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Polarization measurements of stars in the region of the nearby molecular cloud MBM 12

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SUMMARY

Linear polarization measurements of stars in the region of the nearby high-latitude molecular cloud MBM 12 are presented. Stars behind the cloud show a polarization ~2–3 per cent, while stars that are in front of the cloud or are projected outside the cloud boundary show very low values ($\lesssim 0.5$ per cent) of polarization. If the polarization is caused by dust grains aligned by a magnetic field, the observed polarization position angles suggest that the field in the cloud is more or less unidirectional and is roughly parallel to the long axis of the cloud. The cloud magnetic field has a direction that is significantly different from that of the local interstellar field and its strength may be as large as ~60 μG.

Key words: polarization – interstellar medium: clouds – dust, extinction – interstellar medium: magnetic fields.

1 INTRODUCTION

A large population of molecular clouds at high galactic latitudes was discovered by Magnani, Blitz & Mundy (1985, hereafter MBM). Their mean properties have been reviewed by Blitz (1991). With a characteristic distance of ~100 pc the high-latitude clouds (HLCs) are an important component of the local interstellar medium. The HLCs are low-mass clouds (mean mass ~$40 M_\odot$) with large internal velocity dispersions ($\sigma_v \sim 0.3$ km s^{-1} typically) and small mean lifetimes ~2×10^6 yr. For the low kinetic temperature ($T \lesssim 20$ K) of the cloud gas the observed velocity dispersion is highly supersonic. However, if a magnetic field of mean strength ~10 μG threads the cloud gas, the observed velocity dispersion can then be interpreted as due to Alfvén waves and is sub-Alfvénic (Blitz 1990). The magnetic field that permeates the cloud can produce other observable effects. The Zeeman effect has been measured by Heiles (1989) at a few positions that are sites of HLCs, indicating a mean strength of 6.4 μG for one component of the magnetic field. The magnetic field can also align dust grains in the cloud, which can cause polarization of light from stars that are behind the cloud. Polarization measurements of stars in the region of the clouds can be used to infer the existence of any ordered magnetic field in the cloud and map its geometry, as the linear polarization vectors are parallel to the field direction if the dust grain alignment is due to the Davis–Greenstein mechanism (see e.g. Greenberg 1978).

In this paper we present polarization measurements of stars in the region of the high-latitude cloud MBM 12 (see MBM). MBM 12 is located at $l = 159°$, $b = -34°$. The cloud is elongated, extending ~1° in right ascension and ~2°.5 in declination, and is part of a larger cloud complex UT1 (Ungerechts & Thaddeus 1987) that includes the Lynds (1962) dark clouds L1453, 1454, 1457 and 1458. Hobbs, Blitz & Magnani (1986) presented a map of the CO emission from MBM 12, and determined a distance of ~65 pc for the cloud by mapping the interstellar Na I *D* absorption toward several stars at different distances in the direction of the cloud. Its distance of ~65 pc makes MBM 12 the nearest known molecular cloud.

Halpern & Patterson (1987) found a hard X-ray source (H0253 + 193) in the direction of MBM 12, with its *Einstein* IPC position coinciding with the peak in the CO map of the cloud obtained by Hobbs *et al.* (1986). Takano *et al.* (1989) reported the discovery of X-ray pulsations from H0253 + 193 with a period of 206 s. Bhatt (1990) and Patterson & Halpern (1990) have discussed the nature of the X-ray pulsar which could either be a compact star (white dwarf or neutron star) that has accidentally drifted into the cloud or a DQ Herculis type cataclysmic variable behind the cloud.

Pound, Bania & Wilson (1990) have made extensive molecular (CO and CS) and atomic (H I) spectral maps of the MBM 12 region and found that the molecular gas (total mass ~$30 M_\odot$) is in clumps of mass ~$1 M_\odot$. The clumps are not gravitationally bound, either individually or to the complex as a whole. There is no evidence for either embedded heat sources within the clumps or for recent star formation in MBM 12 (Clemens & Leach 1989).

