An X-Ray Spectroscopic Study of the Hot Interstellar Medium toward the Galactic Bulge

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Abstract

We present a detailed spectroscopic study of the hot gas toward the galactic bulge along the 4U 1820–303 sight line by a combination analysis of emission and absorption spectra. In addition to the absorption lines of O VII Kα, O VII Kβ, O VIII Kα, and Ne IX Kα by Chandra LTGS, as shown by previous studies, Suzaku clearly detected the emission lines of O VII, O VIII, Ne IX, and Ne X from the vicinity. We used simplified plasma models with constant temperature and density. An evaluation of the background and foreground emission was carefully performed, including the stellar X-ray contribution based on the recent X-ray observational results and the stellar distribution simulator. If we assume that one plasma component exists in front of 4U 1820–303 and the other one at the back, the obtained temperatures are $T = (1.7 \pm 0.2) \times 10^6$ K for the front-side plasma and $T = (3.9^{+0.4}_{-0.3}) \times 10^6$ K for the back-side. This scheme is consistent with a hot and thick ISM disk, as suggested by extragalactic source observations and an X-ray bulge around the galactic center.

Key words: Galaxy: bulge — X-rays: diffuse background — X-rays: ISM — X-rays: stars

1. Introduction

X-ray surveys, such as the ROSAT All Sky Survey (RASS), show that there is a large enhancement of the emission in the galactic center region, expanding to ±30° in longitude and latitude, which is called an X-ray bulge. Snowden et al. (1997) summed 3/4 keV (0.4–1.2 keV) and 1.5 keV (0.7–2.0 keV) RASS data with 10° wide bins centered on $l = 353°$, and checked the latitude profile of the surface brightness. They found that the intensity distribution of the enhancement in the $b > 0°$ region and the $b < 0°$ region significantly differed. They constructed an isothermal ($T = 10^{6.6}$ K) cylinder plasma model with an exponential fall-off in density with height above the plane, and showed that the enhancement for $b < 0°$ can be well explained by this model. The hot gas cylinder is located at the galactic center, and its required radius is 5.6 kpc, with an electron density of $3.5 \times 10^{-3}$ cm$^{-3}$ in the disk and a scale height of 1.9 kpc. They also suggest that in the $b > 0°$ region, this model always produces less intensity than the data, which implies an additional component, such as Loop I. The total luminosity of the plasma cylinder was $1.9 \times 10^{39}$ erg s$^{-1}$ and the mass was $\sim 3 \times 10^7 M_\odot$. A molecular cloud of $\sim 10^{21}$ cm$^{-2}$ hydrogen column density is opaque to soft X-rays lower than 0.5 keV. Shadowing observations using such molecular clouds located a few kpc away provide important clues. Park et al. (1997) observed the $(l, b) = (-10°, 0°)$ direction with ROSAT, where a molecular cloud is located $\sim 3$ kpc away, and showed

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using a curve of growth, and constrained the column density of each ion as \( \log N_{\text{O VIII}} = 16.2-16.7 \), \( \log N_{\text{O VII}} = 15.9-16.5 \), and \( \log N_{\text{Ne IX}} = 15.7-16.1 \). The velocity dispersion (\( v_b \)) was derived using joint analyses of O VII K\( \alpha \) and O VII K\( \beta \) to \( v_b > 200 \text{ km s}^{-1} \), and the column densities of O VIII and Ne IX were derived assuming the same velocity dispersion constraint as that for O VII. Meanwhile Yao and Wang (2006) used their abline absorption model on the same data, and the column densities of O VIII and Ne IX were derived using a curve of growth, and constrained the column density of each ion as \( \log N_{\text{O VIII}} = 16.3 \pm 0.2 \), \( \log N_{\text{O VIII}} = 16.4 \pm 0.2 \) and \( \log N_{\text{Ne IX}} = 16.0 \pm 0.1 \) and the velocity dispersion was \( 255^{+114}_{-90} \text{ km s}^{-1} \).

In this paper, we use an emission spectrum obtained by Suzaku for a region of \(~2^{\circ}\) away from 4U 1820–303. A combined analysis using the same method as used in the galactic halo study with extragalactic objects by Yao et al. (2009) and Hagihara et al. (2010), in consideration of the foreground diffuse and discrete emission will give us further information about the density and scale of the hot gas in the galactic bulge region.

2. Observation and Data Reduction

The observation logs of the Chandra and Suzaku data are summarized in table 1. 4U 1820–303 was observed three times by Chandra, but we used only the HRC-S + LETG data to obtain the best energy resolution. The dataset and data reduction process is basically the same as in Yao and Wang (2006), but we followed the procedure presented in Yao et al. (2009) to extract the first-order spectra of the LETG.

Our Suzaku observations were taken with the CCD camera X-ray Imaging Spectrometer (XIS: Koyama et al. 2007; Mitsuuda et al. 2007). The XIS was set to the normal clocking mode and the spaced-raw charge injection (SCI) was applied to the data during the observations. We used processing data version 2.2.7.18 for the two observations. In this work, we used only the spectrum obtained with XIS 1.

We adopted the same data screening as in Hagihara et al. (2010), i.e., standard data screening in addition to the exclusion of the thick atmospheric neutral oxygen column density in the line of sight (Smith et al. 2007) and of the Solar wind charge exchange (SWCX) (Fujimoto et al. 2007). We found that the counting rate was constant as a function of the neutral oxygen column density for the cleaned data. Thus, there is no significant neutral oxygen emission from the Earth’s atmosphere in the filtered data. The solar-wind intensity obtained with the Solar Wind Electron Proton and Alpha Monitor (SWEPAM) aboard the Advanced Composition Explorer (ACE) was checked. We removed the time intervals when the proton flux in the solar wind exceeded \( 4 \times 10^{8} \text{ cm}^{-2} \text{ s}^{-1} \) (Masui et al. 2009). With this criterion, we discarded 19.7 ks of the exposure, and the net exposure time became 32.2 ks.

There are no obvious discrete X-ray sources in the X-ray images for the 0.4–1.0 keV energy range. However, there would be many low-luminosity sources in this direction, and thus we applied a wavelet analysis using CIAO: wavdetect to detect such point sources. We found 23 point-source candidates in the fields, and removed a circular region with 1 radius centered at the source position from the data. These candidates can be caused by statistical fluctuations, and so we had to check them. We then compared the spectrum including the possible point sources and the spectrum excluding them, and found no significant difference. To increase the photon counts and to reduce the statistical error, we decided to use data including the point-source candidates in further analysis.

