Disk-Corona Evolution from the Point of View of Reflection

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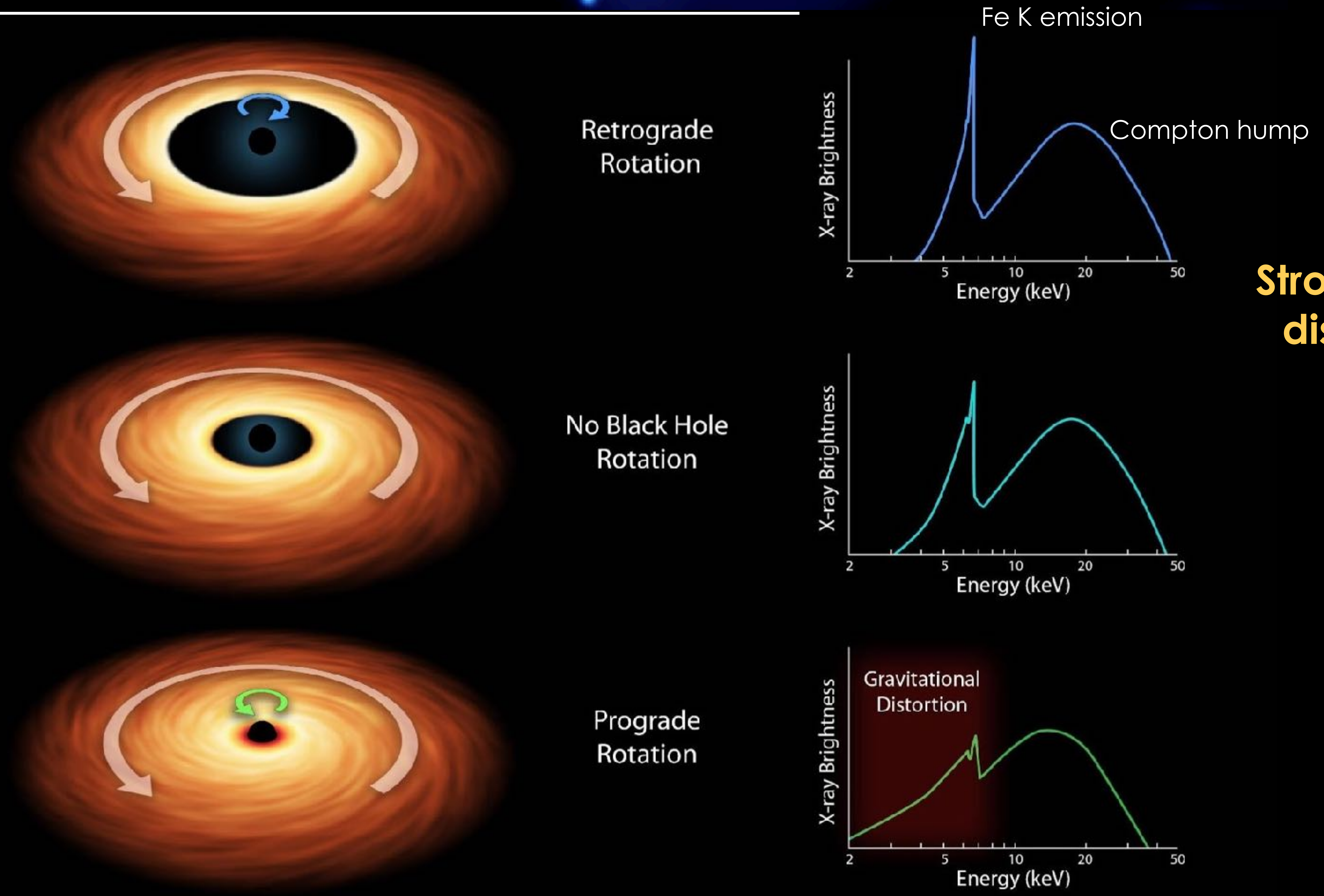
+ Many others

ISSI Workshop "Sombreros and lampposts: The Geometry of Accretion onto Black Holes"
Bern, January 15, 2020

Relativistic Reflection

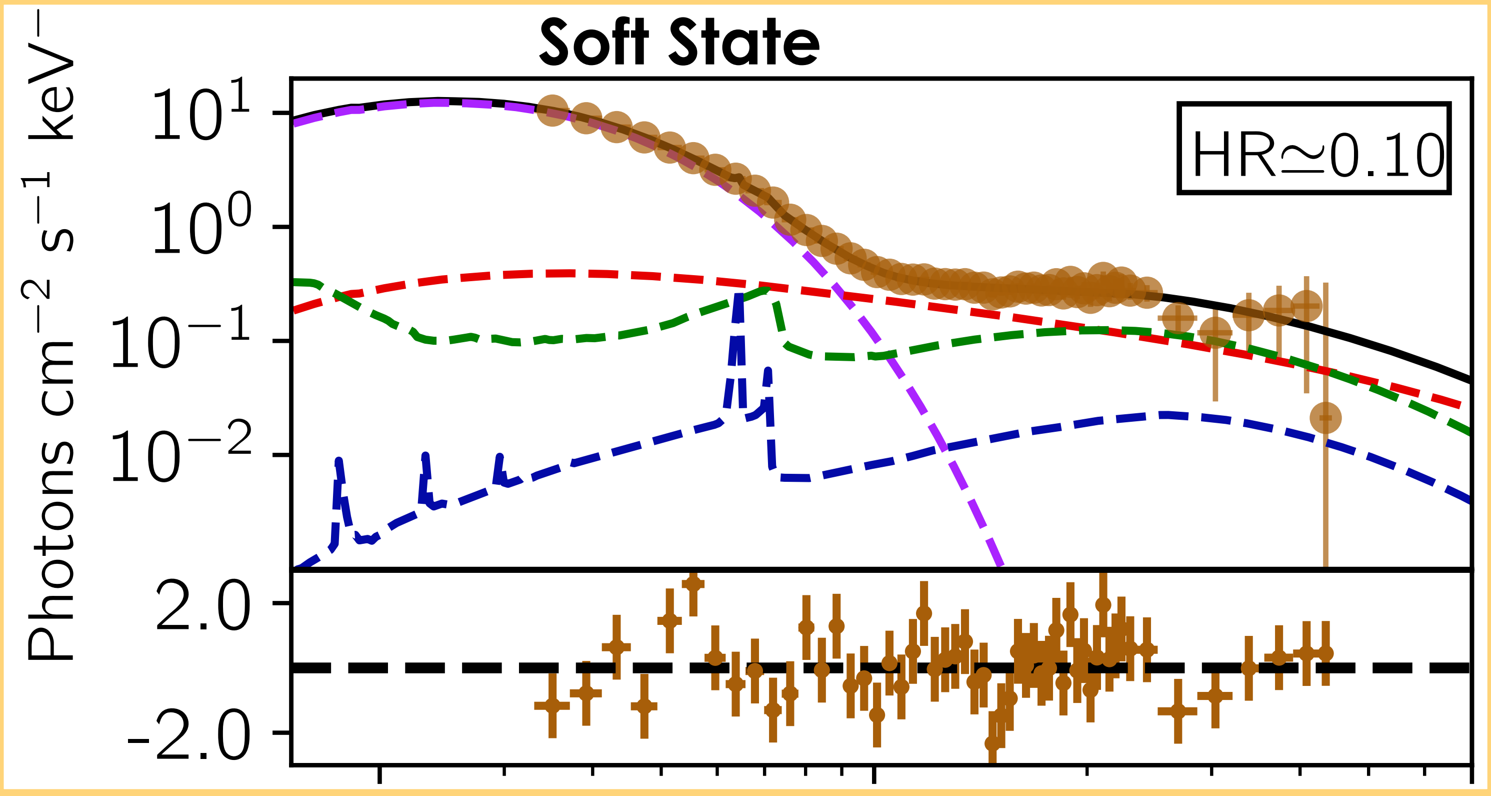
Relativistic Effects

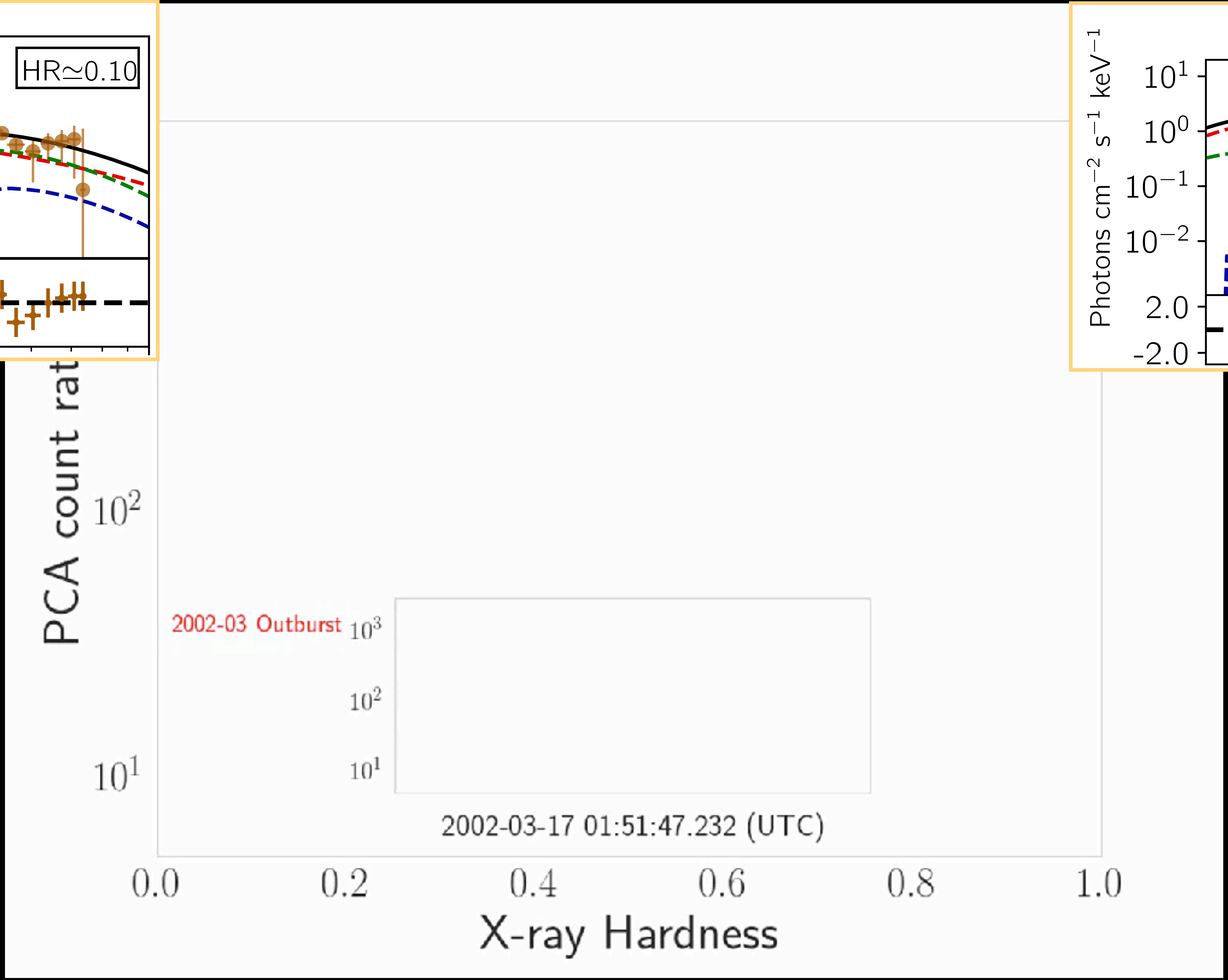
Inner disk closer to the BH

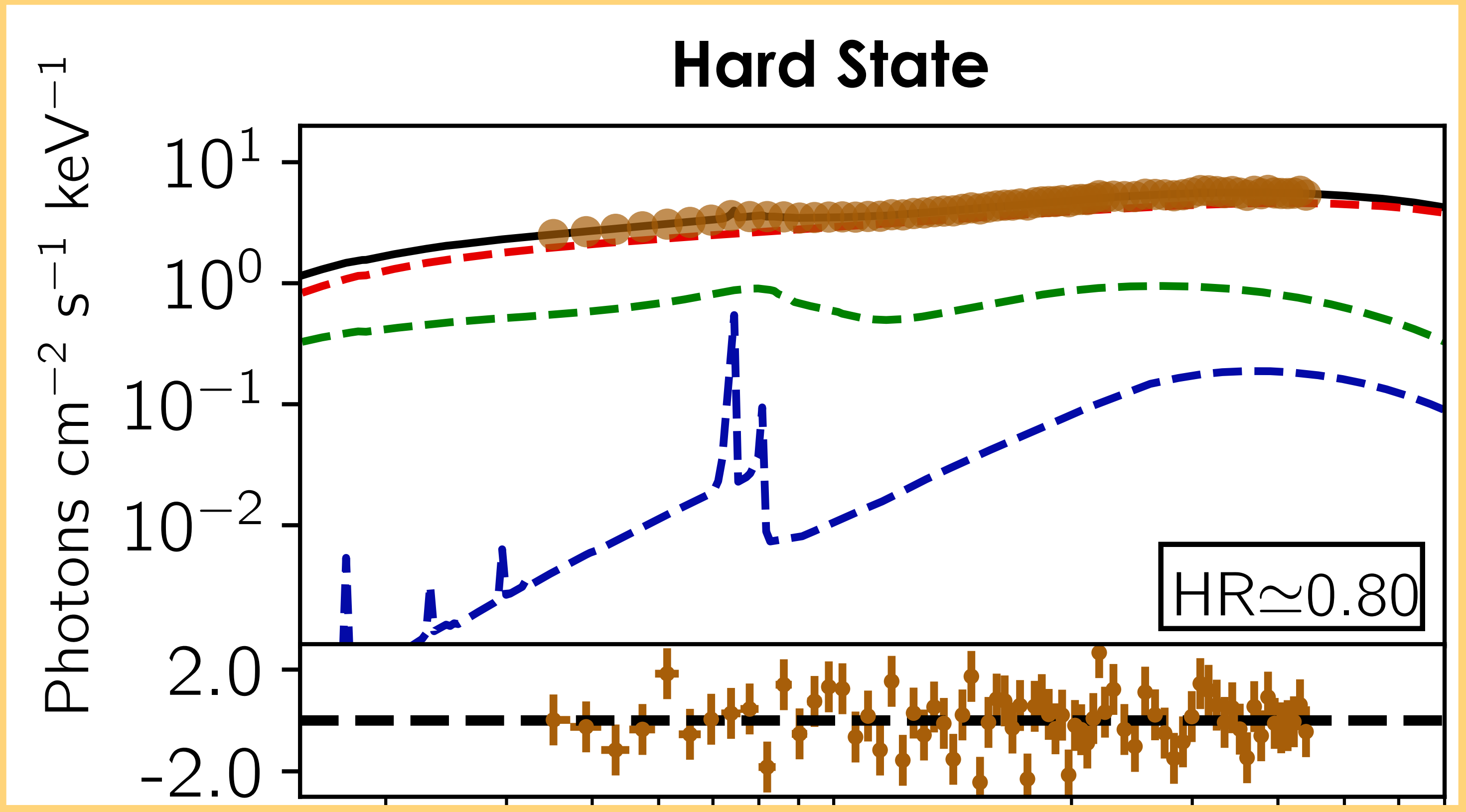


Stronger GR distortion

BHBs in Outburst— GX 339-4







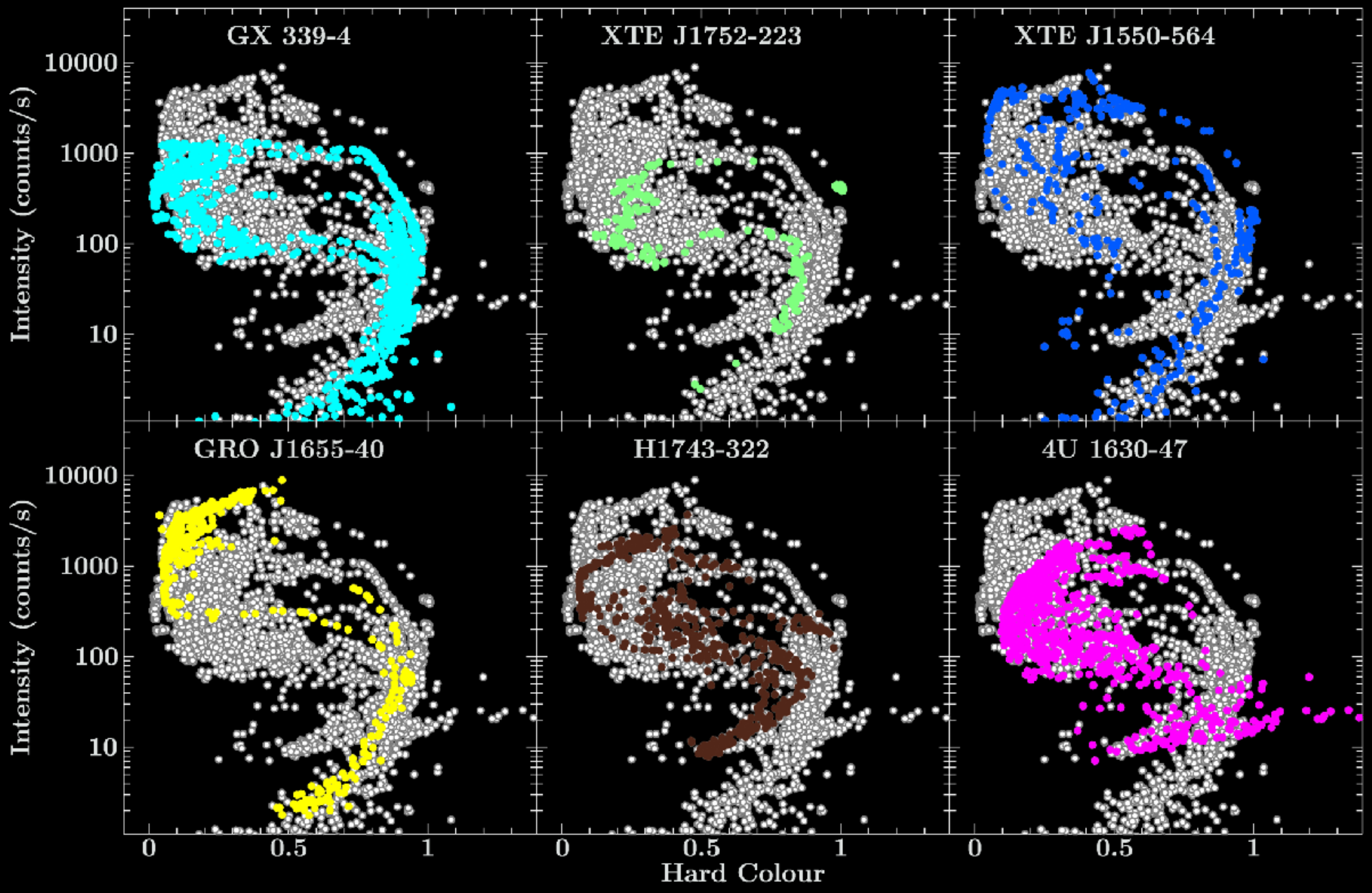
X-ray Luminosity —>

Spectral Slope —>

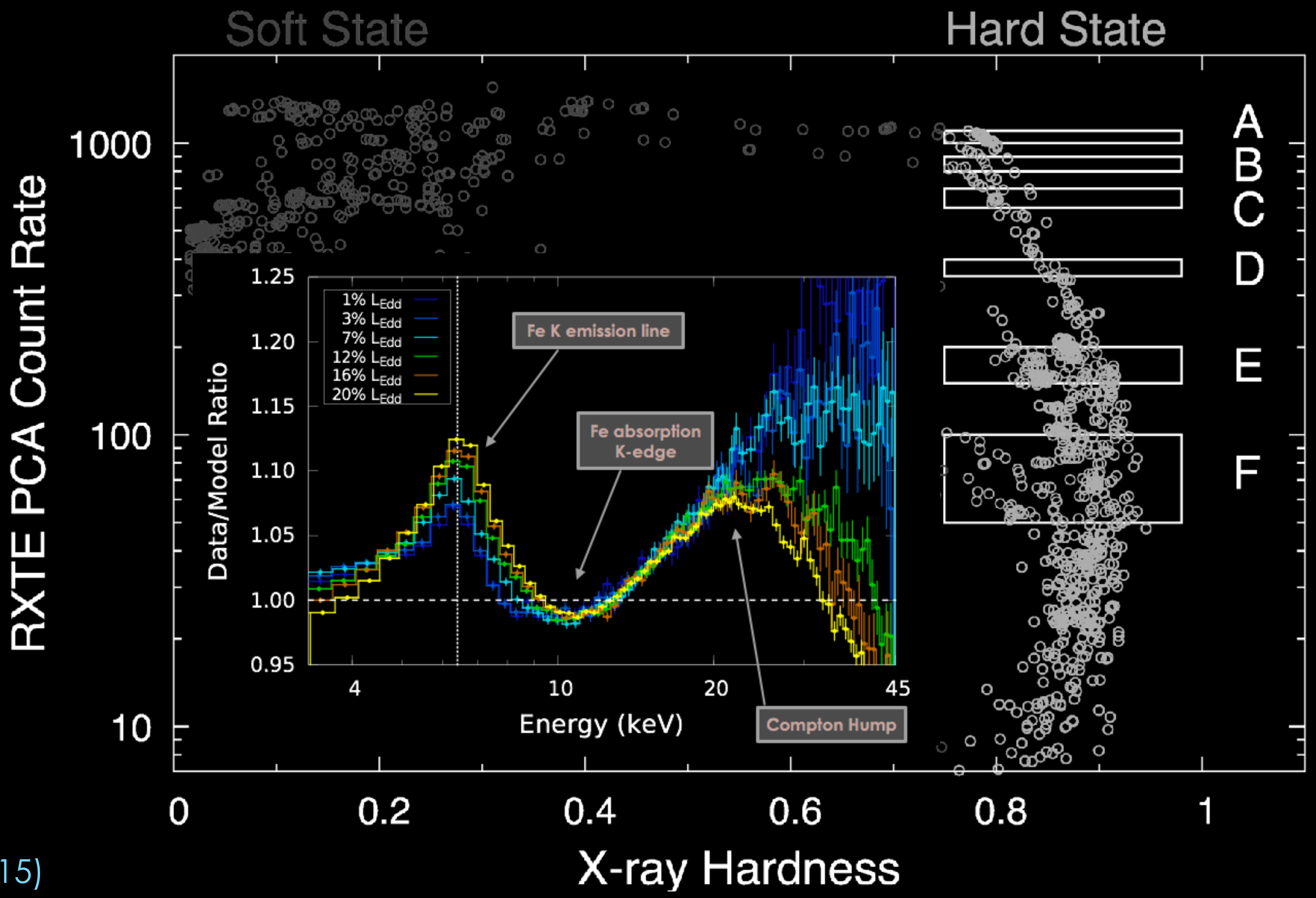
Archival data from the *Rossi X-ray Timing Explorer (RXTE)*
(Animation courtesy of Navin Sridhar)

