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# X-RAY OBSERVATIONS OF NGC 253 AND M83 WITH *GINGA*

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## ABSTRACT

X-ray spectra of two starburst galaxies NGC 253 and M83 in 2–20 keV have been obtained with the X-ray astronomy satellite *Ginga*. The observed spectra can be described by thermal bremsstrahlung models with temperatures of 6–7 keV for both galaxies, with no significant absorption. The estimated luminosities in 2–10 keV are $\sim 1 \times 10^{40}$ ergs $s^{-1}$ and $\sim 8 \times 10^{39}$ ergs $s^{-1}$ for NGC 253 and M83, respectively, consistent with IPC measurements in a lower energy band. No significant iron *K*-emission line was detected from either galaxy with 90% upper limit on the equivalent width $\sim 400$ eV, suggesting a significant depletion of iron if most of the continuum emission is of thermal origin. The spectral shape and the enhanced X-ray luminosity of these two galaxies, compared with M31 or the Galaxy, suggest that a major fraction of the X-ray emission may originate from hot gas. However, the lack of an iron emission line remains a puzzle.

*Subject headings:* galaxies: individual (NGC 253, M83) — galaxies: X-rays — radiation mechanisms — stars: formation

## I. INTRODUCTION

X-ray emission from nearby galaxies with increased starburst activity, such as M82, NGC 253 and M83, has been studied with the *Einstein Observatory* (Watson, Stanger, and Griffiths 1984; Fabbiano and Trinchieri 1984; Trinchieri, Fabbiano, and Palumbo 1985; Fabbiano 1988). The imaging observations have revealed that the X-ray emission is associated with the disk, the starburst nucleus, and the halo. The emission from the starburst nucleus is extended, and the luminosity is several times $10^{39}$ ergs $s^{-1}$ for these galaxies. A remarkable discovery is X-ray emission from an extended halo for M82 and NGC 253 (and possibly for M83). The same feature has recently been found for NGC 3628 (Fabbiano, Heckman, and Keel 1990). Observations of the energy spectrum and the morphology of such a hot halo is very important in understanding the evolution of the galaxy. If the gas is bound by the galaxy, it could be used as a probe of the dark matter around the galaxies, but observations suggest that these halos are due to outflowing winds (Fabbiano 1988).

NGC 253, an Sc galaxy at a distance of 3.4 Mpc seen nearly edge-on, shows an extended X-ray plume extending perhaps in a halo with a radius of $\sim 10'$ in the direction of the galactic minor axis (Fabbiano and Trinchieri 1984; Fabbiano 1988). The IPC spectrum of the whole galaxy is not well constrained with the IPC data. A fit to thermal bremsstrahlung gives a temperature $kT > 1.5$ keV and a hydrogen column density $N_H < 8.4 \times 10^{20}$ $cm^{-2}$, and the spectrum of the nuclear region indicates significant absorption with $N_H \sim 10^{21}$ $cm^{-2}$ (Fabbiano 1988). The 0.2–4.0 keV luminosity of the entire galaxy measured with IPC is $1.1 \times 10^{40}$ ergs $s^{-1}$ (Fabbiano 1988). *HEAO 1* A-2 observations gave an upper limit of the 2–10 keV flux at $\sim 1.5 \times 10^{-11}$ ergs $cm^{-2}$ $s^{-1}$ (Mushotzky 1988).

M83 (=NGC 5236), an almost face-on SAB(S)c I-II galaxy at 3.75 Mpc, shows X-ray emission associated with the plane of the galaxy but not well correlated with the spiral arms (Trinchieri, Fabbiano, and Palumbo 1985). They obtained a 0.5–3.0 keV luminosity of $5.7 \times 10^{39}$ ergs $s^{-1}$ with the IPC. The spectrum of the whole galaxy, fitted with a thermal bremsstrahlung, gives $kT > 0.7$ keV and $N_H < 1 \times 10^{21}$ $cm^{-2}$ (Fabbiano and Trinchieri 1987). The IPC detected a compact X-ray source with a similar flux to M83 at only 0°.34 away from the center of M83 (MS 1332.6−2935, identified as an AGN by Gioia *et al.* 1990). M83 was confused in the field of view (FOV) of the *HEAO 1* A-2 experiment with other stronger sources (Mushotzky 1988).

Thus, the *Einstein* observations of NGC 253 and M83 have resolved the X-ray emission into different components. However, information on the X-ray spectrum has been very limited because of the narrow bandpass of the *Einstein Observatory*.

