Pulsating ULXs: the most extreme accreting Neutron Stars

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Outline:

- Pulsating ULX
- XMM timing analysis: the sample of new X-ray pulsators
- The results of the ULX timing survey
- Implications/The future

ULXs and M82 X-2

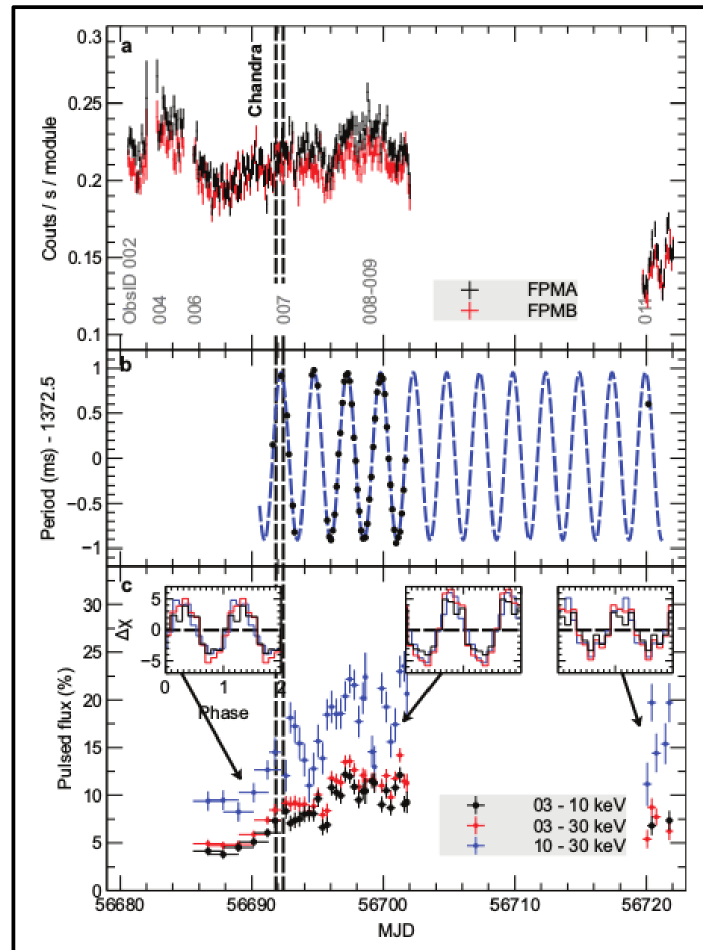
Non-nuclear X-ray sources (ULXs) in nearby galaxies with isotropic X-ray peak luminosities in excess of L Eddington for a NS (1.4 Msun) or a BH (10 Msun). ULXs are usually modeled as stellar-mass black holes accreting at very high rates or intermediate-mass black holes.

Pulsations at 1.3s discovered from NuSTAR obs of M82 X-2
Sinusoidal pulse shape; PF~20%

Lx~2e40 erg/s (@ 3.2Mpc) ~ 100 L_{Edd}
Pdot (secular) -2e-10 s/s
P/Pdot = 300yr
Porb = 2.5days
Mc > 5.2 Msun

ULXs are not only BHs

Listen also talks by Middelton & Bachetti tomorrow morning (Auditorium)



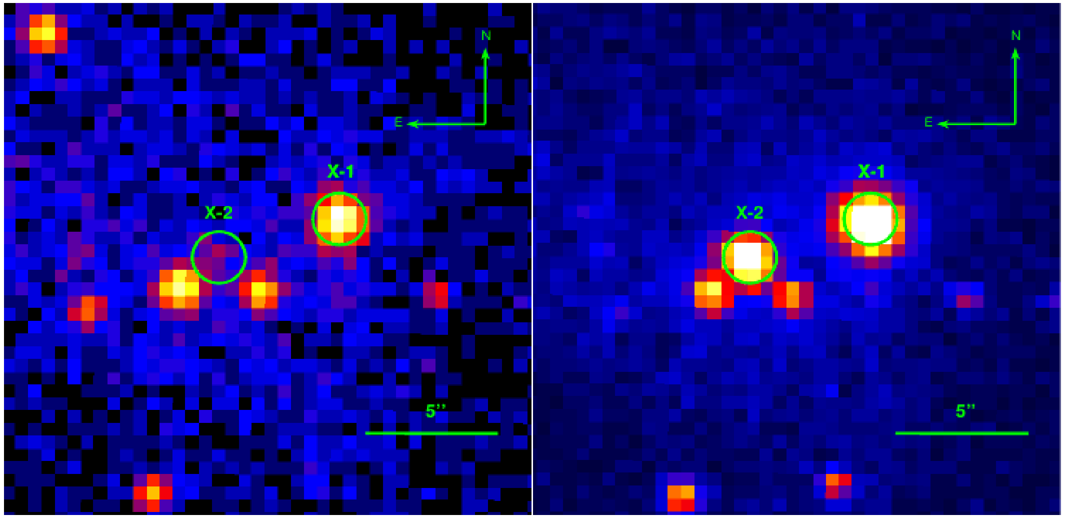
Bachetti+14

M82 X-2: B-field

Variable source with a **bimodal Lx distribution** likely due to the switch between surface and magnetosphere accretion (propeller effect).

The propeller onset and the ratio between the observed Lx of the two modes implies a magnetic field of:

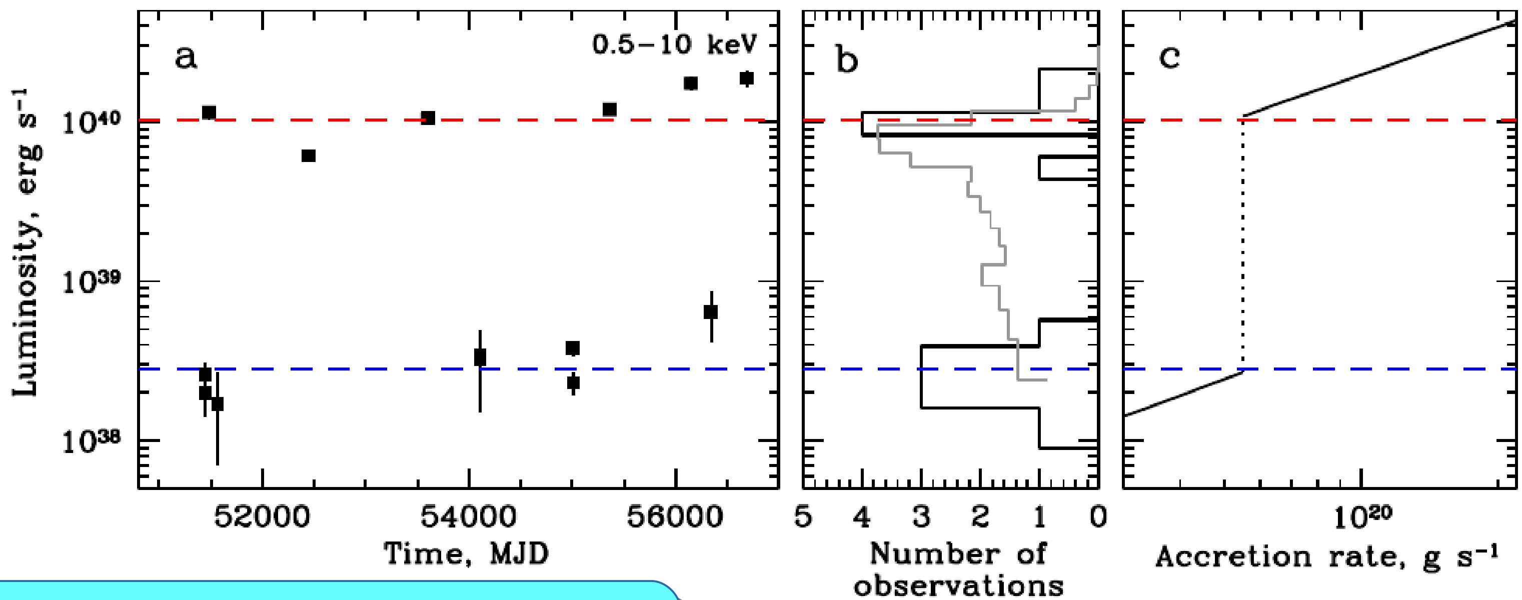
B ~ 10^{14} G



Tsygankov+16

$$L_{\rm lim}(R) \simeq \frac{GM\dot{M}_{\rm lim}}{R} \simeq 4\times10^{37} k^{7/2} B_{12}^2 P^{-7/3} M_{1.4}^{-2/3} R_6^5 \ {\rm erg\ s^{-1}}$$

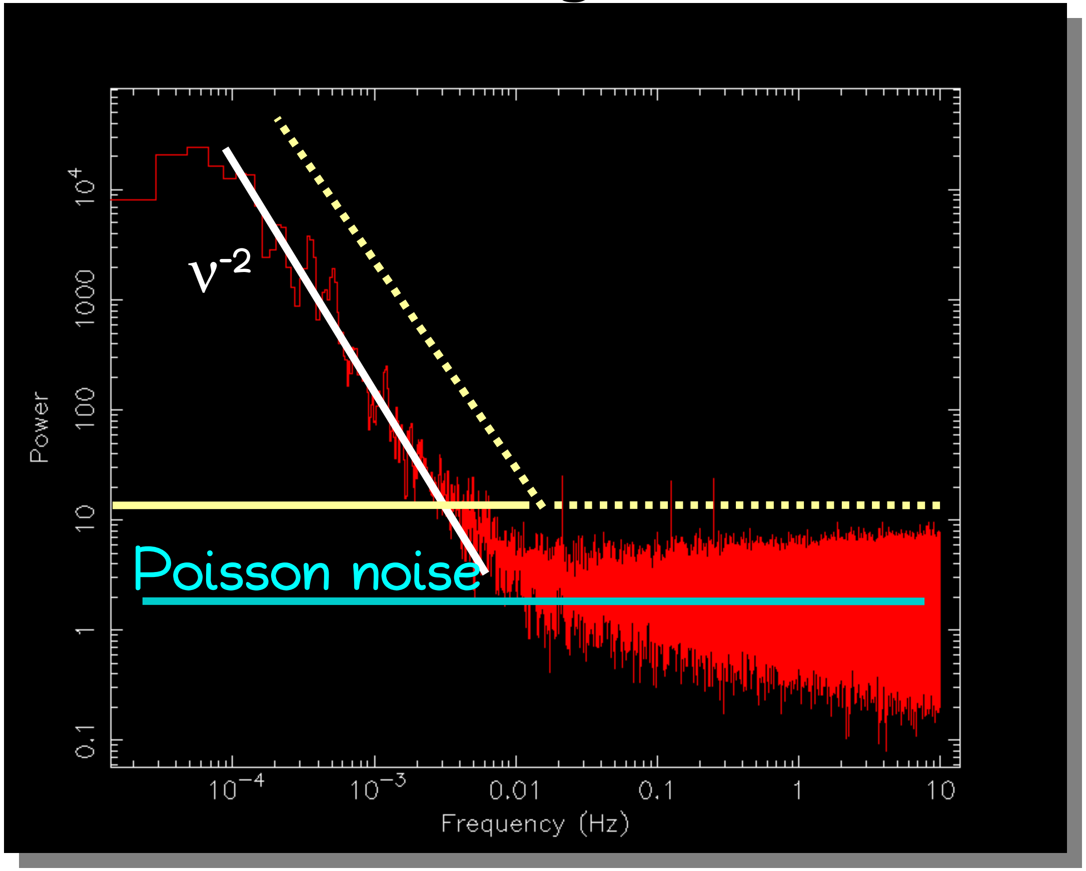
$$\frac{L_{\rm lim}(R)}{L_{\rm lim}(R_c)} = \left(\frac{GMP^2}{4\pi^2 R^3}\right)^{1/3} \simeq 170 P^{2/3} M_{1.4}^{1/3} R_6^{-1}$$



PULXs are highly magnetized accreting NSs (not necessarly Magnetar-like)

and the search for signals

EXploring the Transient x-ray Sky (fp7 funded project; 3Yr 2014-2016; PI Andrea De Luca, **listen talk tomorrow**).
Focused on the time variability of sources in the EPIC 3XMM catalog (~500,000).



We rely upon Fourier transforms plus an adhoc detection algorithm taking into account the PSD non Poissonian noise components and keeping the original time resolution

EXTraS WP3 in numbers:

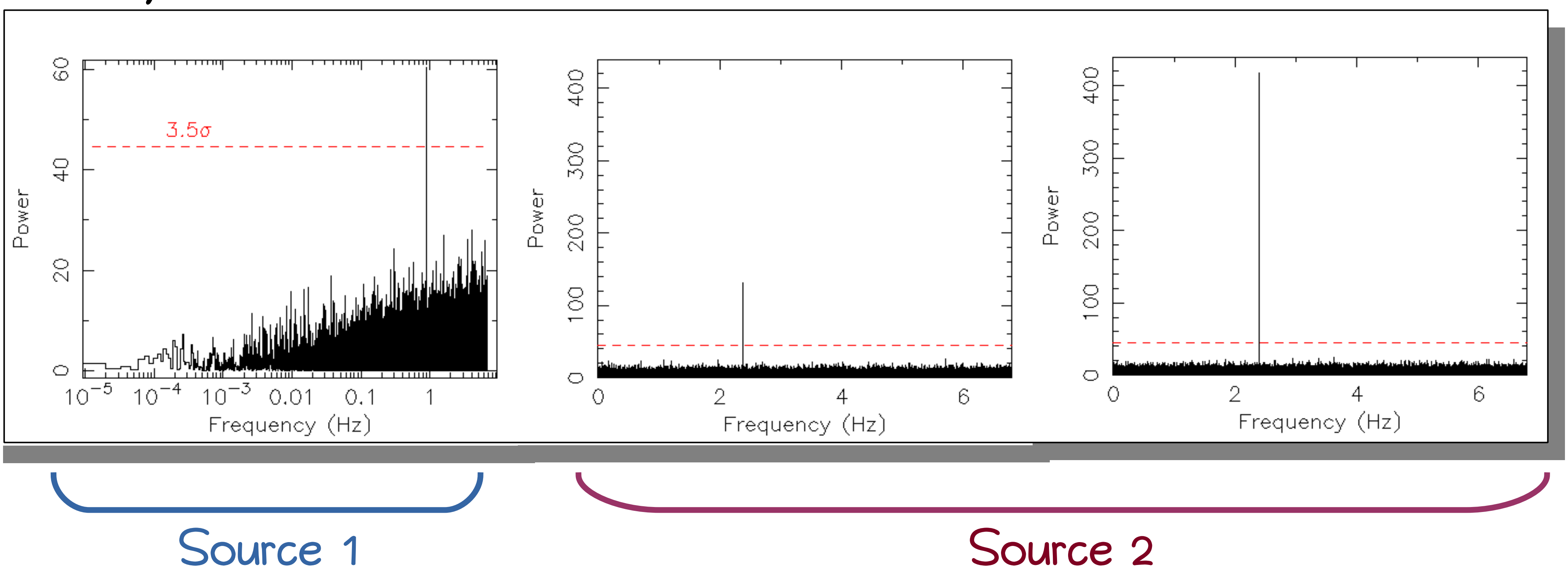
+ 15 years of public data
+ >10,000 datasets
+ >600,000 times series (TSs)
+ ~300,000 TSs with >50 photons searched for signals
+ >10 milions FFTs carried out (different searching modes)
+ ~150,000 peaks
+ ~60 new X-ray pulsators (still counting)

