RevMexAA (Serie de Conferencias), **36**, 9–16 (2009)

PGMS: TO STUDY THE GALACTIC MAGNETISM OUT OF THE GALACTIC PLANE

E. Carretti,[1] M. Haverkorn,[2,3] D. McConnell,[4] G. Bernardi,[5] S. Cortiglioni,[6] N M. McClure-Griffiths,[4] and S. Poppi[7]

RESUMEN

El Parkes Galactic Meridian Survey (PGMS) es un mapeo de la emisión sincrotrón polarizada en una franja de $5° \times 90°$ a lo largo de un meridiano Galáctico, desde el plano Galáctico hasta el polo Galáctico sur. El mapeo se lleva a cabo con el radiotelescopio Parkes a una frecuencia de 2.3 GHz con 30 bandas adyacentes cada 8 MHz que permiten estudios de rotación de Faraday. La meta científica comprende: (1) Sondear el magnetismo Galáctico fuera del plano de la Galaxia, del cual poco se sabe aún. El PGMS ayuda al entendimento del campo magnético en el disco grueso de la Galaxia, en el halo y en la transición entre el disco y el halo; (2) Estudiar la emisión sincrotrón como ruido en primer plano de la radiación cósmica de fondo, especialmente el modo B débil, el cual contiene la firma de la onda gravitacional primordial de fondo, resultante del periodo inflacionario. Las observaciones del PGMS han concluido recientemente, en este trabajo presentamos el mapeo y algunos de los primeros resultados.

ABSTRACT

The Parkes Galactic Meridian Survey (PGMS) is a $5° \times 90°$ strip to map the polarized synchrotron emission along a Galactic meridian from the Galactic plane down to the south Galactic pole. The survey is carried out at the Parkes radio telescope at a frequency of 2.3 GHz with 30 adjacent 8 MHz bands which enable Faraday Rotation studies. The scientific goal is twofold: (1) To probe the Galactic magnetism off the Galactic plane of which little is known so far. PGMS gives an insight into the Galactic magnetic field in the thick disc, halo, and disc-halo transition; (2) To study the synchrotron emission as foreground noise of the CMB Polarization, especially for the weak B-Mode which carries the signature of the primordial gravitational wave background left by the Inflation. PGMS observations have been recently concluded. In this contribution we present the survey along with first results.

Key Words: cosmology: CMB — Galaxy: disk — Galaxy: halo — ISM: magnetic fields — polarization

1. INTRODUCTION

The magnetic field is an important component of the Interstellar Medium (ISM) and, as in almost any astrophysical context from stars to cosmology, the physics of the Galaxy cannot be studied without accounting for it.

Detection of Galactic magnetism is necessarily indirect, and various methods probe different components of the field and/or in different gas phases or locations in the Milky Way (e.g. Heiles 1996; Beck 2001). E.g., Zeeman splitting of emission or absorption lines yields magnetic field strengths in dense and cold clouds or masers. Magnetic field directions in cold clouds can also be studied through dust emission from these clouds, which is polarized due to magnetic fields. In the more tenuous medium, magnetic fields align dust grains which polarize the light of background stars, so that the direction of the field component in the plan of the sky can be inferred. However, the prime method to study magnetic fields on large scales in the ionized interstellar plasma is through radio polarization, which gives information about field strength and structure through a range of diagnostics discussed in detail in § 2.1.

[1]INAF, Istituto di Radioastronomia, Via Gobetti 101, 40129 Bologna, Italy (e.carretti@ira.inaf.it).

[2]Jansky Fellow, National Radio Astronomy Observatory, USA.

[3]Astronomy Department, University of California, Berkeley, 601 Campbell Hall, Berkeley, CA 94720, USA (marijke@astro.berkeley.edu).

[4]Australia Telescope National Facility, CSIRO, P.O. Box 76, Epping, NSW 1710, Australia (david.mcconnell, naomi.mcclure-griffiths@csiro.au).

[5]Kapteyn Astronomical Institute, University of Groningen, P.O. Box 800, 9700 AV Groningen, the Netherlands (bernardi@astro.rug.nl).

[6]INAF, stituto di Astrofisica Spaziale e Fisica Cosmica Bologna, Via Gobetti 101, 40129 Bologna, Italy (cortiglioni@iasfbo.inaf.it).

[7]INAF, Osservatorio Astronomico di Cagliari, Loc. Poggio dei Pini, Strada 54, 09012 Capoterra, Italy (spoppi@ca.astro.it).