The Japanese third X-ray astronomy satellite *Ginga* (Makino and the ASTRO-C Team 1987) enables the spectra of these normal galaxies in the medium energy range (2–20 keV) to be studied for the first time. The LAC instrument has an effective area of about 4000 $cm^2$, a FOV of 1°.1 × 2° FWHM, and a low background rate of $3.5 \times 10^{-4}$ counts $cm^{-2}$ $s^{-1}$ $keV^{-1}$ (Turner *et al.* 1989). With these properties, the LAC is the most sensitive instrument in the energy range 2–20 keV so far. In this paper, we report on the *Ginga* observations of the X-ray spectra of NGC 253 and M83 and discuss the origin of the X-ray emission.

## II. OBSERVATIONS AND RESULTS

### *a)* *Observations*

The observation of NGC 253 was carried out from 1987 November 17, 4:18 UT to November 18, 9:33 UT with a net observation time of 22,100 s, and M83 was observed from 1988 February 1, 20:53 UT to February 2, 19:12 UT for a net 14,000 s, respectively. Both observations were made with the LAC instrument in the MPC-1 mode in either medium or low bit rates (see Turner *et al.* 1989). For the observation of NGC 253, there were no confusing sources in the FOV at a level of $\sim$0.3 mCrab. However, for M83 the nearby AGN, MS 1332.6−2935, was in the FOV of the LAC at a transmission efficiency of 70%. Assuming that the X-ray spectrum of MS 1332.6−2935 is a power-law form with a photon index of 1.7 (Mushotzky 1984; Turner and Pounds 1989) the measured IPC flux indicates that 52% of the LAC flux is from M83 and the rest from MS 1332.6−2935.

The background used in the present analysis was taken either on an adjacent day (NGC 253) or 37 days before (M83) at high Galactic latitudes. (The intrinsic background of the LAC varies with a 37 day period as discussed by Hayashida *et al.* 1989.) The location of NGC 253 is near the Galactic south pole ($l = 97°.40$, $b = -87°.97$). M83 is located at $l = 314°.58$ and $b = 31°.97$, where the contamination of the diffuse X-ray emission in our own Galaxy is less than 0.03 mCrab for the LAC FOV (see Iwan *et al.* 1982); therefore, the effect on the resultant spectrum of M83 is negligible. We also applied the model background described by Hayashida *et al.* (1989) and obtained the same intensity, confirming that the background used here had no significant contamination.

The count rate of NGC 253 in the 2–10 keV band with its 1 $\sigma$ statistical error is $3.00 \pm 0.06$ counts $s^{-1}$. However, the systematic errors are much larger than the statistical errors in these observations. The first cause of error is the subtraction of non-X-ray background. Hayashida *et al.* (1989) have studied the behavior of the intrinsic background in detail and found that the standard subtraction procedure gives a 90% error of 0.3 counts $s^{-1}$ in 2–10 keV for a 1 day long observation. The second origin of the error is the confusion noise caused by unresolved weak sources in the FOV. Recent *Ginga* results on the beam-to-beam fluctuation obtained by Hayashida (1990) shows the 90% limit to be 1.2 counts $s^{-1}$ in 2–10 keV. Including these systematic errors, the intensity of NGC 253 becomes $3.0 \pm 1.2$ counts $s^{-1}$ with errors at 90% confidence. The significance of the detection is 4.0 $\sigma$.

For M83 the derived LAC count rate in 2–10 keV is about 2.0 counts $s^{-1}$, assuming that the 0.5–3.5 keV flux of MS 1332.6−2935 is the same as the IPC value and its spectrum has the "canonical" slope of photon index 1.7 absorbed with the Galactic hydrogen column. The significance of the detection is 2.6 $\sigma$ considering the beam-to-beam fluctuations. However, as discussed later, the consistency with the IPC results would strengthen the case that *Ginga* has detected the 2–10 keV X-ray emission of M83.

