RADIO POLARIMETRIC IMAGING OF THE INTERSTELLAR MEDIUM: MAGNETIC FIELD AND DIFFUSE IONIZED GAS STRUCTURE NEAR THE W3/W4/W5/HB 3 COMPLEX

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ABSTRACT

We have used polarimetric imaging to study the magneto-ionic medium of the Galaxy, obtaining 1420 MHz images with an angular resolution of 1' over more than 40 deg 2 of sky around the W3/W4/W5/HB3 H II region/SNR complex in the Perseus Arm. Features detected in polarization angle are imposed on the linearly polarized Galactic synchrotron background emission by Faraday rotation arising in foreground ionized gas having an emission measure as low as 1 cm -6 pc. Several new remarkable phenomena have been identified, including: mottled polarization arising from random fluctuations in a magneto-ionic screen that we identify with a medium in the Perseus Arm, probably in the vicinity of the H II regions themselves; depolarization arising from very high rotation measures (several times 10 3 rad m -2) and rotation measure gradients due to the dense, turbulent environs of the H II regions; highly ordered features spanning up to several degrees; and an extended influence of the H II regions beyond the boundaries defined by earlier observations. In particular, the effects of an extended, low-density ionized halo around the H II region W4 are evident, probably an example of the extended H II envelopes postulated as the origin of weak recombination-line emission detected from the Galactic ridge. Our polarization observations can be understood if the uniform magnetic field component in this envelope scales with the square-root of electron density and is 20 pG at the edge of the depolarized region around W4, although this is probably an overestimate since the random field component will have a significant effect.

Subject headings: H II regions — ISM: structure — polarization — radio continuum: ISM

1. INTRODUCTION

Linearly polarized electromagnetic waves that pass through a magneto-ionic medium (MIM; that is, a medium containing magnetic fields and free thermal electrons) undergo a rotation of their polarization angle, known as Faraday rotation. Specifically, the amount Δφ (rad) by which the angle is rotated at wavelength λ (m) is Δφ = R M λ 2, where R M is the rotation measure (rad m -2), given by:

\[ R_M = K \int n_e B \cdot dl. \]  

Here K has a numerical value of 0.81 when the electron density n e is in units of cm -3, the magnetic field strength B is in μG, and the path length l is in pc (see Lang 1974). A medium producing such Faraday rotation is also referred to as a Faraday screen.

Diffuse ionized gas threaded by magnetic fields is ubiquitous in the interstellar medium (ISM) of our Galaxy, so clues about the distribution and properties of this MIM can be obtained by studying linearly polarized signals from background emitters. Measurements show that, in the general ISM, |R M| ≤ 10 5 rad m -2 (Clegg et al. 1992; values an order of magnitude higher are not unknown, but are the exception rather than the rule). A range of detectable Δφ is then most readily obtained at centi- and deci-metric wave-lengths; at shorter wavelengths too little rotation results, and at longer wavelengths too much rotation is produced, yielding depolarization from the averaging of nonparallel polarization vectors.

To date, radio observations of Galactic Faraday rotation effects in linearly polarized emission have largely been limited to low spatial resolution (greater than 0.5'), single-antenna studies of the diffuse Galactic synchrotron component over wide areas of the sky (see Brouw & Spoelstra 1976; Spoelstra 1984), or to high spatial resolution but targeted observations of polarized objects (mainly pulsars or extragalactic objects; Tabara & Inoue 1980; Simard-Normandin, Kronberg, & Button 1981; Broten, MacLeod, & Vallée 1988; Lyne & Smith 1989; Clegg et al. 1992). In the presence of spatially varying rotation measure, either approach leads to limited information about the detailed properties of the MIM component of the ISM, in the former case because of the inherent low resolution and averaging effects within a single beam, and in the latter case because of sparse sky coverage. The need for high-resolution measurements covering a wide area has been stressed by Verschuur & Spoelstra (1990).

Any wide-scale study will, by necessity, have to rely on the polarized fraction of the Galactic synchrotron component as the probe radiation. The nonthermal spectrum of this radiation favours longer wavelengths, where the Faraday rotation produced by a given MIM is also greater. Making observations with resolutions of an arcminute or less at wavelengths longer than a few centimetres requires the use of aperture synthesis techniques (the Effelsberg 100 m single-antenna telescope, for example, only achieves sub-arcminute resolution at wavelengths shorter than λ = 3 cm; i.e., frequencies higher than 10 GHz).

