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Detection of CH 3.3 GHz emission from the intermediate-velocity cloud G90+39(Draco)

Ronald Stark[1], **Peter Kalberla**[2], **and Rolf Güsten**[1]

[1] Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, D-53121 Bonn, Germany
[2] Radioastronomisches Institut der Universität Bonn, Auf dem Hügel 71, D-53121 Bonn, Germany

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Abstract. We report the detection of the CH $^2\Pi_{1/2}$, $J = 1/2$ ground-state hyperfine transitions at 3.3 GHz in the intermediate-velocity cloud G90+39(Draco). The lines were measured with the Effelsberg 100m radio telescope and their main-line strength varies between $T_{\rm MB} \simeq 0.04 - 0.06$ K. The emission is found to be optically thin and the derived CH column density ranges between $(1 - 4) \times 10^{13}$ cm^{-2}. The CH column density as well as the derived dust-to-gas ratio indicate that the Draco cloud resembles the translucent high-latitude clouds at local velocities. The measurements are used to calculate the molecular hydrogen column density using the theoretically determined linear relation between N(CH) and $N(H_2)$. We find $N(H_2) \simeq 4 \times 10^{20} - 1 \times 10^{21}$ cm^{-2}. These values are about a factor five higher than the ones found via the empirical CO/H_2 conversion ratio of Herbstmeier et al. (1993).

Key words: ISM: abundances – molecules – ISM: Draco cloud= G 90+39 – radio lines: ISM

1. Introduction

Galactic high-latitude clouds belong to the class of diffuse ($A_V \lesssim 1$ mag) and translucent ($A_V \simeq 1 - 5$ mag) clouds where the $C^+ \rightarrow C \rightarrow CO$ conversion takes place. Much of the carbon in such clouds can still be in atomic form (Stark & van Dishoeck 1994) and the CO abundance is very sensitive to small variations of physical parameters like total hydrogen density and column density, and radiation field (e.g. van Dishoeck & Black 1988). Therefore, structure in the observed CO emission cannot be interpreted easily (Gredel et al. 1992; Stark 1995). A direct consequence is that for diffuse and translucent clouds the relation between the CO emission and the H_2 column density is a complex function which can certainly not be approximated by the often used empirically determined conversion factor. In a recent study Meyerdierks & Heithausen (1996) compared the H I, CO, and FIR emission of two high-latitude clouds. They find a diffuse H_2 component which is not traced by CO emission. Instead, the CH radical seems a better indicator for the amount of molecular hydrogen inside clouds because a linear relation between the CH and H_2 abundance has been established on theoretical grounds for diffuse clouds (Danks et al. 1984); Mattila (1986, 1989) showed that this relation is also valid over the translucent cloud range. Magnani and Onello (1995) used this linear relation to calibrate the CO/H_2 conversion in a sample of high galactic latitude clouds in the local solar neighbourhood. Indeed, they find a large variation in this conversion factor as expected from CO chemistry.

A distinct class of high-latitude clouds is formed by the so-called intermediate-velocity clouds (IVCs). Their radial velocities, -20 km s^{-1} $< V_{\rm LSR} <$ -90 km s^{-1}, are too high to be explained by differential galactic rotation- all velocities in this paper are with respect to the local standard of rest, LSR. Their origin is unclear, but they may represent infalling clouds from the halo or gas that has been swept up by a supernova. Whatever their nature, it is clear that they induce shocks when moving through the interstellar medium. To date only three high-latitude molecular clouds are known at intermediate velocities. These clouds have been detected in the low-level rotational CO lines (Mebold et al. 1985; Heiles et al. 1988; Désert et al. 1990). Their H_2 column densities have been derived via CO emission and are highly uncertain not only because the clouds are diffuse/translucent but also since the CO abundance may be altered through shock chemistry (e.g. Herbstmeier et al. 1993). In this paper we report a successful search for the CH ground-state hyperfine lines at 3.3 GHz in the IVC G90+39 (Draco) which provides an independent method to determine the H_2 column density in this class of anomalous high-latitude clouds. A comparison with CH measurements of high-latitude clouds at local velocities will be interesting since the CH abundance as well as the dust-to-gas ratio may differ significantly.

