The Nature of Unresolved Soft X-Ray Emission from the Galactic Disk

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Abstract

Although about 40% of the soft X-ray background emission in 0.4 to 1 keV range has extragalactic origins and thus is totally blocked by the galactic absorption in midplane directions, it decreases at most by about 20% in midplane. Suzaku observation of the direction, \((\ell, b) = (235^\circ, 0^\circ)\), showed an O VII \(K\alpha\) emission intensity comparable with that of the MBM-12 on cloud Suzaku observation, but revealed a narrow bump peaked at \(\sim 0.9\) keV. This corresponds to about 20% of the total diffuse emission at \(b \sim 2^\circ - 10^\circ\).

Key words: Galaxy: disk — Galaxy: stellar content — X-rays: diffuse background — X-rays: ISM — X-rays: stars

1. Introduction

The soft X-ray sky below 1 keV is spatially smooth after subtracting the local structures, such as Loop I. In high galactic latitudes, \(\sim 40\%\) of the emission is attributed to emission from faint extragalactic objects, i.e., the Cosmic X-ray Background (CXB), in the ROSAT R45 band (\(\sim 0.44 – 1.0\) keV) (McCammon et al. 2002). The rest of the emission is considered to consist of emission lines from hot gas in the disk and halo of our Galaxy (McCammon et al. 2002), and from the Heliosphere by the solar wind charge exchange (SWCX) process (Cox 1998; Cravens 2000; Lallement 2004). A small fraction can arise from intergalactic space. In the galactic midplane, the interstellar X-ray absorption column density, \(N_{\text{H}}\), is \(\sim 10^{22}\) cm\(^{-2}\) even in the anti-center direction. Therefore, the extragalactic X-ray photons below 1 keV are totally blocked. Nevertheless, the R45 band X-ray surface brightness decreases only by 20% or less from high galactic latitude to midplane. This issue has been known as the “M band problem” (McCammon & Sanders 1990; Cox 2005). The M band is the name of a similar energy band in the Wisconsin and the Nagoya–Leiden rocket programs. Since X-ray photons below 1 keV can travel only about 1 kpc in the galactic disk, there must be emission in the midplane within 1 kpc which compensates partly the decrease of the extragalactic emission. Nousek et al. (1982) and Sanders et al. (1983) suggested hot gas of \(\sim 3 \times 10^6\) K as the origin, while Rosner et al. (1981) pointed out emission from dM stars can contribute \(\sim 20\%\) of the total diffuse emission. Cox (2005) showed that if a significant fraction (\(\gtrsim 1/2\)) of emission originates from hot gas in the temperature range of \(2.5 \times 10^6\) to \(6.3 \times 10^6\) K, the hot gas must expand because of its high pressure. He suggested young expanding superbubbles or supernova remnants evolving in low density region as candidates for the emission.

As an example, the surface brightness averaged over rectangular areas of \(\Delta \ell, \Delta b = (10^\circ, 2^\circ)\) along the line of \(\ell = 235^\circ\) is plotted as a function of \(b\) in figure 1. A model surface brightness profile consisting of an unabsorbed constant emission and the CXB absorbed by the average column density is plotted together with the observational data. For \(|b| \lesssim 10^\circ\), there is \(20 \times 10^{-6}\) counts s\(^{-1}\) arcmin\(^{-2}\) of excess over the model. This corresponds to about 20% of the total diffuse emission at high latitudes. Note that the model curve is for the minimum possible absorption: if the other 60% of the R45 emission at high latitudes is produced by a hot halo, then this too would be largely absorbed in the plane, depending on its scale height structure. The surface brightness profile suggests asymmetry between the profiles for \(b > 0\) and \(b < 0\), which is more pronounced in R4 band. In this paper, however, we concentrate on the excess flux at \(b = 0\). In section 3, we will construct a model which can consistently explain the excess at \(b = 0\), although we will find the model cannot explain the excess in \(b \sim 2^\circ - 10^\circ\).