Recently, some interferometric observations have been...
made with the Westerbork Synthesis Radio Telescope (WSRT) at \( \lambda = 92 \) cm (325 MHz), showing widely distributed polarized structures on scales from a few arcminutes to several degrees across a number of 2\(^\circ\) fields at high Galactic latitudes (\( b > 18^\circ \); Wieringa et al. 1993). These structures have no counterparts in total intensity and are interpreted as arising from sight-line dependent Faraday rotation effects in a local, foreground MIM of low density. In order to see “through” this local Faraday screen to probe regions that are more distant and/or of higher column density it is necessary to use a shorter wavelength.

We have used the Dominion Radio Astrophysical Observatory (DRAO) Synthesis Telescope to produce interferometric images of polarization with arcminute resolution at \( \lambda = 21 \) cm (1420 MHz). At this wavelength a rotation measure 20 times as great is required to produce rotation angles comparable to those seen at 92 cm. The region we have studied is the W3/W4/W5/HB 3 complex (Fig. 1). W3, W4, and W5 are large, bright H\(\text{II} \) regions at a distance of 2.2 kpc in the Perseus spiral arm of the Milky Way, related to the OB association Cas OB6. They do not themselves emit polarized radiation but are rich in thermal electrons necessary for Faraday rotation. HB 3 (G132.6 + 1.5; see Fesen et al. 1995) is a supernova remnant (SNR)—and hence may itself be polarized—believed to be interacting with the material in the vicinity of W3 (Caswell 1967; Routledge et al. 1991). This region provides an interesting environment in which Faraday rotation effects may be studied as polarized emission from background sources, the diffuse Galactic emission, and HB3 pass through the H\(\text{II} \) regions and their environs.

Examination of our polarization data has revealed a range of remarkable phenomena evident primarily in polarization angle, consistent with an origin in the Faraday rotation effect. We interpret these phenomena as arising in a Faraday screen located in the Perseus arm of the Galaxy, and see evidence for an extended influence of the H\(\text{II} \) regions on the surrounding ISM. A presentation of our results and discussion of them in relation to ISM studies is the topic of this paper.

2. DATA ACQUISITION AND REDUCTION
2.1. The DRAO Synthesis Telescope

The DRAO Synthesis Telescope (see Roger et al. 1973 for a description of the instrument prior to some recent
upgrades) is a seven-element, east-west aperture synthesis array located near Penticton, in British Columbia, Canada. The standard data product of the ST is described in some detail by Normandeau, Taylor, & Dewdney (1997, hereafter NTD97), but, briefly, it is comprised of simultaneous measurements of 408 MHz ($\lambda = 74$ cm, 3 MHz bandwidth) total radio continuum intensity (see Veidt et al. 1985), 256 channel,$^4$ 1420 MHz ($\lambda = 21$ cm) neutral hydrogen (H\textsc{i}) spectroscopy (up to 4 MHz bandwidth), and, of interest here, 1420 MHz radio continuum (30 MHz bandwidth) with full polarimetry.

A complete synthesis comprises twelve 12 hr observations in various array configurations to provide continuous baseline coverage from 13 to 604 m. At 1420 MHz the resulting images contain information on spatial structures from approximately 1$^\circ$ to 1$^\circ$ across a field of about 2$^\circ$ in diameter, with a noise-limited rms sensitivity of 0.23 mJy beam$^{-1}$. In practice, the images are dynamic-range limited in the vicinity of very strong sources.

2.1.1. The 1420 MHz Polarimeter System

The ST antennas are fitted with orthogonal right- (R) and left- (L) hand circularly polarized feed systems for 1420 MHz operation. The continuum correlator provides all four cross-correlation products (RR, LL, RL, LR), allowing recovery, after appropriate calibration (see Smegal et al. 1997), of the four Stokes parameters, $I$, $Q$, $U$, $V$, representing total intensity, two orthogonal components of linear polarization, and circular polarization, respectively. These four parameters fully describe the polarization state of the incident radiation, but in practice the $V$ data produced by the current system are dominated by artifacts introduced by small ellipticity errors of the nominally circular feeds, so it is mainly linearly polarized emission that is studied. This is not a major limitation since synchrotron sources—which are the ones primarily studied with this instrument—do not emit significant circular polarization, and the error introduced in linear polarization is small.

