THE INTERSTELLAR EXTINCTION CURVE FROM 4000 Å TO 6500 Å

G. A. H. WALKER

Geophysics Dept., University of British Columbia, Vancouver, B.C., Canada

and

J. B. HUTCHINGS and P. F. YOUNGER

Dominion Astrophysical Observatory, Victoria, B.C., Canada

Abstract. Interstellar extinction curves (m_{ext} vs. $1/\lambda$) of 20 Å resolution have been obtained at the DAO from photoelectric scanner observations in the range 4000 Å to 5000 Å for five stars, and of 50 Å resolution for four stars in the range 4000 Å to 6500 Å from Willstrop's photoelectric data. There is a closely linear section between 4900 Å and 5800 Å for all of the curves. There are changes of gradient or discontinuities associated with the broadest diffuse interstellar bands at 6180 Å, 4882 Å, 4761 Å and 4430 Å. There is a marked discontinuity near 5800 Å and for some stars a broad absorption near 4200 Å. The 4430 Å band lies between two unequal wings of anomalously low extinction (one of which has been detected at Edinburgh). The irregularities vary from star to star, and those in the neighbourhood of the 4430 Å band seem to have the same form as those in the region of the absorption peak at 2200 Å

Interstellar extinction curves were derived for five early-type reddened stars in the range 4000 Å to 5000 Å from digitized scans made with a low resolution scanner on the D.A.O. 72-inch telescope in an attempt to define the form of the curve in the region of the discontinuities found by Nandy (1964, 1967). The resolution was 20 Å in the

TABLE I

Pairs of interstellar reddened and unreddened stars (reddened star first)

Star	Sp.	$\Delta E(B-V)$	Data	Curve
37022	O6	0.35	DAO	*f*
Model 98	O9		Underhill	
46711	B3 II	1.05	DAO	*c*
74280	B3 V			
46711	B3 II	1.05	DAO	*d*
Model 63	B2 V		Underhill	
154043	B1 I	0.68	Willstrop	*h*
165024	B0.5 II			
154368	O9.5 Iab	0.77	Willstrop	*g*
149438	B0 V			
160529	A2 Ia +	1.25	Willstrop	*j*
167356	A0 Ia			
167971	O8f	1.04	Willstrop	*i*
149438	B0 V			
183143	B7 Ia	1.23	DAO	*b*
197345	A2 Ia			
198478	B3 Ia	0.47	DAO	*e*
Model 63	B2 V		Underhill	
211971	A2 Ib	0.90	DAO	*a*
197345	A2 Ia			

Houziaux and Butler (eds.), Ultraviolet Stellar Spectra and Ground-Based Observations, 52–56.

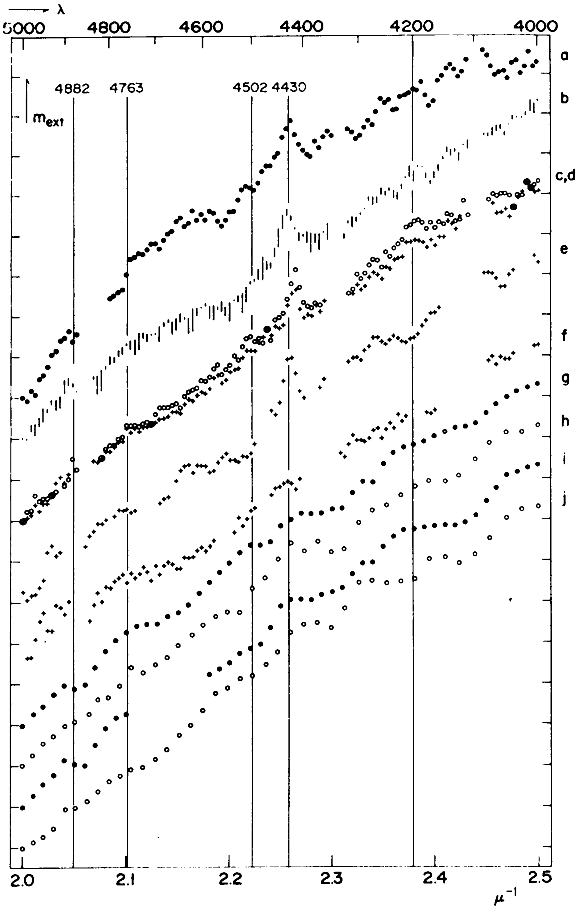

Fig. 1. Interstellar extinction curves (Δm_λ vs. $1/\lambda$) derived for the stars in Table I between 4000 Å and 5000 Å. Curves are normalized to $\Delta m_{5000} = 0$ and $\Delta m_{4000} = 1$. Curves (a) to (f) are based on D.A.O. scans of 20 Å resolution and (g) to (j) are based on Willstrop's (1965) scans of 50 Å resolution. Crosses indicate a comparison with appropriate model atmosphere fluxes. In (b) two curves based on different nights' observations have been superimposed and the points joined by bars. The positions of the diffuse absorption features at 4882 Å, 4763 Å, 4502 Å, and 4430 Å are shown. Further details are given in the text.

