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Imaging polarimetry of some selected dark clouds*

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Abstract. A set of eight Bok Globules CB3, CB25, CB39, CB52, CB54, CB58, CB62 and CB246 were observed polarimetrically in white light, using our Imaging Polarimeter (IMPOL), from the 1.2 m IR telescope at Mount Abu, India. The observations were carried out on different nights during the period December 1997 and April 1998. The CCD images obtained from the instrument (IMPOL) were analyzed, to produce polarization map of the Bok Globules. The stars in the field, which are mostly background to the cloud show typically 2% of linear polarization. Clouds which are less dynamic (having ^{12}CO line widths ΔV $<$ 2.5 km s^{-1}), in general show slightly better alignment of polarization vectors with the projected direction of galactic plane. On the other hand the more dynamic group of clouds, has the polarization vectors more scattered and poorly aligned with the projected direction of the galactic plane. However one of the clouds observed CB58 does not follow this trend very well.

Key words: dark clouds — ISM: dust — ISM: magnetic field-polarization-polarimeter — techniques: polarimetric

1. Introduction

It was first suggested by Bok & Reilly (1947) that small, compact and isolated dark regions in the sky (now called "Bok Globules") may be undergoing gravitational collapse and may eventually form low mass stars. Barnard (1927) had earlier prepared a list of such dark regions in the sky. Lynds (1962) later published a catalogue, with a larger number of such dark objects. Bok (1956) himself studied many such clouds. Subsequently the importance of these clouds as possible sites for star formation were felt by many workers (papers in Lynds 1971; Villere & Black 1980; Leung et al. 1982; Vrba et al. 1981; Keene et al. 1983; Joshi et al. 1985 etc.). Recently Clemens & Barvainis (1988) (henceforth CB) have compiled a list of 248 small (mean size $\sim 4'$) and nearby (distance $<$ 1 kpc) molecular clouds.

Bok's speculations got firmly established through Infra-red (IRAS survey) and millimeter studies (^{12}CO map) on these clouds (Keene et al. 1983; Goldsmith et al. 1984; Yun & Clemens 1990; Clemens et al. 1991; Yun & Clemens 1992 etc.). These clouds undergo gravitational collapse and magnetic force plays a key role in collapse dynamics by mediating accretion, directing the outflows and collimating the jets. The determination of the strength and geometry of the magnetic field in these clouds help to understand the dynamics of the star formation processes (Goodman et al. 1989; Myers & Goodman 1991; Kane et al. 1995 etc.). However, it is not very easy to determine magnetic field geometry in a cloud. When light from a star passes through the interstellar (henceforth IS) medium it gets linearly polarized due to forward scattering by the dichroic IS grains. The IS magnetic field is believed to be responsible for the alignment of these dichroic grains (Davis & Greenstein 1951).

In the past there have been many studies of polarization with a view to trace the geometry of the magnetic field in dark clouds. These studies have shown that the relation between the extinction and polarization of the background

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* Tables 4 to 15 are also available at the CDS in electronic form (ftp 130.79.128.5) or http://cdsweb.u-strasbg.fr/Abstract.html

Figures 1 to 11 are only available at the http://www.edpsciences.org star is far from unique and depends on the environment of the cloud. Thus although quite large values of polarization could be associated with large extinction (Hodapp 1987; Zaritsky et al. 1987; Jones 1989), the polarization efficiency appears to be low for dark clouds (Jones et al. 1984; Klebe & Jones 1990). It was also found that the polarization did not increase linearly with extinction (Jones 1989; Jarrett et al. 1994). Jones (1989) and Goodman et al. (1990) suggested that a combination of regular and random magnetic fields could be responsible for the lack of linear increase in polarization with extinction. Myers & Goodman (1991) and Jones et al. (1992) modeled the magnetic fields in clouds to explain the polarization-extinction relation. On the other hand, Goodman et al. (1995) and Creese et al. (1995) have argued that the grains in dark clouds are poorly aligned and contribute very little to the polarization. These conclusions have been confirmed by theoretical modeling by Lazarian et al. (1997) and further observation by Arce et al. (1998).

There is a need to study further: (i) the relation between physical environment in dark clouds and alignment of grains and (ii) alignment mechanism for the polarization vectors and its connection the ambient magnetic fields in the clouds. With these aims we have carried out imaging polarimetric observations of eight clouds selected from the catalogue by CB. From our observations we construct the polarization maps and report our results with some preliminary discussions.

2. Observation, instrumentation and data reduction

Observations were made at the cassegrain focus (f/13 beam) of 1.2 m telescope of the Gurushikhar Infra-Red Telescope (GIRT; lat. = $24°36'$; long. = $+72°43'$; altitude = 1750 m), Mount Abu, India (operated by Physical Research Laboratory, Ahmedabad, India), in two phases on the nights of Dec. 23, 24, 25, 1997 and Apr. 01, 02, 03, 1998.

From the catalogue by CB we selected a set of eight objects. Some of the clouds listed by CB were surveyed for the existence of Young stellar objects (YSO), IRAS point sources and CO outflows (Yun & Clemens 1990; Clemens et al. 1991; Yun & Clemens 1992; Yun & Clemens 1994). Accordingly the clouds can be divided into several categories (i) Y- where YSO has been detected (ii) R- where IRAS point sources have been detected and (iii) O- where CO outflows have been detected. A cloud can also belong to a category which is a combination of any of these. Further in some cases survey has been carried out, but the cloud has been found to be quiescent having no activity, we call it category Q.