2 OBSERVATIONS

The polarimetric observations were made with the 1-m telescope at the Vainu Bappu Observatory, Kavalur, on the nights of 1990 December 10–11. A total of 19 stars were observed in the region of MBM 12. Due to the limitations imposed by the telescope size and the instrument, only stars brighter than ~13.5 mag were observed. The programme stars were chosen so as to cover different parts of the cloud. The sample of stars was otherwise randomly selected. A fast star-and-sky chopping polarimeter (Jain & Srinivasulu 1991) with an unfiltered dry ice-cooled EMI 9658R photomultiplier tube was used. Briefly, the star and the neighbouring sky, separated by about 2 arcmin at the Cassegrain *f*/13 beam of the telescope, are observed alternately every 20 ms and the signals due to star and sky are stored in separate memory locations in the computer. This is done at 200 orientations of the analyser. Typical integration times for the majority of the programme stars were ~10–12 min. An aperture of 15 arcsec was used in all the observations. The degree of polarization and the position angle were computed by least-squares fitting of a double cosine curve to the data and by computing the Fourier components of the fit. The mean instrumental polarization, determined by observing several of the unpolarized standards listed by Serkowski (1974), was found to be 0.10 per cent. Zero of the position angle was determined each night by observing the polarized standards of Hsu & Breger (1982).

3 RESULTS

In Table 1 we list the results of our polarimetric measurements for stars in the region of MBM 12. The region observed is shown in Fig. 1 reproduced from the Palomar Observatory Sky Survey prints. The stars observed have been numbered in increasing order of right ascension. Table 1 gives the polarization P (in per cent), the position angle θ (in degrees) and the probable errors ε_p and ε_θ associated with P and θ. The position angle θ is measured from north, increasing eastward. In Fig. 1, centred on the stars observed, the polarization vectors have been drawn. The length of the polarization vector is proportional to the percentage polarization P and it is oriented in the direction indicated by θ. Also shown in Fig. 1 is the outermost contour of the CO map of MBM 12 adapted from fig. 1 of Hobbs *et al.* (1986). Column 2 of Table 1 gives the magnitudes of the stars derived from the mean intensity measured. These magnitudes correspond to the effective wavelength of the unfiltered S20 (extended red) cathode $\lambda_{\mathrm{eff}} \simeq 0.7$ μm, and can be considered to approximate the Johnson R band. Probable errors in these magnitudes are ~0.1 mag. Four of the programme stars have been identified with stars in the SAO catalogue. Their SAO numbers are given in column 1 of Table 1.

Table 1. Polarization measurements of stars in the region of MBM 12.

Star No. (SAO NO.)	m (mag)	P (%)	ϵ_p (%)	θ (°)	ϵ_θ (°)
1 (75627)	6.3	0.32	0.06	165	6
2	9.2	1.10	0.05	151	1
3	12.1	2.30	0.23	148	3
4	9.8	0.45	0.07	117	4
5 (75635)	8.4	0.34	0.11	125	9
6	9.7	2.22	0.06	170	1
7	9.8	0.23	0.06	124	8
8	9.3	0.19	0.05	136	8
9	8.6	0.43	0.04	120	3
10	13.5	2.69	0.54	165	6
11	13.2	2.33	0.45	134	6
12	11.3	2.26	0.12	152	2
13	9.5	0.33	0.08	81	7
14 (75664)	8.9	0.40	0.10	144	7
15	9.9	0.35	0.06	118	5
16	10.6	3.09	0.10	156	1
17	9.7	2.71	0.22	159	2
18	11.4	3.08	0.16	165	1
19 (75669)	9.0	3.67	0.11	149	1

4 DISCUSSION

It can be seen from Table 1 that the observed polarization of stars in the region of MBM 12 ranges from ~0.2 to ~3.7 per cent. The histogram of observed polarizations (Fig. 2) shows clearly that there are two groups of stars having low and high values of polarization respectively. Stars (1, 4, 5, 7, 8, 9, 15) showing low values of polarization are seen projected either close to or outside the cloud boundary as defined by the CO contour drawn in Fig. 1, while stars showing high polarization are seen projected within the cloud boundary. This can be understood if the dust in the cloud causes polarization of light from stars seen through the cloud. Stars 13 and 14 are seen projected well within the cloud boundary, but show low values of polarization. These stars may be foreground to the cloud. Star 2 is seen projected just outside the cloud boundary and has an intermediate value of polarization ($P = 1.1$ per cent). It should be noted here that, in reality, the cloud boundaries are not sharp and molecular clouds have lower opacity atomic envelopes. Star 2 may be in the background of such a region.

