Relativistic Lines & Reflection from the Inner Accretion Disks around Neutron Stars

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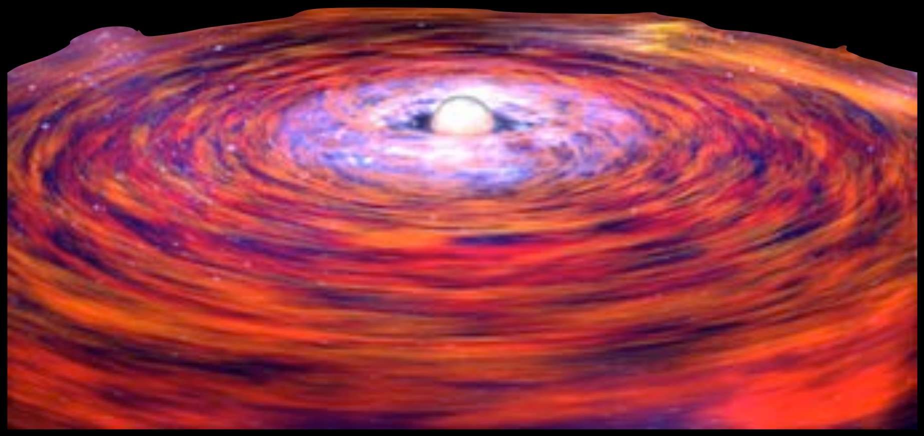
Thanks to: Jon Miller, David Ballantyne, Didier Barret, Sudip Bhattacharya, Cole Miller, Tod Strohmayer, Rudy Wijnands

X-ray binaries: strong gravity and ultra dense matter

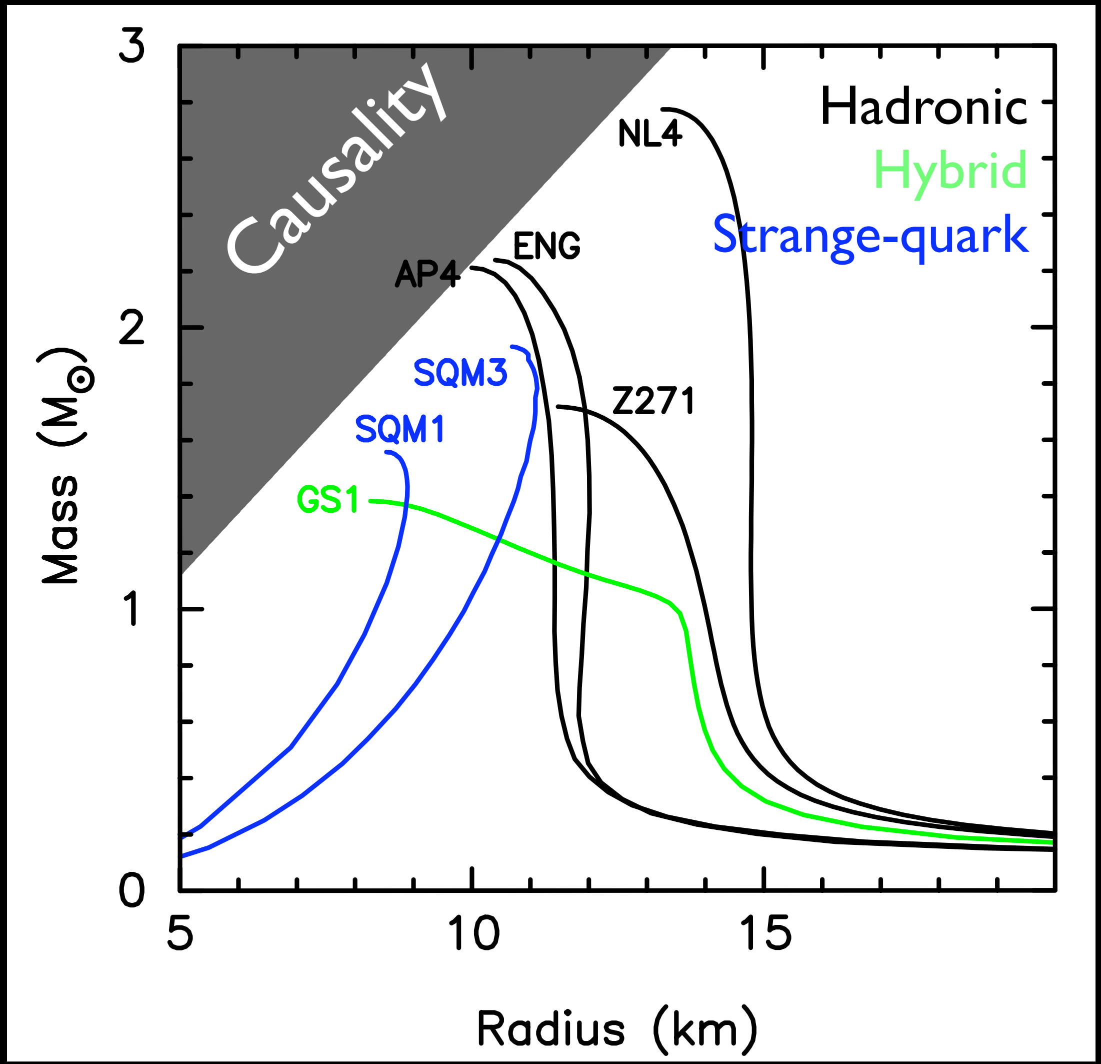
- Both NS and BH probe strong gravity

- Large relativistic effects close to BH or NS
- NS contain matter at densities > nuclear density



