Rev. Mexicana Astron. Astrof. **12**, 303-307 (1986)

THE 2.6 mm CO SURVEY OF THE MAGELLANIC CLOUDS

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ABSTRACT. CO emission in the LMC appears associated with other population I tracers. Preliminary analisis of four CO complexes in the LMC indicate that these complexes are correlated in velocity and position with the highest density of neutral hydrogen. In the SMC, CO has been detected only in the southwest part of the bar and correlates with the lower velocity component of the HI gas. In this area the highest density of neutral hydrogen is observed. In both Clouds, the intensity of the CO emission is apparently weak as compared to galactic giant molecular clouds. Estimations of the molecular mass indicate that the ratio of molecular hydrogen to atomic hydrogen is less than 1 in the Magellanic Clouds.

INTRODUCTION

Giant molecular clouds in our galaxy are a major component of the interstellar medium and are thought to be the sites of all contemporary star formation. Observations of the galactic CO emission have established this molecule as an excellent tracer for molecular clouds and the best way to study their galactic distribution. As the nearest external galaxies, the Magellanic Clouds, offer a best possibility to study molecular clouds in extragalactic systems.

The lack of a major millimeter-wave instrument in the Southern Hemisphere impeded for a long time the study of the molecular content in the Magellanic Clouds. The first observations of the molecular content in these irregular galaxies were done with millimter-wave detectors attached to optical telescopes. Huggins et al (1975) made the first detection of CO emission in the LMC using the 3.9 m Anglo Australian Telescope observing the line (J=1→0) at 115 GHz. Israel et al (1982) and Israel (1984), made a systematic search in both LMC and SMC using, the 3.6 m telescope at La Silla in the CO (J=2-1) line at 230 GHz. The weakness of the CO emission necessitated very long integration times, and only about 25 position in the LMC, and 15 in the SMC were observed.

Since January 1983, Columbia University and the University of Chile have been making a more extensive CO survey in the Magellanic Clouds, using the J=1→0 line at 2.6 mm. The observations have been made using the Columbia Southern Millimeter-Wave Telescope at Cerro Tololo. In the LMC a full coverage survey has been recently finished, and in the SMC low noise observations of selected positions have been done.

OBSERVATIONS

The observations have been made since January 1983 with the Columbia Southern Millimeter-Wave Telescope jointly by Columbia and the University of Chile. The telescope is a 1.2 m Cassegrain with an 8.7 arcminute beam (FWHM) at 2.6 mm. Its liquid nitrogen cooled 115 GHz receiver, has a noise temperature of 370 K (SSB). As a spectrometer, we used a 256

