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The Large-Scale Magnetic Field Structure of Our Galaxy: Efficiently Deduced from Pulsar Rotation Measures

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Abstract. In this review, I will first introduce possible methods to probe the large-scale magnetic fields in our Galaxy and discuss their limitations. The magnetic fields in the Galactic halo, mainly revealed by the sky distribution of rotation measures of extragalactic radio sources, probably have a global structure of a twisted dipole field. The large-scale field structure in the Galactic disk has been most efficiently deduced from pulsar rotation measures (RMs). There has been a lot of progress since the 1980s when the magnetic field in the local area of our Galaxy was first traced by a very small sample of local pulsars. Now we have pulsars distributed in about one third of the whole Galactic disk of the interstellar medium, which shows that the large-scale magnetic fields go along the spiral arms and that the field directions reverse from arm to arm. The RMs of newly discovered pulsars in the very inner Galaxy have been used to show the coherent magnetic field in the Norma arm. The magnetic fields in the Galactic disk most probably have a bisymmetric spiral structure.

1 Introduction

The origin of magnetic fields in the universe is a long-standing problem. It is clear today that magnetic fields play a crucial role in the evolution of molecular clouds and star formation (e.g. Rees 1987). The diffuse magnetic fields are the physical means to confine the cosmic rays (e.g. Strong et al. 2000). The magnetic fields in galactic disks also have a significant contribution to the hydrostatic balance in the interstellar medium (Boulares & Cox 1990). However, it is not clear whether magnetic fields exist in the very early universe, e.g. the recombination phase, and whether the fields affect the structure formation and galaxy formation afterward.

To understand the magnetic fields, the first step is to correctly and properly describe their properties based on reliable observations. Magnetic fields of galactic scales (~ 10 kpc) are the most important connection between the magnetic fields at cosmological scales and the fields in currently observable objects. In the last two decades, there have been many observations on magnetic fields in galaxies (see references in reviews by Beck et al. 1996; Han & Wielebinski 2002). Theoretically the magnetic fields in galaxies are believed to be re-generated and maintained by dynamo actions in the interstellar medium (e.g. Ruzmaikin et al. 1988; Kulsrud 1999). The helical turbulence (the α-effect) and differential rotation (the Ω-effect) are two key ingredients for dynamos in galaxies (e.g. Krause & Rädler 1980).

Our Galaxy is the unique case for detailed studies of magnetic fields, as I will show in this review.

It is certainly desirable to know the structure of our Galaxy and to compare it with the magnetic structures. However, as we live near the edge of the disk of the Milky Way, it is impossible for us to get a clear bird-view of the global structure of the whole Galaxy. As has been shown by various tracers, our Galaxy obviously has a few spiral arms with a pitch angle of about 10°. But there is no consensus on the number of spiral arms in our Galaxy and whether and how these arms are connected in the opposite side. Apart from the thin disk, there is a thick disk or halo, filled by low-density gas and possibly weak magnetic fields.

Pulsars are the best probes for the large-scale magnetic fields in our Galaxy. At present, many new pulsars have been discovered up to distances further than the Galactic center (e.g. Manchester et al. 2001; Morris et al. 2002; Kramer et al. 2003), which can be used to probe the large-scale magnetic fields in about half of the Galactic disk. The magnetic field may further give us some hints to the global structure of our Galaxy. Hundreds of pulsars discovered at high Galactic latitudes (e.g. Edwards et al. 2001) can be used to study the magnetic fields in the Galactic halo.

1.1 Comments on definitions of useful terms

Before we start to discuss observational results of magnetic fields, it is worth to clarify the definition of some useful terms.

Large scale vs. small scale:
How large is the "*large scale*"? Obviously it should be a scale, relatively much larger than some kind of standard. For example, the large-scale magnetic field of the Sun refers to the global-scale field or the field with a scale-length comparable to the size of Sun, up to 10^9 m, rather than small-scale magnetic fields in the solar surface. For the magnetic fields of our Galaxy, we should define the *large scale* as being a *scale larger than the separation between spiral arms*. That is to say, large scale means a scale larger than 2 or 3 kpc.

Note that in the literature, *large scale* is sometimes used for large *angular* scale when discussing the structures or prominent features *in the sky plane*, e.g., the large-scale features in radio continuum radio surveys. These *large angular-scale* features are often very localized phenomena, and not very large in linear scale.

Ordered vs. random fields:
Whether a magnetic field is ordered or random depends on the scales concerned. A uniform field at a 1-kpc scale could be part of random fields at a 10-kpc scale, while it is of a very large scale relative to the pc-scale magnetic fields in molecular clouds.

