The Interaction of X-ray Bursts with its Surroundings

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- NASA/ADAP

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Outline

- X-ray reflection from a neutron star accretion disk during a burst
- Application to the 4U 1820-30 superburst observed by *RXTE*
- Interpretation of results
- Application to the 4U 1636-53 superburst observed by *RXTE* & interpretation
- Other evidence for disk interactions
  - Comment about Poynting-Robertson drag
- Future prospects with *NICER*

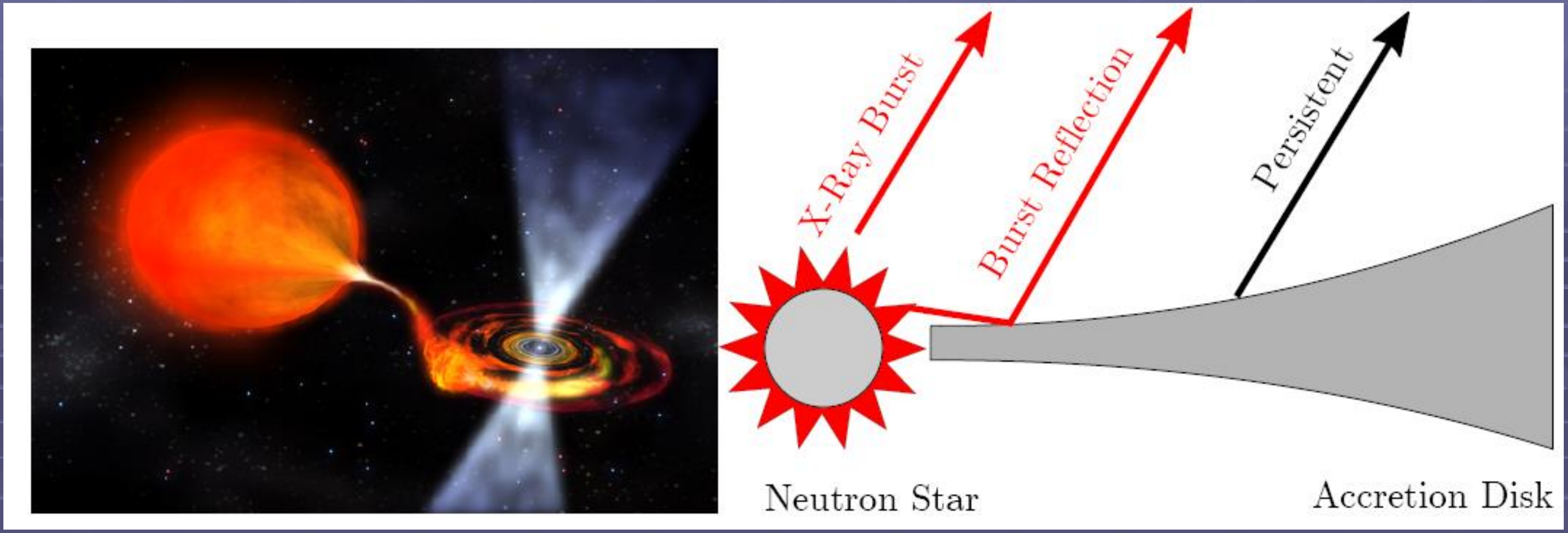

Figure courtesy L. Keek.

- In general, can observe 3 spectral components during a burst:
  - The burst itself (blackbody-ish)
  - The reflected blackbody
  - The persistent emission (cutoff power-law)
- These last 2 components contain information on how the burst may impact the accretion disk.

X-ray Reflection From Accretion Disks during Bursts

Mon. Not. R. astr. Soc. (1991) **253,** *Short Communication,* 35P–38P

A disc-reflected component in the spectra of X-ray bursters

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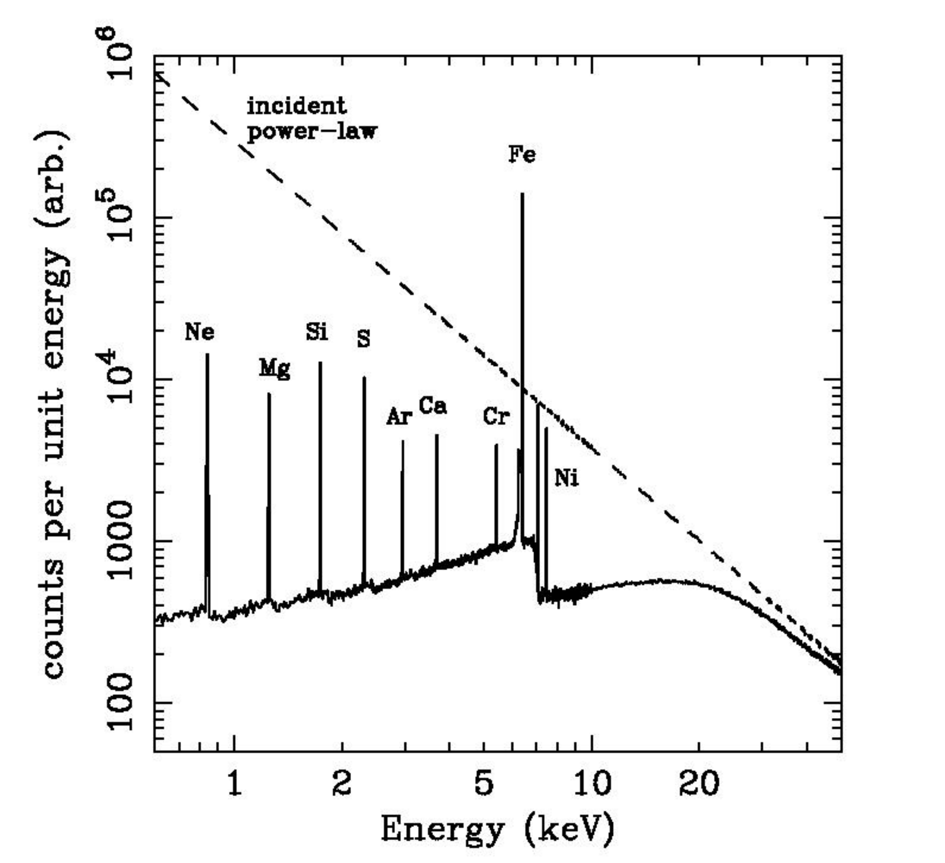
Accepted 1991 October 15. Received 1991 October 12; in original form 1991 August 21

SUMMARY
We show that a disc-reflection component, as seen in AGN, can be detected in the spectrum of X-ray bursts during the burst tail, and speculate on the use of the concomitant absorption edge as a diagnostic of the accretion disc.

- Suggested that disk reflection may cause an Fe absorption edge in a hard tail of a burst.
- Could be used to determine ionization state of the disk as well as its geometry.

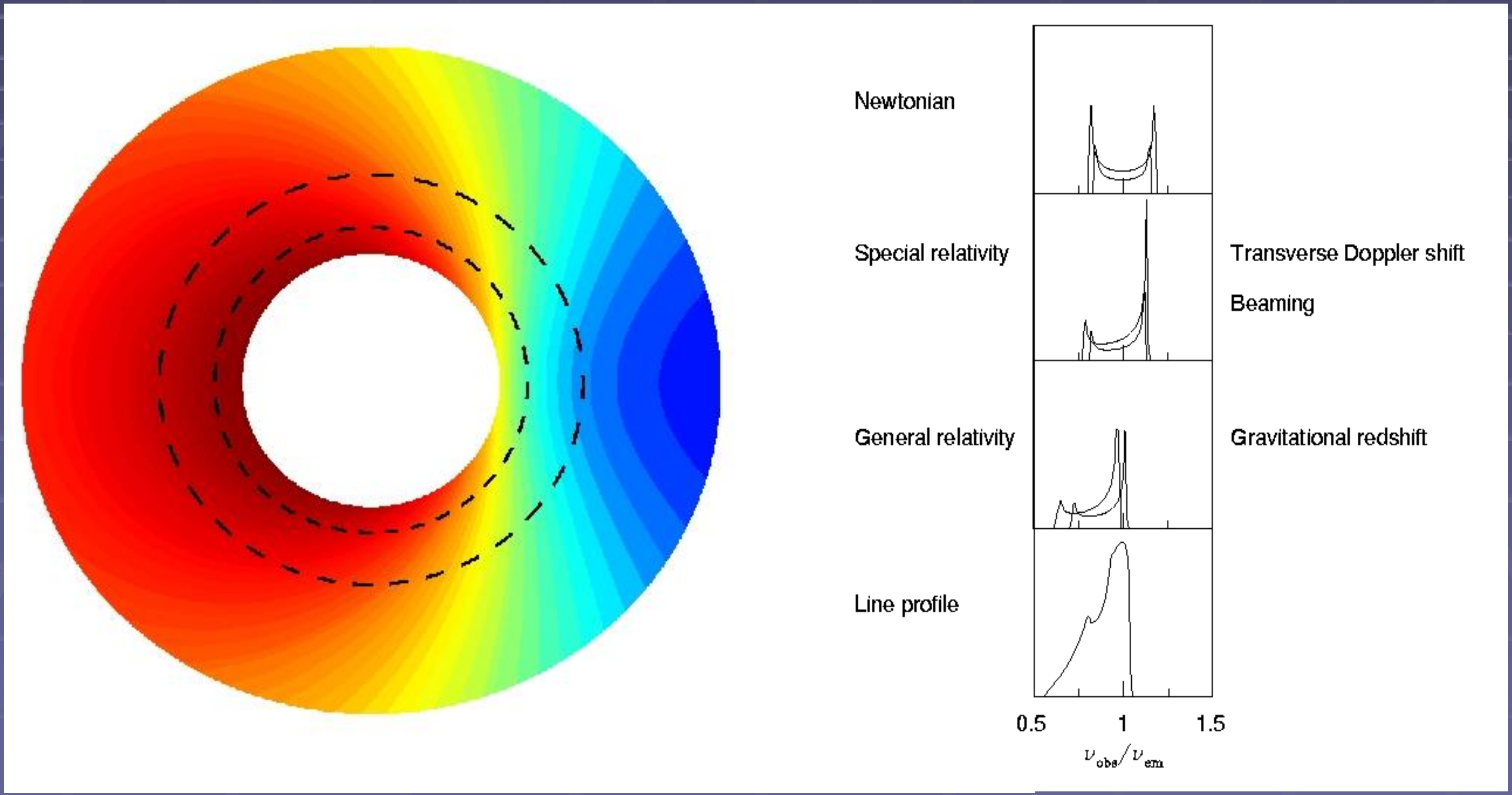
Reflection Basics

- Reprocessing of incident X-rays commonly observed from Seyfert 1 galaxies and Galactic Black Hole Candidates
- Due to its high fluorescent yield and cosmic abundance, the Fe Kα line is predicted to be a prominent feature in X-ray reflection spectra
- Until 2004, no models available for X-ray bursts!



