MOLECULES AND DUST IN THE MAGELLANIC CLOUDS

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1. INTRODUCTION.

A variety of studies over the last decade has shown molecular hydrogen to be a major constituent of the interstellar medium both in our Galaxy and in other spiral galaxies (Morris and Rickard, 1982). Our Galaxy contains roughly $M(H_2) = 4 \times 10^9$ $M_\odot$; between R = 2 kpc and R = 10 kpc the H_2 mass is one to three times that of HI; at the solar circle about 12 per cent of the total disk mass is in the form of H_2; most of this mass is in the form of several thousand giant molecular cloud complexes (GMCs) with sizes d > 20 pc and masses $M(H_2) > 10^5$ $M_\odot$ (Cohen et al, 1980; Sanders, 1981; Dame, 1983). These GMCs mainly consist of clumps with much smaller scales of order a few pc or less (e.g. Bally and Israel, 1983). Apart from their contribution to the total mass of the galactic interstellar medium, molecular clouds are also important as they are the major birthsite of massive early-type stars (see the review by Habing and Israel, 1979).

At least the disks of most late-type spiral galaxies observed thus far appear to share the molecular cloud characteristics of the Galaxy (Morris and Rickard, 1982; Scoville, 1984). In contrast, irregular dwarf galaxies of the Magellanic type are different: they either contain relatively little molecular material, or their molecular clouds are different (Elmegreen et al, 1980). Because of their proximity, the Large and Small Magellanic Clouds offer a unique possibility to study the similarities and differences of molecular clouds in spiral and irregular galaxies. In particular, such studies can provide insight in star formation mechanisms in these galaxies and in the process of formation and destruction of molecular material.

2. OBSERVING DUST AND MOLECULAR CLOUDS.

The most abundant molecule, H_2, can be observed directly only in particular cases (see the review by Shull and Beckwith, 1982). UV absorption lines yield information on molecular hydrogen in relatively unreddened clouds; it is observed only to an effective upper limit of

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order 10^{21} H_2 cm^{-2}. Near-IR emission lines yield information on dense molecular clouds, but only in relatively small zones of shocked molecular gas. Thus, most of the present knowledge of molecular clouds is derived from more easily observed tracers such as dust or less abundant molecules (isotopes of CO, OH, H_2CO, for instance).

Dust is a good indicator for the presence of molecules, because it plays a key role in both the production of molecules (grain surface formation of e.g. H_2) and the shielding of molecules (such as CO) against dissociation by the interstellar radiation field. Dust can in principle be detected and measured directly, by the extinction it causes or by its thermal emission (see Hildebrand, 1983). In the Galaxy, molecular emission is associated with reddening $E(B-V) > 0.05$ mag (Spitzer et al, 1973) and the column density of molecular hydrogen is usually taken to be $N(H_2)/E(B-V) = 3.75 \times 10^{21}$ cm^{-2} mag^{-1} at least for $A_V < 1.3$ mag (Jenkins and Savage, 1974; Dickman, 1978), although it is not yet clear that this relation is universally valid.

More quantitative information is supplied by tracer molecules, of which CO is the most extensively observed in its J=1-0 transitions at 115 GHz (^{12}CO) and 110 GHz (^{13}CO). The extrapolation of the properties of these tracer molecules to those of molecular hydrogen depends usually on somewhat uncertain assumptions regarding, for instance, radiative transfer, abundance ratios and excitation conditions. A good review of the problems associated with these procedures is given by Evans (1980). In case of CO, it is usually assumed that the ratio $N(H_2)/N(^{13}CO) = 5 \times 10^5$ (Dickman, 1978), but reality appears to be more complicated (Frerking et al, 1982).

In the Galaxy, main-line (type I) OH masers and strong H_2O masers commonly indicate sites of recent star formation in molecular clouds (c.f. Habing and Israel, 1979). They do not provide direct information on the properties of the molecular cloud in which they are embedded, but they do mark the presence of molecular clouds engaged in star formation (see the review by Reid and Moran, 1981).

