey-
CLASXS-400ks, 525 sources

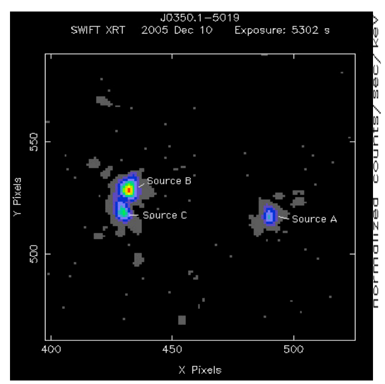
Why is a Hard X-ray census of Black Holes desirable ?

- Hard X-rays are a unique signature of accreting black holes
- Wide field finds rare objects - type II QSOs
- hard X-rays unaffected by absorption yielding a complete census
- The last all-sky hard X-ray survey was HEAO1 in 1977–BAT is 17 times more sensitive.
  - detect rare sources
  - high galactic latitudes for optical follow-up
- complete x-ray follow-up with Swift/XRT and UVOT

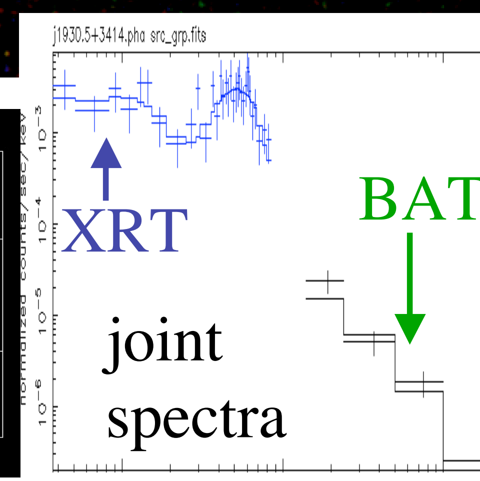




UV image



X-ray Image

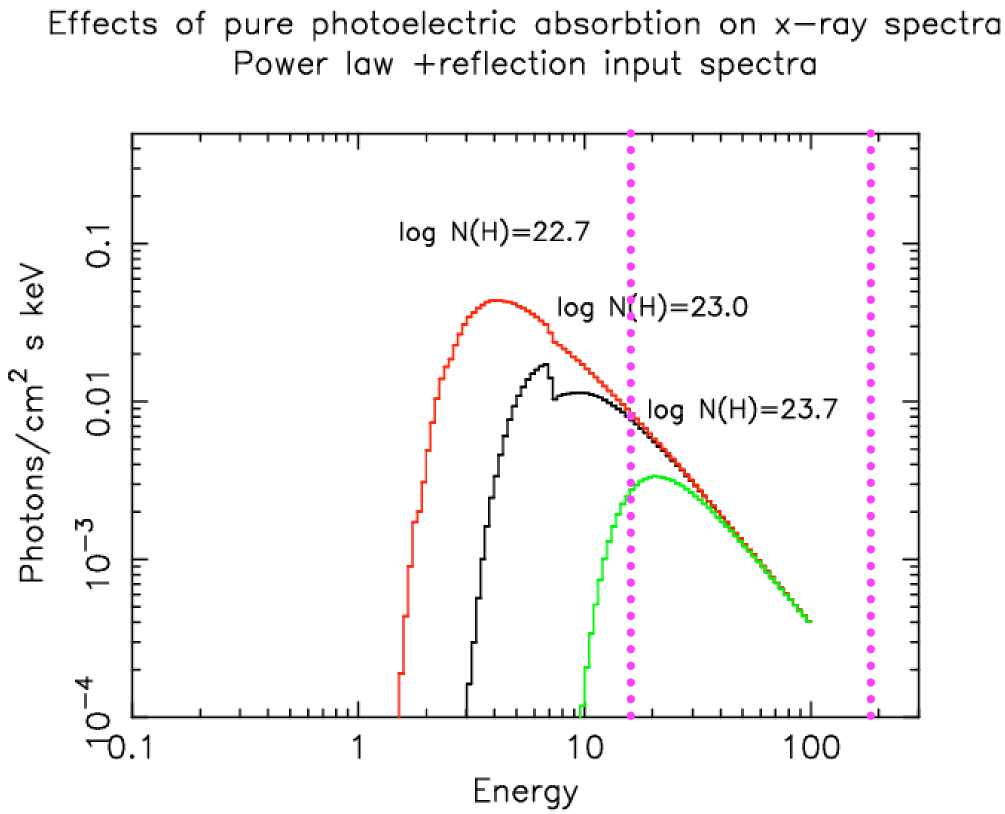


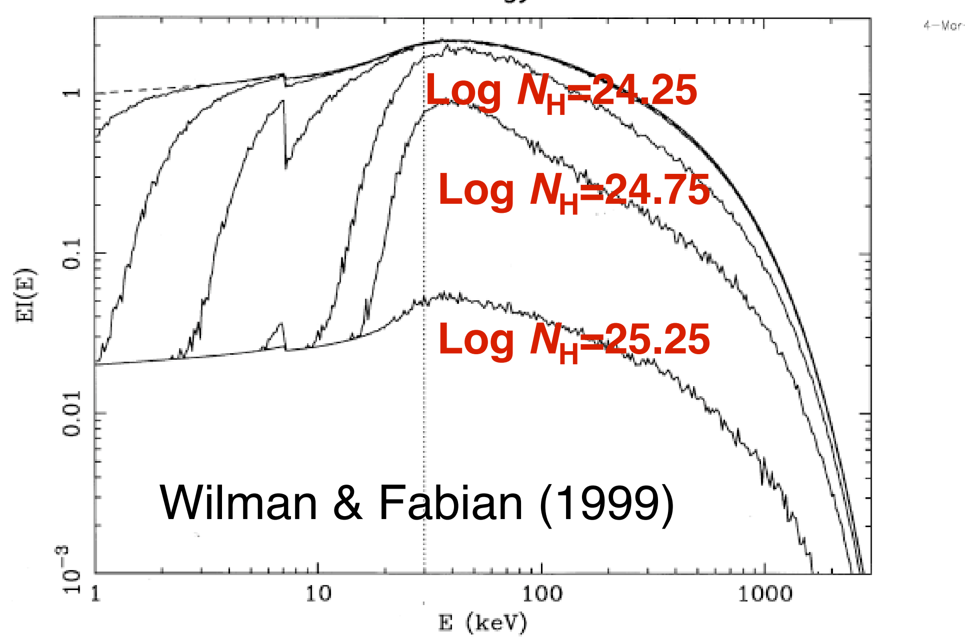
Black Hole Finder

•The absorbing material can have very large column densities block soft x-rays and UV/optical making sources optically and soft x-ray “invisible” .

•Chandra data show that there are >7x more hard x-ray selected than optically selected AGN (at same optical threshold)

•The most numerous AGN ($L_x<10^{44}$ ergs/sec) **evolve inversely from the well studied quasars** and are more numerous in the local than high z universe





AGN X-ray Spectral Components

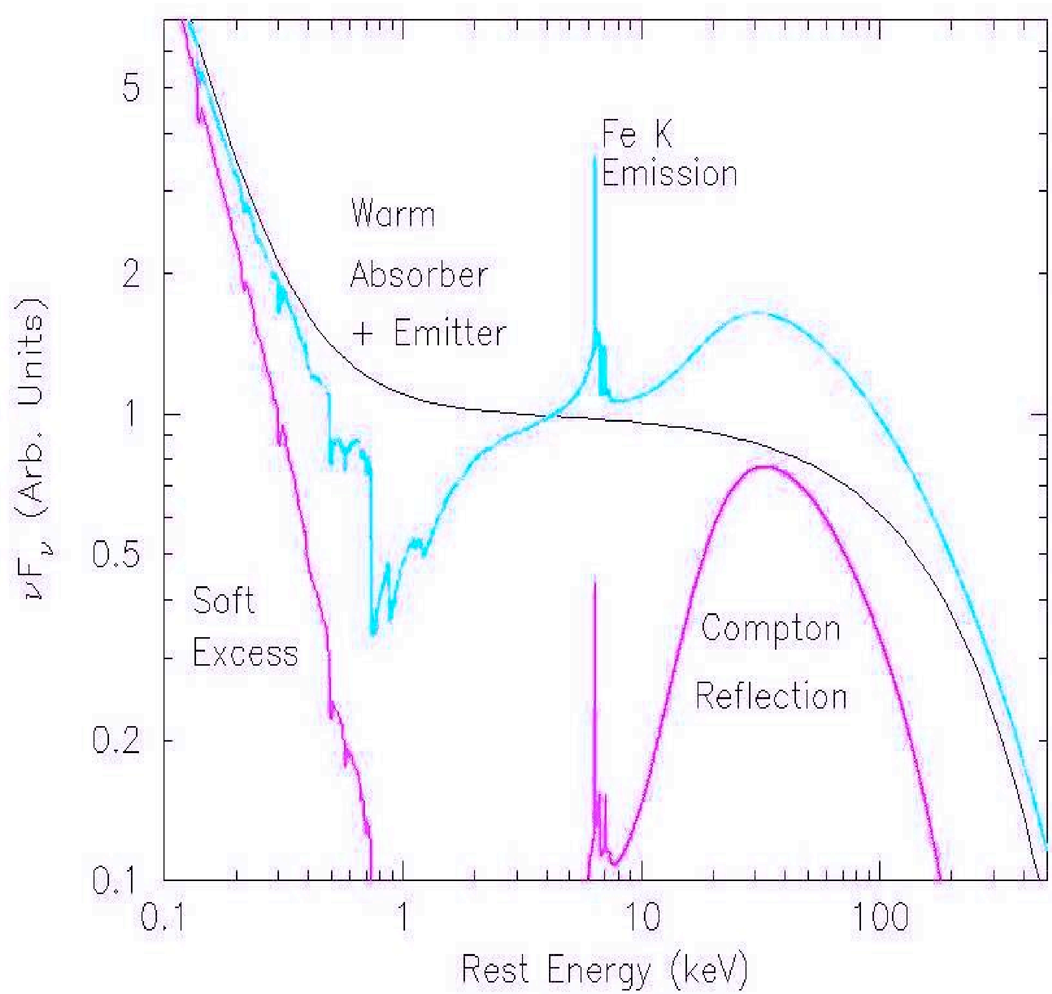
"Power-law" emission via thermal Comptonization of seed disc (UV) photons

Soft excess - hard tail of thermal disc emission ? in EUV (big blue bump)

Warm absorber/Emitter - ionized gas outflowing from nucleus (lightdays - parsec scale)

Iron line emission - accretion disk, BLR, torus, NLR ?

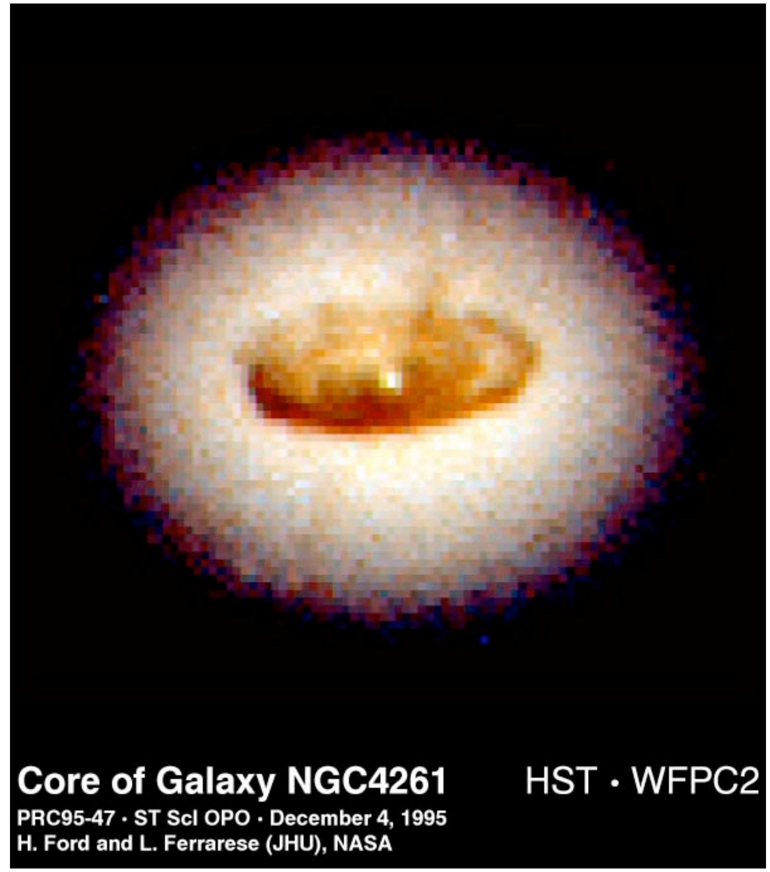
Compton Reflection - off optically thick matter (disc, torus)

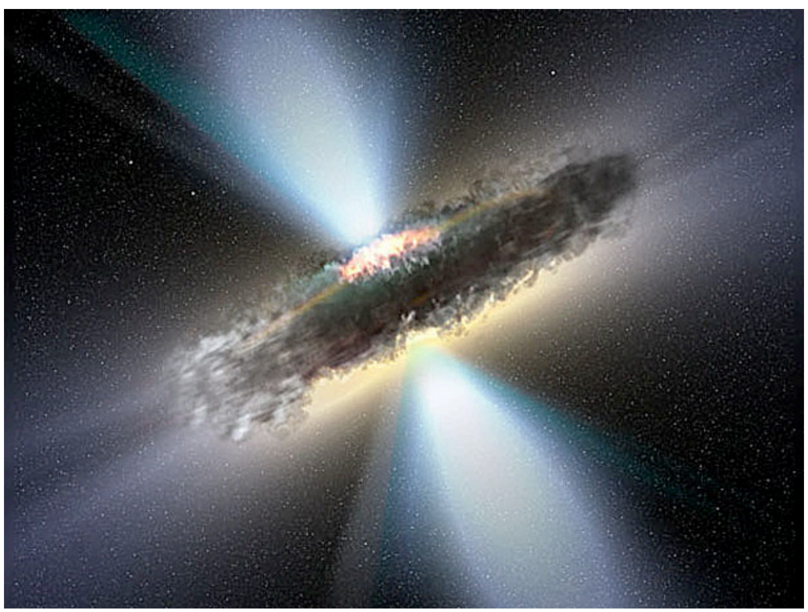


Fabian/Reeves 2005

The Dark Side of AGN

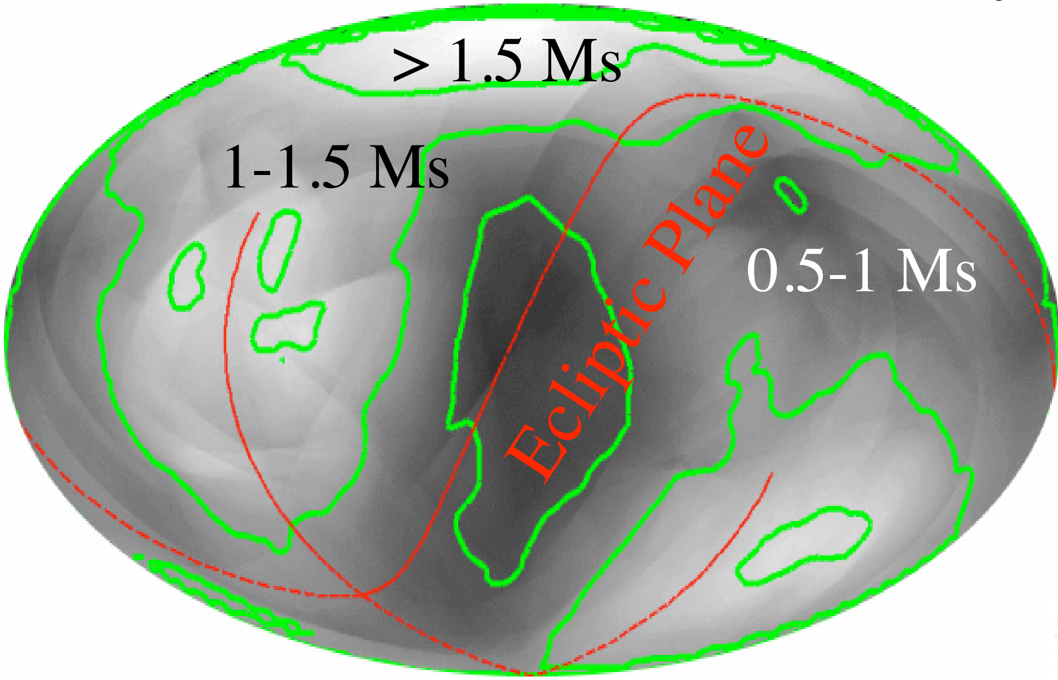
- ***Many*** ***(what fraction?)*** ***of AGN are obscured***- obscuring material is of several types
  - ISM of the host galaxy
  - An AGN wind
  - An 'obscuring torus'
  - Etc
  - Lack of uniform sample not sensitive to absorption or emission from these structures has limited knowledge

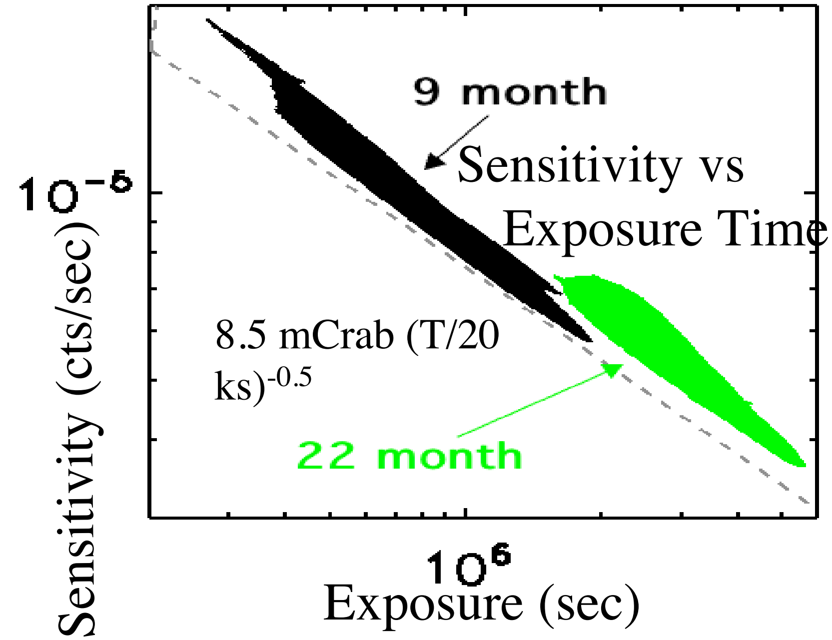




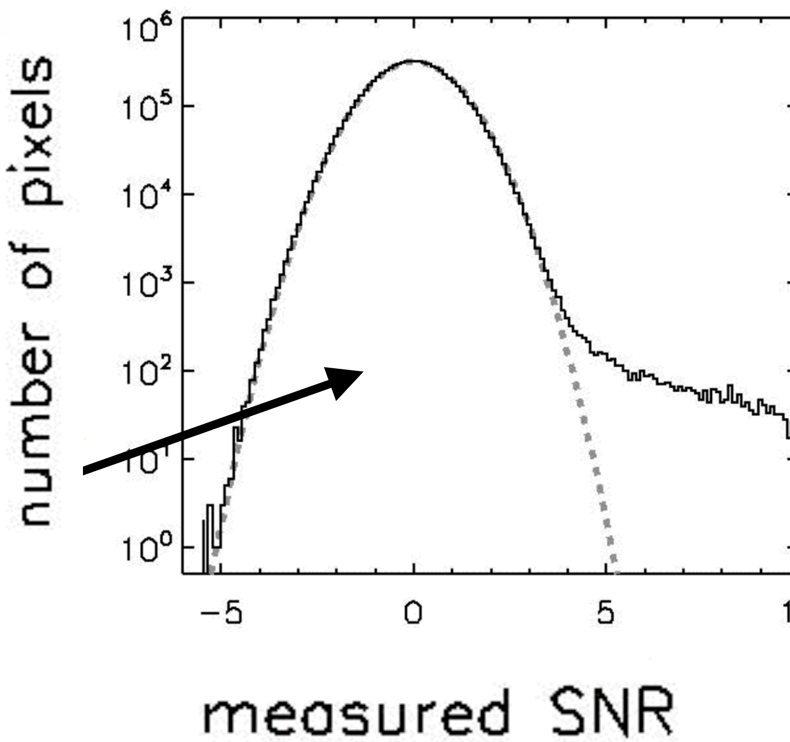
physical conditions in obscuring regions are not the same from object to object - can be complex with large and unpredictable effects on the spectrum

9-month Swift/BAT Survey

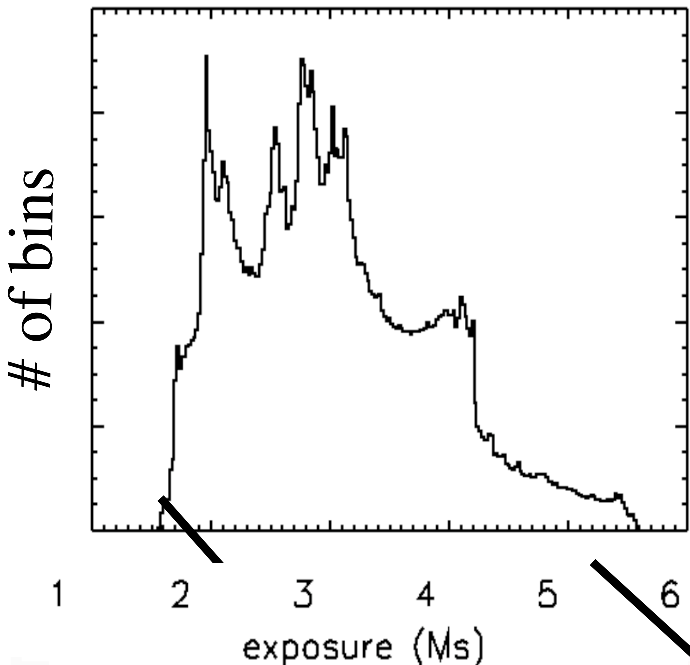


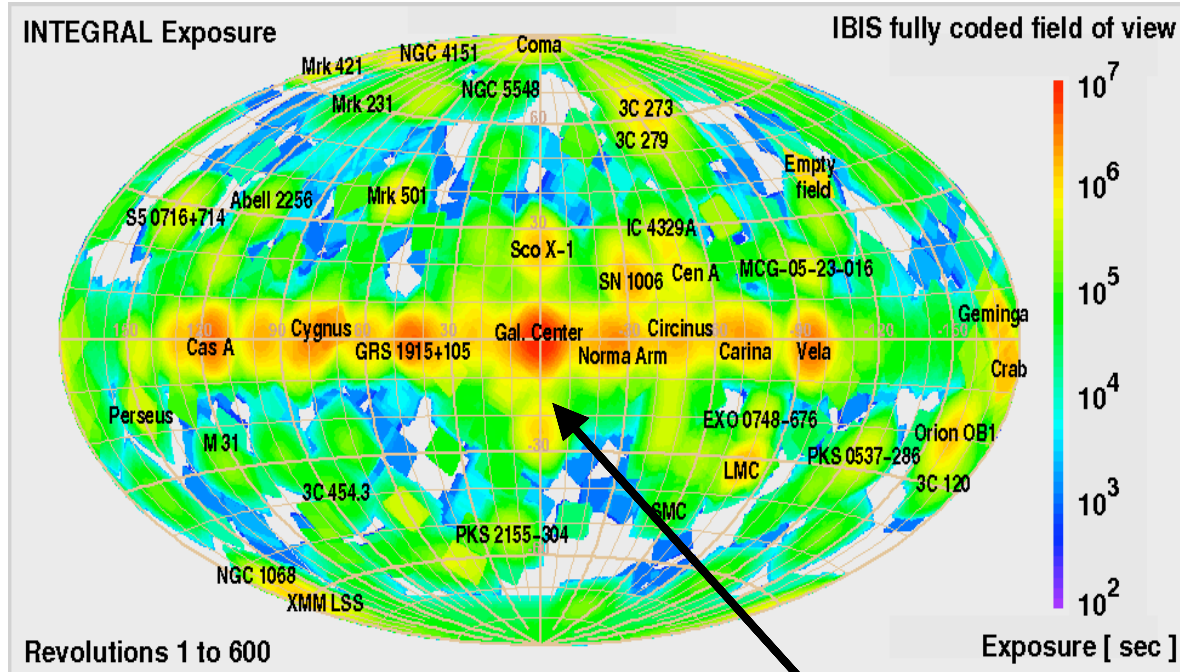


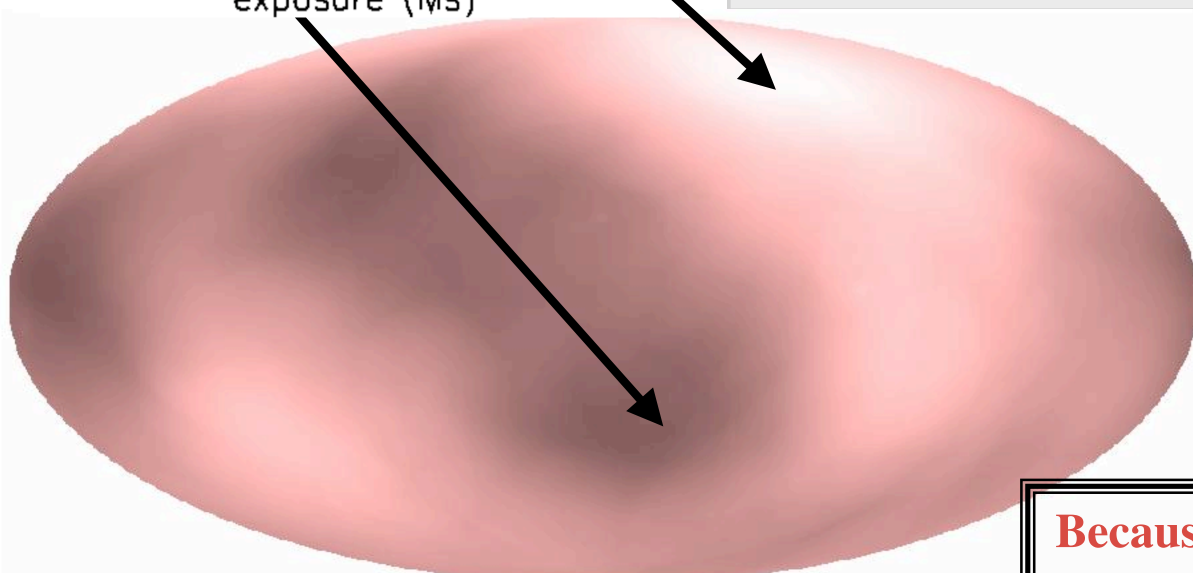
- Covers whole sky, mostly >1Ms
  - deficit on Ecliptic Plane due to Sun avoidance
- Sensitivity improves as square root of time (1.2-2 X statistical) to 0.6 milliCrab in 3 years
- Noise is Gaussian



