

A ^{12}CO SURVEY OF THE SMALL MAGELLANIC CLOUD

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ABSTRACT

The central $2^\circ \times 2^\circ$ area of the Small Magellanic Cloud has been fully surveyed in the $J = 1 \rightarrow 0$ rotational transition of ^{12}CO at an angular resolution of $8''.8$. Most of the emission arises from two large complexes, located in the southwest and northeast regions of the Bar, closely associated with the most intense H I emission from the SMC. Five individual molecular clouds have been identified; their peak antenna temperatures are very weak, ~ 0.035 K. We suggest that for the SMC the conversion factor to derive the column density of molecular hydrogen from the velocity-integrated CO line emission is $6 \times 10^{21} \text{ cm}^{-2} \text{ K}^{-1} \text{ km}^{-1} \text{ s}$, which is about 20 times higher than the value adopted for our Galaxy. The total mass of molecular gas in the SMC is estimated to be $3 \times 10^7 M_\odot$, implying a ratio of molecular to atomic mass of roughly 7%.

Subject headings: galaxies: Magellanic Clouds — interstellar: molecules

I. INTRODUCTION

In the last decade it has become increasingly clear that irregular dwarf galaxies are deficient in CO when compared with spiral galaxies of similar luminosities and star-forming activity (Elmegreen, Elmegreen, and Morris 1980; Gordon, Heidemann, and Epstein 1982; Young, Gallagher, and Hunter 1984; Israel and Burton 1986; Arnault *et al.* 1988). Irregular galaxies would then either contain little molecular material or have CO clouds with characteristics different from those in our Galaxy or other spiral galaxies. Since irregular galaxies are known to contain giant H II regions and OB associations, whose presence suggests episodes of vigorous star formation, several questions are raised by the apparent lack of molecular material. Very sensitive and high-resolution studies of the CO content in irregular galaxies should help clarify the apparent contradiction between a high rate of star formation and the absence of molecular material.

Because they are close and have metallicities and gas-to-dust ratios different from those in our Galaxy, the Large and Small Magellanic Clouds are ideal extragalactic systems to study the relation of molecular clouds to star formation and the properties of the molecular gas in an environment different from our own. A full survey of the CO emission toward the LMC, at an angular resolution of $8''.8$, was recently presented by Cohen *et al.* (1988), who reported the detection of more than 40 molecular complexes, with peak antenna temperatures of typically 0.15 K. Cohen *et al.* concluded that for the LMC the ratio between observed velocity-integrated CO emission, W_{CO} , and H_2 column density, $N(\text{H}_2)$, which is commonly used to determine the mass of the molecular clouds, is probably 6 times larger than for the Galaxy. To explain the weakness of the CO radiation, Rubio and Garay (1988) suggested that in the LMC the emission arises from CO clumps whose sizes are about 3 times smaller than the typical size of clumps making up giant molecular clouds (GMCs) in our Galaxy. The small size of the CO clumps and the different conversion factor are probably due to the high gas-to-dust ratio, low metal abundance, and

relatively strong UV radiation field in the LMC (cf. Israel *et al.* 1986); however, the actual dependence on these parameters has not yet been established. Observations with higher angular resolution and of other nearby dwarf galaxies should provide valuable information to the solution of this problem.

In the SMC the gas-to-dust ratio is ~ 17 times higher than in our Galaxy (Koornneef 1984), and the metal abundance is about 10 times smaller (Dufour 1984). Hence, observations of the distribution and characteristics of the CO emission from the SMC should be of considerable value in understanding the properties of molecular clouds in galaxies with different dust content and metal abundances, and the effects of these parameters on the $W_{\text{CO}}/N(\text{H}_2)$ conversion factor. We report here the results of a complete and unbiased survey of CO, in the $J = 1 \rightarrow 0$ line, from the Small Magellanic Cloud.

II. OBSERVATIONS

The observations were made using the Columbia 1.2 m Millimeter-Wave Telescope, located in Cerro Tololo, Chile. Detailed characteristics of the instrument are given by Bronfman *et al.* (1987). At the frequency of 115 GHz the beamwidth of the telescope is $8''.8$, corresponding to a linear resolution at the SMC of ~ 160 pc. The survey, made with a spacing of $7''.5$, covers the central $2^\circ \times 2^\circ$ area of the SMC. The sensitivity (1σ rms noise) in the antenna temperature of the survey is 0.012 K, which was achieved after ~ 8 hr of integration time per observed position.

