Interpretation of the UV spectrum of some stars with little reddening.

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Abstract. The UV spectrum of a few reddened stars will be decomposed into two terms. One is the direct starlight, $F^0_{\star,\lambda}e^{-\tau_\lambda}$, which is the product of the flux of the star corrected for interstellar extinction, $F^0_{\star,\lambda}$, and of the extinction $e^{-\tau_\lambda}$. The second is starlight scattered by interstellar dust into the beam of the observation. This excess of scattered starlight affects the FUV part of the spectrum ($\lambda < 2200$ Å). The combination of both terms gives the shape of the UV spectrum of a reddened star, with its characteristic depression at 2200 Å.

1. Introduction

This paper is the second of a serie dedicated to the interaction of starlight and interstellar grains in the UV and supported by the observations of the International Ultraviolet Explorer (IUE) satellite.

The properties of the interstellar grains can be studied either by their capacity to scatter starlight, by observations of reflection nebulae, or by their capacity to extinguish starlight, by observing a star through an interstellar cloud. The former method allows the evaluation of the phase function and of the albedo of interstellar grains. The latter gives more specific information on the proportion of starlight to be absorbed or scattered at each wavelength. If extinction is the only process involved, the curve which is obtained by dividing the spectrum of a star by the spectrum of an unreddened star of same spectral type shows the relative capacity, from one wavelength to another, of the grains to extinguish starlight in the direction of the star. This is an intrinsic property of the interstellar grains present in the direction of the observation.

The most salient feature of the UV spectrum of a star is the 2200 Å bump which appears when there is interstellar matter between the star and the observer. From the

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standpoint of interstellar grain properties, and if no scattered starlight is introduced into the beam of the observation, this implies the existence of a particular class of grains, the bump carriers, which extinguish light at wavelengths close to $\lambda_b \sim 2175$ Å. Those particles have never been formally identified to date. Efforts to comprehend the variations of the stars UV spectrum in different interstellar environments, all of which have assumed starlight extinction as the only process involved, did not really succeed in bringing a global understanding of the UV extinction curve (see Savage et al. 1985, Fitzpatrick & Massa 1986 and 1988).

In a preceding paper (Zagury 2000, paper I hereafter) the existence of the bump carriers was questioned as these carriers do not affect the UV spectrum of reflection nebulae. The UV spectrums of the bright nebulae presented in paper I were all interpreted as the result of starlight scattered by interstellar grains with identical albedo and phase function across the UV and in the different directions of space sampled by the nebulae. It was also noted that these properties of the grains may be identical in the optical spectral range. No bump or other particular feature is created at 2200 Å in the spectrum of the light scattered by a nebula.

If the bump carriers are not present in nebulae, the presence of an additional component due to scattering becomes the most reasonable explanation of the bump (Bless & Savage 1972, and the appendix of this paper). To explain the variations of the surface brightness of a nebula in function of its distance θ from the illuminating star (paper I), the interstellar grains must have a strong forward scattering phase function. In paper I it was found that the maximum surface brightness a nebula can reach varies as a power law θ^α ($\alpha < -1$) of θ. A value $\alpha = -2$ was found. Consequently, the starlight scattered into the beam of observation at close angular distance to the star may be a non-negligible proportion of the direct starlight. The scattered starlight will be more important in a wavelength range for which the scattering medium has an optical depth close to $\tau_{max} \sim 1 - 2$.

The present paper will further develop these ideas. I will study the UV spectrum of a selected sample of stars with a bump and little reddening. Contrary to previous studies which use the logarithm of the spectrums as a mean of obtaining the extinction curve, in this paper, the direct linear data will be used. This is necessary if the spectrums can be decomposed into two separate components, the direct starlight and the scattered starlight.

The stars to be studied in this paper have been selected because of the simple and straightforward interpretation which can be given of their UV spectrum. The specific aspect of the UV reduced spectrum of these stars, defined as the ratio of the star to an unreddened star of same spectral type spectrums (section 2), clearly separates two spectral regions. The long wavelength part of the spectrum is correlated with the reddening of the star, $E(B-V)$, and, for some stars, it is fitted down to the bump spectral region by an exponential of $1/\lambda$. The exponential will be interpreted as the extinction of starlight $e^{-\tau_\lambda}$, where τ_λ is a linear function of $1/\lambda$ (section 4). The linear in $1/\lambda$ dependence of τ_λ was established in the optical in the 1930's (Greenstein & Henyey 1941 and references therein) and detailed in more recent studies by Rieke & Lebofsky (1985) and Cardelli, Clayton and Mathis (1989). For the stars I have selected, this law extends to the UV.

At shorter wavelengths, $\lambda < \lambda_b$, a bump-like feature appears, superimposed to the exponential decrease. This feature will be analysed in section 6 and attributed to additional starlight scattered by interstellar dust at very small (compared to the beam of the observations) angle to the star. Hence, the 2200 Å bump is no longer considered as a depression, but rather the point at which scattering becomes noticeable.

The consequences of this interpretation are discussed in the conclusion.

2. Data

The IUE experiment (Boggess et al. 1978a, 1978b) and the process employed to obtain the final IUE spectrums have been described in paper I.

This paper will be concerned with seven stars, listed in table 1. Two of these stars, HD23480 (Merope) and HD200775 illuminate the Merope nebulae and NGC7023, which have been studied in paper I. For each star, the spectrum presented in the paper is an average of the best observations of the object. Some stars having been observed many times, only a few observations were necessary to ensure sufficient accuracy. At times I used high dispersion spectrums and decreased the resolution by a median filter.

The spectrum of the seven stars selected for this study are presented in figure 7, as they can be seen at IUE website.

The ratio of a reddened star spectrum to the spectrum of an unreddened star of same spectral type (reference star) will be called a 'reduced spectrum' of the reddened star. Each star has many reduced spectrums. All reduced spectrums of a star are proportional.

The reduced spectrum of the seven stars, scaled to a common value at $3\,\mu\text{m}^{-1}$, are presented in figure 2.

The 'absolute reduced spectrum' of a star is the reduced spectrum of the star obtained if the reference star is the star itself, corrected for reddening. It characterizes the interstellar medium between the star and the observer (section 3). The logarithm of the absolute spectrum of a star is proportional to the extinction curve, A_λ versus $1/\lambda$, in the direction of the star.

The reference stars which have been used to establish the reduced spectrum of the stars are listed in table 2.

