For these reasons hypothesis (*e*), i.e. an inflow of matter from extra-galactic space, may seem preferable, though also this mechanism meets with serious difficulties. The clouds falling in would originally have acquired velocities of the order of 600 km/sec relative to the local standard of rest; they must have been decelerated in the galactic layer. The intergalactic density required is at least an order of magnitude higher than the presumable overall density in the Universe. However, this is not impossible, in view of the general inhomogeneity of the Universe, and in particular because of the situation of the galactic system in a local group of galaxies.

DISCUSSION

Zwicky. A sixth possibility of accounting for these clouds is as follows. Supernovae of type III are thought to eject clouds of total mass M_0 greater than 1000 $M_{\odot}$, and with velocities v_0 greater than 10 000 km/sec. These clouds coming from a supernova on the south side of the galactic plane (near the Sun) will push the interstellar gases of mass M_i north, leaving the imbedded stars of mass M_s behind. The interstellar gas clouds of mass M_i trap the electrons of the impinging supernova clouds C, while the protons and nuclei of C get stopped only much later by the negative clouds and the stars left behind. Because of this intricate build-up of electric and of gravitational fields between the various clouds of stars and gases, the conversion of the initially available kinetic energy $\alpha M_0 v_0^2/2$ (where $\alpha \sim 0{\cdot}1$), is appreciably elastic, and clouds of mass $M = \alpha\beta\left(\frac{v_0}{v_i}\right)^2 M_0$ can be launched away from the galactic plane, returning later with velocities v_i as a consequence of the collapse of the electric and gravitational fields. If $v_i \cong 100$ km/sec, then $M \sim 10^5\, M_{\odot}$, if $\beta \sim 0{\cdot}1$. It should be added that groups of stars moving in noncircular paths as well as interstellar magnetic fields also find their explanation on the sketched theory.

Oort. There is probably not enough matter in the few supernovae that occur.

Bolton. What are the velocity limits of the survey?

Oort. From -250 to $+250$ km/sec. There might be higher velocities, especially if the objects are extragalactic.

Sciama. A variety of considerations suggests that the density of gas in the local group of galaxies may be as high as 5×10^{-28} gm/cc (Sciama, *Quart. J. R. astr. Soc.* Sept. 1964). By parison, Prof. Oort's requirements are quite modest.

Westerhout. I wonder if these clouds might be related to a gas link between the Galaxy and M31.

Kerr. It is also interesting that the main group is located diagonally opposite to the Magellanic Clouds, in the region where a Magellanic 'countertide' might occur.

5. REGIONAL VARIATIONS OF THE INTERSTELLAR REDDENING LAW

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Introduction

The possible existence of variations of the interstellar reddening law has been investigated since the reddening has been recognized as a dangerous phenomenon for the study of galactic structure, as well as an interesting feature connected with the physical state of the interstellar dust. Almost all studies have been made with conventional photographic or blue-sensitive photoelectric techniques, confining the wavelength coverage to the region 6000Å–3100Å. In contrast, infra-red data are scarce, whereas in the rocket-UV the first reliable measurements are just about to come available.

The Region 6000Å–3100Å

The procedure to investigate the absorption is well known. A highly reddened star is compared with a little reddened star of the same intrinsic energy distribution (as judged from spectral features), in order to eliminate the influence of the illuminating source. The results thus obtained are colour excesses; the relation between two colour excesses leads to the concept of colour excess ratios, useful parameters for a study of the shape of the reddening law. In addition, knowledge of these colour excess ratios is needed for the determination of reddening-free spectral indices, which can be calibrated more or less successfully against important parameters related to temperature, absolute magnitude, age, mass and chemical composition. For these applications it is convenient if the reddening line in the relevant colour-colour diagram is straight, resulting in a colour excess ratio which is independent of colour excess. Curvature of the reddening line, as has been noted in the $U-B$, $B-V$ diagram can be explained as an instrumental effect, caused by the broad response functions of the system (Schmidt-Kaler

