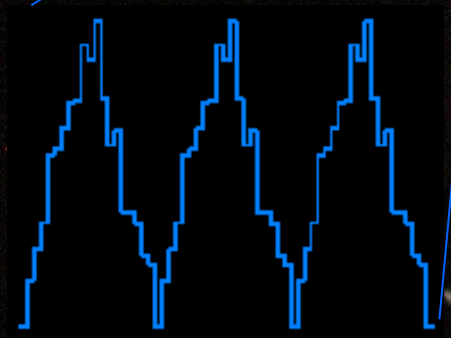
The Extragalactic population of NS: the ULX paradigm revolution



Main questions:

Why PULXs are so Luminous ?

How many NSs among ULXs ?

GianLuca Israel
(AO Roma)
.... and any many other colleagues
(EXTrAS and UNSEEN collaboration)

Outline:

- ULX/PULX class
- too B or not too B
- UNSEEN preliminary results

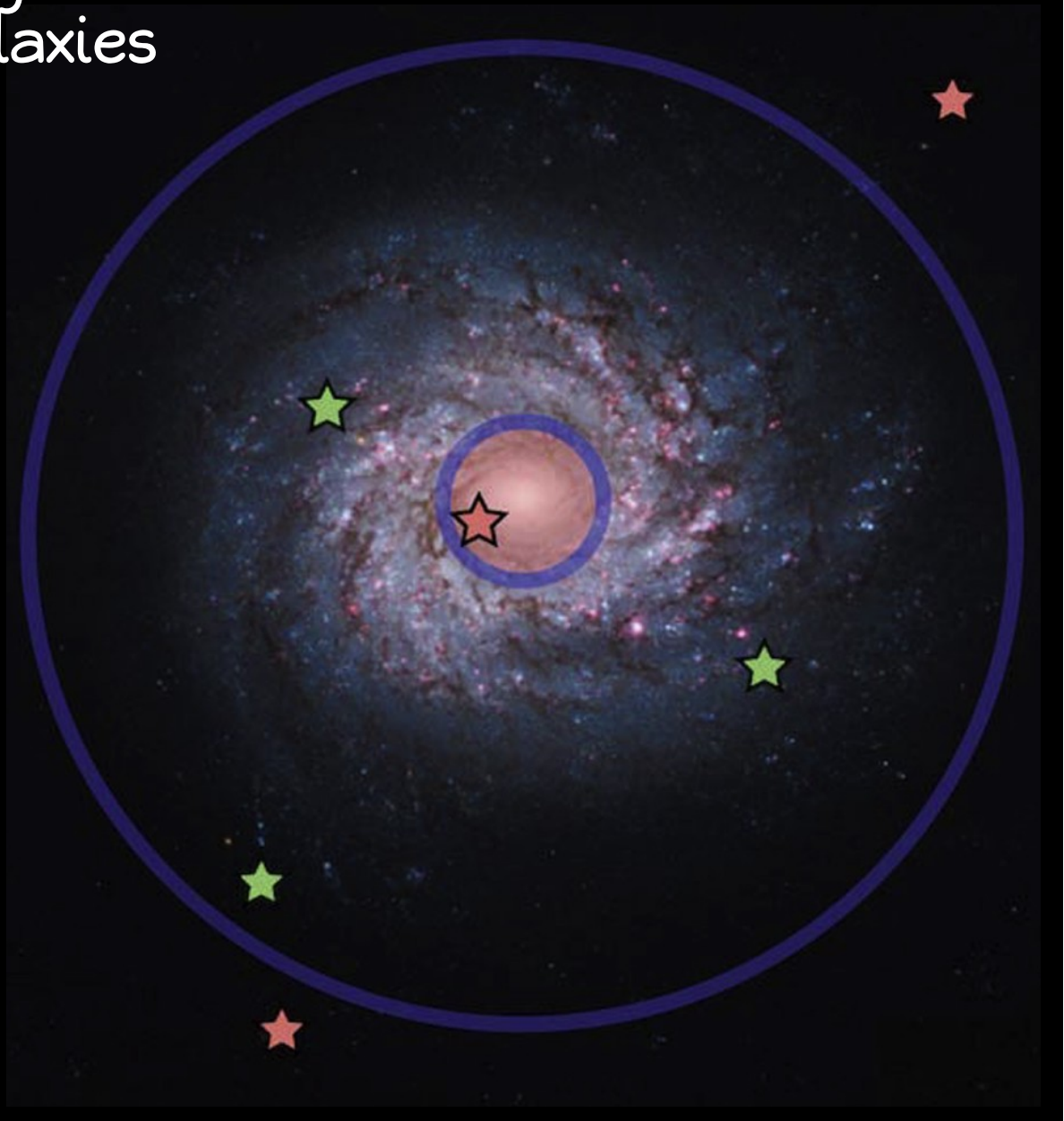
ULX class

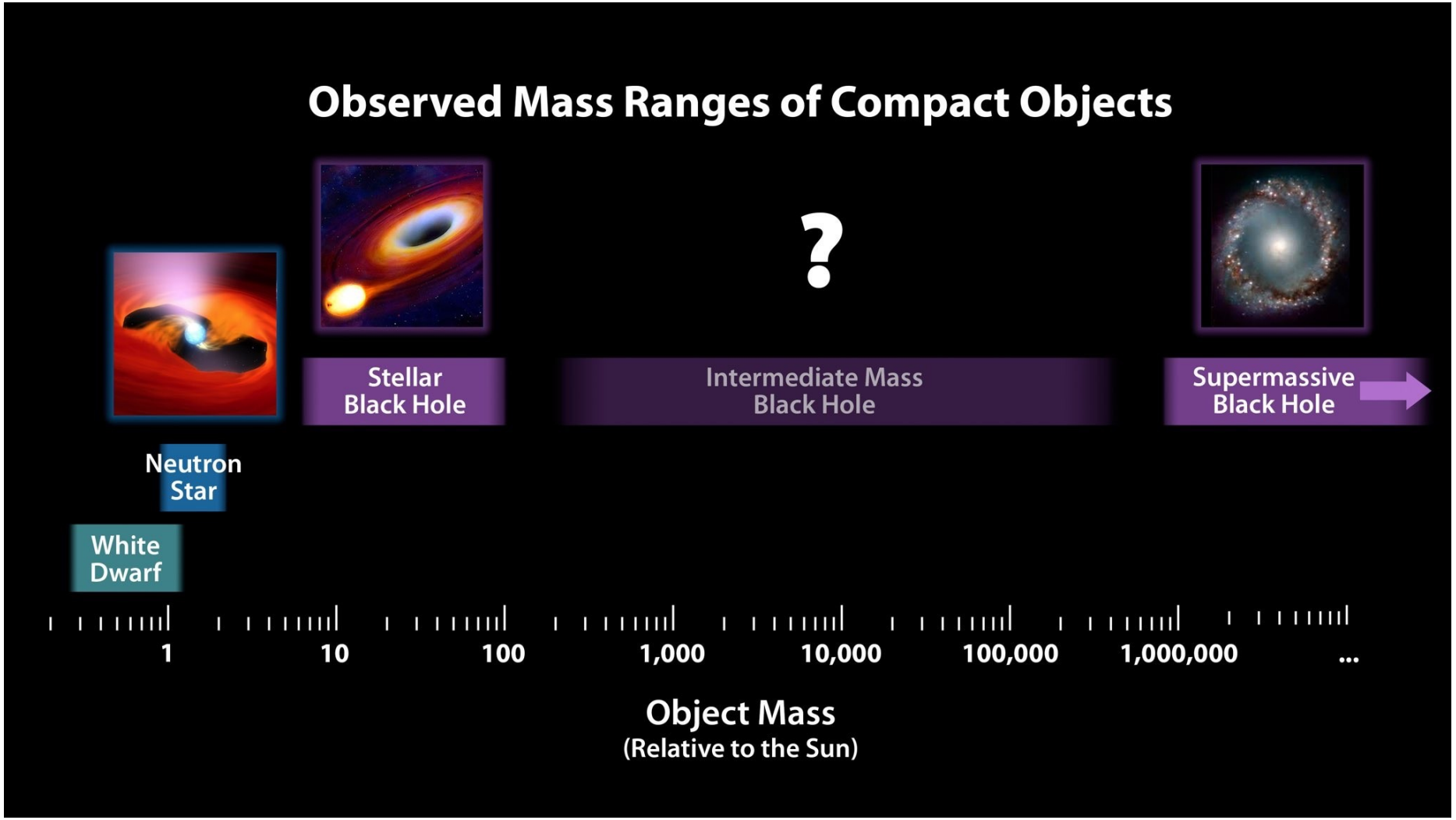
Ultraluminous X-ray sources are *off-nuclear, point-like* X-ray sources in nearby ($d \leq 100$Mpc) galaxies exceeding the (isotropic) Eddington limit for a stellar-mass Black Hole (StBH) of $10 M_\odot$