Fig. 3 shows a plot of polarization P against magnitude m. The brighter stars show low values ($\lesssim 0.45$ per cent) of polarization. There is a jump in the observed polarization to ~2.5 per cent at $m \sim 9.5$. The degree of polarization stays at this level even for much fainter stars. In the absence of information about the spectral types, the distances to the stars cannot be determined. However, Fig. 3 suggests that the stars with low values of polarization are bright foreground stars, while the fainter stars with high values of polarization are behind the cloud. Since the cloud is known to be at a distance of ~65 pc (Hobbs *et al.* 1986) it can be concluded that in this direction the interstellar dust up to a distance of ~65 pc causes a polarization of $\lesssim 0.45$ per cent and the dust in MBM 12 introduces a polarization of ~2–3 per cent in the light of stars behind it.

The polarization position angles show a pattern that is correlated with the degree of polarization. The distribution

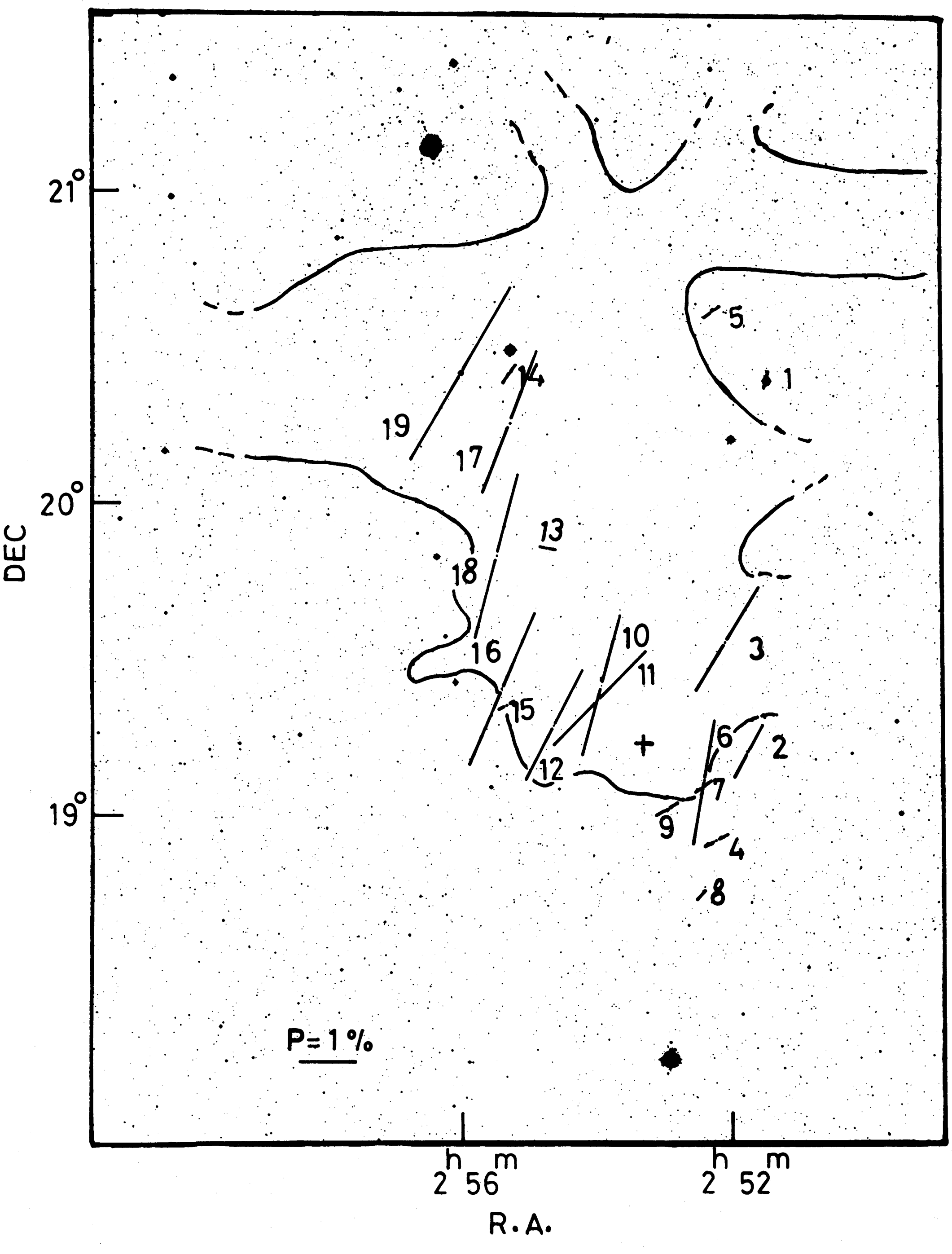

Figure 1. Polarization map for the region of MBM 12. The polarization vectors have been drawn, centred on the stars above. The outermost contour of the CO map of the cloud, adapted from Hobbs *et al.* (1986), has been superposed.

