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THE ULTRAVIOLET INTERSTELLAR EXTINCTION CURVE IN THE PLEIADES

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ABSTRACT

The wavelength dependence of ultraviolet extinction in the Pleiades dust clouds has been determined from *IUE* observations of HD 23512, the brightest heavily reddened member of the Pleiades cluster. There is evidence for an anomalously weak absorption bump at 2200 Å, followed by an extinction rise in the far ultraviolet with an essentially normal slope. A relatively weak absorption band at 2200 Å and a weak diffuse absorption band at 4430 Å seem to be common characteristics of dust present in dense clouds. Evidence is presented which suggests that the extinction characteristics found for HD 23512 are typical for a class of extinction curves observed in several cases in the Galaxy and in the LMC.

Subject headings: clusters: open — interstellar: matter — ultraviolet: spectra

I. INTRODUCTION

The bulk of existing measurements of interstellar extinction in the ultraviolet (see Savage and Mathis 1979 for a comprehensive review) relate to the local galactic environment of diffuse interstellar clouds. The most outstanding characteristic of this extinction is the presence of a broad bump centered near 2175 Å, discovered by Stecher (1965, 1969) and found to be of a strength well correlated with the visual color excess $E(B-V)$ (Savage 1975; Nandy *et al.* 1975). For reasons of insufficient instrumental sensitivity and other observational selection effects, no systematic study has yet been completed of the ultraviolet extinction of stars observed through dense interstellar clouds or nebulae. There are some indications from the observation of individual heavily obscured objects by Bless and Savage (1972), Snow and York (1975), and Wu, Gilra, and van Duinen (1980) that the ultraviolet extinction is reduced in such cases.

The Pleiades dust clouds are of particular interest. Their association with the Pleiades cluster appears to be the result of a chance encounter (Arny 1977), and they may therefore be considered examples of normal dense interstellar clouds, still unmodified by the process of star formation. Estimated densities lie in the range $n_{H_2} \approx 500$–1000 cm^{-3} (Jura 1979; Witt 1977). An added opportunity of study is provided by the high surface brightness of the Pleiades reflection nebulae in the ultraviolet (Andriesse, Piersma, and Witt 1977), opening the possibility of examining separately the extinction and the scattering properties of dust in dense clouds.

The luminous B stars in the Pleiades exhibit only a very very small amount of reddening, indicating that their location is near the front of the Pleiades dust clouds. The brightest among the more heavily reddened members of the Pleiades cluster is HD 23512 (Hz 371, H II 1084).

II. GROUND BASED DATA

The spectral type of HD 23512 is most frequently listed as A0 V (Mendoza 1956; Johnson and Mitchell 1958; Jaschek, Conde, and de Sierra 1964), although there exists also a classification of this star as late as A1.5 (Petrie 1965). Unfortunately, this lack of agreement leads to uncertainties in the shape of the extinction curve at wavelengths $\lambda < 1600$ Å, where the flux of an A1.5 star begins to fall significantly below that of an A0 star (Sitko, private communication). Possibly, one contributing cause for the classification uncertainty is the high rotational speed ($v \sin i = 155$ km s^{-1}, Abt and Hunter 1962, Anderson, Stoeckly, and Kraft 1966). For the purpose of this investigation we shall follow Johnson and Morgan (1953) and Jaschek (1975) in taking the spectral type of HD 23152 as A0: V, a weighted average of existing classifications.

The membership of HD 23512 in the Pleiades cluster has been established by Johnson and Mitchell (1958) on the basis of *UBV* photometry and existing proper motion measurements, thus ensuring that the reddening observed in HD 23512 is indeed local to the Pleiades dust clouds. The photometric data on HD 23512 due to Johnson and Mitchell (1958) are contained in Table 1.

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TABLE 1

PHOTOMETRIC DATA AND SPECTRAL TYPES OF HD 23512 AND COMPARISON STARS

Star	HD	V	$B-V$	$U-B$	Sp.T.
	23512[a]	8.11	0.36	0.29	A0 V
ζ Aql.....	177724[b]	2.99	0.01	0.00	A0 Vn
48 Cet....	9132	5.12[c]	0.02[c]	0.02[c]	A1 V[d]

[a] Photometric data from Johnson and Mitchell 1958.
[b] Data from Cowley *et al.* 1969.
[c] Data from Eggen 1963.
[d] Classification due to Cousins and Stoy 1963.

