

Interstellar polarization at high galactic latitudes from distant stars

VII. A complete map for southern latitudes $b < -70^\circ$

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Abstract. We present a detailed map of interstellar polarization for the South Galactic Pole ($b < -70^\circ$). The map is based on new polarization measurements of 183 stars of spectral classes from A to K at distances of up to 500 pc. We use polarization data to investigate the distribution of dust and to map the Galactic magnetic field at high southern Galactic latitudes and make a comparison with the opposite northern polar zone. In general, the magnetic field is smoother in the south and aligned with the global pattern. There are no extended dusty structures in the south similar to Markkanen's cloud in the north.

Key words. polarization – ISM: dust, extinction – Galaxy: solar neighborhood

1. Introduction

In the present paper we continue our study of dust, extinction and geometry of the magnetic field at high Galactic latitudes from polarimetry of distant stars. A major part of our previous research was devoted to a detailed study of the North Galactic Pole area ($b > +70^\circ$). We found that there is a substantial amount of interstellar dust at high northern galactic latitudes and that the distribution of dust and the directions of the interstellar magnetic field are very inhomogeneous (see Berdyugin et al. 2000, Paper III; Berdyugin & Teerikorpi 2002, Paper VI, and papers cited therein).

The pioneering study of interstellar polarization in the areas of the North (NGP) and South Galactic Poles (SGP) was made by Appenzeller (1968) who noticed that interstellar polarizations in the south seem to be larger and better co-aligned. He also made the first estimates of the lower limit of the interstellar reddening in this area of the sky based on the amount of interstellar polarization: he obtained $E(B - V) > 0.011$ at the NGP and $E(B - V) > 0.016$ at the SGP (Appenzeller 1975). However, his polarization data in the SGP zone cover only the area $45^\circ < l < 195^\circ, -70^\circ > b > -80^\circ$. Our first results for the South Galactic Pole ($b < -70^\circ$), were obtained in 2000 (Berdyugin & Teerikorpi 2001, Paper V). Significant values of the interstellar polarization ($P > 0.4\%$) were detected. We also found that the directions of the observed interstellar polarization are very well aligned with the Galactic latitude $l \approx 80^\circ$. However, the polarization map of the southern circumpolar area at that time was far from complete: less than 30 percent of the 20° zone around the South Galactic Pole had been studied.

In 2001–2003 we have continued our measurements and covered the previously unstudied area. This gives us a detailed picture of the interstellar polarization around the SGP and allows us to make a straightforward comparison with the northern polar direction.

2. Observations

For our program we have chosen stars of A–K spectral types with reliable parallaxes ($\pi > 2\sigma_\pi$) from the HIPPARCOS catalogue (Perryman et al. 1997). Special care was taken to exclude stars with peculiarities and possible variables. Observations were made with the 2.6 m Nordic Optical Telescope (La Palma), the 60 cm KVA telescope (La Palma) and the 2.15 m Jorge Sahade telescope (CASLEO Observatory, El Leoncito, Argentina). The NOT and the CASLEO telescopes are equipped with almost identical copies of the *UBVRI* polarimeter (Piirola 1973, 1988), built at Tuorla Observatory and Turin Observatory, respectively. The polarimeter allows us to measure simultaneously linear polarization in Johnson *UBVRI* bands. On the KVA telescope, a recently constructed CCD polarimeter has been used. This polarimeter is equipped with an Apogee AP47p camera with a Marconi CCD47-10 back illuminated thinned CCD which has high blue sensitivity. It uses a calcite plate as the analyzer and a rotating achromatic $\lambda/2$ plate as the retarder. A detailed description of this instrument will be given elsewhere (Piirola 2004). The instrumental polarization has been found to be very small ($P < 0.03\%$) for all these telescopes. Observations with the

CCD polarimeter have been made in unfiltered (white) light. Polarizations measured in the separate *UBVRI* bands have been averaged in order to increase the statistical precision.