3. DUST IN THE MAGELLANIC CLOUDS.

Estimates of the amount of dust in the Magellanic Clouds are subject to controversy, but the pattern that emerges indicates a relatively low dust content for both LMC and SMC. In the past, three methods have mainly been used to determine the dust content of the Magellanic Clouds: 1. determination of the reddening of individual stars by photometry and spectroscopy; 2. determination of surface extinction values by galaxy counts; 3. mapping of individual dust clouds by tracing their silhouet against the stellar background. All three methods are subject to observational difficulties. The more promising method of tracing the dust distribution throughout the Cloud volume by observing its thermal emission in the mid and far infrared has only recently become practical. Because this emission is optically thin, essentially all dust can be observed.

3.1. Reddening of Individual Stars.

Deducing dust content from line-of-sight extinction measurements requires a priori knowledge of the intrinsic colours of the observed stars and the distribution of reddening values to a certain limiting magnitude (c.f. Isserstedt, 1977). Moreover, this method only measures dust between the star and the observer. Because of the distance of the Magellanic Clouds, there is a systematic bias in favour of the brightest stars, i.e. stars at the near side of the Clouds suffering relatively little extinction. Moreover, the presence of circumstellar shells and double stars complicates the interpretation of observed reddening values (leading to overestimates; c.f. Isserstedt, 1975).

The observations of stars in the LMC show E(B-V) values ranging from 0.1 to 0.4 mag, and in the SMC ranging from 0.1 to 0.2 mag (e.g. Dachs, 1970; Lucke, 1974; Brunet, 1975; Azzopardi and Vigneau, 1977; Nandy et al, 1979). This includes a Galactic foreground reddening of E(B-V) = 0.03 - 0.07 mag for the LMC and E(B-V) = 0.02 - 0.04 mag for the SMC (McNamara and Feltz (1980). Thus, bright stars in both the LMC and SMC show, on average, very little reddening. In an extensive study of interstellar reddening in the LMC, Isserstedt (1975) has shown that the distribution of interstellar dust in the LMC is dominated by a huge dust cloud complex surrounding 30 Doradus. Nevertheless, even there, few stars have E(B-V) > 0.4 mag. A rough, but instructive map of the E(B-V) distribution across the LMC based on OB association extinctions (Lucke, 1974) is given by Page and Carruthers (1981). The dark clouds around 30 Doradus stand out, as well as a cloud complex associated with the HII regions N79/N83/N91 WSW of the Bar. The presence of dust in HII regions, as determined by H-beta photography, was briefly discussed by Johnson (1973).

UV spectroscopy and photometry including the Lyman alpha absorption has been used fruitfully to estimate line-of-sight gas-to-dust, or more exactly gas-to-colour excess ratios. The results indicate moderate dust depletion (by a factor of four) in the LMC and strong dust depletion (by a factor of sixteen or more) in the SMC when compared to Solar Neighbourhood values (see the review by Koornneef, these proceedings; Lequeux et al, these proceedings). Some information on the nature of the dust particles in the LMC and SMC is provided by the shape of the interstellar reddening curve, which is now relatively well-determined (see the review by Nandy, these proceedings; Lequeux et al, these proceedings). In the near-infrared and the visual it is virtually identical to the Galactic reddening law (Brück et al, 1970; Koornneef, 1982; Borgman and Danks, 1977). This is not true in the UV. Compared to the Solar Neighbourhood, the LMC reddening law shows a distinctly weaker 2200Å feature, and significantly higher far-UV extinction; the SMC reddening law shows the same behaviour, but to an even more extreme degree (Koornneef and Code, 1981; Nandy et al, 1981; Lequeux et al, these proceedings). The differences can be explained by assuming a grain size distribution as in the Galaxy, but a progressive absence of graphite particles in the LMC and SMC and, in the case of the SMC, by silicon being underabundant by a factor of ten, and mostly locked up in grains (Bromage and Nandy, 1983; Lequeux et al, these proceedings). The depletion of graphite is consistent with the low C/O ratio in Magellanic Cloud HII regions (Dufour et al, 1982).

