Iron Lines in Neutron Star X-ray Binaries as Probes of Neutron Star Radii

Ed Cackett
ecackett@umich.edu
Postdoc Fellow, University of Michigan

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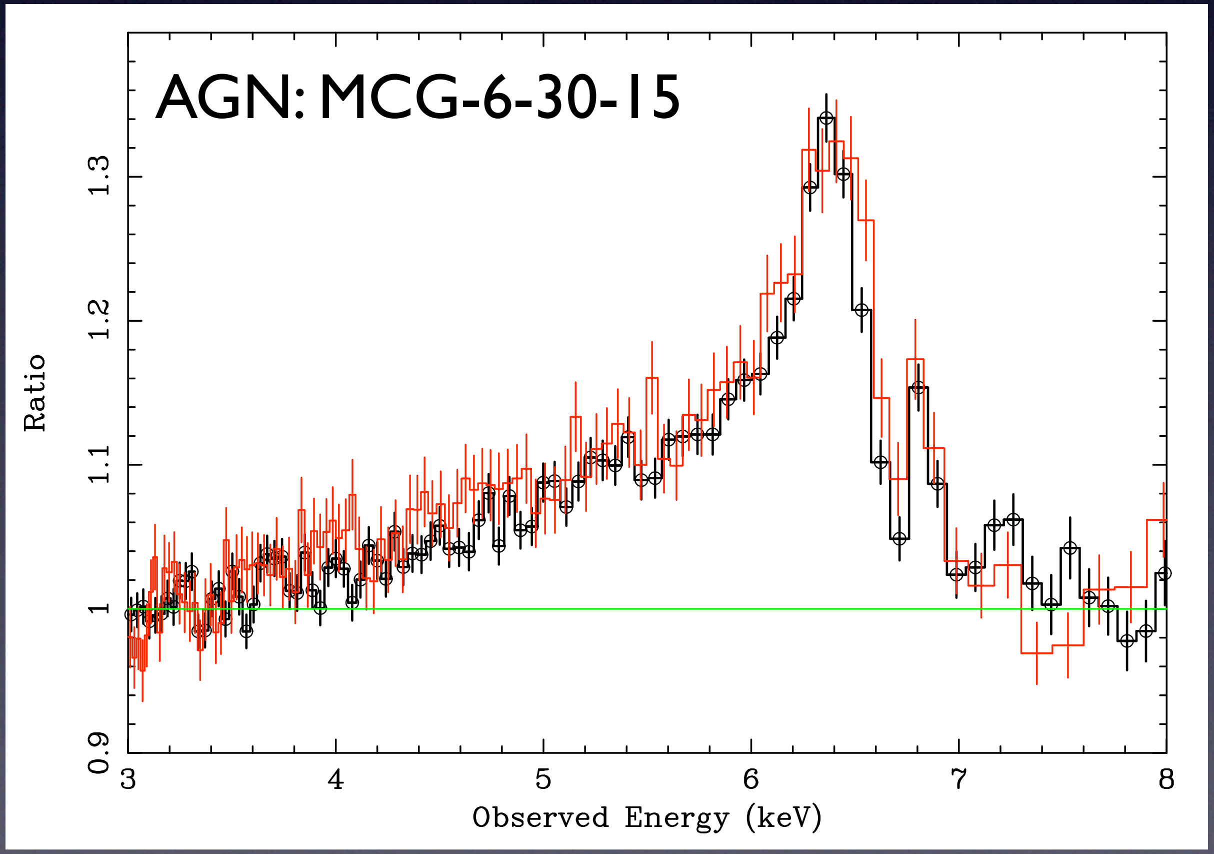
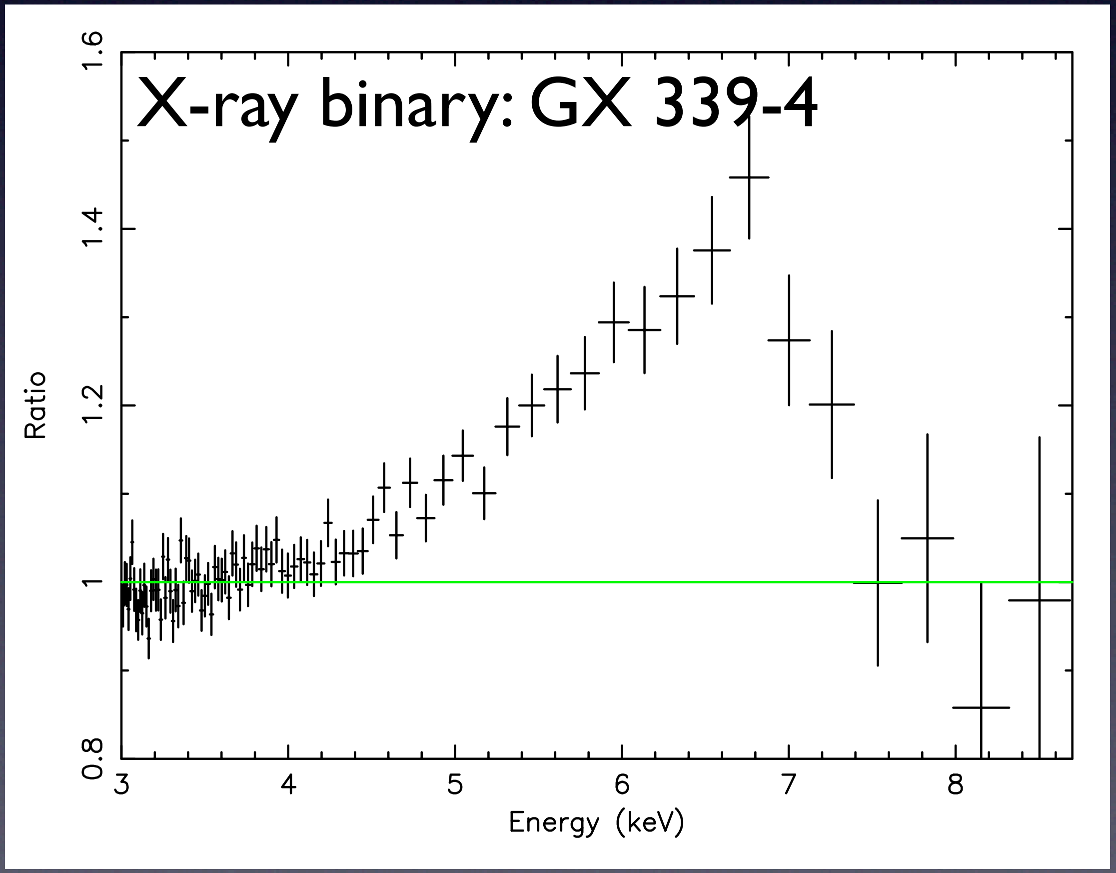
Jon Miller, Sudip Bhattacharyya, Josh Grindlay, Jeroen Homan, Cole Miller, Michiel van der Klis, Tod Strohmayer, Rudy Wijnands

Iron lines in black hole systems

- Broad, asymmetric, Fe K emission lines seen in both AGN and BH X-ray binaries
- Line skewed by Doppler shifts and gravitational redshift - thus sensitive to inner disk radius
- Evidence for BH spin



EW = 320 ± 45 eV
Reeves et al. (2006)



