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POLARIMETRIC MAPPING OF ORION USING MILLIPOL: MAGNETIC ACTIVITY IN BN/KL

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ABSTRACT

The spatial distribution of the polarized component of the thermal dust emission from the core of the Orion molecular cloud has been mapped over 15 positions at a wavelength of 1300 μm using the MILLIPOL instrument on the NRAO 12 m telescope. The chief findings of this study are three-fold. First, the polarization directions deduced for the map positions are quite similar, implying that the embedded magnetic field is strong (of the order of 1 mG) and uniform in direction over the core of the cloud. The angular dispersion, corrected for measurement uncertainty, is $\sim 9°$, roughly identical to that seen in optical starlight polarization studies of dark clouds whose evolution is believed to have been dominated by magnetic fields. Second, the mean polarization percentage, 4.6%, is quite high, and two positions show polarization percentages of nearly 8%, the highest yet detected for polarized thermal dust emission. Finally, the polarization of the BN/KL position (2.70% $\pm$ 0.25%) was found to be significantly lower than the polarizations toward positions 30″ outside BN/KL.

Subject headings: interstellar: grains — interstellar: magnetic fields — magnetic fields — nebulae: H II regions — nebulae: Orion Nebula — polarization

1. INTRODUCTION

The core of OMC-1, identified as the small region containing the Becklin-Neugebauer (BN) object and the Kleinmann-Low (KL) nebula, is an ideal region for polarimetric study of the thermal dust emission. In that region there is massive star formation activity coupled with a high-velocity bipolar outflow, embedded infrared reflection nebulae, shocked molecular hydrogen, and multiple temperature and density gas components (see, e.g., Genzel & Stutzki 1989). However, there have been few successful probes of the embedded magnetic field. At near and mid-infrared wavelengths, scattering dominates, producing large polarizations with the centrosymmetric polarization pattern characteristic of single scattering and not due to the interaction of spinning dust grains with a magnetic field. At shorter wavelengths, the region is opaque, completely blocking background starlight from traversing and probing the region. However, at wavelengths longer than $\sim$50–70 μm, the dust becomes optically thin, enabling the resulting polarization to be dominated by anisotropic emission from magnetically aligned, spinning grains.

Cudlip et al. (1982) first probed this region polarimetrically at 77 μm using a rocket-borne polarimeter, obtaining a fairly low polarization of 2.2%, indicating that scattering was mostly absent at this wavelength. Hildebrand, Dragovan, & Novak (1984) and Dragovan (1986) used the Kuiper Airborne Observatory (KAO) to measure the Orion cloud core polarization at a wavelength of 270 μm, obtaining an even lower value of 1.7%. Recently, Novak et al. (1989) and Gonatas et al. (1990, hereafter G90) used the KAO at 100 μm to measure and map the polarization associated with BN/KL and regions along the continuum emission ridge to the north and south of BN/KL. In the latter work, 10 positions were observed, with significant detections seen in eight of the positions.

Ground-based efforts to measure the polarization of the thermal dust emission from Orion began with our initial MILLIPOL experiment (Barvainis, Clemens, & Leach 1988; hereafter BCL). In that work, polarization of the 1300 μm radiation from BN/KL was detected at the 2.9% level. Using a different polarimeter and telescope combination but also at a wavelength of 1300 μm, Novak, Predmore, & Goldsmith (1990, hereafter NPG) recently repeated our BN/KL observations, finding a similar polarization level of 2.6%.

In this paper, we report results from observations using our upgraded and more sensitive MILLIPOL instrument (Clemens et al. 1990, hereafter CLBK) on the NRAO[2] 12 m telescope. We mapped 15 positions toward BN/KL and the continuum flux peak 2′ south of BN/KL, significantly detecting all positions. In the following sections, we discuss the details of the observations and calibration and the nature of the upgrades to the MILLIPOL instrument. We next present our Orion map in tabular and graphical forms and discuss the information contained in these measurements. In particular, we show that the polarizations found, which average 4.6% and range up to almost 8%, are quite high and uniform in direction. We also show that BN/KL represents a depression in the percentage polarization relative to the background level, and we discuss possible explanations.

