Reflections on RXTE

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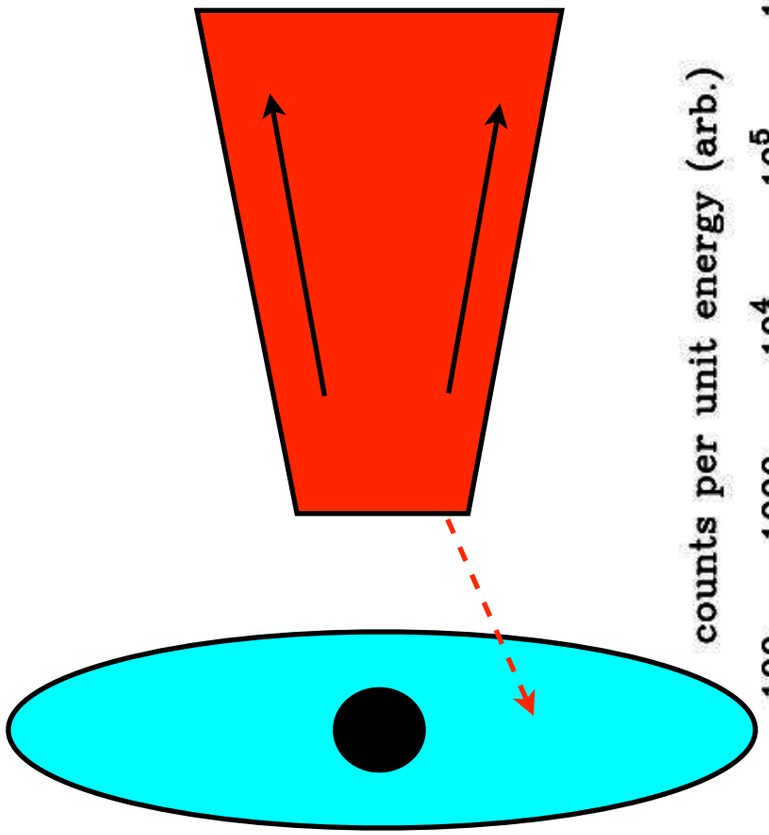
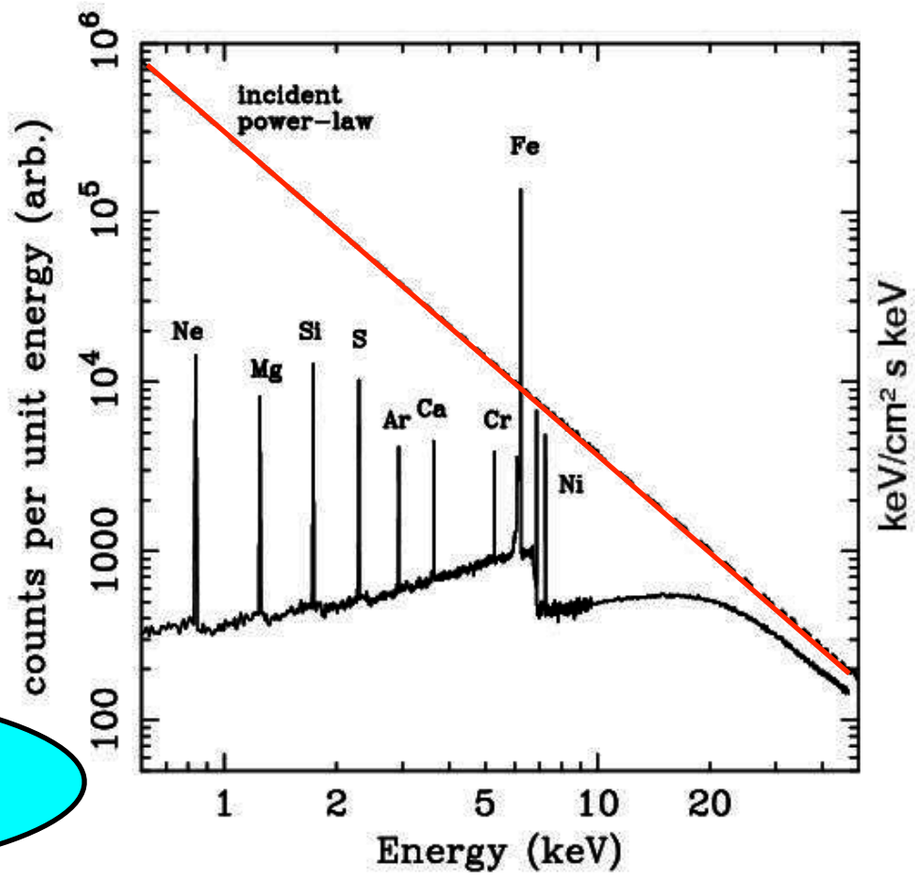
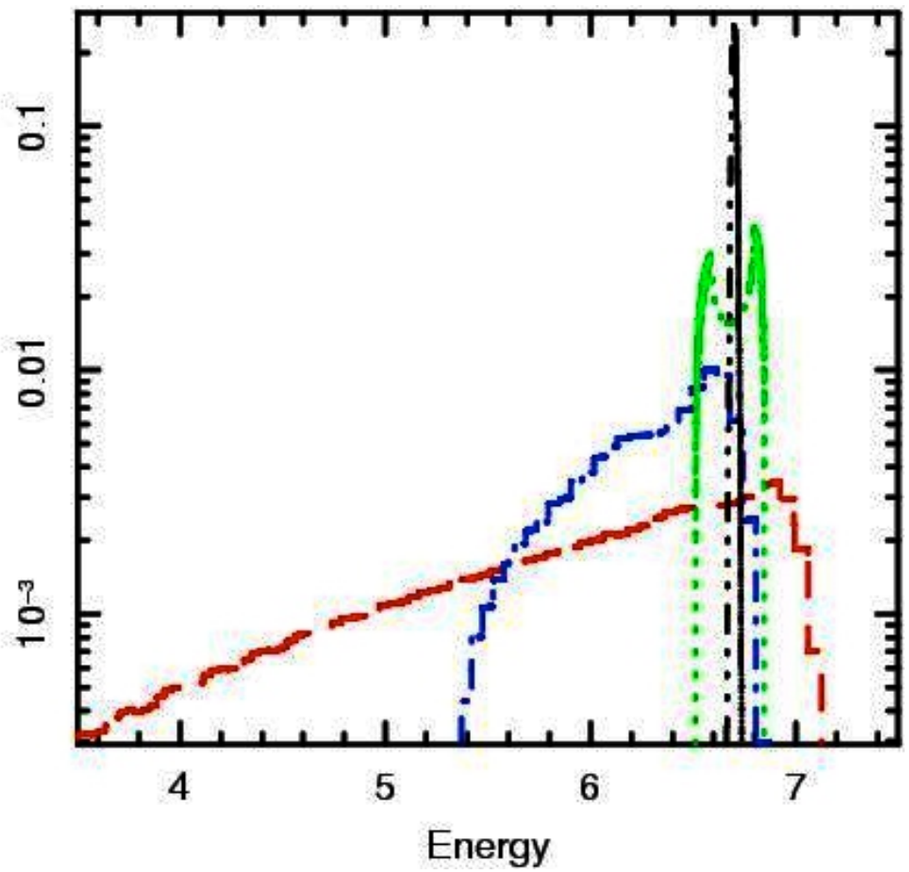
X-ray Disk Lines

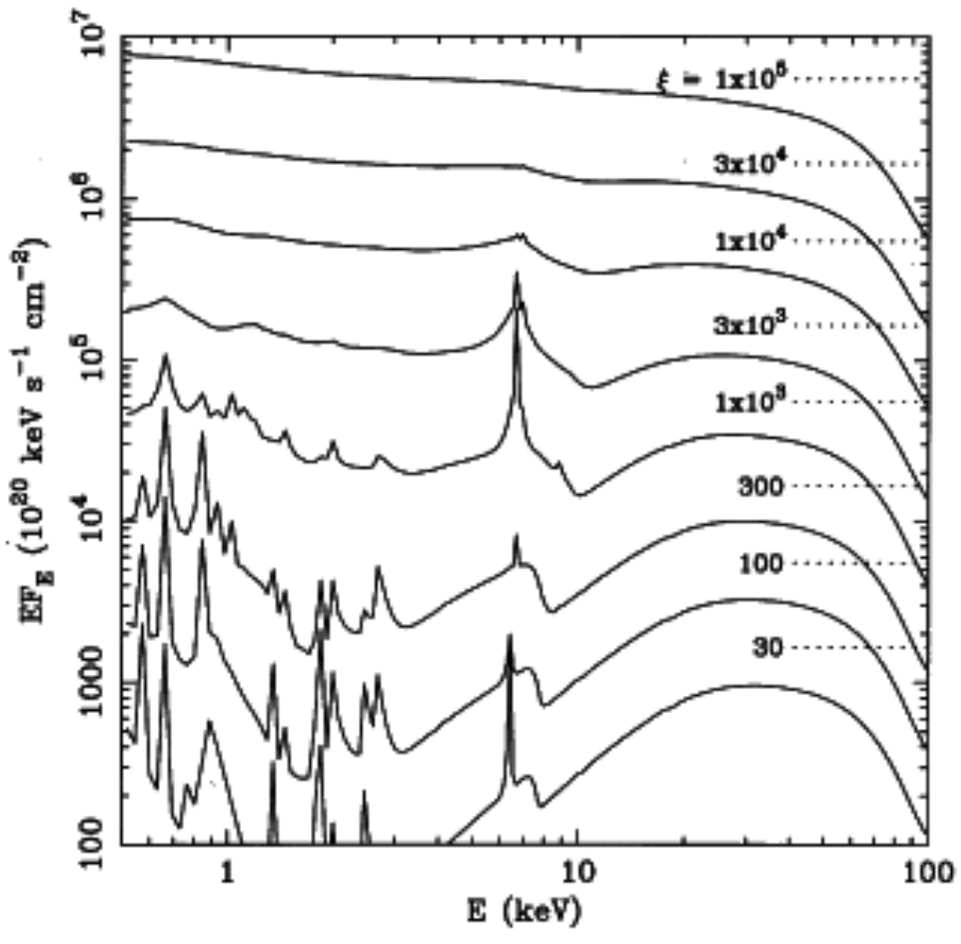




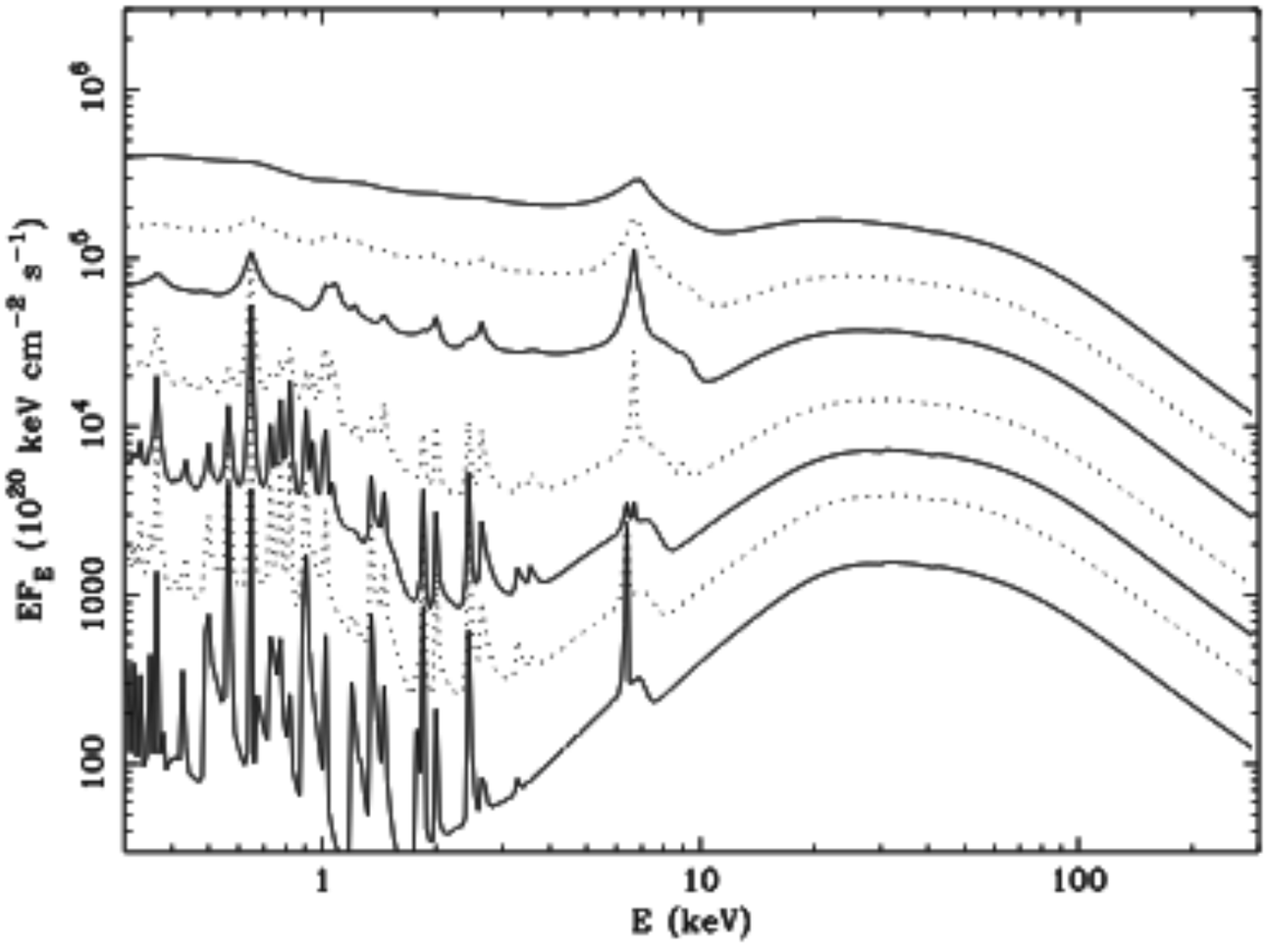


X-ray Disk Reflection

Ross & Fabian 93



Ross & Fabian 07

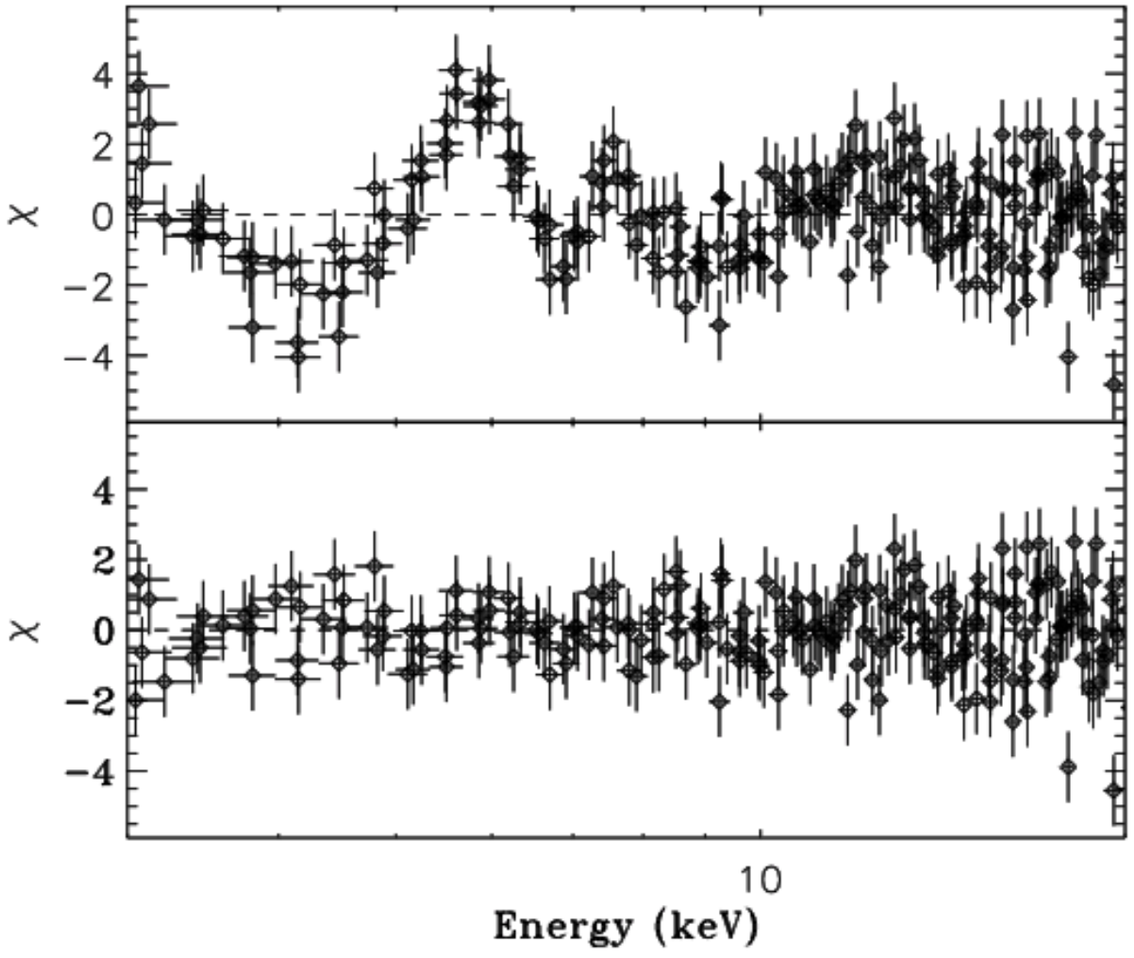


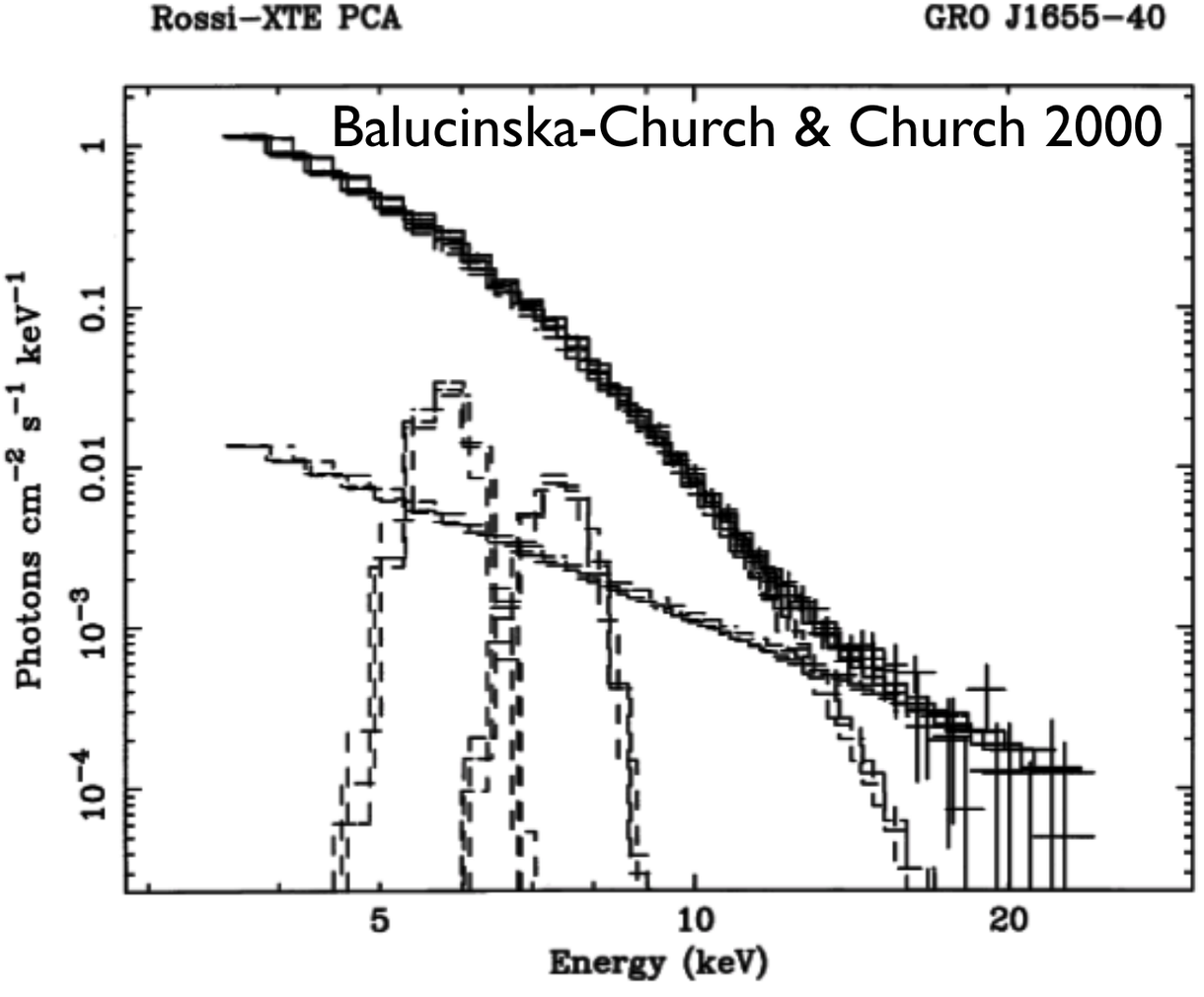
Reflection came of age with RXTE

- Large collecting area --> sensitivity.
- More than made up for modest resolution.
- The right energy range.
- Excellent broad-band calibration.
- Able to observe bright sources easily.
- *RXTE made studies of disk reflection easy.*

