On the Nature of the X-ray Emission from M32

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We have obtained the first broad-band X-ray spectra of the nearby compact elliptical galaxy M32 by using the ASCA satellite. The extracted spectra and X-ray luminosity are consistent with the properties of the hard spectral component measured in giant elliptical galaxies believed to originate from X-ray binaries. Two ASCA observations were performed two weeks apart; a 25% flux decrease and spectral softening occurred in the interval. We have also analyzed archival ROSAT HRI data, and discovered that the X-ray emission is dominated by a single unresolved source offset from the nucleus of M32. We argue that this offset, combined with the extremely rapid large magnitude variations, and hard X-ray spectrum combine to weakly favor a (single) X-ray binary over an AGN origin for the X-rays from M32. The nuclear black hole in M32 must be fuel-starved and/or accreting from a radiatively inefficient advection-dominated disk: the product of the accretion rate and the radiative efficiency must be less than $\sim 10^{-10} \, M_\odot \, \text{yr}^{-1}$ if the X-ray source is indeed an X-ray binary.

Subject headings: galaxies: elliptical – galaxies: individual: M32 – X-rays: galaxies
1. Introduction

At a distance of 700 kpc (Tonry, Ajhar, & Luppino 1990), M32 (NGC 221) is by far the nearest elliptical galaxy to the Milky Way. Although extremely compact, with a half-light radius of \( \sim 110 \) pc and correspondingly low velocity dispersion \( (\sigma \sim 80 \text{ km s}^{-1}) \) and optical luminosity \( (M_B = -15.7) \), M32 is structurally “normal” (Kormendy 1995) and lies on the fundamental plane (Bender et al. 1992). For these reasons it has played a foundational role in studies of stellar populations and kinematics in elliptical galaxies. In particular, M32 represents the earliest, and one of the strongest, dynamical cases for the presence of a massive \( (\sim 3 \times 10^6 M_\odot) \) black hole in a non-active elliptical galaxy (Bender et al. 1996, van der Marel et al. 1997, and references therein). M32 is also a source of X-rays. More than five magnitudes less optically luminous than any other elliptical galaxy detected in X-rays, the proximity of M32 presents a unique opportunity to push the investigation of the nature of X-rays from elliptical galaxies to intrinsically very faint systems and gain new insight into the “hard component.”

It is now well-established (e.g., Fabbiano 1989) that the X-ray emission from the brightest ellipticals is dominated by hot gas that originated as stellar mass loss and subsequently settled into hydrostatic equilibrium in the galactic potential. However, there is a theoretical expectation (e.g., Ciotti et al. 1991) that less luminous galaxies have shallower gravitational potentials, so that below some transitional luminosity the gas becomes unbound and flows out in an unobservable galactic wind, thus revealing the presence of the integrated emission from X-ray binaries. And indeed, the hard X-ray flux from the ensemble of binaries – circumstantial evidence of which was discovered from Einstein Observatory observations (Canizares, Fabbiano, & Trinchieri 1987, Kim, Fabbiano, & Trinchieri 1992) – has been directly detected, first by BBXRT (Serlemitsos et al. 1993), and then more universally by ASCA (Awaki et al. 1994, Matsushita et al. 1994, Matsumoto et al. 1994).
While, as expected, the fraction of the X-ray flux contained within the hard component increases as the X-ray-to-optical flux ratio decreases, the soft component proves to be surprisingly persistent and generally dominates the spectrum at energies less than 2 keV where ASCA and ROSAT are most sensitive. In the 0.5-4.5 keV band, the luminosity of the hard component $L_{x,\text{hard}} \sim 4.1 \times 10^{29} (L_B/L_{B,\odot})$ erg s$^{-1}$, corresponding to a flux less than $5 \times 10^{-13}$ erg cm$^{-2}$ s$^{-1}$ or only $\sim 70$ total (for four detectors, see next section) ASCA source counts ks$^{-1}$ for a $10^{11} L_{B,\odot}$ galaxy at the distance of the Virgo Cluster (Matsumoto et al. 1997). Thus, the combination of the large distance of even the closest giant ellipticals, the intrinsic weakness of the hard component, and the obscuring effect of the ubiquitous hot gas component severely limits what constraints can be placed on the nature of the hard emission. Fits of thermal models to ASCA spectra yield lower limits on the temperature of $\sim 2$ keV for individual galaxy spectra and $\sim 6.5$ keV for a composite spectrum; however, the data is equally well fit by a power-law with photon index $1.8 \pm 0.4$ (Matsumoto et al. 1997). It is not clear whether and, if so, to what extent an active nucleus (AGN) is contributing to the hard emission in some or all elliptical galaxies, as might be expected if they host “dead” quasars with some relic activity (Fabian & Rees 1995). Because of the shallowness of its potential well, any gas bound to M32 will have $kT < 0.1$ keV and an unimpeded view of the hard component is afforded. Despite this, previous X-ray studies have failed to resolve the binaries/AGN ambiguity in the origin of X-rays from M32, with the latest attempt being a detailed analysis of ROSAT PSPC observations by Eskridge, White, & Davis 1996 (hereafter EWD96).

