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Interstellar extinction and galactic structure

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Summary. Colour excesses and photometric distances of open clusters compiled by Janes & Adler and Lyngå have been used to study the distribution of interstellar matter within a few kiloparsecs of the Sun. In general the reddening material is highly concentrated near the galactic plane. It is found that the plane defined by the distribution of interstellar matter is inclined to the formal galactic plane by an angle of $0\overset{\circ}{.}8 \pm 0\overset{\circ}{.}2$ and shows a maximum upward tilt towards $l \sim 60°$. The scale height of the reddening material is found to be 0.16 ± 0.02 kpc. Based on the distribution of whole interstellar matter, the Sun is found to be situated at a distance of about 10 pc above the galactic plane of symmetry defined by the reddening material, while from a subsample in the direction of maximum tilt this figure is found to be 3 ± 4 pc.

1 Introduction

The study of the spatial distribution of interstellar extinction, A_V, is important for many investigations of galactic and extragalactic objects. The patchy distribution of dust within the galactic disc makes it difficult to obtain the distribution of A_V as a function of longitude and distance. Direct optical mapping of the spiral structure is limited to only a small fraction of the Galaxy due to the presence of interstellar extinction. The mapping of the spiral structure is further complicated because of the presence of windows at some longitudes, having low extinction. The spatial distribution of interstellar extinction, A_V, as a function of galactic coordinates (l and b) and distance r has generally been obtained with the help of colour excesses and distances of individual stars. Detailed investigations of this kind have already been published by FitzGerald (1968) and Neckel & Klare (1980). However, all such earlier studies were mainly based on the colour excesses and the distances of individual stars and the error in the distance determinations of individual stars is estimated to be about 16 to 25 per cent (Neckel & Klare 1980). Since the distances and the interstellar extinctions obtained from photometric observations of star clusters are more reliable than those from individual stars, the present study is an attempt to investigate the spatial distribution of interstellar extinction and the galactic plane defined by the reddening material based on the observed distances and the colour excesses of star clusters.

Table 1. Boundaries of the zones used in Fig. 1.

Zone No.	Range of l (degrees)	Zone No.	Range of l (degrees)
1	0 - 15	14	205 - 220
2	15 - 30	15	220 - 235
3	30 - 60	16	235 - 245
4	60 - 75	17	245 - 255
5	75 - 90	18	255 - 270
6	90 - 100	19	270 - 285
7	100 - 110	20	285 - 290
8	110 - 130	21	290 - 295
9	130 - 145	22	295 - 310
10	145 - 160	23	310 - 325
11	160 - 175	24	325 - 340
12	175 - 190	25	340 - 360
13	190 - 205		

2 Data

We have used the colour excesses and the distances of clusters compiled by Janes & Adler (1982). The colour excesses and the distances for another 24 clusters have been taken from the catalogue of Lyngå (1983). The values of colour excesses and distances for four clusters have been taken directly from the available published literature (Mohan & Pandey 1984a, b; Pandey & Mahra 1986; Pandey 1986). Thus, the present study is based on the observed distances and colour excesses of 462 open clusters. The ratio of total to selective absorption, R=3.1 was adopted to obtain total absorption from selective absorption $E(B-V)$.

3 Analysis

3.1 REDDENING IN THE GALACTIC PLANE

In the present study, clusters within 10° of the plane were considered to examine the distribution of reddening material in the galactic plane.

A dust cloud can be recognized by the fact that the extinction, A_V, is higher behind the cloud than in front of it. Therefore, the distribution of reddening material can be obtained from the variations of A_V with distance in different areas of the sky. Data become increasingly incomplete with increasing extinction because clusters with higher A_V values are usually faint and therefore poorly observed. Thus in a field with strong variations of extinction, those parts with the highest obscuration are usually the least observed. This selection effect produces a mean value of A_V systematically too small, which in turn will produce a scatter in the A_V and r relation. Therefore, to avoid the scatter, it is necessary to divide the sky into regions as small as possible considering the number of observations (Neckel & Klare 1980). However, in the present study it is not possible to divide the sky into as many small regions as adopted by other authors (FitzGerald

1968; Neckel & Klare 1980) who have used the distances and the colour excesses of large number of single stars. We have divided the sky into 25 zones of galactic longitudes and the boundaries of these zones are given in Table 1. Fig. 1 shows the A_V versus distance, r, relation for each of the 25 zones. The zones in the present study are not as small as those used by FitzGerald (1968) and Neckel & Klare (1980). However, the scatter in the $A_V(r)$ diagrams is comparable to the scatter in the diagrams given by these authors.