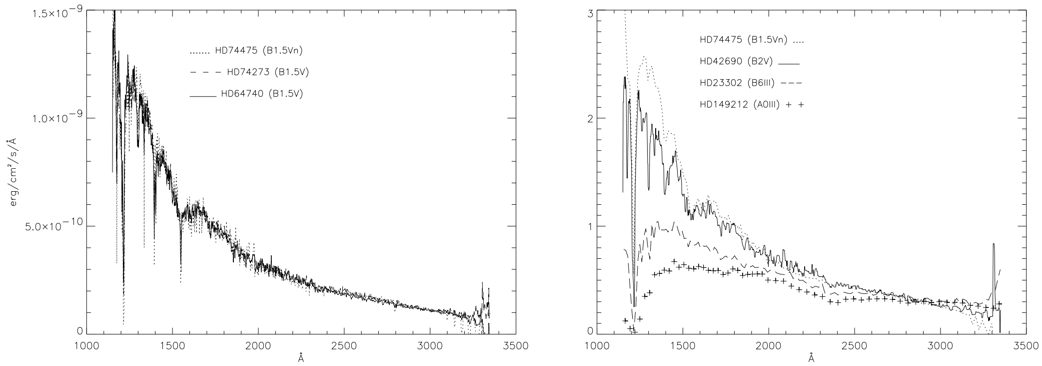

Fig. 1. *Left*: Spectrums of unreddened stars with close spectral type. *Right*: Variations of the UV spectrum of unreddened stars according to the spectral type.

A star spectrum can be presented as a function of the wavelength λ or as a function of λ^{-1}. The former manner keeps close to the data, whereas the latter is preferable since the optical depth varies as $1/\lambda$. The latter presentation, more useful when dealing with scattering, has been chosen for most plots.

3. The 2200 Å bump and the extinction of starlight

When only extinction affects the transport of light between a star and the observer the spectrum of a star is the product of two terms: the unreddened flux of the star $F^0_{\star,\lambda}$ and the extinction $e^{-\tau_\lambda}$, where $\tau_\lambda = 0.92A_\lambda$ is the optical depth at wavelength λ of the medium in front of the star. A reduced spectrum of the star, proportional to $e^{-\tau_\lambda}$, depends only on the interstellar medium between the star and the observer. The absolute reduced spectrum of the star is $e^{-\tau_\lambda}$.

The presence of the bump has complicated the interpretation of the UV spectrum of the stars but has not changed the ideas presented so far: the bump is usually considered as a particular feature in the τ_λ function.

The bump was proven to originate in the interstellar medium and related to the quantity of interstellar matter in front of the star (Savage 1975, see also Savage, Massa and Meade 1985). Stars of same spectral type with a bump have significant differences in their U.V. spectrums while stars with no bump and close spectral types superimpose very well after multiplication by an appropriate factor (figure 1).

4. The exponential decrease

Figure 2 plots the reduced spectrums of the seven selected stars. The reduced spectrums are smoothed by a median filter and scaled to have the same value at $3\,\mu\mathrm{m}^{-1}$. Stars are listed on the figure by order of increasing $E(B-V)$, written after the star name.

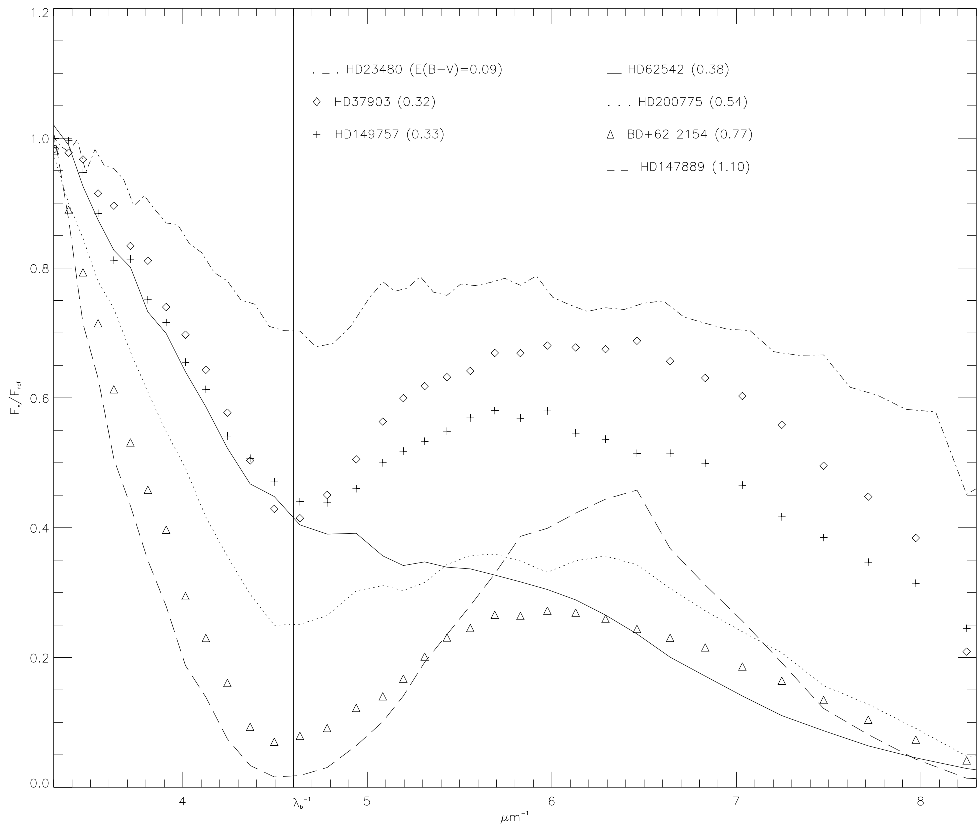

Fig. 2. Reduced spectrums of the stars divided by their value at $\lambda^{-1} = 3\,\mu\mathrm{m}^{-1}$.

