Reflection Spectroscopy with STROBE-X

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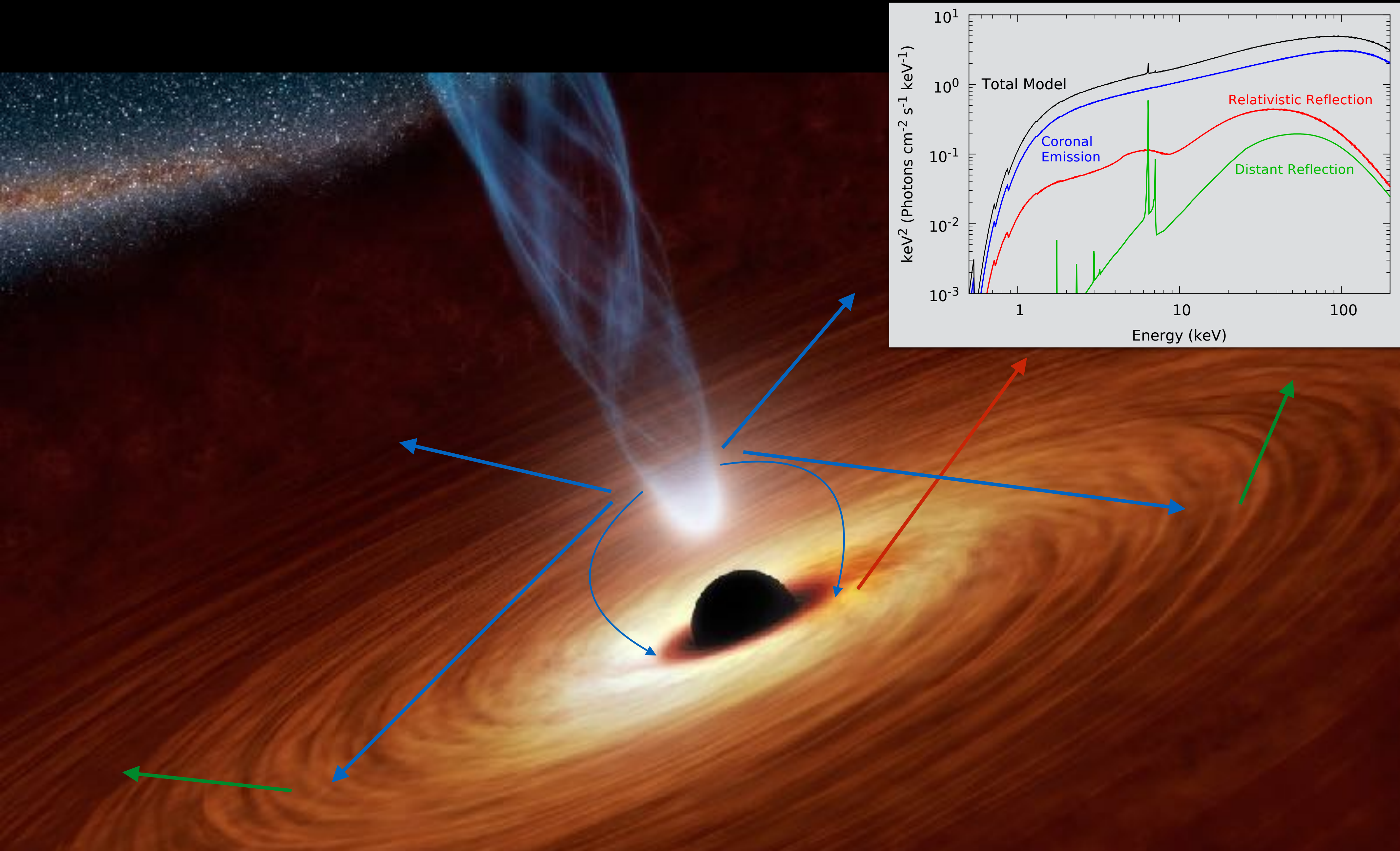
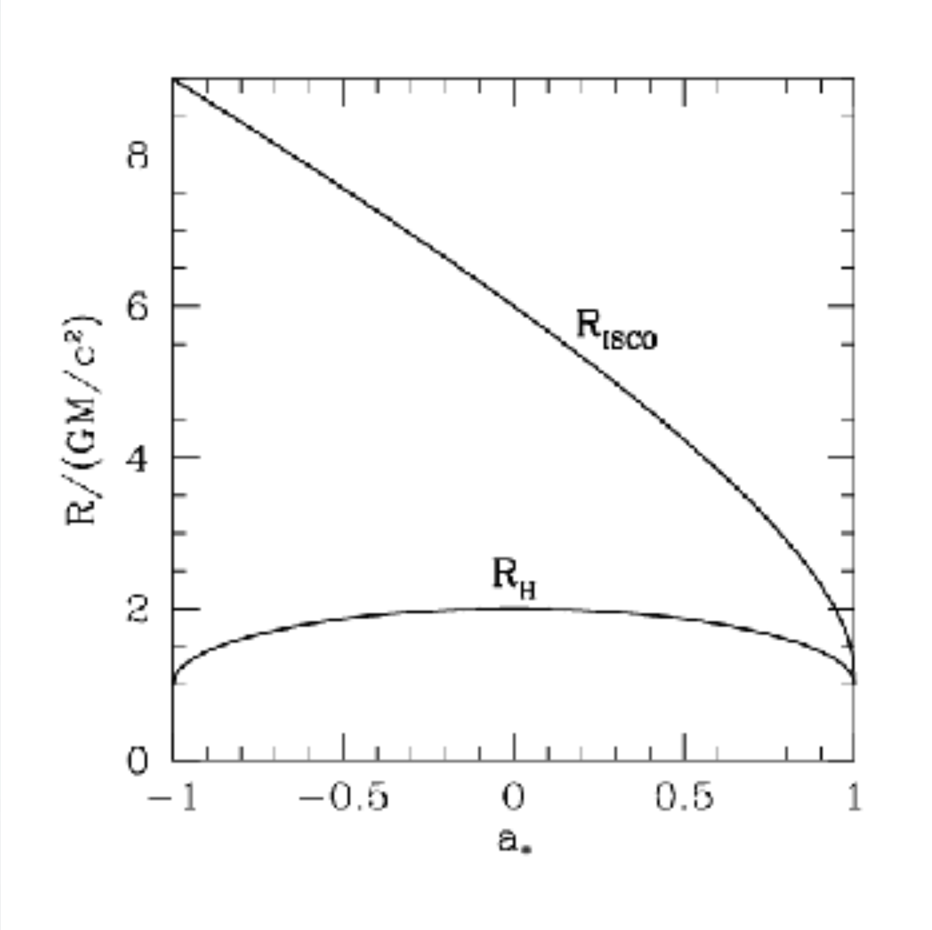
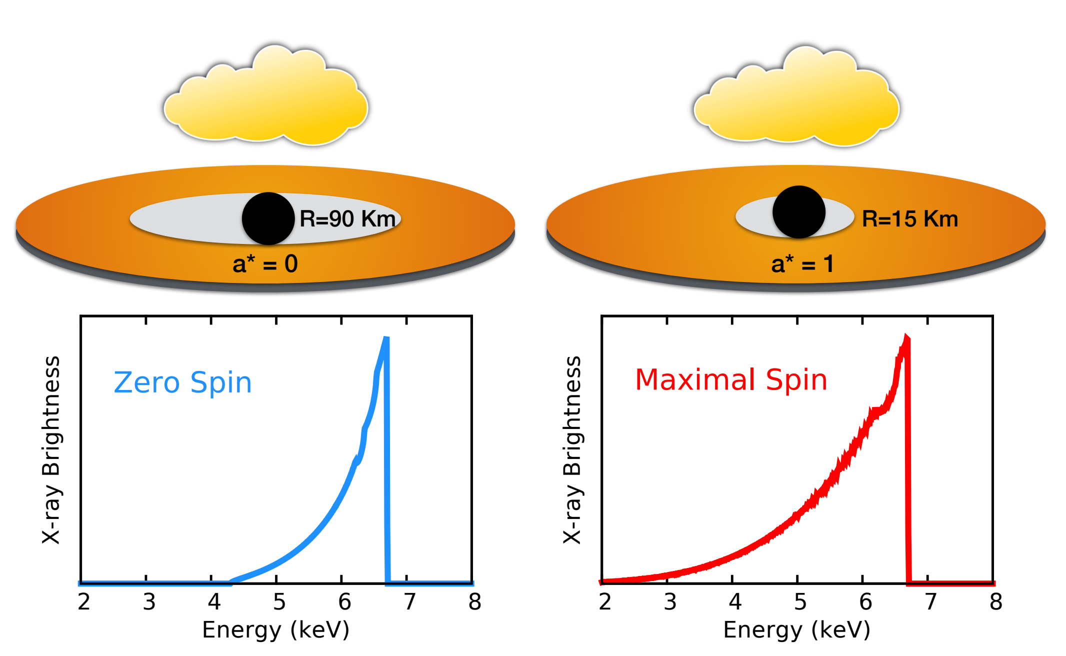


X-ray Reflection from Accretion Disks

Why X-ray Reflection is Important?

X-ray reflection is the corner stone of the Fe-line method to measure the spin of Black Holes





It is also possible to estimate the spin using continuum fitting method, or with QPO's (not covered in this talk).

AGN Physics I: Measuring the Temperature of the Corona

Measuring Ecut with NuSTAR

If the power-law continuum is produced by a Comptonization in a hot gas of electrons:

$$\Gamma = -\frac{1}{2} + \sqrt{\frac{9}{4} + \frac{1}{\theta_e \tau_e (1 + \tau_e/3)}}$$

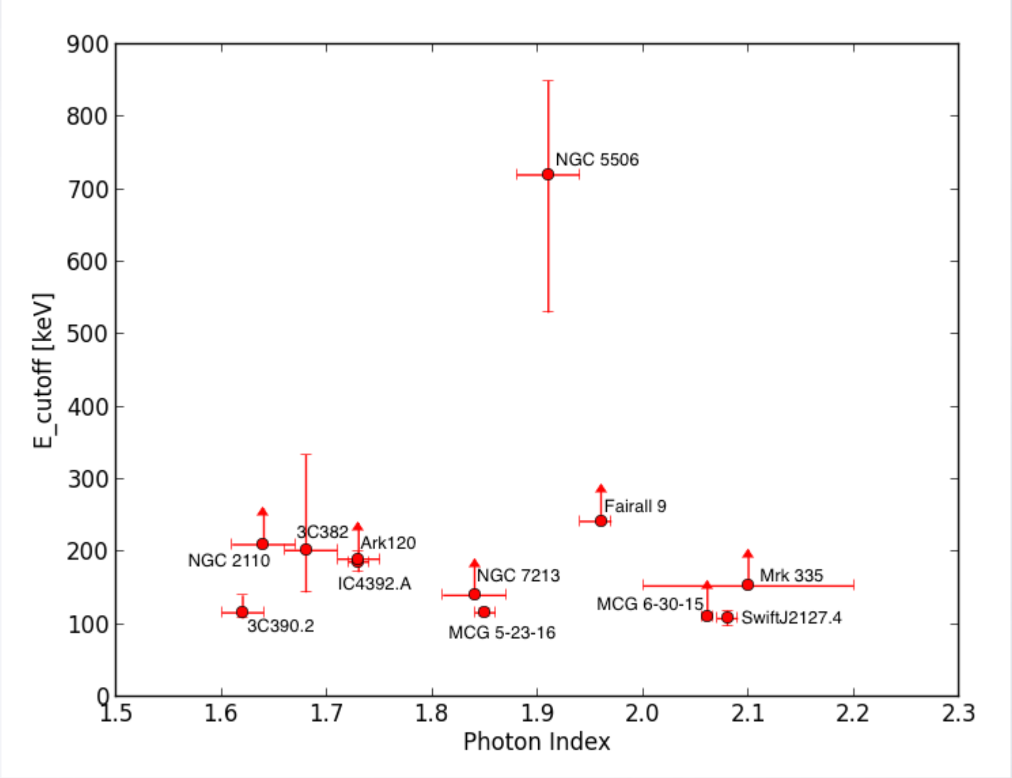
where $\theta_e = kT_e/m_e c^2$ and $m_e c^2 = 511$ keV is the electron rest mass (Lightman+Zdziarski 1987).

