XMM-Newton campaign of the ULP NGC 7793 P13

Determination of the orbital ephemeris

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Ultraluminous X-ray Sources

Definition
Ultraluminous X-ray sources (ULXs) are
off-nuclear point sources in nearby galaxies with luminosities in excess of 10^{39} erg s^{-1}.

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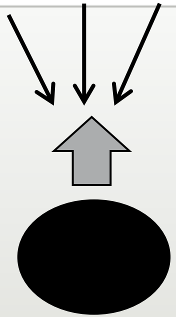
IC 342

Brighter than the Eddington-limit of a $10M_{\odot}$ black hole (stellar remnant)

Eddington limit
Radiation pressure balances ram pressure in **spherical** accretion.
Correlated with mass of the compact object.



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Three possible explanations:

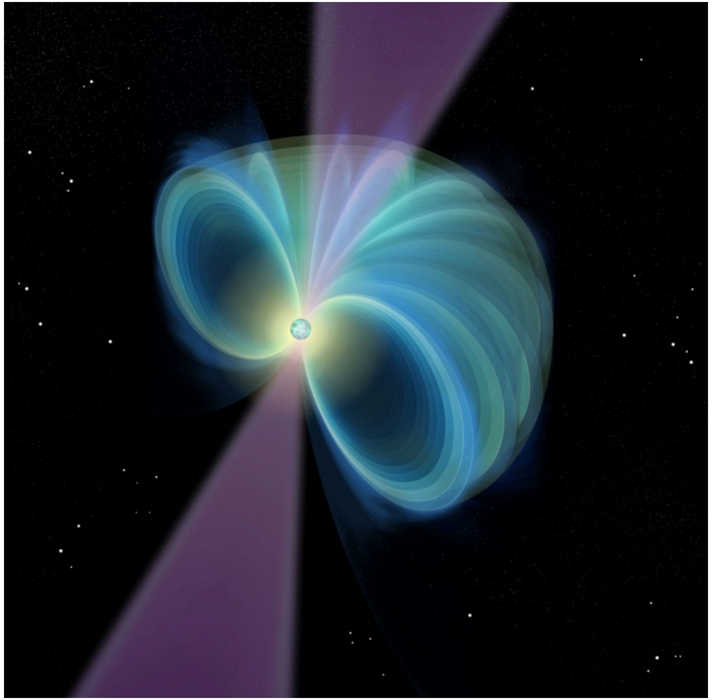
- Normal accretion massive black holes: “intermediate mass” black holes ($M \sim 10^{2\text{-}4}\ M_{\odot}$)
- Super-Eddington accretion on stellar-mass black holes ($\sim 10\ M_{\odot}$)
- **Super-Eddington accretion on neutron stars!**

What is so special about neutron stars?

Mass limited by Oppenheimer-Volkoff limit: 2-3 $M_\odot$
→ Eddington limit is much lower (a few 10^{38} erg/s)

Strong magnetic field: $10^8 – 10^{14}$ G
→ Spherical symmetry breaks down within the magnetosphere

Gives rise to **coherent pulsations**!
→ ultra-luminous X-ray pulsar (ULP)



