Chapter 1 Introduction

1.1 Historical Review

The galactic magnetic field have been investigated from different methods: starlight polarization, Zeeman splitting, rotation measures and radio emission of cosmic ray electrons. From the first method, Ellis and Axon (1978) made a review of studies of the galactic magnetic field and they concluded that the regular field points towards the galactic longitude, $\ell = 45^\circ$ within 500 pc from the Sun and 60° beyond this region but within 2 kpc. Inoue and Tabara (1981) concluded that the regular magnetic field runs along $\ell = 100^\circ$, but their figures show that the field indicated by starlight polarization of low latitude stars (galactic latitude, $|b| < 30^\circ$) is towards $\ell < 90^\circ$. And investigation on the galactic magnetic field from an optical polarization data set of more than 7500 stars, Andreasyan and Makarov (1989) showed that the magnetic field in the galactic plane are concentrated in spiral arms and directed along the axes of the arms. For the second methods, Zeeman splitting, only the magnetic field in clouds in the galaxy can be directly measured. Because of the small filling factor of the clouds, it is impossible to derive the overall magnetic field from the measurements of Zeeman splitting. Nevertheless, the overall averaged field can be derived by properly extrapolating the measured averaged field strength function of gas density in clouds (Myers and Goodman 1990; Han and Qiao 1993). However, the first two methods only study the general properties of the galactic magnetic field, but the next two methods not only investigate characteristic of the galactic magnetic field but also create the field models that are very important in this work.

1.1.1 Rotation Measures (RMs)

Pulsars are excellent probes of the galactic magnetic field, for several reasons. First, they seem to have no intrinsic Faraday rotation. Second, their distances can be estimated from their dispersion measures or from HI absorption measurements. Third, the electron density weighted magnetic field along the line of sight to a pulsar can be directly computed from its rotation measure and dispersion measure. Manchester (1974) analyzed the magnetic field by using RMs of 28 pulsars with distances within 2 kpc and a longitudinal model of the local field to derive a strength of regular component, $H_{reg} = 2.2\pm0.4\ \mu G$ direct toward galactic longitude $\ell = 94°\pm11°$. He also concluded that irregularities of roughly the same strength exist. Thomson and Nelson (1980) used 48 pulsars with distances within 3 kpc and a complicated five-parameter model to derive $H_{reg} = 3.5\pm0.3\ \mu G$, $\ell = 74°\pm10°$, and a reversal of the field toward the inner galaxy at a distance of 170±90 pc. They also find a surprisingly low scale height of the field, 70±40 pc. Rand and Kulkarni (1989) used about 200 pulsar RMs to reveal the local galactic field towards $\ell = 96°\pm4°$ with a strength $H_{reg} = 1.6\pm0.2\ \mu G$.

The extremely large body of extragalactic RM data have been analyzed several times but caution is needed since reliable RMs can be obtained only by restricting the wavelength range to Faraday thin regime. Simard-Normandin and Kronberg (1980) analyzed 552 RMs and found several specific local galactic features in the RM sky, such as Region A and the North Galactic Spur. They showed that a Bisymmetric 4-arm Spiral Field Model, with pitch angle of -14° and field reversals, could reproduce the principal observed features of the RM sky well, but a 3-ring circular field model could not. They also estimated that thickness of the magnetic disk of the galaxy to be about 1.4 kpc. Inoue and Tabara found that the direction of the regular magnetic field is $(\ell, b) = (102°, 21°)$ from 224 sources with $b \leq -30°$ and $|RM| \leq 100$ rad/m2, but from sources in $|b| < 30°$, direction of regular field is toward $\ell = 80°$. They concluded that the regular field is toward $\ell \approx 100°$. Analysis of Sofue and Fujimoto (1983) used a low latitude subset of 1510 RMs measured by Inoue and Tabara (1980) and a Bisymmetric 2-arm Spiral Field Model. A field with pitch angle -5° and nearest reversal at the distance 350 pc was the preferred fit to the data. Their results suggest that the strength of the global field might increase towards the galactic center.

Han and Qiao investigate the magnetic field by using RMs of pulsars and extragalactic radio sources. They found that the galaxy has a global field of Bisymmetric Spiral configuration, rather than a concentric ring or an Axisymmetric Spiral configuration. The galactic magnetic field of Bisymmetric Spiral structure is supposed to be of primordial origin. The pitch angle of the Bisymmetric Spiral structure is –8.2°±0.5°. The field geometry shows that the field goes along the Carina-Sagitarius arm, which is delineated by Giant Molecular Clouds (GMCs). The amplitude of the Bisymmetric Spiral field is 1.8±0.3 μG. the first field strength maximum is at $R_2 = 11.9 \pm 0.15$ kpc in the direction of $\ell = 180°$. The field is strong in the interarm regions and it reverses in the arm region. In the vicinity of the Sun, it has a strength of ~1.4 μG and reverses at 0.2-0.3 kpc in the direction of $\ell = 0°$.