and the ULXs

About 500 XMM datasets including the position of cataloged or suspected ULX.

We simply checked all the peaks detected by our pipeline in the ~500 datasets

We found 3 significant peaks from two different sources (both known ULXs).



Source 1= NGC 5907 ULX

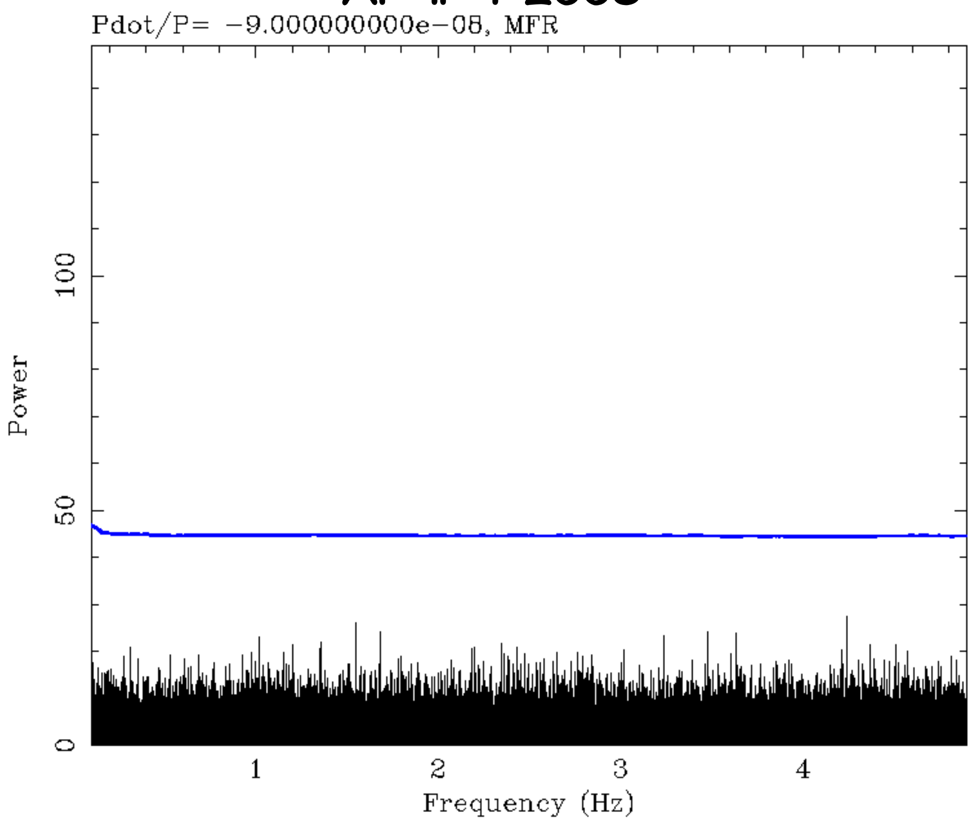
7 XMM pointings (6 source detection)+5 NuSTAR pointings (3 detection)

XMM data reveals a rather large Pdot of several -10^{-9} s/s

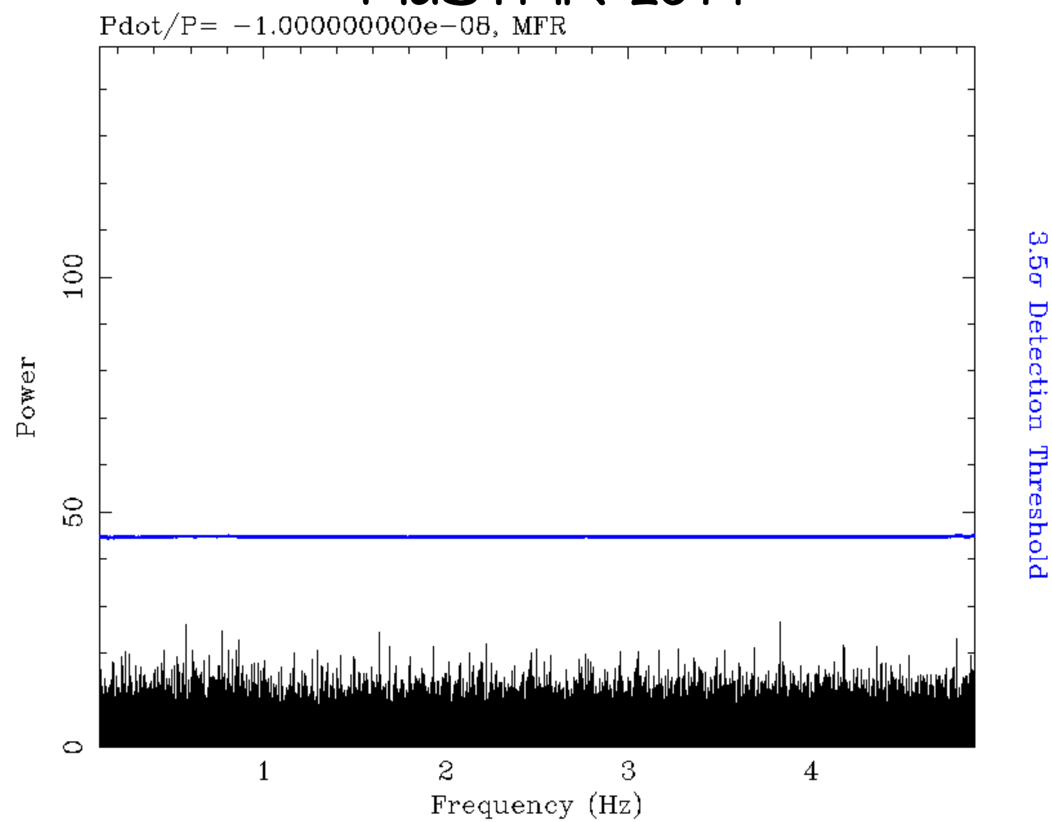
We applied an accelerated search on the 9 XMM+NuSTAR pointings

