Obscured AGN, Near and Far

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Purpose of talk:

★ What can we learn from X-ray spectroscopy of obscured AGN and why is it important?

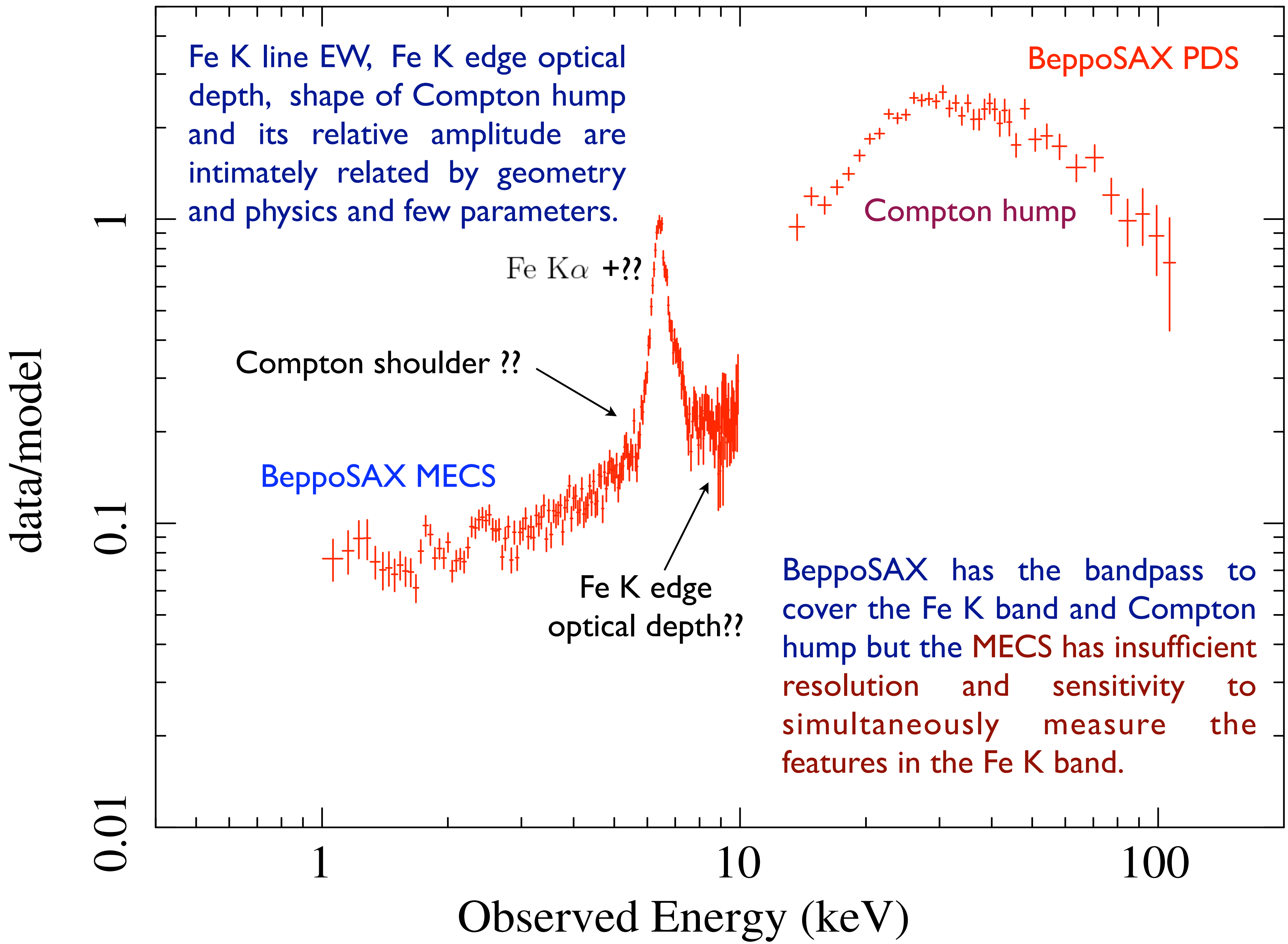
★ What can we measure now in nearby obscured AGN and how well?

★ Superiority of *Suzaku* compared to any other previously flown combination of instruments for studying X-ray reprocessing using broadband X-ray spectroscopy.

★ The Fe K line in *real* Compton-thick X-ray sources. Latest modeling, some under-appreciated observational implications.

★ *IXO* simulations of high-redshift obscured AGN. We want to be able to routinely do the kind of detailed X-ray spectroscopy for high-redshift obscured AGN that we can now do for nearby sources.

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".

$$\mathrm{EW_{refl}} \;=\; 1010\left(\frac{\omega_{\mathrm{K}}}{0.347}\right)\left(\frac{A_{\mathrm{Fe}}}{4.68\times10^{-5}}\right)\left(\frac{\sigma^{0}_{\mathrm{FeK}}}{3.5\times10^{-20}\ \mathrm{cm^{-2}}}\right)\left(\frac{3.55}{\Gamma+1.65}\right)\left[0.90^{\Gamma-1.9}\right] \quad \mathrm{eV}$$

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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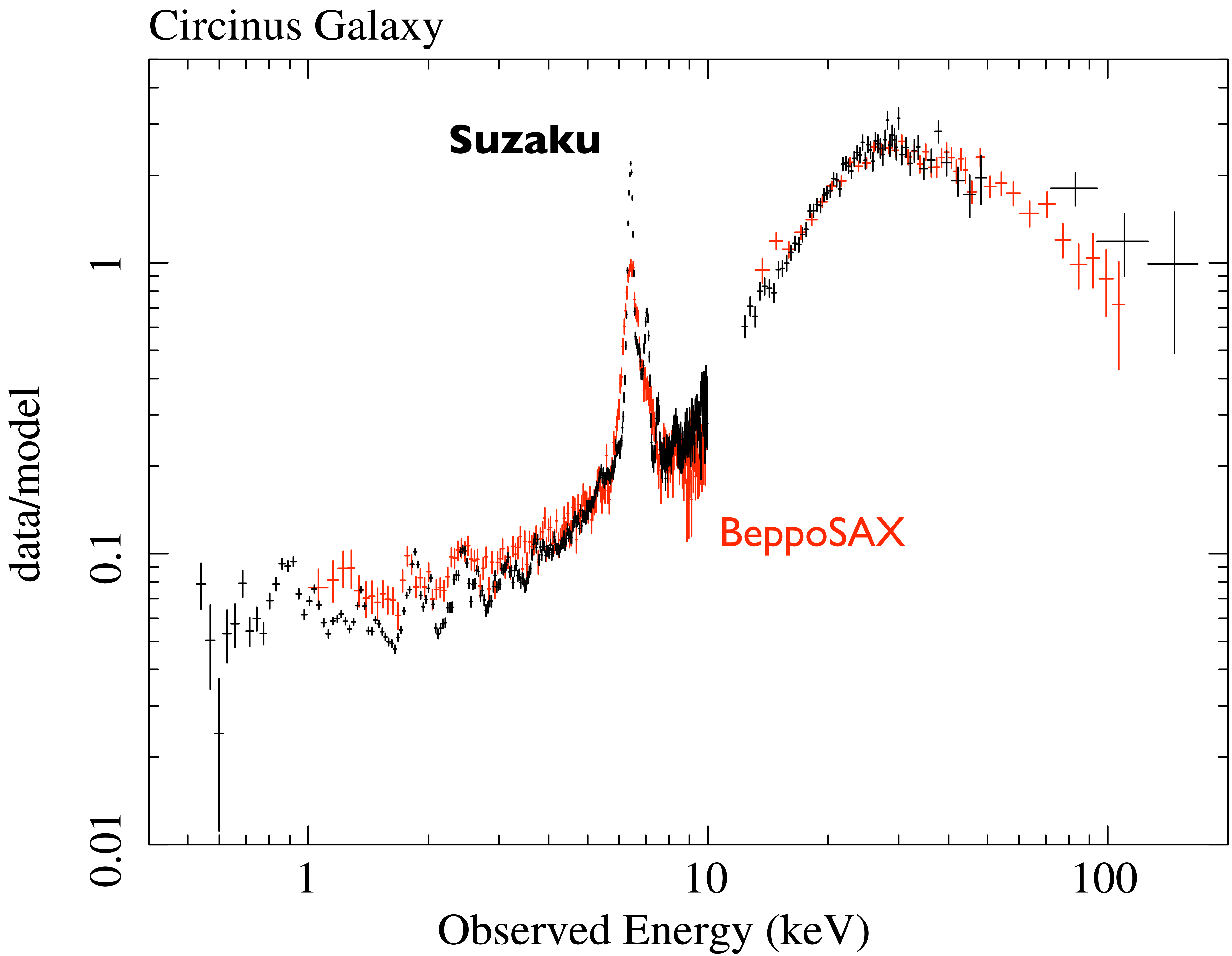