The data were taken in the position-switch mode, switching every 15 s to an OFF position 1° away in azimuth from the ON position. We used a 256 channel filter-bank spectrometer centered at an LSR velocity of 200 km s^{-1} , each channel being 1.3 km s^{-1} wide. All spectra were fitted with linear baselines and calibrated using the chopper-wheel technique (Kutner and Ulich 1981). Radiation temperatures were derived from the measured antenna temperatures, which are corrected for atmospheric attenuation, resistive losses, and rearward spillover and scattering, using a main-beam efficiency of 0.82.

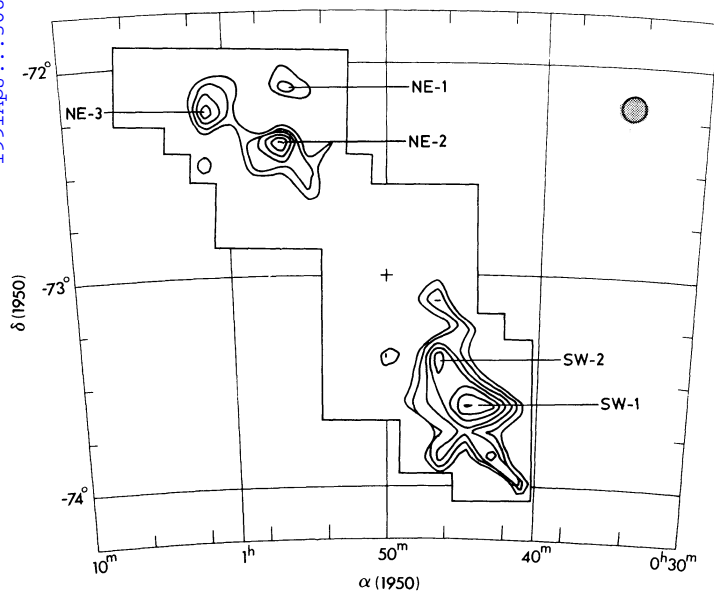


FIG. 1.—Map of the velocity-integrated CO emission from the SMC. The window of velocity integration is 30 km s^{-1} wide, centered on the velocity of the strongest H I component from McGee and Newton (1981). The contour interval is 0.06 K km s^{-1} (1σ rms noise level), and the lowest contour shown is 0.18 K km s^{-1} . The FWHM beam area is shown in the upper right-hand corner.

III. RESULTS

A map of the velocity-integrated CO emission, W_{CO} from the SMC is shown in Figure 1. The window of velocity integration is 30 km s^{-1} wide, centered on the velocity of the strongest H I component from McGee and Newton (1981). About 20% of the area surveyed exhibits emission at the level of sensitivity of the survey. Most of the CO emission comes from two large complexes located in the southwest and northeast regions of the Bar. Maps made with narrower intervals of velocity integration (10.4 km s^{-1}) show that the southwest complex can be separated into at least two components, labeled as clouds SW-1 and SW-2 in Figure 1, while the northeast complex can be decomposed into three well-defined objects, labeled as clouds NE-1, NE-2, and NE-3 in Figure 1.

Observed and derived parameters of the molecular clouds in the SMC are listed in Table 1. The southwest and northeast complexes include all the emission within the lowest contour level shown in Figure 1. The cloud coordinates (cols. [2] and [3]) correspond to the survey position within the cloud that exhibits the maximum antenna temperature. The peak antenna