The *RXTE* Archive of BHBs

NASA ADAP16: ~15,000 ***RXTE*** spectra with PCA (3-45 keV) and HEXTE (20-250 keV) for ~30 BHB with ~1 ks exposures



The Hard State of GX 339-4



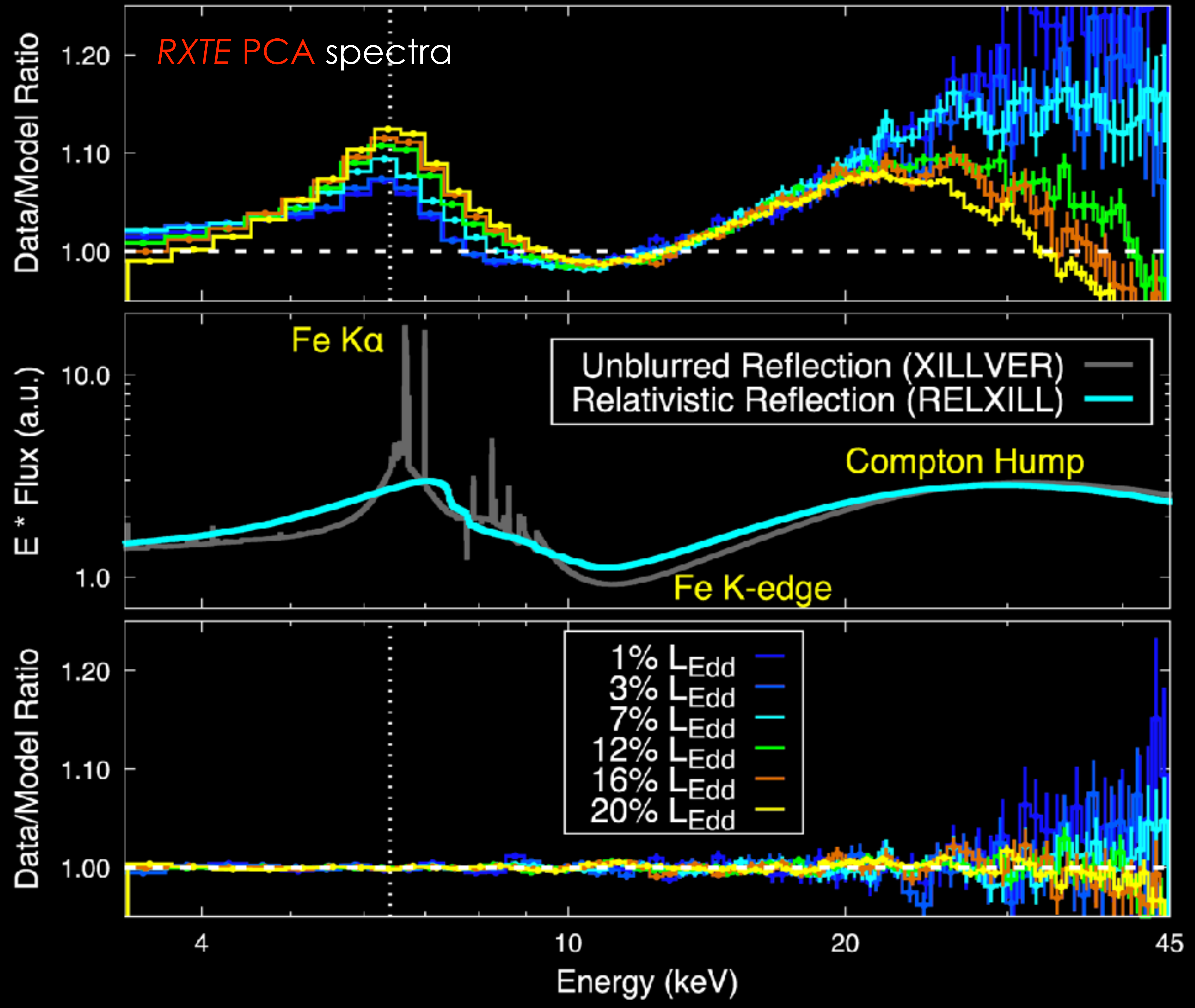
García et al. (2015)

Disk and Corona Evolution

Relativistic reflection fits of the black hole binary system GX 339—4

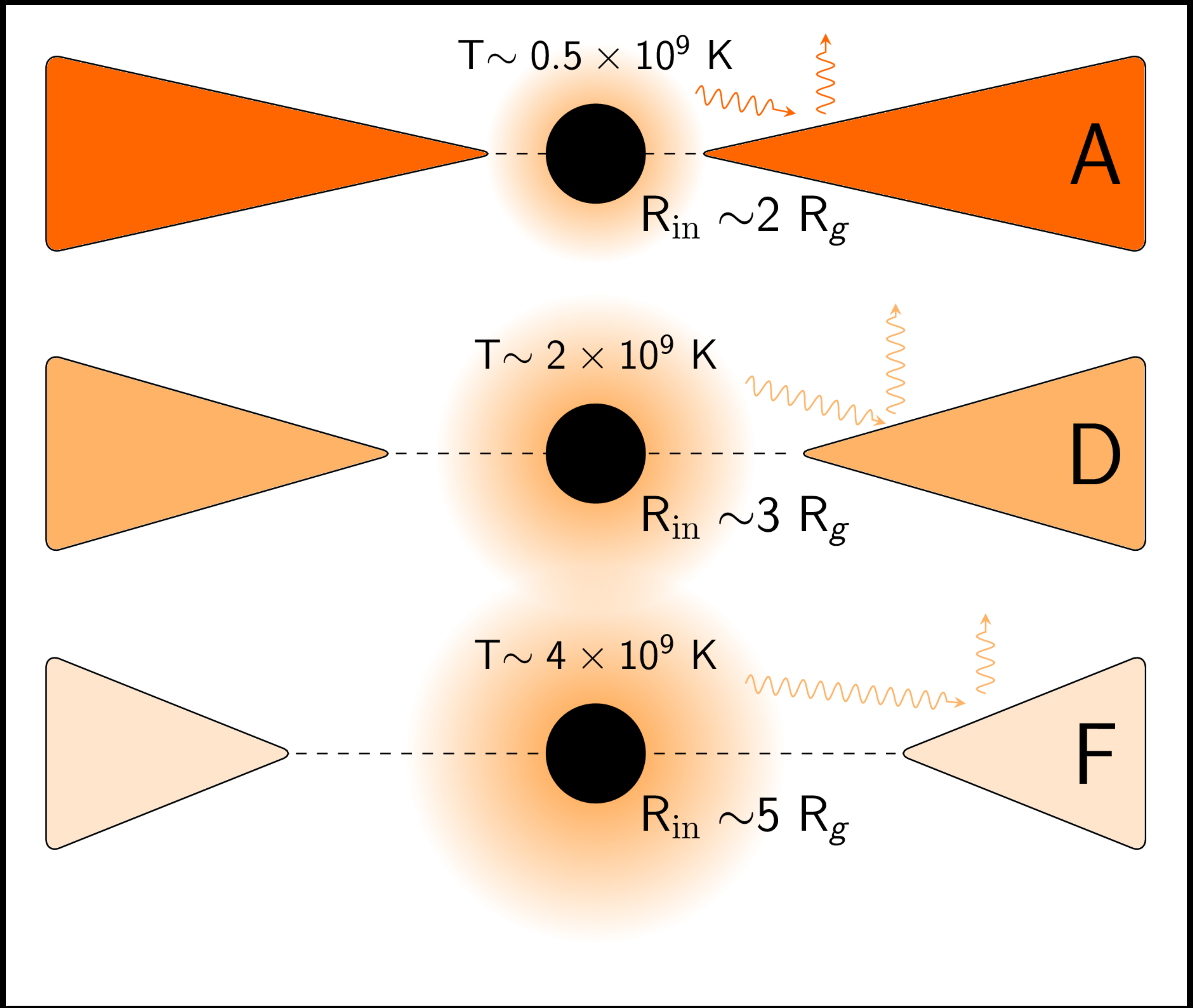
a = 0.95 +/- 0.04
i = 48 +/- 1 deg
Fe abundance 5x Solar

Total of 77 million counts in 6—spectra (3–45 keV)

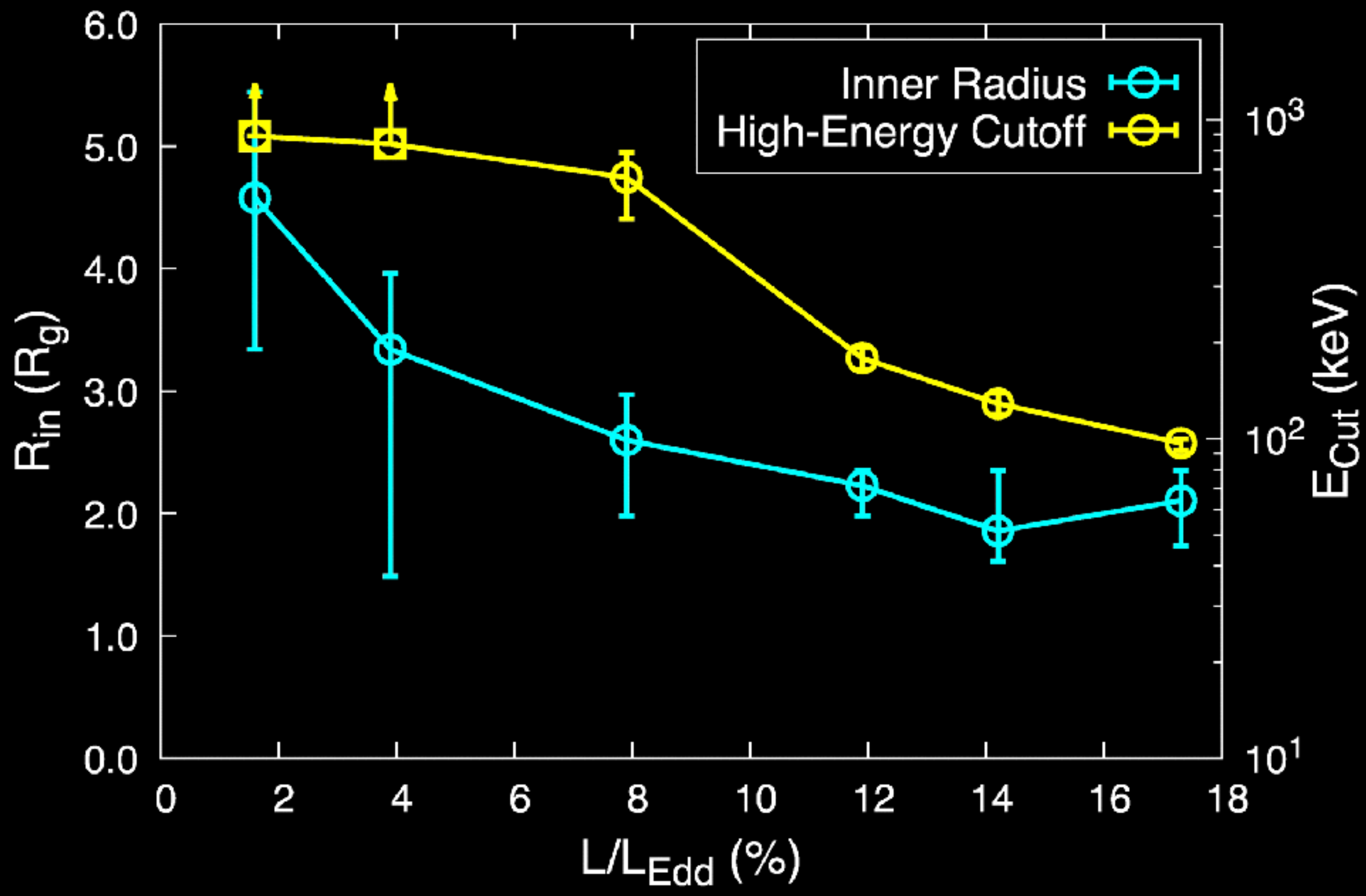


García et al. (2015)

