THE EWOCS' GAZE AT THE COMPACT OBJECT POPULATION IN WESTERLUND 1

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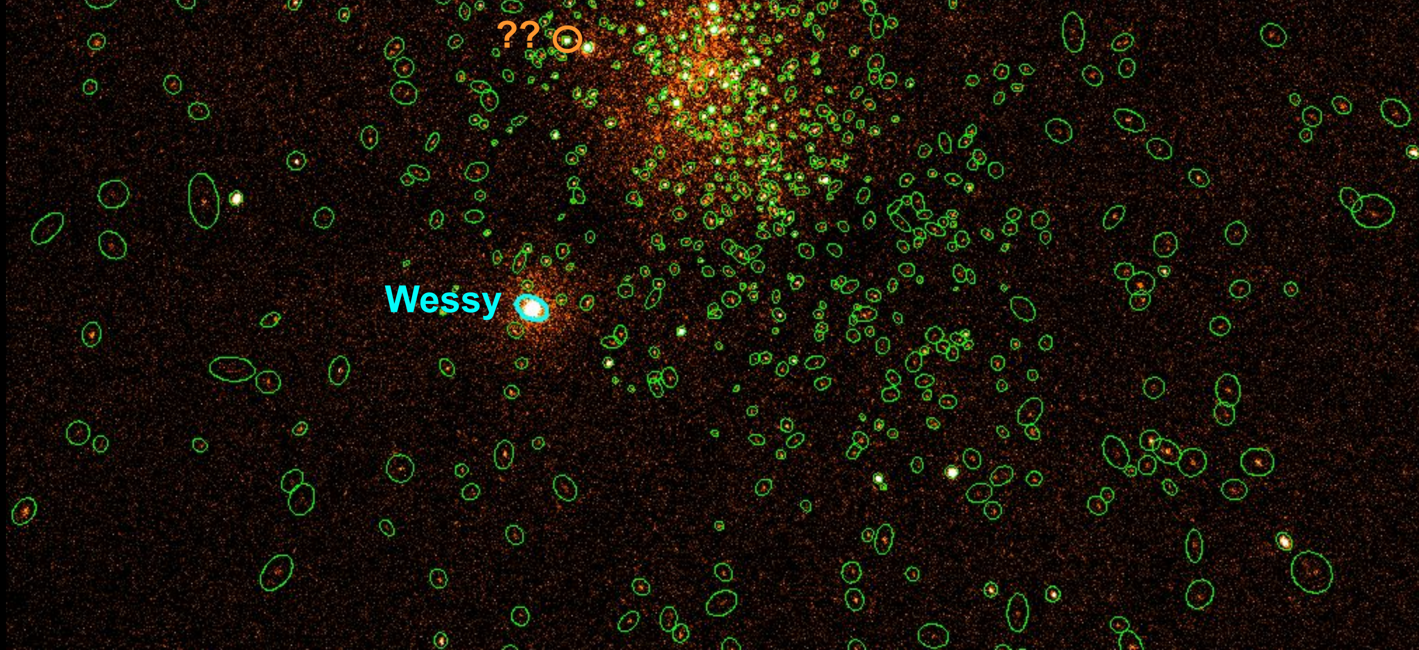


E.W.O.C.S.

THE EWOCS PROJECT

The Extended Westerlund One Chandra (and JWST) Survey (PI Mario Garcello) is based on:

- a 1 Msec Chandra/ACIS-I observation

complemented with

- 19 hours JWST observations

The project is aimed at (among others):

- Unveiling the low-mass stellar content of Wd1 in the core and in the halo;
- Studying protoplanetary disk evolution and planet formation in starburst;
- Determining the nature of massive systems and studying their mass loss;
- Studying the IMF;
- Identifying stars in the halo and studying how starburst clusters form, evolve and disperse;

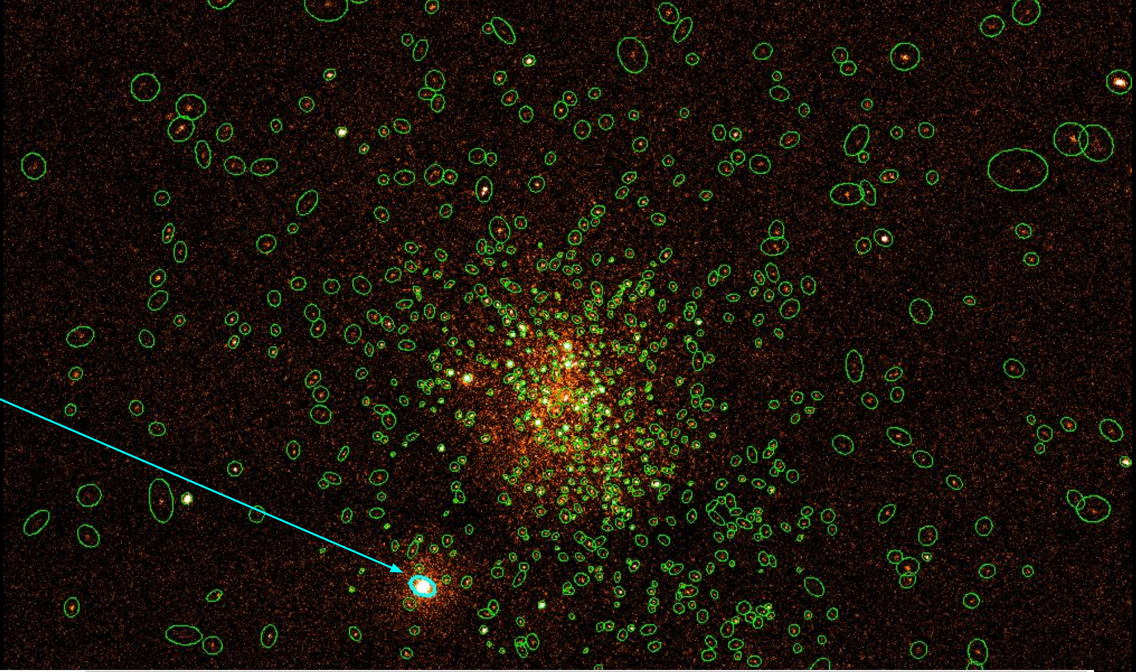
- **Studying the magnetar CXOU J164710.2-455216;**
- **Searching for compact objects and/or signals.**