We constructed instrumental response files (rmfs) and effective area files (arf) by running the scripts xissimarfgen and xissimarfgen (Ishisaki et al. 2007). To take into account stray light coming from outside of the CCD foV, we used a 20 radius flat field as the input emission in calculating the arf. We also included in the arf file the degradation of the low-energy efficiency due to contamination on the XIS optical blocking filter. The versions of calibration files used here were ae_xi1_quantafl_20080504.fits, ae_xi1_rmparame_20080901.fits, ae_xi1_makepi_20080825.fits, and ae_xi1_contami_20071224.fits. We estimated the non-X-ray-background from the night Earth database using the method described in Tawa et al. (2008).

3. Analysis and Results

3.1. Absorption Spectrum Analysis

We first calculated the equivalent widths (EWs). We constructed a model with a power-law and narrow Gaussians, and fitted the spectra in narrow ranges, as shown in table 2, and obtained EWs for each line using the eqwidth tool in Xspec. The errors in the equivalent widths were obtained as follows: (1) we calculated the 90% error range of the normalization of the Gaussian function. (2) Next, we calculated the maximum error of the \( \text{EW} (\text{EW}_{\text{max}}) \) using the normalization values of the best fit (\( N_{\text{best}} \)) and maximum (\( N_{\text{max}} \)) as \( \text{EW}_{\text{max}} = \text{EW} / N_{\text{best}} \times N_{\text{max}} \). Comparing with the previous work, our obtained
value for the O VII Kα (0.65\(^{+0.19}_{-0.14}\) eV) is smaller than those in Futamoto et al. (2004) (1.19\(^{+0.47}_{-0.36}\) eV) and Yao and Wang (2006) (1.06\(^{+0.22}_{-0.27}\) eV). We confirmed that this difference comes from the modeling of the continuum spectrum, with higher-order diffraction photons (Yao & Wang 2006). We used only the 1st-order spectrum of the HRC observation, and modeled the continuum spectrum in a narrow energy range, to obtain reliable values.

To obtain the column density of ions, and to estimate the total column density of the absorbing material, we fit all of the lines simultaneously. We first fitted the continuum between 0.54 and 1.1 keV with a continuum model of a blackbody and a broken power-law. Foreground absorption by the neutral ISM with solar metal abundances by Anders and Grevesse (1989) was assumed. This model returned a minimum \(\chi^2/\text{dof} = 858.1/577\), and the best-fit column density of the neutral ISM \(N_{\text{H}}\) was 1.9 \(\times\) 10\(^{21}\) cm\(^{-2}\). This value is consistent with \(N_{\text{H}}\) estimated from by the 100 \(\mu\)m intensity (2.3 \(\times\) 10\(^{21}\) cm\(^{-2}\)) and reported in Yao and Wang (2006).

This poor fit might be caused by residuals at the metal edge due to uncertainties in the Chandra response matrices. Nicastro et al. (2005) set the metal abundance of the neutral absorption material to be free to deal with this problem. As we followed their method, it decreases the residuals (\(\chi^2/\text{dof} = 761.1/560\)) with the virtual absence of Ne and Na, and an over-abundance of C, N, and Mg by factors of 3, 3, and 26 respectively. These values are due to the uncertainties in calibration, rather than the true ISM metallicity (Nicastro et al. 2005). Though the \(\chi^2\) is still not good, it is difficult to compensate for the calibration uncertainties further, and we use this model to describe the continuum.

We next added two absorption lines representing O VII Kα and O VII Kβ using the absem model, which is the same as in Hagihara et al. (2010). The column density and velocity dispersion of these lines are linked because both lines originate from the same ionization state of oxygen (model A1). The results are given in table 3. We next added absorption lines representing O VIII Kα and Ne IX Kα step by step (model A2, A3). In each step, the velocity dispersion of lines are linked together. The results maintain consistency, and thus in further analysis the velocity dispersion is always linked together. For the next step, we evaluated the hot-phase hydrogen column density assuming solar abundances of O and Ne (model A4) (see figure 2). We then let the Ne abundance vary and fitted the spectrum (model A4\(^{-}\)). Please note that we fixed the abundance of O to the solar value, because the contribution of the continuum emission is small, and it is hard to determine the absolute metallicity. Though the best-fit hydrogen column density becomes smaller, and the Ne abundance is 2.2\(^{+1.8}_{-1.3}\), all of the parameters are consistent with those of the A4 model. We will use this A4 model for further combined analysis, and evaluate the Ne/O abundance effects if necessary. There might be some intrinsic absorbing material around 4U 1820–303. Futamoto et al. (2004) discussed the possibility of intrinsic absorption using a photo-ionization simulator, and concluded that the size of the binary system and the luminosity cannot explain the O VII ionization fraction estimated by the column density ratio. Thus, we considered that all of these absorption lines originate in the hot ISM in the further analysis.

### 3.2. Emission Spectrum Analysis

#### 3.2.1. Modeling of the contribution from foreground emission and stars

The emission spectrum from the 4U 1820–303 vicinity obtained by Suzaku is shown in figure 3. The emission below 2 keV is very bright, and we can easily distinguish the emission lines of O VII, O VIII, Ne IX, and Ne X. We evaluated the intensity of these lines by a simple power-law and
Fig. 2. O and Ne absorption lines in the 4U 1820–303 spectrum. The solid lines are model A4.

Gaussians fitting model (model E1); the results are summarized in table 4. Hereafter, the intensity of the line emission is shown in LU (Line Units), which corresponds to photons s\(^{-1}\) cm\(^{-2}\) str\(^{-1}\). These line ratios are hard to reproduce with a single-temperature plasma. Thus we will consider several components that can contribute to the emission in this region. We first consider the diffuse emission from the Solar neighborhood, Loop I, and the contributions from stars in the Galaxy, step by step.

As shown by the Suzaku shadowing observations of MBM-12 molecular clouds (Smith et al. 2007) and an evaluation of the soft X-ray background spectra of 14 fields (Yoshino et al. 2009), the emission around our Solar neighborhood due to Solar wind charge exchange and/or the Local hot bubble is present. Most of the emission from the Solar neighborhood might be below 0.5 keV, except for \(\sim 2\) LU of the O VII emission line. The apparent spectrum above 0.5 keV can be reproduced by an optically thin thermal plasma emission in collisional ionization equilibrium (CIE) with \(kT \sim 0.1\) keV (Yoshino et al. 2009). Since the uncertainty of the O VII line intensity is \(\sim 1\) LU, we adopt these values as the foreground emission.

The sight line toward 4U 1820–303 would go through Loop I, a large structure seen in the radio waveband. This structure is considered to be an old SNR (10\(^6\) yr) located in the Sco-Cen OB association. Egger and Aschenbach (1995) modeled this SNR based on RASS data. The density and temperature in the cavity are \(2.5 \times 10^3\) cm\(^{-3}\) and \(4.6 \times 10^6\) K. We then assumed the column density and line intensity using these parameters, as shown in table 5. After comparing these values with those in tables 3 and 4, we neglected the effect of Loop I in the absorption line analysis, but took it into account in the emission line analysis.