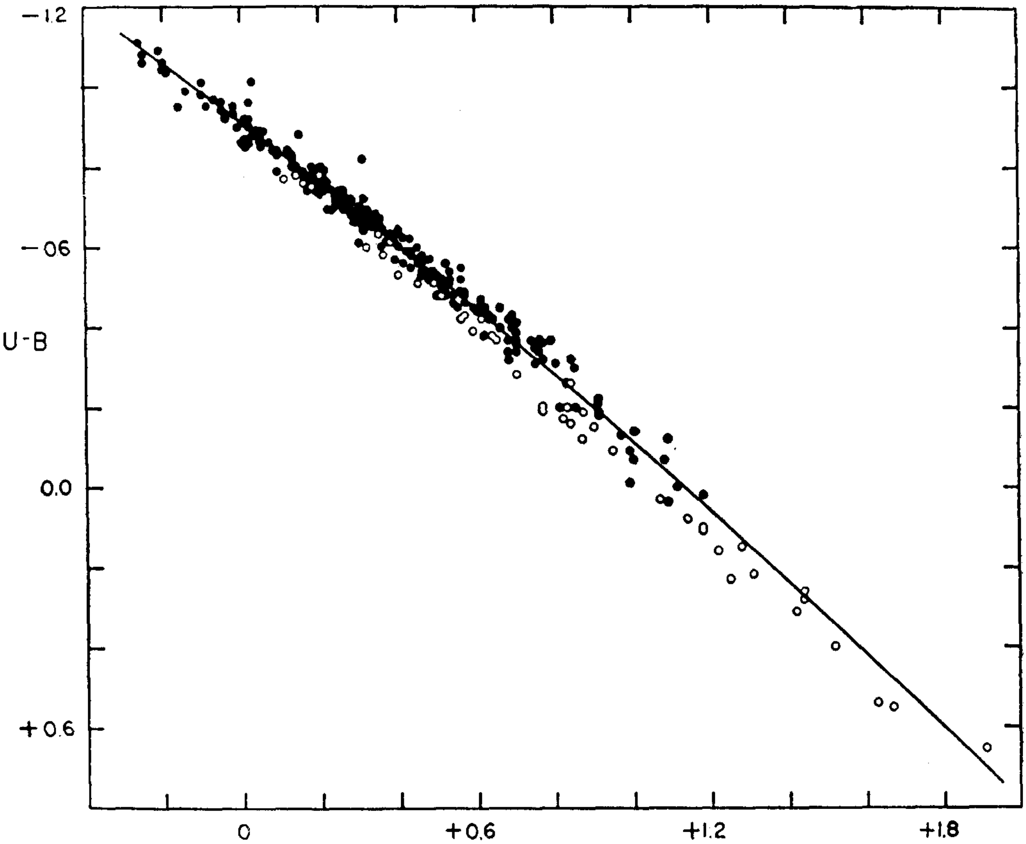

Fig. 1. The $U-B$, $B-V$ diagram of O stars as given by Hiltner and Johnson (1956). The curved reddening line represents the relation

$$E_{U-B} = 0{\cdot}72\, E_{B-V} + 0{\cdot}05\, E^2_{B-V}$$

Open circles designate stars behind the Cygnus Rift.