Observations of other spiral galaxies show that the spiral arms are usually dominated by a turbulent or tangled component. A weaker coherent field aligned with the arms can be present as well. In the inter-arm regions the regular component is more relevant and depicts *magnetic arms* with coherent scales up to the size of the disc (e.g. M51, Patrikeev et al. 2006). The magnetic field in halos is less clear, instead. This is not only because of the weaker signal, which makes hard to detect the synchrotron emission, but also of the many different patterns found so far: from galaxies without evident halo field, to X-shaped fields centred at the galaxy centre (e.g. NGC 891, Krause 2007), and up to large almost spherical magnetic halos (e.g. NGC 4631, Hummel & Dettmar 1990).

Studying other galaxies can help understand the case of the Milky Way, but our position internal to the Galaxy makes it harder to figure out how the Galactic magnetic field is structured.

Probes to study magnetic fields and what is known to date about the Galactic field will be briefly reviewed in § 2, while available data of synchrotron polarized emission and requirements for new surveys will be discussed in § 3. Finally, the Parkes Galactic Meridian Survey will be presented in § 4.

2. THE GALACTIC MAGNETIC FIELD

2.1. *Probes*

Three main probes to investigate magnetic fields at radio frequencies are total synchrotron emission, polarized synchrotron emission, and Rotation Measure (RM) of pulsars and extragalactic sources.

1. The synchrotron emission is sensitive to the total magnetic field (ordered + irregular). It dominates the ISM radio emission at frequencies lower than ~5 GHz[8] and competes with free-free and anomalous dust emission up to a few dozen GHz (e.g. de Oliveira-Costa et al. 2008). Several all-sky class surveys are available, covering the range from 20 MHz to 40 GHz (see de Oliveira-Costa et al. 2008 for a mostly complete data set).

2. The polarized synchrotron emission traces the ordered component by three ways. The synchrotron emission is intrinsically linearly polarized up to 75%, but changes in direction of the polarization angle within the telescope beam or along the line-of-sight depolarize the signal. Only magnetic fields ordered up to large scales can give a net highly polarized emission. The polarization fraction is thus a measure of the ratio between ordered and total magnetic field.

[8] In this frequency range the free-free emission can compete only in HII regions in the plane.

The polarization angle ϕ is rotated by Faraday Rotation (FR) with the wavelength square

$$\Delta\phi = \mathrm{RM}\,\lambda^2\,, \tag{1}$$

where the Rotation Measure RM is

$$\mathrm{RM} = 0.81 \int n_e B_\parallel dl\,, \tag{2}$$

and measures the magnetic field parallel to the line of sight $B_\parallel$ [μG] weighted for the electron density n_e [cm^{-3}] integrated along the path dl [pc] from the source to the observer. Multifrequency observations are required to measure RM and give the strength of the ordered field along the line-of-sight and its direction (either out- or inward).

Finally, the synchrotron polarization angle gives the direction of the magnetic field on the plane of sky ($B_\perp$), once it has been corrected for FR.

Diffuse polarization data sets are far less complete than those in total emission. Only recently all-sky maps have been completed at 1.4 GHz (Wolleben et al. 2006; Testori et al. 2008) and 22.8 GHz (WMAP K-band map: Page et al. 2007), but both of them are single frequency and cannot give RM measures.

3. RM of Extragalactic Sources (EGS) and pulsars. The former probe $B_\parallel$ along the entire line-of-sight through the Galaxy (e.g. Brown et al. 2007). Pulsars, instead, probe out to their position, and, if the position is known with sufficient precision, can map the 3D distribution (e.g. Han et al. 2006). RM data sets are recently getting richer thanks to surveys like CGPS (Taylor et al. 2003), SGPS (Haverkorn et al. 2006), and Parkes RM pulsar surveys (e.g. Han et al. 2006; Noutsos et al. 2008).

2.2. *Magnetic Field in the Disc*

Even though the turbulent component dominates the magnetic field in the Galactic plane making it hard to probe the regular component coherent on large scales, the increase of RM data has enabled first studies of the 3D structure in the disc. What seems most favoured is a spiral structure in the disc down to the molecular ring, where the field gets a ring shape (e.g. Brown et al. 2007; Sun et al. 2008). The field in the local arm is Clock-Wise (CW) as seen from the north Galactic pole, while at least one reversal (inversion of the field heading while keeping the same alignment) seems to take place toward the inner Galaxy. (For a view of the spiral arm structure see Figure 1, where the electron density model by Cordes & Lazio 2002 is reported.)

