A LARGE AREA CO(J=2–1) MAPPING OF THE ORION *GIANT MOLECULAR CLOUDS*

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ABSTRACT. A large-area CO(J=2–1) map of the Orion A and B clouds is presented. The J=2–1/J=1–0 intensity ratio of CO varies systematically over the whole extent of these clouds, i.e., the ratio is ~1 in their main ridges and declines to ~0.5 in their peripheries. This variation of the intensity ratio is understood in terms of the variation of the surface gas density of clumps which is $\gtrsim 3\times10^3$ cm^{-3} for those in the ridges and ~1×10^2 cm^{-3} for those in the peripheries. The peripheral regions seen in low-J transitions of ^{12}CO is more surface-filling ($\gtrsim$0.7) than expected.

1. INTRODUCTION

Large-scale mapping observations of the entire extent of GMC complexes play major roles in understanding overall structures and formation mechanisms of molecular clouds. The J=1–0 lines of ^{12}CO and its rarer isotopes have been mainly used to carry out large-scale mapping observations which have revealed clumpy or filamentary nature as well as spatial extent, mass, and kinematics of molecular gas (e.g., Maddalena et al. 1986). Recent surveys of molecular clouds with higher spatial resolutions showed that clumps or filaments in the regions consist of subclumps (e.g., Tatematsu et al. 1992), in which star- and planetary system-formation is supposed to be undergoing. We know, however, little about physical conditions of molecular gas and their variation in their parent clouds. Studies of physical conditions of molecular clouds are important to understand the entire structure, formation, evolution, and destruction of the clouds.

2. OBSERVATIONS AND RESULTS

We obtained ~2300 spectra within 35 square degrees on the sky using the Tokyo-NRO 60 cm radio telescope, which has the same angular resolution of 9′ at 230 GHz as that of the Columbia 1.2 m telescopes. The spectra were integrated in the LSR velocity range of 0–20 kms^{-1} and were compared with the CO(J=1–0) data taken with the same angular resolution (Maddalena et al. 1986). As shown in Figure 1, the J=2–1 emission exhibits basically similar spatial distribution to that of the J=1–0 emission presented in Maddalena et al. (1986), i.e., both maps show two fragments of elongated clouds with their lengths of ~50 pc and widths of ~10 pc, with their strongest emissions occurring at the positions of HII regions NGC 1976 and NGC 2024 for the Orion A and B clouds, respectively.

Although the basic appearance of these two maps are similar, a systematic difference in spatial distribution between the two maps can be recognized when we make a closer comparison of these line intensities. In Figure 2, the J=2–1/J=1–0 integrated intensity ratio of the transitions (=$R_{2-1/1-0}$) is shown in a gray-scale representation. The regions with high $R_{2-1/1-0}$ values of around unity or larger are concentrated around two HII regions, reflection nebulosities, and the western edges of the clouds which face to I Ori OB associations. We can clearly see that $R_{2-1/1-0}$ decreases systematically toward the peripheries of the clouds.

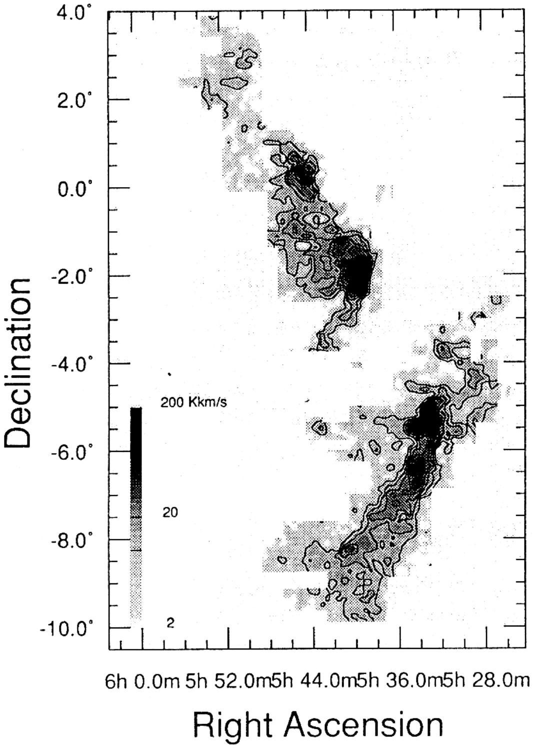

Figure 1._ A gray-scale representation of the CO(J=2–1) integrated intensity map. The effect of atmospheric attenuation and beam efficiency has been corrected.

