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ON THE NEAREST MOLECULAR CLOUDS. II. MBM 12 AND 16

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ABSTRACT

Echelle spectra recorded at the D lines of Na I are reported for three stars projected on the high-latitude molecular cloud MBM 16 at $l = 172°$, $b = -38°$. The foreground G star HD 20779 located at a distance of approximately 60 pc shows no detectable interstellar D-line absorption. The A stars HD 21142 at approximately 95 pc and HD 21134 at about 240 pc show strong absorption of this kind, at the same velocities as the CO emission observed at those positions. The distance to MBM 16 therefore is $60 \lesssim d \lesssim 95$ pc. Similar results for four other A or F stars projected near the cloud are consistent with this conclusion. MBM 16 is only 11° away from MBM 12, previously placed by the same method at $d \approx 65$ pc. The relation of clouds 12 and 16 to the local, hot, low-density, interstellar gas is discussed.

Upper limits on the interstellar λ4300 line of CH toward three of the background stars projected on or near MBM 12 and MBM 16 suggest that no extremely large overabundances of CH molecules exist in these clouds. The observed small color excesses and visual extinctions of background stars indicate that MBM 16 and at least the outer regions of MBM 12 in fact are CO–rich diffuse clouds.

Subject headings: interstellar: matter — interstellar: molecules — nebulae: individual (MBM 12, MBM 16)

I. INTRODUCTION

A number of molecular clouds have been discovered at high galactic latitude by Magnani, Blitz, and Mundy (1985, hereafter MBM), by means 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 ~100 pc to them. Some of these clouds may therefore be immersed in the very hot, low-density gas which pervades much of the local interstellar space at $d \lesssim 100$ pc (Perry and Johnston 1982; McCammon *et al.* 1983). A census of any such clouds in the hot gas and a detailed study of the physical properties especially of the transition zones between the clouds and the surrounding hot gas are potentially important efforts (see Kondo, Bruhweiler, and Savage 1984).

The distance to an individual cloud in the MBM group 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. Measurements only of the interstellar reddening of such stars should also yield a comparably precise estimate of the cloud's distance, in a simpler way. We have begun a program to determine the distances to a few high-latitude clouds of relatively large angular size by these methods. The largest clouds are likely to be among the nearest ones and to allow the largest number of suitable target stars. Our first results led to a distance estimate of ~65 pc to MBM 12 (= Lynds 1457), and we thereby identified it as perhaps the nearest known molecular cloud (Hobbs, Blitz, and Magnani 1986; hereafter Paper I). The cloud apparently contains an embedded T Tauri star, the hard X-ray emission from which is detectable owing in part to the cloud's proximity (Halpern and Patterson 1987). A similar study is reported here of the distance to MBM 16 at $l = 172°$, $b = -38°$, only 11° away from cloud 12.

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II. OBSERVATIONS

a) MBM 16

A map of the CO emission from cloud 16 is shown in Figure 1 (MBM). Seven stars which lie at distances ranging from approximately 60 to 350 pc and which are projected on or near the cloud are listed in Table 1 and are plotted in Figure 1. Three of the stars are seen in projection against the molecular clouds, while four lie slightly outside the region of detectable CO emission on the sky. The photometry and the spectral types for the two brightest stars are taken from the *Bright Star Catalogue* (Hoffleit 1982). The photometry for the other five stars was obtained with the 0.6 m reflector of Yerkes Observatory; the preliminary MK spectral types given in Table 1 for these stars have been determined by Dr. N. Houk in advance of their normal inclusion in the program of reclassifying the spectra of stars in the *Henry Draper Catalogue* (Houk and Cowley 1975; Houk 1987). The resulting color excesses and spectroscopic distances given in Table 1 are based on the absolute magnitude calibration of MK spectral types determined by Blaauw (1963), the intrinsic colors of Johnson (1963), and the assumption that $R = A_V/E(B-V) = 3.0$. The errors in the resulting distances are the usual varied and uncertain ones, but a typical error may be ±25%.

The distance to the metallic-line A star HD 21142, which sets the most restrictive upper limit on the distance to MBM 16, is more uncertain than the others in Table 1 and deserves further discussion. Because their spectra apparently are very similar, HD 21142 probably has physical properties little different from two prototypical metallic-line A stars, 63 Tau and ζ UMa B (Morgan, Keenan, and Kellman 1943). Accurate distances, and hence absolute magnitudes, are known for the latter two stars, since 63 Tau is a member of the Hyades cluster and ζ UMa B shows a well-determined trigonometric parallax of 0″047 (Hoffleit 1982). For 63 Tau the values $V = 5.64$ and $m - M = 3.30$ yield $M_V = 2.34$, while for ζ UMa B the corresponding data are $V = 3.95$, $m - M = 1.64$, and $M_V = 2.31$. An absolute magnitude $M_V = 2.3$ therefore