In this paper we present the results of analyses of two recent ASCA observations of M32, as well as of archival ROSAT HRI data. Compared to the PSPC, ASCA has superior spectral energy resolution and sensitivity at energies greater than 2 keV, enabling us to derive more accurate constraints and address the issue of spectral variability. The excellent spatial resolution of the HRI provides a considerable improvement in determination of the
position and extent of the M32 X-ray emission. We have also examined archival *Einstein Observatory* and *EXOSAT* data, and additional insight is sought from inspecting the long term X-ray variability of M32. Although the evidence remains inconclusive, we argue that the X-ray emission is likely dominated by a single super-Eddington X-ray binary. If this is the case, the very low upper limit on the luminosity associated with accretion by the central black hole implies the presence of an advection-dominated disk and/or fuel-starved AGN with an extremely low value of the product of the accretion rate and radiative efficiency.

2. *ASCA* Observations and Data Analysis Procedures

As described in more detail in Tanaka, Inoue, & Holt 1994, *ASCA* has four identical, co-aligned X-ray telescopes and four focal plane detectors: two gas imaging spectrometers (‘GIS2’ and ‘GIS3’), and two solid state imaging spectrometers (‘SIS0’ and ‘SIS1’). Each SIS consists of four CCD chips. M32 was observed as part of the fourth round of the *ASCA* Guest Observer phase on 1996 July 25 (‘observation A’) and on 1996 August 4 (‘observation B’), with the SIS in single-CCD mode, and the GIS in PH mode. The GIS3 image from observation A is shown in Figure 1, with the optical position of M32 denoted by the ‘+’ symbol. No other bright sources in the field-of-view were anticipated based on previous observations (see EWD96); however, surprisingly, two nearby sources – each roughly twice as bright as M32 – are apparent. These objects evidently are highly absorbed and/or highly variable hard sources, and are of considerable interest in themselves. We defer discussion of their nature to a separate paper (Toneri et al., in preparation).

Standard data screening procedures were followed (see Day et al. 1996). Data taken at elevation angles less than 10 degrees or with cutoff rigidities below 6 GeV/c were excluded. For the SIS, low bit-rate data and data taken at an elevation angle with respect to the bright earth less than 20 degrees were also excluded. Data were further cleaned using the
usual rise-time discrimination for the GIS and hot/flickering pixel removal for the SIS.

Spectra were extracted from approximately circular regions in the plane of the sky mapped onto the detector plane in order to assure accurate spectral response determination — generated in the standard way for point sources (Day et al. 1996). Circles of radii $R \sim 3.0'$ and $R \sim 3.5'$ were chosen for SIS and GIS observations, respectively, with areas lying within $\sim 3.5'$ circular regions centered on the other two bright sources excluded. The proximity of the other point sources, and the chip boundaries for the SIS, precludes the use of larger extraction regions. For each observation, we find accordance in 0.7-8 keV flux between detector pairs at the $5 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$ level; joint spectral fits were not improved by allowing relative normalizations to vary separately. SIS (GIS) spectra were grouped to have a minimum of 20 (25) counts per spectral bin, so that the $\chi^2$ statistic could be used to determine best-fits and uncertainties.

