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The distance to the nearest star-forming clouds: MBM12 and MBM20

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Abstract. We present high-resolution spectra (R $\sim$ 49,000) of stars that have parallax measurements from the *Hipparcos* satellite and are projected along the line of sight to the two nearest known star forming clouds to the Sun: MBM12 and MBM20. The spectra were obtained with the FOCES Echelle Spectrograph at the 2.2 meter telescope in Calar Alto, Spain and the wavelength range was chosen to include the interstellar Na I D lines at $\lambda 5889.950$ Å and $\lambda 5895.924$ Å. Since the stars are at a range of distances, we use their spectra along with their parallaxes from *Hipparcos* to determine the distance to the molecular gas. The stars in front of the cloud do not show interstellar Na I D absorption features while the stars behind the cloud do show interstellar absorption features. We find that both clouds are somewhat more distant than previously estimated. The revised distance to MBM12 is 58$\pm$5 pc $< d <$ 90$\pm$12 pc and the distance to MBM20 is 112 ± 15 pc $< d < 161 \pm 21$ pc.

Key words: stars: formation – ISM: clouds – ISM: individual objects: MBM12 – ISM: individual objects: MBM20

1. Introduction

The two nearest known star forming clouds to the Sun are MBM12 and MBM20. The MBM12 complex consists of clouds 11, 12, and 13 from the catalog of Magnani et al. (1985) and is located at (l,b) $\sim$ ($159\overset{\circ}{.}4$,$-34\overset{\circ}{.}3$) (we will refer to the entire complex as MBM12). It was first identified by Lynds (1962) and appears as objects L1453-L1454, L1457, L1458 in her catalog of dark nebulae. The mass of the entire complex is estimated to be $\sim$ 30–200 $M_\odot$ based on radio maps of the region in ^{12}CO, ^{13}CO and C^{18}O (Pound et al. 1990; Zimmermann & Ungerechts 1990). The cloud MBM20 was first identified as L1642 in the Lynds (1962) catalog of dark nebulae. The mass of MBM20 is $\sim$ 84 $M_\odot$ and it is located at (l,b) $\sim$ ($210\overset{\circ}{.}9$,$-36\overset{\circ}{.}6$) southwest of the Orion star forming complex (Magnani et al. 1985).

Both MBM12 and MBM20 are star forming clouds. Several T Tauri stars have been identified in MBM12 via Hα emission line and X-ray surveys (Herbig & Bell 1988; Stephenson 1986; Hearty et al. 2000). Two binary classical T Tauri stars have been identified in the central region of MBM20 (Sandell et al. 1987). Subsequent high-resolution ^{12}CO(J=1-0) observations near the center of the cloud have shown that the infrared point source IRAS04325-1419 corresponding to one of the binaries is associated with a red and blue-shifted bipolar outflow (Liljeström et al. 1989).

Using *ROSAT* observations, Kuntz et al. (1997) find evidence based on the possible detection of 0.25 keV X-ray shadows of these clouds that both are located either within or at the edge of the Local Bubble. They estimate that distances, d, of $60 \leq d \leq 90$ pc to MBM12 and $d <$ 100 pc to MBM20 are consistent with the foreground 0.25 keV emission seen in the direction of each cloud. The distances are also consistent with previous distance estimates (see Sect. 2).

Since MBM12 and MBM20 are both star forming clouds which are probably located within or at the edge of the Local Bubble, determining an accurate distance to these clouds is important for studies of stars and of the interstellar medium. In addition, observations of MBM12 are already scheduled for *XMM* (50 ks) and *Chandra* (100 ks) to investigate the diffuse X-ray emission of the Local Bubble. Therefore we present observations to improve the distance estimates to both clouds. In Sect. 2 we review previous distance estimates for these clouds and the *Hipparcos* results that revise them. In Sect. 3 we present our spectroscopic observations of *Hipparcos* stars along the line of sight to both of the clouds which we use to improve the previous distance estimates. In Sect. 4 we summarize our investigations and suggest future observations.