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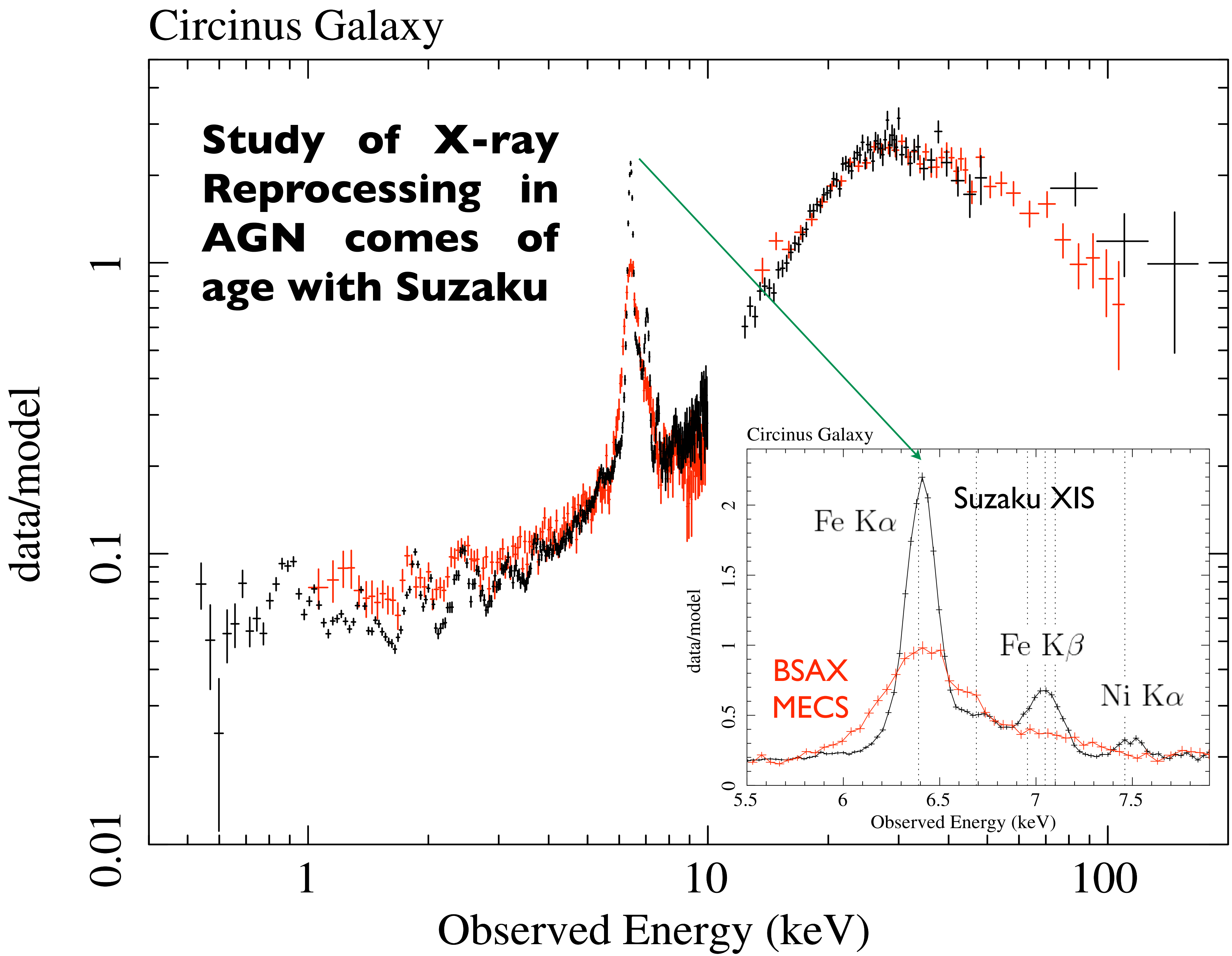

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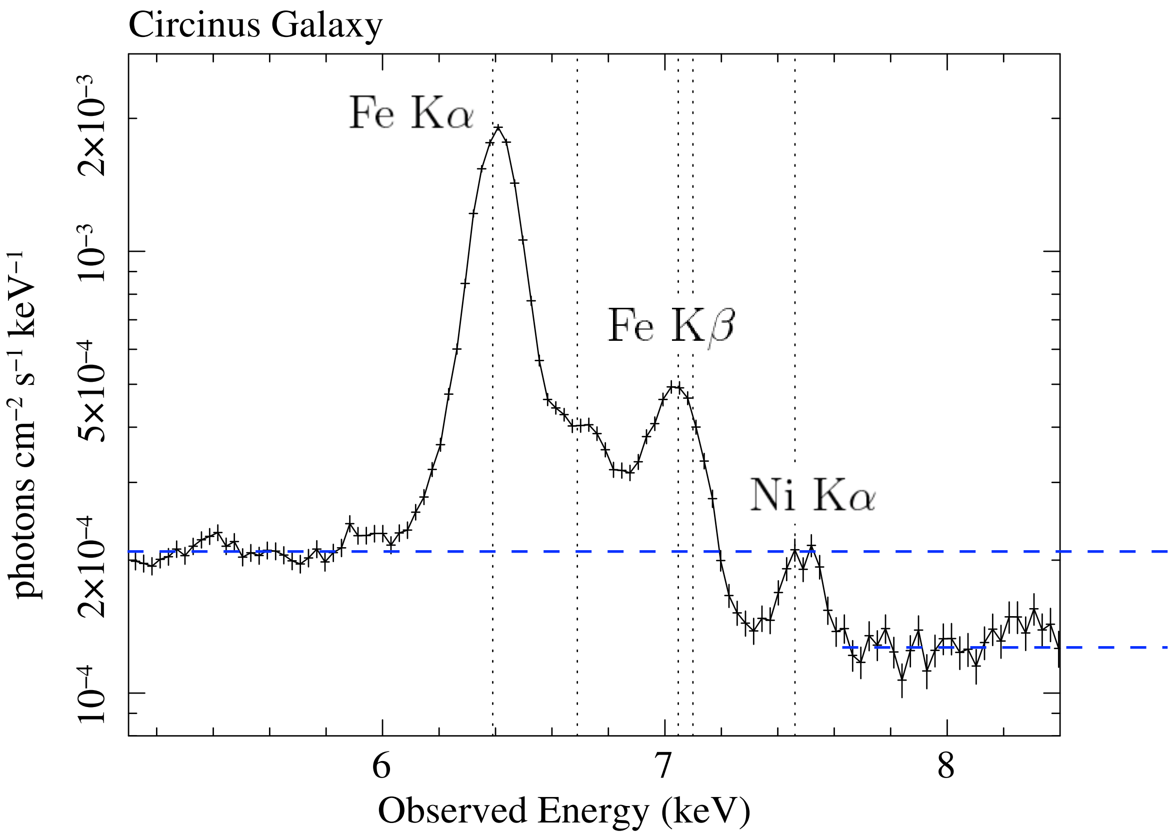
Unprecedented precision with Suzaku

