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# A comprehensive census of X-ray periodic sources in dense star cluster: from *Chandra* to *NewAthena*

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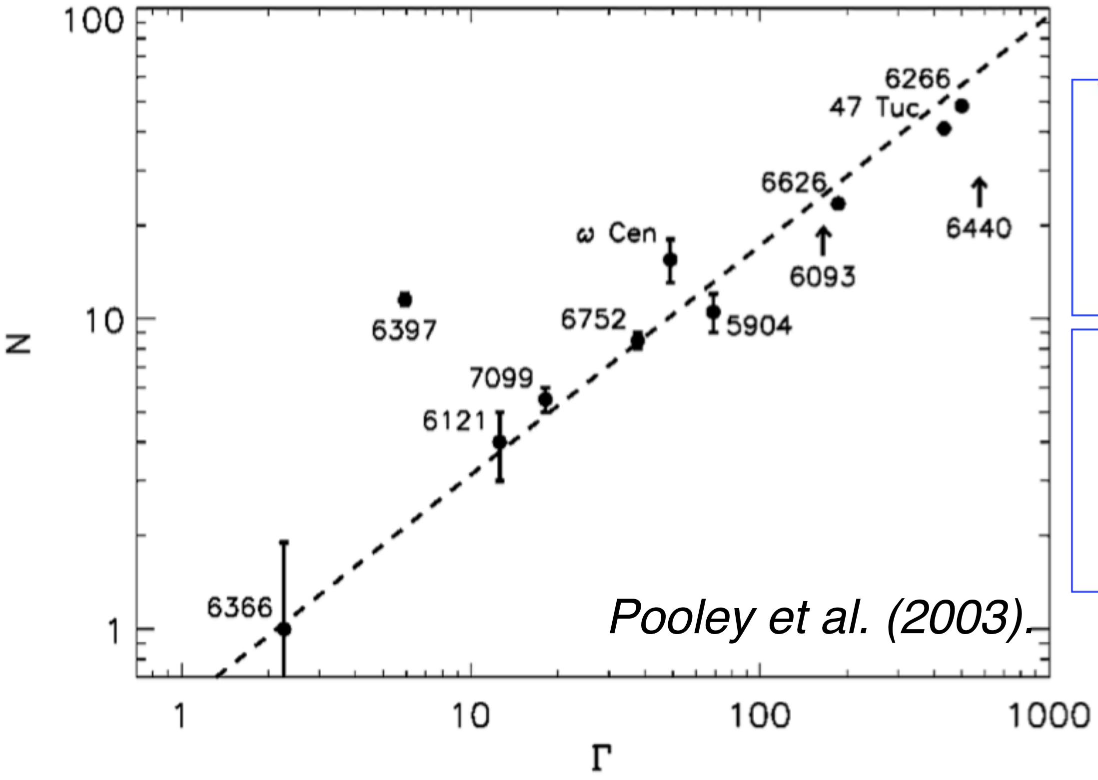
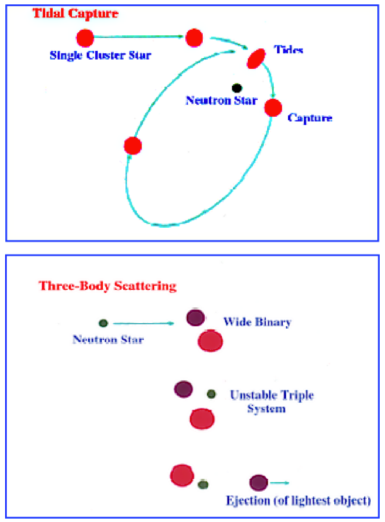
# Are X-ray population in GCs similar to Galactic-field?

## 1. LMXBs are ≃ 100× overabundant in GCs.

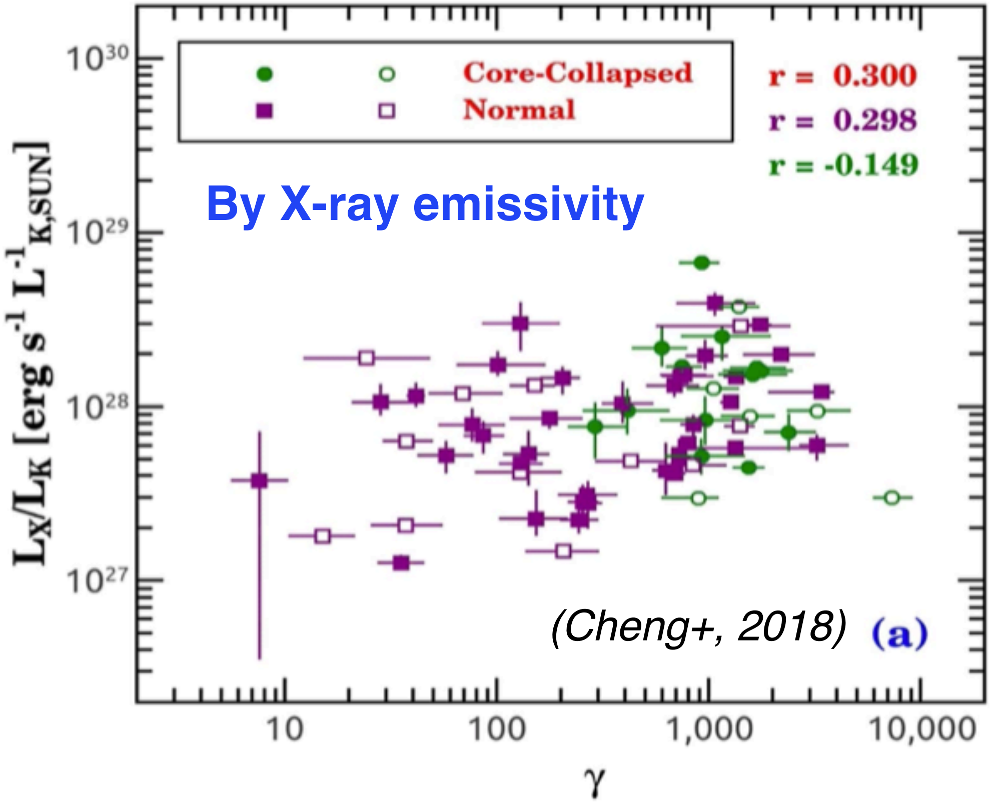



Number of X-ray sources (N) with Lx ≳ 4 × $10^{34}$ erg/s vs. the normalized encounter rate Γ of the cluster.

