New Views of the Magellanic Clouds
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10^6-10^7 K Gas in the Magellanic Clouds

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Abstract. The Large Magellanic Cloud contains an extensive distribution of hot plasma and is one of the brightest extragalactic regions in the diffuse 0.5 – 2.0 keV X-ray sky. The plasma is not isothermal but increases in color temperature from west to east from $\sim 10^{6.6}$ K to $\sim 10^{6.9}$ K. The total flux from this plasma is $\sim 10^{38}$ ergs s^{-1}. The average emission measure is ~ 0.014 cm^{-6} pc, which if the emitting plasma is distributed uniformly throughout the LMC, implies a space density of $n_e \sim 0.002$ cm^{-3}. There is an apparent $^1/_4$ keV enhancement in the southwest of the LMC, which if associated with the LMC implies a considerable emission measure of $\sim 10^6$ K plasma. (The foreground column density of Galactic neutral hydrogen is $\sim 6 \times 10^{20}$ cm^{-2}, or several optical depths for $^1/_4$ keV emission.)

The Small Magellanic Cloud exhibits less diffuse X-ray emission in the 0.5 – 2.0 keV band than the LMC with a total flux of $\sim 4 \times 10^{36}$ ergs s^{-1}. The average emission measure of ~ 0.006 cm^{-6} pc also implies a space density of $n_e \sim 0.002$ cm^{-3}. The optical depth of Galactic HI for $^1/_4$ keV X-rays from the SMC is considerably lower than that for the LMC. However, while there is a significant variation in the $^1/_4$ keV band intensity over the SMC field, it is in general not particularly well correlated with anything associated with the SMC, although there is an enhancement which may be related to the leading edge of the SMC. Considerably more work is needed to unravel the origin of the structure, which may be associated instead with either emission or absorption variations in either the disk or halo of the Milky Way.

1. Introduction

The Magellanic Clouds (MCs) provide ideal subjects for the study of entire galactic systems. They are near enough so that a substantial fraction of their X-ray point and small-scale extended sources can be adequately resolved and separated from any background of diffuse origin. While diffuse X-ray emission (0.1 – 2.0 keV is the energy range of choice to observe the emission from 10^6 K to 10^7 K plasmas) has been previously observed in the Magellanic Clouds (e.g., Wang et al. 1991; Wang 1991) new maps of the Clouds are presented and analyzed here which include essentially all of the *ROSAT* PSPC observations.

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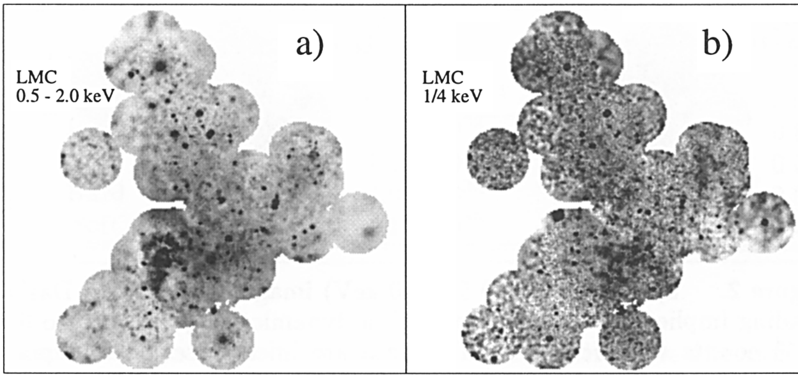

Figure 1. a) Hard band (0.5 – 2.0 keV) image of the LMC. Darker shading implies higher intensity with a dynamic range of 10^{-4} to 3×10^{-3} counts s^{-1} $arcmin^{-2}$. The data are square-root scaled. b) Soft band (0.1 – 0.284 keV) image of the LMC. The dynamic range is 3.5×10^{-4} to 9×10^{-4} counts s^{-1} $arcmin^{-2}$. The data are linearly scaled. The apparent circles of coverage are produced by individual observations and are $\sim 1.5°$ in diameter. The 30 Dor region and Bar are located in the southern half of the image.