of position angles for the two groups of stars is different. The position angles for the 10 stars (2, 3, 6, 10, 11, 12, 16, 17, 18, 19) that have high values of polarization have a distribution characterized by a mean $\theta = 155°$ and a small dispersion $\sigma_\theta = 10°$. The nine stars (1, 4, 5, 7, 8, 9, 13, 14, 15) that have low values of polarization are characterized by a mean $\theta = 125°$ and a larger dispersion in position angle $\sigma_\theta = 21°$. This dispersion is much larger than the mean probable error ($\varepsilon_\theta = 6°$) in the position angle measurements.

If the polarization is caused by dust grains aligned by the magnetic field, the polarization position angles also represent the projected direction of the magnetic field. The distribution of the position angles therefore can be interpreted as follows. The magnetic field in the MBM 12 cloud (at least in the outer parts of the cloud where the stars observed in this study are seen projected) is more or less unidirectional with a projected position angle ~155°. This is because the dispersion in the polarization position angles for stars that have large values of polarization and are behind the cloud is small ($\sigma_\theta \sim 10°$). Stars with low values of polarization are polarized by dust in the low-density interstellar medium outside the cloud or foreground to it. The polarization position angle in

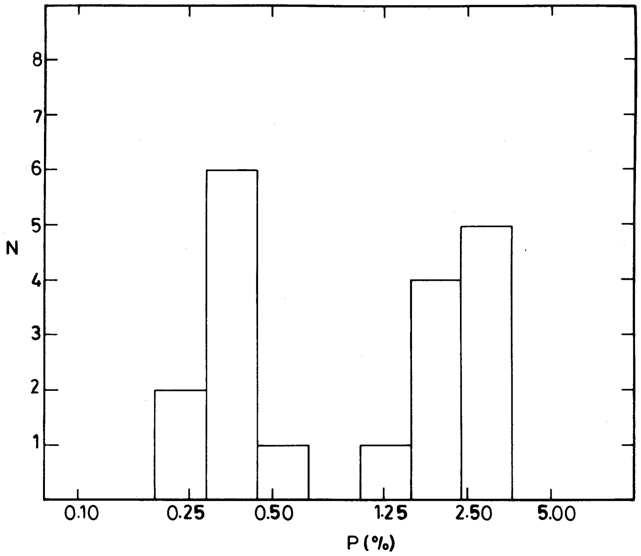

Figure 2. Histogram showing the distribution of the observed polarization for stars in the region of MBM 12.

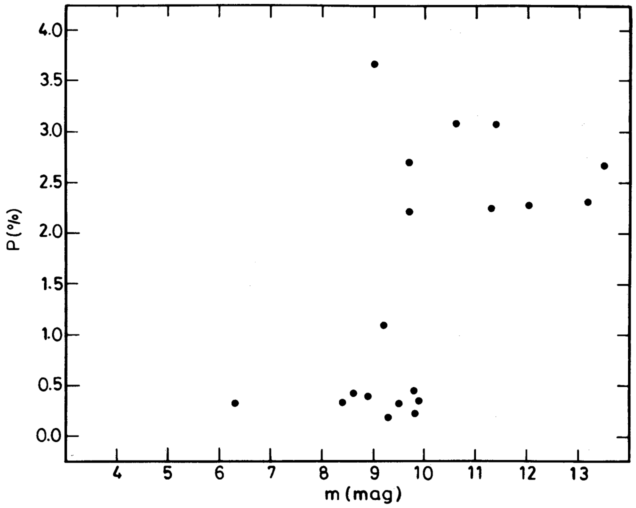

Figure 3. Plot of polarization P against the magnitude m for stars in the region of MBM 12.