The interstellar absorption A_V in the galactic plane at 1 and 2 kpc has been plotted as a function of longitude in Figs 2 and 3, respectively. These plots show a rather sinusoidal variation of absorption A_V with galactic longitude. Maximum absorption occurs towards longitude $l \sim 50°$ and

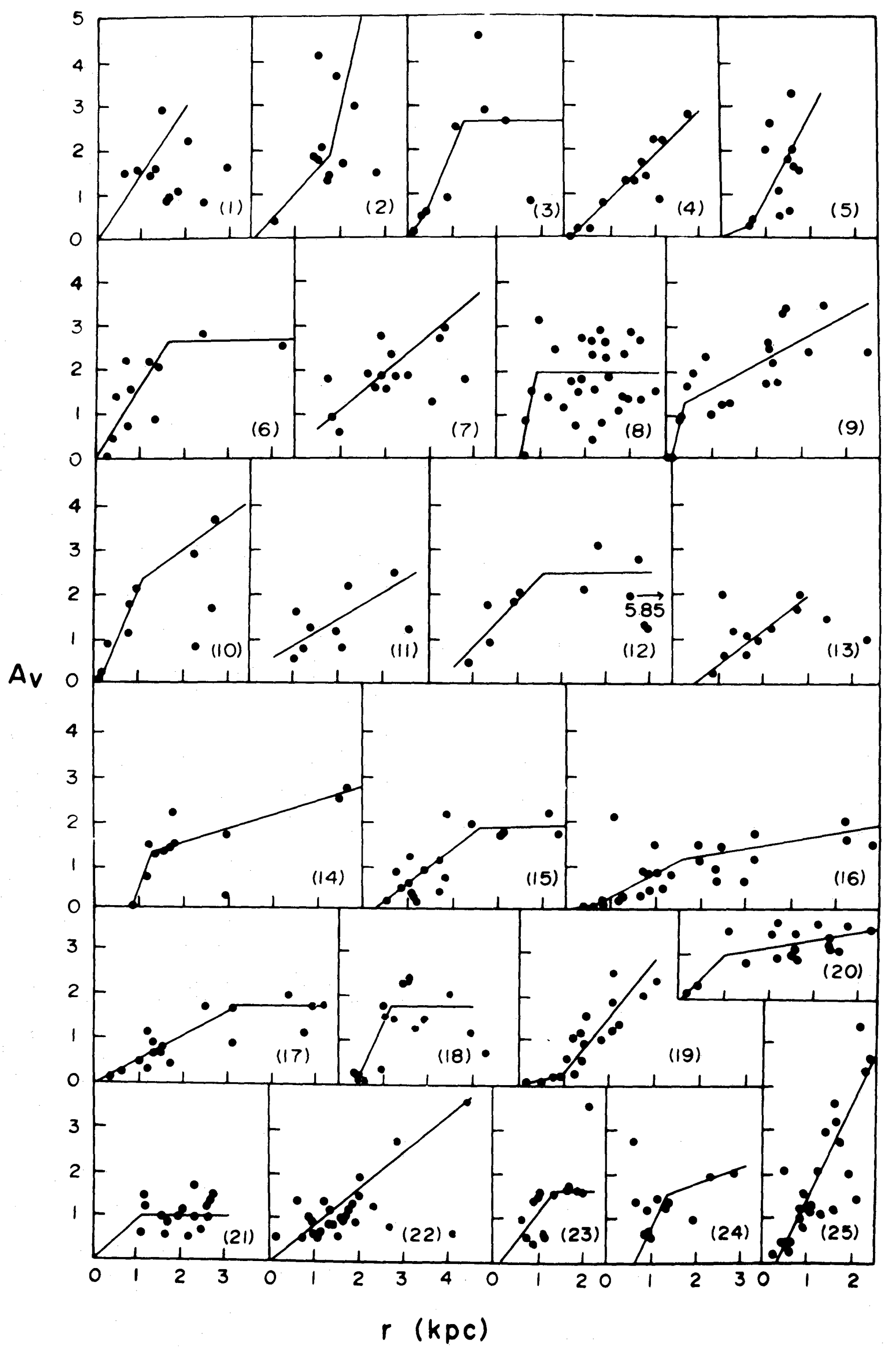

Figure 1. A_V versus distance r (kpc) for 25 different zones of galactic longitudes. In each diagram the marks on abscissae and ordinates correspond to 1 kpc and 1^m, respectively and the origin is at zero.