Recently, the contribution of stars in the soft X-ray background was studied using Chandra, XMM-Newton (López-Santiago et al. 2007), and Suzaku (Masui et al. 2009). The typical luminosity of a stellar corona is as small as \(10^{29}\) erg s\(^{-1}\), but the number density is large in the galactic plane and bulge direction. We estimated the contribution from stars by the following steps. First, we estimated the number of stars in the field-of-view, using a stellar population model. Secondly, we calculated the X-ray flux and spectra based on the currently available observational properties.

We used TRILEGAL simulator ver 1.4\(^1\) (Girardi et al. 2005) to estimate the main-sequence stellar distribution in the observing cone. This simulator synthesizes the stellar population for a given Galaxy field. Vanhollebeke, Groenewegen, and Girardi (2009) used this simulator and compared the results with the Two Micron All Sky Survey (2MASS) (Skrutskie et al. 2006) and the Optical Gravitational Lensing Experiment (OGLE) (Udalski et al. 1997) observational data in 11 directions. There is a discrepancy of about 20% between the model and the data, especially in the number of low-luminosity stars. We used their best model parameters to create the mock population, and counted the stars of several spectral types, and ages, as shown in table 6. Clearly, there are lots of A, F, G, K, and M stars in the Suzaku field of view. Note that we counted the stars in a radius of 20° in the Suzaku sight line, and estimated the observed flux on the detector via the arf. Kuntz and Snowden (2001) estimated the X-ray luminosity of these stars based on the ROSAT data, and Rocks (2009) compiled the X-ray spectra after López-Santiago et al. (2007), which uses XMM-Newton observation. We used the values given in table 7 as a template of each spectral type of stars.

\(^1\) http://stev.oapd.inaf.it/cgi-bin/trilegal.

Table 4. Apparent surface brightness of each line (model E1).

| Line     | (LU) | (LU) | (LU) | (LU) |
|----------|------|------|------|------|
| O VII    | 23.45±3.21 | 18.96±0.87 | 10.49±0.49 | 5.99±0.76 |
| O VIII   |      |      |      |      |
| Ne IX    |      |      |      |      |
| Ne X     |      |      |      |      |
Fig. 3. Spectrum obtained in the galactic bulge region (left) and evaluation of the line intensities by Gaussians (right).

Table 5. Estimated contribution from the Solar neighborhood and Loop I.

| Model           | O VII | O VIII | Ne IX | Ne X | O VII | O VIII | Ne IX | Ne X |
|-----------------|-------|--------|-------|------|-------|--------|-------|------|
| Solar neighborhood | 2     | 0      | 0     | 0    | ...   | ...    | ...   | ...  |
| Loop I          | 1.83  | 2.10   | 0.31  | 0.04 | 14.3  | 14.8   | 14.3  | 13.8 |

Table 6. Criteria and number of stars in the direction of Suzaku observation within a radius of 20' for each spectral type.

| Spectral type | $< B - V >$ | $M_V$ | 0–0.15 Gyr | 0.15–1 Gyr | 1–10 Gyr | > 10 Gyr |
|---------------|-------------|-------|------------|------------|----------|----------|
| O+B           | < −0.01     | ...   | 8          | 6          | 7        | 7        |
| A             | −0.01–0.3   | ...   | 6          | 58         | 12       | 90       |
| F             | 0.3–0.6     | 2–8   | 12         | 78         | 35212    | 41152    |
| G             | 0.6–0.8     | 2–10  | 6          | 58         | 97672    | 29270    |
| K             | > 0.8       | < 8   | 41         | 240        | 454739   | 72546    |
| M (early)     | > 0.8       | 8–15  | 133        | 1054       | 1851091  | 407848   |
| M (late)      | > 0.8       | > 15  | 0          | 0          | 35       | 0        |

Table 7. Stellar-type parameters used in stellar emission estimation.

| Spectral type | Single temperature | Two temperature model | Abundance | $\log L_X$ (erg s$^{-1}$)$^\dagger$ | Age |
|---------------|--------------------|-----------------------|-----------|-----------------------------------|-----|
| F             | 0.58               | ...                   | ...       | 0.5                              | 29.51 |
| G             | 0.67               | ...                   | ...       | 0.3                              | 29.91 |
| K             | 0.83               | 0.17                  | 0.32      | 1.97                             | 28.82 |
| M (early)     | 0.90               | 0.80                  | 0.27      | 2.02                             | 28.52 |
| RS-CVn        | N/A                | 2.59                  | 0.17      | 0.22                             | 30.75 |

$^\dagger$ The empirical spectral model are summarized by Rocks (2009) after López-Santiago et al. (2007) and luminosities estimated by Kuntz and Snowden (2001). RS-CVn type binary parameters after Ottmann and Schmitt (1992) are also shown.

$^\ddagger$ Luminosity in 0.4–4.0 keV independent of age.

In López-Santiago et al. (2007), about half of the K and M stars are represented by the two-temperature coronal model, and the other half is described by a single-temperature coronal model. We added the flux from the mock star distribution to these X-ray luminosity and spectra, by 8 thin thermal plasmas as an empirical mock-up spectrum. The RS CVn type binaries are also bright in X-rays, with a typical X-ray luminosity of $> 10^{30}$ erg s$^{-1}$. We adopted a simple exponential disk model.
by Ottmann and Schmitt (1992), and found that the estimated numbers in a circle of 20' is about ~980.

The H\textsc{i} column density toward the observing direction by 21 cm radio observation is 1.36 × 10^{21} cm^{-2} (Kalberla et al. 2005). The H\textsc{i} + H\textsc{\textsc{2}} column derived by the IRAS 100 \mu m intensity with a conversion formula by Snowden and Freyberg (1993) is 1.42 × 10^{21} cm^{-2}. We also calculated the hydrogen column as a function of the distance from the Sun based on the global Galactic model by Ferriere (1998), and found that ~80% of the absorption material is located within 2 kpc from us. Thus, as a crude assumption, we did not apply absorption by the neutral ISM to the SWCX+LHB component, Loop I, and stars and RS CVNs within 2 kpc, but did apply the absorption of 1.42 × 10^{21} cm^{-2} for stars and RS CVNs beyond 2 kpc.

3.2.2. Hot ISM emission

We then tried to represent the observed energy spectrum with the contributions from stars and RS CVNs and the Cosmic X-ray Background (CXB), which was modeled as an absorbed power-law with a photon index of 1.4 and its normalization of about 10 photon s^{-1} cm^{-2} str^{-1} keV^{-1} at 1 keV (Hasinger et al. 1993). This model only reproduces about 1/10 of the emission below 1 keV. Even though we allowed the normalization of every stellar component to vary, it was impossible to exhibit enough O\textsc{vii} lines because the temperatures of the stellar components were all high.