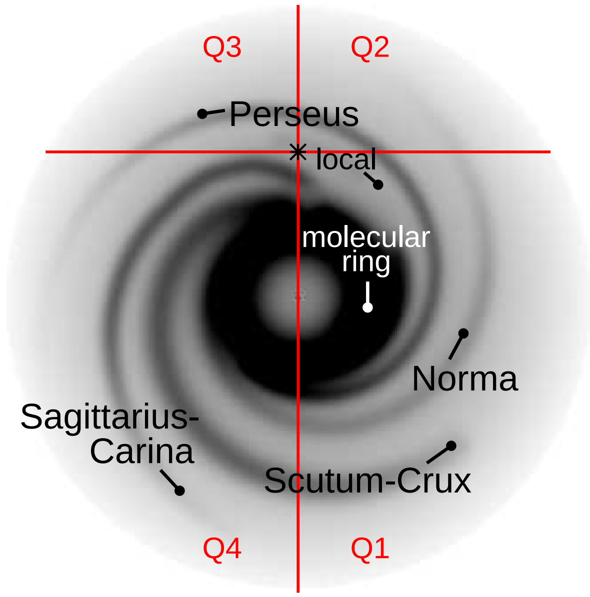

Fig. 1. Spiral arms structure of the Milky Way as traced by the electron density model NE2001 (Cordes & Lazio 2002). Figure courtesy by Jo-Anne Brown.

The number and location of the reversals is still under debate. Han et al. (2006) use pulsar RMs and find evidences for reversals at any passage from spiral arms to inter-arm regions, with all the arms CW and all inter-arms Counter CW (CCW). This would make the Galaxy very peculiar, as all the external galaxies studied so far show either no or only one reversal (Beck 2009).

Brown et al. (2007) use EGS and find evidence for only one reversal at the inner edge of the Carina-Sagittarius arm in the Fourth Quadrant (Q4), with that arm still CW and the Crux-Scutum one CCW. That reversal is then kept down to the molecular ring. They also find that a second reversal is possible in the Norma arm (CW) but with marginal evidence. This view is supported by pulsar RM data recently revised by Noutsos et al. (2008) who find that the field direction in the Carina arm is mainly CW in Q4. This interpretation is supported also by Sun et al. (2008), who set up a model of the Galactic magnetic field accounting for several types of data sets (RMs, total and polarized emission surveys, and others). They find that an Axi-Symmetric Spiral (ASS) structure with one reversal at the inner edge of the Carina-Sagittarius arm best fit the data. They also found that the data are equally well fitted by an ASS model plus a ring structure in the inner Galaxy, with CCW field in the ring and CW in the ASS section.

It is worth noticing that the CW direction of the Carina-Sagittarius arm in Q4 is in contrast with its CCW direction in Q1, which has strong evidences (e.g., Thomson & Nelson 1980). Therefore, the Carina-Sagittarius arm should present a field reversal internal to the arm somewhere close to the Q1–Q4 border. In fact, the arm is *distorted* with respect a *normal* spiral arm, also with a misalignment between spiral arm and magnetic field direction (Beck 2007). This would be compatible with a RING model for the inner Galaxy with a field reversal at the outer edge of the ring. The field reversal internal the Carina-Sagittarius arm would occur where the arm passes through the outer edge of the ring. Besides to be one of the best fits of Sun et al. (2008), the inner RING model has been first proposed by Vallée (2005).

In any case, it is clear that, despite the recent big observational efforts, the framework is not yet fully understood and more data are necessary to disentangle among the different interpretations.

2.3. *Magnetic Field in the Galactic Halo*

The data available for the Galactic halo field are far fewer than those in the disc and models are even less constrained. Our knowledge is basically based on RM data at mid and high Galactic latitudes, which, however, are coarsely and irregularly sampled. Han (2002) finds that RMs values are asymmetric both with respect to the plane and the Galactic centre, which is compatible with a field generated by an α–Ω dynamo model of A0-mode: two toroidal fields above and under the Galactic plane antisymmetric across the plane (sign reversal). However, diffuse polarization maps at 1.4 and 22.8 GHz clearly show very large structures in that region extending from the plane up to high latitudes, which likely are very local emissions. Contamination of RM data by local *anomalies* is therefore possible, jeopardising the interpretation as large scale field. Sun et al. (2008) found that their model cannot yet constrain the halo field essentially for lack of data, and its parameters remain open. It is also worth mentioning that there is no observation of external galaxy with large coherent dynamo pattern yet, and the most extended fields are likely sustained by wind outflows generated by the underlying active star-forming disc (Beck 2009).

