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ROSAT HRI X-RAY OBSERVATIONS OF THE OPEN GLOBULAR CLUSTER NGC 288

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ABSTRACT

A *ROSAT* HRI X-ray image was obtained of the open globular cluster NGC 288, which is located near the South Galactic Pole. This is the first deep X-ray image of this system. We detect a low-luminosity globular cluster X-ray source (LLGCX) RX J005245.0−263449 with an X-ray luminosity of $(5.5 \pm 1.4) \times 10^{32}$ ergs s^{-1} (0.1–2.0 keV), which is located very close to the cluster center. There is evidence for X-ray variability on a timescale of $\lesssim 1$ day. The presence of this LLGCX in such an open globular cluster suggests that dense stellar systems with high interaction rates are not needed to form LLGCXs. We also searched for diffuse X-ray emission from NGC 288. Upper limits on the X-ray luminosities are $L_X^h < 9.5 \times 10^{32}$ ergs s^{-1} (0.52–2.02 keV) and $L_X^s < 9.3 \times 10^{32}$ ergs s^{-1} (0.11–0.41 keV). These imply upper limits to the diffuse X-ray–to–optical light ratios in NGC 288, which are lower than the values observed for X-ray faint early-type galaxies. This indicates that the soft X-ray emission in these galaxies is due either to a component that is not present in globular clusters (e.g., interstellar gas or a stellar component that is not found in low-metallicity Population II systems) or to a relatively small number of bright low-mass X-ray binaries.

Subject headings: globular clusters: individual (NGC 288) — stars: individual (RX J005245.0−263449) — X-rays: galaxies — X-rays: stars

1. INTRODUCTION

Globular clusters are thought to have two distinct populations of X-ray sources (e.g., Hertz & Grindlay 1983). The high-luminosity X-ray sources have $L_X > 10^{34.5}$ ergs s^{-1} and are thought to be binary systems with an accreting neutron star (the so-called low-mass X-ray binaries [LMXBs]; e.g., Verbunt 1996). The nature of low-luminosity globular cluster X-ray sources (LLGCXs) with $L_X < 10^{34.5}$ ergs s^{-1} has been elusive. While a neutron star origin has not been ruled out for the more luminous of the LLGCXs, they are more commonly thought to be associated with white dwarf systems, perhaps related to cataclysmic variables (CVs), which might be produced by stellar interactions in dense cluster cores (Di Stefano & Rappaport 1994). Such a model is not without difficulties: e.g., clusters with high interaction rates are rich in neither CVs nor LLGCXs (Shara & Drissen 1995; Johnston & Verbunt 1996). It would be useful to search for X-ray sources in relatively open globular clusters where stellar interactions are less likely.

Part of the difficulty in determining the origin of LLGCXs arises because of the problem of finding their optical counterparts in crowded globular cluster fields. If accurate X-ray positions are known and the optical field is not too crowded, it may be possible to associate the X-ray sources with unusual optical or UV objects. For example, blue variable (flickering) objects (candidate CVs) have been found to fall within the error boxes of some LLGCXs (Paresce, De Marchi, & Ferraro 1992; Cool et al. 1993, 1995). Alternatively, unusual optical/UV colors may be used to identify the LLGCX. Recently, a number of stars with very unusual and strong UV excesses have been found that appear to be associated with LLGCXs in the globular clusters M13 (Ferraro et al. 1998a) and M92 (Ferraro et al. 1998b). These objects lie far from the traditional globular cluster sequences in UV color-magnitude diagrams. In M13, there are only three such objects in a sample of more than 12,000 stars. Two of the three UV outliers are within a few arcseconds of the positions of X-ray sources observed about 40″ from the center of M13 (Fox et al. 1996). The third object has no associated X-ray peak, but LLGCXs are known to be highly variable (Hertz, Grindlay, & Bailyn 1993). If this connection between UV objects and LLGCXs could be solidified, it would produce a valuable new technique for studying these mysterious objects. To search for associations of LLGCXs and unusual optical/UV objects, one requires accurately determined X-ray positions in regions of moderate stellar density and high-resolution optical and UV observations. This suggests that one compare *ROSAT* HRI observations of relatively open globular clusters with *Hubble Space Telescope* (*HST*) photometry of the same regions.