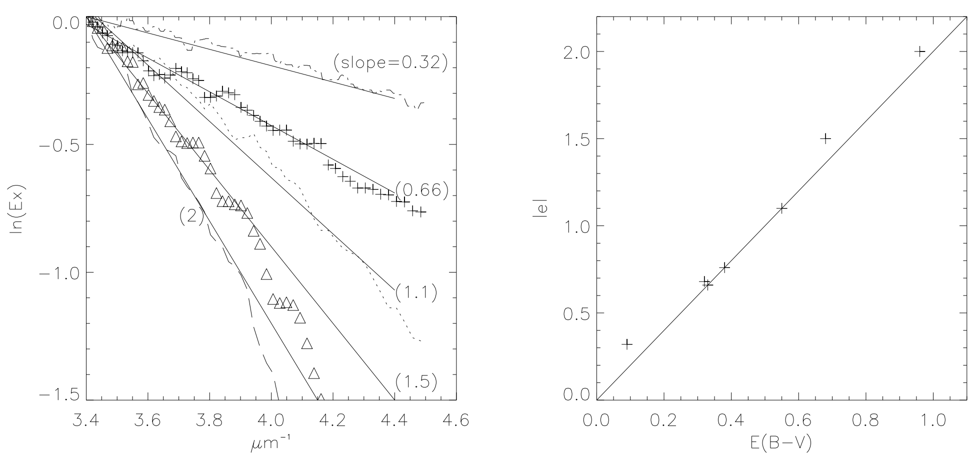

Fig. 3. *left plot*: Logarithm of the reduced spectrum of the stars of figure 2 in the long wavelength range. *right plot*: Correlation between $E(B-V)$ and the exponent of the exponential decrease. The solid line has a slope of 2.

Each spectrum consists of 2 parts, clearly separated at λ_b. The long wavelength part ($3\,\mu\mathrm{m} < 1/\lambda < 1/\lambda_\mathrm{b}$) varies steeply with increasing $1/\lambda$. This decrease will be called the 'exponential decrease'.

There is a close correlation between the $E(B-V)$ value of a star and the steepness of its' exponential decrease: stars with larger $E(B-V)$ have a more rapid decrease.

For all the stars of the sample, the exponential decrease is well fitted by an exponential, $Ex = \beta e^{-e/\lambda}$, of $1/\lambda$. The exponent e can be estimated by taking the logarithm of the reduced spectrums (figure 3, left). In some directions (HD147889, BD +62 2154), especially the directions of highest $E(B-V)$, the exponential fit is best at long wavelengths, close to the optical wavelengths. In other directions, e.g. the directions of lowest $E(B-V)$ (HD23480, HD37903, HD149757, HD62542, HD200775), the fit applies to the totality of the exponential decrease.

Figure 3, right, plots e as a function of $E(B-V)$. Within the error margin of $E(B-V)$ (estimated to be $\sim$ 0.1 mag) and on the determination of e ($\sim 5\%$), we have: $e \sim 2E(B-V)$. This relation is justified if the linear relation which holds between $A_\lambda = 1.08\tau_\lambda$ and $1/\lambda$ in the visible (Cardelli, Clayton & Mathis 1989, Rieke & Lebofsky 1985) is extended to the UV. In this case:

$$
\begin{aligned}
A_\lambda &= \frac{E(B-V)}{\frac{1}{\lambda_B}-\frac{1}{\lambda_V}}\left(\frac{1}{\lambda}-\frac{1}{\lambda_V}\right)+A_V \\
&= 2.2E(B-V)\left(\frac{1\,\mu\mathrm{m}}{\lambda}+0.46(R_V-4)\right) \quad (1)\\
\tau_\lambda &= 2E(B-V)\left(\frac{1\,\mu\mathrm{m}}{\lambda}+0.46(R_V-4)\right) \quad (2)
\end{aligned}
$$

with $R_V^{-1} = (A_B - A_V)/A_V = \tau_B/\tau_V - 1$.

In the spectral range where equation 2 applies, extinction decreases as $e^{-\tau_\lambda} \propto e^{-2E(B-V)/\lambda}$. The Ex functions which fit the near UV spectrum of the stars we are concerned with have an identical exponential dependence on $1/\lambda$ (exponent$= -2E(B-V)/\lambda$). The Ex function prolong the linear optical extinction in the UV. Since there is no reason to suspect an abrupt change in the optical depth -more specifically in the constant term of equation 2- when going from the optical to the UV, relation 2 must hold, in the directions sampled by the stars, from the near infrared to the near UV ($\lambda > \lambda_b$).

The left plots of figures 4, 5 and 6-top represent a reduced spectrum in the directions where the exponential decrease can be fitted by the Ex function down to λ_b. The solid line is the exponential fit. The close fit the Ex function provides to the exponential decrease indicates that, in these directions, the extinction curve is a linear function of $1/\lambda$ according to equation 1 from the optical to λ_b.

5. Absolute reduced spectrums

Knowledge of $E(B-V)$ along with relation 2 permits an exact scaling of the reduced spectrums in the directions where the exponential decrease is well fitted by an exponential function of $1/\lambda$.

