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Spatial correlation between CH, CN and the diffuse interstellar band carriers

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SUMMARY

Observations are presented of the diffuse interstellar bands at 5780 and 5797 Å and of the ultraviolet lines of CH and CN in the light of six bright stars which lie behind isolated interstellar clouds. It is found that CN and CH are only present when the 5797 band is deeper than the 5780 one. Comparisons with satellite measurements of the UV extinction show that the shape of the extinction curve is linked to the same band ratio in these stars. The results support a previous suggestion that the various components of the absorption spectrum of an isolated cloud (the extinction law, atomic and molecular features and the diffuse interstellar bands) all vary together.

Key words: dust, extinction – interstellar medium: clouds – interstellar medium: molecules – ultraviolet: interstellar.

1 INTRODUCTION

It has already been suggested (Kreƚowski 1990) that the absorption interstellar features such as extinction, polarization, atomic lines, molecular features, diffuse interstellar bands (DIBs), and far-IR absorption features are related in some way, i.e. it is not possible to change one of the constituents and not change the others. All of these features are known to characterize the absorption spectra of isolated interstellar clouds. There is preliminary evidence that such clouds tend to fall into one or the other of several distinct categories (Kreƚowski 1990). This fact may be of basic importance in eventually solving the longest standing problem in astrophysical spectroscopy: the identification of the carriers of the diffuse bands.

The availability of sensitive electronic detectors has allowed the accurate measurement of weak spectral features originating in single clouds. It is well known that the molecular content of diffuse clouds may vary significantly from cloud to cloud, as discussed recently by Crawford (1989). Thus molecular absorption features may be very sensitive probes of the conditions inside H I clouds. It has also been suggested that the extinction law may be related to observed abundances of atoms or molecules (Joseph, Snow & Seab 1989). The molecular abundances may depend strongly on the far-UV extinction, as it shields the molecules inside the cloud against the diffuse far-UV photons. The work of Danks, Federman & Lambert (1983) shows rather clearly that the CH molecule is much more abundant (by a factor of 7) toward ζ Oph (HD 149757) than towards σ Sco (HD 147165). The extinction curves of these stars have been well known since the Bless & Savage (1972) paper (the far-UV extinction being much stronger in the former). Moreover, the recent paper of Kreƚowski & Westerlund (1988) showed the very different intensity ratios of 5780- and 5797-Å DIBs observed in the spectra of these two stars. The possible connection between molecular species and UV extinction on the one hand, combined with the suggestion that the DIB ratios might also be linked to UV extinction, argues for a possible spatial correlation between the DIB carrier and simple molecules. In order to test this, it is important to compare spectra of single clouds characterized by different UV extinction curves. It is of basic importance to make such comparisons between the absorption spectra of a couple of clouds belonging to each type.

2 OBSERVATIONS

The main goal of this project is to test whether clouds characterized by very different extinction curves also show systematically different ratios of the diffuse bands and molecular column densities. In selecting stars for our programme, we have focused our attention on bright objects which are very likely to be situated behind isolated clouds (Table 1). These early-type stars are also relatively heavily reddened, which should facilitate precise measurements of the depths and equivalent widths of DIBs. Three of them are known as being obscured by clouds reminiscent of that of σ Sco, and three are similar to ζ Oph – see Fig. 1. The observations of sharp molecular features may additionally

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Table 1. Basic data for programme stars and equivalent widths of diffuse bands.

HD number	E.W. [mÅ] 5780	E.W. [mÅ] 5797	V [mag]	MK Sp/L	B-V	E(B-V)
23180	78	58	3.83	B1 III	0.05	0.26
24398	89	55	2.85	B1 Ib	0.12	0.28
149757	66	35	2.56	O9.5 Vn	0.02	0.29
164353	107	23	3.97	B5 Ib	0.02	0.12
184915	148	22	4.95	B0.5 III	0.00	0.22
198478	295	70	4.84	B3 Iae	0.41	0.53

allow us to confirm our expectations that the dense, molecule-forming portion of the interstellar medium toward our targets consists of only one major component along any line of sight (if the observed profiles of these features are narrow and symmetric, i.e. free of Doppler splitting).

Our observations were obtained at the 3.6-m Canada–France–Hawaii Telescope (CFHT) in 1989 September. The telescope fed the coudé spectrograph which formed the spectra in the Reticon detector system. The system yields an effective (two pixel) spectral resolution of 0.14 Å (about 7.5 km s^{-1}) at 5780 Å. Observing conditions were excellent; the seeing was typically around 0.5 arcsec. The CFHT Reticon yields very high signal-to-noise ratios for short- to moderate-duration exposures, which are dominated by the readout noise.