3.2. Extinction from Galaxy Counts.

Only for the SMC attempts have been made to derive the extinction through the Cloud by way of galaxy counts. Determination of the area integrated extinction by galaxy counts (Hodge, 1974 and references therein) are influenced by galaxy clustering, by confusion of Cloud nebulosities with background galaxies, and by count incompleteness in crowded star fields. Small-scale structure in the dust distribution (such as small clouds with high extinction) is washed out or missed.

Shapley (1951) concluded that the SMC is essentially transparent with A_V at most 0.3 mag. Wesselink (1961a, b) counted 240 galaxies over in total 5 square degrees, but found that $A_V = 1.5$ mag over a large fraction of the SMC with, however, a considerable uncertainty because of count incompleteness. The most extensive work to date is by Hodge (1974a) who counted 2545 galaxies over an area of 85 square degrees. He found $A_V > 0.8$ mag over most of the SMC, reaching a peak at the SW end of the Bar with $A_V = 1.3$ mag. He estimated a total dust mass of $M_d = 5 \times 10^5$ $M_\odot$, yielding an atomic gas-to-dust ratio $M(HI)/M_d = 300$, or a factor of three higher than in the Galaxy. The smoothed contours of dust extinction in Hodge's model show some structure, but its reality is questionable (Hodge, 1974a).

3.3. Discrete Dust Clouds.

Identification of dust clouds by their absorption of background starlight is limited by systematical effects (Hodge, 1972) such as the brightness and clumpiness of background stars (and galaxies). Thus, only dark clouds larger than about one arcmin (or about 20 pc) can be identified, preferentially on the near side and in front of a bright background. Cloud catalogues and maps were published by Hodge (1972, 1974b) and Van den Bergh (1974). Striking composite color photographs of the LMC and SMC clearly showing several dust clouds and dark lanes were published by Madsen and Tarenghi (1982), and Dufour (available from the Hansen Planetarium). McGillivray (1975) found several dark clouds lying outside the main body of the SMC by galaxy counts.

The catalogues by Hodge (1972, 1974b) provide some quantitative data. For the LMC, 68 clouds are listed (mean size 4.2 arcmin or 67 pc) and for the SMC 45 clouds (mean size 2.1 arcmin or 49 pc). In the LMC, a major concentration of dark clouds is found in the area near 30 Doradus, whereas in the SMC this is the case in the Southwest Bar. The dark cloud distribution is summarized in Table 1. Equal numbers of clouds are found in the LMC Bar and the 30 Doradus region, in roughly equal areas; in the SMC the a smaller fraction of the surface is covered despite a higher density of clouds. In Table 1, we have also

Table 1. Discrete Dark Clouds in LMC and SMC. (From Hodge, 1972, 1974b).

	n	%	Mean Size (')	Number Density (kpc^{-2})	Fraction Surface Covered	'Darkness' Mean per Region	'Darkness' % of Total
LMC-Total	68	100	4.2	--	----	9.5×10^3	100
30 Dor	30	44	4.9	17	0.08	13.5	63
Bar	30	44	3.5	15	0.04	5.7	27
Other	8	12	4.1	3	0.01	8.4	10
SMC-Total	45	100	2.1	--	----	4.7	100
SW Bar	21	47	1.9	31	0.03	4.8	48
Mid Bar	13	29	2.2	30	0.04	4.1	25
NE Bar	9	20	2.3	21	0.03	4.0	17
Wing	2:	4:	3.3:	2	0.01	11.3:	11:

defined an empirical 'darkness' as the product [opacity x d^2 (pc)] derived from angular sizes and opacities given by Hodge (1972, 1974b). The 30 Doradus clouds are on average more than twice as 'dark' as clouds elsewhere in the LMC, and they appear to represent almost two thirds of the dark material seen in the form of discrete clouds. The SMC Wing appears to be poor in dark clouds, but the less intense stellar background makes dark clouds more difficult to detect. There is little variation in cloud 'darkness' over the SMC (the high value for the Wing being uncertain because of the above-mentioned selection effect). The average SMC cloud 'darkness' is only slightly lower than that of clouds in the LMC Bar, but only a third of the dark clouds in the 30 Doradus region, thereby confirming the interstellar reddening results reviewed in section 3.1.