In conclusion, very little is known about the Galactic halo field so far and present data cannot significantly constrain models. Even more than for the disc, far more data are necessary to understand the magnetic field structure of the halo.

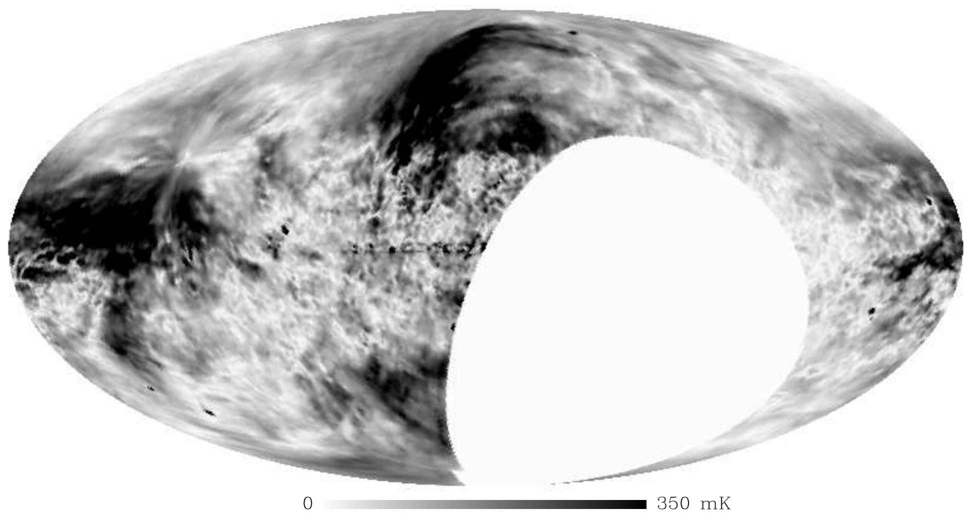

Fig. 2. Polarized intensity emission at 1.4 GHz of the northern sky (DRAO survey, Wolleben et al. 2006). The map is a Mollweide projection in Galactic coordinates using the HEALPix pixelation (Górski et al. 2005). It is centred at Galactic Centre and longitude increases leftward.

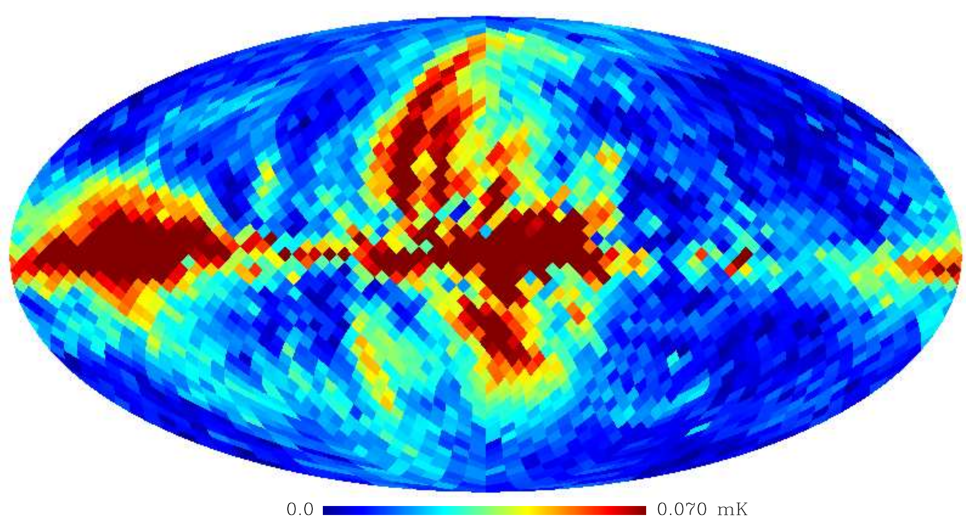

Fig. 3. Polarized intensity emission at 22.8 GHz (WMAP survey, Page et al. 2007). Data are binned in $\sim 4°$ pixels. Projection and pixelation are as for Figure 2

3. POLARIZED DIFFUSE EMISSION: STATUS AND SURVEY NEEDS

Diffuse polarized emission surveys carry much information about magnetic fields (§ 2.1). The most important available data are the two all-sky surveys which have been recently completed at 1.4 and 22.8 GHz.