22 Month Swift/BAT and INTEGRAL Exposure







Integral exposures to $>10^7$ s

BAT Exposure (all sky

2-4 10^6 s/22 months

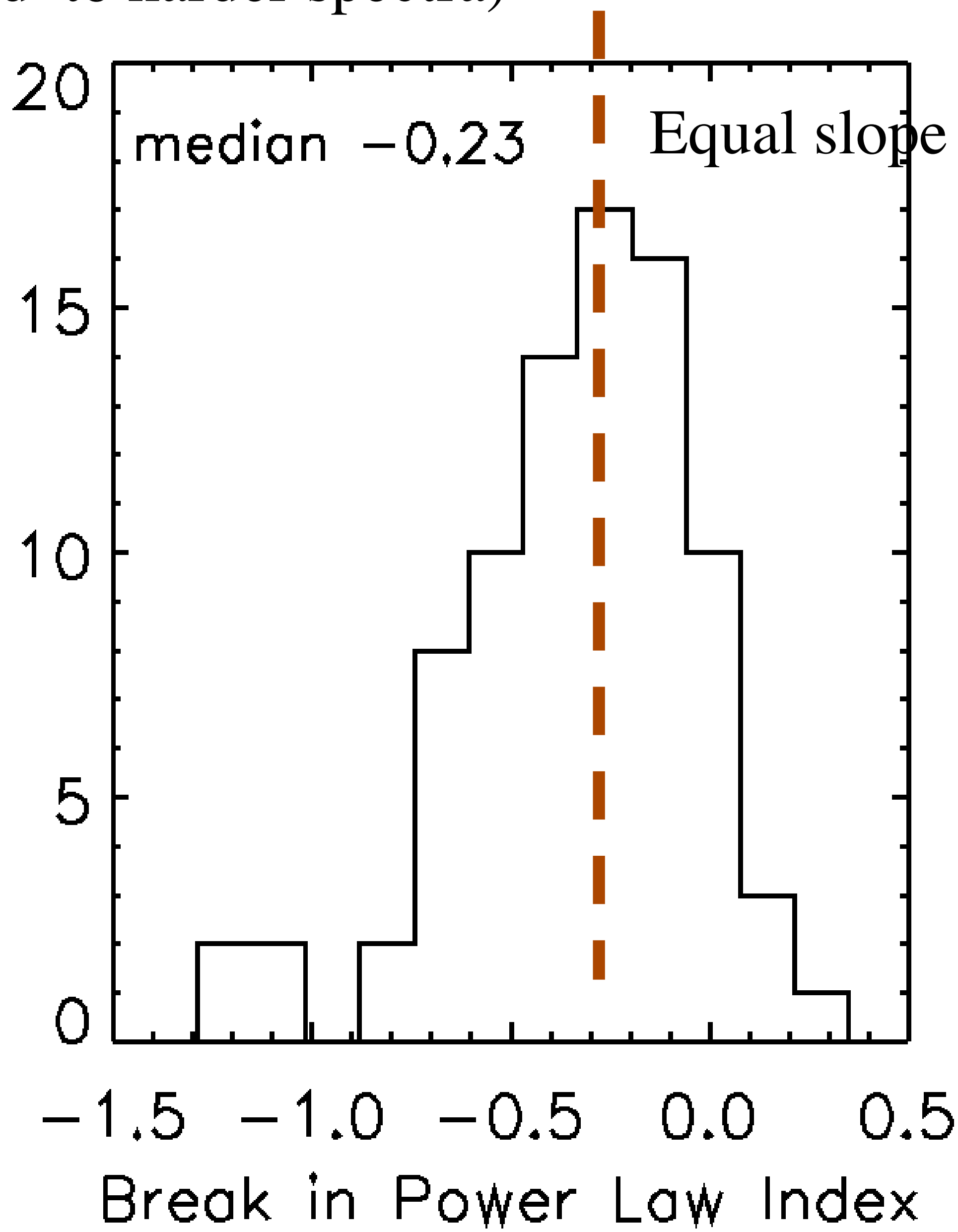
Because of BAT very long exposure more sensitive than Suzaku at E> 60 kev

BAT Spectra Softer than 2-10 keV X-ray

(BAT biased to harder spectra)

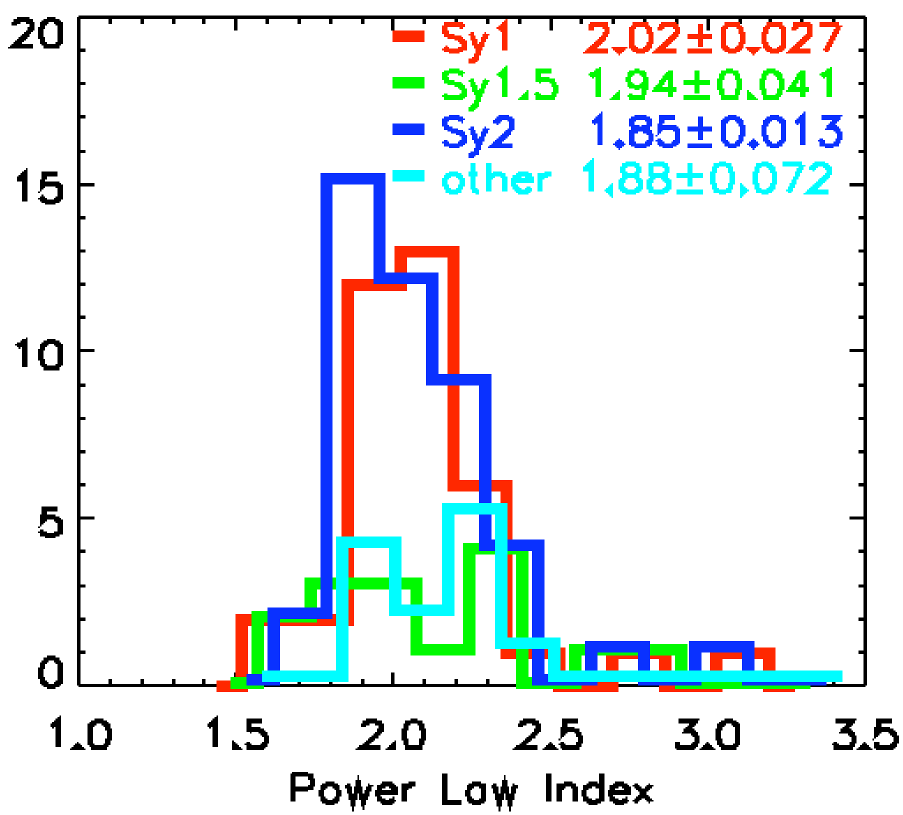
- BAT power law index consistently softer than the 2-10 keV index (RXTE simple Power law fits)
  median x-ray=1.74

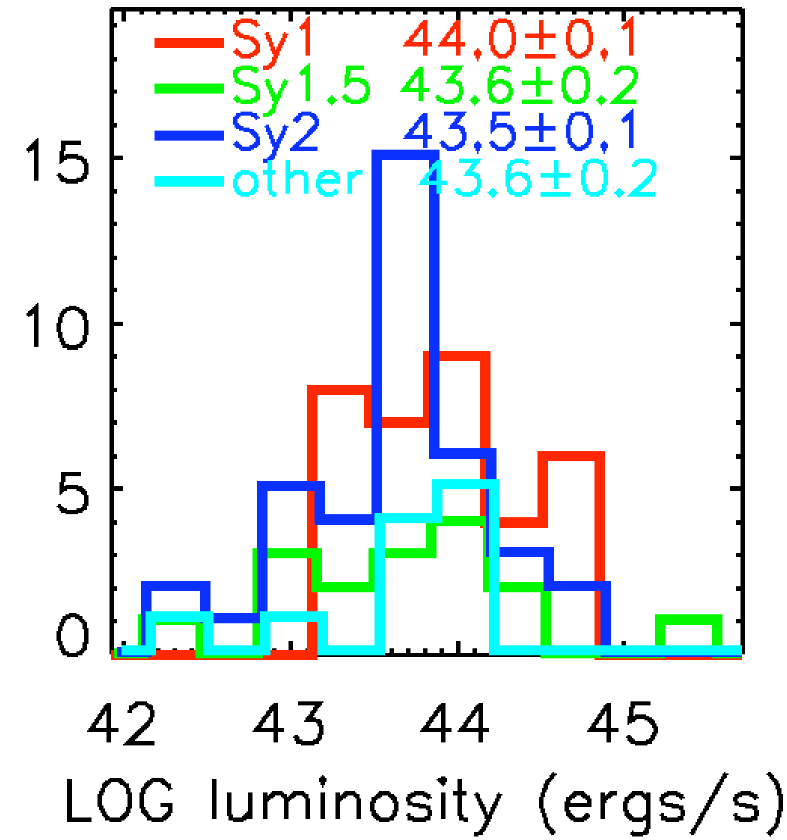
  median BAT=1.96
  - As predicted by reflection models-
  - x-ray spectrum Σ of Pl + reflection, reflection less important at E> 40 keV so see 'true' continuum form
- Break=Γ_{bat}-Γ_{xray}



Tests of the Standard Model

With <E>~50 kev BAT measures the true nature of the continuum relatively unaffected by absorption or scattering

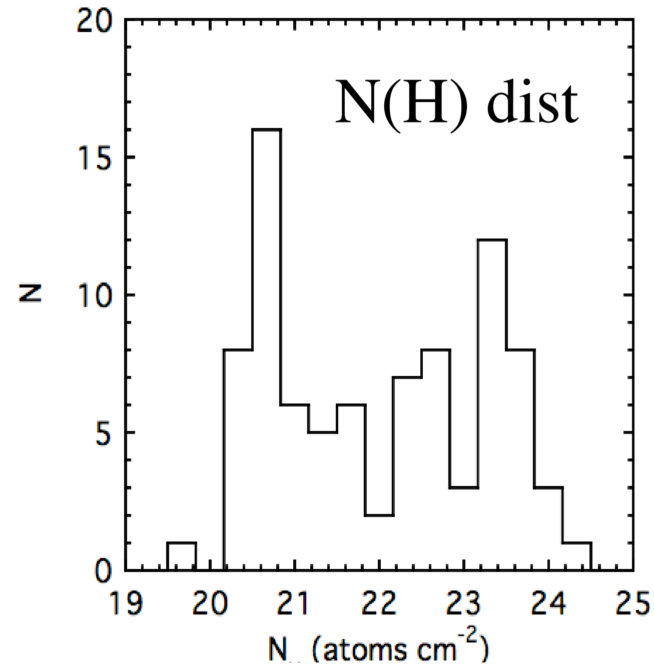


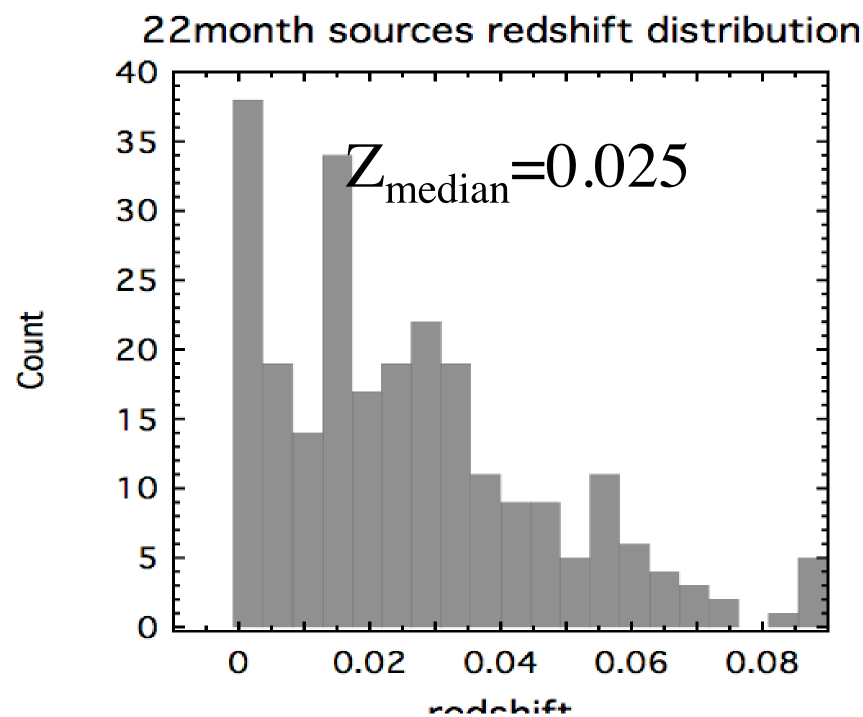


- BAT selected Sy1's have higher luminosity than Sy2's (3.6σ) and steeper indices
- no selection effect for BAT

Detailed Follow-ups with Suzaku and XMM
(L. Winter in press, Ueda et al 2007)

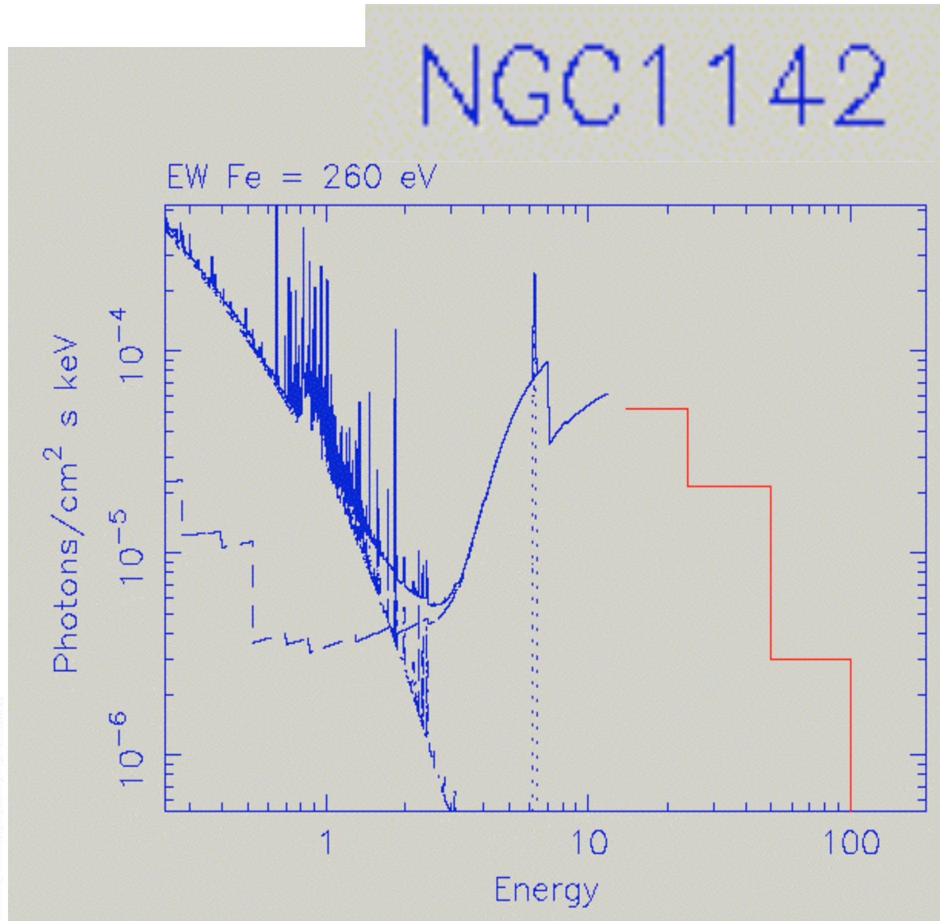
- If BAT survey truly unbiased allows true sample of AGN properties
  - Fraction of Compton thick sources
  - Absorption distribution
  - Incidence of soft excesses, ionized absorber
  - 'New' classes of AGN
  - Fe K lines properties
  - Incidence of absorption features
- Have just started Suzaku analysis



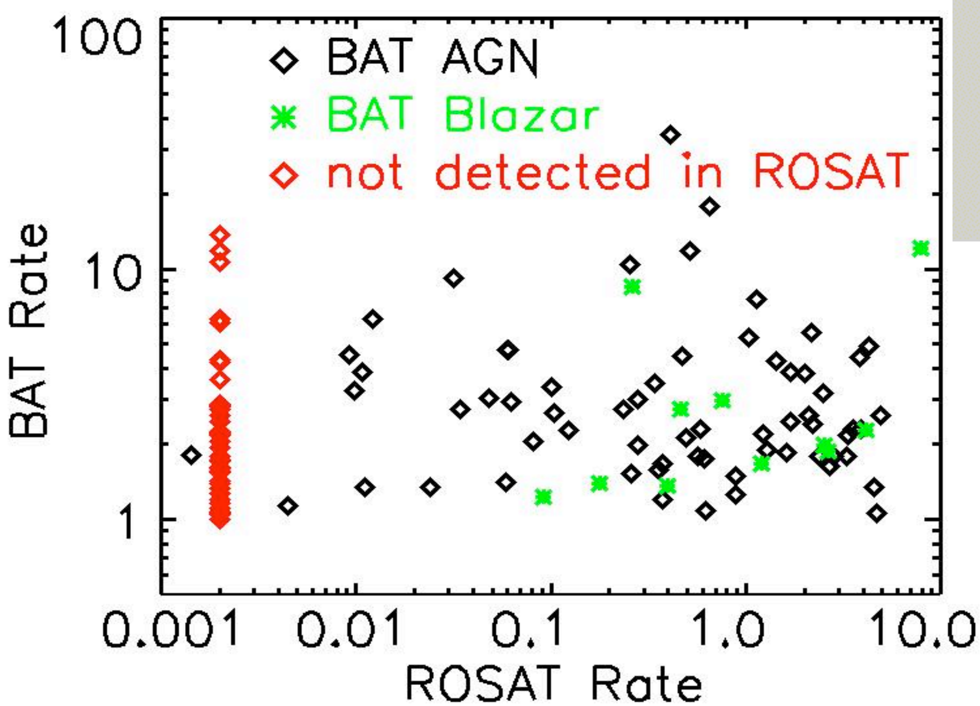


Nature of Hard X-ray selected sources

- Followed up Swift BAT selected sources with XMM, Suzaku and XRT
- Wide range of x-ray spectra
- Many of the IDs have
  - no optical evidence for activity in literature even though they are very low z bright galaxies
- ***No correlation with Rosat flux***



XMM + BAT spectra

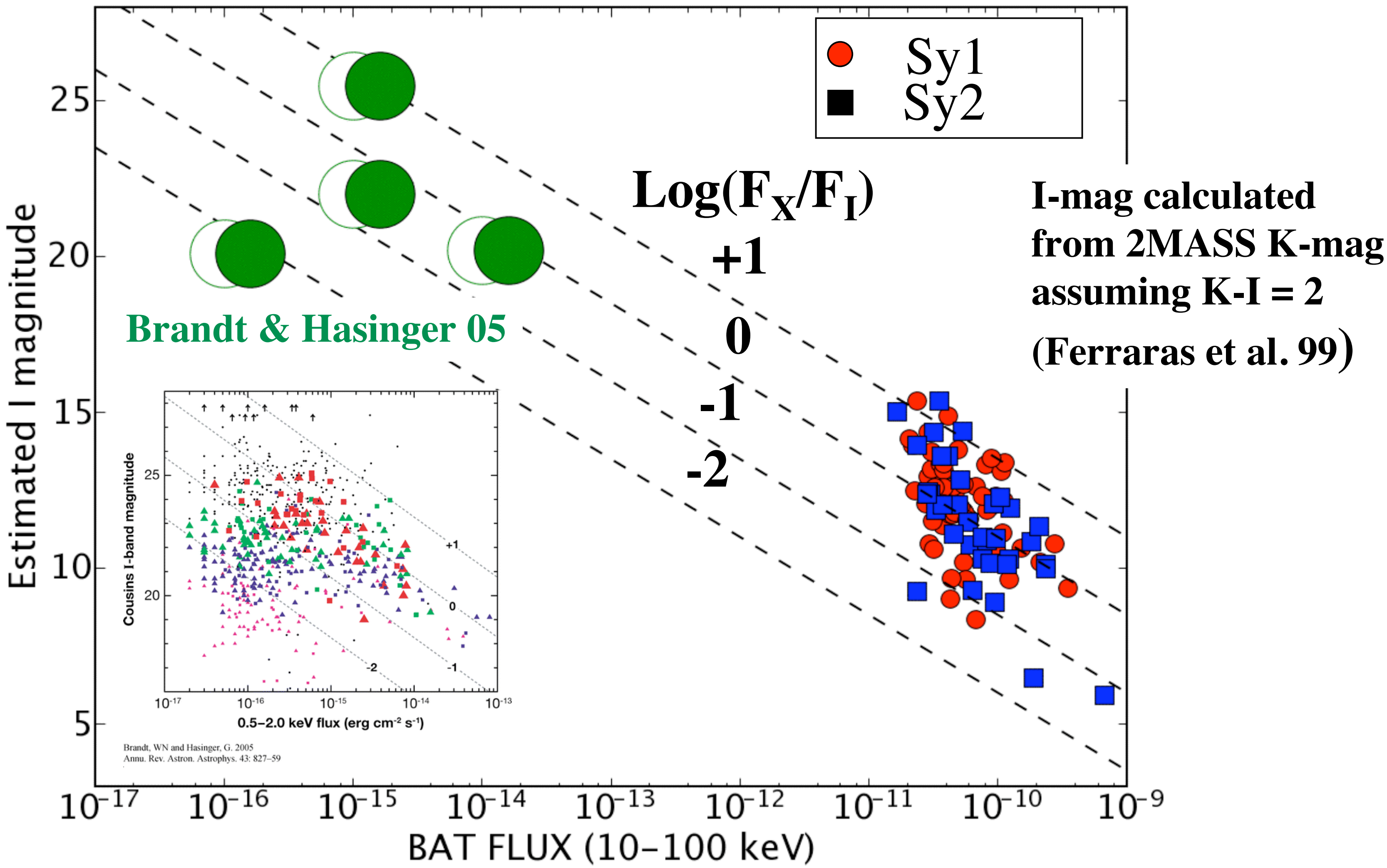


Obvious why soft and hard x-ray band are uncorrelated

SWIFT BAT Survey Compared to Other X-ray Surveys

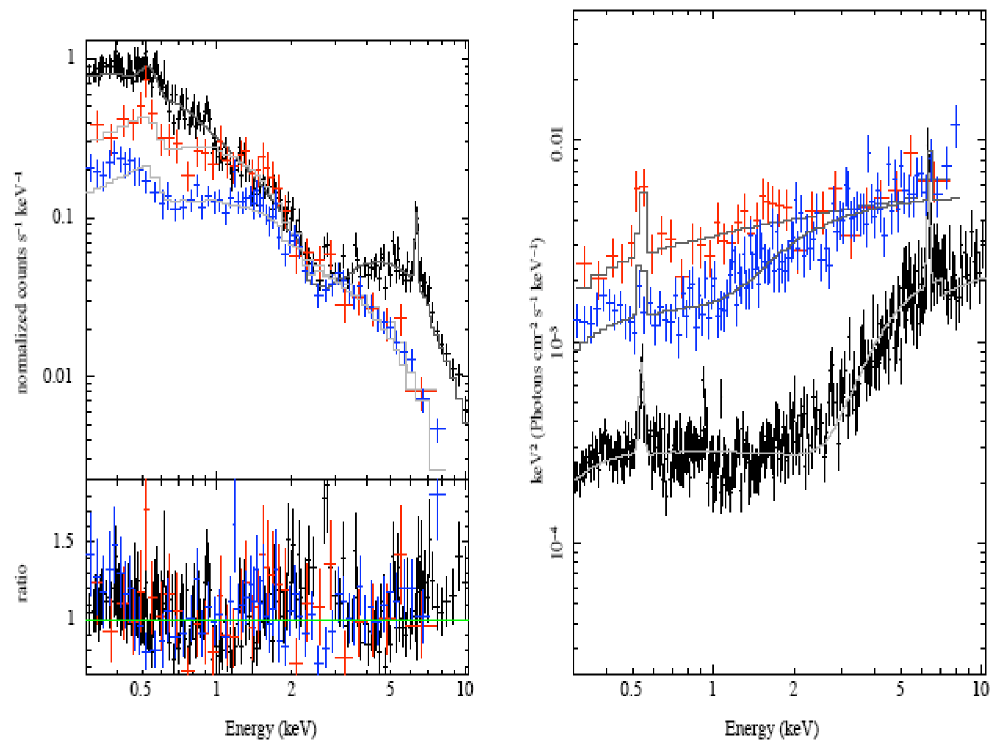
To first order x-ray to optical ratio of the BAT sources consistent with deep x-ray surveys