In addition to adding to our understanding of LLGCXs, X-ray observations of globular clusters might lead to a better understanding of the X-ray emission from elliptical galaxies. In X-ray–bright elliptical galaxies (galaxies with a high ratio of X-ray–to–optical luminosity L_X/L_B), the soft X-ray emission is mainly due to thermal emission from diffuse hot gas, which is not generally present in globulars. However, in X-ray–faint ellipticals (galaxies with a low ratio of X-ray–to–optical luminosity L_X/L_B), much of the emission might be due to stellar sources. Globular clusters are the best local analogs in which we can observe and possibly determine the nature of the X-ray sources in old stellar populations.

This is particularly interesting for the very soft X-ray component observed from X-ray faint elliptical galaxies. In

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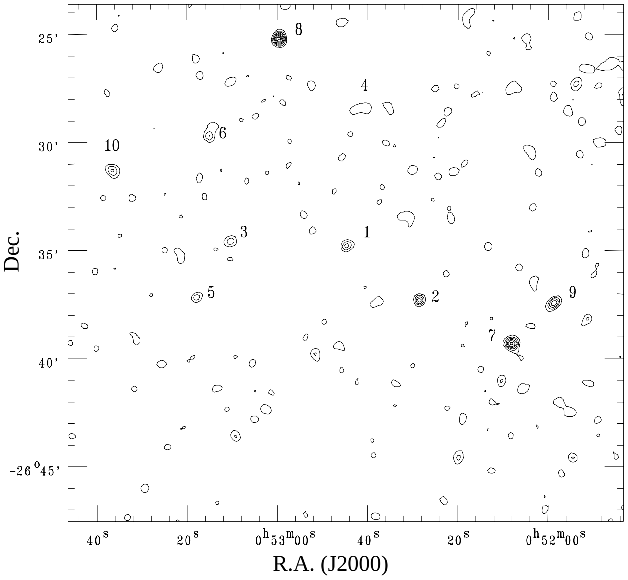

FIG. 1.—Contour plot of the *ROSAT* HRI image of the field around NGC 288. There are nine contours ranging from 0.002 to 0.018 counts s^{-1} $arcmin^{-2}$. The positions of the X-ray sources listed in Table 1 are shown. The center of the globular cluster NGC 288 is very near to the position of source 1.

early-type galaxies, this soft component has an X-ray–to–optical luminosity ratio of $L_X/L_B \approx 10^{29.6}$ ergs s^{-1} $L_\odot^{-1}$ (0.1–2.0 keV; Kim, Fabbiano, & Trinchieri 1992; Irwin & Sarazin 1998a, 1998b) and a spectrum with a temperature of about 0.2–0.3 keV (Fabbiano, Kim, & Trinchieri 1994; Kim et al. 1996). The origin of this elliptical galaxy soft X-ray component is very uncertain. First, is the emission due to stars or to interstellar gas? If it is stellar, what is its origin? Stellar sources known to have soft X-ray spectra such as M dwarfs, RS CVn stars, and supersoft sources seemed like promising explanations, but none of these sources have the required X-ray characteristics to fully account for the soft X-ray emission (Pellegrini & Fabbiano 1994; Irwin & Sarazin 1998b). However, recent work has suggested that LMXBs are a viable candidate for the soft X-ray emission (Irwin & Sarazin 1998a, 1998b). If the soft emission in ellipticals is interstellar, it should not be present in globular clusters. Alternatively, since globulars contain an old stellar population that is similar to that in ellipticals (albeit with lower metallicity), one might expect that globulars would contain any stellar X-ray–emitting component found in ellipticals, as long as the X-ray emission was not very strongly dependent on metallicity (however, see Irwin & Bregman 1998).

For a globular cluster with an optical luminosity of the order of 10^5 $L_\odot$, the expected soft X-ray luminosity would be $\approx 10^{34.6}$ ergs s^{-1}. High spatial resolution X-ray observations of globulars can be used to separate brighter X-ray sources from any diffuse background. We will use the present observations to detect or limit the total diffuse soft emission from NGC 288. Such observations are particularly important to test stellar models for soft X-ray emission from ellipticals in which a large number of individually faint stars (e.g., M dwarfs) would produce the observed X-rays. For the purpose of studying the soft X-ray component from ellipticals, the best globulars are those with low stellar densities (to avoid the effects of interactions of the stellar population) and low absorbing columns.

