Suzaku X-ray Spectroscopy of Obscured AGN

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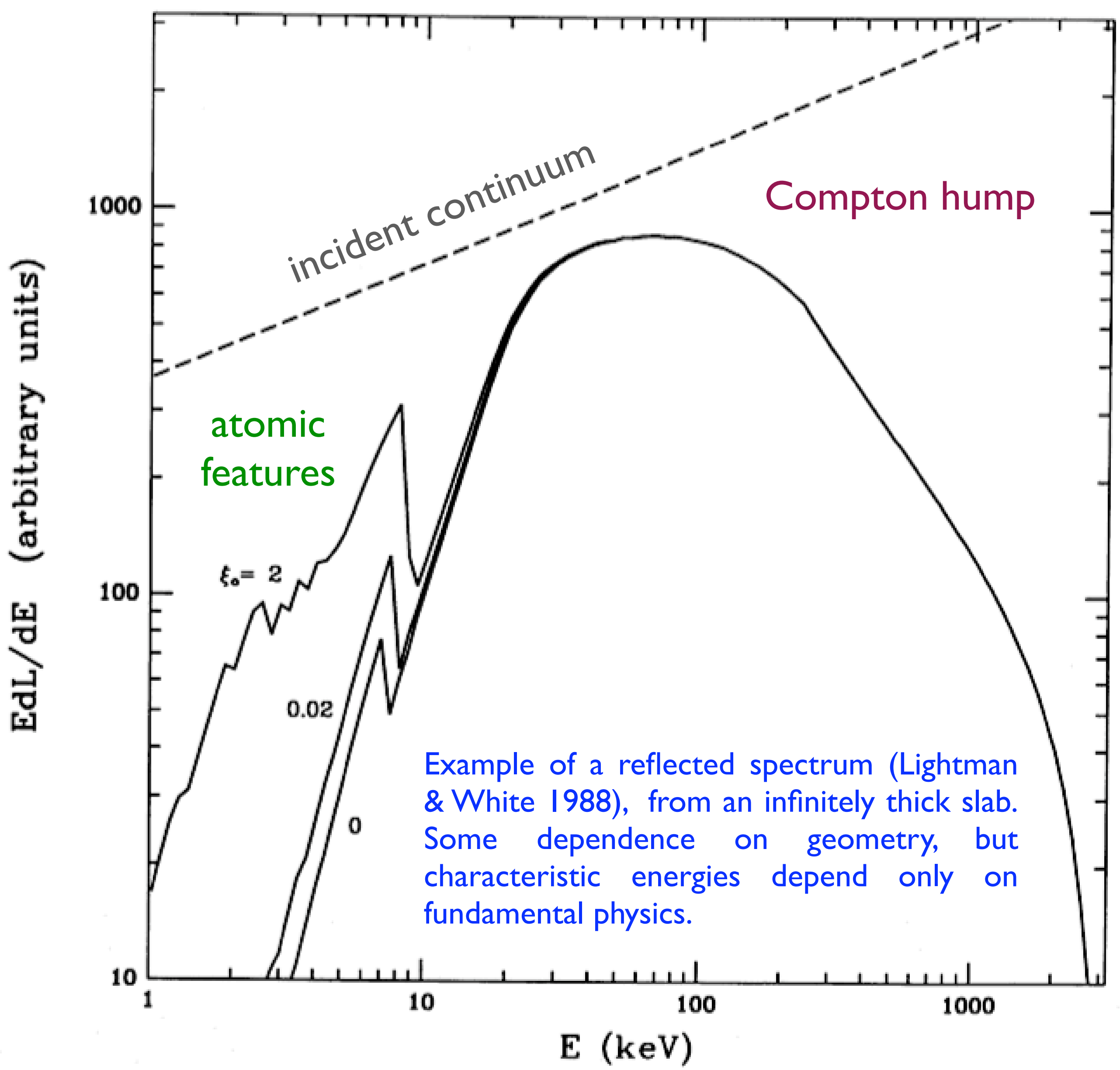
Purpose of talk:

★ 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.
- *Suzaku* observations of obscured AGN

★ Extracting more physical information from the data by replacing *adhoc* modeling practices. Need for new Compton-thick X-ray reprocessing spectral-fitting code and models - see talk by Kendrah Murphy later.

~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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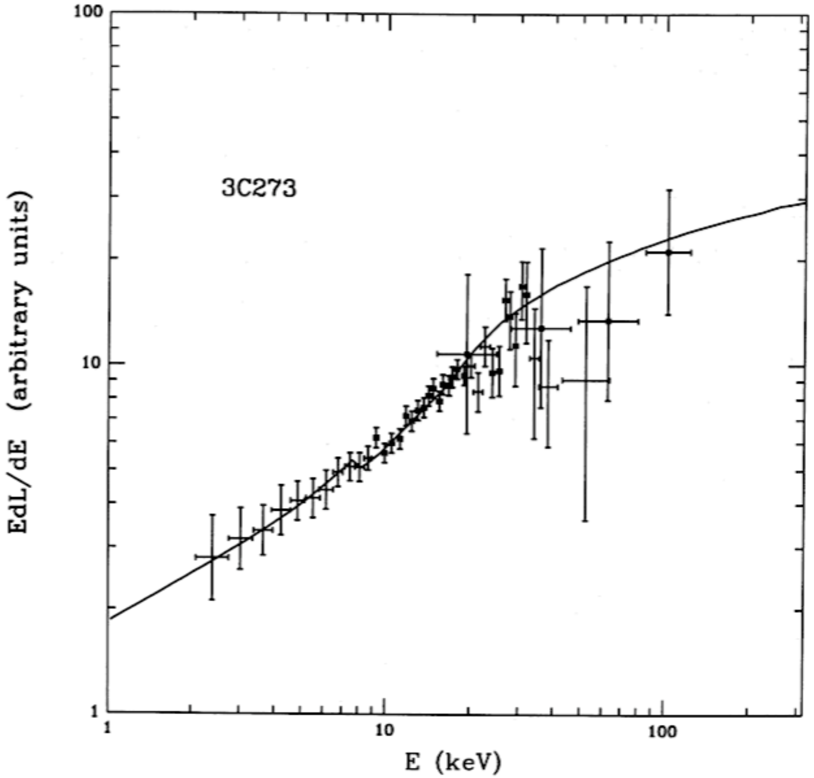

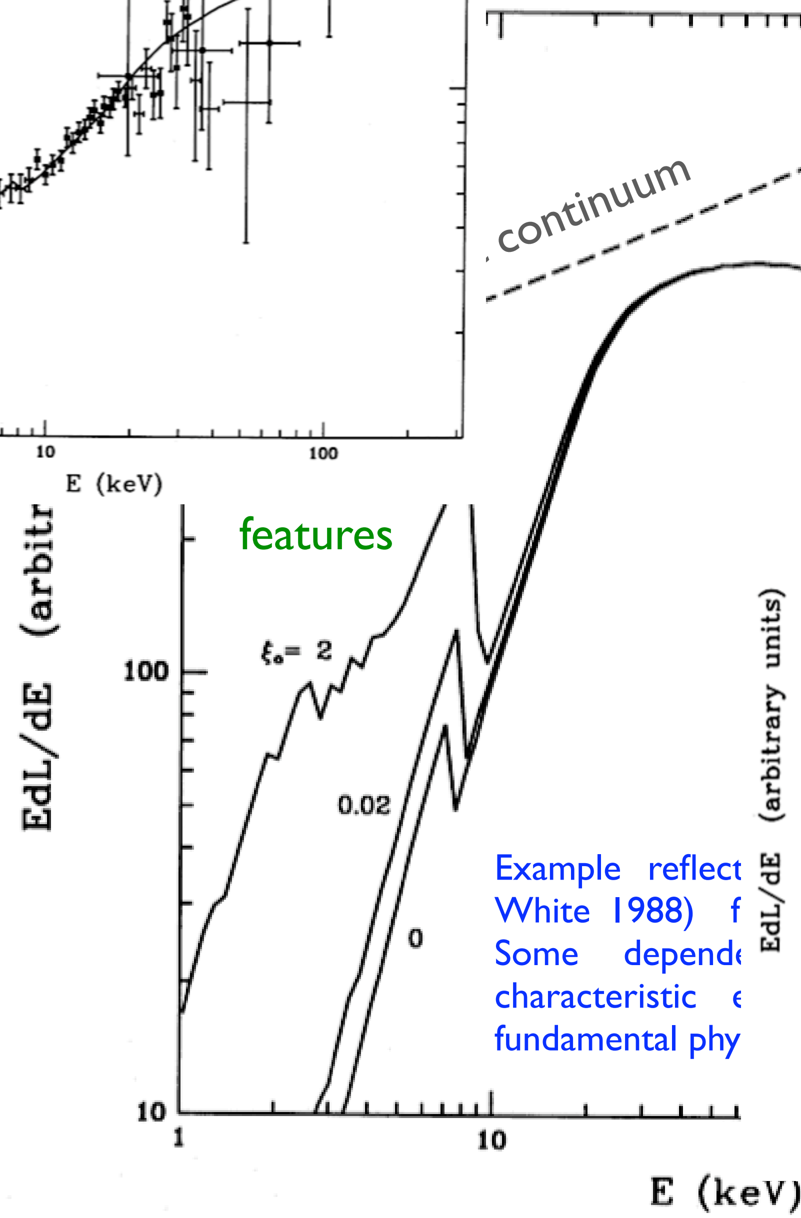

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White 1988) f
Some depende
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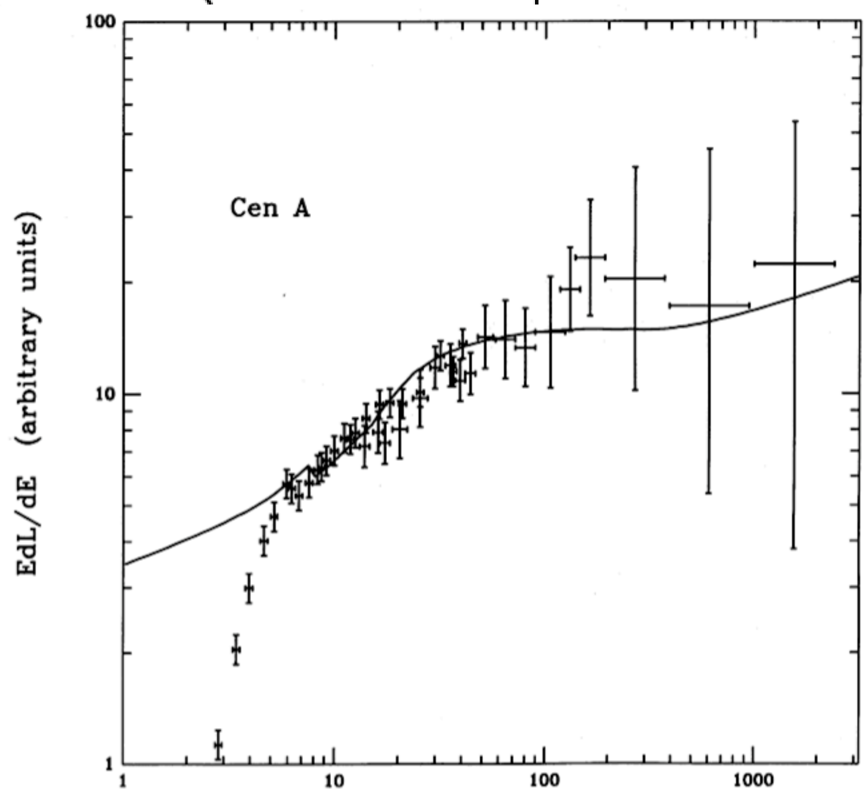
fundamental phy