The 1.4 GHz survey is the combination of a Northern (Figure 2) and Southern section (Wolleben et al. 2006; Testori et al. 2008, respectively). It has been the first all-sky coverage in polarization allowing the first look at the *ordered* magnetized component of the Galaxy. The emission is affected by FR with strong depolarization in the disc up to latitude $b \sim |30°|$ (Wolleben et al. 2006) and alterations up to $b \sim |50°|$ (Carretti et al. 2005). However, the survey is single band and is not self-sufficient to measure RMs and give intrinsic polarization angles.

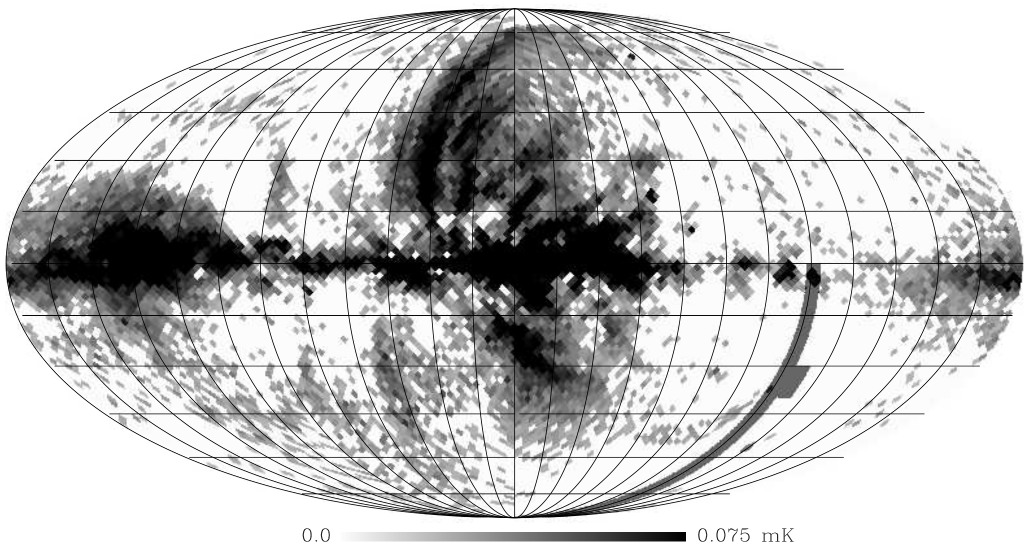

Fig. 4. The PGMS strip (grey) plotted on the WMAP polarized emission map at 22.8 GHz (Page et al. 2007). The map is in Galactic coordinates with $l = 0°$ at centre and longitude increasing leftward. The PGMS strip is centred at $l = 254°$. The enlargement at $b = -35°$ is also shown. Data are binned in $\sim 2°$ pixels and pixels with S/N < 3 have been blanked (white).

TABLE 1

PGMS MAIN PARAMETERS[a]

ν	BW	$N_{\rm ch}$	FWHM	l_0	b-range	Area size	$\sigma_{Q,U}$
2300 MHz	240 MHz	30	$8.9'$	254°	$[0°, -90°]$	$5.0° \times 90.0°$	0.3 mK

[a] ν is the central frequency, BW the bandwidth, $N_{\rm ch}$ the number of frequency channels, FWHM the beam size, l_0 the central strip meridian, and $\sigma_{Q,U}$ the sensitivity of Stokes Q and U in a beam-size pixel. The area size is also reported.

The 22.8 GHz all-sky map by WMAP (Page et al. 2007) is the first map at microwave frequencies where FR effects are negligible (Figure 3). It shows large local structures up to high latitudes. However, it has not sufficient sensitivity to detect the signal out of these local structures both in the disc and at high latitudes (Figure 4; see also Carretti et al. 2006), which prevents the investigation in regions clear by local deviations.

In spite of these recent efforts, the polarized diffuse emission is not yet sufficiently observed and more data are necessary. The features that new surveys should have can read as follows:

– observations at radio frequencies, where the synchrotron emission dominates;

– at frequency $\nu > 1.4$ GHz, to prevent depolarization;

– at frequency not too high, to benefit from a good S/N;

– many frequency channels, to enable RM computation;

– observations at all latitudes from the Galactic plane to the pole, to access all environments;

– observations of regions clear from strong local structures, to prevent contamination from local anomalies.