BAT sources tend to be optically bright- SDSS +6dF spectra



XMM Follow-ups (Winter et al) 22 Objects

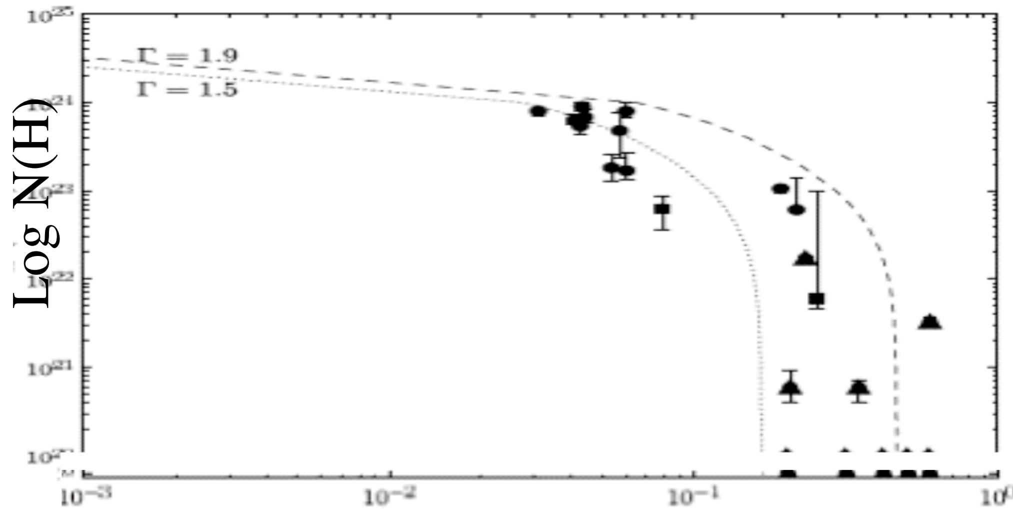
- local (< z >= 0.03) sample
- 9/22 low absorption ($n_H < 10^{23}$ cm^2), simple power law model
- Only 4 have significant soft component
- Only Seyfert 1 source warm absorber (ASCA results WA in 1/2 Seyfert 1 at similar redshifts)
- **14/22 have complex spectra,**
- 4 with v. high covering fraction- the hidden/buried AGN (Ueda et al.2007)
- 6/16 varying column densities,
- 6/16 varying power law indices
- 13/16 sources varying fluxes
- Flux and power law index correlated

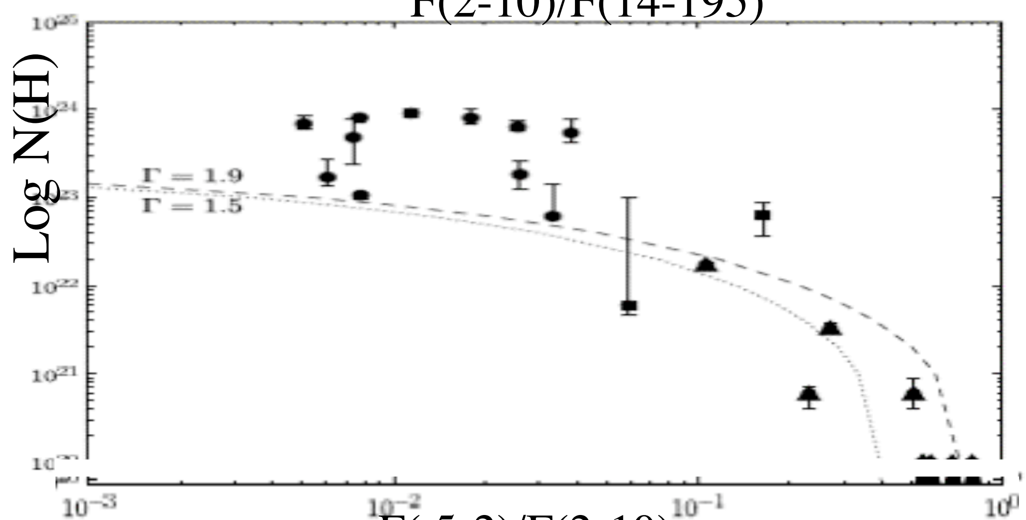


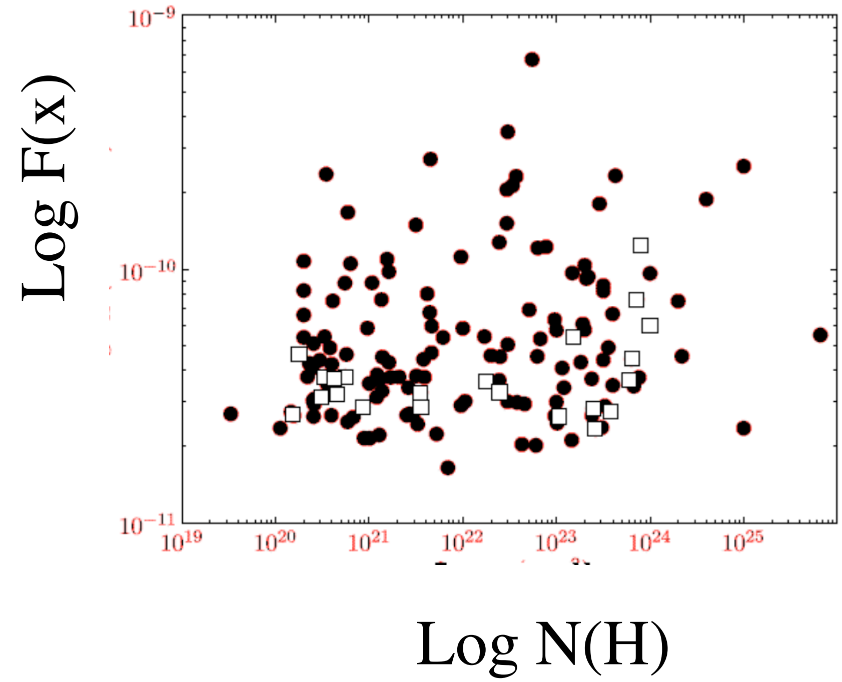
ESO 362-G018- XMM and 2 Swift XRT observations

XMM Follow-ups (Winter et al) 22 Objects

- Sample representative (same distribution of N(H) as in total BAT sample



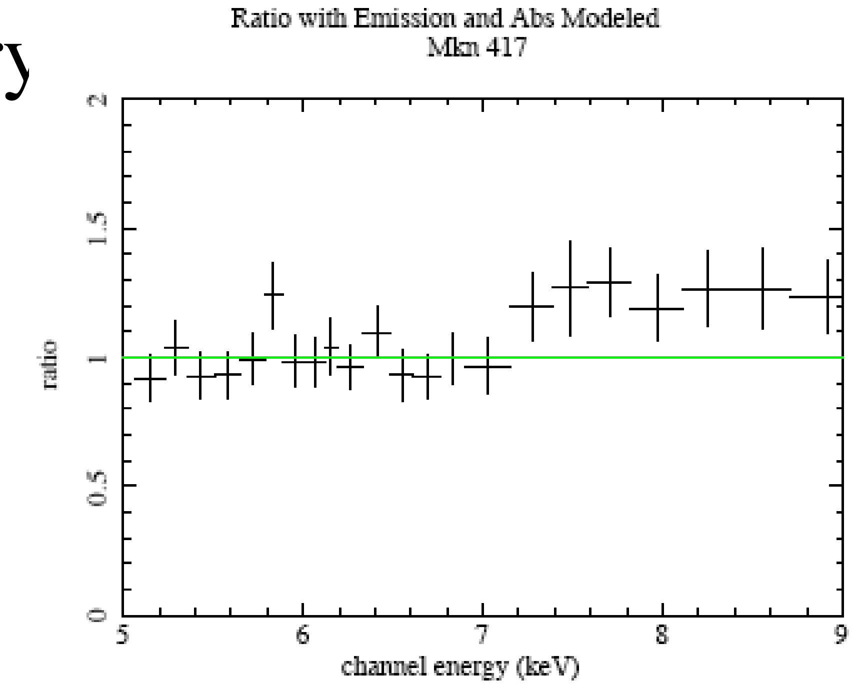


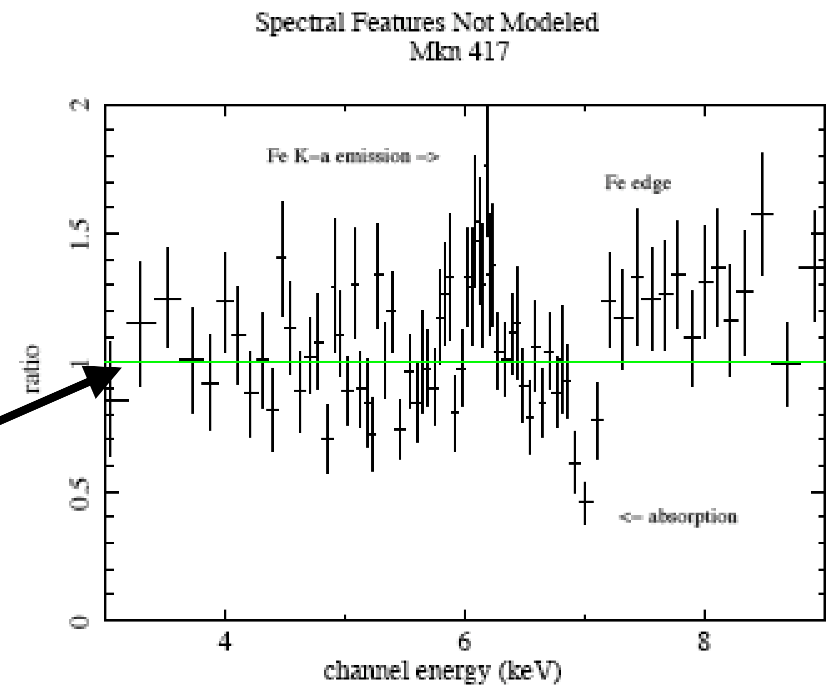


Ratio of F(2-10)/F(14-195) correctly predicts N(H)- but Ratio of F(.5-2)/F(2-10) does not because of complex spectra) - beware use of hardness ratios in analysis of deep surveys!

Suzaku BAT XMM Summary

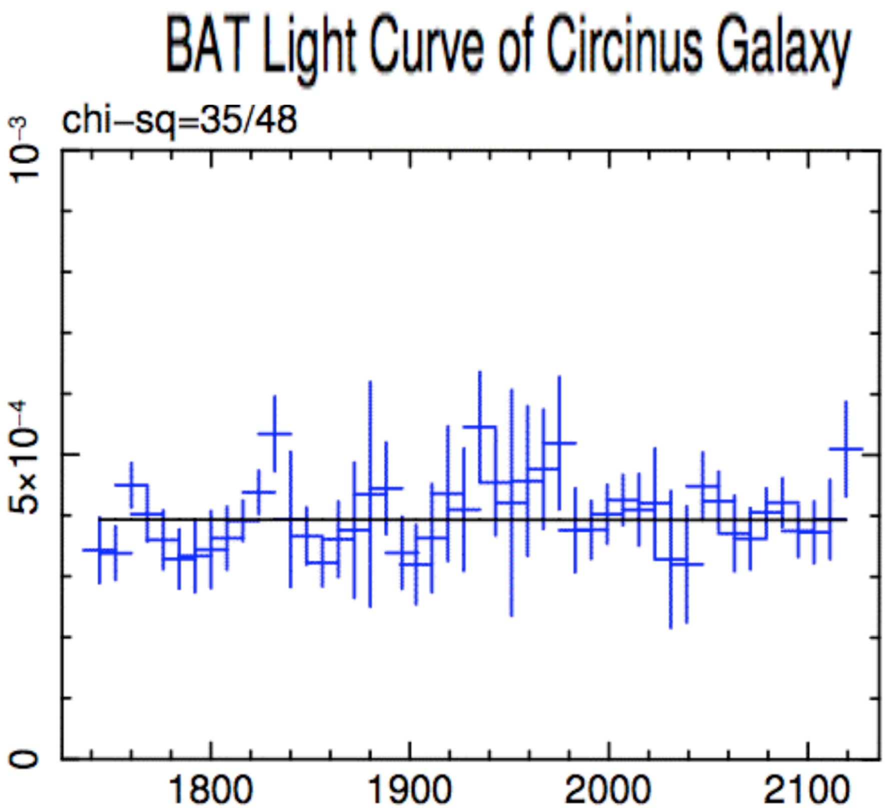
1) distinguishing Compton thick objects from double partial covering is almost impossible and that frequently reflection is very low.
2) lots of fully absorbed objects
3) lots of variability in high column density objects, even high luminosity ones
4) strong [OIII] even in fully absorbed objects.
5) strong correlation of the near IR to the hard x-rays
6) cutoffs are rare but not absent, most objects are power laws to E~140 but there are strong exceptions.
7) Incidence of spectral abs features seems large



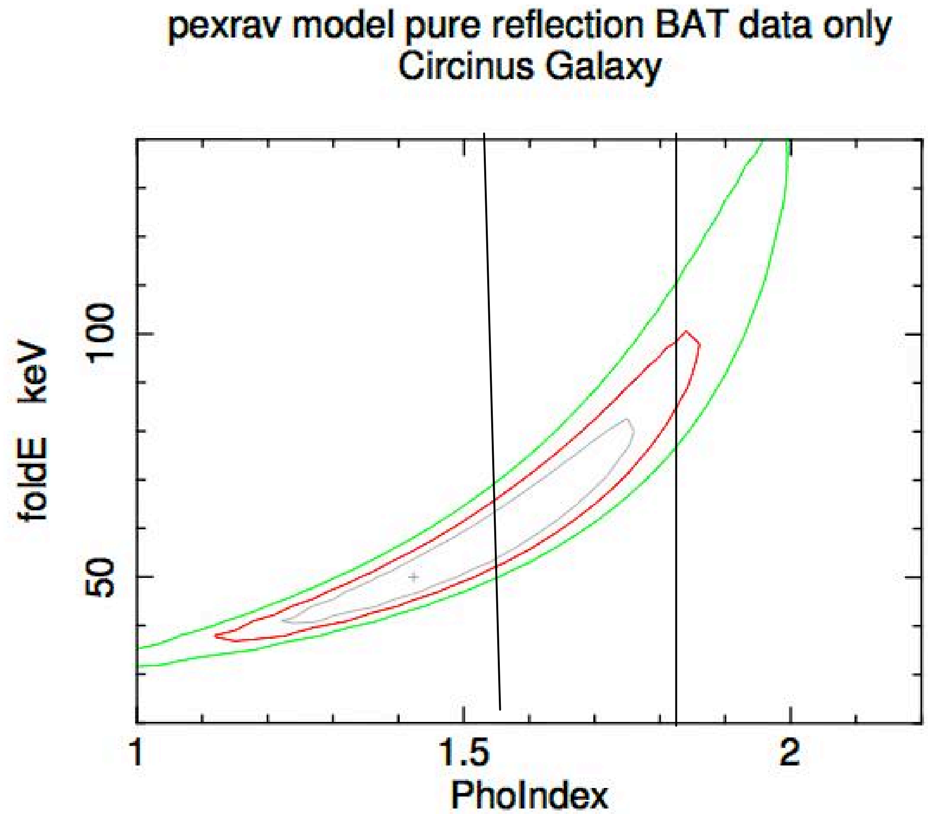


Circinus Galaxy

- It is clear that some objects have high energy cutoffs
- And strong reflection



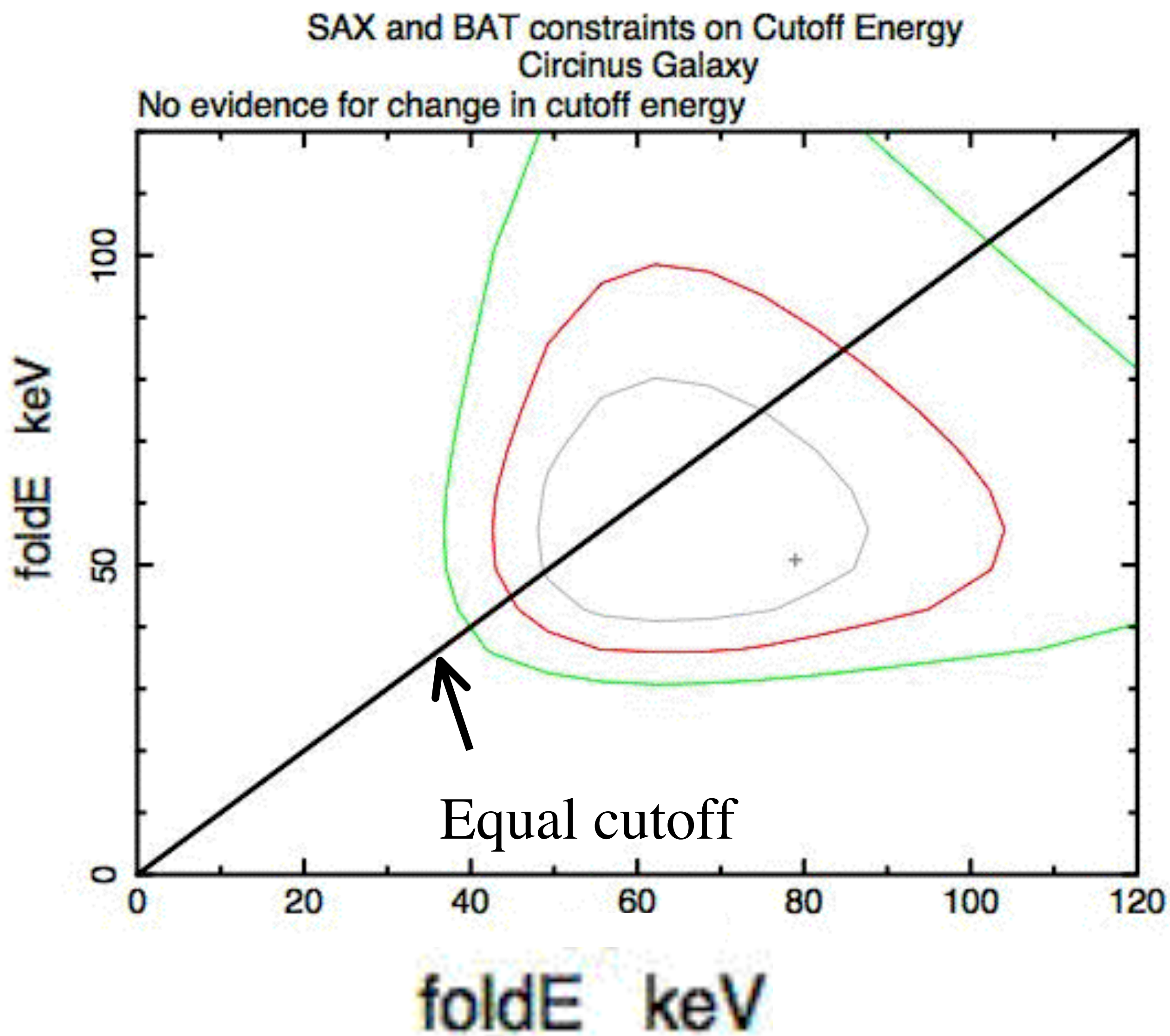
Swift day



Lack of variability on 13 month timescale- BAT norm and SAX are identical- BAT and SAX cutoff are the same

Cutoffs

- There are a few objects for which one can compare the SAX and BAT cutoffs
- For Circinus galaxy, which is Compton thick there is good agreement between the BAT and SAX spectrum



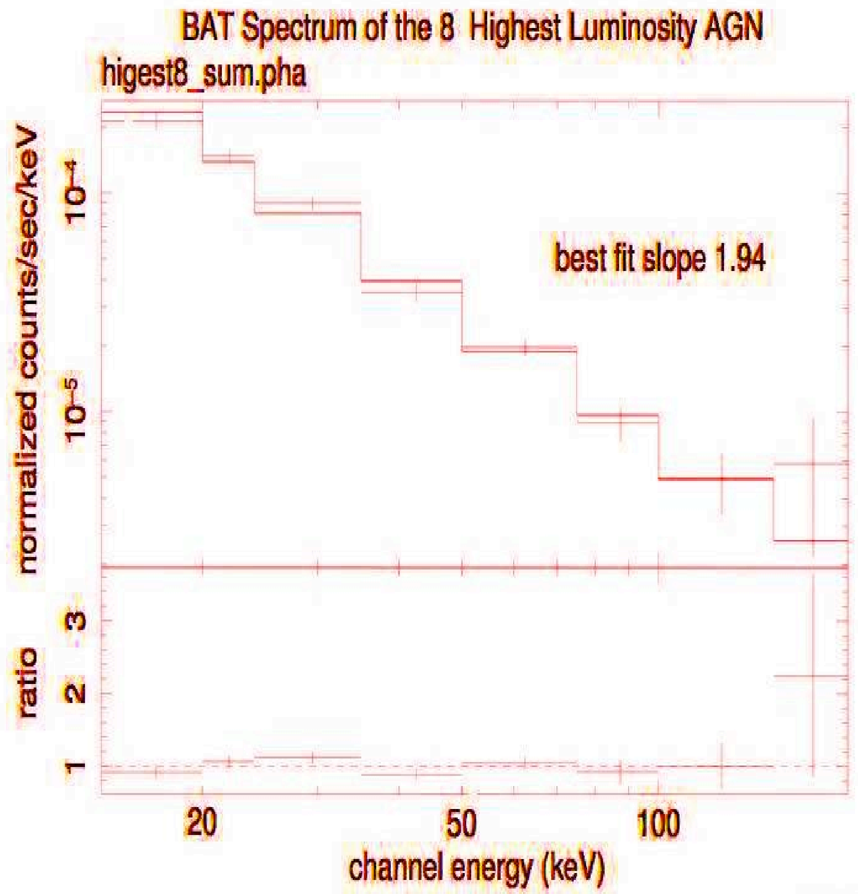
Spectral Differences as a function of luminosity

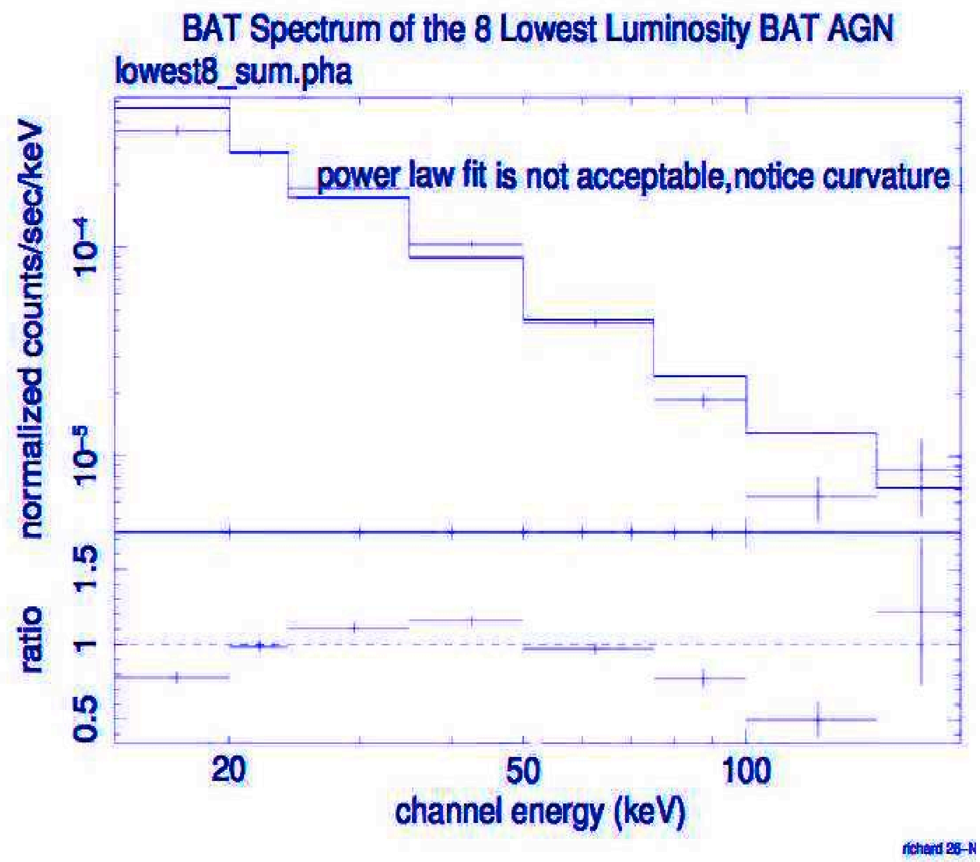
BAT data show that as the hard x-ray luminosity decreases the spectra are more curved

