A TALE OF TWO CLASSES OF X-RAY PULSARS

TWO DECADES OF SWIFT

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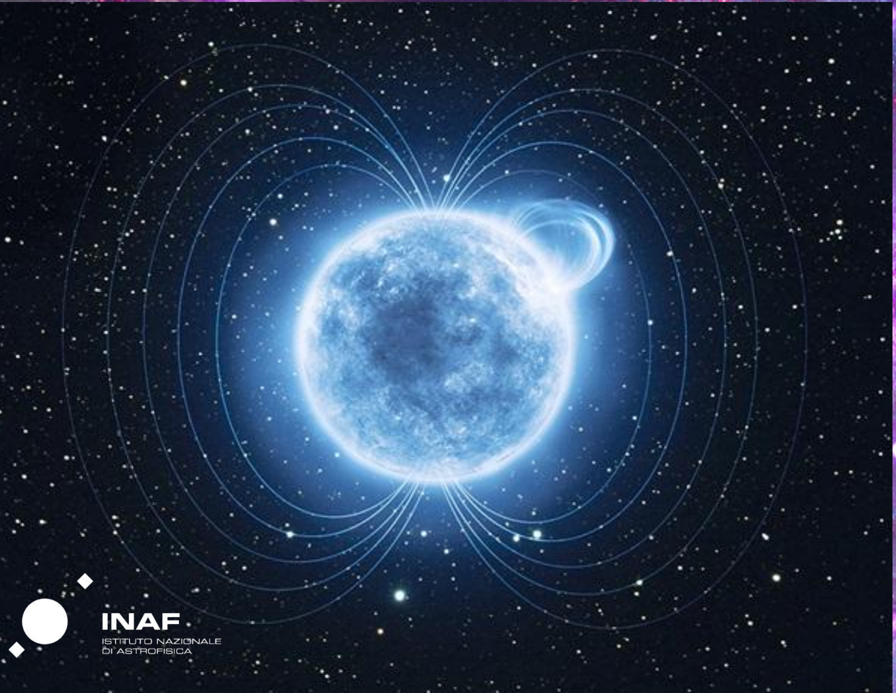
Guillermo Rodriguez, Jay Cummings…. and many many other colleagues



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OUTLINE:

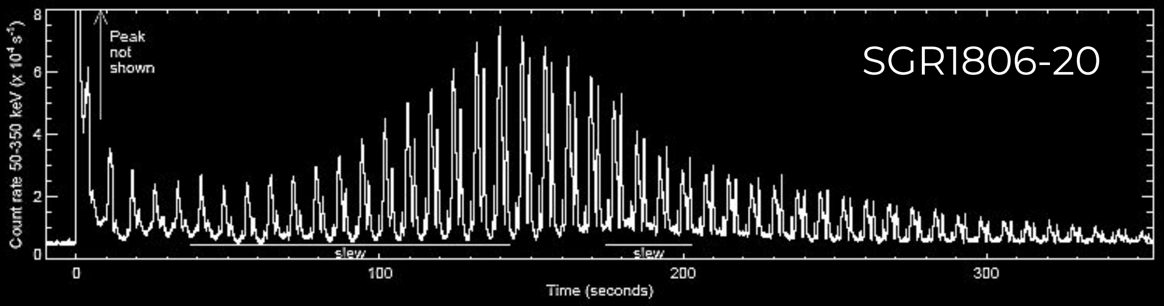
Classes of NS with extreme physical properties

Magnetars: Swift time-resolved study of Intermediate flares

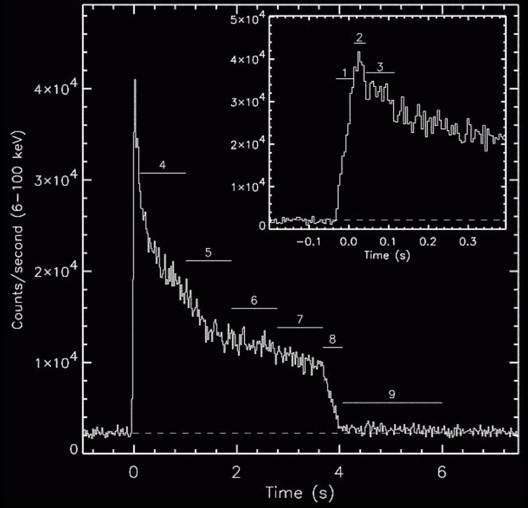
PULXs: Swift long-term monitoring / PULXs vs ULXs and classification issues

MAGNETARS BURSTS

Giant Flares: 3 in 50yrs from 3 magnetars. Minutes-long, $10^{44} < L_X(\mathrm{erg/s}) < 10^{46}$

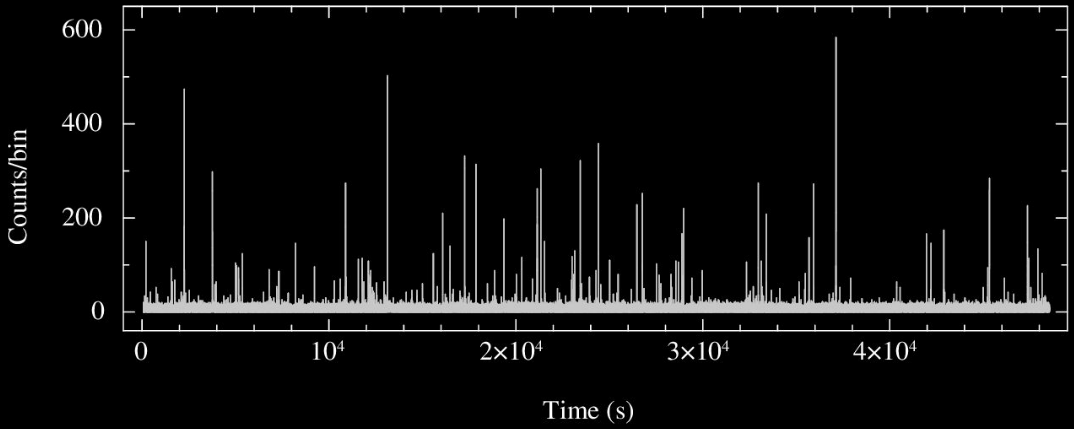


SGR1900+14



Intermediate Flares: Few until the Swift launch, hundreds so far. 0.5s-to-1minute duration, luminosity of $10^{41} < L_X(\mathrm{erg/s}) < \text{few } 10^{42}$

SGR0501+4516



Short Bursts: thousands. 1ms-100ms long, $10^{38} < L_X(\mathrm{erg/s}) < 10^{41}$

WHY STUDYING INTERMEDIATE BURSTS ?