2. Previous distance estimates

The distances to MBM12 and MBM20 have previously been derived using both photometric and spectroscopic techniques. The spectroscopic technique used in this paper was first used by Hobbs et al. (1986) and Hobbs et al. (1988) to estimate the distance to MBM12 and by Penprase (1993) to estimate the distance to MBM20. These studies looked for interstellar Na I D lines at $\lambda 5889.950$ Å and $\lambda 5895.924$ Å in bright stars in the direction of each cloud. Since the distance to each star was known via its *spectroscopic* parallax, the distance to the cloud could be determined. The stars with interstellar Na I absorption features were presumed to be behind the cloud and those

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Table 1. Stars from Hobbs et al. (1986), Hobbs et al. (1988), and Penprase (1993)

HD	HIP	V	SpT	Distance [pc]		Na I
		[mag]		spectroscopic	*Hipparcos*	
			MBM12			
18090	···	8.85	F3V	145	···	yes
18091	13579	7.00	A9V	85	96 ± 11	no
18190	···	8.98	A9V	185	···	yes
18256	13702	5.63	F6V	25	35 ± 1	no
18283	13723	8.78	A8III	380	150 ± 29	yes
18404	13834	5.80	F5IV	60	32 ± 1	no
18484	13892	6.70	A3III	211	141 ± 35	yes
18508	13913	7.34	F2V	80	91 ± 8	no
18519/20[a]	13914	4.63	A2Vs	70	90 ± 12	yes
18654	14021	6.79	A0V	160	128 ± 18	yes
			MBM20			
28497[b]	20922	5.61	B2V	740	483 ± 191	no
28763	21110	6.25	A2/A3V	110	123 ± 13	no
28856	21168	9.28	A1V	500	453 ± 293	yes
29482	21577	7.33	B9.5V	210	441 ± 437	yes
29573	21644	4.99	A0V	65	70 ± 4	no
SAO149801	···	9.76	K5	···	···	no
29851	21837	6.64	A2IV/V	110	161 ± 21	yes

[a] The angular separation listed in the *Hipparcos* catalog for this pair is $1.453 \pm 0.002''$ and the magnitude difference is 0.35 ± 0.01 mag.
[b] Blades et al. (1997) detected 13 interstellar absorption components in an ultra-high-resolution (R $\sim$ 938,000) Na I spectrum of this star, however, none of the components are at the radial velocity of MBM20.

without interstellar features were presumed to be in front of the cloud or not located behind a sufficient column density to detect the interstellar line. Since the *Hipparcos* satellite measured the *trigonometric* parallax for most of the stars used to determine the distance to MBM12 and MBM20, it is no longer necessary to assume a spectral type or intrinsic luminosity (as is necessary for a spectroscopic parallax) to measure their distance.

The stars used by Hobbs et al. (1986), Hobbs et al. (1988), and Penprase (1993) to establish the distance to MBM12 and MBM20 are listed in Table 1 with their apparent magnitude, spectral type, distance based on spectroscopic parallax, distance based on the *Hipparcos* parallax[1] and whether the spectrum presented in Hobbs et al. (1986) and Hobbs et al. (1988) showed interstellar Na I absorption lines.

2.1. MBM12

Previous distance estimates to the cloud MBM12 have already been discussed by Hearty et al. (2000). We just note the *Hipparcos* results here. In their search for interstellar Na I D lines in the spectra of stars along the line of sight to MBM12, Hobbs et al. (1986) found that the star HD18404 (distance $\sim$ 60 pc) showed no interstellar absorption features and is therefore presumably in front of the cloud and the star HD18519/20 (distance $\sim$ 70 pc) did show interstellar absorption features and is therefore behind the cloud. According to *Hipparcos*, the distance to HD18404 is $\sim$ 32$\pm$1 pc and the distance to HD18519/20 is $\sim$ 90$\pm$12 pc. Although the *Hipparcos* results indicate the distance to MBM12 is not as well constrained, it is consistent with previous estimates (i.e., 32$\pm$1 pc $< d <$ 90$\pm$12 pc).