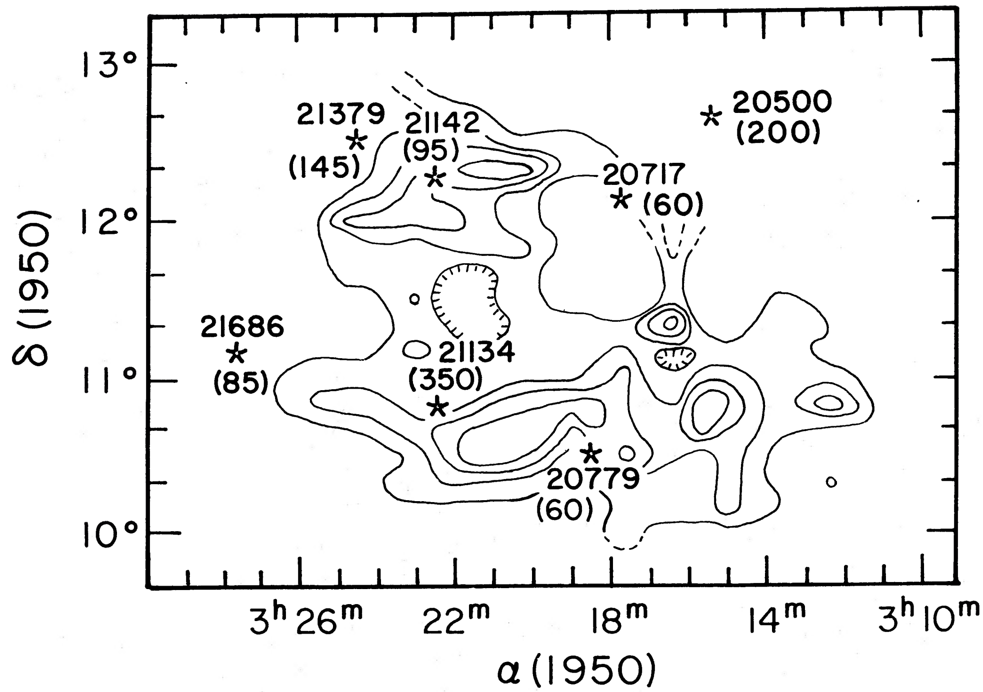

FIG. 1.—CO map of cloud 16 obtained by MBM showing the positions of the program stars. Approximate distances to the stars, in parsecs, are given in parentheses. The map shows values of T_A^* in tervals of 1 K, with the lowest contour at 0.5 K.

has also been assumed for HD 21142. An approximate color excess $E(B-V) \approx 0.06$ can further be adopted for HD 21142, as is suggested by the reddening of the other star seen through MBM 16, HD 21134. The values $V_0 \approx 7.22$ and $M_V \approx 2.3$ finally yield $m - M \approx 4.92$ or $d \approx 95$ pc for HD 21142.

Optical spectra recorded 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 seven stars and, with slightly better velocity resolution, at the K line of Ca II for 4 Tau. The observations were carried out at various times from 1984 to 1987 with the echelle grating and the Digicon detector at the coudé spectrograph of the 2.7 m reflector of McDonald Observatory. The results of the observations at the D lines are summarized in Table 2, and the D_1 profiles are illustrated in Figure 2. An equivalent width $W_\lambda(K) = 11$ mÅ and a radial velocity $RV_{LSR} = 12$ km s^{-1} were obtained for the weak interstellar component seen at the K line of 4 Tau. The derived column densities listed in column (5) of Table 2 were calculated from the optical depth integrals over the profiles of the detected lines (Hobbs 1974). Except in the case of the weaker lines seen toward HD 21379, these values should therefore be regarded as lower limits, owing to the unknown effects of instrumental broadening. The 3 σ upper limits on N(Na I) in Table 2 were derived from the equivalent widths in the optically thin

TABLE 1

STARS OBSERVED

MBM	HD	Name	V	$B-V$	MK	d (pc)	$E(B-V)$
16	20500	...	7.77	0.25	A0 V	200	0.25
	20717	...	7.36	0.47	F6 V	60	0.00
	20779	...	8.47	0.61	G1 V	60	0.00
	21134	...	7.28:	0.12:	A2 III	350	0.06
	21142	...	7.40:	0.29:	A1m A7–F0	95	...
	21379	...	6.28	−0.02	A0 V	145	0.00
	21686	4 Tau	5.14	−0.03	A0 V	85	0.00
12	18090	...	8.85	0.43	F3 V	145	0.03
	18091	...	7.00	0.28	A9 V	85	0.01
	18190	...	8.98	0.39	A9 V	185	0.12
	18256	ρ Ari	5.63	0.43	F6 V	25	0.00
	18283	...	8.78	0.33	A8 III	380	0.12
	18404	47 Ari	5.80	0.41	F5 IV	60	0.00
	18484	...	6.70	0.23	A3 III	210	0.14
	18508	...	7.34	0.37	F2 V	80	0.00
	18519/20	ε Ari AB	4.63[a]	0.04[a]	A2 V	70	0.00
	18654	...	6.79	0.08	A0 V	160	0.08

[a] The combined light of the visual binary.

TABLE 2

INTERSTELLAR Na I ABSORPTION

MBM	Star	$W_\lambda(D_1)$ (mÅ)	$W_\lambda(D_2)$ (mÅ)	N(Na I) (10^{11} cm^{-2})	RV_{LSR}[a] (km s^{-1})	RVL_{LSR}[a,b] (km s^{-1})
16	HD 20500	170.	194.	32.	6	...
	HD 20717	≤9.	≤9.	≤0.4	...	...
	HD 20779	≤24.[c]	≤24.[c]	≤1.2	...	7.2
	HD 21134	110.	114.	17.	6	6.6
	HD 21142	bl[d]	bl[d]	≳17.[e]	8:	5.9
	HD 21379	35.	55.	3.5	6	...
	4 Tau	≤6.	≤12.	≤0.6	...	...
12	HD 18190	225.	275.	40.	2	−2.0

[a] To obtain heliocentric velocities, add 8 and 11 km s^{-1} for stars in MBM 12 and 16, respectively.

[b] CO $J = 1$–0 line. Velocities are from the nearest observed position, generally within a few arcminutes of the star.

[c] A strong stellar D line falls at the interstellar velocity.

[d] A strong interstellar component is blended with a narrow stellar line shifted by ~15 km s^{-1}.

[e] The blended interstellar component appears to be at least as strong as the easily separated one toward HD 21134.

