Diffuse X-ray in the Large Magellanic Cloud : ASCA observation

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Abstract

Successive X-ray satellites, for example, Einstein Observatory and ROSAT Observatory, have observed the Large Magellanic Cloud (LMC) and brought us excellent X-ray maps of this galaxy. The maps told us that there exists a great deal of diffuse X-ray in the main body of the LMC. One theory holds that this diffuse X-ray spreads out from the famous star forming region 30 Dor. However, the detail of the origin of the plasma is not known at all.

ASCA observations have already covered the main body of the LMC. The excellent spectral resolution of ASCA which continues up to hard X-ray band shows that the diffuse X-ray emission in the LMC is thermal in origin. We investigated the spatially resolved temperature of diffuse X-ray emission and found that it did not differ much from place to place. The diffuse emission had only a soft component below ∼2keV. The overall temperature was ∼0.5keV around optical bar region and Super Giant Shell (SGS) LMC4 region. We further investigated the detail characteristics of the plasmas around the optical bar and SGS LMC4 region.

1 Introduction

Since satellites with imaging capability came into use, such as Einstein and ROSAT, many observations of the diffuse X-ray in the LMC 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 the diffuse X-ray extended over a very extensive region and that its surface brightness was far from uniform. They also reported that the temperature of this diffuse X-ray was ∼ 0.94keV around 30 Dor region, and ∼0.27keV in the region 2° away from 30 Dor, assuming that the X-ray is emitted from the thin-thermal plasma. However, in the spectral fitting the abundance was frozen to the solar value, though that in the LMC was ∼0.3 solar value (Russel & Dopita 1992).

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 revealed clearly how the diffuse X-ray was distributed in the LMC. The diffuse X-ray distributes not only along the optical bar but toward south from the 30 Dor, where fewer stars exist than the optical bar region. From the spectral information, if fitted with the thin-thermal plasma model with abundance frozen to 0.3 solar value, the temperature of diffuse X-ray was ranging from ∼0.3keV to ∼0.6keV, and highest around the 30 Dor region.

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 was that of the thin-thermal plasma. Here we present the spectral analysis of this diffuse X-ray in the LMC using the data taken with ASCA satellite, which has better spectral resolution than Einstein IPC and ROSAT PSPC.

2 Observation and Data Reduction

The analysis presented here is based on all the ASCA GIS archive pointing observations in the LMC region and the part of the pointing observations of the LMC survey project, which is now being carried out in ASCA Announce of Opportunity 7 (AO7) phase. In the LMC survey project, 10 pointing observations with 40ksec exposure for each are planned. In this stage, 6 out of 10 pointing observations were already over. Our results contained these 6 pointing observations. All the ASCA archive data used here were taken from the database provided by NASA GSFC. With all of these observations (1760 ksec exposure for total), we could cover about one-third of the LMC, including the main optical body.

The figure 1 and figure 2 show the LMC mosaic images taken with ASCA GIS. The former and latter are the maps in low (0.7–2keV) and high (2–7keV) energy band. The discrete sources seen in these maps are SNRs or X-ray binaries or foreground stars. Besides these discrete sources, the diffuse X-ray spreading over the broad region of the LMC is also detected, which is prominent in figure 1. Note that the apparently diffuse structure distributed around bright X-ray binary LMC X-1 in the hard X-ray band (see figure2) is an artificial, so-called stray light.

We constracted the diffuse X-ray spectra from whole field of the GIS for individual pointings in the following way. First, we subtracted all the discrete sources which exceeded over 5 sigma signal-to-noise level thresholds. Second, from the diffuse X-ray spectra, we subtracted the background spectrum which was accumulated from the observation of the blank-sky region, The background spectrum contains the Cosmic X-ray Background (CXB) and the Non-X-ray Background (NXB). In addition where the effect of stary light from LMC X-1 is serious, we performed an additional subtraction of the stray light spectrum from those of the diffuse X-ray. However, there still exist some pointings with heavily polluted by the stray light from LMC X-1. We didn't use these pointings for the spectrum analysis below.

3 The Diffuse X-ray in the LMC

The ASCA spectrum of the diffuse X-ray is reproduced by those of thin-thermal plasma. The diffuse X-ray spectrum has only a soft component as is seen in the ROSAT band (below ∼2keV) and no significant evidence of the harder component was detected.

If the diffuse X-ray in the LMC really has only a soft component, it is quite different from the plasmas seen in Our Galaxy, which is so-called Galactic Ridge X-ray Emission (GRXE). For the spectral fitting, we fixed the abundances of the elements in the thin-thermal plasma to be 0.3 times that of the solar value (Russel & Dopita 1992).

The spatially resolved X-ray spectra show that the temperature of diffuse X-ray distributed along the optical bar is overall ∼ 0.55keV. However, that of diffuse X-ray slightly upward (to the north) from the optical bar region (near to N44) takes ∼0.15keV. Further upward to the region around Super Giant Shell (SGS) LMC4 and LMC5, the temperature increases again to be ∼0.55keV.

We discuss the two interesting regions in more detail.

3.1 Optical Bar region

The previous ROSAT results said about the diffuse X-ray temperature along the optical bar that the bulk of the diffuse emission has a temperature of 0.3–0.6keV, with maxima occurring to the northeast of LMC X-1 and in the 30 Dor (Trümper et al. 1991). We did not confirm such a temperature gradient. It is partly because we could not use the data around 30 Dor region because of the heavy pollution by the LMC X-1 stray light. However, our temperature determination seems to be more reliable, because ASCA spectral resolution is better than that of ROSAT, and also because their temperature determination was through the thin-thermal plasma model fitting with fixed column density for all region. In our spectral fitting, we left the column density to be free and found that it takes higher value in the region around 30 Dor than rest of the places.

