PART II

DIBs and their relation to other interstellar components and astronomical phenomena

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The Diffuse Interstellar Bands
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DIBs, Interstellar Dust, and Extinction

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Abstract. The relationship between DIBs and dust is still unknown. The correlation between reddening and DIB strength means that the DIBs are mixed in with the dust and gas in interstellar clouds. The DIBs are relatively stronger in the diffuse interstellar medium than in dense clouds. There is only a weak correlation between the DIBs and the UV extinction parameters including the 2175 Å bump strength and the far-UV rise. In addition, the bump dust grains are sometimes polarized, while the DIBs are not. However, observations of DIBs in the SMC show that when the 2175 Å bump is weak or missing so are the DIBs. Two of the four sightlines that deviate strongly from the CCM UV extinction in the Galaxy show weak DIBs.

Keywords. dust, diffuse interstellar bands, extinction

1. Introduction

In the 1930's, it was realized that the diffuse interstellar bands (DIBs), first discovered by Mary Heger, which are absorption features superimposed on the interstellar extinction curve, have strengths which are correlated with the amount of dust present along the line of sight (Merrill 1936; Merrill & Wilson 1938). It was at about the same time, that the role of obscuring clouds of interstellar dust in reddening was confirmed (e.g., Trumpler 1930). Trumpler found that the wavelength dependence of interstellar extinction is proportional to λ^{-1}.

The bands themselves range from about 4000 Å to about 10000 Å, and have widely varying FWHM, from several tenths to tens of Å. Cami *et al.* (1997) have shown that they likely have different carriers, but the identity of the carriers remains a mystery. Some lines also occur in families, raising the possibility that several lines may be carried by similar species (Krelowski & Walker 1987; Cami *et al.* 1997). Most recent works indicate that the carriers are likely to be either large PAHs or very small carbonaceous grains, and are probably ionized, as these have stronger features in the optical band than neutral species. This also explains why DIBs are weaker toward dark clouds, as the increased particle density acts to shield the carriers from ionizing UV radiation (Snow & Cohen 1974; Adamson *et al.* 1991; Cami *et al.* 1997).

2. DIBs and UV Extinction

The UV does have one very strong, broad absorption feature, the famous 2175 Å bump. Clayton *et al.* (2003) found no broad absorptions in UV spectra of strongly reddened sightlines down to a level of 0.02 A_V. So, the bump is the only known "DIB" feature in the UV. Since the current evidence indicates that the carriers are either large molecules or very small grains, it might be expected that there would be some relation between them and some populations of the carriers of UV extinction, as certain characteristics of UV extinction have been attributed to such particles (Desert *et al.* 1995; Cami *et al.* 1997; Weingartner & Draine 2001). Possible correlations between DIB strengths and UV extinction have been studied before by many authors (Nandy & Thompson 1975; Danks 1980; Seab & Snow 1984; Krelowski & Walker 1987; Benvenuti & Porceddu 1989; Desert *et al.* 1995) but the results were often inconsistent. Moreover, only one of these used Fitzpatrick-Massa (FM) parameters to consider the UV extinction characteristics, which are necessary for quantitative comparisons between sight lines (Fitzpatrick & Massa 1990). There are 6 FM parameters, which are found by fitting the extinction curve with the function $k(x) = \frac{E(\lambda-V)}{E(B-V)} = c_1 + c_2 x + c_3 D(x, \gamma, x_0) + c_4 F(x)$, where $x = \frac{1}{\lambda}$, and $D(x, \gamma, x_0) = \frac{x^2}{(x^2 - x_0^2)^2 + (x\gamma)^2}$. For $x \geqslant 5.9\ \mu\mathrm{m}^{-1}$, $F(x) = 0.5392(x - 5.9)^2 + 0.05644(x - 5.9)^3$, while for $x < 5.9\ \mu\mathrm{m}^{-1}$, $F(x) = 0$. Each parameter corresponds to a certain aspect of the extinction curve. The parameters c_1 and c_2 describe the linear portion of the curve, c_4 describes the nonlinear FUV rise, x_0 is the central wavelength of the bump, γ is the bump width, and c_3/γ^2 is the height of the bump at 2175 Å, (Fitzpatrick & Massa 1990). In addition, the area of the bump can be described as $\pi c_3/2\gamma$.