Tidal capture or exchange encounter in cluster core favor the production of LMXBs.

## 2. Not so sure for CVs




Unlike LMXBs, no correlation between the faint X-ray source (mostly CVs) abundance and the normalized stellar encounter rate.

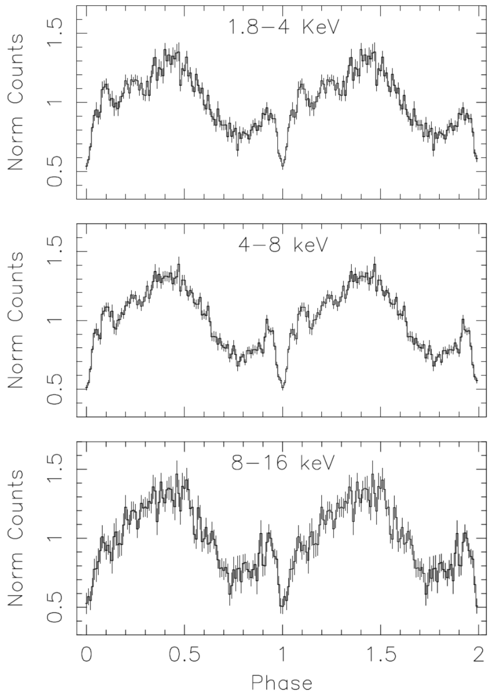
# Why Period matters?

· **Great probe for source classification**.
(challenge of optical/IR matching in dense environment)

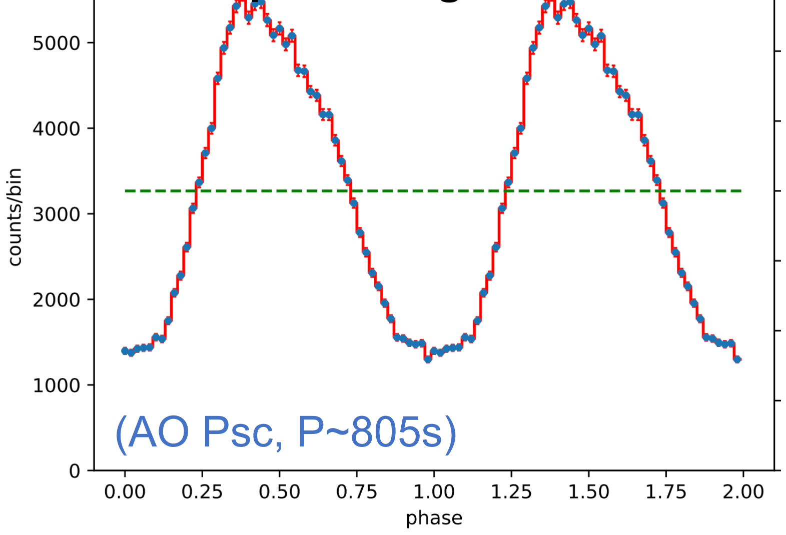
· Direct hint for:
(1) binary evolution;
**(2) Dynamical interactions;**
(3) some exotic binaries (e.g., ultra-compact X-ray binaries, accreting pulsar, …)

