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A MOLECULAR CLOUD IN THE LOCAL, HOT INTERSTELLAR MEDIUM

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ABSTRACT

Echelle spectra recorded at the D lines of Na I are reported for nine A or F stars. Lying at approximate distances ranging from 25 to 230 pc, the stars are projected on or near the high-latitude molecular cloud MBM 12 at $l = 159°$, $b = -34°$. Among a subgroup of five of these stars separated by no more than 1°2 on the sky, four which are located at distances $d \gtrsim 70$ pc show strong interstellar D line absorption near the radial velocity of the CO emission observed in this general direction. The fifth star, at $d \approx 60$ pc, shows no detectable absorption. MBM 12 therefore probably lies at $d \approx 65$ pc, within the local region filled primarily by very hot, low-density gas, a conclusion supported by the large internal velocity dispersion of the molecular cloud complex.

Subject headings: interstellar: matter — interstellar: molecules

I. INTRODUCTION

The nature of the local interstellar medium at $d < 100$ pc has been actively studied in recent years at wavelengths ranging from the radio to the X-ray region (Kondo, Bruhweiler, and Savage 1984). Most of this nearby space appears to be filled with very hot, low-density gas (McCammon *et al.* 1983; Cowie 1984). The question of how much cold, neutral gas is intermixed with the hot gas is of considerable importance, both in understanding this region and in assessing its effect on other observations. Very recently, Magnani, Blitz, and Mundy (1985, hereinafter MBM) have discovered a large number of molecular clouds at high galactic latitude, by virtue of the CO emission seen from them at 2.6 mm. These high-latitude clouds probably are a nearby population, and, from statistical arguments, MBM estimated a characteristic distance of about 100 pc to them.

The distance to an individual cloud in this sample can be determined at optical wavelengths by mapping the interstellar absorption lines toward a set of stars at different distances in the direction of the cloud. A program to estimate such distances to a few clouds of relatively large angular size is in progress. This report describes the results for MBM 12 (= Lynds 1457/8), located at $l = 159°$, $b = -34°$.

II. OBSERVATIONS

A map of the CO emission from MBM 12 is shown in Figure 1. The data were obtained during two observing runs in 1984 and 1985 with the 5 m telescope at the Millimeter Wave Observatory[3] at Fort Davis, Texas. The observations and data reduction are described by MBM. The map gives contours of $\int T_A^* \, dv$, a quantity which is roughly proportional to the column density of H_2 (Dickman 1978; Weiland *et al.* 1986). The cloud has a complex velocity structure with many discrete clumps which have LSR velocities ranging from -7 to $+4$ km s^{-1}. Most of the gas at positive velocities is observed toward the northern portion of the cloud complex.

Nine A or F stars which lie at approximate distances ranging from 25 to 230 pc and which are projected on or near the cloud are listed in Table 1 and plotted in Figure 1. The photometry and the spectral types for the three brightest stars are taken from the *Bright Star Catalogue* (Hoffleit 1982). The remaining, less accurate visual magnitudes and spectral classes are from the SAO and HD catalogs, respectively. An exception is the spectral class of F0 for HD 18091, which is crudely estimated from the present spectra. The spectra show clearly that the star is appreciably cooler than the HD class of A3. The resulting spectroscopic distances listed in the last column of Table 1, which are of decisive importance in this study, are based on the assumptions that (1) the six fainter stars are dwarfs of luminosity class V and (2) the effects of interstellar absorption on the calculated distances can be ignored. The latter must be incorrect for the five stars found here to lie in or behind the absorbing cloud. The presently unknown corrections for absorption would simply reduce the calculated distances of these more distant stars, however, thereby limiting the distance to the cloud even more stringently. The

