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Research Note

Interstellar dust and magnetic field at the boundaries of the Local Bubble

Analysis of polarimetric data in the light of Hipparcos parallaxes*,**

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Abstract. Hipparcos stellar parallaxes have been used to reanalyse existing interstellar polarization data. The main results are:

- The nearest interstellar dust patches are at about 70 pc in some directions, in others beyond 150 pc. Thus the region devoid of dust, commonly identified with the *Local Hot Bubble*, is irregular in shape.
- The interstellar magnetic field revealed by the nearest polarized stars is certainly **not** a smooth, uniform field along the Galactic equator. The structure seen is more complex and can no longer be dismissed as an artefact due to inaccurate stellar distances.

Key words: polarization – ISM: clouds – ISM: magnetic fields – Galaxy: solar neighbourhood

1. Introduction

Different types of observations have revealed the special character of the local interstellar medium around the Sun, in particular the existence of the *Local Bubble*, a relatively depleted and hot region (Cox & Reynolds, 1987). The analysis of soft X-ray radiation provides a good determination of its radius which turns out to be about 50 pc (Snowden et al., 1998). The *walls* of the Bubble are fairly well defined when one measures the interstellar absorption (Frisch, 1995; Heiles, 1998). As far as interstellar polarization is concerned, it is the work by Tinbergen (1982) which has established that one finds almost no polarization in the light of the stars closer than 35 pc. The investigation was extended by Leroy (1993a, 1993b) who obtained the same result for a sample of 1000 stars closer than 50 pc. Only 25 stars which will be considered later have shown a significant polarization.

Polarimetry is well suited to the detection of small amounts of interstellar dust (Appenzeller, 1975; Tinbergen, 1982). At least this statement is true for the dust component which consists of anisotropic particles likely to be aligned by the ambient magnetic field. Thus, polarimetry is a useful means to study the Local Bubble and its surroundings. In the past, the main weakness of this approach was the uncertainty on the stellar distances: this drawback has recently disappeared owing to the "Hipparcos" experiment which has provided a wealth of accurate parallaxes. The typical uncertainty of 10^{-3} arc-second (1 mas) on the Hipparcos parallaxes results in a possible error of ∓ 10 pc on a star located at 100 pc from the Sun, which is adequate for the study of the Local Bubble boundary.

A first inspection of the previous sample of 25 polarized stars (Leroy, 1993a), in the light of the Hipparcos catalogue, reveals that the distances have been systematically underestimated. Except for one or two cases, all these stars are beyond the 50 pc limit that I had tried to impose. I suspected this effect (compare columns 4 and 11 in Table 1 of Leroy, 1993a), but still I underestimated it. With the knowledge of the Hipparcos distances, the origin of the bias becomes clear: suppose that there is something like a *wall* of polarizing dust, at the outer boundary of the Local Bubble, i.e. farther than 50 pc. Searching for the polarized stars within a sphere of *approximately* 50 pc must lead to a selection of the objects farther than 50 pc whose the distance has been underestimated. Obviously, the full power of polarimetric investigations can be reached only when the stellar distances are well known.

In short, the situation at the beginning of this work was as follows: the closest dust clouds were known to be farther than 50 pc, maybe beyond the radius of the Local Hot Bubble (Snowden et al., 1998). Hopefully, the joint analysis of the existing polarimetric data and of the Hipparcos parallaxes offered the opportunity to determine more precisely the geometry of this interesting region.

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* based on observations obtained with the telescope Bernard Lyot of Pic du Midi Observatory

** Tables of the polarimetric cataloque are only available in electronic form at the CDS (Strasbourg) via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/Abstract.html