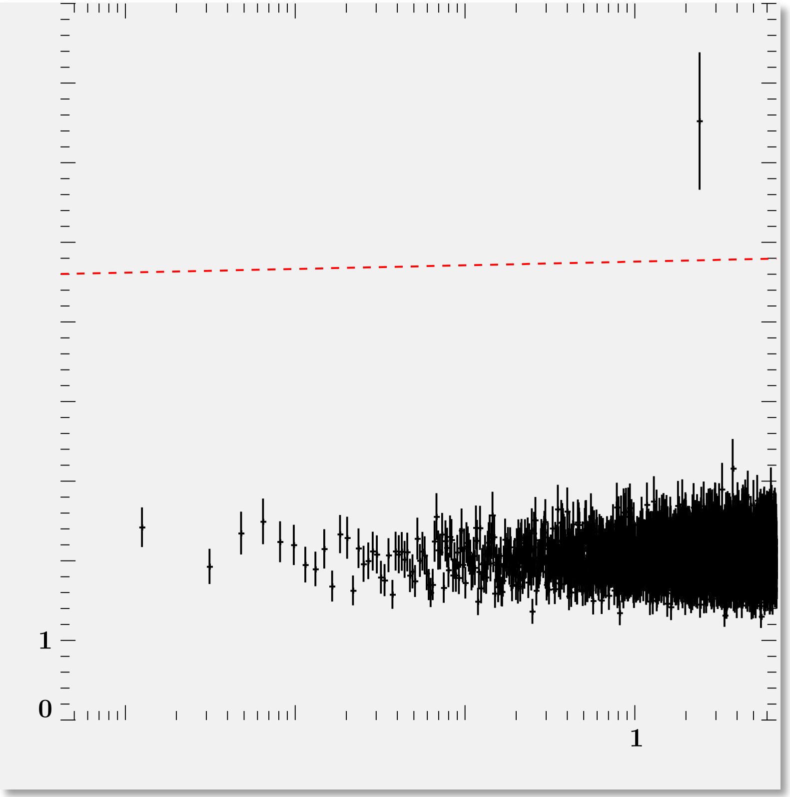
Pulsations detected in NGC 7793 P13

NGC 7793 P13 showed very clear pulsations in 2013, 2014, and 2016 in Fourier spectrum

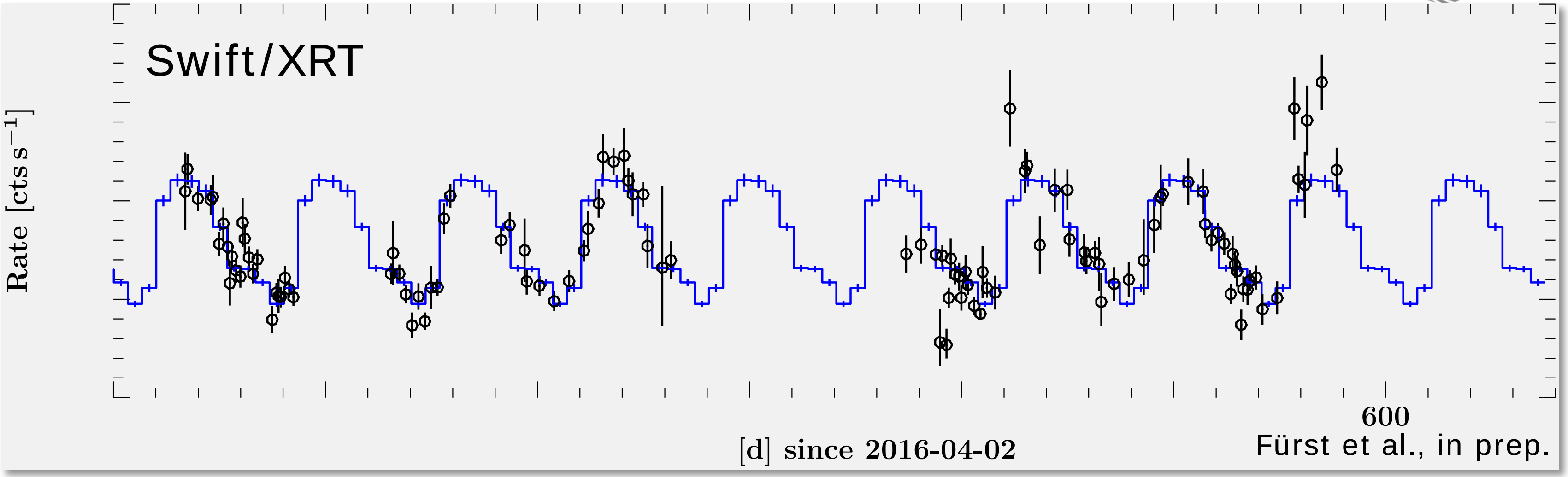
Pulse period is around 415ms.

