X-Ray Reflection Nebulae with Large Equivalent Widths of Neutral Iron K-alpha Line in the Sgr C Region

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Abstract

We report on the results of the Suzaku observation in the Sgr C region, vicinity of the Galactic Center where there are giant MCs. We detected four diffuse clumps with strong line emission at 6.4 keV, K*alpha* from neutral or low-ionized Fe. The X-ray spectra of the two bright clumps, exhibit strong K*alpha* line from FeI with large equivalent widths (EWs) of 2.0–2.2 keV and clear K*beta* of FeI. The GCDX in the Sgr C region is composed of the 6.4 keV- and 6.7 keV-associated components. These are phenomenologically decomposed by taking relations between EWs of the 6.4 keV and 6.7 keV lines. Then the former EWs against the associated continuum in the bright clump regions are estimated to be $2.4^{+2.3}_{-0.7}$ keV. Since the two different approaches give similar large EWs of 2 keV, we strongly suggest that the 6.4 keV clumps in the Sgr C region are due to X-ray reflection/fluorescence (the X-ray reflection nebulae).

Key words: Galaxy: center — ISM: clouds — ISM: molecules — X-rays: ISM

1. Introduction

For the origin of 6.4 keV emission line from molecular clouds (MCs) in the Galactic center (GC), two models have been proposed. One is the impact of low-energy cosmic-ray electrons (LECRe) followed by bremsstrahlung and 6.4 keV line emission, proposed for the origin of the Galactic Ridge X-ray Emission (Valinia et al. 2000). Yusef-Zadeh et al. 2002 proved that this model can be applied to G 0.13−0.13 assuming the Fe abundance of two solar. The other is that the hard X-rays and 6.4 keV lines are due to reflection/fluorescence from MCs irradiated by external hard X-ray sources (X-ray reflection Nebulae; XRNe) (Sunyaev et al. 1993, Markevitch et al. 1993, Koyama et al. 1996, Sunyaev & Churazov 1998, Park et al. 2004). Some observational results supporting the XRN rather than the LECRe model have been accumulating for Sgr B2 (Murakami et al. 2001a, Revnivtsev et al. 2004, Muno et al. 2007, Koyama et al. 2008, Inui et al. 2008). However, for the other regions, in particular Sgr C, observations have been limited and hence the 6.4 keV line origin is still open issue.

The Sgr C region consists of giant MCs and large HII regions. From the ^{13}CO observations, Liszt & Spiker (1995) estimated 6.1×10^5 solar mass for the molecular gas. Murakami et al. (2001b) discovered a 6.4 keV clump with ASCA, and interpreted that the clump is an XRN because it showed a large equivalent width (EW) of the 6.4 keV line with a strong absorption like that in Sgr B2. On the other hand, Yusef-Zadeh et al. (2007) discussed possible association of the 6.4 keV emission lines with some radio non-thermal filaments based on the Chandra observation, and argued that the 6.4 keV line is due to the impact of LECRe. In order to fix the above debates, we, therefore, made a long Suzaku observation on the Sgr C region.

2. Analyses

Figure 1 is the narrow band image of the 6.4 keV-line (6.28–6.42 keV; Kα of FeI). Four 6.4 keV-line clumps are found and designated as M 359.43−0.07, M 359.47−0.15, M 359.43−0.12, and M 359.38−0.00. A bright 2.45 keV-line clump is also found at (l,b)=(359.407, -0.119), hence designated as G 359.41−0.12 and shown with an ellipse.

The Galactic center diffuse X-ray emission (GCDX) in the Sgr A region is phenomenologically decomposed into the 6.7-keV line plus associated continuum (6.7-

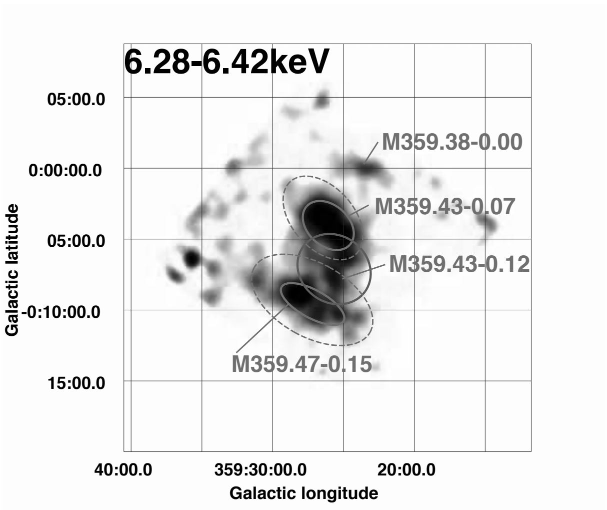

Fig. 1. The 6.4 keV-line (Kα of FeI) image in the 6.28–6.42 keV band. The source and background regions for the spectral analysis are shown with the solid and dashed ellipses, where the data within the ellipse (G 359.41−0.12) were excluded to minimize the contamination from the strong 2.45 keV emission line and its associated continuum.

