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Deposited 09/14/2018

Citation of published version:

Irwin, J., Bregman, J. (1998): The Dependence of the Soft X-Ray Properties of Low-Mass X-Ray Binaries on the Metallicity of their Environment. *The Astrophysical Journal Letters*, 510(1). DOI: [10.1086/311803](https://doi.org/10.1086/311803)

## THE DEPENDENCE OF THE SOFT X-RAY PROPERTIES OF LOW-MASS X-RAY BINARIES ON THE METALLICITY OF THEIR ENVIRONMENT

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Received 1998 October 26; accepted 1998 November 2; published 1998 November 30

### ABSTRACT

We determine the X-ray spectral properties of a sample of low-mass X-ray binaries (LMXBs) that reside in globular clusters of M31 as well as five LMXBs in Galactic globular clusters and in the Large Magellanic Cloud using the *ROSAT* Position Sensitive Proportional Counter. We find a trend in the X-ray properties of the LMXBs as a function of globular cluster metallicity. The spectra of LMXBs become progressively softer as the metallicity of their environment increases. The one M31 globular cluster LMXB in our sample that has a metallicity greater than solar has spectral properties similar to those of LMXBs in the bulge of M31 but markedly different from those that reside in low-metallicity globular clusters, both in M31 and the Galaxy. The spectral properties of this high-metallicity LMXB are also similar to those of X-ray-faint, early-type galaxies. This lends support to the claim that a majority of the X-ray emission from these X-ray-faint, early-type galaxies results from LMXBs and not hot gas, as is the case in their X-ray-bright counterparts.

*Subject headings:* galaxies: individual (M31) — globular clusters: general — stars: abundances — X-rays: galaxies — X-rays: stars

### 1. INTRODUCTION

Nearly all that is known about the X-ray spectral properties of low-mass X-ray binaries (LMXBs) has been derived at energies above 1 keV. The simple reason for this is that most Galactic LMXBs lie in the Galactic plane and are therefore heavily absorbed at soft X-ray energies by Galactic hydrogen. Virtually nothing is known about the X-ray properties of LMXBs below 0.5 keV. Two Galactic examples of LMXBs that lie in directions of low-hydrogen column densities (Hercules X-1 and MS 1603+2600) show strong X-ray emission at energies below 0.5 keV (Choi et al. 1997; Hakala et al. 1998), in addition to the hard (5–10 keV) emission normally attributed to LMXBs.

Fortunately, the bulge of M31 provides a relatively nearby (690 kpc) laboratory for examining the soft X-ray properties of LMXBs. Since bulge populations are known to be old, the X-ray sources found in the bulge are not likely to be contaminated by high-mass X-ray binaries or supernovae remnants. Supper et al. (1997) detected 22 X-ray sources within 5' of the center of the bulge with the *ROSAT* Position Sensitive Proportional Counter (PSPC), 19 of which are most likely LMXBs with 0.1–2.0 keV X-ray luminosities of  $10^{36}$ – $10^{38}$  ergs  $s^{-1}$  (the other three are supersoft sources). Nearly all of these LMXBs exhibit strong, very soft emission, much like Hercules X-1 and MS 1603+2600.

Furthermore, the integrated X-ray spectrum of the inner 5' of the bulge of M31, of which ~80% is resolved into the 22 sources, strongly resembles the X-ray spectra of a class of early-type galaxies that have very low X-ray-to-optical luminosity ratios (Irwin & Sarazin 1998a and 1998b, hereafter IS98a and IS98b, respectively). Trends in the X-ray spectral properties of early-type galaxies were first observed with *Einstein* by Kim, Fabbiano, & Trinchieri (1992). Unlike X-ray-bright, early-type galaxies whose X-ray emission is dominated by thermal emission from ~0.8 keV gas, these X-ray-faint galaxies exhibit two-component (hard + very soft) X-ray emission (Fabbiano, Kim, & Trinchieri 1994; Pellegrini 1994; Kim et al. 1996), with the hard component generally attributed to a collection of LMXBs.

