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CO $J = 7 \rightarrow 6$ Emission in the Large Magellanic Cloud

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Abstract. We present the first detection of ^{12}CO ($J = 7 \rightarrow 6$) emission in the Magellanic Clouds toward the 30 Doradus region using the Antarctic Sub-millimeter Telescope and Remote Observatory (AST/RO).

1. Introduction

Technological advancements in sub-millimeter wave and far-infrared (FIR) spectroscopy have furnished the resources necessary for understanding the physical condition and chemistry of atomic and molecular clouds in the interstellar medium in external galaxies. Sub-millimeter wave and FIR cooling lines are the dominant source of the cooling in the ISM, and therefore regulate star formation in the ISM. While observations of the sub-millimeter lines such as the ^{12}CO and ^{13}CO rotational lines and the sub-millimeter lines of atomic carbon [C I] have revealed a more complete picture of the photo-dissociation regions (PDRs) and the dense gas.

At distance of 55 kpc (Feast 1991), the Large Magellanic Cloud (LMC) can be mapped with a high spatial resolution at high excitation CO lines by the AST/RO. The recent [C I] and CO ($J = 4 \rightarrow 3$) study of the N159/N160 complexes in the LMC by Bolatto et al. (2000) elucidate the condition of atomic and molecular medium in the early stage of star formation. In this paper, we report the first detection of the CO ($J = 7 \rightarrow 6$) emission toward the 30 Doradus region in the LMC. The CO ($J = 7 \rightarrow 6$) and ($J = 4 \rightarrow 3$) lines in the 30 Doradus region will lead to a better understanding of the distribution of C^+, C and CO, the physical and chemical structure of the ISM and the star formation activity in the LMC.

2. Observation and Results

The observations were performed during the austral winter seasons of 2002 at the AST/RO, located at 2847 m altitude in Amundsen-Scott South Pole Station. This site has very low water vapor, high atmospheric stability and a thin troposphere making it exceptionally good for sub-millimeter observations. AST/RO is a 1.7 m diameter, offset Gregorian telescope capable of observing at wavelengths between 200 μm and 1.3 mm (Stark et al. 2001). The receivers used were a dual-

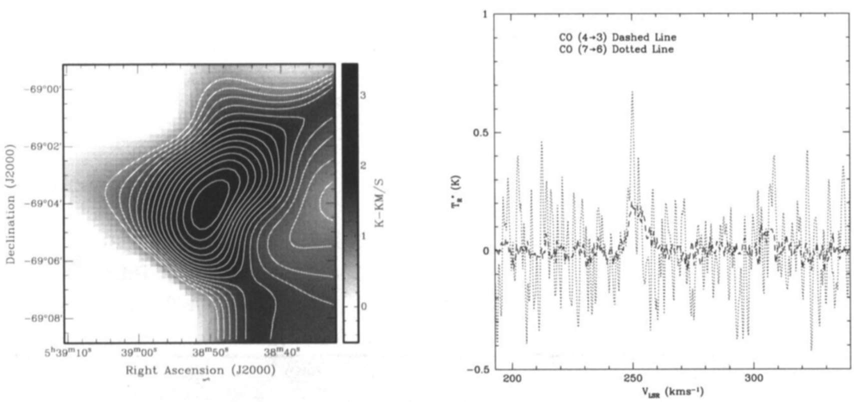

Figure 1. *Left*: Contour and grey scale image of ^{12}CO ($J = 4 \rightarrow 3$) emission. *Right*: Spectrum of ^{12}CO ($J = 7 \rightarrow 6$) and ^{12}CO ($J = 4 \rightarrow 3$) emission lines at $5^h38^m39.8^s$, $-69°03'21''$.

channel SIS waveguide receiver (Walker & Kooi 2001, private communication) for simultaneous 461–492 GHz and 807 GHz observations, with double-sideband noise temperatures of 320–390 K and 1050–1190 K, respectively. Telescope efficiency, η_ℓ, estimated using moon scans, skydips, and measurements of the beam edge taper, was ~81% at 461–492 GHz and 71% at 807 GHz. Atmosphere-corrected system temperatures ranged from 700 to 4000 K at 461–492 GHz, and 9000 to 75,000 K at 807 GHz. A beam switching mode was used, with emission-free reference positions chosen at 20′ away from regions of interest, to make a small map of points near 30 Doradus region. A total integration time on the source was 16 minutes. Emission from the CO ($J = 4 \rightarrow 3$) and ($J = 7 \rightarrow 6$) lines at 461.041 GHz and 806.652 GHz, together with the [C I] line at 492.262 GHz, was imaged over an 14 arc-minute square region centered on $5^h38^m47.3^s$, $-69°03'16.1''$ (J2000) with 0.5′ spacing; i.e., a spacing of a half-beamwidth or less. AST/RO suffers pointing errors of the order of 1′, and the beam sizes (FWHM) were 103–109″ at 461–492 GHz and 58″ at 807 GHz.