- high luminosity sources well fit by simple power law

Curvature is best explained by ‘reflection’

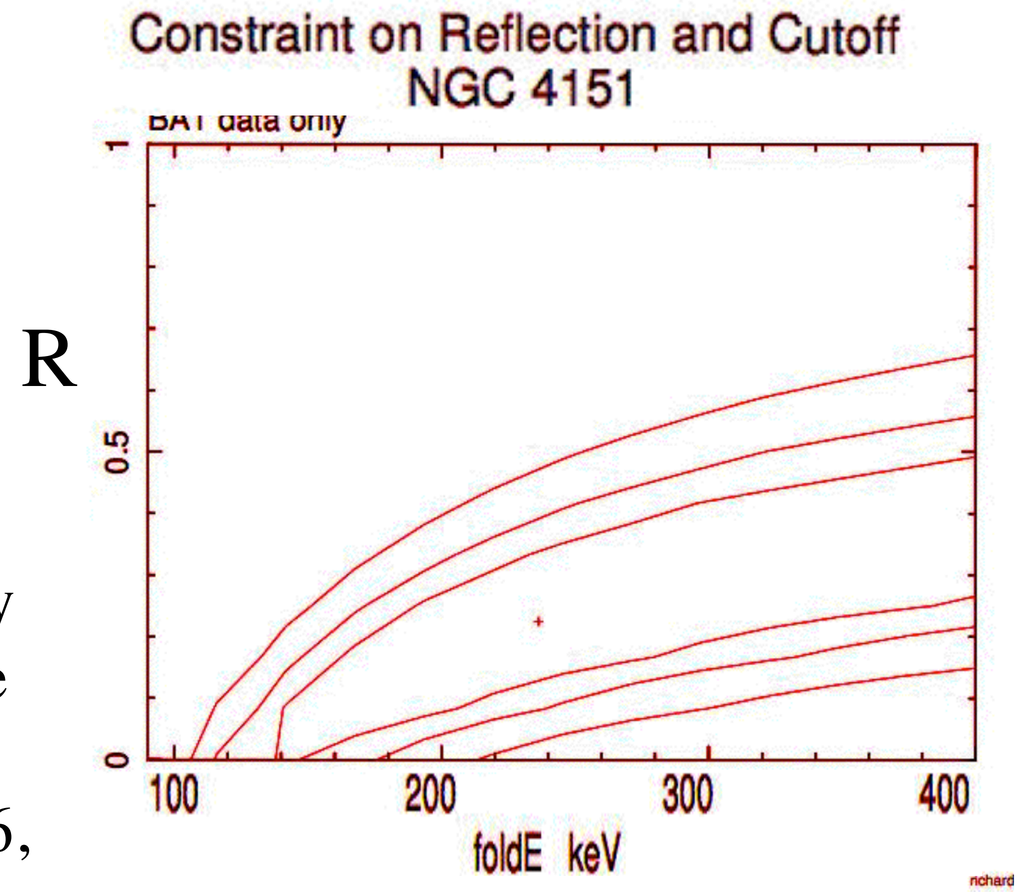
This has not been included in XRB modeling





Curvature in Individual Objects

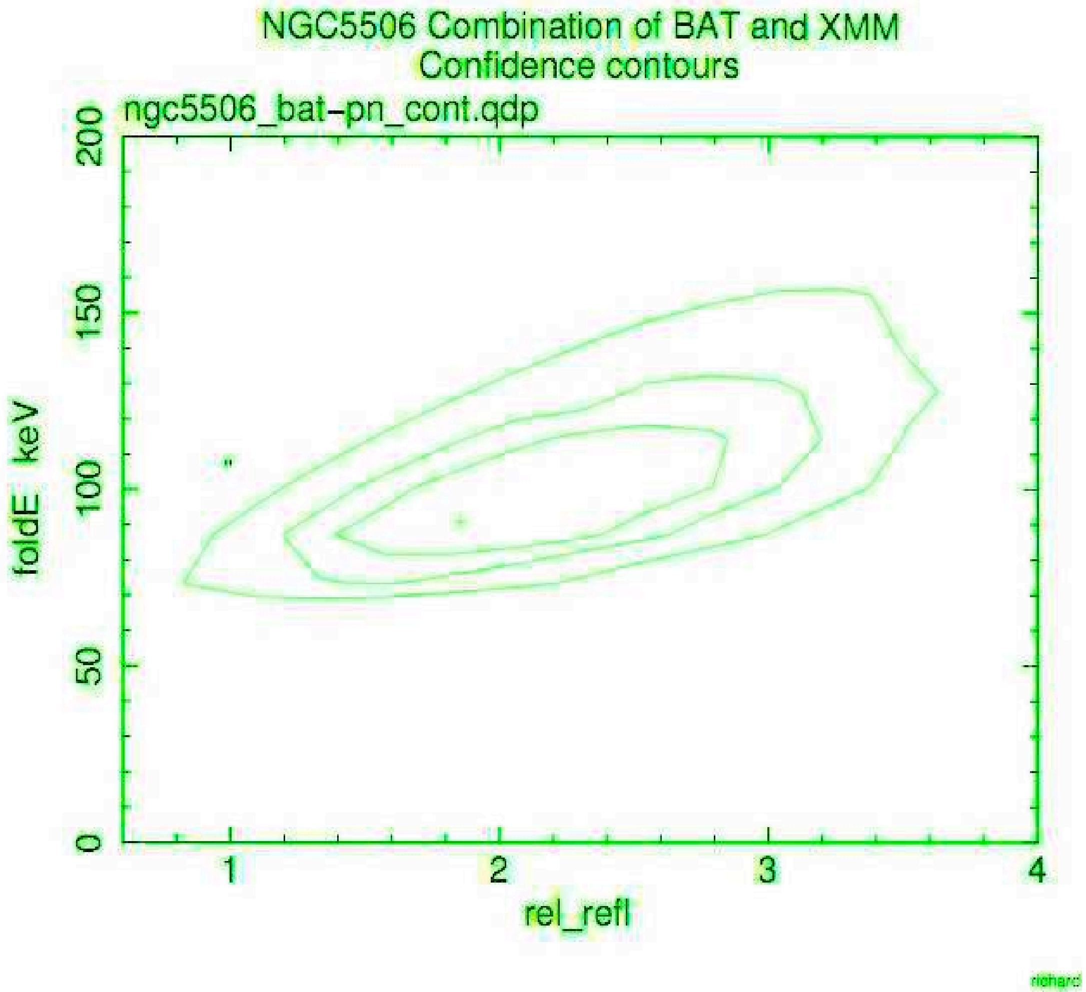
- Because of the limited signal to noise of the BAT data one can only determine curvature in the brightest ~25 objects (e.g. above a flux limit of ~10^{-10} ergs/cm^2/sec in the 14-195 kev band
- Of these 8 are much better fit by a reflection model than a simple power law (NGC 4151, IC4329A, NGC4388, NGC5506, NGC4507, NGC 3227, Mrk 3, IGR2124*)
- all but IC4329A are low luminosity objects



NGC 4151- BAT data only

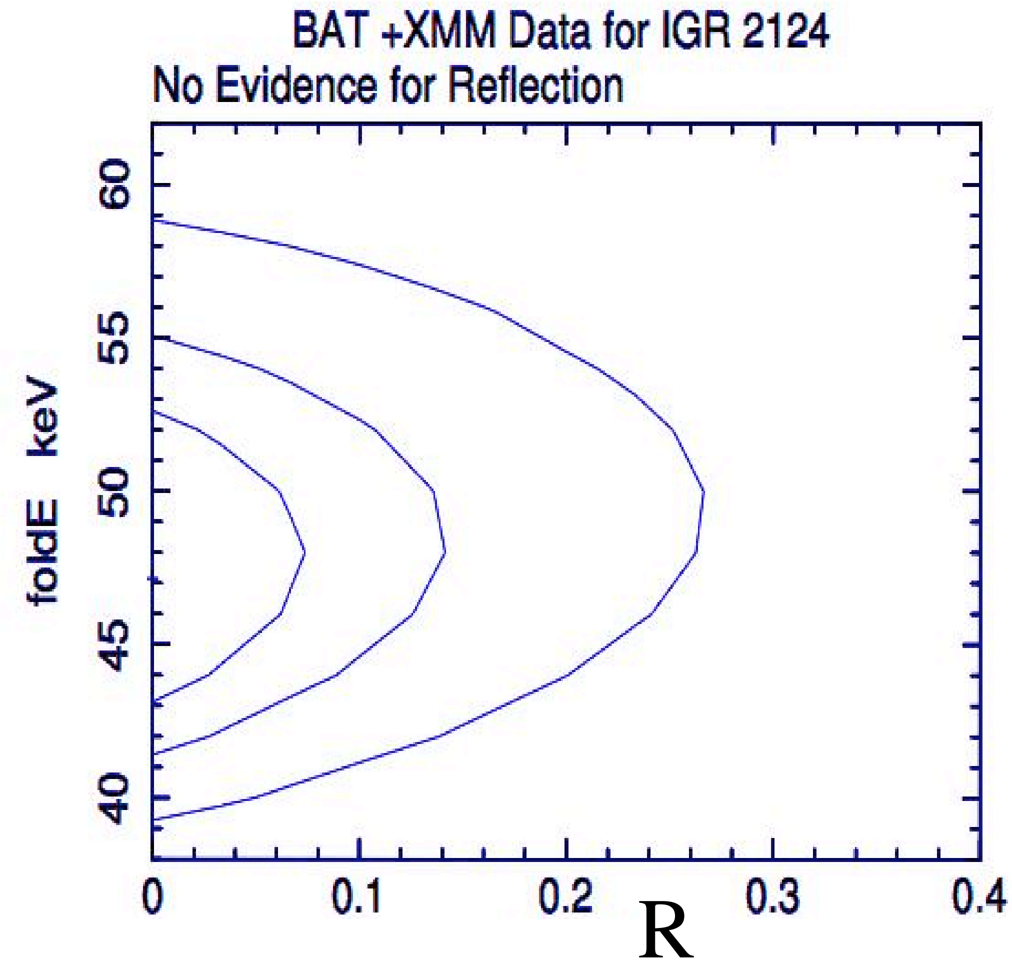
For Bright Sources with Good X-ray Data Constrain R and E(cutoff)

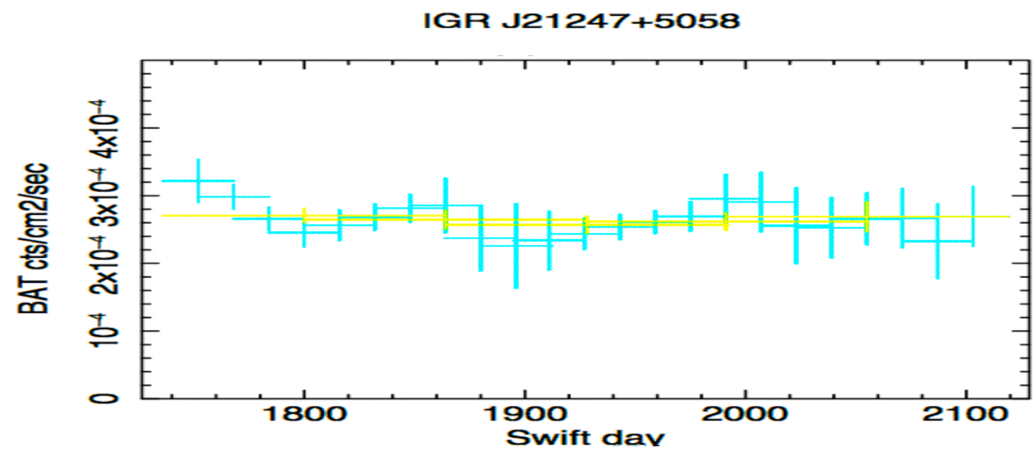
- Assume that
  - slope of the intrinsic power law does not change with time-
  - Cutoff energy is also time independent
- Not necessarily valid
- The BAT data are sums over 22 months of observation and thus represent the average state- Suzaku data give the conditions at one time- which is critical.



IGR2124

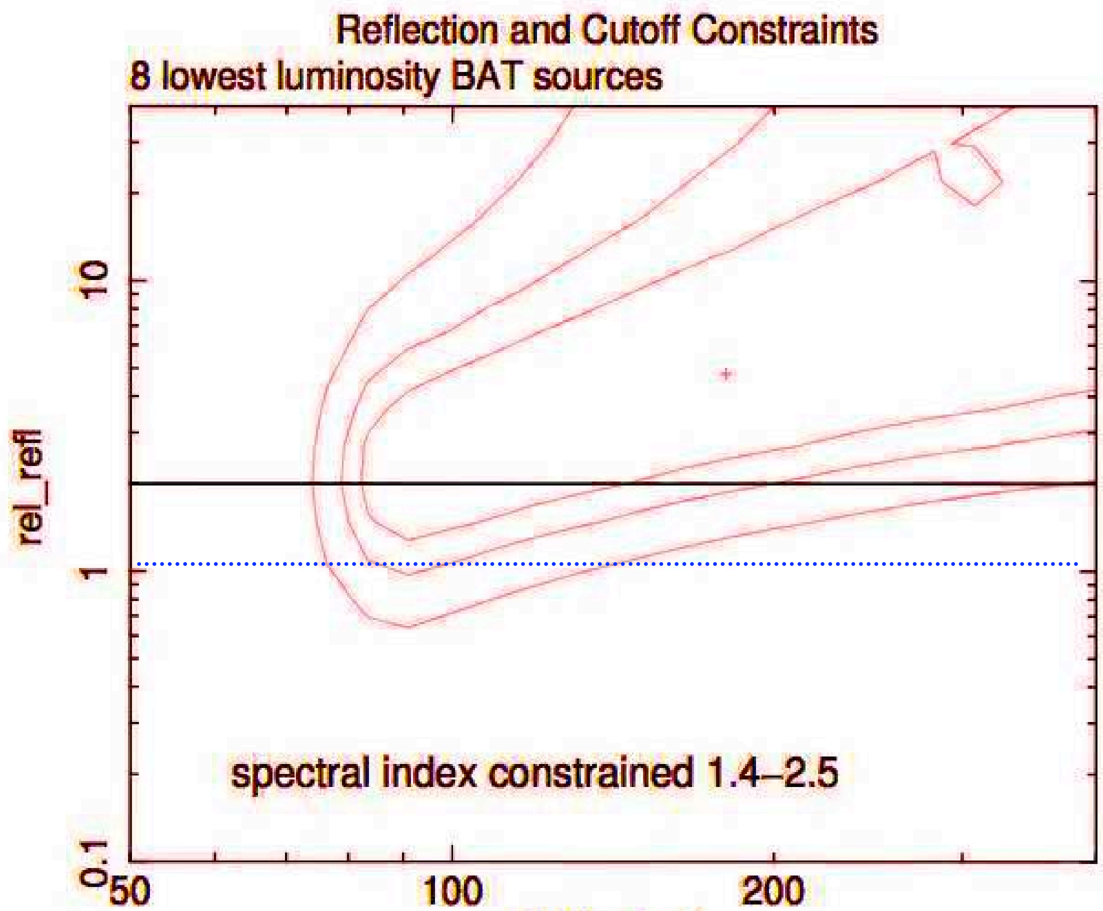
- Z=0.2 radio galaxy. Integral data show no reflection, flat slope Γ~1.5 and a Ecut~70 kev (Molina et al 2007)
- BAT +XMM data EW <30 eV Fe line at 6.4 keV.
- Source ~Constant in flux (!)
- Flatter continuum Γ ~1.3 and E(cut)~42-55 keV
- What sort of object is this??- Log L(X)~44.0
- (unfortunately the PIN bgd model did not work for Suzaku obs of this source)





Best Fit to Low Luminosity Sources

- Using the reflection model the BAT data alone constrain the reflection to be >1 and the cutoff energy to be > 80 keV



E_{cut}

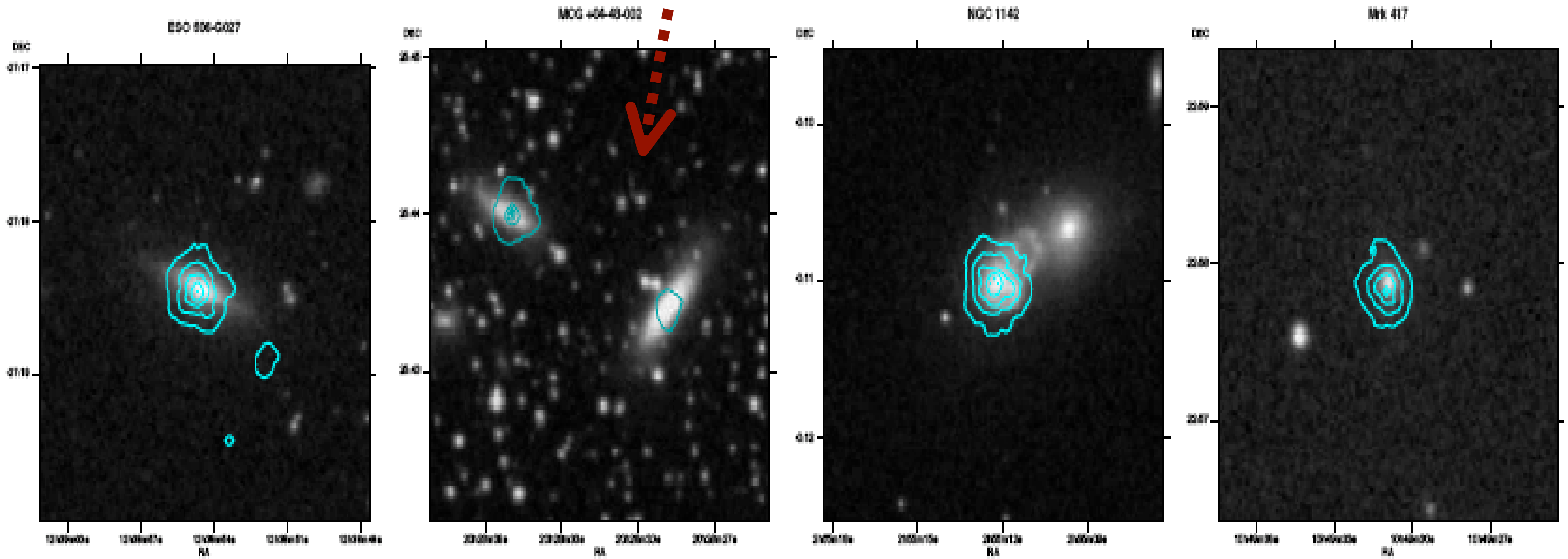
Three Sets of Suzaku data

- ‘Random’ BAT sources with no previous x-ray data (Ueda talk)
- High Luminosity sources-type II quasars ? (Baumgartner poster)
- Objects whose nature could not be determined from XMM and BAT data (Winter poster) . One surprise reversed *MCG+04-48-002 and NGC 6921* intensity between XMM and Suzaku obs by factor of 10 ! All chosen to be ‘easily’ measured with PIN -

ESO 506-G027

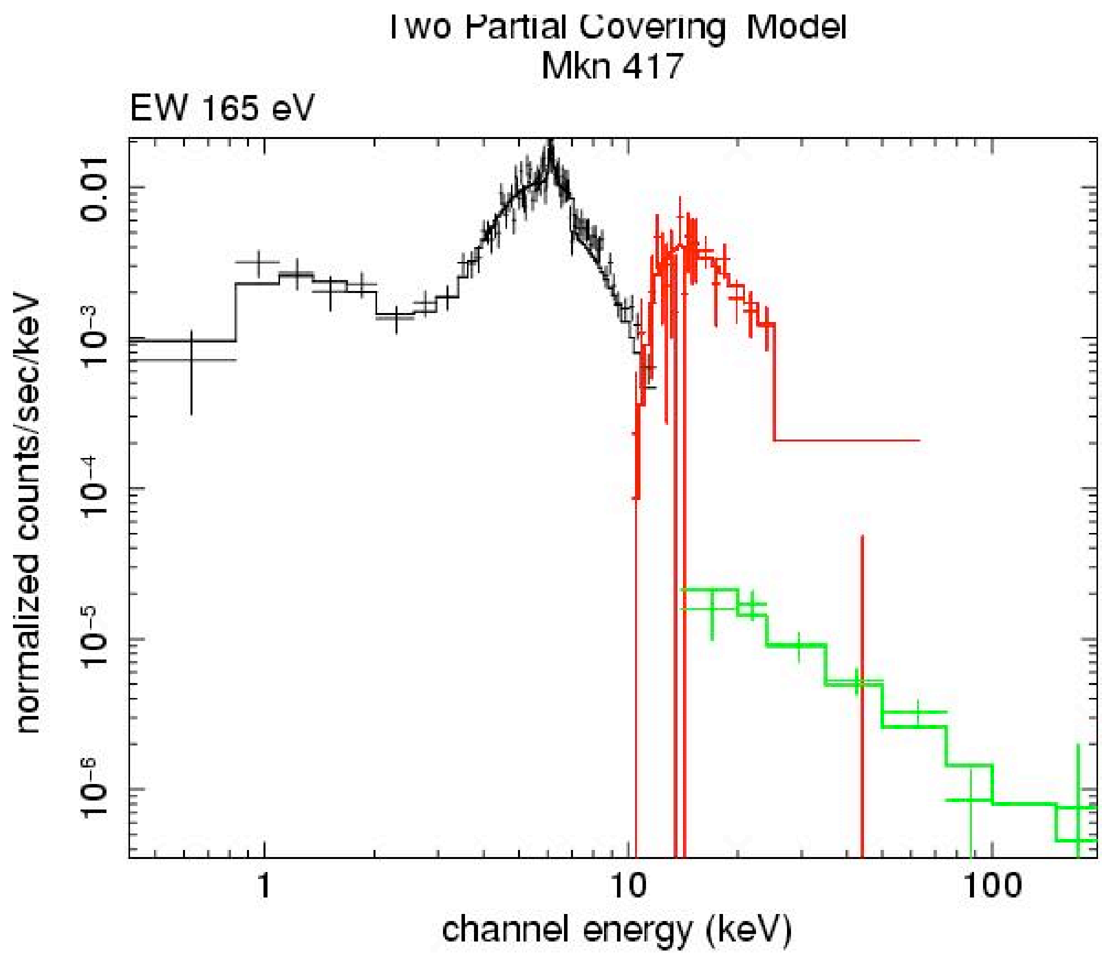
NGC 1142

MKN 417



Suzaku + BAT

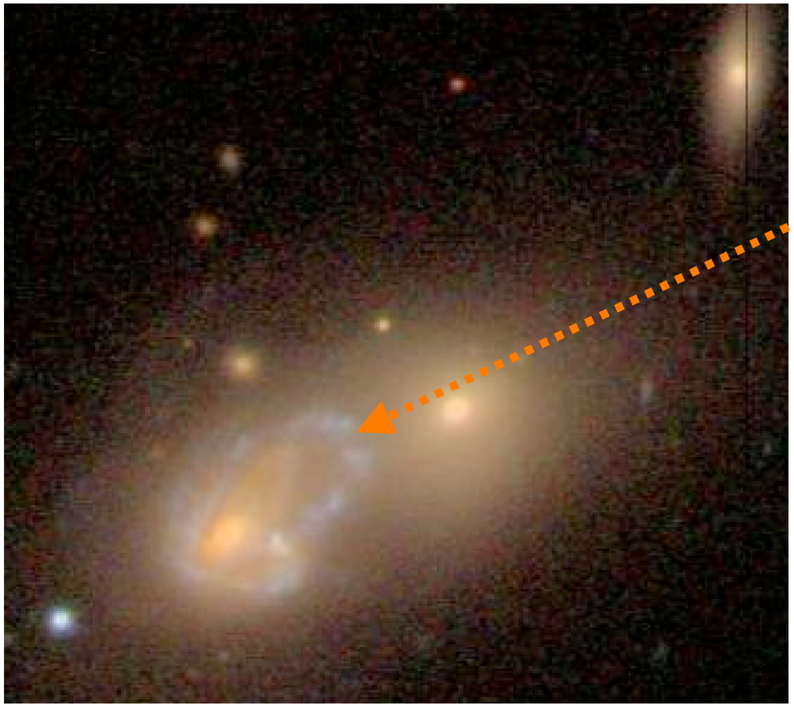
- The combination of Suzaku and BAT is synergistic
- BAT gives the high energy continuum while the PIN determines the amplitude of the reflection component
- The combination of the data sets gives much tighter constraints
- Suzaku adds critical Fe K band data

