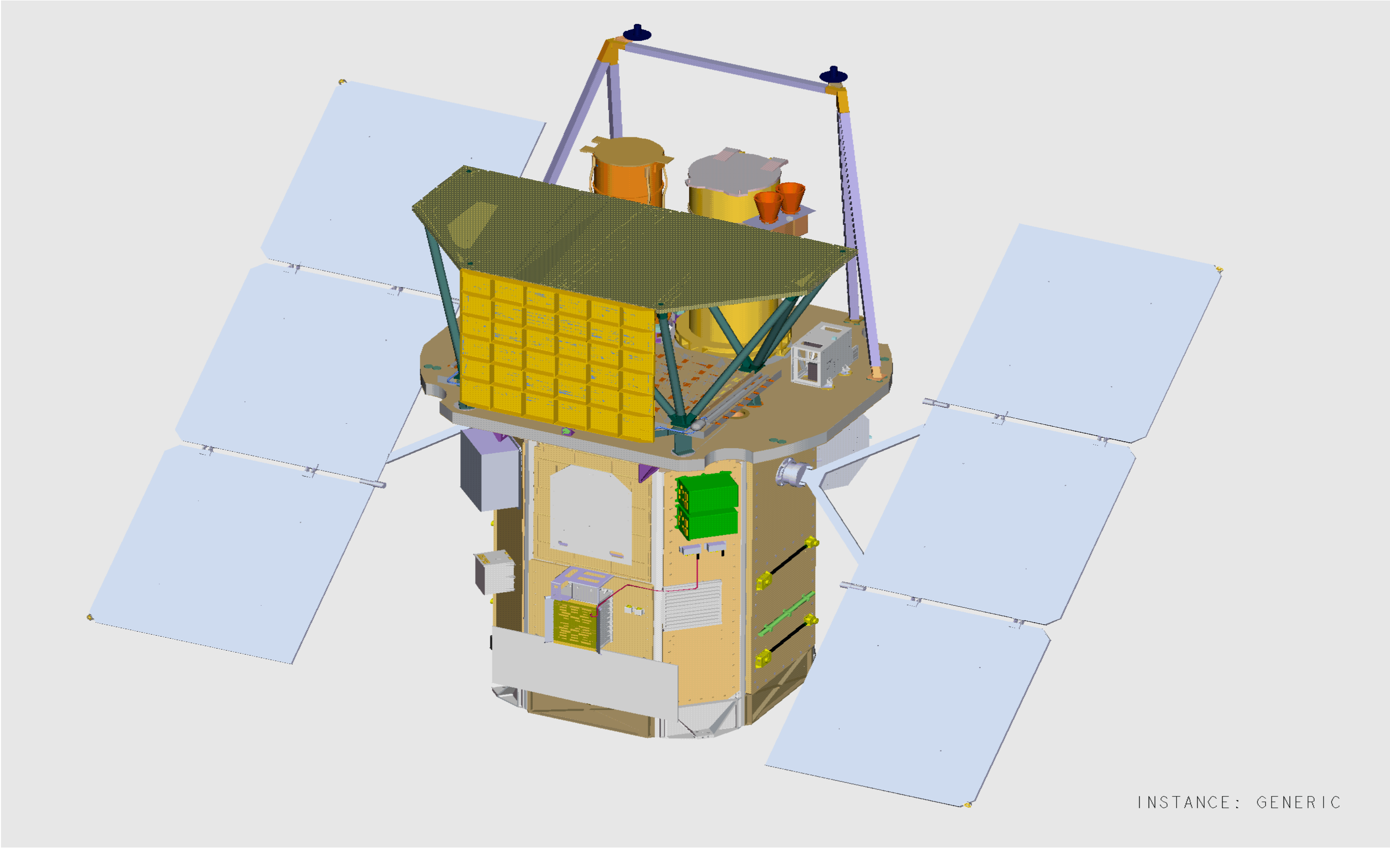
Swift/BAT Hard X-ray Survey

J. Tueller. C. Markward. R. Mushotzkv. L.Winter. G. Skinner

Preliminary results in Markwardt et al 2005

9 month survey

submitted this week



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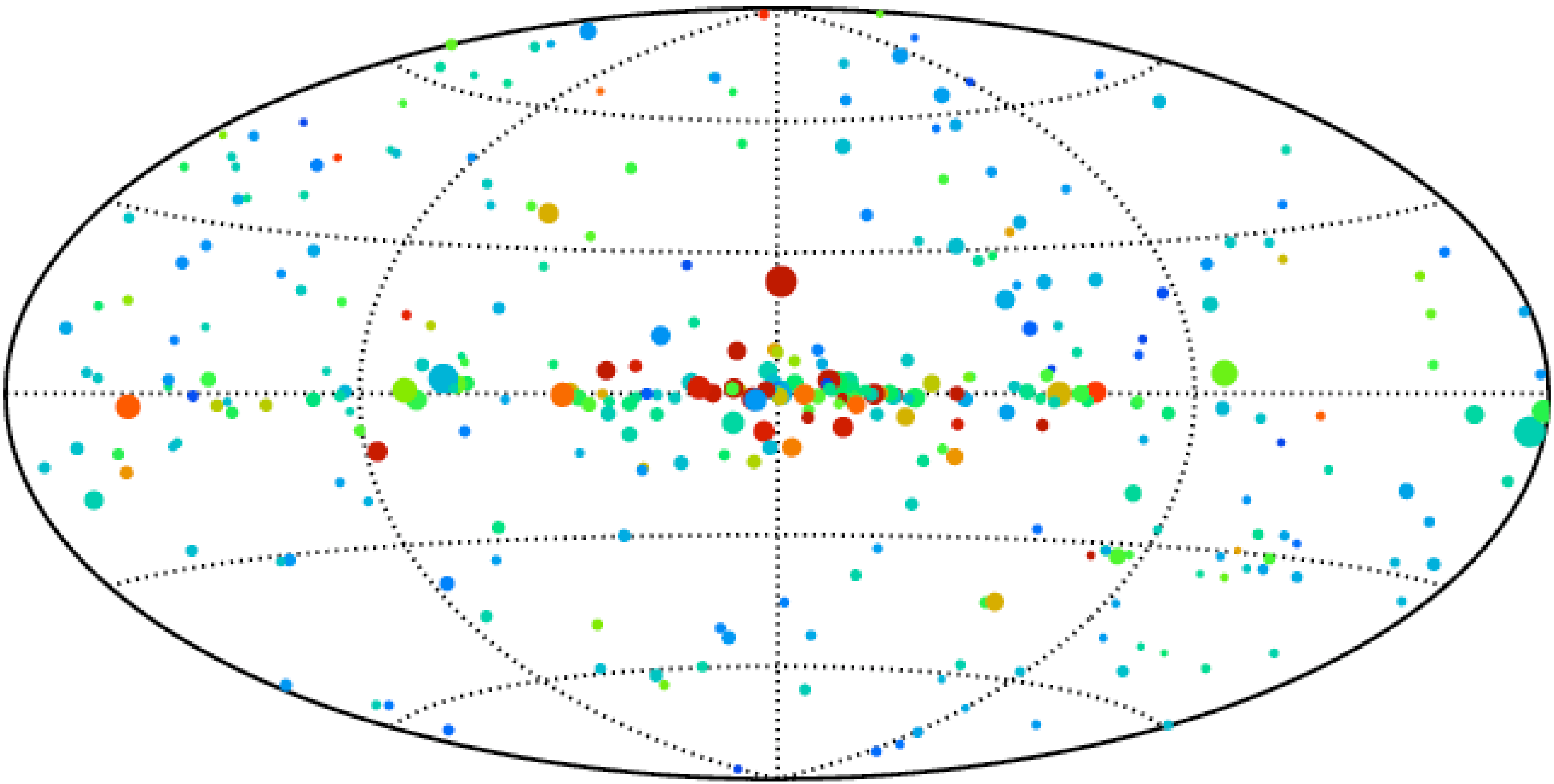

flux coded by size
energy coded by color

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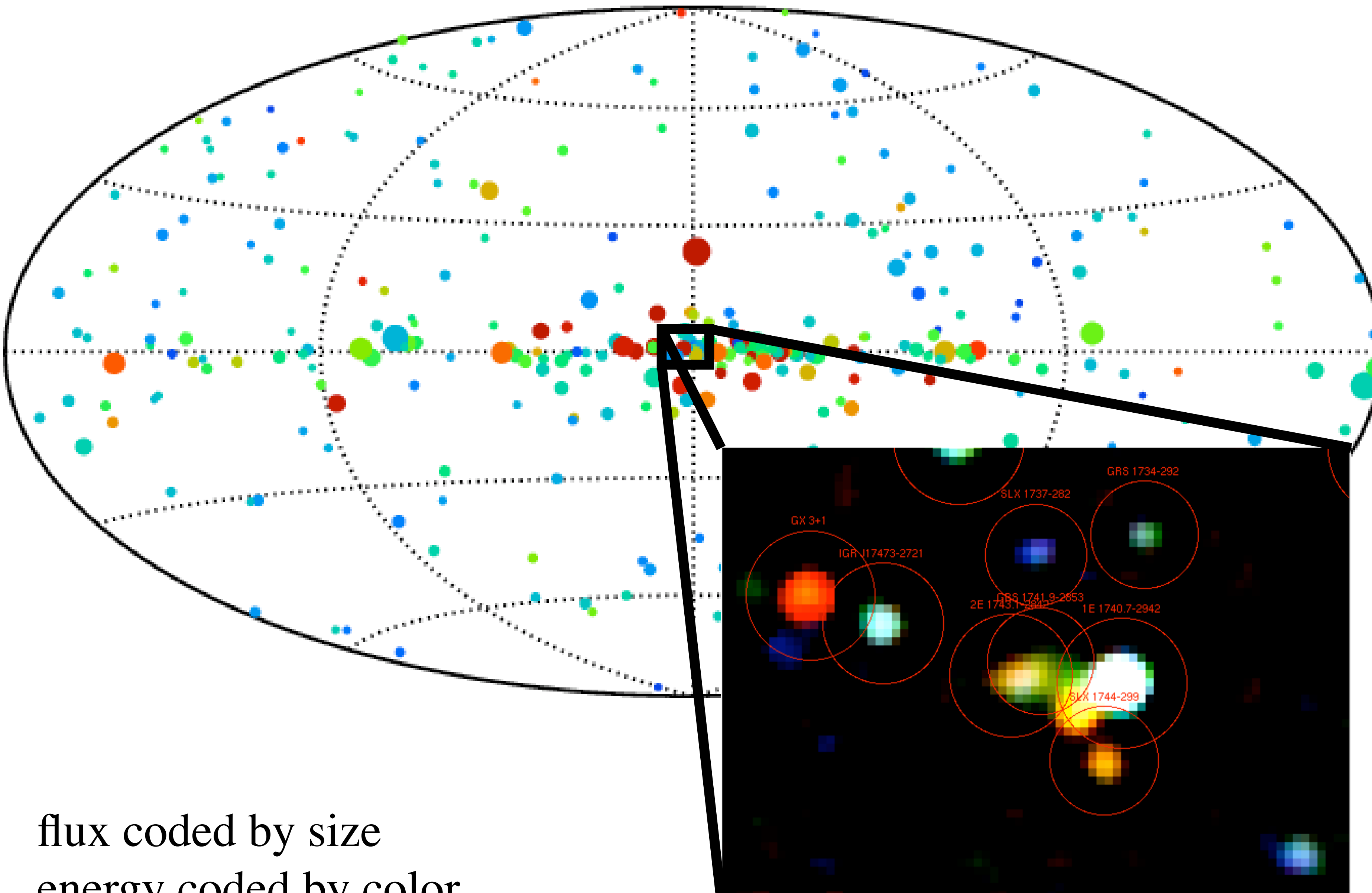

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BAT Instrument Parameters

- **Energy Range** — **14 - 195 keV**
- **Area** — **5200 cm² (x 50% open fraction)**
- **Field of View** — **2 Steradian, partially coded**
- **Background** — **10,000 ct/s (cosmic diffuse dominated)**
- **Spatial Resolution** — **21' sky pixel, uncertainty <1-6' radius**
- **Spectral Resolution** — **6 keV FWHM @ 60 keV, average**
- **Sensitivity** — **few X 10^{-11} ergs cm^{-2} s^{-1}**
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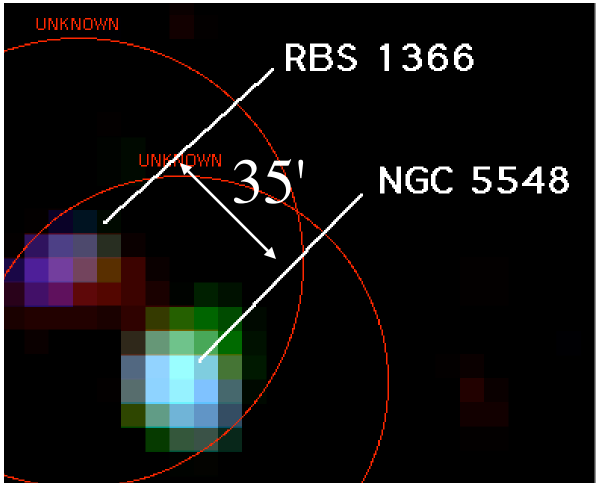

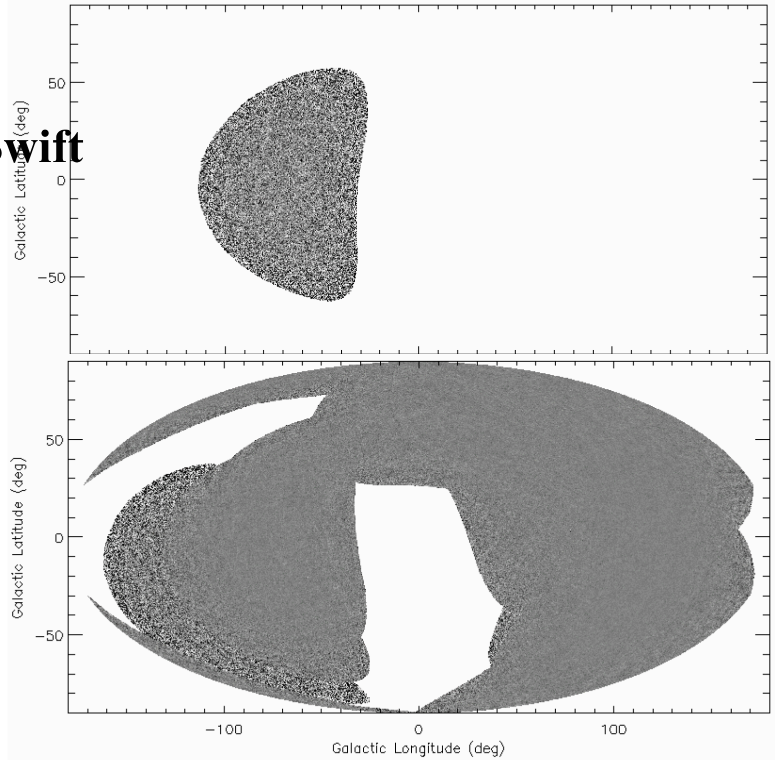

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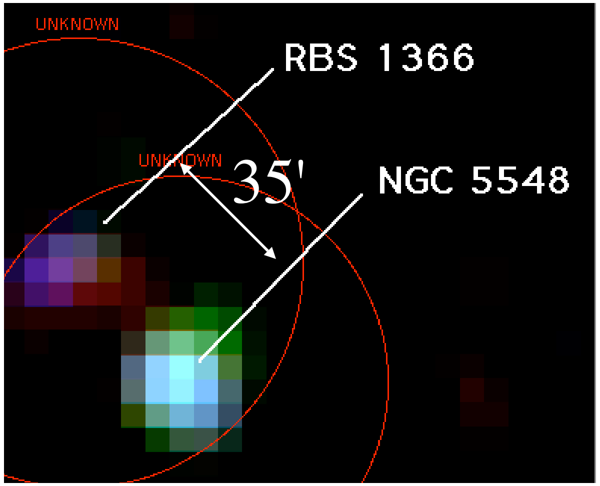

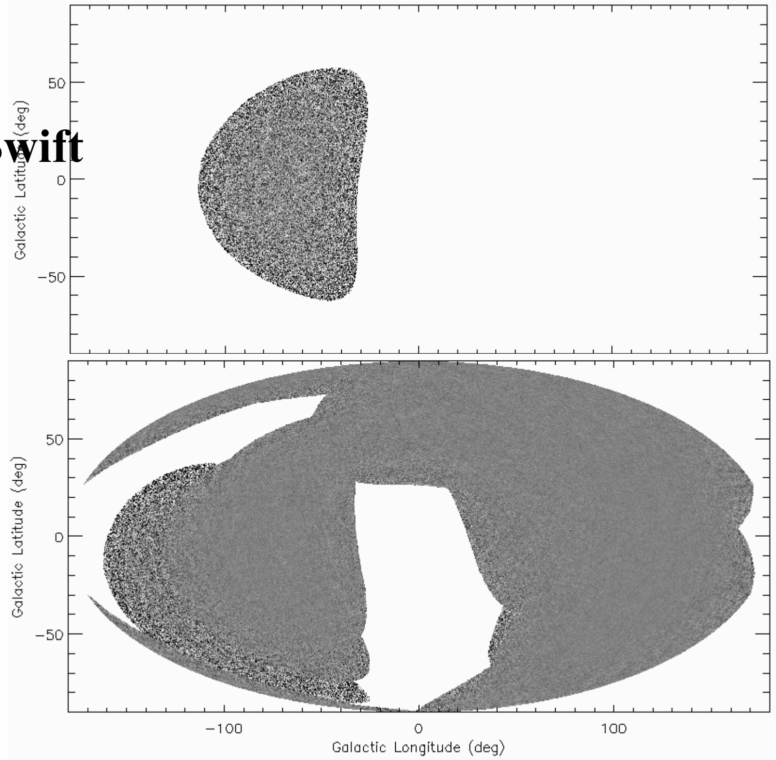

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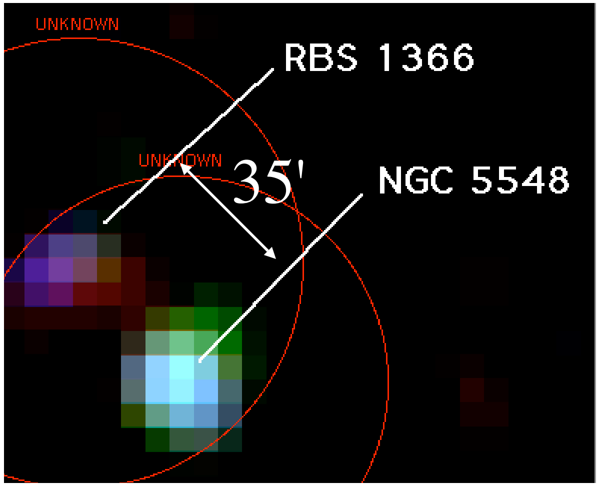

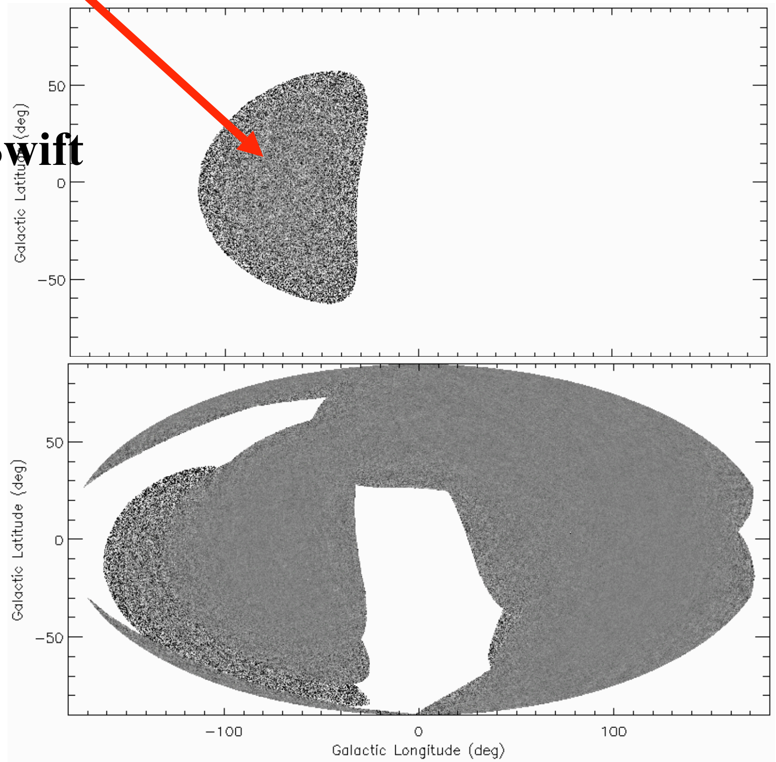

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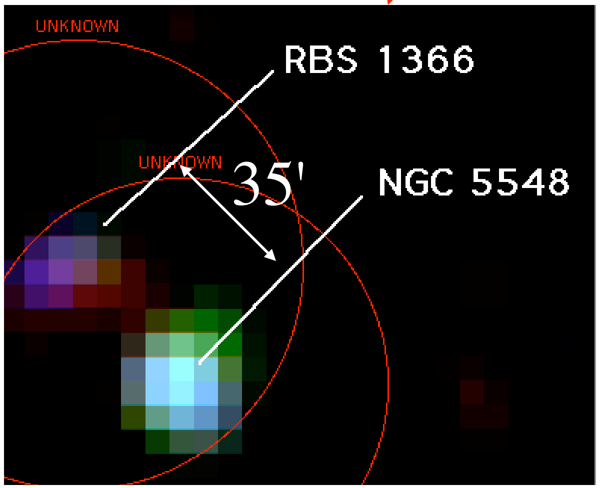

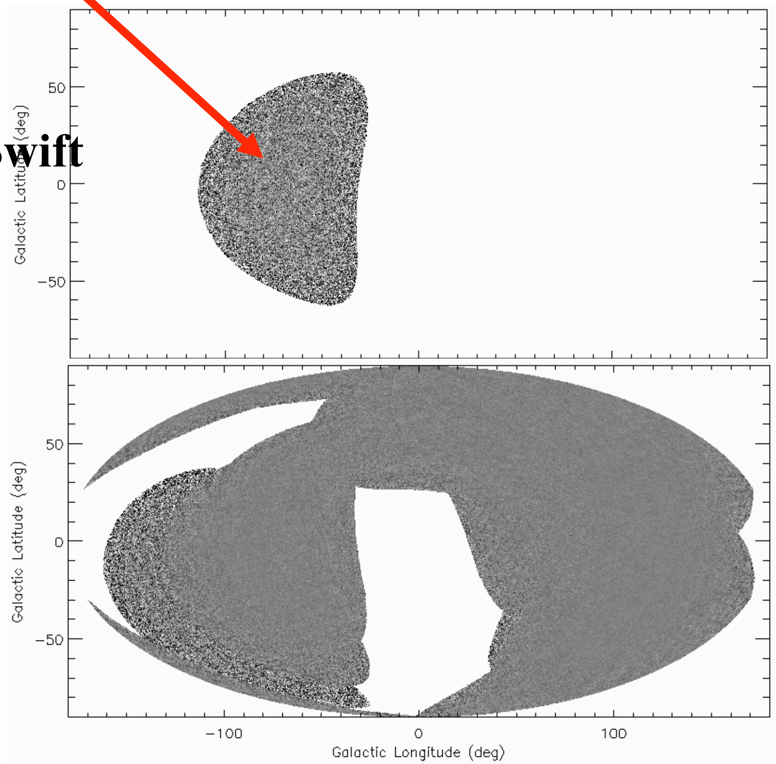

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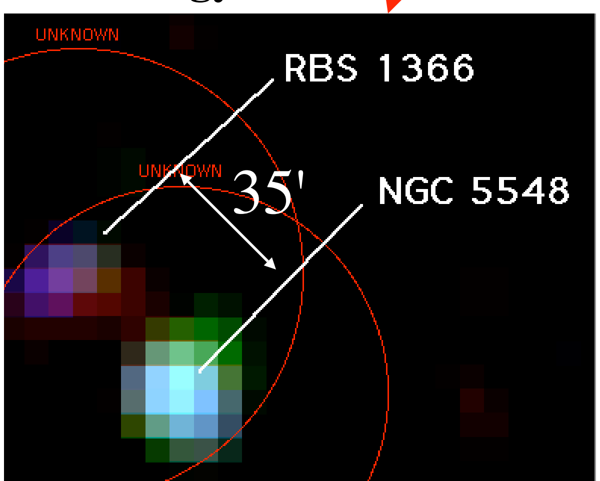
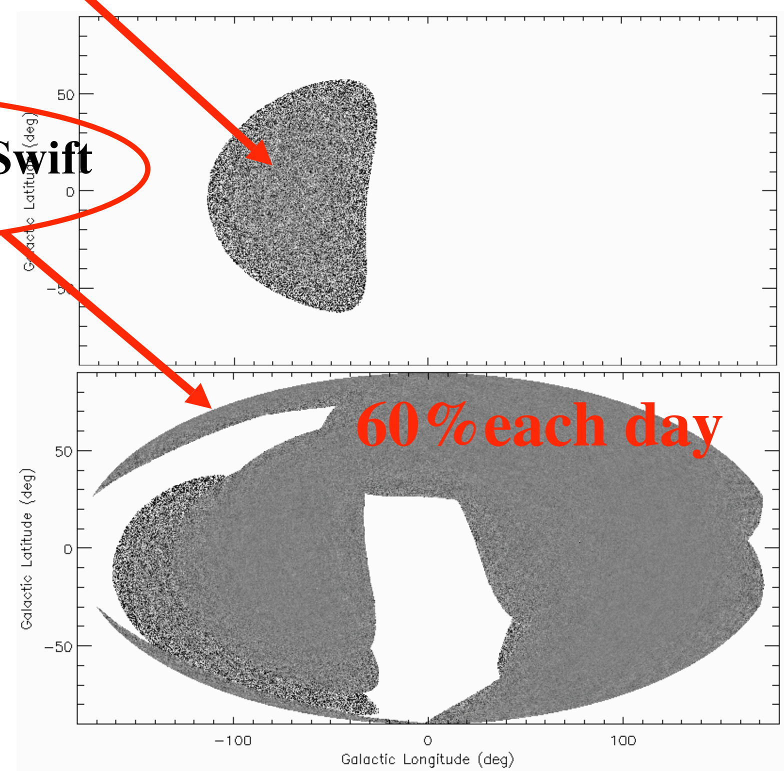