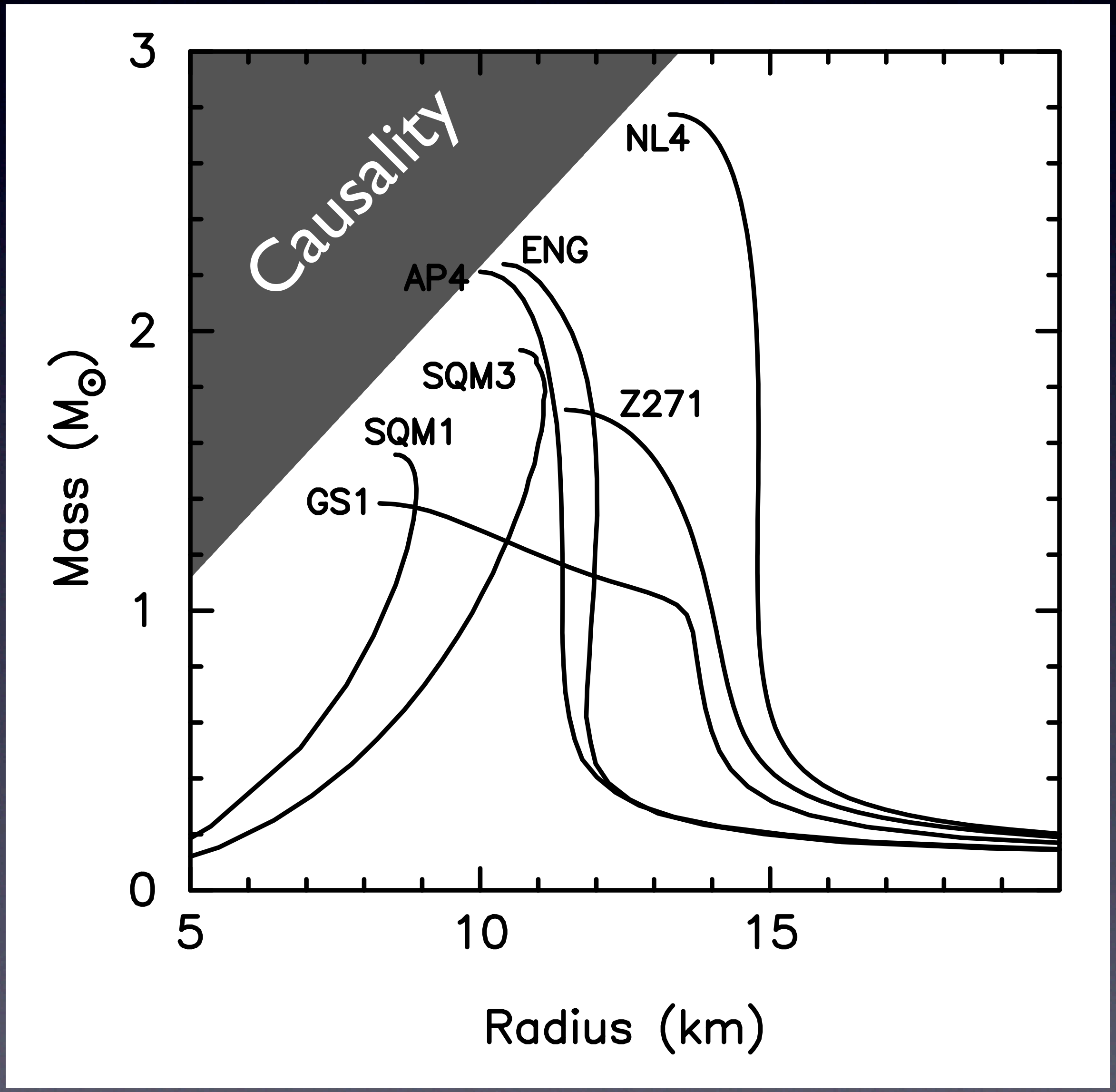
EW = 600 ± 150 eV
Miller et al. (2004)

Iron lines in neutron star systems

- Iron lines known in many NS X-ray binaries (e.g. White et al. 1985, Asai et al. 2000)
- Significantly weaker than in BHs, but can we use the same diagnostics of the inner disk in NSs?
- kHz QPOs are likely associated with the inner disk, but formation unclear - maybe we can learn about them
- Continuum spectroscopy is tough as models are degenerate (e.g. Lin, Remillard & Homan 2007)

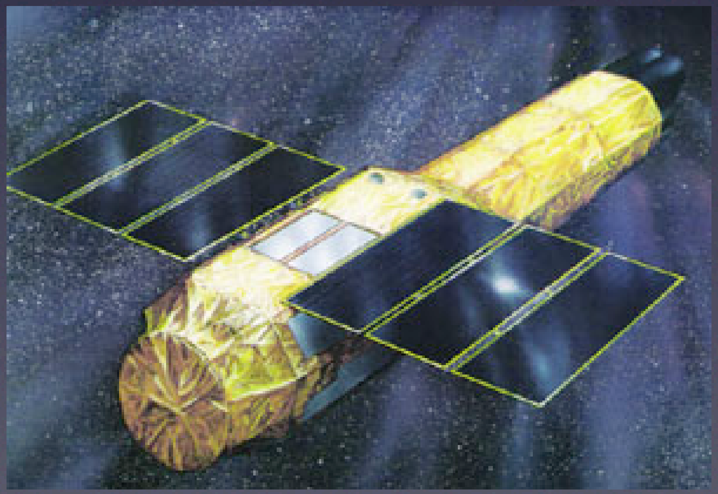
Neutron star equation of state

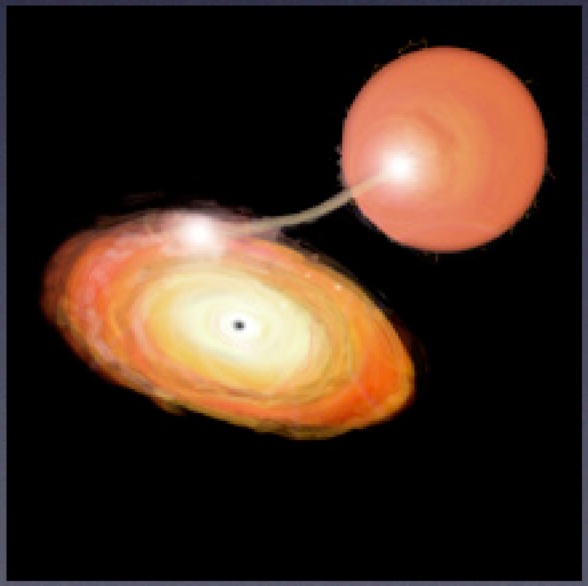
- Nature of ultra-dense matter in neutron star cores still uncertain
- We need accurate measures of neutron star *radius* and/or *mass* to discriminate



