CO AND H_2 IN LOCAL GROUP GALAXIES.

F.P. Israel
Sterrewacht
Postbus 9513
2300 RA Leiden
The Netherlands

Since the detection of molecular line emission from Galactic sources in the seventies, the importance of molecular clouds as a major constituent of the interstellar medium in the Galaxy has become clear. A major problem in Galactic research has been the overall distribution of the molecular component and position-related variations in this distribution. Studies of this problem are greatly hampered by our eccentric location inside the Galaxy. The global view offered by external galaxies eliminates this problem, but now limitations on linear resolution take its place. Only the nearby Local Group galaxies (Magellanic Clouds: 54 and 63 kpc; M31, M33 and NGC 6822: 500 - 700 kpc) combine acceptable linear resolutions with a global view. Their angular size and the low brightness of their molecular component makes mapping of these galaxies slow process. Yet, this is a worthwile undertaking: not only the global properties of the molecular interstellar medium emerge, but also interesting physical differences due to variations in metallicity and ambient radiation field strength in the galaxies of the Local Group. This paper presents a brief review on molecules in the Local Group and preliminary results from ongoing projects.

1. LMC and SMC.

The most important project here is the ESO-SEST Key Program already mentioned by Johansson (these proceedings). With a linear resolution of about 10 pc, both individual cloud complexes in the Doradus region and N11 (LMC) and the southwest Bar (SMC) are carried out, as well as a full sampling of the LMC CO emission in long and perpendicular strips one beam wide and crossing Doradus and the Bar. The main result that has emerged to date is the weakness of CO in the Clouds: in the LMC CO emission is at least three times weaker than that of comparable molecular clouds in the Galaxy, in the SMC it is at least ten times weaker. We suspect that this is a consequence of relatively strong photodissociation (strong UV

F. Combes and F. Casoli (eds.), Dynamics of Galaxies and Their Molecular Cloud Distributions, 13–16.

radiation fields, low metallicity and dust-to-gas ratio). A CO map of the N11 HII region complex shows a striking resemblance to the clumpy filamentary CO structure of the Orion molecular cloud complex. So far, we have not succeeded in finding similar large molecular complexes in the SMC. Interpretation of the SMC results is complicated by confusion introduced by the long line of sight through the southwest Bar, making e.g. determinations of virial mass difficult.

In the LMC, the ratio of ^{12}CO to ^{13}CO peak strengths is about ten, in the SMC perhaps somewhat higher. This is higher than the Galactic ratio, but the significance is not immediately clear. Cloud masses calculated from CO intensities are significantly lower than those calculated from virial masses; the latter range from a few thousand $M_{\odot}$ to a few hundred thousand $M_{\odot}$. Thus, molecular cloud complexes in the LMC and especially the SMC are noticeably different from those in the Galaxy. It should be stressed that the interpretation of these results is not yet clear, but that in any case uncritical use of the velocity integrated CO signal (I_{CO}) to determine H_2 masses is unwarranted.

On a smaller scale (about 2 pc) fourteen compact HII regions have been serached for excited H_2 emission in the near-infrared (Israel and Koornneef, to appear in A&A). In more than half of these objects, H_2 emission was detected. In all cases, radiative excitation (fluorescence) is the energetically dominant mechanism, although shock-excited emission is present in at least three objects. The density of the excited H_2 is of order 5000 cm^{-3}, whereas shock velocities, where estimated, are about 10 km/s, implying Magellanic stellar winds significantly less than stellar winds of comparable Galactic stars. Photometry of these and other compact objects confirms the conclusion drawn by Schwering (1988) that small particles (PAH's) responsible for 12μm excess emission avoid the harsh radiative environment represented by these compact HII regions.

2. M31.

This is the major Local Group spiral (Sb). Metallicities in M31 are comparable to those of the Solar Neighbourhood. Partial CO maps of M31 have been produced with the Bell Labs telescope with a linear resolution of 350 pc (e.g. Ryden and Stark, 1986). The first full CO map of M31 is presented by Dame et al in these proceedings. It shows the CO to be concentrated very strongly in the stellar ring of this galaxy. A recent attempt to use the distribution of far-infrared and HI emission in M31 to 'questimate' the H_2 distribution is presented by Koper et al, likewise in these proceedings. The resulting 'H_2' map resembles the CO map tolerably well, and implies an I_{CO} to $N(H_2)$ conversion factor not more than

https://doi.org/10.1017/S0074180900243398 Published online by Cambridge University Press

twice the standard Galactic factor.

Individual molecular cloud complexes have been mapped in M31 with linear resolutions ranging from 35 to 70 pc (Nakano et al, 1987; Casoli et al, 1987; Casoli and Combes, 1988; Lada et al, 1988). The $^{12}CO/^{13}CO$ ratio appears to be 8 - 10. The M31 molecular cloud complexes are similar in mass and size to those in the Galaxy. This is confirmed by interferometer observations (Vogel et al, 1987).

