Main science goals and accomplishments of Suzaku AGN GO Program - R. Mushotzky for the Suzaku Team

- ***Establish 'reality' of broad Fe K lines-***
  - NGC3516, MCG-5-23-16, MCG-6-30-15, NGC2992 ….
- ***Determine accurate reflection parameters -how the reflection component responds to the continuum and comparison of Fe K line to reflection -***
  - NGC2110 (no reflection)
  - MCG-5-23-,MCG-6-30, NGC3516
- ***Precision measurements of Fe line parameters***

Time variability of different Spectral components and their connection

Work is started preliminary results NGC 4051, MCG-5-23, MCG-6-30

High energy cutoffs- and connection to x-ray background

NGC4388, NGC4945, NGC2992, Cen-A, MKN3, NGC2110
E> 200 keV - problem with XRB models ?

Other Important Results

- Measurement of $K\alpha/K\beta$ + width of narrow Fe K lines allows placement of Fe narrow line (NGC2992, Cen-A)
- Short time scale variability in hard emission from Seyfert II (MKN3- break degeneracy between transmission and reflection)
- Abundance of absorbing gas in line of sight (Cen-A- others ??) and in host galaxy
- Broad soft x-ray lines(?) PG1211, NGC4051
- Differential time variability of reflection, Fe K and power law components

• Confirmation of variability in Fe K line in emission and absorption (PG1211, NGC2992…)

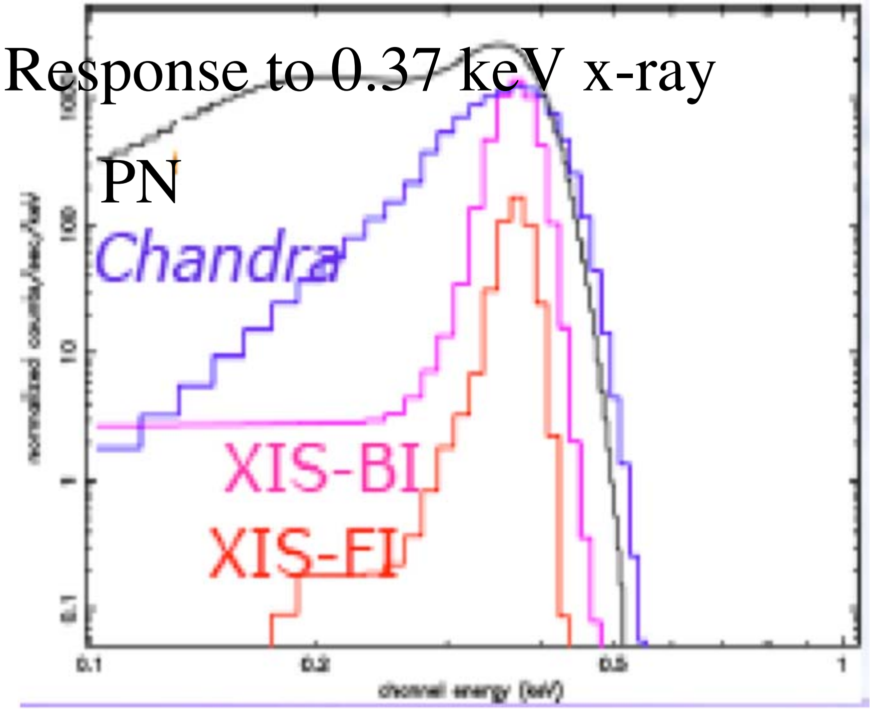
•Measurement of Fe abundance in reflector

Confirmation of relative sensitivity of Suzaku vv previous missions + accuracy of calibration (weak spectral features)

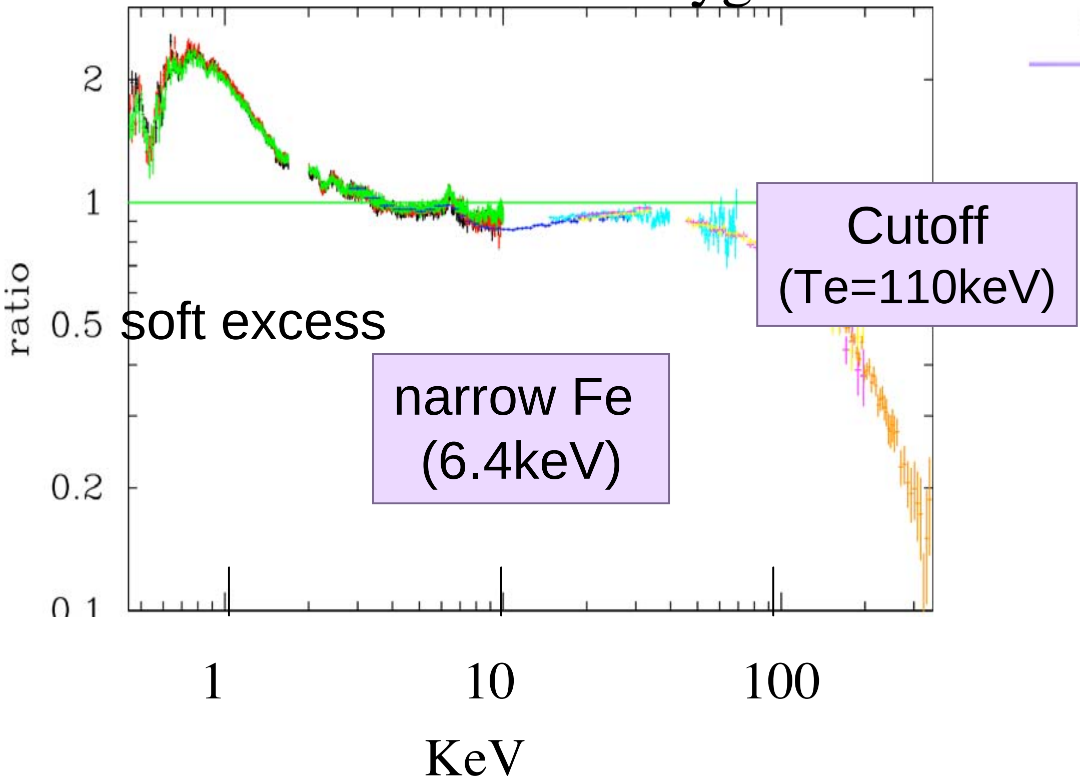
Important Suzaku Properties for AGN research

- High signal to noise from 0.3- 50(200) kev
- Well calibrated
- Good energy resolution (better than XMM and Chandra CCDs)

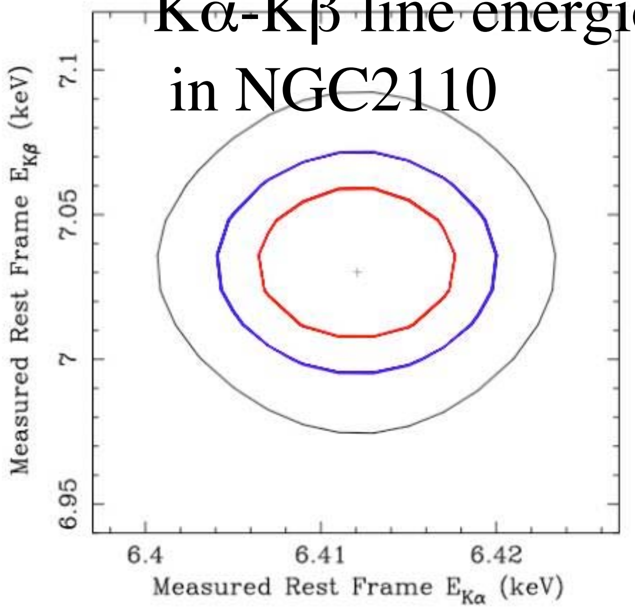
Response to 0.37 keV x-ray



Suzaku data for Cyg X-1

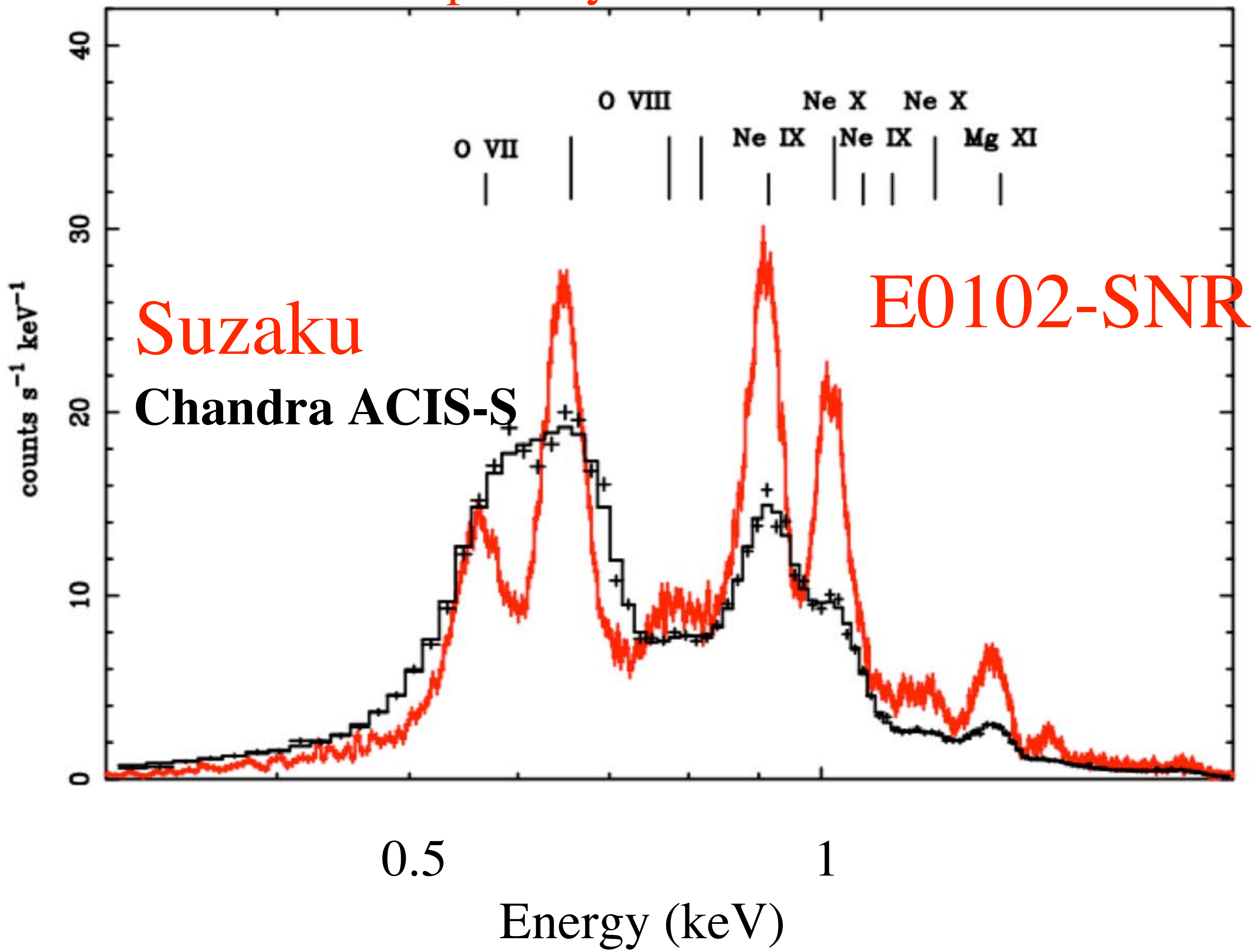


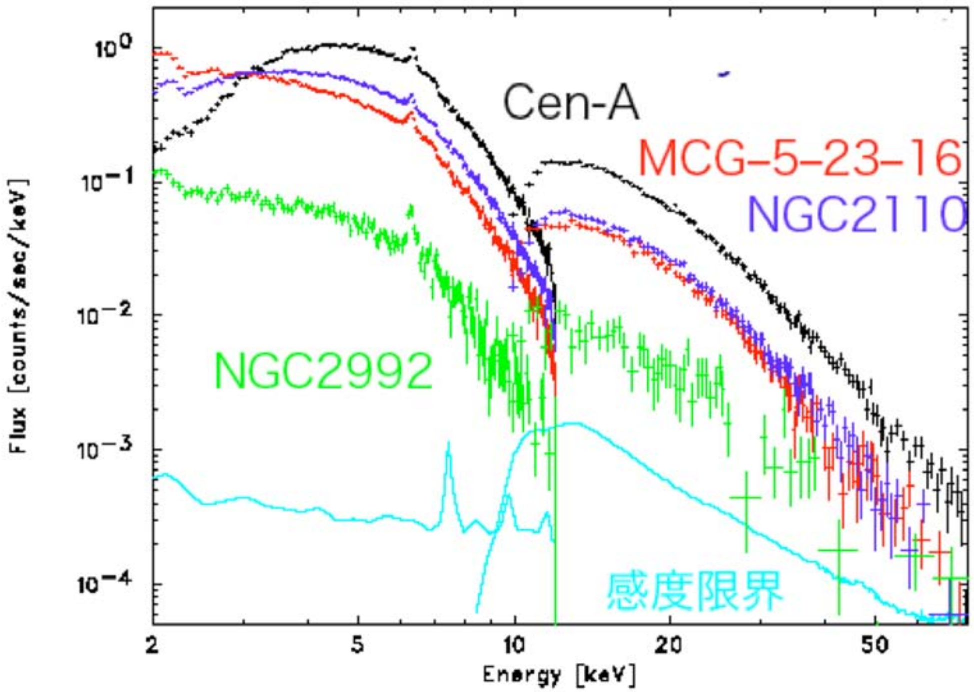
Kα-Kβ line energies in NGC2110

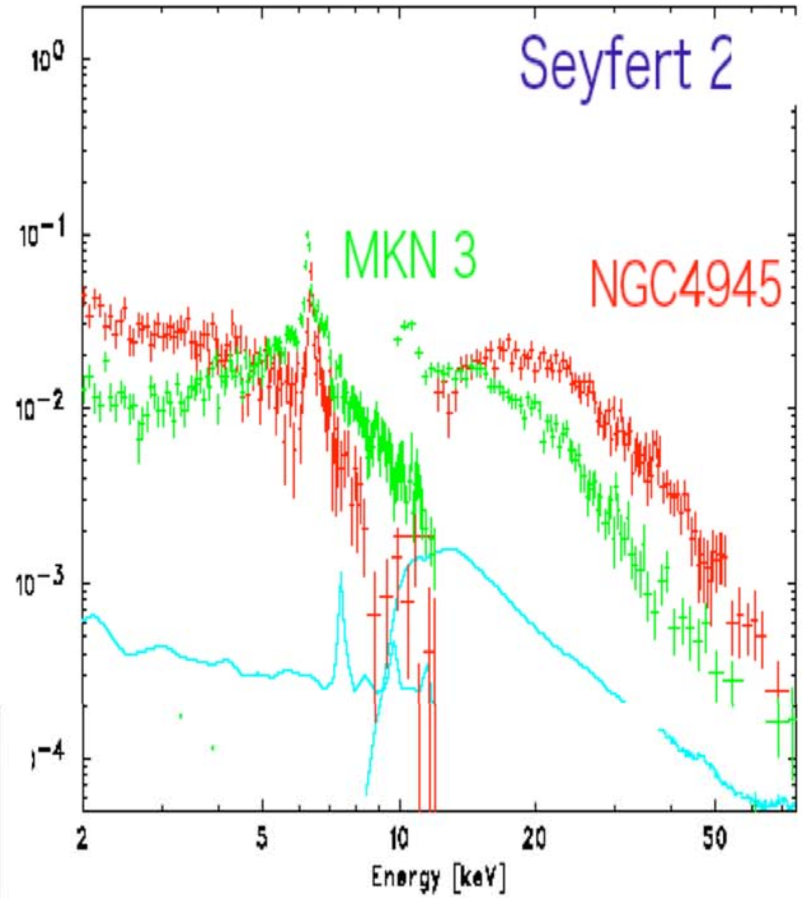


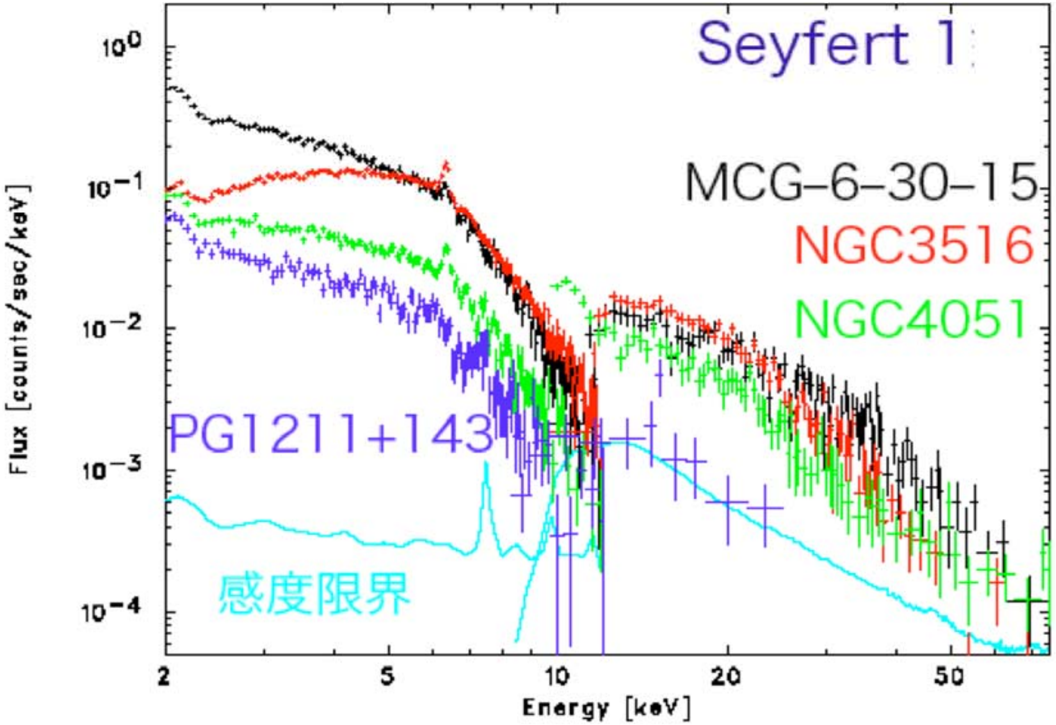
Suzaku XIS: Excellent Spectral Resolution

especially at E < 1 keV





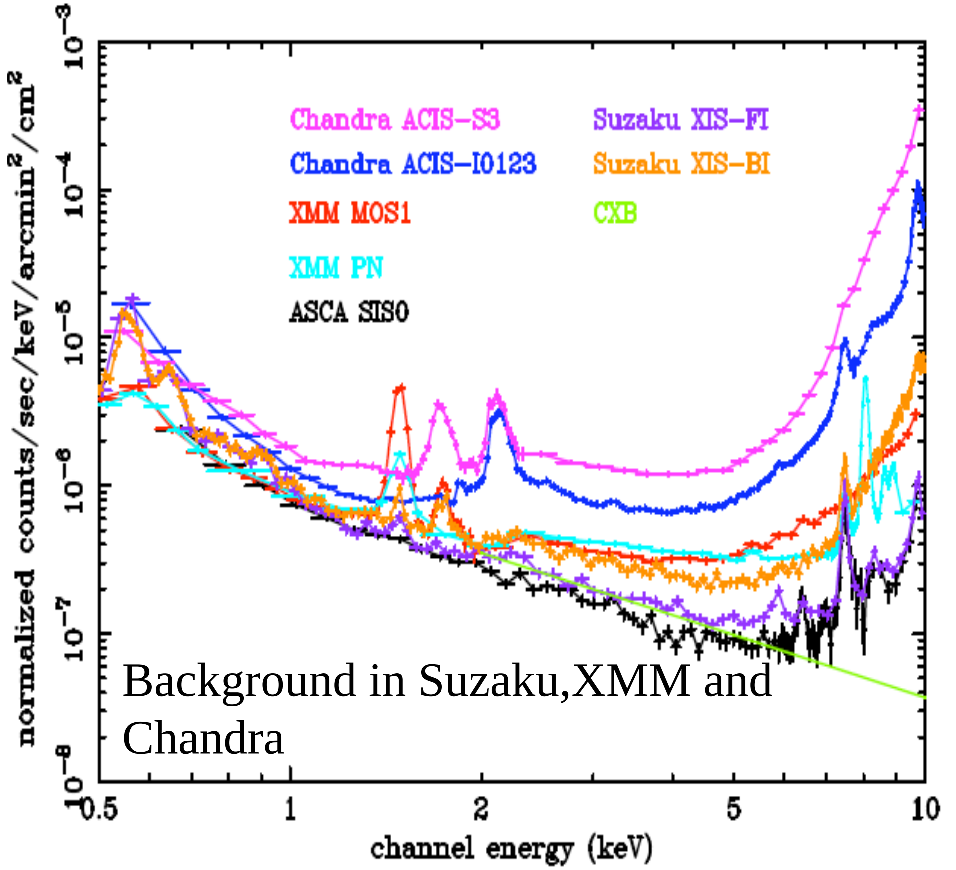




Sample AGN Spectra
Watanabe et al

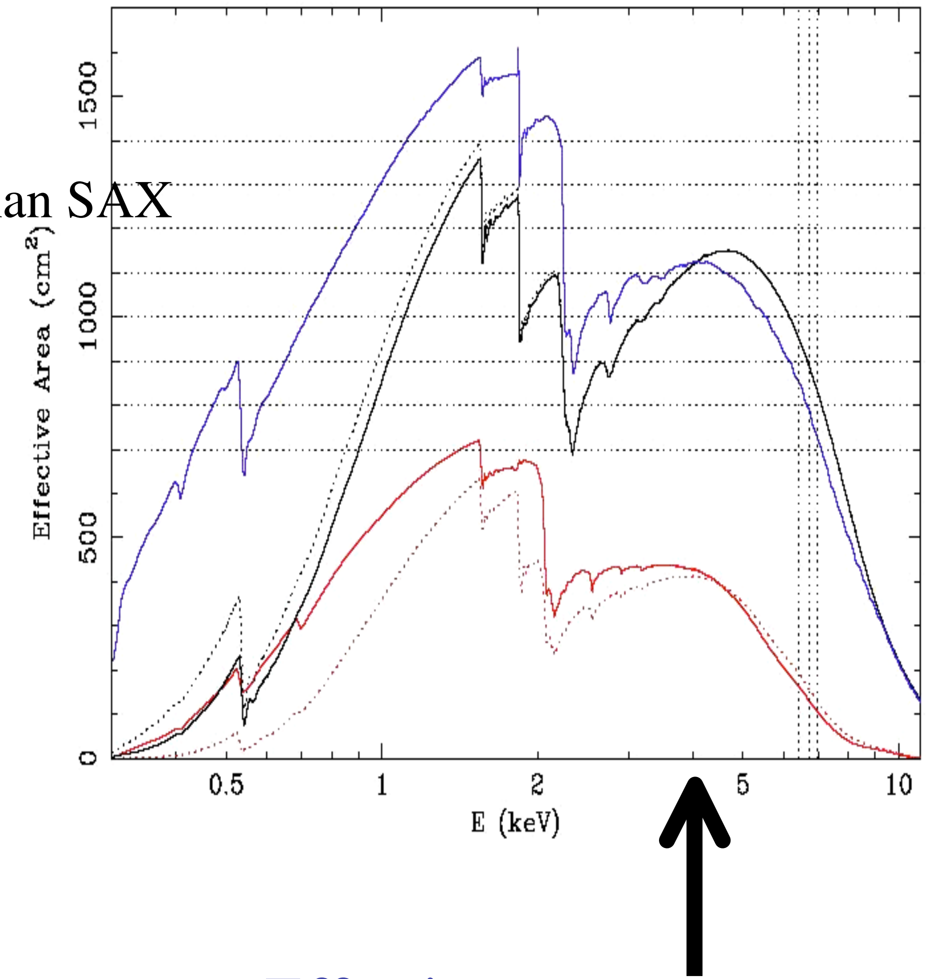
Comparison of Suzaku, XMM and Chandra Background/Areas

