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Citation of published version:

Irwin, J., Bregman, J. (1999): Using the Bulge of M31 as a Template for the Integrated X-Ray Emission from Low-Mass X-Ray Binaries. *The Astrophysical Journal*, 527(1).
DOI: 10.1086/308081

THE ASTROPHYSICAL JOURNAL, 527:125–131, 1999 December 10

USING THE BULGE OF M31 AS A TEMPLATE FOR THE INTEGRATED X-RAY EMISSION FROM LOW-MASS X-RAY BINARIES

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Received 1999 May 3; accepted 1999 July 23

ABSTRACT

We have performed joint *ASCA* + *ROSAT* PSPC spectral fitting on the inner 5′ of the bulge of M31. We find that single-component spectral models provide an inadequate fit to the spectrum, in contrast to previous studies by *Einstein* and *Ginga*. Although the 2–10 keV spectrum can be fitted adequately with a bremsstrahlung model with $kT = 7.4 \pm 0.3$ keV, an additional soft component with $kT = 0.38 \pm 0.03$ keV is required to fit the spectrum below 2 keV. This soft component comprises 38% ± 6% of the total emission in the 0.1–2.0 keV band, and possibly more depending on the absorption value used in the fit. Since previous spatial studies of the bulge of M31 indicate that less than 25% of the X-ray emission from the bulge in this band is from a diffuse gaseous component, this implies that stellar sources, namely, low-mass X-ray binaries (LMXBs), are responsible for some if not all of the soft component. The spectral properties of M31 are very similar to those of the X-ray–faint early-type galaxy NGC 4382. This supports the claim that the unexplained soft X-ray emission seen previously in these galaxies also emanates from LMXBs.

Subject headings: binaries: close — galaxies: elliptical and lenticular, cD — galaxies: individual (M31) — galaxies: ISM — X-rays: galaxies — X-rays: stars

1. INTRODUCTION

Nearly all that is known about the X-ray spectra of low mass X-ray binaries (LMXBs) has come from observations of LMXBs in the Galactic bulge or those that lie in the Galactic plane. Unfortunately, this also means that large quantities of Galactic hydrogen gas ($N_{\rm H} \sim 10^{22}$ cm^{-2}) lie between us and the LMXBs we wish to observe. Nearly all of the X-ray flux below 1 keV from these LMXBs is absorbed by intervening material between us and the LMXB. As a consequence, very little is known about the X-ray properties of LMXBs at very soft X-ray energies. A recent survey of 49 Galactic LMXBs observed with the *Einstein* Observatory found that a majority of the spectra were adequately fitted with a power law plus high-energy exponential cutoff spectral model, with Γ between -0.2 and 1.0 and a high-energy cutoff in the 3–7 keV range. (Christian & Swank 1997). Thermal bremsstrahlung models with $kT = 5$–10 keV are also frequently employed to describe the emission from LMXBs. Such models contribute relatively little to the X-ray emission in the 0.1–1 keV range compared to the 1–10 keV range. Given the large hydrogen column densities toward most these objects, though, any soft component would have been completely absorbed.

Is there reason to believe that the X-ray spectrum of LMXBs is interesting below 1 keV? There are two examples of Galactic LMXBs that lie in directions of low hydrogen column densities that were observed with *ROSAT* and/or *ASCA*. Both LMXBs show evidence for very soft X-ray emission. Choi et al. (1997) confirmed earlier reports of a 0.1 keV blackbody component in addition to a harder power-law component in the X-ray spectrum of Her X-1 with *ASCA*. The very soft blackbody component has been interpreted as the thermal reemission by an opaque distribution of gas around the neutron star. The Galactic LMXB MS 1603+2600 also exhibits very soft emission (Hakala et al. 1998), although there is some question as to whether this system is an LMXB or a cataclysmic variable (Ergma & Vilhu 1993). There are several LMXBs in globular clusters that lie in directions of low column densities that do not show strong excess soft X-ray emission. However, these LMXBs reside in low-metallicity environments. A recent study of 12 LMXBs located in globular clusters of M31 by Irwin & Bregman (1999) found a correlation between the X-ray spectral properties of the LMXB with the metallicity of the host globular cluster. The one LMXB in a globular cluster with greater than solar metallicity had a much softer X-ray spectrum than those LMXBs located in metal-poor clusters.