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

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

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



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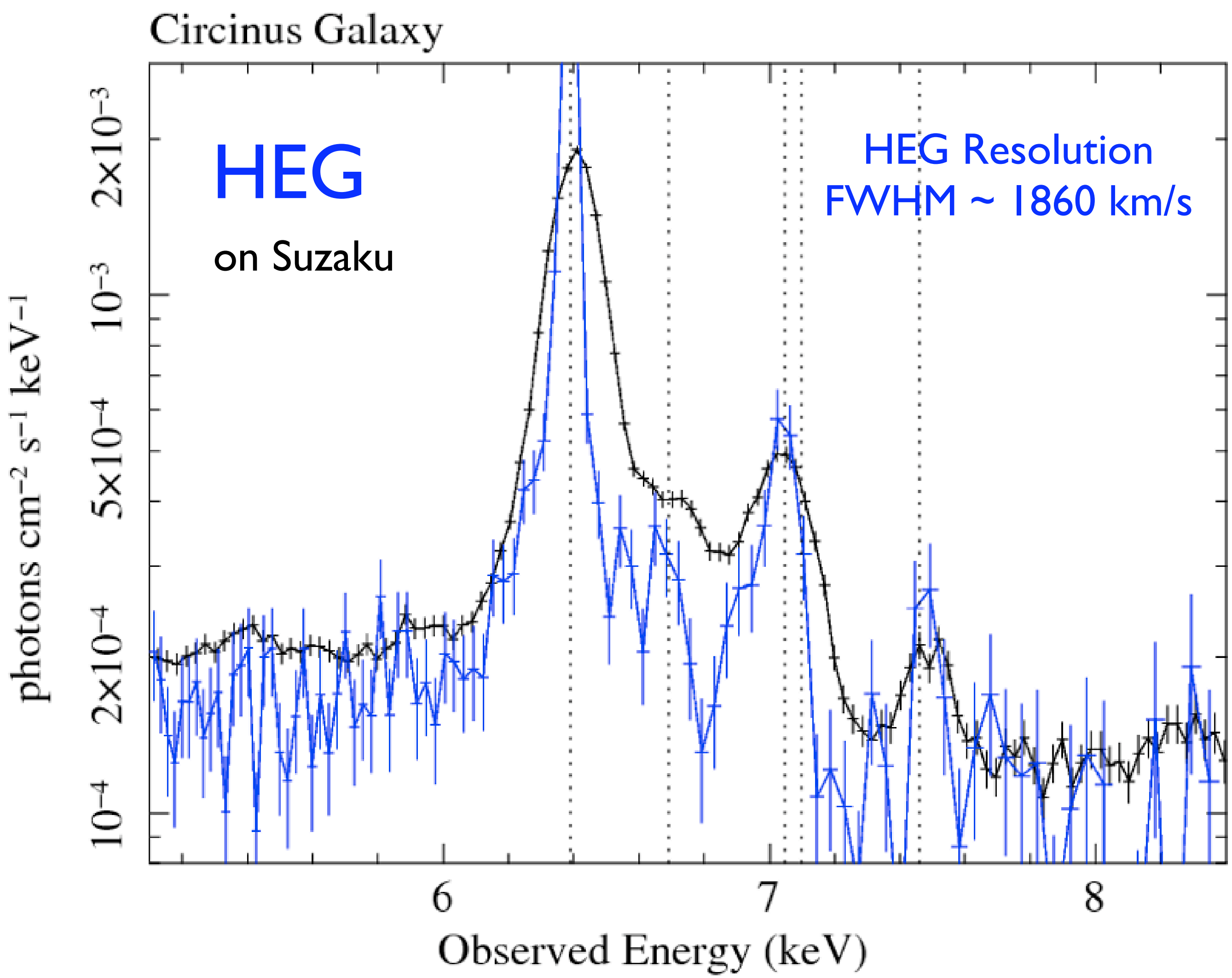
HEG can measure the Fe Kα line width better but Suzaku is superior for measuring the structure around the Fe K edge, critical for constraining models.



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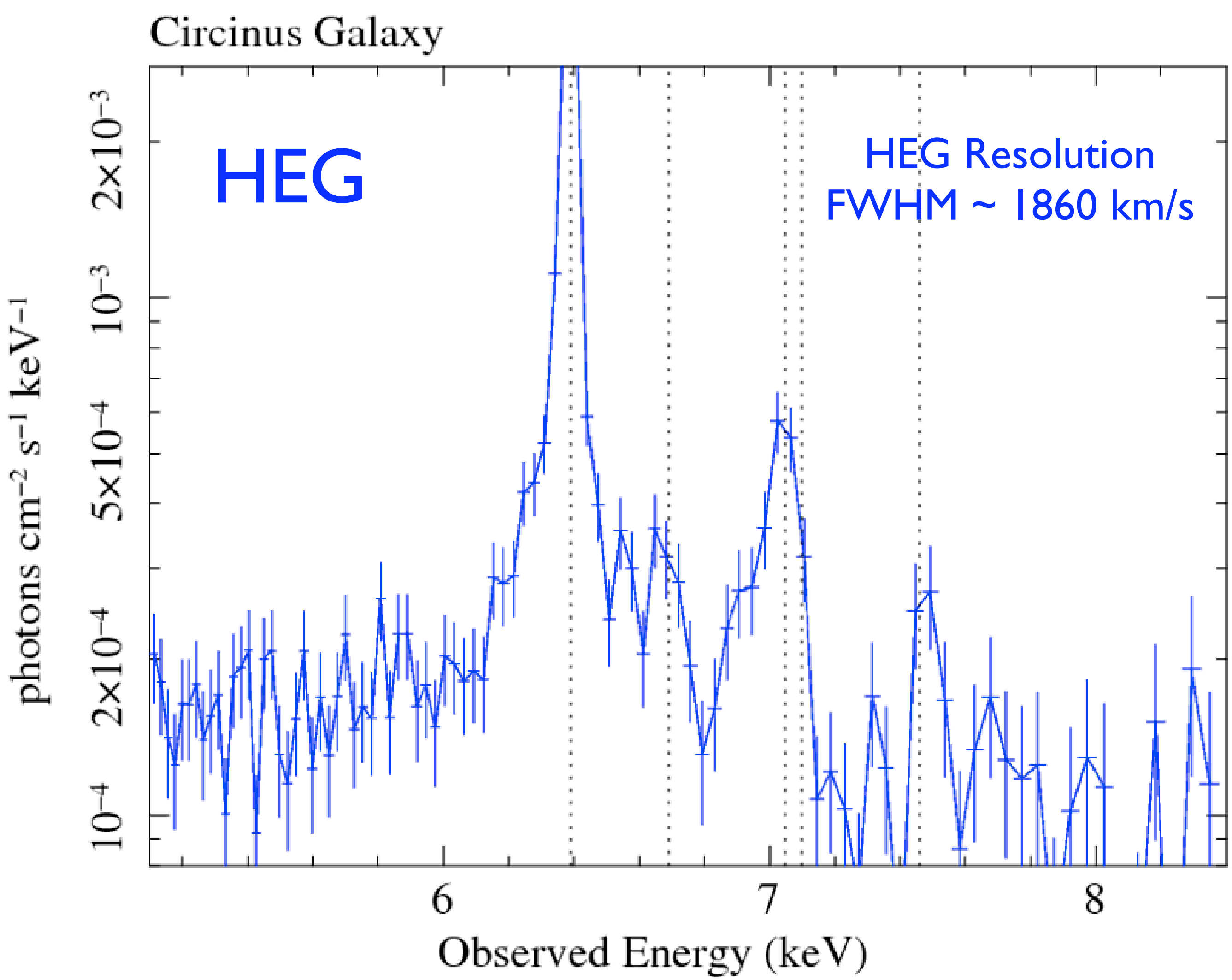