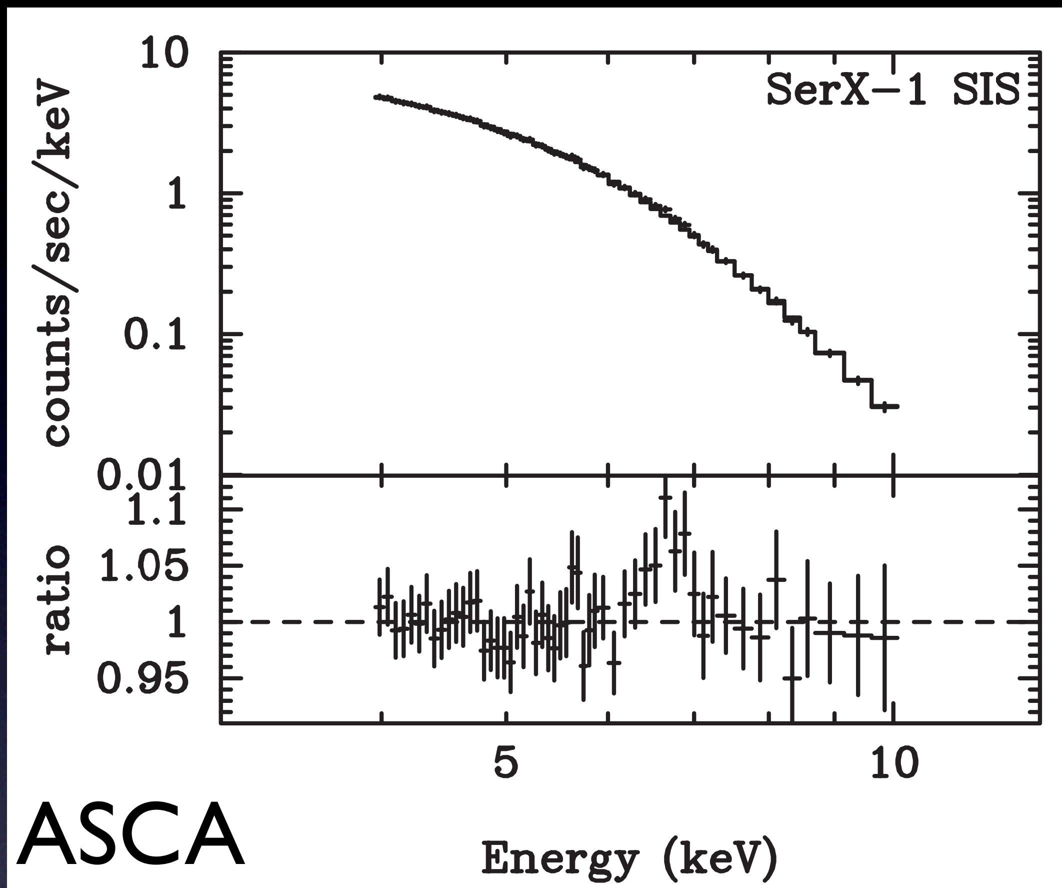
Suzaku Observations

- Broadband energy coverage and ability to observe high count rates efficiently - excellent for observing iron lines in NSs
- *Suzaku* observations of 4 neutron star X-ray binaries (~30 ks, except GX 349+2 ~50 ks):
  - Serpens X-1
  - GX 349+2
  - Cygnus X-2
  - 4U 1820-30

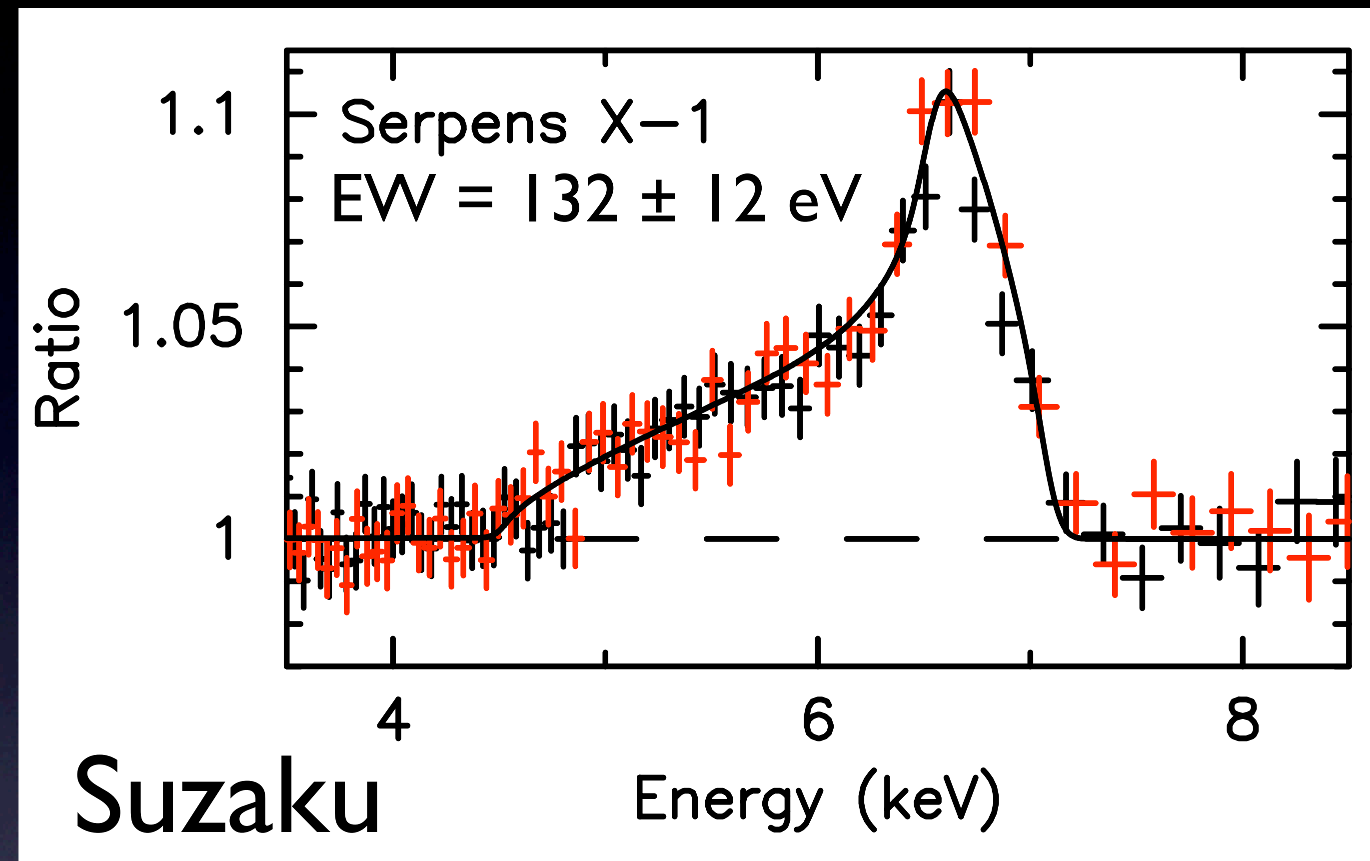




Serpens X-1



Asai et al. (2000)