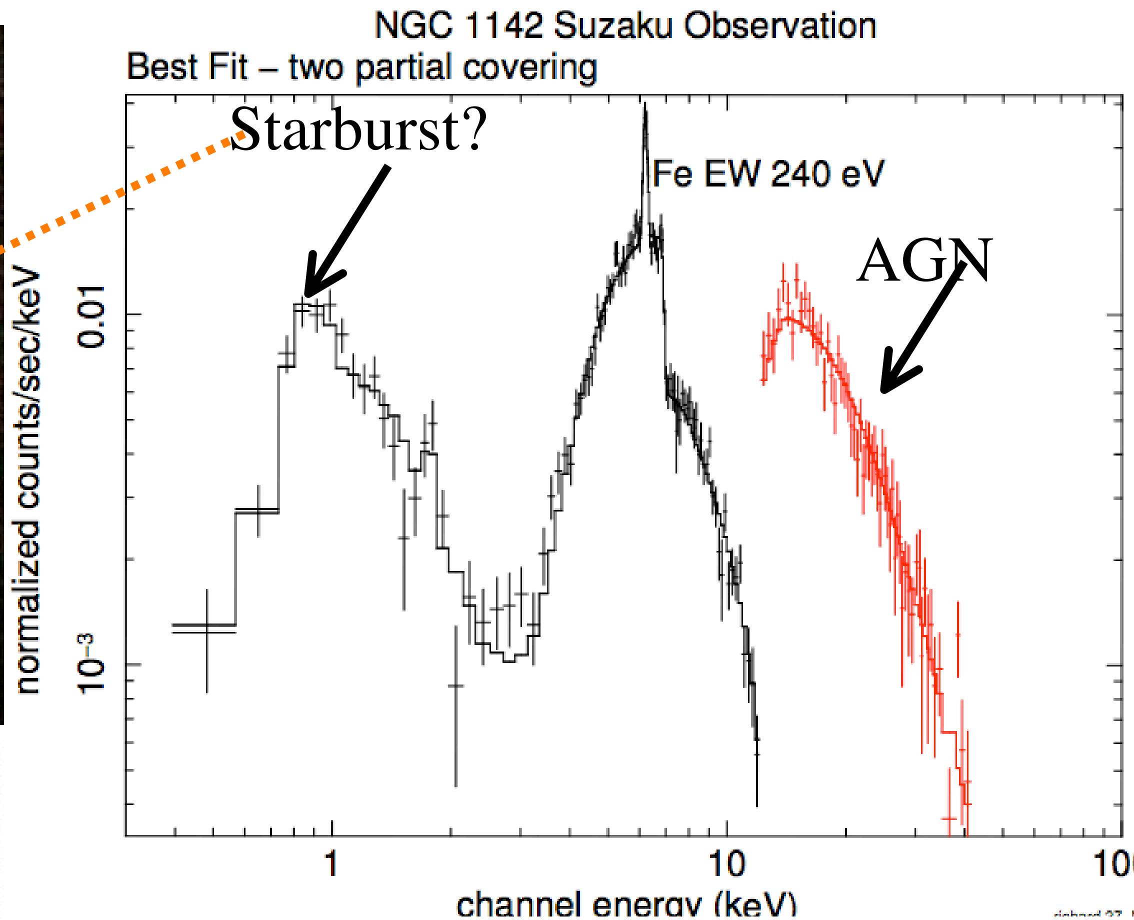


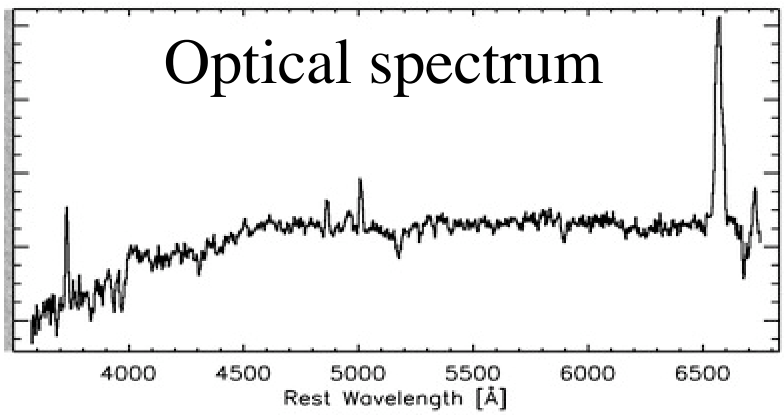
– The widths of the Fe K-α emission line suggest that this component originates in a region between the narrow and broad line regions.

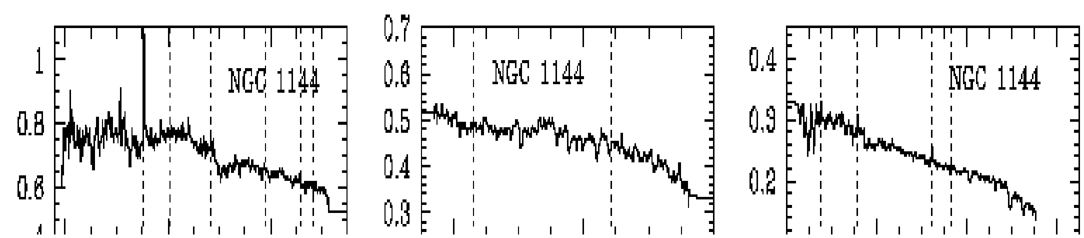
In agreement with Chandra grating data (Yaqoob 2006)

NGC 1142 What Type of galaxy is this?





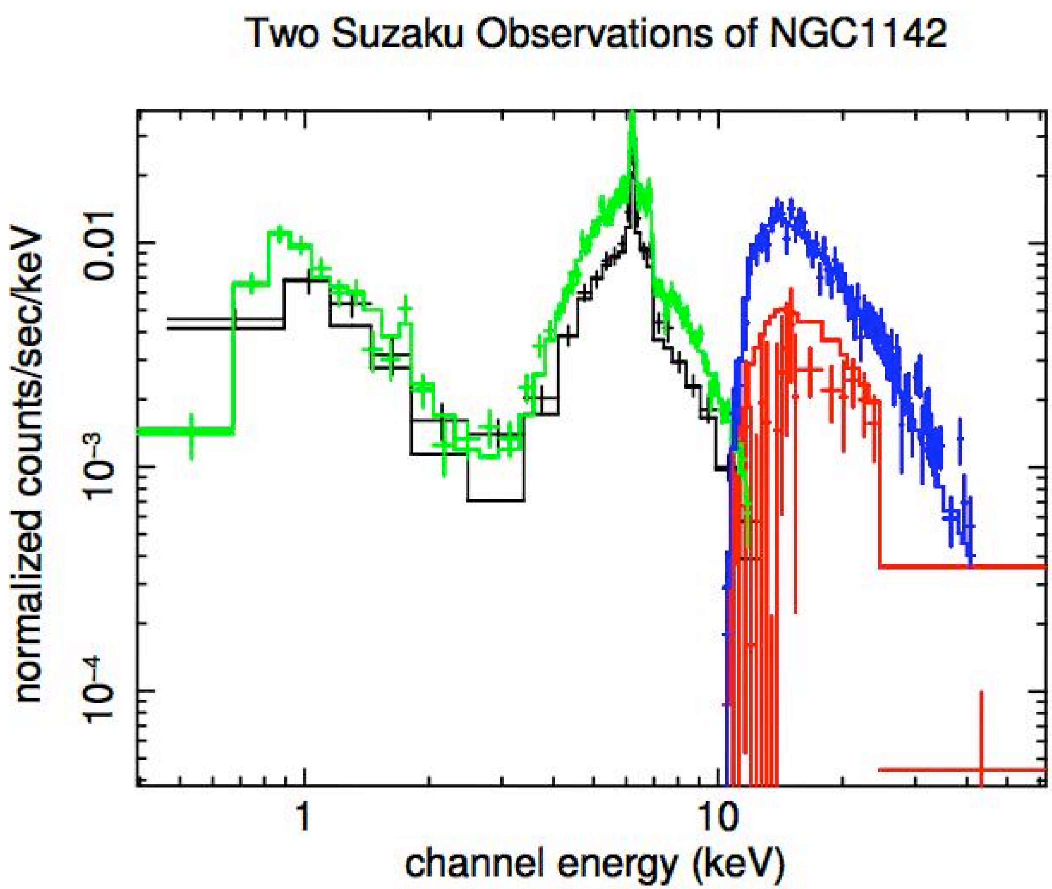




Only IR line is [SIII]

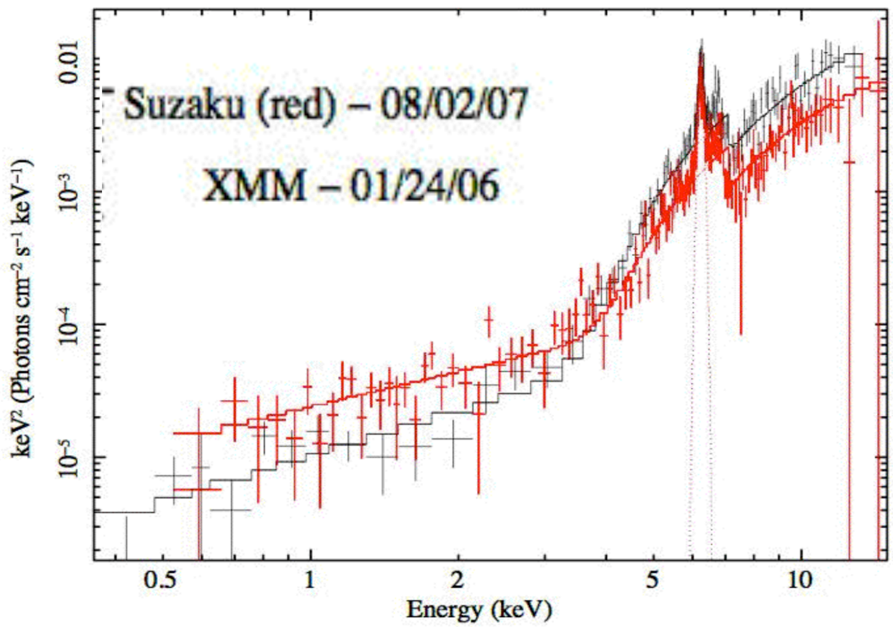
Strong Spectral Variability

- Line flux has varied between the two observations (EW 370 and 250 eV , intensity 9 and 6E-5 ph/cm2/sec)
- Line width is 54+/-20 eV
- Soft component the same

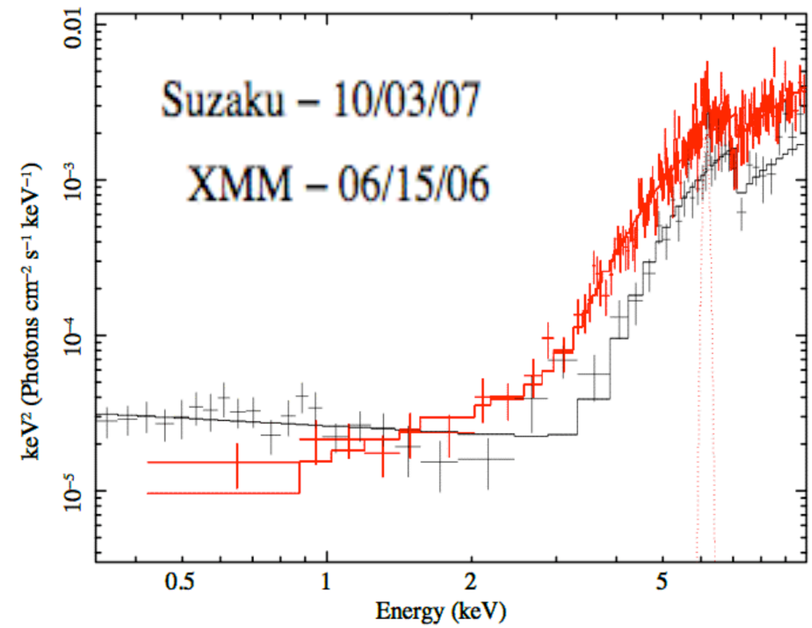


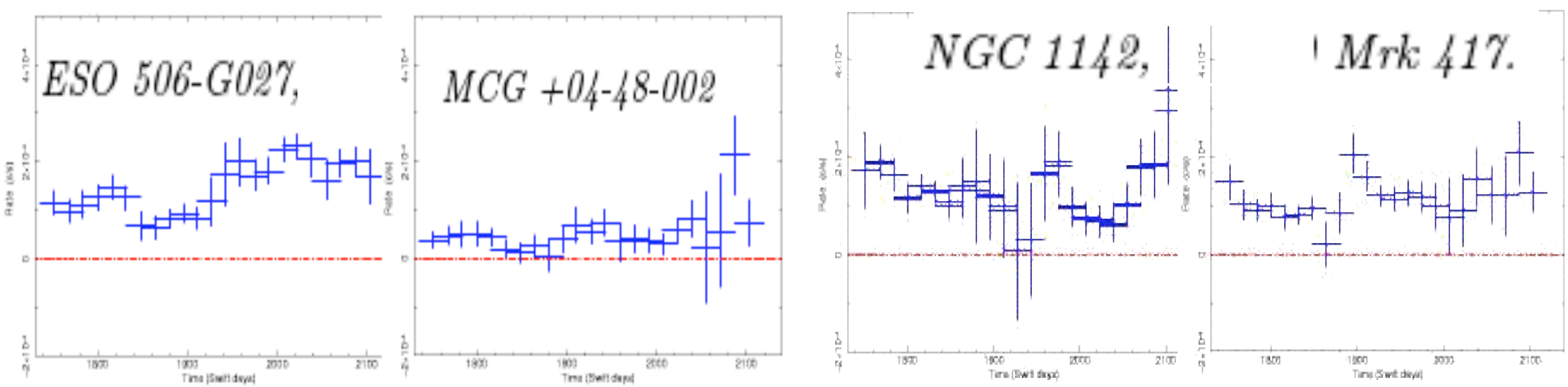
Detailed Changes in Spectra/Flux

ESO 506–G027



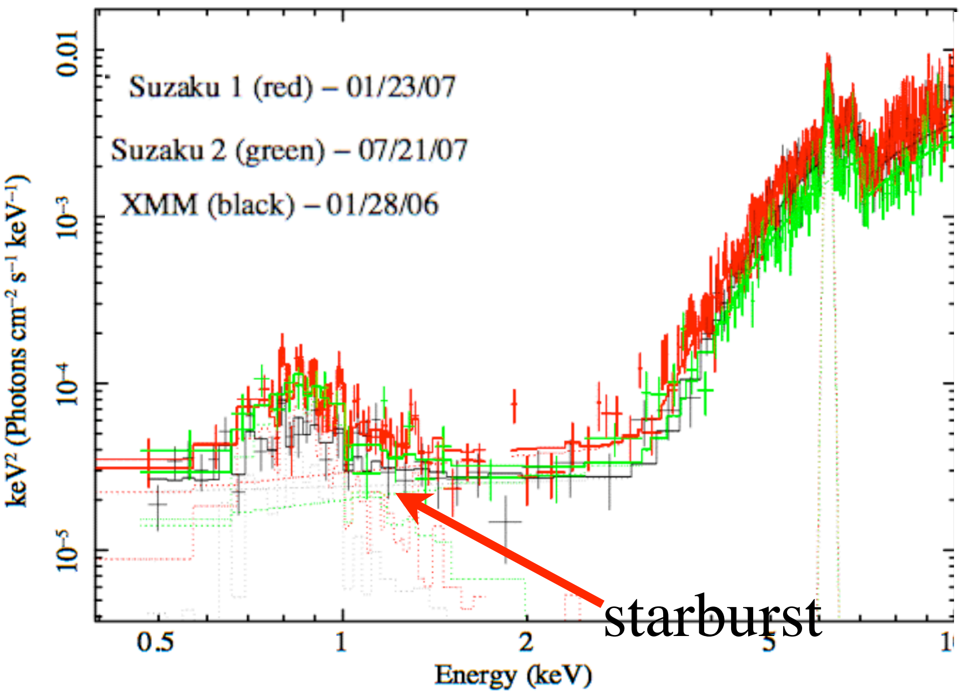
Mrk 417



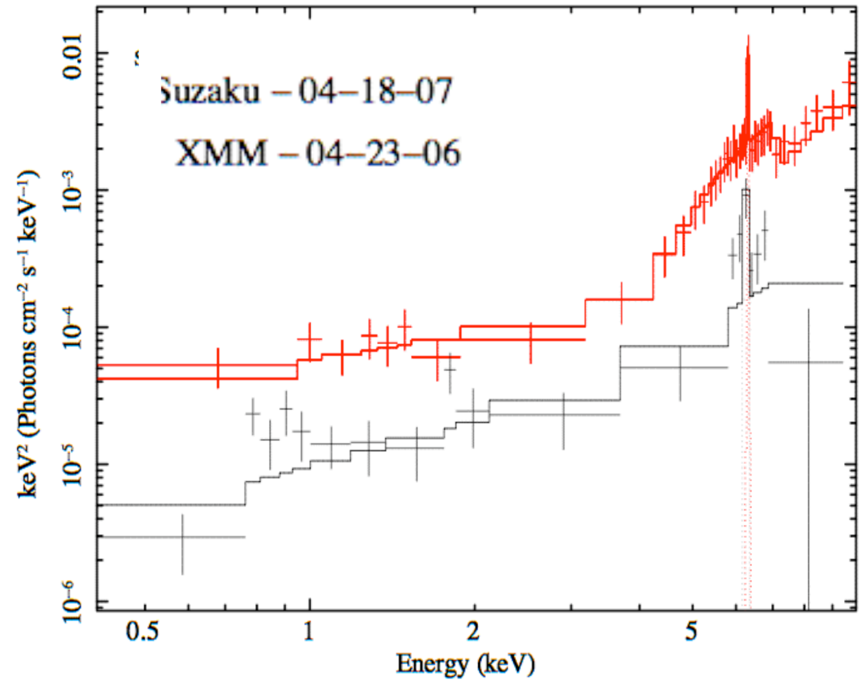


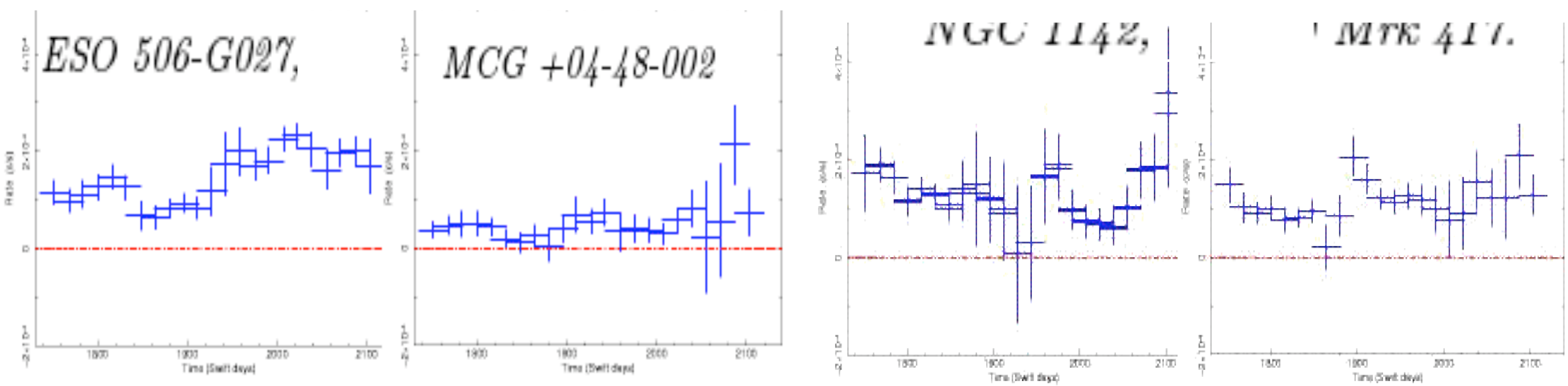
Detailed Changes in Spectra/Flux

NGC 1142



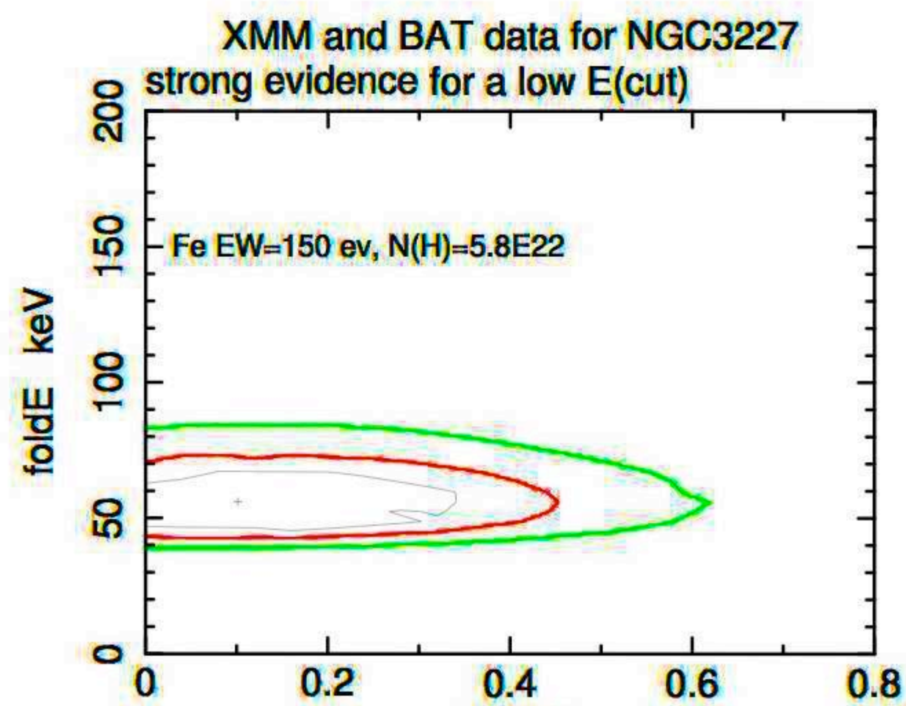
MCG +04–48–002





Spectral Slope/Reflection

- In fitting CCD data it is very difficult to separate reflection and slope if the Fe abundance is allowed to vary….
- Using high E data this degeneracy can be broken
- There exist very flat spectrum objects (e.g. NGC3227,SWIFT 0318…) whose slope and reflection are well constrained-
- only way to get a 'standard' slope for these objects is with 'double' partial coverage- and no reflection which may not be 'nice'
  - - in NGC 3227 the slope changes from 1.3 to 1.7 with this model

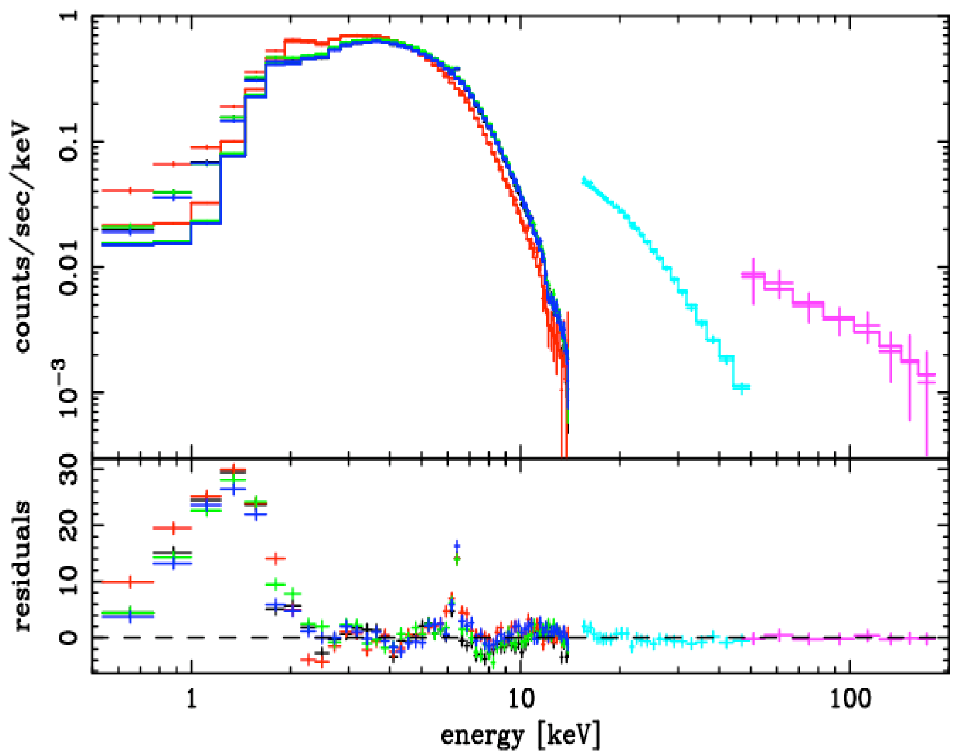


R

$$R=\Omega/2\pi$$

NGC 2110- Okajima

- Absence of reflection component in NGC2110 (R<0.08) !- **yet presence of broad +narrow Fe K line-** breaking the AGN paradigm?
- GSO data photon index and absorption are consistent with the previous obs
- high flux (factor >3) and low iron line EW (<1/3?)
- ==> intrinsic luminosity is changed
- ==> large soft excess
- The soft excess is 10x brighter than the previous obs. the intrinsic luminosity increased -**Proof (?) of scattered component**

