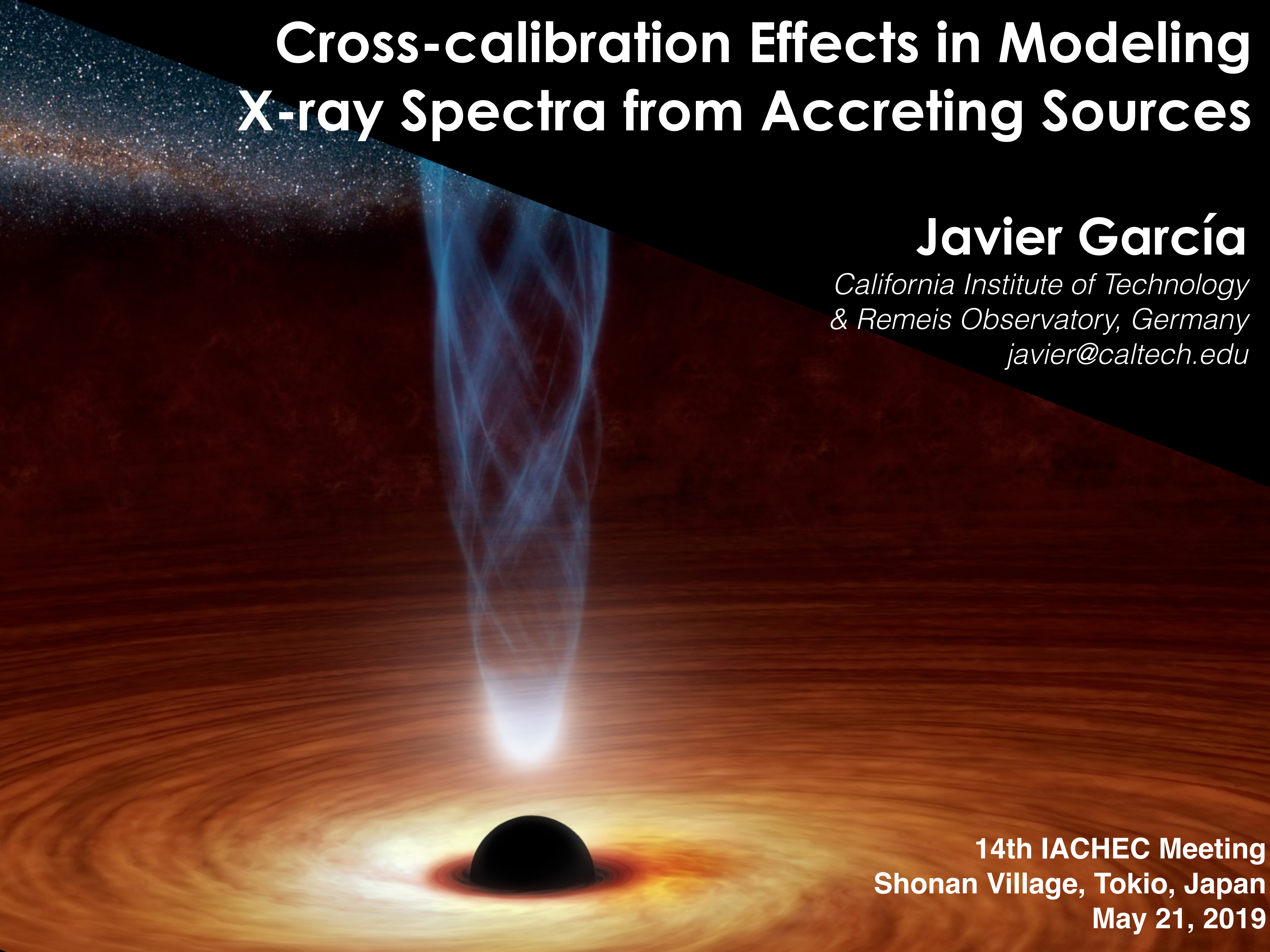
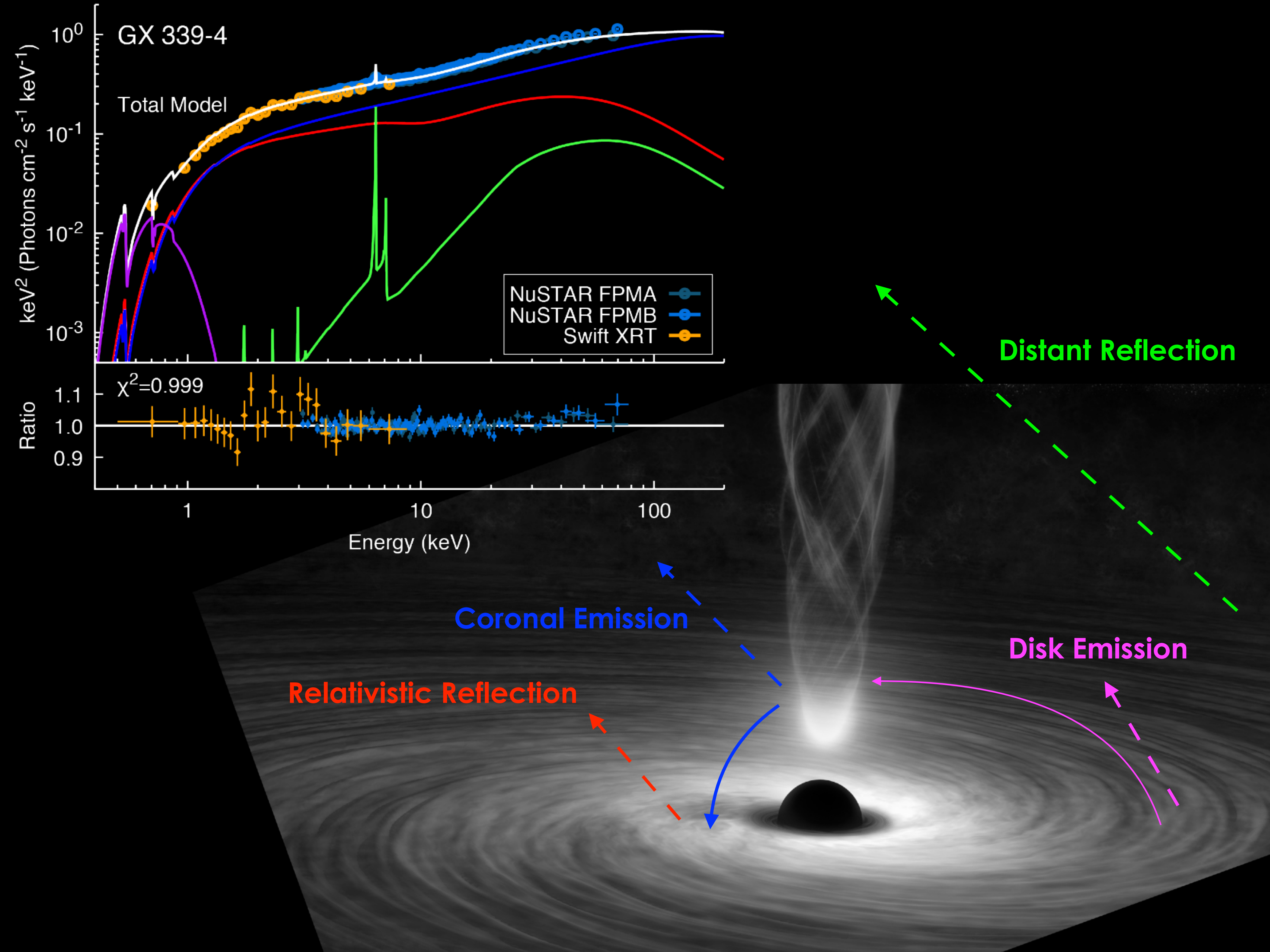


Cross-calibration Effects in Modeling X-ray Spectra from Accreting Sources

Javier García

California Institute of Technology
& Remeis Observatory, Germany
javier@caltech.edu

14th IACHEC Meeting
Shonan Village, Tokio, Japan
May 21, 2019

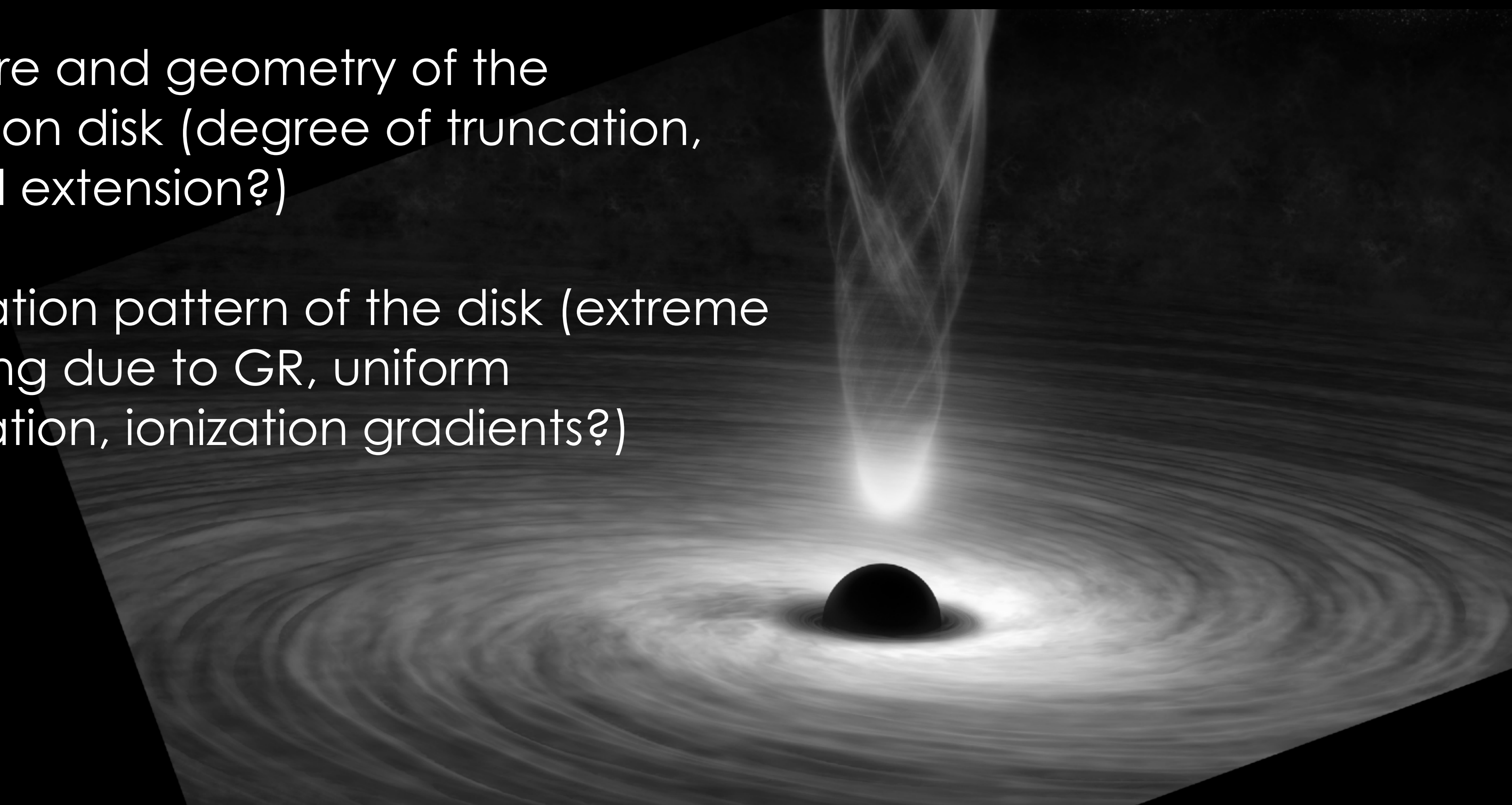


GX 339-4
Total Model
keV^2 (Photons cm^{-2} s^{-1} keV^{-1})
10^0
10^{-1}
10^{-2}
10^{-3}
NuSTAR FPMA
NuSTAR FPMB
Swift XRT
χ^2=0.999
Ratio
1.1
1.0
0.9
1
10
100
Energy (keV)
Distant Reflection
Coronal Emission
Disk Emission
Relativistic Reflection

But this is still a Cartoon Picture!

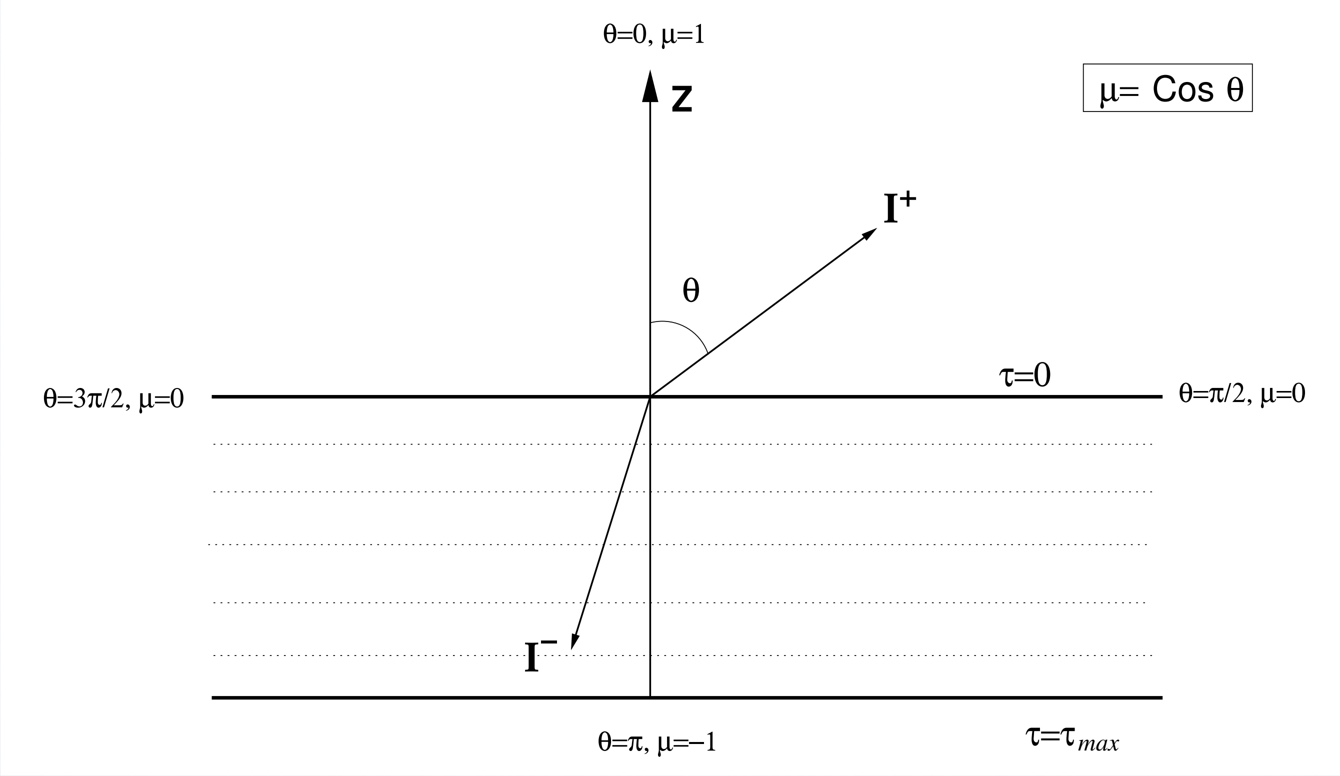
We still don't know:

- The origin and geometry of the corona (base of a jet, extended hot plasma, disk evaporation?)
- Structure and geometry of the accretion disk (degree of truncation, vertical extension?)
- Illumination pattern of the disk (extreme beaming due to GR, uniform illumination, ionization gradients?)