Data reduction was carried out at the Colorado Astrophysics Data Analysis Facility, using routines developed in the IDL language for CFHT reductions. The reductions are quite straightforward: dark counts are subtracted, divisions by flat-field spectra obtained at the telescope are performed to eliminate fixed-pattern noise, and wavelength calibrations are derived from neon–argon lamp spectra obtained at the telescope.

Our targets have been observed both in the spectral ranges of the strong 5780 and 5797 diffuse bands and the molecular features of CN (situated between 3874 and 3876 Å) and CH (3878.8, 3886.4 and 3890.2 Å). The expected weakness of the observed features puts strong requirements on the quality of the spectra. Thus special attention has been paid to the high signal-to-noise ratio of the recorded spectra.

3 RESULTS

Our targets have been divided into two subsamples: one containing the objects characterized by a rather high ratio of 5780 to 5797 (called the 'sigma' family) by Krełowski (1989) and those in which 5797 is deeper than its neighbour (the 'zeta' family). Fig. 1 presents the *TD/1* extinction curves of the target stars. Three of them are taken from the recent atlas by Papaj, Wegner & Krełowski (1991): these are HD 23180, 149757 and 184915. To calculate the extinction curve for HD 24398, we have constructed the artificial standard using the method described by Papaj, Wegner & Krełowski (1990). The extinction curves for the remaining two stars are calculated using unreddened stars as standards: HD 86440 for HD 164353 and HD 53138 for HD 198478. The subsamples are characterized by different extinction laws, the most uncertain case being HD 198478 in which the most far-UV segment of the original spectrum was probably vertically shifted in relation to the other two (see Papaj *et al.* 1990 for

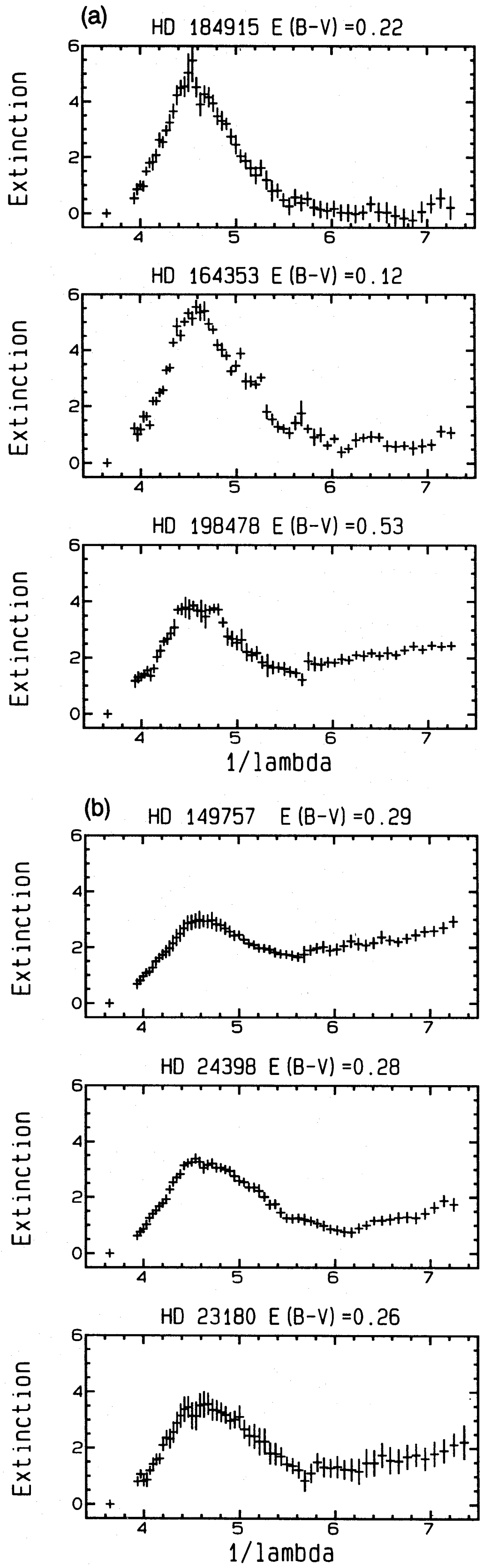

Figure 1. The ultraviolet extinction curves derived from *TD/1* spectra of the programme stars. The 'Extinction' means the ratio of $E(\lambda-2740)/E(B-V)$. Note the differences in shape of the 2200-Å bump and of the far-UV rise between the two families of objects: 'sigma' – (a) and 'zeta' – (b).

comments). The differences in shapes of the 2200-Å extinction bump, as well as in the far-UV rise of extinction, may suggest different physical conditions inside the intervening clouds.