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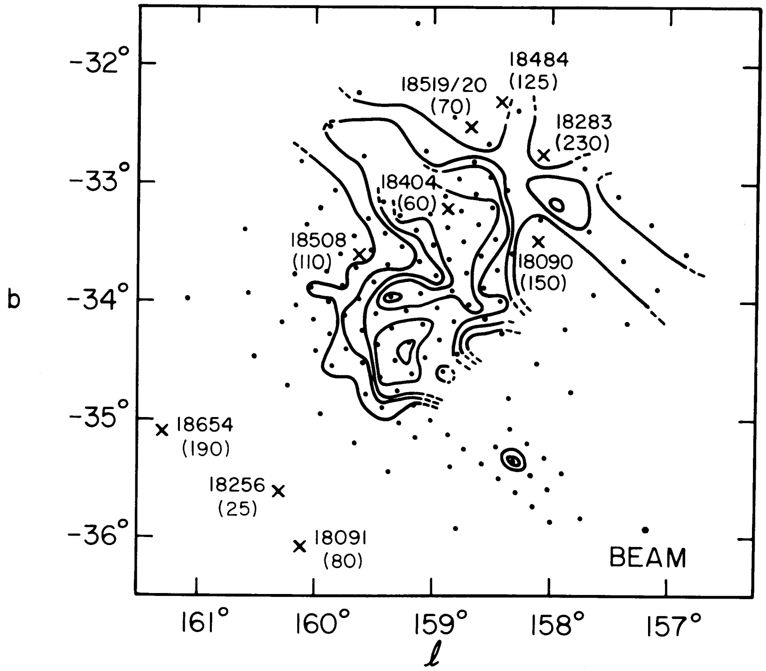

FIG. 1.—A CO map of MBM 12 showing the positions of the program stars. Approximate distances to the stars, in pc, are given in parentheses. A line directed north from ρ Ari (HD 18256) passes very close to HD 18283. The dots show the positions of CO measurements, and the contours give the quantity $\int T_A^* \, dv$. The lowest contour is 1.0 K km s^{-1}, and the succeeding contours are 3.0, 5.0, 10.0, and 20.0 K km s^{-1}.

TABLE 1

THE STARS OBSERVED

HD	Name	SAO	V	$B-V$	Sp	d(pc)
18090	...	75635	8.7	...	F2	150
18091	...	93178	6.9	...	(F0)	80
18256	ρ Ari	93195	5.63	0.43	F6 V	25
18283	...	75652	8.6	...	A5	230
18404	47 Ari	75662	5.80	0.41	F5 IV	60
18484	...	75671	6.7	...	A3	125
18508	...	93221	7.6	...	F0	110
18519/20	ε Ari AB	75673	4.63[a]	0.04[a]	A2 V	70
18654	...	93229	6.9	...	A0	190

[a] The combined light of the visual binary.

absolute magnitudes used in calculating the distances are those of Blaauw (1963).

Only one star, 47 Ari (HD 18404), is seen in projection against the molecular cloud. However, Weiland *et al.* (1986) have shown that the high-latitude molecular clouds are invariably associated with the "cirrus" emission which is seen at 100 μm in the *IRAS* data and which generally extends beyond the boundaries of the detectable CO emission. Figure 2 (Plate L3) shows the 100 μm emission in the vicinity of cloud 12. The bright core corresponds to the dense molecular gas traced by the CO observations, and the fainter, more diffuse emission probably corresponds to an atomic envelope partially surrounding the cloud. The positions of the nine program stars in Figure 2 suggest that strong interstellar absorption lines formed within MBM 12 or its envelope are likely to be seen only toward any of the six northernmost stars which lie beyond the cloud.

Optical spectra at an instrumental resolution (FWHM) of 0.12 Å or 5.9 km s^{-1} were obtained at the D lines of Na I for all nine stars and at slightly better velocity resolution at the K line of Ca II for HD 18484 and ε Ari. The observations were carried out during 1984 and 1985 with the echelle grating and the Digicon detector at the coudé spectrograph of the 2.7 m telescope of McDonald Observatory. The instrumental arrangement has been described previously (Albert 1983). The results of the observations at the D lines are summarized in Table 2 and are illustrated in Figure 3. At the K line, the equivalent widths obtained for the interstellar components are 66 and 32 mÅ for HD 18484 and ε Ari AB, respectively.

The interstellar D lines are found to be either undetectably weak or quite strong, without potentially ambiguous cases of intermediate strength. To our knowledge, interstellar D lines as strong as those toward ε Ari have not been detected toward *any other star within* 70 *pc*. The derived column densities of Na I listed in column 4 of Table 2 were calculated from the optical-depth integrals over the profiles of the detected lines (Hobbs 1974). The column densities for these lines therefore should be regarded as lower limits, owing to the unknown corrections which may be required for instrumental broadening of the lines. The corresponding column densities N(Ca II) are 8.7×10^{11} and 3.5×10^{11} cm^{-2} for HD 18484 and ε Ari AB, respectively. In contrast, the upper limits on N(Na I) in Table 2 which were derived from undetected lines were calculated in the optically thin approximation from the equivalent widths and should be nearly exact results. The observed LSR radial velocities given in the