Detection of the signal in 2 XMM and 2 NuSTAR observations

XMM 2003



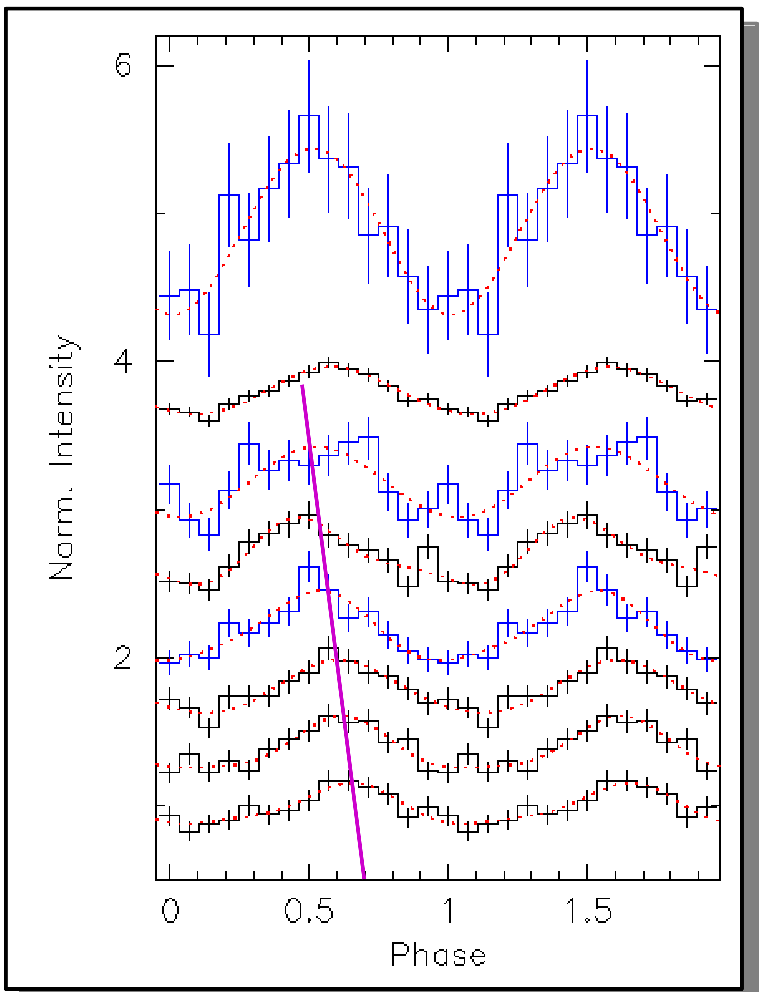
NuSTAR 2014



Pulsation properties

Almost sinusoidal pulse shape with pulsed fraction in the 10-20% range, increasing at high energies.