2. Observations and results

The CH $^2\Pi_{1/2}, J = 1/2$ ground state hyperfine lines around 3.3 GHz were observed with the Effelsberg 100m radio telescope in January 1996. The beamsize at this frequency is 4 arcmin full-width at half-maximum and the main beam and aperture

Table 1. Observations of the CH $^2\Pi_{1/2}$, $J = 1/2$ lines in G90+39 together with the inferred column densities

l (°)	b (°)	species	V_{LSR} (km s^{-1})	T_{MB} (K)	ΔV (km s^{-1})	$\int T_{MB} dV$ (K km s^{-1})	N^a (cm^{-2})	$N(H_2)$ (cm^{-2})
89.5333	+38.4000	CH $F = 0-1$	-23.1 ± 0.3	0.030 ± 0.003	2.1 ± 0.3	0.07 ± 0.02		
		$F = 1-1$	-23.6 ± 0.1	0.057 ± 0.005	2.1 ± 0.1	0.13 ± 0.02	$3(13) - 4(13)$	$9(20) - 1(21)$
		$F = 1-0$	-23.7 ± 0.1	0.034 ± 0.004	2.0 ± 0.3	0.07 ± 0.02		
		CO[b] $J = 1-0$	-23.7 ± 0.1	5.5 ± 0.3	2.0	11.7 ± 0.6	$1(16) - 5(17)$[c]	$1(20) - 2(20)$[d]
89.8167	+38.8333	CH $F = 0-1$		< 0.012				
		$F = 1-1$	-24.3 ± 0.1	0.041 ± 0.004	1.5 ± 0.2	0.07 ± 0.02	$1(13) - 2(13)$	$4(20) - 6(20)$
		$F = 1-0$		< 0.014				
		CO[b] $J = 1-0$	-24.2 ± 0.1	3.5 ± 0.3	1.5	5.6 ± 0.5	$5(15) - 7(16)$[c]	$5(19) - 1(20)$[d]

[a] total CH or CO column density (beam-averaged)
[b] from Mebold et al. (1985)
[c] range in column densities for $T_K = 10 - 30$ K and $n_H = 500 - 5000$ cm^{-3}
[d] calculated via the CO $\rightarrow$ H_2 conversion factor of Herbstmeier et al. (1993)

efficiencies are 0.65 and 0.47 respectively (Genzel et al. 1979). The 3.3 GHz receiver was a single channel cooled HEMT amplifier mounted at prime focus with a system temperature of 36 K. The backend consisted of a 1024 channels digital autocorrelation spectrometer which was split in four parts of 781 kHz each in order to observe the $F = 0 - 1$ line at 3263.794 MHz, the $F = 1 - 1$ line at 3335.481 MHz, and the $F = 1 - 0$ line at 3349.193 MHz simultaneously. The $F = 1 - 1$ main line was measured within two parts of the autocorrelator. The spectral resolution was 3 kHz which corresponds to 0.27 km s^{-1} at 3.3 GHz. The observations were carried out in frequency-switching mode with an in-band throw of 0.3 MHz.

Standard pointing and flux density calibration sources (see Baars et al. 1977; Ott et al. 1994) were regularly observed and yield variations in the brightness temperature and pointing both below 5%. We also observed CH emission toward some of the continuum sources observed by Genzel et al. (1979) and found agreement with their line strengths within 5%.

We observed the CH lines at two positions selected from the $^{12}CO(1 - 0)$ maps obtained by Mebold et al. (1985) with the Bordeaux telescope in a 4.4 arcmin beam. These positions are located at peaks of the integrated CO emission. The total integration time per position was 7 hours. The spectra were folded and smoothed to 0.55 km s^{-1} resolution, resulting in T_{MB}(rms) $\simeq 0.006$ K per resolution element. The spectra are presented in Fig. 1, the results of a gaussian analysis are listed in Table 1. For non-detections we list 2σ upper limits, the uncertainties are 1σ errors from the gaussian fits. At both positions the CH main line is clearly detected with $T_{MB} \simeq 0.04 - 0.06$ K. The strength of the $F = 0 - 1$ and $F = 1 - 0$ satellite lines is always lower than the main line and, if detected, at a level of about half the strength of the main-line intensity. It is clearly seen that the CO and CH emission are well correlated in central velocity and velocity width. This suggests a similar distribution of these species.