The origin of the excess midplane emission is not known yet although this problem has been known for more than 25 years. One major reason is that there has been no energy spectrum available in which emission line structures are resolved. The X-ray Imaging Spectrometer (XIS) (Koyama et al. 2007) on board Suzaku (Mitsuda et al. 2007a)
has a significantly improved spectral line response function compared to previous X-ray CCD cameras, e.g., those onboard XMM-Newton and Chandra, in particular below 1 keV. Although the spectral resolution of the instrument is not high enough to resolve the fine structure (triplet) of O VII Kα emission, emissions from different ions, e.g., N VI, O VII, and O VIII, can be clearly resolved. Combined with the X-ray telescope (Serlemitsos et al. 2007), the XIS also has high sensitivity for spatially extended emission. We have observed the direction (ℓ, b) = (235°, 0°) with Suzaku for 160 ks. The direction was selected because this point is well outside the galactic bulge and north polar spur, and because the direction is an average midplane direction without any special features, i.e., no bright X-ray sources in the XIS field of view, a typical neutral Hydrogen density, and a typical counting rate in the ROSAT all sky survey map. We found that the O VII Kα emission intensity was comparable with that of the MBM-12 on-cloud observation (Smith et al. 2007) and that a narrow bump peaked at ~0.9 keV was compensating the decrease of the extragalactic component. This strong feature, presumably due to a blend of Ne-K and Fe-L lines, makes the b = 0 spectrum qualitatively unlike empty-field spectra at other latitudes and requires plasma at higher temperatures than generally seen in galactic diffuse emission. In this paper we will show the observational results and discuss the origin of the excess emission. We will construct a model spectrum for spatially unresolved faint dM stars and show it can consistently explain the observations.

In this paper we concentrate on the XIS 1 data. This detector has a much larger effective area below 1 keV than the other XIS sensors because it employs backside illuminated CCD. Throughout this paper, we quote single parameter errors at the 90% confidence level unless otherwise specified.

2. Analyses and Results

The midplane direction, (ℓ, b) = (235°, 0°), was observed with Suzaku in the AO-2 period. In table 1 we show the log of the observation. The XIS was set to normal clocking mode and the data format was either 3 or 5. The Spaced-row Charge Injection (SCI) was on throughout the observation. We used version 2.0 processed Suzaku data. We first cleaned the data using the selection criteria, elevation from sunlit, and cut-off rigidity > 80 GeV. We checked the Oxygen column density of the sunlit atmosphere in the line of sight of the screened data and found it to be always below 10^{14} cm^{-2}, which is the criterion for no significant neutral O emission from Earth atmosphere (Smith et al. 2007). We then checked the solar wind proton flux. The spectrum below 1 keV could be contaminated by the SWCX-induced emission from the geocorona if the solar wind flux exceeds 4 × 10^{10} protons s^{-1} cm^{-2} (Mitsuda et al. 2007b). The probability of contamination is high if the altitude of the magnetopause is lower than ~10 Earth radii (R_E) (Fujimoto et al. 2007). Here, the magnetopause is defined by the lowest position along the line of sight whose geomagnetic field is open to

![Figure 1: ROSAT diffuse X-ray R45 band map (Snowden et al. 1997), and the surface brightness and neutral hydrogen column density as functions of b along ℓ = 235°. The thick white circle in the map indicates the pointing direction of the present observation. The surface brightness and the hydrogen column density were averaged over rectangular areas of size (Δℓ, Δb) = (10°, 2°). The surface brightnesses in R4, R5, and R45 bands are plotted as step functions. A model surface brightness for R45 band which consists of an unabsorbed constant emission (65 × 10^{-6} counts s^{-1} arcmin^{-2}) and the cosmic X-ray background emission [10 (E/1 keV)^{-1.4} photons s^{-1} cm^{-2} sr^{-1} keV^{-1}] absorbed by the average column density is shown with a thick curve. There exists about 20 × 10^{-6} counts s^{-1} arcmin^{-2} of excess over the model at midplane. The excess in b = −20° to −30° is partly due to one of the streaks of bright areas which meet together at the South Ecliptic Pole. Thus it could be due to the so-called long term enhancement (Snowden et al. 1994) or scattered solar X-rays.](https://academic.oup.com/pasj/article-abstract/61/sp1/S115/1482271)
interplanetary space. We found that the magnetopause is higher than 10 \(R_E\) throughout the observation. However we removed the time intervals in which the proton flux at 1 AU exceeds \(4 \times 10^8\) protons s\(^{-1}\) cm\(^{-2}\) in order to avoid any contamination by SWCX from the geocorona. After these data selections, the total exposure time reduced to 53 ks.