Here we report on new X-ray observations of the globular cluster NGC 288. There have been no previous *Einstein* or pointed *ROSAT* observations of this cluster. The *ROSAT* All-Sky Survey only had an exposure of 341 s at this location and only gave a weak upper limit on the total X-ray flux of less than 1.3×10^{-13} ergs cm^{-2} s^{-1} (0.5–2.5 keV; Verbunt et al. 1995). We have a series of deep *HST* observations of NGC 288, including UV images, which will be presented in a future paper. In many ways, NGC 288 is an ideal cluster for the identification of soft X-ray sources and the comparison to optical/UV candidates. First, it is a fairly open globular cluster, with a core radius of $r_c = 85''$ and a half-light radius of $r_{1/2} = 135''$ (Trager, Djorgovski, & King 1993). This makes it easier to identify X-ray sources. It is also less likely that binary sources have been affected by core collapse and more likely that any sources are due to the original binary population. Although initially it was expected that LLGCXs would be associated with clusters with large stellar interaction rates, the trend in that direction is not particularly strong (Johnston & Verbunt 1996). Finding LLGCXs in NGC 288 could be especially pertinent to understanding the soft X-ray emission from elliptical galaxies. Second, NGC 288 is near the South Galactic Pole ($b = -89.^\circ3$), which reduces the effects of interstellar absorption on the spectrum and diminishes the chances of superposed Galactic X-ray sources. The reddening of the cluster is fairly low ($E_{B-V} = 0.03$; Peterson 1993), which corresponds to an absorbing column to the cluster of about $N_H = 1.6 \times 10^{20}$ cm^{-2}, using the relation $N_H = 5.3 \times 10^{21} E(B-V)$ (Predehl & Schmitt 1995). At a distance of $d = 8.4$ kpc toward the South Galactic Pole (Peterson 1993), the cluster is likely to lie behind essentially all of the Galactic gas. The total Galactic H I column in this direction is $N_H = (1.5 \pm 0.1) \times 10^{20}$ cm^{-2} (Stark et al. 1992), which is consistent with the reddening of the cluster. The mass and optical luminosity of the cluster are $M = 8 \times 10^4$ $M_\odot$ and $L_V = 4.0 \times 10^4$ $L_\odot$, respectively.

In § 2, we discuss the X-ray observations. The resulting X-ray sources are listed in § 3. We derive a limit on the diffuse X-ray flux from NGC 288 in § 4. Finally, our conclusions are summarized in § 5.

2. X-RAY OBSERVATION

The globular cluster NGC 288 was observed with the *ROSAT* High Resolution Imager (HRI) during the period 1998 January 6–7. The total exposure time was 19,891 s, which is reduced to 19,692 s after correction for dead time. In addition to the normal processing of the data, we examined the light curve of a large source-free region to check for any periods of enhanced background, and none were found. Because we are interested in accurate positions for any X-ray sources located within the globular cluster, we also examined the aspect history for any anomalies during the accepted time in the image. None were found. These data were taken during a period when the standard data pipeline processing included an error in the bore sight, but the data presented here were reprocessed after this error was corrected.

The X-ray image was corrected for particle background, exposure, and vignetting using the SXRB software package of Snowden (1995). For the purposes of display, the image was adaptively smoothed to a minimum signal-to-noise ratio (S/N) of 5 per smoothing beam (Huang & Sarazin 1996). Each smoothing beam was also required to have a larger FWHM than the *ROSAT* HRI point-spread function (PSF). A contour plot of the inner approximately 25′ × 25′ region of the X-ray image is shown in Figure 1. Several point sources are obvious (§ 3), but there is no evidence for any extended diffuse emission (§ 4). The center of the globular cluster NGC 288 is located very near to the position of source 1 in this image.