BAT Source Detections

9 months of data

- 323 sources
- 39 unidentified sources
- 158 galactic
- 5 galaxy clusters
- 158 AGN
  - 16 beamed

|Galactic b| >15 (74%)

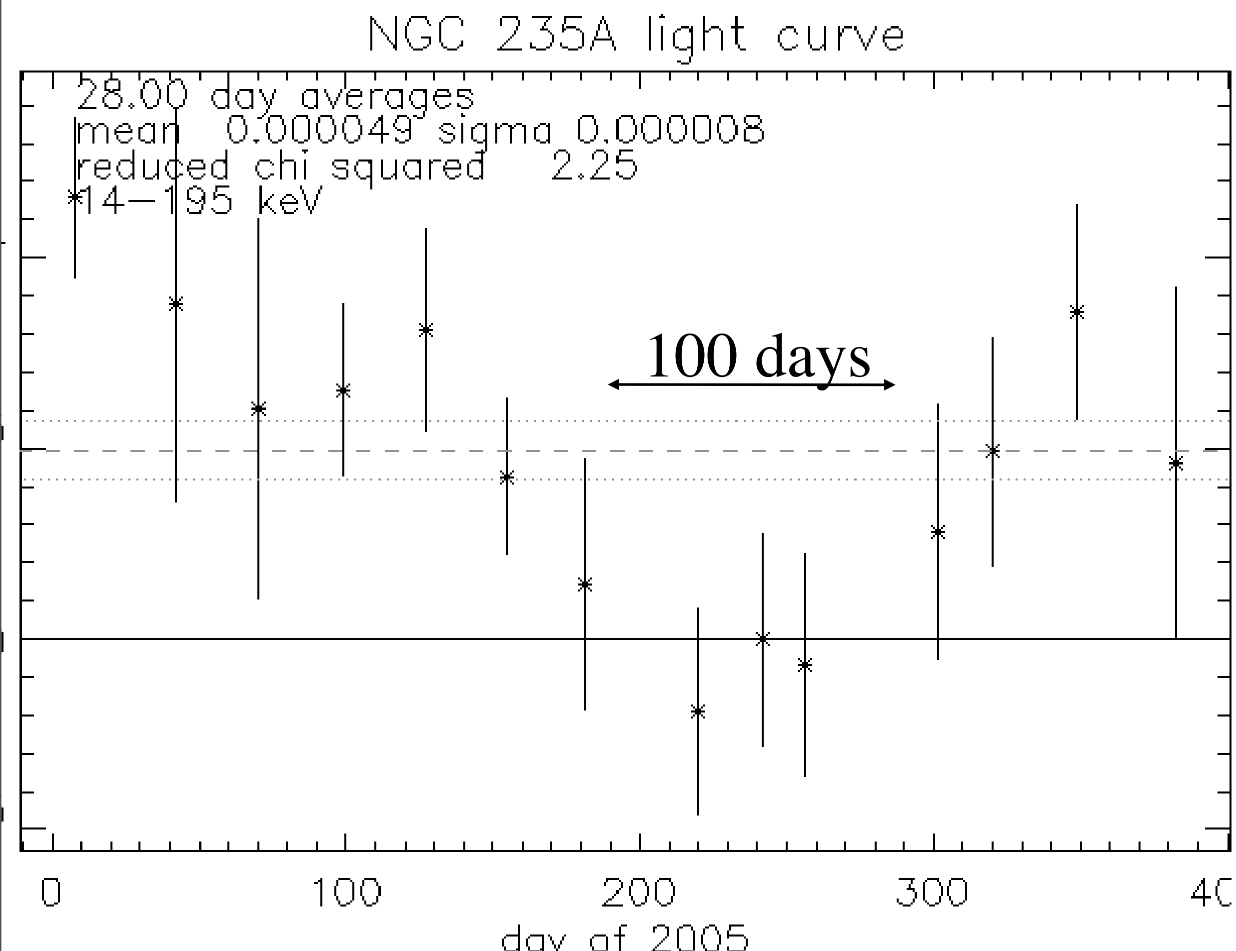
- 159 sources
- ~~9 unidentified sources~~ Now 1 >4.8 σ
- 29 galactic
- 2 galaxy clusters
- 121 AGN
  - 15 beamed

2 years of BAT survey will be available soon.

3rd Integral catalog with 450 sources all sky with 3.5 yrs of data

17 hard x-ray AGN before BAT and Integral

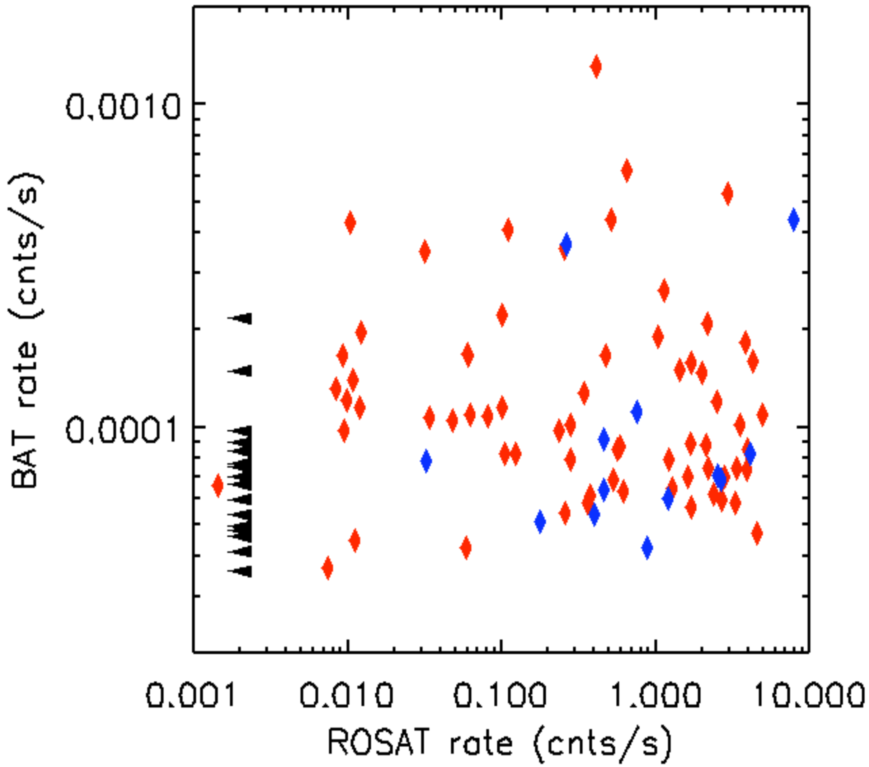
NGC 235A Lightcurve

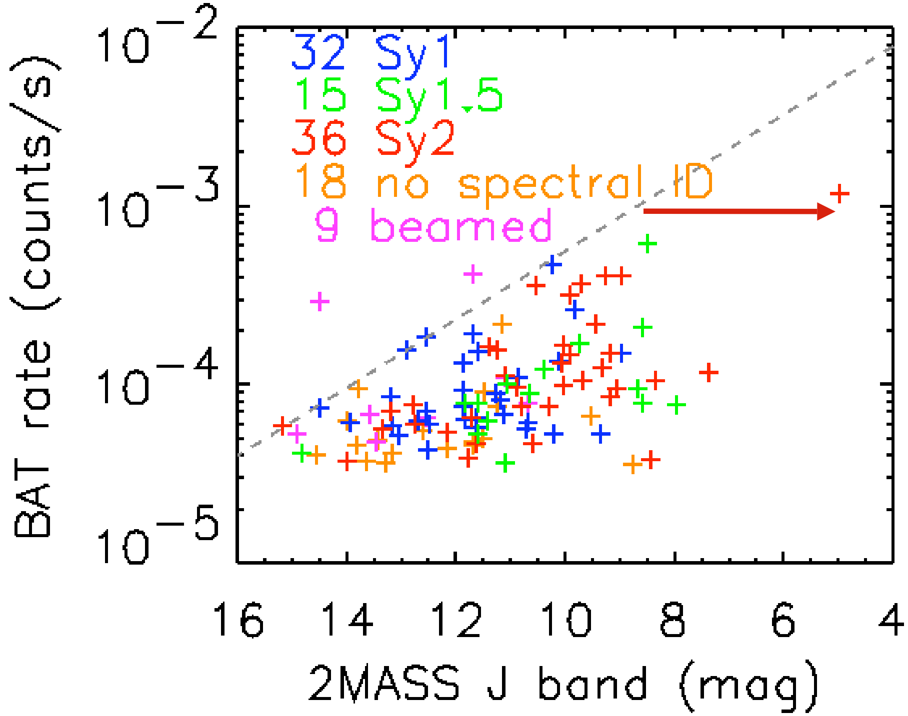


- Light curve for 6 sigma source
- AGN usually vary by <2X
- 100 day turn off (<5X drop)
- light travel time from black hole to torus?
- Beckmann et al papers

Correlations of BAT Rate with other Bands

- no correlation between BAT and ROSAT count rates
- 21 BAT sources not detected by ROSAT



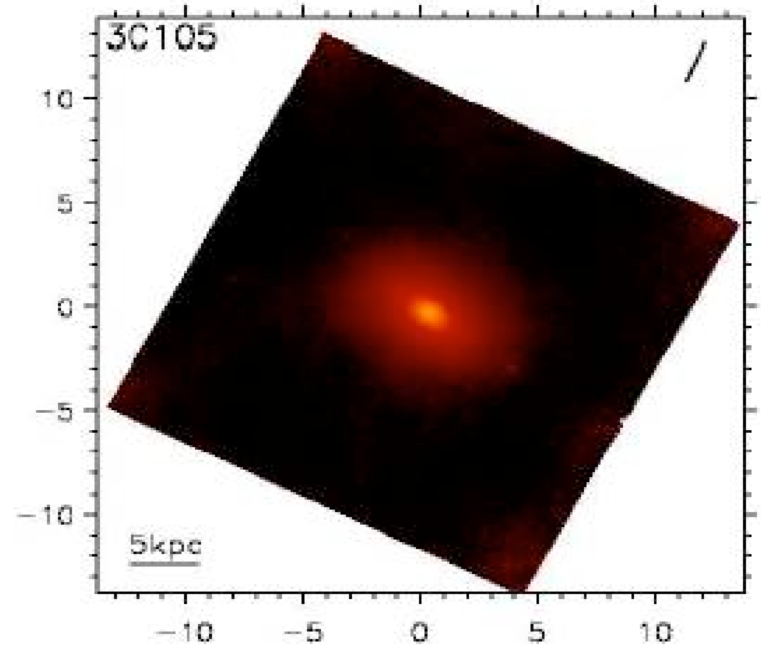


- no close correlation with total 2MASS J band
- soft x-ray and IR do not measure true AGN luminosity or complete populations

Is the absence of optical nuclei

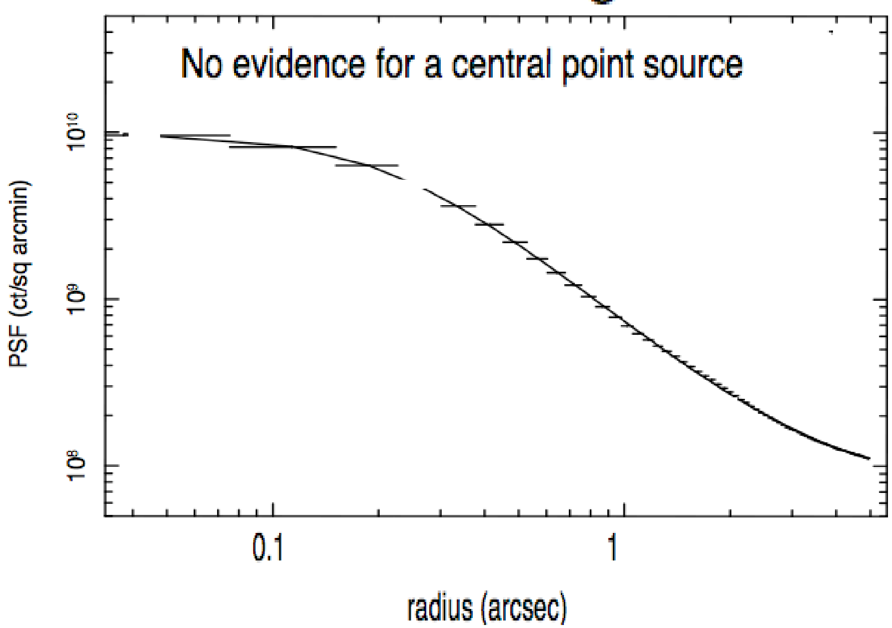
- $Z=0.089$ - no evidence for a IR central point source or polarized broad lines
- X-ray column density ~ $2.5 10^{23}$ atms/cm^2 log $L_{BAT}=44.7$

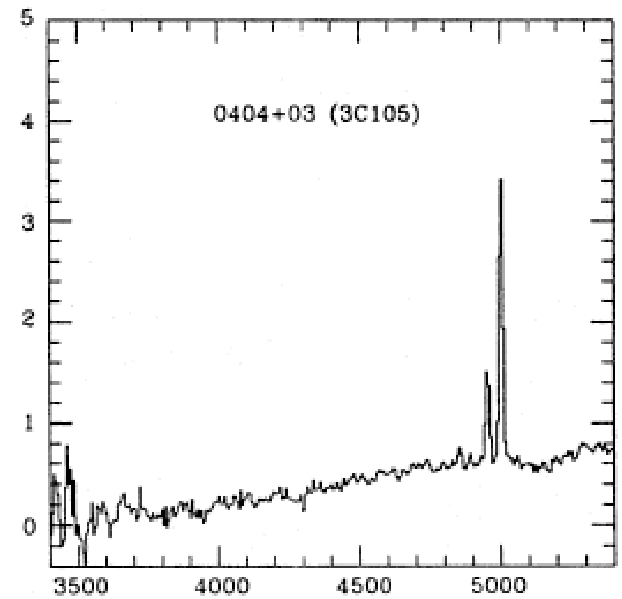
This is not a classical Seyfert II- no evidence for scattering despite the strong [OIII] lines



— HST/NICMOS F160W image

3C105– Nicmos King Profile Fit



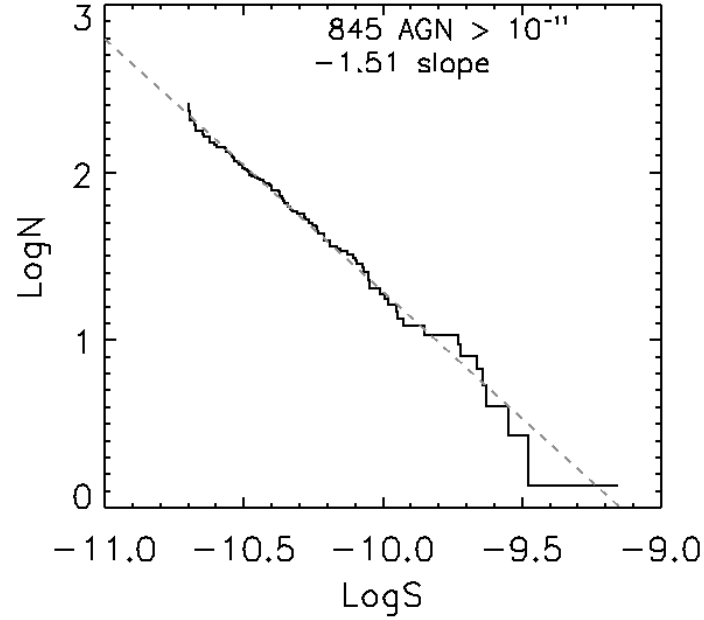


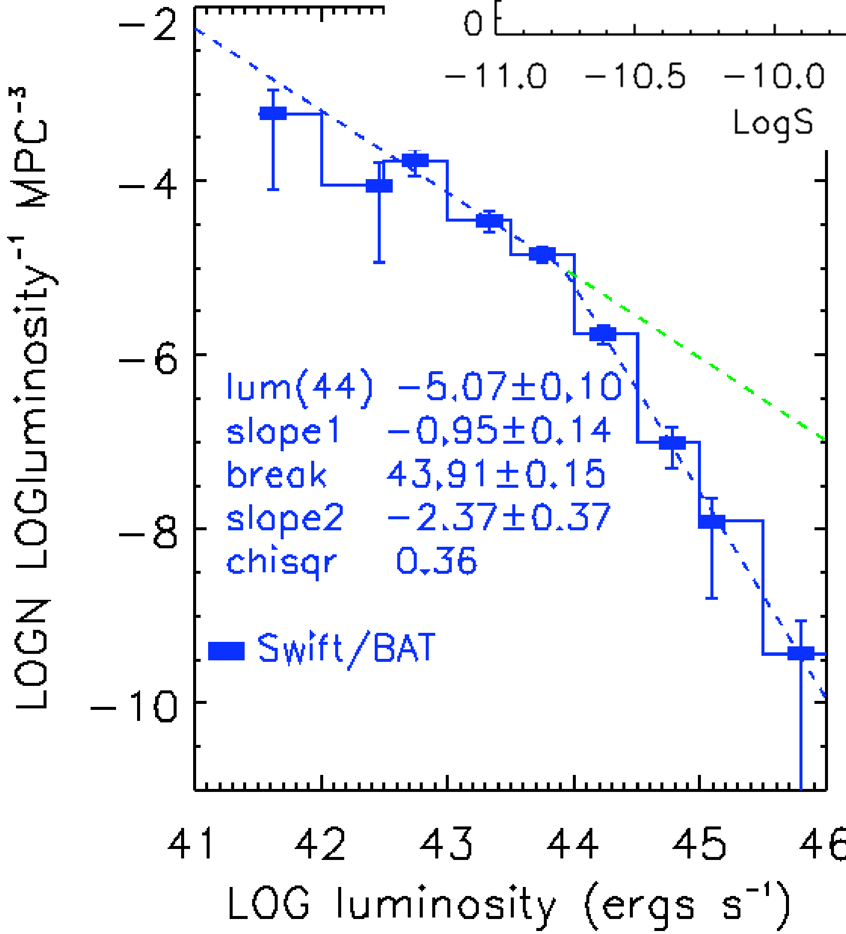
BAT survey goals

- perform uniform and complete census of local AGN with enough galaxies for population statistics
- perform multi-wavelength follow up, long term variability, and spectroscopic studies that are adequate to characterize this sample
- find new examples across the full range of AGN behavior that are near enough and bright enough for detailed study
- including types that are rare in the local universe but more common at high redshifts
- Understand the properties of absorbed AGN
- Investigate the completeness of alternative AGN survey methods and seek approaches to improve/calibrate the effect of absorbed AGN

Log N Log S and Luminosity Function

- LogN LosS slope is –1.51±0.21
- There will be 851 BAT AGN above 10^{-11} ergs $cm^{-2}s^{-1}$
- the local number density of AGN is $3X10^{-3}$ MPC^{-3}
- the luminosity function breaks at 43.9±0.15 from slope -1 to slope >-2

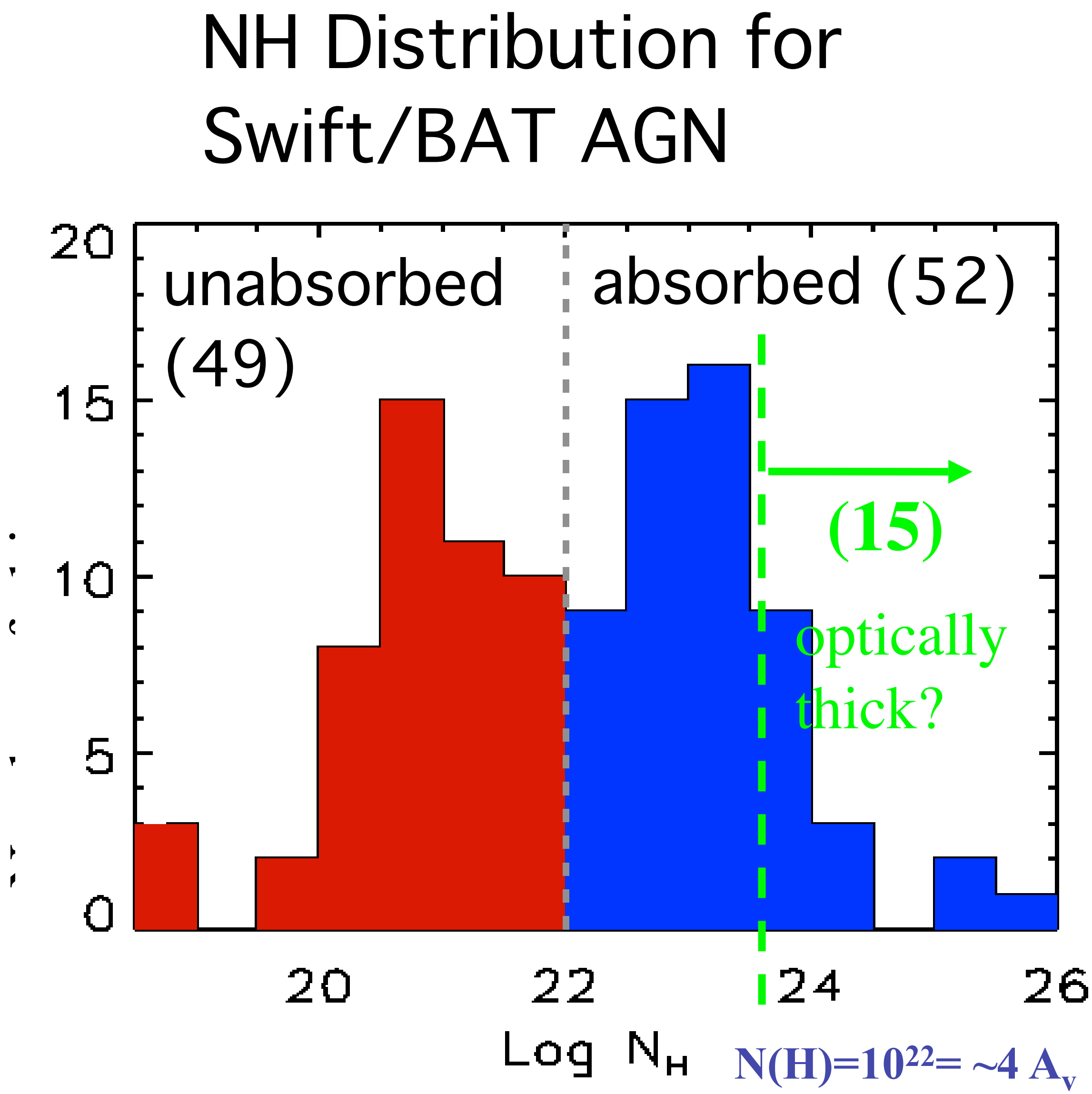




N_H Distribution/Tests of the Unified Model

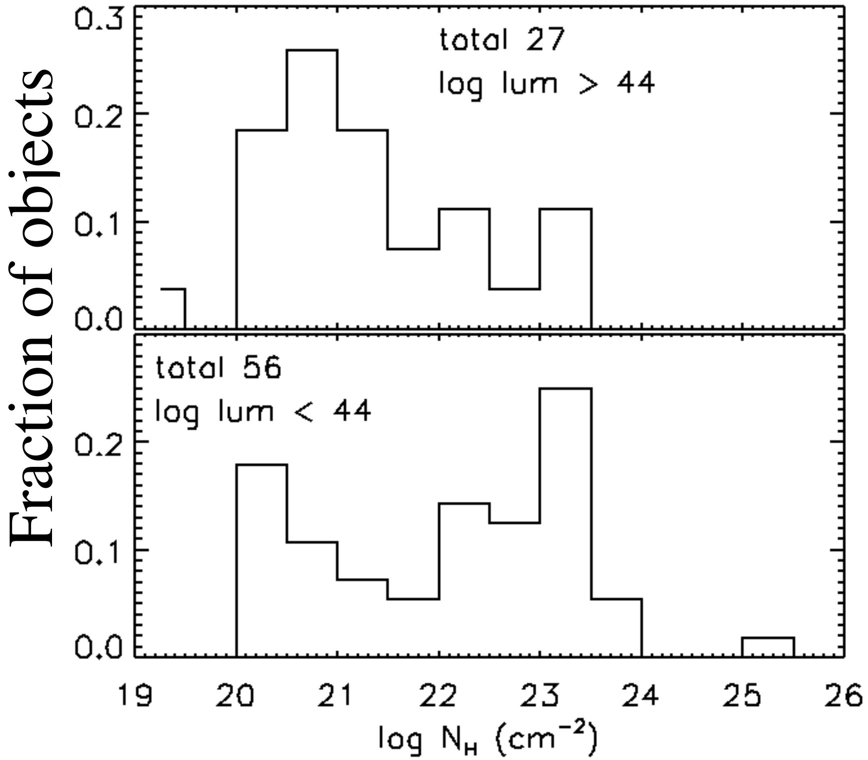
- Unified models of active galaxies try to account for the relative number of different types of AGN (so-called types I and II) predict that the ratio of obscured to un-obscured objects in the local universe **should be 4:1** (Antonucci and Miller 1989, Treister et al 2006)