We then constructed an X-ray image in 0.3 to 2 keV energy range. We detected two faint X-ray sources in the X-ray image and we removed circular regions centered on those point sources with radii of 2’ and 1.5’. The radii were determined by the intensities of the two sources. The counts from the point sources outside the circular regions are estimated, respectively, to be less than 5% and 3% of the diffuse X-ray emission in 0.3 to 1 keV energy range.

The non–X-ray background (NXB) spectrum was constructed from the dark Earth database using the standard method in which the cutoff rigidity distributions of the on-source and background data were made identical (Tawa et al. 2008). We found about 10% discrepancy between the non–X-ray background and the present observation data for XIS 1 in the counting rates above 10 keV, where true X-ray rates are expected to be negligible, suggesting background uncertainty of this level. However, since in the energy range below 1 keV the non–X-ray background is only about 10% of the diffuse X-ray emission, this level of the background uncertainty is negligible.

In order to perform spectral fitting, we generated an efficiency file (arf file) for a flat field using the xissimarfgen software version 2007-09-22 (Ishisaki et al. 2007), assuming the degradation of low energy efficiency due to the contamination of this component to the value determined by 21 cm radio observations (9.0 \(\times\) 10\(^{21}\) cm\(^{-2}\): Dickey & Lockman 1990). The average AGN spectra below \(\sim\) 1 keV becomes steeper than above \(\sim\) 1 keV, and the average photon index was determined to be 1.96 below \(\sim\) 1 keV by Hasinger et al. (1993). We thus first tried three different models for this component: a power-law function with a photon index 1.4, and broken power-law functions with indices of either 1.54 or 1.96 below 1.2 keV and with 1.4 above 1.2 keV (Smith et al. 2007). We set the normalization of the power-law or the broken power-law models free. The narrow line features at 1.3 and 1.6 keV are instrumental lines due to residuals of the NXB subtraction. We first fitted the spectrum in the energy range 1.1 to 5 keV in order to determine the intensities of the NXB residual lines. We employed a power-law function absorbed with a galactic absorption for the continuum and two narrow Gaussian functions for the NXB lines. In the further spectral fits, we account for these instrumental features with two Gaussians with all parameters fixed at the values thus obtained.

We then fitted the energy spectrum in the energy range of 0.4 to 5 keV with a model consisting of three emission components [Model (A)]. In figure 2, the best fit model function and its components convolved with the instrument response function are shown by step functions. The best fit parameter values and their statistical uncertainties are shown in the column labeled with Model (A) in table 2. The first model component represents the CXB. We fixed the galactic absorption column density of this component to the value determined by 21 cm radio observation (9.0 \(\times\) 10\(^{21}\) cm\(^{-2}\): Dickey & Lockman 1990). The average AGN spectra below \(\sim\) 1 keV becomes steeper than above \(\sim\) 1 keV, and the average photon index was determined to be 1.96 below \(\sim\) 1 keV by Hasinger et al. (1993). We thus first tried three different models for this component: a power-law function with a photon index 1.4, and broken power-law functions with indices of either 1.54 or 1.96 below 1.2 keV and with 1.4 above 1.2 keV (Smith et al. 2007). We set the normalization of the power-law or the broken power-law models free. We found all parameters of Model (A) including the normalization of the CXB at 1 keV were same within the statistical errors for these three CXB models. Therefore we will show only the results with the single power-law function. The best-fit value of the power-law normalization is consistent with typical high latitude values (Revnivtsev et al. 2005). The intensity of the

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1 We call this a narrow bump because this structure is broader than a line, but the width is only \(\sim 0.3\) keV FWHM when it is approximated with a Gaussian function.