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2. OBSERVATIONS

The observations were performed using the 12 m telescope of the National Radio Astronomy Observatory on Kitt Peak, Arizona, during 1988 April 1–6 and 1989 January 19–26. To the standard two-channel cooled coherent receivers, we added the two main components comprising the MILLIPOL instrument, namely, a rotating plexiglass half-wave plate located just before the receiver feed horns and a set of fast analog and digital electronics for data collection and binning which sampled the detected continuum signal. The full details of the MILLIPOL instrument, calibration, and operation are contained in CLBK. MILLIPOL operation on the 12 m telescope exhibited instrumental polarization at the 0.2% level, correctable to the 0.03% level. Jupiter mapping during the 1989 observing run established that the polarization sensitivity variation across the 30″ beamwidth (FWHM) was much less than 0.4%. Polarization position angle calibration was performed by observing a set of positions around the limb of the Moon, as described in BCL and CLBK. The uncertainty in the Moon calibration of the polarimeter offset angle was less than 0°.2, much smaller than any of the internal errors in the Orion mapping data. Calibration of the polarization efficiency has been performed only in the laboratory, and showed that the half-wave plate alone was $95 \pm 5\%$ efficient, a value close enough to unity that no correction for this factor has been applied to the data.

The flux calibration rests on beam-switched (secondary nutation) observations of Venus, Mars, Jupiter, and Saturn. We found that the telescope efficiency depended on the presence or absence of illumination by the Sun. As noted in CLBK, this variation was up to a factor of 2 in going from day-to-night observations. This change was not found to be correlated with a change in the beam size or focus. We have calibrated our data collected during daytime against planets observed during the daytime and, similarly, nighttime data against nighttime planets. While this may lead to a larger uncertainty in the percentage polarizations, the position angle uncertainties will not be affected. We adopt a general flux calibration uncertainty of $\sim$20%.

All data have been corrected for atmospheric opacity, which was determined every 2 to 3 hr by measuring the sky emission at different elevation angles. Telescope pointing and focus were similarly frequently monitored using the planets.

The mode of data collection consisted of acquiring a new position in Orion and performing a beam-switched observation to determine the total flux. For these observations, a secondary beam throw of 4′–6′ in azimuth was used. This, in conjunction with our attempt to perform most of the measurements during the hour angles when the Orion ridge was close to a north-south orientation, helped avoid contaminating the total flux measurements by chopping away from the ridge. MILLIPOL observations consisted of a series of 10–12 five-minute duration scans. During each scan, the telescope performed standard position-switching, spending 30 s on source, followed by 30 s toward the reference position, and repeating four more times. The reference positions were chosen to lie 34 s of right ascension eastward of the source positions (almost 9′ away), so that the reference position would traverse the same patch of sky and dome previously traversed by the source position. During polarimetric scans, the half-wave plate was rotated at 6.25 Hz, for an effective polarization switching rate of 25 Hz.

TABLE 1

SUMMARY OF MILLIPOL OBSERVATIONS OF ORION

Position Number (1)	RA Offset (2)	Dec. Offset (3)	Flux (Jy) (4)	P (5)	σ_P (6)	P.A. (ϕ) (7)	σ_ϕ (8)
1	−30″	0″	22	3.74%	0.92%	27°	7°
2	−22	−22	25	4.63	1.03	37	6
3	−22	22	14	5.10	2.24	9	12
4	−18	0	25	4.52	1.11	44	7
5	−10	−120	19	5.10	0.66	33	4
6	−10	−90	21	5.70	1.28	42	6
7	−9	−16	26	7.60	0.87	31	3
8	−9	16	23	1.95	0.64	43	9
9	0	−30	46	4.04	0.23	27	2
10	0	0	44	2.70	0.25	34	3
11	0	30	17	7.93	0.77	44	3
12	9	−16	37	3.65	0.46	34	4
13	9	16	39	4.99	0.62	20	4
14	18	0	35	3.81	0.38	30	3
15	30	0	23	3.65	0.74	14	6