Uniform fields are *ordered fields*. *Regularly ordered fields* can coherently change their *directions*, so they may not be *uniform fields*. Deviations from *regular fields* or *orderd fields* are taken as *random fields*. The fluctuations of fields at scales 10 times smaller than a concerned scale are oftern taken as *random fields*.

Note also that in the literature the measurements of so-called *polarization vectors* only give the *orientations* rather than *directions* of magnetic fields, so they are not real vectors.

Azimuthal and toroidal fields:
Often the magnetic fields in our Galaxy are expressed in cylindrical coordinates $(\theta,\ r,\ z)$. The *azimuthal component*, B_θ, of magnetic fields dominates in the Galactic disk, where the *radial and vertical components*, B_r and B_z, are generally weak. The *toroidal component* refers to the structures (without B_z components) confined to a plane parallel to the Galactic plane, while the *poloidal component* refers to the axisymmetrical field structure around z, such as dipole fields (without B_θ component).

Concerning measurements relative to the line of sight, only one field component, either *perpendicular* or *parallel* to the line of sight, can be detected by one method (see below).

The above terms are artificially designed for convenience when studying magnetic fields. Real magnetic fields would be all connected in space, with all components everywhere.

1.2 Observational tracers of magnetic fields

Zeeman splitting:
It measures the *parallel component* of magnetic fields in an emission or absorption region by using the the splitting of spectral lines.

Up to now, measurements of magnetic fields *in situ* of masers (e.g. Fish et al. 2003) and molecular clouds (e.g. Bourke et al. 2001) are available. The relationship between the field strength and gas density has been supported by observational data (e.g. Crutcher 1999). Despite strong efforts it failed to relate the magnetic fields in situ and the large-scale fields (see Fish et al. 2003), as suggested by Davies (1974) and later promoted by Reid & Silverstain (1990).

Polarization at infrared, sub-mm and mm wavebands:
Dust particles are preferentially orientated due to the ambient magnetic fields. The thermal emission

of dust then naturally has linear polarization. Infrared, mm, submm instruments are the best to detect thermal emission. Polarization shows directly magnetic fields projected in the sky plane. Due to the short wavelengths, such a polarized emission does not suffer from any Faraday rotation when passing through the interstellar space.

The recent advance in technology has made it possible to make direct polarization mapping at infrared, sub-mm and mm wavebands (e.g. Hildebrand et al. 1998; Novak et al. 2003). At present, measurements can only be made for bright objects, mostly of molecular clouds. But in future it could be more sensitive and powerful to measure even nearby galaxies. A combination of polarization mapping for the perpendicular component of magnetic fields with the parallel components measured from Zeeman splitting will give a 3-D information of magnetic fields in molecular clouds (or galaxies in future), which is certainly crucial to study the role of magnetic fields in the star-formation process.

The available measurement, which is really related to large-scale magnetic fields, is the polarization mapping of the central molecular zone by Novak et al. (2003). The results revealed possible toroidal fields parallel to the Galactic disk. This field is probably part of an A0 dynamo field in the Galactic halo, complimented to the poloidal fields traced by vertical filaments in the Galactic center (e.g. Sofue et al. 1987; Yusef-Zadeh & Morris 1987).

Polarization of starlight:
The starlight is scattered by interstellar dust when traveling from a star to the earth. The dust particles are preferentially orientated along the interstellar magnetic fields, which induce the polarization of the scattered star light: more scattering, more polarization.

Starlight polarization was the start for the studies of the large-scale magnetic field. Apparently, the starlight can trace prominent magnetic features on large angular scales, over all the sky! Directly from the measurements in the Galactic pole regions, we can easily see the direction of the local magnetic fields in our Galaxy. However, because the measured stars are mostly within 1 or 2 kpc from the Sun, it is not possible to trace magnetic fields further away. Polarization measurements of stars near the Galactic plane give us only the information that the magnetic fields in the Galactic disk are mainly orientated parallel to the Galactic plane.

Synchrotron radiation:
Synchrotron radiation from relativistic electrons shows the *orientation* of magnetic fields in the emission region. Assuming energy equipartition, one may estimate the field strength from the emission flux. Furthermore, from polarized intensity, the energy in the "uniform field" together with that of anisotropic random fields can be estimated.