Thus the selection has been made from those clouds, which have been surveyed for YSO, IRAS point sources or CO outflows. We included in our list only one cloud (CB62), where no survey has been carried out.

Also clouds were selected on the basis of their availability in the sky, during the time of our observation from our observatory site. We avoided those clouds having very bright field star(s), because this will saturate our CCD. In Table 1, we list these eight clouds, with the category of each cloud mentioned within the bracket. All the observations were taken in open filter or white light (W) with 500 seconds exposure time. Table 1 gives a detail of the observation log. We observed the cloud CB54 in two parts, from the central co-ordinates (RA = 07:04:16.8; DEC = -16:24:33) we moved into two regions and named them CB54A (same RA, DEC = $2.5'$ North of central DEC) and CB54B (same RA, DEC = $2.5'$ South of central DEC). Thus CB54A and CB54B are separated by $5'$ in DEC. Besides we observed a region, which is situated $5'$ south of CB3 and called it CB3N. Similarlry we observed another region $5'$ south of CB25 and called it "CB25N".

The focal plane instrument used was an Imaging Polarimeter (IMPOL) recently commissioned by IUCAA, Pune, India. The instrument measures linear polarization in the wavelength band $0.45 - 0.7$ μm. It makes use of a Wollaston prism as the analyzer to measure simultaneously the two orthogonal polarization components that define a Stoke's parameter. An achromatic half wave plate (HWP) is used to rotate the plane of polarization with respect to the axis of analyzer so that the second Stoke's parameter is also determined. A liquid nitrogen cooled CCD (EEV CCD02-06 series) is used as detector. The CCD has 578×385 pixels of 22μ square each, with approximate spectral response (Q.E.) of 25%, 37% and 39% at the wavelengths of 500 nm, 600 nm and 700 nm respectively as per the EEV data sheet. The instrument has an built-in acquisition and guidance unit. With a field of view (FOV) of about 10 mm $\times$ 10 mm ($6' \times 6'$), it can provide polarization information with an angular resolution of $\sim 2''$ for stellar field or extended objects. The polarimetric accuracies are limited by photon noise. (for details please see Sen & Tandon 1994; Ramaprakash et al. 1998).

For each object within the field of view, two images, called the ordinary and extraordinary, separated by about 33 pixels, are formed on the CCD. These two images correspond to the two orthogonal linear polarization components that are measured simultaneously. The ratio (R) of the difference between the fluxes collected in the two images to their sum, at different orientations (α) of the HWP are related to the linear polarization (p) and its position angle (θ) by the relation

$$R(\alpha) = p \cos(2\theta - 4\alpha). \quad (1)$$

A polarimetric package was developed for data analysis within the IRAF[1] environments using a mixture

[1] IRAF is distributed by National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc, under contract with the National Science Foundation, U.S.A.

Table 1. Obervation log of bok globules

Sr. #	Date	UT	Object Name	RA(2000)	DEC(2000)	bII	size
		h:m		h m s	° ′ ″	°	"×"
1	Dec. 23, 97	16:13	CB3 (YR)	00:28:45.8	56:42:08	−6.03	6.7 5.6
2	Dec. 23, 97	19:33	CB25 (Q)	04:59:04.1	52:03:24	5.85	2.2 × 2.2
3	Dec. 25, 97	16:52	CB39 (YOR)	06:01:58.5	16:30:26	−3.04	4.5 × 3.4
4	Apr. 01, 98	16:30	CB52 (YR)	06:48:42.9	−16:53:27	−8.91	6.7 × 3.4
5	Dec. 25, 97	21:23	CB54A (YOR)	07:04:16.8	−16:22:03	−4.6	5.6 × 3.4
6	Dec. 25, 97	16:30	CB54B (YOR)	as above	−16:27:03	as	above
7	Apr. 03, 98	16:15	CB58 (Y)	07:18:13.2	−23:38:52	−5.04	7.8 × 3.4
8	Dec. 24, 97	00:30	CB62 (NA)	13:30:02.8	79:22:34	37.58	3.4 × 2.2
9	Dec. 24, 97	15:00	CB246 (Q)	23:56:43.6	58:34:29	−3.54	7.8 × 4.5
10	Dec. 24, 97	13:41	CB3N	00:28:45.8	56:37:08	−6.03	-
11	Dec. 23, 97	21:15	CB25N	04:59:04.1	51:58:24	5.85	-

Table 2. Obervation of Polarized Standard stars (Ref. 1 indicates Serkowski, 1975 and Ref. 2 indicates our present observations)

Date	UT	star HD #	$p_{\max}$ (%)	$\theta_{\max}$ (°)	$\lambda_{\max}$ (μm)	p (%)	$E_{\rm p}$ (%)	θ (°)	Filter
			(Ref. 1)			(Ref. 2)			
Dec. 23, 97	13:53	7927	3.4	94	0.51	3.36	0.01	100.2	V
Dec. 23, 97	14:33	23512	2.3	30	0.61	2.15	0.05	36.9	V
Dec. 23, 97	23:16	43384	3.0	170	0.53	2.78	0.02	177.7	W
Apr. 01, 98	16:00	43384	3.0	170	0.53	2.78	0.03	0.3	W
Apr. 02, 98	07:15	147084	4.3	32	0.68	4.23	0.02	39.1	V

of standard IRAF tasks, custom- made CL scripts and FORTRAN routines (Ramaprakash 1998).