Disk and Corona Evolution

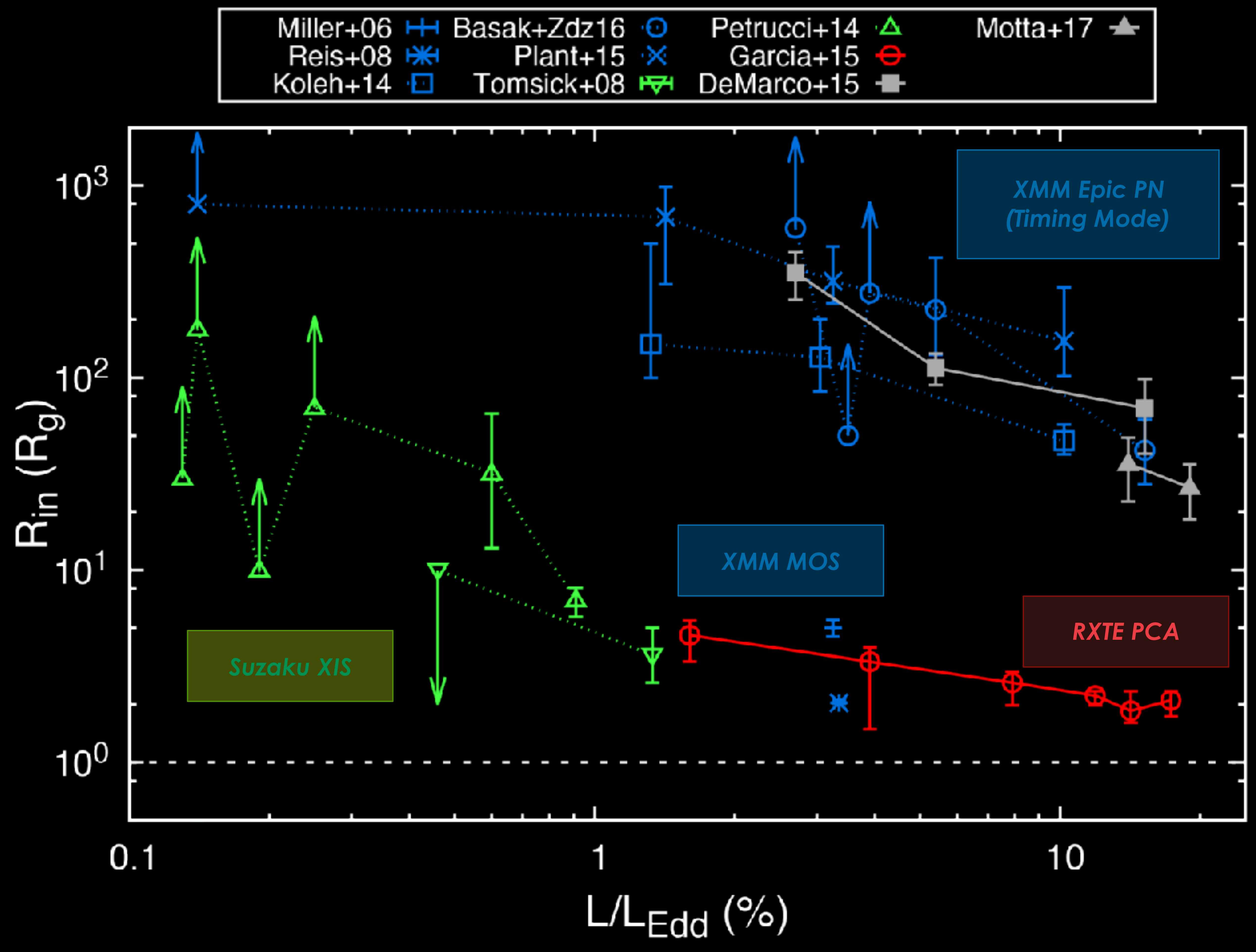


For a 10 Solar-mass BH:
Delta Rin ~45 km

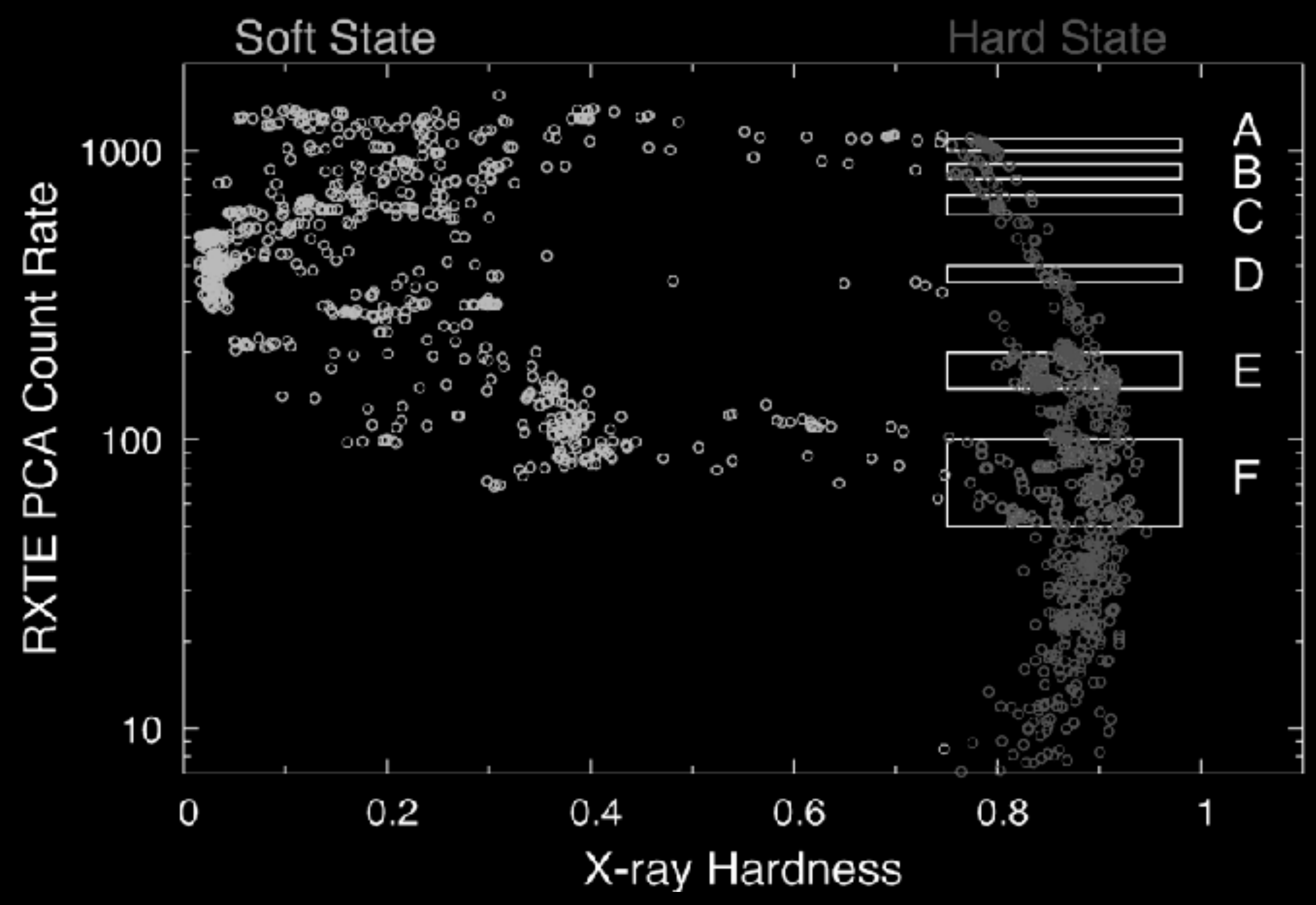


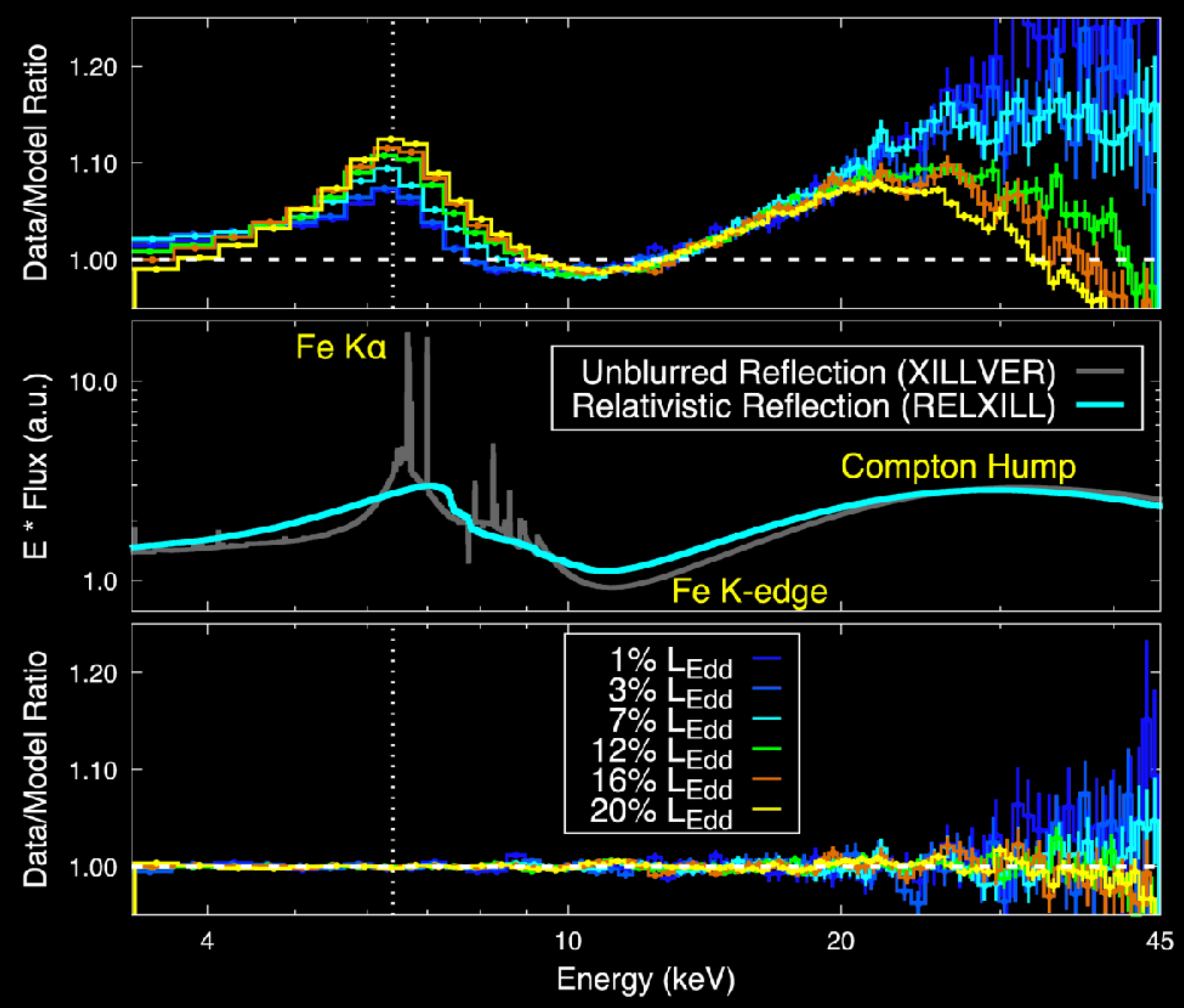
- Luminosity increases by ~20x
- Rin decreases from a few to ISCO
- Coronal Temp decreases by 10x
- Yet, continuum slope remains the same (Γ~1.6)… why?

Controversy on the Disk Truncation



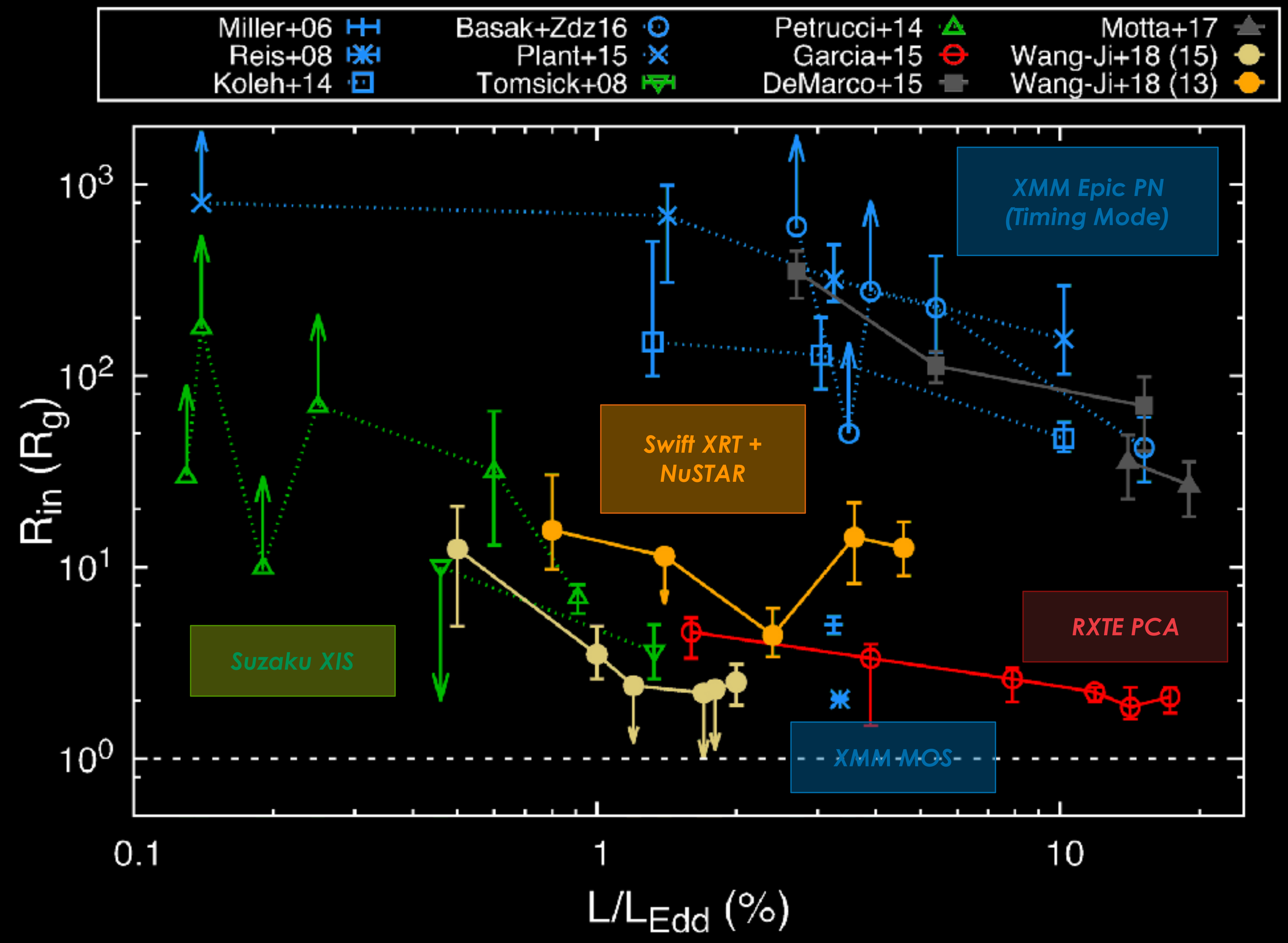
Large discrepancies in the truncation of the accretion disk



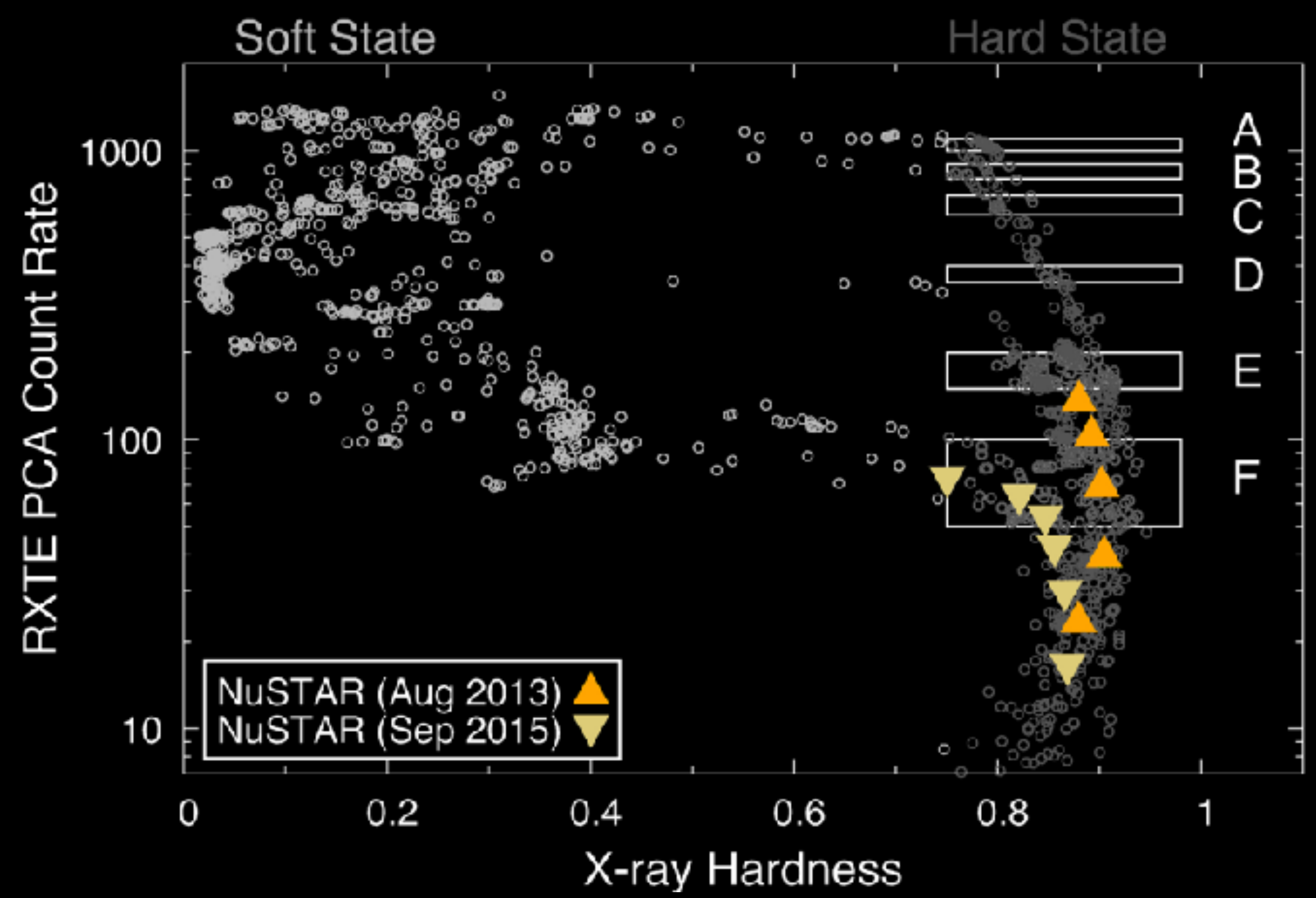


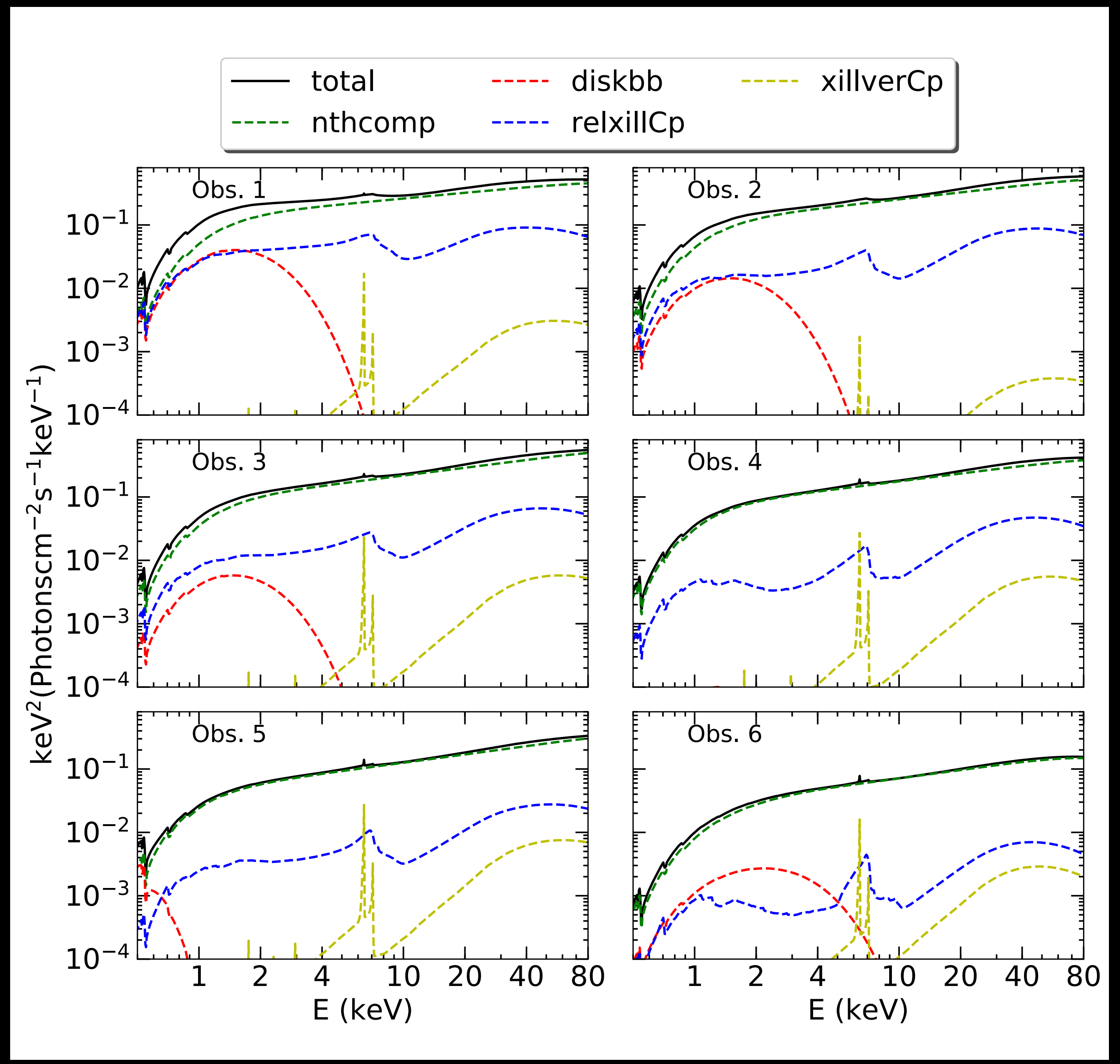
García et al. (2015)

Controversy on the Disk Truncation



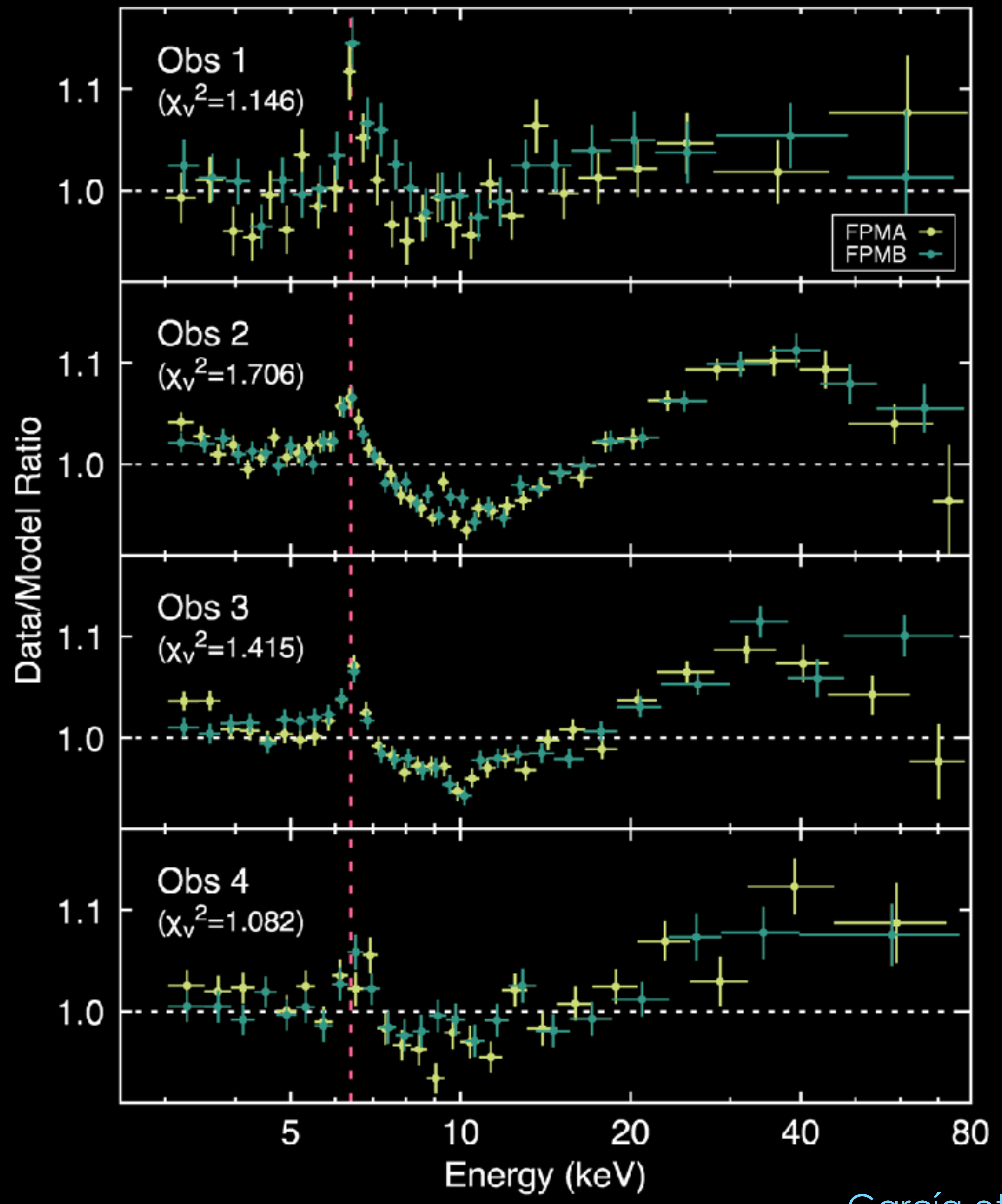
Recent (2013, 2015) *Swift XRT* and *NuSTAR* observations consistent with mild truncation (i.e., Rin ~ 10's Rg, **not** 100's Rg)