3. X-RAY SOURCES

Maximum likelihood and local detection algorithms were used to detect point sources in the HRI image. A final detection criterion of 3 σ was adopted. Table 1 list the 10 sources that were detected. The sources are also labeled on Figure 1. For each source, the table gives its position, its count rate and the 1 σ error, its final S/N, its projected distance D from the center of the globular cluster, and a comment on the identification. The source count rates were corrected for the instrument PSF, for background, and for vignetting. The positions in Table 1 are at the epoch J2000. The statistical errors in the positions are generally less than 3″; there may be a similar systematic error in the *ROSAT* HRI absolute positions. None of the sources were clearly extended; however, for sources far from the center of the field where the instrumental PSF is very broad, the upper limits on their size are large. Source 4 appeared possibly to be extended but was also near the detection limit. Sources 8, 9, and 10 are identified with the quasars QSO 0050.5−2641, QSO 0049−2653, and QSO 0051−267, respectively. The X-ray positions agree with the optical positions of these quasars to better than 4″. Source 7 may be associated with the blue stellar object PHL 3043, which is also likely to be quasar or other distant AGN. We tried to use the positions of the known quasars to improve the absolute positions of all of the sources, including the central X-ray source located near the cluster center. We determined more accurate optical positions for the quasars from the Digital Sky Survey (DSS) image. However, the differences between the optical and X-ray positions of these three quasars do not show any simple systematic pattern and are consistent with the expected random measurement errors. Thus they do not allow us to improve the positions of the other sources.

In Table 1 the sources are ordered by increasing distance D from the center of NGC 288. We assume that the center is located at R.A. $= 00^{\rm h}52^{\rm m}45\overset{\rm s}{.}3$ and decl. $= -26°34'43''$ (J2000; Webbink 1985). Note that this position differs considerably from the more recent determination by Shawl & White (1986). Comparison to the DSS image of the cluster shows that the Shawl & White position does not agree with the apparent center of the cluster, at least within the cluster core, while the Webbink position agrees reasonably well with the DSS image.

The count rate limit corresponding to our detection threshold is about 1.2×10^{-3} counts s^{-1} near the center of the image; vignetting and broadening of the PSF at large distances from the center of the field increase the detection threshold there. We have estimated the number of serendipitous X-ray sources expected in this HRI observation using the deep source counts in Hasinger et al. (1998). For comparison, the count rate was converted into an unabsorbed physical flux using the same assumptions as in Hasinger et al. (1998) but assuming an absorbing column of $N_{\rm H} = 1.6 \times 10^{20}$ cm^{-2}. Based on the source counts in Hasinger et al., we would expect about 8 ± 4 serendipitous sources in our observations. This is obviously consistent with the observed number of 10 sources; there is no overall excess in the number of X-ray sources in this field.

Figure 2 shows the optical image of NGC 288 from the DSS. The small crosses near the center and at the lower right-hand side of the image show the positions of source 1 (RX J005245.0−263449) and source 2. When examined at higher resolution, we find that the DSS image does not show any very bright star that is within 5″ of the position of either source 1 or 2.

With the exception of source 1, the sources appear randomly distributed throughout the HRI image and are not concentrated to NGC 288. On the other hand, source 1 (RX J005245.0−263449) is located very close to the center of the globular cluster. It is unlikely that an unrelated foreground or background source would be accidentally projected this close to the center of the cluster. Including the slight decrease in the detector sensitivity to sources at large radii from the center of the cluster, the probability that such a close association would occur at random is less than 0.2%. If we increase the projected distance of RX J005245.0−263449 from the cluster center by the maximum amount permitted by the errors in the X-ray and cluster center positions, the probability of a source being this close to the center by accident is still less than 1%. Thus we believe that RX J005245.0−263449 is associated with the globular cluster NGC 288.

On the other hand, the other sources (including source 2) are located at projected distances from the cluster center at which serendipitous sources would be likely. All of these sources are at projected radii of at least two half-light radii