3. Polarimetric calibration

For the purpose of calibration, we observed five different polarized and one unpolarized standard stars taken from a list by Sekowski (1975). The results for the standard stars both "polarized" and "unpolarized" are reproduced in Tables 2 and 3 respectively. For the standard polarized stars, the observed polarization (p), error in polarization ($E_{\rm p}$) and position angle (θ) are listed in Cols. 7, 8 and 9 of Table 2. The error in position angle (PA) i.e. E_θ though not listed in the table, can be easily calculated by the relation (Serkowski 1974):

$$E_\theta \simeq \frac{E_{\rm p}}{p} \times 28.65^\circ \tag{2}$$

for $E_{\rm p} \ll p$. The Cols. 3, 4 and 5 represent the maximum polarization value, corresponding position angle and wavelength as listed by Serkowski (1975). A small discrepancy within the two sets of values can be due to the fact that, Serkowski (1975) values are at a particular wavelength where polarization becomes maximum. Whereas our observations were carried out either in white light (W) or V filter ($\lambda = 0.55$ μm). Since the interstellar polarization varies with wavelength, what we should observe in the W filter is an observed value of p which is somewhat lower than $p_{\max}$. Further, if θ also slightly varies with wavelength, the observed θ will be different from $\theta_{\max}$. However, this seems to be more unlikely keeping in mind the constancy of θ for interstellar polarization (Coyne 1975).

At this stage without going into the details of wavelength dependence of interstellar polarization, we conclude from Table 2. that, the observed polarization values are matching with those enlisted by Serkowski (1975) within errors. However, the PA (θ) values show an average offset dθ of $-6.9°$ for three nights in December 1997 and $-10.3°$ for April 01, 98. The instrument was remounted on Apr. 02, 1998 due to technical reasons and we observe a different dθ of $-7.1°$ on April 02, 1998.

Now from our observations for the unpolarized standard star HD 114710 (in Table 3), we can conclude that our instrumental polarization is less than 0.05%.

4. Result and discussions

In Tables 4-13, we reproduce the observed linear polarization (p), error in estimated polarization ($E_{\rm p}$),

Table 3. Obervation of Unpolarized Standard star (Ref. 1 indicates Serkowski, 1975 and Ref. 2 indicates our present observations)

Date	UT	star HD #	$p_{\max}$ (%)	E_p (%)	p (%)	E_p (%)	Filter
			(Ref. 1)		(Ref. 2)		
Apr. 01, 98	18:45	114710	0.018	0.014	0.020	0.021	V

corresponding PA values (θ) and m (relative magnitudes) in Cols. 4, 5, 6 and 7 respectively for the stars in these clouds. These magnitudes are just a conversion from the CCD counts and therefore it is merely an indication of the relative intensity of the stars. One should also note that the magnitude scale is not necessarily same for all the clouds[2]. The PA (θ) values are corrected by the θ-offset as obtained after the observation of polarimetric standard stars (please refer to Sect. 3). The field stars in a cloud can be identified through their RA and DEC co-ordinates available in Cols. 2 and 3.

We draw these polarization vectors on the respective position of the stars on the DSS map (Digital Sky Survey map of Palomar Observatory). The length of the vector is proportional to the degree of polarization. The vector line is drawn making an angle with the N-axis (towards East), which is equal to the PA values tabulated in Col. 6. However before plotting, all these θ values were corrected by the off-set ($d\theta$) discussed earlier for the corresponding nights of observations (please refer to Sect. 3). Also on the left-hand corner of each map we have plotted the direction of increasing galactic longitude (∇l). This will give us the projection of galactic plane in that region of the sky, which is expected to be the projected direction of local galactic magnetic field. These polarization maps for all the above clouds are reproduced in Figs. 1-10.

When we observe polarization for the stars in a particular cloud, we are not sure whether the observed polarization is introduced by the cloud or it is just the interstellar polarization for that part of the sky or a combination of the two. To ascertain this, we observed nearby regions of two individual clouds, viz. CB3N and CB25N. We notice that, both these regions contain a set of almost unidirectional polarization vectors and the observed degrees of polarizational don't differ much from star to star. This can be considered to be characteristic of interstellar polarization for that part of the sky.

Also we can see both the clouds CB3 and CB25 contain polarization vectors which mostly follow the trend observed in their respective nearby regions CB3N and CB25N. But the small twist in the orientation of polarization vectors in CB3 (in the lower part of the map) may be

[2] The magnitudes are expressed in an arbitrary relative scale here and also for all the clouds to follow in the subsequent tables.

