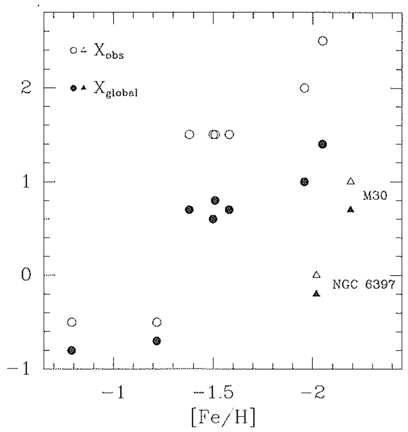

Figure 5: *Observed (light circles) and mass-segregation corrected (filled circles) power law exponents plotted versus metallicity. Note that the present sample seems to exclude any dependences of the MF slopes upon metallicity.*

have been found between the IMFs of disk and halo stars over the range $0.3 < m < 0.8\ M_\odot$. However, we shall note that these investigations consider heterogeneous samples of stars and regions of a vast stellar system which may have experienced a different evolution.

For all these reasons we have started a long-range project aimed at investigating the luminosity functions in different stellar populations. In the present phase we are studying GCs with different structure parameters, with a particular attention for the clusters with low concentration or long relaxation times (such as NGC 1261, M55 and M4), where the amount of mass segregation is expected to be small, and a few irregular galaxies resolved in stars.

References

Alcaíno, G., Buonanno, R., Caloi, V., Castellani, V., Corsi, C.E., Iannicola, G., and Liller, W. 1987, *Astron. J.*, **94,** 917.

Capaccioli, M., Ortolani, S., Piotto, G.P., 1987, ESO Workshop on "Stellar Evolution and Dynamics in the Outer Halo of the Galaxy", eds. M. Azzopardi and F. Matteucci, p. 393.

McClure, R.D., VandenBerg, D.A., Smith, G.H., Fahlman, G.G., Richer, H.B., Hesser, J.E., Harris, W.E., Stetson, P.B., and Bell, R.A. 1986, *Astrophys. J. Letters,* **307,** L49.

McClure, R.D., VandenBerg, D.A., and Bell, R.A. 1987, *Astron. J.,* **93,** 1144.

Peterson, C.J., and King, I.R. 1975, *Astron. J.,* **80,** 427.

Piotto, G.P., Capaccioli, M., Ortolani, S., Rosino, L., Alcaino, G., and Liller, W. 1987, *Astron. J.* **94,** 360.

Piotto, G.P., King, I.R., Capaccioli, M., Ortolani, S., and Djorgovski, S. 1989, preprint.

Pryor, C., Smith, G.H., and McClure, R.D. 1986, *Astron. J.,* **92,** 1358.

Renzini, A., and Fusi Pecci, F. 1988, *Ann. Rev. Astr. Ap.,* **26,** in press.

Richer, H.B., Fahlman, G.G., and VandenBerg, D.A. 1988, *Astrophys. J.,* **329,** 187.

Scalo, J.M. 1986, *Fundamental of Cosmic Physics,* **11,** 1.

Smith, G.H., and McClure, R.D. 1986, *Astrophys. J.,* **316,** 206.

Spitzer, L. 1987, *Dynamical evolution of globular clusters,* Princeton University Press.

VandenBerg, D.A., and Bell, R.A. 1985, *Astrophys. J. Suppl.,* **58,** 561.

Webbink, R.F. 1985, in *Dynamics of Start Clusters,* IAU Symposium No. 113, ed. J. Goodman and P. Hut (Dordrecht: Reidel), p. 541.

Molecular Hydrogen Emission from Star-forming Regions in the Large Magellanic Cloud

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1. Introduction

Molecular hydrogen is probably the most abundant molecule of the interstellar medium. Giant molecular clouds consist mainly of H_2. There are limited possibilities for direct observations of the H_2 molecule.

