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S Immler

QD Wang
University of Massachusetts - Amherst

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ROSAT X-Ray Observations of the Spiral Galaxy M81

Stefan Immler & Q. Daniel Wang
Astronomy Department, University of Massachusetts, Amherst, MA 01003
immler@astro.umass.edu & wqd@astro.umass.edu

ABSTRACT

We present results from the analysis of deep *ROSAT* HRI and PSPC observations of the spiral galaxy M81. The inferred total (0.5–2 keV band) luminosity of M81 is $\sim 3 \times 10^{40}$ ergs s^{-1}, excluding the contribution from identified interlopers found within the D_{25} ellipse. The nucleus of the galaxy alone accounts for about 65% of this luminosity. The rest is due to 26 other X-ray sources (contributing $\sim 10\%$) and to apparently diffuse emission, which is seen across much of the galactic disk and is particularly bright in the bulge region around the nucleus. Spectral analysis further gives evidence for a soft component, which can be characterized by a two-temperature optically thin plasma with temperature at ~ 0.15 keV and 0.60 keV and an absorption of the Galactic foreground only. These components, accounting for $\sim 13\%$ of the X-ray emission from the region, apparently arise in a combination of hot gas and faint discrete sources. We find interesting spatial coincidences of luminous (10^{37}–10^{40} ergs s^{-1}) and variable X-ray sources with shock-heated optical nebulae. Three of them are previously classified as supernova remnant candidates. The other one is far off the main body of M81, but is apparently associated with a dense HI concentration produced most likely by the tidal interactions of the galaxy with its companions. These associations suggest that such optical nebulae may be powered by outflows from luminous X-ray binaries, which are comparable to, or more luminous than, Galactic 'micro-quasars'.

Subject headings: galaxies: general—galaxies: spiral—X-rays: general—X-rays: galaxies—X-rays: ISM

1. Introduction

'Normal' galaxies of all morphological types are known to be X-ray emitters, with luminosities in the soft (~ 0.2–3.5 keV) X-ray band ranging from 10^{38} to some 10^{41} ergs s^{-1} (Fabbiano 1989). Despite this band being a relatively small part of the electromagnetic spectrum and the X-ray output representing only a small fraction of the bolometric luminosity of a galaxy, X-ray observations are uniquely suited to studying various astrophysical phenomena elusive in other wavelength regimes. Whereas the overall emission of a galaxy is dominated by stars in the optical and reprocessed stellar emission in the infrared, X-ray emission is primarily related to the high-energy phenomena associated with end-products of stars: accreting compact objects, supernova remnants, and the shock-heated hot interstellar medium.

M81 (Table 1) is an ideal test-bed for our understanding of the X-ray emission components in early-type spirals since it is the nearest such galaxy outside of the Local Group. It is located in a direction with relatively low Galactic absorption ($N_{\rm H} = 4 \times 10^{20}$ cm^{-2}; Dickey & Lockman 1990), considerably lower than that along the line-of-sight to M31 (7×10^{20} cm^{-2}). Compared to the high disk inclination of M31 ($i = 77°$), the moderate inclination of M81 ($i = 32°$) makes its emission components less obscured internally and easier to disentangle spatially. M81 hosts a low-luminosity Seyfert nucleus with some characteristics of a low-ionization nuclear emission-line region (LINER). The nucleus itself has been studied intensively in many wavelength regimes (e.g., Ishisaki et al. 1996; Kaufman et al. 1996; Ho et al. 1999 and references therein). More recently, the outburst of SN 1993J in M81 led to a large number of addi-

tional observations, especially in the X-ray band (e.g. Zimmermann et al. 1994a).

Previous *Einstein* observations of M81 resulted in the detection of nine individual X-ray sources including the nucleus, with luminosities in excess of 2×10^{38} ergs s^{-1} in the 0.2–4.0 keV band (Fabbiano 1988). Only marginal evidence for variability was found for the nucleus and two other sources. About two-thirds of the non-nuclear emission was not resolved spatially.

Spectral and temporal properties of the M81 nucleus have been studied, based on both *ASCA* and *BeppoSAX* data (Ishisaki et al. 1996; Iyomoto & Makishima 2000; Pellegrini et al. 2000). The spectrum of the nuclear source is well described by a power-law with a photon index $\Gamma = 1.85$. In addition, a softer component with a temperature of 0.6–0.8 keV was also detected. Long-term X-ray variability of the M81 nucleus was found, with variations up to a factor of three over a period of 5.5 years, together with intra-day variability of 30% (Iyomoto & Makishima 2000). The spectral properties, together with the observed high variability, were regarded as being typical for a low-luminosity AGN. The nature of the softer component, however, could not be specified.

This paper reports on the results of deep X-ray observations of M81 obtained with the Position Sensitive Proportional Counter (PSPC) and the High Resolution Imager (HRI) onboard *ROSAT* (Trümper 1983). We focus mainly on the discrete X-ray source population inside the galaxy and the diffuse emission from the disk and the extended bulge of M81. After a description of the X-ray observations and the data calibration (§2), we explain the data analysis strategies for the detection of discrete X-ray sources, their variability and the diffuse emission (§3). X-ray properties of discrete sources are examined in detail in §4, followed by a discussion of the most interesting sources in a multi-wavelength context in §5. Results on the diffuse X-ray emission are presented in §6. In §7, we compare global X-ray properties of M81 and the late-type spiral M101, for which a similar study has been performed. The results and conclusions are summarized in §8.

2. Observations and Data Calibration

ROSAT X-ray observations of M81 were used to construct a single 177 ks HRI image from 72 observation intervals (OBIs) included in 10 individual observations, and a single 101 ks PSPC image from 54 OBIs in 8 individual observations. Table 2 lists individual X-ray observations used in the present study.

Attitude solutions of *ROSAT* pointings derived from the Standard Analysis Software System (SASS, Voges et al. 1992) show residual attitude errors of $\sim 6''$. To improve the attitude solution for the high-resolution HRI observations (spatial resolution $\sim 5''$ FWHM on-axis), we used five bright point-like X-ray sources with off-axis distance $< 8'$ from the pointing direction visible in every single OBI to align each of the different OBIs with respect to the first. Positional offsets were all $\leq 6\farcs5$. A comparison between the radial intensity profiles of the five co-added point sources before and after the attitude correction shows that the average point spread function (PSF) of the *ROSAT* XRT+HRI is improved from $11''$ to $9''$ FWHM. The observations were merged with respect to a nominal pointing direction of R.A., Dec. (J2000) = $09^{\rm h}55^{\rm m}33\fs6$, $+69°04'16''$.

To further correct the merged HRI image for systematic pointing offsets, we compared centroid positions of 8 point-like X-ray sources with optical counterparts listed in the APM catalog (Irwin et al. 1994) and the HST Guide Star Catalog (§4). A satisfactory position alignment was found by shifting the X-ray images $1\farcs0$ to the west and $4\farcs0$ to the north.