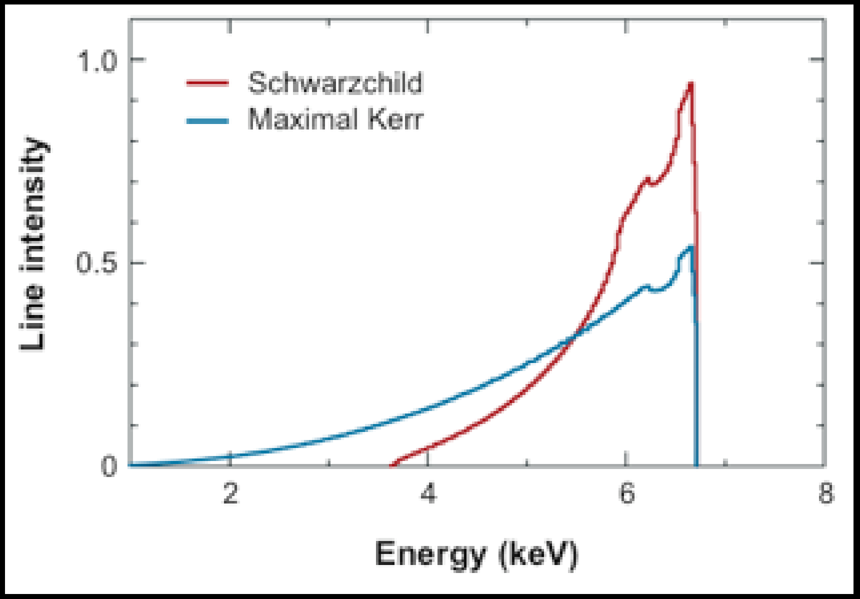
Neutron star equation of state of ultra-dense matter

- Equation of state (EOS) describes relationship between pressure, density, temperature etc.
- Observationally:
  - ➡ measure mass and/or radius

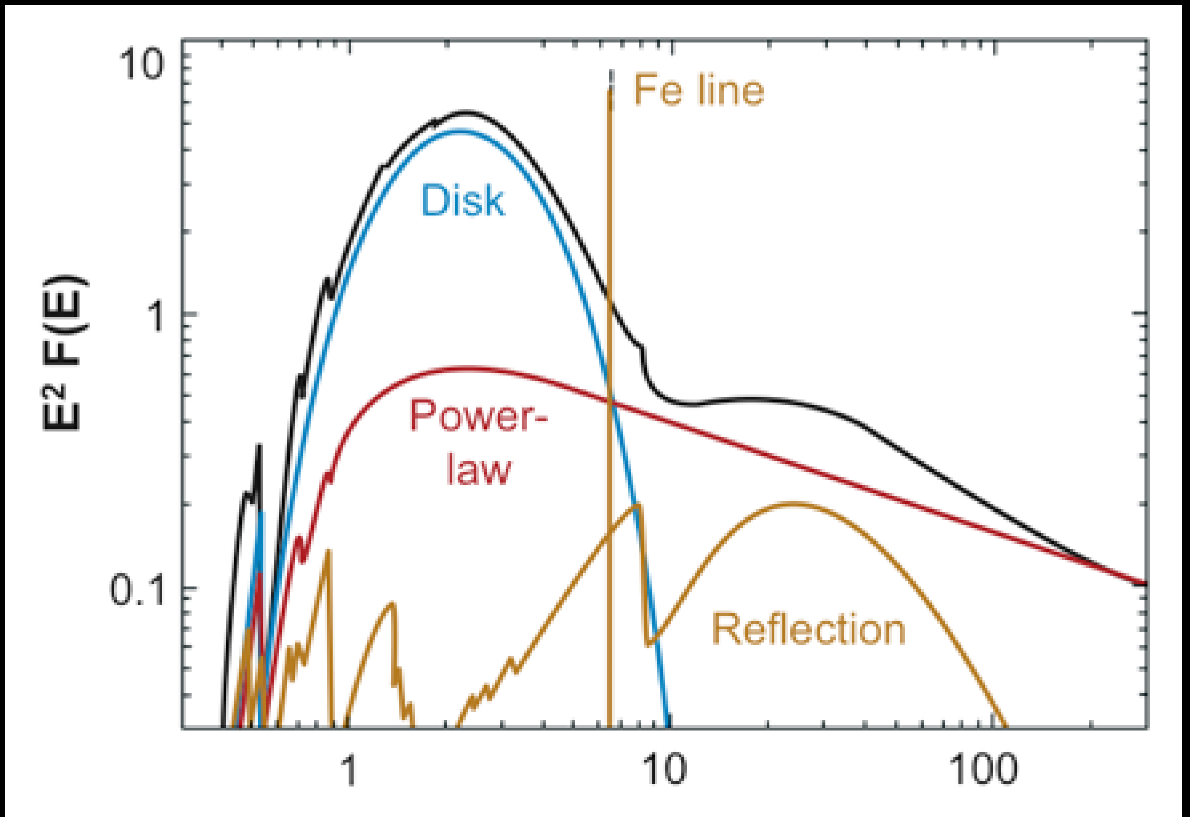


Relativistically broadened disk lines

- Reminder: Fe K line part of reflection spectrum from inner part of accretion disk
- Ability to measure inner accretion disk radius
  - BH spin & NS radius constraints!