The strong, soft component was attributed unsuccessfully to the integrated emission from M star coronae, RS CVn binary stars, and supersoft sources (Pellegrini & Fabbiano 1994; IS98b), leaving only a warm (0.2 keV) interstellar medium (ISM) as a possible alternative. However, LMXBs in the bulge of M31 demonstrated that LMXBs can also be a significant source of very soft X-ray emission, and this is a likely explanation for the excess, very soft X-ray emission in X-ray-faint, early-type galaxies (IS98a; IS98b) instead of a 0.2 keV ISM. The X-ray-to-optical luminosity ratio of the bulge of M31 is comparable to that of X-ray-faint, early-type galaxies, so LMXBs are also luminous and/or numerous in order to account for the X-ray emission.

This seemingly simple solution is complicated by the fact that LMXBs exist outside the disk of the Galaxy or the bulge of M31, which do not exhibit strong, very soft emission. Four of these LMXBs reside in Galactic globular clusters, and another in the Large Magellanic Cloud (LMC). This would seem to weaken the argument that LMXBs are the source of the very soft emission in X-ray-faint, early-type galaxies. However, these five examples differ from the rest in that they reside in low-metallicity environments. The metallicities of NGC 1851, NGC 6624, NGC 6652, and NGC 7078 are 5%, 43%, 10%, and 0.7% solar, respectively (Djorgovski 1993), and the iron abundance of the LMC is ~50% solar (see, e.g., Hill, Andrievsky, & Spite 1995). It is possible that the metallicity of the environment in which an LMXB forms has an effect on the X-ray properties of the binary.

To test this hypothesis, we need a sample of LMXBs that reside in environments that span a range of metallicities and that also lie in directions of reasonably low Galactic hydrogen column densities. The globular cluster system of M31 is ideal for this. Metallicities for most of M31's globular clusters have been determined optically, many of which harbor LMXBs. In addition, the hydrogen column density toward M31 is not excessively high ( $7 \times 10^{20}$   $cm^{-2}$ ). In this Letter, we present the spectral X-ray analysis of a sample of LMXBs that reside in globular clusters of M31 using archival *ROSAT* PSPC data to

