ASCA X-Ray Shadowing in the Lupus Region

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Abstract

X-ray shadowing effects by the nearby dark clouds in our galaxy have mainly been studied by ROSAT observations in the 1/4 - 3/4 keV energy band. However, the cutoff energy of these energy bands are equivalent to Log ($N_{\rm H}$[cm^{-2}]) of ≤ 21 and dense core equivalent to Log ($N_{\rm H}$[cm^{-2}])~ 22 can not easily identified. We have analyzed the X-ray attenuation of Cosmic X-ray Background radiation by the Lupus molecular clouds using the data obtained by the Japanese X-ray Astronomy satellite ASCA. Because of the absence of intense X-ray sources in this region, we could clearly see the X-ray extinction core in the Lupus 1 north region. The positional coincidence of X-ray shadows in the Lupus 1 north region is nearly consistent with CO cloud core, far infrared emission (IRAS 100μm) and visual extinction. The peak equivalent Log ($N_{\rm H}$[cm^{-2}]) is estimated to be 21.5 from the X-ray intensity ratio between 0.7-1.8keV and 1.8-3.5keV energy bands, which is consistent with the value expected from the observations of $C^{18}O$, IRAS 100μm and star counts (visual extinction).

1 Introduction

Attenuation of the soft X-ray background radiation or Cosmic X-ray Background radiation by Galactic Interstellar Medium, so called *X-ray Shadowing*, is studied by many authors using both sounding rockets and astronomical satellites (Knude 1985; Snowden et al. 1993; Wang and Yu 1995; Benjamin et al. 1996; Kuntz et al. 1997; Park et al. 1997; Moritz et al. 1998). One scope of these observations is to estimate the contribution of Local Hot Bubble (LHB; $T \sim 10^6$K) surrounding our solar system. The other is to consider the effect of optical depth of the high latitude clouds. The systematic survey were done by Wang & Yu (1995) and Kuntz, Snowden and Verter (1997) to investigate the physical connection between soft X-ray attenuation and infrared emission by gas and dust concentration among the nearby molecular clouds using ROSAT PSPC observation data. In these studies, target $N_{\rm H}$ is in the range $\leq 10^{21}$[cm^{-2}], because of the energy band of the 0.1-2keV (ROSAT/PSPC). In addition, the lower energy band (1/4keV) data are dominated by LHB component in the field of view and higher energy band of 3/4keV and 1.5keV are also contaminated with LHB due to relatively low energy resolution of the proportional counter. We here present the result of the X-ray data analysis using the data of ASCA observation (Japanese X-ray Astronomical Satellite) in the Lupus 1 north and 5 east region. These data cover the wide energy range of 0.4-10keV and show higher energy resolution. These observations are sensitive up to $N_{\rm H} \geq 10^{22}$[cm^{-2}] which is a typical optical depth of dense cores among molecular clouds.

2 Observations

The observation was carried out using the two different X-ray detectors, the SIS (Solid state Imaging Spectrometer) and the GIS (Gas Imaging Spectrometer), with the energy resolutions of $\sim 2\%$ and $\sim 8\%$ at 6keV, respectively. Four sets of the high throughput X-ray mirror assemblies with a total effective area of more than 1000 cm^2 at 1.5 keV (Burke et al. 1991, Tanaka et al. 1994, Serlemitsos et al. 1995, Ohashi et al. 1996) in the 0.5-10keV energy band for each detector. The total exposure was 30 ks for both Lupus 1 north, centered at $(15^h38^m39^s, -33^o25.5')_{\rm J2000}$, and Lupus 5 east centered at $(16^h22^m7^s, -37^o19.4')_{\rm J2000}$, region, respectively. The typical spatial resolution of GIS and SIS are 1 arcmin due to their detector response and the effect of blurring of X-ray mirrors. SIS observations for both regions are operated in 1CCD mode which covers relatively small field of view (11×11 arcmin^2), to the GIS field of view (40 arcmin diameters), hence, we mainly used the GIS data to obtain on and off sky data of molecular cores. All the X-ray data analysis have done using FTOOLS4.1 and XIMAGE2.5.3 software developed by GSFC/NASA. Lupus 1 and 5 star forming regions are the nearest molecular clouds and relatively less active than other nearby star forming regions (Hughes et al. 1994; Tachihara et al. 1996; Chen et al. 1997). The estimation of the distance to the clouds is still uncertain, ranging 100-190pc (Franco 1990; Krautter 1991; Knude & Hog 1998, Wichmann et al. 1998). The observed regions, Lupus 1 and 5, are massive clouds ($M_{\rm LTE} > 10^3$ solar masses) but have low star forming efficiencies, 0.4% for Lupus 1 and $\geq 0.05\%$ for Lupus 5, respectively. Hence, we have few bright X-ray sources in the field of views (as shown below) and could get almost contamination free structures of absorbed CXBs in the wide energy range. We also observed Lupus 1 north and 5 east regions to estimate maximum equivalent Hydrogen column densities to compare with the X-ray data using *NANTEN* 4m radio observatory (Nagoya Univ.) at Las Campanas in Chili with $C^{18}O$ ($J = 1 - 0$) transition line.

