Testing for Black Holes in Globular Clusters with X-ray Observations

Authors: Kristen Dage(1)*; Steve Zepf(1); Mark Peacock(1); Arash Bahramian(1); Thomas Maccarone(2); Arunav Kundu(3)
*kcdage@msu.edu

1. Physics and Astronomy, Michigan State University, East Lansing, MI, United States. 2. Texas Tech University, Lubbock, TX, United States. 3. Eureka Scientific, Oakland, CA, United States.

0. Abstract

The question whether globular clusters host black holes has been of longstanding interest. This interest has grown dramatically with the LIGO detection of merging black holes, as black hole mergers in globular clusters is one of the leading explanations for these LIGO sources. Determining whether black holes are common in globular clusters has been an observational challenge. **One of the most successful ways to identify candidate black holes in globular clusters is to identify globular cluster X-ray sources with very high luminosities** that are much greater than the Eddington limit for neutron stars (known as ULXs). However, observations of ULXs in star forming galaxies have shown that at least in these young systems neutron star accretors can be extraordinarily bright. In this contribution we discuss ways to compare these to two classes of ULXs, both with current data and future missions, with the **ultimate goal of determining whether black holes are common in globular cluster**s and plausible sources for black hole mergers observed in gravitational waves.

1. Black Holes and Globular Clusters

LIGO's first four detections were black hole-black hole mergers, dynamical interactions among black holes (BHs) in globular clusters (GC) might be their source.

- **A number of ULXs have been found within extragalactic globular clusters**, and are candidate accreting black holes. (see Figure 1 for examples of such sources in NGC 4472)
- Of these, five have been well studied, two in NGC 4472 (Maccarone et al 2007, Maccarone et al 2011), two in NGC 1399 (Irwin et al 2010, Shih et al 2010), and one in 4649 (Roberts et al 2012).
- One source in particular (RZ2109 in NGC 4472) has been well studied in both X-ray and optical. Optical spectroscopy reveals a broad, bright [OIII] emission line which **implies a white dwarf donor.** This emission line also varies considerably (see Figure 2 to the right). There is also a clear absence of hydrogen emission in RZ2109 (Zepf et al 2008, Steele et al 2014); the two other **GC ULXs studied in optical also note an absence of hydrogen emission** (Irwin et al 2010, Roberts et al 2012).

