Classifying ULX populations: neutron stars or black holes??

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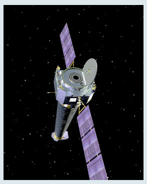
Introduction

Ultraluminous X-ray sources (ULXs) are point-like sources with luminosities exceeding 10^{39} erg s^{-1} that are found outside the center of their host galaxies. Although thought to be compact objects in accreting binary systems,[1,2] the nature of the compact object remains in question. While initially associated with intermediate-mass black holes[3,4] accreting below the Eddington limit, they have also been associated with stellar mass black hole[5,6,7] and several have been identified with pulsars[8,9,10,11]. Here we compare the spectral variations of ULXs with those of Galactic X-ray binaries of known compact object type to identify populations of ULXs that align with black hole XRBs versus those that align with systems containing pulsars.

Observations



Using the Chandra Source Catalog (CSC2)[12], we extracted lightcurves of: 107 ULXs (as identified and with positions provided by Swartz et al. 2011)[13]; extragalactic X-ray binary candidates from both Early-type (as listed with positions in Kim et a. 2019)[14] and Starburst external galaxies. For the few cases where coordinates** are available (and CSC2 had significant detections) we extracted lightcurves of individual ULXs identified with pulsars (M82 X-2, NGC5907 ULX-1, NGC7793 P13, and NGC4599 ULX). (**Figure 1**)

Due to the brightness of Galactic and Magellanic XRBs only Chandra grating data are used in order to avoid problems with instrumental issues such as source cratering or pileup. Data of the ULX M82 X-1 was also extracted using grating data. Lightcurves are extracted using the same energy bands as provided by the CSC2 (0.5-1.2keV; 1.2-2.0keV; 2.0-7.0keV). (**Figure 2**)

Two conversions were used to normalize counts for ACIS data with and without the HETG. The first relates to back illuminated (BI) vs front illuminated (FI) chips which have different responses. The second converts the grating response to that which would be detected on ACIS chips (without grating, and if there were no pileup or cratering). To address both these issues we did simulations for a series of power law spectra using PIMMS (http://cxc.cfa.harvard.edu/toolkit/pimms.jsp). For each power law we determined the count rate in a FI chip, BI chip, and 1st order grating for each energy band. We took the FI chip to be the reference chip and determined a conversion factor to this chip for each energy band and power law. We found that the conversion factor for a given band with different power law models was consistent to within 5% for BI➔FI and within 7-8% for grating observations➔FI.

Relative luminosities of ULXs and extragalactic objects were calculated using distances as given by Swartz et al, Kim et al, and NED; luminosities of the Galactic sources were calculated from parallaxes obtained with GAIA (https://gea.esac.esa.int/archive/) where available. We find that the point sources associated with external galaxies extend to much higher luminosities (up to three orders of magnitude) than XRBs within our Galaxy and the Magellanic Clouds (**Figure 3**).

For all the color-color-luminosity (CCL) plots shown, we used the color ratios "HR" as defined by Park et al (2006)[15,*]: soft color (SC) is defined as the ratio { [(1.2-2 keV)-(0.5-1.2 keV)]/[(1.2-2 kev)+(0.5-1.2keV)] } and hard color (HC) as {[(2-7 keV)-(0.5-1.2 keV)]/[(2-7 kev)+(0.5-1.2keV)]}. Luminosity is the sum of counts in all three bands normalized to a distance of 1 Mpc. For all cases only points with at least 3σ significance in the Catalog were used.

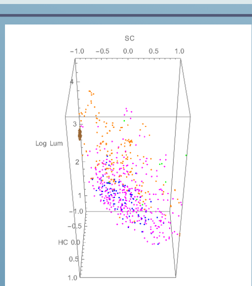


Figure 1. Plot of point sources from: 13 early type galaxies (blue); 13 starburst galaxies (magenta); ULXs from Swartz et al (orange); M82 X-1 (brown); M82 X-2, NGC5907 ULX-1, NGC7793 P13, and NGC4599 ULX (green). Luminosity is normalized to a distance of 1 Mpc.

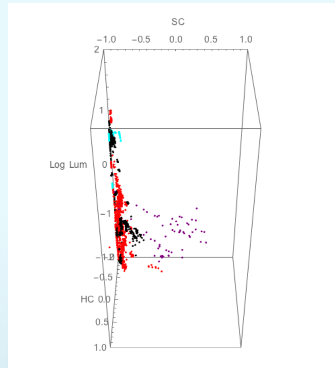


Figure 2. Plot of Galactic and Magelanic Cloud XRBs. Black holes (black); Z sources (cyan); pulsars (red); unknown (purple). Luminosity is normalized to a distance of 1 Mpc.