TABLE 1  
SPECTRAL FITS OF M31 GLOBULAR CLUSTER LMXBs

NAME	ALTERNATE NAME	TOTAL COUNTS	Z/Z <sub>⊙</sub>	TB MODEL			PL MODEL		
				N <sub>H</sub> (10 <sup>20</sup> cm <sup>-2</sup> )	kT <sub>TB</sub> (keV)	χ <sup>2</sup> /dof	N <sub>H</sub> (10 <sup>20</sup> cm <sup>-2</sup> )	Γ	χ <sup>2</sup> /dof
217 .....	143-198	274	1.23	7.26 <sup>+15.06</sup> <sub>-3.20</sub>	0.95 <sup>+1.64</sup> <sub>-0.50</sub>	14.9/17	10.4 <sup>+34.1</sup> <sub>-5.12</sub>	2.63 <sup>+2.29</sup> <sub>-0.82</sub>	14.6/17
228 .....	153-000	820	0.83	7.81 <sup>+4.27</sup> <sub>-1.95</sub>	1.70 <sup>+1.44</sup> <sub>-0.60</sub>	30.0/28	9.47 <sup>+10.05</sup> <sub>-2.73</sub>	2.01 <sup>+0.66</sup> <sub>-0.34</sub>	31.7/28
220 .....	146-000	764	0.37	7.97 <sup>+4.08</sup> <sub>-1.84</sub>	1.46 <sup>+0.99</sup> <sub>-0.47</sub>	25.6/29	9.66 <sup>+9.56</sup> <sub>-2.55</sub>	2.10 <sup>+0.64</sup> <sub>-0.34</sub>	27.3/29
73 .....	005-52	2332	0.21	19.1 <sup>+6.33</sup> <sub>-5.56</sub>	1.47 <sup>+1.13</sup> <sub>-0.47</sub>	65.4/69	27.0 <sup>+10.9</sup> <sub>-7.95</sub>	2.48 <sup>+0.62</sup> <sub>-0.46</sub>	64.9/69
282 .....	225-280	730	0.20	6.21 <sup>+3.64</sup> <sub>-1.74</sub>	3.57 <sup>+12.4</sup> <sub>-1.84</sub>	19.4/25	7.08 <sup>+5.14</sup> <sub>-2.33</sub>	1.64 <sup>+0.40</sup> <sub>-0.33</sub>	19.8/25
150 .....	082-144	987	0.14	44.3 <sup>+18.2</sup> <sub>-8.81</sub>	16.8 <sup>+∞</sup> <sub>-15.0</sub>	37.5/33	43.6 <sup>+24.9</sup> <sub>-20.6</sub>	1.38 <sup>+0.99</sup> <sub>-0.87</sub>	37.6/33
122 .....	045-108	1263	0.11	11.8 <sup>+8.87</sup> <sub>-4.49</sub>	4.25 <sup>+76.9</sup> <sub>-2.76</sub>	60.7/47	14.4 <sup>+14.6</sup> <sub>-6.87</sub>	1.69 <sup>+0.82</sup> <sub>-0.48</sub>	60.8/47
247 .....	185-235	435	0.09	5.59 <sup>+3.43</sup> <sub>-1.53</sub>	>4.15	18.7/17	5.27 <sup>+6.09</sup> <sub>-2.44</sub>	1.10 <sup>+0.50</sup> <sub>-0.44</sub>	18.6/17
349 .....	386-322	1503	0.06	12.8 <sup>+8.03</sup> <sub>-4.69</sub>	3.80 <sup>+14.2</sup> <sub>-2.23</sub>	46.4/50	16.6 <sup>+12.7</sup> <sub>-7.54</sub>	1.79 <sup>+0.69</sup> <sub>-0.47</sub>	46.9/50
318 .....	375-307	5731	0.06	9.83 <sup>+1.60</sup> <sub>-1.17</sub>	9.18 <sup>+18.0</sup> <sub>-4.20</sub>	145.6/137	10.5 <sup>+2.25</sup> <sub>-1.49</sub>	1.42 <sup>+0.16</sup> <sub>-0.13</sub>	145.4/137
205 .....	135-193	1769	0.02	21.2 <sup>+7.82</sup> <sub>-6.01</sub>	7.66 <sup>+∞</sup> <sub>-5.30</sub>	53.9/55	22.8 <sup>+11.1</sup> <sub>-8.47</sub>	1.50 <sup>+0.55</sup> <sub>-0.45</sub>	54.0/55
158 .....	086-148	485	0.02	5.50 <sup>+25.5</sup> <sub>-1.55</sub>	>0.81	15.5/17	5.16 <sup>+42.1</sup> <sub>-2.55</sub>	1.11 <sup>+2.39</sup> <sub>-0.39</sub>	15.6/17

search for trends in the X-ray properties of LMXBs as a function of the metallicity of their environment. We also determine the X-ray spectral properties of the four Galactic globular cluster LMXBs with X-ray luminosities  $\geq 10^{36}$  ergs s<sup>-1</sup> and LMC X-2.

## 2. DATA REDUCTION

Because of the large angular size of M31, the galaxy was imaged by the *ROSAT* PSPC with many different pointings in order to encompass all the X-ray emission. For our analysis, we only analyze the long (>25 ks) observations. For each data set, the error in the gain correction applied by SASS as part of the conversion from detected pulse height to pulse invariant channel (Snowden et al. 1995) was corrected using the FTOOL PCPICOR.