$L_{ULX} > 3 \times 10^{39}$ erg/s up to ~10^{42} erg/s

About 300 objects (Earnshaw+ 18)

First detected by EINSTEIN (Fabbiano 88)





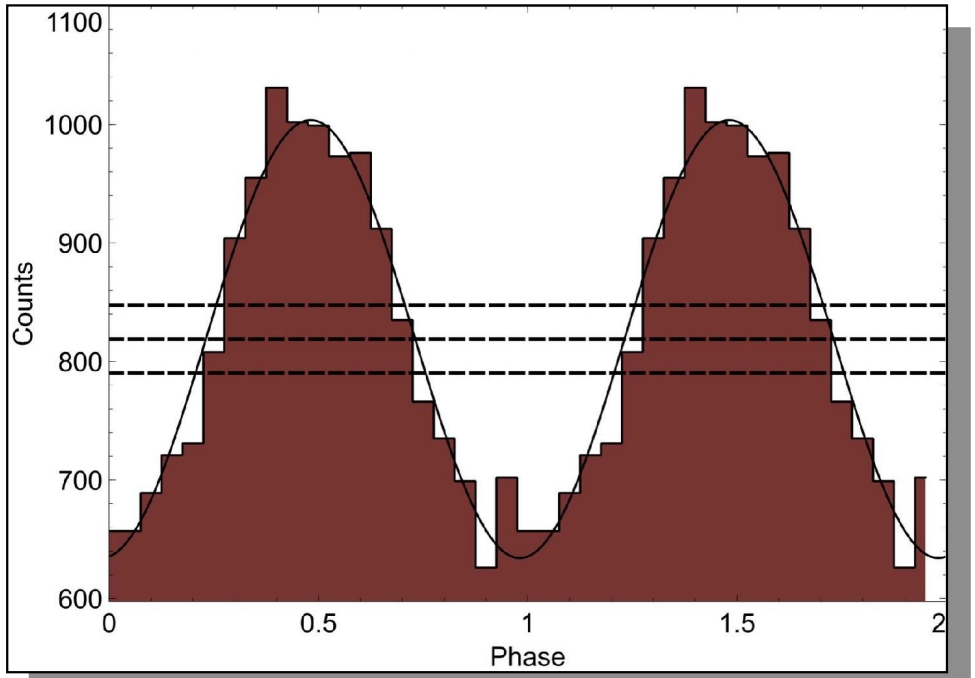
IMBHs needed to form SMBHs in quasars at z>6-7
(Pacucci+ 17)

.. for 25years everybody was convinced of the BH nature of ULXs...

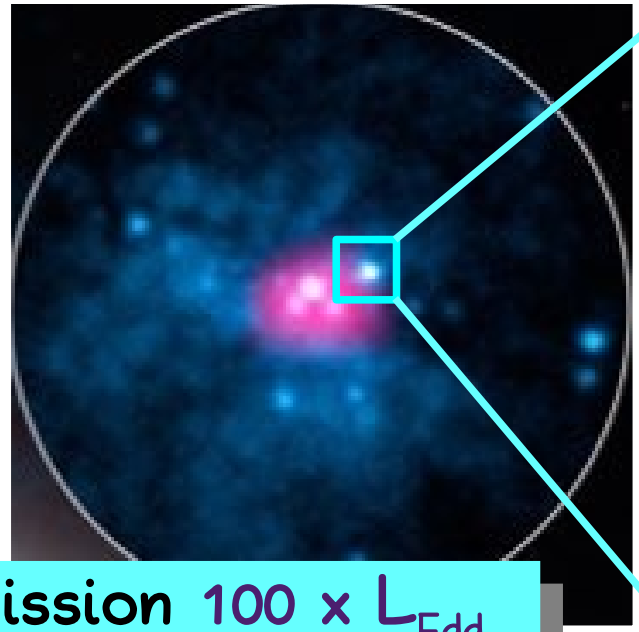
In 2014

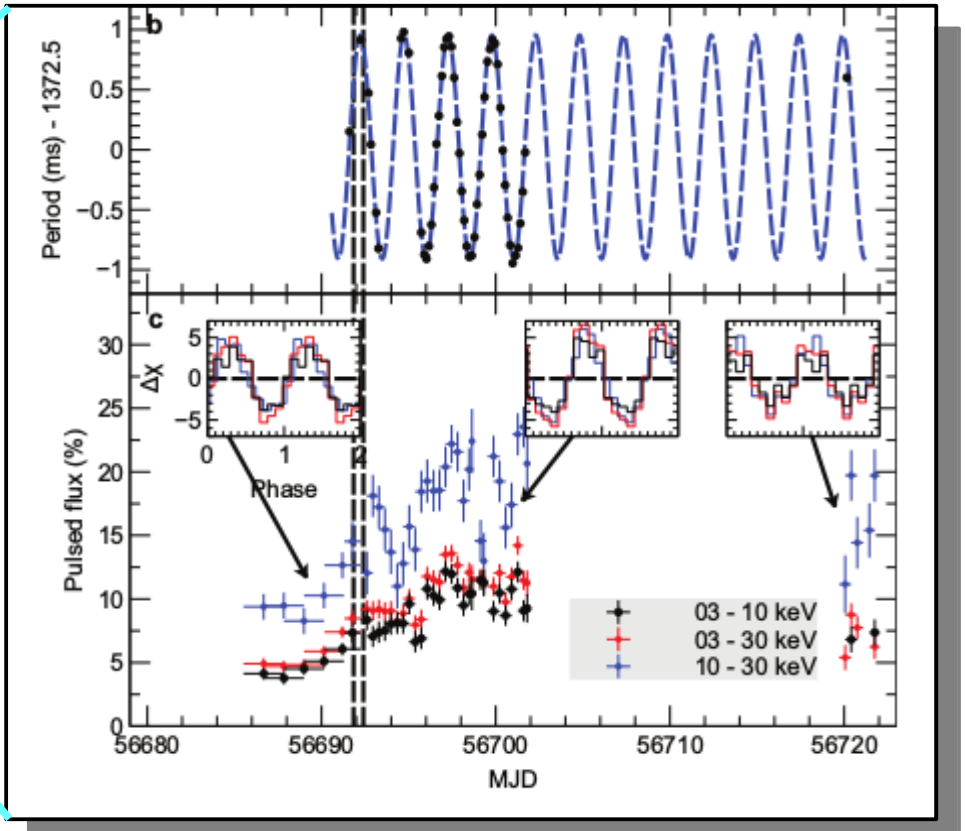
~~A long time ago~~ in a galaxy far, far away. . . .