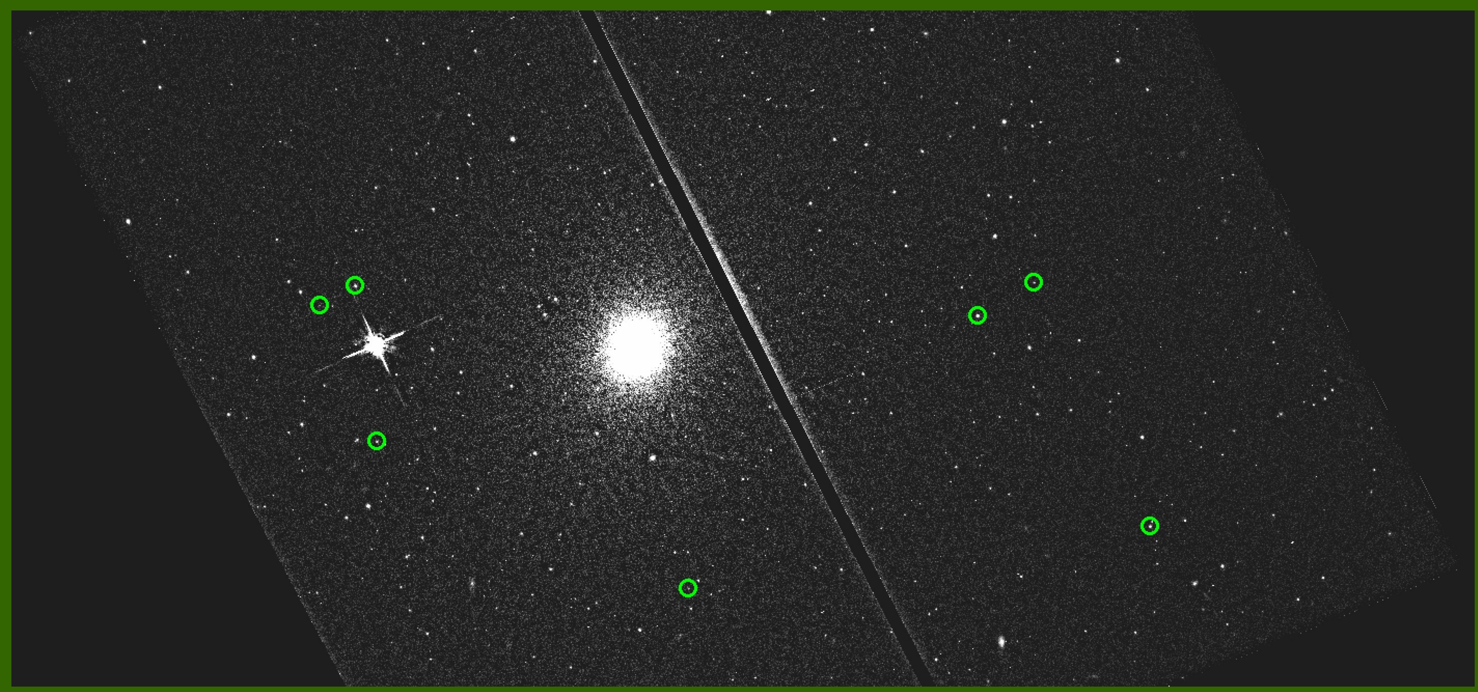

Figure 1: regions of log10(L_x)>38.5 that matched with globular clusters overlaid on Hubble ACS image of NGC 4472.

2. Globular Cluster ULXs

GC ULXs are different than ULXs in star forming galaxies in many ways.

- The **donor star in GC ULX sources has to be a lower mass star and in one case is clearly a white dwarf;** donors in star forming galaxies are typically hydrogen rich, massive stars (Gladstone et al 2009, Kaaret el 2017).
- The **binary in GC probably formed dynamically**, while massive stars in star forming ULXs probably formed together.
- Compact objects in GCs form a very long time ago, whereas in star forming galaxies, the accreting compact object in the ULX was just recently formed. This leads to **significant differences in expected magnetic fields**, as starforming ULXs require around 10^14 G for the neutron star surface field to reach these luminosities (Brightman et al 2018).

