Truncated Black Hole Accretion Disks at Low Luminosities

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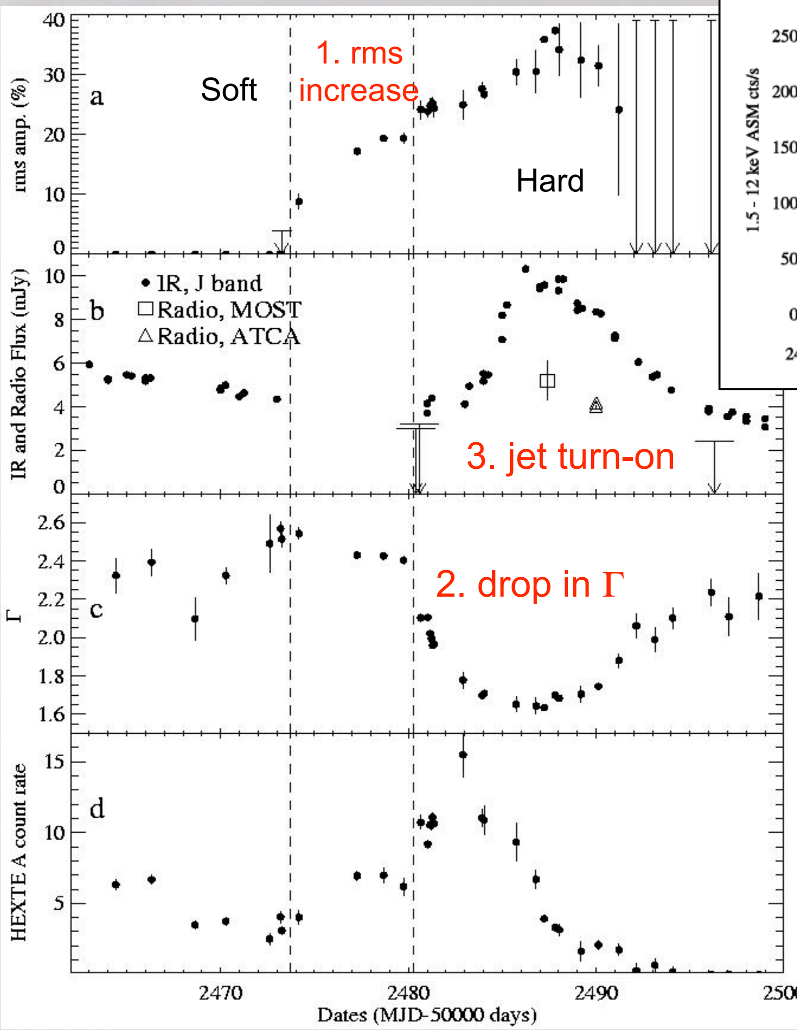
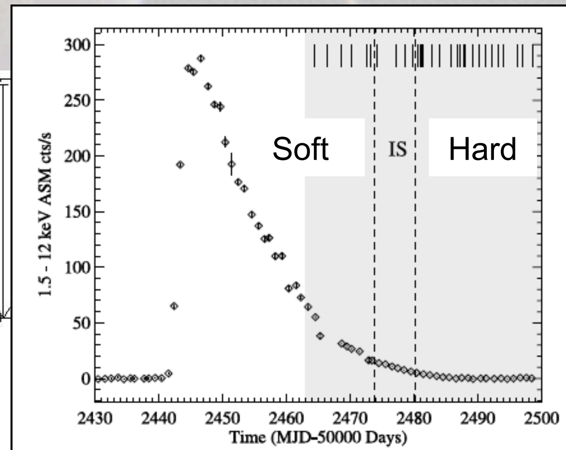
Overview

- Black holes during outburst decay (2000-2005)
  - RXTE monitoring: Transition to the hard state (Kalemci thesis)
  - Multi-wavelength program: Turn-on of the compact jet
- Recent constraints on the accretion geometry by observing the GX 339-4 iron line at low luminosities
  - XMM, Swift, RXTE hard state results (2006-2008)
  - "Truncation of the Inner Accretion Disk around a Black Hole at Low Luminosity" by Tomsick, Yamaoka, Corbel, Kaaret, Kalemci, & Migliari, submitted to ApJ Letters
- Implications for black hole accretion, evaporation of the accretion disk, and the disk/jet connection

Black holes during outburst decay



4U 1543-47, Kalemci, Tomsick, et al. 2005



What happens during transitions to the hard state?

