Broad iron emission lines in X-ray binaries

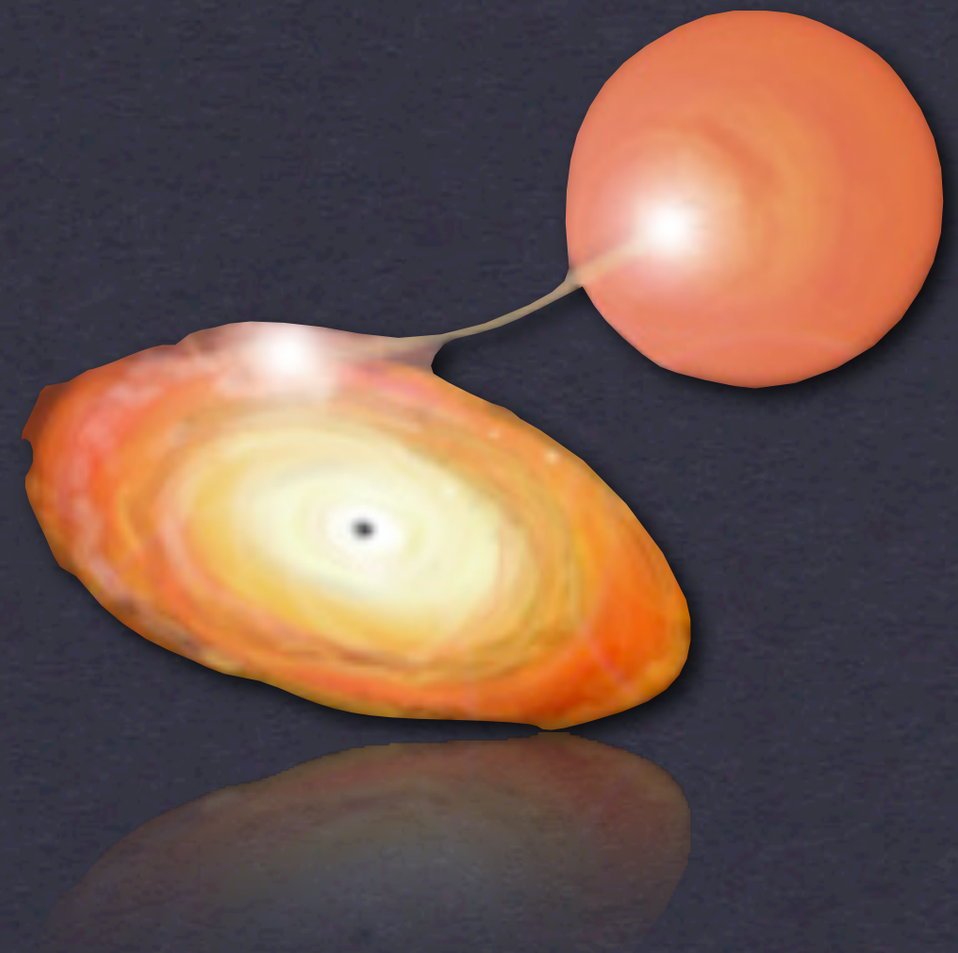
12 Years of science with Chandra

Ed Cackett (Cambridge),

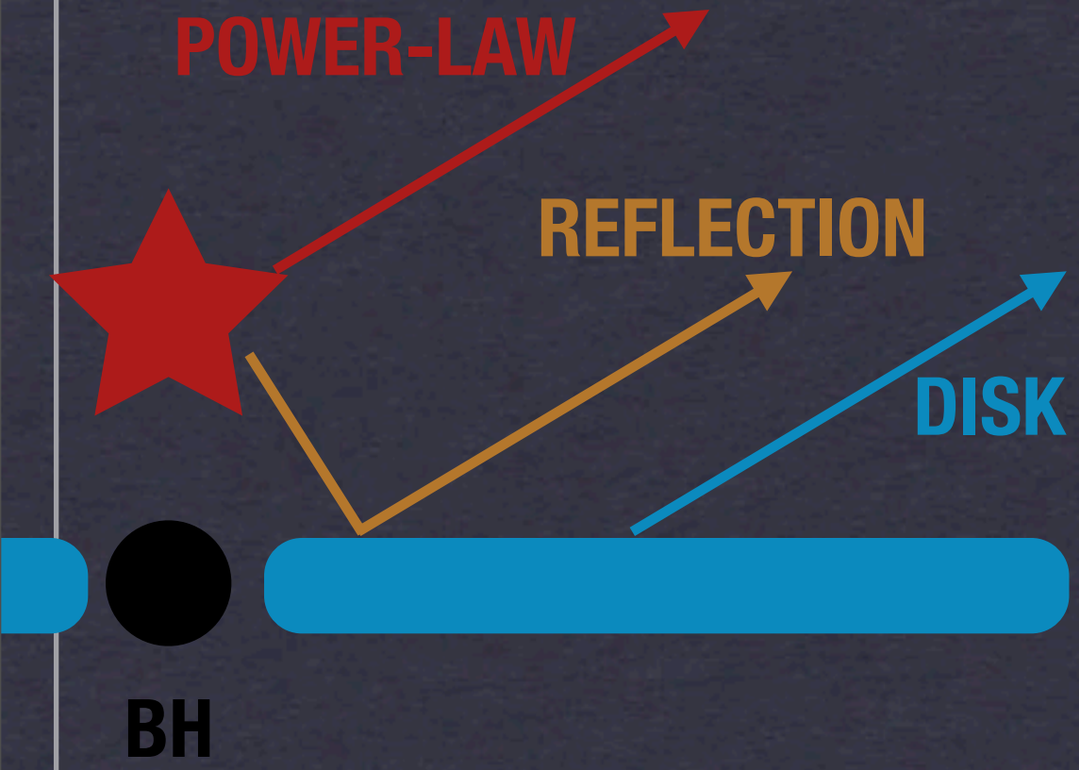
with contributions from Jon Miller and many others.....

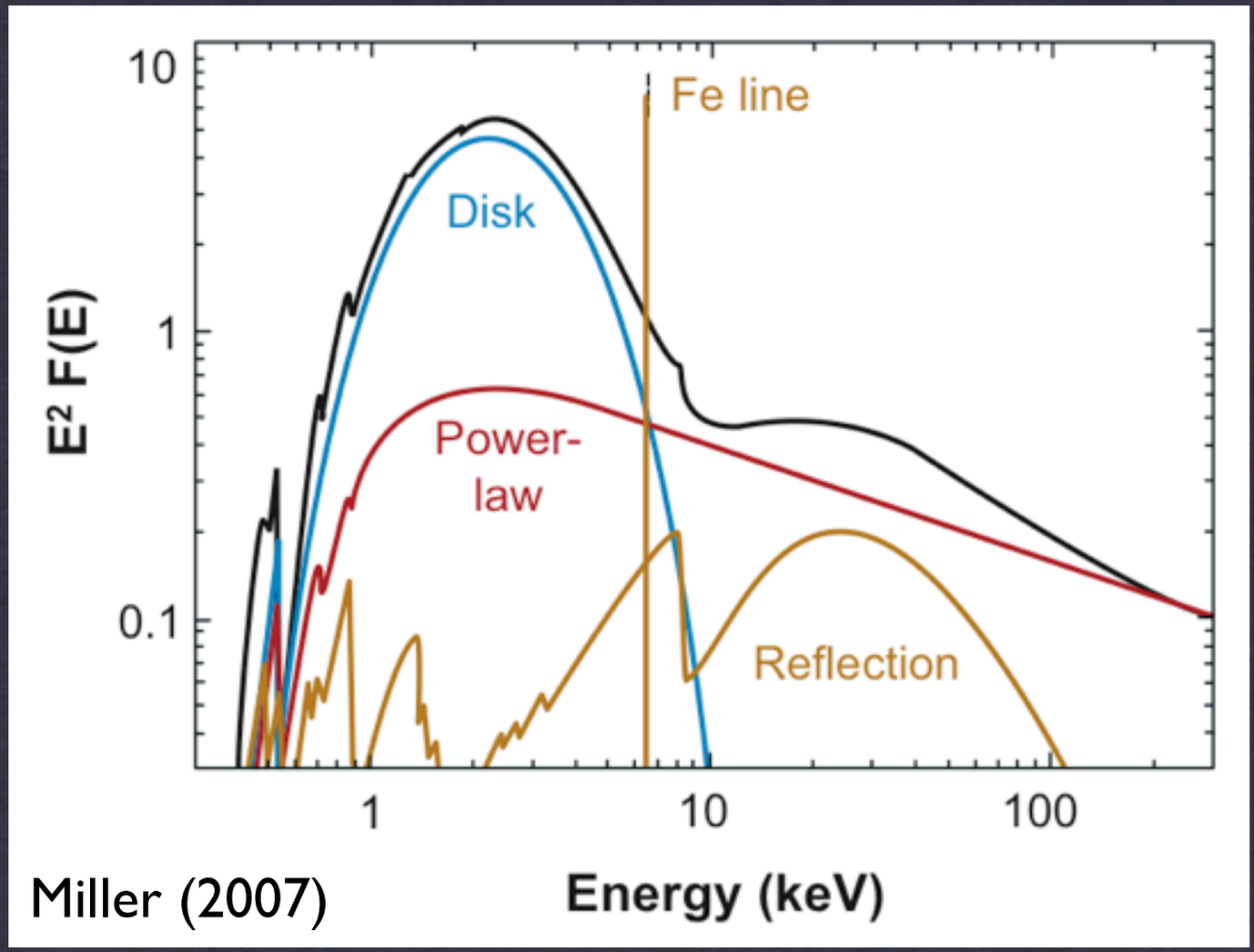
Outline

- Broad iron emission lines and the reflection paradigm
- Broad iron lines from neutron star low-mass X-ray binaries
- Is there a dependence with state?
- *Chandra's* contribution



The reflection paradigm



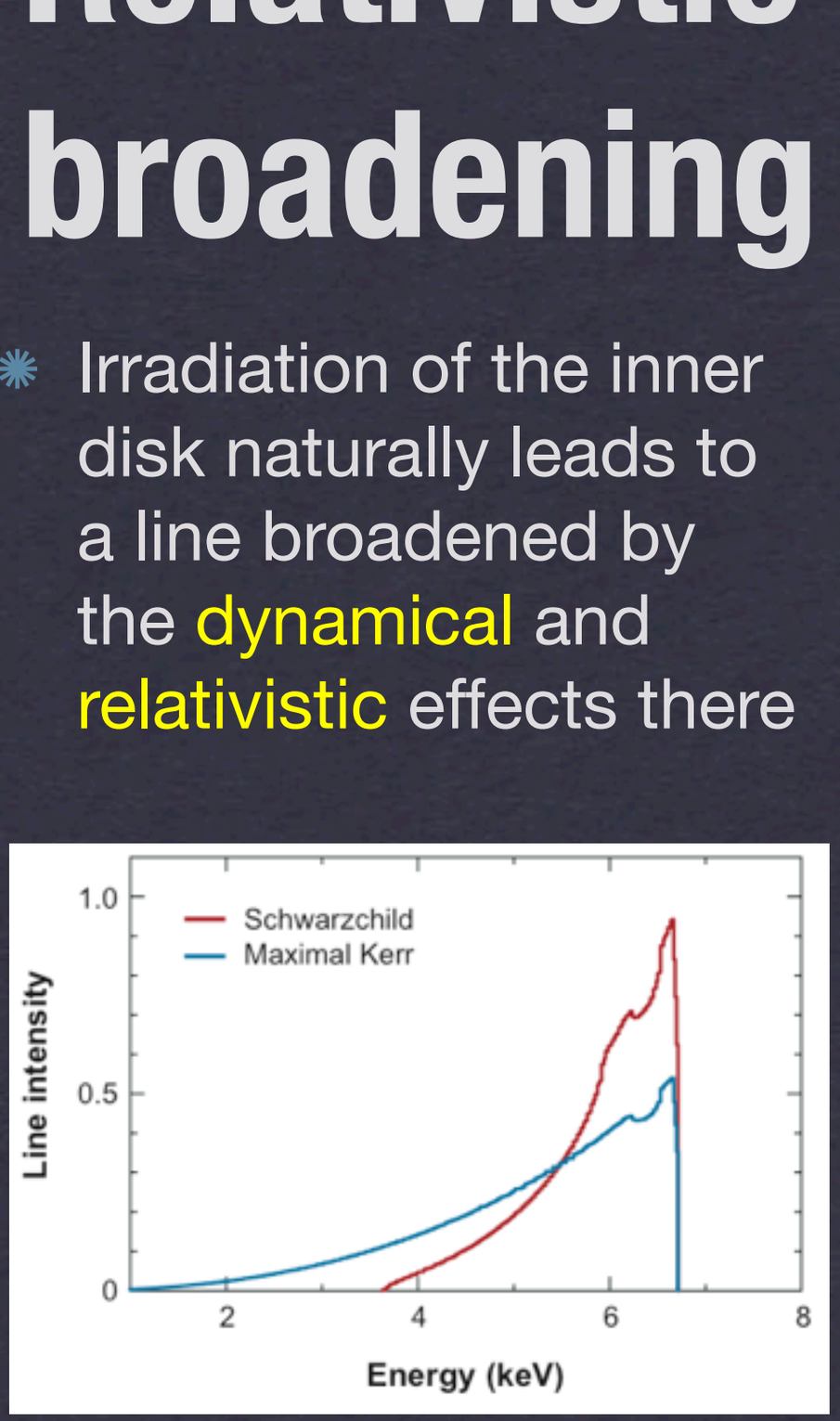


Miller (2007)