Many nearby galaxies have been observed in polarized radio emission. The emission suffers from Faraday rotatation within the medium of the galaxy and from the Milky Way. After correcting the foreground RMs, one can obtain a map of intrinsic *orientations* of the *transverse component* of magnetic fields, though it is often called the "vector" map of the magnetic field. The anisotropic random magnetic fields, such as compressed random fields by large-scale density waves, can also produce such an observed polarization map. So, with a polarization map with a coherent "vector" pattern, one cannot claim the large-scale magnetic field. However, a map of the RM distribution with a regular pattern, especially for the inclined galaxies, provides strong evidence for the large-scale magnetic fields in the halo or the thick disk of a galaxy (see Krause, this volume).

As we will show below, the pulsar RM distribution indeed shows large-scale magnetic fields in our Galaxy, with coherent field *directions* going along the spiral arms. This indirectly proves that the polarization maps of nearby galaxies can be at least partially due to the large-scale magnetic field. The strength of "regular fields" calculated from the polarization percentage may be overestimated, however, as one cannot quantify the contributions from anisotropic random magnetic fields (see Beck et al. 2003).

Faraday rotation of polarized sources:
Faraday rotation occurs when radio waves travel through the magnetized medium. The RM, which is measured as being the rate of polarization-angle change against the square of wavelength, is an integration of magnetic field strength together with electron density along the line of sight from the source to the observer, i.e., $RM = a \int_{\rm source}^{\rm observer} n_e \, B_{||} \, dl$. Here a is a constant, n_e the electron density,

dl is a unit length of the line of sight. Obviously, RMs measure the average diffuse magnetic field if the electron density is known.

In the following I will concentrate on how the RMs of pulsars and extragalactic radio sources can be used to probe the large-scale magnetic fields in our Galaxy. Considering various difficulties in other methods, we are really lucky that we can use the RMs of an increasing number of pulsars to probe the large-scale magnetic field in the Galactic disk. It is very hard to conduct observations of Zeeman splitting, and afterwards it is not possible to relate these measurements to the large-scale magnetic fields. Starlight polarization does measure the diffuse magnetic field, but it is not possible to give any other information than the averaged orientation of the field in just 1 or 2 kpc. Diffuse radio emission from our Galaxy can only show the polarized emission from local regions on large *angular* scales, but not on large linear scales in the Galactic disk.

2 The magnetic field in the Galactic halo: based on the RM sky distribution

In the sky the Milky Way is the largest edge-on Galaxy. This gives us the unique chance to study the magnetic fields in a galactic halo in detail, which is not possible at all for nearby extragalaxies. There is a huge number of extragalactic radio sources as well as hundreds of pulsars, which can be potentially used to probe the magnetic fields in the Galactic halo and in the Galactic disk.

The RM of an extragalactic radio source consists of a RM contribution intrinsic to the source, the RM from the intergalactic space from the source to the Galaxy, and the RM within the Galaxy. The first term should be random and hence reasonably small on average, because a source can be randomly orientated in space with any possible field configuration. We observe a random quantity. The second term is ignorable on average. Intergalactic magnetic fields are too weak to be detectable now. A source can be at any possible location in the universe. Even if there is a weak field in the intergalactic space, an integration over the path-length of the intergalactic magnetic fields with random directions together with extremely thin gas should give a quite small combination. Therefore, the common contribution to RMs of extragalactic radio sources is from our Galaxy. So, the *averaged* sky distribution of RMs of extragalactic sources (see Fig. 1) should be the best presentation for the Galactic magnetic field in the Galactic halo.

Though there are many distinguished characteristics related to specific regions in the RM sky, we noticed that the most prominent feature is the antisymmetry in the inner Galactic quadrants (i.e. $|l| < 90^\circ$). The positive RMs in the regions of $(0^\circ < l < 90^\circ,\ b > 0^\circ)$ and $(270^\circ < l < 360^\circ,\ b < 0^\circ)$ indicate that the magnetic fields point towards us, while the negative RMs in the regions of $(0 < l < 90^\circ,\ b < 0^\circ)$ and $(270 < l < 360^\circ,\ b > 0^\circ)$ indicate that the magnetic fields point away from us. Such a high symmetry to the Galactic plane as the Galactic meridian through the Galactic center cannot simply be caused by localized features as previously thought. The antisymmetric pattern is very consistent with the magnetic field configuration of an A0 dynamo, which provides such toroidal fields with reversed directions above and below the Galactic plane (Fig. 1). The toroidal fields possibly extend to the inner Galaxy, even towards the central molecular zone (Novak et al. 2003).