4. PARKES GALACTIC MERIDIAN SURVEY

The Parkes Galactic Meridian Survey (PGMS) is a project to survey the diffuse polarized emission along a Galactic meridian at a frequency of 2.3 GHz. Carried out at the Parkes radio telescope, it consists of a 5° wide and 90° long strip to cover all the southern meridian at longitude $l = 254°$ from the Galactic plane down to the south Galactic pole (Figure 4). It also includes a $10° \times 10°$ enlargement centred at $b = -35°$. Main features are reported in Table 1.

Multifrequency observations have been conducted in 30 adjacent channels 8 MHz wide to enable RM measurements. The expected performances are:

– In the disc, emission and RM are sufficiently high that RM can be measured with PGMS data alone using its 30 frequency channels. The expected sensitivity is ~ 10 rad m^{-2} on a scale of 9 arcmin, sufficient for disc RM values which are hundreds rad m^{-2}.

– In the halo, RM can be measured in combination with the 1.4 GHz data with an expected sensitivity of ~ 2 rad m^{-2} at the 36 arcmin resolution of the 1.4 GHz survey.

The central frequency of 2.3 GHz has been chosen as a trade-off to be high enough to prevent Faraday depolarization (apart from few degrees around the Galactic plane, possibly), and sufficiently low to ensure the appropriate S/N.

The selected meridian goes through lowest emission regions clear from large local structures, as visible in Figure 4 where the strip is projected onto the WMAP map. This enables PGMS to probe the Galactic field without significant local deviations.

PGMS fulfils the requirements listed in § 3 and the RM performances allows a significant improvement of mapping the Galactic field both in resolution and sensitivity. Although PGMS is not all-sky, its exploration of all the latitudes without local anomalies is expected to give new insights into the field in the halo, disc and at the disc-halo transition.

The structure and strength of the field in the halo are important to distinguish among dynamo models (especially the vertical component) and the high RM sensitivity of PGMS is expected to give important new information.

The 1.4 GHz data are strongly depolarized in the disc at latitudes $|b| < 30°$, which, thus, is mostly unexplored in diffuse polarized emission. Both the higher frequency and resolution are expected to enable PGMS to detect the signal also in the disc.

Finally, the 1.4 GHz data show a sudden transition at $|b| \sim 30°$. PGMS aims at exploring it to monitor the transition from coherent to turbulent field.

The other main goal of PGMS is the study of the synchrotron emission as foreground noise for CMB Polarization observations (CMBP). The CMBP is predicted to carry the signature of the primordial gravitational wave background emitted by the Inflation, which opens the possibility to directly probe that event of the primeval Universe. However, the signal is weak and contaminated by the synchrotron emission even at high Galactic latitude

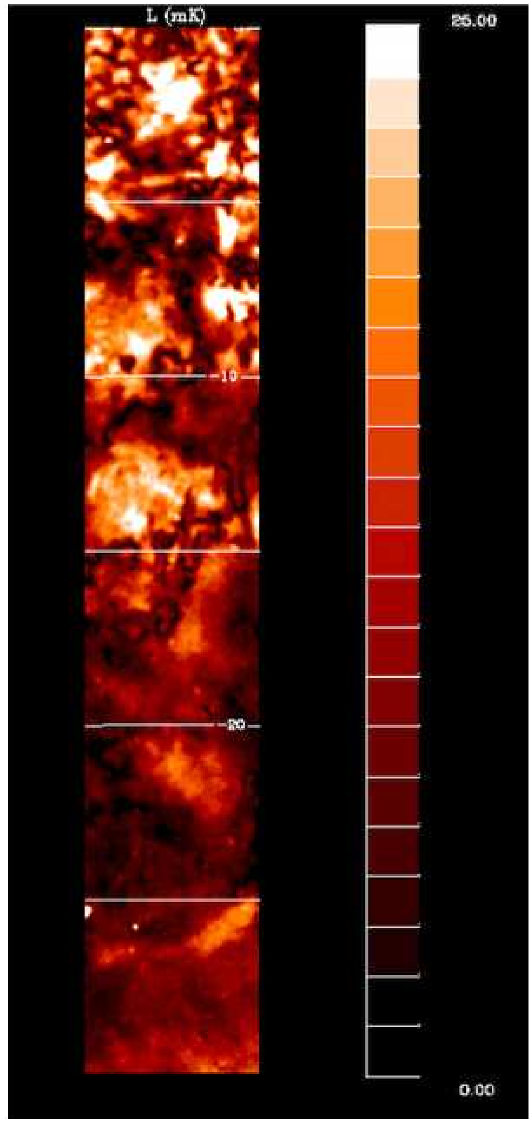

Fig. 5. Polarized intensity $L = \sqrt{Q^2 + U^2}$ [mK] of the PGMS fields in the Galactic disc at latitude $b = [0°, -30°]$. Isolatitude contours are spaced by 5°.