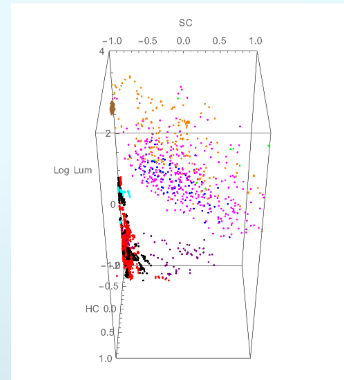


Figure 3. ULXs and extragalactic point sources as in Figure 1. Galactic and Magelanic Cloud XRBs as in Figure 2.

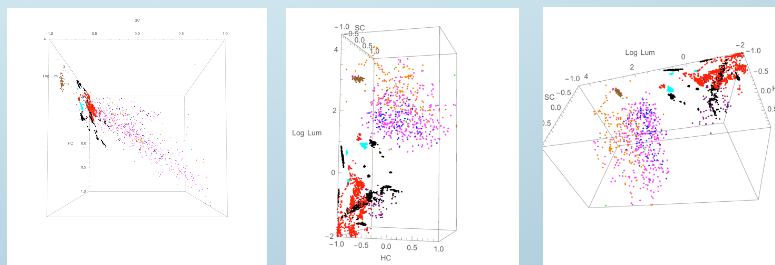


Figure 4. Additional viewing angles of Figure 3.

Summary

It is clear that the distribution of ULXs (orange) is very well matched with point sources from both early-type (blue) and starburst (magenta) galaxies (Figures 1, 3, 4).

However, surprisingly few ULXs line up with Galactic XRBs (black, red, and cyan). The ULX M82 X-1 (brown) coincides in position on the color-color plane with stellar mass black holes in the low/hard state but at luminosities four orders of magnitude higher, consistent with its association with an intermediate mass black hole. It is the only ULX associated with a black hole compact object for which we have CSC2 lightcurves.** While none of the ULX candidates associated with pulsars (M82 X-2, NGC5907 ULX-1, NGC7793 P13, and NGC4599 ULX in green) line up with Galactic pulsars (red) we note that each of these sources had only 2-4 significant detections in CSC2, and overall there are quite a few ULXs that do line up in the color-color plane with Galactic pulsars only at higher luminosities. The peculiar Galactic source V404 Cyg (purple) also lines up with some of the ULXs but at significantly lower.

Some of the extragalactic point sources are likely to be background AGN. However, if we believe that location in a color-color plane is related to the type of compact object in an XRB, then a significant fraction of extragalactic point sources and ULXs do not line up with any type of Galactic XRB. The point sources associated with external galaxies also extend to much higher luminosities than XRBs within our Galaxy.

The fact that the distribution of ULXs line up so well with the distribution of extragalactic point sources both in the color-color plane and in luminosity suggests a population of objects that have no counterpart in the Galaxy or the Magellanic Clouds, or at least no XRB counterpart.

Acknowledgements and requests

*We are grateful to Vinay Kashyap and Andreas Zezas for suggesting use of the HR color definitions of Park et al (2006).[11]

**We would be very obliged if people would provide us with accurate coordinates of their favorite ULXs for extraction of data from CSC2.

References

1. Motch, C. Pakull, M.W., Soria R., Grise, F., & Pietrzynski, G., 2014, Nature, 514, 198
2. Fabbiano, G. 1989, ARA&A, 27, 87.
3. Miller, J.M., Fabbiano, G., Miller, C., & Fabian, A.C. 2003, ApJ, 585, L37
4. Colbert, E.J.M., Mushotzky, R.F. 1999, apJ, 519, 89
5. Brightman, M. et al. 2016, ApJ, 829, 28
6. Zampieri, L., & Roberts, T.P., 2009, MNRAS, 400, 677
7. Walton, D.J., Roberts, T.P., Mateos, S., & Heard, V., 2011 MNRAS, 416, 1844
8. Israel, G.L., et al. 2017, MNRAS, 466, L48
9. Bachetti, M. et al. 2014, Nature, 514, 202
10. King, A. & Lasota, J.P. MNRAS, 458, L10
11. Pintore, F. Zampieri, L., Stella, L., Wolter, A., Mereghetti, S. & Israel, G.L. 2017, ApJ 836, 113
12. Evans, I.N., et al. 2010, ApJS, 189, 37
13. Swartz, D.A., Soria R., Tennant, A.F., & Yukita, M. 2011, ApJ, 741, 49
14. Kim, D.-W. et al. 2019, ApJS, 241, 36
15. Park et al. 2006, ApJ, 652, 610

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