1.1.2 Radio Emission of Cosmic Ray Electrons

In 1959, Mills was the first to suggest that the existence of steps in the galactic plane profile of the radio continuum related to the positions of spiral arms. Many authors have attempted to interpret the galactic synchrotron emission in terms of spiral structure. This problem may be tackled in two ways. Either the Spiral Arm Method, the galaxy's spiral pattern (based on other independent observations) can be used together with a model for the variation of emissivity across an arm to calculate the expected synchrotron emission which may then be compared with observation or the Unfolding Method, the observed profiles may be unfolded, under some assumed symmetries to give the distribution of the emission directly.

The first way has been employed by amongst others, Price (1974), Paul et al. (1976) and Jäkel et al. (1975) with models based on regular two-armed spirals (Lin and Shu, 1967), and by French and Osborne (1976) and Brindle et al. (1977) with a more detailed model based on the spiral pattern derived by Georgelin and Georgelin (1976) within the solar circle.

The second way has been used by a number of authors, including Strong and Worrail (1976), and Caraveo and Paul (1979), for the gamma-ray distribution and has recently been applied to synchrotron data by Kanbach and Beuermann (1979).

The Durham group has made a long-term contribution to this work. French and Osborne (1976) applies the spiral arm method by combining the Spiral Arm Model of Georgelin, based on observations of HII regions, with the map of neutral hydrogen outside the solar circle of Verschuur. Comparison was made with the observed profile at 150 MHz of Landecker and Wielebinski (1970). Brindle et al. (1978) extended the model to three dimensions to compare with the complete 150 MHz maps. A disadvantage of using the Landecker and Wielebinski map was that in fact it was a composite of a number of surveys made at frequencies from 85 to 178 MHz, scaled then added together, and of differing and rather large beam shapes. Much improved radio continuum data were provided by the allsky map of Haslam et al. (1982). This was made from surveys at a common frequency of 408 MHz done at Effelsberg, Jodrell Bank and Parker and smoothed slightly to a Gaussian beam with Half Power Beam Width (HPBW) of 51'. Phillipps et al. (1981a), collaborating with Haslam on the prepublication data, from the galactic plane profile produced a map of the emissivity distribution in the galactic plane.

This time the Unfolding Method was used to convert from 1 to 2 dimensions the assumption being made that the galactic plane could be represented as being divided into 60 logarithmic spiral sections of 12° pitch angle each having its own emissivity level but all having the same radial dependence of emissivity. The Unfolding Method is straightforward to apply and can be used to obtain global parameters of the galaxy such as the total synchrotron emission. The reality of the galactic plane distribution depends, however, on how well the galaxy follows the assumed symmetry. At 408 MHz typically 20 percentage of the emission observed at the galactic latitude, $b = 0°$ is thermal although particular features in the galactic plane profile may be almost entirely thermal. It could be argues that without a prior separation of the thermal features an attempt to obtain a detailed distribution of the synchrotron emissivity in the plane by the Spiral Arm Method is not justified. Nevertheless Kearsey (1983) used it on the 408 MHz data in an unpublished part of his Ph.D. thesis. Phillipps et al. (1981b) the proceeded to derive a three dimensional model of the distribution of the synchrotron emissivity from 2 dimensional map of the whole sky. Again an unfolding technique was used to determine the variation of emissivity with distance, z, from the galactic plane. As the proportion of thermal emission decreases rapidly with z it is not important in this case to have a detailed separation of the thermal component and we believe that deduced z-variation remains valid. Broadbent et al. (1989) developed a technique for separating the thermal and non-thermal components of the radio continuum emission based on the strong empirical correlation between the former and the 60-micron infrared emission as observed by the IRAS satellite. When it applied to the 408 MHz survey it gave a clearer picture of the synchrotron emission and she concluded a three dimensional model of the emissivity distribution derived by the Spiral Arm method.

Sanguansak (1996) refined the model of Broadbent taking into account some more recent information on spiral arm structure and also rescaled the model to put the Sun at the presently accepted distance of 8.5 kpc from the galactic center. At 408 MHz, there is very little absorption in the interstellar medium and the line of sight distribution of synchrotron emissivity was inferred mainly from its presumed relationship to the other tracers of spiral structure via these fitted free parameters. At lower frequencies, the absorption of synchrotron emission due to thermal electrons becomes significant and can give direct information of the non-thermal distribution along the line of sight. She used synchrotron model applies at lower frequencies including the absorption to compare with the surveys of Dwarakanath et al. (1990) at 34.5 MHz and Jones and Finlay (1974) at 29.9 MHz. The result confirms that the absorption model of the synchrotron emissivity in the galactic plane is broadly correct and illustrates the potentials of the absorption technique.

