Diffuse X-ray emission in the Large Magellanic Clouds

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Abstract.

We investigated the diffuse X-ray emission in the Large Magellanic Cloud (LMC), which spreads along the optically bright position, called optical bar region, with ASCA satellite, which has better energy resolution than Einstein and ROSAT. We used all the available archive data in the LMC region and the data obtained in the LMC survey project. We found that the diffuse X-ray emission in the LMC is thermal in origin, and that the spectrum distributes in the energy range of only below $\sim$ 2keV. The diffuse X-ray emission in the Super Giant Shell (SGS) LMC4, which is located at the northern part of the LMC and includes famous star forming region Shapley Constellation III, is also investigated.

1. Introduction

It is well known that there exists a great deal of diffuse X-ray emission in the LMC. Since satellites with imaging capability came into use, such as Einstein and ROSAT, many observations of this diffuse X-ray emission were carried out.

Wang et al. (1991) made the diffuse X-ray map in the LMC with the Einstein IPC data, after removing all the discrete sources. They found that the diffuse X-ray emission extended over a very extensive region and that the surface brightness of it was far from uniform. They also reported that the spectrum of this diffuse X-ray was reproduced by the thin-thermal plasma model with temperature of $\sim$ 0.94keV around 30Dor region, and $\sim$0.27keV 2° away from 30Dor. However, the abundances of the elements were frozen to the solar value, though those in the LMC were quite lower.

Snowden & Petre (1994) made a beautiful map of LMC with the ROSAT PSPC data, making the best use of the good spatial resolution of ROSAT mirror. This map clearly revealed how the diffuse X-ray emission was distributed in the LMC. The diffuse X-ray emission distributes not only along the optical bar region but also toward south direction from the 30Dor, where fewer stars exist than optical bar region. From the spectral information, if fitted with the thin-thermal plasma model, the temperature of diffuse X-ray emission was ranging from $\sim$ 0.22 keV to $\sim$ 0.86 keV. The temperature took highest around the 30Dor region.

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However, the spectral resolution of both the Einstein IPC and ROSAT PSPC was not good enough to verify whether or not the spectrum of this diffuse X-ray emission was that of the thin-thermal plasma. Here we present the spectral analysis of this diffuse X-ray emission in the LMC using the data taken with ASCA satellite, which has good enough energy resolution to solve this problem. The plasma parameters of diffuse X-ray emission along the optical bar region and SGS LMC-4 region, such as surface brightness, electron density, plasma volume, total energy and so on are also investigated.

2. Observations and Data Reduction

ASCA had observed the LMC 58 times by the end of Sep. 1999. We used all those in the archive data (49 pointing observations) and those taken in the LMC survey project during the ASCA Announce of Opportunity (AO) 7 phase (9 pointing observations), which are our own proposal observations. The total exposure time is 1920 ksec. All the archive data were obtained from NASA HEASARC (High Energy Astrophysics Science Archive Research Center) data system. Most of the optically bright position and the region towards the northern part of the galaxy where SGS LMC-4 is located, were covered with these data.

ASCA has 2 Gas Imaging Spectrometers (GISs) and 2 Solid-state Imaging Spectrometers (SISs) at the focal planes of 4 X-Ray Telescopes (XRTs). Details of these instruments are presented separately in Ohashi et al. (1996), and Burke et al. (1994), Serlemitsos et al. (1995).

Not only because GISs have larger effective area and larger fields of view than SISs, but also because the primary objectives of most of the archive data were observations of SNRs or X-ray binaries, SIS data were not suitable for investigating the overall characteristics of diffuse X-ray emission which spread over the broad region in the LMC. Therefore only GIS data were used for the analysis below.

3. Analysis

The X-ray data were screened with the normal criteria: i.e. we rejected the data obtained in the SAA (South Atlantic Anomaly), those with a cut-off rigidity lower than 4 GV, those with an elevation angle lower than 5°, and the particle events with a rise-time discrimination technique.