Early efforts

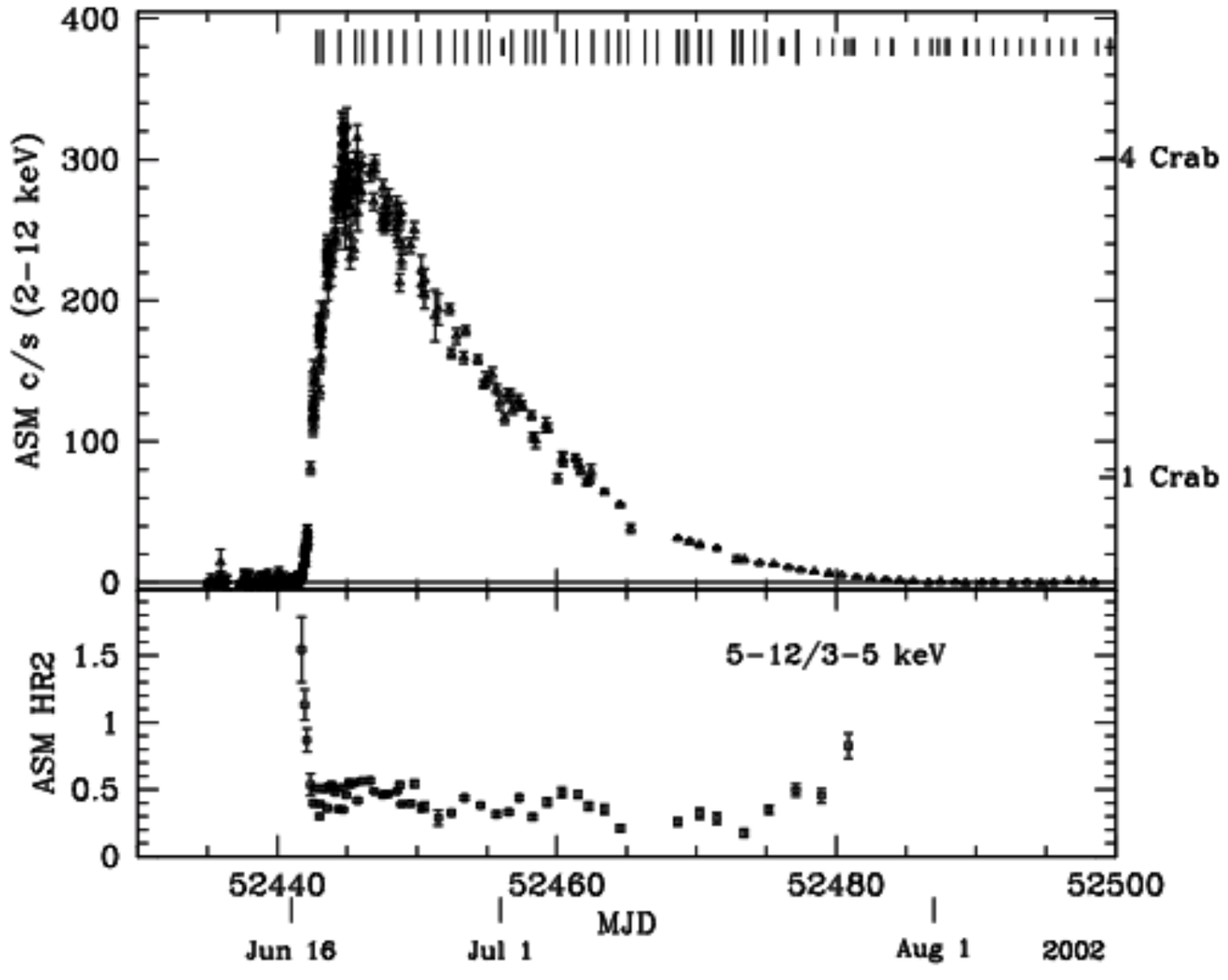
4U 1630-47, Cui ++ 2000

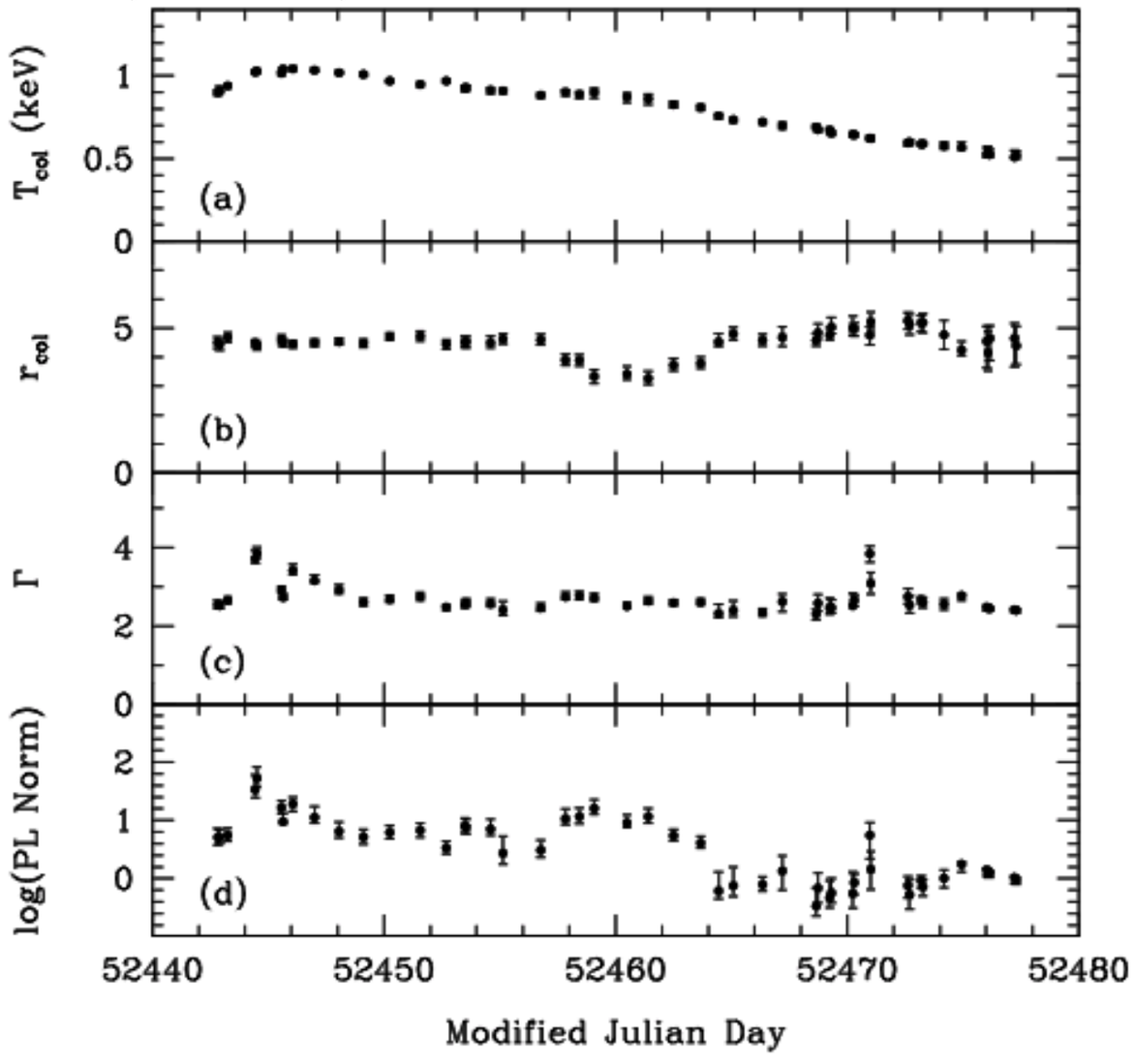




4U 1543-475

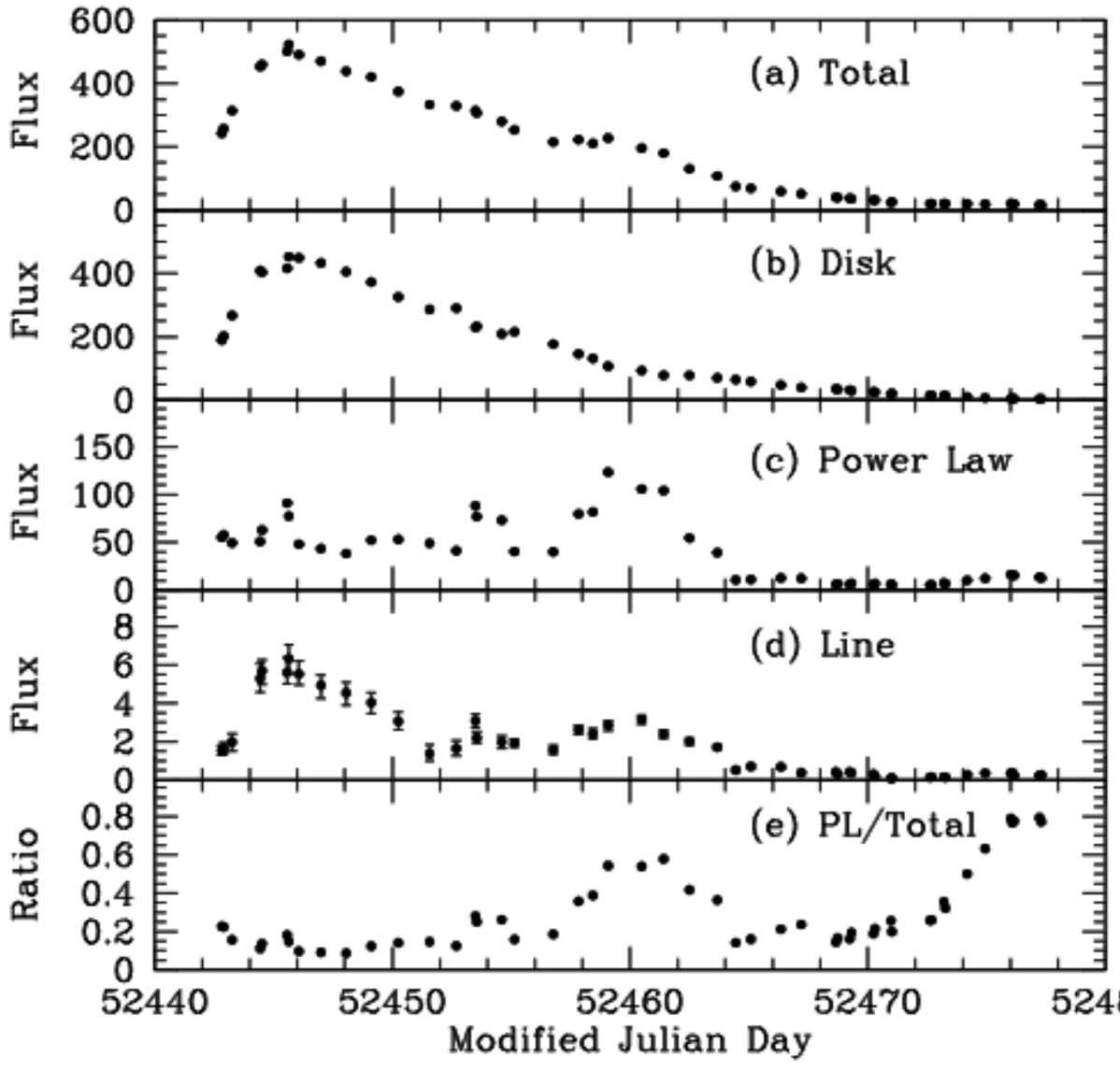
Park, Miller, McClintock, +++, 2004

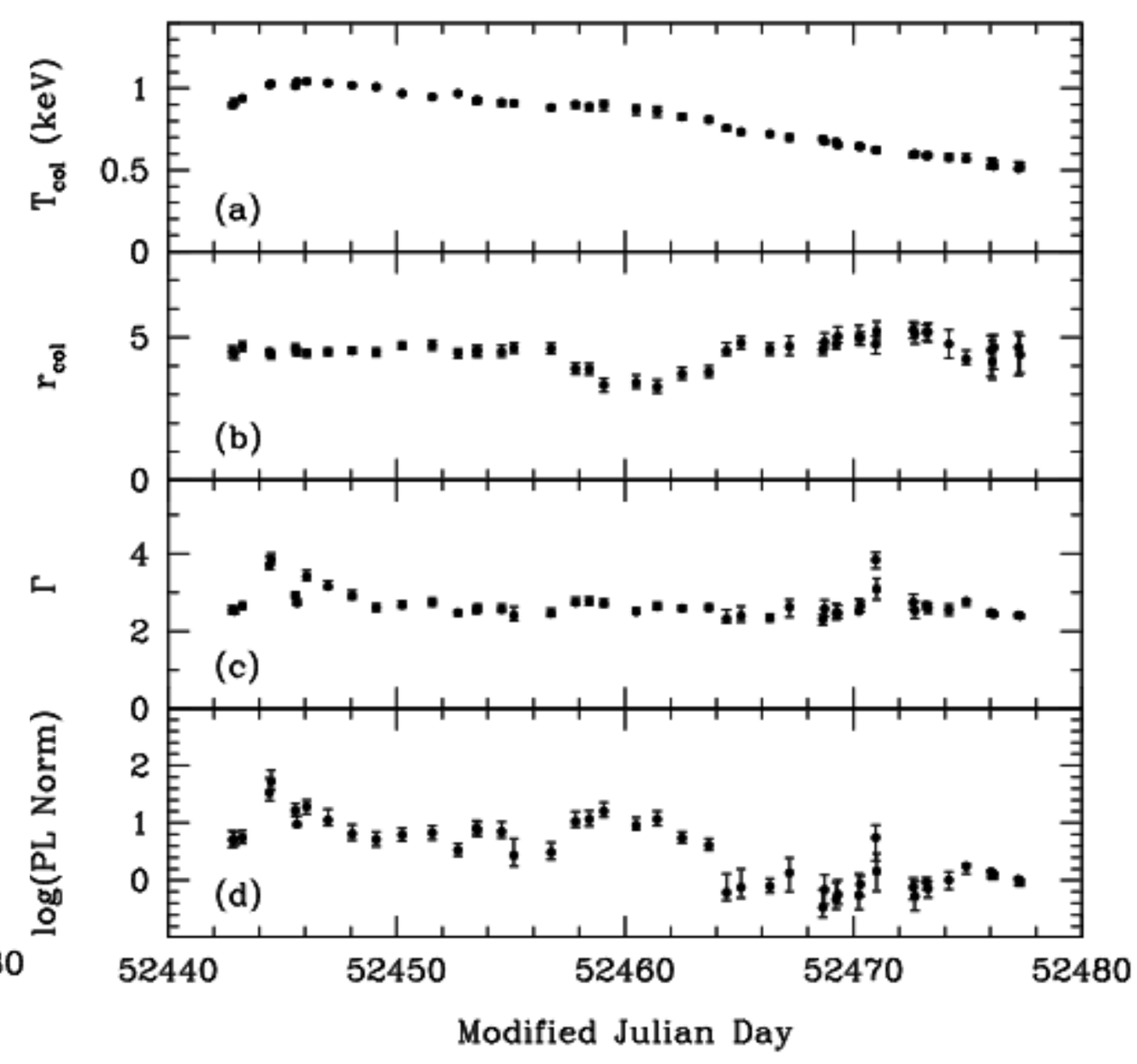




4U 1543-475

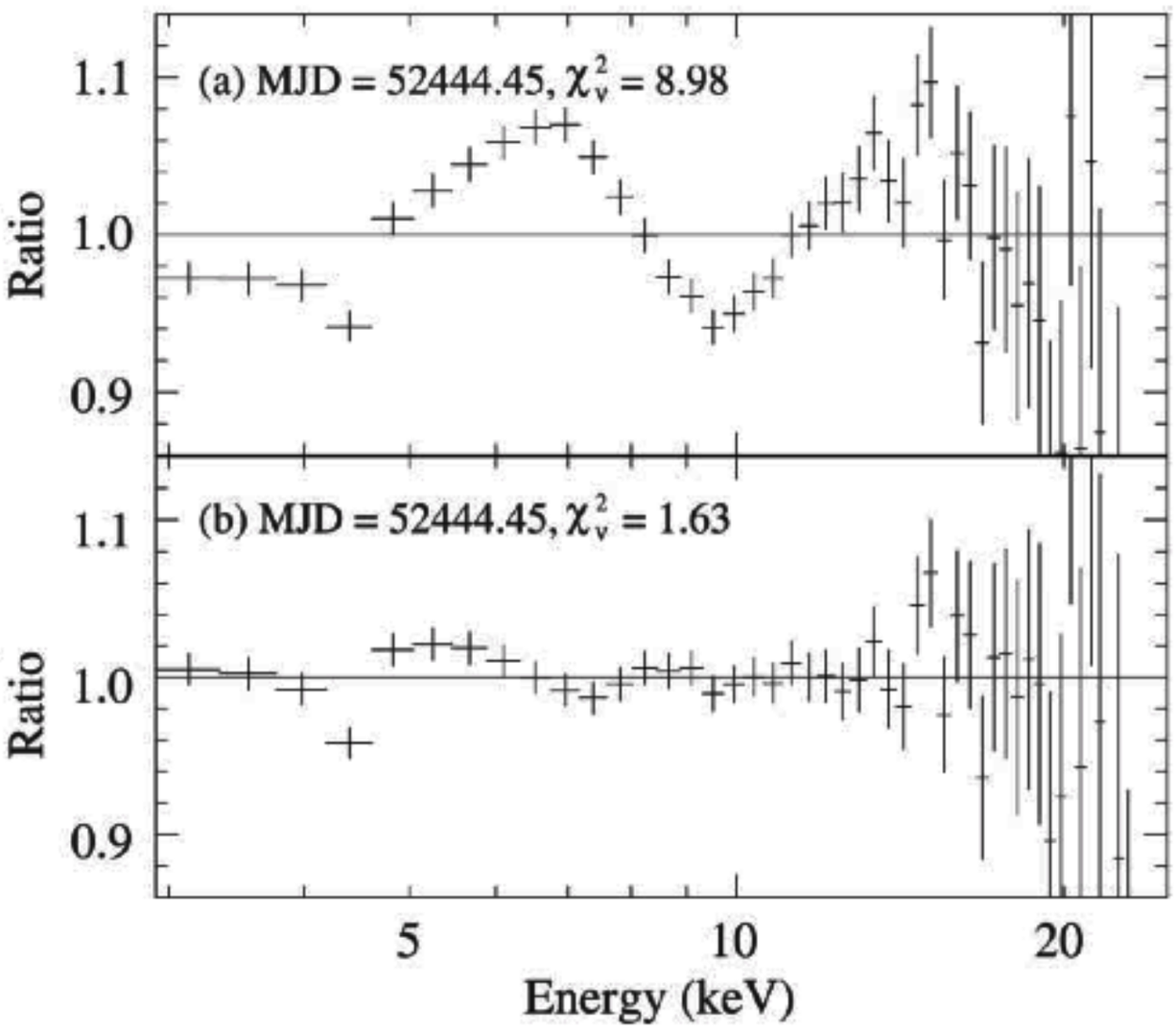
Park, Miller, McClintock, +++, 2004

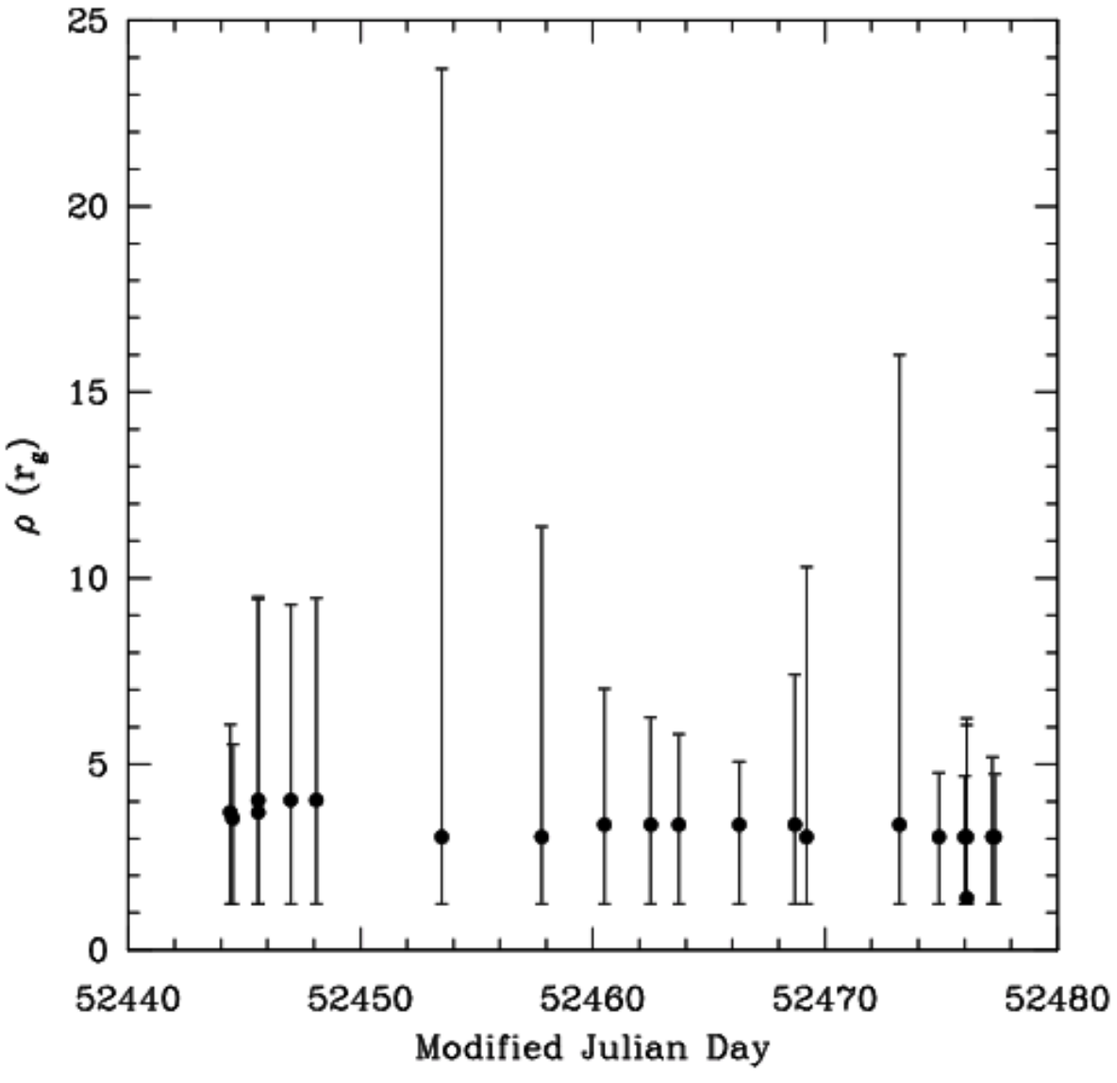




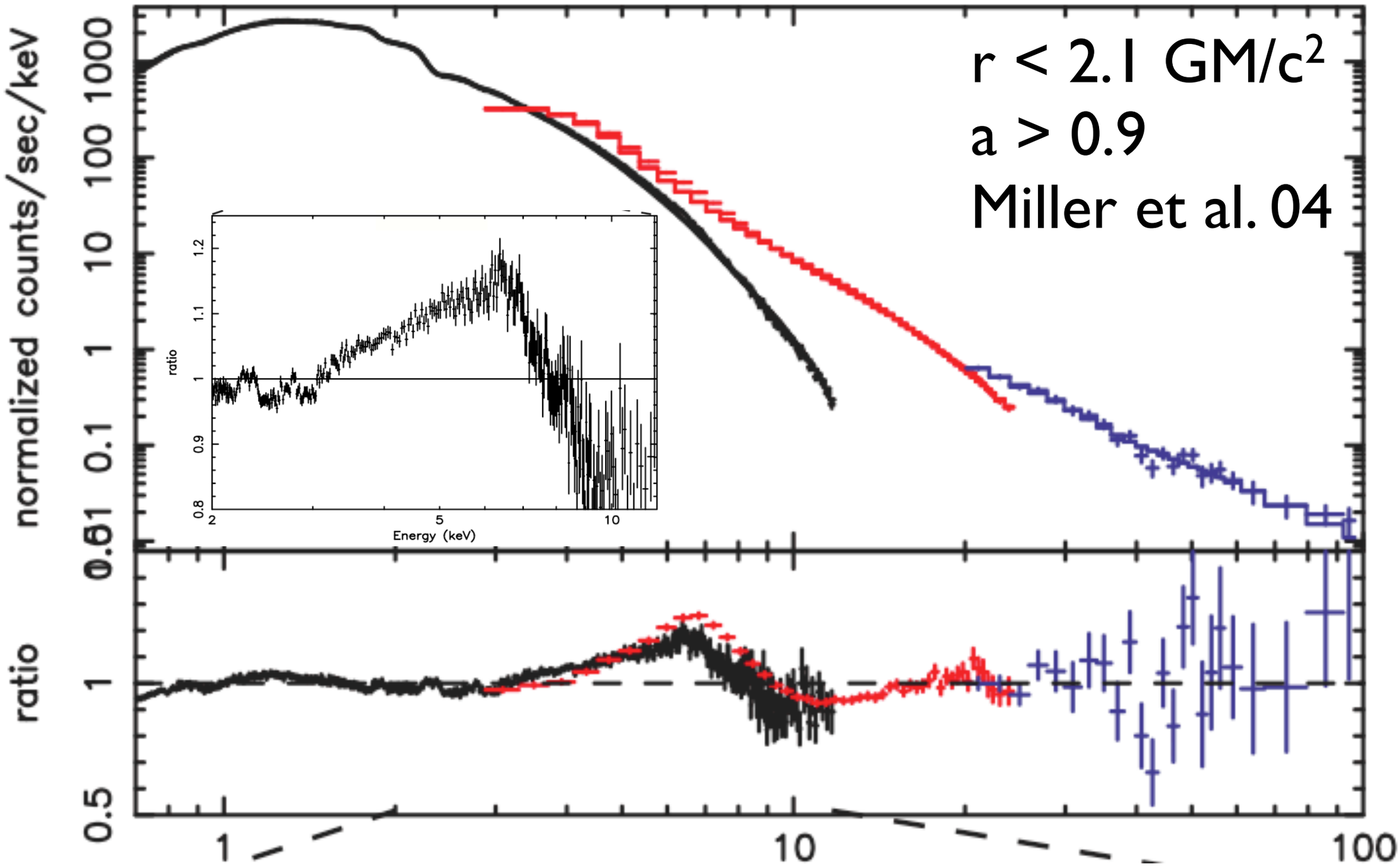
4U 1543-475

Park, Miller, McClintock, +++, 2004

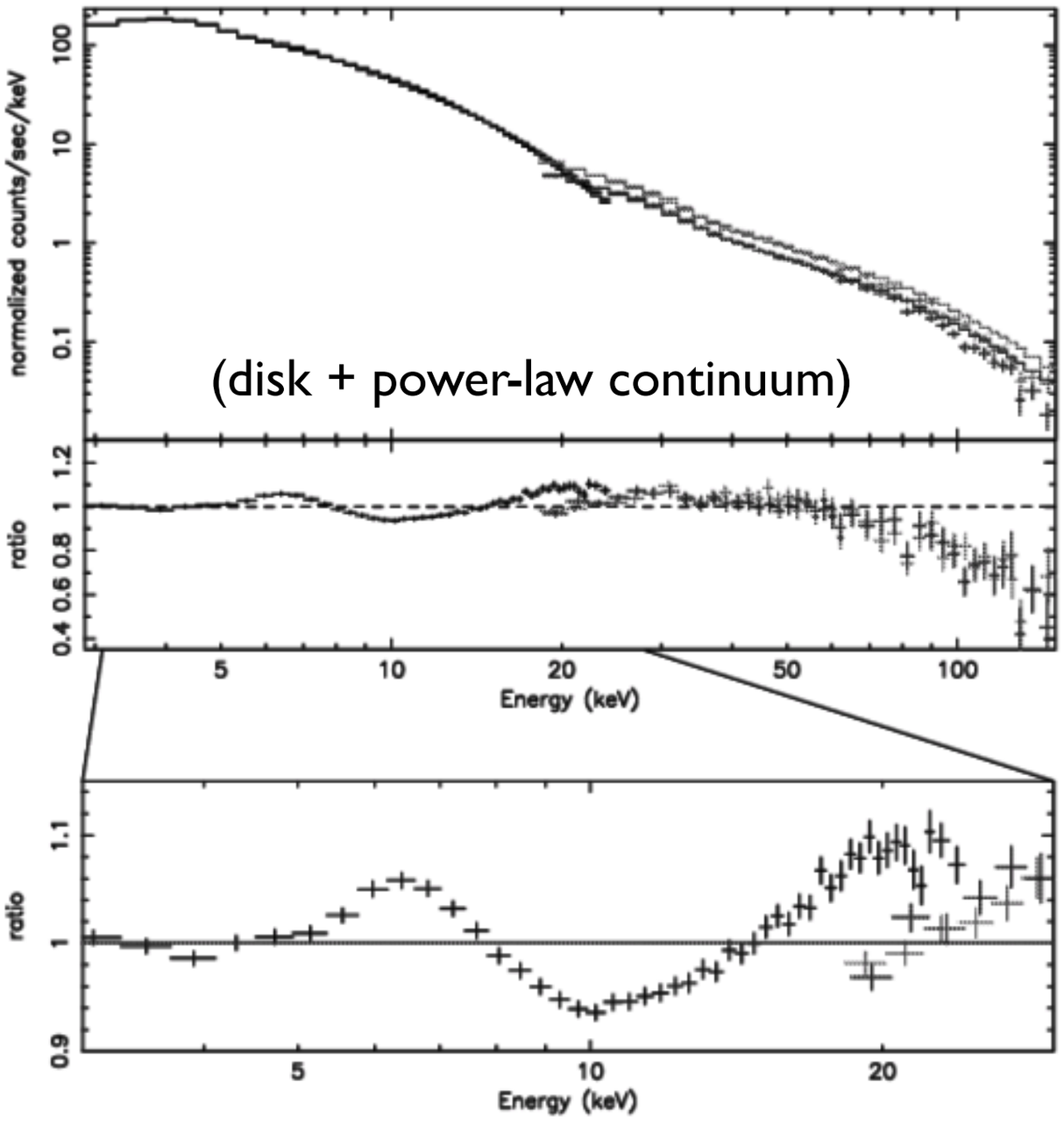