Within the ground electronic state, all rotation-vibration transitions are forbidden for electric and magnetic dipole transitions. The electronic transitions in the Lyman and Werner bands of the H_2, which occur in the UV range of the spectrum, can be observed in absorption against the continuum spectrum of bright stars. Due to the strong interstellar extinction in the ultraviolet, such observations are limited to nearby, low-density interstellar clouds. In giant molecular clouds the extinction prevents such observations. The excitation of the electric quadrupol transitions in the near infrared around 2 μm requires high excitation temperatures ($\geq$ 1000 K). Such high excitation temperatures can be obtained by collisional excitation in regions behind shock fronts (Shull and Beckwith, 1982) or intense ultraviolet radiation from bright massive stars (Black and van Dishoeck, 1987).

The first detections of near-infrared H_2 quadrupol emission from star-forming regions in the Magellanic Clouds were reported from Koornneef and Israel (1985) and Israel and Koornneef (1987).

Compared to spiral galaxies, the Magellanic Clouds have, like other irregular galaxies, a lower metallicity, a low dust content and very weak CO line emission. Direct observations of the H_2 molecule can help to clarify whether these characteristics imply a considerable underabundance of H_2 or not.

2. Observations and Reduction

At the beginning of January 1988, we used the cooled infrared grating spectrometer IRSPEC (cf. Moorwood et al. 1986) attached to the ESO 3.6 m telescope to search for H_2 emission from star-forming regions in the Large Magellanic Cloud. The entrance aperture was 6″ × 6″ and the spectral resolution about 2000. For the flux calibration, flat fielding and cancellation of atmospheric absorption, the object spectra were divided by the spectrum of a standard star that has been observed at a similar air mass with the same instrument settings. The sky background was cancelled by chopping 60″ in declination. The total on-source integration times were 30 to 40 minutes.

The observed H_2 spectra were calibrated with the spectrum of the standard star HR 2015. The infrared magnitudes for this star and the absolute flux densities for zero magnitude are given by Koornneef (1983a, b). The flux density distribution of HR 2015 in the photometric K-band window (1.9–2.5 μm) is given by

$$F\lambda\ (\mathrm{W\ cm^{-2}\ \mu m^{-1}}) = 8.43\ 10^{-16}\ \lambda^{-3.75} \qquad (1)$$

We observed two compact infrared sources of non-stellar nature within the H II regions N160A and N10, found by Jones et al. (1986). N160A is located in a molecular cloud (see Figs. 3 and 4) that itself belongs to an extremely large complex of molecular clouds extending south from 30 Doradus for over 2000 pc (Cohen et al., 1987). N10 is also embedded in a molecular cloud complex (see Fig. 5). The CO observations have been carried out later than the H_2 observations. The beam size was 43″. We find

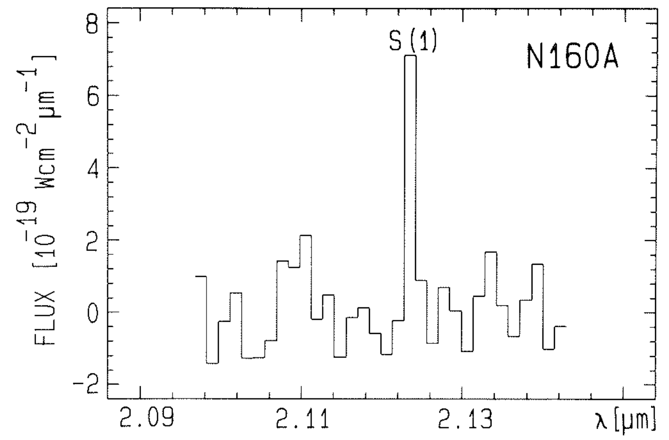

Figure 1: *IRSPEC spectrum of N160A in the wavelength range 2.10 μm to 2.14 μm, with the S(1) line at 2.12 μm.*

