A Chandra Search for Periodic X-ray Sources in the Bulge of M31

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1. Introduction

M31, the closest galaxy to our own, is an ideal target for studying galaxies similar to the Milky Way due to its moderate Galactic foreground absorption.

Period of X-ray sources provides valuable insights into their dynamics and characteristics. The central region of M31 has been deeply observed by Chandra since 1999. **Over 2 Ms observations** are accumulated in the past 20 years. With the high spacial resolution of Chandra, these data enable us to do a systematic study of the periodic XRBs in M31.

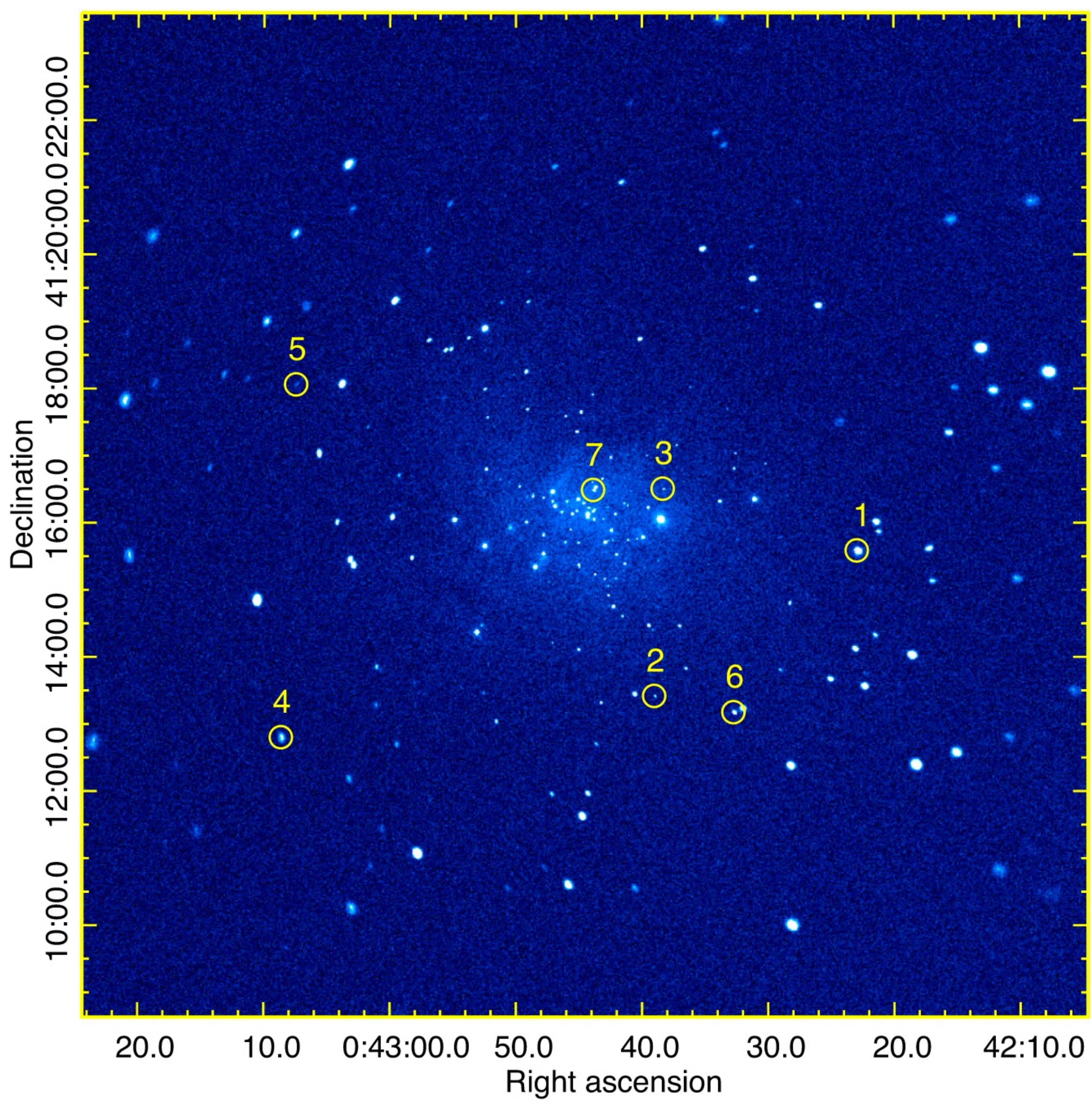


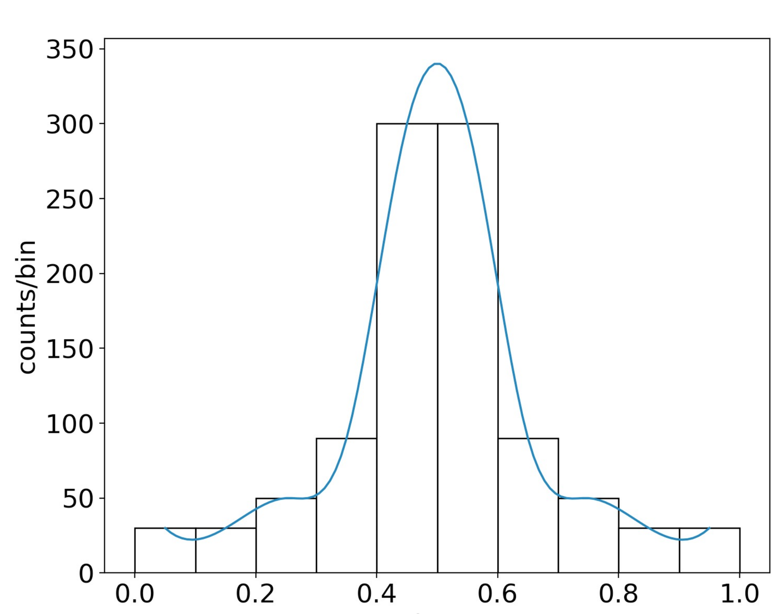
Figure1. 0.5-8 keV counts image of the M31 bulge, combining 116 Chandra/ACIS observations. Locations of the 7 periodic sources are marked.

2. Period Searching Method: Gregory-Loredo Algorithm

The Gregory-Loredo (GL) algorithm[4], which applies the Bayesian probability theory to evaluate the likelihood of a periodic model against a model of constant flux and subsequently determines the most probable period, P. The key of this algorithm is the multiplicity of the phase distribution of events,

$$W_m(\omega,\phi) = \frac{N!}{n_1!\,n_2!\,n_3!\cdots n_m!}$$