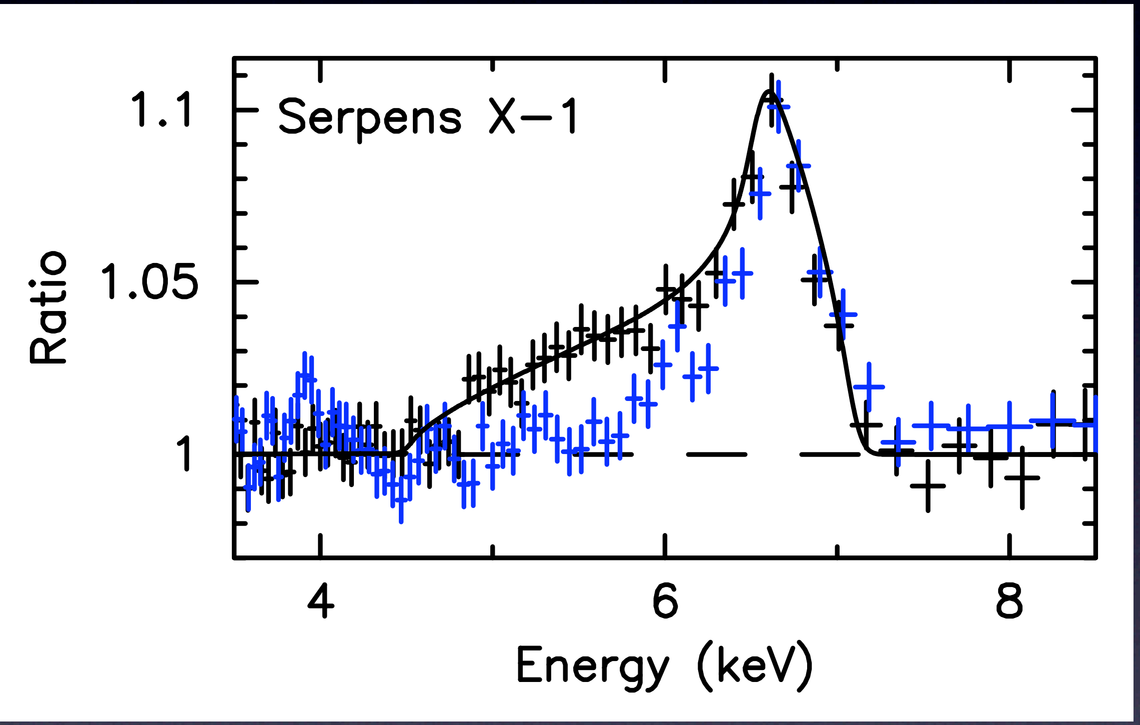


Cackett et al. (2007)

- Broad, asymmetric line revealed by Suzaku
- Well fit by a disk line model
- $R_{in} = 7.7 \pm 0.5\ R_G$ (where $R_G = GM/c^2$)
- Corresponds to 15.9 ± 1.0 km for $1.4\ M_\odot$ NS

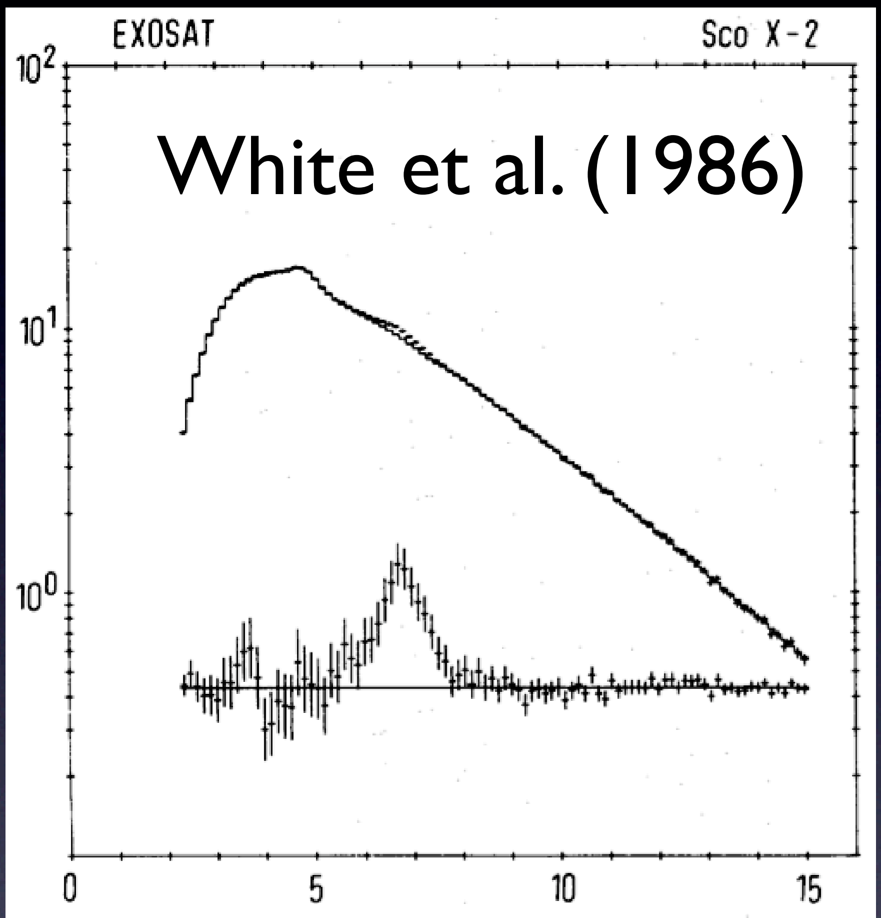
Comparison with XMM

- Asymmetric Ser X-1 line also observed by Bhattacharyya & Strohmayer (2007) with *XMM-Newton*
- Similar profile, though some evidence for variablility - needs further study