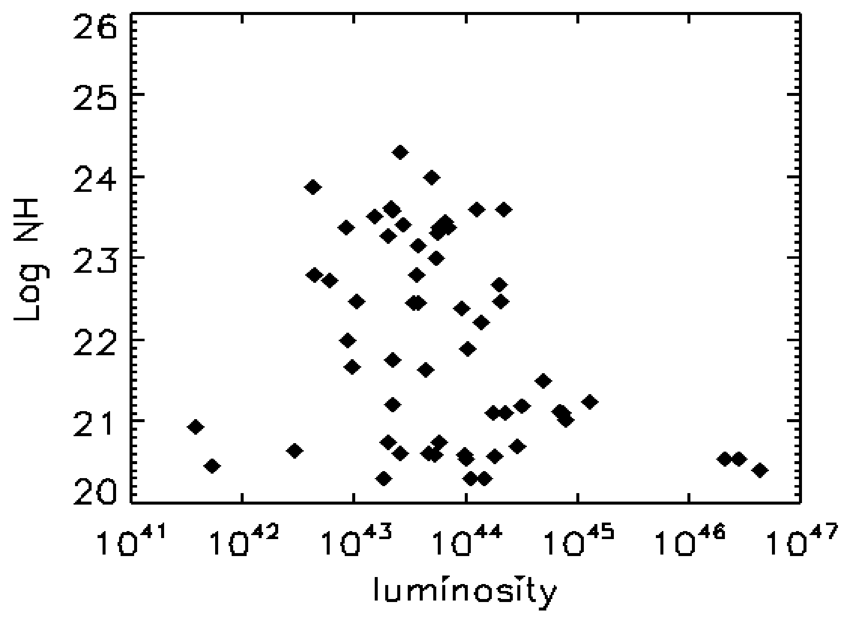
- **BAT finds 1:1 - a serious discrepancy requiring modification of the unified model**



Tests of Unified Model

- The Unified model predicts that the obscuration is geometric - no dependencies of the obscuration on the luminosity of the AGN
- BAT lower luminosity sources are more likely to be obscured than the high luminosity sources
- Consistent with XMM and Chandra results on fainter higher z sources

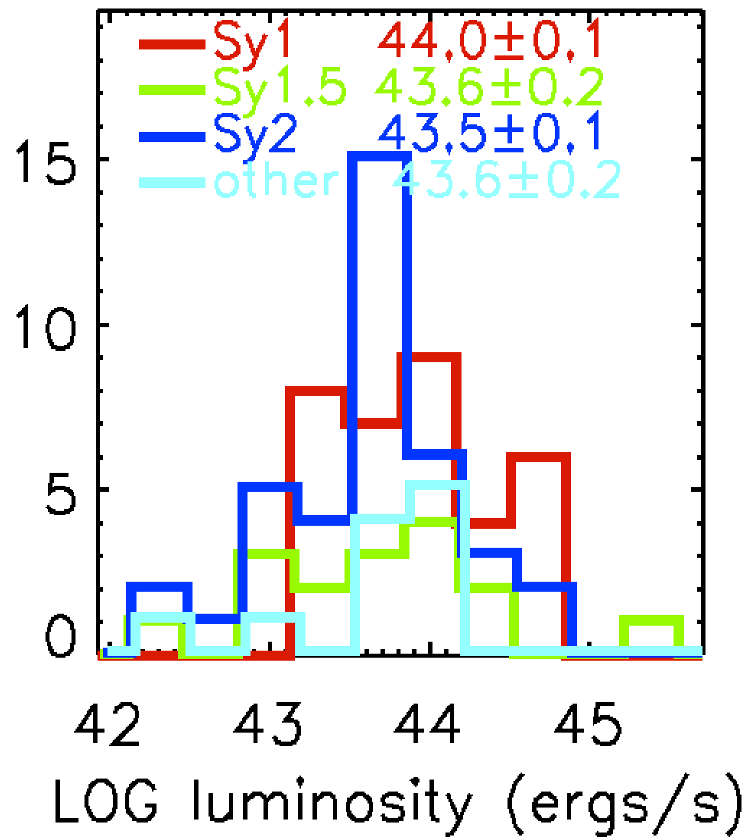


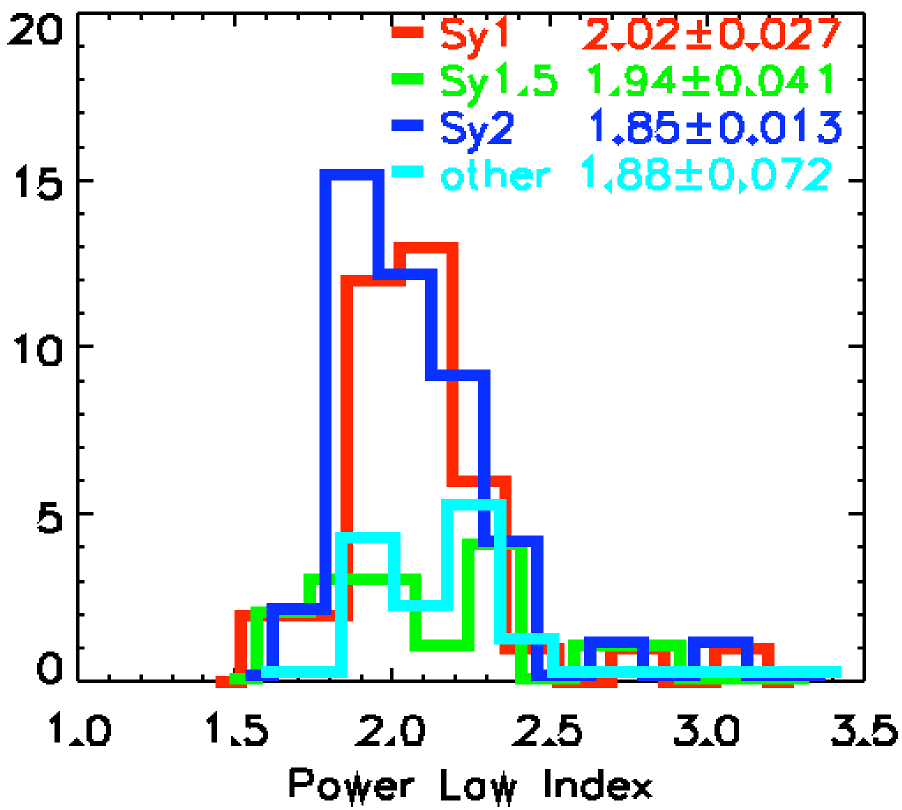


Tests of the Unified Model

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

- BAT selected Sy1's have softer spectra than Sy2's (5.7σ)



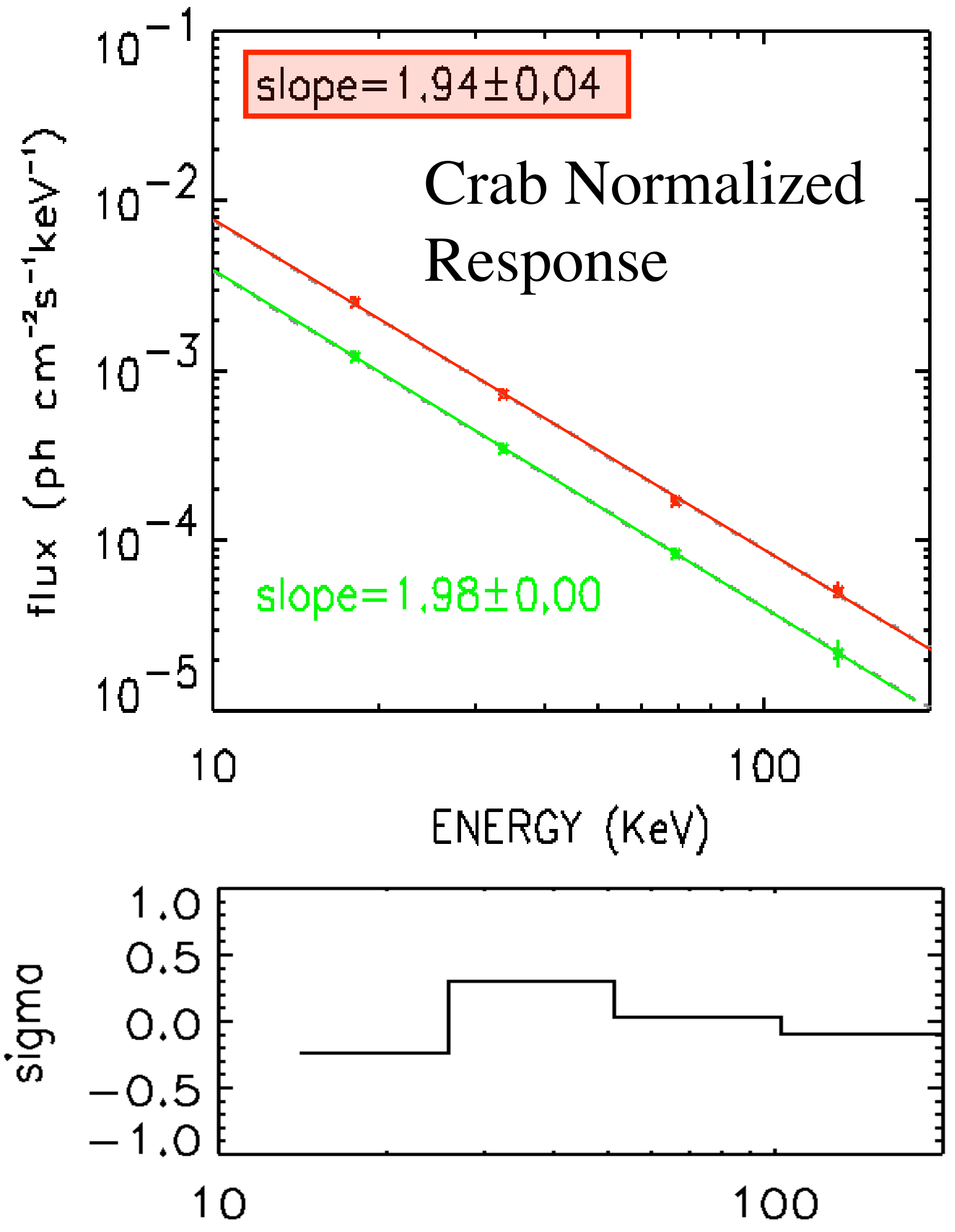


- BAT selected Sy1's have higher luminosity than Sy2's (3.6σ)
- no selection effect for BAT

Average BAT AGN Spectrum

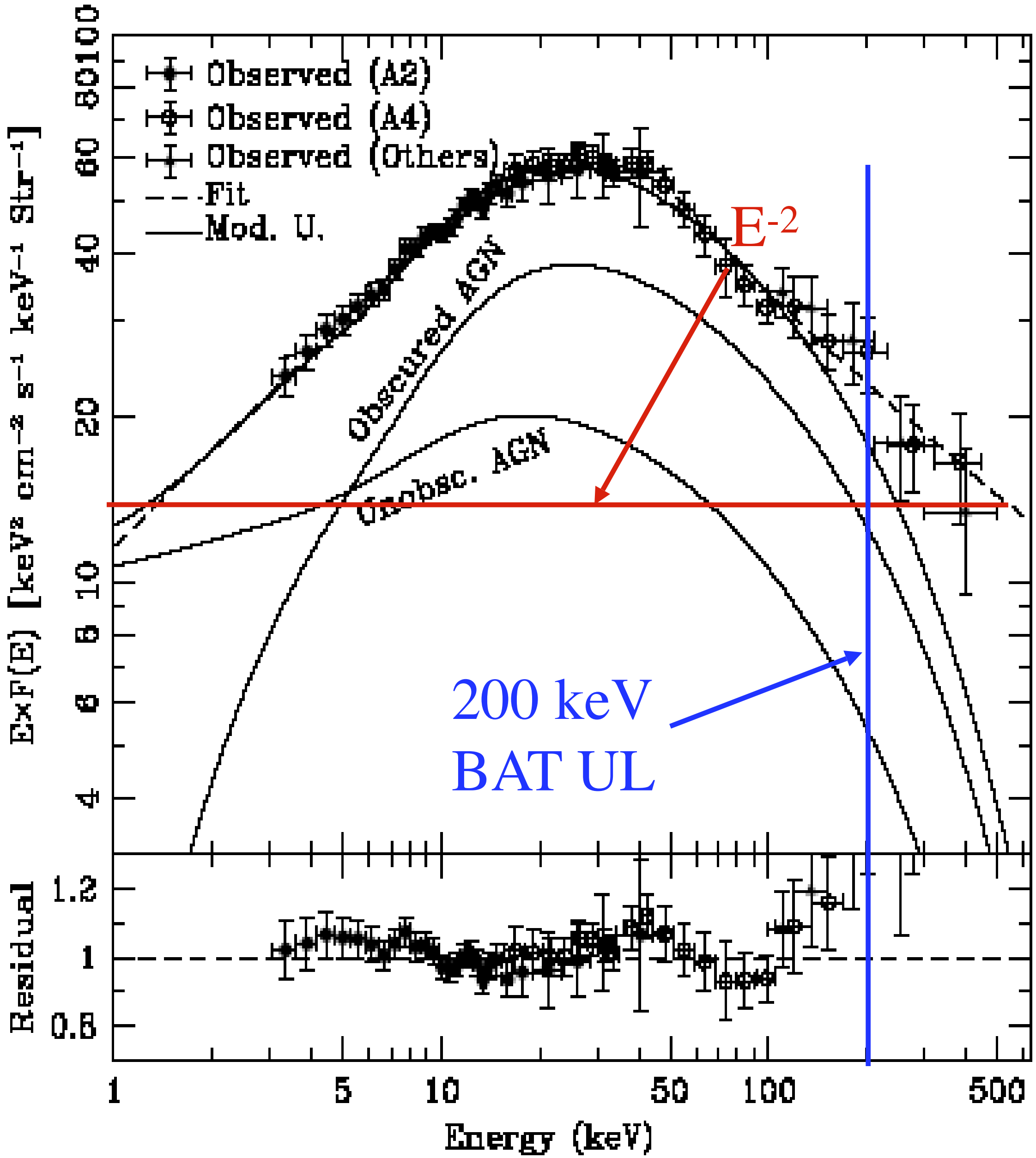
Σ of all AGN- no evidence for a break below 200 keV

- same with brightest 36 AGN removed
- Same for luminosity $<10^{44}$ or $>10^{44}$
- Contrast with strong break at 40 keV in CXB
- spectrum is much flatter than CXB (slope = 2.75) above the break
- 8 channel data are in preparation



Background vs BAT AGN Spectrum

- BAT AGN spectrum is a bad fit to CXB for E>40 keV
- Soft x-ray surveys put source of CXB at Z=0.7
- to fit the CXB the BAT AGN must be at Z > 1 or show strong evolution



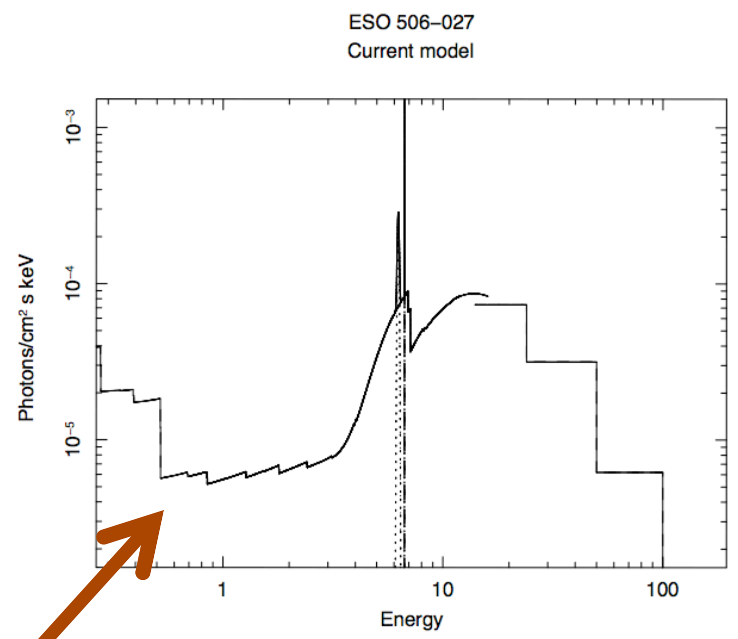
Hard X-ray surveys Swift/INTEGRAL

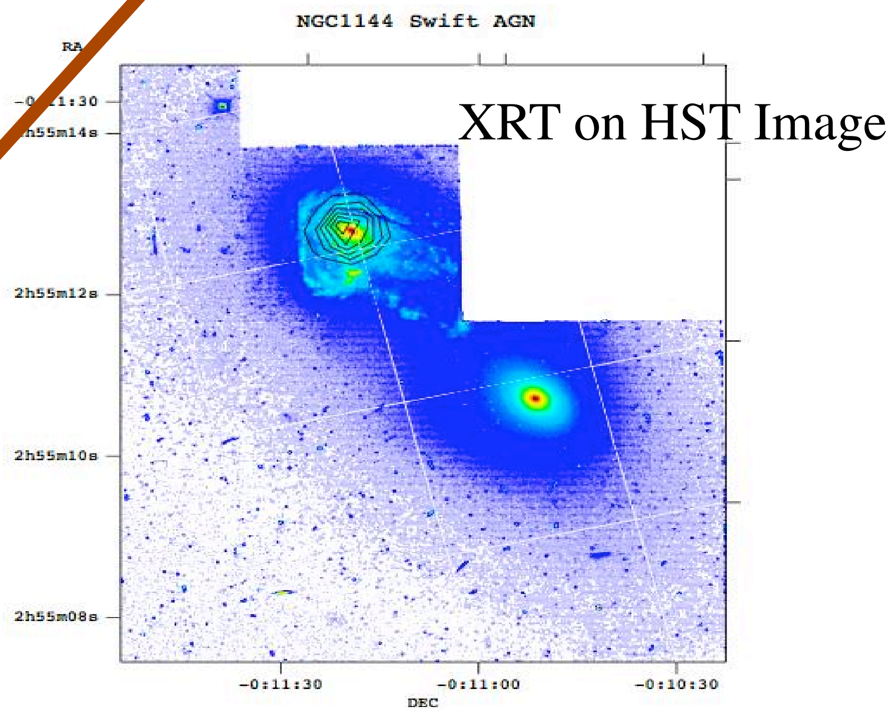
- Finding low z (<0.03) well studied objects with no indication of optical activity at all
- Even soft x-rays may be absent (ESO 506-027, log N (H)=23.9,
  - log L(x)= 44.2 (.1-100 keV)

    log L(x)= 42.7 (2-10 kev)

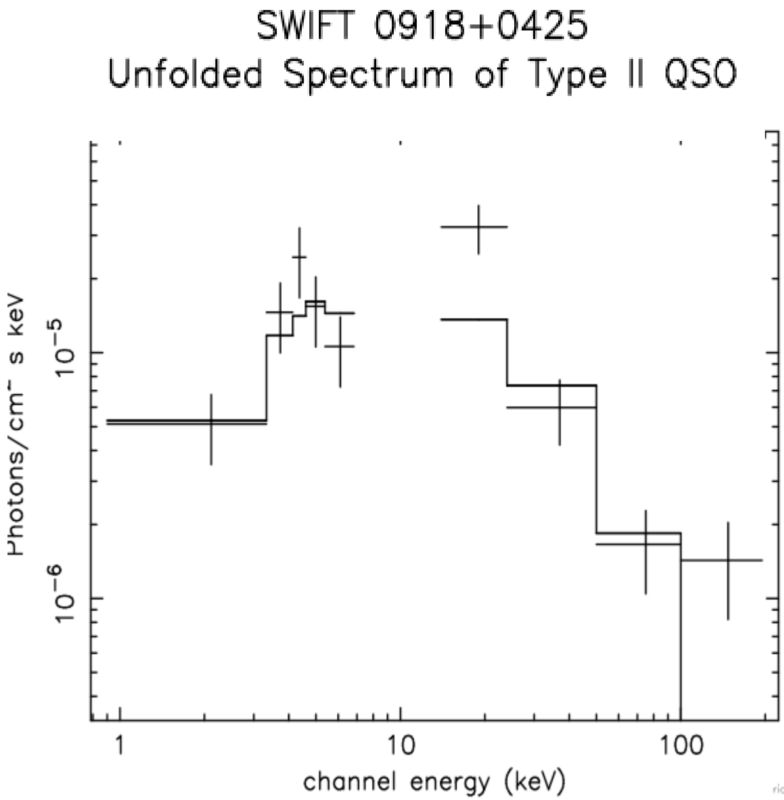
Many objects with the **photon** spectrum peaking at 20 kev- Combination of XMM and BAT Winter et al in prep