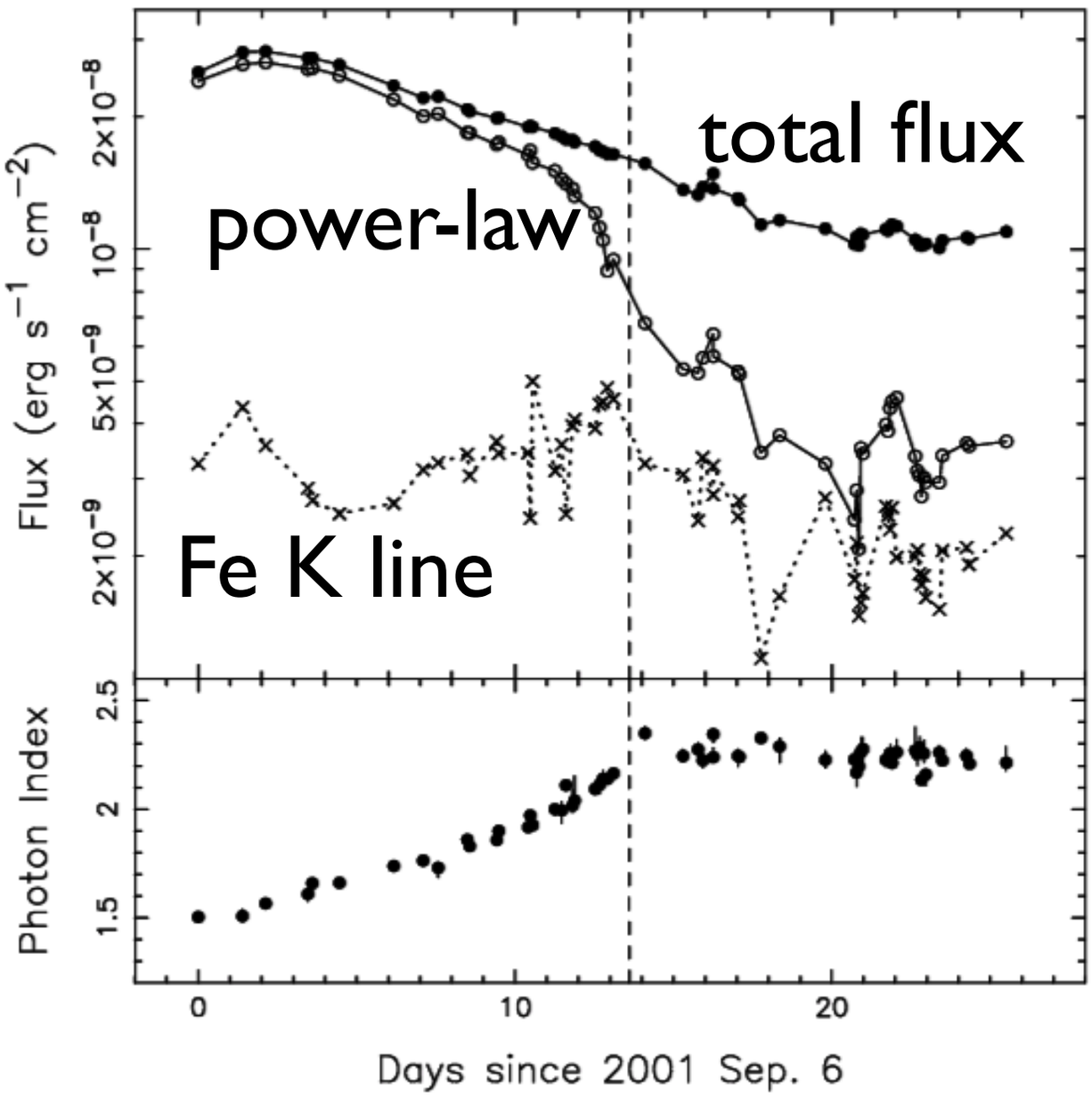
GX 339-4, XMM+RXTE



XTE J1650-500

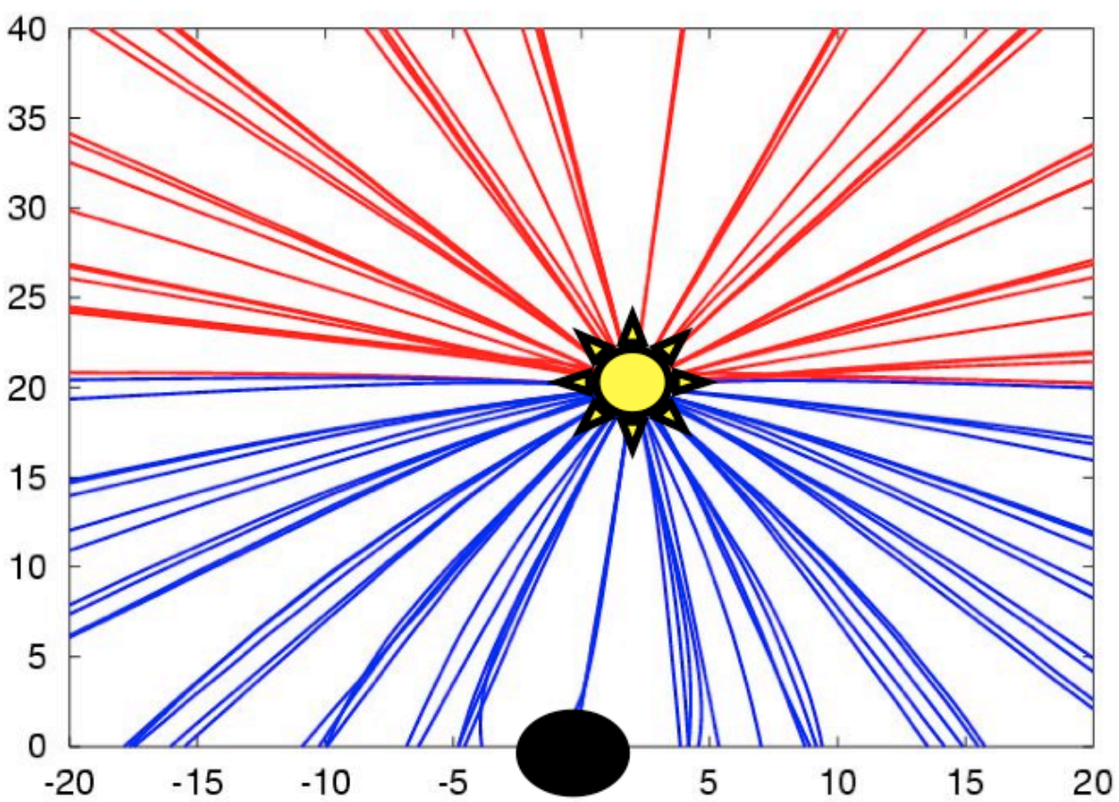


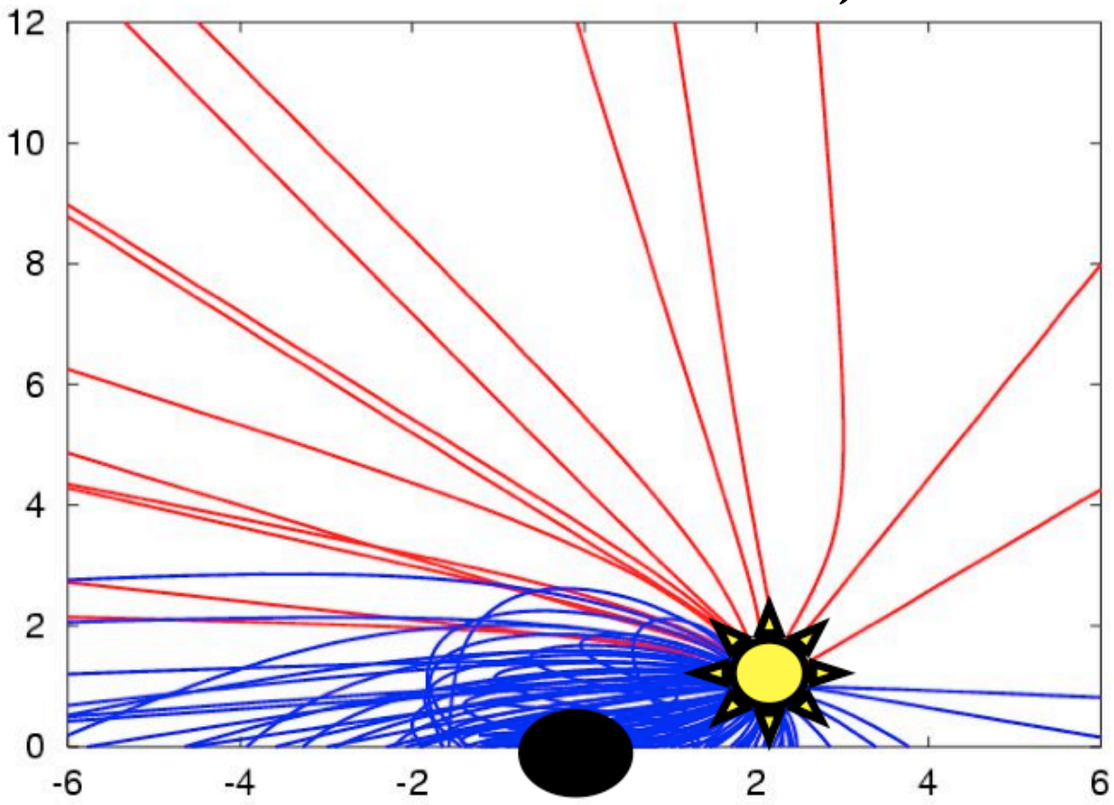
Rossi, Homan, Miller, Belloni 2005



Strong Gravity: Light Bending

Miniutti 2004, 2010

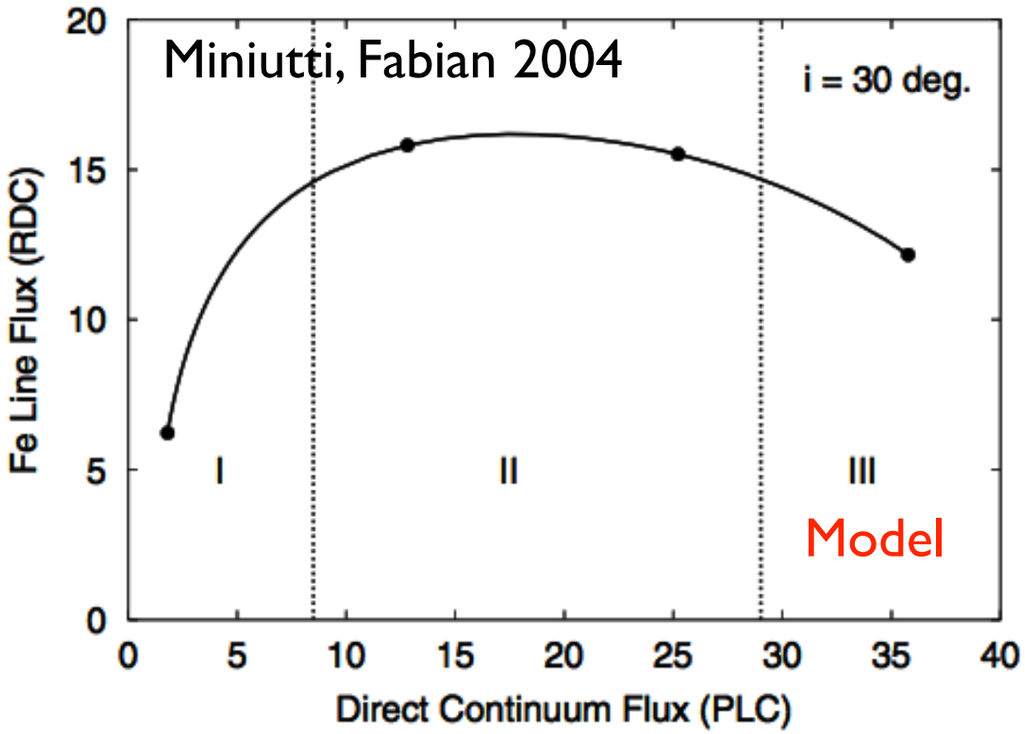


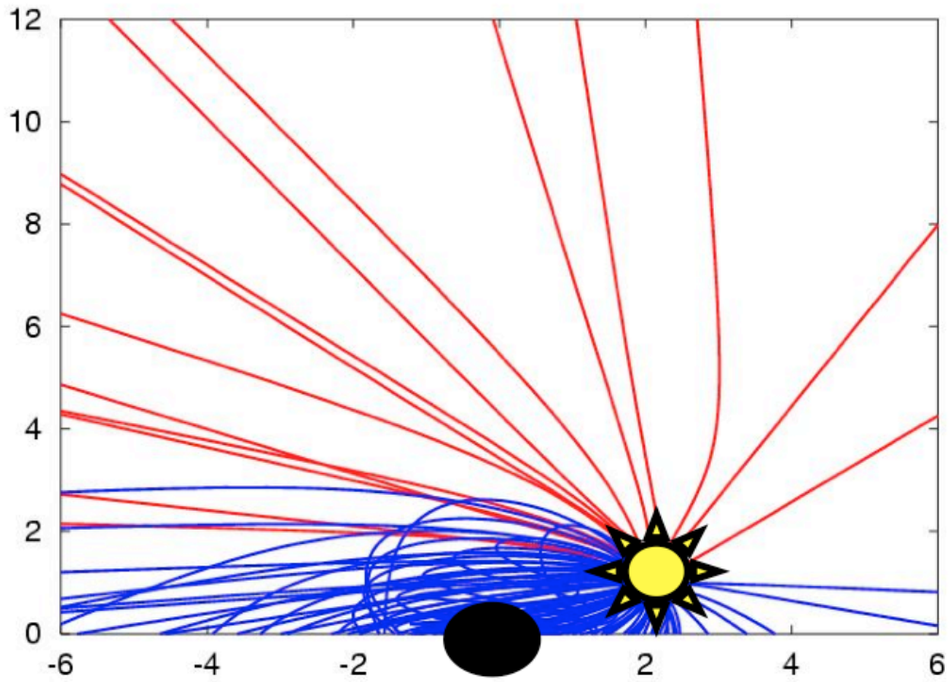


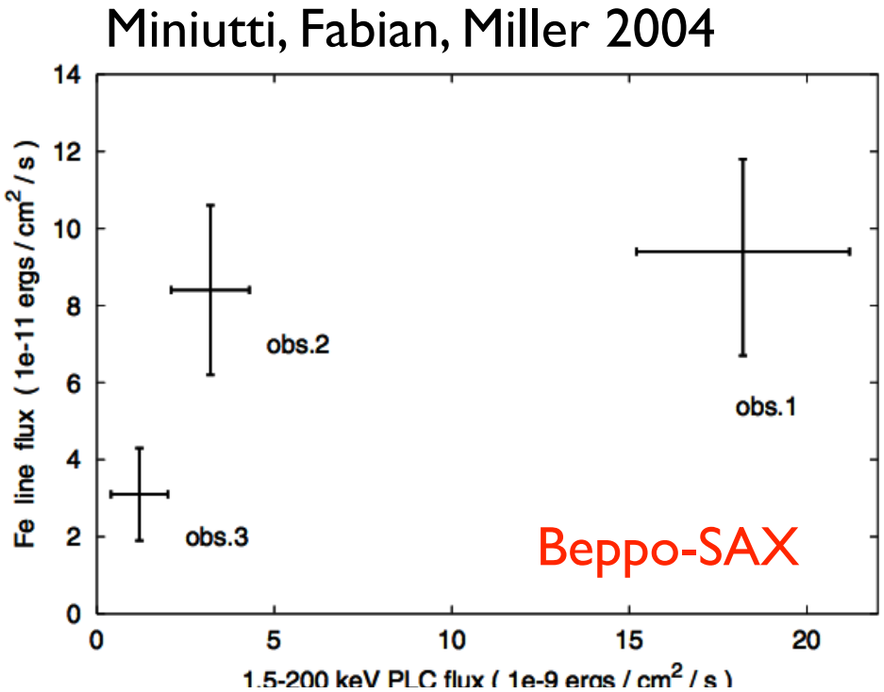
When an X-ray source is close to a spinning black hole, its radiation is strongly affected by strong gravity. It is no longer an isotropic source.