Hobbs et al. (1986) note that it remains possible, although unlikely, that a Na I cloud is located in the foreground of a more distant CO cloud at virtually the same radial velocity. Therefore it is important to note that there are at least two stars located behind the cloud which show a large extinction (see Fig. 1). However, both of these stars are too faint to have been observed with *Hipparcos*. One of the stars, H0253+193, is an eclipsing cataclysmic variable (Koyama et al. 1991; Zuckerman et al. 1992). Zuckerman et al. (1992) estimate a distance of $\sim$ 200 pc and a visual extinction $A_v \sim$ 11.5 mag based on its near infrared colors. In addition, Hearty et al. (2000) showed that the optical spectrum of another star, DC48 (Duerr & Craine 1982), corresponds to a G9 star. Comparing the magnitude and color measured by Duerr & Craine (1982) for this star (V = 18.7 and V-I = 5.6 mag) to the intrinsic values of a G9 star, it could be a main sequence star with $A_v \sim$ 8.9 mag at a distance of $\sim$ 63 pc or a giant star with $A_v \sim$ 8.4 mag at a distance of $\sim$ 950 pc. Future observations to better constrain the distance, the luminosity class, and the spectral type of this star may prove that the CO and the Na I clouds along this line of sight are one and the same and provide a new upper limit on the distance to MBM12.

2.2. MBM20

The cloud MBM20 is located southwest of several cometary globules probably associated with the Orion star forming region. However, previous photometric and spectroscopic observations of MBM20 and the morphology of the cometary globules suggest that MBM20 is much closer to the Sun than the cometary globules in the region. Studies of star formation in Bok globules in the Gum Nebula have identified Bok globules with comet-like tails pointed away from the central OB association (e.g., Reipurth 1983). This type of large scale morphology which Bally et al. (1991) argue is caused by the energy injected from massive stars can also be seen in the cometary clouds surrounding the Orion OB association where many clouds have dense heads with tails pointing away from the center of the Orion OB association. Whatever the mechanisms are that generate the cometary clouds, there are no signs that MBM20 is interacting with the bright stars in Orion (i.e., there is no cometary tail pointed away from the OB association).

Magnani & de Vries (1986) used star counts to estimate an upper limit for the distance to this cloud to be $\sim$ 125 pc. More recently, Penprase (1992) derived a photometric distance, d, to MBM20 of $100 \leq d \leq 120$ pc.

[1] All *Hipparcos* distance errors, σ_d, in this paper are approximated based on the parallax, π, and standard parallax error, σ_π, from the *Hipparcos* catalog using the error propagation equation given by Bevington & Robinson (1992). Thus, the error in distance is given by $\sigma_d = \sigma_\pi/\pi^2$, where σ_d is in parcecs, and π and σ_π are in arcseconds.