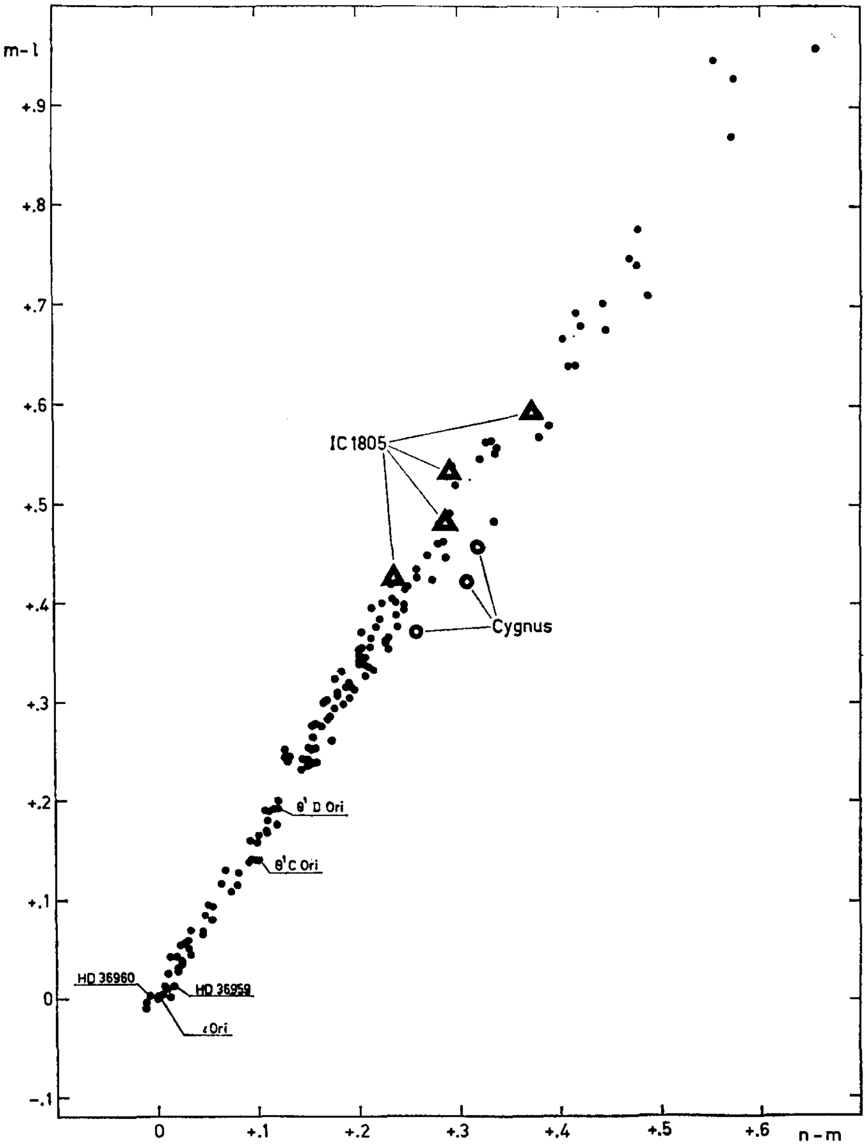

Fig. 2. The $m-l$, $n-m$ diagram of O and B stars as given by Borgman (1961). l, m and n designate filters with peak wavelengths at 5240, 4550 and 4055 Å, respectively.

1961, Serkowski 1963, Nikonov 1964). If the passbands are restricted to 200 Å no effects of this kind are being encountered (Borgman, 1961). More important in the sense of being a criterion for variations of the reddening law is the scatter of individual points in a colour-colour diagram with respect to the mean reddening line. If such scatter increases with reddening and if, moreover, this phenomenon can be attributed to the existence of different reddening lines, each of which is related to some region in the Milky Way, then the conclusion is justified that the reddening law shows regional variations. Both the $U-B$, $B-V$ diagram of Fig. 1 and the $m-l$, $n-m$ diagram of Fig. 2, show the effect of scatter, which increases with reddening; some groups of stars have been indicated by different symbols, illustrating the deviation of their reddening line from the mean. Similar, but much larger effects are present in the E_{V-K}, E_{B-V} diagram of Fig. 3, which will be discussed in the next section.

