6. OPTICAL POLARIZATION OBSERVATIONS

A. Behr

7. RADIO POLARIZATION OBSERVATIONS; FARADAY ROTATION

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Three lines of work are covered: 1. Faraday rotation of the plane of polarized radiation from extra-galactic radio sources, 2. Linearly polarized radiation from the Galaxy, 3. Zeeman splitting of 21-cm absorption lines.

1. It is found that the radiation from extra-galactic radio sources is to some extent linearly polarized at microwave frequencies, a fact which is entirely consistent with the radiation being due to the synchrotron mechanism. In most cases the position angle of the electric vector varies as λ^2, implying that the rotation is due to the Faraday effect. For this:

$$\theta = 0{\cdot}81\, \lambda^2 \int NB_{\|}\, dL$$

where θ = angle of rotation (radians)
λ = wavelength (metres)
N = electron density (cm^{-3})
$B_{\|}$ = longitudinal component of magnetic field (microgauss)
dL = path length (parsecs).

The quantity θ/λ^2 measures a property of the medium and is termed (1) 'rotation measure' (RM). Sources lying near the galactic plane tend to have large RM's (particularly if $|b| < 10°$), indicating that much of the rotation occurs in our Galaxy (1, 2). A typical RM of 40 rad m^{-2} requires, for example, $L = 10^4$ pc, $B_{\|} = 5$ μg and $N = 10^{-2}$ cm^{-3}. Morris and Berge (2) have also noted a grouping of sources with RM's of the same sign (Fig. 1) in such a manner that

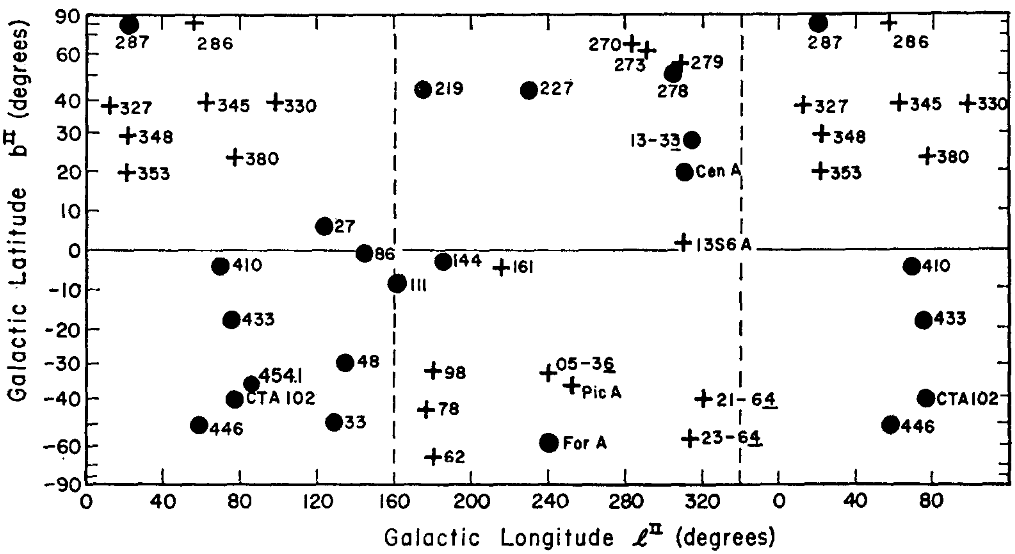

Fig. 1. Variation of the sign of the rotation measure with galactic co-ordinates. Crosses indicate positive RM; dots, negative RM. (Morris and Berge (2)). Positive RM means that the field is towards the observer.