3 Results

Figures 1 show positional coincidence with the molecular core using ^{13}CO ($J = 1 - 0$) (*NANTEN* 4m radio observatory), IRAS 100μm intensity and a cavity of visual image by Digitized Sky Survey. There is a clear sign of the correlation in Lupus 1 north molecular core overlayed on GIS images smoothed with Gaussian function of $\sigma = 1.5$ arcmin. The clear sign of the soft X-ray attenuation is visible in the soft X-ray image (≤ 1.8keV). The effects of CXB absorption features are consistent in both detectors which show $\leq 50\%$ (0-50%) of CXB surface brightness subtracting night earth data (see Ohashi et al. 1996) as detector backgrounds. The X-ray core located at the position of $(15^h39^m3^s, -33^o25.3')_{\rm J2000}$ is coincident with Lupus 1 molecular core.

Then we made intensity ratio between 0.7-1.8keV and 1.8-3.5keV energy bands to estimate maximum equivalent Hydrogen column densities at the center of the X-ray core and obtained $N_{\rm H} = 5(2 - 10) \times 10^{21}$ [cm^{-2}] using the GIS data subtracting detector background (Ishisaki 1995). Estimations of $N_{\rm H}$ was done by simulated X-ray spectra assuming an averaged CXB spectrum extracted from high galactic latitude blank sky data (Ishisaki 1995). *NANTEN* $C^{18}O$ ($J = 1 - 0$) observation data are also used to estimate the maximum $N_{\rm H}$ at the center of the molecular core. The peak value of $N(C^{18}O)$ was consistent with an equivalent $N_{\rm H}$ of 9×10^{21}[cm^{-2}].

We also consider the effect of CXB fluctuation in the soft X-ray energy band. Carrera et al. (1996) implied the value of $\delta I_{\rm CXB}/I_{\rm CXB}$ to be 0.06 ± 0.08 in the 0.73-2.04keV using 80 high galactic latitude ($|b| \geq 28^o$) images of ROSAT (A part of the RIXOS project) after the source subtraction in a 1-3 arcmin scales, which is a typical size of nearby molecular cores. Hence, the soft X-ray attenuation of $\leq 50\%$ is significantly low, in comparison with CXB surface brightness fluctuation.

4 Discussion

To estimate the maximum equivalent $N_{\rm H}$ from other wavelength observations, we investigate IRAS 100μm archival data and visual extinction with the star count method by Cambresy (1999). Boulanger & Perault (1988) investigated infrared (IRAS 60 & 100μm data) and HI correlation of the nearby star forming regions and obtained $I(100\mu{\rm m})$ [MJy/sr^{-1}] / $N_{\rm H}$ [10^{20}cm^{-2}] of 2.4 ± 0.5 for Lupus region. The peak 100μm intensity of $70 - 80$MJy at the center of the X-ray core position (Lupus 1N) indicate a value of $N_{\rm H} \sim 3 \times 10^{21}$ [cm^{-2}]. On the other hand, the maximum visual extinction (Av) of 5.3 (Cambresy 1999) corresponds to 10×10^{21}[cm^{-2}] due to the gas-to-dust ratio of $N_{\rm H}/Av = 1.87 \times 10^{21}$[cm^{-2}] from Savege & Mathis (1979). These results are consistent with X-ray results but have uncertainty of factor of ≥ 2. Table 1 summarizes these results.