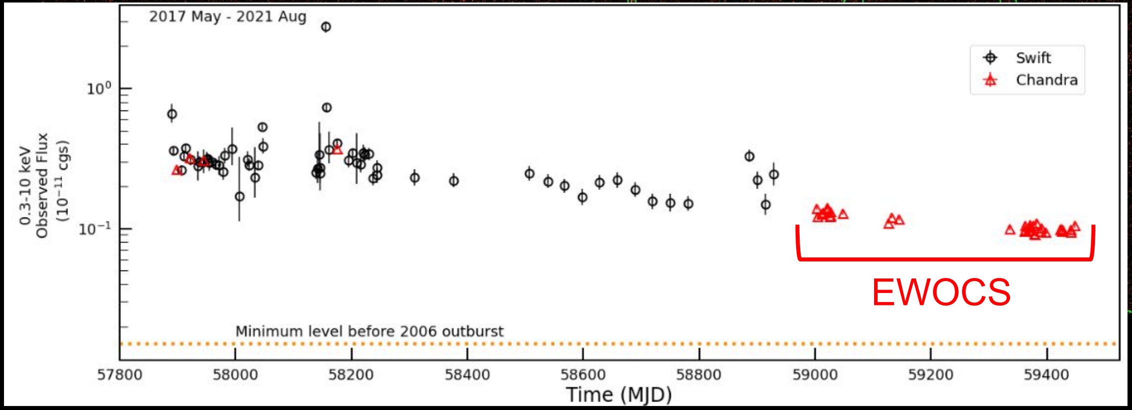
WESSY

Wessy, aka
CXOU J164710.2-455216,
is a 10.6s-spin period magnetar.

A very large outburst occurred in 2006.
Other fainter outbursts occurred in 2011,2017 and 2018.

Smooth decay since 2018.
EWOCS epochs are far from glitch/burst activity (good for timing)

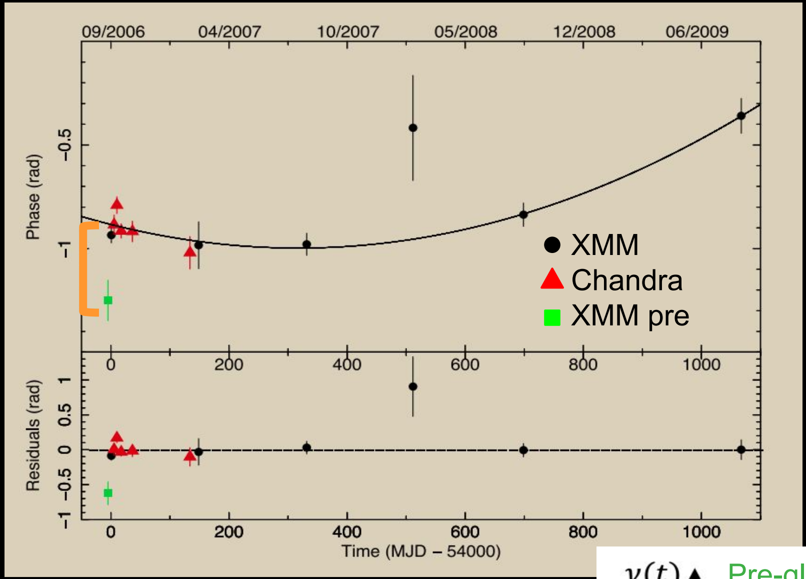




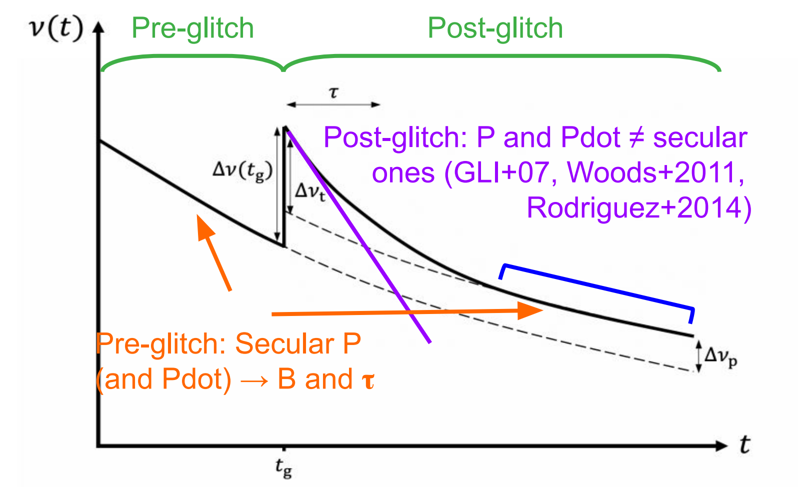
WESSY: TIMING SOLUTIONS

Rodriguez et al. 2014:
~1100days
phase coherent solution

Glitch in September 2006
$\Delta\upsilon/\upsilon$ ~ 1.8(6) x 10^{-5}



inferred values not representative of the secular quantities !



Summary of CXOU J164710.2−455216 timing solutions for the 2006–2009 outbur

	Epoch (MJD)	Period (s)	$\dot{P}^a$ (10^{-12} s s^{-1})	$\ddot{P}^b$ (10^{-20} s s^{-2})	$B \times 10^{14}$ [c] (G)
Israel et al. (2007)	53999.0	10.6106549(2)	0.92(4)	–	1.0
Woods et al. (2011)	54008.0	10.6106563(1)	0.83(2)	–	0.95
Woods et al. (2011)	54008.0	10.6106558(2)	1.3(1)	−10(1)	1.21[d]
An et al. (2013)	53999.1	10.61064(2)	<0.4(6)	–	<0.7
Rodriguez et al. (2014)	54008.0	10.61065583(4)	0.972(1)	−1.05(5)	1.04

