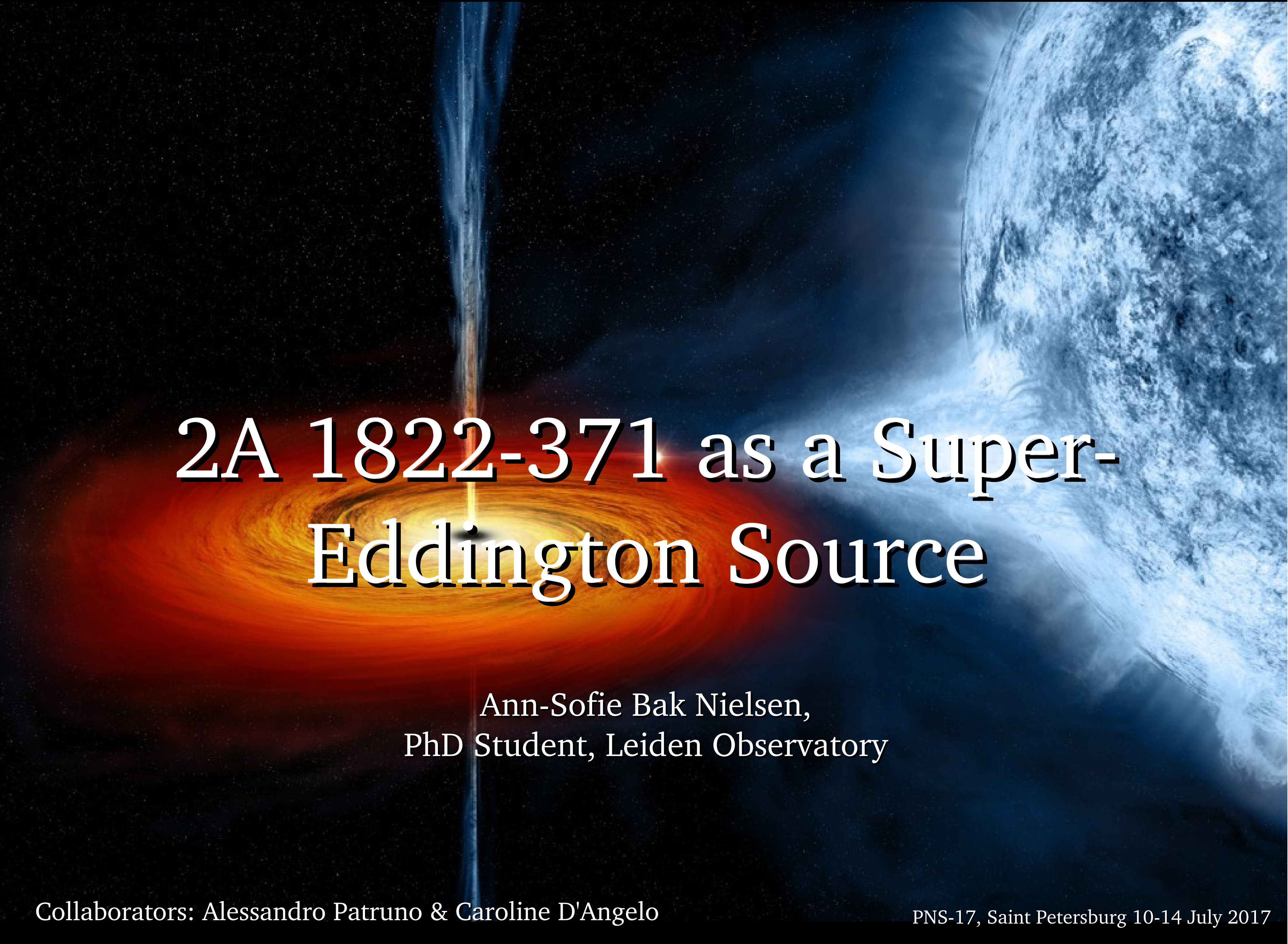


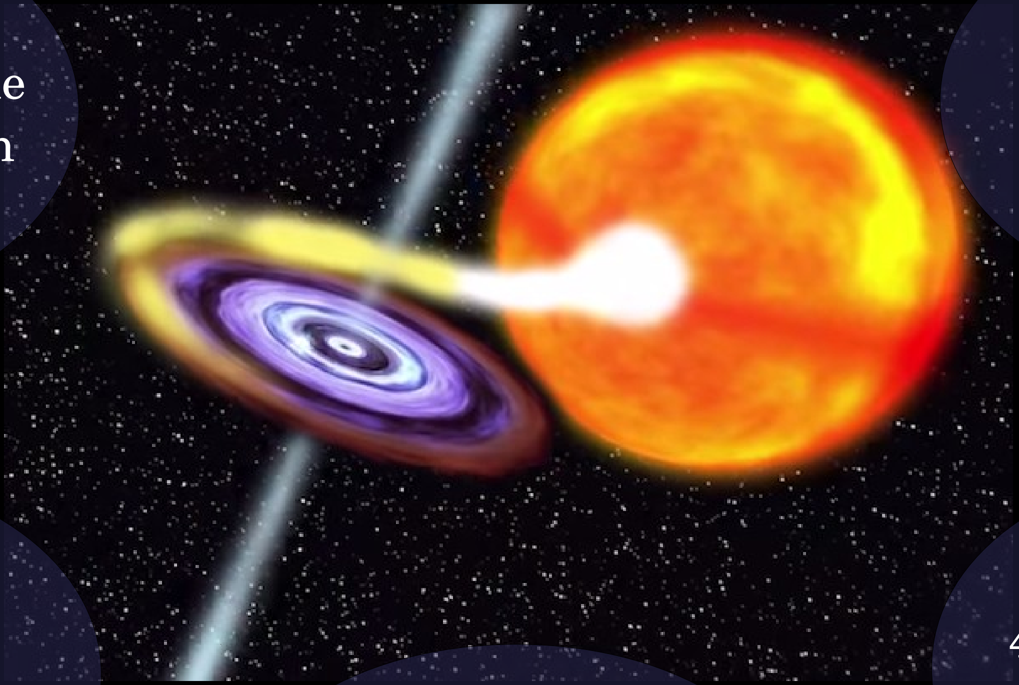
2A 1822-371 as a Super-Eddington Source

Ann-Sofie Bak Nielsen,
PhD Student, Leiden Observatory

Collaborators: Alessandro Patruno & Caroline D'Angelo

PNS-17, Saint Petersburg 10-14 July 2017

Conclusion



1) The surface of the pulsar is never seen

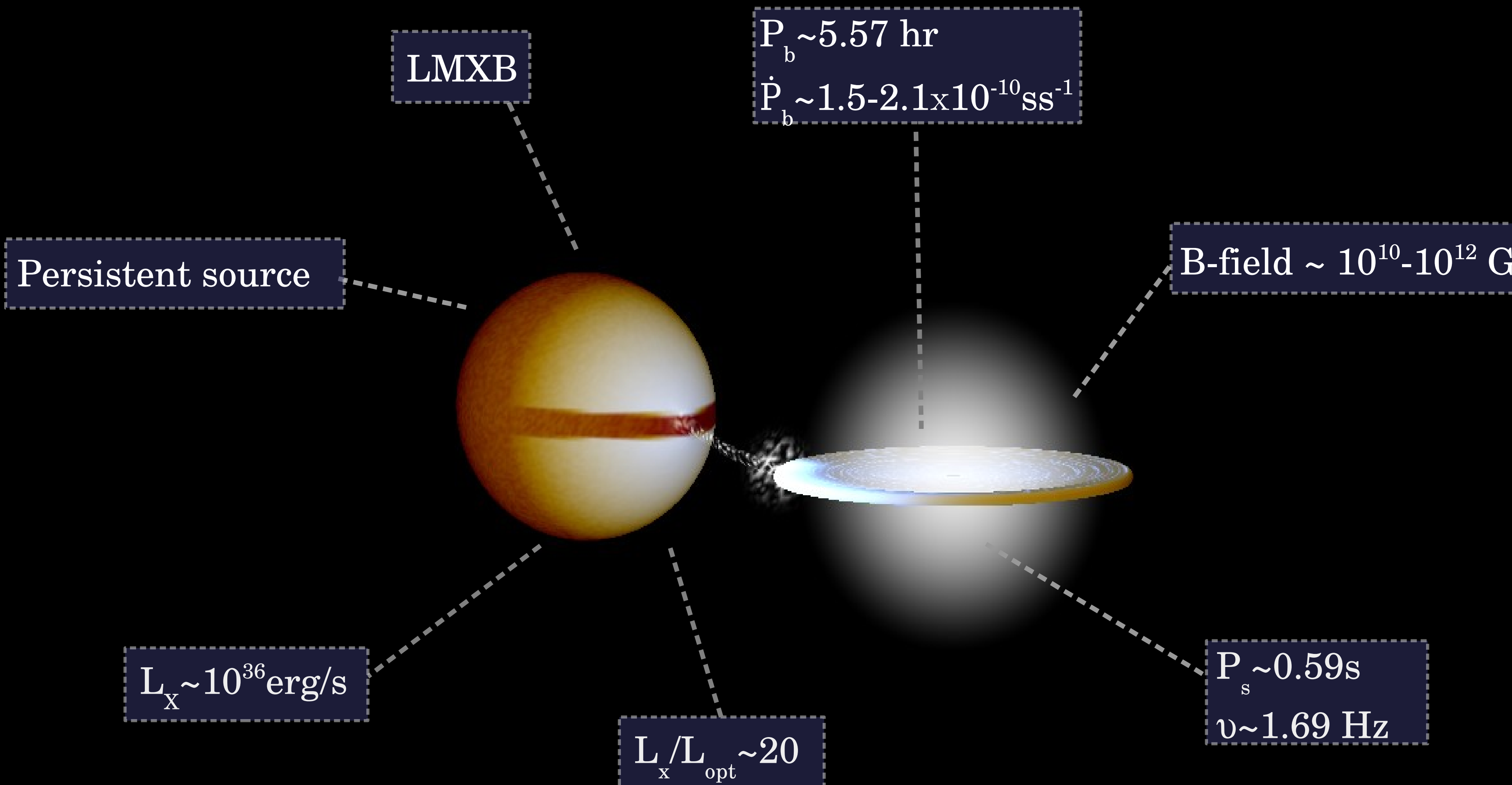
2) Optically thin Accretion disc corona (ADC)