In practice:

$$E_{\rm cut} \sim 2 - 3kT_e$$

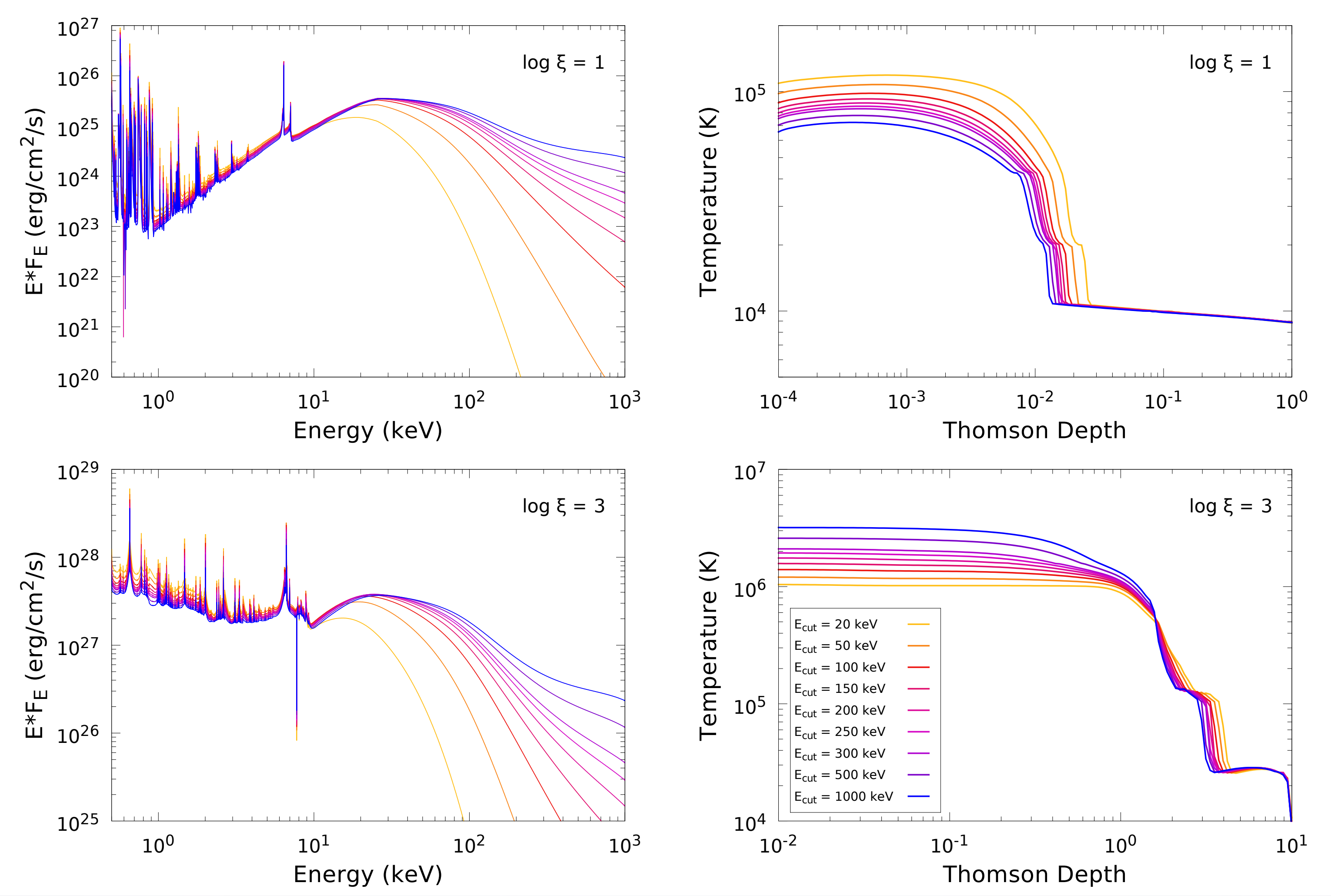
Typically Ecut ~ 200 keV (but it can be higher!)

Ecut: Cut-off of the power-law continuum at high energies



(Courtesy of A. Marinucci.)

Effects on the Reflection Spectrum



Changes in Ecut also affects the ionization balance in the disk atmosphere

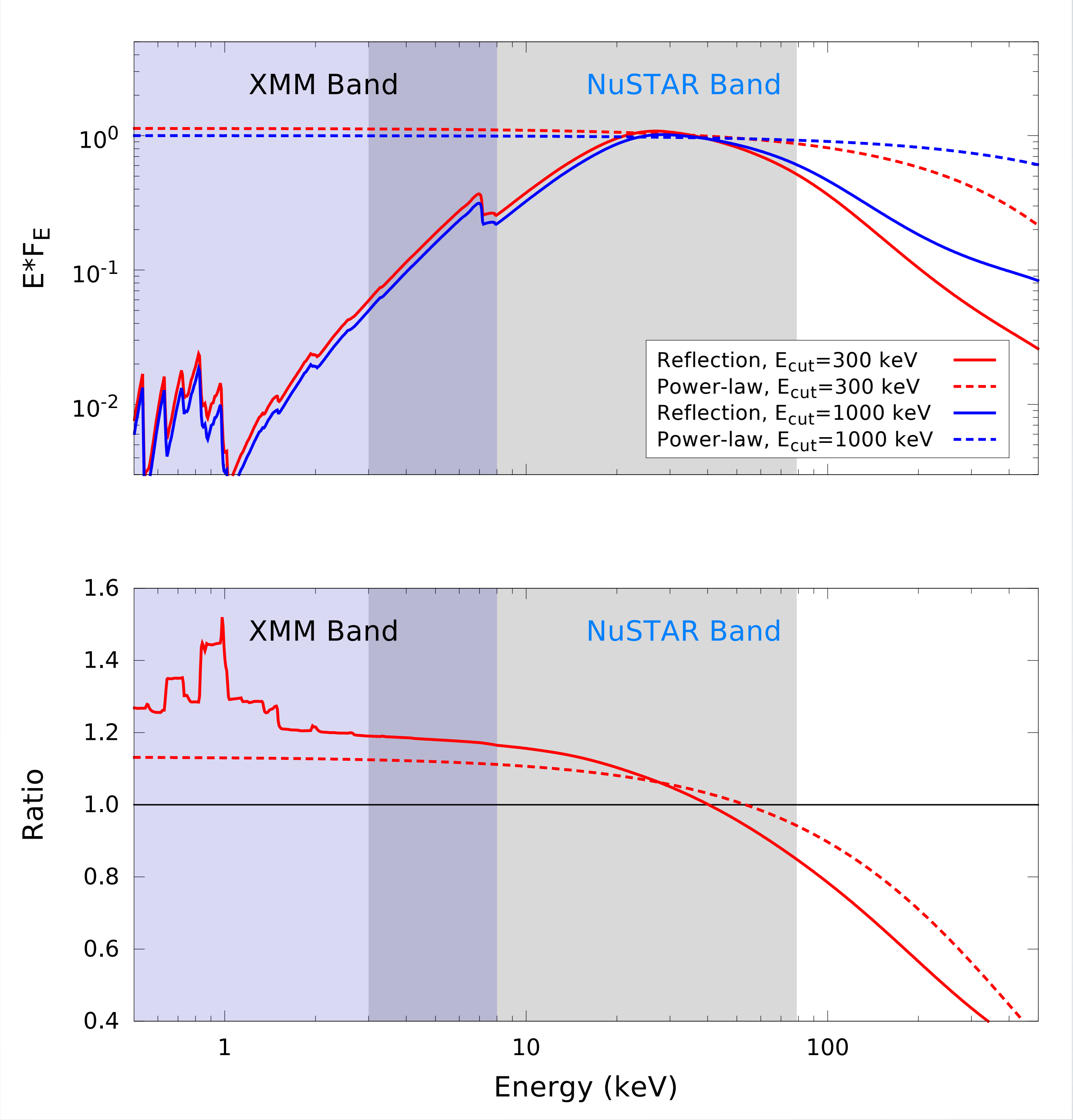
García et al. (2015)

Effects on the Reflection Spectrum

Different Ecut changes the shape of the Compton hump at E > 20 keV

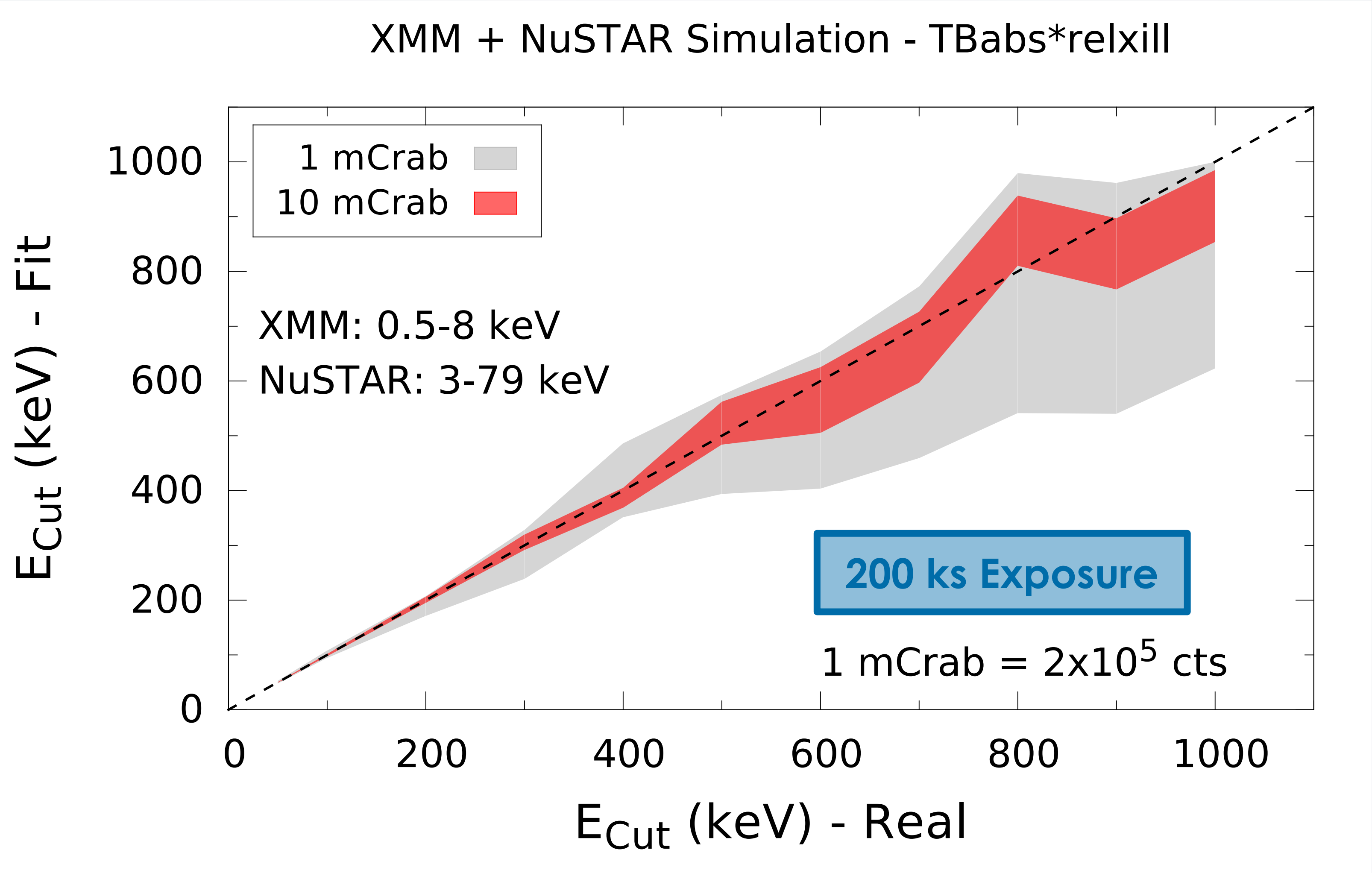
Changes in the ionization affect the emission at soft energies!

(Cannot be mimicked by adjusting ionization parameter)



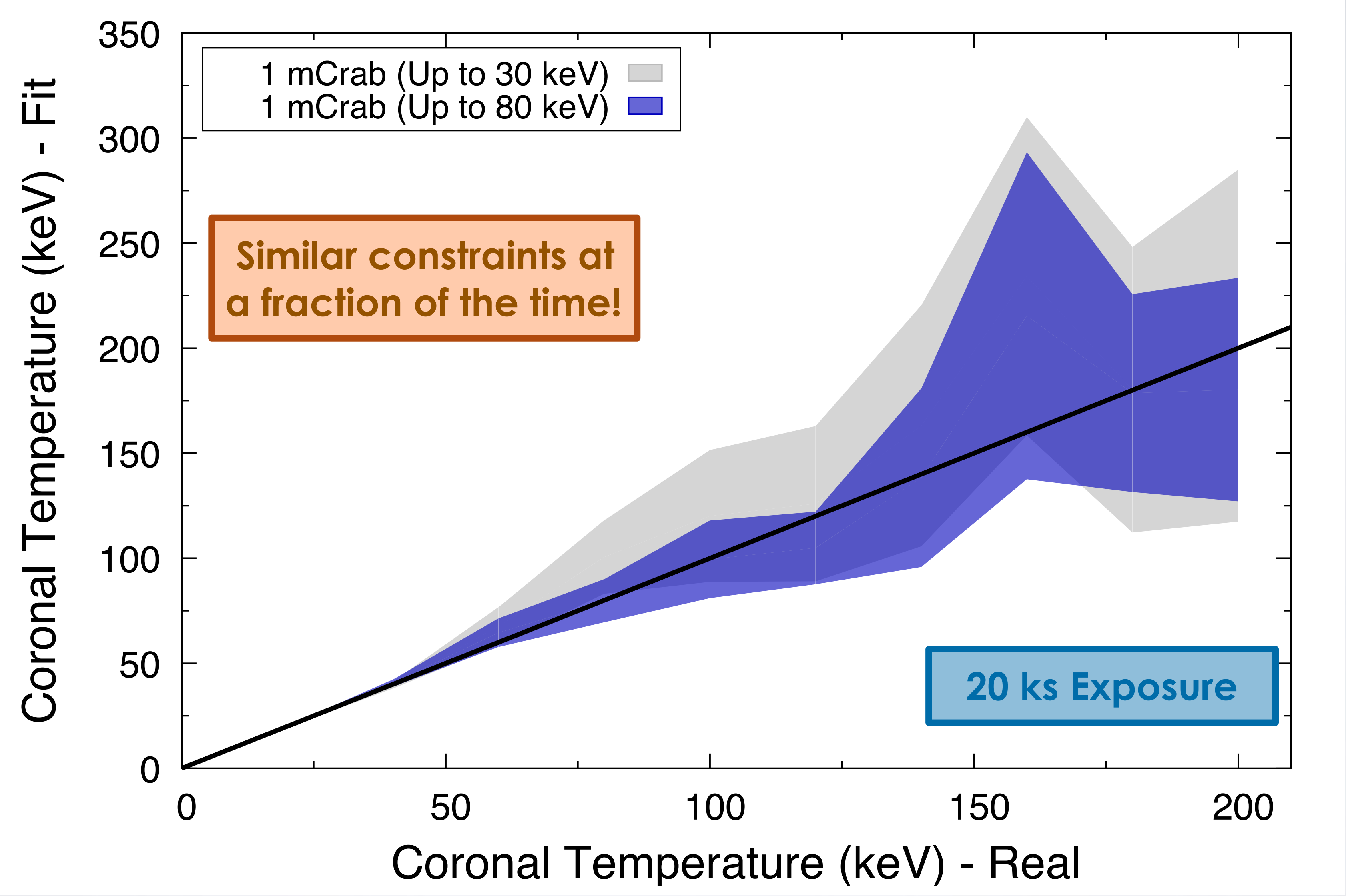
García et al. (2015)