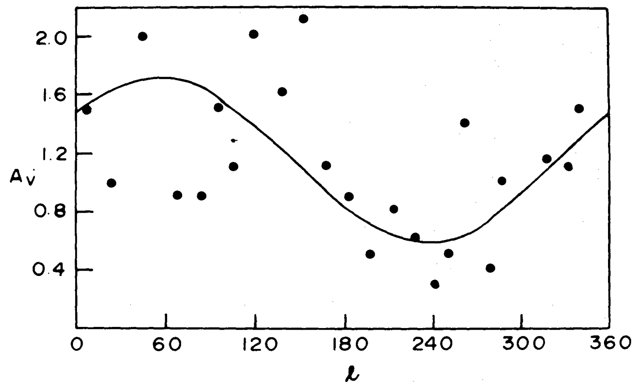

Figure 2. Absorption A_V at 1 kpc as a function of galactic longitude.

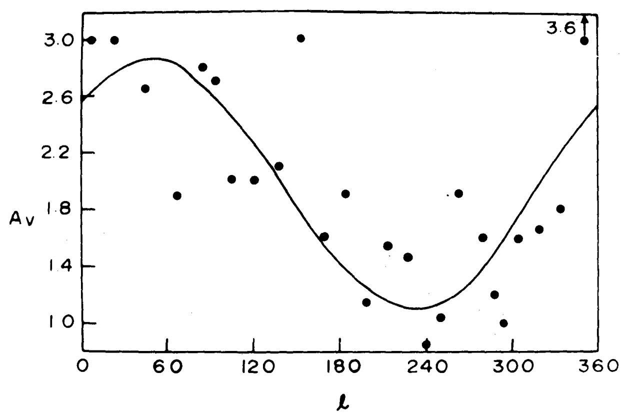

Figure 3. Absorption A_V at 2 kpc as a function of galactic longitude.

minimum towards $l \sim 230°$. Fernie (1962, 1968) and Lyngå (1979, 1982) have also found a maximum average rate of interstellar absorption towards $l \sim 50°$ based on the study of B stars and classical Cepheids, and open clusters, respectively. Figs 2 and 3 also demonstrate that A_V shows less scatter and more systematic variations towards the anticentre direction of the Galaxy. This fact is more prominent in the A_V at 1 kpc diagram. A similar behaviour of interstellar absorption can be seen in fig. 1, given by Fernie (1962) from the observations of B stars.

A comparison of extinction values at 1 kpc obtained in the present study with the extinction values shown in fig. 8 of Neckel & Klare (1980), in general shows good agreement.

Lucke (1978) has found that the region between $l = 10°$–$90°$ shows a very high absorption and in the present study this feature is relatively more prominent in the 2 kpc diagram. Lucke (1978) has also reported higher value of extinction near $l = 260°$ and this feature is quite prominent in both the diagrams (Figs 2 and 3).

3.2 CONCENTRATION OF THE REDDENING MATERIAL PERPENDICULAR TO THE GALACTIC PLANE

To study the distribution of reddening material perpendicular to the galactic plane, the sky was divided into nine zones of galactic longitude. The boundaries of these zones are given in Table 2. The value of interstellar absorption, $a_V = A_V/r$ mag kpc^{-1}, averaged over 10 pc intervals of z, for each zone has been plotted against the mean z distance in Fig. 4. Although the distribution of the reddening material differs significantly from one zone to another, the strong concentration of the reddening material near the galactic plane is obvious in all the zones. Assuming a layer of dust near the galactic plane, in Fig. 4 we have also shown the visually best-fit variation of a_V with z in

Table 2. The boundaries of the zones used to study the variation of the density of the reddening material perpendicular to the galactic plane.

