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Diffuse interstellar bands in Orion

The environment dependence of DIB strength

P. Jenniskens[1], P. Ehrenfreund[2], and B. Foing[3,4]

[1] Sterrewacht Leiden, P.O. Box 9513, NL-2300 RA Leiden, The Netherlands
[2] Service d'Aeronomie, B.P. 3, F-91371 Verrieres-le-Buisson Cedex, France.
[3] Institut d'Astrophysique Spatiale, Bat 121, Université Paris XI, F-91405 Orsay Cedex, France
[4] Space Science Department, ESA/ESTEC(SC), Postbus 299, NL-2200 AG Noordwijk, The Netherlands

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Abstract. Four Diffuse Interstellar Bands (DIB) have been measured in 22 lines of sight towards Orion and GMC214-13. The paper reports on the environment dependence of DIB strength, using reddening, the total extinction in the visual, and column densities of various forms of hydrogen as indicators of line of sight conditions.

In lines of sight with small reddening, $E_{B-V} < 0.08$ mag, a weakening of $\lambda6284$ and $\lambda5785$ is found relative to reddening (= all matter), but no weakening relative to atomic + molecular hydrogen (= all neutral matter). This probably implies that the DIB carriers are absent in the ionised HII medium. At higher reddening, where a significant part of hydrogen is in a molecular form, all DIBs in Orion decrease with increasing E_{B-V} in a similar way as is known for the Taurus and Ophiuchus dark clouds. In Taurus, where even in low reddened lines of sight a significant part of hydrogen is in molecular form, $\lambda6284$ is weakened compared to diffuse medium values at lower reddening than $\lambda6196$. In lines of sight towards the Orion Nebula, where molecular hydrogen is mostly dissociated, $\lambda6284$ is some 70% stronger, while $\lambda6196$ is a factor of 5 weaker than expected from the above dependence.

The results are discussed in the context that the carrier of the diffuse bands might be a large molecule in ionised form. The dissociation and ionisation state of hydrogen is used as an indicator of the UV field. The results above indicate that the $\lambda6284$ carrier is both ionised and destroyed by higher energy photons than the $\lambda6196$ carrier, which is consistent with a molecular carrier.

Key words: interstellar matter: dust, extinction – ISM: individual objects: Orion clouds – ISM: molecules – ISM: abundances

Send offprint requests to: P. Jenniskens, NASA/Ames Research Center, Mail Stop 239-4, Moffett Field, CA94035-1000, USA

1. Introduction

Diffuse Interstellar Bands (DIB) are absorption features in the visual and near infrared spectra of stars due to obscuring interstellar matter. There are more than 150 DIBs known to date and the number is still increasing. None of these has been identified with any certainty (e.g. Herbig 1975; Van der Zwet 1987; Krelowski 1989; Herbig & Leka 1991; Jenniskens & Désert 1993).

Among the many proposed origins are impurity absorptions in small solid grains (Merrill & Wilson 1938; Andriesse & de Vries 1981; Chlewicki et al. 1986) and vibronic transitions in molecules (Smith et al. 1977; Danks & Lambert 1976). Most recent attention has been given to the hypothesis that vibronic transitions in ionised PAHs, polycyclic aromatic hydrocarbons, may be responsible for the DIBs (Van der Zwet & Allamandola 1985; Crawford et al. 1985; Léger & d'Hendecourt 1985). These large molecules are thought to be abundant and have intense absorptions in the visual when in ionised form (e.g. Salama & Allamandola 1992; Ehrenfreund et al. 1992).

However, several observations appear to argue against an origin of DIBs in large molecules. DIBs are found in lines of sight of such a small reddening that molecular hydrogen is effectively dissociated (e.g. Meyer 1983). It was first shown by Snow & Cohen (1974) that the strength of the DIBs (W/E_{B-V}) decreases with increasing reddening E_{B-V} in the Ophiuchus dark cloud. From a similar result found for the Taurus dark cloud complex, Adamson et al. (1991) concluded that the relative weakness of the DIBs in dark clouds is driven by changing grain properties rather than by a suppression of the UV radiation field: differences in local UV radiation field do not show up in the strength of DIBs.

We have examined these arguments using new observations of 20 lines of sight towards the Orion molecular cloud and two lines of sight towards GMC214-13 (Fig. 1). These cloud complexes are well studied at radio wavelengths, from which information about the density distribution is obtained (e.g. Mad-

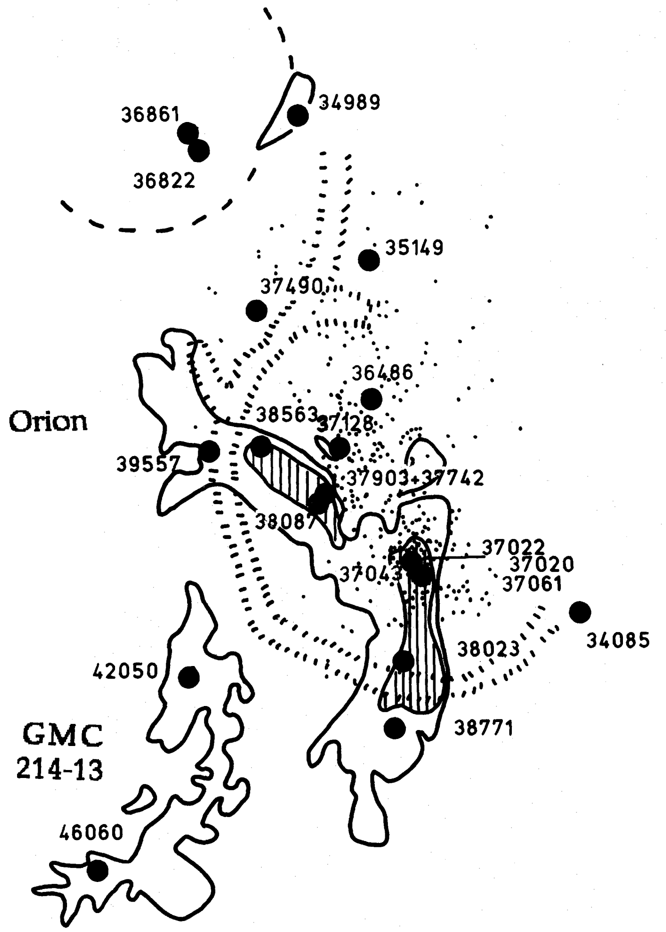

Fig. 1. Sketch of the Orion and GMC214-13 molecular cloud complexes. Small dots show the position of early type stars that are a member of the Orion OB1 association. The locations of the program stars are indicated. Barnard's Loop (double set of dashes) measures about 110 pc across