**Examples:**

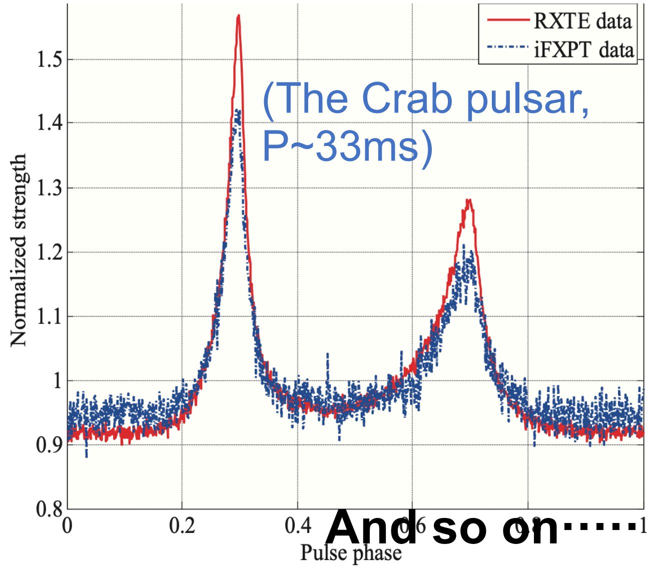
**The eclipsing of LMXBs:**




**WD’s spin in magnetic CVs:**




**X-ray Pulsars:**



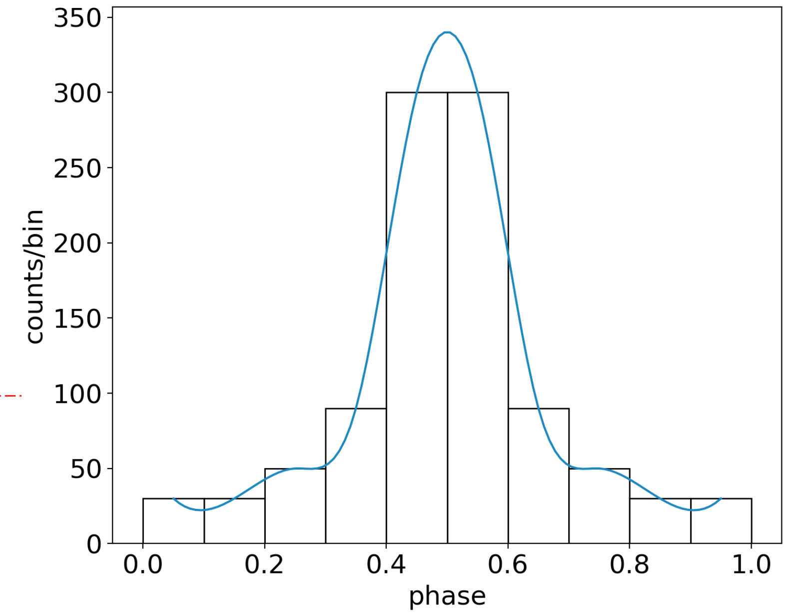

**And so on……**

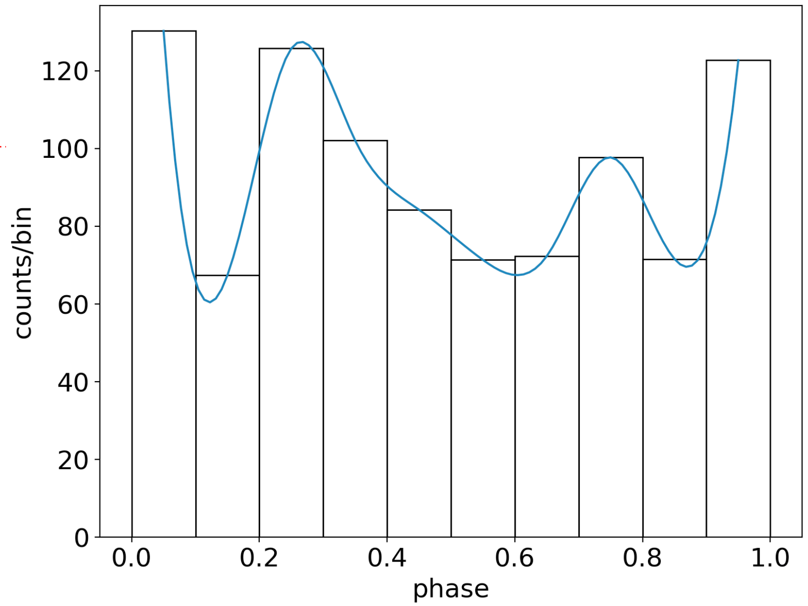
# The outline of GL method

**KEY: The "multiplicity" :** $$W_m(\omega, \phi) = \frac{N!}{n_1!\, n_2!\, n_3! \cdots n_m!}$$ where $\sum_{i=1}^{m} n_i(\omega, \phi) = N$

**$n_i(\omega, \varphi)$:** the number of counts falling into the ith phase bins.

**The more the values of $n_i$ differ from each other (indicating periodicity), the smaller the multiplicity.**




**Probability of periodic signal can be derived numerically.**

(Gregory & Loredo,1992)

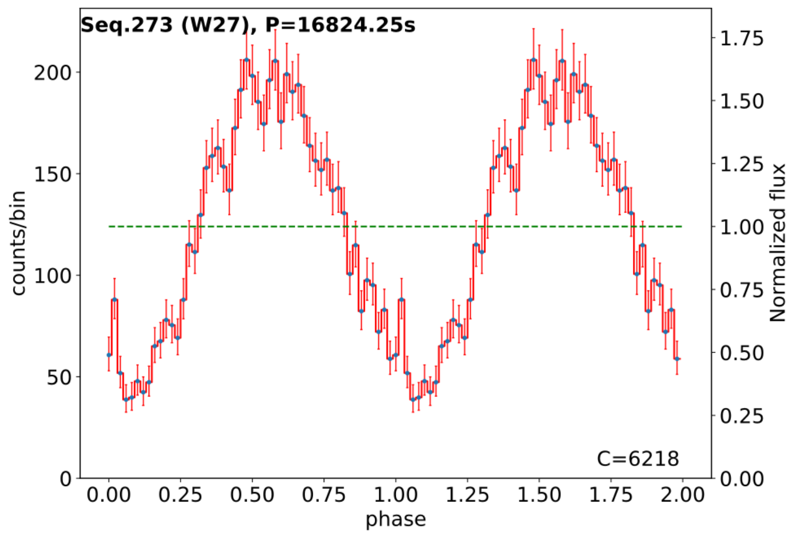
(Bao&Li, 2020)

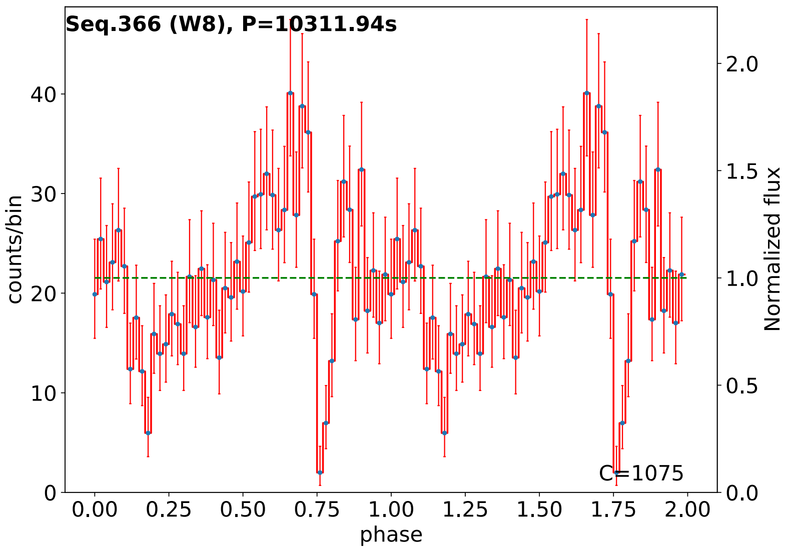
# A systematic search for periodic X-ray sources in the Galactic GCs