(Peak) Phase shift of about 0.2 between 0.2-2.5keV and 7-12keV

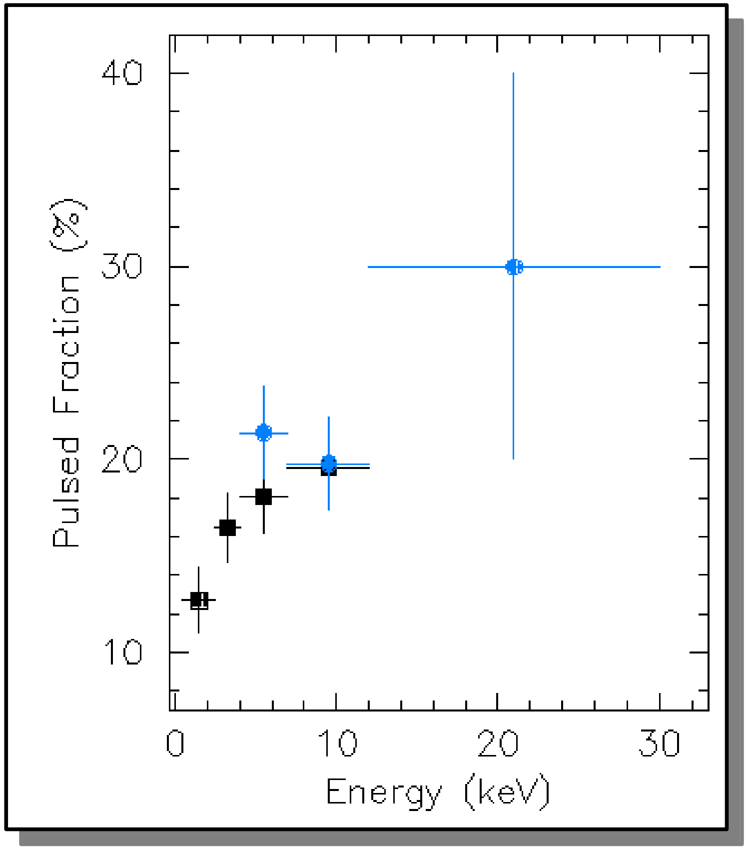


3-30keV NuSTAR

0.2-12keV XMM

7-12keV NuSTAR
7-12keV XMM
4-7keV NuSTAR

4-7keV XMM
2.5-4keV XMM
0.2-2.5keV XMM

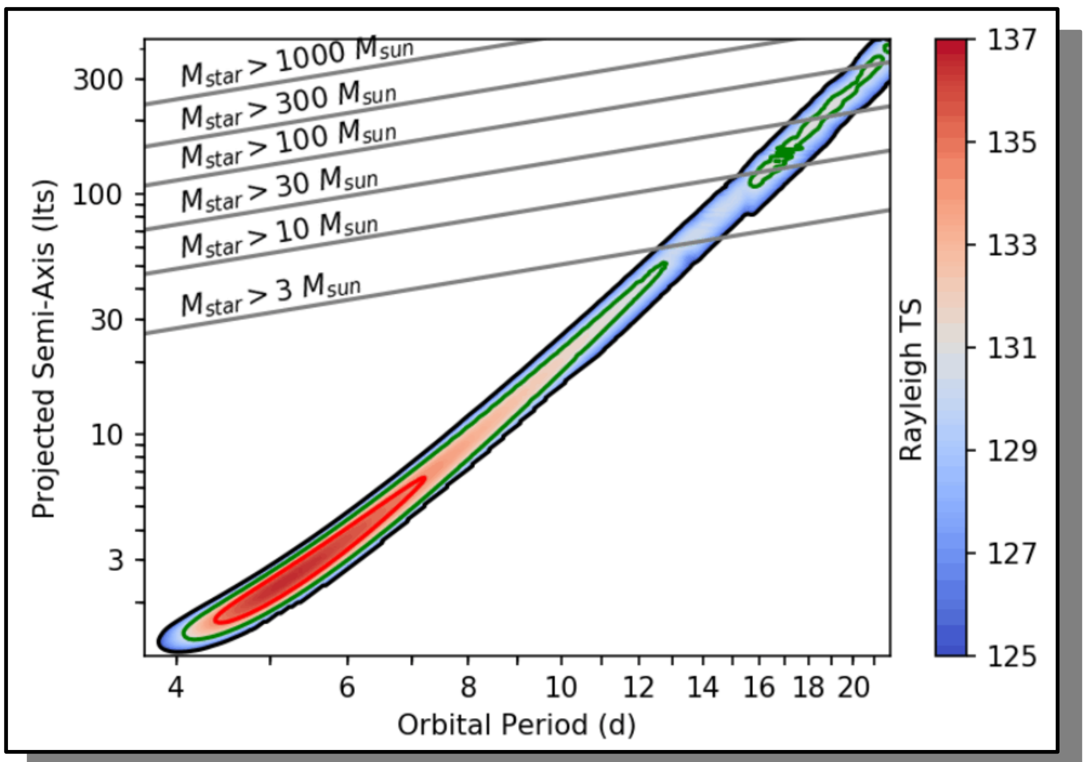


Main parameters

Start Date	2003 Feb. 28	2014 Jul. 09	2014 Jul. 09	2014 Jul. 12
Mission	*XMM–Newton*	*NuSTAR*	*XMM–Newton*	*NuSTAR*
Epoch (MJD)	52690.9	56848.0	56848.2	56851.5
P (s)	1.427579(3)	1.137403(1)	1.137316(2)	1.136041(1)
$\dot{P}$ (s s^{-1})^a $\times 10^{-9}$	-9.6(7)	-5.2(1)	-5.0(4)	-4.7(1)

Pdot(secular) =-8.1(1)e-10 s/s P/Pdot ~ 40 yr !!!

A factor of 10 lower than the local Pdot, suggesting an orbital contribution



Based on the 2014 NuSTAR obs. and a likelihood analysis a most probable Porb is inferred (circular orbit assumed)

Porb=5.3[+2.0,-0.9] days (1σ)

Longer orbits are NOT excluded though a 100Msun companion implies Porb<20days

GLI+17a

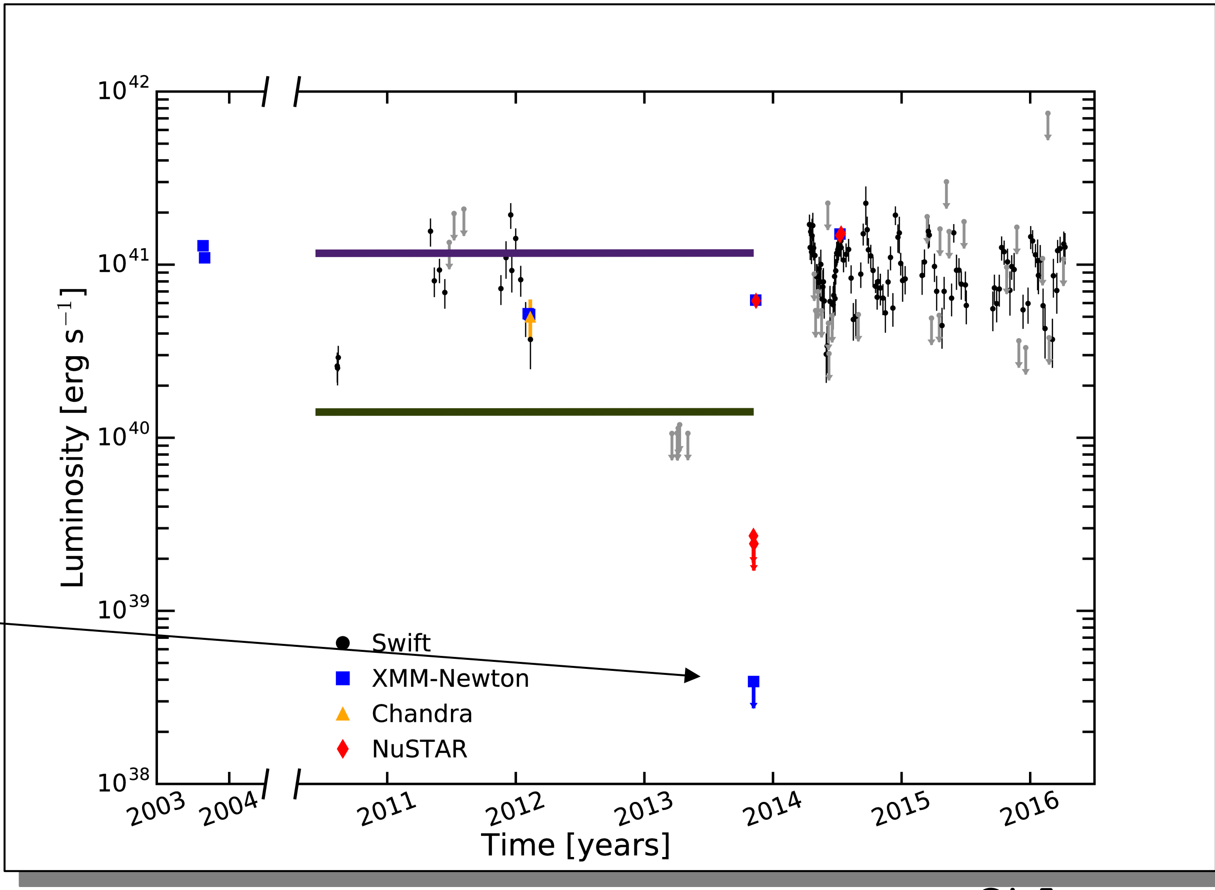
Luminosities

For a distance of 17.1Mpc the (isotropic) luminosity range is

Lx ~ 0.15×10^{41} - 1.6×10^{41} erg/s

With an upper limit of 3×10^{38} erg/s

Propeller regime expected at about 10^{37} erg/s



GLI+17a

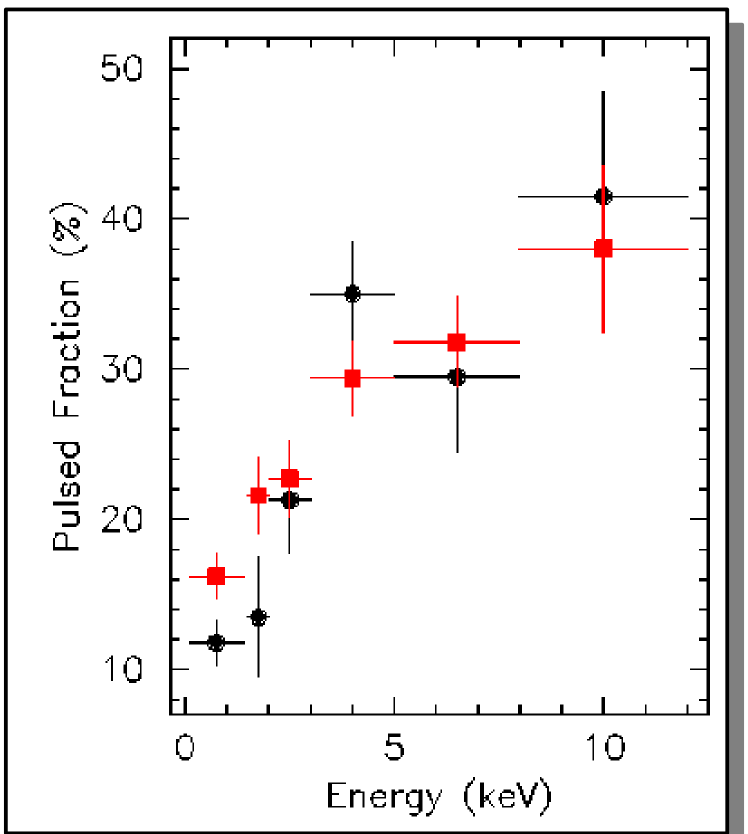
NGC5907 X-1 is therefore the most luminous and distant X-ray pulsar ever detected.