The linear sizes of LMC and SMC dark clouds are similar to those of Galactic giant molecular clouds. As shown in section 4.1, they do indicate the presence of molecular material, but it appears that on average they do not represent very large molecular masses. From star counts, Hodge (1972, 1974b) finds for the cores of these clouds an average visual extinction of order 0.5 mag. Moreover, the largest clouds cause the least extinction. If we assume that cloud core extinctions apply to the whole cloud, and if we take the Galactic value for $N(H_2)/A_V$ from section 3.1, we find mean cloud masses $M(H_2) = 3.5 \times 10^4 M_\odot$ for the LMC clouds and $0.7 \times 10^4 M_\odot$ for the SMC clouds, i.e an order of magnitude less than one finds in Galactic GMCs. The catalogued dark clouds would then imply total H_2 masses of order $10^6 M_\odot$, or less than one per cent of the atomic hydrogen mass of the Magellanic Clouds (c.f. section 5).

This discrepancy might, in principle, be overcome in several ways. 1. The LMC and SMC dark clouds may have a high degree of clumping, so that large amounts of dense material would cause only a relatively small average extinction. This is not unlikely, but it would not increase our mass estimate by much, as we already took extinction values corresponding to the darkest parts as representative for the whole cloud. 2. If the clouds are deeply embedded in the LMC and SMC, star counts underestimate the true extinction. However, this would mean that most clouds present are, in fact, seen. 3. The ratio of dust to molecular gas could be lower in the Magellanic Clouds. If dust is depleted with respect to H_2 to the same extent as with respect to E(B-V) (see section 3.1), the mean dark cloud mass in the LMC would be 1.4×10^5 $M_\odot$ and in the SMC 1.1×10^5 $M_\odot$. These masses are still lower than those of Galactic GMCs, but not dramatically so.

Nevertheless, it is fair to conclude that optical observations, and in particular the apparent low extinctions of the Hodge clouds fail to provide unambiguous proof for the presence of Galactic-type giant molecular clouds on the near side of either the LMC or the SMC.

3.4. Infrared Emission from Dust Clouds.

The best way of measuring dust throughout the Magellanic Clouds is by mapping its thermal infrared emission. So far, there are few published results. Hoffman et al (1973) only obtained an upper limit at 100 microns for 30 Doradus, while in the AFGL survey Price and Walker (1976) found four sources in the LMC at 20 microns (GL 4050, 4055, 4056 and 4057) of which two coincide with the HII regions 30 Doradus and N159. Characteristically, no source was found in the SMC. Werner et al (1978) mapped thermal dust emission between 30 and 200 microns in 30 Doradus, and detected dust in three nearby HII regions (N158C, N160A and N159). Their results show that the dust emission in 30 Doradus arises primarily near the two major ionization fronts. They estimated a dust mass of $M_d = 10^3$ $M_\odot$, and conclude that the average dust density in the observed HII regions is lower by a factor of 2.5 to 5 than in similar Galactic HII regions. Near-IR searches by Gatley et al (1981, 1982) have resulted in the discovery of two heavily reddened objects: in the LMC-N159 and the SMC-N76B, presumably very young and embedded in dust. They found further evidence of small dust clouds with A_V = 5 - 10 mag associated with these HII regions from nearby, heavily reddened background stars.

However, these results will rapidly become superseded as soon as IRAS Magellanic Cloud observations become available; several sources of far-infrared emission have already been identified in both the LMC and the SMC (see Brown, 1983; Habing, private communication).