George & Fabian (1991); Matt, Perola & Piro (1991)

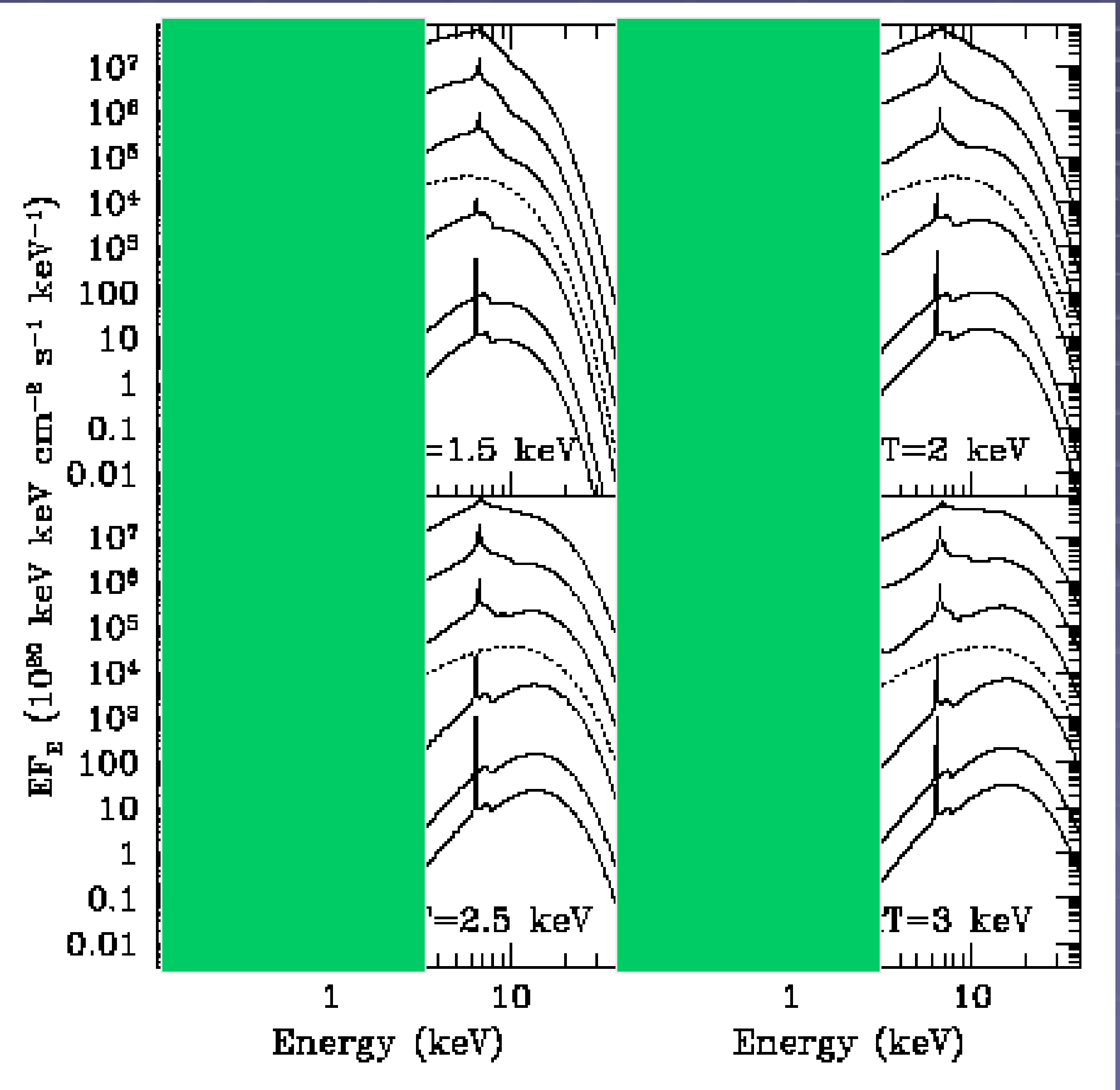
▪ What happens to an emission line which originates from a spinning disc close to a relativistic object like a neutron star?



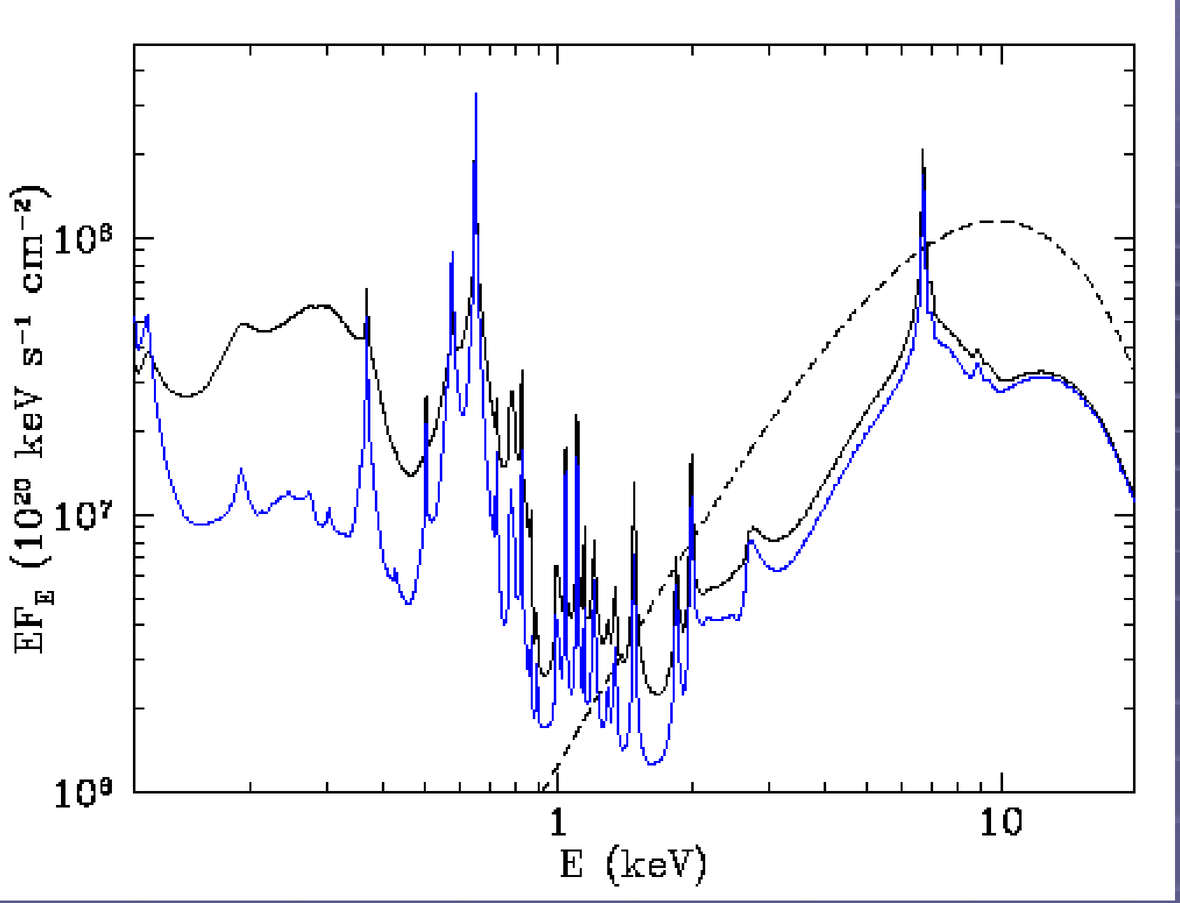
Constant Density Models

- Models parameterized by the ionization parameter

$$\xi = \frac{4\pi F_X}{n_H}$$



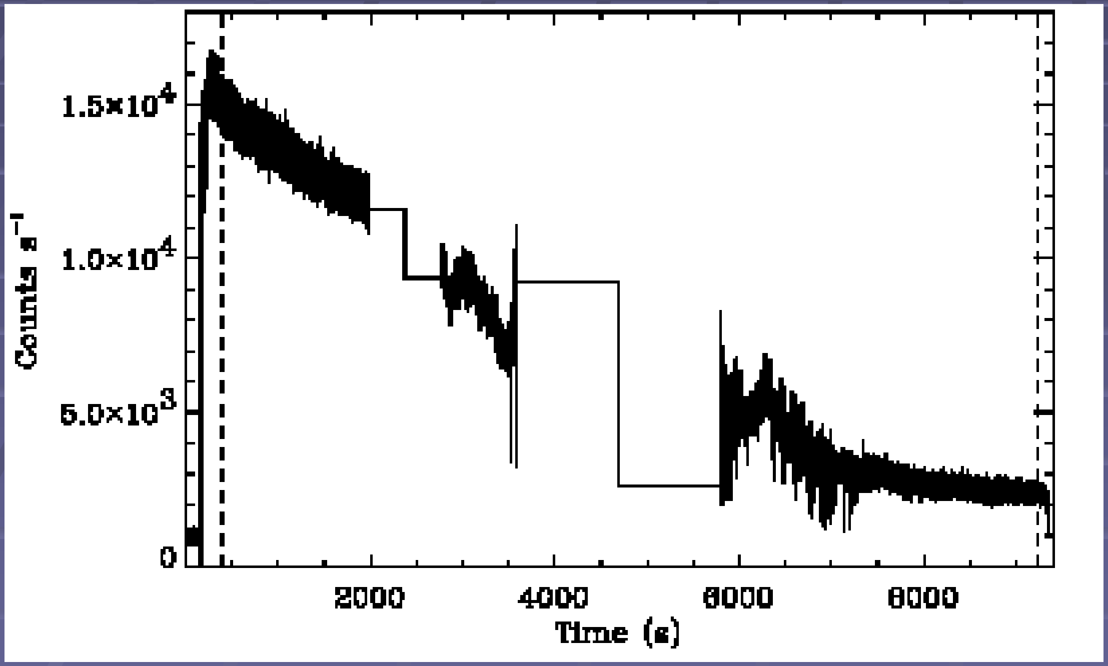
Ballantyne (2004)



Ballantyne (2004)

- Soft X-ray spectrum is sensitive to density of disk
- Above, black=10^{18} cm^{-3}, blue=10^{15} cm^{-3}
- If a broadband instrument such as *Swift*- XRT or *NICER* catches a superburst then a wealth of information on the accretion disk may be available
- Current models limited to densities <~ 10^{20} cm^{-3}

The Superburst from 4U1820-30



Strohmayer & Brown (2002)

LMXB within the globular cluster NGC 6624.

Has a 11.4 minute orbit, so companion is likely an evolved low-mass He star.

Superburst occurred on 1999 September 9. Was being observed by RXTE/PCA.

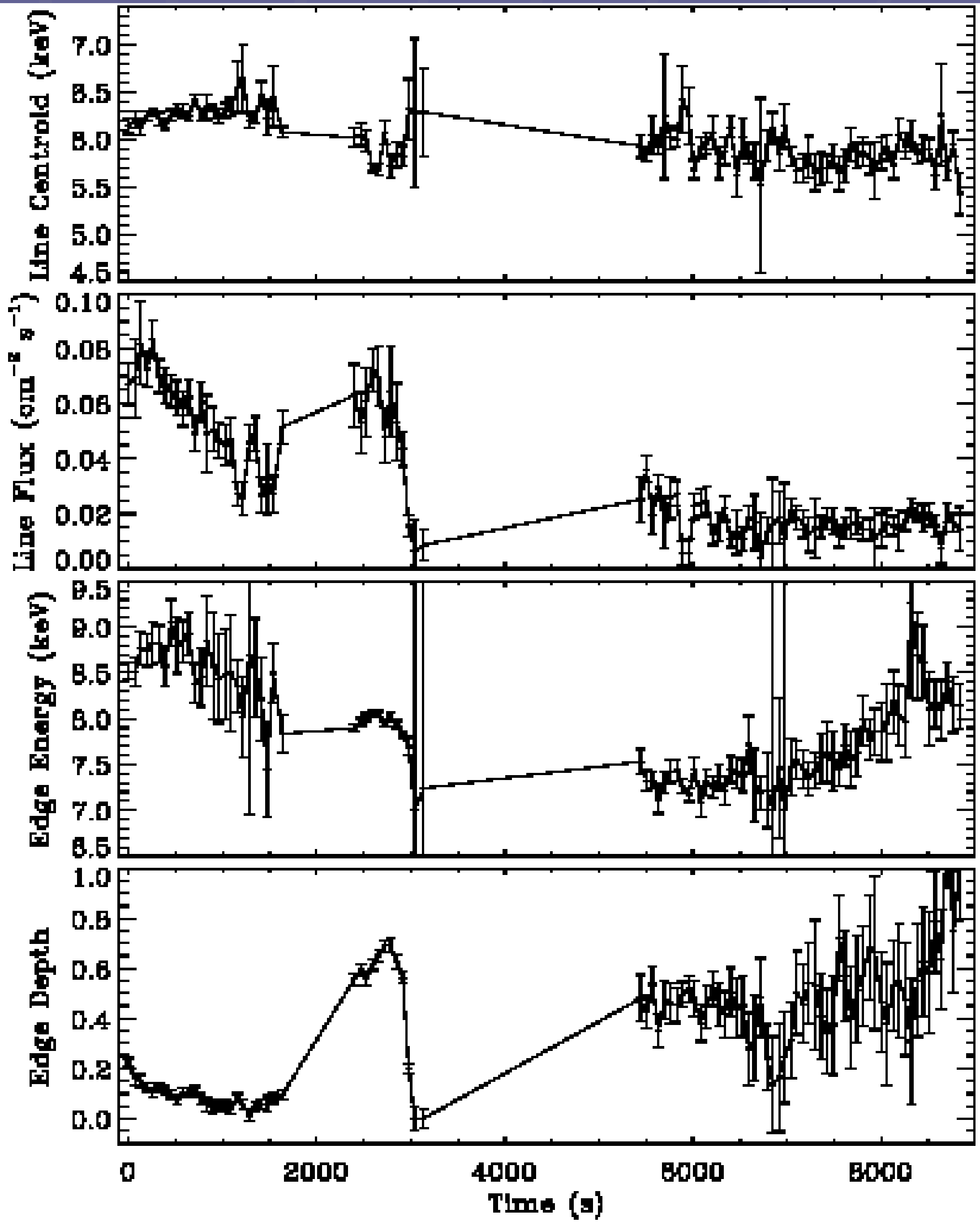
Strohmayer & Brown (2002)