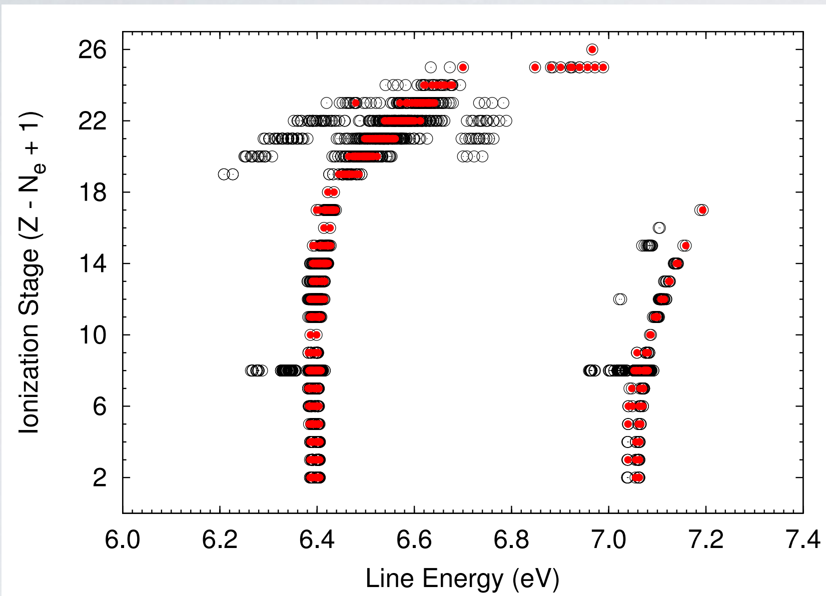
The Reflection Code XILLVER

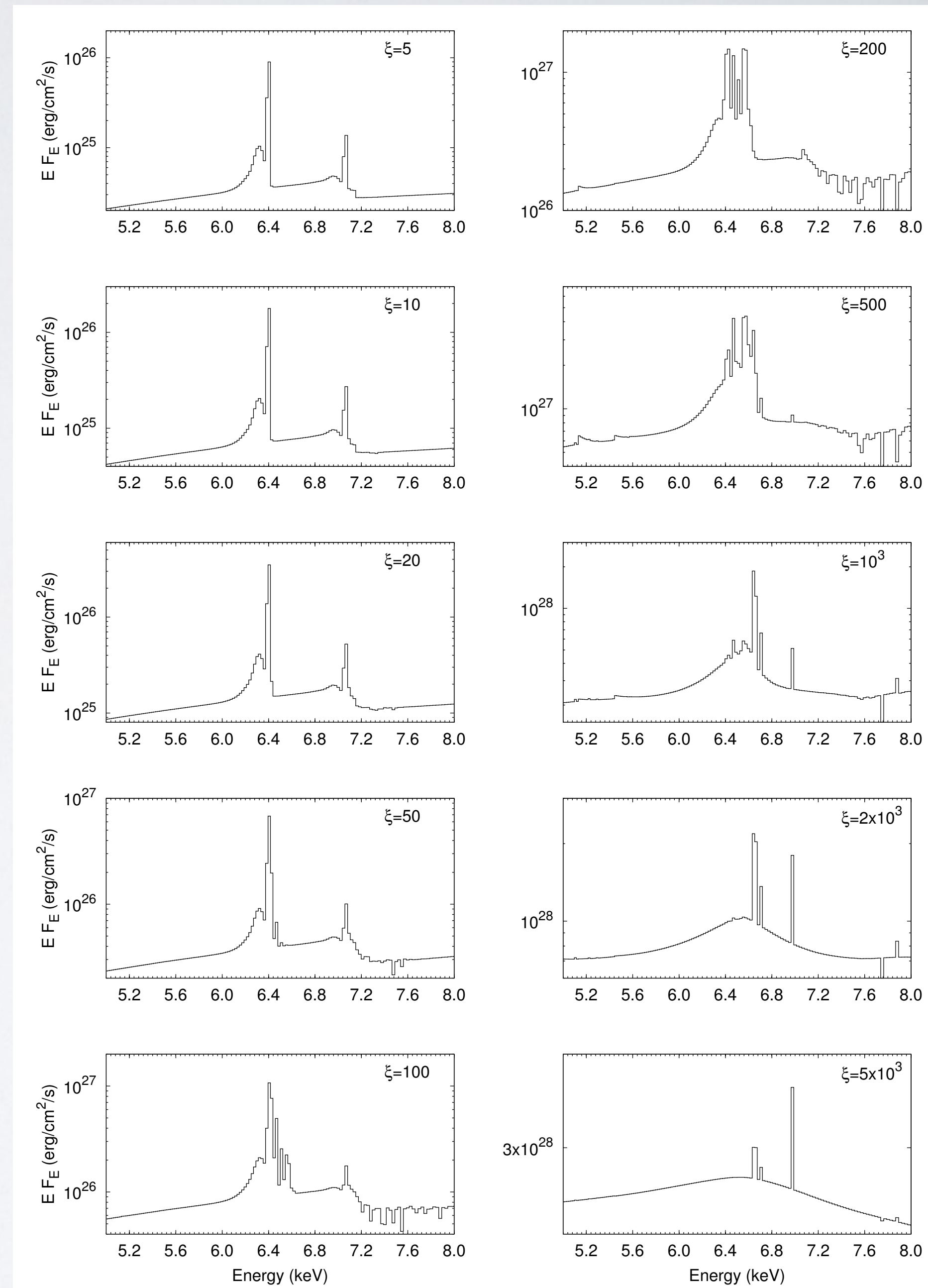
- Solves the Radiation Transfer equation for every energy, angle, and optical depth
- This requires large number of iterations (~ Tau_max^2)
- Solves the ionization balance using the XSTAR routines —> More iterations!
- Includes the most complete and updated atomic data for inner-shell transitions
- Includes Comptonization within the disk —> CPU intensive



García & Kallman (2010)

XILLVER: The Fe K Emission Complex



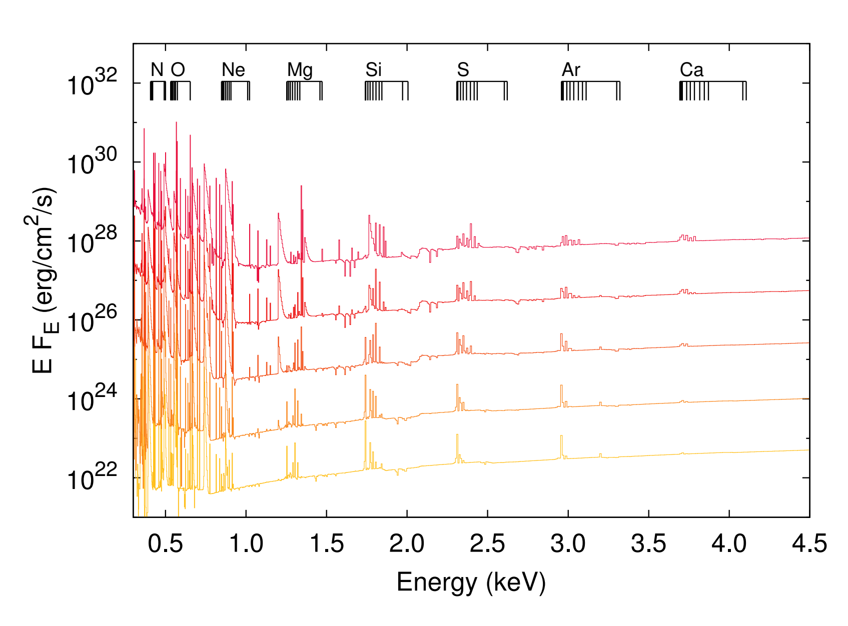


The emission of Fe in the 6-8 keV range is due to a large number of transitions

The line energy changes according with the ionization stage

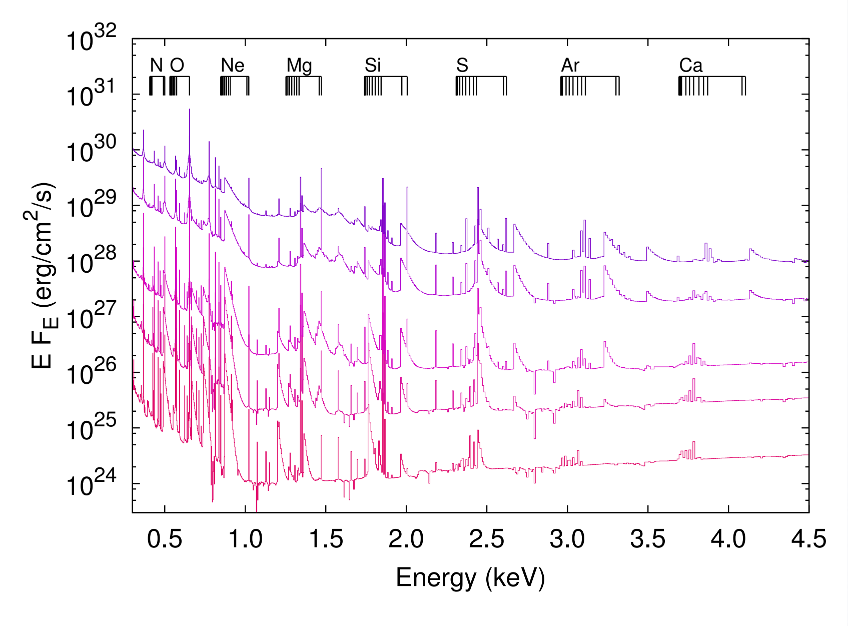
García et al. (2013)

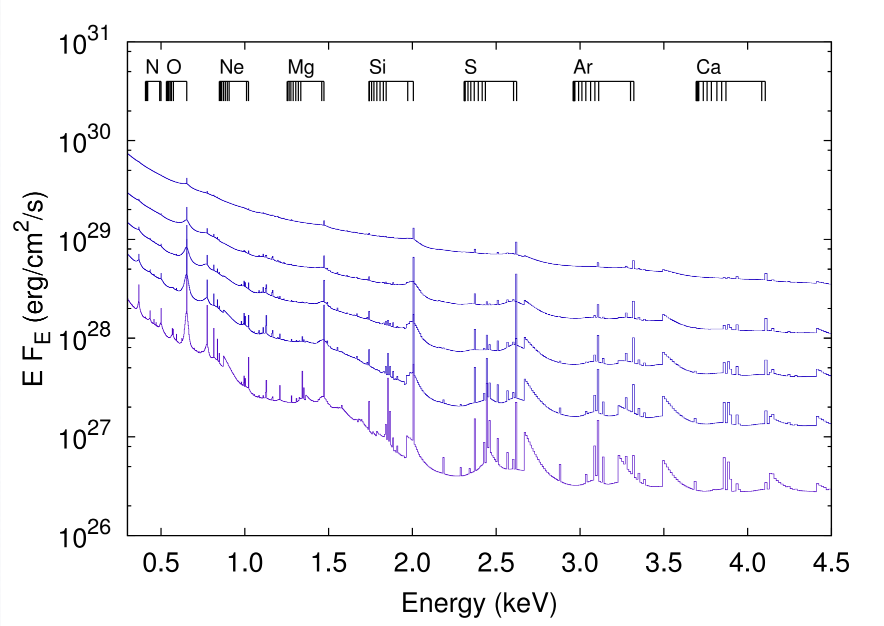
XILLVER: More than Iron



XILLVER includes all astrophysically relevant ions

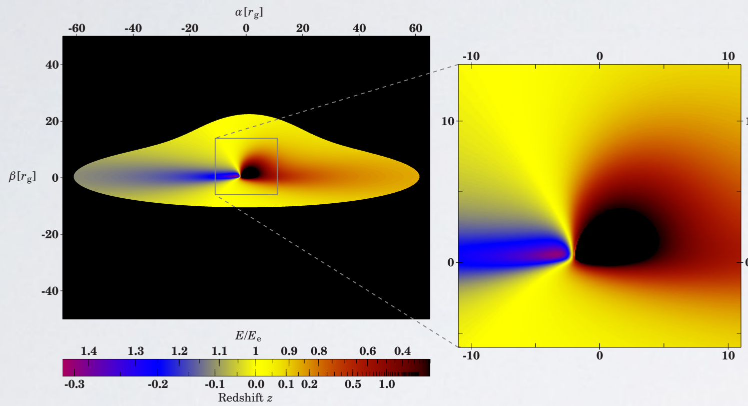
García et al. (2013)





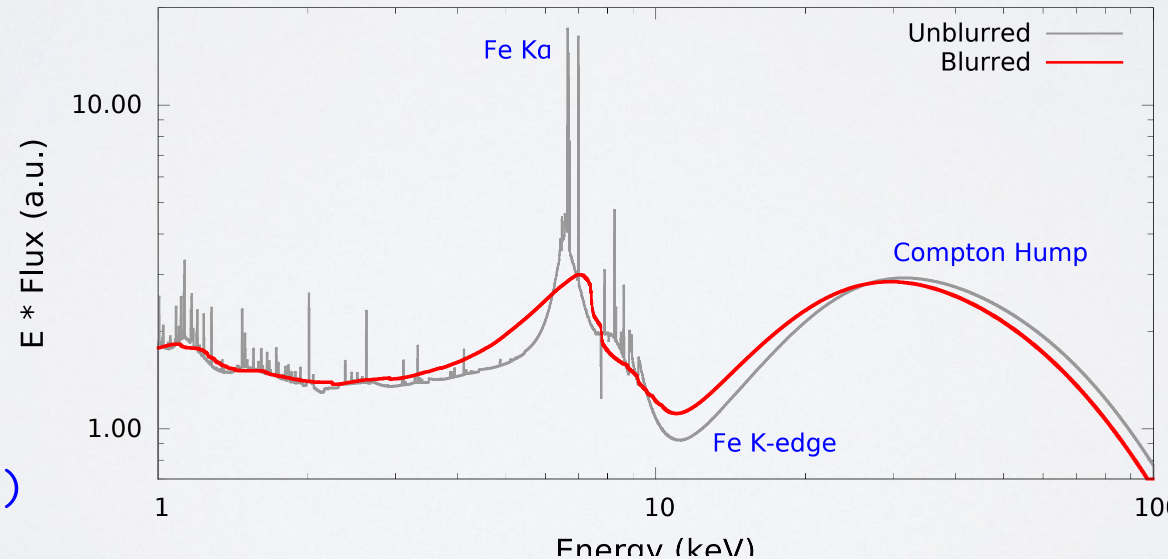
Relativistic X-ray Reflection

RELXILL: Relativistic reflection model that combines detailed reflection spectra from **xillver** (García & Kallman 2010), with the **relline** relativistic blurring code (Dauser et al. 2010).



Model Parameters

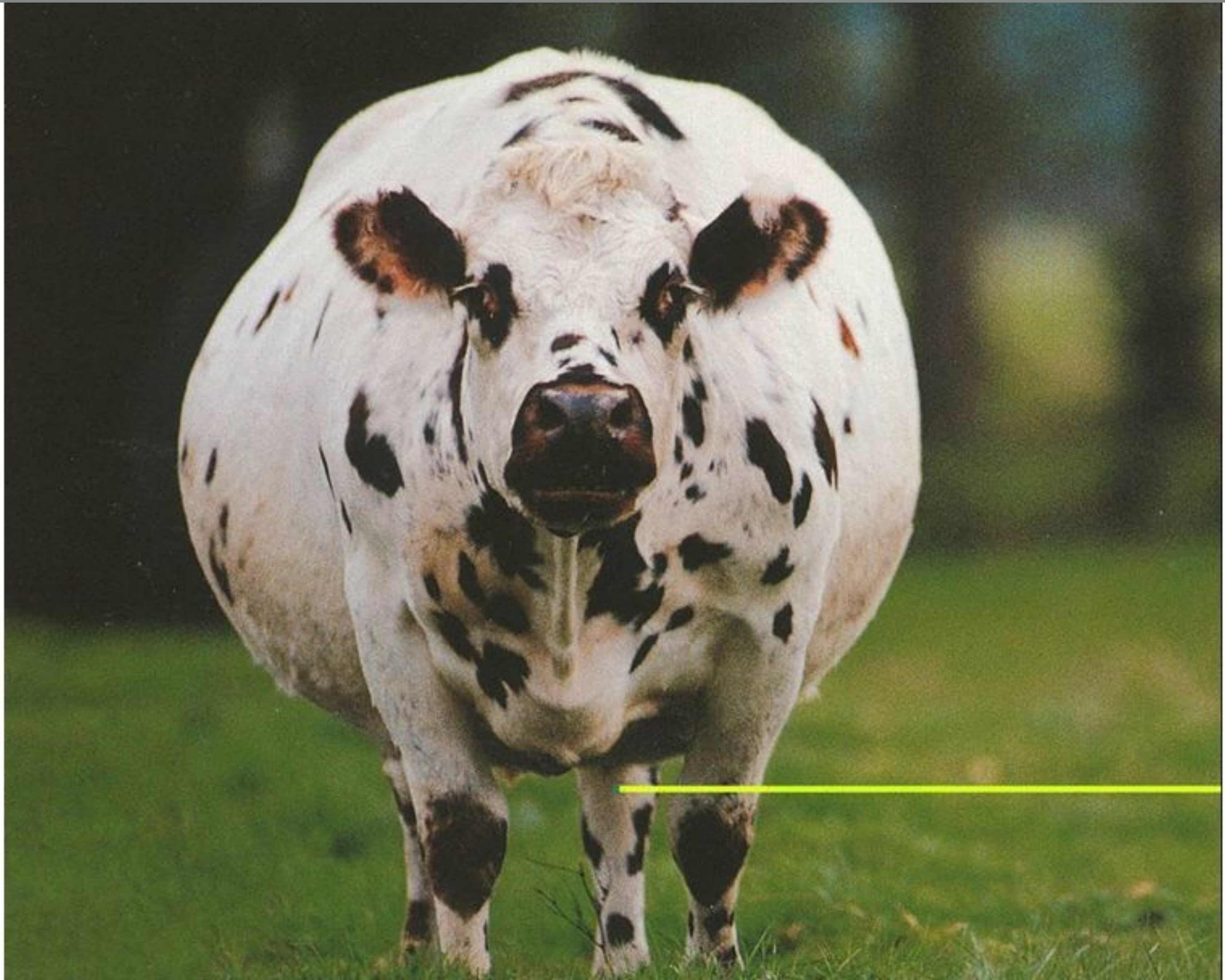
a: Black hole spin, R_{in}: Disk's inner edge
i: Inclination, ϵ: Emissivity index
R_f: Reflection fraction, Γ: Power-law index
E_{cut}: High-energy cutoff, A_{Fe}: Fe abundance



