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Novel correlations between diffuse interstellar bands and optical reddening

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ABSTRACT

The relatively new and expansive Apache Point Observatory Catalog of Optical Diffuse Interstellar Bands was analyzed to identify novel correlations between diffuse interstellar bands (DIBs) and optical reddening $E(B-V)$, with a principal aim being to facilitate future identifications of the host molecular carriers. The following lines exhibit the highest Pearson r correlations in descending order ($0.930 \geq r \geq 0.885$), and are tied to DIBs featuring $n \geq 10$ sightlines and possessing equivalent width uncertainties: $\lambda(\text{Å}) \simeq$ 5236.27, 5793.24, 5797.18, 6449.27, 6795.26, 5948.87, 6113.22, 6860.02, 6059.34, 6520.74. Independent observations to confirm the preliminary trends are desirable, and extinction estimates could be subsequently inferred for targets by relying on longer-wavelength (NIR) photometric calibrations linked to a weighted subset of numerous DIBs. Lastly, several DIBs appear unassociated with $E(B-V)$, thereby reaffirming that diverse carriers exist.

Keywords: Astrochemistry(75) — Diffuse interstellar bands(379) — Interstellar medium(847) — Interstellar reddening(853)

INTRODUCTION

There exists a lack of consensus concerning the chemical carriers of > 500 diffuse interstellar bands (DIBs), as underscored by the C_{60}^{+} debate (Galazutdinov et al. 2021; Schlarmann et al. 2021). A partial list of the sources proposed include fullerenes, anionic hydrogen clusters, and polycyclic aromatic hydrocarbons (e.g., Huang et al. 2019; Bondar 2020). Nonetheless, DIBs may be linked to a common carrier on the basis of correlated equivalent widths (EWs), dust dependencies, and possibly spectral line morphology (e.g., Smith et al. 2021; Fan et al. 2022). The impetus of this work is to continue that broader effort by utilizing the comparatively new and comprehensive Apache Point Observatory Catalog of Optical Diffuse Interstellar Bands (Fan et al. 2019), and to discover highly correlated EW-$E(B-V)$ pairs. The identification of subsets of interrelated DIBs may then be compared to robust quantum chemistry predictions.

Recent efforts aimed in part at characterizing correlations between DIBs and dust include Fan et al. (2017), who analyzed 8 DIBs and determined that the highest correlation with reddening was 4726 Å ($r = 0.89 \pm 0.01$). Galazutdinov et al. (2020) analysed 5 DIBs and concluded that 4430 Å exhibited the highest EW-$E(B-V)$ correlation ($r = 0.91$), whereas Kos & Zwitter (2013) determined $r = 0.41$. This complex DIB can be blended with several stellar lines and Kos & Zwitter (2013) subsequently excluded it from their analysis. Galazutdinov et al. (2020) provide other examples where contamination can yield an uncertain correlation (e.g., 5450 Å). Indeed, differences in r can arise owing to a suite of reasons such as continuum placement, stellar and telluric line contamination, regional anomalies, ambient radiation field, stellar peculiarities, number of clouds along the sightline, sample size, etc.

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OBSERVATIONS AND METHODS

The Fan et al. (2019) catalog provides data for 557 DIBs, and 25 sightlines were surveyed (Fan et al. 2019, their Table 1). The eclipsing binary VI Cyg 5 and hypergiant VI Cyg 12 were omitted from subsequent analysis (e.g., see Herbig 1975; Kashuba et al. 2016, and discussion therein), since Cygnus may be along a sightline exhibiting anomalous dust and those stars could be encompassed by circumstellar material (e.g., Maryeva et al. 2016).

DIB wavelengths, EWs, EW uncertainties, and $E(B-V)$ were adopted verbatim from Fan et al. (2019). A formal uncertainty of $\sigma_{E(B-V)} = 0.03$ mag was assumed following Fan et al. (2017). Pearson correlations and their uncertainties were determined via Monte Carlo simulations. Datasets were created by randomly sampling within the reddening and EW uncertainties. The mean and standard deviation across all generated sets yielded $r \pm \sigma_r$, respectively.