Fig. 2 shows the spectra of our targets belonging to the 'zeta' and 'sigma' families. The former show a deeper 5797 band, while the latter resemble the case shown already by Herbig (1975) with the 5780 DIB being much stronger. The measured equivalent widths of the two diffuse bands are also included in Table 1. The latter case occurs much more frequently in spectra of reddened stars. The high signal-to-noise ratio is clearly seen in our spectra, shown in Fig. 2 without smoothing. Thus the different ratio of the observed DIBs is proved beyond doubt.

Fig. 3 presents the near-UV spectral ranges in the spectra of the same stars. The range contains several stellar lines, observed as very broad features; in ζ Oph and κ Aql the fast rotation makes them invisible. Such spectra are most useful for measuring sharp, interstellar lines. The pattern of quite strong molecular features is clearly observed in the 'zeta' case. The high intensity of spectral features originating in simple molecules such as CN and CH is thus a typical feature of an interstellar cloud producing a relatively weak 5780 DIB and quite strong far-UV extinction, as observed in all 'zeta' cases. The situation in the 'sigma' family seems to be just the opposite. It is quite clear that molecular features are completely absent in this subsample. Thus we have found a very strong effect: the molecular features are proved to be very sensitive probes of the physical conditions inside dark interstellar clouds. We emphasize that the discovered effect is exceptionally marked, as the molecular features are either strong or completely absent. We note that the CN features have already been observed in the spectra of such representative objects of the 'sigma' family as σ Sco and β^1 Sco by

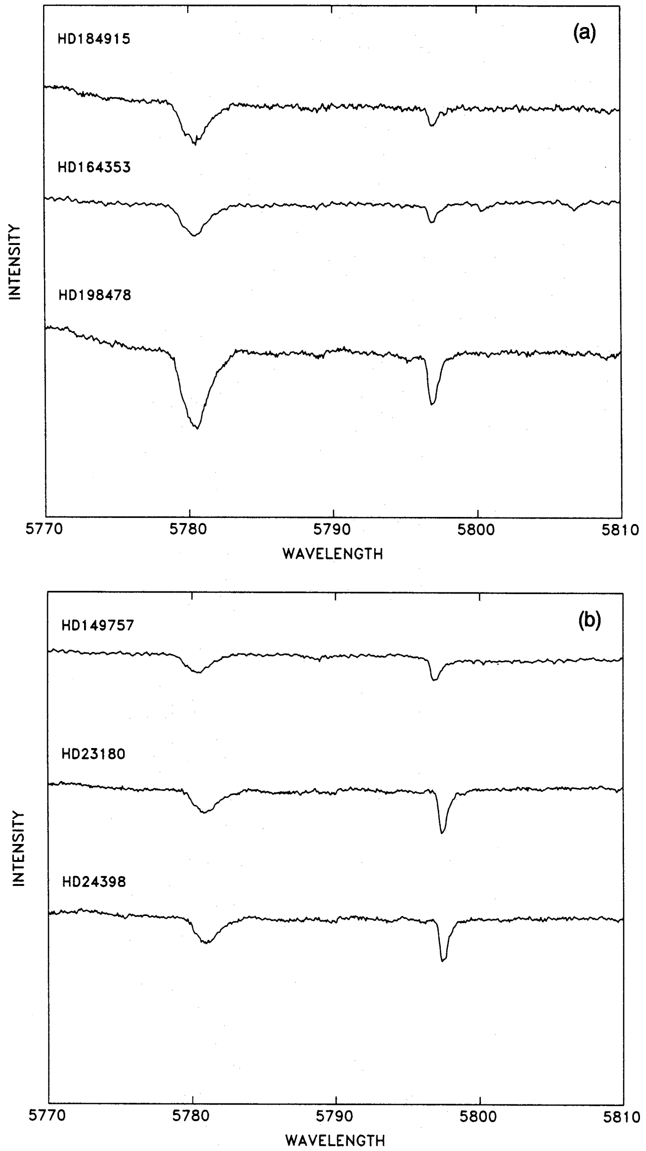

Figure 2. The strong 5780 and 5797 diffuse bands observed in the objects belonging to the 'sigma' family (a) and 'zeta' family (b). Note the significant difference in the intensity ratio of the two bands.