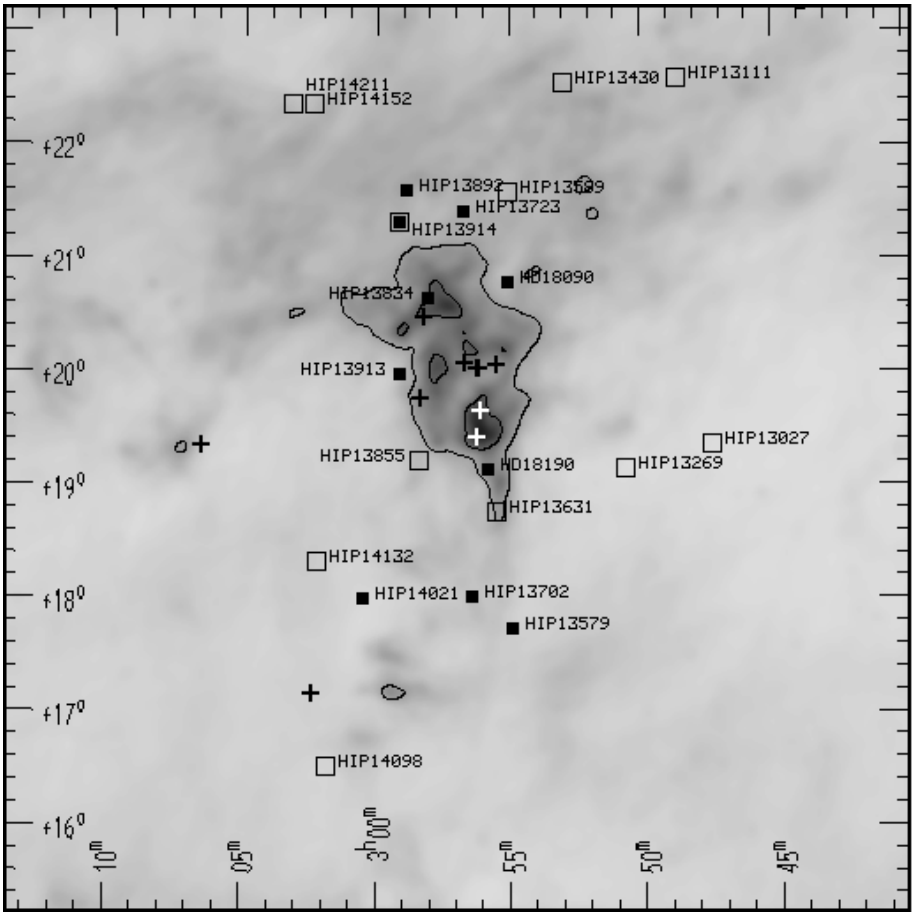

Fig. 1. The gray scale image shows the extent of the IRAS 100μm emission from MBM12. The filled squares are the stars observed by Hobbs et al. (1986) and Hobbs et al. (1988) to determine the distance to the cloud and the open squares are the stars we observed to determine the distance to the cloud. The black plus symbols mark the locations of the eight T Tauri stars in MBM12 (two of which are not resolved in this figure). The white plus symbols mark the two lines of sight toward the cataclysmic variable H0253+193 at (RA,Dec) = (2:56:10.5,+19:26:43) and G9 star DC48 at (RA,Dec) = (2:56:00.4,+19:40:44) which are known to have $A_{\rm v} > 5$ mag (Hearty et al. 2000). The gray scale is linear from 0 to 40 MJy sr^{-1}. The contours are at 15 MJy sr^{-1} and 25 MJy sr^{-1}. This figure is in J2000 coordinates.

Using the same technique we use in this paper, Penprase (1993) arrived at an upper limit for the distance to MBM20 ($\sim$ 110 pc) by observing Na I D interstellar absorption features is stars for which a spectroscopic parallax could be determined (cf. Hobbs et al. 1986). The nearest star which showed interstellar Na I absorption, HD29851, is at a distance of 110 pc based on its spectroscopic parallax. Since none of the stars observed by Penprase (1993) were superimposed on the cloud contours, a lower limit for the distance to the cloud could not be determined. However, even without a lower limit on the distance, these observations showed that MBM20 is among the nearest star forming molecular clouds to the Sun. The *Hipparcos* parallax for HD29851 places it at $\sim 161 \pm 21$ pc. Therefore, the *Hipparcos* results indicate the distance to the cloud could be larger than previous estimates.

3. Spectroscopic observations

Since there are additional *Hipparcos* stars at intermediate distances to the previous estimates in the direction of both MBM12 and MBM20, we obtained high-resolution spectroscopic observations near the Na I D lines of some of these stars to refine the distances to both clouds (cf. Hobbs et al. 1986). The stars used by Hobbs et al. (1986), Hobbs et al. (1988), and by us to determine the distance to MBM12 are displayed on an IRAS 100μm image of the region in Fig. 1 and the stars used by Penprase (1993) and by us to determine the distance to MBM20 are displayed on an IRAS 100μm image of the region around MBM20 in Fig. 2