3. Data selection

The previously published incomplete polarization map of the SGP area (Fig. 2, Paper V) was based on the data we obtained in 2000 and the older data published by Appenzeller (1968), Mathewson & Ford (1970) and Korhonen & Reiz (1986). At that time we were unaware of the paper published by Shröder (1976) which also contains polarization data for the SGP area. Our new polarization map updates the old one with our new data and also includes the older measurements made by Shröder.

To select the stars from different sources we have used the following procedure: first, the measured polarization has been corrected for positive bias using:

$$P_0 = (P^2 - K^2\sigma_P^2)^{1/2} \quad (1)$$

where $K = 1.41$ corresponds to the maximum likelihood estimator in Simmons & Stewart (1985). To account for very little polarized or apparently non-polarized stars we have assumed that if P and $\sigma_P < 0.05$ and $P/\sigma_P < 1.41$ then $P_0 = 0.0$.

All stars in our sample have their distances from HIPPARCOS parallaxes. For the stars observed by other investigators only photometric distances were available at the time of their publications. Whenever possible, we have updated them with the more accurate values given by HIPPARCOS. There are many nearby stars ($d < 40$ pc) in the SGP area observed by previous investigators. They show very small or zero interstellar polarization. This agrees with the general conclusion that there is very little interstellar dust in a region of several tens of parsecs around the Sun (Piirola 1977; Leroy 1993). For the sake of clarity, we did not include these stars in our analysis.

4. SGP polarization map: Comparison with the opposite northern direction

The new updated map of the SGP area is shown in Fig. 1. This map is based on a total of 368 stars: 11 from Appenzeller (1968), 11 from Mathewson & Ford (1970); 73 from Korhonen & Reiz (1986); 45 from Shröder (1976); 43 from our Paper V and, finally, 183 new stars observed by us in 2001–2003. We note that most of the stars observed in the past have distances < 300 pc, while the stars in our sample are located mostly in the range 200 pc–500 pc. The stars with $P_0 > 2\sigma_P$ have been plotted on the map with the directional bars. Under this restriction the error in the direction angle of polarization is not more than 14° .

The map of the NGP area is shown for comparison in Fig. 2. As we have noticed in our previous papers, the main feature seen in the NGP zone is the so-called Markkanen's cloud. It is spread over the north polar area even beyond $l = 70^\circ$ and its direction is roughly parallel to longitude $l = 50^\circ$. Interstellar polarization in this cloud is enhanced and very well co-aligned

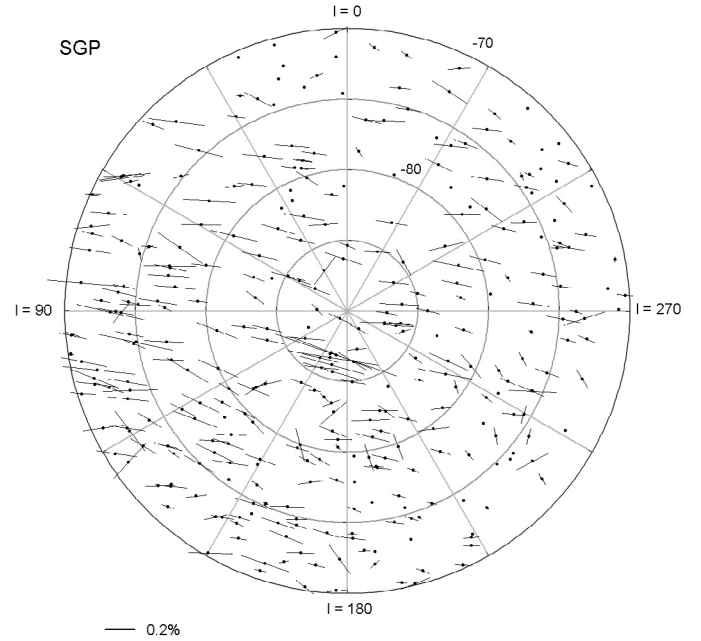


Fig. 1. Polarization of the stars within 20° area of the South Galactic Pole. The length of the bar gives the amount of polarization, its direction gives the direction of the polarization plane. The dots are the stars with $P_0 = 0.0$.