Table 4. Observed linear polarization values for various field stars in CB3

Sr.#	RA(2000)	DEC(2000)	p(%)	E_p(%)	θ	m
1	0:28:48.8	56:39:19	1.145	0.039	62.0	12.08
2	0:28:52.6	56:39:26	1.903	0.509	68.2	15.94
3	0:28:33.4	56:39:33	2.258	0.243	69.9	15.46
4	0:28:43.4	56:39:46	1.714	0.390	64.6	15.81
5	0:28:45.9	56:39:51	1.203	0.071	63.4	13.72
6	0:28:33.9	56:39:54	0.600	0.035	73.2	11.13
7	0:28:47.1	56:40:7	1.182	0.055	64.5	13.07
8	0:28:57.1	56:40:10	1.131	0.303	63.0	15.35
9	0:28:56.2	56:40:13	0.736	0.043	69.7	12.13
10	0:28:39.3	56:40:9	2.221	0.615	45.7	16.27
11	0:28:42.5	56:40:10	0.474	0.056	19.5	13.87
12	0:29:1.8	56:40:38	0.990	0.132	54.5	14.30
13	0:28:43.3	56:40:39	1.669	0.749	28.5	16.45
14	0:28:58.3	56:41:4	2.148	0.424	84.7	15.93
15	0:29:7.8	56:41:12	1.582	0.102	67.9	13.67
16	0:28:39.0	56:41:19	0.846	0.185	73.2	14.60
17	0:28:55.8	56:41:36	0.987	0.156	81.6	14.72
18	0:28:51.3	56:41:42	1.642	0.036	74.6	12.85
19	0:28:49.0	56:41:45	2.586	0.104	76.9	13.34
20	0:28:40.2	56:41:48	2.031	0.090	106.0	13.46
21	0:28:46.1	56:41:50	0.515	0.036	69.9	12.86
22	0:28:22.8	56:42:15	2.817	0.889	75.7	16.39
23	0:28:28.9	56:42:34	2.095	0.338	73.1	15.91
24	0:29:8.1	56:42:46	1.068	0.111	60.4	14.31
25	0:28:57.9	56:42:48	2.144	0.063	58.1	14.15
26	0:28:24.5	56:42:47	0.830	0.068	72.3	13.37
27	0:28:43.5	56:42:52	0.917	0.042	66.3	13.31
28	0:28:58.6	56:43:18	1.014	0.029	59.9	12.87
29	0:28:43.7	56:43:18	0.951	0.202	71.2	14.66
30	0:29:3.0	56:43:42	1.037	0.046	61.3	13.72
31	0:28:32.1	56:44:13	1.449	0.034	48.6	12.49

Table 5. Observed linear polarization values for various field stars in CB25

Sr.#	RA(2000)	DEC(2000)	p(%)	E_p(%)	θ	m
1	4:59:20.2	52:1:5	2.791	0.208	153.8	14.47
2	4:58:54.4	52:1:12	2.452	0.322	150.3	15.72
3	4:59:13.5	52:1:15	1.983	0.270	154.7	15.55
4	4:58:55.2	52:2:14	1.689	0.247	160.9	14.08
5	4:59:4.8	52:2:32	2.478	0.304	148.3	15.61
6	4:59:21.8	52:2:35	3.120	0.489	150.9	15.98
7	4:59:13.0	52:3:19	3.246	0.395	150.7	16.00
8	4:59:20.1	52:3:26	3.033	0.165	149.5	14.81
9	4:58:49.4	52:4:8	2.932	0.069	147.3	12.69
10	4:59:13.1	52:4:24	2.614	0.472	147.8	16.01
11	4:58:50.9	52:4:39	0.693	0.104	167.2	14.01
12	4:58:47.8	52:4:41	1.812	0.461	150.6	16.16
13	4:58:45.2	52:4:55	2.313	0.437	160.2	15.83
14	4:59:21.1	52:5:10	2.969	0.264	150.7	15.82
15	4:58:50.5	52:5:8	2.269	0.061	152.2	13.98
16	4:58:58.7	52:5:10	2.417	0.313	143.8	15.78
17	4:58:56.6	52:5:18	1.729	0.458	144.4	16.36
18	4:59:12.0	52:5:33	1.794	0.676	150.9	16.41
19	4:58:54.5	52:5:55	1.998	0.169	146.3	14.86
20	4:58:49.1	52:5:58	3.858	0.444	147.3	16.70
21	4:59:2.5	52:6:1	1.263	0.707	141.0	16.62

Table 6. Observed linear polarization values for various field stars in CB39

Sr.#	RA(2000)	DEC(2000)	p(%)	$E_{\rm p}$(%)	θ	m
1	6:1:59.2	16:27:56	2.275	0.605	162.3	16.22
2	6:1:58.3	16:27:59	1.730	0.645	134.6	16.09
3	6:1:56.9	16:28:19	2.624	0.052	156.6	13.84
4	6:1:57.4	16:28:29	2.041	0.346	159.7	15.33
5	6:1:55.4	16:28:44	1.897	0.196	155.1	14.71
6	6:1:51.0	16:29:7	2.113	0.875	149.3	16.07
7	6:1:46.9	16:29:10	0.958	0.418	160.6	15.79
8	6:2:4.7	16:29:25	1.728	0.371	141.6	16.27
9	6:1:52.4	16:29:41	2.908	0.050	157.7	13.38
10	6:2:7.6	16:29:55	2.326	0.121	166.1	13.97
11	6:1:50.0	16:30:8	1.921	0.415	164.3	15.46
12	6:2:10.2	16:30:31	2.291	0.464	163.0	16.05
13	6:1:47.4	16:30:56	1.092	0.039	167.0	12.88
14	6:2:5.8	16:31:41	1.937	0.227	152.6	14.63
15	6:1:53.2	16:31:42	2.667	0.603	171.1	15.46
16	6:1:48.1	16:31:51	1.172	0.032	162.5	13.06
17	6:1:49.8	16:32:0	1.862	0.223	178.0	14.84
18	6:2:9.9	16:32:27	1.924	0.160	165.4	14.70
19	6:2:11.8	16:32:29	2.555	0.887	164.6	16.43
20	6:1:49.2	16:32:41	1.593	0.038	165.2	12.92
21	6:2:1.7	16:33:1	1.264	0.051	138.3	13.58