Complementing the *ROSAT* HRI data, PSPC observations of M81 (cf. Table 2) were used to study spectral and timing characteristics of X-ray sources. To match the HRI field of view, only the inner $< 17'$ region of the entire 2° diameter PSPC field-of-view was used. The PSPC observations cover the same (0.1–2.4 keV) band, while having an on-axis angular resolution of $\sim 25''$ and an energy resolution of $\delta E/E \sim 0.43(0.93\ {\rm keV}/E)^{0.5}$.

Data reduction was performed with the EXSAS software (Zimmermann et al. 1994b) and with our own IDL programs. Background and exposure maps were constructed with the ESAS software (Snowden & Kuntz 1998). The background subtracted and exposure corrected images of M81 are given in Figs. 1 and 2.

3. Data Analysis

3.1. Detection of X-Ray Sources

For the HRI source detection, we conducted local (sliding box) and map detections, using images of pixel size $5''$, as well as maximum likelihood analysis of individual sources. In order to reduce the background due to UV emission and cosmic rays, only HRI PI channels 2–10 were used. Sources detected with a likelihood of $L \geq 8$ were accepted and merged in a source list (Table 3). Maximum likelihood values L can be converted into Gaussian probabilities P using the relation $P = 1 - e^{-L}$ (cf., Cruddace et al. 1988). Accordingly, a likelihood of 8 corresponds to 3.6σ significance. All sources with an off-axis angle exceeding $17'$ were excluded from the source list due to the deteriorated PSF and the count rate uncertainties at these large off-axis angles. Special care was taken in regions of enhanced diffuse emission regions. Sources only detected by the map algorithm were not accepted in the bulge region. Similarly, we searched for sources in the PSPC hard band (0.5–2 keV; PI channels 52–201; Table 4). Sources with $S/N \geq 4$ were selected. The PSPC soft band is dominated by the local diffuse Galactic background emission, and no additional source is detected.

Count rates may be converted into fluxes by assuming an X-ray spectral model. The X-ray spectra from Galactic stars, SNRs and hot gas observed in various emission regions within galaxies (e.g. galactic halos, HII regions or accretion of material onto a compact object) can often be characterized as optically-thin thermal plasma with temperatures of a few $\times 10^6$ K. AGNs typically show non-thermal emission, its soft X-ray band spectrum being described by a power-law with a photon index of ~ 2. A reasonably good approximation of the conversion factor for these spectra is 4×10^{-11} (ergs cm^{-2} s^{-1})/(cts s^{-1}) (cf. Fig. 5 in Wang et al. 1999), which is adopted throughout the paper. The uncertainty of this conversion factor for different source spectra is less than a factor of ~ 2, except for sources located within or beyond regions with foreground column densities in excess of several $\times 10^{21}$ cm^{-2}. A count rate of 1×10^{-4} cts s^{-1} hence converts to an unabsorbed (0.5–2 keV band) source flux of $f_{\rm x} \sim 4 \times 10^{-15}$ ergs cm^{-2} s^{-1} and a luminosity of $L_{\rm x} \sim 6 \times 10^{36}$ ergs s^{-1}, assuming a distance of 3.6 Mpc.

For the conversion between the *ROSAT* HRI and PSPC count rates, a factor of 3 was used. For very soft sources or sources with little absorption (e.g. unabsorbed foreground stars), however, the conversion factor can be significantly higher (~ 8), while the conversion factor for sources with strong absorption could be as low as ~ 2.5.

3.2. Timing Analysis of X-Ray Sources

The *ROSAT* data allow for time variability analysis of point sources on various time scales. We constructed lightcurves for all HRI sources (Table 3) and performed statistical tests to check for variability. To achieve reasonable counting statistics, we binned the data into 15 observation blocks with ~ 11 ks exposure time each. Furthermore, PSPC lightcurves were constructed for the five brightest X-ray sources in the M81 field from 13 observation intervals with ~ 8 ks integration time each. The time-dependent background was determined by normalizing the total background map of the HRI and PSPC images according to the total source-removed count rate in each exposure interval. Background subtracted source counts were extracted within the 90% radii around the fixed source positions found by the source detection algorithm. We tested the variability of each source by using a χ^2 test. To verify the χ^2 test, a Kolmogorov-Smirnov test was performed on the unbinned lightcurves of all HRI sources. Both statistical tests resulted in an identical list of variable sources. The combined *ROSAT* HRI and PSPC lightcurves of the five brightest sources are given in Fig. 3.

3.3. Analysis of Diffuse X-ray Emission

A substantial fraction of the X-ray emission from M81 cannot be accounted for by the detected X-ray sources, but is confused by bright X-ray sources, especially the nucleus. For an effective point-like source subtraction, we compared the radial intensity profiles of SN 1993J in the merged HRI image and LMC X-1 in an on-axis calibration observation (obs. ID 150013h; 869 s exposure time); the latter source is substantially brighter. The two profiles agree with each other. Furthermore, the LMC X-1 and the nucleus of M81 have similar X-ray spectra. Thus, we used the LMC X-

1 as an on-axis model PSF for the M81 HRI image. Fig. 4 compares the radial surface brightness profile around the nucleus of M81 with the normalized LMC X-1 profile. Detected X-ray sources were excised, except for the central source. The LMC X-1 profile was scaled to the peak of the M81 X-ray emission. Background was added to match the M81 background level of 1.5×10^{-2} cts arcsec^{-2} s^{-1}, estimated at a radius of $\sim 4'$. The residual was integrated to estimate the enhancement of apparently diffuse emission in the bulge region of M81.

4. Discrete Sources

We detect 46 HRI X-ray sources in the $17'$ radius field. Source positions, together with the source numbers, are illustrated in Fig. 2. The X-ray properties of the sources are summarized in Table 3: source number (col. 1, 'H' denotes HRI), right ascension and declination (cols. 2 and 3), 90% confidence error radius of the source position (col. 4, including $3''\!.5$ systematic error for the attitude solution), net count rate and error, corrected for vignetting, exposure and dead-time (col. 5), and comments regarding the variability of each source (col. 6).