dalena et al. 1986; Jenniskens & Wouterloot 1990 - to which we refer also for a description of the region). Orion offers a more extreme case than Ophiuchus in terms of UV radiation field, and Orion offers the possibility to study low reddened lines of sight as many stars are found in front of the molecular cloud complex. Our attention focusses on the strongest of all DIBs, λ6284, and the neighbouring λ6177, λ6196 and λ6269. Note that the very narrow λ6196 has been assigned to a different DIB family than the broader λ6284 and the wide λ6177 (Chlewicki et al. 1986; Krelowski & Walker 1987). A family is a group of DIBs that responds to some environmental condition in the same way.

This paper compares DIBs towards stars imbedded in the giant molecular cloud with DIBs towards stars in the HII blister M42 and the lightly reddened stars in the rich OB association of Orion (Sect. 3.1) and considers relative DIB intensities in these lines of sight (Sect. 3.2). DIB strength in lines of sight with very low reddening ($E_{B-V} < 0.08$ mag) is discussed in Sect. 3.3. We argue in Sect. 4 that the results are consistent with large molecules rather than small solid grains as being the carriers of DIBs.

2. Observations

2.1. Data aquisition

The data were obtained with the 1.52m f27.6 Coudé telescope at the *Observatoire de Haute Provence*, France. The spectrograph "Aurélie" was equipped with a grating of 1200 lines/mm with a blaze at 5000 Å and a dispersion of 8.1 Å/mm, which covers all DIBs mentioned here in one spectrum. The spectrum is recorded by a 2048 diode linear Reticon array, which is read by two 1024px CCDs. The resulting resolution is R=15,000, $\Delta\lambda$ = 0.3 Å, and each resolution element is covered by 3 pixels.

2.2. Values of equivalent width

Overlaying absorptions of telluric oxygen and stellar HeII are removed from the spectra. The atmospheric O_2 band, with a band head at 6272 Å, is removed by dividing the spectra by that of a reference star scaled at an adequate airmass. The reference stars are HD32630 (B3V with broad stellar lines a.o. at 6267 Å) and HD34085 (bright, B8Ia but with narrow stellar lines at a.o. 6267, 6278 and 6288 Å). Remnants of the telluric band are easily recognized because of the high spectral resolution, and are found to affect the equivalent width of λ6284 only slightly. λ6177 is corrected for stellar line contamination by HeII at 6171 Å in O-type stars using the strength of the HeII line at 6234 Å, which is of the same multiplet (f.e. HD37022 in Fig. 2).

The equivalent width (W) is measured while setting the background consistently in all spectra. Values normalised to unit reddening are summarized in Table 1. Data are presented for λ6177, λ6196, λ6269 and λ6284. We only briefly discuss the blended DIBs λ6203 and λ6205, which were convincingly shown to have variable relative ratio's by Porceddu et al. (1991). The signal to noise in our data does not allow a Gaussian decomposition of those two lines. Occasionally, flatfielding residuals and baseline uncertainties render values for λ6196 and λ6177 of limited use. These are marked '-.-'.

As far as overlap of samples allowes, the reddening in column 2 is derived from Savage et al. (1977). These data are marked 'S' and are accurate to $\pm$0.02 mag. Other values are derived from the photometry listed in the Hipparchos Input Catalogue. The listed errors amount to typically $\pm$0.05 mag in reddening. Large photometric errors are quoted for HD46060 and HD37020 (same observer). However, these errors may be overestimated, because the resulting DIB strengths agree with values found from nearby stars HD42050 and HD37022/23 respectively.

2.3. A diffuse medium standard

The values are compared to those typical for the 'diffuse medium'. The lines of sight marked as such in Jenniskens & Greenberg (1993) have no enhanced 60/100 flux ratio's and no strongly enhanced 100 micron fluxes in the IRAS Skyflux maps. Data from Benvenuti & Porceddu (1989) and Désert et al. (1993) contain data for 9 of these stars: HD36879, HD123008,

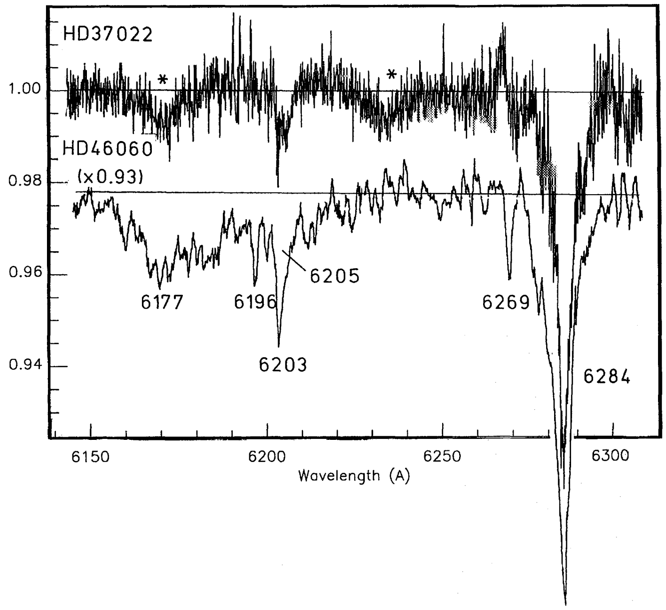

Fig. 2. Two representative spectra. Shown are HD46060 with a typical diffuse medium DIB spectrum (heavily smoothed), and HD37022 with nearly absent λ6177, λ6196, and λ6203 but strong λ6284 and λ6205 (at full resolution)

HD152233, HD152247, HD152248, HD152249, HD154445, HD162978, and HD199216. The average values (and 1 sigma spread) are listed at the bottom of Table 1 (indicated by Dif). It is not guaranteed that the baseline in these measurements has been put at a position consistent with our measurements in Orion. Alternatively, we give two lines of sight with strong DIBs (HD184143 and HD21389) that have been reduced in the same way as the Orion stars. HD184143 is the diffuse medium standard adopted by Herbig (1975) and Herbig & Leka (1991). These lines of sight have line ratio's close to those of the diffuse medium average above (Table 3), while the line strengths are similar to the strongest values in the diffuse medium sample.