For the SIS, there is insufficient proximate source-free area for background calculation, and so standard blank sky events lists obtained from the NASA/Goddard Space Flight Center calibration database were used. For the GIS, we used point-source-subtracted blank sky background spectra kindly generated by K. Ebisawa. Because these files do not take secular changes in the internal GIS background (Miyata 1997) into account, the background may be slightly underestimated in these files; however, since best-fit spectral models to GIS data are not flatter than the corresponding fits to SIS data this evidently is a small effect. Use of local source-free regions resulted in nearly identical spectral fits but with normalizations lower by $\sim 20\%$.

The resulting exposure times and count rates used for spectral analysis are shown in Table 1.
3. *ASCA* Spectral Analysis Results

As described above, we have extracted eight spectra that we will subsequently refer to as G2A, G3A, S0A, S1A, G2B, G3B, S0B, and S1B—shorthand for GIS2 detector spectrum from observation A (“G2A”), SIS1 detector spectrum from observation B (“S1B”), etc.

The four spectra were fit individually, and in various combinations, for each observation to two distinct one-parameter spectral models: a power-law continuum with photon index $\Gamma$ as a model of AGN, and a thermal bremsstrahlung continuum with temperature $kT$ as a model of single or ensembles of X-ray binaries. To optimize the statistical accuracy of the results, simultaneous fits to all four detectors were carried out for each observation. In all cases, the best-fit parameters for individual detectors are consistent, at better than 90% confidence, with the simultaneous fits.

### 3.1. Best-fit Parameters

Spectrum S0A is shown in Figure 2, along with the best power-law fit for observation A. There are $\sim 960$ (background-subtracted) counts in this spectrum. In total, there are $\sim 3200$ ($\sim 2300$) spectral counts for observation A (B); therefore, the effective signal to-noise ratio is 1.8 (1.5) times that of the spectrum in Figure 2. Normalizations are tied together for the GIS and SIS detector pairs for each observation (see above). The best-fit parameters and 90% confidence limits are displayed in Table 2 for thermal and nonthermal fits to each observation. Fits were performed with the column density fixed at the Galactic value ($6.3\times10^{20}$ atoms cm$^{-2}$), as well as with a freely varying absorption column density. In the latter case, the best-fit columns are consistent with the assumption of zero internal absorption and the best-fit parameters only marginally change, although the uncertainties increase slightly. The temperatures of the thermal model fits – $\sim 9.5$-30 keV for observation
A, \sim 5.6-13 \text{ keV} for observation B – and the photon indices of the nonthermal model fits – \sim 1.4-1.6 for observation A, \sim 1.6-1.9 for observation B – are consistent with the constraints on the composite spectrum of the hard component in giant elliptical galaxies (Matsumoto et al. 1997). Unfortunately, because the M32 X-ray source was in a relatively low-flux state during the ASCA observations (see below), thermal bremsstrahlung and power-law models provide equally good fits and are not statistically distinguishable.

