The Low-Mass X-ray Binary - Globular Connection in the *HST* ACS Virgo Cluster Survey

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ABSTRACT

With the sub-arcsecond resolution of *Chandra*, a strong association between low-mass X-ray binaries (LMXBs) and globular clusters (GCs) has been established in early-type galaxies (20-70 % of LMXBs reside in GCs). Most of this association has been based on GC lists generated from ground-based observations, which can not resolve GCs at Virgo, or *HST* WFPC2 observations, which have small field-of-views. With the *HST* ACS Virgo Cluster Survey (VCS), a uniform sample of the GCs in the central 3 arcmin times 3 arcmin of 100 early-type galaxies has been created that contains not only positions and magnitudes, but also structural parameters. We present initial results of a study using this superior list of GCs and archival Chandra observations of LMXBS in a sub-sample of the HST ACS VCS to probe aspects of the LMXB-GC connection.

INTRODUCTION

Chandra has revealed that nearby early-type galaxies (E/S0s) harbor 100s of bright (>10^{37} erg/s) LMXBs. The dense stellar environments of GCs form LMXBs more efficiently than in the fields of galaxies by a factor of a few 100, presumably due to dynamical interactions. In E/S0s, 20-70 % of LMXBs reside in GCs (e.g., Angelini et al. 2001; Kundu et al. 2002; Sarazin et al. 2003). Sarazin et al. (2003), examined a sample of 4 galaxies combining *Chandra* X-ray, ground based, and *HST* WFPC2 observations. With about 50 LMXBs matched to GCs, they found that the fraction of LMXBs in GCs tends to increase along the Hubble sequence, and that LMXBs tend to be associated with brighter and redder GCs.

With its wider field-of-view (3.2' x 3.2') than WFPC2 and much smaller PSF than ground-based observations (≈0.1"), *HST* Advanced Camera for Surveys (ACS) can identify large number of GCs and measure their half-light radii (for r_h >1 pc at the distance of Virgo, e.g., Jordán et al. 2005). The smaller PSF also allows for greater rejection of background galaxies with GC-like colors. The *HST* ACS Virgo Cluster Survey (VCS) observed the centers of 100 E/S0s, in part to measure GC properties. In Jordán et al. 2004b, *Chandra* and *HST* observations of M87 were the first to use structural parameters to find evidence that dynamical processes appear to affect LMXB formation efficiency in early-type galaxy GCs. By extending similar analysis to other early-type galaxies in the *HST* ACS VCS, the dependence of LMXB formation efficiency can be probed as a function of photometric parameters (luminosity, which proxies for mass, and color) and structural parameters (r_h and encounter rate).

SAMPLE / DATA REDUCTION

We searched the *Chandra* archive for all galaxies in the *HST*-ACS VCS with more than 15 ks of ACIS-S observations. We also added NGC 4697, which was observed separately from the *HST* ACS VCS, but used the same setup. For this poster, we concentrate on new results from 9 galaxies (Table 1).

The *Chandra* observations were calibrated using CALDB 2.28 and analyzed using CIAO 3.1. After flare filtering, wavdetect was first run on all observations in the 0.3 – 6.0 keV range to detect sources. We refined the source positions using ACIS Extract 3.34. The *Chandra* data are registered to ground-based optical/near-infrared catalogs.

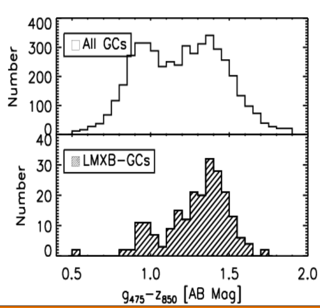
The *HST* observations in the *g*- and *z*-bands were analyzed as part of the *HST* ACS VCS following Jordán et al. (2004a). Globular clusters were identified based on magnitudes, colors, and sizes.

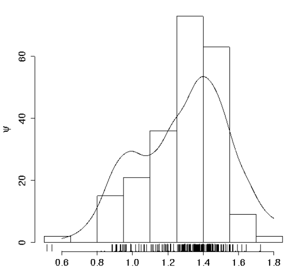
For each galaxy, the X-ray and optical catalogs (including non-GC sources) were cross-correlated to determine relative astrometry. Since the X-ray positions are typically accurate to 0.3-0.5", we considered all sources within 1" to be matched. Some X-ray sources have multiple matches within 1". In these rare cases, the X-ray source and potential optical matches were excluded from our analysis (if all optically matched sources were from the same GC population, they were included for comparing LMXB-GC association dependence on GC population).

Table 1: Sample Properties

NGC #	Hubble Type	*Chandra* Obs. ks (Pointing)	S_N[1]	# GCs	# LMXBs In ACC FOV	# LMXBs In GCs
4365	E3	40.4 (S)	2.1	907	85	43
4374	E1	28.4 (S)	1.2	506	51	18
4382	S0	39.7 (S)	1.0	506	37	11
4472	E2	34.5 (S), 7.2 (I)	1.2	764	86	40
4526	S0	41.5 (S)	1.1	244	34	7
4552	E0	54.4 (S)	2.2	356	78	31
4621	E5	24.8 (S)	1.7	308	44	17
4649	E2	17.1 (S)	1.7	807	60	32
4697	E6	37.2, 39.9, 35.6, 32.0, 40.0 (S)	2.4	298	83	34

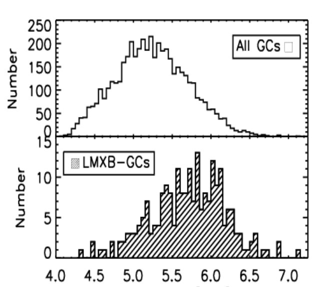
[1] Local Specific Frequency (S_N) has not been corrected for completeness or contamination.