### *b) Results*

The observed energy spectra of NGC 253 and M83 (including MS 1332.6−2935) are shown in Fig. 1. These are the count rate spectra taken with the top layer of the LAC, which provides good signal-to-noise ratio in the energy range below 10 keV (see Turner *et al.* 1989). Only statistical errors are indicated in Figure 1, but a 1% systematic error was added for each data bin in the spectral fitting in order to incorporate the calibration uncertainties. We have carried out the spectral fits with simple theoretical models. Only thermal bremsstrahlung and power-law (photon spectrum follows $E^{-\Gamma}$) models with an emission line were tried. The energy range for fitting was limited to 1.7–20 keV. We employed the Gaunt factor for the thermal bremsstrahlung discussed by Gould (1980) and the interstellar absorption cross section of Morrison and McCammon (1983). In order to cope with the contamination of MS 1332.6−2935 for M83, we included a power-law spectrum with fixed slope ($\Gamma = 1.70$) and fixed intensity ($F_X = 4.7 \times 10^{-12}$ ergs $cm^{-2}$ $s^{-1}$ over 2–10 keV, including the collimator transmission efficiency of 70%) absorbed by the Galactic column ($N_H = 5 \times 10^{20}$ $cm^{-2}$) throughout the analysis. This spectrum

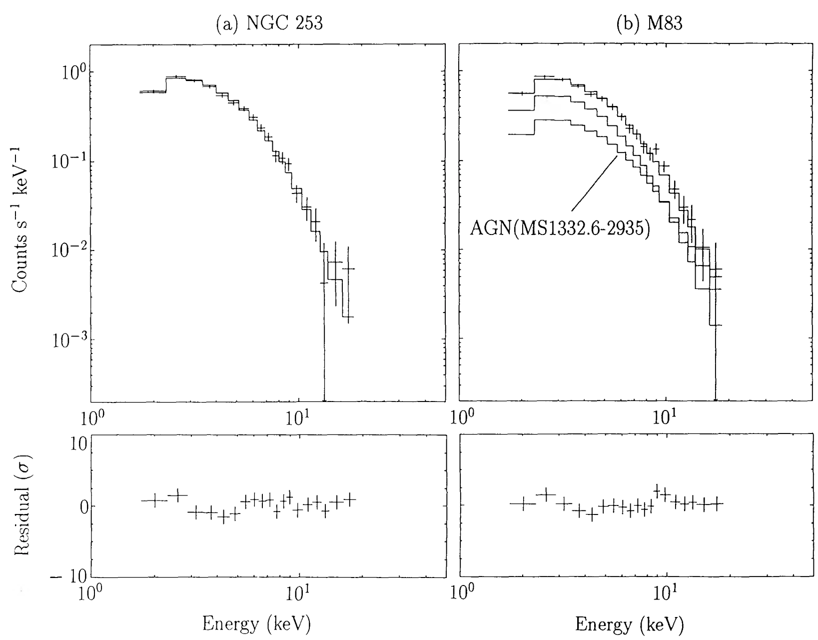


FIG. 1.—Observed pulse-height spectra of (*a*) NGC 253 and (*b*) M83, respectively, fitted with a thermal bremsstrahlung model. For the M83 data, contamination of an AGN, MS 1332.6−2935, is modeled with a power-law spectrum of $\Gamma = 1.7$. The parameters are $kT = 6.0$ keV and $N_H = 1 \times 10^{20}$ $cm^{-2}$ for NGC 253, and $kT = 6.6$ keV and $N_H = 5 \times 10^{20}$ $cm^{-2}$ for M83, respectively. Bottom panels indicate the residuals in units of $\sigma$.

TABLE 1

SPECTRAL PROPERTIES OF NGC 253 AND M83

A.

| Source | Distance (Mpc) | $F_X$ (2–10 keV)[a] (ergs cm$^{-2}$ s$^{-1}$) | $L_X$ (2–10 keV) (ergs s$^{-1}$) |
|---|---|---|---|
| NGC 253 ......... | 3.4 | $7.0 \times 10^{-12}$ | $9.7 \times 10^{39}$ |
| M83[b] ............. | 3.75 | $4.7 \times 10^{-12}$ | $7.9 \times 10^{39}$ |

B.

| SOURCE | THERMAL BREMSSTRAHLUNG | | | | | PULSAR COMPONENT[d] (ergs s$^{-1}$) |
|---|---|---|---|---|---|---|
| | $kT$ (keV) | $N_H$ (cm$^{-2}$) | EW (eV)[c] | $\chi^2_\nu$ | $\nu$ | |
| NGC 253...... | $6.0 \pm 0.8$ | $<1.7 \times 10^{21}$ | $180^{+210}_{-180}$ | 0.94 | 16 | $<3 \times 10^{39}$ |
| M83............ | $6.7 \pm 1.5$ | $<2.8 \times 10^{21}$ | $<290$ | 1.20 | 16 | $<4 \times 10^{39}$ |