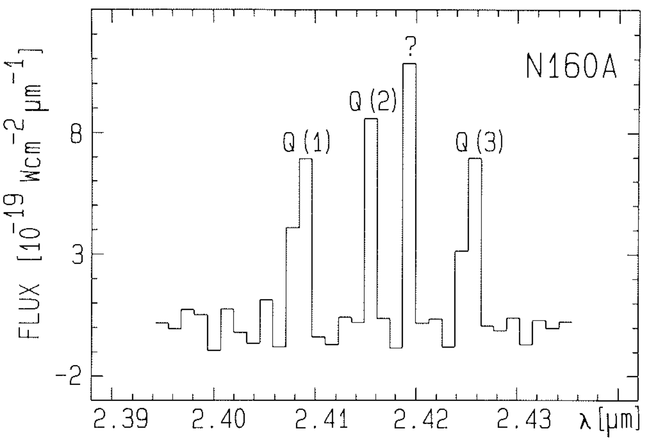

Figure 2: *IRSPEC spectrum of N160A in the wavelength range 2.395 μm to 2.435 μm, with the Q-branch lines and one unidentified line.*

that the observed infrared sources do not coincide with the positions of the strongest CO emission. A more extensive discussion of the CO observations will be given elsewhere.

H_2 emission was detected only from the infrared source in N160A in four quadrupol vibrational-rotational transitions (see Figs. 1 and 2).

The observed transitions occur within the electronic ground state of the H_2 molecule from the first excited vibrational level (v = 1) into the vibrational ground level (v = 0). v is the vibrational quantum number. The vibrational levels themselves split into a number of rotational levels. S-branch lines refer to transitions with $\Delta J = 2$ and the Q-branch lines to $\Delta J = 0$. J is the rotational quantum number.

For the determination of the interstellar extinction, one preferentially compares two lines which arise from the *same* upper state like the S(1) and Q(3) lines in our spectra. A comparison of the observed line ratio to the theoretical one, i.e. Q(3)/S(1) = 0.7, yields the differential extinction between the two wavelength $\lambda = 2.12\ \mu m$ and $\lambda = 2.42\ \mu m$. The accuracy of this method strongly depends on a proper cancellation of telluric absorption near the Q(3) line. So some preference may be given to other methods of extinction analysis (see e.g. Israel and Koornneef, 1987).

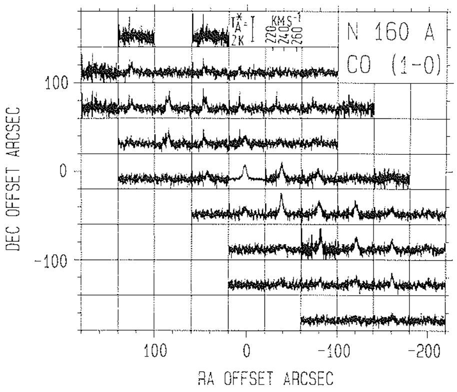

Figure 3: *CO spectra of the J = 1-0 transition of the giant molecular cloud complex associated with N160A, obtained with the 15 m SEST at La Silla. The reference position is α = 05ʰ 40ᵐ 11.6ˢ, δ = −60° 40′ 06″ (1950.0). At this position the H_2 spectra were obtained.*

3. Discussion

The observed quadrupol lines are optically thin. The intrinsic intensity of an optically thin transition is given by

$$I = Ah\nu N\,(v, J)/4\pi\ [\mathrm{W\ cm^{-2} sr^{-1}}] \qquad (2)$$

where A is the Einstein A coefficient, i.e. the spontaneous transition probability, h ν is the photon energy and N (v, J) the molecular level population.

In the thermodynamic equilibrium the level populations are given by a Boltzmann distribution at the temperature T:

$$N(v, J) = N_{H_2} \frac{g(v_J)}{Q(T)} \exp\left(-E(v_J)/kT\right)\ [\mathrm{cm^{-2}}] \qquad (3)$$

where N_{H_2} is the total H_2 column density, $g(v_J)$ is the statistical weight of the level v_J, Q(T) is the partition function, and $E(v_J)$ is the energy of the level v_J.