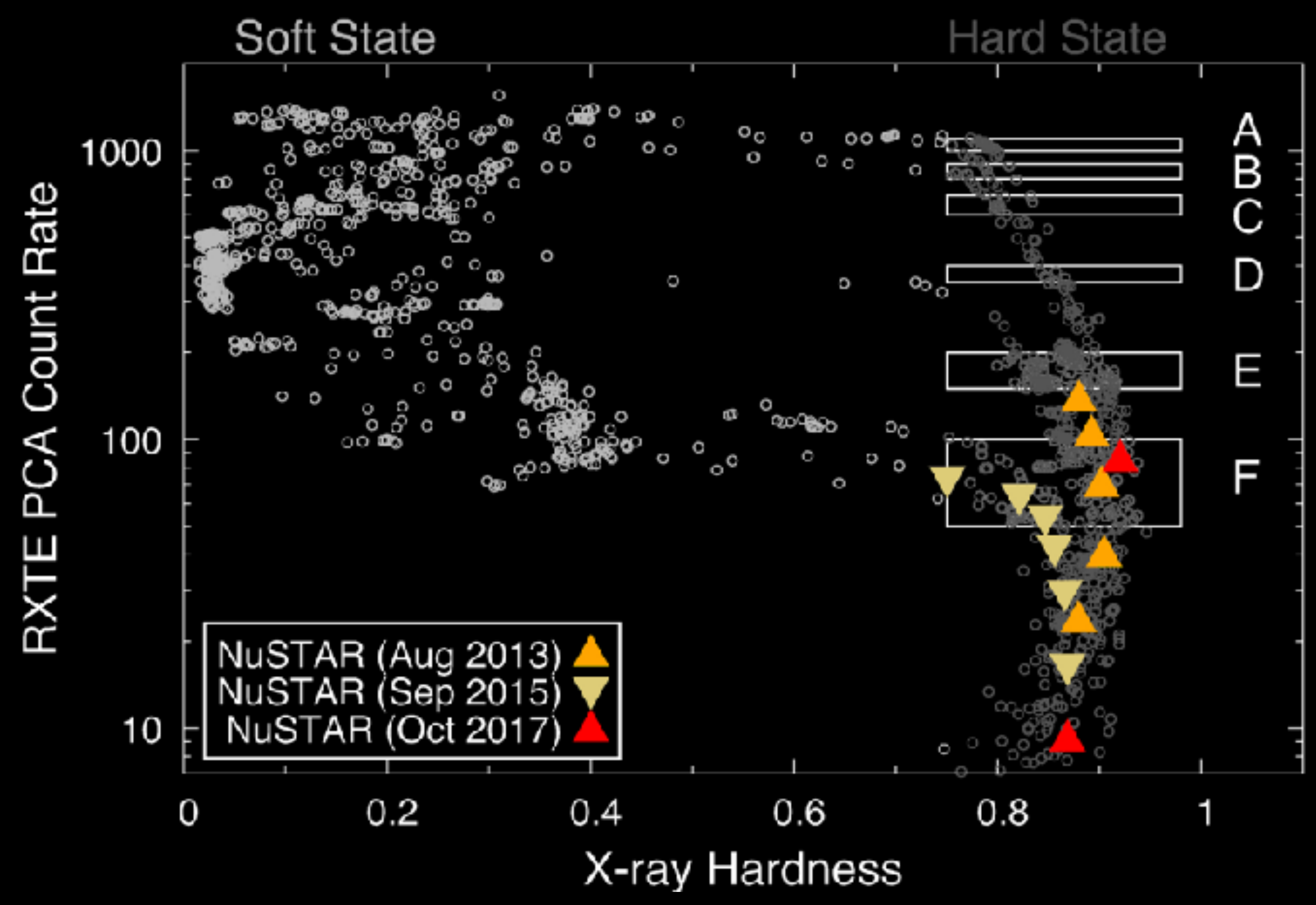


Wang-Ji et al. (2018)

The 2017 Failed Outburst of GX 339-4

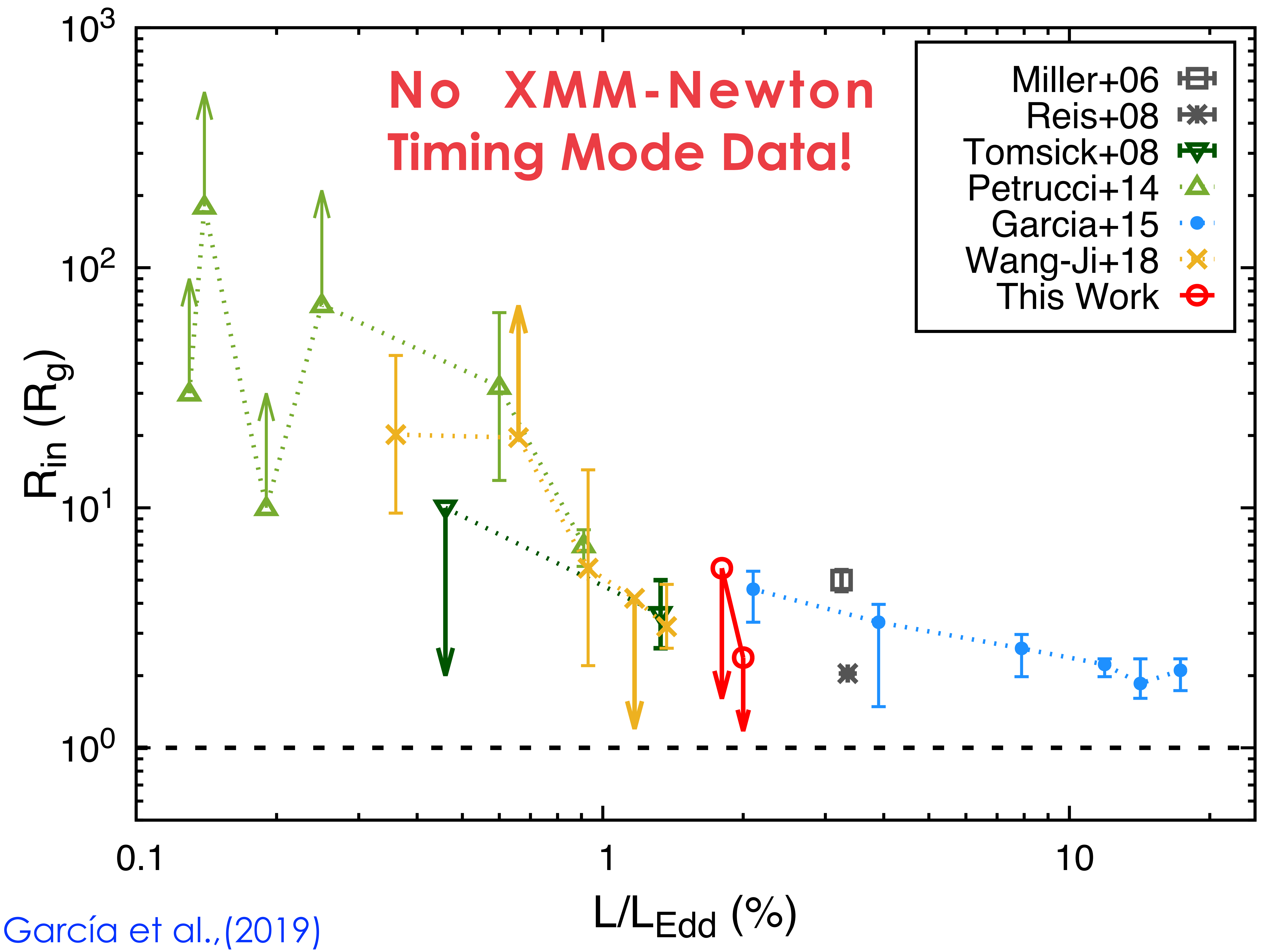


García et al.,(2019)



- Signatures of reflection detected in all the *NuSTAR* exposures
- Broad (relativistic) reflection required in the brightest spectra
- Inner-radius consistent with **small truncation** (Rin ~ 2.4 Rg)

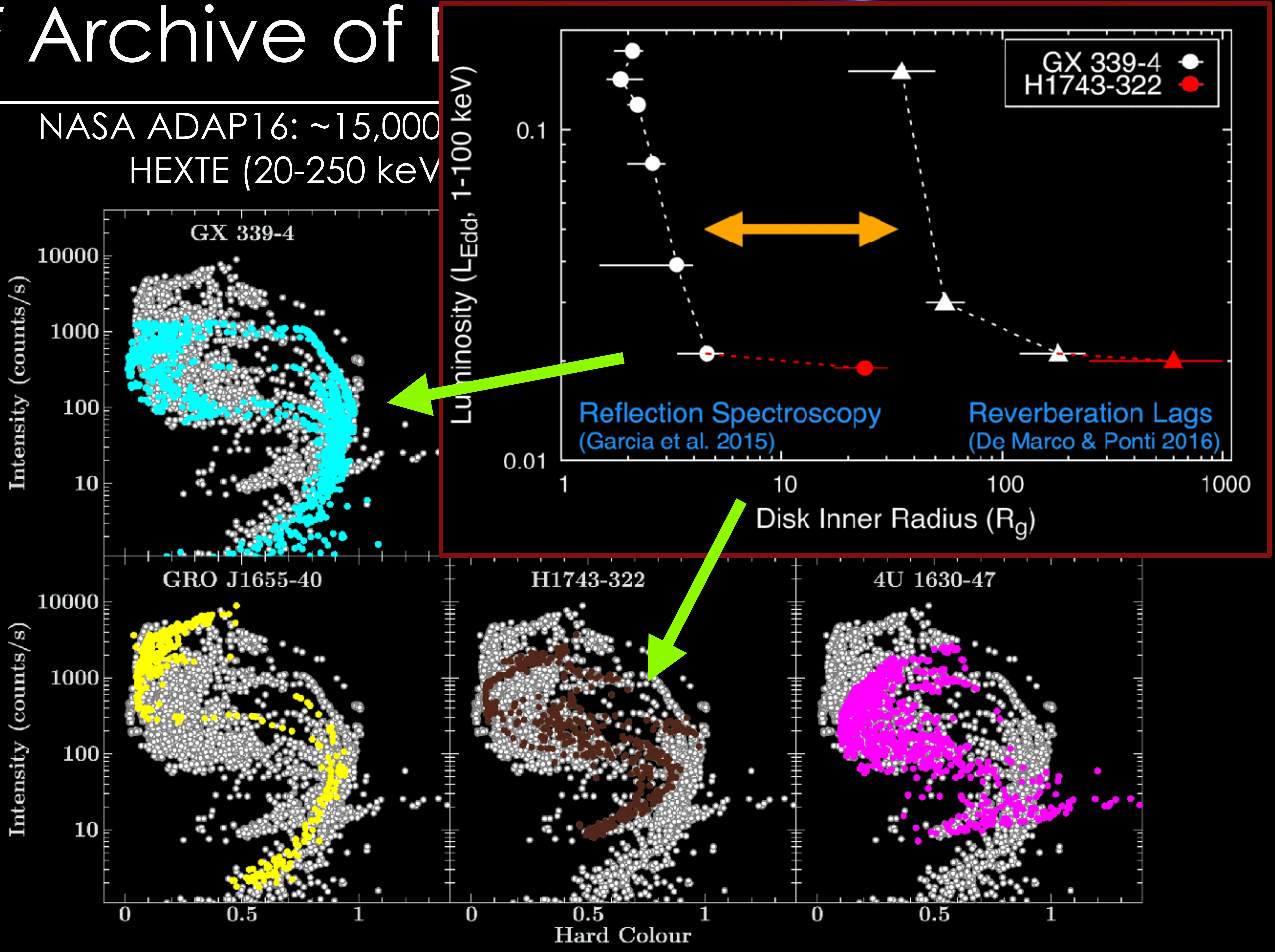
Current Inner-Radius vs. Luminosity



García et al.,(2019)

The *RXTE* Archive of B

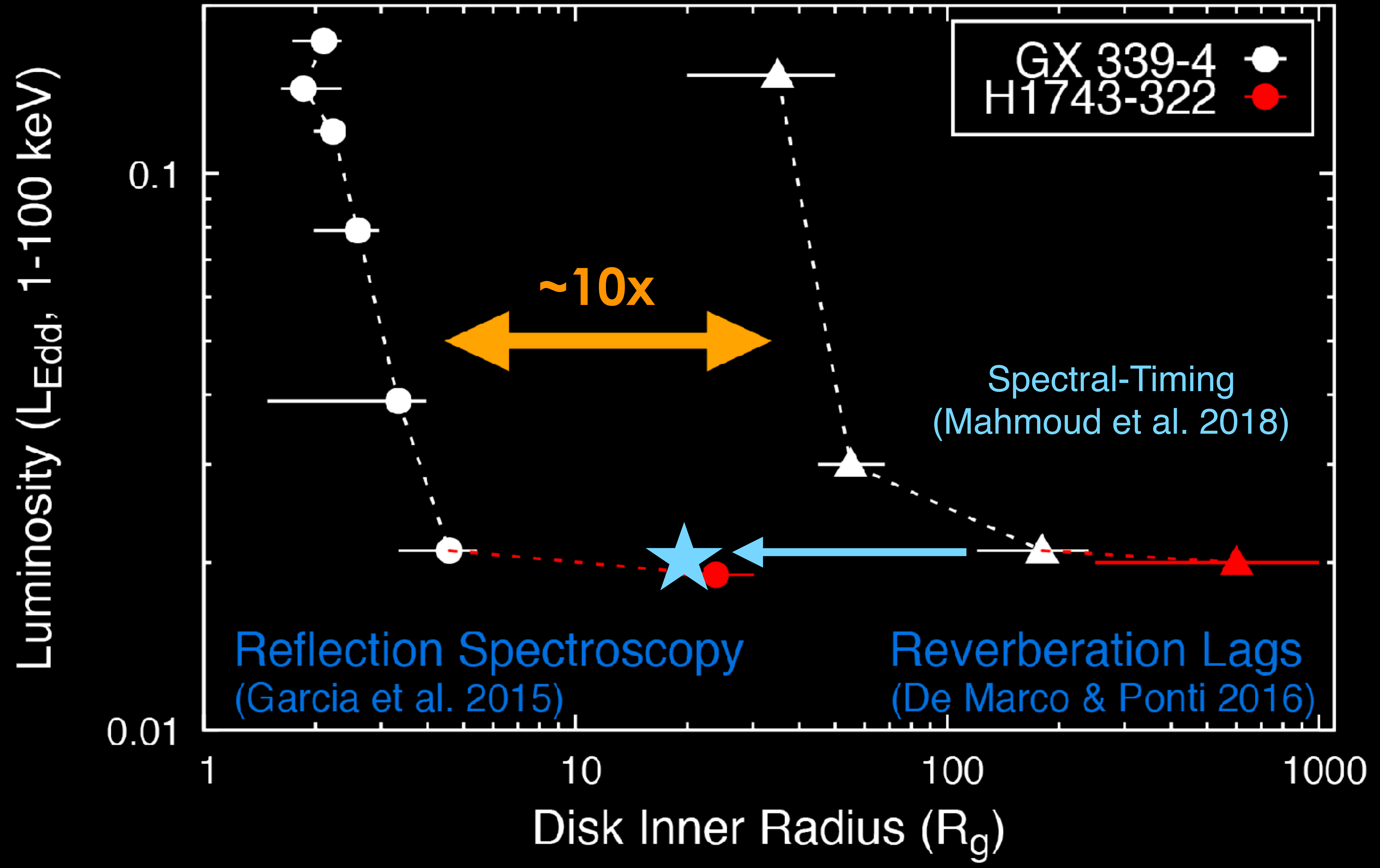
NASA ADAP16: ~15,000
HEXTE (20-250 keV



Controversy on the Disk Truncation

Timing signatures provide independent constraints

—> But require careful interpretation!

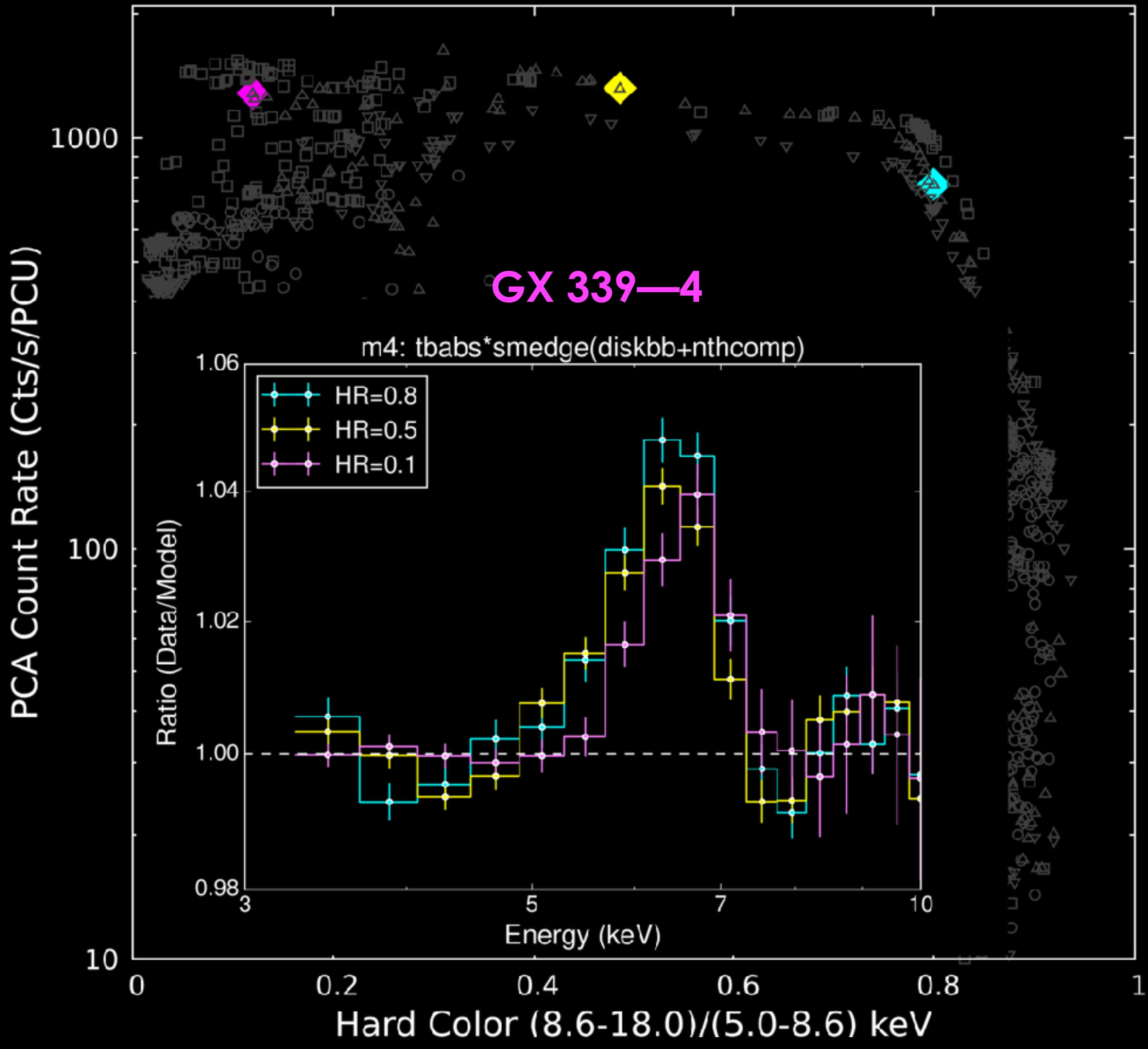


The Fe K line Profile across States

Same Fe K profile for different accretion states

This suggest that the disk has reach the ISCO before it makes the transition

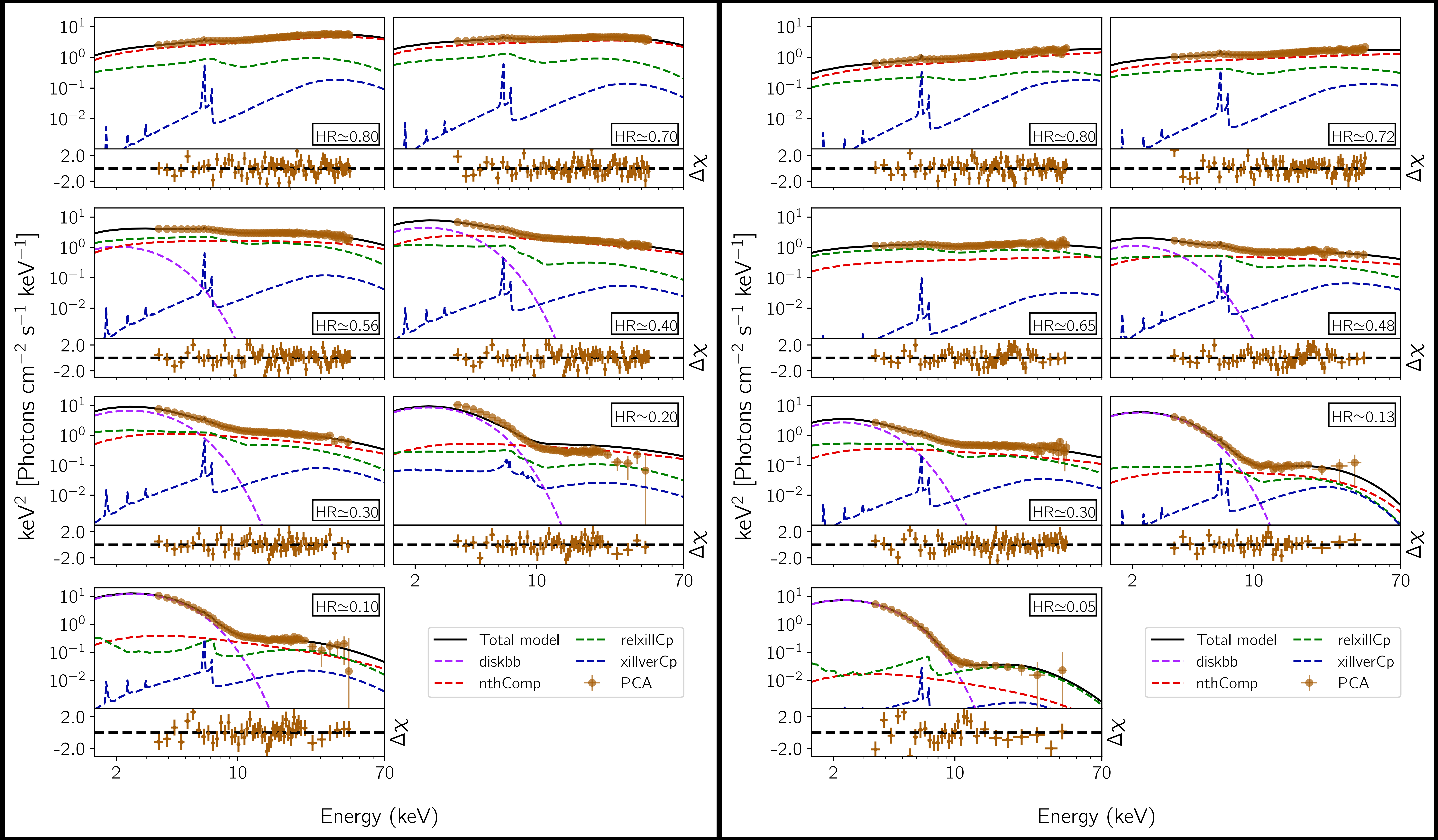
Sridhar et al. (2020)



