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Pairwise Correlations of Eight Strong DIBs and N(H), N(H_2), and E_{B-V}

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Abstract

We discuss the correlations between equivalent widths of eight diffuse interstellar bands (DIBs), and examine their correlations with the column densities of atomic hydrogen (*N*(H)) and molecular hydrogen (*N*(H_2)), and E_{B-V}. The DIBs are centered at λλ5780.5, 6204.5, 6283.8, 6196.0, 6613.6, 5705.1, 5797.1, and 5487.7, in decreasing order of Pearson's correlation coefficient with *N*(H), which ranges from 0.94 to 0.78. The equivalent width of 5780.5 is better correlated with column density of H than with E_{B-V} or H_2, and the same is true for six of the seven other DIBs presented here. Hence, they are not preferentially located in the densest, most UV shielded parts of interstellar clouds. These eight strong DIBs are not correlated well enough with each other to suggest they come from the same carrier. However, the correlations may be useful in deriving interstellar parameters, such as *N*(H) from W(5780.5), when more direct methods are not available. Our future plans include mapping the distribution of DIBs in interstellar clouds, closer examination the excellent correlation between 5705.1 and 5780.5 (almost as good as the near perfect correlation of 6613.6 with 6196.0), and on precise measurements of broad DIBS.

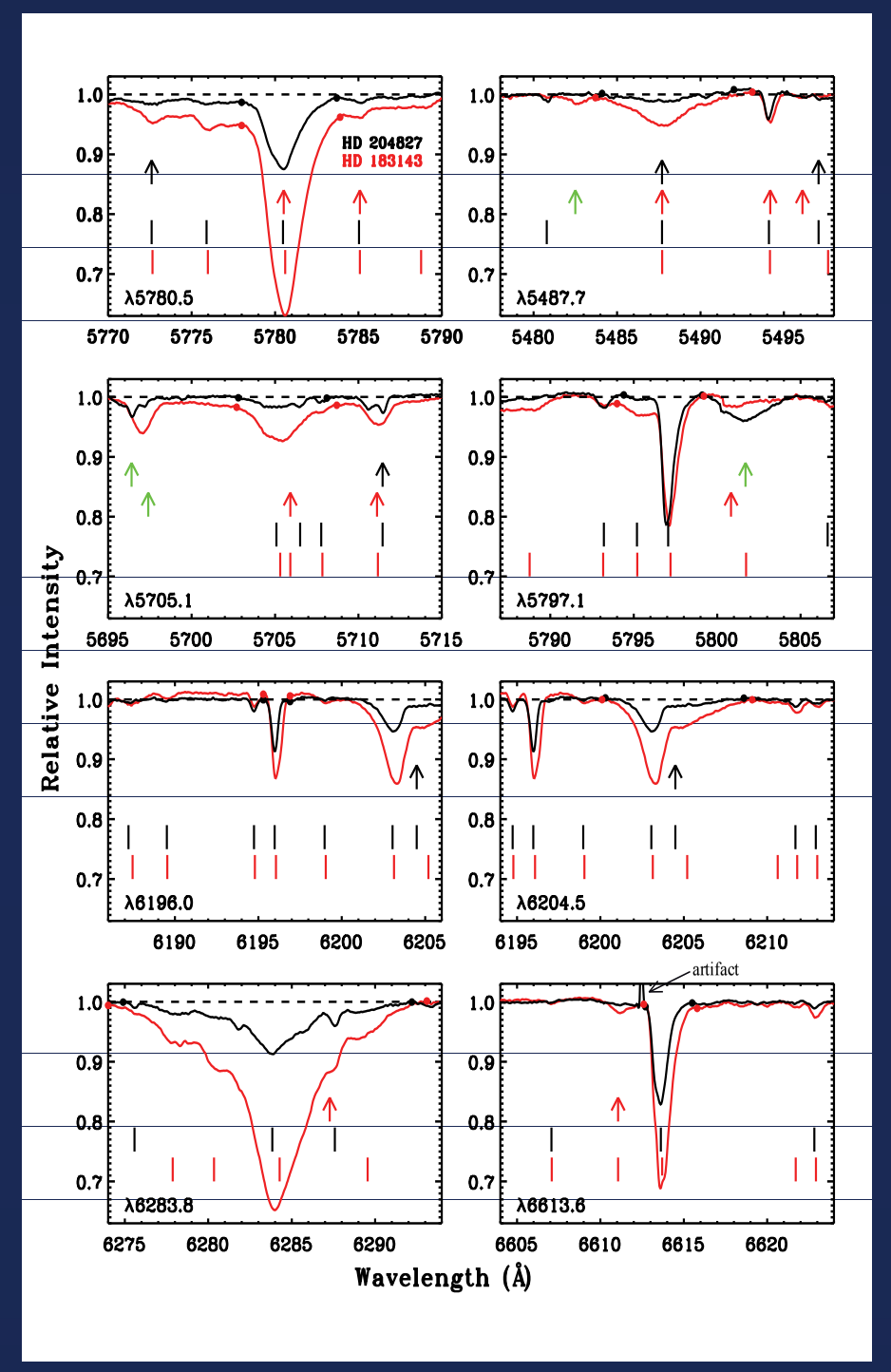

Figure 1 Continuum normalized spectral profiles of the eight DIBs toward HD 183143 (red) and HD 204827 (black). HD 183143 (E_{B-V} = 1.27) is a prototype for studying DIBs. HD 204827 is slightly less reddened (E_{B-V} = 1.11) and exhibits DIBs well-correlated with *N*(C_2). Filled circles indicate the limits of integration for calculating equivalent widths. Red arrows indicate the locations of stellar lines identified in the DIB atlas for HD 183143 and black arrows the stellar lines for HD 204827. Green arrows show additional stellar lines identified in low-reddened comparison stars for these two stars. The vertical scale in all panels is the same to clearly show the relative strengths of the DIBs. Note the presence of wings on several DIBS, such as λλ5780.5, 6204.5, and 6283.8 It is not known whether these are related to the primary DIB or are independent features.