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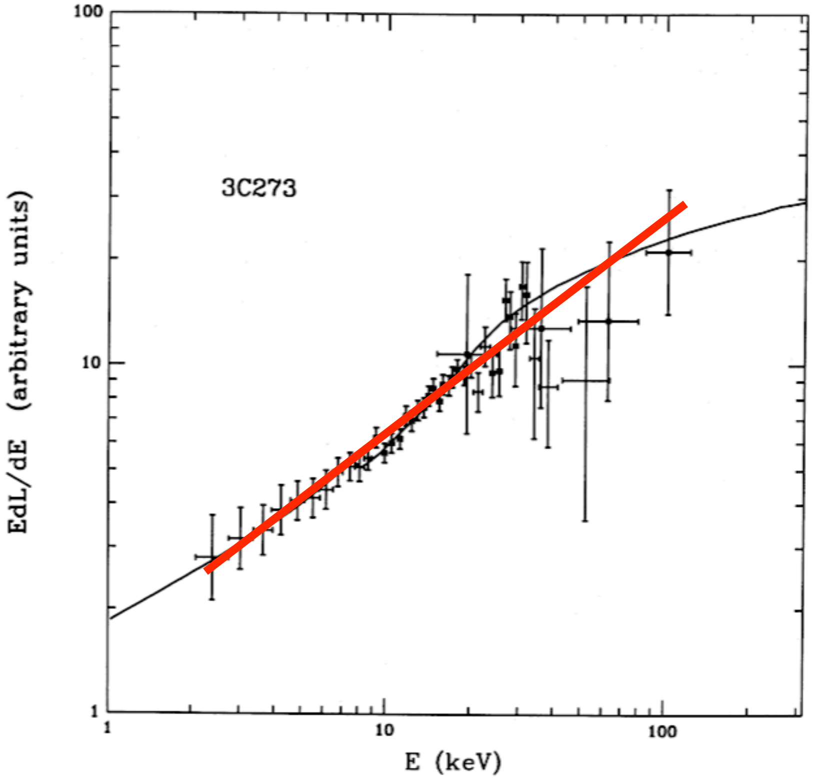

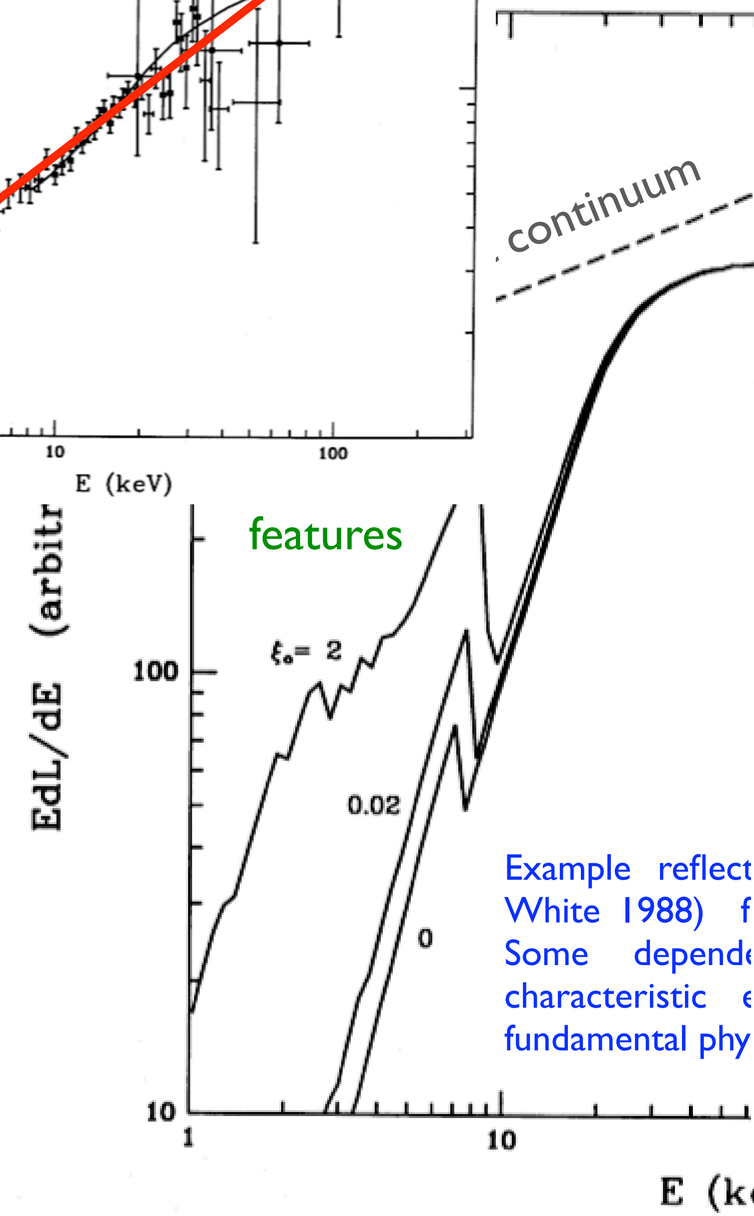

Example reflect
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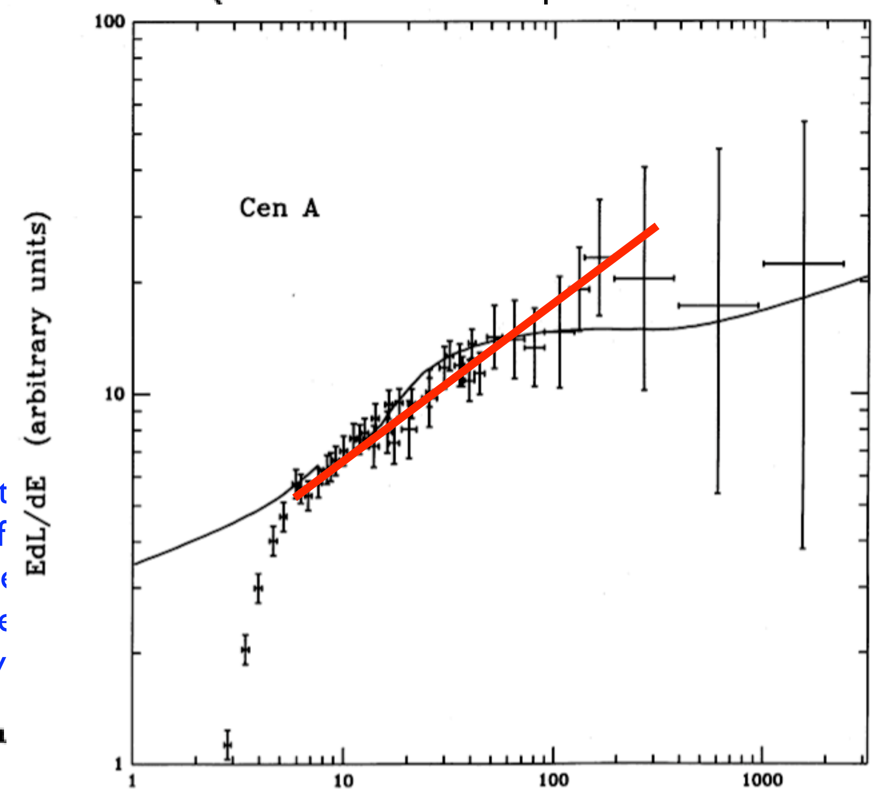

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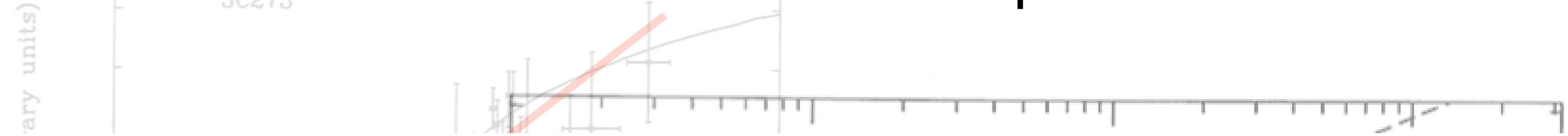

EFFECTS OF COLD MATTER IN ACTIVE GALACTIC NUCLEI: A BROAD HUMP IN THE X-RAY SPECTRA

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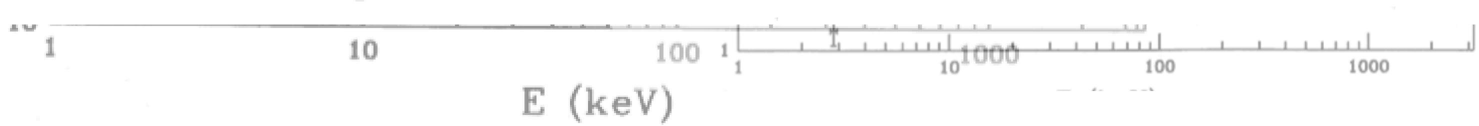
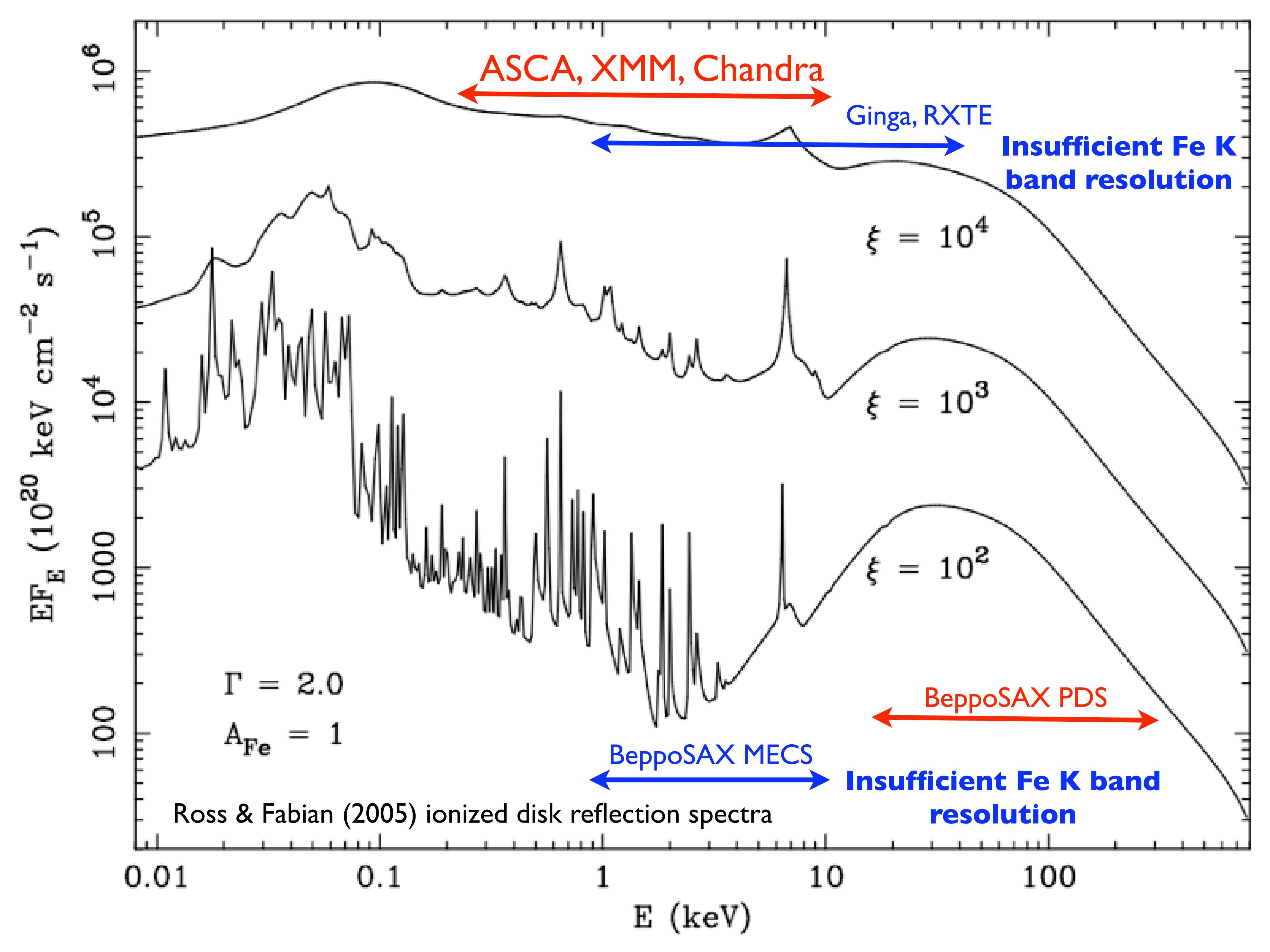
ABSTRACT