Intensive radial velocity studies of HD 23512 by Abt *et al.* (1965) give good reason to assume that the star is single, and an extensive search for pulsating variables in the Pleiades cluster by Breger (1972) has revealed HD 23512 to be constant in its visual magnitude to within 0.001 mag. From these aspects this star should therefore be a suitable object for reddening studies.

There is some evidence that the ratio $R_V = A_V/E(B-V)$ of total to selective extinction for HD 23512 exceeds the normal value of $R_V = 3.1$. A summary of available values of R_V for HD 23512 is given in Table 2 together with an indication of methods used and the references where these results are discussed in detail. Serkowski, Gehrels, and Wisniewski (1969) find a rather unique wavelength dependence of polarization in HD 23512 with a steeper than "normal" rise from the IR to a maximum near 5800 Å, followed by a normal decline toward the UV, ending, however, in a unique rise again at $\lambda^{-1} = 2.78\ \mu m^{-1}$ and $3.03\ \mu m^{-1}$.

Finally, Wampler (1966) identified HD 23512 as one of a small group of significantly reddened stars with barely observable λ4430 absorption. λ4430 is below normal strength in this star by at least a factor of 5.

III. THE ULTRAVIOLET EXTINCTION

Data on the ultraviolet flux distribution of HD 23512 in the 1250–3100 Å range were obtained with the *International Ultraviolet Explorer* (*IUE*). The observed flux distribution is shown in Figure 1. A description of the instrument and its performance has been given by Boggess *et al.* (1978). The record of observations is contained in Table 3. The overexposures, where they occurred, were made deliberately in order to provide adequate data for the weak parts on the correctly exposed spectra. Small-aperture spectra covering the short-wavelength region were normalized to the mean of the large-aperture data in the 1600–1725 Å range and subsequently averaged in 5Å bins. Normalization for the long-wavelength region occurred in the 1950–2150 Å region, also followed by averaging.

The absolute level of response was adjusted to 8°C for short wavelength prime (SWP) and 12°C for long wavelength redundant (LWR) using the −0.8% per degree C temperature coefficient from Bohlin *et al.* (1980). All wavelengths were reduced to those appropriate for the mean dispersion constants given by Turnrose, Bohlin, and Harvel (1979), using the correction technique of Harvel, Turnrose, and Bohlin (1979). Since *IUE* data were used for the comparison stars as well, no uncertainty in the absolute calibration enters into the results. Any change in the *IUE* sensitivity over the time period of the several observations is less than 5% (Holm, private communication).

The derivation of extinction curves was done by comparison of HD 23512 with the standard stars ζ Aql (A0 V), and 48 Cet (A1 V). Photometric data for the comparison stars are listed in Table 1, and the record of their ultraviolet observations is contained in Table 4.

TABLE 2

RATIO OF TOTAL TO SELECTIVE EXTINCTION FOR HD 23512

$R_V = A_V/E(B-V)$	Method	Reference
3.7..................	Variable extinction	Eggen 1950
4.2..................	Variable extinction	Mendoza 1965
3.6..................	*UBVRIJK* extinction curve	Mendoza 1965
3.1..................	Variable extinction	Guthrie and Nandy 1966
3.3..................	*UBVRIJK* extinction curve	Guthrie and Nandy 1966
3.4..................	4-color, H-β photometry	Crawford and Perry 1976
3.97 }	Wavelength of maximum	Serkowski 1968
4.5 }	polarization	Serkowski *et al.* 1969