C.

| SOURCE | POWER LAW | | | | |
|---|---|---|---|---|---|
| | $\Gamma$ | $N_H$ (cm$^{-2}$) | EW (eV) | $\chi^2_\nu$ | $\nu$ |
| NGC 253...... | $2.31^{+0.14}_{-0.19}$ | $7.3^{+2.2}_{-5.7} \times 10^{21}$ | $210^{+210}_{-210}$ | 0.90 | 16 |
| M83............ | $2.1^{+0.3}_{-0.1}$ | $<9 \times 10^{21}$ | $<290$ | 0.84 | 16 |

[a] 90% confidence limit of the confusion noise is $3 \times 10^{-12}$ ergs cm$^{-2}$ s$^{-1}$ in 2–10 keV (Hayashida *et al.* 1989).

[b] Contamination of nearby AGN, MS 1332.6−2935, is corrected for by assuming its spectrum as a power law with $\Gamma = 1.70$ with 0.3–3.5 keV flux consistent with the IPC value of Gioia *et al.* (1990).

[c] Equivalent width for an emission line at 6.7 keV.

[d] The 2–10 keV luminosity of the typical X-ray pulsar spectrum (see text) which can be allowed in the observed spectrum of each galaxy. The upper limit is defined at 90% confidence.

is the most likely one for an AGN based on the previous measurements of numerous objects (Mushotzky 1984; Turner and Pounds 1989), and the intensity was adjusted so as to give a 0.5–3.5 keV flux consistent with the IPC value (Gioia *et al.* 1990).

The results of the spectral fits are summarized in Table 1. For NGC 253, both thermal bremsstrahlung and power-law models give acceptable fits, but the derived $N_H$ for the power-law model ($>1.6 \times 10^{21}$ cm$^{-2}$) is much higher than the Galactic value and contradicts the IPC result ($N_H < 8.4 \times 10^{20}$ cm$^{-2}$) measured for the whole galaxy (Fabbiano 1988). Therefore, a thermal spectrum with $kT \sim 6$ keV is preferred for the 2–20 keV spectrum of NGC 253. On the other hand, for M83 both thermal and power-law models gave only upper limits on $N_H$, consistent with IPC result obtained by Fabbiano and Trinchieri (1987). Confidence contours for the thermal fit for both galaxies are shown in Figure 2. The best-fit temperature of M83 is actually a function of the assumed power-law slope of MS 1332.6−2935, and we find that the former shifts by 1 keV for a change in the latter of 0.1 (lower M83 temperature for harder AGN spectrum). The best-fit thermal models are shown fitted to the data in Figure 1, and the residuals are shown in the bottom panels.

As mentioned in the previous section, the sky fluctuation could bring in large systematic uncertainties when no additional information was available on the source intensity. In order to check its effect, we have carried out the following analysis. The beam-to-beam sky fluctuation for the LAC instrument has been extensively studied by Hayashida *et al.* (1989), Warwick and Stewart (1989), and Hayashida (1990). The recent work by Hayashida (1990) has revealed that the energy spectrum of the fluctuation is fairly uniform in the sky and well described by a power-law model with $\Gamma \sim 1.7$ (with $\Delta\Gamma < 0.1$ at 90% confidence), suggesting that faint AGNs are the principal contributor. Based on this study, we generated two additional pulse-height spectra for each observation either by adding or subtracting the fluctuation spectrum whose intensity was at the 90% limit and carried out the same fitting procedure. It turns out that the combination of acceptable parameter space for these additional spectra makes the confidence limits of the spectral parameters significantly wider than those listed in Table 1; the combined confidence limit of $kT$ is 4.2–7.2 keV for NGC 253 and 3.1–8.2 keV for M83, respectively. Based on this analysis, we conclude that the essential results on the spectra of these two galaxies remain the same even allowing the sky intensity to fluctuate.