For point sources Suzaku is flux limited- with similar counting rates for hard sources to XMM EPIC
Hard x-ray detector is more sensitive than SAX in 10-40 kev band



Background in Suzaku,XMM and Chandra

ure 13: Comparison of the background spectra normalized by the effective area and by the FO\

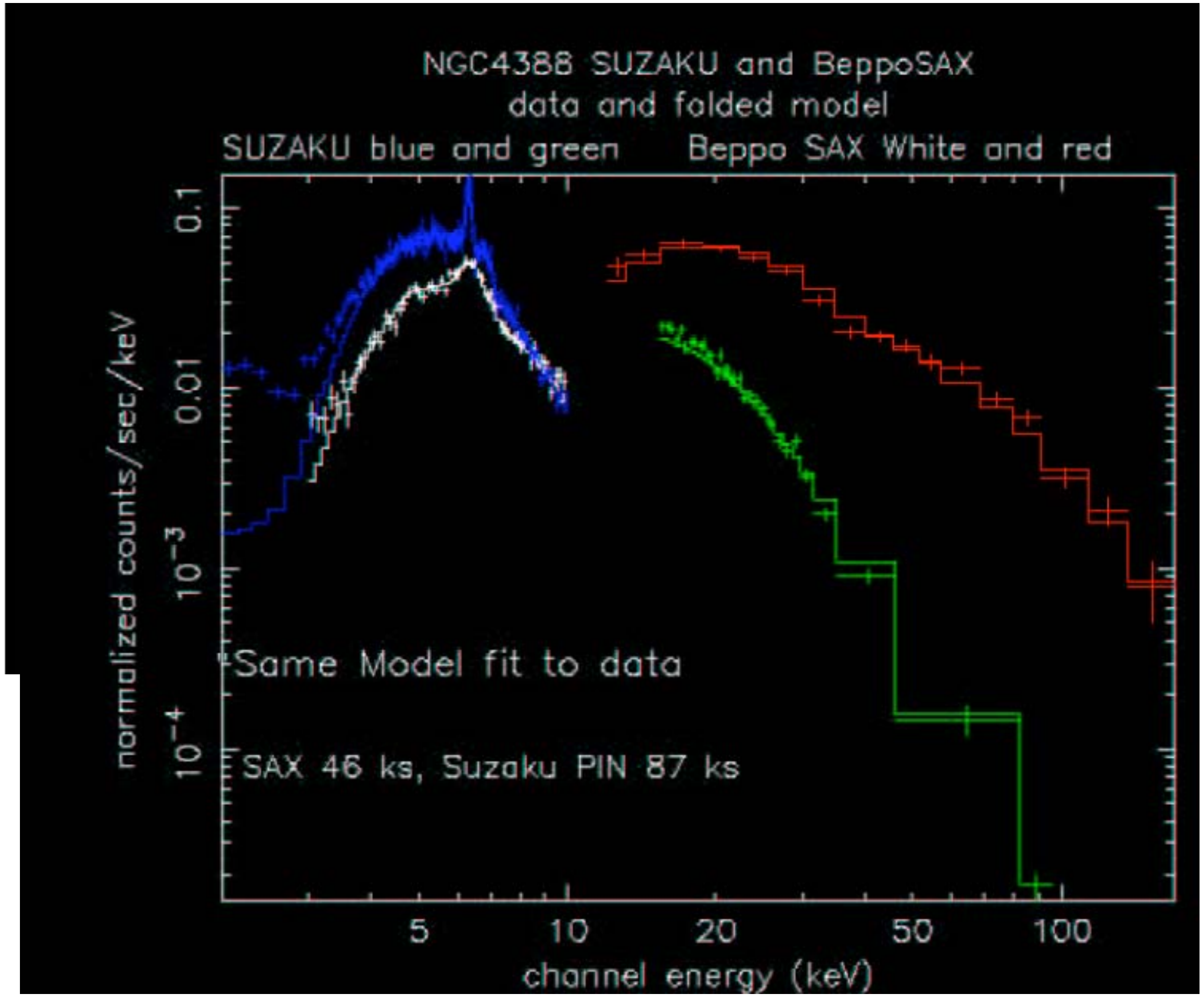


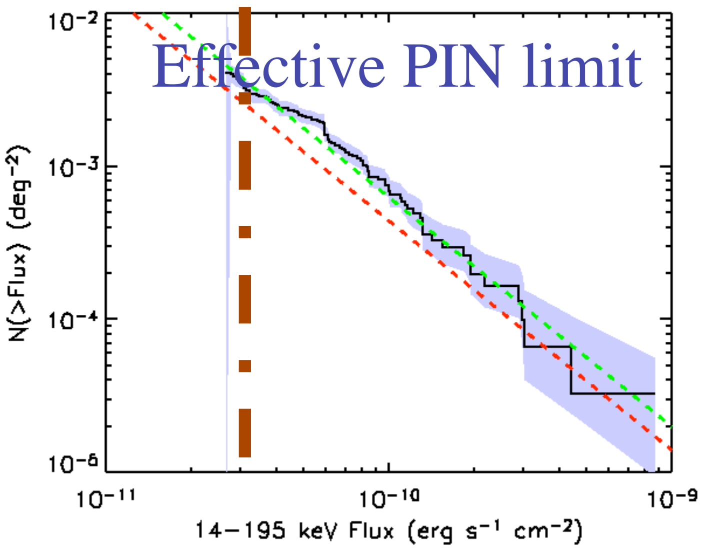
Effective areas

- ***Suzaku in black***
- XMM in blue
- Chandra (ACIS) red

NGC4388 Direct Comparison of Suzaku and BeppoSax

- One XIS (Suzaku)- 2 MECS (SAX)
- Flux state very similar
- Same Model fit to data (Suzaku 0.1 steeper PL slope)
- Swift BAT catalog has ~250 AGN above the flux level limits of the PIN and >100 galactic sources

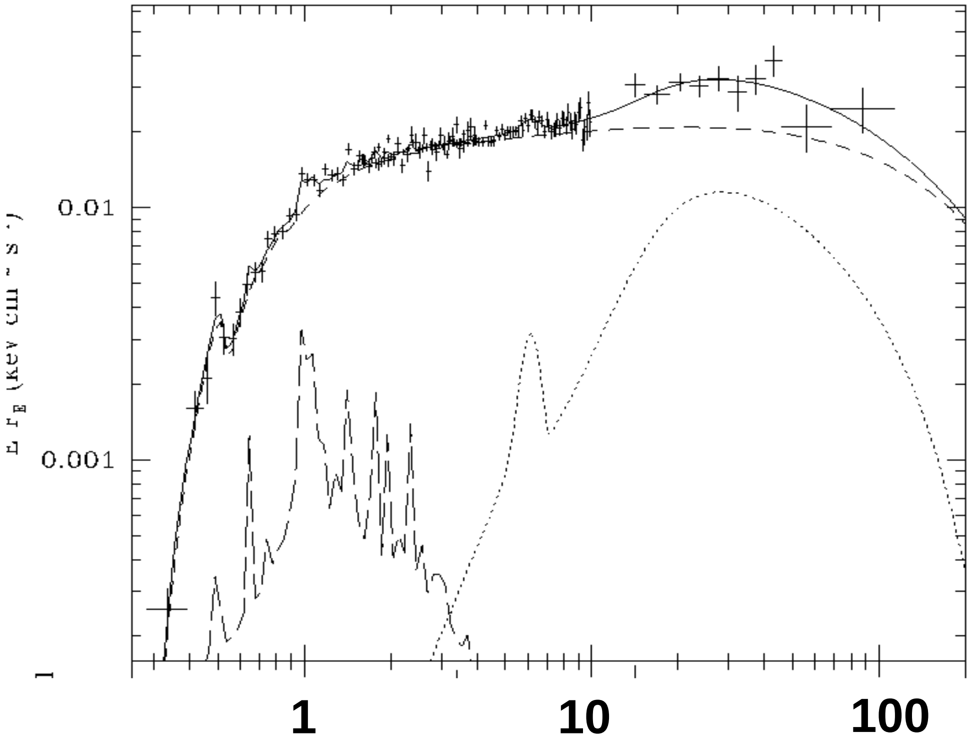


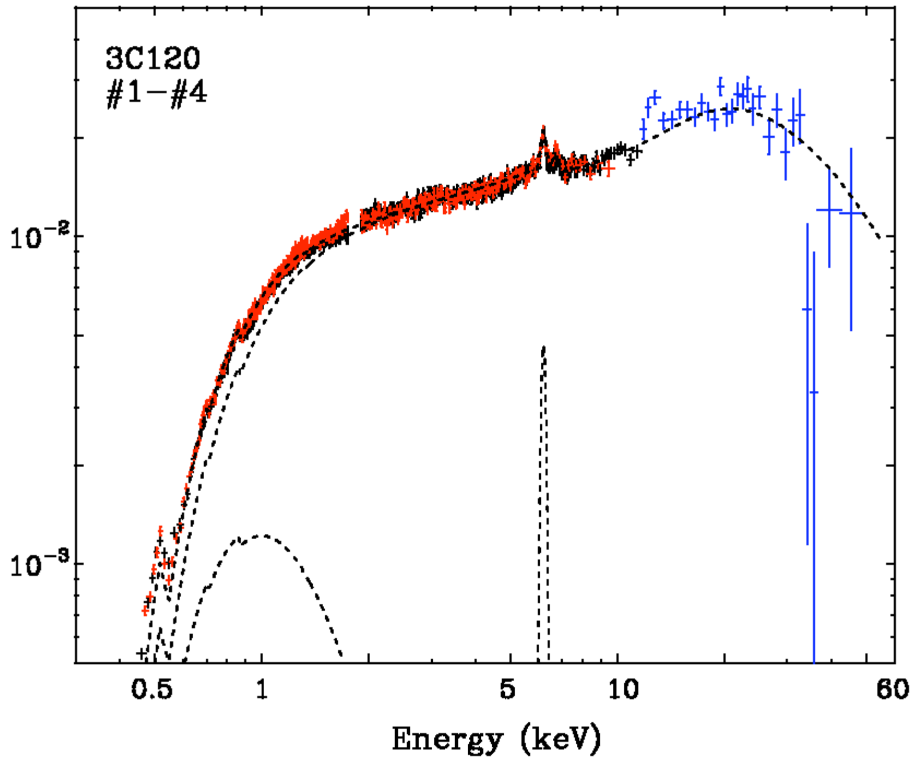


BAT high latitude Log N-Log S (Markwardt et al 2006)

Radio Galaxy 3C120

Suzaku compared to BeppoSAX





Beppo SAX (160ksec)

Suzaku (150ksec)

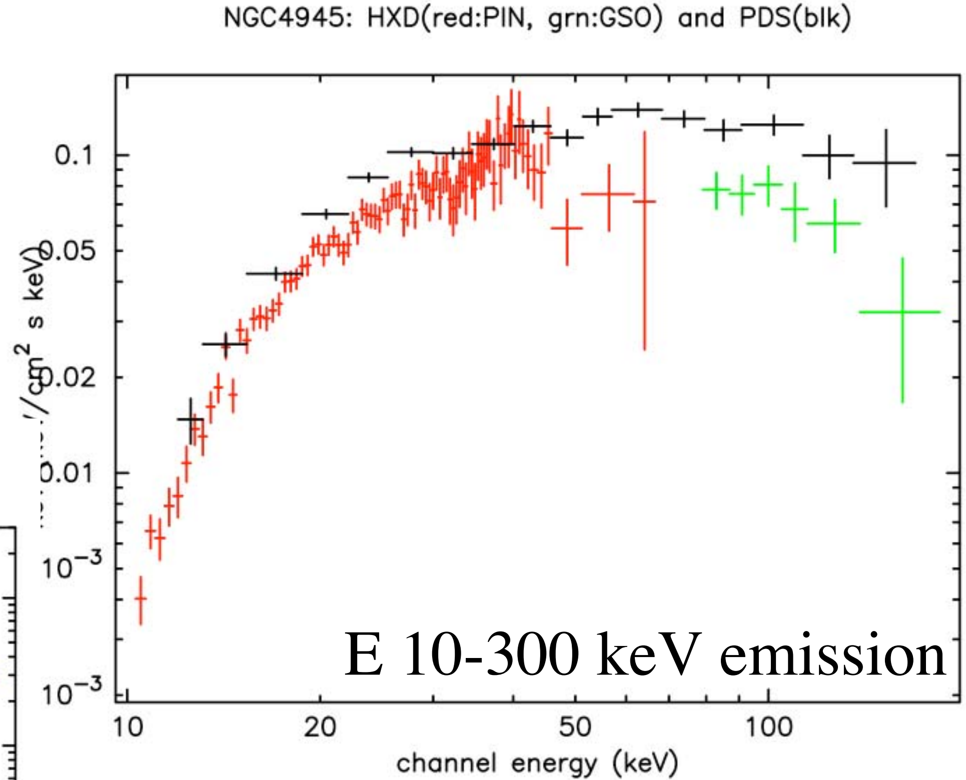
Zdziarski & Grandi, 2001
ApJ, 551, 186

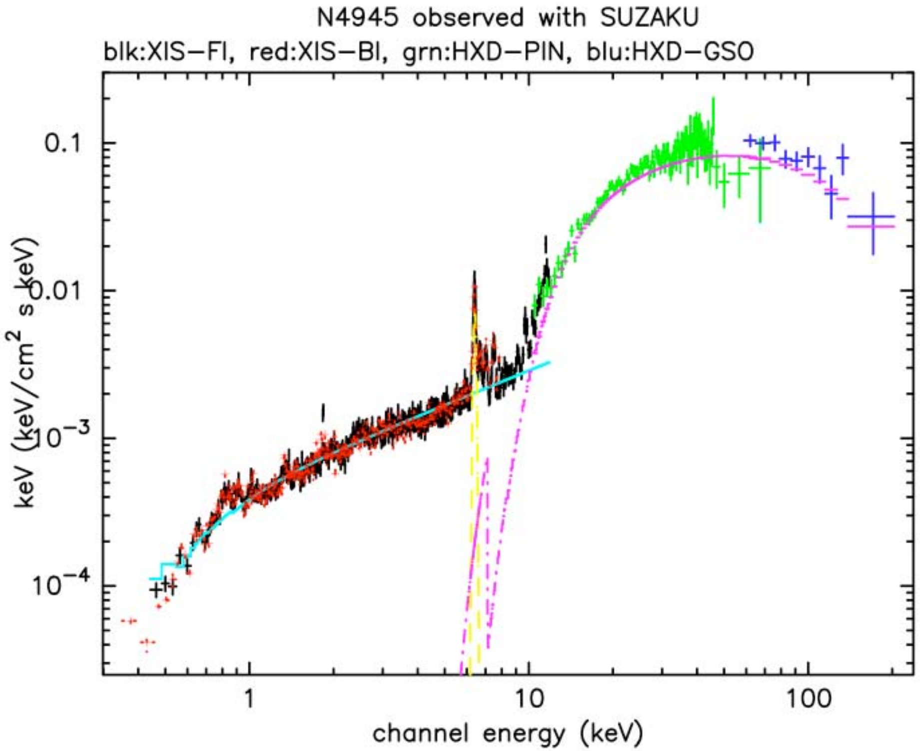
NOTE! **(1) Much better statistics**
(2) Good energy resolution
(3) clear reflection hump

Kataoka et al.

NGC4388 Direct Comparison of Suzaku and BeppoSax

- Complex spectrum with reflection, and transmission requires broad band to deconvolve



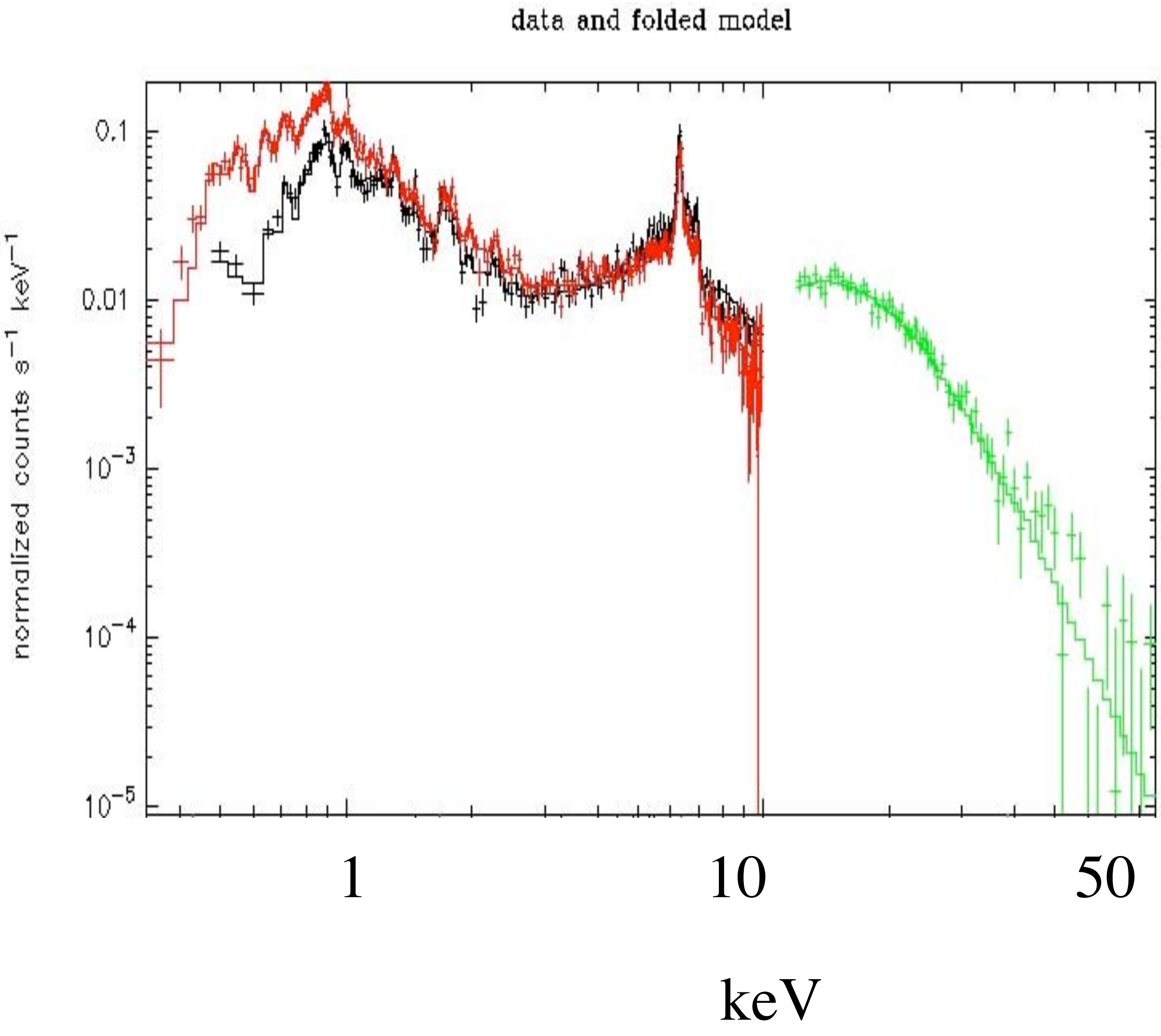


- Fit to Mkn3 (Awaki et al)