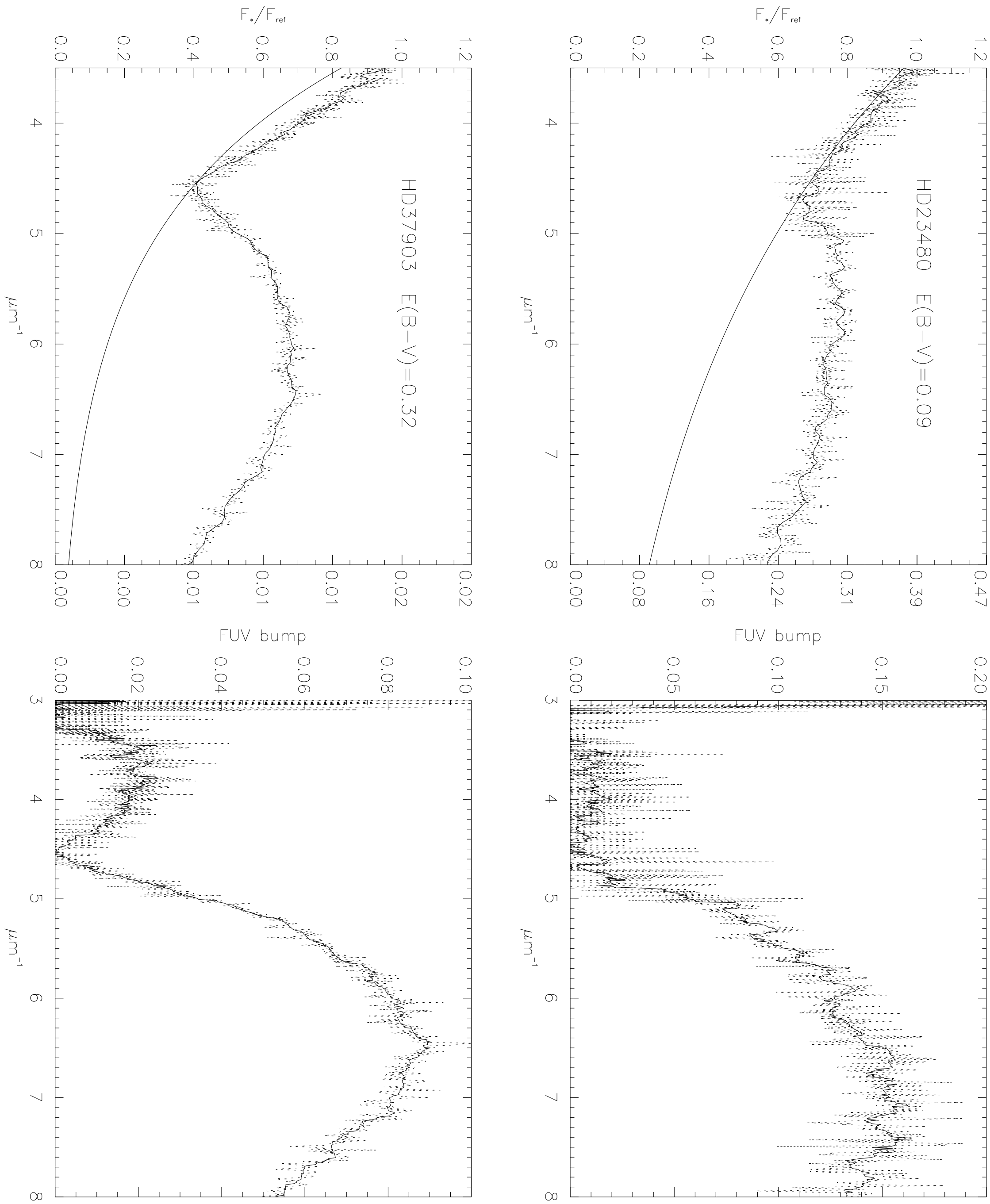

Fig. 4. Figure 4 to figure 6. *left plot*: reduced spectrum of the star and best exponential fit to the long wavelength part of the spectrum. The curve in dots is the unsmoothed spectrum. The solid line spectrum was obtained by applying a median filter to the unsmoothed spectrum. The right y-axis is the absolute calibration of the plot, assuming $R_V = 3$. *right plot*: Absolute reduced spectrum of the star minus the exponential decrease.

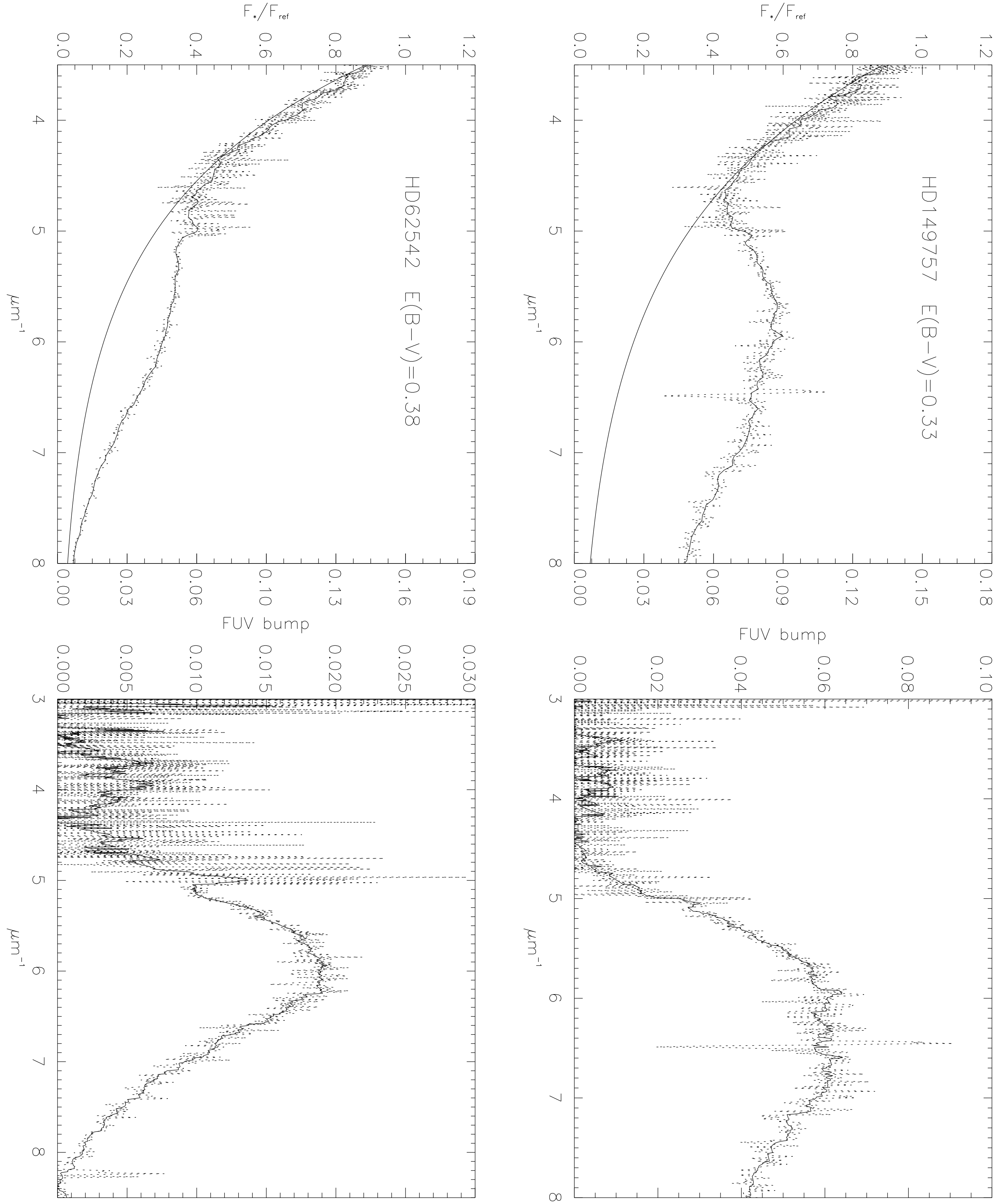

Fig. 5. Same as in figure 4.

