Early Results from the APO Diffuse Interstellar Band Survey

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Abstract

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 astronomical spectra were unassigned. As laboratory spectroscopy progressed, most of the stronger lines were identified with atomic or diatomic species — the DIBs are those lines (more numerous and generally broader) 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, which offers complete spectral coverage from 3700–10,000Å. So far, we have taken data on 75 nights and have obtained S/N>1000 on 63 stars, and S/N>500 on 60 additional stars. Our hope is that this extensive DIB dataset, coupled with complementary measurements of known species at ultraviolet, visible, and infrared wavelengths, will yield new insights into the origin of the DIBs — this paper presents some of our early results.

1. DIB Correlation Studies

In looking through our dataset, 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). Figure 1a depicts these bands, some of which were not identified in previous DIB surveys [e.g., (Tuairisg *et al.* 2000)]. This appears to be the first known set of DIBs which shows systematic line strength correlations with a known molecule. The "C_2 DIBs" will be discussed in more detail in an upcoming paper (Thorburn *et al.* 2002). 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. We have also examined the correlation coefficient of each 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. It is clear that most DIBs are better correlated with H I than with H_2. Our survey is designed to have complete overlap with the new H_2 measurements from the Far Ultraviolet Spectroscopic Explorer, so we should soon have even better statistics for these correlations.

We have also searched for "families" of DIBs whose intensities are tightly correlated from sightline to sightline: such correlations would suggest that those DIBs have the same (or closely chemically related) carriers. We have considered 1060 pairs of DIBs which are observed in at least 40 sightlines. The majority of the correlation coefficients are less than 0.8 (e.g., Figure 1b), and there are relatively few tightly correlated pairs (e.g., Figure 1c). However, we have tentatively identified one set of DIBs which all have $r > 0.94$ ($\lambda\lambda$ 5487, 5780, 6196, 6204, and 6613).

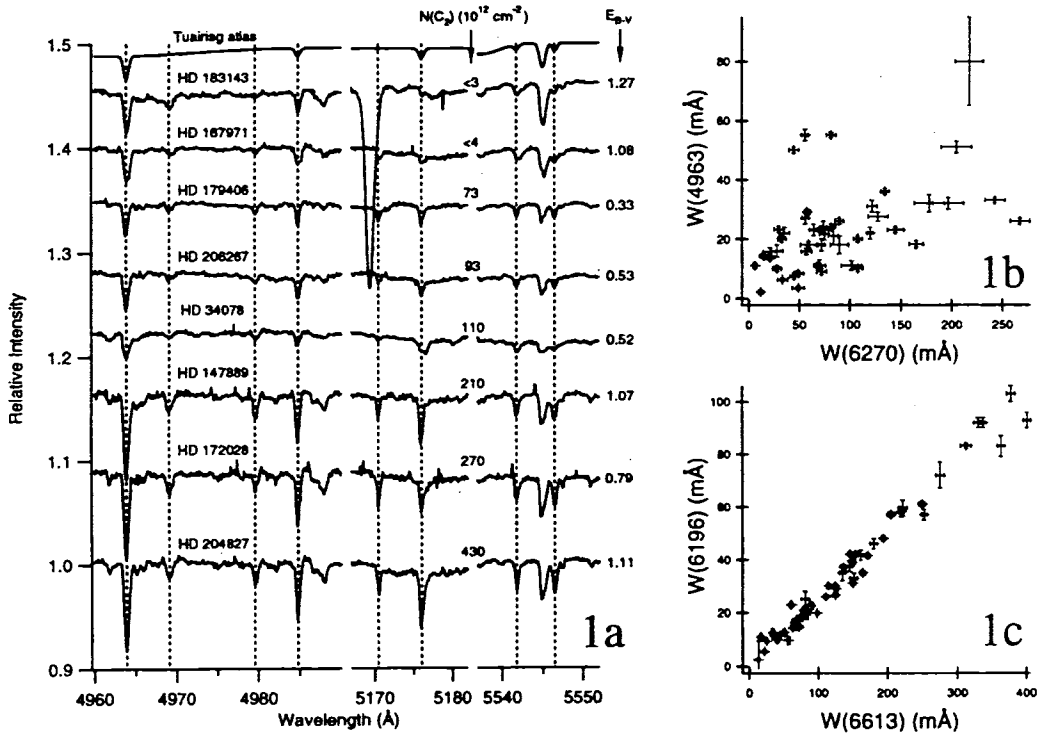

Fig. 1.— (a) The "C_2" DIBs; (b) Two DIBs with $r = 0.50$; (c) Two DIBS with $r = 0.99$

2. Comparisons with Laboratory Data

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.* 1998). At the time, the match seemed plausible, given the uncertainties in both the laboratory and observational data (McCall, York, and Oka 2000). Subsequently, Lakin *et al.* (2000) revisited the C_7^- spectrum with considerably higher resolution and sensitivity. We have recently compared our observations of the λ6270 DIB with simulations of the C_7^- origin band at various temperatures (the simulations use the molecular constants derived by Lakin *et al.* (2000)) — and find that they do not agree in wavelength. Another of the proposed DIB matches with C_7^- (λ5747) turns out to be a stellar line. We also found that the DIB at λ4963, another proposed match with C_7^-, is completely uncorrelated with the supposed "origin band" λ6270. Altogether, we find no evidence supporting the hypothesis that C_7^- is a DIB carrier, as discussed in detail by McCall *et al.* (2001).

More 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.* 2001). We have performed detailed simulations of the expected spectrum of the ℓ-$C_3H_2^-$ origin band and compared them with the λ6993 DIB. 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. We find that there is also little evidence of a match with the vibronic bands. Overall, there seems to be no evidence to support the suggestion that ℓ-$C_3H_2^-$ is a DIB carrier, as discussed in more detail by McCall *et al.* (2002).

3. Other Results

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 $\sim$ 50 K and $n_H \sim$ 500–1000 cm^{-3}. The diatomic molecules CH, CN, and C_2 have high column densities, but the enigmatic CH^+ is not detected. We have observed HD 62542 (along with HD 215733) with UCLES at AAT, and compared these spectra with others from our APO survey. These spectra reveal that the typically strongest DIBs in our UCLES wavelength coverage ($\lambda\lambda$ 5780, 5797, 6270, 6284, and 6614) are essentially absent towards HD 62542. We interpret this as an extreme case of deficient DIB formation in a dense cloud whose more diffuse outer layers have been stripped away (Snow *et al.* 2002).

Another by-product of our survey has been the detection of the $A^1\Pi_u \leftarrow X^1\Sigma_g^+$ transition of C_3 at 4051.6 Å in 15 sightlines. Although the resolution of our spectrograph is not sufficient to resolve individual rotational lines, we clearly detect the central Q-branch. We also find that the C_2 and C_3 column densities are well correlated. Our C_3 detections will be discussed in detail in an upcoming paper (Oka *et al.* 2002).

In collecting our new database of DIBs and related interstellar quantities, we are encouraged by our ability to rule out specific laboratory candidates for the DIBs, to suggest physical associations (as in HD62542) of different DIBs with different types of interstellar clouds, to isolate at least some families of DIBs with high significance, and to discover, for the first time, associations of some DIBs with known small molecules.

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