3. M33.

In the ScIII dwarf spiral M33 metallicities are comparable to those of the LMC and lower than those of the Solar Neighbourhood except in the center. No complete map of the weak CO emission of M33 has yet been published, but CO has been detected at several positions. Molecular cloud complexes have been observed at resolutions varying from 20 to 75 pc. Three complexes in the center have dimensions and masses comparable to those of Galactic complexes (Wilson et al, 1988). Masses derived from integrated ^{12}CO emission are lower than those derived from virial masses, especially if the less optimistic value 2.3×10^{20} (H cm^{-2}) (km s^{-1})$^{-1}$ for the Galactic CO to H_2 conversion factor is used. If these complexes are virialized, then the conversion factor in the center of M33 is of order five times higher than in the galaxy. The opposite was found by Boulanger et al (1988) for three clouds associated with HII regions. Part of the difference may be due to higher CO excitation temperatures near these bright HII regions, but a general note of caution should be introduced here: the so-called missing flux problem inherent in interferometer observations may result in a serious underestimate of cloud complex sizes and cloud structure. In turn, this may lead to virial masses that are significantly and systematically low.

Molecular hydrogen was observed towards the bright HII region NGC 604, and possibly also towards IC 133 and NGC 595 (Israel et al, 1989, 1990). The H_2 complex near NGC 604 has the dimensions of a Galactic GMC, is radiatively excited and has a temperature of 70 K. Its mass is about 3×10^6 $M_\odot$ and implies for this cloud complex a CO to H_2 conversion factor about a factor of ten higher than the Galactic factor. Unpublished CO observations indicate that the NGC 604 molecular could complex consists of two major concentrations to the southeast of the HII region. The complex mapped in H_2 corresponds to the northernmost of these.

4. NGC 6822.

This is an irregular galaxy somewhat reminiscent of the LMC in size, structure and metallicity. At its northern edge,

https://doi.org/10.1017/S0074180900243398 Published online by Cambridge University Press

several major HII region complexes are found. The brightest of these, Hubble V, unpublished observations show strong H_2 emission. With the SEST (linear resolution 100 pc) about twenty positions have been searched for CO until now. Two clear detections have been obtained, the brightest towards Hubble V with I(CO) = 1.5 K km s^{-1}. Half a dozen positions yield marginal detections at levels two to three times weaker. Thus, CO emission from this galaxy is very weak.

The CO luminosity of Hubble V is about a tenth of that of NGC 604, while the 1-0S(1) H_2 luminosity of Hubble V is at least equal to that of NGC 604, and may be higher by a factor up to four. Although the excitation mechanism and extent of the H_2 cloud have not yet been determined, the present results suggest that the Hubble V molecular cloud suffers from strong CO photodissociation and that for this complex the CO to H_2 conversion factor is much higher than the Galactic factor.

Conclusion.

Molecular emission (both CO and H_2) has been found in all Local Group galaxies searched. Overall, the excitation of H_2 is dominated by UV radiation, not by shocks. Although a comparison of H_2 and CO masses and column densities suffers from significant uncertainties in the basic assumptions, there is nevertheless a very clear trend that low metallicity environments are associated with incleasingly weak CO emission, and increasingly higher CO to H_2 conversion factors. As all the environments observed are also characterized by varying, but always strong UV radiation fields, it is very plausible that significant CO photodissociation is the main cause of the observed trend. This implies that CO is an unreliable tracer for molecular cloud masses of external galaxies with radiation fields and metallicties significantly different from those in the Galaxy. This includes most dwarf galaxies and most highly luminous galaxies.

References.

Boulanger, F., et al.: 1988 in 'Molecular Clouds in the Milky Way and External Galaxies', Berlin, p. 401
Casoli, F., et al.: 1987 Astr. Ap. 173, 43
Casoli, F., and Combes, F. 1988 Astr. Ap. 198, 43
Israel, F.P., et al.: 1989 MNRAS 236, 89
Israel, F.P., et al.: 1990 MNRAS 242, 471
Lada, C.J., et al.: 1988 Ap. J. 328, 143
Nakano, M., et al.: 1987 PASJ 39, 57
Ryden, B., Stark, A.A.: 1986 Ap. J. 305, 823
Schwering, P.B.W.: 1988 Ph.D. Thesis Leiden University (NL)
Vogel, S.N., et al.: 1987 Ap. J. Lett. 321, L145
Wilson et al.: 1988 Ap. J. 333, 611

https://doi.org/10.1017/S0074180900243398 Published online by Cambridge University Press