NuSTAR Simulations

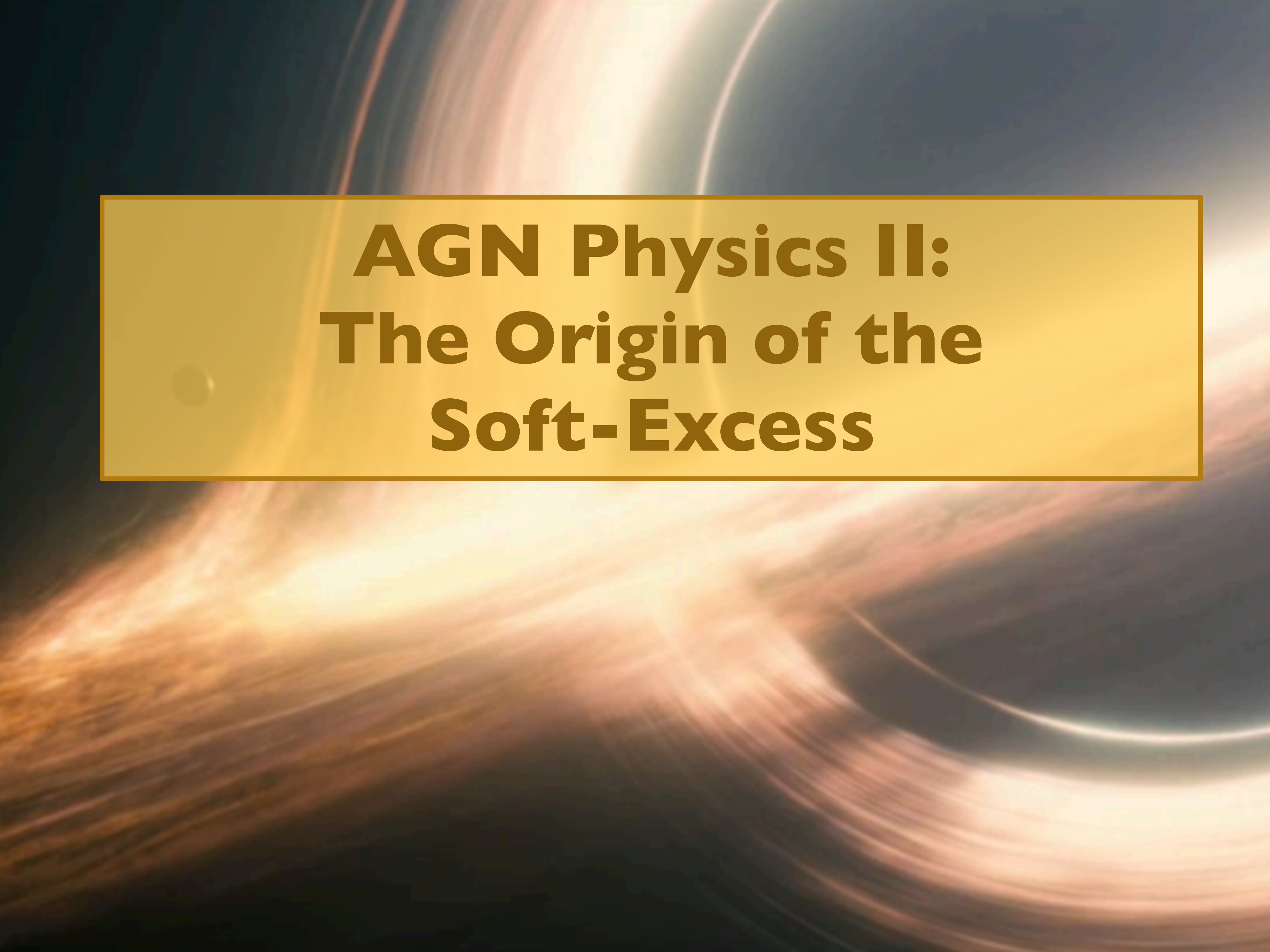


García et al. (2015)

STROBE-X Simulations

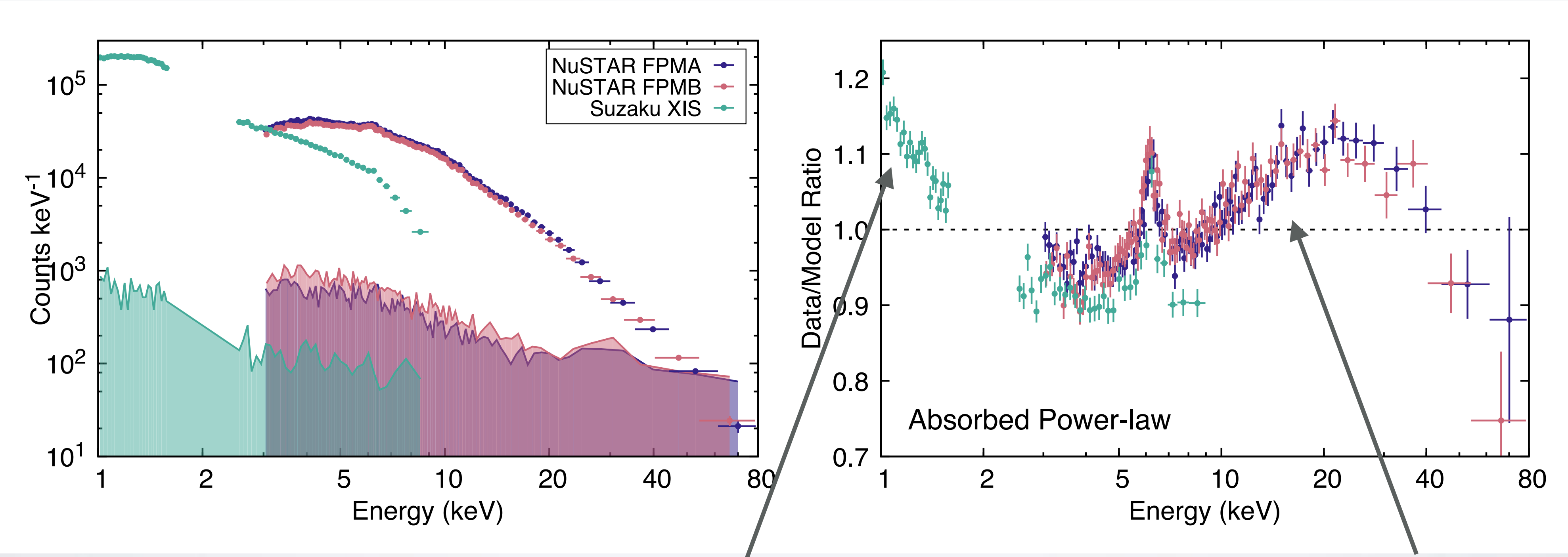


Extending the upper limit from 30 to 80 keV improves the constraints by 20-30%


AGN Physics II:
The Origin of the
Soft-Excess

Understanding the Soft-Excess

Suzaku (50 ks) and NuSTAR (200 ks) simultaneous exposure of Mrk 509



Clear soft-excess emission

Strong reflection spectrum

García et al. (2017, in prep.)

Understanding the Soft-Excess

The origin of the soft-excess is still unknown.
Some possibilities include:

- ~~Thermal disk emission (multicolor blackbody)~~
- Warm Comptonizing "corona" (kTe ~0.5 keV, tau~10-20)
- Relativistic reflection (high density?)
- ~~Some other diffuse emission (Bremsstrahlung?)~~

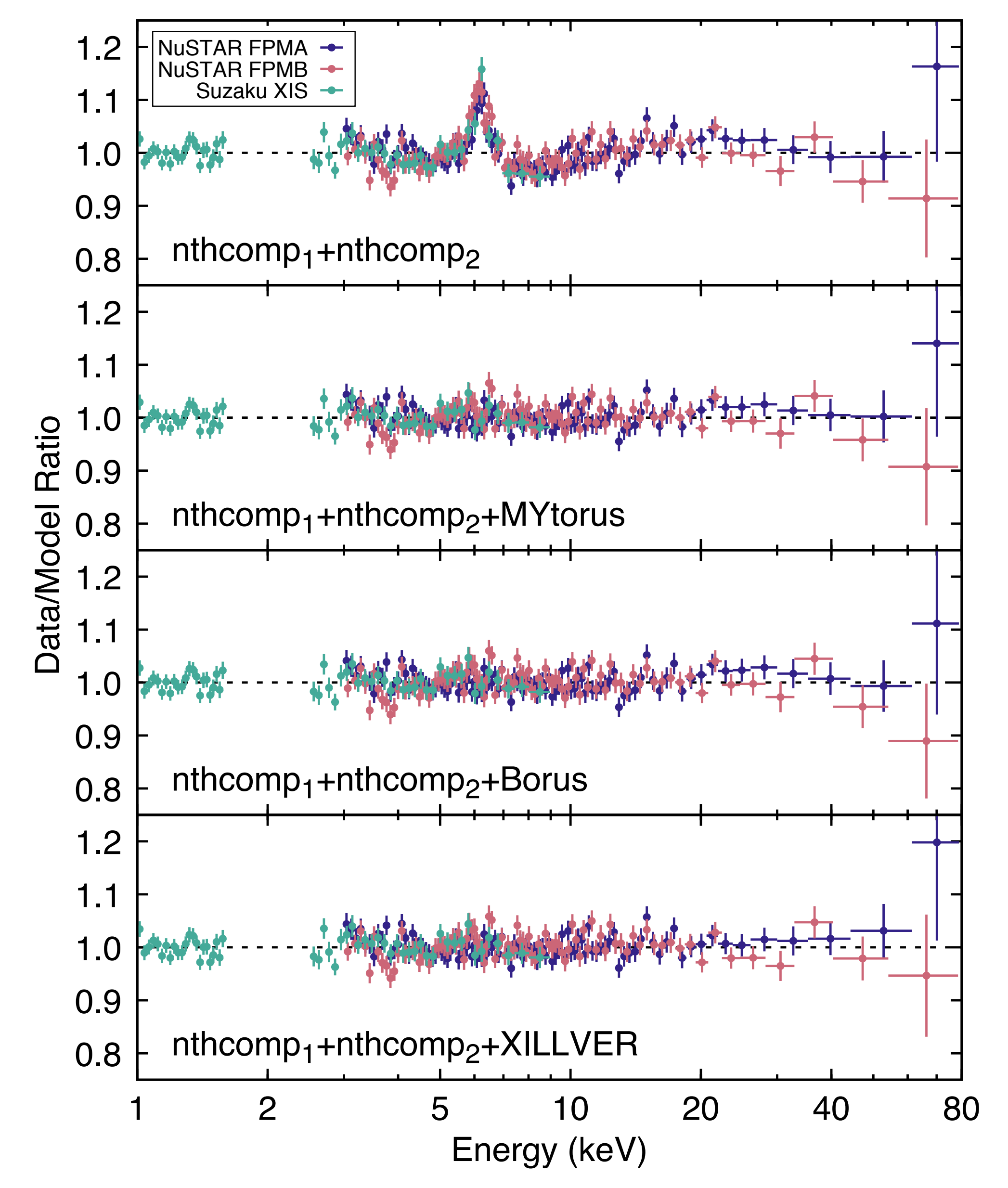
Understanding the Soft-Excess

The Warm "Corona"

Two different Comptonization components describe the continuum.