Following Smith et al. (2021), those DIBs exhibiting $n < 10$ sightlines were excluded from the analysis to minimize artifacts arising from a small sample (leaving 359 DIBs). The remaining data possessing EW uncertainties were subdivided into more reliable correlations featuring $n \geq 15$ sightlines, and $10 \leq n \leq 14$ results that are considered tentative. The DIB (Å), sample size (n), and computed correlation ($r \pm \sigma_r$) are cited in Table 1 for $r > 0.81$. The cited correlation uncertainties are formal and admittedly underestimated. The findings presented are preliminary in the absence of independent observations.

RESULTS

The top correlations in the higher confidence group are (in Å): 5793.24 ($r = 0.916 \pm 0.009$), 5797.18 ($r = 0.915 \pm 0.004$), 6449.27 ($r = 0.912 \pm 0.008$), 6795.26 ($r = 0.910 \pm 0.008$), and 6113.22 ($r = 0.897 \pm 0.006$). Note the marginal wavelength separation between 5793.24 and 5797.18 Å, their high correlations with $E(B-V)$, and between their EWs ($r \simeq 0.92$, unpublished). Similarly, Smith et al. (2021) highlight the case of the proximal DIBs 5779.59 and 5780.64 Å, which possessed the highest EW pair correlation relative to $> 10^4$ DIB combinations they studied. The line 5779.59 Å is the broad feature, whereas 5780.64 Å is narrower and deeper (Galazutdinov et al. 2020, their Fig. 11), and the set may relay substructure. The top correlations in the tentative group are (in Å): 5236.27 ($r = 0.930 \pm 0.007$), 5948.87 ($r = 0.903 \pm 0.019$), 6860.02 ($r = 0.887 \pm 0.009$), 6523.29 ($r = 0.867 \pm 0.012$), and 6245.14 ($r = 0.857 \pm 0.009$).

Several DIBs listed in Table 1 are reported in the literature. For example, the 6195.99 Å DIB was determined here to exhibit $r = 0.868 \pm 0.005$, which compares favorably to previously reported correlations of $r = 0.90$ (Kos & Zwitter 2013) and $r = 0.86 \pm 0.01$ (Fan et al. 2017). The 5797.18 Å DIB is cited to exhibit $r = 0.84$ (Kos & Zwitter 2013) and $r = 0.88 \pm 0.01$ (Fan et al. 2017), which are comparable with the correlation presented here ($r = 0.915 \pm 0.004$). The general agreement is satisfactory, particularly given expected deviations in r for the innumerable reasons described above (e.g., regional anomalies add to the scatter, Herbig 1975).

Certain DIBs may not be correlated with $E(B-V)$ (e.g., Bondar 2012; Fan et al. 2022). It follows that multiple DIB carriers exist, as likewise implied by the spread in EW correlations between DIB pairs (e.g., Smith et al. 2021). The following DIB candidates appear to possess low correlations with optical reddening (in Å): 6067.78 ($r = 0.181 \pm 0.027$), 7031.64 ($r = 0.273 \pm 0.015$), 6663.99 ($r = 0.315 \pm 0.028$), 5788.70 ($r = 0.319 \pm 0.027$), and 4683.03 ($r = 0.411 \pm 0.021$). However, a dedicated and expanded investigation are desirable, as contaminating lines can yield spurious lower correlations.

CONCLUSIONS

The recent publication of the Apache Point Observatory Catalog of Optical DIBs (Fan et al. 2019) was used to evaluate preliminary correlations between DIB EWs and $E(B-V)$. A key objective was to facilitate future identifications of the host carriers. That may potentially be achieved by identifying DIBs with correlated EWs (e.g., Bondar 2020; Smith et al. 2021), *and* comparable correlations with reddening. Those groups of interrelated DIBs may be subsequently compared with molecular spectra inferred from quantum chemistry computations.