We next added a hot ISM component to reproduce the spectrum. We tried a one-temperature hot ISM model with fixed and free (N, Ne, and Fe) abundance, and obtained poor $\chi^2$/dof values of 578.62/133 and 366.20/130, respectively. This poor fit was caused by the spectrum where the O\textsc{vii} and Ne\textsc{x} lines both exist, and it is difficult for a single-temperature plasma to reproduce these lines simultaneously. We then gave up the one-temperature hot ISM model, and tried a two-temperature model with a fixed abundance (model E1). Though the $\chi^2$ was improved to 358.17/131, there were still significant residuals between the model and spectrum, as shown in figure 4. It is obvious that a continuum-like component is needed to reduce the residual between 1 and 3 keV; we thus tried to free the CXB parameters. Though this model reduced the residuals and improved the $\chi^2$/dof to 121.85/129, the best-fit values of the photon index is 2.4 ± 0.1, and the normalization is 41.5^{+3.5}_{-7.8} photon s^{-1} cm^{-2} str^{-1} keV^{-1} at 1 keV. The flux is about 4-times larger than the nominal value (Hasinger et al. 1993), and is not reasonable for the CXB, even though its fluctuation was taken into account.

As mentioned before, there are large uncertainties in the number densities, luminosities, and the energy spectrum of the background low luminosity stars and binaries. For this reason, we tried the following two models:

- **Model E2:** Assuming an underestimation of the stellar contribution, normalization of the background stars and RS CVNs are set to be free.
- **Model E3:** Assuming an unknown thermal component in the bulge, one high-temperature thin thermal plasma emission model is added.

In the E2 model, we set the normalization of stars to be free step by step, and investigated the residuals and the normalization, and then estimated the effect of star contributions on the hot ISM properties. To compensate for the residuals at around 2 keV, we needed an additional ~2 keV component. One plausible component to produce such hard emission is RS CVn binaries, of which we modeled a spectrum with a two-temperature plasma of 2.59 keV and 0.17 keV. Moreover, it is not well-understood how many stars make binaries, and there is uncertainty in the distribution of the RS CVn binaries. Thus, we first set the normalization of the background binary components to be free (Model E2-b: The emission model with background binary normalization is set to be free). Though we found that this model certainly reduced the residuals at around 2 keV, we also found that this model caused significant residuals at around 1 keV and above 2.5 keV. The emission from a plasma of $kT = 2.59$ keV is a little too high to compensate for the residual.

The M-type stars exhibit coronal emission, whose temperature is empirically known to be $kT = 0.5$–1.2 keV, and characterized by complex emission with Ne, and Fe-L lines around 0.9 keV, (López-Santiago et al. 2007; Sciortino et al. 1999); also their low luminosity could cause large uncertainties in the number of stars within the FOV. For the next step, we fixed the binary normalization to the simulated value, and set the normalization of the M-type star to be free (Model E2-m: Emission model with background M-type star normalization is set to be free). This model also could not explain the entire spectrum. However, the residuals caused by these two models (E2-b and E2-m) are complementary.

We thus tried to free the normalization of binary and M stars simultaneously (model E2-mb) as shown in figure 5 left. This model fit the data with a $\chi^2$/dof of 144.37/131. The normalization ratios to the simulated values are 6.57^{+1.17}_{-2.14} and 5.45^{+1.27}_{-2.20} for M stars and binaries, respectively. It is difficult to confirm if these values are correct or not, so we accept this value at present.

We then set the normalization of the K-type star and F and G-type stars to be free sequentially (model E2-mkb, E2-mkfgb). This modification caused no significant changes to the fitting results and the contributions of K, F, and G stars.
vanished. Finally, we linked the normalization of all star components, and set them to be free [model E2-(mgfb)].

The ratios of the obtained normalization to the simulated values are 2.79 ± 0.74 and 6.22 ± 1.35 for all spectral types of stars and binaries, respectively. \( \chi^2/\text{dof} \) is 151.29/129, and it is hard to explain the whole spectra with this model.

The normalizations and temperatures of the cooler and hotter ISM are consistent with each of the three models (E2-mb, E2-mkb, E2-mgfb). From these results, normalization of the stars is of little effect on the hot ISM temperature.

In the E3 model, an additional unknown component is assumed. We therefore fixed all of the components to the simulated values, other than the hot ISM. First, we added a thin thermal plasma to the model because the contribution from an unknown stellar component would be highly possible (model E3). The abundance of the additional plasma was fixed to the solar value. However, this model caused residual features, like the E2-b model, and could not fit the data \( \chi^2/\text{dof} = 165.37/131 \). The metal abundance of the stellar corona is not well understood, and so we set the metal abundance to be free (model E3-A). This model explains the whole spectrum very well \( \chi^2/\text{dof} = 121.04/130 \). However, the best-fit abundance is \( \sim 0 \), and the additional component is quite close to thermal bremsstrahlung of \( kT = 1 \) keV. Actually, we substituted the thermal bremsstrahlung for the thin thermal plasma of the E3-A model, and found no changes in the fitting results (model E3-B). We then set the abundance of the plasma of the E3-A model to the 0.1 Solar value (E3-A'). This model also fit the data with \( \chi^2/\text{dof} = 133.34/131 \) as shown in figure 5 right.

Some 1.5 keV thermal components are reported in the spectra of nearby dM stars (e.g., van den Besselaar et al. 2003), which could be the origin of the unknown component. As shown in table 7, the metallicity of the coronal spectra of the low luminosity stars is very low, which is consistent with the low metallicity of the unknown component. Stellar flares are another possibility for the unknown component. In the flare period, the high-temperature (> 1 keV) component of the stellar corona become brighter than usual. It is not plausible that this unknown component originates from the hot ISM, because the metallicity of the unknown component is not high \( \left( \sim 0.1 \right) \), and the temperature and induced pressure are too high to maintain such a plasma.

