Early Results from the APO Diffuse Interstellar Band Survey

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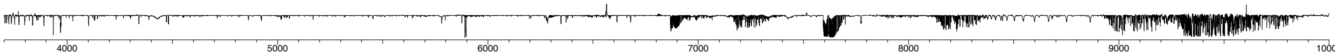

The APO DIB Survey

The diffuse interstellar bands (DIBs) are absorption features observed in the visible spectra of nearly all reddened stars, and were first observed in the early decades of the 20th century when many lines in stellar spectra were unassigned. As laboratory spectroscopy progressed, most of the stronger lines were identified with atomic or diatomic species — the DIBs are those that remain unidentified.

Since the DIBs have remained unassigned for over 75 years despite extensive laboratory efforts, we are trying a new approach. Our goal is to obtain moderate resolution ($\lambda/\Delta\lambda \simeq 37,500$), high signal-to-noise spectra of a large sample of reddened stars. We are using the ARCES echelle spectrograph at the Apache Point Observatory (see below), which offers complete spectral coverage from 3700–10,000Å. So far, we have taken data on 75 nights and have obtained S/N>500 on 114 stars (listed at the right; the stars marked with an asterisk have S/N>1000). Our hope is that this extensive dataset will yield new insights into the origin of the DIBs — this poster presents some of our early results.

HD 886
HD 2905*
HD 10516*
HD 10982
HD 11415
HD 14272
HD 17081
HD 20041
HD 21071*
HD 21389*
HD 21483*
HD 22951*
HD 23180*
HD 23408
HD 23480
HD 24398*
HD 24534
HD 24760*
HD 24912*
HD 26571*
HD 27778*
HD 29647*
HD 30614*
HD 34078
HD 34085*
HD 35149*
HD 36371*
HD 36486*
HD 36822*
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HD 37043*
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HD 37128*
HD 37742*
HD 37903
HD 40626
HD 41117*
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HD 43247*
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HD 53367
HD 58050
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HD 74280*
HD 78362*
HD 87887
HD 91316
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HD 138764*
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HD 143018*
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HD 144217*
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HD 198478*
HD 199579*
HD 200775*
HD 201433
HD 202850
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HD 204172
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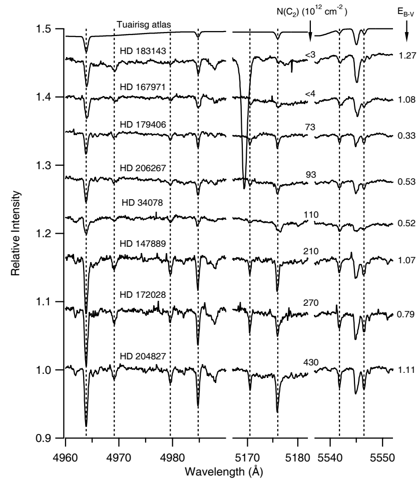
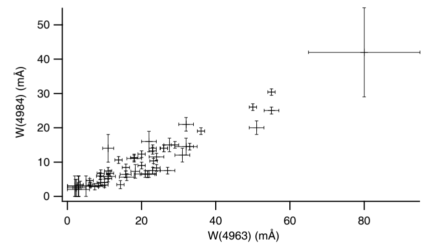
A New Class of DIBs: The C_2 DIBs

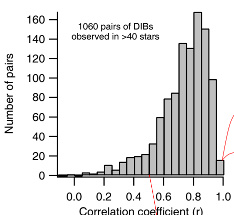


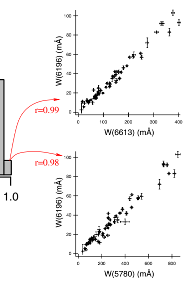
We have discovered a new class of narrow DIBs that appear to be stronger, relative to many broader DIBs, in sightlines with above average C_2 column densities per unit E(B-V). The figure on the left depicts these bands, some of which were not identified in previous DIBs (such as Tuairisg et al., A&AS 142, 225 [2000]). This appears to be the first known set of DIBs which shows a systematic dependence with another molecule.

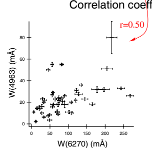
As seen in the figure below, two of the stronger of these bands ($\lambda\lambda$4963, 4984) seem to be well correlated, suggesting that they may have carriers which are closely (chemically) related. It is also remarkable that many of these "C_2 DIBs" happen to occur in pairs with similar splittings of about 20 cm^{-1}. Based on the magnitude of this splitting, we conjecture that this splitting may be due to the spin-orbit interaction in a linear molecule.

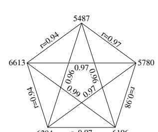


DIB Families?



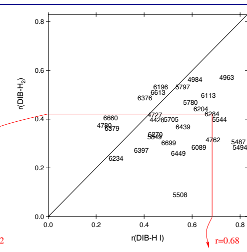


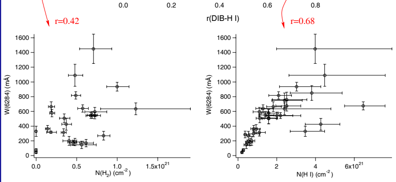




The upper left figure shows a histogram of the correlation coefficients between pairs of DIBs which are observed in at least 40 stars. There are relatively few tightly correlated pairs; correlation plots for two such pairs are shown above. (For contrast, the plot to the left shows two DIBs with r=0.50.) We have tentatively identified one set of DIBs which all have high correlation coefficients, as shown on the lower left. Such good correlations suggest that these DIBs have the same (or closely related) carriers.