The strengths of the 2175 Å bump and the DIB features are naturally correlated because they are all correlated with the amount of dust along the sightline as measured by E(B-V) (Witt *et al.* 1983; Xiang *et al.* 2011). By normalizing the strengths to E(B-V) or A_V, the strengths relative per dust mass can be assessed. Desert *et al.* (1995) looked for correlations between various DIB features normalized to E(B-V) and the FM extinction parameters. They found a weak correlation with bump height, and weak anti-correlations with bump width and c_4, the far-UV curvature, but no correlation with c_2, the linear rise of the UV extinction. On the other hand, Benvenuti & Porceddu (1989) found no correlation between normalized DIB strength and the bump. Xiang *et al.* (2011) correlated nine DIB features along 84 sightlines with measured UV bump strengths. They found that the normalized strengths of the nine DIB features correlated poorly or not at all with the bump strength. Then they took an average of nine DIBs along nine sightlines and still found a poor correlation with the bump strength.

Two sightlines in the Galaxy, including HD 197770, have been measured that show that the 2175 Å feature is polarized (Clayton *et al.* 1992; Wolff *et al.* 1997). Adamson & Whittet (1995) found that the DIB features toward HD 197770 were unpolarized.

In the Galaxy, a few lines of sight show both weak DIBs and a weak 2175 Å bump, in particular HD 23512 (Witt *et al.* 1981), HD 29647 (Adamson *et al.* 1991), and HD 62542 (Snow *et al.* 2002). Valencic *et al.* (2004b) studied the UV extinction properties along 417 lines of sight in the Galaxy and found only four that systematically deviated from the Cardelli *et al.* (1989, CCM) relation, having relatively weak bumps and steep far-UV extinction. These four stars, which include two of the known weak DIB stars, are HD 29647, HD 62542, HD 204827, and HD 210121. The anomalous nature of the UV extinction toward these four stars is likely due to environment, but the stars are not a homogeneous sample. The dust toward HD 62542 and HD 204827 seems to have been swept up by a stellar wind or a supernova, but the dust toward HD 29647 is in a quiescent dense cloud, and HD 210121 is behind a dense cloud in the halo of the Galaxy (Valencic *et al.* 2004b).

Observations of DIBs along the sightlines included in the Valencic *et al.* (2004b) extinction sample were obtained from the literature and normalized to A_V (= E(B-V) × R_V, where R_V is the ratio of total to selective extinction) (Valencic *et al.* 2004a). This representation is preferable, as A_V is a more basic quantity than E(B-V) and is directly related to the optical depth of dust along a sight line (Cardelli *et al.* 1989). Figures 1 and 2 show the normalized equivalent widths for the 5780 and 5797 Å DIBs plotted against the bump area ($\pi c_3/2\gamma$) and the far-UV curvature parameter, c_4. The sightlines are divided in dense ($A_V/d > 0.9$ mag/kpc) and diffuse ($A_V/d < 0.9$ mag/kpc)

