GALACTIC DUST AND EXTINCTION

Gösta Lyngå
Lund Observatory, Sweden

The ratio R between visual extinction and colour excess, is slightly larger than 3 and does not vary much throughout our part of the Galaxy. The distribution of dust in the galactic plane shows, on the large scale, a gradient with higher colour excesses towards $l=50^{\circ}$ than towards $l=230^{\circ}$. On the smaller scale, much of the dust responsible for extinction is situated in clouds which tend to group together. The correlation between positions of interstellar dust clouds and positions of spiral tracers seems rather poor in our Galaxy. However, concentrated dark clouds as well as extended regions of dust show an inclined distribution similar to the Gould belt of bright stars.

1. THE VALUE OF $R=A_V/E_{B-V}$

The extinction of light A by galactic dust has a reddening effect described by the colour excess E. For the UBV system, in which most photometric studies of distant objects are made, one finds a value $R=A_V/E_{B-V}$ slightly larger than 3 when observing early type stars. The variation of R with intrinsic colour due to the wide passbands has been studied by Olson (1975).

Several studies of the value of R have been made, generally involving early type stars. Schalén (1975) demonstrated that several different methods give R=3.1 without much variation from field to field. For some regions much higher values have earlier been proposed but have now been refuted. Penston et al. (1975) have shown that the very high value earlier determined for the Orion cluster (cf. Johnson, 1968) is due to a misinterpretation of infrared excesses for the stars. Moffat and Schmidt-Kaler (1976) have explained the high R value for some associations with reflection nebulae as due to erroneous membership designation. Crézé (1972) derived different R values for spiral arm regions and for interarm regions. However, Sparke (1977) pointed out that these effects can be caused by the use of kinematic distances if, in fact, non-circular motions are present. Infrared photometry (Smyth and Nandy, 1978) for early type stars give a value $R=3.12\pm0.05$. It seems as if R is reasonably constant in the interstellar medium, but there may yet be slight variations. Whittet (1977) finds a systematic change between R=2.91 at longitude 85° and

W. B. Burton (ed.), The Large-Scale Characteristics of the Galaxy, 87–92.

https://doi.org/10.1017/S007418090001425X Published online by Cambridge University Press

R=3.25 at longitude 265°. This systematic trend is very similar to the variation of λmax, the wavelength of maximum linear polarisation, along the Milky Way. Turner (1976) has used the variable extinction method for open cluster reddenings and finds R=3.08 showing a slight variation with galactic longitude in a similar sense.

A high degree of homogeneity is present in the shortwave extinction as shown by Nandy et al. (1976). Even in that case we deal with the near-by dust (within the nearest few kpc).

2. CHARACTERISTICS OF THE DUST DISTRIBUTION

The most obvious clouds are globules (cf. Bok, 1977) but from the viewpoint of interstellar extinction we are mainly interested in the larger clouds, from a few parsecs upwards and the homogenous dust layer. Scheffler (1967) made an analysis of extinction values for distant O and B stars and found that most dust is situated in clouds and that there is a continuous frequency distribution of these. The more frequent are typically 3 pc in diameter, have extinction measures of $0^m.26$ and occur at a rate of 5 per kpc. Corresponding values for the larger clouds are 70 pc, $1^m.6$ and 0.5 per kpc. In a study of the interstellar extinction at intermediate distances in longitudes 280° - 320° Egret et al. (1978) find, from angular autocorrelation of colour excesses, that typical cloud diameters are less than 20 pc. The cloud structures discussed by Lucke (1978) are considerably larger, several hundred parsecs and presumably they can be resolved into smaller clouds. It seems that dust clouds tend to group in larger scale structures, as is also observed in external galaxies. Kron (1977) finds evidence for a uniform dust layer 400-600 pc thick in addition to the clouds.

While the sizes, masses and other properties of globules are becoming increasingly well known, there is still much to be learnt about the characteristics of the extended dust concentrations.

3. LATITUDE VARIATIONS OF EXTINCTION

At high latitudes the cloud structure of the dust will allow some directions to have much lower extinction than average. However, I shall for reasons of convenience first discuss conditions assuming a uniform dust layer.