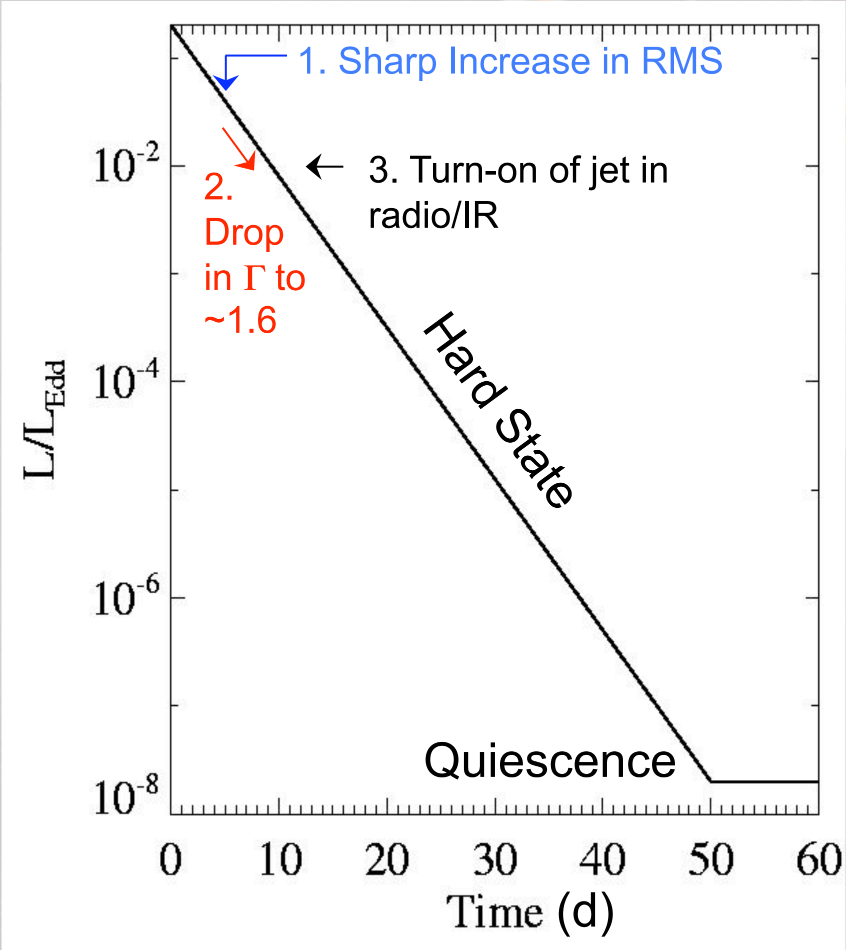
1. Rms (noise) increase
2. Hardening of the spectrum
3. Turn-on of compact jet

The same or very similar X-ray/radio evolution has been seen for:

XTE J1550-564 (Tomsick et al., Jain et al. 2001)
GX 339-4 (Homan et al. 2005; Kalemci et al. 2007)
H 1743-322 (Kalemci et al. 2006)
GRO J1655-40 (Homan et al., Brocksopp et al.)