Magnetar scenario: bursts as magnetically trapped fireballs (MTF)

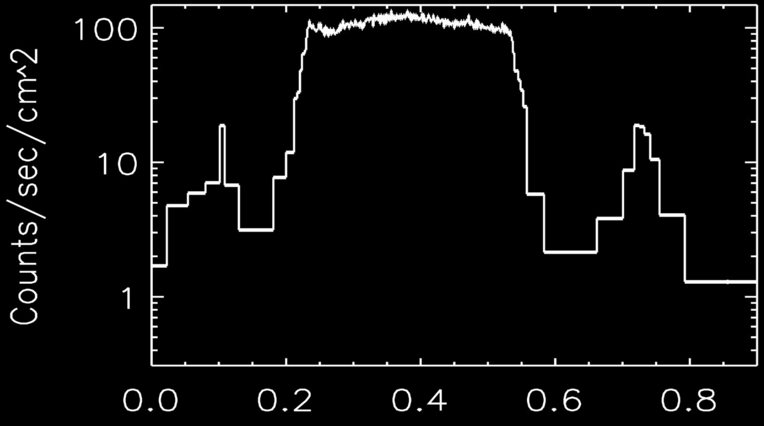
2 photospheres: hard-small E-mode γ / soft-large O-mode γ.

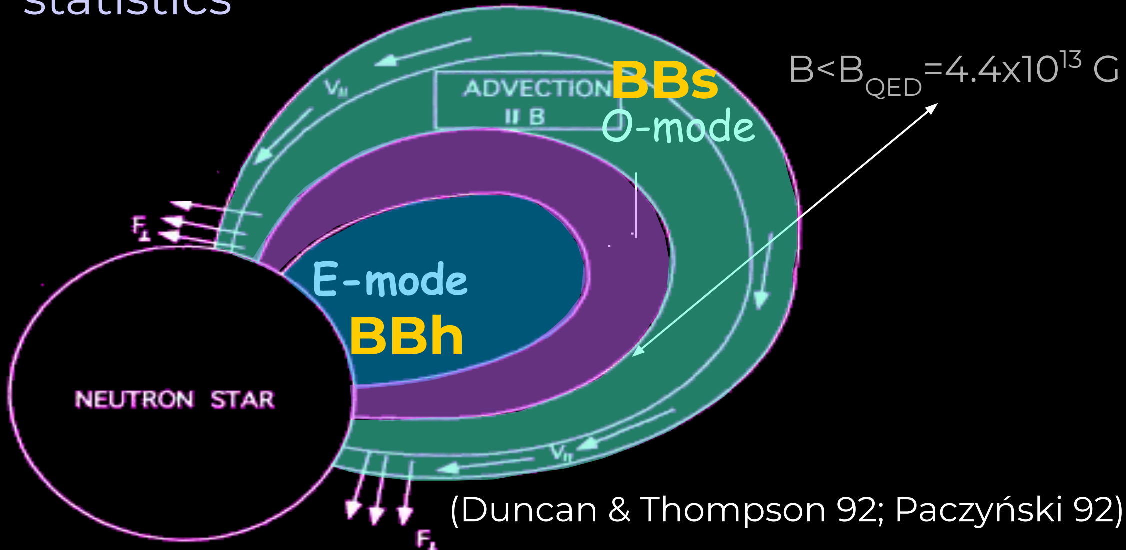
2BBs as first approximation.

Photon splitting (E-to-O mode) and Comptonization and photon merging (O-to-E mode) may change the 2BBs shape.

The IF flat-top shape suggests efficient confinement.

