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Sub-mm observations of molecular clouds in the N 159 region with the NANTEN2 telescope

Y. Mizuno[1], N. Mizuno[1], A. Kawamura[1], T. Ohnishi[1], Y. Fukui[1], T. Minamidani[2], J. Stutzki[3], J. Pineda[4], U. Klein[5], F. Bertoldi[5], B.C. Koo[6], M. Rubio[7], M. Burton[8], J. Ott[9], NANTEN2 Consortium and Spitzer SAGE Team

[1]Department of Astrophysics, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8602, Japan
email: y_mizuno@a.phys.nagoya-u.ac.jp

[2]Department of Physics, Faculty of Science, Hokkaido University, N10W8, Kita-ku, Sapporo, 060-0810, Japan

[3]KOSMA, I. Physikalisches Institut, Universität zu Köln, Zülpicher Straße 77, 50937 Köln, Germany

[4]NASA Jet Propulsion Laboratory, California Institute of Technology, MS 169-506, 4800 Oak Grove Drive, USA

[5]Argelander-Institut für Astronomie, Auf dem Hügel 71, 53121 Bonn, Germany

[6]Seoul National University, Seoul 151-742, Korea

[7]Departamento de Astronomía, Universidad de Chile, Casilla 36-D, Santiago, Chile

[8]School of Physics, University of New South Wales, Sydney, NSW 2052, Australia

[9]National Radio Astronomy Observatory, 520 Edgemont Road, Charlottesviile, VA 22903-2475, USA

Abstract. We carried out CO(J =4–3) observations towards the N 159 region with the *NANTEN2* 4m telescope. We have detected three compact clumps which have been also identified in CO(J =1–0) observations with *SEST*. The northern clumps, N 159W and N 159E, have high CO(J =4–3)/CO(J =1–0) intensity ratios, 1.1 and 1.5 respectively, while the intensity ratio of the southern clump, N 159S, is lower, 0.5. Furthermore, the intensity ratio map shows a similar distribution as the mid-IR image taken with the *Spitzer Space Telescope*. These results indicate that the intensity ratio is very sensitive to star formation activity.

Keywords. stars: formation, ISM: clouds, ISM: molecules, galaxies: individual (LMC), Magellanic Clouds, radio lines: ISM, submillimeter

1. Introduction

There are a lot of massive stellar clusters called populous clusters in the Large Magellanic Cloud. Their formation processes, however, are still only poorly understood. It is important to know the physical conditions of cluster forming regions which can be largely affected by high-mass star formation. Sub-mm CO lines enable us to trace highly excited regions in the molecular clouds and to obtain temperature and density of clumps from calculating the molecular line radiative transfer (e.g., Large Velocity Gradient method). We observed CO(J =4–3) emissions from N 159 with the *NANTEN2* 4m telescope. The N 159 region is known as one of the most active cluster forming regions in the LMC associated with a giant molecular cloud (Fukui et al. 2008). High angular molecular line observations resolved three prominent clumps (named N 159W, N 159E and N 159S) in

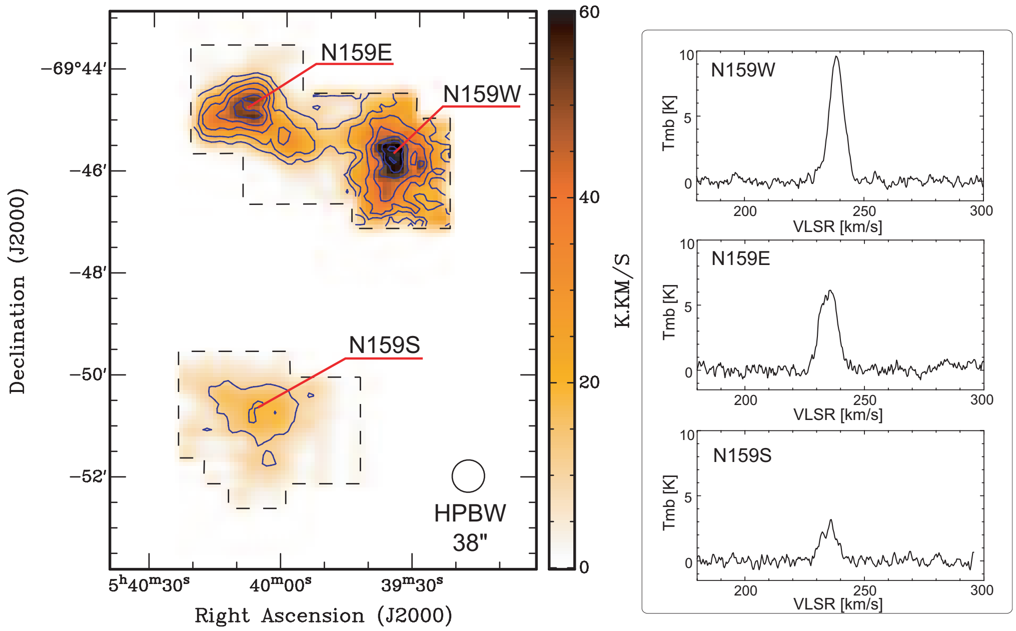

Figure 1. (Right) CO(J =4–3) integrated intensity map of the N 159 region. Clump peaks are labelled. (Left) Peak CO(J =4–3) spectra of each of the clumps.