TABLE 1

X-RAY SOURCES

Source	R.A.	Decl.	Count Rate (counts ks^{-1})	S/N	D (arcmin)	Identification
1	00 52 45.0	−26 34 49	1.59 ± 0.40	4.0	0.12	RX J005245.0−263449 in NGC 288
2	00 52 28.6	−26 37 18	1.57 ± 0.41	3.8	4.52	
3	00 53 10.4	−26 34 36	1.20 ± 0.40	3.0	5.64	
4	00 52 41.0	−26 28 24	1.37 ± 0.46	3.0	6.39	
5	00 53 18.1	−26 37 11	1.40 ± 0.40	3.5	7.76	
6	00 53 15.3	−26 29 38	1.83 ± 0.53	3.5	8.44	
7	00 52 08.4	−26 39 19	3.38 ± 0.61	5.6	9.42	PHL 3043 ?
8	00 52 59.7	−26 25 10	4.85 ± 0.74	6.6	10.09	QSO 0050.5−2641
9	00 51 58.8	−26 37 26	2.37 ± 0.63	3.8	10.72	QSO 0049−2653
10......	00 53 36.4	−26 31 15	2.30 ± 0.66	3.5	11.97	QSO 0051−267

NOTE.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

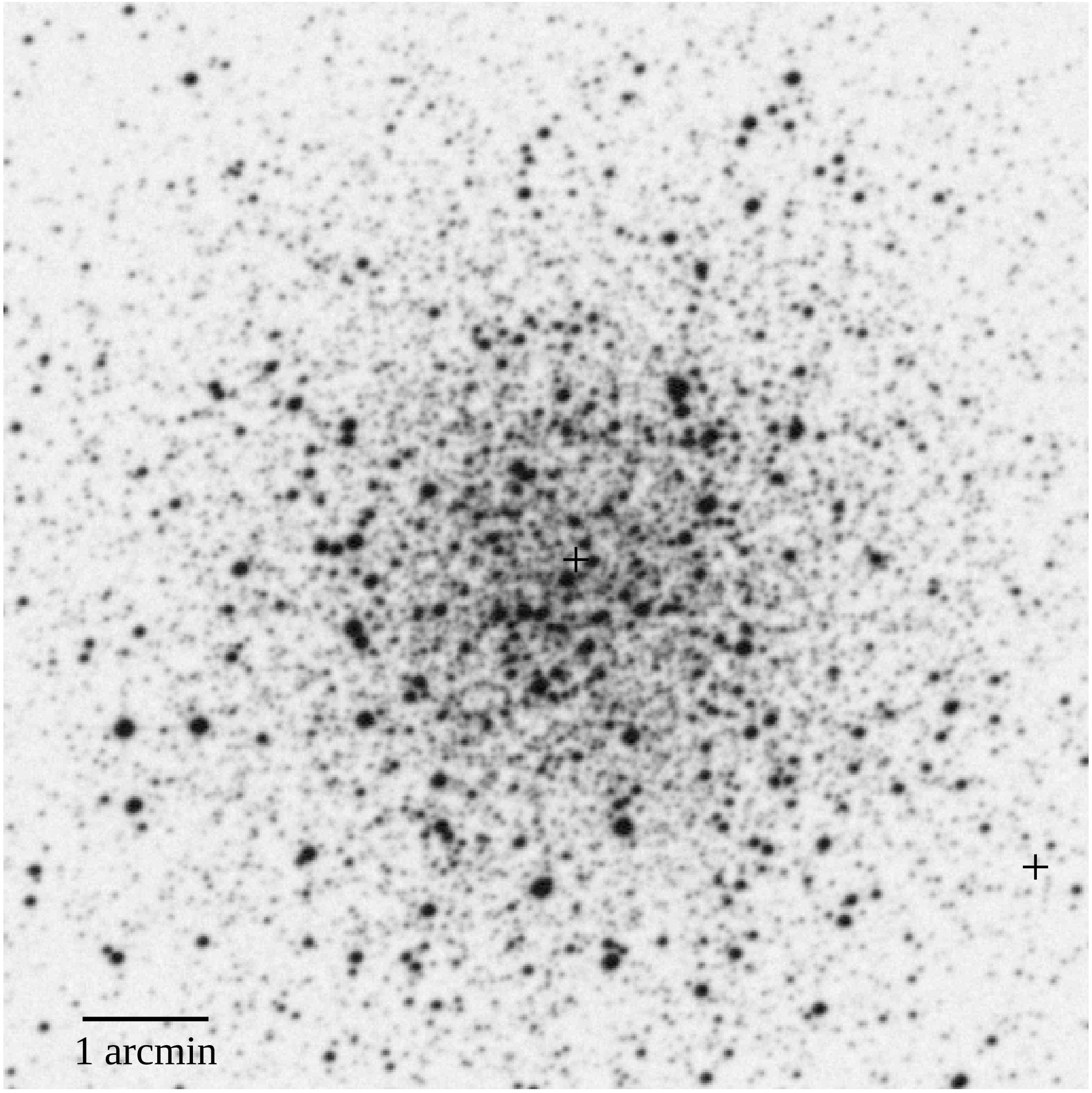

FIG. 2.—DSS image of an approximately 9′ × 9′ field around the center of NGC 288. The cross near the center of the cluster gives the position of source 1, which is RX J005245.0−263449. The cross at the lower right is the position of source 2. The crosses are about twice the size of the error bars in the positions of the sources.

($r_{1/2} = 135''$) where the density of cluster stars is low. Thus, although it is possible that source 2 (or some of the others) might be associated with NGC 288, it seems much more likely that they are only serendipitous foreground or background sources.

If we model the spectrum of RX J005245.0−263449 as 1 keV thermal bremsstrahlung with an absorbing column of $N_{\rm H} = 1.6 \times 10^{20}$ cm^{-2}, the count rate of $(1.59 \pm 0.40) \times 10^{-3}$ s^{-1} corresponds to an unabsorbed flux of $(6.5 \pm 1.6) \times 10^{-14}$ ergs cm^{-2} s^{-1} (0.1–2.0 keV). The flux is only weakly dependent on the form of the spectrum assumed. This implies a luminosity of $L_{\rm X} = (5.5 \pm 1.4) \times 10^{32}$ ergs s^{-1} (0.1–2.0 keV), which places RX J005245.0−263449 among the LLGCXs.

