Diffuse Interstellar Bands (DIBs) on the spectra of GALAH data: Correlation study between DIBs and DIBs with color excess

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Abstract. Diffuse interstellar bands (DIBs) are a collection of weak interstellar absorptions in the spectra of reddened objects. We have successfully measured three strong DIBs (i.e., λ 5780, 5797, and 6614 Å) on the spectra of 125 Galactic Archaeology with HERMES (GALAH) target stars. The fitting uses a template spectrum in order to extract and measure individual DIB. We applied a correlation study between DIBs and confirmed that DIBs are positively correlated with each other, meaning that their carrier(s) are co-existing in the interstellar medium. Also, DIBs are well-correlated with color excess E(B-V). From this result, which is in a good agreement with earlier studies, conclude that DIBs can be used as a tracer of the interstellar medium.

1. Introduction
The interstellar matter (ISM) make up almost 90% volume in the Galaxy and composes of various types of clouds, matters, and physical mechanisms. Due to these variations, many of ISM constituents are not fully understood. One of them is DIBs, a set of weak absorptions appear in the spectra of reddened objects. Despite it has been studied widely in recent decades (see [1] and [2] among others) and had been used as tools to investigate the structure of Galaxy ([3], [4]), DIBs exact carriers are still under investigation.

DIBs are famously known for their correlation between species and with other interstellar quantities (e.g. color excess, hydrogen column density, extinction). Various studies showed that DIBs can perform as agents to trace a variety of interstellar environments and their physical conditions (e.g. [5]). In the 80s, two distinct sightlines characterized by the strength ratio of DIB 5797 and DIB 5780 were first introduced and have been consistently investigated in DIBs studies ([6], [7], [8]). These lines of sight types might be able to give clues on DIBs’ carrier(s) distribution in the Galaxy. In this study, we aim to trace the interstellar condition in two certain fields in the Galaxy using DIBs’ strength and its relations with color excess.

2. Data
We used 125 spectra of GALAH DR2 ([9], [10]) which were observed by 3.9-m Anglo Australian Telescope (AAT) at Siding Spring Observatory. Attached to HERMES spectrograph, the resulting spectra have resolving power around 28,000 (see [11]). Each target was observed in four channels 4718 – 4903, 5649 – 5879, 6481 – 6739, 7590 – 7890 Angstrom. In search of correlations between DIBs and other interstellar quantities, we focus on the strongest DIBs located in green and red channels: DIB 5780, DIB 5797, DIB 6614. The targets are late-type stars with 3700 K ≤ Teff ≤ 7700 K, 0.3 dex ≤ log g ≤ 4.9 ≤ and [M/H] between -1.6 and 1.2. Target distribution in the Galaxy is plotted in Fig 1. For the analysis of the DIBs, we used parallax from Gaia DR2 [12] with relative uncertainty less than 20 % to derive the distance to each target star. Colour excess (E(B-V)) value towards each target and three-dimensional extinction map were taken from [13] and [14], respectively.
Fig 1. Distribution of selected GALAH fields (magenta circles) in Galactic coordinate superimposed with HI maps from the LAB survey (Kalberla et al. 2005). The map is centered at $l, b = (225, 0)$. The 125 target stars are distributed in two certain fields: (1) $l, b = (214.5, -18)$ and (2) $l, b = (251.5, 11.5)$.

3. Method

We quantify the strength of the DIBs by measuring their equivalent width (EW) which is defined by the area between continuum and DIB line profile. In this case, the DIBs of interest line profiles are estimated by a Gaussian function with three parameters: $A$ (depth of the absorption), $\mu$ (fitted central wavelength), and $\sigma$ (width of the absorption). Extracting DIBs from cool star spectra offers its own challenge as stellar lines are present in the vicinity of these DIBs. Even strong DIBs such as DIB 5780 and DIB 6614 suffer from the intervention of stellar lines that more often than not are stronger than their absorptions. Therefore, a template spectrum tailored specifically to each target was used to eliminate stellar lines around DIBs’ absorptions.

A template spectrum is an averaged spectrum made of a collection of observed stellar spectra with similar parameters with a target in question. These stars are called the nearest neighbours. Additional parameter ($E(B-V) < 0.1$) was introduced when choosing the nearest neighbors to guarantee that there are no interstellar absorptions present in the template spectra. This method has been used as part of the DIBs’ extraction process in RAVE [15] and SDSS [16]. The fitted parameters of DIBs’ absorptions were achieved by performing Markov Chain Monte Carlo (MCMC) with informative priors for each parameter. To estimate the uncertainty of equivalent width measurement, we measured the equivalent width of each DIBs using combinations of 16th, 50th, and 84th percentiles of each parameter and took the standard deviation of measured EWs as the uncertainty contributed by the fitting parameters. We were also taking into account uncertainty contributed by the continuum level placement in which some cases aren’t normalized perfectly.
3. Results and Discussion

We have successfully measured three strong diffuse interstellar bands (DIBs) located at around 5780, 5797, and 6614 Angstrom in several fields of GALAH DR2 spectra. All targets are located in 210 < l < 270. One fitting example of DIBs measurement in our dataset is demonstrated in Fig. 2. Each pair of DIB-DIB correlation traces different physical conditions and environments within the interstellar matters. We took into account the error of both quantities to estimate coefficients of linear fitting.