The possible existence of a soft component of LMXBs is particularly important in the case of early-type galaxies that are very underluminous in X-rays for a given optical luminosity (low L_X/L_B). In these galaxies it is suspected that the X-ray emission is primarily stellar in nature. Whereas it is well established that the X-ray emission in X-ray bright elliptical galaxies is predominantly from hot (∼0.8 keV) gas, X-ray–faint galaxies appear to be lacking this component. Instead, their X-ray emission is characterized by a two-temperature (5–10 keV + 0.3 keV) model (Fabbiano, Kim, & Trinchieri 1994; Pellegrini 1994; Kim et al. 1996). The 5–10 keV component is generally regarded as the integrated emission from LMXBs, and has been seen in nearly all early-type galaxies observed with *ASCA* (see, e.g., Matsumoto et al. 1997). The origin of the soft component remains a mystery. Although it has been suggested that the source of the emission might be warm interstellar gas, recent work has suggested that the source of the soft emission is the same collection of LMXBs responsible for the 5–10 keV component (Irwin & Sarazin 1998a, 1998b).

Given the paucity of Galactic LMXB candidates that are not heavily absorbed, the bulge of M31 provides the nearest laboratory for studying a large number of LMXBs in high-metallicity environments at low X-ray energies. At a Galactic hydrogen column density of 6.7×10^{20} cm^{-2}, the 0.1–1

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keV spectra of LMXBs in the bulge of M31 are not completely absorbed (25% transmission at 0.35 keV), as is the case toward the Galactic bulge. Here, we analyze the joint *ASCA* and *ROSAT* PSPC spectrum of the inner 5′ of the bulge of M31. By combining both instruments we are able to fit the spectrum of the bulge of M31 over a broad energy range (0.2–10 keV), using the advantages of both instruments to complement one another. This spectrum can be used as a template for what the spectrum of a collection of LMXBs should look like in more distant early-type galaxies.

2. PREVIOUS X-RAY OBSERVATIONS OF THE BULGE OF M31

The first spectral study of the bulge of M31 was performed with the *Einstein* IPC (0.2–4.5 keV) and MPC (1.2–10 keV) instruments by Fabbiano, Trinchieri, & Van Speybroeck (1987). For the inner 5′ of the bulge, this study found that a thermal bremsstrahlung model with $kT = 6$–13 keV and no intrinsic absorption above the Galactic value fitted the data well. Makishima et al. (1989) used *Ginga* (2–20 keV) data to study all of M31 (disk plus bulge), and found a best-fit temperature of 7.2 ± 0.4 keV with significant excess absorption, although this model yielded a rather large reduced χ^2 value. A better fit was obtained with a power law with high-energy cutoff model with $\Gamma = 1.9 \pm 0.3$ and a cutoff energy of 6.8 ± 0.5 keV. However, the absorption was once again an order of magnitude higher than the Galactic value.

Supper et al. (1997) analyzed a long *ROSAT* PSPC observation of the bulge of M31 and found a best-fit bremsstrahlung temperature of ~ 1 keV, although the authors state that the temperature could not be well determined. We interpret this to mean that the reduced χ^2 value of this model was large, and our analysis of the same data (§ 4) confirms this. Irwin & Sarazin (1998b) analyzed a much shorter (2800 s) *ROSAT* PSPC observation and found a best-fit bremsstrahlung temperature of 0.78 ± 0.07 keV from a fit that was marginally acceptable, although a significantly better fit was found with a two-component model: a Raymond-Smith (1977) thermal model with $kT = 0.36^{+0.09}_{-0.06}$ keV, a metallicity $0.012^{+0.012}_{-0.005}$ solar, and a harder bremsstrahlung component with $kT > 6.4$ keV. Both *ROSAT* PSPC results indicated that below 2 keV, the spectrum of the bulge of M31 was not well represented by a hard 5–10 keV bremsstrahlung model, in contrast to the *Einstein* and *Ginga* results.

3. *ROSAT* PSPC AND *ASCA* DATA REDUCTION

We have chosen a long *ROSAT* PSPC observation of the bulge of M31 from the HEASARC archive (RP600068N00). The exposure time was 30,005 s. The spectrum of the inner 5′ of the bulge was extracted, and the energy channels were rebinned to contain at least 25 counts. A background spectrum, extracted from an annulus of 30′–40′ and corrected for vignetting, was scaled to and subtracted from the source spectrum. Energy channels below 0.2 keV and above 2.4 keV were then excluded.