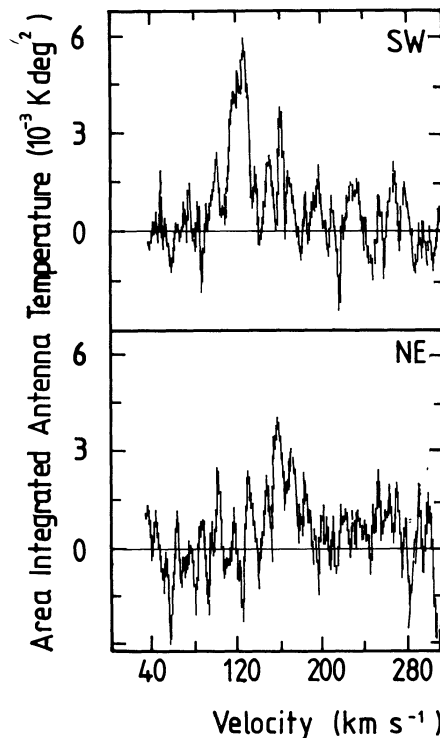


FIG. 2.—Integrated spectra of the CO emission from the southwest (upper panel) and northeast (lower panel) molecular complexes of the SMC.

temperatures, given in column (4), are extremely weak compared with those observed from Galactic GMCs, having an average value of 0.035 K and a maximum value of 0.06 K . The center velocity and full width at half-maximum line width (cols. [5] and [6]) were determined by fitting a Gaussian profile to the spectrum integrated over the whole source. The line widths are comparable to those of the largest Galactic molecular clouds (Dame *et al.* 1986). The integrated spectrum for the southwest and northeast complexes are shown in Figure 2. The linear size (col. [7]) is defined as $(A/\pi)^{1/2}$, where A is the projected area of the cloud at the 3σ level of emission as seen in the narrow velocity width maps. The cloud sizes are 3–4 times greater than the mean size of the largest molecular clouds in our Galaxy. We emphasize, though, that these sizes do not correspond to cloud physical dimensions but just to an effective length of contiguous Columbia beams with CO emission. The CO luminosity, namely, the CO emission integrated over velocity and projected area, is given in column (8). Column (9)

TABLE 1
MOLECULAR CLOUDS OF THE SMALL MAGELLANIC CLOUD

Source (1)	$\alpha(1950)$ (2)	$\delta(1950)$ (3)	T_{max} (K) (4)	v (km s^{-1}) (5)	Δv (km s^{-1}) (6)	R (pc) (7)	L_{CO} ($10^4 \text{ K km s}^{-1} \text{ pc}^2$) (8)	M_{vir} ($10^6 M_{\odot}$) (9)	M_{CO} ($10^6 M_{\odot}$) (10)
SW-1	$0^{\text{h}}44^{\text{m}}41^{\text{s}}$	$-73^{\circ}37'30''$	0.06	120.9	15.9	219	7.24	11.6	9.0
SW-2	0 46 29	$-73^{\circ}30'00''$	0.04	120.8	10.3	134	2.75	3.0	3.4
Southwest .....	...	...	...	122.0	18.5	278	16.22	20.0	20.0
NE-1	0 56 31	$-72^{\circ}07'30''$	0.03	166.0	12.0	110	1.45	3.3	1.8
NE-2	0 56 36	$-72^{\circ}22'30''$	0.03	157.5	9.9	190	5.25	3.9	6.4
NE-3	1 01 29	$-72^{\circ}15'00''$	0.025	170.3	19.9	155	3.24	12.9	4.0
Northwest .....	...	...	...	161.4	26.2	263	14.13	37.9	17.4

gives the virial masses computed assuming that the clouds are in virial equilibrium, $M_{\text{vir}} = 210 \Delta v^2 R$. Finally, column (10) gives the CO mass computed from the CO luminosity as discussed in § IV.

The CO complexes are projected toward regions of atomic gas having the largest ($\geq 10^{22} \text{ cm}^{-2}$) H I column densities. H I observations toward the SMC show that there are four distinct components of neutral hydrogen, with central LSR velocities of 105, 124, 157, and 182 km s^{-1} , exhibiting different but somewhat overlapping spatial distributions (McGee and Newton 1981). The southwest and northeast CO complexes appear projected, respectively, toward the peak of the 124 and 157 km s^{-1} H I components, which are the brightest clouds of neutral hydrogen toward the SMC. In addition, the center radial velocity of the CO emission, of 122 km s^{-1} for the southwest and 161 km s^{-1} for the northeast complexes, is similar to the radial velocity of the associated brightest H I component in the line of sight. We did not detect CO emission toward the peak of the 105 and 182 km s^{-1} H I clouds.