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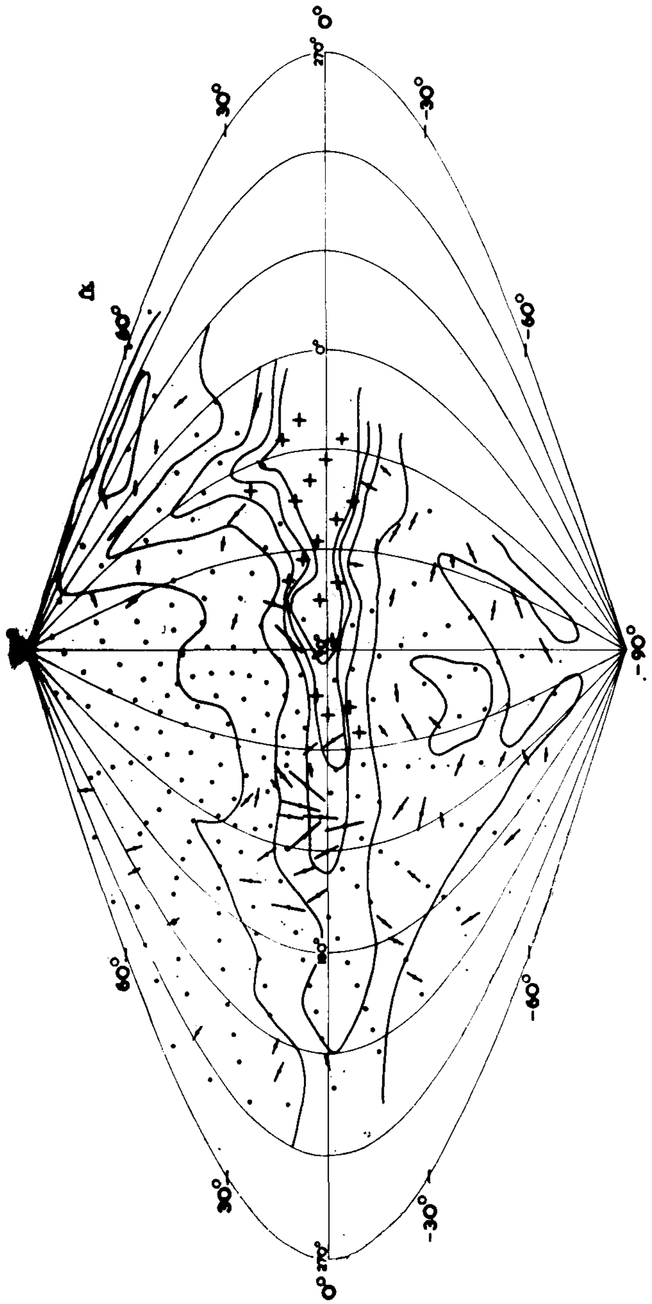

Fig. 2. Distribution of linear polarization in the Galaxy at 408 Mc/s. (Wielebinski and Shakeshaft (6)). The contours are those of brightness temperatures at 404 Mc/s.

the average magnetic field along these lines of sight changes direction across the galactic plane and also across longitudes 160° and 340°. Further unpublished observations by R. D. Davies and Gardner with the 210-foot dish at Parkes show a more complicated but essentially similar variation of RM with direction.

A feature of the source polarization studies which may reveal information on small-scale structure in the Galaxy is a possible dependence of the percentage polarization of the sources themselves on galactic latitude. Seielstad, Morris and Radhakrishnan (3) were the first to consider this with a sample of 30 sources and decided that there was no correlation, while McClain *et al.* (4) of the N.R.L. have recently obtained results with the 300-foot dish at Green Bank for 90 sources suggesting that there is depolarization in the Galaxy. If this indeed proves to be case then there must be structure of the galactic magnetic field and/or electron density on the scale of about 1 pc. Such structure would cause greater depolarization of sources of large angular diameter, an effect which the N.R.L. group believe they have found, although again this is in contradiction to a similar study of double sources by Seielstad *et al.* (3) which shows no such effect.

2. As well as the emission from strong radio sources galactic radio emission has for some time now been generally accepted as being largely due to synchrotron radiation. One might, therefore, expect the galactic radiation to be strongly polarized. This is not in fact so and it is only 3 years since a small linearly polarized component was first convincingly detected by Westerhout *et al.* (5) at Leiden, working at a frequency of 408 Mc/s. Since then further studies have been carried out at Cambridge (6), Sydney (7, 8) and Green Bank (9). It seems that the small percentage of the polarization must be due both to the varying orientation of the magnetic fields along the line of sight and also to Faraday rotation. Surveys of the polarized component at different frequencies can therefore provide information on magnetic fields and electron densities in the Galaxy.

Fig. 2 shows some of the general features of the polarization in relation to the background radiation. It is taken from a survey (6) at 408 Mc/s. The strongest patch (5–10 per cent) is slightly north of the galactic plane at $l^{II} \approx 140°$. Another region also showing polarization is near the North Galactic 'spur' but it is not yet clear whether there is any physical relationship with the 'spur'.