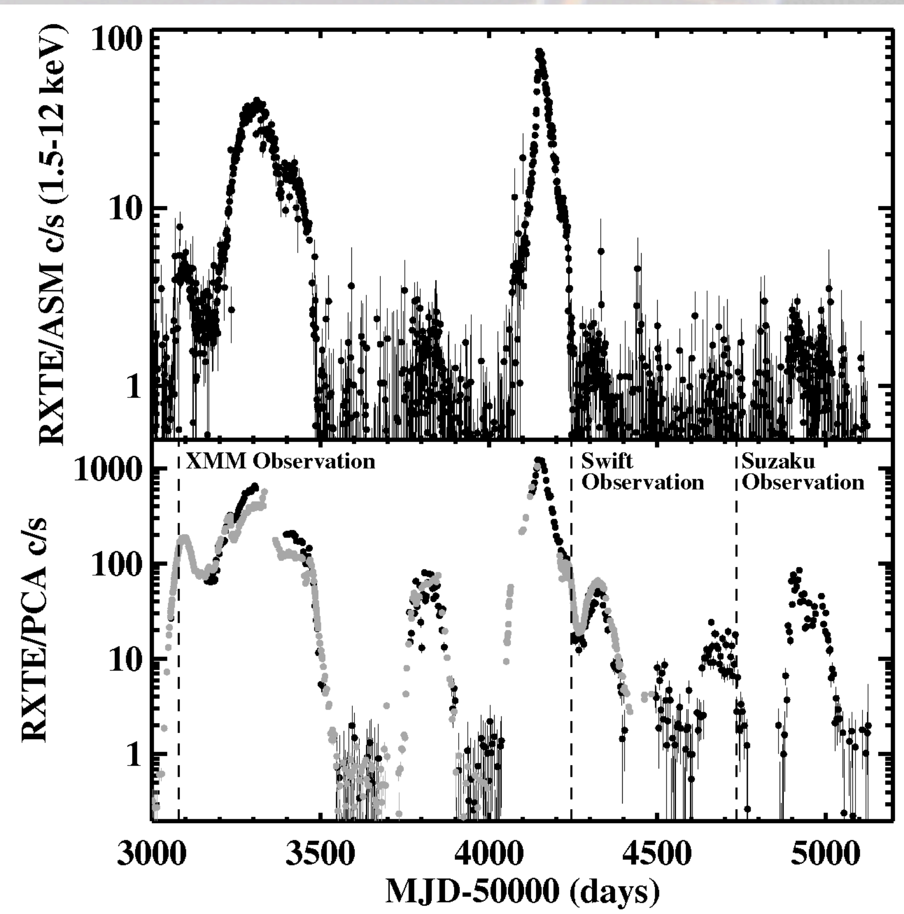
- Jet activity is most closely linked to the hardness of the X-ray power-law.
- Physically, this indicates ...
  - a link between the corona and the jet
  - that possibly the corona needs to reach a critical density to launch the jet

BHs during outburst decay - 2



- The transition occurs at a few % of L_{Edd}.
- Still a factor of 10^6 above "quiescence."
- What happens between the transition and quiescence?
- What is the accretion geometry in the hard state?

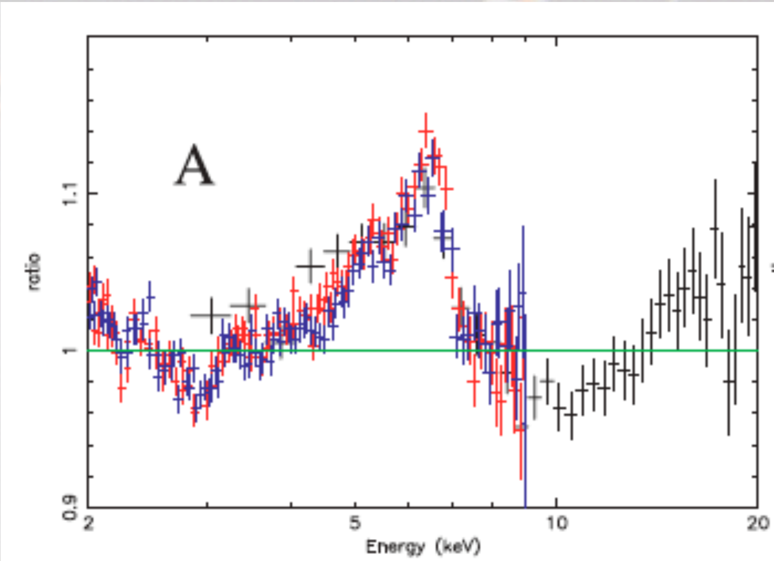
GX 339-4 Monitoring (2004-2009)