Line Energy

Line Flux

Edge Energy

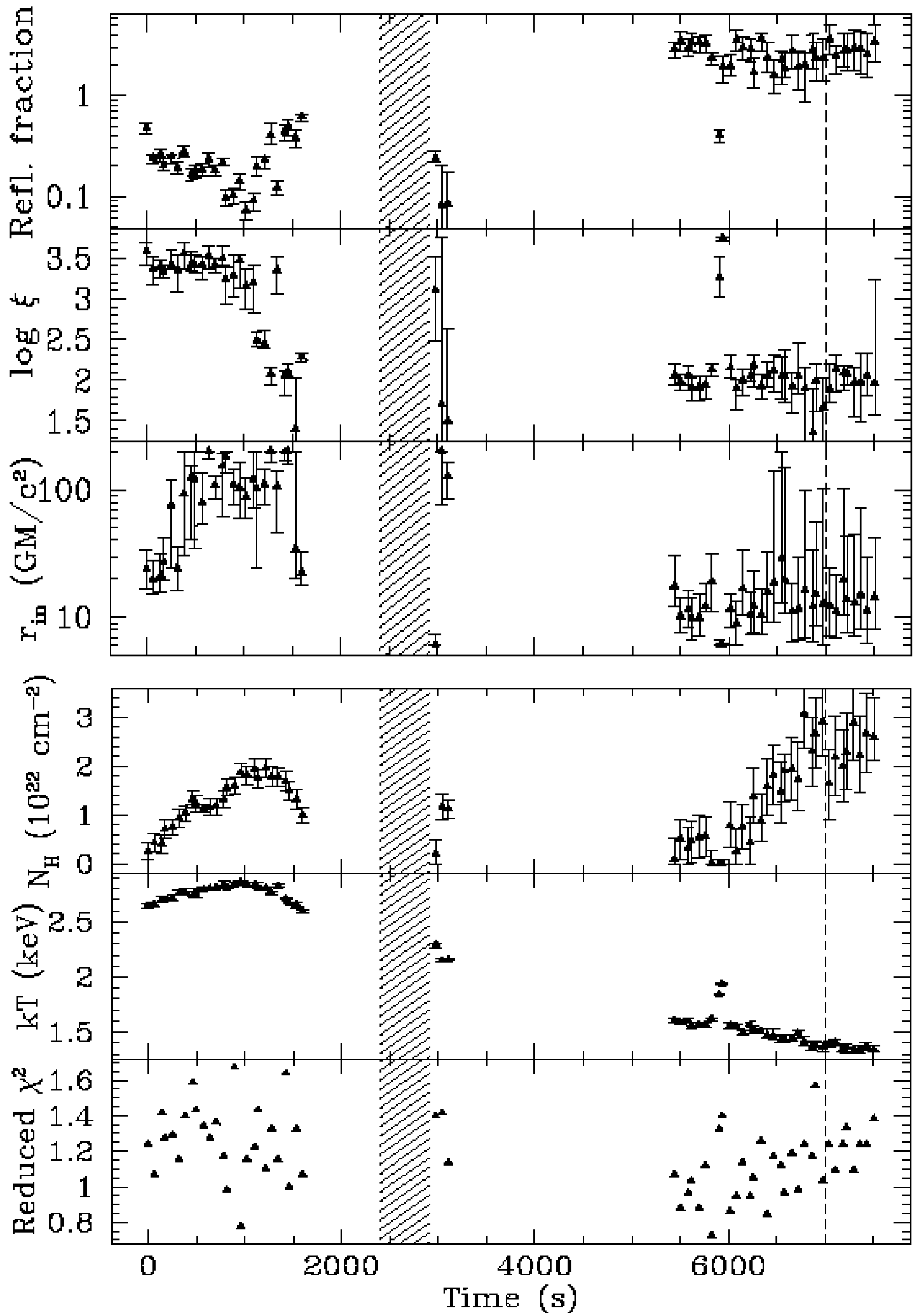
Edge depth



Fitting the Superburst

- have ~80 spectra with a 64s integration time
- could fit between 3-40 keV for most of the spectra; the last 10 or so could only be fit up to 15 keV due to the encroaching background
- fit parameters: N_H (absorbing column density)
  log ξ (ionization parameter)
  R (reflection fraction)
  kT (blackbody temperature)
  r_{in} (the inner disk radius)
- fixed parameters: inclination angle (=30 degrees)
  r_{out} =200 GM/c^2 (the outer disk radius)
  emissivity index = –3
- Used extreme He star abundances from Pandey et al. (2001)

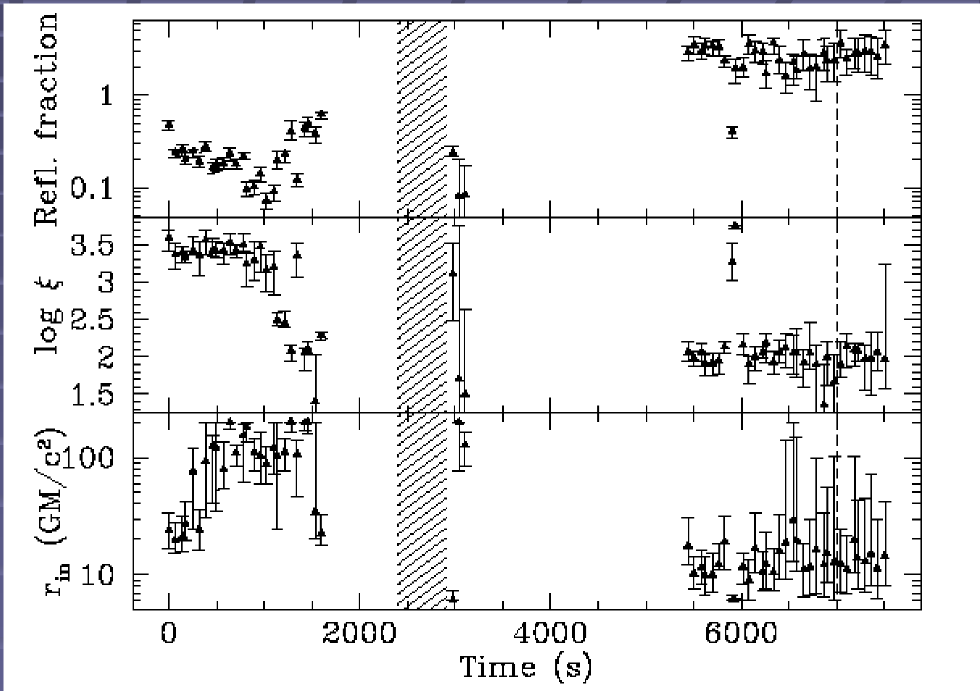
Ballantyne & Strohmayer (2004)



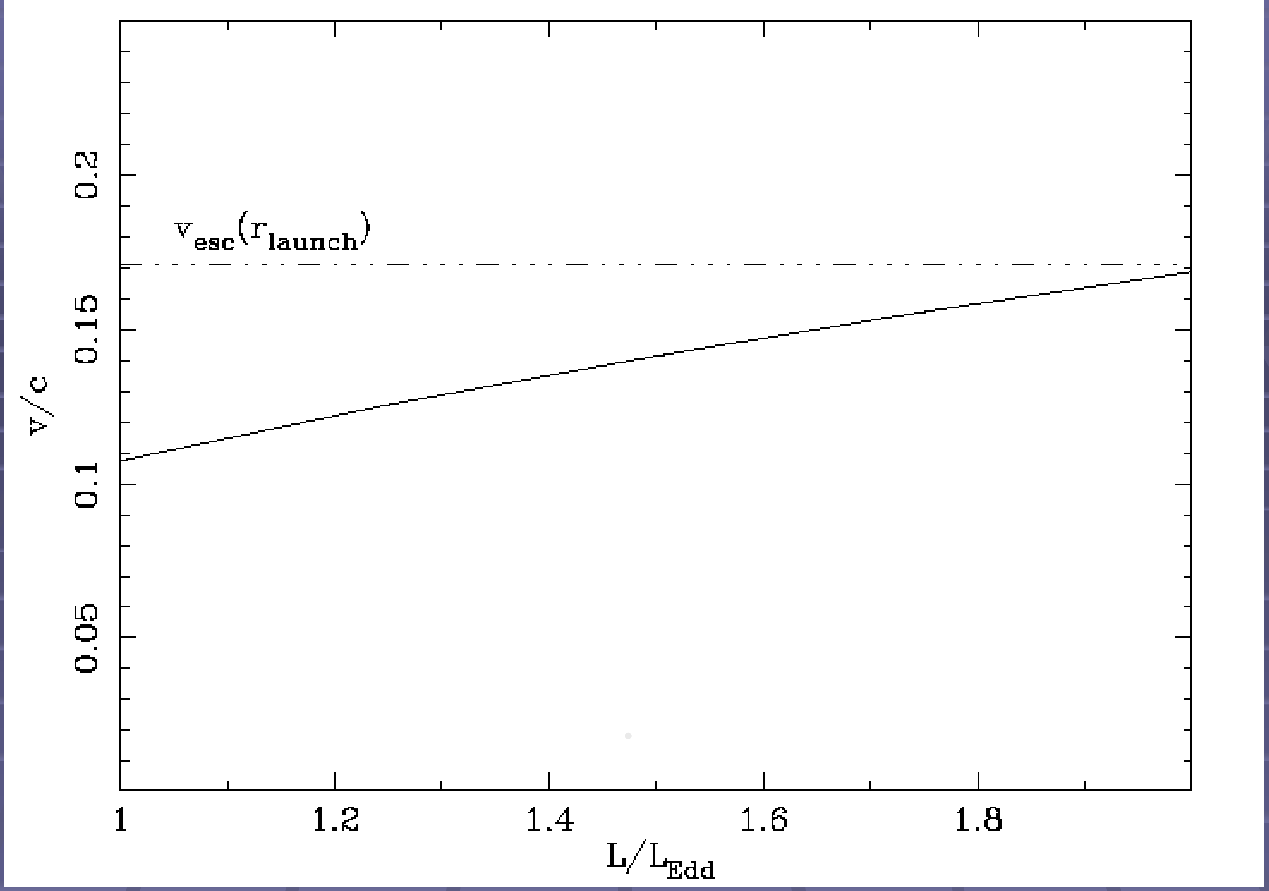
Possible Interpretation (#1)

Ballantyne & Everett (2005)

- Lack of reflection from inner disk during the hottest part of the superburst
- reflecting material not there – inner disk blown out?