The polarimetric data were averaged into 9° wide bins and fitted with a pair of sine waves to determine the Stokes U and Q and uncertainty. These parameters were corrected for the instrumental polarization, the offset angle determined from the Moon calibration, and the angular offset between the two receiver feed horns. The final, calibrated data are presented in Table 1. There, column (1) numerically identifies the observed positions. Columns (2) and (3) list the positional offsets of the beam centers from the nominal BN/KL position [$\alpha(1950) = 5^h32^m46^s.7$, $\delta(1950) = -5°24'16''$] in arcseconds. Column (4) lists the total fluxes measured at 1300 μm using beam-switching. Columns (5) and (6) present the polarization percentages, where the uncertainty in the total flux has not been included in the polarization uncertainty. Hence, these uncertainties are internal errors, determined from the quality of the sine wave fits for U and Q. Columns (7) and (8) list the inferred polarization position angles and the internal uncertainties in those position angles.

The positions observed were not fully independent, given the size of the telescope beam (30″). We chose to spatially oversample in order to test whether the uncertainties measured internally were reasonable estimates of the total uncertainty. As will be shown below, we believe that to be the case. Of the 15 positions observed, roughly half were observed each year. The positions observed only in 1988 include numbers 1, 2, 3, 5, 9, 11, and 15. Those observed only in 1989 include 4, 6, 7, 8, 12, 13, and 14. The central position, number 10, corresponding to the BN/KL position, was observed both years, with the resulting polarization values agreeing within their uncertainties. The position 10 results have been averaged for Table 1.

3. RESULTS

The polarimetric results listed in Table 1 are presented graphically in Figures 1, 2, and 3. Figure 1 compares the polarization position angles found with the contours of total 1300 μm flux, as deduced by Gordon & Jewell (1987) using the 12 m telescope and an image restoration technique. Figure 2 displays the histogram of percentage polarization, and Figure 3 displays the position angle histogram.

The axes in Figure 1 indicate relative offsets from the BN/KL position in arcseconds. In the figure, the positions and size (HPBW) of the 1300 μm telescope beam are indicated by circles. The polarization position angles found at each position

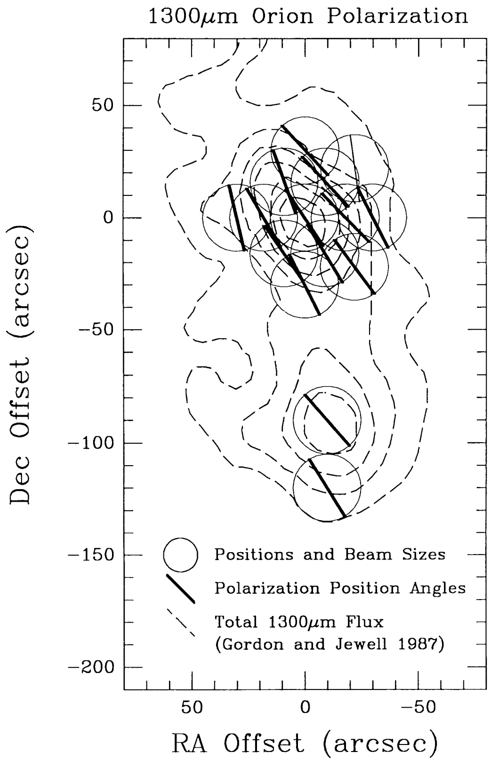

FIG. 1.—Comparison of the Orion cloud core 1300 μm polarization position angles, as measured using MILLIPOL, with the total flux map of Gordon & Jewell (1987; *dashed contours*). The circles indicate the locations observed and the half-power beam size (30″). The heavy lines within each circle indicate the position angle of the measured polarization, which is perpendicular to the embedded magnetic field. Note the general coherence of the polarization pattern, extending down to the southern flux peak.

are indicated as bold lines, with the exception of position number 3. For position number 3 (upper right region), the angular uncertainty is much poorer than for the other positions. Hence, the position angle for position 3 is indicated as a normal line to indicate its larger uncertainty. The dashed contours indicate regions of constant total source flux density at 1300 μm (Gordon & Jewell 1987).