Zone	Range of ℓ (in degrees)	Half width β (pc)
a	0 - 60	125
b	60 - 100	60
c	100 - 140	60
d	140 - 190	55
e	190 - 230	110
f	230 - 250	-
g	250 - 280	-
h	280 - 300	100
i	300 - 360	210

different zones. The half-width, β, of the layers defined by $1/e$ times the maximum value of the interstellar absorption for each zone has been estimated and these are given in Table 2. We find that the thickness of the reddening material, β, varies from 60 to 125 pc and the thickness is at a maximum towards the Galactic Centre and at a minimum towards the anticentre direction.

Parenago (1945) and Sharov (1963) have obtained a half-width value of the reddening material of 114 pc. Kerr & Westerhout (1965) have obtained a thickness of 160 pc (β=100 pc). FitzGerald (1968) has reported that the value of β lies between 40 and 100 pc which is in close agreement with the results obtained by us.

The distribution of the reddening material, in the directions of the nine zones (a) to (i) shown in Fig. 4, is summarized as follows:

(a) The reddening material is distributed around the galactic plane.

(b) The reddening material is seen above the galactic plane. The figure shows another peak below the galactic plane.

(c) The maximum reddening is in the galactic plane. This figure manifests that the concentration of reddening material in the positive z-direction does not decrease systematically with the higher values of z.

(d) This figure shows a large scatter which could be explained in terms of a central peak near the galactic plane and two additional peaks one above and another below the galactic plane.

(e) In this zone the concentration of the reddening material lies below the galactic plane.

(f) This region shows minimum extinction. A similar distribution of the reddening material for this region was obtained by FitzGerald (1968).

(g) In this zone the maximum absorption is below the galactic plane. The distribution of the reddening material in this zone obtained in the present study differs significantly from that obtained by FitzGerald (1968). The value of absorption in this direction obtained by FitzGerald is about five times the value obtained by us.

(h) and (i) These regions show a systematic distribution of reddening material with a peak around 15 pc below the galactic plane.

In Fig. 5 we have plotted the value of z for which the absorption is at a maximum against the mean longitude of the zone and it is found that in the longitude range l~350°–130° the layer of

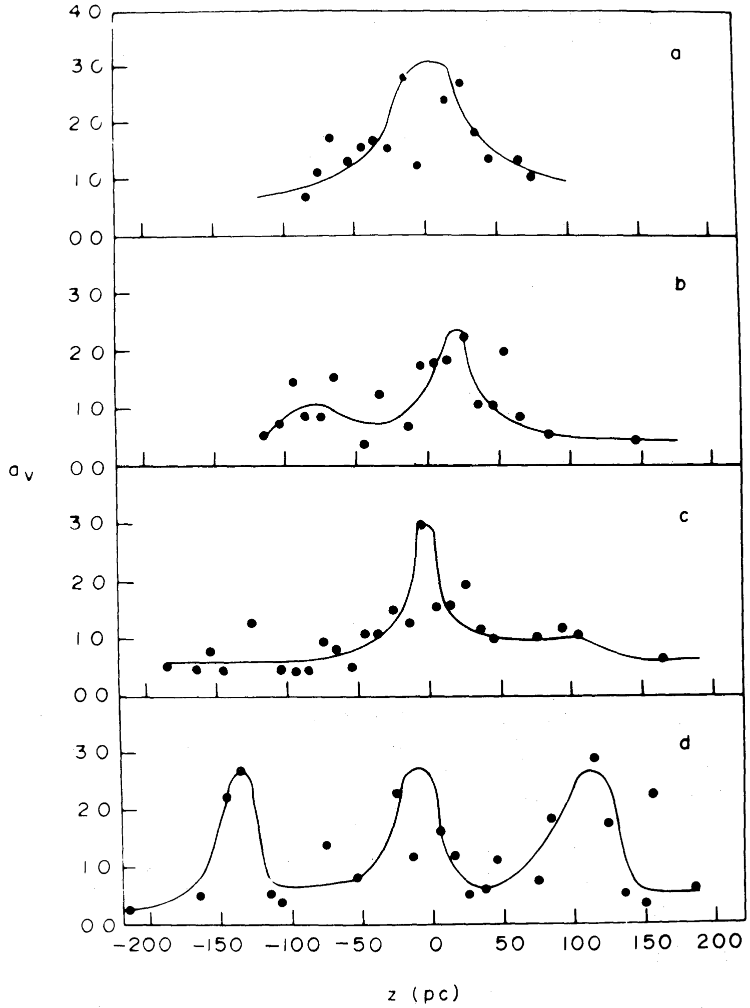

Figure 4. Absorption, $a_V = A_V/r$ mag kpc^{-1}, versus distance, z, from the galactic plane.