F(2-10)=6x10^{-12}

- reflection component, an obscured hard X-ray power-law,
- a scattered soft power-law,
- 5 hard X-ray lines
- 17 soft X-ray lines, showing absorption from neutral and highly-ionized species:

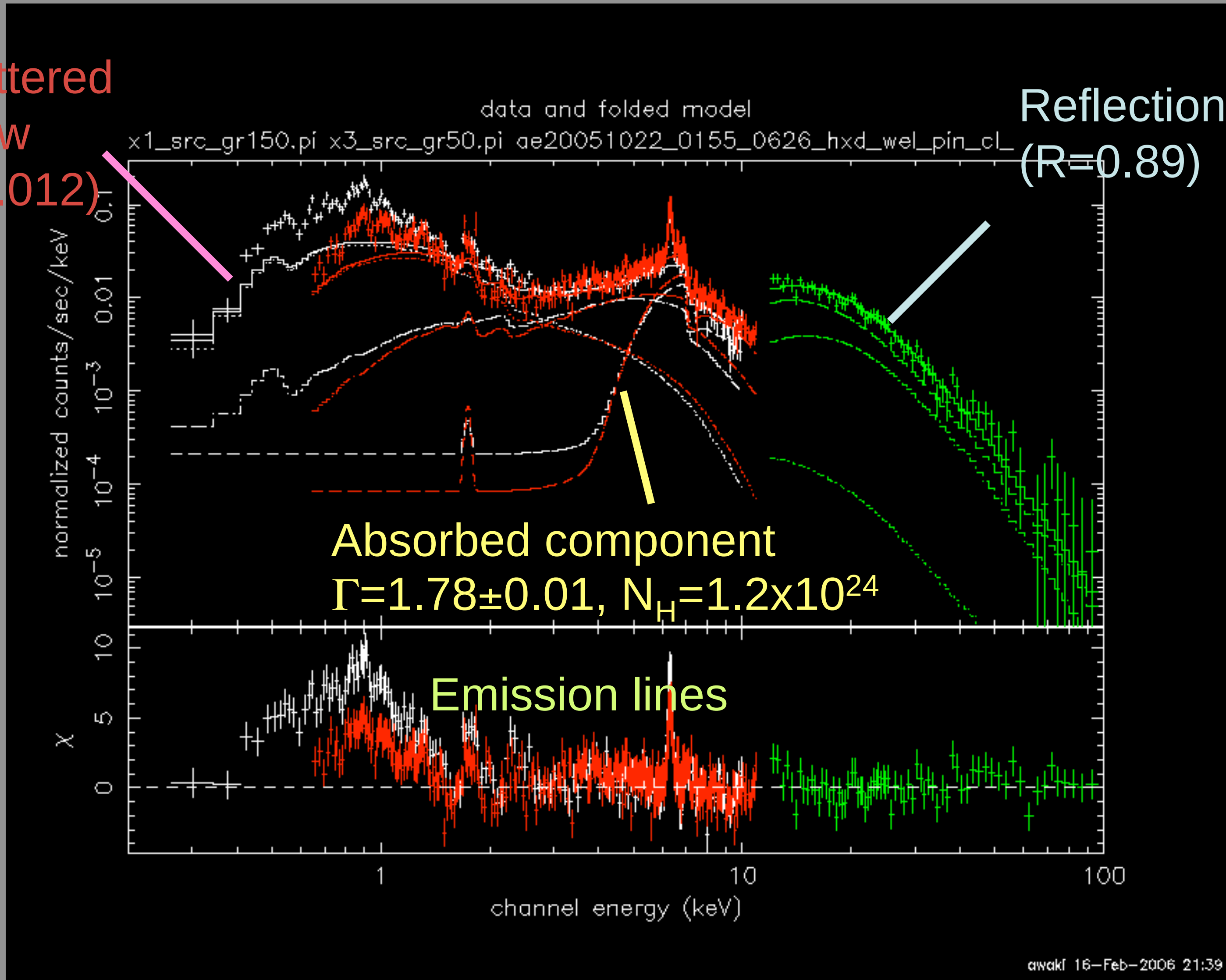
Mkn3



Continuum emission (soft lines + scattered + absorbed + reflection)

$F_{2\text{-}10}$ =5.8x10^{-12} erg/s/cm^2
$F_{10\text{-}96}$=1.1x10^{-10} erg/s/cm^2

Soft, scattered Power-law (N_s/N_h=0.012)

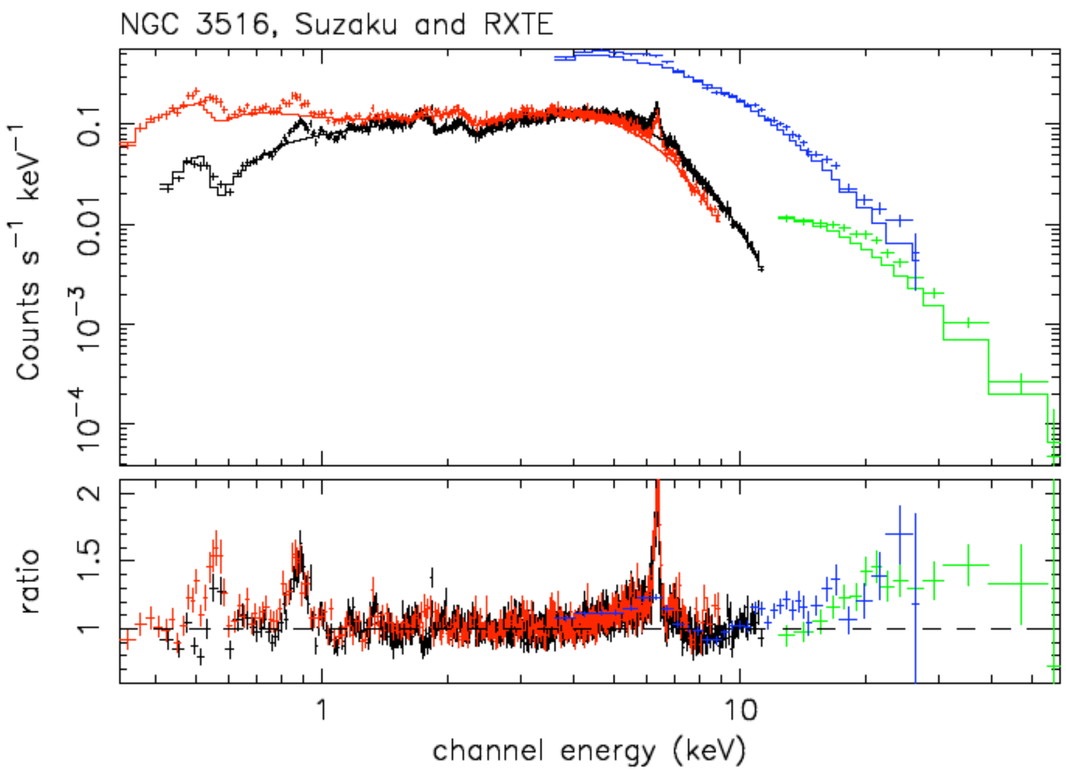


NGC3516

- Both broad (redshifted) and narrow components of the Fe line are required and reflection is seen in HXD,

- several soft X-ray lines are also detected.

A new feature is also observed, due to an absorption edge near 7.6 keV in the rest frame, which is detected in both XIS and RXTE. This could be due to an ionized
absorber or ionized reflection,

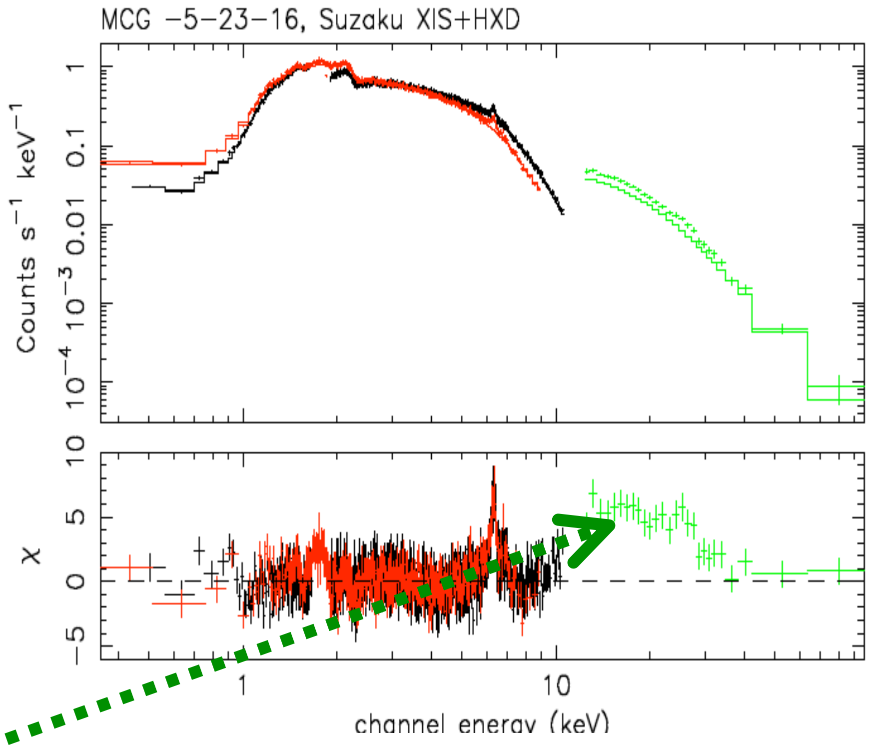


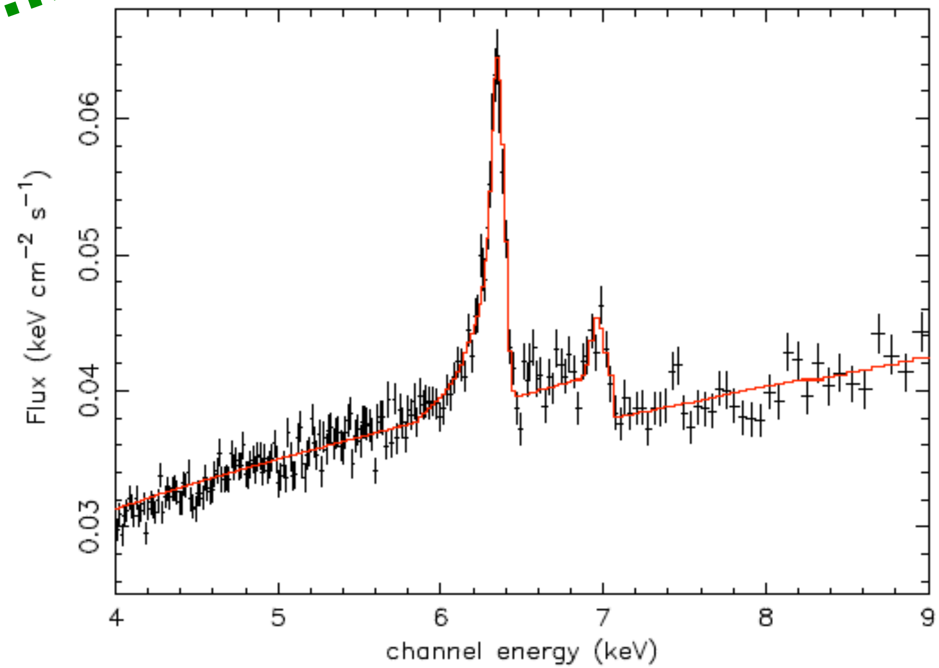
1 10 50

keV

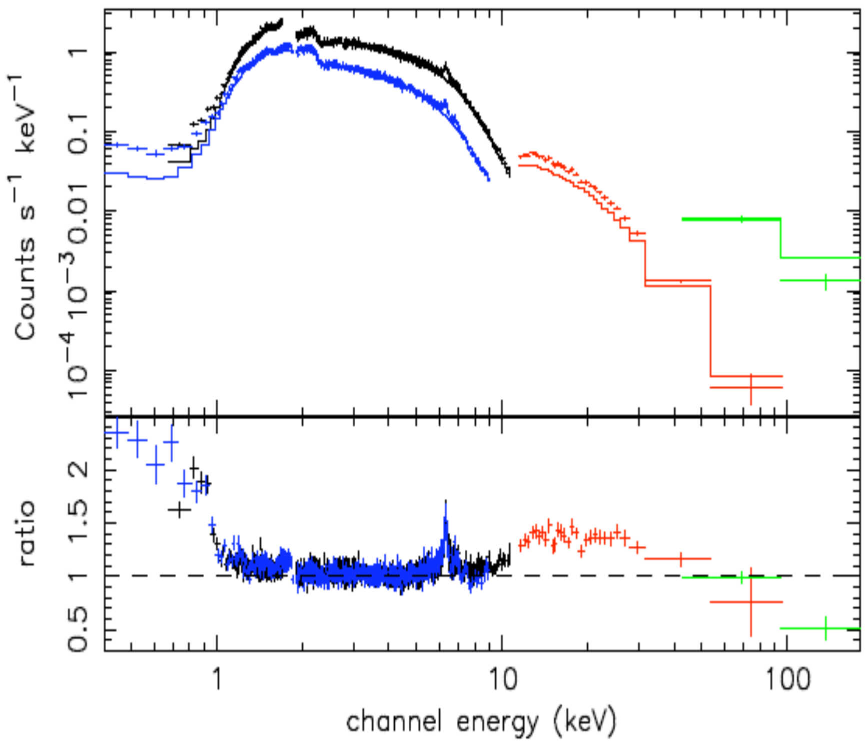
MCG-5-23-16- J. Reeves et al

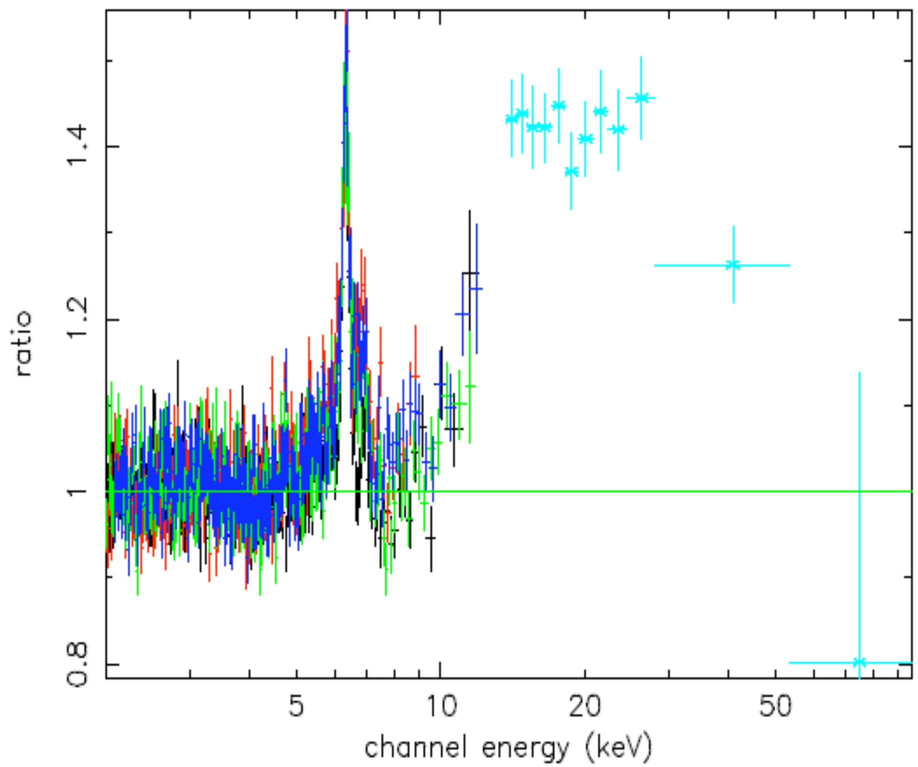
- Fe K line needs two components, a narrow core and a broad diskline or gaussian component to fit the red-tail below 6.4 keV
- . The reflection component is well constrained with R=1.3, with an Fe abundance of 0.6x solar.
- The edge at 7.1 keV and the Compton hump allows us to determine both parameters.





MCG -5-23-16



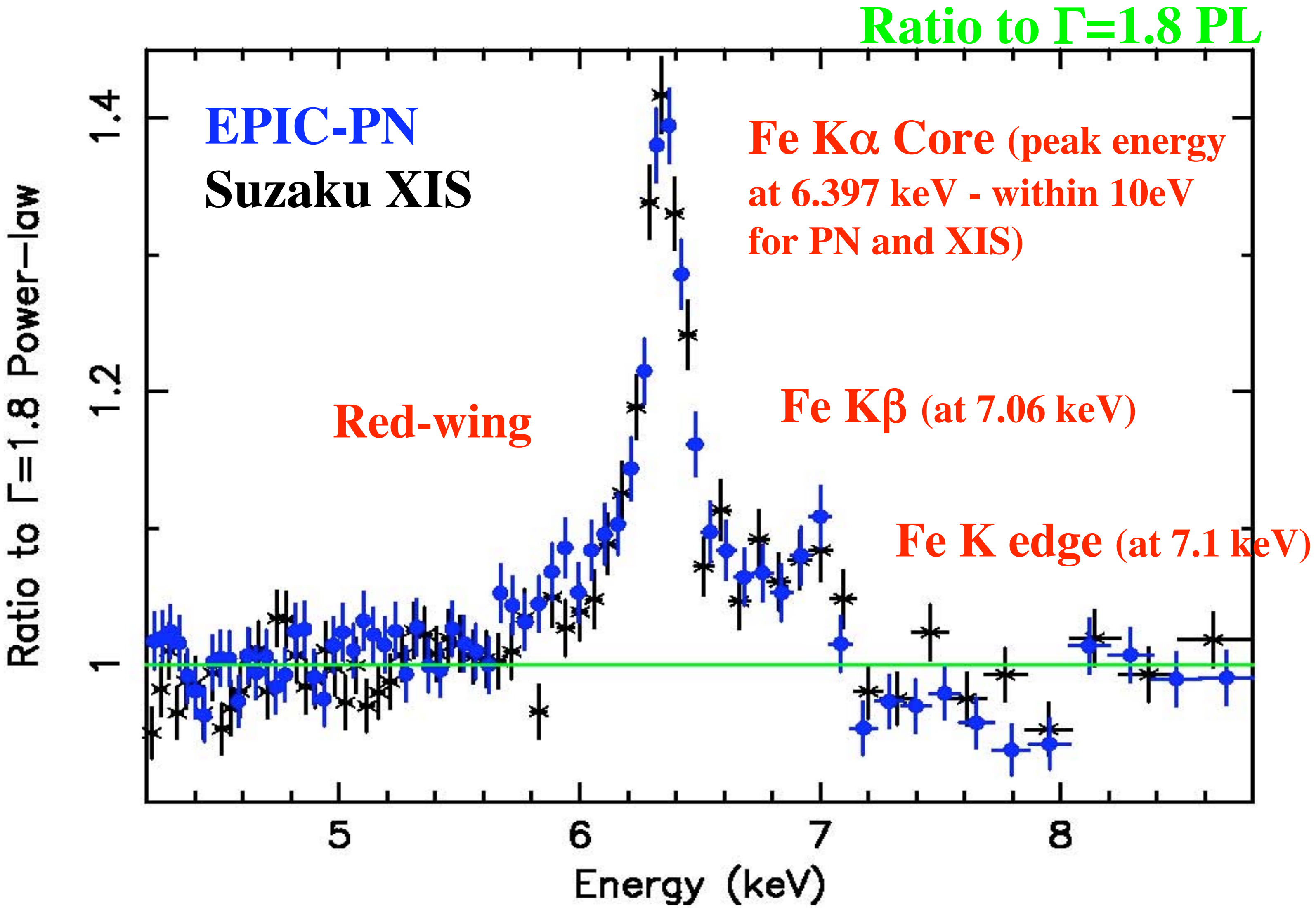


The 4 XIS and PIN spectra
Cross calibration within 5%

Overlap of XIS and HXD allows robust fitting and low systematic errors

Simultaneous Suzaku and XMM Observation- *notice the excellent agreement on Fe K line shape*