Before Swift few cases and poor statistics

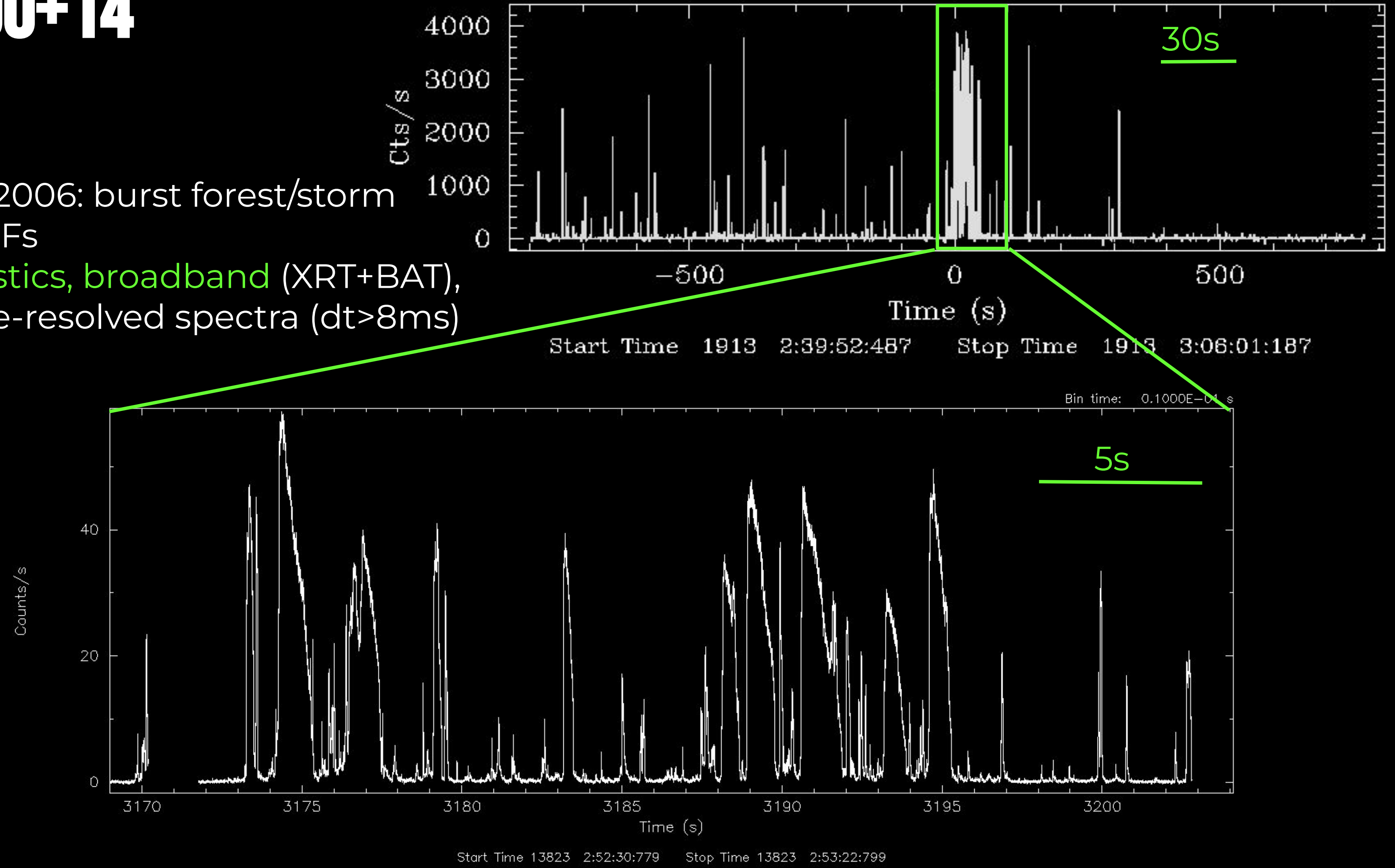




(Duncan & Thompson 92; Paczyński 92)

SGR1900+14

29 March 2006: burst forest/storm
~9 bright IFs
High statistics, broadband (XRT+BAT),
→ 800 time-resolved spectra (dt>8ms)



SGR1900+14

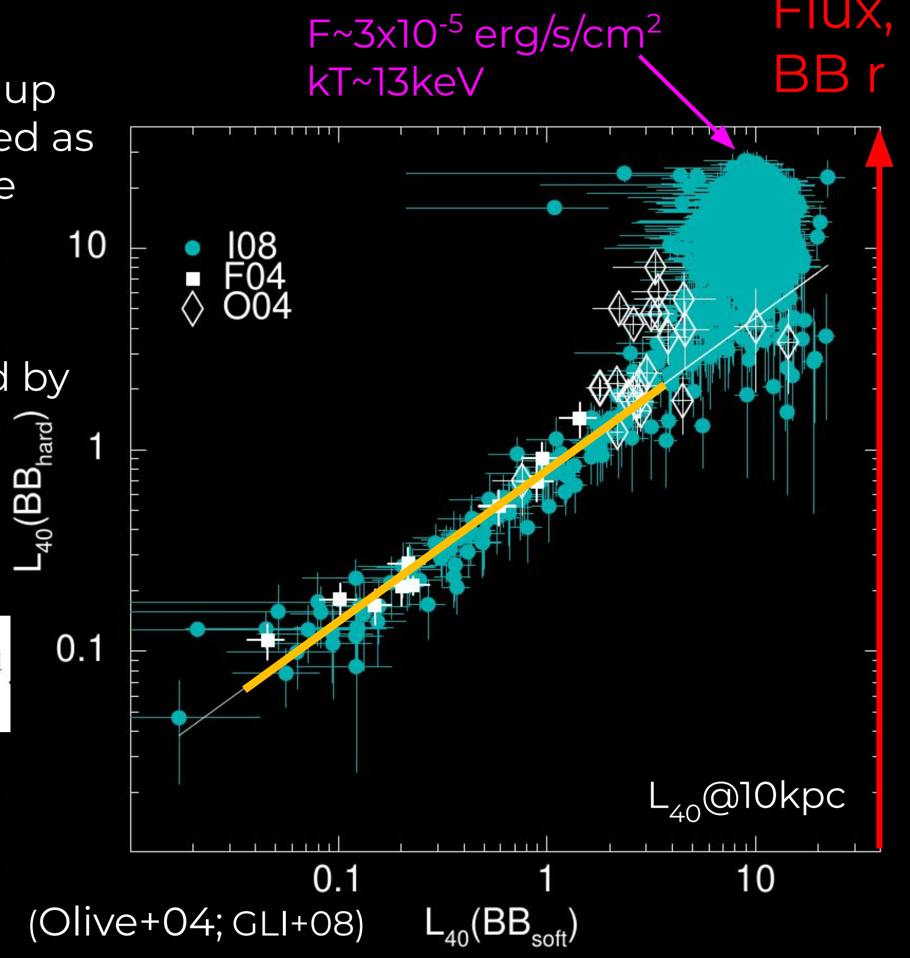
1) Similar energy and evolution for BBs and BBh up to few 10^{40} erg/s. In MTF, BBs and BBh are coupled as far mode switching is efficient, i.e. for radii where $B>B_{QED}\sim4\times10^{13}$ G

2) Above 10^{41}erg/s BBs saturates (B critical radius within E-mode photosphere), while L_{max} attained by BBh for (3-7)x10^{41} erg/s (10-15kpc),

matching well the magnetic L_{Edd}

$$L_{\mathrm{Edd,B}}(r) \simeq 2L_{\mathrm{Edd}}\left(\frac{B}{10^{12}\mathrm{G}}\right)^{4/3} \approx 2\times10^{40}\left[\frac{B}{B_{\mathrm{QED}}}\right]^{4/3}\left(\frac{R}{R_{\mathrm{NS}}}\right)^{2/3} \quad \mathrm{erg\ s^{-1}}$$

for B~(7-14)x10^{14} G inferred from the timing !!



(Olive+04; GLI+08)

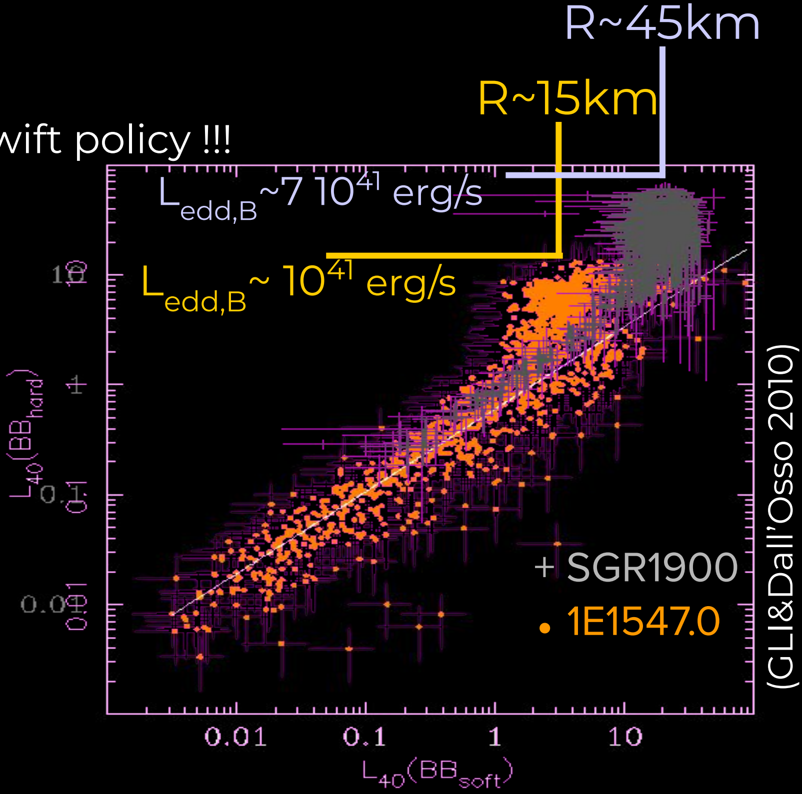
1E1547.0-5408

Several IFs detected by BAT in 2009. No XRT due to Swift policy !!!
~1400 time resolved BAT spectra (dt>2ms).