- Iron emission line is part of a reflection spectrum due to hard X-rays irradiating the disk

Relativistic broadening

- Irradiation of the inner disk naturally leads to a line broadened by the dynamical and relativistic effects there

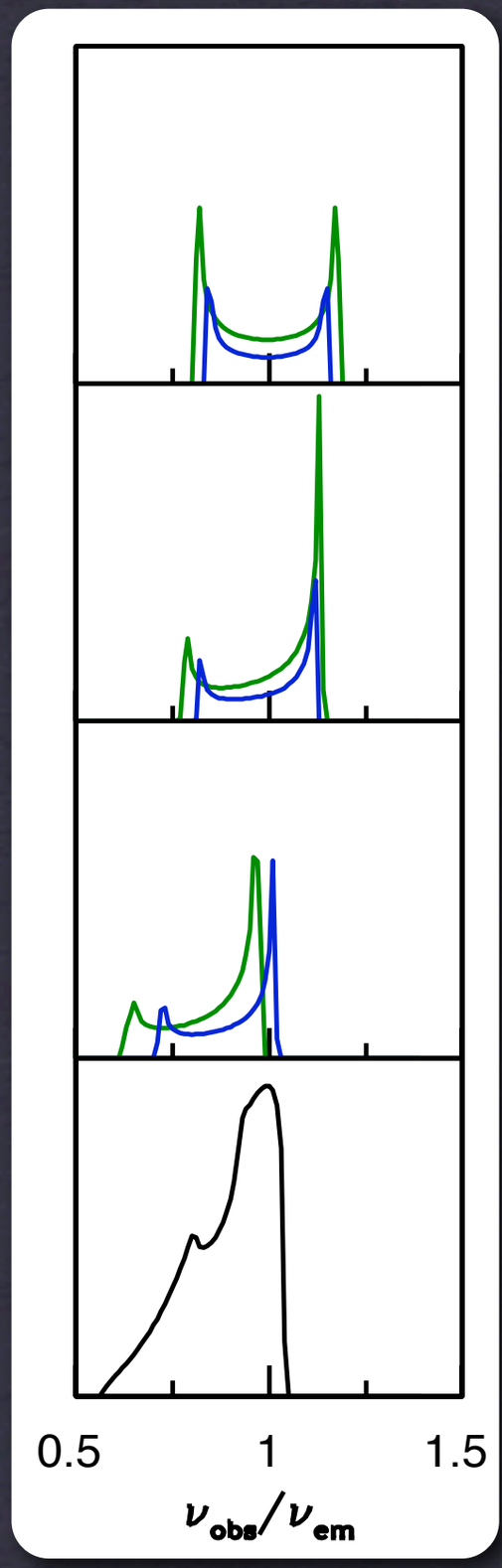


Line profile

After Fabian & Miniutti (2006)

General relativity

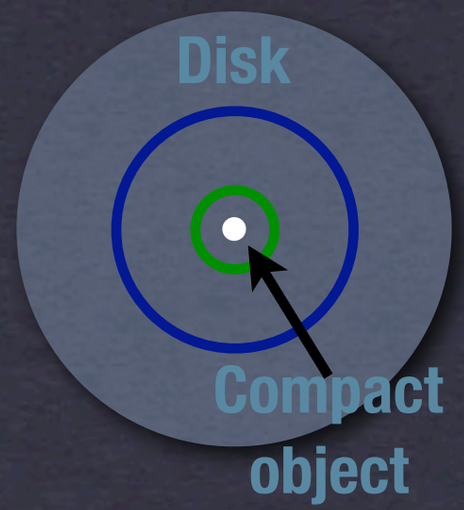
Gravitational redshift



Special relativity

Transverse Doppler shift

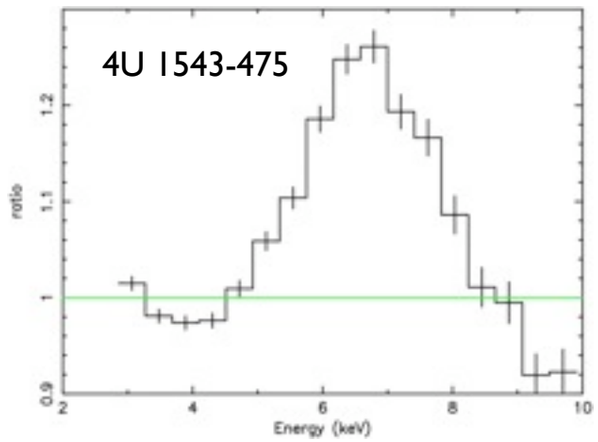
Beaming

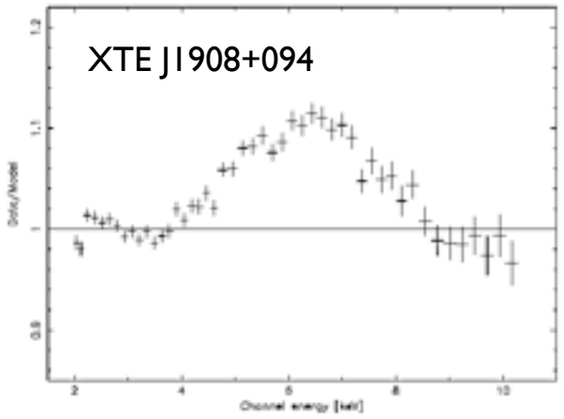


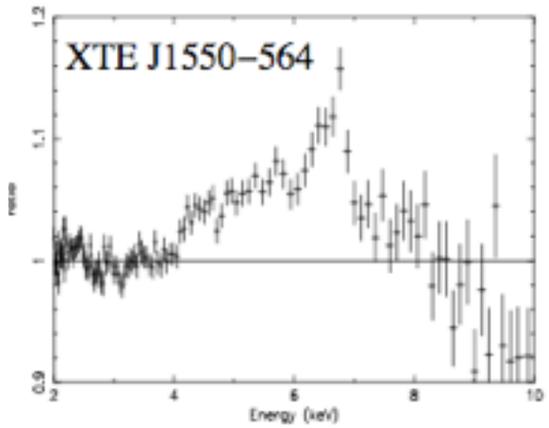
Newtonian

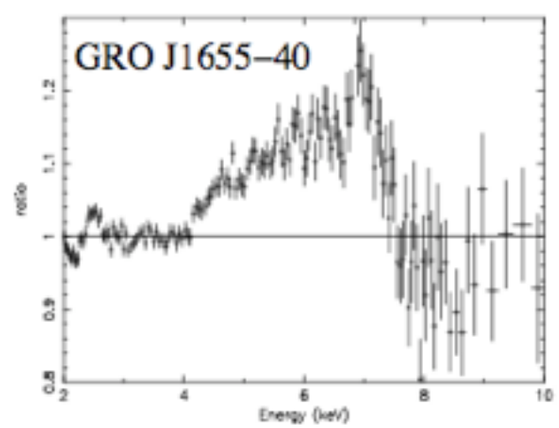
Adapted from Fabian et al. (2000)