- high luminosity objects like these are rare in the local universe



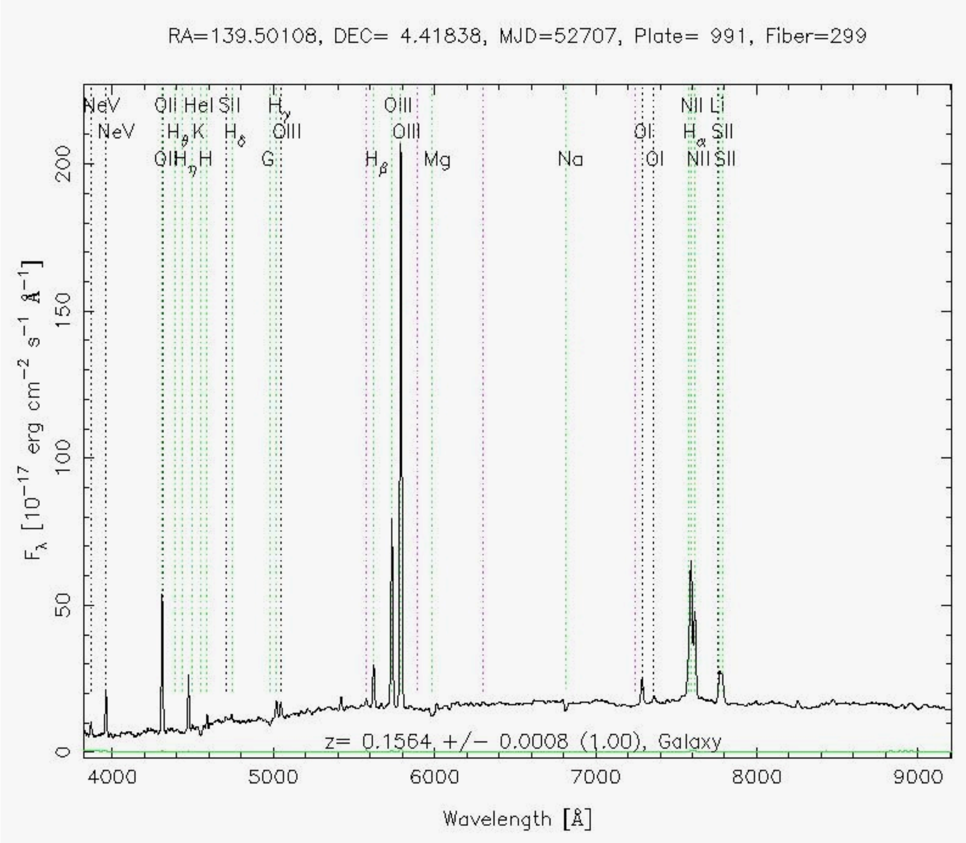


'Discovery' of a type II QSO



Notice in the x-ray spectrum that the PHOTON spectrum peaks at ~10-20 kev

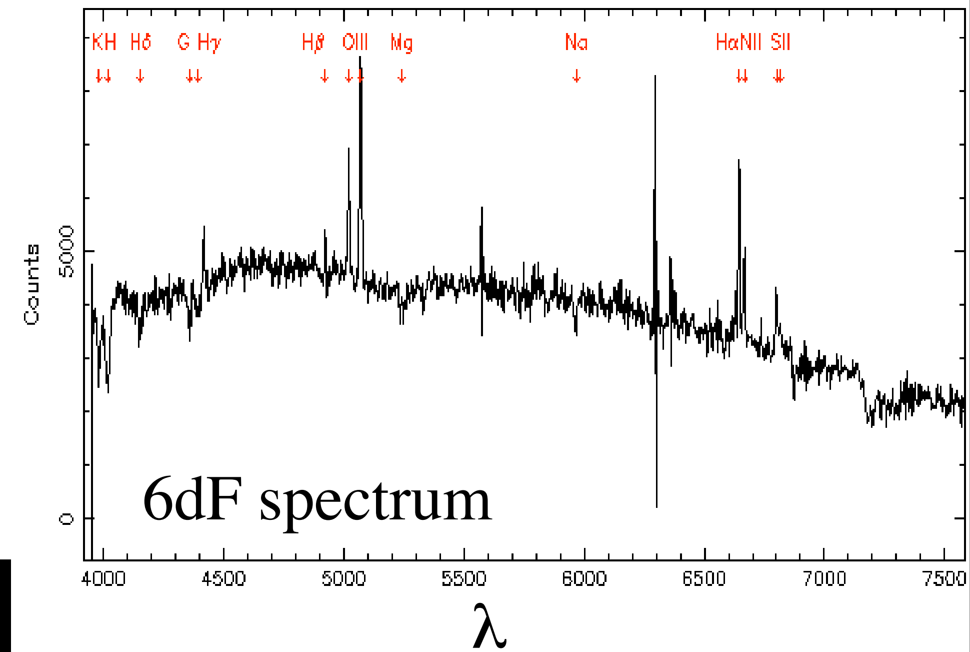
SDSS spectrum

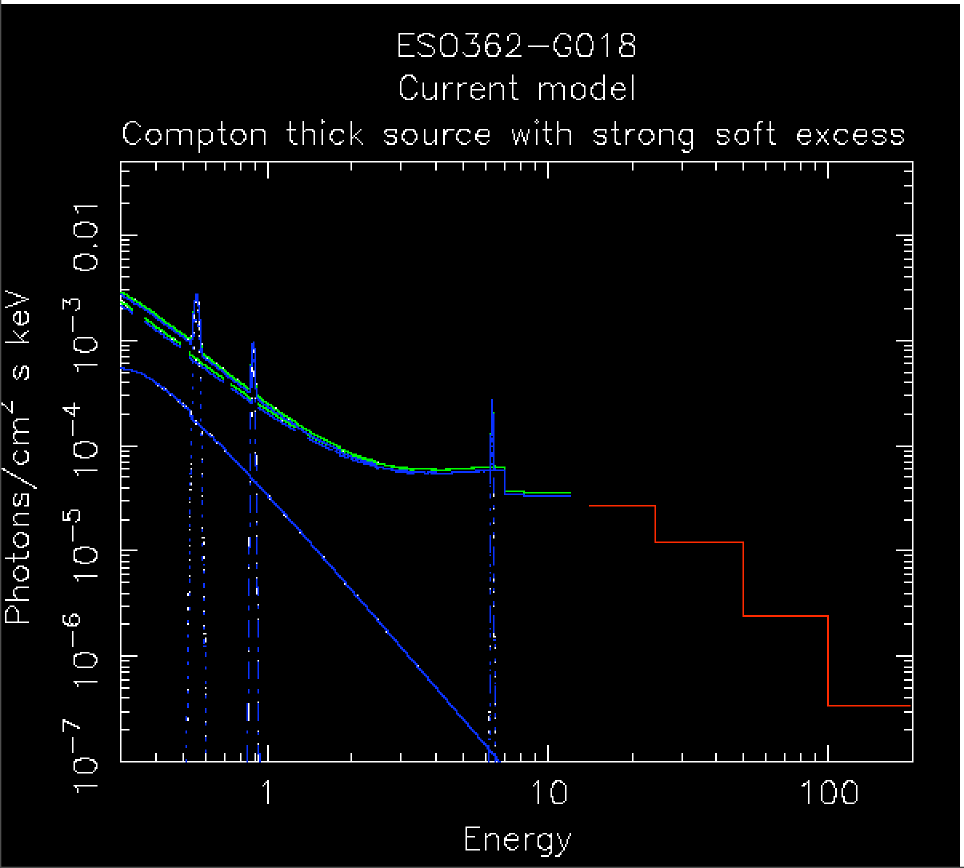


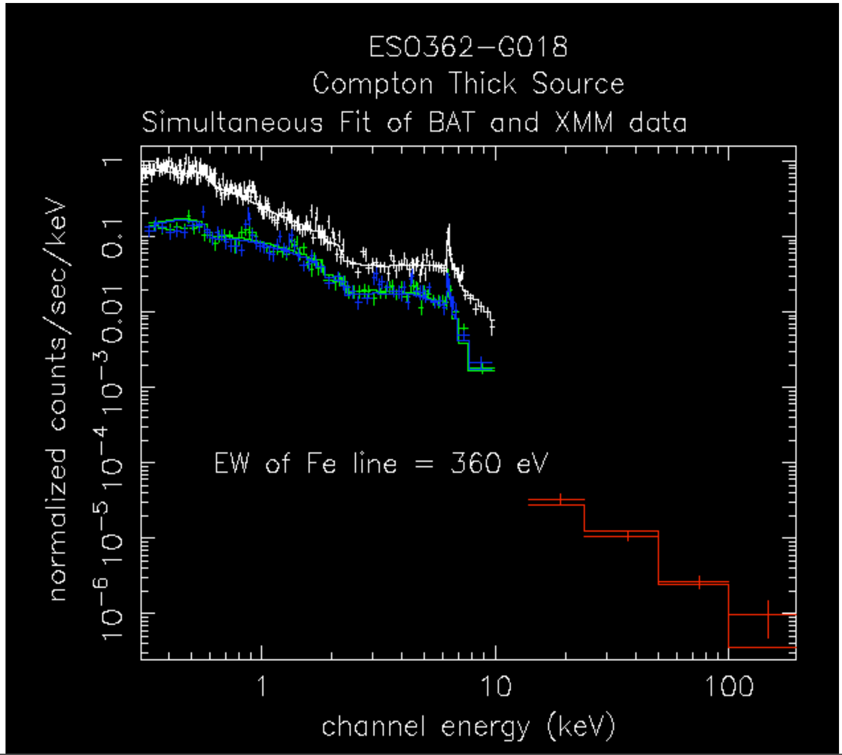
Wide Variety of Interesting

- ESO 362-G018: a Compton thick source with only a 360 eV EW Fe K line and a strong soft excess (like NGC1068??)

evidence of variability- so far; will be able to constrain timescales

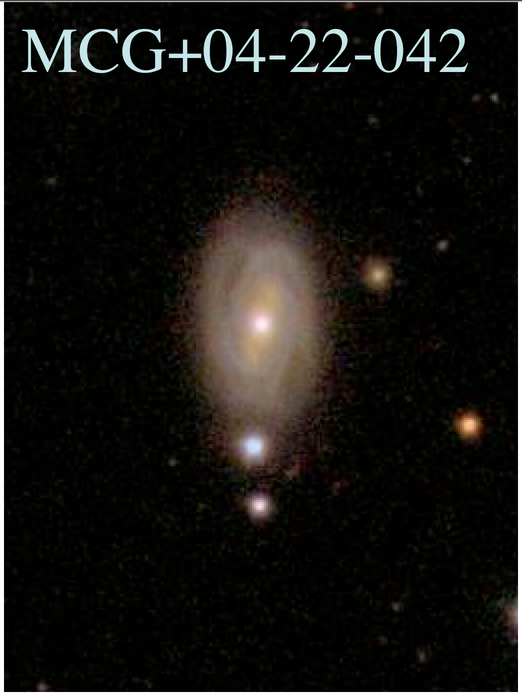


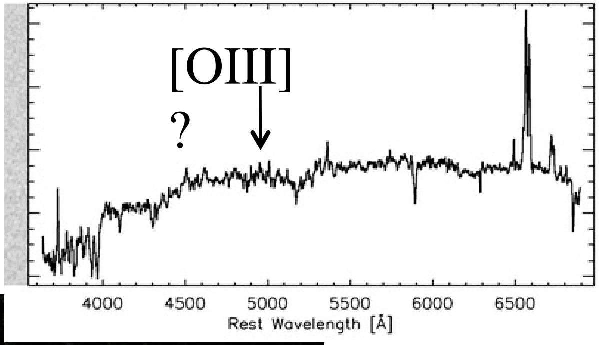


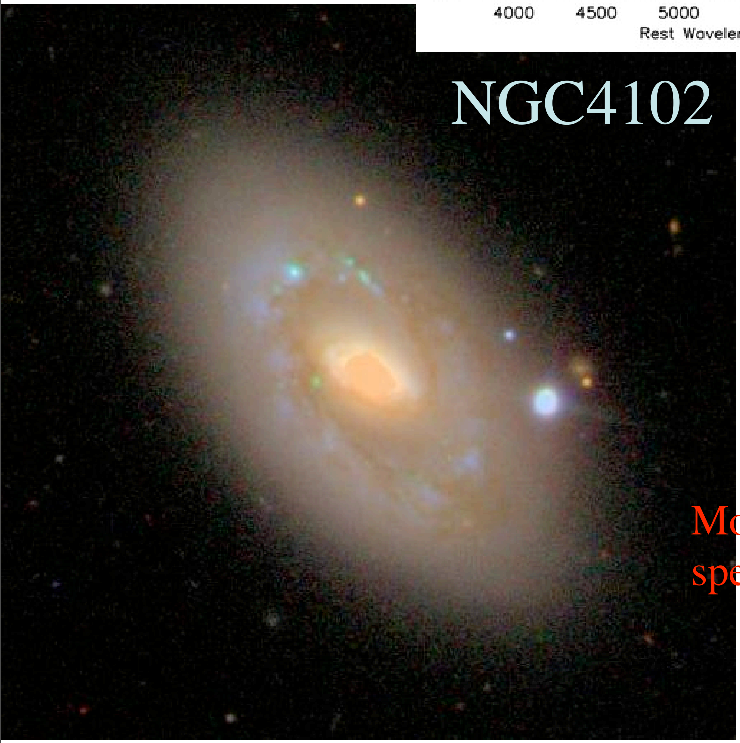


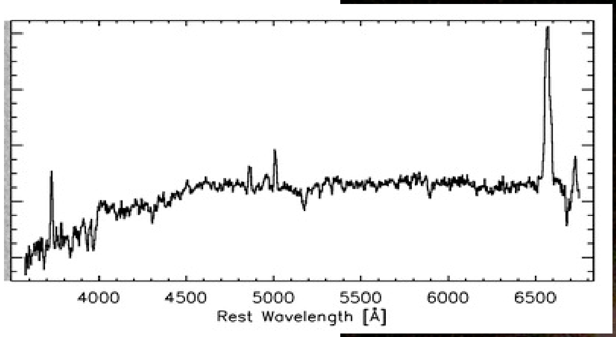
Objects in the SDSS

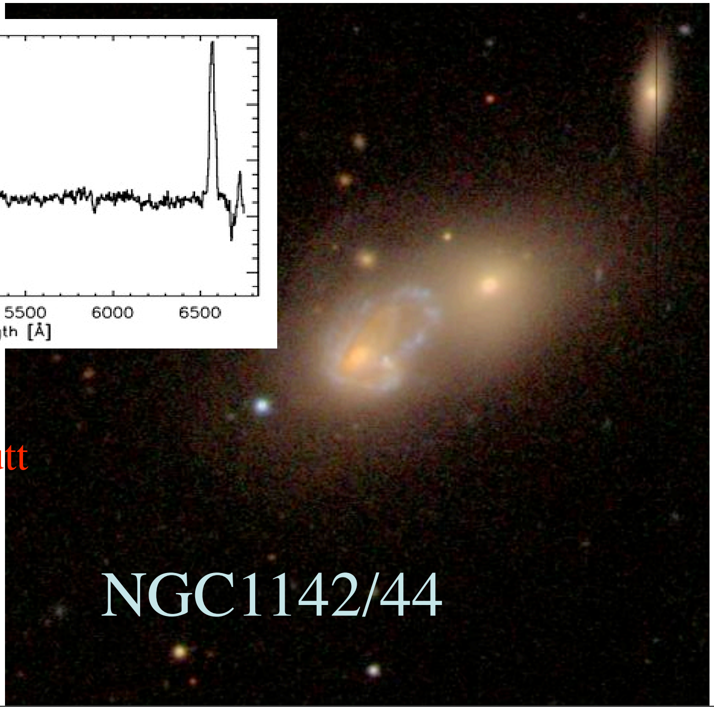
- ~1/2 of the new BAT sources in the SDSS do not have spectra
- However the images are often interesting







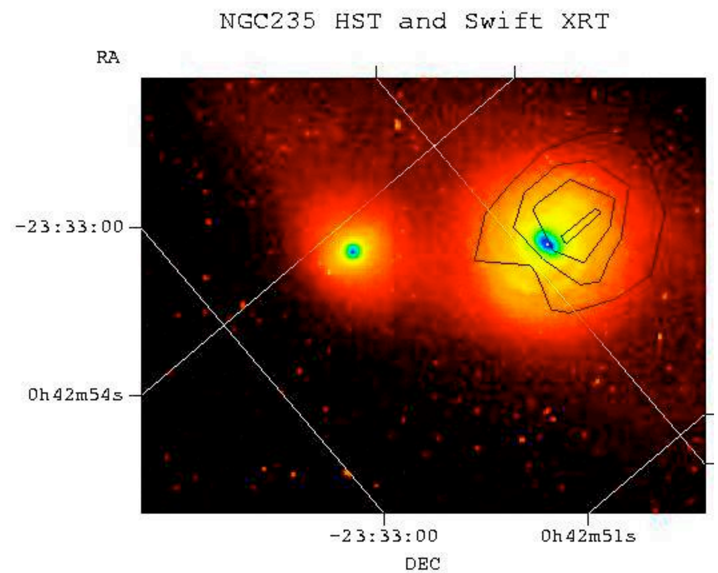


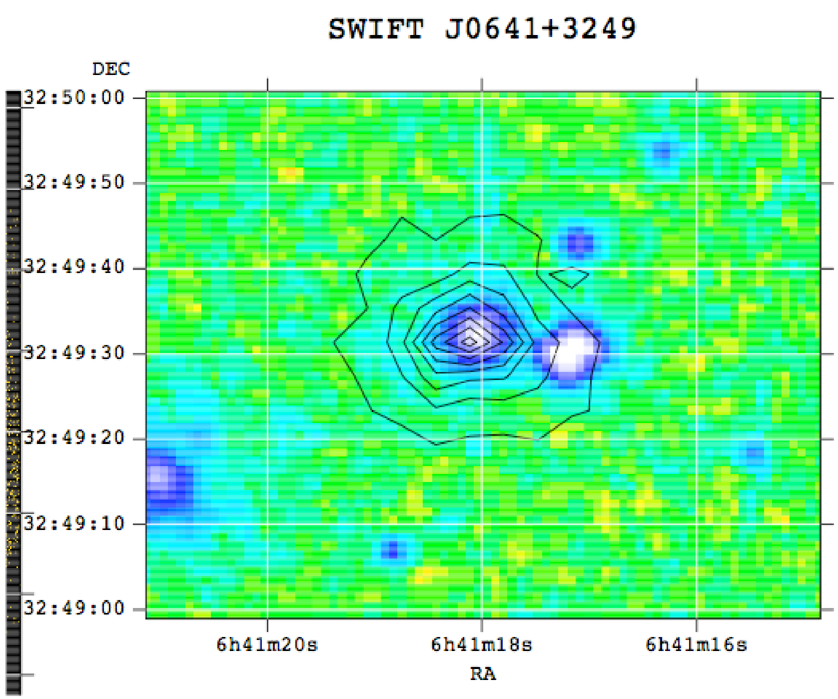


Moustakas and Kennicutt spectra

Mergers Interactions ??

Start to examine the environment of the Swift sources- are they more likely to be in close pairs, mergers, etc ?

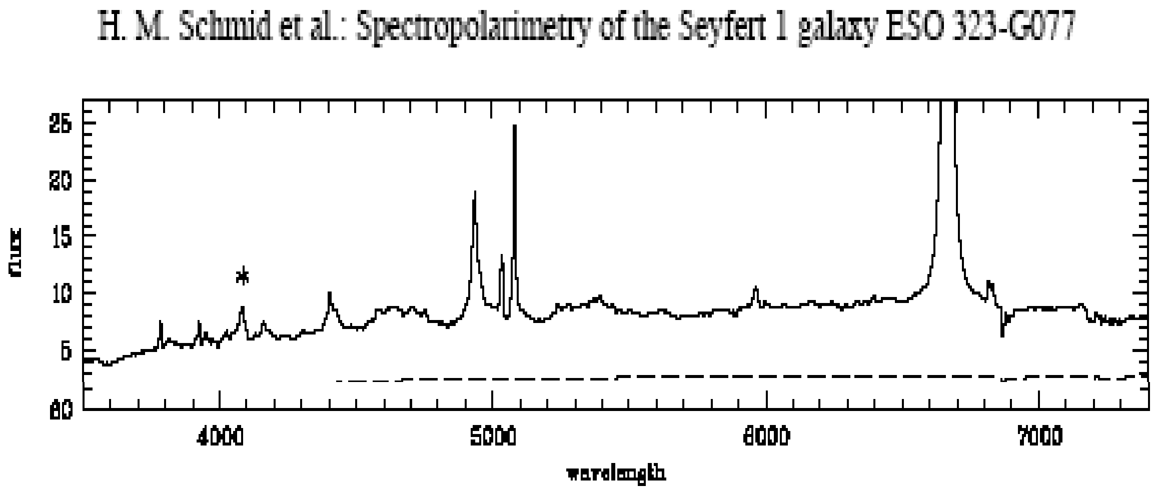


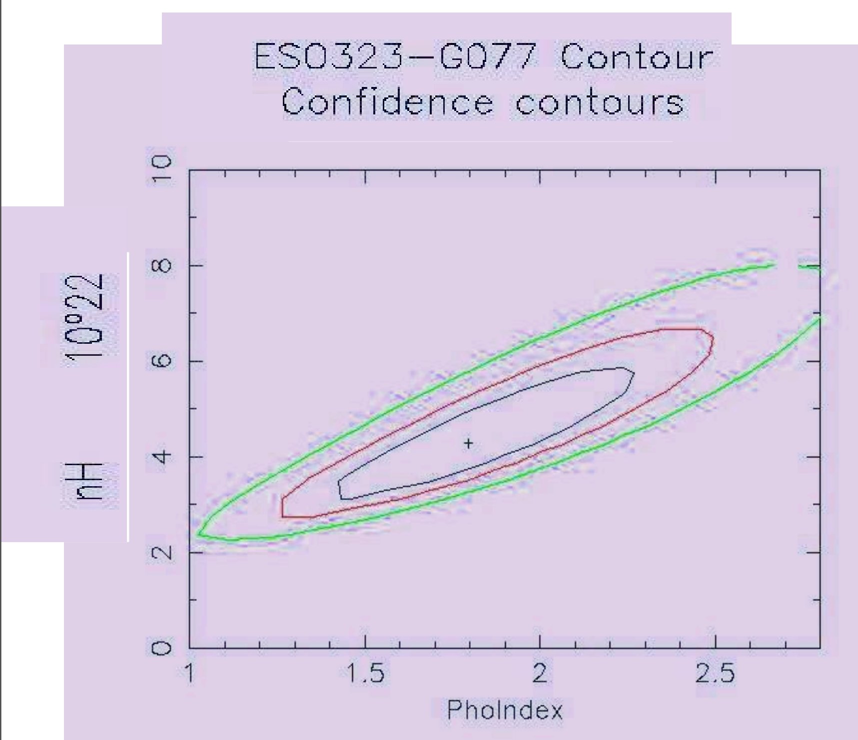


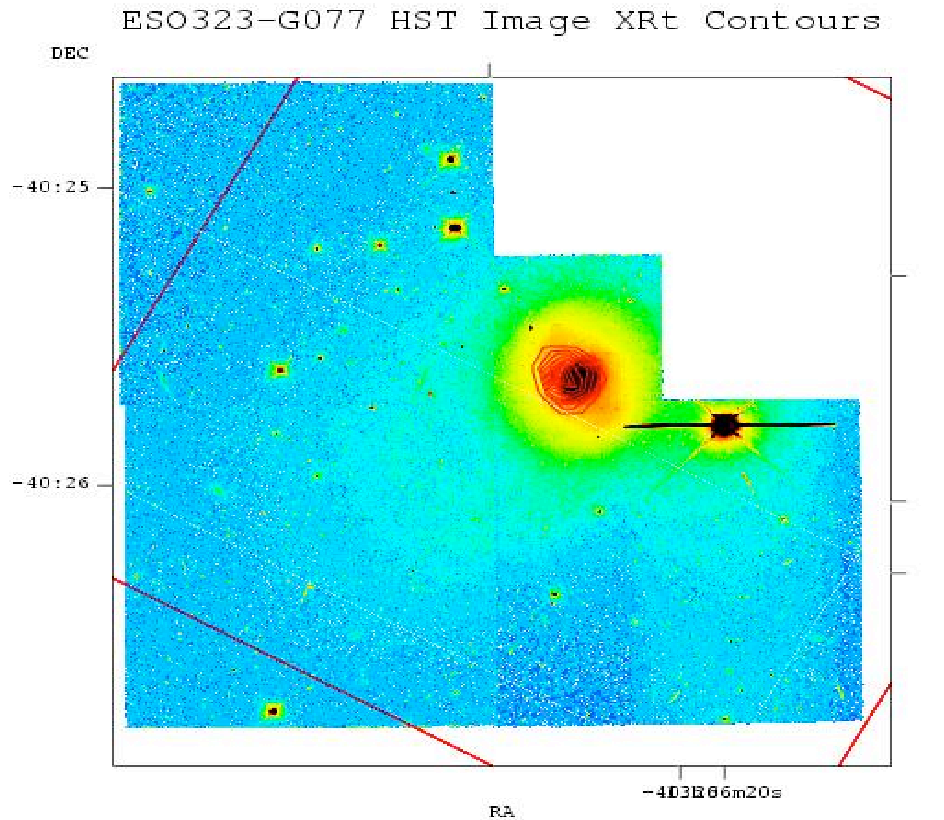
Have not yet done a statistical Comparison of Swift sources with field data

A Seyfert I with High Absorption

- ESO 323-G077 shows classical Seyfert I spectrum
  - (but shows optical polarization (Schmid et al 1999) and an [OIII] ionization cone (Mulchaey et al 1996)
- XRT spectrum gives N(H) ~4x10 ^{22}





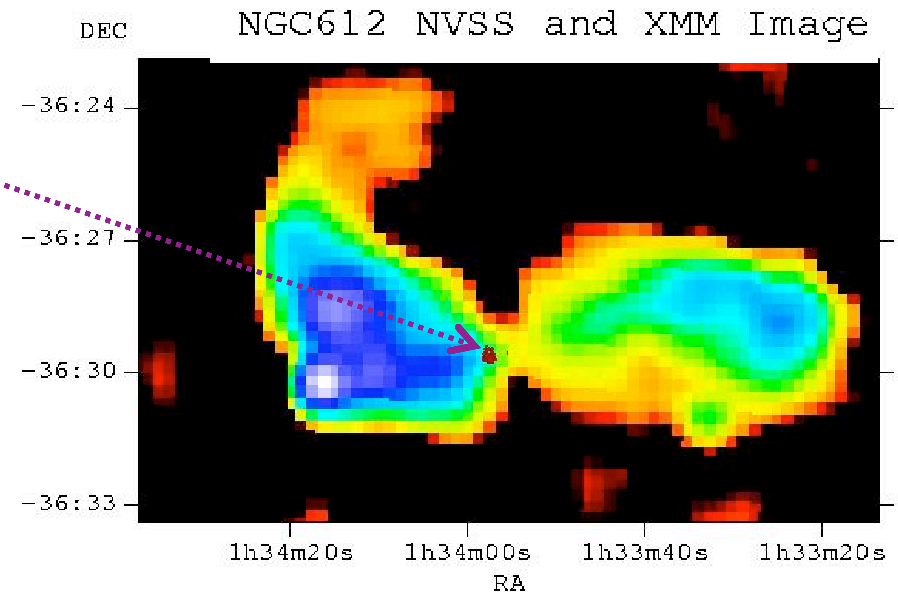


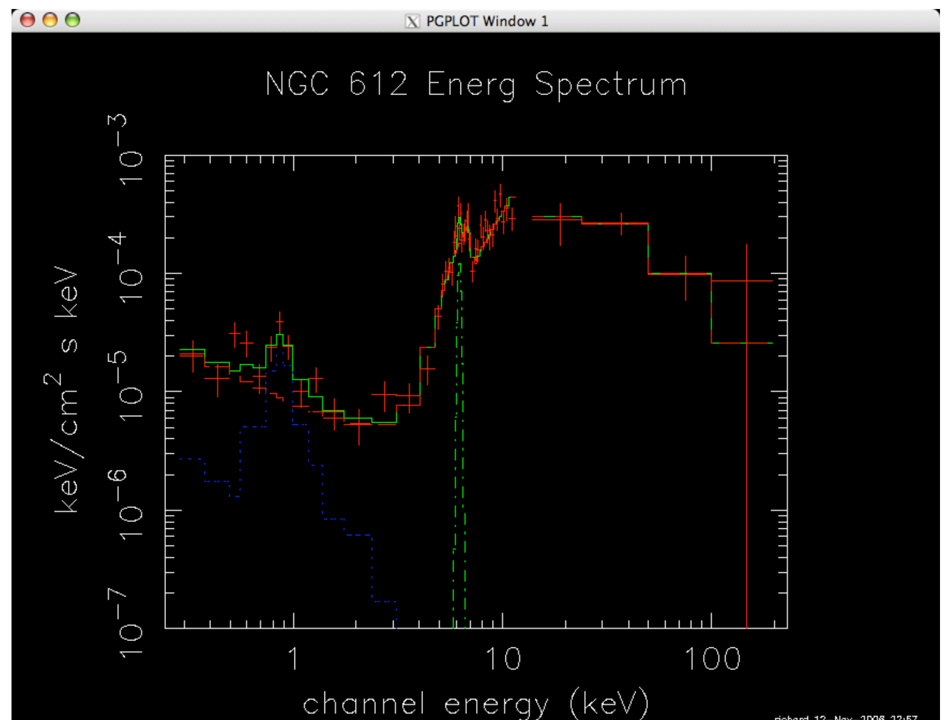
NGC612- A Giant Radio Source

- BAT source is a heavily absorbed AGN and is well fit by a 'pure' reflection spectrum with a line of sight column density of $5x10^{23}$ atms/ cm^2
- BUT the Fe EW is only 115eV.
- Is this a Compton thick object or not??
- The fit is not unique and the spectrum can also be well modeled with a purely absorbed source with N(H)~ $8x10^{23}$ atms/cm^2
- Even with the BAT and XMM data the fits are degenerate

The 10-100 kev flux is $2.5x10^{-11}$
While The 2-10 kev flux is $1.5x10^{-12}$
And the .5-2 kev flux is *$2.9x10^{-14}$*

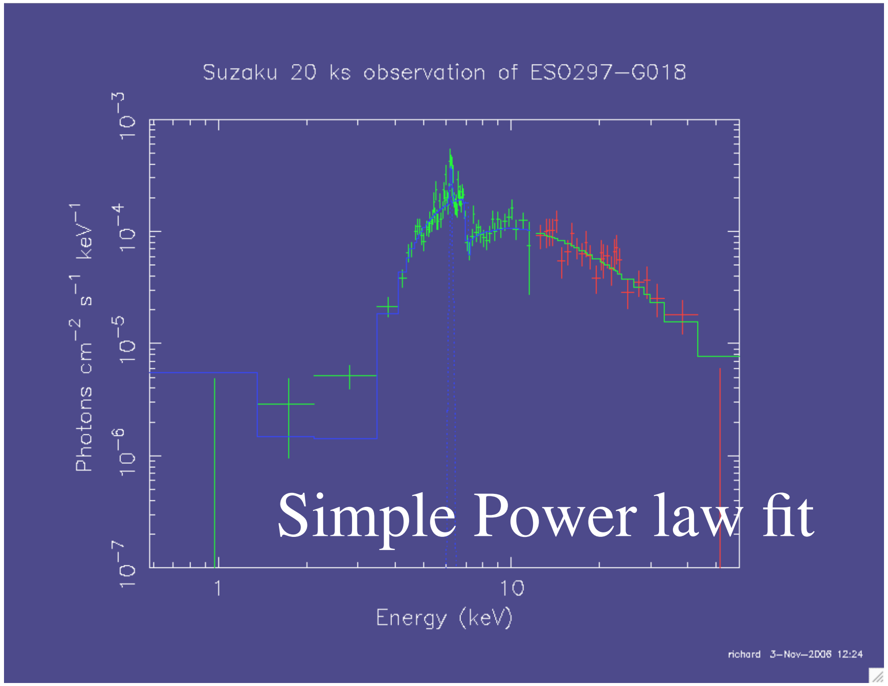
This is Rosat deep survey source !