Similar behaviour of SGR1900+14 !!

Implications on distance and/or B:

$$\left(\frac{d}{\mathrm{kpc}}\right) \simeq 0.4 \times \left(\frac{F\mathrm{max}}{10^{-5}\mathrm{erg/cm^2/s}}\right)^{-1/2} \left(\frac{kT}{\mathrm{keV}}\right)^{5/4} \left[\frac{B_{surf}}{10^{14}\mathrm{G}}\right]^{1/4} \left(\frac{R_{\mathrm{NS}}}{10\mathrm{km}}\right)^{5/8}$$

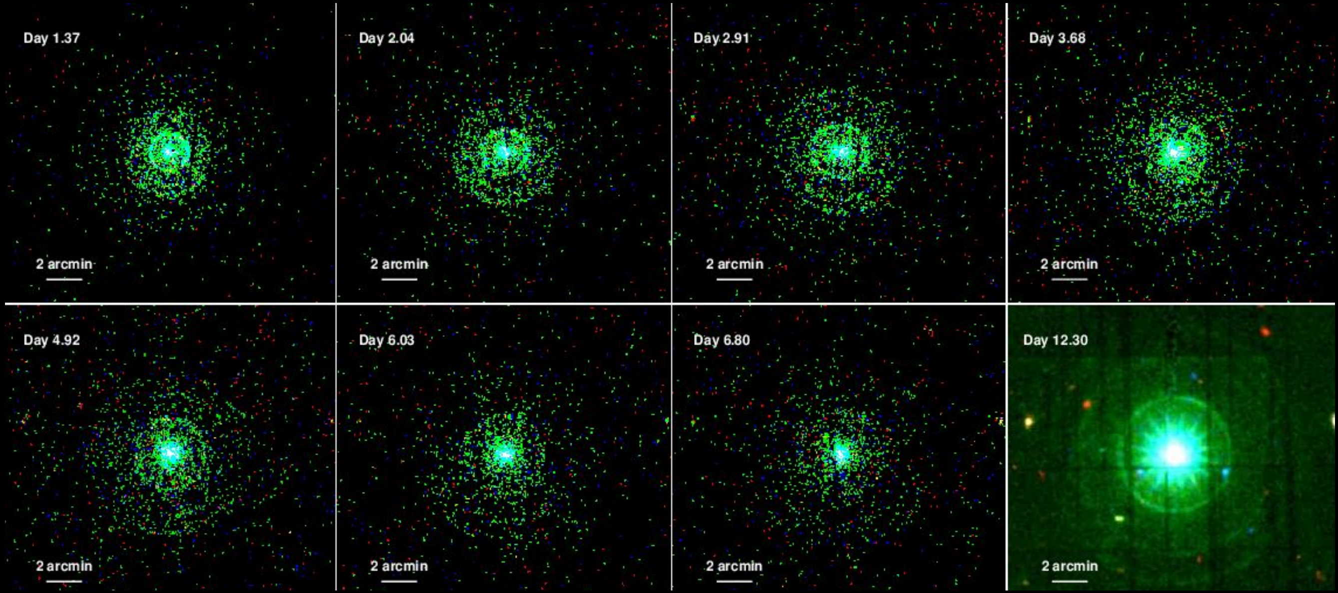


SGR1900+14: F_{max}~3x10^{-5} ergs/s/cm^2, kT~13 keV, B~7-15x10^{14} G d= [9-11] kpc
1E1547.0-5408: F_{max}~6x10^{-5} ergs/s/cm^2, kT~11 keV, B~2-3x10^{14} G d= [3.9-4.3] kpc

Distance of SGR1900 highly uncertain: 10-15kpc; 11-14kpc kinematic distance
(Davies+2009)

….. 3 ~~ONE~~ RING S TO FIND ~~THEM~~ THE DISTANCE

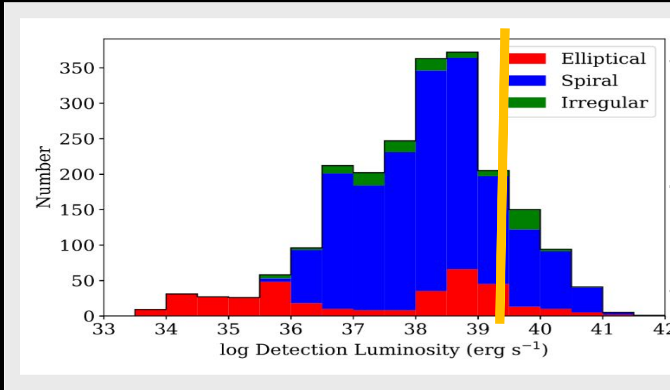
In 2009 Swift observed expanding rings around 1E1547.0-+5408.
A reliable measurement of the distance was possible: 4-5kpc
in agreement with the 3.9-4.3kpc inferred from IF spectroscopy !!