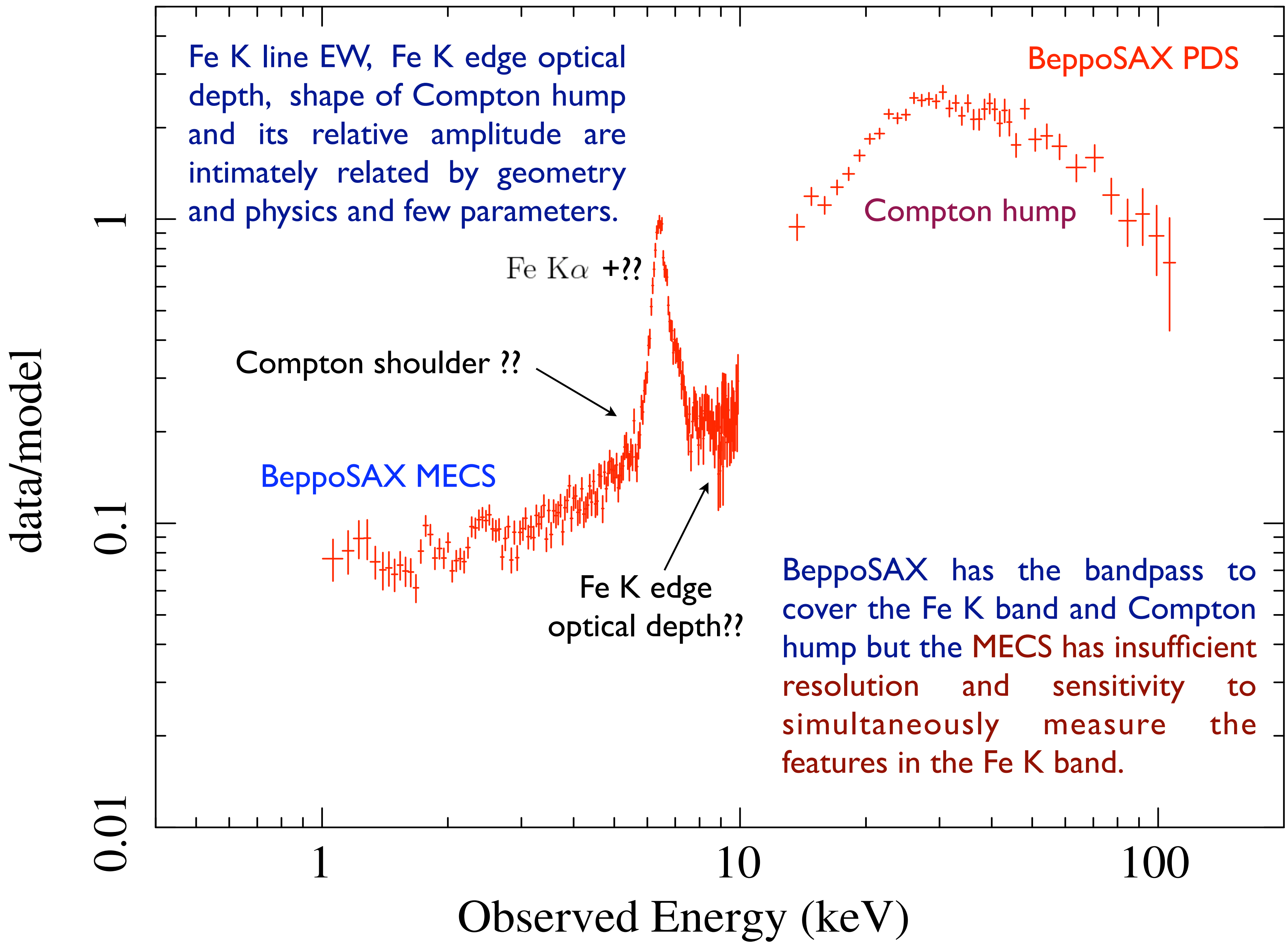
Recent observations and interpretations of the strong UV emission from active galactic nuclei (AGNs) suggest that relatively cold, thermal matter coexists with the hot, X-ray–emitting matter near the centers of these objects. A fraction of the X-rays will be reprocessed by the cold material, and the 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 ~10 keV and ~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 ~0.1–0.5, and observations with smaller error bars are clearly needed.

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




ASCA, XMM, Chandra
Ginga, RXTE
Insufficient Fe K band resolution
ξ = 10^4
ξ = 10^3
ξ = 10^2
Γ = 2.0
A_Fe = 1
BeppoSAX PDS
BeppoSAX MECS
Insufficient Fe K band resolution
Ross & Fabian (2005) ionized disk reflection spectra
EF_E (10^20 keV cm^-2 s^-1)
E (keV)
0.01
0.1
1
10
100
10^6
10^5
10^4
1000
100

Circinus Galaxy BeppoSAX spectrum



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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 $N_H \sim 1.5 \times 10^{24}$ cm^{-2} for "transmission".

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

Higher columns than 1.5 x 10^{24} 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.

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Fe K edge depth in transmission
(zeroth order continuum)

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

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

Fe abundance relative to solar (Anders & Grevesse)	τ_{FeK}
1	0.619
2	0.873
10	1.235

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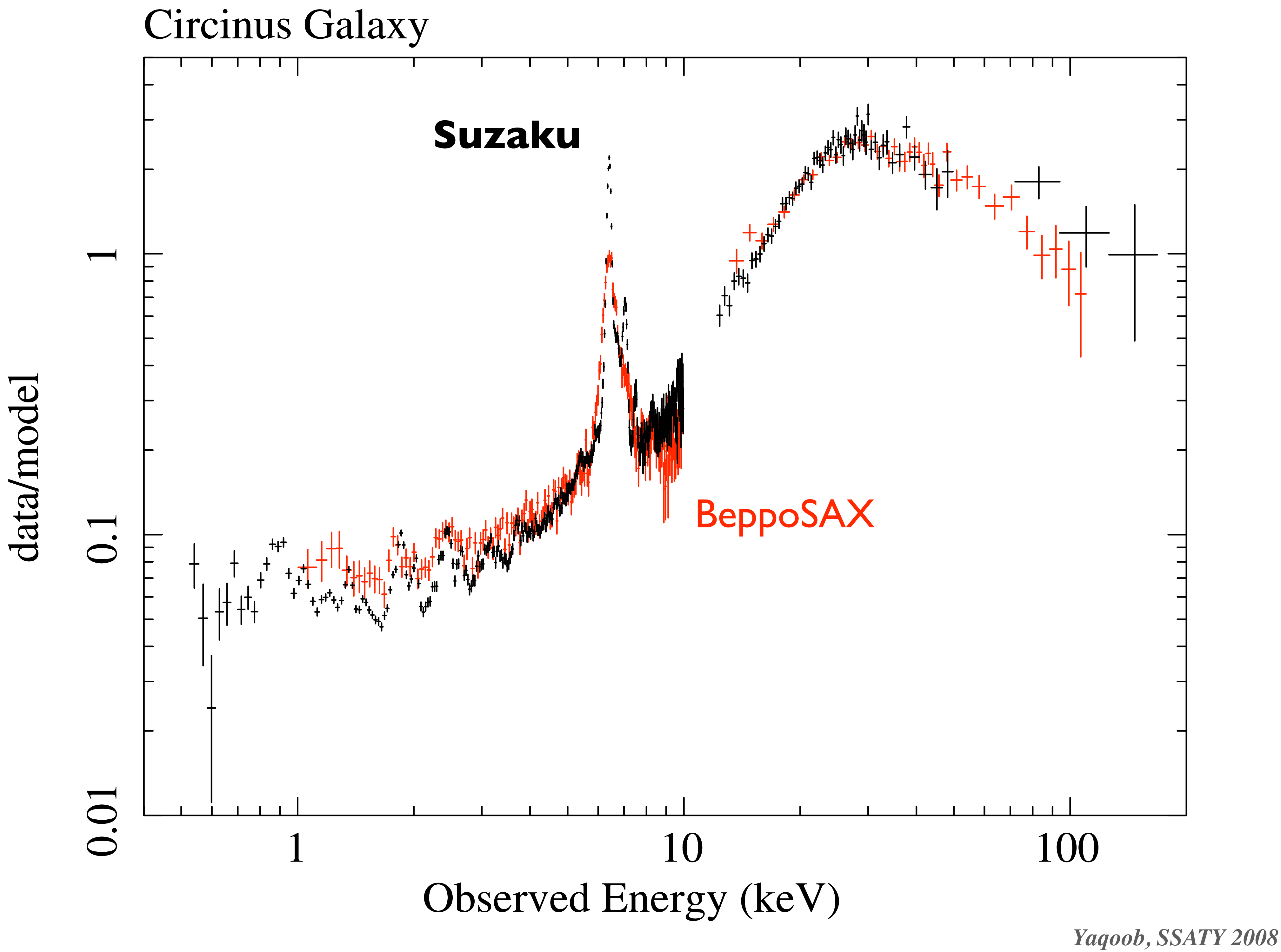

Circinus Galaxy
Suzaku
BeppoSAX
data/model
0.01
0.1
1
1
10
100
Observed Energy (keV)
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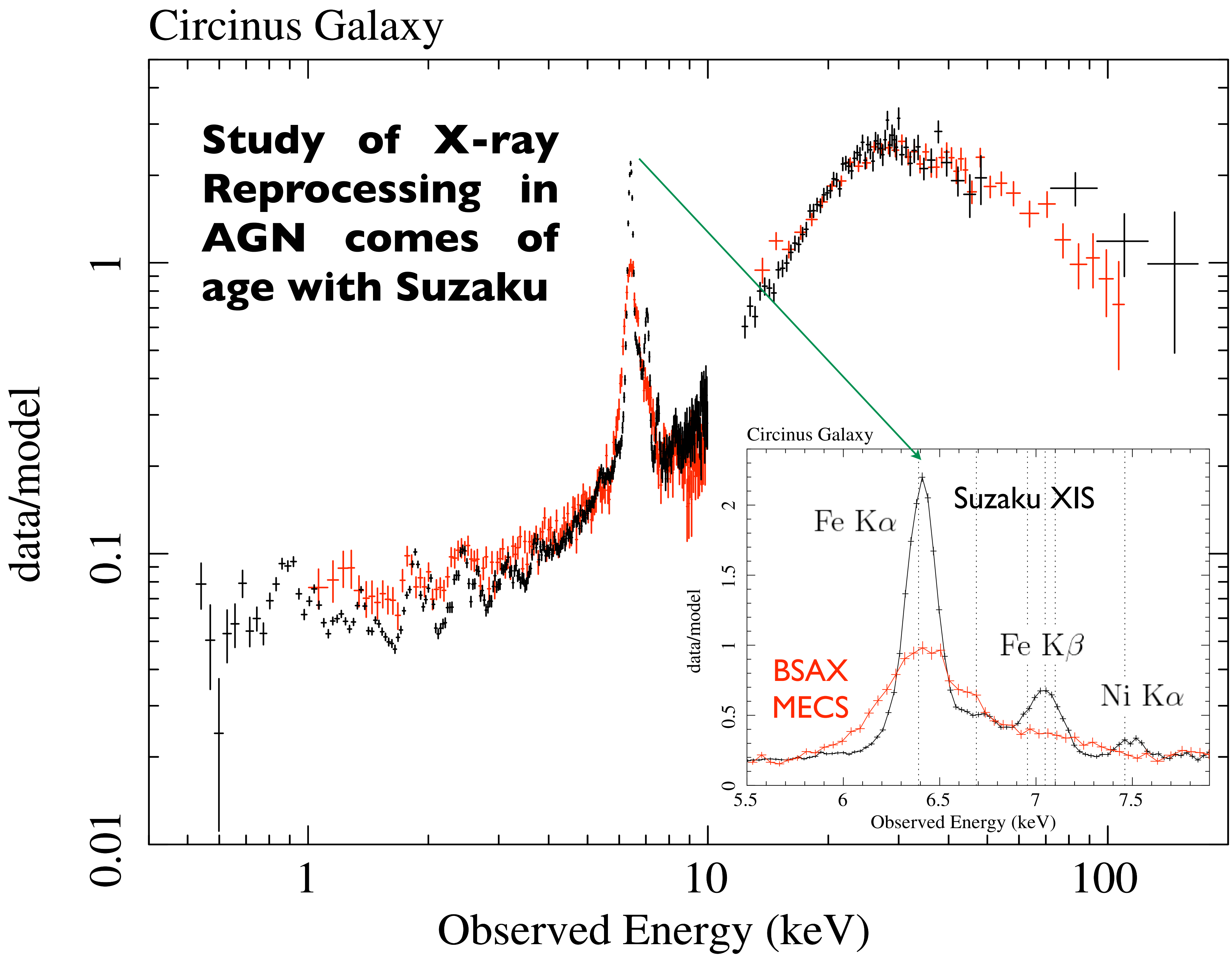