Each M31 X-ray source identified as being coincident with an M31 globular cluster by Supper et al. (1997) was cross-referenced against Huchra, Brodie, & Kent (1991) for an estimate of the metallicity of the globular cluster. If the source contained fewer than 250 X-ray counts, it was removed from the sample. Sources that fell outside the rib support structure at 18' were also removed. Table 1 lists the identification number of the X-ray source (taken from Supper et al. 1997), an alternate identification number taken from Huchra et al. (1991), and total X-ray counts for each X-ray source in our sample.

For each LMXB, its spectrum was extracted from a circular aperture centered on the source. The size of the extraction aperture varied with the off-axis angle of the source to account for the point-spread function of the instrument. A locally determined background was subtracted from the spectra. The spectra were binned so that each channel contained at least 25 counts, and all channels below 0.1 keV and above 2.4 keV were ignored. A similar procedure was used to extract spectra from LMXBs in NGC 1851, NGC 6624, NGC 6652, NGC 7078 (M15), and LMC X-2.

## 3. SPECTRAL FITTING

### 3.1. M31 Globular Cluster LMXBs

The spectra for the 12 M31 globular cluster LMXBs in our sample were fitted individually with a variety of spectral models using XSPEC, and it was found that absorbed thermal bremsstrahlung (TB), power-law (PL), and blackbody models all fitted the data equally well. We chose to let the photoelectric absorption component (Morrison & McCammon 1983) be a

free parameter, since although the Galactic hydrogen column density toward the direction of the LMXB is known, it is not known how much M31 hydrogen the LMXB lies behind. In most cases, when a blackbody model was used, the best-fit column density was well below (and statistically inconsistent with) the Galactic value, so we discarded this model. The best-fit parameters for the TB and PL models, along with 90% confidence levels for one interesting parameter ( $\Delta\chi^2 = 2.71$ ), are shown in Table 1 (all errors in this Letter are quoted at the 90% level). The minimum  $\chi^2$  value, the number of degrees of freedom (dof), and the metallicity of the globular cluster in which the X-ray source is embedded are also shown.

### 3.2. Galactic and LMC LMXBs

Due to the relative proximity of the Galactic LMXBs plus LMC X-2, the observations of these LMXBs yield a much greater number of X-ray counts than the M31 globular cluster LMXBs. Consequently, simple one-component models are not adequate to describe the spectra of these objects as is the case in the M31 LMXBs, which typically yield 1000 or fewer counts. This illustrates the complexity of LMXB spectra at soft X-ray energies. In order to compare fairly the properties between Galactic and M31 LMXBs, we have analyzed only a small fraction of the PSPC data for the Galactic LMXBs, such that each observation yields only  $\sim 2000$  counts. This number was chosen to yield reasonable errors on the spectral parameters, while still containing few enough counts to be directly comparable to the brighter M31 LMXBs.

As a check for consistency, five randomly selected time intervals (each of which yielded about 2000 counts) were analyzed from each observation in order to search for any time dependence in the spectral properties. This was done to ensure that the parameters of the models used to fit the spectra were truly representative of time-averaged properties of the LMXB. We present the *median* best-fit parameters for the five time intervals for each observation.

*NGC 1851.*—Based on a visual extinction of  $A_V = 0.06$  mag (Djorgovski 1993), we have fixed the Galactic hydrogen column density at  $N_H = 1.2 \times 10^{20}$  cm<sup>-2</sup> for both TB and PL models. We have assumed  $N_H = 1.79 \times 10^{21} A_V$  cm<sup>-2</sup> (Predehl & Schmitt 1995). This produced a poor fit for the TB model and a marginal fit for the PL model. However, Walker (1992) found the color excess to be  $E(B - V) = 0.02 \pm 0.02$  for this cluster, so the absorption may be twice the value quoted above given the error. Letting the absorption be free led to acceptable