These two equations can be used to determine the excitation temperature T and the total H_2 column density N_{H_2}. From the Q(1) and Q(3) lines we determine an excitation temperature of 1688 K. The value of the partition function for this temperature is 42.8 and we obtain a total H_2 column density of $N_{H_2} = 8.9\ 10^{17}\ \mathrm{cm^{-2}}$. Adopting a distance of 53 kpc for the LMC and assuming that the observed source is spherical and exactly fills the beam, the volume density is about $0.2\ \mathrm{cm^{-3}}$. This very low value indicates that the source is probably unresolved and that the value for N_{H_2} is a lower limit.

Because it is so difficult to observe the H_2 molecule directly, the H_2 mass within giant molecular clouds is generally estimated from observations of tracer molecules like CO. The first CO rotational transition J = 1-0 at λ = 2.6 mm is easily excited by collisions with H_2 also at low kinetic gas temperatures. A conversion between the H_2 column density N_{H_2} and the integrated brightness temperature of the ^{12}CO J = 1-0 line of the form N_{H_2}/I_{CO} = const is frequently used. The value of the conversion factor depends on the conditions within the molecular clouds, like the kinetic gas temperature, carbon and oxygen abundance, etc. (Maloney and Black, 1988). It is currently one of the major problems to estimate what values have to be used, especially for low metallicity extragalactic systems like the Magellanic Clouds.

Adopting the conversion factor $N_{H_2}/I_{CO} = 1.7\ 10^{21}\ [\mathrm{K\ km\ s^{-1}\ cm\ ^{2}}]^{-1}$ as suggested for the LMC by Cohen et al., we derive from our CO observations an H_2 column density of $1.5\ 10^{22}\ \mathrm{cm^{-2}}$ towards the position of the compact in-

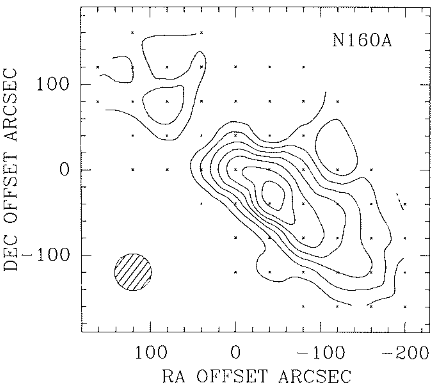

Figure 4: *A J = 1-0 CO contour map of the data shown in Figure 3. The reference position is the same as in Figure 3. Contour levels are 2.5, 4, 5.5 . . . 11.5 K km s^{-1}, integrated over a velocity range of 210 to 255 km s^{-1}. The beam size is indicated in the lower left.*

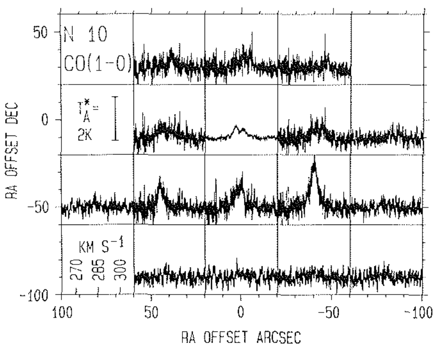

Figure 5: *J = 1-0 CO spectra of the molecular cloud complex associated with N10 measured with the SEST. The reference position is $\alpha = 04^h 56^m 46^s$, $\delta = -66° 28' 20''$ (1950.0).*

frared source in N160A. The reason for the difference to the infrared N_{H_2} value is that in the CO measurements we indirectly observe the much larger amount of cold H_2 gas along the line of sight, while the near infrared H_2 lines yield information only about the very small amount of hot H_2 gas. We also have to consider that the radio beam is much larger than the infrared beam and that the H_2 line emission source is probably unresolved. A comparison of the intensity ratios of the observed lines with those resulting from model calculations for shock excitation (Shull and Hollenbach, 1978) and for radiative excitation (Black and van Dishoeck, 1987) shows that the energy levels may be partly populated from ultraviolet pumping. The strong Q(2) line could result either from a lower ratio of the ortho to para-hydrogen than 3 or from non-thermal equilibrium. In the latter case the gas density would be less than 10^5 cm^{-3}.

