

# Highlights from Suzaku Observations of AGN

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*Collaborators:*

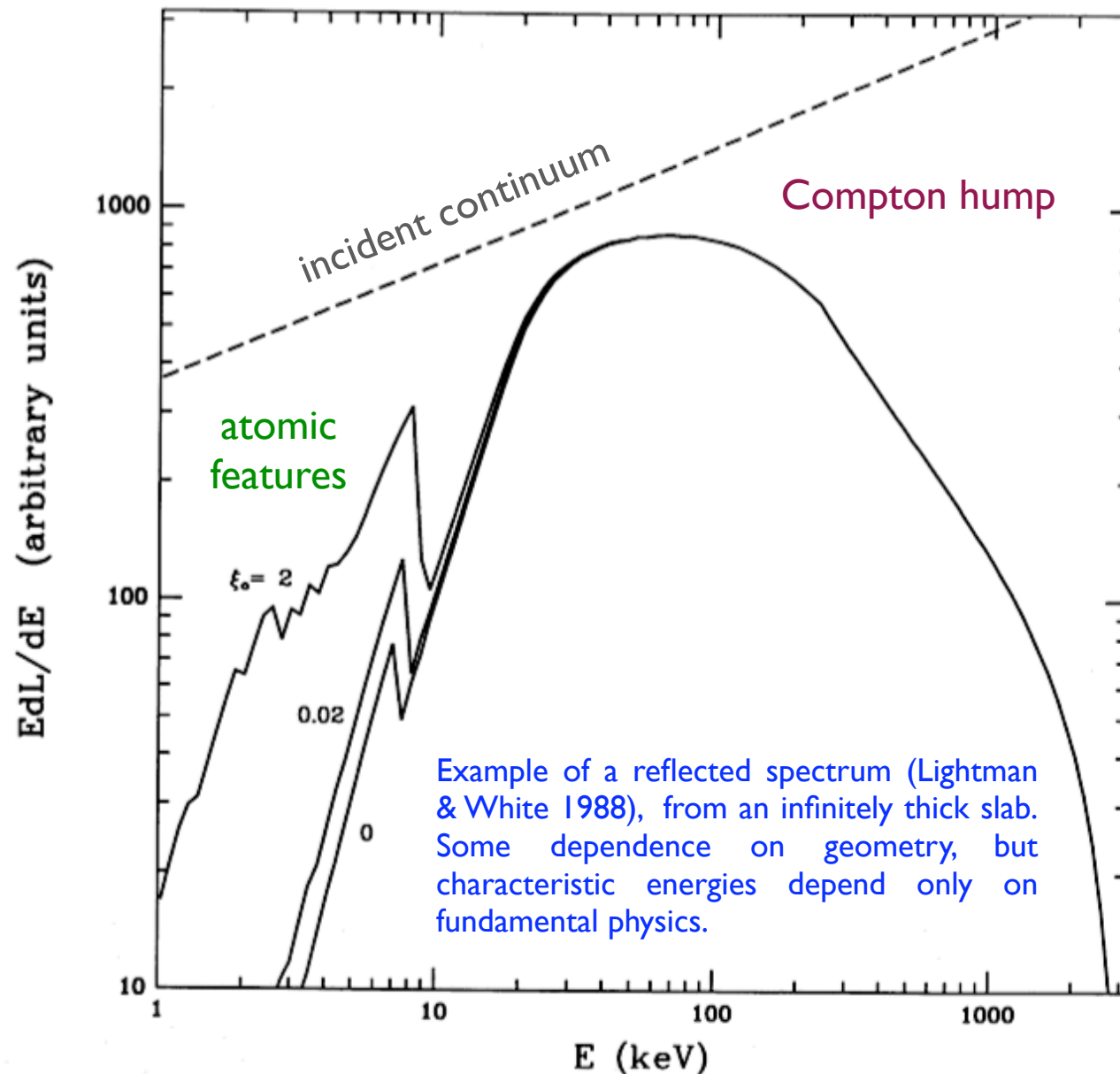
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Reeves (U. Keel), Alex Markowitz  
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(UMBC), R. F. Mushotzky  
(GSFC), A. Ptak (JHU),  
Y. Terashima (U. Ehime), & the  
Suzaku Team*

*Suzaku launched 10 July 2005, public archive opened ~2 years after launch. Mission has matured significantly and scientific output from the accumulated data is now really ramping up.*

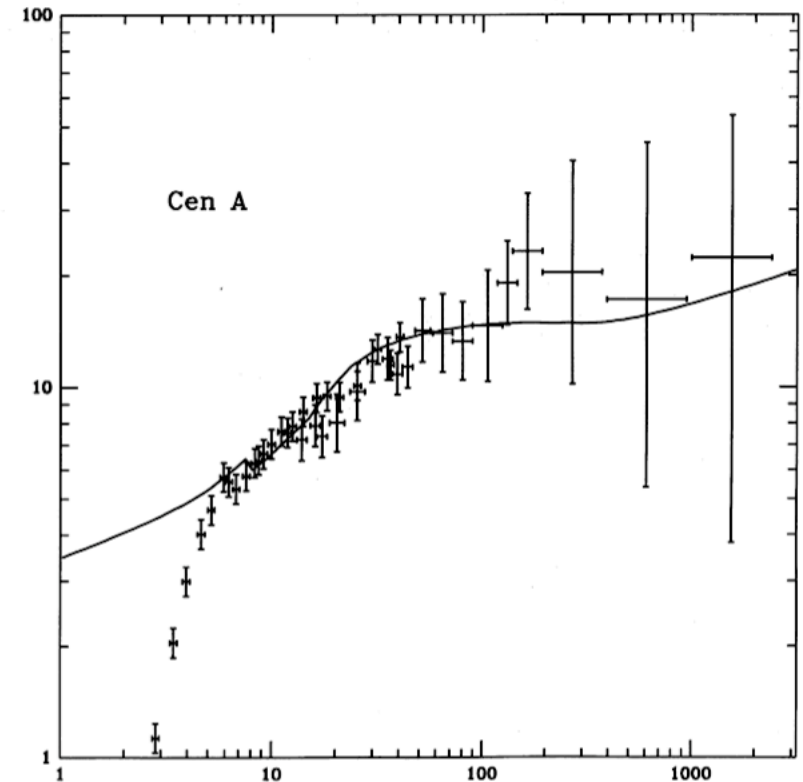
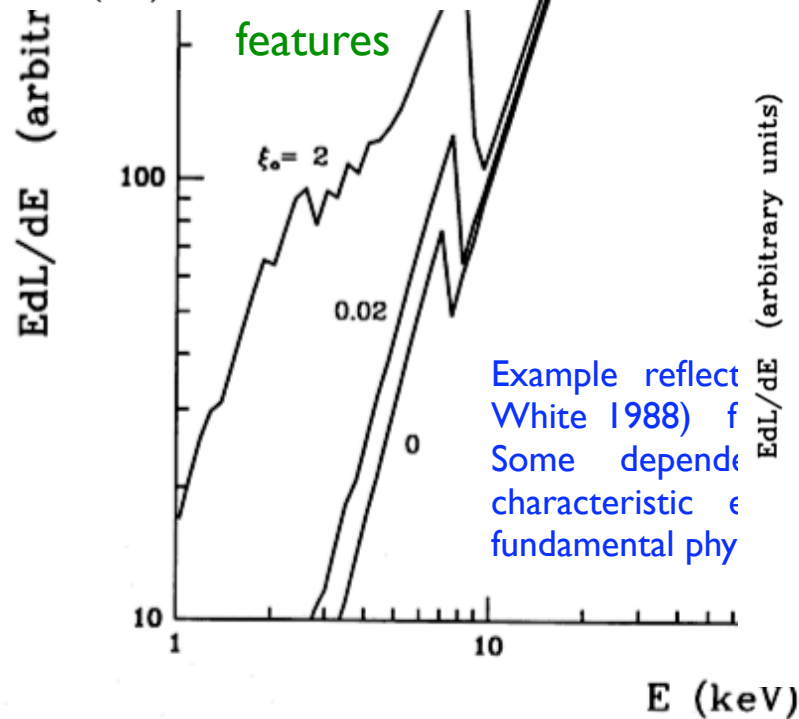
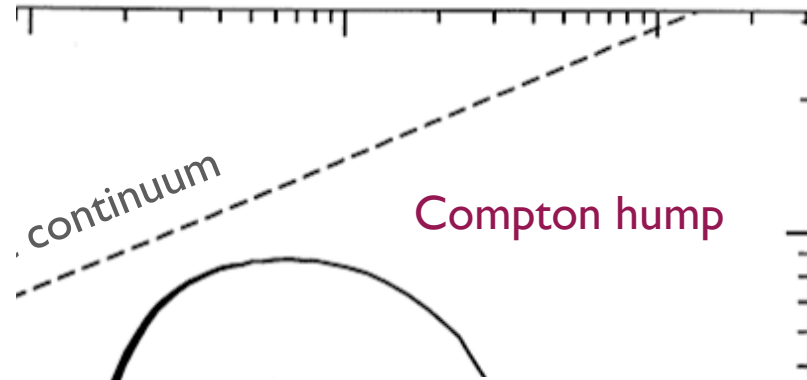
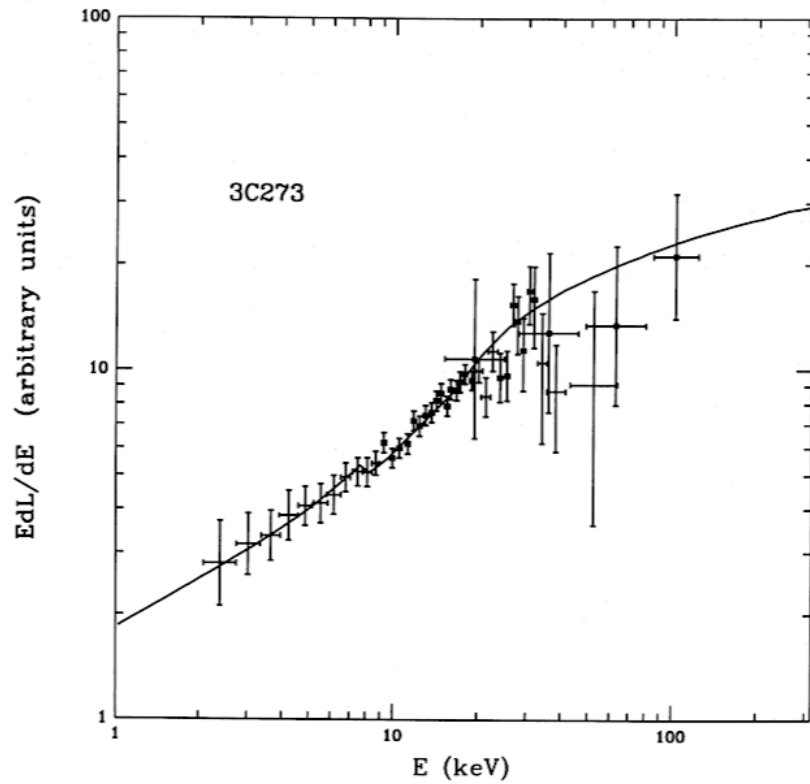
Purpose of talk:

- ★ Demonstrate the capabilities unique to Suzaku
  - What can we measure and how well?
  - Superiority of Suzaku compared to any other previously flown combination of instruments for studying X-ray reprocessing using broadband X-ray spectroscopy.
- ★ Extracting more physical information from the data by replacing *ad-hoc* modeling practices.
- ★ Will talk about general capabilities but citing principally Type 2 AGN- mostly unpublished and work in progress.
- ★ Type 1-1.9 AGN discussed later by Alex Markowitz.
- ★ Suzaku results on radio galaxies discussed later by Rita Sambruna.
- ★ Also see poster by Valentina Braito on 3C 445.

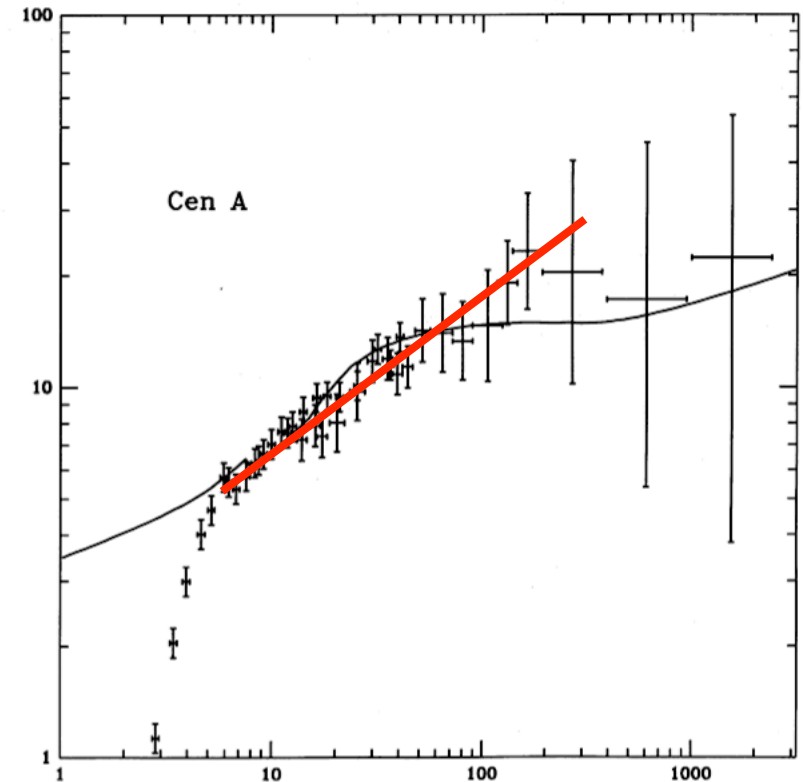
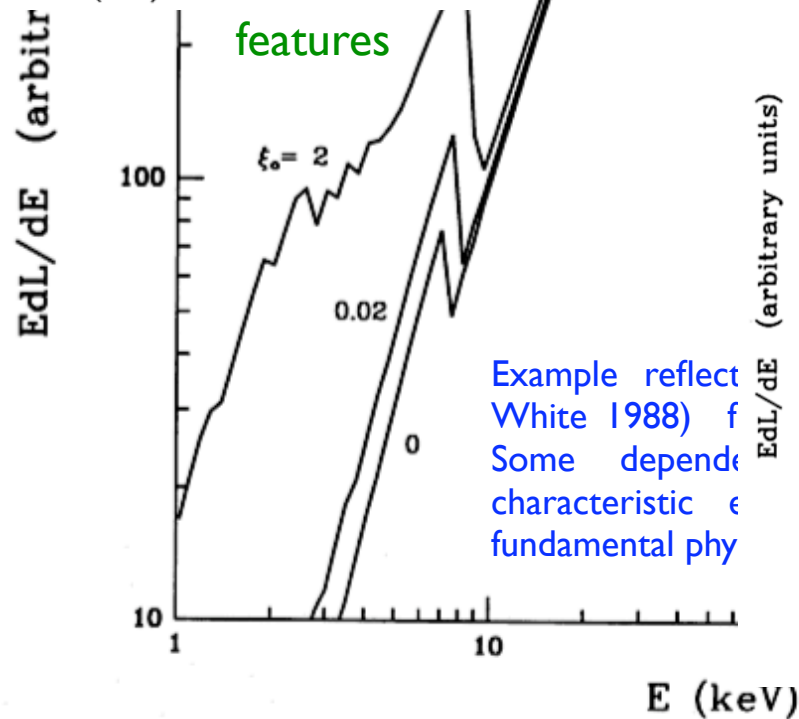
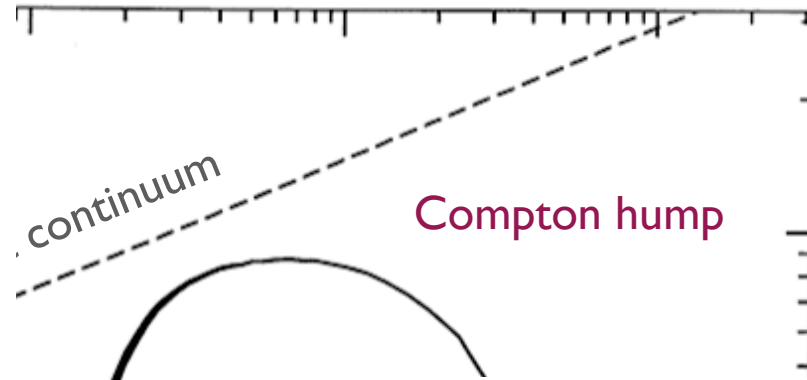
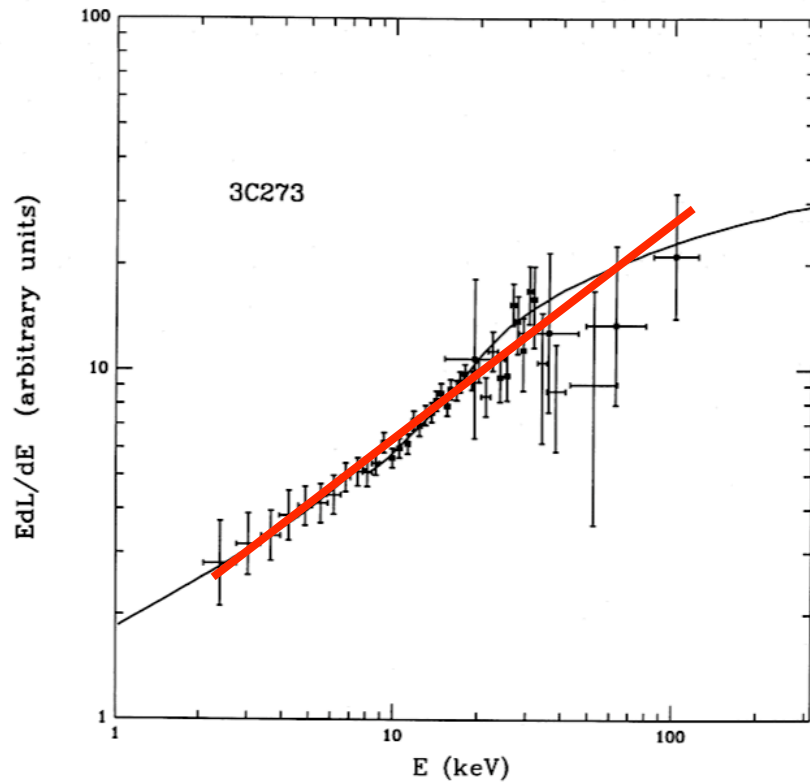
~Twenty years since Lightman & White (1988), Guilbert & Rees (1988), and others calculated distortions in X-ray spectra due to interactions of radiation with Compton-thick matter.



