Iron Lines in Neutron Star Low-Mass X-ray Binaries

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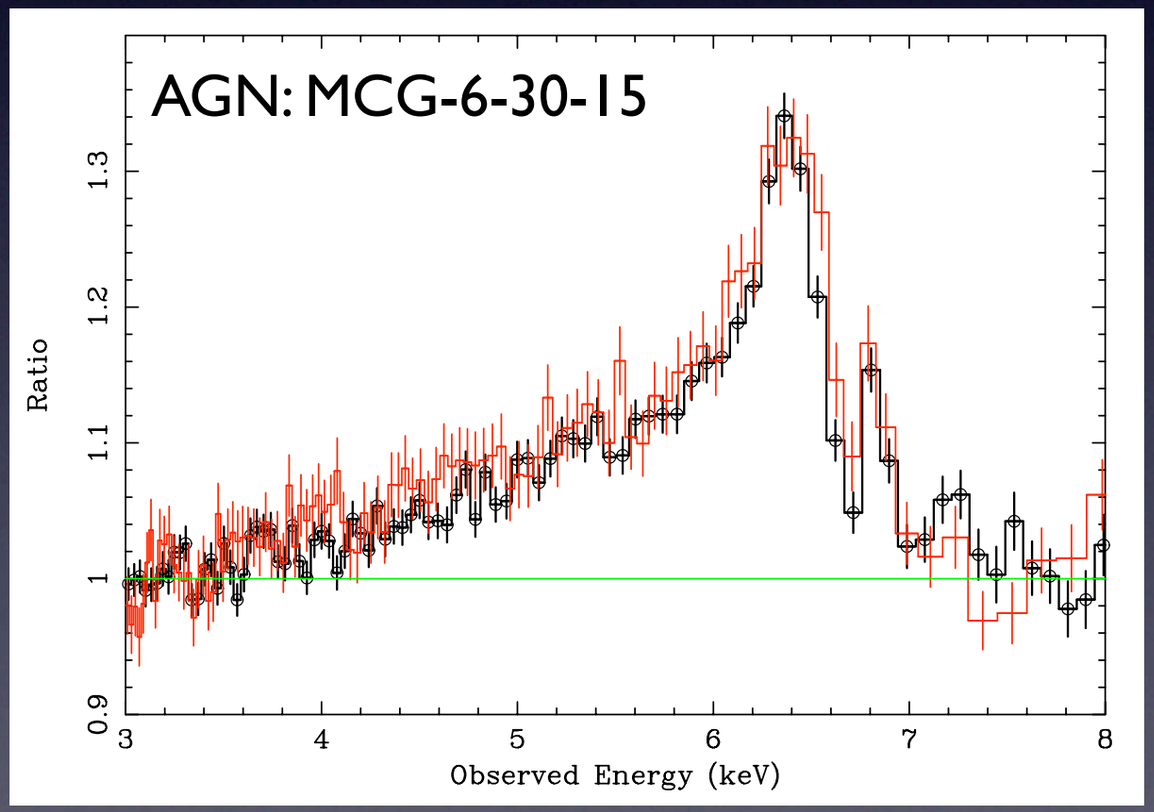
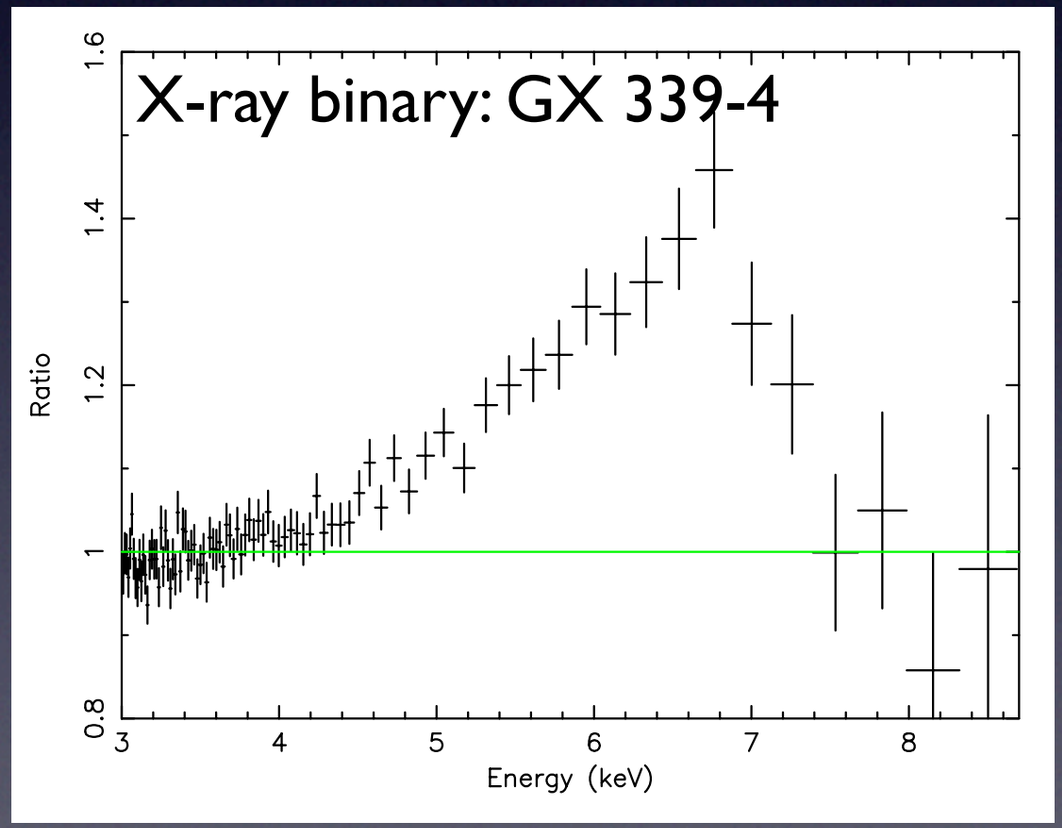
Iron lines in black hole systems

- 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
Miniutti et al. (2007)



