The Question of Hard-State Disk Truncation in Black Holes Binaries

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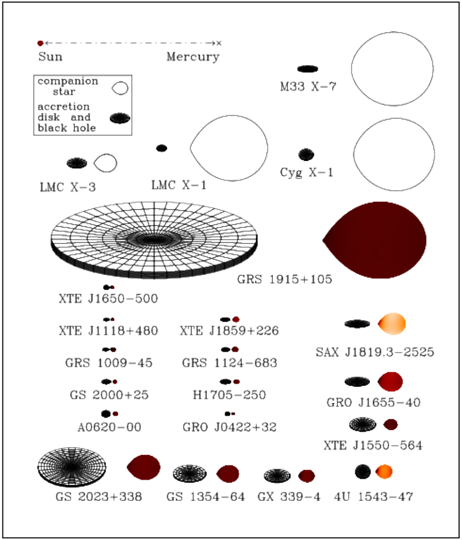
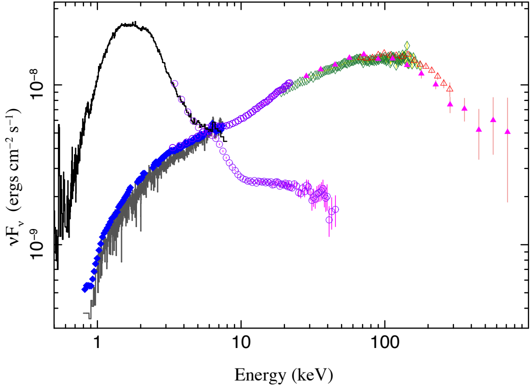
Black Hole Binaries



- Stellar-mass black holes ($\sim$5–30$M_\odot$)
- Modest variability in human timescale
- Many are transient in nature
- Bright outbursts can last several months with up to a billion fold increase in luminosity
- AU-scale persistent jets and parsec-scale ballistic jets
- X-ray QPOs (0.01–450 Hz)
- **Distinct spectral states (hard/intermediate/soft)**

Motivation

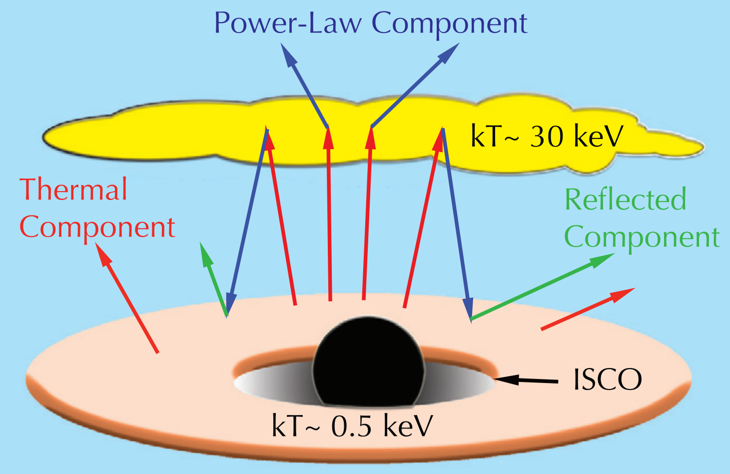
Dramatic spectral changes throughout the outburst!



(Nowak+12)

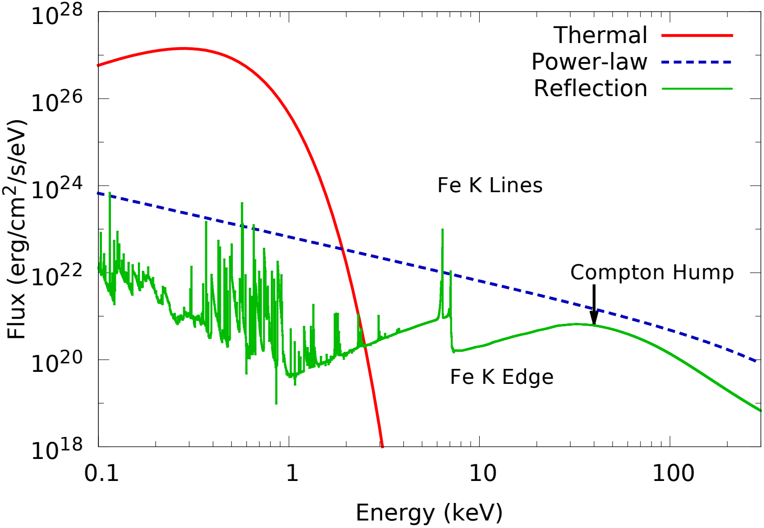
- Study the accretion properties of Galactic Black Holes using the *RXTE* archive
- Detailed analysis of individual sources with physically motivated models
- Dynamically track the evolution of key parameters → **inner radius**