The conversion factor, $I(100\mu{\rm m})/N_{\rm H}({\rm HI})$ of 2.4 (Boulanger & Perault 1988) is relatively larger than the other measurements. One possibility is an enrichment of Hydrogen molecules (H_2) with a factor of 2 in the Lupus region. This makes a value of equivalent $N_{\rm H}$ to be 6×10^{21}[cm^{-2}] from IRAS measurement. Another possibility is that there is hotter dust heated by surrounding objects in spite of low activity

Method	$N_H[\times 10^{21} cm^{-2}]$
X-ray (ASCA; This work)	~5 (2–10)
$C^{18}O$ (NANTEN; This work)	~5
IRAS 100μm (IPAC/NASA)	~3
star counts (Cambresy 1999)	~10

Table 1: The estimations of maximum equivalent N_H

of this star forming region (Chen et al. 1997).
X-ray observations are tracer of oxygen atoms both gas and solid phase in the soft X-ray band of ~1keV, and CO observations directly observe CO column density. On the other hand, IRAS 100μm intensity depends not only total mass of dust but also dust temperature and size population. Visual extinction has also depends on geometrical size distribution of dust and stellar spectra which are used to estimate these values. Then the X-ray observation is a powerful tool to estimate line-of-site equivalent N_H which does not depend on phase of interstellar matter.

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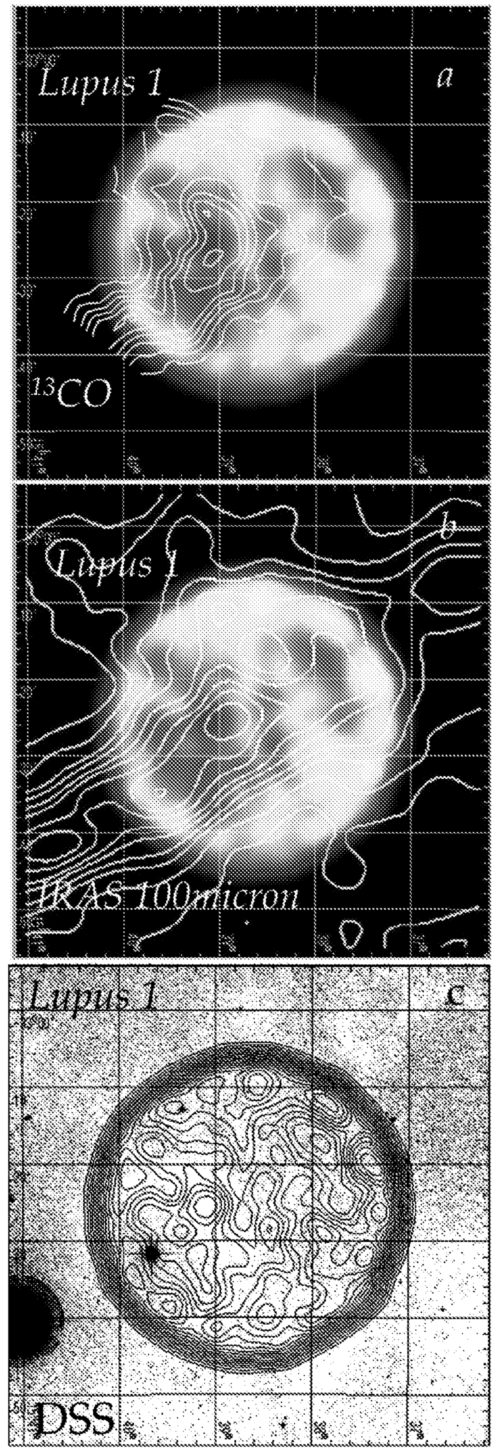

Figure 1: GIS gray scale images in the 0.7-1.8keV energy bands overlaid by the ^{13}CO(a) and the IRAS 100μm(b) intensity map with increments of 1.5 [km/s K] and 4 [MJy], respectively. Digitized Sky Survey image ovserlaid by GIS intensity contour in the save energy band is also shown with increments of 2×10^{-6} [c/s/pixel/sensor] after subtraction of detector background. The IRAS 100 μm data have processed with FRESCO (Full RESolution Survey COadd) method which is distributed from IPAC (Infrared Processing and Analysis Center)/NASA.