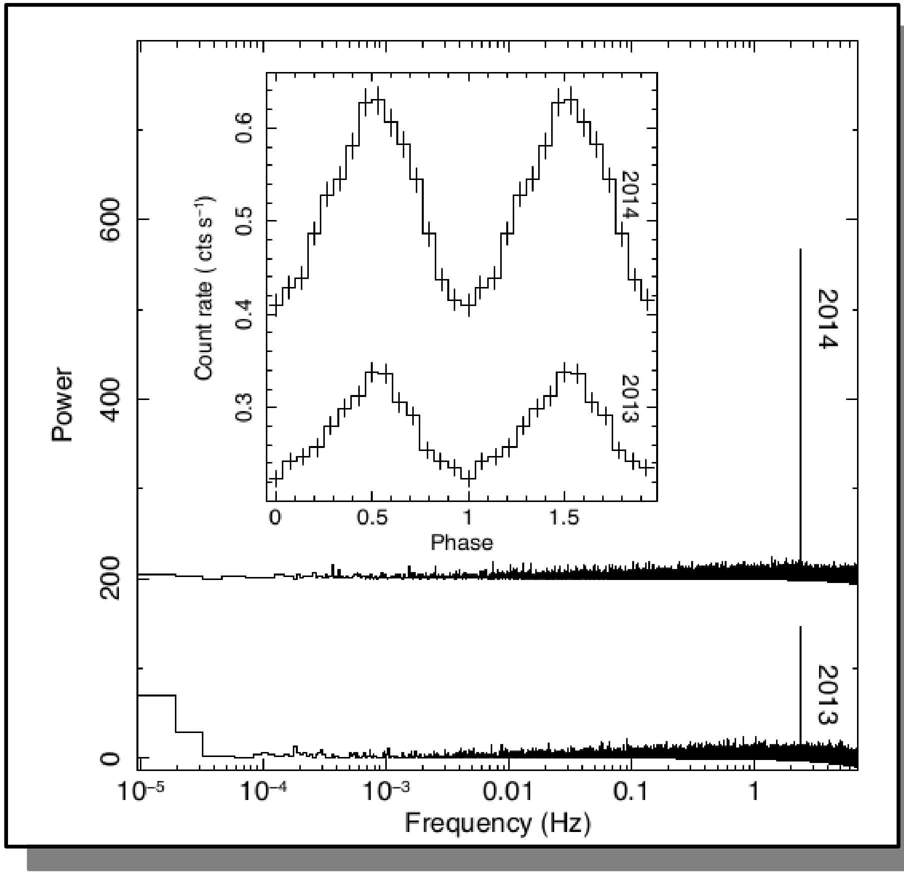
The peak (bolometric) luminosity is ~1000 times the Eddington luminosity

Source 2= NGC 7793 P13

Epoch (MJD TDB)	56621.0	57001.0
P (s)	0.4197119(2)	0.4183891(1)
ν (Hz)	2.382586(1)	2.3901207(6)
$\|\dot{P}\|$ $(10^{-11}$ s s$^{-1})$	<10	<5
$\dot{P}_{\rm sec}$ $(10^{-11}$ s s$^{-1})$	−4.031(4)	
Pulsed fraction (%)[a]	18(1)	22(1)

P/Pdot~320 yr





Almost sinusoidal pulse shape with energy-dependent pulsed fraction: 10-50%

(GLI+17b; also Fuerst et al. 2016)

Luminosities

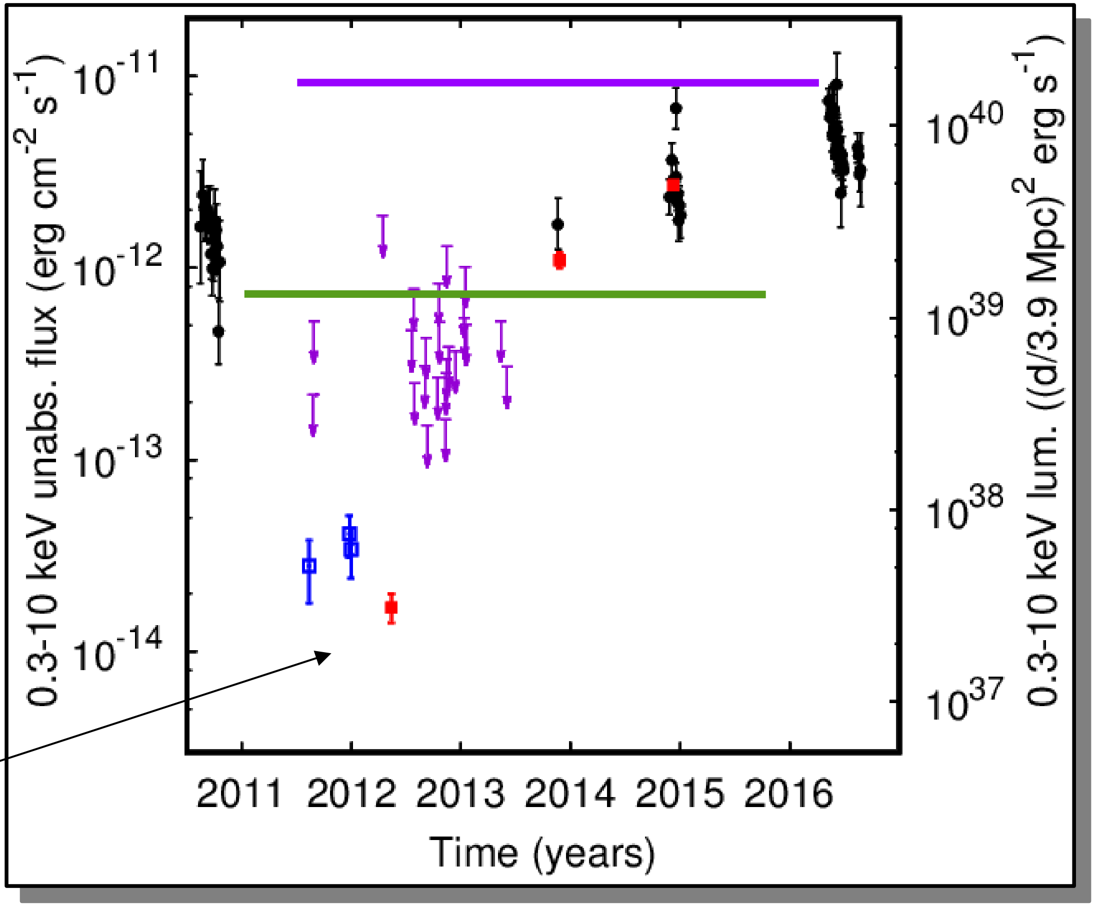
Known Porb: 64 days (Motch et al. 2014) though some concerns do exist