The diffuse X-ray spectra were accumulated from whole field of the GIS from individual pointings, after all the discrete sources which exceeded over 5 sigma signal-to-noise level threshold were subtracted. We accumulated the background spectrum from the observations of blank-sky. This background spectrum contains the Cosmic X-ray Background (CXB) and Non-X-ray Background (NXB) of the instruments. We subtracted the background spectrum from those of diffuse X-ray emission.

There is a bright X-ray binary called LMC X-1 in the LMC. Because of the poor spatial resolution of XRT, the spectra obtained from the region around LMC X-1 strongly suffered from the stray-light of this source. For such a spectra, we performed additional subtraction of the stray light spectrum from the diffuse X-ray spectra. However, there still existed some pointings heavily polluted by

the stray light from LMC X-1. We didn't use these pointings for the analysis below.

4. The diffuse X-ray emission along Optical Bar Region

4.1. Is the diffuse X-ray emission thermal in origin?

We summed up the spectra from all the region available to make diffuse X-ray spectrum in good statistics. The purpose was to address the question whether the diffuse X-ray emission in the LMC had the nature of thermal emission or non-thermal emission, which could not solved by the previous satellite observations.

The diffuse X-ray spectrum is shown in figure 1. Because the spectrum in figure 1 contains the background component, we showed it in the figure. In the spectral fitting, we first tested the absorbed power-law model (non-thermal model). The χ^2 test was performed. The Reduced-χ^2 took 268.1 (79 degree of freedom). The power-law model was absolutely rejected not only from the statistical point of view, but also from the waving behavior of the residuals from the best-fit model shown in the lower panel of figure 2. The peaks in residuals correspond to the line emission from elements.

We next used the absorbed thin-thermal plasma model for the spectral fitting. From the χ^2 test, the thin-thermal plasma model was accepted. The column density and temperature were obtained to be 7.6 (0.0–17.0) $\times 10^{20}$ cm^{-2} and $\sim 0.56(0.53--0.59)$ keV, respectively. The best-fit values of the abundances of Mg, Si and S were 0.48 (0.41–0.55), 0.36 (0.24–0.46) and 2.10 (1.50–2.61) times that of solar, respectively (the abundances of other elements were frozen to 0.3 times that of solar (Russell & Dopita 1992).).

Therefore the diffuse X-ray emission was revealed to be thermal in origin for the first time.

4.2. Do the diffuse X-ray emission have two temperature components?

It is well known that the diffuse X-ray emission in our Galaxy has two temperature plasma components. The temperature of the diffuse X-ray emission are $\sim$ 0.8 keV (called soft component) and $\sim$ 7 keV (called hard component), respectively. The soft and hard components are said to distribute in about the same way along the Galactic plane; the scale height and the scale depth were obtained to be $\sim$100pc and $\sim$10kpc, respectively (Kaneda PhD thesis 1998).

The apparent temperature of diffuse X-ray emission seen in the LMC is as high as that of soft plasma component in our Galaxy. We are curious to know whether the LMC also has the harder temperature plasma component like our Galaxy has, because no other galaxy than Milky Way galaxy is known to have plasma component whose temperature is as high as $\sim$ 7keV.

At the first glance, the diffuse X-ray emission in the LMC has only one temperature plasma component ($\sim$ 0.6 keV). In order to estimate the intensity of the hard plasma component in the LMC, we made an assumption that it distributed in the same way as that of our Galaxy does. The only difference in the situation between the plasmas in both galaxies is the line of sight from us; the Milky Way Galaxy has edge on view while the LMC has face on view.

In the case of our Galaxy, because of the absorption by the interstellar matter, the effective scale depth for the soft plasma component becomes ∼2kpc, which is smaller than the actual scale depth of ∼ 10kpc. However, in the case of the LMC the scale depths for both soft and hard components should be ∼ 10 kpc, not only because we see both plasma components from a face-on view but also the scale heights of ∼ 100 pc is small enough for both components to eliminate through toward us. Therefore, from the plasma parameters of our Galaxy shown in table 1, the intensity of the hard plasma component in the LMC should be ∼ $2\times10^{38}/4\times10^{39} = 1/20$ times that of the soft plasma component.