maximum absorption lies above the galactic plane, while in the longitude range $l \sim 130°–350°$ the layer of maximum absorption lies below the galactic plane. FitzGerald (1968) and Lucke (1978) have also concluded that toward the Galactic Centre the regions of high excesses are above the galactic plane, while in the anticentre direction these are below the plane. One more striking feature in Fig. 5 is that the value of z for which the absorption is at a maximum, shows a sinusoidal variation with longitude with a symmetry around $z = -10$ pc and we conclude that the Sun is situated about 10 pc above the galactic plane of symmetry defined by the reddening material. Another conclusion drawn from the Fig. 5 is that the plane defined by the reddening material is tilted with respect to the formal galactic plane and the upward tilt is maximum towards longitude $l \sim 60°$.

The relationship between these two planes has been further examined with the distribution of z, for which absorption is at a maximum, as a function of distance from the Sun, in two directions of galactic longitude $l = 60°$ and $l = 240°$. The result is shown in Fig. 6, where each point represents an averaged value over an interval of 1 kpc. A least-squares fit to these points in Fig. 6 gives the following relation beteen z and r:

$z = 0.013r - 3;$

$\pm 0.003 \pm 4;$

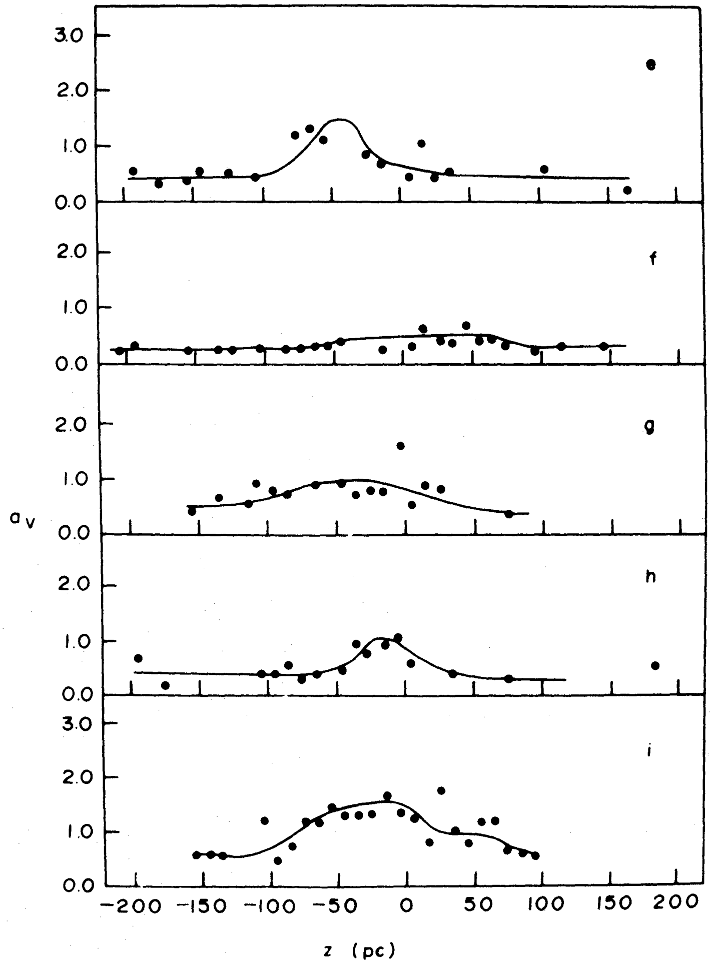

Figure 4 – *continued*

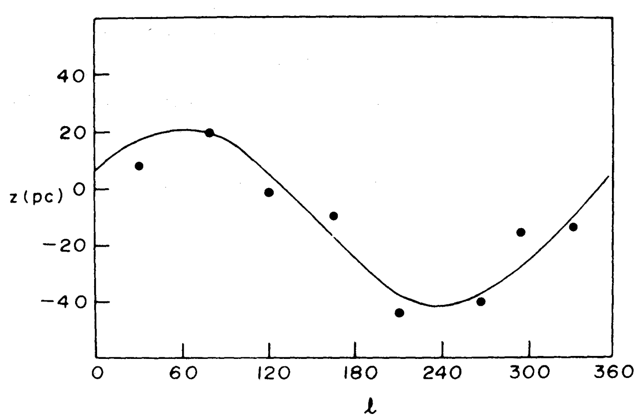

Figure 5. The plot of distance, z, from the galactic plane, for which absorption is at a maximum, against the mean longitude.