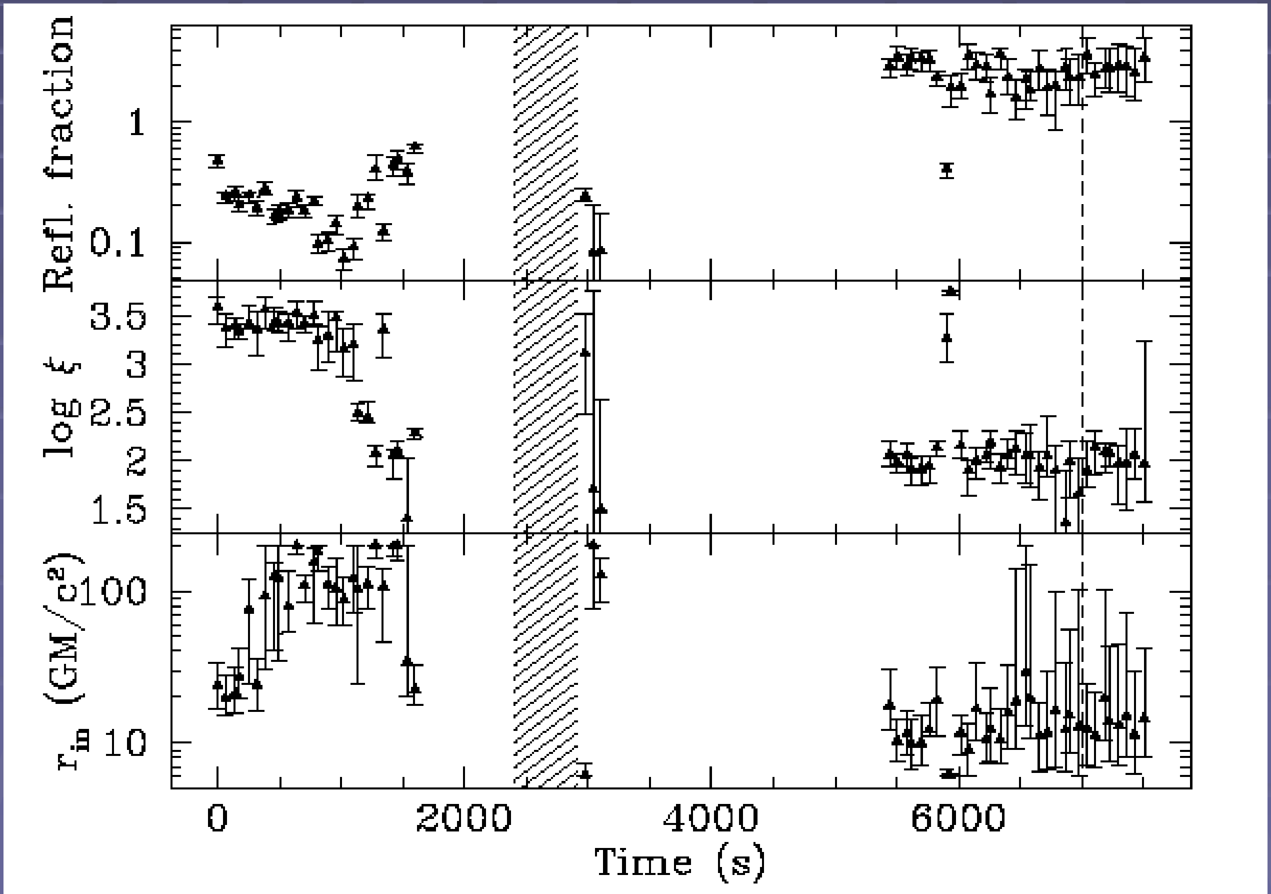


Ballantyne & Everett (2005)



- continuum (electron and b-f) driving of a column of 10^{24} cm^{-2} of gas launched between 20 and 70 r_g by a 2.6 keV blackbody
- gas has negligible H and density 10^{17} cm^{-3}
- assuming a 10% covering fraction, $\dot{m}_{out} \sim 2\times10^{15}$ g s^{-1} (cf. the observed flux implies $\dot{m}_{in} \sim 10^{17}$ g s^{-1})
- takes < 30s to travel from 20 to 100 r_g

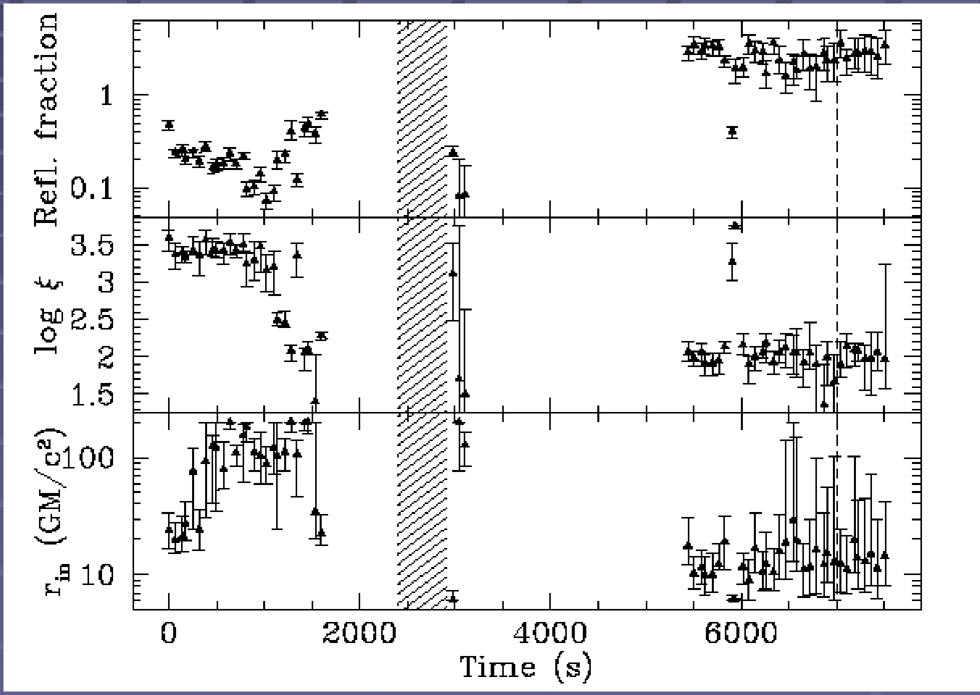
- Assuming SS73 disk models, the average mass outflow rate would have to be 10^{16-17} g s^{-1}
- However, if the disk is being blown away, why is it reflecting for the first 500s?
- Maybe wind is shielding the disk and inhibiting reflection?



Possible Interpretation (#2)

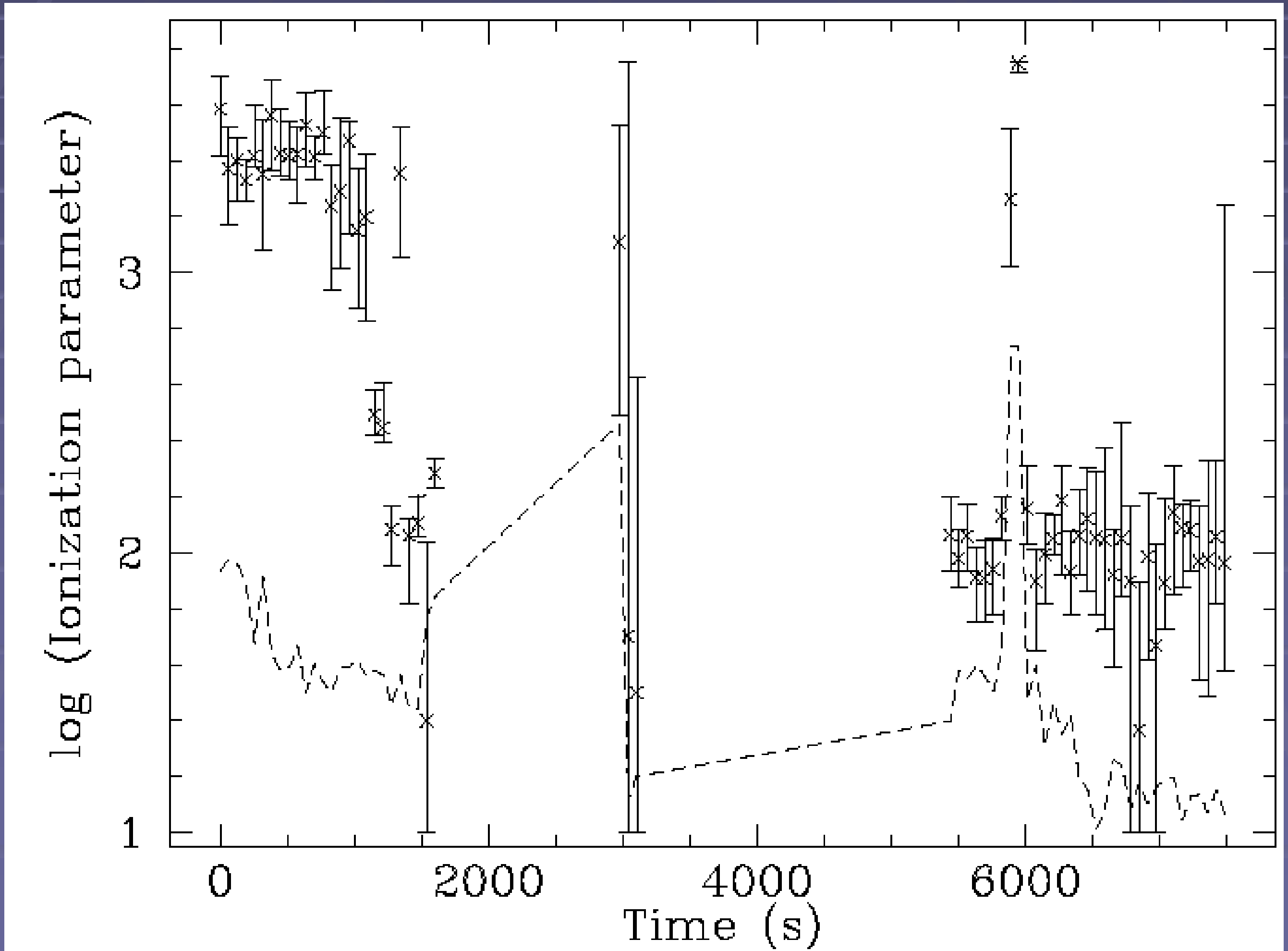
Ballantyne & Everett (2005)

- material there, but too ionized to produce reflection
  - Possible. But ionization parameter is already high at start of burst when inner radius is close to NS.