(Tiengo+2010)

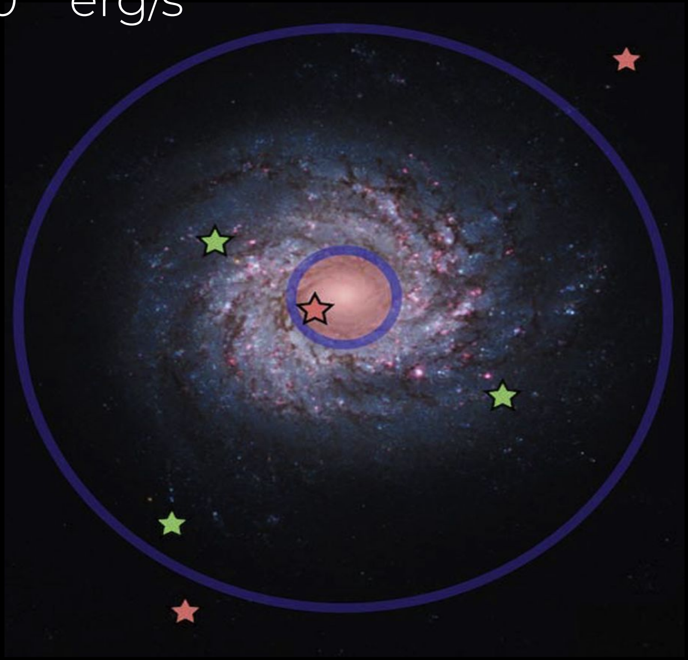
ULX CLASS

Ultraluminous X-ray sources are *off-nuclear*, *point-like* X-ray sources in nearby (d ≤100Mpc) galaxies **exceeding** the (isotropic) Eddington limit for a stellar-mass Black Hole (BH)of 10M☉



(Earnshaw+18)

L_{ULX} > 1-2x10^{39} erg/s up to ~10^{42} erg/s



About 1900 objects
in 1300 galaxies
(Walton+22; Tranin+24)

Hosting massive BHs?

d ≤100Mpc:
angular resolution
and statistics limits

MAXIMUM L_X FOR AN ACCRETING COMPACT OBJECT

$$\frac{4\pi G m_p c}{\sigma_T} M \equiv L_{edd}.$$

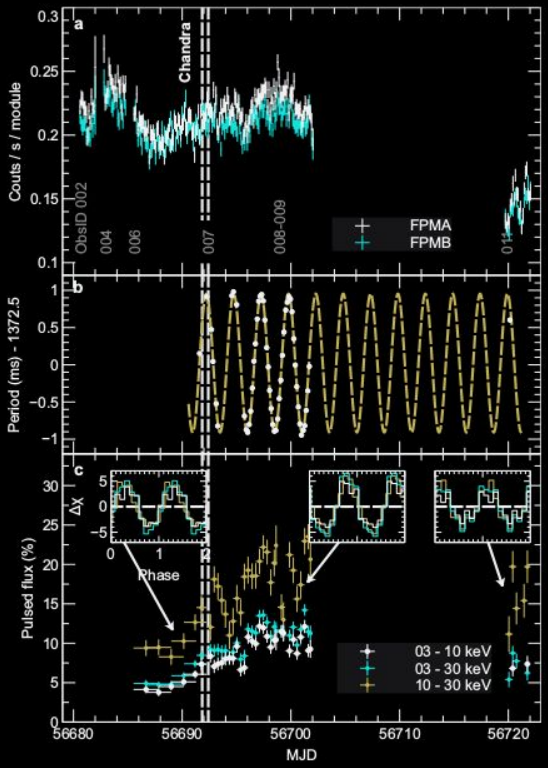
m_p proton mass
$\boldsymbol{\sigma}_T$ Thomson scattering cross section
M mass of the accreting object

$$L_{edd} = 1.2 \times 10^{38} \left(\frac{M}{M_\odot}\right) \quad \text{erg/sec},$$

For a NS [~1.5-3$M_\odot$] → L_{Edd} ~ 2-3.5 x 10^{38} erg/s
or
For a Lx of 10^{41} erg/s → M ~ 1000 $M_\odot$ --→ IMBHs

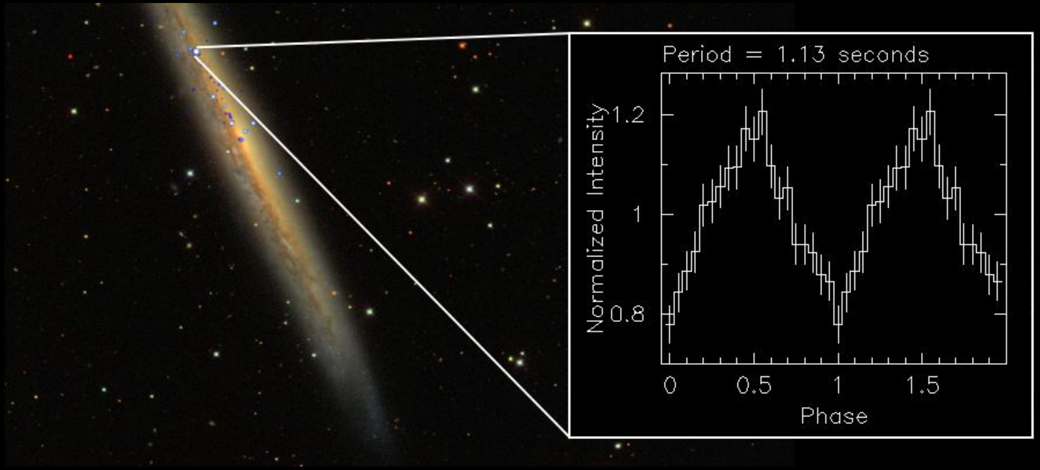
PULSATING ULX S (6 TO 10 OBJECTS)

M82 X-2: 100xL_{Edd}, M_c > 5$M_\odot$



(Bachetti+2014)

NGC5907 ULX1



Most luminous and distant X-ray pulsar ever discovered!

The peak luminosity is ~1000xL_{Edd} for a NS

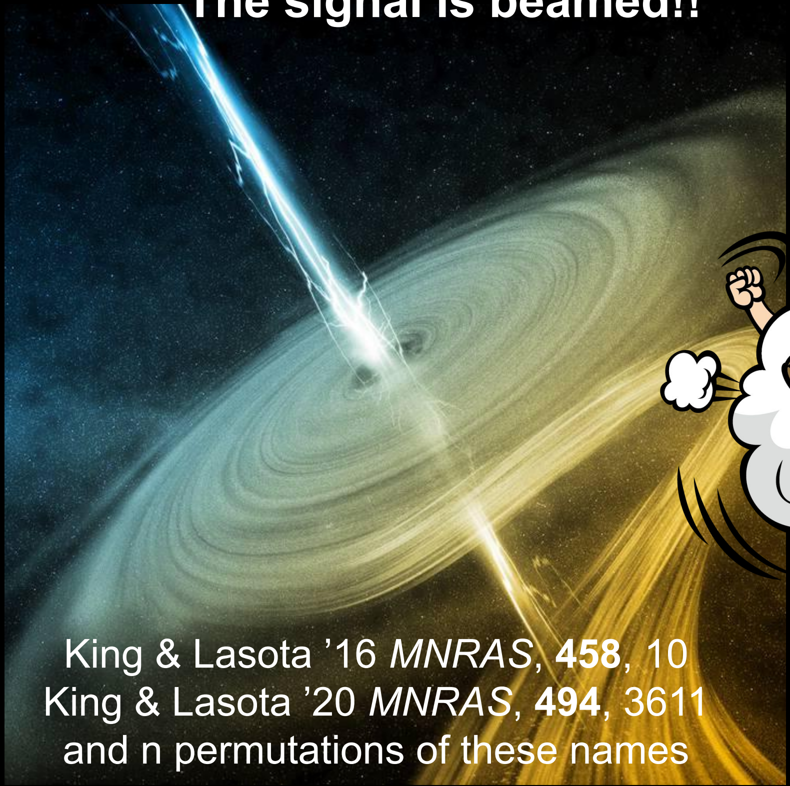
How to account for that L_X ??