We obtained the spectra with the FOCES Echelle Spectrograph at the 2.2-m telescope in Calar Alto, Spain in August 1998. The Tek#13c 1K×1K chip with the FOCES Echelle Spectrograph provided a spectral resolution, $R = \lambda/\delta\lambda \sim$ 49,000, derived from measurements of the FWHM (FWHM $\sim$ 0.12 Å) of several well isolated emission lines of the comparison spectra near the Na I D lines. As a rule, the smallest measurable equivalent width in units of mÅ is approximately the reciprocal dispersion in units Å mm^{-1} (Jaschek & Jaschek 1987). Therefore, given the 24μm pixels of the CCD we used for the observations, the smallest measurable equivalent width for these spectra is $\sim$ 5 mÅ. This corresponds to a minimum detectable column density N(Na I) $\sim 6 \times 10^{10}$ cm^{-2} in the optically thin case. All spectra were given an initial inspection at the telescope. If a particular integration produced fewer than $\sim$ 1000 cts pixel^{-1}, at least one additional integration was performed.

The observed stars are listed in Table 2 with their coordinates, apparent magnitude, spectral type, *Hipparcos* distance, and whether the observed spectrum contains interstellar Na I features. We observed HIP13914, although it was already known to show interstellar Na I absorption, to ensure that we could detect the lines, if present. Although we made no attempt to correct for telluric features, our measured equivalent widths of the inter-

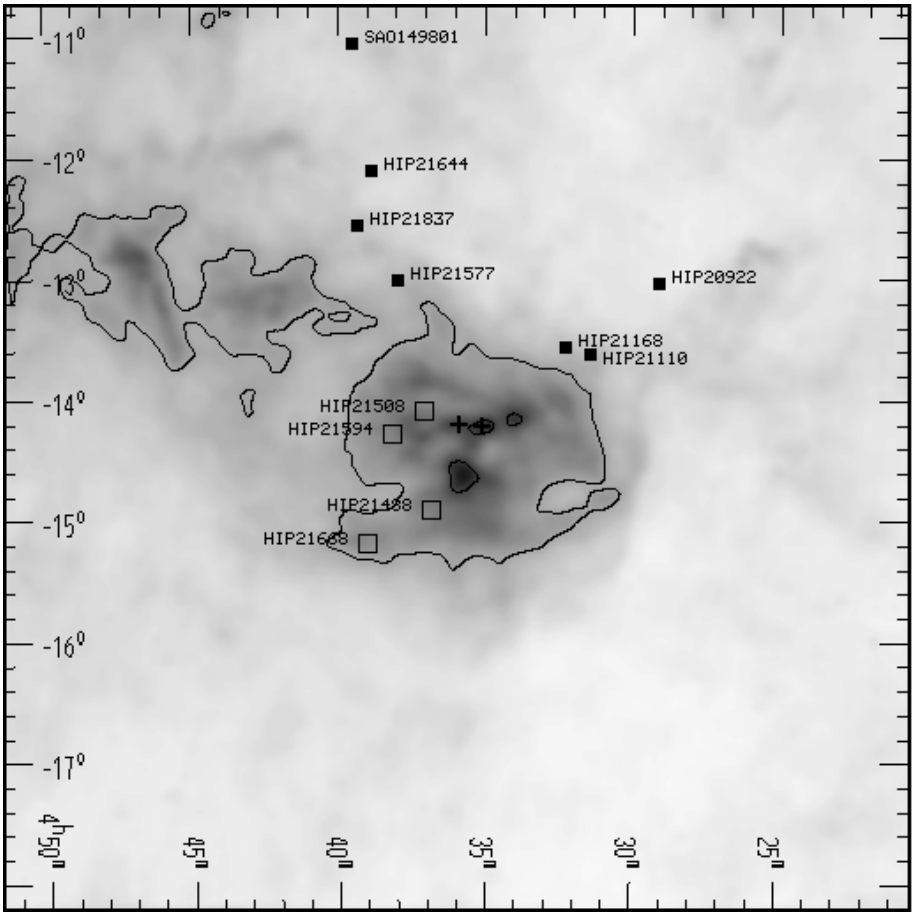

Fig. 2. The gray scale image shows the extent of the IRAS 100μm emission from MBM20. The filled squares are the stars observed by Penprase (1992) to determine the distance to the cloud and the open squares are the stars we observed to determine the distance to the cloud. The black plus symbols mark the locations of two binary T Tauri stars in MBM20. The gray scale is linear from 0 to 20 MJy sr^{-1}. The contours are at 7 MJy sr^{-1} and 15 MJy sr^{-1}. This figure is in J2000 coordinates.