It has been found that colour excess ratios, involving only wavelengths between 4400 Å and 3200 Å are free from regional variations as far as can be checked by precise photoelectric photometry. As illustrated by Fig. 1 and 2, variations have been detected if one of the colour excesses has its wavelength base in the region 4400 Å–6000 Å. These results indicate that caution is required when deriving a reddening-free spectral index from multicolour photo-

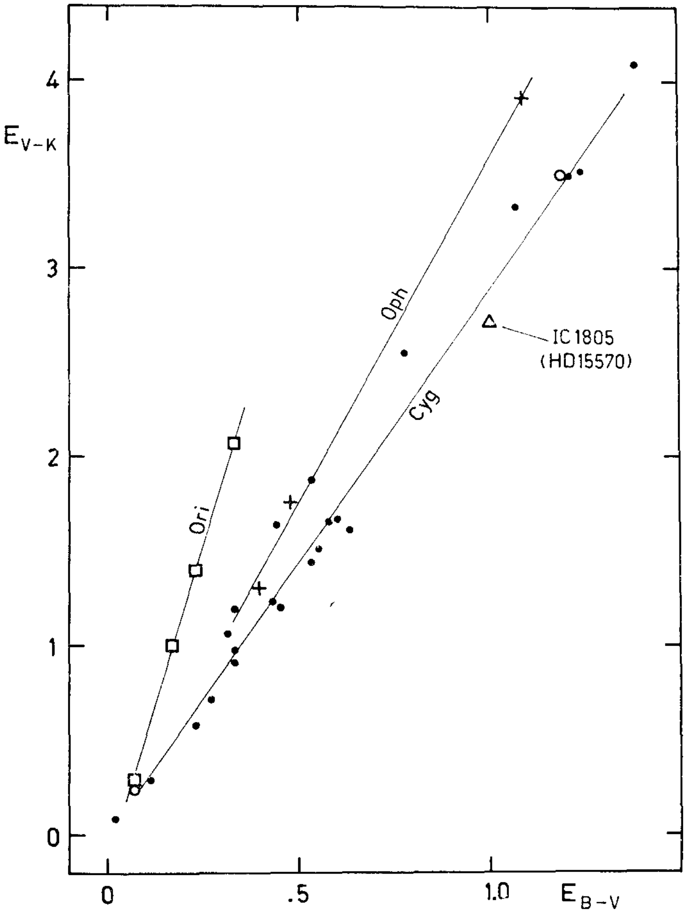

Fig. 3. The E_{V-K}, E_{B-V} diagram of O and B stars, based on observations by Johnson and Borgman (1963); some recently observed stars have been added. B, V and K designate filters with effective wavelengths at 4340 Å, 5470 Å and 2·14 μ, respectively. Symbols designate the following groups of stars:

squares: Orion Nebula region; reddening line slope 6·2
crosses: region around ρ Oph; reddening line slope 3·6
circles: Cygnus; reddening line slope 2·9.
dots: other stars.

The Cygnus reddening line has been taken from Johnson and Borgman (1963).

metry that includes light from either side of 4400 Å, especially if the range of the index in question is small.

It should be noted that there is no general agreement with regard to the reality of variations of the reddening law in the region 6000 Å–3100 Å. Using photographic photometry, Divan (1954) came to the conclusion that all stars investigated in her programme demonstrate the validity of a single reddening law. Rodgers (1961) came to the same conclusion, using a spectrum scanner. Confronting these results with those illustrated partly in Figs. 1 and 2, it seems reasonable to maintain that small variations of the reddening law do exist; such variations may have escaped detection in the studies of Divan and Rodgers because of the relatively small number of stars in their programmes and the more difficult and complicated techniques which they used.