**Sample:** 11 Galactic GCs with Chandra exposure > 100 ks

**Method:** X-ray timing analysis+ cross-matching UV counterparts

**Examples: Different type of CV orbital modulation**

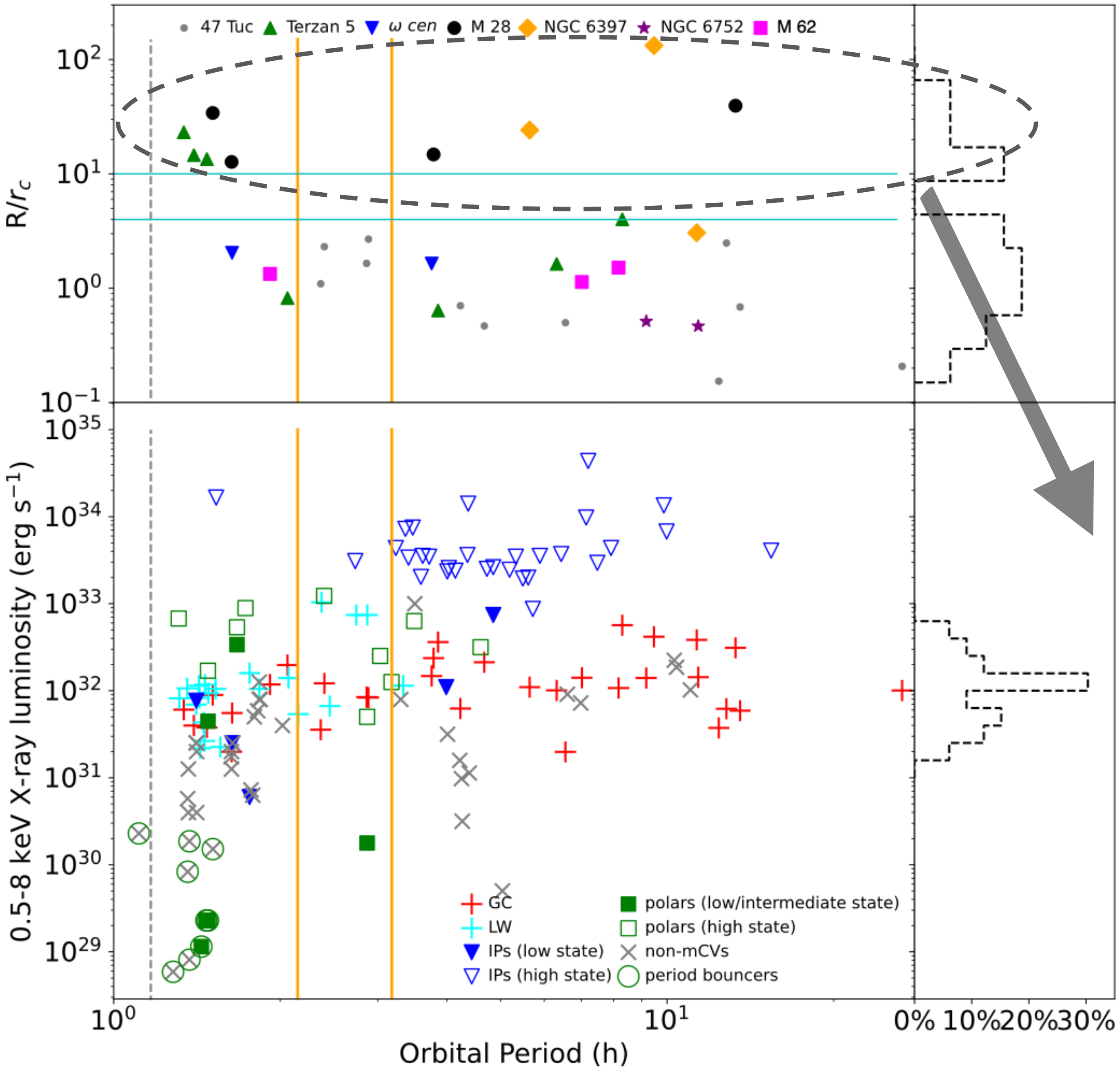



| GC Name | Chandra Obs.ID | Effect. Exposure (ks) | Distance (kpc) | $r_h$ (arcmin) | $r_c$ (arcmin) |
|---|---|---|---|---|---|
| **Terzan 5** | 3798 10059 13225, 13252, 13705, 13706, 14339, 14475, 14476, 14477, 14478, 14479, 14625, 15615, 15750, 16638, 17779, 18881, | 745.6 | 5.5 | 0.72 | 0.21 |
| **47 Tuc (NGC 104)** | 78, 953, 954, 955, 956, 2735, 2736, 2737, 2738, 3384, 3385, 3386, 3387, 15747, 15748, 16527, 16528, 16529, 17420 | 535.1 | 4.5 | 3.17 | 0.36 |
| **NGC 6752** | 19014 20122 20123, 19013 6612 948 20121 | 344.4 | 4.3 | 1.91 | 0.17 |
| **NGC 6397** | 79, 2668, 2669 7461, 7460 | 339.7 | 2.4 | 2.97 | 0.05 |
| M30 (NGC 7099) | 2679, 20725, 18997, 20726, 20732, 20731, 20792, 20795, 20796 | 330.1 | 8.0 | 1.03 | 0.06 |
| **M28 (NGC 6626)** | 2683, 2684, 2685, 9132, 9133, 16748, 16749, 16750 | 325.9 | 5.4 | 1.97 | 0.24 |
| **$\omega$ cen (NGC 5139)** | 653, 1519, 13727, 13726 | 290.9 | 5.2 | 5 | 2.4 |
| **M62 (NGC 6266)** | 2677, 15761 | 144.4 | 6.4 | 0.92 | 0.22 |
| NGC 6121 | 946, 7446, 7447 | 119.2 | 1.9 | 4.33 | 1.17 |
| NGC 6304 | 8952, 11073 | 102.7 | 5.8 | 1.42 | 0.21 |
| NGC 6656 | 5437, 14609 | 100.7 | 3.2 | 3.36 | 1.34 |