Table 1. Equivalent width per unit reddening, W/E_{B-V}, of four DIBs in Å mag^{-1}. 'rms' is the root mean square noise per pixel of 0.1 Å in units of 10^{-3} Å. The error estimates (in parenthesis) are in units of the smallest significant number given and take into account the uncertainty in E_{B-V}. Values of E_{B-V} are from Savage et al. (1977) (marked S) and otherwise derived from photometry listed in the Hipparchos Input Catalogue. 'Dif' refers to the diffuse medium average as defined in the text.

HD	E(B-V)	6177	6196	6269	6284	rms
34085	0.00(1)	-.-	-.-	-.-	-.-	1
34989	0.13(S)	1.2(3)	0.06(3)	0.15(6)	1.38(30)	4
35149	0.11(S)	0.7(4)	0.06(4)	0.07(4)	1.12(15)	4
36486	0.07(S)	-.-	0.08(4)	0.04(2)	0.95(30)	1
36822	0.11(S)	-.-	0.10(4)	0.06(3)	1.56(30)	1
36861	0.12(S)	0.8(4)	0.046(3)	0.10(3)	1.50(30)	1
37020	0.40(56)	0.29(-)	<0.008	0.023(-)	1.10(-)	6
37022	0.35(4)	0.5(2)	<0.007	0.04(1)	1.37(20)	3
37023	0.36(6)	0.4(2)	<0.012	0.023(12)	1.0(2)	6
37043	0.07(S)	no data	0.04(4)	<0.002	0.45(24)	1
37061	0.50(4)	0.41(5)	0.012(6)	0.03(1)	1.07(11)	5
37128A	0.08(S)	-.-	-.-	-.-	0.59(23)	2
37490	0.10(2)	0.5(3)	0.01(2)	0.09(3)	1.5(2)	2
37742	0.08(S)	no data	<0.14	0.07(6)	0.6(2)	7
37903	0.38(6)	0.51(11)	0.035(12)	0.024(8)	0.79(15)	4
38023	0.51(4)	0.2(2)	<0.014	0.05(4)	0.45(10)	13
38087	0.32(6)	0.2(2)	no data	0.04(3)	0.78(20)	11
38563A	0.78(10)	<0.2	<0.018	0.025(12)	0.49(17)	18
38771	0.07(2)	-.-	-.-	-.-	0.86(30)	2
39557	0.60(7)	0.38(16)	0.037(16)	0.08(3)	0.58(10)	9
42050	0.34(6)	1.4(3)	0.07(3)	0.20(6)	2.1(4)	8
46060	0.41(60)	1.04(-)	0.052(-)	0.14 (-)	1.9(-)	11
21389	0.55(6)	0.83(8)	0.069(7)	0.18(2)	2.15(22)	1
183143	1.24(8)	0.93(6)	0.067(6)	0.16(1)	1.73(12)	2
Dif.:	0.49(12)	0.50(17)	0.051(12)	0.13(3)	1.2(4)	-

2.4. *Environments*

The lines of sight in Orion can be grouped in three types of environment: the low-reddened stars in the Orion OBIa association, the medium reddened stars in the Orion Nebula and the highly reddened stars in the outskirts of the Orion giant molecular cloud (GMC).

More precisely, the first group contains the stars 34989 to 36861 in Table 1 and are part of a large association of O and B stars (Fig. 1). The stars HD37020-23 and HD37061 are the ionisation sources for the HII regions M42 and M43, forming the Orion Nebula. The three stars at highest reddening are HD38023, HD38563A and HD39557. These stars are found embedded in the outer regions of the Orion GMC, far away from the active regions M42 and NGC2023, although HD38563A and HD38023 are associated with reflection nebulosity.

Most, if not all, of the reddening in these lines of sight is due to matter that is part of the GMC. Because Orion is nearby (500pc) and far below the galactic plane (180pc), there is little foreground reddening. HD34085 has a reddening of E_{B-V}=0.00.

3. Results

3.1. *DIB strength at high reddening: E_{B-V} dependence*

The stars in Orion show a similar decline of DIB strength per unit E_{B-V} than found for ρOph (Snow & Cohen 1974) and Taurus (Adamson et al. 1991). The decrease with reddening has roughly an E_{B-V}^{-1} dependence. In a log-log plot this is a straight line with a slope of -1.0 (solid line in Fig.3).

This relationship is followed most closely by λ6177 and λ6269. Towards the Orion Nebula, λ6284 is stronger while λ6196 is somewhat weaker than expected from an E_{B-V}^{-1} dependence.

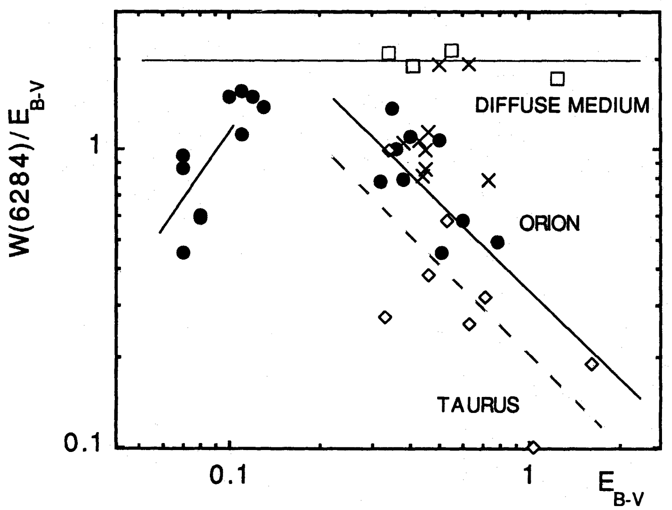

Fig. 3. DIB strength W_{6284}/E_{B-V} versus E_{B-V} for lines of sight passing the Orion Giant Molecular Cloud (filled circles) and the Taurus Dark Cloud (diamonds). Diffuse medium values are given by crosses and by the open squares (HD183143, HD21389 and the stars in GMC214-13). An E_{B-V}^{-1} dependence is fitted to the Taurus data

3.1.1. A_V dependence

Reddening (selective extinction) is not a good measure of the total amount of matter in the line of sight. It is better to consider DIB strength per unit amount of extinction in the visual: A_V.