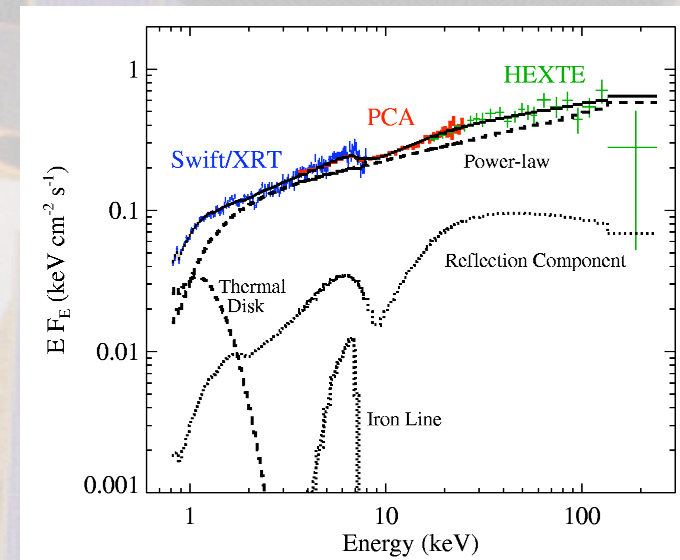


Bottom panel shows PCA measurements:
• Black: Galactic Bulge Scans (Markwardt et al.)
• Grey: Pointed RXTE observations (3-25 keV)

- GX 339-4 has been the most active black hole "transients" during this time period.
- Three X-ray telescope observations made in the hard state:
  - XMM at 5.6% L_{Edd} during the rise (Miller et al. 2006)
  - Swift at 2.3% L_{Edd} during decay (Tomsick et al. 2008)
  - Suzaku at 0.24% L_{Edd} (Tomsick et al. 2009)

Hard State at 2-6% L_{Edd}: Broad Iron lines and thermal components



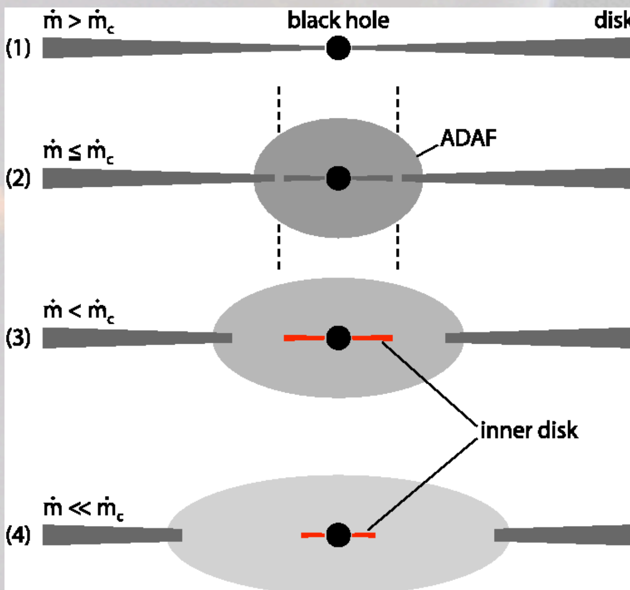


- Iron line profile from the XMM +RXTE observation at 5.6% L_{Edd} (Miller et al. 2006)
- Laor (1991) relativistic modeling of the iron line gives R_{in} = 4±1 R_g