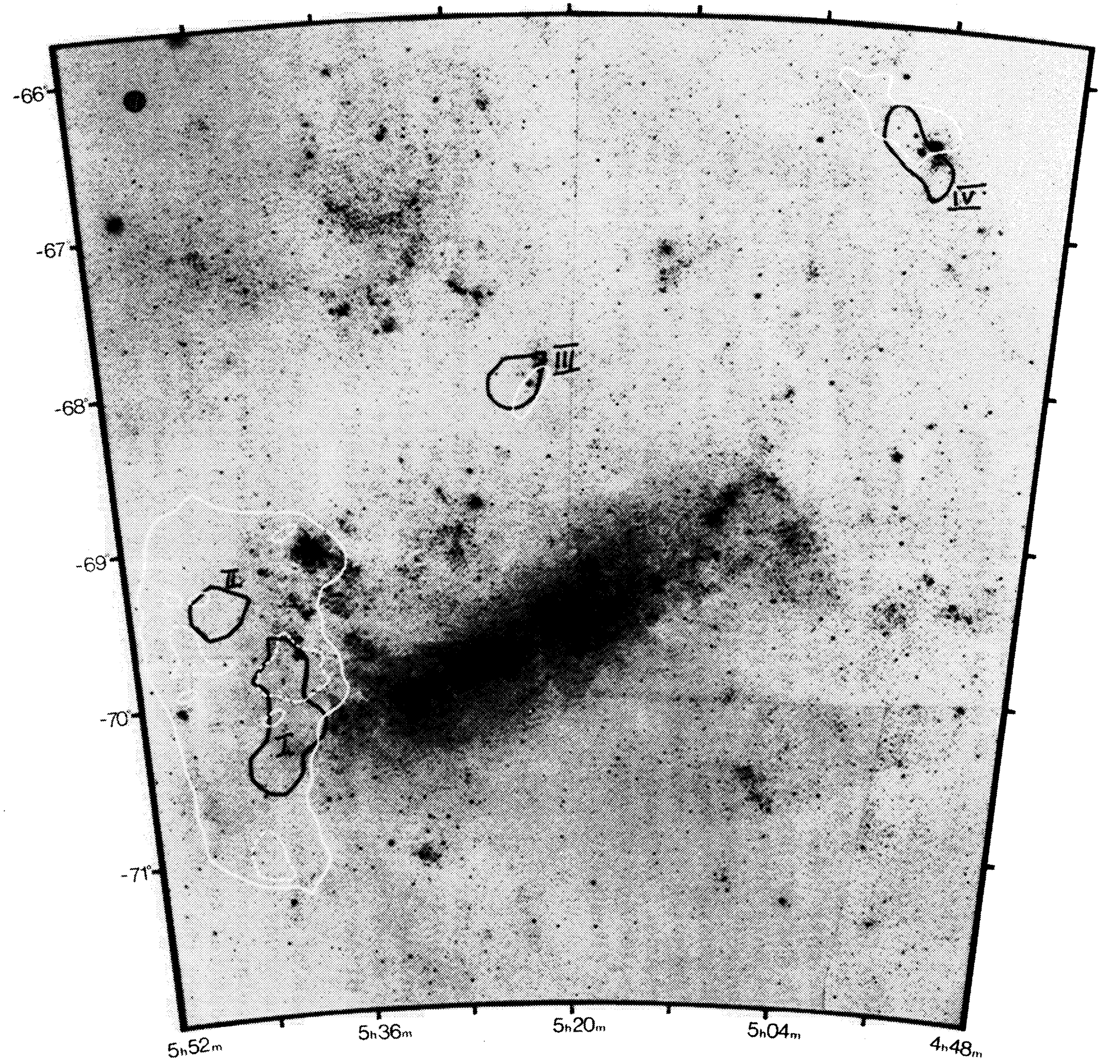

Figure 1. Sketch of the four CO complexes (black contour) where the CO emission was detected with $T_A^* > 0.2$ K and in at least four positions of the survey in the Large Magellanic Cloud. The white contour represent the neutral hydrogen gas as given by Mc Gee and Milton (1964). The HI contour unit is 1.8 x 10^{-19} at cm^{-2}, the contours are given for 200 (full white line) and 300 (broken white line) units. The LMC photograph was taken with the Maksutov telescope at Cerro El Roble Observatory, Chile (courtesy of E. Costa, University of Chile). Coordinates are 1950.0.