ULXs and M82 X-2



Pulsations at 1.37s discovered from NuSTAR obs of M82 X-2
Sinusoidal pulse shape; PF~20%
Lx~2e40erg/s (@3.2Mpc)~ 100 L_{Edd}
Pdot (secular) -2e-10 s/s
P/Pdot = 300yr
Porb = 2.5days
Mc > 5.2 $M_{\odot}$





PULX emission 100 x L_{Edd}

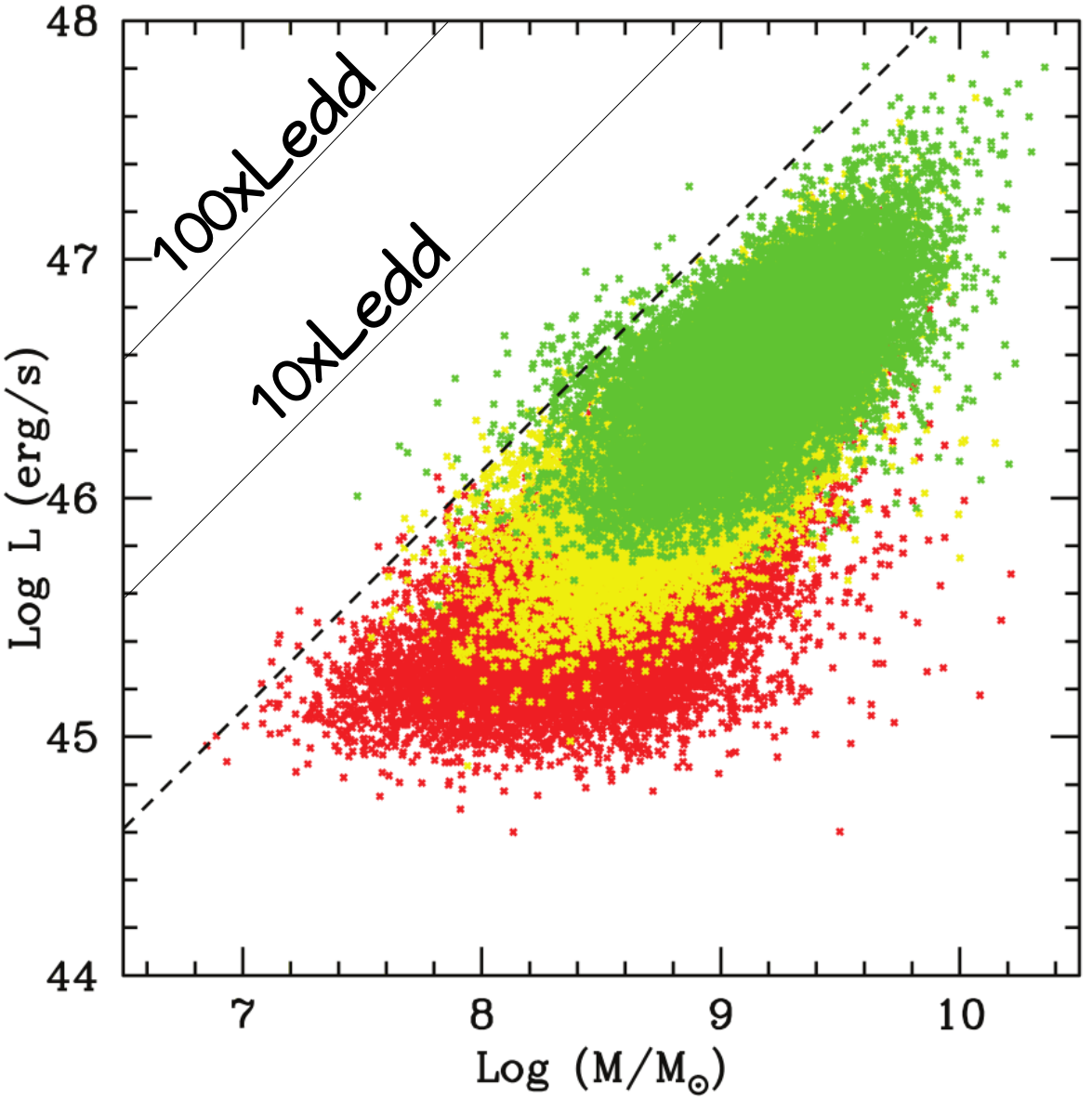
ULXs are not BHs only !!

Bachetti+14

BHs and Ledd

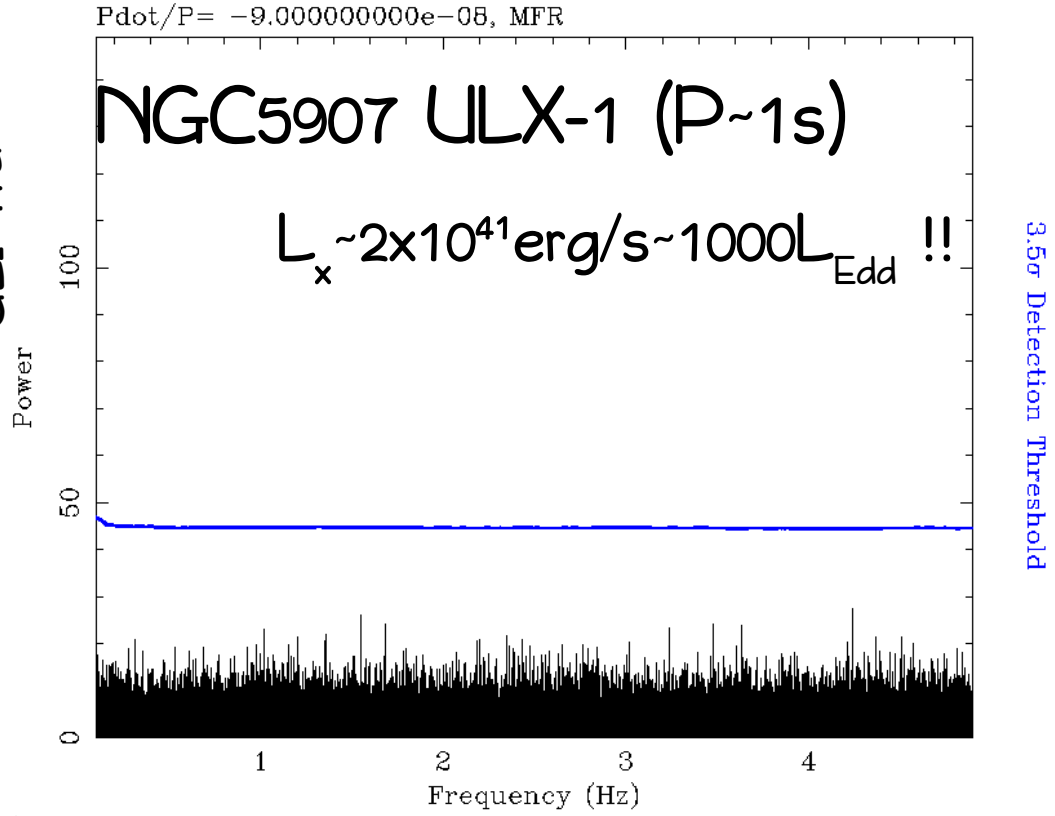
62,000 quasars (BHs) at different z.
Even assuming the uncertainties in the distances and in the virial mass determination NONE of them is above the Ledd by a factor of 10 or 100.