A long *ASCA* observation of M31 was also taken from the HEASARC archive (63007000). The data were screened using the standard screening criteria applied to all the archival data (Revision 2 processing). The spectrum of the inner 5′ was extracted from the GIS2, GIS3, SIS0, and SIS1 data, with a total exposure time of 177,113 s for the combined GIS data and 102,333 s for the combined SIS data. We chose to analyze the BRIGHT2 SIS data, since the data can be corrected for echo and dark frame error effects in this mode. The SIS data were taken in 4-CCD mode, but nearly all of the inner 5′ of the bulge fitted within one chip. Therefore, only data from this one chip were used in the analysis, in order to avoid complications that might arise from averaging together the responses from different chips. Background was obtained from the deep blank sky data provided by the *ASCA* Guest Observer Facility. We used the same region filter to extract the background as we did the data, so that both background and data were affected by the detector response in the same manner. Energy channels below 0.8 keV and above 10 keV were excluded. Once again, the energy channels were rebinned to contain at least 25 counts. Because of differences in the calibrations among the five data sets, as well as possible temporal variations in the flux between the *ROSAT* and *ASCA* observations, we have chosen to let the normalizations of all spectral models be free parameters. In all fits the SIS normalizations were consistent with one another but about 20% less than the GIS and PSPC normalization. This is a result of having excluded a fraction of the data that fell off the primary chip. Table 1 gives details of the observations.

4. RESULTS OF SPECTRAL FITTING

4.1. *One-Component Models*

As a first step, we have attempted to fit a variety of single-component spectral models to the data, the first of which being a thermal bremsstrahlung (TB) model. A very poor fit to the data (reduced $\chi^2 = 3.19$) was found, with a best-fit temperature of 6.0 keV. A similarly poor fit was found when the *ROSAT* and *ASCA* data were analyzed separately. Poor fits were also obtained for blackbody, disk-blackbody, power law, power law with high-energy cutoff (CPL), MEKAL (MKL), a self-Comptonization spectrum after Lamb & Sanford (1979; CLS), and a self-Comptonization spectrum after Sunyaev & Titarchuk (1980) models, with a reduced χ^2 always exceeding two for ~ 1065 degrees of freedom (dof). These models were chosen since they have

TABLE 1

Observational Data Set for M31

Instrument	Observation Number	Exposure (s)	Energy Band Used (keV)	Net X-ray Counts
ROSAT PSPC......	RP600068N00	30,005	0.2–2.4	29,720
ASCA GIS2	63007000	88,109	0.8–10.0	24,900
ASCA GIS3	63007000	89,004	0.8–10.0	29,718
ASCA SIS0	63007000	50,531	0.8–10.0	23,623
ASCA SIS1	63007000	51,802	0.8–10.0	17,141