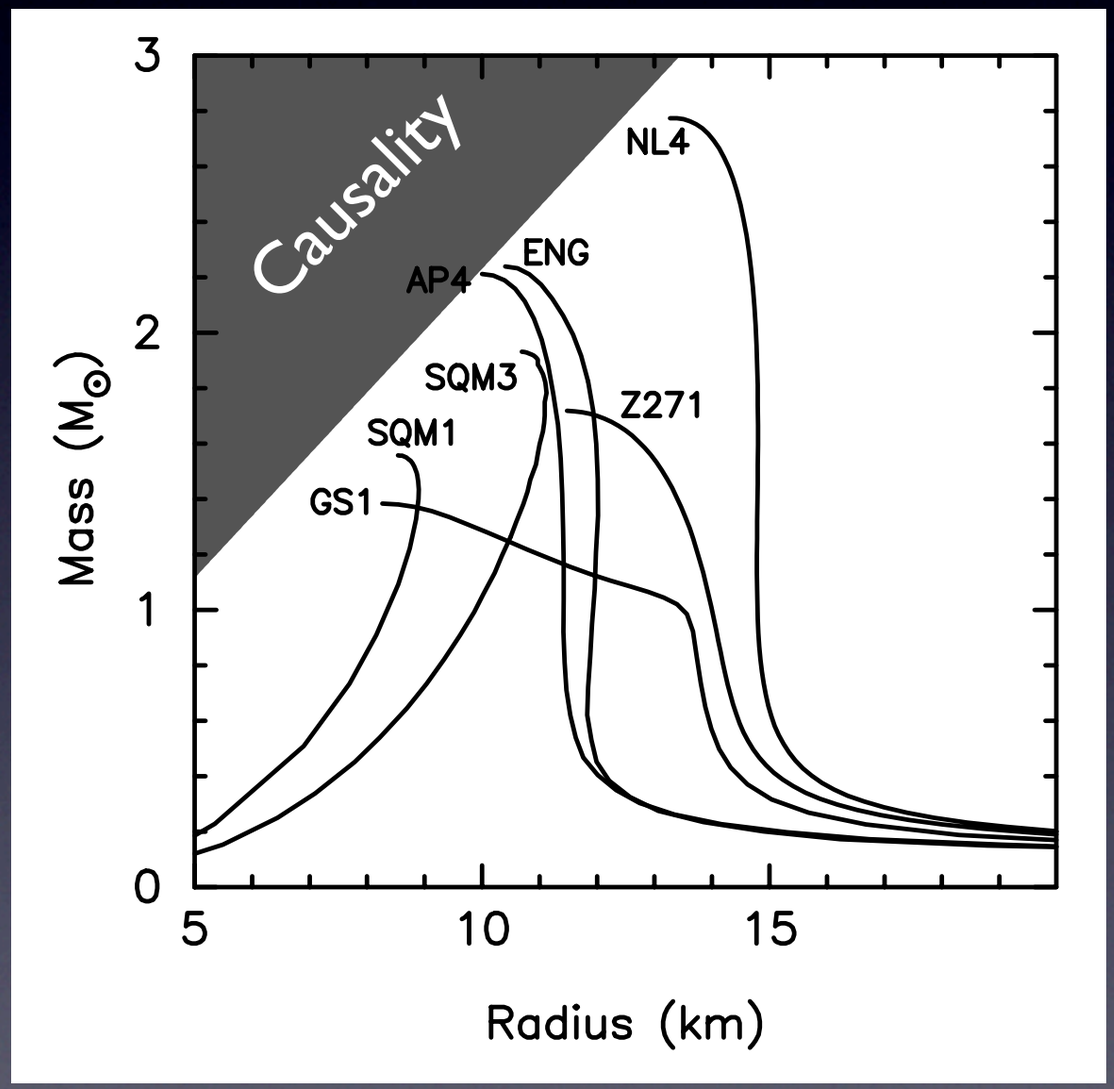
EW = 600 ± 150 eV
Miniutti et al. (2004)

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?
- Continuum spectroscopy is tough as models are degenerate (e.g. Lin, Remillard & Homan 2007)

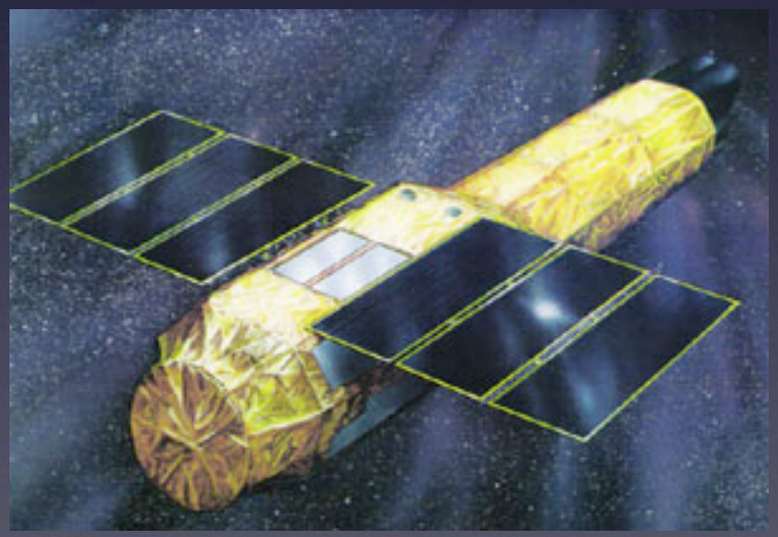
Neutron star equation of state

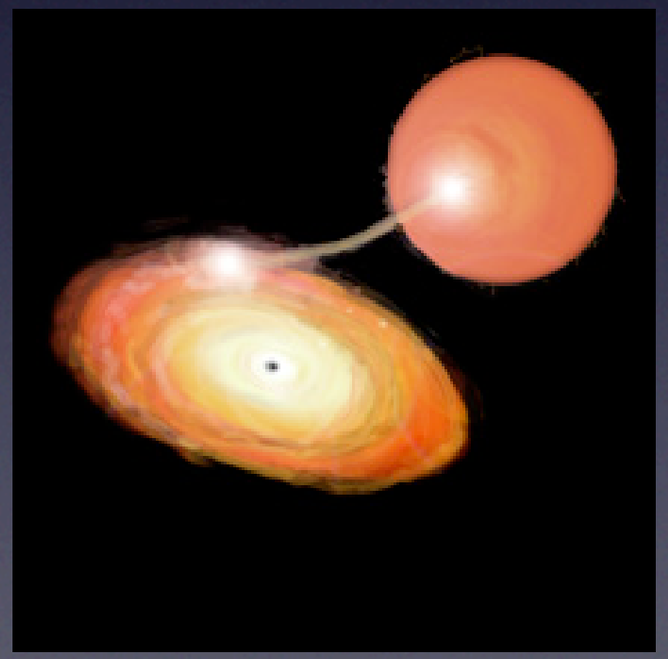
- Nature of ultra-dense matter in neutron star cores still uncertain
- We need accurate measures of neutron star *radius* and/or *mass* to discriminate