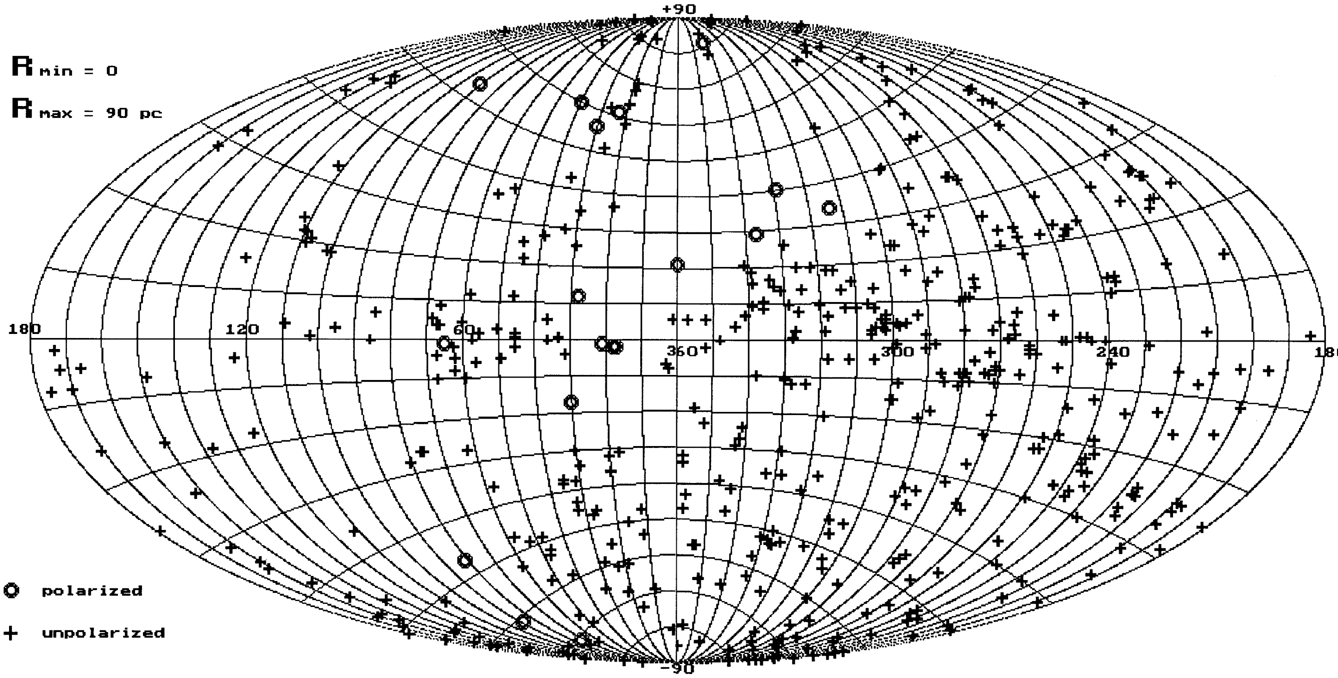

Fig. 1a. Various lines of sight, limited to the sphere of radius 90 pc around the Sun, are displayed. The small circles correspond to the lines of sight which meet a star, closer than 90 pc, showing a polarization of at least 0.10%. The crosses correspond to the lines of sight which meet an unpolarized star farther than 90 pc; thus, they show the regions free of interstellar polarization, within the sphere of radius 90 pc.

2. Analysis of the polarization measurements

2.1. The Pic du Midi sample

Our former observations have resulted in a polarization catalogue of 1000 stars closer than 50 pc, but have also provided additional data bearing on slightly more distant stars. In particular, I observed a significant number of K III giants, selected in the Bright Star Catalogue, because their spectroscopic distance was in the range of interest. In addition, I observed a

large number of stars which, according to the existing catalogues, were both nearby and polarized objects. Although the former distance estimates have no more interest now, the polarimetric data remain and they can be used in conjunction with the Hipparcos distances.

It is important to ascertain the polarization detections. In Fig. 2, I have stressed the polarimetric data concerning the stars which have been observed at least twice: this condition helps to discard erroneous polarimetric data (or spurious star identifications), but also the stars which display a variable polarization, presumably of intrinsic origin. The (electronic) table and the figures which summarize the results of this article refer to three distance intervals: 60 to 90 pc, 90 to 120 pc and 120 to 150 pc. This partition has been chosen to fit the distance resolution expected given the Hipparcos parallaxes accuracy (nominally 1 m.a.s., i.e. about 10 pc at a distance of 100 pc).

