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

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Chandra Fellows Symposium 2008

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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  
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?
- 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)

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

Cackett et al. (2008)

EW = 132 ± 12 eV
Robustness of line profile

- Line profile virtually unchanged with different continuum models
- $R_{\text{in}}$ consistent
Compilation of NS iron lines

- \( R_{\text{in}}: 6.7 - 8.8 \text{ GM/c}^2 \) 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: $\nu = (GM/R)^{1/2}$

- Combining both we can measure NS mass: $M = \nu^3 / 2\pi G\nu$

Mendez et al. (1998)
Cyg X-2: kHz QPOs and iron lines

- Need simultaneous observations to test this
- Cyg X-2 has known mass: $1.78 \pm 0.23 \, M_\odot$ (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: $1.3 \pm 0.2 \, M_\odot$

\[ R_{\text{in}} = 8.6 \pm 0.7 \, \text{GM/c}^2 \]
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?