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 ith Compton-thick matter.

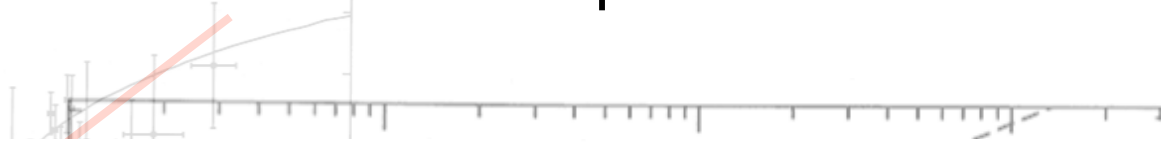


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ary units)



## EFFECTS OF COLD MATTER IN ACTIVE GALACTIC NUCLEI: A BROAD HUMPH IN THE X-RAY SPECTRA

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AND

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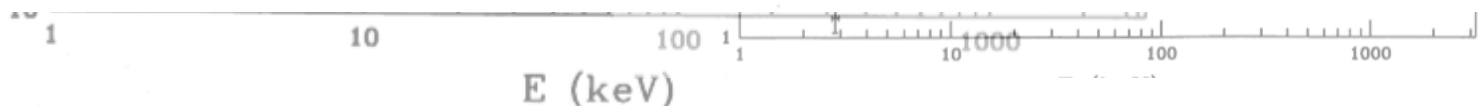
Department of Physics, Harvard University

*Received 1988 February 25; accepted 1988 May 24*

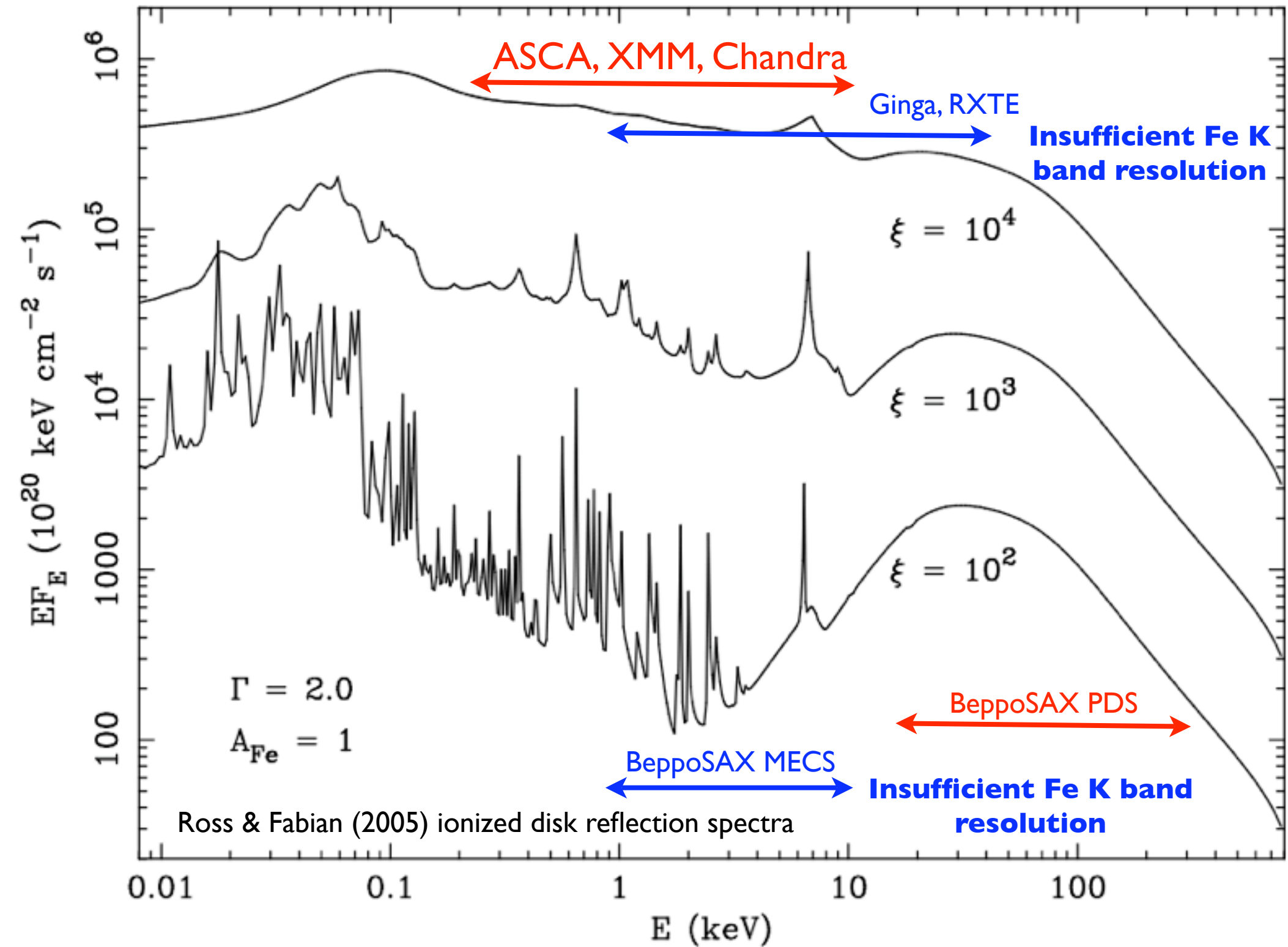
### ABSTRACT

Recent observations and interpretations of the strong UV emission from active galactic nuclei (AGNs) suggest that relatively cold, thermal matter coexists with the hot, X-ray-emitting matter near the centers of these objects. A fraction of the X-rays will be reprocessed by the cold material, and the composite X-ray spectrum should help diagnose the conditions of this material and its energy source. In a variety of situations, reprocessing of the X-rays should lead to a composite X-ray spectrum with a broad hump between  $\sim 10$  keV and  $\sim 300$  keV. The lower limit of this energy range is determined by atomic absorption and the upper limit by electron scattering in the cold material. Where available, observed spectra are consistent with such a broad hump; however, the predicted amplitude of the hump is  $\sim 0.1$ – $0.5$ , and observations with smaller error bars are clearly needed.

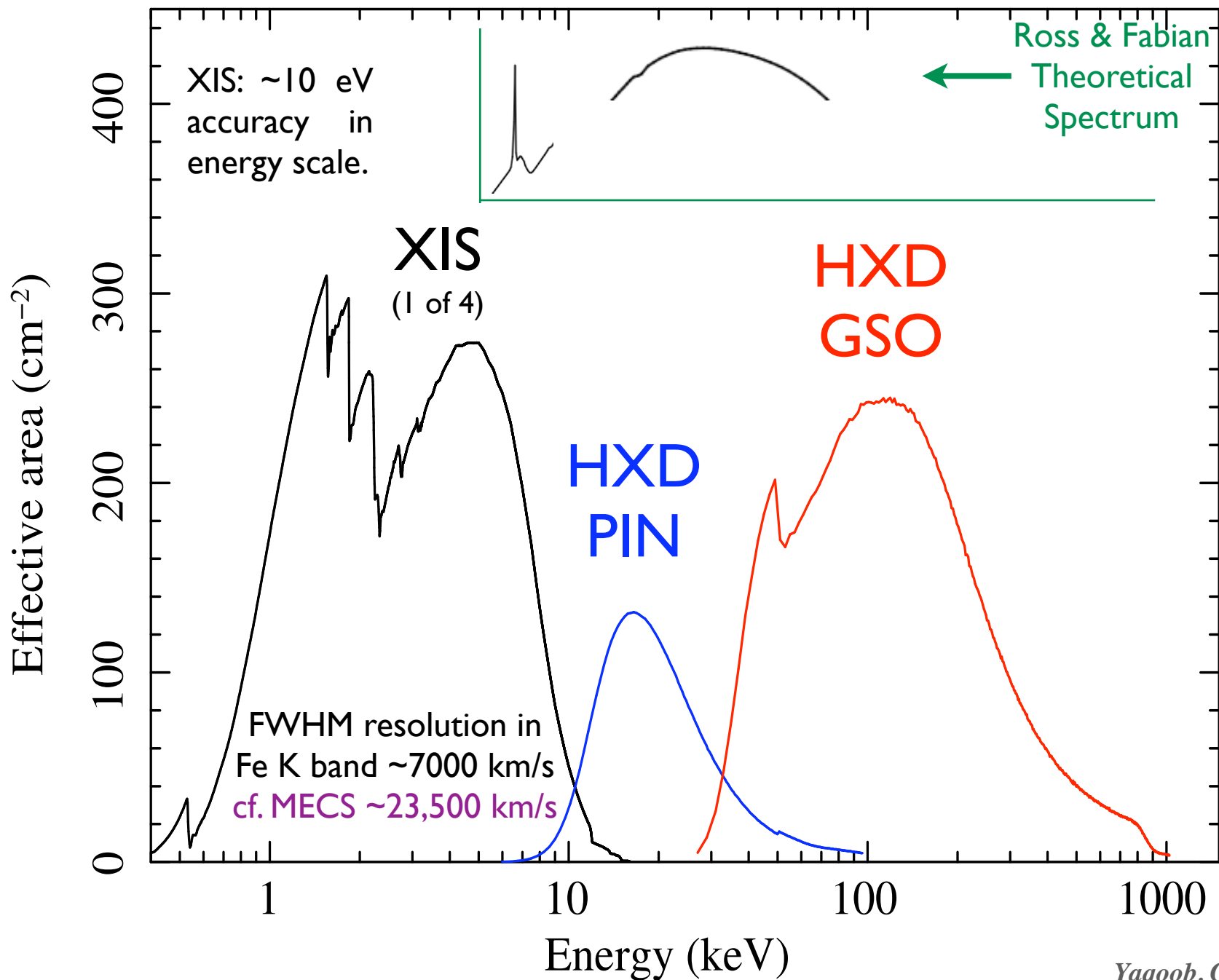
*Subject headings:* galaxies: nuclei — X-rays: spectra





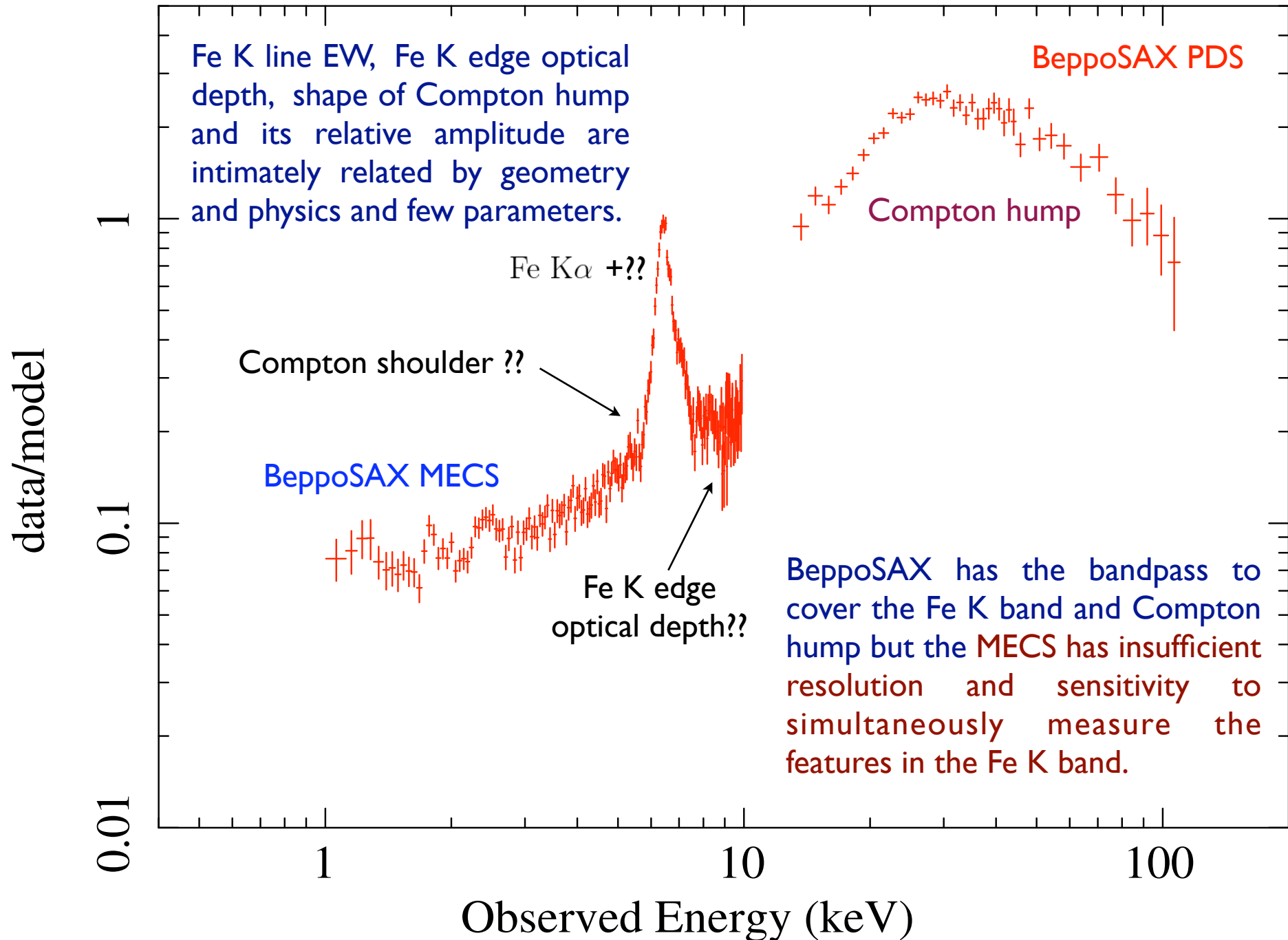


# Suzaku XIS-PIN-GSO Effective Area





# Circinus Galaxy **BeppoSAX** spectrum



Some basic relationships (for X-ray reprocessing in cold, neutral matter)