*(Bao T, et al., 2024)*

# Identified CVs in the Galactic globular clusters



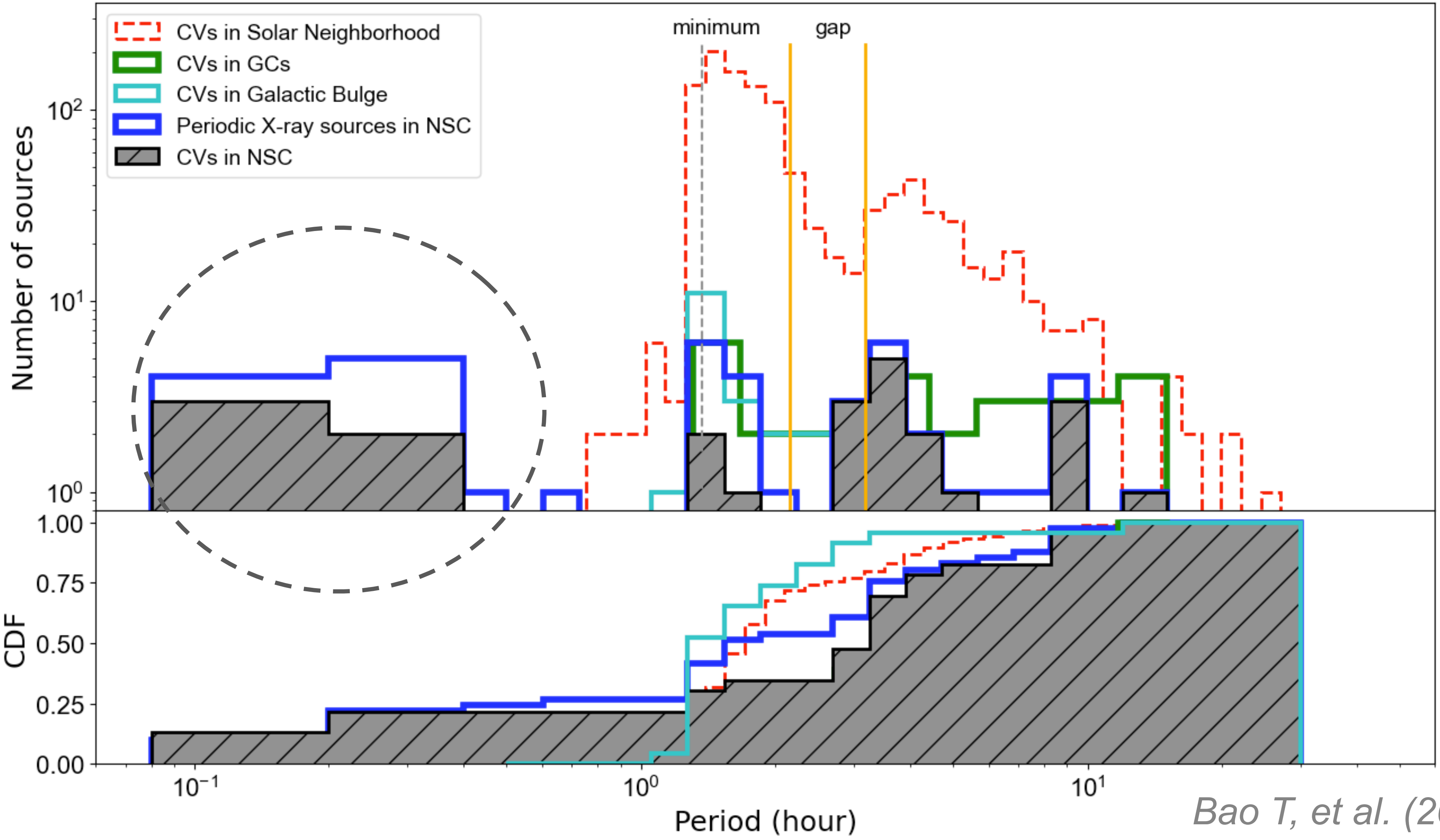

**Total: 46 periodic sources** (classified as CVs, LMXBs, MSPs and ABs.)

1. **32 periodic CVs in 7 GCs**, enlarging the previous sample in GCs by 3 times.

2. **Dynamically-ejected CVs are firstly found in the GC's outskirts**, confirming the predictions by MOCCA simulation (Belloni+, 2019).

3. No IPs in GC so far.

# Periodic CVs as *Probes* of different dense environment




*Bao T, et al. (2020, 2023, 2024)*

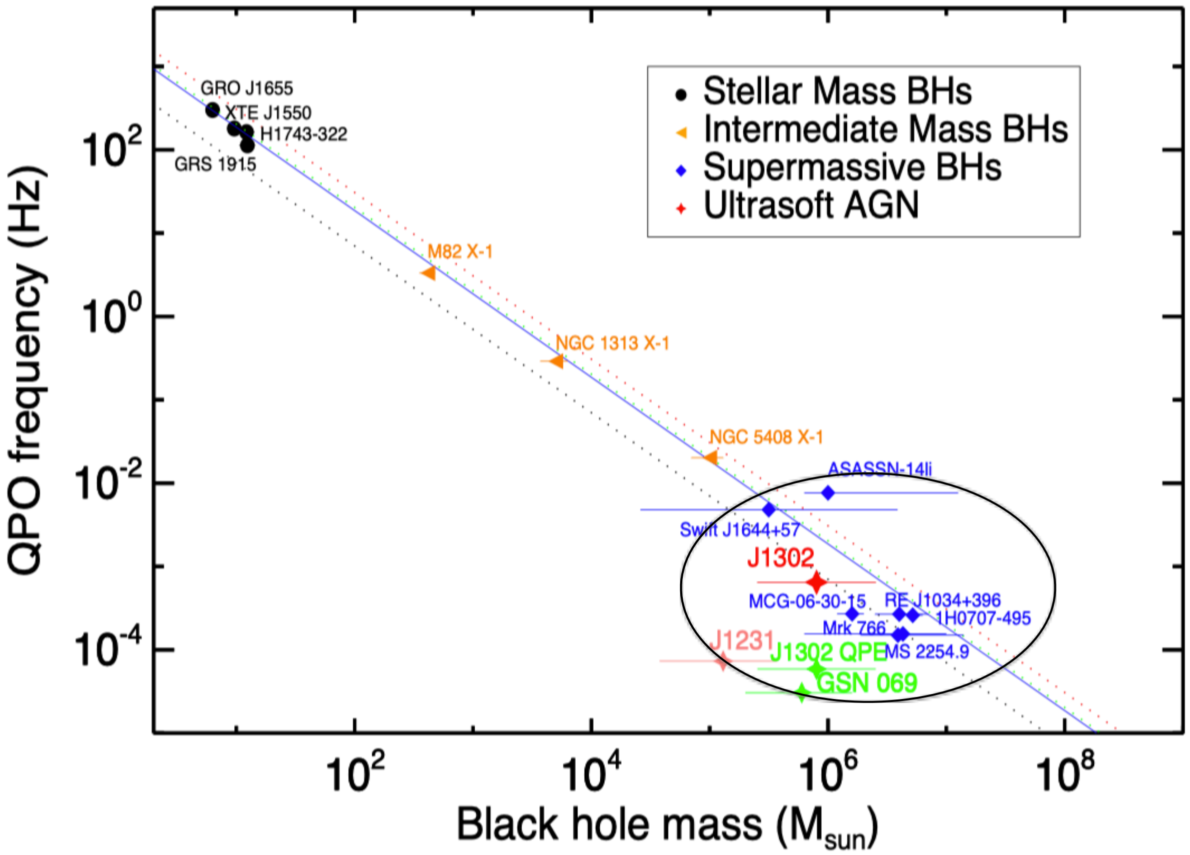
**Galactic bulge:** CV orbits distributed between 1-3 hours; probing a typical old stellar population.
**Globular clusters:** more long-period CVs ($P_{orb}$ > 4 hours), affected by strong dynamic interactions.
**NSC:** ~25% of periods of identified CVs are lower than 1 hour. (more magnetic CVs?)