The basis for determining high latitude extinction from galaxy counts has been re-examined by Heiles (1976). For the extinction in blue light at the North Galactic Pole (NGP) he finds $A_{90}=0^m.25$ in good agreement with Holmberg (1974). The surface magnitudes of galaxies at different galactic latitudes (Holmberg, 1958) give $A_{90}=0^m.22$. These values are considerably lower than earlier determinations which may not have taken due regard to the cloud structure causing small scale variations in the extinction. The principle of the galaxy count method has been criticized by Knapp and Kerr (1974) on the ground that galaxies as surface objects have surface brightnesses independent of distances. Considering the mentioned agreement with the surface magnitude effects on external galaxies we shall, however, accept $A_{90}=0^m.25$ for blue light.

The colour excess corresponding to this value has been determined from a variety of sources. Holmberg (1974) has collected some of the most reliable results and gives $E_{B-V}=0^{m}.054$ as a mean value. This would give R=3.6, approximately equal to the standard value.

Heiles (1976) shows that there is a latitude variation of the relation between lg (N) and E_{B-V}. At higher latitudes the galaxy counts decrease relatively slowly with increased colour excesses, which would point to larger R values and possibly indicate larger grain sizes than in the disk (Serkowski et al., 1975).

The colour excess towards the SGP has been determined by Knude (1977) who found $E_{B-V}=0^{m}.057 \pm 0^{m}.004$ and by Eriksson (1978) who found $E_{B-V}=0^{m}.04$ from an extensive material involving stars later than A. As is the case towards the NGP several authors get lower excesses from studies of A stars and other more luminous objects. To some extent this is due to the cloud structure of the dust, but it may also be due to a population related difference between intrinsic colours of stars with the same spectral class.

Comparing the observed extinctions towards the galactic poles it seems that the sun is not significantly displaced from the plane of symmetry of the galactic dust. However, Lucke (1978) confirms earlier views that the dust has an inclined galactic distribution similar to that of Gould's belt of bright stars. The distribution of discrete dark clouds is similar to this, as has been discussed by several investigators since Hubble (1922) and as is clearly shown from the catalogues by Lynds (1962) and by Sandqvist (1977). Turon and Mennessier (1975) have discussed the inclined distribution of clouds in terms of a model with elongated dust clouds aligned at an angle with the galactic plane.

4. RELATION OF DUST TO GALACTIC STRUCTURE

It was shown by Lynds (1970) that the lanes of dark nebulae are situated on the insides of arms in Sc galaxies. A particularly striking case is M 51 as studied by Mathewson et al. (1972) where dust lanes are shown to coincide with radio continuum radiation distribution on the inside of the bright arm structure. Trying to examine whether a similar situation obtains in our galaxy one must first get an impression of the distribution of clouds on a larger scale; the dark patches which show dust distribution in other galaxies correspond to dimensions of 50 pc or more.

4.1. Extinction studies in particular longitudes

Stellar statistical investigations (reviewed by McCuskey, 1976) are useful for comparing the amount of dust at intermediate distances in different galactic directions. The geometrical sizes of the dust clouds are, however, difficult to determine because of the dispersion in absolute magnitude for stars of a certain spectral or colour class as simple numerical experiments will show (Lyngå, 1976). The main use of extinction studies by stellar statistics is to give a sound basis for determinations of luminosity functions.

4.2. Colour excesses observed for distant stars

The investigations by Neckel (1967) and by FitzGerald (1968) give an overall view of the extinction situation. Although some early type stars are observed at large distances, there are two selection effects that become serious for distances of more than 2 kpc: the dispersion in absolute magnitude (cf. Malmquist, 1920) and the cloud structure of the interstellar dust.

