Astron. Astrophys. 203, L23–L26 (1988)

ASTRONOMY AND ASTROPHYSICS

Letter to the Editor

Detection of CH and CH^+ in a high latitude molecular cloud*

C.P. de Vries[1,2] **and Ewine F. van Dishoeck**[3]

[1] Sterrewacht Leiden, P.O. Box 9513, NL-2300 RA Leiden, The Netherlands
[2] Laboratory for Space Research, P.O. Box 9504, NL-2300 RA Leiden, The Netherlands
[3] Princeton University Observatory, Peyton Hall, Princeton, NJ 08544, USA

Received June 2, accepted June 24, 1988

Summary. Interstellar absorption lines of CH and CH^+ have been detected toward the star HD 210121, which is located behind a previously unknown high latitude cloud. The CH observations and the measured extinction toward the star provide independent measures of the H_2 column density along the line of sight, which are compared with that deduced from CO millimetre observations. The inferred CH^+ column density is comparatively small, suggesting that shocks do not play a dominant role in the chemistry in the cloud.

Key words: interstellar medium: molecules–clouds: HD 210121

1. Introduction

The presence of molecular gas at high galactic latitudes has recently been established by observations of CO line emission at 2.6 millimetre (Blitz, Magnani and Mundy 1984; Magnani, Blitz and Mundy 1985; Mebold *et al.* 1985; Keto and Myers 1986). These molecular clouds also appear as regions of obscuration on photographic plates, and are associated with the "cirrus" emission which is seen at 100μm in the IRAS data (de Vries and Le Poole 1985; de Vries 1986; Weiland *et al.* 1986; de Vries, Heithausen and Thaddeus 1987). They are estimated to lie mostly within 100 150 pc of the Sun (Blitz *et al.* 1984; Magnani and de Vries 1986), and appear to be condensing out of loops and filaments of atomic hydrogen (Mebold *et al.* 1985; Blitz 1988).

Although a considerable amount of information is available on the global properties and morphology of the clouds, little is known about the physical and chemical properties of individual clouds. The clouds have low visual extinctions $A_V \approx 1$ 2 mag (Magnani and de Vries 1986) comparable to those of the classical diffuse clouds such as the ζ Oph cloud, which have been studied extensively by optical absorption line techniques; yet their high CO abundances are much more characteristic of those found in dense clouds (Magnani *et al.* 1985; Lada and Blitz 1988). Heithausen, Mebold and de Vries (1987) and Magnani, Blitz and Wouterloot (1988) have also recently found large abundances of H_2CO and OH in a number of high latitude clouds, leading Magnani *et al.* to conjecture that shocks may play a significant role in the chemistry.

Important tests of the chemical processes that occur in individual clouds can be obtained from absorption line observations of atoms and molecules. Although almost no bright early-type stars are available as background light sources in these directions, absorption line observations toward less bright, later-type stars have become possible due to recent improvements in the sensitivity of detectors. We have therefore started a program to search for atomic and molecular absorption lines in Southern high latitude clouds, and report here the first detection of absorption lines of CH and CH^+. Measurements of the CH abundance are of special interest because they permit an independent measure of the total H_2 column density along the line of sight. Searches for the CH^+ ion are important because its abundance is thought to be a signature of shock processes occurring in the cloud (Elitzur and Watson 1978; Draine and Katz 1986; Pineau des Forêts *et al.* 1986; Hartquist *et al.* 1989). In addition, observations of Na I absorption lines put constraints on the distance to the cloud, as has recently been demonstrated by Hobbs, Blitz and Magnani (1986) and Hobbs *et al.* (1988).