In these directions, the exponential $Ex = \beta e^{-2E(B-V)/\lambda}$ multiplied by a scaling factor α_s must equal the extinction of starlight, $e^{-\tau_\lambda}$. α_s is unambiguously determined from equation 2 by:

$$\alpha_s = \frac{1}{\beta} e^{-0.92E(B-V)[R_V-4]} \quad (3)$$

$$= \frac{1}{\beta} e^{-0.92A_V(1-\frac{4}{R_V})} \quad (4)$$

α_s is the factor to be applied to the star reduced spectrum in order to obtain the absolute reduced spectrum and the extinction curve in the direction of the star.

In low density regions where R_V is supposed to be ~ 3 (Cardelli et al. 1989), we have:

$$\tau_\lambda = 2E(B-V)(\frac{1\,\mu\text{m}}{\lambda} - 0.46) \quad (5)$$

$$\alpha_s = \frac{1}{\beta} e^{0.92E(B-V)} \quad (6)$$

With equation 6 the absolute reduced spectrum in the direction of a star can be deduced from a reduced spectrum and from the associated Ex function. This property was used to calibrate the right axis of the left hand plots and the right hand plots of figures 4 to 6.

6. The FUV spectrum

6.1. Analysis

There is no evident correlation between $E(B-V)$ in the direction of a star and the short wavelength part ($1/\lambda_{\rm b} < 1/\lambda < 8\,\mu$m) of its reduced spectrum (figure 2). The bump-like feature at $1/\lambda > 1/\lambda_b$ is added to the tail of the exponential decrease. When the latter is slow, indicating small $E(B-V)$, the bump feature is tilted because of the underneath exponential decrease. HD23480, HD149757, HD62542, HD200775 are typical examples (see figure 2 and the left plots of figures 4 and 5).

In the directions of the stars selected in figure 4 to figure 6, the Ex function fits the exponential decrease down to λ_b, showing no excess of extinction or other peculiarity at this wavelength. In all directions the reduced spectrum seems to catch up with the exponential decrease for large τ_λ-values.

The reduced spectrum of the stars, right hand plots of figure 4 to figure 6, comprises the expected exponential extinction of starlight and the additional bump-like feature at short wavelengths. The bump feature can be isolated if, for each direction, $e^{-\tau_\lambda}$ is substracted from the absolute reduced spectrum in the same direction. The resulting curves are plotted at the right hand of figure 4 to 6.

The short wavelength bump in the different directions are represented on the same plot, figure 6, down and left. With increasing $E(B-V)$, the height of the bumps tends to decrease and the short wavelength decrease (high τ_λ) is steeper.

6.2. Scattering

Scattering was ruled out as an explanation of the 2200 Å bump for reasons which are summarized in the appendix and are questionable. The spectrum of nebulae (paper I) did not reveal the presence of the bump carriers in the interstellar medium. The exponential decrease of the UV spectrums can also logically be interpreted as the extinction of starlight by the same mean grain population responsible of the 'normal' extinction process of starlight. For the stars studied here there does not seem to be any peculiarity at λ_b, and there is no need of a particular class of grains which would extinguish starlight at this wavelength. The bump-like FUV feature is superimposed on the exponential decrease and appears as an additive feature to the extinction of the direct starlight $e^{-\tau_\lambda}$. It must arise (Bless et Savage 1972 and the Appendix, this paper) as a result of the introduction of scattered starlight into the beam of observation.

If scattering is added to direct starlight, the light we receive from the direction of a star is the sum of the direct starlight, $F^0_{\star,\lambda}e^{-\tau_\lambda}$, and of the scattering component $F^0_{\star,\lambda}Sca_\lambda e^{-\tau'_\lambda}$. $F^0_{\star,\lambda}$ is the stellar flux at λ corrected for reddening, Sca_λ is the proportion (relative $F^0_{\star,\lambda}$) of starlight at wavelength λ scattered into the beam. $\tau'_\lambda < \tau_\lambda$ is the optical depth which accounts for the extinction of starlight between the star and the scattering medium and for the extinction of the scattered light.

The Sca_λ function depends on the structure of the medium sampled by the line of sight. The light scattered by a medium made of clumps with low density will not have the same spectrum as the light scattered by high density clumps. The small scale structure of the medium, that is the density distribution of the different regions which compose the scattering medium at scales probably smaller than the IUE beam (Falgarone et al 1998), determines the shape of the Sca_λ function.

With increasing $E(B-V)$ the FUV bump has a smaller maximum and a steeper FUV decrease (left-bottom plot of figure 6). This can be attributed to the $e^{-\tau'_\lambda}$ term of the scattered emission which affects the shortest wavelengths.

In the right hand bottom plot of figure 6 the FUV bumps are multiplied by an appropriate function $e^{-\tau'_\lambda} = e^{-\gamma\tau^0_\lambda}$, τ^0_λ given by equation 5 with $E(B-V)=1$, and γ an appropriate constant. γ is adjusted for all the curves to have comparable maximums. All the curves of the figure have an identical growth between λ_b and the maximum.

The curves for the direction of lowest reddening (HD23480, HD37903, HD149757) superimpose well, supporting the idea of scattering by a medium with similar characteristics in these directions: the Sca_λ functions are identical and the scattered component of the absolute reduced spectrums differ by the extinction term $e^{-\tau'_\lambda}$ only.

The curves for the directions of HD200775 and HD62542 cannot be superimposed to the others, thus differing by the Sca_λ function, which indicates an environment of different nature.

6.3. Implications

If scattering is responsible for the FUV bump of a star, the bottom plots of figure 6 show that it can represent up to $\sim 15\%$ of the direct starlight received on earth and corrected for extinction.

Most of the additional light has to be scattered within the $\theta_0 = 1$" angle of the small S aperture of the IUE telescope since the differences between observations made with the S and with the large L apertures of the IUE telescop are explained by pointing problems (section A.1.). Because the ratio of L to S observations is generally greater than 1.2, the difference of the amount of scattered starlight between the two types of observations must be less than 20%.

Thus, if scattering is responsible for the FUV bump of a star, the scattered light is necessarily an appreciable proportion of direct starlight and scattering by interstellar dust must be strongly oriented in the forward direction.

