OPTICAL POLARIZATION AS A PROBE OF THE LOCAL INTERSTELLAR MEDIUM

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The use of interstellar polarization as a measurement tool for dust or magnetic field presents practical difficulties (dust and magnetic field configurations inextricably mixed up; limited number of suitable stars). This general rule applies even more in the local environment, for which the polarizations are small and the influence of errors of observation changes in character. Because of this, the use of polarimetry and the design of polarimetric observing programmes for the local interstellar medium must be approached with even greater care than in the general case. I propose in this review to amplify this point, so that the reader can judge for himself to what extent he can use published results and can also, given the opportunity and instrumentation, design an observing programme that will really pay off.
In the immediate solar neighbourhood the average degree of polarization per unit distance is less (possibly much less) than 2.5 10^{-6} per parsec. At distances between 50 and 100 parsec this figure increases to approximately 3 10^{-5} per parsec in the Galactic plane and 1 10^{-5} at the Galactic poles. This information should be taken as very approximate. It is a composite of data from Behr (1959), Walborn (1968), Appenzeller (1974), Piirola (1977) and Markkanen (1979). Table 7 of Tinbergen (1982) provides a summary of this work and relates it to extinction data by Knude (1979) and Neckel and Klare (1980). This sets the astronomical scene. The precision with which polarimetry can nowadays be performed at a number of observatories is about 1 10^{-4} and this determines the extent to which polarimetry can be used as a local interstellar probe.

The most immediate (<30 pc) local region may be thought of as mostly intercloud medium (the polarization per unit distance, when translated into extinction per unit distance, is consistent with Knude's (1979) intercloud medium). The precision quoted above corresponds to a distance of 40 pc. It is therefore unrealistic to expect to use polarimetry to see detailed structure in this intercloud medium; one may expect to see only local thickenings, which by definition should really not be reckoned part of such a medium, but should perhaps be thought of as the tail of the "cloud" distribution. At larger distances, and particularly in the Galactic plane, the precision quoted corresponds to perhaps 5 pc, so that more spatial detail may be seen. This detail should, however, be interpreted in terms of cloud statistics, rather than a continuous medium.

So far, I have not considered a very practical question: the availability of sufficiently bright stars to obtain the photons required for the precision which we need (and which we can obtain in the way of systematic errors). To obtain a degree of polarization with a precision of 10^{-4} we need approximately 3 10^9 incident photons (Q.E.$\simeq$0.1). Using a 300 nm passband and a 10^4 cm^2 telescope on a 10th magnitude star, we obtain roughly 3 10^6 photons per second and a single observation is going to take 20 minutes of integration

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time. One may therefore observe perhaps 20 stars once in a single night and a large programme of n stars each observed 4 times will typically take n/5 nights of dark or grey time on a 1.5-metre telescope. This shows that $m_V=10$ will always be a rough limit in apparent magnitude for a practicable programme (this does of course depend on the square of the precision one demands). The existing programmes of better than 10^{-4} precision have been limited to the brightest stars ($m_V=5$), to the first 50 pc, or to special areas like the Galactic poles (see Tinbergen (1982) for references). For extensions to 150 pc denser sky coverage and fainter apparent magnitudes, the potential number of suitable stars is more than 10 000 (extrapolated from 180 with $m_V<5$ within 35 pc; Tinbergen 1982).

I have mentioned that the influence of observational error has to be examined with care. The reason is that linear polarization is a vector quantity and that we are interested in vectors (either absolute or differential) which are of the same order as the error vectors. It is not a valid approximation to compute the degree of polarization of individual observations and average that. Instead, one must average the Q and U Stokes parameters, but this requires an appropriate frame of reference in which to express them. I have used above a quantity one may loosely refer to as "all-sky average of degree of polarization" as a function of distance. For this the appropriate coordinate frame is not obvious. A quantity which is independent of coordinate frame is the mean square degree of polarization; this can be unambiguously corrected for observational error (Tinbergen 1982, appendix). For use as a probe of dust content this has a slight advantage over the degree of polarization itself. Since linear polarization is proportional to the transverse component of the magnetic field, it is equal to <u>or less than</u> the scaled extinction (e.g. Serkowski et al. fig. 9). The mean <u>square</u> polarization accentuates the higher values, amongst others those where the projection factor is favourable and may therefore be a more reliable dust estimator than the mean polarization itself (it does of course also introduce a bias towards higher values of dust content; it is best to regard the mean square as the prime observable and to compare that with models).
Another kind of error one has to be careful of is that introduced by intrinsic polarization of the stars used as background sources. Criteria for possible intrinsic polarization are:

1) supergiant (extended, anisotropic outer atmosphere);
2) close binary (scattering polarization on companion or gas shell);
3) emission or other spectral peculiarity;
4) CaII K-line activity (solar analogue, but more active);
5) IR excess (circumstellar dust);
6) variable polarization (even when not accompanied by one of the other criteria).

Bearing these many sources of error in mind, we may well ask what we do know of the local interstellar medium from polarization observations. I like to believe that the following statements are approximately correct:

a) on the scale of several hundred parsec, there is a preferential magnetic field direction, as evidenced by observations at the Galactic poles (Appenzeller 1974, Markkanen 1979) and selected longitudes in the Galactic plane (Appenzeller 1974);

b) the local (r< 50 pc) region is particular devoid of dust, as evidenced by the mean square degree of polarization as a function of distance (Tinbergen 1982, using also the results by Piirola 1977);

and, less certainly,

c) at a distance of less than 5 pc, there is a patch of dust (Tinbergen 1982) which may be of interest in connection with cloud models.

Lastly, what of the future? When HIPPARCOS flies, reliable distances will become available on a homogeneous system. It would be worthwhile to carry out a polarization programme, extended to the same magnitude limit, at about the same time. For this, the requirements would be:

A) Two telescopes of 10^4 cm^2 aperture, one in the North and the other in the South. 100 to 1 000 nights on each will be needed, depending on the scope of the programme;
B) exclude all stars with possible intrinsic polarization;
C) use a passband from 500 to 700 nm, to discriminate for interstellar and against many types of intrinsic polarization;
D) observe each star at least 4 times and use all possible tricks to randomise error vectors but detect real variability.

Such a programme is time-consuming and requires awareness of all the various pitfalls. It must be carried out by observers and instrumentation dedicated to this for several years. It is only worth doing if the date on local magnetic field, dust content and individual clouds are of sufficient interest and cannot be obtained by more economic means; the present Colloquium should contribute to an informed opinion on this point.

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Postcript to "Optical Polarizaton" - J. Tinbergen

Worried by the expense in telescope time and manpower of the very precise polarimetry required for local interstellar medium investigations, I asked in the general discussion whether it was all worth while, particularly:

-- is the magnetic field of any consequence for local considerations, or is it merely the result of wherever the ionised matter has swept it?
-- if the latter, can the magnetic field configuration tell us something about the history of the gas that drove it into that configuration (cf. SNR radiopolarimetry)?
-- failing this also, can polarization serve some other purpose locally?

Two discussion answers were:

-- magnetic field forces are of importance in supporting hot coronal gas at high z.
-- one may detect that a line of sight passes through a dust cloud from polarimetry of stars at various distances. This technique is 5 to 10 times more sensitive than colour excesses.

I feel this is a somewhat restricted use of hard-to-obtain data. The trouble is that most other techniques applicable to the local interstellar medium are expensive, too.

A point I did not mention explicitly is that in localising clouds in space, one uses differences in colour excess or polarization between 2 stars. Therefore the observing precision required is the same throughout the volume investigated. The problem is <u>not</u> eased as one obtains larger colour excesses and polarizations at increasing distance. This is why I did not mention the older, less precise polarimetry at distances greater than about 50 pc. Such polarimetry is useful for line-of-sight integrals, but is not precise enough to be used differentially as considered during this Colloquium.

If the mismatch between colour excess and polarization precision can be reduced by improved photometry (e.g. by a longer wavelength base and redundant photometry of several absorption lines or spectrophotometry), one may expect to be able to derive approximate magnetic field projection factors from the ratio of (differential) polarization to colour excess (this would assume "uniform" magnetic field strength and dust alignment).

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