Identifying the nature of point sources in external galaxies

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Introduction

The exquisite spatial resolution of the Chandra X-ray satellite allows it to resolve individual X-ray point sources in external galaxies **(Figure 1).** The populations of XRBs are likely to differ with galaxy age and type (Fabbiano 2006; Kim & Fabbiano 2010; Zhang, Gilfanov, & Bogdan 2012). In this study we compare point sources detected in external galaxies by Chandra with Galactic X-ray binaries also observed by Chandra. With a relatively small sample we find systematic differences between late and early-type galaxies.

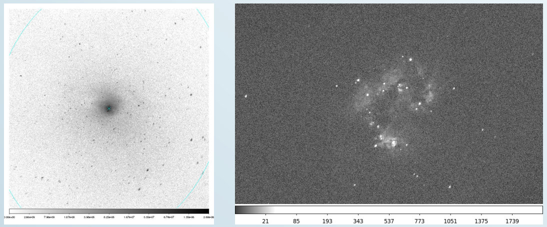
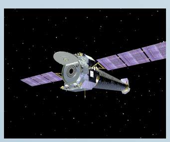


Figure 1. *Left*: Early type galaxy NGC4472 (16 Mpc). Most of the black dots represent individual X-ray sources. *Right*: Late type (starburst) galaxies NGC 4038/4049 (21 Mpc). The white dots indicate individual X-ray sources.

Observations



Data were extracted for point source binary candidates of 62 early-type (ETG) and 13 late-type (LTG) galaxies observed with with Chandra ACIS (**Figure 2**).

Data were extracted of 52 Galactic (and Magellanic Cloud) X-ray binaries and 1 ULX (M82 X-1) that were multiply observed by the Chandra HETG. Due to the brightness of the Galactic sources only grating data are used in order to avoid problems with instrumental issues such as source cratering or pileup.

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 an 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.

Data are extracted in three energy bands (1-3 keV, 3-5 kev, and 5-8 keV) in order to construct color-color-intensity diagrams (CCI; Vrtilek & Boroson 2013). Soft color (SC) is defined as the ratio (3-5 keV)/(1-3 keV) and hard color (HC) as the ratio (5-8 keV)/(1-3 keV). Intensity is the sum of counts in all three bands.

Extragalactic source intensities were adjusted for distances as given by NED. For the Galactic sources adjustments are made for distance using parallaxes obtained from GAIA when available (https://gea.esac.esa.int/archive/). For the current study we restrict ourselves also to systems that have E(B-V) less than 1 **(Figure 3).**

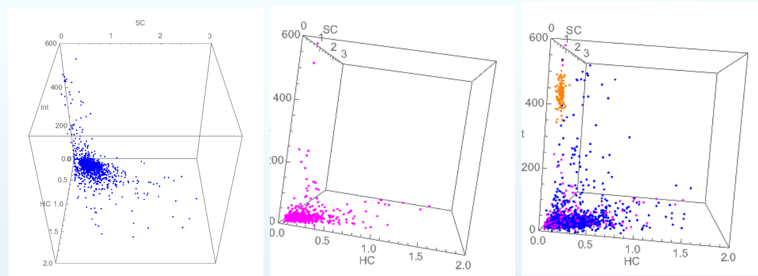


Figure 2. Color-Color-Intensity (CCI) plots of point sources from: 62 early type galaxies (blue); 13 starburst galaxies (magenta); and M82 X-1 (an ULX candidate from M82, in orange). Plotted are cts/sec normalized to a distance of 1 Mpc. Rates for sources in ETGs went up to 800 cts/sec at the normalized distance, and for LTGs up to 300.

The ULX has countrates two orders of magnitude greater than the brightest BHXRBs plotted in Figure 3 (upper panels: LMC X-1 and LMC X-3) but at a similar position in the color-color plane.

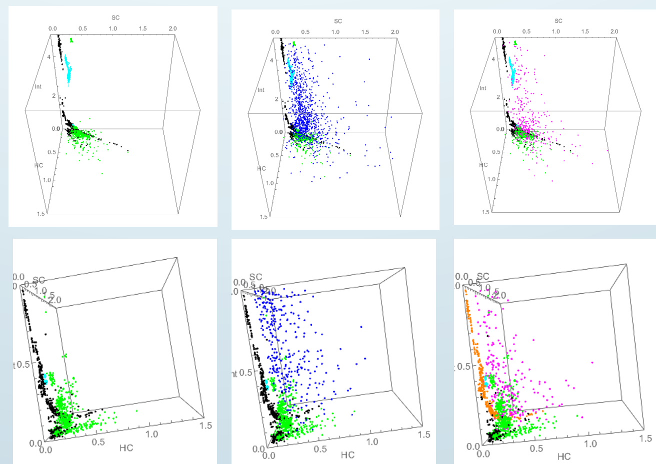


Figure 3. *Left:* CCI plots of Chandra grating observations of 20 X-ray binaries (black holes in black, non-pulsing neutron stars in cyan, and X-ray pulsars in green). Plotted are cts/sec at a standardized distance of 1 Mpc. *Center:* including sources from early type galaxies (blue). *Right:* including sources from starburst galaxies (magenta).

Upper panels show a count range from 0-5 cts/sec. The high luminosity BHXRBs coincide in position on the color-color plane with the much higher luminosity ULX depicted in Fig. 2c. EGTs show more sources that coincide with non-pulsing neutron stars (associated with LMXBs). A number of objects at this location of the color-color plane could be associated with background AGNs.

Lower panels show the same data as the upper, but with the count range limited to 0-1 cts/sec. The majority of the Galactic XRBs fall within this range. LTG galaxies have significantly more sources that coincide with the X-ray pulsars which are associated with HMXBs. In the plot with sources from LTGs we have depicted Cyg X-1 (the only known persistent BH in our Galaxy) in orange. No Cyg X-1 type source or BHXRBs in their low state appear in either ETGs or LTGs. There is no overlap with the lowest luminosity Galactic sources and point sources in either ETG or LETG.

Summary

Chandra observed Galactic XRBs for short pointed observations which do not capture the entire tracks/states of these sources. The observations of extra-galactic point sources are also relatively brief snapshots. While this does not provide sufficient data to establish one to one relationships between individual Galactic and extragalactic systems we can reach some general conclusions.

We find that the point sources associated with external galaxies extend to much higher luminosities than XRBs within our Galaxy and the Magellanic Clouds (Figure 2). Sources associated with ETGs extend to luminosities over two orders of magnitude higher, whereas LTGs have sources with luminosities about 30-60 times higher. However, this could be a selection effect since we observed five times as many ETGs as LTGs. The ULX candidate, M82 X-1, coincides in position on the color-color plane with stellar mass black holes in the high state at luminosities two orders of magnitude higher, consistent with its association with an intermediate mass black hole.

Sources from LTGs show significant overlap with X-ray pulsars that are mostly associated with HMXBs. EGTs show more sources that coincide with non-pulsing neutron stars (associated with LMXBs). A number of objects lie in points of the color-color plane that have no counterparts in Galactic sources and could be associated with background AGNs. Our next goal is to use the distance of observed sources from the central galaxy in order to set a limit on the percentage of sources that are due to background AGN,

The least luminous sources in our Galaxy (BH transients in their low state and and low luminosity pulsars) are barely detectable at a distance of 1 Mpc; none of our external galaxies are close enough to detect them.

References

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