Fits with Relativistic Reflection

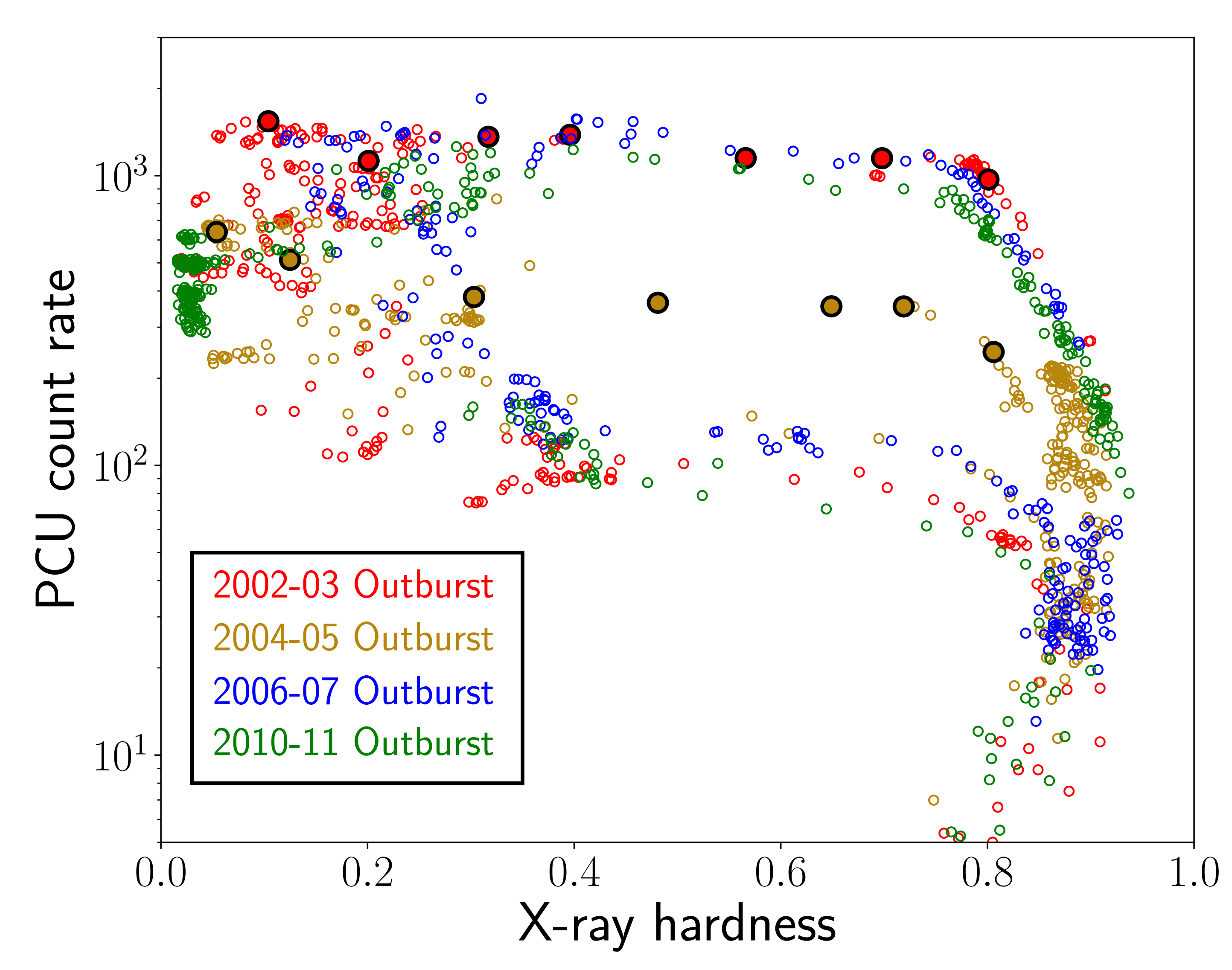
Modeling:
TBabs*(diskbb + relxillCp)

Implements an Illumination continuum produced by thermal Comptonization (nthComp)

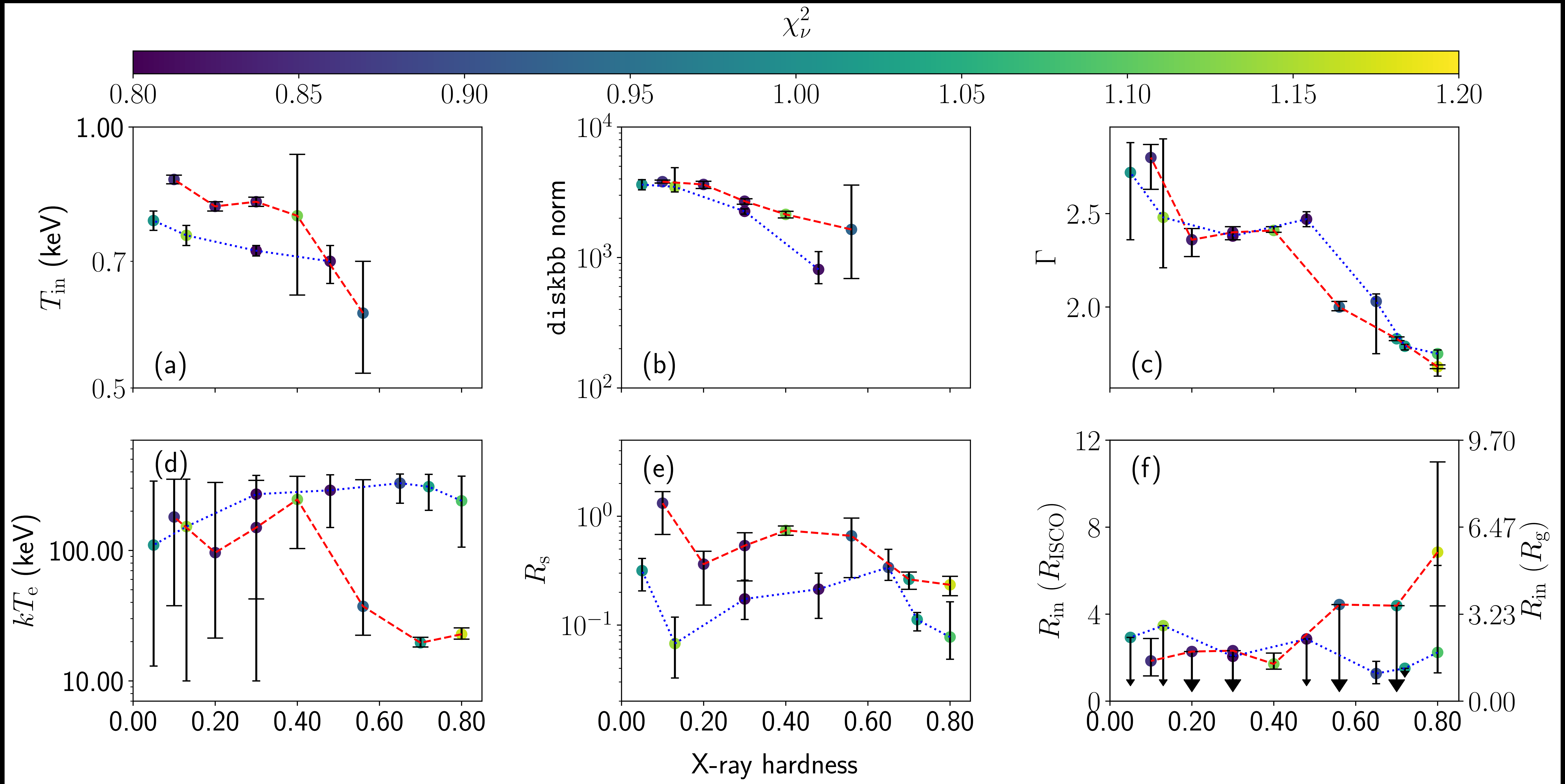


Sridhar et al. (2020)

Fits with Relativistic Reflection



Modeling:
TBabs*(diskbb + relxillCp)



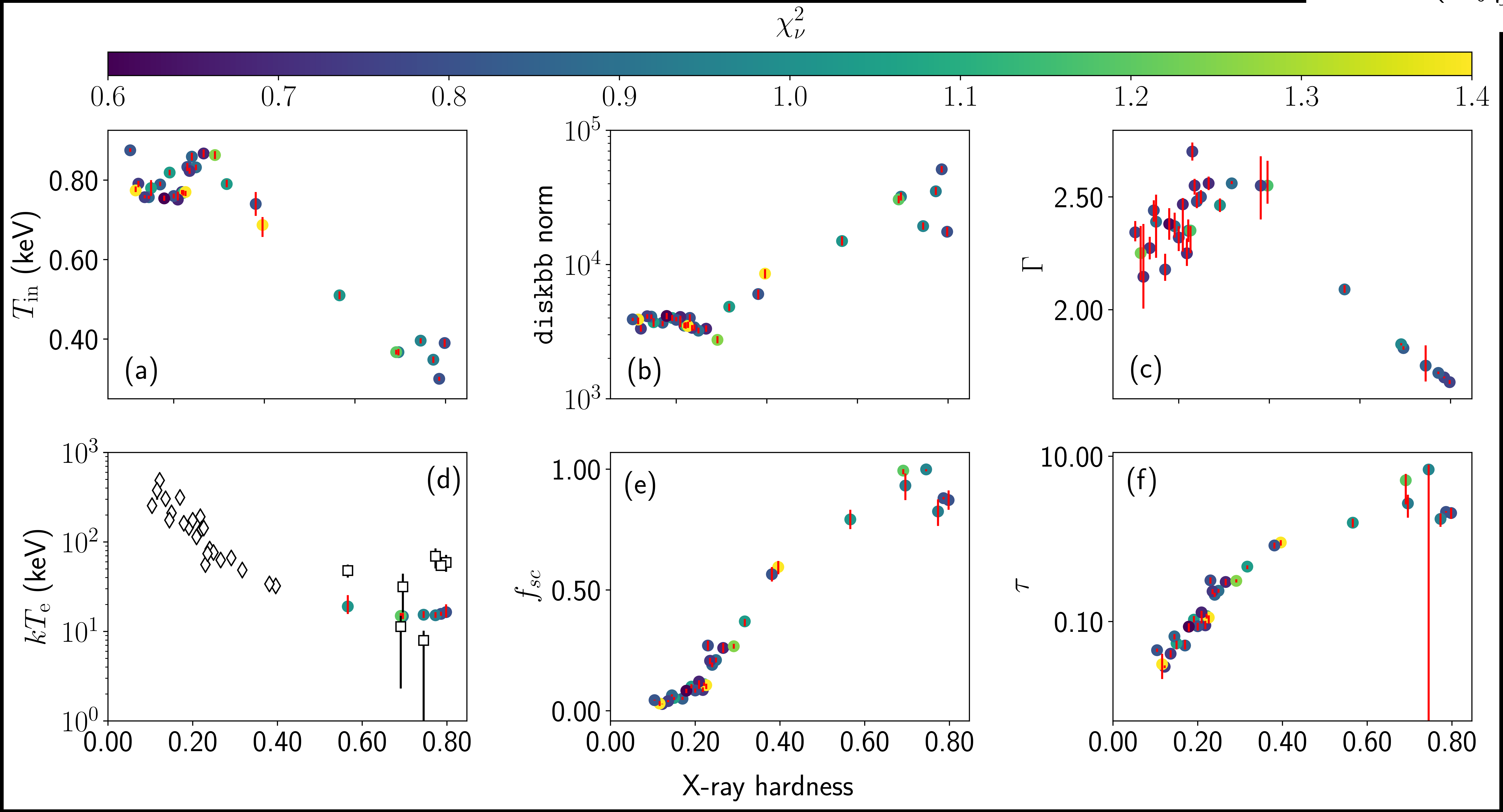
Sridhar et al. (2020)

The Fe K line Profile across States

"Simple" Modeling:
TBabs*(simplcutx*diskbb + Gaussian)

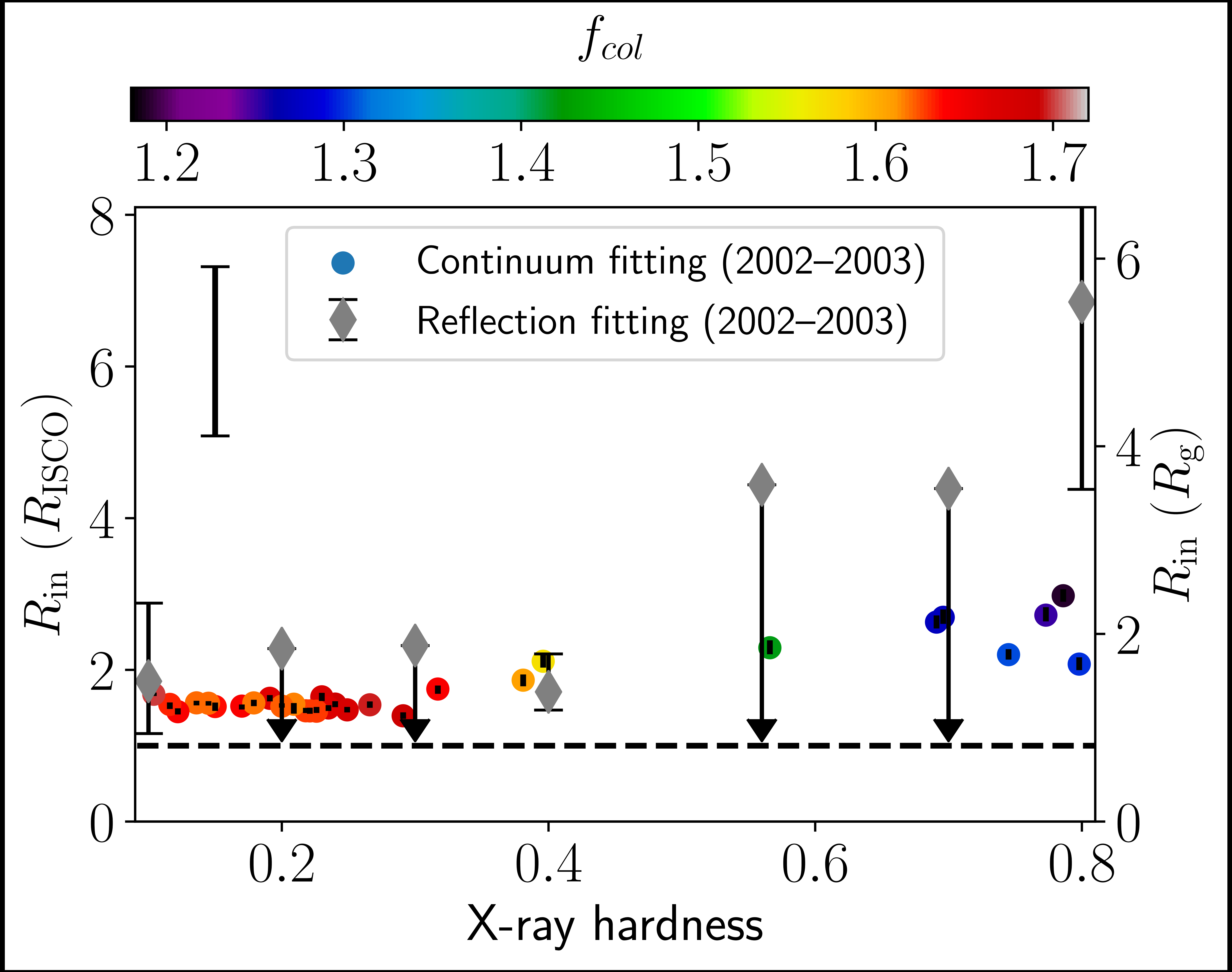
$$N = \left(\frac{r_{in}}{\Xi f_{col}^2 D_{10}}\right)^2 \cos\theta,$$

$f_{col} \sim T_{in}^{1/3}$



Sridhar et al. (2020)

The Fe K line Profile across States

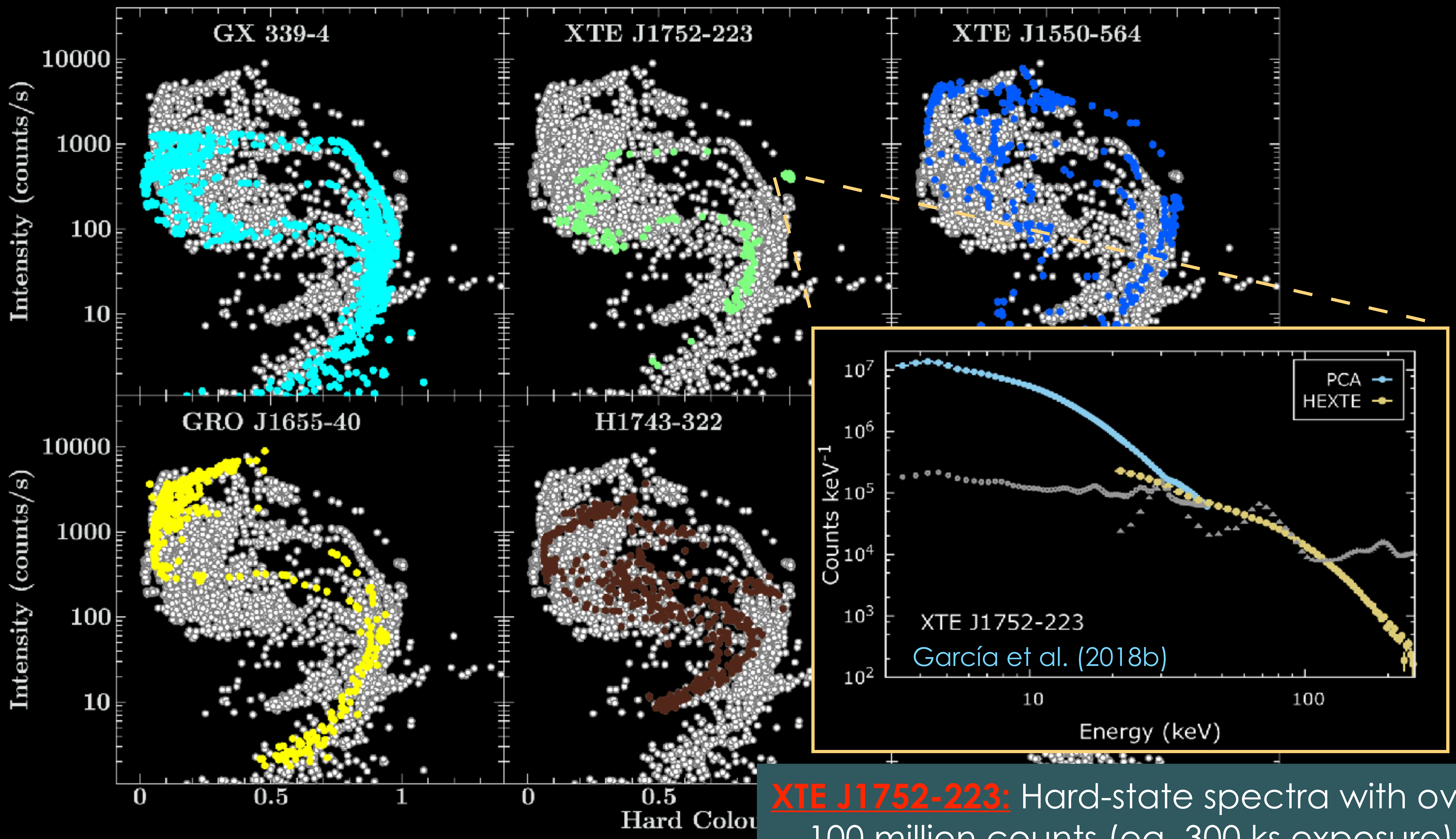


Inner Radius stable across the state transitions!