This magnetic field model is also supported by the nonthermal radio filaments observed in the Galactic center region for a long time, which have been thought to be indications for the poloidal field in dipole form (Yusef-Zadeh & Morris 1987; Sofue et al. 1987).

We noticed that the antisymmetric RM sky is also shown by pulsar RMs at high Galactic latitudes ($|b| > 8^\circ$). This implies that the magnetic fields responsible for the antisymmetry pattern could be nearer than the pulsars. Indeed, the fields nearer than the pulsars contribute to the RMs, but this is not the only contribution. If it is only a local effect, then there would be no symmetric RM distribution beyond the pulsars. We made computer simulations, which show that large-scale magnetic field structures further away than the pulsars (i.e. the more inner Galaxy) should result in a strong antisymmetry of RM sky within 50° from the Galactic center, and that the magnitudes of RMs are systematically increasing towards the Galactic plane and the Galactic center.

To judge if antisymmetry is produced by a large-scale magnetic field, it would be necessary to subtract the foreground pulsar RMs induced by local magnetic fields from the RMs of extragalactic

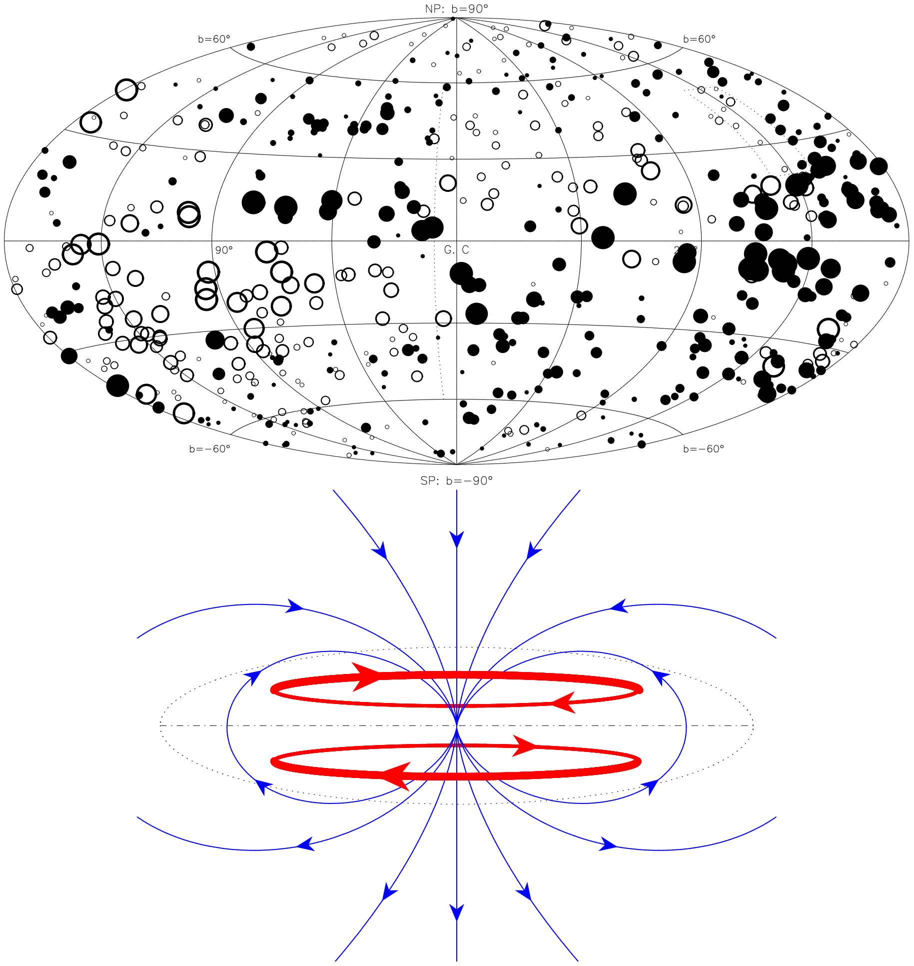

Fig. 1. The sky distribution of RMs of extragalactic radio sources and the magnetic field model in the Galactic halo, as discussed by Han et al. (1997).

radio sources and then check the antisymmetry of the residual RM map. If there is antisymmetry in the residual RM map, then it is large-scale, otherwise it is local. However, both the RM data of pulsars and extragalactic radio sources are so sparse that such a subtraction cannot give a clear result at the moment. We checked the magnitude distribution of RMs of extragalactic radio sources, which is indeed systematically larger than those of pulsars, as expected from the large-scale halo field (Fig.2).