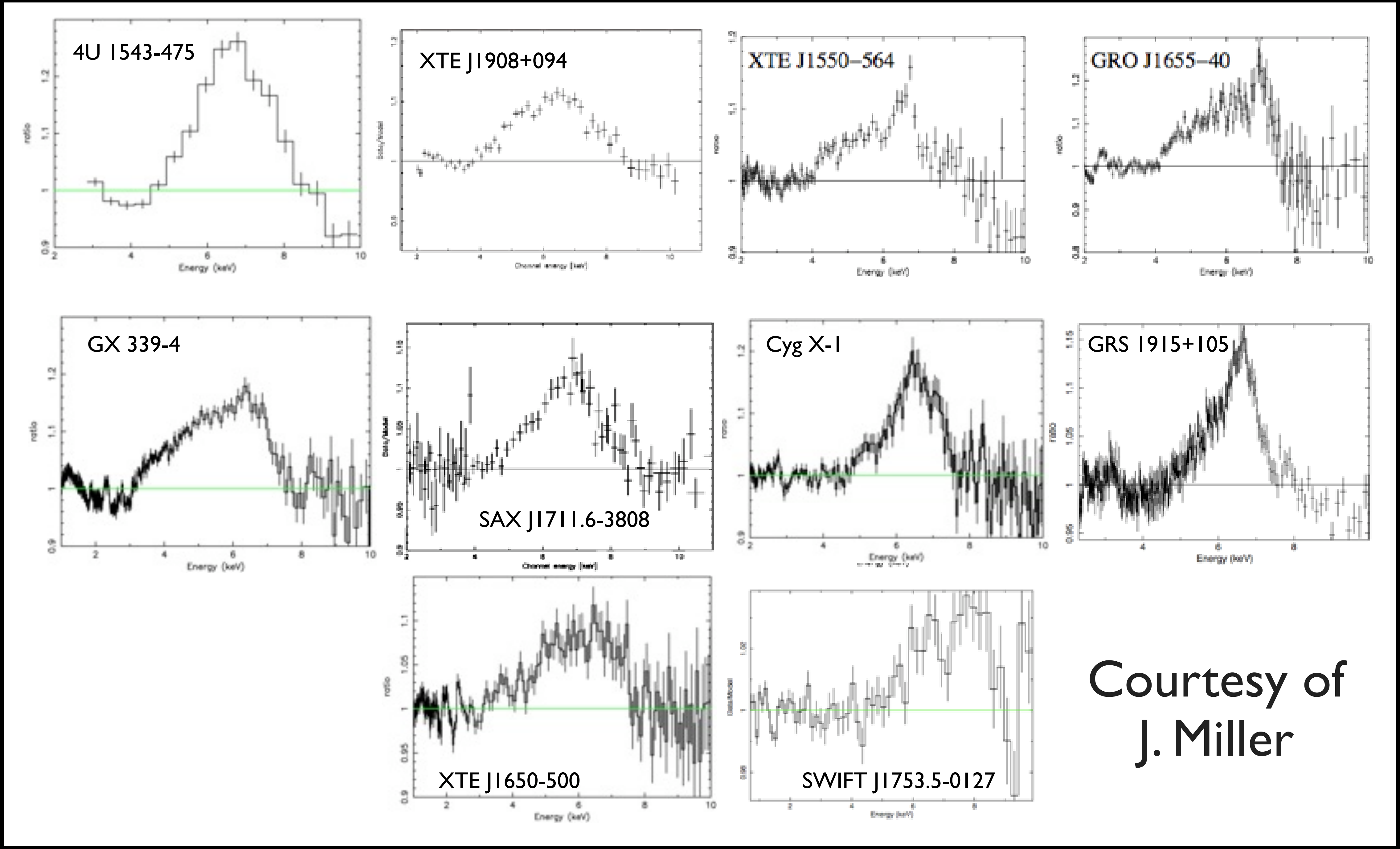


After Fabian & Miniutti (2006)



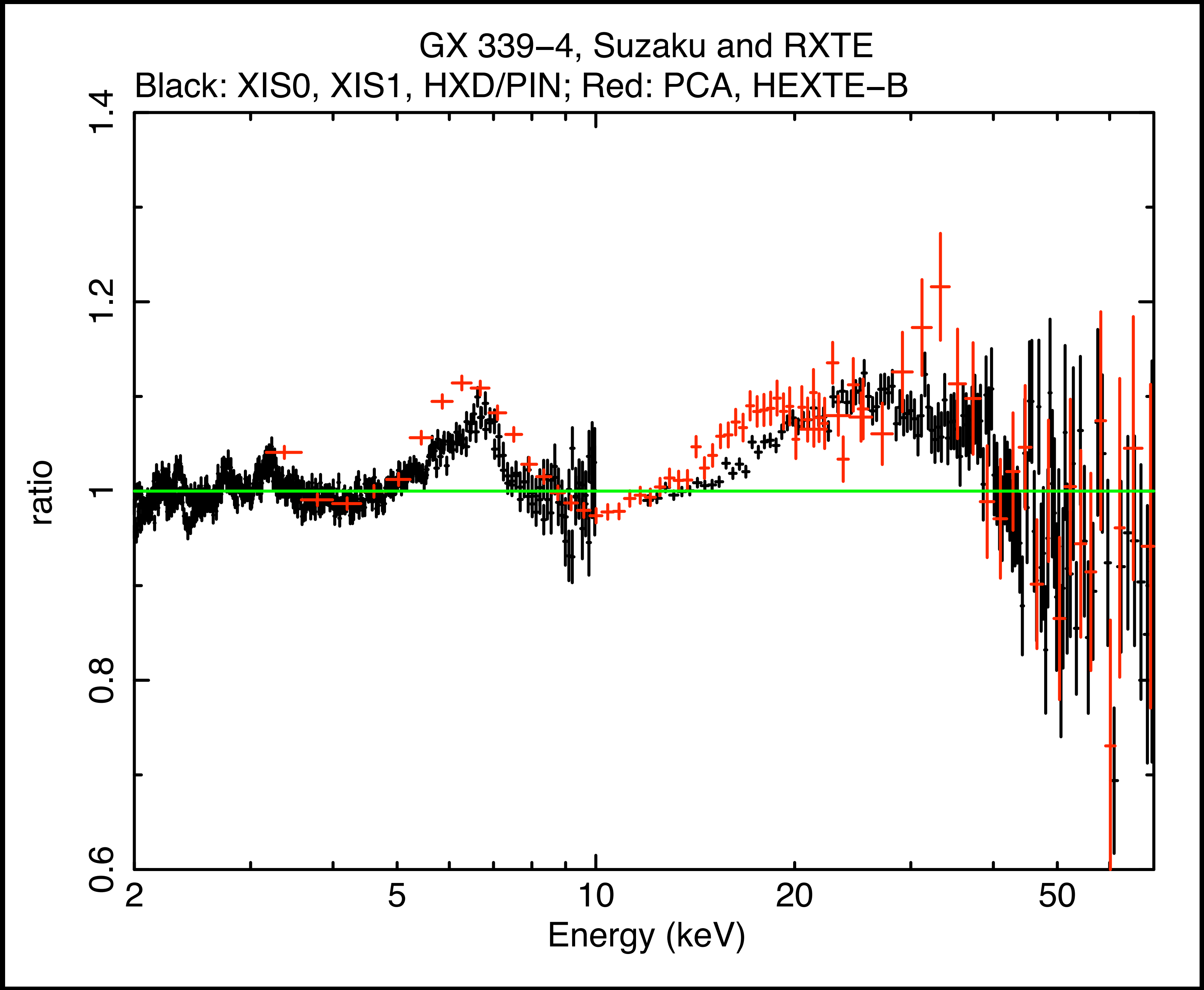
Miller (2007)