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

Meet 2A 1822-371



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

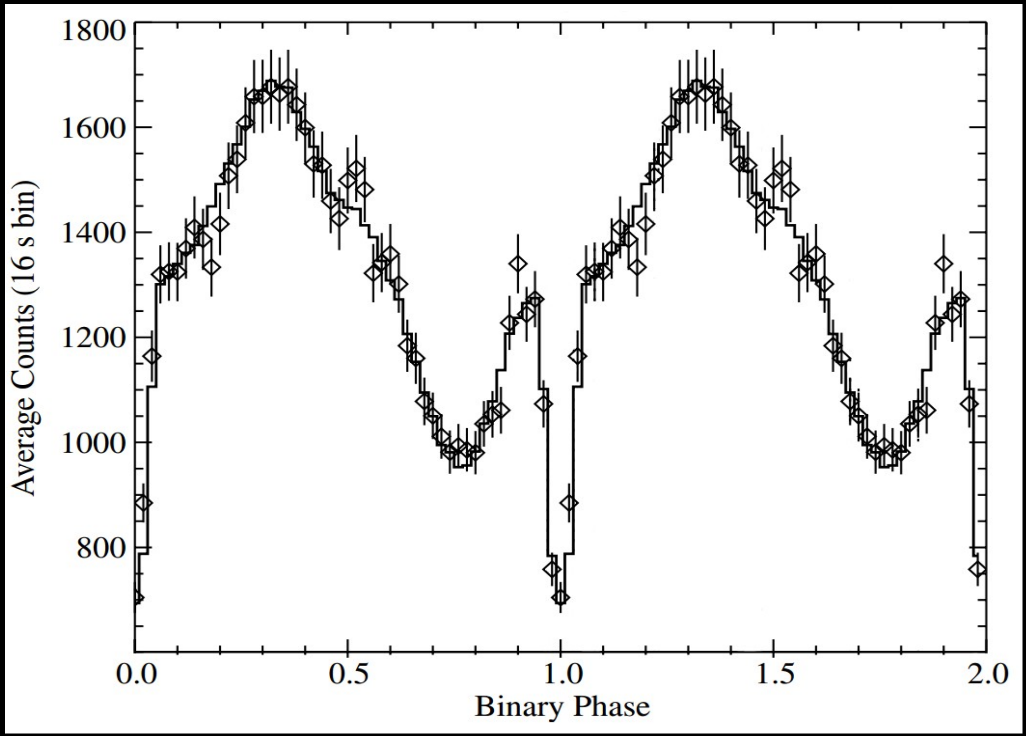
1) The Light curve

Eclipsed LMXB

Edge on view

50% eclipsed

Extended X-ray emitting region → wide eclipses, partially eclipsed



Heinz et al. 2001

1) The surface of the NS is never seen

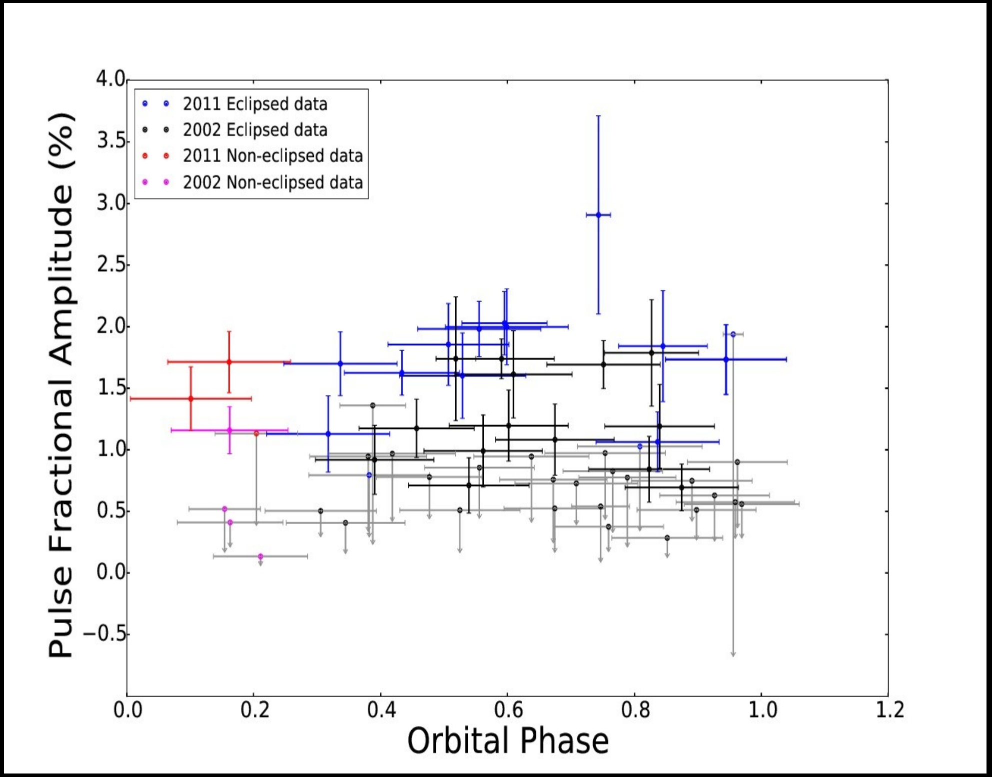
Is the surface seen?