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Table 1. Log of observation.

| Observation ID | 502021010 |
|----------------|-----------|
| Aim point*     | (235.00, 0.00) \(_{\text{galactic}}\) |
| Observation start time (UT) | 2007 April 22 20:39:20 |
| Observation end time (UT)   | 2007 April 25 10:04:24 |
| Net exposure time           | 189.5 ks   |

* Aim point on the focal plane was the XIS nominal position.

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Fig. 2. Observed spectrum (crosses), best-fit model and its components (step functions) of Model (A) convolved with the instrument response function and residuals of the fit (bottom panel). The vertical error bars of data points correspond to the 1\(\sigma\) statistical errors.
The CXB component decreases rapidly below \( \sim 1.5 \text{ keV} \) because of galactic absorption and has negligible contribution below 1 keV.

The second component is a thin thermal emission model, APEC, which we consider to represent the emission from hot gas in the local hot bubble (LHB) and from the SWCX process in the Heliosphere. We estimated the \( \text{O VII} \ K\alpha \) emission intensity by setting the \( \text{O} \ ) abundance of this APEC model to zero and substituting with a narrow Gaussian line at the \( \text{O VII} \ K\alpha \) energy, fixing the temperature of the emission component to the best fit value. The \( \text{O VII} \ K\alpha \) emission intensity was determined to be \( 2.1^{+0.8}_{-0.6} \) LU, where LU is photons \( \text{s}^{-1} \text{cm}^{-2} \text{keV}^{-1} \text{sr}^{-1} \). This value is smaller than the \( \text{O VII} \ K\alpha \) emission intensity obtained from the MBM-12 on-cloud observation by Smith et al. (2007) with Suzaku (3.34\( \pm \)0.26 LU). MBM-12 is located at 60 to 280 pc from the Earth, and the \( \text{O VII} \ K\alpha \) emission beyond the cloud is completely blocked. Thus the intensity represents the emission from the LHB and Heliospheric SWCX. Smith et al. (2007) determined the emission intensity by fitting the spectrum with a power-law continuum and Gaussian lines. However the emission intensity is dependent on how we describe the weak lines. Furthermore, both the data processing and the calibration of the instruments have been improved since the analysis by Smith et al. (2007). We thus reanalyzed the data and determined the emission intensity using the same recipe used here. We employed the same models to describe the CXB and the point source in the field of view as Smith et al. (2007). We found the LHB + SWCX component of the MBM-12 on-cloud direction is well described with an APEC model without absorption with \( kT = 0.109^{+0.006}_{-0.012} \) keV, and normalization \( = (13.4^{+6.1}_{-2.2}) \times 10^{14} \text{ cm}^{-5} \text{ sr}^{-1} \). The \( \text{O VII} \ K\alpha \) emission was determined to be \( 2.93 \pm 0.45 \) LU. Both the APEC model parameters and the \( \text{O VII} \ K\alpha \) emission intensities are consistent with the present midplane observation.

The third component is an APEC thin thermal emission model at a higher temperature need to produce the bump peaked at around 0.9 keV. In this model the broad feature is produced by a sum of Fe-L and Ne-K lines. We had to set the \( \text{O} \ ) abundance of this component free in order to better describe the \( \text{O VIII} \ K\alpha \) emission. The best fit values of the temperature and the \( \text{O} \ ) abundance were respectively \( 0.77 \pm 0.45 \) keV and \( 3 \pm 1 \) solar abundance.

Although the \( \chi^2 \) value of the fit is statistically acceptable, we find excess emission in the 1–1.2 keV range, which suggests existence of even higher temperature emission. The large required \( \text{O} \ ) abundance also suggests existence of a lower-temperature component which emits \( \text{O VIII} \ K\alpha \) emission more efficiently. Thus, the narrow bump at around 0.9 keV is likely multi-temperature emission. In the second model [Model (B)], we represented the narrow bump with two APEC components with the abundance fixed to 1. We found the fitting is unstable