More RM data of both pulsars and extragalactic radio sources towards medium Galactic latitudes in the inner Galaxy are desired to check this crucial issue of Galactic dynamo.

If such a large-scale magnetic field model is confirmed by more data, then our Galaxy is the first galaxy in which the dynamo signature is clearly identified. In other words, it is the first time to identify a dynamo at a galactic scale. This is very difficult for other galaxies. We studied all possible RM data for M31, and got some evidence for the magnetic field configuration of a possible S0 dynamo (Han et al. 1998).

3 Magnetic fields in the Galactic disk: based on pulsar RMs

Pulsars are the best probes for Galactic magnetic fields. First of all, pulsars are highly polarized in general. So their RMs are relatively easy to measure, in contrast to the great difficulties to do Zeeman splitting measurements. Second, pulsars do not have any intrinsic RM. So, what one gets from RMs is just the contribution from the interstellar medium, an integration of diffuse magnetic fields along the

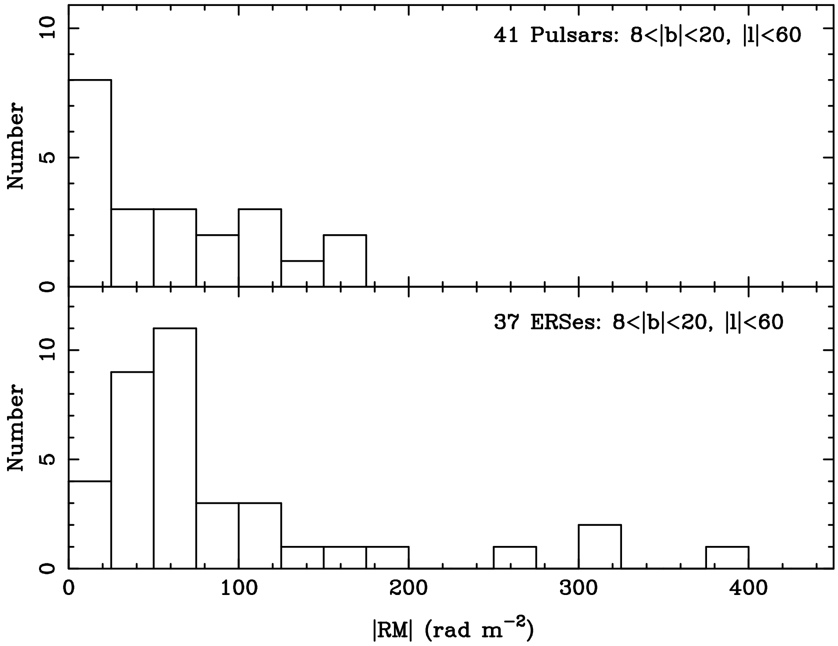

Fig. 2. The RM amplitudes of extragalactic radio sources in the very inner Galaxy are systematically larger than those of pulsars, indicating that the antisymmetric fields extended towards the Galactic center, far beyond the pulsars.

path from a pulsar to the observer, rather than *in situ* measurements in emission regions. Third, the total amount of the electron density between a pulsar and an observer can be measured independently by the pulsar dispersion measure, $DM = \int_{\rm psr}^{\rm obs} n_e \; dl$. This leads to a direct measure of the averaged magnetic field along the line of sight by using $\langle B_{||} \rangle = 1.232 RM/DM$. There have been many pulsars discovered, which are widely spread in our Galaxy. After measuring their RMs, it will not be very hard to find a 3-D magnetic field structure in our Galaxy.

3.1 Historical landmarks of using the pulsar RMs for the large-scale magnetic fields

A close look at the historical landmarks of using pulsar RMs to study the Galactic magnetic fields will show the progress in the last two or three decades.

Soon after the pulsars were discovered, Lyne & Smith (1969) detected their linear polarization. They noted that this “opens up the possibility of measuring the Faraday rotation in the interstellar medium” which “gives a very direct measure of the interstellar magnetic field”, because $\int_{\rm obs}^{\rm obj} n_e dl$ can be measured by DM so that $\langle B_{||} \rangle$ can be directly obtained from the ratio RM/DM. Manchester (1972, 1974) first systematically measured a number of pulsar RMs for Galactic magnetic fields and concluded that the local field (within 2 kpc!) is directed toward about $l \sim 90°$. Thomson & Nelson (1980) modeled the pulsar RMs mostly within 2 kpc and found the *first* field reversal near the Carina-Sagittarius arm. The largest pulsar RM dataset was published by Hamilton & Lyne (1987), mostly for pulsars at about 5 kpc and some up to 10 kpc. Then Lyne & Smith (1989) used pulsar RMs to further study the Galactic magnetic field. They confirmed the first field reversal in the inner Galaxy and found evidence for the field reversal in the outer Galaxy by a comparison of pulsar RMs with those of extragalactic radio sources. Rand & Kulkarni (1989) analyzed 185 pulsar RM data and proposed the ring model for the Galactic magnetic field. Rand & Lyne (1994) observed more RMs of distant pulsars and found evidence for the clock-wise field near the Crux-Scutum arm (at about 5 kpc). Han & Qiao (1994) and Indrani & Deshpande (1998) reanalyzed the pulsar RM data and found that the RM data are more consistent with the bisymmetric spiral model than with the ring model.