Fe K lines in black hole X-ray binaries



see Miller 2007 (ARA&A, 45, 441) for a detailed review

Reflection in BH systems

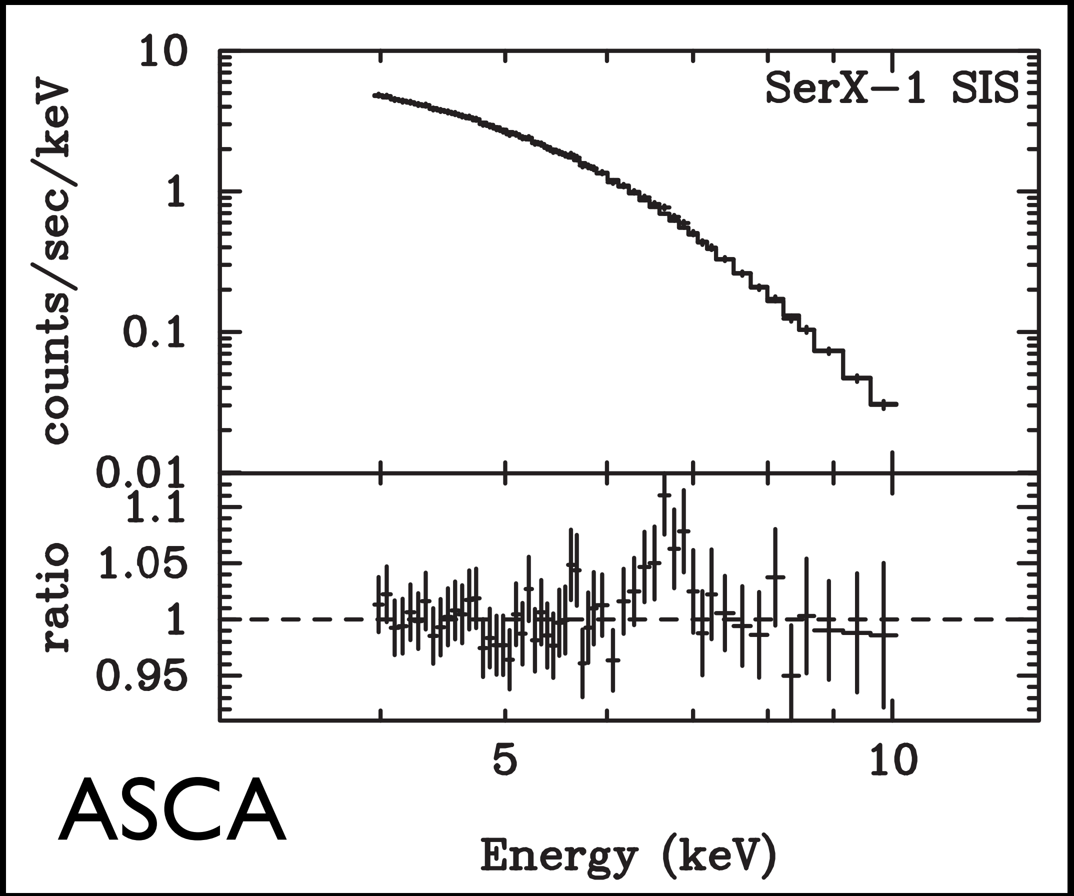


GX 339-4: Relativistically broadened Fe K line and strong Compton hump - clear signatures of reflection

Miller et al. 2008

Fe K lines in neutron star low-mass X-ray binaries

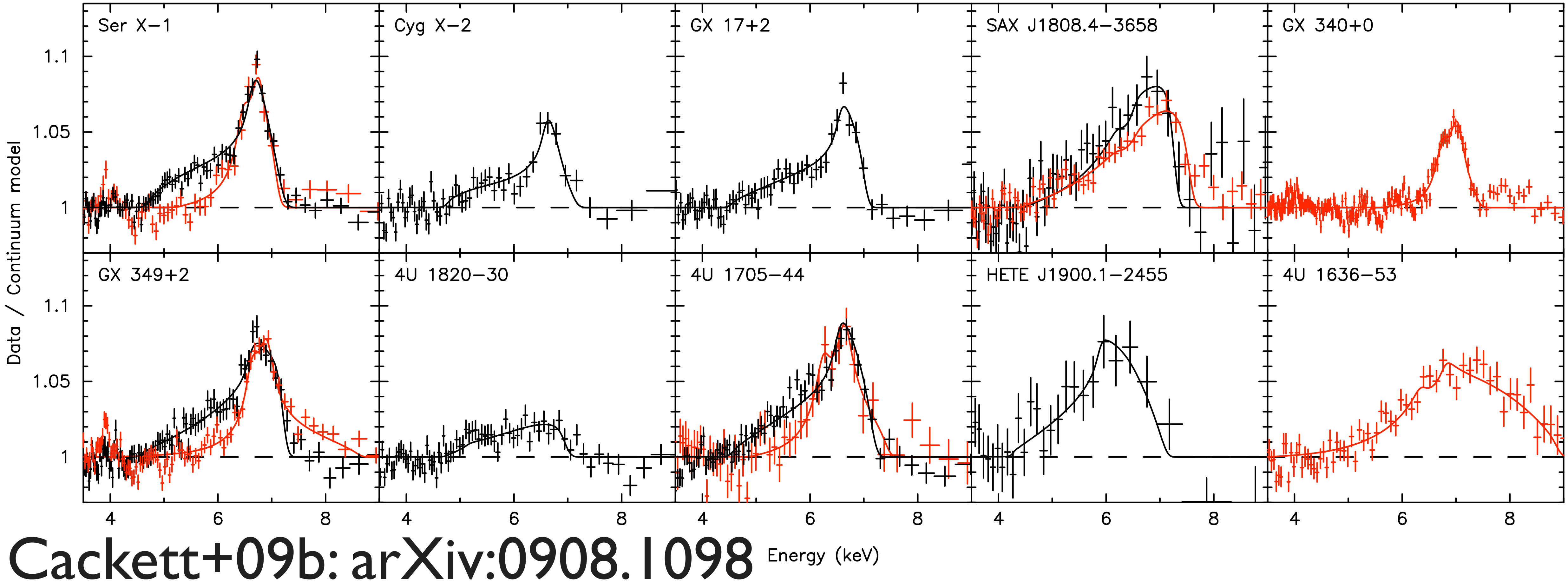
- Iron lines known in many NS X-ray binaries (e.g. Asai et al. 2000)
- Weaker than in BHs, but can use the same diagnostics of the inner disk
- Recent *Suzaku* & *XMM* observations have revealed many broad, asymmetric lines