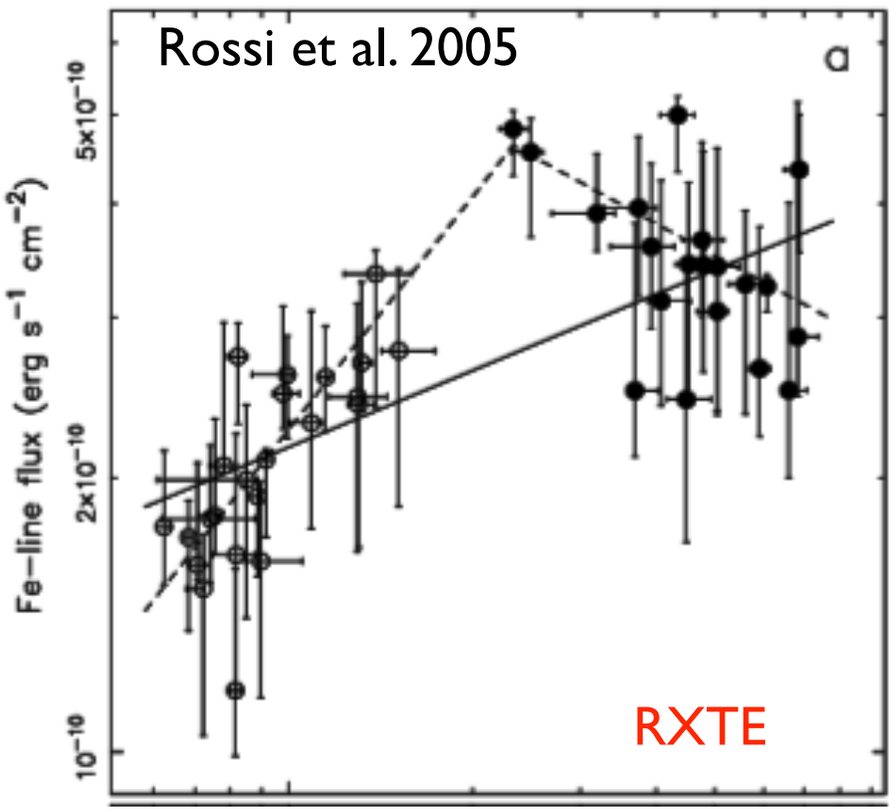
Many models invoke magnetic flaring to fuel coronae, jets.
Microlensing (Chartas, Kochanek) shows that emission region is only ~10 M.

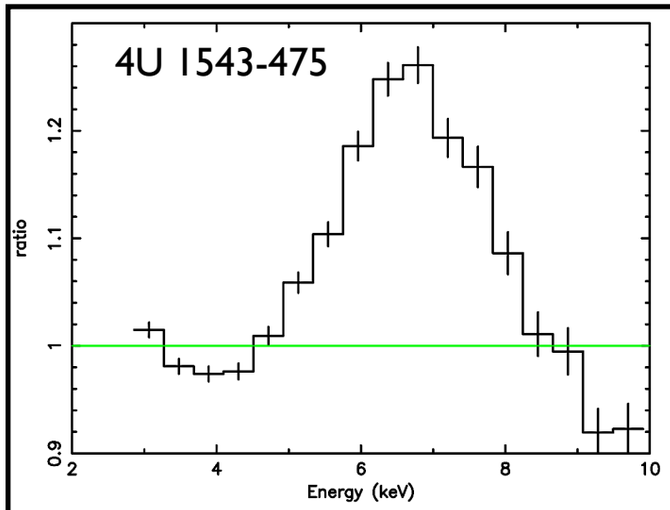
XTE J1650: Light Bending?

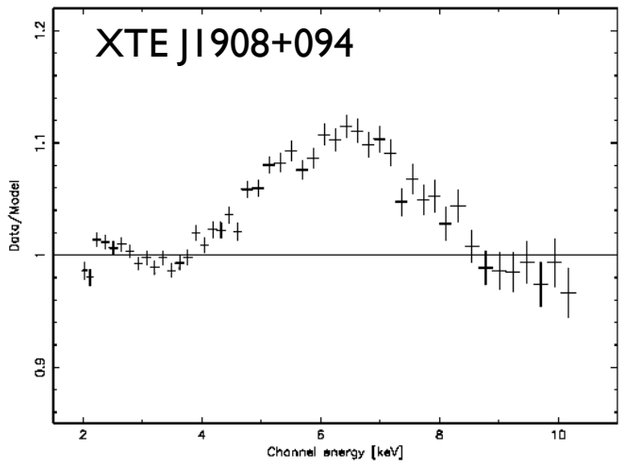


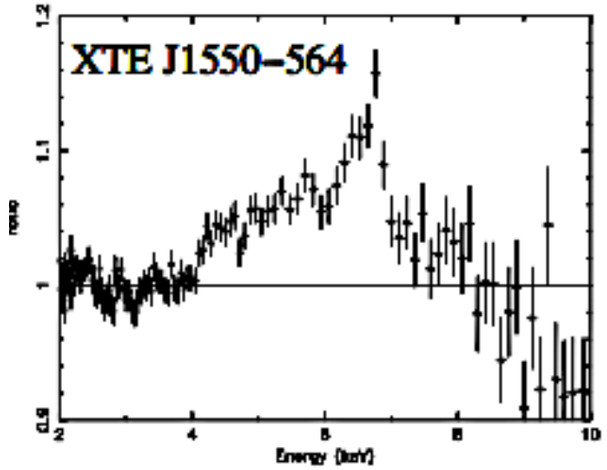


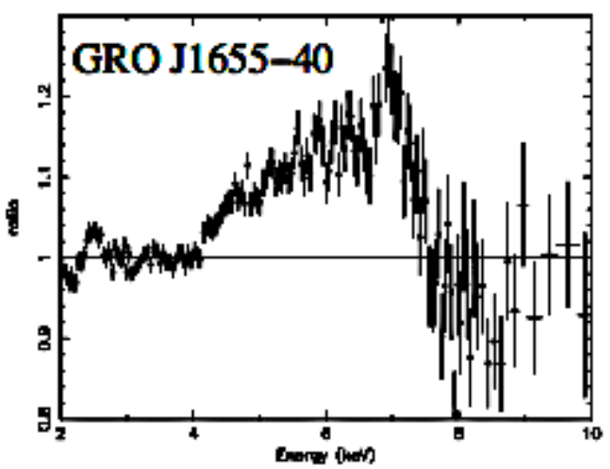


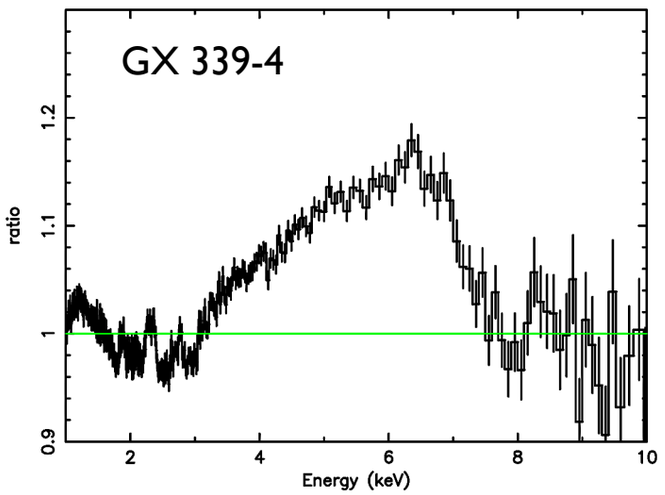


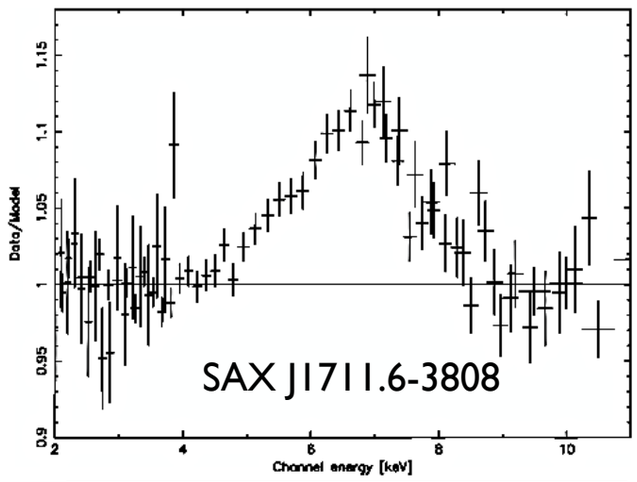

4U 1543-475
ratio
Energy (keV)

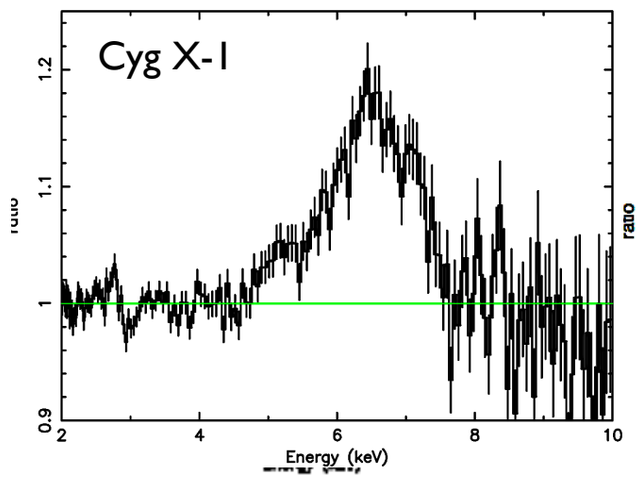

XTE J1908+094
Data/Model
Channel energy [keV]

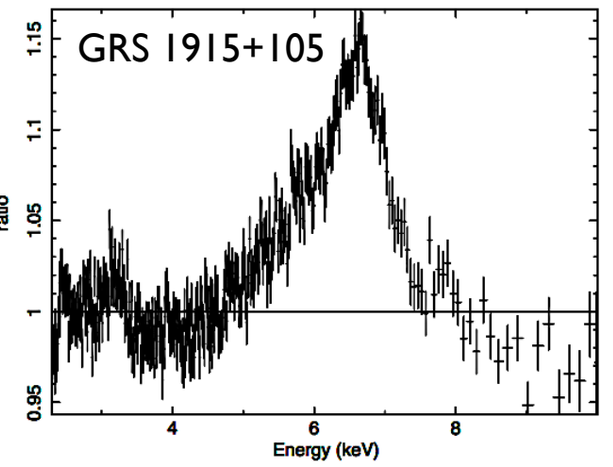

XTE J1550−564
Energy (keV)

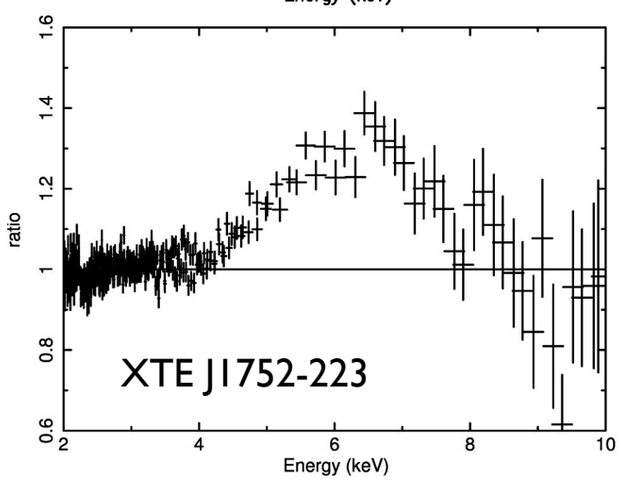

GRO J1655−40
Energy (keV)

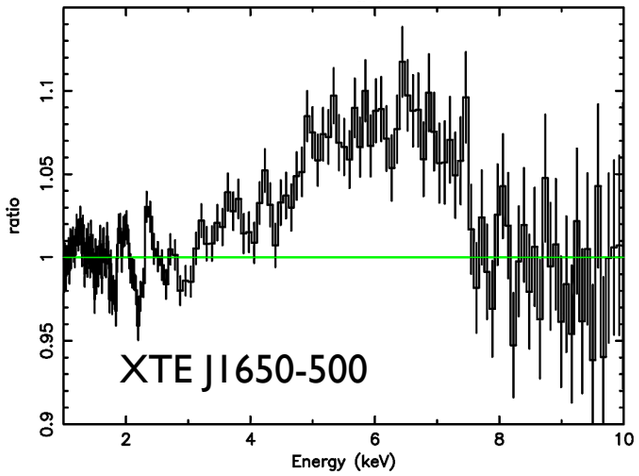

GX 339-4
ratio
Energy (keV)

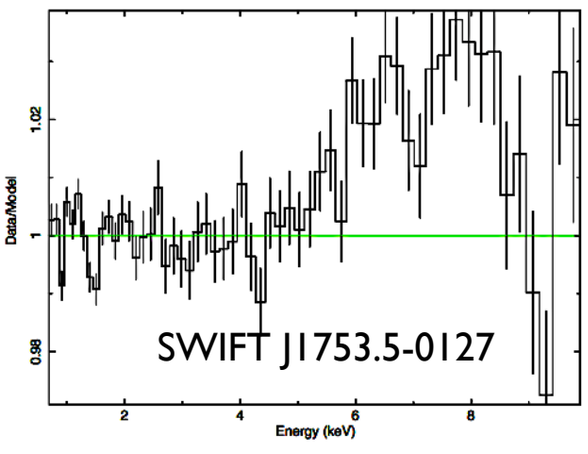

SAX J1711.6-3808
Data/Model
Channel energy [keV]

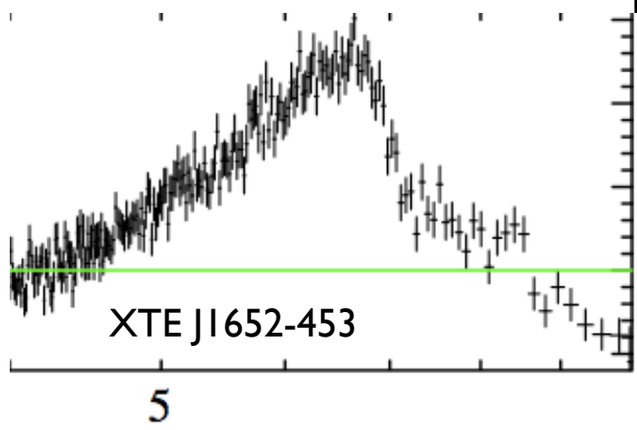

Cyg X-1
Energy (keV)


GRS 1915+105
ratio
Energy (keV)


XTE J1752-223
ratio
Energy (keV)


XTE J1650-500
ratio
Energy (keV)


SWIFT J1753.5-0127
Data/Model
Energy (keV)


XTE J1652-453

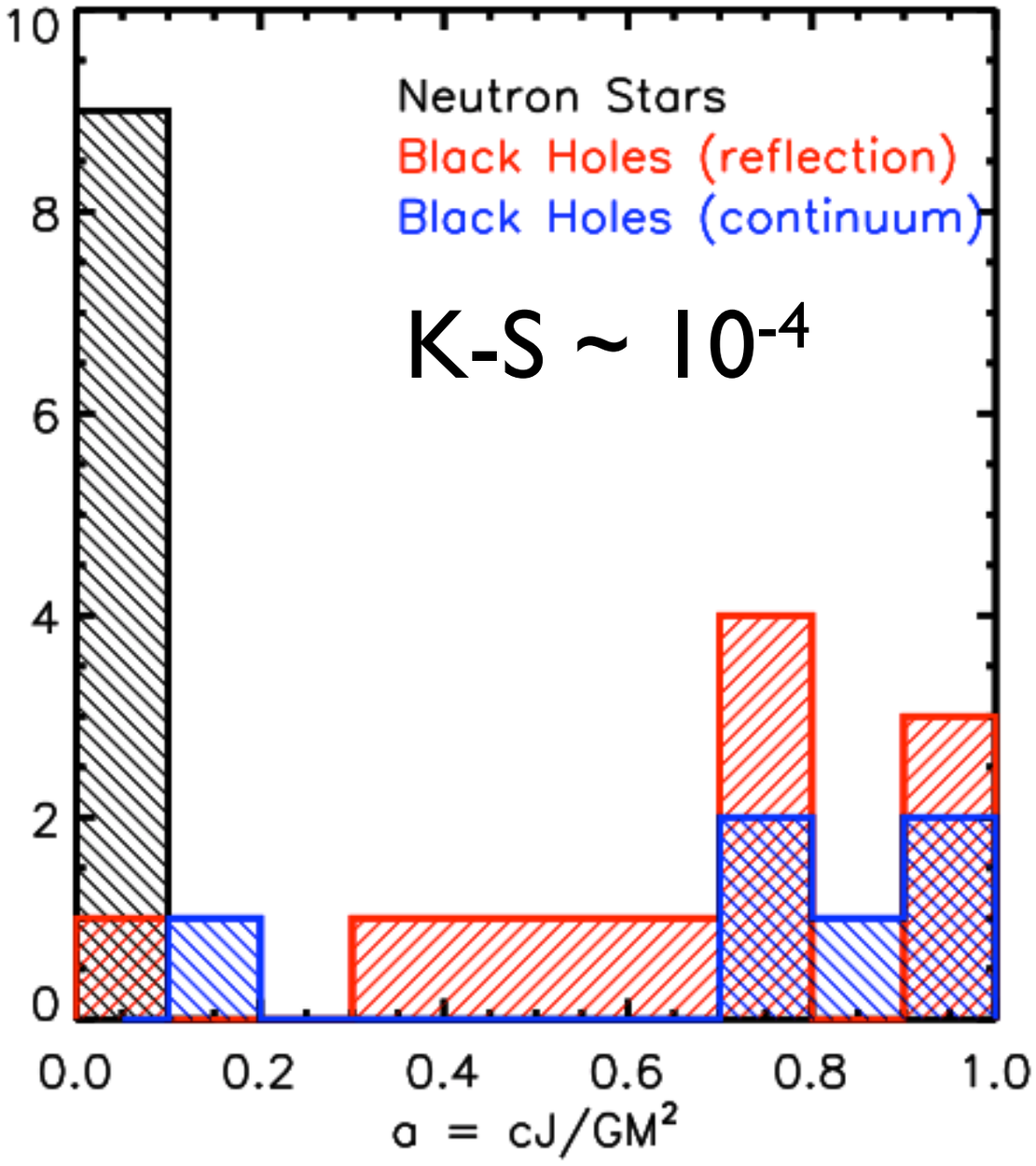
SNe, GRBs, NS, BHs

• Small but growing number of estimates for natal NS spins.

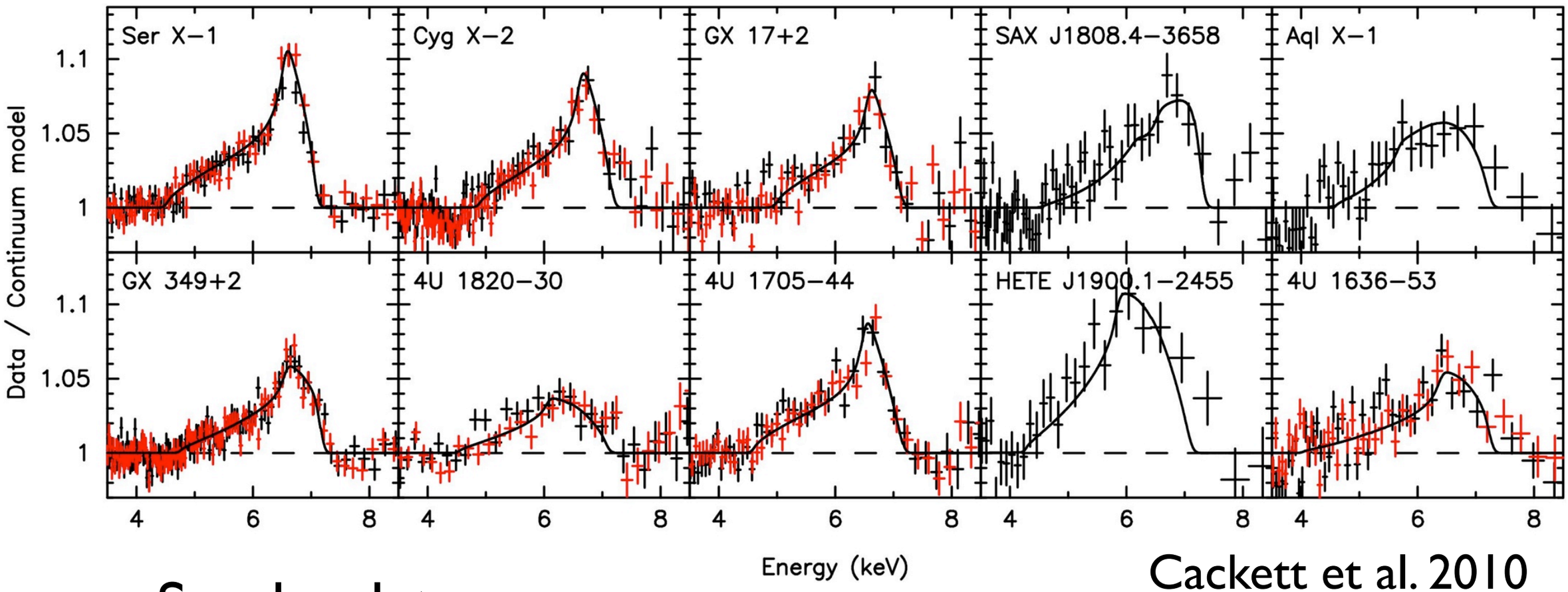
• Spin can be estimated in BHs via two independent methods.