- can check this using SS73 disk theory
- writing $n_{He} = \Sigma / m_{He} H$ & $F_X = L / 4\pi R^2$ we obtain

$$\xi \approx \frac{L m_{He} H}{R^2 \Sigma}$$

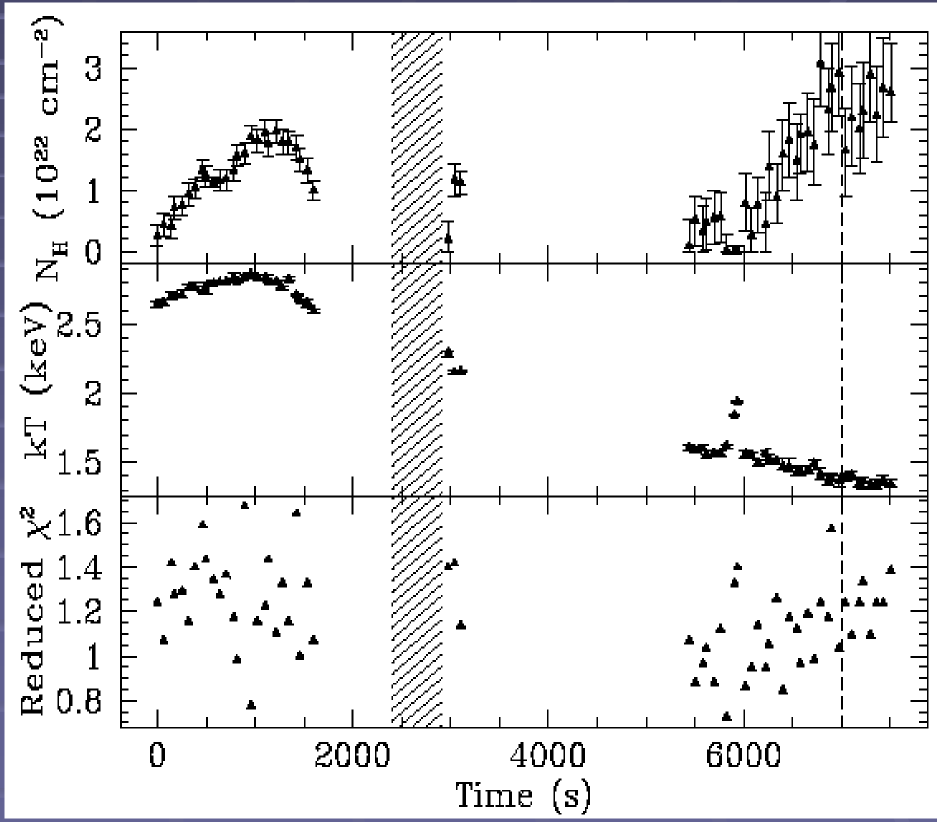


Ballantyne & Everett (2005)

Possible Interpretation (#3)

Ballantyne & Everett (2005)

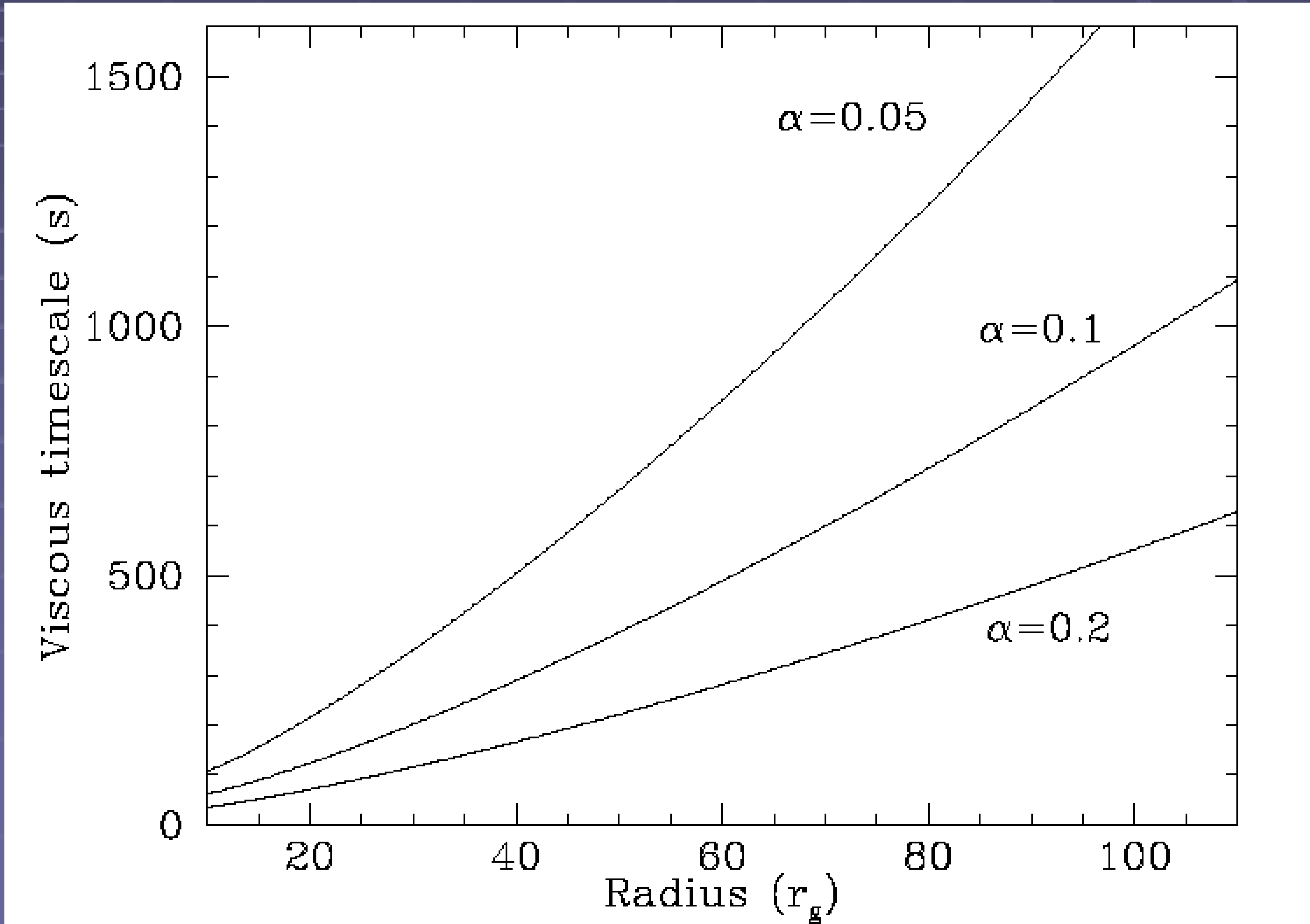
- Lack of reflection from inner disk during the hottest part of the superburst
- material there, but unable to reflect due to change in disk structure
  - the evolution in the inner radius and reflection fraction seem closely related to kT, and not the flux
  - disk could be puffed up due to the massive X-ray heating
  - lower the surface density and gas would be highly ionized and unable to reflect
  - $H \propto c_s r^{3/2} \propto T^{1/2} r^{3/2}$



- large changes to disk surface density occur on viscous time

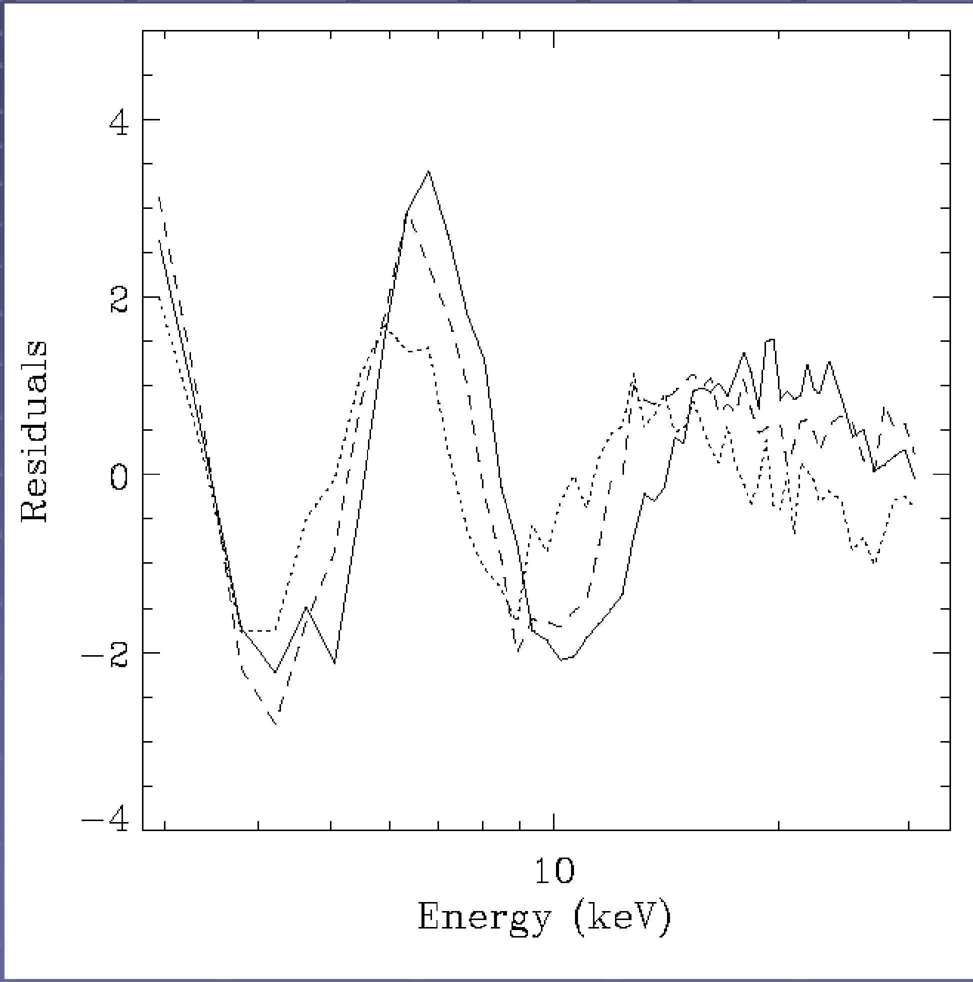
$$t_{visc} \sim \alpha^{-1}(H/R)^{-1} R c_s^{-1}$$

Ballantyne & Everett (2005)

