PULSARS AS PROBES OF THE GALACTIC MAGNETIC FIELD

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The high linear polarization of pulsar radiation allows a reasonably easy determination of the Faraday rotation measure. Unlike other radio sources, the impulsive nature of pulsar emission also permits a determination of the number of electrons responsible for the rotation, through the dispersion measure, DM.

The ratio of the two quantities gives a measure of $\langle B_L \rangle = \langle B\cos\theta \rangle$, the value of the interstellar magnetic field averaged along the line-of-sight and weighted by the local electron density.

$$\langle B_L \rangle = \frac{\int n_e B\cos\, d\ell}{\int n_e d\ell} = 1.232 \frac{RM}{DM} \text{ microgauss}$$

With a knowledge of the Galactic electron density distribution the DM also incidentally gives an estimate of the distance to the pulsar (e.g. Lyne, Manchester and Taylor 1985). Roughly, $n_e \sim 0.03$ cm^{-3}, so that the distance, $d \sim DM/30$ kpc. Hence pulsars have the potential of providing a powerful probe of the Galactic magnetic field.

Lyne and Smith (1968) established the first such measurements on the pulsar 0950+08, indicating a magnetic field of about a microgauss. Subsequently, Manchester (1974) used data on 40 relatively local pulsars, all with distance less than about a kiloparsec, and determined that the local Galactic magnetic field had a value of 2.2±0.4 μG directed towards galactic longitude 94±11°, i.e. in a roughly tangential direction. The magnetic field was not perfectly uniform and there was clearly an irregular component of similar strength with random orientation on a scale of about 100 pc.

Recently, Hamilton and Lyne (1987) made measurements on a further 120 pulsars, mostly having distance greater than 1 kpc. With 25 other determinations, there are a total of 185 measurements now available. The projection on the sky of $\langle B_L \rangle$ shows clumping on scales of 90° downwards, indicating that the field does not have a simple dipolar structure. In some areas, we see the superposition of positive and negative values. For instance near $\ell = 50°$, the nearby low DM objects have negative RMs while the more distant ones are positive, clearly due to a change in the magnetic field direction.

We can present these data for study in two ways. Firstly, we can study the projection onto the Galactic plane of the values of RM, as in figure 1, where the sizes of the symbols are proportional to the values

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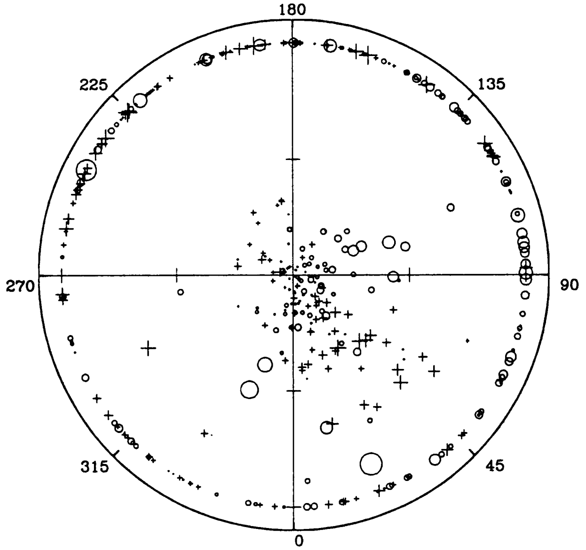

Figure 1 A projection on the plane of the Galaxy of all pulsars and extragalactic sources with Galactic latitude b in the range $-30^\circ<b<+30^\circ$. The values of RM are proportional to the square of the linear dimension of the symbols; positive values are indicated by + symbols, negative values by circles, the largest corresponding to a value of $-1000 \mathrm{rad\ m}^{-2}$. The Sun is at the centre, and galactic longitude is indicated around the edge of the diagram. The ticks along the axes are at 5 kpc intervals.

of RM. Here, a uniform field shows an increasing size of symbol with distance, as seen for instance near longitude $\ell=110^\circ$. One can see the local field of 2-3 μG directed towards $\ell=90^\circ$ and for instance the field reversal at $\ell=50^\circ$ can clearly be seen.

An alternative presentation is to take longitude "wedges" of this diagram, and plot the RM against DM for these pulsars. The local slope of the data gives a measure of the local value of B_L. Figure 2 for example shows the data around $\ell=50^\circ$. In this diagram extragalactic values of RM are shown at an arbitrarily large value of DM = 300 pc cm^{-3}. There is clearly a local B_L away from the Sun of perhaps -2.0 μG, but between 1 and 2 kpc the direction of the magnetic field reverses. Up to about 5 kpc $B_L \sim +5$ μG, when the field must get smaller, and eventually reverse again in order to provide the near-zero values of RM seen in the extragalactic sources.

Studies of these data provide the following rough description of the Galactic magnetic field:

1. A local spiral arm field of 2-3 μG directed towards $\ell=90^\circ$.
2. There is a random field of about the same magnitude having a scale size of about 100 pc.
3. A reversed field region of 5-7 μG seen between longitudes $0^\circ<\ell<70^\circ$. Again this is roughly tangential and has a Galactocentric radius of $\lesssim R_0-1$ kpc where R_0 is the Galactocentric Solar radius.

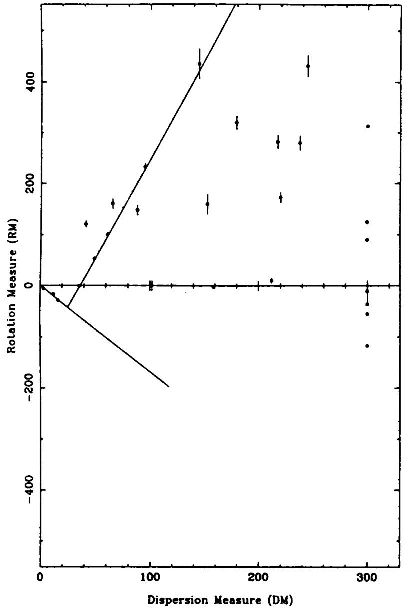

Figure 2 Plot of RM against DM for pulsars at low galactic latitudes, i.e. $-30^\circ < b < +30^\circ$, and for $40^\circ < \ell < 60^\circ$. The lines correspond to line-of-sight fields of -2.1 and 4.8 μG.

4. Further reversals seem to exist inside this in order to explain the low extragalactic RMs.
5. A reversal must also exist outside the Solar radius in order to explain the low extragalactic RMs.

Present observations are severely limited by the lack of data in the fourth quadrant of the Galaxy, that part of the plane which is only observable from the Southern Hemisphere. There are numerous known pulsars in this area but they lack RM determinations. We also require data on more distant pulsars in order to study the larger scale Galactic structures. New surveys at L-band are finding such pulsars (e.g. Clifton and Lyne 1987). Rotation measures for about 40 of these pulsars will be available soon (Rand and Lyne 1989) and should provide valuable data for future studies.

A full account of this work is given elsewhere (Lyne and Smith 1989).

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