2. Data and Data Reduction

The data presented here were obtained over the life time of the *ROSAT* (Trümper 1992) PSPC in a large number of mostly independent observations. The data were accessed through the *ROSAT* public archive of the HEASARC at NASA/GSFC. In order to create the large-area coverage of the fields, the observations ($\sim$ 140 for the LMC, $\sim$ 20 for the SMC) needed to be mosaicked together requiring careful analysis of non-cosmic background constituents and uniformity of treatment of the observations. The processing required three separate steps.

Step 1: Reduction of individual observations – Following the methods laid out in Snowden et al. (1994) and using the software[1] described in Snowden & Kuntz (1998), all pointings at targets in the LMC and SMC were analyzed. Times of anomalous backgrounds were excluded, the particle background, scattered solar X-ray background, and long-term enhancements (see Snowden et al. 1994; Snowden et al. 1995) were modeled and subtracted, and the effective exposure (including vignetting and detector artifacts) determined. Observed counts, modeled background counts, and effective exposure were cast into images in sky coordinates. Multiple pointings in the same target direction, from either the same or different observations, were merged into one set of maps.

Step 2: Determination of residual background offsets – Because of their temporal nature, the contamination from long-term enhancements mentioned

[1]The Extended Source Analysis Software, ESAS, package can be obtained from the NASA/GSFC *ROSAT* Guest Observer Facility through the legacy anonymous ftp account under ftp://legacy.gsfc.nasa.gov/rosat/software/fortran/sxrb.

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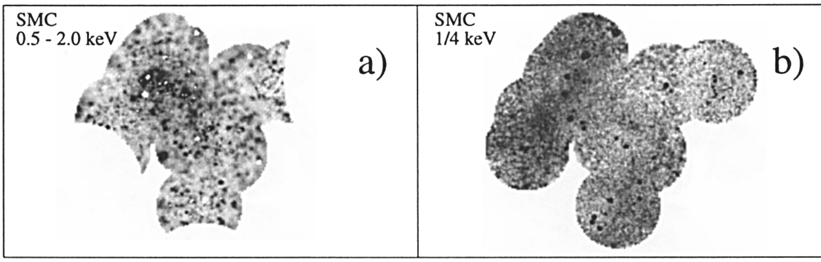

Figure 2. a) Hard band (0.5 – 2.0 keV) image of the SMC. Darker shading implies higher intensity with a dynamic range of 10^{-4} to 6×10^{-4} counts s^{-1} $arcmin^{-2}$. The data are linearly scaled and point sources have been removed for clarity of the diffuse emission. b) Soft band (0.1 – 0.284 keV) image of the SMC. The dynamic range is 7×10^{-4} to 1.4×10^{-3} counts s^{-1} $arcmin^{-2}$. The data are linearly scaled. The Bar runs from the southwest to the northeast through the image.

above in general can not be completely purged from individual observations. This can lead to a variable zero-level offset between observations. The zero-level offset, while perhaps not removed, can be at least made more uniform over the set of observations by analyzing the region of overlap between all adjacent pointings. For these observations, a set of simultaneous equations including all of the overlaps was set up and solved by single-value deconvolution to determine the best-fit offset values for each observation. Software to do this is included in the ESAS package and is discussed in Kuntz & Snowden (1998).

Step 3: Mosaicking of the observations – The final step was to mosaic the maps from the individual or combined observations into a common projection. This was done individually for the count, model background count, and exposure maps. The model offset counts from Step 2 were cast into sky coordinates at this time using normalized individual exposure maps as the probability distribution. When the model background and offset-count mosaics were subtracted from the count mosaic and divided by the exposure mosaic, with a proper scaling factor, the result was a count-rate image of the entire field normalized to the on-axis response of the PSPC.

3. Diffuse X-ray Emission from the Magellanic Clouds

Figures 1a,b and 2a,b show hard (0.5 – 2.0 keV) and soft (0.1 – 0.284 keV) band maps of the LMC and SMC. The LMC clearly exhibits extensive diffuse emission in the hard band while in the SMC it apparently exists but at a lower level and is confused with the emission from point sources. Higher angular resolution observations with the *ROSAT* HRI do not show evidence for additional point sources, implying that some of the unresolved emission originates in diffuse gas.

The MC maps in the soft band relate a different story. While the LMC $^1/_4$ keV map shows a region of significant enhancement in the southwest, the structure is completely unlike that seen at higher energies. The enhancement

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Table 1. Diffuse emission parameters.