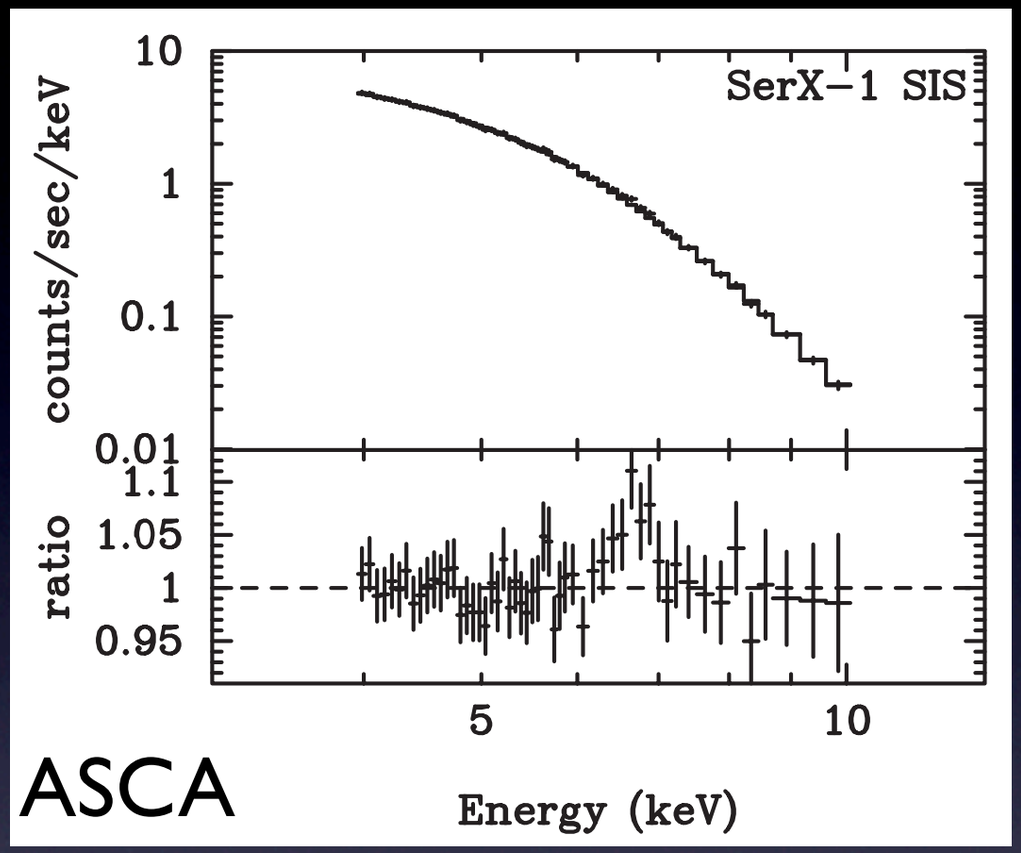
Suzaku Observations

- Broadband energy coverage and ability to observe high count rates efficiently - excellent for observing iron lines in NSs

