A Population Explosion: The Nature and Evolution of X-ray Binaries in Diverse Environments
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LMXBs in the Normal Elliptical Galaxy NGC 3379

N. J. Brassington

Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138

Abstract. Presented here are the highlights from the deep *Chandra* observation of the elliptical galaxy NGC 3379. From the multi-epoch observation of this galaxy, 132 discrete X-ray sources have been detected within the region overlapped by all observations, 98 of which lie within the D_{25} ellipse of the galaxy. Of these 132 sources, 71 exhibit long-term variability, indicating that they are accreting compact objects. 11 of these sources have been identified as transient candidates, with a further 7 possible transients. In addition to this, from the joint *Hubble/Chandra* field of view, nine globular clusters (GCs) and 53 field low mass X-ray binaries (LMXBs) have been detected in the galaxy. Comparisons of these two populations reveals that, at higher luminosities the field LMXBs and GC-LMXBs are similar. However, a significant lack of GC-LMXBs has been found at lower luminosities, indicating that not all LMXBs can form in GCs.

1. Introduction

Low-mass X-ray binaries are the only direct fossil evidence of the formation and evolution of binary stars in the old stellar populations of early-type galaxies. First discovered in the Milky Way (see Giacconi (1974)), the origin and evolution of Galactic LMXBs has been the subject of much discussion, centered on two main evolution paths (see Grindlay (1984); review by Verbunt (1995)): the evolution of primordial binary systems in the stellar field, or formation and evolution in Globular Cluster.

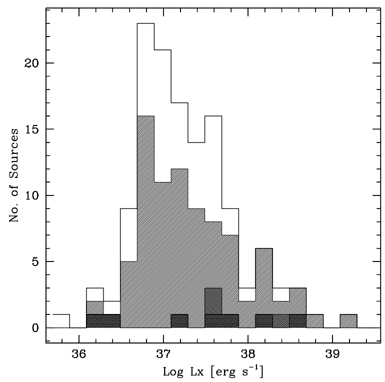
With the advent of *Chandra*, many LMXB populations have been discovered in early-type galaxies (see review Fabbiano (2006)), and the same evolutionary themes (field or GC formation and evolution) have again surfaced. However, most observations have consisted of fairly shallow individual snapshots for each observed galaxy, with limiting luminosity of a few 10^{37} erg s^{-1}. It is important to study these old populations down to typical luminosities of the Galaxy and M31. For this reason, alongside the need to identify the variability of LMXB populations, we proposed (and were awarded) a very large program of monitoring observations of nearby elliptical galaxies with *Chandra* ACIS-S3.

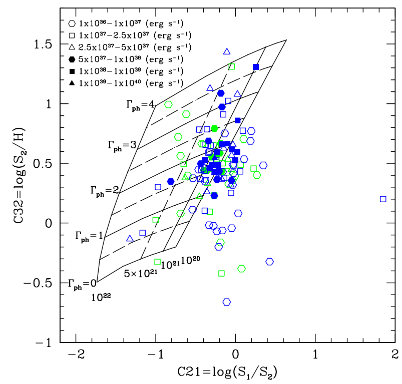
NGC 3379, in the nearby poor group Leo (D=10.6 Mpc) was chosen for this study because it is a relatively isolated unperturbed 'typical' elliptical galaxy, with an old stellar population and a poor globular cluster system. These characteristics make NGC 3379 ideal for exploring the evolution of LMXB from primordial field binaries.

2. The Catalog

NGC 3379 was observed by *Chandra* in five separate observations, carried out over a six year baseline, with the first of these, a 30-ks pointing, being performed in February 2001. This observation has been followed by four deeper pointings, all carried out between January 2006 and January 2007, resulting in a total exposure time of 337-ks.

From this co-added observation, 132 individual X-ray sources were detected within the region overlapped by all observations, with 98 of these sources lying within the D_{25} ellipse of the galaxy. From these source detections, source counts were extracted and fluxes, luminosities and colors were calculated. Detailed analysis of this work, along with the full catalog, is presented in (Brassington et al. 2007), where flux and spectral variability are also





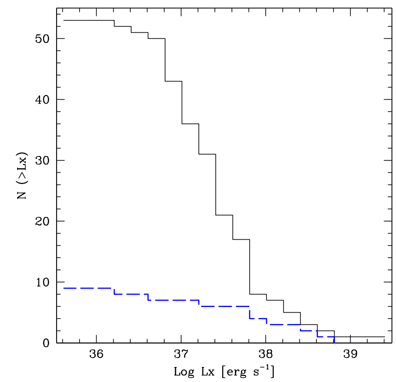


Figure 1. Figure 2. Figure 3.