2.2. The polarization catalogues

A study of the polarization catalogues available in the literature enabled me to select another sample of stars located within the range of interest (60–150 pc) according to Hipparcos. The catalogues which have been investigated are:

1. The Mathewson & Ford (1970) catalogue which gathered all the data available at that time.
2. The Axon & Ellis (1976) catalogue which included additional data and tried to provide accurate distances.
3. Various catalogues concerning the neigbourhood of the Sun: Appenzeller (1966, 1968), Behr (1959), Piirola (1977), Tinbergen (1982) and Leroy (1993b).
4. Other catalogues which have been published in the two last decades: Schröder (1976), Krautter (1980), Korhonen & Reiz (1986), Berdyugin et al. (1995), Reiz & Franco (1998); one finds in this last article a wealth of valuable data which are much wanted for the whole celestial sphere.

I have not tried to study the nearest, thin cloud observed by Tinbergen (1982), but not by Leroy (1993a). Rather, as we are interested in the detection of the *dust wall* which may lie at the boundary of the Local Bubble, I have looked for the detection of polarization levels of 0.10% or more. Thus, I consider as *unpolarized* stars the objects which present a polarization of 0.10% or less (crosses on Figs. 1a to c), and I classify as *polarized* stars the objects with a polarization larger than 0.10% (I have added the constraint that the polarization must have been detected in two distinct observational runs, or in a single occasion but at the 6σ signal-to-noise level).

I am well aware of the weakness of a selection based on highly inhomogeneous data: not only is the accuracy of measurements different from one author to the other, but even the spectral bands of the instruments may not be the same (generally,