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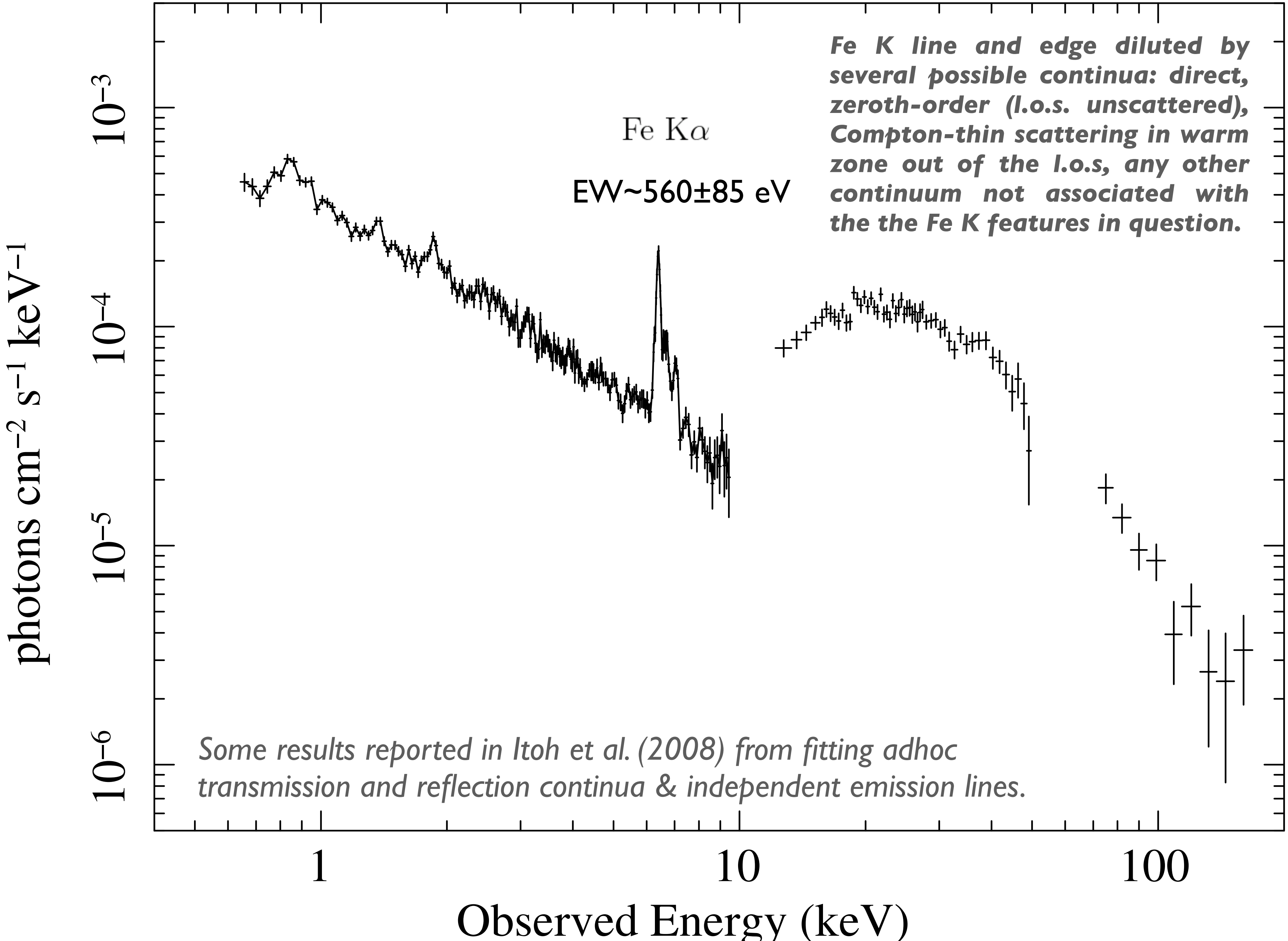
NGC 4945

Suzaku data



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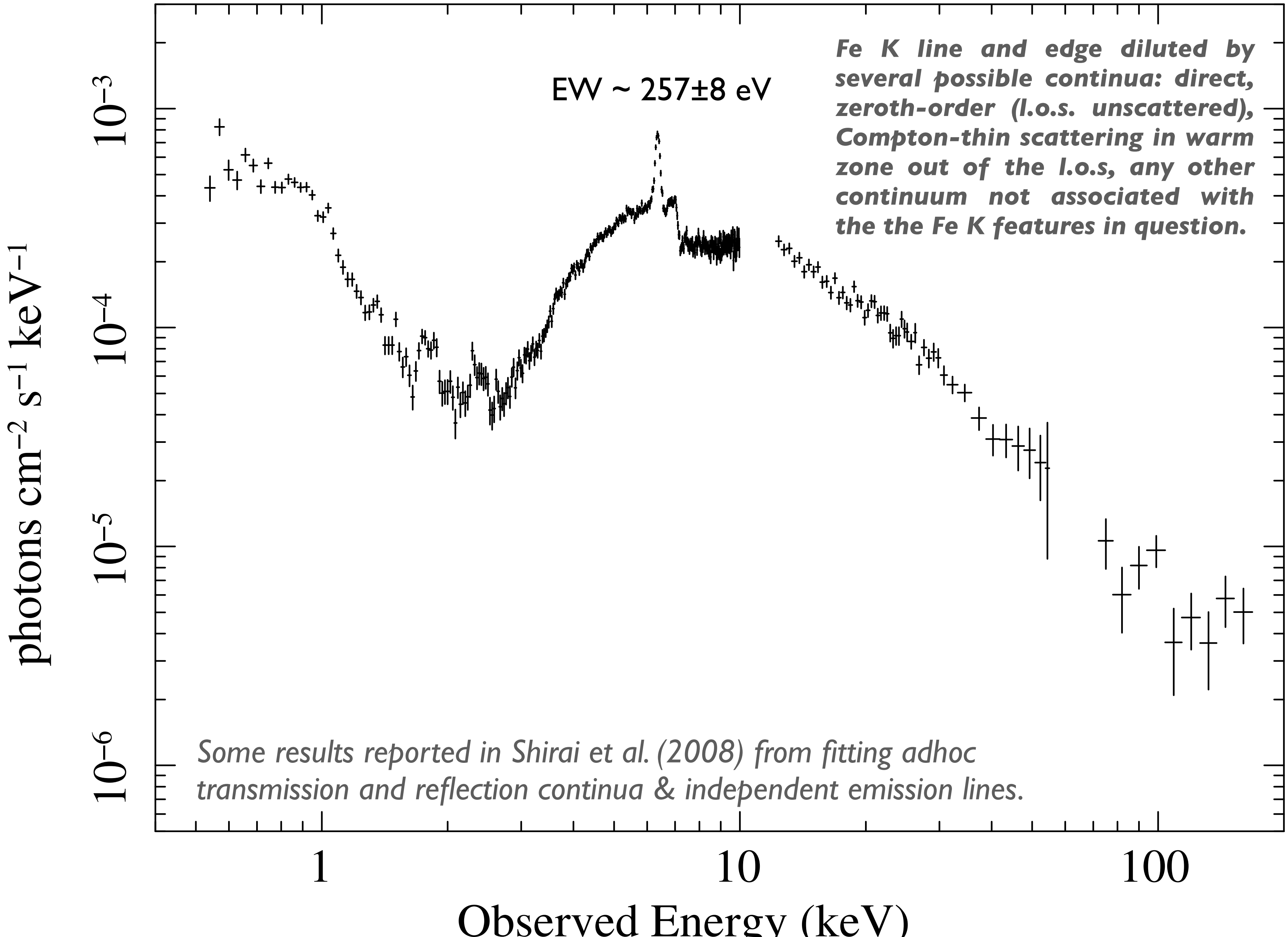
NGC 4388