WESSY NEW TIMING

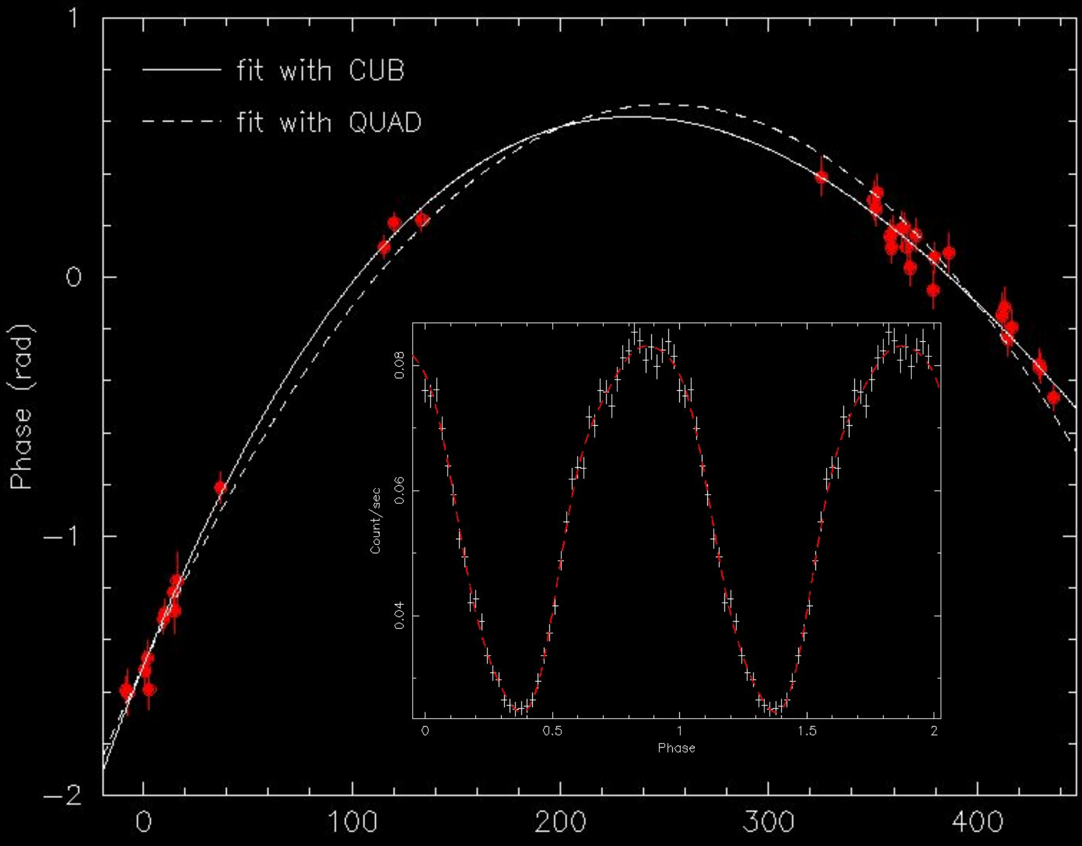
Previous Timing Solution
(Rodriguez+14) over ~1100days:
P_{old}=10.61065583(4) s,
$\dot{P}_{old}$=9.72(1) 10^{-13} s/s
P_{old}=-1.05(5) 10^{-20} s/s^2

New Timing Solution:
over ~450days;
P_{new}=10.6107220(1)s,
$\dot{P}_{new}$=2.5(1) 10^{-13} s/s ~ $\dot{P}_{old}/4$
P_{new}=-4.8(1.5) 10^{-21} s/s^2

P significance:
Prob(F-test): 1.55E-03 → 3.3σ

Significant variation of $\dot{P}$!!

Chandra EWOCS



WESSY NEW TIMING EXTENDED

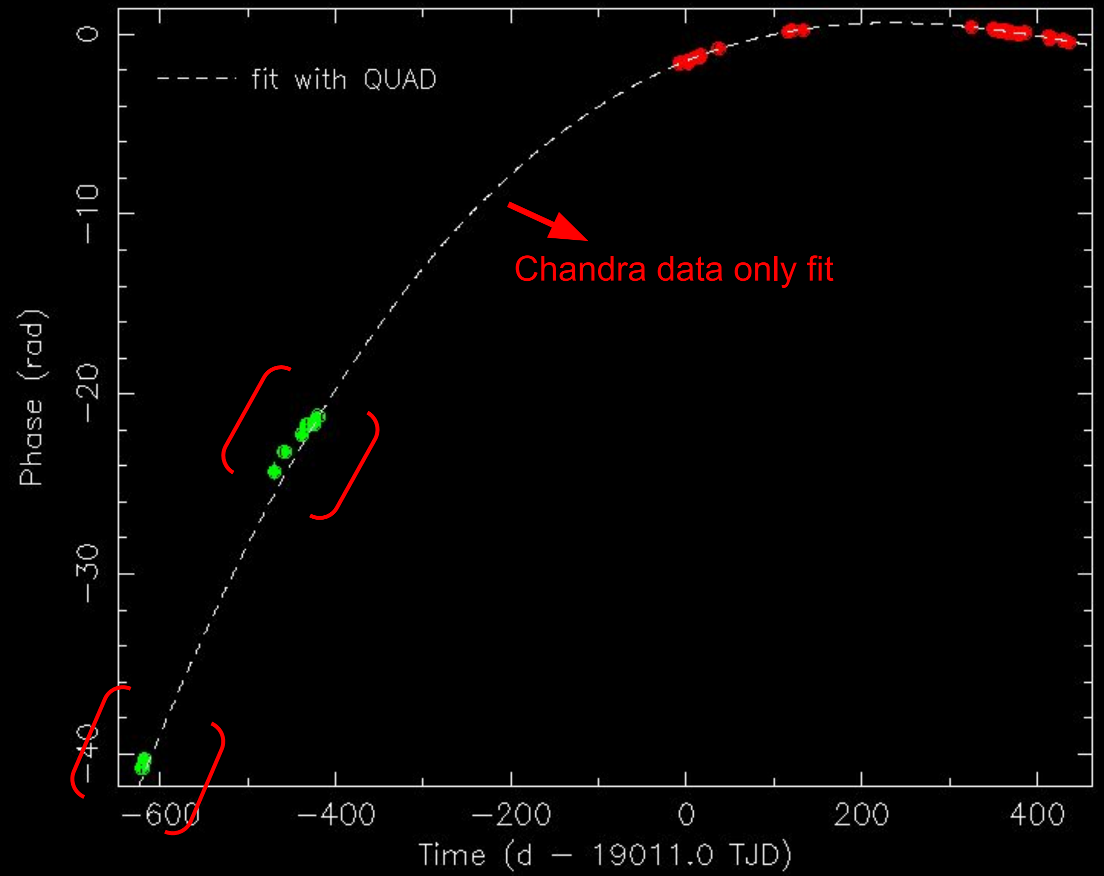
Previous Timing Solution
(Rodriguez+14) over ~1100days:
P_{old}=10.61065583(4) s,
$\dot{P}_{old}$=9.72(1) 10^{-13} s/s
P_{old}=-1.05(5) 10^{-20} s/s^2

New Timing Solution:
over ~1100days:
P_{new}=10.61072198(5)s,
$\dot{P}_{new}$=2.49(1) 10^{-13} s/s ~ $\dot{P}_{old}/4$
P_{new}=-4.9(4) 10^{-21} s/s^2 ~ $P_{old}/2$

P significance:
Prob(F-test) > 12σ

Significant variation of both $\dot{P}$ and P !!