A Hot Corona and a Cold Disk



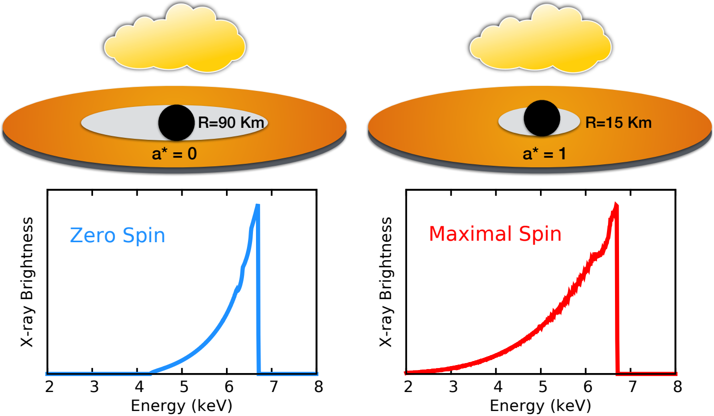
(Gou+11)

Spectral Components



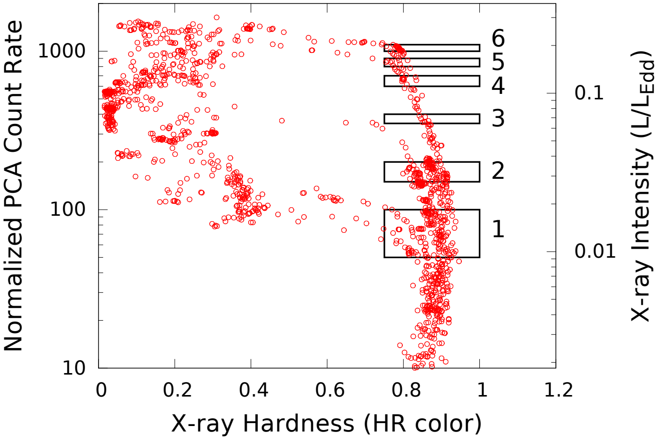
Relativistic Effects on the Fe K line

The radius of the Inner Most Circular Orbit (ISCO) changes monotonically with the black hole spin



Is the inner radius truncated in the hard state?

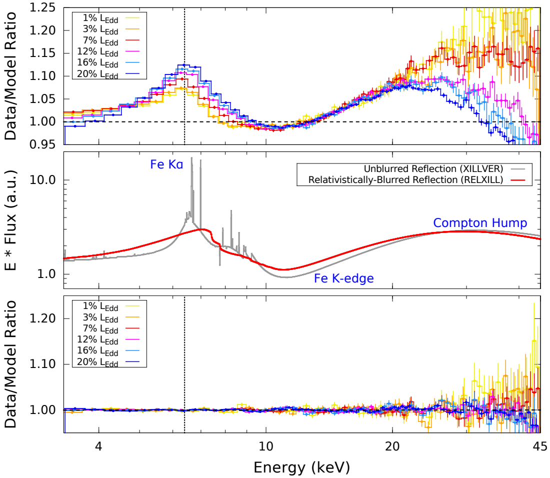
The Prototypical BHB GX 339-4



GX 339-4 + *RXTE* **PCA:** Vast amount of observations in a wide range of luminosities and accretion states. Data is **free of pile-up**.

Fitting Reflection in the Hard-State

Excellent constraints on fundamental parameters of the system: BH spin ($a* = 0.95 \pm 0.04$), inclination ($i = 48 \pm 1$ deg), and Fe abundance ($A_{Fe} = 5 \pm 1$)

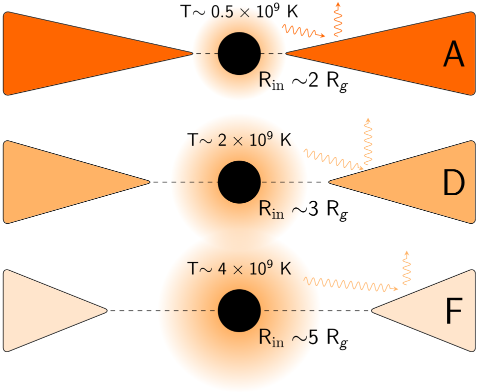


Fit with `relxill`:

- 106 observations
- 77 million total counts
- 0.1% systematic errors!

$$\chi^2_\nu = 1.06$$

Detecting Geometrical Changes



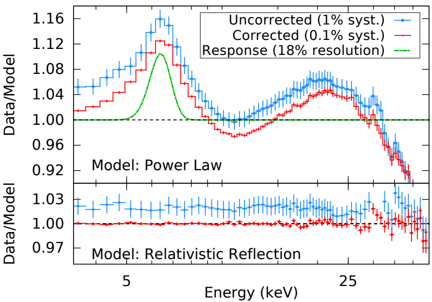
For increasing luminosity, the disk's inner edge moves inward and the corona cools down

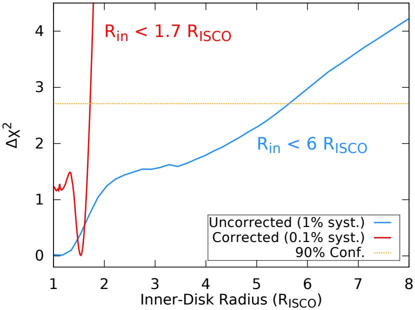
For a $10M_\odot$ black hole, these changes in inner-radius correspond to changing from $R_{\rm in} =$ 75 km to $R_{\rm in} = 30$ km

(García+15)

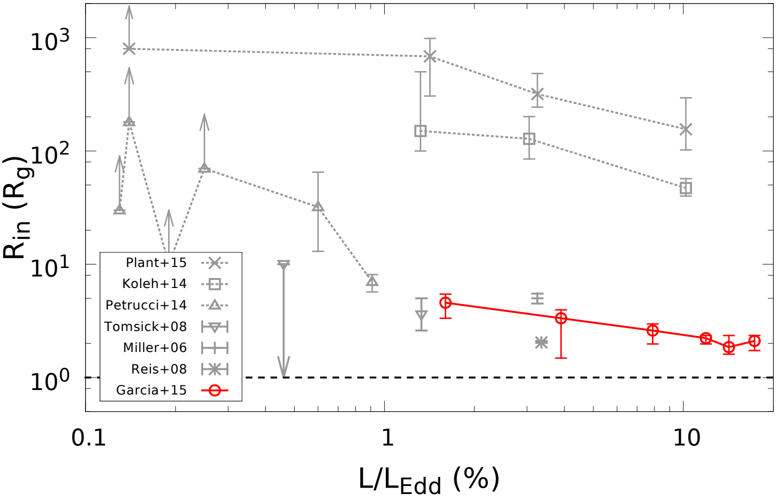
Accurate Estimation of the Inner Radius

Data recalibration with the PCACORR tool (García+14) allows a **ten fold** increase in sensitivity to the reflection features → **increased accuracy!**