Distance 3.6Mpc
L_x(max) ~ 6×10^{39} erg/s
(>30x Eddington)

Fürst et al. 2016, Israel et al., 2017a



Long-term photometric period



65d period discovered in optical photometry (Motch et al. 2014) and in X-ray flux (Hu et al., 2017).

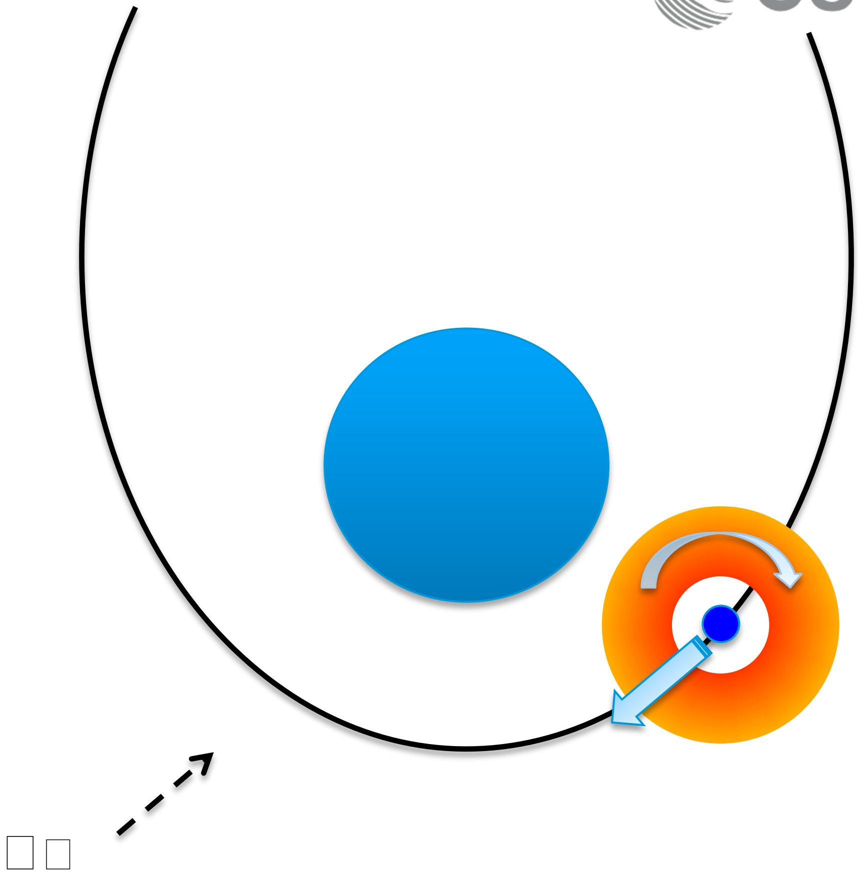
→ Is this the orbital period? Variability due to eccentric orbit?
→ If yes, it’s much longer than in the other known ULPs