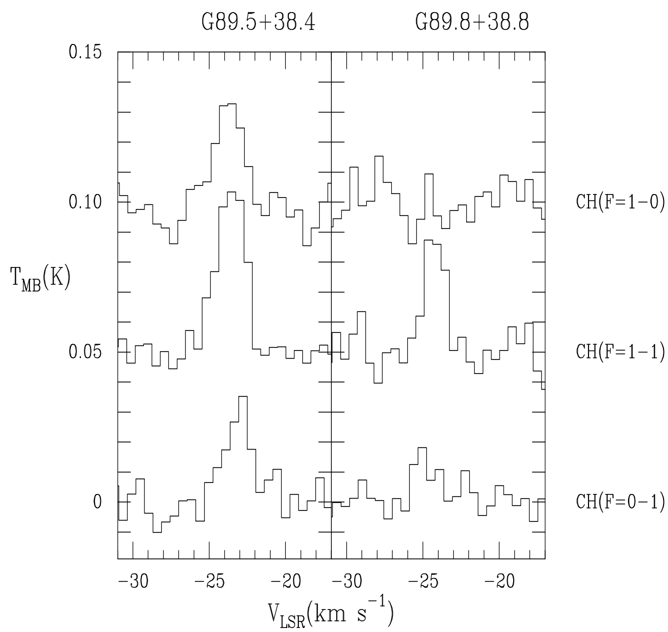

Fig. 1. Observed spectra of the CH(1 − 0), CH(1 − 1), and CH(0 − 1) lines in the intermediate-velocity cloud G90+39

3. Analysis

The simplest carbon-bearing molecule is CH and its formation involves only a few reactions (e.g. see Black & Dalgarno 1977). Observations of the CH radical at 3.3 GHz revealed that it is widespread in the Galaxy and that it often behaves like a weak maser in dark clouds (Rydbeck et al. 1976; Genzel et al. 1979). This can be explained from parity selection rules in the collisional transition rates between the rotational ground state and first excited stage of CH, analogous to OH (e.g. Bertojo et al. 1976; Elitzur 1977). Since the excitation parameters for CH are not well determined, statistical equilibrium calculations including collisional excitation and de-excitation cannot be carried out. For an optically thin CH line which is uniformly filling the beam the total column density can be calculated from the main-line intensity via detailed balancing (e.g. Genzel et al. 1979):

$$N(\mathrm{CH}) = 2.82 \times 10^{14} \frac{T_{\mathrm{ex}}}{T_{\mathrm{ex}} - T_{\mathrm{bg}}} \int T_{\mathrm{MB}}(F = 1-1)\, dV \qquad (1)$$

where T_{ex} is the excitation temperature and $T_{\mathrm{bg}} = 2.7$ K is the brightness temperature of the background continuum radiation. In the optically thin LTE case the line ratio between the main and satellite lines would be equal to their statistical weights, i.e. 1 : 2. This is exactly as observed for G89.5+38.4. The main line toward G89.8+38.8 is weaker and the non-detection of the satellite lines is consistent with optically thin emission, too. In Table 1 we list the calculated CH column densities for the commonly adopted range $T_{\mathrm{ex}} = -60 \pm 30$ K which was derived for the translucent cloud toward 3C123 (Genzel et al. 1979). Note that N(CH) is very sensitive to the excitation temperature for low values of T_{ex}, see Eq. (1). However, the dependence is weak as long as $|T_{\mathrm{ex}}| >> 2.7$ K. If the CH emission were thermalised, i.e. $T_{\mathrm{ex}} = T_{\mathrm{K}} \simeq 10$ K, or as long as $|T_{\mathrm{ex}}| > 10$ K, the CH column densities of Table 1 would be overestimated by at most 20%.