IV. DISCUSSION

a) Weakness of the CO Emission

The antenna temperature of the ^{12}CO line emission from molecular clouds in the SMC is much weaker than would be expected from a typical Galactic GMC located at the distance of the SMC. For the 27 largest Galactic GMCs in the sample of Dame *et al.* (1986), the mean area-integrated brightness temperature is $5 \times 10^4 \text{ K pc}^2$, and the mean linear diameter is $\sim 160 \text{ pc}$. Thus, a typical large Galactic GMC located at the distance of the SMC would then show an antenna temperature of $\sim 2 \text{ K}$ when observed with the Columbia telescope (beam area of $3 \times 10^4 \text{ pc}^2$ at the distance to the SMC of 63 kpc). The observed antenna temperatures are, however, only $\sim 0.04 \text{ K}$. Low intrinsic CO intensities from molecular clouds in the SMC were previously reported by Rubio, Montani, and Cohen (1984) and Israel *et al.* (1986).

Several mechanisms appear able to explain the weakness of the CO emission (Elmegreen, Elmegreen, and Morris 1980): (1) optically thin ^{12}CO emission, (2) low excitation temperatures, and (3) small dimensions of the CO clouds. Recent observations of the $^{12}\text{CO}(1 \rightarrow 0)$, $^{12}\text{CO}(2 \rightarrow 1)$, and $^{13}\text{CO}(1 \rightarrow 0)$ lines toward a few selected positions in the SMC, made with the Swedish-ESO Submillimeter telescope (SEST), suggest that the ^{12}CO emission is probably optically thick (Israel 1989). Thus, the first possibility is unlikely. Regarding the second possibility, if the cosmic-ray flux in the SMC is smaller than that in our Galaxy, then the CO excitation temperature would be lower. However, Israel *et al.* (1986) argue that, since the present supernova rate per unit total mass is higher in the Magellanic Clouds than in the Galaxy, this is also an unlikely situation.

We suggest that the most probable reason for the low values of the observed ^{12}CO antenna temperatures is that the CO-emitting regions in the SMC have smaller dimensions than those in our Galaxy. Assuming that the CO emission is optically thick, then the ratio of the antenna temperature of the ^{12}CO emission from a molecular cloud in the SMC and from a hypothetical typical large Galactic GMC located there is

$$\frac{T_A^*(\text{SMC})}{T_A^*(\text{GAL})} = \frac{\Omega_{\text{SMC}} [J(T_{\text{ex}}) - J(T_b)]_{\text{SMC}}}{\Omega_{\text{GAL}} [J(T_{\text{ex}}) - J(T_b)]_{\text{GAL}}}, \quad (1)$$

where T_{ex} is the excitation temperature, T_b is the blackbody

background temperature, $J(T) = T_0 [\exp(T_0/T) - 1]^{-1}$, with $T_0 = hv/k$, where ν is the frequency of the transition and Ω_{SMC} and Ω_{GAL} are the solid angles subtended, in a 160 pc beam, by CO clumps in the SMC and in the Galaxy, respectively. Using $T_A^*(\text{SMC}) = 0.035 \text{ K}$ and $T_A^*(\text{GAL}) = 2 \text{ K}$, and assuming that molecular clouds in the SMC and our Galaxy have equal excitation temperatures, equation (1) implies that the effective radius of CO emission of molecular clouds in the SMC is ~ 8 times smaller than that of Galactic GMCs. Were the excitation temperatures different, then the ratio of effective radius will scale with the ratio of excitation temperatures roughly as $(T_{\text{ex}}^{\text{SMC}}/T_{\text{ex}}^{\text{GAL}})^{-0.8}$. Support for our suggestion, that the sizes of the CO-emitting regions in the SMC are smaller than those in our Galaxy, is provided by recent theoretical studies which show that, for a molecular cloud of given H_2 column density and size, a decrease in the CO abundance (or metallicity) of the interstellar medium makes the region where CO is the dominant carbon-containing species smaller relative to the size of the hydrogen molecular cloud (Bel, Viala, and Guidi 1986; Viala *et al.* 1988; Maloney and Black 1988).

b) $N(\text{H}_2)/W_{\text{CO}}$ Conversion Factor and the Mass of Molecular Gas

The velocity-integrated CO emission, W_{CO} , from clouds in our Galaxy has been used as a tracer of molecular cloud mass on the basis that the ratio $X = N(\text{H}_2)/W_{\text{CO}}$ appears to be constant over most of the Milky Way. However, owing to differences in the physical properties of molecular clouds and in the physical conditions of the interstellar medium, X is unlikely to be the same constant for other galaxies. For instance, Maloney and Black (1988) found that in systems with low metallicity the filling factors of CO clumps are small. This result implies a decrease in the observed W_{CO} from galaxies with low metal content and hence the need of a different conversion factor. In particular, Cohen *et al.* (1988) estimated, from the observed CO luminosity versus line width relationship, that X for the LMC is ~ 6 times larger than in the Galaxy.