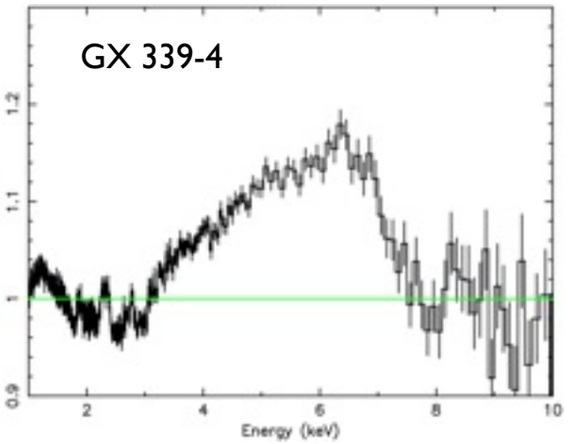
Broad lines in BH X-ray binaries

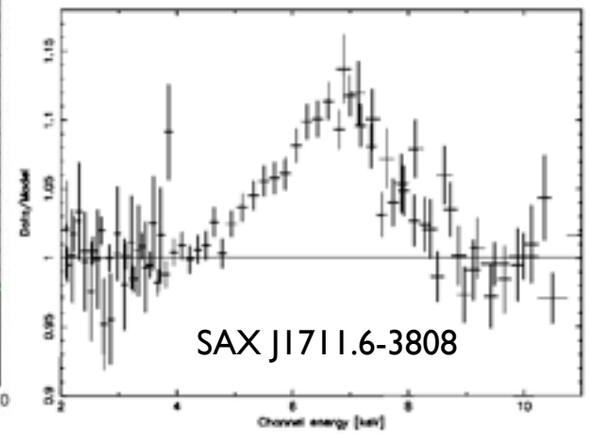


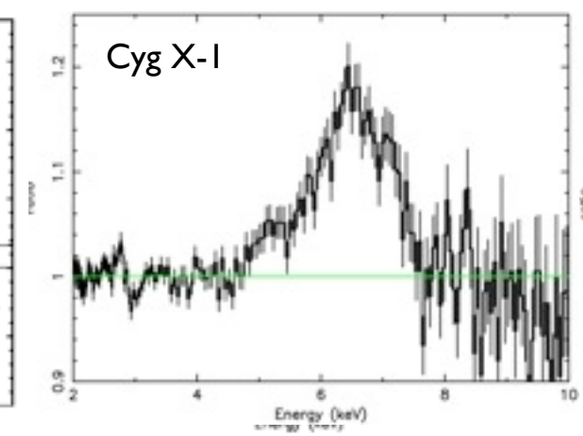


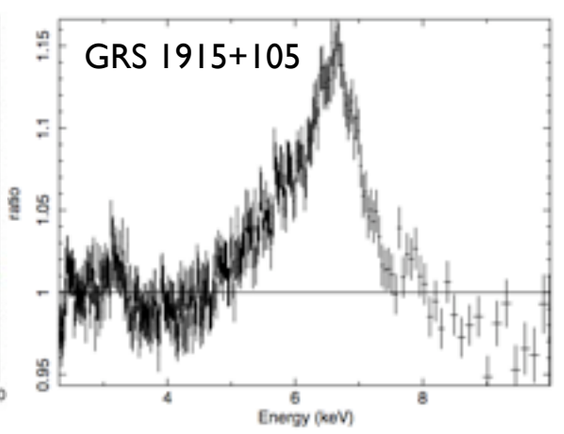


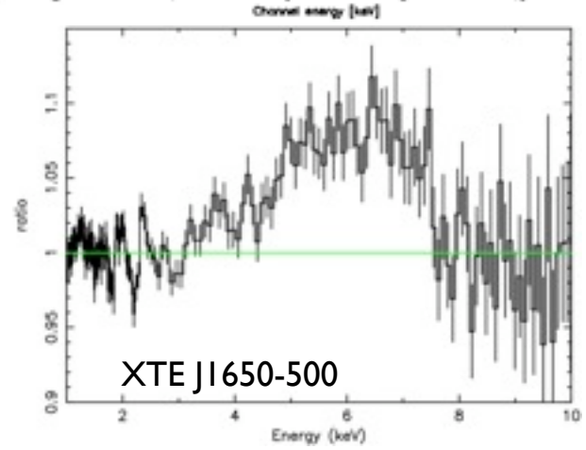


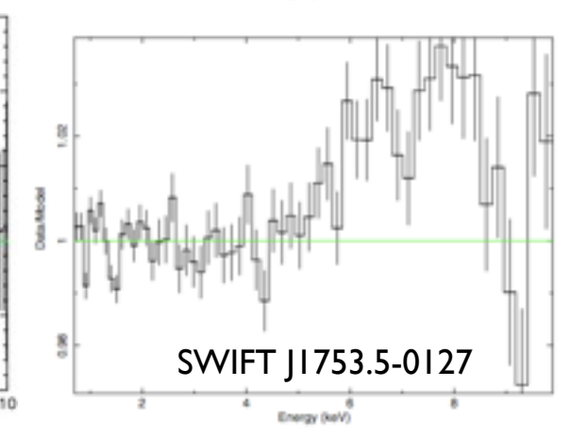






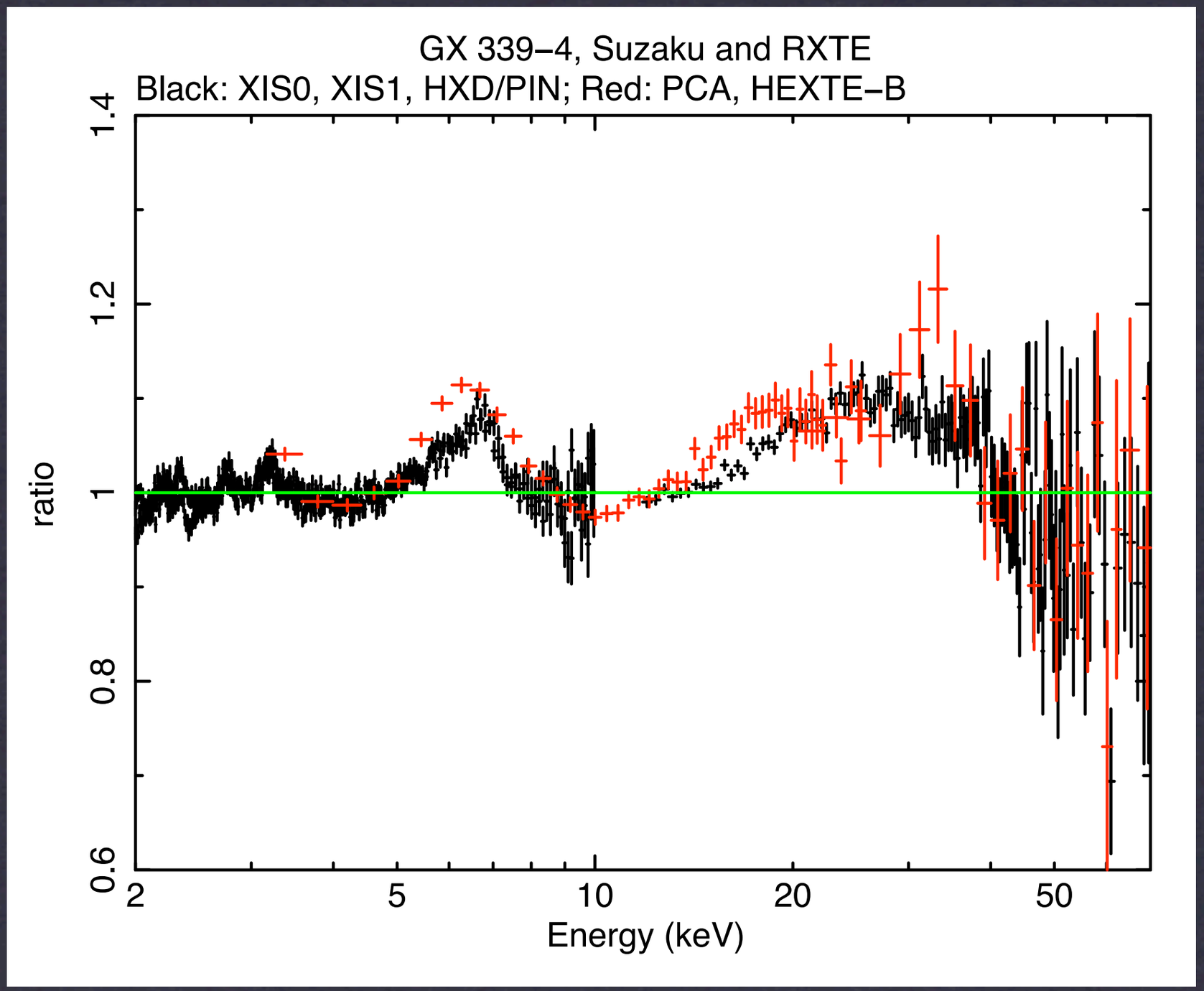






Courtesy of J. Miller

Reflection in BH X-ray binaries

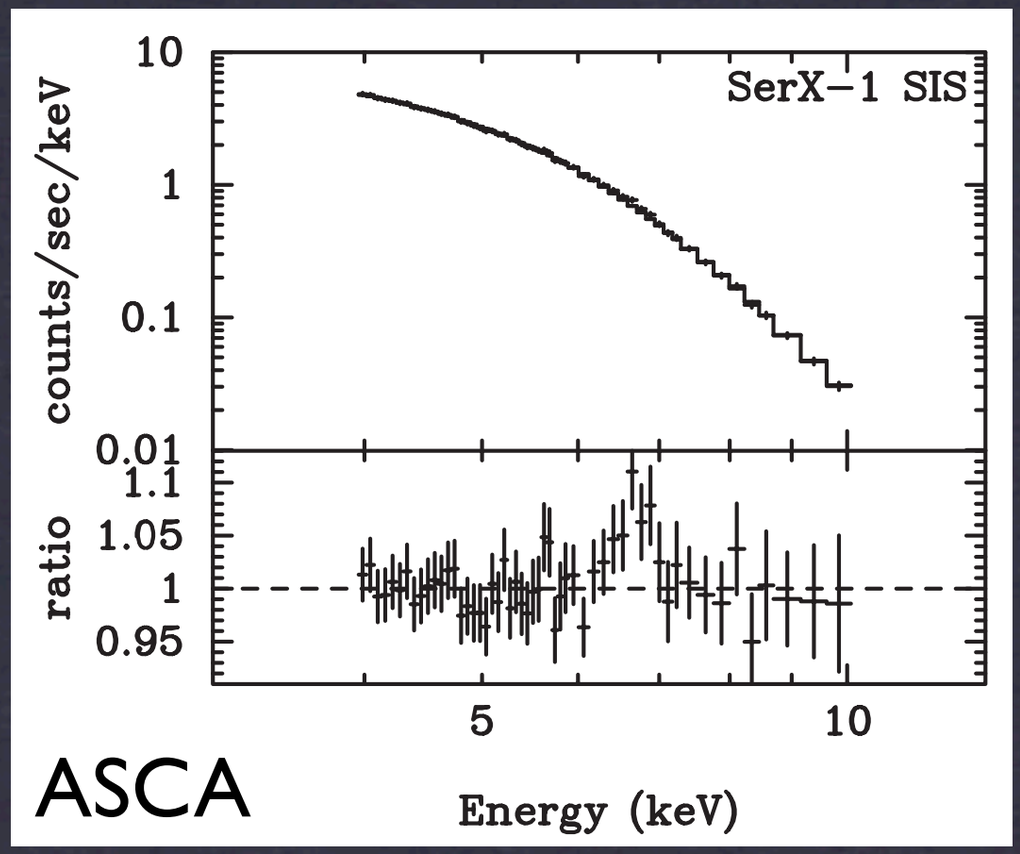


GX 339-4: Relativistically broadened Fe K line and strong Compton hump - clear signatures of reflection

Miller et al. (2008)

Broad iron lines in neutron star LMXBs

- Iron lines known in many NS X-ray binaries (e.g. White et al. 1985, 86, Hiraino et al. 1987 etc....)
- Weaker than in BHs, but can use the same diagnostics of the inner disk

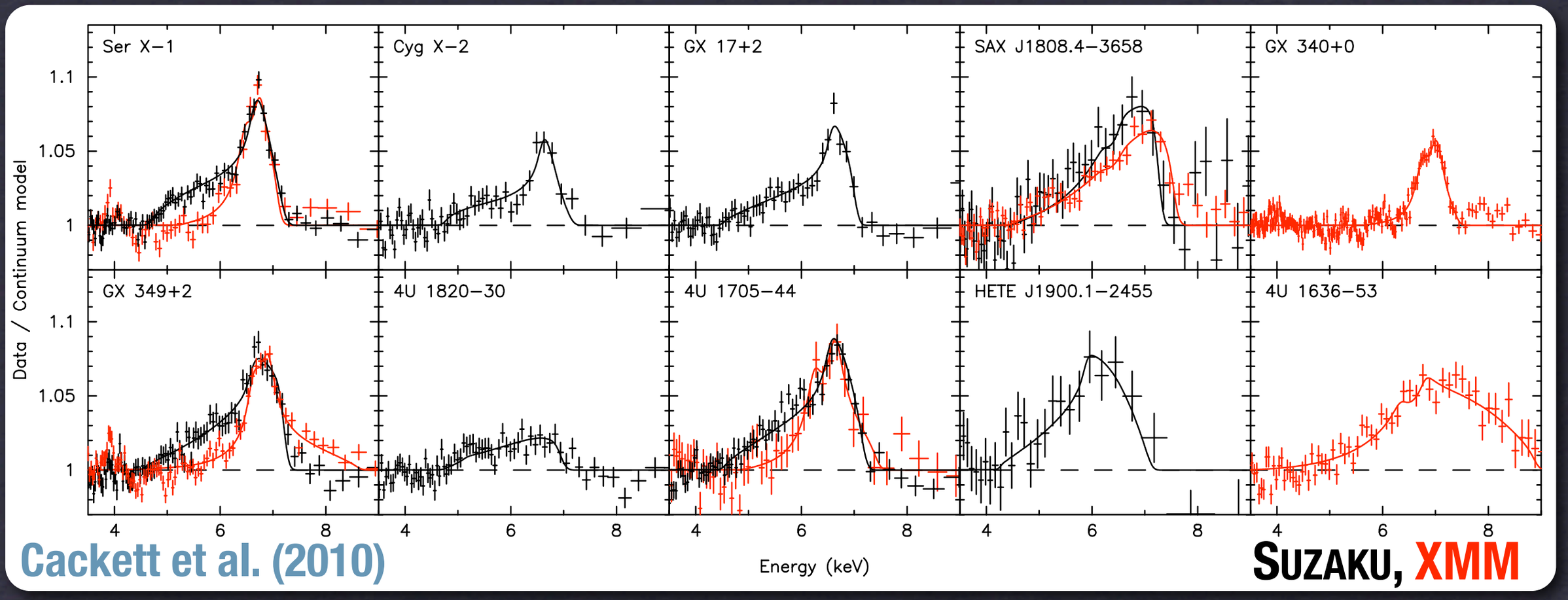


Asai et al. (2000)

ISCO for Schwarzschild metric is 6 GM/c^2 → 12.4 km for a 1.4 M$_\odot$ neutron star

The inner accretion disk radius places an upper limit on the stellar radius

Neutron star line collection

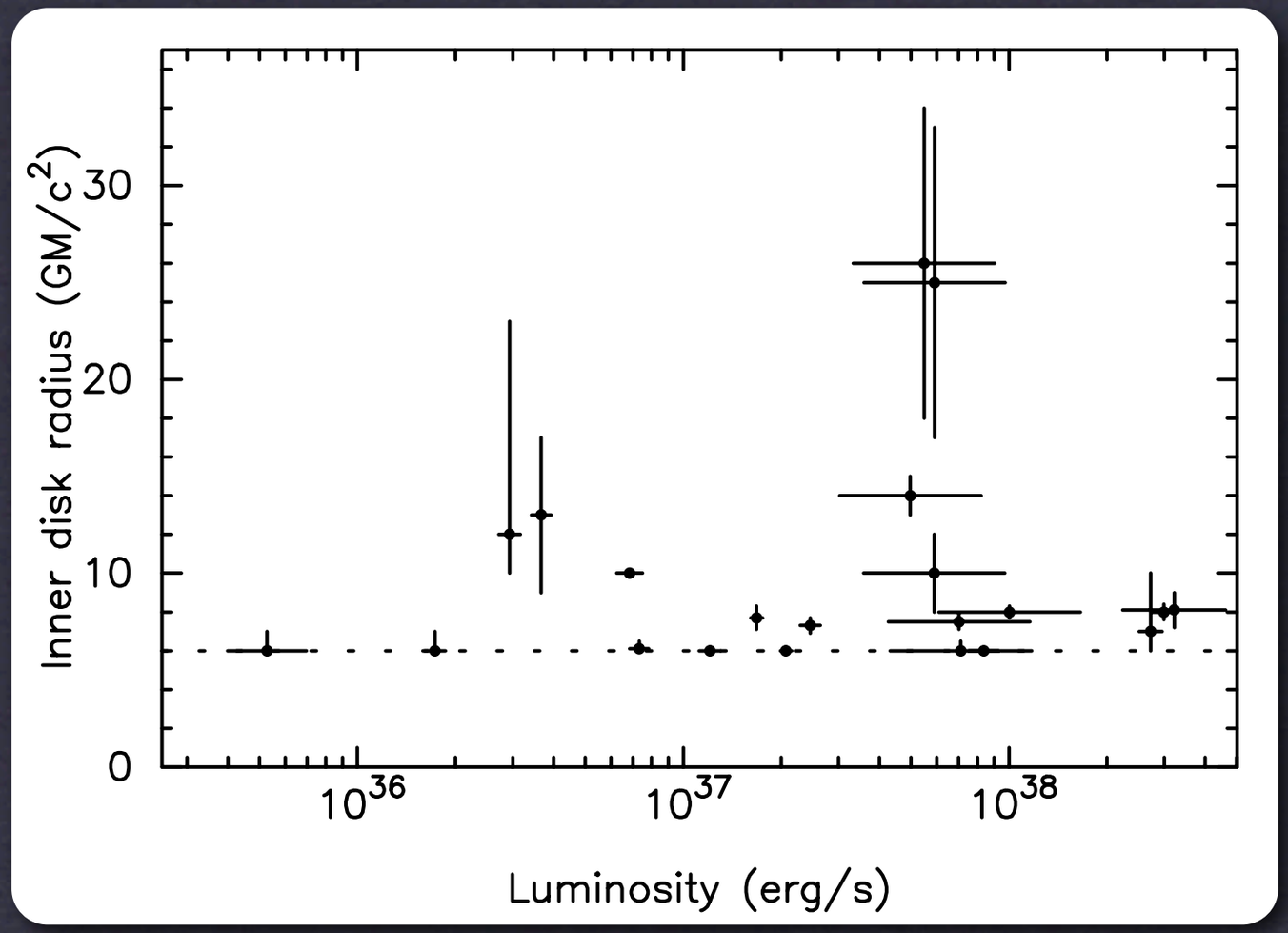


Many broad, asymmetric lines
observed over the last few years

Originally published by: Bhattacharyya & Strohmayer (2007), Cackett+ (2008), Pandel+ (2008), D' Ai+ (2009), Cackett+ (2009), Papitto+ (2009), Reis+ (2009), Di Salvo+ (2009), Iaria+ (2009)