(Steinhardt & Elvis 10)



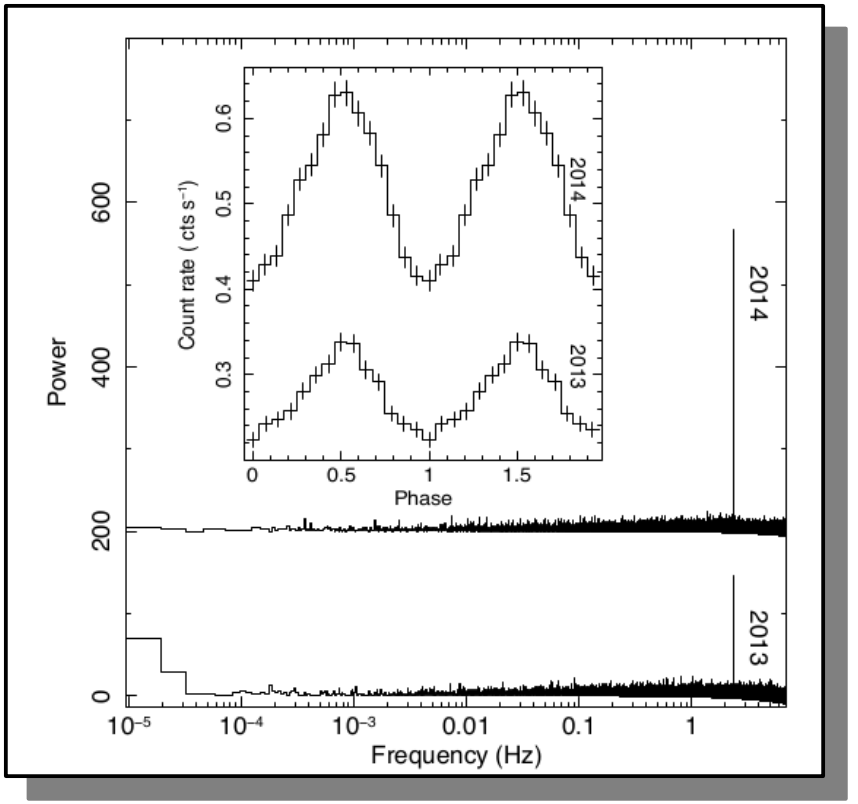
More PULXs discovered

GLI+17a



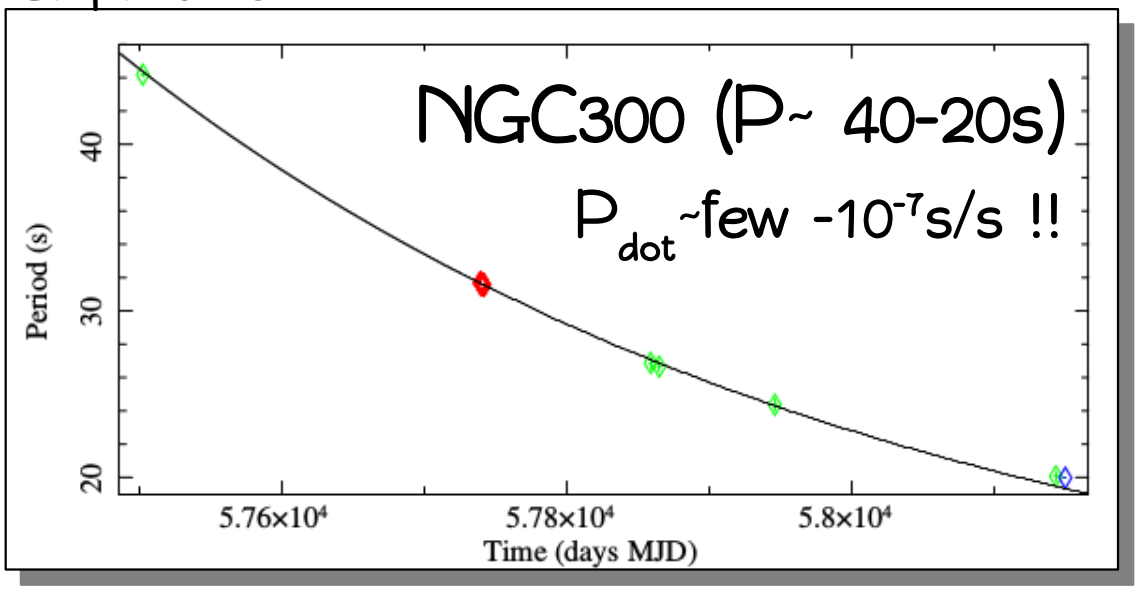
+ 2 transient pulsars in NGC1313 (766s) and NGC2403 (18s) with L_x~few 10^{39} erg/s (Trudolyubov 2008,2010)

(GLI+17b, Fürst+ 16)



NGC7793 P13 (P~0.42s)

Carpano+18



PULXs overall properties

	M82 X-2	NGC 7793 P13	NGC 5907 ULX1	NGC300 ULX1
Pulse Period	1.37s	0.42s	1.1s	40-20s
Spin-up (Ṗ)	2×10^{-10} s/s	3.5×10^{-11} s/s	8×10^{-10} s/s	$6x10^{-7}$
Orbital Period	2.5 d	64d	5.3 d	Long or face-on
Superorb. P.	63.8 d	?	78 d	?
Max. Luminosity	2×10^{40} erg/s	6×10^{39} erg/s	$>10^{41}$ erg/s	$5x10^{39}$ erg/s
Min. Luminosity	$<2.5\times10^{38}$ erg/s	$\sim4\times10^{37}$ erg/s	$<4\times10^{38}$ erg/s	transient
Optical Comp.	M > 5 $M_\odot$	SG B9I	M $\lesssim$ 30$M_\odot$	M<20M⊙
References	Bachetti et al. 2014; Brightman et al. 2017; Dall'Osso et al. 2015	Fürst et al. 2016; Israel et al. 2017a	Israel et al. 2017b; Fürst et al. 2017; Walton et al. 2015	Carpano+ 18

Not easy to identify convincing similarities....

Lx > 10^{39} erg/s and likely massive companions (HMXB or IMXB)

Luminosities

NGC5907 X-1 isotropic peak Lx,bol is **1000** times L_{Edd}
NGC7793 P13 isotropic peak Lx,bol is **500** times L_{Edd}
M82 X-2 isotropic peak Lx,bol is **100** times L_{Edd}
NGC300 X-1 isotropic peak Lx,bol is **50** times L_{Edd}

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

$$L_{\mathrm{Edd},B}(r) \simeq 2 L_{\mathrm{Edd}} \left(\frac{B}{10^{12}\ \mathrm{G}}\right)^{4/3}$$

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

A moderate beaming factor b<1 (b*Liso=Lacc) is also likely present (at least because we see pulsations),
1/10<b<1/100 (King+ 2001)

Moreover, with that B value and 1.13s spin period **the NS in NGC5907 ULX should be deeply in the propeller phase ($r_m >> r_c$)!**

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

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

NGC5907 ULX: **(3-30)e13 G**

Accretion stream is channeled by the dipolar field on large scale but feels the quadrupolar component on small scales (polar region)

Fiore+19 show that the scenario is possible (numerical calculation)

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p-CRSFs detected in magnetars → B~1-10x10^{14} G close to the surface, 10 timeslarger then their dipolar component (Tiengo+13).