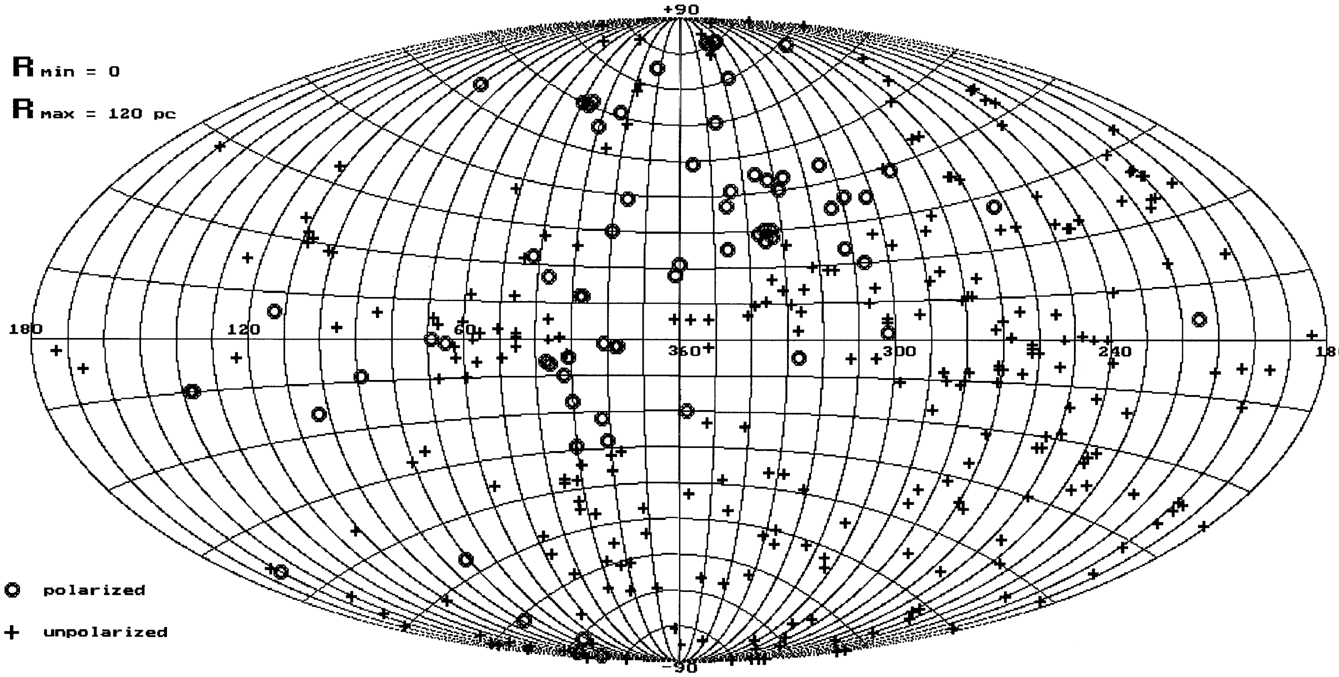

Fig. 1b. Same as for Fig. 1a except that the radius of the sphere under study has been raised to 120 pc.

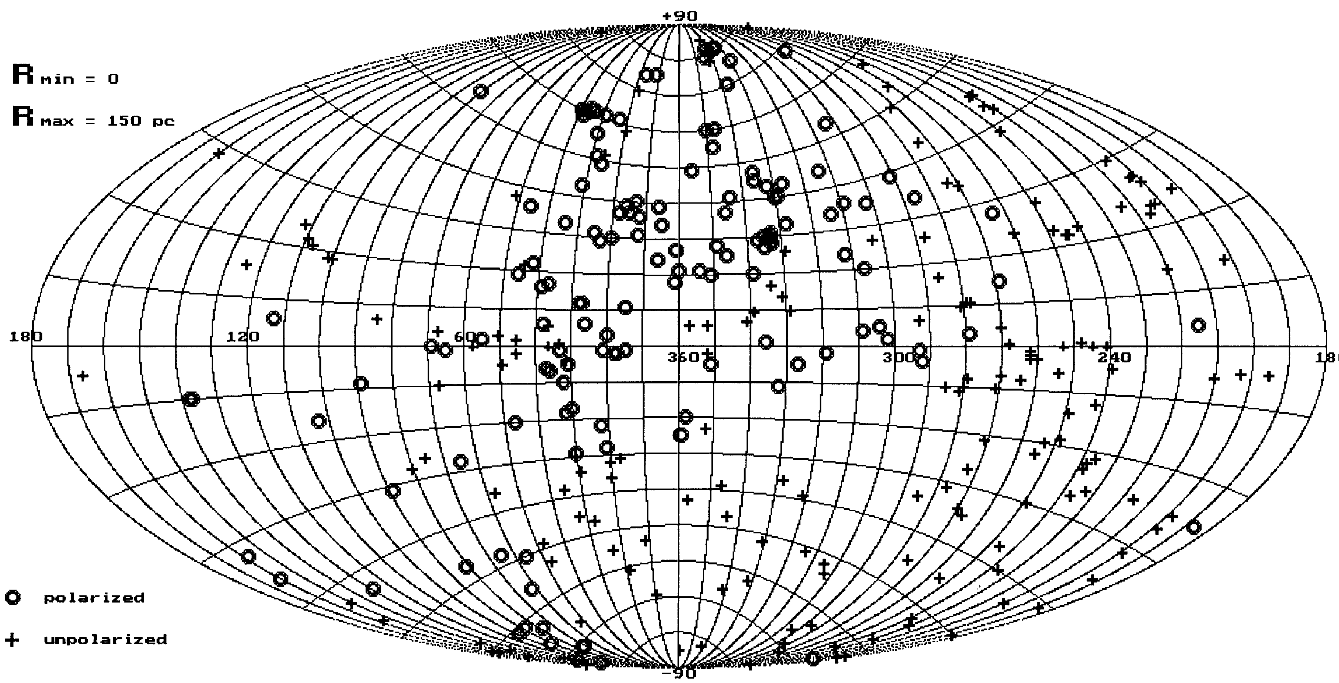

Fig. 1c. Same as for Figs. 1a and 1b but the radius is now equal to 150 pc.

it was the standard B band, but in some cases it was rather the B+V domain). More homogeneous measurements are wanted and they will be certainly obtained in the near future. But, imperfect as it is, the data sample that I have gathered already contains interesting information.