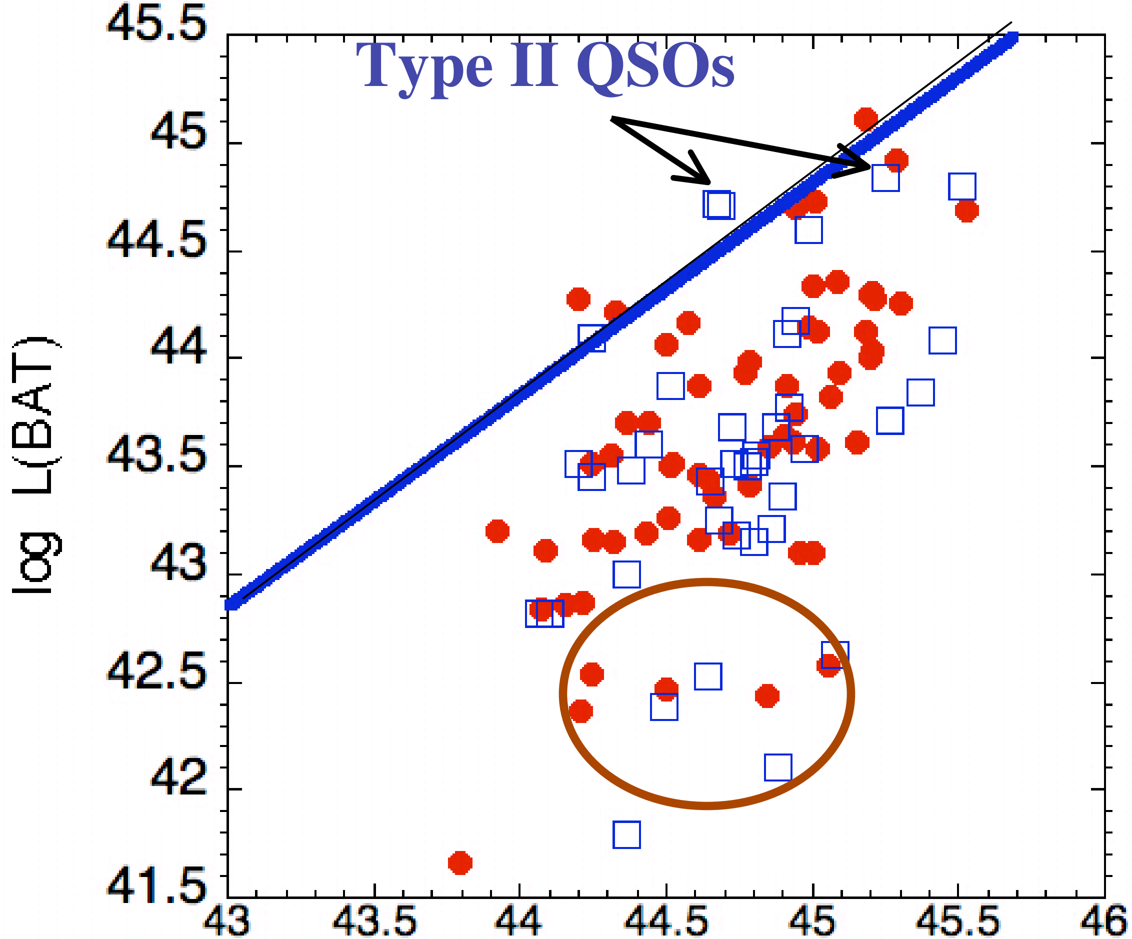


Objects without reflection signature or soft disk bb emission-
(E.G. NGC 3227, NGC 2110. Cen A. no broad line nor reflection)

Where is the disk?
Can it be hidden (Reynolds et al 2006)
Is it absent (ADAF?)

The Most Luminous Objects in the BAT Sample

- The most luminous type II objects in the BAT sample are Cyg-A, PKS 0442-28, 3C452*, 3C105, Swift 0318*, Swift 0918*.
- We have received Suzaku data for 3 (*), however the PIN data for Swift 0318 are not of good quality
- Two have a high reflection fraction, the other a low upper limit

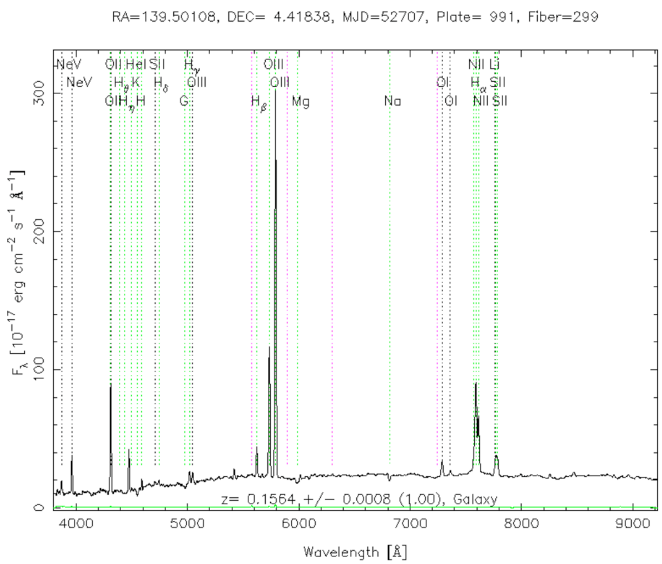


L(K)
dot= type I, square = type II

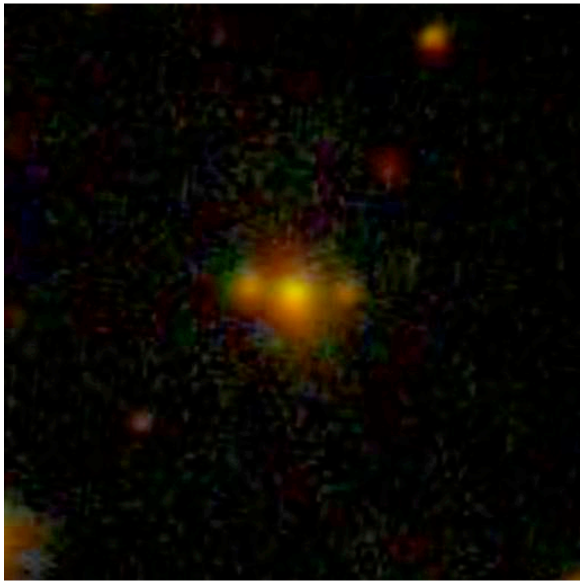
Most luminous sources

- Of the 18 most luminous BAT sources only 4 require high column densities-
- e.g. based on BAT selection the most luminous sources have a lower probability of being absorbed than the lower luminosity sources.
- Most are well fit by power laws in BAT band
- However the type II AGN are different.

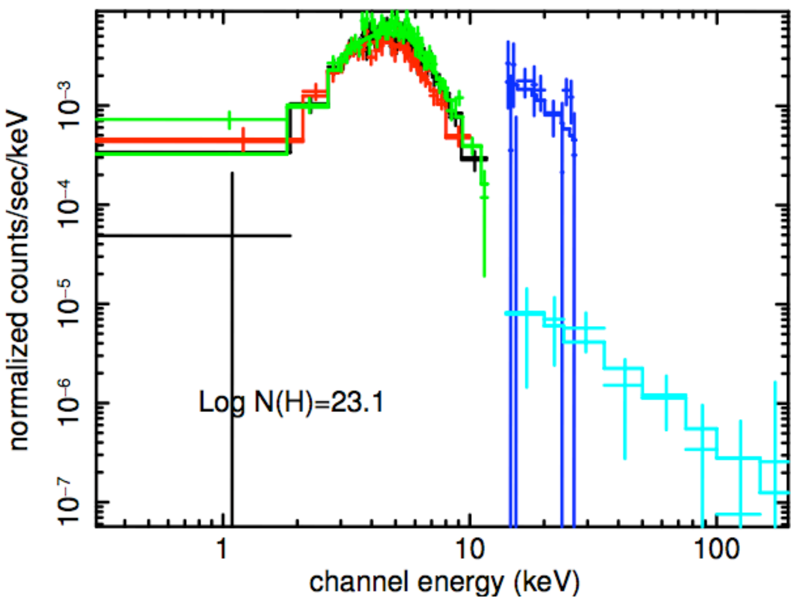
Swift 0918, z=0.156, log L(x)(0.1-100)=45.0



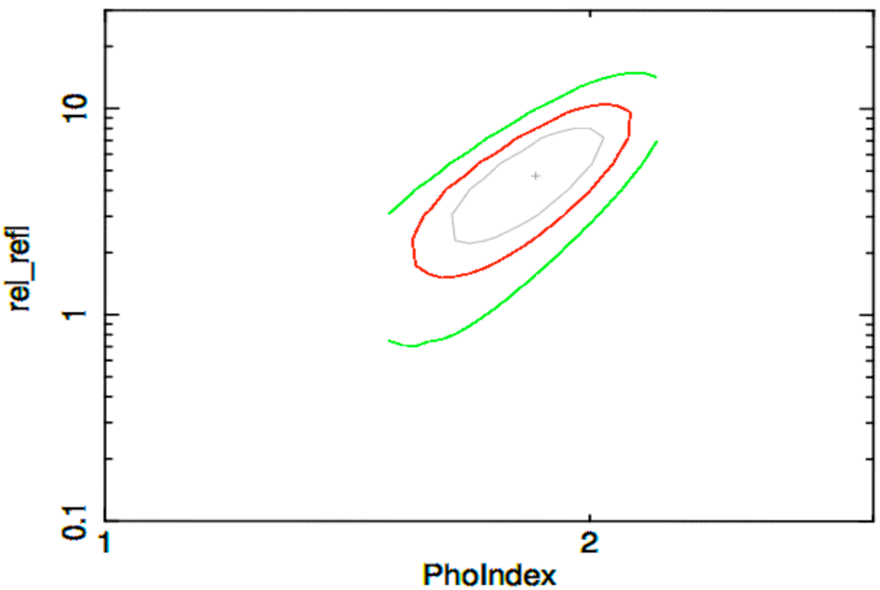
- Log N(H)=23.1 C(F)=0.992
- R >2
- Fe K EW < 73 eV
- V. strong narrow [OIII]



SUZAKU+ BAT data

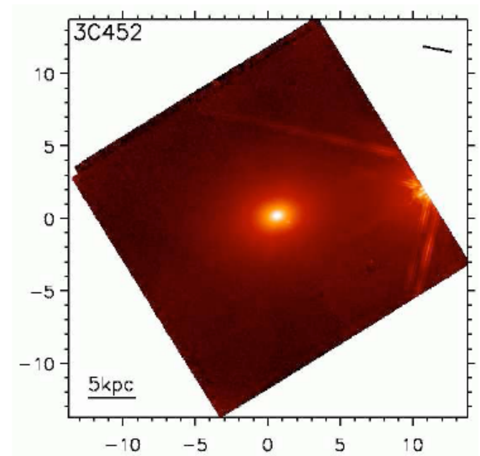


Suzaku +BAT data for SWIFT 0918

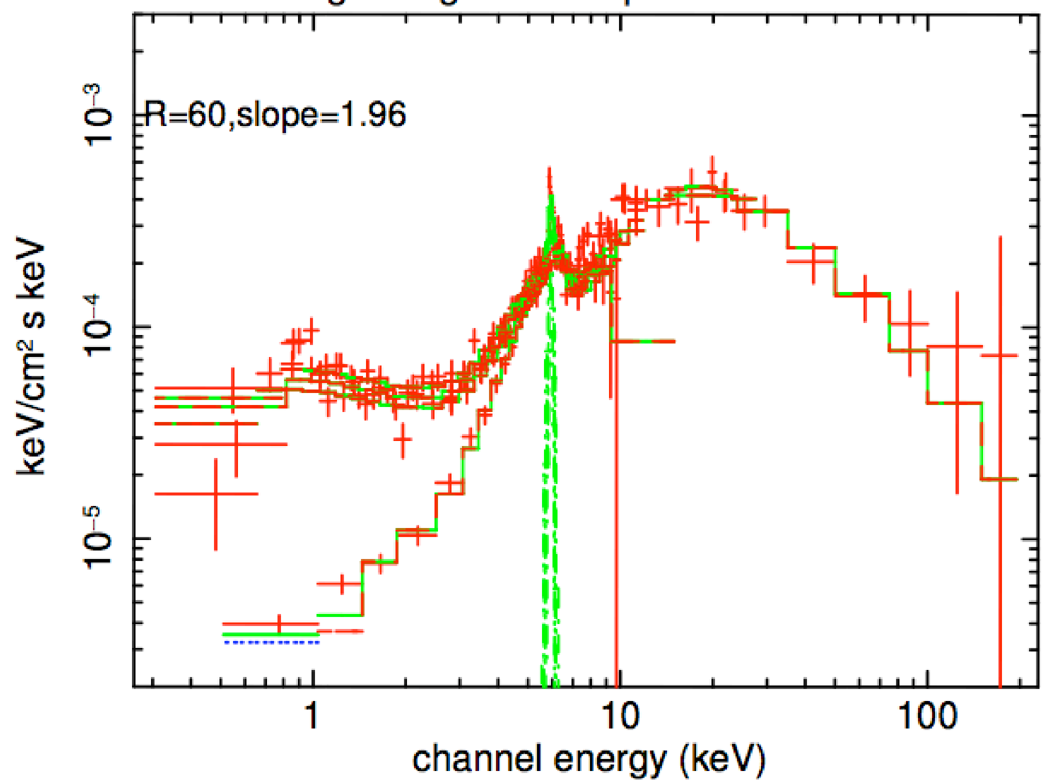


3C452, z=0.089, L(x)=44.7

- Needs R> 12, cutoff >60 keV
- Fe EW ~180 eV
- Best fit is pexrav+ PCF
- C(F)=.8,.67 log N(H)= 23.3,
- Comparison of Chandra and Suzaku data indicate source varied by ~20 % at 4<E< 10 keV
  - the covering fraction changed dramatically - major change in a geometry in a highly luminous source in a few years.
- 21 cm data column is only $6x10^{20}$ atms/cm^2
- No nucleus is visible in HST I data

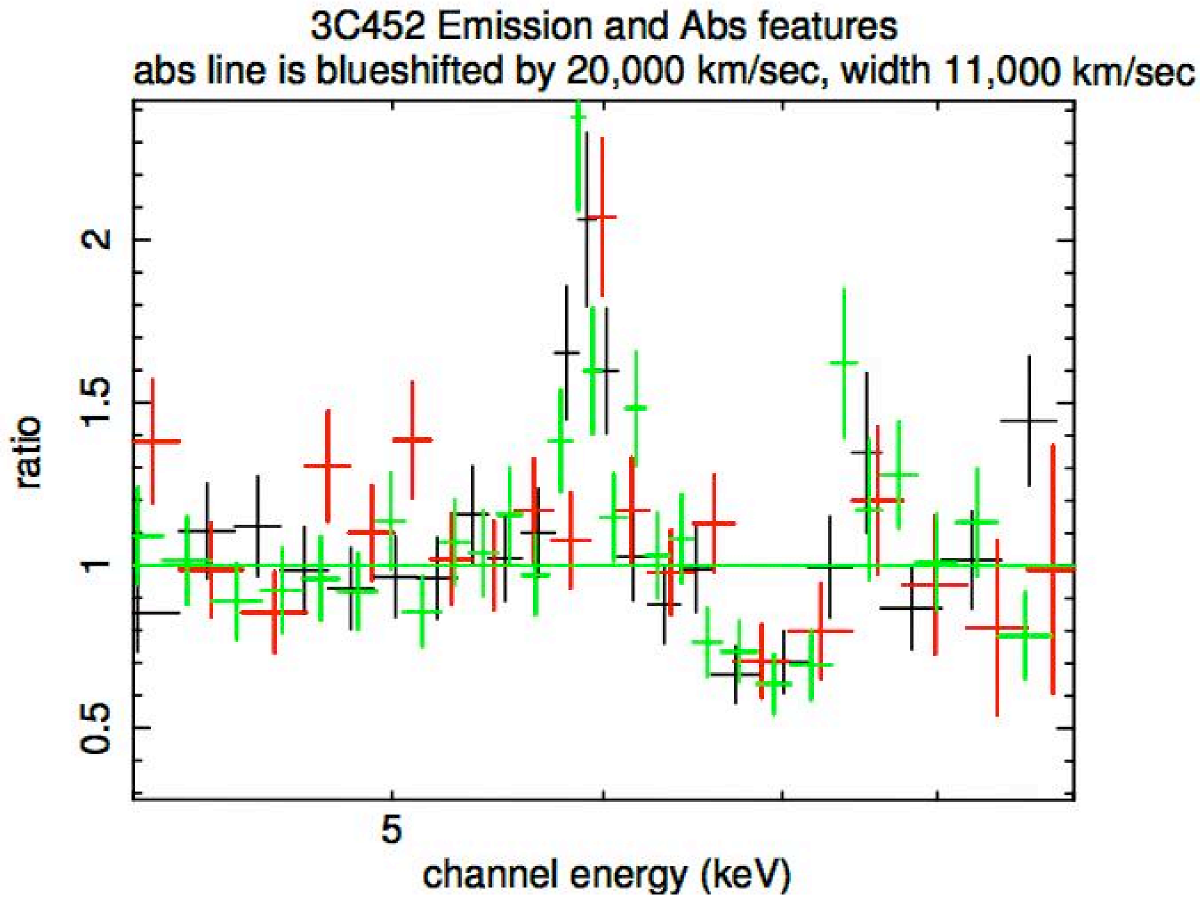


3C452 Chandra,Suzaku,BAT
notice strong change in absorption



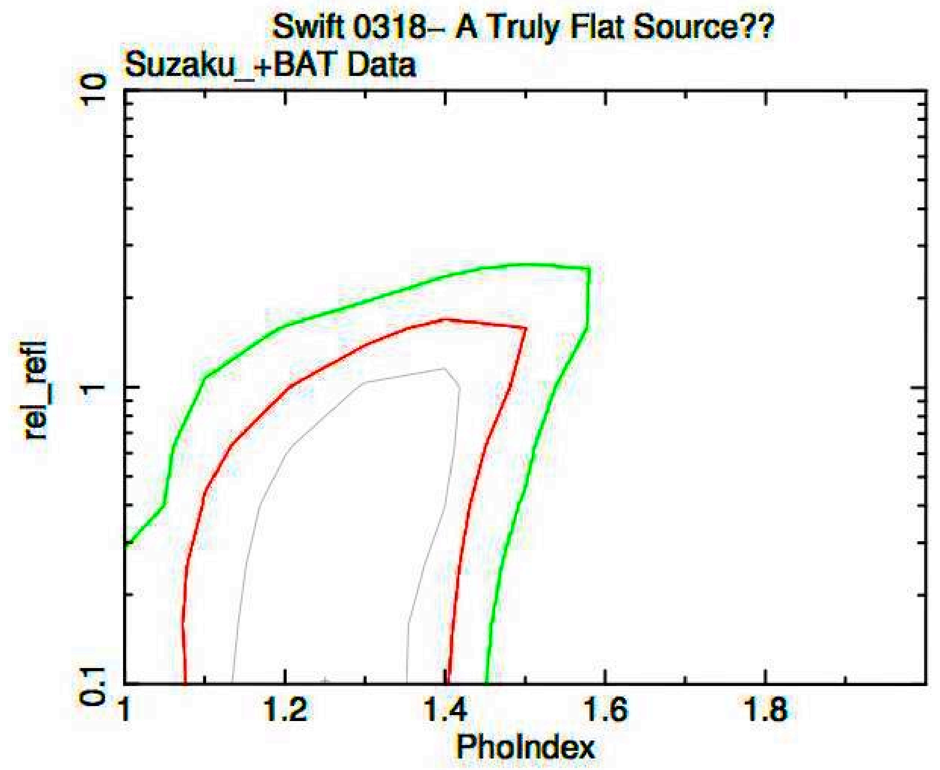
3C452, z=0.089, L(x)=44.7

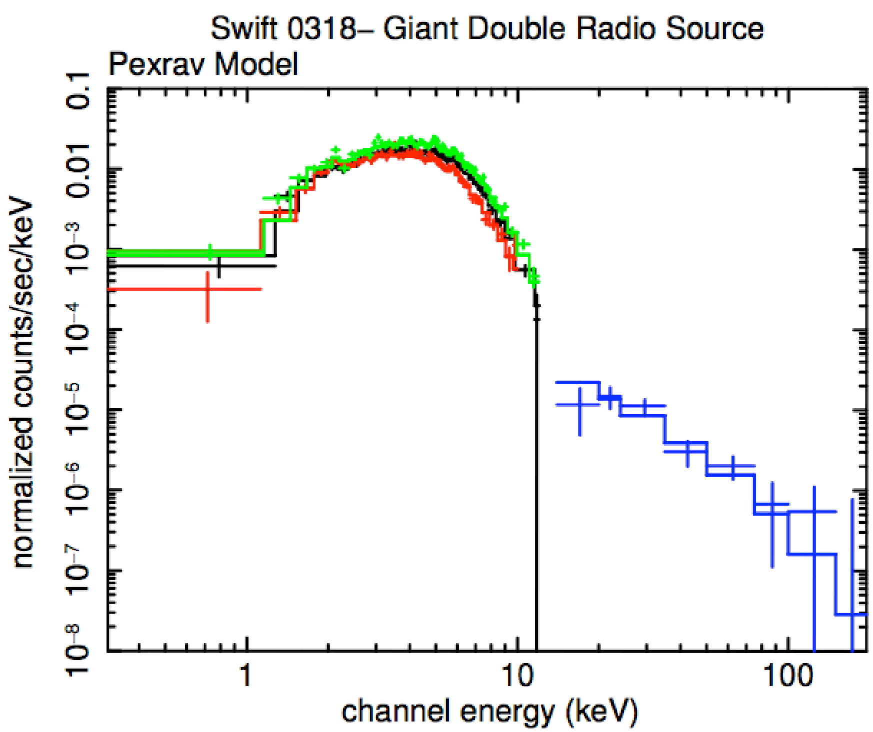
- See high velocity abs feature with a blueshift of 20,000 km/s and a width of 11,000 km/s



Degeneracy of Spectra

- Despite the good signal to noise and high bandwidth we still have objects whose spectral fits are degenerate





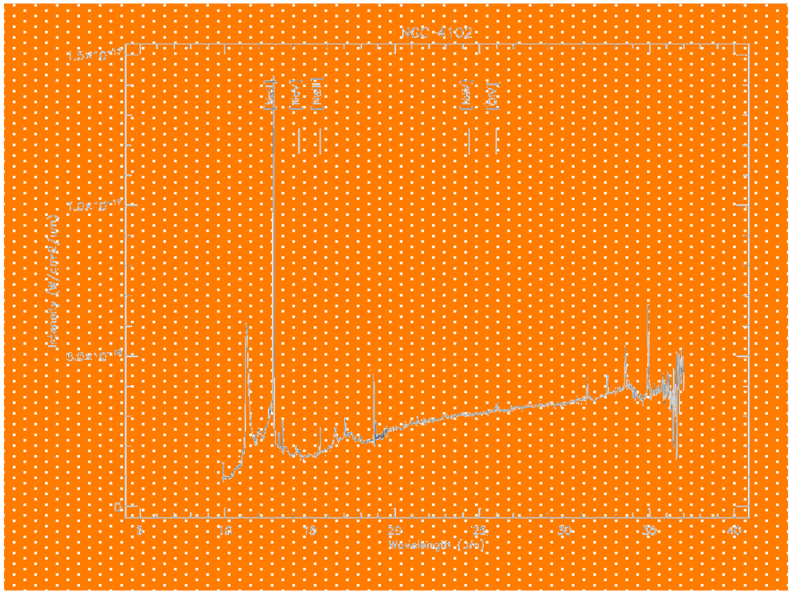
Swift 0318- a highly luminous source Γ=1.4 with or without reflection