### Table 2. Best fit spectral parameters.

| Component                  | Model function | Parameter (unit) | Model (A)   | Model (B)   | Model (C)   |
|----------------------------|----------------|------------------|-------------|-------------|-------------|
| CXB                        | Absorption     | \( N_{\text{H}} \ (10^{22} \text{ cm}^{-2}) \) | 0.90 (fixed) | 0.90 (fixed) | 0.90 (fixed) |
|                            | Power law      | Photon index     | 1.4 (fixed) | 1.4 (fixed) | 1.4 (fixed) |
|                            |                | Normalization*   | 11.1 ± 0.9  | 11.1 (fixed) | 11.1 (fixed) |
| LHB + Heliospheric SWCX    | APEC           | \( kT \) (keV)   | 0.105 \( \pm \) 0.031 | 0.105 (fixed) | 0.105 (fixed) |
|                            |                | Normalization‡   | 14.1 \( \pm \) 4.6 | 13.8 ± 3.2  | 11.1 \( \pm \) 2.6 |
| Broad line-like feature    | (V)APEC        | \( kT \) (keV)   | 0.765 \( \pm \) 0.039 | 0.658 \( \pm \) 0.079 |
|                            |                | Normalization‡   | 3.7 \( \pm \) 0.35 | 2.80 \( \pm \) 0.45 |
|                            |                | O abundance (Solar†) | 3.1 \( +1.3_{-1.2} \) | 1 (fixed) |
|                            | APEC           | \( kT \) (keV)   | 1.50 \( \pm \) 0.50 | 0.90 \( \pm \) 0.28 |
|                            |                | Normalization‡   | 3.7 \( +1.7_{-1.2} \) | |
|                            | Absorption     | \( N_{\text{H}} \ (10^{22} \text{ cm}^{-2}) \) | 0.034 \( \pm \) 0.012 | 0.032 \( \pm \) 0.010 |
|                            | Bremsstrahlung | \( kT \) (keV)   | 0.183 \( \pm \) 0.074 | 0.28 \( \pm \) 0.053 |
|                            |                | Normalization‡   | 4.3 \( +3.0_{-3.7} \) | |
| NXB residuals†             | Gaussian       | Centroid (keV)   | 1.32 (fixed) | 1.32 (fixed) | 1.32 (fixed) |
|                            |                | Normalization‡   | 0.24 (fixed) | 0.24 (fixed) | 0.24 (fixed) |
|                            | Gaussian       | Centroid (keV)   | 1.63 (fixed) | 1.63 (fixed) | 1.63 (fixed) |
|                            |                | Normalization‡   | 0.23 (fixed) | 0.23 (fixed) | 0.23 (fixed) |

\[ \chi^2 / \text{dof} \]

|                          | 76.5/84 | 61.6/85 | 68.3/86 |

\[ ^* \text{ The unit is photons} \text{s}^{-1} \text{cm}^{-2} \text{keV}^{-1} \text{sr}^{-1} \text{ at } 1 \text{ keV.} \]

\[ ^† \text{ The emission measure integrated over the line of sight, i.e., } (1/4\pi) \int n_{e} n_{\text{H}} d\ell \text{ in units of } 10^{14} \text{ cm}^{-5} \text{ sr}^{-1}. \]

\[ ^‡ \text{ Solar abundance by Anders and Grevesse (1989).} \]

\[ ^†† \text{ The emission measure integrated over the line of sight. The unit is } 3.02 \times 10^{-12} \text{ cm}^{-5} \text{ sr}^{-1}. \]

\[ ^\dagger \text{ Two intrinsically narrow Gaussians are included to represent residual instrumental emission lines.} \]

\[ ^\# \text{ The unit is photons} \text{s}^{-1} \text{ cm}^{-2} \text{ sr}^{-1}. \]
because of strong coupling among the two APEC components and the other remaining two components. We thus fixed the normalization of the CXB power-law function, and the temperature of the LHB + SWCX component to the best fit values of Model (A), respectively. In table 2, we show the best fit parameters. The temperatures of the emissions were 0.66$^{+0.08}_{-0.07}$ and 1.5$^{+0.7}_{-0.3}$ keV, respectively.