From model E2 and model E3, we can see that \( \sim 5 \) times normalization of stellar components or another thermal bremsstrahlung or a low abundance thin thermal plasma is needed to explain the whole spectrum. As shown in tables 8 and 9, there is at most a 10% difference in hot ISM parameters between acceptable models. Our model assumes two extreme possibilities, and it is reasonable to consider that the star contribution would change the hot ISM parameters by at most 10% in any case. Thus, we used model E2-mb and E3-A', which are shown in figure 5, to represent the emission model in the further analysis.
affected by the stellar or additional background models, but the intensity and ratio of the O lines are little
Table 10. The intensity and ratio of the O lines are little

| Model | Foreground* and backgrounds | ISM | Additional background | $\chi^2$/dof |
|-------|-----------------------------|-----|------------------------|--------------|
|       |                             | cool | hot                    |              |
|       | log $T$ (K) [kT (keV)]      | Norm$^t$ | log $T$ (K) [kT (keV)] | Norm$^t$ | Abundance |
| E3    | fixed                       | 6.019$^{+0.056}_{-0.062}$ | 205.1$^{+182.1}_{-87.3}$ | 6.567$^{+0.023}_{-0.021}$ | 27.3$^{+2.6}_{-2.1}$ | 7.54$^{+0.104}_{-0.082}$ | 17.4$^{+2.1}_{-2.0}$ | 1.0 (fixed) | 165.37/131 |
|       |                             | [0.090$^{+0.012}_{-0.010}$] | [3.015$^{+0.816}_{-0.519}$] | [1.109$^{+0.303}_{-0.248}$] 
| E3-A  | fixed                       | 6.022$^{+0.078}_{-0.072}$ | 171.0$^{+190.7}_{-88.4}$ | 6.546$^{+0.027}_{-0.028}$ | 24.0$^{+2.8}_{-3.2}$ | 7.10$^{+0.105}_{-0.110}$ | 64.3$^{+27.3}_{-16.5}$ | <0.03 | 121.04/130 |
|       |                             | [0.091$^{+0.014}_{-0.013}$] | [3.030$^{+0.020}_{-0.019}$] | [1.109$^{+0.303}_{-0.248}$] |
| E3-B  | fixed                       | 6.023$^{+0.077}_{-0.071}$ | 169.4$^{+185.8}_{-86.9}$ | 6.547$^{+0.026}_{-0.025}$ | 23.9$^{+2.8}_{-2.9}$ | 7.10$^{+0.108}_{-0.098}$ | 69.6$^{+26.2}_{-18.4}$ | ... | 120.94/131 |
|       |                             | [0.091$^{+0.014}_{-0.013}$] | [3.030$^{+0.020}_{-0.019}$] | [1.109$^{+0.303}_{-0.248}$] |
| E3-A' | fixed                       | 6.017$^{+0.073}_{-0.071}$ | 193.7$^{+224.9}_{-87.5}$ | 6.548$^{+0.026}_{-0.022}$ | 25.9$^{+2.7}_{-2.6}$ | 7.20$^{+0.096}_{-0.077}$ | 38.5$^{+4.8}_{-5.8}$ | 0.1 (fixed) | 133.34/131 |
|       |                             | [0.090$^{+0.014}_{-0.013}$] | [3.030$^{+0.020}_{-0.019}$] | [1.109$^{+0.303}_{-0.248}$] |
| E3-A'†| fixed                       | 6.440$^{+0.015}_{-0.015}$ | 37.3$^{+2.3}_{-2.3}$ | ... | ... | 7.15$^{+0.038}_{-0.039}$ | 49.8$^{+4.7}_{-4.7}$ | 0.1 | 231.45/133 |
|       |                             | [0.237$^{+0.008}_{-0.008}$] | [1.22$^{+0.112}_{-0.104}$] |

* All parameters of LHB + SWCX, Loop I, stars, and CXBs are fixed to referred or simulation based values.
† Emission Measure $10^{-3} \int n_e n_b dV$: in unit of cm$^{-6}$ pc.
‡ One hot ISM model.

Fig. 5. Best-fitted model and spectra by model E2-mb and E3-A'. The dotted lines indicate the foreground (unabsorbed) components, and the solid lines indicate the background (fully absorbed) components. Hot ISM (green), CXB (black), SWCX + LHB, and Loop I (blue), stars except for M stars (orange), M stars (light blue), and RS CVNs (magenta). Additional background continuum in E3 model is indicated by gray line.

Table 10. Surface brightness of the O and Ne lines.

| Model | O VII (LU) | O VIII (LU) | Ne IX (LU) | Ne X (LU) |
|-------|------------|-------------|------------|-----------|
| E2-mb | 14.72$^{+2.74}_{-1.47}$ | 9.8$^{+0.22}_{-1.48}$ | 0.61$^{+1.29}_{-0.54}$ | <0.19 |
| E3-A' | 15.80$^{+2.73}_{-1.51}$ | 10.75$^{+1.48}_{-1.32}$ | 3.09$^{+1.05}_{-0.54}$ | 2.17$^{+1.05}_{-2.12}$ |

We evaluated the line intensities corresponding to the hot ISM component with model E2-mb and E3-A', as summarized in table 10. The intensity and ratio of the O lines are little affected by the stellar or additional background models, but the contribution of the Ne lines changes by the assumption of the stellar components, especially of the high-temperature stars.

3.3 Combined Analysis

Two thermal components are at least required to describe the emission spectrum. Assuming the geometry of the two-temperature plasmas and the absorption toward the target, there are two possibilities for combined analysis. One is that only one plasma contributes to the absorption; the other is that both plasma contribute to the absorption. Thus, we consider these two cases in this subsection.

3.3.1 Uniform model with one absorbing plasma

We first assumed a combined model that only one plasma contributes to the absorption (model C1). The geometry is as follows: one uniform plasma (front-side plasma) exists in front of 4U 1820-303, and another uniform plasma (back-side plasma) exists in back of 4U 1820-303, as illustrated in figure 6.

We constructed two isothermal plasma models with a uniform density, and a length $L$ along the sight of line. We put an upper limit of 7.6 kpc on the length of the front-side plasma, to maintain consistency with the geometry. The velocity dispersions of the plasmas were linked together because this value was mainly determined using the ratio of O VII Kα to O VII Kβ in the absorption spectrum. We tried four sets of models; C1-1 and C1-2 is the combination of the E2-mb and...
A4 model, and the Ne / O abundance ratio was set to be free in C1-2. In the C1-3 and C1-4 model, we adopted the E3-A′ model for the emission model, and the Ne / O ratio was set to be free in C1-4.

The fitting results are given in table 11. The temperature of the front-side plasma ($T \sim 1.7 \times 10^6$ K) is determined mainly by the absorption spectra, and is consistent with the temperature obtained by the absorption analysis ($T \sim 1.8 \times 10^6$ K). The temperature of the front- and back-side plasma ($1.7 \times 10^6$ K and $3.9 \times 10^6$ K) are both higher than those determined only by emission analysis ($1.1 \times 10^6$ K and $3.6 \times 10^6$ K). A plasma of $1.7 \times 10^6$ K could emit O VII and O VIII lines three-times and thirty-times more effectively than a plasma of $1.1 \times 10^6$ K. Though this makes the emission measure of the front-side plasma smaller to maintain the intensity of the O VII lines, O VIII lines are produced more effectively. Thus, to suppress the O VIII intensity, the temperature of the back-side plasma becomes higher. Residuals caused by this adaptation could be compensated by the background components, and this model also can reproduce the O, Fe, and Ne emission lines. However, in the energy range lower than 0.5 keV, there are residuals caused by the deficit of N lines, because the lower temperature plasma ($1.7 \times 10^6$ K) is too hot to emit N lines effectively.