→ Fractional amplitude vs. orbital phase

→ Eclipsed vs. non-eclipsed data

No difference in eclipsed/non-eclipsed

→ Surface of NS never seen



Bak Nielsen et al. 2017

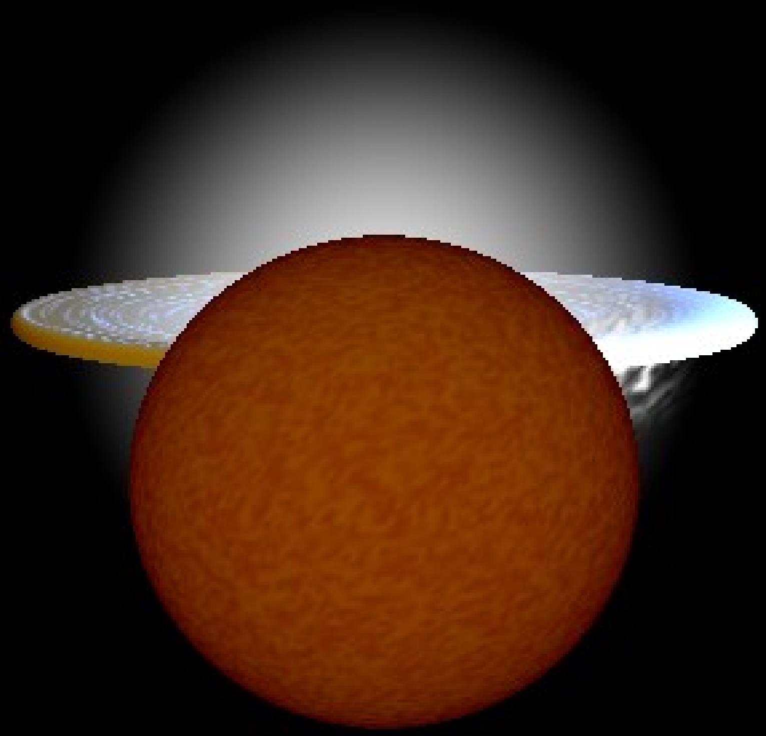
For more details on the light curve and eclipses see e.g. Heinz & Nowak 2001 & Parmar et al. 2000

2) The Accretion Disk Corona

Edge on, inclination ~ 83°

Spectral analysis:

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

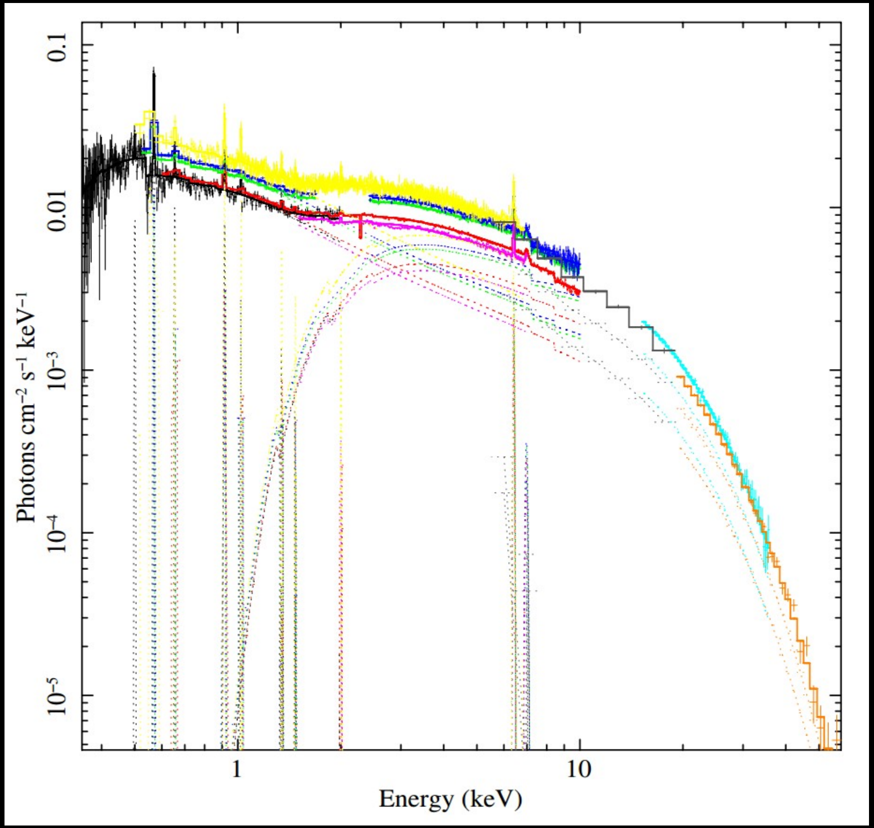


For other discussion on ADC see e.g. White & Holt 1982 and Iaria et al. 2013. For discovery of pulsations see Jonker & van der Klis 2001.

2) The Accretion Disk Corona

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

So look at the spectra + models of spectra
→ cut-off PL, BB, compTT …
→ cut-off at ~10keV



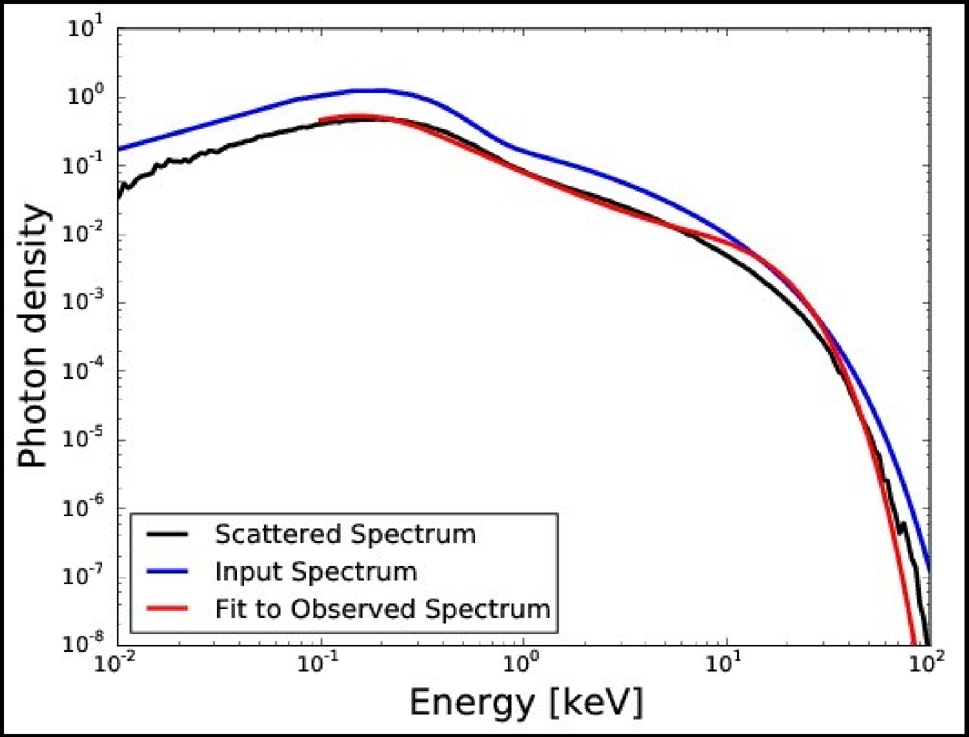
Iaria et al. 2015

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%)



Bak Nielsen et al. 2017

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.