The narrow bump at around 0.9 keV may be represented by other model functions. For example, if it is a sum of emissions from faint X-ray binaries, it may be modeled with continuous spectra. Thus, as the third model, Model (C), we tried to fit with a strongly absorbed continuous spectrum. As the continuum we adopted a bremsstrahlung model. As shown in table 2, the spectrum was fitted well with model parameters of $kT = 0.18^{+0.07}_{-0.05}$ and absorption column density $N_{\text{H}} = (7.2^{+8.1}_{-8.0}) \times 10^{21}$ cm$^{-2}$.

Finally, we divided the XIS image regions into two sub-regions and extracted the energy spectra separately. We found that the two spectra were identical to each other and to the total spectrum within the statistical errors. This suggests the emission region of the narrow bump is not located within a limited image region, but spatially extended at least to the size of the XIS field of view (18').

3. Discussion

The pointing direction of the present observation has no special features. Thus we can consider the spectrum to be representative of midplane, off-center directions. Therefore a similar narrow-bump emission is likely to fill partly the absorption of the extragalactic component in other midplane directions, although more observations of different midplane directions are necessary to confirm this assumption.

First we consider spatially extended hot plasma as the origin. Assuming an average interstellar neutral H density of 1 cm$^{-3}$ and cosmic abundance, the absorption length of a 0.9 keV photon is estimated to be 1 kpc in midplane. Thus the line of depth of the observation, $L$, is about 1 kpc. Then the local H density of the plasma, $n_{\text{H,hot}}$, is estimated from the best fit model parameters of Model (A) to be $n_{\text{H,hot}} = 1.1 \times 10^{-3}$ (L/1 kpc)$^{-1/2}$ f$^{-1/2}$, where $f$ is the volume filling factor. The pressure is then $p/k = 2.3 \times 10^4$ cm$^{-3}$ K (L/1 kpc)$^{-1/2}$ f$^{-1/2}$. Since $f < 1$, the pressure is likely to exceed the total midplane pressure derived from the vertical matter density and the vertical gravity, $2.2 \times 10^4$ cm$^{-3}$ K (Cox 2005). We thus consider that a large fraction of the emission might arise from faint individual sources rather than diffuse gas.

The faint sources must satisfy the following three conditions: (1) the sources have to have energy spectra which can be approximated either by a thin-thermal emission ($kT = 0.8$ keV) or by an absorbed ($N_{\text{H}} = 6 \times 10^{21}$ cm$^{-2}$) bremsstrahlung ($kT = 0.2$ keV), (2) individual sources must be faint and enough number of sources exist in the XIS field of view (18' x 18'), and (3) the sources must have a relatively small vertical scale height so that the emission is enhanced only near the galactic plane.

If we require at least 30 sources in the XIS field of view with a line-of-sight depth of 1 kpc, we need X-ray sources with a density higher than 0.003 pc$^{-3}$. Only normal stars and white dwarfs have high enough spatial densities. Among those objects, the contribution of main sequence M stars (dM stars) dominates the emission in the 0.3 to 1 keV energy range because they have relatively high X-ray luminosities and high number density (Kuntz & Snowden 2001). Young (\(<\) 1 Gyr) stars have a large X-ray luminosity and dominate the total X-ray emission. They have a small vertical scale heights (a few 10's pc, e.g., Bienaymé et al. 1987).

Giampapa et al. (1996) determined the energy spectra of six nearby (<10 pc) dM stars with ROSAT PSPC observations. The spectra were found to consist of two thermal components. The average temperatures were $kT = 0.138$ and 0.78 keV, respectively, when they were fitted with solar-abundance plasma models. The two components have comparable emission measures. The high resolution spectrometers onboard Chandra and XMM-Newton observatories resolved the emission spectra into number of emission lines (Maggio et al. 2004; Güdel et al. 2004). Maggio et al. (2004) determined the emission measure distribution (EMD) as a function of temperature for the dM3e star, AD Leo. The EMD show two peaks at $\log T = 6.2$ and $\log T = 6.9$, thus at $kT = 0.14$ keV and 0.68 keV, which is consistent with the two temperature model from the ROSAT observations. The temperature of the higher-temperature component is consistent with that producing the narrow bump in the spectrum of present observation. The lower-temperature component of dM stars emits mostly O VII Kα in the XIS band. Because opacity at O VII is about twice as high as that for 0.9 keV photons, the line-of-sight depth contributing to the present observation is a factor of two shorter. Thus if we assume the narrow-bump emission arises from the 0.78 keV component of dM stars, we find the O VII Kα emission intensity from the 0.14 keV component of dM star is only about 30% of that of the LHB + HS-SWCX component, which is within the statistical error of the intensity. Thus the existence of the M-star’s lower-temperature component in the present observed spectrum is statistically acceptable.