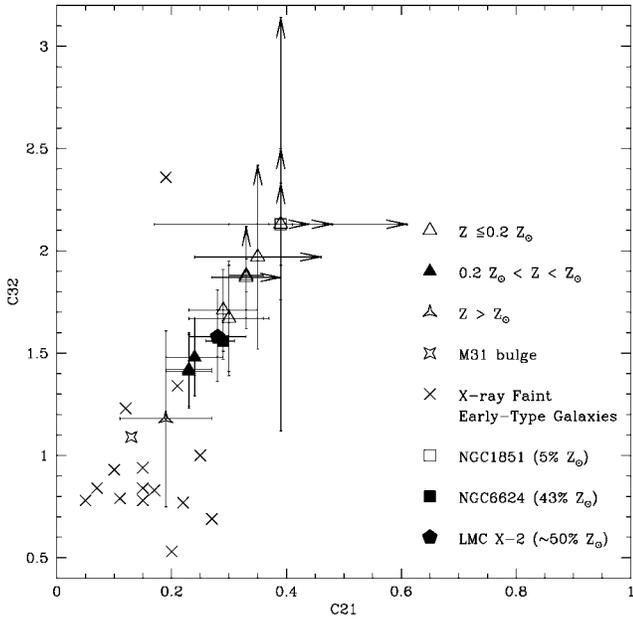


Fig. 1.— C21 vs. C32 plot of the best-fit TB models of the 12 M31 globular cluster LMXBs, NGC 1851, NGC 6624, and LMC X-2. The colors of the bulge of M31 and many X-ray-faint, early-type galaxies (taken from IS98a) are also shown. The arrows indicate that only lower limits were found for the temperatures. The trend of X-ray colors with the metallicity is evident. Note that the high-metallicity M31 LMXB has colors similar to those of the bulge of M31 and the X-ray-faint galaxies.

fits with best-fit parameters of  $N_{\text{H}} = 2.57_{-0.25}^{+0.29} \times 10^{20} \text{ cm}^{-2}$  and  $kT_{\text{TB}} > 19.4 \text{ keV}$  for the TB model and  $N_{\text{H}} = 1.90_{-0.45}^{+0.49} \times 10^{20} \text{ cm}^{-2}$  and  $\Gamma = 1.03 \pm 0.14$  for the PL model. This is somewhat steeper than the value of  $\Gamma = 0.61$  found by Verbunt et al. (1995) with the *ROSAT* All-Sky Survey data.

*NGC 6624.*— We have fixed the absorption component at  $N_{\text{H}} = 1.56 \times 10^{21} \text{ cm}^{-2}$  ( $A_{\text{V}} = 0.87 \text{ mag}$ ). Good fits were found with a best-fit parameter of  $kT_{\text{TB}} = 3.77_{-1.23}^{+2.72}$  for the TB model and  $\Gamma = 1.57 \pm 0.14$  for the PL model. Again, this is slightly steeper than the value of  $\Gamma = 1.36$  by Verbunt et al. (1995).

*NGC 6652.*— The absorption was fixed at  $N_{\text{H}} = 5.55 \times 10^{20} \text{ cm}^{-2}$  ( $A_{\text{V}} = 0.31 \text{ mag}$ ). A marginal fit ( $\chi_{\nu} \sim 1.7$ ) was found for a TB model with an unreasonably high lower limit on the temperature of  $kT_{\text{TB}} > 100 \text{ keV}$ . However, a good fit was obtained with a PL model with  $\Gamma = 0.80 \pm 0.10$ . Verbunt et al. (1995) found a value of  $\Gamma = 0.72$ .

*NGC 7078.*— The absorption was fixed at  $N_{\text{H}} = 1.97 \times 10^{20} \text{ cm}^{-2}$  ( $A_{\text{V}} = 0.11 \text{ mag}$ ). A TB model gave a very poor fit to the data. A better fit was obtained with a PL model with  $\Gamma = 0.12 \pm 0.10$ .