Lucke (1978) has made a study which takes the z distribution into account. From a material of 4000 O and B stars he determined the overall structure of interstellar dust clouds within 2 kpc from the sun. Comparing Lucke's fig. 10 with a plot of spiral tracers such as fig. 2 in the paper by Humphreys (1976) one finds no positional correlation or anti-correlation except a slight similarity between the angles made by the different structures and the direction to the galactic centre. The lack of detailed agreement between well studied features makes me doubtful of analogies with a high luminosity galaxy like M 51. The situation reminds rather of less luminous galaxies where dust concentrations do not well correlate with other features and where also in general structural features have dimensions of one kiloparsec or smaller.

4.3. Extinction determined for open clusters

The most reliable determinations of interstellar extinction come from cluster studies. Well determined distances and colour excesses exist for more than 300 open clusters. To interpret the colour excesses in

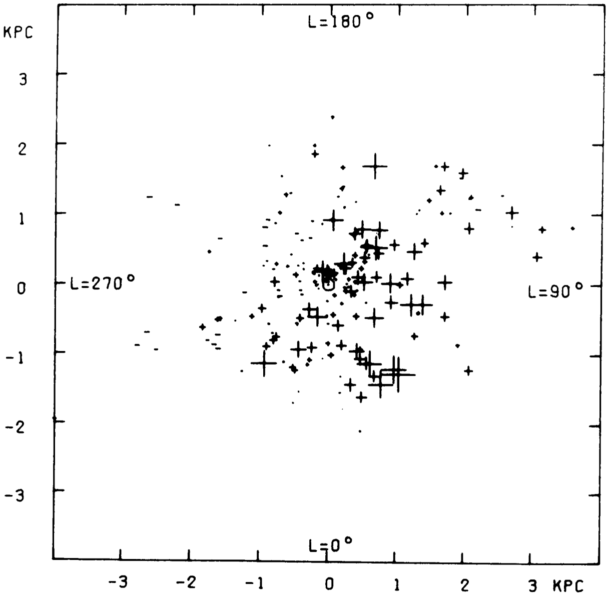

Figure 1. Extinction excesses Δ for open clusters. Scale of marks is 1.5 mm per magnitude.

https://doi.org/10.1017/S007418090001425X Published online by Cambridge University Press

terms of dust distribution I have assumed a uniform dust layer of 100 pc thickness. Inside the layer there is an extinction rate $a_v = 0\overset{m}{.}7$ per kpc so that a cluster at galactic latitude b and distance r is expected to suffer an extinction $0\overset{m}{.}7$ r if it is inside the dust layer and an extinction $0\overset{m}{.}035$ r cosec b if it is outside that layer. The observed extinction value exceeds the expected by an amount Δ, the sign of which has been displayed in figure 1. The size of each mark corresponds to the numerical value of the excess and the position corresponds either to the position of the cluster or the position where the line of sight enters the dust layer. Figure 1 shows clearly that towards $l=50^{o}$ there is a preponderance of + signs and in the opposite direction mostly - signs. A least square solution shows that a gradient of about $0\overset{m}{.}1$ per kpc near the sun would describe the asymmetry.

4.4 Galactic windows

In some directions the galactic disk is more transparent than normal. A well established such galactic window is situated in Vela at longitude 245^{o}- 255^{o} (FitzGerald, 1974; Dodd and Brand, 1975) and another is found in Circinus at a longitude of 311^{o} (Lyngå, 1977). In a number of other directions one finds a relatively small extinction out to about 4 kpc from the sun (cf. FitzGerald and Moffat, 1976). Such features are not easily assimilated by a large scale model of spiral structure.

Added to other evidence given above the presence of galactic windows will support the view that the distribution of interstellar dust has a large scale structure which is not well correlated with the distribution of spiral arm tracers.

ACKNOWLEDGEMENTS

I thank Prof. C. Schalén and Dr. S. Wramdemark for useful comments on the manuscript.