Physical reasons for spin-up

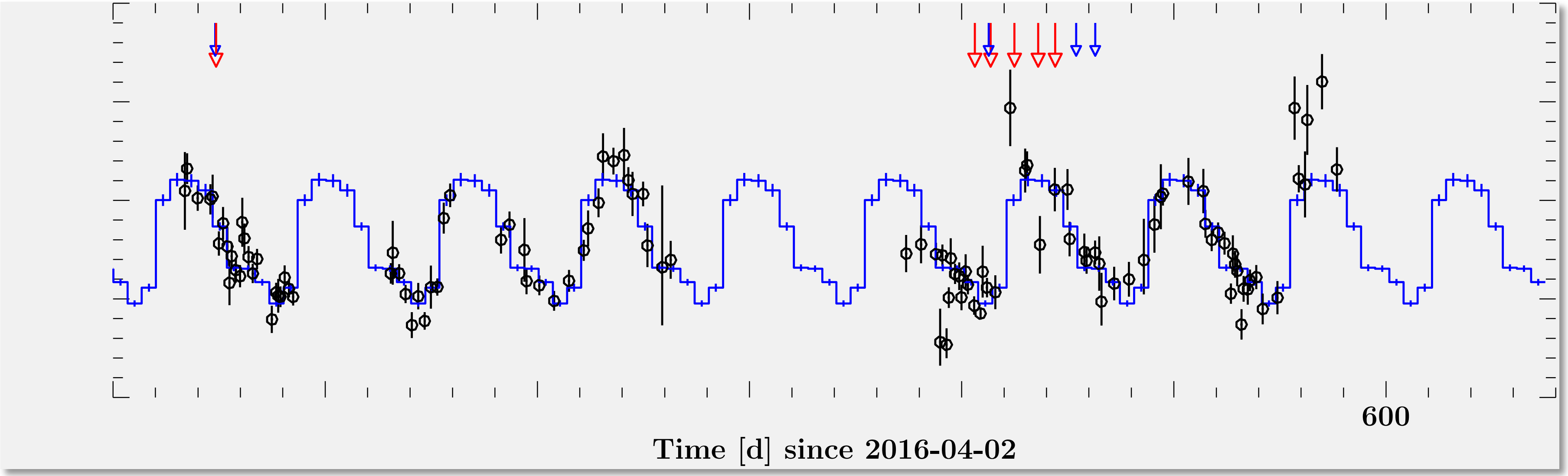
Change of period due to:

- Transfer of angular momentum on the neutron star (secular spin-up); depends on mass-accretion rate/luminosity/magnetosphere
  (Ghosh&Lamb 1979)

- Doppler effect due to orbital movement; depends on inclination, can **increase** the apparent period!