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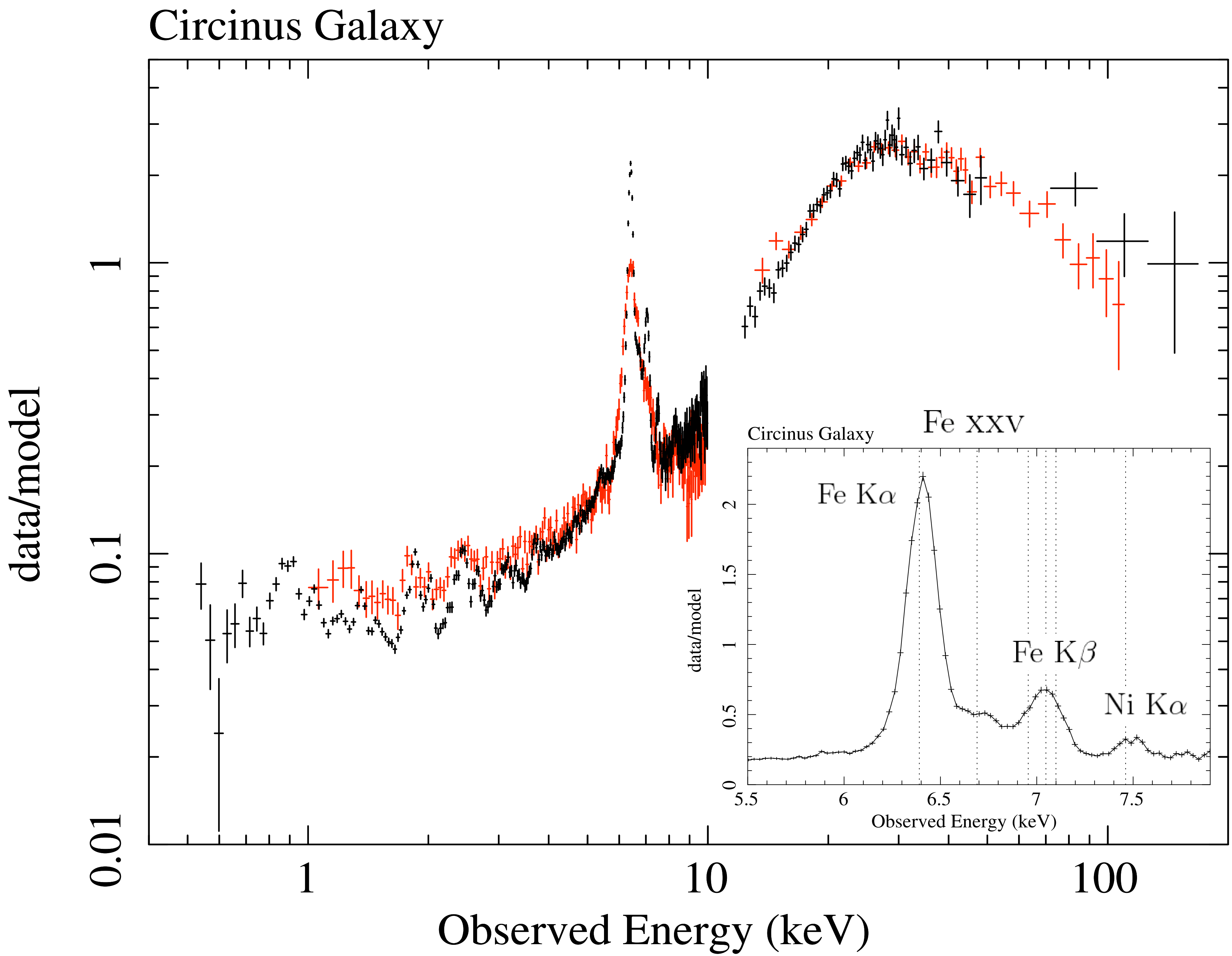

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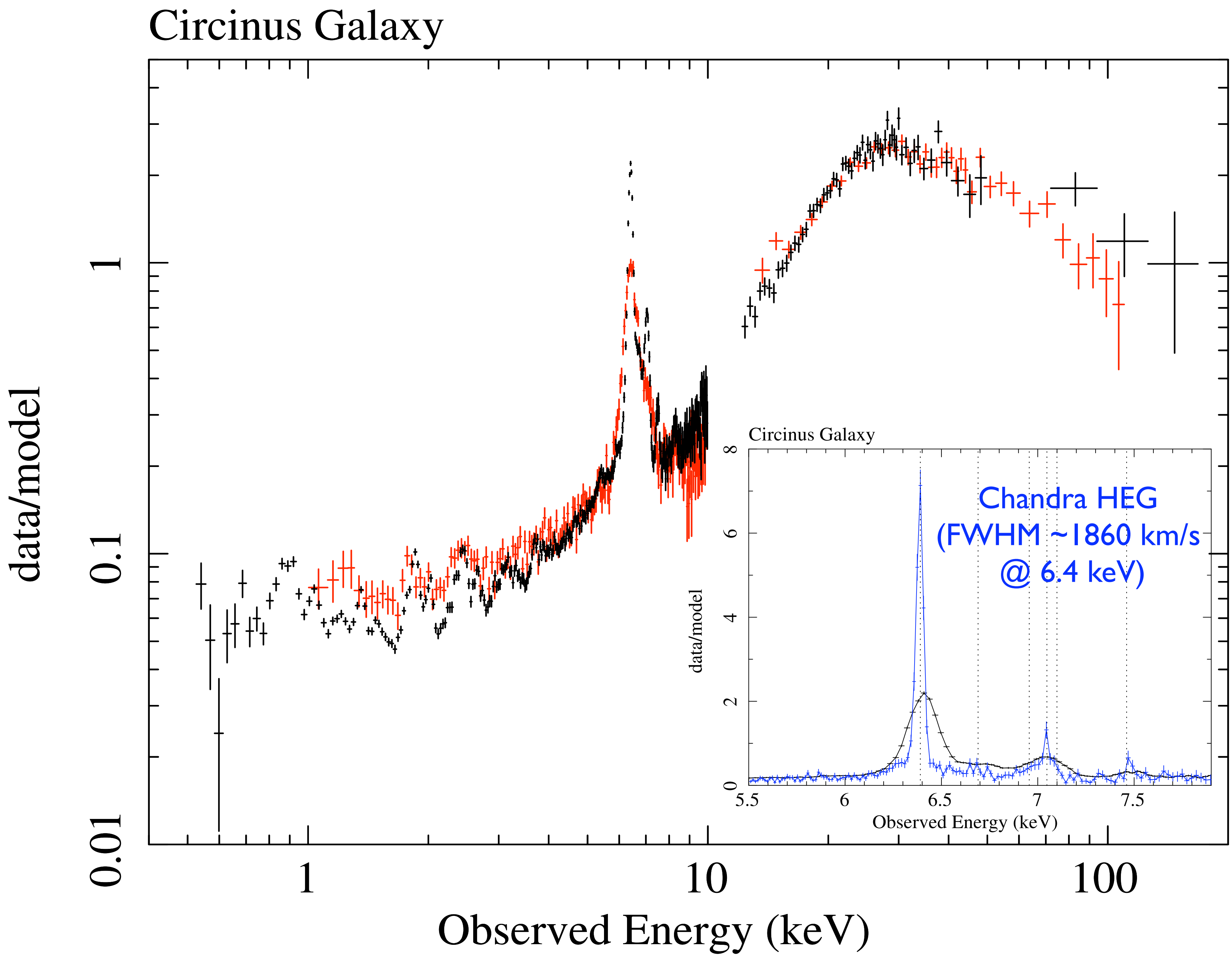

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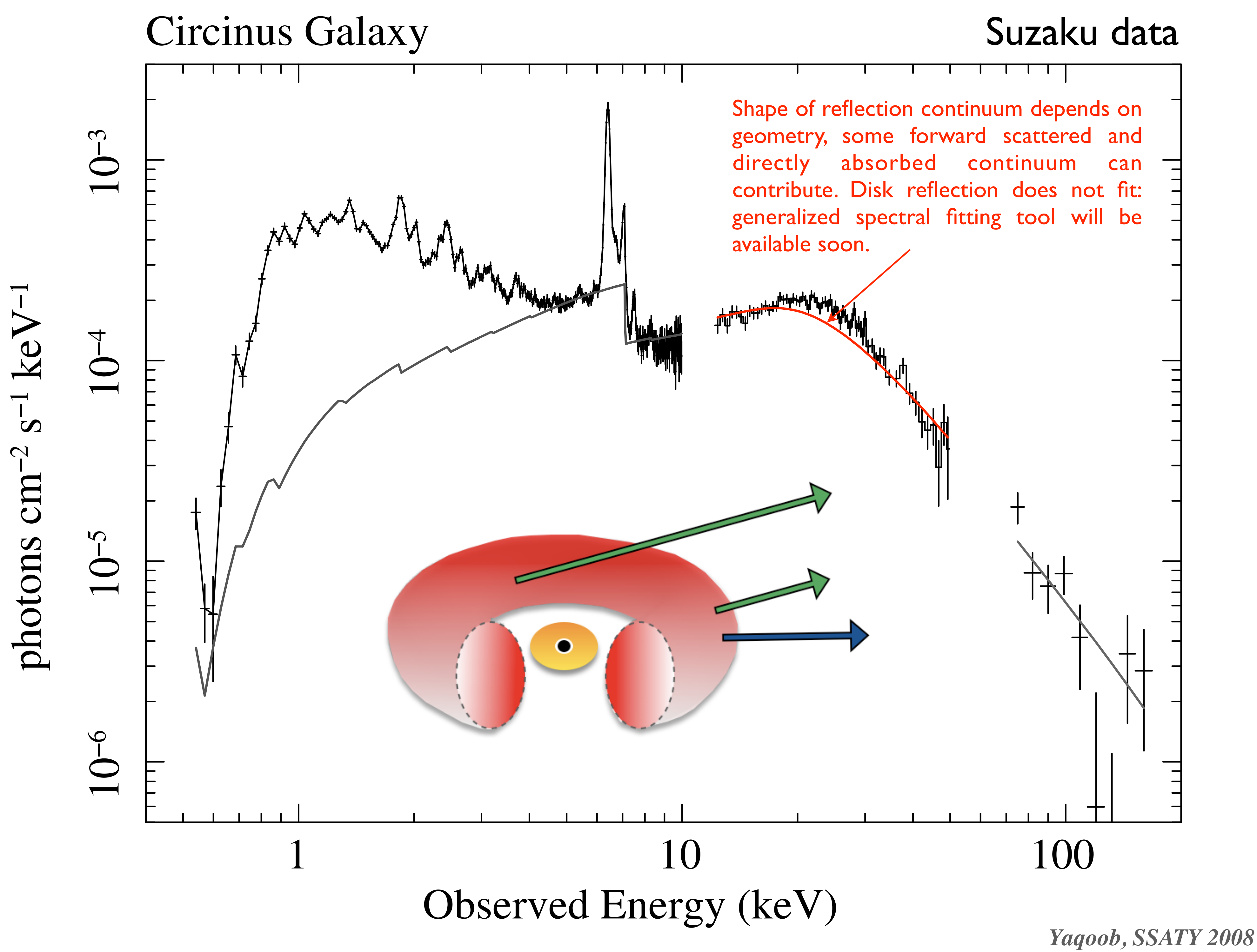