We note that the 2–10 keV flux obtained for the average background-sky intensity leads to the 0.2–4.0 keV flux consistent with the IPC measurement as detailed in the next section. If we take the 90% limit of the sky fluctuation, it causes flux change of 40% for NGC 253 and 60% for M83, respectively, and the consistency with the measured IPC flux is lost. In other words, the flux consistency between the *Ginga* and the *Einstein* results confirms that the sky background has been correctly

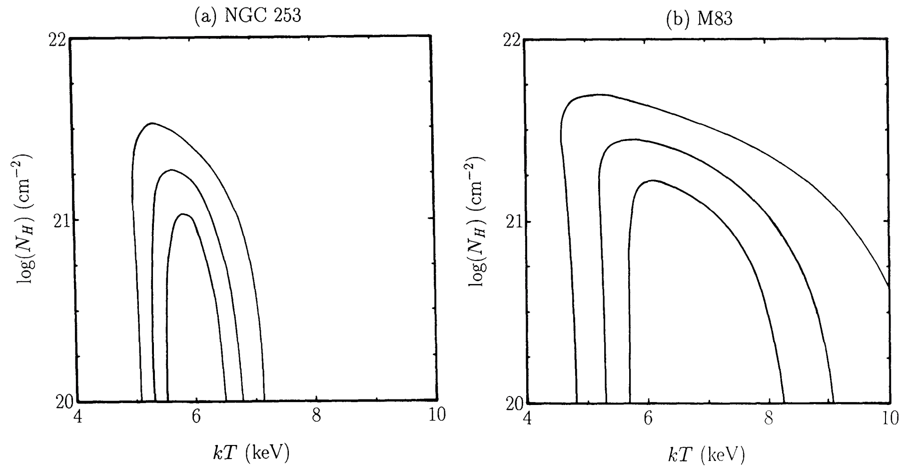


FIG. 2.—Confidence contours at 68%, 90%, and 99% with two interesting parameters for the spectral fits of (*a*) NGC 253 and (*b*) M83, respectively. The model is thermal bremsstrahlung, and the free parameters are normalization, hydrogen absorption column $N_{\rm H}$, and the temperature $kT$.

subtracted in the present analysis. In the following analysis and discussion, we will not, therefore, explicitly include the systematic errors caused by the sky fluctuation.

Neither galaxy shows significant iron line emission. The 90% upper limits on the equivalent width (EW) of a line at 6.7 keV are 420 eV and 290 eV for NGC 253 and M83, respectively. A thermal plasma of $kT = 6 \sim 8$ keV having solar abundance would have an EW around 1 keV. Therefore, iron lines for these galaxies are factors of 2–3 less than expected from the simple thermal plasma.

The X-ray luminosity from the starburst nucleus of NGC 253 originating from collapsed stellar remnants (neutron stars or black holes) would amount to several times $10^{39}$ ergs s$^{-1}$ (Rieke *et al.* 1980). These stellar remnants should reside in massive binaries by analogy with the Galactic X-ray sources, hence producing very hard X-ray spectra. The observed spectra of starburst galaxies discussed here are significantly softer than those of X-ray pulsars. We have studied the maximum allowed flux of X-ray pulsars by inclusion of their spectral form in the spectral fitting. The assumed pulsar spectrum has a power-law form of photon index 1.0, with an exponential cutoff (*e*-folding energy of 25 keV) introduced above 10 keV (see, e.g., White, Swank, and Holt 1983). Thermal bremsstrahlung is assumed for the rest of the galaxy spectra, and $N_{\rm H}$ is fixed at the Galactic value. The 90% upper limits of the pulsar luminosities are shown in Table 1. Since our data cannot distinguish the nuclear luminosity from those coming from other regions, the upper limit for NGC 253 ($3 \times 10^{39}$ ergs s$^{-1}$) allows the Rieke *et al.* estimation on the nuclear luminosity. We note that the allowed pulsar luminosity is higher than the measured nuclear X-ray luminosity by Fabbiano and Trinchieri (1984).

## III. COMPARISON WITH THE *Einstein* RESULTS

The present observations of NGC 253 and M83 with *Ginga* have provided X-ray spectra of these starburst galaxies in the energy range 2–20 keV for the first time. It is found that these galaxies produce fairly hard X-ray emission, and the spectra can be fitted with thermal bremsstrahlung of $kT = 6 \sim 7$ keV. By comparing the *Ginga* results with the previous *Einstein* observations, we can investigate the origin of the X-ray emission.