The molecular hydrogen column density can now be calculated from the relation determined by Mattila (1986) for translucent clouds with $A_V \leq 3$ mag

$$N(\mathrm{H_2}) = 2.1 \times 10^{7}\, N(\mathrm{CH}) + 2.2 \times 10^{20}\ \mathrm{cm^{-2}} \qquad (2)$$

This relation is an average over a number of clouds, and for individual clouds the CH / H_2 ratio may be different if the density, carbon depletion and/or radiation field varies (van Dishoeck and Black 1989). However, at high galactic latitudes, away from early-type stars, the general interstellar radiation field is the main source of illumination and chemical models of diffuse and translucent clouds can reproduce Eq. (2) for a depletion factor $\delta_{\mathrm{C}} = 0.1 - 0.15$ (van Dishoeck & Black 1989). The same models predict CH column densities which are only a factor two higher if δ_{C}=0.4. In Table 1 we present the inferred H_2 column densities. These can be compared with the empirically derived H_2 column densities from Herbstmeier et al. (1993) based on an assumed linear correlation with CO. The CO column densities have been estimated using statistical equilibrium calculations for the range $T_{\mathrm{K}} = 10 - 30$ K and $n_{\mathrm{H}} = 500 - 5000\ \mathrm{cm^{-3}}$ to illustrate that a large range in physical parameters matches the observed CO emission.

4. Discussion and conclusions

The estimated CH column densities (see Table 1) are comparable with the values derived by Magnani et al. (1989) for high-latitude clouds at local velocities. This indicates that the CH column density of the class of intermediate-velocity clouds is not altered through shock processing.

In combination with the IRAS FIR emission we find a dust-to-gas ratio $I_{100\ \mu\mathrm{m}}/N_{\mathrm{CH}} \simeq (2.5 \pm 1.5) \times 10^{-13}$ MJy sr^{-1} cm^{-2}. This is in agreement with the observed ratio that we find for the high-latitude cloud L1780, which we calculated from the CH data of Mattila (1986). The extinction can be estimated from the relation $I_{100\ \mu\mathrm{m}}/A_V \simeq 8 - 35$ MJy sr^{-1} mag^{-1} which was found for diffuse molecular clouds at high galactic latitude (Stark 1995). From this relation we derive values between 0.1 and 0.6 mag at both observed CH positions. These extinctions are in line with those of Herbstmeier et al. (1993). The low extinctions indicate that the distance toward the Draco cloud may be less than the estimated lower limit of 800 pc by Goerigk and Mebold (1986), see also Lilienthal et al. (1991), since it was obtained by comparing starcount data to the extinction derived from CO emission ($A_V \simeq 2$ mag).

Thus, the CH column density, the dust-to-gas-ratio, as well as the low A_V indicate that the Draco cloud resembles the translucent high-latitude clouds in the local solar neighbourhood, apart from its velocity. From Table 1 it is clear that the H_2 column densities obtained via the CH main-line emission are about a factor five larger than those of Herbstmeier et al. This difference can be explained from the CO chemistry and/or the presence of diffuse H_2 which is not traced by CO (Sect. 1). Assuming a distance to the Draco cloud of 200 pc, as was determined e.g. for the well studied high-latitude cloud toward HD 210121 (Welty & Fowler 1992), we find for the molecular hydrogen mass in the beam $M(\mathrm{H_2}) \simeq 0.07 - 0.4\ \mathrm{M_\odot}$, and the total gas mass is about a factor 1.5 higher. These values lie two orders of magnitude below the virial mass of a clump which is uniformly filling the beam.

Recently, Magnani and Onello (1995) argued that the CO conversion method for high-latitude clouds can be calibrated by means of observing a few positions per cloud in the CO and CH lines. But even for an individual diffuse/translucent cloud, the CO $\rightarrow$ H_2 conversion remains a complex function which can only locally be calibrated. The CO emission is only a qualitative but not a quantitative tracer of the molecular hydrogen content in a diffuse or translucent cloud and should not be used to derive $N(\mathrm{H_2})$. Instead, mapping the CH emission over a cloud seems to provide better information on the H_2 distribution. Because of the relative weakness of the CH lines, the development of focal plane array receivers at 3.3 GHz would be useful.

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