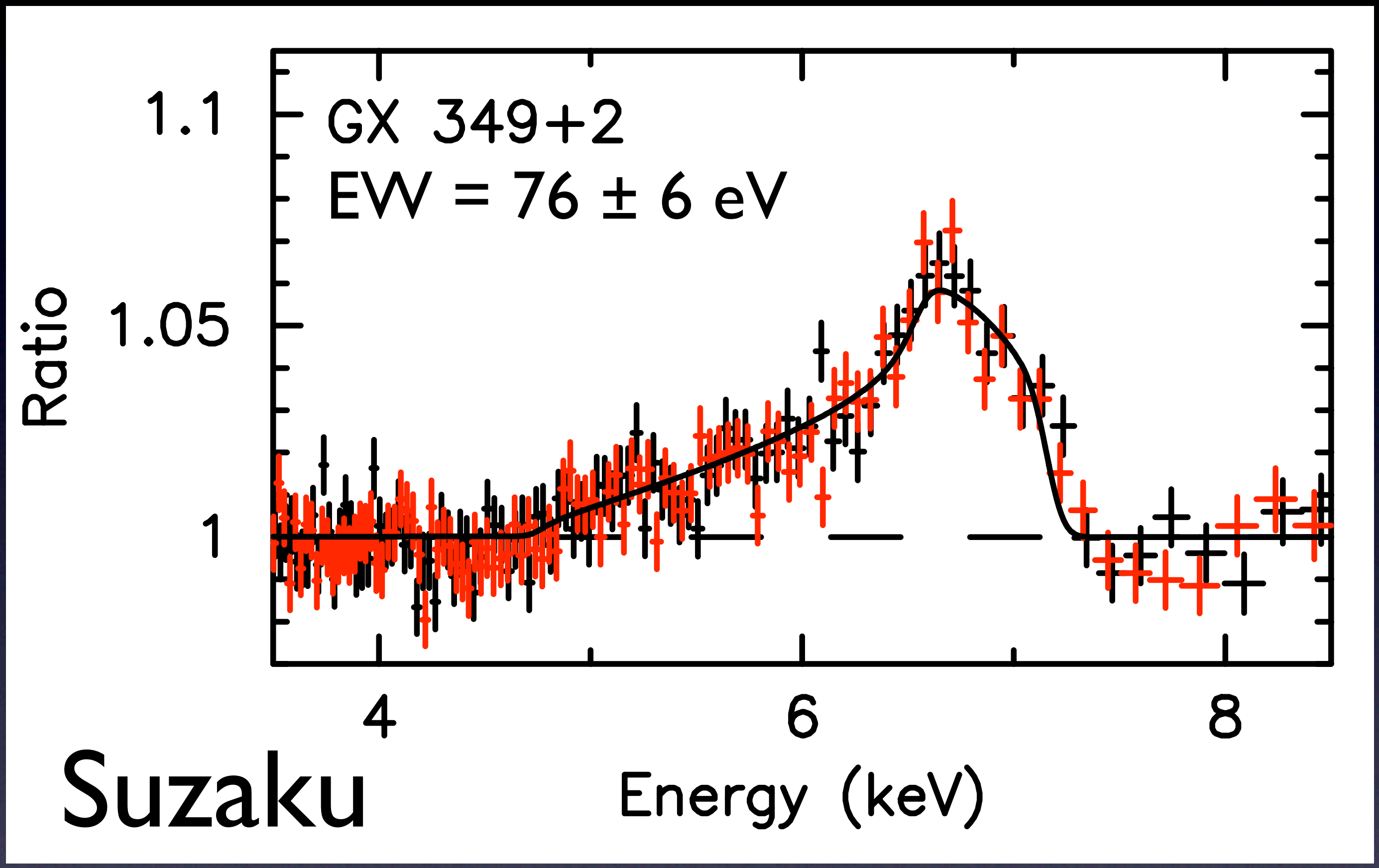


Blue - XMM
Black - Suzaku

GX 349+2 (Sco X-2)



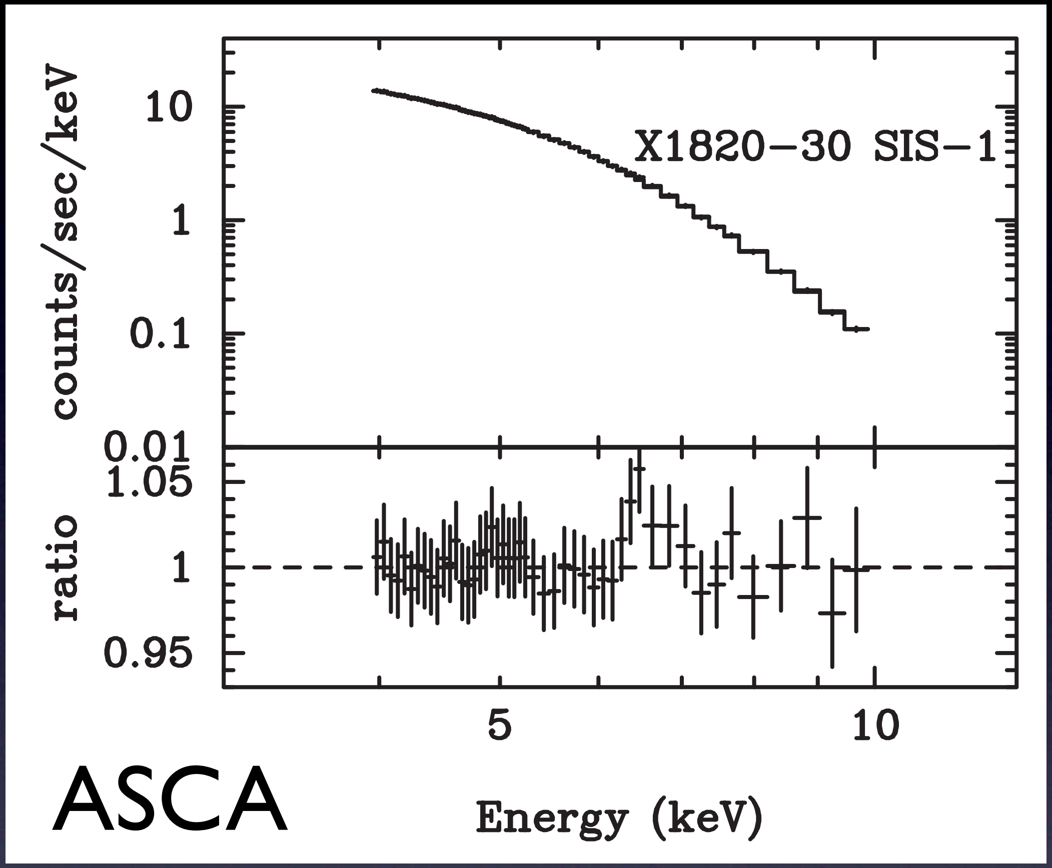
Energy (keV)



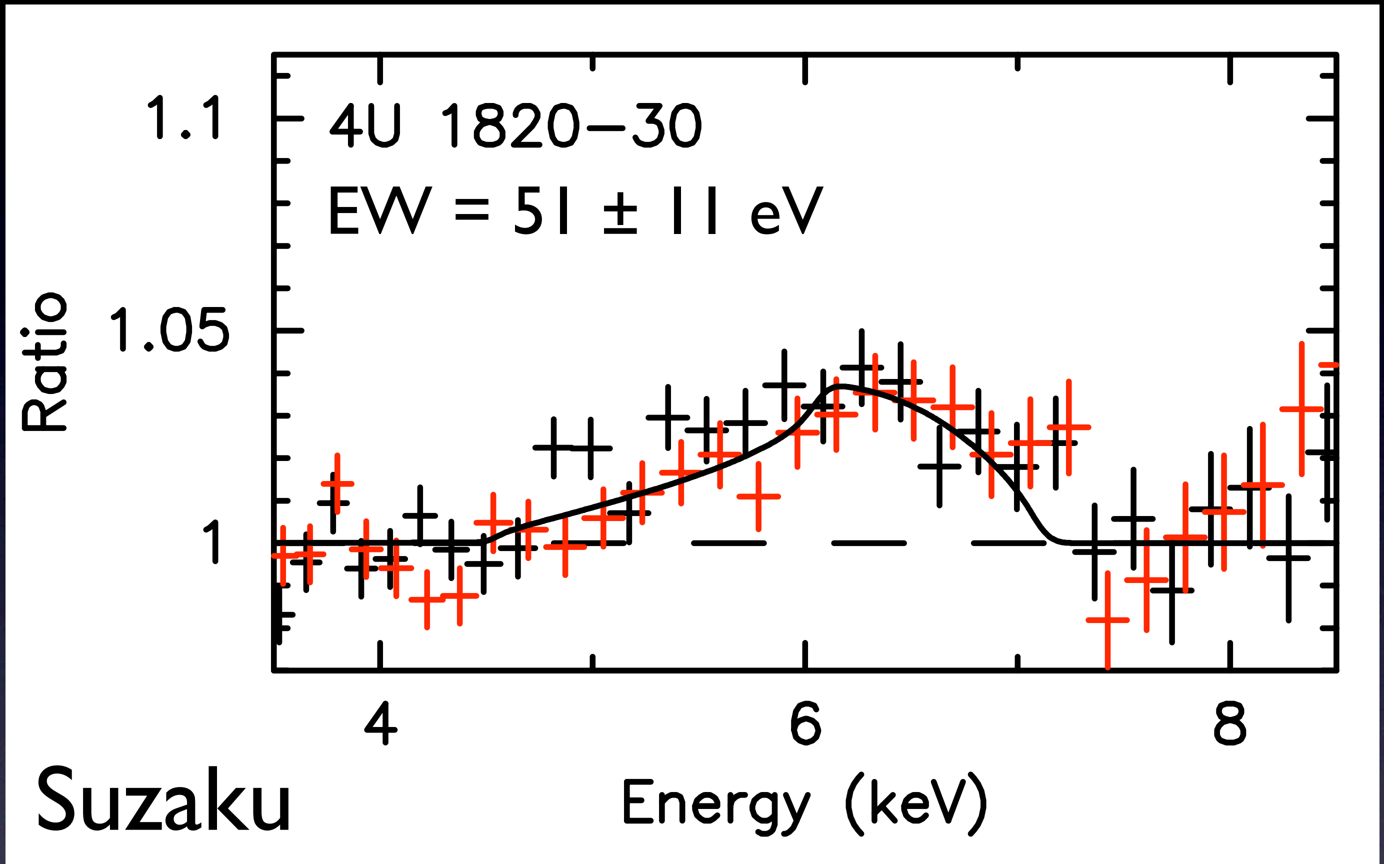
Cackett et al. (2007)