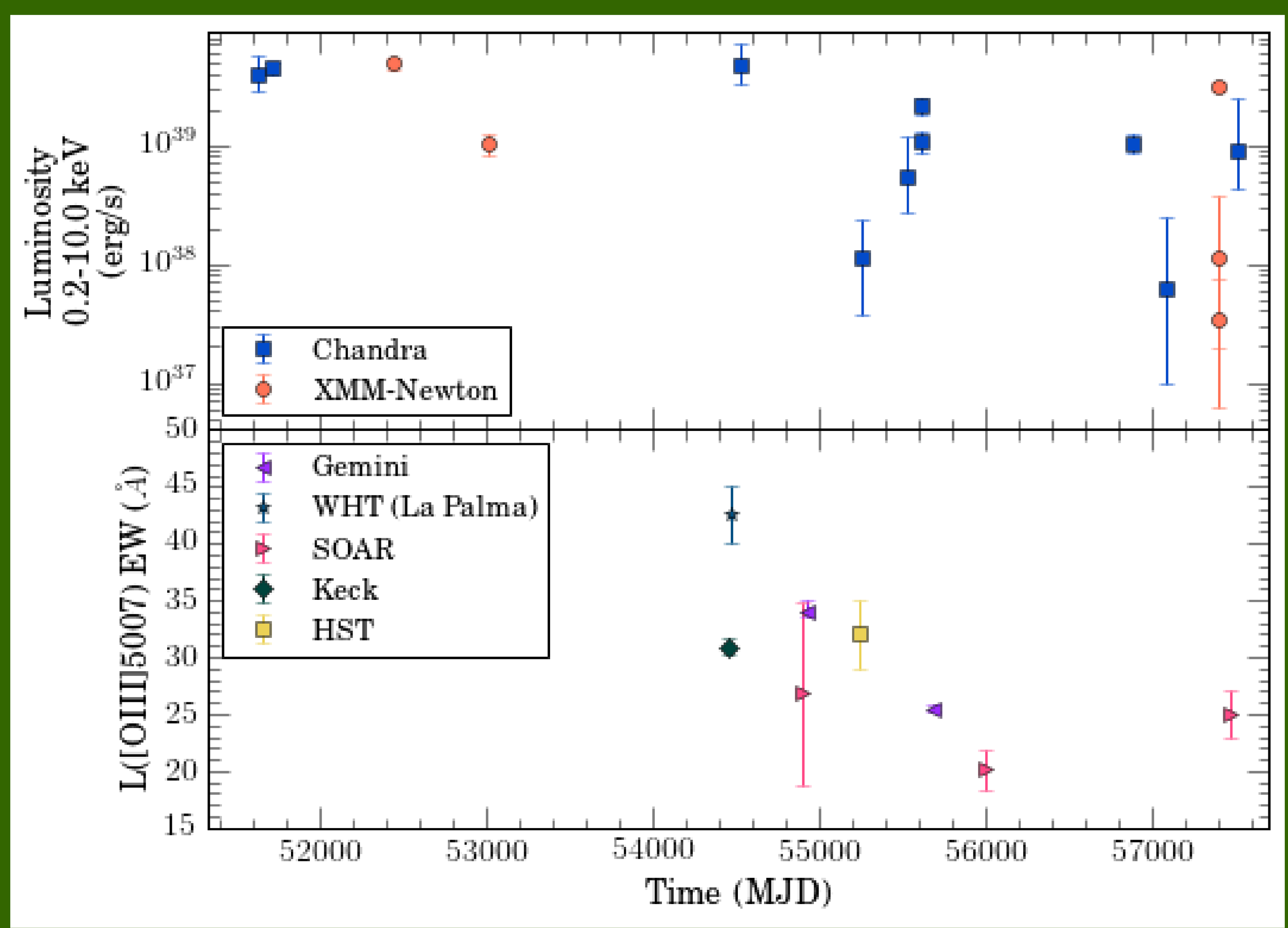

Figure 2. Long term X-ray and optical luminosities of RZ2109 shows strong variability in both.

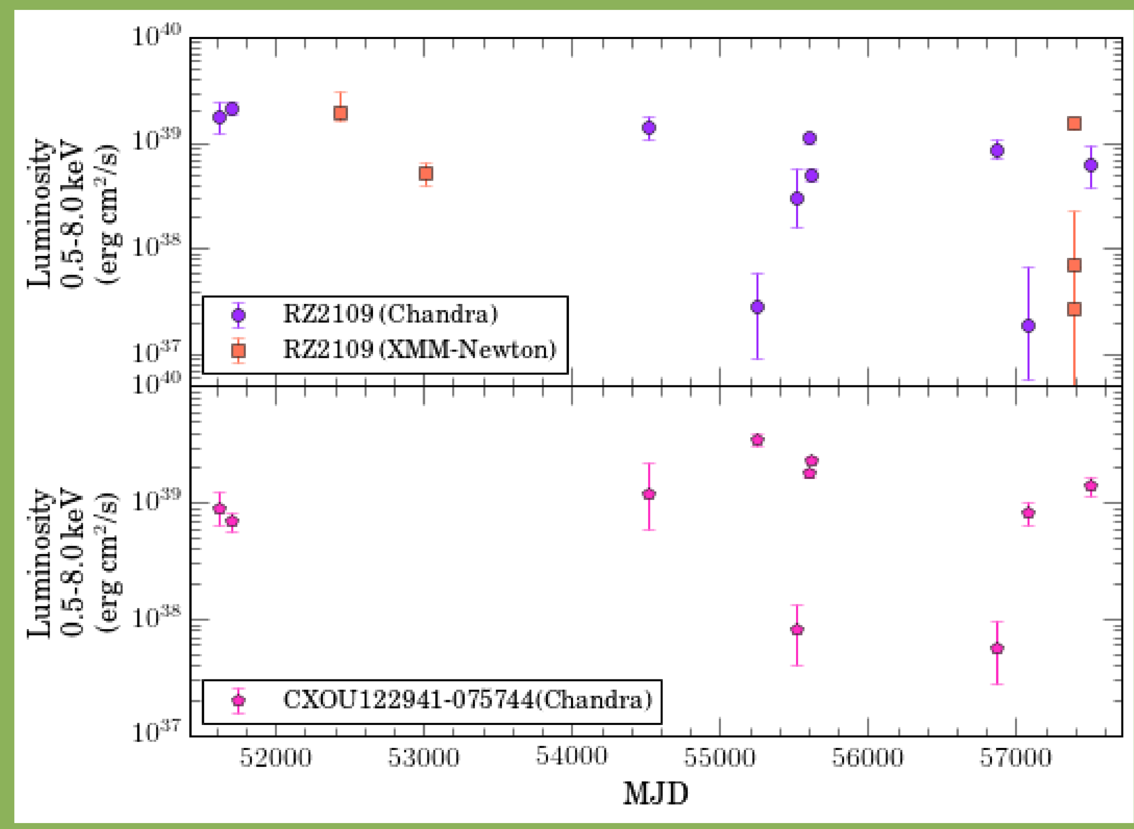

Figure 3 Long term X-ray lightcurves for two GC ULXs from NGC 4472. Both sources exhibit strong variability.