REFERENCES

Bok, B.J.: 1977 Publ. Astron.Soc.Pacific 89, p. 597
Crézé, M.: 1972 Astron.Astrophys. 21, p. 85
Dodd, R.J., Brand, P.W.J.L.: 1975 Astron.Astrophys. Suppl. 25, p. 519
Egret, D., Lyngå, G., Ochsenbein, F.: 1978 In preparation
Eriksson, P.-I.: 1978 Uppsala Astron.Obs. Rept. No. 11
FitzGerald, M.P.: 1968 Astron.J. 73, p. 983
FitzGerald, M.P.: 1974 Astron.Astrophys. 31, p. 467
FitzGerald, M.P., Moffat, A.F.J.: 1976 Sky Telesc. 52, p. 104
Heiles, C.: 1976 Astrophys.J. 204, p. 379
Holmberg, E.B.: 1958 Meddelanden Lunds Astron.Obs., Ser. II, No. 136
Holmberg, E.B.: 1974 Astron.Astrophys. 35, p. 121
Hubble, E.: 1922 Astrophys.J. 56, p. 162
Humphreys, R.M.: 1976 Publ. Astron.Soc. Pacific 88, p. 647
Johnson, H.L.: 1968 In Kuiper, Stars and Stellar Systems Vol VII, p. 167
Knapp, G.R., Kerr, F.J.: 1974 Astron.Astrophys. 35, p. 361
Knude, J.K.: 1977 Astrophys. Letters 18, p. 115

Kron, G.: 1977 Bull.Am.Astron.Soc. 9, p. 581
Lucke, P.B.: 1978 Astron.Astrophys. 64, p. 367
Lynds, B.T.: 1962 Astrophys.J. Suppl. 7, p. 1
Lynds, B.T.: 1970 IAU Symp. No. 38, p. 26
Lyngå, G.: 1976 Astron.Astrophys. 46, p. 369
Lyngå, G.: 1977 Astron.Astrophys. 54, p. 71
Malmquist, K.G.: 1920 Meddelanden Lunds Astron.Obs. II, No. 22
Mathewson, D.S., van der Kruit, P.C., Brouw, W.H.: 1972 Astron.Astrophys. 17, p. 468
McCuskey, S.W.: 1976 IAU Trans. XVIA, part 3, p. 44
Moffat, A.F.J., Schmidt-Kaler, Th.: 1976 Astron Astrophys. 48, p. 115
Nandy, K., Thompson, G.I., Jamar, C., Monfils, A., Wilson, R.: Astron. Astrophys. 51, p. 63
Neckel, Th.: 1967 Veröffentl. Heidelberg-Königstuhl 19
Olson, B.I.: 1975 Publ.Astron.Soc.Pacific 87, p. 349
Penston, M.V., Hunter, J.K., O´Neill, A.: 1975 Monthly Notices Roy. Astron.Soc. 171, p. 219
Sandqvist, Aa.: 1977 Astron Astrophys. 57, p. 467
Schalén, C.: 1975 Astron.Astrophys. 42, p. 251
Scheffler, H.: 1967 Z. Astrophys. 65, p. 60
Serkowski, K., Mathewson, D.S., Ford, V.L.: 1975 Astrophys.J. 196, p. 261
Smyth, M.J.,Nandy, K.: 1978 Monthly Notices Roy.Astron.Soc. 183, p. 215
Sparke, L.S.: 1977 Astron.Astrophys. 56, p. 307
Turner, D.G.: 1976 Astron.J. 81, p. 1125
Turon, P., Mennessier, M.O.: 1975 Astron.Astrophys. 44, p. 209
Whittet, D.C.B.: 1977 Monthly Notices Roy. Astron.Soc. 180, p. 29

DISCUSSION

Yahil: Could you comment on the clumpiness of absorption within, say, 60° of the Galactic poles, and the appropriate absorption correction for extragalactic objects.

Lyngå: According to colors for globular clusters as discussed by Sandage a few years ago, one finds directions with practically no extinction. This would be due to clumpiness in the cloud distribution. I believe that Dr. Kron has more details about the situation.

Kron: My work on reddening pertains only to an average minimum covering a considerable volume of the solar neighborhood. No direct measurement of reddening at either pole is implied; however an extrapolated value of $0^m.02$ to $0^m.03$ can be deduced from an application of the cosecant b "law".

https://doi.org/10.1017/S007418090001425X Published online by Cambridge University Press