Table 4 lists properties of 69 PSPC sources detected in the the same field: source number (col. 1, 'P' denotes PSPC), right ascension and declination (cols. 2 and 3), net count rate and error in the 0.5–2 keV band (col. 4), and 'hardness ratios' HR1 and HR2 (cols. 5 and 6). The hardness ratios are defined as HR1 = (hard − soft)/(hard + soft) and HR2 = (hard2 − hard1)/(hard2 + hard1), where 'soft' and 'hard' denote source net count rates in the 0.11–0.41 keV and 0.52–2.01 keV bands, respectively. 'Hard1' and 'hard2' are the split of a hard-band rate into two: 0.52–0.90 keV for 'hard1' and 0.91–2.01 keV for 'hard2'. We set HR1 = 1.0 for several sources with unphysical values of HR1 > 1, which are a result of statistical uncertainties in the data, most seriously in the soft band. The hardness ratios, which are sensitive to both the line-of-sight X-ray absorption (HR1) and the intrinsic 'hardness' of the spectrum (HR2), are helpful for discriminating between Galactic and extragalactic sources (Wang et al. 1999). A source with HR1 $\lesssim$ 0.4 is most likely a Galactic foreground star, whereas a source with HR2 $\gtrsim$ 0.4 is likely to be extragalactic. Also included in Table 4 are corresponding HRI source numbers based on positional coincidences within the detection apertures, as well as comments on the variability for each individual source (col. 7).

The 0.5–2 keV band flux range for all sources found in the M81 field is 5×10^{-15} – 1.2×10^{-11} ergs cm^{-2} s^{-1}. Within the D_{25} ellipse of M81, 27 HRI and 28 PSPC sources are detected. Six of the PSPC sources (P20, P21, P28, P30, P32, P50) have no HRI counterpart, whereas two PSPC sources (P41, P43) are composites of multiple HRI sources. Excluding identified interlopers and the nuclear sources, the remaining 26 X-ray sources detected within the D_{25} ellipse of M81 (22 HRI sources and 4 additional PSPC sources) have fluxes ranging from 0.5 to 78 $\times 10^{-14}$ ergs cm^{-2} s^{-1}. The corresponding luminosity range is 8×10^{36} – 1.2×10^{39} ergs s^{-1}.

We flagged sources with a probability of variability $\gtrsim 0.9973$ (corresponding to 3 Gaussian sigmas) as 'var' in Tables 3 and 4 (sources H9/P21, H13/P29, H15, H17/P35, H18/P36, H21/P37, H22/P38, H25, H38/P47 and H44/P66). Each of the five brightest sources in M81 is variable with a significance $> 3\sigma$ (Fig. 3). The nuclear X-ray source, for example, shows strong variability with amplitude up to a factor of 2.5, consistent with previous *ASCA* observations (Ishisaki et al. 1996; Iyomoto & Makishima 2000).

5. Multi-Wavelength Properties of X-ray Sources

Table 5 presents our preliminary classifications of the detected X-ray sources, based on their optical properties. We cross-correlate the positions of the X-ray sources with various publically available catalogs and identify plausible optical counterparts within twice the 90% confidence radius around each X-ray source. The APM magnitude limit is 21.5 mag for the DSS1 blue plates and 20.0 mag for the red plate (Irwin et al. 1994). The USNO A-v2.0 Catalog of Astrometric Standards has limiting magnitudes of O = 21, E = 20, J = 22, and F = 21. As results, we classify eleven HRI and nine additional PSPC sources as foreground or background objects ('interlopers', i.e. AGN, quasars, Galactic stars, etc.). Given a limiting X-ray flux of 4×10^{-15} ergs cm^{-2} s^{-1}, the

number of expected interlopers in the 17′ radius field is ~ 13, using results of the *ROSAT* Medium Sensitivity Survey (Hasinger et al. 1991). Thus, our identification of detected X-ray sources with interlopers is nearly complete and the bulk of the remaining X-ray sources within the D_{25} ellipse of M81 is associated with the galaxy. In the following, we discuss the most interesting sources in a multi-wavelength context.

• *Correlation of X-ray sources with supernova remnant candidates:*
Of the 22 HRI sources assumed to be associated with M81, we find that three sources spatially coincide with SNR candidates (Table 6). The identification of 41 SNR candidates in M81 was obtained by Matonick & Fesen (1997; hereafter MF), based on measured [SII]/H$\alpha \gtrsim 0.45$ ratios. The three proposed SNR candidates in M81 have luminosities in the range 10^{37}–10^{39} ergs s^{-1}. In comparison, X-ray luminosities of SNRs in our Galaxy typically are in the order of 10^{35}–10^{37} ergs s^{-1}. Both M83 and M101 show significant correlations between similarly bright X-ray sources with SNR candidates (Immler et al. 1999; Wang 1999). For M81, the random chance coincidence of any of the 41 SNR candidates being inside the search radius of any of the HRI sources is 0.3. If progenitors of SNe and X-ray sources are spatially correlated, however, the probability for the chance coincidence will be higher. Nevertheless, the apparent spatial coincidence of the X-ray sources with the SNR candidates are intriguing.

Interestingly, our X-ray timing analysis shows that all three X-ray sources are variable (Table 3). Source H9 is only detected in the first of the 15 HRI observation blocks used for the timing analysis. Also, source H13 is only detected in observations no. 1–3 and 15 while being below the detection threshold for the remaining epochs ($\lesssim 10^{37}$ ergs s^{-1}). The X-ray lightcurve of the bright X-ray source H21/P37 shows both long-term and short-term variability, with variations in the X-ray flux of a factor ~ 2 within six days (Fig. 3 at day 950). A PSPC spectrum, extracted from within a circle of 25″ radius around the source, is well fitted by a thermal bremsstrahlung model with a temperature of (1.7 ± 0.5) keV and an absorbing column of $N_{\rm H} = (2.6 \pm 0.4) \times 10^{21}$ cm^{-2}, or by a power-law model with a photon index $\Gamma = 2.4 \pm 0.4$ and an absorbing column of $(3.4 \pm 0.2) \times 10^{21}$ cm^{-2}. An optically thin thermal plasma model does not give an acceptable fit. The high X-ray luminosity, the strong variability, and apparently heavily absorbed spectral properties are the characteristics of a superluminous X-ray binary containing a black hole primary.

Could the association between X-ray binaries and the remnants be physical? Energetically, an X-ray binary has an energy capacity of $\sim 2 \times 10^{53} M_{\rm c}/M_{\odot}$ ergs (i.e., $\sim 10\%$ of the rest mass $M_{\rm c}$ of the companion). A large fraction of the energy can be released as outflows as observed in Galactic 'micro-quasars' (e.g., Mirabel & Rodríguez 1994). Such outflows may well create ISM structures such as the remnant candidates, and even some superbubbles.

