A search of diffuse interstellar bands (DIBs) in planetary nebulae environment

E Puspitaningrum¹, L Puspitarini², H L Malasan³

¹ Master Program in Astronomy, Faculty of Mathematics and Natural Sciences, Bandung Institute of Technology, Jalan Ganesha 10, Bandung 40132, Indonesia
² Department of Astronomy and Bosscha Observatory, FMIPA Institut Teknologi Bandung, Jalan Ganesha 10 Bandung 40132 Indonesia
³ Lampung Astronomical Observatory, Institut Teknologi Sumatera, Way Hui, Lampung, Indonesia

Abstract. Diffuse Interstellar Bands (DIBs) are set of absorption features, mostly at optical and near infrared wavelengths, that are found in the spectra of reddened stars and other objects. DIBs are actively being investigated to understand the nature of their properties and carriers and also their roles in interstellar matter enrichment. Among of the proposed carriers is large carbonaceous molecules (fullerenes). Interestingly, such as C60 and C70 have been detected in Planetary Nebulae (PN) environment. This detection allows us to study DIBs in fullerene-rich space environment. In this work, we study the presence of DIBs in central star of planetary nebulae (CSPN) by using archival data of optical spectra observed with 8.1-m Gemini South Telescope and Gemini Multi-Object Spectrographs (GMOS, spectral range of 3900 Å - 5900 Å and resolution of R ~ 2300) and also from 2.5-m Isaac Newton Telescope with IDS spectrograph (R ~ 2300). We measured the equivalent width of 4430, 5870 and 6283 Å DIB by fitting the detected DIB profile with the empirical template derived from higher resolution data. We investigated 4430, 5870 and 6283 Å DIBs in the spectra of CSPN and their correlation with the colour excess (E(B-V)). The correlation between the DIB strength and E(B-V) has positive value. We found that the 4430 and 5870 Å DIBs are generally more abundant on the PN environment.

1. Introduction
The space between stars are not empty, they are filled with some things like matter, radiation, dark matter etc. that are known as the interstellar medium (ISM). In the universe, ISM has important role on the cosmic material recycling. Stars are born within the ISM, while star evolution process enriched the chemical composition of the ISM by ejecting material from stellar atmosphere via stellar wind. Based on their initial mass, stars explode as supernovae or eject the outer shell in form of planetary nebula into the ISM at the end of their life.

In 1921, M. L. Heger discovered for the first time which nowadays is known as the "Diffuse Interstellar Bands" or (DIBs). The DIBs are set of absorption features, mostly at optical and near infrared wavelengths, that are found in the spectra of reddened stars or other objects. These lines are generally quite broad and unresolved [7, 8, 13, 14, 15, 21 and 22]. If it is observed by using high resolution spectrograph, some of them also shows substructure and they appear "diffuse" [4]. They are known to
be part of the ISM because they do not follow periodic Doppler shifts that associated with stellar lines in binary star systems.

Although recently more than 400 DIBs had been found [10], the carriers of DIBs are still remain unknown and have been long standing problem on spectroscopy. Their variable strength ratios demonstrate a variety of carriers. Whereas their substructures support molecular origin. Various carrier candidates have been proposed, i.e. dust grains, to molecular species. Among of the proposed carriers is large carbonaceous molecules (fullerenes) and interestingly it has been detected on circumstellar and interstellar environment including Planetary Nebulae (PN) [1, 5, 16, and 20]. Besides, C60+ had been confirmed as the carriers of 9577 and 9633 Å DIB from the laboratory spectroscopy [3].

DIBs are known to be well correlated with the interstellar extinction [9]. The relationship between the DIBs strength and interstellar extinction can be used to indicate which DIBs that sensitive to the stellar radiation field [10]. We aim to investigate the DIBs in the central star of planetary nebulae (CSPN) spectra and their correlation with the interstellar extinction. Also, to investigate the effect of stronger radiation field caused by high temperature of CSPN. As a matter of fact, investigating DIBs in planetary nebulae is important because planetary nebulae play an important role in the chemical evolution of the galaxy due to the enrichment of material (in particular heavy element to the interstellar medium). Planetary nebulae environment is an active site for molecules and probably DIBs carrier(s) production, thus we expect higher abundance of DIBs in PNe spectra.

2. Data

For this work, we used central star of planetary nebulae (CSPN) spectra that were taken from the archive [23]. We selected 40 CSPN that have enough high signal-to-noise ratio values. The spectra were observed by using 8.1-m Gemini South Telescope and Gemini Multi-Object Spectrograph (GMOS) with spectral range of 3900 – 6500 Å and R ~ 2300. There are also 12 spectra that are observed by using 2.5-m Isaac Newton Telescope and IDS spectrograph with spectral range of 3900 – 5200 Å and R ~ 2300. We focus on some strong DIBs such as 4430, 5780 and 6283 Å DIB that are strong enough to be detected in low resolution spectra in most targets. The interstellar extinction data were obtained from [11].

3. Method

Our goal is to detect and identify (4430, 5780 and 6283 Å DIBs) on the CPSN spectra and to measure their equivalent width (EW). Before we can measure the EW of each DIB on the spectra, we should remove other spectral features such as stellar absorption or telluric lines. Since the telluric lines were weak in our spectral region, these features were neglected.

To distinguish the DIBs from the stellar absorption features, we compared the observed spectrum with stellar lines (absorption and/or emission) that had been identified from [23] to see whether our selected DIBs are blended with the stellar features or not. For the DIBs that blend with stellar absorption/emission, we provided a caution flag to the measurement results. Moreover, we used the empirical DIBs template from [17, 18, priv. comm.]. The empirical DIBs template can be used since in general the DIB shape profiles are pretty consistent in the Milky Way or other galaxies. In addition, it helps to avoid DIB features misidentification from stellar features.