Sridhar et al. (2020)

The *RXTE* Archive of BHBs

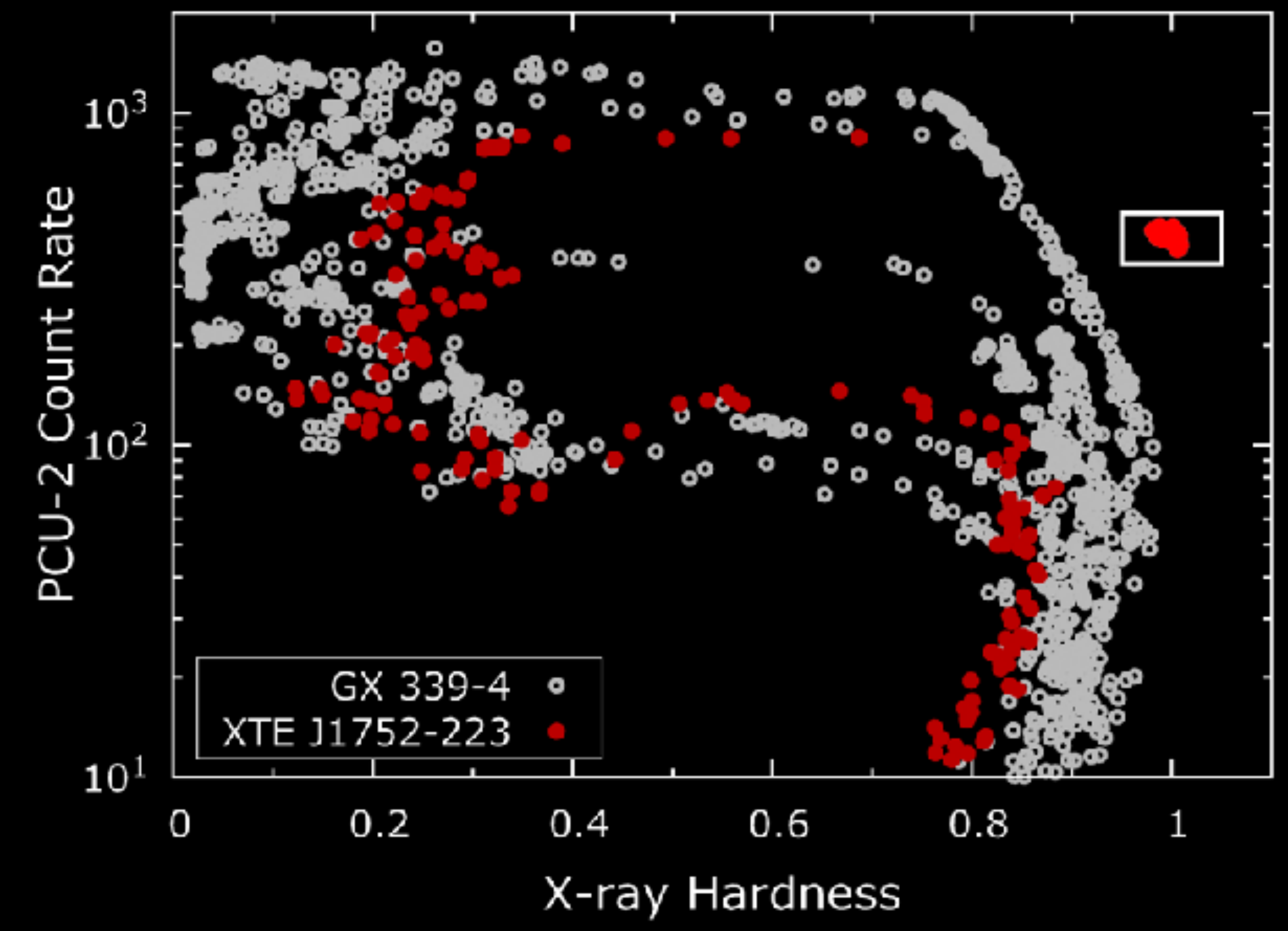
NASA ADAP16: ~15,000 ***RXTE*** spectra with PCA (3-45 keV) and HEXTE (20-250 keV) for ~30 BHB with ~1 ks exposures

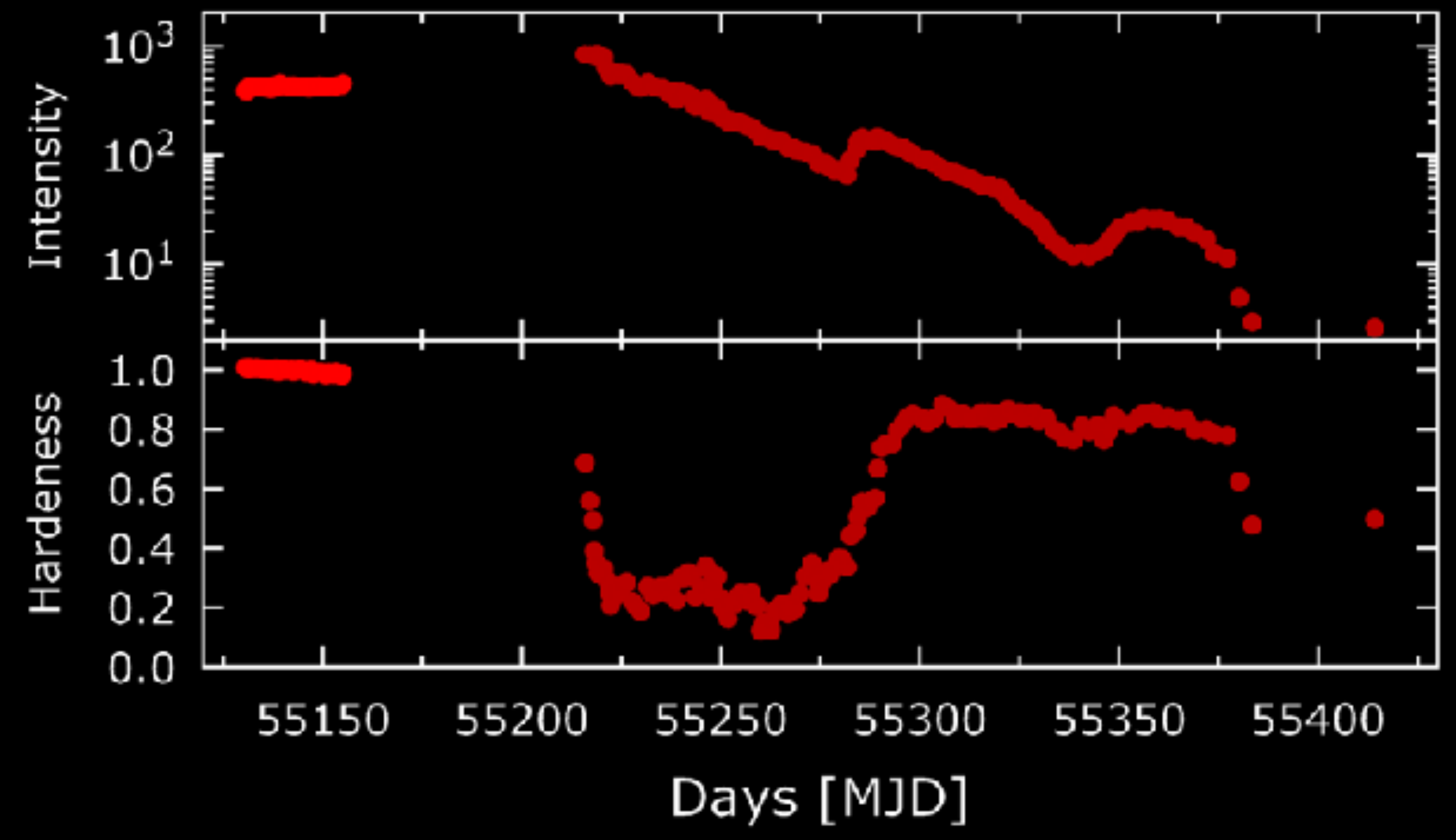


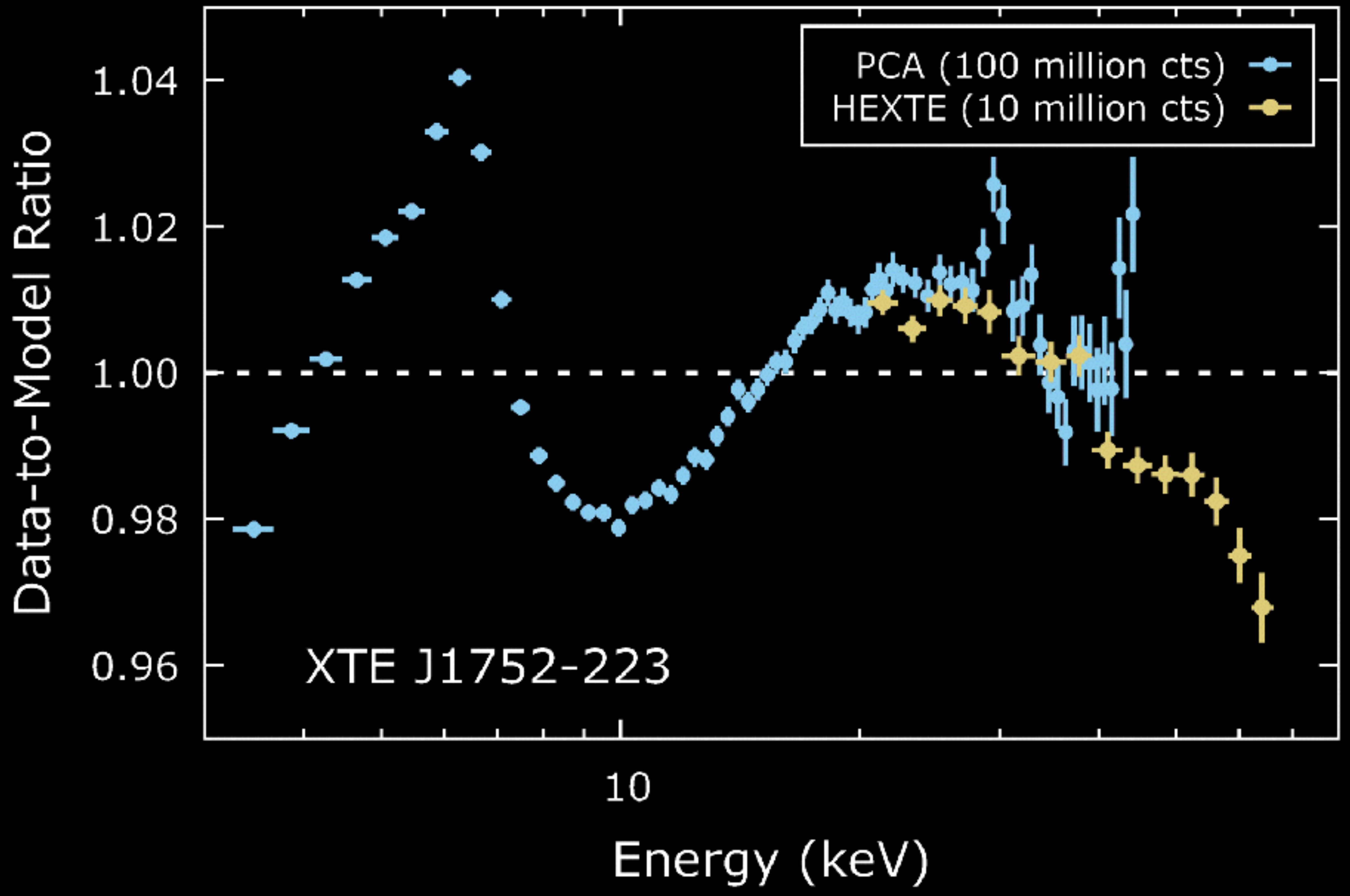
XTE J1752-223: Hard-state spectra with over 100 million counts (eq. 300 ks exposure)

The Hard-State in XTE J1752—223

Particularly stable hard state with constant hardness and luminosity for nearly 1 month!







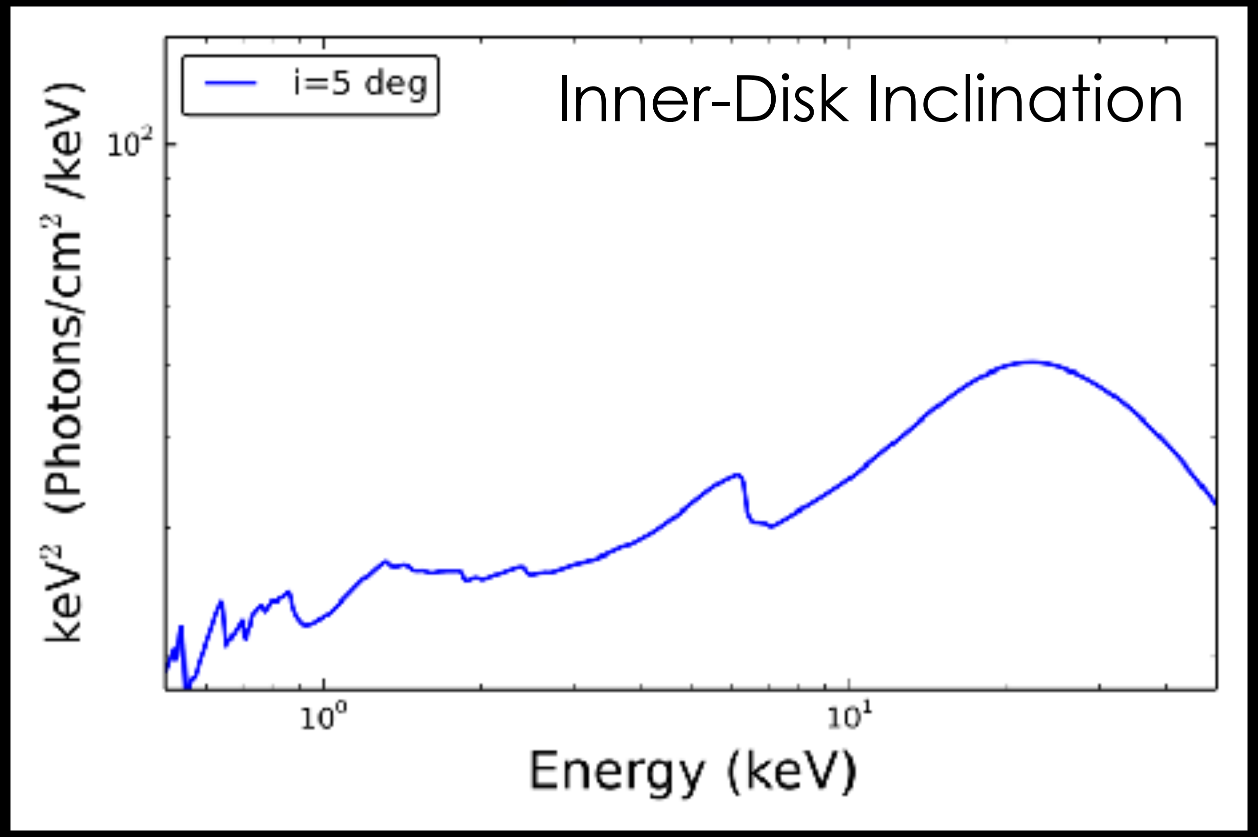
Very high signal-to-noise X-ray reflection spectrum (S/N ~ 3000)

García et al. (2018)

Orientation of the Inner-Disk

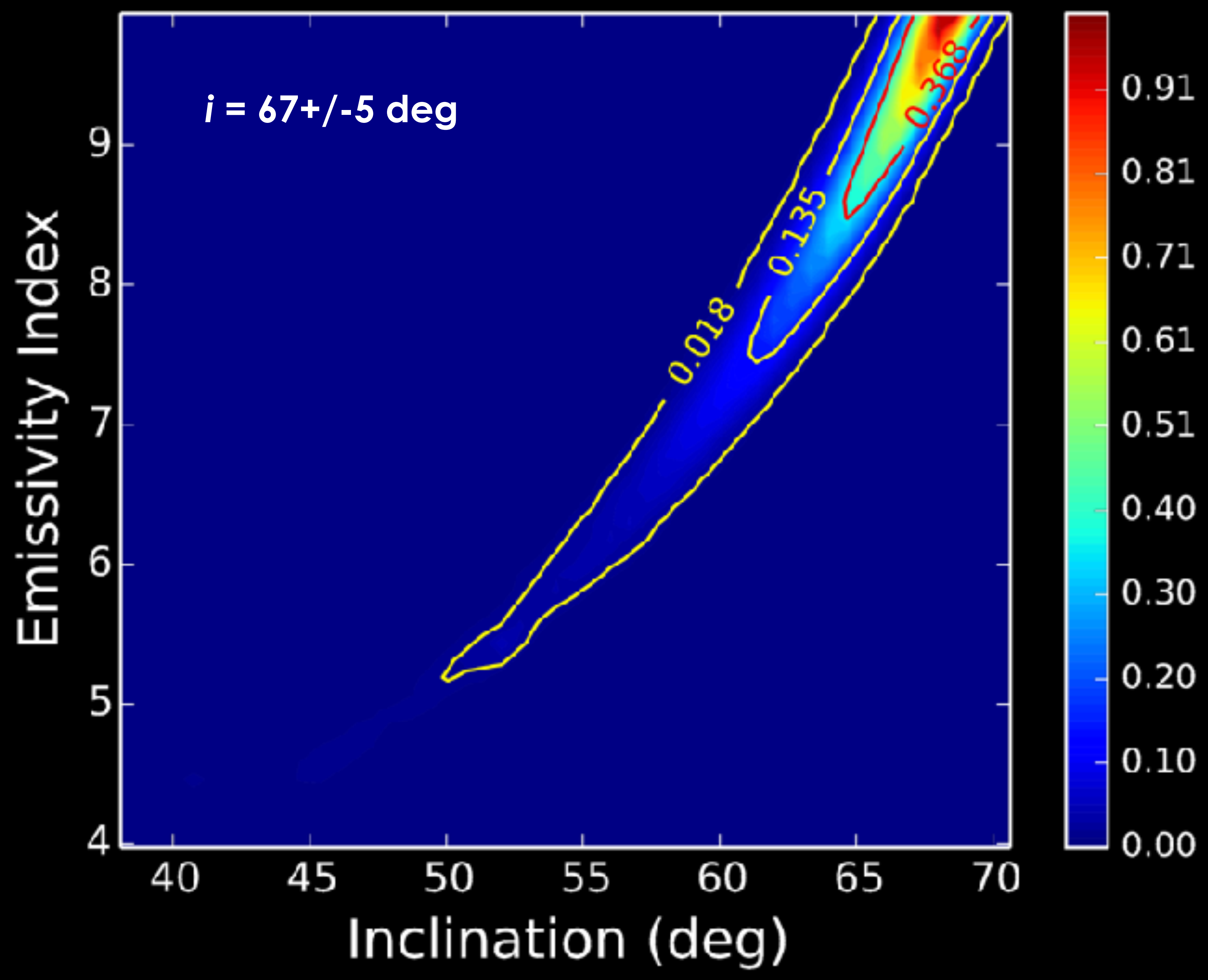
Reflection Spectroscopy of XTE J1752—223 with different geometries for the illumination of the disk show consistent parameters, except for the inclination

García et al. (2018)

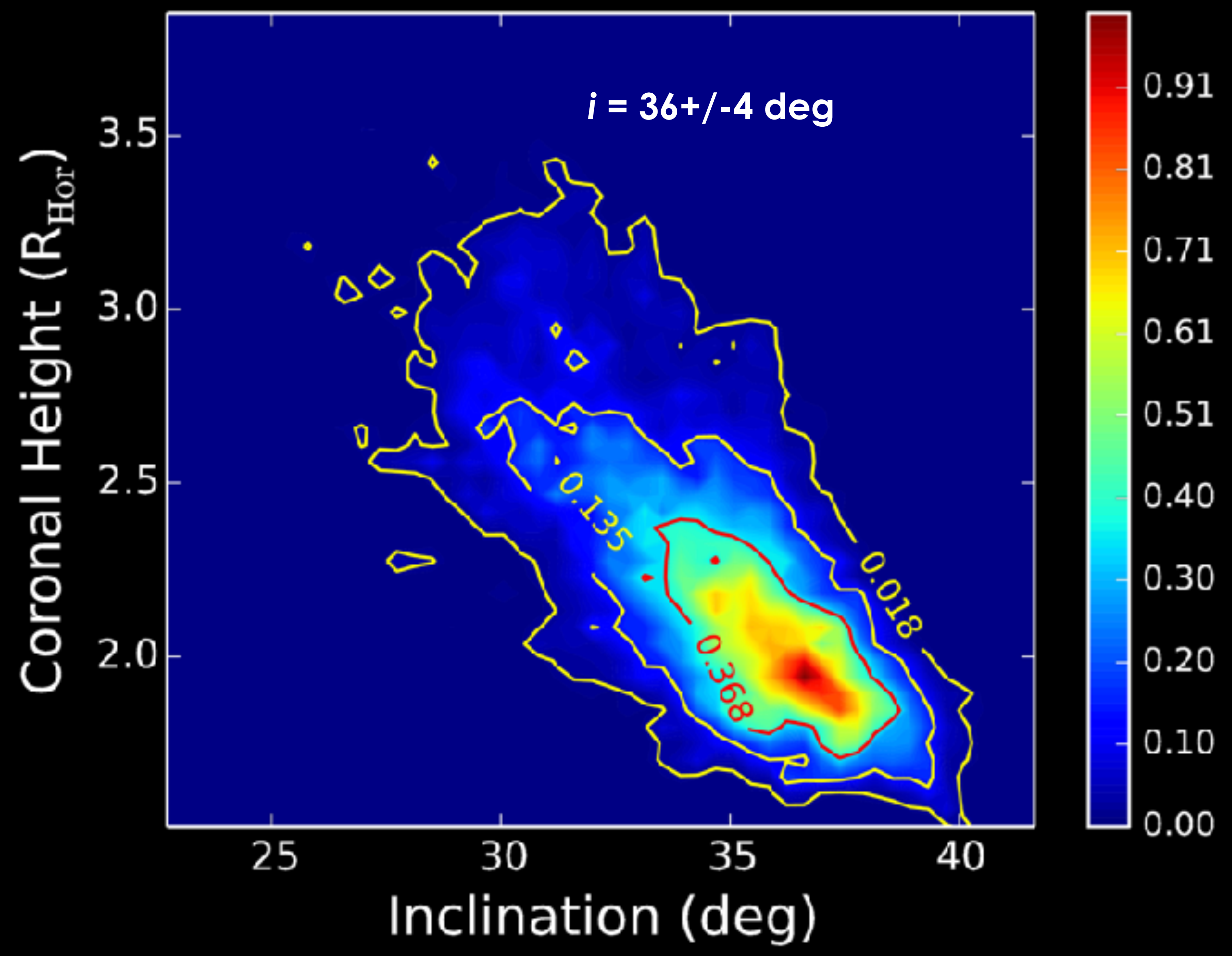


Inclination from the lamppost model consistent with radio jet determinations of ***i* < 49 deg** (Miller-Jones et al. 2011).