• *H44/P66 and a superbubble:*
The second-brightest X-ray source (H44/P66) in the field positionally coincides with an identified emission-line nebula (Miller 1995) located $\sim 2'$ east of the dwarf companion Ho IX. The source was first detected by an *Einstein* observation (source X9; Fabbiano 1988), with a flux consistent with the mean *ROSAT* flux. A shell-like optical nebula of size $\sim 14'' \times 27''$, corresponding to ~ 250 pc $\times$ 475 pc at the distance of M81, was later identified in the region (Miller 1995). The presence of strong [SII] and [OI] emission lines in optical spectra indicate that the nebula is shock-heated. The nebula was thus classified as a superbubble. Our timing analysis, however, reveals strong variability with an amplitude exceeding a factor of 2.5 (cf. Fig. 3). Therefore, the X-ray emission cannot originate in diffuse hot gas. We also find that the PSPC spectrum is reasonably well characterized by a thermal bremsstrahlung spectrum with a temperature of (1.0 ± 0.1) keV or a power-law with index $\Gamma = 2.1 \pm 0.2$. In both cases the absorbing column density (~ 2 and $\sim 3 \times 10^{21}$ cm^{-2}, respectively) is significantly higher than the expected Galactic absorption, but is consistent with the inclusion of the column density seen in the HI map of M81 (Fig. 7; Yun et al. 1994). This indicates that the source is within or beyond the HI concentration in the same region. An *ASCA* observation of the source in the 0.5–10 keV range further shows a flat and featureless spectrum, which will be presented in a separate publication. Therefore, the source is most likely an X-ray binary that contains an accreting black

hole primary. The apparent source/nebula association then again indicates a physical connection between a superluminous X-ray binary and a shell-like ISM structure.

• *Supernova 1993J:*
The type IIb SN 1993J is the main motive for the wealth of the *ROSAT* M81 data. Due to the large temporal coverage of the X-ray data, starting just six days after the explosion and comprising approximately one year of PSPC and five years of HRI observations, SN 1993J is one of the best observed SNe in the X-ray regime (Zimmermann et al. 1994a). The complete *ROSAT* HRI+PSPC lightcurve of SN 1993J is presented in Fig. 3 (source H18/P36). For the observed maximum PSPC count rate of 7.89×10^{-2} cts s^{-1}, an unabsorbed (0.5–2 keV band) flux of $f_{\rm x} = 1.3 \times 10^{-12}$ ergs cm^{-2} s^{-1} is obtained for an assumed thermal plasma with a temperature of $T = 10^{6.5}$ K typical for young SNe. This converts to a peak X-ray luminosity of $L_{\rm x} = 2.0 \times 10^{39}$ ergs s^{-1}. The PSPC data show $S_{\rm x} \propto t^{-\alpha}$ with $\alpha = (0.65 \pm 0.13)$, consistent with the observed decline of radio emission ($S_\lambda \propto t^{-0.64}$ at $\lambda = 1.3, 2, 6$ and 20 cm; van Dyk et al. 1994). Since both the radio and X-ray emissions are considered to be linked to the interaction of the SN blast wave with the ambient circumstellar medium, similar results regarding the rate of decline are expected. An in-depth analysis of the X-ray characteristics and implications for the SN progenitor evolution will be presented in a separate publication.

• *The dwarf companion Holmberg IX:*
H42/P63 coincides with the position of the Magellanic irregular dwarf galaxy Holmberg IX (DDO 66, UGC 05336; R.A., Dec. (J2000) = $09^{\rm h}57^{\rm m}30^{\rm s}.1, +69^\circ02'52''$; offset $3''.1$). A revised distance estimation of Ho IX by Georgiev et al. (1991) shows that this dwarf galaxy is a close neighbor of M81 not only in projection but also in space (maximum offset 500 kpc). Assuming a distance of 3.6 Mpc, the inferred X-ray luminosity is 2.5×10^{37} ergs s^{-1}. A SNR was also detected in Ho IX (Hopp et al. 1996). The observed X-ray flux may be due to the presence of several unresolved young massive stars and/or relatively young SNRs.

6. Diffuse X-ray Emission

The X-ray emission around the nucleus of M81 is clearly extended (Fig. 4), indicative of the presence of diffuse X-ray emission in the bulge region and/or a combination of faint point-like sources. Excluding the two detected sources H23 and H25 and subtracting the LMC X-1 profile, the total residual luminosity is $(3.8 \pm 0.2) \times 10^{39}$ ergs s^{-1} (17%) in the bulge region and $(7.0 \pm 0.3) \times 10^{39}$ ergs s^{-1} (25%) within the D_{25} ellipse of M81 (Table 7).

Our spectral analysis provides further evidence for multiple X-ray components in the central region of M81. A simple power-law fit to the PSPC spectrum, extracted from a circle of $1'$ radius around the nucleus, is far from being satisfactory (the reduced $\chi^2 \sim 10$). To constrain the potential presence of other spectral components, we fix the power-law photon index at 1.85, as has been well determined by both *ASCA* and *BeppoSAX* observations, which are sensitive to photons in higher energy bands ($\gtrsim 2$ keV). We find that at least two more components are required to provide a satisfactory fit to the PSPC spectrum. We choose optically thin plasma models to characterize these two components. Table 8 lists the spectral parameters obtained from the spectral fit (reduced $\chi^2 \lesssim 1$). The higher temperature component is typical for a combination of X-ray binaries and SNRs, as observed in other nearby galaxies (e.g., for the disk of NGC 253; Pietsch et al 2000). The lower temperature component indicates the presence of diffuse hot gas. The two thermal components together account for $\sim 13\%$ of the total M81 emission from the central region, in reasonably good agreement with the amount of the residual emission estimated from the radial surface brightness profile after the nuclear source subtraction. Our results are consistent with a recent examination of a *Chandra* M81 observation (Tennant et al. 2000) which also indicates the presence of diffuse hot gas within the bulge, unaccounted for by weak unresolved sources.

7. Comparison with M101

It is interesting to compare the X-ray properties of M81 and M101 (Fig. 5), for which we have carried out a similar analysis based on deep *ROSAT* observations (Wang et al. 1999). While the former is an early-type spiral, the latter is a late-type

(Sc) spiral with active star formation. The X-ray emission from M101 is well correlated with spiral arms, especially the active southeast arm, and is detected and resolved in the most luminous giant HII regions (NGC 5447, 5455, 5461, and 5462). Although a fraction of the emission may be due to X-ray binaries and to very young SNRs, hot gas is most likely an important contributor. In general, there is a good correlation of diffuse X-ray emission with tracers of recent massive star forming activities in M101 (e.g., Hα intensity). In contrast, the M81 near-UV emission can be clearly decomposed into an inner $< 2'$ bulge and prominent spiral arm emission. The X-ray emission from M81 is not significantly enhanced along the spiral arms but more confined to the inner region of the galaxy.