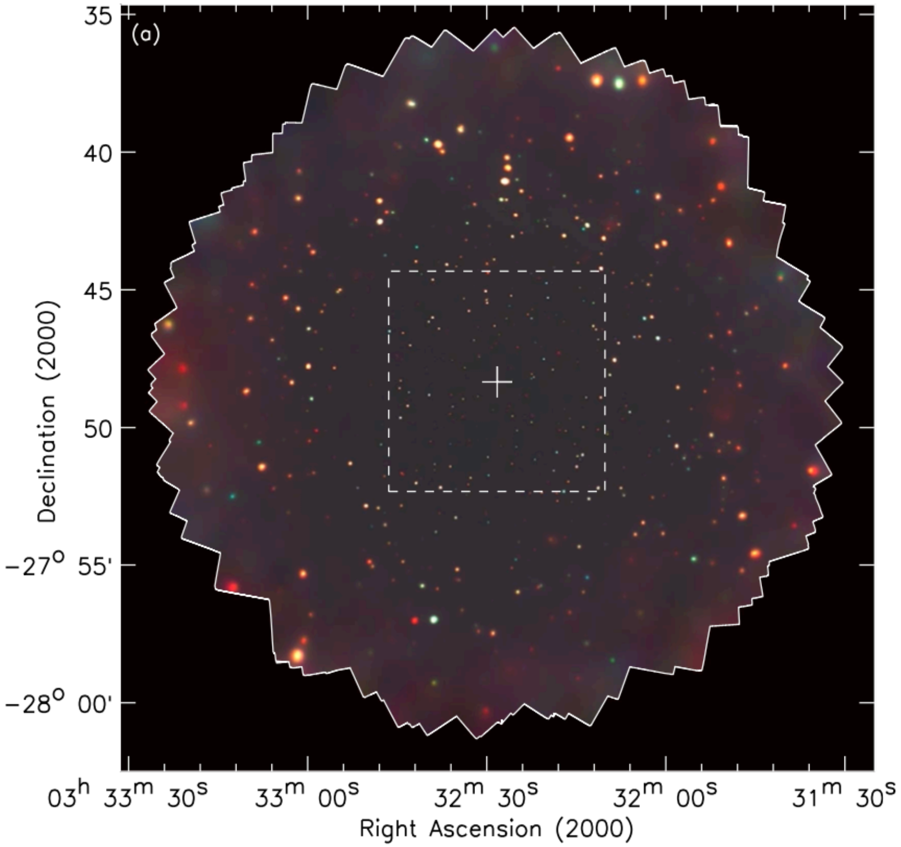
# Some related “by products”

# 1. How much is the contribution from background AGN?

*(Bao T & Li Z., 2022)*

AGN QPO: between 200s and 20000s




**Result:** 0 QPOs in ~1000 sources over a span of ~ 20yrs (7 Ms exposure).

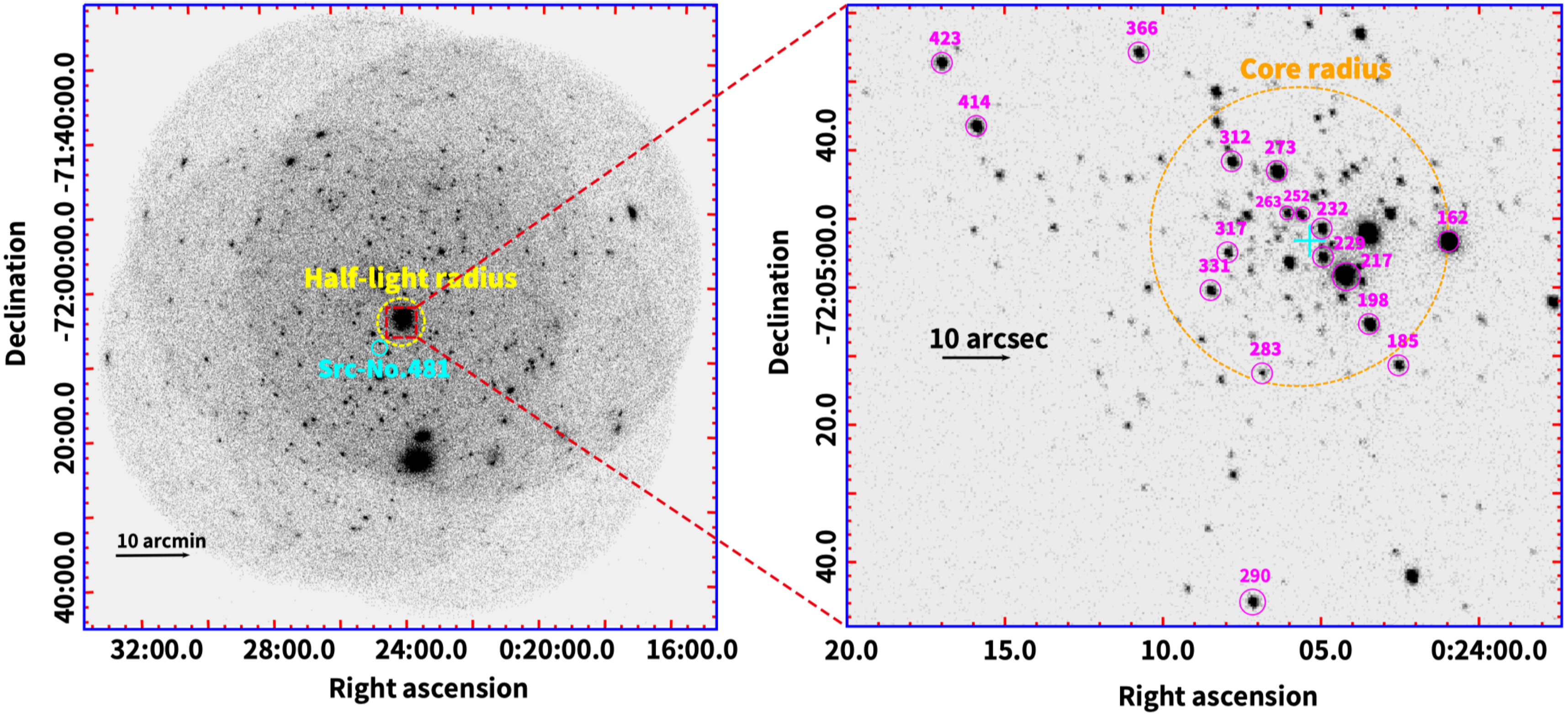
$$N_{\rm QPO,det} = DE \times f_{\rm QPO} \times N_{\rm sou}$$