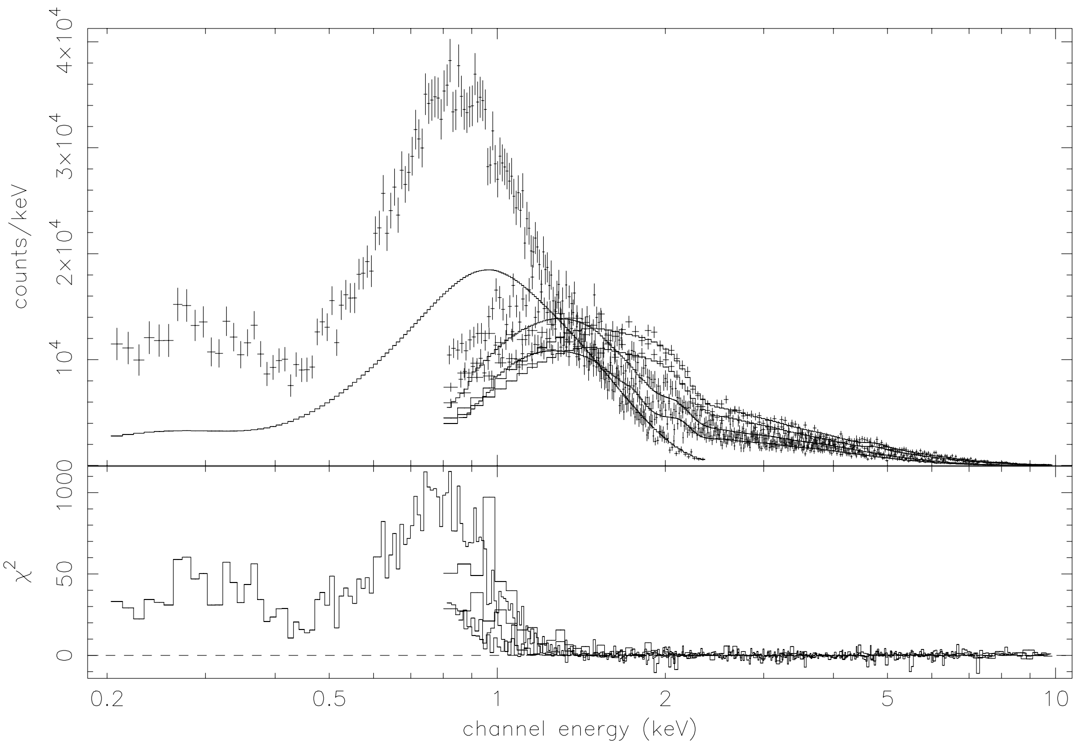

FIG. 1.—*ROSAT* PSPC + *ASCA* data with best-fit one-component TB model fitted to the 2.0–10 keV bandpass only. Data below 2.0 keV was then added in after the fit. For all five instruments, an excess of soft emission below 1.5 keV was detected.

often been found in the literature to describe the emission from LMXBs.

To illustrate that a soft component is needed in addition to the hard component, we have excluded the *ROSAT* data and fitted the *ASCA* data only in the 2.0–10 keV range with a single-component bremsstrahlung model with the absorption fixed at the Galactic value. Now the fit is good (reduced $\chi^2 = 1.09$) with $kT = 7.4 \pm 0.3$ keV, consistent with the best-fit bremsstrahlung model obtained by *Ginga* over a similar energy range. We have extrapolated this model down to an energy of 0.2 keV and plotted the *ROSAT* PSPC data and *ASCA* data below 2.0 keV over it in Figure 1. Although the 7.4 keV bremsstrahlung model provides a reasonable fit to the *ROSAT* data between 1.5–2.4 keV, below 1.5 keV there is a considerable excess of soft X-ray emission. This same feature is present in the *ASCA* data in the 0.8–1.5 keV range. A similar exercise using a cutoff power law (CPL) model yielded similar results, with best-fit values of 1.5 ± 0.1 and $12.4^{+6.9}_{-3.3}$ keV for the power law exponent and cutoff energy, respectively.

4.2. *Two-Component Models*

Next, various combinations of the spectral models described above were fitted to the data. Whereas the parameters for the models were linked between the five data sets, the normalizations of each model were allowed to be independent of one another. The absorption was left as a free parameter. Of all the possible combinations, only three gave a fit with a reduced χ^2 less than 1.3—the MKL + TB, MKL + CLS, and MKL + CPL models. The best-fit parameters for these models are shown in Table 2. The errors given are 90% confidence levels for one interesting parameter. For all fits there were approximately 1060 dof. The three models gave identical reduced χ^2 values. Despite the low reduced χ^2 values, the null hypothesis probability for the fits was quite small (0.1%) because of the large number of degrees of freedom in the fit. However, the residuals had an approximately Gaussian distribution about zero, so although the models are not formally acceptable, they should lead to accurate fluxes for the two com-

TABLE 2

SPECTRAL FITS OF M31 BULGE

		SOFT COMPONENT		HARD COMPONENT				
MODEL	$N_H(10^{20}\ \mathrm{cm}^{-2})$	kT(keV)	$Z/Z_\odot$	kT(keV)	τ (10^{-3})	Γ	High-Energy Cutoff (keV)	χ^2_ν
MKL + TB........	$4.38^{+0.44}_{-0.27}$	$0.38^{+0.03}_{-0.03}$	$0.20^{+0.34}_{-0.08}$	$7.8^{+0.3}_{-0.3}$	...	...	...	1.14
MKL + TB........	6.73 (fixed)	$0.36^{+0.03}_{-0.02}$	$0.04^{+0.01}_{-0.01}$	$8.0^{+0.3}_{-0.3}$	...	...	...	1.23
MKL + CLS	$4.43^{+0.42}_{-0.48}$	$0.38^{+0.04}_{-0.03}$	$0.18^{+0.27}_{-0.07}$	$9.4^{+1.8}_{-1.7}$	$1.23^{+0.21}_{-0.14}$	...	...	1.14
MKL + CLS	6.73 (fixed)	$0.36^{+0.02}_{-0.02}$	$0.04^{+0.01}_{-0.01}$	$10.3^{+2.1}_{-1.9}$	$1.15^{+0.17}_{-0.15}$	...	...	1.22
MKL + CPL......	$4.41^{+0.45}_{-0.48}$	$0.38^{+0.04}_{-0.03}$	$0.21^{+0.64}_{-0.10}$	...	...	$1.26^{+0.07}_{-0.08}$	$6.86^{+1.13}_{-0.89}$	1.14
MKL + CPL......	6.73 (fixed)	$0.36^{+0.03}_{-0.02}$	$0.03^{+0.01}_{-0.01}$	...	...	$1.19^{+0.07}_{-0.09}$	$6.13^{+0.93}_{-0.80}$	1.22