Asai et al. (2000)

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

Fe K lines in NS systems



Cackett+09b: arXiv:0908.1098

Black: *Suzaku*, Red: *XMM*

Many recent papers: Bhattacharyya & Strohmayer (2007), Cackett+ (2008), Pandel+ (2008), D' Ai+ (2009), Cackett+ (2009a,b), Papitto+ (2009), Reis+ (2009), Di Salvo+ (2009), Iaria+ (2009)

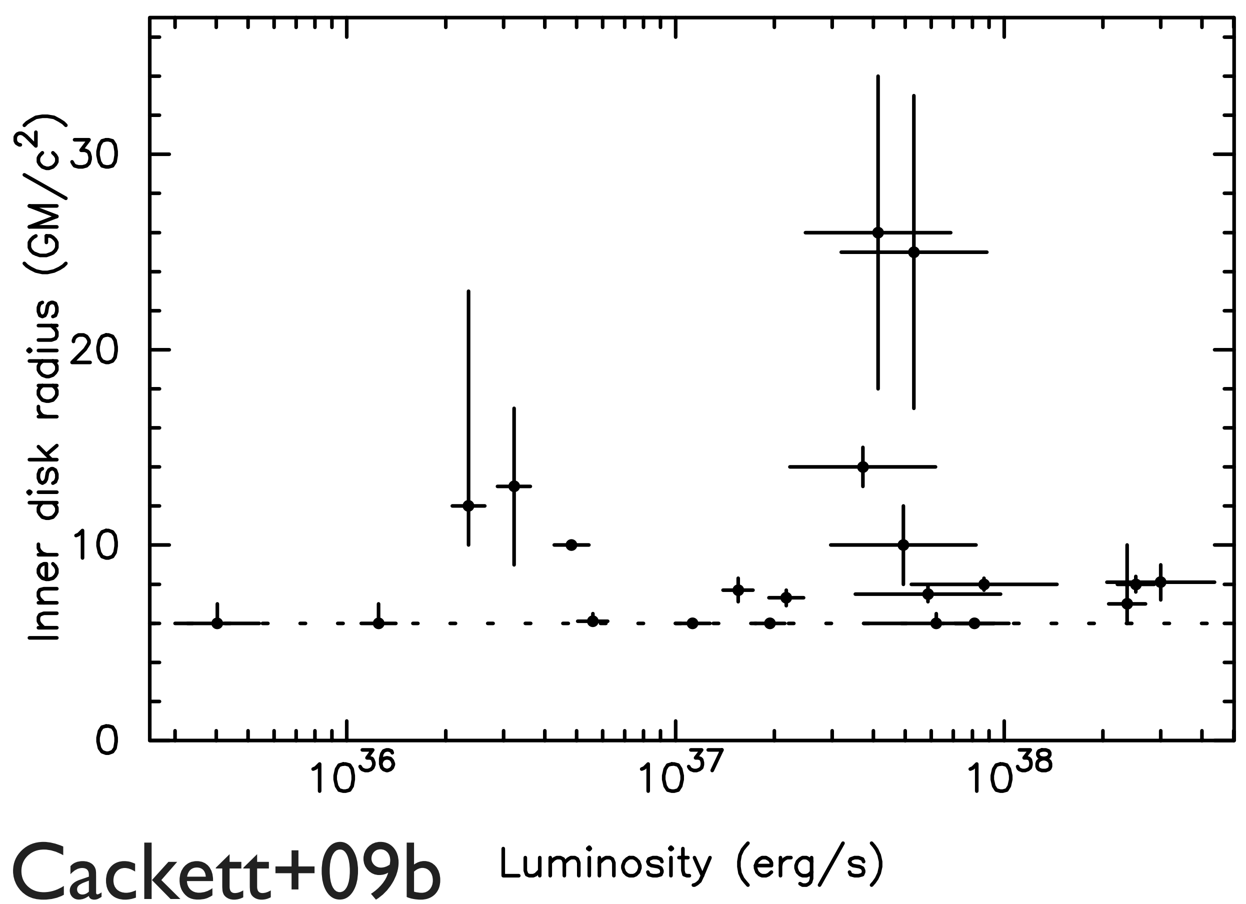
NS Fe K lines......

- Continuum model: absorbed disk + blackbody (from boundary layer) + power-law (when required)
- Disk line model for a Schwarzschild metric (Fabian+ 1989) fits line well (as expected)

