New CO Views of the Magellanic Clouds

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Abstract

NANTEN, a 4-m radio telescope installed at Las Campanas was dedicated to survey the southern molecular clouds in millimeter rotational transitions of carbon monoxide, providing new molecular views of the Magellanic Clouds. The giant molecular clouds have been identified as the sites of on-going cluster formation in the LMC. Comparisons with clusters, H II regions, and supernova remnants suggest that formation and destruction processes of the giant molecular clouds are fairly rapid. In particular, destruction of the clouds seems to take place very quickly after the formation of clusters. A possible importance of supergiant shells in triggering cluster formation and cloud formation is suggested.

1 Introduction

Most dwarf irregular galaxies, including the Magellanic Clouds, tend to be gas-rich, irregularly shaped systems showing scattered, on-going star formation while spiral structures are absent. In irregular galaxies, it is expected that shells, produced by supernova explosions and/or stellar winds from OB stars, play a more important role than in spiral galaxies, in forming clouds and stars, and thereby influencing the galactic structure and evolution.

It is notable that the irregular galaxies, such as the Magellanic Clouds and NGC 1569, contain young, gravitationally bound, rich clusters of $\sim 10^{4-5}$ stars. These clusters are referred to as "populous clusters" in the Magellanic Clouds (e.g., Hodge 1961; van den Bergh 1981). Apparently, they resemble globular clusters in the Galactic halo, although they contain fewer stars than the globular clusters by a factor of ~ 10. These gravitationally bound clusters, with properties distinctly different from those of the unbound open clusters in the Galactic disk, may provide clues to understand the formation of globular clusters that happened in the early age of the Galaxy.

The star formation process and the structure of the interstellar medium in the irregulars are only poorly understood, mainly due to the lack of comprehensive observations of molecular clouds where stars are formed. As they have lower metallicities, higher gas-to-dust ratios, and stronger UV radiation fields, CO emission from such galaxies is weak compared with that of spiral galaxies (e.g., the Galaxy). Though several of the irregular galaxies have been observed in CO (e.g., IC 10, NGC 6822, NGC 1569), these observations are either of low linear resolution or of small spatial coverage due to limited resolution and sensitivity. This makes it difficult to perform a detailed multi-wavelength comparison with various components of the interstellar medium. In contrast, the Magellanic Clouds (MCs) are nearby ($D \sim$ 50–60 kpc), have small extinction and have been extensively observed at nearly all wavelengths; thus, the MCs provide excellent sites to study star formation and interstellar structures of a galaxy in detail.

We have performed new observations of the MCs in the J = 1–0 rotational transition of interstellar carbon monoxide (CO) at 2.6 mm wavelength in order to reveal detailed molecular gas distribution at a linear resolution of ~ 40 pc (Fukui et al. 1999; Mizuno et al. 2000; Mizuno et al.

"Dwarf Galaxies and their Environment"; Bad Honnef, Germany, 23-27 January 2001; Eds. K.S. de Boer, R.-J.Dettmar, U. Klein; Shaker Verlag

2001). These observations were made with NANTEN, a 4m radio telescope newly installed at the Las Campanas Observatory, Chile in 1996 and should allow us to have a complete view of the giant molecular clouds in the MCs for the first time. In this contribution, we will present main results of the study for the LMC.

2 Giant Molecular Clouds as Sites of Cluster Formation

The central $6^\circ \times 6^\circ$ area of the LMC was covered at a $2'$ grid spacing with a $2.'6$ beam, and 32800 positions were observed (Fig. 1). The CO distribution is found to be remarkably clumpy. We discovered a new prominent feature "CO Arc", which is a few kpc scale ordered structure of very young GMCs along the southeastern optical edge of the galaxy. In total 107 CO clouds were identified based on the spatial and velocity distributions. This is the first complete sample of GMCs in the LMC at a linear resolution of $\sim$ 40 pc. Among them we analyzed 55 clouds which were detected at more than 3 observed points, whose physical quantities are reliable. The cloud mass ranges from $\sim 6 \times 10^4$ to $2 \times 10^6\, M_\odot$, and the total molecular mass has been estimated to be (4–7) $\times\ 10^7\, M_\odot$ for a molecular column density of $\geq 1.0 \times 10^{21}$ cm^{-2}, corresponding to 5–10% of the atomic mass. The mass spectrum for the clouds is fitted by a single power-law of an index -1.5 in mass $\geq 10^5 M_\odot$, which is similar to that found for the clouds in the Galaxy. On the other hand, CO luminosity in the LMC is apparently weaker by a factor of $\sim$ 3 relative to those in the Galaxy. The ratio of H_2 column density to ^{12}CO intensity for CO clouds in the LMC is estimated to be $X_{\rm LMC} \sim 9 \times 10^{20}{\rm cm}^{-2}/({\rm K\ km\ s}^{-1})$.