where z and r are in parsecs. Thus, from the above relation, we find that the Sun is situated at a distance of 3 ± 4 pc above the plane of symmetry defined by the reddening material. However, it may be considered that the accuracy of ±4 pc is due to the least-squares solution of the averaged values of z and r. The distance of the Sun obtained in the least-squares solution is found to be 3 pc while considering the whole material we find that the Sun is situated about 10 pc above the

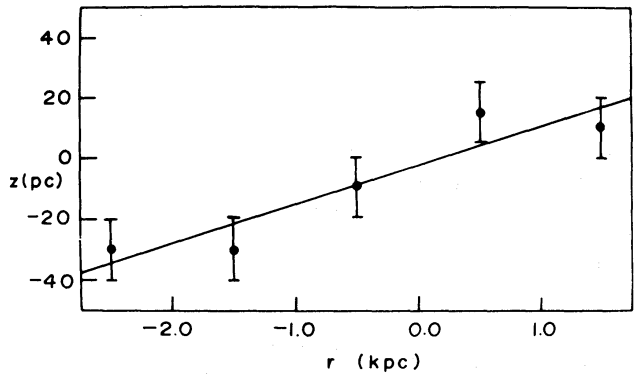

Figure 6. Average distance of high absorption regions from the galactic plane as a function of distance from the Sun. The distance towards l=60°(±35°) is counted positive and the distance towards l=240°(±35°) is counted negative. The straight line shown in the figure is a least-squares fit to the points.

galactic plane of symmetry defined by the reddening material. Gum, Kerr & Westerhout (1960) have found that the Sun is located at a distance of 4±12 pc above the hydrogen plane. However, Fernie (1968) has shown that the Sun is located 45±15 pc above the Cepheid plane and Lyngå (1982) has found that the Sun is situated at a distance of 19±69 pc above the galactic plane of symmetry defined by the galactic clusters.

The coefficient 0.013 in the above relation is the value of sin ϕ, where ϕ is the angle between the plane defined by reddening material and the formal galactic plane. The angle, ϕ, comes out to be 0°.8±0°.2. Fernie (1968) has also obtained exactly the same value of the angle between the Cepheid plane and the formal galactic plane. The neutral hydrogen layer in the vicinity of the Sun, shows an inclination of 1°.5±0°.12 to the formal galactic plane (Gum *et al.* 1960). However, the longitudinal direction of the maximum upward tilt of the plane defined by reddening material in the present study differs significantly from the results obtained by Gum *et al.* (1960) and Fernie (1968). The neutral hydrogen layer and the Cepheid plane show an upward tilt towards l~90° and l~97°, respectively. Lucke (1978) has demonstrated that the interstellar dust in the l~60° direction is more or less in the formal galactic plane. However, in the present study we find that the maximum upward tilt for the reddening plane is toward l~60°.

In order to estimate the scale-height of the distribution of reddening material, we have obtained the mean values of a_V in 25 pc intervals of z. We have used only those clusters which are

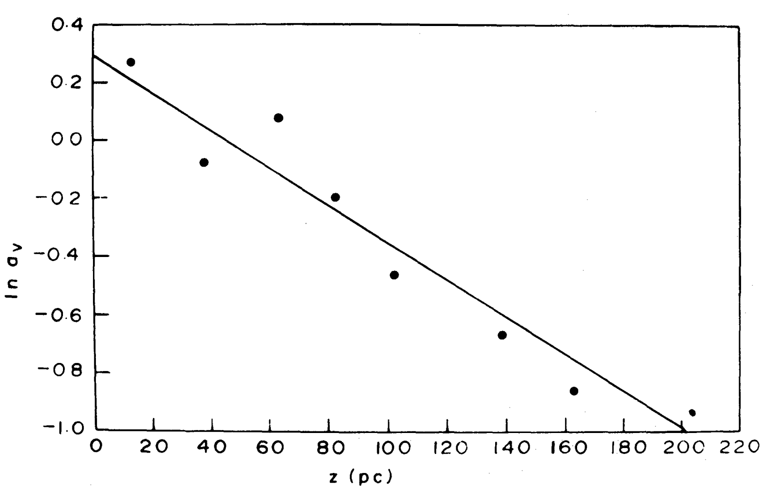

Figure 7. The distribution of absorption, $a_V=A_V/r$ mag kpc^{-1}, averaged in 25 pc intervals of z as a function of mean z.