this case is determined by the magnetic field direction over a longer path-length (~ 70 pc) than for the background stars for which most of the polarization is caused by dust within the cloud (linear size ~ 1 pc). Changes in the field direction over the longer path-length could cause the larger dispersion in the observed polarization position angles for the stars with low values of polarization. The projected interstellar magnetic field in the direction of MBM 12 has a mean position angle $\sim 125°$. The magnetic field in the cloud has a direction ($\theta \sim 155°$) that is significantly different from the direction of the local interstellar magnetic field. It is noted here that MBM 12 is an elongated cloud (this is more clearly seen in fig. 2 of Pound *et al.* 1990), and the long axis of the cloud is nearly parallel to the magnetic field direction in the cloud. This suggests that the magnetic field has played an important role in the dynamics of the cloud and influenced its morphology.

The polarization map shown in Fig. 1 also suggests that the entire MBM 12 complex is at the same distance. The distance of 65 pc obtained by Hobbs *et al.* (1986) is based on Na I spectra of 47 Ari and ε Ari AB that lie projected on the upper part of the complex, and, strictly interpreted, should apply only to the upper part of the cloud (Pound *et al.* 1990). The similarity of the polarization position angles for stars projected on the lower part of the complex to those for stars projected on to the upper part indicates that the entire complex is threaded by a more or less uniform single field pattern. All parts of the complex are therefore likely to be at the same distance and the field direction does not change significantly across the cloud complex.

The strength of the magnetic field in MBM 12 should be large enough to align dust grains on a time-scale shorter than the time-scale for disorientation due to collisions with gas particles. The dust in the cloud causes a polarization $P \sim 2.5$ per cent. The average extinction A_V due to dust in the outer parts of the cloud (through which the background stars have been observed in this study) is of the order of ~ 1–2 mag, as indicated by the relative star counts in the outer parts of the cloud and in the higher opacity inner regions of the cloud (L1453, 1454, 1457, 1458) that have $A_V \sim 3$–4 mag (Lynds 1962). Thus the P/A_V ratio for the outer parts of MBM 12 is ~ 1–2 per cent mag^{-1}. This ratio is similar to that for the general interstellar medium. Therefore the dust grains in the cloud must be aligned as efficiently as in the interstellar medium. Since the cloud density is large, the magnetic field required to achieve grain alignment is also large. Following Greenberg (1978), the required magnetic field B is given by

$$B^2 = 0.5 a n_{\mathrm{H}} T_{\mathrm{d}} T_{\mathrm{g}}^{1/2}, \tag{1}$$

where a is the average grain size in μm, T_{d} and T_{g} are the dust and gas temperatures and n_{H} is the hydrogen gas number density. With an average density $n_{\mathrm{H}} \sim 10^3$ cm^{-3} for MBM 12 which is about 1 pc in extent and has a mass $\sim 30 M_{\odot}$ (Pound *et al.* 1990), $a = 0.1$ μm, $T_{\mathrm{d}} \sim 25$ K (Clemens & Leach 1989) and $T_{\mathrm{g}} \sim 10$ K (Pound *et al.* 1990), we obtain $B \sim 60$ μG.

5 CONCLUSIONS

We have presented the results of linear polarization measurements for 19 stars in the region of MBM 12. Our conclusions can be summarized as follows.

(i) The dust in the cloud introduces ~ 2–3 per cent polarization in the light of stars behind it.

(ii) The magnetic field in the cloud is more or less unidirectional and has a position angle $\theta \sim 155°$.

(iii) The field is roughly parallel to the long axis of the cloud, suggestive of an important role played by the magnetic field in the dynamics of the cloud.

(iv) The magnetic field in the cloud has a direction significantly different from the direction of the local interstellar field.

(v) The strength of the magnetic field in the cloud could be as large as ~ 60 μG.

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