stellar Na I D1 and D2 lines 129 mÅ and 167 mÅ, respectively, in HIP13914 are in good agreement with the measurements of Hobbs et al. (1986), 127 mÅ and 149 mÅ which were performed at the same spectral resolution. All of the observed spectra are displayed in Fig. 3.

None of the observed stars along the line of sight to MBM12 except HIP13914 showed interstellar Na I absorption, therefore the upper limit on the distance to the cloud remains $\sim 90 \pm 12$ pc. Since HIP13631 is the only star we observed that is superimposed directly on the cloud and it does not show interstellar Na I absorption, we can place a lower limit on the distance to the cloud of $\sim 58 \pm 5$ pc. Therefore the distance to MBM12 is 58 ± 5 pc $< d < 90 \pm 12$ pc.

The observed stars along the line of sight to MBM20 are all projected on the central region of that cloud. Since we did not detect interstellar Na I D lines in any of the observed stars, we can place a lower limit on the distance to MBM20 of $\sim 112 \pm 15$ pc. Therefore the distance to MBM20 is 112 ± 15 pc $< d < 161 \pm 21$ pc.

Table 2. Observed Stars

HIP	RA	Dec	V [mag]	SpT	Distance [pc]	Na I
			MBM12			
13027	02 47 27.4	+19 22 19	6.90	G0	33 ± 2	no
14211	03 03 13.7	+22 22 11	10.78	M0	43 ± 4	no
13631	02 55 32.3	+18 46 26	9.74	K0	58 ± 5	no
13269	02 50 42.6	+19 09 38	6.63	F8	61 ± 3	no
13589	02 55 04.9	+21 35 42	8.66	F8	63 ± 5	no
14152	03 02 27.4	+22 22 25	7.92	F5	72 ± 6	no
13855	02 58 23.8	+19 13 45	8.78	G0	74 ± 8	no
14098	03 01 50.6	+16 31 05	8.24	F5	81 ± 8	no
14132	03 02 15.6	+18 19 45	9.60	G5	84 ± 21	no
13914	02 59 12.7	+21 20 25	4.63	A2Vs	90 ± 12	yes
13111	02 48 37.4	+22 35 54	10.10	G4	91 ± 13	no
13430	02 52 57.6	+22 34 09	10.60	$\cdots$	107 ± 22	no
			MBM20			
21594	04 38 10.8	$-$14 18 14	3.86	K1III	34 ± 1	no
21488	04 36 53.9	$-$14 55 33	7.93	G2V	68 ± 7	no
21668	04 39 05.3	$-$15 12 59	9.32	G5	93 ± 12	no
21508	04 37 08.3	$-$ 14 07 03	8.93	F5V	112 ± 15	no

4. Conclusions

We have investigated the *Hipparcos* parallax measurements of stars to estimate the distance to the two nearest star forming clouds to the Sun: MBM12 and MBM20. The *Hipparcos* observations of previously observed stars suggest that the distances to both of these clouds are not as well constrained as previously thought, although they are consistent with the previous estimates. Therefore, we obtained high resolution spectra of ad-