1.2 The Aim of the Present Work

The recent magnetic field models of Milky Way Galaxy are investigated by several methods and have different dominant properties. This work has the aim to propose the field model, which merge the dominant characteristics of the magnetic field from two recent models. First, Bisymmetric Spiral Model is investigated in the field component, which parallel to the line of sight by Faraday rotation of the linearly polarized radio emission of pulsars. The other, Synchrotron Emission Model is investigated in the field component, which perpendicular to the line of sight by the brightness temperature, the outcomes of the synchrotron emission from the cosmic ray electrons. To test the adapted model in the perpendicular component, we compute the brightness temperature, and then compare to the 408 MHz allsky survey of Haslam et al. after separation of its thermal component with the help of IRAS 60 micron emission (Broadbent et al.).

1.3 Galactic Spiral Structure

In order to calculate synchrotron emission from the galaxy, we have to consider its spiral structure. There have been many efforts for tracing the spiral arm pattern of the galaxy. There are three main tracers: 1) the recombination lines of HII regions, 2) the 21 cm emission of HI gas, and 3) the CO lines associated with molecular hydrogen.

HII regions surrounded by young hot O and B type stars are used as spiral tracers of spiral galaxies. HII regions can be seen optically or as thermal radio sources. In the plane of our galaxy, beyond about 8 kpc from the Sun, because of dust it is difficult to make the optical detection of HII regions so radio measurement must be used. Therefore in the inner part of the galaxy, HII regions are useful tracers because the ambiguity in their kinematic distances can be solved through the use of absorption spectra and optical measurements. Georgelin and Georgelin studied the distribution of bright HII regions in the galaxy, which involved the determination of distance by using observations at optical and radio wavelengths. Distances measured from radio recombination lines are determined kinematically but there is a problem whether the HII region is at the 'near' or 'far' distance. Georgelin and Georgelin suggested that a four-armed spiral pattern give the best fit to the distribution of HII regions.

The study of the spiral structure from 21-cm line observations has been based on the differential galactic rotation, which is the main cause of broadening of line profiles. In general, radiation from the various spiral arms along a line of sight will be received at different frequencies because the arms will have different apparent radial velocities. These velocity line profiles can be used to find a mean rotation curve i.e. the variation of the rotation velocity of gas with galactocentric radius assuming that the motion is all in circular orbits and is axisymmetric. In addition, the line profile for a particular direction gives a relationship between brightness temperature and frequency (or velocity). In order to get the distribution of HI over the galactic plane, one has to convert this relationship to the density of HI gas in terms of distance under a certain set assumptions. In early studies of the distribution of HI gas in the galaxy, it was assumed that the gas was optically thin with a constant spin temperature and the motion of the gas was in a circular orbit. Burton (1971) found the evidence of non-circular motion of HI gas with deviations from the mean rotation curve of the order of ±10kms^{-1}, which is a few percent of the circular rotation velocity. Weaver (1974) looked for the curves and loops in the $T_b(\ell, v)$ diagram of the Berkeley 21 cm survey but still assumed circular rotation. Later studies of density and kinematic variation model had to consider the density wave theory. Simonson (1976) constructed a spiral pattern consisting of two arms with a small pitch angle originating 4 kpc from the galactic center with a multiple arm structure of larger pitch angle beyond the solar circle.

To study the galactic structure from CO emission line surveys is a relatively new approach but there has been much discussion about their suitability. Cohen et al. (1980) shows good evidence of spiral arm structure from CO data. These features also appear in the 21-cm surveys but the CO surveys showed a higher contrast of intensity between arms and interarms than in 21-cm measurements. Cohen et al. (1985) and Grabelsky et al. (1987) studied a similar CO survey made in the fourth quadrant and showed that the Carina arm can be clearly distinguished. Solomon, Sanders and Rivolo (1985) concluded from another CO survey of the north side of the galaxy that it is only the warm molecular clouds that are the spiral tracers and the cold clouds have a more widespread distribution. We should bear in mind that H_2 and CO prevails in the central and inner parts of our galaxy but there is mostly HI and very little HII in the outer parts. Robinson et al. (1983) studied CO data in the southern part jointly with the northern part analyzed by Cohen et al. The result showed the four-armed spiral pattern. All the spirals fitted to data by Robinson et al. Have pitch angles of 11° –12°. Blitz et al. (1983) reported a result from an analysis of the Weaver-Williams HI survey and northern CO surveys that the four-armed spiral was traced but it is different from the model by Robinson et al.

Broadbent studied several models of spiral structure of our galaxy and adjusted it in order to fit with the synchrotron emission at 408 MHz. Sanguansak modified the field model and cosmic ray electron density. We use this model with sinusoidal component of Bisymmetric Spiral Model, which Han and Qiao studied from rotation measures of pulsars, to improve it for our work.