where N represents the total number of counts, $n_i\ (\omega,\phi)$ is the number of counts falling into the i th of m phase bins, given the frequency $\omega = 2\pi/P$ and phase ϕ, satisfying $\sum_{i=1}^{m} n_i(\omega,\phi) = N$. The multiplicity is the number of ways that the binned distribution is arisen by chance and the more n_i differ from each other, the smaller the multiplicity.



ID	R.A.	Decl.	Period (s)	Notes
1	00 42 22.953	+41 15 35.52	463.24	LMXB, 464 s
2	00 42 39.030	+41 13 25.50	4685.82	Nova
3	00 42 38.350	+41 16 30.87	4933.40	Nova, 1.3 h
4	00 43 08.636	+41 12 48.42	6432.94	LMXB, 1.78 h
5	00 43 07.453	+41 18 03.98	7183.91	Nova
6	00 42 32.746	+41 13 10.94	22835.09	LMXB
7	00 42 43.877	+41 16 29.72	69417.50	LMXB

Table1. **The result of periodic X-ray sources in M31**. Seq. 1, 3, 4 are reported in previous work [5][9], and other periodic sources are reported in this work for the first time.

3. Results

Based on an 80-minute threshold, Seq. 1 is classified as Ultra-compact X-ray Binaries (UCXBs). It is **the shortest-period UCXB observed to date and a potential extragalactic gravitational wave source for future detectors**. Seq. 2, 3, and 5 are Chandra-detected novae during their outbursts. Source 7 displays a distinctive light curve with two eclipses in one period, suggesting **a possible three-body system**. If the three bodies form an equilateral triangle, it represents a stable central configuration of the system. The presence of a third companion introduces additional variability, leading to variations in the light curve.

