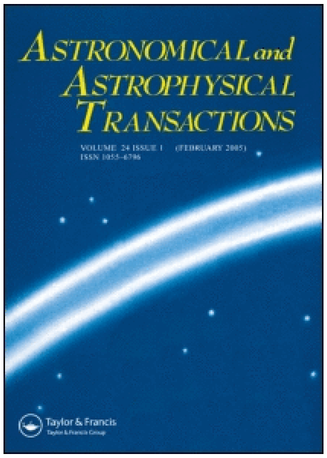

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DIFFUSE INTERSTELLAR BANDS

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The identification of diffuse interstellar bands (DIBs) remains an open problem since discovery of the first two such features 80 years ago. Any attempt to solve the mystery of the carrier(s) of the DIBs must involve interdisciplinary collaboration between molecular physicists, chemists and astronomers. It is expected that progress in this field will be possible when all known DIBs are divided into families in such a way that only one carrier is responsible for all bands belonging to a given family. In this paper we review some attempts to solve the problem of the origin of the DIBs and we present our latest trials on dividing DIBs into spectroscopic families. We define and discuss the problem of 'noisy correlation' between strengths of different DIBs. Noisy correlation has to be controlled carefully when we look for spectroscopic families of DIBs.

Keywords: Diffuse interstellar bands; Spectroscopic families of diffuse interstellar bands; Noisy correlation

1 INTRODUCTION

Interstellar (IS) absorption lines are lines produced by atoms and molecules in the IS medium and they are seen as absorption against the spectrum of a background star. They are relatively sharp and always come from the ground state of the atoms and molecules concerned. Ground-based observations include the following lines: Ca II (H) at 3968.5 Å, Ca II (K) at 3933.7 Å, Ca I (g) at 4226.7 Å, the sodium doublet Na I (D) at 5890 and 5895.9 Å, and the potassium doublet at 7664.9 and 7699 Å. There are also several lines of Fe I and Ti II and lines of the molecules CH, CN and CH^+.

The separate group of IS absorption lines observed in the visible region is represented by relatively broad absorption features, called diffuse interstellar bands (DIBs). The most prominent DIBs are those at 4428 and 6284 Å. No consensus has been reached as to the source of these features; suggestions include polycyclic aromatic hydrocarbons (PAHs), fullerenes, carbon chains and dust grains. In other words, in the IS medium we have to deal with particles, that produce easily observable spectral features, and we are not able to identify them.

The DIBs were first mentioned by Heger (1922) while their stationary character and their IS origin were confirmed by Merrill and Wilson (1938). An extensive survey has been pub-

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lished by Herbig (1975) on the basis of photographic plate spectra; he reported 39 DIBs in the spectral range 4400–6700 Å. A comprehensive review on the topic of DIBs, together with an extensive bibliography, has been published more recently by Herbig (1995).

At present the DIB mystery must surely be the most outstanding unsolved spectroscopic problem in astronomy, ranking with the longest-standing problems of the last two centuries. The solution to this mystery is likely to elucidate greatly the nature of the IS medium. More than 300 DIBs have been detected to date in the optical infrared region (Galazutdinov *et al.*, 2000). Some of these are very broad (with half-widths (HWs) of their profiles greater than 10 Å) and some are quite narrow (with HWs less than 1 Å). DIBs, in general, are weak structures with line depths being as low as 0.1–2% of the continuum level. Few DIBs have, however, greater depths in some directions above 10% of the continuum level. The strongest DIBs are those with the central wavelengths 4428, 5780, 5797, 6203, 6270, 6284, 6614, 6993 and 7224 Å. Some stronger DIBs show an internal structure in their, usually a symmetrical profiles (5797, 6196 and 6614 Å).

2 THE DEPENDENCE OF THE STRENGTH OF DIFFUSE INTERSTELLAR BANDS ON INTERSTELLAR REDDENING

Merrill and Wilson (1938) were the first to speculate, from the dependence of the DIB strength on IS reddening, that the DIBs were produced by small solid particles. That idea gained momentum in the years that followed, and much attention has been devoted to it and to elaborating it. However, as the measurements of DIB strengths and reddenings were refined, it became clear that the dependence of one on the other is not fired. This is a reason to doubt whether the dust grains are the carriers of DIBs.

However, there could be objections to a straightforward negative conclusion about dust grains as DIB carriers. Firstly, only for a few DIBs from a large list of these structures were appropriate investigations made. We expect many families of DIBs corresponding to different carriers. One cannot exclude the possibility that some DIBs originate in dust grains. Secondly, in different IS clouds we may have to deal with different ratios of large grains (giving grey extinction and not contributing to reddening but hypothetically contributing to the DIB strength) to small grains. This would give a scatter of points in DIB strength–reddening diagrams.