### 3.2. Variability Between ASCA Observations

Because of the broad wings of the ASCA point-response function (PRF), there is a small but significant contamination to the source counts at the position of M32 from the relatively bright point source \sim 5' away (see Figure 1). The effect is more pronounced for the GIS, since it produces additional blurring to that of the ASCA X-ray Telescope alone (half-power radius \sim 1.5'). Moreover, the level of this contamination varies slightly from detector to detector and between observations due to small differences in source positions on the image plane relative to the optical axis of the telescope. Therefore, care must be taken in deriving the true M32 source flux, and we have used the following procedure to estimate 0.7-7 \text{ keV} fluxes (averaged over the four detectors for each observation). First, counting rates and spectra are extracted from a 3.5' radius circular region (in the detector plane) centered on M32, and are used to derive a photon flux that consists of contributions from both M32 and the nearest bright point source. Next, the contamination component is estimated by multiplying the photon flux of the second source by the ratio of effective areas (averaged over the 0.7-7 \text{ keV} band). These areas have been convolved with the PRF at the position of each source and then integrated over the M32 extraction region, and are computed in the same way as the effective area curves used for spectral analysis. The corrected flux is then the difference between the total flux and the contamination.
component (∼ 20% of the total for the GIS, ∼ 10% for the SIS). Our final estimated 0.7-7 keV fluxes for M32 are 1.35 $10^{-12}$ erg cm$^{-2}$ s$^{-1}$ for observation A, and 1.05 $10^{-12}$ erg cm$^{-2}$ s$^{-1}$ for observation B. The above procedure was utilized for all four detectors, and the deviation from the averages given above are less than 7 $10^{-14}$ erg cm$^{-2}$ s$^{-1}$ for all detectors. Comparison of the above fluxes with those corresponding to our extracted spectra show that there is some residual contamination in the latter. The effect of this is to artificially harden the M32 spectra, since the nearby source is slightly harder than M32 and the PRF is broader for higher energies. However, since the best fit models to the relatively uncontaminated SIS spectra are not softer than those to the GIS spectra, this effect evidently is relatively unimportant.

In addition to the 25% decrease in flux, there is marginal evidence for spectral softening between observations A and B. If the column density is assumed to be Galactic, the best-fit parameters differ at the 90% confidence level; although, there is marginal agreement if the columns are freely varied. We note that spectral variability is only significant with the relatively small errors in joint spectral fits to GIS and SIS data, and not in either GIS or SIS fits independently. If SIS spectra for both observations are fitted simultaneously $\chi^2$ decreases by ∼ 7-8 if $\Gamma$ or $kT$ are allowed to vary separately compared to when they are constrained to be identical. And, finally, there is a statistically significant (> 99%) difference in hardness ratios ($R$), defined as the 2-10 keV flux divided by the 0.5-2 keV flux $-R = 2.8 \pm 0.13$ for observation A and $R = 2.3 \pm 0.14$ for observation B (1σ errors).

Using ASCA spectra, we derive fairly tight constraints on the X-ray spectral parameters from a single observation. EWD96 found it necessary to combine several ROSAT PSPC observations in order to maximize the signal-to-noise ratio of their spectrum. Reexamination of the ROSAT PSPC spectra reveals some evidence for spectral variability in these data as well – the best fit power-law index (assuming the Galactic column density) is 1.47(±0.08)
for pointing “WP600068” (27 July 1991) and 1.27(±0.12) for pointing “WP600079” (14 July 1991), where the errors quoted are 90% confidence uncertainties. Thus, the best-fits in EWD96 should be considered as luminosity-weighted time-averages.

4. **ROSAT HRI Data Analysis**

M32 was observed with the *ROSAT* HRI for 12913 s spread out over the week of 1994 July 19-26. Approximately 160 source counts were detected (see below), which was sufficient to place significant constraints on the position and extent of X-ray emission from M32. Prior to spatial analysis, the data were flat-fielded and corrected for particle background using the suite of programs provided by the NASA/GSFC *ROSAT* Guest Observer Facility (Snowden 1995). A contour map of the M32 emission, superimposed on the optical image from the Digitized Palomar Observatory Sky Survey (DSS), is shown in Figure 3; the lowest contour corresponds to ∼ 10 times the mean background level.

The position of M32 was estimated using both the sliding-cell method in XIMAGE (Angelini et al. 1995) and maximum-likelihood method (“LDETECT”) in IRAF/PROS. The derived positions are consistent to better than 2″. However, the image is slightly asymmetrically elongated (see below) and the image centroids and peaks do not quite coincide. We adopt a position α = 00h42m42.5 ± 0.2s, δ = 40d51′52″ ± 2″. The best-estimate position is consistent with the *Einstein* HRI position (Crampton et al. 1984) and is shown as an ‘X’ in Figure 3. The X-ray position is ∼ 10″ offset from the optical position published in the RC3 catalog (de Vaucouleurs et al. 1991). The spatial coincidence of HRI and optical positions of a globular cluster in the halo of M31 supports the accuracy of this offset (see below).