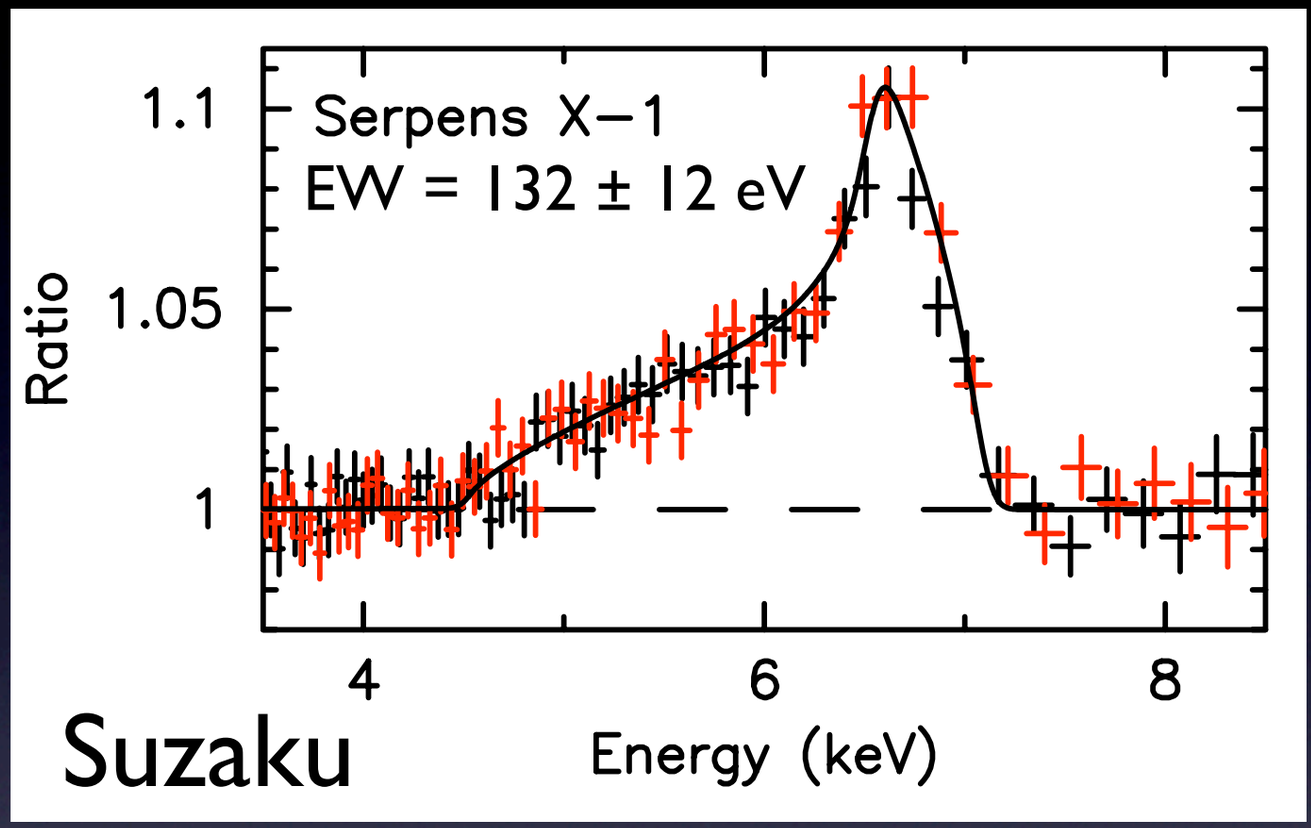




Serpens X-1



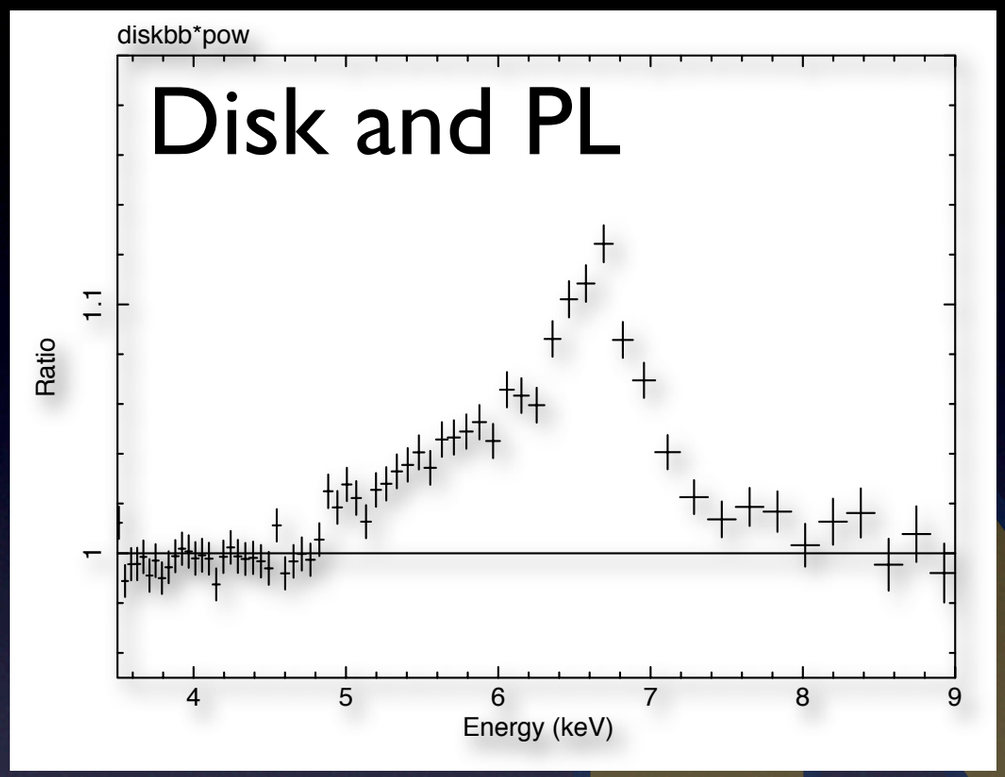
Asai et al. (2000)