(García+14b)

http://www.sternwarte.uni-erlangen.de/research/relxill/

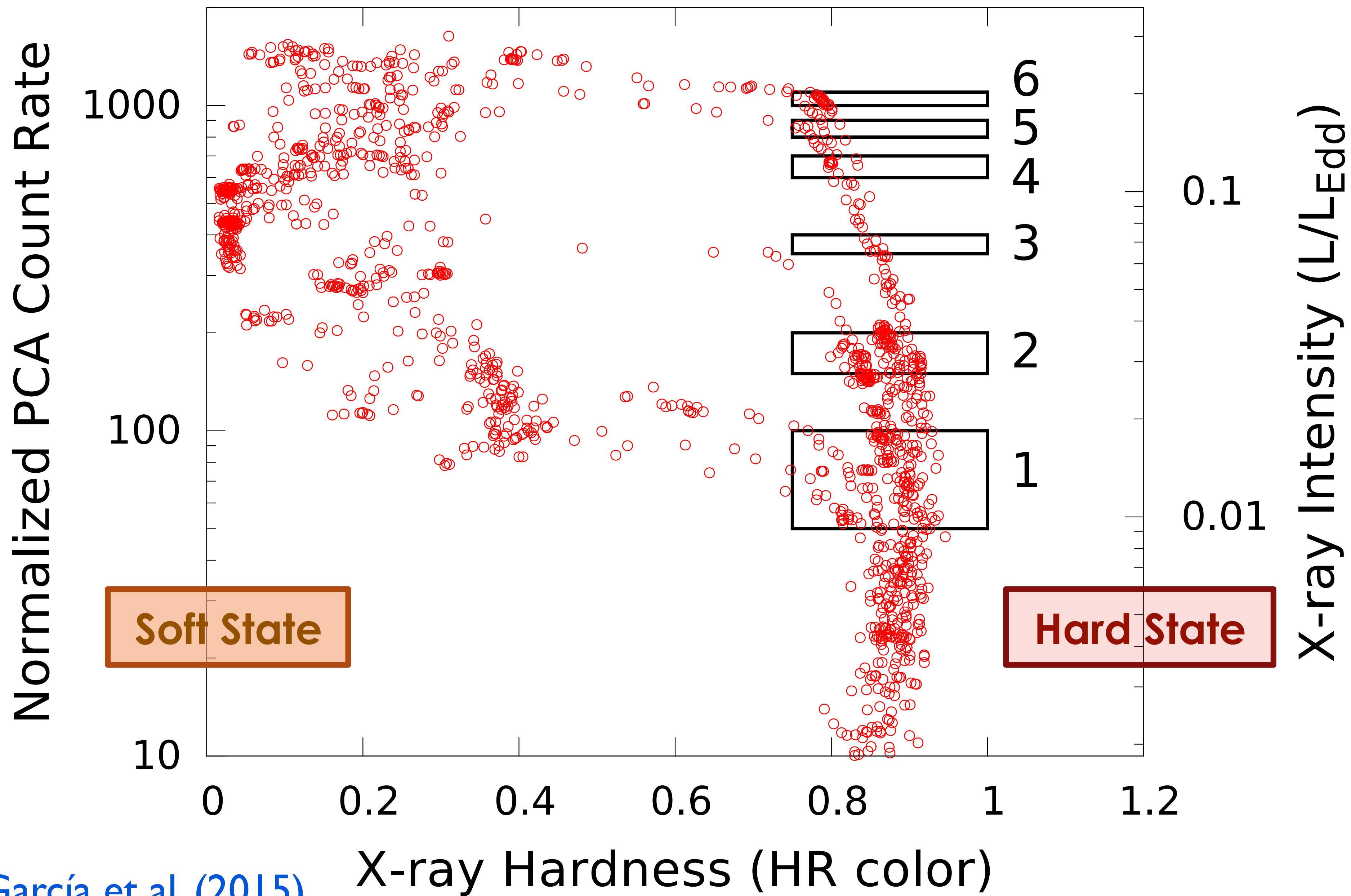
But, we work with a few assumptions



RELXILL: Assumptions & Issues

- Assumes Rin = Risco to measure spins.
- Can't fit both Rin and spin (can we?)
- Emissivity profile: what's the right shape?
- Lamppost Geometry
- Degeneracies: incl. vs spin, Afe vs spin, etc.
- Single ionization vs. gradients
- High-density Plasma Effects

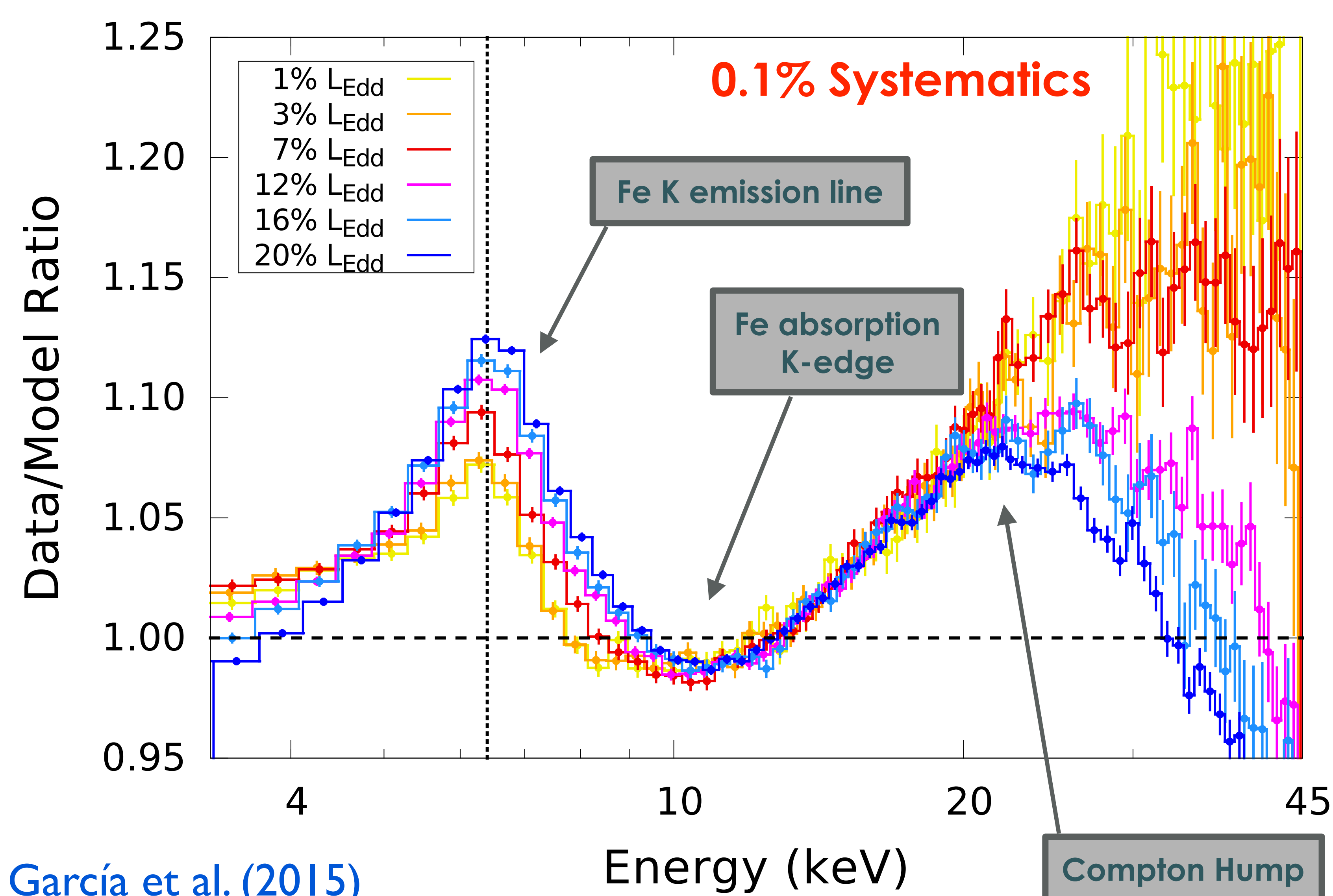
The HID of GX 339-4



García et al. (2015)

GX 339-4: Reflection Signatures

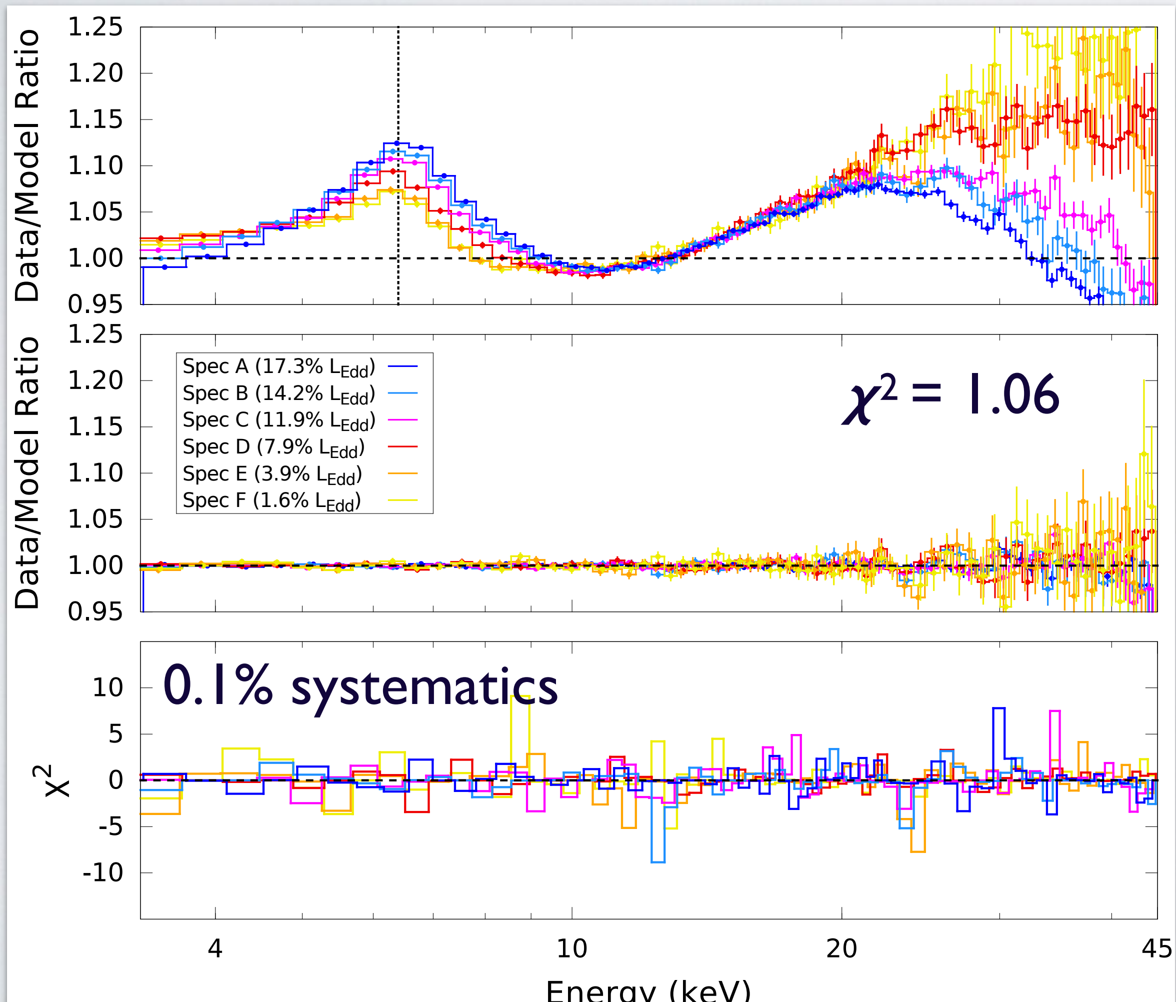
Ratio to a power-law model shows the signatures of reflection

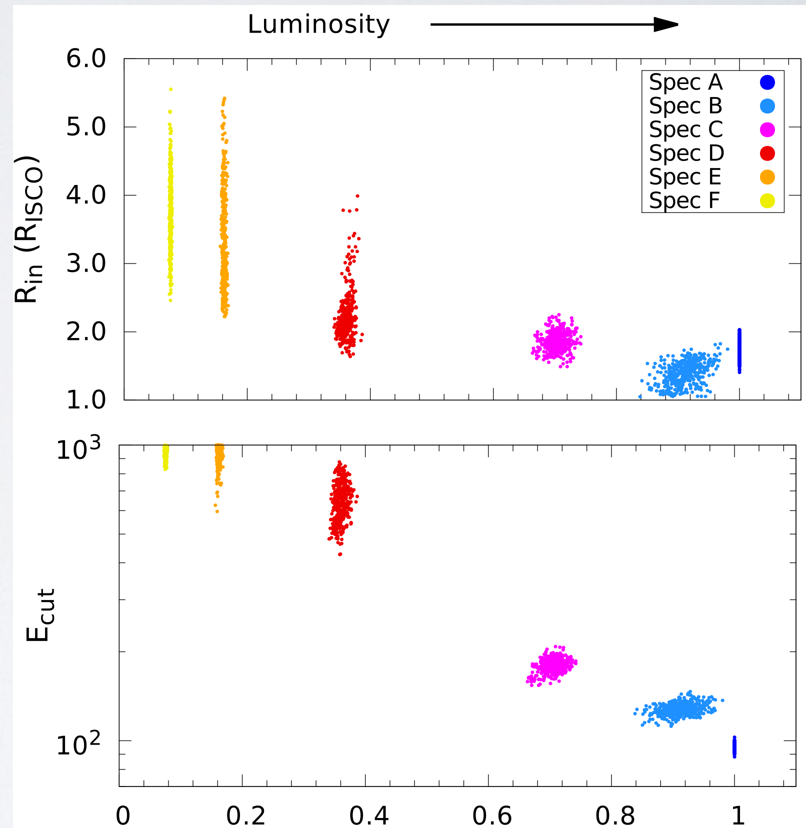


García et al. (2015)

Disk and Corona Evolution

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



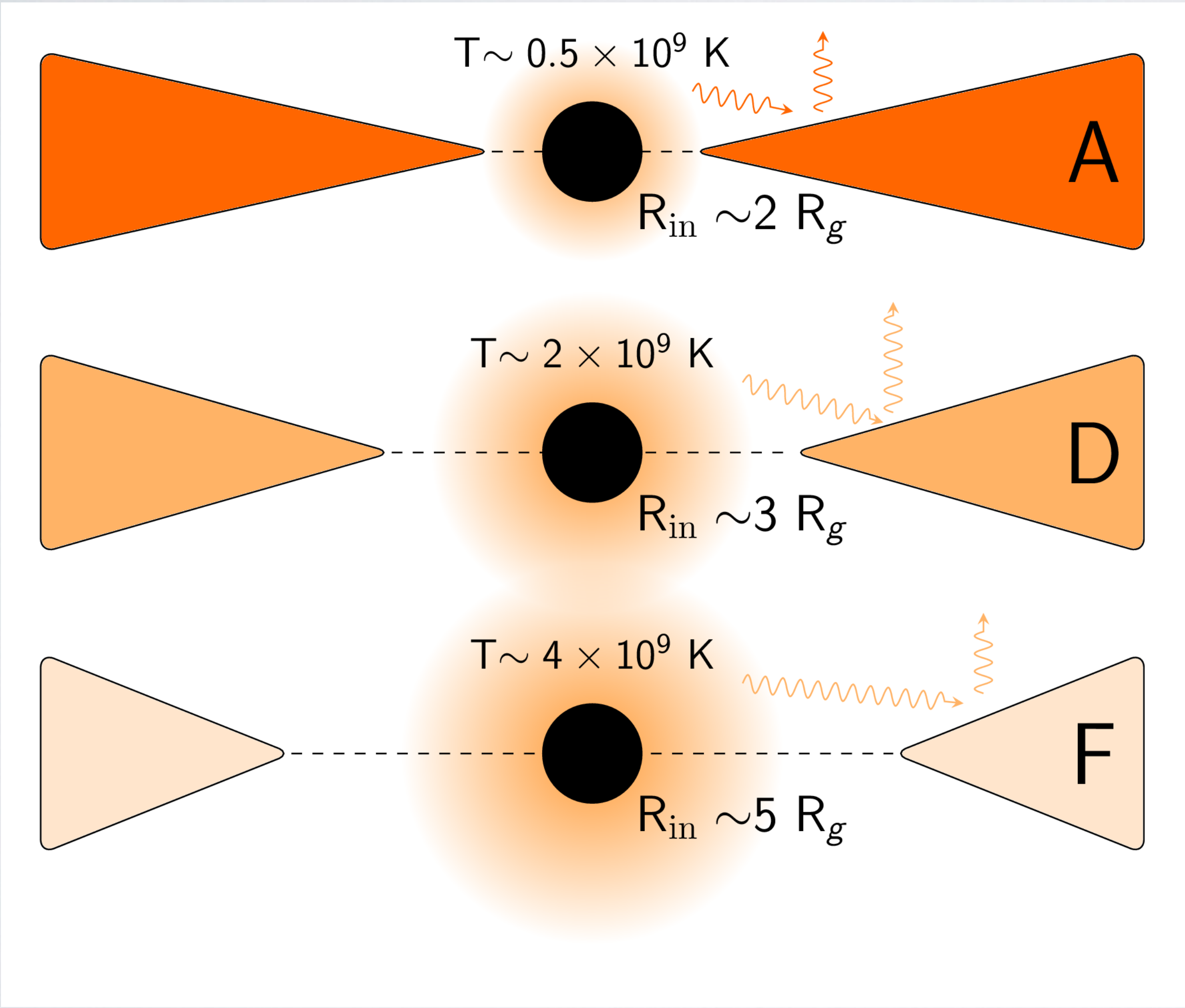


García et al. (2015)