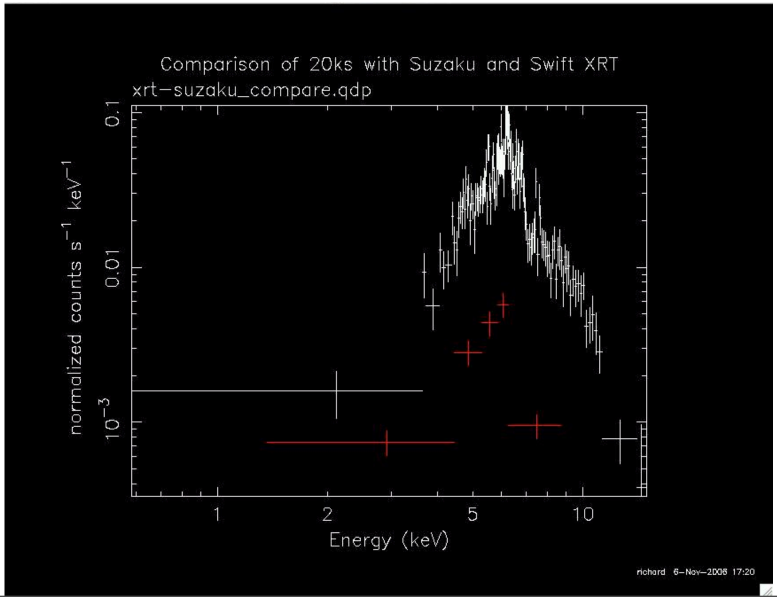


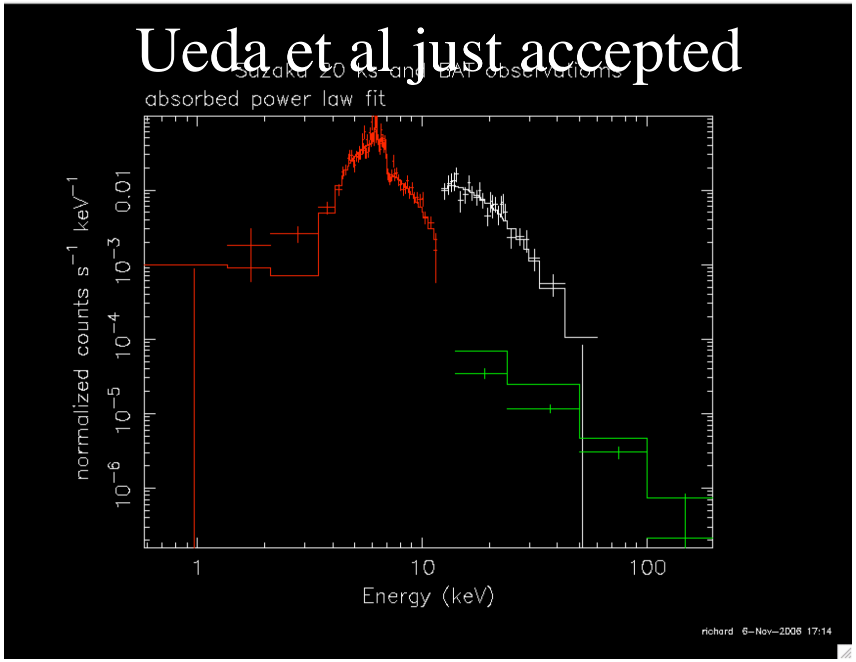


Suzaku Observations

- Suzaku follow-up of BAT selected objects- for many objects the BAT&XRT spectra are not sufficient for unique modeling.
- Suzaku can provide simultaneous x-ray and hard x-ray measurements for better limits on transmitted components in Compton thick sources.
- Direct comparison with BAT data shows source is variable.



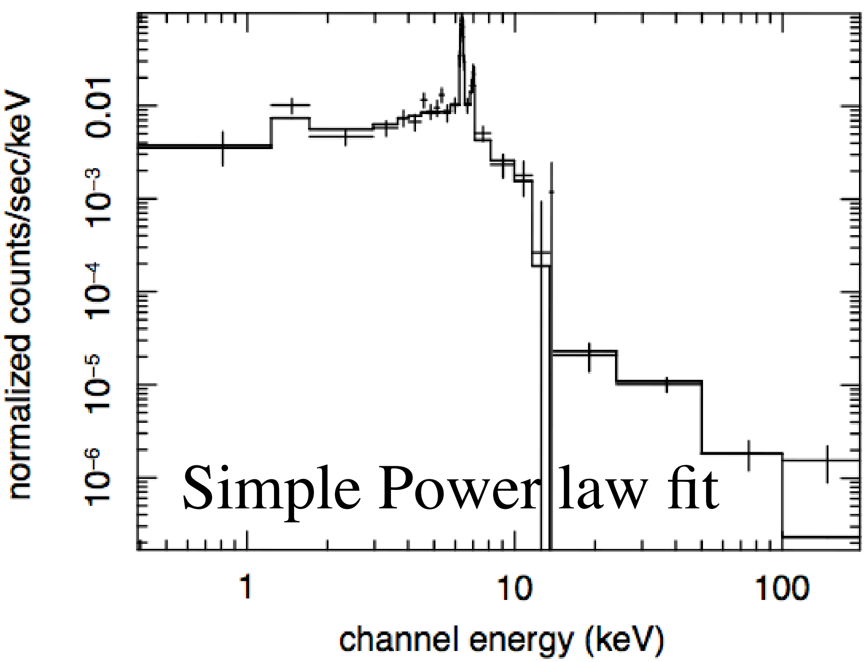


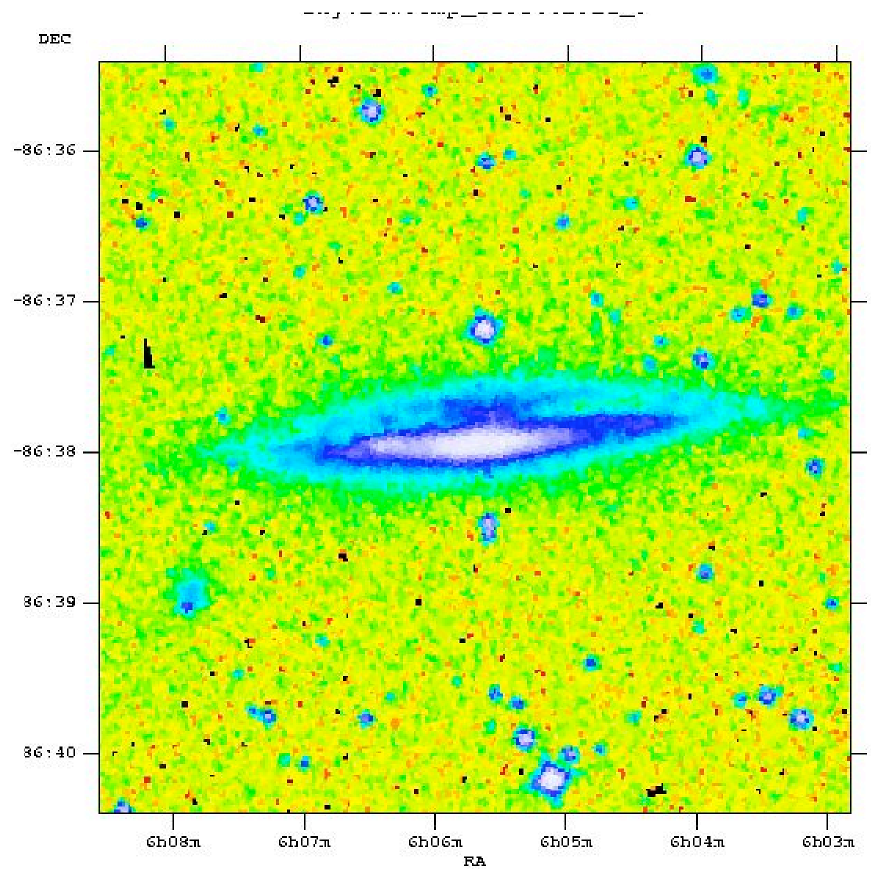


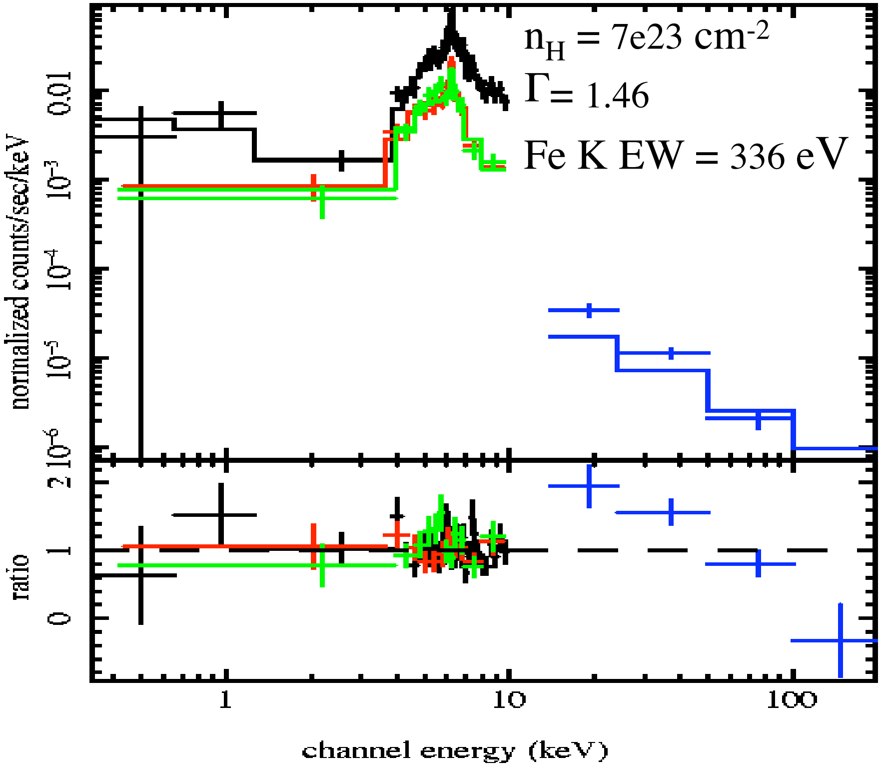
Suzaku Observations

- SWIFT J0601.9-8636- alias ESO 005-G 004
- Has a very strong Fe K a and b lines and almost no continuum at E< 6 keV
- many new BAT sources are edge on making optical ID difficult

SWIFT 0601 – Suzaku + BAT Spectrum
Fe EW 1.58,262 eV Compton thick

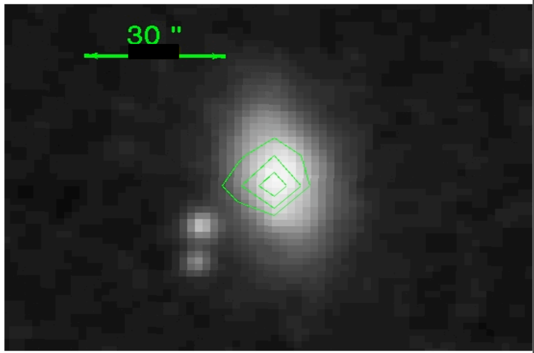


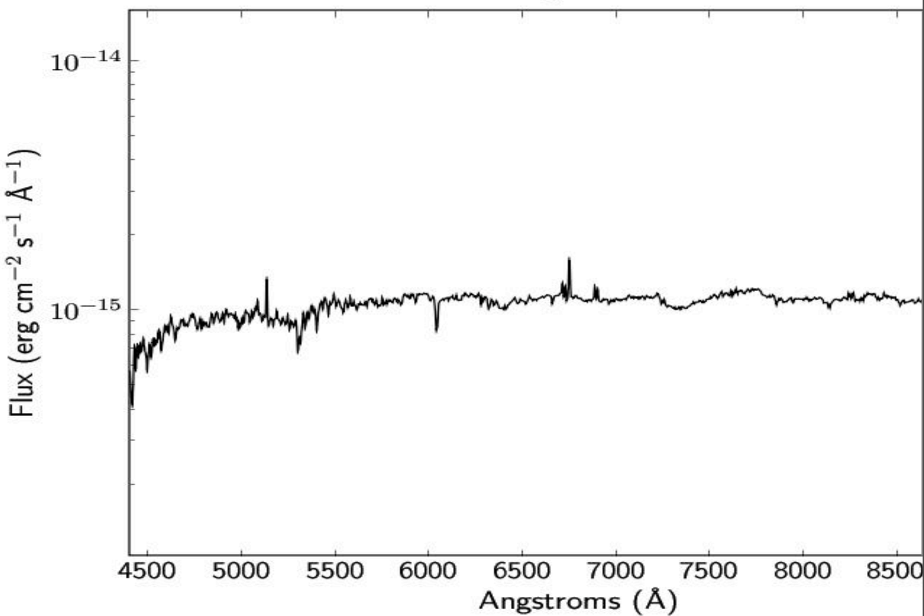




Combined spectrum and fit for the XMM-Newton and BAT X-ray spectra. Shown is a partial covering absorption model*power law along with a Gaussian fit to the Fe K-α line.

(Right) Optical image NGC 4992 with a contour of the XMM X-ray source in green.

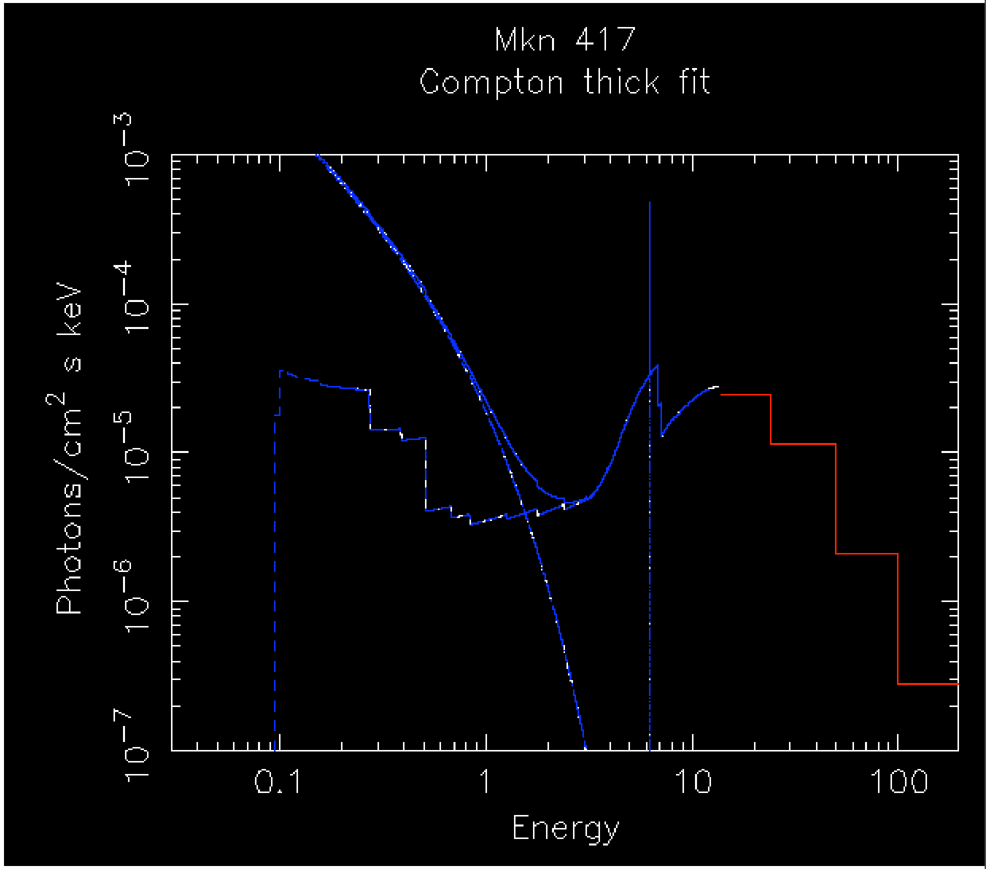


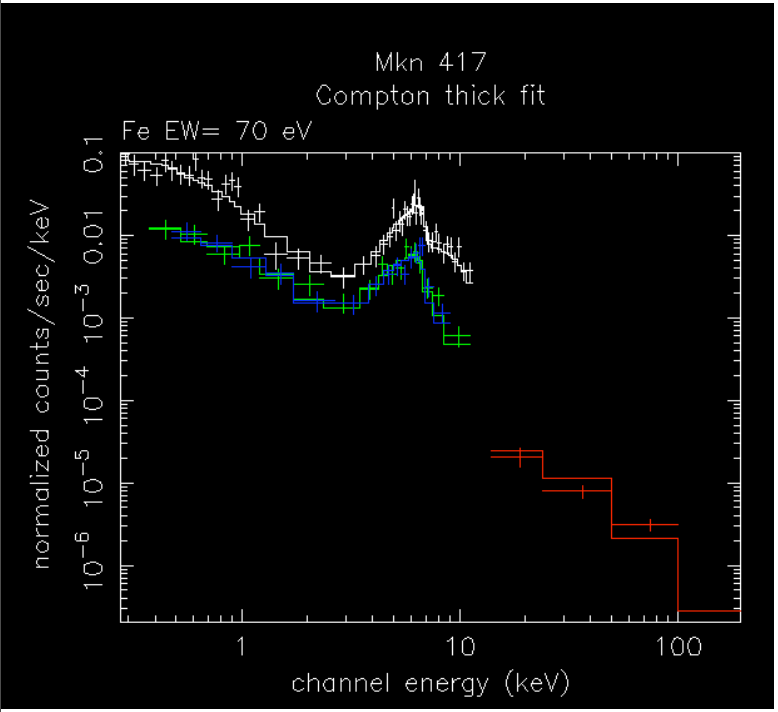


NGC 4992: the SDSS optical spectrum of this BAT AGN source is that of an optically normal galaxy. However, the XMM data shows a heavily absorbed AGN with an Fe K-α emission line. This source (also detected by INTEGRAL, see Massetti et al. 06) shows a potentially interesting class of AGN that would clearly be missed by optical surveys.

To ID Compton Thick Sources requires Good Signal to

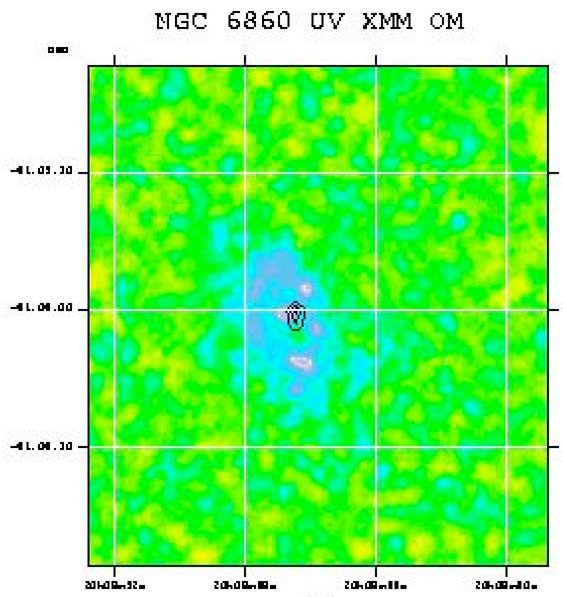
- Some of the apparently Compton thick sources in the BAT sample have Fe EW <500 eV
- For example Mkn 417 has Fe EW ~70 eV
- It is not yet clear what this means

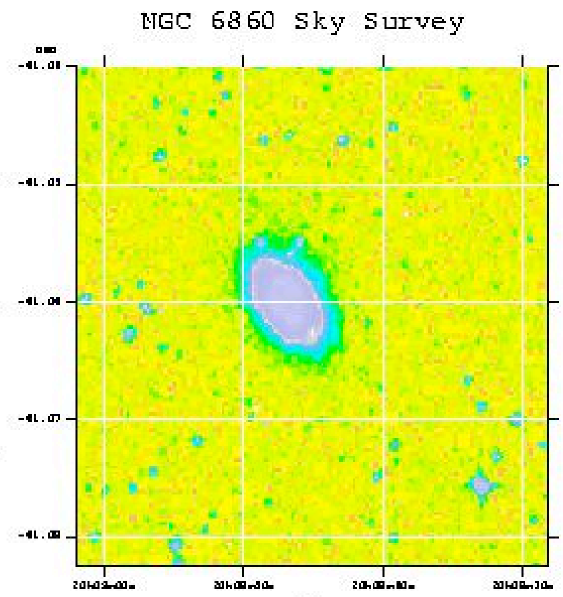




Why do We Need XMM Follow-Ups

- All other AGN surveys are biased (!) only by following up the BAT and Integral sources can one obtain the true distribution of x-ray spectral properties necessary for 'solving' all the AGN science problems
- Only XMM and Suzaku have sufficient collecting area to obtain good quality spectra in short (<40ks) exposures (with loss of XIS 2 XMM has ~30% more collecting area than Suzaku)
- Only XMM can do 'lots' of ~10ks exposures which are sufficient for these 'bright' sources to characterize the .3-10 keV spectrum
- Only XMM has simultaneous optical/UV data necessary for the SED and estimate of star formation rate .