4. MOLECULES IN THE MAGELLANIC CLOUDS.

4.1. Searches for Molecular Clouds.

The present paucicity of molecular observations of LMC and SMC, in particular of systematic surveys, primarily reflects the lack of major millimeter-wave facilities in the southern hemisphere over most of the past period. In fact, most Magellanic Cloud CO observations published till now have been made with millimeter-wave detectors attached to optical telescopes. The situation is aggravated by the large angular extent of the Magellanic Clouds and their weak molecular emission necessitating long integration times at a large number of positions. The first detection of molecular emission in the Magellanic Clouds was that of CO(1-0) by Huggins et al (1975), using the AAT. So far, the only published systematic search for molecular clouds in both LMC and SMC is the one by Israel et al (1983a, b) in the CO(2-1) line at 230 GHz, covering only a small fraction of the Clouds and thus far from complete. A major step forward is the large-scale CO(1-0) survey undertaken by the New York group (Cohen et al, these proceedings; Rubio et al, these proceedings). The survey uses an 8 arcmin beam and aims at full coverage of at least the LMC. In the SMC, full coverage has been abandoned in view of the weakness of CO emission, and instead selected positions are observed with very long integration times.

Table 2 summarizes the presently available results of molecular line observations in the Magellanic Clouds; numbers in parentheses refer to the number of positions searched. The only observations of H_2 itself are those by Koornneef and Israel (1983) who detected weak emission at two microns in LMC-N159 and SMC-N81, but the data do not lend themselves to quantitative interpretation. In the survey by Israel et al (1983), CO is detected towards the known LMC and SMC masers (see also Gardner, these proceedings), most of the dark clouds and bright HII regions observed. Positions in the LMC and SMC Bars not associated with such objects yielded poor detection rates. The LMC HII region/maser source N159 has a CO intensity higher by a factor of two

Table 2. Summary of LMC and SMC Molecular Observations.

Molecule	N of Detections LMC	N of Detections SMC	Reference
H_2	1(3)	1(2)	Koornneef & Israel, 1983
OH (abs)	1(1)	---	Whiteoak & Gardner, 1976b
	1(1)	---	Caswell & Haynes, 1981
	0(1)	---	Haynes & Caswell, 1981
HCO^+	1(1)	---	Batchelor et al, 1981
CO(1-0)	1(3)	---	Huggins et al, 1975
	3(4)	---	Gardner, these proceedings
	(many)	---	Cohen et al, these proceedings
	---	1(40)	Rubio et al, these proceedings
CO(2-1)	11(22)	5(15)	Israel et al, 1982; 1983
H_2CO (abs)	1(2)	---	Whiteoak & Gardner, 1976a
	0(1)	---	Haynes & Caswell, 1981
OH Maser	1(1)	---	Caswell & Haynes, 1981
	1(1)	---	Haynes & Caswell, 1981
H_2O Maser	2(17)	2(15)	Scalise & Braz, 1982
	3(10)	---	Whiteoak et al (1983)

than any other position in the LMC; a similar cloud is found towards the SMC H_2O maser/HII region N19. N159 is clearly the most succesful target for molecular observations: every species searched for has been found in this source. Israel et al (1982) argued that the N159 molecular cloud complex is the closest to a Galactic GMC yet found in the Magellanic Clouds. Its association with an OH/H_2O maser, shocked H_2 emission and an embedded infrared source shows it to be an active site of star formation (Gatley et al, 1981, 1982; Israel et al, 1982).

In the LMC, CO is concentrated in the region south of 30 Doradus and in Shapley's Constellation I (Israel et al, 1983a, b; Cohen et al, these proceedings), in good agreement with the dust distribution (sections 3.1 and 3.3). In the SMC, CO is detected almost exclusively in the southwestern part of the Bar (Israel et al, 1983a, b; Rubio et al, these proceedings). The outstanding characteristic of CO emission from the Magellanic Clouds is its almost uniformly low intensity as compared to that of the Galaxy. In the LMC, and in the SMC-SW Bar, CO intensities are lower than expected from an extrapolation of Galactic GMC's to Magellanic distances by a factor of two to four. In the remainder of the SMC the difference is a factor of six or more.