Power-law Emissivity

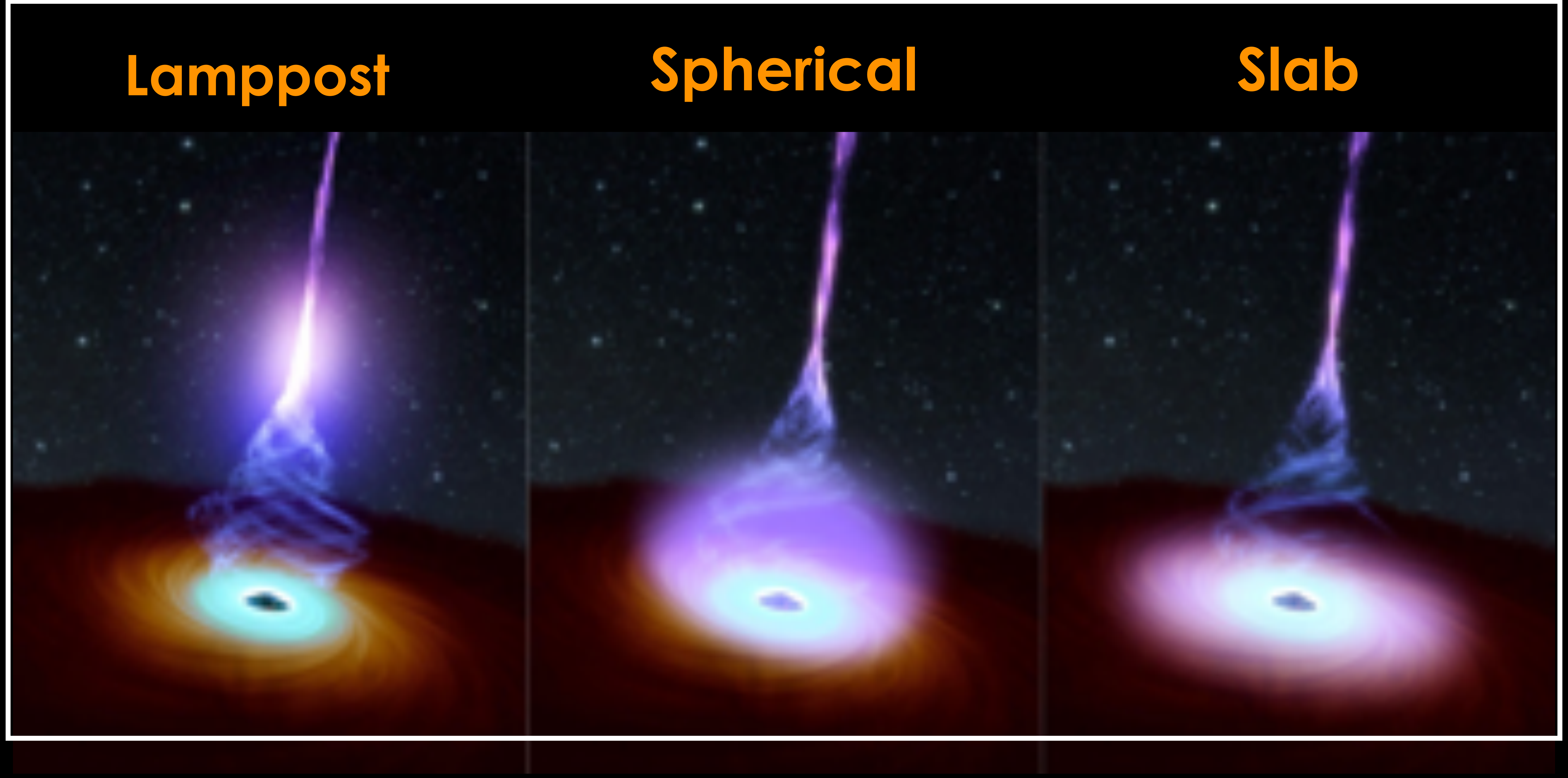


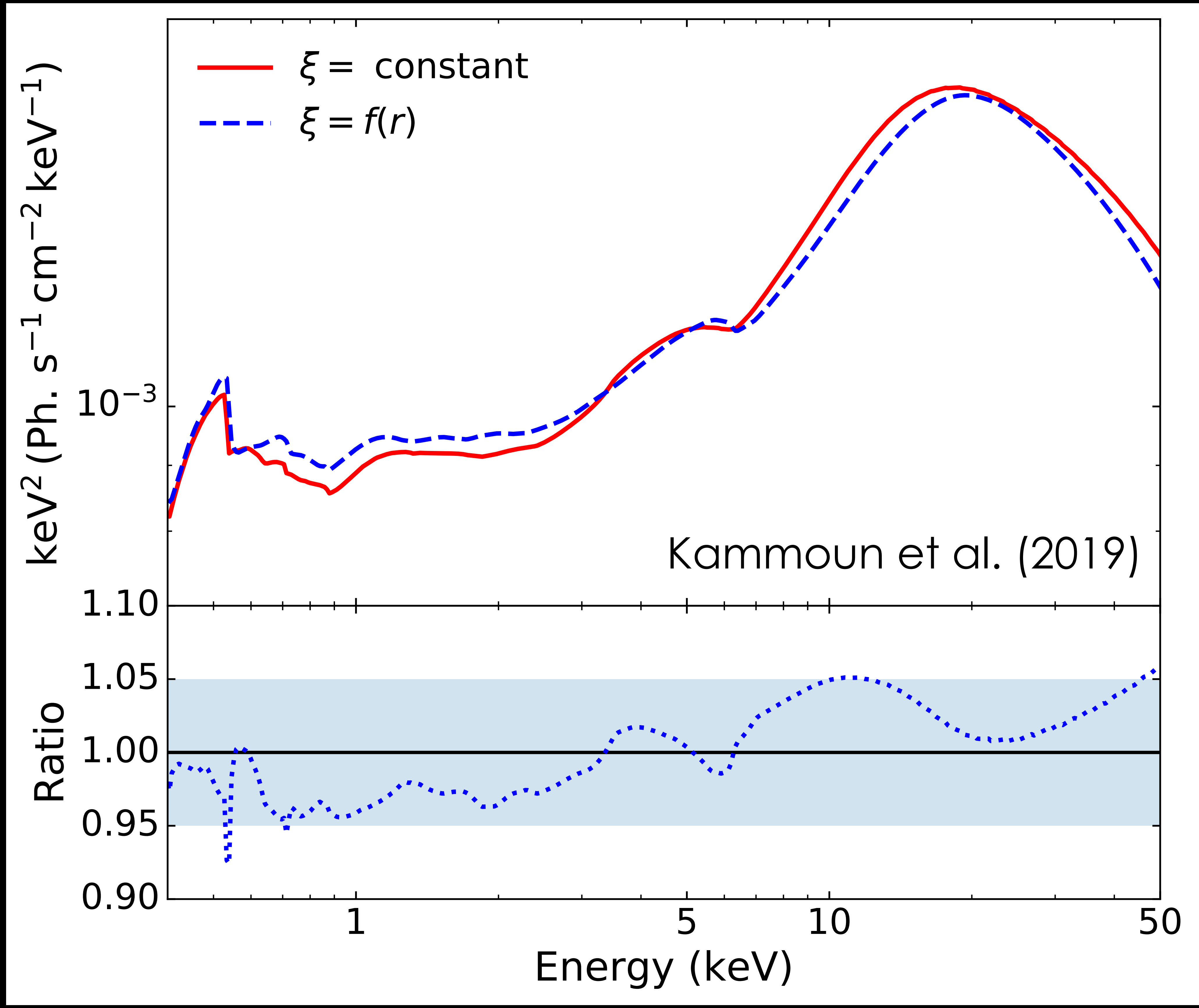
Lamppost Geometry



Coronal Geometry

Gradients of ionization in the disk can explain steep emissivities (Svoboda et al. 2012)
But differences are ~5% (Kammoun et al. 2019)





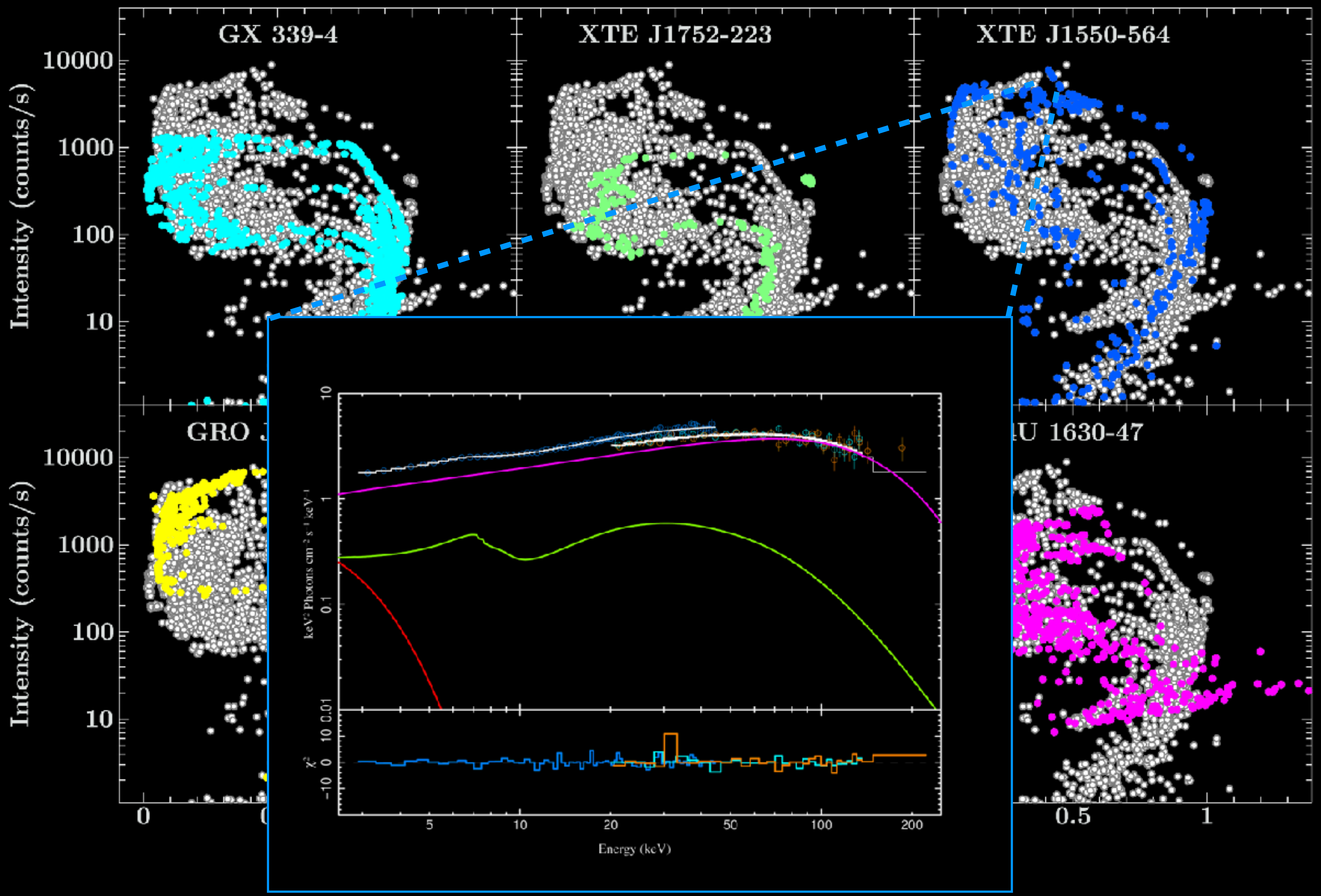
*** Ionization gradient models are now included in RELXILL v1.3.0 ***

The *RXTE* Archive of BHBs

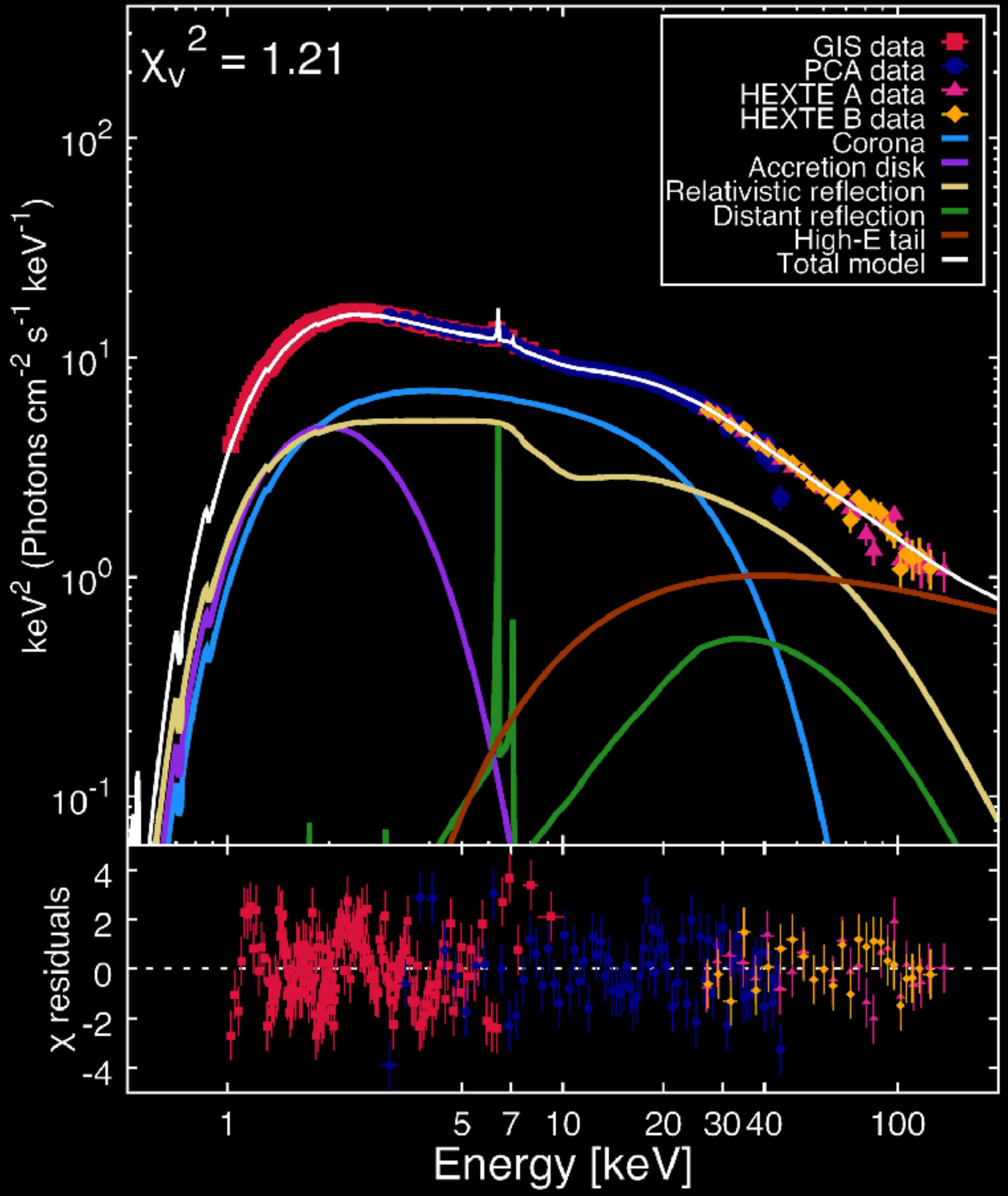
NASA ADAP16: ~15,000 ***RXTE*** spectra with PCA (3-45 keV) and HEXTE (20-250 keV) for ~30 BHB with ~1 ks exposures

XTE J1550-564:
Intermediate spin (a~0.5) from continuum fitting method

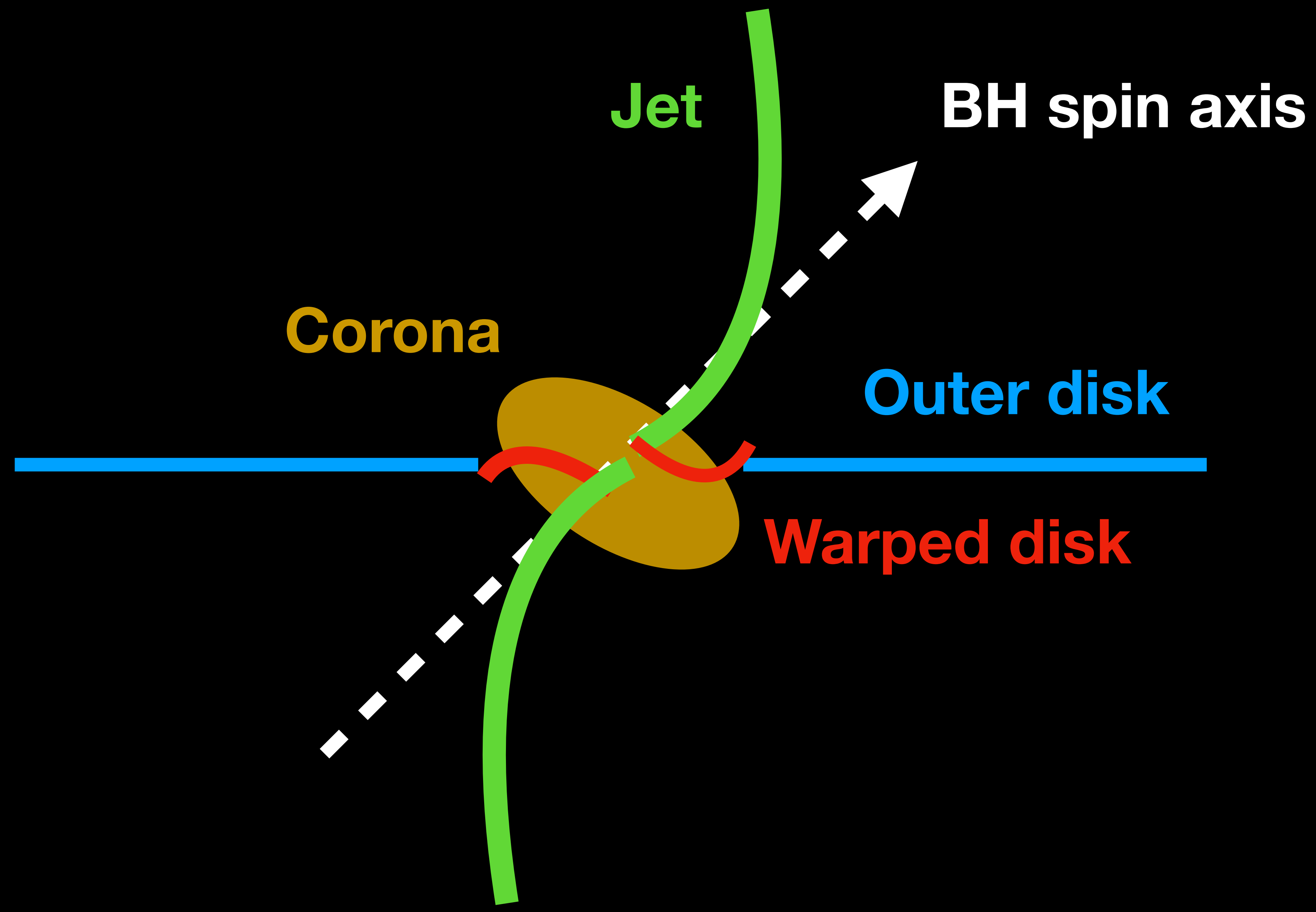
Connors et al., (2019)



XTE J1550-564 - LOW INCLINATION DISK?