**EW of Fe K line relative to scattered continuum does not depend on geometry, covering factor, or column density as long as the first scattering dominates the scattered continuum.**

i.e. a slab of infinite Compton thickness - or up to  $N_H \sim 1.5 \times 10^{24} \text{ cm}^{-2}$  for “transmission”.

$$EW_{\text{refl}} = 1010 \left( \frac{\omega_K}{0.347} \right) \left( \frac{A_{\text{Fe}}}{4.68 \times 10^{-5}} \right) \left( \frac{\sigma_{\text{FeK}}^0}{3.5 \times 10^{-20} \text{ cm}^{-2}} \right) \left( \frac{3.55}{\Gamma + 1.65} \right) [0.90^{\Gamma-1.9}] \text{ eV}$$

**Higher columns than  $1.5 \times 10^{24} \text{ cm}^{-2}$  can only give LARGER EW**  
(relative to scattered continuum).

**Dilution of pure scattered continuum with zeroth order or other continuum reduces the apparent EW.**

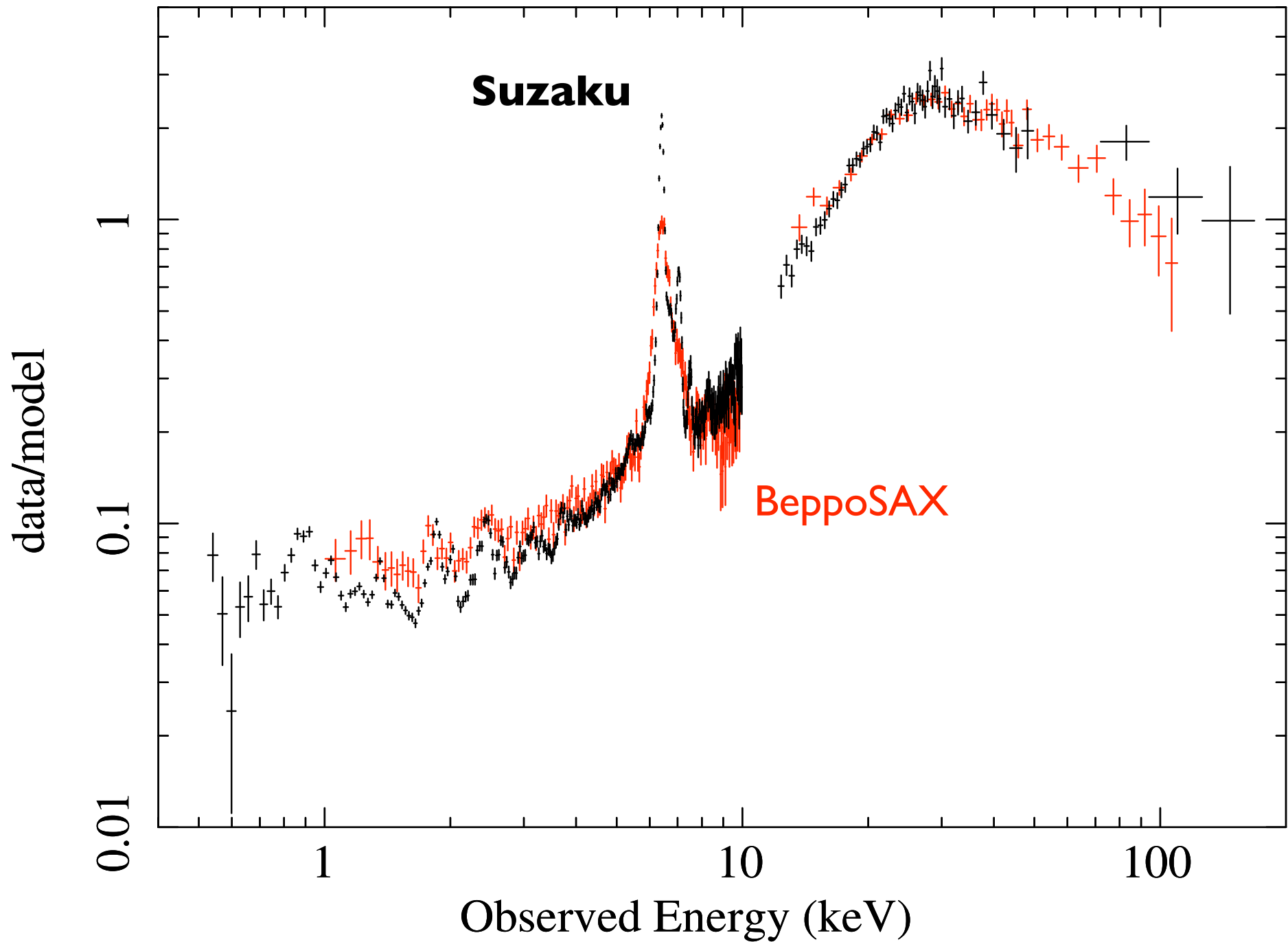
Fe K edge depth in transmission  
(zeroth order continuum)

$$\tau_{\text{FeK edge}} = 1.638 \left( \frac{\sigma_{\text{FeK}}^0}{3.50 \times 10^{-20} \text{ cm}^{-2}} \right) \left( \frac{A_{\text{Fe}}}{4.68 \times 10^{-5}} \right) \left( \frac{N_H}{10^{24} \text{ cm}^{-2}} \right)$$

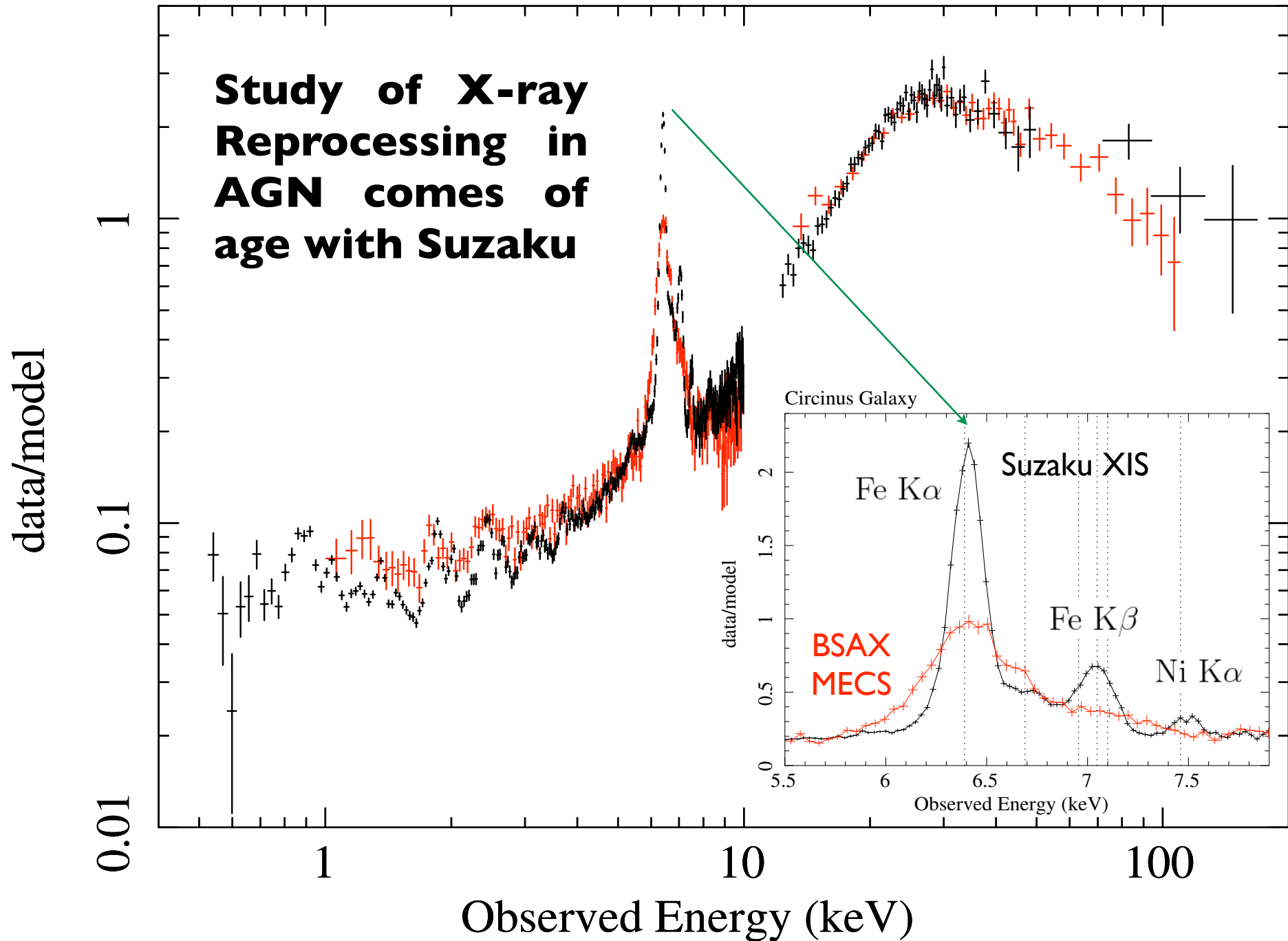
Fe K edge depth in pure reflection  
(>zeroth order)

Fe abundance relative to solar (Anders & Grevesse)	$\tau_{\text{FeK}}$
1	0.619
2	0.873
10	1.235