4.2. Searches for OH and H_2O Masers.

After unsuccessful attempts by Johnston et al (1971) and Kaufmann et al (1977) the first detection of a Magellanic Cloud maser was that of an H_2O maser in LMC-N159 (see section 4.1) by Scalise and Braz (1981). Caswell and Haynes (1981) then found an OH maser in the same source. This was followed by the discovery of a second OH/H_2O maser in LMC N105 (Haynes and Caswell, 1981; Scalise and Braz 1982), stimulating more extensive and still continuing H_2O maser surveys (Scalise and Braz, 1982; Whiteoak et al, 1983). In the SMC, 15 HII regions and dark clouds have been searched; there are two detections, one in the SW Bar, the other to the north, outside the SMC optical image, but coincident with a radio continuum source (McGee et al, 1976). In the LMC, a total of 22 HII regions and dark clouds have been searched with four detections, three in the region south of 30 Doradus. Only one detection (that of N105A) is common to both surveys. The luminosities of the H_2O masers discovered are comparable to those of H_2O masers (3 x 10^{29} erg s^{-1}) in the Galaxy but there is a conspicuous lack of masers comparable to the strongest (10^{33} erg s^{-1}) found in the Galaxy (Scalise and Braz, 1982; Whiteoak et al, 1983). In contrast, the N105 OH maser has a luminosity comparable to that of the strongest Galactic OH masers (Haynes and Caswell, 1981)

5. LACK OF DUST AND MOLECULES IN THE MAGELLANIC CLOUDS.

5.1. Lack of Dust.

Almost all studies reviewed in the preceding indicate that the Magellanic Clouds are lacking in dust as compared to the Galaxy. This lack of dust is particularly clear in determinations of the gas to dust ratio. Compared to the Solar Neighbourhood, the LMC appears to be underabundant in dust by a factor of four, and the SMC by a factor of seventeen (Koornneef, 1982; these proceedings; Lequeux et al, these proceedings). The lack of dust correlates well with the low abundances of heavy elements in the Magellanic Clouds, such as that of carbon (see the review by Dufour, these proceedings). It is particularly pronounced in view of the high atomic gas content of the Magellanic Clouds (section 5.3). Although the cause of these low abundances has not yet been established, it may well turn out to reflect a *mean* star formation rate significantly lower than the *present* star formation rate in the Magellanic Clouds or Galactic star formation rates. This would be consistent with models of stochastic star formation (Matteucci and Chiosi, 1983; Feitzinger et al, 1981).

5.2 *Lack of CO*.

CO is less widespread in most of the LMC and SMC than in the Galaxy, and where detected, it has intensities significantly less than that of comparable Galactic molecular cloud complexes (section 4.1). This result for the archetypical Magellanic Clouds is consistent with that obtained for other Magellanic dwarf irregulars by Elmegreen et al (1980). Most likely, the observed low CO intensities do not primarily reflect low CO *abundances*, because the results have been obtained by observing the ^{12}CO $J=1-0$ and $J=2-1$ transitions which are expected to be optically thick. Measured instead is the product of brightness temperature and the fraction of the beam filled with CO clumps. The CO observations of the LMC, the SMC and other Magellanic galaxies thus indicate low brightness temperatures, few clumps per beam or both.