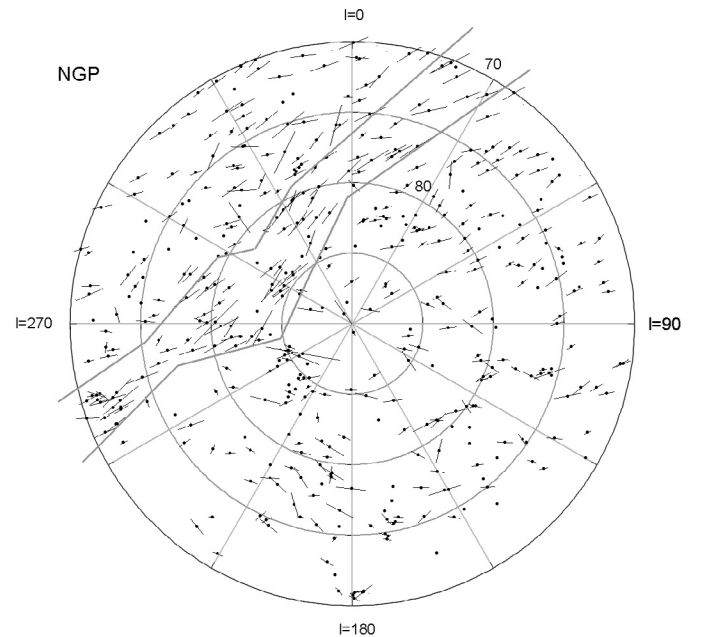


Fig. 2. The same as Fig. 1, but for the North Galactic Pole. Markkanen's cloud is also shown.

in the same direction. On the IRAS 100μ map this cloud shows up as an area of bright emission filaments (see Paper III). Interstellar polarization in the sectors $260^\circ < l < 360^\circ$ and $30^\circ < l < 90^\circ$ is lower, but its direction, in general, is co-aligned with the same longitude $l \approx 50^\circ$. In the remaining part of the NGP zone, polarization seems to be rather low and also irregular. There is, however, a group of distant stars ($d > 300$ pc) in the area $180^\circ < l < 210^\circ, 75^\circ < b < 83^\circ$ with the polarization roughly orthogonal to the direction of the

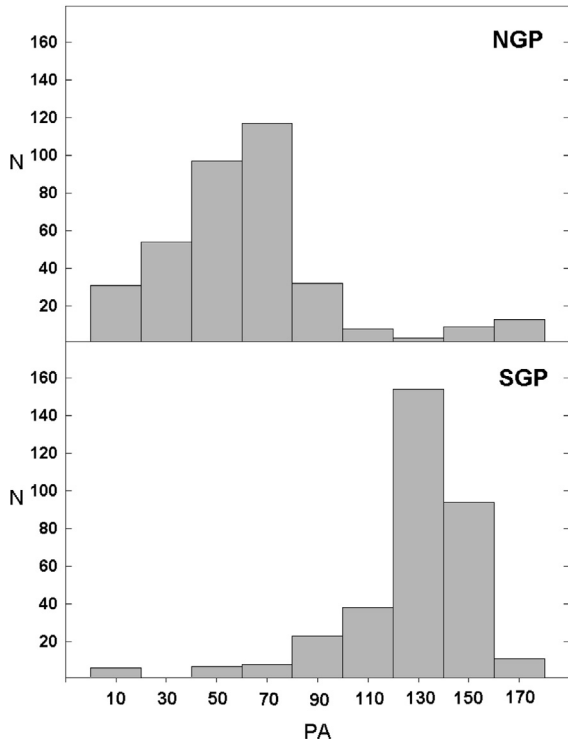


Fig. 3. Distribution of the polarization directions in the equatorial coordinate system for the NGP (*upper plot*) and SGP (*lower plot*). The maxima at 70° in the north direction and 130° in the south direction correspond to 53° and 83° in the Galactic coordinate frame.

polarization in Markkanen’s cloud (Berdyugin & Teerikorpi 1997).