In the spectral fitting for the diffuse X-ray emission in the LMC, we interpolated the hard plasma component whose temperature and the intensity were frozen to 7keV and 1/20 times that of soft component, respectively (abundances are frozen to 0.3 solar). However, no improvement was found in the χ^2 value. We concluded that no significant evidence of the hard plasma component was found in the diffuse X-ray emission in the LMC within the statistics.

4.3. Plasma parameters

The average surface brightness of the diffuse X-ray emission was revealed to be ∼ 1.8×10^{-6} ergs s^{-1} cm^{-2} str^{-1} (0.7–10keV). The systematic error of the surface brightness caused by the uncertainty of the arf response was within 30%. The average volume emissivity obtained from the expression, $\bar{\varepsilon} = (4\pi B)/(\eta l)$ (B : surface brightness, η : filling factor, l : the depth of plasma), was ∼$7\times$ 10^{-27} η^{-1} ergs s^{-1} cm^{-3}.

The electron density of the plasma explained as $n_{\rm e} = \sqrt{\varepsilon/\lambda(T)}$ ($\lambda(T) = 3.6\times10^{-23}(kT)^{-0.6}$, $0.01< kT <$3keV : cooling function), became ∼1.2 $\times$ 10^{-2} $\eta^{-0.5}$ cm^{-3}.

From the extent of diffuse X-ray emission in the ROSAT map and the depth shown in Wang et al. (1991), the volume of X-ray emitting plasma V was assumed to be ∼$7\times10^{64}\beta$ cm^3 (β represents the uncertainty of the volume).

Therefore the total energy of the X-ray emitting plasma ($U = 3\ n_{\rm e}\ kT\ V$) along the optical bar region was ∼2.0 $\times$ 10^{54} $\eta^{-0.5}$ β ergs, while that of soft component in our Galaxy was ∼ $2\times$ 10^{55} β_s $\eta_s^{-0.5}$ ergs. If we consider the mass ratio between LMC and our Galaxy (1 : 10), the total energy of this diffuse X-ray along the optical bar region alone is as large as that in our Galaxy.

The average pressure of the diffuse X-ray plasma was ∼2.1 $\times$ 10^{-11} $\eta^{-0.5}$ ergs cm^{-3}, an order more than that of the typical warm ionized medium pressure in the LMC (∼ 5.5 $\times$ 10^{-13} ergs cm^{-3}) (de Boer & Nash 1982). It clearly shows that some kind of forces must be working to the diffuse X-ray emitting plasma to confine them or else it is extending outward.

5. The diffuse X-ray emission in the SGS LMC-4

The average temperature of the diffuse X-ray emission in the SGS LMC-4 was 0.58 (0.47–0.62) keV, though the previous ROSAT result indicated it was ∼0.2keV (Bomans et al. 1994). It may be partly because the region from which we accumulated spectrum was a little bit different from that they chose. We found the average surface brightness of the diffuse X-ray around SGS LMC4 region to be ∼8.4 $\times$ 10^{-7} ergs s^{-1} cm^{-2} str^{-1} in the 0.7–10keV band. For the

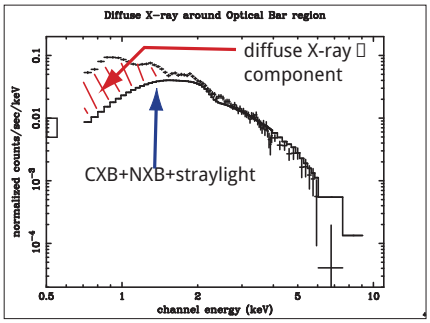

Figure 1. The diffuse X-ray spectrum around the optical bar region.