We summarize the physical properties of the plasma in table 12. We assumed 1, 2, and 10 kpc for the length for the back-side plasma to estimate its the density and pressure, because the back-side plasma contributes to the emission, and we could not determine the length and density separately. There could be two schemes. Assuming the back-side plasma confined in the galactic bulge region, its length is at most 2 kpc, which leads to a dense, high-pressure plasma. Thus, this leads to a picture that a hotter dense plasma exists around the galactic center region and a warm thin plasma covers the disk. The other is that by assuming pressure equilibrium between the front-side plasma and the back-side plasma, the length of the back-side plasma becomes ~8 kpc. This means that a hotter plasma of large depth exists over the warm thin disk, because 4U 1820–303 lies 1 kpc below the galactic disk.

### Table 12. Physical properties obtained by the model C1-4.

| Model | Component       | Length (kpc) | Density ($10^3$ cm$^{-3}$) | Temperature (10$^6$ K) | Pressure (10$^3$ cm$^{-3}$ K) |
|-------|----------------|--------------|-----------------------------|------------------------|-------------------------------|
| C1-4  | Front-Side plasma | 3.08±0.52    | 3.6±10.4                    | 1.7±0.2                | 6.0±20.6                      |
|       | Back-Side plasma | 1            | 4.3±0.6                     | 3.9±0.4                | 16.8±2.9                      |
|       |                 | 2            | 3.1±0.6                     | 3.0                      | 12.1±3.7                      |
|       |                 | 10           | 1.4±0.2                     | 5.1±1.3                | 2.5                           |

### Table 11. Fitting results of the C1 model.*

| Model | Front-Side plasma | Back-Side plasma | Stars | Binaries | Additional | $\chi^2$/dof |
|-------|-------------------|------------------|-------|----------|------------|--------------|
|       | $N_{H_{2}}$ (cm$^{-2}$) | Length (kpc) | log $T$ (K) | Ne/O | $v_p$ (km s$^{-1}$) | log $T$ (K) | Norm | Ratio | log $T$ (K) | Norm |
| C1-1  | E2-mb             | 19.7±0.90       | 6.2±0.8       | 0.50 | ...     | 6.58±0.055     | 15.5±5.1     | 7.00±1.90 | 4.66±1.51 | ...    | 819.82/704 |
|       | A4                | ↑                | ↑             | ↑     | ...     | 109±140        | 29            |
| C1-2  | E2-mb             | 19.60±0.18      | 6.22±0.05     | 1.4±1.2 | ...     | 6.588±0.047     | 15.3±5.2     | 6.67±1.98 | 4.86±1.48 | ...    | 819.05/703 |
|       | A4                | ↑                | ↑             | ↑     | ...     | 126±164        | 45            |
| C1-3  | E3-A′             | 19.66±0.16      | 6.20±0.04     | 1.4±1.2 | ...     | 6.574±0.041     | 22.0±3.0     | 7.254±0.085 | 37.7±5.2 | ...    | 810.11/704 |
|       | A4                | ↑                | ↑             | ↑     | ...     | 111±84         | 34            |
| C1-4  | E3-A′             | 19.54±0.21      | 6.23±0.05     | 2.3±1.4 | ...     | 6.592±0.040     | 18.9±5.1     | 7.265±0.073 | 37.1±5.0 | ...    | 805.94/703 |
|       | A4                | ↑                | ↑             | ↑     | 139±195 | 53           |               |

* All the parameters not written the table is fixed to the simulation based values.
1 Emission Measure $10^{-3} \int n_e n_p d l$: in unit of cm$^{-6}$ pc.
2 Normalization of background M-type star is set to be free.
3 Ratio of the normalization of the background stars or binaries to the simulation based value.

### Fig. 6. Schematic view of the model C1.
the two plasma components are separate, or mixed together with some filling factors, but we again set an upper limit for the length to be 7.6 kpc and a common velocity dispersion.

As with the previous model C1, we constructed two models with model sets of E2- mb + A4 (C2-1, C2-2) and E3- A’ + A4 (C2-3, C2-4). The fitting results are given in table 13. These values can be understood as follows: First, two plasma components of temperatures \( \sim 3.5 \times 10^6 \) K and \( \sim 1.0 \times 10^6 \) K are required to reproduce the emission spectra. The ionization fraction and the emissivity of each plasma was determined by their temperature; then, the column density and the emission measure to reproduce the absorption spectrum were obtained. We confirmed this flow, and found that the emission measures obtained here are about half of those obtained in the emission analysis. This is caused by the slight temperature decrease of the hotter plasma induced by this combined analysis.

With the model C2 results and the assumption of the Ne abundance of solar value, and the temperature dependence of the ionization fraction, the Ne X column density is at most \( 1 \times 10^{15} \) cm\(^{-2}\). The upper limit of the column density of Ne X from that of \( EW \) in the absorption spectrum in table 2 is \( \log N_{\text{NeX}} = 15.4 \), and is consistent with this upper limit.

We summarize the induced physical properties of the plasma in table 14. The length of the hotter plasma is almost on the upper limit. However, the cooler component has a very short length of < 0.7 kpc, and the pressure is higher than that of the hotter by a factor of \( \sim 7 \). This assumption gives a scheme of a thin-warm and thick hot-disk halo model.

### 3.4. Uncertainty due to the Model Systematics

In the absorption analysis, the energy resolution of the detectors (\( \sim 0.05 \) Å) corresponds to \( v_b \sim 400 \) km s\(^{-1}\)), and is not sufficient to determine the \( v_b \) of the plasma only with the line shapes. The lower limit of \( v_b \) can be determined from the thermal limits. Thus, to determine the velocity dispersion, we used the ratio of the absorption depth of O VII K\( \alpha \) and O VII K\( \beta \) instead, and assumed that the O VIII, Ne IX and Ne X originate from the same plasma, and linked the velocity dispersion of all lines. Because \( v_j \) and the column density are coupled, and if the plasma has a temperature gradient and local structure, this assumption causes systematic errors, but it little effects the temperature of the ISM, as shown by Hagihara et al. (2010).

In table 15 we summarize the systematic errors of the background and foreground models as well as their effect on the best-fit values of the hot ISM parameters. The obtained hot ISM parameters are all within 90% statistical error, and cause no change to our results and conclusions.

