An X-ray Face-on View of the Galactic Center Molecular Clouds Observed with Suzaku

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Abstract

We present a new methodology to derive positions of the Galactic center molecular clouds (MCs) along the line of sight, as an application study of the Galactic center diffuse X-rays (GCDX). We examined the Suzaku X-ray images and spectra of the GCDX near at MCs of Sgr B and Sgr C, and found that the GCDX can be divided into two parts: one suffers strong absorption by the MCs ($N_{\rm H}$ >10^{23} H cm^{-2}) and the other does not ($N_{\rm H}$ ~6×10^{22} H cm^{-2}). Assuming that the plasma of the GCDX is a sphere with a uniform volume emissivity around Sgr A*, we quantitatively estimated the line-of-sight positions of the MCs from the flux ratios of the GCDX. We successfully drew a face-on view showing that the MCs near at Sgr B and Sgr C are respectively located at the near and the far sides with respect to Sgr A*.

Key words: Galaxy: Center — ISM: molecules, clouds, structure — X-rays: spectra

1. Introduction

The Galactic center (GC) region is a concentration of molecular gas (central molecular zone (CMZ); $|l| \leq 1°$). The Molecular clouds (MCs) near Sgr B and Sgr C are the most massive ones among the CMZ. In principle, the 3-D structure of the CMZ is very hard to estimate due to our inevitable edge-on perspective. So far, some face-on images has been constructed by the deconvolution of (l, V) diagrams of the radio molecular lines (e.g., Sofue 1995; Tsuboi et al. 1999). However in the traditional method, larger uncertainties due to assumptions of the dynamical motion around the GC are unavoidable. Our aim is to develop a more direct and reliable method with X-ray to derive the line-of-sight distribution of the MCs.

The GC region is bright in the Galactic center diffuse X-rays (GCDX; e.g., Koyama et al. 2007b) .The GCDX contains thermal emission from the hot plasmas (hereafter GCPE) and the non-thermal emission from the MCs (hereafter XRNE). The GCPE (Fe XXVI 6.7 keV-line) symmetrically extends over 2° in longitude around the supermassive black hole Sgr A* (e.g., Yamauchi et al. 1990). The XRNE (FeI 6.4 keV-line), produced by reflections of external X-rays, is tracing the dense MCs ($N_{\rm H} > 10^{23}$ H cm^{-2}) of the CMZ (Koyama et al. 2007a; Nobukawa et al. 2007; Nakajima et al. 2009).

2. Observation

Deep multiple pointing observations covering the GC region of $-1° < l < 1°$ were performed with the X-ray Imaging Spectrometer (XIS) at the focal planes of the X-ray Telescope (XRT) on board the Suzaku satellite during 2005 to 2008. The total effective exposure time is ~3 Ms after the data screening. We construct band images and spectra of the Sgr B and Sgr C regions with the instrumental Non–X-ray backgrounds excluded using HEADAS software version 6.5.1.

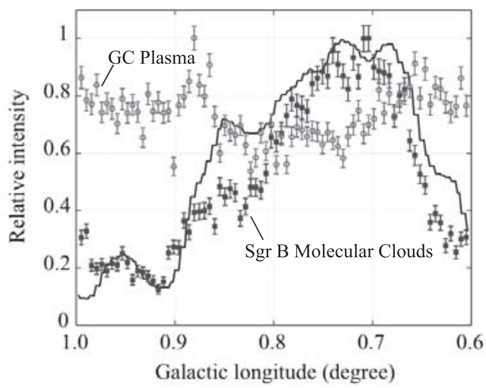

Fig. 1. Profile along the Galactic longitude. Red: X-ray 2.5-3.5 keV band; Blue: X-ray 6.4 keV band (Ryu et al. 2009). Black: radio CS line (Tsuboi et al. 1999).

3. Analysis

3.1. Images and Profiles

We made images of the 2.5-3.5 keV band for the GCPE continuum and the 6.4 keV band for the MCs to investigate their spatial distribution. We found a anti-correlation near the Sgr B region: the GCPE is relatively weak in contrast to the strong 6.4 keV emission from the MCs. We confirmed this in profiles along the Galactic longitude at 0.7-0.85 deg (see figure 1). Since X-rays in 2.5-3.5 keV band is sensitive to absorption in $N_{\rm H}$ ranges of 10^{22}-10^{24} H cm^{-2}, the weak GCPE flux would be due to the absorption by MCs ($N_{\rm H} > 10^{23}$ H cm^{-2}) overlapped in the line of sight.