2. Observations and Results

The absorption line observations were performed with the Coudé Echelle Spectrometer fed by the 1.4m Coudé Auxiliary Telescope at the European Southern Observatory in Chile in the period June 26 July 2, 1987. The detector consists of a 1024×640 pixels RCA CCD chip with a pixel size of 15 μm square (Dekker *et al.* 1986). The resolving power $\lambda/\Delta\lambda$ was set at 60,000, corresponding to a resolution of about 70 mÅ ($\approx$ 2 pixels) at the wavelength of the CH and CH^+ lines, or 4.9 km s^{-1} in velocity units. Early type stars with featureless spectra were used as standard stars to correct for the pixel to pixel sensitivity variations. Wavelength calibration was provided by emission lines from a thorium lamp. The spectra were reduced with the European Southern Observatory IHAP image processing system. The spectra of the CH 4300.313 Å, CH^+ 4232.548 Å and the Na I D lines at 5889.95 and 5895.92 Å, were centered at 4300 Å, 4244 Å and 5892 Å respectively. The resulting central wavelengths of the interstellar lines are uncertain by about 30 mÅ, corresponding to about 2 km s^{-1}.

The observations reported here refer to a previously unnamed high latitude cloud, which was identified on the basis of IRAS 100 μm sky flux maps. It extends over an area of about $10^o \times 5^o$, centered at $\ell = 56^o$, b=-44^o. After submission of this manuscript, we received a preprint by Désert, Bazell and Boulanger describing an all-sky search for molecular cirrus clouds. Our cloud can be identified with their cloud nr. 80

* Based on observations made at the European Southern Observatory, La Silla, Chile

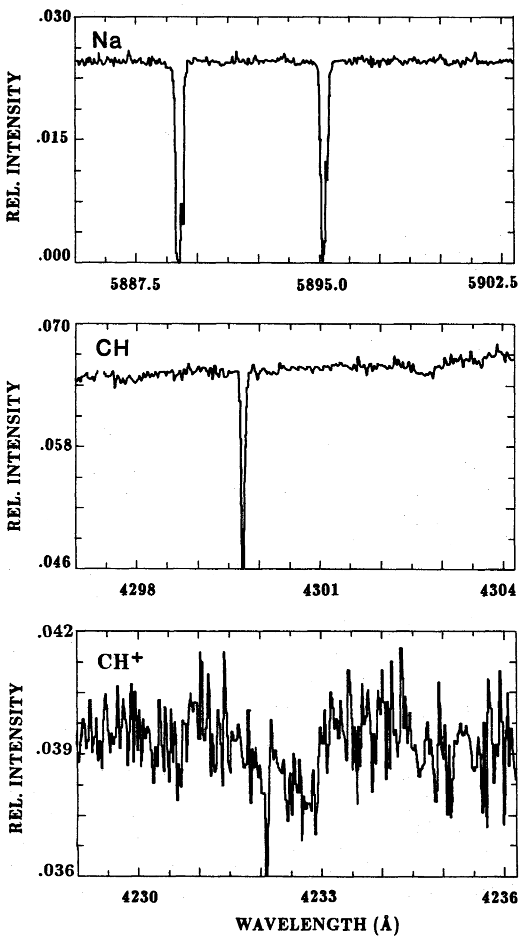

Fig. 1. *Spectra obtained toward HD 210121 in the wavelength region of the Na I (top), CH (middle) and CH^+ (bottom) lines. The abscissa indicates wavelength with respect to a laboratory frame. The broad depression at 4233 Å near the interstellar CH^+ line is a stellar Fe II line.*

Background stars were selected by comparison with the catalogue of stellar identifications (CSI). In addition to a number of fainter A and F-type stars, a bright B star with V=7.5 (HD 210121: $\alpha(1950)=22^h\ 05^m\ 36^s$, $\delta(1950)$=-3° 46′ 36″; ℓ=56°.9, b=-44°.5) was found to lie behind the thickest portion of the cloud. VBLUW photometric observations of the star (Lub 1979) were performed using the Dutch 90 cm telescope at the European Southern Observatory, and suggest that the star is of spectral type B5–6 V with a color excess $E(B-V)\approx$0.32 mag. If the conventional value for the ratio of total to selective extinction, $A_V/E(B-V)$=3.1, is adopted, $A_V\approx$ 1 mag is obtained. The estimated photometric distance to the zero-age main sequence star is (210±30) pc, which is an upper limit to the distance of the cloud.