Inner disk radius

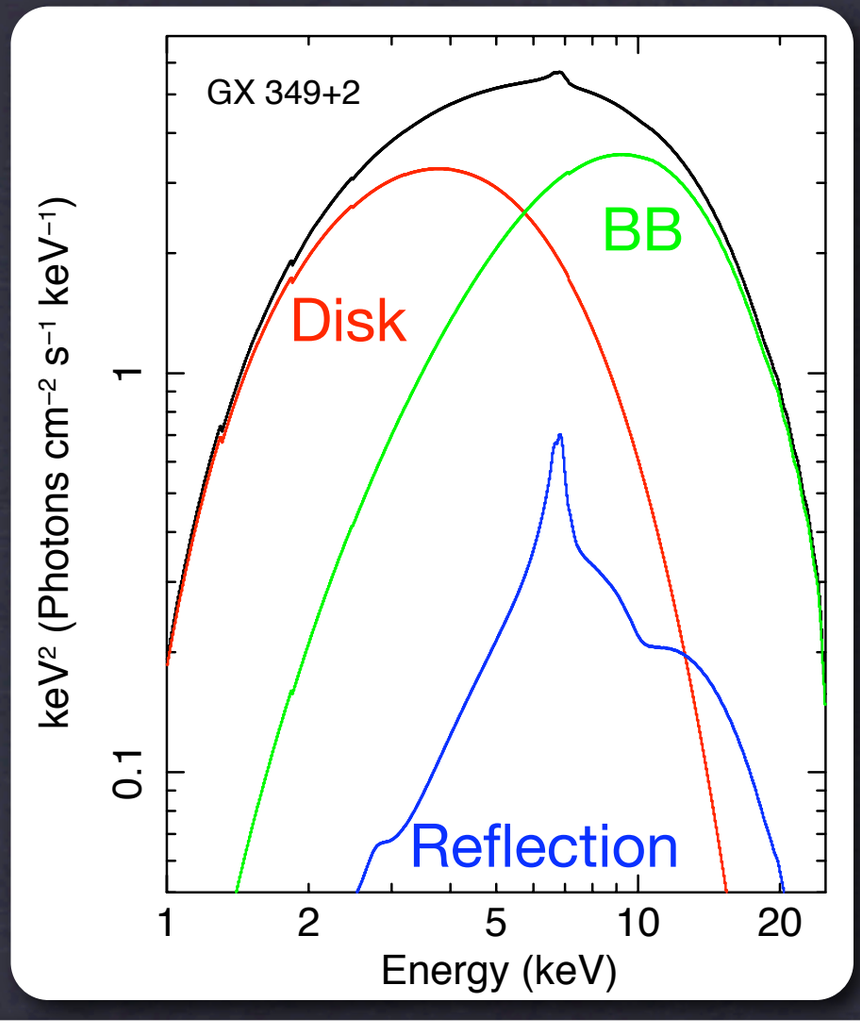
- Disk line model for Schwarzschild metric (Fabian+89) fits lines well
- Small range in inner disk radius across a large luminosity range

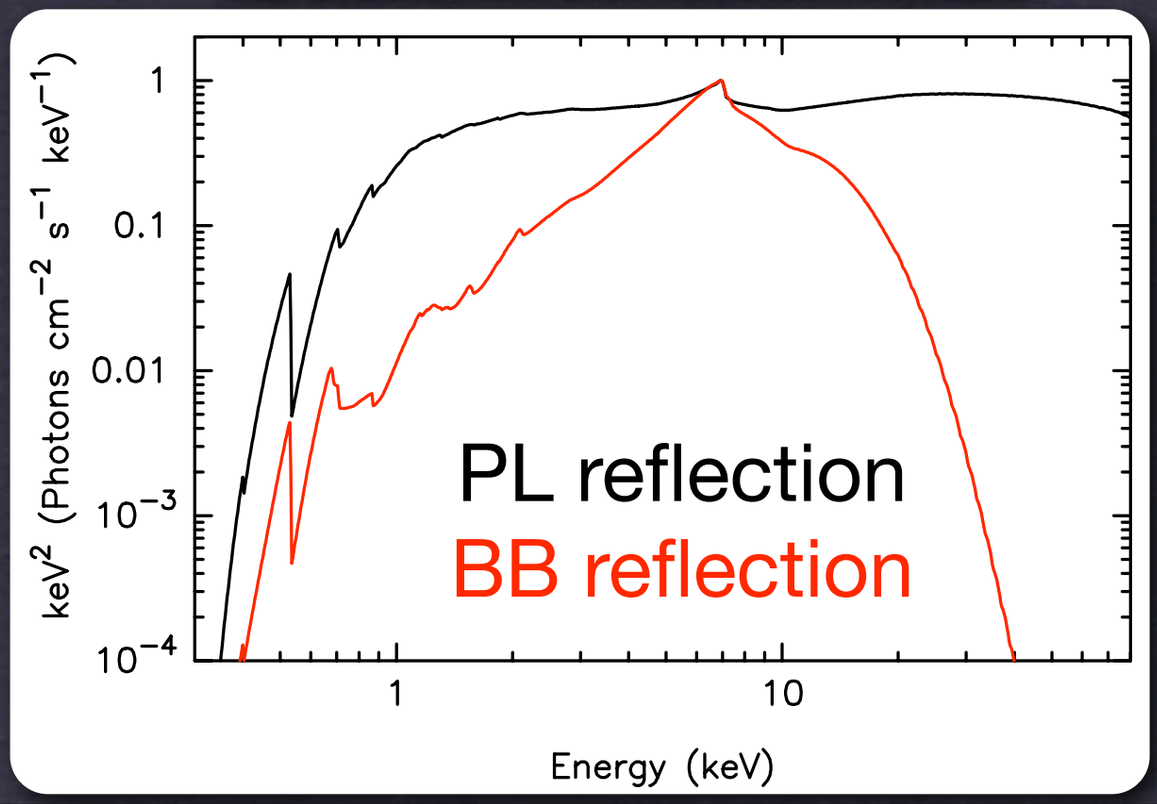


Cackett+ (2010)

Reflection in neutron star LMXBs

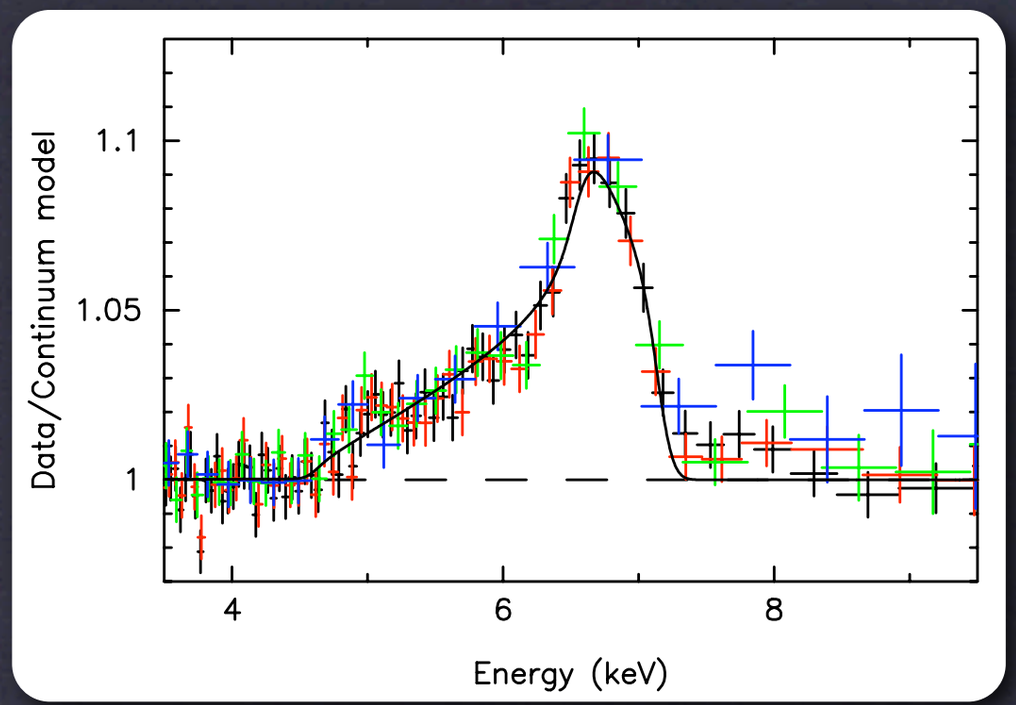
- Boundary layer prominent in spectra of soft/intermediate states
- Shape approximates a blackbody (Revnivtsev & Gilfanov 2006)
- Boundary layer irradiates disk leading to Fe K line (at least in soft states)



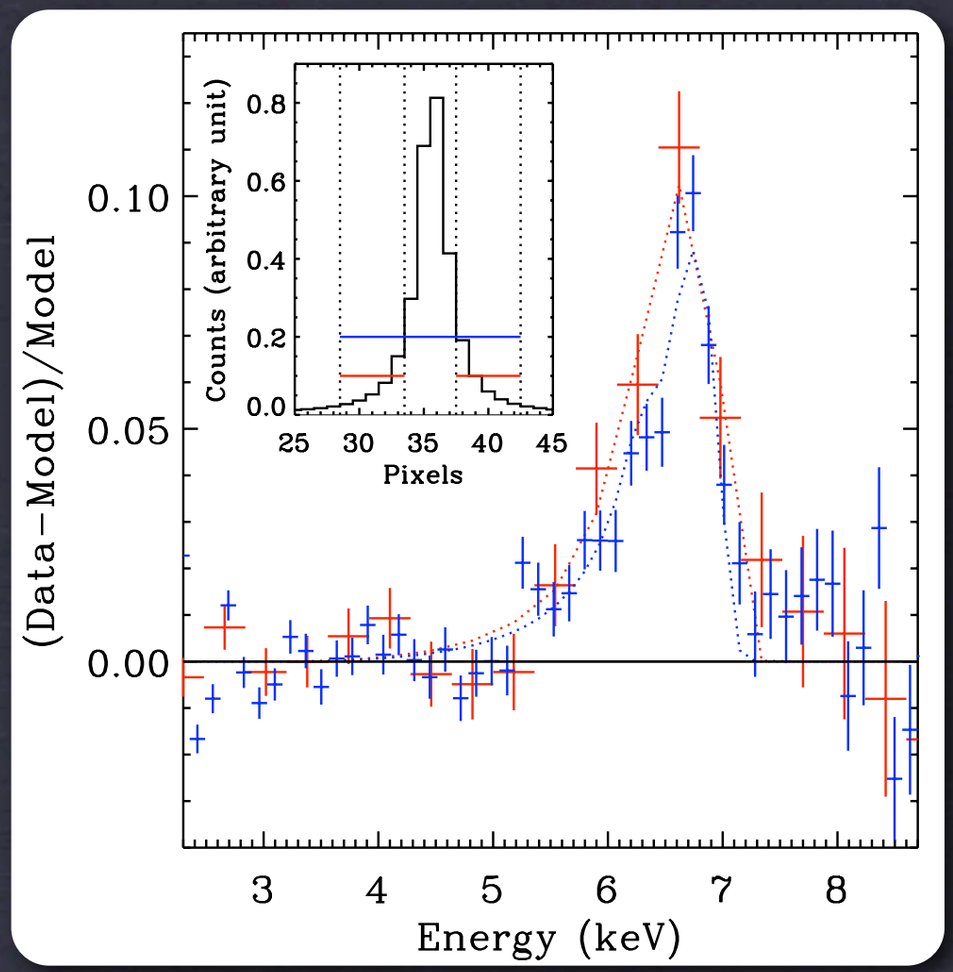


A few words on pile-up....

- Ng+ (2010) look at XMM pn-timing mode spectra: pile-up present, remove core of PSF, conclude lines are Gaussian and state that therefore pile-up broadens lines!
- **Pile-up does not broaden lines** - profiles are consistent with just reduced S/N

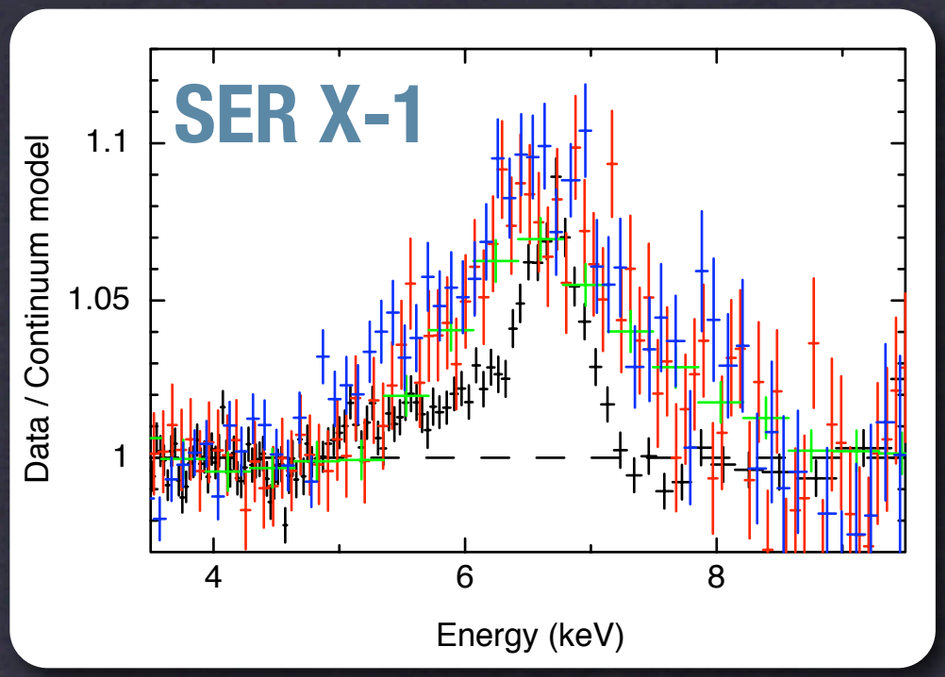


Ser X-1 with *Suzaku*: Cackett+(2010)



Ser X-1 with *XMM*: Bhattacharyya & Strohmayer (2007), Miller+(2010)