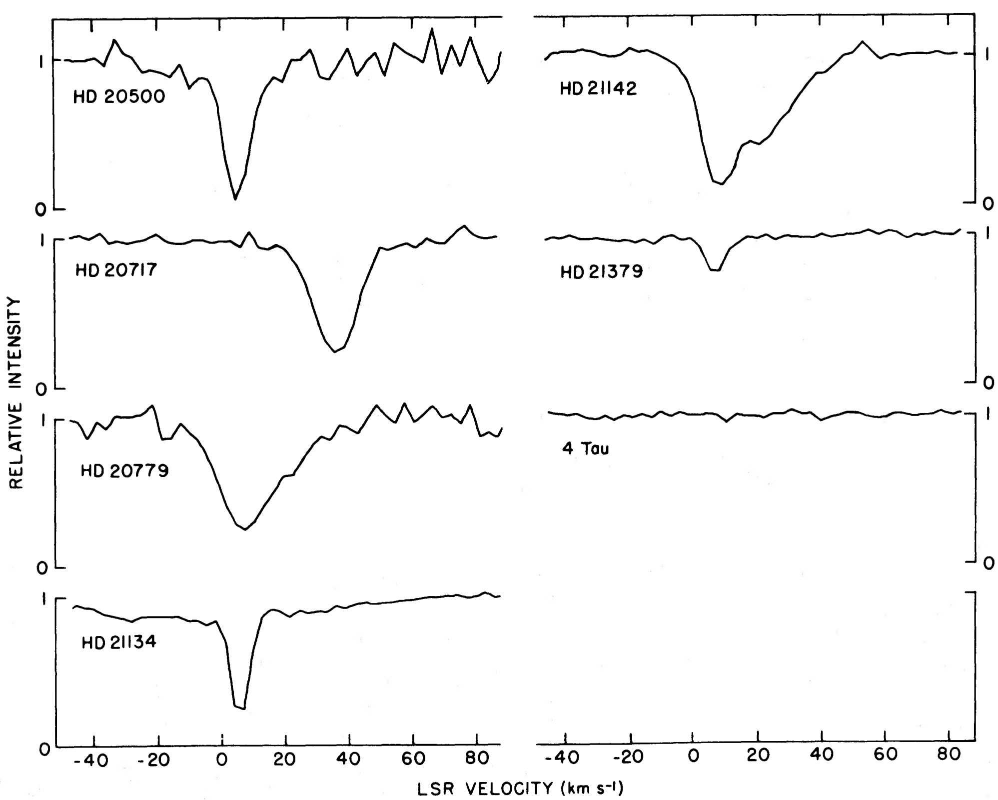

FIG. 2.—Spectra of seven stars located near MBM 16, recorded in the region of the Na I D_1 line. All of the stars show a discernible stellar D_1 line, except that the extremely shallow, broad stellar profile of 4 Tau has been removed here. In the cases of HD 20500, HD 20717, HD 20779, and HD 21142, the stellar line is narrow enough to be fully included here; the stellar D_1 line of HD 20500 is quite shallow. The many telluric lines in the region have been removed by dividing each spectrum by that of either σ Sgr, α Gru, or α Peg, telluric standard stars which effectively show an otherwise featureless continuum in this region.

approximation. The observed radial velocities of the interstellar absorption with respect to the LSR which are given in column (6) are accurate to about ± 2 km s^{-1}. The agreement between the Na I and the CO velocities at the positions of HD 21134 and HD 21142 is excellent.

Stellar D lines are present in the spectra of all seven stars (Fig. 2), as is expected from their spectral types. Only for HD 21142, where the separation of the stellar and interstellar components is approximately 15 km s^{-1}, does the stellar line interfere significantly with measurements of the partially resolved interstellar one, which nevertheless is clearly seen to be quite strong. In the important case of HD 20779, the strong, fairly narrow, stellar line falls almost exactly at the interstellar velocity and could in principle conceal a moderately strong interstellar component. However, both the equivalent widths $W_\lambda(D_2) = 490$ mÅ and $W_\lambda(D_1) = 390$ mÅ and the profiles of the lines fail to suggest the presence of an interstellar component comparable in strength to those seen toward HD 21134 or HD 21142. A negative result is also expected on the basis of the star's proximity.

As noted for cloud 12 in Paper I, the interstellar Ca II K line can usefully be measured toward a few of the program stars, in order to verify that the accessible physical properties of the MBM clouds, such as the ratio N(Ca II)/N(Na I) are generally "normal." A column density $N(\text{Ca II}) = 1.3 \times 10^{11}$ cm^{-2} is obtained from the spectrum of 4 Tau described above. The resulting ratio N(Ca II)/N(Na I) $\gtrsim 2$ is higher than average but is not demonstrably exceptional (see Hobbs 1983). A further check of this kind consists of observations of the λ4300 line of CH, which are reported in Table 3 and Figure 3. These spectra were obtained at an instrumental resolution of 0.078 Å or 5.4 km s^{-1}. A negative result is obtained in MBM 16 toward HD 21134, a star which is projected on the cloud and which also shows strong interstellar D lines. For comparison, observations of the λ4300 line which arises in the well-known molecular cloud in front of ζ Per (Chaffee 1974) were also acquired and are shown in Figure 3. The ratio N(CH)/N(Na I) ≤ 4 derived here toward HD 21134 can be compared to the value N(CH)/N(Na I) ≈ 0.6 obtained by Chaffee toward ζ Per, for example. The comparison suggests qualitatively, but does not prove, that CH is not exceptionally overabundant in at least this part of cloud 16, relative to other molecular clouds.

b) MBM 12

The data for cloud 12 were presented and discussed in Paper I. Some supplementary, new data have been acquired in the interim, however. Improved photometry and spectral types for the six faintest stars described in Paper I have been obtained by the same means as noted above for cloud 16. These stellar data are also listed in Table 1, along with the derived distances and reddenings. These additional data leave the conclusions reached in Paper I unchanged. Two of the background stars which show the strongest interstellar absorption, HD 18283 and HD 18484, prove to be giants located at somewhat greater distances than previously estimated, a possibility anticipated in Paper I. The reduction in the distance of HD 18508 to about 80 pc also allows, within the uncertainties of this estimate, an easier interpretation of this star as a foreground object, a conclusion which better agrees with the observed absence of interstellar Na I absorption along this light path.