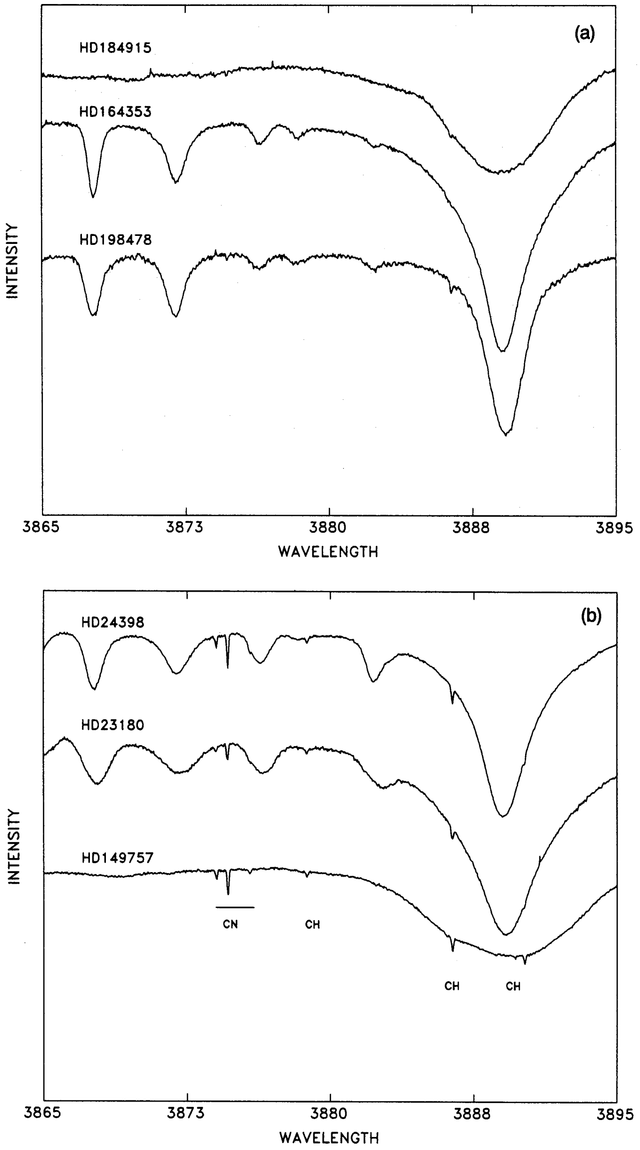

Figure 3. The sharp features of CN and CH molecules observed in the spectra of programme stars. Note the lack of these features in the 'sigma' family objects (a).

Federman, Danks & Lambert (1984). In that work, the authors were able to set only upper limits to the CN features, and these are consistent with our results.

4 CONCLUSIONS

Several important conclusions may be inferred from the above-mentioned observational results.

(i) The absorption spectra of dense diffuse interstellar clouds differ significantly from one object to another.

(ii) The differences in the shapes of the extinction curves are quite evidently related to differences in DIB ratios and intensities of molecular features. This fact is probably due to different shielding of cloud cores against the penetration of energetic, far-UV photons.

(iii) The behaviour of DIBs is strongly related to the observed intensities of molecular features formed in the same clouds.

(iv) The simultaneous changes of all components of absorption spectra of dark interstellar clouds suggest the possibility of a classification scheme for H I clouds based on simple optical diagnostics, a point already made by Joseph *et al.* (1989) and Krełowski (1989) – such a scheme would be helpful for finding a correct interpretation of the complicated cloud chemistry and physical processes which take place in the interstellar medium and influence the evolution of our Galaxy.

We must regard our current results as very suggestive, but yet also quite incomplete, since they are based on only six lines of sight [but recall that a similar conclusion was reached by Joseph *et al.* (1989) for a different and somewhat larger sample]. Our plan now is to compile data of comparable quality for a larger number of stars. This effort is already under way, using data from a recent CFHT observing run.

If our conclusions are substantiated when a larger sample has been studied, it may become possible to use optical indicators such as diffuse band ratios or molecular line strengths to predict the shape of UV extinction curves. This would be very helpful in analysing the conditions in interstellar clouds and would also have practical benefits for scientists planning UV observations for other purposes.

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