The IRAS 100 μm map shows an excess flux of about 10 MJy sr^{-1} at the position of the star with respect to the background (which consists in part of the zodiacal light). Application of the relation between 100 μm flux and extinction found by de Vries and Le Poole (1985) results in an extinction $A_V\approx$1.1 mag, in harmony with the photometric estimate.

The spectra obtained toward HD 210121 in the wavelength regions of the Na I, CH and CH^+ lines are presented in Figure 1, and measured equivalent widths W_λ are summarized in Table 1. The observed lines are narrow and are clearly of interstellar origin. The Na I D lines at 5889 and 5895 Å are very strong and show a double structure. A decomposition of the profiles into two components gives a measured Doppler shift for the stronger component of -(36–37) km s^{-1}, and for the weaker component of -27 km s^{-1}. With respect to the local standard of rest, the velocities are v_{LSR} =-4 km s^{-1} and +5 km s^{-1}, respectively. Estimates of the column density of Na I from these saturated lines using the doublet ratio method are highly uncertain (Nachman and Hobbs 1973) and give a lower limit to the total column density of about 8×10^{12} cm^{-2}. The actual column density may be larger by an order of magnitude, and could be determined more accurately through observations of the weaker lines around 3302 Å (Crutcher 1975). On the basis of detailed profile fits, the column density in the stronger component is estimated to be at least an order of magnitude larger than that in the weaker component.

The spectra centered at the CH^+ 4232.5 Å rest wavelength include the line of Ca I at 4226.7 Å. A weak interstellar feature with an equivalent width of (2 ± 1) mÅ is marginally present at the expected velocity of the stronger Na I component. If the detection is real, the inferred column density is N(Ca)≈ 8×10^9 cm^{-2} for any Doppler parameter b >1 km s^{-1}.

The CH $A^2\Delta$–$X^2\Pi$ transition at 4300 Å appears strongly in the spectrum toward HD 210121. The measured equivalent width implies a column density N(CH)=(2.7±0.3) × 10^{13} cm^{-2} in the optically thin limit, if the oscillator strength f_{00} = 5.06 × 10^{-3} (Larsson and Siegbahn 1983*a*) is adopted. Saturation corrections would raise the column density to N(CH)≈ 3.5 × 10^{13} cm^{-2} if the Doppler parameter were as small as b = 1 km s^{-1}. The observed width of the CH line is close to the experimental resolution, suggesting a broadening parameter b < 3 km s^{-1}. Its central velocity v_{LSR}=-7 km s^{-1} is consistent with that of the stronger Na I component within the uncertainties.

In contrast with CH, the CH^+ $A^1\Pi$–$X^1\Sigma^+$ interstellar line at 4232 Å is comparatively weak in the high latitude cloud. The inferred column density is $N(CH^+)\approx 6\times10^{12}$ cm^{-2} if f_{00} = 5.45×10^{-3} (Larsson and Siegbahn 1983*b*) is used. The velocity of the CH^+ line differs at most a few km s^{-1} from that of the CH line.

CO J = 1 → 0 millimetre emission at 2.6 mm has been observed in the direction of HD 210121 by Knapp *et al.* (1988) using the Bell Labs 7 m telescope. The integrated antenna temperature is $T_A^*\Delta V$=(3.2±0.2) K km s^{-1} with a width $\Delta V\approx$1.5 km s^{-1}, corresponding to $b\approx$ 0.9 km s^{-1}. The inferred CO column density is N(CO)≈ (0.5 – 1.5) × 10^{16} cm^{-2}, based on statistical equilibrium calculations for a range of physical conditions. The CO line is centered at v_{LSR} =-6.3 km s^{-1}, consistent with the velocity found for the CH line.