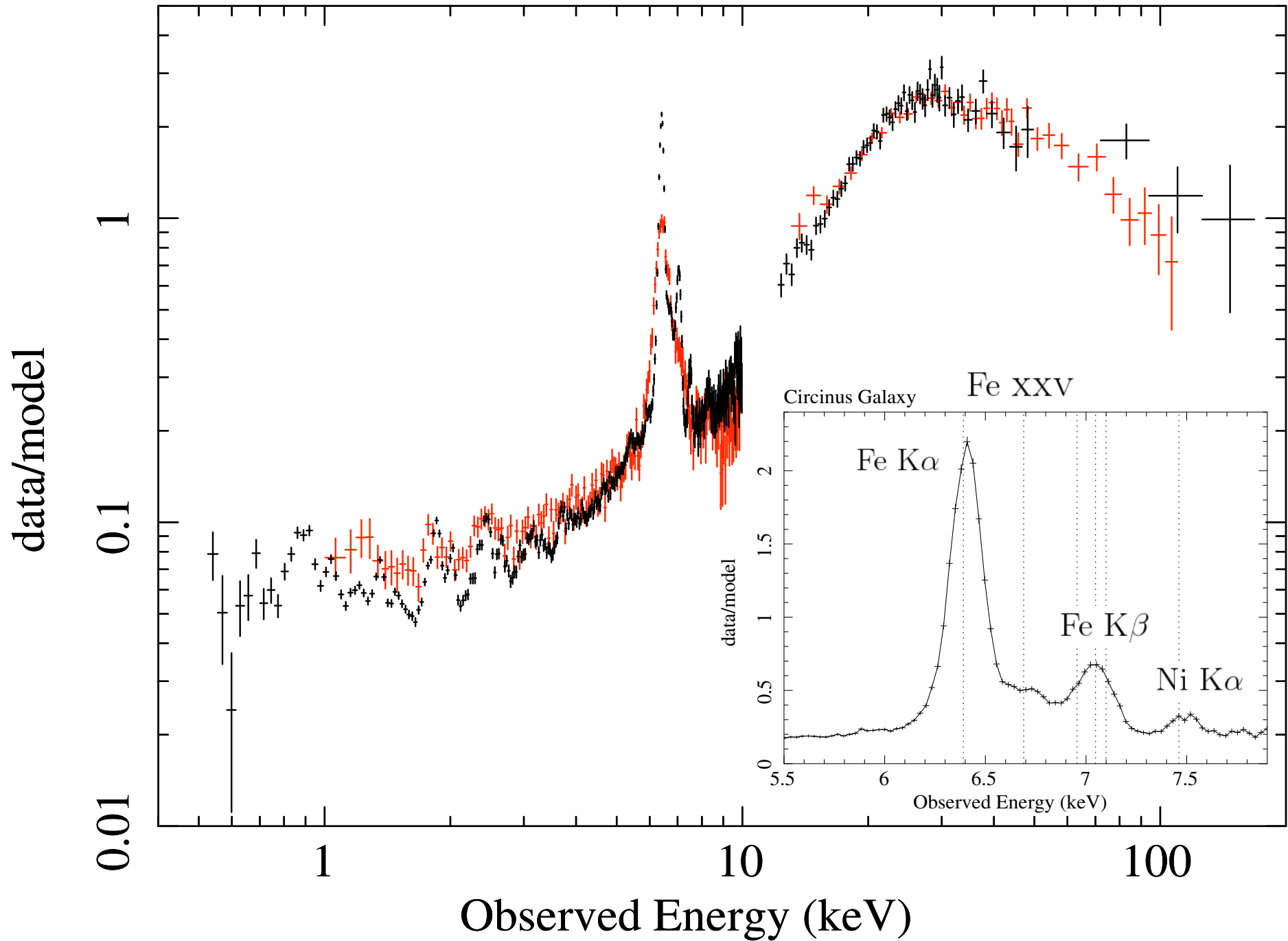
# Circinus Galaxy



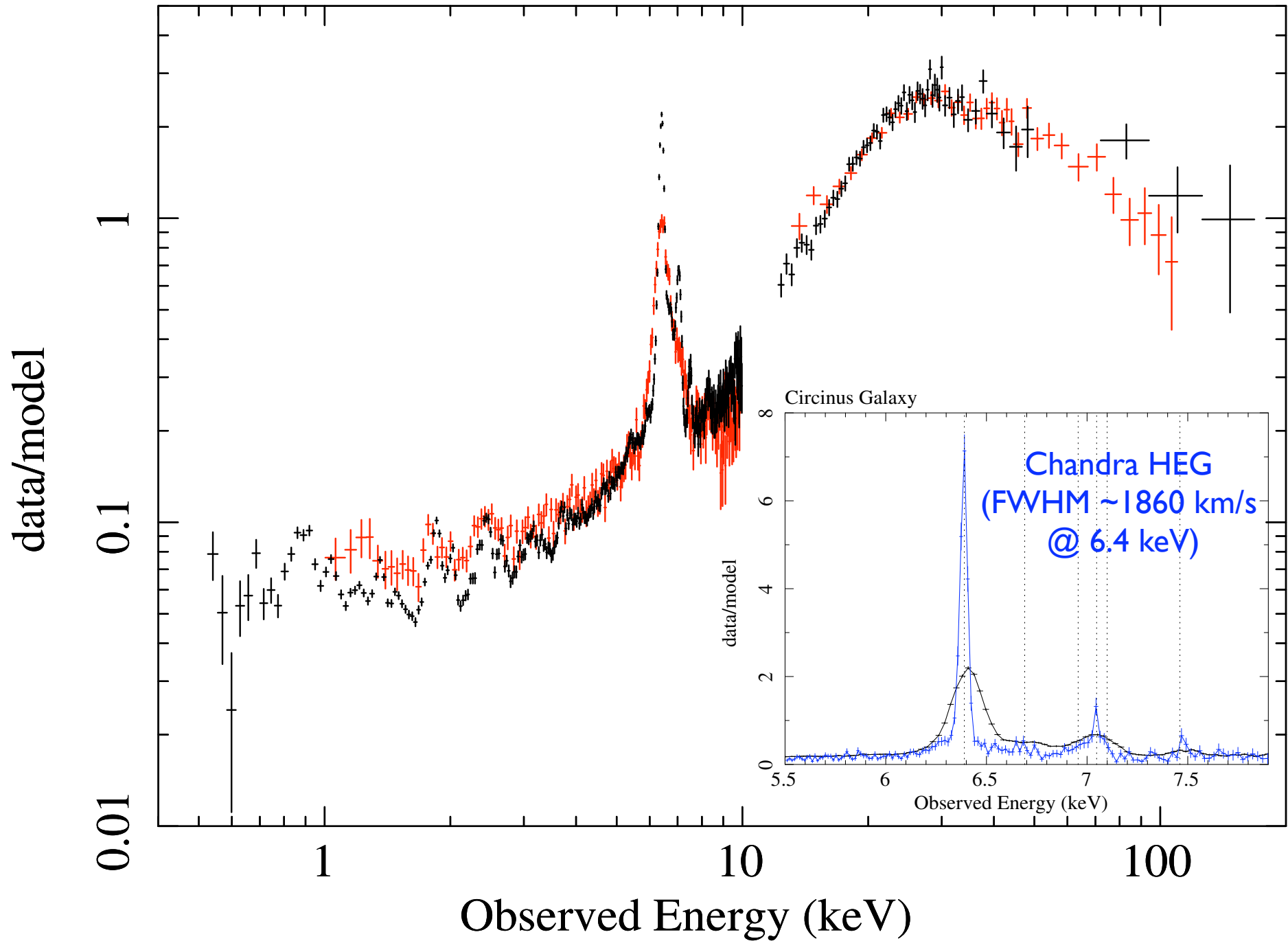
# Circinus Galaxy



# Circinus Galaxy



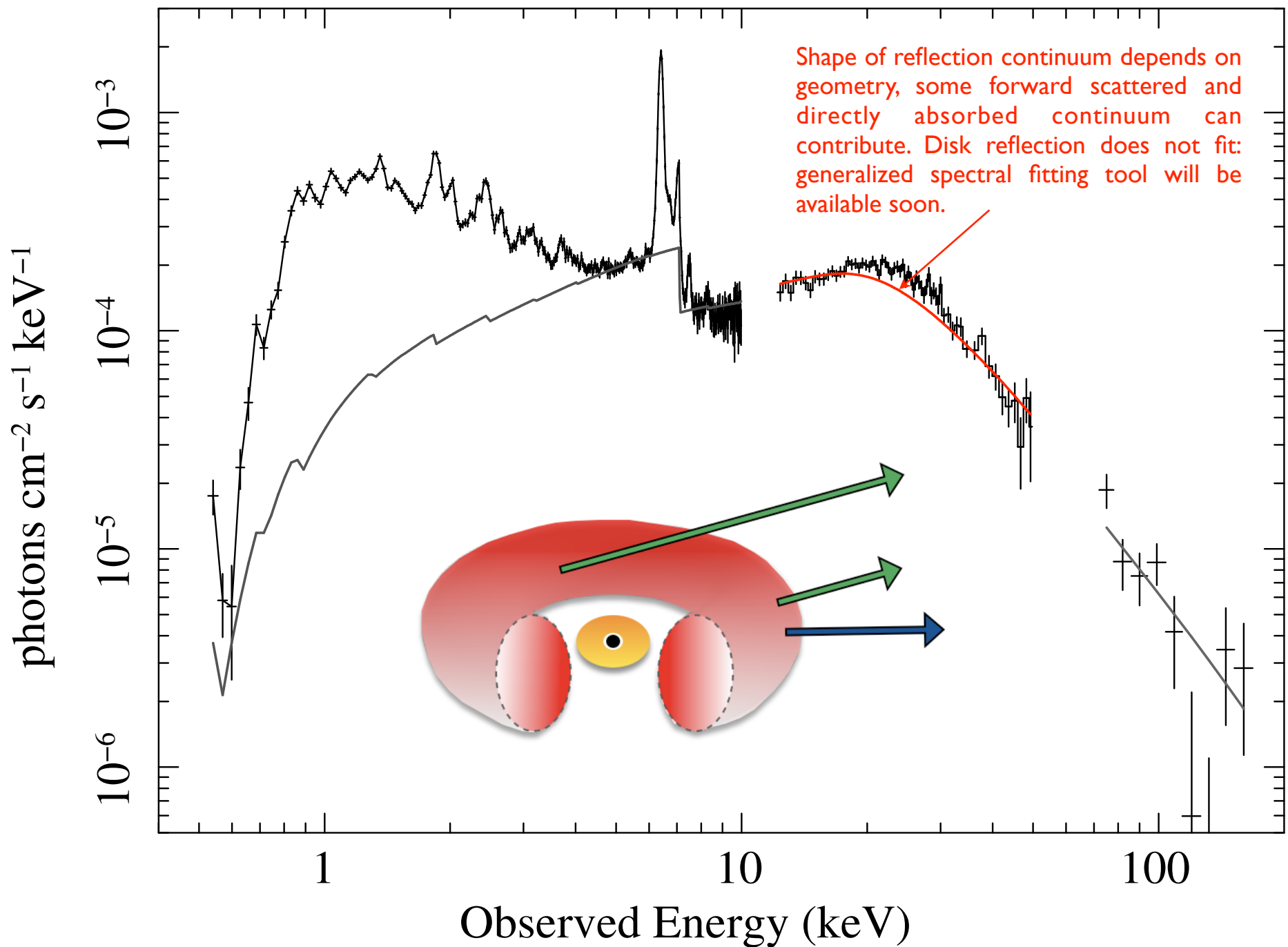
# Circinus Galaxy





# Circinus Galaxy

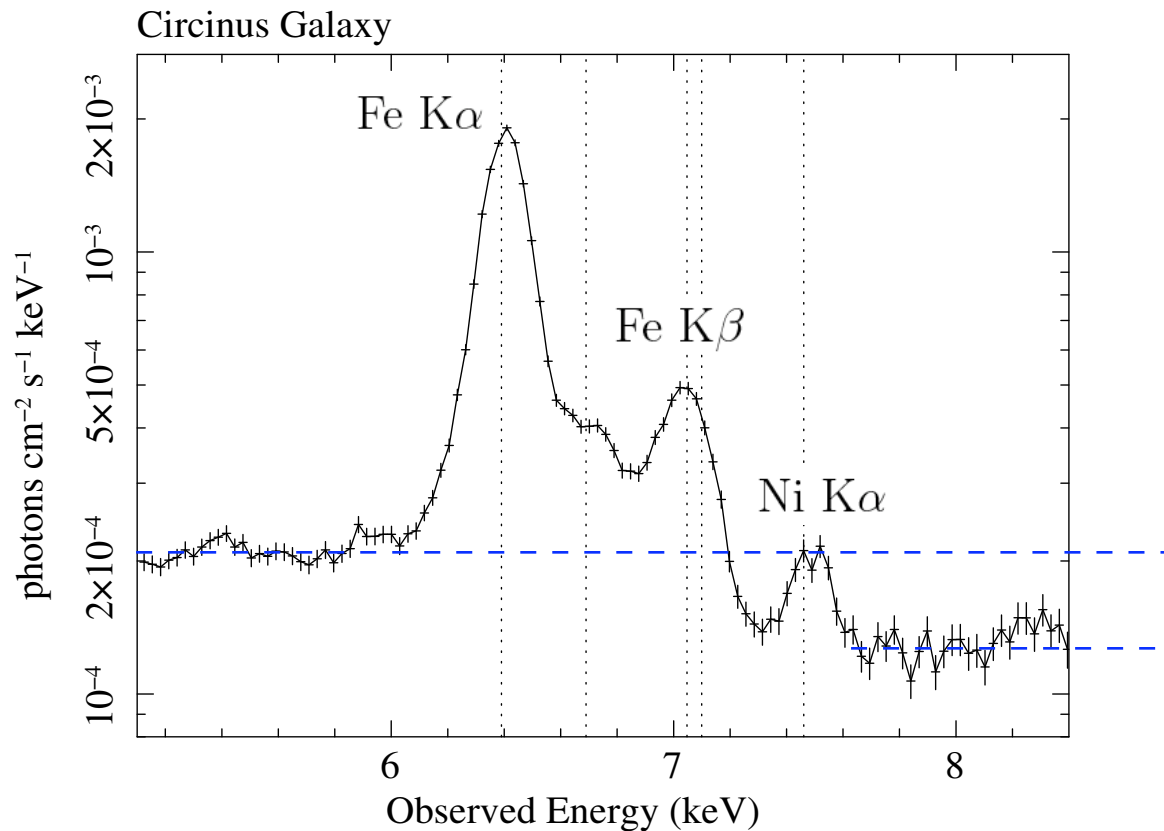
Suzaku data



## Unprecedented precision with Suzaku

$$\begin{aligned}\frac{EW_{\text{Ni( refl)}}}{EW_{\text{Fe( refl)}}} &= \left( \frac{\omega_{\text{Ni}}}{\omega_{\text{Fe}}} \right) \left( \frac{A_{\text{Ni}}}{A_{\text{Fe}}} \right) \left( \frac{\sigma_{\text{NiK}}^0}{\sigma_{\text{FeK}}^0} \right) \left( \frac{E_{\text{K,Ni}}}{E_{\text{K,Fe}}} \right)^{1-\Gamma} \left( \frac{E_{0,\text{Fe}}}{E_{\text{K,Ni}}} \right)^{\Gamma} \left( \frac{\Gamma + \alpha_{\text{Fe}} - 1}{\Gamma + \alpha_{\text{Ni}} - 1} \right) \\ &= 1.284 \left( \frac{A_{\text{Ni}}}{A_{\text{Fe}}} \right)\end{aligned}$$

Ni abundance can be measured to better than 20% accuracy in Circinus: 1.6-3.9 times higher than values in the literature.



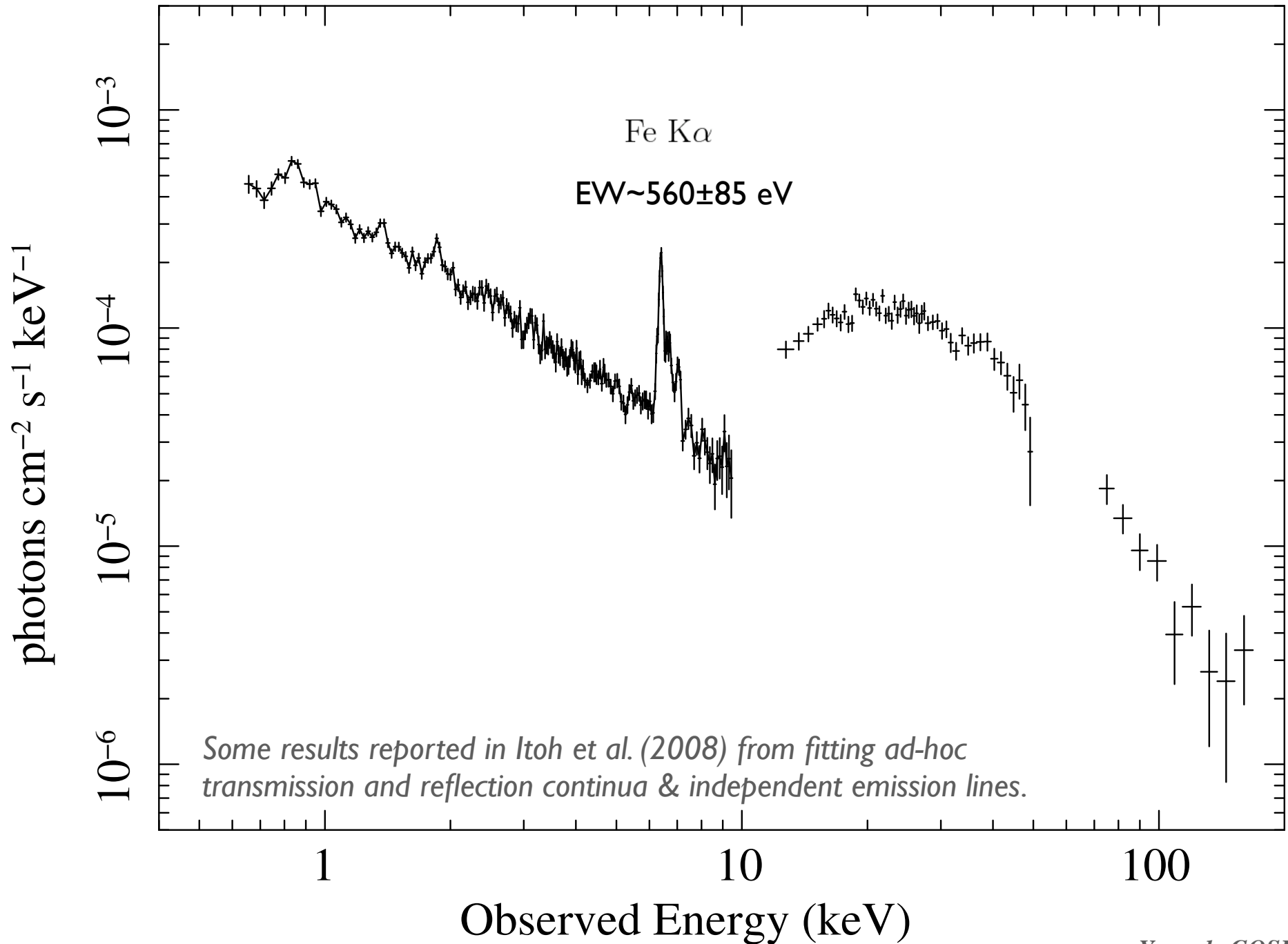
Fe K edge depth  
0.70 +/- 0.15 pure  
reflection in this  
band.