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

GX 339-4: Detecting Geometrical Changes

These changes seem to be correlated…



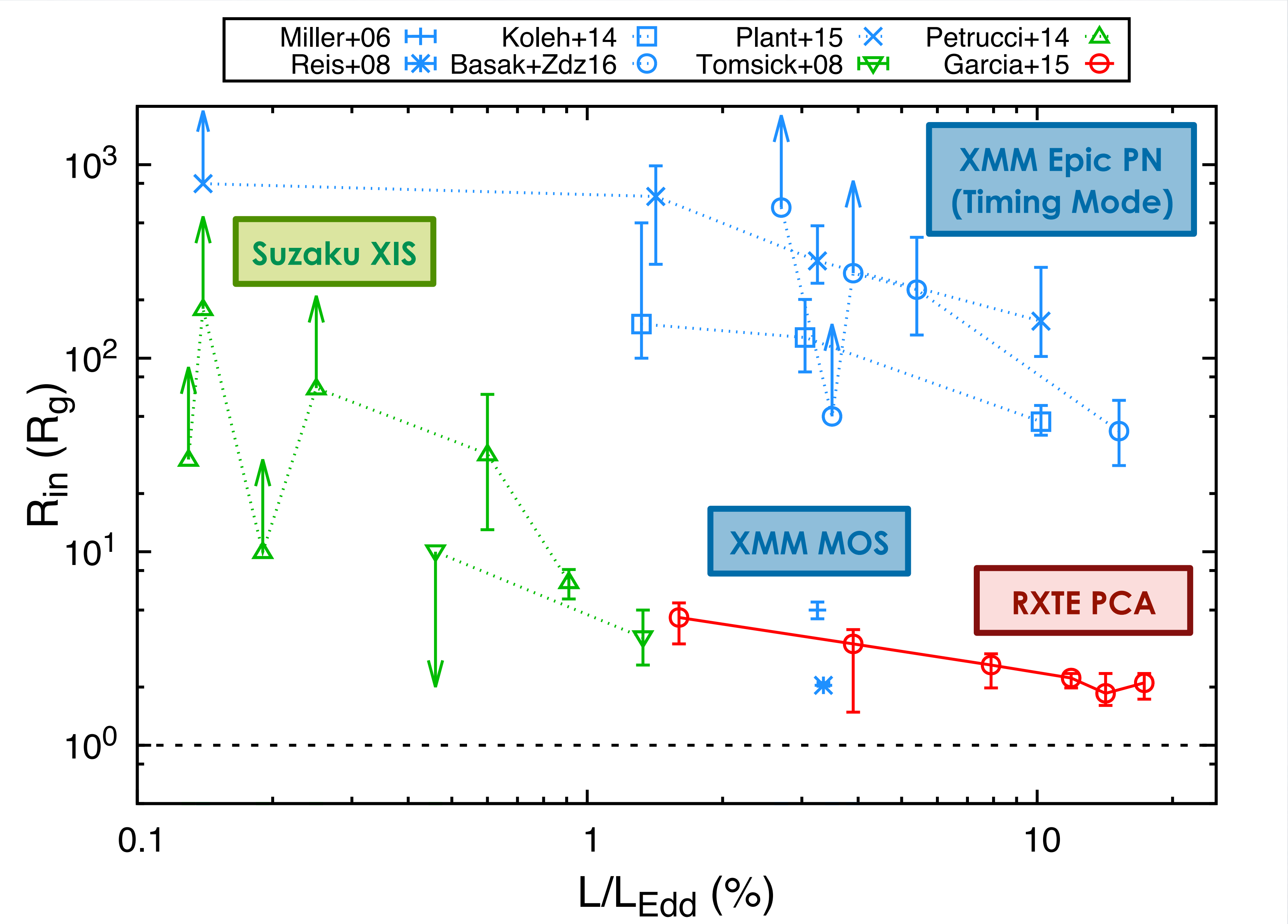
For increasing luminosity, the disk moves inward and the corona cools down.

For a 10 solar-mass BH, these changes correspond to a differential of ~45 km!

García et al. (2015)

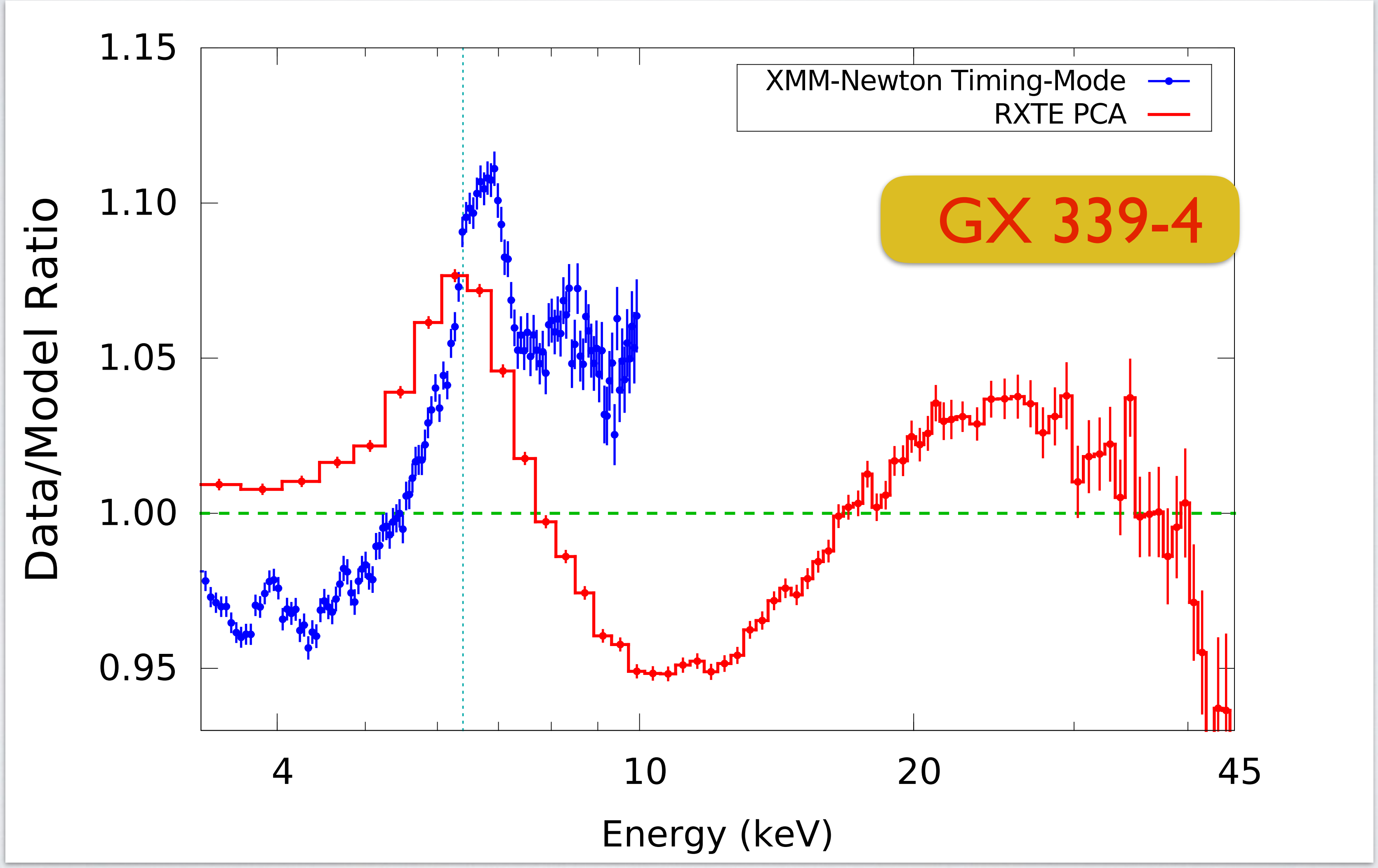
Controversy on the Disk Truncation

Large disagreement with other reflection spectroscopy results!



XMM Timing Mode vs. RXTE PCA

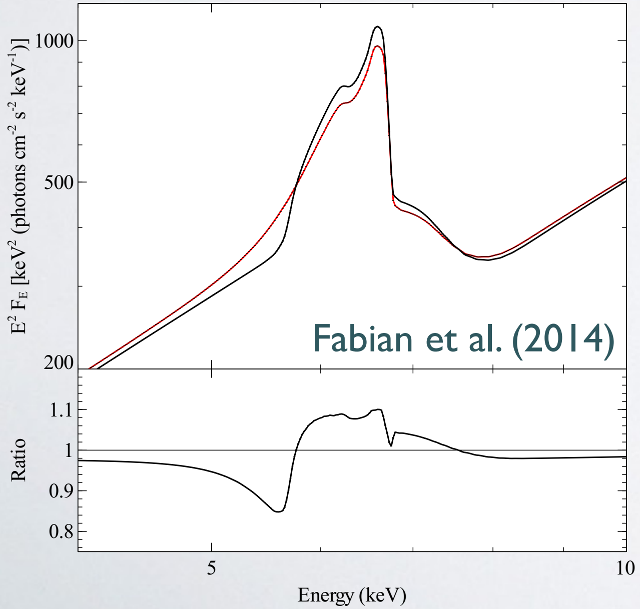
The XMM timing mode data shows a much narrower Fe K emission profile than the simultaneous RXTE data

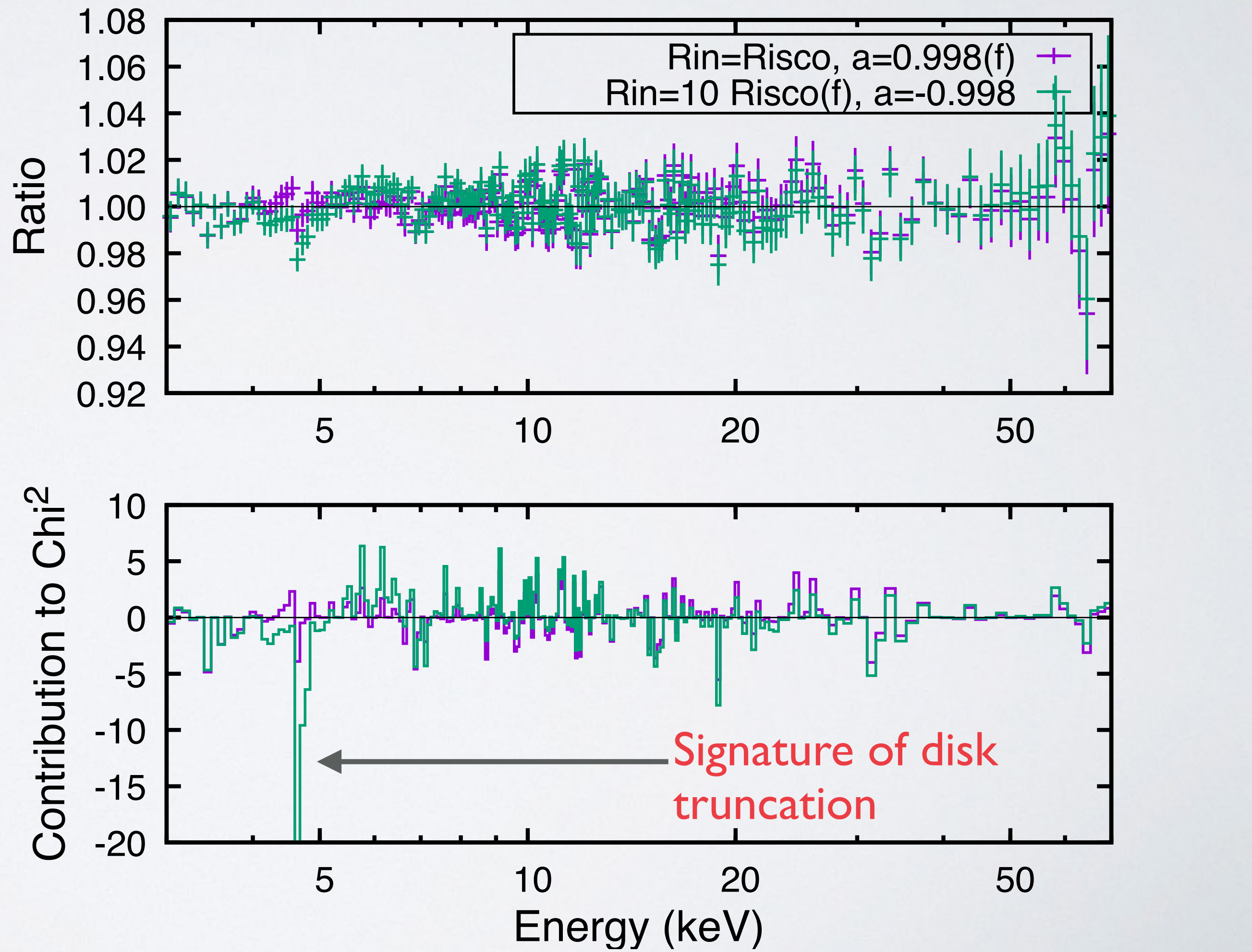


Possibly due to uncertain PSF in XMM Timing Mode?