spectrum. Each scan was corrected for atmospheric extinction and sky background, and, in some cases calibrated in absolute flux units by reference to standards listed by Oke (1964). Two to four scans were taken and an average formed for each star. Wavelength calibration was applied using the stronger stellar absorption lines of H and He I. To derive an extinction curve spectral energy distributions of the reddened stars were ratioed with spectral energy distributions of unreddened stars or model atmosphere fluxes for stars of corresponding spectral type. The luminosities of the pairs of stars were never quite the same and consequently the members of the Balmer series which are strongly luminosity sensitive do not match and these regions have been

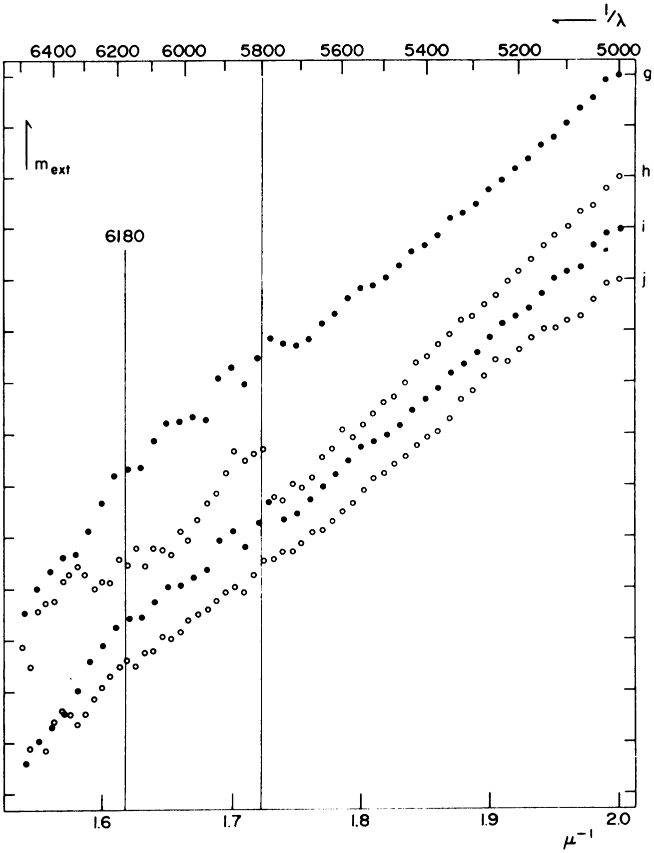

Fig. 2. Interstellar extinction curves between 5000 Å and 6500 Å at 50 Å resolution for stars observed by Willstrop (1965) in Table I. Curves normalized to $\Delta m_{5000} = 0$, $\Delta m_{4000} = 1$.

omitted from the curves. Only continuous opacity sources have been considered in calculating model atmosphere fluxes and consequently there is no matching in the region of either the Balmer series or the stronger He I lines which have been omitted from the curves.

The pairs of reddened stars and unreddened standards are listed in Table I. The extinction curves are shown in Figure 1. Each curve is normalised to give $m_{5000} = 0$, $m_{4000} = 1$. Two extinction curves derived from scans taken on different nights for HD183143 are shown superimposed with the pairs of points joined by bars. In the case of HD46711 curves have been derived from comparisons both with an unreddened standard star and with model atmosphere flux predictions. The close agreement of the two sets of results for HD183143 shows that none of the irregularities discussed below can be ascribed to observational error. The very close agreement of the two curves for HD46711 indicates that none of the larger observed irregularities in the extinction curves is caused by incomplete compensation for the stellar absorption lines between the standard and reddened star spectra since in general this should lead to oppositely directed errors in these two comparisons.

The data published by Willstrop (1965) for four pairs of reddened and unreddened early-type stars has been treated in the same manner as the D.A.O. observations to yield extinction curves at 50 Å resolution between 4000 Å and 6500 Å. The stars are listed in Table I and the extinction curves are shown in Figures 1 and 2. The region of the stronger '*f*' emission has been omitted for HD167971. The positions of the broad diffuse interstellar absorption bands at 6180 Å, 4882 Å, 4763 Å, 4430 Å are shown (Wilson, 1958).