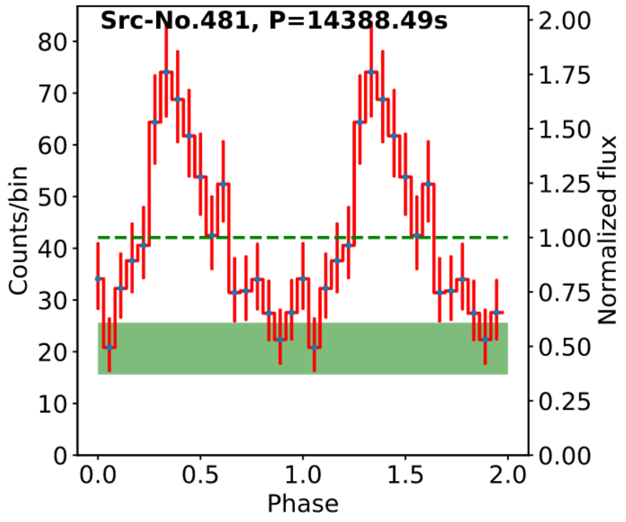
Detection efficiency

Intrinsic fraction of AGNs with QPO

$f_{QPO}$< 15-20%

# 2. A MSP in eROSITA study of the 47 Tucanae




Both the sinusoidal-like light curve and extremely soft spectra (**kT~0.06 keV**) indicates it as a MSP.

**Low occurrence rate (1/888) of periodic sources in outskirts of 47 Tuc:**

(1) Higher background in light curves;

(2) Most of sources are background AGN

# 3. An UCXB system in M31

*(Zhang, Bao, Li., 2024)*
*(Ma,Q, Zhang J, et al. 2025)*

www.the-innovation.org

## The first extragalactic ultra-compact X-ray binary: A candidate black hole-white dwarf system

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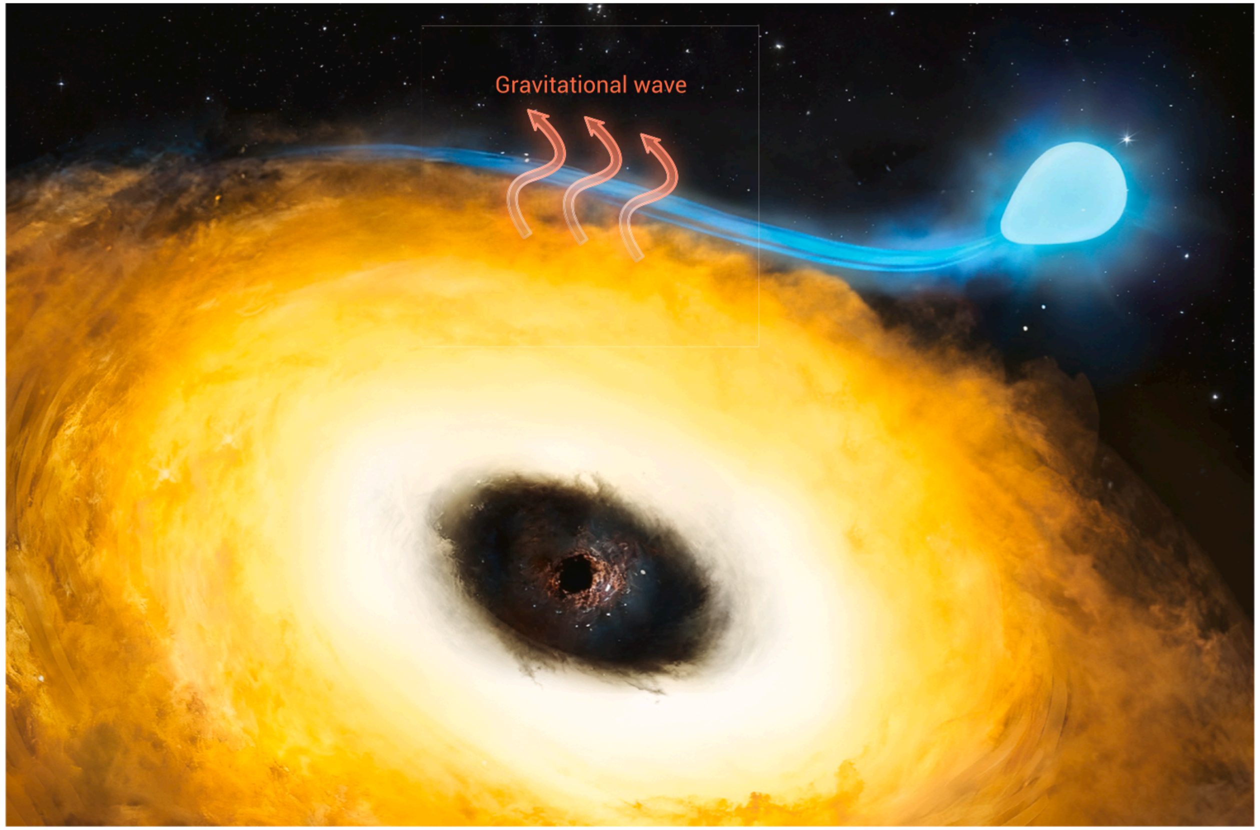
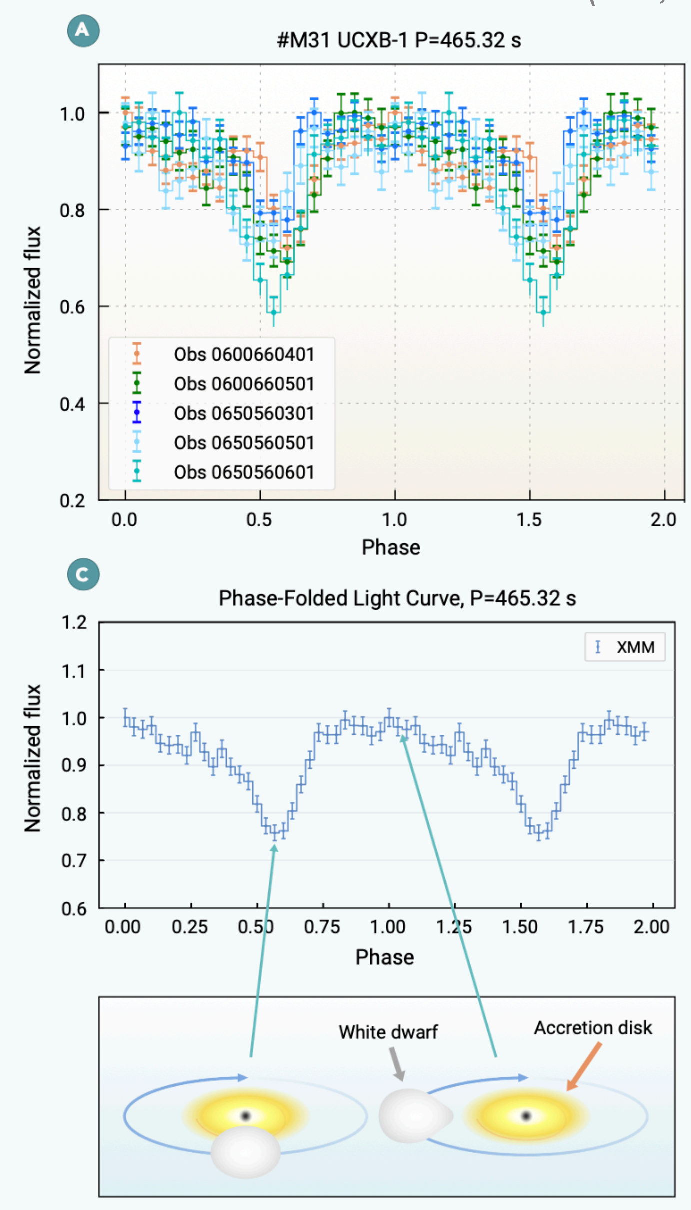
### GRAPHICAL ABSTRACT