beaming or B?

too b on not too b ?/ too B or not too B ?

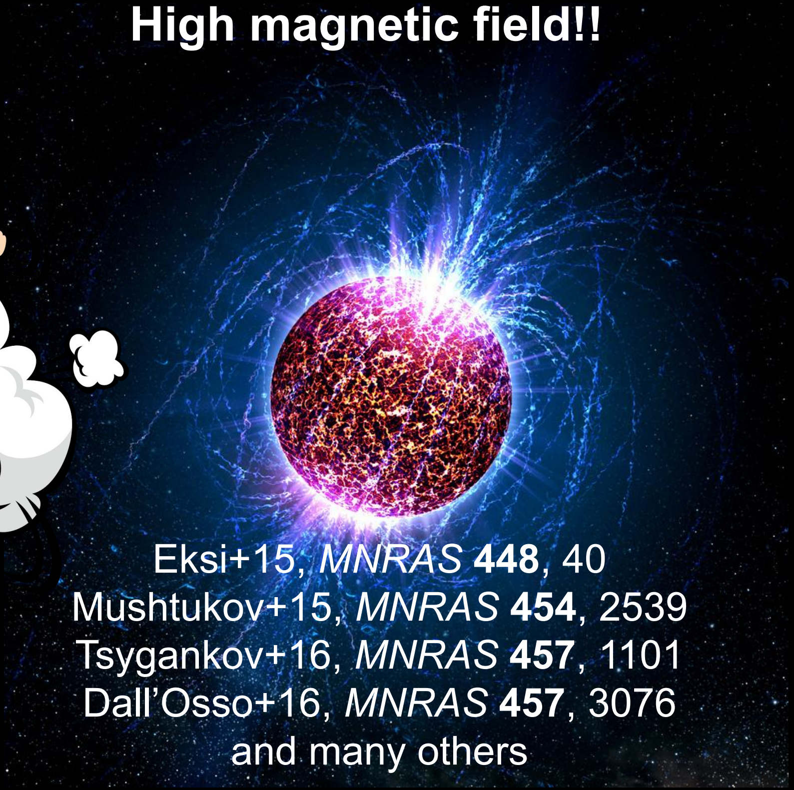
(GLI+2017)

AN ONGOING FRIENDLY DEBATE



The signal is beamed!!

King & Lasota ’16 *MNRAS*, **458**, 10
King & Lasota ’20 *MNRAS*, **494**, 3611
and n permutations of these names

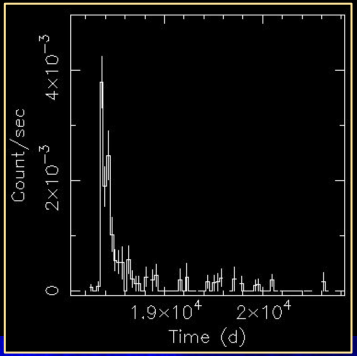


High magnetic field!!

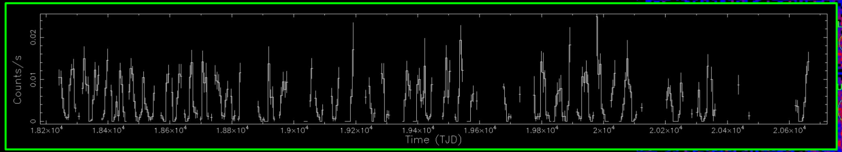
Eksi+15, *MNRAS* **448**, 40
Mushtukov+15, *MNRAS* **454**, 2539
Tsygankov+16, *MNRAS* **457**, 1101
Dall’Osso+16, *MNRAS* **457**, 3076
and many others