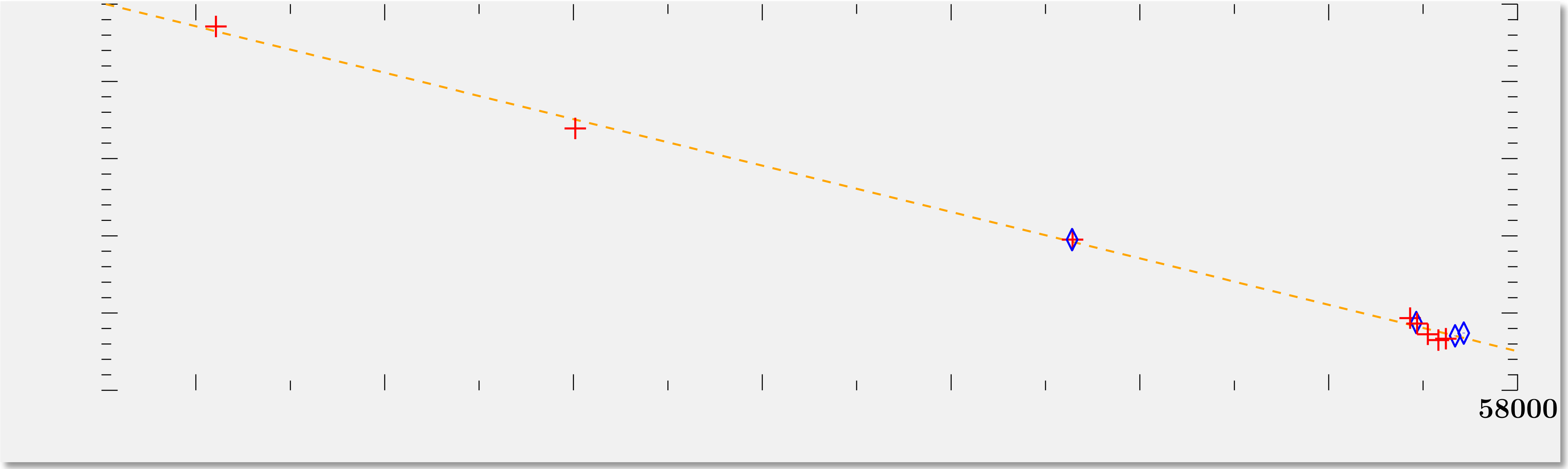


XMM-Newton campaign: timing



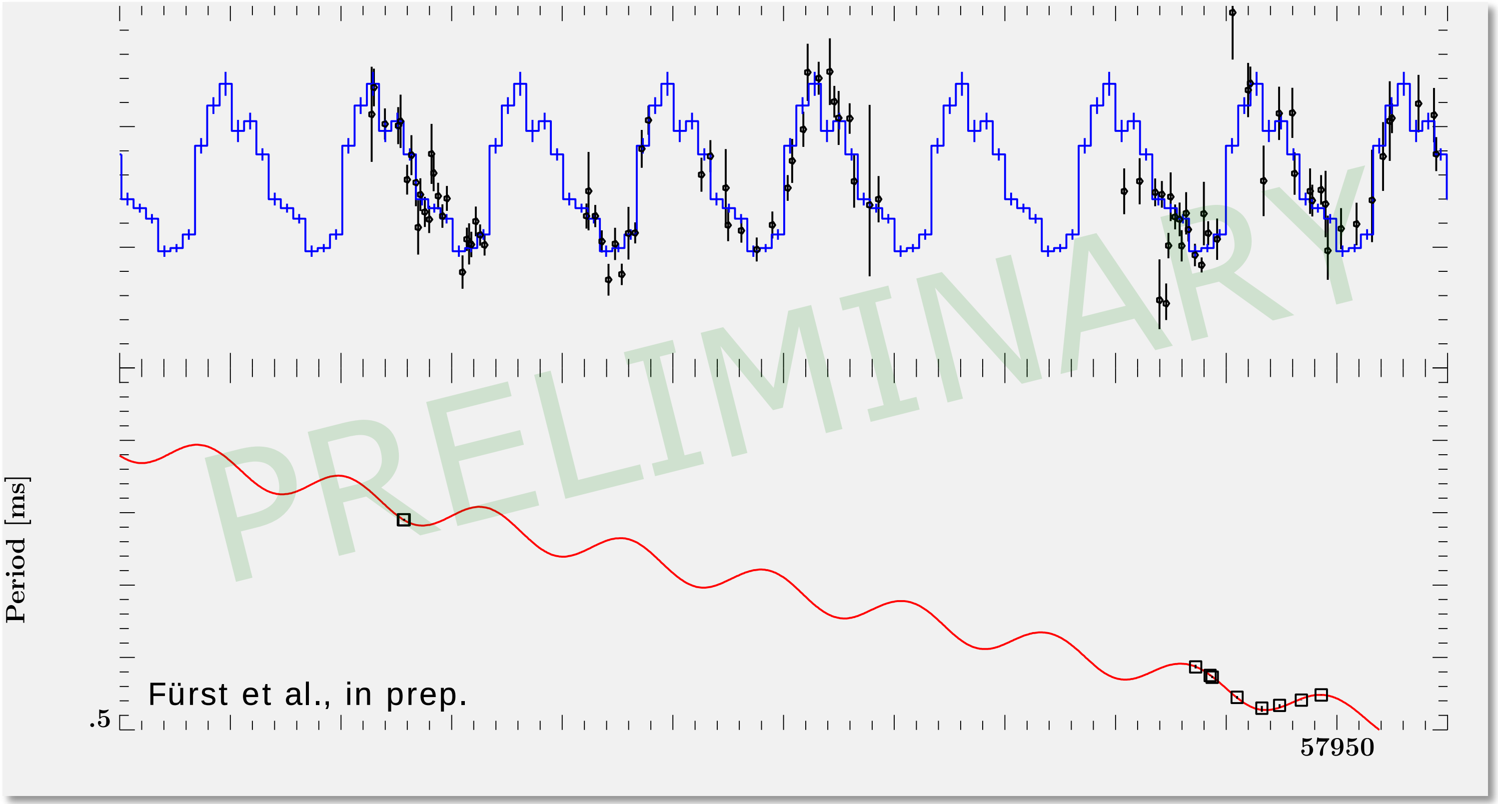
5 evenly spaced *XMM-Newton* observation over one 65d cycle.
Supported by *NuSTAR* during periods, when source was not visible to *XMM*
As well as ~weekly *Swift*/XRT monitoring