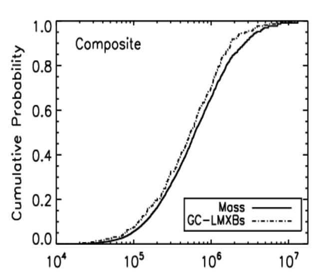




COLOR (*g-z*)

The GCs containing LMXBs (LMXB-GCs) are clearly not drawn from the GC parent sample (above, left: 20σ result). Dividing each galaxy into a blue and red GC population (e.g., Peng et al. 2005), **the red-GCs have 3.6±0.6 more matched LMXBs/GC than blue-GCs**. Converting color to metallicity, the best-fit power-law dependence on metallicity, $Z^{0.23\pm0.04}$, is consistent with Jordán et al. 2004b. This relation predicts a 2:1 red:blue ratio; the underestimation of red LMXB-GCs appears to be a common feature in figures applying this power-law relation (e.g., above, right) suggesting that a different relation needs to be explored.





MASS

Following Jordán, A. et al. (2004b), the *z*-band magnitude can be converted to *V*, and then mass assuming a mass-to-light ratio of 1.45. As shown above and to the left, the GC parent sample and LMXB-GCs differ greatly (42σ result). More massive GCs are more likely to contain an LMXB. The simplest explanation is that there are more stars in such GCs. Therefore, we test whether the probability of finding an LMXB is proportional to GC mass (above, right). **This hypothesis is marginally rejected (90%) .** The best-fit probability is proportional to $\mathbf{M^{0.89\pm0.06}}$, consistent with M87. Another parameter may play a role.

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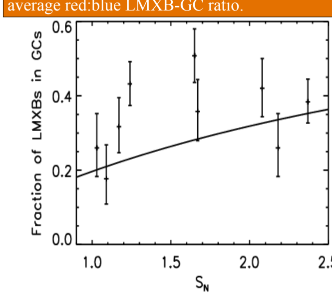
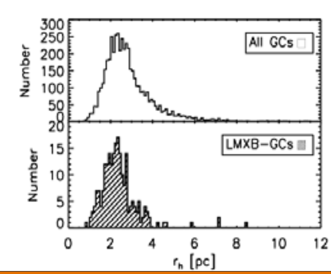
FRACTION OF LMXBS IN GCS

Below and to the left, the fraction of LMXBs in GCs as a function of specific frequency is plotted; the line is the fit found by form Juett (2005) where the increased LMXB-GC connection in E/S0 is just due to more numerous GCs. The two points below the line are the S0s; GC disruption may play a role in decreasing the observed fraction (Irwin 2005). The two points most above the line are NGC 4472 and NGC 4649. If GCs at the centers of galaxies are more disrupted, X-ray bright galaxies like these may exhibit a higher fraction due to detection difficulties at their centers. Also, we note that these two galaxies have a higher than average red:blue LMXB-GC ratio.



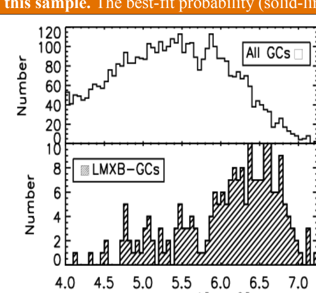


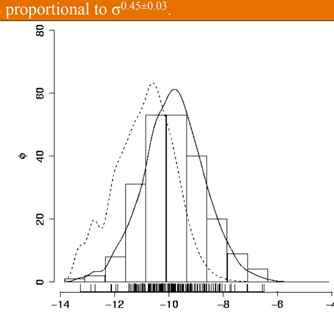
SIZE (r_h)

The LMXB-GCs clearly tend to avoid GCs with large half-light radii, as shown above and to the right (21σ result). It is unclear if this is a primary relation or due to a physical effect that depends on GC density.

ENCOUNTER RATE (σ)

The tidal capture and exchange interaction encounter rate, $\Gamma \propto \rho^2 r_c^3 v^{-1}$, is one such effect. It can be linearly traced with the observable quantity, $\sigma \propto M^{1.5} r_h^{-2.5}$, assuming the virial theorem and a constant concentration for the sample. The GCs with higher encounter rates tend to host LMXB-GCs (below, left: 48σ result). LMXB-GCs occur in GCs with higher encounter rates. In the Galaxy, the number of GC X-ray sources is proportional to σ (Pooley et al. 2003). **That linear trend is rejected (below, left dashed-line: 6 σ result) for this sample.** The best-fit probability (solid-line) is proportional to $\sigma^{0.45\pm0.03}$.





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