3 CORRELATION WITH THE GAS

It was found that the equivalent widths (EWs) of DIBs (5780 and 5797 Å) and IS atomic lines (Na I, K I and C I) are reasonably well correlated (see for example Herbig (1993)). There is considerable scatter about the mean relationship, however, and a systematic departure from it at the highest Na I column densities. The major constituent of the IS gas is H, which exists mainly as neutral (H I) or as H_2. A crucial issue is whether the DIB abundance is tied to H I or to H_2. If it is not correlated with H_2, then the DIB carriers must not be produced in the same way as, for example, the neutral carbon diatomic molecules (CN and CH) whose abundances in diffuse clouds have been explained by gas-phase chemistry beginning with H_2.

It is now clear (see for example Herbig (1993)) that the 5780 and 5797 Å DIBs follow a power-law dependence upon N(H I), and do not depend in a systematic way upon $N(H_2)$, at least in those clouds sufficiently transparent to have permitted the far-ultraviolet spectroscopy of H I and H_2.

4 LOCATION OF DIFFUSE INTERSTELLAR BANDS

As far as the evidence goes, it indicates that the DIB carriers are constituents of the clouds, of the diffuse clouds in particular and not of some other fraction of IS medium. The reasons for this belief are twofold:

(i) DIBs are observed towards stars of low to only moderate extinction.
(ii) The narrowest of the DIBs (6196 Å) has been partially resolved into two components whose displacements match those of the IS K I lines in the spectrum of the same star.

5 FAMILIES OF DIFFUSE INTERSTELLAR BANDS

There is now general agreement that the sheer number of DIBs, their widespread distribution across the optical spectrum, and the fluctuations in individual band strengths from one line of sight to another indicate that more than one carrier is involved.

Clearly, in some directions some DIBs appear unusually weak or strong with respect to the mean correlation with reddening. The first indication of a pattern in these discrepancies was provided by Chlewicki *et al.* (1986). They found that they could divide the DIBs into two classes:

(i) 5797 and probably 5849 Å, which correlated well with reddening;
(ii) 5780, 6195, 6203, 6269 and 6283 Å, which showed a much weaker dependence on reddening, but a good correlation with each other.

The specific claim that there are families of DIBs originated with Krełowski and Walker (1987). These families were defined as groups of bands whose strengths in different lines of sight are more closely correlated with one another than with other DIBs, and which obey a common dependence on reddening. The groupings proposed by Krełowski and Walker, are as follows:

(i) the broad shallow bands 4428 and 6177 Å (and perhaps 4882 Å);
(ii) the relatively symmetric DIBs 4763, 4780, 5362, 5449, 5487, 5780, 6196, 6203, 6269 and 6283 Å (and perhaps 5535 Å);
(iii) the relatively sharp but usually asymmetric 4726, 5545, 5797, 5849, 6376 and 6613 Å (and possibly 5494, 5508 and 6379 Å).

Josafatsson and Snow (1987) carried out an analysis of the mutual correlation, and of the individual correlation with reddening, for the DIBs in the 5690–5870 Å region. They defined three classes of the DIBs:

(i) the rather narrow DIBs 5780, 5797 and 5849 Å, which correlate well with each other and with reddening;
(ii) the two broad bands 5778 and 5844 Å correlating with each other but very poorly with reddening;
(iii) 5705 Å, which shows only a fair degree of correlation with other DIBs and with reddening.

A considerable body of new DIB data has appeared in recent years, and it would be desirable to re-examine the situation anew. The mystery of the carriers of DIBs should be much easier to solve after extracting ‘spectroscopic’ families of DIBs from astronomical spectra. A DIB family in the spectroscopic sense should include such bands, which certainly originate from the same carrier.

From our own experience with high-quality spectra taken with CFHT and at the McDonald Observatory we see that a formal statistical approach, where we look simply for mutual correlation between different DIBs, does not satisfy isolated spectroscopic families. This is due to the 'noisy' component in the correlation found. The noisy correlation comes not from the same carrier of considered pair of DIBs but from the fact that, on average, all carriers are more abundant if the IS medium becomes denser.

Krełowski and Westerlund (1988) showed that the DIBs 5780 and 5797 Å do not belong to the same family. The conclusion arise from the observational fact that drastic variations in the ratio of these DIB strengths were revealed when changing target stars. On the other hand, 5780 and 5797 Å DIBs are very well correlated when we take into account a few dozen stars. Their correlation is purely 'noisy'.