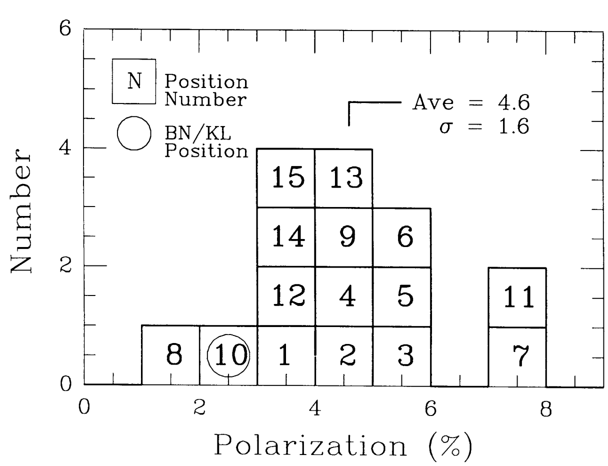

FIG. 2.—Histogram of percentage polarizations measured at 15 positions toward the Orion cloud core using MILLIPOL. The average polarization, 4.6%, is quite high, and two positions exhibit values of nearly 8%. However, the BN/KL position, number 10, has unusually low polarization.

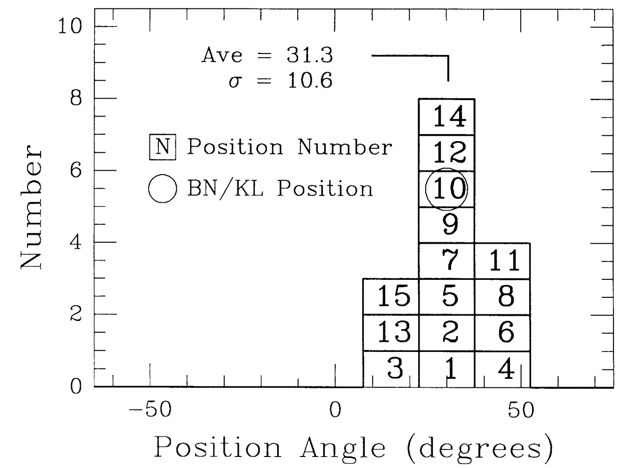

FIG. 3.—Histogram of polarization position angles measured at 15 positions toward the Orion cloud core using MILLIPOL. The average position angle is 30°.5, with a standard deviation of 10°.7, which is quite low. In this figure, the BN/KL position, number 10, shows a position angle similar to that seen for many other positions.

There are several points to note in Figure 1. The first, and strongest, point is that the polarization vectors are surprisingly uniform in direction. The direction of the polarization seen toward BN/KL is maintained down to the southern flux peak. Second, the mean direction is quite similar to the direction along which the northern flux peak is elongated. There are no cross-coupling mechanisms which might cause the elongated source flux distribution to be mimicked in our polarization position angle measurements. This is because we effectively only change the position angles of the linearly polarized receiver feed horns without affecting the beam size or forward gain. Also, the polarization modulation frequency is 4 times the half-wave plate rotation frequency, and thus 4 times the frequency of any beam wobble introduced by refraction in the half-wave plate. Hence, the polarization position angles found are real and not an artifact of the source distribution. The third point to note in Figure 1 is that our observed positions are not sampling fully independent parts of the source, given the 30″ beam size. There is a ring of six positions (numbers 4, 7, 8, 12, 13, and 14) which are offset by 18″ from the BN/KL position. There is a partial ring of six more positions (numbers 1, 2, 3, 9, 11, and 15) which are offset by 30″ from the BN/KL position. In this fashion, we obtain an outer ring of positions which are fully independent of BN/KL, and an inner ring of positions which share part of the BN/KL emission and part of the outer ring emission. This inner ring is useful for verifying our estimates of the polarization uncertainties, as well as enabling somewhat higher spatial sampling of the polarization information.