~20Msun B9Ia companion

For a distance of 3.9 Mpc the Isotropic Lx range is

Lx ~ 9×10^{39} and ~1.6×10^{40} erg/s

With a faint state at about 3×10^{37} erg/s



GLI+17b

Propeller regime is expected at 2×10^{37} erg/s consistent with the lowest observed fluxes

Luminosities

NGC5907 X-1 isotropic peak Lx is **1000** times L_{Edd}
NGC7793 P13 isotropic peak Lx is **500** times L_{Edd}

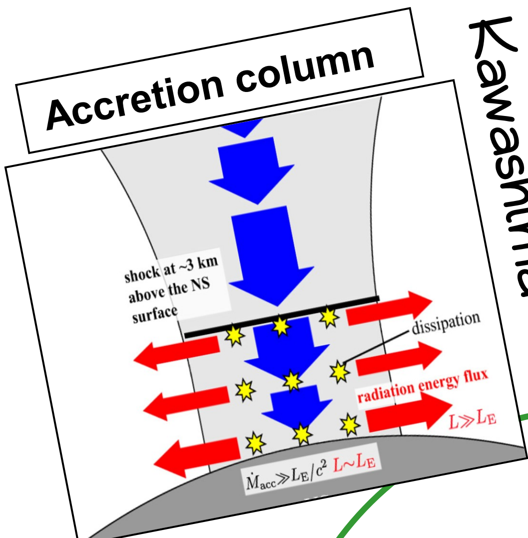
In principle, if B is high enough the electron scattering cross section is reduced (in the extraordinary mode for $E<E_{cyc}$).

For B = few x10^{15} G up to 10^{41} erg/s can be released on the NS surface ...

... however with that B value and 1.13s spin period **the NS in NGC5907 ULX should be deeply in the propeller phase!**

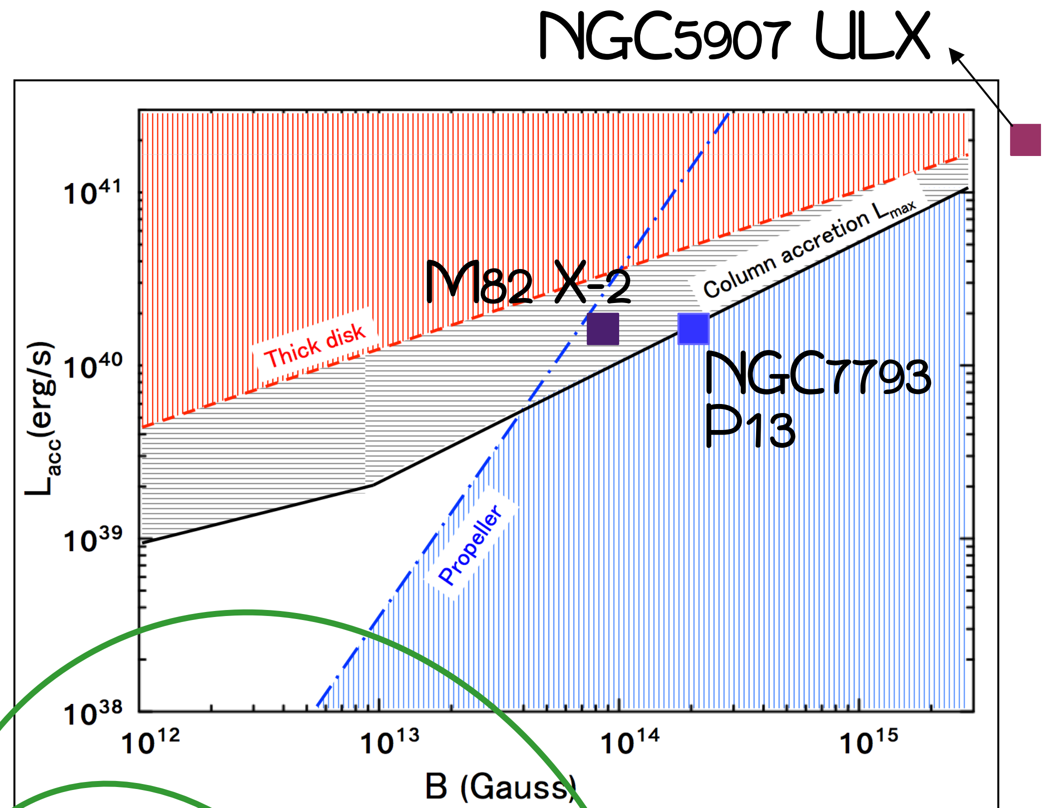
Accretion

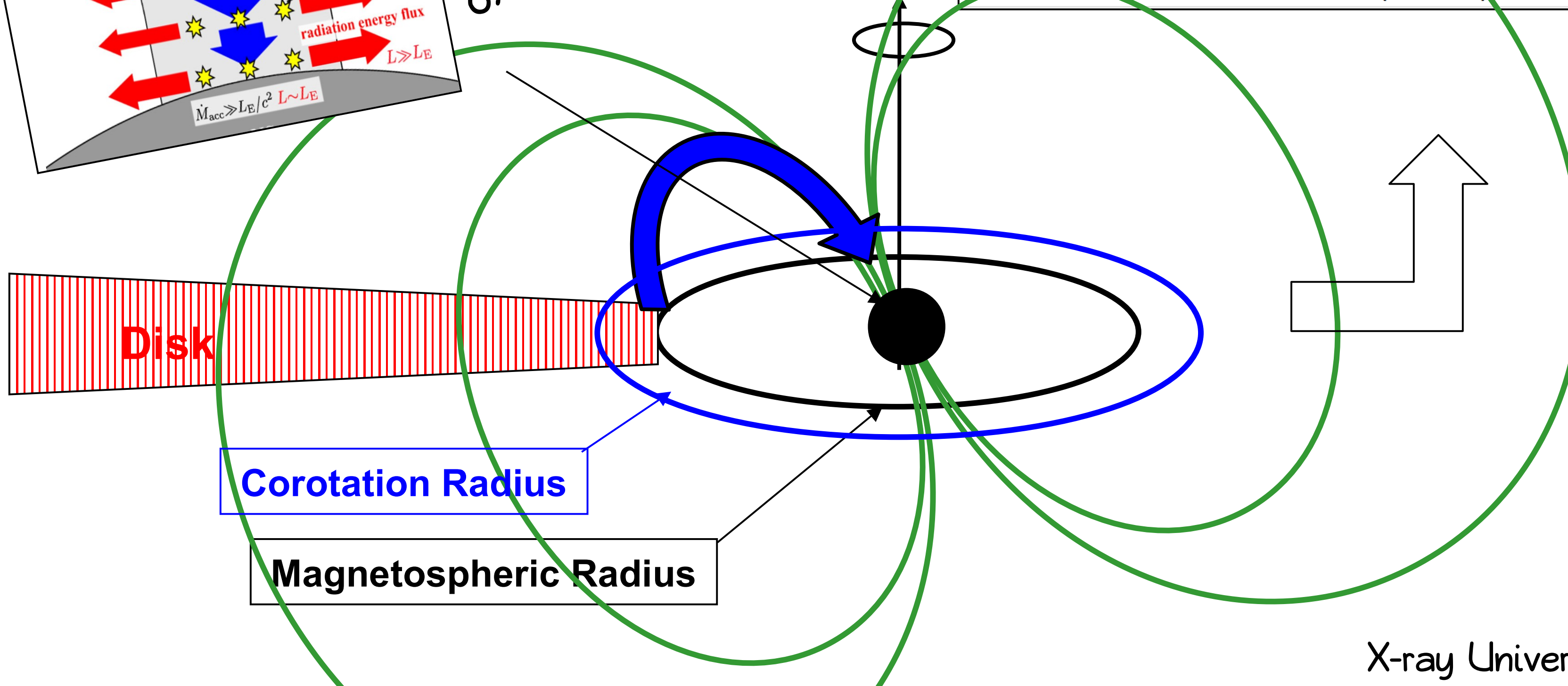
Conditions for superEddington accretion onto rotating magnetic neutron stars
(Mushtukov et al. 2015)