• Collapse models:
NS-forming SNe have too little J to drive strong MHD jets;
BH-forming SNe drive jets.

Jon Miller, Cole Miller, Chris Reynolds 2011



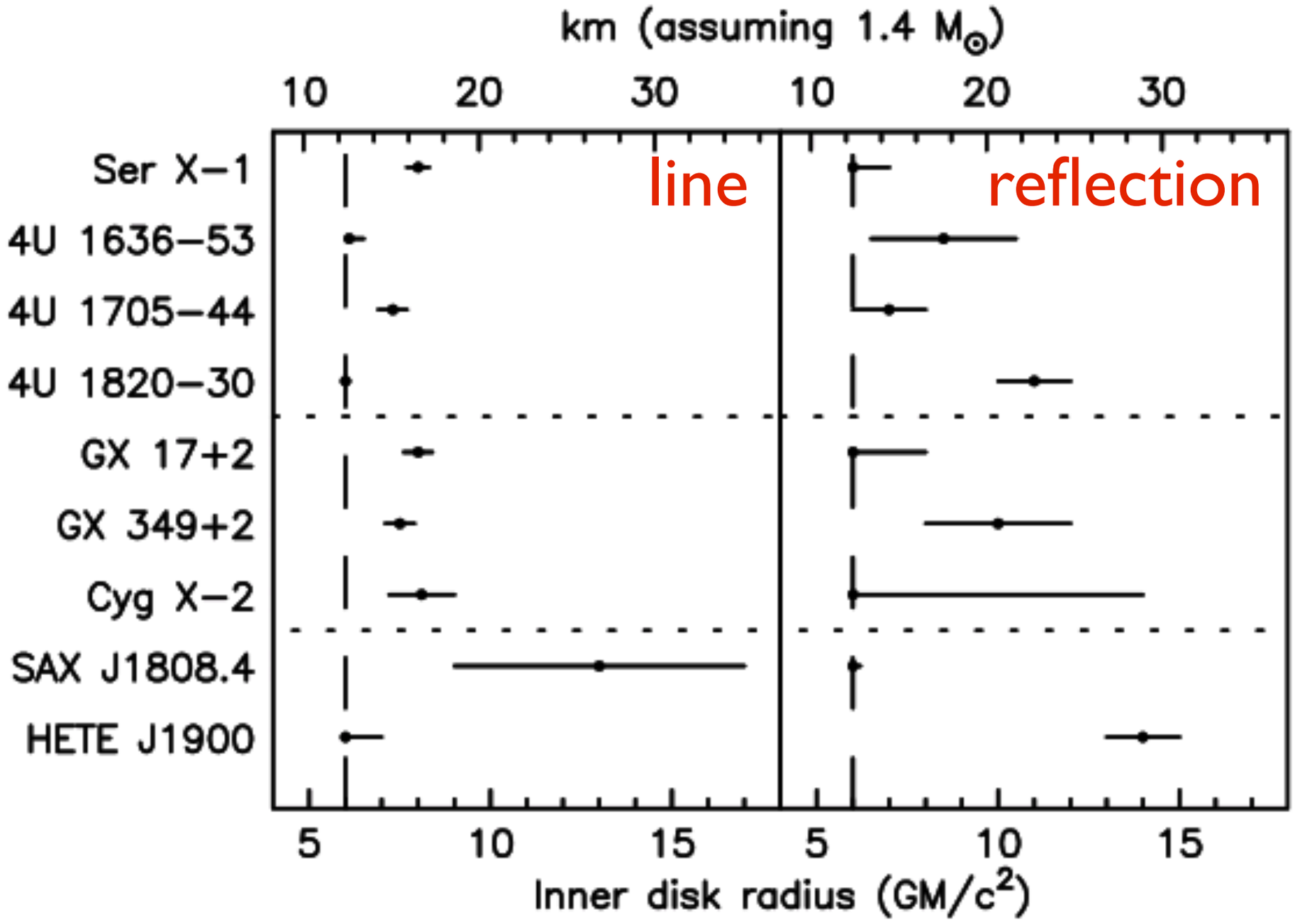
Reflection in neutron stars



- Suzaku data.
- R < 12-16 km.
- Boundary layer illuminates the disk.

Cackett et al. 2010
D'Ai, Reis, Di Salvo, Lin, +++

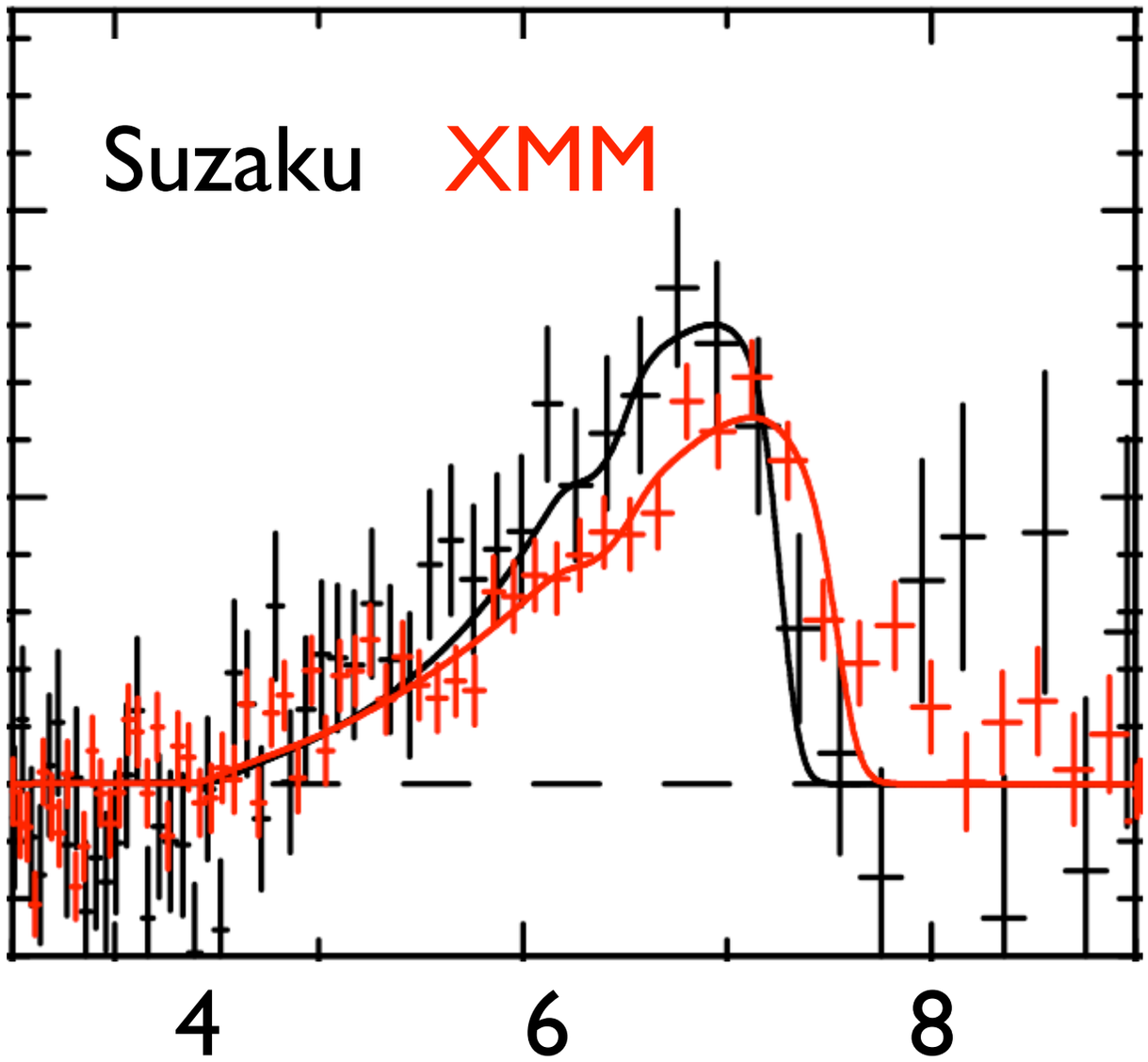
Toward stellar radii



Cackett et al. 2010

SAX J1808.4-3658

Cackett et al. 2010



Initial evidence for broad line and reflection seen with RXTE (Gierlinksi, Done, & Barret 02).

Relativistic line seen with **Suzaku** (Cackett et al. 2009), and **XMM** (D' Ai et al. 2009).

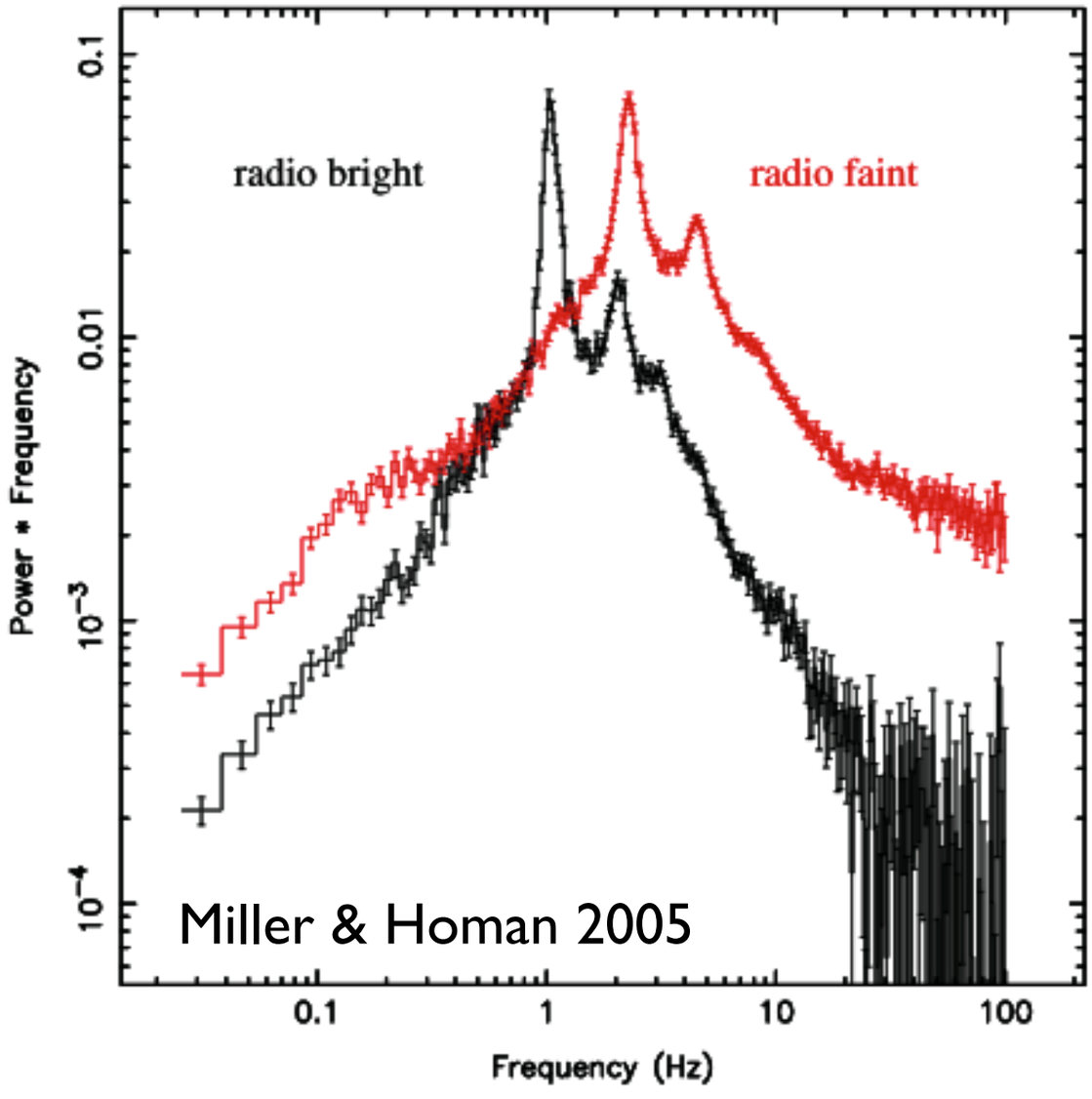
Resulting estimate of B is consistent with timing results (Cackett 09).

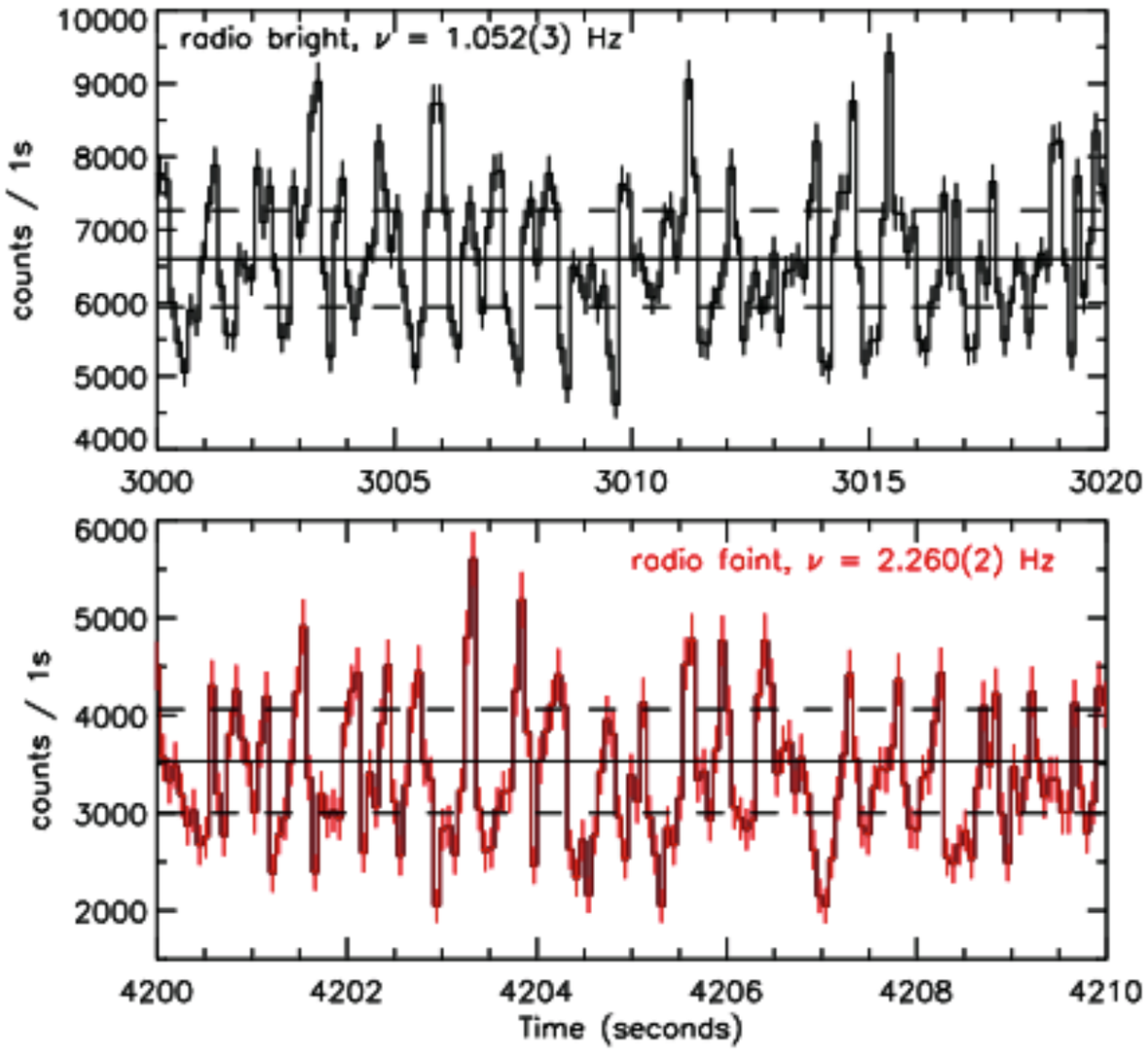
Astrophysics dominates over any detector issues.

Reflection + timing

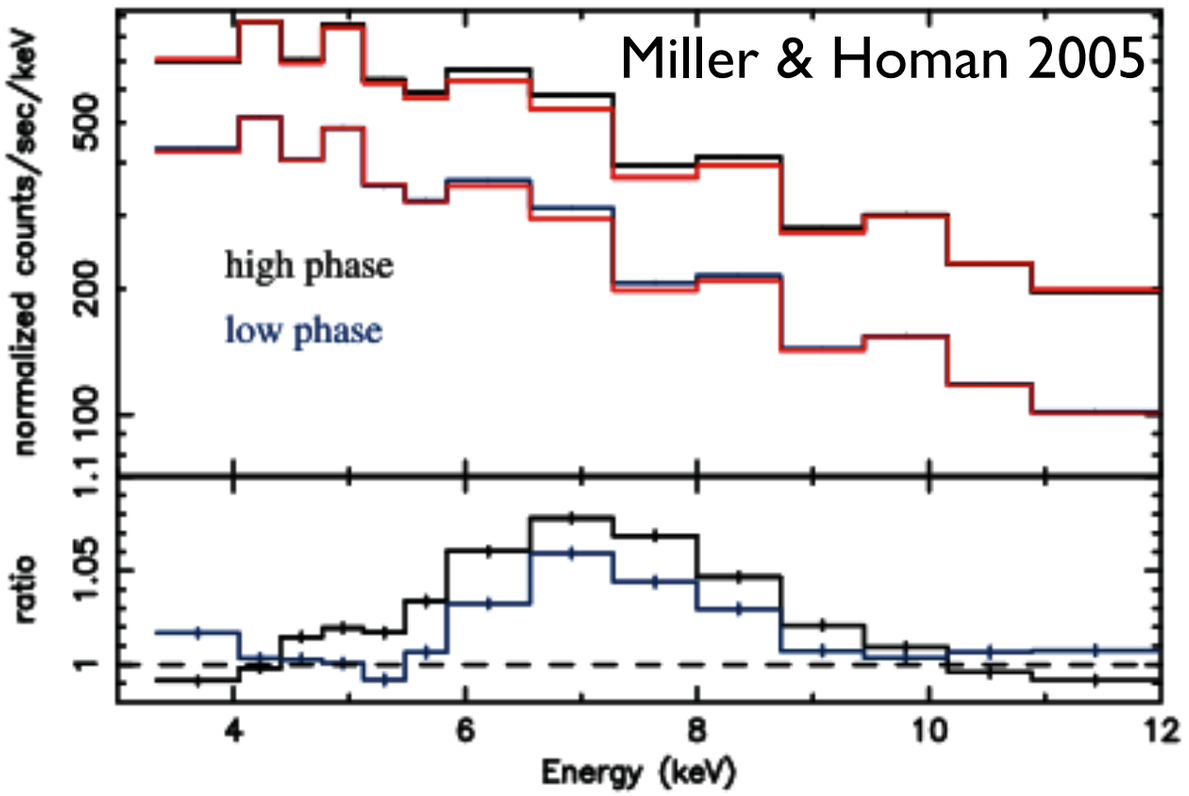
- Reflection lags are already very exciting. Very compact coronae (Fabian, DeMarco). Agrees with microlensing (Kochanek ++).
- Independent angles on the inner flow.
- May reveal QPOs e.g. warps, precession.
- Real promise for AXTAR, LOFT, Astrosat.