4.1 DIB and DIB correlation

There are clear positive correlations between each pair (DIB 5780 – DIB 5797, DIB 5780 – DIB 6614, and DIB 5797 – DIB 6614), as also seen in van Loon et al. 2014, although some scatter are also present (fig. 3). Even though the correlation is not perfect, this means that carrier(s) of these DIBs are co-existing to a certain degree in these two fields. Pearson correlation coefficient for DIB 5780 – DIB 5797 relation is 0.93 (hot stars, [17]), 0.96 inside Local Bubble region, and 0.95 outside Local Bubble [8] meanwhile our value is only 0.81. [18] found that the correlation is 0.86 and 0.77 for DIBs in the SMC and LMC, respectively. Meanwhile, the correlation of DIB 5797 – DIB 6614 is 0.95 [17] and DIB 5780 – DIB 6614 is 0.96. From our dataset, we find the correlation coefficient is somewhat significantly lower, 0.85 and 0.93 for DIB 5797 – DIB 6614 and DIB 5780 – DIB 6614. This might be caused by different spectral types (thus interstellar) used in this study and [17]. Low EW5797/EW5780 (σ sightline) value indicates a harsh radiation field, as the carrier(s) of DIB 5797 traces neutral cloud in the ISM. On the contrary, DIB 5780 traces the star-forming region within the ISM.
4.2 DIB and Color Excess correlation

Similar to the DIB-DIB correlation, we also find that our measured DIBs correlate well with foreground color excess (see Fig. 5). Among DIBs that are investigated in this work, DIB 5780 is well-known for having the strongest correlation. We investigate the correlation of DIB 5780 and DIB 5797 with color excess by considering EW5797/EW5780 which value provides a threshold to separate ζ and σ sightlines. The exact boundary is not very critical as there is a smooth transition between these sightlines, [6] adopted 0.3 as boundary value whereas [5] took 0.4 as the threshold. This work adopted 0.35 as a boundary. This value indicates the condition of the interstellar matter towards a target star: EW5797/EW5780 < 0.35 (σ sightline) is a sightline compromised by UV shielded cloud meanwhile EW5797/EW5780 > 0.35 (ζ sightline) shows that the cloud tends to be more diffuse. Using this ratio, it is evident that within a field, two distinct interstellar environments are observed (Fig 4). By grouping the DIBs based on EW5797/EW5780 values we noticed that in DIB 5780 and DIB 6614 relation with color excess, σ sightlines have a steeper slope than ζ sightlines. On the contrary, DIB 5797 sightlines have a steeper slope compared to σ sightlines. However, the slopes differences are not significantly noticeable in DIB 5797 and DIB 6614. The correlation coefficients are tabulated in Table 1.
Fig 4. Spatial distribution of $\sigma$ (red circle) and $\zeta$ (blue triangle) sightlines in field 1 (right) and field 2 (left).

Fig 5. Correlation between DIBs equivalent width with color excess for both types of sightlines. Color excess value is taken from Green et al. 2018.
[8] stated that in and around the Local Bubble region (up to 90 pc from the Sun), σ-type clouds are more abundant compared to ζ-type clouds with low color excess (< 0.1). However, using our dataset, we find that both cloud types are in par within similar color excess boundaries. We also notice that ζ-type clouds are increasing along with greater color excess, contrary to the findings [8]. This may indicate certain mechanisms in the Local Bubble might not take place in regions farther than the Local Bubble. Increasing ζ-type cloud is characterized by greater EW5797/EW5780 and thus leads to two perspectives: stronger DIB 5797 while DIB 5780 stays the same or vice versa. The first point of view may imply that carrier(s) of DIB 5797 more favor dust-rich ISM while the latter may confirm that carrier(s) of DIB 5780 is not well-mixed with dust.

Table 1. DIBs and E(B-V) correlation. The relation is EW DIB = a · E(B-V) + b

| DIB  | σ        | ζ        |
|------|----------|----------|
|      | A        | b        | A          | B          |
| 5780 | 0.2843 ± 0.0346 | 0.0127 ± 0.0129 | 0.1833 ± 0.0279 | 0.0110 ± 0.0063 |
| 5797 | 0.0826 ± 0.0103 | 0.0036 ± 0.0040 | 0.0993 ± 0.0014 | 0.0110 ± 0.0063 |
| 6614 | 0.2262 ± 0.0220 | -0.0082 ± 0.0079 | 0.1858 ± 0.0180 | -0.0049 ± 0.0099 |

4.3 DIB and extinction function

Figure 6 shows the spatial distribution of DIBs' strength along the distance of target stars within the same field with interstellar extinction at 5500 Angstrom (A0) that taken from a three-dimensional interstellar extinction map by [14]. We present the plot in A0 versus distance as converting AV (from A0) to E(B-V) straightforwardly without prior knowledge of R needs to be done carefully as there is a great span of R for targets located in a field. The 3D interstellar extinction map is reliable up 3 kpcs in
several lines of sights within the disk. Towards our fields, we find that the map traces up to ~ 1.4 kpc from the Sun. For field 1, we find that the DIBs’ strength follows a similar trend as extinction. From this distribution, we can conclude DIBs in the visual regions can be used to trace extinction while direct methods are limited to do so.

5. Conclusion
From this study, based on GALAH DR2 spectra, we find that DIBs measured in GALAH DR2 spectra are well-correlated with each other although some scatters are present. The DIBs have also a positive correlation with color excess. However, the correlation varies across DIB species. With the data, it is clear that DIB 5780 has the strongest correlation with color excess compared to DIB 5797 and DIB 6614. We notice that by grouping the DIBs based on σ and ζ line of sight reduce the scatter on correlation studies. From our dataset, we conclude that DIBs are a useful constituent to trace the interstellar medium toward sightlines within the Galaxy.

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