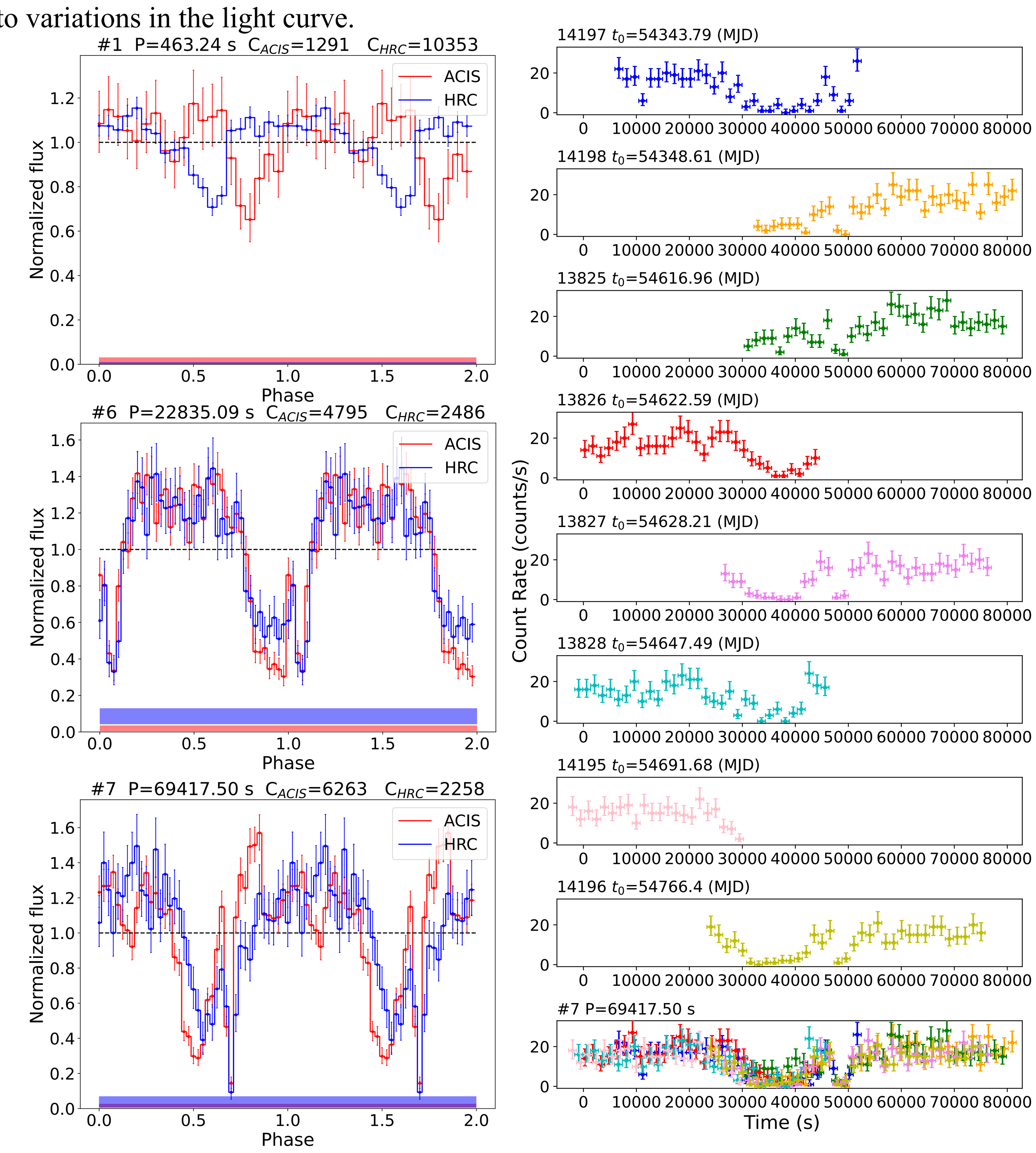


Figure2. Left panel: Phase folded light curve. Seq. 1, 6, 7 shows the orbital period of XRBs. Right panel: Phase-aligned light curves of eight long observations for Seq.7. The top eight rows show the light curves of each individual observation, for which the ObsID and start time of the light light curve are labeled. The bottom row overlays the eight light curves, highlighting the double eclipsing behaviour in Seq.7.

4. Discussion

We plot a period-luminosity diagram using the Galactic LMXB catalog from previous work and M31 LMXB. Source 1 shows ultra compact nature according to the period. It is also currently the brightest UCXB. Seq. 4, 6, 7 have period and luminosity in the region of LMXB. However, due to the limited sample size, it is not possible to statistically compare the two groups.