Fig. 6 further compares the mean radial intensity distributions of the diffuse (i.e. individual detected sources excised) X-ray emission with optical and UV intensity profiles of the galaxies. The optical profiles are significantly different from both the UV and the X-ray profiles for both galaxies. The X-ray distribution of M101 is nearly identical to that of the UV radiation and is substantially flatter than that of the optical light, suggesting that massive stars are responsible for much of the diffuse X-ray emission from the galaxy. The X-ray distribution of M81, on the other hand, is much steeper at radii $\leq 2'$ compared to M101. The UV profile of M81 in general resembles the X-ray profile, apart from a clear excess at an off-center distance of $\sim 2'$–$7'$. This excess is caused by an enhanced UV surface brightness in the spiral arms, especially along the northern spiral arm. But no enhanced diffuse X-ray emission is observed in these regions. We find that the lack of enhanced X-ray emission associated with spiral arms in M81 can be explained by the strong X-ray absorption by cool gas, as traced by HI (Fig. 7). The typical column density in the arms is several times 10^{21} cm^{-2}, which is sufficient to absorb the bulk of the X-ray emission from hot gas with a characteristic temperature of $\sim$ 0.2 keV. Unlike M101, M81 contains no giant HII regions that may produce hot superbubbles energetic enough to blow out from spiral arms. Furthermore, M101 is a nearly face-on galaxy. So the line-of-sight absorption is significantly smaller than in M81 and a better correlation between soft X-ray emission and spiral arms in M101 is expected. We thus conclude that the soft diffuse X-ray emission in M81 is also likely associated with recent massive star forming activities.

8. Summary

We have systematically analyzed *ROSAT* PSPC and HRI observations of the early-type spiral M81 to disentangle different emission components and to derive spatial, spectral and timing characteristics of X-ray sources in the field. The main results and conclusions are as follows:

• Within a region of $17'$ radius around the M81 nucleus, 69 PSPC and 47 HRI sources are detected. Ten of them are found to be variable. Eleven HRI and nine additional PSPC sources are likely foreground or background objects (i.e. AGN, quasars, Galactic stars, etc.). Excluding these interlopers and the nucleus, 26 X-ray sources are within the D_{25} ellipse of the galaxy and have luminosities in the range of $8 \times 10^{36} - 1.2 \times 10^{39}$ ergs s^{-1} in the 0.5–2 keV band. These sources account for $\sim 10\%$ of the total luminosity ($\sim 3 \times 10^{40}$ ergs s^{-1}) of the galaxy.

• We find an apparent association of luminous and variable X-ray sources with shock-heated optical nebulae. These sources are in the luminosity range of 10^{37}–10^{40} ergs s^{-1}. Three position coincidences are with nebulae that are previously classified as SNR candidates, and one with a nebula as a superbubble. These associations suggest that such ISM structures may be powered by energetic outflows from X-ray binaries.

• X-ray emission is also detected from Holmberg IX, the dwarf companion of M81. Assuming a distance (3.6 Mpc) similar to that of M81, the inferred X-ray luminosity of Ho IX is 2.5×10^{37} ergs s^{-1}, which can be easily account for by a number of relatively young SNRs and X-ray binaries.

• We present strong spatial and spectral evidence for the presence of an apparently diffuse X-ray component in M81. The diffuse X-ray emission is most prominent in the bulge region of the galaxy, although a fraction must arise in faint discrete stellar sources. Diffuse X-ray emission fills much of the D_{25} ellipse of M81, accounting for $\sim 25\%$ (7×10^{39} ergs s^{-1}) of the total X-ray luminosity of the galaxy. A significant amount of X-ray emission may be absorbed by cool gas in the spiral arms.

Nevertheless, the similarity between the radial X-ray and UV intensity profiles and a comparison with M101 suggest that the diffuse X-ray emission is associated with recent massive star activities in M81.

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Table 1
General parameters of M81 (NGC 3031)

Parameter	Value	Ref.
Type	SA(s)ab	1
....	Sy1.8/LINER	2
Position of center (J2000) ..	R.A. $09^{h}55^{m}33\overset{s}{.}2$	2
....	Dec. $+69°03'55\overset{s}{.}06$	2
Distance	3.6 Mpc	3
....	($1' \widehat{=} 1$ kpc)	
Galactic foreground $N_{\rm H}$	4.3×10^{20} cm^{-2}	4
Inclination	32°	5
Position angle of major axis	150°	5
Diameter	$27' \times 14'$	2
Blue Magnitude	8 mag	1

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Table 2
ROSAT Observations of M81

Instr.	Sequence No.	Date	Obs. (ks)
HRI	600247h	1992 Oct 23 – 27	26.6
	600247h-1	1993 Apr 17 – May 14	21.3
	600739h	1994 Oct 19 – 21	20.0
	600740h	1995 Apr 13 – May 4	19.2
	600881h	1995 Oct 12 – 25	14.9
	600882h	1996 Apr 15 – May 7	18.5
	600882h-1	1996 Oct 27 – Nov 10	5.1
	601001h	1997 Mar 29 – Apr 1	19.4
	601002h	1997 Sep 30 – Oct 16	19.8
	601095h	1998 Mar 25 – 26	12.6
PSPC	600101p	1991 Mar 25 – 27	9.6
	600101p-1	1991 Oct 16 – 17	11.5
	600382p	1992 Sep 29 – Oct 3	28.1
	180015p	1993 Apr 3 – 24	18.6
	180015p-1	1993 May 4 – 6	9.0
	180035p	1993 Nov 1 – 2	18.4
	180035p-1	1993 Nov 7 – 8	4.4
	180050p	1994 Mar 31 – Apr 2	1.9