Chandra EWOCS + NICER 2018-2019



WESSY: PHYSICAL PARAMETERS

Latest measurements (based on a semi-phase-fitting timing analysis, An & Archibald 2019, ApJ, 877, L10):

- $B_{dip} \sim 4 \times 10^{13}$ Gauss
- $\tau \sim$ 1-2 Myr

New values (based on coherent phase-fitting technique, this work):

- $B_{dip} \lesssim 5 \times 10^{13}$ Gauss [$<10^{14}$ G in RC+14]
- $\tau \gtrsim$ 0.7 Myr [>0.5 Myr in RC+14]

Note that the pulsar age is less than that of Wes1 [two possible ranges; 3-6Myr and 9-11Myr].

CONCLUSIONS

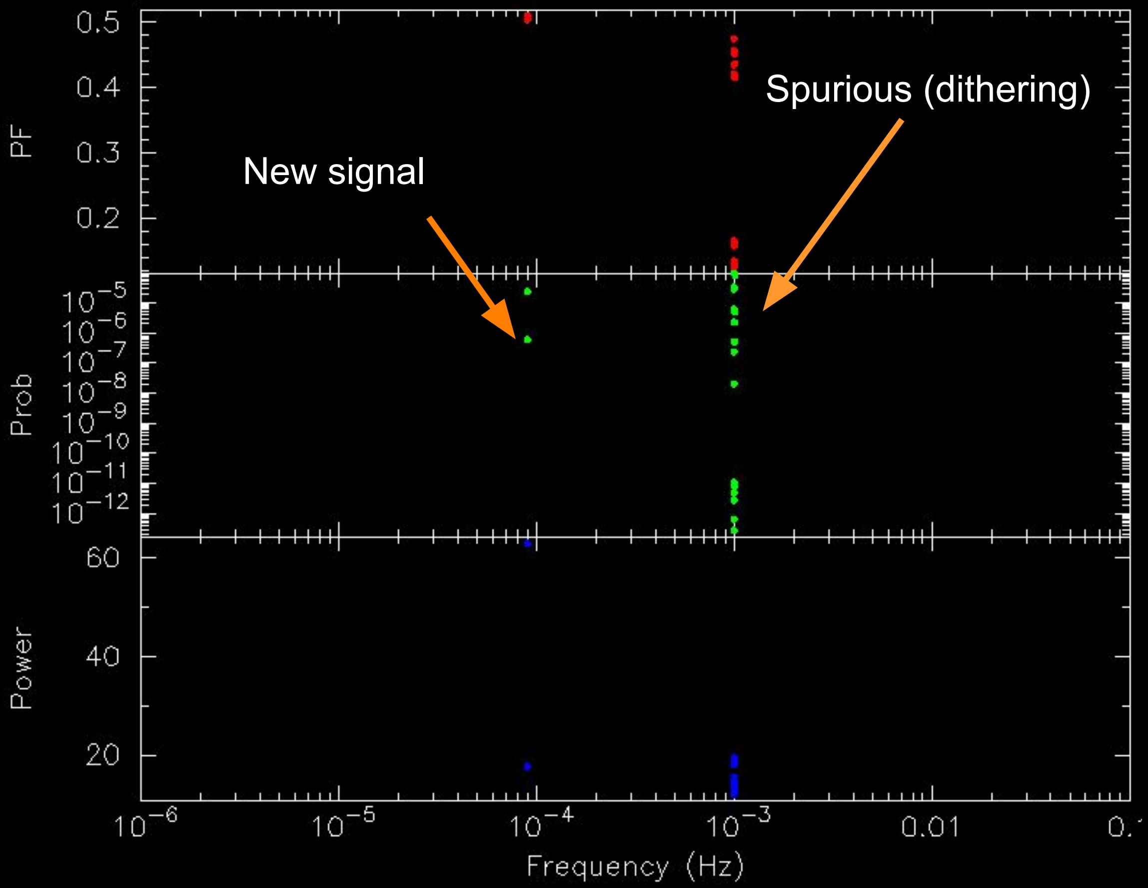
first phase-coherent solution far from (out)bursts/glitches since its discovery in 2005 !

SEARCH FOR NEW PULSATORS

~800 objects detected (>15 events) in merged image

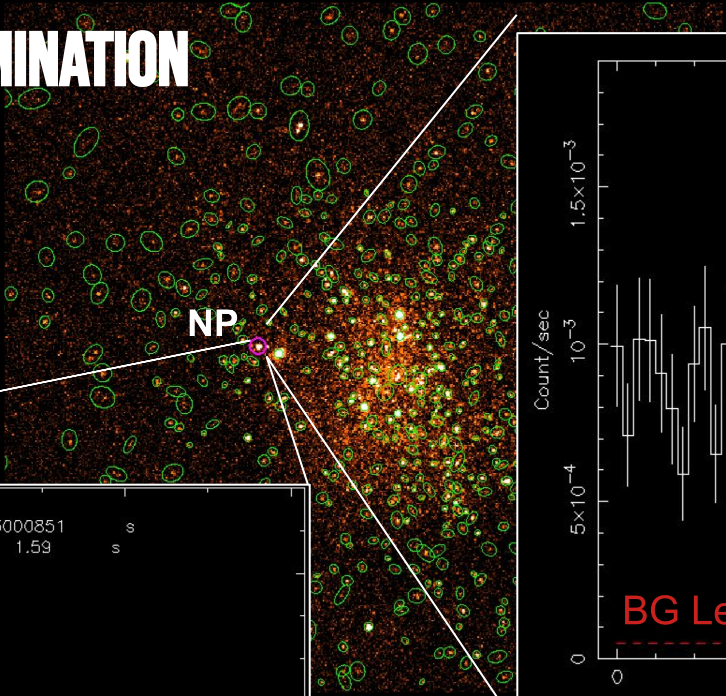
~100 objects (> 100 events) searched for signals