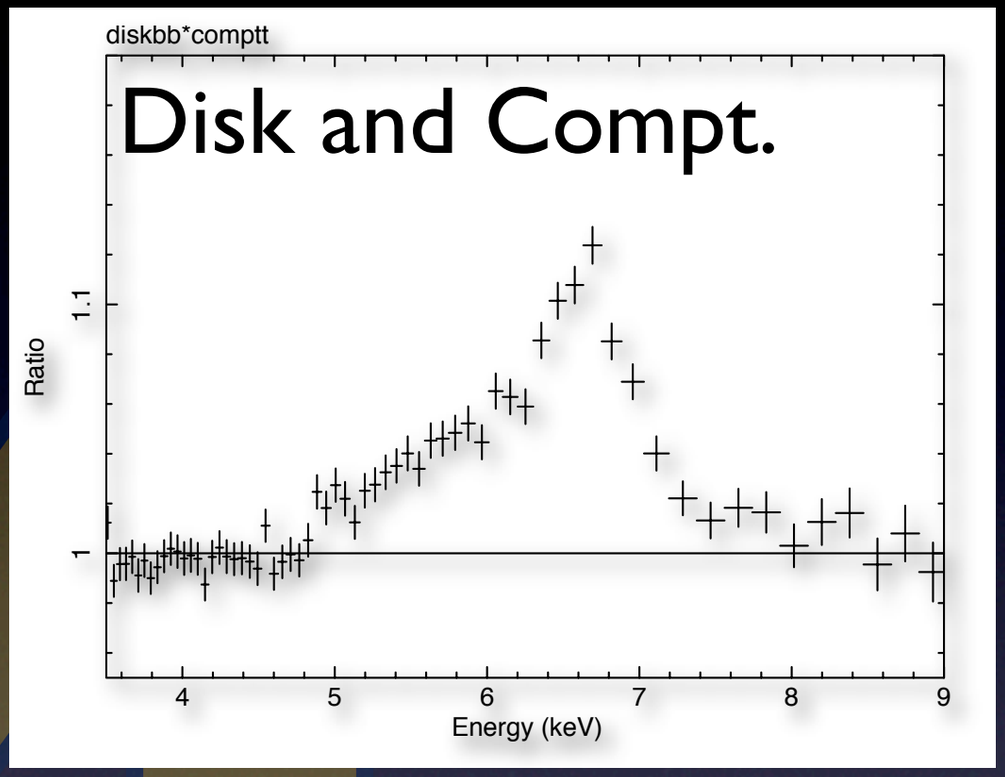


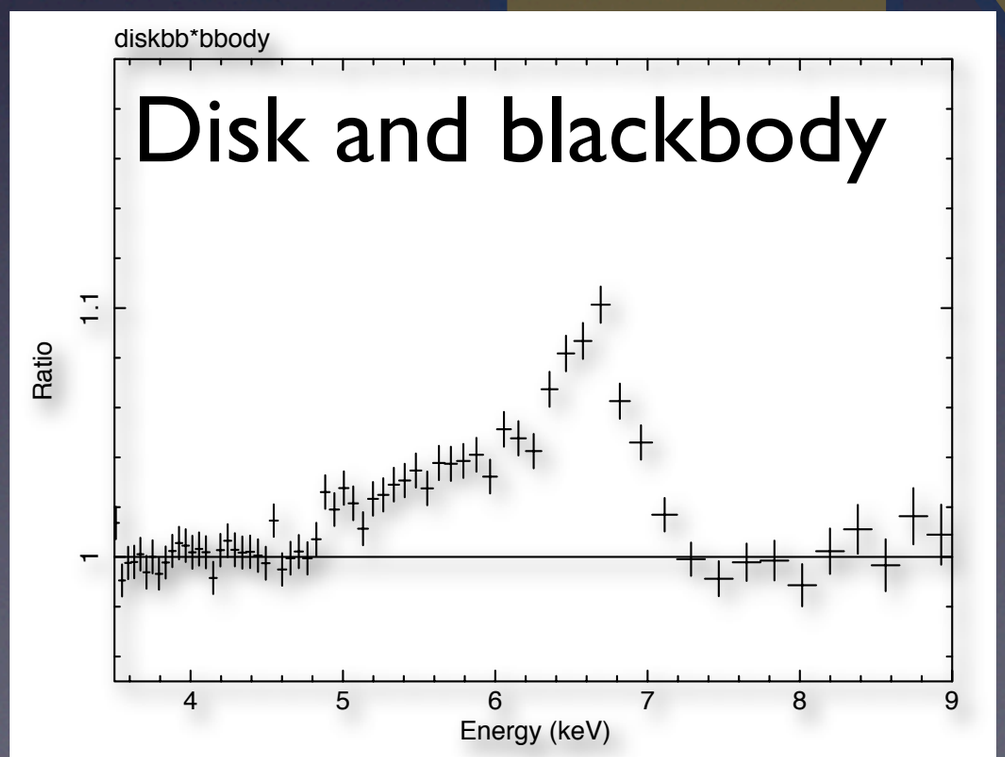
Cackett et al. (2008)

- Broad, asymmetric line revealed
- Well fit by a disk line model
- R_{in} = 7.7 ± 0.5 R_G (where R_G= GM/c^2)
- Corresponds to 15.9 ± 1.0 km for 1.4 $M_\odot$ NS
- Line also seen with XMM by Bhattacharyya & Strohmayer (2007)

