2A 1822-371 as a Super-Eddington Source

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Collaborators: Alessandro Patruno & Caroline D'Angelo
1) The surface of the pulsar is never seen
2) Optically thin Accretion disc corona (ADC)
3) Long-term and Short-term spin up
4) Super-Eddington source ($B \sim 10^{10} G$)
5) Other sources show similarities to 2A 1822-371

Conclusion
Meet 2A 1822-371

Persistent source

LMXB

$P_b \sim 5.57 \text{ hr}$

$\dot{P}_b \sim 1.5-2.1 \times 10^{-10} \text{s}^{-1}$

$P_s \sim 0.59 \text{s}$

$\nu \sim 1.69 \text{ Hz}$

$B\text{-field} \sim 10^{10}-10^{12} \text{ G}$

$L_x \sim 10^{36} \text{ erg/s}$

$L_x / L_{\text{opt}} \sim 20$

For the magnetic field, see e.g. Sasano et al. 2014 and Iaria et al. 2015. For $\dot{P}_b$ see e.g. Burderi et al. 2010
Meet the telescope

Rossi X-ray Timing Explorer (RXTE)
Launched in 1995
Operating 1995-2012

2A 1822-371:
28 June 1998 – 30 November 2011
1) The Light curve

Eclipsed LMXB

Edge on view

50% eclipsed

Extended X-ray emitting region $\rightarrow$ wide eclipses, partially eclipsed

Heinz et al. 2001
1) The surface of the NS is never seen

Is the surface seen?
→ Fractional amplitude vs. orbital phase
→ Eclipsed vs. non-eclipsed data

No difference in eclipsed/non-eclipsed
→ Surface of NS never seen

For more details on the light curve and eclipses see e.g. Heinz & Nowak 2001 & Parmar et al. 2000
2) The Accretion Disk Corona

Edge on, inclination ~ 83°

Spectral analysis:
→ Extended x-ray emitting region
→ ADC
→ Evaporated material
→ Very opaque corona

For other discussion on ADC see e.g. White & Holt 1982 and Iaria et al. 2013. For discovery of pulsations see Jonker & van der Klis 2001.
2) The Accretion Disk Corona

Previously → ADC optically thick ($\tau \sim 10$-$20$) (post 2001)
→ Problem
  → coherent pulsations

So look at the spectra + models of spectra
→ cut-off PL, BB, compTT ...
→ cut-off at $\sim 10$keV

Iaria et al. 2015
2) The Accretion Disk Corona

Previously → ADC optically thick (τ~10-20) (post 2001)
→ Problem
  → coherent pulsations

Model:
→ BB + Power law
→ inverse compton up-scattering code (Monte Carlo)

Results:
→ Possible non opaque medium (Opt. thin)
→ ADC (τ~1) (norm rms deviation of 28%)

For other discussion on ADC see e.g. White & Holt 1982 and Iaria et al. 2013. For discovery of pulsations see Jonker & van der Klis 2001. MC Compton code see Giannios & Spruit 2004.
3) Long-term spin-up

2A 1822-371 shows spin-up over 13 years

\[ \dot{\nu} = 7.6(8) \times 10^{-12} \text{ Hz s}^{-1} \]

\( \nu \sim 1.69 \text{ Hz} \)

\( P_s \sim 0.59 \text{ s} \)

Varying residuals – short term changes?

Bak Nielsen et al. 2017
3) Short-term spin-up

- 2 data segments
- Phase connected
- Length of 8-10 days
  ~ 1-11 July 2001
  ~ 2-9 August 2002

\[ \dot{\nu} = 6.7(4) \times 10^{-12} \text{ Hz s}^{-1} \]
\[ \dot{\nu} = 8.2(5) \times 10^{-12} \text{ Hz s}^{-1} \]

Figure shows 1-11 July 2001 data

Bak Nielsen et al. 2017
Possible torque reversal system
4U 1626-67
→ spin 7.66s
→ Spin freq. 0.13 Hz
→ $P_b \sim 0.69$ hr

Spin up over 13 years
Spin down over 18 years
40 years of observation

Show same spin up/down time in both states $\rightarrow 5000$ yrs

Torque reversal for 2A 1822-371?