Count rates are estimated using the XIMAGE “SOSTA” routine, and “SRCINTEN”
within IRAF/PROS on the raw image. Both of these programs account for effects due to background, vignetting, and the PRF. We also utilized the IRAF/PROS “IMCNTS” program on the cleaned image. These methods yield 12.8, 13.6, and 13.3 cts ks$^{-1}$, respectively with a statistical uncertainty of 1.2 cts ks$^{-1}$. The signal-to-background ratio is $\sim 8:1$. We adopt a count rate of $13 \pm 2$ cts ks$^{-1}$, or $160 \pm 25$ total source counts (because of vignetting the effective exposure time is not precisely equal to the actual duration of observation).

XIMAGE produces a marginal ($\sim 3\sigma$) detection of a second point source coincident with the optical position, and with a count rate of $1.0 \pm 0.36$ cts ks$^{-1}$. Moreover, the image is slightly elongated in the east-west direction (not the direction of the spacecraft wobble) and an azimuthally-averaged surface brightness profile shows excess counts between $10''$ and $20''$ above what is expected from the on-axis PRF. Figure 4 shows the results of subtracting a smoothed image corresponding to the re-normalized PRF from that shown in Figure 3. There is excess emission, significant at the $4\sigma$ level, to the west of the overall emission peak. Examination of the other point sources in the field using the same analysis method does not show any excess like that seen in M32. The peak of the M32 excess emission is nearly coincident with the optical position, shown as a ‘+’ symbol in Figure 4. Although, these deviations from a point source centered on the optical position are on the order of the HRI systematic aspect errors (Morse et al. 1995), they may indicate that there is only a very weak source at the nucleus of M32, with the bulk of the emission originating from one very luminous X-ray binary near, but not at, the galactic center. The globular cluster “G144” (source 15 in Crampton et al. 1984) detected by the Einstein HRI is also detected by the ROSAT HRI within 1'' of the optical position, lending confidence in the accuracy of our derived X-ray position. (This position is also marked in the GIS image – Figure 1.) Since the X-ray emission is distributed differently than the stellar light (off-centered and more compact), there seems to be no significant contribution from a population of relatively faint
unresolved discrete sources.

5. Long and Short Term Variability

Figure 5 shows the 17-year 0.2-2 keV light curve, including *Einstein* IPC and HRI, *EXOSAT* CMA, *ROSAT* PSPC and HRI, and *ASCA* observations. The PSPC data points are from EWD96 and correspond to distinct observations of M31. The conversions to the 0.2-2 keV band are made using the *ASCA*-derived spectral constraints, and systematic uncertainties associated with the emission model are included in the error bars. At the distance of M32, $10^{-13} \text{ erg cm}^{-2} \text{ s}^{-1}$ corresponds to $5.86 \times 10^{36} \text{ erg s}^{-1}$. Since the 0.5-10 keV flux is $\sim 3$ times the 0.2-2 keV flux, the luminosity is at times well-above the Eddington luminosity for a $1 \, M_\odot$ neutron star, with a peak 0.5-10 keV luminosity of $\sim 6.7 \times 10^{38} \text{ erg s}^{-1}$. The flux varies over a full range of greater than 50, and can vary by factors of several on timescales of days or less (EWD96).

We have also examined the M32 0.7-7 keV *ASCA* light curves, binned into 1024 s intervals, to search for variability on still shorter timescales. For all four detectors and for both observations, the variations in total (source-plus-background) count rate are roughly consistent with statistical fluctuations from a constant-flux source ($\chi^2$ per degree-of-freedom = $38/28$ and $18/27$ for summed SIS and GIS 1024-bin lightcurves from observation A, and $30/25$ and $30/21$ from observation B). However, the (nearly constant) background level is significant and, when subtracted for each bin, source-only light curves remain that are not formally consistent with a constant flux: variances are twice what would statistically be expected. However, the variations are often not coherent from detector to detector, and the statistical significance of the variability is dependent on the details of how source and background counts are extracted. As inclusion of a modest systematic uncertainty would restore consistency with constancy, the evidence for short term variability currently is
marginal at best. Background-subtracted coadded GIS and SIS light curves are shown in Figure 6.