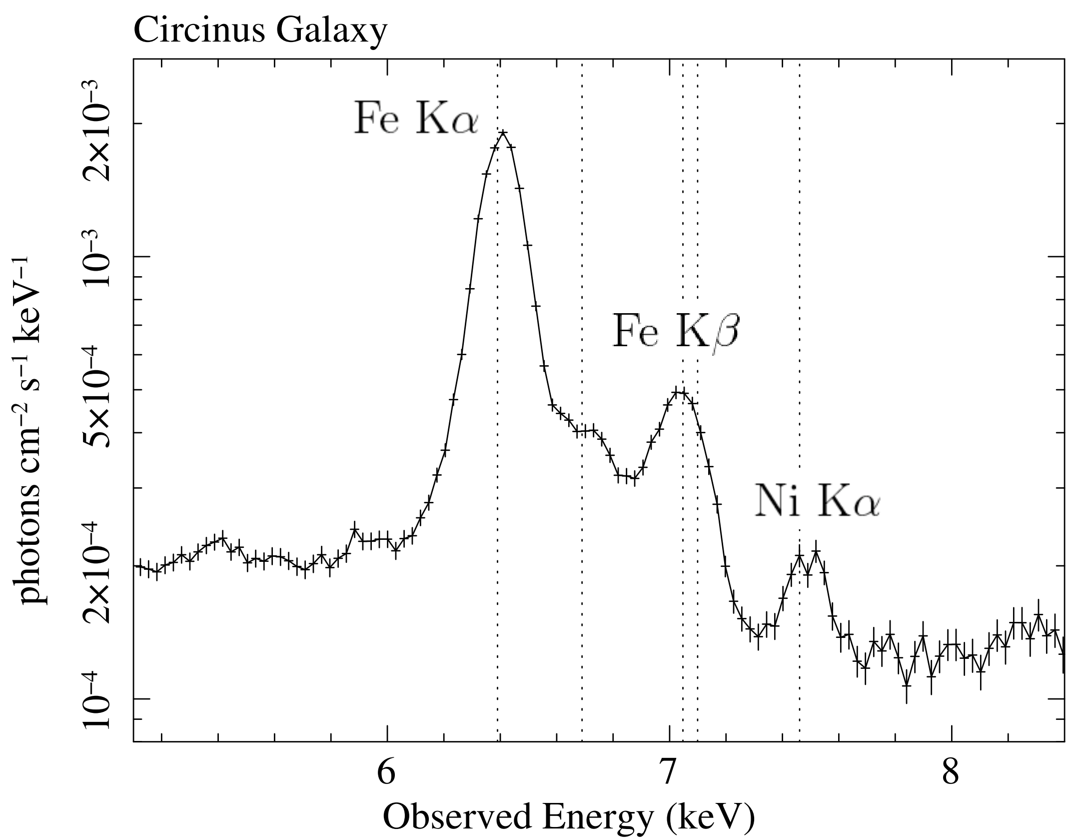
Circinus Galaxy
Suzaku data
Shape of reflection continuum depends on geometry, some forward scattered and directly absorbed continuum can contribute. Disk reflection does not fit: generalized spectral fitting tool will be available soon.
photons cm^{-2} s^{-1} keV^{-1}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
1
10
100
Observed Energy (keV)
Yaqoob, SSATY 2008

Unprecedented precision with Suzaku

$$\frac{EW_{Ni(refl)}}{EW_{Fe(refl)}} = \left(\frac{\omega_{Ni}}{\omega_{Fe}}\right)\left(\frac{A_{Ni}}{A_{Fe}}\right)\left(\frac{\sigma^0_{NiK}}{\sigma^0_{FeK}}\right)\left(\frac{E_{K,Ni}}{E_{K,Fe}}\right)^{1-\Gamma}\left(\frac{E_{0,Fe}}{E_{K,Ni}}\right)^{\Gamma}\left(\frac{\Gamma+\alpha_{Fe}-1}{\Gamma+\alpha_{Ni}-1}\right)$$

$$= 1.284\left(\frac{A_{Ni}}{A_{Fe}}\right)$$

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



How to disentangle Fe K edge?

Fe Kα

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

Yaqoob, SSATY 2008

Unprecedented precision with Suzaku

$$\frac{EW_{\rm Ni(refl)}}{EW_{\rm Fe(refl)}} = \left(\frac{\omega_{\rm Ni}}{\omega_{\rm Fe}}\right)\left(\frac{A_{\rm Ni}}{A_{\rm Fe}}\right)\left(\frac{\sigma^0_{\rm NiK}}{\sigma^0_{\rm FeK}}\right)\left(\frac{E_{\rm K,Ni}}{E_{\rm K,Fe}}\right)^{1-\Gamma}\left(\frac{E_{\rm 0,Fe}}{E_{\rm K,Ni}}\right)^{\Gamma}\left(\frac{\Gamma+\alpha_{\rm Fe}-1}{\Gamma+\alpha_{\rm Ni}-1}\right)$$
$$= 1.284\left(\frac{A_{\rm Ni}}{A_{\rm Fe}}\right)$$

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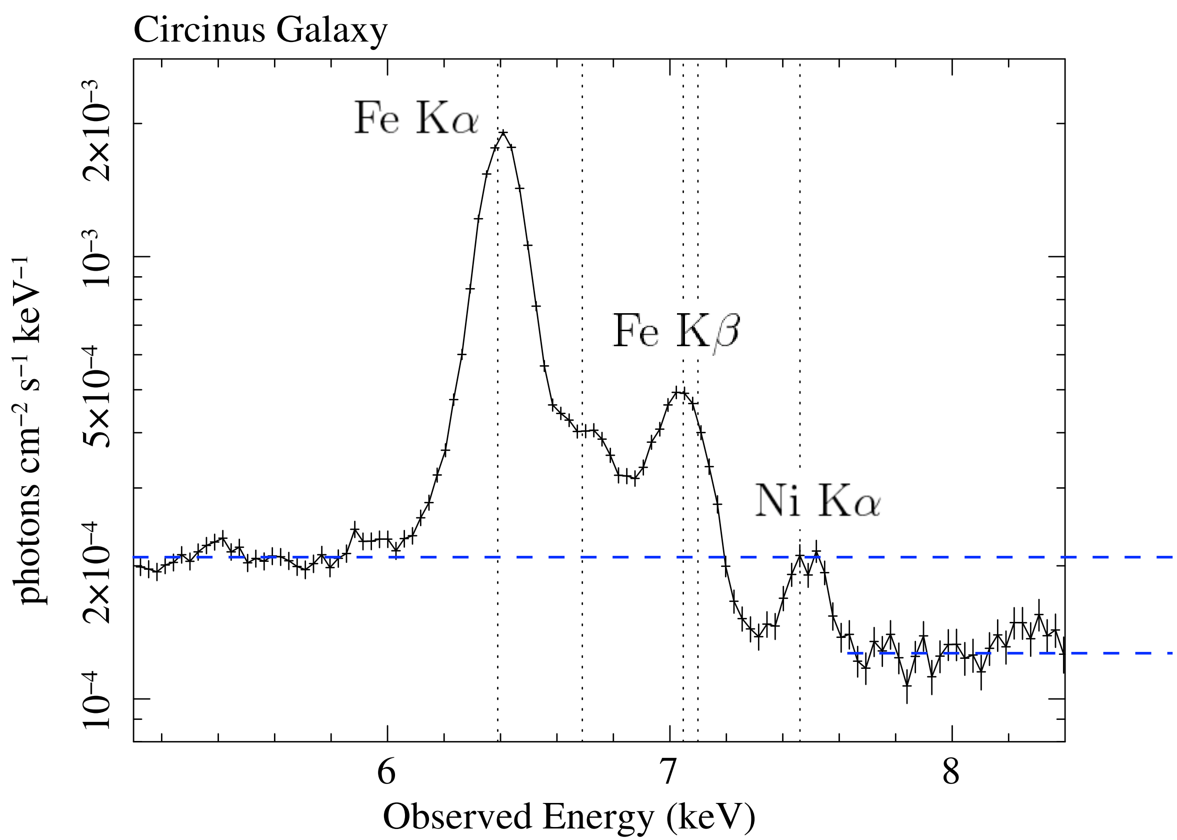

Fe K edge depth 0.70 +/- 0.15 pure reflection in this band.

Fe Kα

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

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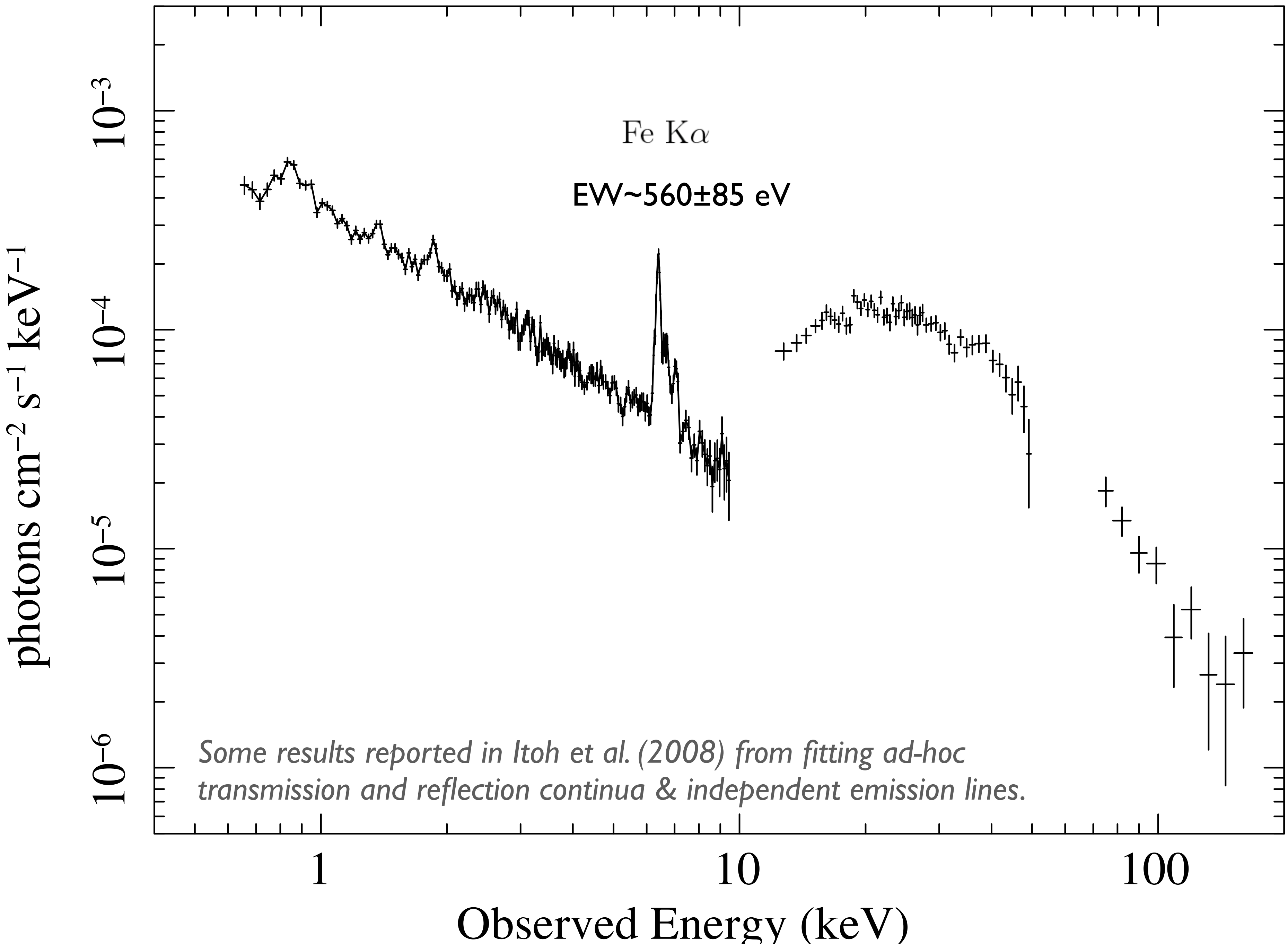
NGC 4945 **Suzaku data**