Suzaku data



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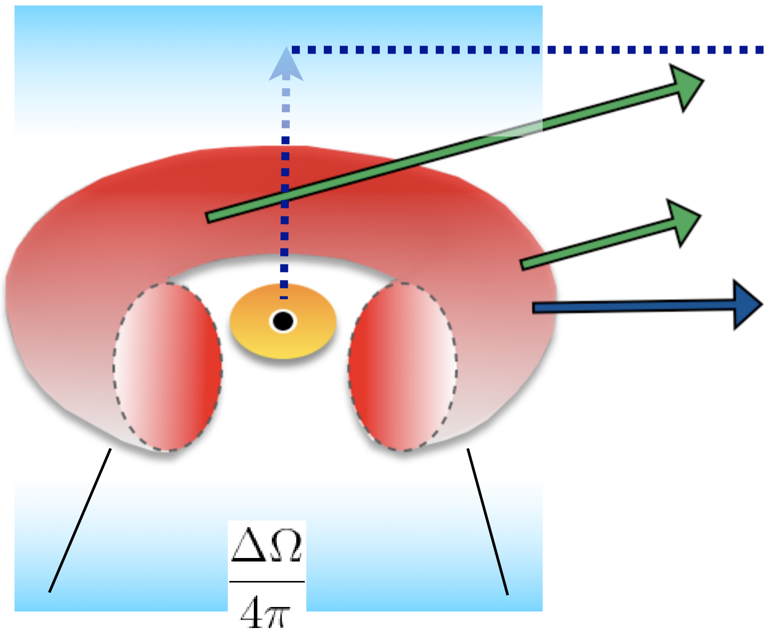

warm optically-thin zone:
scattered fraction

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

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

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

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

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

$\lambda_{6.4} \equiv$ 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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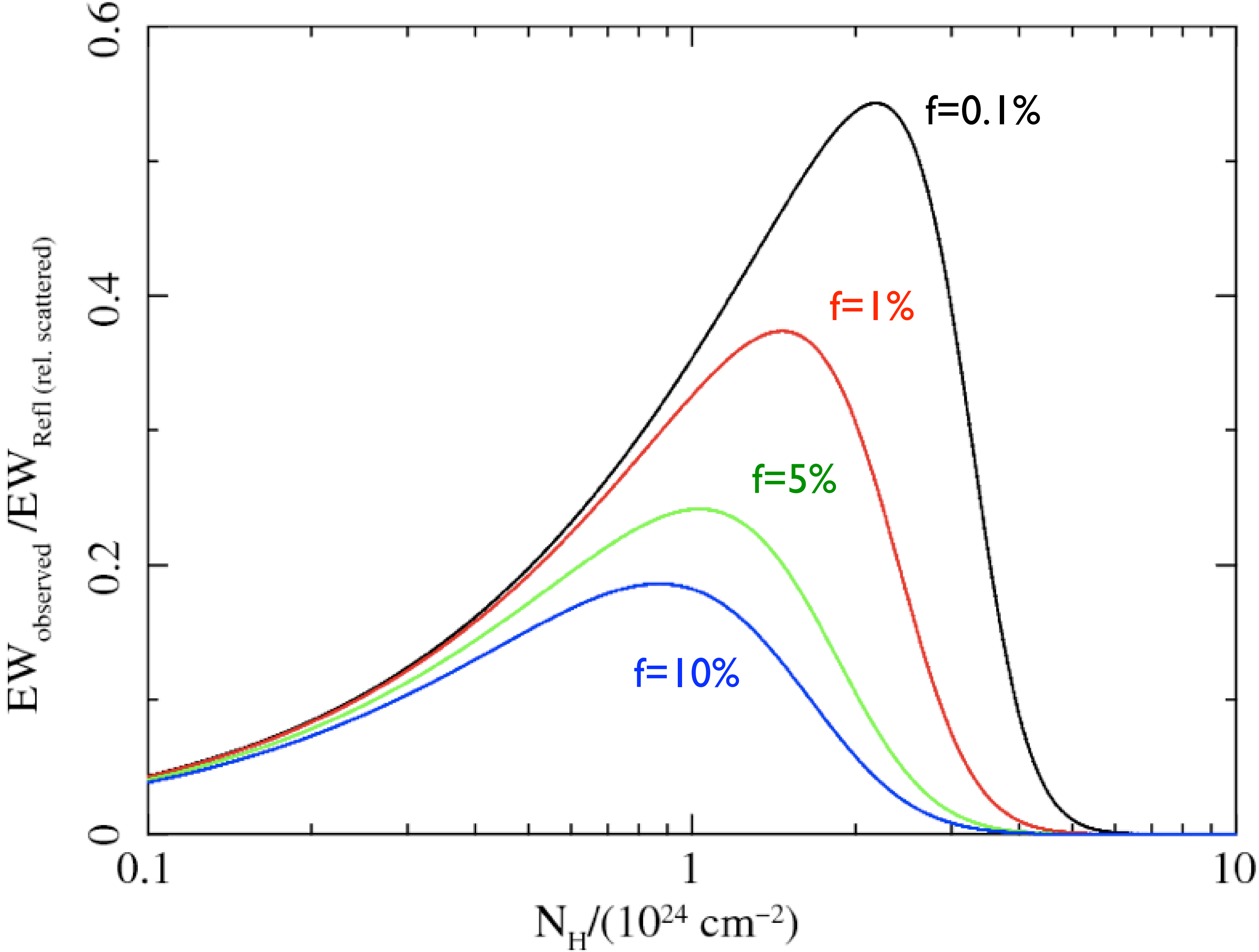

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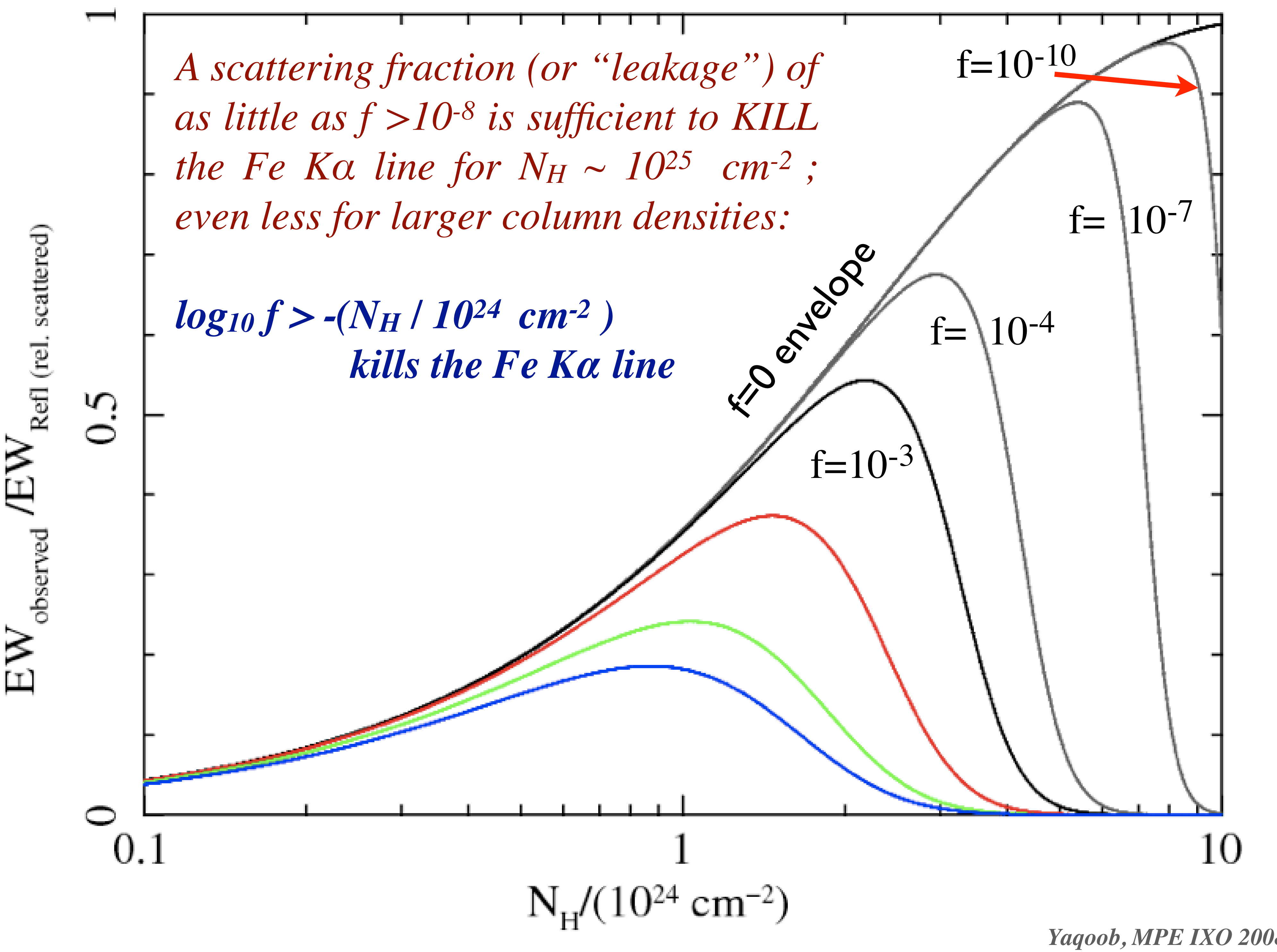