In the absence of a direct method to calibrate X for the SMC, we have adopted the same criteria applied to the LMC, namely, demand that the mass-line width relation for SMC clouds agrees with the Galactic relation, to determine a value for the $X_{\text{SMC}}/X_{\text{GAL}}$ ratio. Figure 3 plots the CO luminosity versus line width relation for molecular clouds in the SMC, the LMC (Cohen *et al.* 1988), and our Galaxy (Dame *et al.* 1986). The curves correspond to least-squares fits to the data of molecular clouds in each galaxy. The relations are such that at the average line width of molecular clouds in the SMC, Galactic clouds are ~ 20 times stronger in CO than SMC clouds. This result suggests that using the Galactic conversion factor to derive masses of molecular clouds in the SMC might greatly underestimate the amount of H_2 . The need for a different conversion factor can also be recognized if we compare molecular masses obtained from the CO luminosity using the Galactic conversion factor with the virial masses (col. [9] of Table 1), the former being about 30 times smaller than the latter ones. Consequently, we propose that the conversion factor to derive molecular masses from the CO luminosities for the SMC is about 20 times larger than that for the Galaxy. This value is probable good to a factor of 2, and only with higher resolution observations we will be able to calibrate X_{SMC} more precisely. Using the canonical value for the Galaxy of $X_{\text{GAL}} = 2.8 \times 10^{20} \text{ cm}^{-2} \text{ K}^{-1} \text{ km}^{-1} \text{ s}$ (Bloemen *et al.* 1986), we then suggest that X_{SMC} is $\sim 6 \times 10^{21} \text{ cm}^{-2} \text{ K}^{-1} \text{ km}^{-1} \text{ s}$.

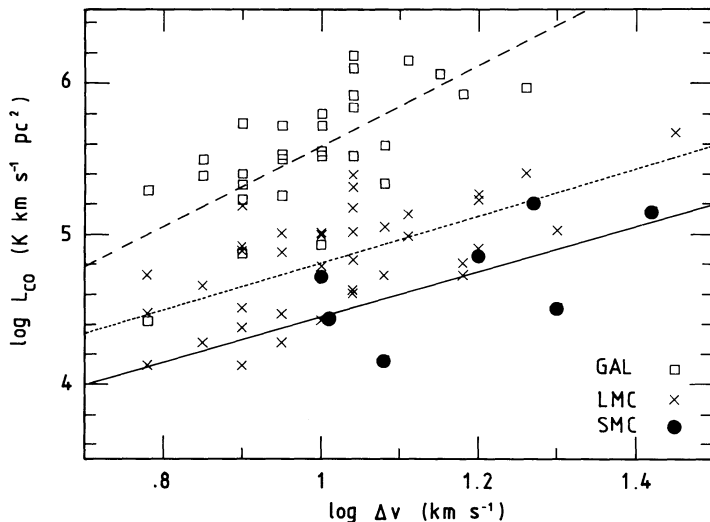


FIG. 3.—Plot of CO luminosity, L_{CO} , vs. line width, Δv , for molecular clouds. Squares, crosses and filled circles indicate, respectively, values observed for molecular clouds of the Galaxy (Dame *et al.* 1986), the LMC (Cohen *et al.* 1988), and the SMC (this paper). Long-dashed, short-dashed, and continuous curves indicate least-squares fit, to the Galaxy ($\log L_{\text{CO}} = 2.7 \log \Delta v + 2.9$), LMC ($\log L_{\text{CO}} = 1.6 \log \Delta v + 3.2$), and SMC ($\log L_{\text{CO}} = 1.5 \log \Delta v + 2.9$) data, respectively.