A comparison with gas spectrometers

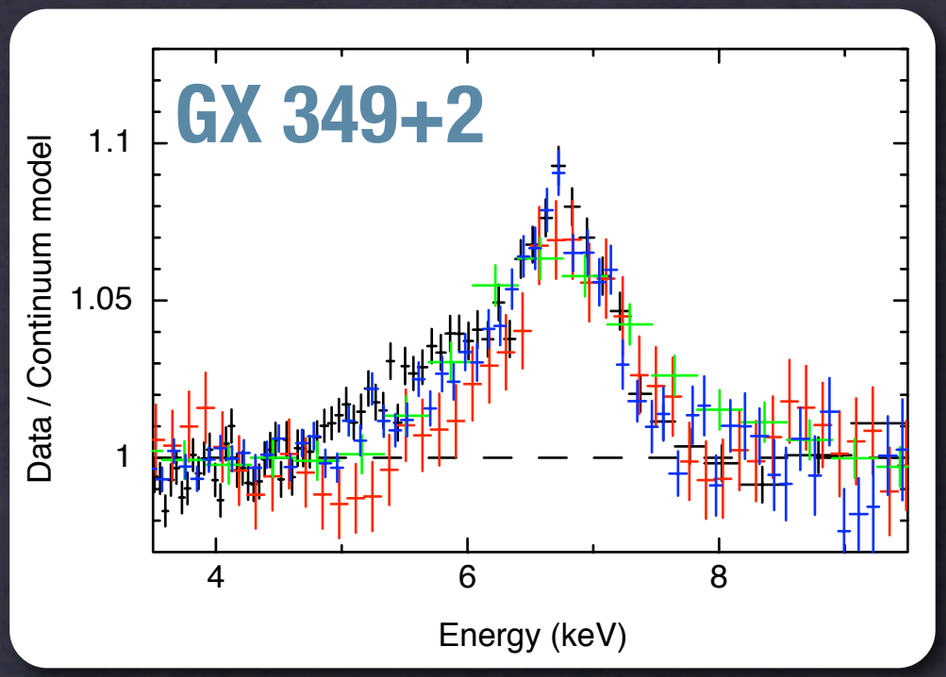


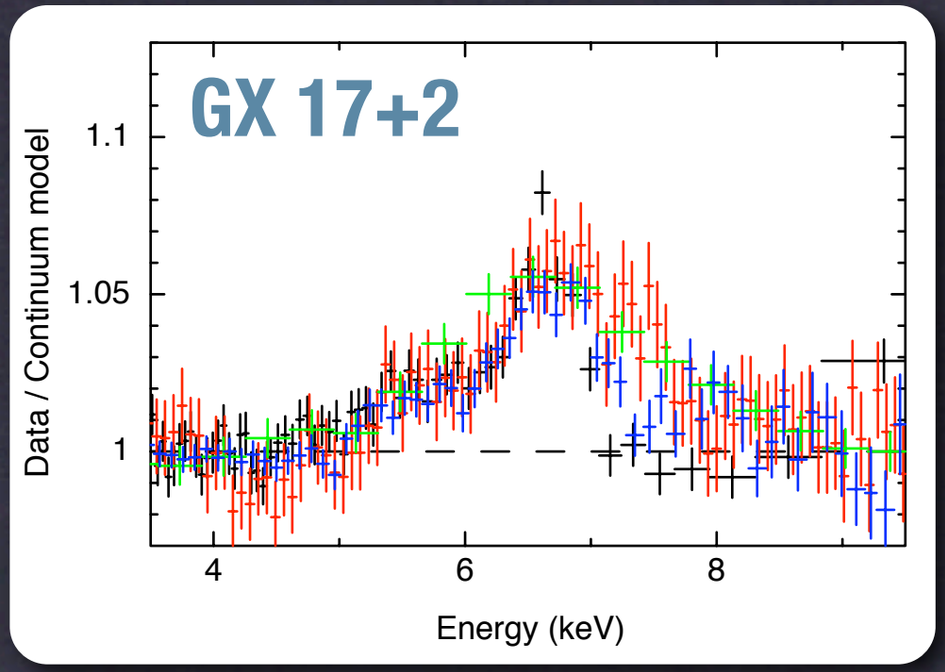
SUZAKU

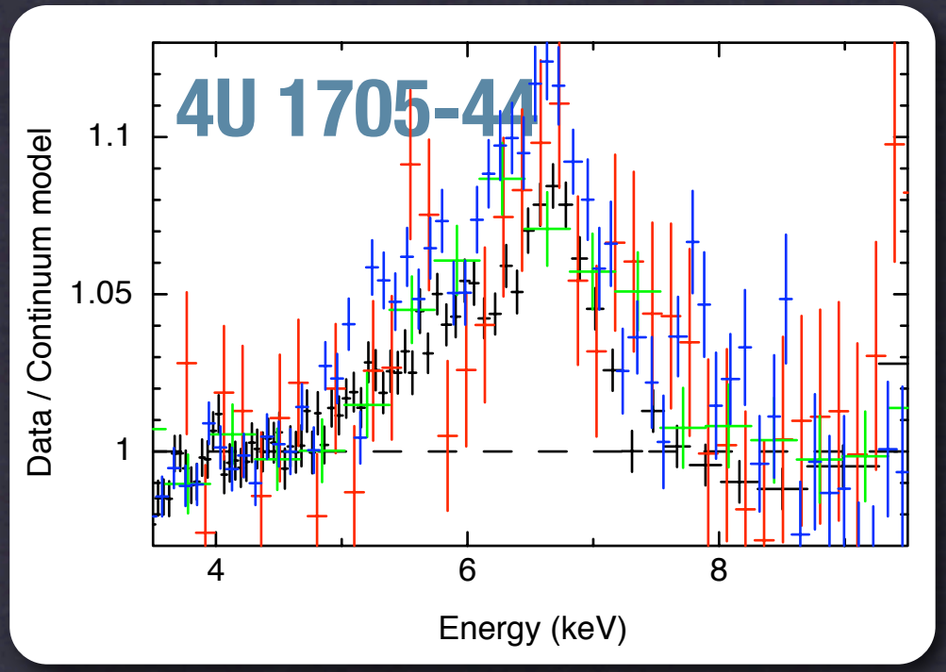
EXOSAT

RXTE

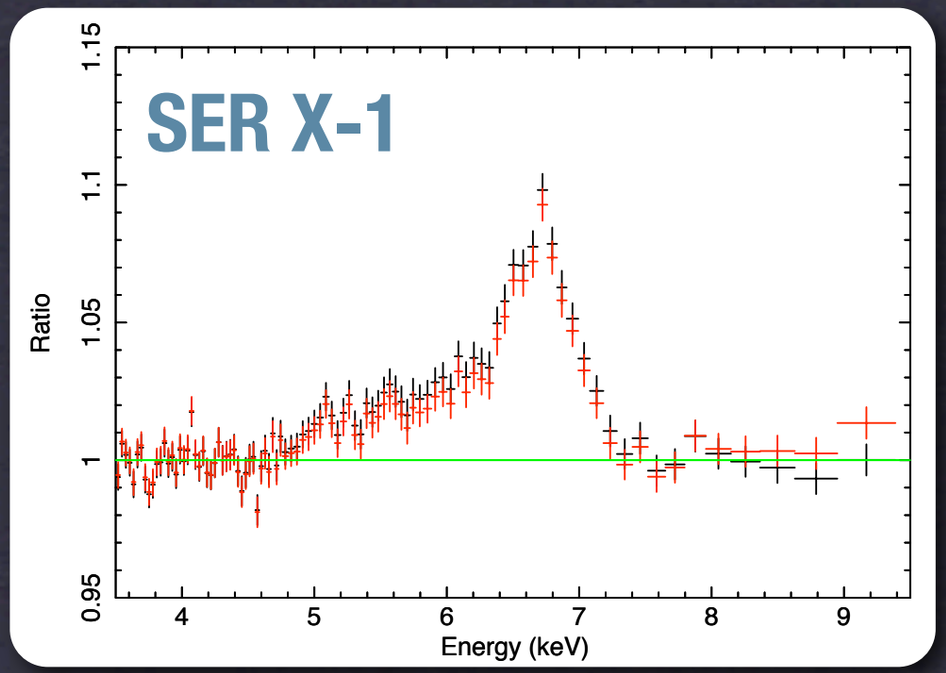
BEPPOSAX

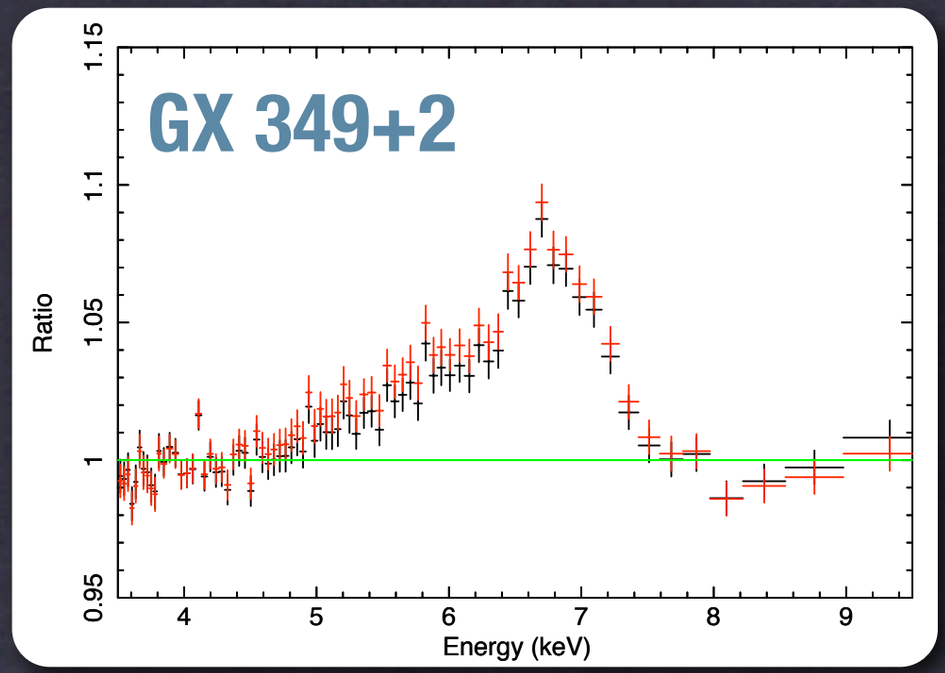






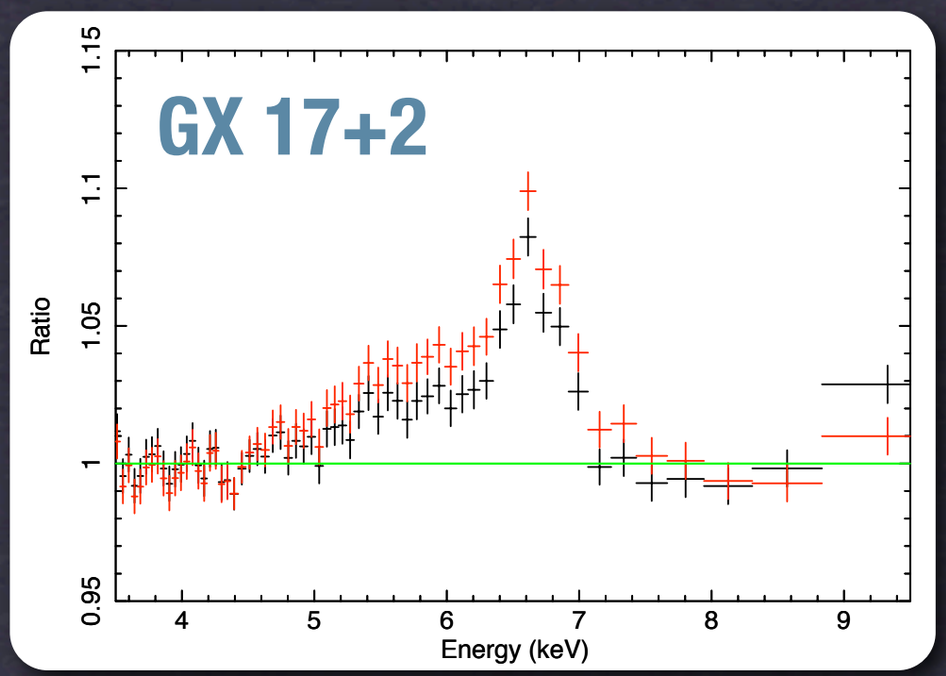
Robustness to continuum model

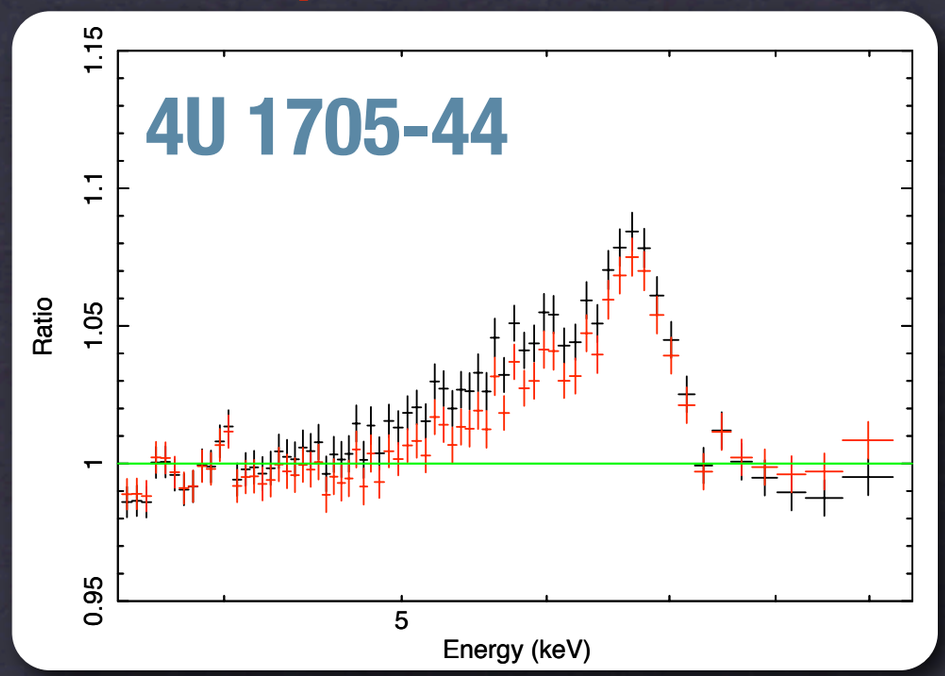




DISKBB+BBODY (+POWERLAW)

