Diffuse Interstellar Bands (DIBs) as a tracer of warp in the Third Galactic Quadrant: Preliminary Results

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Abstract. We measured 6613.6 Å diffuse interstellar band (DIB) recorded in the 318 stellar spectra of stars located in the Third Galactic Quadrant. In agreement with previous studies, we found that the DIB strength has a positive correlation with the interstellar extinction, even though significant deviations were found. The correlation study between the DIB strength and the extinction is limited by the fact that the 3D extinction survey in the Galaxy is incomplete. The DIB spatial distribution toward the South Galactic Pole indicates that the DIB carrier(s) are distributed similarly as other Galactic warp tracer. More data, especially DIB measurements from target stars above Galactic principal plane, are needed to demonstrate that DIB can be used as a tracer of Galactic warp.

Keywords: Galactic Warp, Interstellar Matter, Diffuse Interstellar Bands

1. Introduction
The discovery of Galactic warp based on HI observations is groundbreaking revolution and is an important step to understand the structure of our Galaxy. From HI observation, it was found that the gas layer in outer disk is warped away from the Galactic principal plane \((b = 0^\circ)\) [1]. It becomes warped towards North Galactic Pole in the First and Second Galactic Quadrants; and towards South Galactic Pole in the Third and Fourth Quadrants [2]. Over decades, large-scale surveys have been conducted in order to reveal the mysterious warp of our Galaxy. Interestingly, the Galactic warp is not only seen in Galactic gas, but also in other Galactic disk’s tracer such as stars, molecular clouds, and interstellar extinction [3,4,5]. This indicates that the warp affects the distribution of both stellar and interstellar components in the Galaxy. A longstanding mystery in astrophysical spectroscopy associated with interstellar materials is diffuse interstellar bands (DIBs). The absorption appears to be weak and diffuse in spectra of objects that reside behind interstellar clouds. Almost 500 DIBs were cataloged along optical and infrared wavelength, but only two DIBs in NIR have known carrier. Even though the carriers of DIBs are still under investigation, DIBs can be used as they have interesting properties, e.g., have positive correlation with interstellar extinction, HI and H\(_2\) column density [6,7]. Thus, DIBs can be used as alternative tracer of the interstellar medium.

2. Data Analysis
2.1 Data
This work used high SNR, medium resolution \((R \sim 17,000)\) spectra from Gaia-ESO Spectroscopic Survey Data Release 3.1 supplement [8,9] observed by using GIRAFFE instrument (with HR15N setting) of targets located in the Third Galactic Quadrant. The HR15N setting yields wavelength coverage from 6470 Å to 6790 Å, allowing us to measure strong DIB with a wavelength center of 6613.6 Å [10] (hereafter 6614 DIB). Most of the Gaia-ESO Spectroscopic Survey targets are members of both open and globular
clusters, as the GIRAFFE instruments was designed to obtain several objects at one exposure (multi-object spectrograph). The targets are dwarf to sub-giant late-type stars, with effective temperature ranging from 3800 K to 8000 K and wide range overall metallicity (-0.5 dex to 1.0 dex). Distance estimation towards each target was obtained from [11].

2.2 DIB extraction and error estimation
As mentioned earlier, the dataset consist of late-type stars. In such low stellar temperature, many atomic and molecular lines present. It is challenging to distinguish between the DIB feature and the stellar features. We, therefore, compared each observed spectrum to a stellar synthetic spectrum based on atomic line list in order to distinguish stellar lines from DIB absorption. Predetermined stellar parameters for each target were obtained from Gaia-ESO Catalogue (Version 2). Based on these parameters, we performed stellar modeling and spectrum synthetizing using MARCS [12] and SPECTRUM [13]. In the stellar modeling, we assumed that geometry of stellar atmosphere to be plan-parallel and obey Local Thermodynamical Equilibrium (LTE). Since microturbulence velocity can contribute to the line broadening, we adopted 2 km/s as a default value of microturbulence velocity. Stellar radial velocity was determined by using cross-correlation method, with initial value taken also from Gaia-ESO Catalogue. In this work, we didn’t are negligible [14]. The equivalent width of DIB 6614 (corresponding to DIB strength) towards each target was measured by performing single Gaussian profile fitting with Levenberg-Marquardt algorithm to minimize chi-squared value [15]. The error of equivalent width measurement were estimated by taking the fitting error and continuum placement into account, thus $\sigma^2 = \sigma^2_{fit} + \sigma^2_{cont}$.