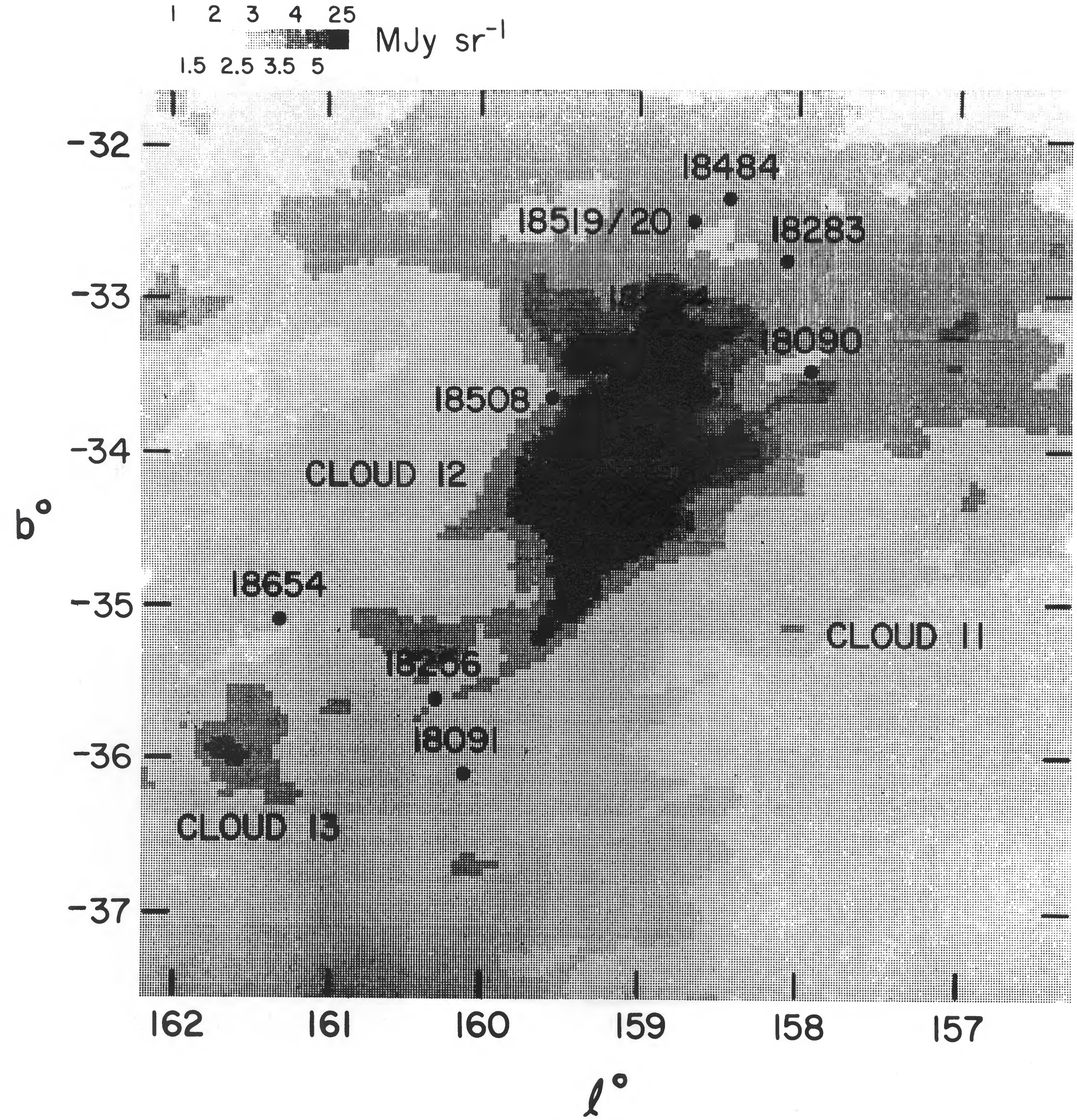

FIG. 2.—The 100 μm emission in a 6° × 6° field centered near the brightest part of MBM 12. The positions of the 9 program stars are shown. The map is a Spline1 map which includes no subtraction of zodiacal emission.