In addition to the systematic errors mentioned above, we have to consider systematics caused by the combined analysis, itself. Figure 8 shows contours of the temperatures of the hot ISM derived from emission analysis (E3- A’) and combined analysis (C1-4, C2-4). As shown in figure 8, contours only overlap partially, and those from combined analysis are shifted to each direction. The best-fitted \( \chi^2/\text{dof} \) value of the C1-4

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### Table 13. Fitting results with the C2 model. *

| Model   | Uniform hot plasma 1 | Uniform hot plasma 2 | Stars | Binaries | Additional | \( \chi^2/\text{dof} \) |
|---------|----------------------|----------------------|-------|----------|------------|---------------------|
|         | \( N_{\text{H} \text{I}} \) (cm\(^{-2}\)) | \( T \) (K) | \( v_b \) (km s\(^{-1}\)) | \( N_{\text{H} \text{I}} \) (cm\(^{-2}\)) | \( T \) (K) | Ratio\(^{3} \) | Ratio\(^{3} \) | \( T \) (K) | Norm\(^{8} \) | |
| C2-1   | E2- mb 19.55(2.01) 7.6(2.8) 6.48(2.04) ... | 19.26(1.53) 0.17(0.06) 5.09(0.07) ... | 19.55(2.01) 0.18(0.06) 5.09(0.07) ... | ... | ... | 805.65/703 |
| A4     | ↑ ... ... ... | ↑ ... ... ... | ↑ ... ... ... | ↑ ... ... ... | ↑ ... ... ... | ... | ... | ... | ... |
| C2-2   | E2- mb 19.55(2.01) 7.6(2.8) 6.48(2.04) 0.14(0.04) ... | 19.26(1.53) 0.18(0.06) 5.09(0.07) ... | 19.55(2.01) 0.18(0.06) 5.09(0.07) ... | ... | ... | 805.65/703 |
| A4     | ↑ ... ... ... | ↑ ... ... ... | ↑ ... ... ... | ↑ ... ... ... | ↑ ... ... ... | ... | ... | ... | ... |
| C2-3   | E3- A’ 19.57(2.01) 7.5(2.8) 6.51(2.04) ... | ... | ... | ... | ... | ... | 7.247(0.069) 40.6(5.0) 4.7 | 800.67/703 |
| A4     | ↑ ... ... ... | ↑ ... ... ... | ↑ ... ... ... | ↑ ... ... ... | ↑ ... ... ... | ... | ... | ... | ... |
| C2-4   | E3- A’ 19.52(2.01) 7.5(2.8) 6.51(2.04) 0.14(0.04) ... | ... | ... | ... | ... | ... | 7.270(0.069) 39.0(5.2) 5.3 | 796.36/702 |
| A4     | ↑ ... ... ... | ↑ ... ... ... | ↑ ... ... ... | ↑ ... ... ... | ↑ ... ... ... | ... | ... | ... | ... |

* All the parameters not written the table is fixed to the simulation based values.
† Normalization of background M-type star is set to be free.
‡ Ratio of the normalization of the background stars or binaries to the simulation based value.
§ Emission Measure \( 10^{-3} f N_{\text{H} \text{I}}dl \): in unit of cm\(^{-6}\) pc.

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### Table 14. Physical properties obtained by model C2-4.

| Model | Component | Length (kpc) | Density \( \left(10^{-3} \text{ cm}^{-3}\right) \) | Temperature \( (10^6 \text{ K}) \) | Pressure \( (10^3 \text{ cm}^{-3} \text{ K}) \) |
|-------|-----------|-------------|-------------------------------|-----------------|-----------------|
| C2-4  | Plasma 1  | 5.9 \( \pm 1.7 \) 3.7 | 1.8 \( \pm 0.5 \) 9 | 3.2 \( \pm 0.2 \) 0.3 | 5.7 \( \pm 18.1 \) 3.2 |
|       | Plasma 2  | 0.13 \( \pm 0.05 \) 0.41 | 38.6 \( \pm 0.05 \) 34.5 | 1.0 \( \pm 0.2 \) | 38.6 \( \pm 59.0 \) 35.4 |

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Fig. 7. Schematic view of model C2.
model is worse than those of the other models. These shifts would be caused by modeling a multi-temperature plasma with two temperature plasmas. To check the contribution of the uncertainty of the star and an unknown component, we fixed the parameters of the unknown component to the best-fit value of the E3-A’ model (table 9), and performed a combined analysis with the C1-4 and C2-4 models. The results are consistent with those of the C1-4 and C2-4 model. These two models (C1-4, C2-4) are representative of the other combined analysis models, and we concluded that the systematics originate in the combined analysis. Using these contours, the temperature range of the two plasmas were determined to be (2.8–4.3) \times 10^6 \text{ K} and (0.68–1.9) \times 10^6 \text{ K}.

We also checked the self-absorption effect of the emission lines with the obtained column density and velocity dispersion of ions. When the column density O VII is \(10^{16} \text{ cm}^{-2}\) and the minimum velocity dispersion \(v_b = 200 \text{ km s}^{-1}\), the opacity, \(\tau\), at the center of the resonance line is \(\approx 1.1\), which was evaluated in the same way as Futamoto et al. (2004). The reduction due to the self-absorption for the resonance line is about 30% after integrating over the emission line profile. Note that we measured all resonance, inter-combination, and forbidden lines as O VII line, with the energy resolution of the Suzaku XIS. Since the oscillator strength of the forbidden line is very small, the apparent reduction is diluted to be half as small as 15%. Also, we neglected the effect of scattered–in photons from outside the line of sight. The \(\tau\) at the O VII line center is less than the unity with \(v_b = 200 \text{ km s}^{-1}\) and \(N_{\text{O VII}} = 10^{16} \text{ cm}^{-2}\), and the total reduction is less than 20% without considering the O VII Kβ line. These effects will systematically reduce the emission-line intensity, but we neglected the effect in this paper because the correction is as much as the systematic and statistical errors. When we obtain a better energy resolution for the diffuse emission, we will be able to evaluate by the ratio between the resonance and forbidden lines.

### 4. Discussion

In this paper, we analyzed emission and absorption spectra toward the galactic bulge region, and found that there are at least two models to explain the emission and absorption data in this direction. We summarize the results in table 16. Only the emission measures were obtained for the back-side component, because there were no absorption data. Since we simplified the models as much as possible, we will discuss the hot plasma within our Galaxy by a possible extension from current simple models, and by comparing the previous results at high latitude.