Table 1. Summary of measurements toward HD 210121

Species	v_{LSR} (km s^{-1})	W_λ (mÅ)	N (cm^{-2})
Na I	-4, +5	342±4	>8(12)
	-4, +5	288±3	
Ca I	-5	2±1:	(8.0±4.0)(9):
CH	-7	22±2	(3.5±0.5)(13)
CH^+	-4	5±2	(6.0±2.0)(12)
CO	-6		(1.0±0.5)(16)[a]

[a] *Knapp et al. (1988); the notation $a(b)$ indicates $a\times10^b$.*

3. Discussion

The CH observations permit an independent determination of the column density of H_2 along the line of sight toward HD 210121. The molecular hydrogen content of high latitude clouds has been the subject of considerable discussion. Initial estimates of H_2 column densities were made from the measured integrated CO millimetre line intensities I_{CO} using a conversion factor $\alpha = N(H_2)/I_{CO} = 2.5 \times 10^{20}$ cm^{-2} (K km s^{-1})$^{-1}$ that has been calibrated from Giant Molecular Clouds in the inner Galaxy (Bloemen *et al.* 1986). It is not clear *a priori* that this conversion factor also applies to the high latitude clouds (van Dishoeck and Black 1987). Attempts to determine the conversion factor specifically for high latitude clouds have resulted in a wide range of values: de Vries *et al.* (1987) suggest $\alpha \approx 5 \times 10^{19}$ cm^{-2} (K km s^{-1})$^{-1}$, whereas Magnani *et al.* (1988) find a range $\alpha = (1\text{–}6) \times 10^{20}$ cm^{-2} (K km s^{-1})$^{-1}$ centered at $\alpha = 3.2 \times 10^{20}$ cm^{-2} (K km s^{-1})$^{-1}$. If the Bloemen *et al.* (1986) conversion factor is applied to the CO emission measured by Knapp *et al.* (1988) toward HD 210121, $N(H_2) \approx 8 \times 10^{20}$ cm^{-2} is found. A similar result, $N(H_2) \approx 1 \times 10^{21}$ cm^{-2} is obtained with the average value suggested by Magnani *et al.* (1988), whereas the conversion factor of de Vries *et al.* (1987) gives a much lower column density, $N(H_2) \approx 2 \times 10^{20}$ cm^{-2}.

The CH observations may discriminate between these different results. Extensive absorption line observations of diffuse clouds by Danks, Federman and Lambert (1984) show a linear correlation between the CH and H_2 abundances, which is well understood by gas-phase chemistry models. Application of their relationship gives $N(H_2) \approx 1.1 \times 10^{21}$ cm^{-2} for the HD 210121 cloud. If the relation derived by Mattila (1986; 1988) for darker clouds is used, $N(H_2) \approx 9.6 \times 10^{20}$ cm^{-2}, consistent with the value found using the Danks *et al.* relation. However, both sets of observations show a scatter in CH column density of about a factor of two around the average relation. Also, they refer to clouds that are in a different environment than the high latitude clouds, although it appears that the empirical results for diffuse clouds, dark clouds, and lines of sight toward globular clusters are very similar. On theoretical grounds, the CH/H_2 ratio is expected to depend on the physical conditions in the cloud. In particular, the CH/H_2 ratio is predicted to be lower in regions with a higher than average radiation field, a lower gas-phase carbon abundance and/or a lower density. Since the radiation field incident on high latitude clouds is probably lower than average (see below), the empirical relations may slightly overestimate the amount of H_2 in the clouds. In spite of these uncertainties, the H_2 column densities inferred from the CH measurements are most consistent with those obtained from the CO observations if the larger H_2/CO conversion factors are used.