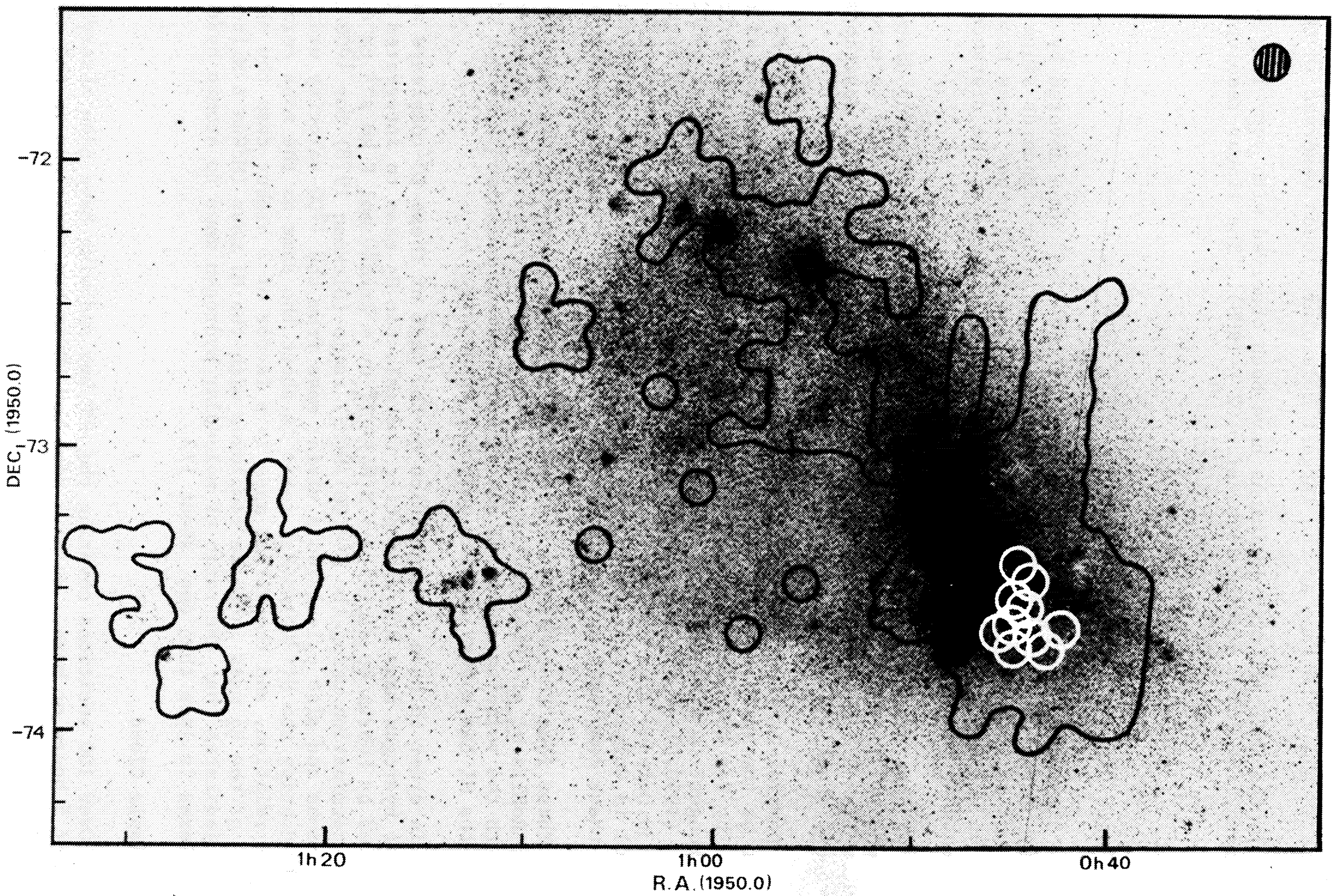

Figure 2. Sketch of the ^{12}CO observations in the SMC, superimposed on an ESO plate. CO has been detected only in the south west part of the bar as indicated by the circles. This region has the major concentration of dark clouds in the SMC.

channel filter bank with a resolution of 5000 kHz per channel corresponding to a velocity resolution of 1.3 km sec^{-1}.

The LMC survey consist of over 2000 points spaced every beamwidth and covering an area of 6°x6°. Each point was observed about 40 minutes to obtain a noise of 0.05 K (RMS) per channel. The beam of the telescope, 140 pc at the LMC, is large enough to make a complete map practical and is about the same as the largest molecular clouds observed in the Milky Way.

In the SMC, selected positions have been observed with very long integration time, 5 hours or more, to obtain a noise level of 0.02 K (RMS). The linear resolution at the SMC is 160 pc.

RESULTS

Large Magellanic Cloud

CO emission has been detected in 5% of the 6°x6° area covered by the LMC survey. The intensity of the CO emission is weak compared to galactic standards since the strongest line detected has an antenna temperature of $T_A^* = 0.48$ K and all other lines have antenna temperatures of about 0.2 K. A galactic giant molecular cloud placed at the distance of the LMC would produce an antenna temperature of about 1K.

We have selected four areas of CO emission for the following discussion. These areas, sketched in figure 1, correspond to emission where the CO lines detected have antenna temperatures $T_A^* > 0.2$ K and were detected in a group of at least four positions in the survey. They represent about 35% of the total CO emission detected.

Complex I, located south of the 30 Doradus nebula is the major CO concentration in the LMC. Starting at the north of N159 (Henize 1956) and extending LMC over one kiloparsec further south, it is by far the most extended region of CO emission, and also the strongest in intensity. The strongest CO line detected in the survey lies in this complex at $\alpha=5^h20^m21^s$ $\delta=-69°52'30''$ (1950.0) at 6.5 south of N159 where CO was first detected by Huggins (1975). To the east of 30 Doradus lies Complex II, and coincident with Shapley's Constellation I or N44 (Henize 1956) is Complex III. Far in the north we have sketched complex IV near N11 (Henize 1956). All these complexes appear associated with areas of young population in the Cloud.

