The 'Tomography' of the Magnetic Interstellar Medium

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Abstract The Galaxy is a conglomerate of many components. We observe starlight, radio continuum, HI radio line, various molecular lines, UV and IR radiation, X-ray emissions and even γ-ray events. Recent observations have shown that this interstellar medium is permeated by magnetic fields. Hence we should talk of the magnetic interstellar medium (MISM) that will be the subject of this paper.

1 Introduction

We know little about the origin of magnetic fields. We have just started to trace the distribution of magnetic fields in our Galaxy, nearby galaxies, radio galaxies and clusters of galaxies. At this stage we can say that every object seems to possess a magnetic field. However we still cannot decide if the magnetic fields are just a consequence of rotation only or if they play an active role in the dynamics of galaxies. For a review of the present situation the reader is referred to Han & Wielebinski (2002) or Beck (2000).

There are several methods of measuring magnetic fields. The classical approach is to search for the signature of the Zeeman effect. However considerable magnetic field intensity is needed to "see" the effect and hence observations of this type are limited to molecular clouds, in particular to regions with masers. Magnetic fields have been observed by polarization studies of both optical and radio waves. In the optical wavelength range it is the aligned dust that gives a measurable effect. At cm radio wavelength the polarized synchrotron emission is caused by electrons braked in magnetic fields and hence the measurement of polarization gives us the information about the magnetic fields in the emission regions. The emitted wave polarization is perpendicular to the magnetic field orientation (i.e. $B_\perp$). The polarized wave will however be rotated by the Faraday effect in the intervening thermal regions. This has to be corrected for, or else the Faraday effect can be used to give us information about $B_\parallel$. In any direction of observation usually several Faraday screens are seen as illustrated in Fig. 1.

I will present some recent observations on our Milky Way and for nearby galaxies. In particular I will show how different types of observations can be combined, especially for our Galaxy, to reconstitute the distribution of the magnetic fields in three dimensions: hence perform a 'tomography' of the MISM.

2 The Galactic Foreground

The radio Galaxy is best seen as low-frequency radio emission, like in the 408 MHz survey of Haslam et al. (1982). Polarization surveys of the northern sky have been made by Brouw & Spoelstra (1976) at several frequencies which led to the suggestion by Speolstra (1984) that we have very low rotation measures (RM $\sim \pm 8\,\mathrm{rad/m^2}$) in our Galaxy. New polarization surveys of the Galactic plane at 2.3/2.7 GHz by Duncan et al. (1997; 1999) showed a considerable depolarization implying Faraday thick regions. More recently observations

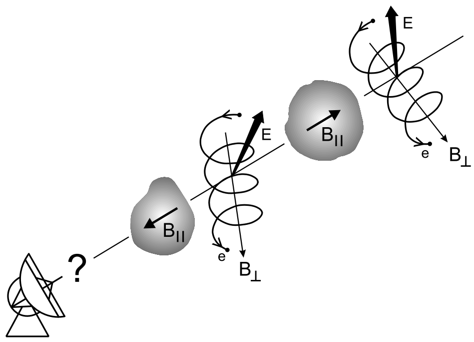

Fig. 1 Observation of two emission regions with two intervening Faraday screens

by Uyaniker et al. (1999) at 1.4 GHz with an angular resolution of $9'$ showed deep nulls in polarized intensity, a consequence of RMs of $70\,\mathrm{rad/m^2}$ or more. Also Gaensler et al. (2001) observed a section of the Galactic plane towards $l = 330°$ and found RMs of $\pm150\,\mathrm{rad/m^2}$. The Faraday effects in the Galactic foreground can be considerable, particularly at lower radio frequencies. The numerical values for Faraday effects are given in Table 1. In the radio continuum of the Milky Way we find RMs of $\sim$ 1—150 $\mathrm{rad/m^2}$. RM of pulsars or extragalactic radio sources (EGRS) can be as high as $1000\,\mathrm{rad/m^2}$. In the Galactic Center but also in AGNs we have RMs of $5000\,\mathrm{rad/m^2}$ or more. An example of a recent high angular resolution map of a section of the Galaxy is shown in Fig. 2. We see highly polarized regions away from the Galactic plane. Some polarized sources appear apparently not connected with any total intensity emission. This can happen only when considerable Faraday depth exists in the Galactic plane emission.