RX J005245.0−263449 appears to be a variable X-ray source. Figure 3 shows a histogram of the cumulative fraction of the counts from the 20″ radius circle centered on the source as a function of the cumulative exposure time. The dashed line shows the expected linear increase with exposure time, assuming the source and background are constant. The assumption that the source and background are constant can be rejected at a confidence level of greater than 95% for either the Kolmogorov-Smirnov or Cramer–von Mises test. Figure 3 shows that most of the photons arrived during the end of the cumulative exposure time. Because the

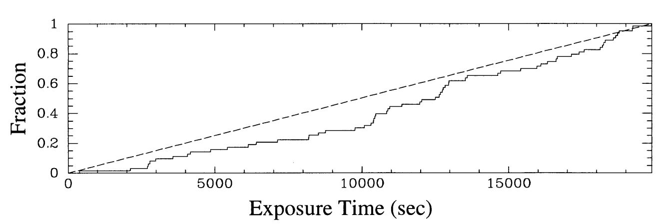

FIG. 3.—Arrival times of the photons from the X-ray source RX J005245.0−263449 near the center of NGC 288. The abscissa gives the cumulative exposure time, while the ordinate gives the cumulative fraction of the photons from the source and background that have arrived by that time. The solid histogram gives the data, while the straight dashed line is the prediction if the source and background are constant.

exposure time of 19,891 s was broken into five observing intervals spread over about 1.2×10^5 s, this indicates that the source in probably variable on a timescale of $\lesssim 1$ day. Unfortunately, the number of source counts is too low to allow any more detailed analysis of the source variability.

4. LIMIT ON DIFFUSE X-RAY EMISSION

We also used the *ROSAT* HRI observations to place a limit on any diffuse X-ray emission from the globular cluster. We determined the emission from within the projected area of the half-light radius of the cluster, which is $r_{1/2} = 135''$. Any point sources were removed from within the regions used for determining the cluster emission and the background. The background was determined in two ways. First the Snowden (1995) SXRB routines were used to determine the particle background and the exposure map of the HRI image. The particle background was removed from the image, and the image was flat-fielded by dividing by the exposure map. The X-ray background was determined from an annulus from $8'$ to $15'$. Second, the background was determined from the background image provided with the standard data products, using the same region as was used to collect the counts from the cluster. These two methods gave consistent results, but the second technique gave a more conservative (larger) upper limit on the X-ray flux, which is the one we adapt.