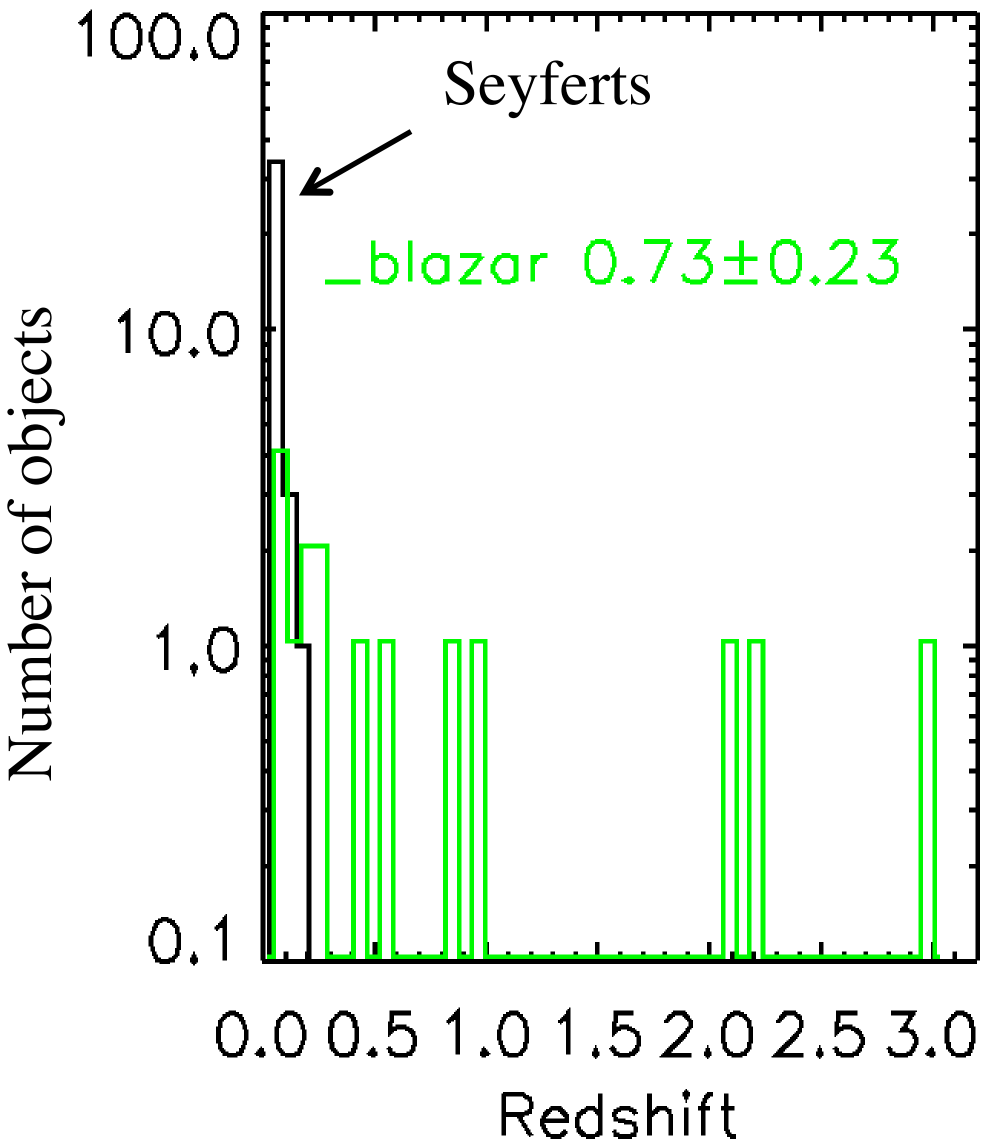




Redshift of BAT Blazars

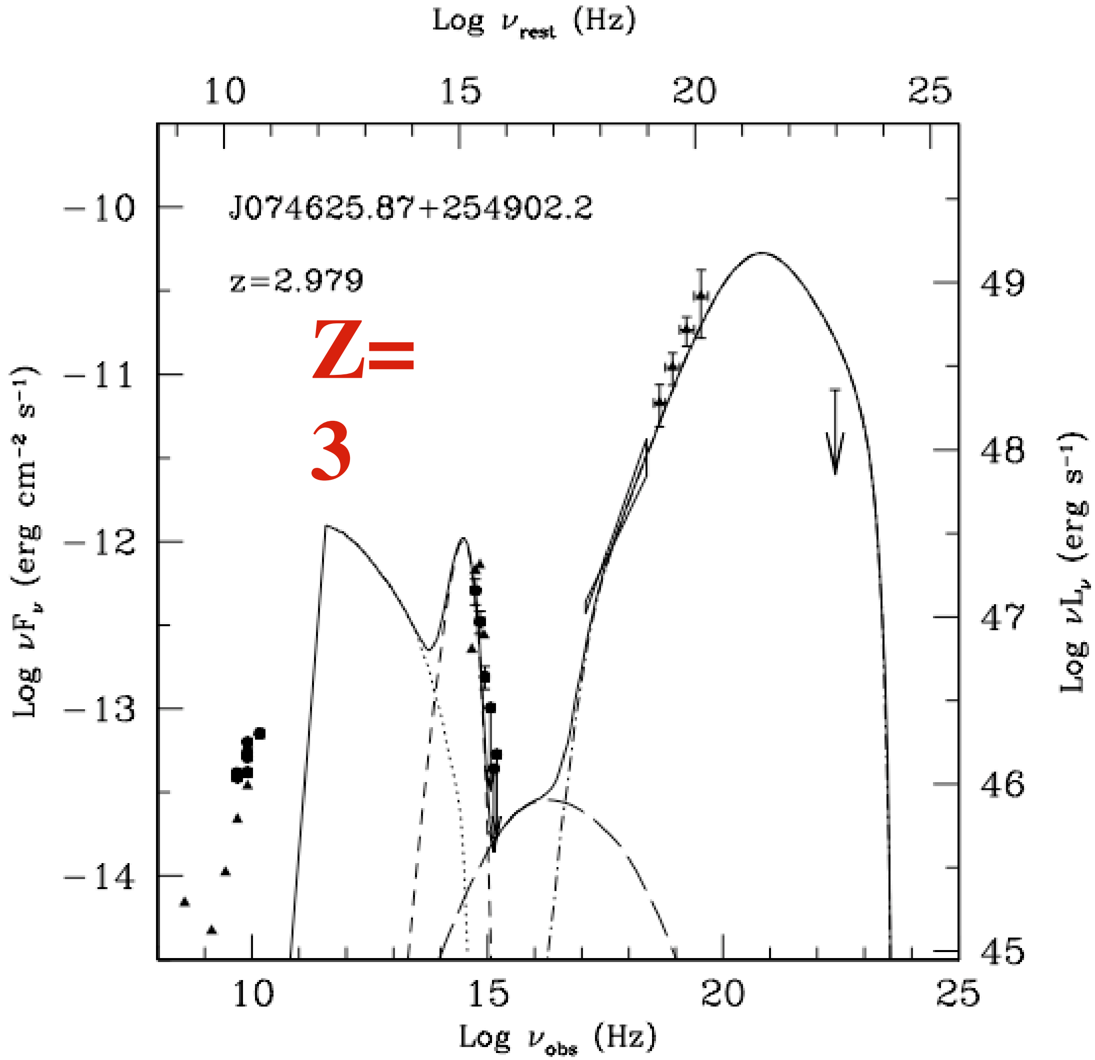
- 17 BL Lac, QSO, and blazars (all-sky)
- Blazar redshift distribution very different from Seyfert population
- 6 high redshift blazars detected (z >2), 4 not previously identified
- Tend to be optically dim (m~19th mag)

- **$z_{Seyfert}$ ~0.03**



Why Does BAT See So Many High Z Blazars?

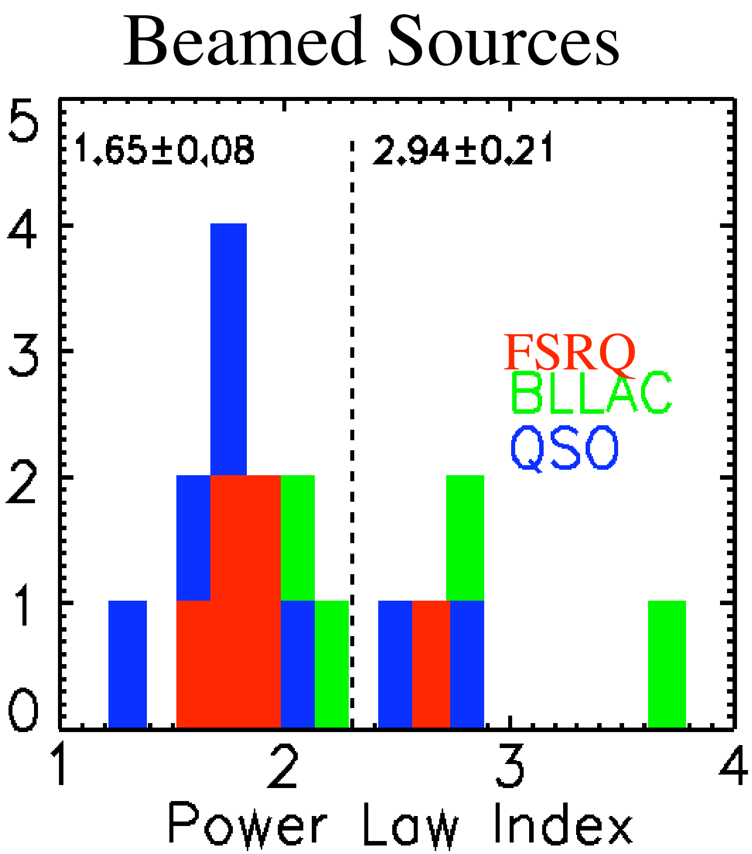
- for EGRET blazars the BAT band is between the two peaks in the SED
- at high Z the gamma peak is shifted into the BAT band
- As the Z increases, the BAT luminosity increases compensating for the greater distance
- BAT detects EGRET blazars at Z > 2

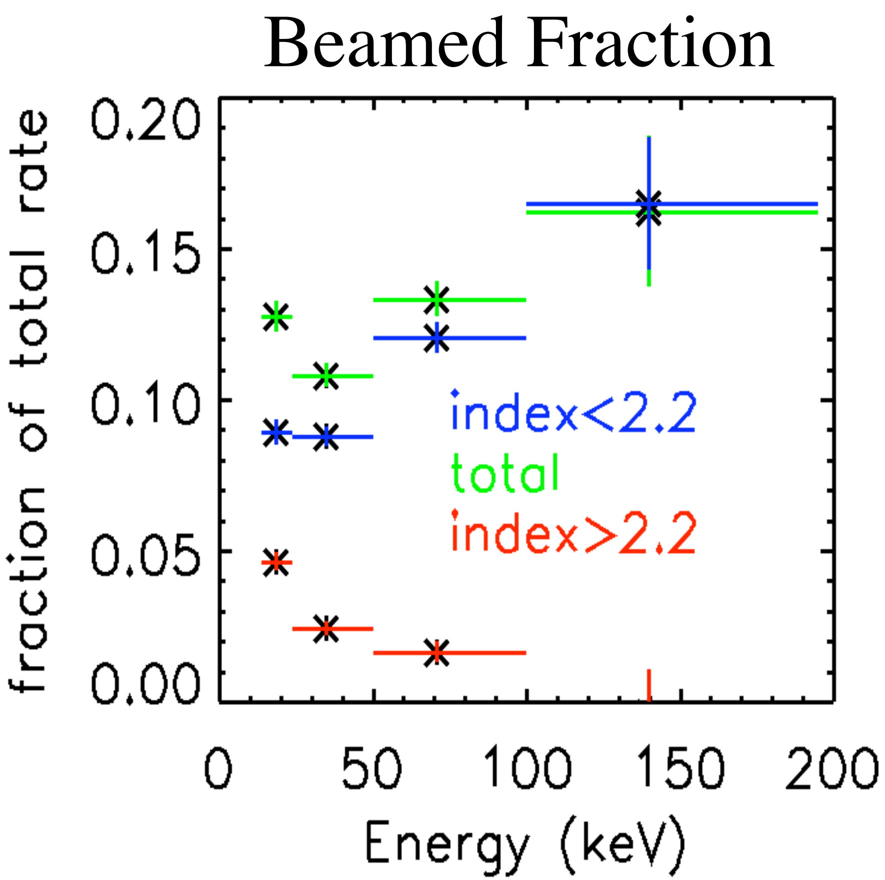


SWIFT J0746.3+2548
Rita Sambruna (submitted)

What is the Blazar Contribution to the CXB?

- BAT beamed sum spectrum is 10-16% AGN sum- Blazars are an important contribution to the hard x-ray sky
- In 3 years, BAT will detect >40 beamed sources.





- BAT survey is determining the first Blazar distribution in the hard band

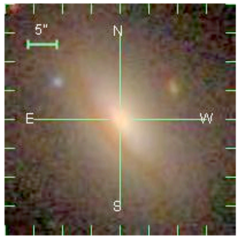
Objects in the SDSS

- ~1/2 of the new BAT sources in the SDSS do not have spectra !
- When spectra are available they are often rather interesting

SDSS J120057.93+064823.1

GALAXY ra=180.241393, dec=6.806423, ObjId = 588017724398436382

mode	PRIMARY
status	TARGET PRIMARY OK_STRIPE OK_SCANLINE PSEGMENT RESOLVED OK_RUN GOOD SET
flags	STATIONARY BAD_MOVING_FIT MOVED BINNED1 INTERP COSMIC_RAY CHILD
PrimTarget	TARGET_GALAXY TARGET_GALAXY_RED
SecTarget	



run	rerun	camcol	field	obj	rowc	colc
3841	41	2	103	30	482.4	1641.8

u	g	r	i	z
16.42	14.85	14.05	13.60	13.24

fiberMag_r	petroMag_r	devMag_r	expMag_r	psfMag_r	modelMag_r
16.43	14.17	14.05	14.40	16.81	14.05

extinction_r	petroRad_r	parentId	nChild
0.05	13.664	588017724398436381	0

No scienceprimary SpecObj linked to this PhotoObj
(Click on "All Spectra" link if you think this object has a spectrum)

Cross-identifications

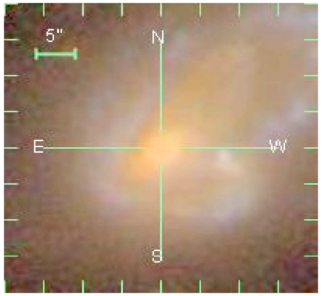
catalog	delta	propermotion	angle	blue	red
USNO	0.051	0.614	277.766	10.93	9.89

catalog	delta	peak	major	minor	pa
First	0.344	3.8	4.13	2.27	178.8

SDSS J025512.22-001100.8

GALAXY ra=43.800937, dec=-0.183556, ObjId = 587731512616747013

mode	PRIMARY
status	TARGET PRIMARY OK_STRIPE OK_SCANLINE PSEGMENT RESOLVED OK_RUN GOOD SET
flags	DEBLEND_DEGENERATE BAD_MOVING_FIT BINNED1 INTERP COSMIC_RAY CHILD
PrimTarget	TARGET_GALAXY TARGET_GALAXY_RED
SecTarget	



run	rerun	camcol	field	obj	rowc	colc
2738	40	3	211	5	280.5	311.8

u	g	r	i	z
16.16	14.35	13.39	12.91	12.46

fiberMag_r	petroMag_r	devMag_r	expMag_r	psfMag_r	modelMag_r
16.03	13.55	13.39	13.62	16.11	13.39

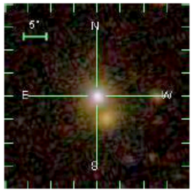
extinction_r	petroRad_r	parentId	nChild
0.20	14.180	587731512616747012	0

No scienceprimary SpecObj linked to this PhotoObj
(Click on "All Spectra" link if you think this object has a spectrum)

SDSS J141756.67+254326.2

GALAXY ra=214.486145, dec=25.72395, ObjId = 587739706335756332

mode	PRIMARY
status	TARGET PRIMARY OK_STRIPE OK_SCANLINE PSEGMENT RESOLVED OK_RUN GOOD SET
flags	STATIONARY MOVED BINNED1 INTERP CHILD
PrimTarget	TARGET_ROSAT_D TARGET_ROSAT_C TARGET_ROSAT_B TARGET_ROSAT_A TARGET_GALAXY TARGET_QSO_CAP
SecTarget	



run	rerun	camcol	field	obj	rowc	colc
4646	40	1	137	44	662.9	1167.8

u	g	r	i	z
17.78	17.36	16.80	16.47	16.24

fiberMag_r	petroMag_r	devMag_r	expMag_r	psfMag_r	modelMag_r
17.48	16.92	16.80	17.06	17.27	16.80

extinction_r	petroRad_r	parentId	nChild
0.05	1.874	587739706335756331	0

No scienceprimary SpecObj linked to this PhotoObj
(Click on "All Spectra" link if you think this object has a spectrum)

Cross-identifications

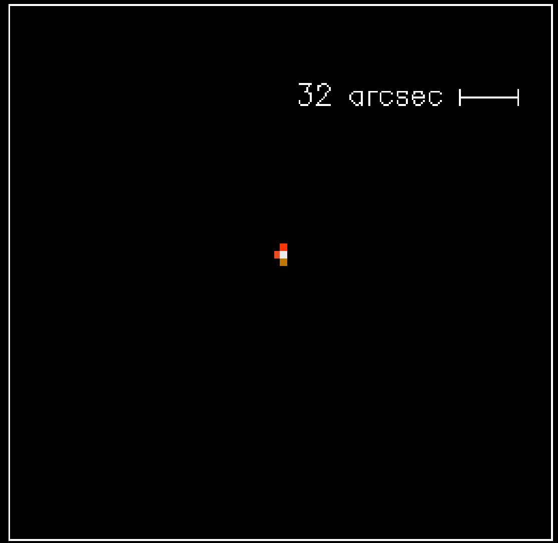
catalog	delta	propermotion	angle	blue	red
USNO	0.932	1.418	14.404	16.79	14.57

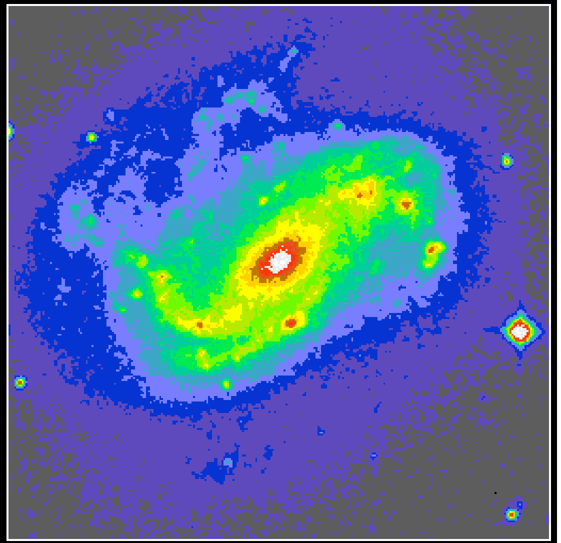
catalog	delta	peak	major	minor	pa
First	0.074	39.5	1.95	0.73	71.5

catalog	delta	cps	hard1	hard2	extent
Rosat	3.678	1.708	0.09	0.22	12

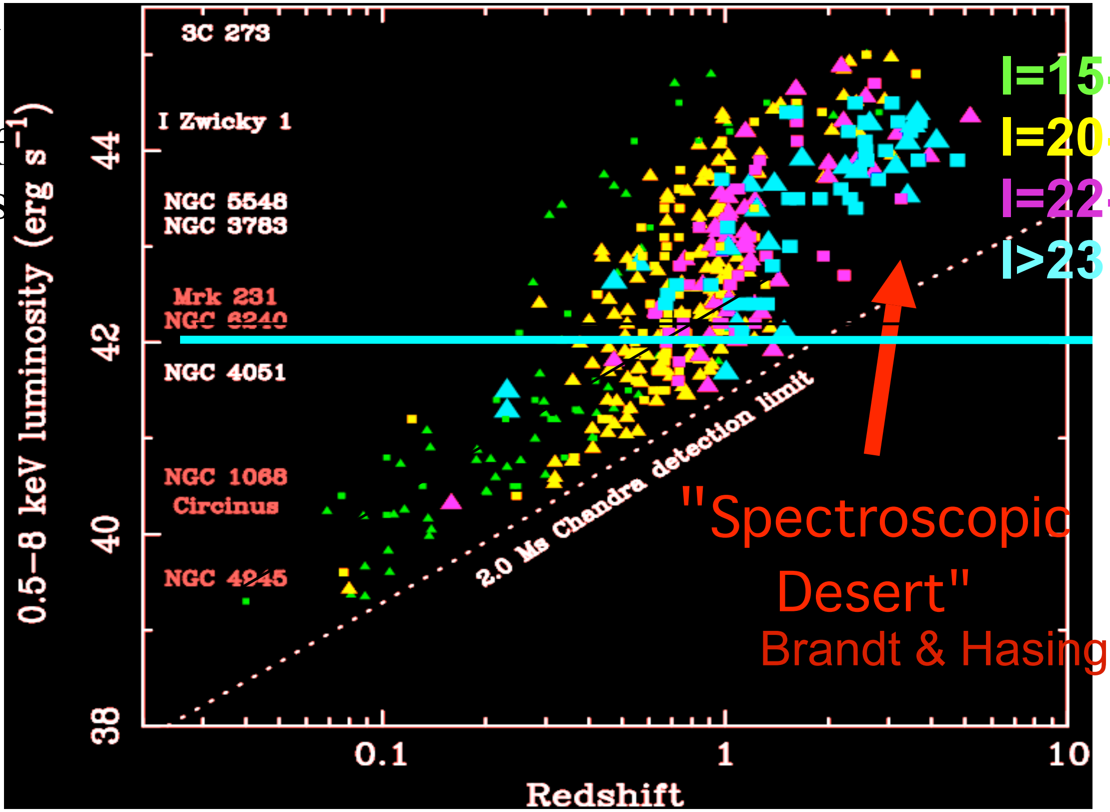
X-ray Selection of Active galaxies

- X-ray and optical image of a nearby AGN NGC4051-
- Note the very high contrast in the x-ray image





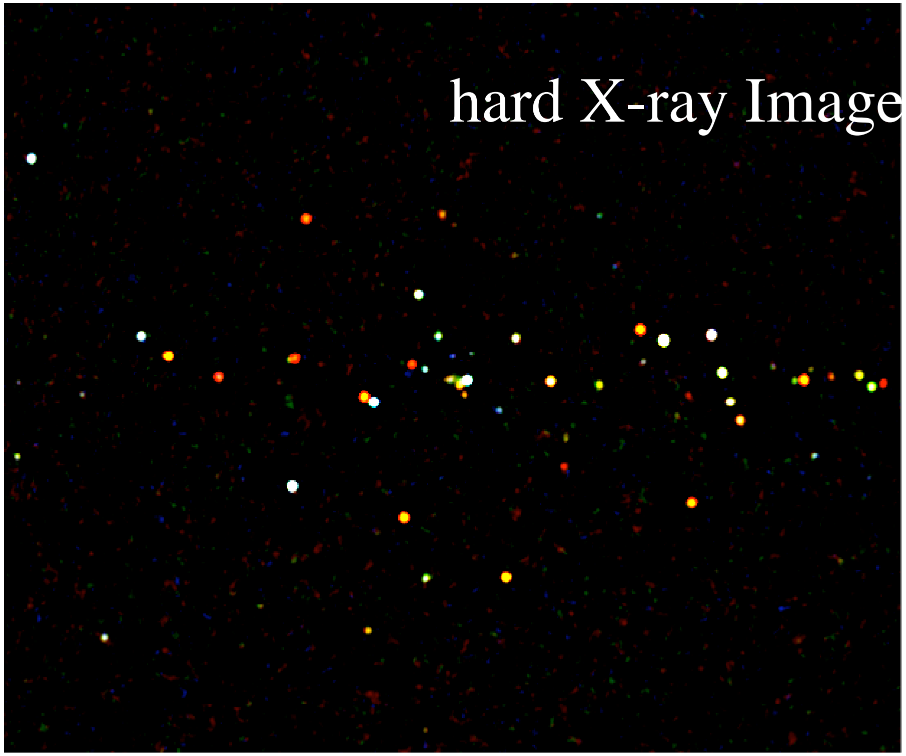
- the upper limit of x-ray luminosity of ULXs ~5x10^{41} ergs/sec and of entire starburst galaxies ~3x10^{42} ergs/sec
  - **All nuclear souces with L(x > 10^{42} are AGN**
- **Right now we know more about x-ray selected AGN at z~0.8 than at z~0**



Brandt & Hasinger. 2005

Why is the Swift/BAT census of Black Holes desirable ?