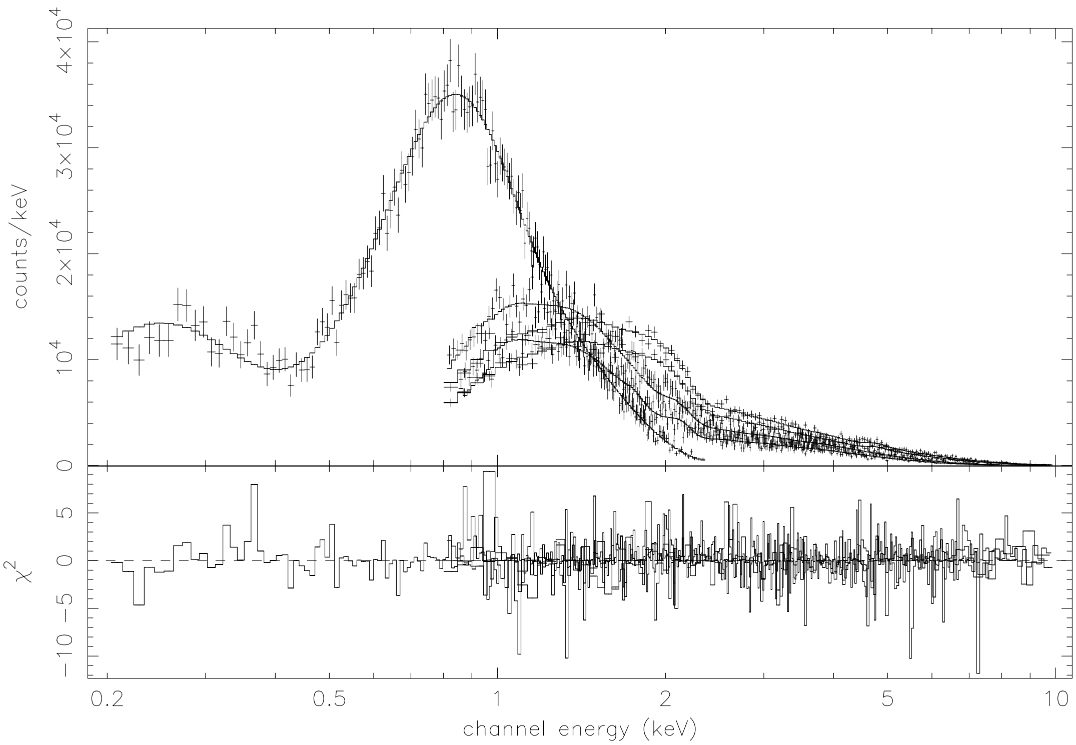

FIG. 2.—*ROSAT* PSPC + *ASCA* data with best-fit MEKAL + TB model using data in the 0.2–10 keV bandpass

ponents. The best-fit MKL + TB model is shown in Figure 2 along with the residuals. In all three models, the best-fit absorption was ~35% below the Galactic H I value of Stark et al. (1992); therefore we have also fixed the absorption at the Galactic value for these two models, and determined the best-fit parameters. This caused an increase in the reduced χ^2 with a very small null hypothesis probability but still provided a better fit than other models with the absorption left as a free parameter. Other than the metallicity of the MEKAL component, the best-fit parameters did not change significantly by fixing the absorption at the Galactic value.

The temperature of the MEKAL component was well determined (better than 10% accuracy) with a value between 0.36–0.38 keV and a metallicity around 20% solar when the absorption was left free and around 4% solar when the absorption was fixed at the Galactic value. For the hard component, the TB model gave a temperature 7.8 ± 0.3 keV. The temperatures are consistent with the results of the analysis of a shorter PSPC observation (Irwin & Sarazin 1998b), but now the *ASCA* data have tightly constrained the temperature of the hard component, whereas only a lower limit was found before. For the CLS model, a slightly higher temperature was found along with a low optical depth. For the CPL model, values of $\Gamma = 1.2$–1.3 and a cutoff energy of 6–7 keV are similar to those found for individual Galactic LMXBs with *Einstein* data by Christian & Swank (1997). Table 3 gives the unabsorbed fluxes for the soft and hard components for each model over various energy ranges.