No diffuse emission was detected from the cluster; the net count rate was actually very slightly negative (although consistent with zero). The 90% confidence upper limit on the count rate from within the half-light radius was $\leq 4.5 \times 10^{-3}$ counts s^{-1}. As discussed above, we adapt a hydrogen column to the cluster of $N_H = 1.6 \times 10^{20}$ cm^{-2}. In order to permit a more detailed comparison to the soft X-ray emission of X-ray faint elliptical galaxies and to that expected from M stars (which also have a very soft spectrum), the diffuse emission is modeled as a 0.2 keV thermal spectrum with solar abundance. The upper limit on the count rate corresponds to an unabsorbed flux limit of $F_X^h < 1.13 \times 10^{-13}$ ergs cm^{-2} s^{-1} in the 0.52–2.02 keV *ROSAT* hard band and $F_X^s < 1.10 \times 10^{-13}$ ergs cm^{-2} s^{-1} in the 0.11–0.41 keV *ROSAT* soft band. The hard band flux limit is nearly independent of the spectrum assumed, but the soft band limit is affected by the spectral model. At an assumed distance of $d = 8.4$ kpc, these flux limits correspond to luminosity limits of $L_X^h < 9.5 \times 10^{32}$ ergs s^{-1} (*ROSAT* hard band 0.52–2.02 keV) and $L_X^s < 9.3 \times 10^{32}$ ergs s^{-1} (*ROSAT* soft band 0.11–0.41 keV). If the luminosity of RX J005245.0−263449 is added to these numbers to give a limit on the total X-ray luminosity of the cluster (either diffuse or resolved), the luminosity limits are increased by 35%. The total *B*-band optical luminosity of the cluster is $L_B = 3.91 \times 10^4$ $L_\odot$ (Peterson 1993), and the luminosity from within the projected half-light radius is obviously one-half of this value. This leads to upper limits on the diffuse X-ray–to–optical luminosity ratio of the cluster of $L_X^h/L_B < 4.9 \times 10^{28}$ ergs s^{-1} $L_\odot^{-1}$ and $L_X^s/L_B < 4.8 \times 10^{28}$ ergs s^{-1} $L_\odot^{-1}$.

5. CONCLUSIONS

We have obtained the first deep X-ray image of the open globular cluster NGC 288, which is located near the South Galactic Pole. We detect an LLGCX source RX J005245.0−263449, which is located within $\sim 10''$ of the cluster center. The X-ray luminosity is $L_X = (5.5 \pm 1.4) \times 10^{32}$ ergs s^{-1} (0.1–2.0 keV). There is evidence that RX J005245.0−263449 is variable and that the X-ray flux increased during the ~ 1 day period of the observation. The fact that this LLGCX is present in such an open globular cluster adds evidence to the argument that dense stellar systems with high interaction rates are not needed to form LLGCXs (Johnston & Verbunt 1996). On the other hand, the fact that RX J005245.0−263449 is located so close to the cluster center (its projected distance from the center is less than one-tenth of the core radius) is consistent with its being a binary system more massive than the typical cluster star.

A series of deep *HST* images of NGC 288 have been obtained (observation 6804) and are now being analyzed; these include UV images. It may be possible to identify RX J005245.0−263449 on these images. It should also be possible to test the hypothesis that LLGCXs are associated with stars with extremely blue UV colors (Ferraro et al. 1998a). Obviously, one would expect RX J005245.0−263449 to be identified with such a UV-bright star. Also, one would not expect to find a large number of other UV bright sources in the *HST* image, since RX J005245.0−263449 is the only X-ray source detected in the central region of the cluster. On the other hand, LLGCXs are highly variable, so the detection of a single UV star without an X-ray counterpart would not prove that LLGCXs are not associated with UV stars. For example, RX J005245.0−263449 seems to be variable and might not have been detected if it had been faint throughout our observation.