Theoretical expressions, derived from models of molecular clouds, show that the conversion factor is mainly a function of the excitation temperature, the filling factor of the emitting gas, the metal abundance, and the ambient UV radiation field (Elmegreen 1989). In addition, the filling factor of the CO clumps depends on the metallicity (Maloney and Black 1988), so this parameter is considered to be the most important factor controlling the value of X . Using the conversion factors derived for the SMC (this paper) and for the LMC (Cohen *et al.* 1988), we find that X scales with metallicity, Z , as $Z^{-1.3 \pm 0.1}$. This dependence is, however, only indicative, since differences in excitation temperature and UV radiation field may play an important role.

The molecular mass of the SMC clouds, derived from the CO luminosity using the conversion factor proposed above, are given in column (10) of Table 1. The total mass of molecular hydrogen in the SMC is $3 \times 10^7 M_{\odot}$, corresponding to $\sim 7\%$ of the mass of neutral hydrogen gas. The ratio of molecular to atomic gas in the SMC is about 15 times smaller than the ratio derived in our Galaxy.

c) Molecular Clouds and Dense Cores of Atomic Gas

Molecules occur in the cores of clouds where the outer gas and dust shield the photodissociative radiation. The critical column density of the transition region, N_{cr} , required to shield the cloud interior from the external UV field is given by (Federman, Glassgold, and Kwan 1979; Elmegreen 1989)

$$N_{\text{cr}} = 2.5 \times 10^{20} \left(\frac{n_{\odot}}{n} \right)^{3/2} \left(\frac{G_0}{G_{0,\odot}} \right)^{3/2} \left(\frac{Z_{\odot}}{Z} \right)^{3/2} \text{ cm}^{-2}, \quad (2)$$

where G_0 is the photodissociation rate at the surface of the cloud; n is the mean density in the transition region; and Z is the heavy-element abundance. The values of n and G_0 for H I clouds in the SMC are not well known, but it is probably that they are similar to the Galactic values. Assuming that the ratios n_{\odot}/n_{SMC} and $G_{0,\text{SMC}}/G_{0,\odot}$ are equal to unity, and that

$Z_{\text{SMC}} = 0.1 Z_{\odot}$, then we find $N_{\text{cr}}^{\text{SMC}} \sim 8 \times 10^{21} \text{ cm}^{-2}$. Franco and Cox (1986) derived, assuming that the opacity to the photodissociative UV light is mainly provided by dust grains, that the critical H I column density is given by $5 \times 10^{20} (Z_{\odot}/Z) \text{ cm}^{-2}$. This criterion gives a similar critical column density above which molecular clouds should be formed in the SMC.

The CO emission in the SMC is closely associated with the regions of atomic gas exhibiting the largest column densities. Toward the CO sources the derived column densities of H I are $\sim 10^{22} \text{ cm}^{-2}$. In addition, the radial velocities of the CO and associated H I gas are similar. The good agreement between the observed and theoretical critical column density suggests that the molecular clouds in the SMC are the dense cores of large and massive regions of atomic gas, that are shielded from the ambient UV radiation field. Further support for this conclusion is provided by the nondetection of CO emission toward the 105 and 182 H I clouds, whose H I column densities are smaller than 10^{22} cm^{-2} . These column densities are probably too low to allow the formation of a molecular core.

d) CO Clouds, Population I Objects, and Star Formation

The CO emission from the SMC is closely associated with several Population I objects. About 60% of all dark clouds within the surveyed area (Hodge 1974) are located in the southwest region of the SMC bar. Of these, approximately 60% are projected within the contours of the southwest CO complex. In the northeast region of the SMC the number of dark clouds is smaller, about 20% of the total, most of them appearing projected around the NE-2 CO source.

CO clouds are generally found in the direction of bright and small regions of ionized gas. Toward the southwest area of the Bar, a large fraction of the H II regions corresponds to bright knots, most of which appear projected within the contours of the CO emission. In particular, N19 and N30, the brightest H II regions in this direction (Henize 1956), are found projected close to the peak of the SW-2 CO cloud, which exhibits the strongest antenna temperature of the survey and is associated with water maser emission (Scalize and Braz 1982). On the other hand, toward the northeast area of the Bar the morphologies of the H II regions are predominantly those of large shells and filaments (Davies, Elliot, and Meaburn 1976), the number of bright and compact objects being considerably smaller than in the southwest. The CO emission toward the northeast lies projected roughly in between the extended sources of ionized gas, but is associated with the smaller and brighter H II regions. In particular, N66, the brightest H II region in the SMC, is projected toward the NE-2 cloud.