Giampapa et al. (1996) also suggested that the intensity of the higher temperature component shows positive correlation with X-ray intensity during flare events. The EMD of AD Leo obtained with the Chandra grating observation is extended at temperatures above the peak at 0.68 keV up to \(\sim\) 2 keV. Van den Besselaar et al. (2003) showed that the EMD of AD Leo is significantly enhanced in the temperature range of $kT = 1$–2 keV during the decay of a flare. Wargelin et al. (2008) detected a flare from the nearby M star, Ross 154 with Chandra ACIS and found that the temperature of the higher temperature component increased during the flare when it was fitted with a two component model. During the decay phase of the flare, the temperature was 1.9 keV and the emission measure increased by a factor of about three compared to that during quiescence. The higher temperature ($kT = 1.5$ keV) component in Model (B) has an emission measure comparable to that of 0.7 keV component. This could be the contribution of high temperature emission in EMD of dM stars in quiescence and flare. The emission measure in 1 to 2 keV range is about 0.3 times that in 0.7 to 0.9 keV range for AD Leo. Then if about 20% of dM stars in the field of view are in flaring state, the 1.5 keV component can be explained. Since the dM stars are
The contributions of stars to the soft X-ray background have been estimated by several authors (Rosner et al. 1981; Schmitt & Snowden 1990; Guillout et al. 1996; Kuntz & Snowden 2001). However, they estimated contributions only for high latitudes ($b > 20^\circ$). The X-ray luminosities of stars are distributed in a relatively narrow range and the distribution function can be approximated by a log-normal function, when they are sorted by spectral type and age (Schmitt & Snowden 1995). Assuming a double-component thin thermal emission of the dM star luminosity (Kuntz & Snowden 2001). The energy flux of the faintest class of the dM stars is $3.8 \times 10^{-16}$ erg s$^{-1}$ cm$^{-2}$, the logN–logS relation in the 0.4–2 keV energy band is significantly contaminated by extragalactic sources (Hong et al. 2005). Moreover, as we will show later the surface density of the dM star drops rapidly with $|b|$. We thus estimate the number of sources in the XIS field of view.

The energy flux of the faintest class of the dM stars is estimated to be $6 \times 10^{-16}$ erg s$^{-1}$ cm$^{-2}$, assuming the average luminosity of the age class, a 1 kpc distance, and the average galactic absorption. The sensitivity of the Chandra Multiwavelength Plane (ChaMPlane) Survey reaches close to the limit. However, since the ChaMPlane fields contain directions with galactic latitude up to $|b| = 10^\circ$, the logN–logS relation in the 0.4–2 keV energy band is significantly contaminated by extragalactic sources (Hong et al. 2005). Moreover, we will show later the surface density of the dM star drops rapidly with $|b|$. We thus estimate the number of sources in the XIS field using the source counts in 0.4–2 keV range of the two low-latitude ChaMPlane fields: ObsID 2810 ($b = 0^\circ.18$) and ObsID 2218 ($b = 0^\circ.14$) which have modest exposure times: 48.8 ks and 30.2 ks, respectively. Simply scaling the source counts of the level 3 analysis of Hong et al. (2005) by the ratio of the field of views, we obtained 70 and 24 as the expected source counts for the XIS field of view. The nature of those sources are yet not known. However these source numbers are consistent with the above estimation of dM stars, i.e., 60.