The polarimetric catalogue which has been finally obtained, and has allowed us to manage the present work, is available only in electronic form at the CDS (anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr//Abstract.html).

3. Interstellar polarization in the range 60–150 pc

I have plotted in Figs. 1a, 1b, 1c, the lines of sight which show no polarization, and those which show some polarization, according to the preceding definitions. The pattern of the unpolarized

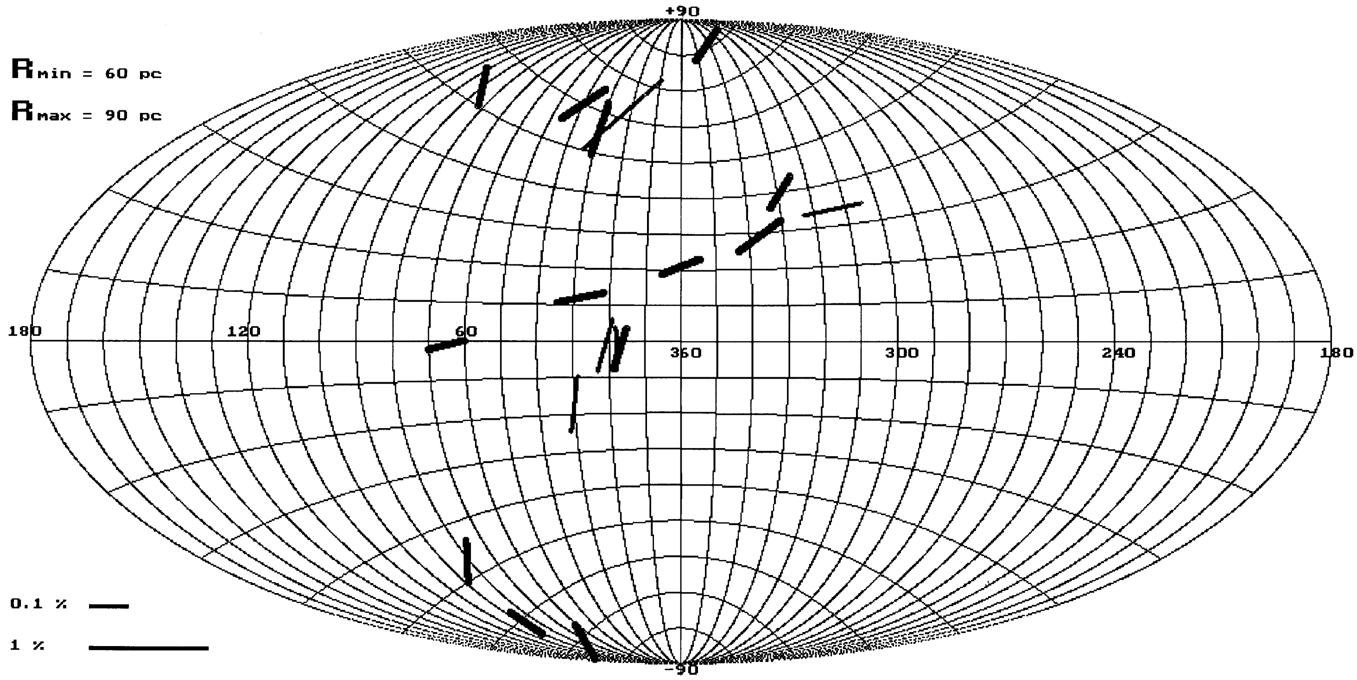

Fig. 2a. Polarization vectors corresponding to the sample of polarized stars within the range 60–90 pc. Thick vectors refer to the stars which have been observed at least twice. The length of the vectors is proportional to the square root of the polarization degree, as sketched in the bottom left corner.

lines of sight reveals that some regions of the sky have not yet been sampled adequately (see for instance the regions around longitudes $80°$ and $150°$, in the Northern hemisphere). Anyway, the number of unpolarized lines of sight decreases when the distance increases from 90 pc (Fig. 1a), to 120 pc (Fig. 1b), and finally to 150 pc (Fig. 1c), which is quite natural. However, one finds almost no interstellar polarization, even at 150 pc, around longitude $240°$, especially in the Southern hemisphere. This well known trend has be interpreted as being due to an elongation of the Local Bubble in this direction, or possibly to a connexion with another nearby bubble (Heiles, 1998).