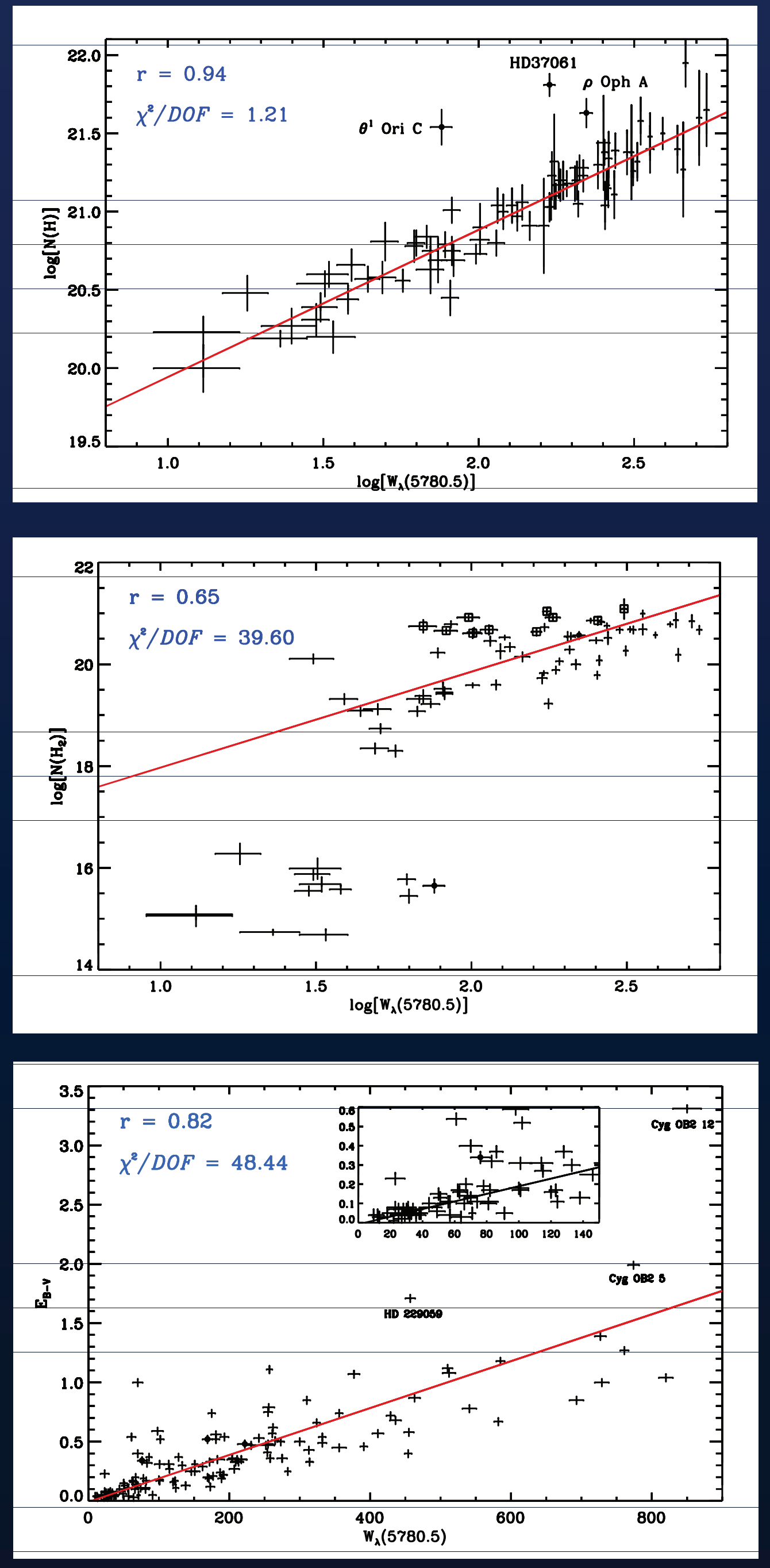

Figure 2 Correlations of equivalent widths of DIB λ5780.5 with the column densities of neutral hydrogen (top), molecular hydrogen (middle), and E_{B-V} (bottom). The three outlier stars indicated by name in the top figure are in the high radiation fields, and were originally rejected by Herbig (1993). These stars have also been excluded from our computation of the correlation coefficient r and χ^2 indicated in the figures. (In Table 1 we show r and χ^2 with these stars both included and excluded.)

In the middle plot the straight line is through the points with log[*N*(H_2)] > 18, where the H_2 is self-shielded, and the open squares indicate sight lines for which the molecular fraction *f*(H_2) > 0.5. The correlation coefficient is very poor, even for this subset of sight lines. This suggests that the DIBs are not preferentially located in the densest regions of interstellar clouds. Note that the column density of H_2 can vary by 5 orders of magnitude for a given value of W_λ(5780.5).

Most interstellar quantities will show a positive correlation with each other simply due to the increase of interstellar material with distance. This is most clearly reflected in the correlation of DIBs with extinction. For the eight DIBs considered here the correlation coefficients with E_{B-V} ranges from 0.80 to 0.85, with an average of 0.82. Thus, we may regard *r* ~ 0.86 – 0.88 as the minimum required to indicate that two quantities are physically correlated at a significant level. The correlation of λ5780.5 with *N*(H) far exceeds this.

Diffuse Interstellar Bands (DIBs)

DIBs are often said to represent the longest outstanding problem in astrophysical spectroscopy: the unidentified presence of hundreds of weak absorption features in the optical spectral range (Herbig 1995). They were first observed as early as 1919 (Heger 1922). DIBs are known to arise in the interstellar medium and are thought to be associated with large molecules. However, no DIB has been conclusively identified with a known molecule in the laboratory.