Table 7. Observed linear polarization values for various field stars in CB52

Sr.#	RA(2000)	DEC(2000)	p(%)	$E_{\rm p}$(%)	θ	m
1	6:48:52.1	−16:56:50	0.451	0.073	96.8	12.38
2	6:48:53.3	−16:56:0	1.457	0.853	95.0	16.45
3	6:48:40.1	−16:56:9	0.462	0.552	45.2	15.14
4	6:48:43.0	−16:55:58	1.908	0.325	149.7	15.77
5	6:48:56.9	−16:54:40	2.695	1.449	24.1	16.70
6	6:48:32.1	−16:54:29	0.226	0.170	43.6	13.94
7	6:48:39.1	−16:54:7	1.416	0.117	152.8	12.88
8	6:48:35.6	−16:53:52	1.180	0.804	137.2	15.68
9	6:48:56.9	−16:53:29	3.286	1.114	12.8	16.26
10	6:48:57.3	−16:53:12	0.948	0.064	52.6	13.70
11	6:48:53.9	−16:53:7	2.192	0.557	146.2	15.39
12	6:48:53.8	−16:52:8	1.145	1.149	81.0	16.13
13	6:48:51.2	−16:51:36	1.121	0.891	140.8	15.72
14	6:48:34.8	−16:51:10	0.472	1.012	24.4	15.48
15	6:48:34.8	−16:50:44	0.209	0.365	34.9	15.64
16	6:48:54.5	−16:50:25	1.207	0.431	7.9	15.81

due to some reasons intrinsic to the cloud. CB25 mostly contain undisturbed polarization vectors.

Clemens et al. (1991) describe some classification scheme for these clouds and divide them into different groups A, B and C. Out of 248 clouds catalogued by CB, most (74%) of the clouds belong to group A, where gas temperatures are cool ($T < 8.5^\circ$ K) and turbulent gas motions are less (characterized by ^{12}CO line widths $\Delta V < 2.5$ km s^{-1}). When line widths are broader (> 2.5 km s^{-1}), we get another set of cool clouds with unusual dynamical activity, these are group C clouds. Under group B we have warm clouds ($T > 8.5^\circ$ K) but

Table 8. Observed linear polarization values for various field stars in CB54A

Sr.#	RA(2000)	DEC(2000)	p(%)	$E_{\rm p}$(%)	θ	m
1	7:4:6.9	−16:24:48	0.105	0.027	153.6	11.41
2	7:4:27.4	−16:24:33	0.304	0.023	140.4	11.05
3	7:4:3.8	−16:23:28	0.215	0.086	115.5	12.24
4	7:4:8.9	−16:23:13	0.824	0.196	126.5	15.24
5	7:4:8.7	−16:23:1	0.203	0.131	154.2	14.60
6	7:4:27.7	−16:22:53	0.957	0.270	123.3	14.20
7	7:4:13.3	−16:22:43	1.019	0.214	177.5	13.97
8	7:4:25.9	−16:22:22	1.526	0.592	58.8	15.82
9	7:4:6.9	−16:22:23	0.913	0.206	96.1	14.14
10	7:4:25.2	−16:21:40	0.865	0.176	108.3	14.32
11	7:4:13.8	−16:21:32	1.306	0.421	146.7	15.74
12	7:4:12.4	−16:21:27	0.203	0.029	148.4	12.79
13	7:4:24.5	−16:21:20	0.787	0.195	78.2	14.80
14	7:4:17.9	−16:21:16	0.885	0.321	132.2	14.77
15	7:4:27.5	−16:21:5	0.475	0.239	76.8	14.67
16	7:4:19.5	−16:20:45	0.378	0.356	117.2	15.61
17	7:4:6.5	−16:20:34	1.494	0.126	74.5	14.12
18	7:4:9.9	−16:20:30	1.091	0.515	100.3	16.02
19	7:4:19.9	−16:20:23	0.758	0.391	91.2	16.23
20	7:4:10.1	−16:20:11	0.877	0.550	146.6	15.93
21	7:4:5.7	−16:20:9	3.635	0.610	50.2	16.71
22	7:4:6.8	−16:20:7	0.374	0.090	102.9	12.24
23	7:4:26.7	−16:19:50	0.764	0.570	108.7	16.12
24	7:4:5.4	−16:19:46	1.167	0.766	73.8	16.71
25	7:4:9.3	−16:19:39	0.450	0.323	123.1	15.46
26	7:4:22.5	−16:19:28	0.206	0.243	154.3	14.85
27	7:4:8.4	−16:19:18	0.546	0.123	116.5	12.56

Table 9. Observed linear polarization values for various field stars in CB54B

Sr.#	RA(2000)	DEC(2000)	p(%)	$E_{\rm p}$(%)	θ	m
1	7:4:21.7	−16:29:36	0.571	0.098	128.2	14.32
2	7:4:0.5	−16:29:30	0.396	0.027	111.8	11.08
3	7:4:22.9	−16:29:17	1.446	0.113	174.4	14.74
4	7:4:11.1	−16:28:43	0.531	0.097	141.4	14.21
5	7:4:9.2	−16:28:40	1.628	0.511	164.4	15.94
6	7:4:2.0	−16:28:37	0.549	0.133	80.6	14.29
7	7:4:20.3	−16:28:31	0.234	0.047	147.0	12.64
8	7:4:16.9	−16:28:23	1.102	0.303	164.8	15.28
9	7:4:4.8	−16:27:53	0.624	0.051	135.1	13.71
10	7:4:17.6	−16:27:48	1.022	0.171	138.7	15.15
11	7:4:10.1	−16:27:41	1.141	0.236	130.6	15.09
12	7:4:1.8	−16:27:13	0.936	0.137	119.2	14.45
13	7:4:22.4	−16:26:46	0.671	0.112	113.0	13.64
14	7:4:5.4	−16:26:33	2.062	0.474	140.6	15.90
15	7:4:9.9	−16:26:20	0.678	0.161	115.2	14.04
16	7:4:3.0	−16:26:2	0.131	0.061	157.5	13.19
17	7:4:18.7	−16:25:56	0.292	0.088	92.4	13.79
18	7:4:24.9	−16:25:54	3.130	0.292	164.3	15.26
19	7:4:19.4	−16:25:38	1.142	0.336	137.8	15.52
20	7:4:8.1	−16:25:2	0.501	0.034	120.0	12.22
21	7:4:6.6	−16:24:47	0.123	0.042	153.4	11.50