Figs. 1a to c, display two interesting features: firstly, significant dust clouds appear at 70–80 pc, slightly beyond the Local Bubble boundary defined with the help of X-ray measurements. One could argue that polarizing dust is located *in front* of the stars, and thus must be closer than 70 pc. However, as we find almost no polarization up to 50 pc, the range of uncertainty turns out to be rather small. Secondly, the first traces of polarization appear at high as well as at low latitudes (see for instance the polarized patches at $+70°$). The classical model of a galactic bubble having its smallest radius in the galactic plane does not fit well our data on the nearest polarizing clouds.

The average behaviour that I have described suffers a single peculiarity: according to Mathewson & Ford (1970), the star HD 131334 ($l = 23°$; $b = +61°$), located by Hipparcos at 51 pc only, shows a strong polarization of 0.76%! It is necessary to confirm this observation, and, moreover, one cannot discard some kind of intrinsic polarization. However, one notes that the nearby line of sight towards HD 133582, at 77 pc, is polarized in the same direction, at the 0.2% level, and it may be that one meets the nearest polarizing cloud at a latitude as high as $60°$.

Let us concentrate now on Figs. 2a, 2b, 2c where I have plotted the polarization directions on a planisphere inspired from the Airy projection system (which achieves a compromise between area errors and angle errors). As the polarization degrees are not essential at this stage of the work, I have plotted polarized vectors proportional to the square root of the polarization degree: with this convention, the figure is no longer crowded with long vectors and one gets a better view of the orientation pattern. Finally, to emphasize the safest data, I have plotted as thick vectors the polarimetric data which result from two independent measurements, or more.

The most approaching maps published earlier were those by Mathewson & Ford (1970, Fig. 3a) and by Axon & Ellis (1976, Fig. 1a), which both referred to the distance interval 50–100 pc. These maps were not identical to each other, and the comparison with my present result also reveals significant differences. It is likely that the previous maps have been seriously spoilt by the uncertainty on the stellar distances, whatever the good quality of the properly polarimetric data.

The polarization directions which are observed in Fig. 2, a to c, are somewhat confusing if one believes, as usually assumed, that the polarization vectors reflect the magnetic field organization, because two dominant polarization directions appear simultaneously. The first one is more or less meridional, grossly parallel to the meridian with longitude $30°$. The other one, more consistent with the classical description of the galactic magnetic field, is slightly inclined on the galactic equator between $310°$ and $70°$. Some meridional organization is also