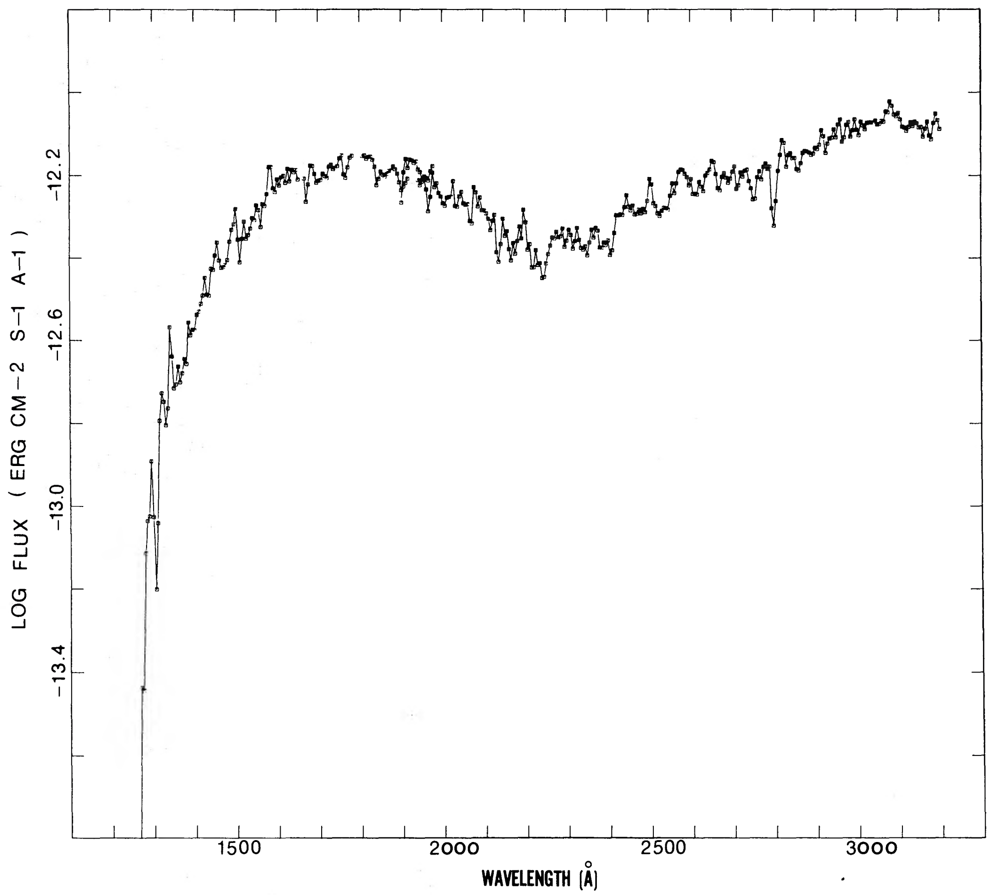

FIG. 1.—The ultraviolet flux distribution of HD 23512 as derived from the IUE observations listed in Table 3.

We followed the standard procedure of deriving extinction curves:

$$E(\lambda-V)=(m_\lambda-V)_{\mathrm{HD}\,23512}-(m_\lambda-V)_{\mathrm{comp}}, \quad (1)$$

where $(m_\lambda-V)_{\mathrm{comp}}$ is the color of the comparison star in each case. The results are plotted in Figure 2 in the normalized form $E(\lambda-V)/E(B-V)$ against inverse wavelength, together with an average reddening curve of Savage and Mathis (1979).

The weakness of the 2200 Å feature is pronounced in HD 23512 and is not dependent upon this star's spectral type being A0 V or A1 V. In this regard HD 23512 joins a group of stars with weak 2200 Å absorption involved in dense nebulosity, with θ^1 Ori and NU Ori

TABLE 3

IUE OBSERVATIONS OF HD 23512

Exposure (°C)	$\mathrm{TH_D}$ A	Exposure Time[a] (min)	Remarks
SWP 5981....	6.1	20 LA	TV readout problem (not used)
LWR 5198...	12.8	8 LA	Some overexposure
		30 SA	Some overexposure
LWR 5201...	12.2	5 LA	OK
		30 SA	Some overexposure
SWP 7575....	6.5	20 LA	OK
SWP 7576....	6.8	40 LA	Some overexposure

[a] LA = large aperture; SA = small aperture.

TABLE 4

IUE OBSERVATIONS OF STANDARD STARS

Star	*IUE* Image Numbers
ζ Aql ...	SWP 8269 LA, SWP 8273 LA
	SWP 8270 SA, SWP 8271 SA, SWP 8272
	LWR 7292 LA, LWR 7296 LA
	LWR 7293 SA, LWR 7294 SA, LWR 7295
48 Cet...	SWP 6475 LA, SA
	LWR 5557 LA, SA

(Bless and Savage 1972; Savage 1975) and HD 200775 (Witt and Cottrell 1980; Walker *et al.* 1980) being notable examples. These stars also have ratios $A_{4430}/E(B-V)$ significantly below normal (Wampler 1966). In the case of θ^1 Ori it has been suggested that the weakness of the 4430 Å and the 2200 Å absorptions is a result of the star's influence on the grains in its vicinity. Now that the relatively cool star HD 23512 shows a similar relationship, it appears to us that the simultaneous weakness of the two broad bands at 4430 Å and at 2200 Å is more a result of the general conditions in dense obscuring clouds than of a star's strong radiation field.

