Compact Objects and Binaries in Dense Star Clusters
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Young Ultracompact X-ray Binaries in Extragalactic Globular Clusters: A Multiwavelength Perspective

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Abstract. We present multiwavelength evidence that the globular cluster X-ray source GCU7 is a young ultracompact X-ray binary in its initial, high-luminosity phase. *Chandra* observations from 1999–2023 show a persistently stable X-ray luminosity of $L_X \approx 1.2 \times 10^{39}$ erg s^{-1}, ruling out a transient nature such as a tidal disruption event. Correspondingly, long-term optical spectra consistently feature a unique signature of [N II] and [O III] emission, with a clear absence of hydrogen and helium. This combination of features strongly identifies GCU7 as a system with a helium white dwarf donor that is supplying material to a neutron star or black hole at a sustained super-Eddington rate. GCU7 thus serves as a key example of the early stages of UCXB evolution.

Keywords. globular cluster, X-ray binary, neutron star, black hole

1. Introduction

Ultracompact X-ray binaries (UCXBs) are a subclass of low-mass X-ray binaries (LMXBs) with short orbital periods (< 80 min) and hydrogen-deficient donors (van Haaften et al. 2012; Armas Padilla et al. 2023). They are key gravitational-wave sources (Wang et al. 2021) and laboratories for studying binary evolution and accretion in H-poor environments (van Haaften et al. 2012). Many UCXBs are found in globular clusters (GCs), formed via dynamical interactions such as neutron star–red giant collisions (Hut et al. 1991; Ivanova et al. 2005). However, the most luminous systems, particularly during the early phases of UCXB evolution when they can reach ultraluminous X-ray source (ULX) luminosities ($L_X \geq 10^{39}$ erg s^{-1}), are rare and observed only in extragalactic GCs. Multiwavelength observations show long-term X-ray stability and optical spectra with [N II] and [O III] lines, lacking H or He. We review these signatures using GC ULX CXO J033831.8-352604 (GCU7) as a case (Oh et al. 2025). These features identify young UCXBs with He WD donors, offering insight into their initial evolution and the full UCXB life cycle.

2. X-ray Signatures: A New Perspective on Stability in the Early Stages

While the X-ray emission from UCXBs often exhibits significant variability, the most luminous examples found in extragalactic GCs offer a new perspective on their early evolution. A prime case study is GCU7, which has displayed a stable luminosity of $L_X \approx 10^{39} erg\ s^{-1}$ for over two decades of *Chandra* observations (Fig. 1). This sustained, high-luminosity emission strongly disfavors transient models, such as a tidal disruption event, which would predict a significant decay over this timescale. Instead, this points

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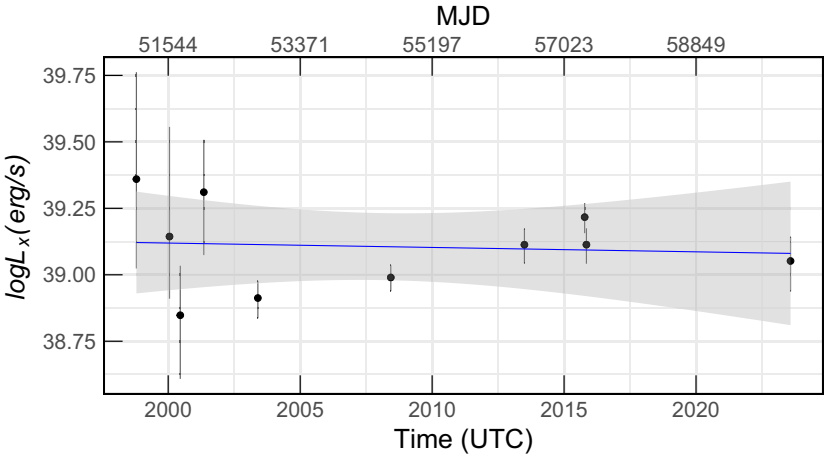


Figure 1. The long-term X-ray light curve of GCU7 from 1999 to 2023, combining data from 13 *Chandra* observations in the 0.5–8.0 keV range. The luminosity has remained remarkably stable for over two decades, which is a key characteristic which argues against a transient origin.

towards a continuous and regulated mass transfer process. We interpret it as a key signature of a young UCXB in its initial, super-Eddington accretion phase, offering a rare glimpse into the earliest stages of its evolution before it transitions into the less luminous, more variable systems commonly observed in the local universe.