- Hard X-rays are a unique signature of accreting black holes



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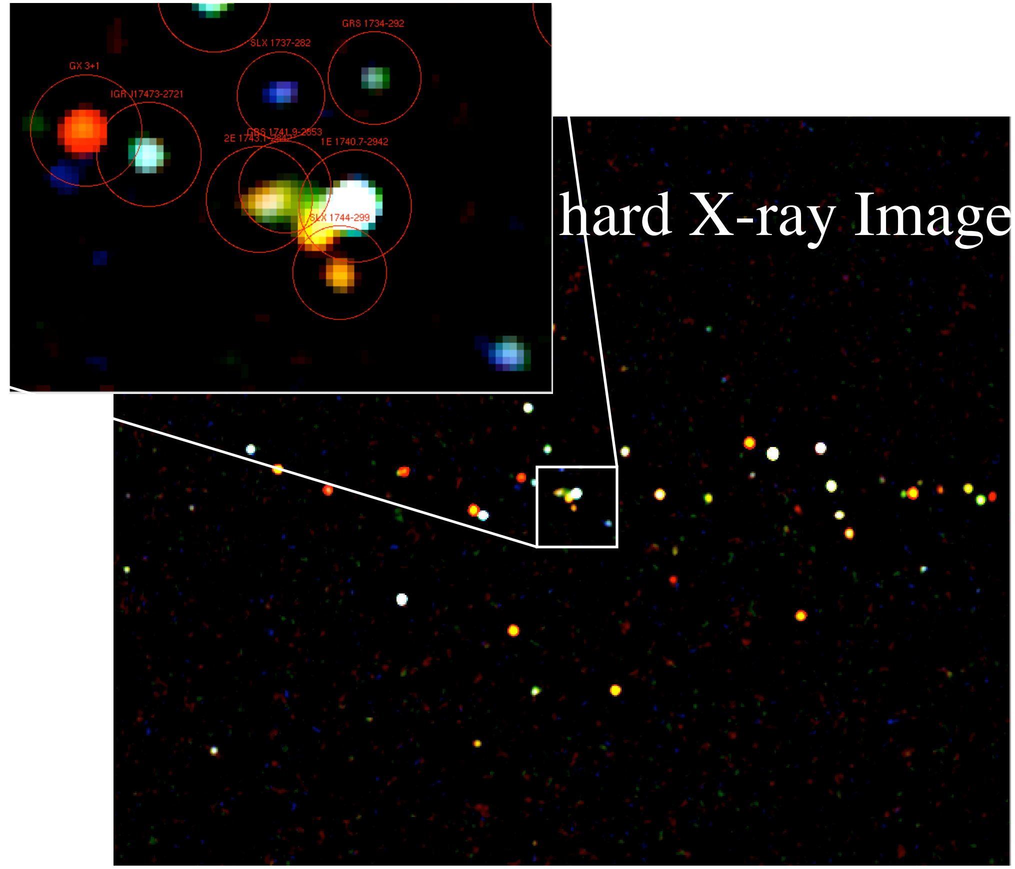

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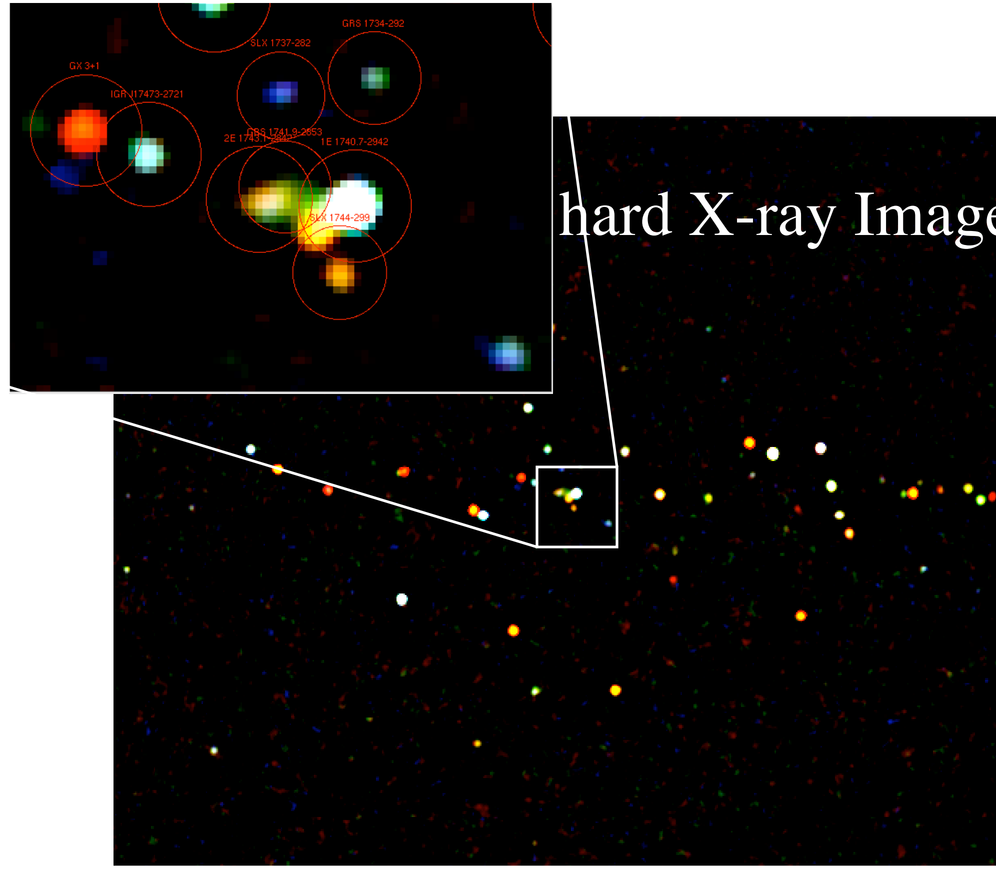

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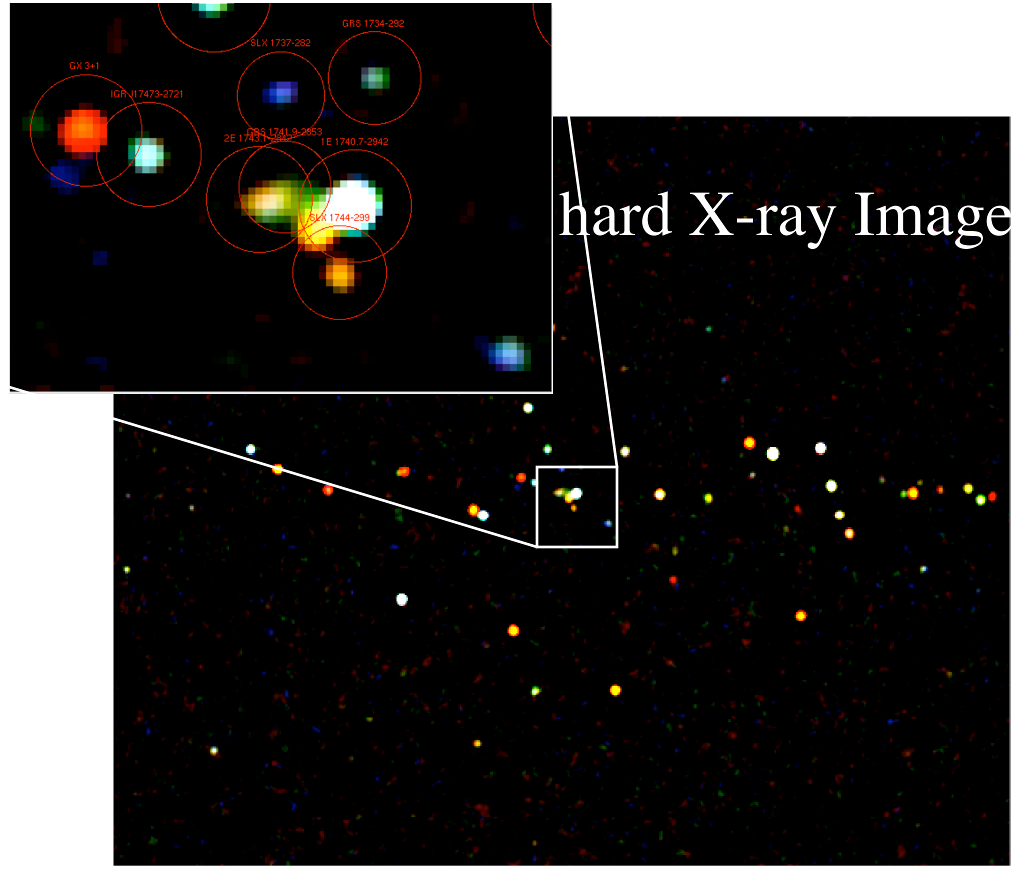

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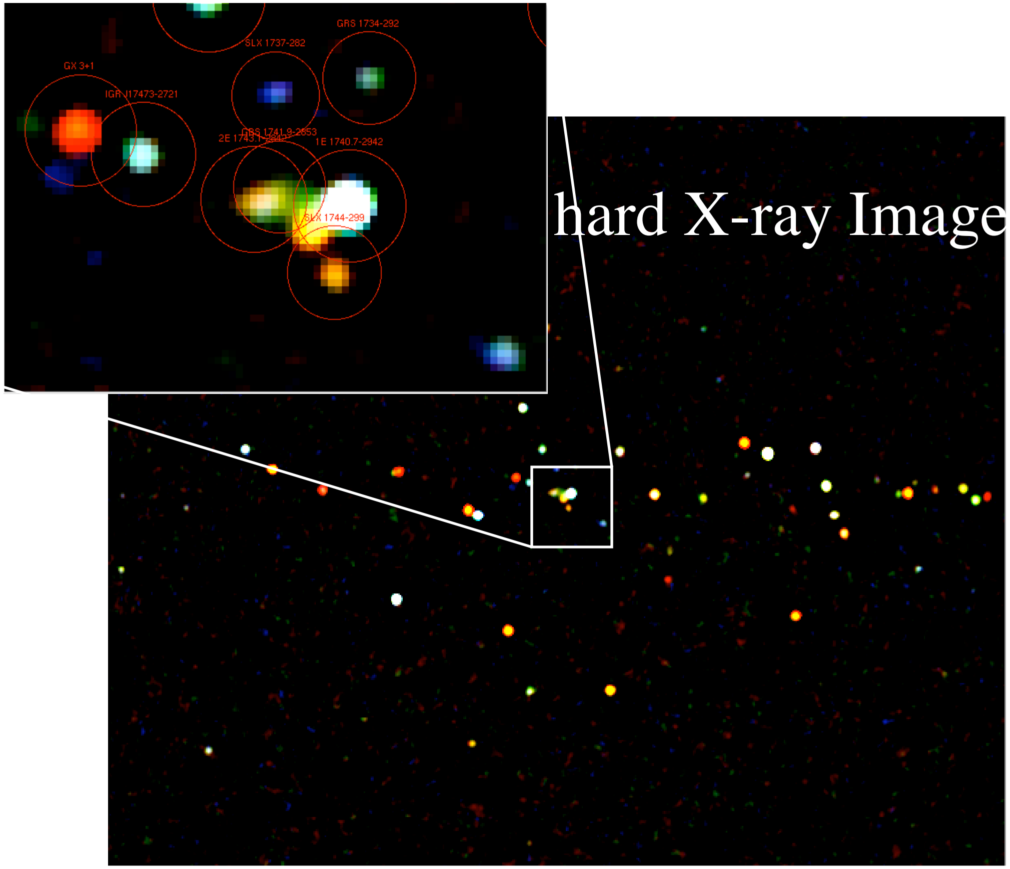

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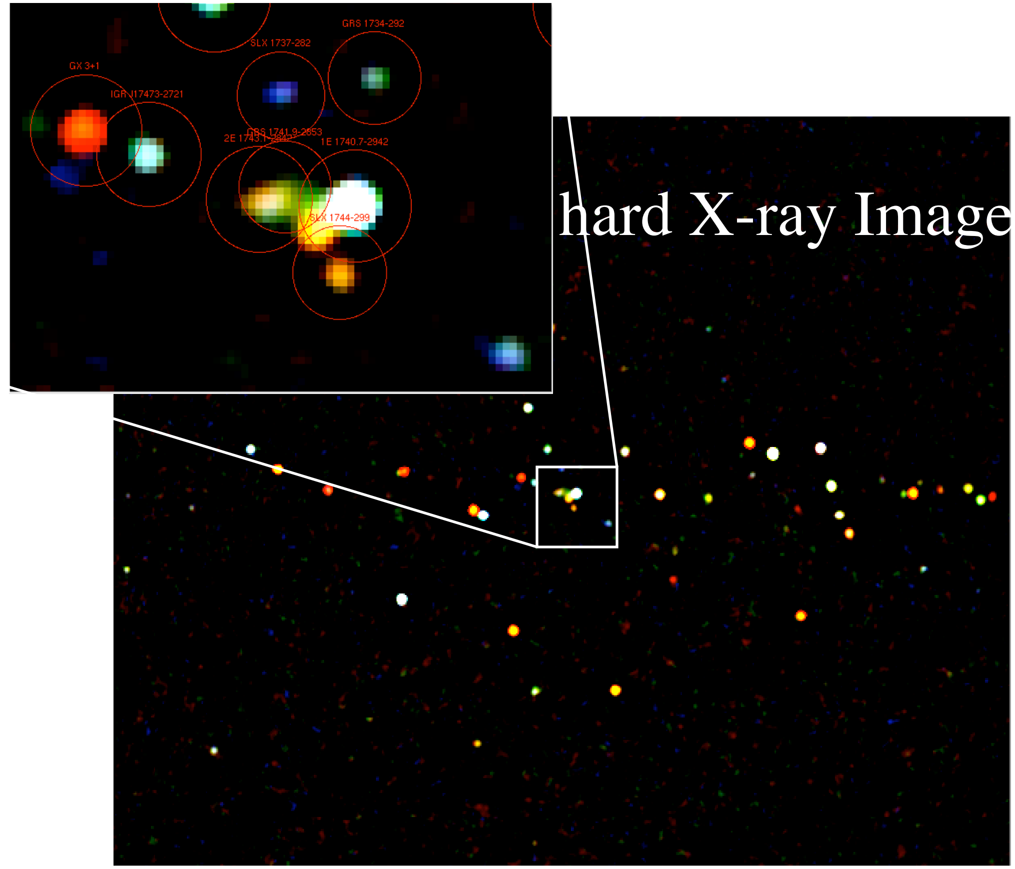
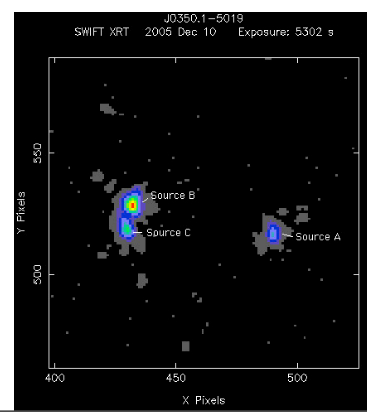


X-ray Image



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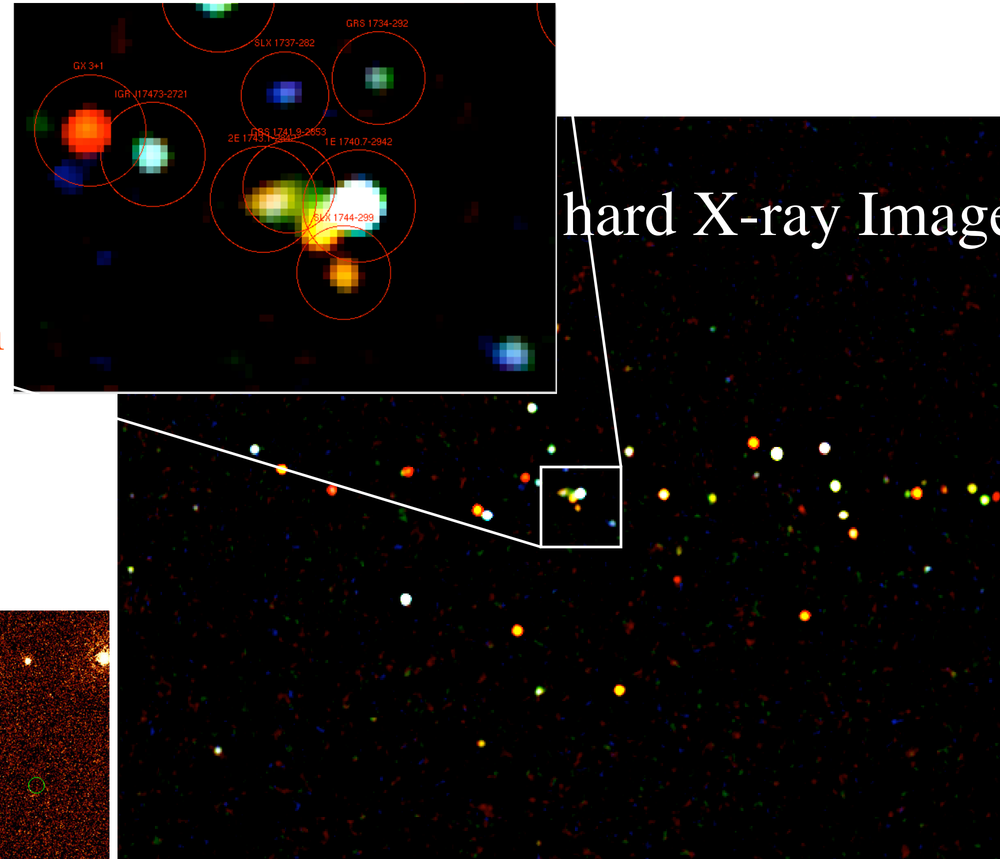
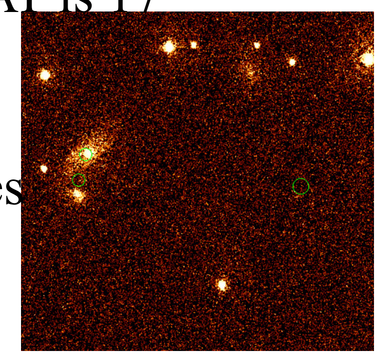
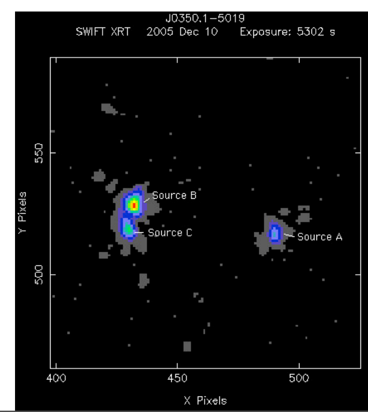


hard X-ray Image


UV image



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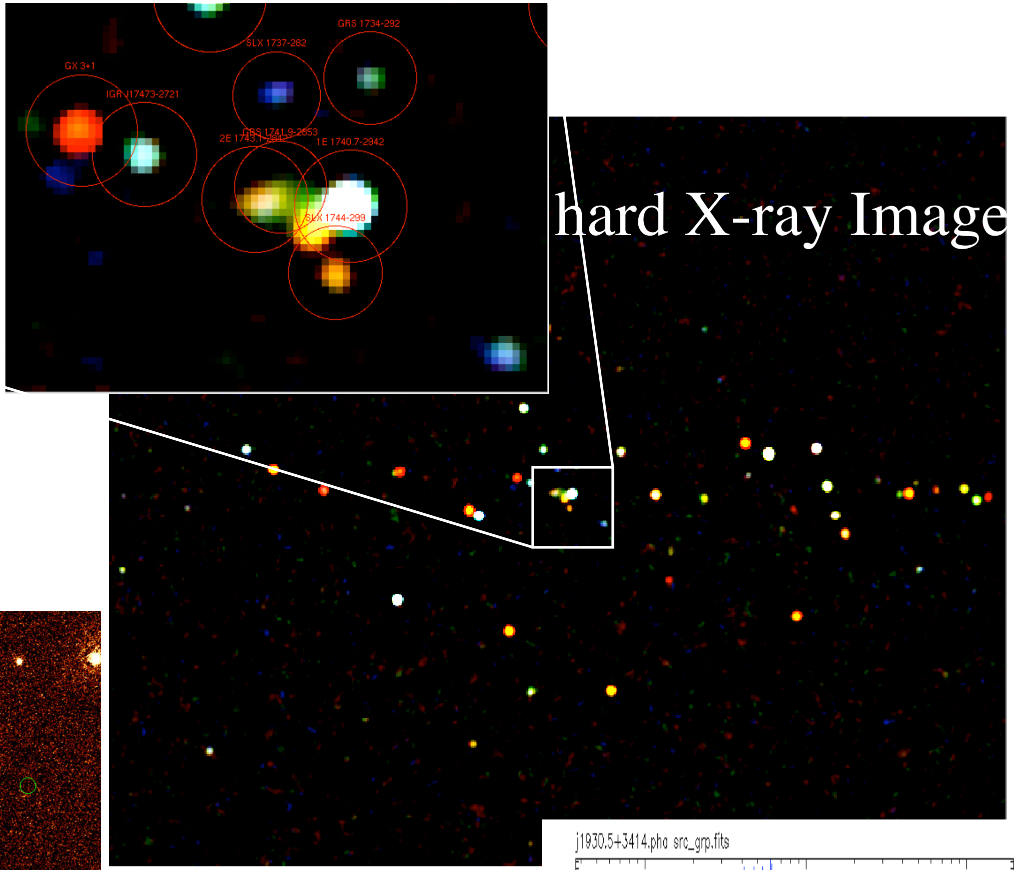

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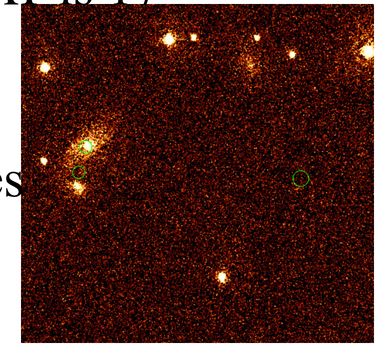

UV image

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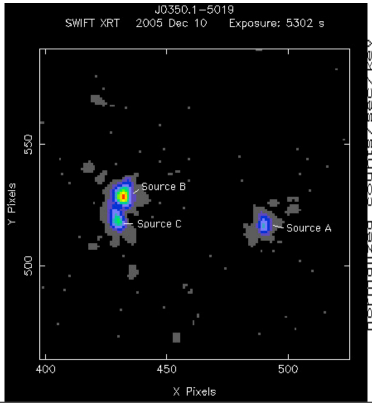
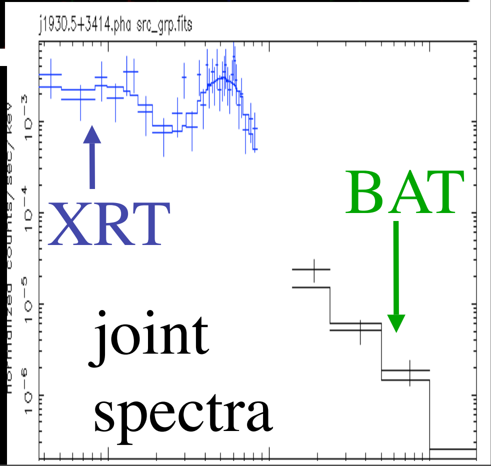
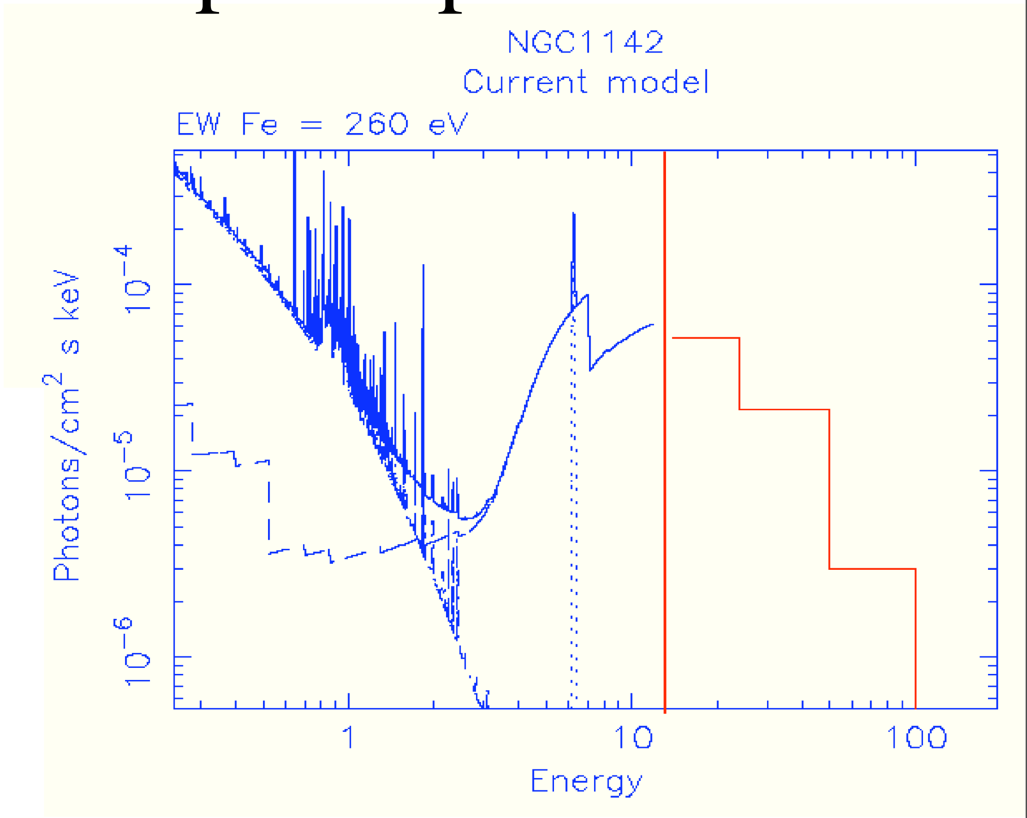


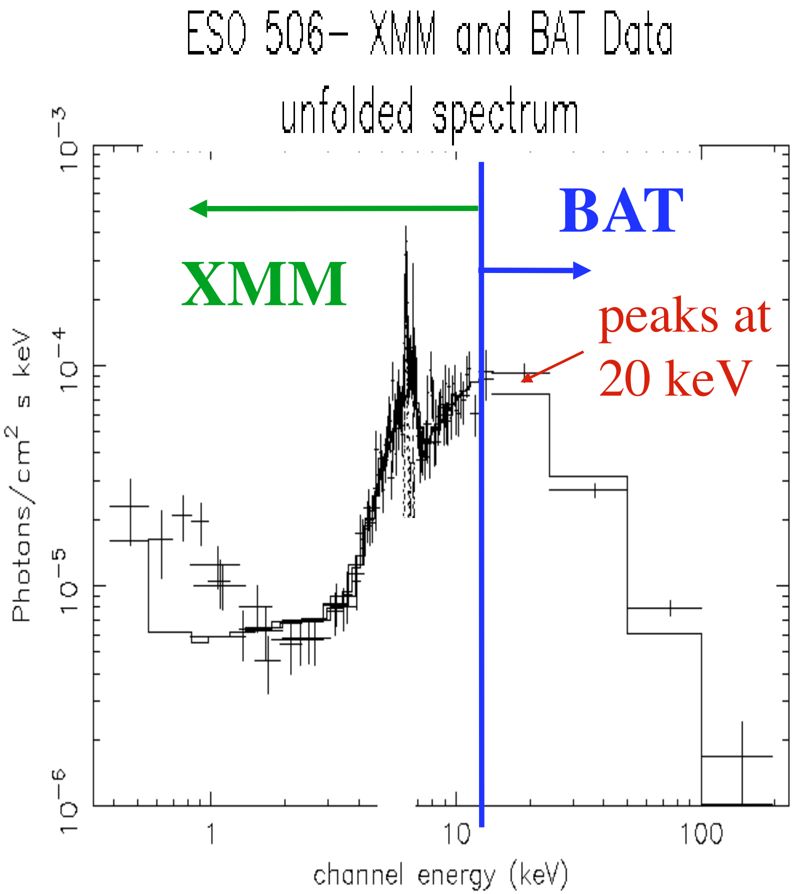
X-ray Image



Heavily Absorbed and Complex Spectra **Abound**

- >25% of BAT sources have soft X-ray emission-**spectral models used in XRB synthesis are wrong**
- only a survey at >20 keV is unbiased by absorption





- Many have extremely complex spectra with soft and hard components that seem unrelated- need high quality x-ray spectra- *low S/N data are highly misleading*