this region (Johansson et al. 1998). Huge H II regions and five young massive clusters (Bica et al. 1996) are associated with two northern clumps (N 159W and N 159E), while the southern part of that (N 159S) is relatively quiet in star formation. So, this region is an ideal site to study relations between conditions of molecular clouds and cluster forming activities.

2. Observations

We observed the ^{12}CO(J =4–3) rotational line at 461.0408 GHz with the *NANTEN2* 4m sub-mm telescope situated at 4800m altitude on Pampa la Bola in Chile. We used the dual-channel 460/810 GHz receiver developed by Cologne University. The double sideband receiver temperature for the 460 GHz band was 250 K and the typical system noise temperature during these observations was 900 K. The telescope provided 38″ angular resolution which enabled us to resolve molecular cloud structure at the size scales of a populous cluster. We mapped an area of about $2' \times 2'$ around each of the three prominent clumps.

3. Results

Fig. 1 shows the map of CO(J =4–3) in N 159. Three prominent peaks are well resolved and N 159W is the strongest peak in this region. We defined clumps as the half intensity of the peak intensity value and obtained clump physical properties (table 1). $T_{\rm mb}$, Δv and $R_{4-3/1-0}$ are averaged values over each clump, and $M_{\rm vir}$ was calculated as $190R(\rm pc)\Delta v(\rm kms^{-1})^2$. Intensity maps of the three different transition lines at the same resolution are plotted in Fig. 2. N 159W is the strongest peak in these maps. N 159E has higher intensity at the higher transition, however N 159S has lower intensity at the higher transition. Therefore, it may be warmer in N 159E than in N 159S.

Table 1. Clump physical properties.

	N 159W	N 159E	N 159S
Size (pc)	7.6	7.6	9.6
$T_{\rm mb}$ (K)	5.6	5.0	1.8
Δv (km s^{-1})	8.2	7.5	8.2
$M_{\rm vir}$ ($M_\odot$)	1×10^5	1×10^5	1×10^5

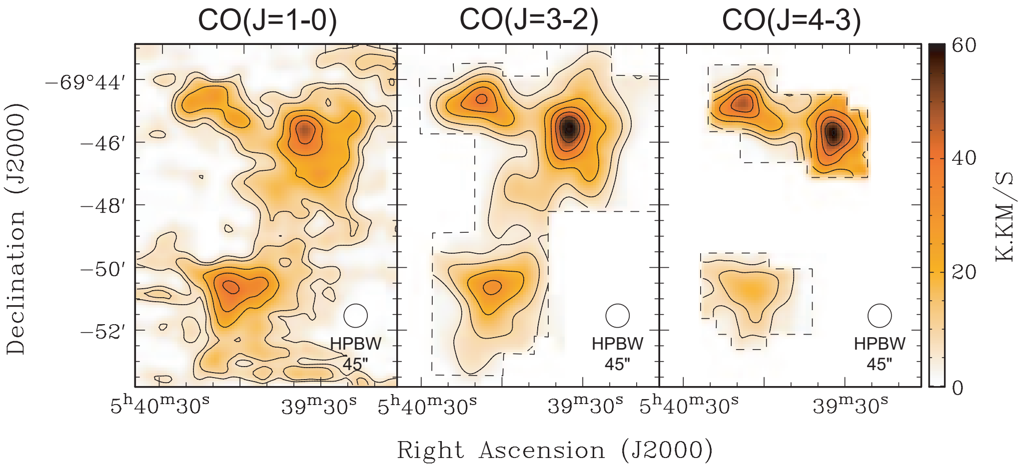

Figure 2. Integrated intensity map of CO(J =1–0) from the *MOPRA* telescope(PI. Ott et al.), CO(J =3–2) from the *ASTE* telescope (Minamidani et al. 2008) and *NANTEN2* telescope (this work). All map are smoothed to the same beam size of 45″.

Table 2. The results of LVG analysis.