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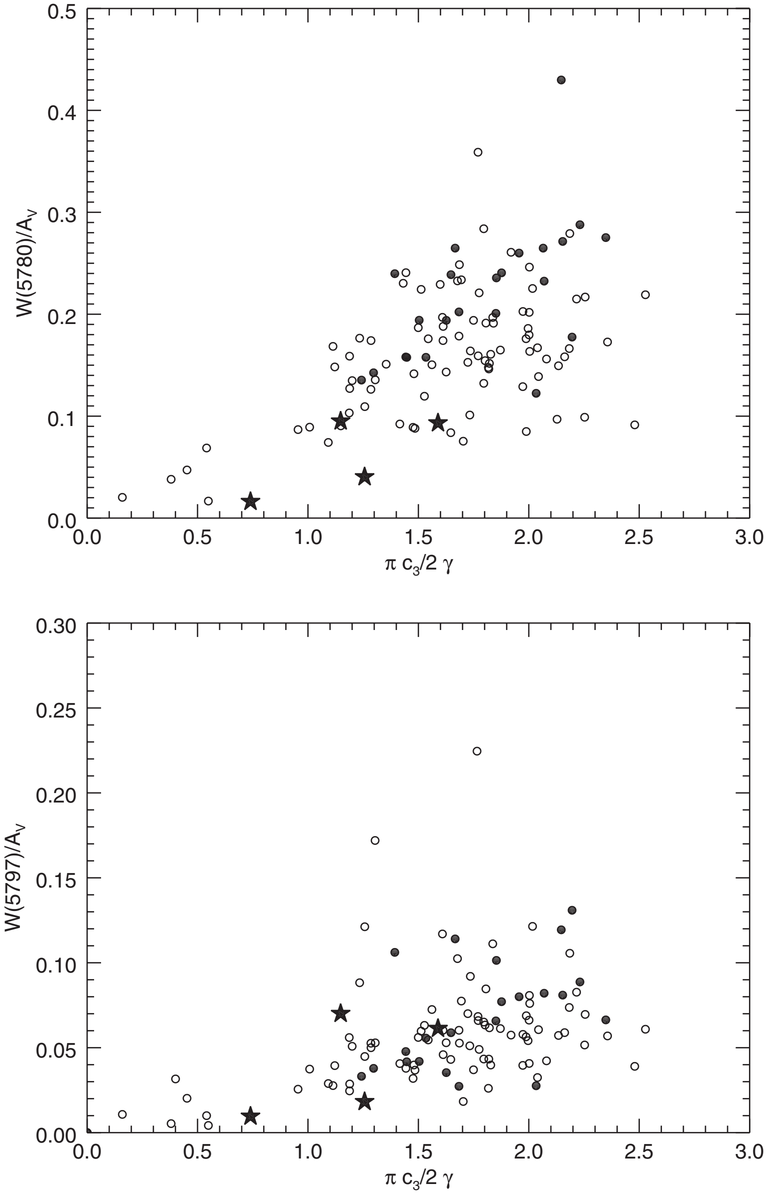

Figure 1. Normalized equivalent widths for the 5780 and 5797 Å DIBs plotted against the bump area ($\pi c_3/2\gamma$). Filled circles indicate "diffuse" sight lines and open circles indicate "dense" sight lines. The stars represent the four anomalous sightlines of Valencic *et al.* (2004b).

environments. The A_V/d cutoff, differentiating between diffuse and dense lines of sight, is from Jenniskens & Greenberg (1993). There does not seem to be any significant difference in the relationships between DIB strength and the UV extinction parameters in the dense and diffuse sightlines. In Figure 1, it can be seen that the anomalous extinction stars, HD 29647 and HD 62542 are indeed weak compared to the bump area but the other two stars are not. In Figure 2, all four stars either have weak DIB strengths or strong far-UV curvature.