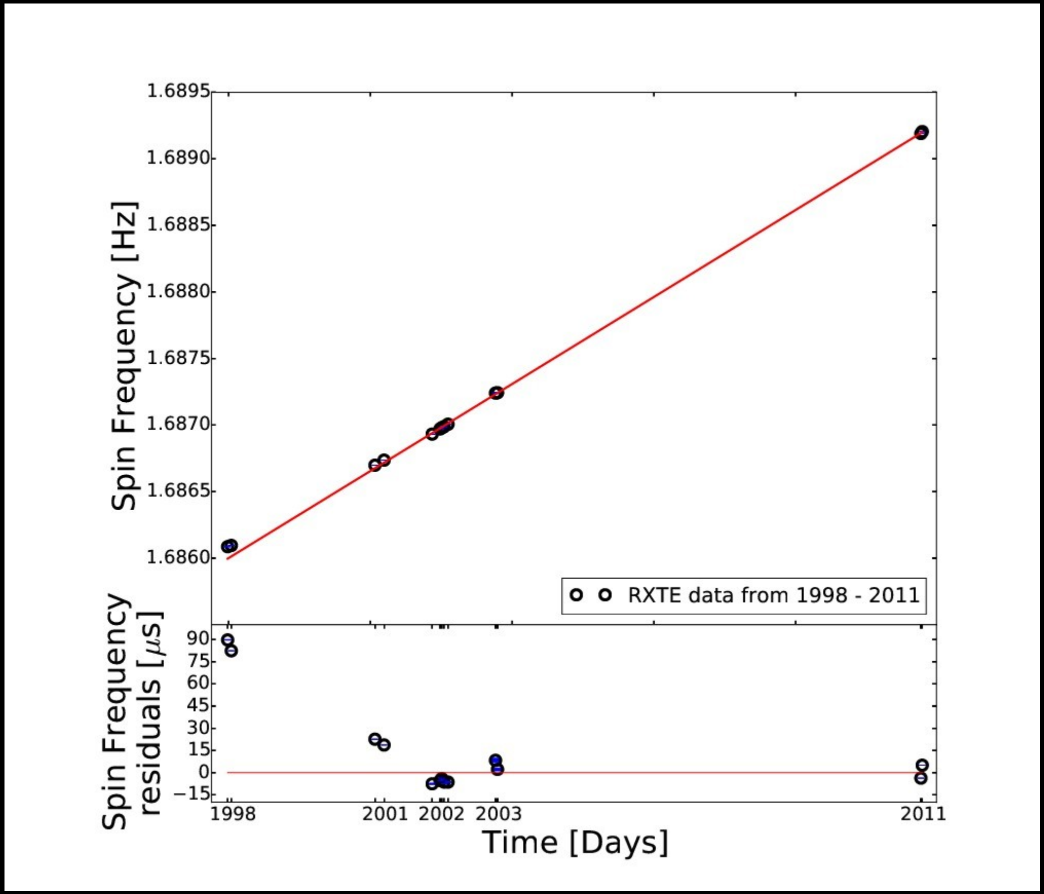
3) Long-term spin-up

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

$$\dot{\nu} = 7.6(8) \times 10^{-12}\ \mathrm{Hz\,s^{-1}}$$

υ ~ 1.69 Hz
P_s ~ 0.59 s

Varying residuals – short term changes?



Bak Nielsen et al. 2017

3) Short-term spin-up

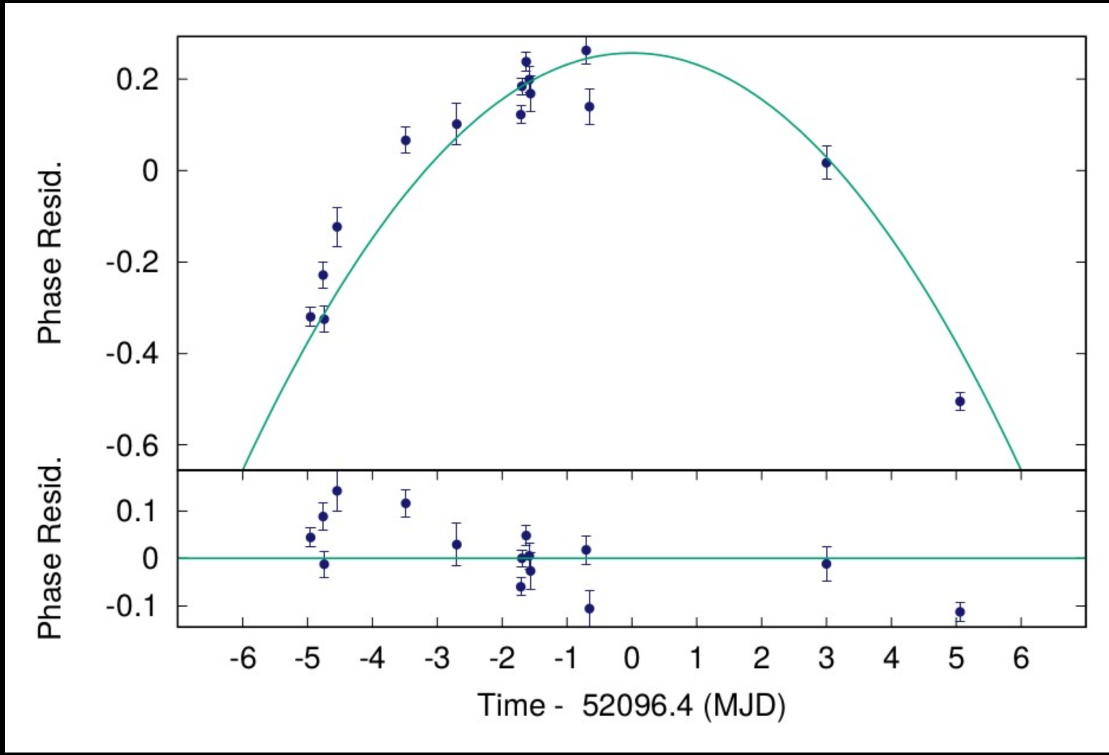
Short-term spin-up

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

$$\dot{\nu} = 6.7(4) \times 10^{-12}\ \mathrm{Hz\,s^{-1}}$$

$$\dot{\nu} = 8.2(5) \times 10^{-12}\ \mathrm{Hz\,s^{-1}}$$

Figure shows 1-11 July 2001 data



Bak Nielsen et al. 2017

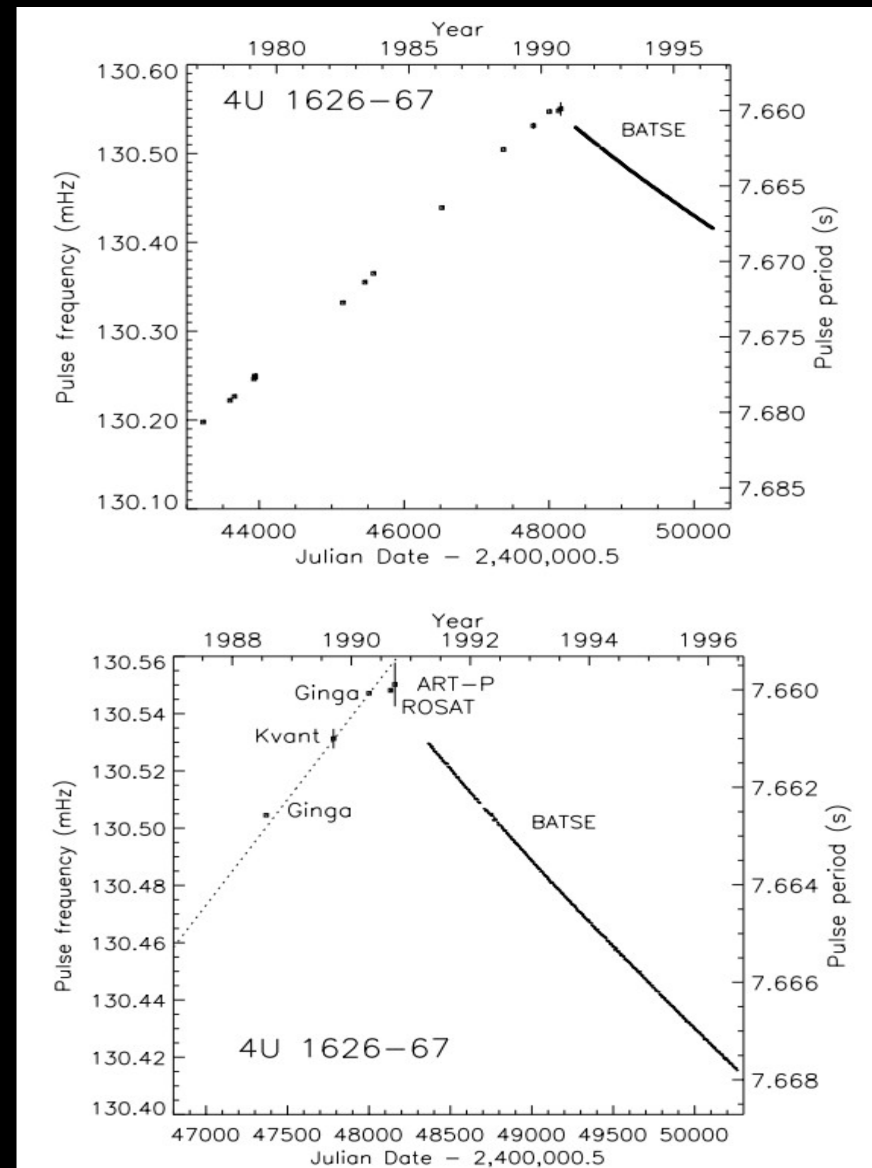
Future of 2A 1822-371

Possible torque reversal system
4U 1626-67
→ spin 7.66s
→ Spin freq. 0.13 Hz
→ P_b~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 → 5000yrs

Torque reversal for 2A 1822-371?