The Region 6000 Å–10 μ

Observational data on the reddening law in the red and infra-red are scarce. The first observations were obtained by Hall (1937), who observed ζ and ϵ Per down to 1 μ, followed by the Stebbins and Whitford six-colour photometry (1943, 1945) and Whitford's (1948, 1958) infra-red observations of a few stars in the 2·2 μ region. During the last years the observational material has been considerably enlarged. Hallam (1959) obtained photometry of carefully selected stars down to 1·1 μ. Johnson and Borgman (1963) published a list of red and infra-red photometry, including a passband in the 2·2 μ atmospheric window, designated as K. When plotted in a colour-colour diagram they found evidence for regional variations of the reddening law in the infra-red. The E_{V-K}, E_{B-V} diagram of Fig. 3 shows reddening lines for some groups of stars. The extreme cases are the lines with slope 2·9 and 6·2 labelled Cyg and Ori, respectively. It is of interest that the two extreme cases in Fig. 2, Cygnus and IC 1805, are not well separated in Fig. 3, whereas the two extreme reddening lines in Fig. 3 cannot be recognized separately in Fig. 2. Apparently the shape of the absorption curve in the visible is neither a sensitize, nor a reliable parameter for its infra-red characteristics.

The red and infra-red behaviour of the absorption law in the Orion Nebula region was first suggested by Baade and Minkowski (1937) and subsequently confirmed by the work of Stebbins and Whitford (1945), Stebbins and Kron (1956) and Hallam (1959). Attempts to interpret the observations in terms of unseen red companions lead to unrealistic constructions (Johnson and Borgman, 1963). Infra-red spectra of θ^1 Ori and θ^2 Ori, covering the spectrum up to 9000 Å show no evidence of late-type companions (Sharpless, 1963 and Hallam, 1959).

Though the observers appear to agree among themselves it must be noted that the interpretation of observations as presented in Fig. 3 has been contested, notably by Miss Underhill, who believes that the observations reflect nothing more than technical difficulties and intrinsic differences between the stars. The discussion is being carried on in the 'Correspondence' section of *The Observatory*.

Very few observations are available beyond 2·2 μ. Photometry of two reddened stars (HD 183143 and VI Cyg no. 12) at an effective wavelength of 3·4 μ has been published (Johnson and Borgman, 1963); in the near future more such data may become available. At 10 μ one reddened M-type supergiant, μ Cephei, has been observed by Wildey and Murray (1964) as well as by Low and Johnson (1964). Unfortunately, the flux measurements differ by a factor 7, whereas all other stars in common show better agreement. This may indicate that μ Cephei is an infra-red variable star.

Absolute Absorption

Studies of the spatial distribution of reddened stars require knowledge of absolute absorption, e.g. in the visual region of the spectrum. This visual absorption is usually derived from an observed colour excess, by multiplication with a constant. With regard to Johnson's B, V system, the relation $A_V = 3\ E_{B-V}$ has been adopted in many investigations. The factor $R = 3$ follows from the relation between apparent visual magnitude and colour index $B-V$ of intrinsically similar stars in clusters, which show variable reddening over their surface. In this way, Schmidt-Kaler (1961) finds $R = 3{\cdot}05 \pm 0{\cdot}15$ from a material which includes O-B3 stars in Cygnus as well as in Perseus. In contrast, Sharpless (1952) indicates $R = 6$ in the Orion Nebula region. From a paper by Borgman and Blaauw (1964) a value of 4 can be deduced for the region around ρ Oph in the Scorpio-Centaurus association.

An independent determination of R is possible by extrapolating the observed absorption curve to infinite wavelength, using a theoretical curve which fits the observations. The dielectric grain extinction curves of van de Hulst (1949) have been applied to the 2·2 μ photometry of Johnson and Borgman; they concluded that the colour excess ratio E_{V-K}/E_{B-V} has to be increased by approximately 10 per cent in order to obtain $R = A_V/E_{B-V}$. It is found that R is approximately 3·1 in Cygnus, Perseus and most other regions, but larger values are associated with regions of young clusters. A value as high as 7 has been found for the Orion Nebula region, rapidly decreasing with increasing distance from the Trapezium stars. Infra-red photometry (unpublished, but partly included in Fig. 3) of stars around ρ Oph points to $R = 4{\cdot}0$ in this region of the Scorpio-Centaurus association. Each of these values is in very satisfactory agreement with those obtained by the independent method discussed previously. This agreement indicates that the deviations from the usually adopted value $R = 3$ are most probably real and also that the run of the absorption curve between 4400 Å (B filter) and infinite wavelength can be represented reasonably well by one of the model curves of van de Hulst. However, these models are probably not entirely correct. Apart from some minor systematic deviations in the wavelength region between 4400 Å and 2·2 μ it has been noted that no satisfactory representation is possible in the violet and ultra-violet (Divan, 1954; Borgman, 1961), where the observations indicate a linear or almost linear run of absorption with λ^{-1} (except for θ^1 Ori), whereas the theory requires a distinct curvature. One may doubt whether the extrapolation of the extinction curves to infinite wavelength as based on the model curves is really a sufficiently reliable procedure. In the coming years important new observational data on interstellar absorption in the infra-red and the rocket-*UV* will become available, which possibly will help to understand the nature of the grains and improve the model extinction curves.