3. Unveiling Donor Nature through Optical Spectroscopy

Optical spectroscopy is key to identifying the chemical composition of UCXB donors, confirming their hydrogen-deficient nature through the absence of hydrogen spectral features (van Haaften et al. 2012; Armas Padilla et al. 2023). Specific emission lines of helium, carbon, nitrogen, or oxygen distinguish donor types, such as helium stars, He WDs, or CO WDs. For instance, the GC ULX RZ 2109's optical spectrum shows a strong, broad [O III] doublet without hydrogen, indicating a CO WD donor, likely associated with a fast outflow or jet (Dage et al. 2024). By contrast, GCU7 presents a different but equally informative spectral signature. Its optical spectrum consistently shows prominent [N II] and [O III] emission lines (left panel of Fig. 2), while both hydrogen and helium features are clearly absent, consistent with its UCXB nature. This specific combination of lines–strong nitrogen and oxygen without helium–offers a powerful diagnostic for its donor. As shown by photoionization modeling with CLOUDY, this spectral appearance is best reproduced by an outflow from a system with a He WD donor (see right panel in Fig. 2).

4. Synthesis and Future Outlook

GCU7's multiwavelength evidence, including stable X-ray luminosity and an optical spectrum with [N II] and [O III] lines but no hydrogen or helium, identifies it as a young UCXB with a He WD donor accreting at super-Eddington rates. Theoretical models suggest UCXBs evolve from high to low mass transfer over Gyr timescales due to gravitational wave radiation (Bildsten & Deloye 2004). As shown in evolutionary tracks (Fig. 3), a system like GCU7 represents this early stage, which may last for only 10^3 to 10^4 years (Oh et al. 2025). GCU7 thus provides a rare snapshot of this fleeting, high-luminosity phase that is statistically difficult to capture in the Milky Way.

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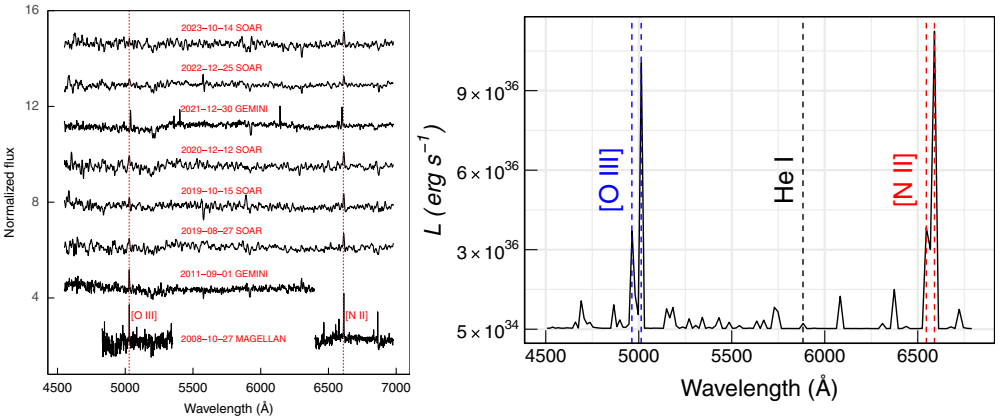


Figure 2. Left: The optical spectrum of GCU7, showing the prominent [N II] and [O III] emission lines. Right: A CLOUDY model spectrum of a photoionized outflow from a He WD donor system, supporting the hypothesis of a He WD donor.

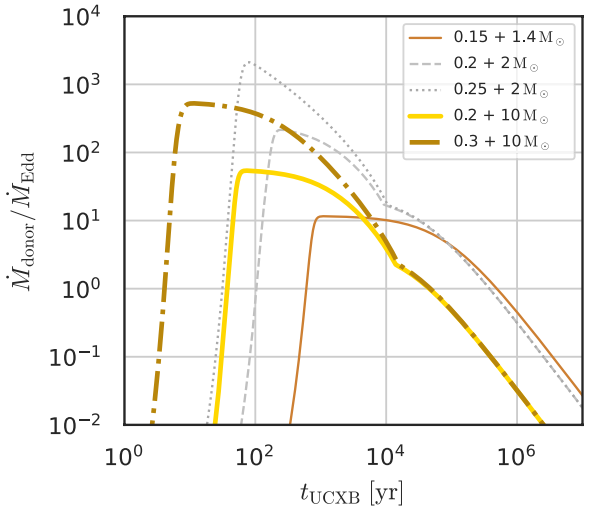


Figure 3. Evolutionary tracks for UCXB systems with He WD donors. The tracks show an early phase of highly super-Eddington mass transfer, corresponding to the state of GCU7.

In conclusion, the study of extreme, extragalactic systems like GCU7 is essential for constructing a complete and observationally-grounded picture of UCXB formation and evolution. Studying such extragalactic systems is vital for understanding UCXB evolution and refining population synthesis models by identifying more young UCXBs in nearby galaxies.

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