More detailed surveys have been carried out at Leiden at 408 (10, 11) and 610 (12) Mc/s. Fig. 3 shows results from the latter and Fig. 4 a comparison of the intense patch as seen at the

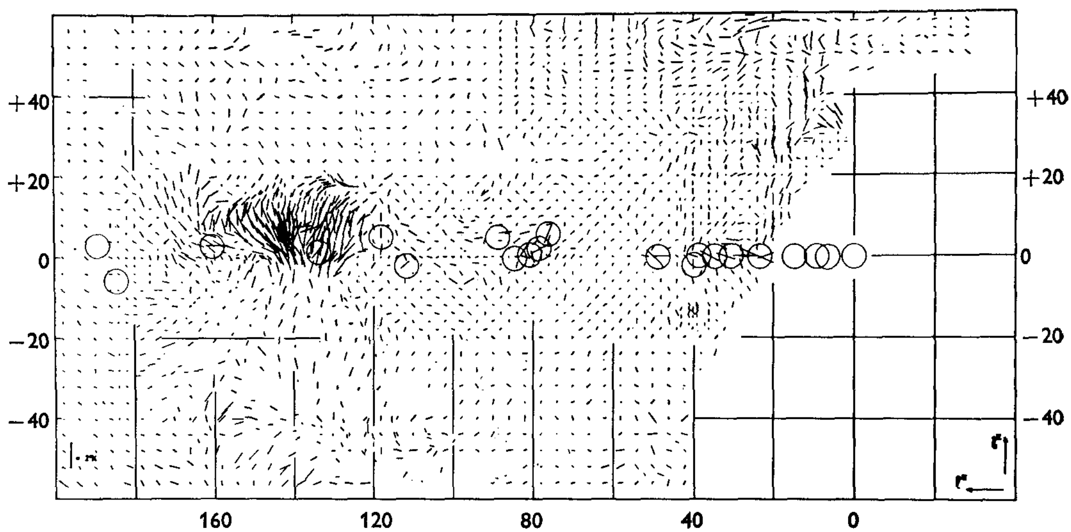

Fig. 3. Polarization map at 610 Mc/s (12).
The circles show regions affected by the strongest point sources.

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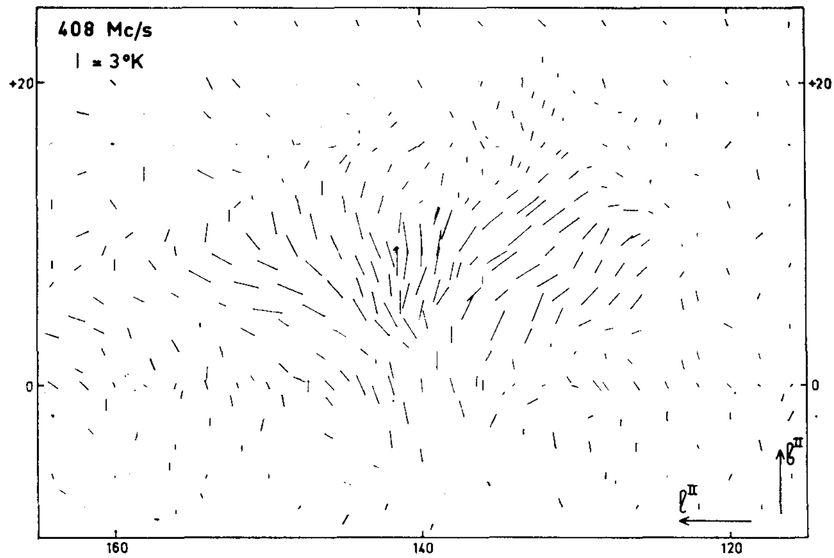

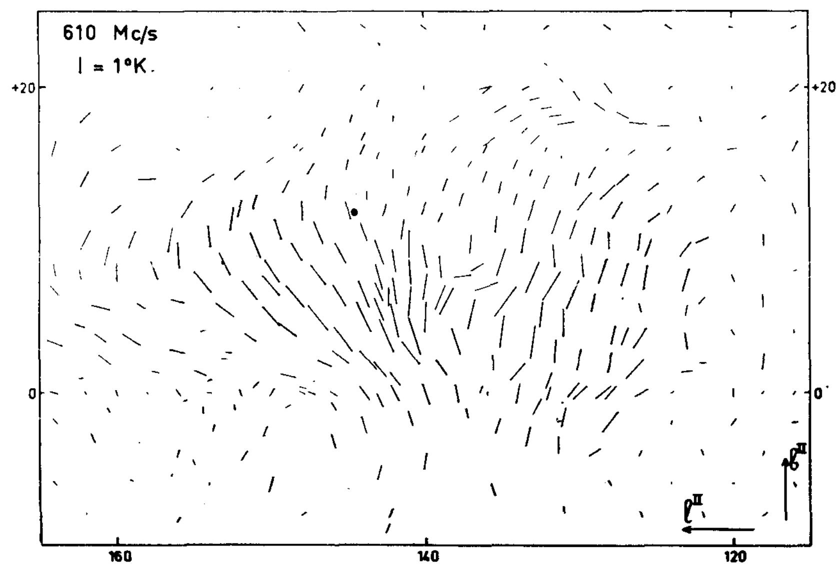

Fig. 4. Comparison of detailed polarization structure in one region at 408 and 610 Mc/s (12).