Iron line Profile of MCG -5-23-16

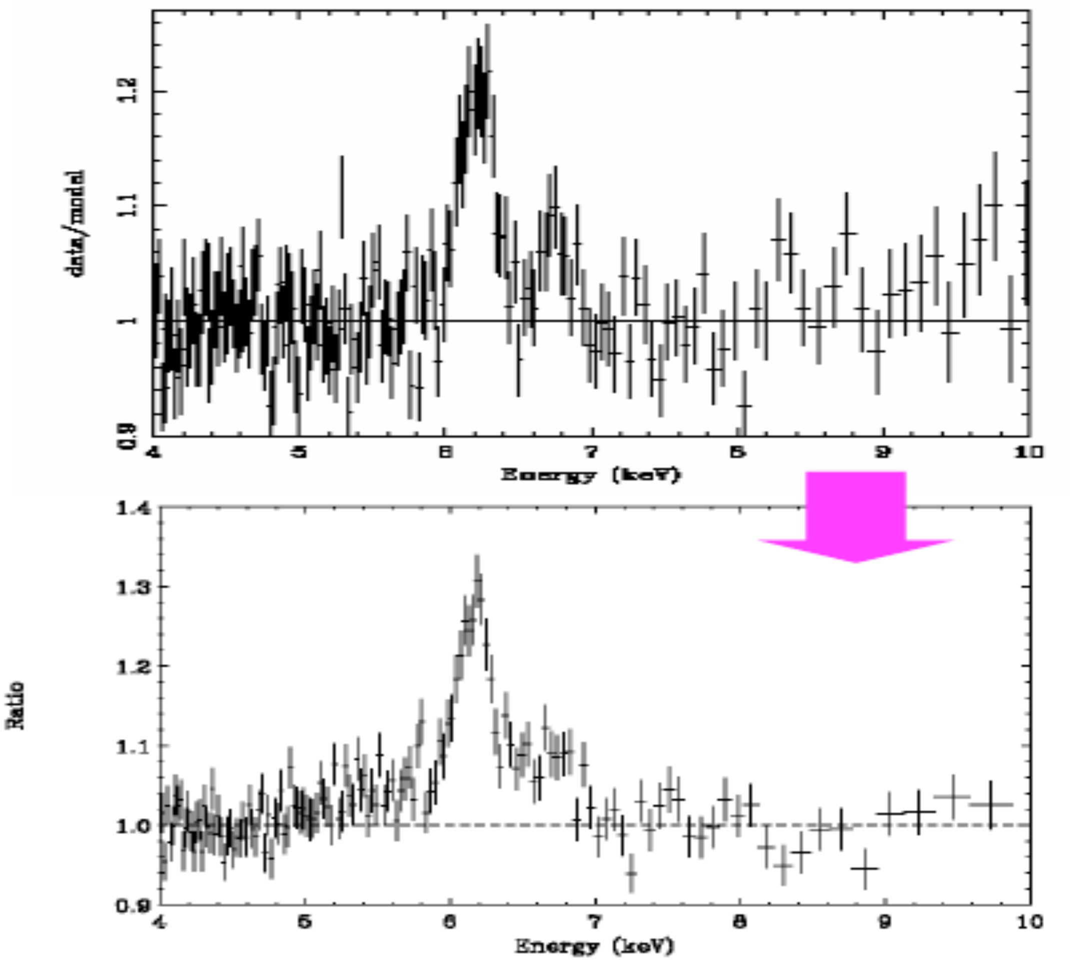


Non-Simultaneous Suzaku and XMM Observation- *notice the variation of the Fe K line shape*

Iron line Profile of 3C120

Kataoka et al

Comparison with XMM: revisited



XMM (130ksec)

Ballantyne, Fabian & Iwasawa 2004, MNRAS, 354, 839

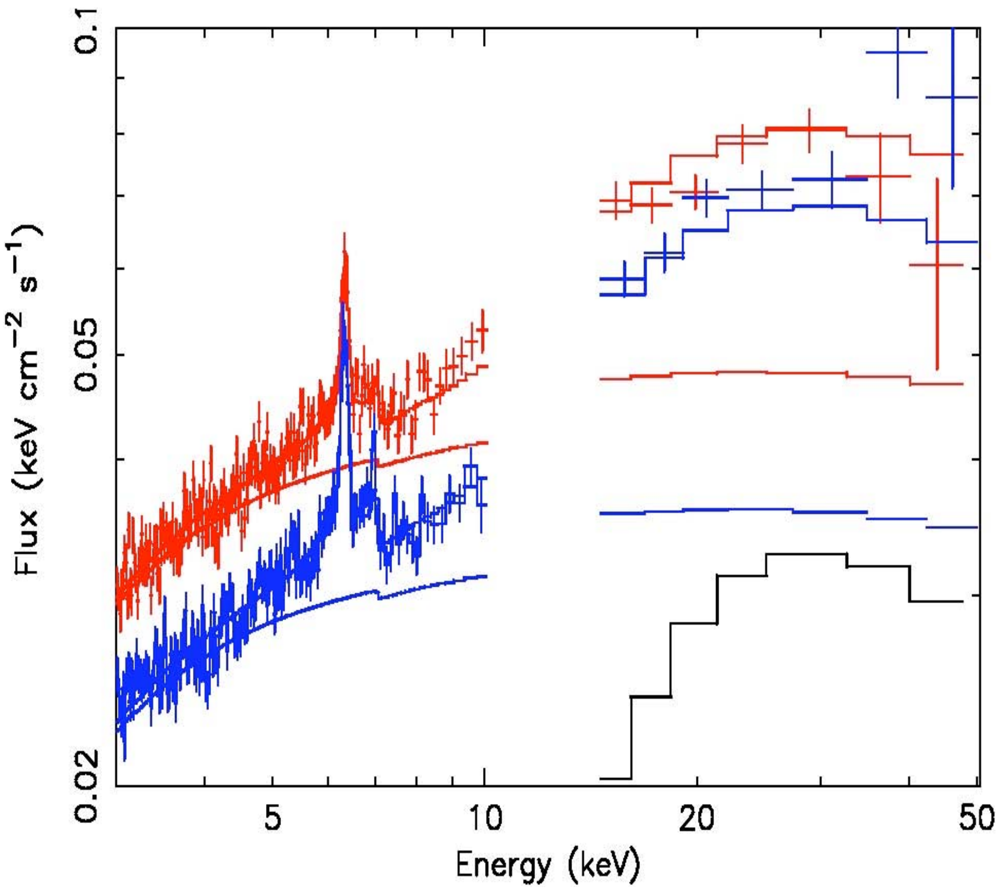
See, also Ogle et al., 2005, ApJ, 618, 139

Suzaku (150ksec)

(1) red-wing in 6.4 keV
(2) much better statistics
(3) clear 6.9 keV bump
(4) extremely low BGD

Variations in the iron K line and Reflection Component

High flux = Red; Low flux = Blue;
Reflection:Black



Observation split into high and low flux states

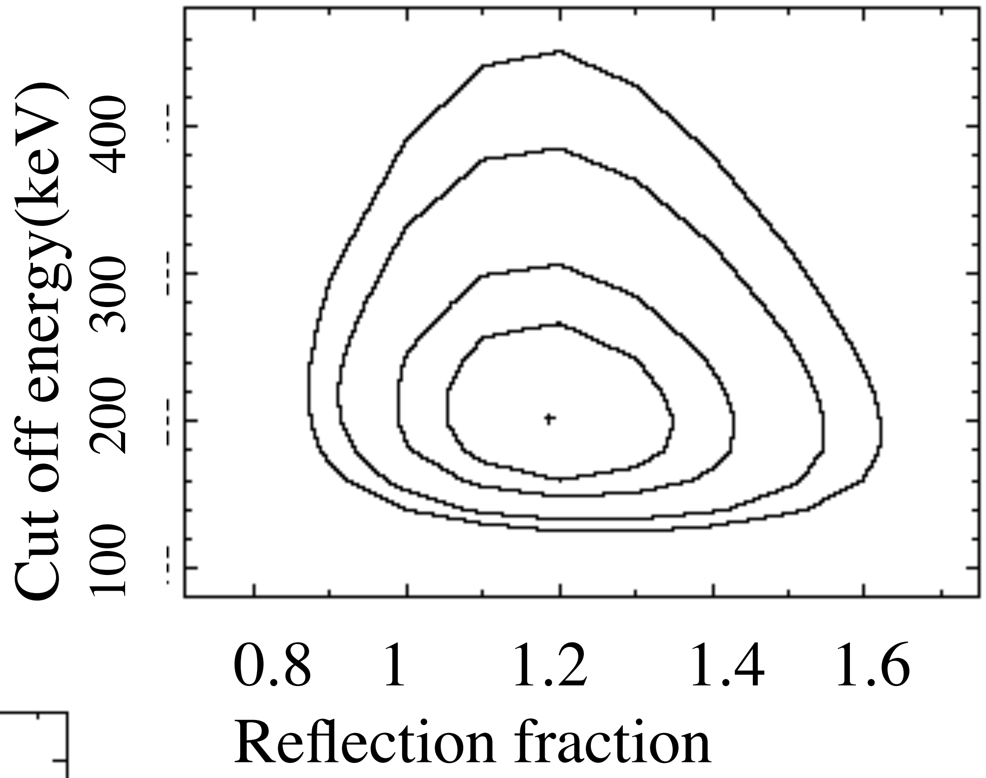
Iron K line and reflection component do not appear to vary during observation.

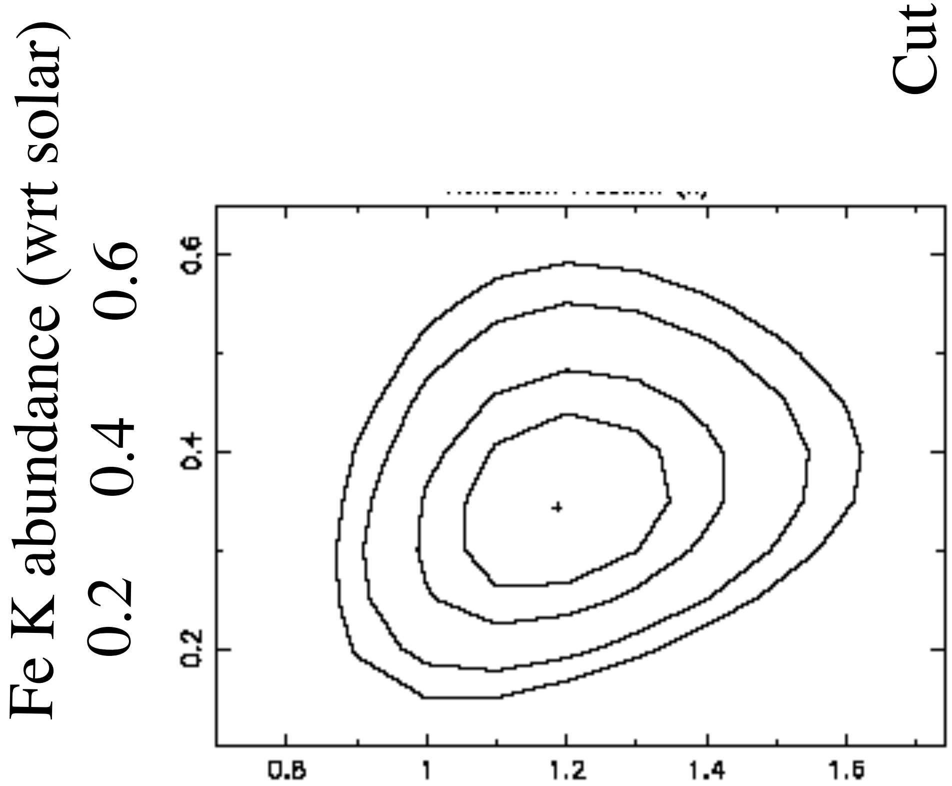
Spectra can be fit with a superposition of a variable power-law and constant Fe line + reflection hump.

Weak variations in broad Fe line cannot be statistically excluded though.

MCG-5-23-16 Parameters are well determined

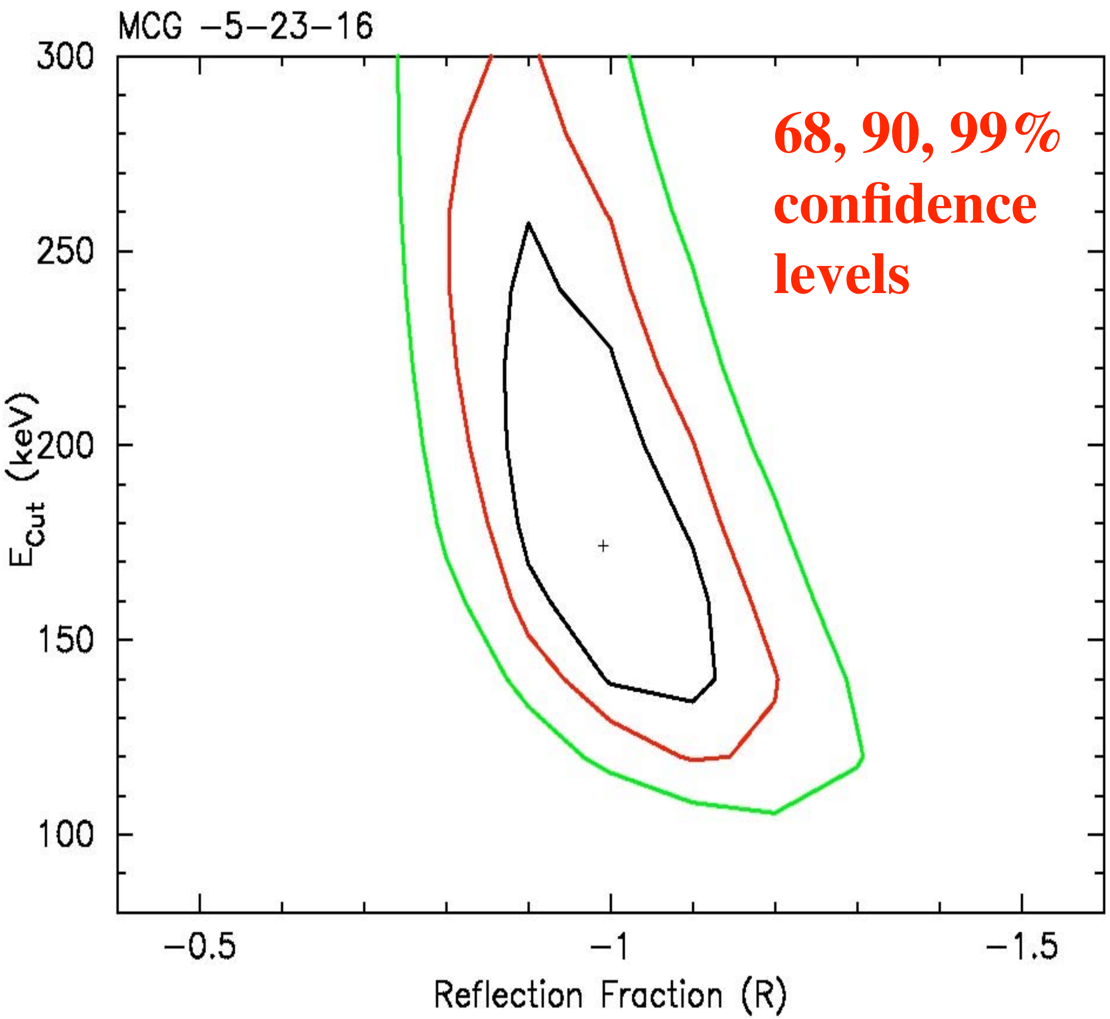
- Fe abundance of reflector, cutoff energy and reflection fraction are all well determined and are not highly correlated with each other





Accurate measurement of the Fe abundance of material near the black hole

Reflection component is not strongly dependent upon cut-off energy



Joint fit between Suzaku XIS+HXD and XMM/PN. Best fit R=1.1±0.2, E_{cut}~150 keV.

Only very weak dependence between reflection fraction (R) and high energy cut-off

Consistent measurement with simultaneous RXTE data (R=1.0±0.4).

Previous SAX measurement poorly constrained R (90% error R=0.2-1.4)

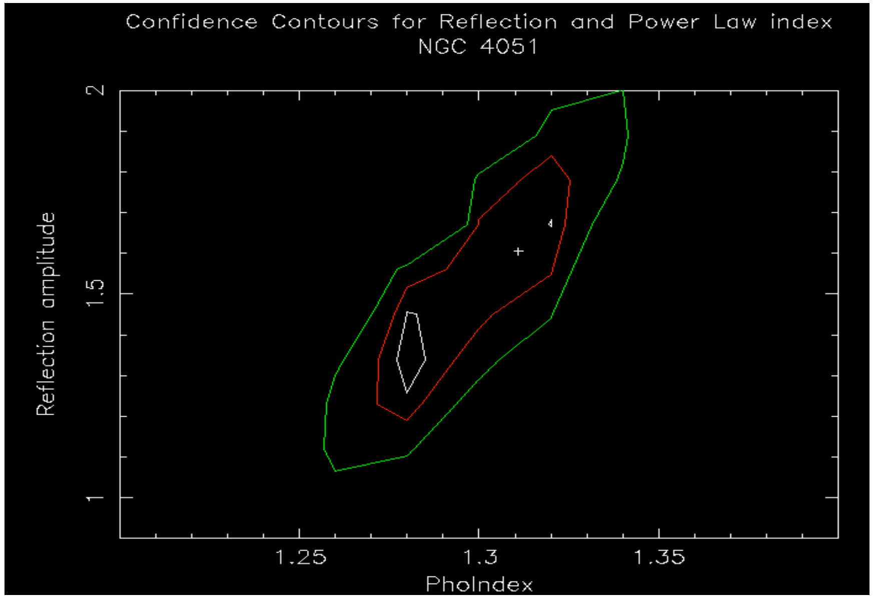
NGC4051- Terashima et al

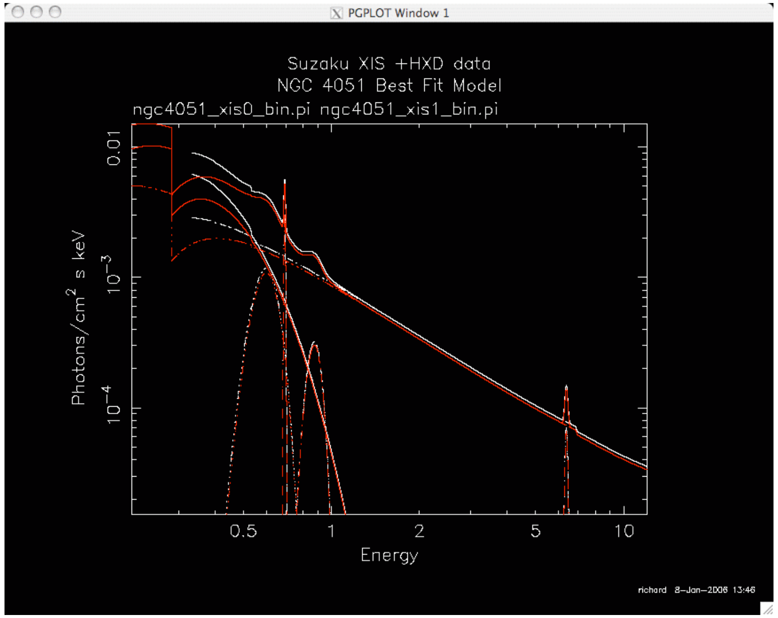
- Object also in a low state
- Clear spectral features at low energies- these can be modeled by 3 emission lines

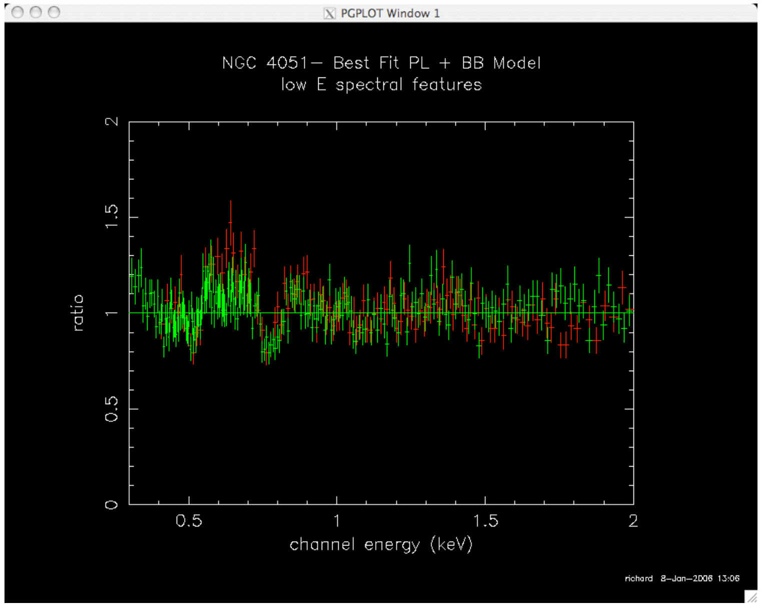
E=0.87,E= 0.597, E=0.692

While solution is not unique, need for emission features is secure

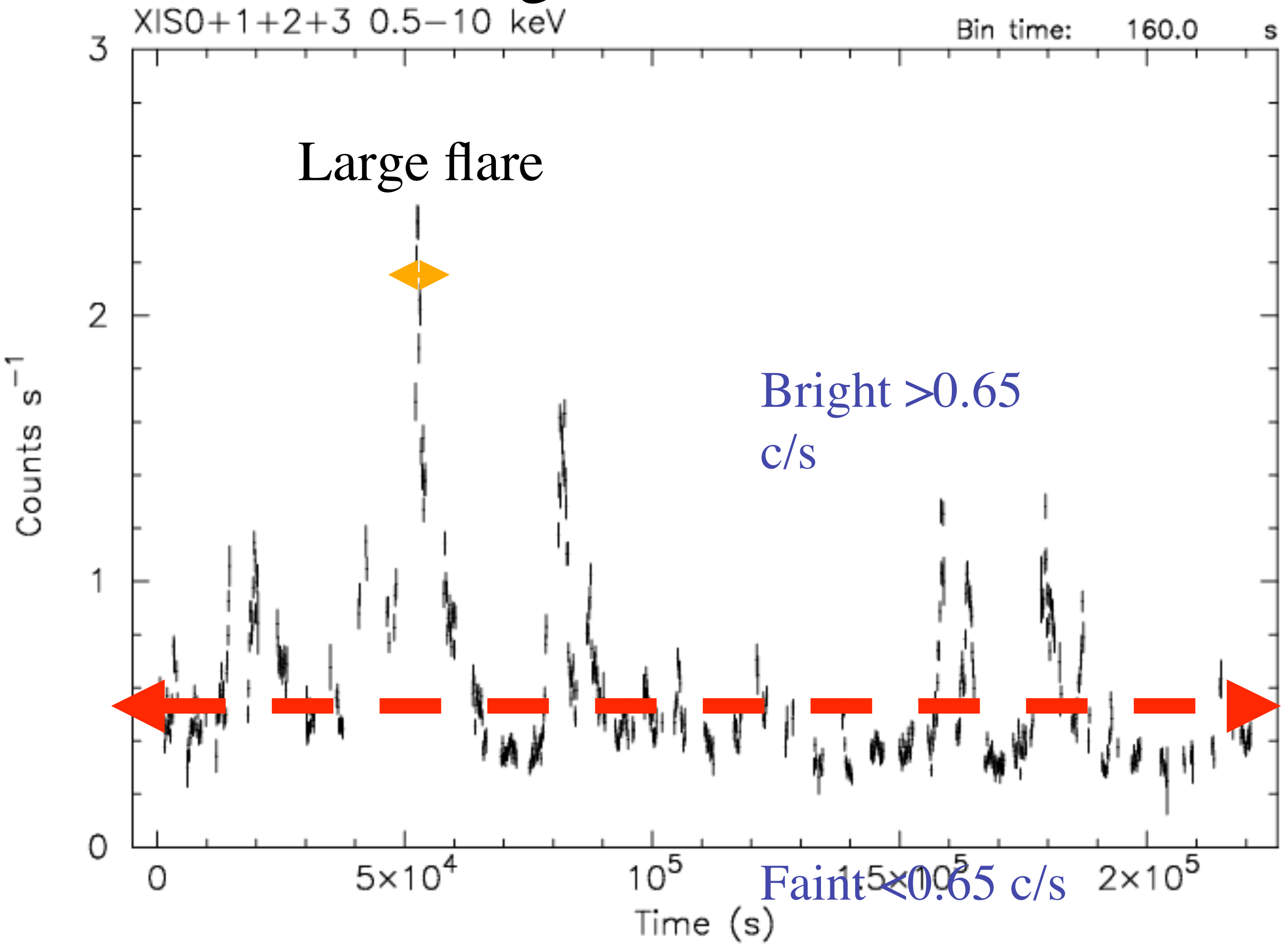
High energy emission can be well described by a Γ= 1.3 PL + reflection with R=1.6 (1.15-1.85) if E(cutoff)=100 keV