	N 159W	N 159E	N 159S
$R_{4-3/1-0}$	1.1	1.5	0.53
$n(H_2)$ (cm^{-3})	$6 \times 10^3 - 8 \times 10^5$	$1 \times 10^4 - 2 \times 10^5$	$1 \times 10^3 - 6 \times 10^3$
$T_{\rm kin}$ (K)	> 40	> 80	20 – 60

4. Analysis

4.1. *LVG Analysis*

We calculated the density and temperature range of clumps using the Large velocity gradient method (LVG, Goldreich and Kwan 1974). Calculations were made by adding the $R_{4-3/1-0}$ value to the results of Minamidani et al. (2008) and by assuming a spherical clump with uniform density and temperature. This result suggests N 159W and N 159E are denser and warmer than N 159S. Furthermore, physical conditions of clumps were determined more accurately using CO(J =4–3) data (table 2).

4.2. *Compare with Starformation activities*

Fig. 3 is 8 μm emission observed in *Spitzer* SAGE overlaid with the integrated intensity ratio map of CO(J =4–3) / CO(J =1–0). The northern part has high ratios over 1.0 and the high-ratio region is well correlated with the active star forming region detected through PAH emission. It suggests that the gas is heated and compressed by star forming activities. On the other hand, N 159S show monotonous variations and the line ratio is gradually-increased towards the east from the west.

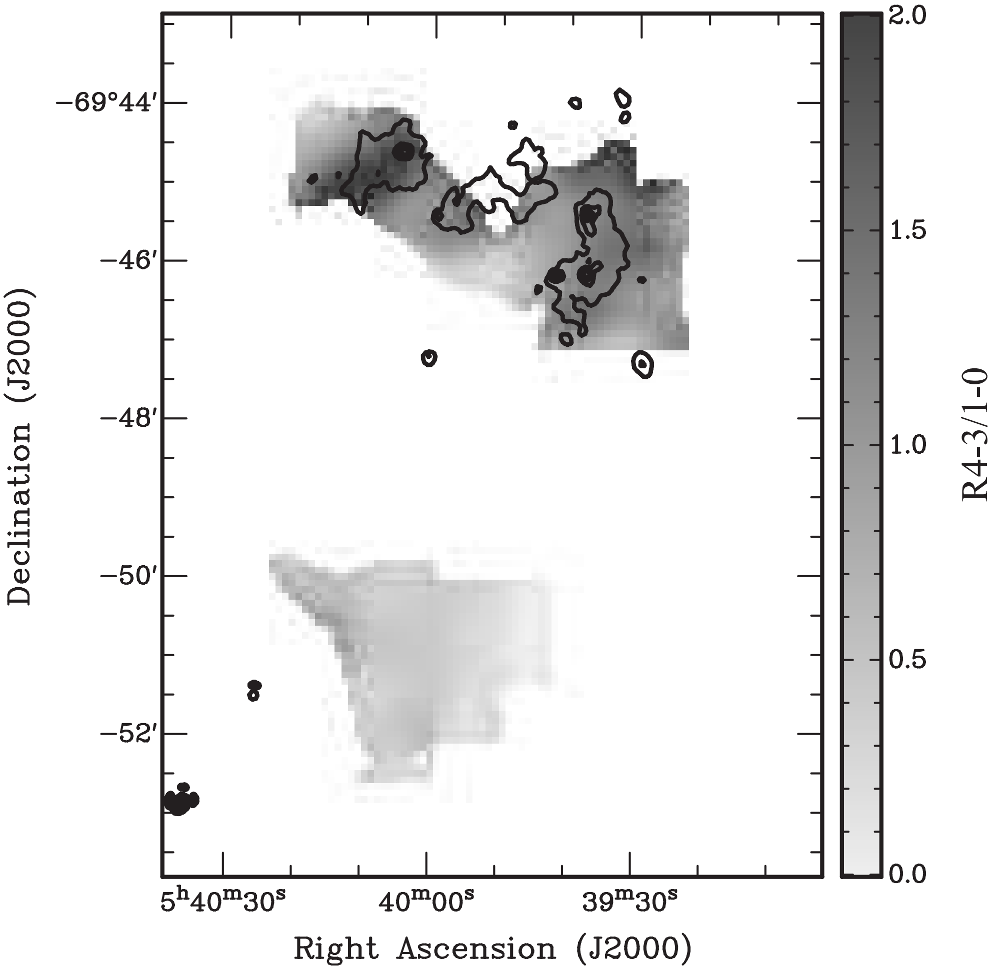

Figure 3. (Grey scale) CO(J =4–3)/CO(J =1–0) integrated intensity ratio map. (Contour) 8-μm emission from *Spitzer* SAGE observations.

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