Suzaku Observations of the Galactic Plane

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Abstract

In order to examine spectral variation of Galactic Ridge X-ray Emission, we analyzed Suzaku data observed in various regions on the Galactic plane and compared their properties, an especially Fe-K line feature. Suzaku resolved the Fe line complex into three narrow lines: \(~6.4\) keV, \(~6.7\) keV, and \(~7.0\) keV, which are K-lines from neutral (or low-ionized), He-like, and H-like irons, respectively. No significant broadening in the width of the Fe lines was found. The \(~6.7\) keV line is clearly found in all the regions. On the other hand, it seems that there are some differences in the flux ratios of the \(~6.4\) keV/\(~6.7\) keV and \(~7.0\) keV/\(~6.7\) keV lines, although the errors are large.

1 Introduction

Galactic Ridge X-ray Emission (GRXE) is unresolved X-ray emission along the Galactic plane (Worrall et al. 1982; Warwick et al. 1985; Koyama et al. 1986; Yamauchi et al. 1996; Kaneda et al. 1997; Sugizaki et al. 2001; Ebisawa et al. 2001, 2005; Tanaka 2002; Revnivtsev et al. 2006), and its origin is one of the most important problems in the X-ray astronomy. The previous observations with the several X-ray satellites have revealed characteristics of GRXE, summarized as follows. (1) GRXE is located along the Galactic plane and in the Galactic bulge (Warwick et al. 1985; Yamauchi and Koyama 1993; Revnivtsev et al. 2006). The distribution of GRXE is very similar to that of near infrared emission (Revnivtsev et al. 2006). (2) The GRXE spectrum exhibits a strong emission line at the energy of \(~6.7\) keV which is a K\(_\alpha\) line from He-like iron (Koyama et al. 1986). The X-ray spectrum in the \(3-10\) keV energy band is well represented by a thin thermal emission model with a temperature of \(~5-10\) keV (Koyama et al. 1986; Kaneda et al. 1997; Sugizaki et al. 2001). The total luminosity of the thermal component and the total thermal energy were measured to be \(~2\times10^{38}\) erg s\(^{-1}\) in the \(2-10\) keV energy band and \(~10^{56}\) erg (a filling factor = 1), respectively (Warwick et al. 1985; Koyama et al. 1986; Yamauchi and Koyama 1993; Kaneda et al. 1997). (3) Above \(10\) keV, a significant excess from the thermal emission is found (Yamasaki et al. 1997; Valinia and Marshall 1998). This component is considered to be non-thermal emission. (4) The spectral properties of GRXE are very similar to those of the diffuse emission in the Galactic center region (Tanaka et al. 2000). (5) The fluctuation analysis using the ASCA data gave a constraint for X-ray sources contributing to GRXE: if GRXE is composition of numerous faint X-ray sources, the number of the sources in the Galaxy (\(N\)) and their luminosity (\(L_X\)) are \(N > 1.4 \times 10^7\) and \(L_X < 1.9 \times 10^{34}\) erg s\(^{-1}\), respectively (Sugizaki et al. 1999). (6) The deep observation with Chandra showed that only 10 \% of the GRXE flux was resolved into discrete sources with an X-ray flux (\(F_X\)) of \(F_X > 3 \times 10^{-15}\) erg s\(^{-1}\) cm\(^{-2}\) (Ebisawa et al. 2001, 2005).

Our knowledge on GRXE has increased since its discovery. However, the origin of GRXE remains unsolved. Which is GRXE truly diffuse emission or composition of numerous faint X-ray sources? In the case of the diffuse origin, the hot plasma gas can not be confined by the gravity of the Galaxy. What is the mechanism to produce and maintain the hot plasma gas in the Galaxy? On the other hand, in the case of the point source origin, what kind of sources makes GRXE?

Systematic study of the GRXE spectra, an especially Fe-K line band, is expected to give a crucial key to investigate the origin of GRXE. Suzaku has better spectral resolution, wider energy band, and lower intrinsic background than the previous satellites (Mitsuda et al. 2007). Therefore, Suzaku is the best instrument to study the GRXE spectra. We analyzed GRXE spectra obtained in various regions on the Galactic plane and compared their spectral properties.
2 Data and Analysis

Suzaku observed various Galactic plane regions during the Science Working Group (SWG) time. We picked up fields not including significant point sources and analyzed the data. The pointing positions and exposure times used for this analysis are listed in table 1.

Constructing the GRXE spectra, we extracted X-ray photons from the entire region of the XIS field of view (FOV), but excluded point-like sources found in the FOV and the calibration source at the corner of the XIS sensors. For maximizing photon statistics, the data obtained with XIS0, 2, and 3 were combined. The rmf and arf files were made for each field using xisrmfgen and xissimarfgen (Ishisaki et al. 2007), respectively.