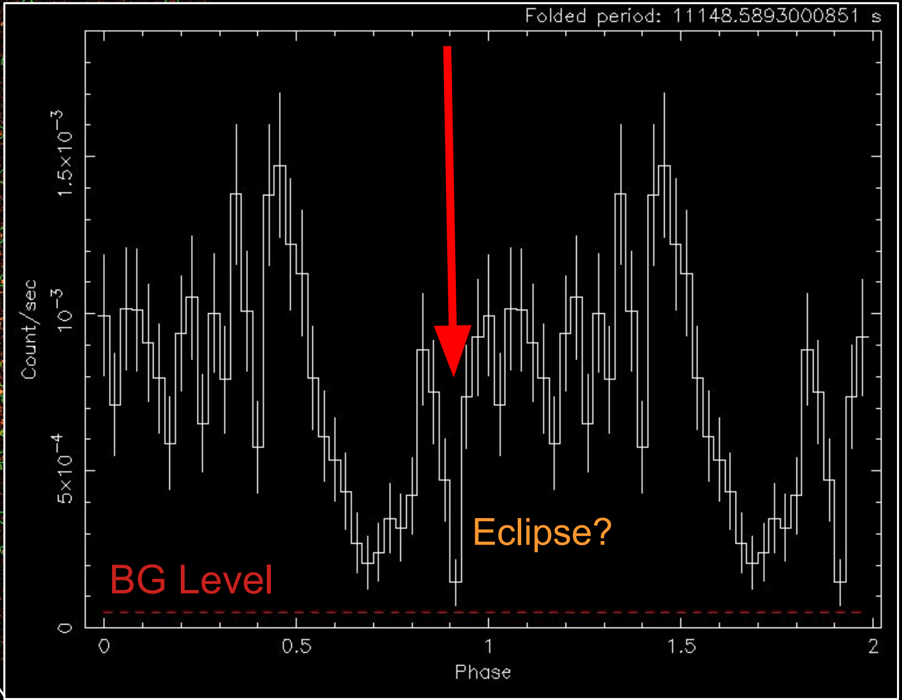
1 good candidate signal found (from a source at about 1’ from the cluster centre)

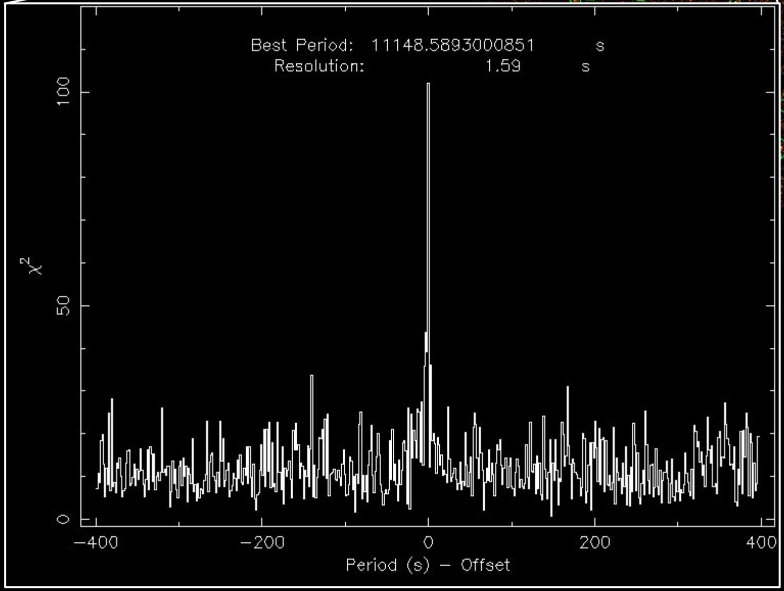


NP: PERIOD DETERMINATION

NP = **N**ew **P**ulsator







P = 11148.6(1) s 1σ [3.096833(3)hr]
|Pdot| < 1.3e-7 s/s 3σ
PF ~ 50%

NP: SPECTRUM

26 obs (out of 34 summed)

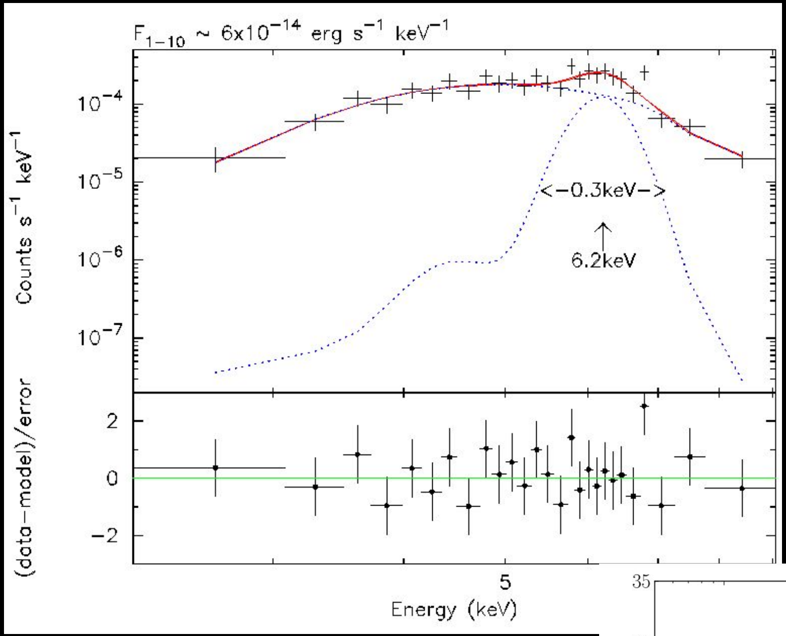
PL with Γ ~ 0.5
N_H~1.6(4) $10^{23}cm^{-2}$
A_V~30mags !!!
($N_{H,W1}$~2 10^{22} cm^{-2})

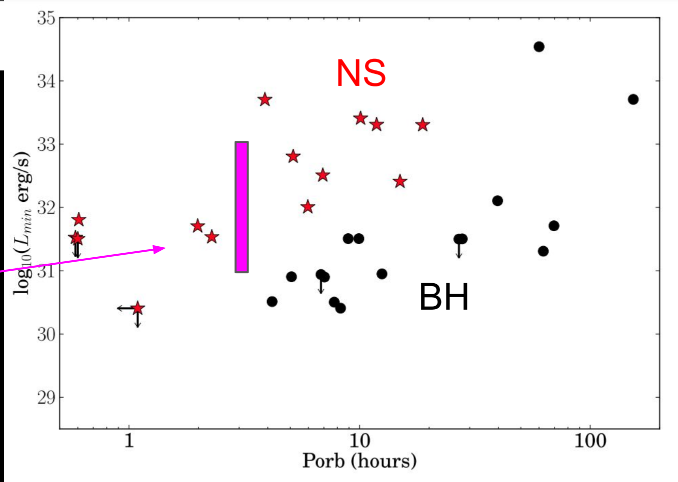
Possible Gaussian at 6.2(1)keV, σ~0.3(1)keV, EW~0.8keV (F-test~4%)

Unabs 0.1-10keV flux:
~1e-13 erg/s/cm^2

χ^2 ~ 18 for 21 d.o.f.