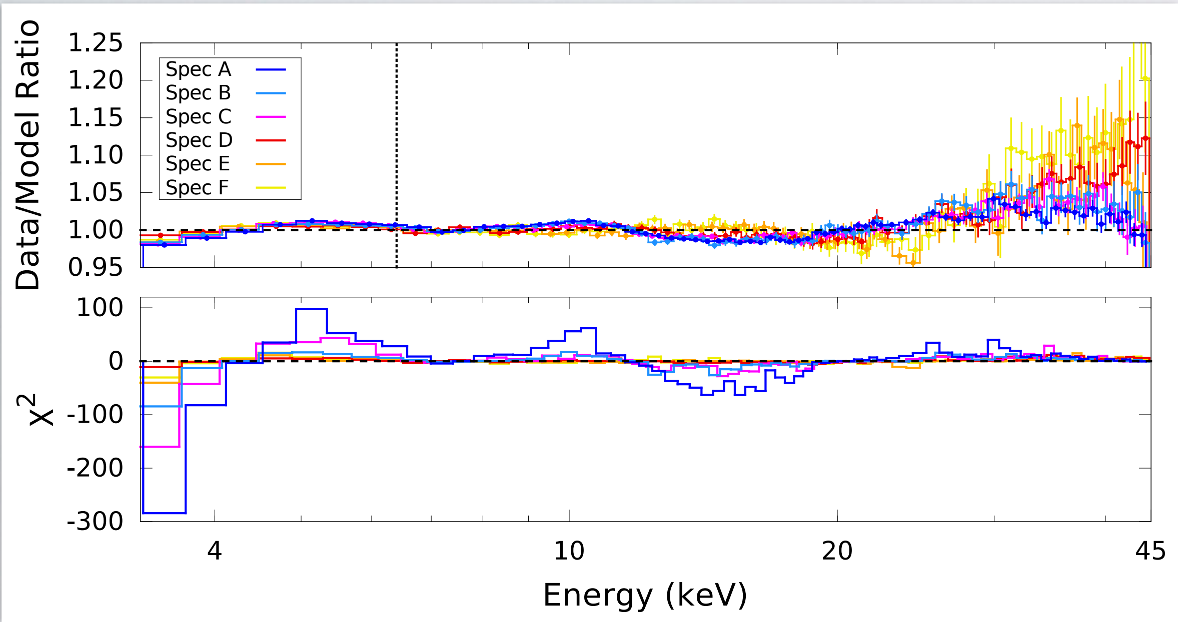
Spin and Inner Radius

- If the disk is truncated (Rin > Risco), then fitting with Rin=Risco will under predict the spin
- Conversely, if Rin is desired, fixing spin to max (a=0.998) will estimate largest possible truncation
- We can't measure both spin and Rin, can we?
- Typically very loose constraints

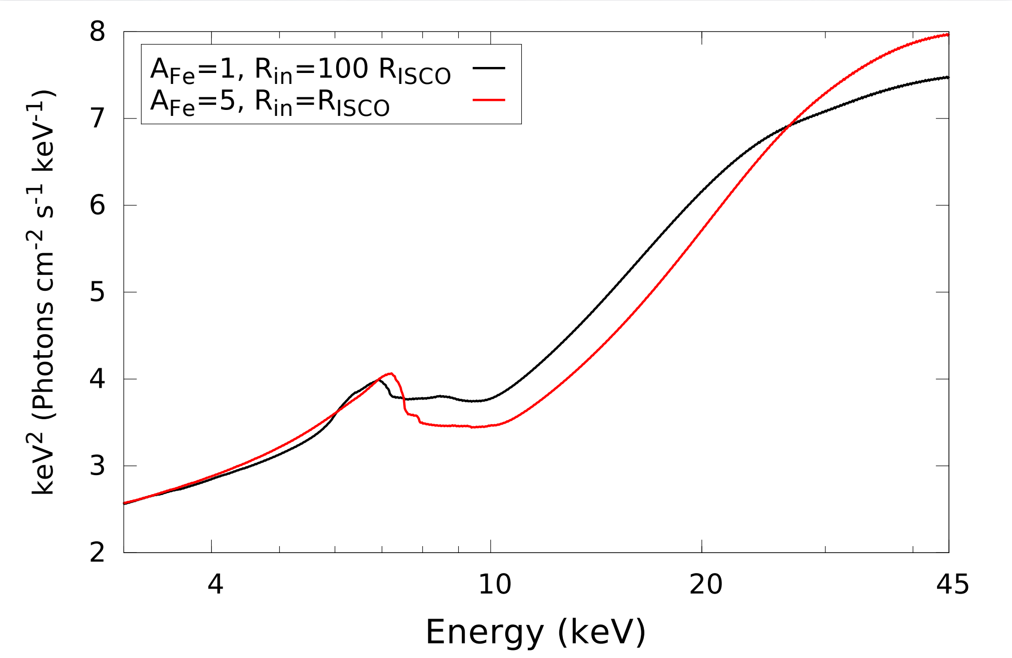




Connection between R_{in} and A_{Fe}



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

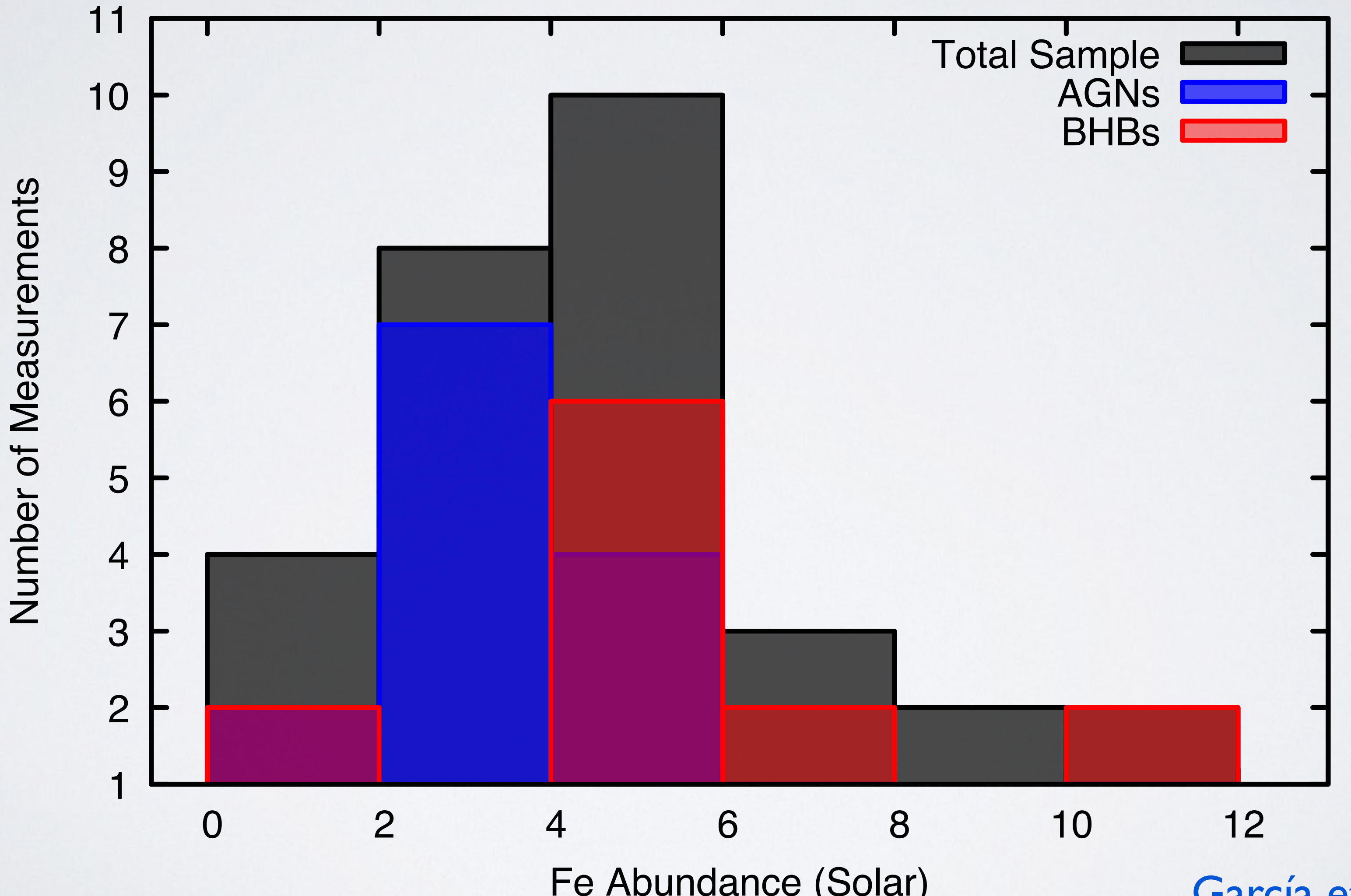


A truncated disk with Solar abundance produces an Fe K line similar to an over-abundant disk reaching the ISCO

García et al. (2015)

The Problem of the Fe Abundance

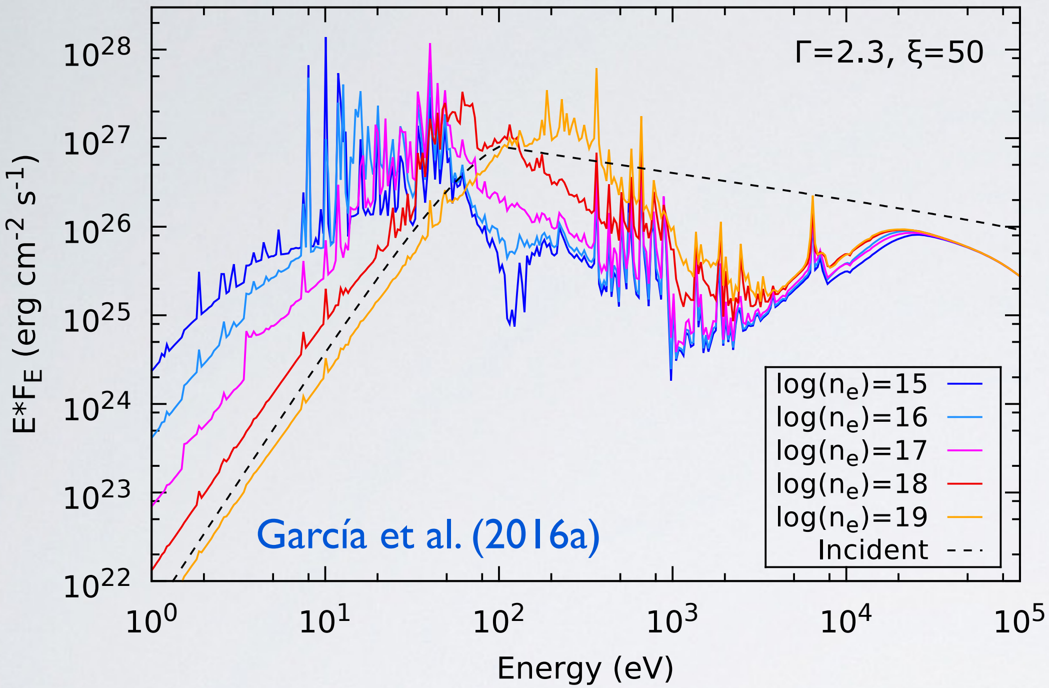
Iron abundance determinations using reflection spectroscopy from publications since 2014 tend to find a few times the Solar value! WTF? (Why The Fe?)



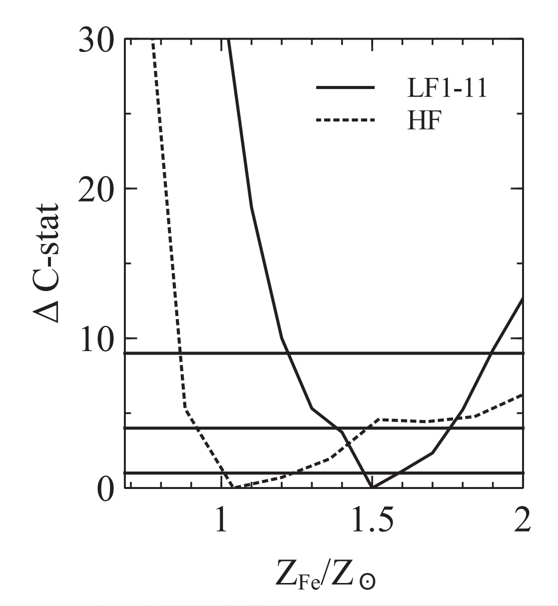
13 AGNs
9 BHBs

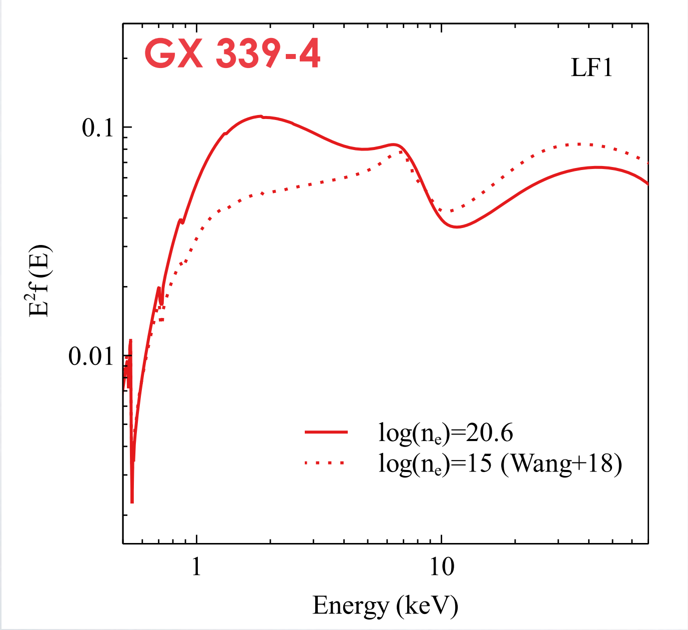
García et al. (2018)

Possible High-Density Effects

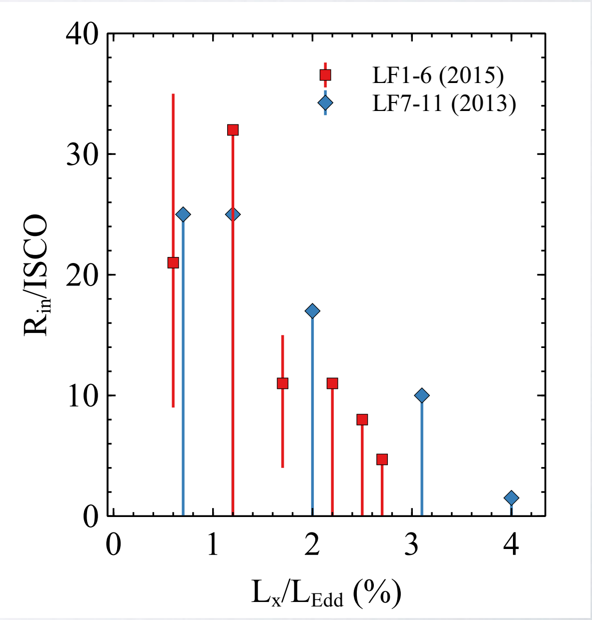


Fe abundance close to Solar value





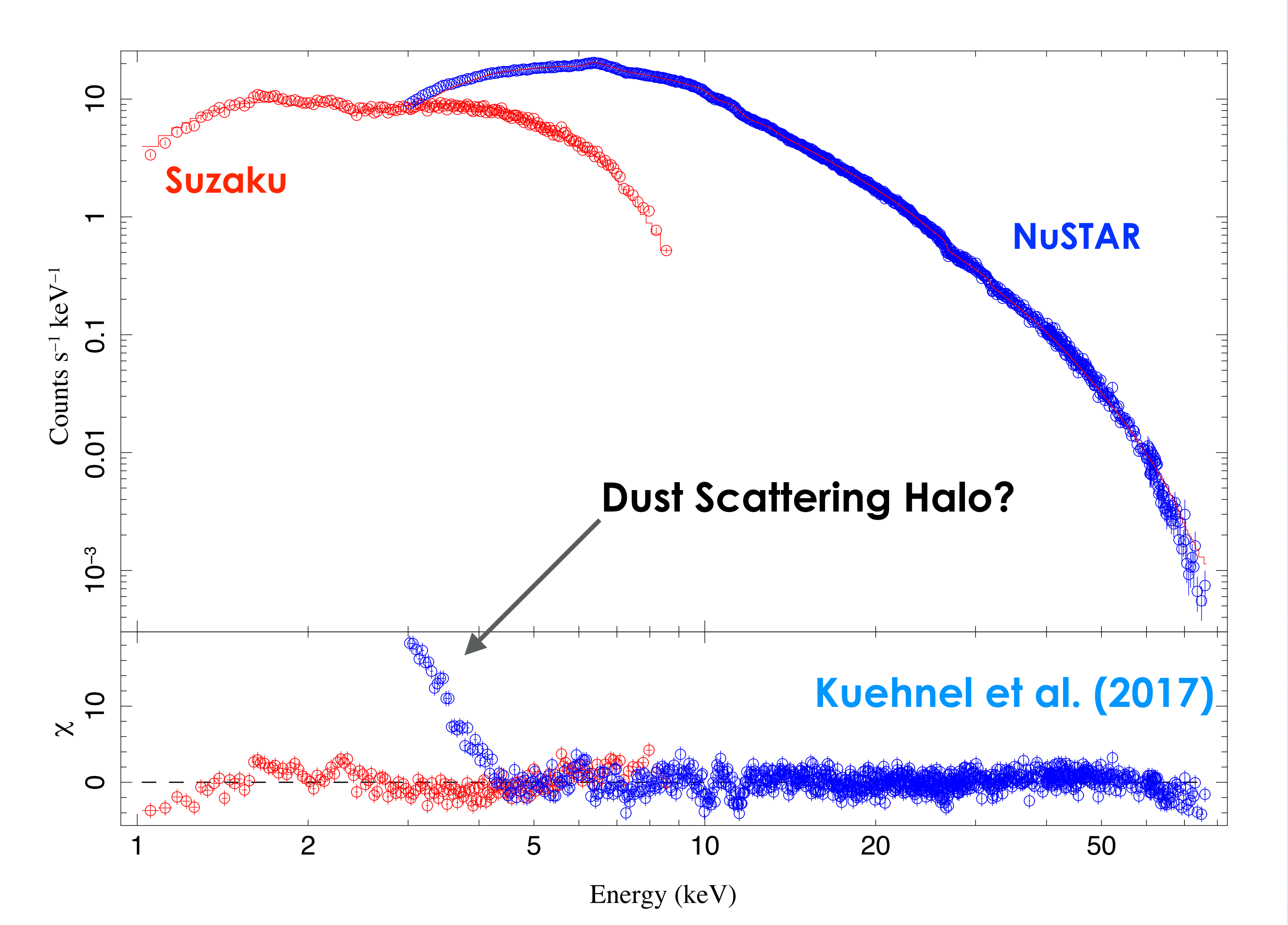
Inner radius mildly truncated (~1-30 Risco)