*LMC X-2.*— The column density was a free parameter. The best-fit values were  $N_{\text{H}} = 1.30_{-0.44}^{+0.62} \times 10^{21} \text{ cm}^{-2}$  and  $kT_{\text{TB}} = 2.47_{-1.08}^{+3.91}$  for the TB model and  $N_{\text{H}} = 1.87_{-0.44}^{+0.62} \times 10^{21} \text{ cm}^{-2}$  and  $\Gamma = 2.06_{-0.53}^{+0.59}$  for the PL model. Estimates made from color excess maps of the LMC by Schwering & Israel (1991) give a column density of  $\sim 10^{21} \text{ cm}^{-2}$ , in rough agreement with the X-ray measurements.

#### 4. DISCUSSION

From Table 1, the correlation between the best-fit TB temperature or PL exponent and the metallicity is evident. Source 217, which has the highest metallicity of the LMXBs in the sample, also has the lowest measured temperature ( $kT =$

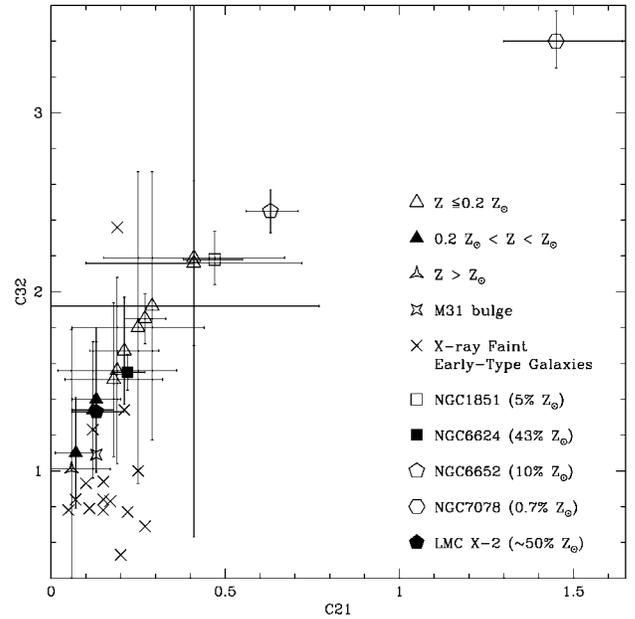


Fig. 2.— Same notation as in Fig. 1, but this time including the colors of NGC 6652 and NGC 7078 for the PL case. Although the errors are larger than in the TB case, the trend of X-ray colors with the metallicity is still evident.

0.95 keV) or steepest power-law exponent ( $\Gamma = 2.63$ ). Conversely, the lower metallicity LMXBs have higher temperatures or flatter power-law exponents. In some cases, the best-fit  $N_{\text{H}}$  value is considerably higher than the Galactic value, indicating that the LMXB spectrum is being absorbed by hydrogen in the disk of M31. In other cases, the derived  $N_{\text{H}}$  value is consistent with the Galactic value in that direction. This trend with metallicity is supported by the four Galactic globular cluster LMXBs and LMC X-2. The two LMXBs in higher metallicity environments (NGC 6624 and LMC X-2) have softer spectra than the three low-metallicity LMXBs.

Previous studies (IS98a; IS98b) have concluded that the X-ray properties of a subclass of early-type galaxies with very low X-ray-to-optical luminosity ratios are similar to those of LMXBs in the Galaxy and the bulges of M31 and NGC 1291. In these studies, two X-ray “colors” (ratio of counts in three X-ray bands) were used to characterize the X-ray emission. For a comparison with those studies, we compute the same colors from the best-fit TB and PL fits described above. The two X-ray colors, C21 and C32, are defined as

$$C21 = \frac{\text{counts in } 0.52\text{--}0.90 \text{ keV band}}{\text{counts in } 0.11\text{--}0.41 \text{ keV band}} \quad (1)$$

and

$$C32 = \frac{\text{counts in } 0.91\text{--}2.02 \text{ keV band}}{\text{counts in } 0.52\text{--}0.90 \text{ keV band}} \quad (2)$$