Spectral-Timing Analysis

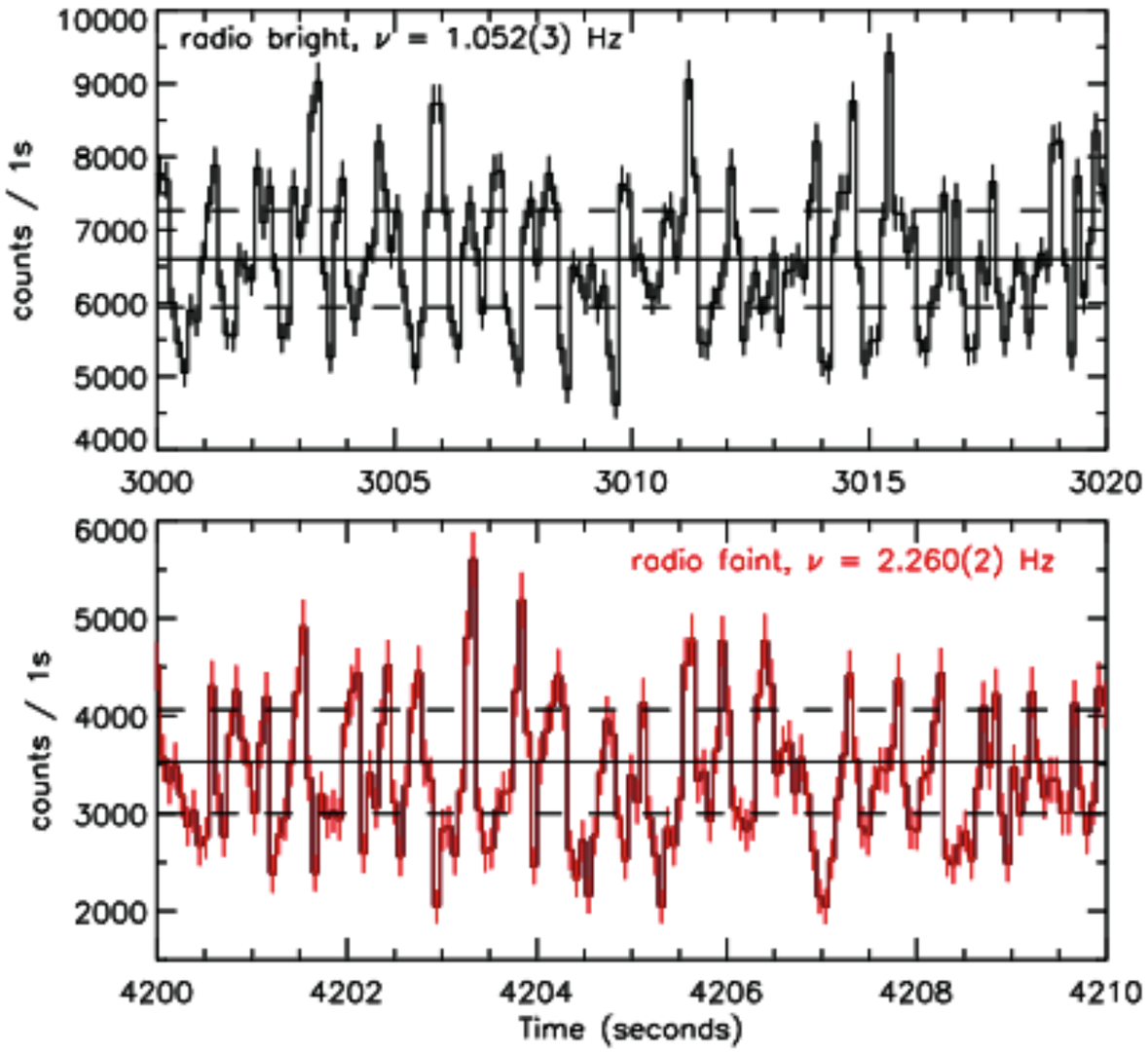




Spectral-Timing Analysis

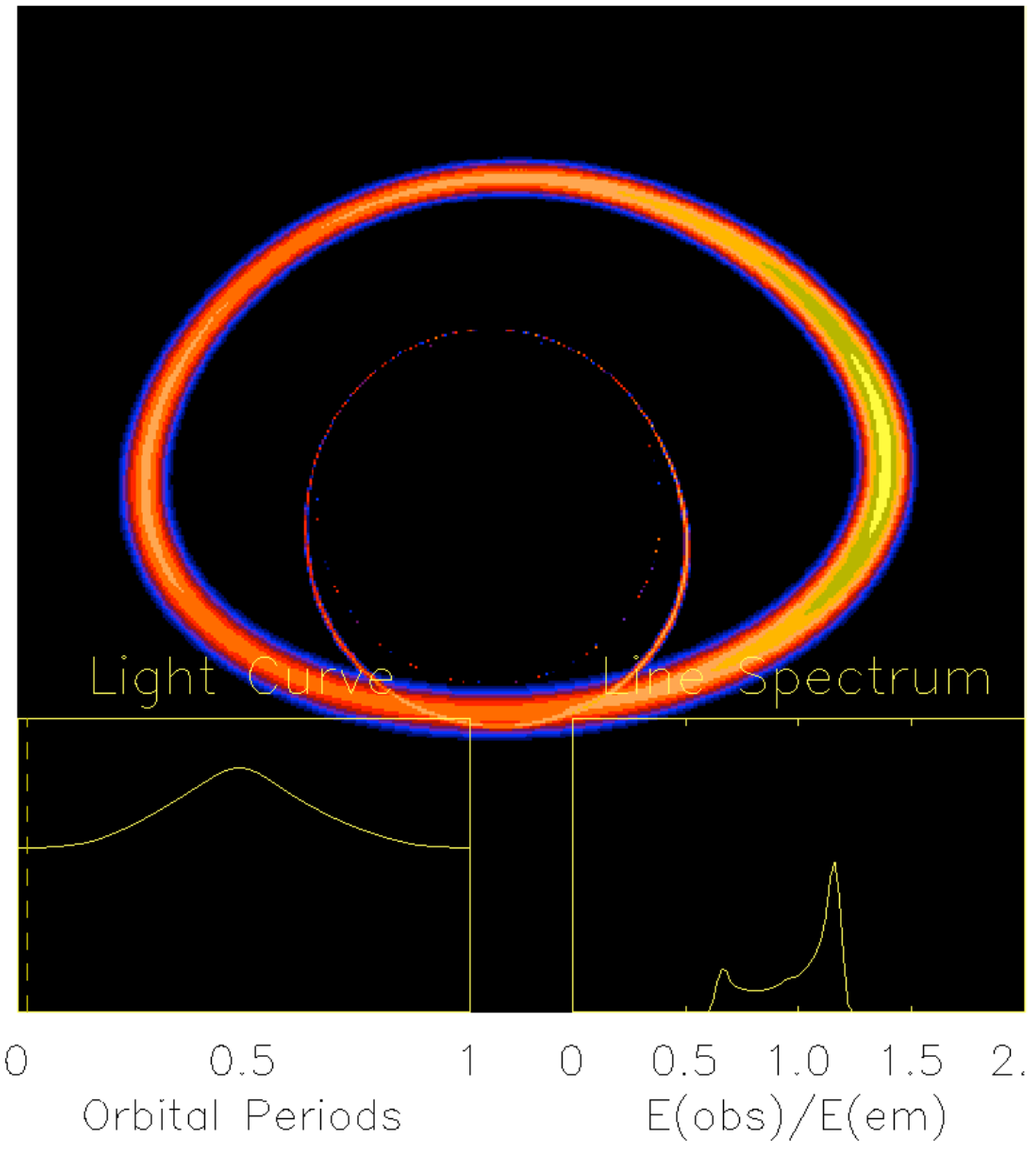


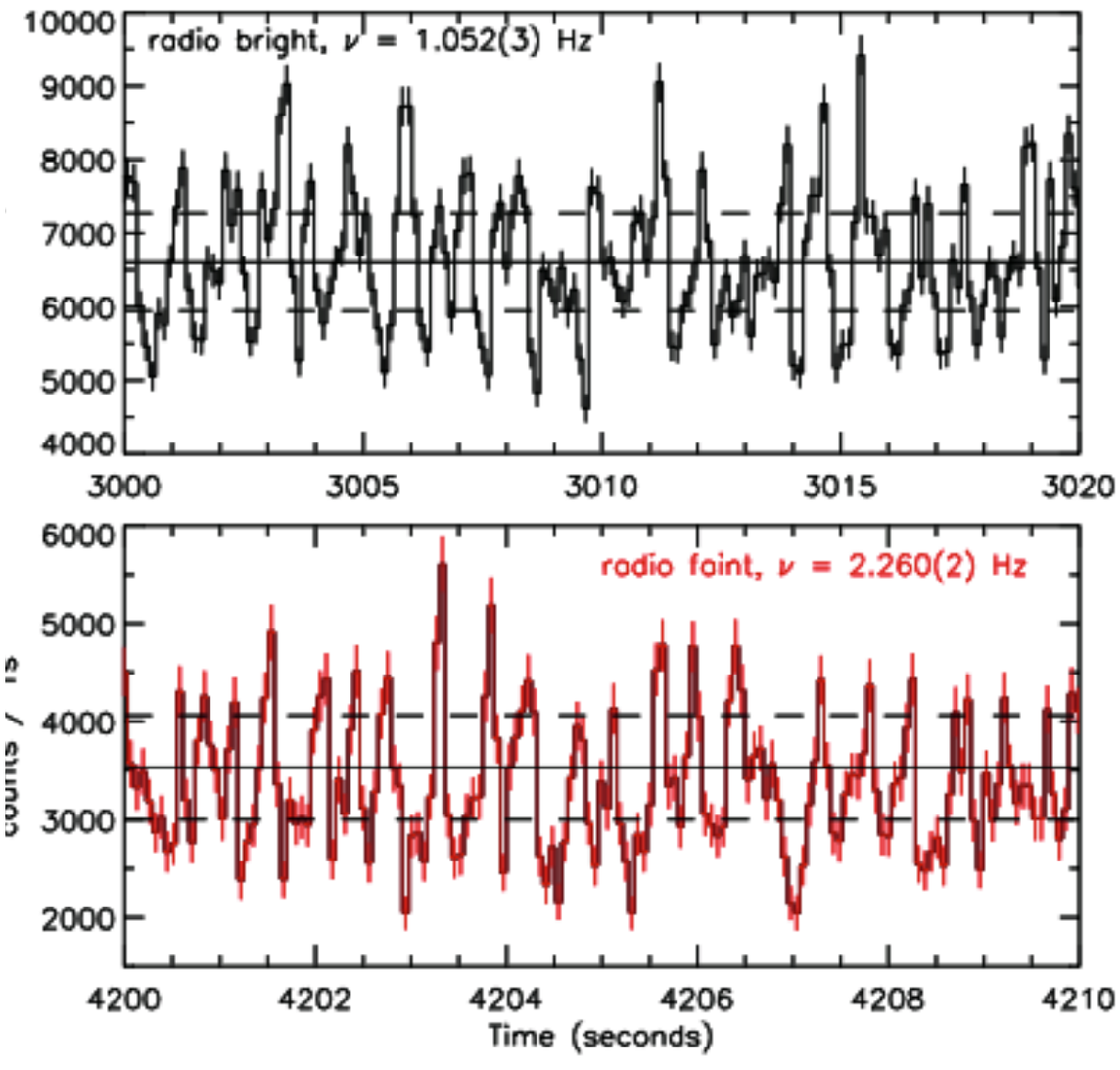
The iron line (reflection) is stronger and broader in the crests than troughs. Precession? Warps?



Spectral-Timing Analysis

Schnittman, Miller, Homan, 2005





Summary

- Disk reflection enables studies of:

  1) black hole spin,

  2) the disk+corona geometry,

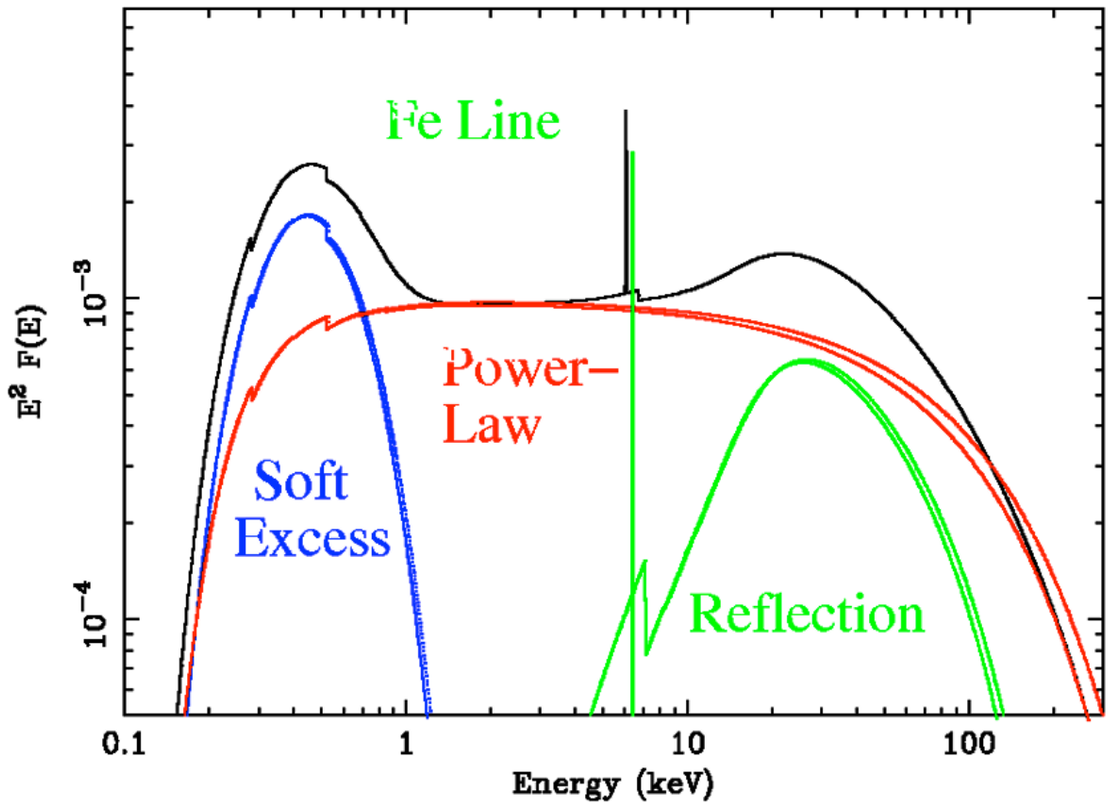
  3) strong GR effects (light bending)

- RXTE revolutionized such studies through its extraordinary sensitivity and flexibility.