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References

Black, J.H., van Dishoeck, E.F.: 1987, *Astrophys. J.* **20,** 163.
Cohen, R.S., Dame, T.M., Garay, G., Montani, J., Rubio, M., Thaddeus, P.: 1987, *Astrophys. J.* **331,** L95.
Israel, F.P., Koornneef, J.: 1987, *Astron. Astrophys.* **190,** 21.
Jones, T.J., Hyland, A.R., Straw, S., Harvey, P.M., Wilking, B.A., Joy, M., Gatley, I., Thomas, J.A.: 1986, *Monthly Notices Roy. Astron. Soc.* **719,** 603.
Koornneef, J.: 1983a, *Astron. Astrophys. Suppl.* **51,** 489.
Koornneef, J.: 1983b, *Astron. Astrophys.* **128,** 84.
Koornneef, J., Israel, F.P.: 1985, *Astrophys. J.* **291,** 156.
Maloney, P.R., Black, J.H.: 1988, *Astrophys. J.* **325,** 389.
Moorwood, A., Biereichel, P., Finger, G., Lizon, J.L., Meyer, M., Nees, W., Paurean, J.: 1986, *The Messenger* **44,** 19.
Shull, J.M., Beckwith, S.: 1982, *Ann. Rev. Astron. Astrophys.* **20,** 163.
Shull, J.M., Hollenbach, D.J.: 1978, *Astrophys. J.* **220,** 525.

Search for HCOCN in Interstellar Space

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1. Interstellar Molecules

More than 80 different molecular species have been observed in the interstellar medium (ISM) in one or more molecular sources (cf. the review of Irvine et al., 1987). Most of them were discovered and identified via their centimetre and millimetre lines. However, to get a better understanding of the complex chemical processes at work in interstellar clouds, we need to observe many more species. On the one hand, only a few among all species involved in the reaction networks are observed: most of the reactions are exothermic and involve radicals and/or molecular ions. These species have low abundances and complex spectra, and are therefore very difficult to detect, but their observation would provide important constraints on the chemical models. On the other hand, there are often competitive ways to synthesize complex molecules, with poorly known reaction rates. Observations of these elaborated species could provide constraints on the reaction rates, synthesis modes, and give an insight into the degree of complexity that this kind of chemical system can reach (how many heavy atoms, and what structure can we observe/are present in complex molecules?). This research topic was initiated by the search of Glycine and Urea after several organic molecules were found in the ISM in the mid 1970's (Hollis et al., 1980; Guelin 1989).

When searching for new interstellar species, several approaches are possible: systematic frequency surveys of a given molecular source provide a good picture of this source, and some non-identified lines! These lines are due both to new molecular species and to high excitation lines of already known species. The mulecular source near Orion IRc2 is very hot, and vibrationally excited molecules like CH_3OH radiate a lot of lines in the millimetre and submillimetre domain. (Methyl formate $HCOOCH_3$ has about 1 line per GHz from 80 to 300 GHz!). The main problem of this kind of work is to achieve a good and uniform sensitivity in a complete frequency range (>20 GHz).

Another method is to concentrate on a few interesting species and obtain long integration times for a few lines on well-known molecular sources. For both methods, the knowledge of the line frequencies with an accuracy better than 100 kHz ($\Delta v/v < 10^{-6}$) is crucial to get a secure identification; there are so many lines at a noise level of 10 mK that the probability of a random coincidence is quite large. Spectroscopic work in the laboratory is therefore required before each new identification can be made, even though the lines were first detected in the ISM. This is particularly difficult for radicals and molecular ions which are very unstable and difficult to produce in sufficient quantities to complete spectroscopic measurements.

For this observing run, we had scheduled the observations of several lines of two new species: HCOCN and CH_2D^+. The first one was studied by J.L. Destombes and his colleagues at the "Laboratoire de Spectroscopie Hertzienne" of the Lille University. We have a long-term collaboration with them, which has already succeeded in observing new species in the ISM, such as CCD (Combes et al., 1985), C_3HD (Gerin et al., 1987), Acetone (Combes et al., 1987), etc. The other one, CH_2D^+ (is a tracer of the important ion CH_3^+, which is one of the main reactants of the