After a complete synthesis observation the polarimeter precision is limited to about 5% in amplitude by calibration uncertainties, with polarization angles determined to within 5$^\circ$, although there is an additional 3$^\circ$ day-night variation of ionospheric origin that is not routinely accounted for at present. There is also an additive instrumental term of approximately 0.3% of $I$ on axis, rising quadratically to $\sim 3\%$ of $I$ at a radius of 1$^\circ$ from the centre of the image. Techniques are presently being developed to reduce the magnitude of these various errors and uncertainties, but all

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$^4$ 128-channel at the epoch of the data described in this paper.
2.2. The Observations

The observations of the W3/W4/W5/HB 3 region presented in this paper were made in 1993 June, July, November, and December as a pilot study for the Canadian Galactic Plane Survey. Ten fields were observed, spanning an 8° × 6° region centred near \( l = 134.7 \), \( b = +1.2 \) (see Fig. 1). Processing of the Stokes I and spectrometer data are discussed in NTD97. Additional processing applied to the polarimeter data included polarization calibration to account for differing antenna polarization responses, as well as calibration of polarization angle using 3C286, assumed to have a polarization angle of 33.5° at 1420 MHz.

The raw Stokes Q and U images were affected by side-lobes arising from the spurious instrumental response to W3, and also from the bright, compact, off-field SNR 3C 58 (G130.7+3.1, SN 1181; see Green 1988, and references therein). The individual fields were therefore processed using MODCAL, a visibility-based scheme for removing such artifacts (see Willis & Higgs 1996), applied in combination with a standard CLEAN algorithm for deconvolution of the synthesized beam. The processed fields were then added together—with appropriate primary beam weighting—to form composite images of the full pilot survey region. Figures 2 and 3 show the composites of Stokes Q and U, respectively, while Figures 4 and 5 show polarized intensity \( P = \sqrt{Q^2 + U^2} \) and polarization angle \( \theta_p = \frac{1}{2} \arctan U/Q \). Since the images of Stokes Q and U (and hence \( P \) and \( \theta_p \)) do not include data on spacings shorter than 12.9 m we will refer to them as “interferometer images.” Figure 6 shows the Stokes Q composite with overlaid contours of 2695 MHz Stokes I, to show the positions of the various sources in relation to the detected polarization.

3. POLARIMETRY AS A PROBE OF THE INTERSTELLAR MEDIUM

To make use of polarimetry to probe the ionized component of the interstellar medium requires an understanding of the interaction of instrumental effects with the vector nature of polarization, particularly in the presence of spatially varying and frequency-dependent Faraday rotation.

Faraday rotation does not, in itself, alter the amplitude of the polarized signal or its corresponding unpolarized portion. The observed polarized amplitude can, however, be altered by three depolarization mechanisms.

1. **Bandwidth depolarization** occurs when the rotation measure is sufficiently high that the Faraday rotation changes significantly across the observing bandwidth, which intrinsically averages the resulting non-parallel
vectors. For the DRAO Synthesis Telescope at 1420 MHz, 50% depolarization occurs for $R_M = 790 \text{ rad m}^{-2}$, and 99% depolarization occurs for $R_M = 1250 \text{ rad m}^{-3}$ (assuming a perfectly rectangular band shape).

2. Beam depolarization occurs when large rotation-measure gradients occur within the instrumental beam-width, again resulting in the averaging of disparate polarization vectors.

3. Front-back depolarization occurs when polarized emission arises within an MIM, in which case polarized emission originating in different regions will have different polarization angles, and vector averaging will again take place (see Burn 1966).

For simplicity the last mechanism is not discussed further in this paper; its inclusion would not change the conclusions, as the phenomena discussed in this paper arise from propagation effects on a diffuse background, not from intrinsic polarization within the MIM.

The above depolarization mechanisms mean that a MIM which produces observable effects at a given wavelength must have a specific range of properties, having a rotation measure that is neither too low to produce measurable angle changes nor so high that it causes bandwidth depolarization. Similarly, any spatial rotation-measure gradients cannot be too large on scales small enough to cause beam-width depolarization. Faraday rotation, even though it only directly affects polarization angle, can thus produce structures in images of both observed polarized intensity and polarization angle simply through depolarization.