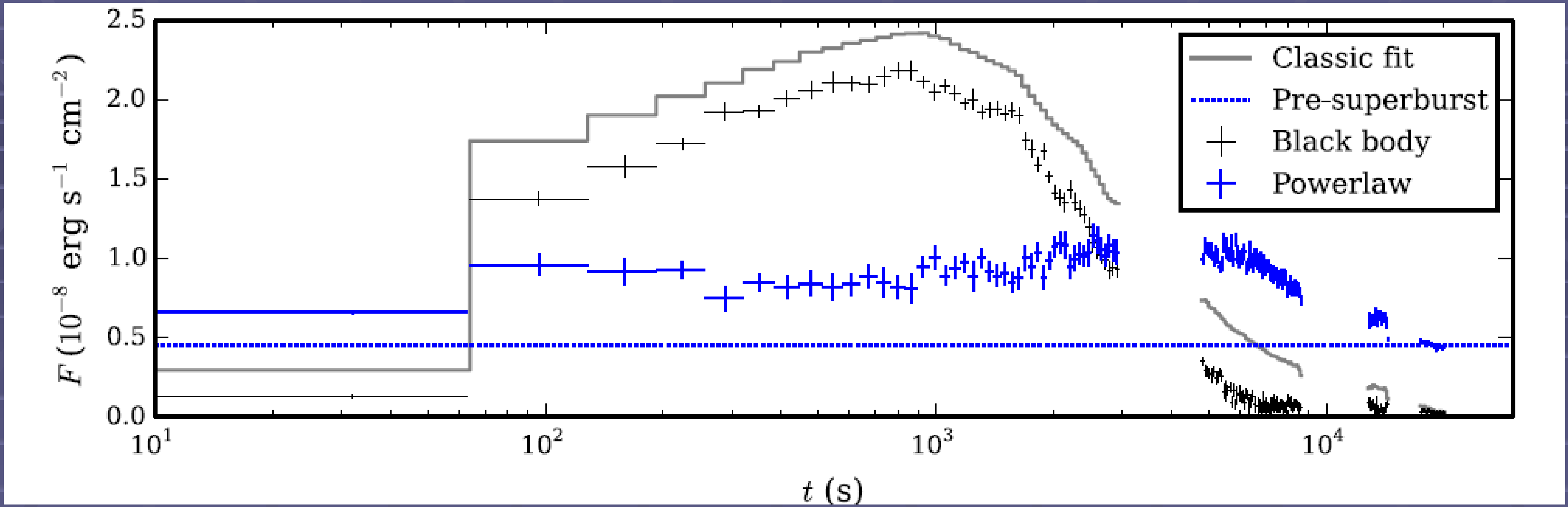


The superburst from 4U 1636-53

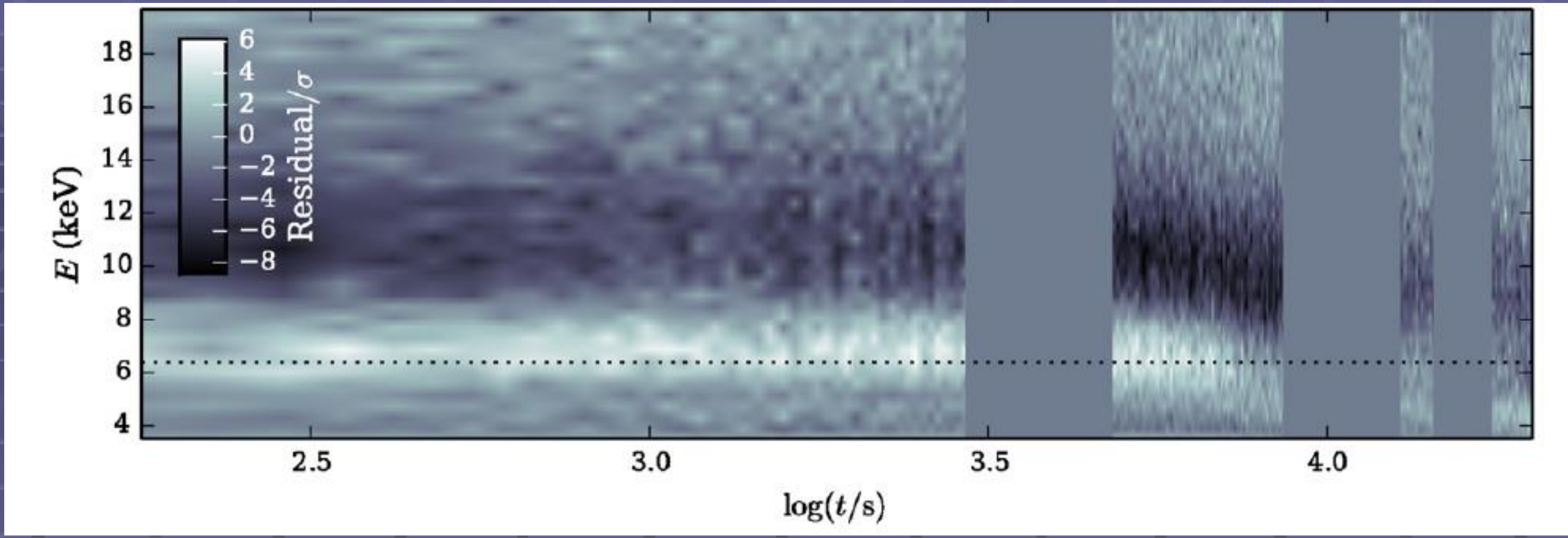
- The 2001 superburst from 4U 1636-53 was also caught by RXTE/PCA
- Burst oscillations were detected near the peak of the burst @ 582 Hz (Strohmayer & Markwardt 2002)
- → rapidly spinning NS
- A hard component in spectrum, probably due to persistant emission
- Fainter burst, so features may be weaker



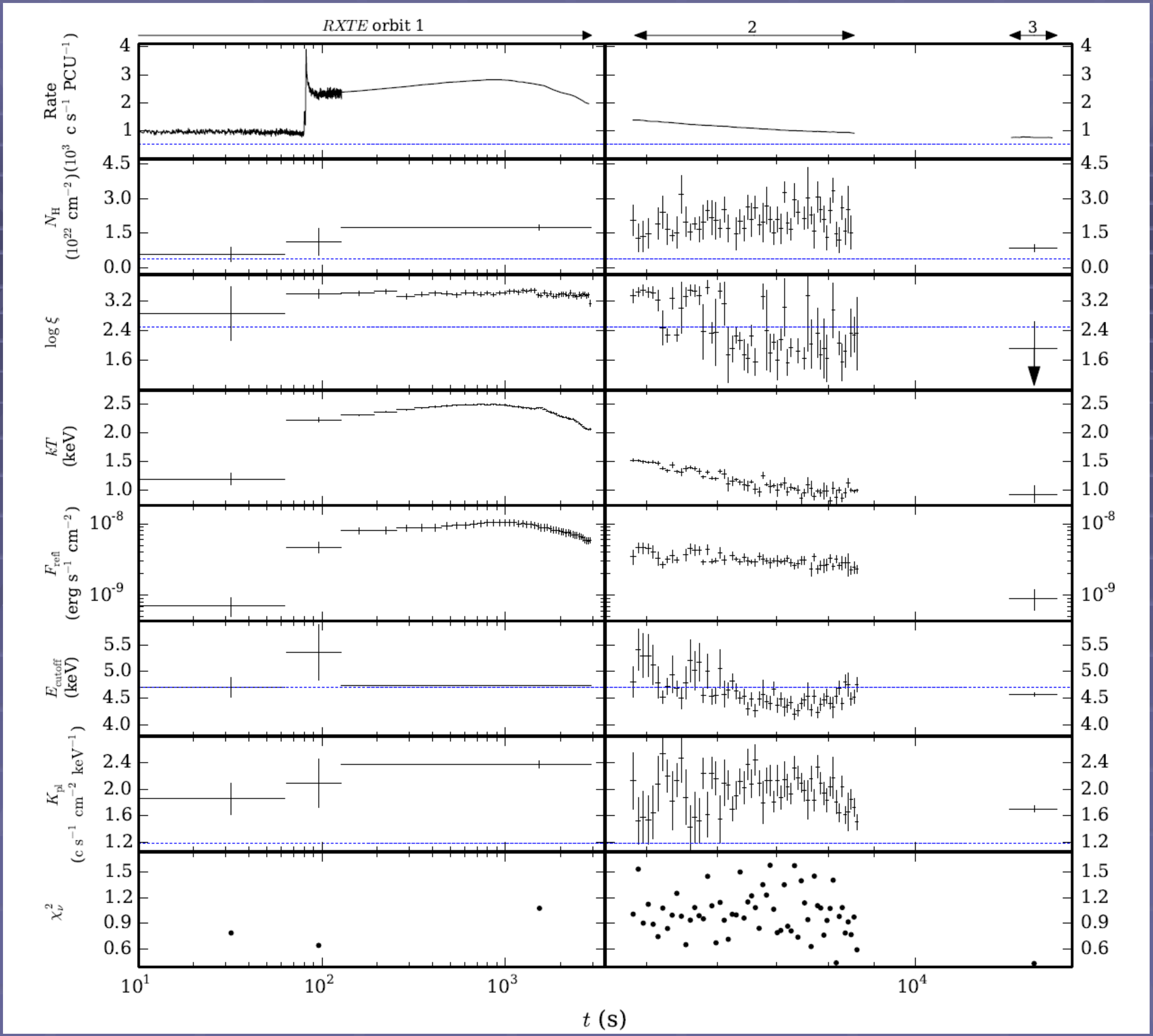
Strohmayer, private communication



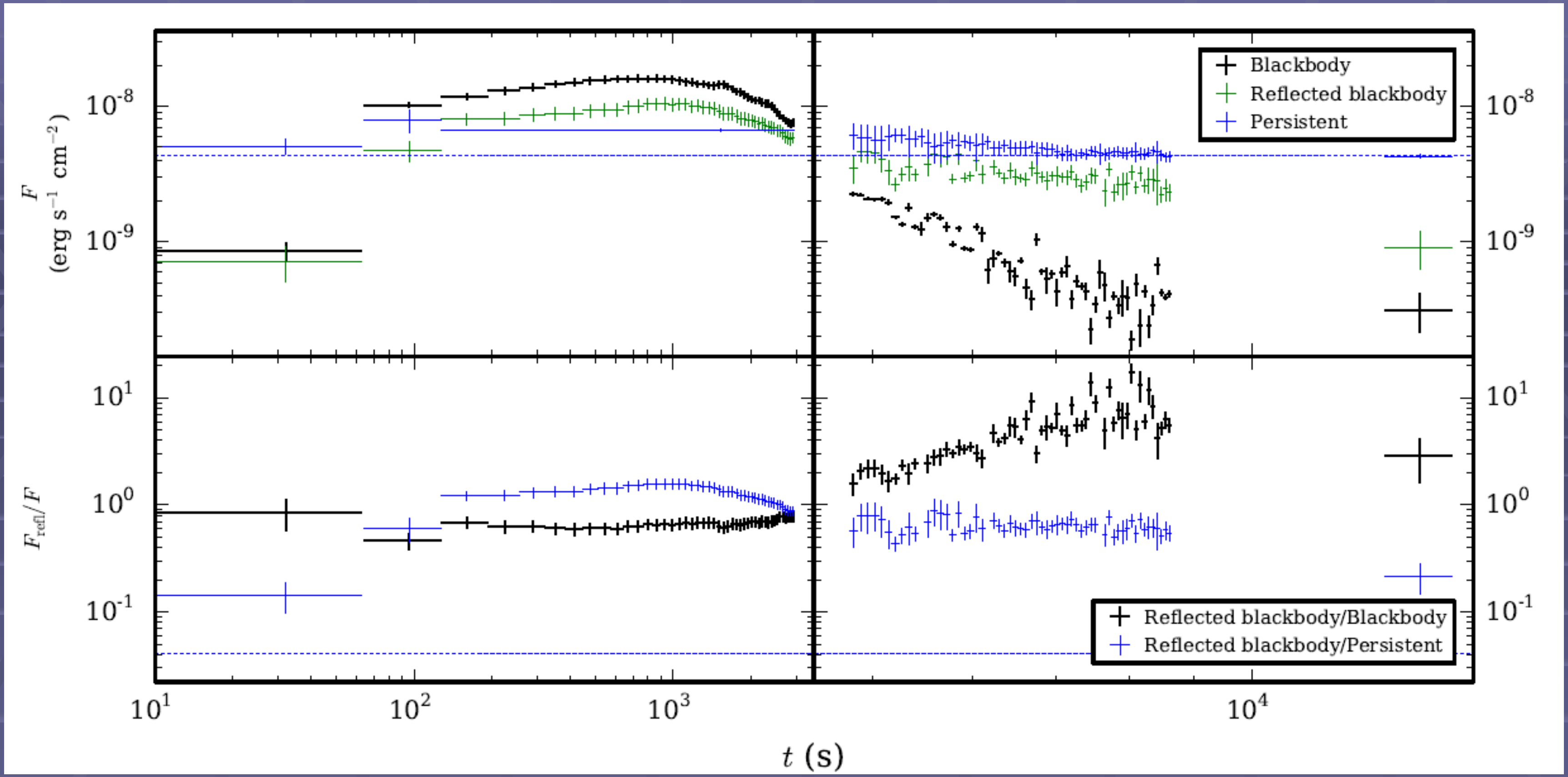
- Persistent flux (i.e., the accretion flux) increased during the burst.
- Maybe seen in other Type 1 bursts (Worpel et al. 2013, 2015)
- Does the burst cause an increase in accretion rate, or just a change in the corona?