An echelle spectrum taken at the D lines also has been obtained for a 10th star, HD 18190 (Table 1), at $l = 159^\circ.37$, $b = -34^\circ.77$. In contrast to the other nine stars studied in Paper I, HD 18190 lies within the detected CO contours and shows strong interstellar D line absorption. The light path to this star therefore clearly passes through at least part, and probably all, of the molecular cloud. The resulting equivalent widths and radial velocity and the corresponding column density N(Na I) are listed in Table 2. The agreement of the Na I and the CO velocities near this position is acceptable and further strengthens the assumption that the optical absorption and the radio emission arise in the same object (Paper I). The D_1 line of HD 18190 is shown in Figure 4, along with those of the other nine stars as well. A wider region in three of these spectra already was shown in Paper I, primarily to illustrate the stellar D lines which are present.

Spectra centered near the CH λ4300 line also have been acquired for ϵ Ari AB and HD 18484, two stars which show strong interstellar Na I absorption but lie just outside the lowest contour of the CO emission. The negative results obtained are given in Table 3 and are illustrated in Figure 3.

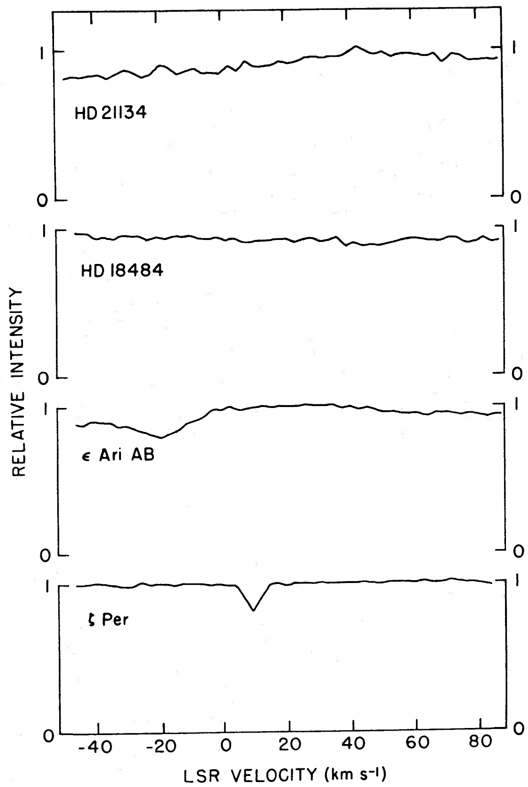

FIG. 3.—Spectra, in the region of the4300 Å line of CH, of three stars located near MBM 12 or MBM 16, and, for comparison, of ζ Per. The variation in the intensity of the "continuum" for each of the three A stars arises from the presence of stellar lines, principally Fe I λ4299.24 and Ti II λ4300.05.

TABLE 3

INTERSTELLAR CH ABSORPTION

MBM	Star	W_λ(4300) (mÅ)	N(CH) (10^{12} cm^{-2})	RV_{LSR} (km s^{-1})
16	HD 21134	≤6.	≤6.9	...
12	HD 18484	≤4.	≤4.6	...
12	ϵ Ari AB	≤4.	≤4.5	...
... .	ζ Per	16.	20.	9

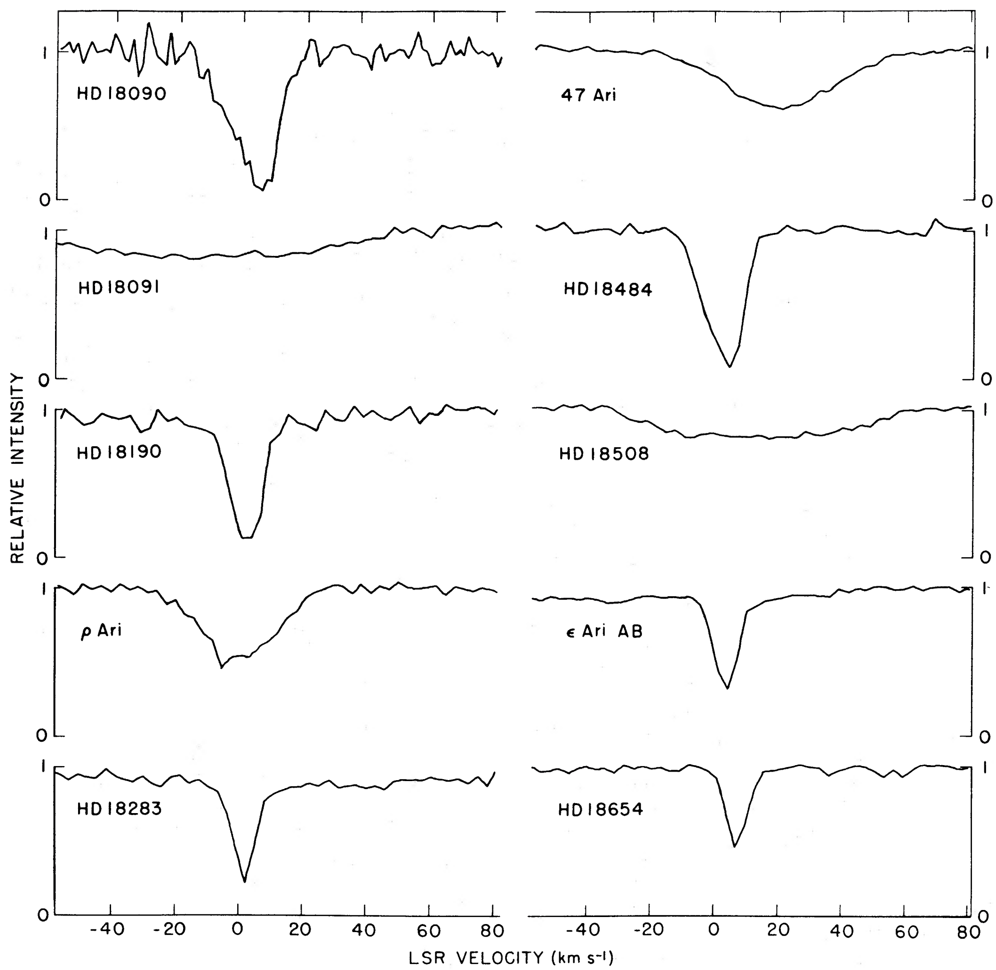

FIG. 4.—Spectra of 10 stars located near MBM 12, recorded in the region of the D_1 line. The instrumental resolution used for HD 18090 was 3.0 km s^{-1}. All of the stars show a discernible stellar D_1 line, except that the extremely shallow, broad stellar profiles of HD 18484 and HD 18654 have been removed here. In the cases of HD 18090, ρ Ari, 47 Ari, and HD 18508, the stellar line is narrow enough to be fully included here. The telluric lines have been removed as in Fig. 2.