This result is also significant because Dorschner, Friedemann, and Gürtler (1977) have shown that for the general interstellar medium the strength of both bands is more closely correlated to the visible reddening $E(B-V)$ than are the strengths of the two bands with each other. This points at the existence of two partially independent agents for the absorptions at 2200

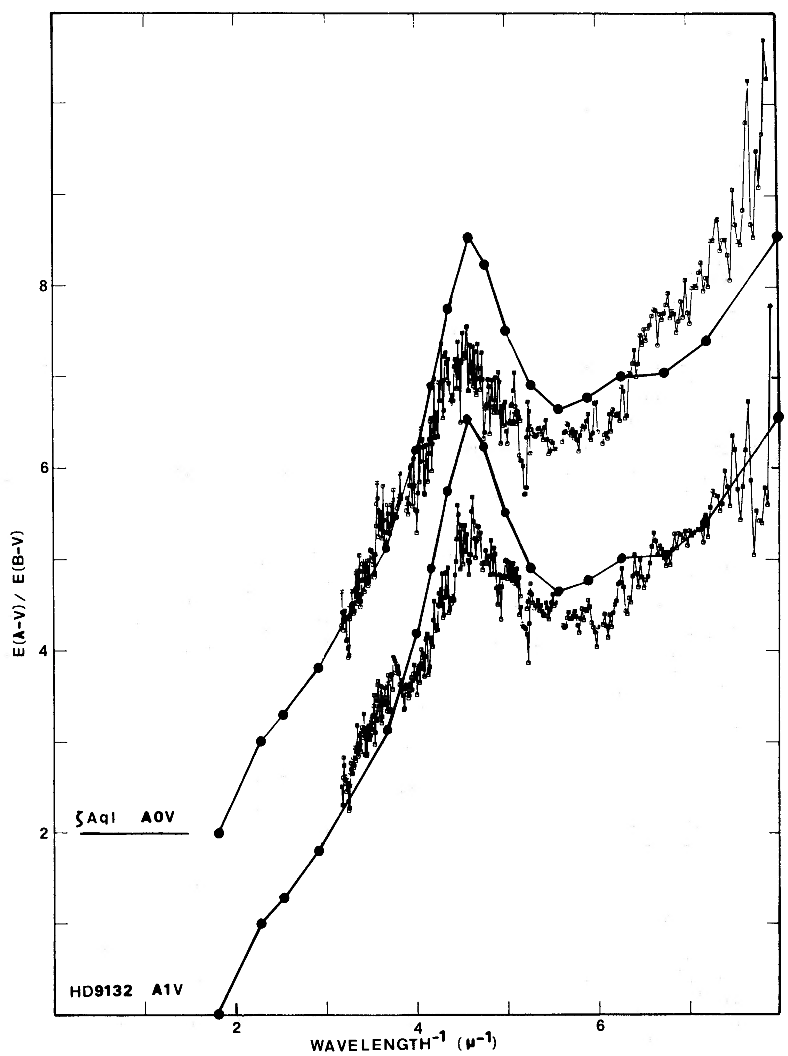

FIG. 2.—The UV reddening curve of HD 23512 as derived by comparison with ζ Aql (A0 V) (*top*) and 48 Cet (A1 V) (*bottom*). The two curves are vertically displaced by two units, and are individually compared with the average wavelength dependence of interstellar extinction according to Savage and Mathis (1979).

Å and at 4430 Å, which are affected, however, in a very similar fashion in high density clouds. This is in agreement with the conclusions of Ferro (1980), who finds the 4430 Å band strength to be not particularly well correlated with ultraviolet extinction.

Whittet and Blades (1980) found three stars in the CMa R1 association (HD 52721, HD 53367, HD 53974) to have weak diffuse bands for their observed reddening with HD 53367, the most heavily reddened one of the three having a weak 2200 Å extinction bump as well, which provides further support for the indicated trend. Data at 2200 Å for the other two stars were not yet available.