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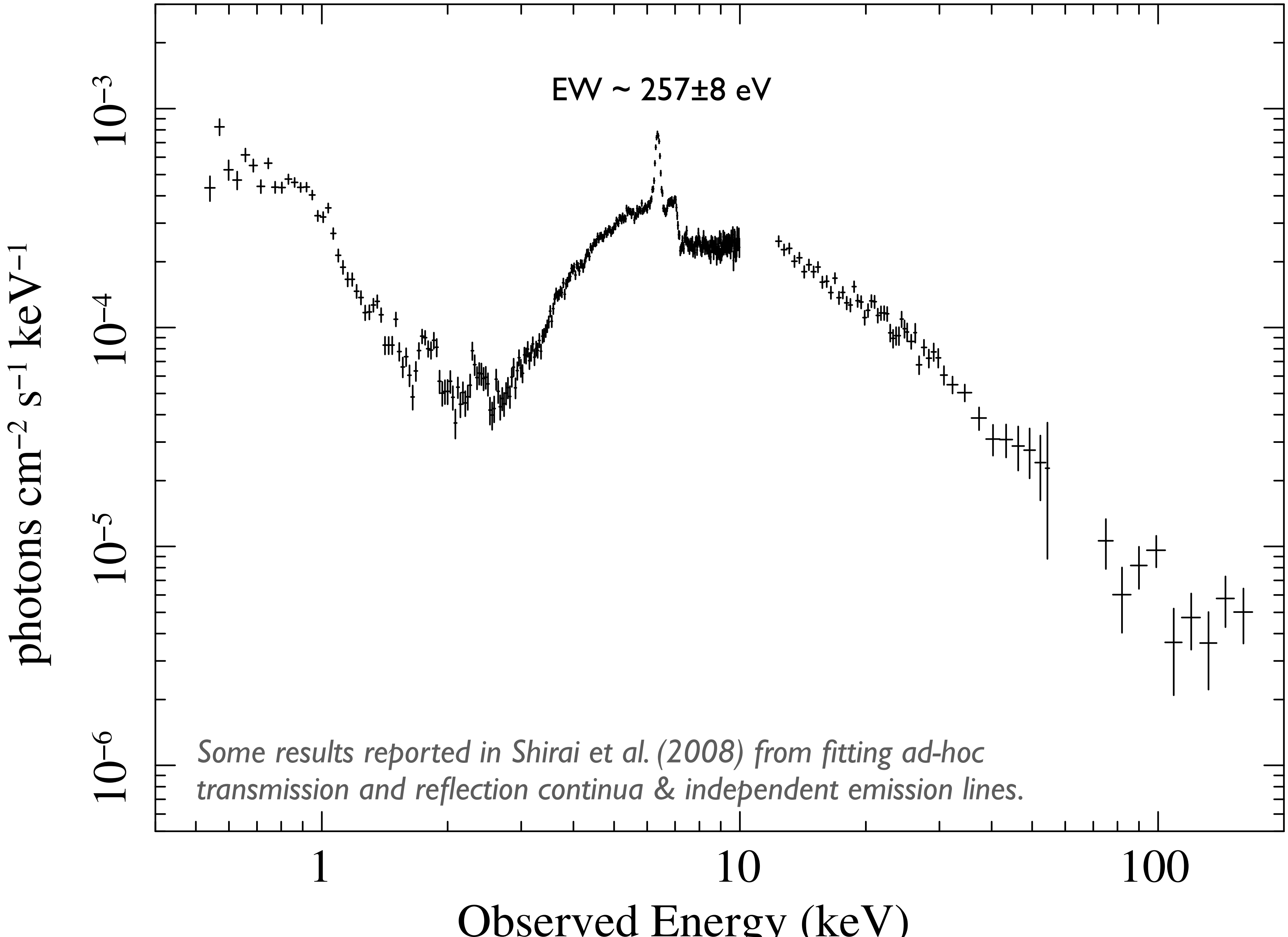
NGC 4388

Suzaku data



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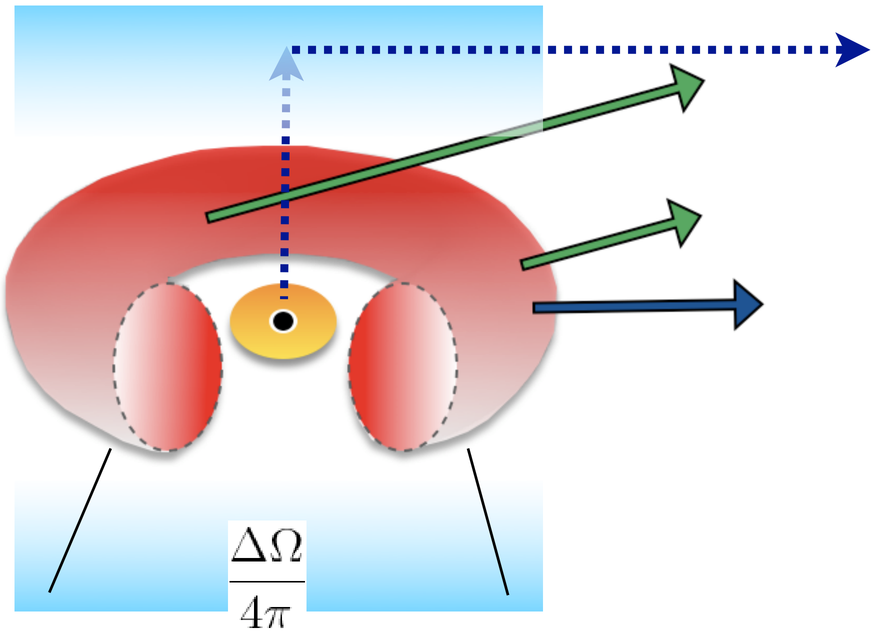

$$f \equiv \tau_{\rm es}\left(\frac{\Delta\Omega}{4\pi}\right)$$

$$\frac{\rm EW_{observed}}{\rm EW_{Refl\ [scattered\ C.]}} = \frac{1}{1+x}$$

$$x \equiv \frac{\rm direct\ +\ 0^{th}order + \ other\ scattered\ continua}{\rm continuum\ scattered\ in\ Fe\ K\ line - producing\ region}$$

$$\rm EW_{observed} \sim EW_{Refl}\left[\frac{1\ -\ \exp\left(-0.81 N_{24}\lambda_1/\lambda_{6.4}\right)}{1\ +\ f\ \exp\left(0.81 N_{24}\lambda_2/\lambda_{6.4}\right)}\right]$$

where $N_{24} \equiv N_H/(10^{24}\ {\rm cm^{-2}})$

$\lambda_{6.4} \equiv$ single scattering albedo for Fe-K line photons (~ 0.30 at 6.4 keV).

$\lambda_1 \equiv 1 - \sqrt{(1-\lambda_{6.4})}$, $\lambda_2 \equiv \sqrt{(1-\lambda_{6.4})}$

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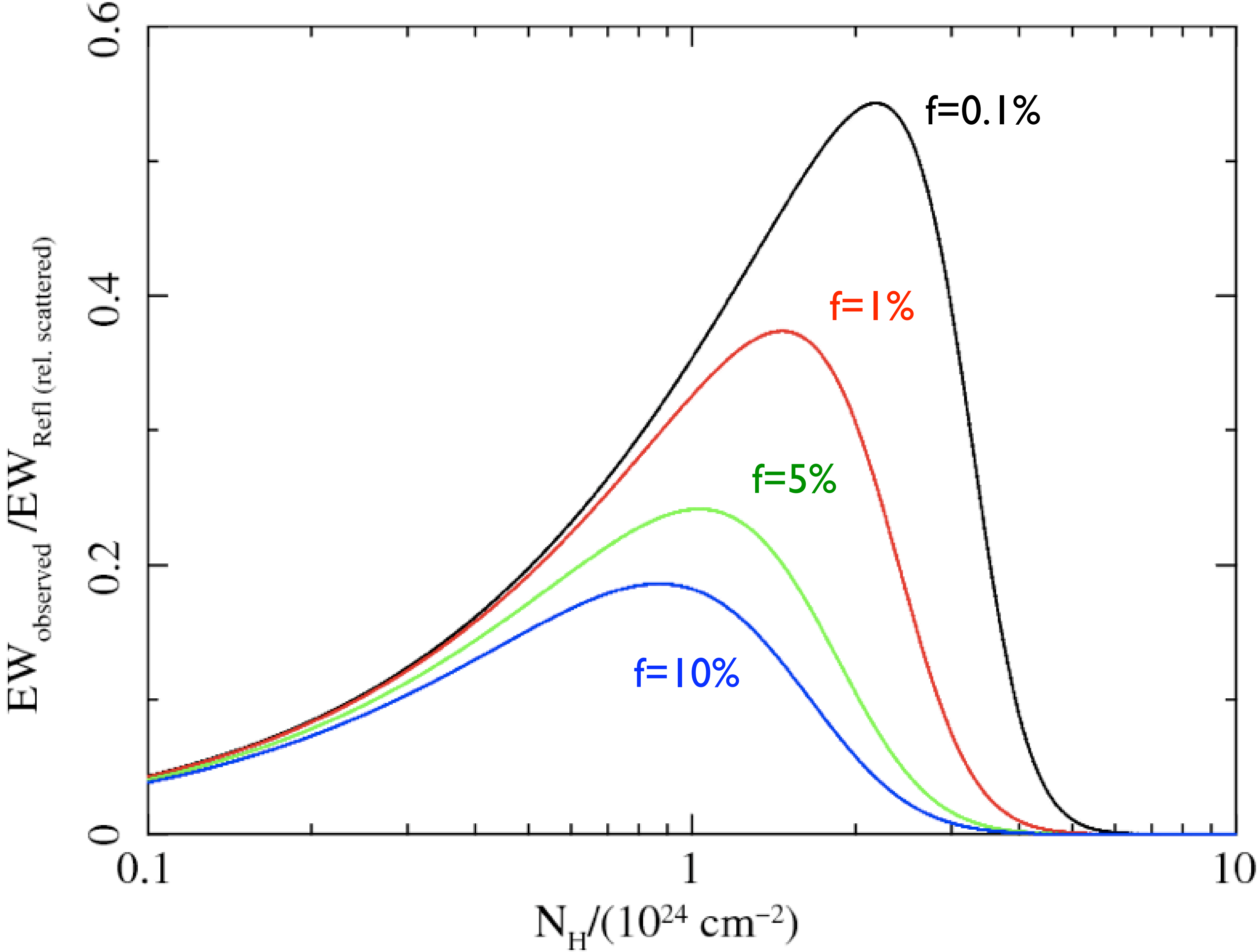