BBODY+COMPTT (+POWERLAW)





Studying the accretion flow

- Iron lines inform about the innermost accretion flow - learn about geometry and inner flow

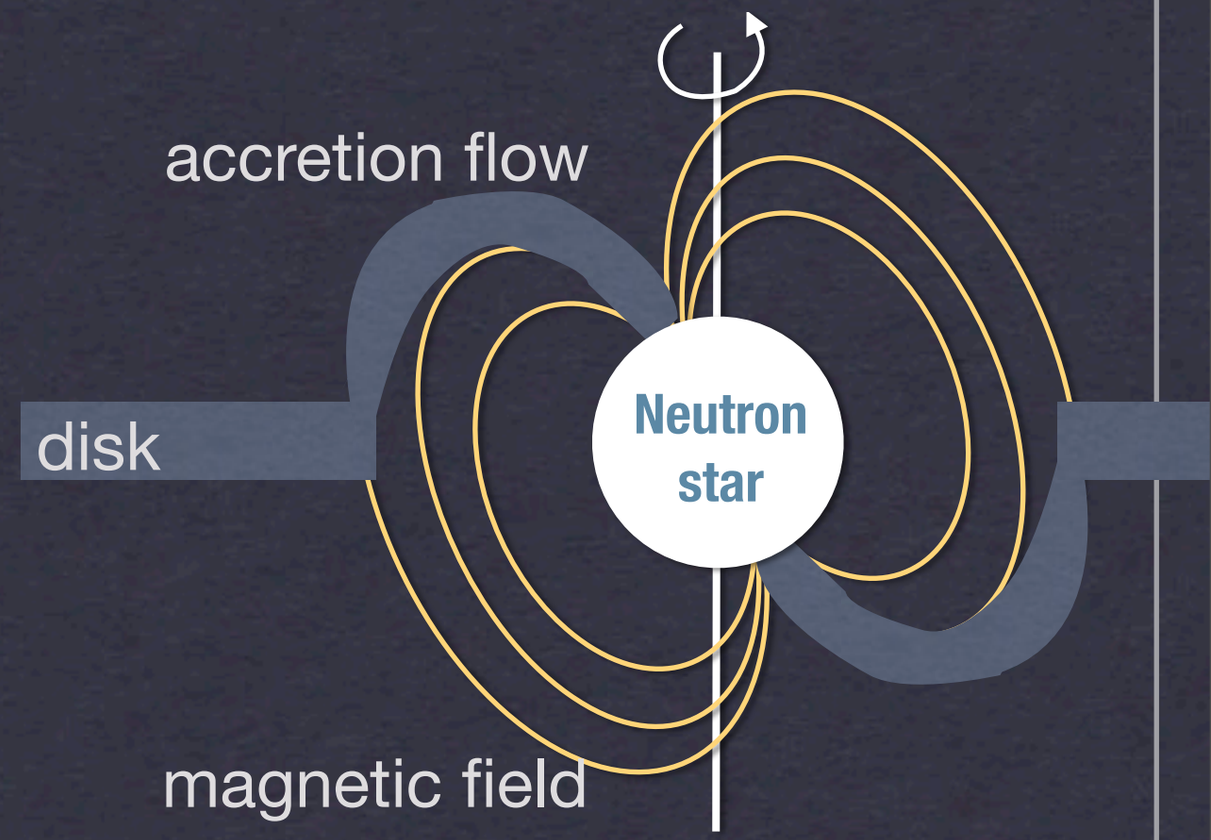
- Millisecond X-ray pulsars:

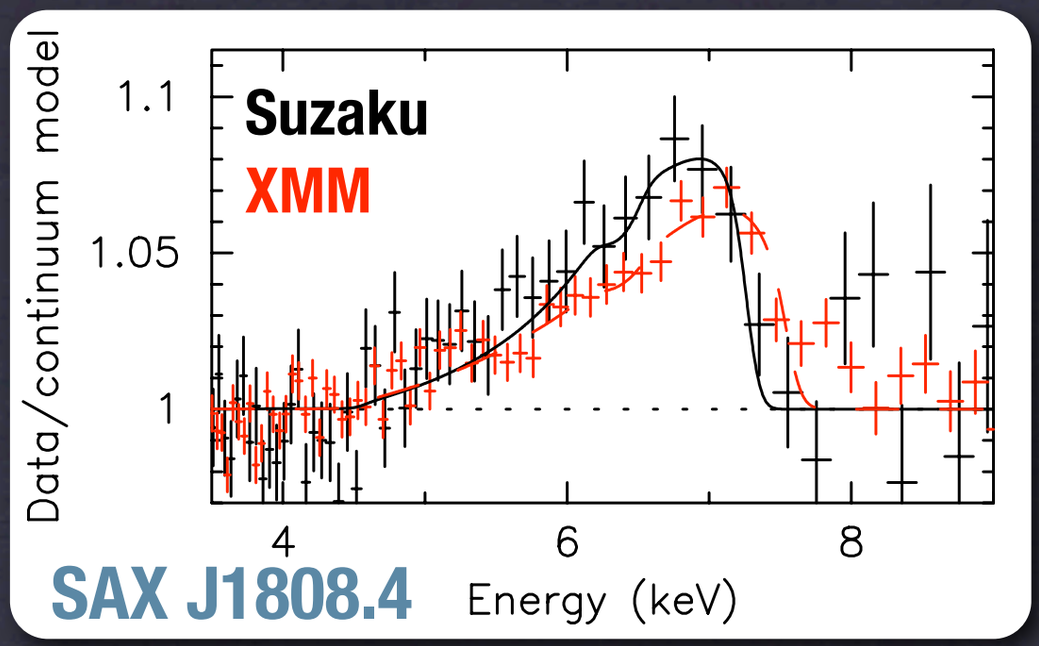
  - we see pulsations so disk should be truncated by magnetic field

  - use broadened iron line to measure inner disk radius & estimate magnetic field strength

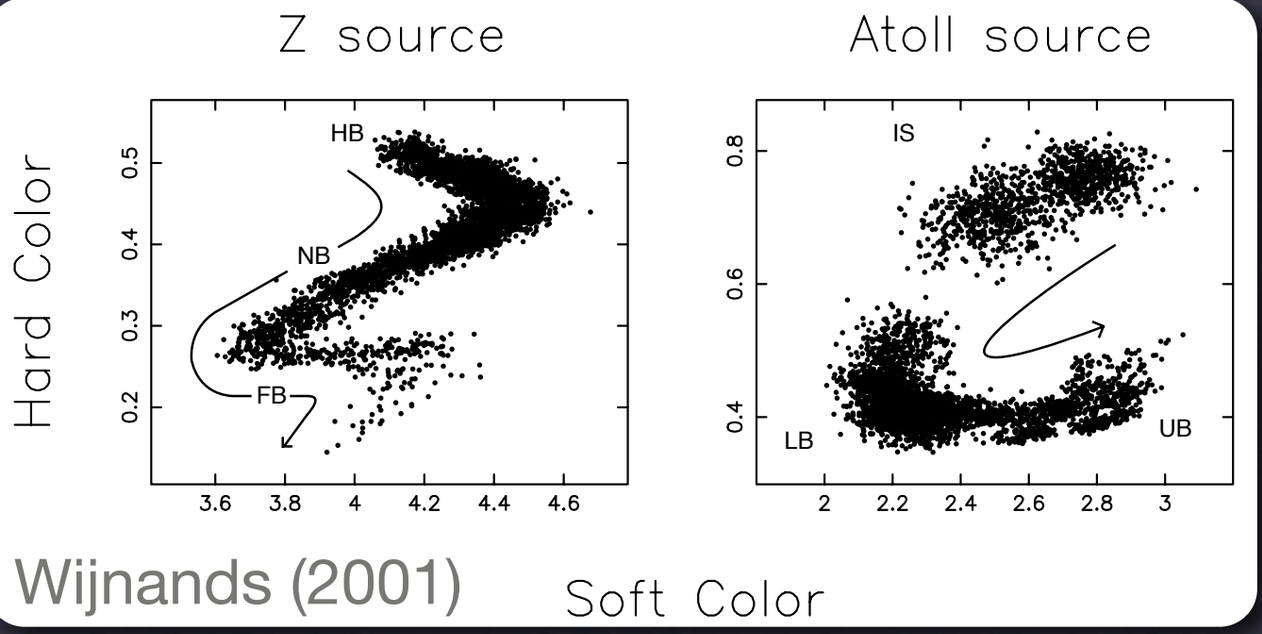
  - SAXJ1808: R_{in} = 13±3 GM/c^2 → B ~ 3x10^8 G

(see Cackett et al. 2009)

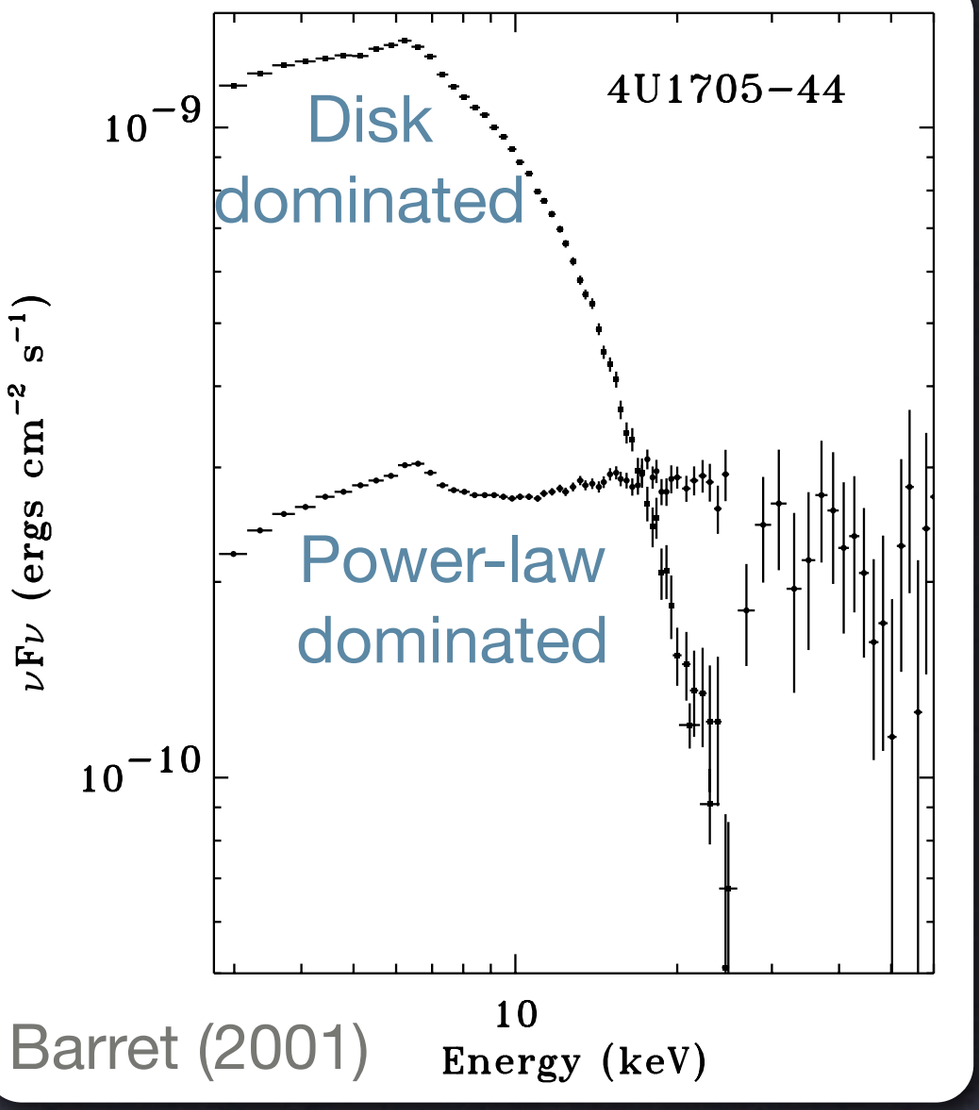




Color-color diagrams and states



Wijnands (2001)