In our approach to the problem of spectroscopic families of DIBs (Wszołek and Godłowski, 2003) we decided to find DIBs related to the strong DIBs 5780 and 5797 Å from their close positional neighbourhood. From numerous set of star spectra we have chosen two subsets:

(i) with EW (5780 Å) almost constant, while EW (5797 Å) varies over a relatively broad range of values;
(ii) with EW (5797 Å) constant, while EW (5780 Å) varies in the spectral range from 5760 to 5860 Å there exist a dozen weak DIBs (Fig. 1). The DIBs that are considered to be

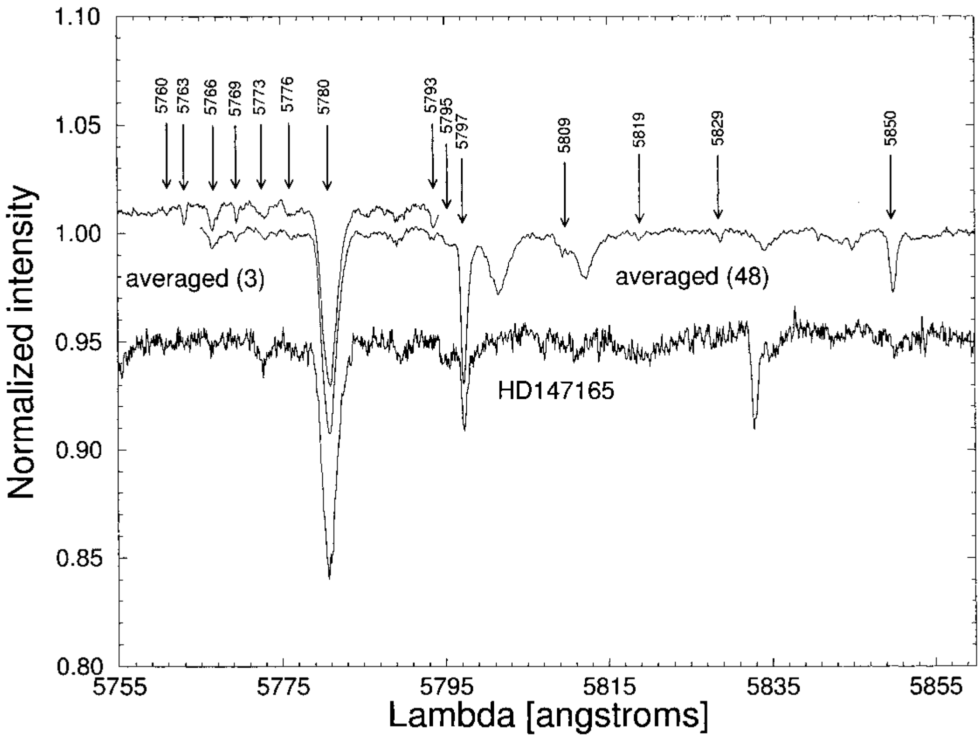

FIGURE 1 Averaged (over different stars) CFHT spectrograms. The vertical arrows indicate positions of the weak DIBs found in the positional neighbourhood of the 5780 and 5797 Å bands. The shorter spectrogram is a result of averaging over three stars (but spectrograms were of the highest signal-to-noise ratios) whereas the longer spectrogram is in fact an average over 48 spectrograms of moderate (like that of star HD 147165) signal-to-noise ratios. (Taken from the paper of Wszołek and Godłowski, 2003.)

related to the 5780 Å DIB should strictly follow the behaviour of this line in the sample where the 5797 Å DIB is stable. In the same way, DIBs related to the 5797 Å DIB should follow the changes in this DIB while the 5780 Å DIB is constant.

We have found that the weak DIBs 5776 and 5795 Å belong to the 5780 Å DIB family and that the DIBs 5793, 5819, 5829 and 5850 Å belong to the family of the DIB 5797 Å. Further investigations of this kind are strongly desirable.

6 CONCLUSIONS

The central issue of the DIB problem is the identity of the carrier or carriers. The DIB spectrum is produced not by one but by a number of carriers. The recognition of DIB families arising from a single or closely related species is an important issue that is not yet solved.

There remains no compelling evidence that the DIBs represent a solid-state phenomenon or are produced by some material trapped in the interstellar grains.

The widespread presence of DIB carriers in diffuse clouds indicates that, in general, carriers must be produced not in stars but rather in the clouds themselves.

The DIB carriers are not formed by reactions involving H_2, which controls the abundance of the carbon diatomic molecules in diffuse clouds.

Because of the very high level of noisy correlation between EWs of different DIBs the statistical abilities to isolate spectroscopic families are very limited. Our method of extracting spectroscopic families, described in the previous section, is more highly recommended than the formal statistical approach.

It should be noted here that the problem of noisy correlation, found during our analysis of data, may not be recognized at all in various astrophysical contexts and can lead to false conclusions.

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