A hot (kTe ~100 keV) and optically thin (tau~1) corona produces the hard power-law

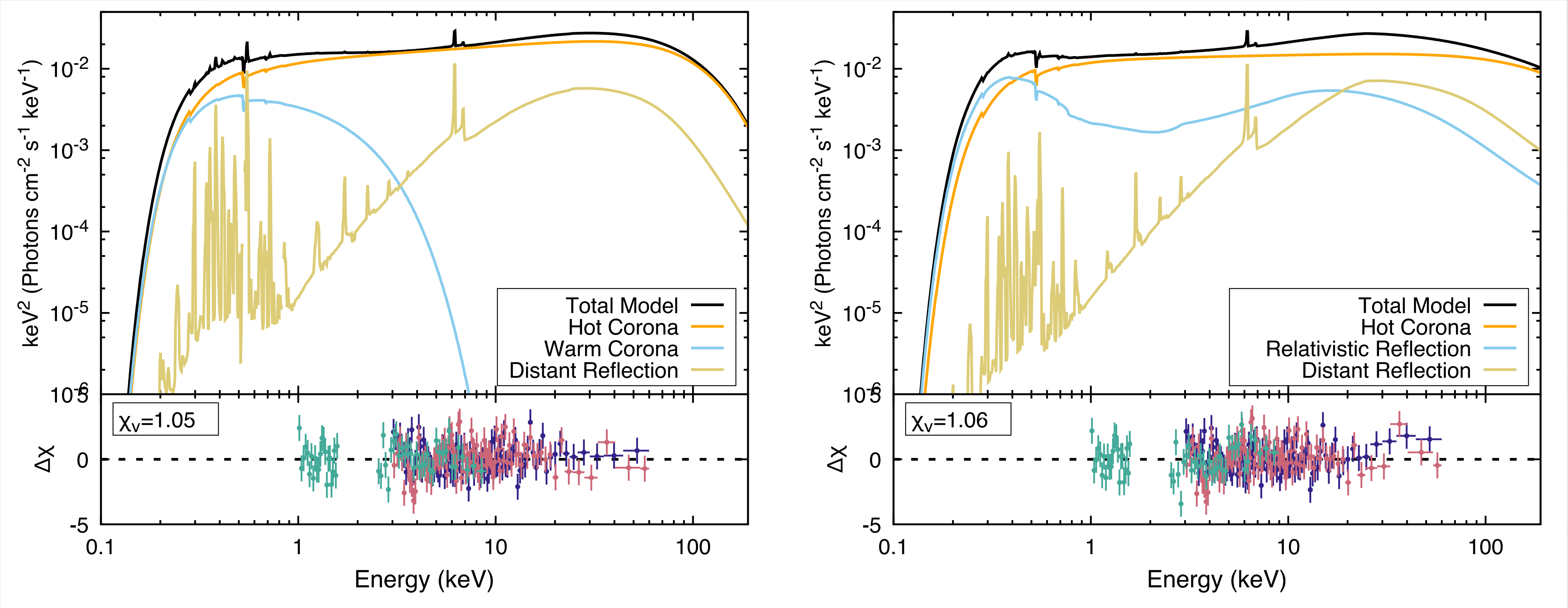
While a warm (kTe~0.5 keV) and optically thick (tau~15) corona produces the soft-excess (e.g., Petrucci et al. 2013; Porquet et al. 2017).



García et al. (2017, in prep.)

Understanding the Soft-Excess

Warm "Corona" | **Relativistic Reflection**

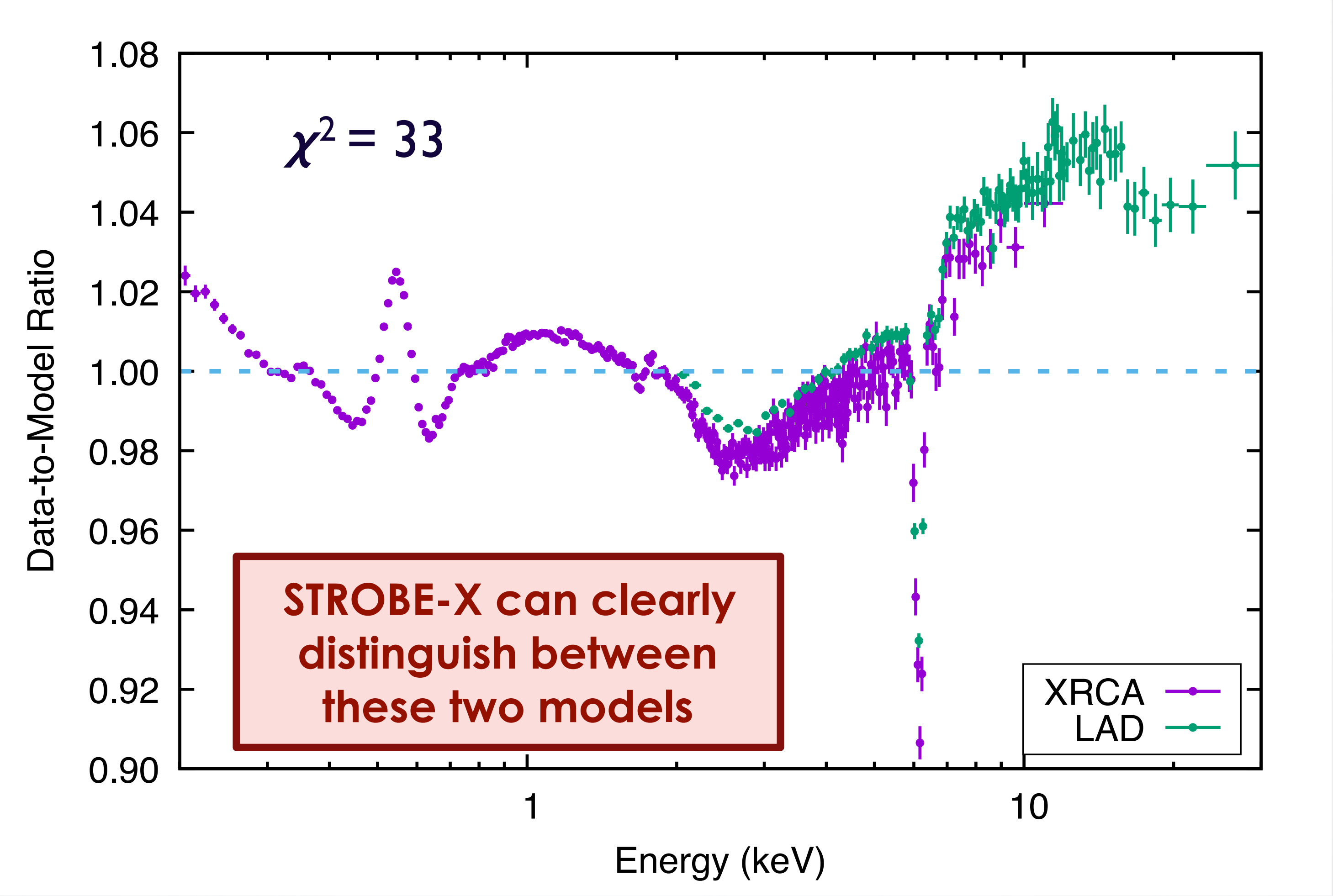


García et al. (2017, in prep.)

The two models are statistically indistinguishable, but with very different interpretations —> Which one is correct?

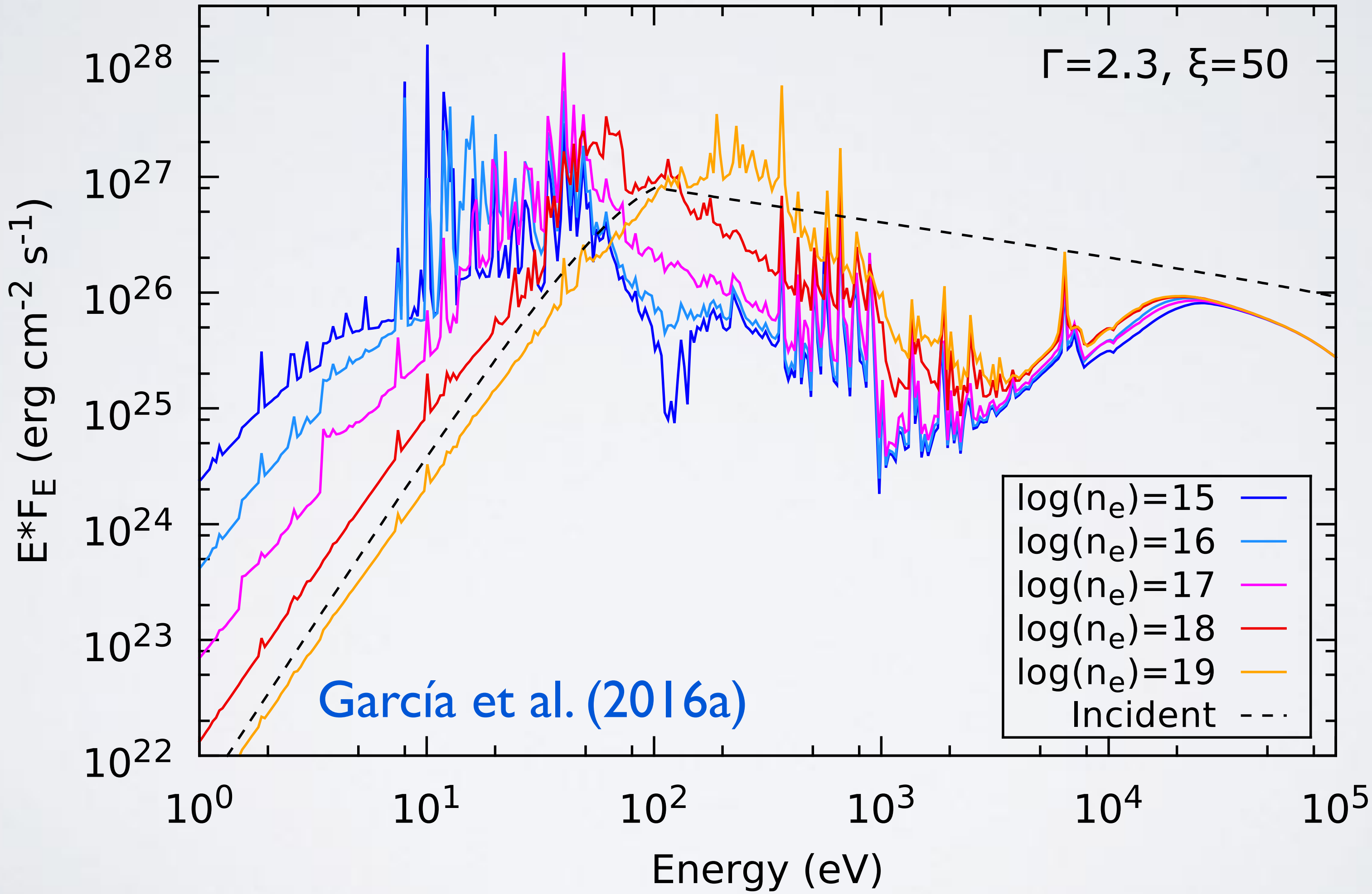
STROBE-X & the Soft-Excess

STROBE-X simulated data using the Warm Corona model, and fitted with the Relativistic Reflection model



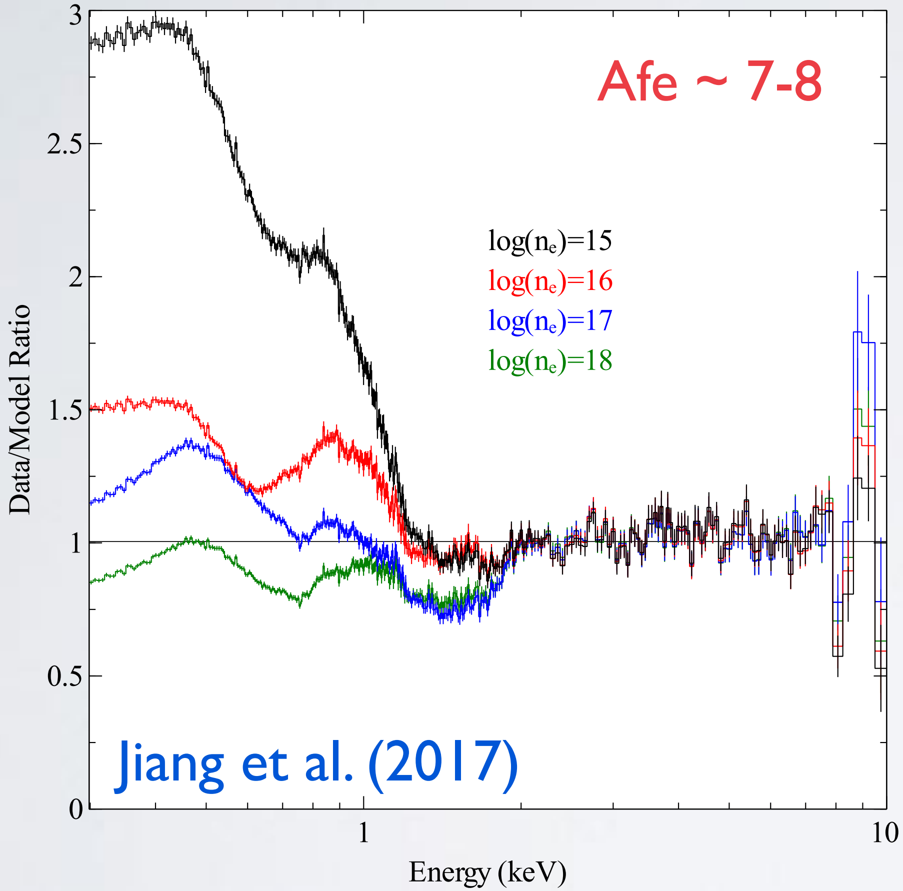
High Density Effects

Models with high gas density ($n_e >> 10^{15}$ cm^{-3}) produce a remarkable flux excess at soft energies as free-free emission becomes important.