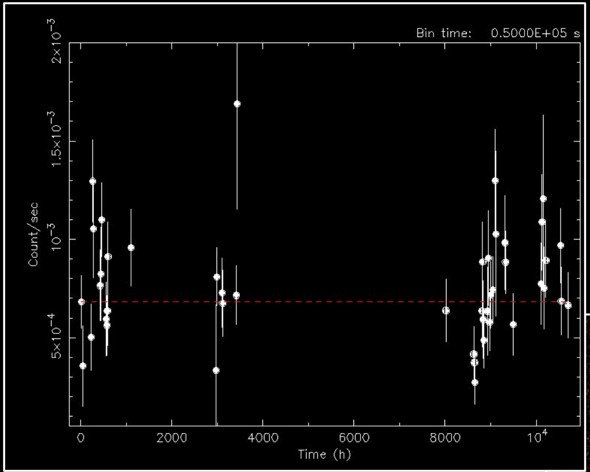
L_x~1-200x10^{31} erg/s (95% c.l.; if in Wes1 @ 2-5kpc)





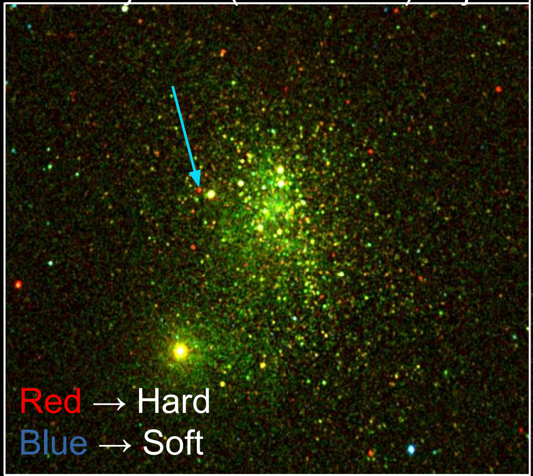
(Armas Padilla+14) for quiescent binaries

NP: MAIN PROPERTIES

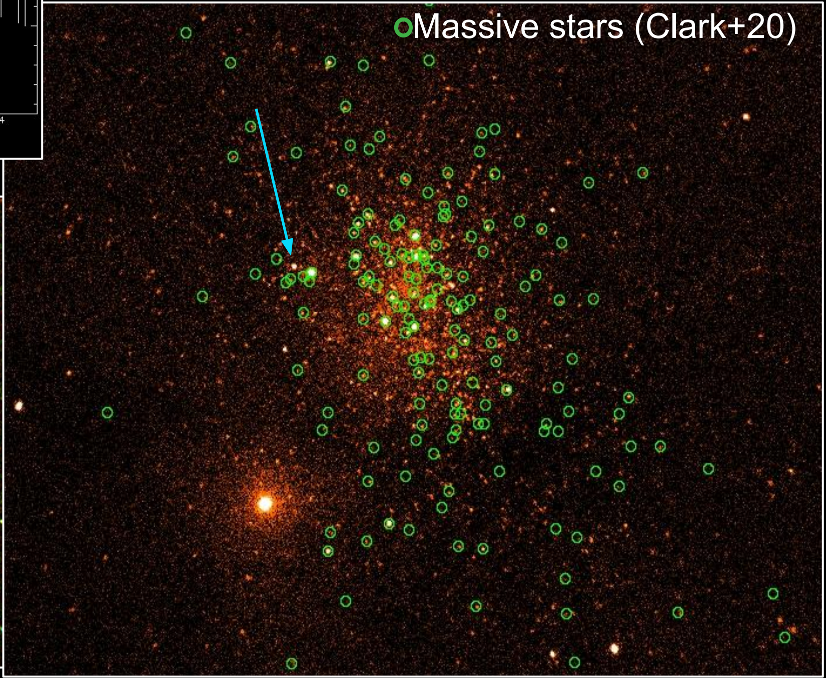


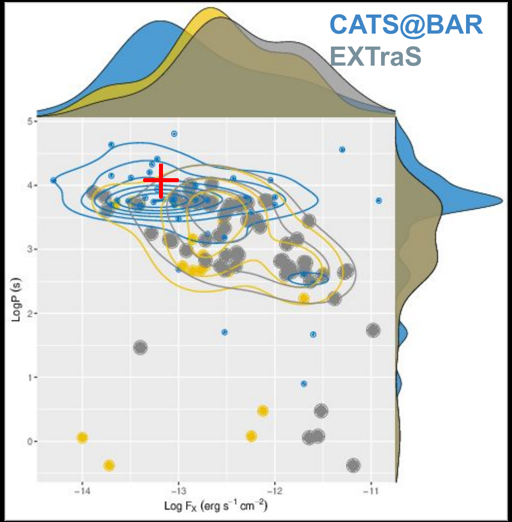
No short-/long-term aperiodic variability (RMS~0.26+/-0.07);

Relatively hard (absorbed?) object



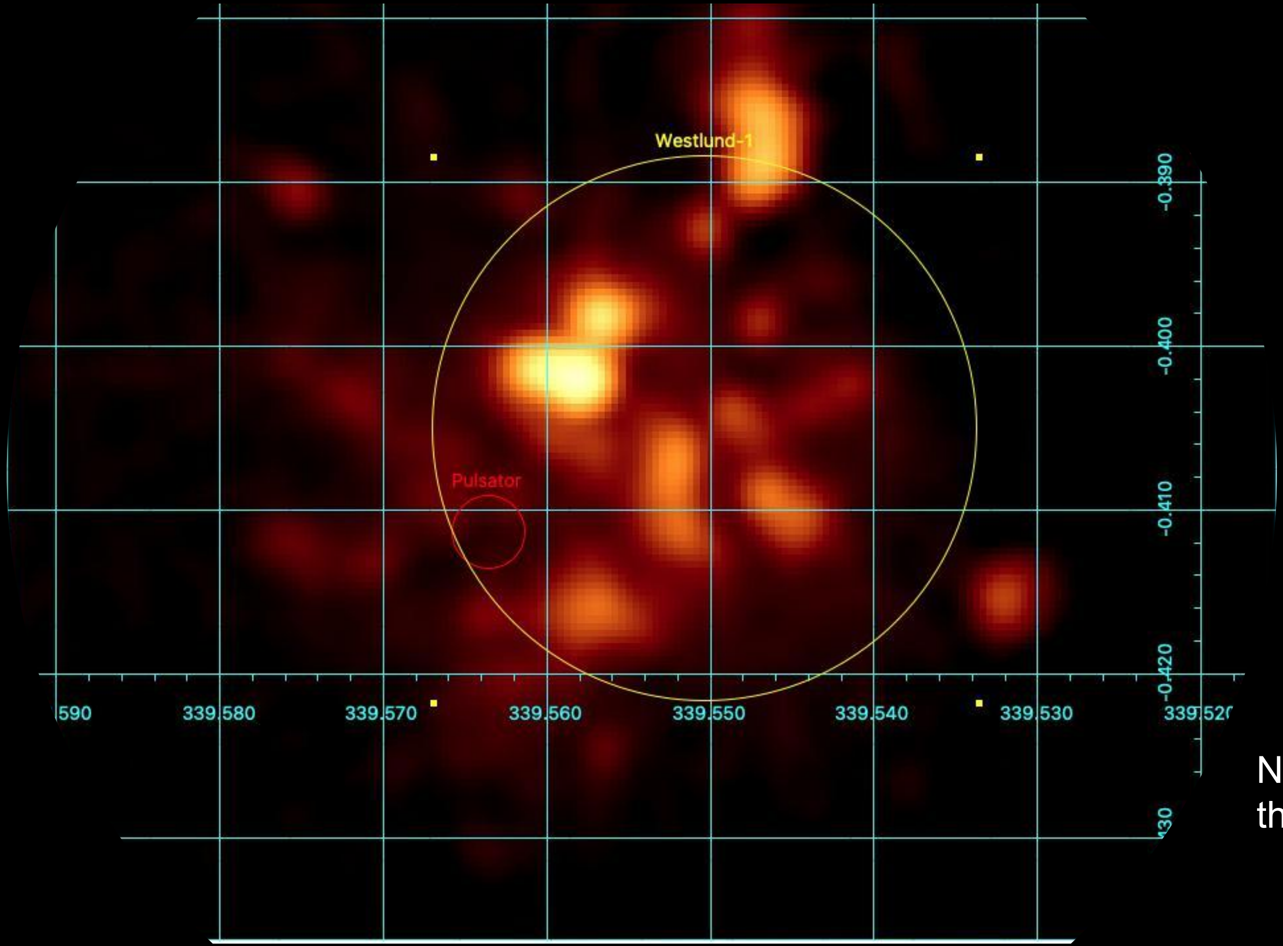
Unrelated to known massive stars in Wes1