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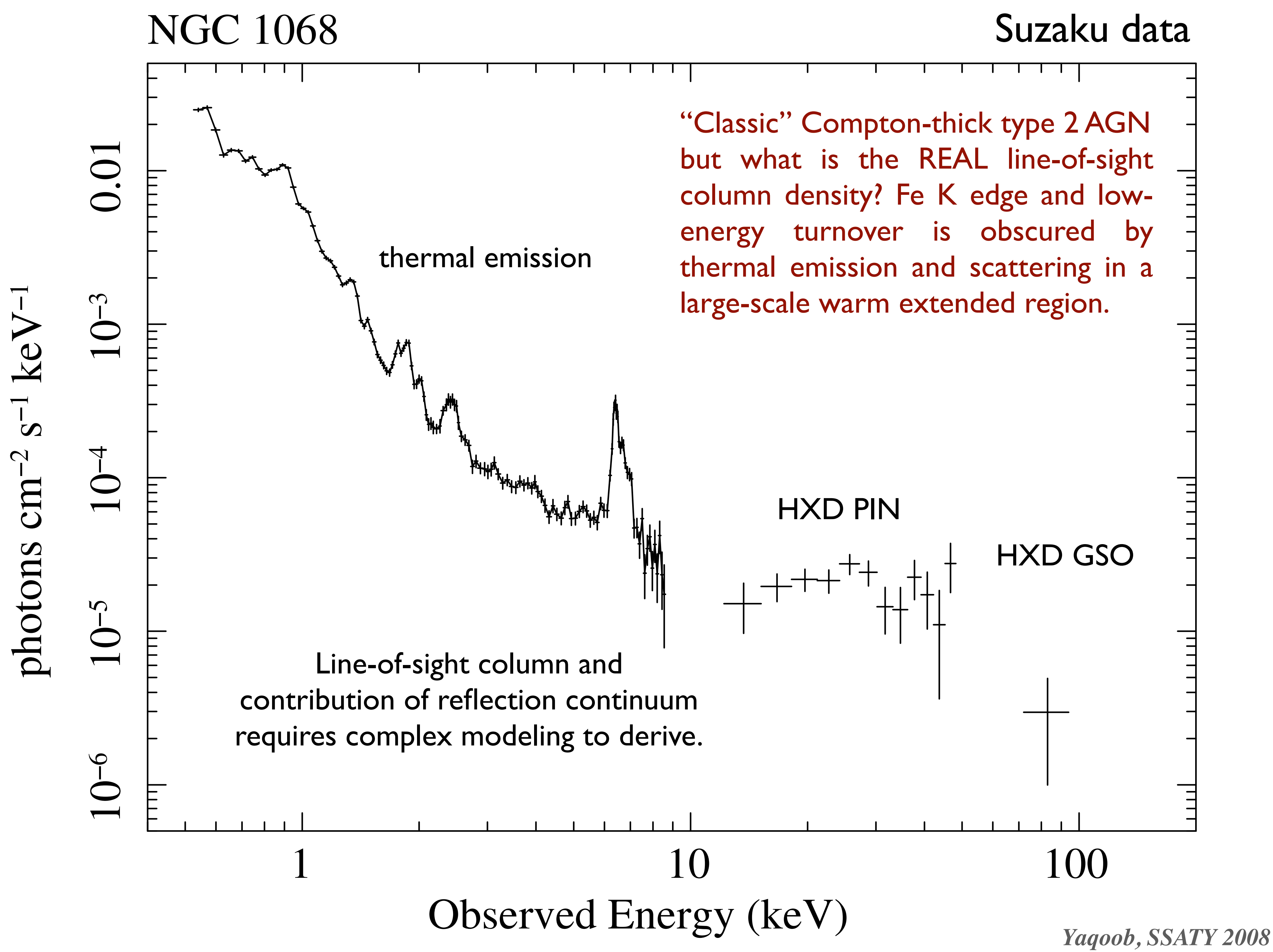

NGC 1068
Suzaku data
photons cm^{-2} s^{-1} keV^{-1}
0.01
10^{-3}
10^{-4}
10^{-5}
10^{-6}
1
10
100
Observed Energy (keV)
"Classic" Compton-thick type 2 AGN but what is the REAL line-of-sight column density? Fe K edge and low-energy turnover is obscured by thermal emission and scattering in a large-scale warm extended region.
thermal emission
HXD PIN
HXD GSO
Line-of-sight column and contribution of reflection continuum requires complex modeling to derive.
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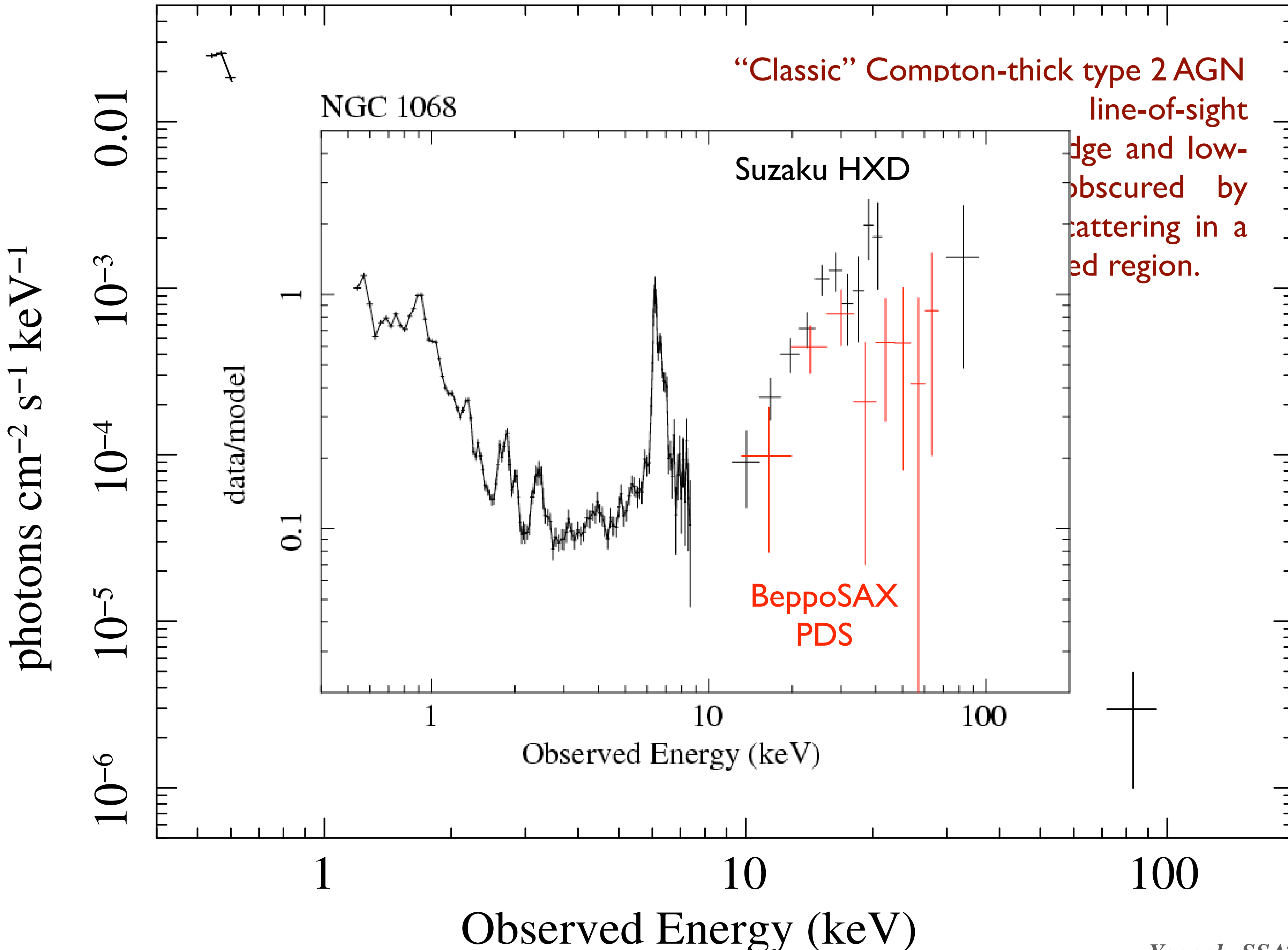
NGC 1068

Suzaku data



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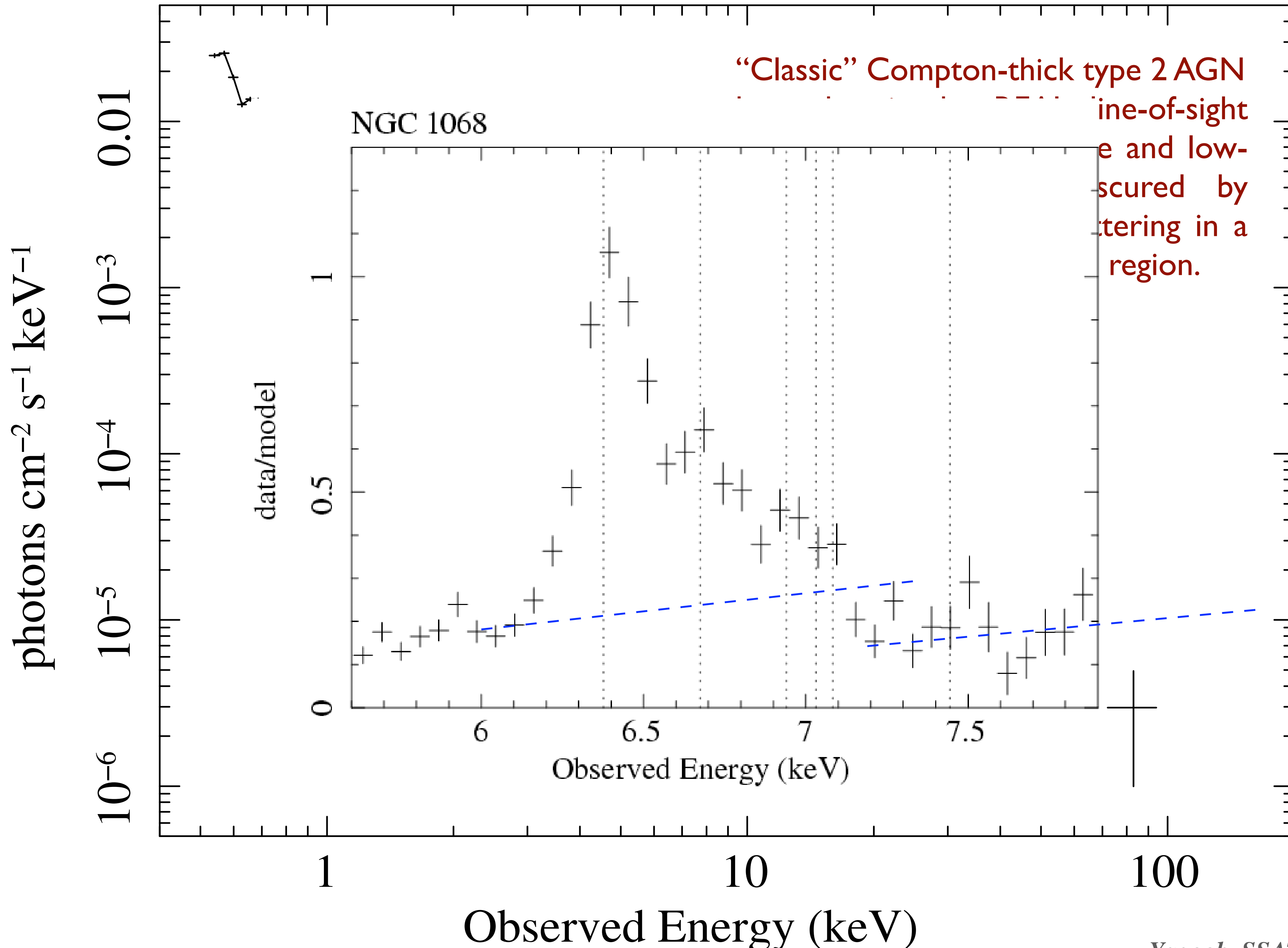
NGC 1068 — Suzaku data



