FARADAY ROTATION AND THE TURBULENT STRUCTURE OF THE GALAXY

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Abstract. We extend Jokipii and Lerche's analysis of the turbulent structure of our Galaxy by means of a study of the rotation measure of extragalactic sources. Like them we use a simple, statistically homogeneous and isotropic disc model of the Galaxy and assume that the magnetic field has both an average component and a fluctuating one. We assume that the electron density is proportional to some power of the magnetic field \(N_e \propto B^n\) with \(1 \leq n \leq 2\). Using the rotation measure data on 242 extragalactic sources given by Vallé and Kronberg we consider both an exponential and a Gaussian two-point correlation function for the (Gaussian) fluctuating component of the magnetic field with a correlation length \(L\). We find reasonable agreement between theory and observations for an average magnetic field of about \(3 \mu G\), a fluctuating magnetic field component with an amplitude of about \(2.6 \mu G\), an average electron density of about \(0.03 \text{ cm}^{-3}\), a fluctuating density component of about \(0.05 \text{ cm}^{-3}\), and a correlation length of about 300 pc.

1. Introduction

In 1949 Fermi suggested that the galactic magnetic field has a random component which leads to the isotropy of cosmic rays. This idea was further studied by Jokipii and Parker (1969a, b) who investigated in detail the propagation of cosmic rays. Jokipii et al. (1969) showed that such a model of the galactic magnetic field is consistent with observed fluctuations in the polarization of starlight and Jokipii and Lerche (1969) (quoted in what follows as JL) considered fluctuations in Faraday rotation due to this model. Jones (1971) and Kaiser (1973) improved the models used by JL and by Jokipii and Parker (1969a, b). In the present paper we shall further refine the model, but the main purpose of the paper is to derive improved values for the parameters of the model. This is possible because whereas JL in their discussion of the Faraday rotation had available data on 79 sources given by Berge and Seielstad (1967), we can use the much larger sample of 251 sources studied by Vallé and Kronberg (1975). We shall see that the basic features of the model used by Jokipii and Lerche remain unaltered.

In our analysis we shall assume that there is a correlation between the fluctuations in the electronic density and those in the magnetic field strength and we shall consider different forms for the two-point correlation function. In Section 2 we shall briefly discuss the observational data and in Section 3 we present the basic equations for the model used to interpret the observational data on the Faraday rotation. The last section is devoted to a discussion of the results following from applying our model to the observational data and to stating the conclusions we are led to by our calculations.
2. Observational Data

Vallée and Kronberg (1975) give the rotation measures for 251 sources. The rotation measure, $RM$, is defined as follows. If $\psi(\lambda)$ is the observed angle of polarization of an electromagnetic wave of wavelength $\lambda$ and if $\psi_0(\lambda)$ is the intrinsic angle of polarization at the source, we have

$$\Delta \psi = \psi(\lambda) - \psi_0(\lambda) = RM \lambda^2.$$  

(1)

The standard theory of Faraday rotation in a not too dense medium with electron density $N_e$ gives (see, e.g., Ginzburg, 1970; p. 140)

$$RM = \frac{e^3}{\pi m^2 c^4} \int N_e B_\parallel ds = 8.1 \times 10^5 \int N_e B_\parallel ds,$$  

(2)

where $-e$ and $m$ are the electron charge and mass, $c$ is the velocity of light, and $B_\parallel$ is the component of the magnetic induction along the direction of the line of sight, while the integral is taken along the line of sight from the source to the observer. The numerical value follows, if $RM$ is measured in radians $m^{-2}$, $N_e$ in $cm^{-3}$, $ds$ in parsec, and $B$ in Gauss.

Of the 251 sources, nine are galactic sources which we discard, as we want to deduce a model for our Galaxy which means that we want the line of sight to extend beyond the limits of our Galaxy. In Table I we show how the values of $RM$ of the remaining 242 sources are distributed.

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The scatter in the $RM$ values for $RM > 300$ is rather large, and as there are less than 7% of the total number of sources with such large $RM$, we have neglected them. We feel that they would merely introduce an extra scatter which would not be meaningful from a physical point of view.

Our next step was to group the $RM$-values into bins of $10^\circ$ galactic latitude amplitude and to calculate for each of these bins the average value of $RM$, $\langle RM \rangle$, and its variance, $\sigma^2$. In Table II we show the number in each bin for three possible samples:

(i) $|RM| < 100$ radians $m^{-2}$; (ii) $|RM| < 200$ radians $m^{-2}$; (iii) $|RM| < 300$ radians $m^{-2}$.

In parentheses we have, for comparison, shown the numbers for the sources used by JL, and we see that their data correspond most closely to our sample (i). We also show within square brackets the numbers for the complete sample of 242 sources. In Figures...