No special properties wrt other serendipitous X-ray pulsators in **CATS@BAR** (•) and **EXTraS** (•)

NP: RADIO BAND (MEERKAT)

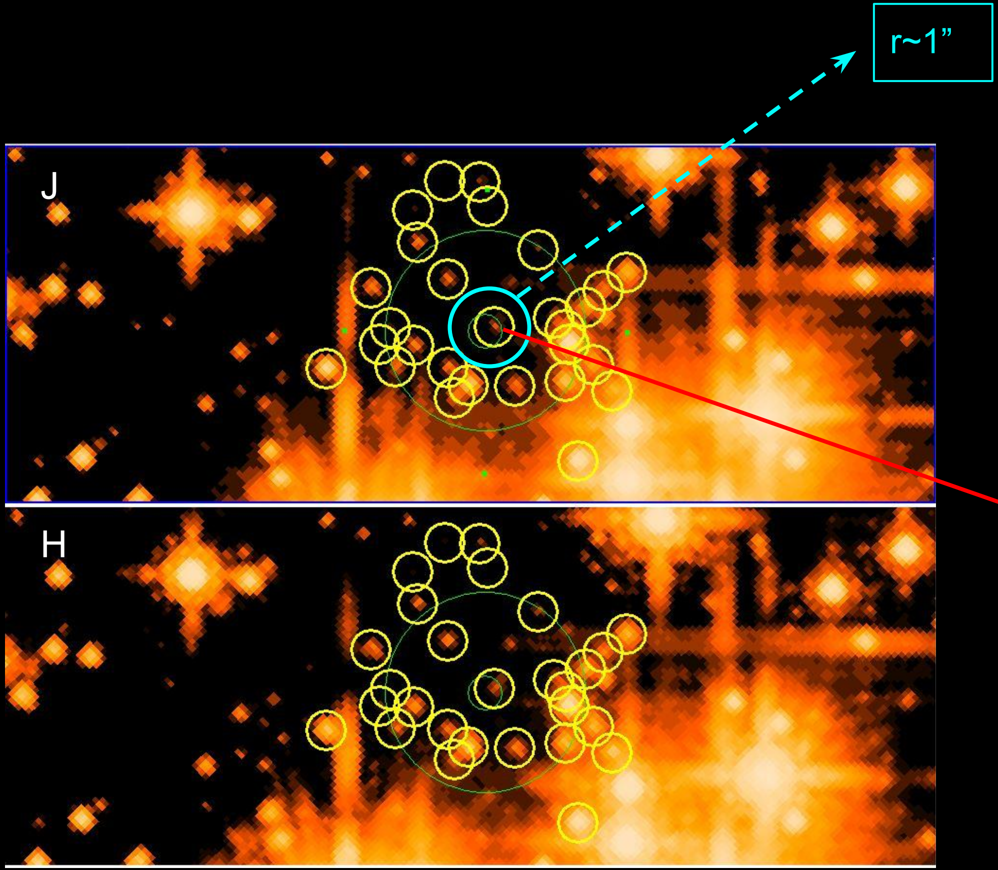


Westlund-1 as observed in the 1.28 GHz MeerKAT Galactic Plane Survey

Goedhart et al., in progress

No radio counterpart detected at the pulsator position (rms=100 μJy)

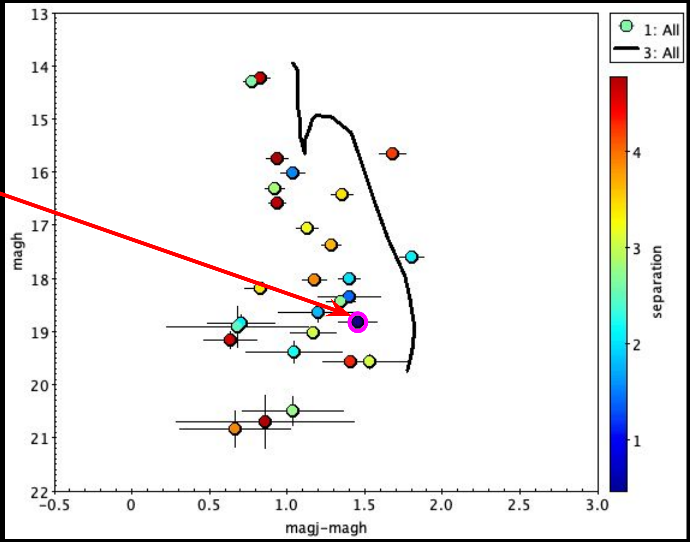
NP: ARCHIVAL (HST) IMAGES



These results suggest a low-mass star

How much low ?

Any constraint ?



NP: POSSIBLE SCENARIOS

A rude estimate of the probability of a foreground object (any kind of X-ray object!) in a πR^2 area (R = 1 arcmin) in the core of Wes1 is 1% from the Log*N*-Log*S* in van der Berg 2012 (ChaMPlane survey). Prob < 0.01% for an X-ray pulsating object (from CATS@BAR).