Secular spin-up is significant

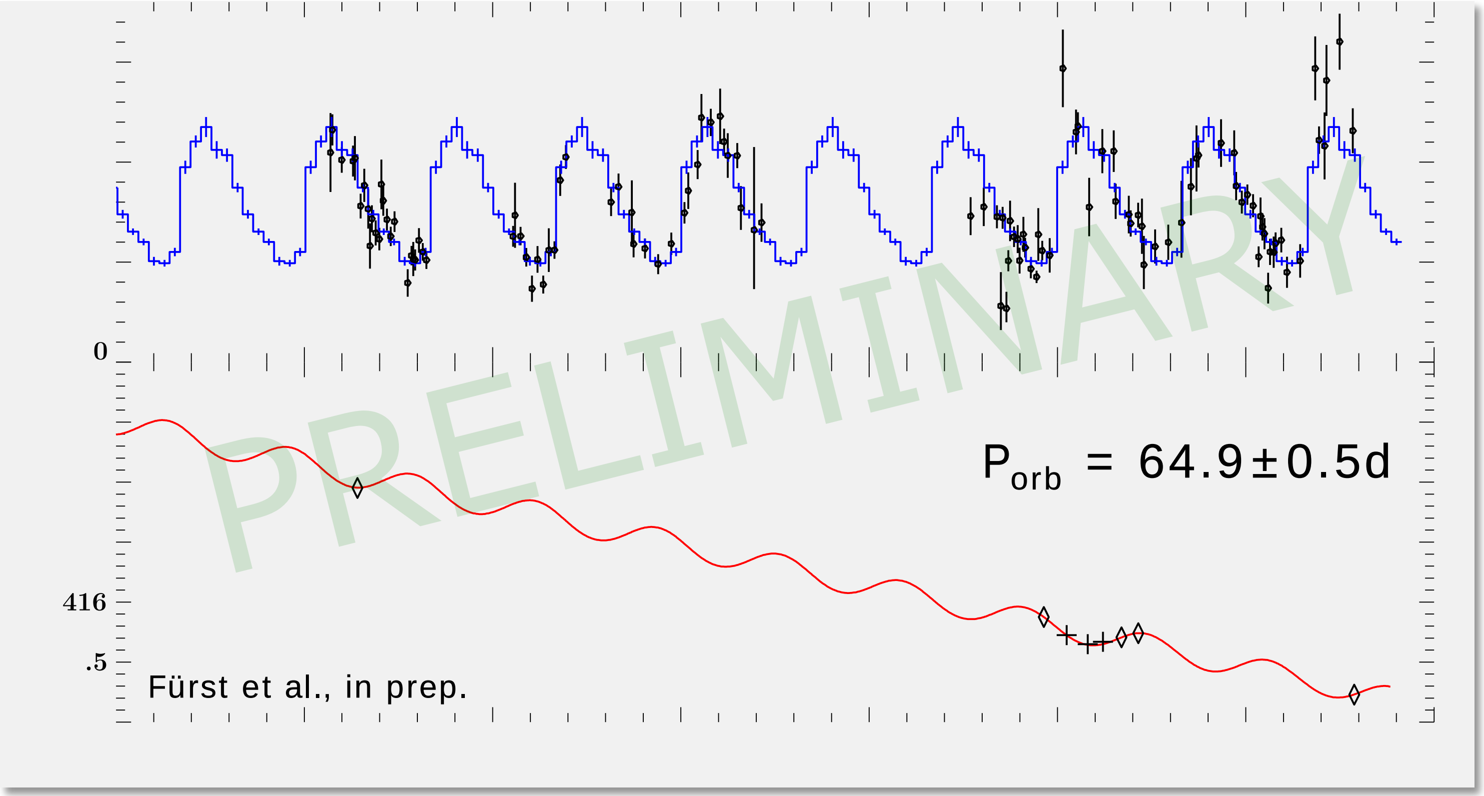


Secular spin-up is about 3.5×10^{-11} s/s
Additionally: periods Doppler shifted due to orbital motion!

Period evolution well fitted by 65d orbit



Hot off the satellite (VERY preliminary)



Orbital ephemeris

Pulse period: 420.15ms @ MJD 56621.21

Secular spin-up: 6.7×10^{-11} s/s @ $11\times^{40}$ erg/s

asini: 201 lt-s

Eccentricity: <0.01 (circular orbit!)

Motch et al. (2014), optical data:

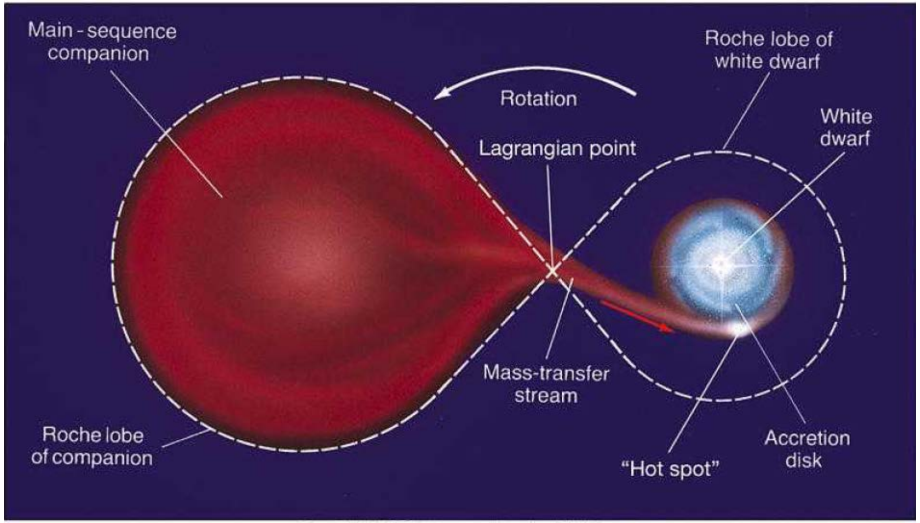
asini ~ 350 lt-s
Eccentricity ~0.3

Orbital ephemeris

Pulsar timing shows a very **circular orbit** with **65d** period!

So where does the photometric period come from?

How is super-Eddington accretion sustainable?