Fe Kα

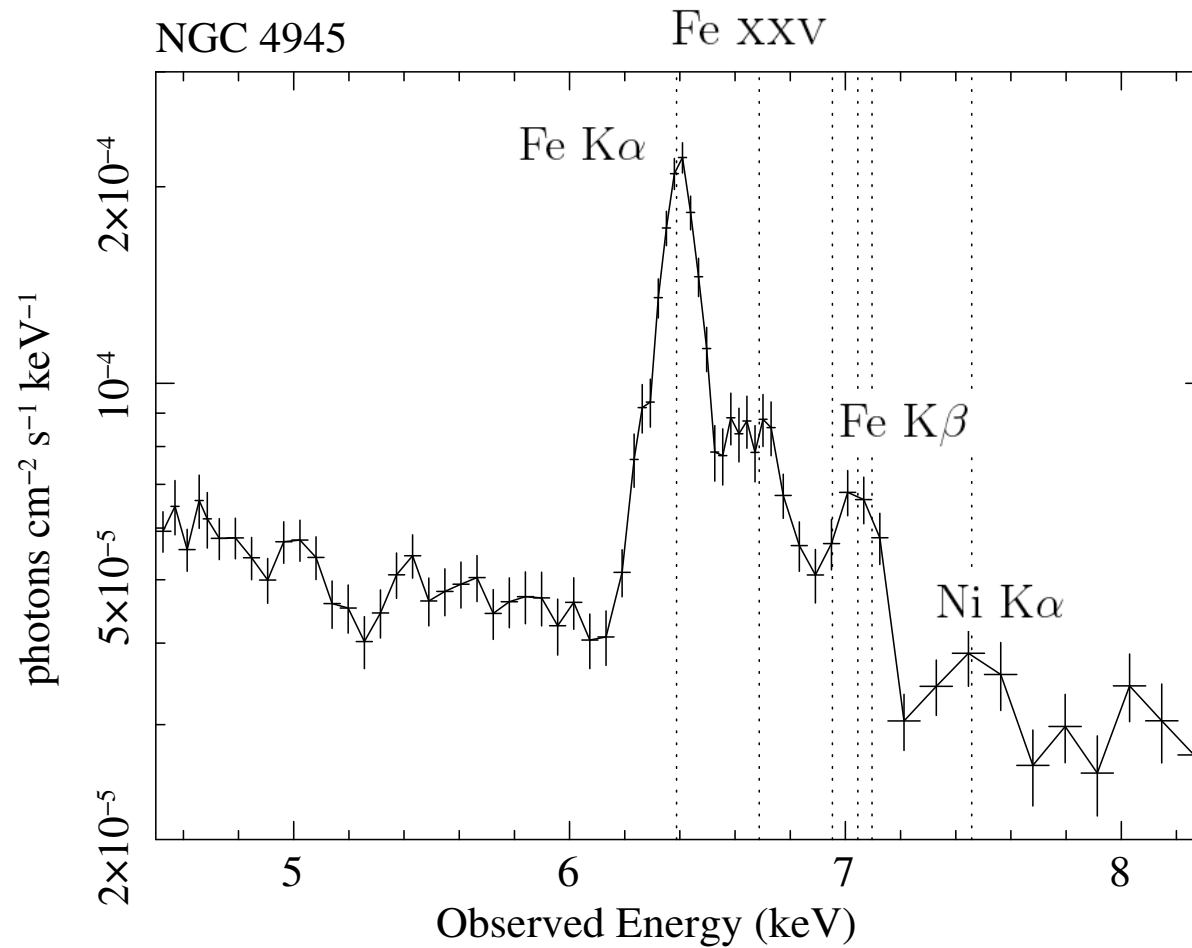
Fe neutral. EW = 1340 (-14,+17)  
eV; Fe abundance ~1.3 × A&G solar.

NGC 4945

Suzaku data



# Fe K line and edge diluted by Compton-thin scattered continuum



NGC 4388

Suzaku data

EW  $\sim 257 \pm 8$  eV

photons  $\text{cm}^{-2} \text{s}^{-1} \text{keV}^{-1}$

$10^{-3}$   
 $10^{-4}$   
 $10^{-5}$   
 $10^{-6}$

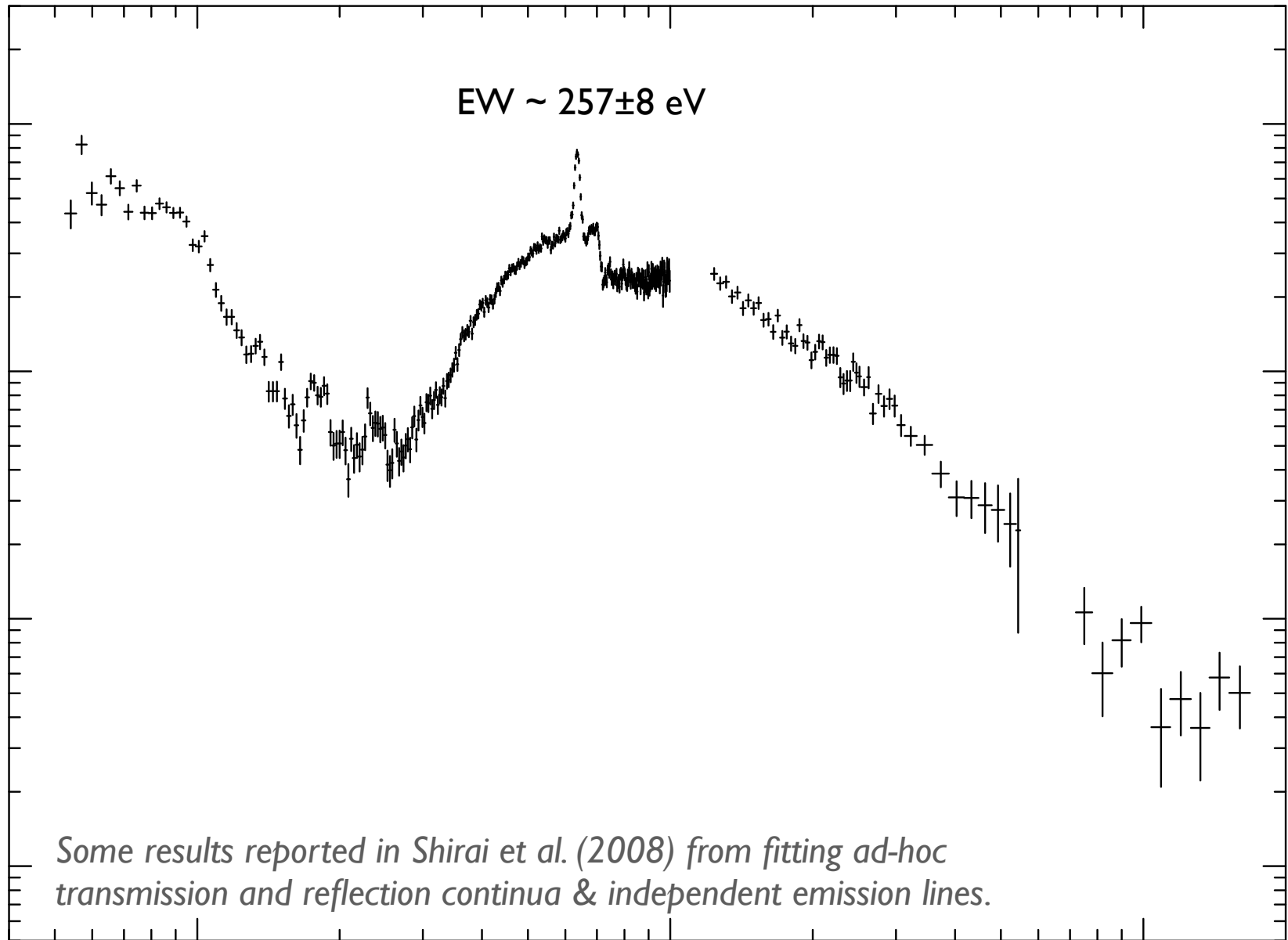
*Some results reported in Shirai et al. (2008) from fitting ad-hoc  
transmission and reflection continua & independent emission lines.*

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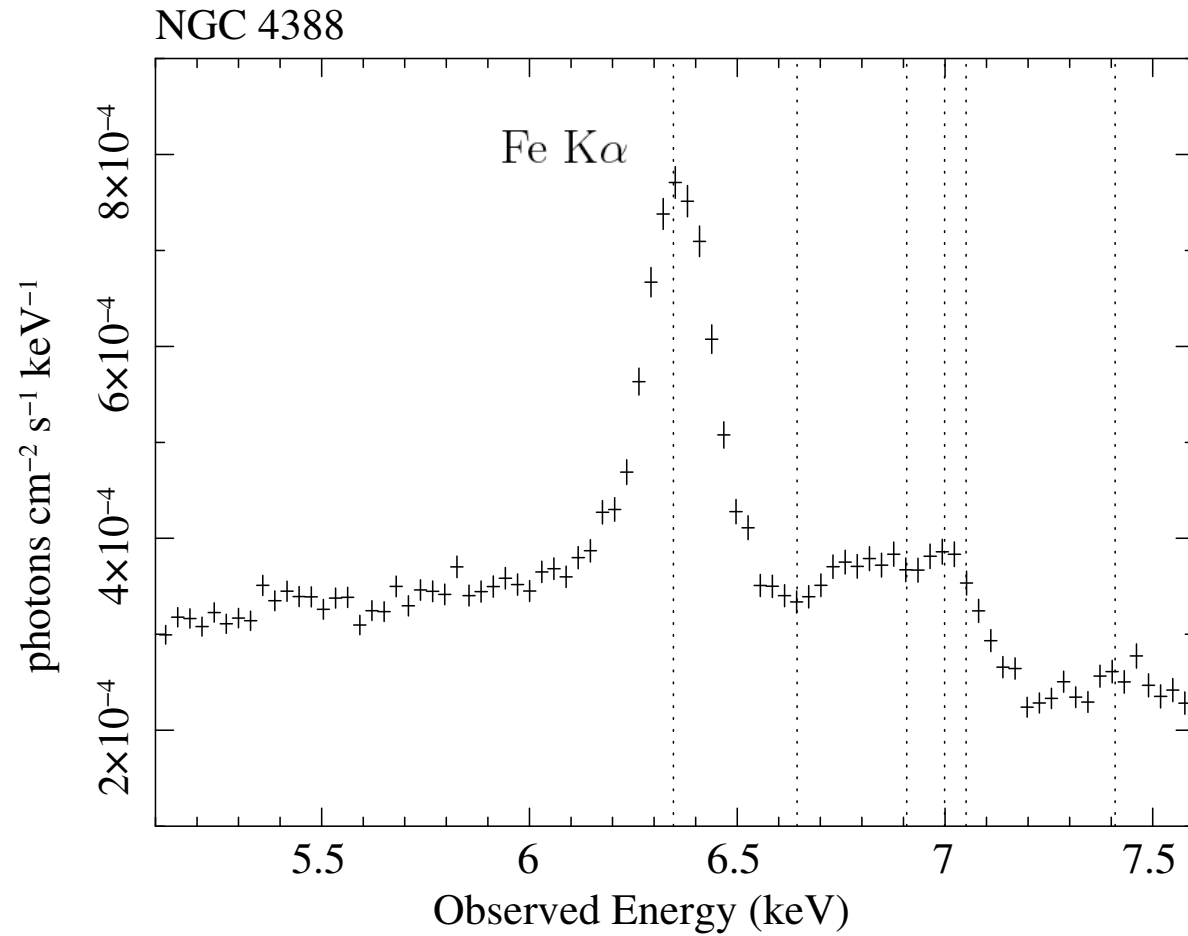
10

100

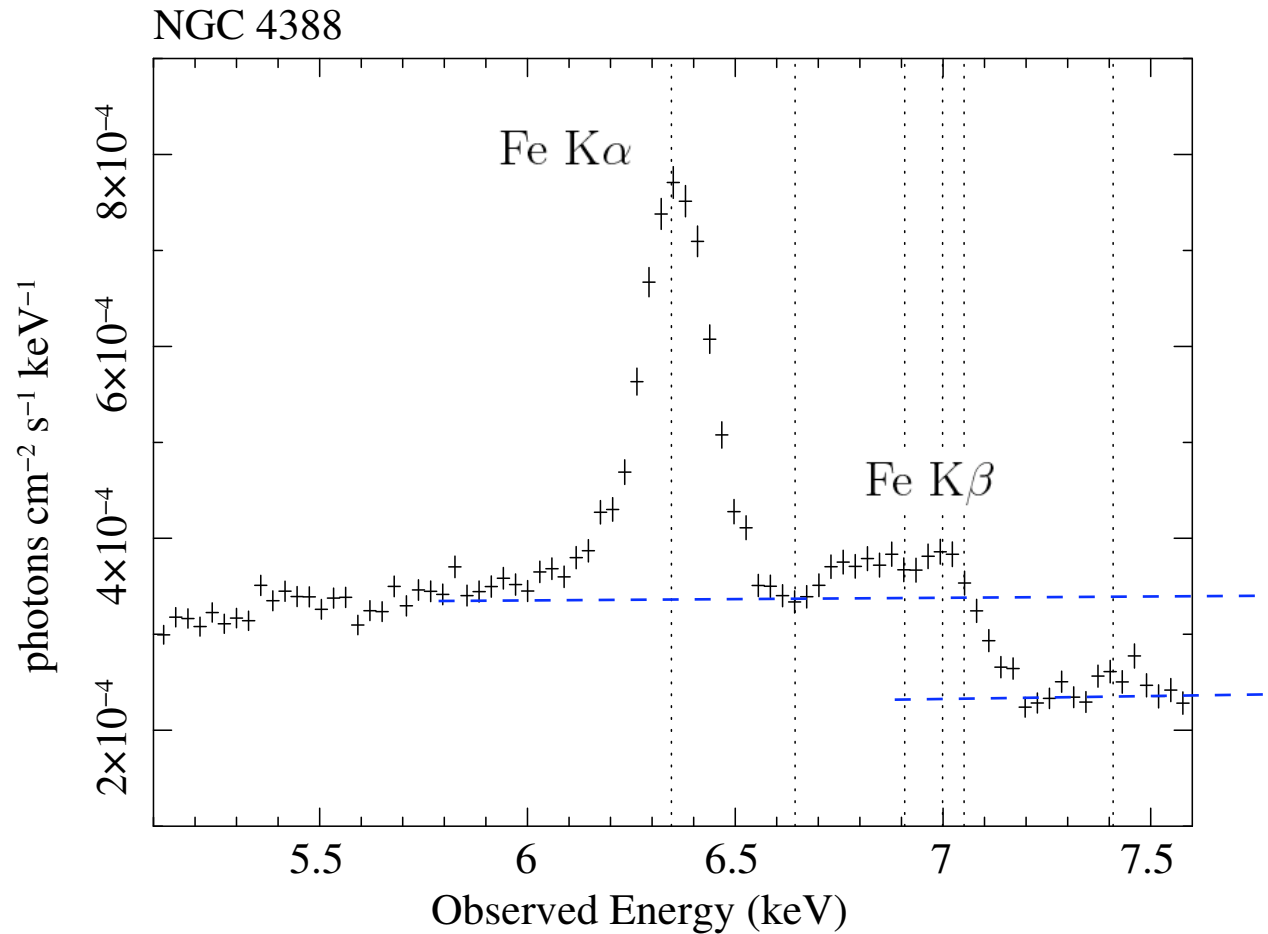
Observed Energy (keV)