➡ Small range in inner disk radii

➡ Radius upper limit of just 12 km (for 1.4 $M_\odot$) in some cases

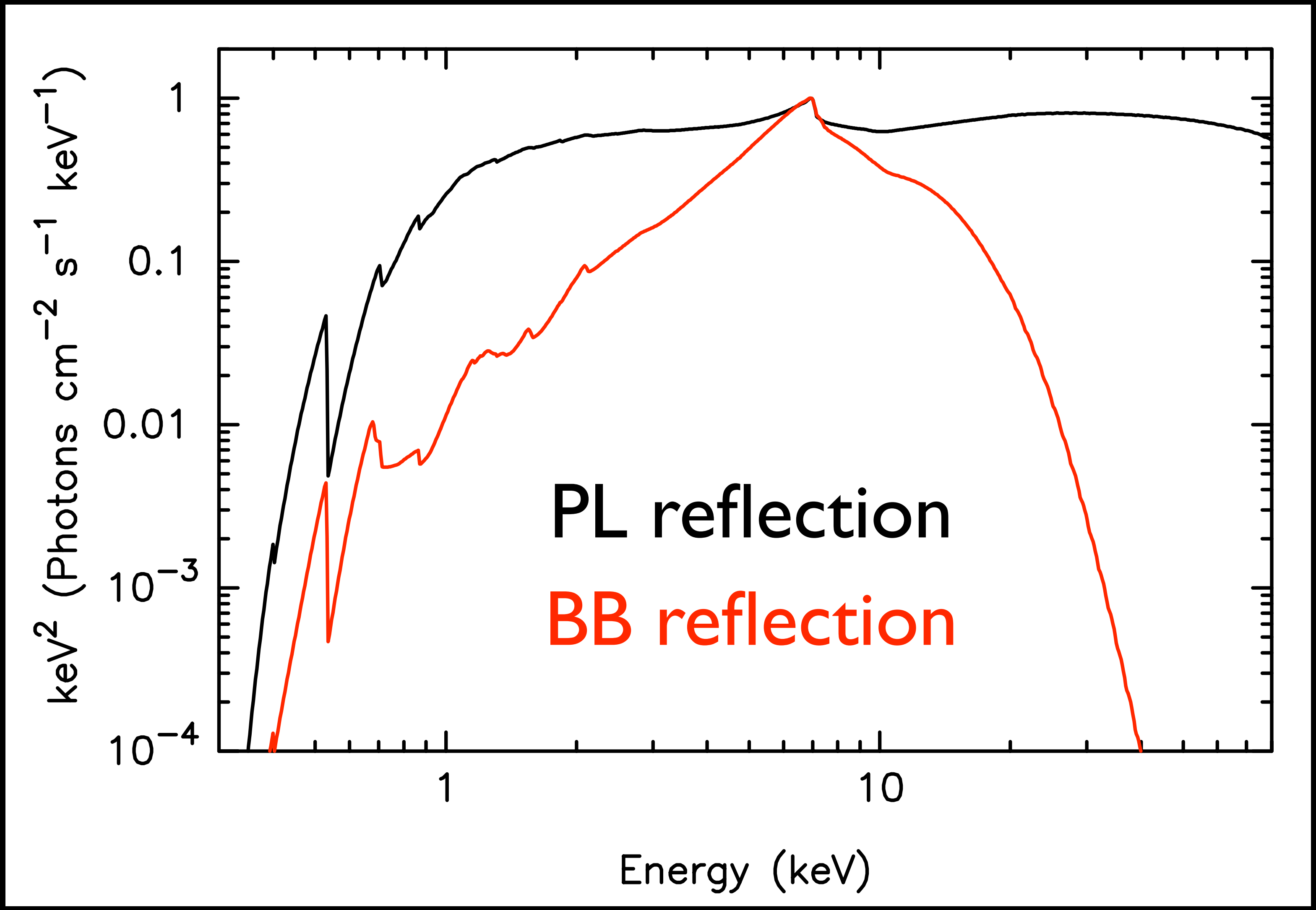
➡ No obvious dependence on luminosity



Cackett+09b

Reflection in NS systems

- Blackbody (from boundary layer) dominates from 7-20 keV
- Compton hump harder to see when illuminated by blackbody: reflection component drops off fast



Thanks to David Ballantyne for reflection models (see Ballantyne & Strohmayer 2004)

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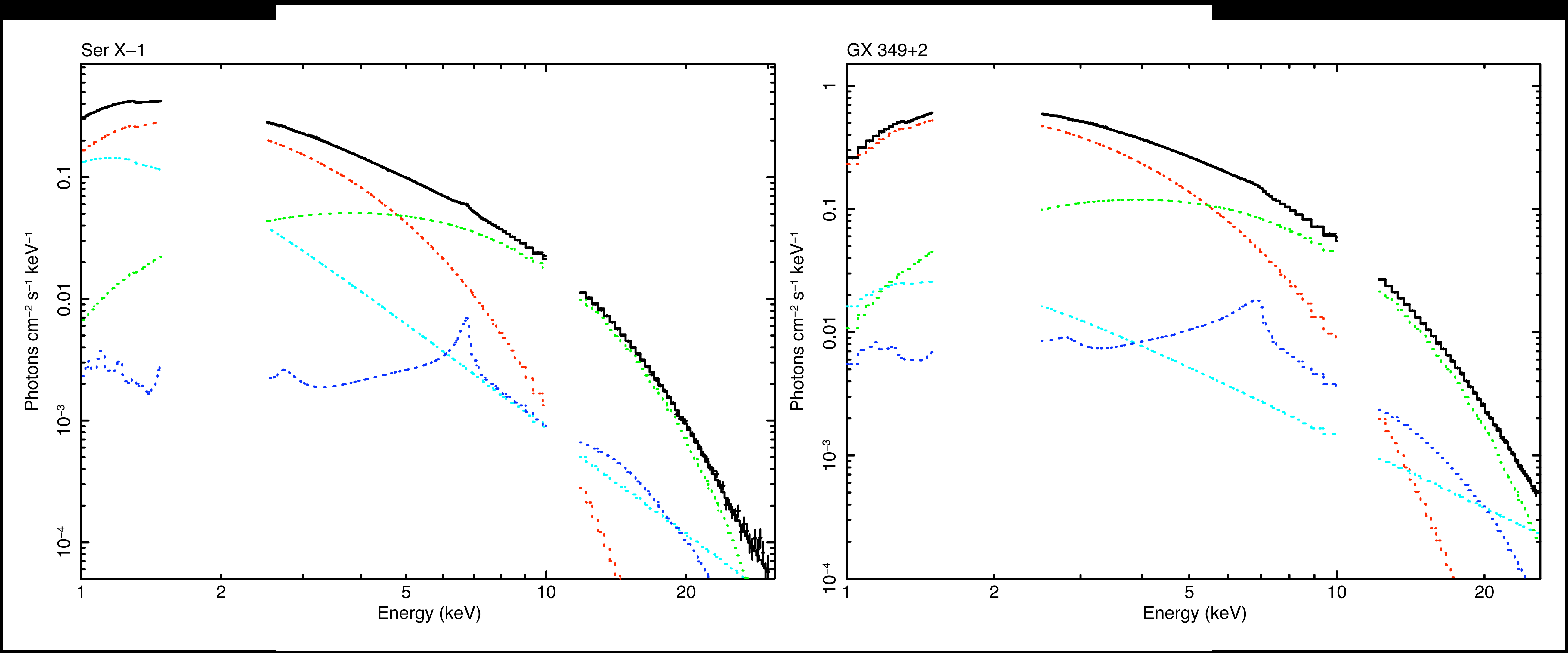