The absorption-corrected colors derived from the best-fit models for the 12 LMXBs are shown in Figures 1 and 2 for the TB and PL models, respectively. The errors shown are the colors derived from spectral models using the 90% upper and lower limits on the temperature or power-law exponent. The M31 globular cluster sample has been broken into three groups based on metallicity:  $Z \leq 0.2 Z_{\odot}$ ,  $0.2 Z_{\odot} < Z < Z_{\odot}$ , and  $Z >$

$Z_{\odot}$ . The colors of the four Galactic LMXBs and LMC X-2 are also shown, although NGC 6652 and NGC 7078 have been omitted in the TB case since this model did not produce an acceptable fit to the spectra. In the TB case, the temperature of some of the low-metallicity LMXBs was unconstrained, so the colors given are those predicted by a bremsstrahlung temperature of 200 keV (the highest temperature allowed by XSPEC). The colors for the bulge of M31 and many X-ray-faint, early-type galaxies (taken from IS98b) are also shown. The error bars on these quantities have been omitted for clarity.

The segregation of the colors with metallicity of the globular cluster is clear, although the errors are rather large in the power-law case. As the metallicity of the cluster decreases, the colors increase, indicating a hardening of the spectra. The lone LMXB in the sample that resides in a cluster with a metallicity greater than solar has colors very similar to that of the bulge of M31, which has a metallicity of about twice solar (Bica, Alloin, & Schmidt 1990). As mentioned above, the X-ray emission from the bulge of M31 is dominated by LMXBs. The three moderate-metallicity M31 LMXBs as well as NGC 6624 and LMC X-2 occupy a region of C21-C32 space above and to the right of the high-metallicity LMXB and the bulge of M31. The lowest metallicity LMXBs lie farther still to the right and above. The three low-metallicity Galactic globular cluster LMXBs have especially hard colors in the PL case.

For both the TB and PL case, the colors of the high-metallicity M31 LMXB (source 217) are consistent with those of the X-ray-faint, early-type galaxies. As mentioned above, the LMXBs in the bulge of M31 give X-ray-to-optical luminosity ratios comparable to those of the X-ray-faint galaxies. The colors of the high-metallicity M31 globular cluster LMXB add further evidence that LMXBs can produce the spectral characteristics observed in X-ray-faint, early-type galaxies. Given the high central metallicities of early-type galaxies, the LMXBs in these systems should resemble more closely the LMXBs in high-metallicity systems, such as the bulge of M31 or source 217, and not the LMXBs in low-metallicity systems, such as those in NGC 1851, NGC 6652, and NGC 7078.

Previous studies (i.e., Davis & White 1996) have found a correlation between ISM temperature and metal abundance by assuming that the X-ray spectra of the X-ray faintest galaxies could be described by a single-component, zero-metallicity Raymond-Smith model with  $kT \sim 0.6$  keV. Although this model is not excluded by the *ROSAT* PSPC data, a subsequent *ASCA* study of at least one X-ray-faint galaxy excluded this model (Kim et al. 1996). If a majority of the X-ray emission from the X-ray faintest galaxies is stellar in nature, this calls into

question the relation between ISM temperature and abundance, as well as the relation between ISM temperature and stellar velocity dispersions.

Finally, we note that the small discrepancy in C32 between the bulge of M31 and the mean of the X-ray-faint, early-type galaxies may be caused by the presence of small amounts of warm interstellar gas in the X-ray-faint systems, although the gas is not the dominant X-ray emission mechanism, as is the case in X-ray-bright galaxies. There is evidence that the amount of ISM increases with increasing  $L_x/L_b$ . As a comparison, X-ray-bright, early-type galaxies whose emission is dominated by  $\sim 0.8$  keV gas have X-ray colors in the range (C21, C32) = (0.5–1, 0.8–2), well separated from the X-ray-faint, early-type galaxies (IS98b).