(Page et al. 2007). To clean it is mandatory, which requires high sensitivity mapping. On the other hand, some areas of the sky seems cleaner (cfr. Carretti et al. 2006 for a review). The areas observed so far are too few and small to extend their results to larger sky areas, however. PGMS goes through lowest emission regions and can give statistically robust estimates of the contamination level of these best areas. This is especially important for ground-based and balloon-borne experiments, like CLOVER (Taylor 2006) and EBEX (Oxley et al. 2004), which usually observe in small sky areas and can benefit of particularly clean regions.

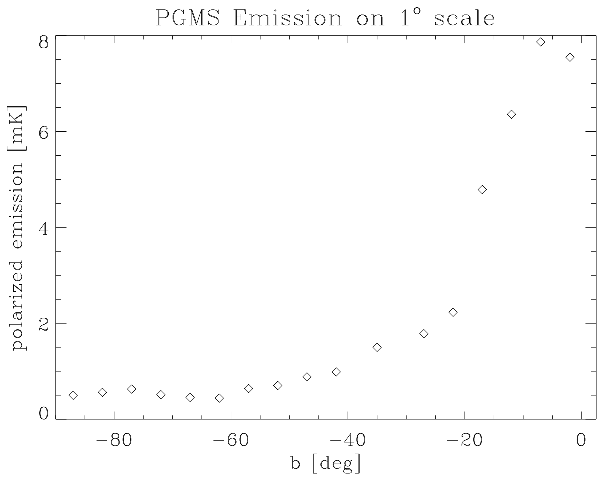

Fig. 6. Polarized emission on 1° scale of the PGMS fields plotted versus Galactic latitude b.

PGMS observations have been completed in September 2007 after 4 runs spread in 2 years. The strip to observe has been divided in $5° \times 5°$ fields, except the enlargement centred on $b = -35°$ which is $10° \times 10°$. Each field includes a 1° enlargement along b at the north edge, so that the actual area of each field is $5° \times 6°$ with a $5° \times 1°$ overlap with the next northern field. The final sensitivity per beam-size pixel is ~ 0.3 mK for high latitude areas ($|b| > 30°$) and ~ 0.5 mK for those of the disc ($|b| < 30°$).

Figure 5 shows the polarized intensity of the disc fields. The strongest emission is near the Galactic plane and keeps high up to $|b| = 15°$–$20°$, where it starts to drop down. This behaviour can be better appreciated in Figure 6, where the emission on 1° scale versus latitude is plotted. A transition at $|b| = 15°$–$20°$ is evident, while the decline continues at higher latitudes up to $|b| \sim 40°$ where the emission sets on low levels up to the south Galactic pole. This behaviour differs from the 1.4 GHz data, where the disc emission is depolarized and weaker than at high latitude.

In addition, the 2.3 GHz emission looks mottled from the plane up to $|b| = 6°$–$7°$, but then becomes smooth. This supports that FR effects are marginal even in the disc at this frequency and affect the emission only within a few degrees around the Galactic plane. Figure 6 also shows a slight depletion in the first field at $b = [0°, -5°]$.

This behaviour supports that 2.3 GHz (and $9'$ resolution) is a frequency sufficiently high to show the polarized emission in most of the disc with no (or marginal) Faraday depolarization. Faraday rotation modulation is evident only in the very few degrees close to the plane, but it is not yet clear whether there is depolarization and, if yes, how much it is. The on-going multifrequency analysis should help us work it out especially through the RM analysis.

About the CMB foreground analysis, the low Faraday effects ensure safe extrapolations to the CMB frequencies at high latitudes. Computation of the angular power spectra is on-going and a full analysis will be soon published. Here we want only to notice the presence of a best clean area at $b = [-75°, -60°]$ which looks of high interest for sub-orbital experiments.