Table 10. Observed linear polarization values for various field stars in CB58

Sr.#	RA(2000)	DEC(2000)	$p(\%)$	$E_{\rm p}(\%)$	θ	m
1	7:18:6.1	−23:40:40	2.368	1.088	93.4	15.78
2	7:18:2.2	−23:40:7	1.859	0.447	152.5	15.32
3	7:18:1.8	−23:40:6	0.890	0.258	139.8	14.10
4	7:17:57.5	−23:39:45	0.773	0.336	46.6	15.18
5	7:17:56.2	−23:39:38	2.495	0.920	118.2	16.25
6	7:17:59.0	−23:39:29	0.902	0.198	125.3	13.29
7	7:18:1.2	−23:39:3	1.136	0.577	109.6	15.46
8	7:18:14.3	−23:39:6	3.500	1.159	70.7	16.36
9	7:18:0.5	−23:38:59	3.026	1.140	105.6	15.77
10	7:18:21.6	−23:38:51	1.786	0.241	57.2	14.37
11	7:17:54.5	−23:38:39	0.614	0.238	140.9	14.33
12	7:17:57.3	−23:38:32	1.818	0.275	136.2	15.47
13	7:17:53.7	−23:38:24	1.404	0.502	113.2	15.29
14	7:17:53.3	−23:38:21	4.926	1.785	159.7	16.35
15	7:18:20.6	−23:38:13	2.159	0.925	18.4	15.57
16	7:18:16.0	−23:37:41	0.205	0.053	28.1	12.03
17	7:17:59.4	−23:37:32	0.111	0.043	101.6	12.07
18	7:18:7.1	−23:37:34	4.079	1.200	169.2	16.66
19	7:17:57.7	−23:37:21	0.998	0.344	89.1	15.29
20	7:18:5.1	−23:37:4	2.214	0.441	156.7	15.50
21	7:18:2.7	−23:37:3	1.229	0.442	118.8	15.57
22	7:18:1.2	−23:36:56	4.164	1.995	46.8	16.70
23	7:17:55.6	−23:36:40	0.810	0.185	103.9	13.33
24	7:18:19.9	−23:36:26	0.212	0.087	136.5	13.39
25	7:18:7.2	−23:36:13	0.111	0.048	48.8	12.23
26	7:17:57.3	−23:36:0	0.697	0.310	107.1	14.36
27	7:18:10.3	−23:35:45	0.357	0.126	9.3	13.42
28	7:17:60.0	−23:35:31	1.789	0.433	123.2	15.21
29	7:18:15.1	−23:35:19	5.772	2.576	104.3	16.77

they are less dynamic with narrow line widths. We have observed four clouds CB25, CB246, Cb39 and CB58 from group A and three clouds CB3, Cb54 (comprising two parts) and CB52 from group C (Clemens et al. 1991). Only for one cloud CB62 the group is not known. Keeping these classification in mind we can analyze the observed polarization values for each cloud.

For cloud CB3, the typical polarization values are between $1-2\%$ and sometimes even more than 2%. There is not much dispersion among the observed polarization values. However, the polarization vectors do not seem to be aligned in the direction of ∇l, which is the projection of galactic plane. Except for three or four stars, all the polarization vectors seem to be directed in some common direction. As discussed in Sect. 2. this cloud contains YSO, IRAS point source, further it belongs to group C, where some dynamical activities are expected.

CB25 and CB39 are two clouds, which exhibit the best alignment of their polarization vectors in the direction of ∇l, among all the clouds we observed. Also the dispersion in PA (θ) values seem to be very small in both the clouds. The alignment is slightly better in CB25 as compared to CB39. Both these clouds belong to A- group. Therefore we can expect, less dynamical activities and turbulences and here we observe better alignment of the grains (or polarization vectors). The cloud CB25, has polarization values typically near 2%, sometimes even exceeding 3%, however these polarization values can be attributed to the interstellar polarization as discussed earlier, with small contribution from the cloud.

Table 11. Observed linear polarization values for various field stars in CB62

Sr.#	RA(2000)	DEC(2000)	$p(\%)$	$E_{\rm p}(\%)$	θ	m
1	13:30:32.2	79:20:23	0.223	0.118	164.7	16.83
2	13:29:23.5	79:19:39	0.664	0.355	43.9	17.34
3	13:30:15.3	79:20:35	0.404	0.249	54.3	14.22
4	13:30:38.9	79:21:49	1.849	0.991	105.1	17.40
5	13:29:10.0	79:20:38	1.186	0.685	132.5	17.37
6	13:30:52.4	79:22:13	0.196	0.126	54.5	13.80
7	13:30:56.8	79:22:41	0.200	0.104	55.4	16.47
8	13:30:29.8	79:22:49	0.125	0.065	99.8	16.60
9	13:30:20.2	79:23:51	0.387	0.203	69.3	17.08
10	13:30:53.9	79:24:46	2.590	1.296	173.4	17.20
11	13:28:51.7	79:23:18	0.149	0.076	62.3	14.01
12	13:30:18.8	79:24:02	0.157	0.101	7.2	16.65
13	13:30:14.0	79:24:16	0.962	0.498	36.9	17.18