Robustness of line profile

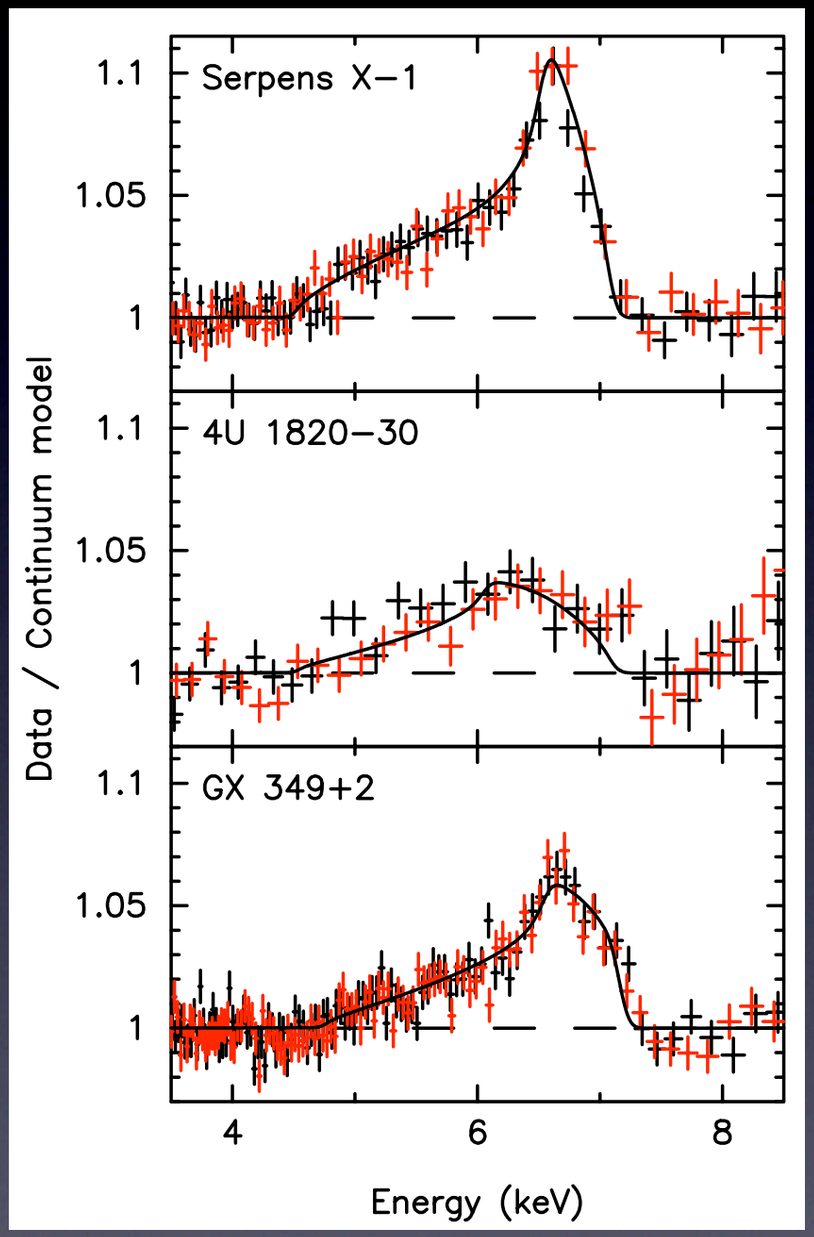




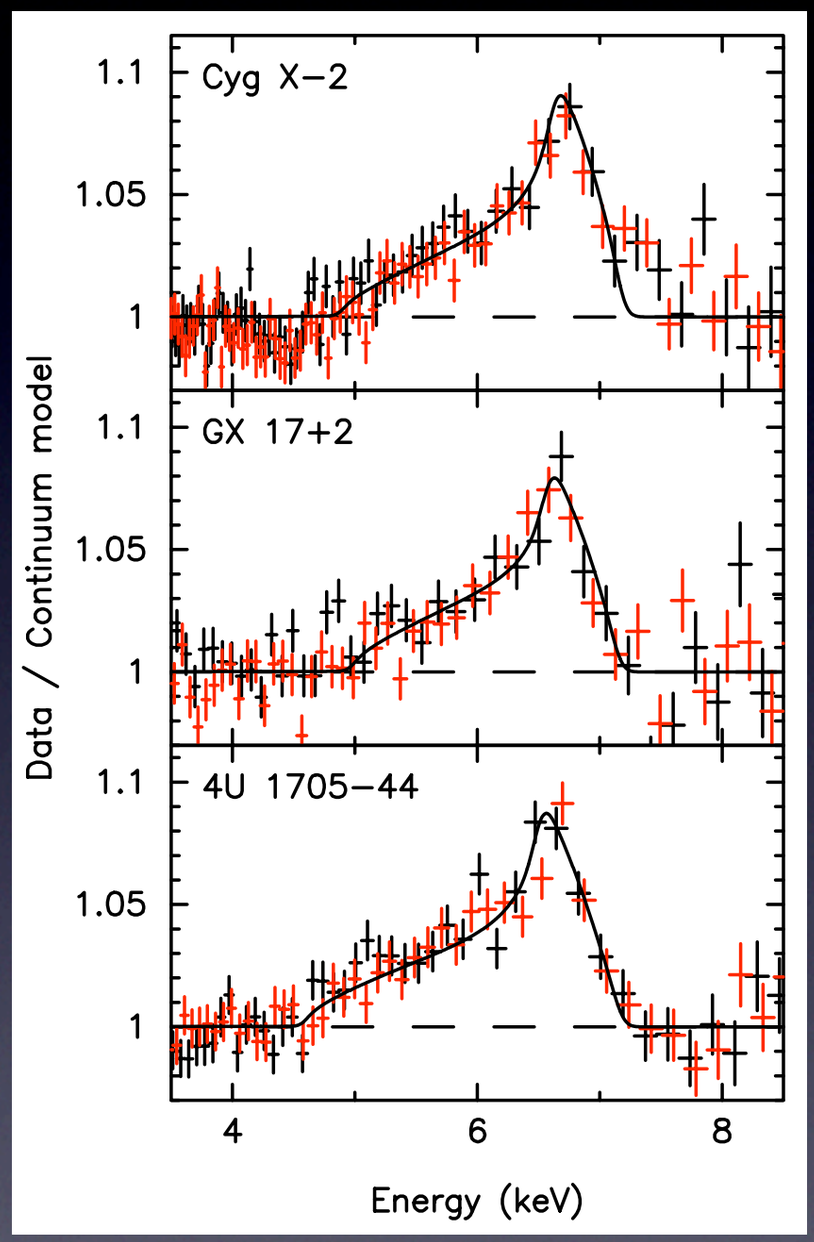


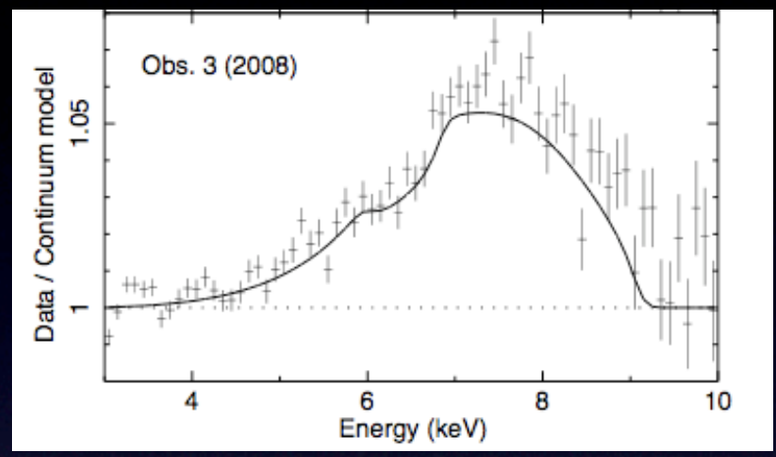
- Line profile virtually unchanged with different continuum models
- R_{in} consistent

Compilation of NS iron lines



Cackett et al. (2008)



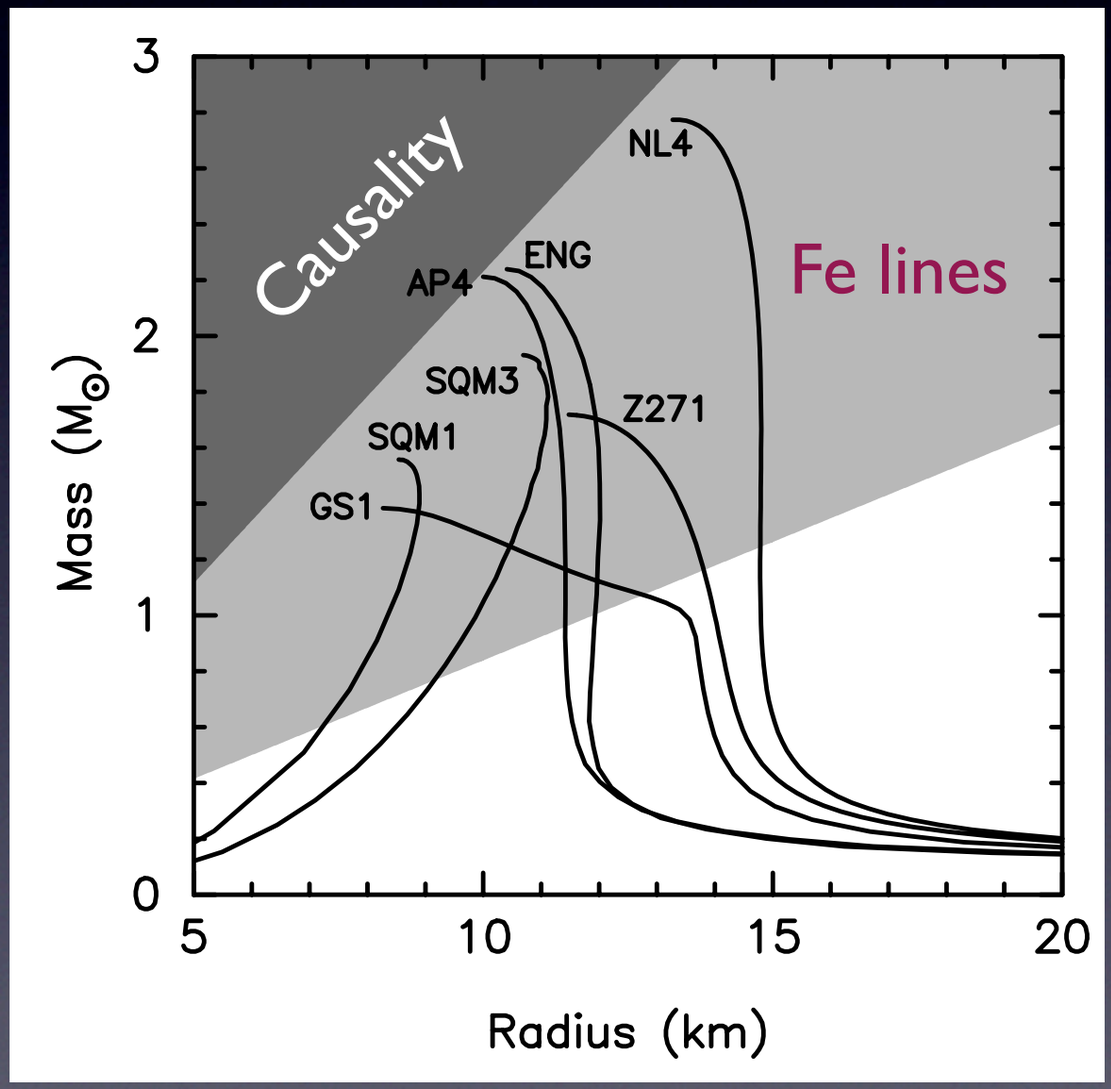


4U 1636-523: Pandel+ (2008)