III. RESULTS

a) The Distance to MBM 16

HD 20779, HD 21134, and HD 21142, the three stars projected within the CO contours of cloud 16, restrict the cloud's distance to $60 \lesssim d \lesssim 95$ pc. The absence of interstellar Na I absorption marks HD 20779 as a foreground star, while the strong D-line absorption seen toward HD 21134 and HD 21142 shows that the cloud lies in front of each of these two stars. The column densities N(Na I) toward the two background stars exceed that toward the foreground one by a factor of at least 14. The excellent agreement between the Na I and the CO velocities at the positions of the two background stars argues that both species exist in a single sample of gas, so that the molecular cloud probably is not a separate object lying indefinitely farther beyond the gas in which the D-line absorption occurs. Among the remaining four stars located near but outside the CO contours, HD 20717 and 4 Tau show no detectable Na I absorption at $d \lesssim 85$ pc, while HD 20500 and HD 21379 at $d \gtrsim 145$ pc show strong and intermediate interstellar D lines, respectively. These results are consistent with the limits $60 \lesssim d \lesssim 95$ pc deduced from the previous three stars. Our result agrees with and refines significantly the estimate $d = 100 \pm 50$ pc previously derived by Magnani and de Vries (1986) from star counts in MBM 16.

The distance $d \approx 65$ pc to MBM 12 established in Paper I remains unchanged.

b) The Local, Hot Interstellar Gas

The averaged reddening maps of Perry and Johnston (1982) for stars at distances $-50 \leq z \leq 0$ pc below the galactic plane are available to delineate, in the directions of clouds 12 and 16, the large-scale features of the boundary of the local volume filled predominantly with hot, low-density gas. Even at its maximum allowed distance of ~ 70 pc, cloud 12 at $(x, y, z) = (21, 54, -39)$ pc is likely to be an isolated cloud immersed in the hot gas (Paper I). At its minimum allowed distance of ~ 60 pc, cloud 16 at $(x, y, z) = (7, 47, -37)$ pc would be similarly situated; on the other hand, at its maximum allowed distance of ~ 95 pc, it might lie outside the local "bubble," in regions that contain large amounts of widespread, cold, neutral gas. The corresponding reddening maps of Perry, Johnston, and Crawford (1982) show the individual color excesses of the nearly 3600 stars which they observed, rather than only the averaged values within cubes 50 pc on a side. The higher spatial resolution provided by these maps in fact reveals that all of their program stars closer than ~ 100 pc in the general directions of the two molecular clouds are essentially unreddened, in agreement with most of our results in Table 1. Such a comparison emphasizes, however, that even the extensive study conducted by those authors results, in general, in a surface density of stars which is too low to be useful for detailed studies on angular scales as small as $\sim 2°$, the angular diameter of clouds 12 and 16. In particular, only one of our 17 program stars in Table 1, HD 18508, appears in these photometric studies.

The similar absence of directly applicable measurements of the interstellar Lyα line toward nearby stars also should be noted. Such measurements provide an extremely sensitive means of detecting any intervening neutral gas and hence the boundaries of the local region. Stars at $d \lesssim 100$ pc toward which column densities N(H I) have been determined are unfortunately at least 15° away from MBM 12 and MBM 16 (Frisch and York 1983; Paresce 1984). These closest adjacent stars include two well-determined members of the Pleiades cluster, 20 Tau and η Tau, which long have been known to lie behind substantial amounts of neutral gas (e.g., Adams 1949). The distance to these two stars adopted by Frisch and York should be revised upward by a factor near 2 and therefore cannot prove the presence of strong concentrations of neutral gas as close as $d \lesssim 70$ pc. A Hyades distance modulus of $m - M = 3.3$ and the apparent magnitude difference $\Delta V \approx 2.5$ mag between the main sequences of the Pleiades and the Hyades (Johnson 1957; Johnson and Mitchell 1958) yield a distance $d \approx 140$ pc to the Pleiades. Therefore 20 Tau and η Tau probably lie well beyond MBM 16, which, on the grounds of this comparison alone, could still be a foreground object which lies within the local hot gas. The same conclusion also applies to δ Per, on the more uncertain basis of a spectroscopic distance (e.g., Hobbs 1969).

We conclude that MBM 12 is likely to be an isolated cloud immersed in the hot gas (Paper I), but that insufficient data exist at present to locate MBM 16 conclusively in relation to the local hot gas.

c) The CH *Abundances*

The observed upper limits on the ratio N(CH)/N(Na I) at one position in MBM 16 and at two positions adjacent to MBM 12 provide only weakly restrictive limits on the CH abundances in the two clouds. Because the density ratio n(Na I)/n(H) at any point in the clouds depends upon the unknown electron density n_e, reliable quantitative estimates of the fundamental ratio N(CH)/N(H) cannot be obtained from the data available at present alone. It should be noted in this connection, however, that the observed ratios N(Na I)/$E(B-V)$, and therefore presumably of the corresponding ratios N(Na I)/N(H), are entirely "normal" in the directions of HD 21134 and HD 18484 (e.g., Hobbs 1974). Despite the noted uncertainty, the results in Table 2 and 3 make unlikely the possibility that CH is overabundant in these high-latitude clouds by more than one order of magnitude, compared with other molecular clouds such as the one in the light path to ζ Per. Observations of the CH λ4300 and of the CH^+ λ4232 line in several other MBM clouds, which lead to generally comparable conclusions, will be reported in a subsequent paper.