3. DISCUSSION

What causes this systematic variation of $R_{2-1/1-0}$? Opaque low-J transitions of ^{12}CO mainly originate from thin photodissociative surface of clumps (Gierens et al. 1992). Results of detailed LVG analysis attribute this variation of the intensity ratio to the variation of gas density of clumps rather than that of gas kinetic temperature and chemical abundance. Derived surface gas density is $\gtrsim 3\times10^{3}$ cm^{-3} for clumps in the central ridges and $\sim 1\times10^{2}$ cm^{-3} for clumps in the peripheries of the clouds.

More careful treatment considering dilution of brightness due to unfilled beam bring interesting conclusion on clumpiness of the clouds. The $R_{2-1/1-0}$ value in the peripheral regions takes a small value of typically 0.5, while the peak *J*=2–1 intensity is as large as 2 K. If portion *f* of the beam is filled with clumps, observed brightness temperature of the clumps should be divided by *f* to derive real brightness temperature. If a surface filling factor in the peripheries is significantly smaller than unity, such a high *J*=2–1 intensity cannot be explained simultaneously with the observed low intensity ratio. The lower limit of the surface filling factor is ~0.7.

The *J*=2–1/*J*=1–0 luminosity ratio integrated over the observed regions of the Orion A and B clouds is 0.77 and 0.66, respectively. Extrapolation to less bright unobserved regions gives 0.75 and 0.62 as plausible luminosity ratios for these clouds. These values are consistent with those observed typically in disks of spiral galaxies (~0.6; Casoli 1991 and references therein) and in the Galactic disk along the Solar circle (Hayashi et al. 1993), and are significantly lower than large values often observed in active star-forming regions in galaxies (~2; e.g., Eckart et al. 1990) and in the Galactic center (~1.1; Oka et al. 1993). Active star-forming regions in galaxies cannot be explained by an ensemble of Orion-like GMCs.

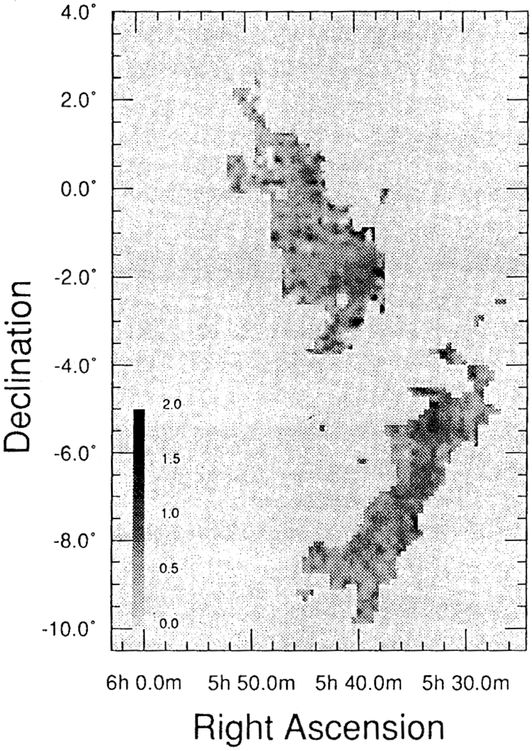

Figure 2._ A gray-scale representation of the CO(*J*=2–1)/CO(*J*=1–0) integrated intensity ratio map. The effect of atmospheric attenuation and beam efficiency has been corrected.

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QUESTIONS and ANSWERS

Title : A Large Area ^{12}CO (J=2-1) Mapping of the Orion Giant Molecular Clouds

Speaker : Sakamoto, S.

Choe, S.-U. : I realize there are big pressure differences about a factor of 10 among your observed regions. What kinds of forces support the pressure gradients inside the observed giant molecular cloud?

Sakamoto, S. : It can be explained in terms of large gravitational potential in the central regions of the clouds.

Y. C. Mihn : (1) What are observational uncertainties including regional uncertainties in the ratio?
(2) $n(H_2)$ resulted from LVG models incorporates with the uncertainties in the collisional cross-sections. $n(H_2)=100$ near the dense molecular cloud Orion A seems to be too small?

Sakamoto, S. : (1) Both J=1-0 and J=2-1 data contain calibration errors of ~10%. So the ratio contains an error of ~15%.
(2) I confirmed that my result of an LVG calculation is consistent to the former result. The absolute value of derived $n(H_2)$ itself might be the target of uncertainties. The decreasing outward tendency of $n(H_2)$, however, certainly exists.

MAO, X. J. : How do you measure the kinetic temperatures which are different from skirts to the central region, a non-thermal equilibrium case? How do you calculate the LVG model for the geometrically not symmetric case?

Sakamoto, S. : Yes. I calculated on assumption of LVG. Although LVG analyses are based on an unrealistic assumption, they give roughly consistent results to those obtained by more complicated, realistic calculations. It is pointed out by several authors that the assumed geometry play a minor role to the derived results.