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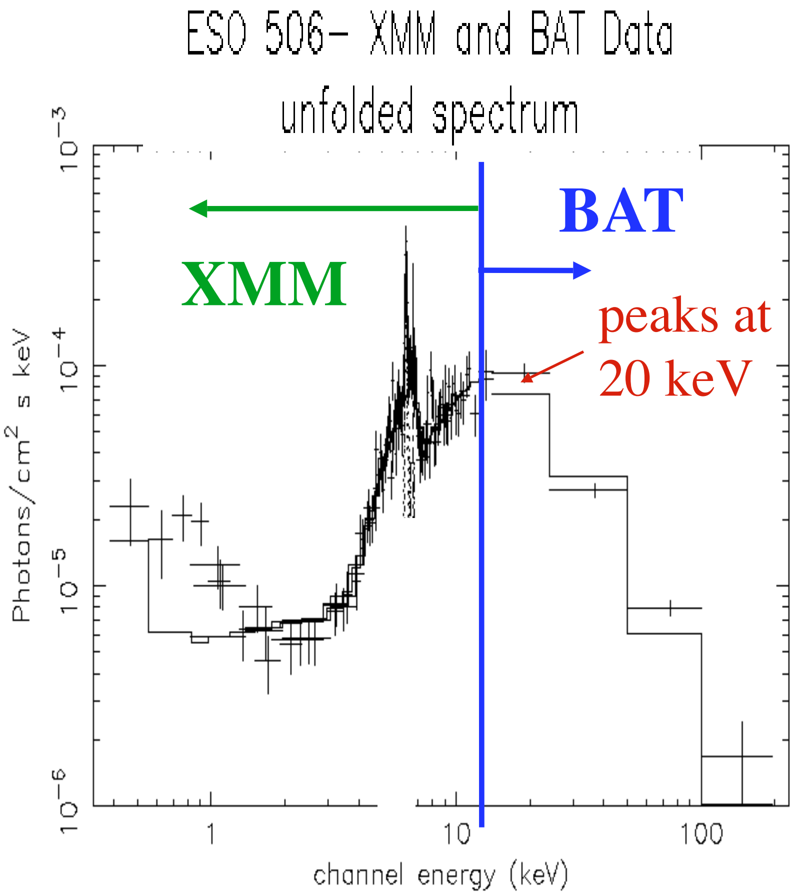

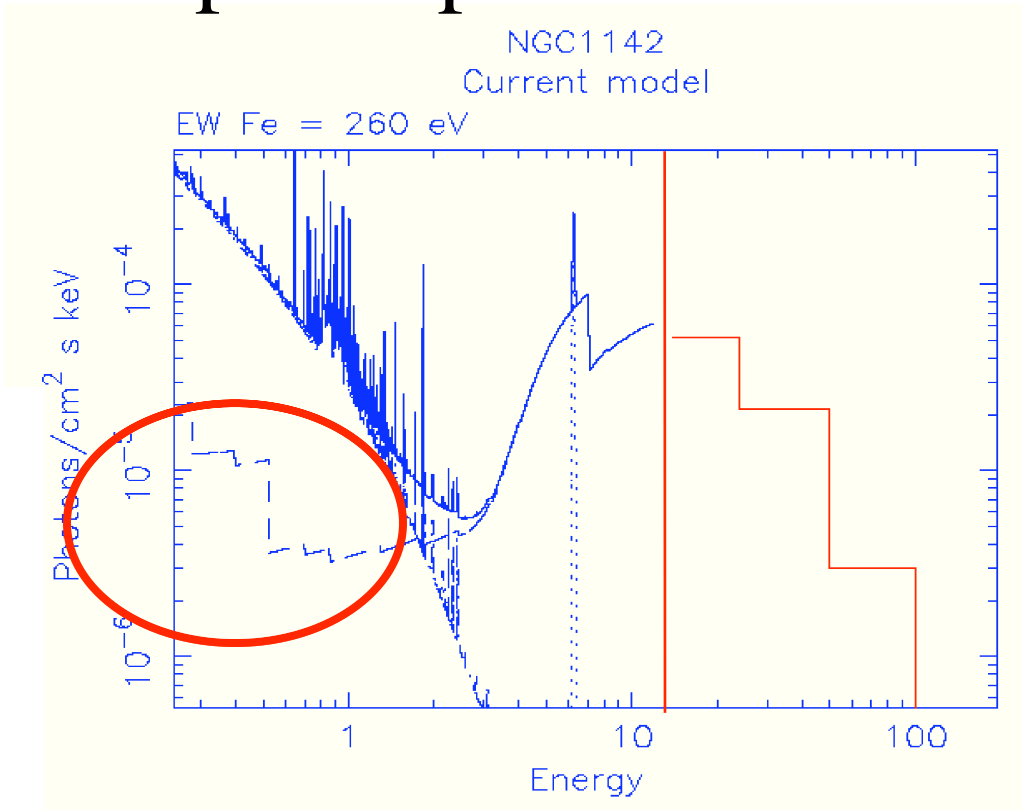

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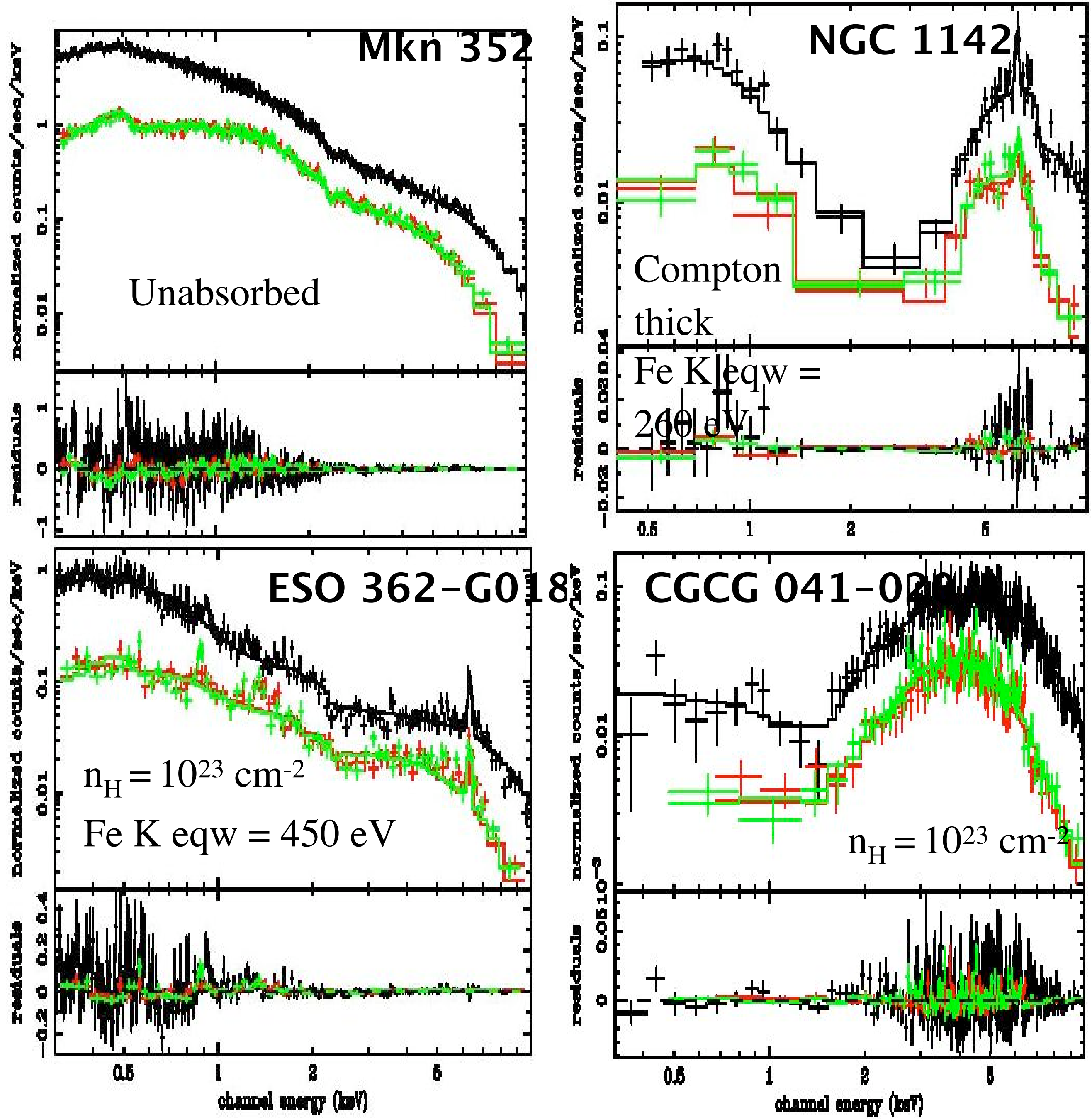


XMM follow-up:

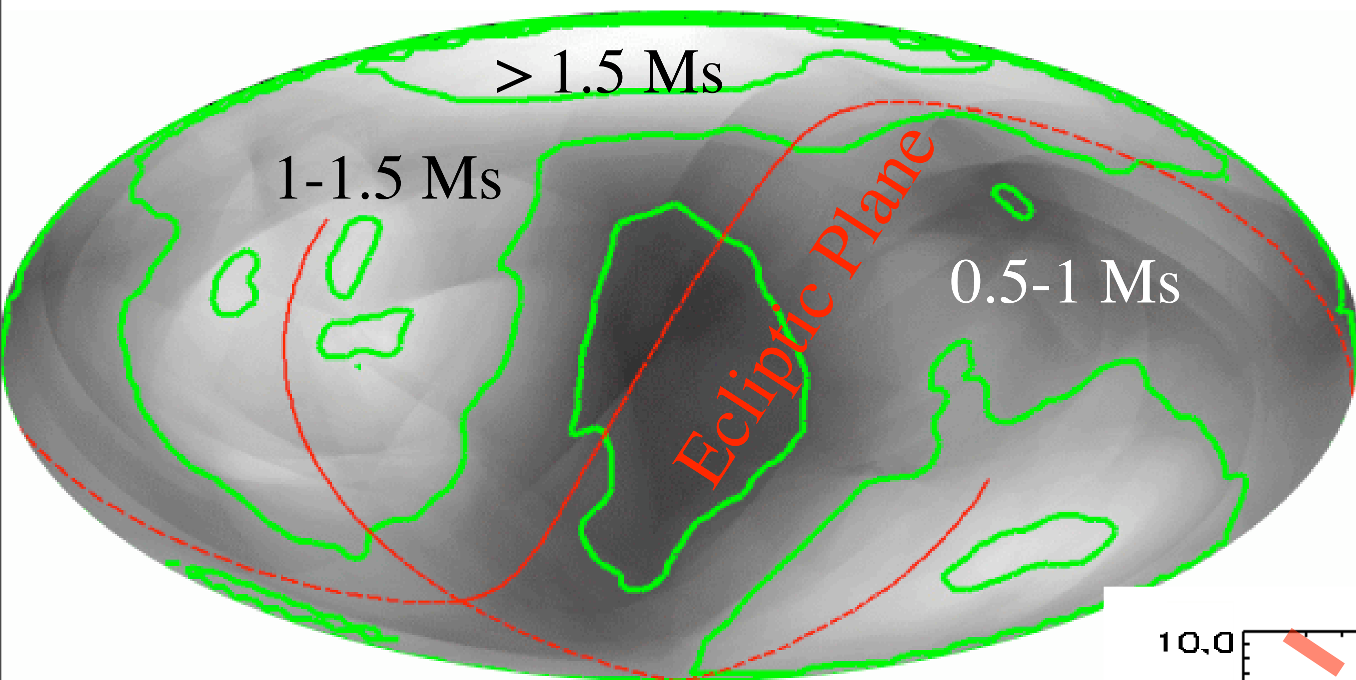
-Range of fluxes (F_X(0.3-10 keV)) from 1.6×10^{-12} to 3.0×10^{-11} erg/s cm^2

-8 “unabsorbed” sources ($n_H < 10^{21}$)

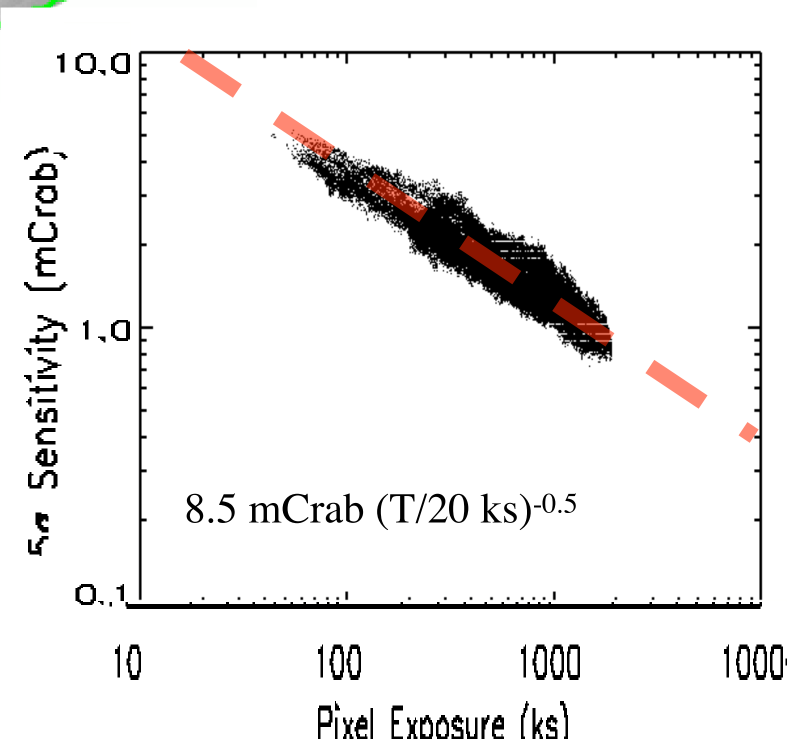
-14 “absorbed” sources, 5 of which are “Compton thick”

-Similar data exists for ~80 other sources

9-month Swift/BAT Survey



Sensitivity vs Exposure Time

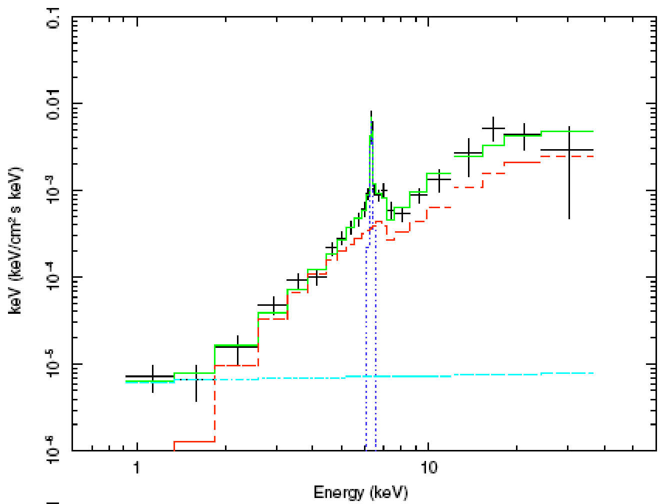


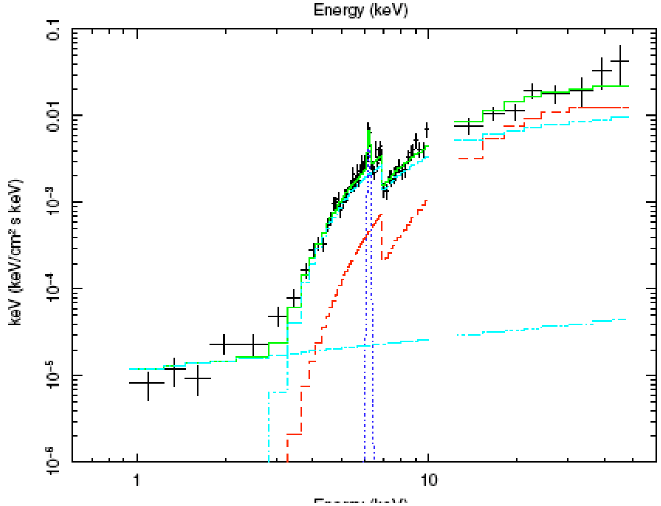
Exposure Map

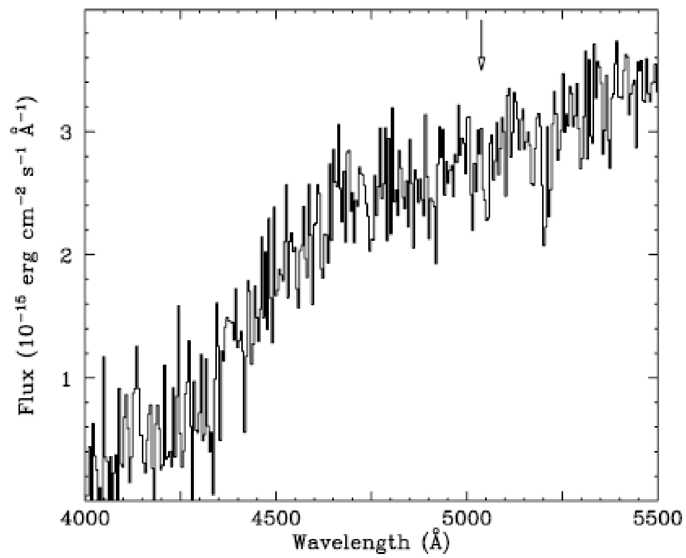
- Covers whole sky, mostly >1Ms
- deficit on Ecliptic Plane due to Sun avoidance
- Sensitivity improves as square root of time (1.2-2 X statistical) to 0.6 milliCrab in 3 years

Suzaku Follow-up

- We (Ueda et al 2007) have received 2 of our Suzaku observations of the Follow-up to Swift AGN.





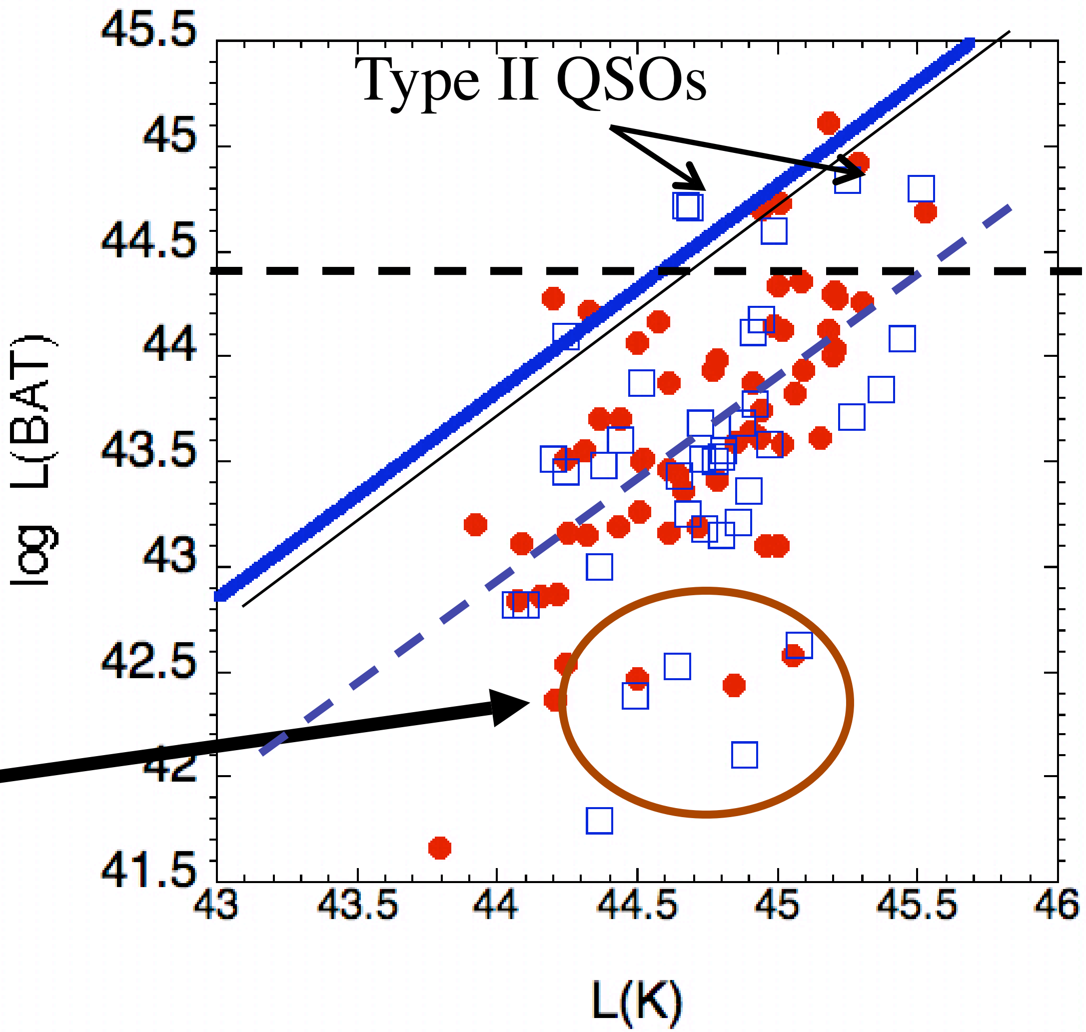


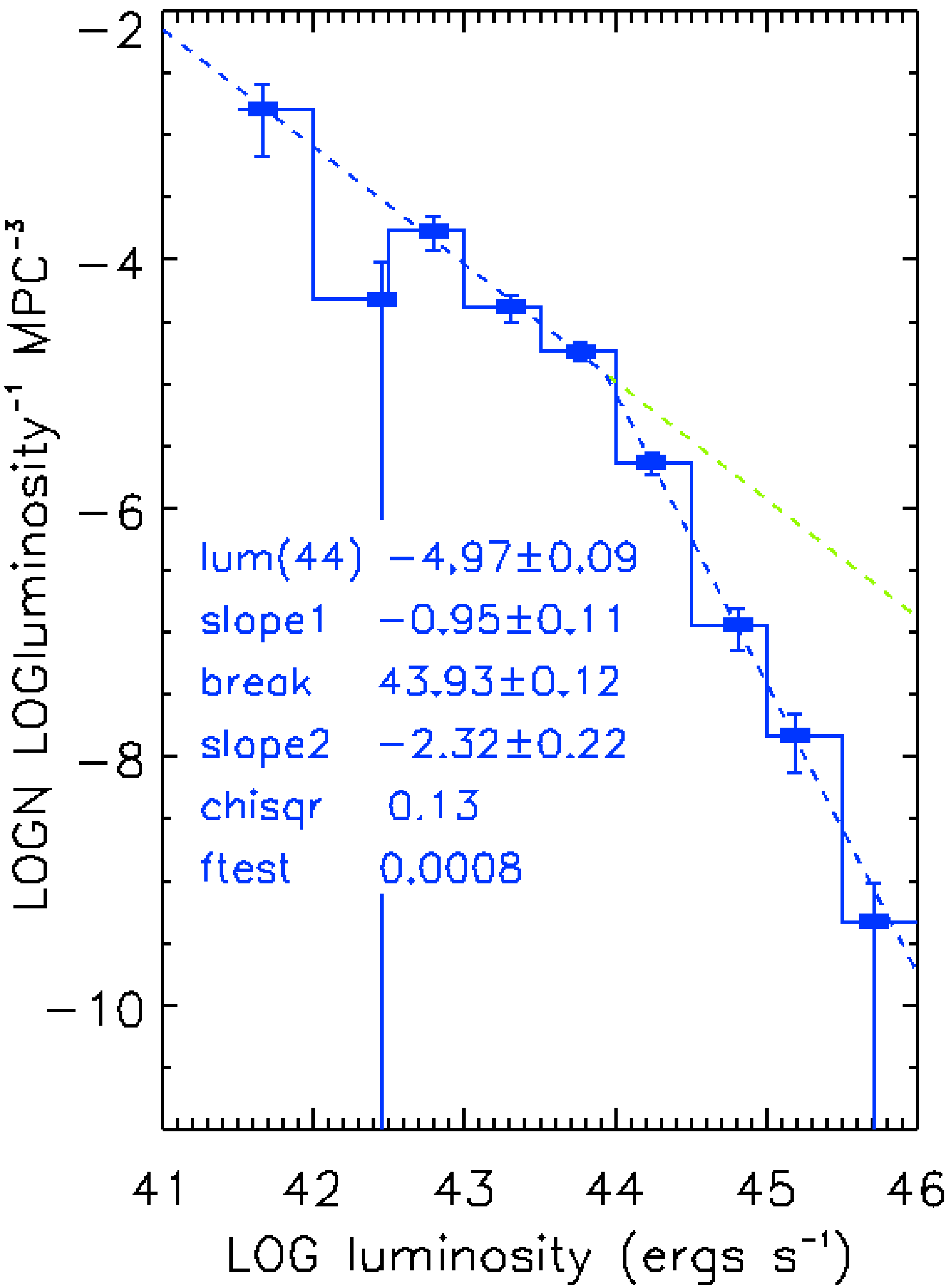
— The optical spectrum of the nucleus region of Swift J0601.9–8636 (ESO 005–G004)
4000-5500 Å wavelength range, taken with the SAAO 1.9-m telescope. The arrow
; the position of the [O III] λ5007 line.

Both of these sources show very high absorption and very small soft components
One shows a weak Fe K line, the other is strong.

K band vs Hard X-ray

- The literature (e.g.Glass 1981, Ward et al 1987) provides small beam K band magnitudes for ~20 objects
  - 2 MASS total is 1-2 mags greater than nuclear K mag for Seyfert Is (e.g. NGC 4593)
    - But in some cases the nucleus dominates
  - Probably overestimated M_{BH} ~ 2-6 and L/L_{Edd} ~0.01-0.1
  - There is a set of objects of very low L(BAT)/M(K)-
    - both very low Eddington ratio - and Compton thick objects with suppressed hard x-rays.
    - All but one of the high L (BAT) sources are radio loud





Luminosity Function

- break at 10^{44} ergs/s
- slope -1 below the break and slope -2.3 above the break
- errors of ~20% in normalization, ~10% in slopes and <1% in break luminosity and
- New, much tighter constraints will test CXB models