No trend of hardness ratio with count rate is detected; however, the errors on the hardness ratio are large for the low count rate intervals.

6. Discussion

While not definitively conclusive, the evidence points toward an X-ray binary rather than an AGN origin for the X-ray source in M32. The relatively short timescale and large magnitudes of the transient variations in flux (Figure 5) are more characteristic of X-ray binary than AGN behavior, and – most significantly – the X-ray emission region seems to be centered $\sim 30$ pc from the center of M32.

The X-ray source in M32 is unlikely to be a high mass X-ray Binary because of the old stellar population of M32. Among low mass X-ray Binaries (LMXBs), the X-ray temporal and spectral characteristics most resemble high luminosity non-transient neutron star LMXBs such as Sco X-1 or Cyg X-2 (Lewin et al. 1995). Another possibility is a binary containing a relatively massive ($> 5 \, M_\odot$) black hole, such as G2023+338.

The extrapolation of the linear relationship between blue luminosity and the integrated X-ray luminosity from binaries leads to a predicted 0.5-4.5 keV luminosity of $\sim 10^{38}$ erg s$^{-1}$ for M32 – comparable to the average observed luminosity. However, the hard component is expected to be spatially distributed as the optical light if it consists of many unresolved, faint, discrete sources. Such an extended component would easily be detected by the ROSAT HRI since it would produce $\sim 200$ counts inside the half-light radius of $\sim 40''$ – about nine times the background. Any unresolved component cannot be much more luminous than $10^{37}$ erg s$^{-1}$. That the X-ray emission from M32 is more centrally
concentrated than the light may simply be a consequence of the fact that, in elliptical galaxies, the integrated luminosity of discrete X-ray sources is dominated by the brightest ($\sim 10^{38}$ erg s$^{-1}$) binary systems. If this is the case, it would not be surprising if, at the low optical luminosity of M32, a single binary dominates the X-ray emission and that it is located near the galactic nucleus where the overall stellar density is highly concentrated. The X-ray variability shown in Figure 5 implies that a single source dominates the emission, and not a compact population of discrete sources. If the X-ray emission were instead associated with an active nucleus (of an unusual kind), the ratio of integrated X-ray binary luminosity to optical luminosity would be lower than what has been measured in other observed spheroidal systems (Matsumoto et al. 1997).

If the X-ray emission in M32 indeed originates in an X-ray binary, then the X-ray luminosity of any AGN is less than $5 \times 10^{36}$ erg s$^{-1} - \sim 10^{-8}$ of the Eddington luminosity of the central massive black hole. (A conservative upper limit from the highest point in the long-term light curve – see Figure 5 – is only a factor of $\sim 100$ greater.) This represents a uniquely low ratio of X-ray luminosity to black hole mass ($\sim 3 \times 10^6 M_\odot$; van der Marel et al. 1997), compared with other objects in the sample of Hayashida et al. 1998. This is consistent with the lack of AGN indicators at other wavelengths (EWD96), and implies that $\epsilon_x \dot{M} < 10^{-10}$ M$\odot$ yr$^{-1}$, where $\dot{M}$ is the accretion rate and $\epsilon_x$ the efficiency of converting fuel into X-rays. Evidently, the black hole is fuel-starved and/or has a highly radiatively inefficient accretion disk. The integrated mass loss from stars in M32 is $\sim 0.005$ M$\odot$ yr$^{-1}$. Since the central inflow rate would be of this order for a global cooling flow, this would seem to argue against a lack of sufficient available fuel for the central black hole. However, until there are direct observational limits on the central gas density in the relevant 50-100 eV temperature range, this possibility cannot be excluded.