component) and the 6.4-keV line plus associated continuum (6.4-component) (Koyama et al. 2009). Using the data of GCDX-unsubtracted spectra, we derived the relation between $EW_{6.4}$ and $EW_{6.7}$. The best-fit linear relations for the Sgr C region is; $EW_{6.7} + 0.22(\pm 0.12) \times EW_{6.4} = 0.53(\pm 0.06)$[keV]. This indicates that $EW_{6.7}$ in the 6.7-component is 0.53 ± 0.06 keV (at $EW_{6.4} \rightarrow 0$). On the other hand, $EW_{6.4}$ in the 6.4-component is $2.4^{+2.3}_{-0.7}$ keV (at $EW_{6.7} \rightarrow 0$), which is larger than those in the Sgr A region (Koyama et al. 2009).

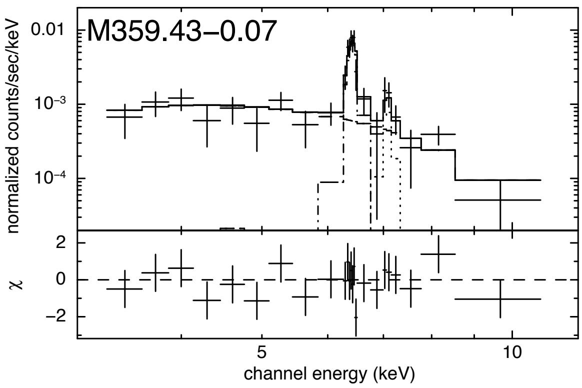

Fig. 2. GCDX-subtracted spectrum of M 359.43−0.07. The Kα and Kβ lines of FeI and power-law are shown by dot-dashed, dotted, and dashed lines, respectively. The spectrum of BI was simultaneously analyzed, but the figure is not shown here, for brevity.

These large EWs are also found in GCDX-subtracted spectra of these 6.4 keV clumps as shown in figure 2. We simultaneously fit a model of a power-law and a narrow Gaussian lines with absorption (table 1) to the FIs and BI spectra. The center energy of the second narrow Gaussian for the FeI Kβ line was fixed to 1.103 times of that of Kα. The best-fit parameters are listed in table 1.

Table 1. The best-fit parameters of the spectral fittings to the GCDX–subtracted spectra of M 359.43−0.07 and M 359.47−0.15.

Parameter	M 359.43−0.07	M 359.47−0.15
Absorbed power-law model:		
N_H (10^{23}cm^{-2})	0.92 (0.48-1.41)	0.82 (0.65-1.18)
Photon index	1.67 (1.51-1.82)	1.61 (1.52-1.86)
Gaussian 1 (FeI Kα):		
Line energy (keV)	6.41 (6.39-6.42)	6.41 (6.40-6.42)
Line flux (10^{-6} ph cm^{-2} s^{-1})	6.43 (5.27-7.39)	8.82 (7.87-10.0)
Equivalent width (keV)	2.18 (1.79-2.51)	1.96 (1.75-2.23)
Gaussian 2 (FeI Kβ):		
Line energy (keV)	7.07	7.07
Line flux (10^{-6} ph cm^{-2} s^{-1})	1.05 (0.43-2.14)	1.91 (1.22-3.00)
Flux (10^{-13}erg cm^{-2} s^{-1})	2.70	4.11
χ^2/d.o.f.	27.92/41	49.67/46

3. Discussions

The LECRe scenario expects $EW_{6.4}$ of ~ 300 eV for the solar abundance Fe (Tatischeff et al. 2003, Yusef-Zadeh et al. 2007), and hence is difficult to explain the observed large $EW_{6.4}$ of ~ 2 keV, unless Fe is extremely over-abundant by a factor of 6–7. We found no observational evidence for such over-abundance. On the other hand, XRN scenario naturally explain the large $EW_{6.4}$ of the two clumps and hence is more likely.

The mass of M 359.43−0.07 and M 359.47−0.15 are estimated from the absorption columns to be $\leq 4 \times 10^4$ and $\leq 3 \times 10^4$ solar mass, respectively. From these masses and fluxes of the 6.4 keV lines, the luminosity of photo-ionizing source can be estimated following Sunyaev & Churazov (1998) as $\geq 1 \times 10^{38}$ erg s^{-1} and $\geq 2 \times 10^{38}$ erg s^{-1}. There is no X-ray object bright enough inside or nearby Sgr C region. Even the brightest near-by sources, KS 1741−293 and the Great Annihilator (1E 1740.7–2943) are impossible to explain this luminosity. Thus we arrive to the same conclusion for the 6.4 keV clumps origin near Sgr B2, a past Sgr A* activity of $\geq 1 \times 10^{38}$ erg s^{-1} at 240 yr ago.

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