For NGC 253, the *Ginga* spectrum implies 0.2–4.0 keV and 1.2–10.2 keV unabsorbed luminosities of $\sim 1.2 \times 10^{40}$ ergs s$^{-1}$ and $1.3 \times 10^{40}$ ergs s$^{-1}$, respectively, assuming that the spectrum is absorbed only by the Galactic $N_{\rm H}$ of $1.3 \times 10^{20}$ cm$^{-2}$ (Heiles 1975). The 0.2–4.0 keV luminosity is very close to the derived IPC value of $1.1 \times 10^{40}$ ergs s$^{-1}$ by Fabbiano (1988), although the 1.2–10.2 keV luminosity is a factor of 2 lower than the less reliable MPC value. This flux agreement supports that the overall X-ray spectrum of NGC 253 is described by a simple thermal spectrum over the IPC and *Ginga* energy range.

The *Einstein* IPC result indicates that the count rate from the nuclear region of NGC 253 (within about 3 kpc in radius) is about the same as that from the surrounding disk and the halo component, but the nuclear emission showed significant absorption with $N_{\rm H} \sim 10^{21}$ cm$^{-2}$ (Fabbiano 1988). The temperature is very loosely constrained with IPC. A broad range of temperature, 1–7 keV, is allowed for both nuclear and the outer regions. These IPC results suggest that both nuclear and outer regions can equally contribute to the *Ginga* flux from NGC 253. The X-ray spectrum obtained with *Ginga* can be fitted both with thermal and power-law models. The thermal bremsstrahlung model indicates smaller $N_{\rm H}$ ($< 1.7 \times 10^{21}$ cm$^{-2}$) consistent with the IPC result for the whole galaxy by Fabbiano (1988), whereas the power-law model requires much higher absorption column ($N_{\rm H} > 1.6 \times 10^{21}$ cm$^{-2}$). Therefore, it is likely that the overall emission from NGC 253 in 2–20 keV is better described by the thermal spectrum with a temperature of $\sim 6$ keV than the power-law model. However, we note here that spectra from low-mass X-ray binaries look very similar in 2–10 keV to the thermal spectra (Mitsuda *et al.* 1984; Makishima *et al.* 1989). Since the quality of the present data is insufficient to make a detailed comparison, the agreement with the thermal spectrum does not exclude a significant contribution from point sources.

The spectrum of M83 corrected for the nearby AGN, MS 1332.6−2935, is as hard as that of NGC 253 and characterized by either thermal emission with $kT \sim 7$ keV or a power law with photon index $\Gamma \sim 2$. No significant excess absorption over the Galactic $N_{\rm H}$ ($5 \times 10^{20}$ cm$^{-2}$; Stark *et al.* 1990) is required for either model. The best-fit thermal model implies a 0.5–3.0 keV luminosity of $6 \times 10^{39}$ ergs s$^{-1}$. Given the uncertainty due to the AGN contamination in the LAC field of view, this is in good agreement with the IPC value of $6 \times 10^{39}$ ergs $s^{-1}$. Trinchieri, Fabbiano, and Palumbo (1985) suggest that it is unlikely that M83 has a Seyfert-like nucleus based on the extended HRI image and the low ratio of X-ray to H$\alpha$ emission.

## IV. DISCUSSION

The statistical studies on the X-ray properties of spiral galaxies (Fabbiano, Trinchieri, and Macdonald 1984; Fabbiano and Trinchieri 1985) show that the X-ray luminosities are well correlated with the blue magnitudes, rather than the mass indicators ($H$ and $B-H$). The HRI image of M83 shows that the X-ray surface brightness does not correlate with the spiral arms but is distributed more smoothly (Trinchieri, Fabbiano, and Palumbo 1985), suggesting that it originates from the old exponential disk. They suggest that the major origin of the X-ray emission from spiral galaxies is a population of discrete sources, possibly low-mass X-ray binaries (LMXBs).

The *Einstein* observations of the nearest spiral galaxy M31 revealed that its X-ray emission is indeed dominated by $\sim 100$ discrete sources. In particular, most of the X-ray luminosity comes from the so-called bulge sources resolved with the HRI (Van Speybroeck *et al.* 1979). The spectrum of M31 observed with *Ginga* can be approximated with a thermal emission with $kT \sim 7$ keV, but the superior statistics of the data have allowed Makishima *et al.* (1989) to demonstrate that it is much better described by a superposition of many LMXB spectra. The X-ray emission of the Galaxy as a whole is also dominated by LMXBs, and the total luminosity is estimated to be roughly half as much as that of M31 (e.g., Forman *et al.* 1978). Since the mass of the Galaxy is also about half that of M31 (e.g., Allen 1973), the X-ray luminosity per unit mass would be similar between these two galaxies.