- $R_{in} = 8.0 \pm 0.4\, R_G$ (where $R_G = GM/c^2$)
- Corresponds to 16.5 ± 0.8 km for 1.4 $M_\odot$ NS

4U 1820-30



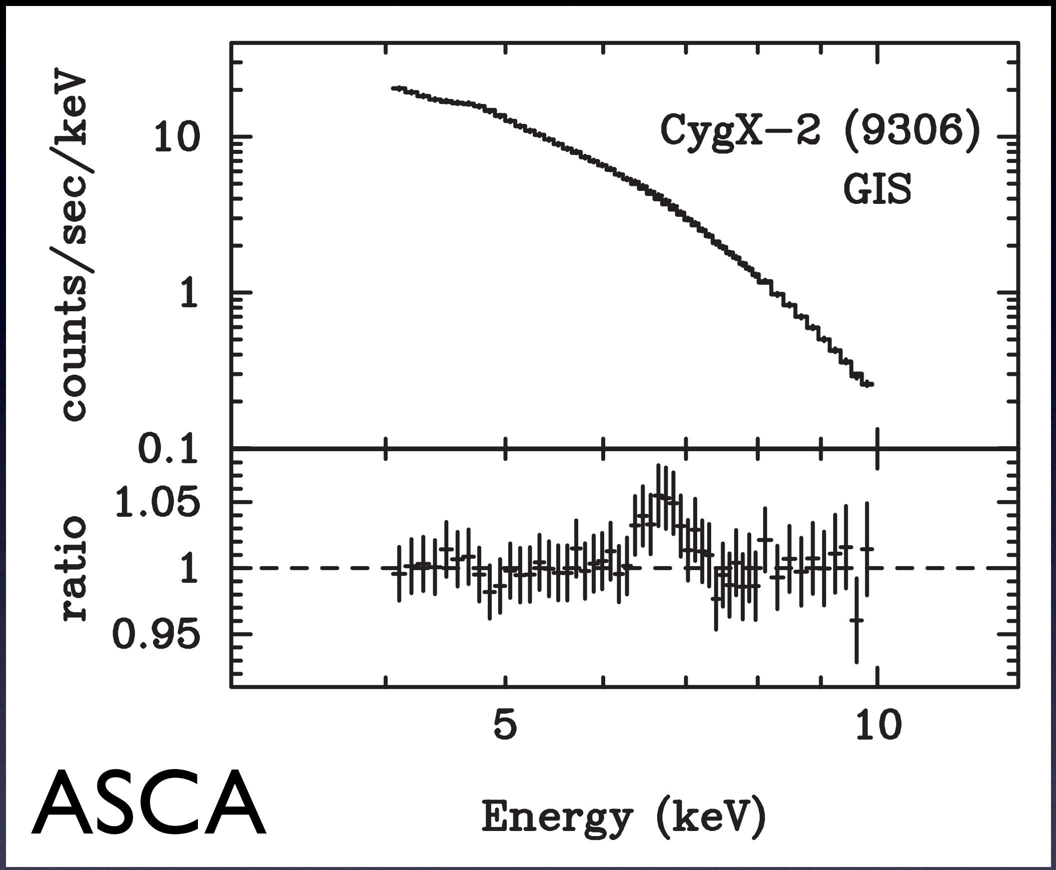
Asai et al. (2000)

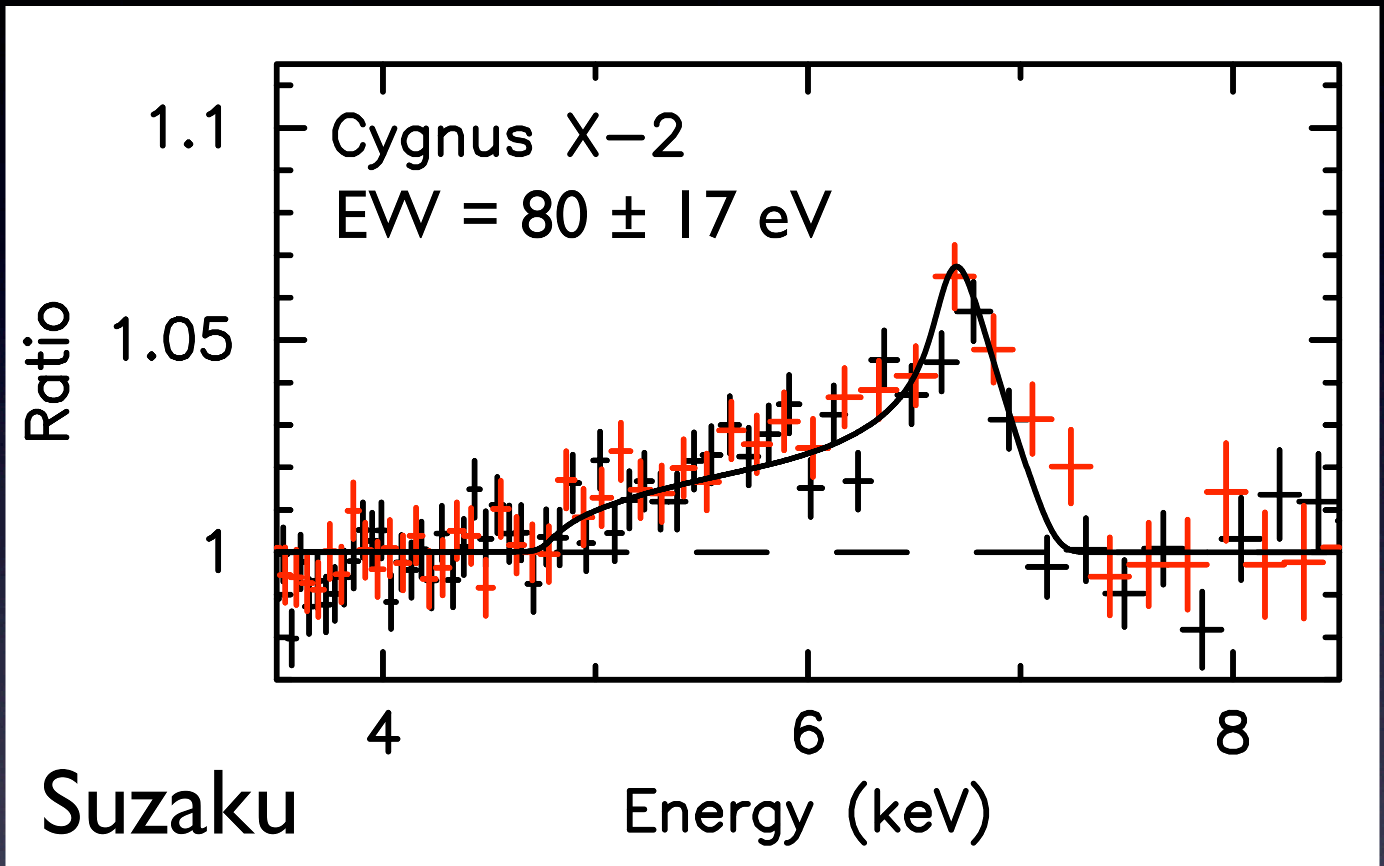


Cackett et al. (2007)