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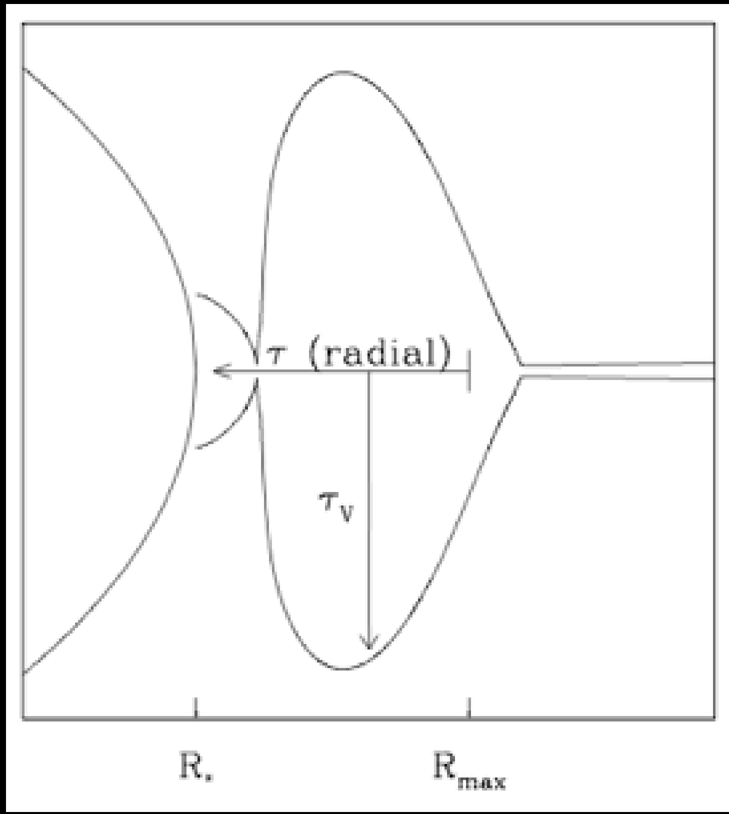
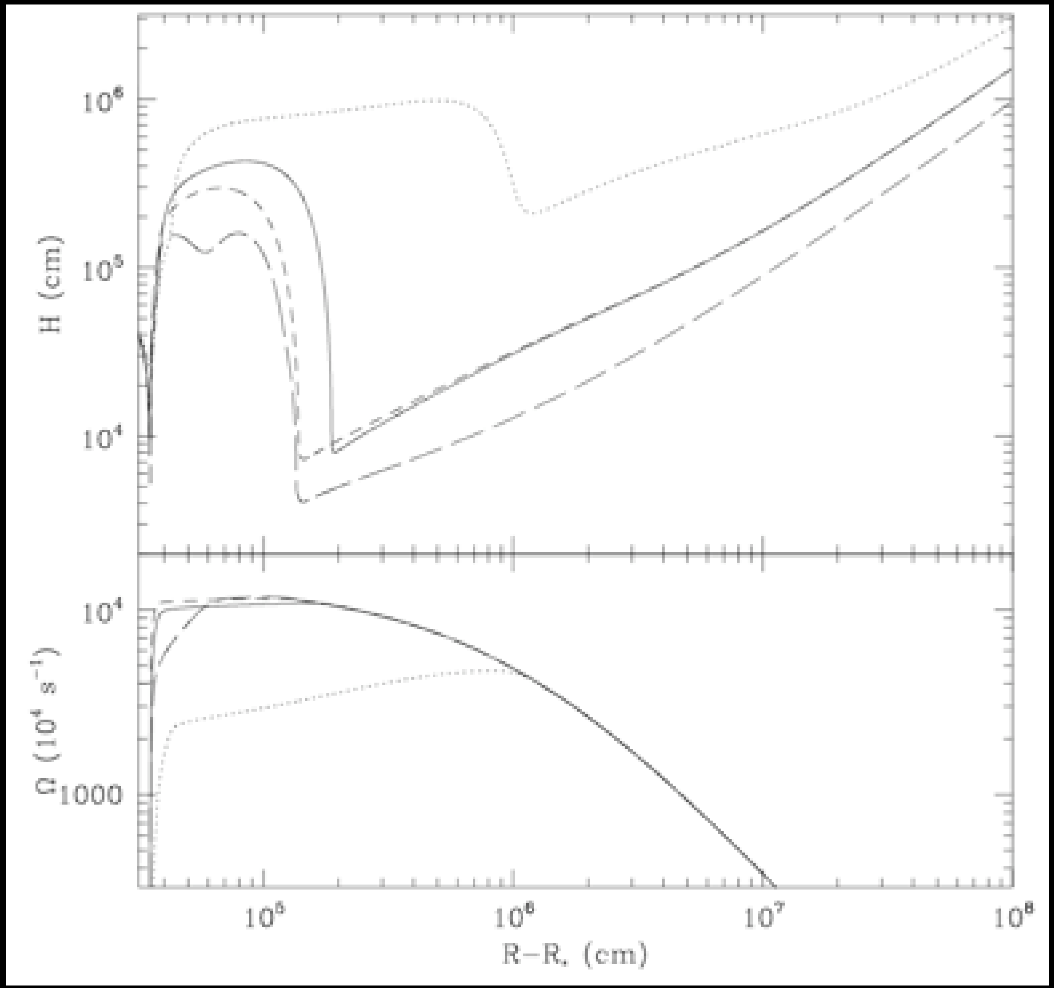
Accretion flow and boundary layer