In order to elucidate star formation in the LMC, comparisons between GMCs and young objects such as young stellar clusters, H II regions, and supernova remnants have been made. The GMCs exhibit a good spatial correlation with H II regions and the youngest stellar clusters whose ages are $\leq$10 Myr, demonstrating that cluster formation is on-going in these clouds (Fig. 2). In addition, compact groups of the young clusters are often found at the peak position of the GMCs, e.g., N159 and N44, while much looser groups are away from the GMCs. This suggests that the clusters are formed in groups and are dispersed as they become old. On the other hand, GMCs show little correlation with older clusters or with supernova remnants, suggesting that the GMCs are being rapidly dissipated in several Myrs. From a comparison between the distribution of the CO, [CII], and UV, the GMCs are likely to be rapidly dissociated and/or dissipated due to the strong UV photons of massive stars in clusters. The evolutionary time scale of the GMCs is summarized as follows; the GMCs form massive stars in a few Myrs after their birth, and form clusters within next a few Myrs, and are dissipated within several Myrs after their birth.

3 Supergiant shells in the LMC

It has been well known that the LMC contains a number of (super)giant shells (SGSs) as demonstrated by optical and H I images (e.g., Meaburn 1980 and Kim et al. 1999). We have performed deeper CO(J=1–0) observations of LMC4 with NANTEN (Yamaguchi et al. 2001). The result is the discovery of 18 clumpy CO clouds, 17 of which well delineate the SGS traced by Hα and H I. The remaining one cloud seen inside the SGS exhibits a cometary shape with H I tail heading towards the center of LMC4 (Fig. 3). A comparison between the CO clouds and young stars including H II regions and stellar clusters indicates that all the associated young stars are located on the inner side of the clouds facing to the center of the shell. The typical separation between the cloud peaks and young stars is $\sim$ 40–100 pc. These facts strongly suggest that star formation has been triggered by the expanding shell that is driven by OB stars, indicating an important role of SGSs in cluster formation in the LMC.

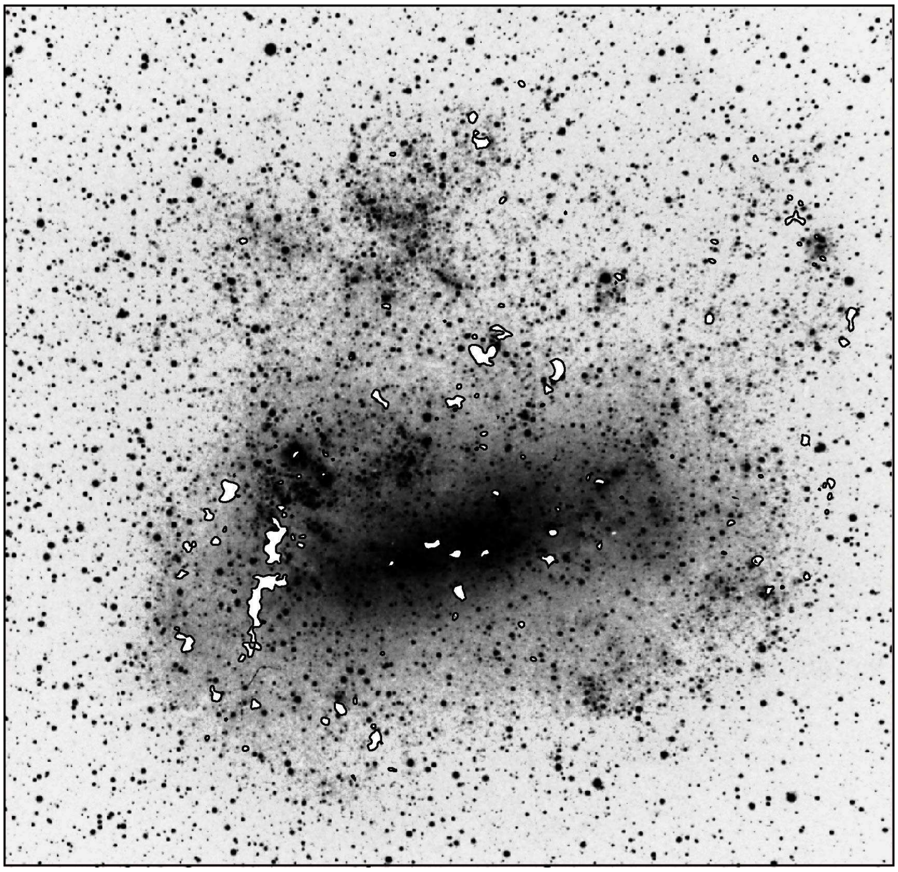

Figure 1: Distribution of the giant molecular clouds obtained with NANTEN superposed on the optical image. An ordered arc-like distribution of molecular clouds is located at the southeastern optical boundary of the galaxy.