Chakrabarty et al. 1997

The Super Eddington Source

4) A Super-Eddington source

Weakness of model

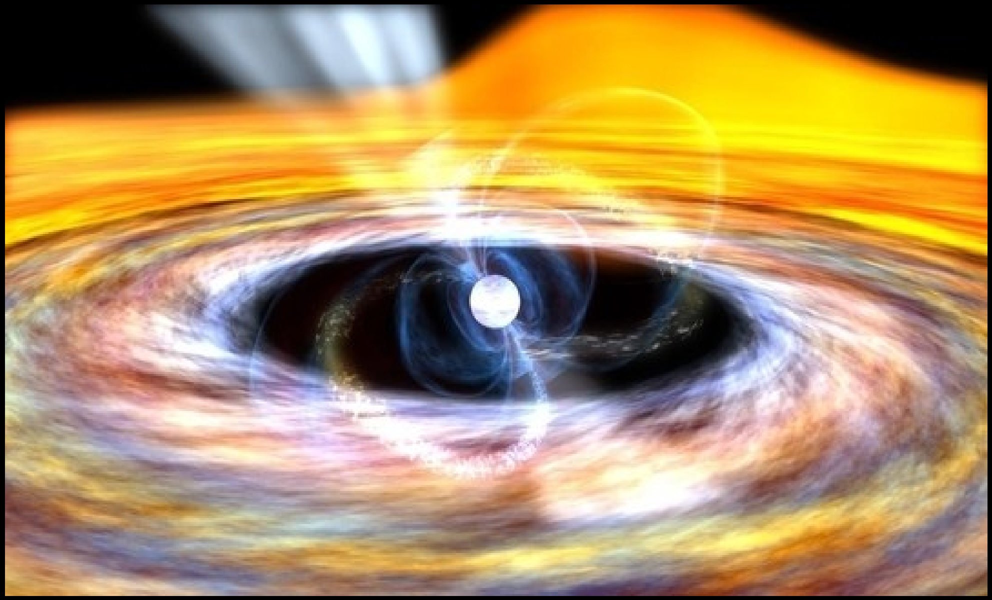
→ Needs Eddington limited accretion

→ 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)



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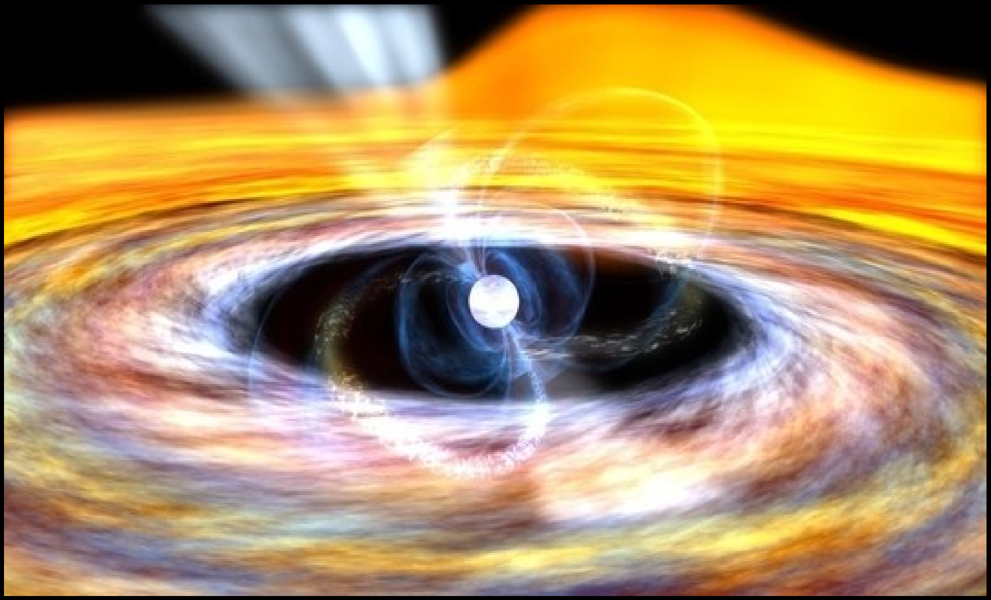


Mass transfer proceeds on thermal timescale

- → $\tau \sim 10^7$yr
- → So $\dot{M}_{tr} \sim 10^{-7} M_\odot$/yr
- → $\dot{M}_{Edd} \sim 10^{-8} M_\odot$/yr

4) A Super-Eddington source

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

→ $\dot{a}/a \sim 2\dot{P}_b/3P_b$

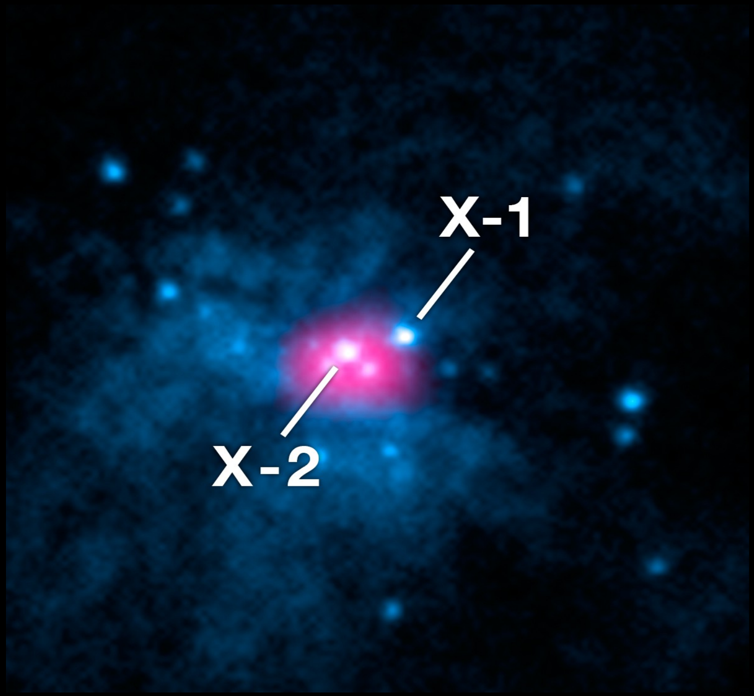
→ Similar to within an order of magnitude

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

→ King & Lasota 2016 idea for ULX as NS

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

→ Estimate magnetic field from R_m and R_{sph}



Img. Credit: NASA

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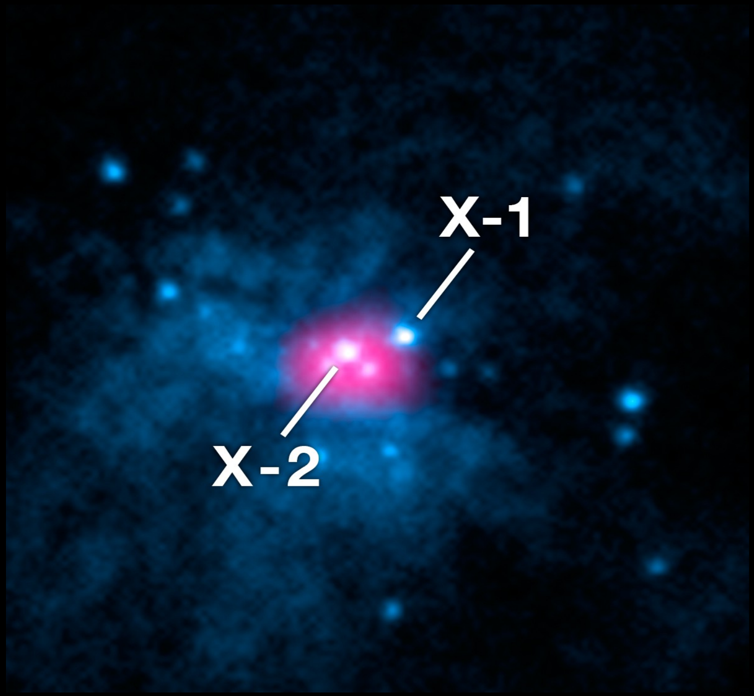
Following King & Lasota 2016, we find:

→ $R_{sph} \sim 10^7$cm

→ $R_m \sim 10^6$-10^7cm

→ B-field $\sim 10^{10}$G (at poles)



Img. Credit: NASA

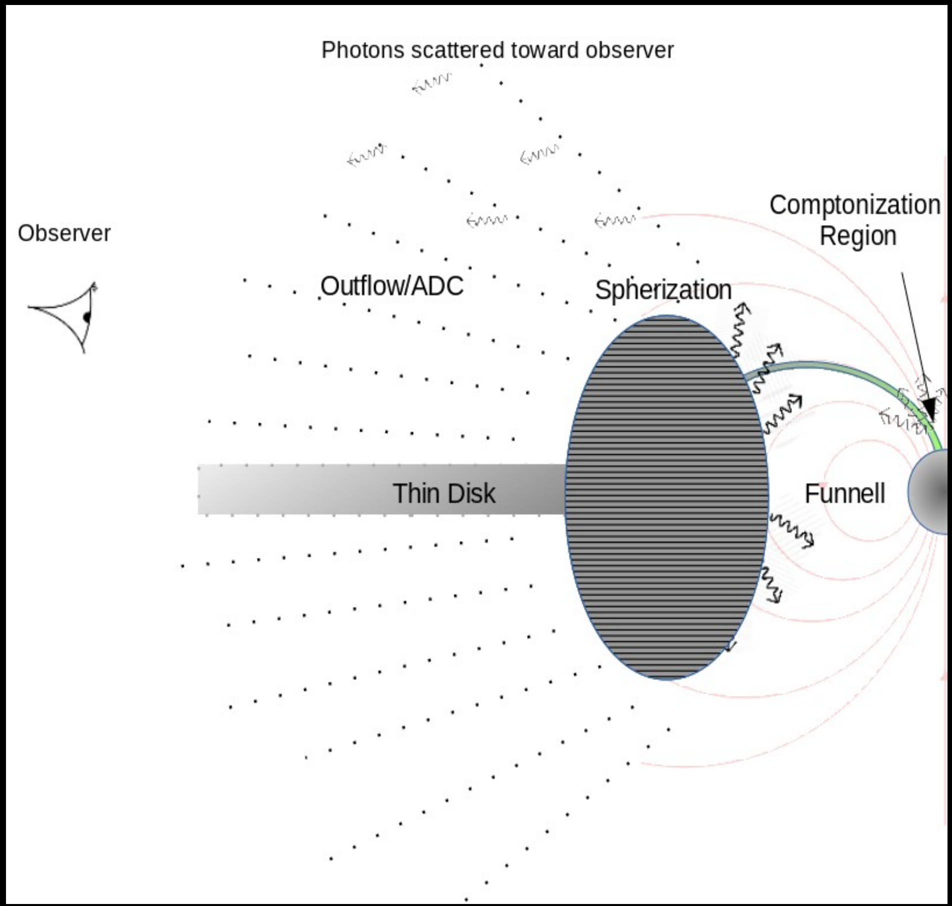
4) A Super-Eddington source

Where $R_m \sim R_{sph}$
Inner disk puffed up

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

See pulsations in the outflow

See around disk/inner part of disk



Bak Nielsen et al. 2017

Geometrically thick inner disk

Beaming of emission → possibly Jet/Outflow

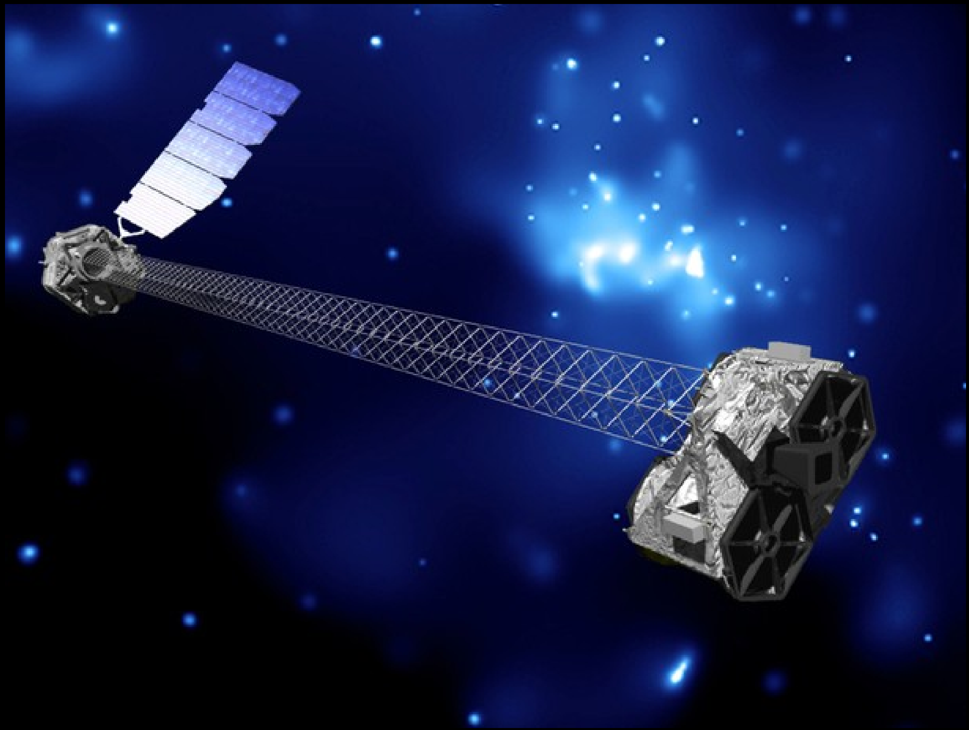
B-field ~ 10^{10}G

4) A Super-Eddington source - Tests

Tests:
- Is the magnetic field ~ 10^{10}G
  → NuStar observation confirm/contradict 10^{12}G B-field

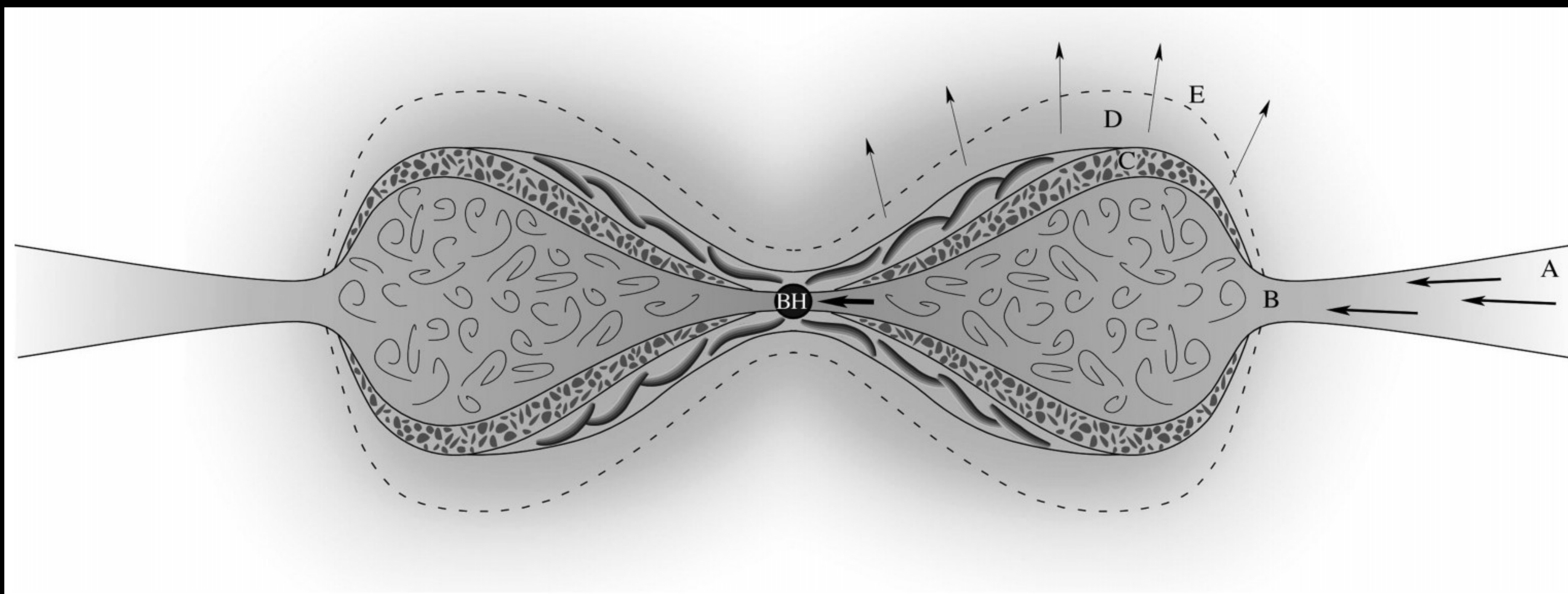
- Source should not show Torque reversal
  → Similar to what 4U 1626-67 or GX1+4 does