NGC 4051 Light curve-Terashima et al

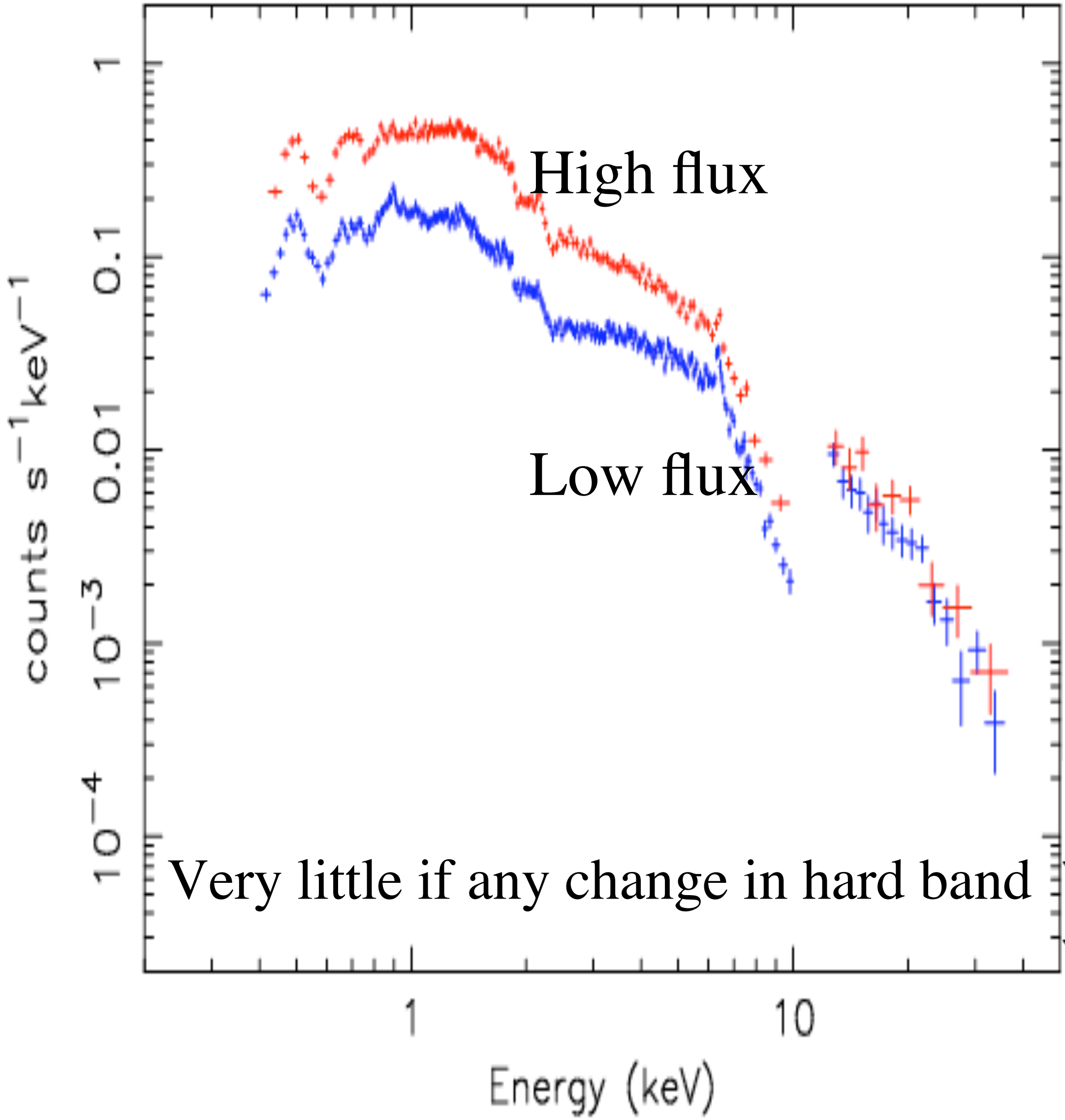


86 ksec XIS+HXD simultaneous exposure

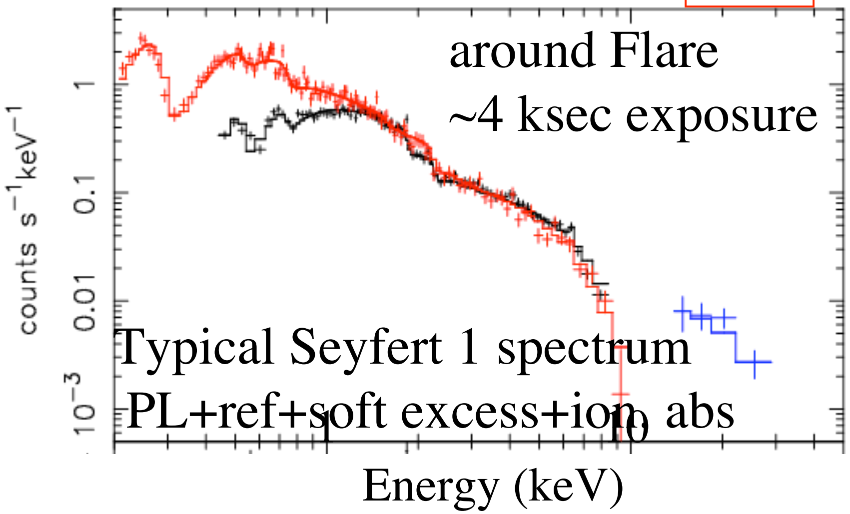
Average flux in 2-10 keV

9×10^{-12} erg/s/cm^2

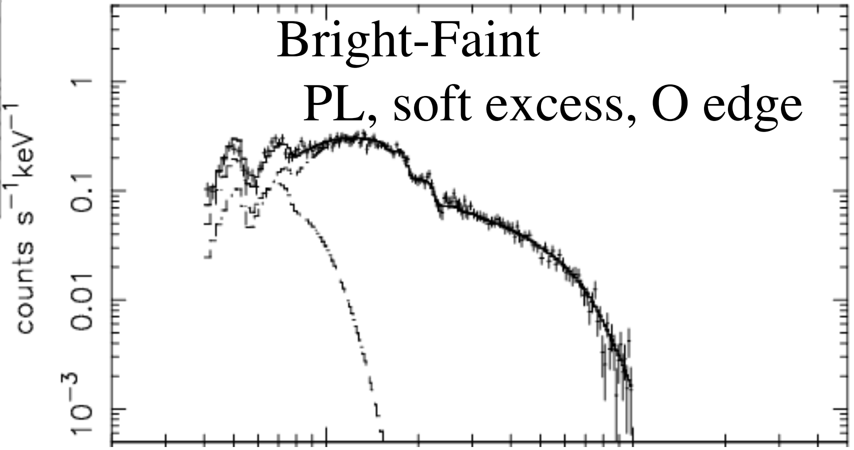
NGC 4051- Spectral Variability



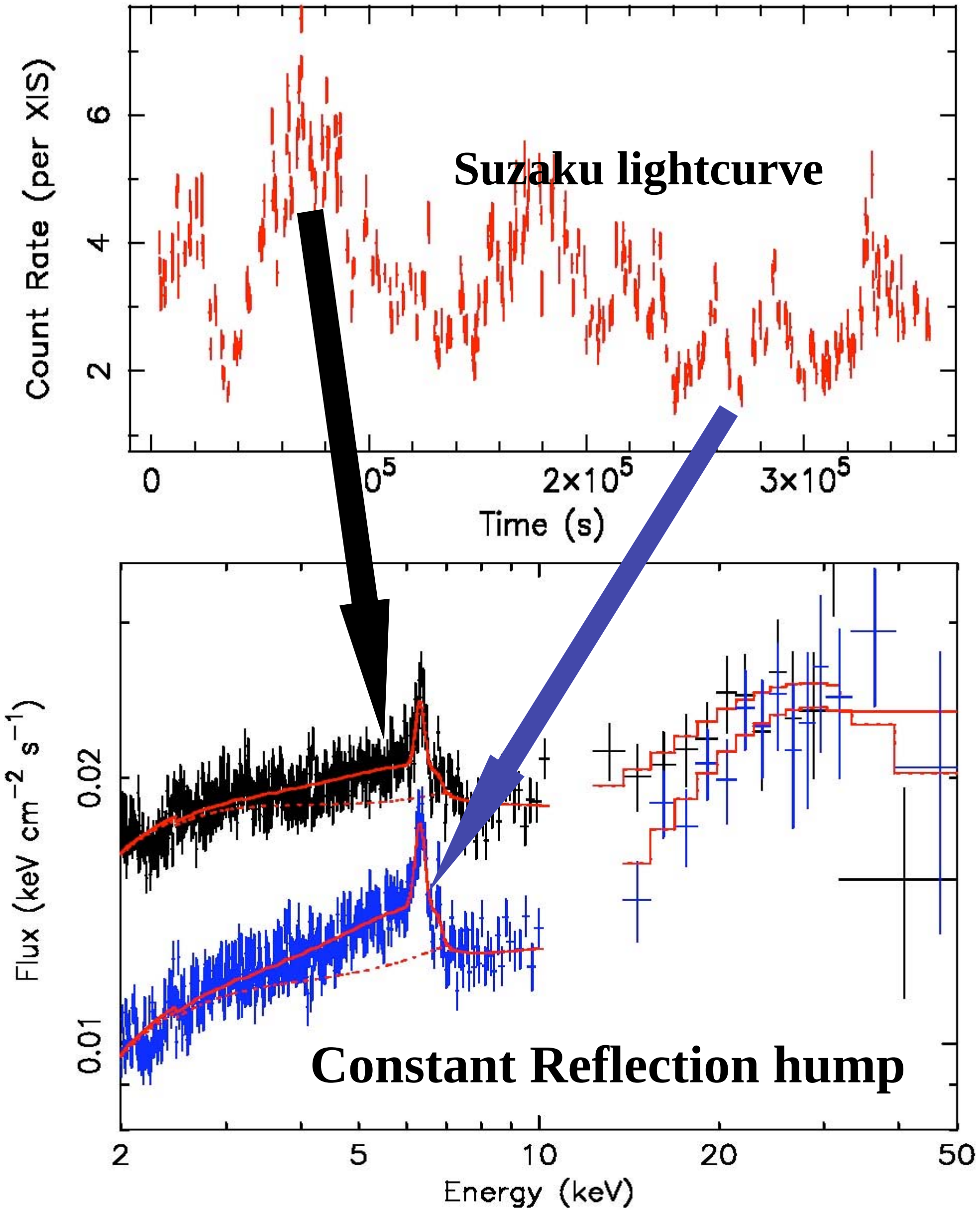
Time resolved hard-X spectra:



Convex continuum at fainter flux
partial coverer?, reflection?

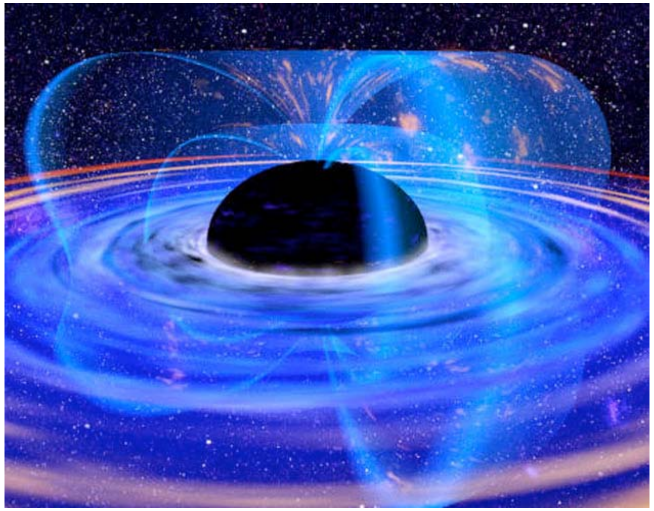


Probing the Innermost Disk - the Suzaku Long Look of MCG-6-30-15 Fabian et al (Jan 06)



Strong iron K line and disk reflection from around a Kerr (spinning) black hole

No variations in Fe line/reflection - gravitational light bending around a Kerr BH? (Miniutti & Fabian 2004)



MCG-6-30-15

Time Resolved Hard X-ray Light curve- 25ks time resolution

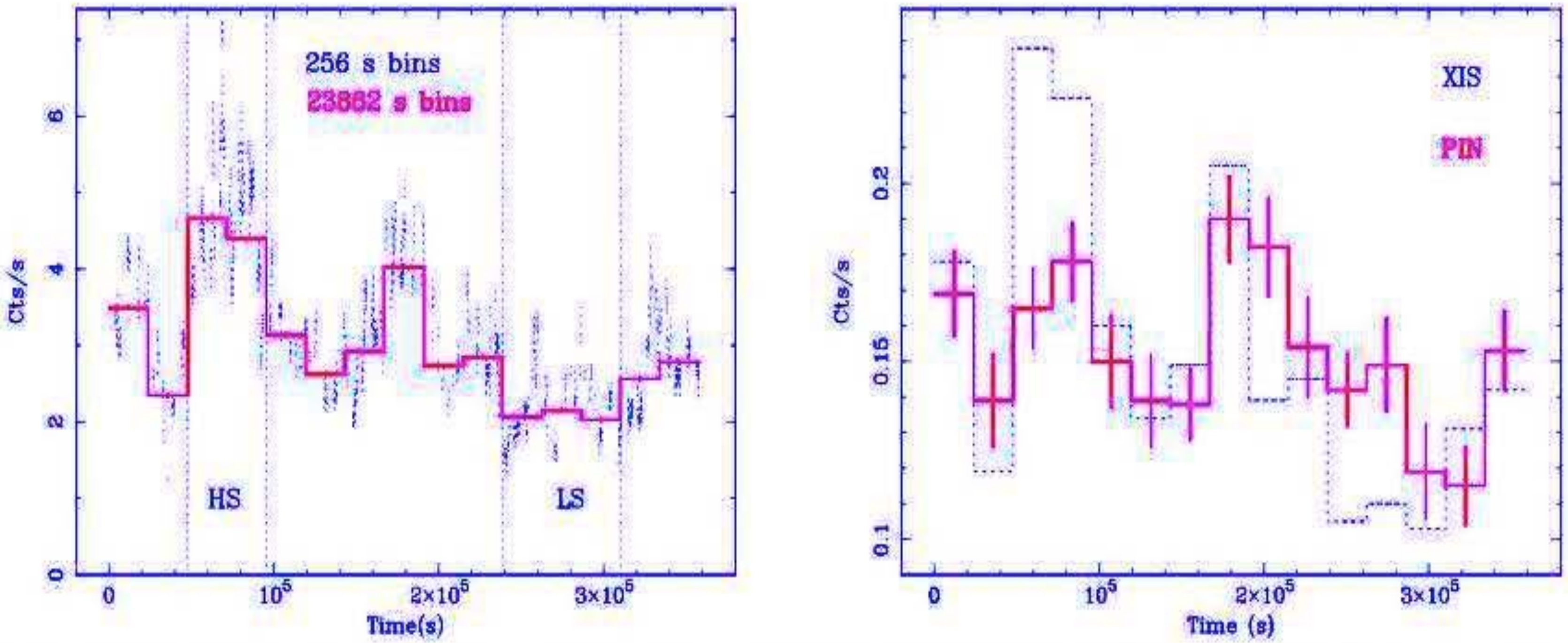
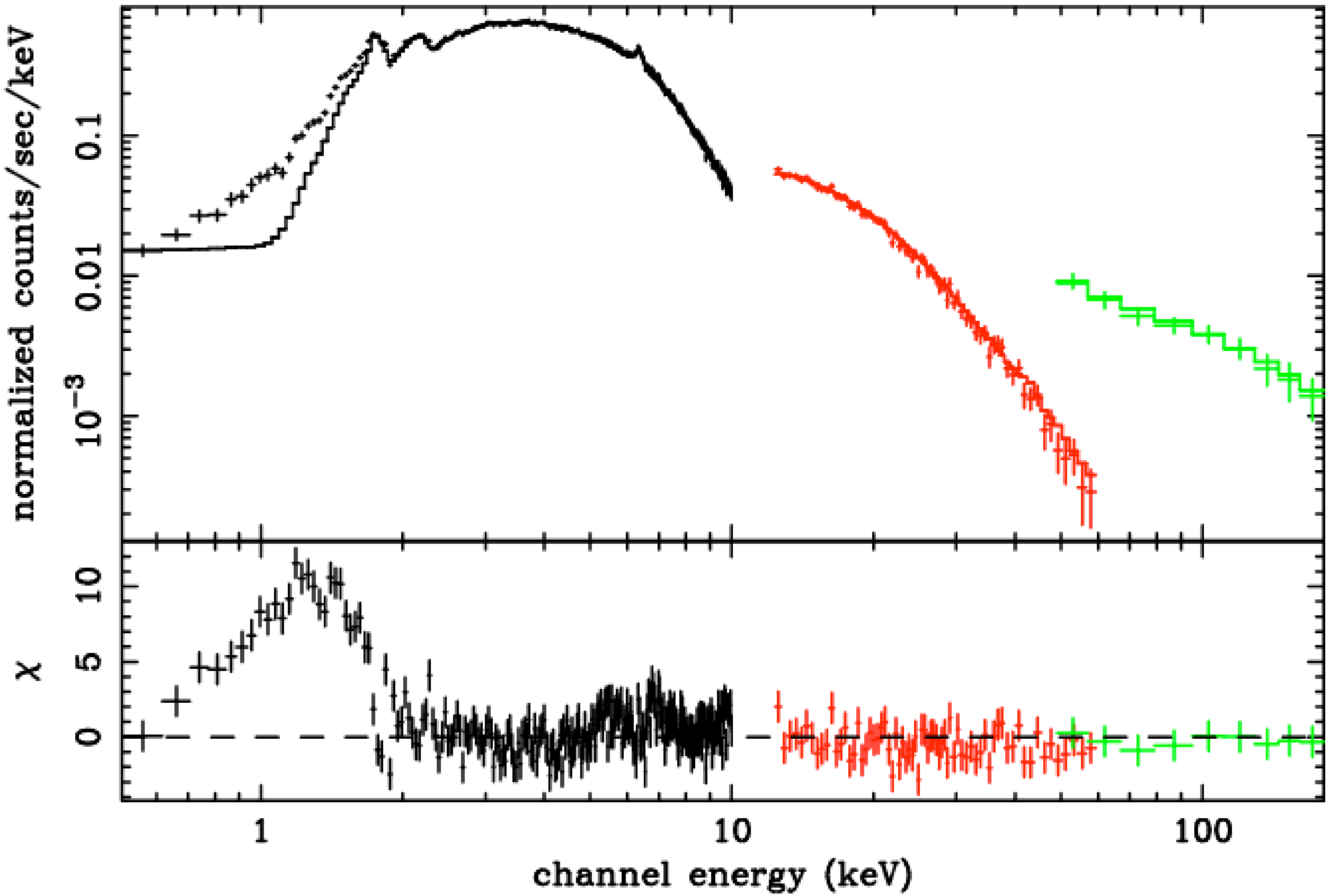


Figure 1: LEFT: The 0.5–10 keV XIS 3 light curve binned at 256s (black) and at 23.862 ks (the chosen timescale for the analysis). We also show two periods defining the source High State (HS) and Low State (LS) during this observation. RIGHT: 12–45 keV PIN light curve on the 23.862 ks timescale chosen for the analysis. We also show in black dotted line the XIS light curve rescaled to the PIN averaged rate for comparison.