There is a further effect to be considered with interferometer data. Interferometers are inherently spatial filters, being unable to image emission components that are distributed smoothly on large scales. The exact cut-off depends on the instrument: with the DRAO Synthesis Telescope we are able to detect structures up to about $1^\circ$ in size, with a rapid decline in sensitivity to larger structures. The effect of this cut-off is readily understood for images of scalar quantities (e.g., Stokes $I$), when it simply means that emission components on larger scales are absent from the images. The situation is slightly more complex, however, for a vector quantity like polarization.

Consider the case of a large-scale, uniform polarization field, i.e., constant polarized intensity and polarization angle, and hence constant Stokes $Q$ and $U$. Attempting to image such a field with an interferometer would result in a nondetection since all of the emission is on large scales. If this polarization field first passes through a nonuniform
MIM that produces spatially varying Faraday rotation then the polarization angle, and hence $Q$ and $U$, will vary according to the local properties of the MIM. The polarized intensity, which is the quadrature sum of $Q$ and $U$, will still be uniform, since Faraday rotation does not affect intensity. However, spatially filtering this distribution by observing it with an interferometer will result in detected signal only where the variations in $Q$ and $U$ occur on scales to which the interferometer is sensitive. That is, apparent structure will be induced in polarized intensity due solely to variations in polarization angle. Since Faraday rotation depends on both electron density and magnetic field orientation, both of which vary on small scales, there may be smaller scale variations visible in the vector polarization than in the scalar total intensity (Stokes $I$) data. The interferometer is thus a valuable tool for studies of ISM polarization properties on small scales.

It is important to note that, since the vector field effectively subtracted by spatial filtering is not spatially uniform, the interferometer image will not preserve the difference in polarization angle measured between two widely separated points in the image. However, provided that any such difference is measured over scales small compared to the largest structure that the interferometer can image, the error introduced will be negligible, since the subtracted vector field does not vary rapidly on such scales.

### 4. RESULTS

Several notable features are seen in the polarization images, including:

1. A mottled pattern, most prominent south of W3/W4/W5/HB 3, but present over much of the field shown here;
2. An absence of detected polarization on lines of sight toward the H II regions; and
3. An elliptical feature roughly coincident with W5.

All of these features are seen in raw images from the telescope, and are consistent in regions where the fields overlap. All are also seen in—and are consistent with—new data for this region obtained for the Canadian Galactic Plane Survey project, which used different pointing centres from the data presented here.

In this paper we concern ourselves with the details of features 1 and 2, which we will show are likely to be manifestations of the ISM in the Perseus arm, in which W3/W4/W5/HB 3 reside. Feature 3 points to a more local effect in the ISM, since it is superimposed on the depolarized zone (Feature 2) of W5. This phenomenon is mentioned in the following discussion, but is examined in detail elsewhere (Gray et al. 1998).

#### 4.1. Mottled Polarization Structures

The images of Stokes $Q$ and $U$ (Figs. 2 and 3) display a
Fig. 6.—Same gray scale as Fig. 2, but with overlaid contours of 2695 MHz Stokes $I$ (Fürst et al. 1990) at 0.3, 0.6, 1.2, 2.4, 4.8, 9.6, and 19.2 K, showing the relative locations of the Stokes $I$ emission.

widespread mottled pattern. The pattern extends to the edge of the observed region, but is most prominent to the south of W3/W4/W5. Defining the “cell size” as the scale size over which polarization angle variations of 180° occur, the cells range from ~1° close to W4 to ~10° farther away. Elsewhere they range up to several tens of arcminutes in size. Similar structures are seen in essentially all images made of other regions in and near the Galactic plane, so this is not just a peculiarity of the W3/W4/W5/HB 3 region.

The mottling is reflected strongly in polarization angle $\theta_p$ (Fig. 5), but there is only weak structure in polarized intensity $P$ (Fig. 4), and no corresponding Stokes $I$ emission. If the mottled $P$ structure represents some component with varying $P$ then its absence in $I$ would require that the polarized fraction $P/I$ also vary to keep $I$ constant. Since, with few exceptions, there is also no structure in $P$ that is not in $\theta_p$, and the $P$ structure is most prominent where $\theta_p$ varies most rapidly, the simplest explanation is that, as described in §3, the $P$ structure here is merely that expected in interferometer data from a pure polarization angle effect. That is, the underlying phenomenon is indeed Faraday rotation.