6.4. Case of a θ^{-2} dependence of the maximum surface brightness of nebulae

Suppose the θ^{-2} dependence of the maximum surface brightness of a nebula (paper I) on angular distance θ to the illuminating star is verified and applies to very small angles, down to a lower limit θ_{min}. According to the equation 6 of paper I, the amplitude of the FUV bump, 15% of the unreddened flux of the star measured on earth, will be justified if:

$$\theta_{min} < \theta_0 e^{-\frac{0.07}{\pi c}} \tag{7}$$

$$\theta_{min} < 6\,10^{-4}\,"$$

The latter inequality assumes $c \sim 3\,10^{-3}$ and $\theta_0 = 1\,"$. Note that this upper estimate of θ_{min} is extremely sensitive to the c parameter. A value of $c = 15\,10^{-3}$, within the possible range of values observed in paper I, gives $\theta_{min} < 0.2\,"$. $c = 10^{-3}$ gives $\theta_{min} < 2\,10^{-10}\,"$.

If r_a is the ratio of the maximum light received from the direction of a star observed with apertures θ_1 and θ_0:

$$\begin{aligned} r_a &= \frac{\pi c(1 + 2\ln(\theta_1/\theta_{min}))}{\pi c(1 + 2\ln(\theta_0/\theta_{min}))} \\ &\sim \frac{\ln(\theta_1/\theta_{min})}{\ln(\theta_0/\theta_{min})} \\ &\sim 1 - \frac{\ln\theta_1}{\ln\theta_{min}} \end{aligned} \tag{8}$$

with θ_1 and θ_{min} in arcsecond.

If $\theta_1 \sim 10$", corresponding to the large aperture of the IUE telescope, and θ_{min} is of order $10^{-\alpha}$", equation 8 has the simple form:

$$r_a = 1 + \frac{1}{\alpha} \tag{9}$$

Within this framework, conditions 7 and 8 refine the validity domain of the θ^{-2} law. Condition 7 must be satisfied to account for the amount of scattered light which is observed. The power received in the direction of a star will not differ from the small ($\theta_0 \sim 1$") to the large ($\theta_1 \sim 10$") aperture of the IUE telescope if $\alpha \gg 1$ (equation 9). r_a less than 1.2 will be achieved for $\alpha \geq 5$, i.e. $\theta_{min} \leq 10^{-5}$".

In general, for observations made with an aperture $\theta_1 \sim 10^{\alpha_m}$", and provided that the θ^{-2} dependence of the surface brightness extends to 10^{α_m}", r_a will be $1 + \alpha_m/\alpha$. This result also depends upon the filling factor of the scattering medium.

7. Conclusion

The UV spectrum of selected stars with a bump and moderate reddening was decomposed into two parts. The first part is the expected extinction of starlight, $e^{-\tau_\lambda}$, with τ_λ a linear function of $1/\lambda$. The second is the FUV bump, observed in figure 2, which is superimposed on the tail of the exponential decrease. This additional component was interpreted as starlight scattered by interstellar dust at very small angle to the star.

This decomposition is justified by the very close exponential fit which can be applied to the long wavelength exponential decrease of the spectrums (figure 4 to 6). The exponent of the exponential is $e = 2E(B-V)/\lambda$, as in the optical. The exponential fit extends to the UV the linear relation between A_λ and $1/\lambda$ which applies in the optical. There is no excess of extinction at 2200 Å in the spectrum of the stars which have been selected.

The additive nature of the FUV bump follows from the analysis of figure 2 carried out in sections 4 and 6. Its' interpretation as scattered starlight is then the most credible one. This interpretation provides a simple explanation of the similarities and of the differences between the bumps in the different directions (section 6.2). If scattering is present in the spectrum of the stars, most of it must occur at less than 1" to the star. It implies a strong forward scattering phase function of the interstellar grains, as found in paper I. An attempt to justify the amount of scattered light ($\sim 15\%$ of the star flux measured on earth and corrected for reddening) was proposed in section 6.4. It involves the power law found in paper I, which need to be confirmed, of the variation of a nebula maximum surface brightness with angular distance to the illuminating star.

This interpretation of the UV spectrum of the stars has two important consequences.

If the UV spectrum of some stars with a bump is explained without requiring an excess of extinction from the bump carriers at λ_b, all the stars' UV spectrum must have a similar interpretation. There is no reason why scattering should affect the spectrum of some stars solely and/or why the bump carriers should be present in some nebulae only.

In the directions of the selected stars, the extinction curve, A_λ as a function of $1/\lambda$, is a straight line from the near infrared to the FUV. The value of A_λ at wavelength λ is given by the equation 1. If, as it was suggested in paper I, grains have the same properties in all directions of space, this law must hold for all directions.

Why is scattering so important in the FUV? A first reason comes from the extinction of starlight which is increased when moving to the shortest wavelengths. Consequently, at short wavelengths, the scattered starlight will be a larger part of the total light received in the direction of a star. It is also plausible that the structure of the interstellar medium favors scattering at particular wavelengths. A medium constituted of small clumps of similar A_V will scatter starlight in a particular wavelength range: high A_V clumps will preferentially scatter toward the red while very low column density clumps will scatter in the UV. Although this aspect of scattering was not developped here, it may be an important step in the comprehension of the spectrum of the stars.