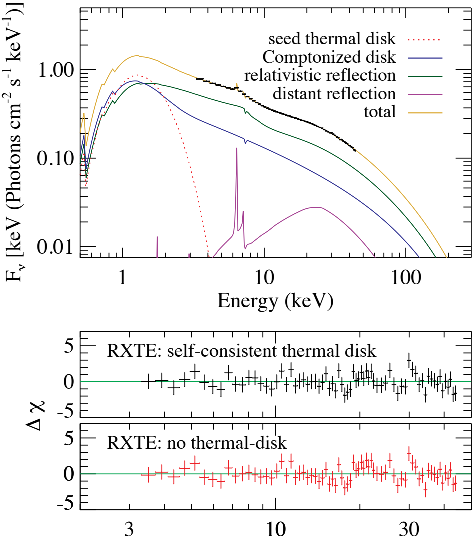


Location of the Inner Radius



García+15

Including the Disk Emission



Steiner+16

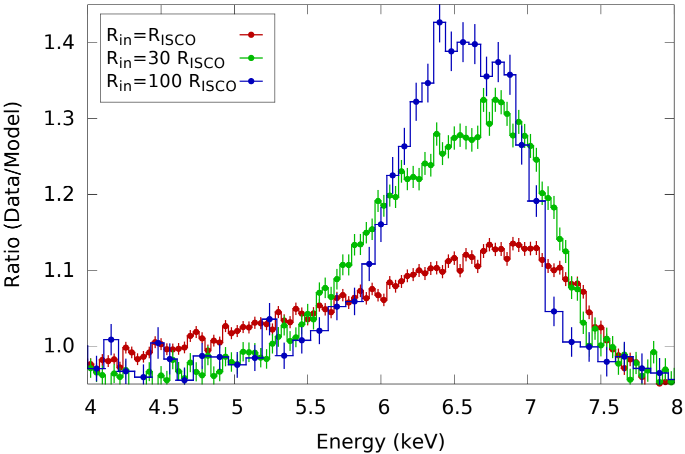
* Self-consistent model including disk emission
* Parameters linked to the inner radius and the accretion rate from the soft-state data:

$$kT_{\rm disk} = kT_{\rm soft}\left(\frac{\dot{M}}{\dot{M}_{\rm soft}}\right)^{3/5}\left(\frac{R_{\rm in}}{R_{\rm ISCO}}\right)^{-6/5}$$

$$N_{\rm disk} = N_{\rm soft}\left(\frac{\dot{M}}{\dot{M}_{\rm soft}}\right)^{-4/5}\left(\frac{R_{\rm in}}{R_{\rm ISCO}}\right)^{18/5}$$

RXTE insensitive to the predicted disk emission $\rightarrow$ Need low-energy coverage from Chandra!

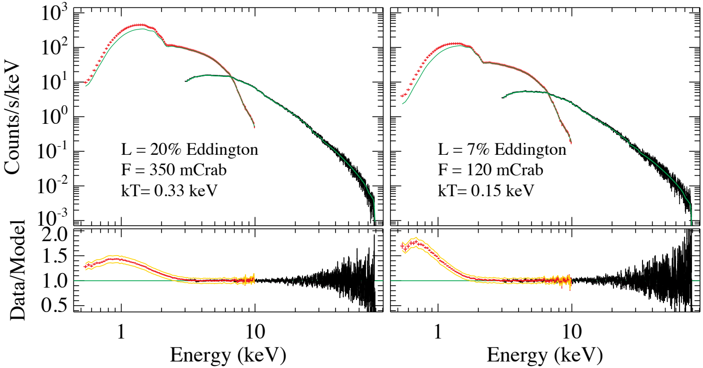
NuSTAR Sensitivity to $R_{\rm in}$



NuSTAR: Higher spectral resolution than RXTE makes it more sensitive to small changes in the inner radius

The Future: *Chandra + NuSTAR*

NuSTAR's bandpass similar to RXTE (also insensitive to the disk emission), whereas Chandra data is highly sensitive to its presence.



Chandra will open a new window into the thermal disk emission in the bright hard state!

Final Remarks

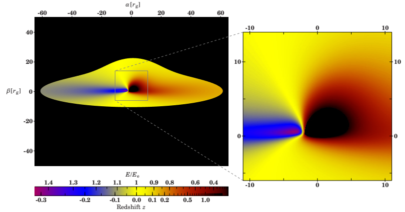
- Combined *RXTE* data with 0.1% systematics provide **unprecedent precision** to measure X-ray reflection from accretion disks.
- In the case of GX 339-4 in the hard-state, clear signatures of reflection are observed over a wide range of luminosities (factor of ~ 20). The variations in L/L_{Edd} are well correlated with changes in ionization ξ.
- These fits present evidence of R_{in} moving inwards with increasing luminosity, and possible disk truncation of just a few R_{ISCO} for low L/L_{Edd}.

While **NuSTAR** is currently the best instrument for reflection spectroscopy, **only** simultaneous **Chandra** observations will provide a definitive test of the truncation paradigm for the bright hard state.

Backup Slides

Modeling Relativistic Reflection: RELXILL

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



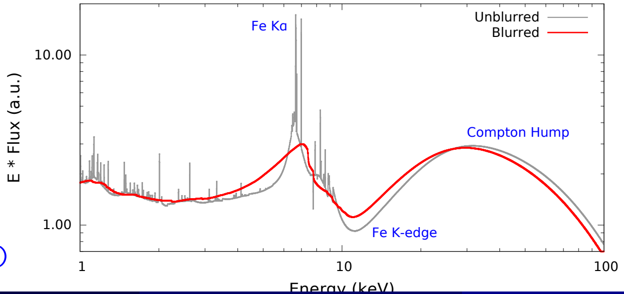
Model Parameters

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)

Comparing XMM-Newton TM and RXTE PCA