- Fit residuals as a function of time when spectra modeled with a blackbody, a cutoff power-law and absorption (Keek et al. 2014a)



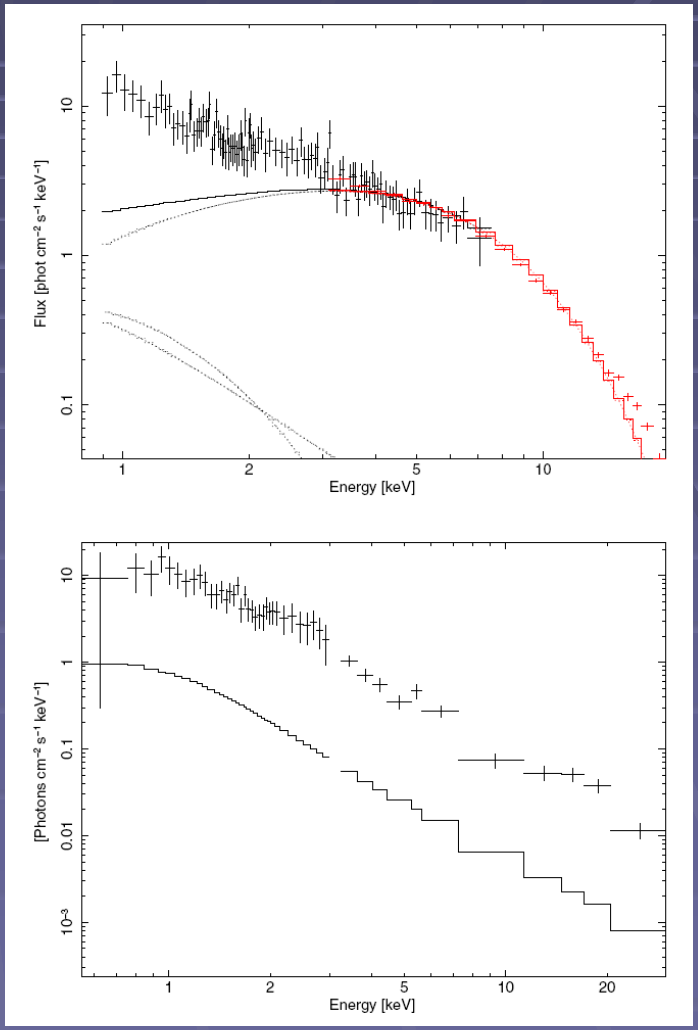
Keek et al. (2014b)



- In 1st orbit, observing one highly ionized reflector. Low reflection strength implies material is more distant.
- Mixture of ionization states in 2nd orbit + increase in reflection strength -> observing multiple reflectors in 2nd orbit
- Inner disk may therefore be overionized or disrupted during the 1st ~ks
- Similar timescale to 4U 1820-30. A viscous process at work?

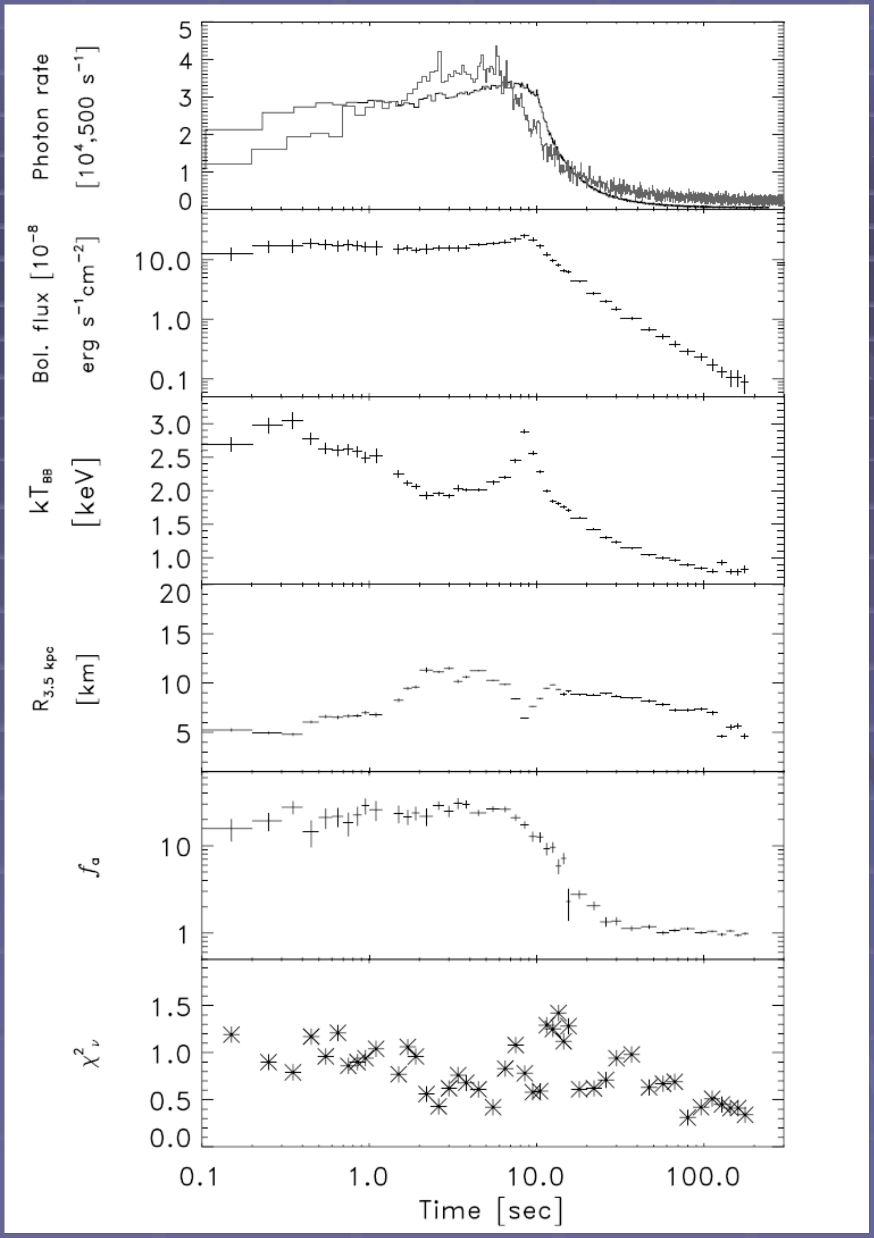
Changes in Persistent Spectrum and Poynting-Robertson Drag

- Burst from SAX J1808.4-3658 observed with both RXTE and Chandra.
- Excess at both low and high energies consistent with additional persistent emission.
- Reflection will also contribute to soft excess.



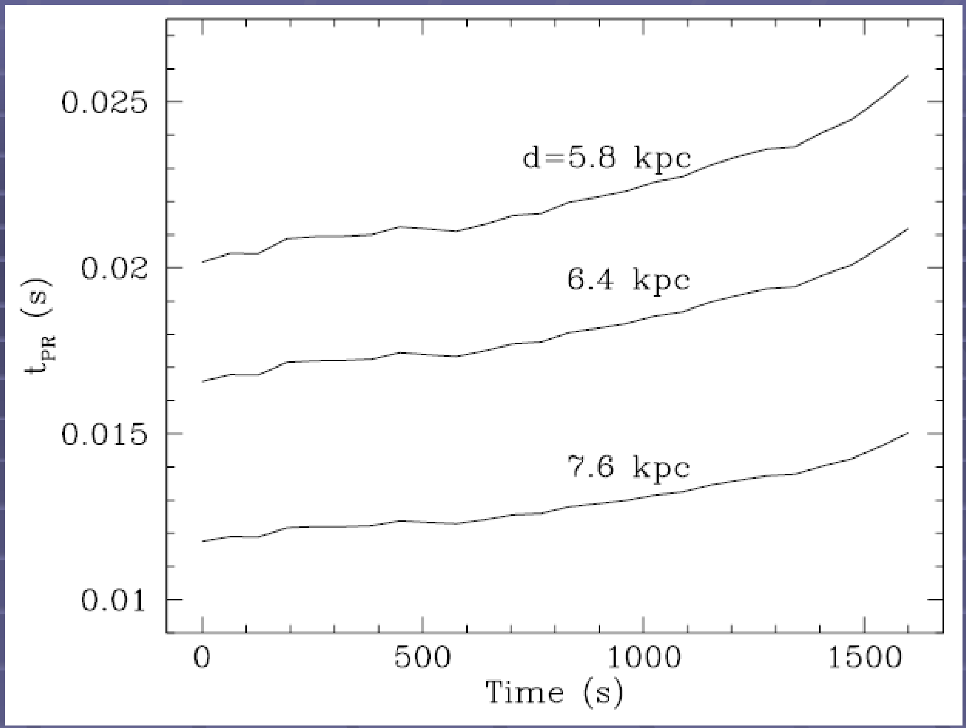
in t' Zand et al. (2013)

- If the increase in persistent emission is real, implies a change in corona properties.
  - Larger corona.
  - More accretion power from an increase in accretion rate.
    - PR drag



in t’ Zand et al. (2013)

- PR drag timescale is extremely rapid.
- Would indicate rapid draining of accretion disk.
- Plus, f_a returns to 1.
  - No indication that disk has been drained of material
- However, very simple estimate. Ignores other processes.
  - Needs to be checked with simulations.



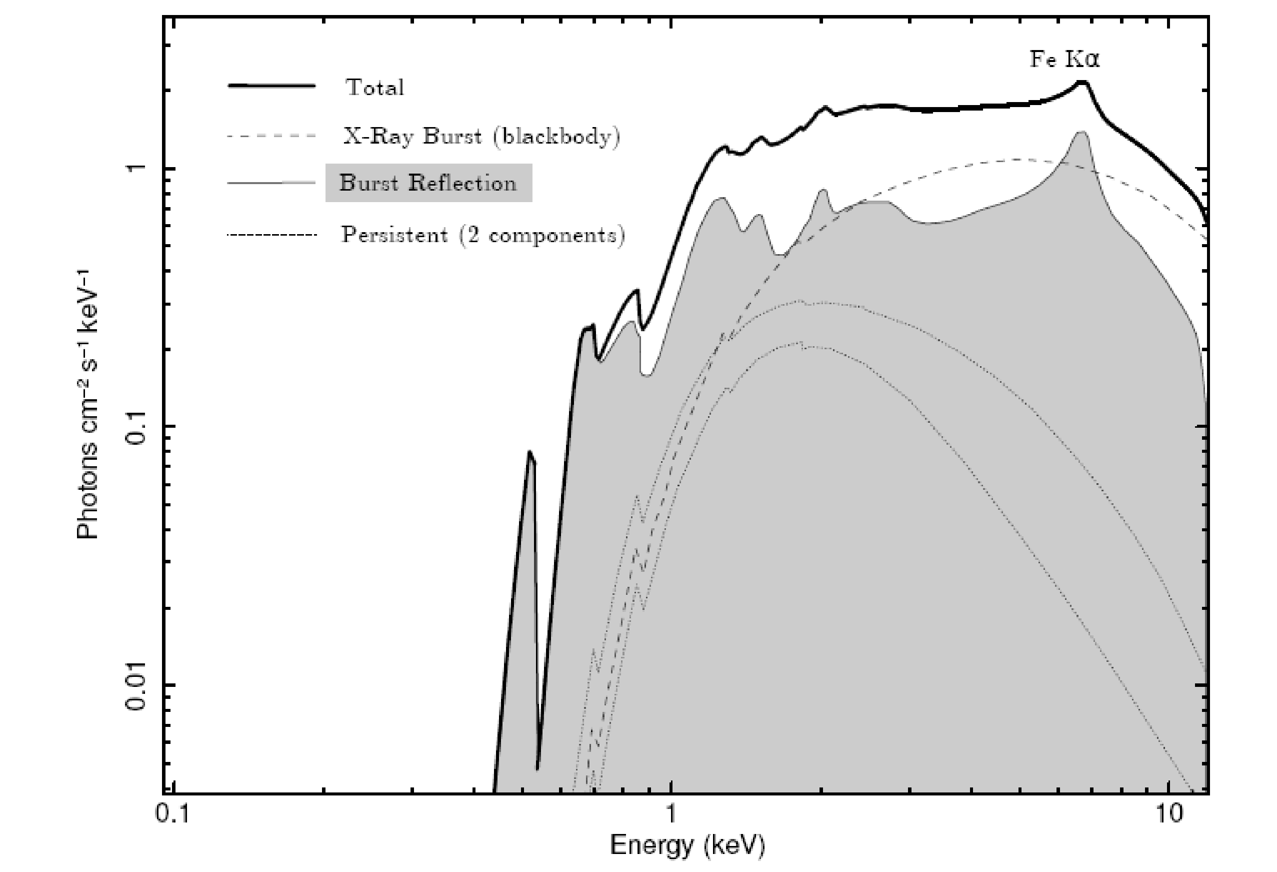
$$t_{PR} = 2 \times 10^{-6} \left(\frac{M}{1.4\,M_\odot}\right)^2 \left(\frac{L}{L_{Edd}}\right)^{-1} \left[\left(\frac{r_0}{r_g}\right)^2 - \left(\frac{r_*}{r_g}\right)^2\right] \mathrm{s}$$