The widespread nature of the polarization seen here indicates that the radiation must originate in the diffuse Galactic background emission, and is being acted on by some foreground screen of MIM.

It is possible to place some constraints on the location of the Faraday screen. An upper limit to the distance to the screen is obtained by considering the total 1420 MHz diffuse background emission in this region, which has a brightness temperature of 4.2 K (see Kallas & Reich 1980). This will include some thermal emission at this frequency, but assuming a polarized fraction of 35% (Spoelstra 1984) yields an upper limit on the polarized emission of 1.5 K. Roger (1969) measured synchrotron emissivity between W4 and the Sun at 22 MHz and found that 29% of the total emission originates behind W4, corresponding to at most 0.45 K of polarized emission at 1420 MHz. We detect up to 0.3 K of diffuse polarized intensity in our images, which is a lower limit on the total signal passing through the screen, since large-scale structure is not detected by the interferometer. Since the synchrotron emissivity of the Galaxy is concentrated in the spiral arms (Beuermann, Kanback, & Berkhuijsen 1985), this suggests that the screen cannot be located much farther away than W3/W4/W5, or there would be insufficient polarized signal behind it to account for our observations.

A lower limit for the distance derives from the fact that the 71% (or up to 1.1 K) of the polarized emission that arises in front of W4 is not acted on by the screen, otherwise we would see it in the depolarized zones coincident with the
FIG. 7.—As for Fig. 6, magnified to show the region around W4 in greater detail. Note how the limit of the detected polarization follows a line of constant intensity—the lowest contour at 0.3 K—which lies well outside the boundary of the strongest emission. Even small-scale irregularities in this contour are apparently followed by the limit of detected polarization.

FIG. 8.—Plot showing the sky brightness temperature as a function of radius from the center of W4. The two dashed curves are data averaged over two sectors, each 10° wide, centered at P.A. 210° and 220° (i.e., extending southwest of W4). The solid curve is a Gaussian approximation to the rise at large radii (see text). Within about 60° radius the sky temperature rises more steeply than the Gaussian. It is within this region that the polarization is no longer detected.

$H \Pi$ regions (discussed in § 4.2 below). The screen must therefore lie behind this emission. But where does this emission originate? Wilkinson & Smith (1974) argue that the strong, ordered polarization detected towards the W3/W4/W5/HB 3 region in single-antenna measurements arises within 500 pc of the Sun. The strength of this polarized signal at 1411 MHz is about 0.5 K (see Brouw & Spoelstra 1976), a lower limit since single-antenna measurements will tend to underestimate the signal strength due to beam depolarization. The location of the remainder, up to 0.6 K, is likely to be closer to the Perseus arm since the synchrotron emissivity is concentrated in the arms (Beuermann et al. 1985). We know that the screen does not act on this component, and also that the thermal electrons necessary to produce the Faraday rotation are also concentrated in the spiral arms (Taylor & Cordes 1993). It is therefore most likely that the screen is located in the Perseus arm itself.

This screen may be an extended halo around the $H \Pi$ regions. In § 4.2 we present a model of the electron density profile of the halo around W4. If this halo is parameterized as being 100$L$ pc in size ($L$ is of order 1), then the thermal electron density in the tail of the Gaussian model is $n_e = 0.3/L$ cm$^{-3}$. The magnetic field in the Perseus arm has a
line-of-sight component of $B_{\parallel} = 2.5 \mu G$, with variations $\delta B / B = 1.4$ (Agafanov, Ruzmaikin, & Sokolov 1988). For this electron density and magnetic field variation a change in polarization angle between adjacent sight lines of 180° requires a path of length 80L pc. That is, the depth of the screen needs to be essentially the same as the depth of the W4 halo.

4.2. Depolarized Zones around H II Regions

While the mottled polarization is detected over large areas, closer to the H II regions a different behavior is seen in our data. Across the face of W3 and W4 and on sight lines immediately adjacent to them there is no apparent polarization (Figs. 2–5; a small amount of instrumental polarization is visible in these images as faint “ghosts” of the total intensity emission). We attribute the lack of observed polarization to high rotation measures and rotation measure gradients on small scales in the dense, turbulent environment of the H II regions, resulting in a strong spatial and frequency dependence of polarization angle. Beam and bandwidth depolarization effects then dominate, with the result that the detected signal falls to zero. Some weak polarization is seen from the nonthermal emission from the SNR, HB 3, but large portions appear unpolarized, possibly as a result of depolarization by the adjacent H II regions.