A third estimate of the H_2 column density is obtained from the measured extinction toward the star, using the relation between total column density $N_H = N(\text{H}) + 2N(H_2)$ and visual extinction A_V determined for diffuse clouds by Savage *et al.* (1977). If the extinction were normal in the direction of HD 210121 with $A_V/E(B-V) = 3.1$, $N_H \approx 1.6 \times 10^{21}$ cm^{-2} is obtained. A very rough estimate of the atomic hydrogen column density can be obtained from the H I 21 cm survey of Heiles and Habing (1974), which shows a peak antenna temperature of about 25 K at the position and velocity of the cloud. The inferred column density in the 36′ beam for a linewidth $\Delta V = 2\text{–}10$ km s^{-1} is $(1\text{–}5) \times 10^{20}$ cm^{-2}. For comparison, the measured H column density in the direction of the relatively nearby star π Aqr (HD 212571) is about $(4\text{–}5) \times 10^{20}$ cm^{-2} (Lockman *et al.* 1986). Thus the atomic hydrogen column density contribution is likely to be small, and $N(H_2) \approx (6-8) \times 10^{20}$ cm^{-2} is found.

The effect of a possibly abnormal extinction curve on the inferred column density is difficult to assess, but it is unlikely to be larger than 50%. It is concluded that the best estimate of the H_2 column density toward HD 210121 based on the various methods is $N(H_2) \approx (8 \pm 2) \times 10^{20}$ cm^{-2}.

Table 2 compares the inferred molecular column densities in the high latitude cloud toward HD 210121 with those measured for the classical diffuse clouds toward ζ Oph and ζ Per. In addition, the observed abundances for the translucent molecular clouds toward HD 169454 (Jannuzi *et al.* 1988) and HD 147889 (Crutcher and Chu 1985) are listed. It appears that both the CH absorption line and the CO millimetre emission line are somewhat stronger toward the high latitude star compared with ζ Oph and ζ Per, but not as strong as those found toward the more reddened stars HD 169454 and HD 147889. The result that CH is not highly overabundant in the HD 210121 cloud is consistent with the fact that Hobbs *et al.* (1988) did not detect CH toward stars behind the high latitude clouds MBM 12 and 16. In contrast, the CH^+ abundance is considerably less in the high latitude cloud compared with the ζ Oph cloud and the translucent clouds, and is comparable to that found in the ζ Per cloud. Although the amount of CH^+ is still more than can be explained on the basis of steady-state chemistry only, it suggests that shock processes are responsible for the production of a smaller fraction of the molecules containing heavy elements in this high latitude cloud than in the classic diffuse and translucent clouds.

The somewhat larger column densities of CH and CO compared with the classical diffuse clouds most likely result from the facts that the total column density of molecular gas is somewhat larger in the direction of HD 210121, and that the high latitude clouds are exposed to less intense ultraviolet radiation than clouds in the galactic plane (van Dishoeck and Black 1988*a*, *b*; Lada and Blitz 1988). Steady-state models of the HD 210121 cloud have been constructed using the techniques described by van Dishoeck and Black (1986, 1988*a*). The results of a model with a density $n_H = 500$ cm^{-3}, temperature $T = 40$ K and a scaling factor $I_{UV} = 0.5$ with respect to the radiation field of Draine (1978), are presented in Table 2. Large column densities of CO and CH are readily obtained in these models. In particular, if the carbon depletion factor δ_C is taken to be similar to that found for diffuse clouds, the models overproduce CH by a factor of about 2. The observed CH abundance thus suggests that carbon may be more depleted from the gas phase in the high latitude cloud. A similar conclusion was reached by van Dishoeck and Black (1988*c*) for translucent clouds, who discuss this result in more detail. The combination of a lower radiation field and a smaller gas-phase carbon abundance could also explain the relatively large OH abundances found by Magnani *et al.* (1988) in high latitude clouds: a lower radiation field destroys OH less rapidly through photodissociation, and also results in less C^+ throughout the cloud, the other principal destroyer of OH. Predicted OH and C_2 column densities for the HD 210121 cloud are included in the table. The computed atomic hydrogen column density is $N(\text{H}) < 10^{20}$ cm^{-2}, somewhat below the (uncertain) estimate from the 21 cm emission line. However, if the cloud has not yet reached full chemical equilibrium and if it is formed from mostly atomic gas, the steady state models would underestimate the amount of atomic hydrogen (Wagenblast and Hartquist 1988).