Table 12. Observed linear polarization values for various field stars in CB246

Sr.#	RA(2000)	DEC(2000)	$p(\%)$	$E_{\rm p}(\%)$	θ	m
1	23:56:49.1	58:31:29	0.699	0.200	57.9	11.05
2	23:56:26.0	58:32:21	3.719	0.284	90.7	15.50
3	23:56:36.2	58:32:34	0.597	0.051	66.4	11.98
4	23:56:51.9	58:33:53	2.265	0.641	55.7	16.12
5	23:57:5.4	58:34:16	2.773	0.625	64.5	16.00
6	23:56:57.9	58:34:25	2.282	0.153	49.9	14.57
7	23:56:20.2	58:35:8	2.113	0.246	93.9	15.85
8	23:56:54.6	58:35:20	3.839	0.785	59.1	16.66
9	23:57:2.3	58:35:25	0.879	0.353	65.3	14.79
10	23:56:24.3	58:36:26	1.844	0.184	117.2	14.98
11	23:56:53.8	58:36:33	2.314	1.107	52.4	16.72
12	23:56:53.3	58:36:45	1.600	0.185	67.1	15.21
13	23:56:55.1	58:36:49	0.756	0.298	40.3	15.35
14	23:56:41.7	58:36:48	1.263	0.125	63.6	14.88

For CB39 the polarization vectors are relatively less unidirectional, rather they represent some pattern. The cloud contains YSO, IRAS point sources and CO out flows, so it is definitely more active than CB25.

For CB52 (belonging to group C), the alignment of the polarization vectors appear to be disturbed. The polarization values quite dispersed. Some of the polarization vectors are aligned in the direction of ∇l. This cloud contains YSO and IRAS point sources.

In CB54, there seems to be some emission nebulosity associated with the cloud and we have made observations on the north and south of this. For the northern part (CB54A) the alignment of the polarization vectors is rather poor, as compared to the southern part (CB54B). However, in the northern part of CB54A, the orientation of

Table 13. Observed linear polarization values for various field stars in CB3N

Sr.#	RA(2000)	DEC(2000)	p(%)	E_{p}(%)	θ	m
1	0:28:43.9	56:34:52	1.135	0.157	61.2	14.92
2	0:28:49.5	56:35:21	1.193	0.095	60.9	13.80
3	0:28:59.5	56:35:25	1.390	0.113	60.7	14.70
4	0:29:8.6	56:35:37	1.104	0.189	72.3	14.85
5	0:28:59.2	56:35:42	1.355	0.083	63.7	14.24
6	0:28:59.1	56:35:50	0.932	0.229	66.3	15.15
7	0:28:42.7	56:36:7	1.268	0.111	55.8	13.87
8	0:28:56.0	56:36:24	1.131	0.132	65.4	14.70
9	0:29:2.9	56:36:26	1.309	0.047	66.2	13.57
10	0:29:10.8	56:36:27	1.226	0.073	62.7	13.42
11	0:28:53.7	56:36:31	1.436	0.630	60.2	16.48
12	0:28:52.7	56:36:34	0.734	0.244	67.6	15.68
13	0:29:1.0	56:36:52	1.241	0.141	65.5	14.68
14	0:28:42.4	56:37:6	0.854	0.091	67.5	13.66
15	0:28:27.7	56:37:12	0.800	0.103	70.3	13.83
16	0:29:7.7	56:37:17	1.281	0.146	59.2	14.77
17	0:28:51.8	56:37:21	0.368	0.142	88.5	14.75
18	0:29:6.7	56:37:32	1.422	0.090	73.9	13.83
19	0:28:38.3	56:37:36	1.189	0.338	63.7	15.92
20	0:28:25.2	56:37:44	1.281	0.112	73.1	14.56
21	0:28:32.7	56:38:2	0.958	0.263	46.2	15.76
22	0:28:54.6	56:38:5	0.968	0.356	71.8	16.04
23	0:29:10.3	56:38:42	1.456	0.074	64.8	14.07
24	0:29:5.1	56:38:43	0.509	0.352	46.9	16.61
25	0:28:40.8	56:38:57	0.324	0.065	67.1	12.70
26	0:29:2.7	56:39:4	1.296	0.161	59.4	15.12
27	0:29:7.7	56:39:6	1.567	0.053	55.8	12.99
28	0:28:47.6	56:39:17	1.181	0.051	62.5	12.09
29	0:28:25.4	56:39:15	0.194	0.127	37.6	14.94
30	0:28:46.6	56:39:21	0.684	0.102	67.3	13.69
31	0:28:51.5	56:39:23	1.399	0.371	57.7	15.93
32	0:28:44.7	56:39:50	1.147	0.065	58.0	13.68
33	0:28:55.3	56:40:11	0.794	0.032	60.7	12.16

Table 14. Observed linear polarization values for various field stars in CB25N

Sr.#	RA(2000)	DEC(2000)	p(%)	E_{p}(%)	θ	m
1	4:58:54.0	51:57:16	3.874	0.242	152.5	15.61
2	4:59:16.2	51:57:17	2.154	0.545	162.2	16.52
3	4:59:17.6	51:57:19	2.695	0.077	160.5	14.53
4	4:58:57.2	51:57:56	3.658	0.083	155.0	12.78
5	4:58:45.3	51:58:9	1.714	0.048	163.7	11.66
6	4:59:22.8	51:58:12	1.810	0.187	163.1	16.00
7	4:59:5.1	51:58:20	2.821	0.875	139.2	16.25
8	4:59:7.6	51:58:53	2.104	0.884	129.4	16.86
9	4:58:53.7	51:59:1	3.769	0.366	145.9	16.35
10	4:59:1.4	51:59:46	4.064	0.669	160.0	16.26
11	4:58:53.5	52:0:8	3.485	0.956	155.7	16.96
12	4:59:12.9	52:0:20	1.343	0.482	155.9	16.54
13	4:58:41.8	52:0:33	1.250	0.625	154.6	15.62
14	4:59:16.7	52:0:36	1.967	0.190	153.8	15.36
15	4:59:1.8	52:0:54	2.267	0.154	149.7	14.67
16	4:59:21.1	52:1:1	2.412	0.233	154.1	14.68
17	4:59:14.2	52:1:12	1.815	0.181	159.0	15.68
18	4:58:54.7	52:1:12	1.970	0.215	148.7	15.84