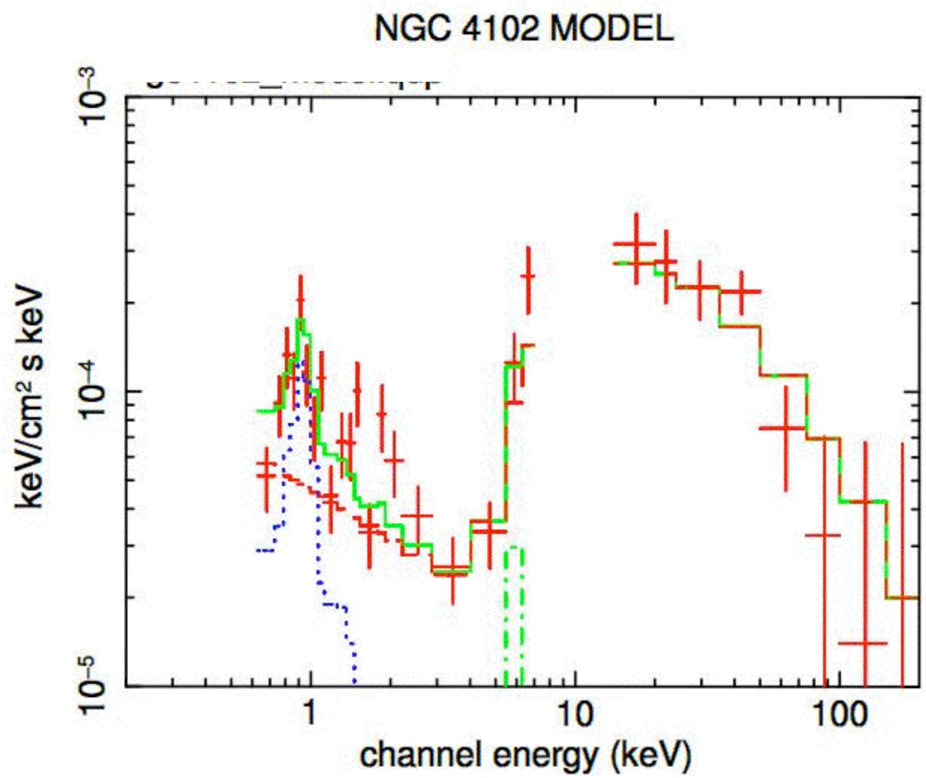
Best fit is a double partial covering model $\delta\chi^2$=20

2 weak lines at 5.38 and 6.34 keV (41 and 57 eV EW)

N(H)=5×10^{22}, C(F)=.994

NGC 4102- IR spectra and Imaging- No AGN





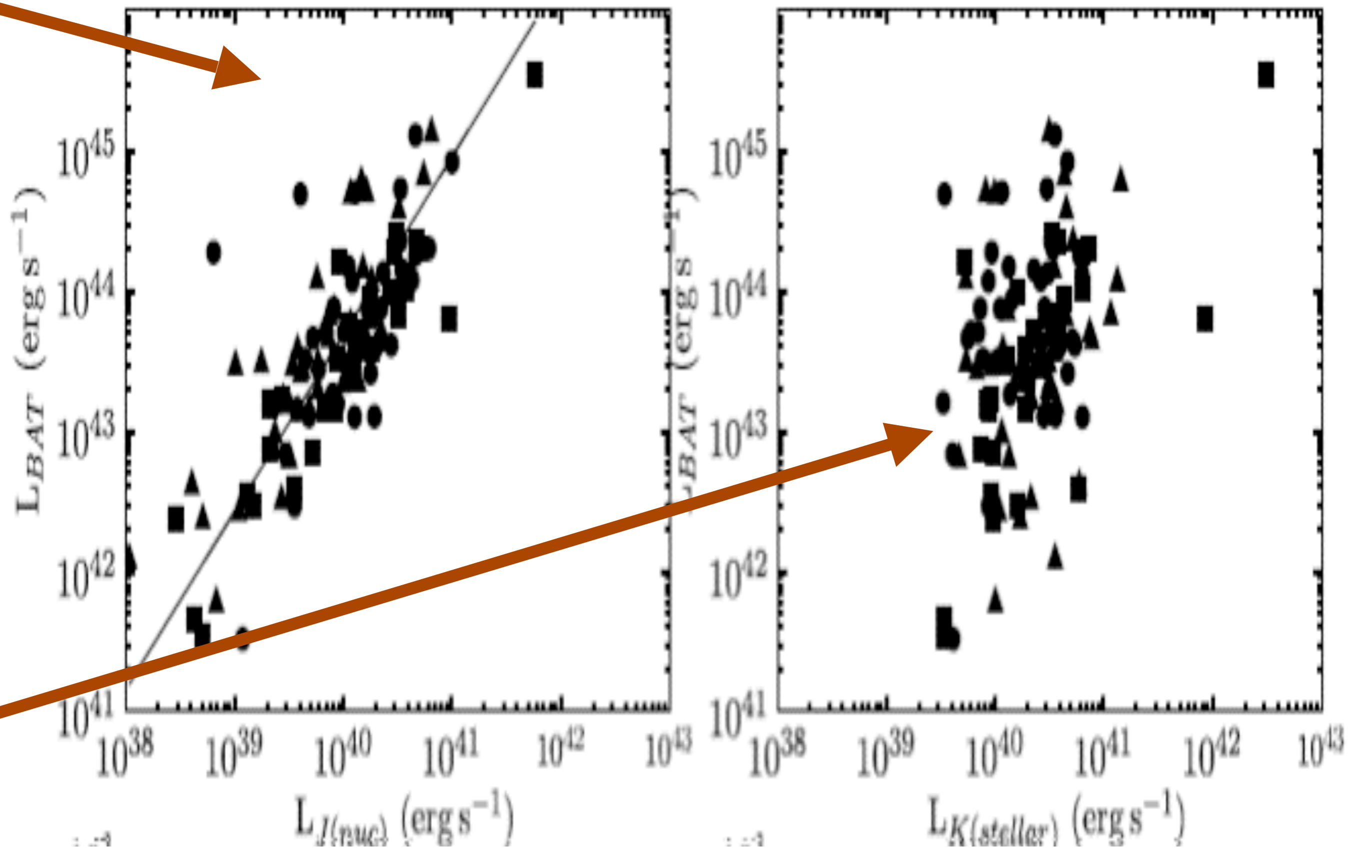
In Chandra band only Fe K line is indicative of an AGN

Fully Covered Objects

- With Suzaku and XMM follow-up of the BAT sample we now have a large number of ‘fully’ covered objects (Ueda et al 2007)e.g. NGC1142, Swift 0318 …
- These are objects that show no soft x-rays e.g. no scattered x-ray emission, no photoionized gas.
- This is not at all expected in the unified model.
- Also unexpected some of them show strong [OIII]- this breaks the connection between the soft component (thought to be either scattered x-rays and/or photoionized gas) and the [OIII] ionization

Near IR and Hard X-ray Correlation

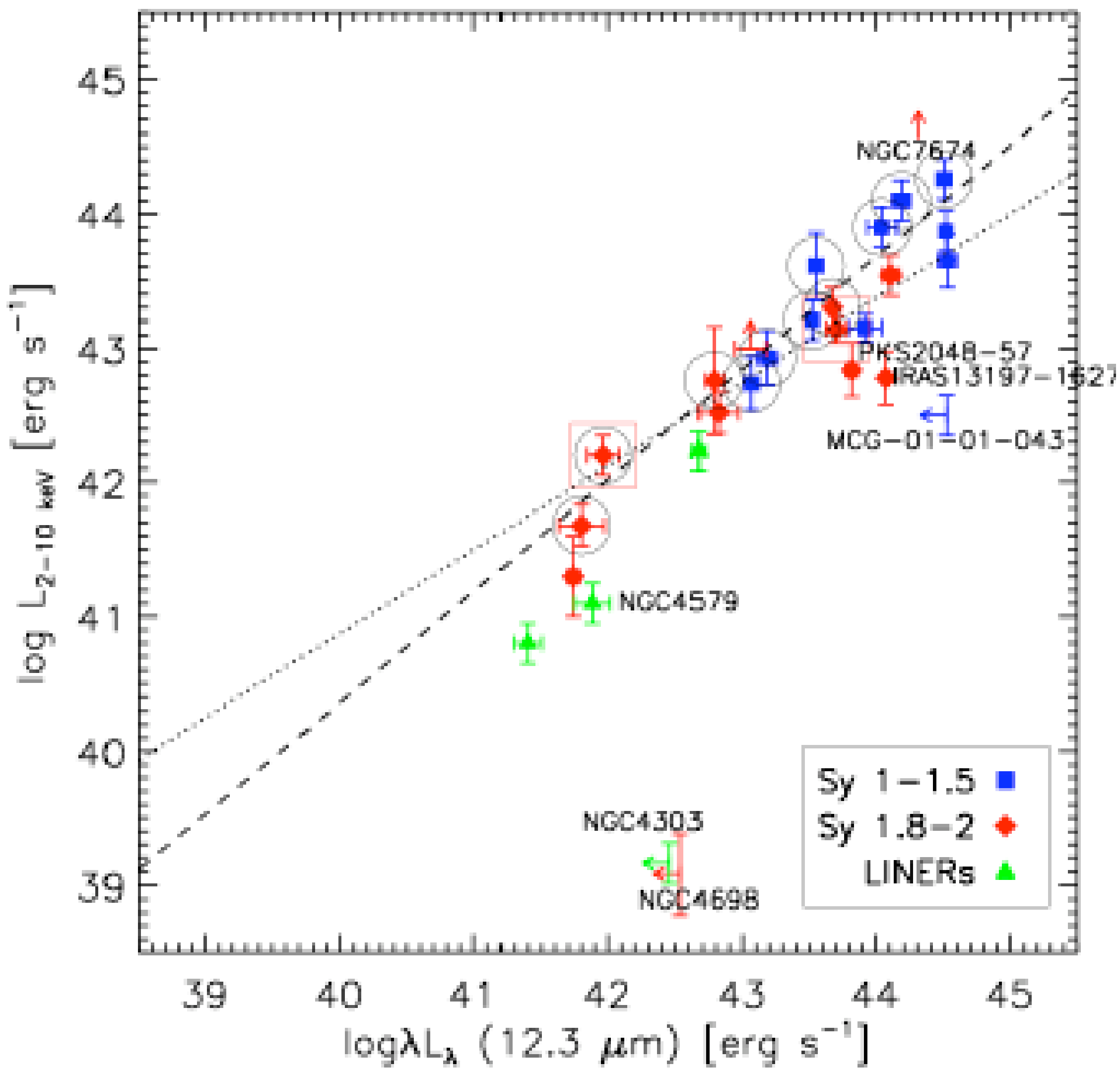
- Strong correlation between near IR (J and K band) and hard x-ray luminosity
- No correlation of hard x-ray with stellar mass of galaxy



Mushotzky et al 2007

IR and X-rays

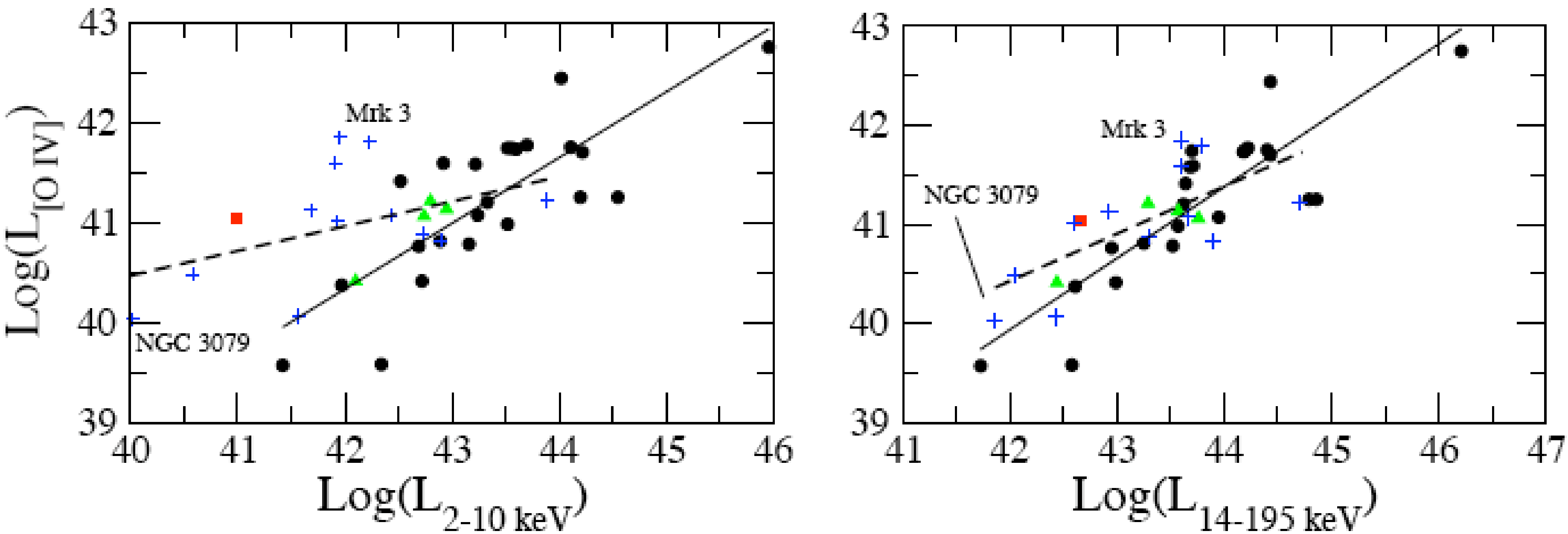
- Similar results from higher angular resolution instruments
- How can the near IR and hard x-ray be physically so closely connected- thought that IR was dust which is not heated by x-rays



Horst et al 2007

Connection of [OIII] and [OIV] (IR line) to x-ray

- Melendez et al (2007) have shown a linear relation with small scatter between 2 ‘obscuration’ free measures of AGN power- the 25.89 μ [OIV] line and the 14-195 keV luminosity



2.— Correlation between [O IV] and [O III] luminosities with hard X-ray (2-1(
and BAT (14-195 keV) luminosities. The solid line represent the linear regı

- Have learned a lot in last year
  - Many 'narrow' Fe K lines resolved*
  - Some objects have reflection, some do not*
  - Hard to distinguish reflection from double Partial covering (totally different physics) *
  - High frequency of abs lines *
  - Lots of spectral variability *
  - Do not know true incidence of
    - Warm absorbers
    - Soft emitters
  - Systematic changes in the spectrum of sources with hard x-ray luminosity (Low L sources much more likely to show reflection)
  - Most objects have E(cut)>140 kev, but some definitively show lower E cutoff- origin not yet clear

15 things I learned this year

•1-10 μ IR and x-rays strongly connected
As are [OIV]
•There are 'fully' and partially covered objects- but no obvious relation to optical lines *
•High luminosity strongly absorbed objects exist- but are rare at z<0.2- have wide range of covering (soft x-ray invisible) *
•Low z objects with no signature of an AGN in optical or IR exist.
•Hard x-ray luminosity function different from 2-10 keV
•Unified model is badly broken
•Complex spectra abound

Broad band pass, high signal to noise and high resolution are _essential_- need BAT and Suzaku *

Blue= high Eddington ratio
Black = low

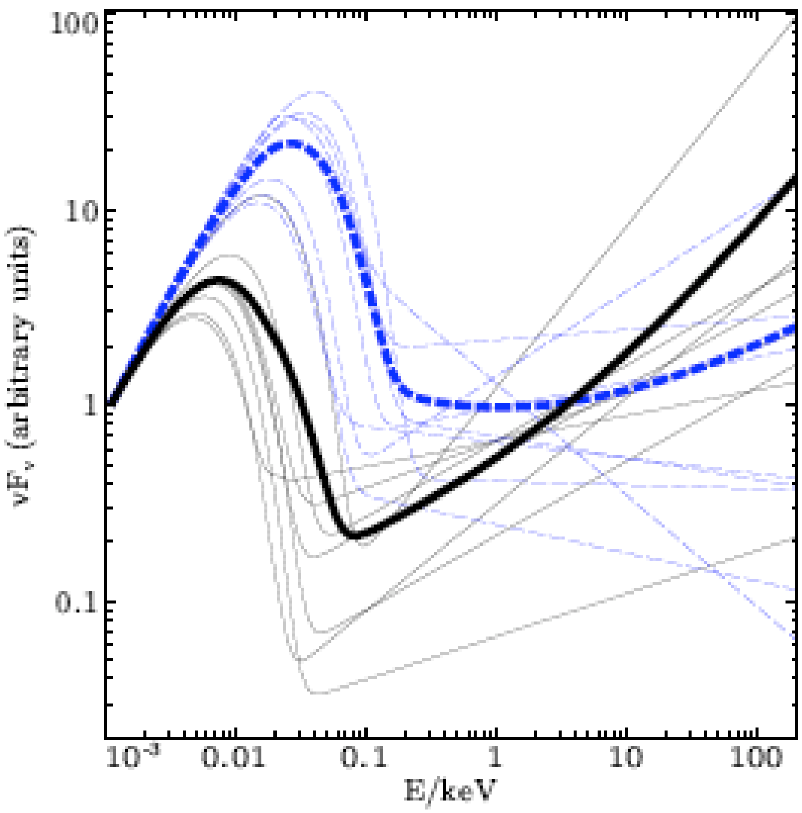
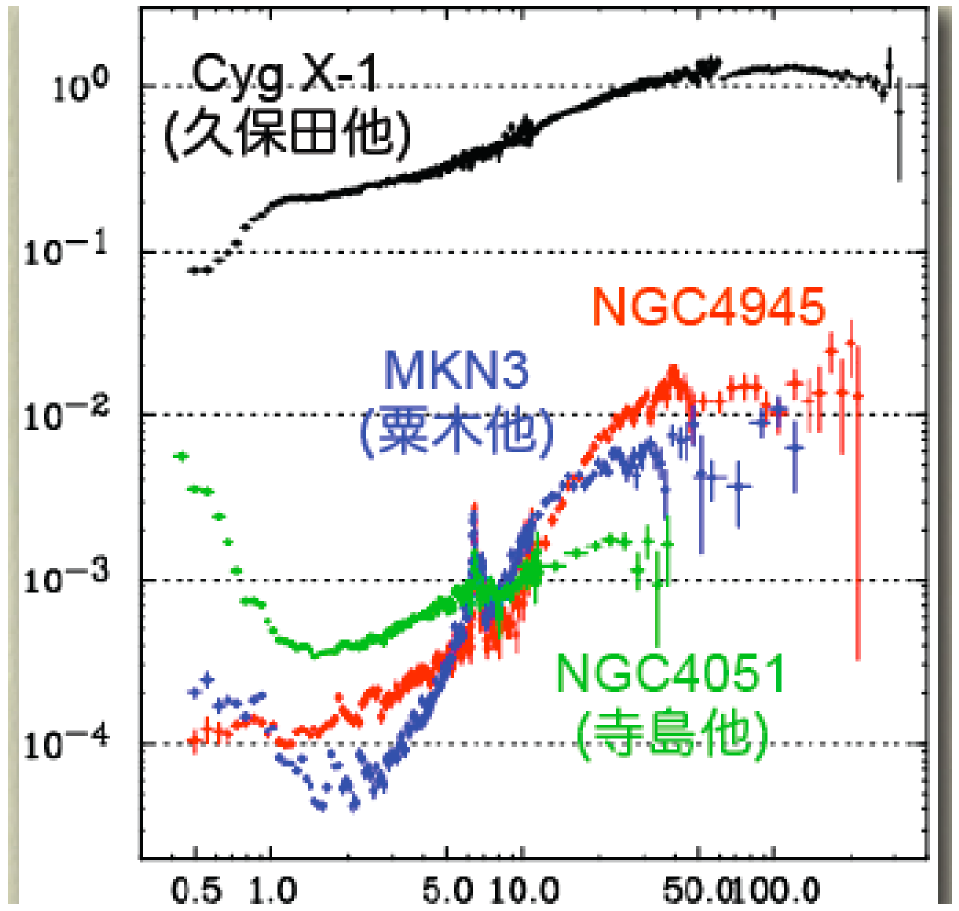


Figure 13. SEDs (normalised at 1 eV) for AGN with Eddingto

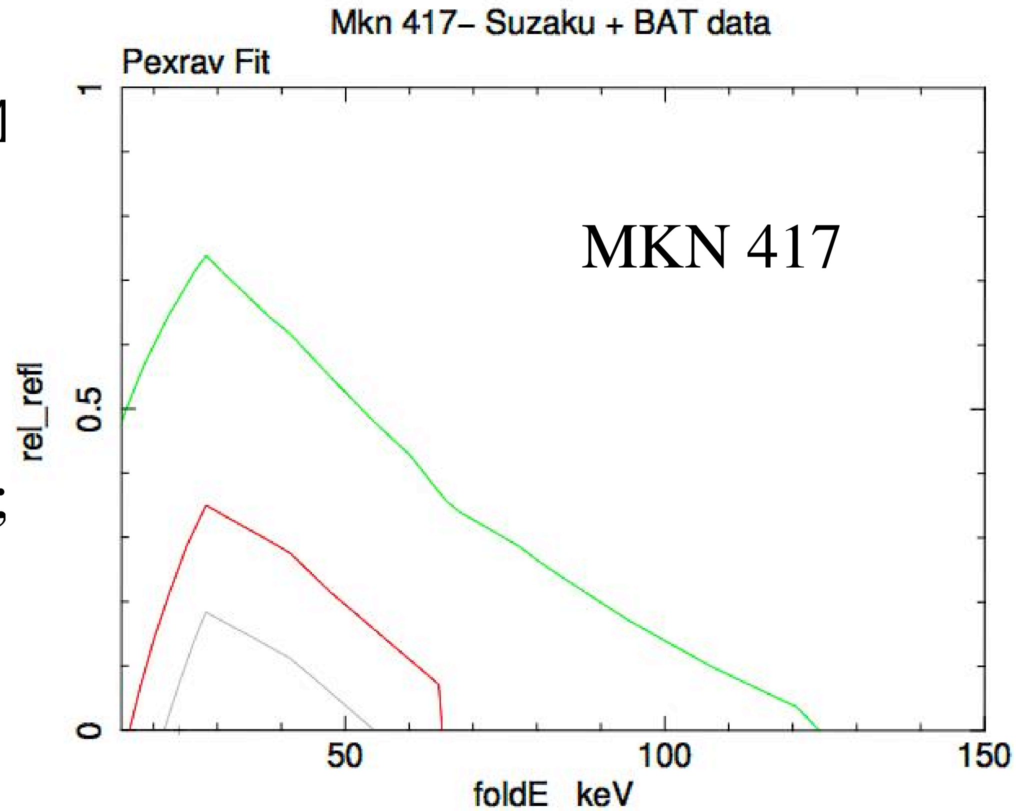
Vasudevan and Fabian 2007



Itoh et al 2007

See Poster by L. Winter et al

- MCG+04, 140 eV EW Fe K in Suzaku, much stronger in XMM
- Two AGN in the field, in Suzaku observation one much brighter than the other
- Again no requirement for reflection from the Suzaku data; upper limit is not restrictive except it is not Compton thick
- Cannot use BAT since the two sources are confused.