A scattering fraction (or "leakage") of as little as $f > 10^{-8}$ is sufficient to KILL the Fe Kα line for $N_H \sim 10^{25}$ cm^{-2} ; even less for larger column densities:
$\log_{10} f > -(N_H / 10^{24}$ cm^{-2})
kills the Fe Kα line
f=0 envelope
$f=10^{-10}$
$f=10^{-7}$
$f=10^{-4}$
$f=10^{-3}$
$EW_{observed} / EW_{Refl\ (rel.\ scattered)}$
$N_H/(10^{24}$ cm$^{-2})$
0
0.5
1
0.1
1
10
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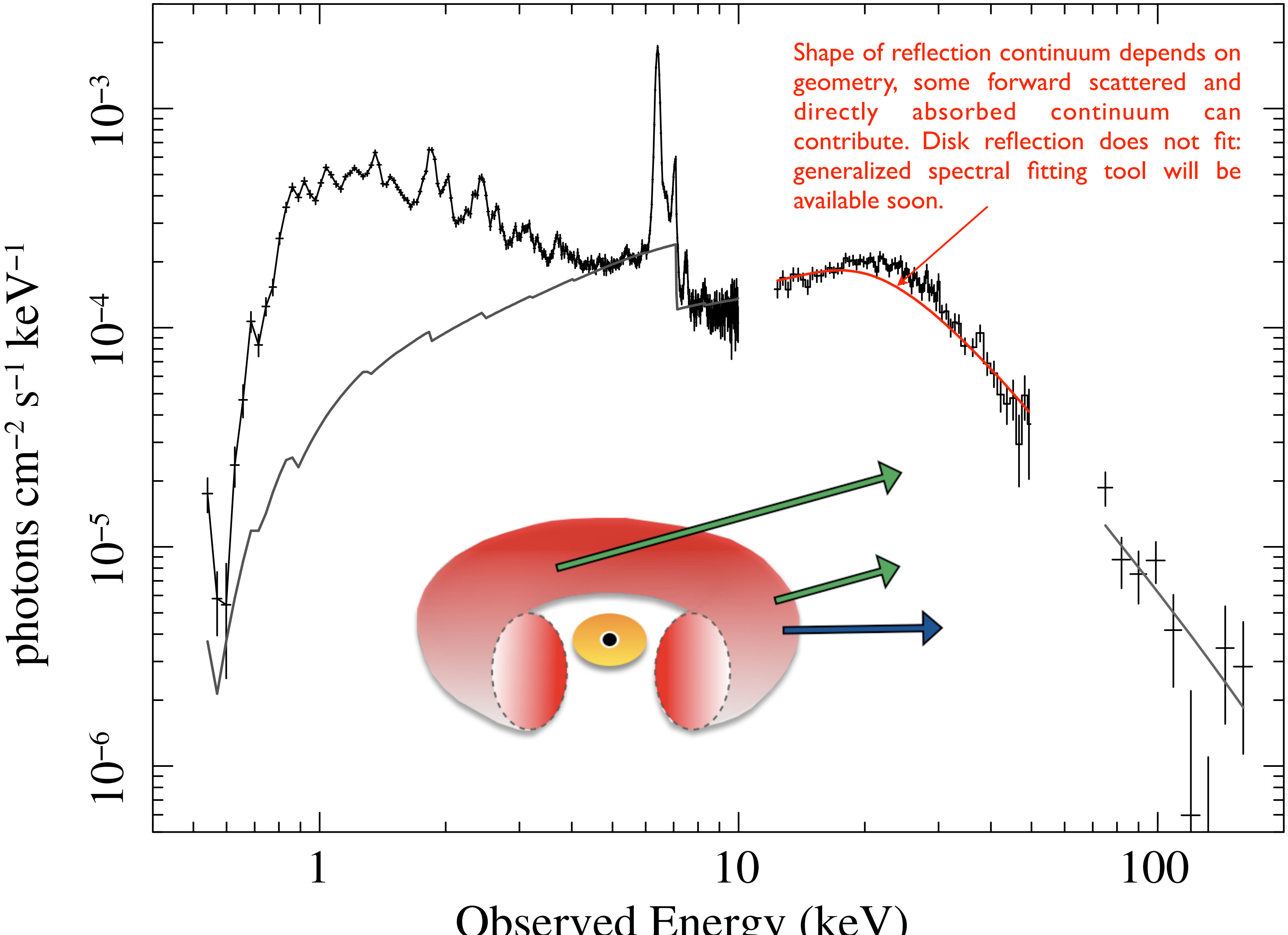
Circinus Galaxy