![Figure 1. Observed spectra, synthetic spectra and fitted DIB profile in blue, red, and dashed black lines, respectively. The DIB profile is not only shifted from its wavelength center but also blends with stellar lines. The fitting region are showed by the dashed black line.](image)

3. Results and Discussions
We have measured 318 DIB out of 696 spectra of GES DR3.1 (HR15N). However, we faced some problems regarding the spatial distribution of out target stars and the stellar model. Unfortunately, in this work, the available target stars are not widely and regularly distributed in the Third Galactic Quadrant. The measured targets distribution, leaving only field in $212.6^\circ < l < 213.0^\circ$, $251.2^\circ < l < 253.6^\circ$, and $262.2^\circ < b < 269.9^\circ$ with Galactic latitude spans from $-1.8^\circ < b < -8.9^\circ$ as shown in Figure 2. Furthermore, we can see from Figure 1., there were overestimated stellar lines in the synthetic. As blended DIB extraction relies much on the synthetic spectra (see Figure 1.), we gave caution flag to mark blended DIB with stellar lines.
Incomplete 3D interstellar extinction survey has limited our DIB correlation study. However, Figure 2. shows correlation of DIB and extinction toward late-type stars in Field A, which was the only field with available interstellar extinction value. Lines resulted from [7] and [17] were derived from nearby, early-type stars in all of their fields.

In this work, Galactic warp is inspected toward each target field by converting DIB abundance into interstellar extinction. This conversion makes use DIB correlation obtained by [14]. Interstellar extinction towards Field A, as shown in Figure 3., is in agreement with [16] work even though some scatters are present. Increasing in abundance in < 2 kpc and > 4 kpc denote dense regions toward this field. These regions are Local (Orion) and Perseus Arm as revealed by [18]. Plateau in 2 – 4 kpc indicates a less dense region, probably interarm region.
Figure 4. Interstellar extinction towards Field A. Top, middle, and bottom dashed gray lines are interstellar extinction curves toward $b \sim -3^\circ$, $0^\circ$, and $+3^\circ$, respectively.

Due to incomplete interstellar extinction information in [16], we used interstellar extinction derived from stellar clusters studies by [19] instead. As we can see in Figure 4., DIB abundance has similar trend with those from stellar cluster studies. Despite of this fact, we can not draw conclusion on interstellar environment towards Field B and C for it shows noticeable scatter in $> 2$ kpc. This illustrates the complex structure of the interstellar matter itself as denotes by Galactic CO emission in [20]. Interestingly, interstellar extinction from stellar clusters studies fill in the gaps where there are lack of data from this work in $< 2$ kpc. Furthermore, DIB abundance in these fields also show steep increasing in $< 2$ kpc, mainly due to Local (Orion) Arm.
Figure 5. Similar to Figure 4., but for Field B (top panel), C (middle panel), and D (lower panel). Red circle is interstellar extinction from stellar cluster studies [18].

4. Conclusions
With the current data, although there was a subtle indication of increasing DIB abundance towards SGP and DIB strength is in agreement with interstellar extinction, it is still too early to conclude that we detect the warp by using DIB as ISM tracer. Therefore, we need more targets that are well-distributed along the galactic longitude and latitude also distances to be able to draw a conclusion about the Galactic warp traced by the interstellar matter.

Acknowledgement
ANI would like to thank P3MI for providing travel and accommodation support to attend SEAAN Meeting 2018.
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