- R_{in}: 6.7 - 8.8 GM/c^2 from these objects (4U 1636 may be larger)
- 13.8 - 18.1 km assuming 1.4 $M_\odot$

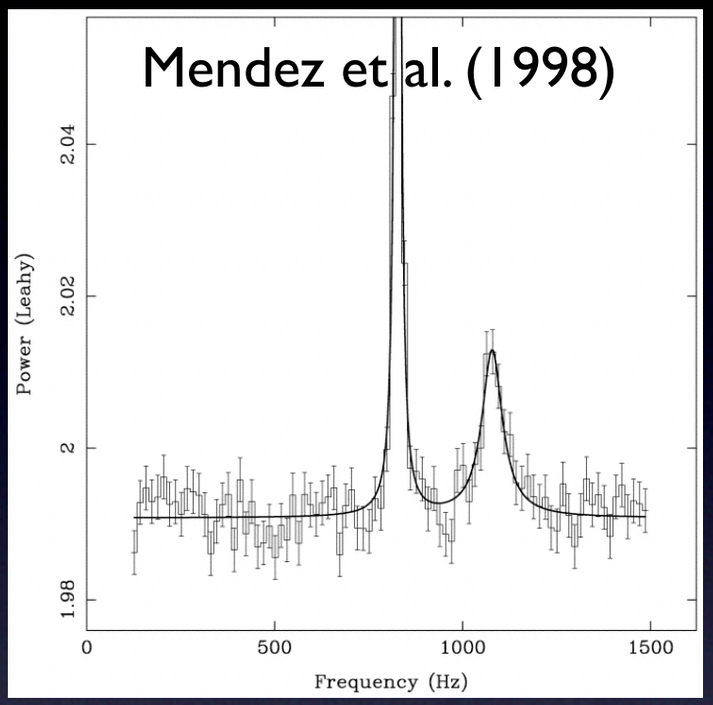
Equation of state constraints from iron lines

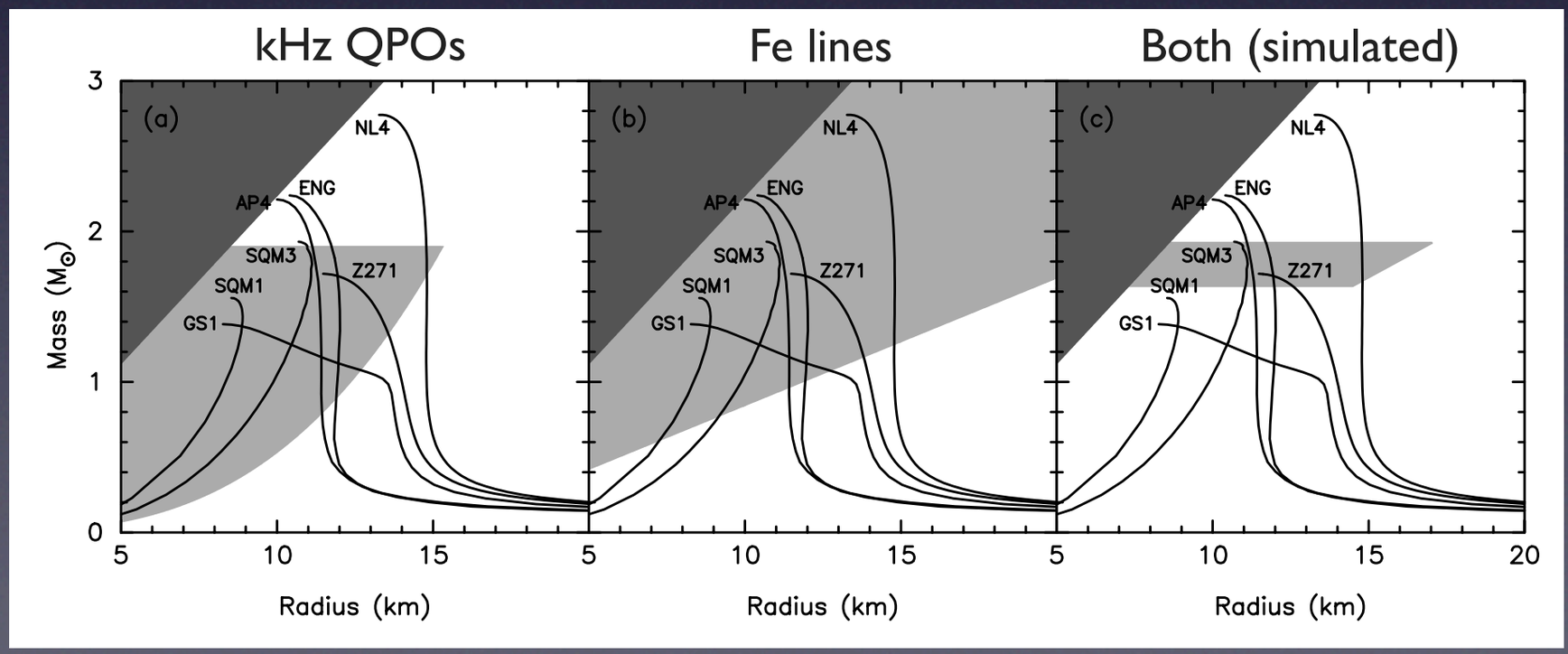
- Observations do not rule out any EoS
- Need some extra info.....
- Can combine with Quasi-Periodic Oscillations (QPOs)