Table 3

ROSAT HRI M81 Source List

Source	R.A.^{2000} (h m s)	Dec.^{2000} (° ′ ″)	R_{err} (″)	Rate (10^{-4} cts s^{-1})	Comment
(1)	(2)	(3)	(4)	(5)	(6)
H1	09 52 41.15	+69 02 44.0	16.8	6.2 ± 1.5	
H2	09 53 10.04	+69 00 07.6	9.6	5.6 ± 1.2	
H3	09 53 17.01	+69 06 46.0	9.3	3.5 ± 0.9	
H4	09 53 49.15	+68 52 42.2	8.6	7.9 ± 1.4	
H5	09 53 51.32	+69 02 47.6	6.3	2.7 ± 0.7	
H6	09 53 57.04	+69 03 57.0	4.8	3.9 ± 0.7	
H7	09 54 16.49	+69 16 27.8	10.7	4.9 ± 1.2	
H8	09 54 45.27	+68 57 00.1	3.9	10.7 ± 1.0	
H9	09 54 50.96	+69 02 53.5	4.2	2.4 ± 0.5	var
H10	09 55 00.06	+69 07 48.4	3.7	9.2 ± 0.8	
H11	09 55 01.87	+68 56 22.1	4.0	11.7 ± 1.0	
H12	09 55 02.43	+68 50 50.9	12.7	4.8 ± 1.2	
H13	09 55 09.74	+69 04 10.1	3.7	7.5 ± 0.7	var
H14	09 55 10.27	+69 05 04.7	3.6	13.1 ± 0.9	
H15	09 55 22.04	+69 05 14.0	3.8	8.9 ± 0.8	
H16	09 55 22.03	+69 06 41.2	4.2	1.7 ± 0.4	
H17	09 55 24.37	+69 10 02.0	3.5	34.9 ± 1.5	var
H18	09 55 24.72	+69 01 15.0	3.5	79.4 ± 2.2	var
H19	09 55 25.78	+69 15 49.8	10.1	3.1 ± 0.9	
H20	09 55 28.86	+69 06 16.1	4.9	1.2 ± 0.4	
H21	09 55 33.05	+69 00 34.9	3.5	200.3 ± 3.4	var
H22	09 55 33.32	+69 03 57.5	3.5	2948.5 ± 12.9	var
H23	09 55 35.06	+69 03 20.6	3.8	18.5 ± 1.2	
H24	09 55 35.08	+68 55 15.7	6.3	2.5 ± 0.6	
H25	09 55 42.13	+69 03 39.4	3.7	18.4 ± 1.2	var
H26	09 55 43.60	+69 17 01.8	9.7	5.9 ± 1.2	
H27	09 55 43.95	+68 59 07.3	4.0	2.4 ± 0.5	
H28	09 55 47.44	+69 05 54.5	4.1	3.7 ± 0.6	
H29	09 55 49.42	+68 58 38.0	3.9	5.6 ± 0.7	
H30	09 55 49.54	+69 08 16.0	4.0	3.0 ± 0.5	
H31	09 55 50.10	+69 05 34.8	3.6	19.6 ± 1.1	
H32	09 55 58.79	+69 05 29.7	4.1	2.6 ± 0.5	
H33	09 56 02.23	+68 59 01.0	4.3	3.1 ± 0.6	
H34	09 56 02.90	+68 59 36.7	4.5	2.2 ± 0.5	
H35	09 56 09.59	+69 12 53.4	5.5	5.0 ± 0.8	
H36	09 56 09.22	+69 01 09.6	3.7	8.9 ± 0.8	
H37	09 56 13.85	+69 06 34.0	4.4	2.3 ± 0.5	
H38	09 56 14.19	+68 57 24.8	3.7	10.5 ± 0.9	var
H39	09 56 36.87	+69 00 30.1	3.8	7.3 ± 0.8	
H40	09 57 01.58	+68 55 01.3	4.3	16.3 ± 1.3	
H41	09 57 11.37	+69 05 04.1	5.3	2.7 ± 0.6	
H42	09 57 31.26	+69 02 31.9	12.3	4.1 ± 1.0	
H43	09 57 35.80	+69 00 09.1	7.0	7.5 ± 1.1	
H44	09 57 53.76	+69 03 50.3	3.5	552.9 ± 5.9	var
H45	09 57 56.44	+69 11 39.2	12.6	6.9 ± 1.4	
H46	09 58 02.94	+68 57 10.1	5.4	22.7 ± 1.8	