Chakrabarty et al. 1997
The Super Eddington Source
4) A Super-Eddington source

Weakness of model

→ Needs Eddington limited accretion
→ Orbital period evolution not explained by conservative mass transfer
→ $\dot{P}_b$ possibly due to huge mass loss
→ Or donor star out of thermal equilibrium

→ $\dot{M}_{tr}$ not via Ang. Momentum loss (magnetic breaking/Grav. radiation)
4) A Super-Eddington source

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→ $\dot{M}_{tr}$ not via Ang. Momentum loss (magnetic breaking/Grav. radiation)

Mass transfer proceeds on thermal timescale
→ $\tau \sim 10^7 \text{yr}$
→ So $\dot{M}_{tr} \sim 10^{-7} M_\odot / \text{yr}$
→ $\dot{M}_{Edd} \sim 10^{-8} M_\odot / \text{yr}$
4) A Super-Eddington source

Test if $\dot{M}_{tr}$ explains the orbital evolution

$\rightarrow \dot{a}/a \sim 2\dot{P}_b/3P_b$

$\rightarrow$ Similar to within an order of magnitude

$\dot{M}_{tr}$ super Eddington $\rightarrow$ close to idea for ULX

$\rightarrow$ King & Lasota 2016 idea for ULX as NS

$\rightarrow$ KL16 test if ULX M82 X-2 fits in picture of ULX as beamed X-ray sources.

$\rightarrow$ Estimate magnetic field from $R_m$ and $R_{sph}$

Img. Credit: NASA
4) A Super-Eddington source

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Following King & Lasota 2016, we find:

$\rightarrow R_{sph} \sim 10^7$ cm

$\rightarrow R_m \sim 10^6$-$10^7$ cm

$\rightarrow$ B-field $\sim 10^{10}$ G (at poles)
4) A Super-Eddington source

Where $R_m \sim R_{\text{sph}}$

Inner disk puffed up

Outflow created by Super Eddington $\dot{M}_{tr}$

See pulsations in the outflow

See around disk/inner part of disk

Geometrically thick inner disk

Beaming of emission $\rightarrow$ possibly Jet/Outflow

$B\text{-field} \sim 10^{10}\text{G}$

Bak Nielsen et al. 2017
4) A Super-Eddington source - Tests

Tests:
- Is the magnetic field $\sim 10^{10}$ G
  $\rightarrow$ NuStar observation
  confirm/contradict $10^{12}$ G B-field

- Source should not show Torque reversal
  $\rightarrow$ Similar to what 4U 1626-67 or GX1+4 does

- A Jet/outflow should be present (Radio)
  $\rightarrow$ If beaming is present

Img. Credit: NuStar
5) Comparison to ADC sources

SS 433 similar geometry to 2A 1822-371

Dotan et al. 2011
5) Comparison to ADC sources

- 4U 1624-49, 1999 data
  - Smale et al. 2001

- 2A 1822-371
  - Heinz et al. 2001

- AC 211, glob. Cluster, 2-20keV
  - Ionannou et al. 2002

- RXTE 96a

- 2U 1626-67, AC 211, and 2A 1822-371
  - Ioannou et al. 2002
5) Comparison to ADC sources

Some ADC sources have spectra that drop off at ~ 8-12keV
   → 4U 1624-49
   → 2S 0921-630 (?)

4U 1624-49, AC 211, MS 1603+2600 have little info on spectra or spectra does not seem to show cut-off

Iaria et al. 2015
Conclusion

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2) Optically thin Accretion disc corona (ADC)

3) Long-term and Short-term spin up

4) Super-Eddington source (B~$10^{10}$G)

5) Other sources show similarities to 2A 1822-371
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Thank you!
5) Comparison to ULX sources
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3 known ULX-pulsars, M82 X-2, NGC 7793 P13, NGC 5907

→ Sinusoidal pulse profiles