Han et al. (1997) first noticed that the RM distribution of high-latitude pulsars is dominated by the azimuthal field in the halo. Afterwards, any analysis of pulsar RMs for the disk field was limited

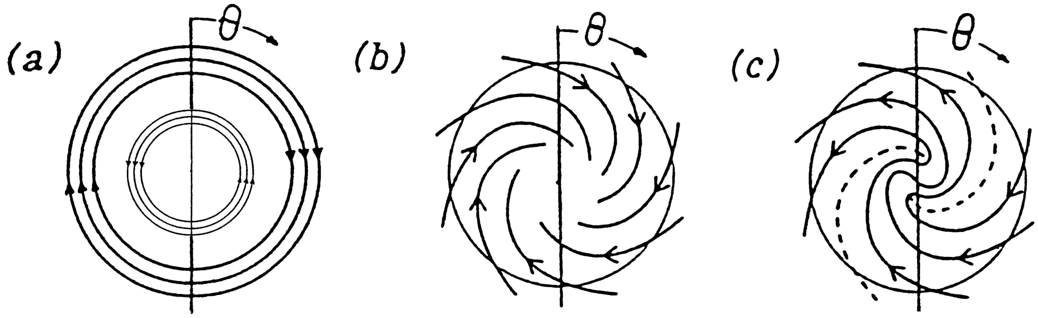

Fig. 3. A sketch of three models for Galactic magnetic fields, namely, (a) the concentric ring model, (b) the axisymmetric spiral model, and (c) the bisymmetric spiral model.

to pulsars at lower Galactic latitudes ($|b| < 8°$). Han et al. (1999) then observed 63 pulsar RMs and divided all known pulsar RMs into those lying within higher and lower latitude ranges for studies of the halo and disk field, respectively, and they confirmed the bisymmetric field structure and refined estimates of the vertical field component.

3.2 The large-scale magnetic field models

There have been three models to describe the global magnetic field structure of our Galaxy. In the early stage, Simard-Normandin & Kronberg (1980) showed that the RMs of extragalactic radio sources and pulsars are consistent with the bisymmetric spiral model. This was later confirmed by Sofue & Fujimoto (1983). The currently available pulsar RM data are mostly consistent with a bisymmetric spiral model as we will discuss below. While Vallée (1991, 1995) has argued for an axisymmetric spiral model. In this model, the field reversal occurs only in the range of Galactic radii from 5 to 8 kpc (Vallée 1996). No field reversals are allowed beyond 8 kpc or within 5 kpc from the Galactic Center. This is in contrast to the field reversals suggested beyond the solar circle and detected interior to the Crux-Scutum arm (e.g. Han et al. 1999, 2002). We noticed that recent arguments favour no field reversal outside the Perseus arm (e.g. Brown et al. 2003), which need more RM data of pulsars in the Perseus arm to check. Extragalactic radio source data are not enough to make a solid conclusion. The concentric ring model, proposed by Rand & Kulkarni (1989) and Rand & Lyne (1994), has a pitch angle of zero, but the observed pitch angle of fields of $-8°$ favours a spiral form of the field structure. Both the ring model and axisymmetric spiral model show that the magnetic field lines go across the spiral arms, which seems not to be physically possible.

3.3 Current status and future directions

Up to now, among about ∼1450 known pulsars, 535 pulsars have measured values of RM and 373 of them are located at lower latitudes ($|b| < 8°$). This includes 200 RM data from Parkes observations, which will be published soon (Han et al. in prep.). Significant progress has been made in the last decade on the magnetic fields in the Galactic disk, mainly because many pulsars have been discovered in the nearby half of the whole Galactic disk (e.g. Manchester et al. 1996; Lyne et al. 1998; Manchester et al. 2001) and extensive observations of pulsar RMs (e.g. Hamilton & Lyne 1987; Rand & Lyne 1994; Han et al. 1999) were conducted.