As noted by Braunsfurth (1983), both W3 and W4 are embedded in an extended halo of diffuse radio continuum emission; this is visible in single antenna, Stokes I maps of this region at 1420 MHz (Kallas & Reich 1980) and 2695 MHz (Fürst et al. 1990; see Fig. 1). The depolarized zone around W4 is particularly clear to the south, where the zone boundary closely follows a contour of total intensity (see Fig. 7). Since the halo is not visible in the Stokes I interferometer images, it must not have significant structure on scales smaller than about 1°. Examination of the radial profile of the halo at 2695 MHz to a distance of about 3° southwest of the centre of the W4 loop, a region relatively free from discrete emission, shows that its rise is well approximated by a Gaussian (temperature $T / \text{mK} = 550 e^{-0.978 r^2} + 30$, for $r$ in arcminutes) until within about 1° of the center of W4, after which it rises much more sharply (Fig. 8). It is at this point, which we refer to as the “vanishing point,” that the polarization also disappears sharply, strongly suggesting that this is a related phenomenon.

Modeling the halo around W4 as a spherical Gaussian yields an electron density of $n_e = 2.8 \times 10^3 \text{ cm}^{-3}$ at the vanishing point, corresponding to thermal electron column density of $3.5 \times 10^{18} \text{ cm}^{-2}$ pc. The interstellar magnetic field strength varies as a power law with electron density, with index $\frac{1}{2} < \alpha < \frac{3}{2}$ (see Gordon 1988). The Faraday rotation produced by such a cloud would vary in a Gaussian fashion with radius, and hence the observed polarization angle will also vary with radius, “wrapping” at $\pm 180°$ with some spatial interval that will depend on the magnitude of the Faraday rotation. In the case of our data, wrapping on scales smaller than 1° would produce beam depolarization, so we require that the scale size of the wrapping be no smaller than 1° at the vanishing point, otherwise the polarization would be seen to disappear outside the brightest emission from W4 rather than at its boundary. This condition is met for a line-of-sight magnetic field at the vanishing point of approximately 20 $\mu G$. This value does not depend strongly on $x$ within the range quoted above, but random fluctuations (§ 4.1) confuse the radial variation of polarization angle in our data, so this value is an upper limit. However, we note that the bandwidth depolarization effects produced by the resulting Faraday rotation are also consistent with our observations, and the spatial interval between polarization angle wrap points would be about 25° at a radius of 3°, which may mean that the barlike structure at the bottom of Figure 5 is related to the halo.

So far we have considered only the W3/W4 region; the case of W5 is complicated by the presence of the elliptical polarization feature. This is discussed in detail by Gray et al. (1998), who conclude that it is a foreground phenomenon, probably arising from a MIM in the interarm region. Nonetheless, it is superimposed on a region of low or absent polarization, consistent with a depolarized zone coincident with W5, but there is no obvious “vanishing point” associated with W5, which lacks the extended halo of W4 (Braunsfurth 1983; see also Fig. 1).

5. DISTRIBUTION OF THE FARADAY SCREEN

Although the limited region presented here does not offer any direct constraint on the overall extent of the Faraday screen in either latitude or longitude, there are some qualitative indications in other observations.

5.1. Comparison with Other Data

DRAO 1420 MHz data that we obtained for several of the Wieringa et al. (1993) high latitude ($b = 18°$–52°) fields showed little significant polarization, and none similar to the structures observed by Wieringa et al. at 325 MHz. If these structures were intrinsic to the polarized emission we should still be able to detect them at 1420 MHz despite the falling spectrum of Galactic background emission, particularly with the decreased Faraday rotation and associated depolarization effects. However, if we assume that these structures are due to Faraday rotation then our result is entirely expected, and indeed supports the Wieringa et al. model of this phenomenon, namely, that the structures seen at 325 MHz are due to a local, foreground screen.