Figure 2 shows the histogram of polarization percentages measured. In this figure, position identifying numbers are indicated inside the histogram boxes, and position 10, the BN/KL position, is further indicated by a circle. The unweighted average of the polarization percentage is 4.6%, with a standard deviation of 1.6%. This average polarization is quite high and will be discussed further below. Note that two positions show polarizations of nearly 8%. These are the largest polarizations yet seen from thermal dust emission. More important, the BN/KL position shows an unusually low polarization percentage, relative to the other positions observed.

Figure 3 shows the histogram of polarization position angles; again positions are indicated by their identifying numbers. The unweighted average position angle is 31°.3, with a standard deviation of 10°.6. Since the average uncertainty in any one position angle is somewhat less than 6°, if we correct the observed standard deviation for the effect of the measurement uncertainty of each point, the intrinsic sample dispersion estimate is reduced to 9°.3. As will be discussed below, this dispersion is extremely small, indicating that the magnetic field in this region has had a strong influence on the evolution of the Orion cloud core.

4. DISCUSSION

4.1. *Comparison with Other Polarization Data*

Before beginning a detailed discussion of the underlying physical meaning of our results, we should compare our new results with similar results already reported in the literature. The first measurement of the 1300 μm polarization toward Orion was obtained by our group using an earlier version of MILLIPOL and was reported by BCL. That work reported detection of polarization from the BN/KL position at a percentage level of 2.9% $\pm$ 0.6% at an angle of 11° $\pm$ 6°. Recently, NPG have measured the same BN/KL position using the 14 m FCRAO telescope at 1300 μm with a polarimeter based on a sapphire half-wave plate. Their polarization values, $P = 2.6\% \pm 0.8\%$ and $\phi = 40° \pm 8°$ are in excellent agreement with the value listed for our position 10 in Table 1. The quality of the MILLIPOL instrument has greatly increased since our preliminary measurements (see, e.g., CLBK), hence the disagreement with our earlier position angle is not strongly significant. *Both* previous measurements agree with our new results in percentage polarization to well within the uncertainties. We regard this agreement as confirmation of the unusually low polarization associated with BN/KL.

A more important comparison involves the 100 μm mapping of the Orion cloud core by G90. They observed 10 positions in the Orion cloud, detecting significant polarization from eight of the positions. The agreement in both polarization percentages and position angles between their results and ours is quite good. The significance of both data sets is high enough that any differences seen are likely true differences, indicative of real astrophysical effects, and not measurement error. G90 similarly found a high degree of order in the embedded magnetic field and that the BN/KL position was one of unusually low polarization. Their position angles generally agree well with ours, even though the areas covered in the maps are different.

4.2. *Uniformity and Strength of the Magnetic Field*

The average direction of the polarization position angles in Table 1 is 31°.3 $\pm$ 2°.8 for equal weighting and only mildly changed with weighting by the inverse of the angular uncertainty squared, to 31°.5 $\pm$ 1°.0. The inferred magnetic field direction is orthogonal to this average, at a position angle of 121°.5, in excellent accord with the direction of the high-velocity outflow and the direction of the optical starlight polarization outside the Orion cloud.

The intrinsic angular dispersion of the polarization position angles measured, once corrected for the measurement uncertainty, was 9°.3. Similarly, for the G90 detected polarization position angles, an intrinsic dispersion of 11° was inferred. However, exclusion of their southernmost position reduced the intrinsic dispersion to 5°.9. These dispersions could be used to estimate the importance of the magnetic field during the evolution of the cloud, as has been done for optical polarization measurements of stars behind nearby dark clouds by Vrba, Strom, & Strom (1988). For example, Heyer et al. (1986) found that the optical polarization position angles for stars behind the clouds B216−217 showed an angular dispersion of 16°, while for B18 the dispersion found was 11°. These were argued by Vrba, Strom, & Strom to represent cases in which the magnetic field played an important role during the collapse of the clouds, in contrast to the case for L1641, where they found a large angular dispersion of 33° and only marginal alignment of the dark cloud axis with the magnetic field.