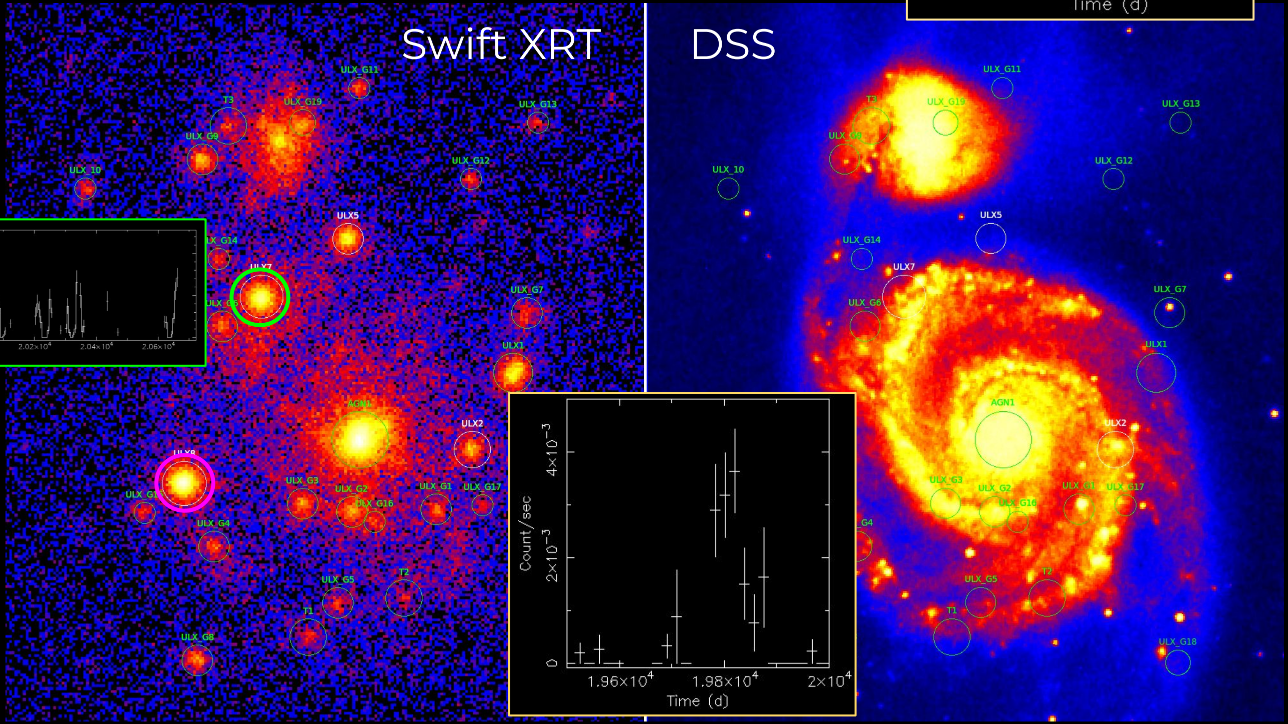
M51 / M52

Exposure: 751ks
Baseline: 19.5 yrs
Several ULXs, 1 PULX (ULX-7), 1 cPULX (ULX-8)



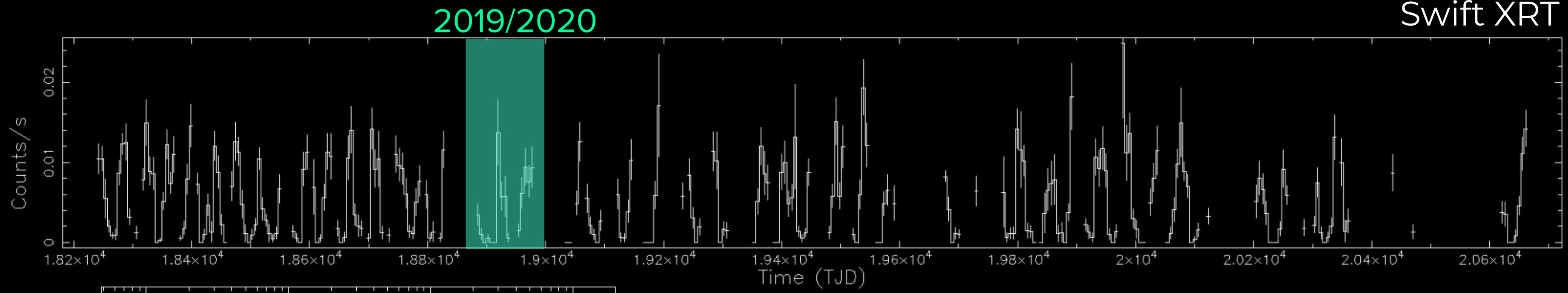
Long-term studies, transients

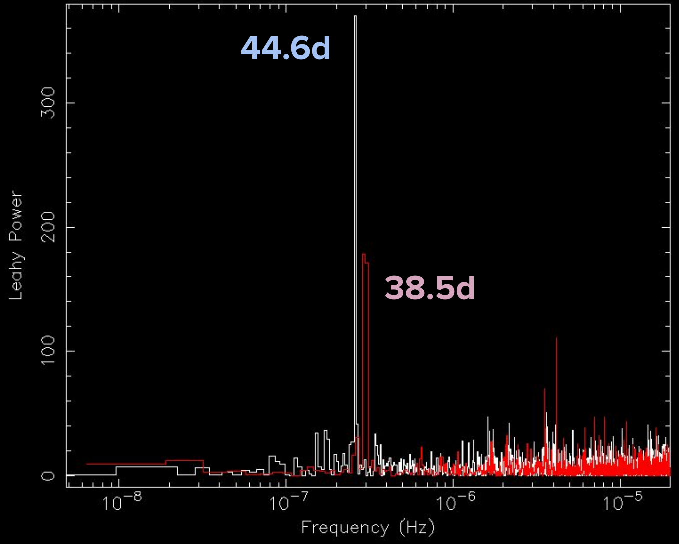


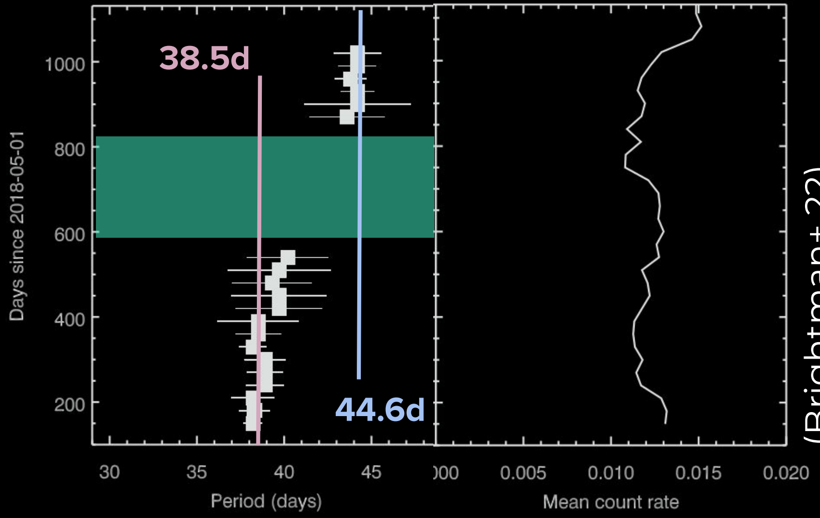


M51 ULX-7

P_{spin}: 2.8s, P_{orb}: 1.99d, $a_x \sin i$: 28 lt-s , Mc > $8M_\odot$, P_{s-o}: 39d-45d