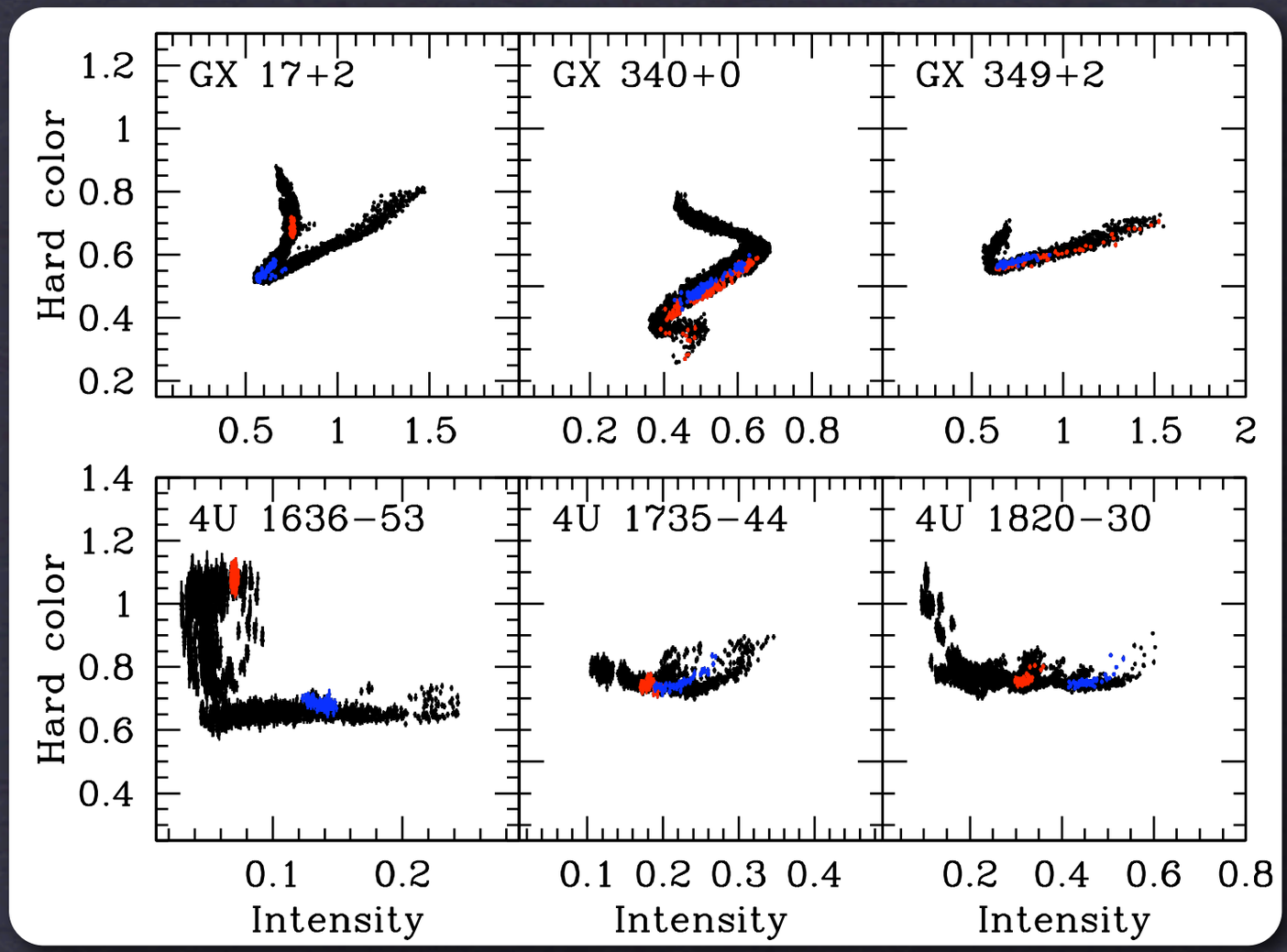
Barret (2001)

- What drives state changes?
- Important Q: is there a change in the inner disk radius across the states?

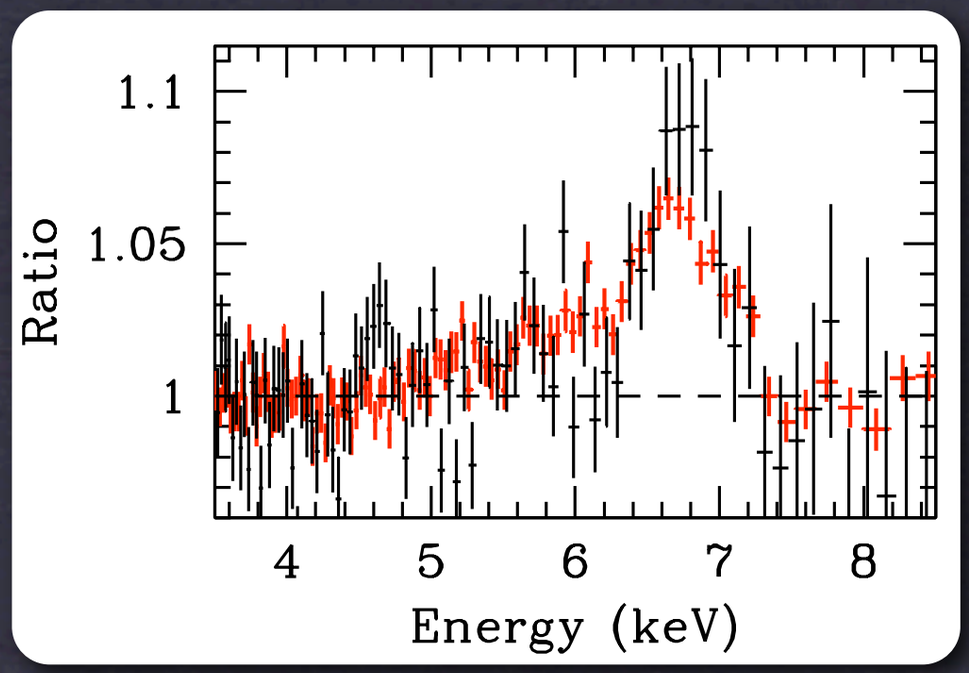
CHAZSS: Chandra Atoll & Z Spectroscopic Survey

SEE CACKETT ET AL (2009)

- Chandra HETG and RXTE observations of 3 atoll and 3 Z sources
- No clear dependence on state for where lines observed or not



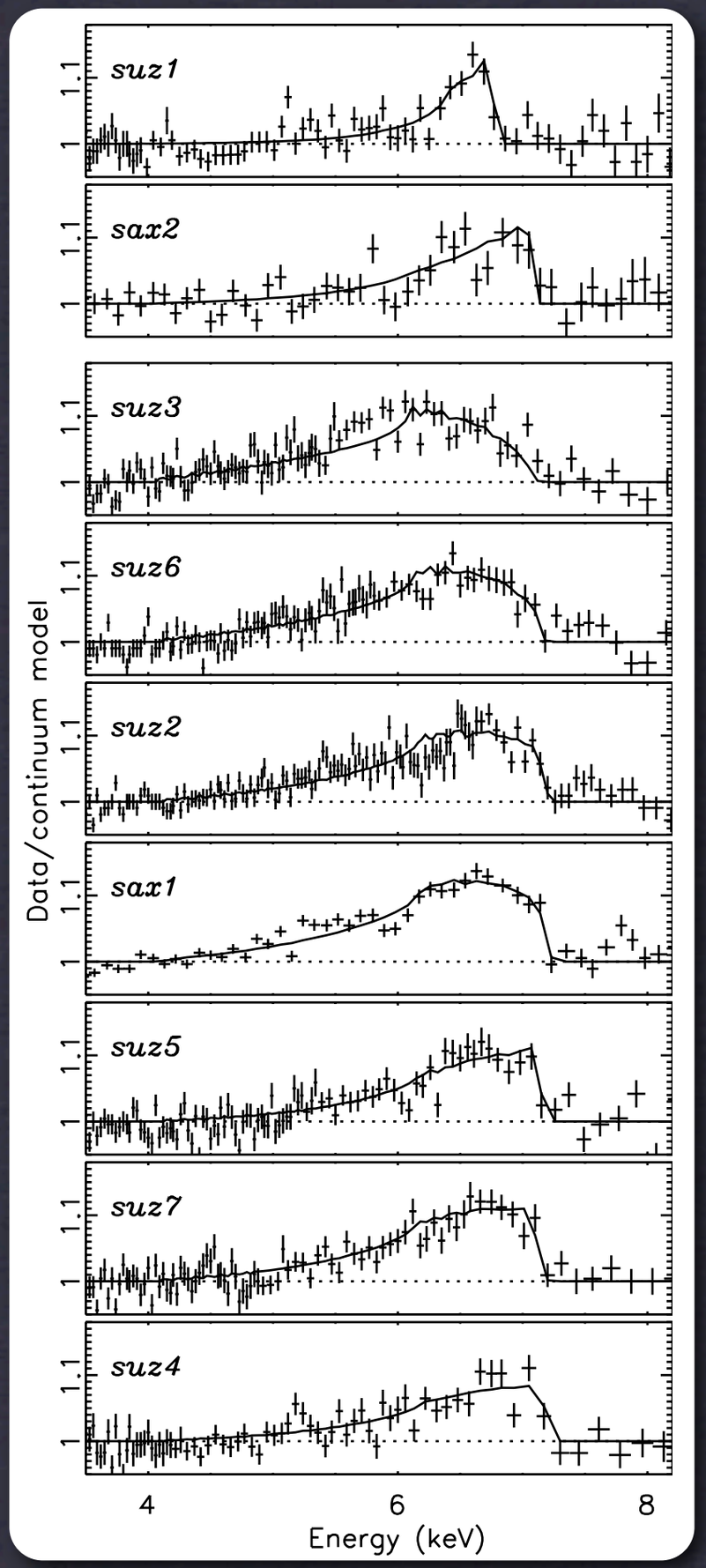
RXTE long-term hardness-intensity diagram with location of CHAZSS observations



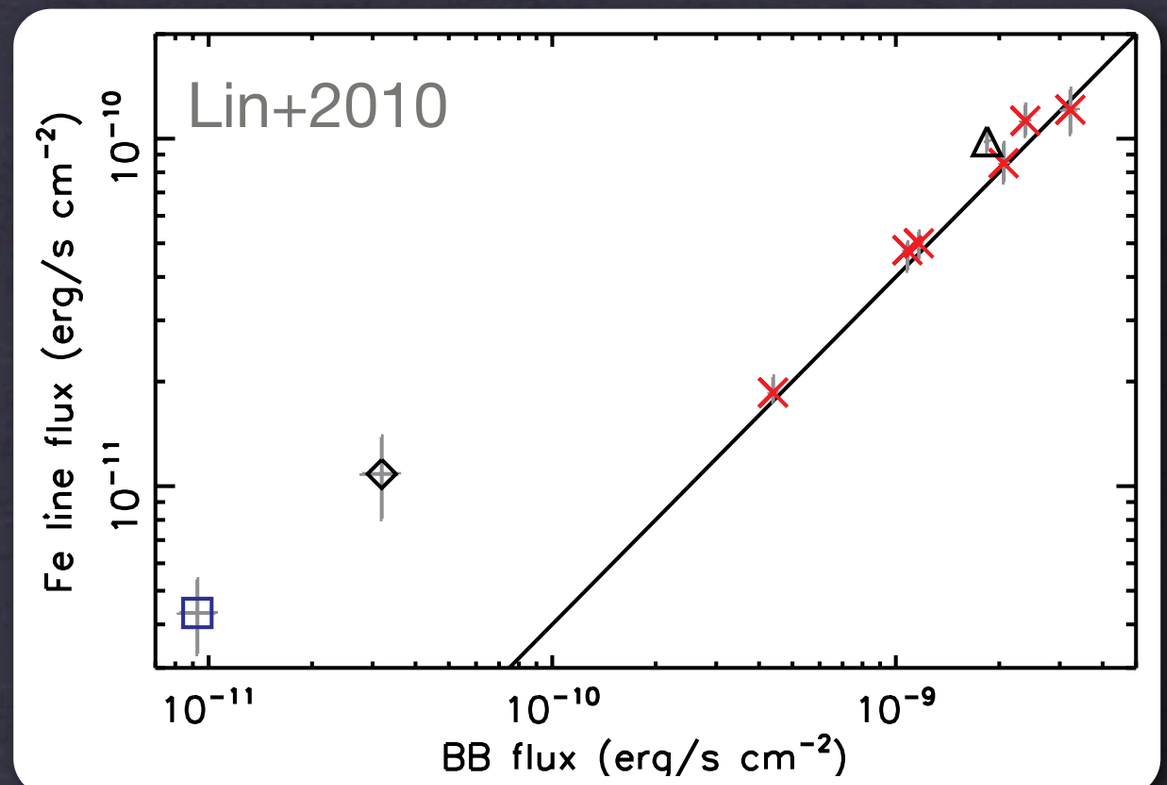
Suzaku, Chandra HEG

NS Fe K lines across the states

- Current evidence for inner radius change: **inconclusive**
  (e.g. Cackett+10, D'Ai+10, Lin+10)