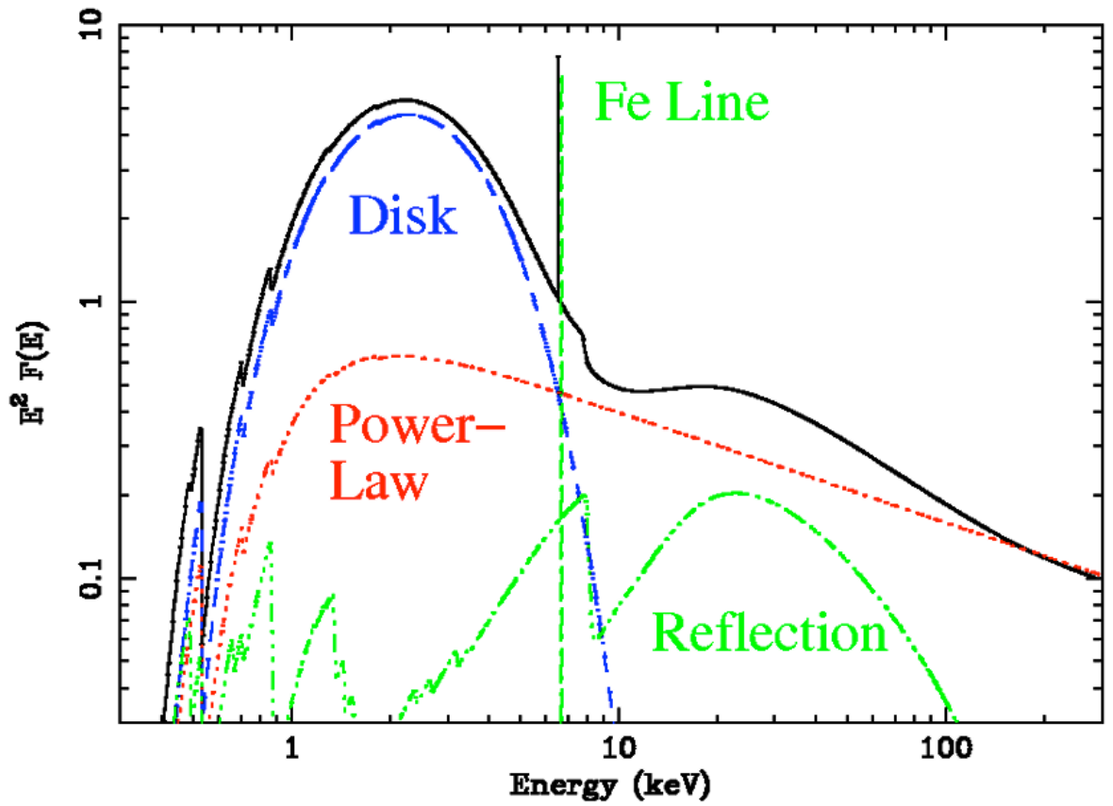
- extra slides

X-ray Spectra

Seyfert-1 AGN

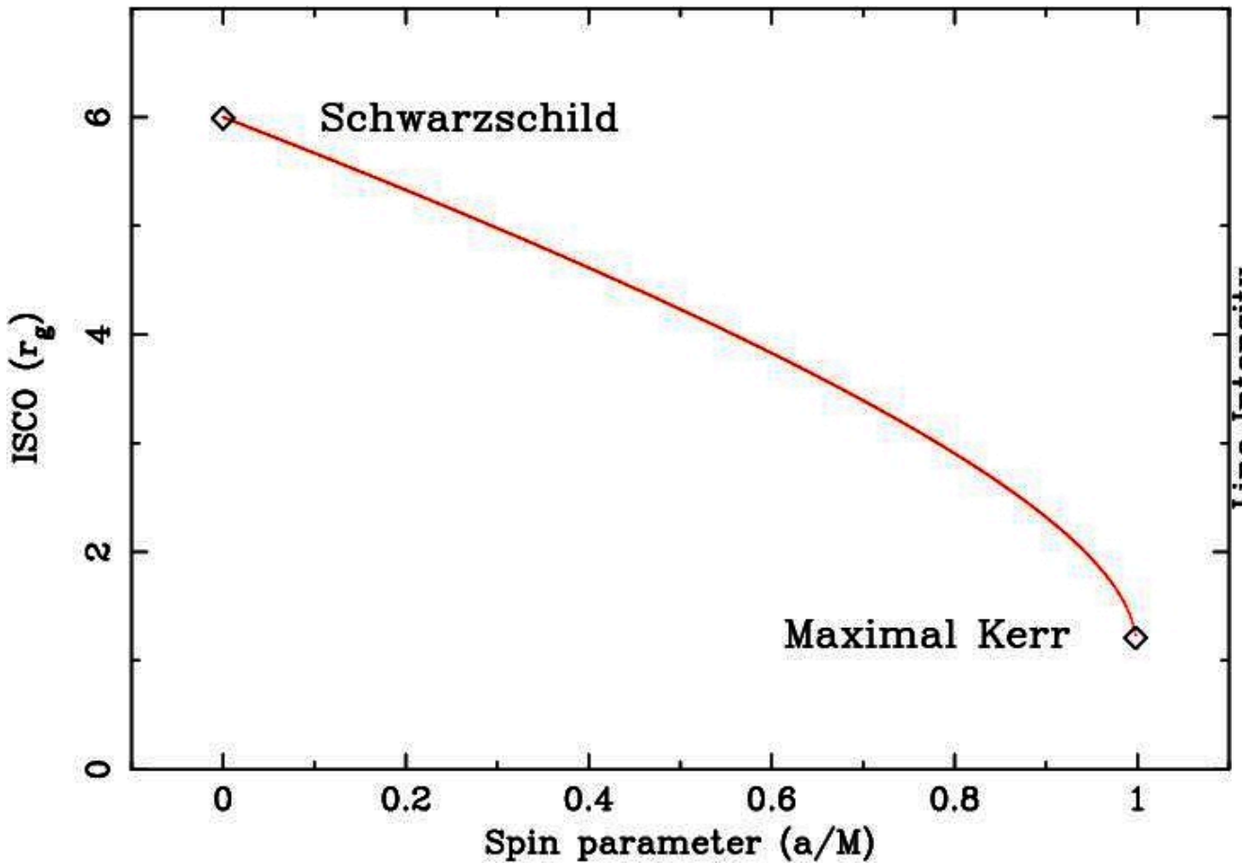


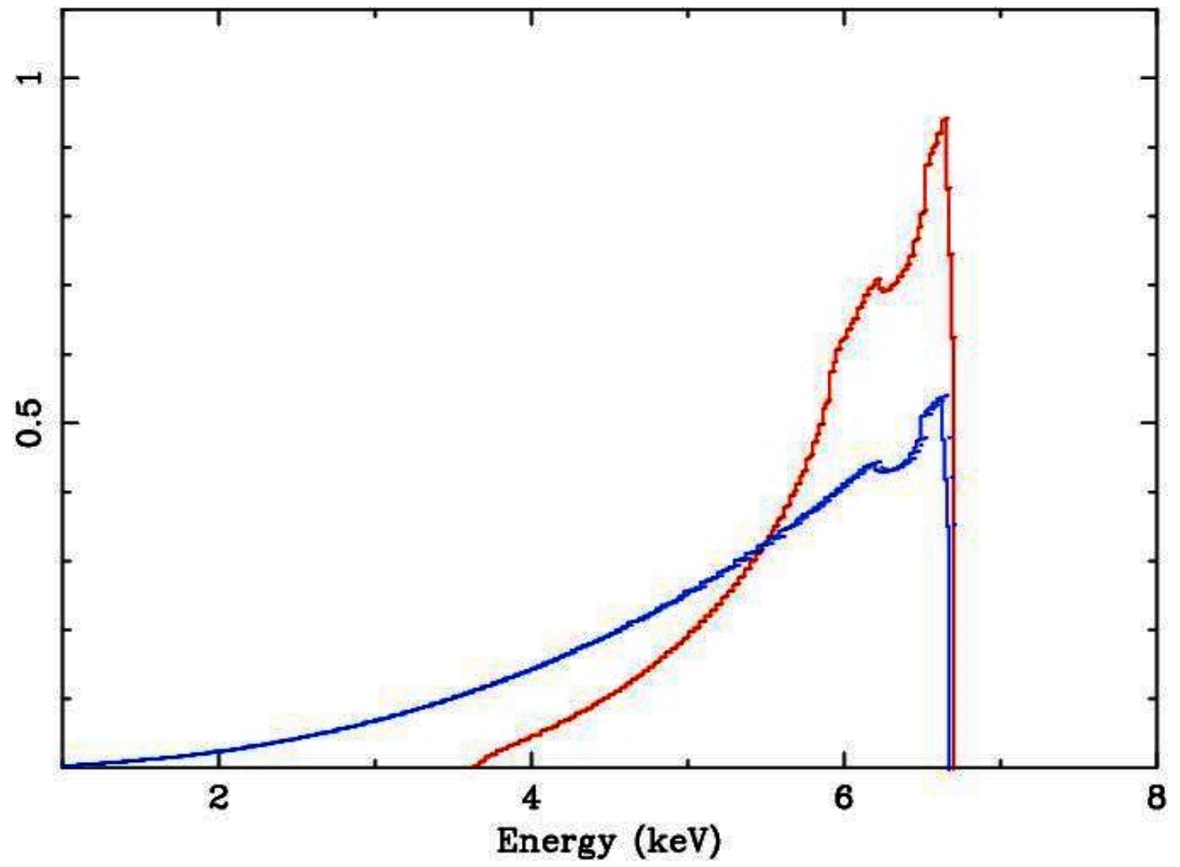
Stellar-mass black hole



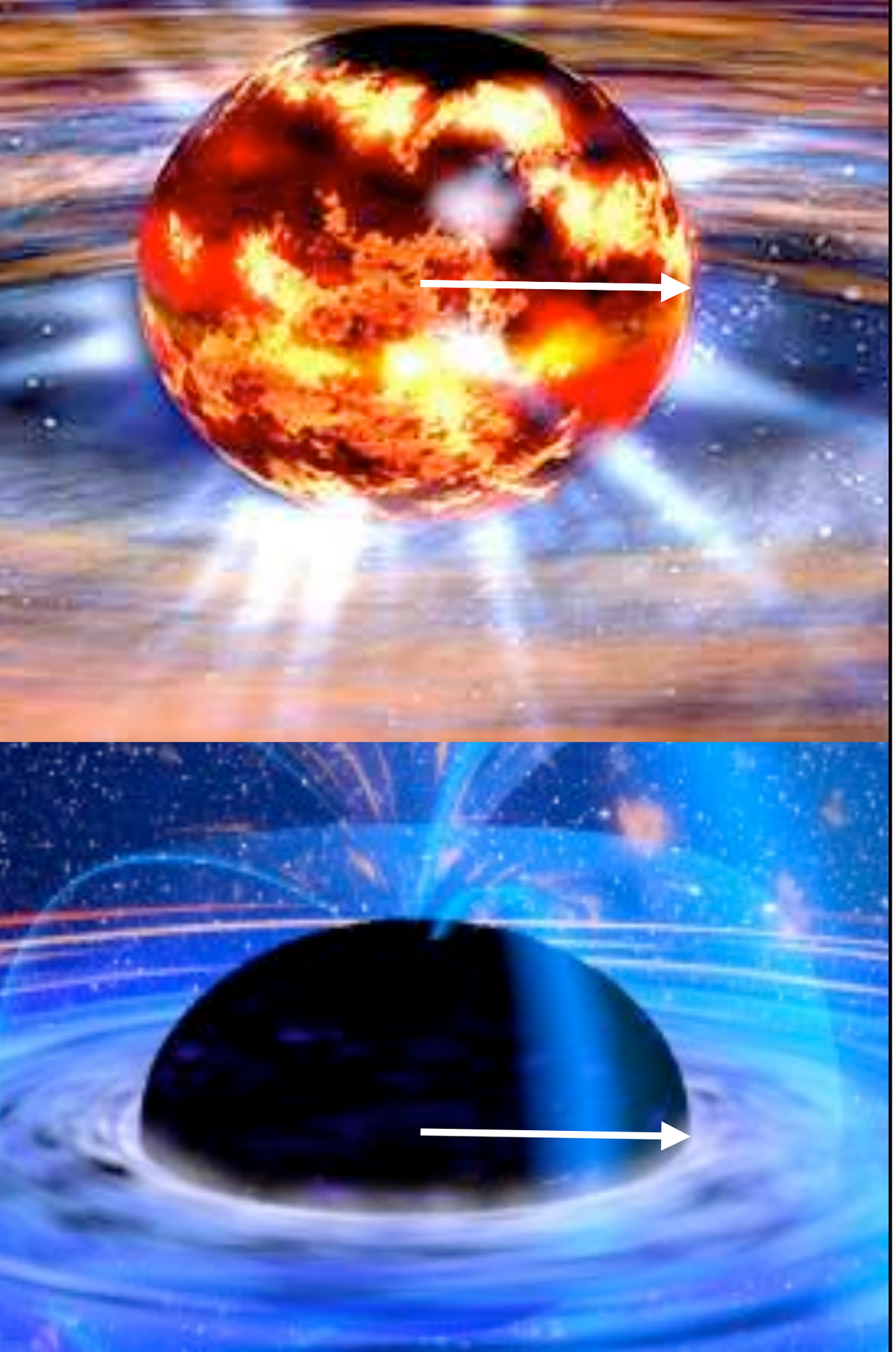
- The continuum in stellar-mass BHs is rather simple.
- Any "warm absorber" < 0.01 of Sy1s (N_OVIII)

X-ray Disk Lines





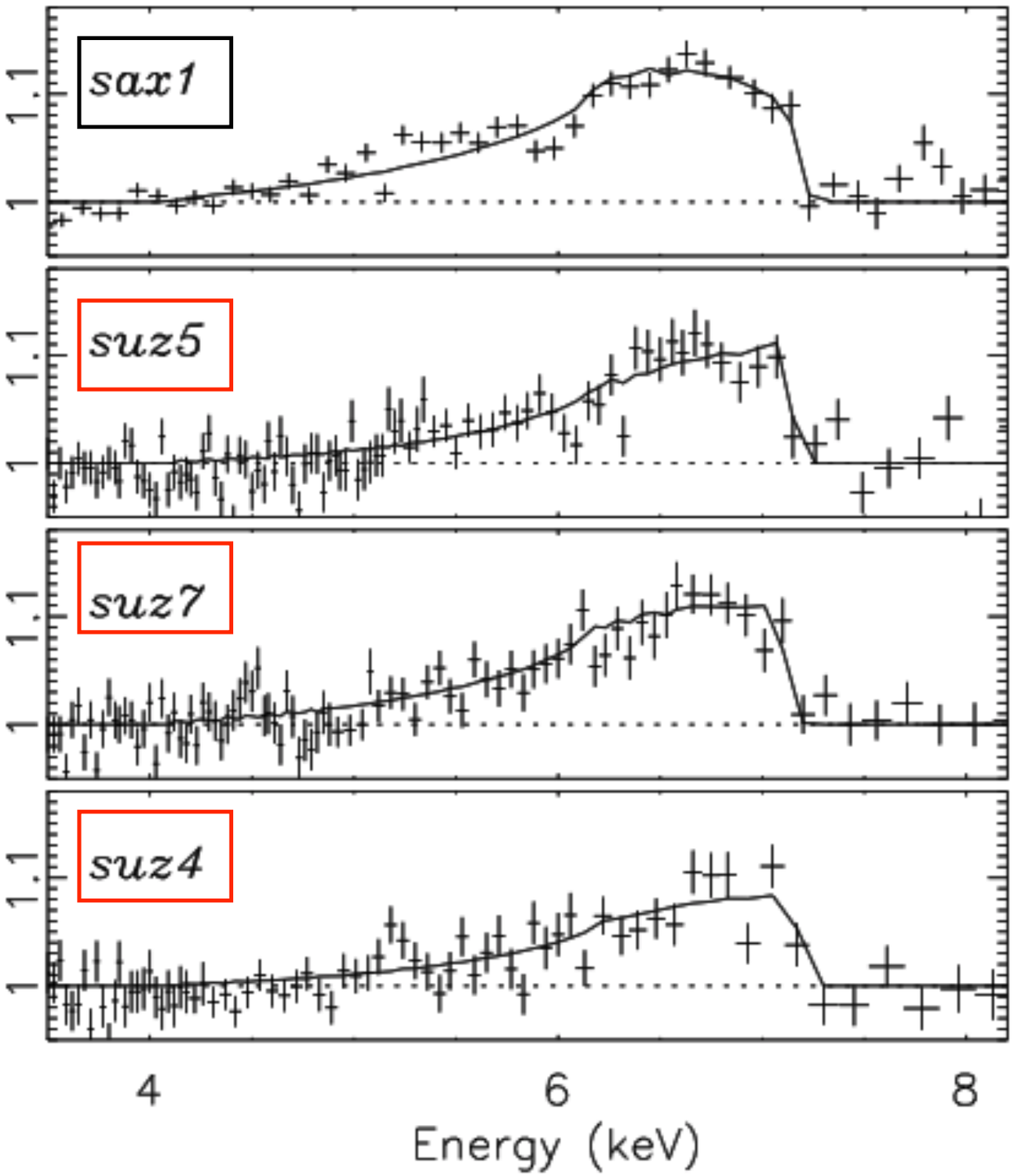
Ray tracing --> line profiles.
Diskline (a=0), Laor (a=0.998).
3 cases where spin is variable
(Karas, Beckwith, Brenneman).



1.4 Msun neutron star
R~10 km ~ 4.5 GM/c^2.

This is very similar to 6 GM/c^2 ISCO expected for a=0 BHs.

4U 1705: Suzaku & SAX



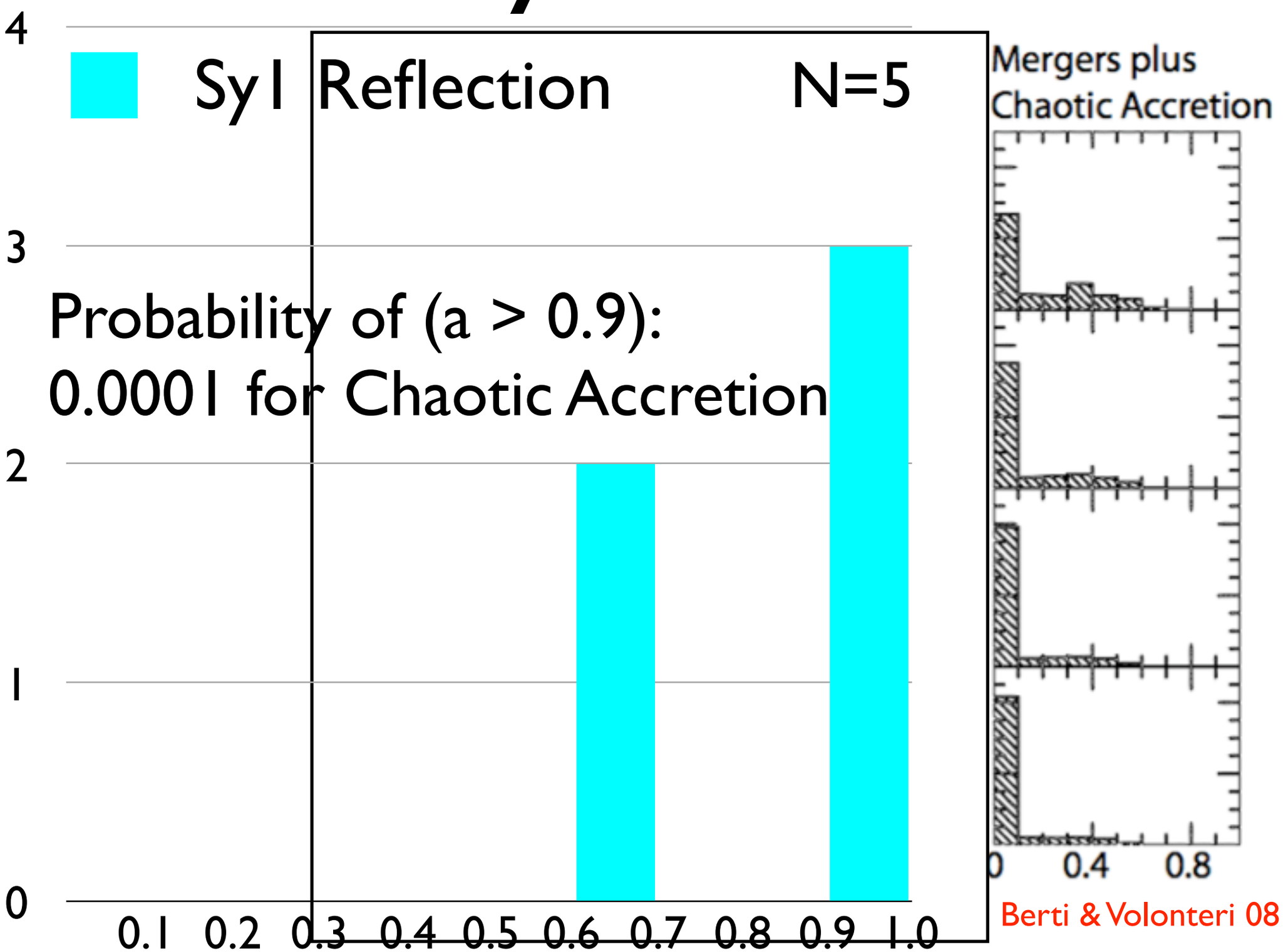
Strong detections of relativistic lines using missions with broad spectral bandpass.

Spectrometers are very different.

Detector issues are secondary to the astrophysics.

Lin, Remillard, Homan 2010

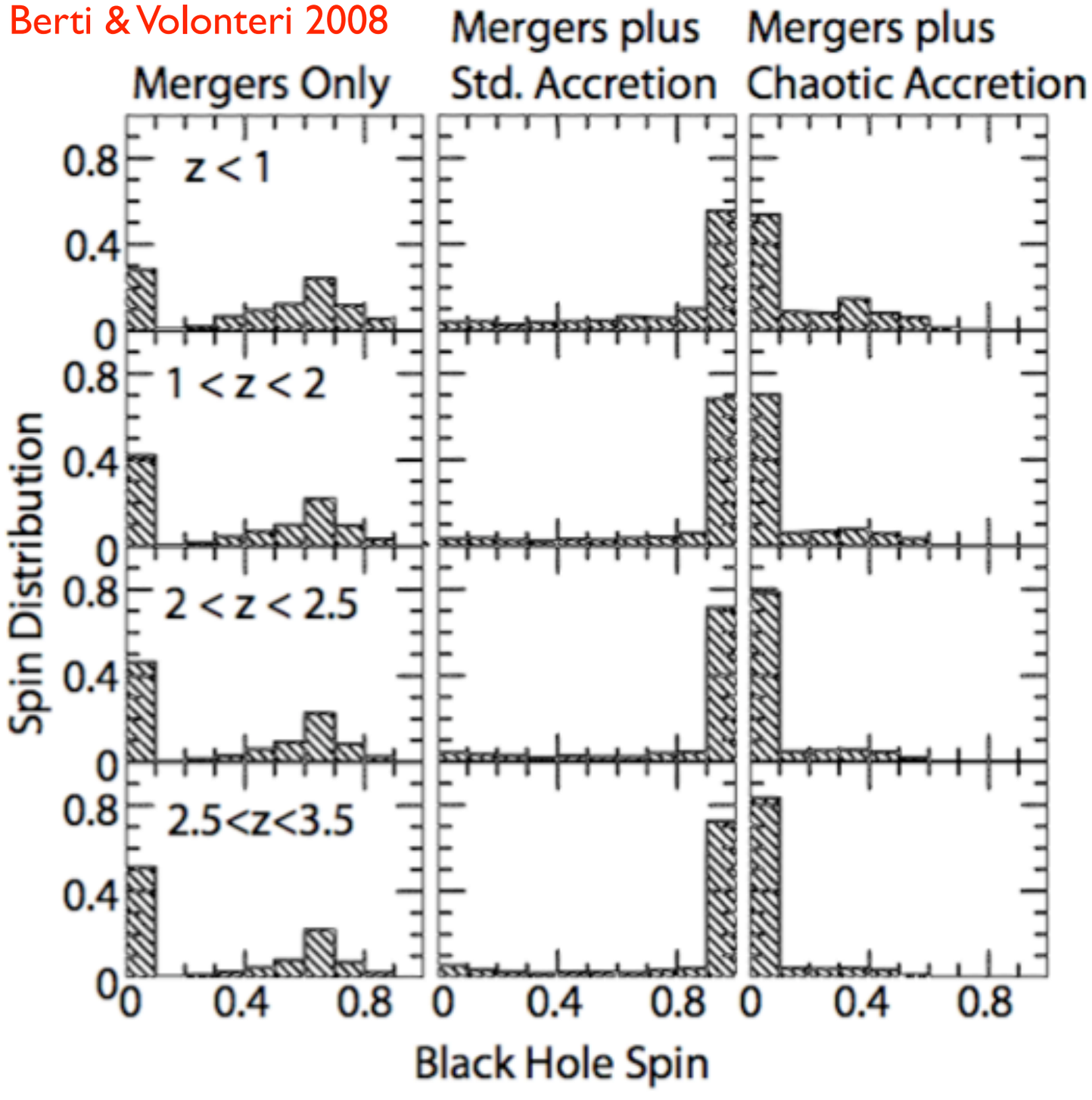
BH-Galaxy Co-Evolution

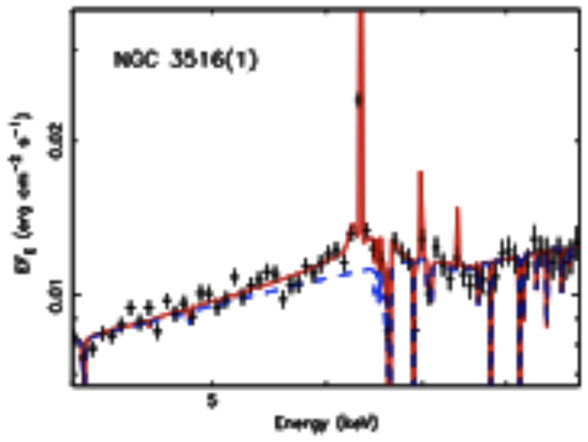


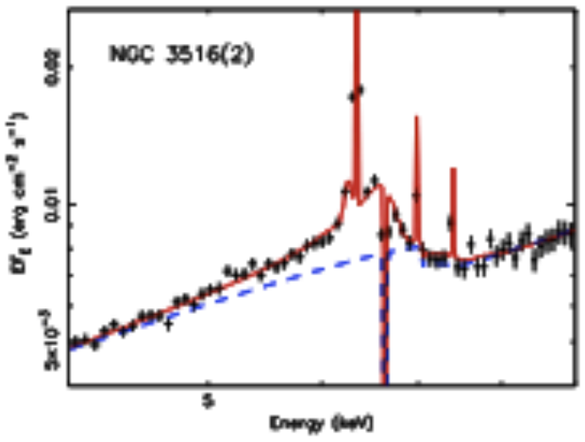
Berti & Volonteri 08

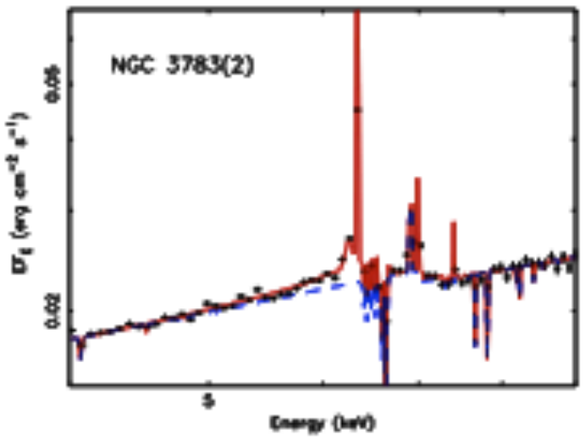
BH-Galaxy Co-Evolution

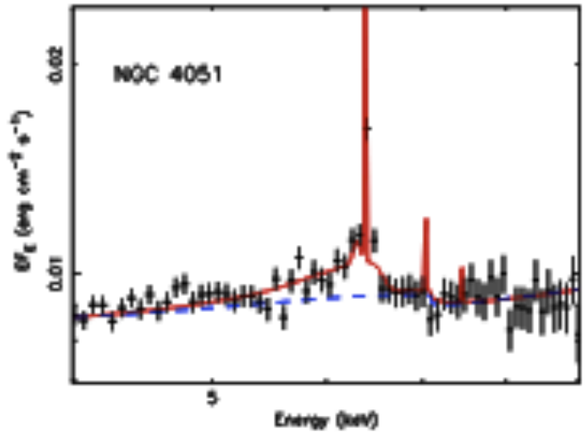
Berti & Volonteri 2008

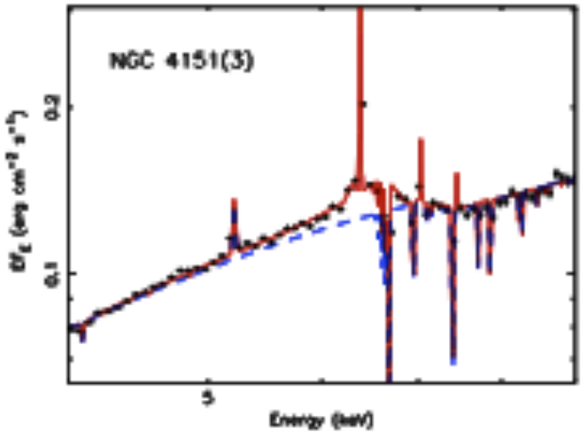


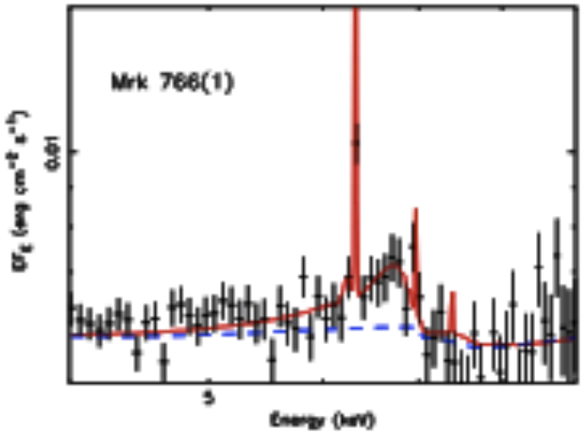

NGC 3516(1)
Energy (keV)

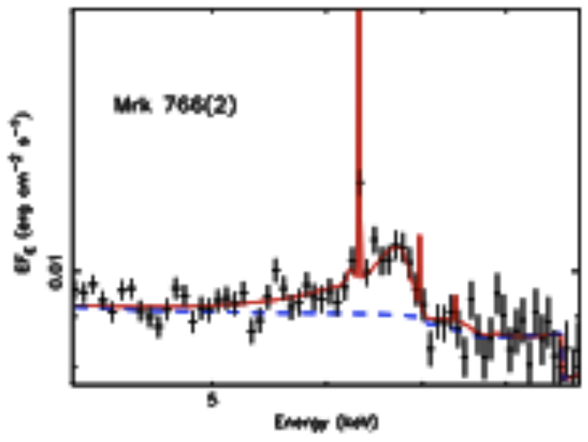

NGC 3516(2)
Energy (keV)

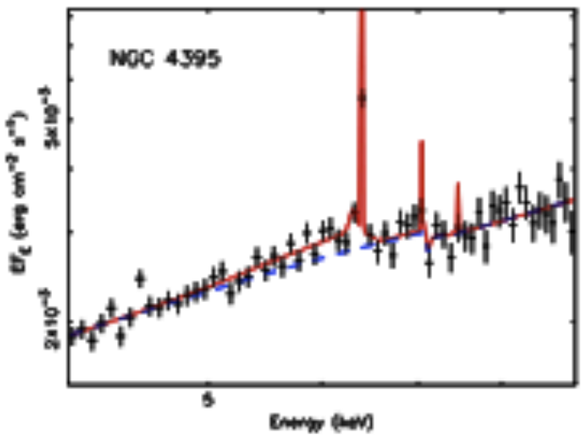

NGC 3783(2)
Energy (keV)