Jiang et al. (2019)

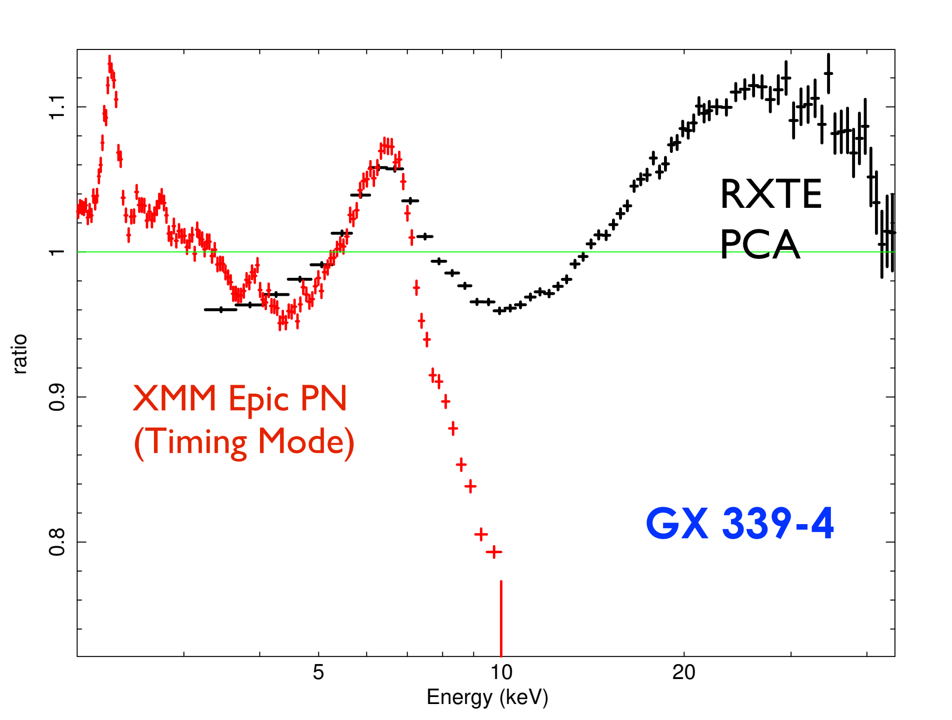
NuSTAR vs. Swift Below 5 keV

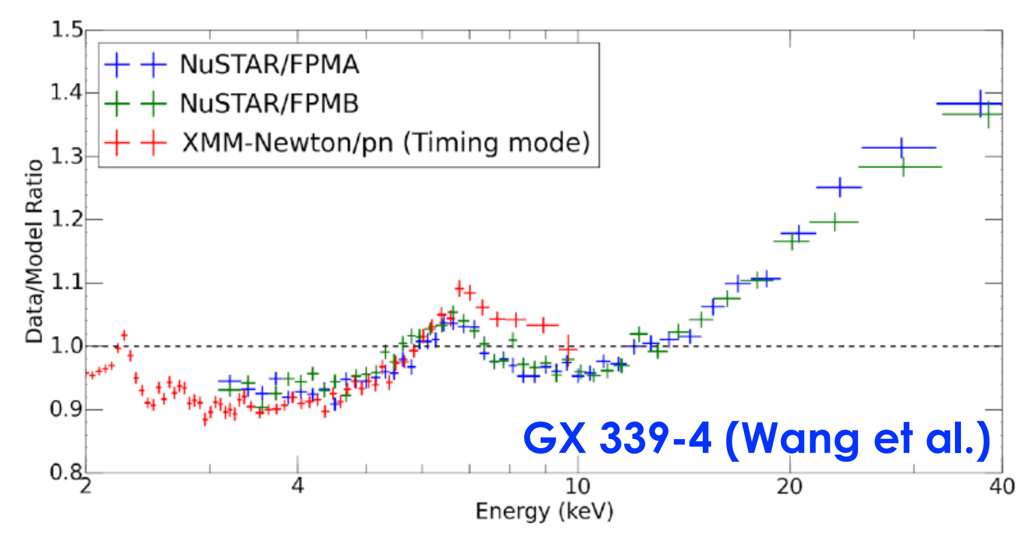
Be X-ray Binary GRO J1008-57



Line Shape and Continuum Slope

Is it dependent on the source's count rate?





XMM (TM) vs. RXTE

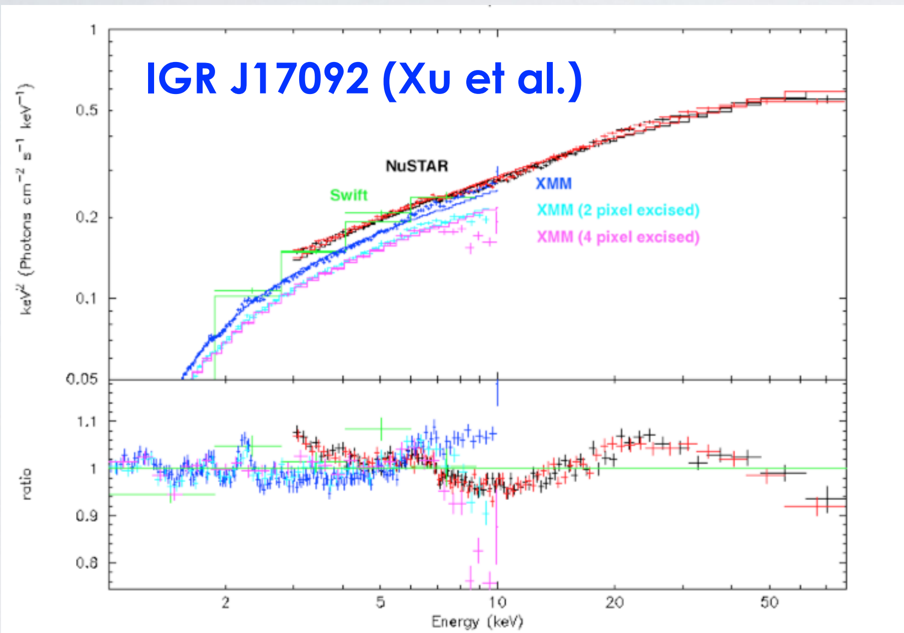
- 2009 Outburst: High count rate
- Very different Fe K line profile: XMM looks narrower

XMM (TM) vs. NuSTAR

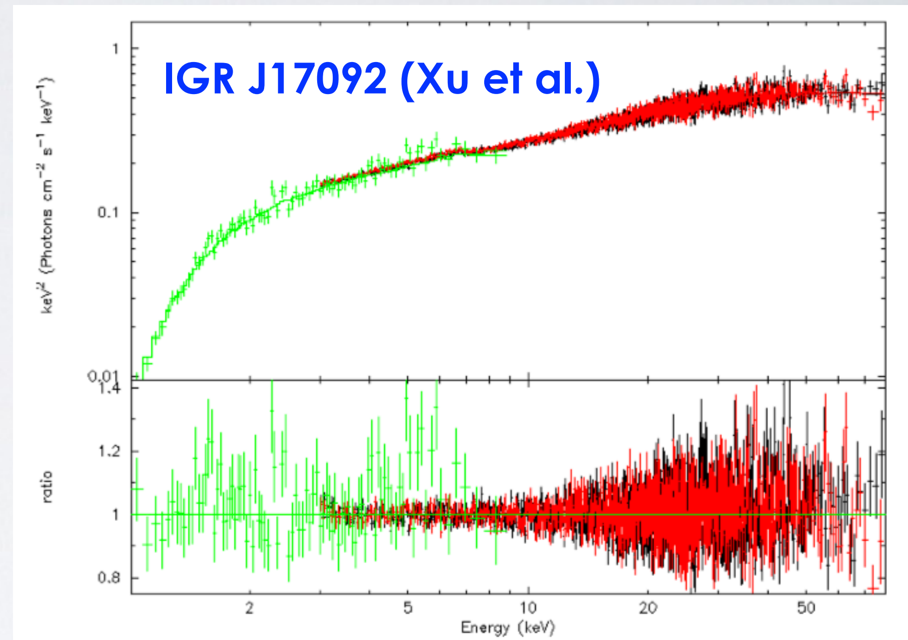
- 2015 Outburst: lower count rate
- Significantly different continuum slope
- But good agreement between NuSTAR and Swift XRT

Discrepancies in the Continuum Slope

XMM Epic PN (TM) vs NuSTAR



Swift XRT vs NuSTAR

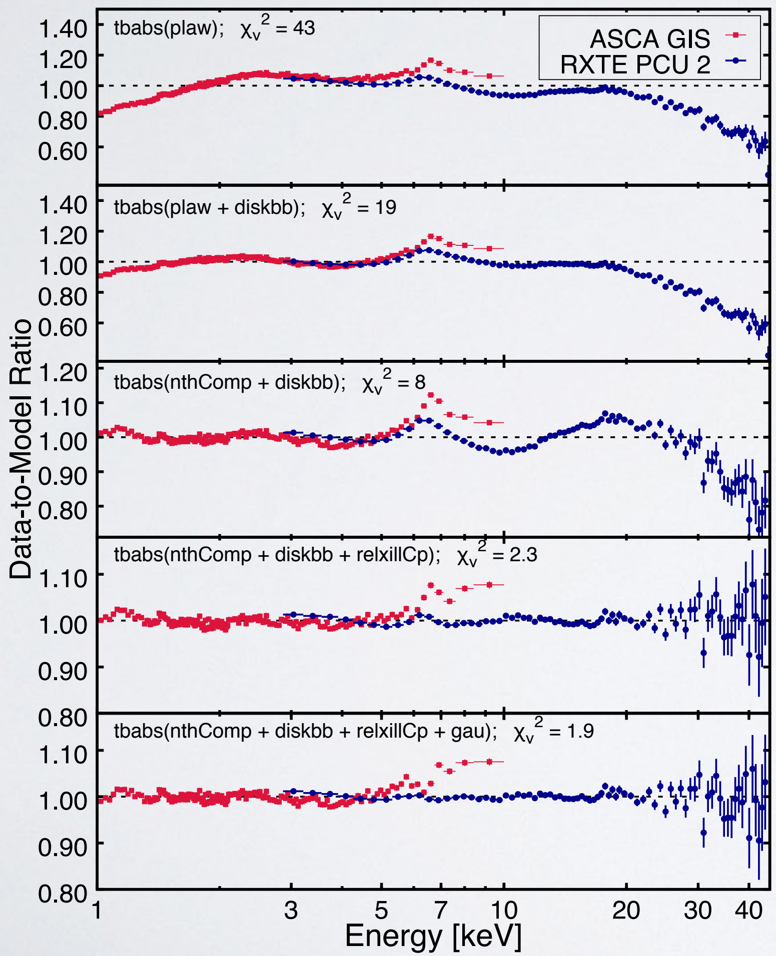


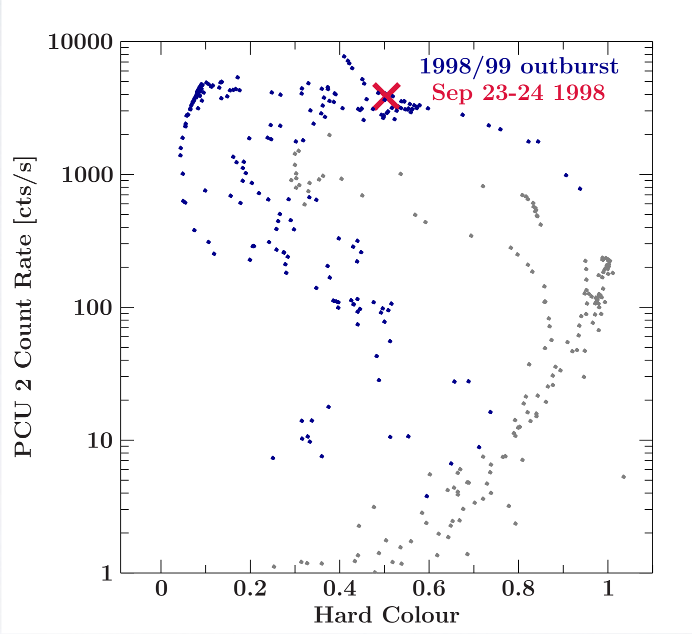
XMM-Newton Timing Mode vs. NuSTAR has the largest discrepancies (as opposed to Swift/XRT)

Discrepancies in the Continuum Slope

But other detectors also can show this problem…

XTE J1550-564

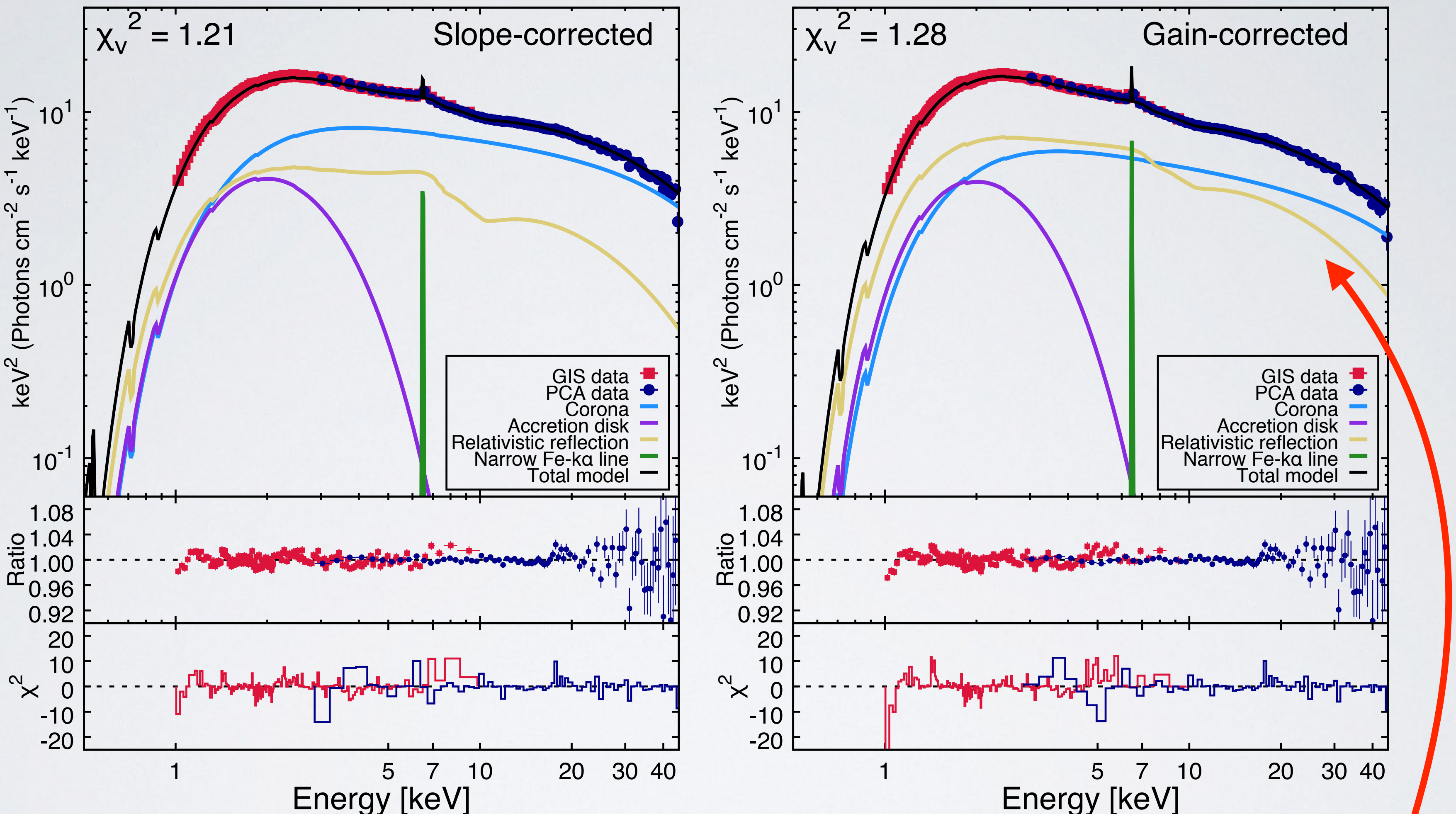




- Very bright outburst ~0.5 Crab (Sep 1998).
- Strong discrepancy in the continuum slope between ASCA/GIS and RXTE/PCA ($\Delta\Gamma \sim 0.1$)

(Connors et al., in prep.)