Hence, if we apply this understanding of magnetic activity traced via polarization directions of dark clouds to the Orion cloud core, the embedded magnetic field there must be very important. Put another way, the field is so strong that turbulence has not significantly twisted the embedded field lines. Instead, the high-velocity outflow, at $\phi \sim 125°$ (Erickson et al. 1982), seems to proceed along the field lines. Also, the magnetic field direction inside the cloud is very similar to the field direction outside the cloud ($\sim$110°; Vrba, Strom, & Strom 1988). Finally, the position angle of the Orion ridge (10°–30°) similarly argues for a magnetically influenced formation.

An estimate of the strength of the embedded magnetic field follows from the ratio of the turbulent gas velocity in the region to the dispersion of the magnetic field line directions (Chandrasekhar & Fermi 1953). We follow G90 in assuming the mean density of the gas is $\sim 10^5$ cm^{-3} and that the turbulent velocity is 0.9 km s^{-1}, and using our intrinsic angular dispersion obtain a field strength of the order of 1 mG, similar to the values deduced by G90.

4.3. *Highly Polarized Dust Grains*

It is useful to quantitatively compare the percentage polarizations seen at 1300 and 100 μm. Such a comparison can place constraints on the nature of the dust grains involved in generating the polarization. The ratio of mean 1300 μm polarization to the mean 100 μm polarization is 1.5 $\pm$ 0.3, when all G90 detections and all of our positions are included. Similarly, considering only the BN/KL position, the ratio is 1.5 $\pm$ 0.2. G90 argue that scattering can reduce the true 100 μm polarization relative to that observed, and they estimate a maximum correction factor of 1.2. Including their correction factors, the mean 100 μm polarization over the detections in their map is 3.7% $\pm$ 0.5% and the 1300 to 100 μm ratio becomes 1.2 $\pm$ 0.2.

Hence the change in polarization with wavelength is essentially flat, or only mildly increasing. Such a lack of wavelength dependence is a signature of silicate dust grains (Dall'oglio et al. 1974). Silicate grains tend to exhibit more highly polarized emission than other grain types, also in accord with our high average polarization percentages. Interestingly, the wavelength dependence of the polarization does not change in the vicinity of BN/KL. Since this slope of log (P)/log (λ) is unchanged in going from the entire 100 and 1300 μm maps to the BN/KL position, we deduce that grain compositions and sizes do not strongly change over the regions mapped.

4.4. *A Polarization Hole toward BN/KL*

Earlier, in the discussion of Figure 2, it was noted that the polarization percentage found for the BN/KL position was significantly lower than the average found for all observed positions. A similar discrepancy was found at 100 μm by G90. This effect has been illustrated graphically in Figure 4. In that figure, we plot the average polarization percentage as a func-

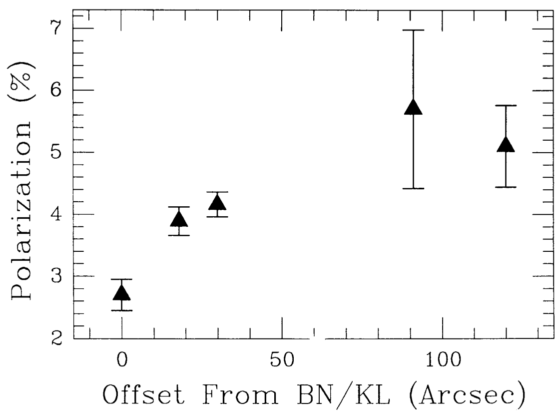

FIG. 4.—Plot of the radial averaged percentage polarizations measured at 1300 μm using MILLIPOL vs. angular offset from the BN/KL position. The points at 18″ and 30″ offset represent averages of all of the data at those offsets (six positions each). The remaining measurements are all single position measurements, although the BN/KL point represents many separate observations. Away from the BN/KL position, the average polarization rises to 4%–5%, while at BN/KL, the polarization drops to 2.7%.

tion of radial offset from the BN/KL position. The six data points which we collected at positions 18″ from BN/KL were averaged to form one value at that radial offset. The six positions offset by 30″ were similarly averaged.