Analysis of pulsar RMs needs to consider three important factors for the diagnosis of the large-scale field structure. First, one normally assumes that the azimuthal field component B_ϕ is greater than the vertical and radial components B_z or B_r. This is reasonable and has been justified (Han & Qiao 1994; Han et al. 1999). Second, it is *the gradient of the average or general tendency of RM variations* versus pulsar DMs that traces the large-scale field. The scatter of the data about this general tendency is probably mostly due to the effect of smaller scale interstellar structure. Finally, the large-scale field structure should produce a coherence in the gradients for many independent lines of sight (see e.g. $l = \pm 20°$ near the Norma arm in Fig. 4).

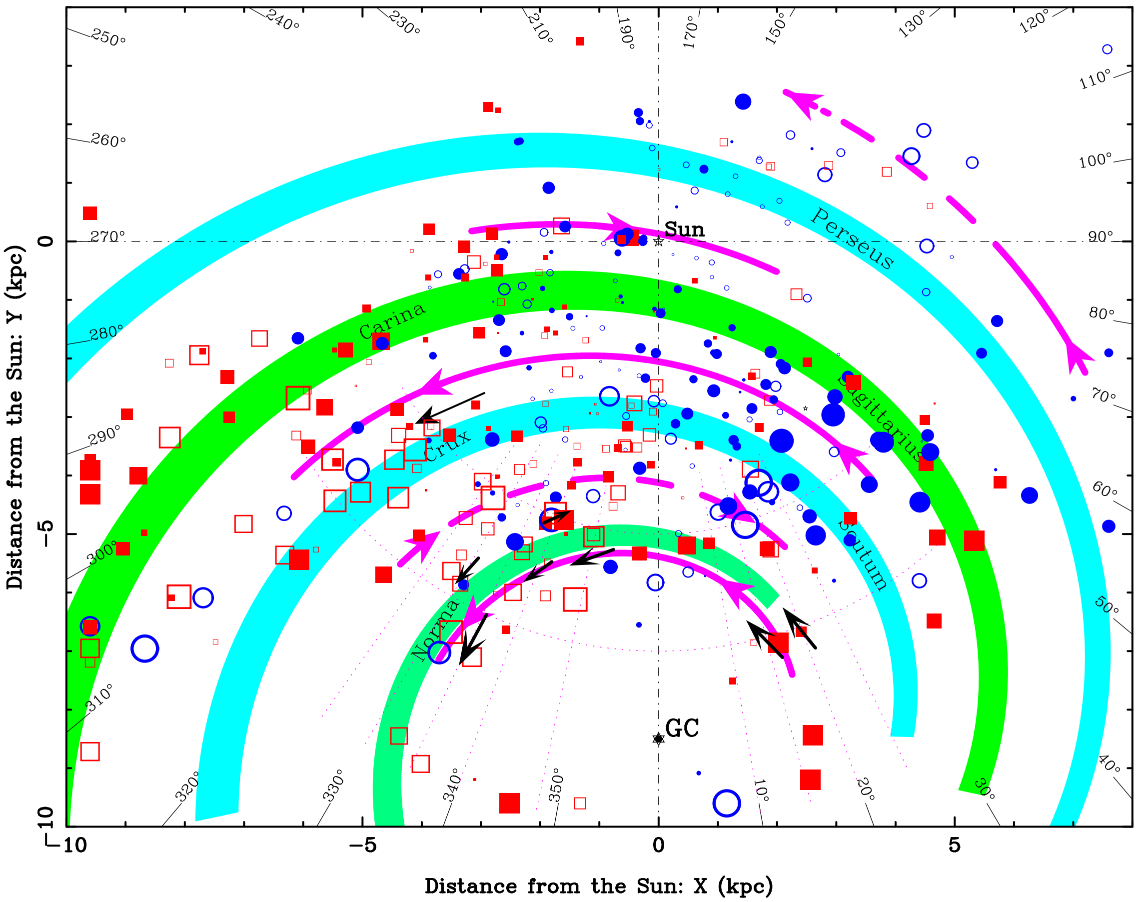

Fig. 4. The RM distribution of pulsars projected onto the Galactic plane. Red data (squares) are newly observed, and blue (circles) are previously published. Filled symbols stand for positive RMs and open ones for negative RMs. The large-scale magnetic fields are drawn by arrows, which was inferred from RM data. Solid-line arrows stand for confirmed field structures, while dashed-line arrows stand for proposed field structures in controversy and to be confirmed. The pulsar distances were estimated by a new electron density model (NE2001: Cordes & Lazio 2002). The magnetic fields are very probably going along the spiral arms, with *coherent directions* over more than 10 kpc interior to Carina-Sagittarius arm.