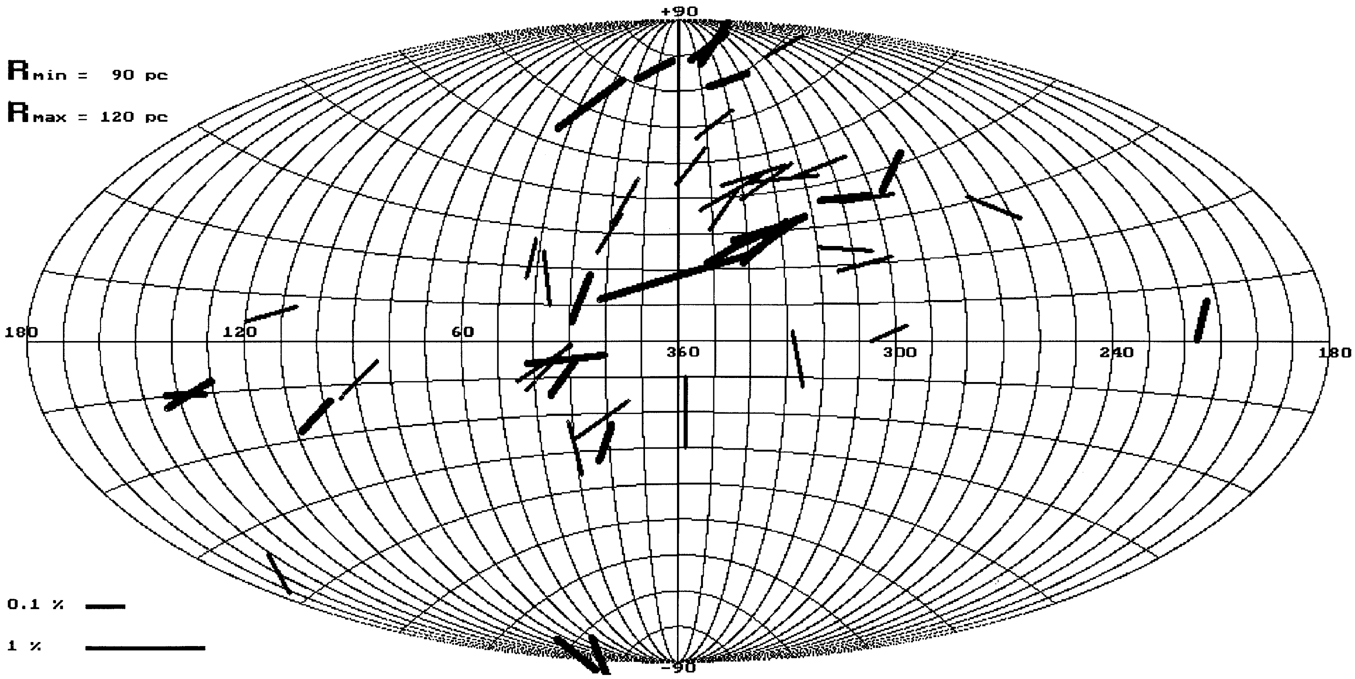

Fig. 2b. Same as for Fig. 2a except that the distance interval is now 90–120 pc.