- suggests boundary layer irradiates inner disk
- boundary layer must be more extended (vertically) than inner disk

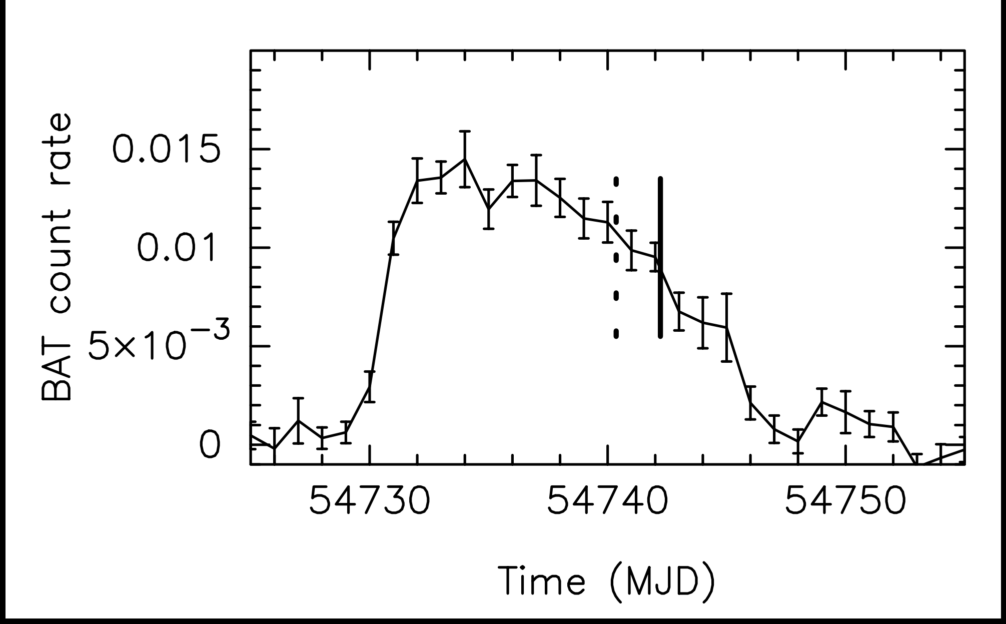




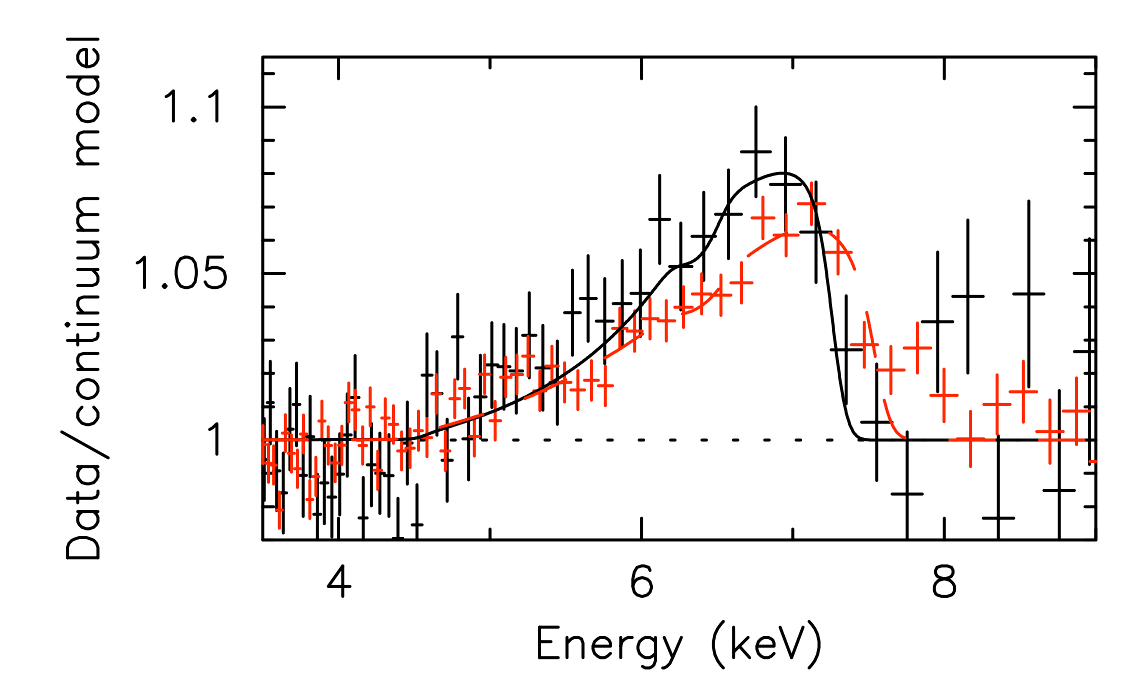
Popham & Sunyaev (2001)

Accreting millisecond pulsar: SAX J1808

- Fe K line from SAX J1808 seen with Suzaku & XMM (Cackett+ 2009a, Papitto+ 2009)
- For pulsations, disk should be truncated at (or greater than) the magnetospheric radius
- Can use $R_{in} = 13 \pm 3\ GM/c^2$ to estimate the magnetic field strength, B ~ 3×10^8 G
- Compares well with Hartman+ (2008) value from spin down and other estimates (Psaltis & Chakrabarty 1999, Di Salvo & Burderi 2003)



Cackett+ 2009a



Summary

- Now 10 neutron star systems in addition to 10 stellar-mass black hole systems with relativistically broadened iron lines
- Neutron stars:
  - potential to constrain NS radius
  - can also be used to constrain magnetic field strength in millisecond pulsars
  - can be modeled well by reflection illuminated by a blackbody: boundary layer irradiating inner disk

Wind line origin??

- Laurent & Titarchuk (2007), Shaposhnikov+(2009), Titarchuk+ (2009): suggest broad Fe lines are created in a high velocity wind
- (Some) problems with this:
    - outflow rate extremely high: 6 times Eddington rate
    - winds are seen in high/soft states when disk lines are typically absent
    - lines are often, not always, seen when QPOs present