two frequencies. The 'fan' structure should be noted and the greater alignment at the higher frequency. It is clear that there is little Faraday rotation at $l^{II} = 140°$ suggesting that in this direction the line of sight is transverse to the local field. It is significant that this is also the direction of strong optical polarization and Fig. 5 (12) shows that the electric vectors of the optical and intrinsic radio polarized radiation are perpendicular, which is to be expected if the Davis-Greenstein mechanism is causing the optical polarization and the magnetic field direction

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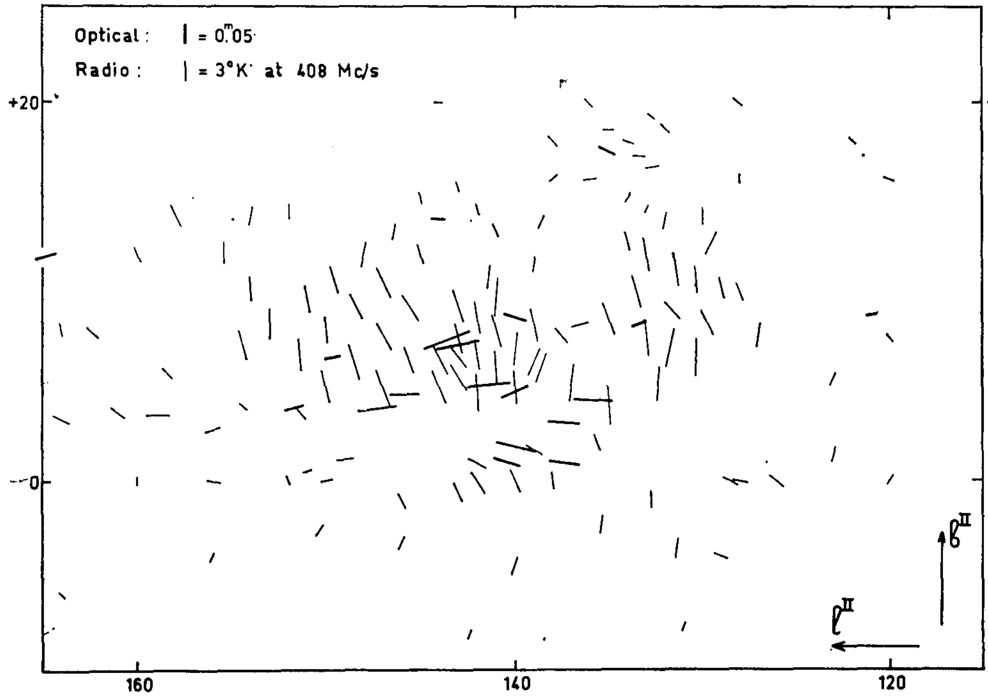

Fig. 5. Comparison of estimated intrinsic radio polarization at 408 Mc/s (**12**) (thin lines) with polarization of starlight (thick lines), from results of Hall and Behr.

is along the spiral arm. This field direction is also indicated by the finding by Mathewson and Milne (**7**) with the 210-foot dish that more than 90 per cent of the polarized radiation at 408 Mc/s comes from a belt (Fig. 6) about 50° wide centred on the great circle perpendicular to the galactic Equator and cutting it at $l^{II} = 160°$ and 340°. In this belt there is a general trend for the electric vectors to be perpendicular to the plane.

Polarized radiation has also been detected at 750 Mc/s (**9**) and 1400 Mc/s (**8, 13**), and the results bear out the conclusion that the observations relate only to the local region within a few hundred parsecs.

Burn and Sciama (**14**) have considered the interpretation of observations of polarized radiation and their work indicates that it is, unfortunately, impossible in principle to unravel the data to produce a unique model.

