Simultaneous spectral and timing features in the UCXB 4U 0614+091

Oliwia Madej, Peter Jonker

collaboration: Paul Groot, Randy Ross
Ultra-compact X-ray binaries

- subclass of Low Mass X-ray binaries
- orbital period: less than 80 minutes
- neutron star or black hole + white dwarf

4U 0614+091

- orbital period: 51.3 min (Shahbaz et al. 2008)
- neutron star (type I X-ray bursts, Kuulkers et al. 2010)
- donor: CO or ONe white dwarf (Nelemans et al. 2006)
- neutron star spin: 414.7 Hz (Strohmayer et al. 2008)
- relativistically broadened O VIII Lyα line (Madej et al. 2010, in press)
- high frequency quasi-periodic oscillations (QPOs, Boutelier et al. 2009)
constraining Mass and Radius of the neutron star

**X-ray spectroscopy**

- relativistically broadened O VIII Lyα line

\[ R \ [\text{GM}/c^2] \]

Madej et al. 2010
constraining **Mass and Radius** of the neutron star

**X-ray timing**
- kHz quasi-periodic oscillations

(upper kHz QPO reflects motion in Keplerian orbit)

\[ M = (2\pi f)^2 G^{-1} R^3 \]

**optical spectroscopy**
- time resolved spectroscopy
- from mass function: \( M \sin^3 i \)

van Straaten et al. 2000
Broad band spectrum: XMM-Newton + RXTE

- broad features at $\sim 0.7$ keV ($\text{O VIII Ly}\alpha$)
- $\sim 6.4$ (Fe K$\alpha$ ?)

$\chi^2 = 1.42$ (3427 dof)
$\chi^2 = 1.17$ (3421 dof)
Broad band spectrum: XMM-Newton + RXTE

abs*(power-law+bbody+reflionx)

reflionx (Ross & Fabian 2005) takes into account Compton scattering

disk overabundant with oxygen but
abundance of oxygen in the model solar (Lodders 2003)
X-ray spectra

reflection spectrum + diskline profile

$R_{\text{out}} = 1000 \text{ GM/c}^2$

$i \sim 60 \text{ deg}$

- low S/N
- need for better reflection model
Quasi-periodic oscillations in 4U 0614+091

- Max kHz QPO observed: $f = 1224$ Hz
  - at ISCO=6GM/c$^2$
- Upper limit on the mass $M < 1.8M_{\odot}$
- $\Delta f = 320$ Hz (Boutelier et al. 2009)

- If observed QPO upper one
  - 500 Hz & $1.8M_{\odot} \Rightarrow 11$ GM/c$^2$
- If observed QPO lower one
  - 500+320 Hz & $1.8M_{\odot} \Rightarrow 8$ GM/c$^2$

Boutelier et al. 2009
Optical spectra

- $M \sin^3 i$
- $M_{ns} = 1.8 M_{\text{Sun}} \Rightarrow i \sim 14 \text{ deg}$

Nelemans et al. 2006

Madej et al., in prep
Conclusions

• For the first time we can apply the method to constrain the neutron star mass and radius using kHz QPOs as a ‘new tool’ - relativistically broadened O VIII Lyα line.

• The data were not of sufficient quality yet to draw secure conclusions about the mass and the radius of the neutron star.

• The target: 4U 0614+091 is a very good candidate to apply the described method and provide valuable information about structure of the neutron stars.
X-ray spectra

- R$_{\text{out}}$ = 1000 GM/c$^2$
- GR effects weak but Doppler effect still strong

Laor profile
- R$_{\text{in}}$ = 3±0.2 GM/c$^2$
- Spin correction of 1%

Diskline profile
- R$_{\text{in}}$ pegs at 6 GM/c$^2$
- i=(70,90) deg

R$_{\text{out}}$ ~ 1e5 GM/c$^2$

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Diskline profile
- R$_{\text{in}}$ pegs at 6 GM/c$^2$
- i=(70,90) deg

R$_{\text{out}}$ ~ 1e5 GM/c$^2$

- at R$_{\text{out}}$=1000 GM/c$^2$ GR effects weak but Doppler effect still strong
no eclipses visible in the light curve...

twisting, warping of the disc:
1. precession in the system (Petterson 1977)
2. Irradiation by neutron star