Ballantyne & Everett (2005)

Summary of Potential Interactions

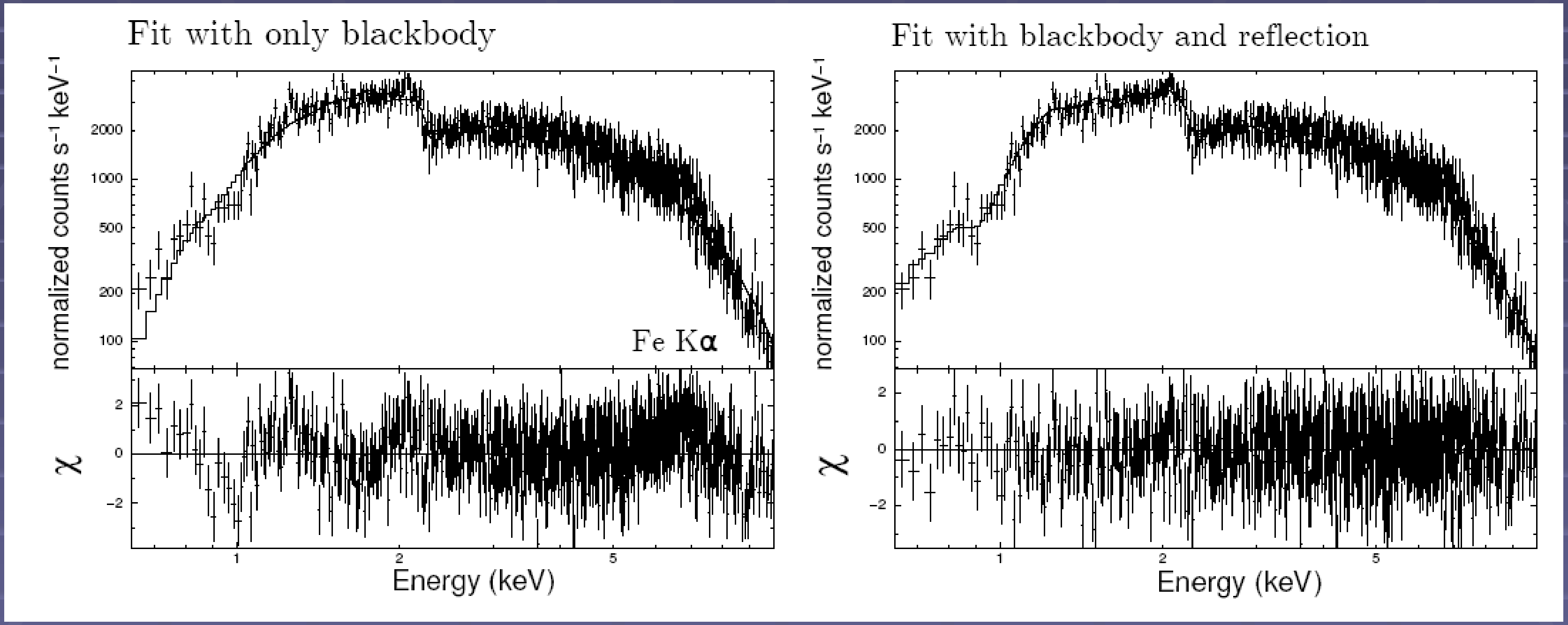
- The superburst from 4U 1820-30 seemed to disrupt the inner part of the accretion disk in about 1000 s. It is possible that this as a heating effect which puffed the disk up.
- A qualitatively similar behavior is observed from the less powerful superburst from 4U 1636-53.
  - Implies impact on accretion disk may be a common consequence of X-ray bursts
- Understanding the physics of the interaction is complicated
  - Outflow, inflow and heating processes are all relevant
  - Numerical simulations are needed to fully understand the physical consequences of the burst-disk interaction.

Future: *NICER*

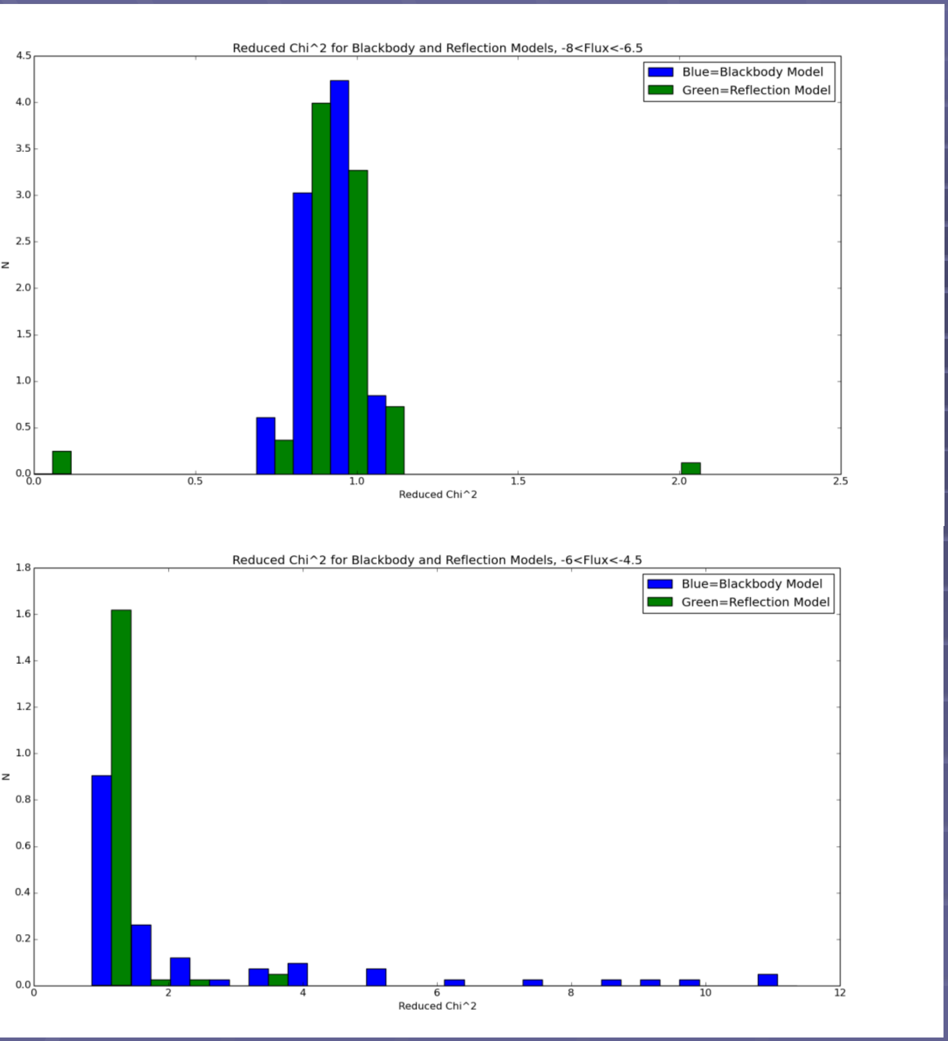


- Assume the above spectral model for a burst from 4U 1608-52
- The following work led by L. Keek and Z. Wolf (GT Undergrad)

NICER



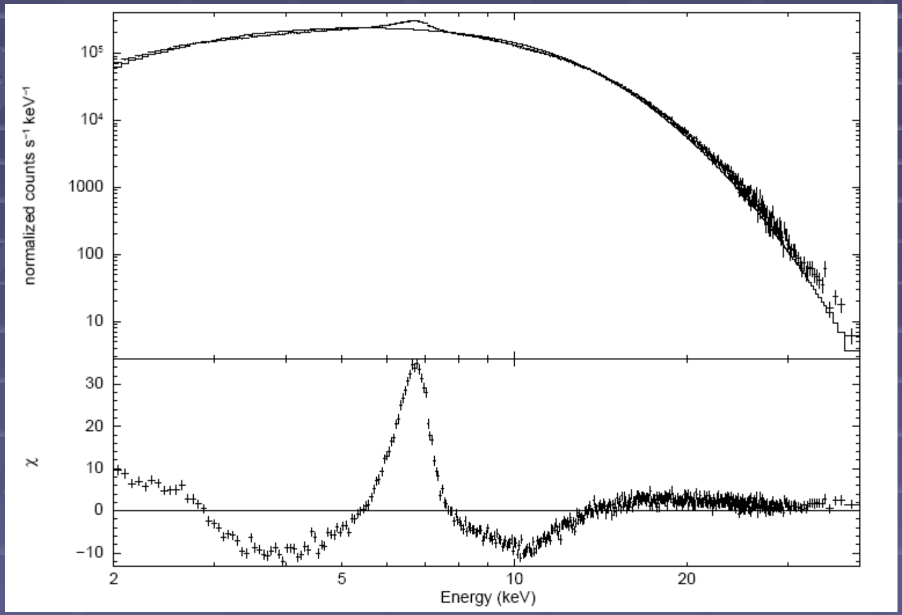
- 2 s *NICER* exposure; parameters recovered with <8% uncertainty
- The broadband sensitivity provided by *NICER* will open up the possibility of detecting soft X-ray reflection features.
  - Constraints on density & abundances in addition to ionization and geometry

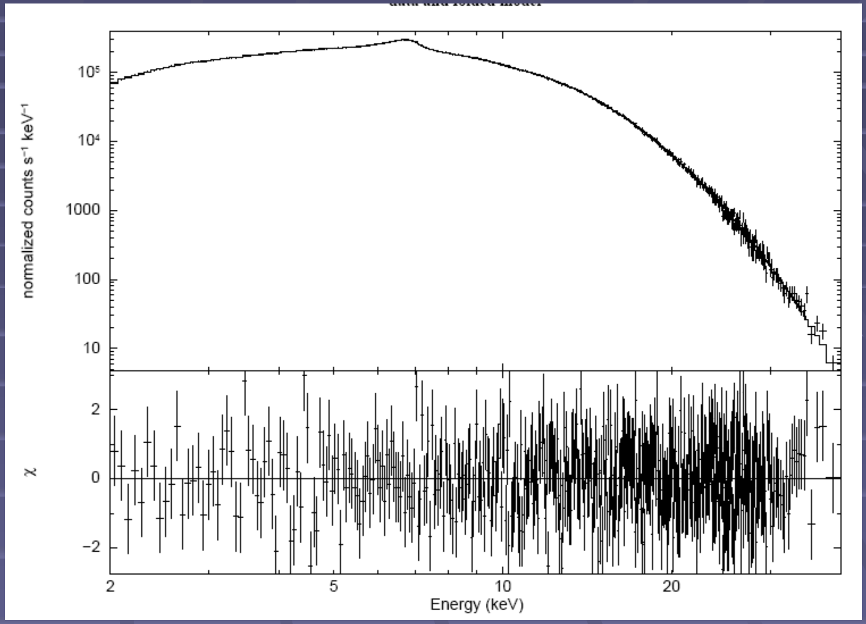


Wolf et al. in prep.

- Consider bursts at different fluxes and kTs with a range of ξ.
- 2 s exposures with *NICER*
- Then fit with either a \`typical' BB model or include reflection
- BB model can fail for fluxes >10^{-6} erg/cm^2/s

A *LOFT*-like Mission…





- 1 s exposure; inner radius of reflecting zone measured to < 15% uncertainty
- The large collecting area of a *LOFT*-like mission will allow the evolution of the burst-disk interaction to be viewed in real-time for hundreds of bursts