Obs	n_H	Cvr.	Γ	$F_{0.5-2.0}$	$F_{2.0-10.0}$
MCG +04-48-002	–	104.1/284			
XMM	$88.3^{+87.2}_{-69.1}$	$0.899^{+0.072}_{-0.899}$	$0.95^{+0.03}_{-0.03}$	0.02	0.33
Suzaku	$63.8^{+15.3}_{-12.7}$	$0.978^{+0.013}_{-0.023}$	$1.51^{+0.45}_{-0.36}$	0.14	2.88

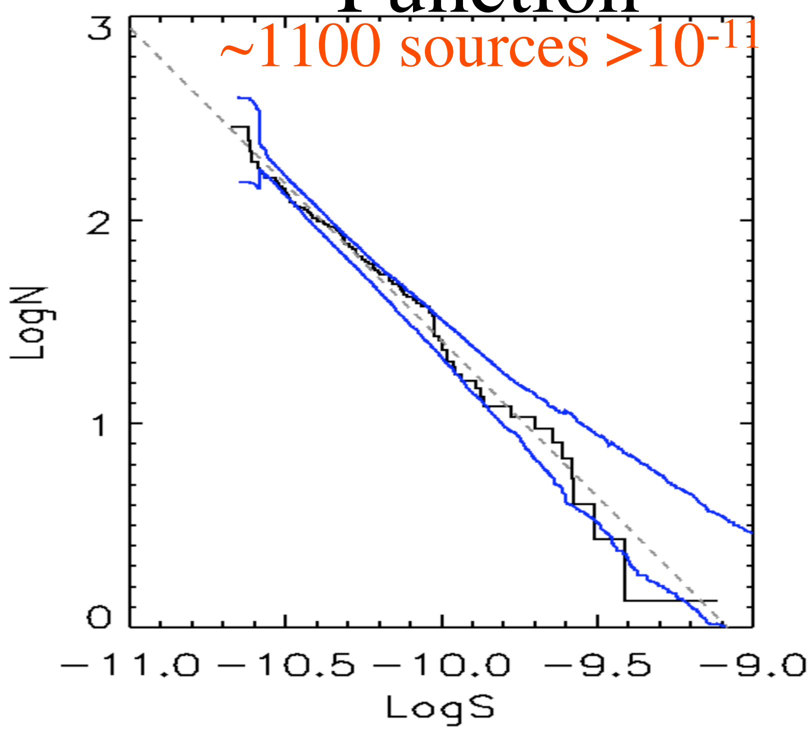
Energy (keV) Energy (keV)

Obs	$\mathbf{n}_H$	**Cvr.**	Γ	$\mathbf{F}_{0.5-2.0}$	$\mathbf{F}_{2.0-10.0}$
ESO 506-G027	–	324.9/248			
XMM	$77.1^{+9.4}_{-8.7}$	$0.822^{+0.005}_{-0.009}$	$0.98^{+0.22}_{-0.25}$	0.03	3.88
Suzaku	$89.2^{+5.9}_{-6.4}$	$0.970^{+0.008}_{-0.012}$	$1.12^{+0.23}_{-0.23}$	0.06	2.23
MCG +04-48-002	–	104.1/284			
XMM	$46.8^{+9.4}_{-8.7}$	$0.987^{+0.005}_{-0.009}$	$0.88^{+0.22}_{-0.25}$	0.02	0.31
Suzaku	$63.8^{+5.1}_{-5.0}$	$0.971^{+0.011}_{-0.016}$	$1.39^{+0.23}_{-0.23}$	0.14	2.90
NGC 1142	–	232.3/229			
XMM	$90.9^{+14.5}_{-12.5}$	$0.995^{+0.002}_{-0.003}$	$2.16^{+0.17}_{-0.17}$	0.05	1.43
Suzaku1	$44.7^{+5.1}_{-5.0}$	$0.968^{+0.011}_{-0.016}$	$0.97^{+0.23}_{-0.23}$	0.03	3.01
Suzaku2	$44.7^{+5.1}_{-5.0}$	$0.968^{+0.011}_{-0.016}$	$0.97^{+0.23}_{-0.23}$	0.03	3.01
Mrk 417	–	232.3/229			
XMM	$90.9^{+14.5}_{-12.5}$	$0.995^{+0.002}_{-0.003}$	$2.16^{+0.17}_{-0.17}$	0.05	1.43
Suzaku	$44.7^{+5.1}_{-5.0}$	$0.968^{+0.011}_{-0.016}$	$0.97^{+0.23}_{-0.23}$	0.03	3.01

Analysis of BAT spectra

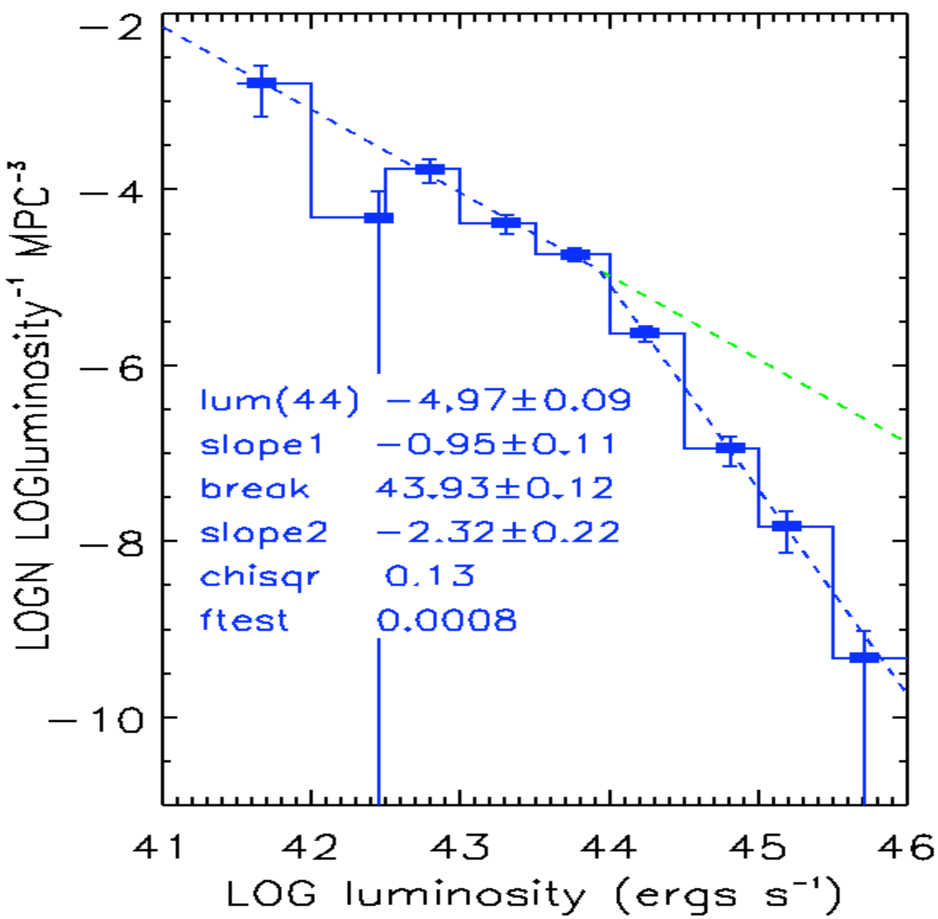
- ~ 30 sources which are strong enough for detailed analysis with BAT
- 9 of them show complex (curved) spectra
- Most of these well fit by reflection model with no cutoff- there are 3 which ‘need’ cutoffs

LogN/LogS and Luminosity Function



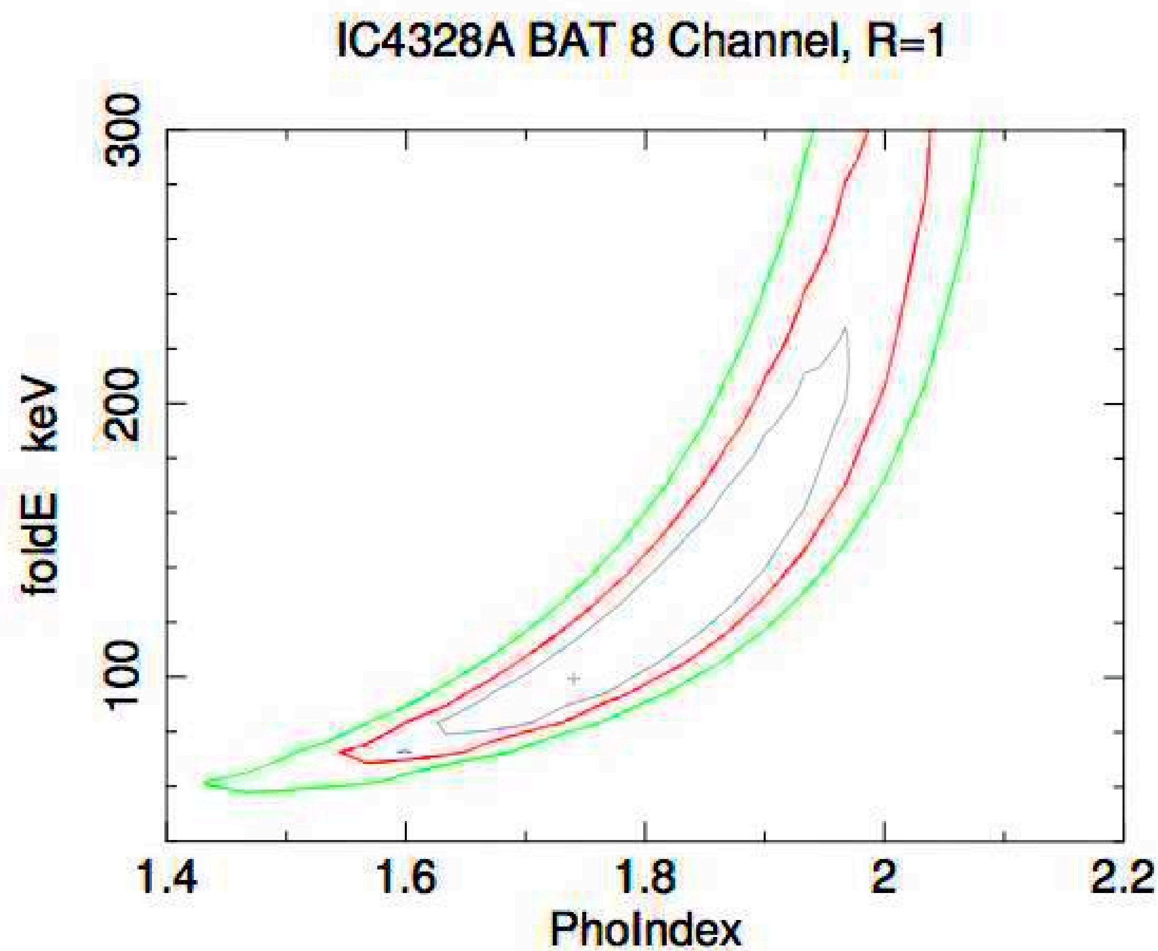
- Two models that predict the XRB make different predictions for source counts at $L_{BAT}>10^{-11}$ergs cm^{-2} s^{-1}
  - •Treister, Urry, and Lira: standard unified AGN model predict 2500 AGN
  - •Ghandi model predict 800 AGN
  - • BAT measures 1100 AGN

- errors 25% in normalization, ~10% in slopes and <1% in break luminosity
- New, much tighter constraints test CXB models- in particular ratio of abs:unabs sources
- **Break luminosity in hard band is < than 2-10 kev band; 2x more luminosity density**



For Bright Sources Constraints Can be Obtained

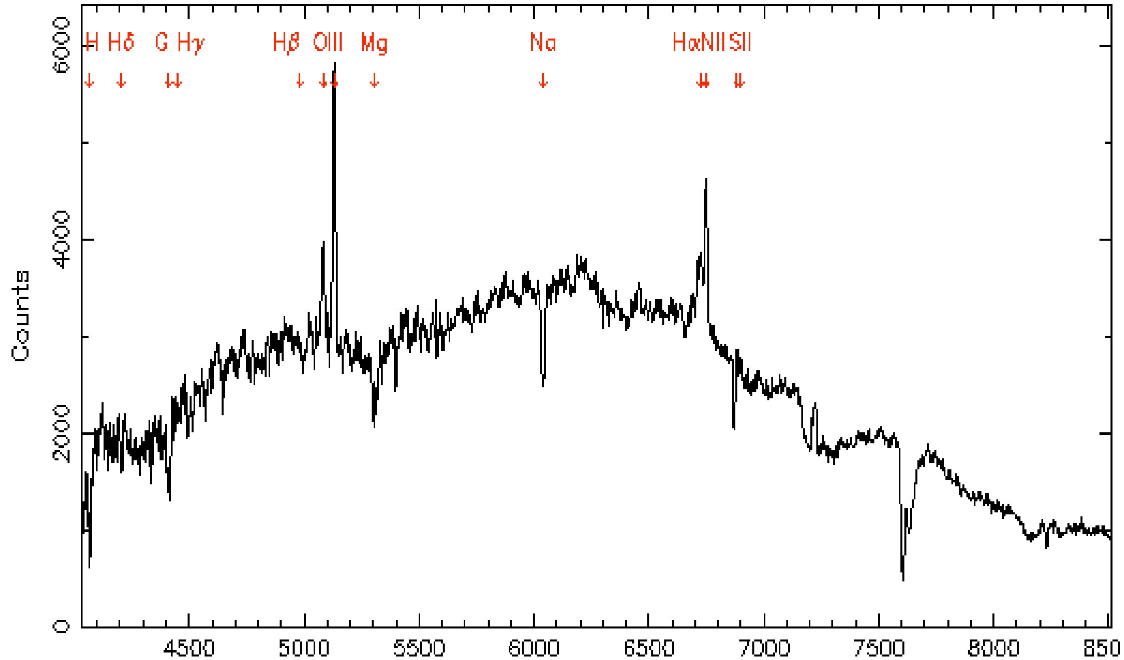
- The 3 D surface of slope, E(cut) and reflection fraction is highly correlated.
- Using literature value for IC4329A for R- good constraints on E(cut) and slope.

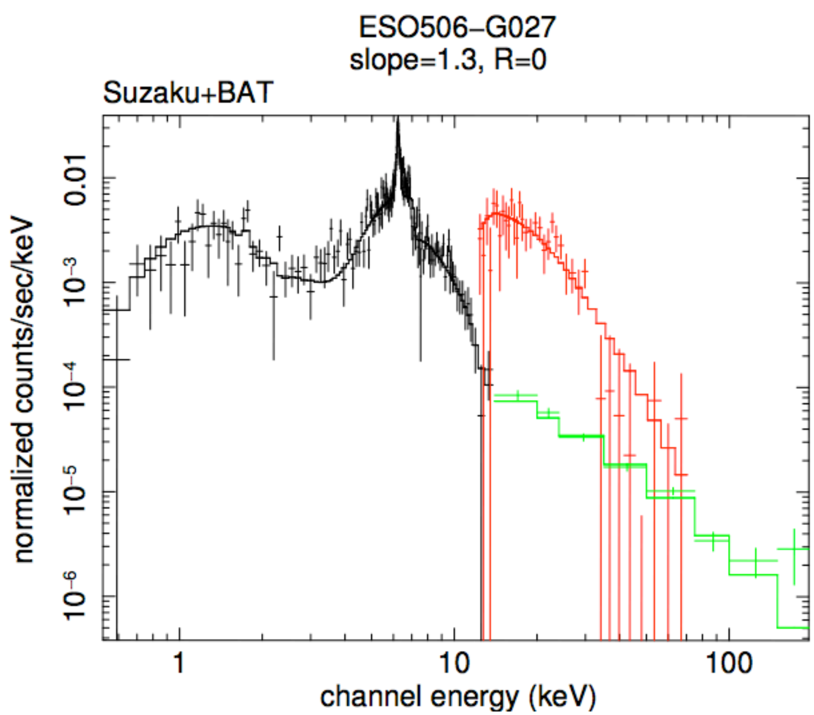


ESO506-G027

- Suzaku data show definitively that the flat spectrum is not due to reflection R<0.9 with PIN data only, $N(H)=6.3x10^{23}$

  Even though EW of Fe K is 650 eV !
- If one does not like the flat spectrum need 'double' partial covering otherwise intrinsic spectrum is flat.
- the source has varied by a factor of 2 (XMM vs Suzaku)
- We now have several such objects ! Reflection is not universal and high EW are not necessarily from reflection





Degeneracy Between Double Partial Covering and Reflection

- 4U1344-60, very bright, very high S/N z=0.0128 best fit by a very flat continuum , zero reflection and a low energy cutoff of ~60 kev(42-75).
  - E(line)=6.97, EW= 146 eV !
- Or it is a 'double partially covered source"(Piconcelli et al 2005)
- With no high energy cutoff and a diskline !

Objects without reflection signature or soft disk bb emission-(E.G. NGC 3227, NGC 2110. Cen A. no broad line nor reflection)

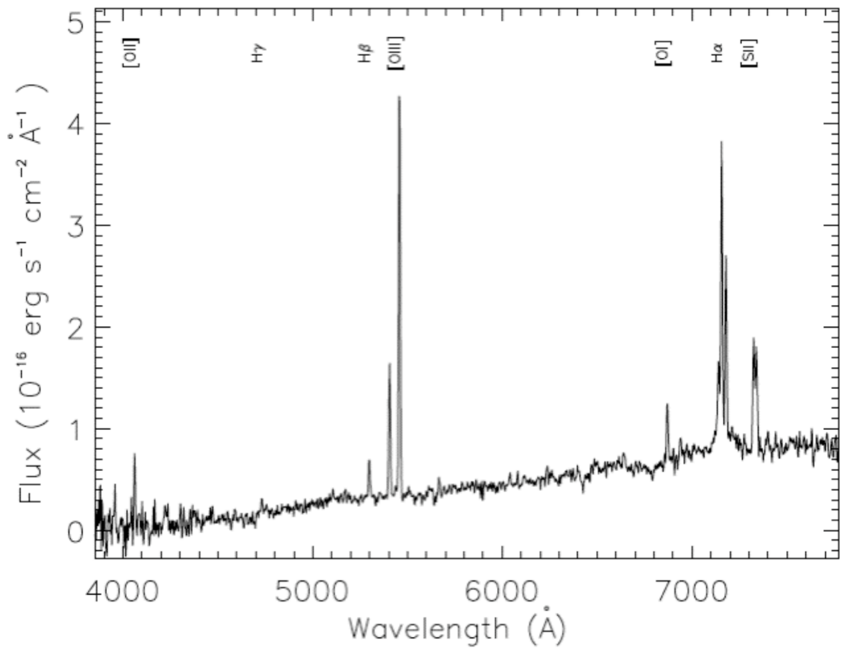
Where is the disk?

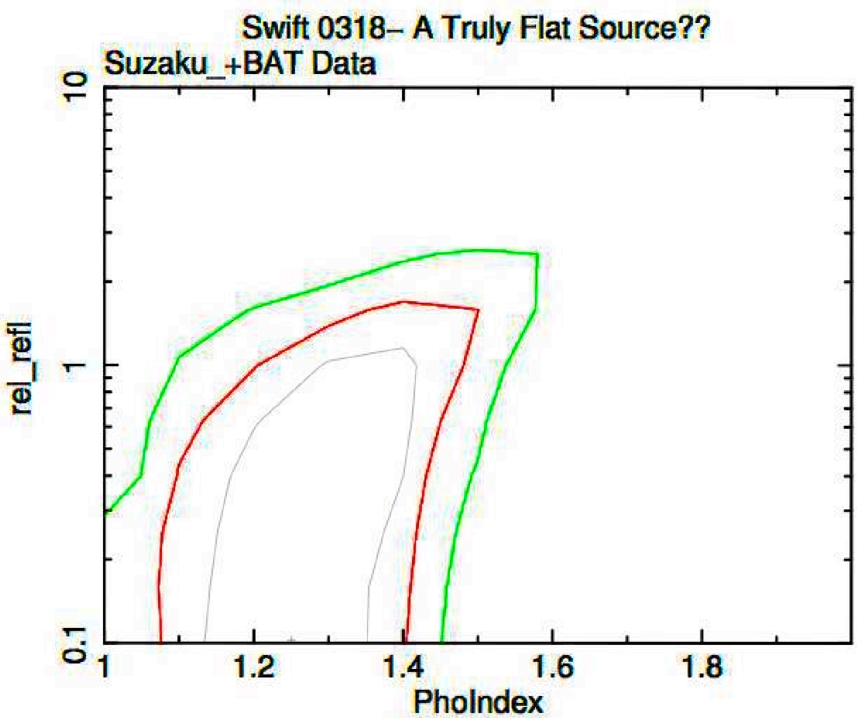
Can it be hidden (Reynolds et al 2006)

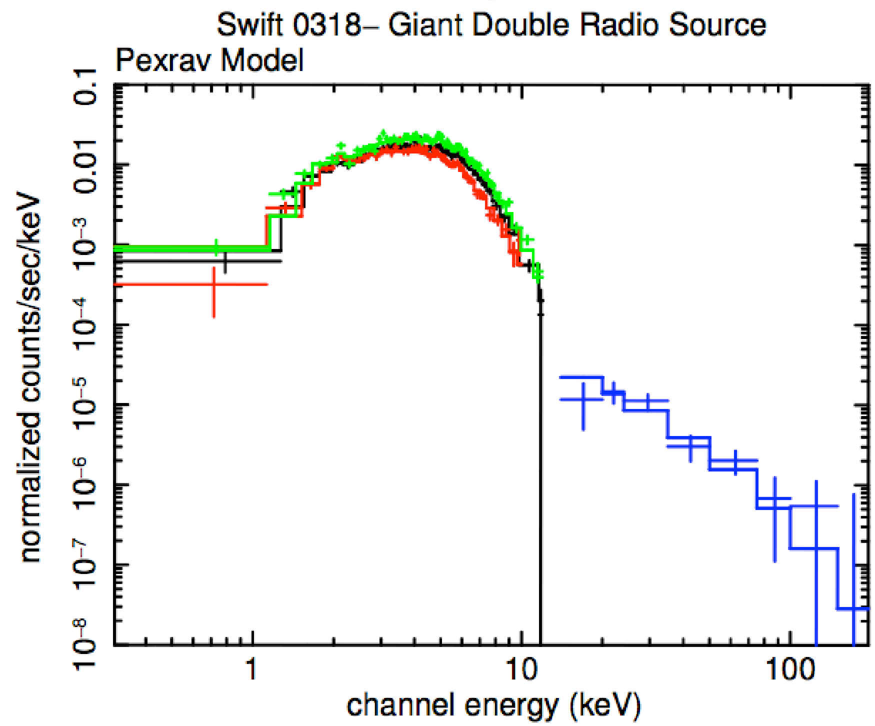
Is it absent (ADAF?)

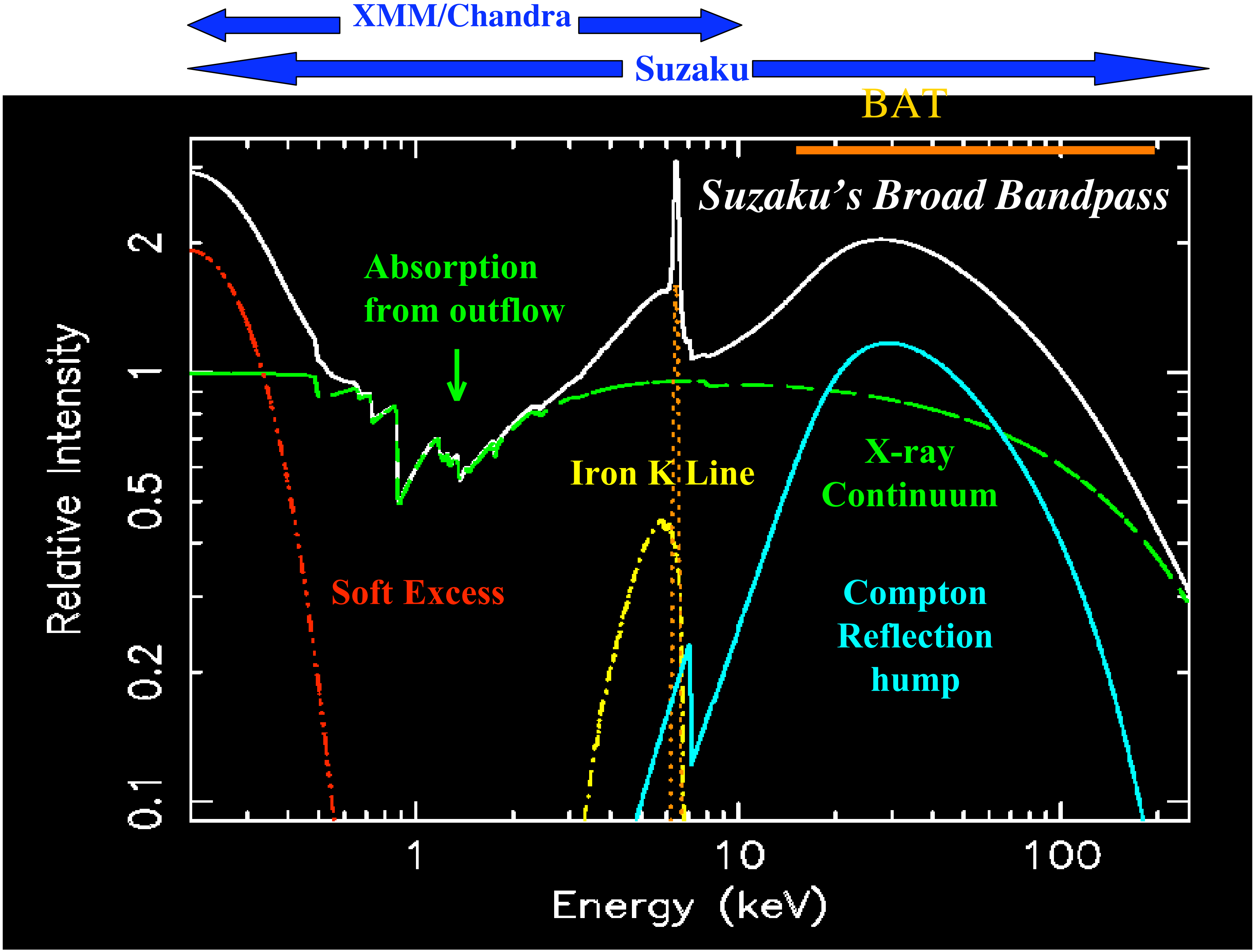
Swift 0318, z=.09

- This is a giant double radio galaxy - strong narrow lines Schoenmakers et al 1998
- (PIN not useful)
- very large covering fraction (0.99), log N(H)= 22,7 weak Fe K 65eV EW, statistically significant evidence for a line at E=5.38 keV (54 eV EW) ?
- Flat continuum and weak reflection








XMM/Chandra
Suzaku
BAT
Suzaku's Broad Bandpass
Absorption
from outflow
Iron K Line
X-ray
Continuum
Soft Excess
Compton
Reflection
hump
Relative Intensity
0.1
0.2
0.5
1
2
1
10
100
Energy (keV)