The ratio of total to selective extinction $R_V = A_V/E_{B-V}$ is known only for the stars in the Orion Nebula and Horsehead regions in Orion ($\sim 5.1 - 5.5$ and 4.1 for HD37903; Cardelli et al. 1989). For the two other environments we make an assumption for R_V. A typical diffuse medium value of $R_V = 3.0$ is adopted for low reddened lines of sight, while R_V is probably close to 4 in the embedded stars in the outskirts of the Orion Molecular Cloud. Table 2 compares the resulting values of W/A_V for Orion with those for Taurus (Adamson et al. 1991) and the diffuse medium lines of sight.

Figure 4 shows the most accurate data: the strong λ6284 and the weak but well defined λ6196. Symbols are as in Fig. 3. Crosses show the diffuse medium lines of sight. The solid line is a fit of an A_V^{-1} dependence to the Taurus data. Again, λ6284 is about a factor of two stronger in Orion as compared to Taurus. More precisely, the high reddened stars are a about a factor of 1.5 stronger, the stars in the Orion Nebula as much as a factor of 2.6.

There are some significant differences between λ6284 and λ6269. λ6284 is typically more reduced in strength at A_V=1 than λ6196 compared to the diffuse medium standards. The stars in the Orion Nebula show a factor of about 2.6 stronger W_{6284}/A_V, while on the other hand λ6196 is weaker than expected for an A_V^{-1} dependence in the Orion Nebula by about a factor of 5.

The DIBs in Orion do not show an obvious dependence on R_V, except for λ6196 (weak in M42). λ6196 does show a similar correlation with R_V for the Taurus sample (Adamson et al. 1991). However, λ6196 is systematically stronger in Orion compared to Taurus for given R_V.

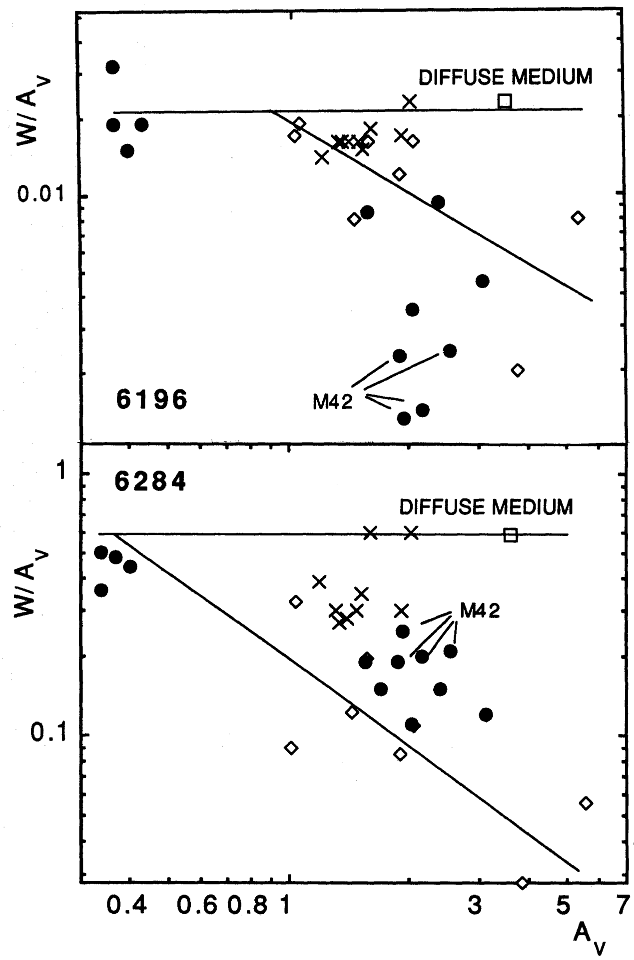

Fig. 4. The strength of λ6284 and λ6196, in units of W/A(V), versus A_V. Symbols as in Fig. 3. An A_V^{-1} dependence is fitted to the Taurus data. Note that the stars in M42 have somewhat stronger λ6284 and weaker λ6196 compared to an A_V^{-1} dependence fitted to other stars in Orion

3.2. *Relative DIB strength*

Another way to consider DIB strength is by comparing line ratio's, which do not depend on normalisation to E_{B-V} or A_V (Table 3). The data are divided into groups as done before.

The embedded stars HD38023, HD39557 and HD38563 have weak DIBs, but no significant deviant band ratio's for the DIBs in this study. In general, there is no strong trend of line ratio with E_{B-V}, in agreement with Snow & Cohen (1974) for line ratio's of λ5797/λ5780. However, small variations of the order 20% may exist. For example, such variations are present in the λ5797/λ5780 ratio in the highly reddened lines of sight towards the CygOB2 and Be87 associations (Chlewicki et al. 1986).