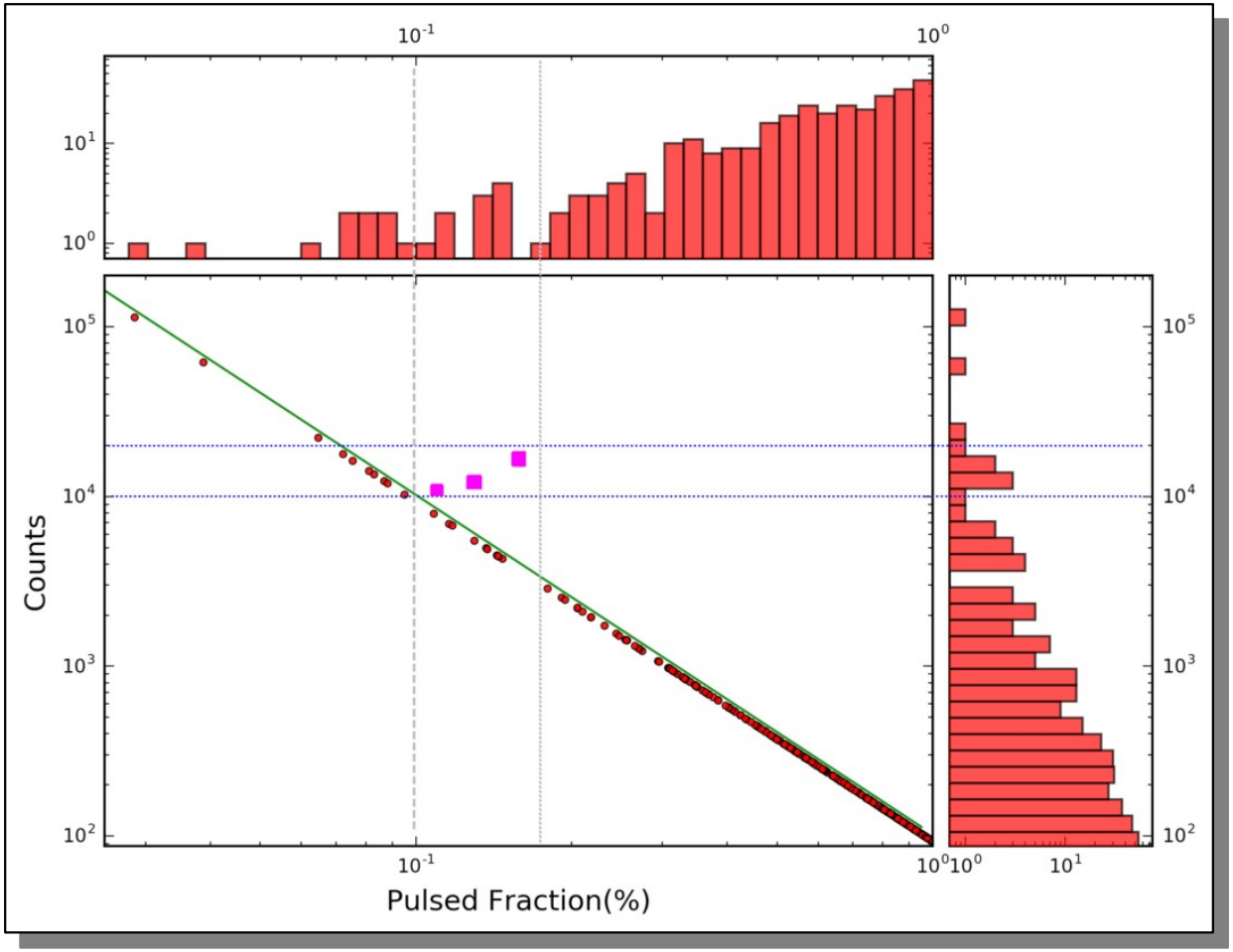
Super-Eddington outburst of SMC X-3 (Tsygankov+17):
Dipolar (1-5x10^{12} G) + Multipolar (2-3x10^{13} G) components

New directions

How many PULXs?
4 out of 300, ~1% ?

We detected PULXs in observations with at least 10,000 counts (XMM)

How many ULXs with such statistics?



14 ULXs (<5% of all known ULXs) → 29% are PULXs

How many ULXs with a statistics such that pulsations with 20% pulsed fractions might be detected?

18 ULXs → 21% are PULXs

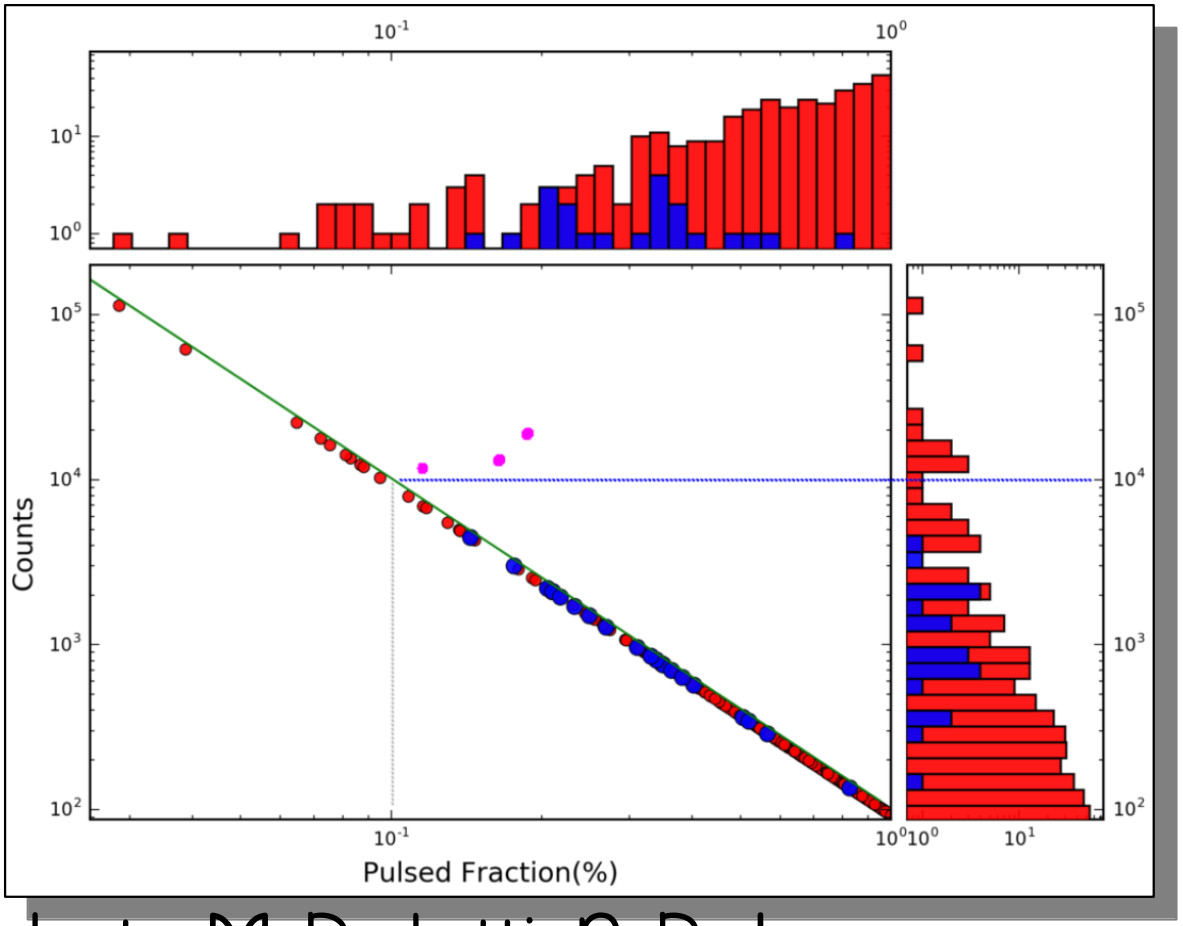
Not all pulsars are expected to be beamed towards us.

Taking the beat of the UNSEEN

UNSEeN:
Ultraluminous
NS Extragalactic
Extreme populatioN

Recently accepted as LP in AO17:

8 pointings + **3** DDTs
986.000 seconds
274 hours
~15 ULXs (>10.000 cts)
~30 additional S-Edd sources
1-3 new PULXs expected to be detected!