- Line weaker, though still a 7.5σ detection
- Profile broad, though shape not well defined
- $R_{in} = 6.7^{+1.4}_{-0.7}\ R_G$ (where $R_G = GM/c^2$)
- Corresponds to $13.8^{+2.9}_{-1.4}$ km for 1.4 $M_\odot$ NS

Cygnus X-2



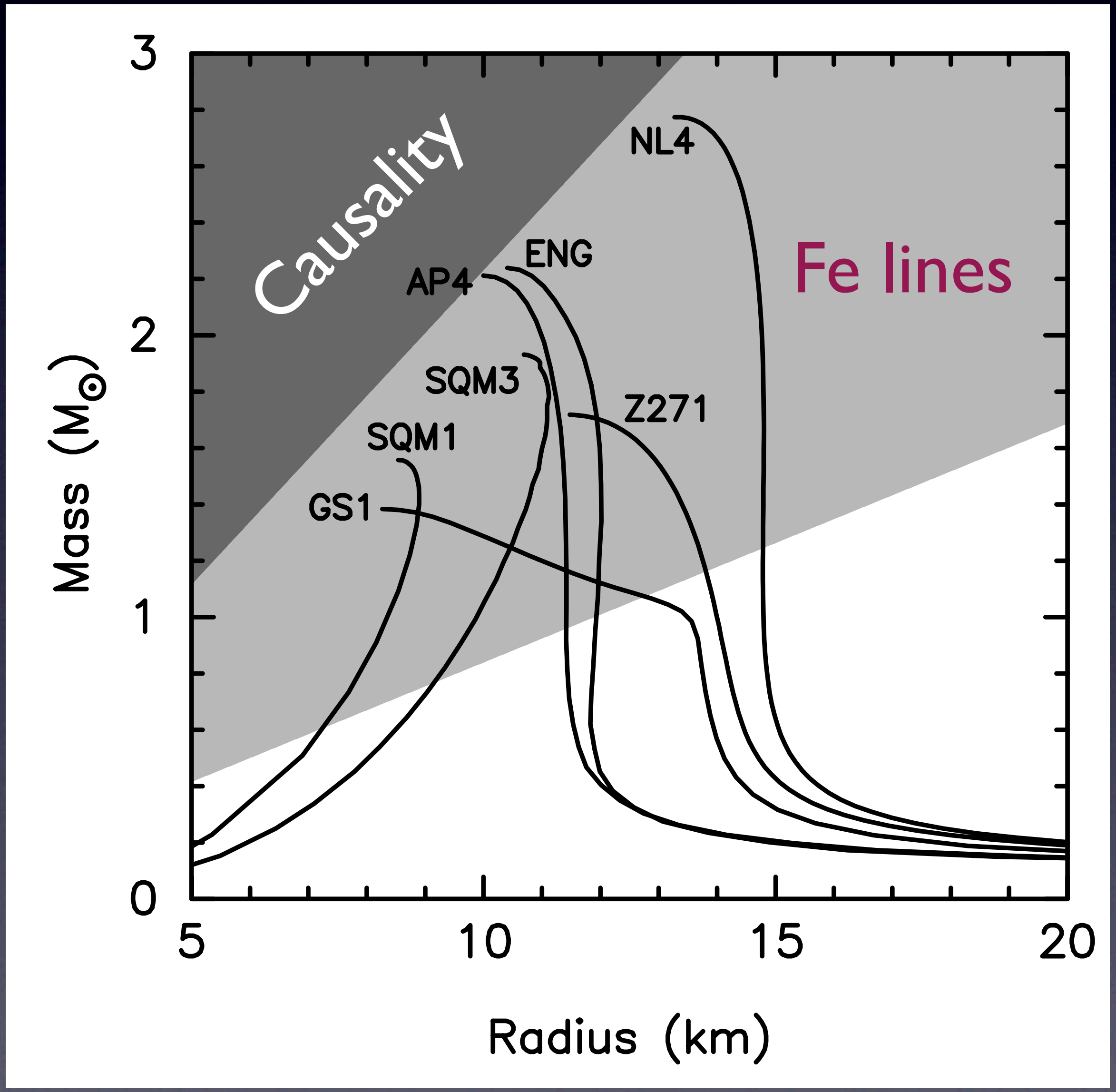


Asai et al. (2000)

- R_{in} = 8.4 ± 0.9 R_G (where $R_G = GM/c^2$)
- Corresponds to 17.3 ± 1.9 km for 1.4 $M_\odot$ NS

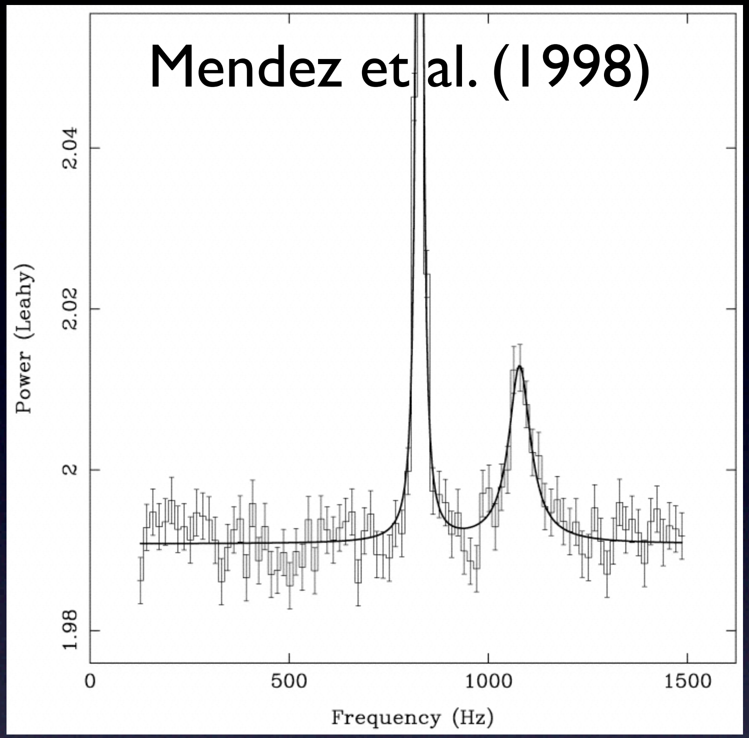
Equation of state constraints from iron lines