# Fe K line and edge diluted by Compton-thin scattered continuum



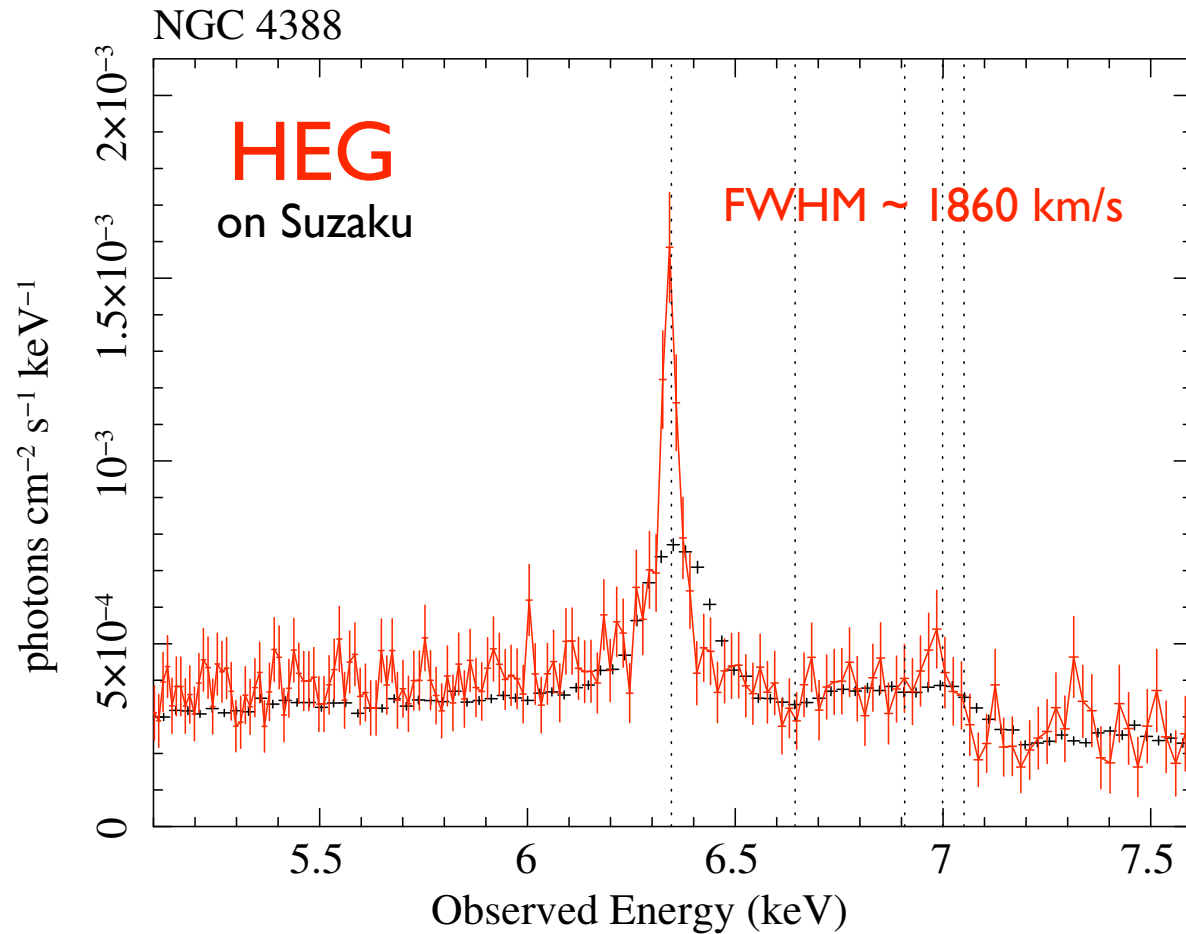
# Fe K line and edge diluted by Compton-thin scattered continuum



Complexity in the Fe K band: correct Fe K edge depth and obtained when Fe K $\beta$ /K $\alpha$  ratio properly included.

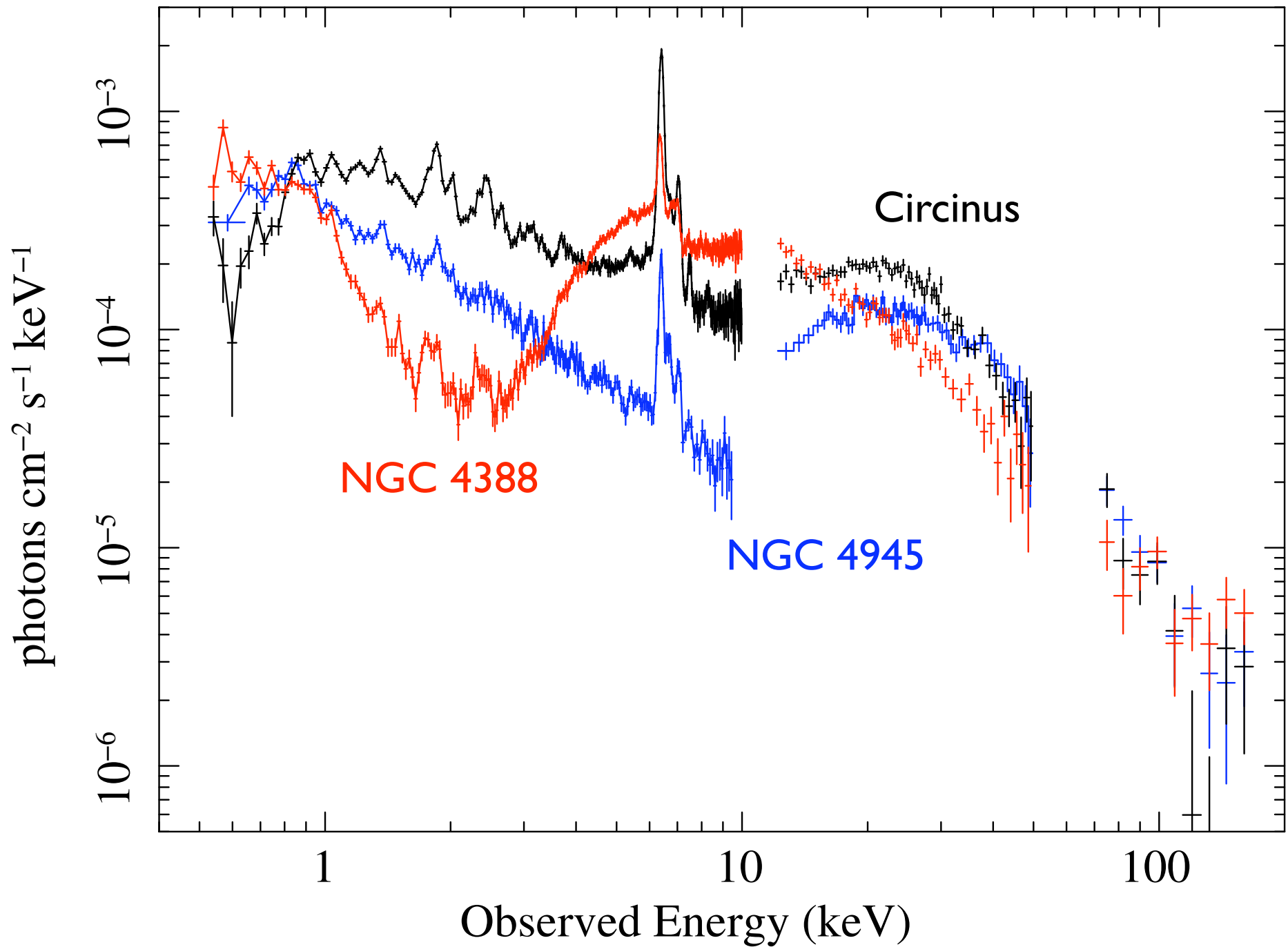


HEG can measure the Fe K $\alpha$  line width better  
but Suzaku is superior for measuring the structure around  
the Fe K edge, critical for constraining models.