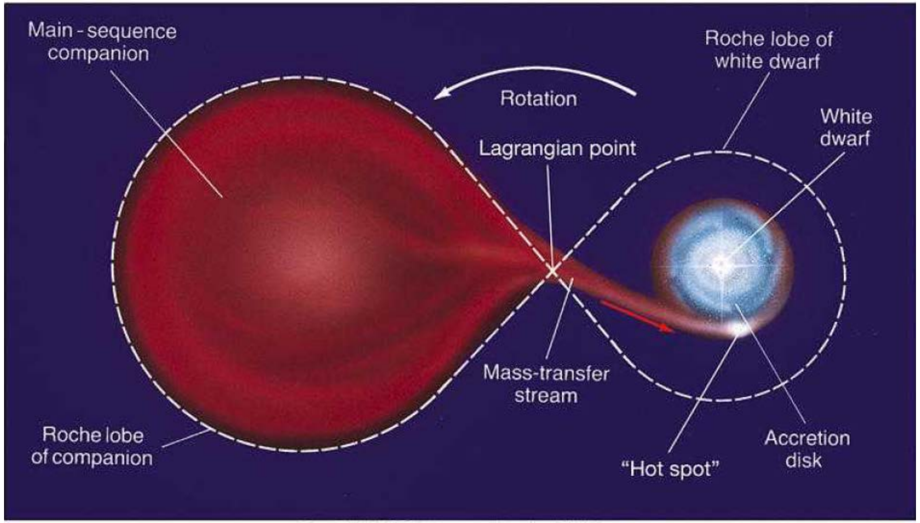


Accretion through Roche-Lobe-Overflow (RLOF)

Very high accretion rates only sustainable through Roche-Lobe-Overflow (RLOF)

But for RLOF with a B9Ia super-giant, orbit needs to be < 40d!

Focused wind or Be-like circumstellar disk?

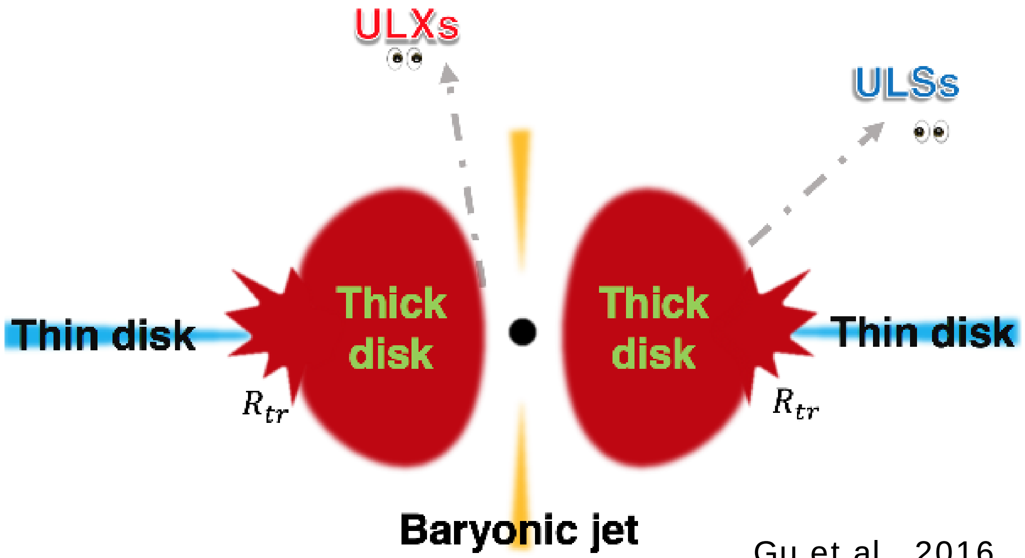


Full description of system ephemeris

Companion type known: constrains mass function!

A-sini known: constrains orbital size

→ Limit on inclination is about 30°!
→ Limits beaming factor (if orbital aligned with accretion disk!)
→ Constraints on "unified model" of ULXs



Gu et al., 2016

Summary & next steps

Ultra-luminous pulsar challenge our understanding of accretion (500x above Eddington limit)

Long circular orbit of P13 makes things even more complicated to explain!

- Measure the B-field via Ghosh & Lamb spin-up mechanism
- Investigate spectral changes as function of orbital phase
- Continue to follow-up period and refine the orbit

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First determination of full orbital ephemeris of ultra-luminous pulsar leaves scientists speechless.

X-ray timing reveals circular orbit of extremely bright neutron star: was Eddington wrong?