Cloud	Band	Temperature K	Luminosity ergs cm^{-2} s^{-1}	Region Diameter pc	n_e cm^{-3}
LMC	Hard	$10^{6.6} - 10^{6.9}$	1.1×10^{38}	3500	0.002
	Soft	$10^{6.0}$	1.1×10^{37}	1550	0.008
SMC	Hard	$10^{6.9}$	3.9×10^{36}	1660	0.001
	Soft	$10^{6.2}$	2.1×10^{35}	500	0.003

itself is unexpected as the column density of Galactic HI in the direction of the LMC is $\sim$ 4 optical depths at $^1/_4$ keV. The structure in SMC in the soft band is also nearly completely different from that in the hard band. The structure is extensive enough in solid angle that it may not be related to the SMC at all but be associated with emission and/or absorption variations related to the Milky Way. There is a slight apparent $^1/_4$ keV enhancement along the bar of the SMC. It is this enhancement and the enhancement in the southwest of the LMC that are used to derive luminosity estimates.

A simple estimate can be made for the luminosity of the Magellanic Clouds in X-rays from diffuse emission. The hard and soft bands are first subdivided to provide additional spectral information. The excess emission (after point sources have been masked) over the average emission of the surrounding region is summed to provide a total intensity for each band. (The additional bands cover 0.47 – 1.29 keV and 0.76 – 2.02 keV for the hard band, 0.11 – 0.284 keV and 0.14 – 0.284 keV for the soft band, the limits are the 10% of peak area values in all cases.) The intensity ratio of the subdivided bands then provide an effective temperature for the broad-band emission assuming a thermal emission model (in this case, Raymond & Smith 1977 spectra, 1995 vintage, with Morrison & McCammon 1984 interstellar absorption). The total emission for each broad band can be scaled to a luminosity. Finally, using the angular extent of the emission enhancements and the assumption of a spherical emission region, the densities of the emitting regions can be determined. Table 1 shows the results. While there are a number of obvious caveats, such as the contribution of unresolved point sources to the diffuse emission and the possibility of additional absorption intrinsic to the Clouds, these results offer a reasonable order-of-magnitude estimate for the diffuse emission parameters.

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Discussion

You-Hua Chu: How do you determine the plasma temperatues without knowing the absorption column densities?

Snowden: I don't. I use the measured Milky Way column densities from existing surveys. However, I included no absorption which might be intrinsic to the Magellanic Clouds.

Despina Hatzidimitriou: In the $^1/_4$ Kev band map of the SMC shown, you mentioned that the observed enhancements are probably not associated with the SMC. However, I find it a bit disturbing that they happened to be approximately where the Magellanic Stream and the Magellanic Bridge are starting. Could you comment on that?

Snowden: I didn't say the $^1/_4$ emission enhancements in the SMC field are not associated with the SMC; I don't know the answer to that, and it would be very interesting if they are physically associated. There are alternative explanations which must be investigated. The enhancements are comparable in size and intensity to emission and absorption variations produced in the halo and disk of the Milky Way. Accurate maps of Galactic HI to separate absorption effects and inclusion of ROSAT all-sky survey data to obtain the larger-scale emission context are needed to address the issue.

Frank Winkler: In removing individual X-ray sources, you noted that you mask out not only point sources, but also individual extended sources. At what size scale do you draw the line between individual extended sources and the overall diffuse emission you have described?

Snowden: This is, of course, a subjective cut. Bright, relatively young SNRs are removed as they can easily be studied in the context of individual observations. Older, larger scale, and/or fainter superbubbles which extend beyond observation boundaries and need as much exposure as possible are included. The critical aspect is that when the analysis of the diffuse data is complete, it must be folded back in with the rest of the source populations to derive a global view of the Magellanic Clouds.

Tetsuo Hasegawa: How do the temperatures, luminosities, and densities you derive compare with those parameters for the Milky Way Galaxy?

Snowden: The temperatues of the diffuse plasmas in the Magellanic Clouds are quite consistent with those seen in the Milky Way. This may have a lot to do with regions of relative stability in the cooling curve of the diffuse plasma around 1-5$\times10^6$ K. Densities of around 0.002 cm^{-3} are also quite reasonable. The $0.5 - 2.0$ kev luminosity of the Milky Way bulge is $\sim 2 \times 10^{39}$ ergs s^{-1}, so the LMC luminosity is reasonable given its relative size.