Strongly deviant line ratio's are found in regions with strong UV radiation fields, that is, with associated nebulosity and

Table 2. Average DIB strength in units of W/A_V for lines of sight for which R_V is known (Cardelli et al. 1979). Taurus data are from Adamson et al. (1991). 'Dif' contains the stars in the diffuse medium sample. Errors give 1σ spread in each sample.*

W/A(V)	Orion[1] high reddening	Orion[2] HII region	Orion[3] low reddening
λ_{6284}	0.13(2)	0.20(4)	0.43(9)
λ_{6269}	0.013(6)	0.0062(12)	0.028(14)
λ_{6196}	<0.0056	<0.0036	0.023(7)
λ_{6177}	0.07(3)	0.08(3)	0.3(1)
R_V	~4	5.1	~3.0
A_V	2.5	1.9	0.3

W/A(V)	Taurus[1] ice band	Taurus[2] no ice band	Dif.	HD183143
λ_{6284}	0.04	0.16(9)	0.38(13)	0.59(6)
λ_{6269}	0.005	0.015(4)	0.043(11)	0.055(5)
λ_{6196}	0.021	0.039(27)	0.017(3)	0.023(3)
λ_{6177}	-.-	-.-	0.17(5)	0.32(3)
R_V	3.6	3.0	3.1	3.0
A_V	4.7	1.5	1.5	3.7

*Orion[1] contains embedded stars: HD38023, HD38563A, HD39557. Orion[2] stars in HII regions/refl. neb. M42 and NGC2024: HD37022, HD37023, HD37061, HD37903, HD38087. Orion[3]: low reddening HD34989, HD35149, HD36486, HD36822, HD36861. Taurus[1] contains stars with R~3.6: HD29647, HD283809, while Taurus[2] has R~3.0: HD27778, HD27311, HD30168, HD283800, HD28975, HD283812.

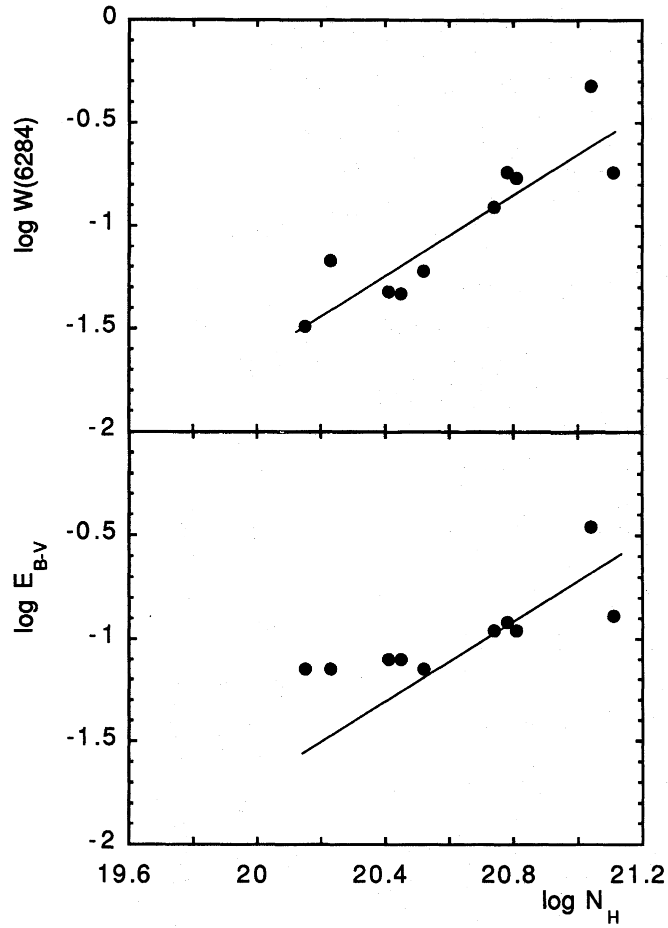

Fig. 5. The equivalenth width of λ6284 correlates well with the column density of all neutral matter in the line of sight N_H = N(HI)+ 2N(H_2). The solid lines have slope = +1

high 60/100 IRAS flux ratio's. The most extreme case, that of HD37022 in the direction of the Orion Nebula, has also the most extreme line ratio's: λ6196 and λ6203 are not detected while λ6205 and λ6284 are clearly present (Fig. 2). This line of sight is also one of extreme cases in the sample of Porceddu et al. (1991). They detected λ6196 as weak as W/E_{B-V}=0.016(4). We have measured W/E_{B-V} <0.012 for HD 37023 and < 0.007 for HD 37022, which is not significantly different. One implication is that λ6196 (and λ6269) are not in the same family as λ6284, contrary to the assignment of Krelowski & Walker (1987).

The line of sight towards HD46060 has anomalous 1665/1667 MHz flux ratio's indicative of non-LTE conditions (Jenniskens & Wouterloot 1990), but does not have anomalous DIB ratio's (Fig. 2): the spectra towards GMC214-13 are similar to those of diffuse medium lines of sight.

3.3. DIB strength at low reddening

A number of Orion stars have low reddening ($0.07 < E_{B-V} < 0.2$). In all of these stars λ6284 is detected. The equivalent width values agree with data of Kumar (1986), who finds W_{6284}=0.030, 0.033 and 0.055 (± 0.015) Å for HD37128, HD37043 and HD36486 respectively, while we have 0.047±0.014, 0.032±0.014, and 0.068±0.09 Å respectively.

There is a weakening of W_{6284}/E_{B-V} for lines of sight with $E_{B-V} < 0.1$ compared to the typical diffuse medium values (Fig. 3). The data do not allow us to tell whether or not other DIBs show a similar decline, that is, whether the line ratio's remain constant.

The equivalent width of λ6284 is plotted in Fig. 5 against the column density of all neutral matter $N_H = N(HI)+2N(H_2)$ for the ten stars in Orion of which such data have been published. The atomic (HI) and molecular hydrogen (H_2) column densities are from Savage et al. (1977) and are derived from Copernicus far UV data. There is no decrease of DIB strength with N_H. As a matter of fact, the equivalent width of λ6284 correlates well with N_H: slope 1.12 and correlation coefficient r=0.90 in log-log relation, better than with E_{B-V} (r=0.79).

3.3.1. λ5780 in other low reddened lines of sight

Most other studies of DIB strength at low reddening in the literature consider λ5780. This DIB correlates well with λ6284 (Jenniskens & Désert 1993). Kumar et al. (1982) and Federman et al. (1984) reported a weakening of λ5780 from a comparison of two groups of lines of sight with low and high H_2 column density. Since then, solid state detector observations have been published for 34 of the lines of sight in the sample of Savage et al. (1977) (i.e. Snell & Vanden Bout 1981; Meyer 1983; Federman et al. 1984; Josafatsson & Snow 1987; Benvenuti & Porceddu 1989; Désert et al. 1993). Fig. 6a and 6b show log-log plots of these data, instead of the log-normal plots discussed in Federman et al. (1984) and Kunmar (1986). Again, the reddening in Fig. 6a is adopted from Savage et al. The lines of sight with no HI data are given by open squares. Upper limits are indicated by arrows. The crosses are data from Désert et al. (1993). Straight lines with slope 1.0 have been aligned with the high reddened part of the data in order to show the dependency expected in case of proportionality.