The DIBs templates were derived from high resolution spectra data, therefore we need to degrade their resolution (R ~ 75000 for 4430, 5780 Å DIB and R ~ 48000 for 6283 Å DIB) to match our target spectral resolution. We fitted each DIB that were detected on the spectra with the DIB template by fitting on its strength and shift. The fitting used the LevenbergMarquardt algorithm and with Python programming language. From the fitting result, we calculated EW of the DIB.
**Figure 1** Examples of DIB fitting for 4430 Å DIB on the spectrum of Hen 2-107, Hen 2-47 and M 3-16. The x-axis shows the wavelength in Angstrom unit, the y-axis shows the normalized flux. The black solid line shows the best-fitting result, the black dash line shows the empirical DIB template that was derived from higher resolution spectra data, the grey lines shows the shifted-template that fitted to match the observation data.

**Figure 2** The plot between the equivalent width (EW) measured from central star of planetary nebulae spectra for 4430, 5780 and 6283 Å DIBs vs. E(B-V) adopted from [19]. The blue line shows the correlation line from [11]. The plot shows that the DIBs have positive correlation with the E(B-V).

**4. Results and Discussions**

Fig. 1 shows some examples of the DIB fitting result from Hen 2-107, Hen 2-47 and M 3-16 spectra (from left to right) by using empirical template for 4430 Å DIB. From the fitting, we could measure the EW of 4430, 5780, 6283 Å DIB profile which corresponds to abundance of their carrier(s). We plot the EW measurement results of 4430, 5780 and 6283 Å DIB vs. E(B-V) from [19] for each PN (see Fig. 2). In our measurement results (Fig. 2), we excluded those which have problems, e.g., low S/N, blending with other spectral features (stellar absorption or telluric lines), etc.

Fig. 2 shows that the DIBs have positive correlation with colour excess. The Pearson correlation coefficients that we obtained are 0.74, 0.77 and 0.64 respectively. Some dispersions in the correlation might be caused by stellar radiation field or measurement error (continuum placement, blending features, etc.).

We compared our correlation results with [11] who used stellar spectra from SDSS data. For 4430 and 5780 Å DIB, the measurement shows that the EW measured from CSPN is generally larger than from [11]. It suggests that formation of 5780 Å DIB carriers might relate to the UV radiation field [12]. The 5780 DIBs in PN environment might be more abundant. However, further studies are needed, in particular for the 6283 Å DIB which their measurements might be contaminated with sky emission in the spectral range.
5. Conclusions

Planetary nebulae is important object to understand molecules and x DIBs carriers. The 4430, 5780 and 6283 Å DIBs were detected and their equivalent widths were measured from the central stars of planetary nebulae spectra in this study. The measured EW shows positive correlation with E(B-V) in agreement with previous study [11]. We obtained the Pearson’s coefficient for 4430, 5780, and 6283 Å DIBs of 0.74, 0.77 and 0.64. We compared the correlation with [11] and found that the measured EW of DIBs from CSPN are generally higher. This result is in agreement with [2, 6]. More investigation about DIBs in PNe environment might give a hint about the DIBs carriers, in particular their relationships with the known molecules (such as C2 and C60).

References

[1] Cami J, Bernard-Salas J, Peeters E, and Malek E S 2010 Science 329 1180
[2] Diaz-Luis J J, García-Hernández D A, Rao N K 2015 A&A 573 A97
[3] Campbell E K, Holz M, Gerlich D, and Maier J P 2015 Nature 523 322
[4] Galazutdinov G A, Krelowski J, Musaev F A, Ehrenfreund P and Foing B H 2000 MNRAS 317 750
[5] García-Hernández D A, Manchado A, García-Lario P, et al 2010 ApJ 724 L39
[6] García-Hernández D A and Diaz-Luis J J 2013 A&A 550 L6
[7] Heger M L 1922 Lick Obs. Bull. 10 146
[8] Herbig G H 1993 ApJ. 407 142-156
[9] Herbig G H 1995 Ann. Rev. Astron. Astrophys.33 19-74
[10] Hobbs L M, et al 2008 ApJ 680 1256-1270
[11] Lan T-W, Menard B and Zhu G 2015 MNRAS 452 3629
[12] Megier A, Krewolski J and Weselak T 2005 MNRAS 358 563-571
[13] Merrill P W 1934 PASP 46 206
[14] Merrill P W 1936 PASP 48 179
[15] Merrill P W, Sanford R F, Wilson O C and Burwell C G 1937 ApJ 86 274
[16] Otsuka M, Kemper F, Hyung S, Sargent B A, Meixner M, Tajitsu A and Yanagisawa K 2013 ApJ. 764 77
[17] Puspitarini L, Lallement R, Chen H-C 2013 A&A 555 A25
[18] Puspitarini L, Lallement R, Babusiaux C et al 2015 A&A 573 AA35
[19] Schlafly E F and Finkbeiner D P 2011 ApJ 737 103
[20] Sellgren K, Werner M W, Ingalls J G, et al 2010 ApJ 722 L54
[21] Snow T P, York D G and Welty D E 1977 AJ 82 113
[22] Snow T 1995 Astrophysics and Space Science Library vol. 202, ed A G G M Tielens and T P Snow pp 325 -340
[23] Weidmann W, Gamen R, Mast D, et al 2018 A&A 614 A135