ASCA vs. RXTE Discrepancies

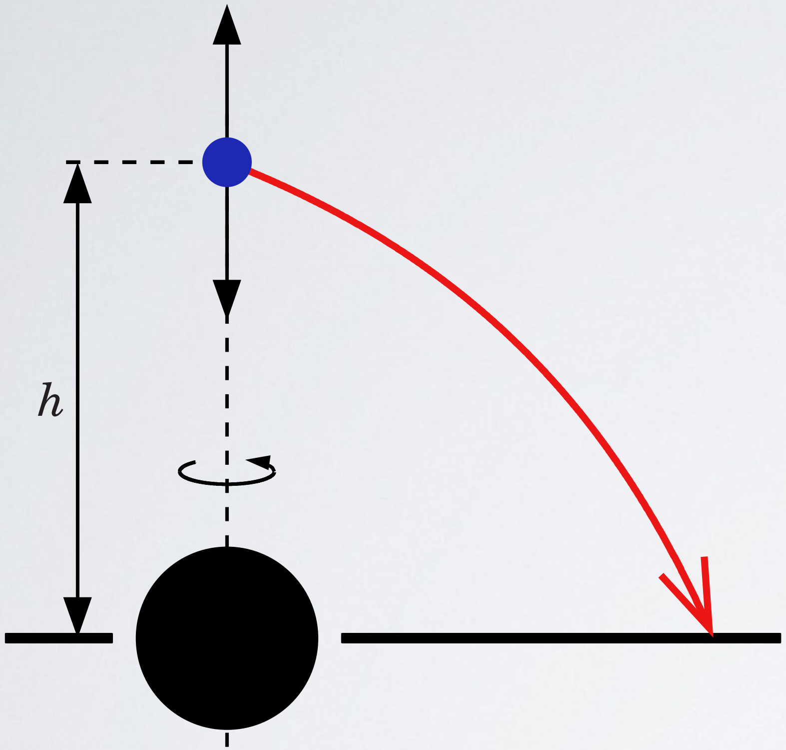


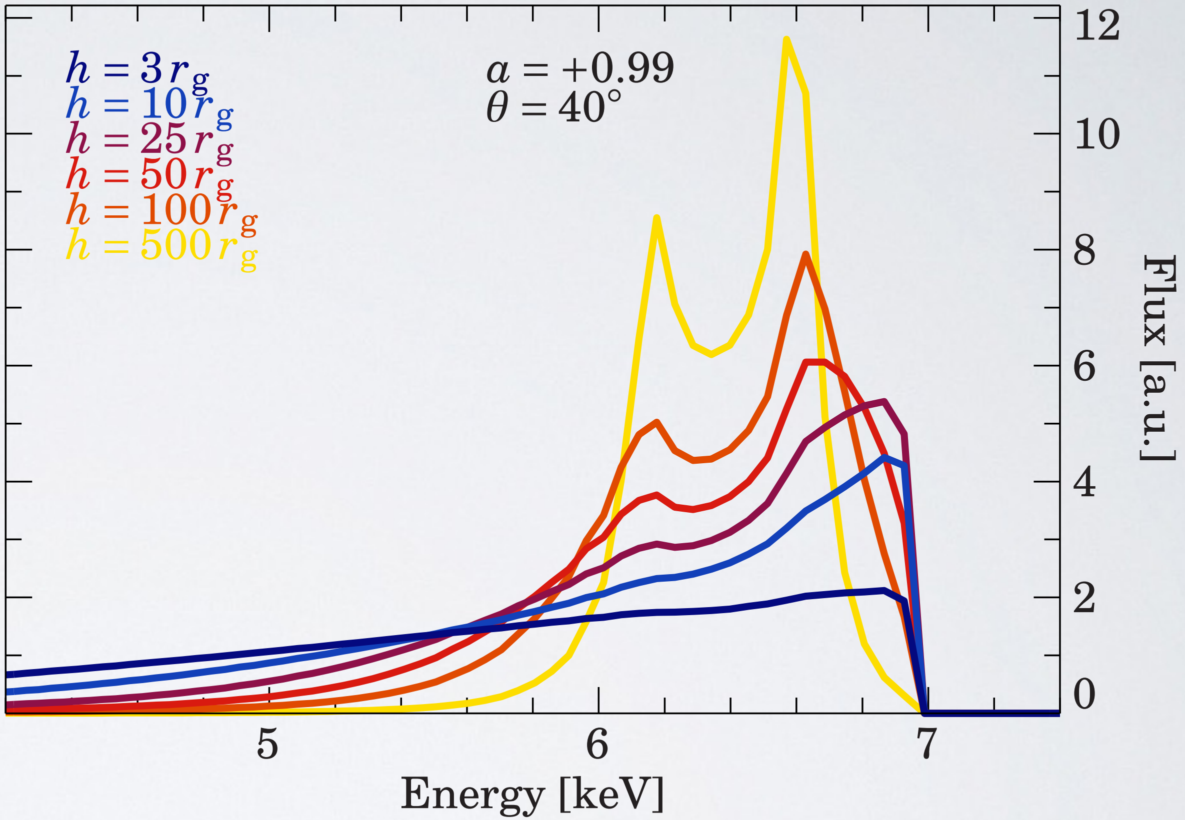
Large differences in the predicted Reflection Fraction:

Which detector is right/wrong? Are they both wrong???

(Connors et al., in prep.)

RELXILL: Lamppost Geometry



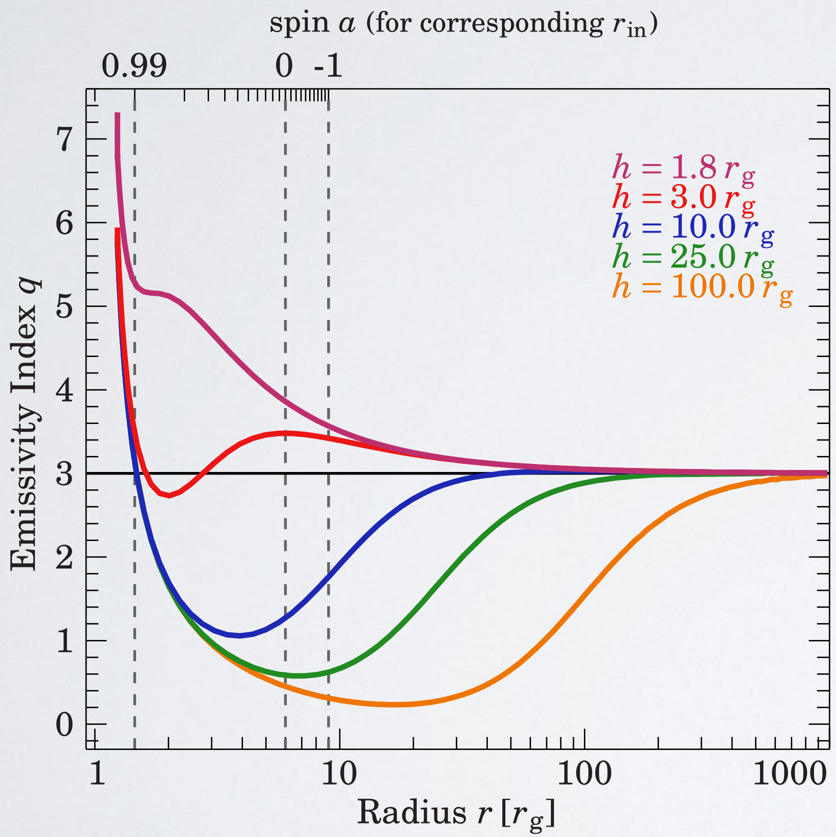


Probe geometry and location of the primary source

Low height implies enhanced irradiation of the inner regions

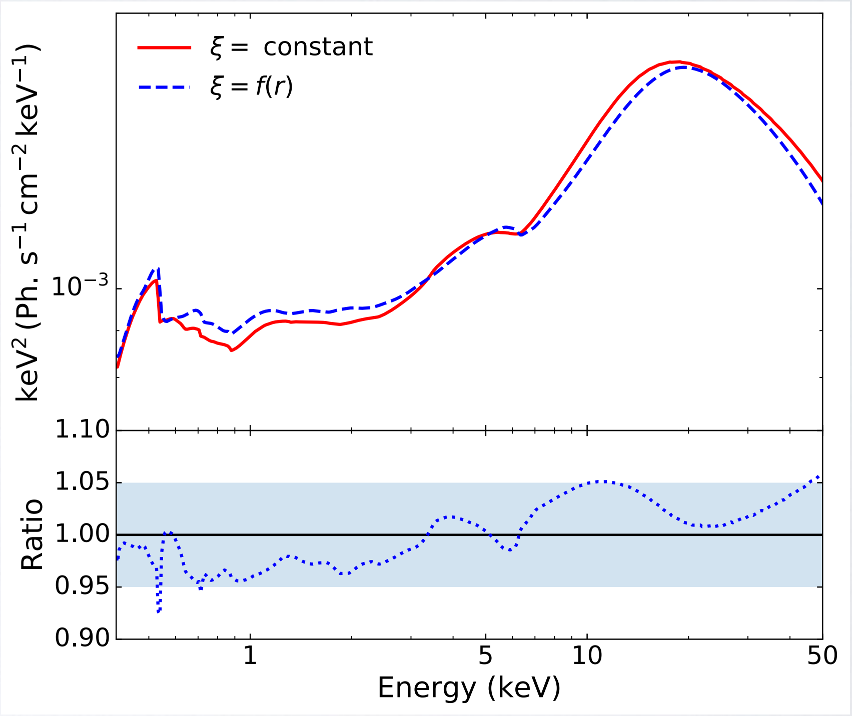
RELXILL: Emissivity Profile

Large reflection fraction predicted by the lamppost model, for low heights…



Wilkins & Fabian (2012)
Dauser et al. (2013)

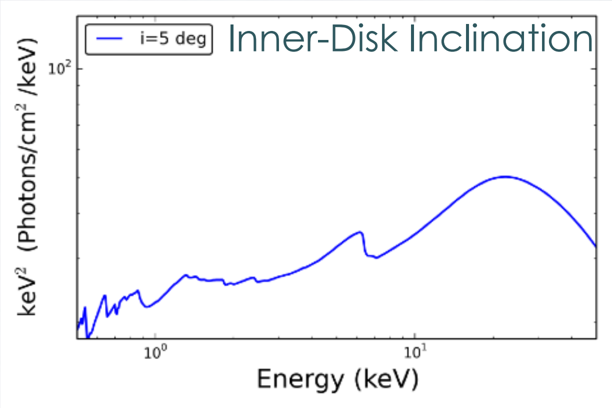
…But also if ionization gradients in the disk are considered.



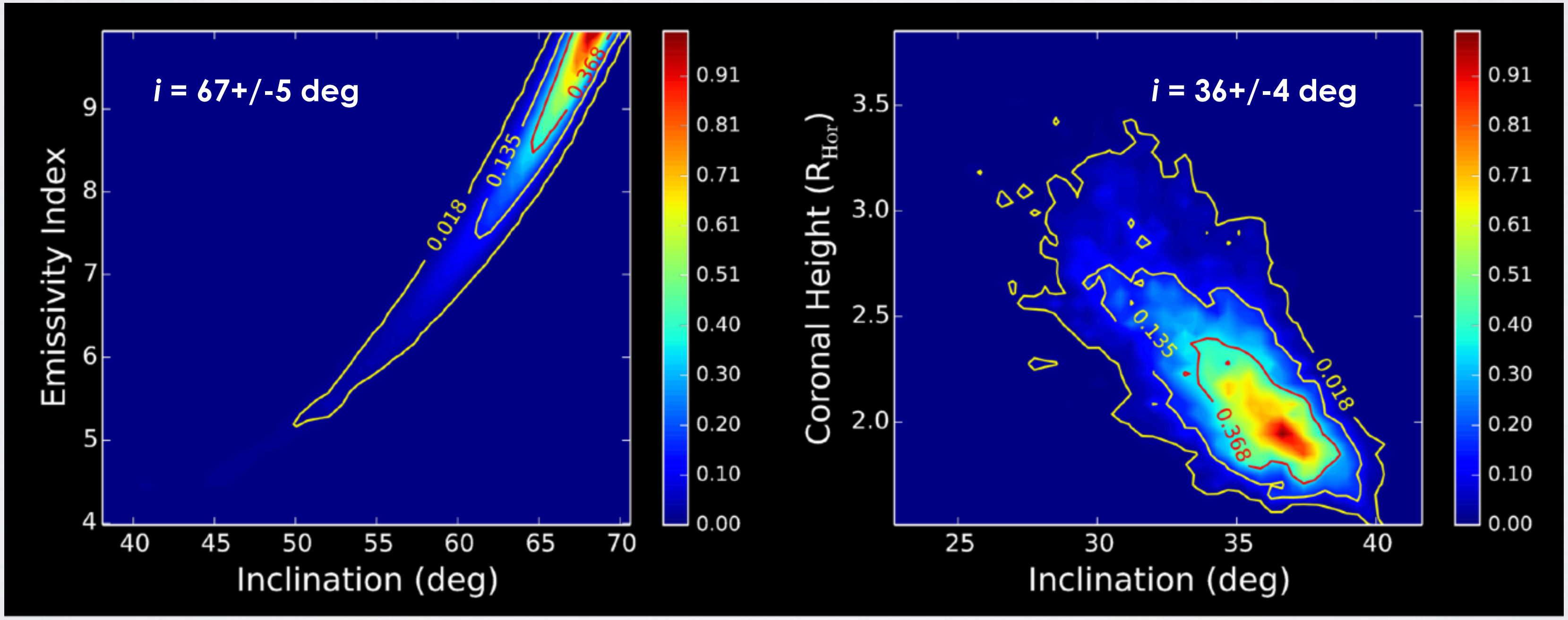
Svoboda et al. (2012)
Kammoun et al. (2019)

Emissivity Profile on XTE J1752-223

Reflection Spectroscopy of XTE J1752—223:
Highest signal-to-noise reflection spectrum to date (S/N ~ 3000)
****Update: MAXI J1820+70****



Power-law Emissivity **Lamppost Geometry**



Inclination from the lamppost model consistent with radio jet determinations of ***i* < 49 deg** (Miller-Jones et al. 2011).

García et al. (2018b)

Conclusions

- The state-of-the-art atomic data and reflection modeling are allowing us to impose tight constraints on important parameters such as spin, inclination, and Fe abundance (among other important parameters).

- Biggest calibration issues for reflection spectroscopy are:

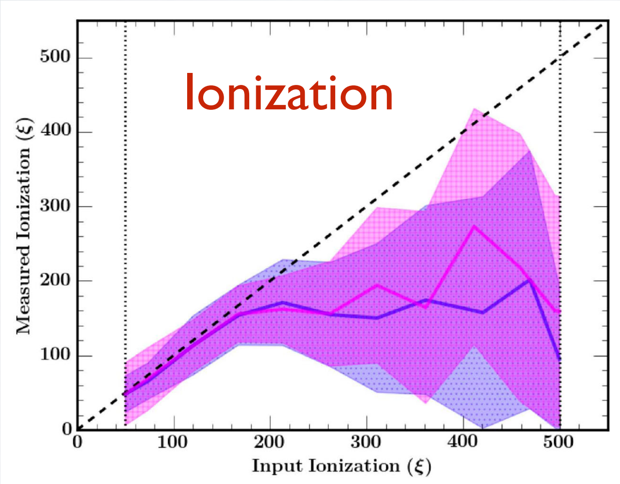
  - (i) Discrepancies in the shape of the Fe K emission complex (e.g. XMM TM)
  - (ii) Discrepancies in the slope of the continuum (e.g., XMM, NuSTAR, XRT,..)
  - (iii) Uncertainties in the spectral shape at low energies (i.e., NuSTAR low energy tail?)

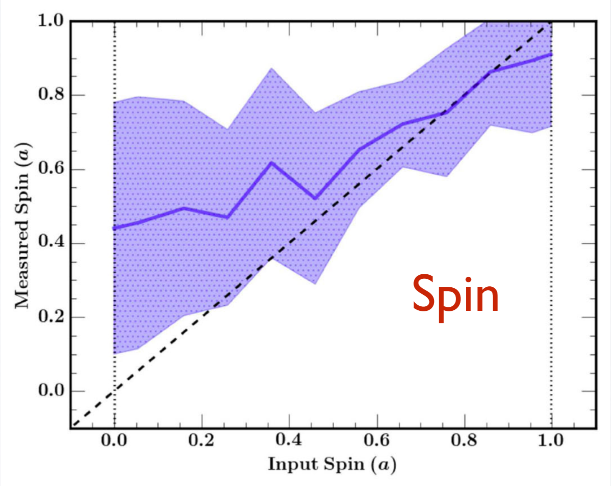
- Requirements in slope calibration depend on S/N. Ideally, we wish **$\Delta\Gamma$**<0.01 (or whatever it is for FPMA/FPMB), and systematics ~0.01 %

- Flux calibration between instruments is relatively unimportant.