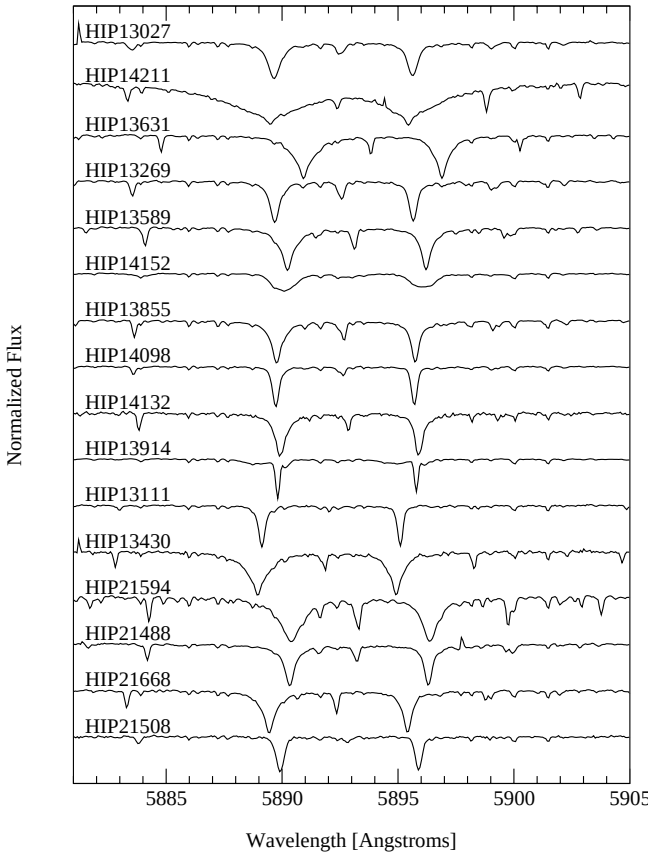

Fig. 3. Spectra are displayed for the observed Hipparcos stars along the line of sight to MBM12 and MBM20. The only star which shows interstellar Na I D absorption is HIP13914. All of the other stars have broader stellar Na I D lines.

ditional *Hipparcos* stars at intermediate distances and improved the distance estimates to both clouds. The distance to MBM12 is 58±5 pc $< d <$ 90±12 pc and the distance to MBM20 is $\sim 112 \pm 15$ pc $< d < 161 \pm 21$ pc. Since there are additional stars that were observed with *Hipparcos* that are projected near each cloud (though farther off axis than the stars we observed), future spectroscopic observations like those presented here may further refine our distance estimates.

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References

Bally J., Langer W.D., Wilson R.W., Stark A.A., Pound M.W., 1991, In: Falgarone E., Boulanger F., Duvert G., et al. (eds.) Fragmentation of Molecular Clouds and Star Formation.
Bevington P.R., Robinson D.K., 1992, In: Data Reduction and Error Analysis for the Physical Sciences. McGraw-Hill, New York, p. 43
Blades J.C., Sahu M.S., He L., et al., 1997, ApJ 478, 648
Duerr R., Craine E.R., 1982b, PASP 94, 567
Hearty T., Neuhäuser R, Stelzer B., et al., 2000, A&A, in press
Herbig G.H., Bell K.R., 1988, Lick Observatory Bulletin, Santa Cruz: Lick Observatory
Hobbs L.M., Blitz L., Magnani L., 1986, ApJ 306, L109
Hobbs L.M., Blitz L., Penprase B.E., Magnani L., Welty D.E., 1988, ApJ 327, 356
Jaschek, C., Jaschek, M., 1987, The Classification of Stars. Cambridge University Press, Cambridge, p. 13
Koyama K., Takano S., Matsumoto T., et al., 1991, ApJ 377, 240
Kuntz K.D., Snowden S.L., Verter F., 1997, ApJ 484, 245
Liljeström T., Mattila K., Friberg P., 1989, A&A 210, 337
Lynds B.T., 1962, ApJS 7, 1
Magnani L., Blitz L., Mundy L., 1985, ApJ 295, 402
Magnani L., de Vries C.P., 1986, A&A 168, 271
Penprase B.E., 1992, ApJS 83, 273
Penprase B.E., 1993, ApJ 88, 433
Pound M.W., Bania T.M., Wilson R.W., 1990, ApJ 351, 165
Reipurth B., 1983, A&A 117, 183
Sandell G., Reipurth B., Gahm G., 1987, A&A 181, 283
Stephenson C.B., 1986, ApJ 300, 779
Zimmermann T., Ungerechts H., 1990, A&A 238, 337
Zuckerman B., Becklin E.E., McLean I.S., Patterson J., 1992, ApJ 400, 665