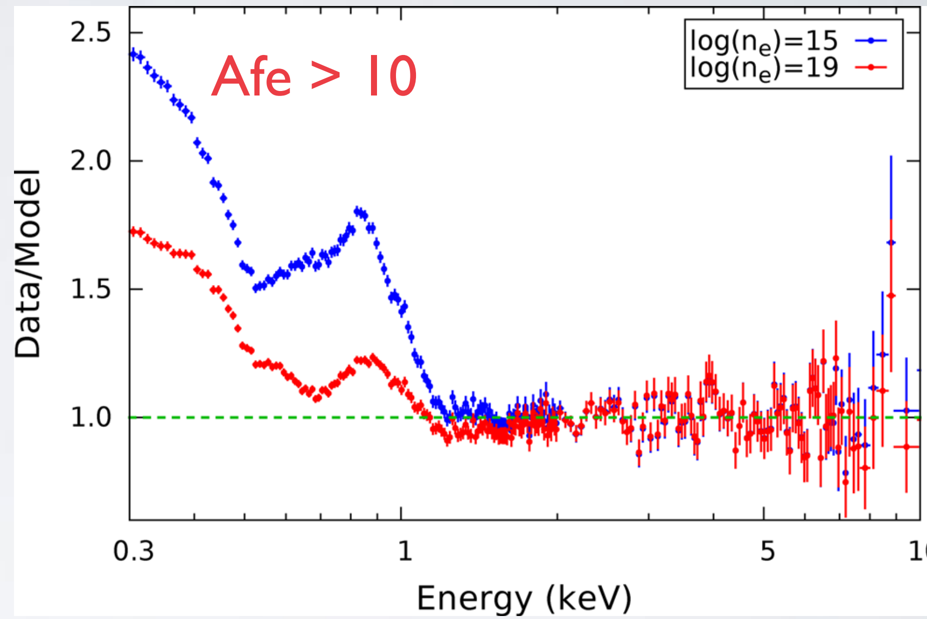


High Density Effects in AGN

IRAS 13224—3809



1H0707–495

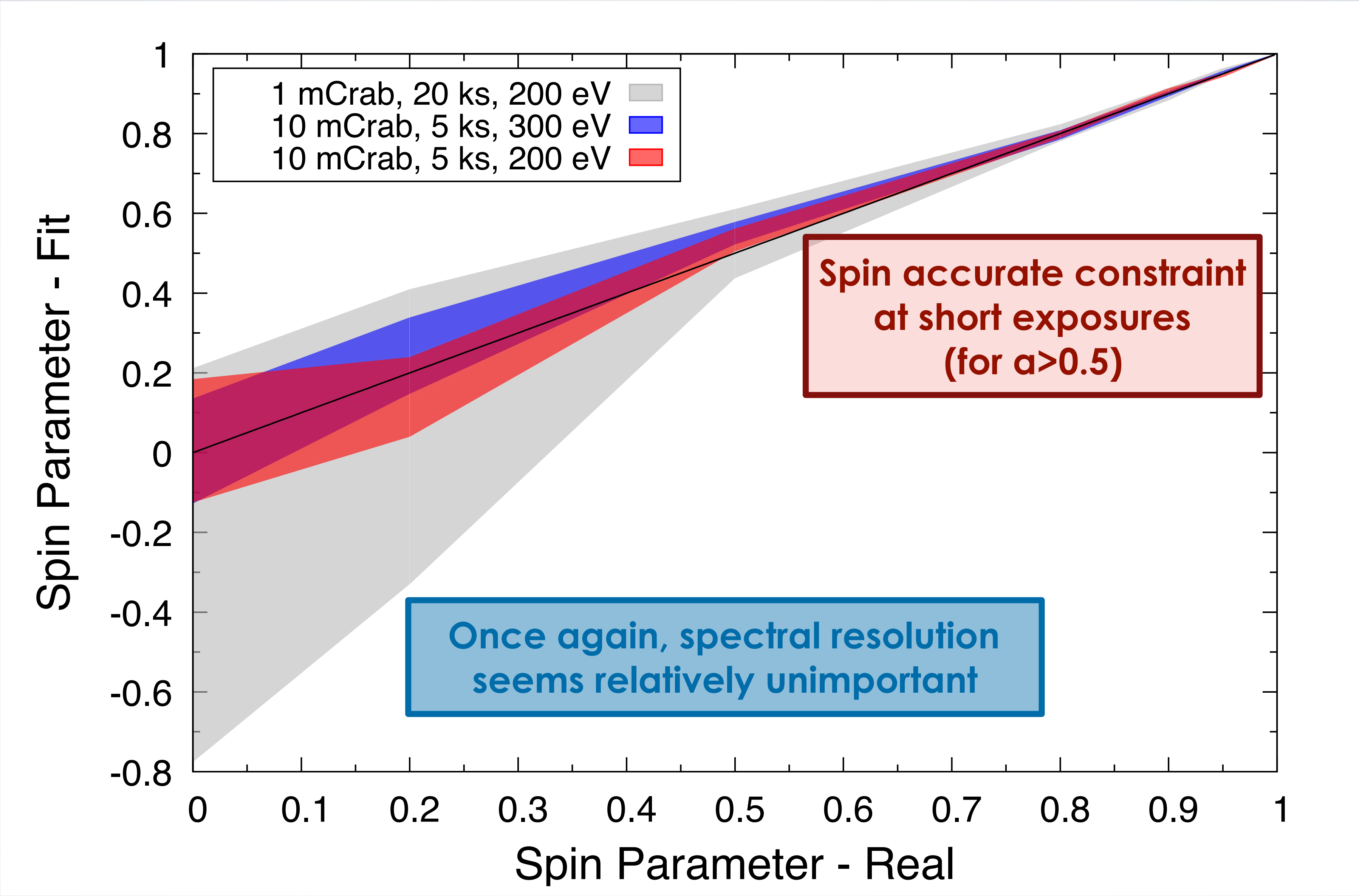


García et al. (2016a)

Strong implications in modeling the soft-excess in AGN!

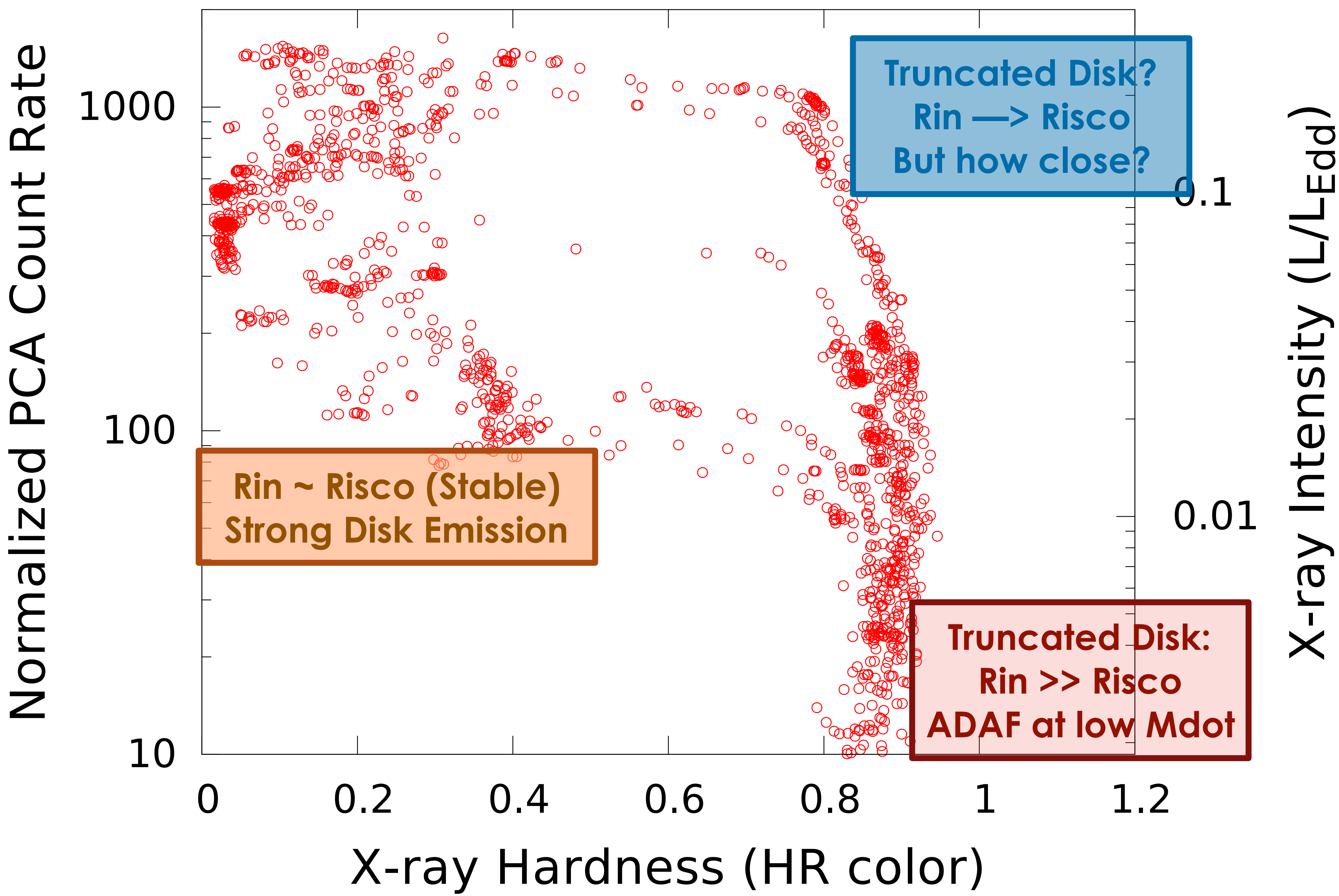
Spin Measurements (Applicable to BHB & AGN)

STROBE-X Simulations for Spin



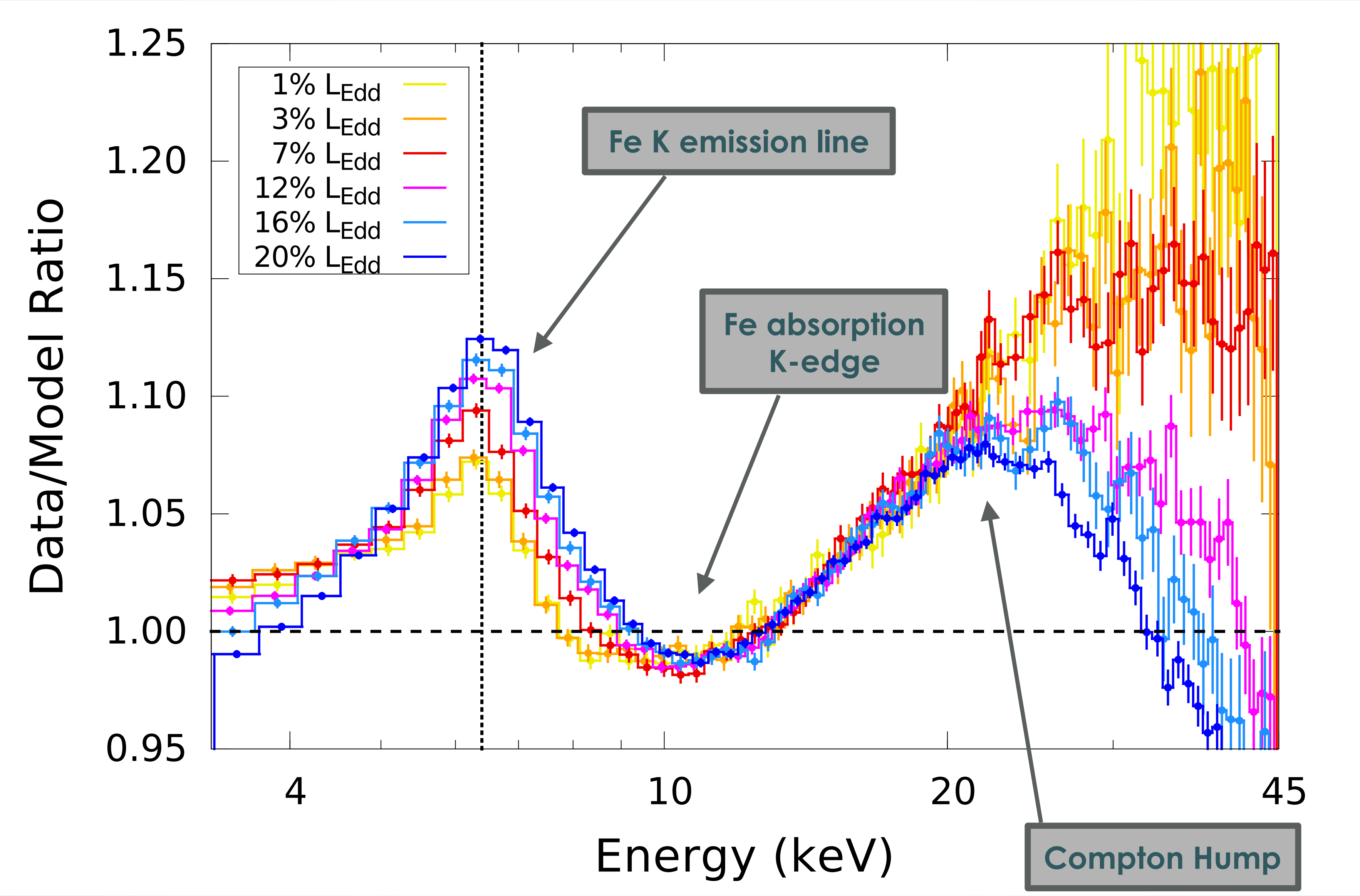
BHB Physics I: The Controversy of the Disk Truncation