Radiatively inefficient, advection-dominated accretion has been suggested as an
explanation for the relatively low X-ray luminosities in LINERs (e.g., NGC 4258, Lasota et al. 1996), and for the paucity of bright nuclear X-ray sources in elliptical galaxies that statistical arguments suggest should host $10^8$-$10^9 M_\odot$ black holes (Fabian & Rees 1995, Mahadevan 1997). The ratio of X-ray luminosity to black hole mass in M32 is greater than 1000 times lower than in NGC 4258 if, as we have argued, the AGN is not the primary X-ray source. The corresponding accretion rate for an advection dominated disk with the ‘standard’ structure parameters of Mahadevan 1997 is less than $2.5 \times 10^{-4} (\eta_x/0.1)^{-1/2}$ in Eddington units, where $\eta_x$ is the fraction of the disk luminosity emitted in the ROSAT band. Since this corresponds to $\dot{M} < 1.6 \times 10^{-5} (\eta_x/0.1)^{-1/2} M_\odot$ yr$^{-1}$, the M32 black hole cannot be fueled at the rate expected for a global cooling flow unless $\eta_x < 10^{-6}$. The low luminosity and accretion rate in M32 is more in line with the advection-dominated accretion disk model for the putative black hole in the center of our own galaxy (Narayan, Yi, & Mahadevan 1995) than with NGC 4258 or other LINERS.

7. Summary

We have attempted to illuminate the nature of the X-ray emission from the nearby compact elliptical galaxy M32 by analyzing two newly obtained ASCA observations, as well as archival ROSAT HRI data. The X-ray luminosity is consistent with the observed ratio between optical luminosity and integrated emission from X-ray binaries observed in giant elliptical galaxies; moreover, the best-fit emission models to ASCA spectra are consistent with the hard component detected in X-ray spectra of giant ellipticals (characterized by $\Gamma \sim 1.8$ power-law or $kT \sim 10$ keV bremsstrahlung models). Thermal and nonthermal models are not distinguishable through analysis of the ASCA spectra. The 0.7-7 keV luminosity decreases from $\sim 8$ to $\sim 6 \times 10^{37} \text{ erg s}^{-1}$, and the spectrum softens slightly in the two weeks between ASCA observations. The HRI image of M32 is dominated by unresolved
emission apparently centered $\sim 10''$ (30 pc) to the east of the optical position, although there is marginal evidence for excess emission at a position consistent with the optical nucleus. There is no evidence for diffuse, extended emission consisting of unresolved discrete sources. The X-ray/optical offset, combined with the relatively rapid large magnitude variations, and hard spectrum combine to weakly favor a single (Low Mass) X-ray binary over an AGN origin for the X-rays from M32. More precise identification of the source (i.e. as either a neutron star or black hole LMXB) requires higher quality spectral and temporal data. If the X-ray source is an X-ray binary, then the nuclear black hole in M32 must be fuel-starved and/or accreting from a radiatively inefficient advection-dominated disk with $\epsilon_x \dot{M} < 10^{-10} \, M_\odot \, \text{yr}^{-1}$, and the M32 nucleus has the lowest X-ray luminosity-to-mass ratio of any identified black hole.

We have made extensive use of the HEASARC data base, and SKYVIEW, XANADU (XSPEC, XRONOS, XIMAGE), FTOOLS, IRAF/PROS, and IDL software packages. ML wishes to thank L. Angelini, K. Ebisawa, K. Gendreau, U. Hwang, R. Mushotzky, A. Ptak, and T. Yaqoob for advice and assistance. This paper benefited from a constructive referee’s report.
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Table 1. ASCA Spectra of M32

| Observation | Detector | Good time (s) | Count Rate\(^a\) (cts ks\(^{-1}\)) |
|-------------|----------|---------------|-------------------------------------|
| A           | GIS2     | 28848         | 22.7                                |
| A           | GIS3     | 28850         | 26.7                                |
| A           | SIS0     | 28086         | 34.2                                |
| A           | SIS1     | 28116         | 29.0                                |
| B           | GIS2     | 28372         | 17.7                                |
| B           | GIS3     | 28368         | 23.3                                |
| B           | SIS0     | 22963         | 26.8                                |
| B           | SIS1     | 22791         | 23.3                                |

