TITLE
*ASP Conference Series, Vol. **VOLUME**, **PUBLICATION YEAR***
EDITORS

The Magnetic Field of the Milky Way

Mark J. Reid
Harvard–Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138, USA

Abstract. Models of the magnetic field configuration of the Milky Way are reviewed. Current analyses of rotation measure data suggest that the Milky Way possesses a bi-symmetric-like spiral magnetic field, that field reversals among spiral arms exist, and that the magnetic spiral may not closely match the mass spiral structure. Zeeman measurements of OH masers may provide alternative magnetic field information.

1. Introduction

Observations of the polarization of synchrotron emission from spiral galaxies have demonstrated that these galaxies have large scale, ordered, magnetic field structures (see Beck, this volume), which often appear to have have bi-symmetric spiral (BSS) configurations. Unfortunately, since we observe from inside the Milky Way, it is not easy to measure its magnetic field. Considerable controversy exists over whether the magnetic field of the Milky Way is better described by a spiral or a circular pattern, whether the magnetic field is strongest in or between spiral arms, and whether or not the direction of the field reverses from arm to arm. In this review, we will describe our current level of understanding of the magnetic field (in the plane) of the Milky Way, and briefly describe the possibility of using Zeeman measurements of OH masers to help model this magnetic field.

2. Rotation & Dispersion Measure Results

Rotation measures (RM) for extragalactic sources and pulsars are sensitive to the integral, along the line to the source, of the product of the electron density and the line-of-sight component of the magnetic field. Were the electron density constant in the Milky Way and the magnetic field entirely uniform along any line-of-sight, then "inverting" the RM data to yield a magnetic field structure for the Milky Way would be straight forward. However, the electron density is almost surely far from constant (c.f., Taylor & Cordes 1993). In this context, RMs of pulsars have a significant advantage over extragalactic sources, because the dispersion of pulses, characterized by the dispersion measure (DM), is proportional to the integral of the line-of-sight electron density. Thus, forming the observable "RM/DM" for pulsars gives an electron density *weighted* magnetic field estimate.

A second difficulty in analyzing RM data is that the magnetic field in the Milky Way probably curves and different azimuthal segments (e.g., spiral arms) may reverse direction. Thus, one cannot simply invert the RM, or even RM/DM, data to obtain a magnetic field. Instead, model fitting is the method of choice: one postulates a model field configuration and adjusts parameters of the model in order to minimize the sum of the squares of the differences (χ^2) between the model and the data. Selected results are given in Table 1.

Table 1. Selected Magnetic Field Models for the Milky Way

Reference	Favored Model	B (μG)	Angle (deg)	Reversals
Simard-Normandin & Kronberg 1979				yes
Inoue & Tabara 1981	ring/shock		+10	no
Sofue & Fujimoto 1983	2-arm BSS	3	−5	yes
Lyne & Smith 1989				yes
Rand & Kulkarni 1989	4 rings	1	...	yes
Valée 1991	4 rings	~ 3	~ 6	yes
Clegg et al. 1992				no
Rand & Lyne 1994	3 rings	2–7	...	yes
Han & Qiao 1994	2-arm BSS	2	−8	yes
Indrani & Deshpande 1999	2-arm BSS	2	−7	yes
Han, Manchester & Qiao 1999	BSS			yes

Significant problems which plague modeling are as follows: (1) RMs are inherently very "noisy," owing to large random-like fluctuations of the magnetic field throughout the Milky Way. (2) Local magneto-ionic anomalies (e.g., the Gum Nebula) that are close to the Sun partially corrupt RMs over large angles on the sky. (3) Distances for pulsars, necessary for modeling, are highly uncertain. In part because of these problems, there is considerable latitude for variations in data editing. As a result, as one can see from Table 1, there are significant and fundamental differences among researchers in preferred models, which are usually rings or BSSs, the characteristic magnitude of the magnetic field strength (B), and the pitch angles (Angle).

It is worth noting that Rand & Kulkarni (1989) in their influential paper favor a ring over a spiral model, because their best fit spiral model appeared to have a pitch angle with an opposite sign to that deduced for the (matter) spiral arms of the Milky Way. However, Gilbert (1995) shows (1) that χ^2's for spiral models usually have nearly equal, double minima for positive and negative pitch angles, and (2) that a confusion over sign conventions resulted in Rand & Kulkarni rejecting a spiral model. Since this result propagates to the analysis of Valée (1991) and Rand & Lyne (1994), it is possible that a consensus favoring BSS models over ring models for the Milky Way may exist.

Recently Indrani & Deshpande (1999) noted that best fitting spiral models have the magnetic field *anti-correlated* with the mass spirals. Specifically, they point out that using the electron density model of Taylor & Cordes (1993), which is based on the empirical spiral model of Georgelin & Georgelin (1976), the magnetic field peaks in the inter-arm region and is near minimum in the arms. Since both the mass spiral structure of the Milky Way remains poorly determined and the log-periodic spirals usually used as magnetic field models may not be realistic, more work is needed to relate magnetic fields to the mass distribution in the Milky Way.

3. OH Maser Zeeman Measurements

Information about the magnetic field of the Milky Way may come from measurement of the Zeeman effect in hydroxyl (OH) masers found in regions of massive star formation. Davies (1974) based on a small sample of OH Zeeman measurements noted that the line-of-sight direction of the inferred magnetic field pointed in the direction of Galactic rotation. Reid & Silverstein (1990) examined a larger sample OH Zeeman measurements and concluded that the magnetic field in these star forming regions seemed to indicate a systematic field over large regions of the Galaxy. If OH masers sample, *in situ,* a compressed Galactic magnetic field, then they offer new data, independent of RMs, that can be used to constrain models of the magnetic field of the Milky Way. A large scale surveys of OH masers, capable of detecting Zeeman pairs, has just been completed by Argon, Reid & Menten (2000). Analysis of this data is now in progress.

References

Argon, A. L., Reid, M. J. & Menten, K. M. 2000, ApJS, 129, 159

Clegg, A. W., Cordes, J. M., Simonetti, J. H. & Kulkarni, S. R. 1992, ApJ, 386, 143

Davies, R. D. 1974, in IAU Symp. 60, Galactic Radio Astronomy, ed. F. Kerr & S. C. Simonson III (Dordrecht: Reidel), 275

Georgelin, Y. M. & Georgelin, Y. P. 1976, A&A, 49, 57

Gilbert, A. M. 1995, *Modeling the Galactic Magnetic Field*, Senior Thesis, Harvard U.

Han, J. L. & Qiao, G. J. 1994, A&A, 288, 759

Han, J. L., Manchester, R. N. & Qiao, G. J. 1999, MNRAS, 306, 371

Indrani, C. & Deshpande, A. A. 1999, New Astron., 4, 33

Inoue, M. & Tabara, H. 1981, PASJ, 33, 603

Lyne, A. G. & Smith, F. G. 1989, MNRAS, 237, 533

Rand, R. K. & Kulkarni, S. R. 1989, ApJ, 343, 760

Rand, R. K. & Lyne, A. G. 1994, MNRAS, 268, 497

Reid, M. J. & Silverstein, E. M. 1990, ApJ, 361, 483

Simard-Normandin, M. S. & Kronberg, P. P. 1980, ApJ, 242, 74

Sofue, Y. & Fujimoto, M. 1983, ApJ, 265, 722

Taylor, J. H. & Cordes, J. M. 1993, ApJ, 411, 674

Valée, J. P. 1991, ApJ, 366, 450