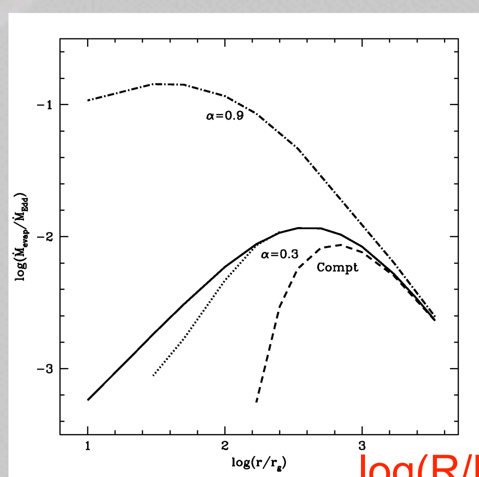
- Swift+RXTE spectrum at 2.3% L_{Edd} (Tomsick et al. 2008)
- Relativistic modeling of the iron line gives $R_{in} = 3.6^{+1.4}_{-1.0}\ R_g$.
- The thermal disk component has been seen for several systems in the hard state.

An inner cool disk in the hard state?

Meyer-Hofmeister et al. 2009



dM/dt (evaporation)

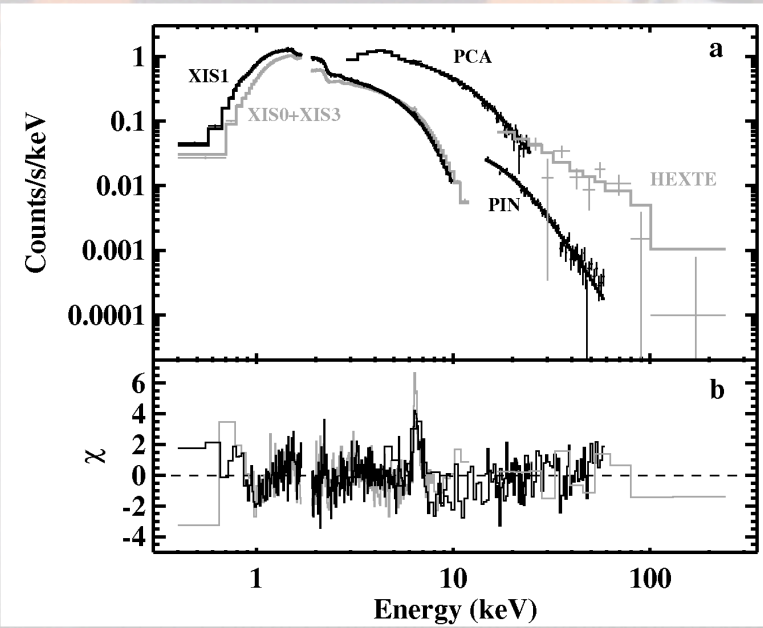


$\log(R/R_g)$

Liu et al. 2002

- Due to radial variations in thermal conduction from corona to disk, an inner optically thick disk can form (Liu et al. 2002,2007).
- To persist, matter can condense into the inner disk from a Compton-cooled corona (Liu et al. 2006,2007; Meyer et al. 2007; Taam et al. 2008).
- One prediction is that the entire inner disk will evaporate below about 0.1% L_{Edd} (Liu et al. 2007; Taam et al. 2008).