Kawashima+16

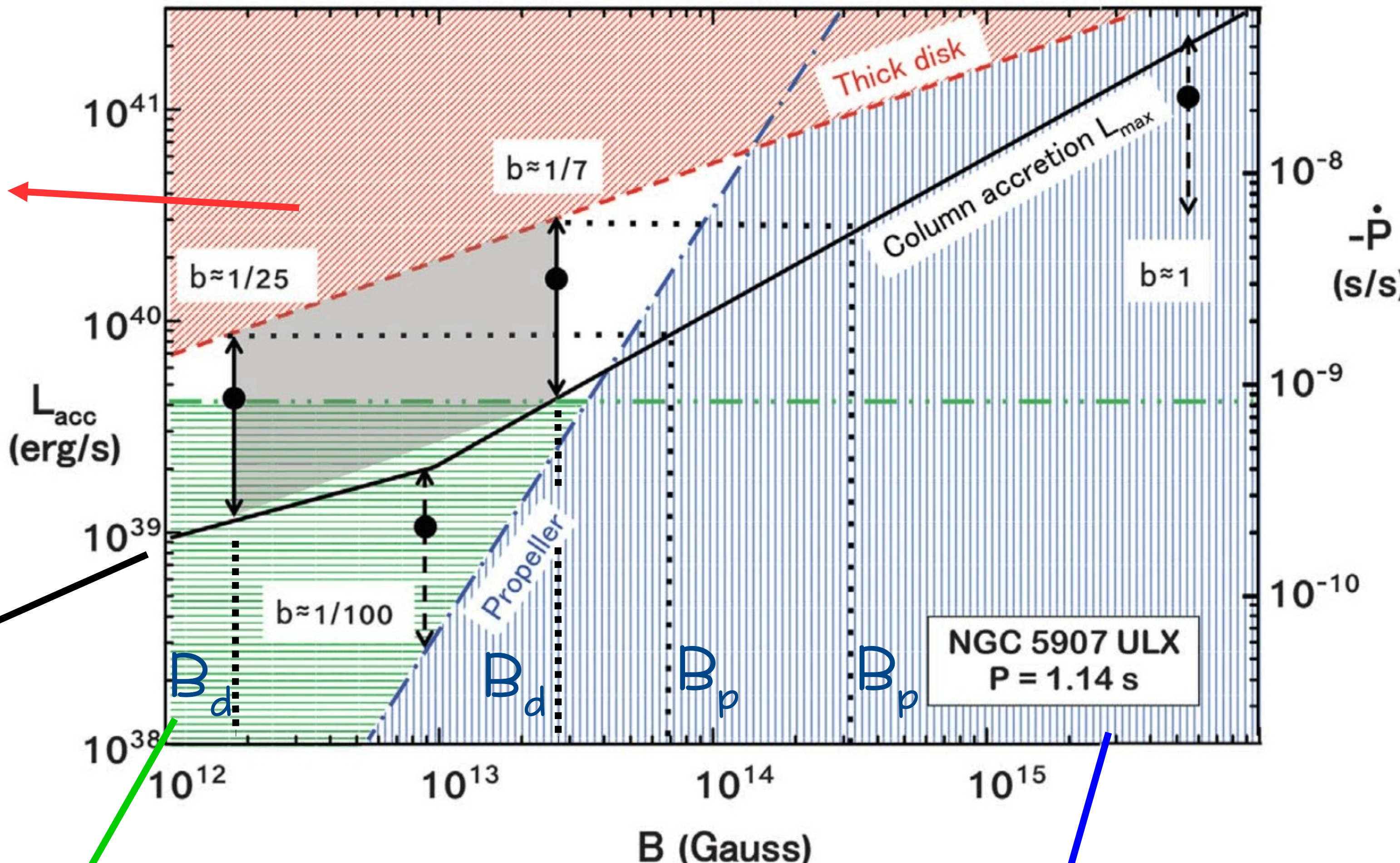
Fan beam emission is consistent with the almost sinusoidal shape observed in the 3 PULXs





Possible scenario for NGC5907 ULX

Super-Eddington emission from the disk; escaping radiation stopped



Maximum Lx atteinable by the accretion column

Minimum Mdot in order to obtain the observed Pdot

Propeller regime: no accretion possible on the NS surface, no pulsations

Listen talk by Zampieri tomorrow

Possible scenario

Expected **dipolar B component** (close to the Magnetospheric boundary) of the order of

NGC5907 ULX: (0.7 - 3.0)e12 G @ b~1/10-1/7
NGC7793 P13: (0.3 - 0.5)e12 G @ b~1/6-1/2

Multipolar B component (close to the surface/bottom of the accretion column) of the order of

NGC5907 ULX: (3-30)e13 G
NGC7793 P13: (2-10)e13 G

Some implications/Conclusions

+ Even extreme ULXs (>1e41 erg/s), like NGC5907 ULX, can hosts an accreting NS

+ Spectral classification is not an unambiguous way to classify ULXs: both NGC 5907 ULX and NGC7793 P13 have ULX spectra not that dissimilar from other ULXs (but harder; **see poster by Pintore**).

+ The large "local" Pdot, the orbital effects, the pulse intermittance make difficult the detection of these pulsars with standard tools.

+ Pulsed fractions increases with Energy making hard X-ray imaging likely an important channel to discover them

+ Pulsars with luminosity of hundreds times the Eddington one challange the current models of accretion onto NS, even assuming realistic beaming factors.

Future directions

The probability that other ULXs host a pulsating NS is high.
The probability of being able to detect pulsations from them is likely small.
XMM is by far the best imaging instrument for searching PULXs: time resolution/psf/throughput combination

Based on the timing properties of the 3 PULXs we are carrying out an ad hoc timing analysis which also takes into account a (large) Pdot component: Pulsation Accelerated Search for Timing Analysis - PASTA

PASTA is currently being applied to the EXTraS time series of all known or suspected ULXs (by means of the CINECA supercomputer). It will be also applied to NuSTAR data.Joint collaboration with Bachetti and FuerstTeam