(1) Orbital period (LMXBs hosting a NS or a BH): Possible

(2) Orbital/spin period of a CV: unlike given the $\sim 25 M_\odot$ turn-off of W1

(3) Long-P low-Lx HMXB (X-Per-like) or symbiotic system: unlike due to the lack of relatively bright objects in the nIR HST band ($A_k \sim$ 1-3mags) and the dip/eclipse

Extended simulations carried out for scenario (1)

RESULTS

Output:

(1) These binary systems can form in environments like Wd1 (high metallicity, young age);

(2) No systems with age < 5Myr

(3) The companion tends to be a low-mass main sequence star (if NS) and a generally more massive naked He-core star (if BH);

(4) These systems are quite rare: ~1 object out of 10^6 $M_\odot$ for a NS-star system and 1 object out of 10^8 $M_\odot$ for a BH-star system;

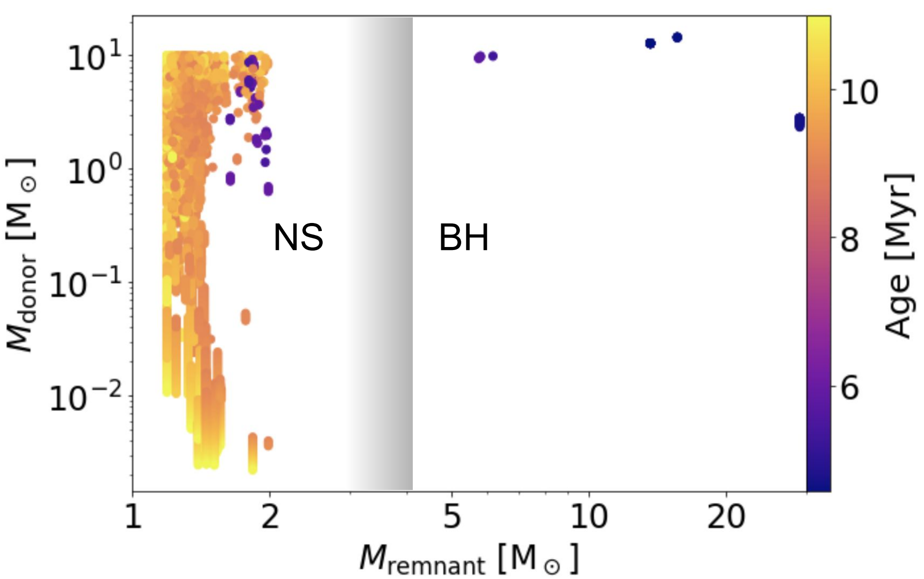
(5) The results of simulations combined with the detection of a faint object) suggest that this system is more likely a NS binary system than a BH binary system.

Outputs of the population synthesis code SEVN (Spera et al. 2019)

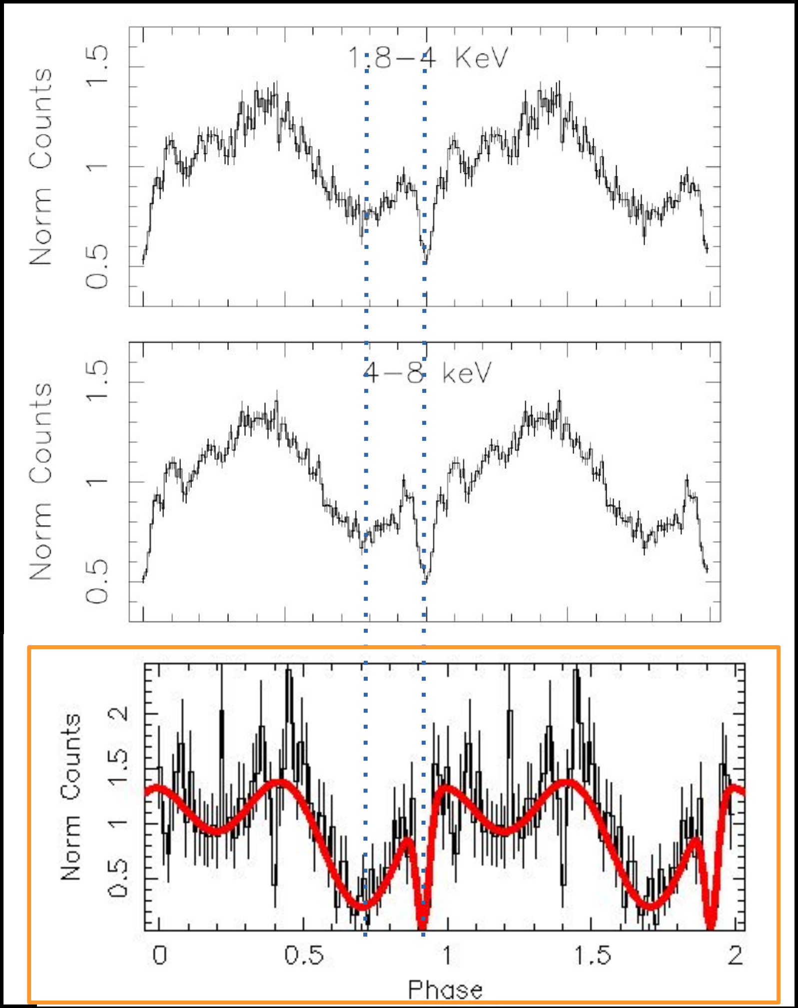
Notice: we considered valid systems only the ones with:

- 3.0h<Period<3.2 h + Age [3-6] Myr or [9-11] Myr
- The star is filling or almost filling the Roche-Lobe (Radius > 0.8 RL)
- The actual stellar mass is lower than 10 Msun

Mass of the two objects in the W1 pulsator-like systems color coded by the Age



X 1822-371	vs New pulsator
P_{orb} ~ 5.57hr	P_{orb}=3.1hr
dP_{orb}/dt ~ 1.5 10^{-10} s/s	-
PF_{orb} ~ 50%	PF_{orb} ~ 50%
P_{spin} ~ 0.59s	-
dP_{spin}/dt ~ -2.6 10^{-12} s/s	-
Lx ~ 1.2 10^{36} erg/s @ 2.5kpc	Lx ~ 0.1-20 10^{32} erg/s @ 2-5kpc
M_c ~ 0.6 $M_\odot$ K-Mstar	Low-mass
V ~ 15.1 mags	V > 20 mags
L_x/L_{opt} ~ 20 (often 500-1000 in LMXBs)	L_x/L_{opt} > 1
In a stellar cluster ?	Wes1
ADC system with i~85°	high i




THANKS FOR THE ATTENTION