The Case of GX 339-4



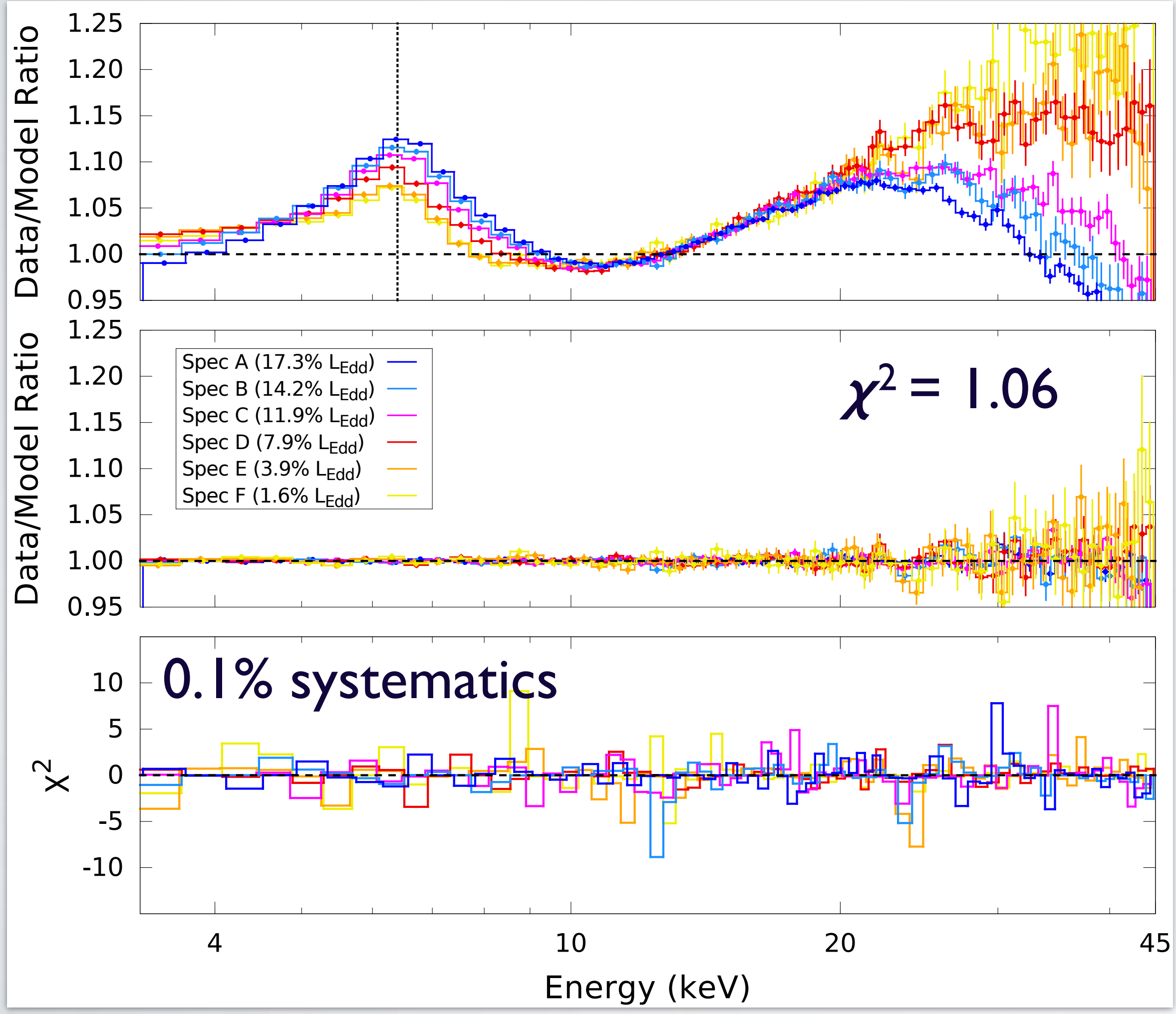
Reflection Signatures

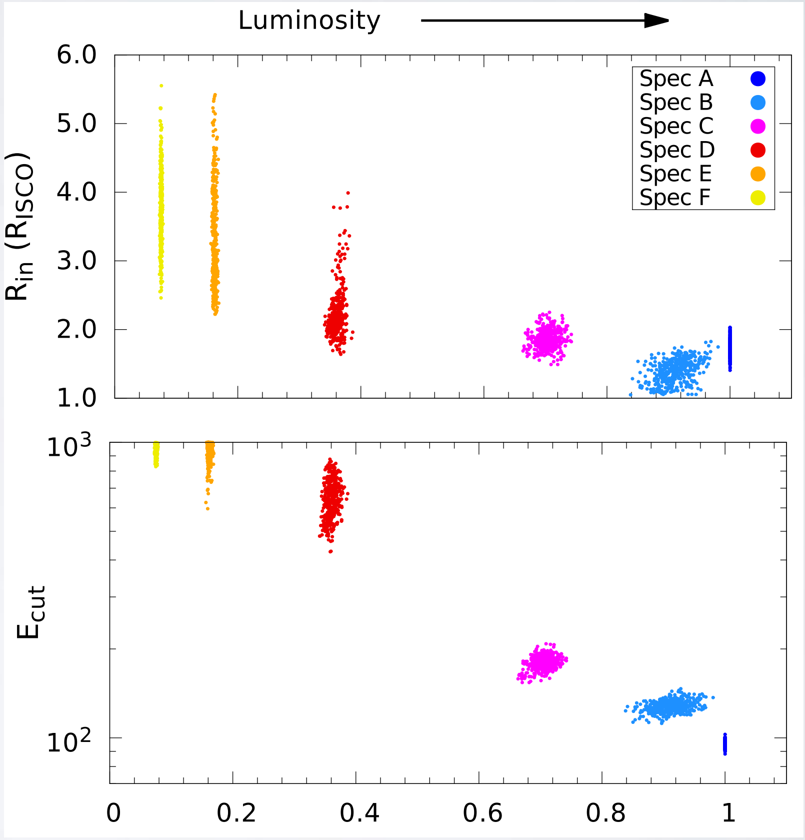
Ratio to a power-law model shows the signatures of reflection



Disk and Corona Evolution

Simultaneous fit of the RELXILL model to a 77 million count RXTE spectra revealed changes in disk and corona.



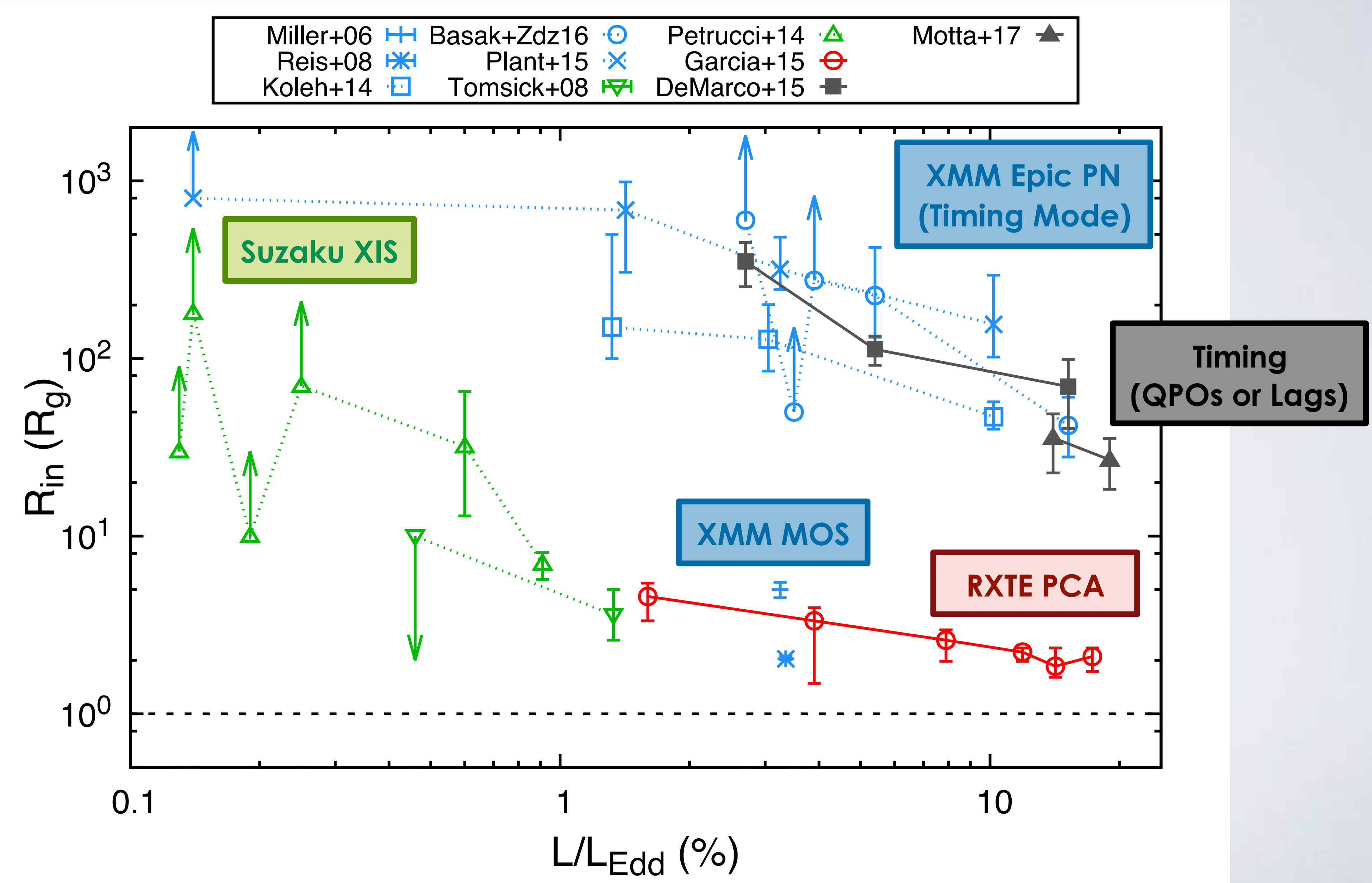


a = 0.95 +/- 0.04 (90% conf)
i = 48 +/- 1 deg
Fe abundance 5x Solar

García et al. (2015)