Other high-latitude fields observed at DRAO at 1420 MHz also show few significant polarization structures, but polarization structures apparently unrelated to Stokes I emulsion appear essentially ubiquitous in fields observed for the Canadian Galactic Plane Survey project as well as other fields observed near the Galactic plane in the course of normal DRAO operations. It is clear, then, that the structures of interest at 1420 MHz are generally confined to lower latitudes ($b \leq 10°$), and hence the MIM responsible for their formation must be confined to the disc component of the Galaxy. The general properties of these structures are similar to those detected in the WSRT 325 MHz observations, but they cannot be manifestations of the same MIM since depolarization effects will become important at 325 MHz by the time the detectable variations are present at 1420 MHz. For example, a change in rotation measure of $\Delta \rho = 2 \text{ rad m}^{-2}$ will produce a change in polarization angle of only $\Delta \theta_p = 5°$ at 1420 MHz, which, when averaged within a beam, will have a negligible depolarizing effect, but at 325 MHz $\Delta \rho = 97°$, which will produce essentially complete depolarization. Similarly, at the narrowest band used at 325 MHz (2.3 MHz) there would be total bandwidth depolarization for a rotation measure of approximately
\[ R_M = 260 \text{ rad m}^{-2}, \] which would produce only 6\% depolarization in our data. The difference in latitude extent observed at 325 and 1420 MHz further suggests that the media being probed are not only distinct but lie at different distances.

### 5.2. Environment of H II Regions

In our data there is also some evidence of a longitude dependence both in the structures themselves and in their latitude extent. Indications in the data at hand, both in the W3/W4/W5/HB 3 region and elsewhere along the Galactic plane, are that the presence of large H II regions may be a factor in enhancing the polarization structures and increasing their latitude extent. Since the detection of the polarized structures depends on thermal electron density, this suggests that the H II regions might be responsible for a surrounding region of weakly enhanced levels of thermal electrons—that is, enough to cause significant rotation measures, but of sufficiently low emission measure that they are not detected in total intensity data—in the ISM over an area several times large than the nominal boundary of the H II region. We may be detecting the effect of the extended H II envelopes (EHEs) proposed by Anantharamaiah (1985, 1986) to explain widely distributed 325 MHz radio recombination-line (RRL) emission from the Galactic ridge. These RRLs have not previously been localized sufficiently well that they could be associated with known H II regions (see Kassim 1989), but appear to originate in gas with densities and path lengths (Anantharamaiah 1986) comparable to those we propose for the Faraday screen. Our Faraday rotation technique may thus provide the link required to establish this connection. As more data become available from the Canadian Galactic Plane Survey we will gain a clearer insight into this issue.

### 6. CONCLUSION

The DRAO Synthesis Telescope's 1420 MHz polarimeter system has provided us with a powerful new tool for probing the interstellar medium over wide fields, yielding information on the structure of the MIM that is not obtainable by other means. The study presented here has shown widespread Faraday rotation effects in the background Galactic synchrotron emission in the direction of the W3/W4/W5/HB 3 complex, with several interesting phenomena which can be associated with very low densities of thermal electrons (emission measures as low as 1 cm\(^{-6}\) pc) threaded by the interstellar magnetic field. These include:

1. A widespread mottled polarization structure that we attribute to the action of a widely distributed screen, which is constrained to lie in the Perseus arm, probably in the immediate vicinity of the the H II regions themselves.
2. Depolarization zones around the H II regions, arising due to very high rotation measures of at least several times \(10^3 \text{ rad m}^{-2}\) and spatial rotation measure gradients.
3. The suggestion of an extended region of influence around the H II regions, well beyond the apparent boundary of thier emission evident in radio and other wave bands, potentially providing an observational confirmation of the extended H II envelopes postulated by Anantharamaiah (1985, 1986).
4. The elliptical feature coincident with W5 which, although not discussed in detail here (see Gray et al. 1998), is probably a foreground object seen against the depolarized zone of the H II region. This leads to the important observation that regular polarization structures may be widespread, but their existence will generally be masked by the presence of random fluctuations in the ISM.

One important aspect of this work is that it demonstrates the possibility of using objects of known distance to estimate the distribution of the polarized emission as well as the MIM along the line of sight. It is also important to note that the \(\chi^2\) dependence of Faraday rotation means that substantial differences in the MIM properties are necessary to produce comparable results at widely differing wavelengths. Data at other, nearby wavelengths may also be useful in establishing the absolute rotation measure, and hence the absolute properties of the MIM (the data at hand constrain the variations in the MIM properties, but not the underlying distribution). Data at more disparate wavelengths will provide information about regions of lower or higher density. Multiwavelength studies of this type are thus important in obtaining information about the ionized component of the ISM and the interstellar magnetic fields in our Galaxy.

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