Table 15. The average direction of polarization and its dispersion (stars with $p < 0.5\%$ and/or $\frac{E_{\mathrm{p}}}{p} > 0.5$ have been excluded)

Cloud	$\theta_{\mathrm{average}}$ (in degree)	σ_θ (in degree)
CB3	65.6	15.6
CB3N	63.5	6.0
CB25	151.4	5.8
CB25N	153.6	8.8
CB39	158.9	10.7
CB52	147.2	50.4
CB54A	106.1	37.5
CB54B	135.5	23.8
CB58	108.5	39.6
CB62	poor data	poor data
CB246	67.4	20.2

polarization vectors seem to follow some circular pattern. This is interesting and need to be studied more carefully. CB54 belongs to the dynamic group (C) and it contains YSO, IRAS point sources and CO out flows. The measured polarization values are generally close to 1% and there is wide dispersion among the direction of polarization vectors.

CB58 (belonging to group A) seems to be an interesting cloud with low to very high (4−5%) polarization values and direction of polarization vectors are scattered. This cloud seem to be violating the trend where we observed, group A clouds exhibiting slightly better alignment of the polarization vectors among themselves and also with the direction of ∇l. This cloud contains YSO alone.

CB62 is the only cloud cloud which is quite above the galactic plane (bII $= 37.58°$).

Otherwise all the clouds we observed are within the galactic disk (bII $< \pm 10°$ please refer Table 1). Also we have no information about the group in which it belongs. Very few stars appear to be polarized in CB62. This is expected as the cloud is well above the galactic plane, so that the polarization caused by interstellar dust will be relatively less. The directions of polarization vectors seem to be scattered, with degree of polarization ranging from very low to above 2%. The polarization vectors do not appear to be aligned with the projected direction of galactic plane (∇l). If a typical A_v for stars in CB62 is found to be similar to the A_v for stars in the plane, this proves polarization is mostly interstellar in all the other cases (not arising from the cloud itself).

In CB246 (belonging to group A), polarization vectors are poorly aligned amongst themselves and also with the direction of ∇l. However, if one separately considers the eastern and western regions in the cloud, one can see within these two individual regions the vectors are moderately aligned. This observed feature can be related to some activities in the cloud. However, as seen from Table 1, it does not contain YSO, IRAS point source or CO outflows.

The reason that the more "dynamic cloud" shows generally poorer alignment with the galactic plane is that these regions tend to be warmer. Warmer regions have been shown to have better grain alignment. So it is possible that only in these clouds polarimetry is tracing the field, which in fact does not align with the galactic plane.

Also to draw a firmer conclusion about the alignments one needs a "control sample" of "off/nearby" positions where the projection direction is compared to the plane direction in the same way as for the globules. We have done it in a way for CB3 and CB25. However, we want to do it for all the globules in future.

In order to discuss about the alignment of the field or the lack of it in individual clouds, we have tabulated the average directions of polarization vectors ($\theta_{\rm average}$) and the dispersions in the direction of polarization (σ_θ) in Table 15. If all the stars have $\frac{E_{\rm p}}{p} = 0.5$, the error on the angle (E_θ) would be ~ 14 degrees. Hence one can say that a $\sigma_\theta < 10$ degrees would mean that the field is very well aligned, whereas a $\sigma_\theta \sim 50$ degrees would mean randomly directed polarization vectors (or field). Therefore CB52 represents almost random directions and CB54A & CB58 represent highly dispersed directions of polarization vectors with themselves and the galactic plane.

The disturbance in the polarization directions, that we have mentioned has been discussed extensively by Myers & Goodman (1991). Their analysis includes several clouds and the number distributions of polarization direction have a single maximum, with dispersion $0.2-0.4$ radians. The observed distribution of polarization was modeled as arising from a magnetic field with uniform and non-uniform parts. The uniform part has an isotropic probability distribution of direction, a Gaussian distribution of amplitudes and N correlation lengths along the line of sight through the cloud (with the estimated upper limit $N_{\rm max} \sim 10$, based on the cutoff wavelength of hydromagnetic waves).

5. Conclusions

Imaging polarimetry of eight dark clouds have been carried out in white light and polarization maps have been constructed.

Except for one cloud, we see that the clouds which are marked by less dynamical activities (^{12}CO line widths $\Delta V < 2.5$ km s^{-1}) exhibit slightly better alignment of their polarization vectors among themselves and also with the direction of galactic plane (∇l). On the other hand more dynamic clouds (having ^{12}CO line widths $\Delta V > 2.5$ km s^{-1}) seem to have poorer alignment of polarization vectors with themselves and the Galactic plane.

However, one needs to quantify the degree of alignment, dispersions in the direction of polarization vectors etc. and then correlate them with physical parameters of the cloud like ^{12}CO line widths etc. This calls for a detailed analysis in future.

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