Table 2. Comparison of the HD 210121 cloud with other clouds[a]

Species	HD 210121	ς Oph[b]	ς Per[b]	HD 169454[c]	HD 147889[d]	Model[e]
H_2	(0.6–1.0)(21)	4.2(20)	4.8(20)	(1–2)(21)	>2(21)	8.0(20)
H	(1–5)(20)	5.2(20)	6.5(20)	≥9(19)	...	6.8(19)
CH	3.5(13)	2.5(13)	2.0(13)	4.6(13)	8.0(13)	4.1(13)
CH^+	6.0(12)	2.9(13)	3.5(12)	...	3.0(13)	...
CO	(0.5–1.5)(16)	2.0(15)	7.0(14)	(1–9)(16)	>1(16)	7.4(15)
OH	...	4.8(13)	4.2(13)	...	...	2.0(14)
C_2	...	2.4(13)	1.9(13)	7.0(13)	1.2(14)	5.4(13)
A_V (mag)	1.0	0.9	1.0	3.5	~4	1.0

[a] *The table lists the column densities in* cm^{-2}. [b] *Observed values taken from van Dishoeck and Black (1986).* [c] *Jannuzi et al. (1988).* [d] *Crutcher and Chu (1985).* [e] *Model for the HD 210121 cloud with* n_H*=500* cm^{-3}, T*=40 K,* I_{UV} *=0.5, and a carbon depletion factor* δ_C*=0.1 with respect to the solar abundance of* 4.7×10^{-4}.

4. Conclusions

The observed abundances of CH and CH^+ toward HD 210121 suggest that the chemistries of these species in the high latitude cloud do not differ significantly from those occurring in classical diffuse or translucent clouds. In particular, the measured moderate amount of CH^+ does not support the suggestion that shock processes are mostly responsible for the high abundances found for some other molecules in high latitude clouds. Differences in molecular abundances in high latitude clouds compared with classical diffuse clouds most likely result from a reduced intensity of the ultraviolet radiation field, from slightly larger total H_2 column densities, and possibly from different gas phase elemental abundances. More extensive absorption line observations of CH, CH^+, CN and Na I toward other high latitude stars, which lead to similar conclusions, will be presented in a subsequent paper.

Acknowledgments. The authors are grateful to G.R. Knapp for obtaining CO millimetre observations toward the high latitude star, to D. Hartmann for performing the photometric observations and to E.J. de Geus for help with the photometric reduction. They are indebted to L. Blitz for communicating his absorption line data before publication, and thank J.H. Black and the referee, T.W. Hartquist, for useful comments. This work was supported in part by NSF grant RII 86-20342 to Princeton University.

References

Blitz, L. 1988, in "Structure of Galaxies", Proc. 10[th] European Regional Meeting of the IAU, ed. J. Palous (Czech Academy of Sciences, Prague), p. 204.

Blitz, L., Magnani, L., and Mundy, L. 1984, *Astrophys. J. (Letters)*, **282**, L9.

Bloemen, J.B.G.M. *et al.* 1986, *Astron. Astrophys.*, **154**, 25.

Crutcher, R.M. 1975, *Astrophys. J.*, **202**, 634.

Crutcher, R.M. and Chu, Y.-H. 1985, *Astrophys. J.*, **290**, 251.

Danks, A.C., Federman, S.R. and Lambert, D.L. 1984, *Astron. Astrophys.*, **130**, 62.

Dekker, H., Delabre, B., D'Odorico, S., Lindgren, H., Maaswinkel, F., and Reiss, R. 1986, *The Messenger*, **43**, 27.

Désert, F.X., Bazell, D., and Boulanger, F. 1988, preprint.

de Vries, C.P. 1986, Ph. D. Thesis, University of Leiden.

de Vries, C.P. and Le Poole, R. 1985, *Astron. Astrophys.*, **145**, L7.

de Vries, H.W., Heithausen, A., and Thaddeus, P. 1987, *Astrophys. J.*, **319**, 723.

Draine, B.T. 1978, *Astrophys. J. Suppl.*, **36**, 595.