Suzaku data



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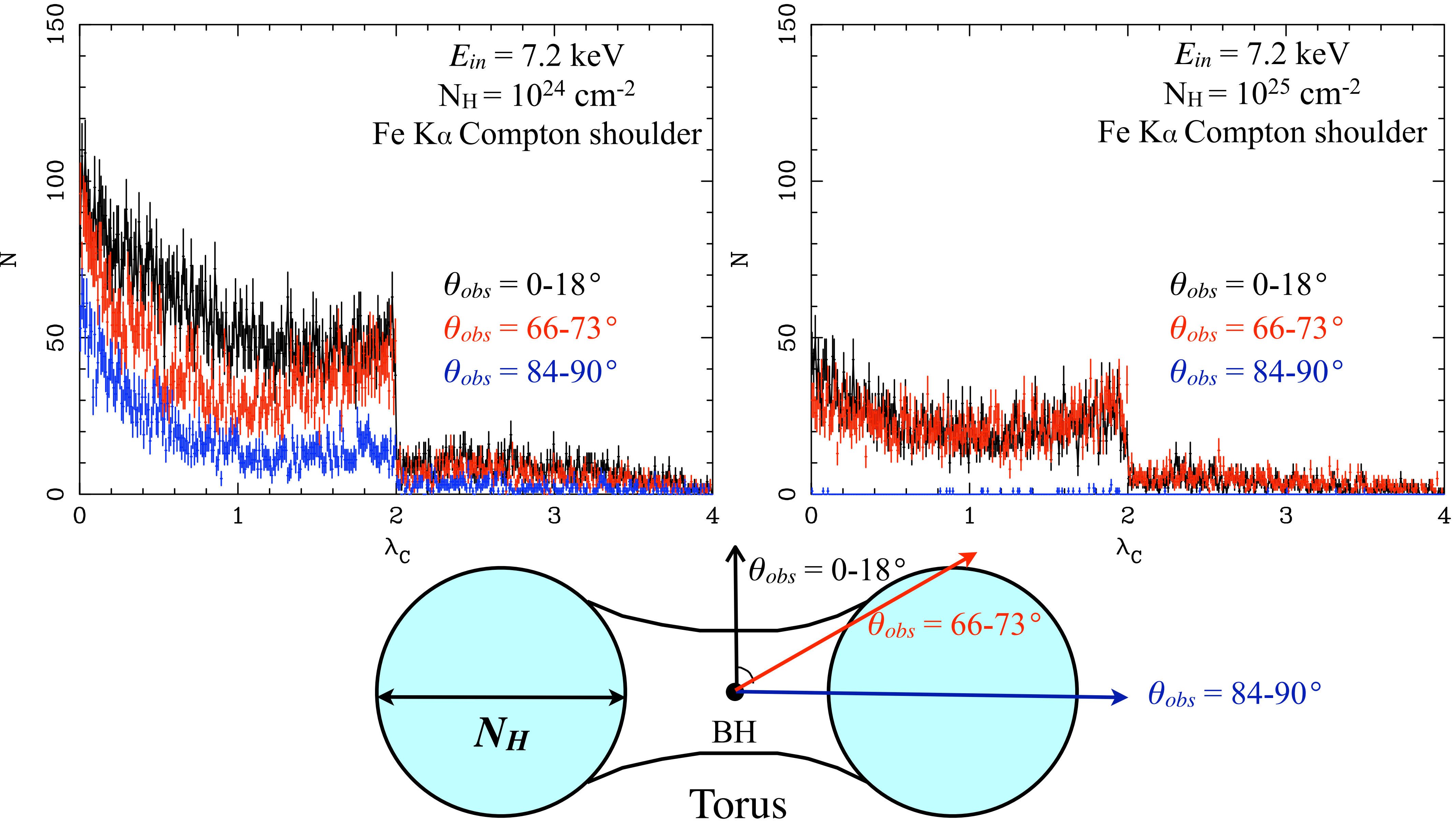
Sample Green's Functions: Fe Kα Compton Shoulder



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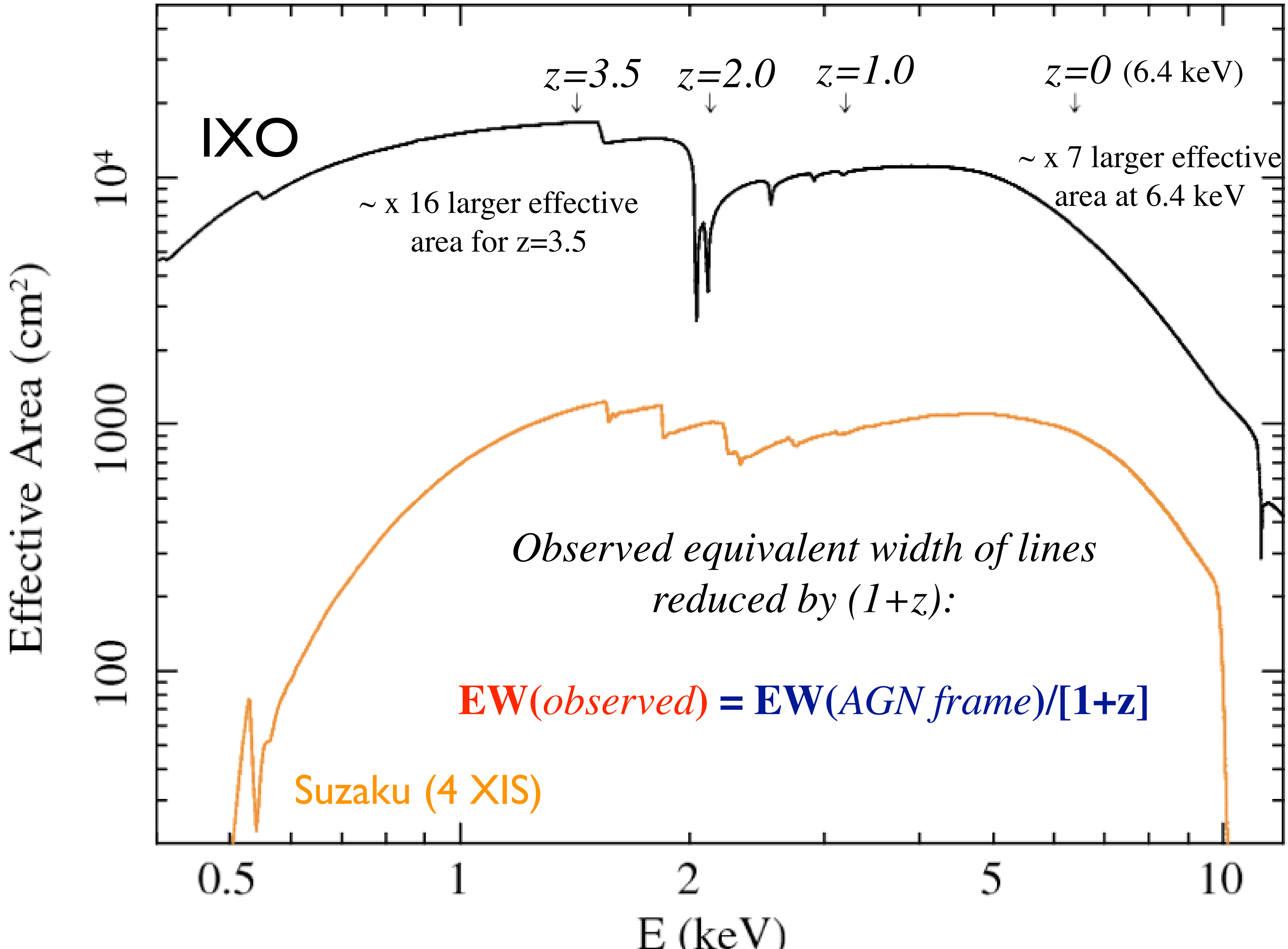

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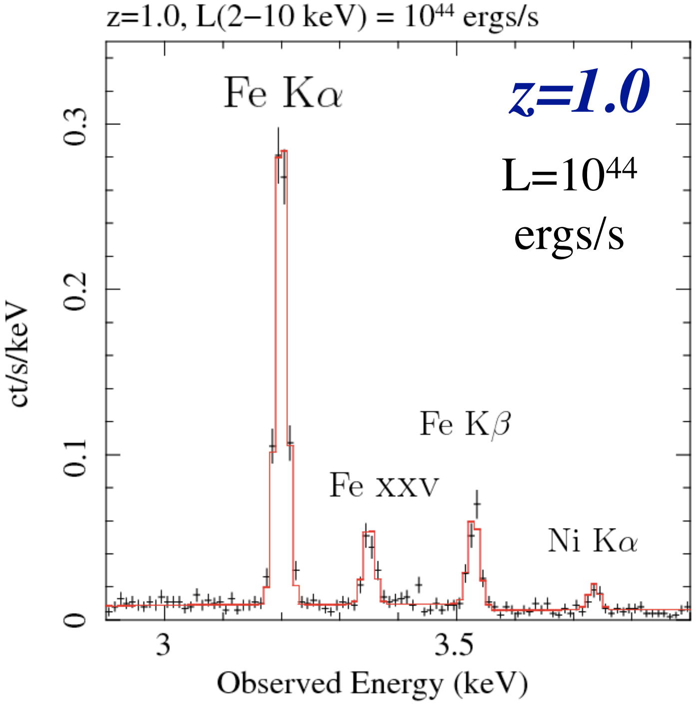