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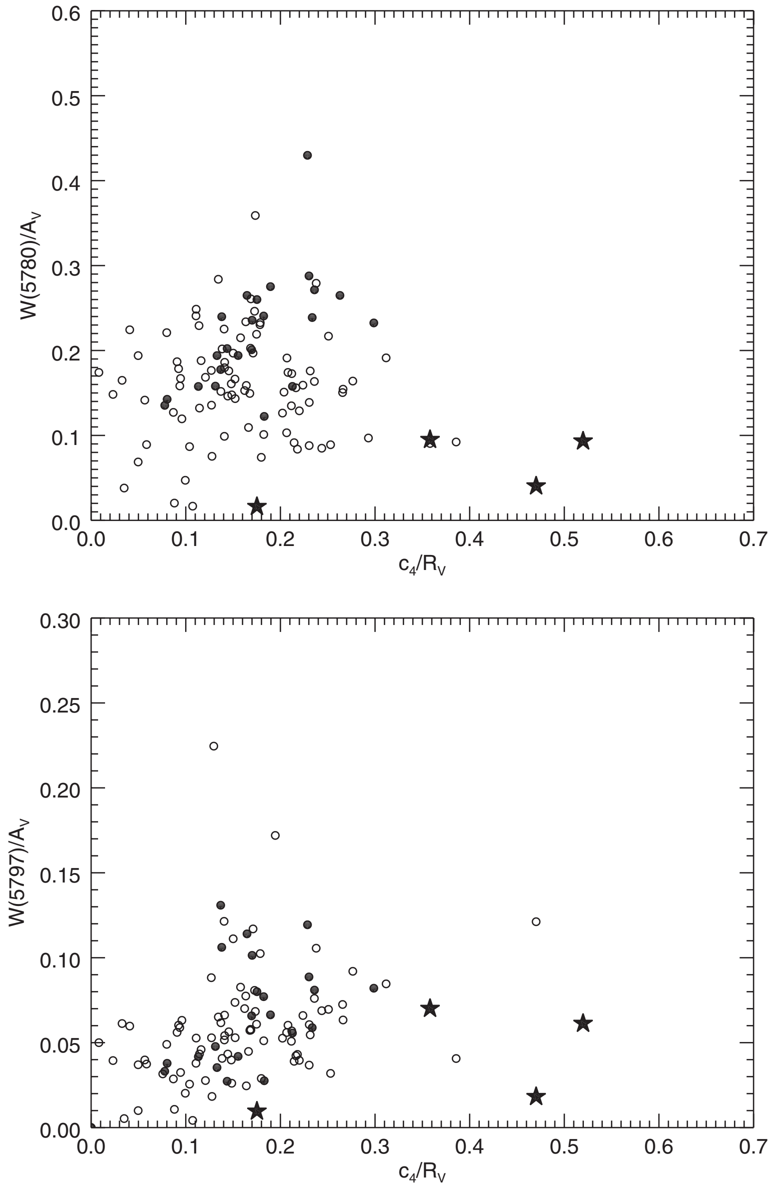

Figure 2. Normalized equivalent widths for the 5780 and 5797 Å DIBs plotted against the far-UV curvature parameter, c_4. The symbols are the same as in Figure 1.

The Large Magellanic Cloud shows a similar general relationship between DIB strength and reddening as is seen in the Galaxy (Cox *et al.* 2006). The Small Magellanic Cloud is more interesting. The UV extinction in the SMC has only been measured along 5 sightlines (Gordon *et al.* 2003). Four of these show the typical SMC extinction which is very steep with little or no evidence for the 2175 Å bump. The last sightline shows UV extinction more typical of the Galaxy with a significant bump. Cox *et al.* (2007) report that the DIB features in the three of the SMC sightlines with no bump are extremely

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weak or absent, while they are of normal strength in the one sightline showing a 2175 Å bump.

3. Conclusions

The relationship between DIBs and dust is still unknown, but there are some interesting facts,

• The correlation between reddening and DIB strength means that the DIBs are mixed with the dust and gas in interstellar clouds.
• The DIBs are relatively stronger in the diffuse interstellar medium than in dense clouds.
• There is only a weak correlation between the DIBs and the UV extinction parameters including the 2175 Å bump strength and the far-UV rise.
• The bump dust grains are sometimes polarized, while the DIBs are not.
• Observations of DIBs in the SMC show that when the 2175 Å bump is weak or missing so are the DIBs.
• The few sightlines that deviate strongly from the CCM UV extinction in the Galaxy do not correspond to unusual DIB strengths, although two of the four sightlines show weak DIBs.

So there is no strong evidence that the source of the DIB absorption is closely related to the interstellar dust components responsible for extinction and polarization in the visible and the UV.

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