IV. DISCUSSION

a) The Color Excesses and the Extinctions

In principle, the interstellar reddening determined from the photometry and the spectral types alone should satisfactorily distinguish background stars from foreground ones. Such a method would eliminate the need for high-resolution spectra to reveal the interstellar absorption lines and, consequently, would accelerate these investigations. The results collected in Tables 1 and 2 here and in Paper I generally confirm this expectation. In particular, the correlation between the color excesses $E(B-V)$ and the column densities N(Na I) is good for both MBM 12 and MBM 16, being comparable to that found generally in the interstellar medium (Hobbs 1974). Among the 17 program stars, all seven which have $E(B-V) \geq 0.06$ also show $N(\text{Na I}) > 15 \times 10^{11}$ cm^{-2} and therefore would be identified as background stars by either method. The rough assumption that $E(B-V) \approx 0.06$ has again been used temporarily for HD 21142 (§ II*a*). Similarly, seven of the nine stars with $E(B-V) \leq 0.01$ show $N(\text{Na I}) \leq 1.2 \times 10^{11}$ cm^{-2} and could therefore be recognized as foreground sources by either method. We emphasize that the Na I column density toward any star in the reddened group in fact exceeds that toward any star in the group of seven unreddened stars by a factor always greater than 12.

Two of the three remaining stars, HD 18090 and HD 21379, may be intermediate cases. The interstellar D lines for HD 18090, which are significantly obscured by stellar blending, indeed roughly look neither very strong nor very weak, while correction of a hypothetical, small, but plausible error in either the spectral type or the $B-V$ color of HD 21379 could also yield an intermediate reddening. Finally, the only apparent discrepancy between the reddening and the strength of the interstellar absorption lines arises in the important case of ϵ Ari AB, which is nominally unreddened but shows a strong interstellar Na I line. However, this system consists of a visual binary, one component of which is itself a double-lined spectroscopic binary, as seen in our spectra; the correct intrinsic color to be assumed for the combined light of this triple system is therefore subject to errors potentially large enough to reconcile the apparent discrepancy.

It thus appears retrospectively that, except for the multiplicity of ϵ Ari, the photometric method alone would have yielded the same distance limits as those obtained here from the interstellar line data, at least for clouds 12 and 16, and that this simpler method therefore should be pursued for other high-latitude clouds. At least two potential difficulties are evident from the comparisons, nevertheless. First, because the overall results would rest heavily in the purely photometric case on the color excesses of only a few stars, fairly small observational errors amounting to perhaps only 0.03 mag in the $B-V$ color excesses deduced for those stars could seriously distort the final distance estimate, even if the extinction properties of the grains in the MBM clouds are entirely normal. In particular, suitably accurate intrinsic stellar colors are required, as is conspicuously illustrated by the case of ϵ Ari. Second, occasionally anomalous mixtures of dust grains in the molecular clouds could in principle lead to untrustworthy results, despite the indications to the contrary presented by Weiland *et al.* (1986). In this case, the visual absorption might be inferred incorrectly from a measured color; furthermore, the absorption could depend significantly on local grain properties as well as upon path length through the cloud, i.e., on distance.

Star counts toward eight high-latitude molecular clouds (HLC), including MBM 16, provide additional evidence that photometry alone can establish the distances to the clouds (Magnani and de Vries 1986). The mean interstellar absorption so deduced within the lowest CO contour of cloud 16 is $\langle A_V \rangle = 0.9$ mag, and the mean of the corresponding measurements for all eight clouds is 0.6 mag. For normal grain properties, color excesses $E(B-V) \approx 0.3$ mag are therefore expected for typical light paths passing entirely through MBM 16, with still lower values near 0.2 mag for a typical HLC. Table 1 shows that the measured excesses are comparable to, although smaller than, the values expected from counting stars, indicating that no major discrepancy exists between the reddening and the extinction properties of both MBM 12 and MBM 16. This rough agreement suggests that the properties of grains in the HLC are not grossly different from those in other interstellar clouds.

An independent assessment of the grain properties can be obtained from the broad-band *IRAS* data, which have been analyzed for three high-latitude clouds, including MBM 16 (Weiland *et al.* 1986). For MBM 16, a value $A_V/I_{100} = 0.043$ is found, where I_{100} is the intensity at 100 μm in units of MJy sr^{-1}. This is to be compared with a value of 0.038 determined by Boulanger, Baud, and van Albada (1985) for infrared "cirrus" without molecular emission. Low *et al.* (1983) instead calculated A_V/τ_{100} for four HLC without molecular emission and found a mean value of 2500; the value for MBM 16 was measured to be 2900. These far-IR data therefore also indicate that the grains in HLC do not differ in a major way from those in other interstellar clouds of relatively low density. Dark clouds may have somewhat higher values of these measured quantities, however (Weiland *et al.* 1986; Boulanger and Perault 1987).

b) Are These Diffuse Clouds?

The conspicuously small values of the stellar color excesses and extinctions attests to the transparency of these two high-latitude clouds. Except for the distant background star HD 20500, the color excesses $E(B-V) \leq 0.14$ for all of our program stars, in particular. Such reddening is very modest, yet there can be little question that the light path to the giant HD 21134 at $d \approx 350$ pc passes completely through cloud 16, as is independently confirmed by the strong interstellar Na I absorption seen in the star's spectrum. Similarly, although the light paths to them pass just outside the region from which CO emission has been detected, the giants HD 18283 and HD 18484 almost certainly lie behind all of cloud 12. MBM 16 and the outer parts of MBM 12 should therefore be unambiguously classed as diffuse clouds, although cloud 12 apparently has a dark core.