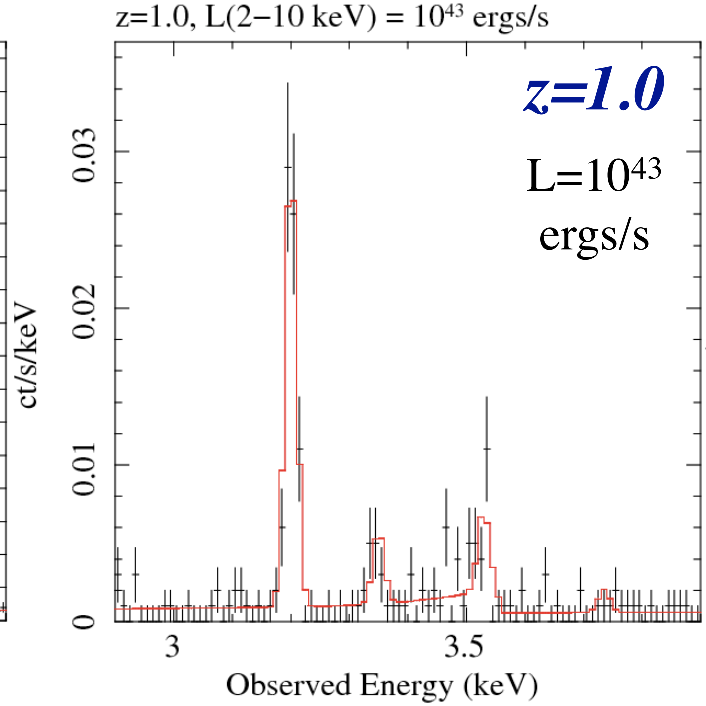

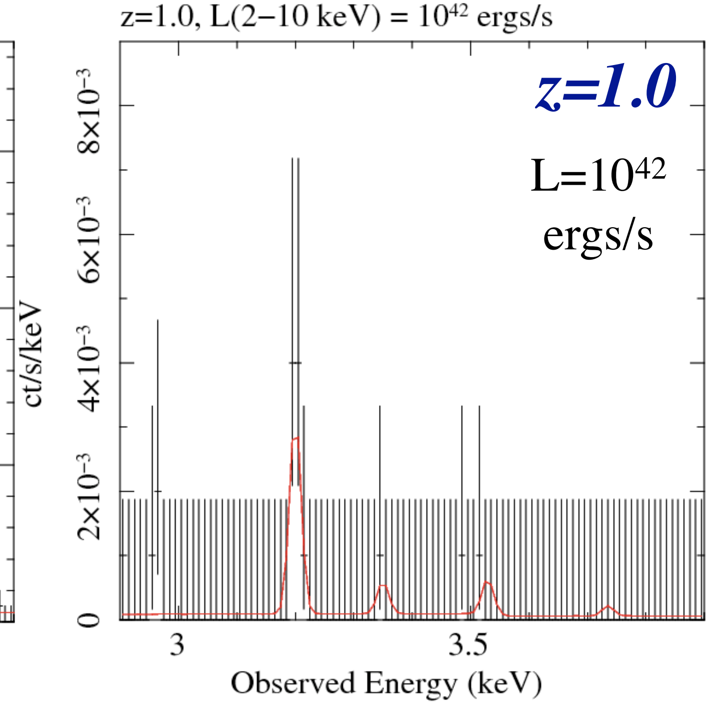

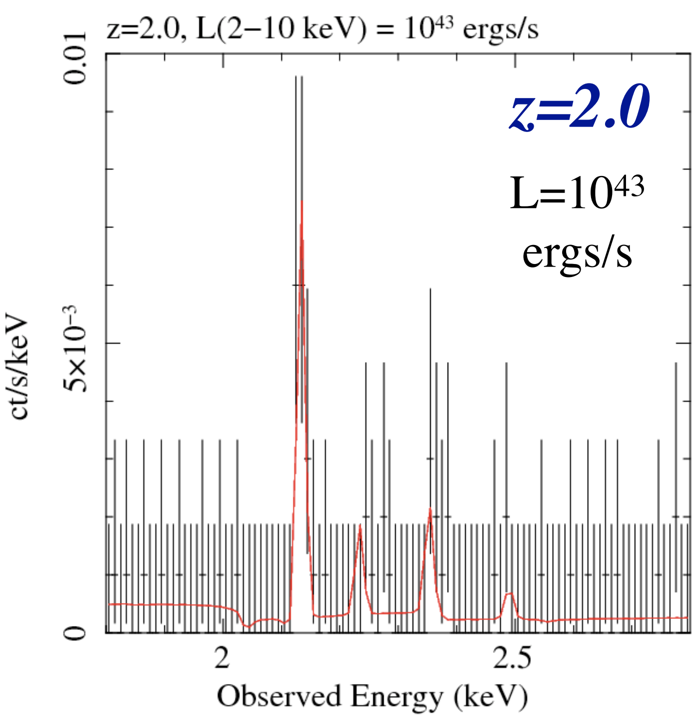

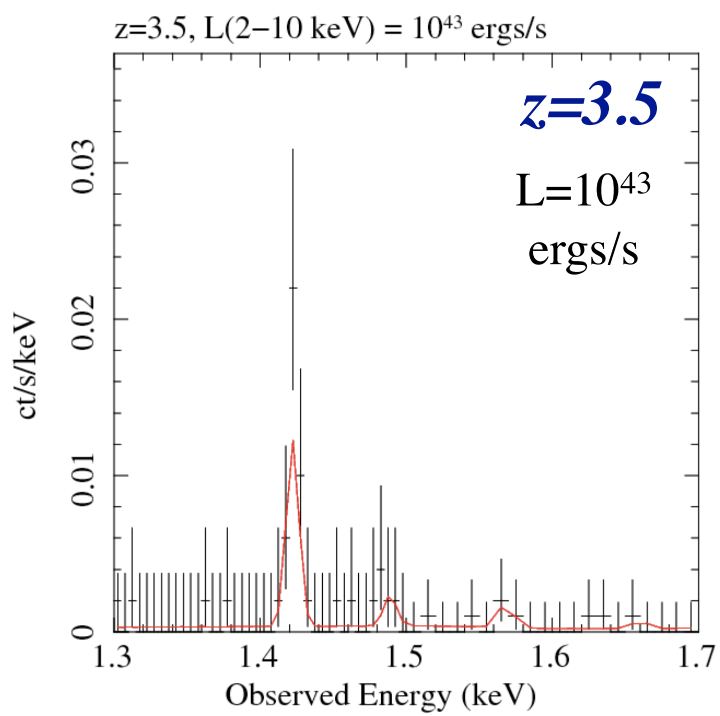

IXO high-redshift simulations

Circinus at z=1, 2, 3.5, with different intrinsic luminosities. T=100 ks,

Fe Kα EW(rest) = 1.26 keV

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Conclusions

★ Study of X-ray reprocessing in AGN comes of age with *Suzaku*. Robust spectroscopy of Fe K region, excellent for studying nearby obscured AGN.

★ *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). Fe/Ni abundance ratio can be robustly measured for the brightest AGN.

★ A neutral Fe K emission line with a large EW (hundreds of eV or more) is only expected for a fairly restricted range in column density in Compton-thick sources. For N_H larger than ~ 10^{25} cm^{-2} dilution by even a tiny fraction of optically-thin scattered continuum kills the 6.4 keV Fe K line, rendering it undetectable. Lines from ionized Fe may then dominate the spectrum. This effect is already observed in ULIRGs.

★ In ~100 ks, IXO will be able to do such detailed spectroscopy of high-z obscured AGN as is possible now with nearby sources, from L(2-10 keV) down to ~ 10^{43} ergs/s for z~1, but only down to ~10^{44} ergs/s for z~2-3.5.