We detect a strong ^{12}CO ($J = 4 \rightarrow 3$) emission (Figure 1) in the 30 Doradus region (Tarantula nebulae) which is well known luminous giant HII regions in irregular galaxies and bright in the Hα image (Figure 2) taken at the Siding Spring Observatory (Kim et al. 1999). For the first time, ^{12}CO ($J = 7 \rightarrow 6$) emission is detected in the LMC at $5^h38^m39.8^s$, $-69°03'21''$ and is $\sim 2.'5$ away from the peak of CO ($J = 4 \rightarrow 3$) (Figure 1). The ^{12}CO $J = 7 \rightarrow 6$ and $J = 4 \rightarrow 3$ emissions appear at V_{LSR}=251±0.1 kms^{-1} and 249.6±0.1 kms^{-1} respectively. The CO $J = 7 \rightarrow 6$ emission from this region is bright as T_{MB}=0.8±0.25 K. Based on the current observations and previous observations of low-J CO rotational lines (Israel et al. 1993; Johansson et al. 1998) and HI observations taken with the Australia Telescope Compact Array (Kim et al. 1998; Kim et al. 2003), we suggest that this region consists of dense clouds (density of 10^5 cm^{-3}) immersed in a low density inter-clump medium with dense clump volume filling factor of about 0.01 and area covering factor of about 0.5. The estima-

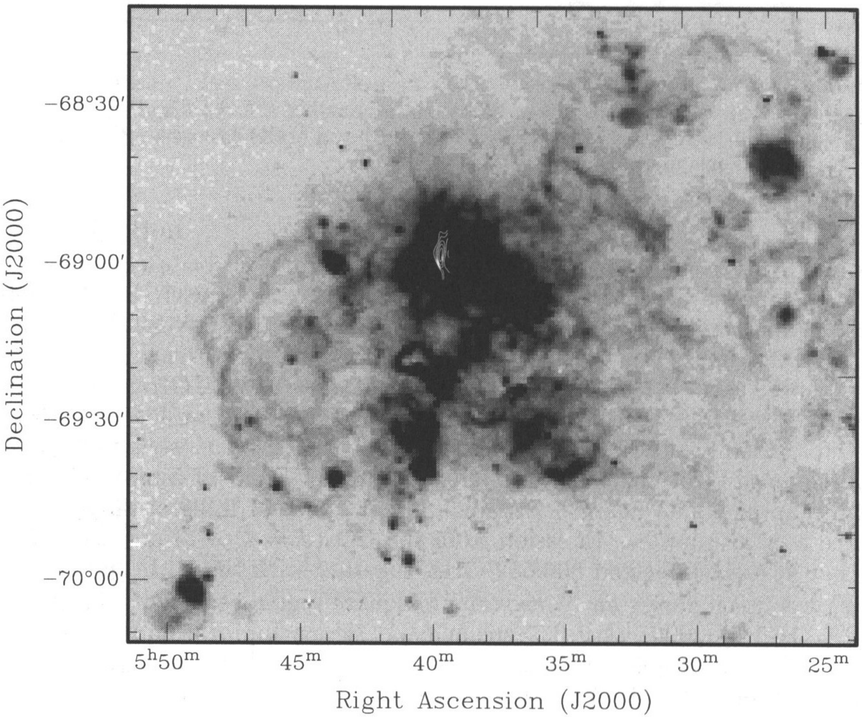

Figure 2. ^{12}CO ($J = 4 \rightarrow 3$) emission (White Contours) from Tarantula nebula (30 Doradus) in the LMC is overlaid on the Hα image (Kim et al. 1999) made with 16 inch telescope at Siding Spring Observatory (Image Credit: S. Kim).

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tion of $T_{kin} \approx 70$ K and $n(H_2)$ was made by applying radiative transfer code (http://www.astro.umass.edu/~skim/prog2.html) to ratios of observed line intensities. The lowest 30 rotational levels of the ground vibrational level for ^{12}CO and ^{13}CO are included in the radiative transfer calculation by M. Yan & S. Kim.

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