From the most updated RM distribution (see Fig. 4), we can conclude that magnetic fields between the Perseus arm and Carina-Sagittarius arm have a clock-wise direction when looking from the Northern galactic pole. Apparently this at least holds for about 5 kpc along the spiral arms. Between the Carina-Sagittarius arm and the Crux-Scutum arm, the positive RMs near $l \sim 50°$ and negative RMs near $l \sim 315°$ show the coherently counter-clockwise magnetic field along the spiral arm over more than 10 kpc! From the RMs of pulsars discovered by the Parkes multibeam survey, the counter-clockwise magnetic field along the Norma arm (i.e. the 3-kpc arm) has been clearly identified (Han et al. 2002). There have been some indications for clockwise magnetic fields between the Crux-Scutum arm and the Norma arm, while more RM data are obviously desired for a definite conclusion.

In the outer Galaxy the magnetic fields directions in or outside the Perseus arm have been in controversy recently. The magnetic field reversals suggested by Lyne & Smith (1989) have been confirmed by Han et al. (1999) and Weisberg et al. (2004) using available pulsar RMs mostly near $l \sim 70°$. While Mitra et al. (2003) and Brown et al. (2003) have argued for no reversal near or outside the Perseus arm from the RM data of pulsars and extragalactic radio sources in the region of $145° < l < 105°$. The average of RM values seems not to be significantly different for the foreground pulsar RMs near the Perseus arm and to the background extragalactic radio sources. This fact probably indicates two field reversals outside the Perseus arm which cancels their RM contributions. It is necesary to compare RM data of pulsars in the Perseus arm and background extragalactic radio sources between $45° < l < 110°$ for that purpose. A solid conclusion about the magnetic field configurations in this region would come out soon after many more pulsars in this region will be discovered in a future Arecibo L-band multibeam pulsar survey.

3.4 Discussions

Beside the large-scale magnetic field, naturally there are small-scale magnetic fields in our Galaxy. The strength of the large-scale magnetic field has been estimated to be 1.8 ± 0.5 μG (Han & Qiao 1994; Indrani & Deshpande 1998), while the total field strength estimated from cosmic-rays or using the equipartition assumptions is about 6μG. We have composed the energy spectrum of Galactic magnetic fields at different scales, from 0.5 kpc to 15 kpc (Han et al. 2003). Based on this spectrum, we estimate the fluctuations of magnetic fields have an rms field strength about 6 μG, which is very consistent with estimates for the total field strength by other methods. This confirms that the magnetic field strengths estimated from pulsar rotation measures are statistically fine for the diffuse interstellar medium. The field strength of regular magnetic fields estimated from the percentage of polarized continuum emission of nearby galaxies then probably has been two or three times overestimated.

Recently, Mitra et al. (2003) have shown that two or three pulsar RMs are affected by H II regions as these pulsars can be easily identified by their large DMs. In fact, the large DM should lead to an overestimated distance for the pulsar in a given electron density model. However, only a very small number of pulsars can be affected by chance, according to simulations made by Cordes & Lazio (2002).

The coherent variation of RMs versus DMs in different directions not only provides the information about the large-scale magnetic fields, but also indicates that the data scattering from the general tendency of variation due to small-scale regions does not influence the analysis of RMs for the large-scale magnetic fields.

4 Conclusions

Pulsars provide unique probes for the *large-scale* interstellar magnetic field in the Galactic disk. Other methods seem to have many difficulties for that purpose. The increasing number of RMs, especially of newly discovered distant pulsars, enables us for the first time to explore the magnetic field in nearly one third of the Galactic disk. The fields are found to be *coherent in directions* over a linear scale of more than ~ 10 kpc between the Carina-Sagittarius and Crux-Scutum arms from $l \sim 45°$ to $l \sim 305°$ and more than 5 kpc along the Norma arm. The magnetic fields reverse their directions from arm to arm. The coherent spiral structures and field direction reversals, including the newly determined counter-clockwise field near the Norma arm, are consistent with a bisymmetric spiral model for the disk field.

At high latitudes, the antisymmetric RM sky is most probably produced by the toroidal field in the Galactic halo. Together with the dipole field in the Galactic center, it strongly suggests that an A0 dynamo is operating in the halo of our Galaxy.

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