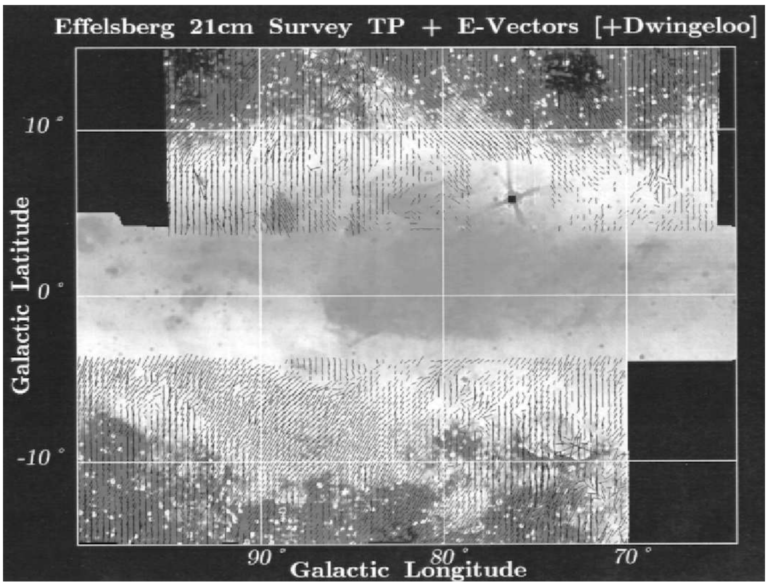

Fig. 2 A section of a 1.4 GHz survey from Uyaniker et al. (1999)

Table 1 Faraday rotation

RM = $(\Theta_1 - \Theta_2)/(\lambda_1^2 - \lambda_2^2)$, where Θ is in radians and λ in meters.
Examples of rotation (in degrees) at several wavelengths are:

λ [cm]	RM [rad/m^{-2}]	1	10	100	1000
91	Θ [degrees]	70	700		
74		31.2	312	3120	
21		2.5	25	250	2500
11		0.69	6.9	69	689
6		0.205	2.05	20.5	205
2.8		0.045	0.45	4.5	44.7
0.9		0.0046	0.046	i 0.46	4.6

electron density in cm^{-3} and dl is the path length in parsecs.

3 Pulsars and EGRSs

Pulsars and extragalactic radio sources are observed through the Galactic foreground. As seen in Table 1 the effects of pulsar RM or on EGRS RM can be considerable if they pass through dense thermal regions. These thermal regions can be identified either from high frequency radio surveys or the more recent Hα surveys. We (Mitra et al. 2002) have studied the RM of pulsars towards the anticentre of the Milky Way. Towards $l = 150°$ several pulsars are seen through the HII region S205. This HII region increases the Dispersion Measure of the observed pulsar and changes the sign of the RM. It seems HII regions are involved in a coupling process to the magnetic field. The possible schematic model for this situation is shown in Figure 3. A winding magnetic field has a $B_{\parallel}$ component in one region towards the observer and in other region away from the observer.

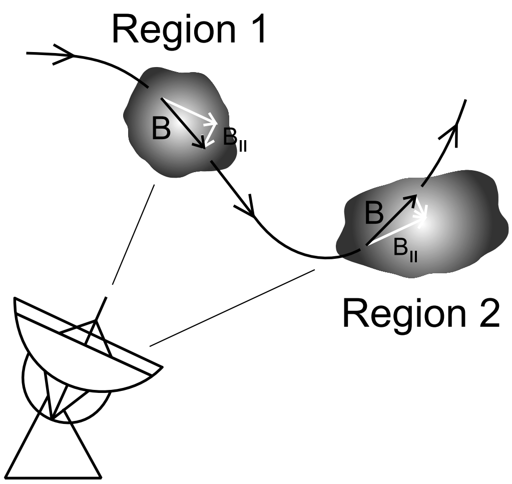

Fig. 3 A schematic model showing the B field orientation towards the Perseus arm

4 The 'Tomography' of the MISM

In medical investigations a patient is scanned in thin slices so that the doctor can in the end reconstruct a three-dimensional picture of the patient. Using radio polarization data at several frequencies and the Faraday rotation data from pulsars and EGRS we may get enough information to reconstruct the magnetic field structure in our Galaxy. In the Faraday data of pulsars or EGRS we need good sampling of the Galaxy, a situation that has not yet been reached. The surveys are just getting to a situation that well sampled data becomes available. In Effelsberg the observations of a Medium Latitude Survey ($b = \pm 20^\circ$) at 1.4 GHz (with polarization) were completed. In Australia a survey of the Galactic plane at 1.4 GHz is in progress. We still need a survey at some higher frequency, say $\lambda = 6$ cm, to have the good information about a wide band of the Galactic plane and to understand the Faraday effects. This, I hope, will be done with the Urumqi telescope. We also need more RMs of pulsars. At present only some $\sim$ 400 RMs are known. Also a large sample of EGRS is needed, some of which is under way in Canada (Brown & Taylor 2001). Only through the combination of all this data a model of the magnetic field of the Galaxy will be possible.

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