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TABLE 2

INTERSTELLAR ABSORPTION

Star	$W_\lambda(D_1)$ (mÅ)	$W_\lambda(D_2)$ (mÅ)	N(Na I) (10^{11} cm^{-2})	RV_{LSR}[a] (km s^{-1})	T_A^*[b] (K)	$\int T_A^*\, dv$[b,c] (K km s^{-1})	RV_{LSR}[a] (km s^{-1})
HD 18090.......	bl[d]	bl[d]	...	6:	< 0.62	< 0.43	...
HD 18091.......	≲ 8	≲ 8	≲ 0.4	...	< 0.60	< 0.42	...
ρ Ari	≲ 8	≲ 12	≲ 0.6	...	< 0.55	< 0.35	...
HD 18283.......	133	156	19.	3	< 0.31	< 0.20	...
47 Ari	≲ 8	≲ 8	≲ 0.4	...	3.7	10.2[e]	−3.1
HD 18484.......	238[f]	284[f]	45.[f]	−1,5	< 0.24	< 0.17	...
HD 18508.......	≲ 8	≲ 10	≲ 0.5	...	< 0.55	< 0.35	...
ε Ari AB	127	149	17.	4	< 0.29	< 0.19	...
HD 18654.......	84	103	10.	9	< 0.57	< 0.37	...

[a] To obtain heliocentric velocities, add 8 km s^{-1}.

[b] Upper limits are 2 σ values at a resolution of 0.325 km s^{-1}.

[c] Upper limits assume a line width of 1.3 km s^{-1}.

[d] A strong interstellar component is blended with a narrow stellar line.

[e] Includes a contribution of 3.5 K km s^{-1} from a broad wing which does not appear to be a baseline artifact.

[f] Two partially resolved interstellar components are present.

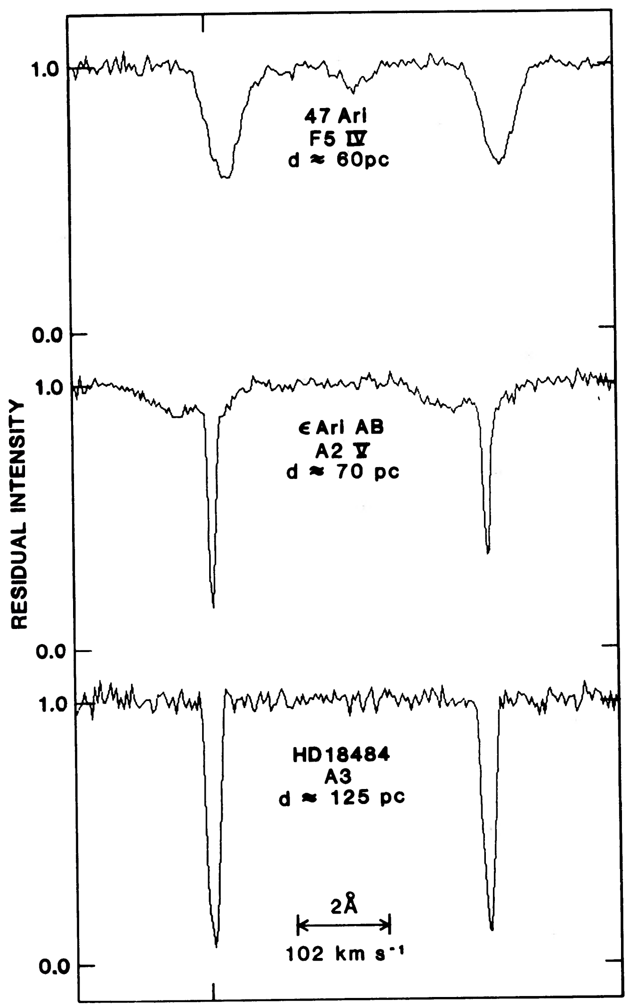

FIG. 3.—The spectra of 47 Ari, ε Ari AB, and HD 18484 in the region of the D lines of Na I. These three stars are mutually separated by less than 1° on the sky. Wavelength increases to the right, and the D lines are separated by 6.0 Å. The tick mark shown for the abscissae gives the zero point of LSR radial velocities for the D_2 line. 47 Ari and ε Ari show broad stellar lines, while the very broad, shallow stellar lines of HD 18484 have been divided out. The many telluric lines in the region have been removed by dividing each of the three spectra by that of the telluric standard star α Gru, which shows an otherwise featureless continuum in this region. The weak stellar line between the Na I lines of 47 Ari arises from Ni I.

fifth column of Table 2 for the interstellar absorption are accurate to about ± 2 km s^{-1} for stars other than HD 18090.