There is a clear indication that the average polarization away from BN/KL is ~4%–5%, and that as BN/KL is approached, the polarization percentage drops. The G90 data also show the same sort of effect, although not as dramatically. The amount of polarization decrease at the BN/KL position is 1.5% at 1300 μm (0.6 times the average over the map).

There has been some concern that the change in polarization away from BN/KL might be the result of off-axis polarization sensitivity effects in the telescope-instrument combination (Gonatas et al. 1989; NPG). However, we believe this effect is not biasing our measurements for the following two reasons. First, we have measured the off-axis polarization sensitivity of MILLIPOL on the NRAO 12 m telescope by observing Jupiter at the half-power points of the telescope beam (CLBK). We found no effects larger than the 0.4% variation likely produced by the polarization of Jupiter's radiation zones. Second, the effect has been argued to be strongest at the edges of flux peaks (Gonatas et al. 1989). However, our two positions covering, and just off of, the southern flux peak show no such effects. In fact, the lack of such a change in the polarization toward the southern flux peak indicates that the change seen toward BN/KL must be real. The remarkable agreement of the BN/KL polarization percentage between NPG and this work further confirms the odd nature of BN/KL.

Having established that something different is going on toward BN/KL, we now turn to possible explanations.

4.4.1. *Projection of the Magnetic Field along the Line of Sight*

One possible explanation for the decrease in apparent polarization percentage toward BN/KL is that the direction of the magnetic field changes there from being modestly inclined to being more strongly inclined with respect to the plane of the sky (G90). A magnetic field which is directed along the line-of-sight direction will produce no net polarization in the thermal dust emission. A field tangent to the line of sight will produce a maximum value of polarization. Hence, we can solve for the inclination angle of the magnetic field for every position observed, once the purely tangential field polarization percentage is known.

We assumed that the pure tangential case was represented by the two highest polarization values, whose average was 7.8%, and computed the projection angles for the remaining positions as $\theta = \cos^{-2} (P/P_{\rm max})$. The mean inclination angle found was 37° with a dispersion of 16°. Crude correction for the polarization measurement uncertainty reduces the dispersion to just under 15°. The inclination angle needed to explain the low BN/KL polarization is 54°, similar to the 56° computed by G90. The resulting picture is one where the general Orion magnetic field direction is at a position angle of 90° + 31°.5 = 121°.5, measured east from north, and inclined with respect to the plane of the sky at an angle of around 37°. At the BN/KL position the field direction changes, becoming more inclined, as though pulled into, or pushed out of, BN/KL.

There may be some rather direct corroboration of this scenario contained in the analyses of the Orion KL SiO maser emission performed by Barvainis (1984) and Plambeck, Wright, & Carlson (1990). In order to explain the polarization (Barvainis) and maser spot location (Plambeck, Wright, & Carlson) characteristics, the SiO emission is thought to arise in a magnetized, rotating, and expanding tilted disk centered on IRc2. The models which well represent the observed SiO spectral lines require position angles near 35° and inclinations of 45°–57°, values very close to those determined for the 1300 and 100 μm polarization of BN/KL. An additional source of support for this scenario comes from the Zeeman splitting of the OH maser lines from KL (Hansen 1982), which imply a magnetic field strength of ~4 mG. Hence it is plausible that the magnetic field in BN/KL is tied to the tilted, inclined SiO disk, leading to a reduction in the measured dust polarization there.

However, this explanation is not fully satisfying. While there is undoubtedly some general inclination of the magnetic field, near BN/KL the required line of sight angular change, around 17°, must be much larger than the change measured in the plane of the sky, less than 6°. Since it is unlikely that we would be in a position to see the field tilt only along the line of sight, we regard the majority of the change in percentage polarization from position to position in Orion as arising from a cause other than mere projection angle changes.

4.4.2. *Two-Component Polarization: Random or Tangled Fields?*

A second approach would be to ask whether a second polarization component, present only at the BN/KL position, could be added to the pervasive background polarization component to produce the polarization we detect. Mathematically, this consists of computing the difference between the Stokes U and Q at the BN/KL position and the background and determining the polarization implied by those differences.