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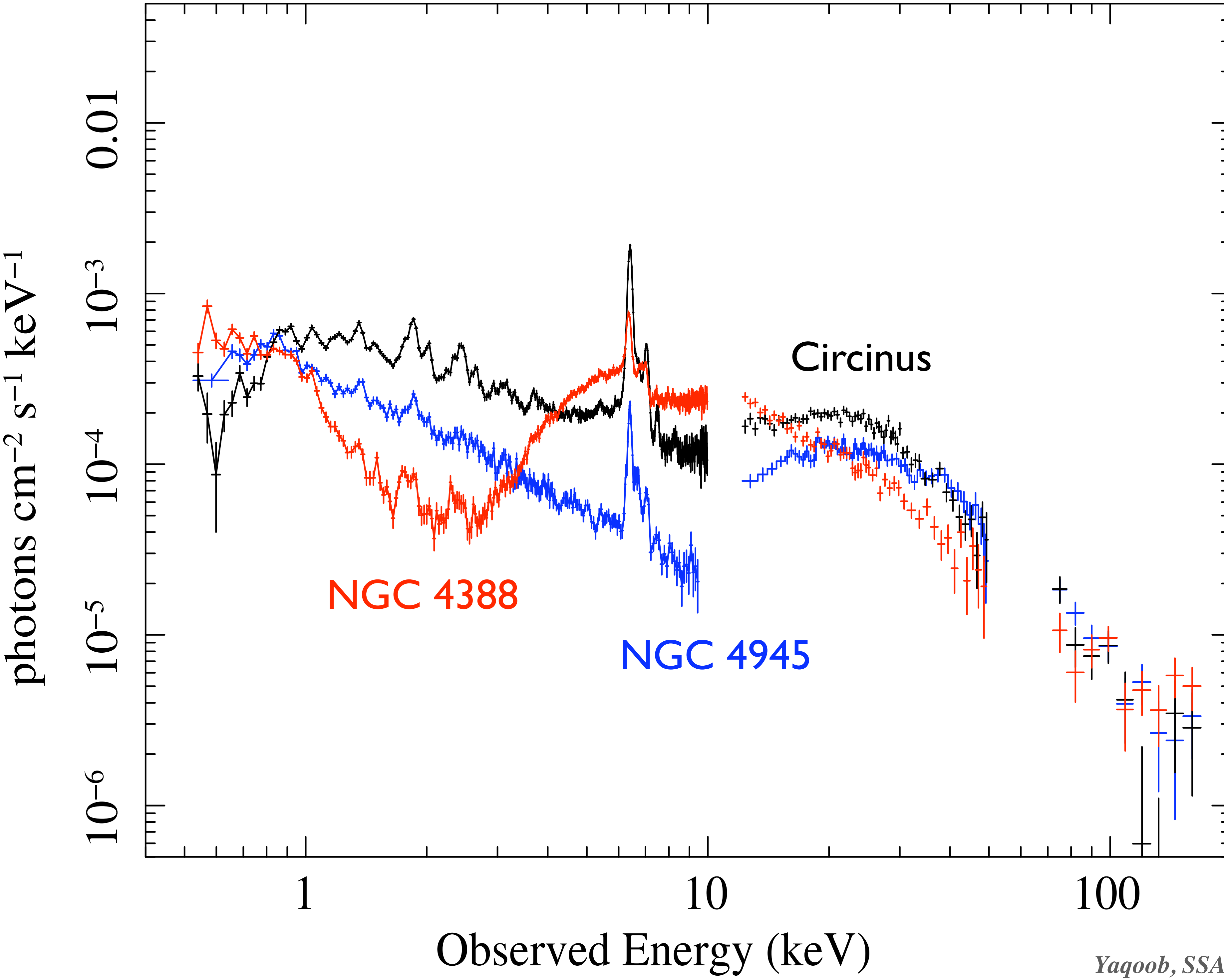

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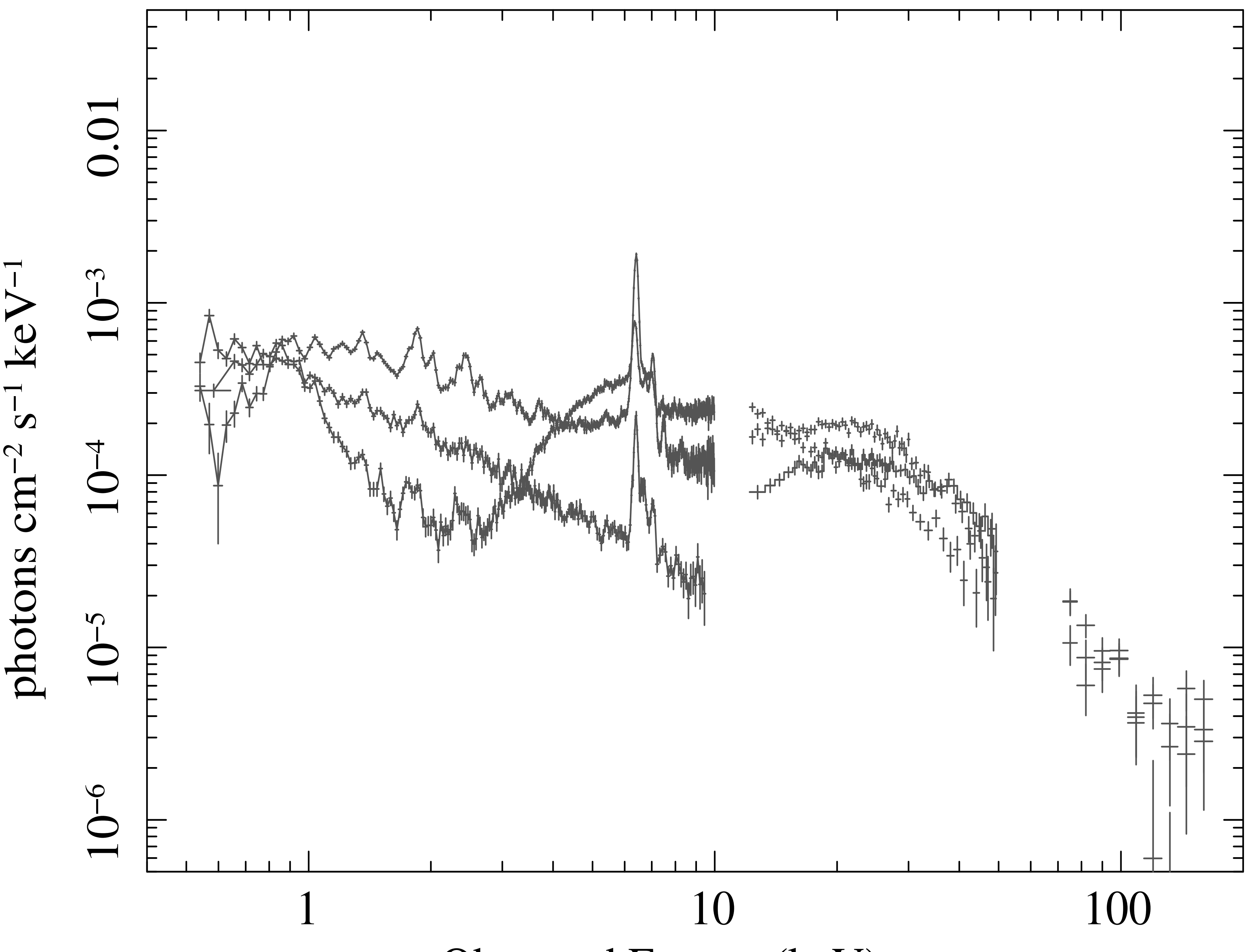

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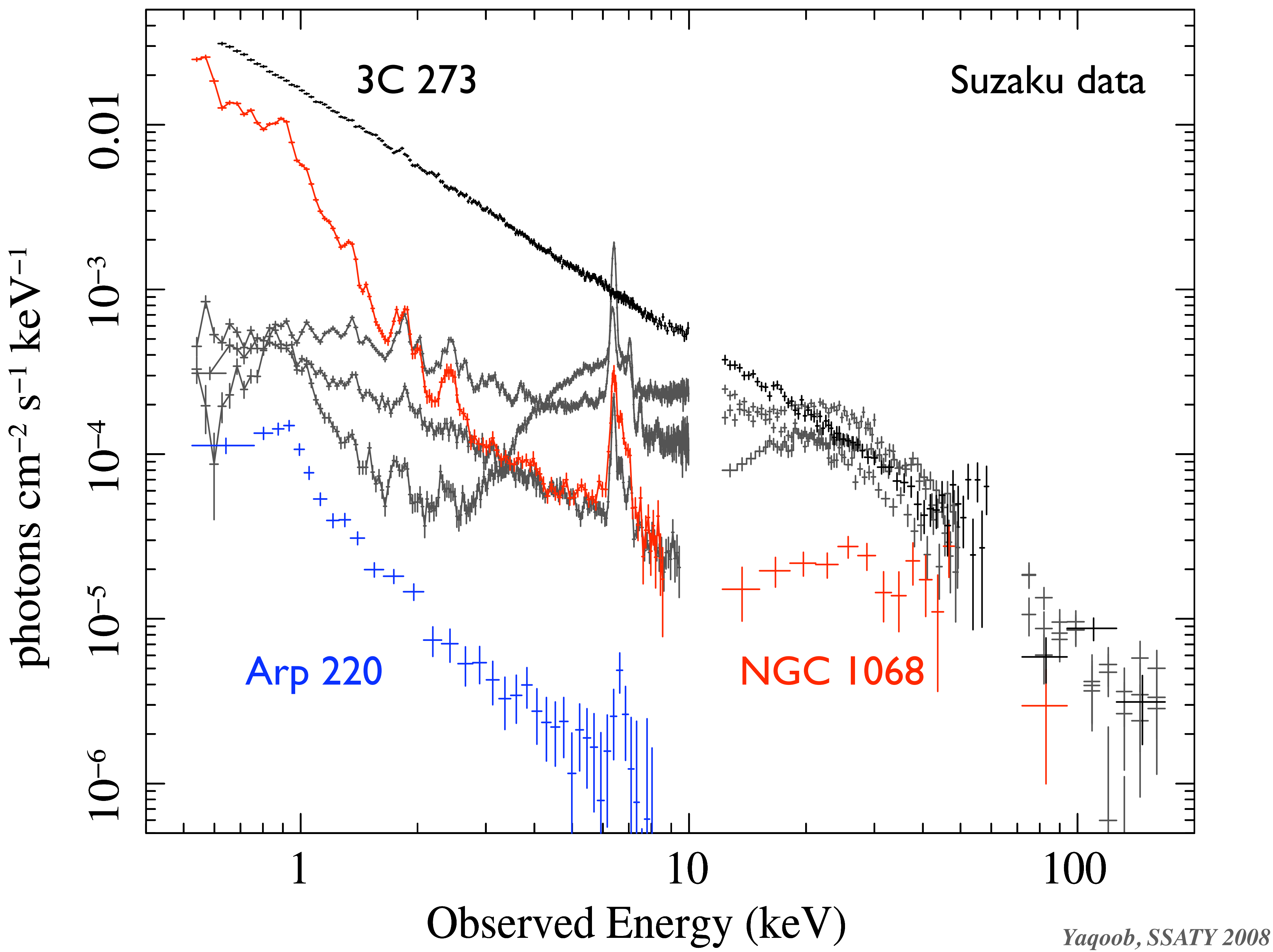
3C 273
Suzaku data
photons cm^{-2} s^{-1} keV^{-1}
0.01
10^{-3}
10^{-4}
10^{-5}
10^{-6}
Arp 220
NGC 1068
1
10
100
Observed Energy (keV)
Yaqoob, SSATY 2008

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 Kβ) 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 *adhoc* 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 ~200 keV.