- A Jet/outflow should be present (Radio)
  → If beaming is present



Img. Credit: NuStar

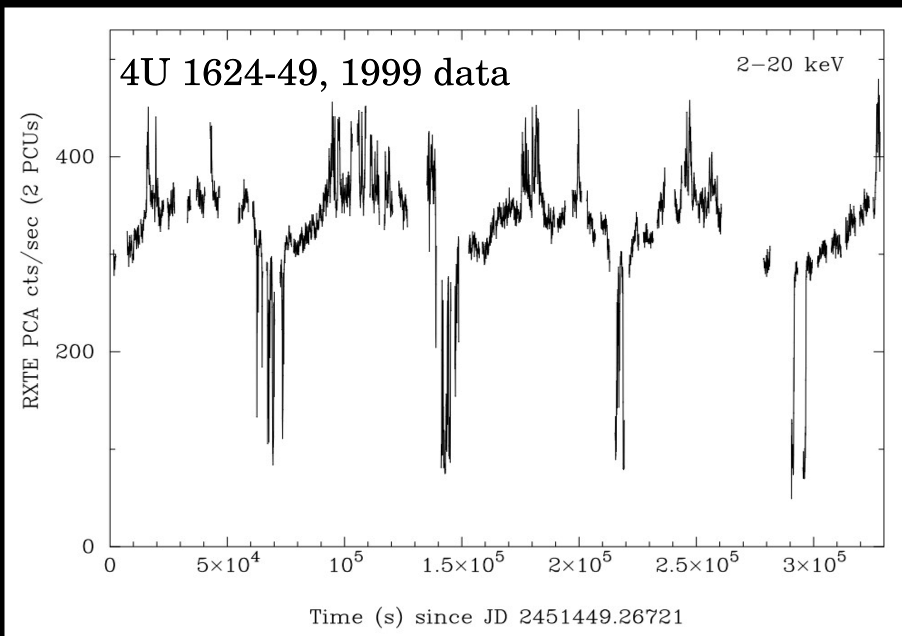
5) Comparison to ADC sources



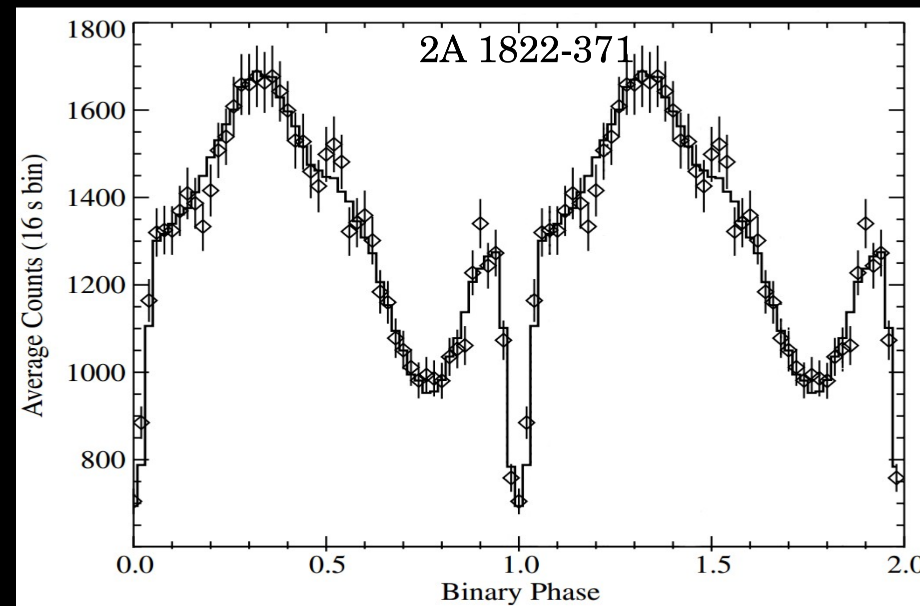
Dotan et al. 2011

SS 433 similar geometry to 2A 1822-371

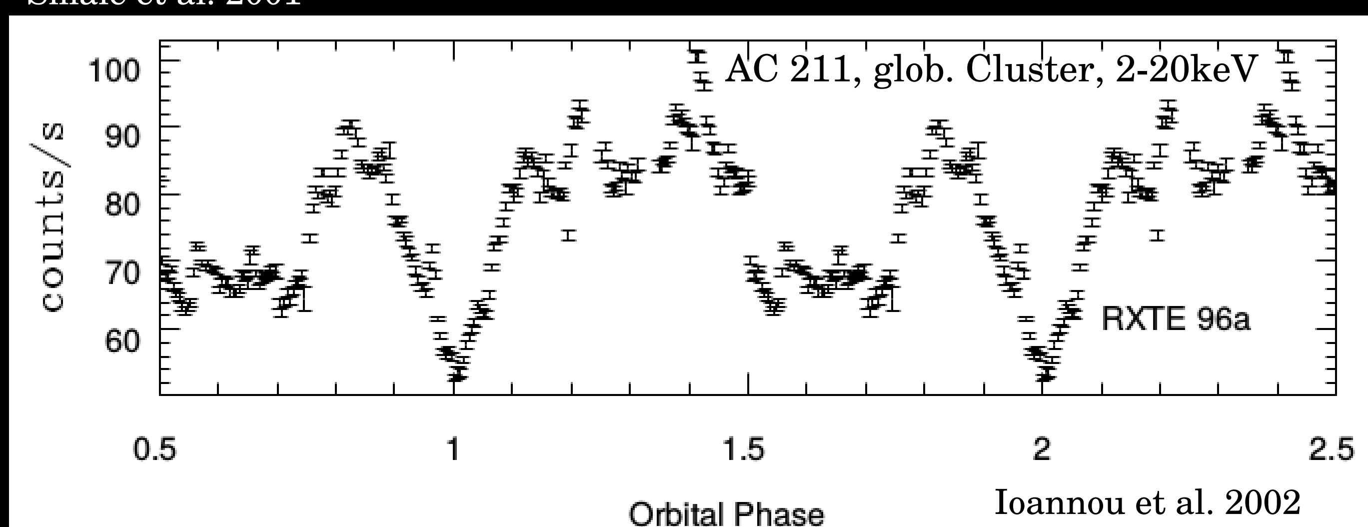
5) Comparison to ADC sources



Smale et al. 2001



Heinz et al. 2001



Ioannou et al. 2002

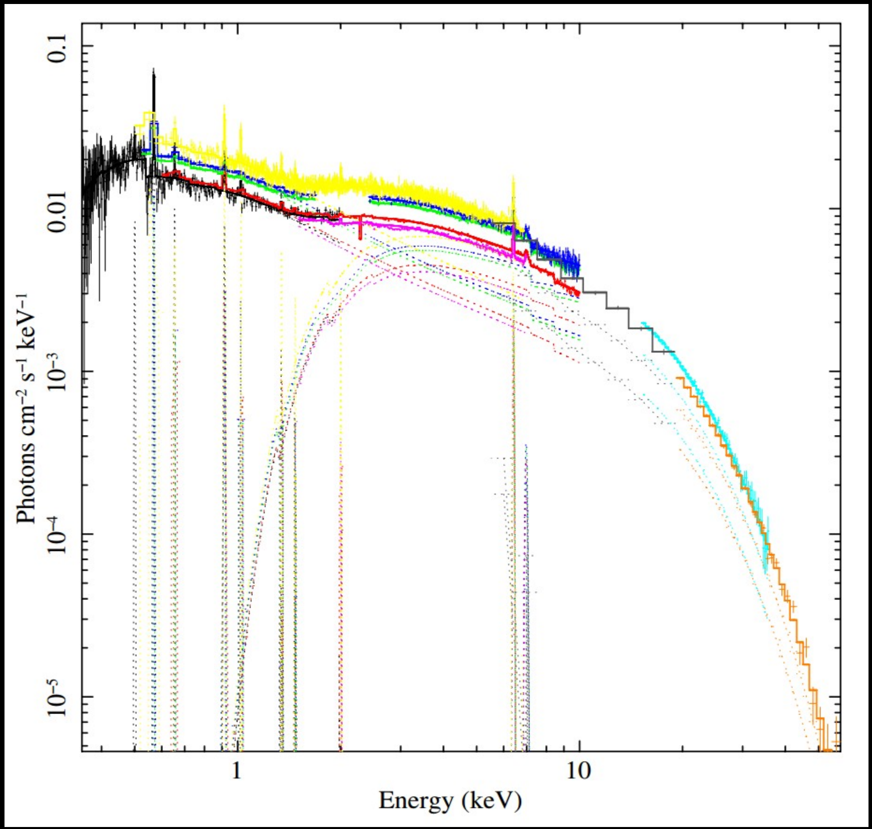