4.1. Direction of polarization in the SGP

The general picture of the interstellar polarization in the direction of the South Galactic Pole differs clearly from the NGP. As seen from Fig. 1, the direction of polarization is much more regular. Unlike the NGP, where the most prominent direction of interstellar polarization corresponds to $l \approx 50$, the polarization is aligned along the longitude $l \approx 80^\circ$. Figure 3 shows the histograms of the polarization directions for the NGP and SGP areas. Again, only the stars for which $P_0 > 2\sigma_P$ have been used. The histogram for the NGP has a maximum at 70° which corresponds in Galactic coordinates to $l = 53^\circ$. For the SGP area the histogram shows a maximum at 130° which corresponds to the longitude 83° . Note, that the maximum around $l \approx 80^\circ$ in the SGP area is significantly narrower than the maximum at $l \approx 50^\circ$ in the NGP. In other words, the distribution of the polarization direction in the SGP zone has a smaller dispersion and the interstellar polarization is much better aligned.

4.2. Dependence of interstellar polarization on distance

Figure 4 shows the dependence of polarization on distance for both polar Galactic zones. There is an interesting difference between the poles: in the north the polarization first grows rapidly with distance, but reaches its maximum soon

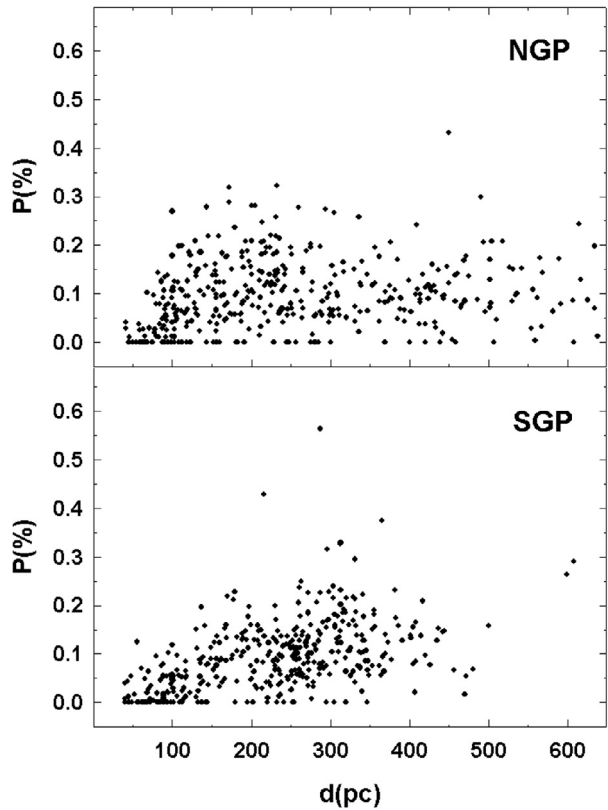


Fig. 4. Dependence of the polarization on distance for the NGP and SGP areas.

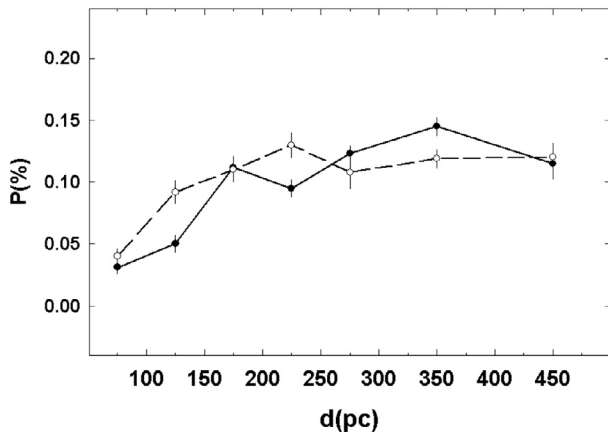


Fig. 5. Median line of the polarization – distance dependence calculated by binning the distances for the NGP (dashed line) and SGP (solid line). Vertical bars are 2σ errors computed from the dispersion.