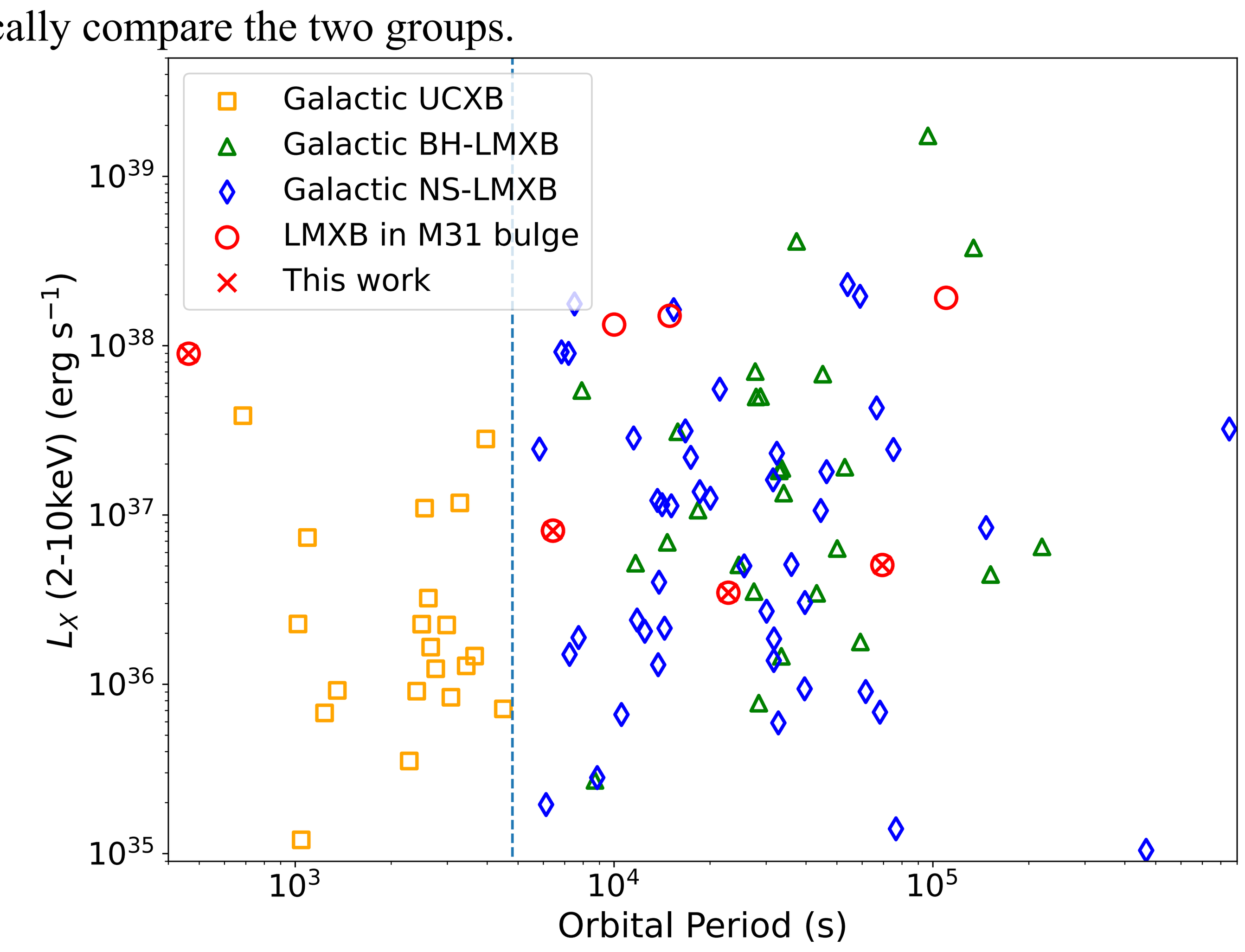


Figure3. Period-luminosity diagram of Galactic XRBs and periodic X-ray sources in this work. BH-LMXBs and NS-LMXBs are from[2]. Ultra compact X-ray binaries (UCXBs) are from [1].

5. Summary

We detected 7 periodic sources, out of which **4 are newly identified.** 4 of them are orbital period of XRB, and 3 are orbital period of novae.
The shortest-period UCXB observed to date and **a potential three body system** are also discovered.

https://doi.org/10.1093/mnras/stae1002

Reference

[1] Armas Padilla M. et al. 2023, A&A, 677, A186[2] Avakyan A. et al. 2023b, A&A, 675, A199[3] Bao T. & Li Z. 2020, MNRAS, 498, 3513[4] Gregory P. C. & Loredo T. J. 1992, ApJ, 398, 146[5] Henze M. et al. 2014, A&A, 563, A2[6] Hofmann F. et al 2013, A&A, 555, A65[7] Kaaret P. 2002, ApJ, 578, 114[8] Kong A. K. H. et al. 2002, ApJ, 577, 738[9] Mangano V. et al. 2004, A&A, 419, 1045[10] Neumann M. et al. 2023, A&A, 677, A134[11] Osborne J. P., et al., 2001, A&A, 378, 800