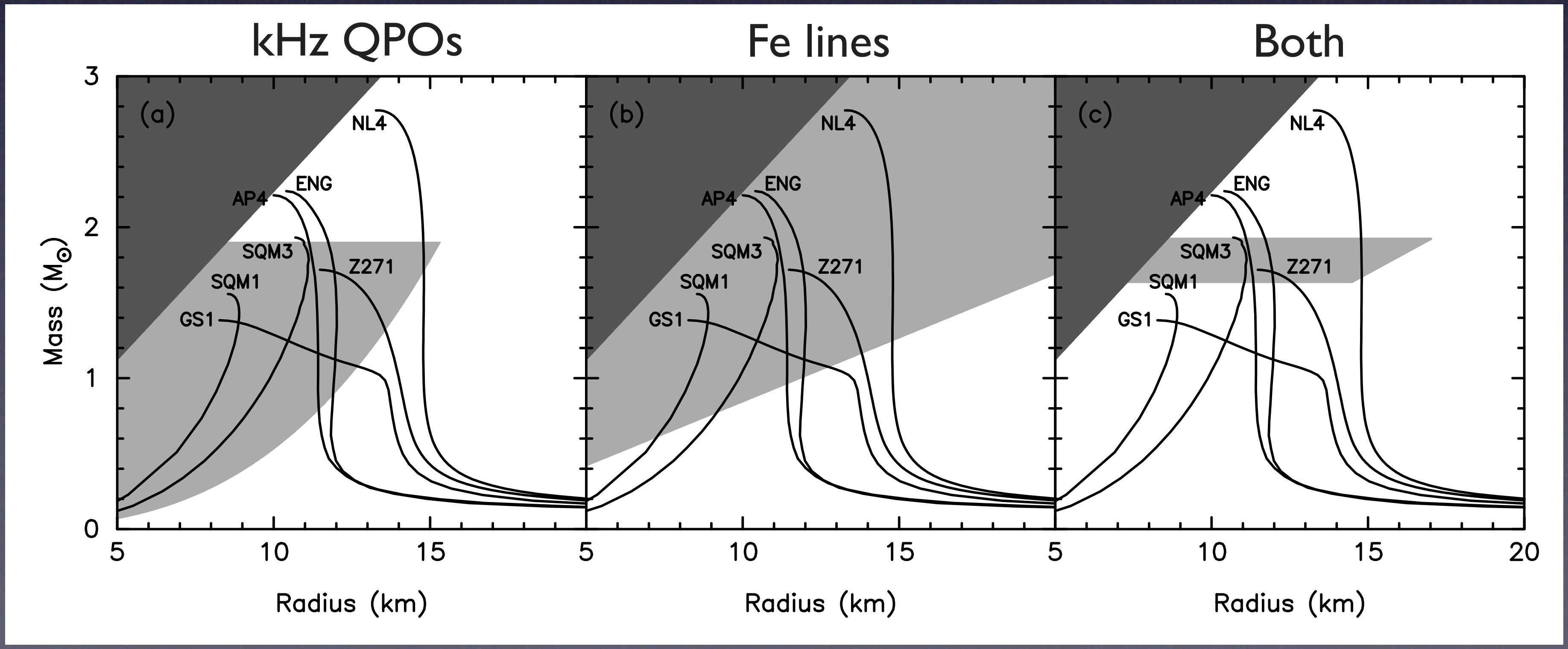
- Observations do not rule out any EoS
- Can combine with kHz QPOs……



Getting NS mass using kHz QPOs

- If upper kHz QPO is orbital frequency then $\nu \sim (GM/R^3)^{1/2}$
- We get velocity in disk from iron lines: $v = (GM/R)^{1/2}$
- Combining both we can measure NS mass: $M = v^3 / 2\pi G\nu$



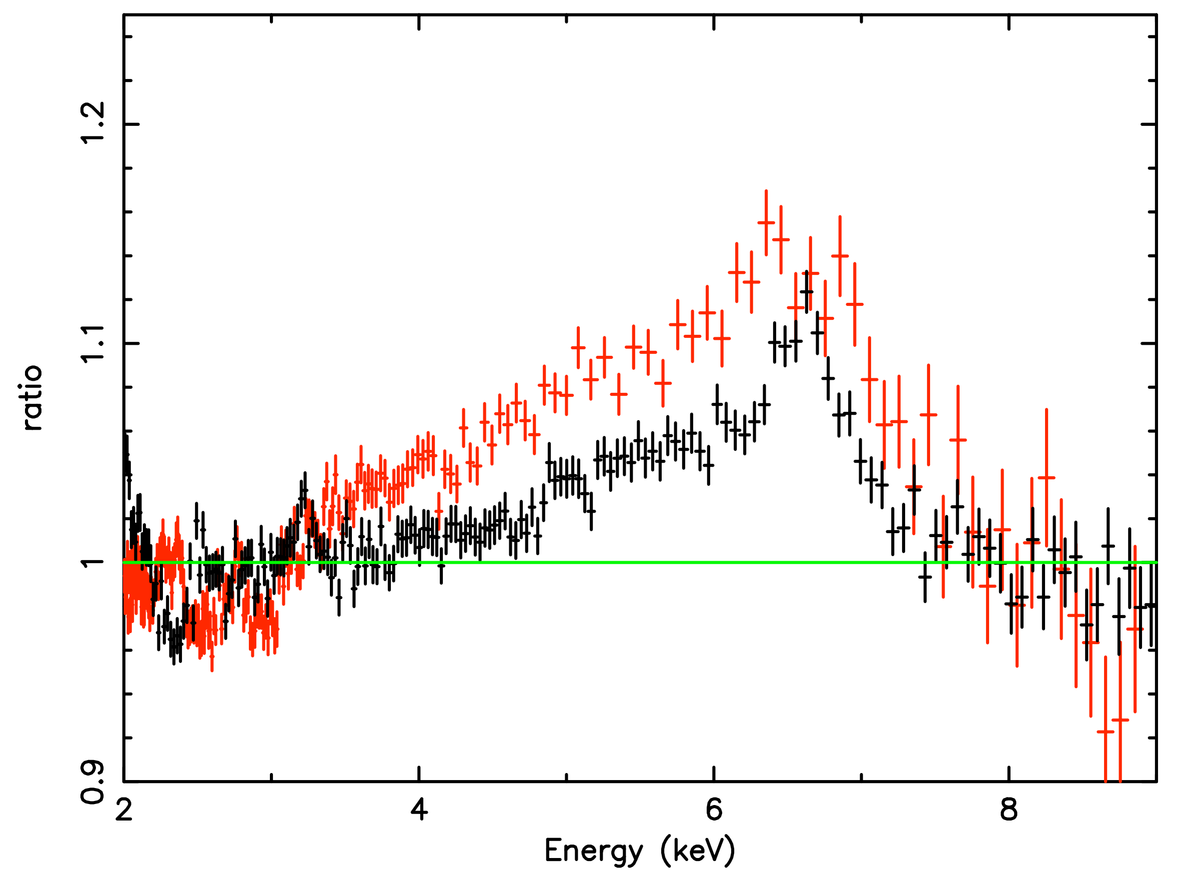


kHz QPOs and iron lines

- Would need simultaneous observations to test this
- But, GX 349+2, 4U 1820+30 and Cyg X-2 all have kHz QPOs
- Make crude comparison - find general agreement with radii
- Cyg X-2 has known mass from optical obs.
  - ★ *can test origin of kHz QPOs*

Comparison with black holes

- NS lines *narrower* than the most extreme BH lines - in NS, R_{in} is greater than ISCO for Schwarzschild metric
- Doesn't contradict use of BH lines for measuring spin



Black hole: Red - GX339-4 (XMM)
Neutron star: Black - Ser X-1 (Suzaku)

Conclusions

- Broad, asymmetric iron lines revealed in 4 neutron star X-ray binaries
- Inner disk radius measured
  - upper limit on NS radius
  - disk extends almost to NS surface (boundary layer small)
- Test for kHz QPO origin and method for measuring NS mass
- Can we follow the evolution of the disk in NS transients using iron lines?