The most significant features of the curves in Figures 1 and 2 seem to be the following: the 4882 Å diffuse band appears as a discontinuity rather than an enhanced absorption; the 4763 Å diffuse band shows as a change of slope or discontinuity in all cases; the stars in Cygnus, HD183143, 198478, and 211971, show the 4430 Å band between unequal low absorption wings and the short wavelength wing can be seen for HD46711, and, weakly, both wings for several other stars. A broad absorption or change of slope can be seen near 4200 Å for HD46711 and to a lesser extent for the other stars. If it is real, however, the feature is not at the same wavelength for all of the stars. The star HD37022, the brightest member of the Trapezium, shows the most pronounced change of slope near 4763 Å and virtually no 4430 Å band absorption confirming Morgan's (1944) observation. The short wavelength low absorption wing associated with the 4430 Å band has already been reported by Brück and Nandy (1968). There is a change of gradient at 6180 Å for all of the curves and there is a marked discontinuity for all of the curves at 5800 Å except for HD160529. The difference between the curves for HD160529 and 154043 in Figure 2 is not as extreme as it appears. When the two curves between 5000 Å and 6500 Å are superimposed the curve for HD165024 has a smaller slope between 5000 Å and 5800 Å and the effect of the large discontinuity of slope at 5800 Å for HD154043 is to bring the curves into coincidence.

Although different in scale, the form of the curves in Figure 1 in the region of the 4430 Å interstellar band resembles the ultraviolet extinction curve in the region of the absorption peak near 2200 Å found by Stecher, and Bless and Savage, which they have presented at this symposium. Their results seem to show a change of slope of the extinction curve on passing through the region of the absorption peak and there appear to be wings of low absorption on either side of the peak.

References

Brück, M. T. and Nandy, K. N.: 1968, *Nature* **220**, 46.
Morgan, W. W.: 1944, *Astron. J.* **51**, 21.
Nandy, K. N.: 1964, *Publ. Roy. Obs. Edinburgh* **3**, 141.
Nandy, K. N.: 1967, *Publ. Roy. Obs. Edinburgh* **5**, 13.
Oke, J. B.: 1964, *Astrophys. J.* **140**, 689.
Underhill, A. B. and Walker, G. A. H.: 1966, *Monthly Notices Roy. Astron. Soc.* **131**, 475.
Willstrop, R. V.: 1965, *Mem. Roy. Astron. Soc.* **69**, 83.
Wilson, R.: 1958, *Astrophys. J.* **128**, 57.

https://doi.org/10.1017/S0074180900101846 Published online by Cambridge University Press

Discussion

Underhill: You mentioned a hump (weaker extinction) just longward of 4430 Å. Do you think this is related to the emission wings of 4430 Å which Wampler thought he had detected in a few stars?

Walker: I don't think so. Wampler considered a smaller baseline in wavelength. I think he did find an asymmetry of profile.

Greenberg: How deep are the emission wings? Are they comparable to the height of the absorption peaks relative to the continuum?

Walker: I would prefer to consider these wings just as regions of lower extinction rather than 'emission' and their depth of course depends on the 'normal' level assumed for the extinction. However, one can extrapolate the linear portions of the extinction curve from 4882 Å and 4200 Å and they tend to intersect close to the bottom of the 4430 Å band. So, to this extent, the wings have the same depth as the absorption band.

Morton: To what extent are these effects general properties of the interstellar medium and how much do they depend on the particular stars used for the comparison? In other words are any of these effects proportional to $E(B-V)$?

Walker: The curves do vary from star to star although they are all normalized to the same color excess between 4000 Å and 5000 Å. There are not enough to separate possible regional differences from those for individual stars.

Wickramasinghe: Do you find that the discontinuity in the slope of the extinction curve is in any way dependent on the strength of the 4430 Å band? For example is the sharpness, or the ratio of the slopes any different in the case of stars with very weak 4430 Å?

Walker: I don't think so. HD37022 has virtually no 4430 Å absorption but it does show a marked change of slope near 4763 Å.

Borgman: Are the features only found when comparing observations with model atmospheres?

Walker: No, some of the presented graphs are based on comparison of reddened and unreddened stars.

Greenberg: I do not want to overemphasize the following point. I should merely like to point out that an 'apparent' discontinuity in the slope of the extinction curve at about $\lambda^{-1} = 2.2\mu^{-1}$ occurs in my theoretical calculations for cylinders which give a good match to extinction. I believe that this manifestation is due essentially to the fact that we are reproducing a curve which has a change from one sign of curvature to another occurring just about at this point. On my theoretical calculations there are no intrinsic discontinuities in the optical properties of the grains.

(Note added in subsequent discussion.) I should like to suggest that a possible way of establishing the emission and absorption features around 4430 Å would be to draw a 'theoretically' derived continuum rather than try to guess where the continuum runs from the observations. By a theoretically derived continuum I mean one which fits the extinction curve in the other spectral regions and is derived perhaps like the one which I presented.