Our group, led by D.G. York, has assembled one of the largest datasets on DIBs: spectra of about 200 stars with the following characteristics:
- λ/Δλ = 38,000 from 3600 Å to 9000 Å
- signal-to-noise ratio of approximately1000 at 5780 Å for each sight line
- A very large range of reddening, E_{B-V} ~ 0.01–3.31 mag

Previous studies by our group have led to the identification of a class of weak DIBs which are well correlated with *N*(C_2) (Thorburn et al, 2003), observations of C_3 in translucent sight lines (Oka et al, 2003), and two DIB atlases of HD 204827 and HD 183143 (Hobbs et al. 2008, 2009). 113 of 380 (30%) DIBs tabulated in the first atlas had not been detected in four previous modern surveys, and 135 of 414 (33%) in the second atlas, due to the high S/N and sensitivity of our observations. Correlation studies among DIBs and with interstellar parameters may yield information about DIB "families," and reveal clues about their origin. We found a near–perfect correlation between DIBs λλ6196.0 and 6613.6 (McCall et al. 2010), possibly indicating a common progenitor molecule ("carrier"). Here we report on the mutual correlations among 8 strong DIBs and with *N*(H), *N*(H_2) and E_{B-V} (Friedman et al. 2011).

Figure 3 For most of the correlations of DIBs with λ5780.5 the best fit line goes through the origin. However, this is not true for λ6283.8 and especially for λ6613.6, shown here. The expanded view of the origin shown in the inset shows possible evidence of a threshold effect, such that a substantial amount of 5780.5 must be produced before 6613.6 can begin to form. Since *N*(H) is very well correlated with 5780.5, this implies that some minimum column density of H may required before some DIBs form.

