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CO / CI observations of N83C in the early stage of star formation in SMC with ALMA

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Abstract. The Magellanic Clouds offer the opportunity to obtain a spatially resolved view of external galaxies at reduced metallicity with no distance ambiguity. Our ALMA observations of the active star-forming region N83C in the Small Magellanic Cloud (SMC) revealed subparsec-scale molecular structures in ^{12}CO and ^{13}CO (2-1) emission Muraoka *et al.* (2017). We found strong CO peaks associated with Young Stellar Objects(YSOs) and derived a typical gas density of $\sim 10^4$ cm^{-3} and gas temperature of 40-60 K from the excitation analysis. The high gas density and temperature are presumably due to the effect of the HII region under the low-metallicity environment. We have found that the column density ratios N(CI)/N(CO) are generally high throughout the cloud compared with the Galaxy, ranging from 0.2 to 2.0. A peak of the ratio is observed toward a CO peak associated with a massive protostar.

Keywords. ISM: structure, galaxies: dwarf, Magellanic Clouds

1. Introduction

Metallicity in the interstellar medium has an important role in the star formation process and it influences the properties of the giant molecular clouds. A low metallicity environment causes a reduction of the shielding against far-UV radiation from massive stars. High-resolution observations of the molecular gas in low metallicity environments are needed to better understand the star formation process in different environments. The Magellanic Clouds offer the opportunity to obtain a spatially resolved view of external galaxies at reduced metallicity with no distance ambiguity. Especially, the Small Magallenic Cloud (SMC) represents a unique astrophysical laboratory because of its

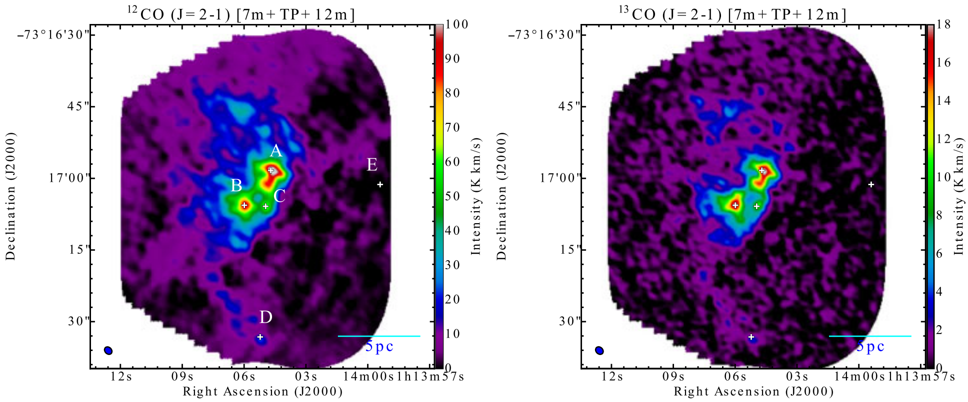

Figure 1. Integrated intensity map of the ^{12}CO (left) and ^{13}CO (right) (2-1) emission based on the combined 12 m, ACA and TP data. Blue ellipse in the lower left corner shows the synthesised beam, 1.75"×1.40". White crosses indicate the bright Spitzer YSOs identified by Sewiło *et al.* (2013); Kamath *et al.* (2014)

proximity (~60 kpc; Hilditch *et al.* 2005), lower ISM metallicity (Z~0.2 $Z_\odot$, Dufour 1984; Kurt *et al.* 1999; Pagel 2003), and tidally disrupted interaction status. The SMC offers a rare glimpse into the physical processes in an environment with a metallicity that is below the threshold of 1/4 - 1/3 $Z_\odot$, where the properties of the ISM in galaxies change significantly. The SMC's dust-to-gas ratio is 17 times smaller than that in the Milky Way Koornneef (1984).

Previous studies Israel *et al.* (1993, 2003); Rubio *et al.* (1993, 1996); Lequeux *et al.* (1994); Mizuno *et al.* (2001) observed the ^{12}CO and ^{13}CO emission in the molecular clouds in the SMC with a resolution of 2.6' - 23" using several single dish telescopes. One of the isolated, active star-forming region, N83 is located in the southeast wing of the SMC.

CO is not necessarily a good tracer of the molecular cloud because it is selectively photo dissociated Leroy *et al.* (2009). CI could be also an important tracer of molecular gas (Papadopoulos & Greve 2004).

2. Observations and results

ALMA Cycle 2 and Cycle 3 observations toward N83C were carried out in Band 6, Band 7 and Band 8 with the 12 m Array, the Atacama Compact Array (ACA) 7 m antennas, and total power (TP) 12 m antennas. The observations were centered on (RA_{J2000}, Dec_{J2000}) = ($01^h14^m05.^s414$, 73°17'03."908) in the N83C region. The target molecular lines were ^{12}CO, ^{13}CO and $C^{18}O$ (J=2-1) in Band 6; ^{12}CO and ^{13}CO (J=3-2), CS (J=7-6) in Band 7 and CI ($^3P_1$-$^3P_0$) in Band 8. The data were reduced using the Common Astronomy Software Application (CASA) package. See details in Muraoka *et al.* (2017).

The observations revealed subparsec-scale molecular structures in ^{12}CO and ^{13}CO (2-1) emissions. We found strong CO peaks associated with the Spitzer YSOs (A and B) and derived a typical gas density of $\sim 10^4$ cm^{-3} and gas temperature of 40-60 K from the excitation analysis. Figure 1 shows the integrated intensity map of the ^{12}CO and ^{13}CO (2-1) emission based on the 12 m, ACA and TP combined dataset. The high gas density and temperature are presumably due to the effect of the HII region under the low-metallicity environment in the SMC; far-UV radiation can easily penetrate and photodissociate the outer layer of ^{12}CO molecules in the molecular clouds, and thus only the innermost parts of the molecular clouds are observed even in ^{12}CO emission.

The CI cloud in N83C shows similar distribution with the CO cloud.

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We investigated the photodissociation of CO in this low metallicity environment using the [CI] (1-0) observations. The column density ratios of N(CI)/N(CO) are generally high throughout the cloud compared with the Galaxy, ranging from 0.2 to 2.0. The northern and southern parts of the N83C molecular cloud show the highest ratio, it is is likely due to the PDR nature at lower density. This high ratio can be the consequence of non-equilibrium chemical states, turbulent diffusive mixing or cosmic rays Papadopoulos *et al.* (2004). A peak of the ratio is observed toward a CO peak associated with a massive protostar; the enhancement of the ratio toward the dense gas is rarely seen in molecular clouds in the Galaxy.

3. Summary

The main results of our ALMA Cycle 2 CO and Cycle 3 CI observations are:

• The ^{12}CO/^{13}CO observations are tracing high-density ($\sim 10^4\,\mathrm{cm}^{-3}$) regions, which are one order of magnitude higher than that of our Galaxy.

• The spatial relations between the CI and the CO molecule are globally similar and the ratio of N(CI)/N(CO) is found to be significantly higher than that in the general star-forming regions in our Galaxy.

• The high-resolution (∼0.3") observation of CI with the ALMA 12 m array revealed a shell-like CI cloud around the 0.6 mm continuum peak and a massive protostar. The average H_2 volume density of the cloud is $\sim 10^5\,\mathrm{cm}^{-3}$, indicating that the CI cloud may be tracing dense parts of the molecular cloud in the SMC.

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