As an estimate of the background polarization, we averaged the Stokes U and Q for the six positions offset by 30″ from the BN/KL position. The difference between these values and the values at BN/KL amounted to $-0.9\% \pm 0.3\%$ for U and $-1.4\% \pm 0.3\%$ for Q. The polarization percentage and position angle implied in this second component are 1.7% ± 0.3% and 119° ± 5°. That the second component is almost perpendicular to the background component is required since the change in polarization position angle from the background to BN/KL is quite small.

This second polarization component idea raises four possible explanations. The first is that right at BN/KL, the optical depth is high enough that cold foreground dust, laced by the magnetic field, is inducing anisotropic *absorption* on the previously induced anisotropic emission from warmer, thinner background dust. The second possibility is that in BN/KL the dust is being destroyed, with no change to the magnetic field. Then the polarization change would be due to reduced grain sizes or densities, or to modification of the shapes of grains, reducing their polarization efficiencies. Third, the presence of a second component, with a polarization direction orthogonal to the background component, could signify a change in the direction of the alignment of the dust grains with respect to the magnetic field. Finally, the second component may represent depolarization due to twisted or tangled magnetic field lines within our 30″ telescope beam.

If the magnetic energy contained in a random (or highly twisted or wrapped) field becomes substantial relative to the energy in the uniform field, the net polarization will decrease, compared to regions with a similar uniform field but little random component. Following Gardner & Whiteoak (1966), the reduction of 1300 μm polarization at BN/KL could be explained by a random magnetic field containing about half of the energy of the uniform magnetic field. If the magnetic field in BN/KL is tied to the rotating SiO disk, then field line wrapping within our beam would mimick a random field nicely. Higher angular resolution will be required to test this picture.

4.5. *A Scenario*

It may be possible to build a fairly complete scenario to explain almost all of the polarization results for the Orion cloud core as follows. On the largest scales, probed by the 100 μm polarization map of G90, the magnetic field is both fairly strong and very uniform, showing an angular dispersion of less than 5°. The region just outside BN/KL, traced by our 1300 μm polarization map, has active gas—stirred by outflows, shocks, and ionization from massive stars, leading to a larger angular dispersion for the magnetic field lines (even though the field is likely stronger here because the gas density is higher). Right toward BN/KL, several things probably happen together. The magnetic field may be tied to the dense SiO disk, resulting in an inclination angle change *and* in field line wrapping within a very small region, perhaps the size of the inner part of the high-velocity CO outflow, $\sim$0.03–0.1 pc. In the densest part of the KL region, and including the SiO disk, the field is quite strong (at least 4 mG) and is responsible for the Zeeman splitting of the OH maser lines.

5. SUMMARY

We have used the MILLIPOL instrument in conjunction with the 12 m NRAO telescope to measure the polarized signal from thermal dust emission toward the Orion cloud core. Significant polarized flux was detected at every one of the 15 positions observed.

The findings of this study are as follows:

1. The polarization position angles found are remarkably uniform. The dispersion in position angle, corrected for measurement uncertainty is $\sim$9°. This indicates that the underlying magnetic field is also very uniform in direction over the 0.3 pc region surveyed and may be quite strong (of the order of 1 mG).

2. The average percentage polarization found, 4.6%, is quite high. Two points show polarizations of nearly 8%, the highest yet observed for thermal dust emission.

3. The percentage polarization found for the BN/KL position, 2.7%, is significantly lower than the average for positions just 30″ removed from BN/KL. The difference represents 36% of the polarization away from BN/KL.

4. The lower BN/KL polarization could be due to (1) a change in the magnetic field inclination angle, from mostly tangential to mostly radial; (2) the destruction or modification of the shapes of grains; or (3) the presence of a second polarization component, with direction almost perpendicular to the background direction. This latter component could arise from a cold layer of absorbing dust in front of the dust generating the background polarization, or from field line tangling or other random components of the field. We favor a combination of inclination change and field line tangling or wrapping.

5. The ratio of polarization percentage detected at 1300 μm to that at 100 μm is in the range 1.25–1.5.

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