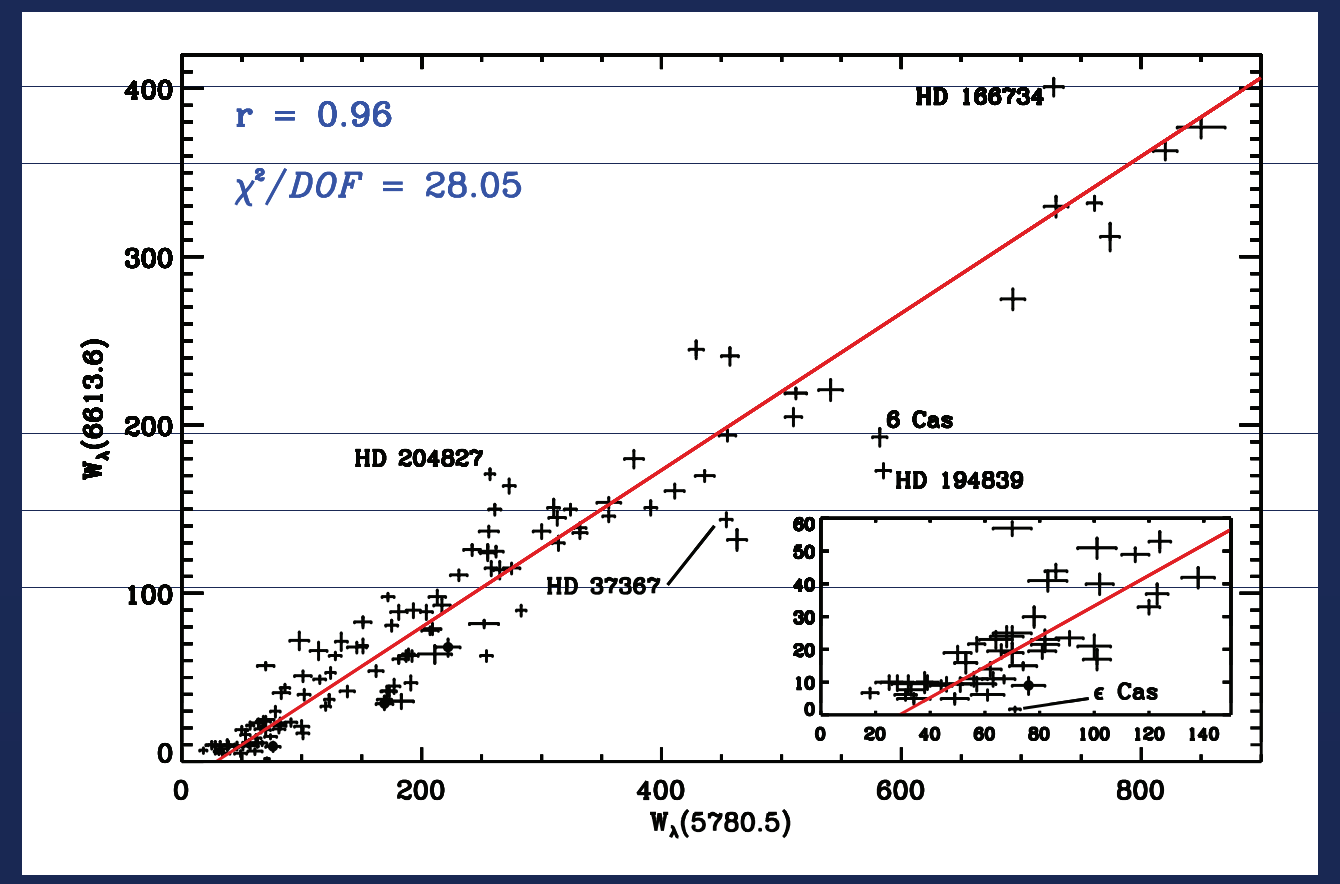

Table 1 Correlation coefficients of the eight DIBs with *N*(H). The correlation of λ5780.5 with *N*(H) exceeds that which would be expected from the general growth of interstellar material. It is large enough to be a useful tool for estimating *N*(H) in Galactic sight lines based on a simple optical observation of the equivalent width of λ5780.5, when space-based UV observations of the Lyman series are unavailable. This correlation is significantly greater than another that is commonly used to estimate *N*(H), that with E_{B-V}.