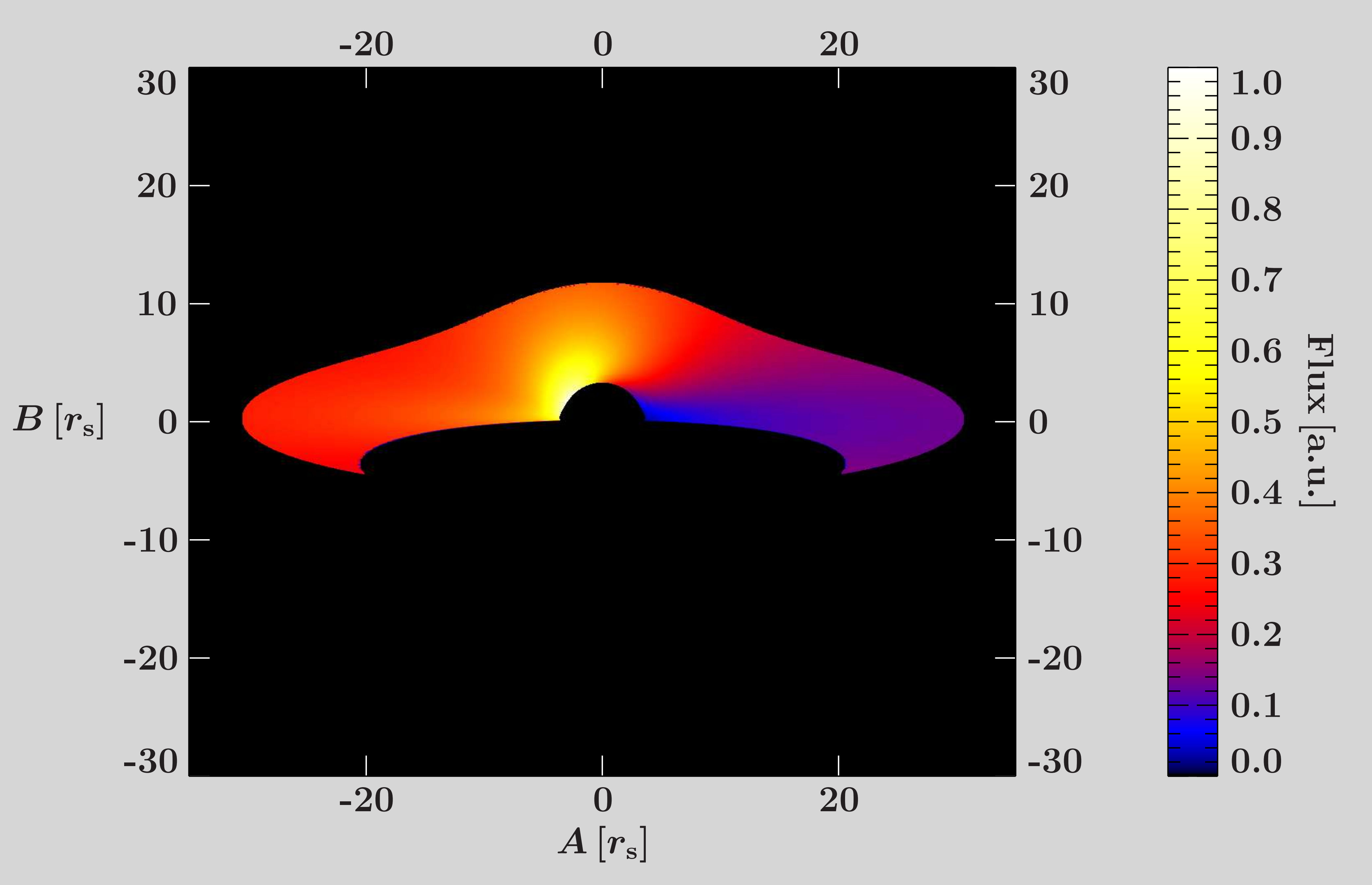
Inclination from reflection modeling inconsistent with radio jet and optical monitoring determinations of the orbital inclination, ***i* ~ 40 deg**, as opposed to ***i* ~ 75 deg** (Orosz et al. 2011, Steiner et al. 2012).



Possible misaligned inner accretion region?

Connors et al. (2019)

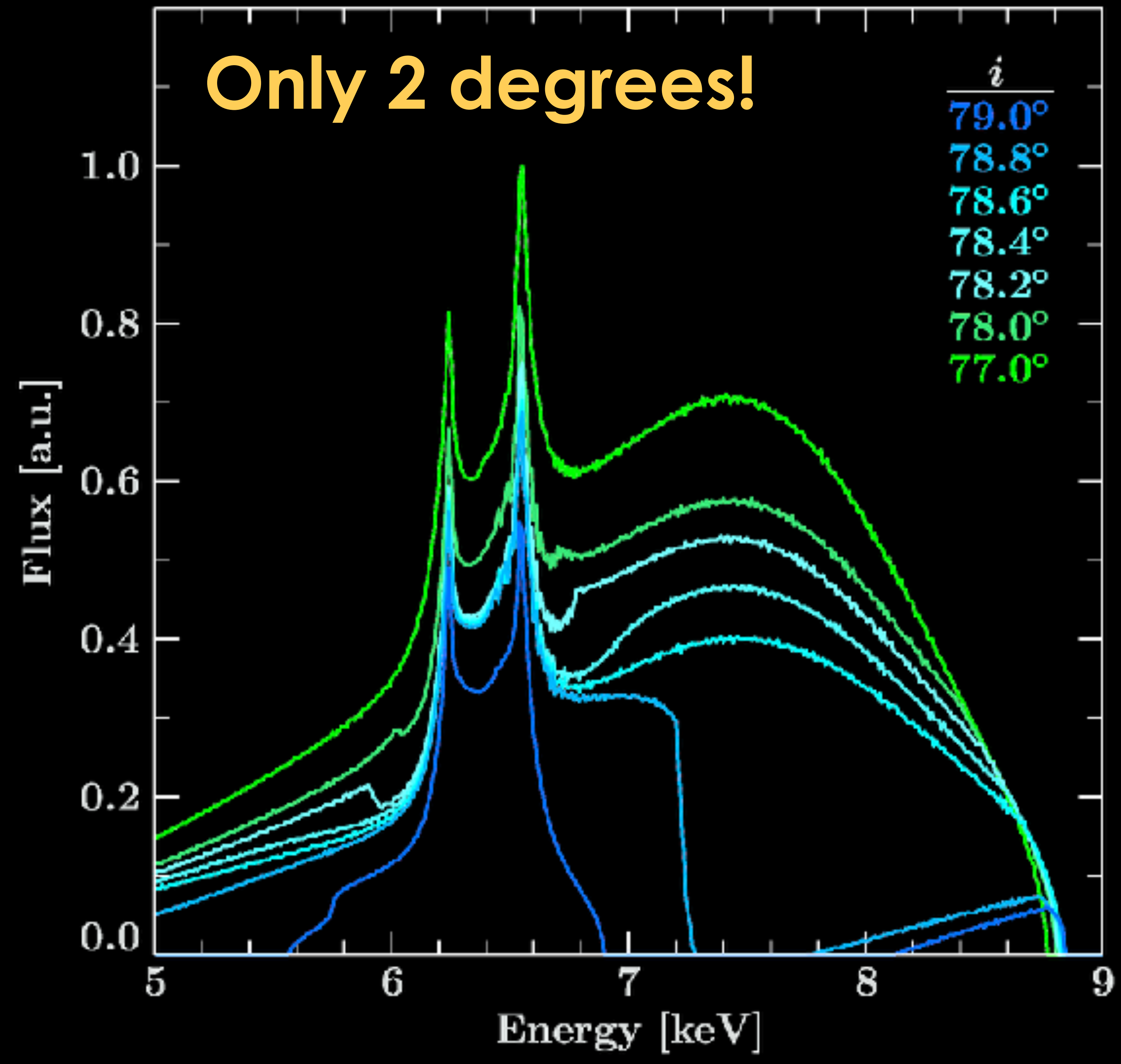
Irradiation of Flared Disks



Brod et al. (2013)

Obscuration effects:

Under an inclination of **78.5°**, part of the disk is covered, affecting both the line profiles and the time lags

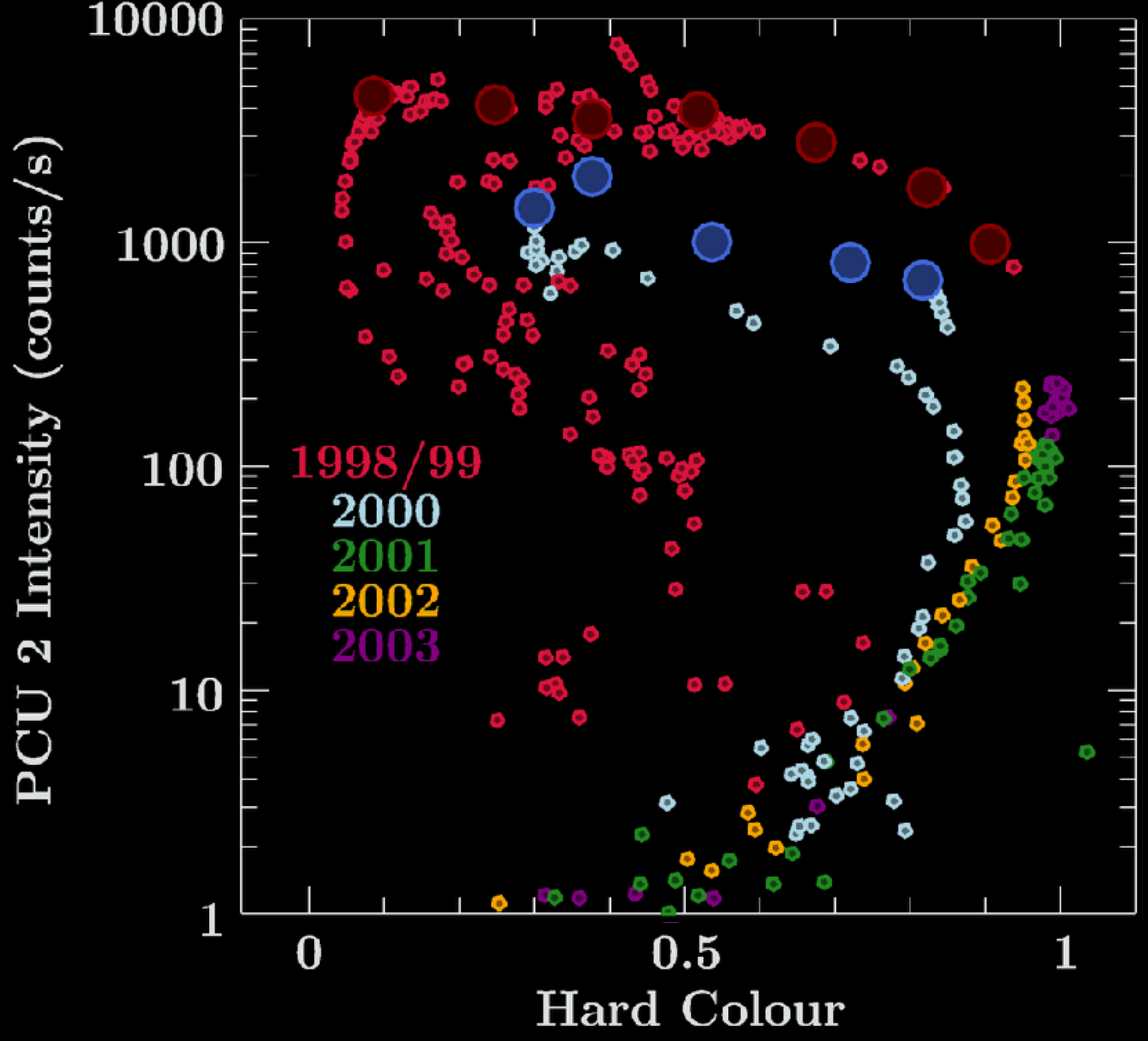


Disk obscuration reduces the blue-wing of the Fe K emission

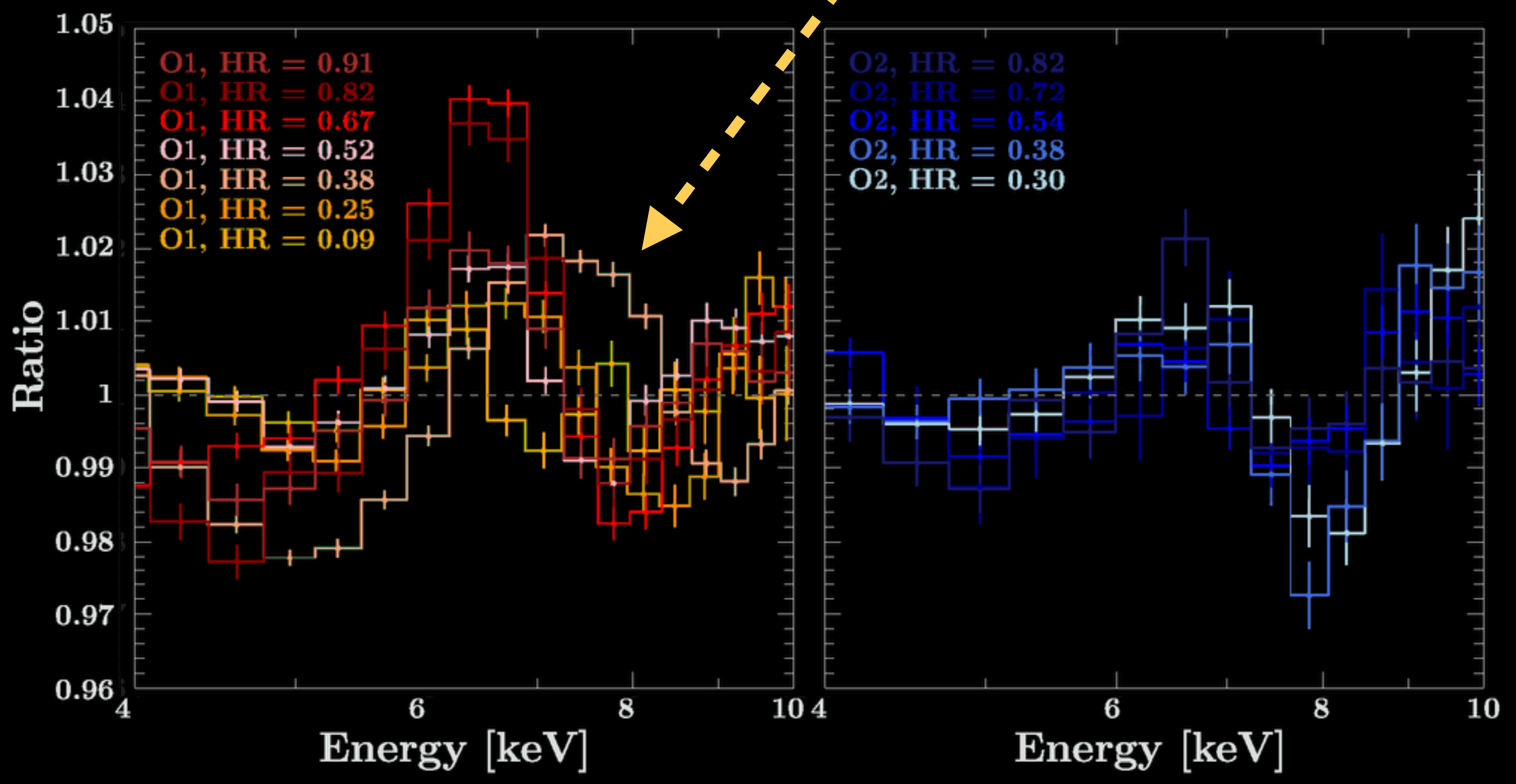
—> Resembles lower inclination!

(see Taylor & Reynolds 2018)

State Transitions in XTE J1550-564



Excess flux



Fe K profile change in the Soft State

Excess flux at higher energies

Connors et al. (2019b, submitted)

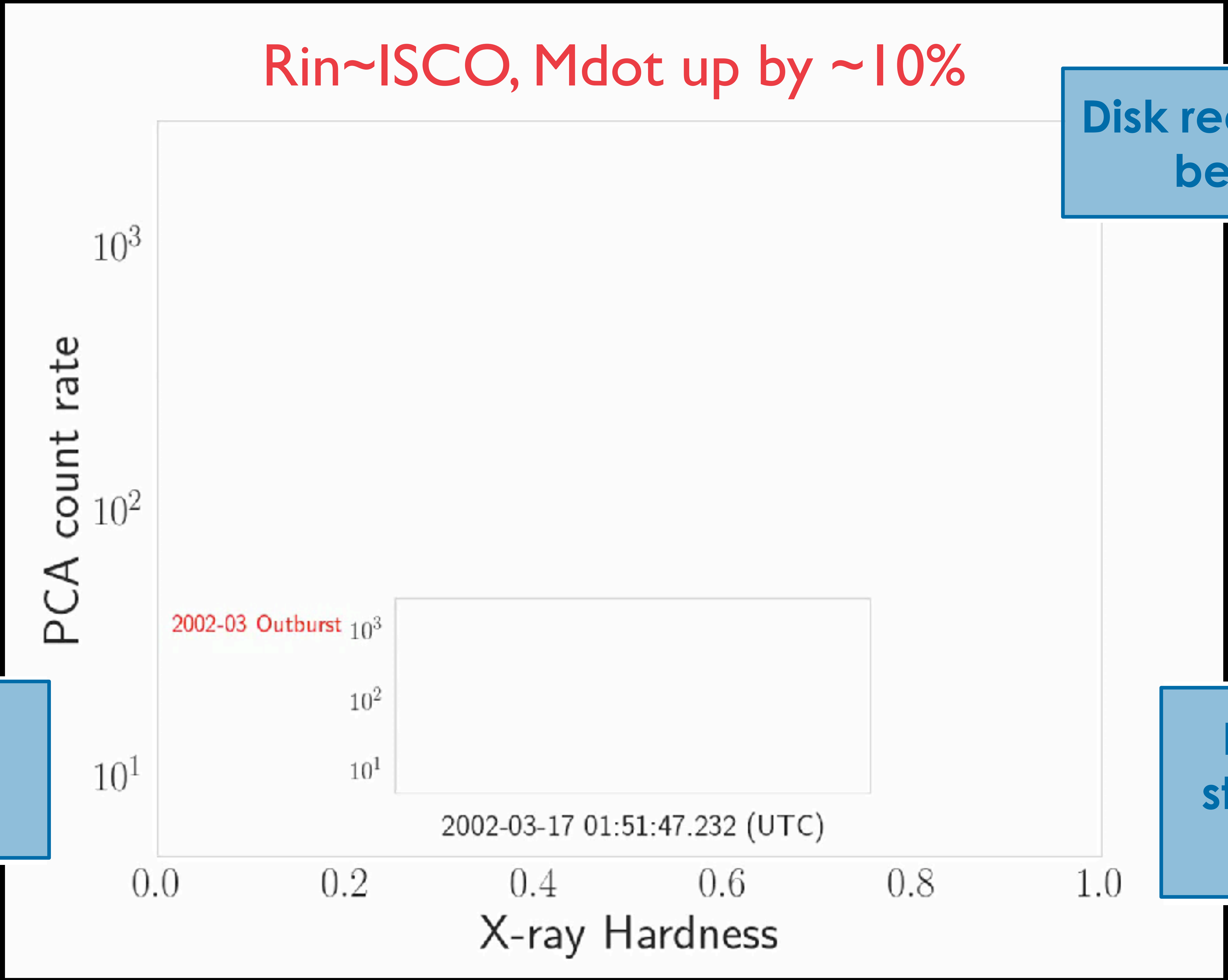
State Transition in GX 339-4

Since Mdot keeps increasing, the disk temperature also increases

Rin=ISCO
Mdot decreases

Decay phase mainly driven by the lack of accretion material

Rin and Mdot decrease



Disk reaches ISCO (or close) before the transition

Rin and Mdot increase

Evolution in the hard state mainly driven by filling of the disk

Summary

X-ray Reflection Spectroscopy provides one of the most powerful tools to study accreting black holes, with which one can study:

* **The Evolution of Disk and Corona**: changes in the corona and accretion disk appear to be correlated. This indicates a connection in the physics that governs the evolution of both structures.

* **The Truncation of the Disk**: All current reflection spectroscopy analysis indicate small or no truncation even at the initial phases of the outbursts. Difference with estimates from timing studies need to be revisited.

* **The Inclination of the Inner Accretion Flow:** The inclination derived from X-ray reflection do not always agrees with the binary orbit. This suggest possible disk warps, or perhaps more complicated, such as obscuration of the inner regions (only important in high inclination systems).