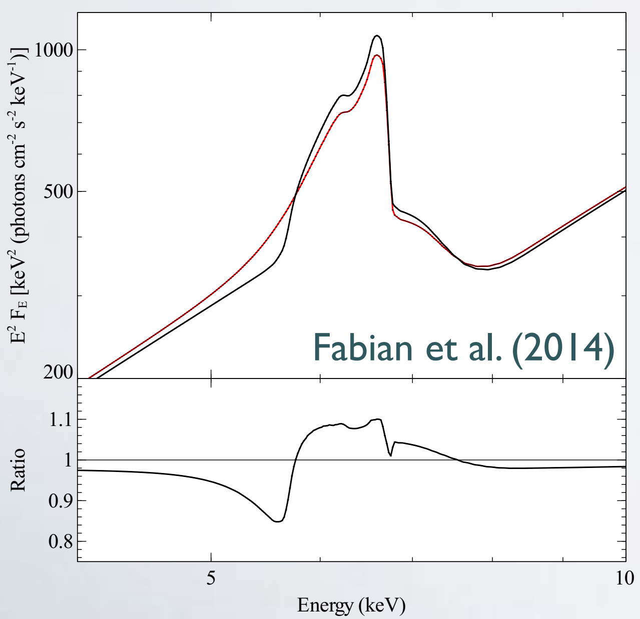
Controversy on the Disk Truncation

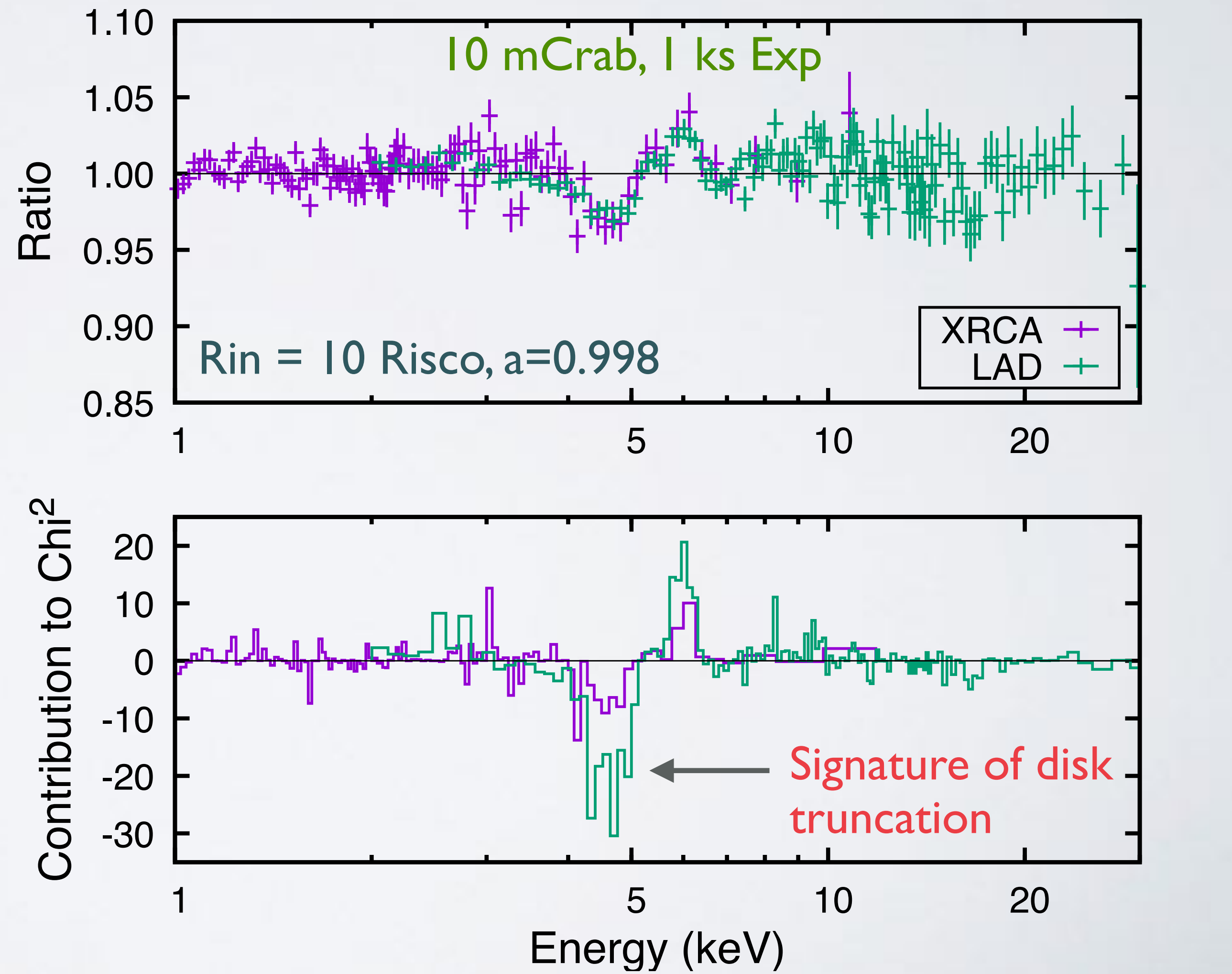
Large disagreement with both spectral (reflection) and timing results!



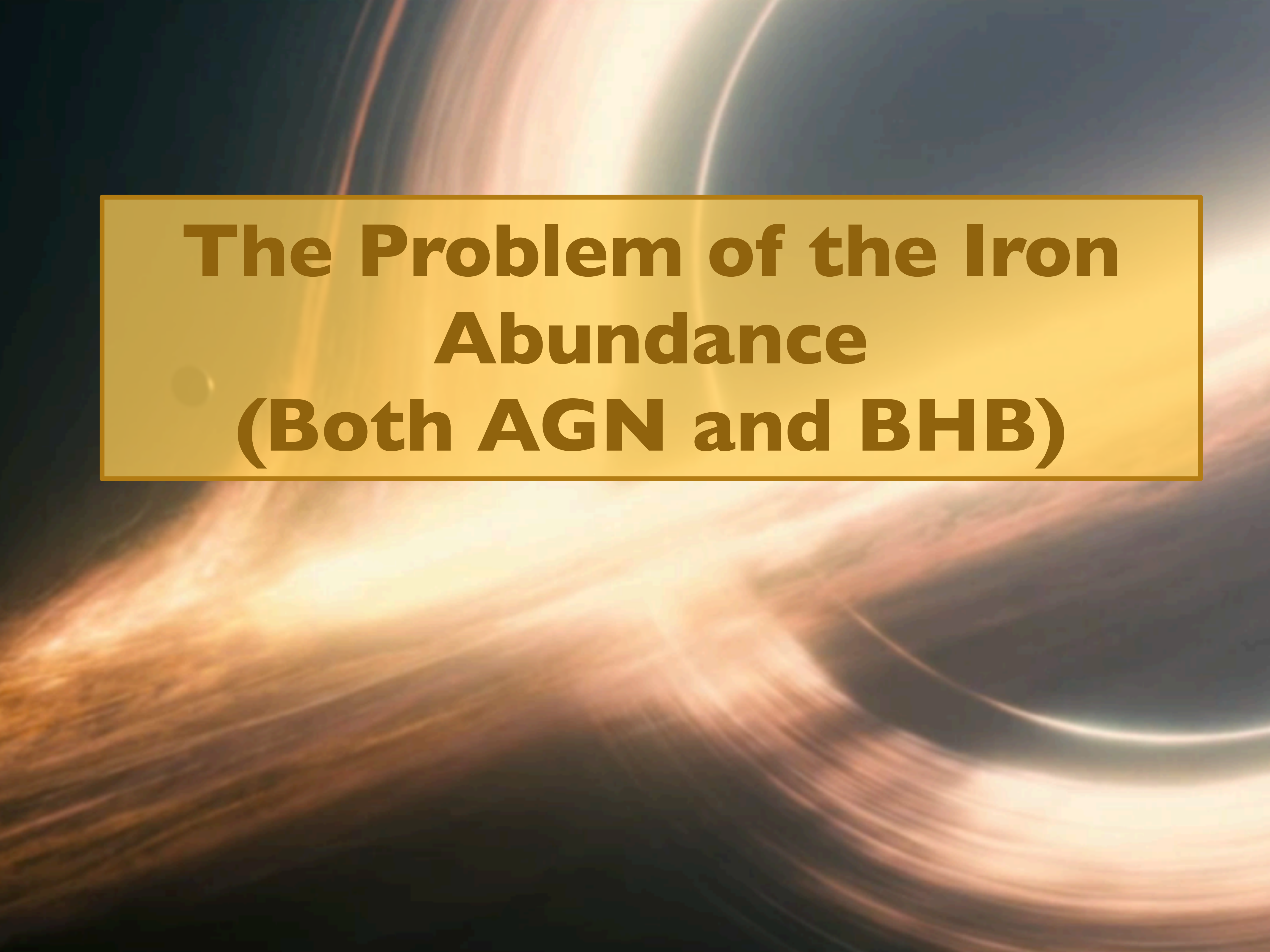
STROBE-X: Spin and Inner Radius

- A truncated disk fitted with Rin=Risco will under-predict the spin
- With a short exposure (1 ks), STROBE-X will be able to differentiate disk truncation
- Possibly, we will be able to measure both Rin and spins! (More simulations required…)



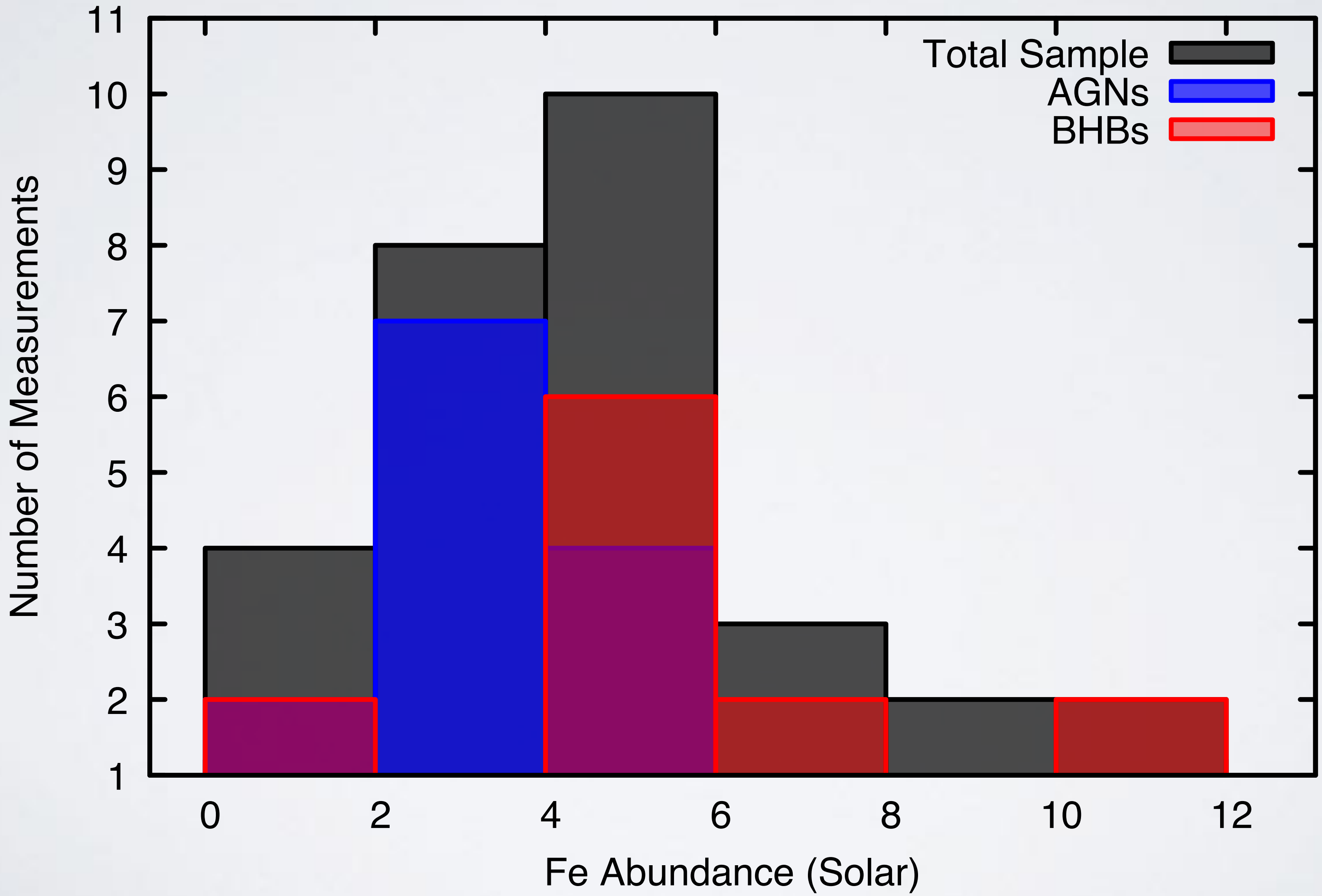


The Problem of the Iron Abundance (Both AGN and BHB)



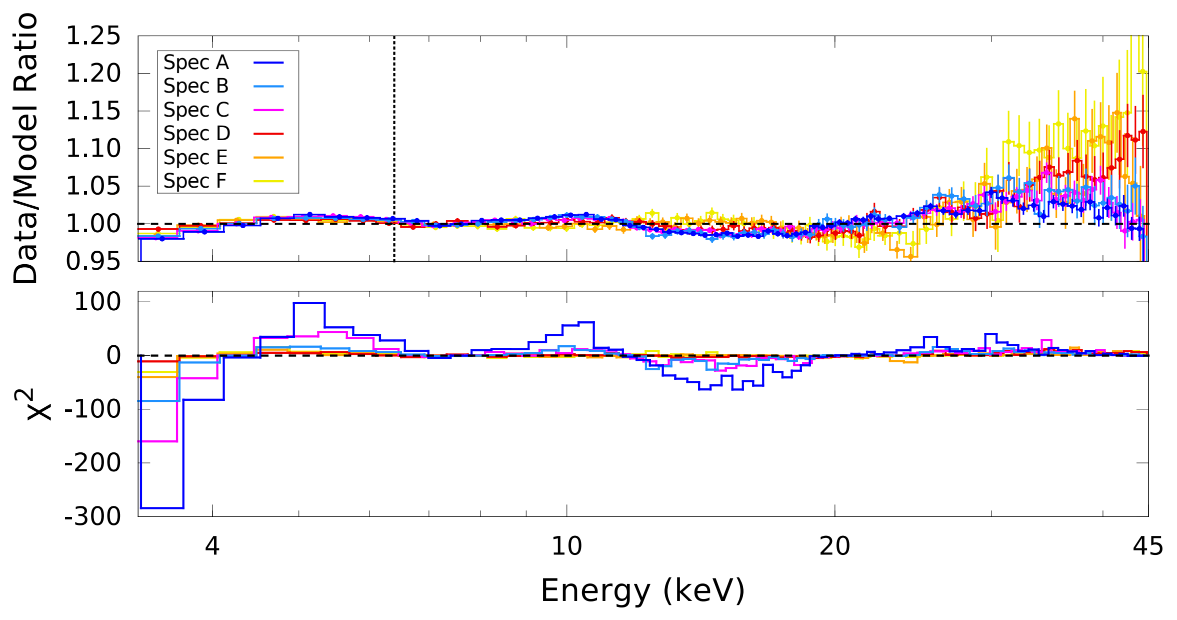
The Problem of the Fe Abundance

Iron abundance determinations using reflection spectroscopy from publications since 2014 tend to find a few times the Solar value!