Just completed

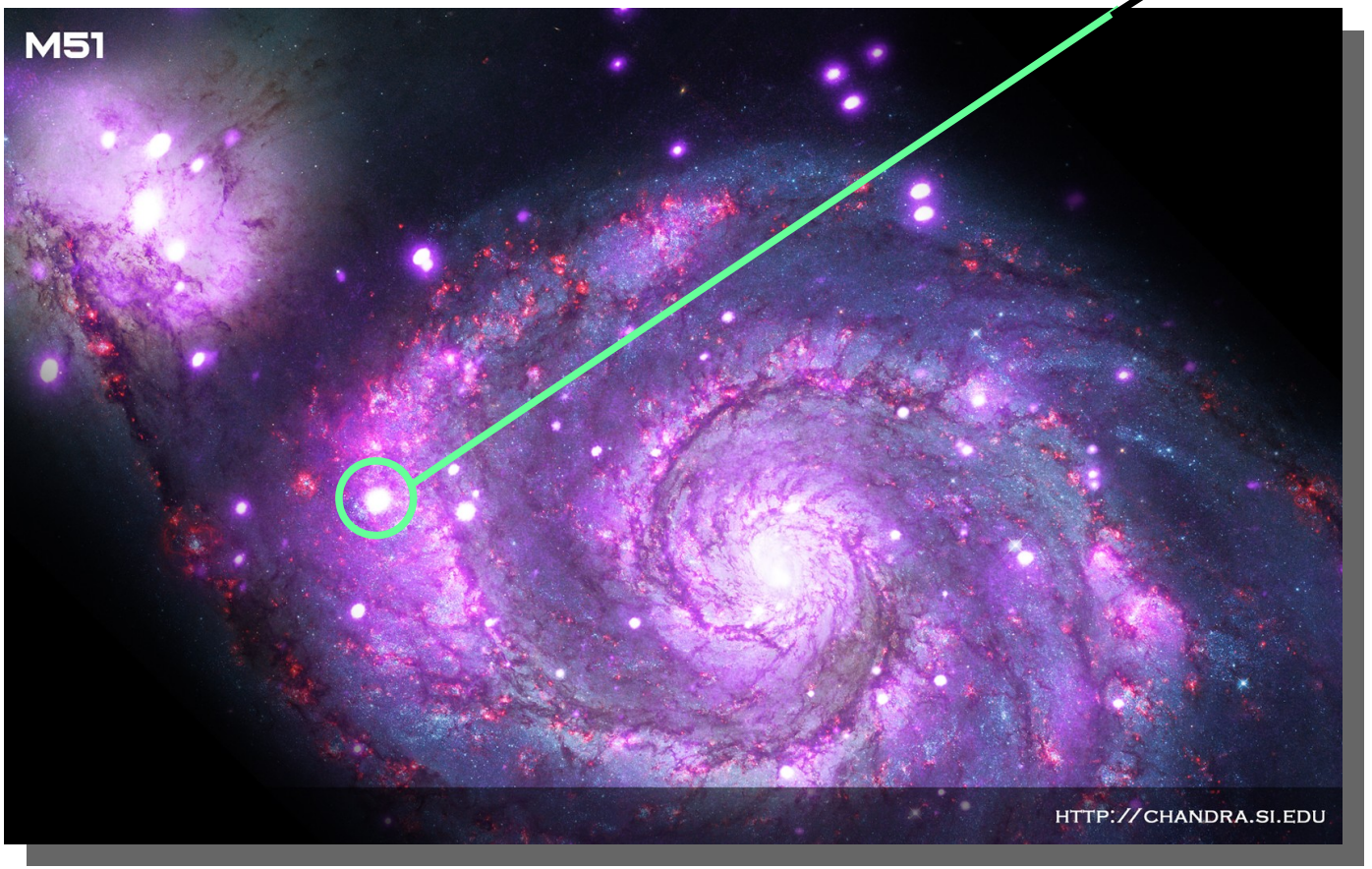
The UNSEEN Collaboration:
G.L. Israel, G. Rodriguez, F. Bernardini, H. Earnshaw, T. Roberts, M. Bachetti, A. De Luca, A. Tiengo, A. Belfiore, R. Turolla, M. Mapelli, L. Zampieri, F. Pintore, M. Middelton, P. Esposito, F. Fuerst, D. Walton, P. Casella, S. Dall'Osso, D. Dagostino, G. Novara, R. Slavaterra, F. Harrison, M. Brightman, C. Pinto, F. Haberl, M. Marelli, A. Walter, L. Stella, A. Papitto

XMM LP

M51 observed in May 2018 for about 75ks

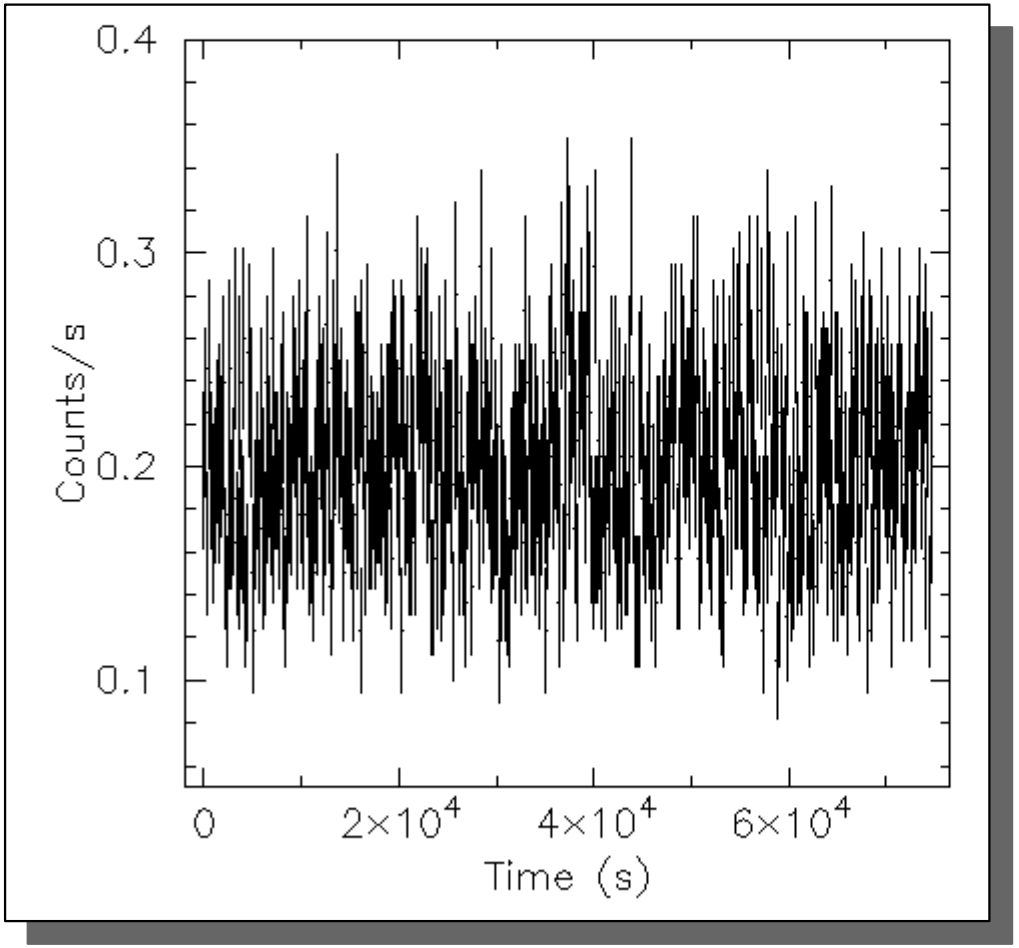
+ 3 DTT (96+63+64ks) requested on in June 2018