The values of $N(\text{Na I})/E(B-V)$ observed toward the six program stars with $E(B-V) \geq 0.06$ yield a range $2.2 \times 10^{-9} \leq N(\text{Na I})/N(\text{H}) \leq 5.7 \times 10^{-9}$, if a normal "gas-to-dust ratio" $N(\text{H})/E(B-V) = 5.8 \times 10^{21}$ cm^{-2} is assumed in agreement with the results discussed above (Bohlin, Savage, and Drake 1978). These Na I/H ratios, which depend upon the electron densities in the clouds (Hobbs 1974; Ferlet, Vidal-Madjar, and Gry 1985), are indeed in excellent agreement with direct measurements of the ratio $N(\text{Na I})/N(\text{H})$ in a sample of diffuse clouds observed toward 30 other stars (Hobbs 1971). Typical diffuse clouds also show $N(\text{CO})/N(\text{H}_2) \approx 10^{-6}$ (e.g., Federman *et al.* 1980), while ratios $N(\text{CO})/N(\text{H}_2) \geq N(\text{CO})/N(\text{H}) \approx 10^{-4}$ are similarly deduced here toward the six appreciably reddened stars, on the basis of the observed color excesses and the standard value of $N(\text{H})/E(B-V)$. The corrections of the CO/H ratios for the undetermined molecular fractions $f = 2N(\text{H}_2)/[N(\text{H I}) + 2N(\text{H}_2)]$ along these light paths will yield resulting CO/H_2 ratios above this lower limit. At $E(B-V) \leq 0.25$, these corrections may be substantial (Savage *et al.* 1977). Such ratios $N(\text{CO})/N(\text{H}_2) \gtrsim 10^{-4}$ resemble those found in dark, rather than diffuse, clouds. Recent CO observations by Lada and Blitz (1987) indeed suggest that there are two populations of diffuse clouds, one of which is "CO rich" and the other "CO poor." The CO–poor clouds are the conventional diffuse clouds toward which CO is not generally detectable through its millimeter transitions; the CO–rich clouds show CO abundances typically larger by two orders of magnitude, like those in dark clouds. The two cloud groups evidently are not defined simply by their extinctions, which show considerable overlap between the groups. MBM 16 and at least the outer regions of MBM 12 apparently are CO–rich diffuse clouds.

c) The Extent of the Taurus-Auriga Molecular Complex

MBM 16 is located in Aries, southwest of the Taurus dark clouds. Recent CO mapping of the molecular clouds in Perseus, Taurus, and Auriga by Ungerechts and Thaddeus (1987) reveals seven small clouds southwest of Taurus, identified as clouds 1–7 in the catalog assembled by those authors. Their cloud 1 corresponds to MBM 12, and their cloud 6 to MBM 17. Although MBM 16 is located $\sim 10°$ south of these seven small clouds, cloud 16 is at a distance about half that of the principal Taurus dark clouds (~ 140 pc; Elias 1978), and it shares a nearly identical mean LSR velocity of ~ 7 km s^{-1} with them. It is therefore reasonable to associate MBM 16 and possibly MBM 12 with the Taurus-Auriga complex of molecular clouds.

The *IRAS* 100 μm data for this region support this conclusion. Figure 5 (Plate 3) shows the 100 μm Skyflux map of a $40° \times 50°$ area centered at $l = 177.5°$ and $b = -30°$; the map is neither destriped nor background subtracted, but it serves to show the morphology of the dust emission. Clouds 1–7 from the survey by Ungerechts and Thaddeus are marked, as are the MBM clouds. The connection between MBM 11–14 and MBM 16–19 with the Taurus clouds is obvious. Based on the *IRAS* data, the roughly comparable distances, and the similar mean radial velocities, the MBM clouds are likely to define the nearest edge of the Taurus-Auriga complex of molecular clouds, which extends to latitudes as high as $b = -45°$.

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REFERENCES

Adams, W. S. 1949, *Ap. J.*, **109**, 354.
Blaauw, A. 1963, in *Stars and Stellar Systems*, Vol. **3**, *Basic Astronomical Data*, ed. K. Aa. Strand (Chicago: University of Chicago Press), p. 401.
Bohlin, R. C., Savage, B. D., and Drake, J. F. 1978, *Ap. J.*, **224**, 132.
Boulanger, F., Baud, B., and van Albada, G. D. 1985, *Astr. Ap.*, **144**, L9.
Boulanger, F., and Perault, M. 1987, preprint.
Chaffee, F. H. 1974, *Ap. J.*, **189**, 427.
Elias, J. H. 1978, *Ap. J.*, **224**, 857.
Federman, S. R., Glassgold, A. E., Jenkins, E. B., and Shaya, E. J. 1980, *Ap. J.*, **242**, 545.
Ferlet, R., Vidal-Madjar, A., and Gry, C. 1985, *Ap. J.*, **298**, 838.
Frisch, P. C., and York, D. G. 1983, *Ap. J.* (*Letters*), **271**, L59.
Halpern, J. P., and Patterson, J. 1987, *Ap. J.* (*Letters*), **312**, L31.
Hobbs, L. M. 1969, *Ap. J.*, **157**, 135.
———. 1971, *Ap. J.*, **166**, 333.
———. 1974, *Ap. J.*, **191**, 381.
———. 1983, *Ap. J.*, **265**, 817.
Hobbs, L. M., Blitz, L., and Magnani, L. 1986, *Ap. J.* (*Letters*), **306**, L109 (Paper I).
Hoffleit, D. 1982, *The Bright Star Catalogue* (4th ed.; New Haven: Yale University Observatory).
Houk, N. 1987, private communication.
Houk, N., and Cowley, A. P. 1975, *University of Michgan Catalogue of Two-Dimensional Spectral Types for the HD Stars*, Vol. 1 (Ann Arbor: University of Michigan).
Johnson, H. L. 1957, *Ap. J.*, **126**, 121.
———. 1963, in *Stars and Stellar Systems*, Vol. **3**, *Basic Astronomical Data*, ed. K. Aa. Strand (Chicago: University of Chicago Press), p. 214.
Johnson, H. L., and Mitchell, R. I. 1958, *Ap. J.*, **128**, 31.
Kondo, Y., Bruhweiler, F. C., and Savage, B. D., eds. 1984, *The Local Interstellar Medium* (NASA CP-2345).
Lada, E., and Blitz, L. 1987, in preparation.
Low, F. J., *et al.* 1984, *Ap. J.* (*Letters*), **278**, L19.
Magnani, L., and de Vries, C. P. 1986, *Astr. Ap.*, **168**, 271.
Magnani, L., Blitz, L., and Mundy, L. 1985, *Ap. J.*, **295**, 402 (MBM).
Magnani, L., Blitz, L., and Wouterloot, J. G. A. 1987, in preparation.
McCammon, D., Burrows, D. N., Sanders, W. T., and Kraushaar, W. L. 1983, *Ap. J.*, **269**, 107.
Morgan, W. W., Keenan, P. C., and Kellman, E. 1943, *An Atlas of Stellar Spectra* (Chicago: University of Chicago Press).
Paresce, F. 1984, *A.J.*, **89**, 1022.
Perry, C. L., and Johnston, L. 1982, *Ap. J. Suppl.*, **50**, 451.
Perry, C. L., Johnston, L., and Crawford, D. L. 1982, *A.J.*, **87**, 1751.
Savage, B. D., Bohlin, R. C., Drake, J. F., and Budich, W. 1977, *Ap. J.*, **216**, 291.
Ungerechts, H., and Thaddeus, P. 1987, *Ap. J. Suppl.*, **63**, 645.
Weiland, J., Blitz, L., Dwek, E., Hauser, M. G., Magnani, L., and Rickard, L. J. 1986, *Ap. J.* (*Letters*), **306**, L101.