The PGMS data analysis is in progress and results will soon be published, but its *successor* has started already. The S-PASS (S-band Polarization All Sky Survey, Carretti et al. 2007) is aimed at surveying the whole southern sky with the Parkes telescope and with the same set up of PGMS, with obvious advantages of full spatial characterization of the polarized diffuse emission in this band. S-PASS is 30% complete to date (April 2008) and is expected to be finished by 2009.

This work is partly supported by the ASI project COFIS. MH acknowledges support from the National Radio Astronomy Observatory (NRAO), which is operated by Associated Universities Inc., under cooperative agreement with the National Science Foundation. Part of this work is based on observations taken with the Parkes Radio telescope, which is part of the Australia Telescope, funded by the Commonwealth of Australia for operation as a National Facility managed by CSIRO. Some of the results in this paper have been derived using the HEALPix package (`http://healpix.jpl.nasa.gov`, Górski et al. 2005). The Dominion Radio Astrophysical Observatory is operated as a national Facility by the National Research Council Canada. We acknowledge the use of WMAP data, and the Legacy Archive for Microwave Background Data Analysis (LAMBDA). Support for LAMBDA is provided by the NASA Office of Space Science.

REFERENCES

Beck, R. 2001, Space Sci. Rev., 99, 243
Beck, R. 2007, EAS Publ. Ser., 23, 19
Beck, R. 2009, Ap&SS, 320, 77
Brown, J. C., Haverkorn, M., Gaensler, B. M., Taylor, A. R., Bizunok, N. S., McClure-Griffiths, N. M., Dickey, J. M., & Green, A. J. 2007, ApJ, 663, 258
Carretti, E., Bernardi, G., & Cortiglioni, S. 2006, MNRAS, 373, L93
Carretti, E., Bernardi, G., Sault, R. J., Cortiglioni, S., & Poppi, S. 2005, MNRAS, 358, 1

Carretti, E., Haverkorn, M., Staveley-Smith, L., Bernardi, G., Cortiglioni, S., Gaensler, B., Kesteven, M. J., & Poppi, S. 2007, S-band Polarization All Sky Survey, ATNF Parkes project P560
Cordes, J. M., & Lazio, T. J. W. 2002, arXiv:astro-ph/0207156
de Oliveira-Costa, A., Tegmark, M., Gaensler, B. M., Jonas, J., Landecker, T. L., & Reich, P. 2008, arXiv:0802.1525
Górski, K. M., Hivon, E., Banday, A. J., Wandelt, B. D., Hansen, F. K., Reinecke, M., & Bartelmann, M. 2005, ApJ, 622, 759
Han, J. 2002, in AIP Conf. Proc. 609, Astrophysical Polarized Backgrounds, ed. S. Cecchini, S. Cortiglioni, R. Sault, & C. Sbarra (Melville: AIP), 96
Han, J. L., Manchester, R. N., Lyne, A. G., Qiao, G. J., & van Straten, W. 2006, ApJ, 642, 868
Haverkorn, M., Gaensler, B. M., McClure-Griffiths, N. M., Dickey, J. M., & Green, A. J. 2006, ApJS, 167, 230
Heiles, C. 1996, in ASP Conf. Ser. 97, Polarimetry of the interstellar medium, ed. W. G. Roberge & D. C. B. Whittet (San Francisco: ASP), 457
Hummel, E., & Dettmar, R.-J. 1990, A&A, 236, 33
Krause, M. 2007, Mem. Soc. Astr. Italiana, 78, 314
Noutsos, A., Johnston, S., Kramer, M., & Karastergiou, A. 2008, MNRAS, 386, 1881
Oxley, P., et al. 2004, Proc. SPIE, 5543, 320
Page, L., et al. 2007, ApJS, 170, 335
Patrikeev, I., Fletcher, A., Stepanov, R., Beck, R., Berkhuijsen, E. M., Frick, P., & Horellou, C. 2006, A&A, 458, 441
Sun, X. H., Reich, W., Waelkens, A., & Enßlin, T. A. 2008, A&A, 477, 573
Taylor, A. C. 2006, NewA Rev., 50, 993
Taylor, A. R., et al. 2003, AJ, 125, 3145
Testori, J. C., et al. 2008, A&A, submitted
Thomson, R. C., & Nelson, A. H. 1980, MNRAS, 191, 863
Vallée, J. P. 2005, ApJ, 619, 297
Wolleben, M., Landecker, T. L., Reich, W., & Wielebinski, R. 2006, A&A, 448, 411