Getting NS mass using kHz QPOs

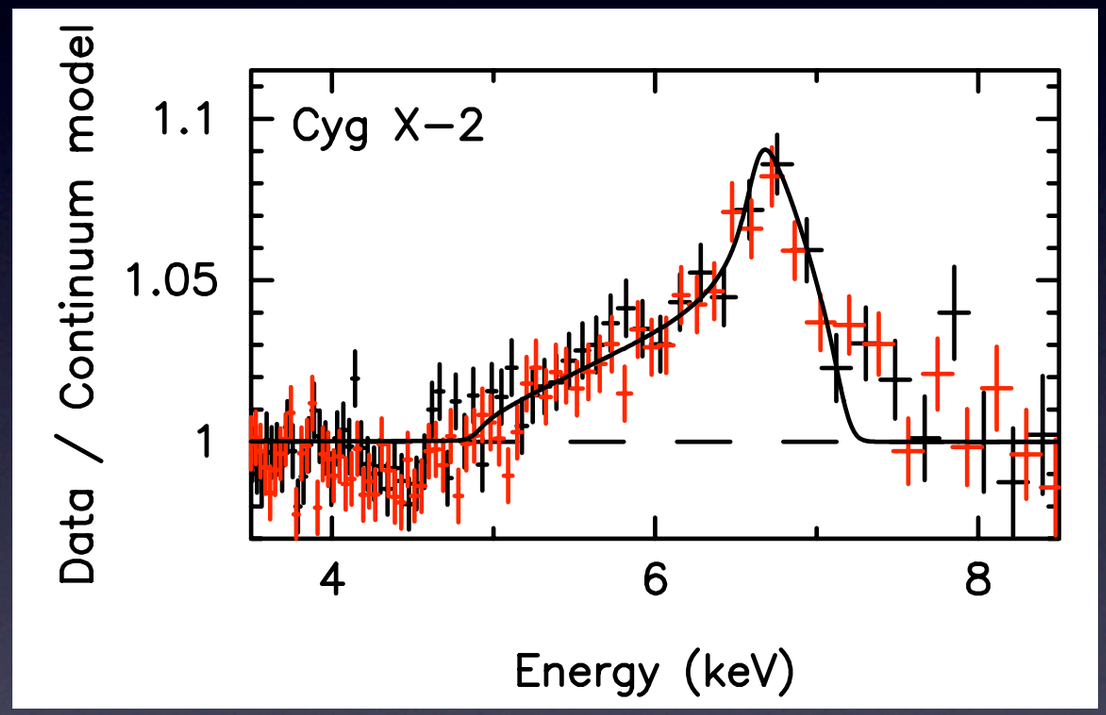
- If upper kHz QPO is orbital frequency then $\nu \sim (GM/R^3)^{1/2}$
- We get velocity in disk from iron lines: $v = (GM/R)^{1/2}$
- Combining both we can measure NS mass: $M = \nu^3 / 2\pi G v$





Cyg X-2: kHz QPOs and iron lines

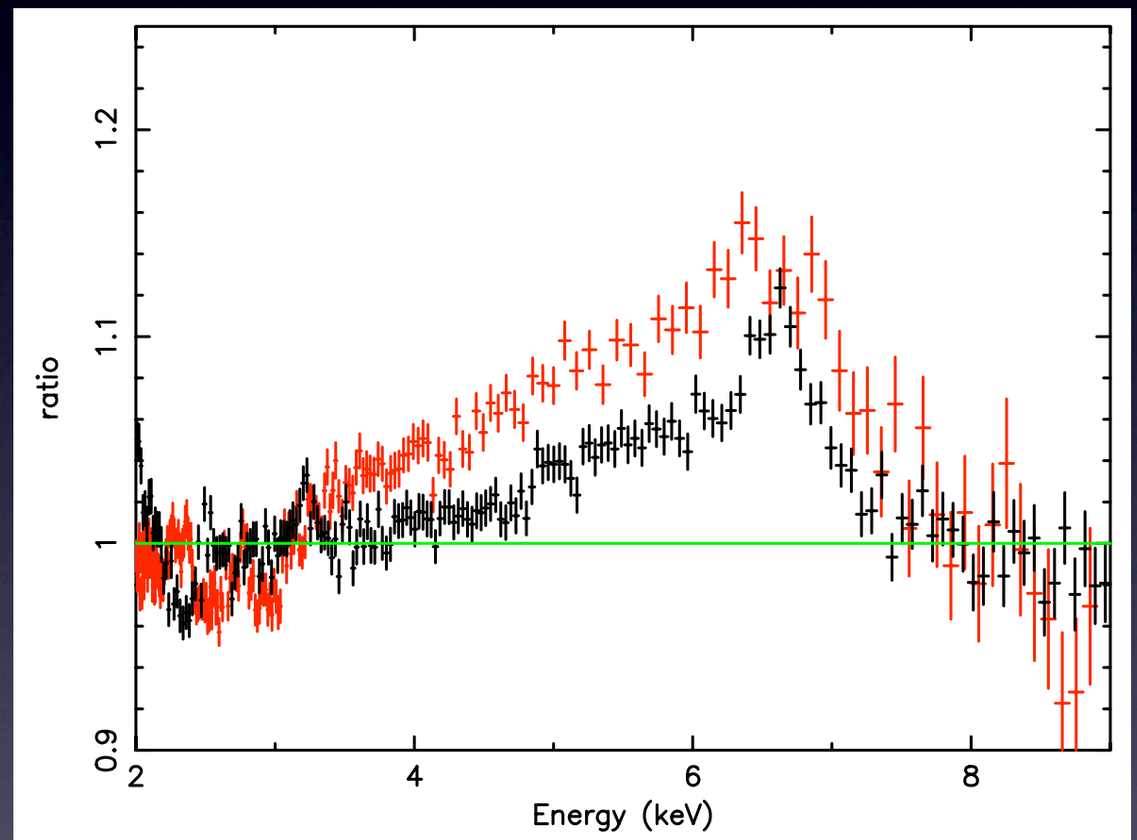
- Need simultaneous observations to test this
- Cyg X-2 has known mass: 1.78 ± 0.23 $M_\odot$ (Orozs & Kuulkers 1999)
- 100 ks *Suzaku* observation with some simultaneous RXTE coverage - unfortunately, no kHz QPOs
- But, using lit. value for upper kHz QPO get: 1.3 ± 0.2 $M_\odot$



$R_{in} = 8.6 \pm 0.7\ GM/c^2$

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 seen in 7 neutron star X-ray binaries - **every** system observed by *Suzaku* or sensitive *XMM* observations
- 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 as NS change state using iron lines?