Conclusion

Summarizing we may say that regional variations of the reddening law appear to be well established. These variations become evident in the wavelength region $\lambda > 4400$ Å. A practical and important parameter to describe the behaviour of the reddening law in this spectral region is $R = A_V/E_{B-V}$, which ranges from 3 (in most regions) to 7 (in the Orion Nebula) with intermediate values in the direction of young clusters. There is good evidence that the interstellar material, causing the anomalously large values of R is concentrated in regions of young stars.

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DISCUSSION

Miss Underhill. My remarks are really directed towards the question of how to handle observations in order to reveal regional variations of the law of interstellar reddening. In my opinion the data discussed by Borgman have not been handled in a way to reveal a definite regional variation. All the photometric work implicitly assumes that O stars form a homogeneous group with similar intrinsic colours and that these colours are known accurately from the assigned spectral types. Astrophysical studies indicate that O stars form a very inhomogeneous group. Observations by Wildey (*Astrophys. J. Suppl.* 1964) give some evidence for a range of 0·3 mag in the intrinsic colours, $(B-U)_0$, of O stars. Now to data specially presented by Borgman:

1. When a line is fitted to the O star data of Hiltner and Johnson by least squares, the solution for the black dots cannot be distinguished statistically from the line fitting the open circles (Cygnus stars).

2. In Borgman's two-colour diagram made from observations with moderate-width bands much of the scatter can be shown to be due to the fact that one of the bands falls on the O*f* emission. The O*f* stars are displaced to the lower right.

3. It is impossible to accept $R = 7$ for the Orion Nebula and to reconcile the appearance of the spectra of the Trapezium stars with a modulus of about 8·0 mag and the observed V_0 magnitudes for these stars. These stars are on the lower part of the main sequence, not above it. A value of R near 3 gives no difficulty, but leaves one with too much infra-red radiation from θ^1 Ori C. Various fascinating possibilities exist for producing such extra radiation from the dense nebula and dust in which the stars are embedded. I prefer to leave open the possibility of such an explanation of the observations than to conclude that a star with a spectrum indicating a relatively low absolute magnitude has instead an above-main-sequence absolute magnitude.

Borgman. If intrinsic peculiariries of O stars are reponsible for the scatter in the E_{V-K}, E_{B-V} diagram then one wonders why this scatter increases with reddening. Considering some individual groups it becomes even more puzzling why this 'peculiarity' should increase linearly with reddening. It will be of interest to see a quantitative evaluation of the postulated shell and its photometric significance. It should be added that the peculiar behaviour of the reddening law in Orion is confirmed by observations of HD 37042 which is an unsuspected B1V star. A simple computation shows that in the case of θ^1 Ori C (O6*p*) $R = 7$ results in $M_v = -5{\cdot}2$ mag, whereas $R = 3$ gives $M_v = -4{\cdot}0$ mag, both being based on a distance modulus of 8·1 mag. The first value is not improbably high; in fact it is very normal for an O star. In connection with Miss Underhill's statement about the large range in properties of O stars, where θ^1 Ori C's spectrum must be even called peculiar, I wonder how one safely can apply the MK luminosity calibration with such precision that it has fatal consequences for the value $R = 7$.