Elmegreen et al (1980) gave an extensive discussion of possible explanations for weak CO emission. They note the complex nature of CO formation, destruction and excitation mechanisms, and advance two categories of explanations. One is based on lower heating rates in irregular galaxies and the other on lower CO abundances. For instance, low heating rates of molecular clouds, and hence low CO excitation temperatures may result if cosmic ray fluxes are relatively low. Also, the CO formation rate might be lowered. This could be the case either because of low production rates or poor confinement of cosmic ray particles. However, the present supernova rate *per unit mass* of both the LMC and the SMC is three times higher than that of the Galaxy (Tammann 1982; Mathewson et al, 1983). In order to achieve a tenfold decrease in cosmic-ray fluxes (necessary to decrease CO excitation temperatures by a factor of two or three) confinement would have to be poor (see also the restraints on magnetic field strengths and energy densities derived from polarization measurements by Schmidt, 1970).

High luminous star formation rates and efficiencies may cause rapid desintegration of parent molecular clouds, shortening their mean lifetimes. This effect probably explains the lack of CO near giant HII regions such as 30 Doradus (Israel et al, 1982) but seems insufficient to explain the overall lack of CO in the Magellanic Clouds.

Discussing their CO observations, Israel et al (1983b) attempted to explore the consequences of the known low dust-to-gas ratio in the Magellanic Clouds. They argue that the lack of dust allows deeper penetration of individual gas clumps in a molecular cloud complex by a stronger interstellar UV radiation field, thus leading to higher CO destruction rates, hence to fewer CO clumps within the observing beam. Therefore, a low CO content would be the direct consequence of a low ratio of dust to gas. The results of a simple model show that the observed underabundance of dust may well explain the observed low CO antenna temperatures. The greater lack of dust in the SMC and the equally low heavy-element abundances (in particular the low C/O ratio) may conspire to create extremely low CO column densities, perhaps even leading to the unusual presence of a significant fraction of optically thin CO in the SMC. The best way of verifying this are measurements of the ^{13}CO isotope, but the line is expected to be very weak.

5.3 The H_2 Abundance.

Direct determination of H_2 column densities towards a few of the brightest stars in the Magellanic Clouds may, in the near future, come within reach of the high-resolution spectrograph of the Space Telescope. Such observations are of great importance, as they provide virtually the only way of determining the molecular hydrogen content of the Clouds. In the meantime, the different radiation field and dust particle properties suggested by UV observations of the LMC and the SMC complicate model calculations of H_2 formation, whereas in view of the above the value of the CO molecule as a quantitative tracer for H_2 is diminished. For instance, if H_2 formation and destruction is not influenced by the different physical conditions in the Magellanic Clouds, contrary to CO, the CO/H_2 ratio in the LMC would be lower than in the Galaxy by a factor of five or more, and in the SMC by a factor of ten or more, depending on CO destruction rates and on CO abundances. If the depletion of H_2 were to go linearly with that of dust, the effect on the CO/H_2 ratio would be less; probably not more than a factor of two for the LMC, and a factor of four or so for the SMC. Whatever the case, the use of the Galactic CO/H_2 ratio as given in section 2 is suspect and probably leads to underestimates for the molecular hydrogen content of the Magellanic Clouds.

One pertinent observation remains. The LMC and SMC have surprisingly high amounts of neutral atomic hydrogen. The LMC has M(HI) = 5.4×10^8 $M_\odot$ (McGee and Milton, 1966) and the SMC has M(HI) = 4.8×10^8 $M_\odot$ (Hindman, 1967), which must be contrasted with total (dynamic) masses M(tot) = 6×10^9 $M_\odot$ for the LMC (McGee and Milton, 1966; Feitzinger, 1980 and references therein) and M(tot) = 1.5×10^9 $M_\odot$ for the SMC (Hindman, 1967). The HI surface density is almost an order of magnitude higher in the SMC than in the LMC. Thus the atomic hydrogen mass fraction M(HI)/M(tot) is 0.09 for the LMC and 0.32 for the SMC, as compared to about 0.01 for the Galaxy as a whole, and about 0.06 for the Solar Neighbourhood. Such large amounts of atomic hydrogen appear to preclude the possibility that an appreciable fraction of hydrogen is in molecular form. In the LMC and the SMC we are unlikely to find H_2 to HI ratios of one to three as CO observations are taken to indicate for the disks of the Galaxy and Sc galaxies (Sanders, 1981; Young and Scoville, 1982; Dame, 1983). We finally note that the very high M(HI)/M(tot) ratio of the SMC indicates the presence of even less molecular hydrogen than in the LMC, in line with the lower dust, CO and heavy-element abundances.