The phenomenal anti-correlation gives a hint that the Sgr B MCs is located in foreground to the GCPE. In detail, we noticed that the GCPE flux drops in 2.5-3.5 keV band is only about 15%, indicating that not all but only a part of the GCPE in the line of sight is absorbed by the MCs.

3.2. Spectra

To study more quantitatively, we constructed a universal spectra model for the GCDX:

$$\begin{aligned}&\mathrm{Abs1} \times \mathrm{Abs2} \times ((1 - R) \times \mathrm{GCPE} + \mathrm{XRNE})\\ &+\mathrm{Abs2}\times(R \times \mathrm{GCPE}) + \mathrm{Foreground\ Emission} \quad \cdots (1)\end{aligned}$$

The details of the model construction and its justification is explained in Ryu et al. 2009.

The model in equation (1) nicely fits the observed spectra near the GC region (figure 2: right). The GCPE is divided into two parts by different absorption of Abs1 and Abs2. The part suffers Abs1 of $N_{\rm H} > 10^{23}$ H cm^{-2} is the GCPE beyond the MC in the line of sight, while the part suffers Abs2 of $N_{\rm H} \sim 6 \times 10^{22}$ H cm^{-2} is the GCPE in foreground to the MC. Thus the parameter R in equation (1) represents the emission-measure ratio of the GCPE in foreground to the MC (figure2: left). We fit the spectra of the Sgr B and Sgr C regions and obtained the values of R for each MC.

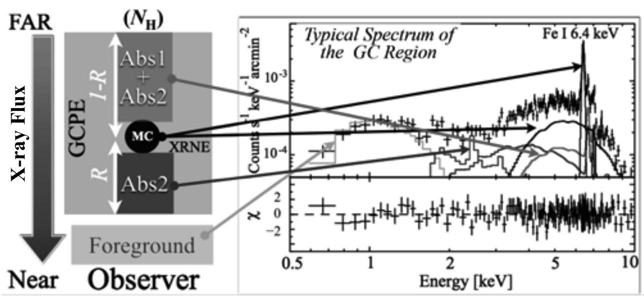

Fig. 2. Schematic view along the line of sight (left) and the typical spectrum (right).

4. Results

We made an assumption that the GCPE is a sphere of uniform volume emissivity around Sgr A* and take the boundary radius at l =1.25° or 175 pc@8kpc, following the observation results of the 6.7 keV-line (Fe XXVI) by Yamauchi et al. (1990). In this case, the values of R obtained in the spectra fittings (section 3.2) technically

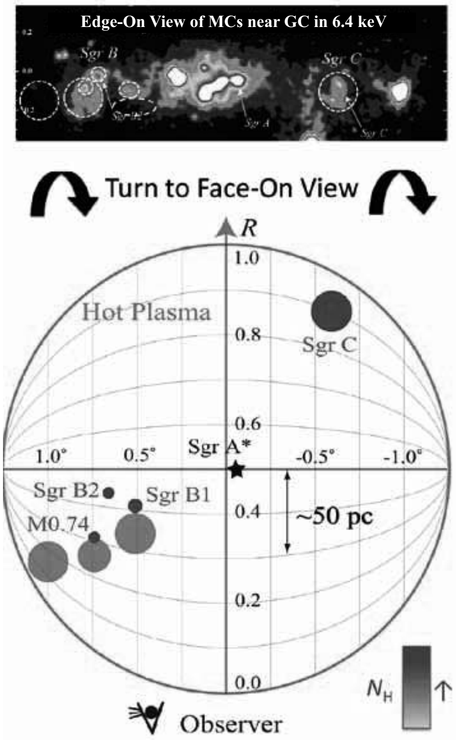

Fig. 3. 3-D view of MCs near the Sgr B and Sgr C regions.

indicate the relative line-of-sight position of MCs inside the GCPE (Ryu et al. 2009). We then drew the face-on view of the MCs perpendicular to the Galactic plane (figure 3: bottom).

As demonstrated in the figure 3, the Sgr B MCs are generally located on the nearer side, while Sgr C MCs are on the farther side, with respect to Sgr A*. If all of these MCs re-emitting the 6.4 keV-line are the constituent parts of the CMZ, the results demonstrate that the CMZ has a inclined bar-like distribution.

We have developed a new methodology to directly derive the positions of the MCs along the line of sight: a correlation study between the 6.4 keV-line from the MCs (i.e. XRNE) and the line-of-sight absorption of the GCPE by utilising the X-ray band images and spectra. We applied this method to the Sgr B and Sgr C MCs and successfully obtained the 3-D view (see figure 3).

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