3. The possibility of using observations of Zeeman splitting of the 21-cm hydrogen line to measure interstellar magnetic fields was first suggested by Bolton and Wild (**15**) in 1957. The effect is very small, only 2·8 c/s per microgauss; one therefore needs as narrow a line as is available and in fact all observations have been done on the narrow absorption features in bright radio sources. The splitting of the R.H. and L.H. circularly polarized components gives the weighted mean value of the longitudinal field over the absorbing region.

Attempts have been made principally by R. D. Davies and his colleagues at Jodrell Bank (**16, 17, 18, 19**) who have concluded that the general magnetic field in the disk is less than 10 microgauss. In one cloud in the direction of Taurus A there appeared to be a field of 25 microgauss away from the observer (**16**), but this value is in conflict with upper limits due to Weinreb (**20**) at M.I.T. and Morris, Clark and Wilson (**21**) at Cal. Tech. Further work is obviously

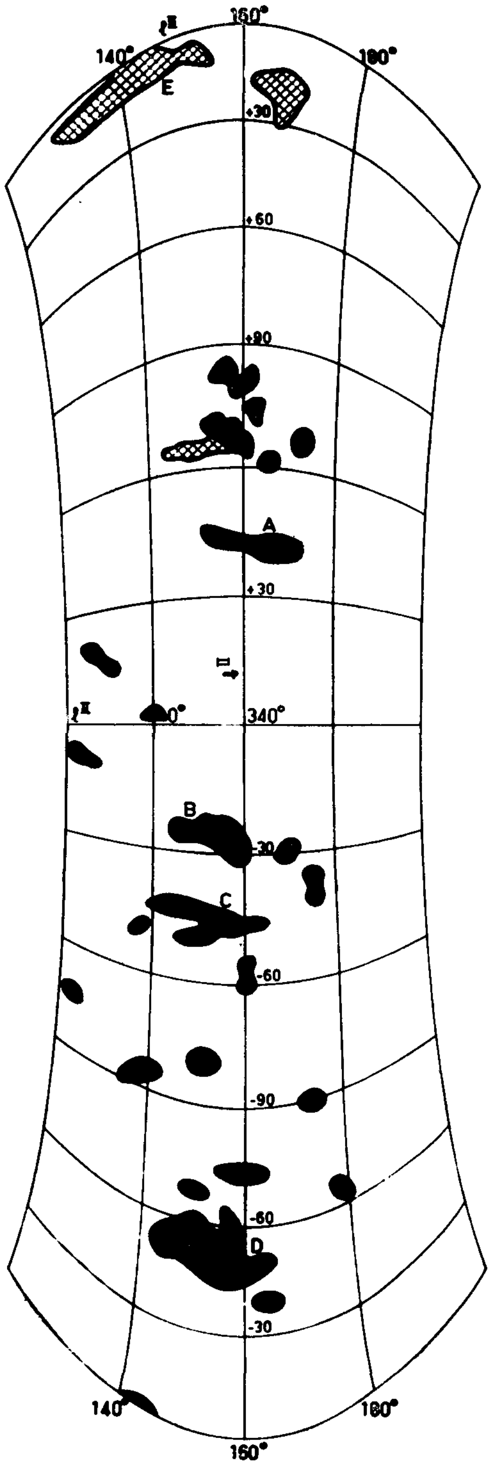

Fig. 6. Regions with polarization temperature of 4°K or more, in a co-ordinate system with the north pole at $l^{II} = 70°$, $b^{II} = 0$ (7). Dark areas, Parkes; hatched areas, Dutch data.

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required to resolve this discrepancy, possibly using one of the OH lines because of the smaller thermal broadening. Even if $B_{\parallel}$ can be determined for a particular cloud, however, it is not clear (**22**) what this will tell us of the general field.

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DISCUSSION

Davies. The distribution of rotation measure within the Galaxy, determined by Gardner and Davies from linear polarization of the radio emission from extragalactic radio sources, can in principle be used to derive an estimate of the strength of the magnetic field in the galactic spiral structure near the Sun. This requires a knowledge of the distribution of electron density, which in turn may be derived from radio estimates of the emission measure in various directions. Since the latter gives the mean square electron density, a knowledge of the packing factor in ionized clouds is required. For a packing factor of 100 which approximates the value for neutral hydrogen clouds, the resultant field in the spiral arm passing near the Sun is 10^{-6} gauss. Packing factors of 10^5 would be required to give fields of 10^{-5} gauss. The significant values of rotation measure observed at higher latitudes could be due to the existence of concentrations of magnetic field and electrons in localized systems similar to the northern galactic spur, in the Local System or in concentrations in the galactic halo.