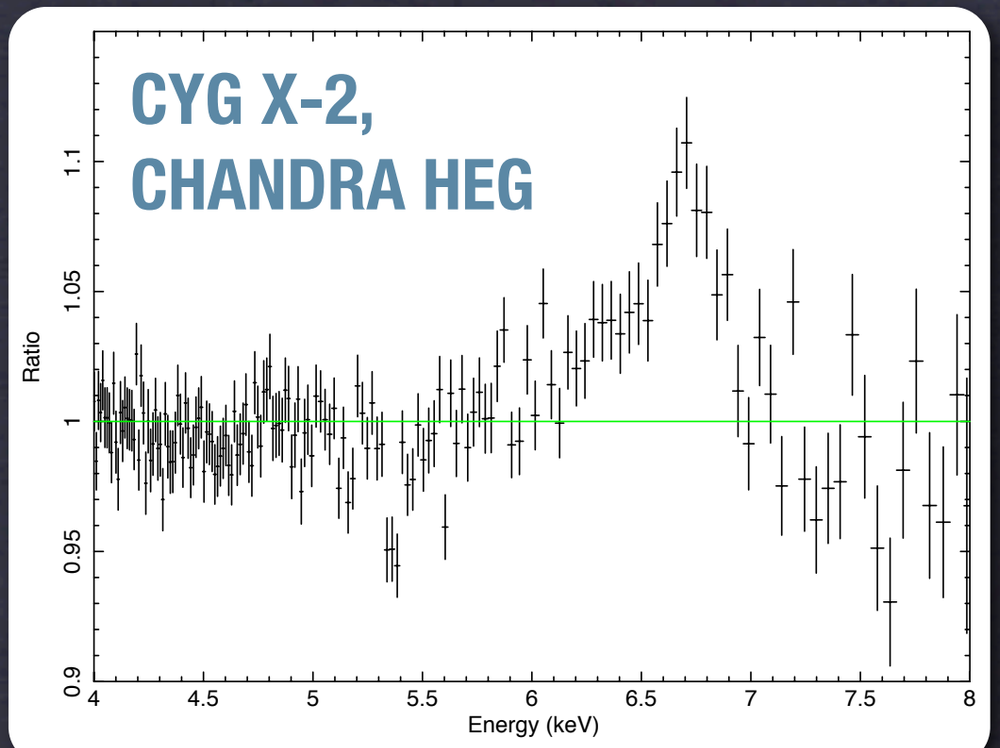
Left:
4U1705-44
from Lin
+2010

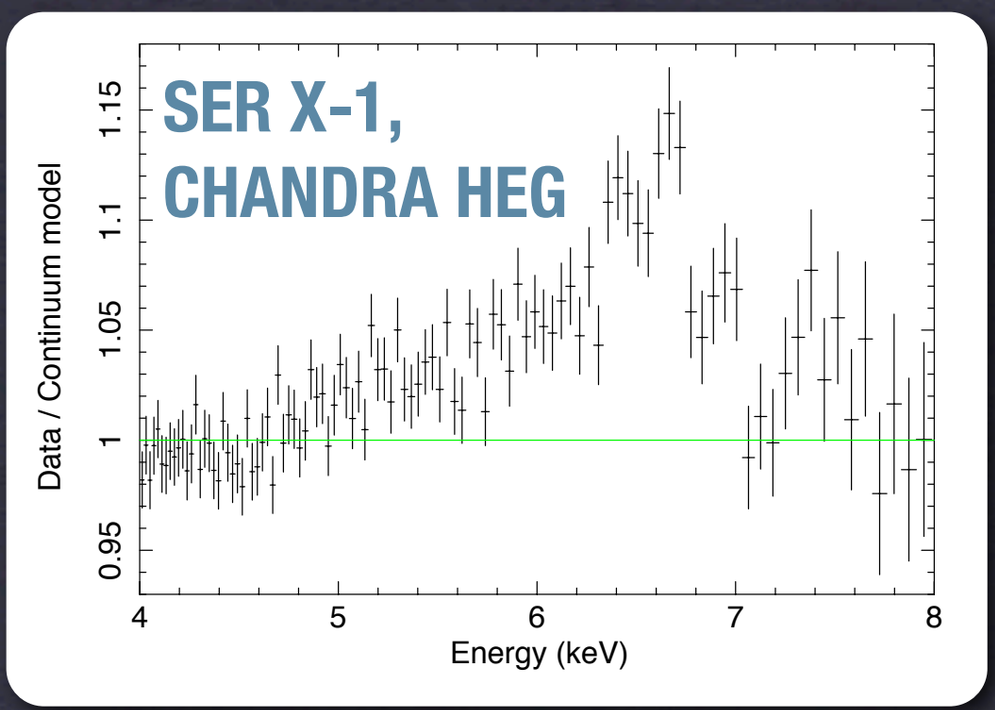


Irradiating BB flux correlates with Fe line flux in the soft states
– **supporting reflection**

Chandra's future contribution

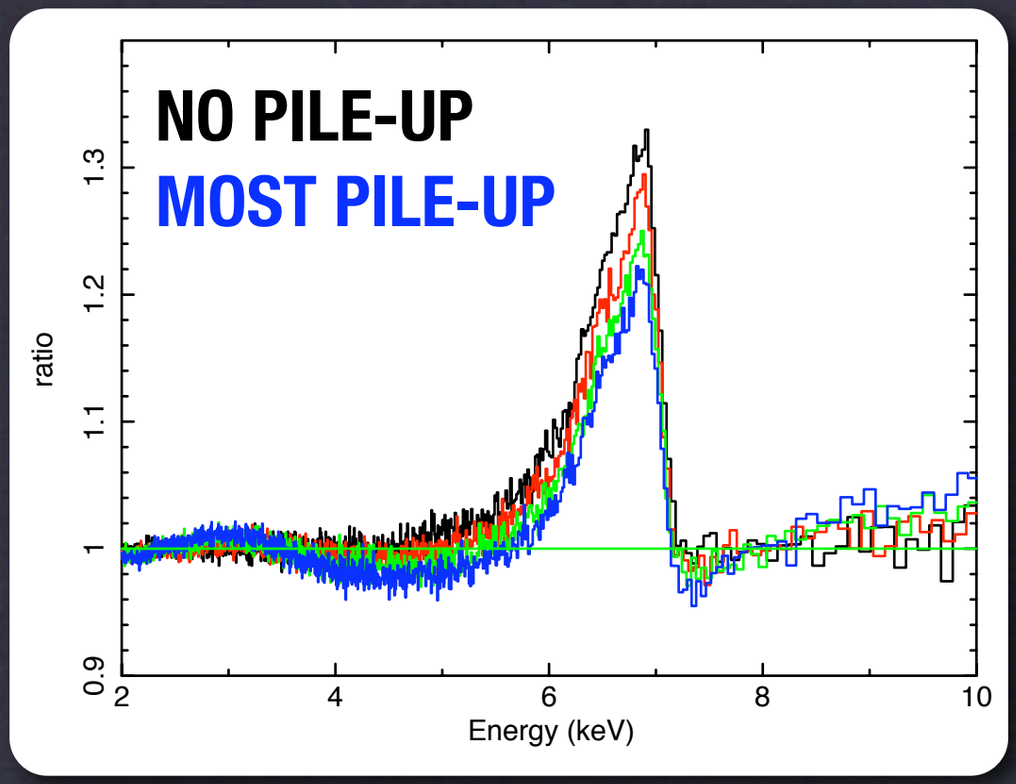
- Schulz et al. (2009) resolve Cyg X-2 line into multiple narrow components
- However, doesn't account for broad wing seen with *Chandra* and Suzaku
- Torrejon et al. (2010) searched for narrow Fe K lines in LMXBs....found them to be rare
- Deep *Chandra* gratings observations in 'CC' mode can make a big impact:
  - definitely address the issue of pile-up
  - search for multiple narrow lines

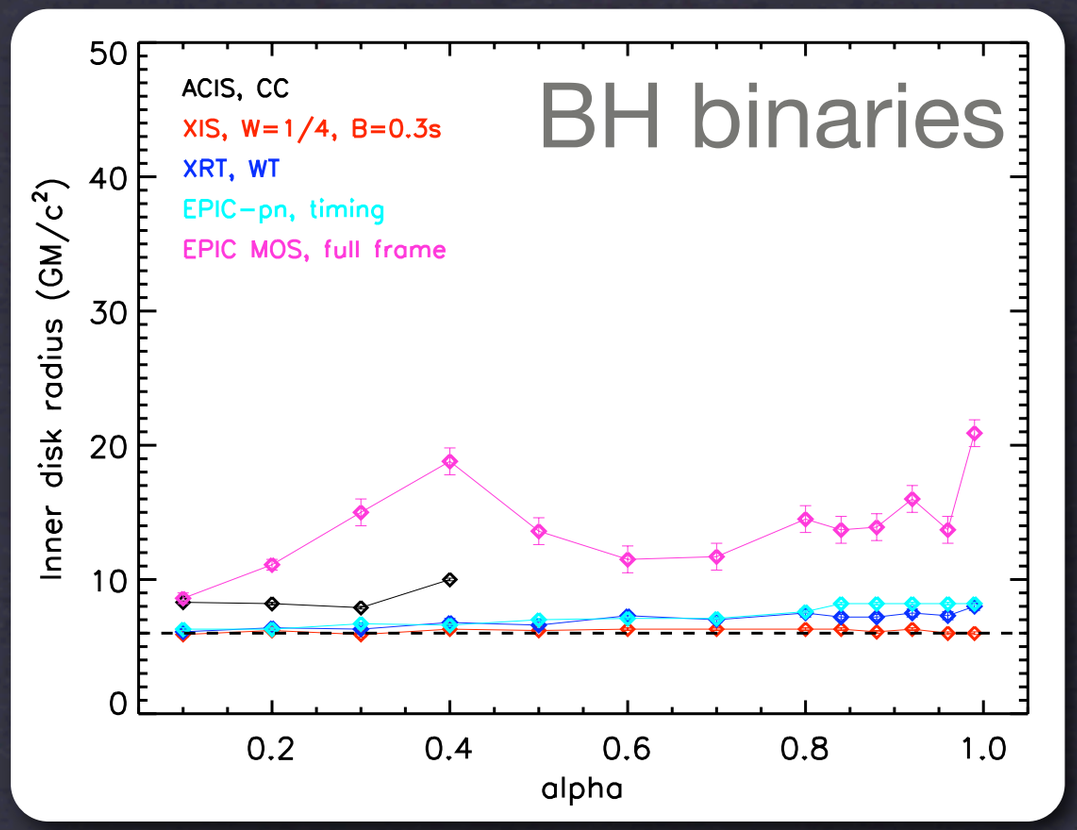


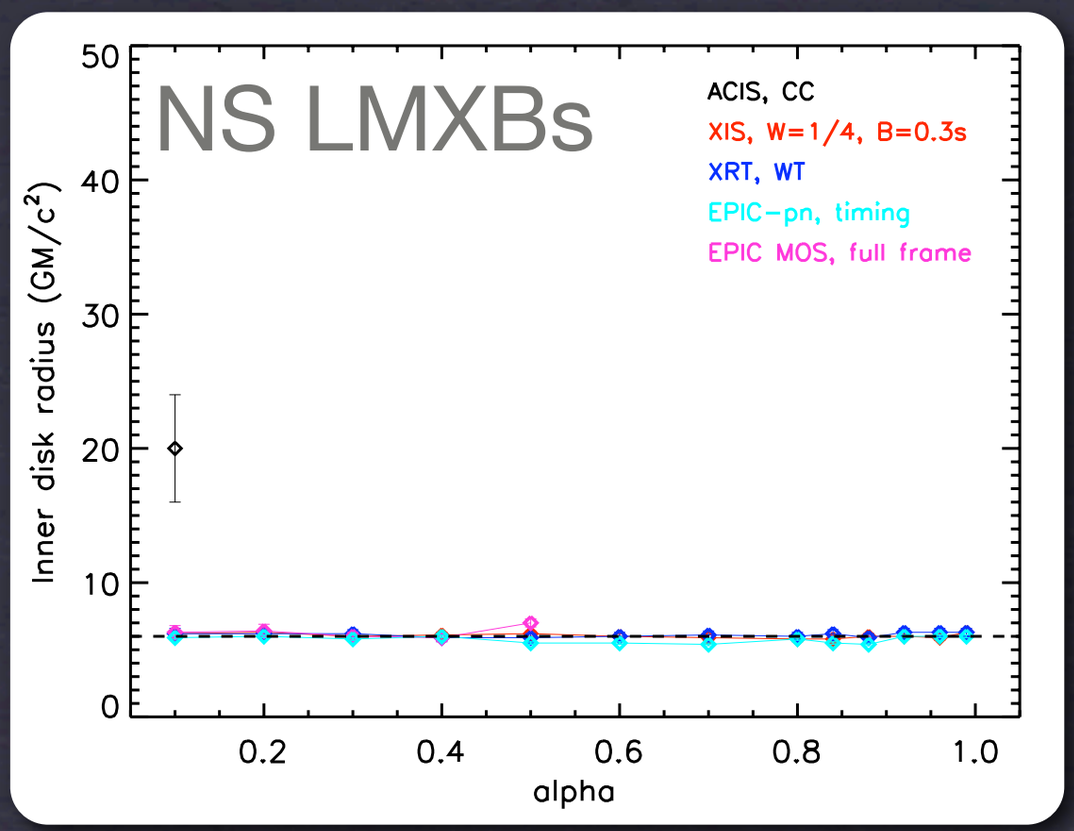


Pile-up simulations

Thorough simulations demonstrate **pile-up actually narrows lines** (Miller+2010)







INCREASING PILE-UP ⟶

Alternative wind line origin

- Laurent & Titarchuk (2007), Shaposhnikov+(2009), Titarchuk+ (2009): suggest broad Fe lines are created by Compton scattering in a wide-angle optically thick high velocity wind
- (Some) problems with this:
    - outflow rate extremely high:
        - Ser X-1: outflow rate ~ Eddington inflow rate
        - GX 339-4: outflow rate is 30-100 inflow rate in low/hard state
    - outflow rate must not be coupled with inflow rate - we see similar line profiles over 2 orders of magnitude in luminosity
    - winds are seen in high/soft states when disk lines are typically absent
    - lines are often (not always) seen when QPOs present