Below E_{B-V} = 0.08 molecular hydrogen is effectively dissociated (Fig. 6a lower part) due to lack of self shielding (e.g. Savage et al. 1977). We conclude that also the λ5780 DIB tends to weaken for E_{B-V} less than or equal 0.08 mag. As for λ6284, the effect is much less obvious than for molecular hydrogen.

The total neutral gas column density N_H decreases too for E_{B-V} < 0.08 mag (upper graph of Fig. 6a). According to Bohlin et al. (1978), the decrease of N_H at low reddening is probably because hydrogen is partially in ionised form. N_H includes only the neutral atoms and molecules and does not count the ionised atoms. The equivalent width of λ5780 follows N_H closely down to $N_H = 10^{20}$ cm^{-2} (Fig. 6b), in a similar way as λ6284 (Fig. 5). Assuming that reddening is proportional to the total column density of all matter, we conclude that the DIB carriers of λ5780 and λ6284 are confined to the neutral gas and are weakened in low reddened lines of sight where a significant fraction of hydrogen is in ionised form.

There are a few lines of sight at low reddening with high column densities of molecular hydrogen (open squares in Fig. 6a). These are probably lines of sight with weaker than normal UV radiation fields (some of them are towards Taurus). DIBs are detected in these lines of sight, even if E_{B-V} <0.08. This is consistent with the notion that the DIB carrier is destroyed only when hydrogen is dissociated *and* ionised.

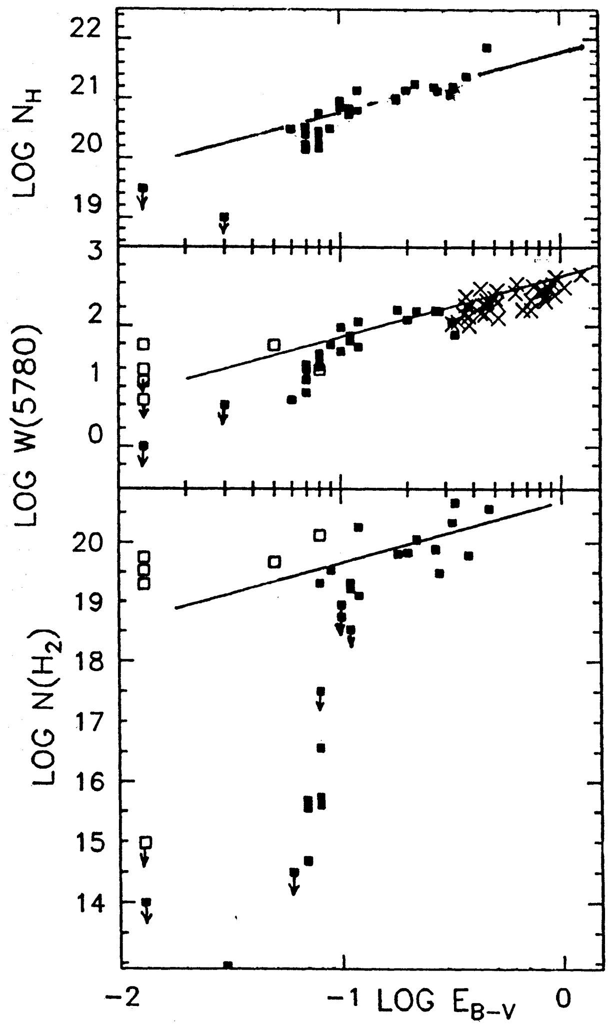

Fig. 6a. DIB strength as a function of HI and H_2 column density. Data from Snell & Van den Bout (1981), Meyer (1983), Federman et al. (1984), Josafatsson & Snow (1987) and Benvenuti & Porceddu (1989). Crosses are the DIBs reported in Désert et al. (1993). The data on atomic and molecular gas column densities are from Savage et al. (1977). Open symbols mark lines of sight for which no atomic hydrogen column density is given. The solid lines have slope +1

4. Discussion

4.1. The role of the UV field

In general there is a good correlation between DIB equivalent width and reddening (e.g. Herbig 1975), but in some lines of sight significant weakening is observed (Wampler 1966; Snow & Cohen 1974; Baines & Whittet 1983). This weakening has been linked to 'dark clouds'. Obviously, the trend is not due to mere column density differences, that is, E_{B-V} or A_V. The weakening does not occur towards GMC214-13 and towards HD183143 (E_{B-V}=1.24, A_V=3.7). The most obvious difference between GMC214-13 and Orion at the positions where the most reddened stars are found is that the average mean density in Orion is higher than in GMC214-13. The volume averaged mean densities on scales of the smallest structures seen in the maps (0.5° angular resolution), derived from radio observations of the main line Λ-doublet transitions of OH at 1665 and 1667 MHz, is n_H=800 cm^{-3} for Orion at the position of HD38023 (Jenniskens & Wouterloot 1990), while as low as n_H=250 cm^{-3} for GMC214-13. Similar high values are derived by Wouterloot (1981) for Ophiuchus (n_H=650 cm^{-3}) and the Taurus dark cloud core (n_H=430 cm^{-3}). The dark clouds are highly clumped and densities on smaller scales are probably even higher. The relative low number of lines of sight with weakened DIBs is a selection effect because most low reddened lines of sight are expected to have low mean densities.