The observed spectra of NGC 253 and M83 are similar to those of low-mass X-ray binaries (LMXB) but significantly softer than those of X-ray pulsars as shown earlier. The observed 2–10 keV luminosities of NGC 253 and M83 are roughly twice that of M31 ($L_X = 4 \times 10^{39}$ ergs $s^{-1}$; Makishima *et al.* 1989). On the other hand, the blue-band luminosities of NGC 253 and M83 are lower than that of M31 by 30%–40%. The relationship between 2–10 keV luminosity and blue luminosity is plotted for these three galaxies in Figure 3. The estimated mass of M83 ($8 \times 10^{10}$ $M_\odot$) is a factor of 2.5 smaller than that of M31 ($2 \times 10^{11}$ $M_\odot$; Faber and Gallagher 1979). Therefore, the X-ray emission of NGC 253 and M83 can be up to 5 times more efffcient per unit mass than in M31 and the Galaxy.

The study by Fabbiano and Trinchieri (1985) shows that, if X-ray luminosity is normalized by $B$ band luminosity of the galaxy, M31 in one of the most underluminous in X-rays. *IRAS* observations show very weak IR radiation from M31 (Habing *et al.* 1984), indicating that the starburst activity in M31 is extremely low (Rieke, Lebofsky, and Walker 1988). On the other hand, X-ray-to-optical luminosity ratios for NGC 253 and M83 are within the general scatter for spiral galaxies (Fabbiano and Trinchieri 1985). The predominancy of LMXBs in the overall X-ray emission is estabished in M31 and the Galaxy, the two rather inactive galaxies in the star formation. This in turn suggests that the higher X-ray luminosities of NGC 253 and M83 (and other spirals) may be related to the higher starburst activities in these galaxies.

The *Einstein* images of NGC 253 clearly show the presence of a population of individual bright X-ray sources, whose integrated luminosity is estimated at about $4 \times 10^{39}$ ergs $s^{-1}$ in 0.2–4.0 keV (Fabbiano and Trinchieri 1984). Therefore, some 40% of the X-ray luminosity could come from discrete point sources. In M83, the agreement between the stellar surface brightness distribution and the X-ray surface brightness distribution seen in the *Einstein* data argues for the presence of a population of evolved stellar X-ray–emitting sources (Trinchieri, Fabbiano, and Palumbo 1985).

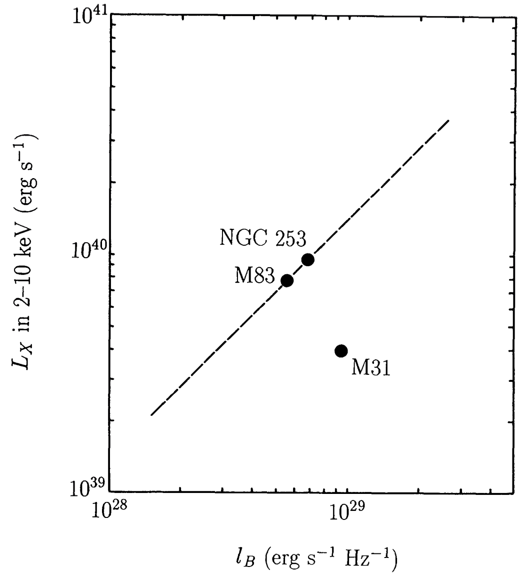


FIG. 3.—Correlation between the 2–20 keV X-ray luminosity $L_X$ and the blue luminosity $l_B$ for NGC 253, M83, and M31 (taken from Makishima *et al.* 1989). Dashed line indicates the constant $L_X/l_B$ value consistent with those for NGC 253 and M83.

The most important young stellar component which can contribute to the 2–10 keV X-ray emission is X-ray pulsars, by analogy with the Galaxy. We have shown, however, that the hard pulsar spectrum can be present at most 30% of the total 2–10 keV flux from NGC 253. Therefore, the dominance of the same kind of massive X-ray pulsars as seen in the Galaxy is excluded. The same view has been presented for M83 by Trinchieri, Fabbiano, and Palumbo (1985) based on the lack of correlation between the X-ray surface brightness and the spiral arms.