The uncertainties in the spectral classifications of HD 23512 and of the two standards allow us only to state that the far-UV extinction at $\lambda^{-1} > 6.5$ appears to be normal for HD 23512, but the possibility that the far-UV extinction is higher than normal cannot be ruled out entirely. In either case, such a finding would lend support to the result of Massa (1980), who showed that the extinction in the 2200 Å bump and the rise in the far-UV extinction observed in a large sample of stars by the TD-1 satellite are the likely result of two different components of the interstellar grain distribution.

Other recent observational support for this concept can be found in the extinction curve of HD 200775, the central star in the bright reflection nebula NGC 7023. This reddening curve closely resembles that of HD 23512 if one assumes a reasonable amount of intrinsic reddening $E(B-V)_{\rm intr}$ for the Be star HD 200775 (Viotti 1976; Witt and Cottrell 1980; Walker *et al.* 1980). Figure 3 shows the extinction curve of HD 200775 for the cases $E(B-V)_{\rm intr} = 0.19$ and 0.00 with η UMa as comparison star, as derived from our *IUE* observations of these objects. Additional evidence for a more widespread existence of extinction conditions involving a relative overabundance of small grains, resulting in excess far-UV extinction while leaving the extinction at visual wavelengths relatively normal, has been provided by Nandy *et al.* (1980) and by Koorneef (1980). Based on recent *IUE* observations, the authors found that numerous stars in the LMC revealed extinction conditions characterized by a weak 2200 Å bump and above normal far UV extinction. Finally, the classic study of UV extinction of Bless and Savage (1972) revealed the star ζ Oph to exhibit a similar extinction curve.

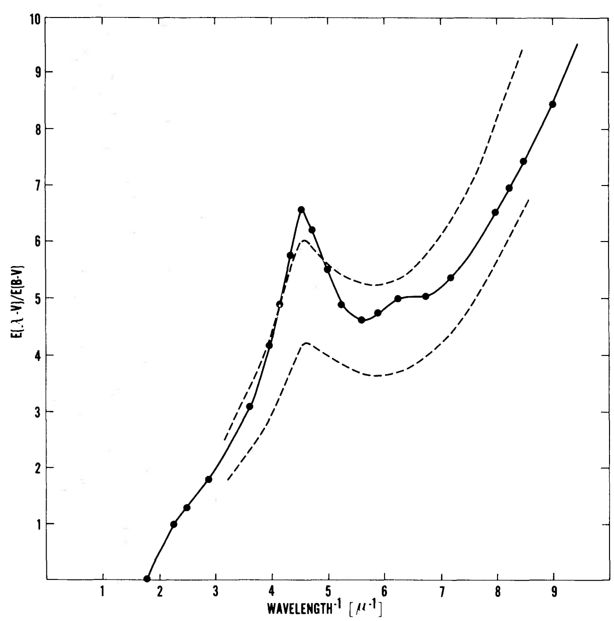

FIG. 3.—Extinction curves for HD 200775 (B3 Ve) derived with the assumption of intrinsic reddenings $E(B-V)_{\rm intr} = 0.19$ (*upper dashed curve*) and $E(B-V)_{\rm intr} = 0.0$ (*lower dashed curve*). The comparison star is η UMa (B3 V). The standard curve (*solid line*) is the average extinction curve of Savage and Mathis (1979). The same vertical scale applies to all three curves shown.

We are therefore led to the conclusion that in addition to the class of anomalous extinction curves as represented by those of θ^1 Ori, σ Sco, and NU Ori, where both the 2200 Å absorption and the far-UV extinction are below normal for the observed reddening in the visual, there is a second class of extinction curves with a weak 2200 Å absorption band but with a normal or above normal far-UV extinction. This suggests that the 2200 Å absorption and the rise in the far-UV extinction are caused by two different components in the interstellar dust. It is possible, therefore, that in molecular clouds where the dust has been affected by the presence of hot stars such as in the case of θ^1 Ori, the observed weakness of the 2200 Å extinction bump is an intrinsic property of the dust in the dense cloud, and only the decreased ultraviolet extinction is caused by the presence of hot stars.

Our result of a steep extinction rise in the far-UV in dense clouds is important because a significant fraction ($\sim$50%) of the interstellar matter in the Galaxy is contained in dense molecular clouds. The wavelength dependence of far-UV extinction is of major influence in determining the density of far-UV photons in these environments, and our result, if generally applicable, would lead to a reduction in the photon density compared with previous estimates.

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