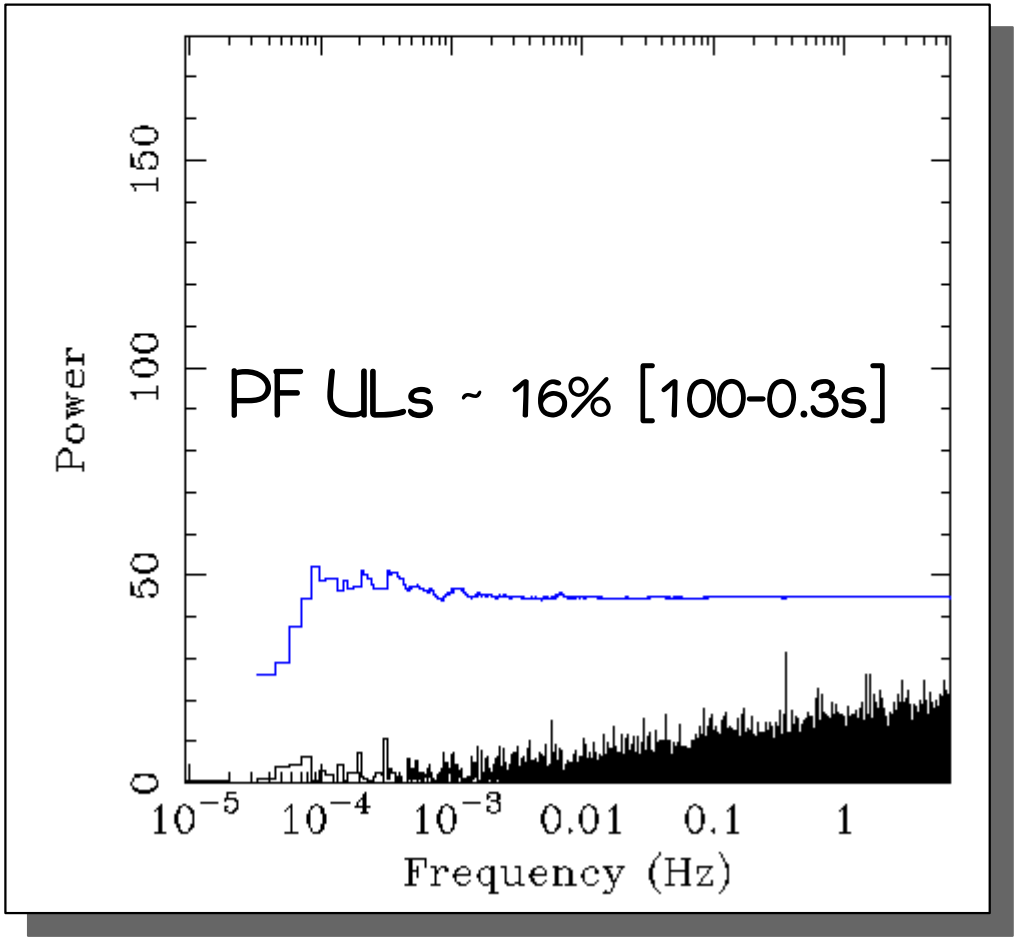
ULX7: a variable source: L_X peaks at almost 10^{40} erg/s



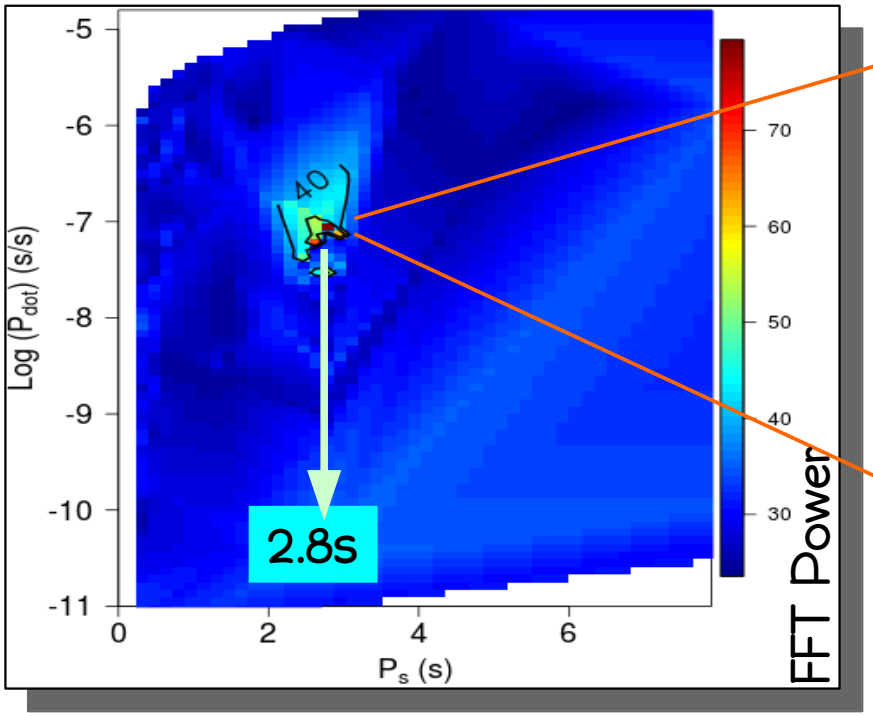
M51 ULX7

One of the best example of Poissonian process and white noise !