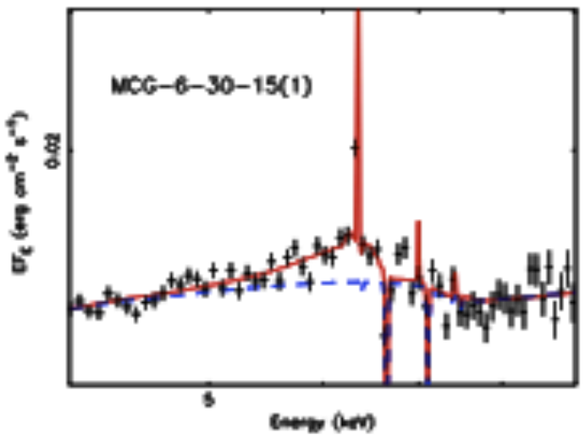

NGC 4051
Energy (keV)

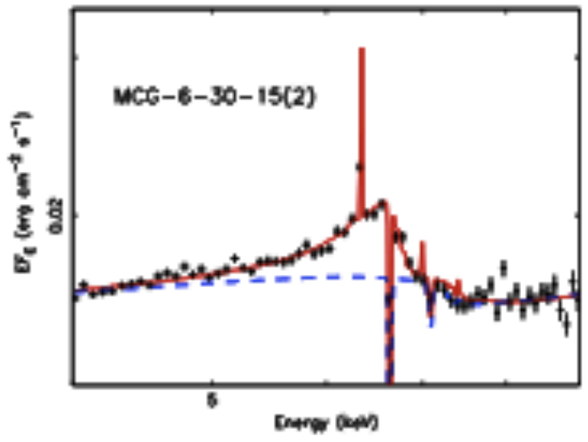

NGC 4151(3)
Energy (keV)

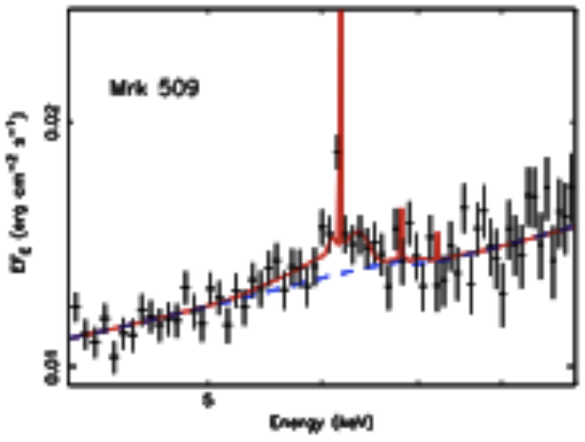

Mrk 766(1)
Energy (keV)

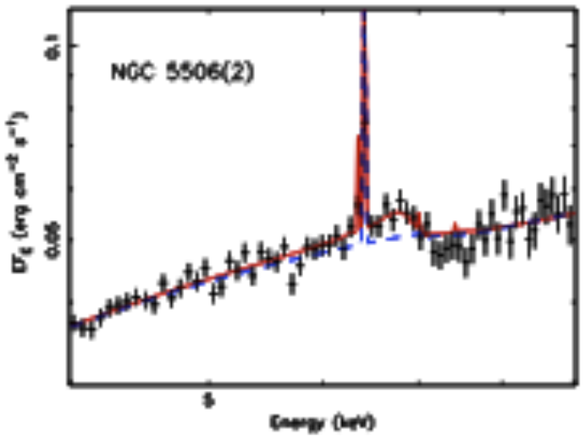

Mrk 766(2)
Energy (keV)


NGC 4395
Energy (keV)


MCG−6−30−15(1)
Energy (keV)

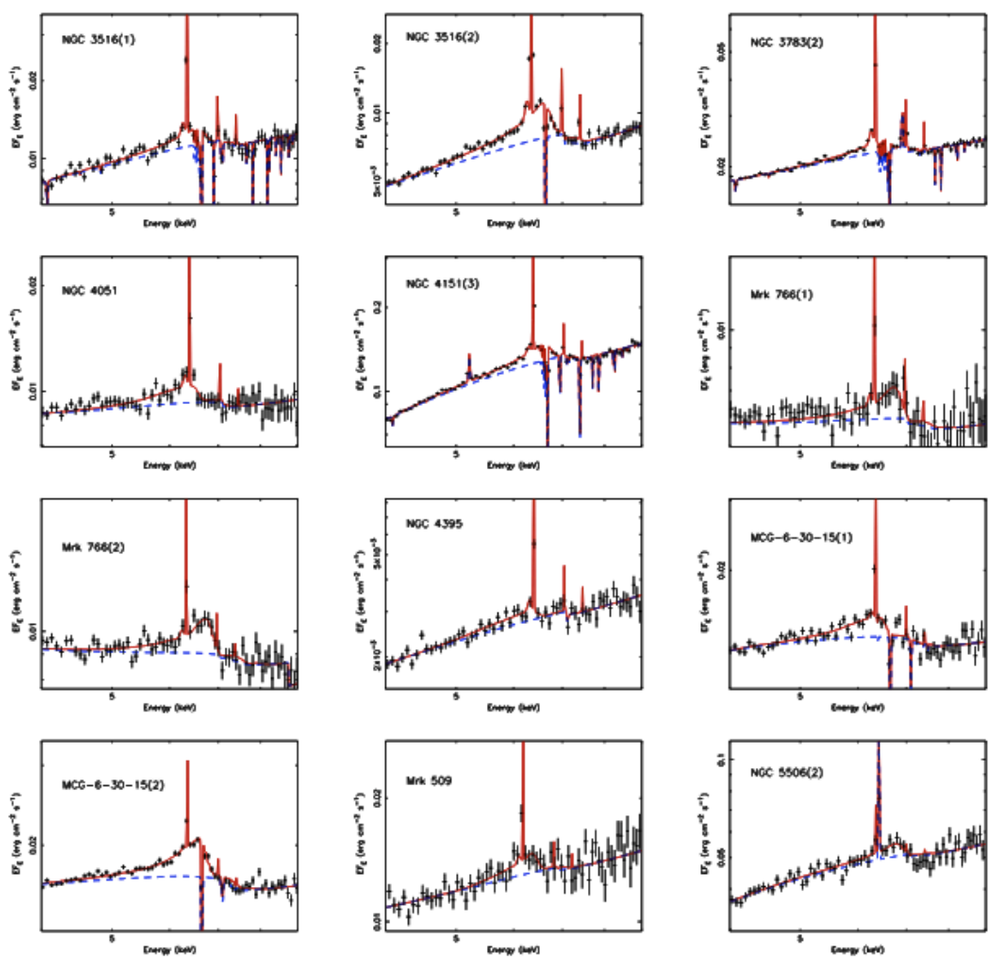

MCG−6−30−15(2)
Energy (keV)


Mrk 509
Energy (keV)


NGC 5506(2)
Energy (keV)

Relativistic line surveys

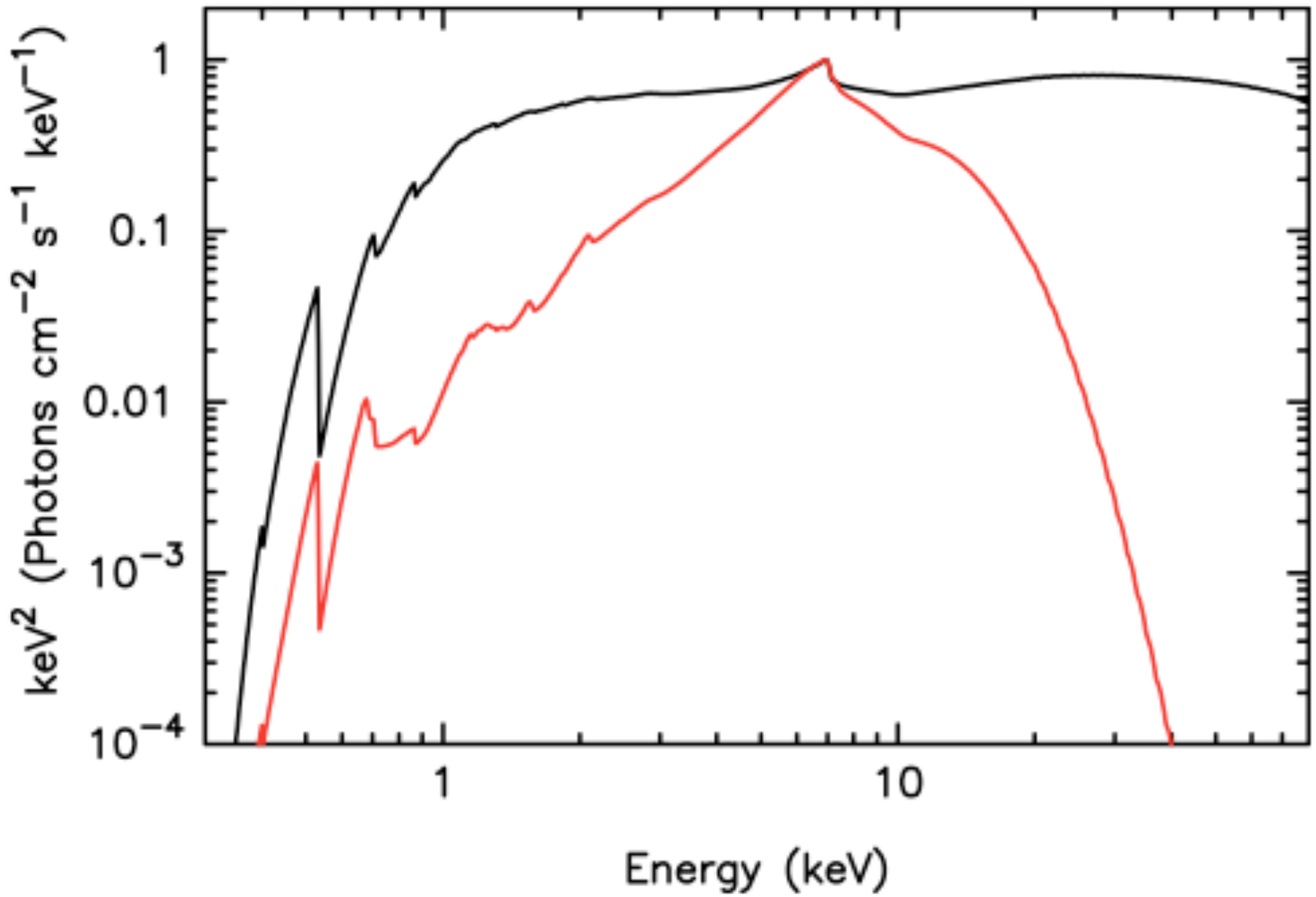
- Quality Metric: >100,000 cts
- Model warm absorber(s).
- Incl. narrow lines in Fe K band.
- ~50% require relativistic lines. (Geometry, acc. rate, ionization.)
- ~75% w/ Suzaku (HXD helps)
- Some sources may require spin.
- More deep spectra are needed.



Guainazzi et al. 2006
Nandra et al. 2007
Brenneman & Reynolds 2009

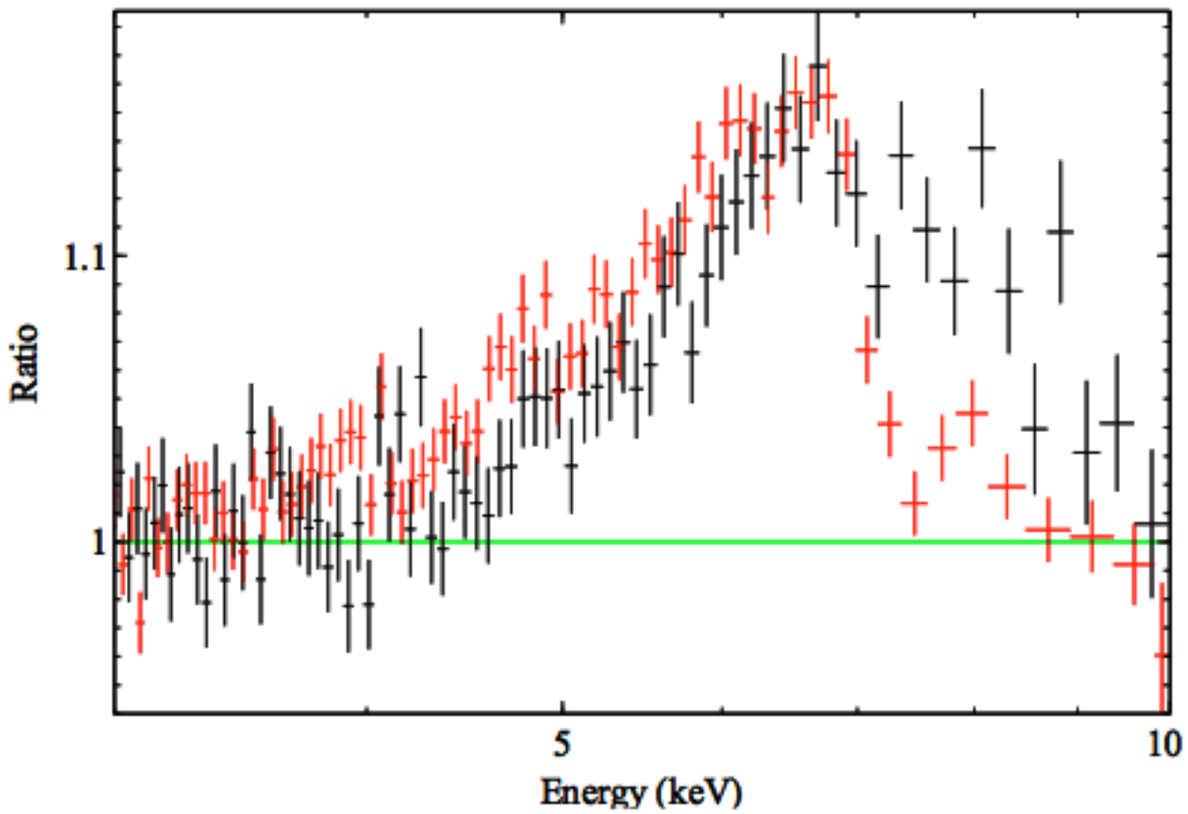
NS reflection

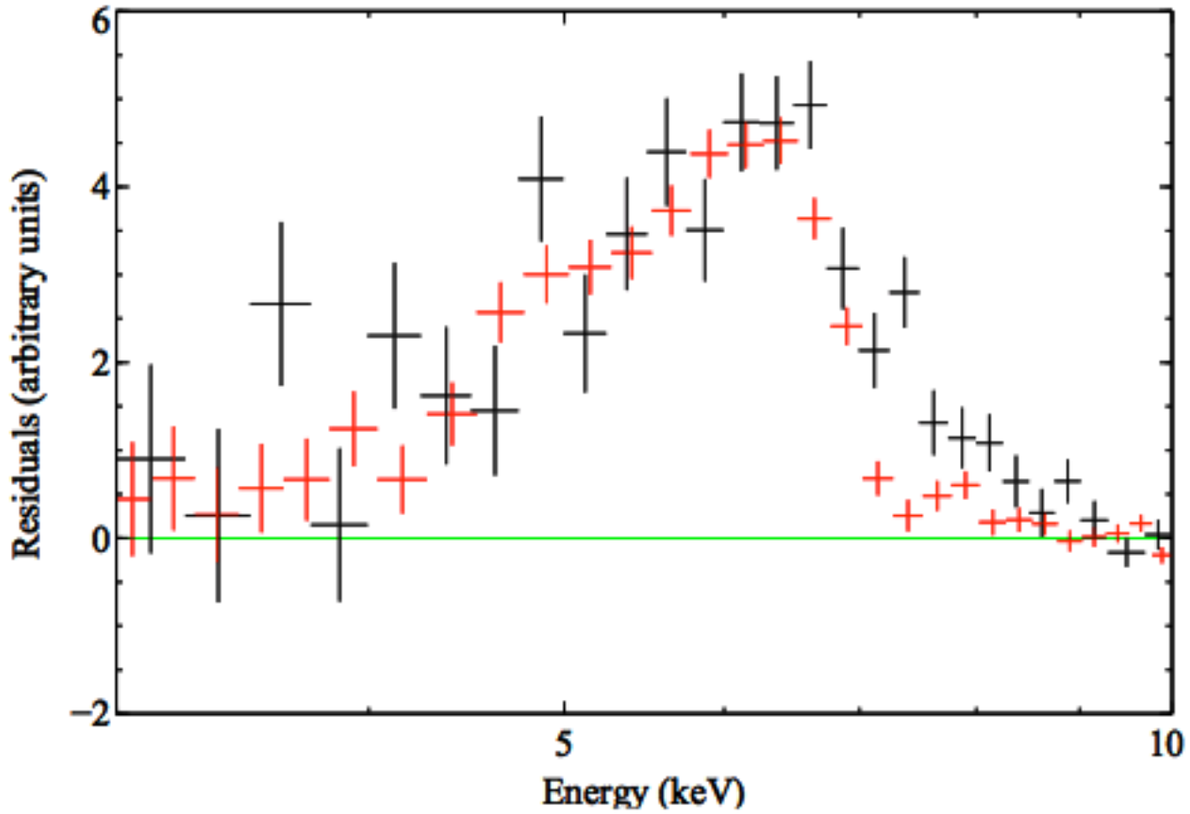
Cackett et al. 2010



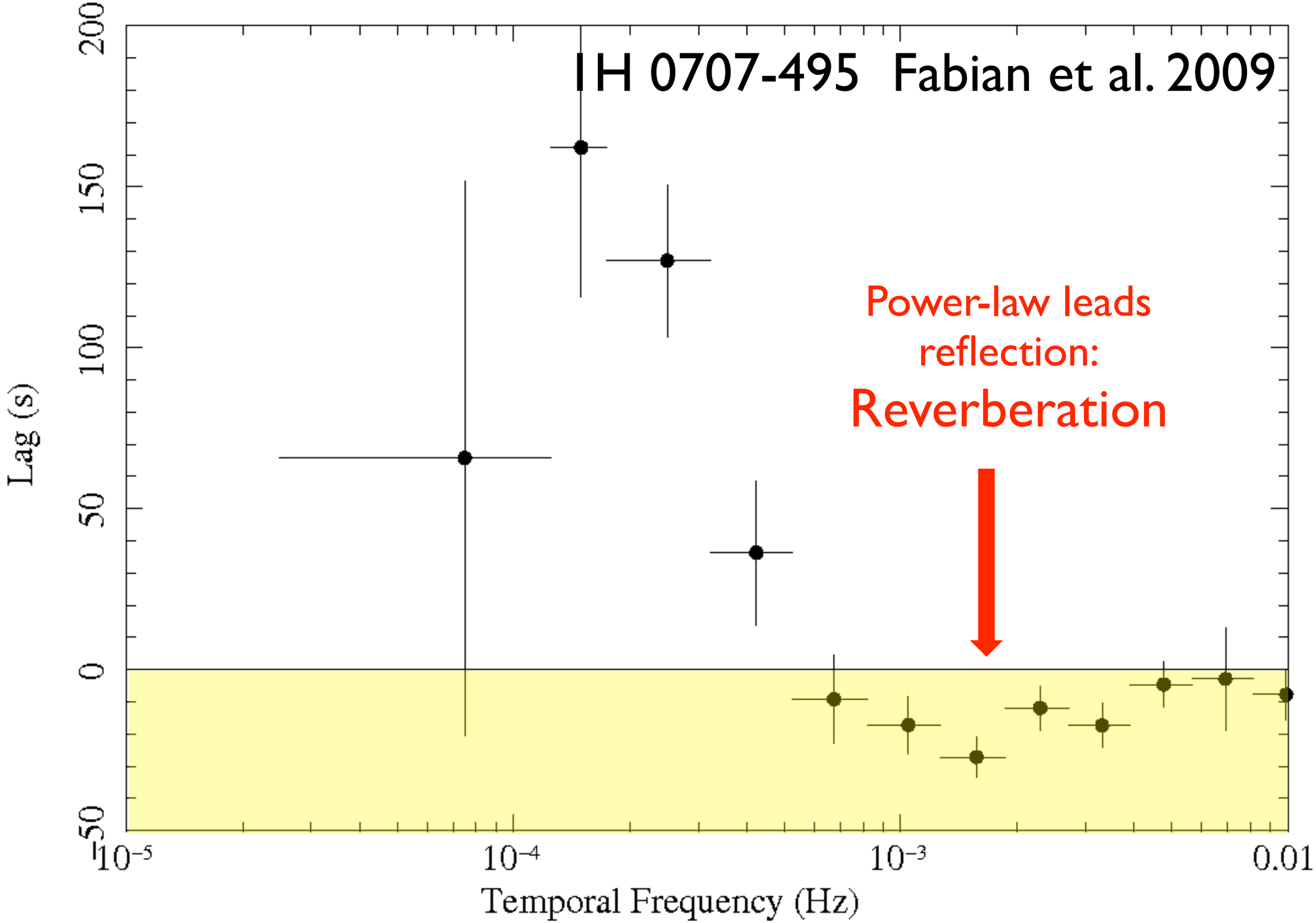
XTE J1650-500

XMM-Newton: XTE J1650-500, MCG-6-30-15





Walton et al. 2012


IH 0707-495 Fabian et al. 2009
Power-law leads
reflection:
Reverberation
Lag (s)
200
150
100
50
0
−50
10^{-5}
10^{-4}
10^{-3}
0.01
Temporal Frequency (Hz)

Thanks

- Thanks to Jean. And Hale and Rick. And Fred.
- And Tod, Craig, Keith, Frank, Will, Evan, Padi, John.
- And Ron, Al, and Ed at MIT.
- And the whole team.

It made a difference.

- Data ... lots and lots of data.
- This meant lots work, and lots of Ph.D.s
- Taught countless students how to plan observations, analyze data, how to interact with a mission director.
- Quarterbacked a generation of X-ray efforts with many other missions.