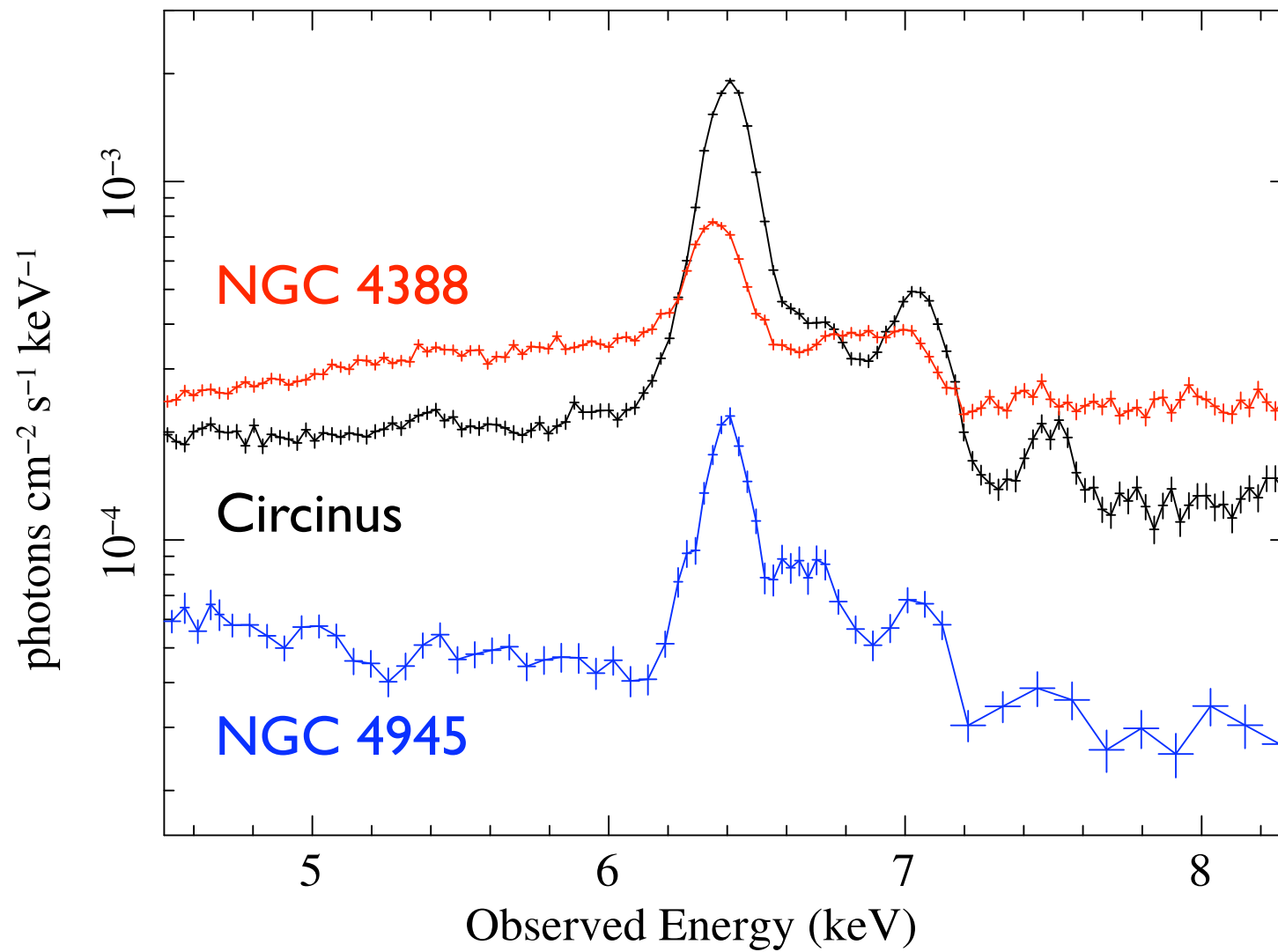
Circinus Galaxy, NGC 4338, NGC 4945

Suzaku data



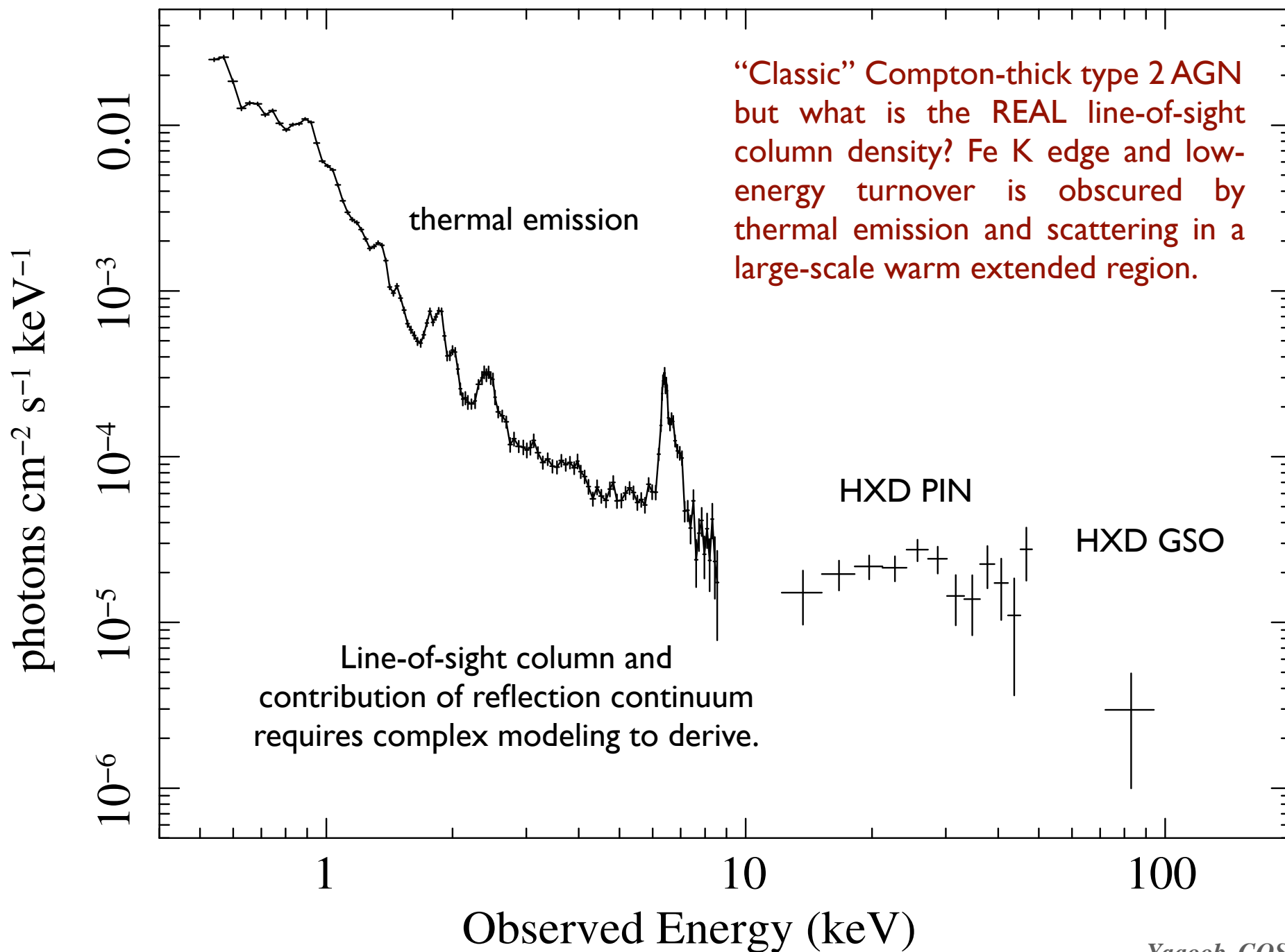
Circinus Galaxy, NGC 4338, NGC 4945

Suzaku data



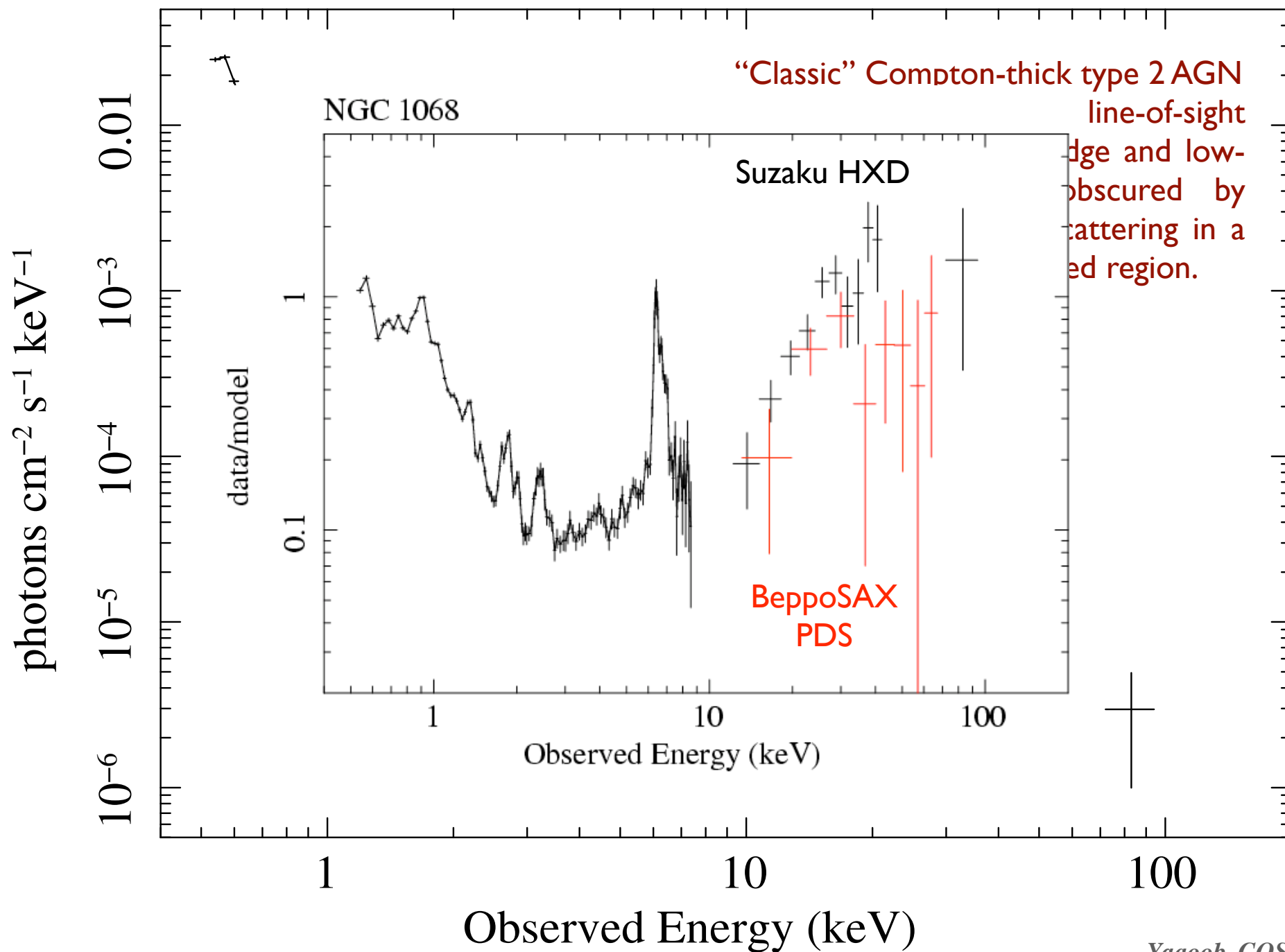
NGC 1068

Suzaku data



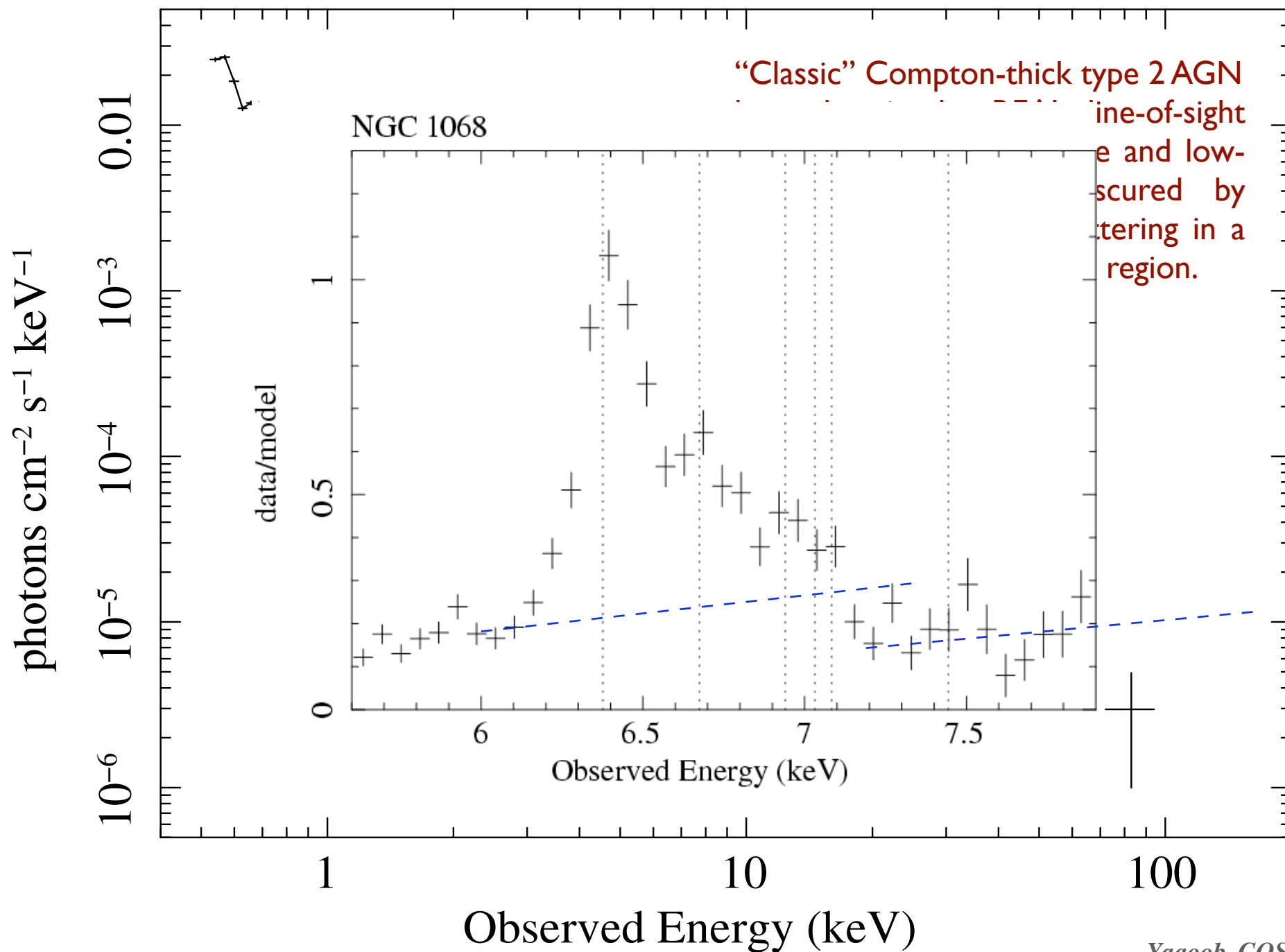
NGC 1068

Suzaku data



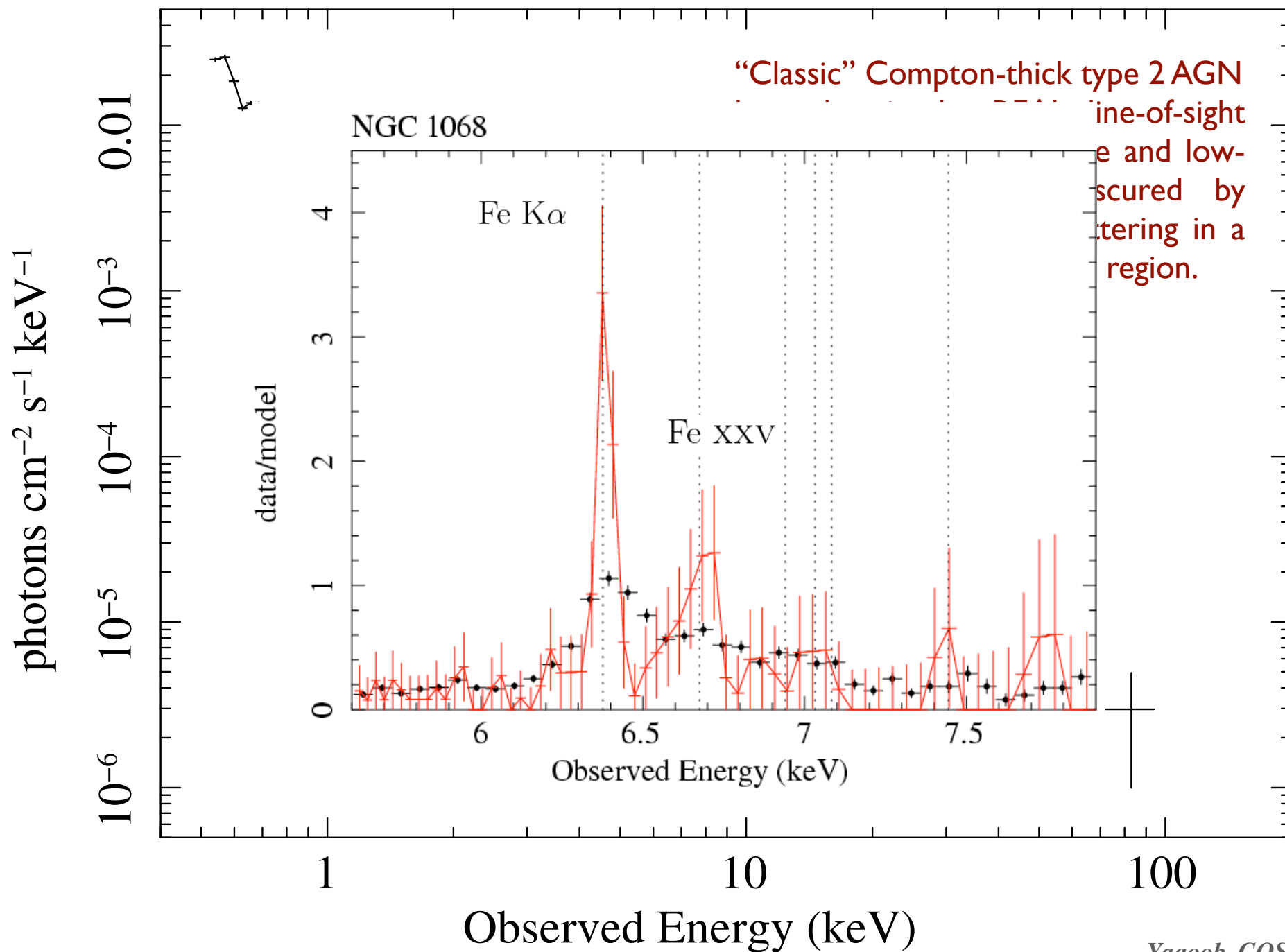
NGC 1068

Suzaku data



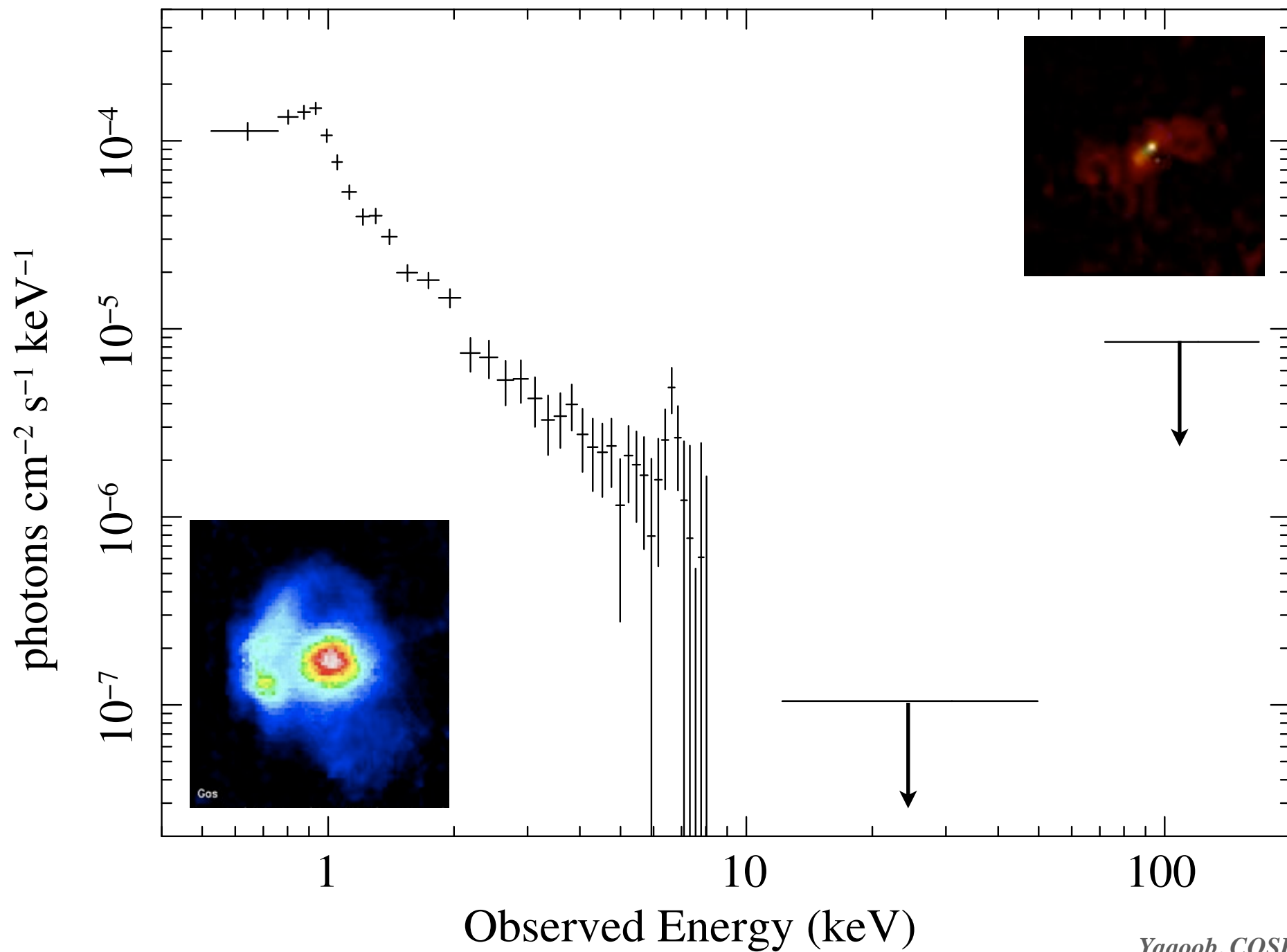
NGC 1068

Suzaku data

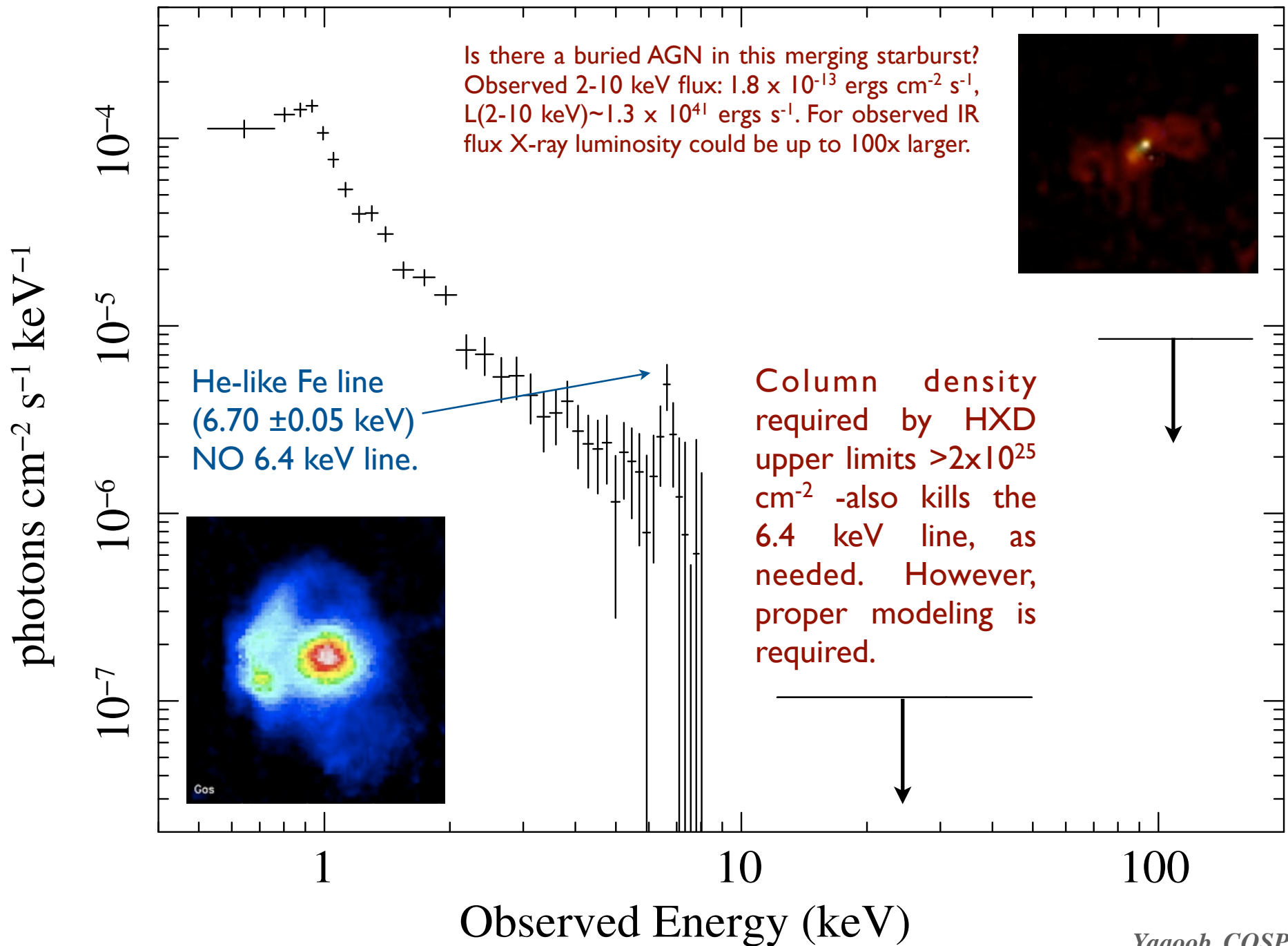


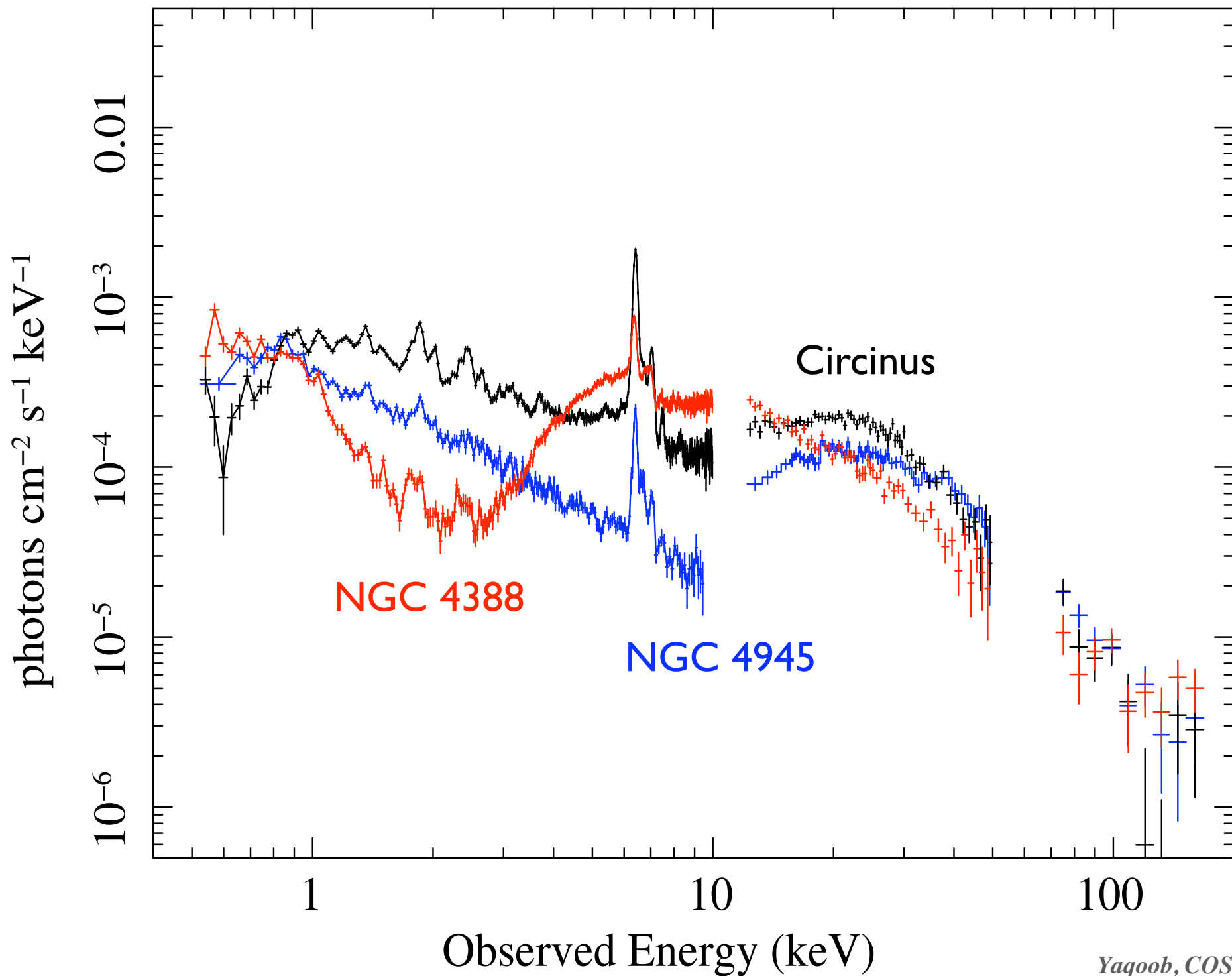


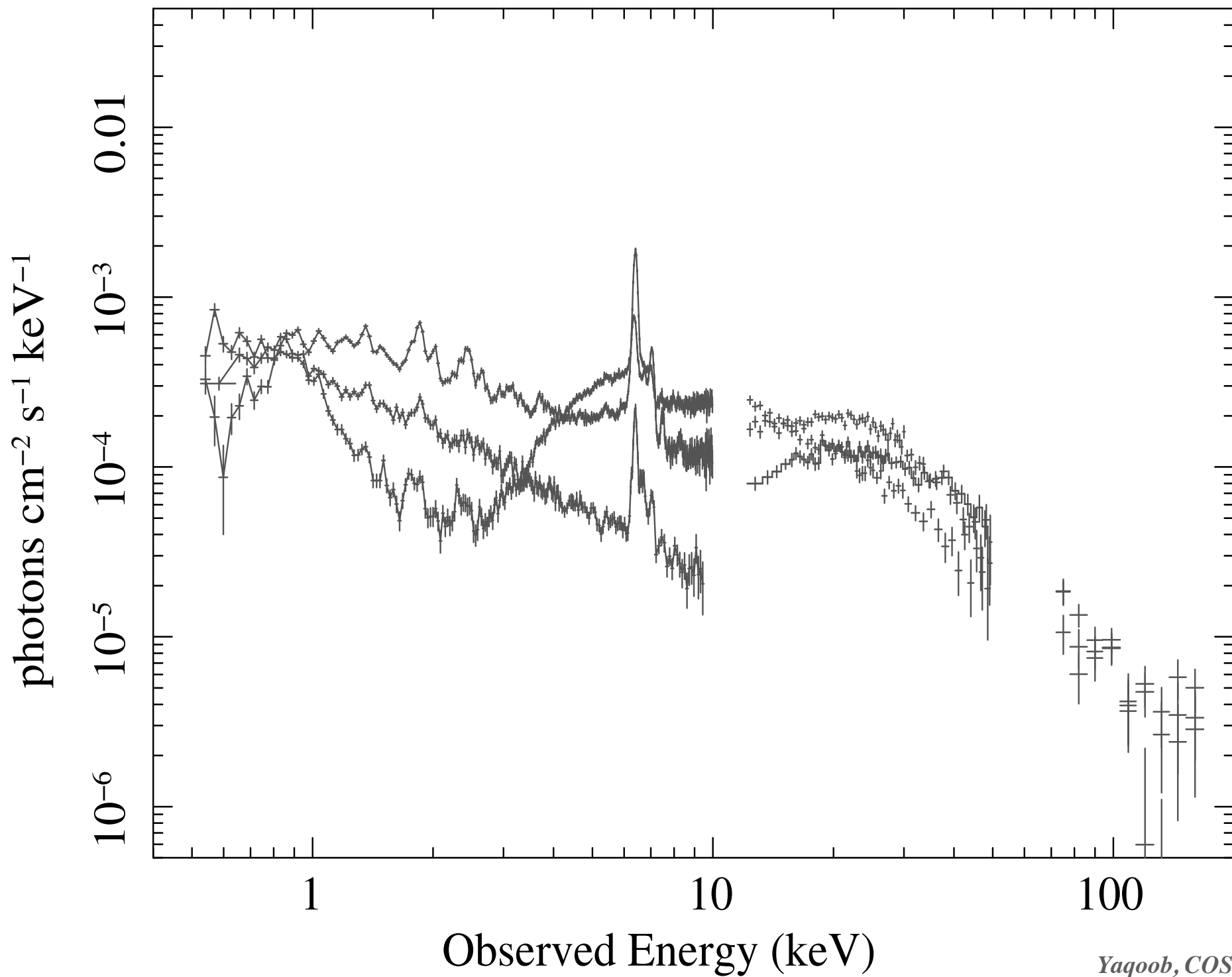
# Arp 220

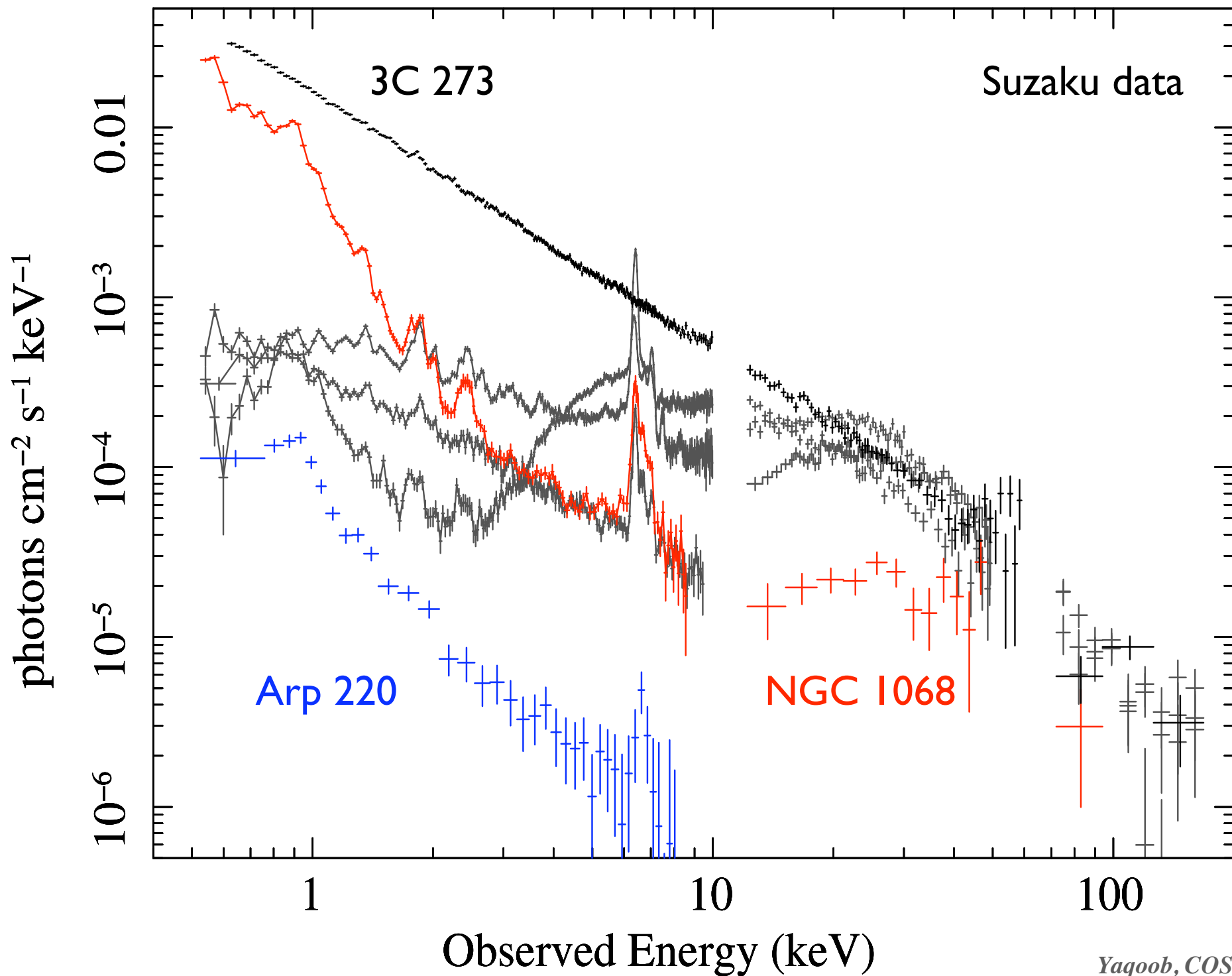


# Arp 220









# Conclusions

- ★ Study of X-ray reprocessing in AGN comes of age with Suzaku.
- ★ XIS CCD detectors combined with simultaneity of the hard band data makes Suzaku superior to any previous set of instruments flown for constraining the physics and structure of AGN using broadband X-ray spectroscopy.
- ★ Suzaku data demonstrate that good effective area at 7-8 keV (Fe K edge, Fe K $\beta$ ) is critical for reducing degeneracy of reprocessing models. Except for line widths, Suzaku wins in the 6-8 keV band over the Chandra HEG (effective area beats spectral resolution).
- ★ Suzaku data demand getting away from *ad-hoc* models (which provide ambiguous or no physical information). The Fe K line, scattered/reflected continua, and absorption features are physically linked. New spectral fitting code will utilize these relationships.
- ★ Suzaku can provide robust, model-independent constraints on Fe and Ni abundance in some cases. In Circinus the Ni abundance can be estimated to better than 20% and is significantly higher than cosmic values in the literature.
- ★ Some of the bright Seyfert 2 AGN yield good quality GSO spectra out to  $\sim 200$  keV.

# Sample Green's Functions: Fe K $\alpha$ Compton Shoulder