The average surface brightness of the diffuse X-ray around the bright optical bar region was revealed to be $\sim 1.80 \times 10^{-6}$ ergs/s/cm^2/str (0.7–10keV). The systematic error of the surface brightness caused by the uncertainty of arf response is about 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), is $\sim 7\times 10^{-27}\ \eta^{-1}$ ergs/s/cm^3.

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

From the extent of diffuse X-ray in the ROSAT map and the depth shown in the Wang et al. (1991), the volume of X-ray emitting plasma V was assumed to be $\sim 7\times 10^{64}\beta$ cm^3 (β represents the uncertainty of the volume).

Therefore the total energy of the X-ray emitting plasma (U = 3 n_e kT V) along the optical bar region is $\sim$2.0 $\times$ 10^{54} $\eta^{-0.5}$ β ergs, while that of soft component in our Galaxy is $\sim$ 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 is $\sim$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 ($\sim$ 5.5 $\times$ 10^{-13} ergs/cm^3) (de Boer & Nash 1982). It clearly shows that the diffuse X-ray plasma along the optical bar region is extending outward, which is consistent with the scenario that SGS LMC2 (which is located inside the optical bar region and the diffuse X-ray from this SGS accounts for large amount of that along the optical bar region) is a blowing out supperbubble (Wang and Helfand 1991). It is likely that the diffuse X-ray along the optical bar region is originated from the same mechanism, possiblly the continuous heating by the supernova explosions and stellar winds. This is because no clear differences are seen among the plasma parameters (temperature and abundance) from variable positions along the optical bar region. The surface brightness is the largest in the eastern region around 30 Dor and decreases towards the western region along the optical bar, therefore the pressure of hot gas decreases towards the western region. This is likely that both the star forming activity and the supernova explosion rate are higher at eastern region.

3.2 Super Giant Shell LMC4 region

The previous ROSAT result indicated that the temperature of the diffuse X-ray in the SGS LMC4 was $\sim$0.2keV (Borman et al. 1994), which is quite different from our result. It may partly because the region from which we accumulated spectrum is a little bit different from that they chose. However, more careful check between two results should be needed.

We found the average surface brightness of the diffuse X-ray around SGS LMC4 region to be $\sim$8.4 $\times$ 10^{-7} ergs/s/cm^2/str in the 0.7–10keV band. For the 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 $\times$ 10^{-6} ergs/s/cm^2/str, assuming the best fit model holds below the ASCA band (0.7–10keV). The results is 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/k are $\sim$ 3.0$\times$$10^{-27}$ η_{LMC4}^{-1} ergs/s/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$9.7 $\times$ 10^4 $\eta_{LMC4}^{-0.5}$ K, 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 $\sim$ π $\times$ (600pc)^2 $\times$ 1200pc, as is shown in Bomans et al. (1994).

4 References

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

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

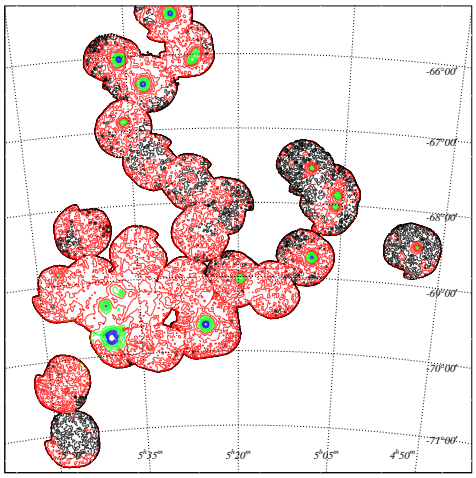
Russel S.C. & Dopita M.A. 1992, ApJ 384, 508

Snowden S.L. & Petre R. 1994, ApJL 436, L123

Trümper J., Hasinger G., Aschenbach B., et al. 1991, Nature 349, 579

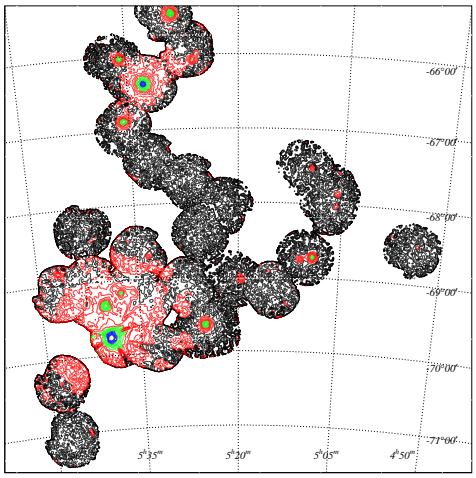
Wang Q., Hamilton T., Helfand D.J., Wu X. 1991, ApJ 374, 475

Wang Q. & Helfand D.J. 1991, ApJ 379, 327



LMC Mosaic Image (0.7--2.0keV)

Figure 1: The Mosaic image of the LMC in 0.7–2.0 keV band.



LMC Mosaic Image (2.0--7.0keV)

Figure 2: The Mosaic image of the LMC in 2.0–7.0 keV band.