located within 2 kpc of the Sun to avoid selection effects. The average value of absorption/kpc has been plotted as a function of z in Fig. 7. If we assume that the distribution of the reddening material quite closely obeys a law of the form

$$a_V = A_0 \exp(-z/s);$$

where A_0 is the value of absorption per kpc in the galactic plane and s is the scale-height. From Fig. 7, we obtain

$$A_0 = 1^{\mathrm{m}}.35 \pm 0^{\mathrm{m}}.12 \text{ per kpc};$$

$$s = 0.16 \pm 0.02 \text{ kpc}.$$

The extinction towards the galactic poles can be obtained using the values of A_0 and s obtained in the present study, in the relation $A_V^{\mathrm{pole}} = A_0 s$ (Lyngå 1982). Thus, the absorption towards the galactic pole comes out to be $A_V^{\mathrm{pole}} = 0^{\mathrm{m}}.22 \pm 0^{\mathrm{m}}.05$. The values of A_V for the North Galactic Pole obtained by different authors are $A_{90} = 0^{\mathrm{m}}.25$ (Heiles 1976), $A_{90} = 0^{\mathrm{m}}.22$ (Holmberg 1958), $A_{90} = 0^{\mathrm{m}}.25$ (Lyngå 1979), and these are in good agreement with the value of A_V^{pole} obtained in the present study. However, Burstein & Heiles (Lyngå 1982) have obtained a lower value for $A_V^{\mathrm{pole}} \leqslant 0^{\mathrm{m}}.1$.

Taking the value of $A_0 = 1^{\mathrm{m}}.35$ and $s = 0.16$ kpc, it is found that most of the reddening material ($a_V > 0^{\mathrm{m}}.5\ \mathrm{kpc}^{-1}$) lies within about 160 pc of the galactic plane.

References

Fernie, J. D., 1962. *Astr. J.,* **67,** 224.

Fernie, J. D., 1968. *Astr. J.,* **73,** 995.

FitzGerald, M. P., 1968. *Astr. J.,* **73,** 983.

Gum, C. S., Kerr, F. J. & Westerhout, G., 1960. *Mon. Not. R. astr. Soc.,* **121,** 132.

Heiles, C., 1976. *Astrophys. J.,* **204,** 379.

Holmberg, E. B., 1958. *Meddelanden Lunds astr. Obs., Ser. II, No. 136.*

Janes, K. & Adler, D., 1982. *Astrophys. J. Suppl.,* **49,** 425.

Kerr, F. J. & Westerhout, G., 1965. *Galactic Structure,* chap. IX, eds Blaauw, A. & Schmidt, M., University of Chicago Press, Chicago.

Lucke, P. B., 1978. *Astr. Astrophys.,* **64,** 367.

Lyngå, G., 1979. *The Large-Scale Characteristics of the Galaxy, IAU Symp. No. 84,* p. 87, ed. Burton, W. B., Reidel, Dordrecht, Holland.

Lyngå, G., 1982. *Astr. Astrophys.,* **109,** 213.

Lyngå, G., 1983. *Catalogue of Open Cluster Data,* 3rd edn, Stellar Data Centre, Observatoire de Strasbourg, France.

Mohan, V. & Pandey, A. K., 1984a. *Bull. astr. Soc. India,* **12,** 217.

Mohan, V. & Pandey, A. K., 1984b. *Astrophys Space Sci.,* **105,** 315.

Neckel, Th. & Klare, G., 1980. *Astr. Astrophys. Suppl.,* **42,** 251.

Pandey, A. K., 1986. *Bull. astr. Soc. India,* **14,** 20.

Pandey, A. K. & Mahra, H. S., 1986. *Astrophys. Space Sci.,* **120,** 107.

Parenago, P. P., 1945. *Astr. Zh.,* **22,** 129.

Sharov, A. S., 1963. *Astr. Zh.,* **40,** 900.