Our results contrast with those of Fabbiano et al. (1987), who found no evidence for a soft component despite the fact that the *Einstein* IPC was sensitive to photon energies down to 0.2 keV. Although the IPC had poor energy at low energies, a soft component should have been detected. The soft excess emission becomes apparent around an energy of 1.5 keV (Fig. 1), so energy resolution effects should not have hindered its detection. We find no obvious explanation for

TABLE 3

FLUXES[a]

		SOFT COMPONENT			HARD COMPONENT		
MODEL	$N_{\rm H}$ (10^{20} cm^{-2})	0.1–2 keV	0.2–4 keV	0.25–10 keV	0.1–2 keV	0.2–4 keV	0.25–10 keV
MKL + TB........	$4.38^{+0.44}_{-0.27}$	0.70 ± 0.16	0.59 ± 0.11	0.55 ± 0.09	1.16 ± 0.03	1.73 ± 0.03	2.62 ± 0.03
MKL + TB........	6.73 (fixed)	1.51 ± 0.07	1.14 ± 0.05	0.99 ± 0.04	1.16 ± 0.02	1.72 ± 0.03	2.62 ± 0.03
MKL + CLS......	$4.85^{+0.17}_{-0.37}$	0.73 ± 0.17	0.61 ± 0.11	0.57 ± 0.10	1.15 ± 0.03	1.72 ± 0.02	2.61 ± 0.02
MKL + CLS......	6.73 (fixed)	1.53 ± 0.08	1.15 ± 0.05	1.01 ± 0.03	1.14 ± 0.03	1.71 ± 0.02	2.60 ± 0.03
MKL + CPL......	$4.41^{+0.45}_{-0.48}$	0.69 ± 0.19	0.58 ± 0.14	0.54 ± 0.12	1.19 ± 0.06	1.75 ± 0.05	2.63 ± 0.05
MKL + CPL......	6.73 (fixed)	1.55 ± 0.09	1.17 ± 0.07	1.02 ± 0.06	1.12 ± 0.06	1.69 ± 0.05	2.58 ± 0.05

[a] In units of 10^{-11} ergs s^{-1} cm^{-2}.

this discrepancy. The soft component is seen in multiple *ROSAT* PSPC pointings and in all four instruments of *ASCA*. In addition, we analyzed a shorter *ASCA* observation of M31 from the HEASARC archive (60037030) and found similar evidence for a soft component.

5. DISCUSSION

5.1. *The Origin of the Soft Component*

From spectral fitting, the need for a soft component in the bulge of M31 is clearly evident. But what is the source of the emission? Two possibilities exist. First, the soft emission may emanate from a warm interstellar medium (ISM). The second alternative is that the source of the soft emission is the same as that of the hard component, namely LMXBs. The case for each is presented below.

A high-resolution *ROSAT* HRI study of the bulge of M31 (Primini, Forman & Jones 1993) found that 45 point sources within the inner 5′ of the bulge accounted for 58% of the bulge emission, with the remaining emission being diffuse. Of the remaining emission, the authors estimate that about 14% is the result of the large-angle scattering component of the point response function of the HRI from the resolved point sources, and another 15%–26% is attributable to the integrated emission from point sources below the detection threshold, given their derived luminosity function for the bulge sources. This leaves between 25%–30% of the total emission unexplained by discrete sources or instrumental effects. Other sources such K and M dwarf stars, cataclysmic variables, and RS CVn stars were insufficient to explain the remaining diffuse emission. Primini et al. (1993) were forced to conclude that the diffuse emission is either a new class of X-ray sources or a hot component of the interstellar medium.

At first glance the interstellar medium explanation seems quite attractive. From the spectral fits presented here, the soft component represents 35%–40% of the total X-ray emission in the 0.1–2.0 keV range (Table 3), at least for the case where the absorption was allowed to vary. This is roughly the same percentage of the total emission as the unexplained diffuse emission found by Primini et al. (1993). Furthermore, the soft emission is best-described by a MEKAL model, which is often used to describe the X-ray emission from a metal-enriched, optically thin thermal plasma. The stellar velocity dispersion of the bulge of M31 is 151 km s^{-1} (Whitmore 1980). Using the velocity dispersion–X-ray temperature relation derived from a sample of 30 elliptical galaxies by Davis & White (1996) of $kT \propto \sigma^{1.45}$, gas in a potential well of this magnitude should have a temperature of about 0.3 keV, in good agreement with the spectral fits. The best-fit metallicity value is consistent with metallicity measurements obtained from the hot gas in early-type galaxies (see, e.g., Matsumoto et al. 1997).