The CO emission is also closely associated with far-infrared emission from the SMC. The strongest emission at $60 \mu\text{m}$ and $100 \mu\text{m}$ is found in the southwest region (Schwering 1988), the peak position being coincident with the CO source SW-2. Toward the northeast direction there are three peaks of emission at $100 \mu\text{m}$, two of which are associated with CO emission (sources NE-2 and NE-3).

Finally, we suggest that the association and distribution of the CO emission relative to other Population I objects might possibly reflect the star formation history of the SMC. The association with strong $100 \mu\text{m}$ emission, bright knots of ionized gas, and water maser emission, suggest that the SW-2 cloud is an active site of current star formation. Toward the SW-1 object, which is associated with the largest density of dark clouds and is the most luminous source in CO, the $100 \mu\text{m}$ emission is less prominent and the density of H II regions

smaller than toward SW-2, suggesting that the SW-1 complex may be a massive but rather quiescent ensemble of molecular clouds. On the other hand, toward the northeast region of the SMC the presence of large shells and filaments of ionized gas suggest that a burst of massive star formation may have occurred earlier on in this region than in the southwest. The CO emission is weaker than in the southwest, suggesting that in the northeast region the molecular clouds may have been strongly disrupted by the previous burst of star formation. Evidence for more recent massive star formation is, however, also present. For instance, the brightest H II region, N66, which lies near the CO cloud NE-2, is excited by the cluster NGC 346, which contains O3 stars that must be at most $(3-4) \times 10^6$ years old (Walborn and Blades 1986).

V. SUMMARY

We fully surveyed the central $2^\circ \times 2^\circ$ region of the SMC, at an angular resolution of $8''.8$, in search of ^{12}CO emission in the $J = 1 \rightarrow 0$ transition. Each position was observed to an rms noise in the antenna temperature of 0.012 K per channel (1.3 km s^{-1} wide). The main results of the observations and conclusions are summarized below.

1. We detected ^{12}CO emission from two large complexes located in the southwest and northeast regions of the SMC Bar. The southwest and northeast complexes can be separated into two and three individual components, respectively. Most of the CO sources are found projected near bright and compact optical H II regions and/or radio continuum sources, suggesting that the molecular clouds are invariably associated with regions of recent star formation. Only one cloud, the most luminous in CO, appears to be a massive but quiescent molecular cloud with few signs of star formation.

2. The ^{12}CO antenna temperatures of the SMC molecular clouds measured with the Columbia telescope are extremely

weak, of ~ 0.035 K. A typical large Galactic molecular cloud at the distance of the SMC would produce an antenna temperature of ~ 2 K. We suggest that the reason for the low ^{12}CO antenna temperatures is that the characteristic size of the CO clumps of molecular clouds in the SMC is smaller (roughly by a factor of 8) than that in our Galaxy.

3. The CO sources are usually projected in the direction of H I clouds having the largest column densities [$N(\text{H I}) > 10^{22}$ cm^{-2}]. In addition, the (CO) radial velocities of the molecular clouds are about the same as the (H I) radial velocities of the associated atomic gas clouds. We suggest that the molecular clouds are the dense cores of large and massive regions of H I gas that are shielded from the UV radiation pervading the SMC.

4. From a comparison of the CO luminosity versus line width relation for molecular clouds in the SMC, LMC, and our Galaxy, we concluded that for the SMC the conversion factor to derive molecular masses from the velocity-integrated CO emission is 6×10^{21} cm^{-2} K^{-1} km^{-1} s, which is about 20 times larger than the value adopted for our Galaxy.

5. The masses inferred using this conversion factor are in good agreement with the masses determined assuming virial equilibrium. The total mass of molecular gas in the SMC is roughly $3 \times 10^7 M_\odot$. The ratio of molecular to atomic gas is about 7%, 15 times smaller than that observed in our Galaxy.

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