We also searched for diffuse X-ray emission from NGC 288. Upper limits (90%) on the X-ray luminosities of $L_X^h < 9.5 \times 10^{32}$ ergs s^{-1} for the *ROSAT* hard band (0.52–2.02 keV) and $L_X^s < 9.3 \times 10^{32}$ ergs s^{-1} for the *ROSAT* soft band (0.11–0.41 keV) are obtained within the optical half-light radius of the cluster, $r_{1/2} = 135''$. These imply upper limits to the diffuse X-ray–to–optical light ratios of $L_X^h/L_B < 4.9 \times 10^{28}$ ergs s^{-1} $L_\odot^{-1}$ and $L_X^s/L_B < 4.8 \times 10^{28}$ ergs s^{-1} $L_\odot^{-1}$. These upper limits are lower than the values observed for most X-ray faint early-type galaxies (Irwin & Sarazin 1998a, 1998b). This indicates that the soft X-ray emission in X-ray faint elliptical galaxies is due to a component that is not present in globular clusters (e.g., interstellar gas or a stellar component that is not found in low-metallicity Population II systems) or that the soft emission comes from a relatively small number of bright X-ray sources (e.g., LMXBs; Irwin & Sarazin 1998a). If the emission were due to a small number of bright X-ray sources, then the expected number in a typical globular would be less than unity.

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REFERENCES

Cool, A. M., Grindlay, J. E., Cohn, H. N., Lugger, P. J., & Slavin, S. D. 1995, ApJ, 439, 695
Cool, A. M., Grindlay, J. E., Krockenberger, M., & Bailyn, C. D. 1993, ApJ, 410, L103
Di Stefano, R., & Rappaport, S. 1994, ApJ, 423, 274
Fabbiano, G., Kim, D.-W., & Trinchieri, G. 1994, ApJ, 429, 94
Ferraro, F. R., Paltrinieri, B., Fusi Pecci, F., Dorman, B., & Rood, R. T. 1998a, MNRAS, 292, L45
Ferraro, F. R., Paltrinieri, B., Fusi Pecci, F., Rood, R. T., & Dorman, B. 1998b, in Ultraviolet Astrophysics—Beyond the *IUE* Final Archive, ed. R. González-Riestra, W. Wamsteker, & R. A. Harris (Noordwijk: ESA), 561
Fox, D., Lewin, W., Margon, B., van Paradijs, J., & Verbunt F. 1996, MNRAS, 282, 1027
Hasinger, G., Burg, R., Giacconi, R., Schmidt, M., Trümper, J., & Zamorani, G. 1998, A&A, 329, 495
Hertz, P., & Grindlay, J. E. 1983, ApJ, 267, L83
Hertz, P., Grindlay, J. E., & Bailyn, C. D. 1993, ApJ, 410, L87
Huang, Z., & Sarazin, C. L. 1996, ApJ, 461, 622
Irwin, J., & Bregman, J. N. 1998, ApJ, 510, L21
Irwin, J. A., & Sarazin, C. L. 1998a, ApJ, 494, L33
———. 1998b, ApJ, 499, 650
Johnston, H. M., & Verbunt, F. 1996, A&A, 312, 80
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
Paresce, F., De Marchi, G., & Ferraro, F. R. 1992, Nature, 360, 46
Pellegrini, S., & Fabbiano, G. 1994, ApJ, 429, 105
Peterson, C. J. 1993, in Structure and Dynamics of Globular Clusters, ed. S. G. Djorgovski & G. Meylan (San Francisco: ASP), 377
Predehl, P., & Schmitt, J. H. M. M. 1995, A&A, 293, 889
Shara, M. M., & Drissen, L. 1995, ApJ, 448, 203
Shawl, S. J., & White, R. E. 1986, AJ, 91, 312
Snowden, S. L. 1995, Cookbook for Analysis Procedures for *ROSAT* XRT/PSPC Observations of Extended Objects and the Diffuse Background (Greenbelt: GSFC)
Stark, A. A., Gammie, C. F., Wilson, R. W., Bally, J., Linke, R. A., Heiles, C., & Hurwitz, M. 1992, ApJS, 79, 77
Trager, S. C., Djorgovski, S., & King I. R. 1993, in Structure and Dynamics of Globular Clusters, ed. S. G. Djorgovski & G. Meylan (San Francisco: ASP), 347
Verbunt, F. 1996, in Dynamical Evolution of Star Clusters: Confrontation of Theory and Observations, ed. P. Hut & J. Makino (Dordrecht: Kluwer), 183
Verbunt, F., Bunk, W., Hasinger, G., & Johnston, H. M. 1995, A&A, 300, 732
Webbink, R. F. 1985, in Dynamics of Star Clusters, ed. J. Goodman & P. Hut (Dordrecht: Reidel), 541