The contribution of the cosmic X-ray background (CXB) to the observed spectra was estimated using the data of North Ecliptic Pole. After the subtraction of the non-X-ray background, the X-ray spectrum of CXB was fitted to a model of a power-law with a photoelectric absorption. The normalization of the power-law model ($N_{PL}$) was set to be free, but the photon index ($\Gamma$) and the $N_H$ value were fixed to 1.412 and $4.4\times10^{20}$ Hcm$^{-2}$, respectively.

<table>
<thead>
<tr>
<th>Table 1: Pointing position and exposure time used for the present analysis</th>
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<tr>
<td>Position ($l$, $b$)</td>
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<tr>
<td>P1 (332.00, -0.15)</td>
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<tr>
<td>P2 (347.63, 0.71)</td>
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<td>P3 (8.04, -0.05)</td>
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<td>P4 (28.46, -0.20)</td>
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3 Results and Discussion

In the observed Suzaku spectra, we found many emission lines from highly ionized ions, such as Mg, Si, S, and Fe. In this analysis, we focused on the Fe line feature. Figure 1 shows the observed spectra in the 4.5–10.0 keV energy band after the subtraction of the non-X-ray background. We can clearly see three emission lines in the 6–7 keV range, which are thought to be K-lines from neutral (or low ionized), He-like, and H-like irons. In order to identify the emission lines, we fitted them to a model as follows;

Absorption ($N_H = 3\times10^{22}$ Hcm$^{-2}$; fixed) $\times$ (Bremsstrahlung + Emission lines) (for GRXE)

+ Absorption ($N_H = 6\times10^{22}$ Hcm$^{-2}$; fixed) $\times$ Power-law ($\Gamma$ and $N_{PL}$; fixed) (for CXB).

The emission lines included in the model were Fe I Kα (6.4 keV) and Kβ (7.05 keV), Fe XXV Kα (6.7 keV), and Fe XXVI Kα (6.97 keV). Since the center energy and the intensity of Kβ line from Fe I could not be constrained from the data, we assumed the center energy of Fe I Kβ = 1.103 $\times$ that of Fe I Kα and the intensity of Fe I Kβ = 0.1 $\times$ that of Fe I Kα. The best-fit model is also plotted in figure 1. The center energies of three emission lines were determined to be 6.36–6.45, 6.66–6.71, and 6.96–7.00 keV. Thus, Suzaku clearly resolved the Fe line complex into K-lines from Fe I, Fe XXV, and Fe XXVI. No significant broadening in the width of the Fe lines was found.

The $\sim$6.7 keV line is clearly found in all the regions, which indicates that a thin thermal plasma with a temperature of several to 10 keV is located along the Galactic plane. Comparing the spectra, we found that the Kα line from H-like iron at $\sim$7 keV in the the l $\sim$ 347° region (P2) is very weak. Furthermore, the intensities of the $\sim$6.4 keV and $\sim$7 keV lines relative to that of the $\sim$6.7 keV line seems to vary from field to field. Figure 2 shows the flux ratios of the $\sim$6.4 keV/$\sim$6.7 keV and $\sim$6.97 keV/$\sim$6.7 keV lines. Since the errors are large, a model that the flux ratio is constant in all the fields can not be excluded from the statistical point of view, but it seems that there are some differences in the flux ratios.

The X-ray spectrum of cataclysmic variables (CVs) exhibits a thermal emission with $\sim$6.4, $\sim$6.7, and $\sim$7.0 keV lines (e.g., Ezuka and Ishida 1999), while that of active binary stars (ABs) such as RS CVn type stars exhibits a thermal emission with $\sim$6.7 keV line (e.g., Güdel et al. 1999). Since a large number of
Figure 1: The background-subtracted GRXE spectra observed in the various regions on the Galactic plane (see table 1). (Blue) Kα and Kβ lines from a neutral iron, (red) Kα line from a He-like iron, and (green) Kα line from a H-like iron.

CVs and ABs are expected to be in the Galaxy, it is pointed out that a large fraction of GRXE would be composition of unresolved CVs and ABs (Revnivtsev et al. 2006). If GRXE is composition of numerous faint X-ray sources such as CVs and ABs, the GRXE spectrum would be an averaged spectrum of the X-ray sources contributing to GRXE, and hence the GRXE spectra observed in the various regions would be quite similar to each other. The Suzaku spectra show a hint that the flux ratios of the Fe lines vary from field to field. However, the number of samples and the photon statistics are limited. In order to confirm the difference in the iron line feature, further analysis is required.

References
Koyama, K., Makishima, K., Tanaka, Y., and Tsunemi, H. 1986, PASJ, 38, 121
Figure 2: The flux ratios of $\sim 6.4$ keV/$\sim 6.7$ keV (upper) and $\sim 7.0$ keV/$\sim 6.7$ keV (lower) lines observed in the various regions on the Galactic plane (see table 1). The error shows the single-parameter 90% confidence level.

Mitsuda, K., et al. 2007, PASJ, 59, S1