\(^a\)Spectra were extracted over the 0.7-8 (0.6-7.5) keV energy band for GIS (SIS) spectra; count rates are background subtracted.
Table 2. Best-fit Parameters and 90% Confidence Errors from Joint SIS+GIS Spectral Analysis

| obs. | $N_H^a$ | $\Gamma$ or $kT^b$ | $\chi^2/\nu^c$ |
|------|---------|---------------------|-----------------|
| A    | 6.3*    | $1.49^{+0.07}_{-0.06}$ | 154/154         |
| A    | 7.6^{+8.9}_{-7.5} | $1.51^{+0.15}_{-0.14}$ | 154/153         |
| B    | 6.3*    | $1.68^{+0.08}_{-0.08}$ | 124/122         |
| B    | $10^{+10}_{-8.7}$ | $1.74^{+0.20}_{-0.18}$ | 123/121         |
| A    | 6.3*    | $12.6^{+5.1}_{-2.8}$  | 153/154         |
| A    | $2.9^{+6.8}_{-2.9}$ | $15.4^{+14}_{-5.9}$  | 152/153         |
| B    | 6.3*    | $6.94^{+1.90}_{-1.29}$ | 128/122         |
| B    | $1.4^{+7.9}_{-1.4}$ | $8.23^{+5.57}_{-2.62}$ | 127/121         |

$^a$Column density in units of $10^{20}$ cm$^{-2}$; asterisk denotes column density fixed during spectral fitting.

$^b$Best-fit photon index for power-law model fits (initial four entries), or temperature for thermal bremsstrahlung model fits (final four entries); also shown are $\chi^2 + 2.7$ uncertainties for one-parameter fits, $\chi^2 + 4.6$ uncertainties for two-parameter fits.

$^c$Minimum value of $\chi^2$ per degree of freedom.
Fig. 1.— GIS3A image of M32 field, smoothed with a 30″ Gaussian. M32 is the faintest, southernmost of the three point sources. The cross denotes the optical position of M32, the star that of a globular cluster in the halo of M31. The contour levels are 1.1, 2.2, 3.3, 4.4, 5.5, and 6.6 counts pixel$^{-1}$ (1 pixel = 15″ × 15″) – the lowest contour is at about 2.5 times the average background level. 1 count pixel$^{-1}$ corresponds to ≈ 4.7 $10^{-14}$ erg cm$^{-2}$ s$^{-1}$ arcmin$^{-2}$ in the ASCA (0.5-10 keV) bandpass.

Fig. 2.— S0A spectrum (rebinned for presentation) with power-law model that provides the best simultaneous fit to G2A, G3A, S0A, and S1A spectra (histogram).

Fig. 3.— Linearly spaced ROSAT HRI contours (in white) superimposed on the DSS optical image of M32. The HRI image has been flat-fielded, background-subtracted, and smoothed with a 5″ Gaussian. The contour levels are at 1, 4, 7 and 10 counts pixel$^{-1}$ (1 pixel = 5″ × 5″); the average background level is ≈ 0.1 counts pixel$^{-1}$; and, 1 count pixel$^{-1}$ corresponds to ≈ 3.8 $10^{-13}$ erg cm$^{-2}$ s$^{-1}$ arcmin$^{-2}$ in the ROSAT (0.2-2 keV) bandpass. The ‘+’ denotes the optical and the ‘X’ the X-ray position of M32. Since the HRI contours deviate from point-like emission, the X-ray centroid and peak do not precisely coincide. The GIS3a contours from Figure 1 have been replotted (in black).

Fig. 4.— Same as Figure 3, but now with the smoothed image of the renormalized on-axis HRI PRF subtracted. The contour levels are now 1 and 2 counts pixel$^{-1}$. The significance of this feature is ≈ 4σ.

Fig. 5.— M32 Lightcurve – flux in the PSPC band (0.2-2 keV) vs. time – encompassing Einstein, EXOSAT, ROSAT and ASCA observations. The solid lines denote the fluxes corresponding to the $1M_\odot$ Eddington luminosity (“Ledd”) and one-third Ledd at the distance of M32 – the bolometric X-ray luminosity is at least three times the 0.2-2 keV value.

Fig. 6.— Background-subtracted, co-added ASCA GIS and SIS M32 lightcurves for
observations A and B.