Giovanni, Fabian et al.

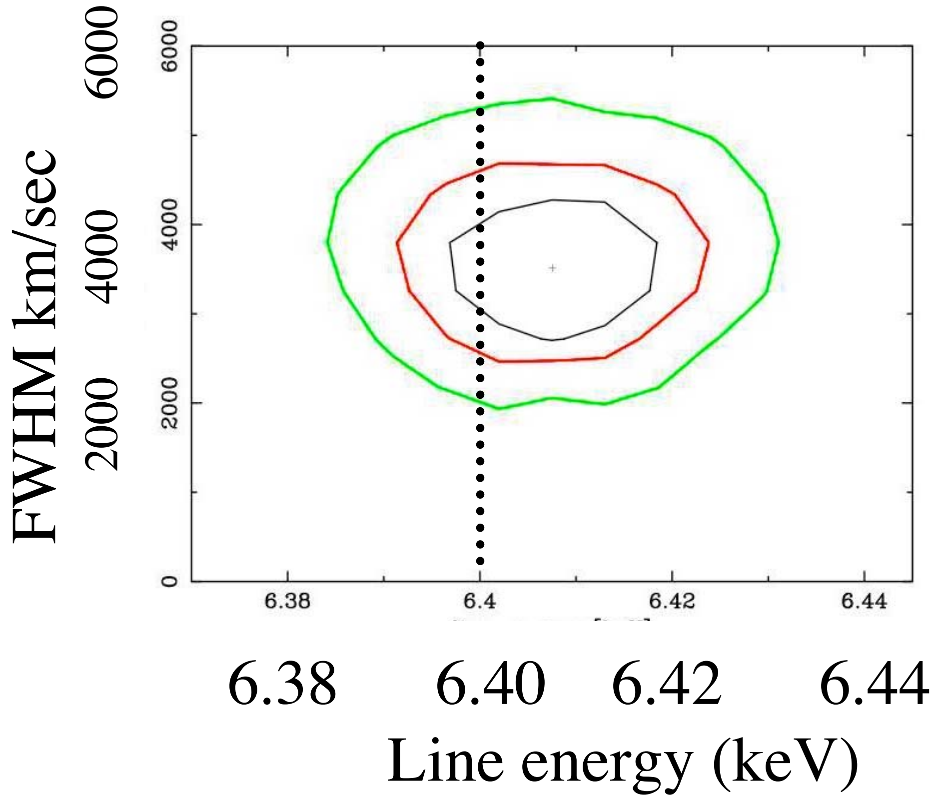
- Probable detection to E>150 keV
- Best fit puts strong upper limit on reflection

NGC2110-Okajima et al



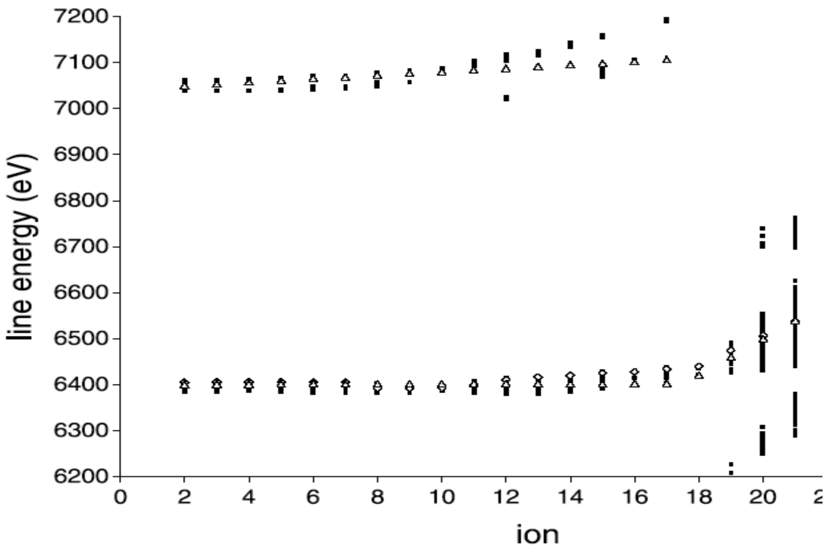
NGC2110- narrow line resolved

- Suzaku data have allowed the resolution of several of the ‘narrow’ Fe K lines with errors similar to that of the Chandra HETG
- The ionization state of the Fe can be determined from the ratio of Kα/Kβ and the energy of the Fe K line

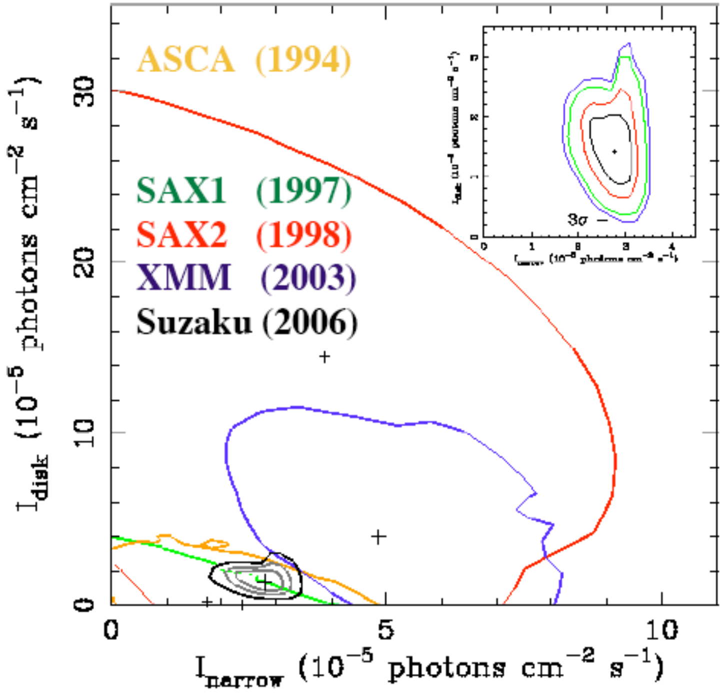


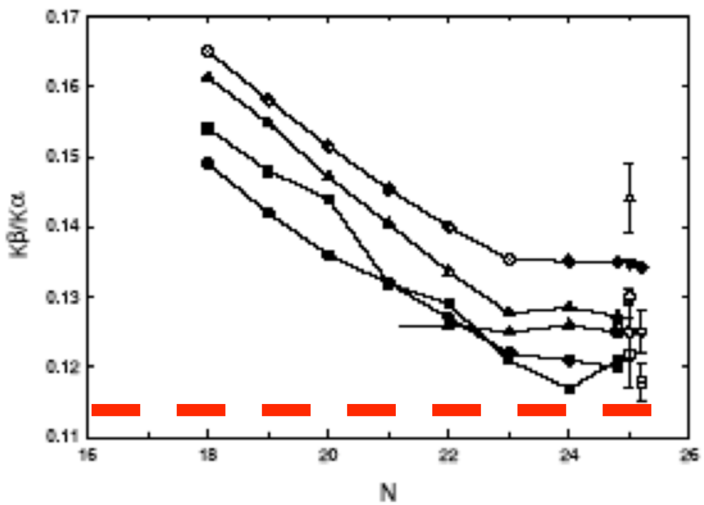
Fe Line shapes ratio and energies

- The ratio of Kα/Kβ is sensitive to the ionization state of Fe (Palmieri et al 2003) as are the line energies
- The Suzaku data can decouple the narrow and broad Fe components in some objects
- In NGC2110 the Kα/Kβ ratio indicates that Fe is less ionized than Fe IX



NGC 2992: Comparison with attempts at the Fe K line complex deconvolution from previous data.





NGC2992- Yaqoob et al

- By combining the energy and line ratio information one can get a tight constraint on the ionization state of Fe.

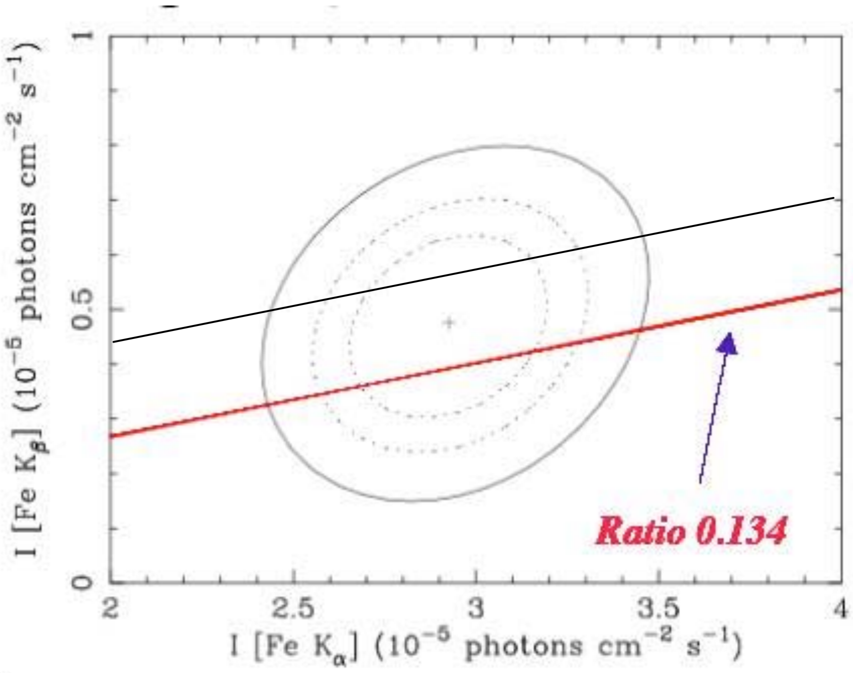
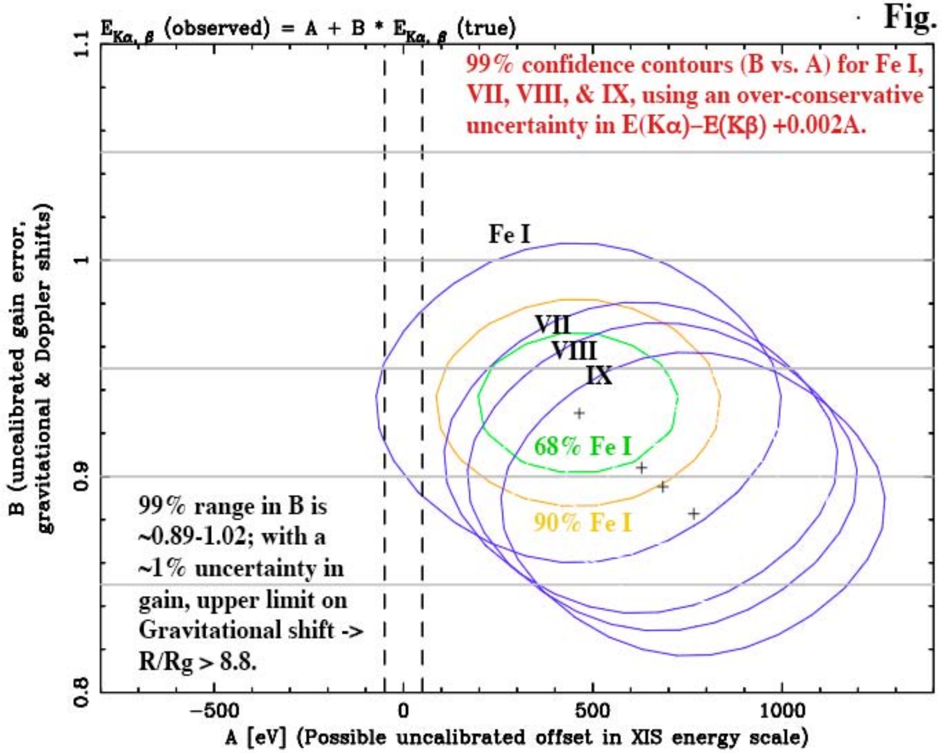
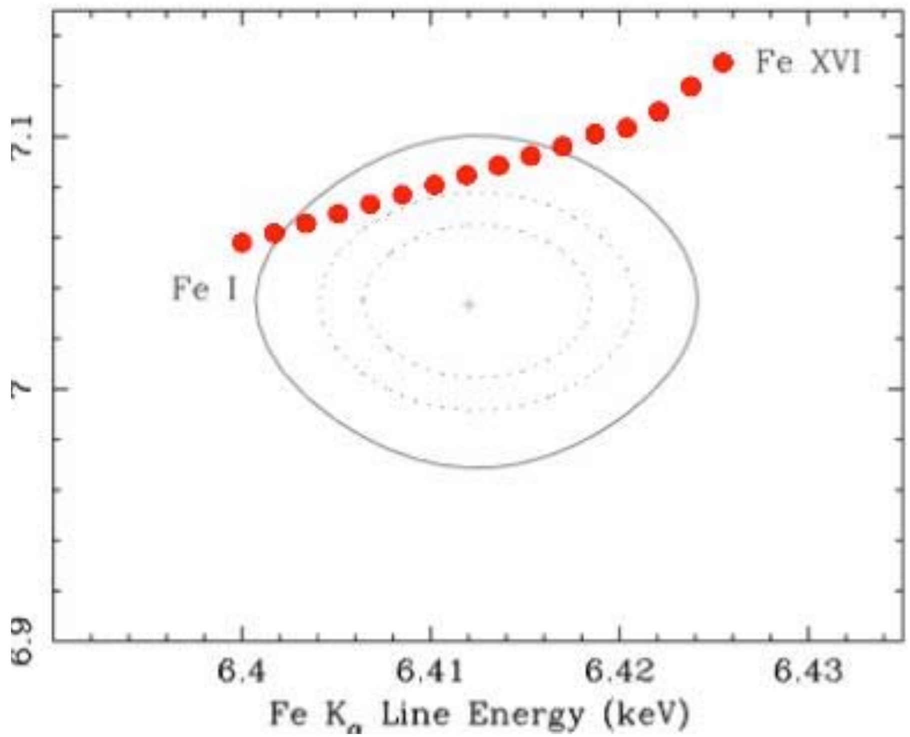


Fig. 5





Cen -A Fe K bandpass emission-

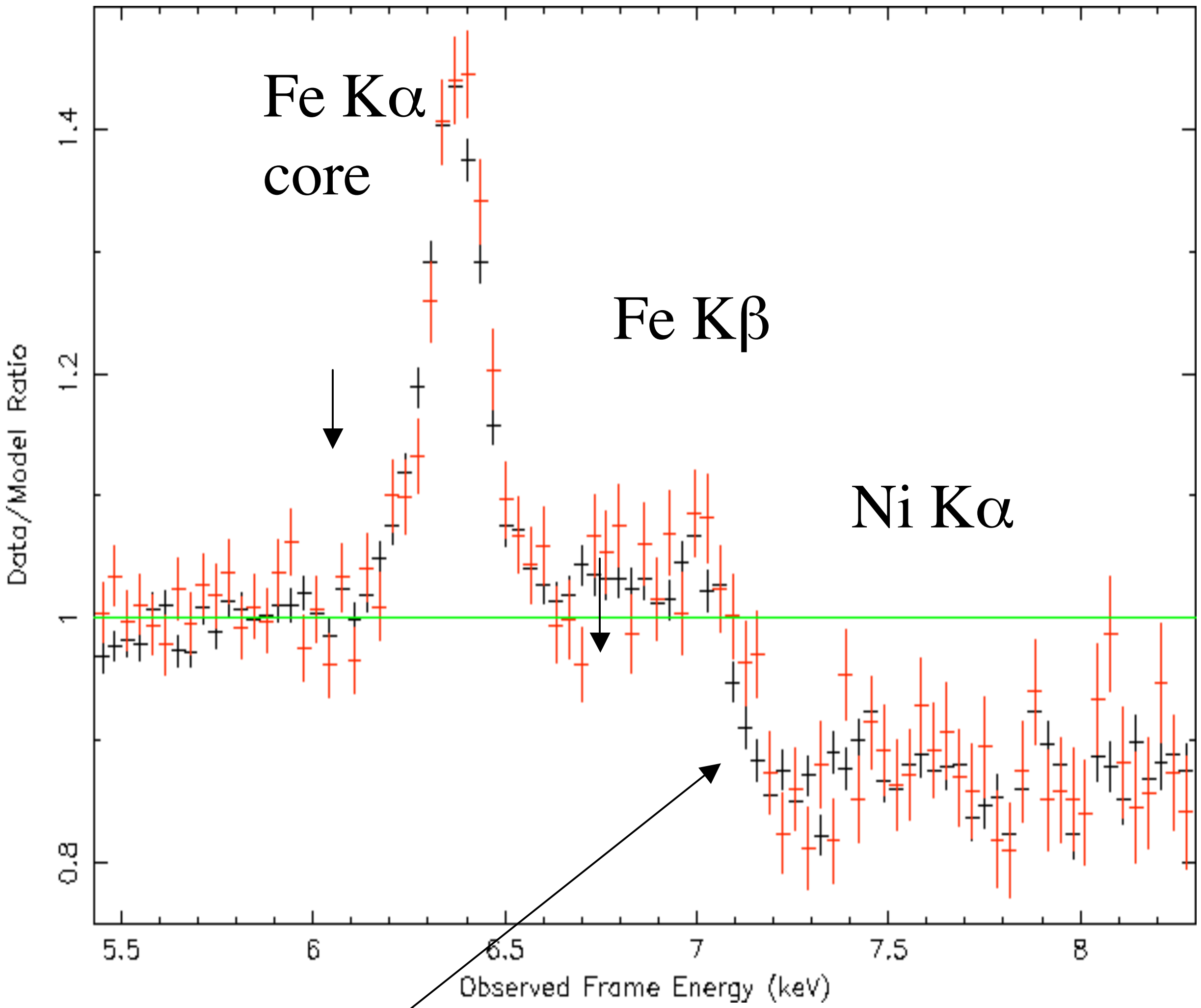
Markowitz et al

Line width of emission lines: $\sigma = 29\ (+6,-22)$ eV, v= 3100 (+600,-2500) km/s, suggesting $R_{Fe} > 6600\ R_{\_Sch}$ (Chandra HETG result of Evans+ 2004).

for a 1.8 $10^8\ M_{sun}$ black hole, this is ~120 light-days from the nucleus.

The absorbing material is consistent being the origin for the Fe K α line, ina uniform-density gas (as opposed to gas distributed as r^{-2}) (Leahy & Creighton (1993).