New Result: Hard State at 0.24% L_{Edd}: Narrow Iron Line

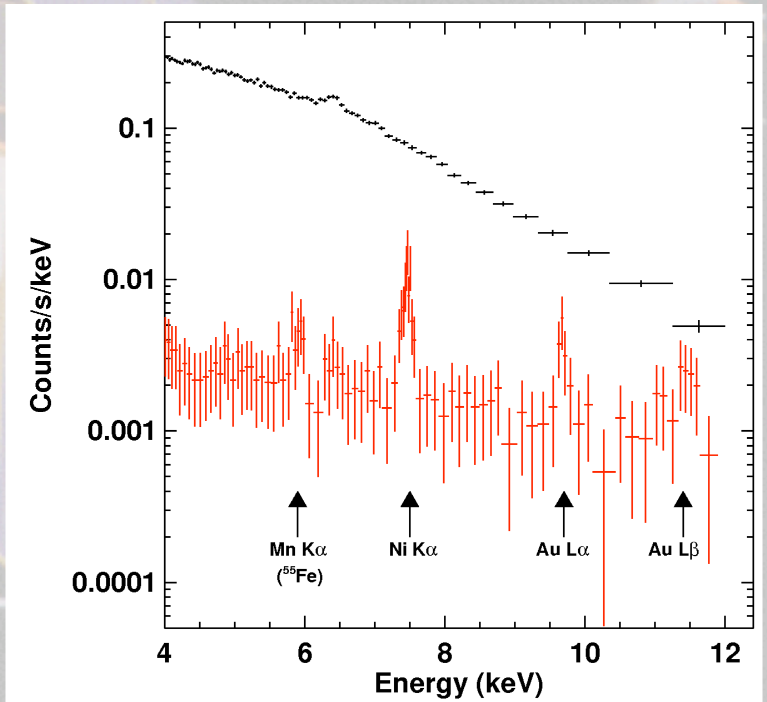


- Suzaku+RXTE spectrum for GX 339-4 taken in 2008 September (Tomsick et al. 2009)

- Suzaku
  - T_{XIS} = 105 ks, $T_{HXD/PIN}$ = 107 ks
  - Triggered by RXTE
- RXTE
  - T_{PCA} = 15 ks, T_{HEXTE} = 5 ks
- Power-law continuum:
  - $\Gamma = 1.573 \pm 0.006$
  - L/L_{Edd} (1-100 keV) = 0.24%
- Iron line parameters:
  - $E_{line} = 6.45^{+0.03}_{-0.02}$ keV
  - $\sigma_{line} = 0.14^{+0.04}_{-0.03}$ keV
  - EW = 77^{+12}_{-10} eV

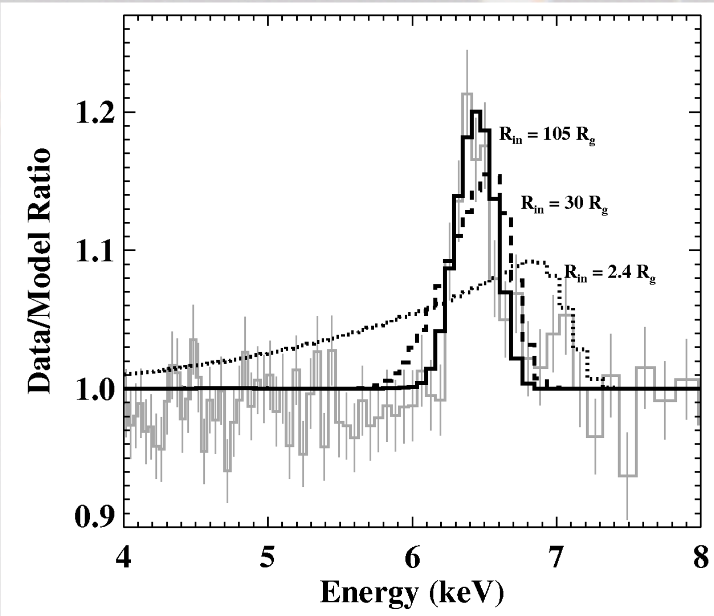
Is the line really from GX 339-4?

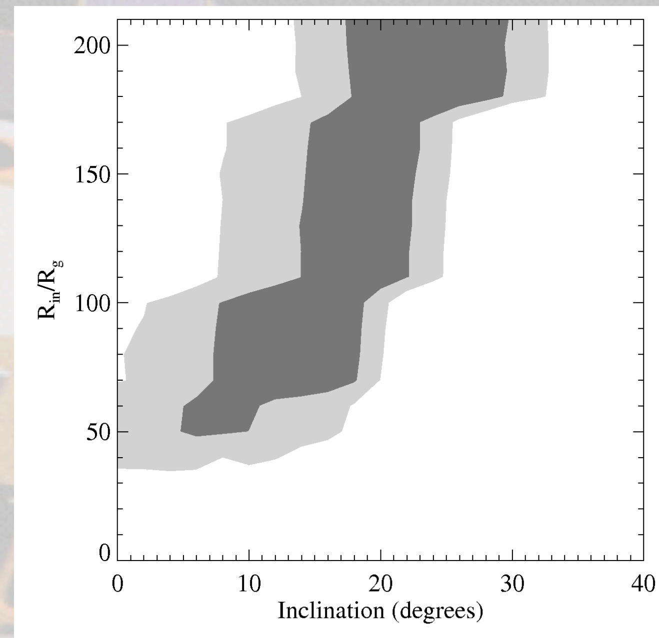
- Could this narrow line be from the background or part of the Galactic Ridge emission?
- Suzaku/XIS background rate is 1.9% of source rate and does not have a strong line at 6.4 keV.
- We made a second XIS spectrum with an extraction region that is 25 times smaller, and the iron line EW does not change.
- We have used quiescent PCA observations to subtract ridge emission from the PCA spectrum.
- We conclude that the iron line is from GX 339-4.