The E_{B-V}^{-1} (or more likely A_V^{-1}) trend is not due to different grain properties in high density environments. Although λ6196 is found to correlate with R_V, the dependence of λ6196 on R_V does not (only) reflect changing dust grain properties (Snow & Cohen 1974; Adamson et al. 1991) or grain surface chemistry

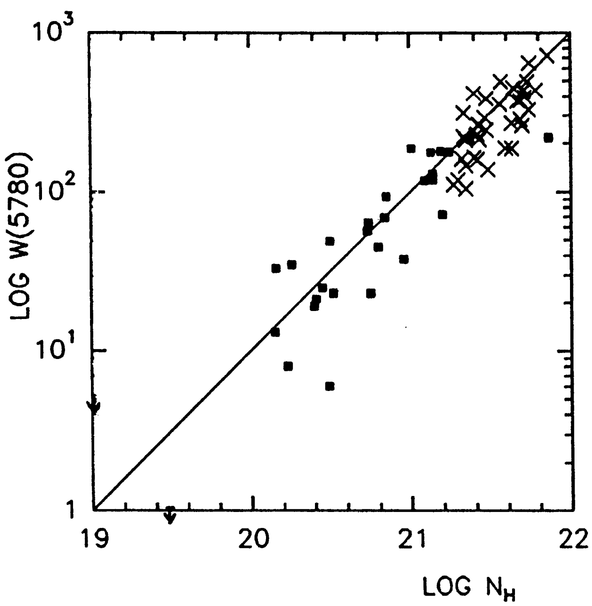

Fig. 6b. Same data as in Fig. 6a. The equivalent width of λ5780 (mÅ) is plotted versus the column density of neutral matter $N_H = N(HI) + 2N(H_2)$ cm^{-2}. There is no indication of a relative weakening of the DIB for low values of N_H

Table 3. Ratios of equivalent width relative to that of λ6284. Error estimates include random noise only and are given in units of the smallest significant number.

name	6177/6284	6196/6284	6269/6284	
dif.:	0.41(5)	0.046(10)	0.12(3)	diffuse medium
HD21389	0.39(2)	0.032(1)	0.084(1)	weak UV field
HD183143	0.54(2)	0.039(1)	0.092(1)	
HD42050	0.67(3)	0.034(4)	0.096(6)	GMC214-13
HD46060	0.55(3)	0.027(5)	0.074(7)	weak UV field
HD39557	0.66(6)	0.064(10)	0.138(13)	Orion[1]
HD38563	<0.4	<0.04	0.051(22)	very weak UV
HD38023	0.44(13)	<0.04	0.11(3)	high density
HD34989	0.89(6)	0.040(8)	0.108(11)	Orion[3]
HD35149	0.89(7)	0.076(10)	0.13(4)	weak UV field
HD37490	0.37(5)	0.038(10)	0.069(10)	low density
HD36822	-.-	0.086(8)	0.050(4)	
HD36861	0.64(5)	0.033(4)	0.087(8)	
HD37020	0.26(3)	<0.007	0.021(6)	Orion[2]
HD37022	0.37(2)	<0.005	0.029(3)	strong UV field
HD37023	0.40(4)	<0.012	0.036(8)	high density
HD37061	0.38(2)	0.011(3)	0.028(4)	
HD37903	0.65(3)	0.044(5)	0.030(6)	
HD38087	0.26(10)	-.-	0.05(2)	

after accretion of the carrier, since λ6196 is stronger in Orion than in Taurus for given R_V and other DIBs do not show such a dependence. Notably λ6284 is as strong in the Orion nebula, with $R_V \sim 5.2$, as in the quiescent Taurus dark cloud complex with $R_V \sim 3.0$. More generally, from a large sample of DIB measurements we find no correlation between DIB strength and the linear rise in the UV extinction curve (Désert et al. 1993; see also Herbig 1975). The linear rise is related to R_V (Cardelli et al. 1989; Jenniskens & Greenberg 1993). Assuming that the carriers of λ6196 and λ6284 are not completely different, the results are consistent only if another mechanism influences the DIB strength also.

Instead, the E_{B-V}^{-1} dependence might be due to a *constructive* role of the UV field (or related phenomena like the presence of ions), which is attenuated inside clouds. This suggests that there are morphology differences in high and low density environments that cause a high attenuation per unit A_V in 'dark cloud' (high density) environments.

However, Kumar (1986) and Adamson et al. (1991) pointed out that the decrease of band strength per unit A_V is less than expected if the DIBs are due to ionisation of neutral precursors by UV photons. In Ophiuchus the decrease of DIB strength per unit A_V is about as fast as in Taurus despite of a five times higher UV field (Adamson et al. 1991). This result is confirmed for Orion. The high UV field in the direction of HD37020-23 and HD37061, where most matter is close to luminous O-type stars, coincides with λ6284 being not more than a factor 2-3 stronger. For other lines of sight, W_{6284}/A_V is only some 50% stronger than in Taurus, while all given lines of sight in Orion should have a considerably stronger UV field. Because, UV photons of $\lambda > 0.2\mu$m originate mainly from early type stars and the low reddened stars are part of a cluster that contains at least 350 stars earlier than A0 (Warren & Hesser 1977, 1978), while the embedded stars have most matter close to a luminous early type star.

One answer to this apparent inconsistent role of the UV field is that UV photons can have a *destructive* role also. The observed deficiency for lines of sight with $E_{B-V} < 0.08$ mag is strongly linked to whether hydrogen is in neutral or ionised form, which argues for a destructive role of UV photons with energy higher than 13.6 eV. Of course, this strictly applies only to λ6284 (and λ5780). On the other hand, also the weak λ6196 (and λ6269) towards the Orion nebula may be interpreted as the result of a similar destruction by UV photons. Because molecular hydrogen is mostly dissociated in these lines of sight, with log N_{H_2} <17.55 and log N_{HI}=21.04 towards HD37022 (Savage et al. 1977), the destruction in this case is due to photons with energy slightly less than 13.6eV.

4.2. The large molecule hypothesis

From the observation that DIBs show a much smaller variation of DIB strength with N(H_2) than any gas phase molecule, Federman et al. (1984) and Kunmar (1986) correctly concluded that DIBs are not due to small molecules from gas phase chemical networks involving H_2.

After the suggestion that the near infrared emission bands in regions with strong UV fields may be caused by larger molecules, such as polycyclic aromatic hydrocarbons, it became clear that such large molecules are good candidates for the DIB carriers (van der Zwet & Allamandola 1985; Crawford et al. 1985; Léger & d'Hendecourt 1985). The abundances inferred from the infrared emission bands are high and it is known that ionized PAHs have strong absorptions in the visual (e.g. Salama & Allamandola 1992; Ehrenfreund et al. 1992).