However, equally compelling pieces of evidence support the claim that the source of the soft emission is LMXBs. First of all, a similar spatial study of the bulge of M31 with *Einstein* HRI data by Trinchieri & Fabbiano (1991) came to a different conclusion than Primini et al. (1993) concerning the nature of the unresolved emission. Trinchieri & Fabbiano (1991) found that 75% of the bulge emission was resolved into 46 point sources (as opposed to 58% found by Primini et al. 1993 with *ROSAT*), with the remaining diffuse emission easily attributable to point sources below the detection threshold. Trinchieri & Fabbiano (1991) also found a somewhat steeper luminosity distribution function than Primini et al. (1993). *Einstein* covered a harder energy bandpass than did *ROSAT*, so if the fainter sources had harder spectra than the brighter sources, this could lead to a difference in the measured slope between the two studies. Whether this is the cause of the discrepancy between the two studies is unclear. Deep observations with *Chandra* will be necessary to determine exactly what percentage of the total bulge emission cannot be attributed to point sources.

Second, the determination of the contribution of the soft component relative to the total emission is dependent on the magnitude of the absorption component assumed. When the absorption was fixed at the Galactic value, the amount of (unabsorbed) soft flux increased considerably when compared to the case where the best-fit column density was less than the Galactic value (Table 3). When the column density was fixed at the Galactic value, the soft component accounted for 55%–60% of the total emission in the *ROSAT* (0.1–2.0 keV) band. This is twice the amount of unexplained diffuse emission found by Primini et al. (1993). Thus, at least half of the soft emission must emanate from the discrete sources themselves rather than from any gas present in the bulge, if the model in which the absorption is fixed at the Galactic value is used.

But perhaps the strongest evidence supporting a soft component emanating from the LMXBs rather than an interstellar medium lies in the spectra of the individual LMXBs that have been resolved in the bulge. Supper et al. (1997) analyzed the spectra of 7 of the 22 bulge point sources resolved by the *ROSAT* PSPC and fitted them with simple bremsstrahlung fits. Since the statistics for any one LMXB were poor, this simple model provided an adequate fit to the spectra. The best-fit temperatures were in the range 0.45–1.5 keV, well below the canonical temperature of 5–10 keV previously assumed for LMXBs. This is consistent with the value of $kT = 0.78 \pm 0.07$ keV derived for the bulge of M31 as a whole with the same model by Irwin & Sarazin (1998b), although the fit in that case was only marginal owing to better statistics. Nearly all of the remaining 15 point sources had X-ray colors (ratio of X-ray counts in three separate energy bands covering the bandpass of the PSPC) that were similar to the seven for which temperatures were derived, indicating that they had similar spectra. Since the bright sources, faint sources, and the total emission from the bulge all seem to have similar spectra, this strongly suggests that the soft component seen in the integrated emission from the bulge is emanating from the LMXBs themselves, with little emanating for a hot interstellar medium component.

One final piece of evidence involves comparing the bulge of M31 to the bulge of the nearby Sa galaxy NGC 1291. Bregman, Hogg, & Roberts (1995) fit the *ROSAT* PSPC spectrum of NGC 1291 with a hard + soft component model similar to the one used to fit the bulge of M31. In fact, the X-ray colors of the bulge of NGC 1291 are nearly identical to those of the bulge of M31, despite the fact that the 0.5–2.0 keV X-ray–to–optical luminosity ratio of NGC 1291 is a factor of 1.7 higher than that of the bulge of M31 (Irwin & Sarazin 1998b). It seems unlikely that the difference in the L_X/L_B values can be due to there being a higher percentage of the ISM component in NGC 1291 than in M31; this would lead to a difference in the X-ray colors between the two galaxies. Irwin & Sarazin (1998b) found that the C32 color (defined as the ratio of counts in the

0.91–2.02 keV band to the counts in the 0.52–0.90 keV band) for M31 and NGC 1291 was 1.16 ± 0.05 and 1.15 ± 0.14, respectively, after correcting for absorption (this color is only modestly dependent on absorption). Taking the MKL + TB spectral model for M31 presented in this paper, we added an additional MEKAL component to represent an ISM component that might be present in the spectrum of NGC 1291. This model had a temperature of 0.3 keV and a metallicity of 30% solar. This component was added in an amount such that the 0.5–2.0 keV luminosity increased by a factor of 1.7, to represent the difference in the L_X/L_B values between M31 and NGC 1291. Doing this caused the C32 value to decrease by more than 30%. Yet the C32 value for NGC 1291 was identical to that of M31. If the difference in L_X/L_B is due in part to an ISM, the ISM component needs to be exactly matched by an increase in the LMXB component to keep C32 in NGC 1291 the same as in M31. A more likely explanation is that the X-ray emission mechanism is identical in the two galaxies (solely LMXB emission), with NGC 1291 having a higher percentage of LMXBs per unit optical luminosity than M31.