No Compton hump seen: Fe K line originates in Compton-thin material

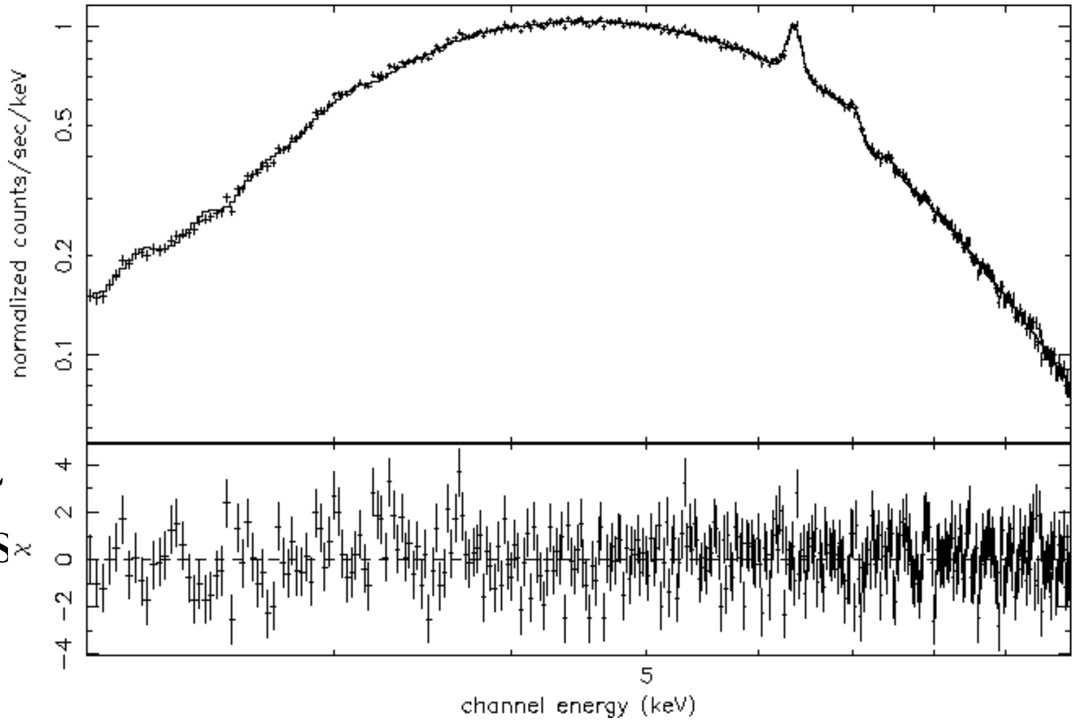


Edge at 7.15 ± 0.01 keV corresponds to optical depth $\tau = 0.20 \pm 0.01$

Cen-A Hard X-ray Nuclear Emission & Absorption

The absorbing material has a column $N_H = 1.81 \pm 0.04 * 10^{23}$ cm^{-2} with almost solar **abundance ratios**

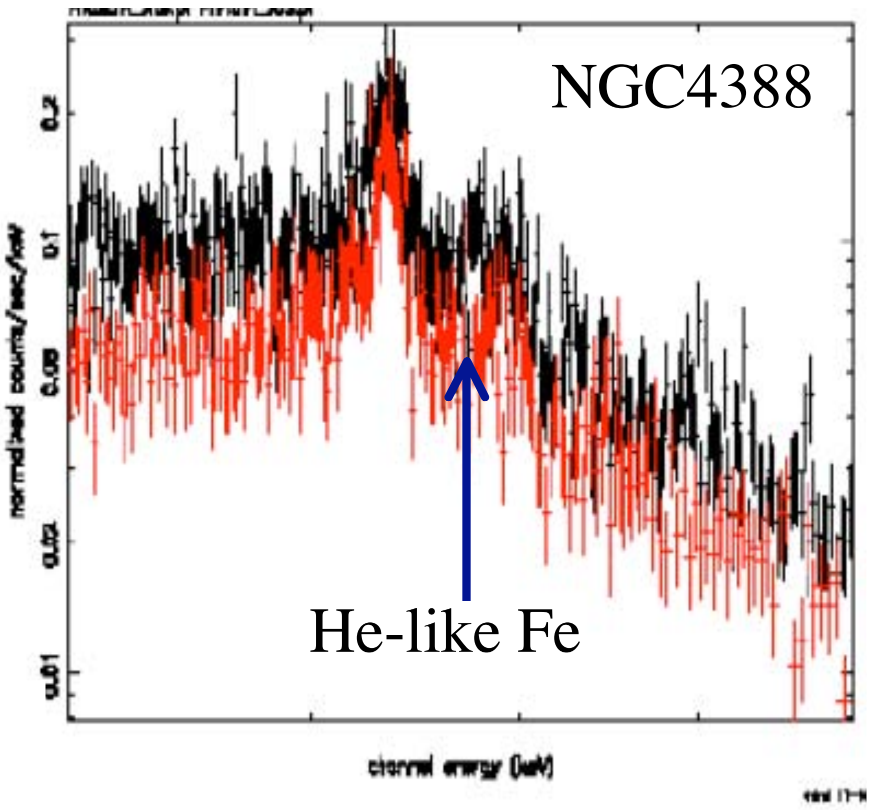
Abundances determined from the Si and Fe edges and the strength of Ni K α, Ca K α and Ar K α emission lines

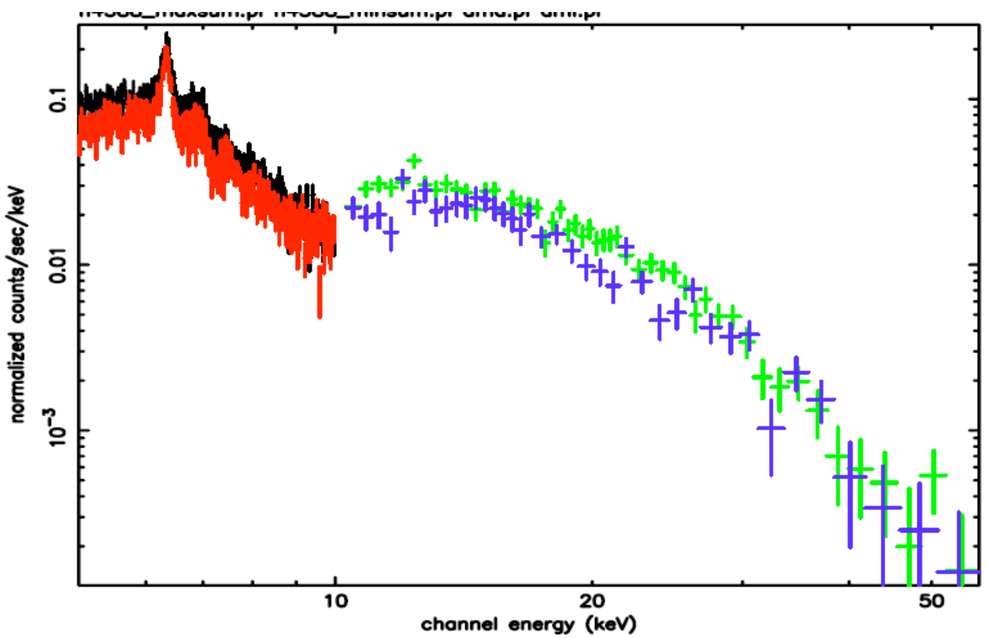


Ni/Fe	1.8 (+2.1,-1.4)
Ca/Fe	1.2 (+1.2,-0.7)
Ar/Fe	0.8 (+0.7,-0.6)
Si/Fe	1.1 (+0.6,-0.4)

Spectral Changes During variability

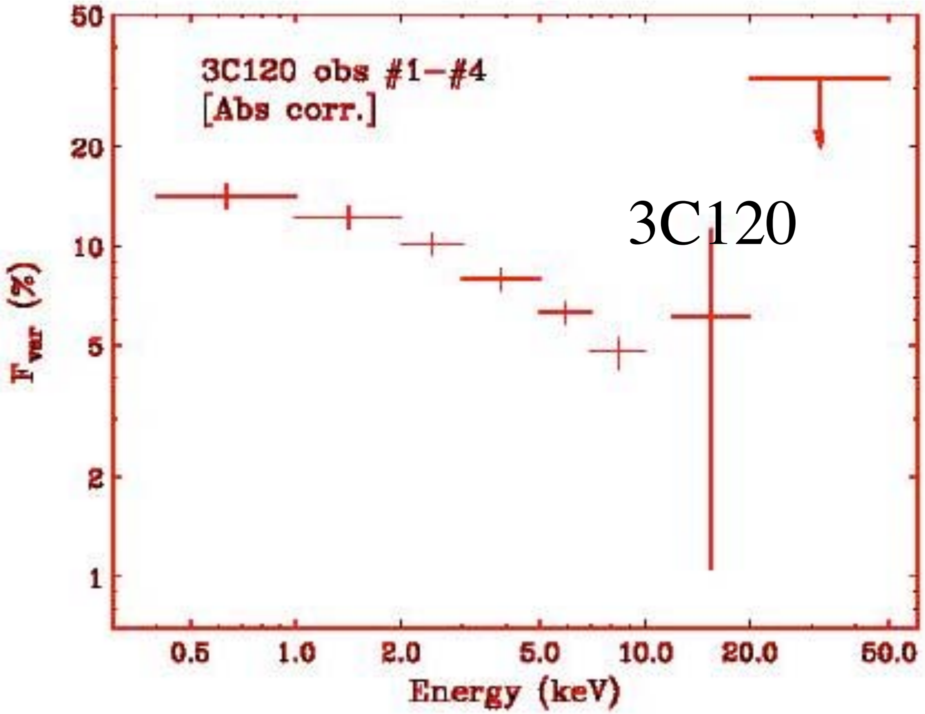
- NGC4388 (Fukazawa et al) shows spectral changes between the brighter and dimmer flux states in both line strengths and continuum form (less variable at E>30 keV)
- In particular the He-like line responds to continuum changes



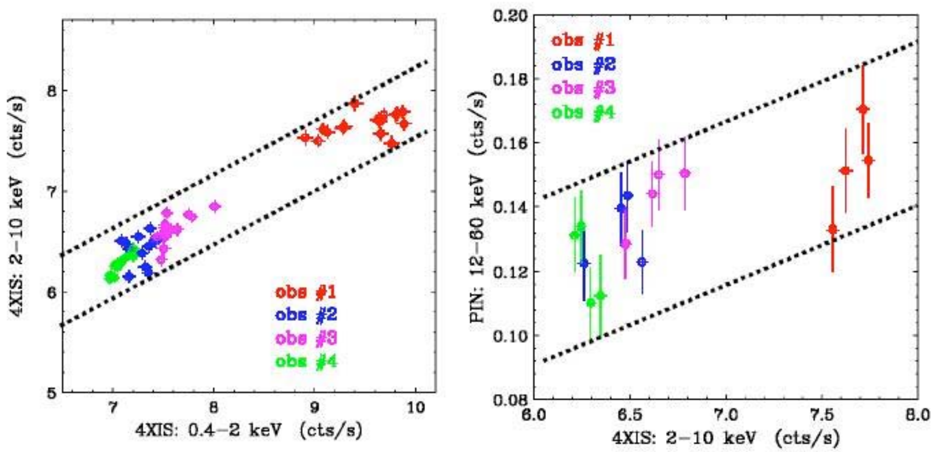


Spectral Changes During variability

- In 3C120 the .4-2 and 2-10 kev fluxes are strongly correlated, but the 20-100 and 2-10 kev are much less well correlated (Kataoka et al)
- Variability amplitude decreases with energy

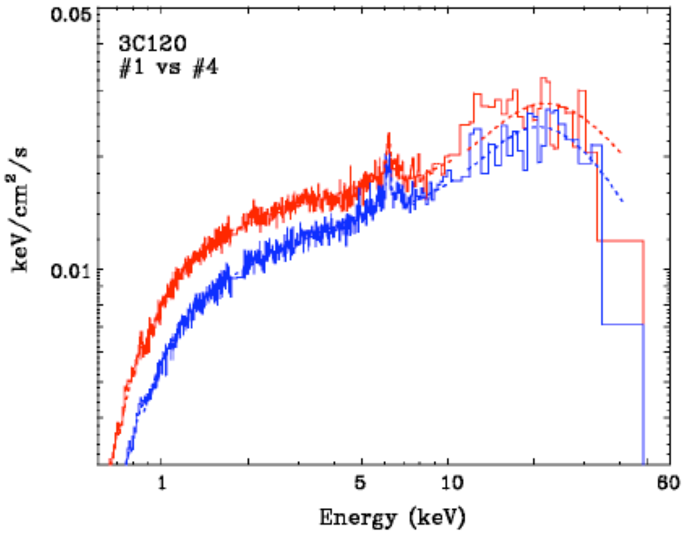


Variability Correlations



- Soft and hard X-ray fluxes are well correlated, but not very much tightly (see some "width" in the left panel).
- XIS (2-10keV) and PIN variability is also weakly correlated.

SED in Low & High States



- Comparison of SEDs in obs#1 (HIGH) and obs

Conclusion

- Suzaku will add a large sample of very high quality AGN spectra and times series data.
- With the combined power of the XMM EPIC and (better than) Integral or SAX hard x-ray capabilities this will allow
  - Breaking the degeneracies between broad Fe K lines and continuum shape
  - Measurement of reflection component
  - Connection between soft x-ray ‘excess’ and reprocessing
  - Abundance determinations of the reprocessing material

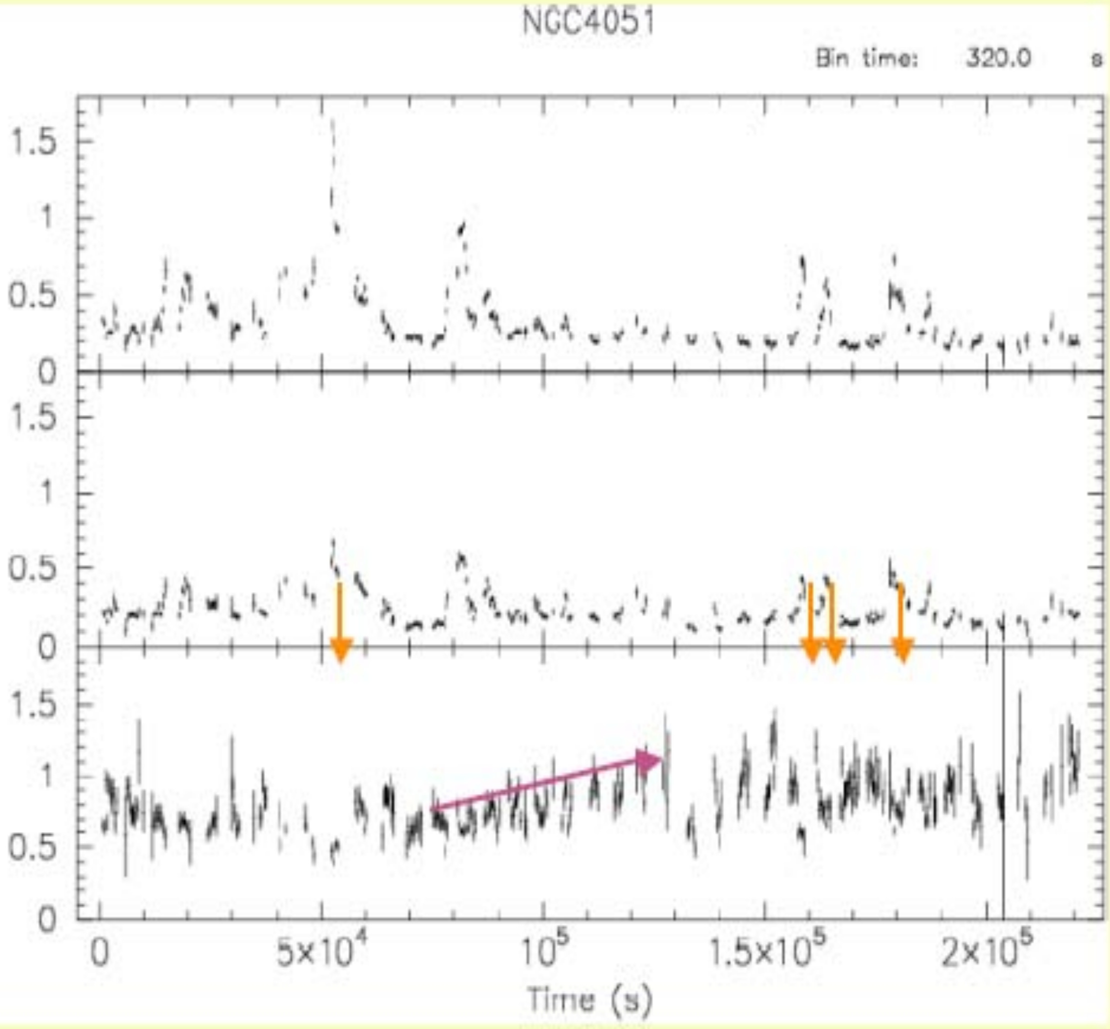
over **200** Swift BAT detected AGN available for detailed study with the HXD and similar quality data can be obtained

The Integral and Swift BAT hard x-ray galactic plane samples will allow similar results for >150 galactic sources.

NGC4051- Complex Spectral Temporal Behavior

- Many large amplitude flares detected.
- Spectrum softens at most of the flares (↓).
- Spectrum gradually hardens in the middle of the observation (↗).

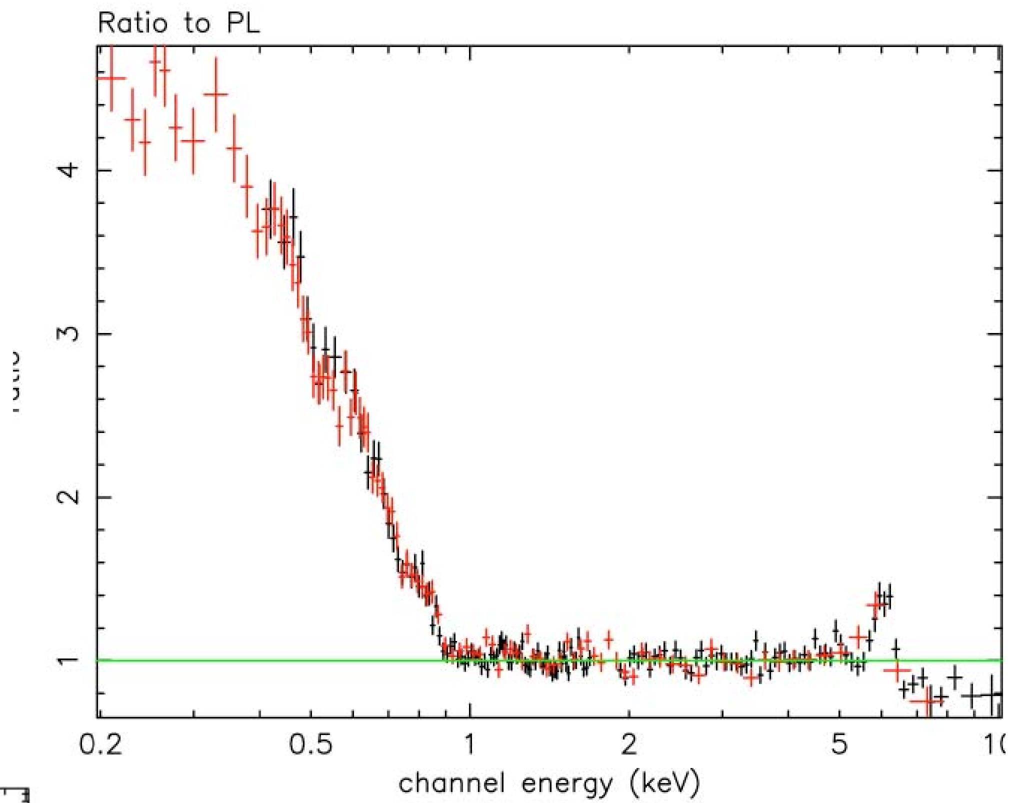
0.5-2 keV, 2-10 keV and hardness

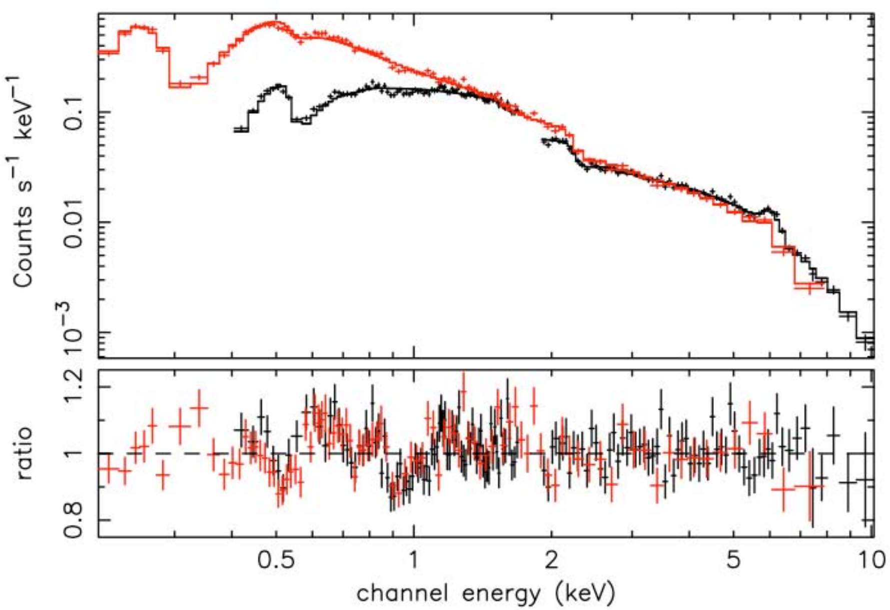


Fe K line region shows complexity- if fit with a narrow Fe K line, it is resolved with σ ~3000+/-500 km/sec similar to the Chandra result

PG1211-
J. Reeves et al

- Narrow line Seyfert I that has shown evidence for relativistic outflows
- Suzaku obs was at a very low state F(X)-3x10^{-12}
- Spectrum shows a strong soft excess- overall continuum well modeled by Γ =1.7 Pl +100 ev Diskbb spectrum
- PIN UL consistent with CXB emission

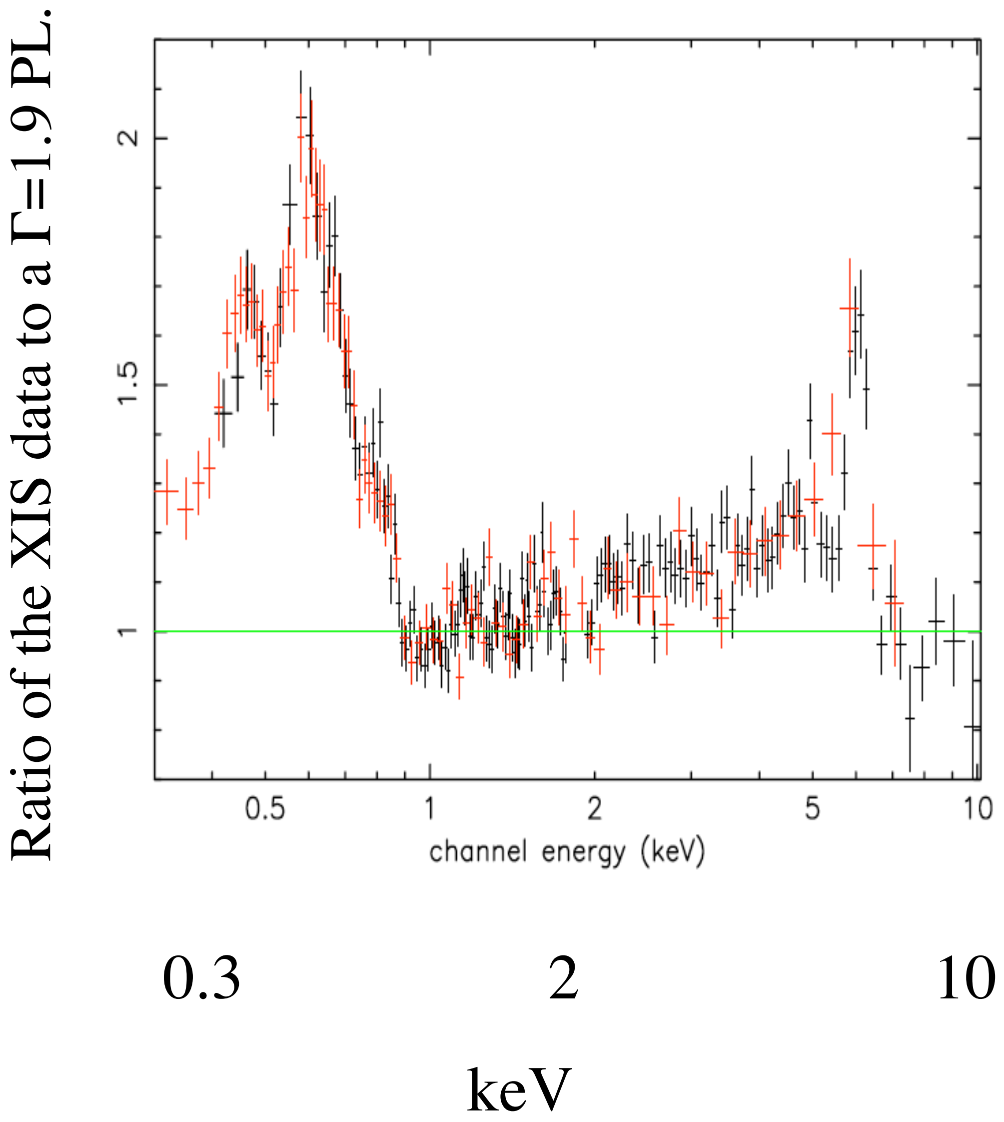




clear residuals which show low energy lines can be fitted with 3 lines EWs of a few 10s eV) from
OVIII Lya (0.65 keV),
Ne IX/Fe L (0.90 keV)
Mg XI (1.35 keV).