In order to have strong absorptions in the visual, PAH's have to be ionised. The abundance of singly ionised PAHs is a complex balance of ionisation by photons with energy > 7eV, recombination and destruction (and possibly formation from solid organic matter on grains - e.g. Jenniskens et al. 1993). The ionisation degree of PAHs is more or less proportional to the interstellar radiation field over electron density ratio (Omont 1986), which reflects ionisation and recombination. In the diffuse medium 10-40% of PAHs are thought to be ionised (Verstraete et al. 1990; Jenniskens et al. 1992), while this fraction is about 1 for HII regions. This may be reflected in the relatively strong λ6284 towards the Orion Nebula.

The weakness of λ6196 in the Orion Nebula and the weakness of λ6284 in the tenuous HII medium involves destruction of the carrier as opposed to mere recombination. Destruction of PAHs probably involves doubly-charged PAHs. Irrespectible of the molecule considered, the lowest dissociation limit usually lies below the double-ionisation threshold due to Coulomb repulsion forces (Leach 1987). The consequent instability can lead to rapid dissociation. Large PAHs like coronene, ovalene, hexabenzocoronene and picene have ionisation potentials in the range 6.7-7.6 eV, and second ionisation potentials in the range 19-22 eV. Leach (1987) argued that doubly-charged PAH's can be formed by a sequential two-photon process, i.e. PAH > PAH^+ >PAH^{++}. Therefore, PAH destruction is due to photons of energy 12-15 eV (19-22 minus 6.7-7.6 eV) (Leach 1986, 1987).

We want to point out that this range contains the ionisation limit of hydrogen at 13.6 eV. If the difference between first and second ionisation potential is larger than 13.6eV, the molecules survive in all environments where neutral hydrogen is found. If less than 13.6 eV, the DIBs are destroyed in photodissociation regions. (This behaviour would be interpreted as these DIBs being part of a different 'family'.)

The values of first and second ionisation potential vary from molecule to molecule, but irrespectible of the molecule considered, the ratio of double to single ionisation potential is about 2.8 (Leach 1987). Therefore, the photon energy at which ionisation occurs scales with the energy needed for destruction. Our results indicate that both ionisation and double ionisation of the carrier of λ6196 are at lower photon energy than that of λ6284, which is consistent with a large molecule carrier: because λ6284 falls of more quickly with A_V than λ6196, it follows that the large molecule responsible for λ6284 is singly ionised by more energetic photons than the carrier of λ6196, while the strong value of λ6284 towards the Orion Nebula indicate that λ6284 is destroyed (doubly ionised), similarly, by more energetic photons than λ6196. The extreme weak values of λ6196 in the Orion Nebula may be related to the high values of R_V and associated absence of a linear rise in the extinction curve. This causes destruction of PAHs ($PAH^+ > PAH^{++}$) to be efficient down to a similar depth in the cloud as creation through ionisation ($PAH > PAH^+$).

4.3. Future work

This interpretation predicts that λ6196 is weak compared to λ6284 in very low reddened lines of sight. Smith et al. (1981) give some tight upper limits to the strength of λ6196 in the low reddened lines of sight towards HD37742, HD37128, HD38771 and HD37043. The DIB strength is less than for the high reddened lines of sight, but the line ratio's λ6196/λ6284 that are obtained by combining the data with our measurements are only <0.05, <0.036, <0.0024 and <0.097 respectively. These upper limits are similar to the values found in more highly reddened lines of sight, and therefore are not able to prove the point.

There is some indication that λ5797 too seems to be created *and* destroyed by lower energy photons than λ5780. At an extinction of A_V=1 the stars in Taurus have weaker λ5780 than λ5797 relative to HD183143 (factor 2.8 and 1.6 respectively, Adamson et al. 1991). And in lines of sight with low N(H_2) the DIB strength of λ5797 is indistinguishable from 0 mÅ (Federman et al. 1984) and the line ratio λ5797/λ5787 is less than in the diffuse medium.

At some point creation of neutral PAHs may be needed to sustain a high abundance. In situ creation of PAHs might occur from UV photoprocessed organic residue mantles on grains (Jenniskens et al. 1993), but this mechanism needs further study.

5. Conclusions

Qualitatively, the data are consistent with DIBs being due to large ionised molecules, where the relative DIB strength W/E_{B-V} reflects an interplay between ionisation and recombination and between destruction (and creation) of the carrier.

The argument that DIBs are found in low reddened lines of sight cannot be considered an argument against a molecular carrier. Some lines of sight with E_{B-V} < 0.08 mag *do* contain significant amounts of λ6284 (and λ5780), but only when there is significant neutral hydrogen present. A depletion of the carrier is observed and linked to the presence of ionised hydrogen in the line of sight. This probably implies that the carrier(s) are resistant against UV photons of energies <13.6 eV, but are destroyed by photons of higher energy. Other indications of a destructive role of UV photons is the observation that λ6196 is depleted from an A_V^{-1} dependence in the Orion Nebula. Hydrogen is in atomic form here, which is consistent with the carrier being destroyed by photons with energy somewhat less than 13.6 eV. λ6284 is resistant against these photons and is actually somewhat enhanced relative to an A_V^{-1} dependence. This suggests that a slightly larger fraction of the carrier is in ionised form.

The other argument that is used against a molecular carrier, which is that DIBs are not much stronger in environments with a strong UV field, neglects this destructive role of UV photons. Also the enhanced presence of electrons, which leads to recombination, may have to be taken into account. As expected for an attenuation of the UV field, DIB strength decreases with increasing depth in the cloud, but only when the local mean density is high, which probably reflects the cloud volume filling factor, that is, the geometric structure.

DIBs may be a useful tool for probing various conditions in the interstellar medium, however the specific DIB carrier molecules have to be identified. For correct and quantitative diagnostics, the carrier's physical properties concerning absorption, ionisation, and destruction must be better determined in the experimental laboratory, and in theoretical/empirical models and can also be studied by using comprehensive observations in given astrophysical environments.

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