The top correlations found are (in Å): 5236.27 ($r = 0.930 \pm 0.007$), 5793.24 ($r = 0.916 \pm 0.009$), 5797.18 ($r = 0.915 \pm 0.004$), 6449.27 ($r = 0.912 \pm 0.008$), 6795.26 ($r = 0.910 \pm 0.008$), 5948.87 ($r = 0.903 \pm 0.019$), 6113.22 ($r = 0.897 \pm 0.006$), 6860.02 ($r = 0.887 \pm 0.009$), 6059.34 ($r = 0.886 \pm 0.011$), and 6520.74 ($r = 0.885 \pm 0.006$). Independent observations are desirable to support the findings. Extinction estimates could be inferred from a weighted set of DIBs that are highly correlated with reddening, thereby minimizing the standard error, and certain anomalies could be advantageously mitigated by relying on NIR photometry (e.g., J, K_s). Lastly, numerous DIBs could exhibit relatively low correlations with $E(B-V)$. A separate analysis may (in)validate those tentative results, and possibly yield pertinent conclusions on the diversity of DIB carriers and their formation mechanisms.

Table 1. Preliminary DIB EW-$E(B-V)$ correlations

$n \geq 15$			$10 \leq n \leq 14$		
DIB (Å)	n	$r \pm \sigma_r$	DIB (Å)	n	$r \pm \sigma_r$
5793.24	19	0.916 ± 0.009	5236.27	13	0.930 ± 0.007
5797.18	23	0.915 ± 0.004	5948.87	10	0.903 ± 0.019
6449.27	21	0.912 ± 0.008	6860.02	12	0.887 ± 0.009
6795.26	18	0.910 ± 0.008	6523.29	12	0.867 ± 0.012
6113.22	18	0.897 ± 0.006	6245.14	10	0.857 ± 0.009
6059.34	15	0.886 ± 0.011	5515.95	11	0.854 ± 0.023
6520.74	20	0.885 ± 0.006	6737.26	13	0.854 ± 0.011
6439.51	22	0.875 ± 0.006	5859.06	10	0.848 ± 0.044
6376.14	21	0.875 ± 0.005	5814.28	11	0.848 ± 0.018
5545.08	19	0.874 ± 0.006	6803.35	14	0.844 ± 0.012
6613.74	23	0.869 ± 0.005	5947.28	14	0.842 ± 0.009
6195.99	22	0.868 ± 0.005	6110.77	10	0.842 ± 0.031
6211.69	19	0.866 ± 0.007	6498.00	14	0.826 ± 0.011
6379.25	21	0.865 ± 0.005	6654.72	13	0.825 ± 0.019
5849.82	23	0.859 ± 0.006	6594.30	11	0.821 ± 0.017
5923.51	20	0.855 ± 0.007	6657.34	11	0.819 ± 0.013
6194.73	16	0.855 ± 0.010			
6400.49	18	0.845 ± 0.008			
5494.10	18	0.845 ± 0.008			
5487.64	18	0.842 ± 0.008			
6445.30	19	0.834 ± 0.007			
5705.12	18	0.833 ± 0.007			
6689.35	17	0.828 ± 0.008			
7367.08	20	0.828 ± 0.006			
5779.59	23	0.826 ± 0.007			
6367.30	20	0.826 ± 0.008			
6234.01	19	0.826 ± 0.008			
7559.43	18	0.825 ± 0.010			
5925.91	17	0.822 ± 0.016			
6377.07	20	0.820 ± 0.007			
6330.03	19	0.814 ± 0.010			
6139.95	18	0.813 ± 0.011			
6089.85	22	0.813 ± 0.006			
6553.88	19	0.812 ± 0.010			
6108.06	19	0.812 ± 0.009			

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