Except for the case of HD 18090, which is a sharp-lined F2 star, the generally strong stellar D lines which are present do not interfere significantly with the measurement of the interstellar lines (see Fig. 3). The projected rotational velocities $v \sin i$ exceed 60 km s^{-1} for all of the stars except the three coolest ones, for which $v \sin i < 20$ km s^{-1}. Two of these three lower luminosity stars are nearby and show no detectable interstellar lines. Even in a spectrum acquired at the higher resolution of 3.0 km s^{-1}, the interstellar components toward HD 18090 are seen only as a well marked but unresolved asymmetry in the stellar D lines. The much stronger stellar K lines of HD 18484 and ϵ Ari in general prevent accurate measurement of the interstellar Ca II components. The values of W_λ(K) and N(Ca II) cited above for ϵ Ari could therefore be in error by a factor of at least 2. The great width of the stellar lines of HD 18484 allows accurate measurement of the corresponding quantities, however. The resulting ratios N(Na I)/N(Ca II) = 5 toward HD 18484 and ϵ Ari are "normal" for cold interstellar gas (Hobbs 1974).

At the 12 m telescope of the NRAO[4], spectra of the $J = 2$–1 transition of CO at 1.3 mm were obtained at the positions of the nine stars. The line was detected only at 47 Ari, in general agreement with the earlier 2.6 mm map of Figure 1. The resulting line parameters are given in the last three columns of Table 2. An estimate of the visual absorption, in magnitudes, to stars located behind the entire molecular cloud at these positions can be obtained from the relation $A_V = 0.3 \times \int T_A^* \, dv$. This expression is based on a comparison of CO emission and visual absorption for several high-latitude molecular clouds (Magnani, Blitz, and Wouterloot 1986).

III. CONCLUSIONS

The interstellar Na I absorption toward the nine stars shows a fairly simple pattern. The four stars at $d > 120$ pc show strong lines, while four of the five remaining foreground stars show no detectable absorption. The Na I column densities to the former group exceed those to the latter, excluding ϵ Ari, by factors exceeding 15 in all cases and 100 in some cases. The maximum separation of 4°.0 between any pair of the nine stars corresponds to a linear distance of 8.4 pc at a distance of 120 pc. Thus, in this 4° field at $b = -34°$, there seem to be one or more interstellar clouds present at a distance of less than 120 pc.

The most interesting subgroup of stars consists of the northernmost five, however. They lie within a circle of diameter 1°.2, which corresponds to a transverse separation of only 1.4 pc at a distance of 65 pc. All four stars at $d > 65$ pc, including ϵ Ari at 70 pc, show strong interstellar D lines, while 47 Ari shows no detectable absorption at its distance of 60 pc (Fig. 3). The MK spectral types of, and hence the distances to, ϵ Ari and 47 Ari are relatively well determined (Table 1). 47 Ari is the only star projected against the molecular cloud and is obviously a foreground star; ϵ Ari and the other three northern stars, which are projected against the more extended 100 μm emission apparently related to MBM 12, can plausibly be interpreted as lying behind the cloud's atomic envelope. The CO velocities measured near the four northernmost stars are positive and similar to those of the interstellar D lines. Unfortunately, a direct velocity comparison is not possible, because no CO was detected at the positions of stars which show measurable interstellar D lines.

The complex velocity structure of MBM 12 is itself of importance in these arguments, however. Across the face of the cloud, the velocity centroid of the CO line varies from -7.1 to $+4.2$ km s^{-1} and yields an intensity-weighted dispersion of these centroids of 2.63 km s^{-1}, the second largest value found for the high-latitude clouds (MBM). This exceptionally wide range of velocities, which indicates that the cloud is bound neither gravitationally nor by external pressure, may reflect the cloud's immersion in the local, very hot interstellar gas.

We conclude that, if the CO cloud and the neutral gas in which the strong D line absorption arises constitute a single object, its distance of about 65 pc makes this the nearest known molecular cloud. The hot gas which occupies most of the local interstellar volume appears to extend to at least 100 pc in the direction of MBM 12 (Perry, Johnston, and Crawford 1982; Frisch and York 1983; Paresce 1984). Therefore, the molecular cloud probably lies within the hot, low-density interstellar gas. Alternatively, although the D lines of ϵ Ari show that there appears to be in any case an unprecedentedly strong concentration of nearby, neutral gas at less than 70 pc in the direction of MBM 12, the molecular cloud lies indeterminately farther behind that foreground gas. In view of this directional coincidence, the small surface filling fraction of high-latitude clouds (Magnani, Lada, and Blitz 1986), and the close association of these clouds with the 100 μm "cirrus" emission, we consider the latter alternative unlikely.

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