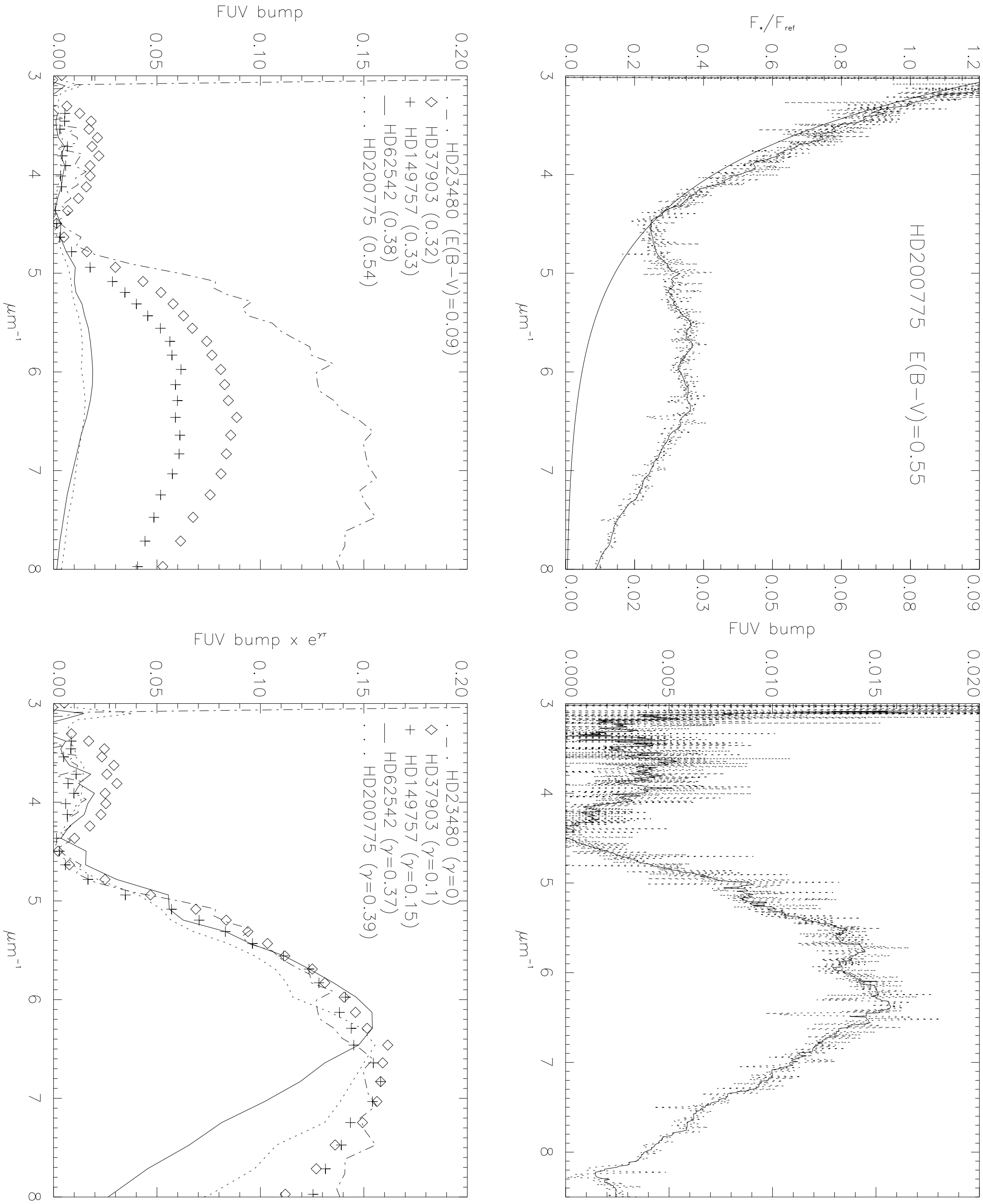

Fig. 6. *upper plots*: Same as in figure 4. *bottom left*: The absolute reduce spectrum of the stars are presented on the same plot. *bottom right*: The absolute reduce spectrums are scaled to a similar maximum value (~ 0.15). The spectrum are multiplied by an $e^{-\tau'_\lambda}$ function. τ'_λ was empirically determined using equation 2 and $R_V = 3$.

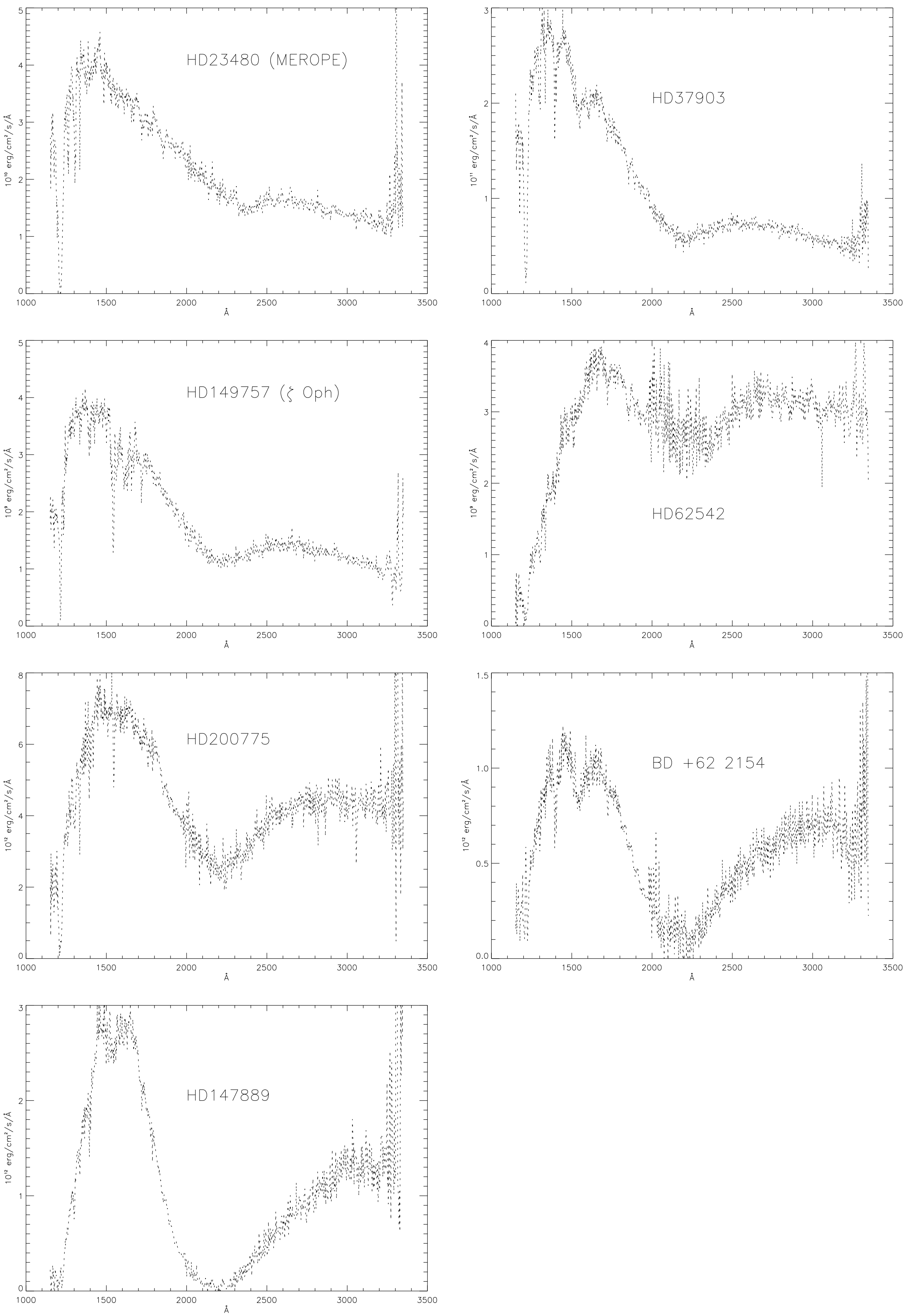

Fig. 7. UV spectrum of the reddened stars used in the paper.