## 5. A FEW WORDS OF WARNING

It should be stressed that the low-energy spectra of LMXBs are quite complicated and cannot, in general, be described by a single TB or PL model. The good fits obtained here are solely the result of having a paucity of X-ray counts for the M31 sample. For the well-observed Galactic LMXB sample, even two-component fits did not always produce a good fit. However, there is no reason to believe that the simple models used here should lead to misleading results regarding the trend of the X-ray colors with metallicity.

Another issue not addressed here is the presence of absorbing material intrinsic to the LMXB. For the five Galactic/LMC LMXBs, as well as eight of the 12 M31 LMXBs, the best-fit absorption value is consistent with what is expected from intervening material in our own Galaxy. We have assumed that those showing excess absorption do so because they lie behind absorbing material in the disk of M31. Although it is possible that the excess absorption is from material intrinsic to the LMXB, the removal of these four LMXBs will not alter the conclusions drawn here. Three of the four LMXBs have a low metallicity and already have hard colors, so using a lower value for the line-of-sight (nonintrinsic) absorption will only make their colors harder. Furthermore, inspection of the raw C32 color *uncorrected* for absorption shows the same trend with metallicity. The trend in C21 is lost, though, since this color is highly dependent on absorption.

This research has made use of data obtained through the High Energy Astrophysics Science Archive Research Center Online Service, provided by the NASA Goddard Space Flight Center. This work has been supported by NASA grant NAG5-3247.

## REFERENCES

- Bica, E., Alloin, D., & Schmidt, A. A. 1990, *A&A*, 228, 23  
 Choi, C. S., Seon, K. I., Dotani, T., & Nagase, F. 1997, *ApJ*, 476, L81  
 Davis, D. S., & White, R. E., III. 1996, *ApJ*, 470, L35  
 Djorgovski, S. G. 1993, in *ASP Conf. Ser. 50, Structure and Dynamics of Globular Clusters*, ed. S. G. Djorgovski & G. Meylan (San Francisco: ASP), 373  
 Fabbiano, G., Kim, D.-W., & Trinchieri, G. 1994, *ApJ*, 429, 94  
 Hakala, P. J., Chaytor, D. H., Vilhu, O., Piirola, V., Morris, S. L., & Muhli, P. 1998, *A&A*, 333, 540  
 Hill, V., Andrievsky, S., & Spite, M. 1995, *A&A*, 293, 347  
 Huchra, J. P., Brodie, J. P., & Kent, S. M. 1991, *ApJ*, 370, 495  
 Irwin, J. A., & Sarazin, C. L. 1998a, *ApJ*, 494, L33 (IS98a)  
 ———. 1998b, *ApJ*, 499, 650 (IS98b)  
 Kim, D.-W., Fabbiano, G., Matsumoto, H., Koyama, K., & Trinchieri, G. 1996, *ApJ*, 468, 175  
 Kim, D.-W., Fabbiano, G., & Trinchieri, G. 1992, *ApJ*, 393, 134  
 Morrison, R., & McCammon, D. 1983, *ApJ*, 270, 119  
 Pellegrini, S. 1994, *A&A*, 292, 395  
 Pellegrini, S., & Fabbiano, G. 1994, *ApJ*, 429, 105  
 Predehl, P., & Schmitt, J. H. M. M. 1995, *A&A*, 293, 889  
 Schwering, P. B. W., & Israel, F. P. 1991, *A&A*, 246, 231  
 Snowden, S. L., Turner, T. J., George, I. M., & Yusaf, R. 1995, *OGIP Calibration Memo CA1/ROS/95-003*  
 Supper, R., Hasinger, G., Pietsch, W., Trümper, J., Jain, A., Magnier, E. A., Lewin, W. H. G., & van Paradijs, J. 1997, *A&A*, 317, 328  
 Verbunt, F., Bunk, W., Hasinger, G., & Johnston, H. 1995, *A&A*, 300, 732  
 Walker, A. R. 1992, *PASP*, 104, 1063