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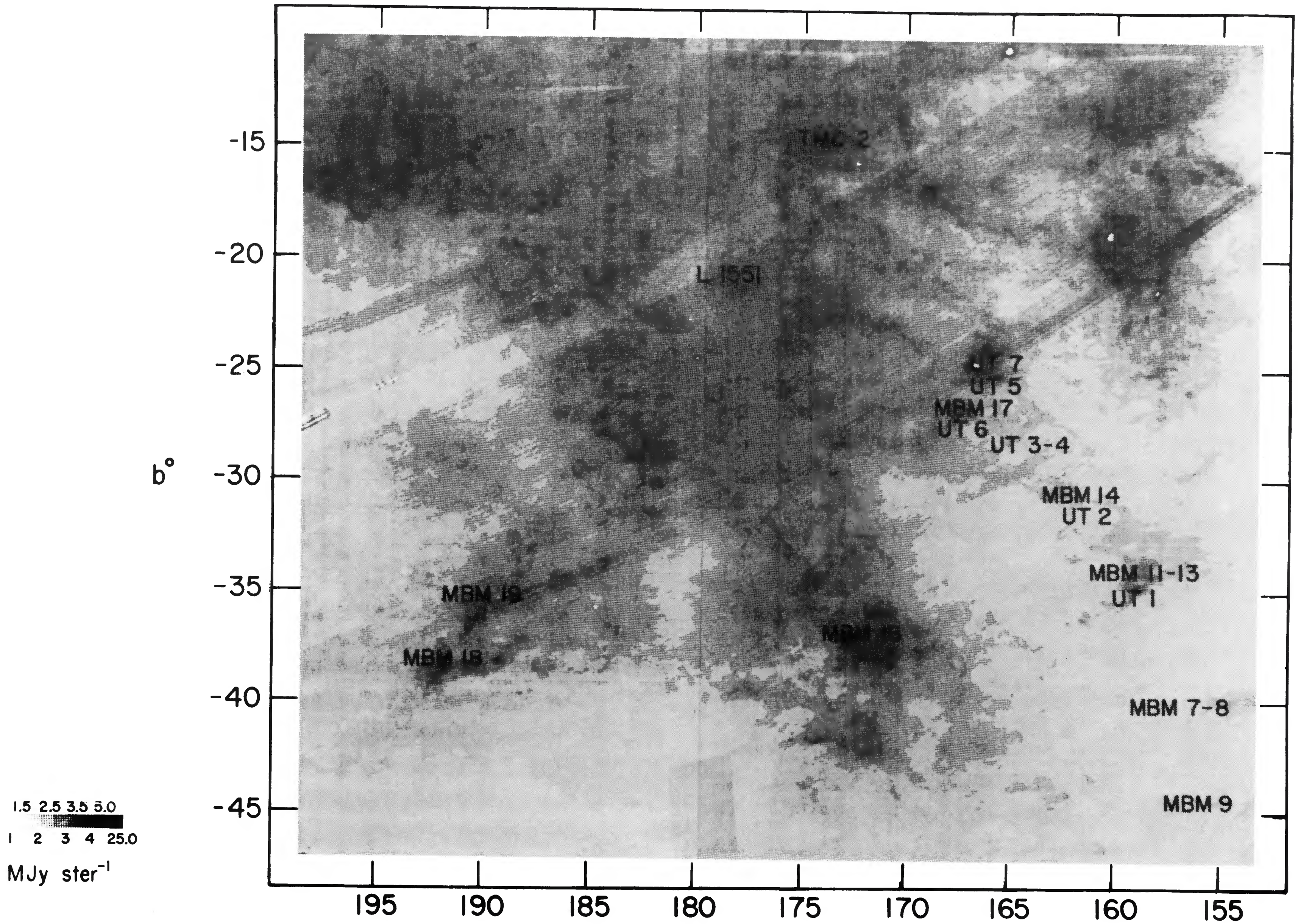

FIG. 5.—*IRAS* Skyflux map of the 100 μm emission from the Taurus-Auriga complex of dark clouds. The MBM designations are from Magnani, Blitz, and Mundy (1985), and the UT designations are from Ungerechts and Thaddeus (1987).

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