DIB Correlation Data with log[*N*(H)][a,b]

DIB (FWHM[c])	Correlation Coefficient	Reduced χ^2	Number of Sight Lines	Correlation Coefficient[d]	*a*[e]	*b*[e]
5780.5 (2.11)	0.94	1.209	74	0.90	19.00 ± 0.08	0.94 ± 0.04
6283.8 (4.77)	0.89	1.250	71	0.87	17.65 ± 0.20	1.30 ± 0.07
6204.5 (4.87)	0.89	1.559	69	0.84	19.02 ± 0.11	1.12 ± 0.06
6196.0 (0.42)	0.89	2.035	68	0.79	19.90 ± 0.06	0.95 ± 0.05
6613.6 (0.93)	0.87	2.794	70	0.77	19.89 ± 0.06	0.67 ± 0.03
5705.1 (2.58)	0.83	1.278	52	0.73	19.38 ± 0.16	1.08 ± 0.09
5797.1 (0.77)	0.82	3.269	65	0.72	19.59 ± 0.09	0.85 ± 0.05
5487.7 (5.20)	0.78	1.516	55	0.60	19.28 ± 0.16	1.13 ± 0.09

Notes.
[a] All entries computed using logarithmic values of DIB equivalent widths.
[b] Data in Columns 2, 3, 4, 6, and 7 exclude ρ Oph A, θ^1 Ori C, and HD 37061.
[c] FWHM from Paper II. All wavelengths are in units of Å.
[d] Includes all sight lines.
[e] Coefficients for $\log[N(\mathrm{H})] = a + b \times \log[W_\lambda(\mathrm{DIB})]$.

Table 2 Mutual correlation coefficients of the eight DIBs in this study. Of the 28 pairs, 27 have correlations greater than 0.9. DIBs which arise from the same carriers, or whose carriers may have been formed in the presence of a third, common carrier, would have correlation coefficients very close to unity. None of the pairs considered here has such a high correlation, with the exception of λλ6196.0 – 6613.6 (McCall et al. 2010) and possibly λλ5780.5 – 5705.1.

DIB–DIB Correlation Coefficients[a,b]

DIB	5780.5	6204.5	6196.0	6283.8	6613.6	5705.1	5797.1	5487.7
5780.5	1	0.97	0.97	0.96	0.96	0.98	0.93	0.95
6204.5	0.97	1	0.96	0.98	0.94	0.96	0.91	0.95
6196.0	0.97	0.96	1	0.93	0.99	0.93	0.96	0.94
6283.8	0.96	0.98	0.93	1	0.91	0.94	0.86	0.92
6613.6	0.96	0.94	0.99	0.91	1	0.93	0.95	0.91
5705.1	0.98	0.96	0.93	0.94	0.93	1	0.90	0.93
5797.1	0.93	0.91	0.96	0.86	0.95	0.90	1	0.87
5487.7	0.95	0.95	0.94	0.92	0.91	0.93	0.87	1

Notes.
[a] All entries computed using linear values of DIB equivalent widths.
[b] Excluding ρ Oph A, θ^1 Ori C, and HD 37061.

Future Work

We have a large program aimed at eventually identifying the carriers of DIBs. Our investigations have multiple approaches.
- Our atlases (Hobbs et al. 2008, 2009) have tabulated narrow DIBs. We are now obtaining lower-resolution spectra to increase our sensitivity to broad (> 6Å), shallow DIBs. We expect to discover new DIBs and to explore some of the possible unrecognized blends among DIBs (see Figure 1). This may reduce systematic errors and increase correlation coefficients.
- We will observe many stars distributed behind high latitude clouds in order to map the abundances of DIBs as a function of depth within the cloud. This will shed light on the σ – ζ effect (Krelowski & Sneden, 1995), and the relationship between DIB abundance, ionization state, and PAH abundance.
- McCall et al. (2010) found that if their errors, dominated by systematic effects such as continuum placement errors, were underestimated by only a factor of 2, then the data are consistent with a perfect correlation between λλ6613.6 and 6196.0. This suggests that these DIBs might arise from the same carrier. We are attempting to reduce the systematic errors and are investigating other relations that might be perfectly correlated, such as that of λλ5780.5 – 5705.1.
- A general goal is to characterize DIBs in a variety of environments, both to aid in identifying their carriers and to establish and calibrate them as diagnostics for conditions in interstellar clouds.