As mentioned above, association of X-ray emission with evolved stellar population has been suggested by Trinchieri, Fabbiano, and Palumbo (1985). However, the time scale for starburst activity is estimated to be around $\sim 10^7$ yr (Rieke, Lebofsky, and Walker 1988). This is significantly shorter than the typical lifetime of LMXBs ($\gtrsim 10^9$ yr; see, e.g., Joss and Rappaport 1979); therefore, it is very unlikely that the high X-ray luminosity (compared with M31) of NGC 253 and M83 is caused by LMXBs even though their spectral shape is compatible with the observed ones. Emission from hot gas (both within and outside of supernova remnants) formed from repeated supernova explosions is the remaining natural interpretation of the observed spectra. Therefore, the observed spectra, combined with the *Einstein* results, supports the view that a thermal component is making a considerable contribution ($>50\%$) in the X-ray emission rather than LMXBs or X-ray pulsars. Note that, given the quality of the *Ginga* data as well as the *Einstein* images, we have no way to conclude simple dominancy of the thermal component for these galaxies. As shown below, the absence of strong iron emission line also makes the simple hot gas interpretation difficult.

It seems certain that at least some fraction (>20% in NGC 253; Fabbiano 1988) of the hard X-ray emission from NGC 253 and M83 come from the thermal emission from hot gas, whose existence in the form of an extended halo has been established for NGC 253 with the *Einstein* imaging observations (Fabbiano and Trinchieri 1984; Fabbiano 1988). Thermal emission with temperatures of 6–7 keV should produce a strong iron emission line at 6.7 keV with EW $\sim 900$ eV (e.g., Rothenflug and Arnaud 1985) for material with solar abundance (e.g. Allen 1973). However, the observed EWs for NGC 253 and M83 are factors of 2–3 less than this. A similar deficiency of the iron line intensity (EW $\sim 200$ eV) is also reported for M82 (Makishima and Ohashi 1988; Ohashi *et al.* 1990) which is a very active starburst galaxy showing a pronounced X-ray halo (Watson, Stanger, and Griffiths 1984; Fabbiano 1988; Ohashi *et al.* 1990). Although we cannot precisely separate the contributions from hot gas and discrete X-ray sources, these results suggest that there may be some common reason that can explain the lack of strong iron emission line in these starburst galaxies. IR observations have revealed that a significant fraction of interstellar gas remains in the form of dust in these galaxies (Telesco 1988). Most of the iron may be initially contained in dust grains, and in this case such iron-containing grains may not be sufficiently ionized within the rather short time scale of the starburst activities.

Fabbiano and Trinchieri (1985) estimate the contribution from discrete sources in X-ray emission from NGC 253 as $4.4 \times 10^{39}$ ergs s$^{-1}$ in 0.2–4.0 keV. Following this estimation and assuming that the remaining 60% of the 2–10 keV flux of NGC 253 is entirely from an isothermal hot gas, we can give an upper limit on the mass of the hot gas component. (Because of the AGN contamination, estimation for M83 is highly uncertain.) Using the best-fit values of the thermal bremsstrahlung model shown in Table 1, the emission integral $n_e^2 V$, with $n_e$ the electron number density and $V$ the volume, becomes $3 \times 10^{62}$ cm$^{-3}$. Since the gas cannot be gravitationally bound to the galaxy, it should escape with thermal velocity from the system. Using a crude assumption that the distribution of the hot gas is spherical with a radius of 3 kpc (see Fabbiano 1988), the total mass and the electron density become $\sim 3 \times 10^7 \eta^{1/2}$ $M_\odot$ and $\sim 1 \times 10^{-2} \eta^{-1/2}$ cm$^{-3}$, respectively, where $\eta$ denotes the filling factor of the hot gas and ranges from 0.01 to 0.1 (Fabbiano 1988). If the gas is escaping with the sound velocity, the mass loss rate would be $\sim 40\eta^{1/6}$ $M_\odot$ yr$^{-1}$. Rieke, Lebofsky, and Walker (1988) discuss that in the course of the starburst activity of NGC 253 a total mass of $10^8$ $M_\odot$ would have been ejected in a time scale of $10^7$ yr. This value is compatible with the upper limit estimated here.

The *Ginga* observations of two starburst galaxies, NGC 253 and M83, have provided the overall 2–10 keV spectra, which suggest major contribution from hot gas component rather than X-ray pulsars. For further study of this interesting possibility, we need to separate the halo emission from those of discrete sources in the 0.1–10 keV energy band. An imaging X-ray mission which has moderate angular resolution ($\sim 1'$) with good X-ray sensitivity up to 10 keV (with sufficient energy resolution to resolve weak iron emission lines) will make a significant progress in the physics of normal galaxies.

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