These four CO complexes lie regions of highest neutral hydrogen density (Mc Gee and Milton 1964; Rohlfs et al. 1984) in the LMC. Also, the velocity of the CO emission is in good agreement with the velocity of the HI gas although the CO emission is almost always a single line, while the HI has a very complex velocity structure.

In order to have an estimation of the mass of these CO complexes we have calculated the molecular hydrogen mass $N(H_2)$ adopting the galactic H_2 mass to integrated CO luminosity relation derived by Lebrun et al. (1983): $N(H_2)/\int T_A^*\, dv = 2x10^{20}$ mol K km s^{-1} cm^{-2}. We have tested this mass determination using the $N^{13}(CO)/N(H_2)$ ratio (Dickman 1978) for ^{13}CO observations made at two positions and also calculated a virial mass from the ^{12}CO velocity width. The H_2 mass calculated adopting the $N(^{13}CO)/N(H_2)$ ratio is about the same as the mass derived from the $N(H_2)/\int T_A^*\, dv$ relation, and the virial mass is a factor of 2 higher than the other determinations A comparison of the H_2 mass in these complexes with the HI mass (McGee & Milton 1966, Rolfhs et al. 1984) indicates that the ratio of molecular hydrogen mass to atomic hydrogen mass in these LMC CO complexes is less than one, about 1/3.

Small Magellanic Cloud

Over 100 positions covering the SMC bar and wing have been observed with integration times of 5 hours or more. We have detected CO in ten positions in the south west part of the bar. Figure 2 shows the area we observed and the position where CO was detected, all near the major concentration of dark clouds (Hodge 1974). Seven detections are centered on dark clouds, the other three are near HII regions.

As in the LMC, all the CO lies in the region with the highest density of neutral hydrogen gas (McGee and Newton 1981). A well known characteristic of the HI profiles is their multiple peaks separated by 30 to 40 km s^{-1} in velocity (Hindman 1967, McGee and Newton 1981, Bajaja and Loiseau 1982). McGee and Newton (1981) find HI gas in four distinct large masses separated from one and other in radial velocity: the V_{LSR} = 105 km s^{-1}, 124 km s^{-1}, 157 km s^{-1} and 182 km s^{-1} component. The most intense component is the HI-gas centered at 124 km s^{-1}. The CO emission is observed centered around V_{LSR}(CO) $\sim$ 120 km s^{-1} in all detections in very good agreement with the velocity of the most intense component of the HI gas. An important difference between the CO emission and the HI gas is that the CO lines are narrow with velocity halfwidth of less than 10 km s^{-1} while the HI gas at this velocity has an average halfwidth of 26 km s^{-1}. In some cases, the CO profiles are double with the two component separated less than 10 km s^{-1} probably due to emission from more than one cloud inside the beam.

We have estimated the molecular hydrogen mass in the SMC as we have done for the LMC. In this case, we have calculated the molecular hydrogen mass by integrating all the CO emission in a two beamwidth radius centered at $\alpha=0^h46^m06^s$ $\delta=-73°31'11''$ (1950.0). The resulting spectrum has an antenna temperature of T_A^* = 0.03 K centered at V_{LSR} = 120 km s^{-1} with Δv(FMHP) = 18 km s^{-1}. Adopting the galactic $N(H_2)/\int T_A^* dv$ relation (Lebrun et al. 1983) we get a molecular hydrogen mass of $M(H_2)=1.6\times10^5 M_\odot$. In this same region the mass associated to the most intense component (V_{LSR} = 124 km s^{-1}) of the hydrogen gas (McGee and Newton 1981) is 3.6 x $10^6 M_\odot$. Thus the ratio of molecular hydrogen to atomic hydrogen is only about 0.05 averaged over the area, much smaller than in the LMC and our galaxy.

M.R. would like to acknowledge partial support for attending the IV I.A.U. Latin American Regional Astronomy Meeting, 1984, Rio de Janeiro, the Departamento de Investigación, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile.

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