### PUBLIC SUMMARY

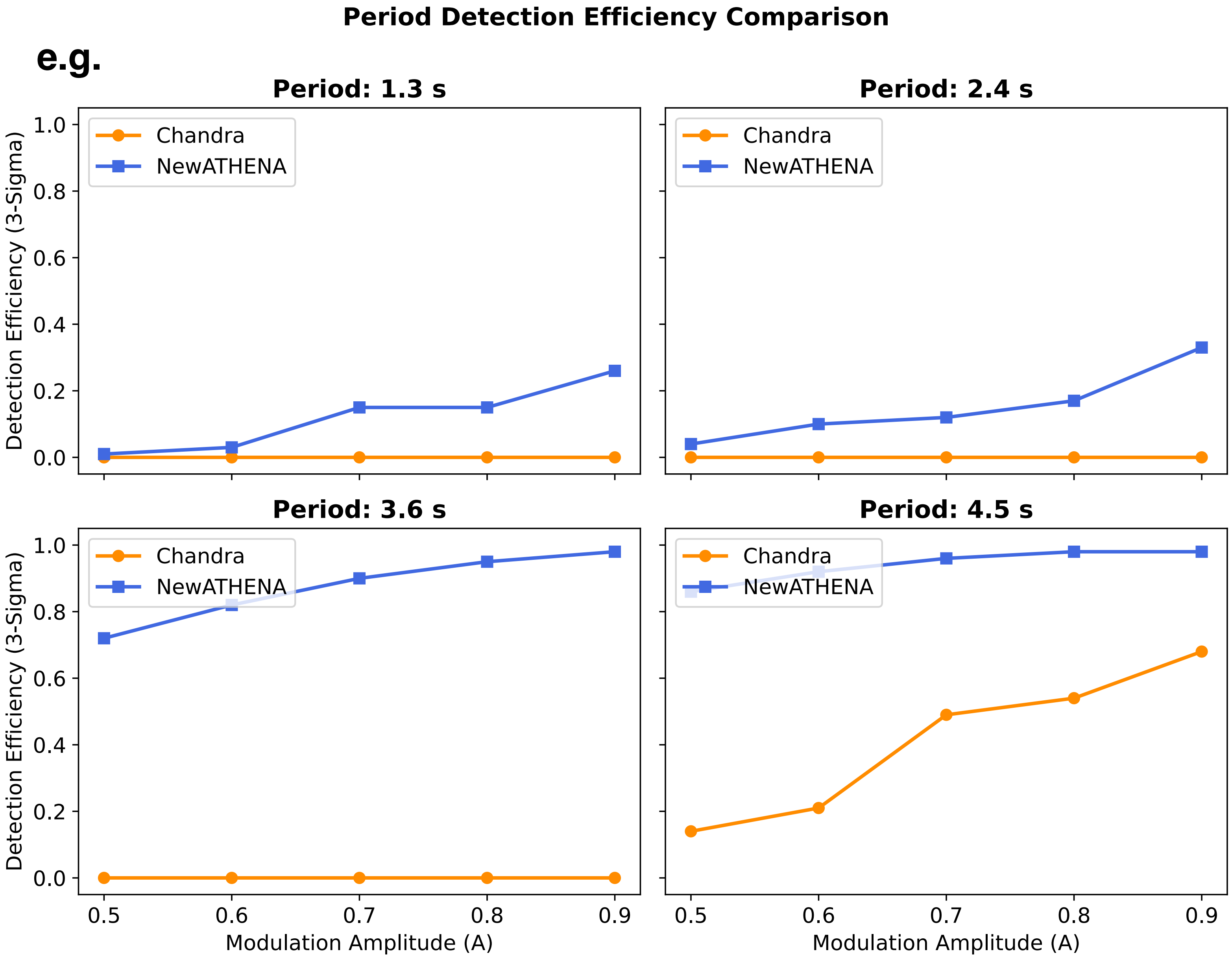
- M31 UCXB-1 is the first extragalactic ultra-compact X-ray binary (UCXB) candidate.
- M31 UCXB-1 is in excellent agreement with the black hole/neutron star-white dwarf system.
- The primary in M31 UCXB-1 is more likely to be a black hole than a neutron star.
- This source hosts the shortest orbital period and the most massive white dwarf among the known UCXBs.




P~8 minutes

# Detectability for short-periods with *NewAthena*

**e.g.**




**Time resolution: 3.2s (Chandra) to 80 $\mu$s**

**New discovery space for:**

(1) magnetars;

(2) QPO in IMBH candidates (in the core of globular cluster?)

(3) WD pulsars
…

# Summary

1. **We found about ~ 80 periodic X-ray sources in different dense environment, including Galactic bulge/center, globular clusters. They serve as great hint for the different parent population.**

2. Evidence are found for dynamical-ejected CVs in globular clusters, providing strong validation for the predictions made in the preceding simulation work.

**Mining compact binaries:** Period searches map parent populations and reveal exotic systems.

**NewAthena Advantage:** Superior timing(~80$\mu$s) and positional resolution are ideal for discovering new, short-period systems.