Figure 1: $L_{\rm X}$ distribution of the 132 X-ray sources detected within the overlapping region covered by all five *Chandra* pointings. The unshaded histogram indicates sources that have been determined to be non-variable sources, with no GC counterpart. The lightly shaded region shows variable sources that have no GC counterpart. The darker histogram indicates non-varying sources associated with a GC and the darkest histogram shows varying sources that have a confirmed GC counterpart. **Figure 2**: Color-color diagram of the X-ray point sources detected in the co-added observation. Blue points indicate variable sources, and green denotes non-variable sources. **Figure 3:** Observed cumulative XLFs of field (solid black line) and GC (dashed blue line) LMXBs; both distributions are from the joint *Hubble/Chandra* field.

investigated. In addition to the X-ray observation detailed in this catalog paper, optical data are also presented, and X-ray/optical correlations are listed.

3. Characterizing the LMXB Population

The X-ray luminosity of the sources detected within NGC 3379 ranges from 6×10^{35} erg s^{-1} up to 2×10^{39}erg s^{-1}, where the brightest source is the only ULX detected within this system. The properties of this source from the first two observations have been reported in Fabbiano et al. (2006), and the analysis of the full data set of the ULX will be presented a forthcoming paper. The $L_{\rm X}$ distribution of all of the detected X-ray sources within NGC 3379 is shown in Figure 1, where GC correlations are also shown. From this figure it can be seen that the majority of sources detected from this observation lie in the luminosity range of 5×10^{36}erg s^{-1}–5×10^{37}erg s^{-1}, with a mode luminosity of $\sim 6\times 10^{36}$erg s^{-1}. Figure 2 presents the LMXB population color-color diagram, based on the photometry of the co-added observation. Here, sources are divided into luminosity bins, with symbols of each bin indicated by the labeling in the panel. Also in this figure source variability is shown, where blue points indicate variable objects and green denotes non-variable ones. Additionally, a grid has been overlaid to indicate the predicted locations of the sources at redshift z=0 for different spectra, described by a power law with various photon indices ($0\leq \Gamma_{ph} \leq 4$, from top to bottom.) and absorption column densities ($10^{20} \leq N_{\rm H} \leq 10^{22}$ cm^2, from right to left). From this figure it can be seen that most of the well defined colors lie within the area of a typical LMXB spectrum of $\Gamma = 1.5 - 2.0$, with no intrinsic absorption (e.g. Irwin et al. (2003); Fabbiano (2006)).

3.1. Variable and Transient Sources

A characteristic of compact accretion sources such as LMXBs is variability, and, as a result of the monitoring nature of the observing campaign, we have been able to search for this behaviour in NGC 3379. Out of the 132 sources, 53, 40% of the sources within NGC 3379, have been defined as variable. A further 18 sources are transient candidates; sources that either appear or disappear, or are only detected for a limited amount of contiguous time during the observations and have a flux ratio between the ‘on-state’ and ‘off-state’ of greater than 10 for transient candidates (11 objects), and 5 for possible transients (7 objects).

One of the specific aims of our monitoring campaign has been to identity these transient candidate sources as it has been suggested that field LMXBs are expected to be transients (Piro & Bildsten 2002; King 2002) and low luminosity ultracompact binaries in GCs are also expected to be transient in nature (Bildsten & Deloye 2004). This sub-population is investigated in the forthcoming paper Brassington et al. (2007b, in preparation).

3.2. The Absence of Low Luminosity GC-LMXBs

From the optical data, 10 GC-LMXB associations have been found in NGC 3379. Nine of these lie within the joint *Hubble/Chandra* field, where 53 field LMXBs have also been detected. From comparing the cumulative XLFs of these two populations, shown in Figure 3, we have found that there is a significant lack of GC-LMXBs at luminosities $L_{\rm X} <\sim 4 \times 10^{37}$ erg s^{-1}, with a KS test excluding that the two distributions may be derived from the same parent population at 99.82% confidence (Fabbiano et al. 2007). This result indicates that there is a dearth of GC-LMXBs at lower luminosities, excluding a single formation mechanism for *all* LMXBs, resolving a long standing controversy in LMXB formation.

4. Future Work

The full results of the work presented here are discussed in detail in the catalog paper Brassington et al. (2007), and the GC-LMXB paper Fabbiano et al. (2007). In addition to these, further highlights from the X-ray binary population of NGC 3379 will also be presented in Brassington (2007b); an investigation into the transient population of NGC 3379, and Brassington (2007c); a study of the radial number density of LMXBs. Forthcoming papers will also present: the properties of the ULX, the X-ray luminosity function and the diffuse emission of the galaxy, as well as the properties of the nuclear source and the spectral variability of the luminous X-ray binary population. The results from this deep observation will then be compared to the X-ray source catalog of the old, GC rich elliptical galaxies NGC 4278, which has also recently been the subject of a deep *Chandra* observation.

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