after 200 pc, while in the south the polarization grows more gradually up to 350 pc. To facilitate comparison, Fig. 5 shows median curves for both areas determined by binning the polarization within 50 pc up to 300 pc and within 100 pc for the distances 300–500 pc. As seen from this figure, the polarization at the NGP reaches its maximum value between 200 and 250 pc, while at the SGP the maximum occurs between 300 and 400 pc. It is difficult to make any comparison beyond 500 pc, as there are so few stars at such distances with reliable parallaxes. It is tempting to conclude from this comparison that the dust layer in the direction of the NGP has smaller thickness and, on the

Table 1. Polarization of stars in the 2° area around $l = 160^\circ, b = -86^\circ$.

Star	$P(\%)$	σ_P	θ°	σ_θ	$d(\text{pc})$	l	b	Sp
HD 5867	0.38	0.05	125	3	365	159.67	-86.81	G8IV
HD 6001	0.57	0.05	128	3	290	165.85	-86.78	F5V
HD 5866	0.43	0.02	134	1	216	158.69	-86.70	F6V
HD 5961	0.00	0.02			139	159.70	-86.46	F3V
HD 6428	0.27	0.03	130	3	599	166.40	-85.55	K1III
HD 6205	0.29	0.03	131	3	608	164.11	-86.01	K1III

average, higher density up to 200 pc. Beyond this distance there is very little dust in the 20° area around the NGP. There is evidence that at the SGP the dust layer has a lower density up to 200 pc, but still extends beyond 300 pc.

4.3. Distribution of the dust in the SGP area

On the average, the dust distribution at the SGP seems to be more regular than at the NGP. There are no large and well distinguished structures resembling Markkanen's cloud in the south. However, there is one interesting feature; a relatively small region at $l \approx 160^\circ, b = -86^\circ$ where interstellar polarization is significantly larger than in the surrounding area. Table 1 lists the stars within 2° of this region with their polarization, polarization direction, distance, Galactic coordinates and spectral types. Three stars in this group, HD 5867, HD 6001 and HD 5866 have polarization $P > 0.3\%$ and two, HD 6428 and HD 6205 have $P \approx 0.3\%$. Directions of polarization for these five stars are co-aligned within 10° . We note that the distances for HD 6428 and HD 6205 have been derived from photometry and may not be precise. HD 5961, which is the closest star in this group, seems to be unpolarized. Our data show that there could be a compact dust cloud in this part of the sky, whose detailed structure is not well determined yet. We also note that according to Fong et al. (1987) there is a peak of $100 \mu\text{m}$ flux in this area.

5. Conclusions

The interstellar polarization gives the direction of the Galactic interstellar magnetic field. The direction of the global Galactic magnetic field associated with the nearby global spiral arm is $l \approx 78^\circ$ (Vallee 1995). It is interesting to note that towards the South Galactic Pole this direction is clearly seen from the observed interstellar polarization. However, in the North Galactic Pole area the global Galactic magnetic field is apparently disturbed, probably by the local spiral pattern (see Papers III and VI). Another interesting finding is the indication for a greater vertical extent of the dust layer in the South Galactic Pole direction.

By taking the maximum values of the average interstellar polarization from the median line shown in Fig. 5, we can make

new estimates for the interstellar reddening: $E(B - V) > 0.014$ at the NGP and $E(B - V) > 0.017$ at the SGP. The lower limit of reddening for the SGP is remarkably similar to that obtained by Appenzeller (1975), but slightly larger than his value for the NGP. However, the reddening is not uniform: $E(B - V) > 0.043$ in the area $l \approx 160^\circ, b = -86^\circ$ in the SGP zone and $E(B - V) > 0.030$ inside Markkanen's cloud in the North.

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