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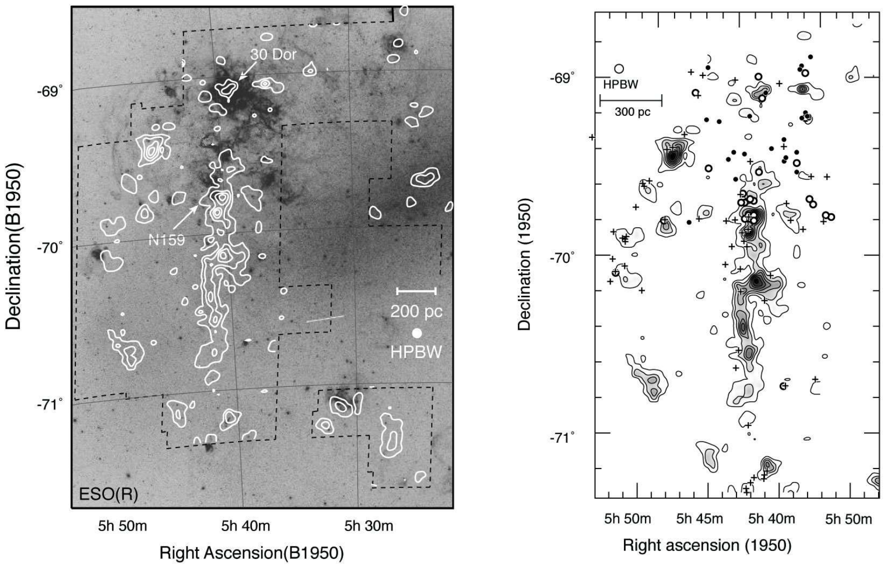

Figure 2: (*left*) Close up view of the southeastern region of the LMC. Contours are integrated ^{12}CO(1-0) image obtained by sensitive observations with NANTEN, overlaid on the ESO(R) plate. (*right*) Distribution of CO clouds, HII regions, and stellar clusters. The open and filled circles are the clusters of age $\tau < 10$ Myr and $10 < \tau < 30$ Myr, respectively (Bica et al. 1996). The crosses represent the positions of the H II regions (Davies, Elliott, & Meaburn 1976).

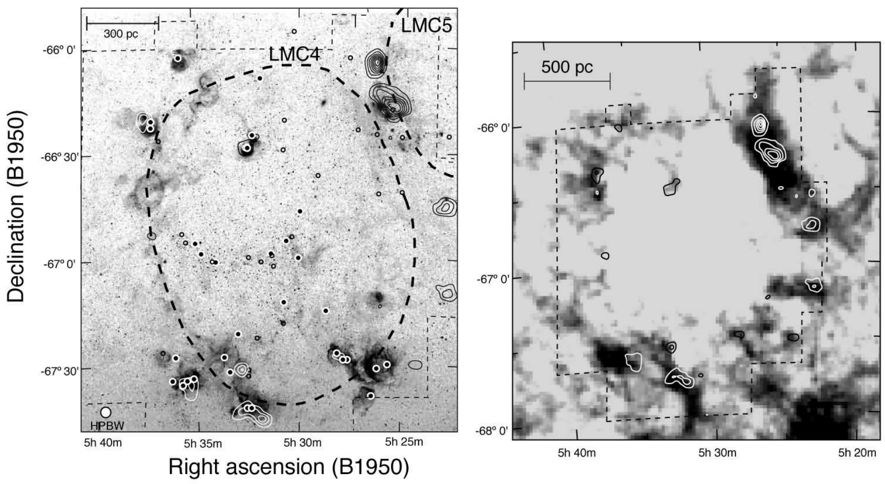

Figure 3: (*left*) ^{12}CO(1-0) image superposed on the Hα plate (Kennicutt & Hodge 1986). The filled and open circles are the clusters of age $\tau < 10$ Myr and $10 < \tau < 30$ Myr, respectively (Bica et al. 1996). (*right*) Distribution of CO superposed on the H I map (Kim et al. 1999).