GX 339-4 spectrum (black) and Suzaku/XIS background (red)

Constraints on R_{in} at 0.24% L_{Edd}

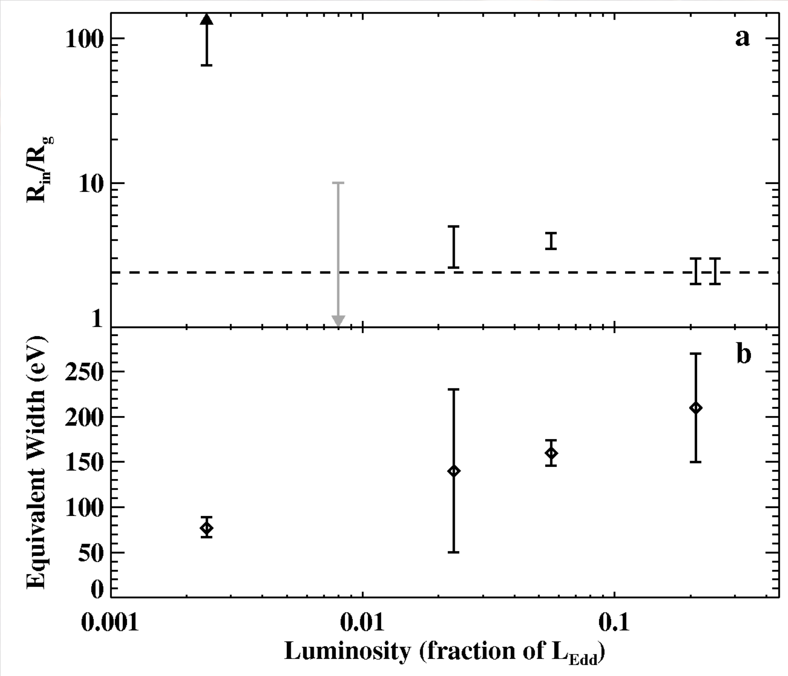




- GX 339-4 Suzaku/XIS iron line profile with theoretical profiles (Laor 1991) for different values of Rin, assuming i = 18° (from Miller et al. 2008).

- 68% and 90% confidence error regions for R_{in} and disk inclination
  - $R_{in} > 35\ R_g$ at i = 0°
  - $R_{in} > 175\ R_g$ at i = 30°

Summary and Conclusions



GX 339-4 Iron line constraints on R_{in} and EW as a function of L_{Edd} (Miller et al. 2004, 2006, 2008; Reis et al. 2008; Tomsick et al. 2008, 2009)

- Results tell us about accretion models
  - e.g., ADAF is viable at low luminosities
- Results tell us about accretion disk evaporation
  - evolution is consistent with the inner disk model
- Results tell us about jets
  - radio emission from jets detected during all 3 hard state observations
  - jets may not be related to optically thick disk ... strengthens connection to corona

RXTE Contributions

- RXTE has been a pathfinder for this sort of study.
- RXTE monitoring has been crucial for triggering observations.
  - Even considering MAXI and Swift/BAT, the RXTE Galactic Bulge monitoring has the best sensitivity.
- For spectral studies, both PCA and HEXTE provide important constraints on the continuum.
- Of course, RXTE also does timing!
  - We are working on this for GX 339-4 as well (Kalemci et al., in prep.)