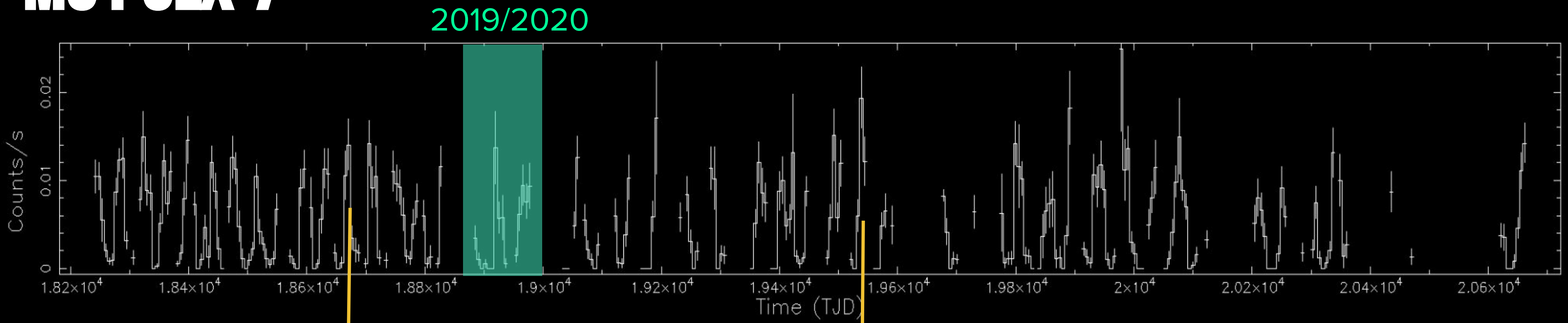


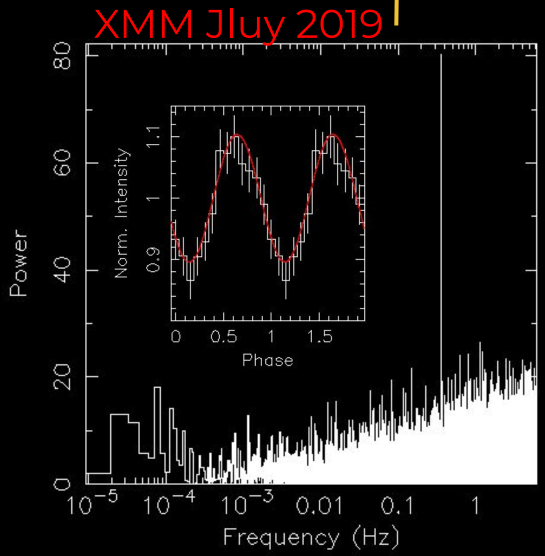




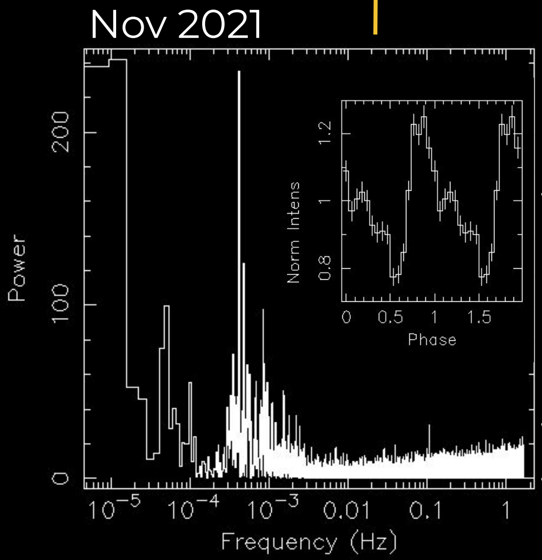
(Brightman+ 22)

M51 ULX-7





(Brightman+2022)



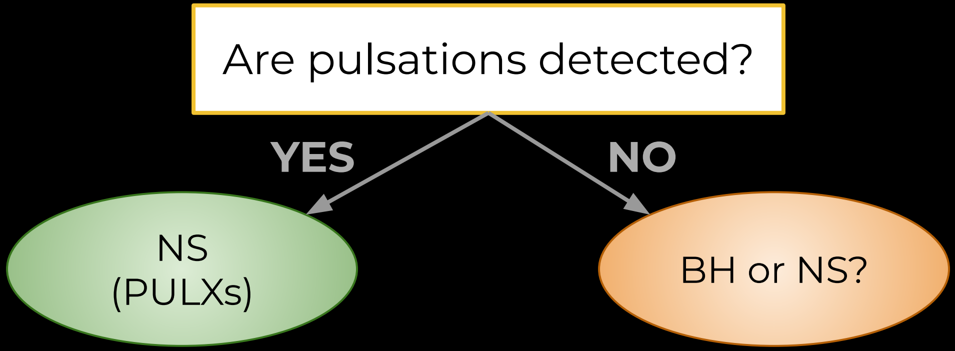
(Imbrogno+2024)

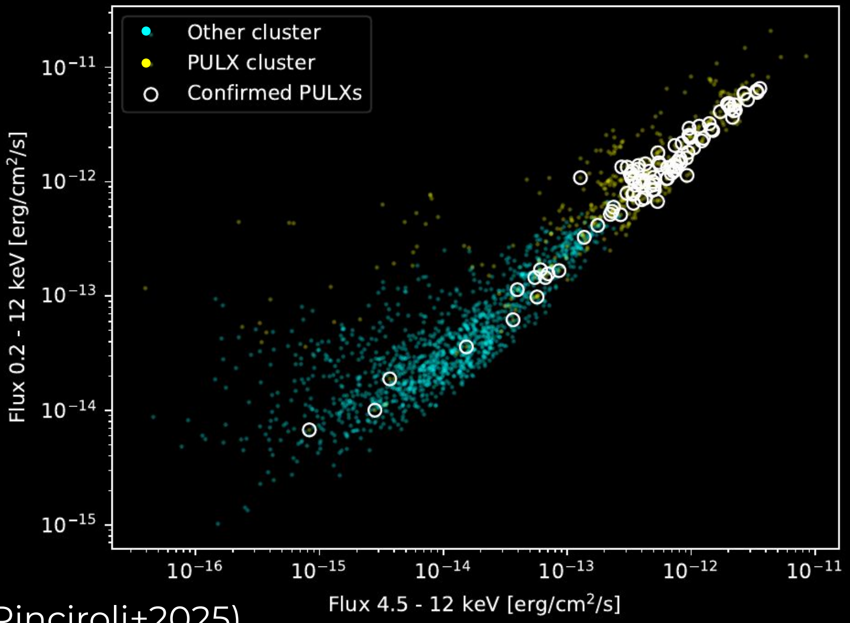
Is there any connection between the Ps-o variation and the timing properties (pulsations and QPOs) of ULX-7 ?
Spectral shape does not change.

Important to continue the monitoring

ULXs VS PULXs: AI AT RESCUE

Can we already say something if no pulsations are detected ?
using archives/catalogs (XMM-DR13+)





(Pinciroli+2025)

~11 observables + AI clustering algorithm

Short answer: there is a clear separation in 2 groups (clusters), in the 11D phase-space, for ULXs without pulsations.

Known (confirmed) PULXs used *a posteriori* to decide where to separate the two clusters

85 new candidate PULXs

Long Life Swift !!