Table 4

ROSAT PSPC M81 Source List

Source	R.A.^{2000} (h m s)	Dec.^{2000} (° ′ ″)	Rate (cts ks^{-1})	Hardness Ratio HR1	HR2	Comment
(1)	(2)	(3)	(4)	(5)	(6)	(7)
P1	09 52 40.9	+69 03 50	0.8 ± 0.1	0.89 ± 0.28	0.73 ± 0.19	
P2	09 52 44.0	+69 02 52	0.7 ± 0.1	1.00 ± 0.36	0.62 ± 0.21	H1
P3	09 52 47.4	+69 09 01	0.7 ± 0.1	1.00 ± 0.36	0.39 ± 0.22	
P4	09 52 50.7	+68 59 21	0.5 ± 0.1	0.79 ± 0.41	0.06 ± 0.28	
P5	09 53 00.1	+69 07 27	0.5 ± 0.1	0.80 ± 0.36	0.56 ± 0.24	
P6	09 53 11.7	+68 59 59	1.0 ± 0.1	1.00 ± 0.21	0.18 ± 0.14	H2
P7	09 53 18.1	+69 06 37	0.9 ± 0.1	0.56 ± 0.14	0.42 ± 0.12	H3
P8	09 53 27.4	+69 04 13	0.9 ± 0.1	1.00 ± 0.18	0.55 ± 0.12	
P9	09 53 29.8	+68 58 35	1.8 ± 0.2	0.33 ± 0.08	0.23 ± 0.10	
P10	09 53 37.0	+69 05 36	0.5 ± 0.1	0.96 ± 0.35	0.27 ± 0.22	
P11	09 53 40.8	+68 59 16	1.4 ± 0.2	0.87 ± 0.12	0.59 ± 0.10	
P12	09 53 43.6	+69 16 00	0.5 ± 0.1	1.00 ± 0.53	0.51 ± 0.32	
P13	09 53 50.2	+68 52 39	3.3 ± 0.2	0.84 ± 0.06	0.42 ± 0.07	H4
P14	09 53 52.2	+69 02 51	1.1 ± 0.1	1.00 ± 0.15	0.35 ± 0.12	H5
P15	09 53 58.0	+69 03 56	1.3 ± 0.1	0.62 ± 0.12	0.28 ± 0.12	H6
P16	09 54 21.0	+69 00 03	1.0 ± 0.1	0.90 ± 0.14	0.47 ± 0.12	
P17	09 54 21.7	+68 54 36	1.7 ± 0.2	0.90 ± 0.13	0.23 ± 0.11	
P18	09 54 31.8	+68 52 36	0.4 ± 0.1	0.21 ± 0.24	0.45 ± 0.27	
P19	09 54 39.3	+69 19 13	0.8 ± 0.2	1.00 ± 0.29	0.09 ± 0.19	
P20	09 54 41.3	+69 04 51	0.7 ± 0.1	0.97 ± 0.25	0.26 ± 0.18	
P21	09 54 42.6	+69 02 38	0.4 ± 0.1	0.39 ± 0.24	0.46 ± 0.24	H9; var
P22	09 54 45.3	+68 56 58	3.3 ± 0.2	0.90 ± 0.05	0.10 ± 0.06	H8
P23	09 54 47.6	+69 11 22	0.4 ± 0.1	1.00 ± 0.43	0.19 ± 0.25	
P24	09 55 00.2	+69 19 14	0.7 ± 0.1	0.78 ± 0.30	0.11 ± 0.22	
P25	09 55 00.8	+69 07 40	4.4 ± 0.2	0.95 ± 0.04	0.51 ± 0.05	H10
P26	09 55 02.4	+69 10 29	0.7 ± 0.1	1.00 ± 0.26	0.37 ± 0.16	
P27	09 55 02.4	+68 56 21	1.7 ± 0.2	−0.09 ± 0.06	−0.06 ± 0.10	H11
P28	09 55 05.5	+68 58 53	0.3 ± 0.1	1.00 ± 0.44	0.06 ± 0.28	
P29	09 55 10.5	+69 04 04	5.1 ± 0.3	0.92 ± 0.03	0.35 ± 0.05	H13; var
P30	09 55 11.0	+69 08 29	0.6 ± 0.1	1.00 ± 0.27	0.25 ± 0.19	
P31	09 55 11.0	+69 04 60	5.6 ± 0.3	0.99 ± 0.03	0.48 ± 0.04	H14
P32	09 55 13.6	+69 12 32	0.4 ± 0.1	0.74 ± 0.38	0.85 ± 0.27	
P33	09 55 22.7	+69 06 31	7.3 ± 0.3	0.89 ± 0.03	0.43 ± 0.04	
P34	09 55 23.7	+69 05 08	6.1 ± 0.3	0.91 ± 0.03	0.44 ± 0.04	H15
P35	09 55 24.6	+69 09 54	12.3 ± 0.4	0.90 ± 0.02	0.28 ± 0.03	H17; var
P36	09 55 24.9	+69 01 13	27.0 ± 0.6	0.96 ± 0.01	0.43 ± 0.02	H18; var
P37	09 55 33.1	+69 00 34	70.1 ± 0.9	0.98 ± 0.00	0.54 ± 0.01	H21; var
P38	09 55 33.6	+69 03 54	666.5 ± 2.8	0.86 ± 0.00	0.26 ± 0.00	H22; var
P39	09 55 41.0	+69 17 21	1.1 ± 0.2	0.60 ± 0.15	0.52 ± 0.13	H26
P40	09 55 49.2	+68 58 41	2.2 ± 0.2	0.90 ± 0.07	0.23 ± 0.08	
P41	09 55 49.4	+69 05 32	8.1 ± 0.3	0.86 ± 0.02	0.43 ± 0.04	H28+H31
P42	09 55 50.0	+69 08 09	1.5 ± 0.2	0.91 ± 0.09	0.20 ± 0.09	H30
P43	09 56 01.5	+68 59 09	1.8 ± 0.2	0.86 ± 0.10	0.20 ± 0.10	H33+H34
P44	09 56 08.9	+69 01 07	1.5 ± 0.1	0.81 ± 0.10	−0.60 ± 0.10	H36
P45	09 56 09.2	+69 12 45	1.0 ± 0.1	1.00 ± 0.17	0.18 ± 0.14	H35
P46	09 56 12.7	+69 06 29	0.4 ± 0.1	1.00 ± 0.37	0.35 ± 0.22	H37
P47	09 56 14.2	+68 57 27	2.2 ± 0.2	0.39 ± 0.07	0.07 ± 0.08	H38; var
P48	09 56 36.3	+69 00 28	2.8 ± 0.2	0.86 ± 0.06	0.31 ± 0.07	H39
P49	09 56 43.7	+68 53 51	1.8 ± 0.1	0.87 ± 0.12	0.54 ± 0.10	
P50	09 56 46.0	+68 54 40	1.9 ± 0.2	1.00 ± 0.10	0.58 ± 0.09	
P51	09 56 52.0	+69 07 41	0.5 ± 0.1	0.78 ± 0.26	0.36 ± 0.20	
P52	09 56 52.6	+69 10 42	0.9 ± 0.1	0.76 ± 0.16	0.09 ± 0.15	
P53	09 56 52.9	+69 11 59	0.8 ± 0.1	1.00 ± 0.20	0.49 ± 0.15	
P54	09 56 55.8	+69 08 60	0.4 ± 0.1	0.78 ± 0.33	0.47 ± 0.23	
P55	09 57 01.4	+68 54 60	4.4 ± 0.3	0.88 ± 0.04	0.12 ± 0.06	H40
P56	09 57 01.6	+68 56 49	0.6 ± 0.1	0.93 ± 0.32	0.14 ± 0.23	
P57	09 57 10.9	+69 05 01	0.6 ± 0.1	1.00 ± 0.27	0.13 ± 0.20	H41
P58	09 57 14.4	+69 11 35	0.5 ± 0.1	0.94 ± 0.29	0.21 ± 0.21	
P59	09 57 17.2	+69 10 12	0.5 ± 0.1	0.94 ± 0.30	0.48 ± 0.21	
P60	09 57 17.5	+68 58 27	1.4 ± 0.2	0.95 ± 0.12	0.33 ± 0.11	
P61	09 57 26.9	+68 53 16	0.6 ± 0.1	1.00 ± 0.41	0.08 ± 0.25	
P62	09 57 28.4	+69 13 30	1.8 ± 0.2	0.99 ± 0.11	0.25 ± 0.10	
P63	09 57 29.8	+69 02 32	0.8 ± 0.1	0.80 ± 0.18	0.02 ± 0.16	H42

Table 4—*Continued*

Source	R.A.^{2000} (h m s)	Dec.^{2000} (° ′ ″)	Rate (cts ks^{-1})	Hardness Ratio HR1	HR2	Comment
(1)	(2)	(3)	(4)	(5)	(6)	(7)
P64	09 57 35.6	+69 00 09	1.6 ± 0.2	1.00 ± 0.11	0.11 ± 0.10	H43
P65	09 57 35.7	+69 16 07	0.7 ± 0.2	0.98 ± 0.27	0.37 ± 0.18	
P66	09 57 53.3	+69 03 48	198.0 ± 1.6	0.97 ± 0.00	0.39 ± 0.01	H44; var
P67	09 57 55.7	+69 11 33	3.1 ± 0.2	0.84 ± 0.07	0.22 ± 0.07	H45
P68	09 57 57.3	+69 06 11	0.9 ± 0.2	0.70 ± 0.21	0.24 ± 0.20	
P69	09 58 02.2	+68 57 10	3.7 ± 0.3	0.16 ± 0.05	0.03 ± 0.07	H46

Table 5

ROSAT M81 Source Identifications

Source	Offset (″)	R (mag)	B (mag)	$B-R$ (mag)	Identification[a]
(1)	(2)	(3)	(4)	(5)	(6)
H2 = P6	6.0	11.82	14.13	2.31	GS 0438301079; U1575 03021793
H3 = P7	5.4	18.0	19.40	1.40	U1575 03022008
P9	12.0	11.02	12.47	1.72	GS 0438300727; U1575 03022347
P11	6.9	19.27	–	> 1.92	non-stellar
H4 = P13	3.6	19.06	20.69	1.63	U1575 03022935
P14	12.6	18.17	21.18	3.01	non-stellar
H6 = P15	4.2	19.77	–	> 1.42	stellar
P19	3.1	19.81	–	> 1.38	U1575 03024392
H8 = P22	1.8	12.45	13.55	1.10	GS 0438300613; U1575 03024587
H9	5.0	–	–	–	SNR MF4
P23	7.4	18.90	19.50	0.60	U1575 03024612
H11 = P27	5.9	10.31	11.62	1.31	GS 0438301127; U1575 03025086
H13 = P29	4.5	–	–	–	X2; SNR MF11
H14 = P31	2.9	–	–	–	X3
H17 = P35	6.3	–	–	–	X4
H18 = P36	1.3	–	–	–	SN 1993J
H21 = P37	2.7	–	–	–	X6; SNR MF22
H22 = P38	3.3	–	–	–	X5; M81 nucleus
H31	5.2	–	–	–	X7
H38 = P47	0.5	16.85	19.37	2.52	X8; U1575 03027313
H39 = P48	2.3	17.07	17.24	0.17	U1575 03027973
P49	15.3	14.72	15.93	1.21	GS 0438300776; U1575 03028257
H40 = P55	0.7	16.91	17.37	0.46	U1575 03028660
P56	5.0	18.71	20.48	1.87	U1575 03028666
P58	8.0	14.84	16.09	1.25	GS 0438300612
P62	10.6	18.51	–	> 2.68	non-stellar
H42 = P63	3.1	–	19.92	< −0.08	Ho IX
H44 = P66	4.3	17.80	–	> 3.39	X9; U1575 03030069; nebula
H45 = P67	8.5	19.44	21.17	1.73	non-stellar
H46 = P69	2.4	9.95	11.51	1.56	GS 0438301132