PG1211- Broad soft X-ray Lines in Low State?

- very low (2.8x10^{-12} cgs 2-10 band) flux level,
- a resolved Fe K line and the drop above 7 keV expected from the XMM data.
- the soft excess- is very poorly fit with a continuum model (BB or PL) but instead can be fitted with three broad emission lines (N, O, Ne perhaps).
- There was a indication of these broad lines in the earlier RGS spectrum.

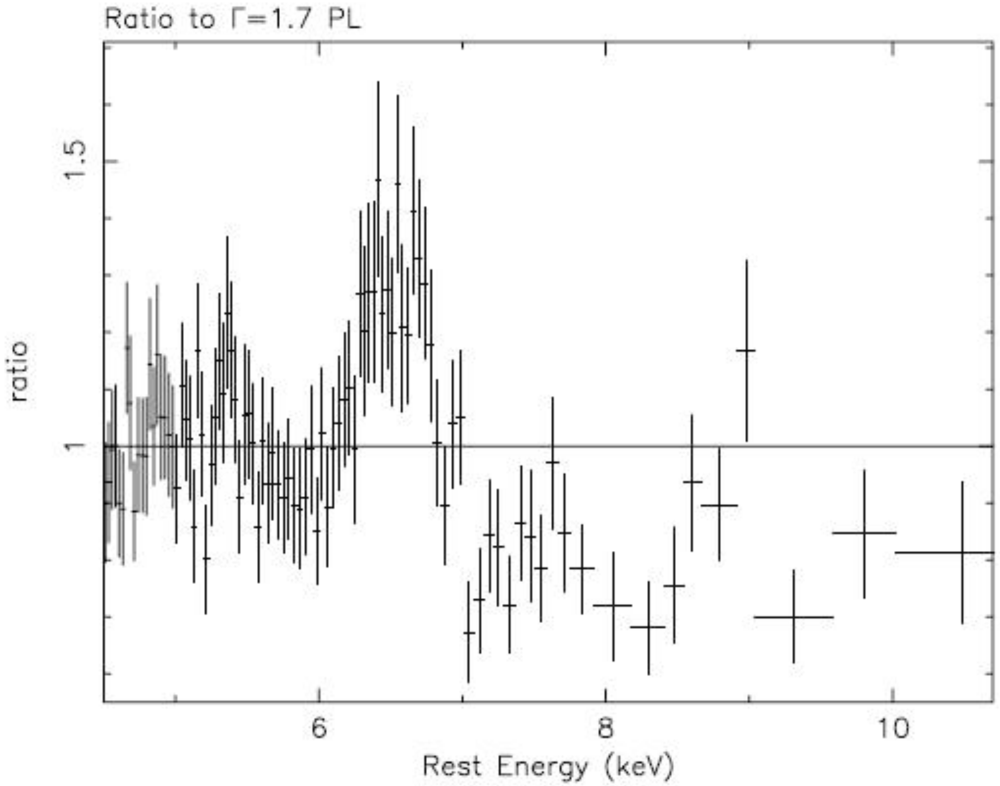


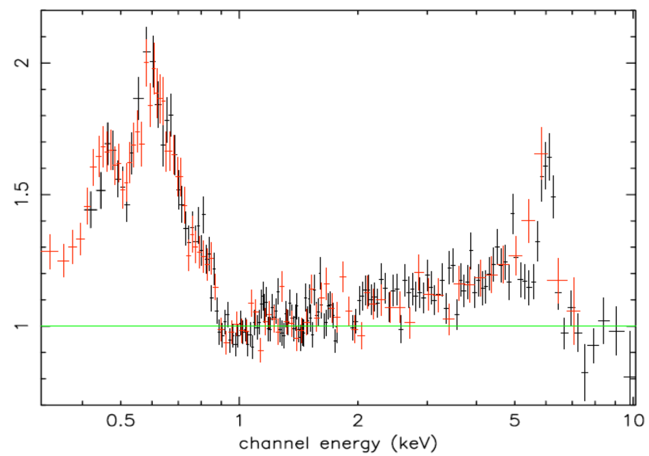
PG1211- Fe Band

- Clear Fe residuals in both emission and absorption The Fe K emission line is broad, centered at 6.6 keV rest frame, with a width of σ =230eV (i.e. FWHM 25000 km/s).
- EW is 250 eV. Intriguingly,

there appears to be at least 2 Fe K absorption troughs centered at 7.2 keV and 8.2 keV rest frame

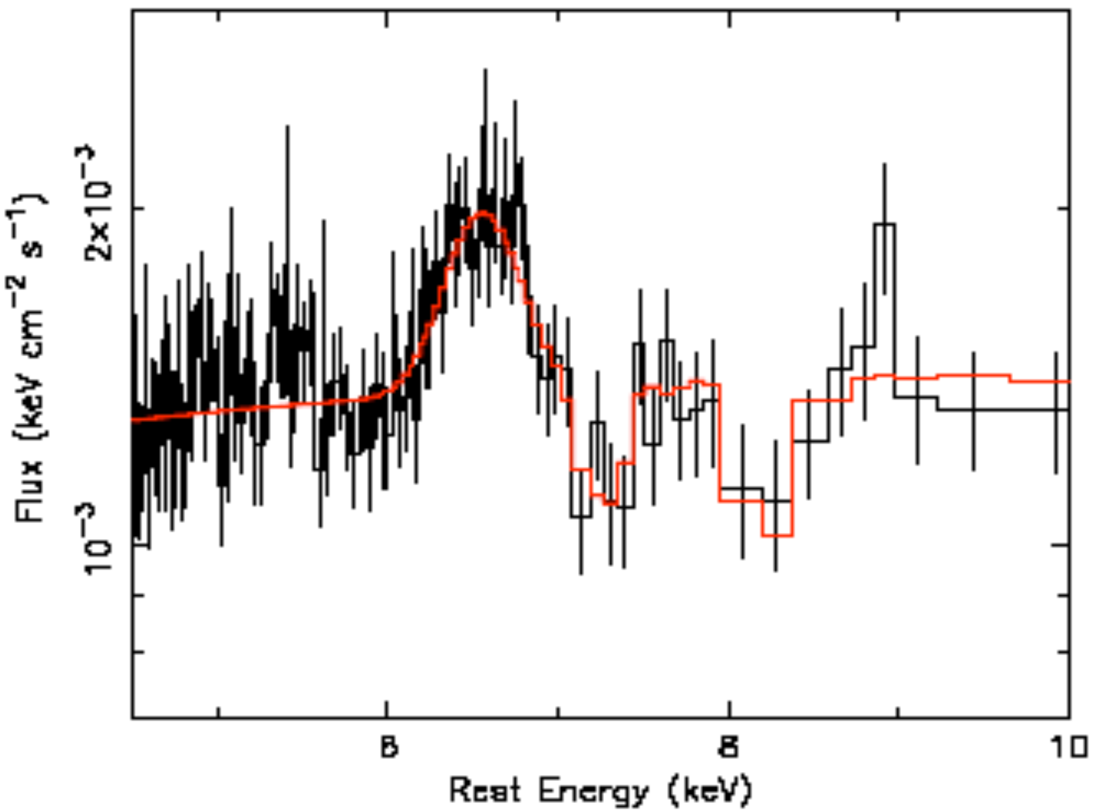
- . Could be velocity broadened resonance abs lines from either Fe XXV or Fe XXVI Kalpha?
- In that case the outflow velocities would be 0.08c and 0.22c (for Fe XXV) or 0.03c and 0.18c for Fe XXVI.





PG1211-XSTAR Fit

- 2 outflow components, velocities 0.1 and 0.2c.
- turbulent velocity is high, σ=3000 km/s (column densities are 10^{22} cm^{-2} and ionization parameter of logxi=2.5-3.0)
- most of the absorption is arising from Fe XXV resonance in the Xstar model.
- lower velocity component (>99.9% conf), the 2nd one is more marginal (about 99% conf, F-test)



PG1211-Comparison of XMM and Suzaku

- 2002 XMM data (red dots)

show relativistic outflow

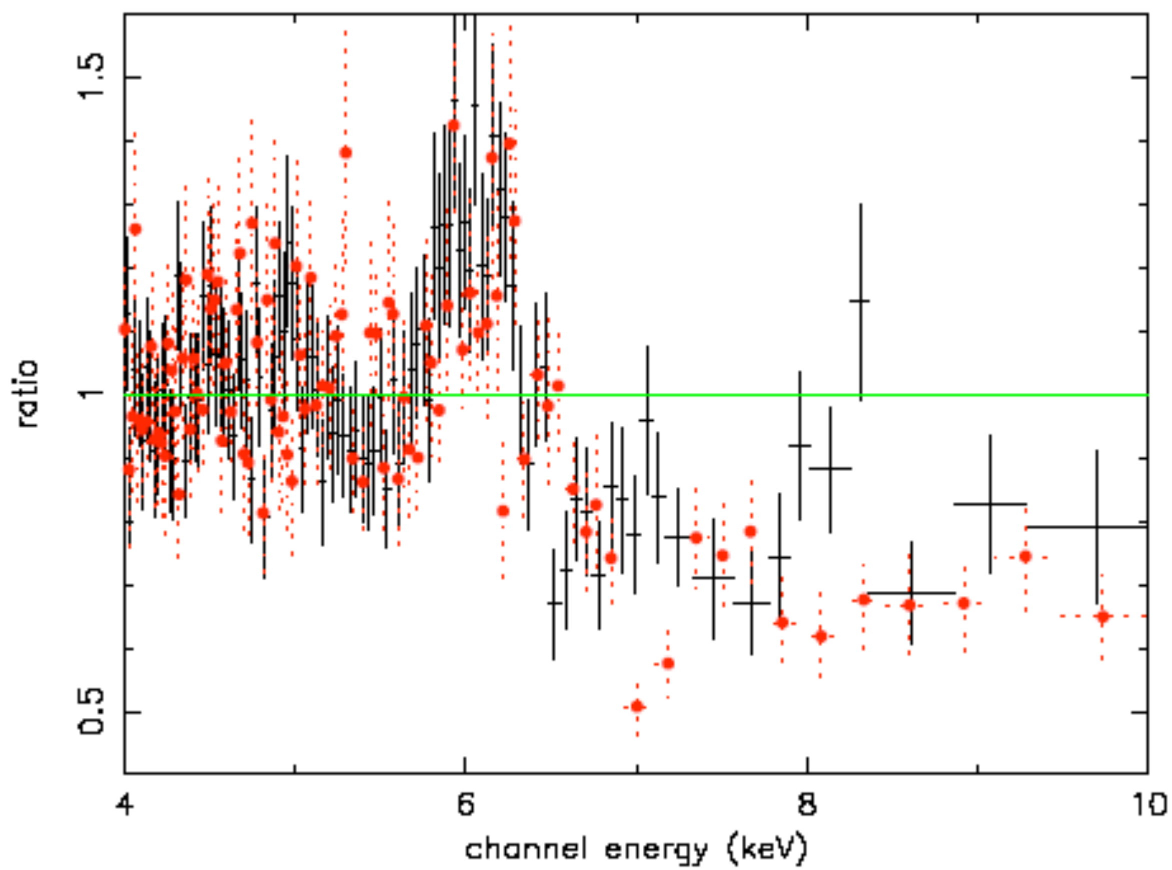
Clearly see changes in the Fe abs line profile

In the XMM RGS data there is a hint of broad low E lines- but not required .

Suzaku data best fit Fe K line is broad ~230 eV sigma. (FWHM 25,000 km/s) at

E_{REST}=6.6 keV

EW ~ 250 eV



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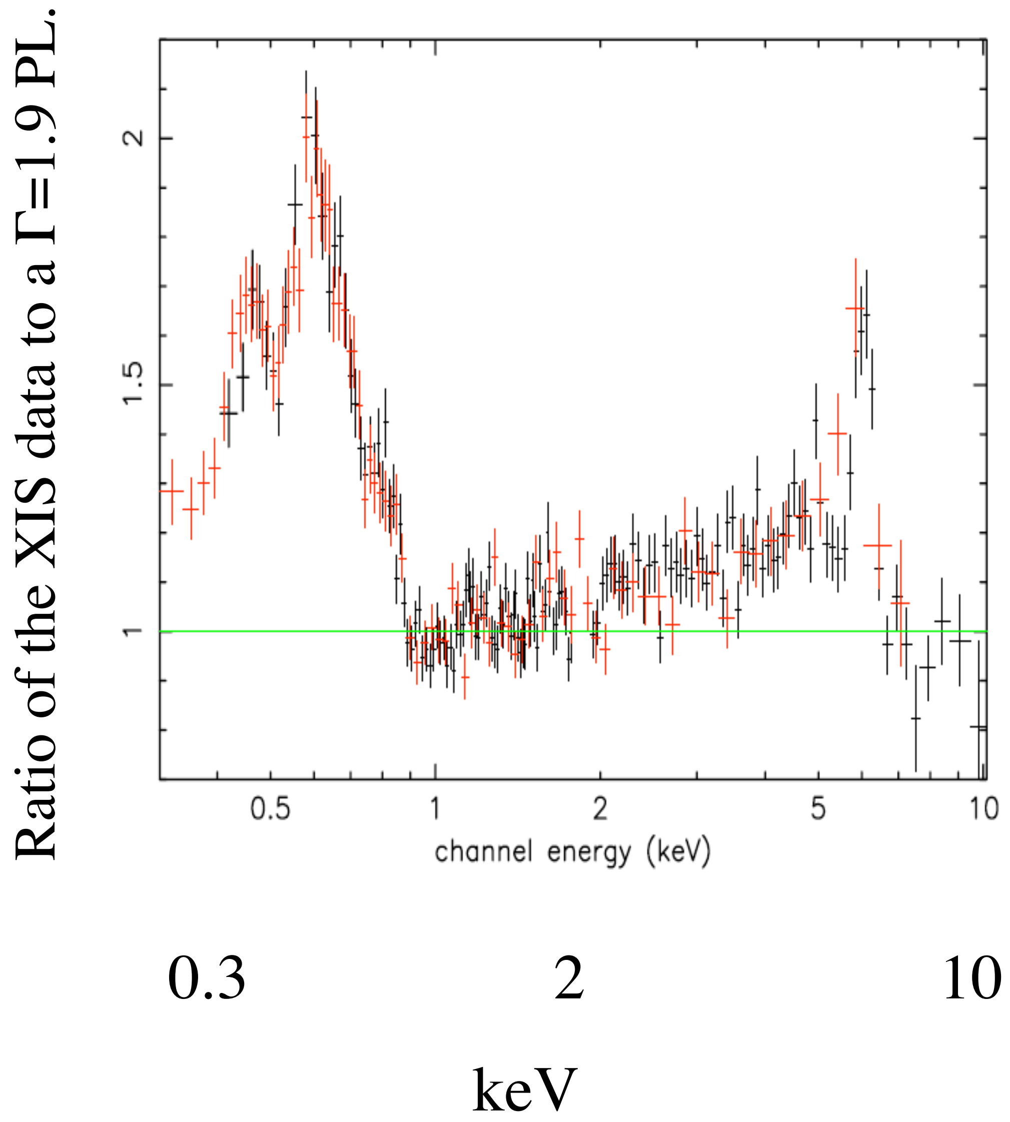
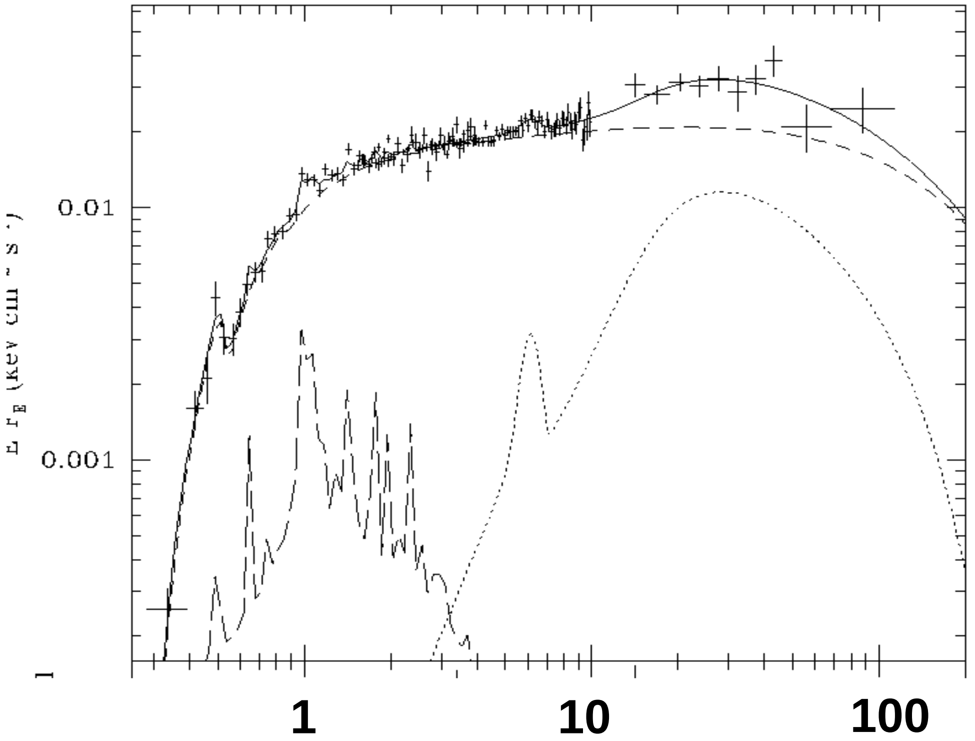
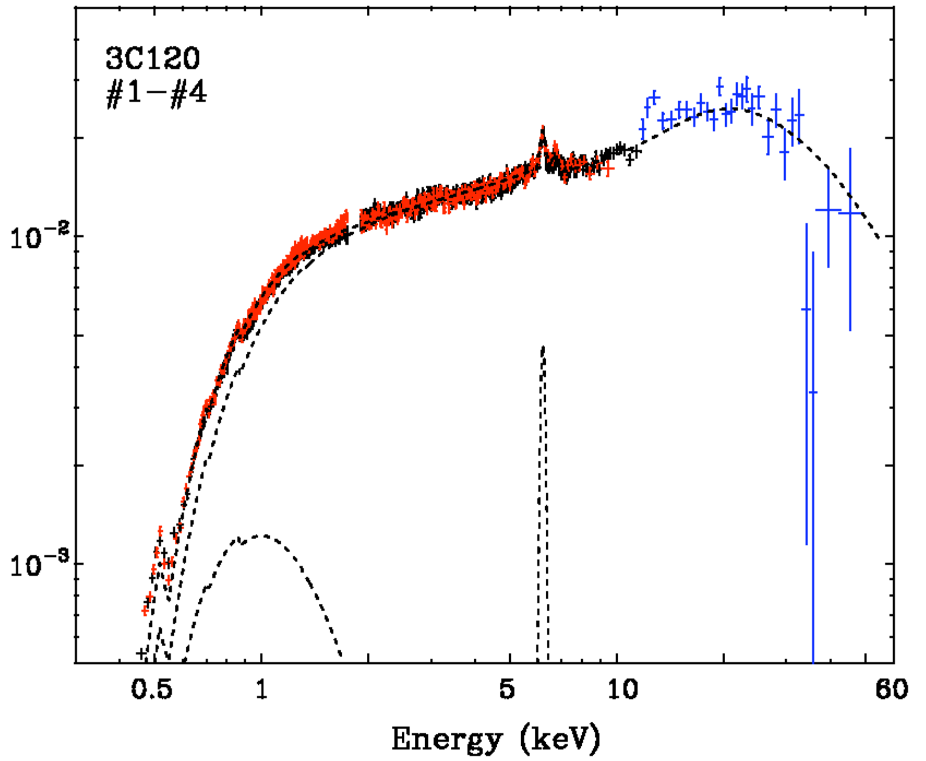


Radio Galaxy 3C120

Suzaku vs BeppoSAX





Beppo SAX (160ksec)

Suzaku (150ksec)

Zdziarski & Grandi, 2001
ApJ, 551, 186

NOTE!
(1) Much better statistics
(2) Good energy resolution
(3) clear reflection hump

Kataoka et al.