Draine, B.T. and Katz, N.S. 1986, *Astrophys. J.*, **306**, 655.

Elitzur, M. and Watson, W.D. 1978, *Astrophys. J. (Letters)*, **222**, L141.

Hartquist, T.W., Flower, D.R., and Pineau des Forêts, G. 1989, to appear in *Molecular Astrophysics —A volume honoring Alexander Dalgarno*, ed. T.W. Hartquist (Cambridge University Press).

Heiles, C. and Habing, H.J. 1974, *Astron. Astrophys. Suppl.*, **14**, 1.

Heithausen, A., Mebold, U., and de Vries, H.W. 1987, *Astron. Astrophys.*, **179**, 263.

Hobbs, L.M., Blitz, L., and Magnani, L. 1986, *Astrophys. J. (Letters)*, **306**, L109.

Hobbs, L.M., Blitz, L., Penprase, B., Magnani, L., and Welty, D. 1988, *Astrophys. J.*, **327**, 356.

Jannuzi, B.T., Black, J.H., Lada, C.J., and van Dishoeck, E.F. 1988, *Astrophys. J.*, in press.

Keto, E.R. and Myers, P.C. 1986, *Astrophys. J.*, **304**, 466.

Knapp, G.R. *et al.* 1988, in preparation.

Lada, E.A. and Blitz, L. 1988, *Astrophys. J. (Letters)*, **326**, L69.

Larsson, M. and Siegbahn, P.E.M. 1983*a*, *Chem. Phys.*, **79**, 2270.

Larsson, M. and Siegbahn, P.E.M. 1983*b*, *Chem. Phys.*, **76**, 175.

Lockman, F.J., Hobbs, L.M., and Shull, J.M. 1986, *Astrophys. J.*, **301**, 380.

Lub, J. 1979, *The Messenger*, **19**, 1.

Magnani, L., Blitz, L., and Mundy, L. 1985, *Astrophys. J.*, **295**, 402.

Magnani, L., Blitz, L., and Wouterloot, J.G.A. 1988, *Astrophys. J.*, **326**, 909.

Magnani, L. and de Vries, C.P. 1986, *Astron. Astrophys.*, **168**, 271.

Mattila, K. 1986, *Astron. Astrophys.*, **160**, 157.

Mattila, K. 1988, *Astron. Astrophys.*, in press.

Mebold, U., Cernicharo, J., Velden, L., Reif, K., Crezelius, C., and Goerigk, W. 1985, *Astron. Astrophys.*, **151**, 427.

Nachman, P. and Hobbs, L.M. 1973, *Astrophys. J.*, **182**, 481.

Pineau des Forêts, G., Flower, D.R., Hartquist, T.W., and Dalgarno, A. 1986, *Mon. Not. R. Astron. Soc.*, **220**, 801.

Savage, B.D., Bohlin, R.C., Drake, J.F., and Budich, W. 1977, *Astrophys. J.*, **216**, 291.

van Dishoeck, E.F. and Black, J.H. 1986, *Astrophys. J. Suppl.*, **62**, 109.

van Dishoeck, E.F. and Black, J.H. 1987, in *Physical Processes in Interstellar Clouds*, eds. G. Morfill and M.S. Scholer (Reidel, Dordrecht). p. 241.

van Dishoeck, E.F. and Black, J.H. 1988*a*, *Astrophys. J.*, in press.

van Dishoeck, E.F. and Black, J.H. 1988*b*, in *Rate Coefficients in Astrochemistry*, eds. T.J. Millar and D.A. Williams (Kluwer, Dordrecht), in press.

van Dishoeck, E.F. and Black, J.H. 1988*c*, *Astrophys. J.*, submitted.

Wagenblast, R. and Hartquist, T.W. 1988, *Mon. Not. R. Astron. Soc.*, **230**, 363.

Weiland, J.L., Blitz, L., Dwek, E., Hauser, M.G., Magnani, L., and Rickard, L.J 1986, *Astrophys. J. (Letters)*, **306**, L101.