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NIR polarimetry as a probe of the large-scale structure of the galactic magnetic field

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Abstract. H-band (1.6 μm) starlight polarimetry was used to test predictions of the large-scale symmetry of the Galactic magnetic field and to measure the Galactic magnetic pitch angle. Polarimetry was obtained with the Mimir instrument on the 1.8m Perkins Telescope outside of Flagstaff, AZ USA along a line of constant Galactic longitude for a range of Galactic latitudes. Comparison with all-sky predictions of starlight polarimetry allows significant rejection of disk anti-symmetric Galactic magnetic field geometries and favored disk symmetric geometries. The Galactic magnetic field pitch angle was also constrained to be p=–6±2° towards this direction.

Keywords. Galaxy: disk, ISM: magnetic fields, magnetic fields, polarization, radiative transfer

Much of the previous work attempting to understand the large-scale structure of the Galactic magnetic field has relied on Faraday rotation towards Galactic pulsars and polarized extragalactic sources. However, Faraday rotation only probes the line-of-sight component of magnetic fields in the hot, ionized interstellar medium (ISM), and this may bias our understanding of the large-scale structure of the Galactic magnetic field.

Here, a different method, polarization of background starlight, was used to probe the large-scale structure of the Galactic magnetic field in the disk. All-sky predictions for near-infrared (NIR) starlight polarimetry were created for several different magnetic field geometries. Observations of starlight polarization in the outer Galaxy were then used to test these predictions. In particular, the magnetic symmetry with respect to the Galactic disk and the spiral-type magnetic pitch angle were each constrained.

Starlight polarization arises from dichroic extinction of unpolarized background starlight by magnetically-aligned dust grains throughout the Galactic disk. The resulting polarizations trace the orientations of the magnetic fields between the background stars and the observer. Two major classes of disk-symmetry were considered: disk-symmetric (S0) and disk-antisymmetric (A0). Here only axisymmetric magnetic fields are considered. Starlight polarization is only sensitive to the orientation of magnetic fields, not their directions, and therefore is insensitive to magnetic reversals along any line-of-sight.

All-sky predictions of NIR starlight polarization require magnetic fields, dust, and background stars. Three S0 and three A0 magnetic field geometries were taken from Ferrière & Schmitt (2000) as representative examples of those classes. Three additional S0/A0-hybrid magnetic field models were taken from Moss *et al.* (2010). Two different models (Spergel *et al.* 1996 and Drimmel & Spergel 2001) were used to estimate the Galactic dust distribution. The stellar population model of Robin *et al.* (2003) was used to create synthetic star fields (to a limiting magnitude of H=14) for 10 × 10 arcmin pointings equally spaced every five degrees in Galactic latitude and longitude across the sky. Predicted starlight polarizations were calculated using a Stokes radiative transfer

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model (Pavel 2011), and the average starlight polarization towards each pointing was calculated to produce all-sky predictions. The 1σ dispersions in the averaged polarization quantities were taken as estimates of the uncertainties in the predictions. Maps were produced for the combination of each magnetic field geometry and dust model, but the choice of which dust model to use was shown to be unimportant (Pavel 2011). A0 and S0 magnetic fields produce significantly different predictions for starlight polarizations, while the S0/A0-hybrid models are essentially indistinguishable from the S0 models.

H-band (1.6 μm) starlight polarimetry was obtained towards ℓ=150°, -75°<b<10° (Pavel *et al.* 2012) with the Mimir instrument (Clemens *et al.* 2007) on the 1.8m Perkins Telescope outside Flagstaff, AZ. The observations were reduced using the Mimir data reduction pipeline (Clemens *et al.* 2012). Polarimetric observations were complete to H=14, matching the all-sky predictions. For each 10×10 arcmin observation, the average starlight polarization was calculated in an identical manner to the all-sky predictions.

The observed change in polarization position angle (PA) with Galactic latitude was compared to the predictions at the same locations on the sky. The average of the differences (ΔPA) between the predicted and observed polarization PAs (in all directions with observations) were calculated for each model to test each prediction. From this comparison, all A0 models were rejected at the 50σ level, or higher. Predictions from S0 and S0/A0-hybrid magnetic field models were marginally consistent with the observations.

To constrain the magnetic pitch angle in the Galactic disk, additional analytic magnetic field models were created consisting of a disk-symmetric (S0), log-spiral magnetic field. The pitch angle of these magnetic field models (defined as p=arctan[$\mathbf{B}_\mathrm{r}/\mathbf{B}_\phi$]) was varied from 0-24° in steps of 0.5°. Similar all-sky predictions were calculated for these analytic magnetic field models and compared to the observations. All analytic models consistent with ΔPA=0° (within the 1σ uncertainty in that quantity) were used to constrain the magnetic pitch angle in the disk of the Galaxy to $p = -6 \pm 2°$. While only measured towards one Galactic longitude in the outer Galaxy ($\ell = 150°$), this result is consistent with other measurements using optical starlight polarimetry (Heiles 1996) and Faraday rotation (Vallee 1988; Han & Qiao 1994; Beck 2007; Pshirkov *et al.* 2011).

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