$^{(a)}$ see §4 for details. Identifications are denoted by:
GS – HST Guide Star Catalog v1.1;
U – USNO A-v2.0 Catalog of Astrometric Standards;
MF – SNR candidate number from Matonick & Fesen (1997);
X – *Einstein* X-ray source number from Fabbiano (1988);
Ho IX – Holmberg IX dwarf galaxy.

Table 6

Position Coincidence between X-ray Sources and SNR Candidates

SNR Name	R.A. (h m s)	Dec. (° ′ ″)	Δ_{x-o} (″)	$L_{H\alpha}$ (ergs s^{-1})	[SII]/Hα	Size (pc)	Optical Shape	*ROSAT* Source	L_x (ergs s^{-1})
MF4	09 54 51.3	+69 02 58.5	6.2	4.5×10^{36}	0.58	40	stellar	H9	1.5×10^{37}
MF11	09 55 09.6	+69 04 14.6	4.5	2.2×10^{36}	1.58	40	stellar	H13/P29	4.7×10^{37}
MF22	09 55 32.7	+69 00 32.9	2.7	1.7×10^{37}	0.85	90	filled	H21/P37	1.2×10^{39}

Table 7

X-Ray Emission Components in the Field of M81

Emission component	HRI Rate (cts s^{-1})	L_x[a] (10^{40} ergs s^{-1})	Fraction (%)
Total Galaxy	0.457	2.83	100
Point-like nuclear source (H22)	0.295	1.83	65
Interlopers (H11, H39, H40, H41)	0.005	0.03	1
Point sources[b]........................	0.044	0.27	10
Diffuse emission within the D_{25} ellipse	0.113	0.70	24
Total bulge emission ($< 2'$ radius)	0.354	2.19	100
Point-like nuclear source ($< 2'$ radius)	0.292	1.81	83
Extended bulge emission ($< 2'$ radius)[c]	0.062	0.38	17

(a) 0.5–2 keV band luminosities.

(b) Point sources within the D_{25} ellipse of M81 (Table 3), excluding identified interlopers and the nuclear X-ray source.

(c) Derived from the radial intensity profile of the point-like X-ray source Her X-1, scaled to the peak of the X-ray emission from the bulge (Fig. 4; §3.3).

Table 8

X-ray Spectral Properties of the Bulge Region

Model[a]	T, Γ[b] (keV)	N_H[b] (10^{20} cm^{-2})	L_x[c] (ergs s^{-1})
Three-component model:			
• Thermal Plasma 1	0.15 (0.13–0.17)	4.8 (4.7–4.9)	2.0×10^{39}
• Thermal Plasma 2	0.63 (0.52–0.74)	6.0 (5.7–6.3)	0.5×10^{39}
• Power Law	1.85 (1.83–1.87)	23 (22–25)	1.7×10^{40}

(a) Metal abundances for both X-ray-emitting and -absorbing materials are assumed as 100% solar.

(b) 90% confidence intervals.

(c) 0.5–2 keV band luminosities.

Fig. 1.— *ROSAT* PSPC (0.5–2 keV band) contour map of M81, overlayed onto a digitized DSS2 plate. The PSPC intensity map was adaptively smoothed with a Gaussian with size adjusted to achieve a constant signal-to-noise ratio of 6. Contours are at 4.5, 6, 10, 20, 50, 100, 500, 2000 and 5000 $\times 10^{-3}$ cts arcmin^{-2} s^{-1}.

Fig. 2.— *ROSAT* PSPC (0.5–2 keV band) intensity contour map of M81. The map was smoothed with a Gaussian filter of $35''$ (FWHM). Same X-ray contour levels as in Fig. 1. HRI and PSPC source positions are marked with crosses and boxes, respectively, and are enumerated according to the source lists (Tables 3 and 4) in the right-hand panels. The D_{25} ellipse of M81 is indicated by a dotted line. The lower panel shows a high-resolution HRI close-up of the inner $11' \times 11'$ region. The map was smoothed with a Gaussian filter of $9''$ (FWHM). Contours are at 2, 4, 6, 10, 20, 50, 100, 500, 2000 and 5000 $\times 10^{-3}$ cts arcmin^{-2} s^{-1}.

Fig. 3.— Lightcurves of the five brightest X-ray sources in the M81 field. PSPC data are marked as boxes, HRI data are indicated by a horizontal bar. Dashed lines give the mean count rates over the *ROSAT* PSPC period of observation, the dotted lines indicate the mean count rates over the complete *ROSAT* HRI observation. Error bars are 1σ statistical errors, arrows indicate 3σ upper limits.

Fig. 4.— Radial X-ray surface brightness profile of the M81 bulge region (solid line), compared to the profile of the point-like X-ray source LMC X-1 (dashed line), which is scaled to the peak of the bulge emission.

Fig. 5.— *ROSAT* HRI intensity contours of M81 (left-hand panel) and M101 (right-hand panel), overlaid on UIT UV images. The HRI images are adaptively smoothed with a S/N equal to 6. Contour levels are at 0.4, 0.6, 1.0, 1.5, 2.3, 3.3., 5.3, 11, 23, 47, 80, 160, 300, 600, 1200, and 2400 $\times 10^{-3}$ cts arcmin^{-2} s^{-1}.

Fig. 6.— Radial diffuse X-ray intensity distributions of M81 (left-hand panel) and M101 (right-hand panel), compared with UV (solid line) and optical (dashed line) intensity profiles around the galaxies nuclei. The intensity units are for X-ray data only; the optical (POSS E survey) and UV (Astro-1 UIT) profiles are arbitrarily normalized.

Fig. 7.— HI contours overlaid on the near-UV image of M81. The HI data are the same as in Yun et al. (1994) and the contours are at 5, 10, 15, 20, and 25 $\times 10^{20}$ cm^{-2}.

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