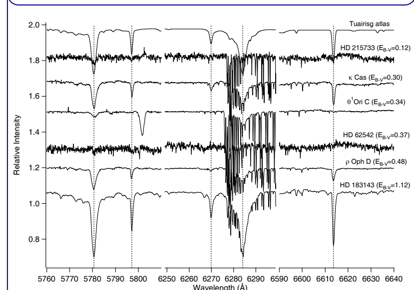
DIBs versus H I and H_2





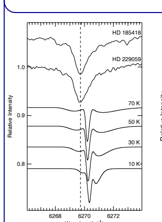
The top graph shows the linear (Pearson's) correlation coefficient for a given DIB with H_2, versus that with H I, for all DIBs that have been measured in at least 20 stars where H I and H_2 have been measured. Clearly, most DIBs are better correlated with H I than with H_2, as seen in the lower graphs for the specific example of λ6284.

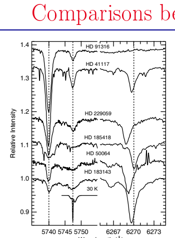
Weak DIBs toward HD 62542



The moderately reddened B5V star HD 62542 is known to have an unusual UV extinction curve of the type usually identified with dark clouds. The excitation of C_2 in this sightline suggests T ~ 50 K and n_H ~ 500–1000 cm^{-3}. The diatomic molecules CH, CN, and C_2 have high column densities, but the enigmatic CH^+ is not observed. Our DIB observations (see figure above) show that several of the strongest DIBs ($\lambda\lambda$ 5780, 5797, 6270, 6284, and 6614) are essentially absent in this sightline. We interpret this as an extreme case of deficient DIB formation in a dense cloud whose more diffuse outer layers have been stripped away. [T. P. Snow et al., ApJ in press (astro-ph/0203254)]

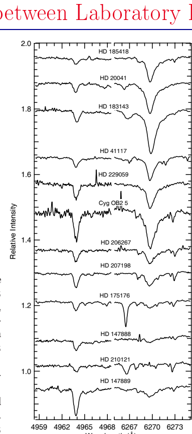
Comparisons between Laboratory Data and the DIBs



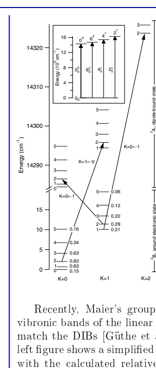


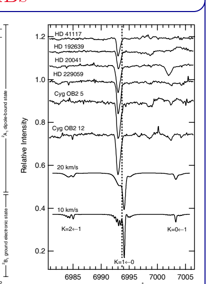
In 1998, J. P. Maier's group reported a possible match between the DIBs and the origin and four vibronic bands of the lowest electronic transition ($A^2\Pi_u \leftarrow X^2\Pi_g$) of C_7^- [Tulej et al., ApJ 506, L69]. At the time, the match seemed plausible, given the uncertainties in both the laboratory and observational data. In 2000, Maier's group revisited the C_7^- spectrum with considerably higher resolution and sensitivity [Lakin et al., JCP 113, 9586].

The upper left figure compares the λ6270 DIB in two sightlines with simulations of the C_7^- origin band at various temperatures (the simulations use the molecular constants derived by Lakin et al.), and shows they do not agree in wavelength. Another of the proposed matches with C_7^- (λ5747) turns out to be a stellar line, as shown in the middle figure where the spectra have been aligned in velocity with the Si III stellar line at 5740Å. Finally, the figure at the right shows that the DIB at λ4963, another proposed match with C_7^-, is completely uncorrelated with the "origin band" λ6270. Altogether, we find no evidence supporting the hypothesis that C_7^- is a DIB carrier.



For more details on the comparison between C_7^- and the DIBs, see B. J. McCall et al. ApJ 559, L49 (2001).

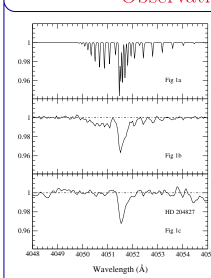


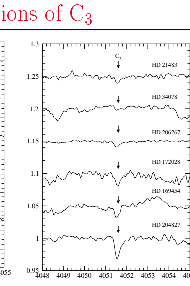


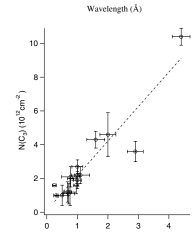
Recently, Maier's group suggested that the origin and three vibronic bands of the linear propadienylidene anion ℓ-$C_3H_2^-$ might match the DIBs [Güthe et al., ApJ 555, 466 (2001)]. The upper left figure shows a simplified energy diagram of this molecule, along with the calculated relative populations of each rotational level assuming a kinetic temperature of 30 K, a collision partner number density of 100 cm^{-3}, and an *ortho*:*para* ratio of 3:1.

The upper right figure shows the λ6993 DIB in several sightlines and a simulation of the ℓ-$C_3H_2^-$ spectrum. Given the accuracy of the spectroscopic constants used in the simulations, the lack of wavelength agreement rules out ℓ-$C_3H_2^-$ as a carrier of λ6993. There is also little evidence of a match with the vibronic bands [see McCall et al., ApJ 567, L145 (2002). Overall, there seems to be no evidence to support the suggestion that ℓ-$C_3H_2^-$ is a DIB carrier.

Observations of C_3







Our survey has also yielded detections of the $A^1\Pi_u \leftarrow X^1\Sigma_g^+$ transition of C_3 at 4051.6Å in 15 sightlines. Although the resolution of our spectrograph is not sufficient to resolve individual rotational lines, we clearly detect the central Q-branch. The top left figure shows a high-resolution simulation of the C_3 (Fig 1a), a simulation at our resolution and S/N (Fig 1b), and our spectrum of HD 204827 (Fig 1c). The upper right figure shows several examples of our C_3 spectra. The figure at the left shows that C_2 and C_3 are well-correlated in our sample.