6. REMARKS ON STAR FORMATION IN THE MAGELLANIC CLOUDS.

The present (luminous) star formation rates per unit mass are higher than that of the Galaxy by factors of 2.7 for the LMC and 1.5 for the SMC (see the review by Lequeux, these proceedings; also Israel, 1980). The present supernova rates are consistent with these numbers (see section 5.2). Thus, the lack of dust, medium-heavy elements (C, N, O) and molecules does not appear to prohibit vigorous formation at least of massive ($M > 10\ M_{\odot}$) stars; if anything, the contrary is the case. Some relevant considerations are that <u>a.</u> formation of massive stars may be favoured at low metallicity levels because of lower cooling rates in the contraction phase and <u>b.</u> the molecular content of the densest and most massive clumps will be least affected by enhanced radiative destruction due to dust depletion, also favouring the formation of massive stars over those of low-mass.

The major site of molecules and dust in the LMC is the 30 Doradus complex; the northern part of this complex contains HII regions and OB associations that represent up to 30 per cent of all newly formed stars in the LMC. The morphology of this Greater Doradus complex suggests a sequence of star formation in a north-south direction, with star formation presently taking place in the middle (in N159). Less outstanding concentrations in the LMC are Constellation I and perhaps the outlying N79/N91 complex. Similarly, in the SMC current star formation appears to be limited mainly to the southwest Bar.

7. FUTURE PROSPECTS.

It is unlikely that optical as opposed to UV observations will add much to our present knowledge of the dust content of the Clouds, but IRAS far-IR observations will allow us to study in detail the dust component of the Magellanic Clouds. Further molecular observations, especially the completion of the ^{12}CO survey by the New York Group, and additional observations of e.g. ^{13}CO are urgently needed. If feasible, H_2 UV absorption measurements with the Space Telescope, would be of great importance. More generally, theoretical modelling of molecular formation and destruction processes as a function of the dust and radiation field properties appears worthwhile. Finally, the rapidly increasing data base on dust and molecules in the Magellanic Clouds should stimulate further theoretical investigations linking star formation processes to the evolutionary history of the Clouds.

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DISCUSSION

van den Bergh: I have two comments:
1. In small fields it is dangerous to estimate absorption from counts of relatively bright galaxies. Because the distribution of galaxies is so clumpy the absence of galaxies may only imply that there are no galaxies.
2. It is tempting to assume that the difference in dust abundance between the LMC and the SMC is responsable for the fact that the Large Cloud HI has a much clumpier distribution than that of the Small Cloud gas.

Israel: I quite agree. With respect to your second point I think we should also take into account the fact that there will, in any case, not be very much molecular hydrogen either, because the M(HI)/M(tot) ratio is already so high.

Shull: If possible, please describe in more detail the structure of a giant molecular cloud. You said it was a swarm of clumps (1 pc in size) moving balistically. What are your guesses about densities (within and between clumps), distances between clumps, and so forth.
My interest in this is related to my investigation of the inhomogeneous environments in which SNs explode: I have SNR spectra showing clumps about 1 pc in size that have been accelerated outward by the blast wave.

Israel: ^{12}CO pictures of molecular cloud complexes are rather misleading, because they really only show the temperature distribution. If you look at molecular cloud complexes in ^{13}CO or NH_3, you see a fair number of clumps; typically of parsec size, moving with velocities of a few km/s with respect to one another; typical masses are a few hundreds of solar masses (in H_2!). The projected separation is of order of a few clump diameters. Quite possibly, there are HI clumps of lower mass and density in between the molecular clumps.