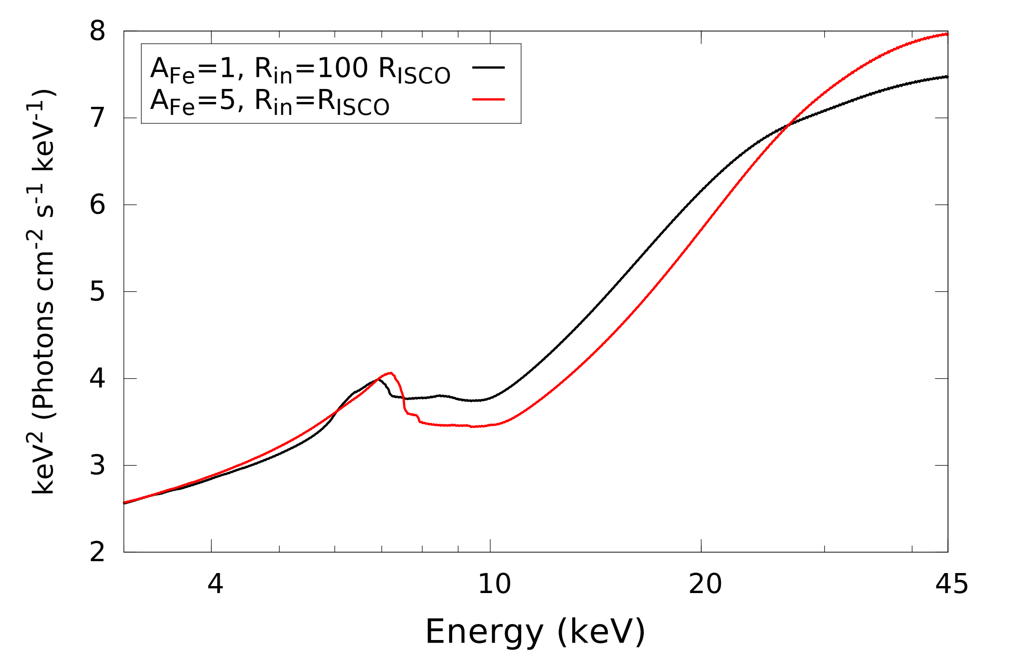


13 AGNs
9 BHBs

Inner Radius and Fe Abundance

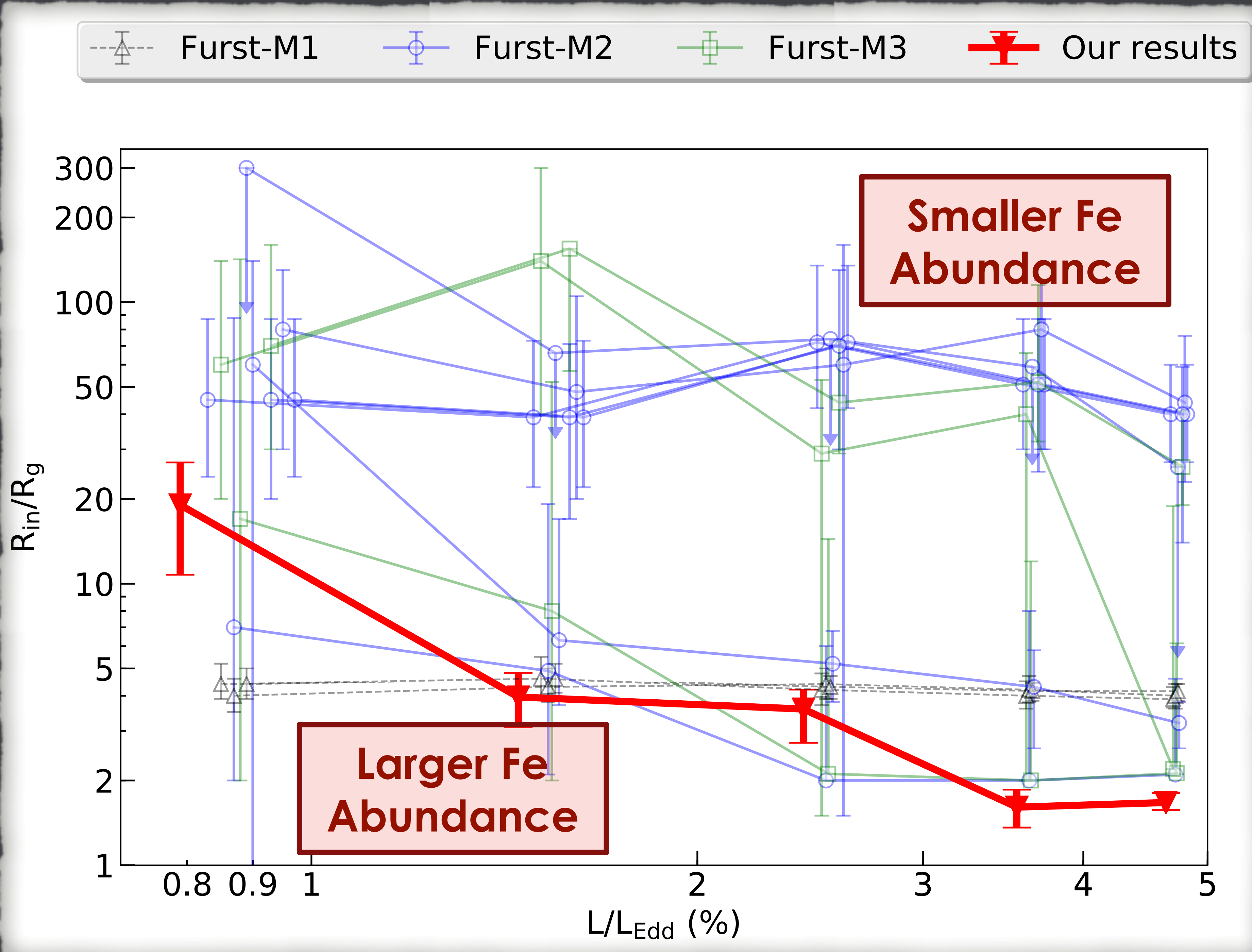


Fixing the Fe abundance to its Solar value resulted in poor fits with $\chi^2 \sim 10$



A truncated disk with Solar abundance produces an Fe K line similar to an over-abundant disk reaching the ISCO

García et al. (2015)



Furst-M1
Furst-M2
Furst-M3
Our results
Smaller Fe Abundance
Larger Fe Abundance
R_{in}/R_g
300
200
100
50
20
10
5
2
1
0.8
0.9
1
2
3
4
5
L/L_{Edd} (%)

The Problem of the Fe Abundance

There are two possibilities:

1) The over-abundances are **real**, but we don't know why

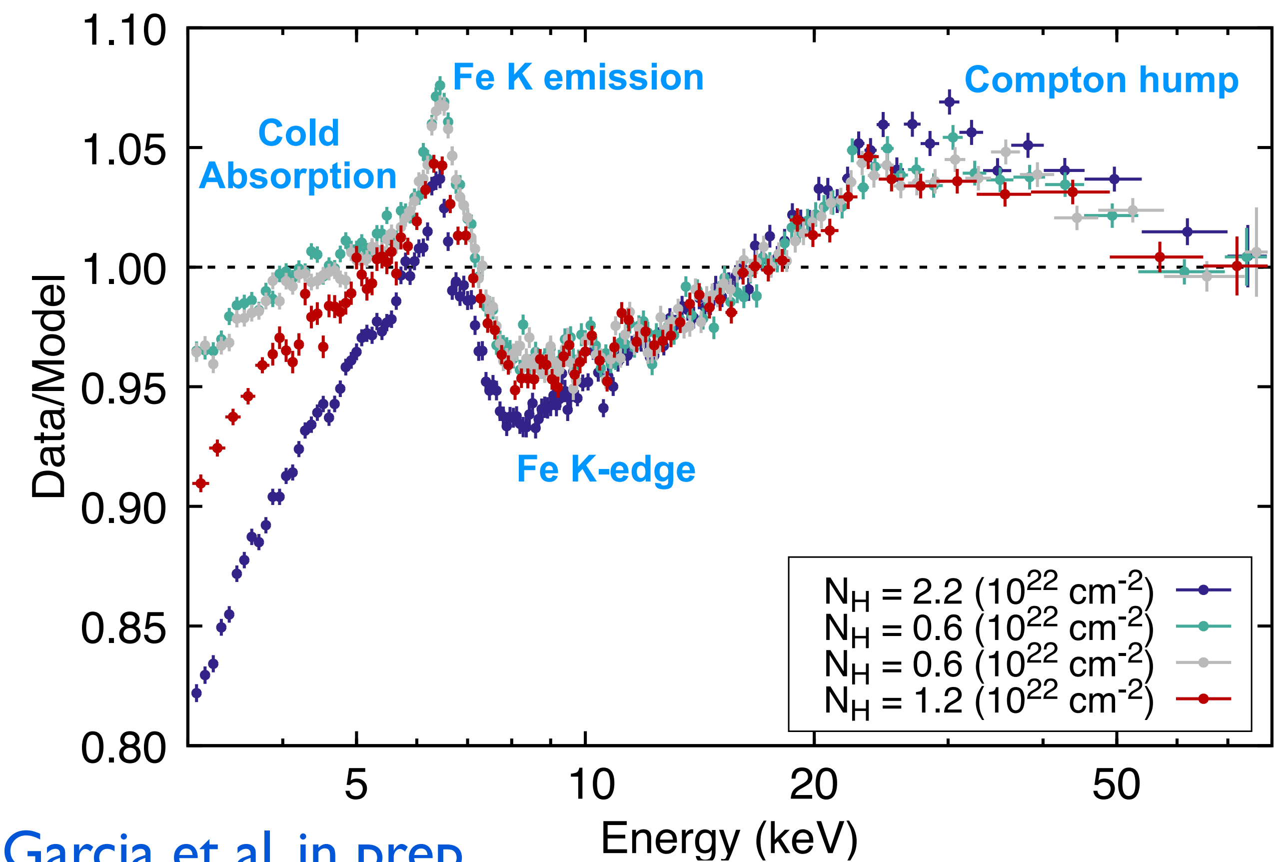
2) The over-abundances are **not real**:

   - Exotic mechanisms of apparent enhancement (e.g.; ion levitation)
   - Key physics is missing? (e.g.; high-density plasma effects)

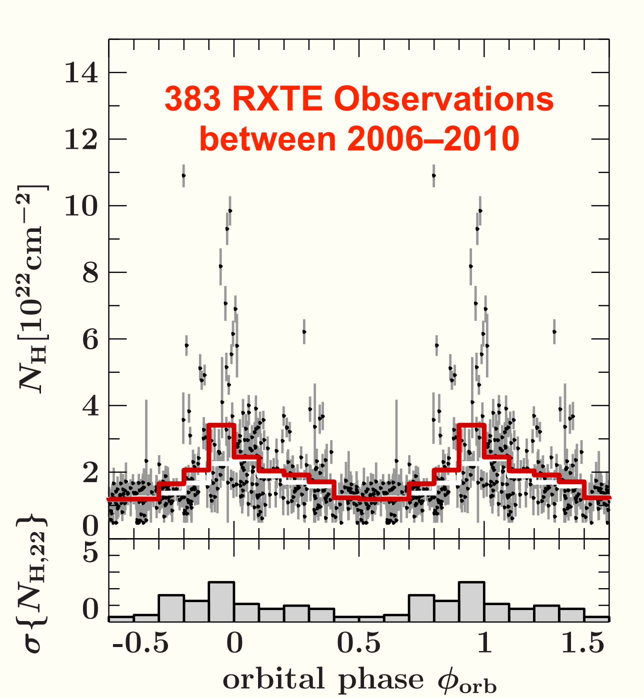
Decoupling Absorption from Reflection (Warm Absorbers, UFOs, Wind-fed Systems)

Wind & Reflection in Cyg X-1

The reflected spectra is constant while the changes are due to the variation of the absorbing column



Garcia et al. in prep.



Large changes in the absorbing column are observed throughout the orbital period of Cyg X-1 (Grinberg et al. 2015).

Need high spectral resolution to disentangle these components!

STROBE-X Simulations

Caveats:

- Relatively small number of simulations (should run a lot more)
- Optimistic scenario: bright source, simple spectrum (continuum plus reflection)
- Only one set of relativistic parameters —> Results likely affected by reflection fraction, slope of the continuum, etc.

Questions:

- Why to stop at 30 keV? The effective area is still much larger than NuSTAR in the same band (up o 80 keV).
- Can we reduce the background? This probably limits detections at lower fluxes
- Resolution seems to be unimportant for the coronal temperature (although more detailed simulations are probably needed)

- My simulation codes in Github https://github.com/jajgarcia/StrobeXsim