5.2. *Implications For Early-Type Galaxies*

At some level, stellar X-ray emission must contribute to the total X-ray emission in early-type galaxies, although that level is yet to be determined. In X-ray bright (high L_X/L_B) galaxies, there is little doubt that a hot ($\sim$0.8 keV) interstellar medium is responsible for most of the X-ray emission in these galaxies. But even in these galaxies, a measurable hard (5–10 keV) component has been detected with *ASCA* (Matsumoto et al. 1997), that seems to scale roughly with optical luminosity and has been attributed to the integrated emission from LMXBs. The X-ray–faint early-type galaxies remain a puzzle. Low X-ray count rates in these galaxies make them difficult to study, but the emerging picture is that their X-ray spectra are much different than their X-ray bright counterparts.

The first piece of evidence that the spectra of X-ray–faint early-type galaxies differed from those of X-ray bright galaxies came from observations performed by *Einstein*. Kim, Fabbiano, & Trinchieri (1992) found that X-ray–faint galaxies exhibited significant excess very soft X-ray emission. Subsequent observations using *ROSAT* found the X-ray emission of several X-ray–faint galaxies to be described by a two-component (very soft + hard) model, with the hard component attributed to LMXBs and the very soft component of unknown origin (Fabbiano et al. 1994; Pellegrini 1994; Fabbiano & Schweizer 1995). Irwin & Sarazin (1998b) showed this to be the case in all X-ray–faint early-type galaxies. The temperature of the hard component was unconstrained, however, because of the limited bandpass of *ROSAT*.

Kim et al. (1996) performed a joint *ROSAT* + *ASCA* analysis of the X-ray–faint galaxy NGC 4382. The agreement between their derived spectral parameters for NGC 4382 and the ones presented here for the bulge of M31 are remarkable. Kim et al. (1996) found a good fit (reduced $\chi^2 = 1.03$ for 190 dof) with a Raymond-Smith + TB model with variable absorption. Although we used a MEKAL model instead of a Raymond-Smith model, the difference between the two models was found to be minimal, affecting the metallicity the most. For the Raymond-Smith component Kim et al. (1996) found a temperature of $kT = 0.27$–0.41 keV (90% confidence) and a metallicity unconstrained but greater than 10% at the 90% confidence level. They found the temperature of the TB component to be $kT = 4.3$–12.8 keV. A best-fit column density that was $\sim 2 \times 10^{20}$ cm^{-2} below the Galactic value was also found for NGC 4382 as was the case for the bulge of M31. In addition, the contribution of each component to the total emission are in good agreement for both galaxies. Kim et al. (1996) found an unabsorbed hard–to–soft flux ratio of 1.5 (1.1–1.9), 2.5 (1.7–2.3), and 3.6 (2.5–4.7) in the 0.1–2, 0.2–4, and 0.25–10 keV bands, respectively (the error ranges were calculated using the 1 σ confidence levels on the fluxes given by Kim et al. 1996). From Table 3, our flux ratios in those energy bands are 1.7 (1.3–2.1), 2.9 (2.4–3.4), and 4.8 (4.0–5.6), respectively (90% confidence levels). This agreement in the spectral properties of NGC 4382 and M31 suggests a common emission mechanism.

The fact that the X-ray spectral properties of M31 and NGC 4382 are virtually identical, coupled with the fact that no more than 25% of the X-ray emission from the bulge of M31 can result from a warm ISM component, points to the interesting (yet not entirely unexpected) conclusion that LMXBs constitute the majority of the X-ray emission in X-ray–faint early-type galaxies. In these galaxies, it is quite possible that the ISM has been removed from the galaxy either by Type Ia supernovae–driven winds, or by environmental effects such as ram-pressure stripping from the intracluster medium through which the galaxy is moving.

The question of whether the soft component seen in the bulge of M31 is stellar or gaseous will soon be unambiguously answered by *Chandra*. With its excellent spatial resolution, *Chandra* will easily determine if the soft emission is resolved or diffuse. In addition, *Chandra* will be able to resolve point sources in nearby early-type galaxies, at least those at a distance of Virgo or closer. The results presented above predict that in both cases the soft component will be found to emanate primarily from LMXBs.

We thank the anonymous referee for useful comments and suggestions. 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 NAG 5-3247.

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