#### 4.1. Extension of the Current Simplest Geometry

First, we took notice of the length of the front component. It is not likely that such a fully filled component is confined only to the sight line, which implies that these components fill and prevail throughout the disk. Thus, we consider that such a long extended plasma is a part of the hot ISM disk. Except for Plasma 2 in the C2 model, the error range includes the upper limit determined by the geometry, which is the distance.
of 7.6 kpc toward 4U 1820–303. It is not reasonable that the boundaries of the two plasmas coincide at 4U 1820–303. It is useful to consider what happens when a plasma of the same temperature exists beyond 7.6 kpc, as in figure 9. Additional plasma at the backside of 4U 1820–303, which does not contribute to the absorption, makes the emission measure of the original plasma decrease to maintain the emission intensity, while the column density is constant. The length becomes longer and the density becomes smaller, assuming additional plasma at the backside of 4U 1820–NUL. The total length and the total column density are calculated as \[cL + c(c - 1)L = c^2L = 19.4 \text{ kpc} \text{ and } nL + (c - 1)nL = cnL = 10^{19.93} \text{ cm}^{-2}.\] The thickness of the disk is 19.4 × sin(b_{4U}) = 2.7 kpc, where b_{4U} = −7°9 is the galactic latitude of 4U 1820–303. This is comparable to that of the exponential disk. The column density is also comparable to that found for PKS 2155–304, considering the difference of the galactic latitude, as 10^{19.93} × sin(b_{PKS})/sin(b_{4U}) = 10^{19.17} \text{ cm}^{-2}, where b_{PKS} = −52°2 is the galactic latitude of PKS 2155–304. This value is consistent with the column density for the PKS 2155–304 direction, log N_H = 10^{19.07} ± 0.08 obtained by an exponential disk model (Hagihara et al. 2010).

### Table 16. Results of the analysis of the galactic bulge region.

| Model   | Component       | T (10^6 K) | Front-Side log N_H (cm⁻²) | Length (kpc) | T (10^6 K) | E_M (10⁻³ cm⁻⁶ pc⁻¹) |
|---------|-----------------|------------|--------------------------|--------------|------------|---------------------|
| C1      | Front-Side Plasma | 1.7 ± 0.2  | 19.53 ± 0.2              | 3.1 ± 0.4    | ...        | ...                |
|         | Back-Side Plasma | ...        | ...                      | ...          | ...        | ...                |
| C2      | Plasma 1        | 3.2 ± 0.3  | 19.52 ± 0.16             | 5.9 ± 0.4    | ...        | ...                |
|         | Plasma 2        | 1.0 ± 0.2  | 19.19 ± 0.33             | 0.13 ± 0.11  | ...        | ...                |

4.2. Comparison with the Exponential Disk Observed at the High Latitude

The C1 model implies a thin, warm disk with a length of 3.1 kpc in the front, and a hot plasma at the back, toward the bulge region. The hot plasma is possible to associate with the bulge, or to be a hot thick disk above the warm disk. We will compare the properties of the warm disk with the exponential disk model obtained by the combined analysis with absorption to extragalactic objects: PKS 2155–304 (Hagihara et al. 2010) and LMC X-3 (Yao et al. 2009). In the extreme case, we can assume that the warm plasma has an extent of 7.6 kpc, which corresponds to \(c = 7.6/3.1 = 2.5\) in the above equations (1) and (2). The total length and the total column density are calculated as \[cL + c(c - 1)L = c^2L = 19.4 \text{ kpc} \text{ and } nL + (c - 1)nL = cnL = 10^{19.93} \text{ cm}^{-2}.\] The thickness of the disk is 19.4 × sin(b_{4U}) = 2.7 kpc, where b_{4U} = −7°9 is the galactic latitude of 4U 1820–303. This is comparable to that of the exponential disk. The column density is also comparable to that found for PKS 2155–304, considering the difference of the galactic latitude, as 10^{19.93} × sin(b_{PKS})/sin(b_{4U}) = 10^{19.17} \text{ cm}^{-2}, where b_{PKS} = −52°2 is the galactic latitude of PKS 2155–304. This value is consistent with the column density for the PKS 2155–304 direction, log N_H = 10^{19.07} ± 0.08 obtained by an exponential disk model (Hagihara et al. 2010). Thus, the front plasma of the C1 model corresponds to the exponential disk.

To confirm this similarity, we applied an exponential disk model with parameters, which well represents both the emission and absorption spectra of PKS 2155–304 (Hagihara et al. 2010). The exponential model well matched the absorption spectrum, but failed for the emission spectrum due to the residuals below 1 keV. If we add components that only contribute to the emission like C1 model, the fit returns a \(\chi^2 = 809.8/706\) with two thermal components with log T = 6.597 ± 0.046 and 6.023 ± 0.251 with a stellar contribution the same as in E3-A'.

The hot plasma at the backside was not observed at high latitude with LMC X-3 and PKS 2155–304 (Yao et al. 2009; Hagihara et al. 2010), but was detected in observations toward other bulge regions (Almy et al. 2000). The temperature and estimated electron density, assuming a size of 10 kpc, is consistent with those by the RASS image model by Snowden et al. (1997). These support the idea that the back-side plasma is a hot plasma associated with the bulge region. The location, size, and pressure are, however, not determined by current observations, and the relation between the disk and the bulge is hard to be considered.
The C2 model implies a thin-warm and thick hot-disk halo model. Such a thin disk has not been observed by previous studies, and its pressure is as high as $4 \times 10^6$ cm$^{-3}$ K, and almost twice of the typical value at the midplane estimated by Cox (2005) with thermal and non-thermal (Cosmic rays and magnetic field) components. The pressure of the warm plasma is also not balanced by a factor of 6. In addition, this simple C2 model assumes that the hot ISM is spatially limited in front of 4U 1820–303, and no plasma in the bulge region. If the hotter plasma can be extended beyond 4U 1820–303, like C2-B in figure 10, the pressure will decrease in proportional to the density. We thus need some mechanism to confine the warm $T \sim 10^6$ K plasma close to the galactic disk.

5. Conclusion

We have analyzed high resolution X-ray absorption/emission data observed by Chandra and Suzaku to determine the physical properties of the hot ISM toward the galactic bulge (4U 1820–303) direction with an estimate for the contribution from normal stars in the soft X-ray band.

A two-component plasma model can reproduce the absorption and emission spectra. One model assumes that only one component contributes to the absorption in front of 4U 1820–303. The temperature, column density and length of the front plasma are determined to be $(1.7 \pm 0.2) \times 10^6$ K, $(3.4^{+2.1}_{-1.2}) \times 10^{19}$ cm$^{-2}$ and $3.1^{+4.5}_{-1.8}$ kpc. The temperature and emission measure of the back-side plasma are determined to be $(3.9^{+0.4}_{-0.3}) \times 10^6$ K and $18.9^{+7.1}_{-4.0}$ cm$^{-6}$ pc. This model is consistent with a scheme with a hot X-ray bulge and an exponential disk model obtained from extragalactic source observations. If there are two plasma components contributing to the absorption, a thin warm plasma disk with a temperature of $(1.0 \pm 0.2) \times 10^6$ K and a length of $0.13^{+0.56}_{-0.11}$ kpc is confined to the galactic disk, and it is not pressure-balanced with a thick disk with a temperature of $(3.2^{+0.2}_{-0.3}) \times 10^6$ K.

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