3. Observational Signatures

There is now strong evidence many star forming ULXs are accreting NSs (e.g. Bachetti et al. (2014), Fürst et al. (2016), Israel et al. (2017b), Israel et al. (2017a)). However, **there are significant differences in astrophysical origin and observational characteristics for GC ULXs**:

- GC ULXs vary more than typical star forming ULXs. Figure 3 shows the long-term X-ray lightcurves for two GC ULXs from 4472. RZ2109 shows **significant variability**, dropping by more than a factor of ten in a very short period of time. Some of these changes show no observed change in spectra shape (see Figure 4), RZ2109's **spectral shape is surprisingly constant** over the range of luminosities it reaches (Dage et al (2018, submitted)).
- There is a class of objects known as ultrasoft ULXs (ULSs) have greater variability at high energies, (e.g., Earnshaw & Roberts 2017; Urquhart & Soria 2016), while variability in RZ2109 is either mostly at low energies (e.g., Shih et al. 2008), or independent of energy.
- GC ULXs are very different in those found in star forming galaxies, both on their astrophysical origin and in their observational characteristics. While star forming ULXs turn out to have mostly NS primaries, the **GC ULXs appear to be more readily explained by having BH primaries.** Further observations will test this conclusion and perhaps answer the question whether merging BHs in GCs are a viable source for the LIGO events.

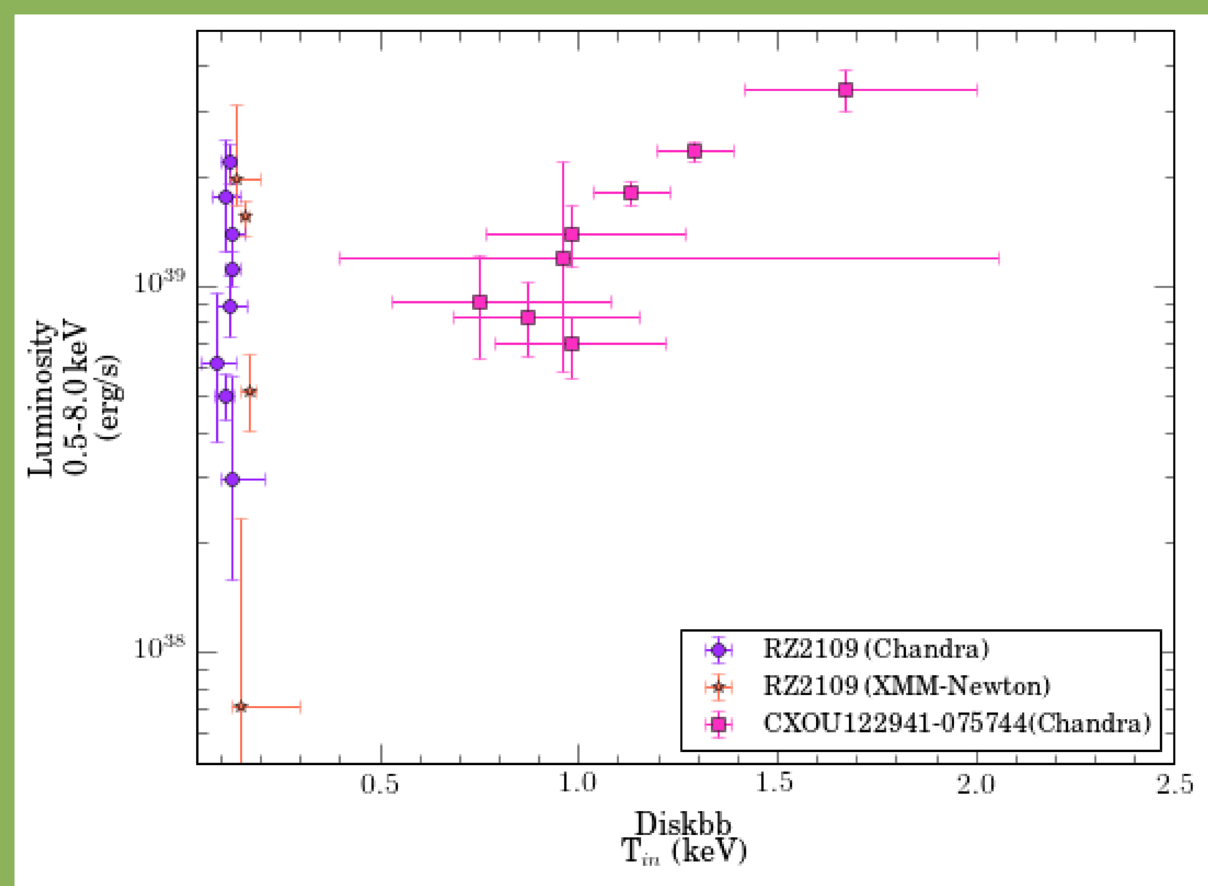

Figure 4: L_x vs inner disk temperature for two 4472 GC ULXs. RZ2109 shows very little spectral variability.

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