name	α_{1950}	δ_{1950}	l	b	B	$B-V$	$E(B-V)$	sp. type	Par^{a1}	$\star_{st}^{a2}$
BD +62 2154	22 58 33	+63 14 52	110.94	+03.26	9.76	0.43	0.68	B1V		6
HD147889	16 22 23	−24 21 07	352.86	+17.04	8.66	0.71	0.96	B2III/IV	7.36	3
HD149757 ζ Oph	16 34 24	−10 28 02	62.8	+23.59	2.595	0.017	0.33	O9V	7.12	1
HD200775	21 01 00	+67 57 55	104.06	+14.19	7.73	0.31	0.55	B2Ve	2.33	5
HD23480 Merope	03 43 21	+23 47 39	166.57	-23.75	4.113	-0.051	0.09	B6IVe	9.08	2
HD37903	05 39 07	−02 16 58	206.85	-16.54	7.91	0.07	0.32	B1.5V	2.12	6
HD62542	7 40 58	−42 06 37	255.92	-09.24	8.21	0.18	0.38	B3V	4.06	4

$a1$ parallaxe in $marcsec$ measured by Hipparcos

$a2$ associated standard star number. Refers to table 2

Table 1. Stars used in the paper. Except for notified exceptions, all informations come from Simbad database (http://simbad.u-strasbg.fr). $(B-V)_0$ from FitzGerald 1970

N°	name	α_{1950}	δ_{1950}	l	b	B	$B-V$	$E(B-V)$	sp. type	Par^a
1	HD214680	22 37 00	+38 47 22	96.65	-16.98	4.673	-0.2	0.1	O9V	3
2	HD215573	22 45 48	−80 23 19	309.03	-35.53	5.190	-0.123	0.017	B6IV	7.35
3	HD31726	04 55 27	−14 18 28	213.5	-31.51	5.928	-0.206	-0.034	B2V	3.28
4	HD32630	05 03 00	+41 10 08	165.35	+00.27	3.012	-0.146	0.054	B3V	14.87
5	HD58050	07 21 37	+15 36 58	202.53	+14.19	6.261	-0.187	0.053	B2Ve	0.67
6	HD74273	08 39 30	−48 44 36	267.13	-04.27	5.69	-0.21	0.04	B1.5V	2.12

a parallaxe in $marcsec$ measured by Hipparcos

Table 2. Standard stars used for the stars in table 1. All informations come from Simbad database (http://simbad.u-strasbg.fr). $(B-V)_0$ from FitzGerald 1970

Appendix A: The possible explanations of the 2200 Å bump

Bless & Savage (1972) review the possible causes of the bump: stars with a bump have a peculiar energy distribution; a large amount of starlight is scattered into the line of sight by interstellar dust; the extinction properties of the interstellar medium are particular in the UV.

Because of its relation to $E(B-V)$, the bump does not originate in the stars' atmosphere, nor does it come from a special energy distribution.

One explanation has been widely accepted and developped in all studies of the feature: the bump is due to a special class of interstellar grains which extinguish light at 1175 Å. According to studies of the bump in various environments (Savage 1975, Jenniskens & Greenberg 1993, Nandy et al. 1976), those grains are well mixed (in all environments) to the large grains population responsible for the 'normal' extinction process of starlight.

The last possibility, that scattered light enters into the beam, was ruled out for reasons to be discussed in A.1..

A.1. Arguments used against scattering

3 types of arguments were used to rule out the possibility of scattering as an explanation for the bump.

According to Bless & Savage (1972), Code has calculated that grains of albedo close to one are required to produce enough scattering to explain the UV extinction curve. However those calculations suppose isotropic scattering. The importance of forward scattering, and its' consequences for our interpretation of the UV spectrum of nebulae has been emphasized in paper I. Introduction of forward scattering will invalidate Code's calculations.

Snow & York (1974) have compared the spectrums of σ Sco from 2 different observations, each of which involves a camera of different aperture. The Wisconsin spectrometer aboard the Orbiting astronomical Observatory 2 (OAO-2) has a large aperture of $8' \times 3°$, while the Princeton OAO-3 has an entrance slit $0.3'' \times 39''$, 10^3 smaller than OAO-2. Thus, if the UV spectrum of stars with a bump was due to pollution by scattered nebular light, the authors expect to find differences between the 2 spectrums. No such difference is observed.

Snow & York's work imposed a serious constraint on interstellar grains but did not demonstrate the abscence of scattering in the UV spectrum of stars. If the phase function is strongly forward scattering, that is if the assymetry parameter g_0 is close to 1, significant scattering will come only from directions very close to the star. Both observations used by Snow & York have relatively large apertures, and will receive nearly equal amounts of scattered light.

Snow & York's experiment can be repeated with IUE data. In most of the stars observed with both apertures of the IUE camera there is a scaling factor of 1.2 to 2 between the L and S aperture spectrums, regardless of the star reddening. This difference also affects unreddened stars and is probably due to the difficulty of holding the star within the beam when using the small aperture. Hence, if UV spectrums are affected by scattering, it must occur at angular distances less than 1.5" from the star.

Witt & Lillie (1973) study the diffuse Galactic light (DGL) spectrum from the OAO-2 satellite. The arguments of this paper rely on models of both the interstellar medium, assumed to be a plane parallel slab of uniform density, and of interstellar grains. The apparent disagreement between the model and the observations is attributed to changes of dust albedo with wavelength and to a pronounced minimun of the albedo at 2200 Å

(λ_b). No DGL spectra is presented in Witt & Lillie's paper but their results imply a pronounced minimum of the DGL at λ_b.

IUE has observed over 400 off-positions, 'IUE SKY', free of luminous objects. Many of the observations have some cirrus on their line of sight, the 100 μm IRAS emission can range from 1 to a few 10 MJy/sr. The only region I have found with a reliable signal across the entire LWR camera wavelength range is spatially close to -and probably scatters the light of- the star cluster NGC1910. It has a level of $8\,10^{-14}$ erg/cm^2/s/Å and no bump. In all other observations the emission shortward of 2600 Å has a very broad amplitude which can be attributed either to noise or to a very low level of signal. None of the spectrums, even when many of them are co-added, shows evidence for extinction at 2200 Å.

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