We then constructed model energy spectra, taking into account the galactic absorption and vertical star distribution, in order to compare the emission spectrum with observation, and to estimate the dependence of the surface brightness on galactic latitude. For the neutral hydrogen column density, we used equations (1) (molecular) and (2) (atomic) of Ferrière (2001). We scaled the midplane densities at the various galactocentric radii by the surface density in figure 1 of the same paper. For molecular gas we used the curve from Clemens, Sanders, and Scoville (1988) in the figure. The atomic gas surface density depends on galactocentric radius only outside 14 kpc; thus it does not affect the model spectrum constructed below. For the star density, we follow Kuntz and Snowden (2001) and used equations (A1) (0–0.15 Gyr old stars) and (A2) (0.15–1 Gyr old stars) of Bienaymé, Robin, and Crézé (1987). Then the emission spectrum is given by

$$f(E) = \frac{1}{4\pi} \int_{d_0}^{\infty} ds \sum_i \left[ \Lambda(E, T_{H}) + \Lambda(E, T_{L}) \right] E M_i \rho_i (s) \times \exp \left[ -\sigma_{abs}(E) \int_{s'}^{s} ds' n_H(s') \right].$$

where the integrations with $s$ and $s'$ are done along the line of sight, while the summation by $i$ is taken for different classes, i.e. spectral types and age groups, of dM stars. $E M_i$ and $\rho_i$ are, respectively, the emission measure of the average luminosity star and spatial density of class $i$. The emission spectrum from a plasma with a temperature of $T$ and unit emission measure is given by $\Lambda(E, T)$, and $\sigma_{abs}$ and $n_H$ are respectively the X-ray absorption coefficient and the neutral hydrogen density. Finally, $d_0$ is the distance within which dM stars are resolved as individual stars. We varied it from 5 pc to 20 pc and found there was no significant difference in the resultant model spectra.

We performed spectral fits using the model function $f(E)$

| Type | Age (Gyr) | $\log L_X$ | $\sigma (\log L_X)$ | $EM_i$ | Density | Total $EM_i$ |
|------|----------|------------|---------------------|-------|---------|-------------|
| M(early) | 0–0.15 | 29.19 | 0.32 | 48.3 | 4.28 | 1.72 |
| 0.15–1 | 27.89 | 0.72 | 7.30 | 8.96 | 0.55 |
| 1–10 | 26.86 | 0.77 | 0.830 | 3.29 | 0.23 |
| M(late) | 0–0.15 | 29.12 | 0.49 | 59.3 | 2.45 | 1.21 |
| 0.15–1 | 28.2 | 0.49 | 7.12 | 5.12 | 0.30 |
| 1–10 | 27.22 | 0.49 | 0.746 | 18.8 | 0.12 |

Table 3. Rough estimation of midplane emission measures of dM stars.
instead of a thin thermal emission model for the narrow bump in Model (A). In the fit, we introduced a scaling parameter for \( f(E) \) and set it free. We also set the normalization factors of the LHB+SWCX and the CXB components free. The result is shown in figure 3. A minimum \( \chi^2 \) value of 87.87 with 87 degrees of freedom was obtained for a scaling parameter value of 1.27\(+0.10\)/\(-0.12\). The normalization of both the CXB component (10.1\(+1.0\)/\(-0.8\)) and the LHB+SWCX component (13.2\(+3.0\)/\(-2.3\)) were smaller than that of Model (A), however their differences are within the statistical errors. Therefore, both the surface brightness and spectrum of the diffuse emission at \((\ell, b) = (235, 0)\) can be consistently explained by introducing the unresolved emission from dM stars.

In figure 4, we show the dM star model fluxes in the ROSAT R45 band as functions of \( b \) for \( \ell = 235^\circ \). We also show the residuals of the observed ROSAT R45 band flux from the unabsorbed constant emission + CXB model in figure 1. As shown in this figure, the dM star emission can fill in the notch in \( |b| < 2^\circ \), as well as providing the high-temperature feature seen in the Suzaku observation. However, there exists more excess flux at \( b \approx 2^\circ - 10^\circ \) than the dM star model predicts. Thus yet another emission component which should have a double-peaked latitude structure must fill the notch. More Suzaku observations in \( |b| = 2^\circ - 10^\circ \) are necessary to elucidate this unknown emission component.

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