comparison with the previous ROSAT results (Bomans et al. 1994), we got the surface brightness in the 0.1–2.4keV band to be 1.5×10^{-6} ergs s^{-1} cm^{-2} str^{-1}, assuming the best fit model holded below the ASCA band (0.7–10keV). The results was consistent with the previous results shown in Bomans et al. (1994). We also got the plasma parameters of the diffuse X-ray in the LMC4 region. The average volume emissivity $\bar{\varepsilon}$, electron density n_e, total energy U and the pressure p were $\sim 3.0 \times 10^{-27}$ η_{LMC4}^{-1} ergs s^{-1} cm^{-3}, $\sim 7.6 \times 10^{-3}$ $\eta_{LMC4}^{-0.5}$ cm^{-3}, $\sim 7.3 \times 10^{53}$ $\eta_{LMC4}^{-0.5}$ β_{LMC4} ergs and $\sim 1.3 \times 10^{-11}$ $\eta_{LMC4}^{-0.5}$, respectively (again, η_{LMC4} and β_{LMC4} are the filling factor and the uncertainty of the volume in LMC4 region, respectively). In the analysis above, the geometry and the volume of the LMC4 were assumed to be cylindrical and $\sim \pi \times (600\mathrm{pc})^2 \times 1200\mathrm{pc}$, as were shown in Bomans et al. (1994).

power-law model + NH

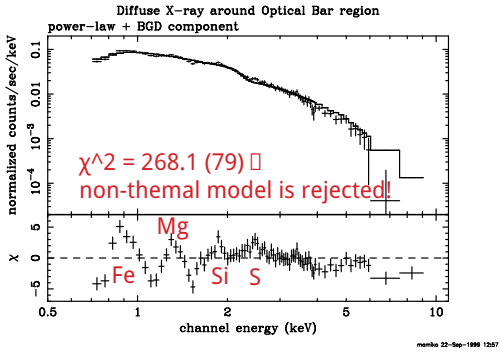

Figure 2. The absorbed power-law model fit.

thin-thermal model + NH

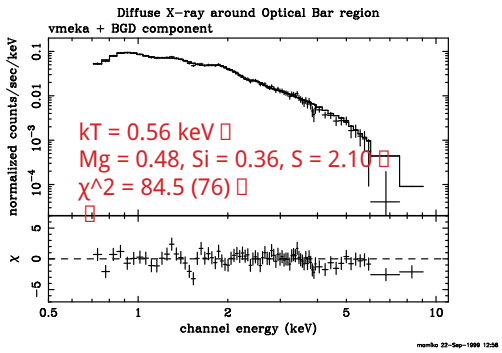

Figure 3. The absorbed thin-thermal plamsa model fit.

References

Bomans, D. J., Dennerl K & Kurster, M. 1994, A&AL 283, L21

Burke, B. E., Mountain, R. W., Daniels, P. J., Dolat, V. S., & Cooper, M. J. 1994, IEEE Trans. Nucl. Sci., 41, 375

de Boer, K. S. & Nash, A. G. 1982, ApJ 255, 447

Kaneda, H. 1998 PhD thesis

Table 1. Plasma parameters of our Galaxy

	soft component	hard component
surface brightness (ergs s^{-1} cm^{-2} str^{-1})	1.9×10^{-6}	5.3×10^{-7}
emission volume(cm^3)	1.0×10^{66} β	1.0×10^{66}
overall luminosity(ergs s^{-1})	4×10^{39} β	2×10^{38}
total energy(ergs)	2×10^{55} β $\eta^{0.5}$	1×10^{56} η'$^{0.5}$

[1]All the parameters are obtained within the energy band of 0.7–10keV.

[2]β represents the uncertainties of the volume.

[3]η and η' represent the filling factor.

Ohashi, T., et al. 1996, PASJ 48, 157
Serlemitsos, P. J., et al. 1995, PASJ 47, 105
Snowden, S. L. & Petre, R. 1994, ApJL 436, L123
Wang, Q. & Helfand, D. J. 1991, ApJ 379, 327