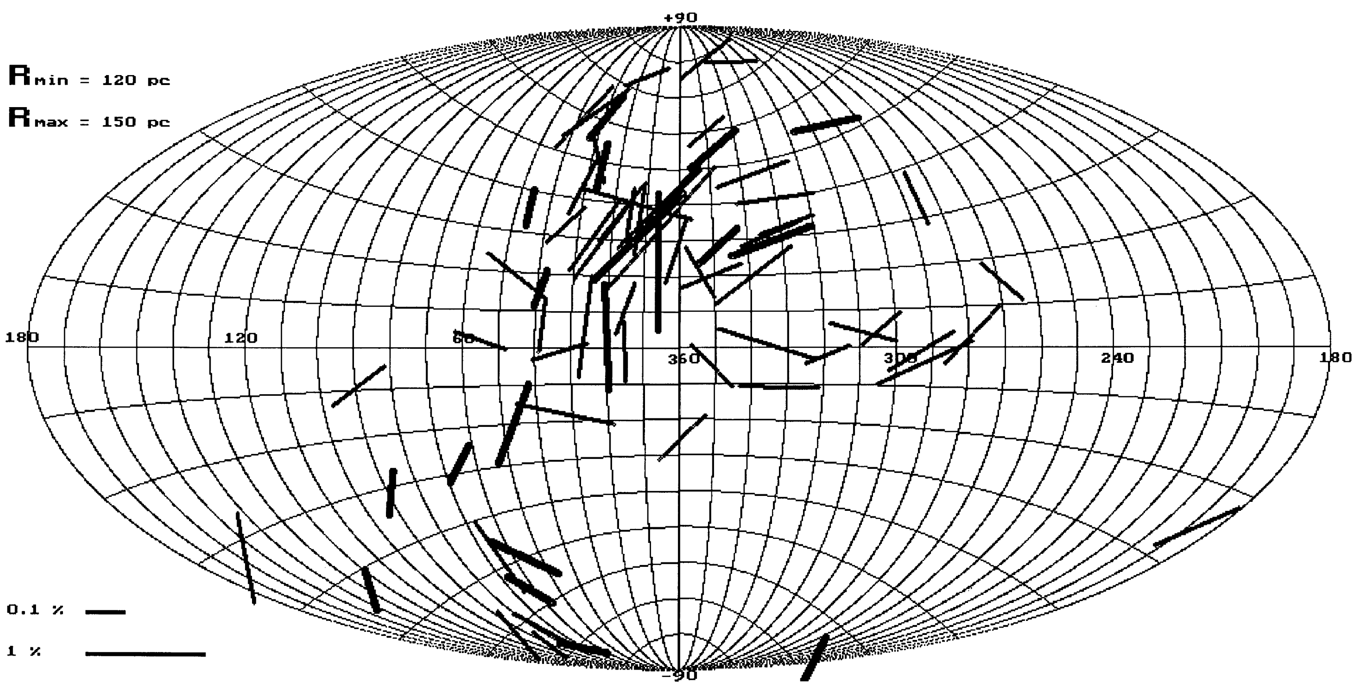

Fig. 2c. Same as for Figs. 2a and 2b except that the distance interval is 120–150 pc.

visible in Fig. 1 and it is difficult to believe that this effect is a chance result, due to the measurement errors, because a significant number of stars have been observed accurately. Fig. 2c also shows another interesting feature, namely a possible loop centered around 320°, in the Northern hemisphere. It mimics the feature known as the Loop I (which includes the North Polar Spur) but its radius is smaller in my map than the radius reported for Loop I (see e.g. Ellis & Axon, 1978, Fig. 5).

The complex situation depicted by these maps, specially around the longitude interval 0°-30°, had been already noticed by Mathewson (he proposed a model of helical magnetic field able to fit his data; see Mathewson, 1968, Fig. 1). On the other hand, one may remember that the polarimetric study of more distant absorbing clouds has frequently revealed multiple orientation patterns (Myers & Goodman, 1991, Fig. 1). In such cases, it has often been assumed that discrepant orientations reflected the presence of distinct star samples, at different distances along the line of sight. However, given the accuracy of the Hipparcos parallaxes, such an interpretation does not seem adequate to explain our present results. Thus, the magnetic field organization at the outer boundary of the Local Bubble may be rather complicated.

4. Conclusion

The accurate parallaxes provided by Hipparcos have already induced major advances in many fields of stellar astronomy. The present work shows how they can support also some classes of studies of the interstellar medium: the investigations on the absorption, reddening and polarization due to the interstellar medium are much more convincing now that the distances of the light sources under study are well known. Owing to the Hipparcos experiment, it is possible now to have a good geometrical picture of the Sun surroundings to at least 150 pc.

The region which lies at 50–100 pc from the Sun is specially interesting: one finds there the boundary of the Local Bubble, maybe also some intersections of the Local Bubble with other neighbouring bubbles. The exploration of this medium may rely on measurements performed in a broad spectral range, from the far infra-red to the X-rays. The present work concentrates on a more classical approach, optical polarimetry, which is still one of the best means to detect small amounts of interstellar dust and trace magnetic field patterns. The polarimetric method has become truly powerful since a major drawback, the inaccuracy of stellar distances, has been overcome, and it is possible now to draw up good polarization maps for different samples of stars lying at well known distances, between 50 to 150 pc from the Sun.

This work is a first attempt to get improved diagnoses based on the optical parameters available for nearby stars. The polarimeters which are currently in operation will easily collect, in a few years, a large amount of homogeneous data. Nevertheless, our recent measurements, complemented with additional observations available in the literature, already reveal several interesting features: the nearest dust patches are found at 70–80 pc from the Sun, slightly farther than the boundary of the Local Hot Bubble. They are detected at all galactic latitudes, but within a narrow sector of longitudes (Fig. 1a), which becomes wider and wider for increasing distances (Fig. 1b, 1c).

The interpretation of the maps of polarization vectors (Figs. 2a to c) is not straightforward, because the maps show simultaneously two field alignment directions. The new point here is that this conflicting situation cannot be assigned to erroneous distance estimates. Additional observations are much wanted since it is possible, now, to get for the first time a three-dimensional map of the galactic magnetic field, in the solar neighbourhood.

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