5) Comparison to ADC sources

Some ADC sources have spectra that drop off at ~ 8-12keV

→ 4U 1624-49

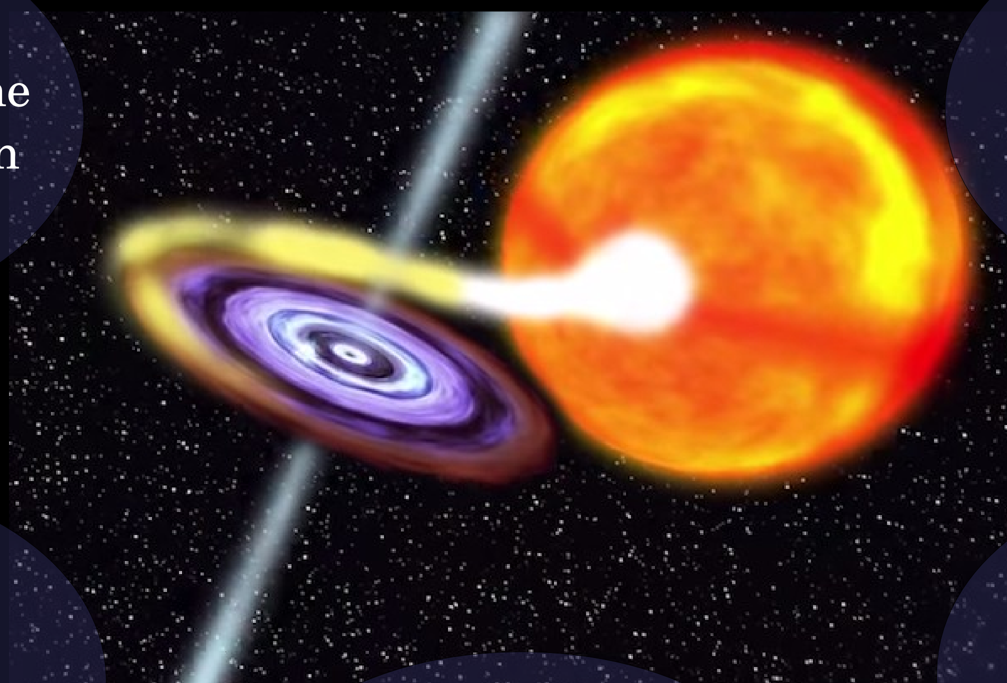
→ 2S 0921-630 (?)

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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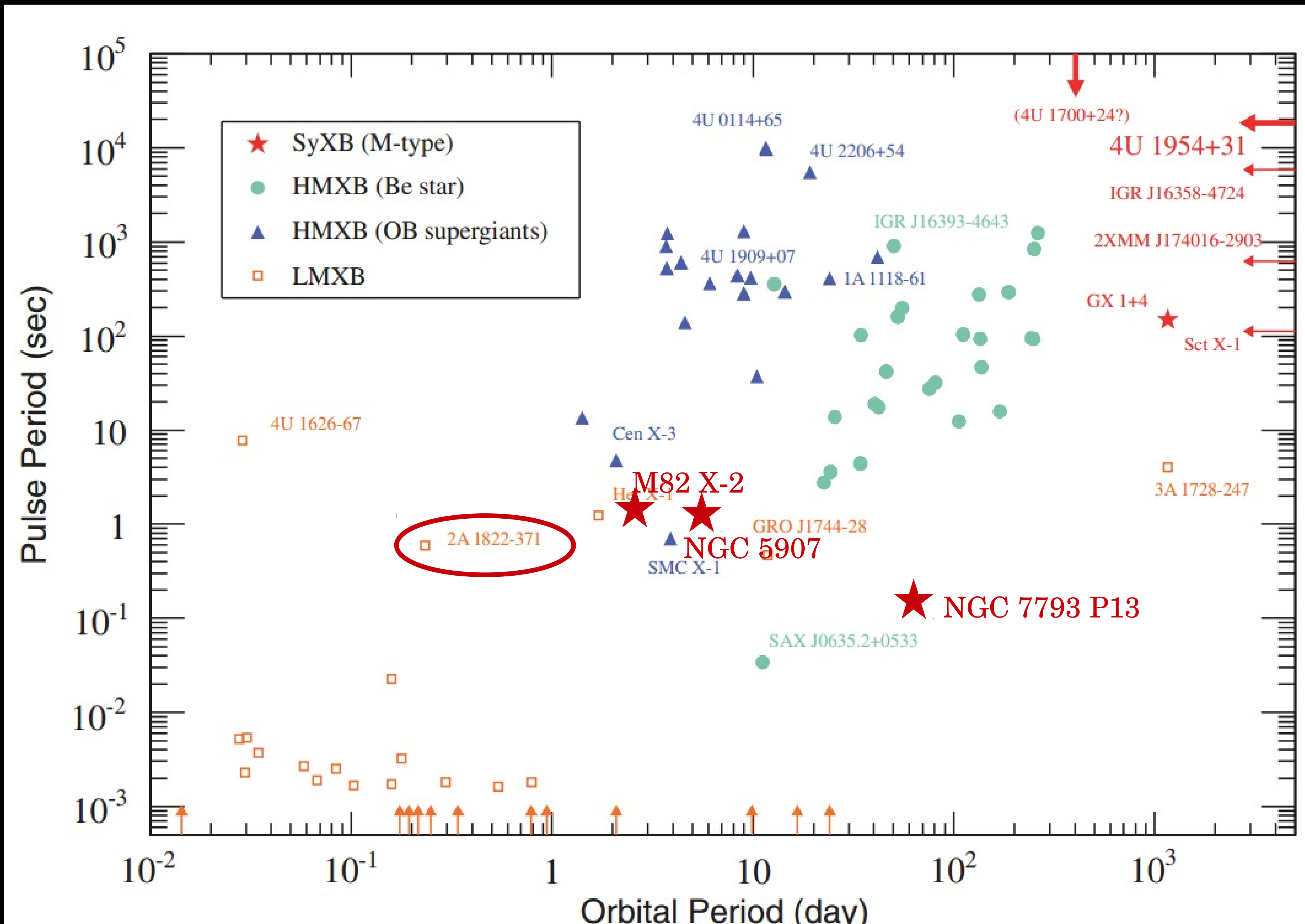
Thank you!

5) Comparison to ULX sources



5) Comparison to ULX sources

3 know ULX-pulsars, M82 X-2, NGC 7793 P13, NGC 5907

→ Sinusoidal pulse profiles