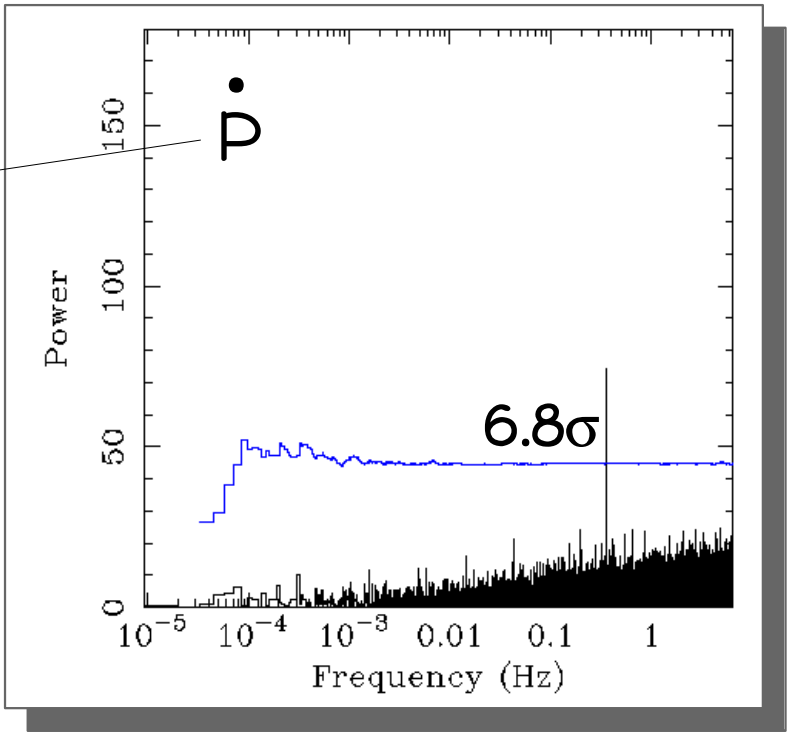


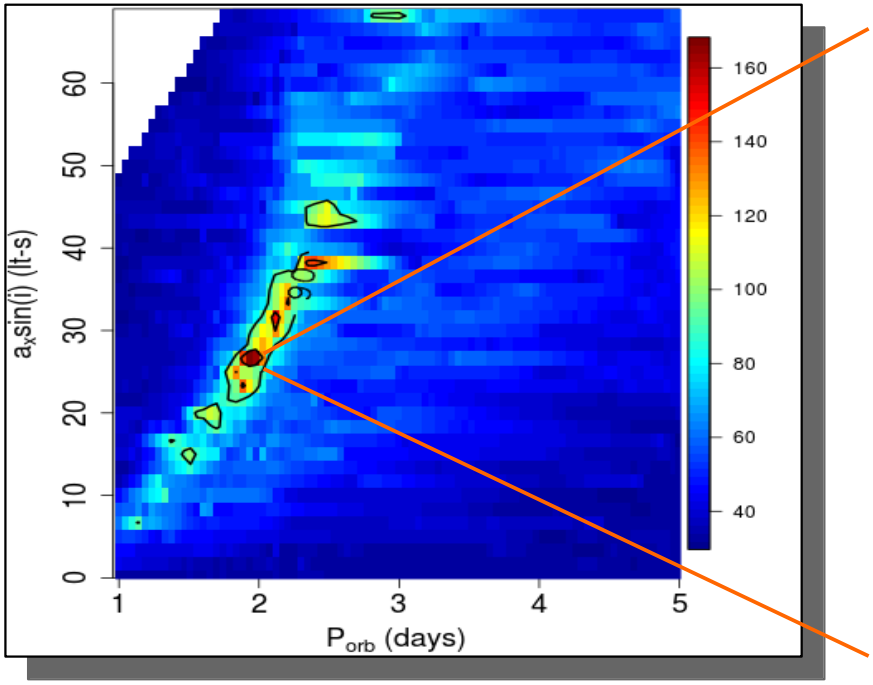


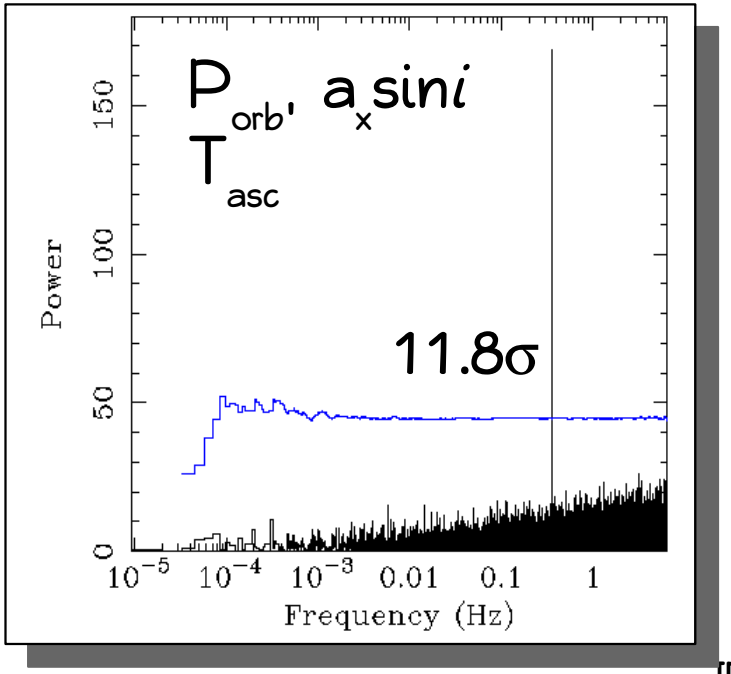
Accelerated search



Dominated by orbital motion







Up to 10^6 FFTs needed to cover the 4D phase space.

Use of HPCs

Some implications/Conclusions

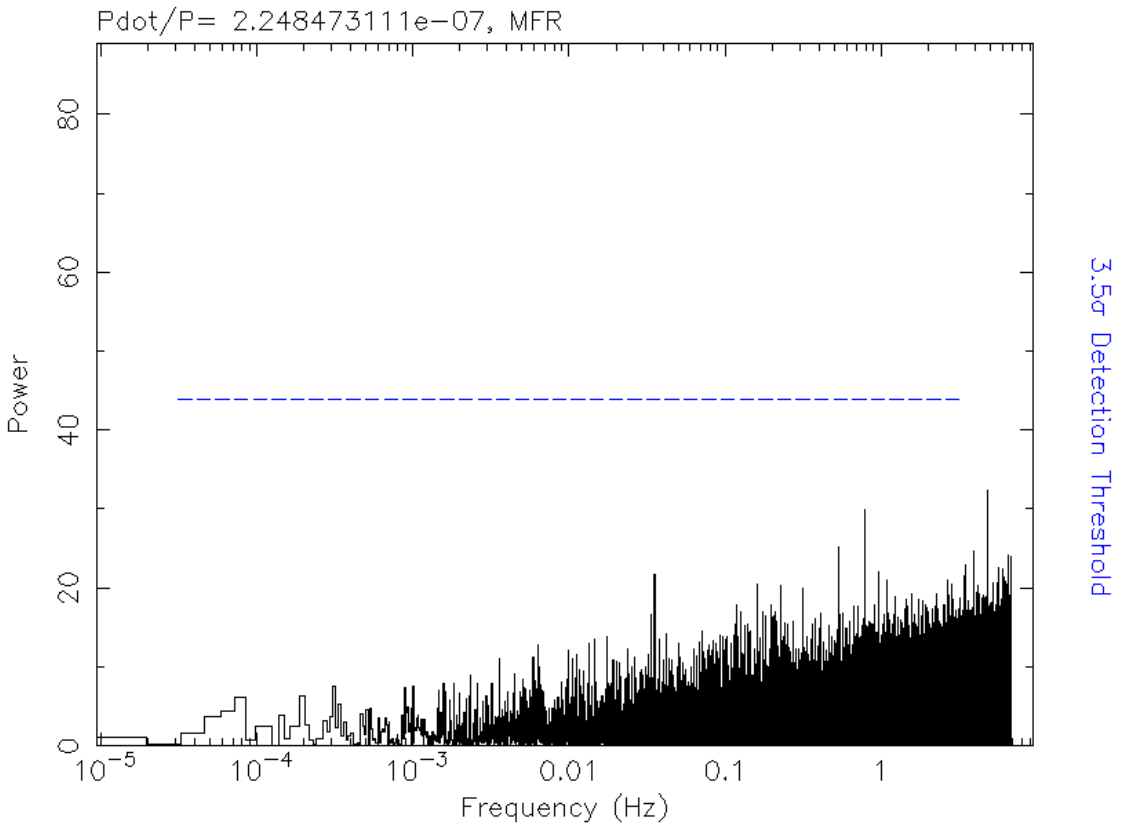
- Even **extreme ULXs** (>1e41 erg/s), like NGC5907 ULX-1, can **hosts accreting NSs**

- **Spectral classification/Lx is not an unambiguous way to classify ULXs:** NGC 5907 ULX, NGC7793 P13 and M51 ULX7 have spectra/Lx not dissimilar from other ULXs (but harder). Alternatively, many ULXs are NSs

- The large "local" Pdot, the orbital effects, the pulse intermittance and small PF make **difficult the detection of these pulsars** with standard tools and current instruments.
  Athena is expected to make a significant contribution fr PULXs.

- **PULXs challange the current models of accretion**, even assuming a moderate beaming.
  A multipolar B component close to the surface might account for The PULXs properties (other scenarios are still viable)

- Developed pipelines can be applied straightforwardly to NuSTAR, NICER and Chandra data and, in the future, to eXTP and Athena


Pdot/P= 2.248473111e-07, MFR
Power
0
20
40
60
80
10^{-5}
10^{-4}
10^{-3}
0.01
0.1
1
Frequency (Hz)
3.5σ Detection Threshold

UNSEEN!