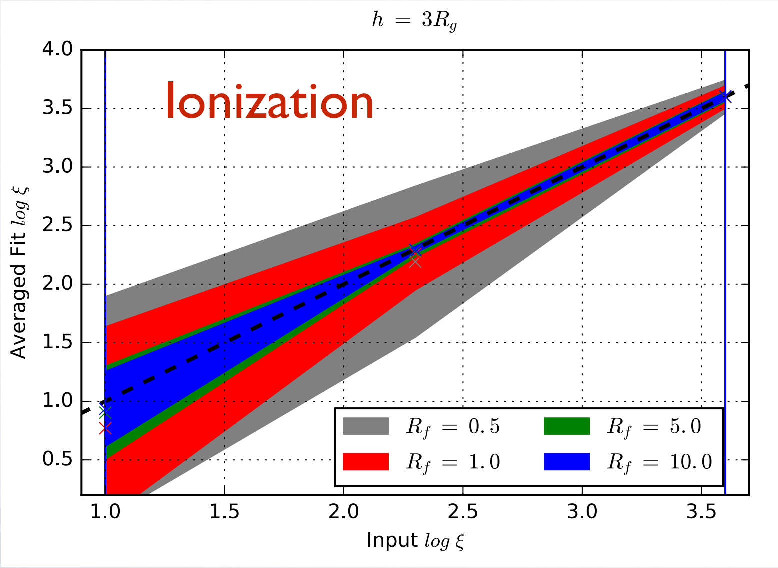
Understanding the Model Systematics

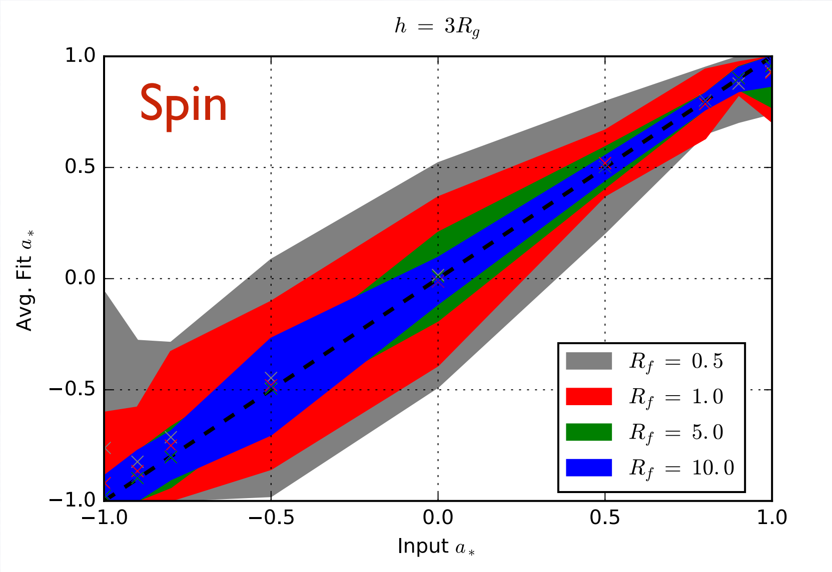
Bonson & Gallo (2016): Relatively large uncertainties in recovering fundamental parameters





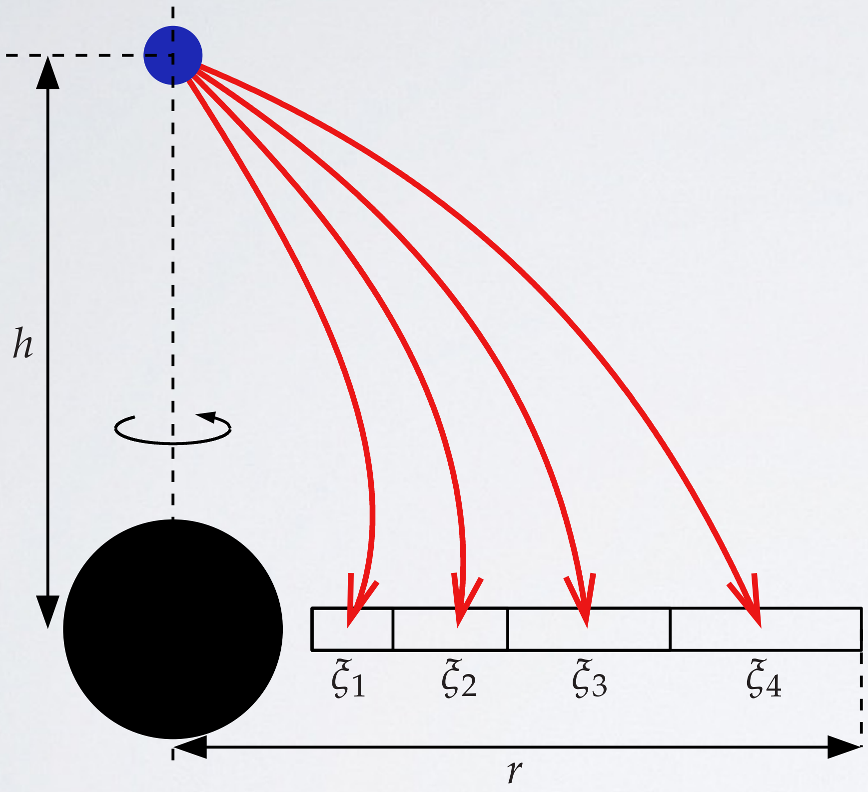
Choudhury et al. (2017): Uncertainties are highly dependent on the initial values, proper spectral binning, and minimization methods!

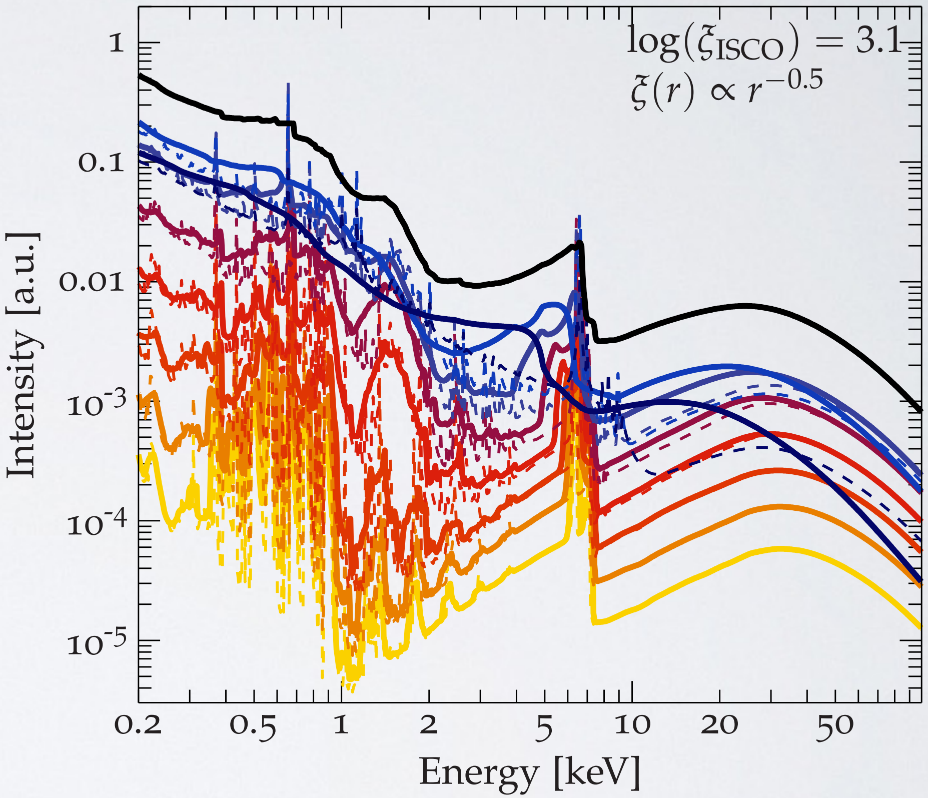




RELXILL: Radial Ionization Gradients

If the lamppost model is accepted, we must then consider the possibility of large ionization gradients in the radial direction.

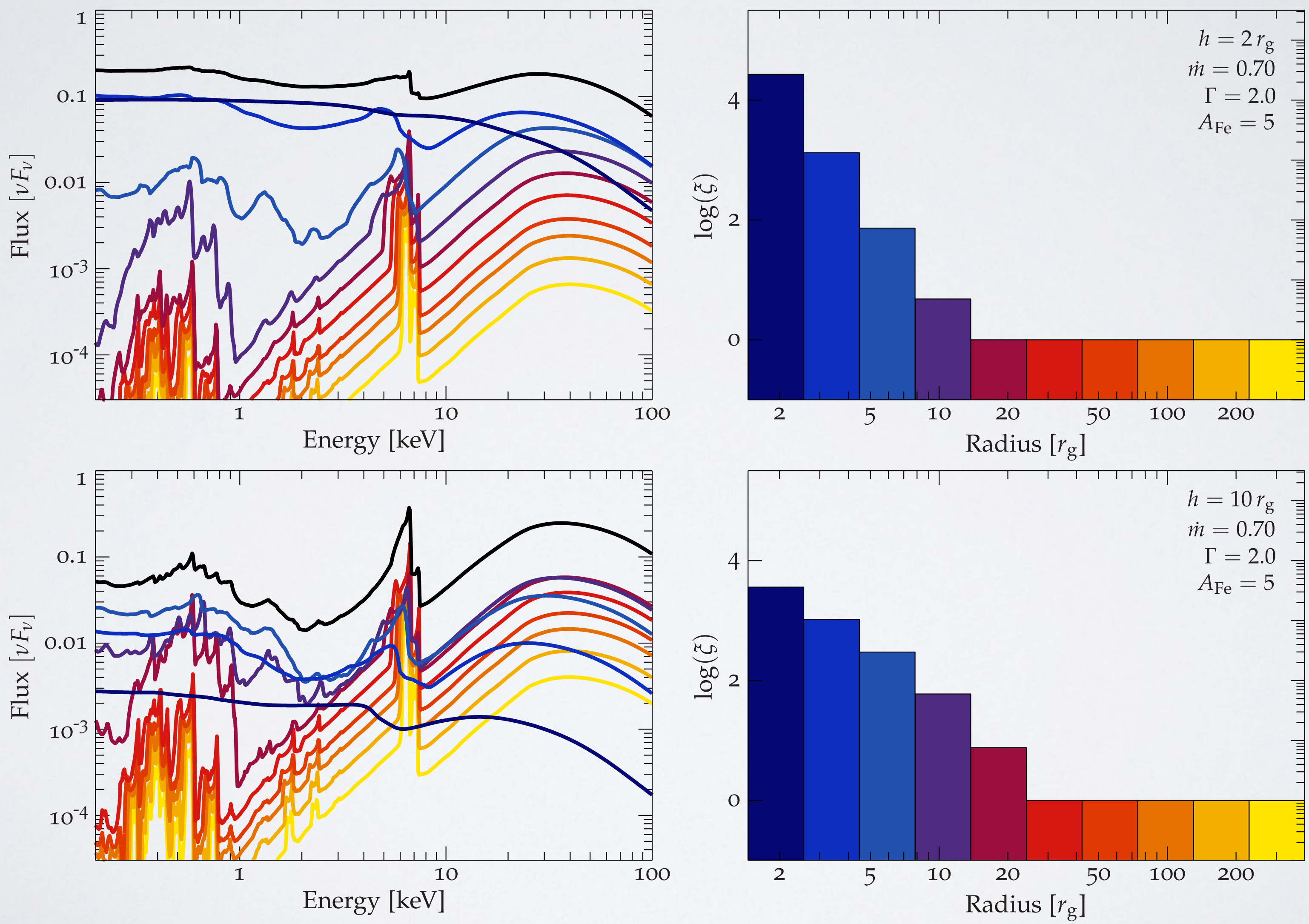




The profile of the gradient will depend not only on the illumination (prescribed by the lamppost) but also on the density profile, which is not well known.

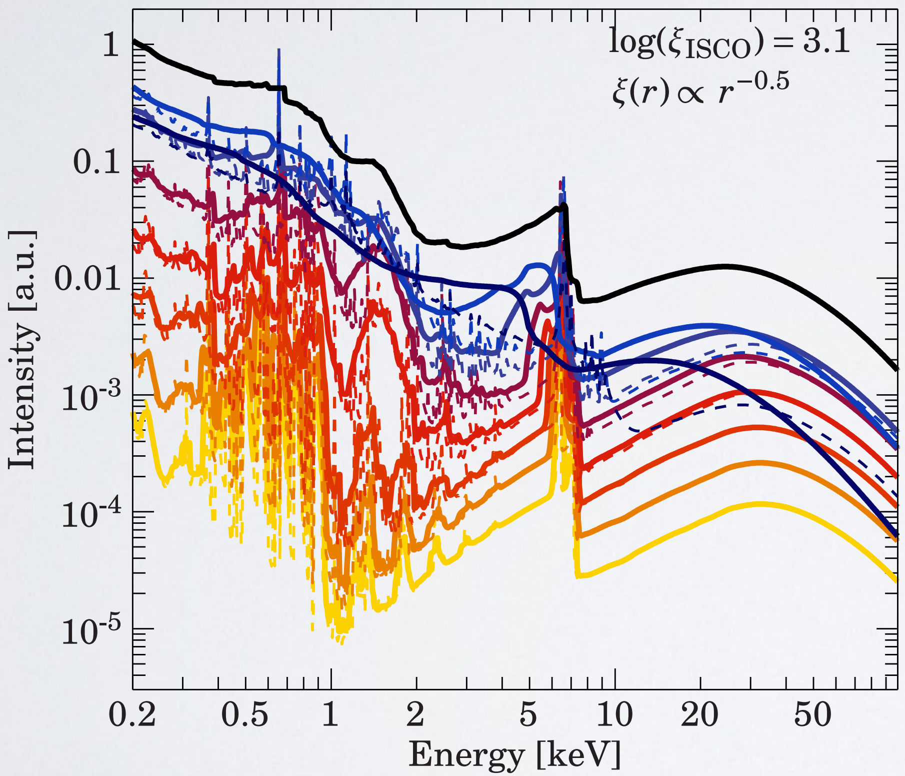
RELXILL: Radial Ionization Gradients

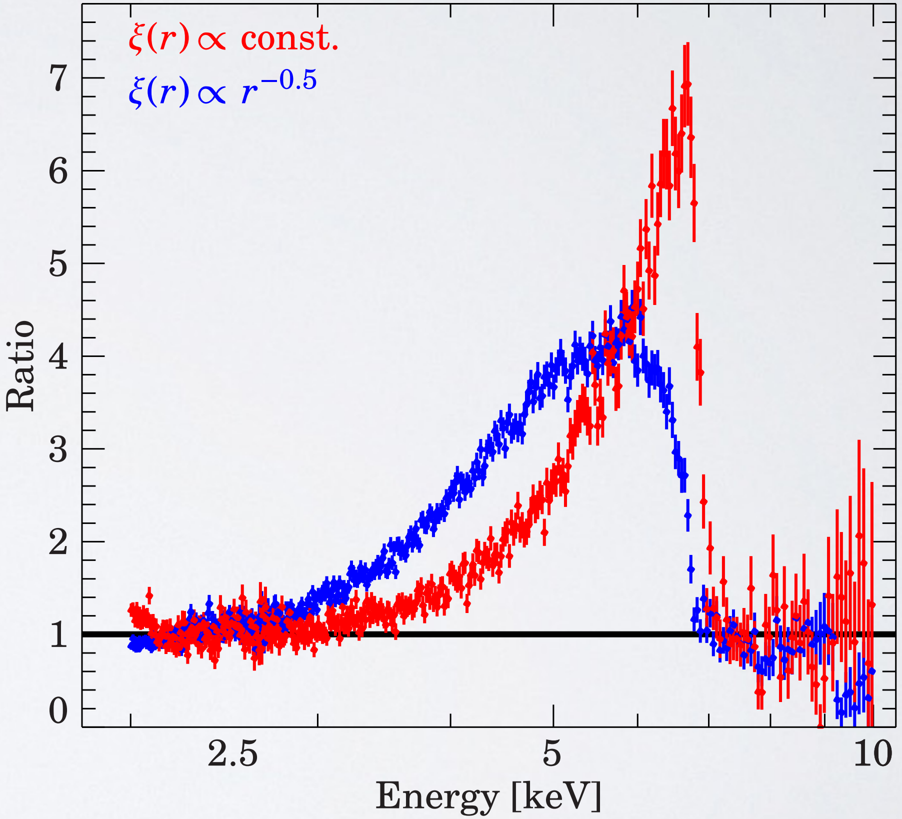
A much more complex Fe K emission profile is expected —> Soft energies are also affected



RELXILL: Radial Ionization Gradients

But so far, no real observations have been fitted with this model (relxill_ion). It appears that most sources agree with a single ionization zone, which points to a very concentrated and focused illumination —> Extreme cases are the brightest!





Future Reflections

- High sensitivity and low background at hard energies are crucial to observe reflection. NuSTAR is our best resource, but HEX-P will do a lot better!