The Diffuse Interstellar Bands
Proceedings IAU Symposium No. 297, 2013
J. Cami & N. L. J. Cox, eds.

doi:10.1017/S1743921313015731

Spatial Correlations of Selected DIBs to the CH and CH^+ Molecules

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Abstract. The analysis of radial velocities in the spectra of HD 151932 and HD 152233, performed for the optical lines of interstellar CH and CH^+ molecules on one hand, and for the diffuse bands 4964 and 6196 Å on the other hand, suggests that the carrier of the former DIB is spatially related to CH, while the carrier of the latter - to CH^+. A further analysis, based on the sample of 106 reddened OB stars, partly confirms this suggestion, showing that the CH column density correlates indeed much better with the equivalent width of the 4964 DIB than with that of the 6196 DIB.

Keywords. Diffuse Interstellar Bands, Molecules

1. Introduction

Diffuse interstellar bands (DIBs) discovered by Heger (1922) are numerous narrow to broad absorption features mostly found in the visual and near infrared (4 000-10 000 Å) spectra of early type OB–stars (Herbig 1995, Galazutdinov *et al.* 2000). Despite many observational efforts DIBs remain one of the longest standing puzzles in stellar spectroscopy.

Methylidyne (CH), first identified in the ISM by McKellar (1940), is closely related to molecular hydrogen (H_2), as already shown by Mattila (1986) and Weselak *et al.* (2004). On the other hand, the column density of the corresponding cation, CH^+, correlates very poorly with that of H_2 - indicating no relation between the abundances of these two molecules (Weselak *et al.* 2008a). It is also known that column densities of CH molecule are very well correlated with strength of 5797 DIB (Weselak *et al.* 2008b).

The aim of this work is to present the relations between the column densities of simple diatomic molecules CH and CH^+, and the equivalent widths of two narrow DIBs: 4964 and 6196 Å.

2. The Observational Data

Our observing material was acquired using four echelle spectrometers:

- fiber-fed echelle spectrograph installed at 1.8-m telescope of the Bohyunsan Optical Astronomy Observatory (BOAO) in South Korea; R = 30.000, 45.000, and 90.000
- Feros spectrograph, fed with the 2.2m ESO telescope in Chile; R = 48.000 (http://www.ls.eso.org/lasilla/sciops/2p2/E2p2M/FEROS/)
- HARPS spectrometer, fed with the 3.6m ESO telescope in Chile (see http://www.ls.eso.org/lasilla/ sciops/3p6/harps/); R = 115.000

Table 1. Adopted molecular parameters. References: 1 – Galazutdinov *et al.* (2000), 2 – Gredel *et al.* (1993), 3 – Weselak *et al.* (2009a).

Species	Vibronic band	Rotational lines	Position [Å]	Ref.	f-value	Ref.
DIB 4964			4963.85	1		
DIB 6196			6195.97	1		
CH	$B^2\Sigma^- - X^2\Pi$ (0, 0)	$Q_2(1)+{}^Q_P R_{12}(1)$	3886.409	2	0.00320	2
	(0, 0)	${}^Q_P Q_{12}(1)$	3890.217	2	0.00210	2
CH^+	$A^1\Pi - X^1\Sigma^+$ (0, 0)	R(0)	4232.548	2	0.00545	2
	(1, 0)	R(0)	3957.689	3	0.00342	3
	(2, 0)	R(0)	3745.308	3	0.00172	3

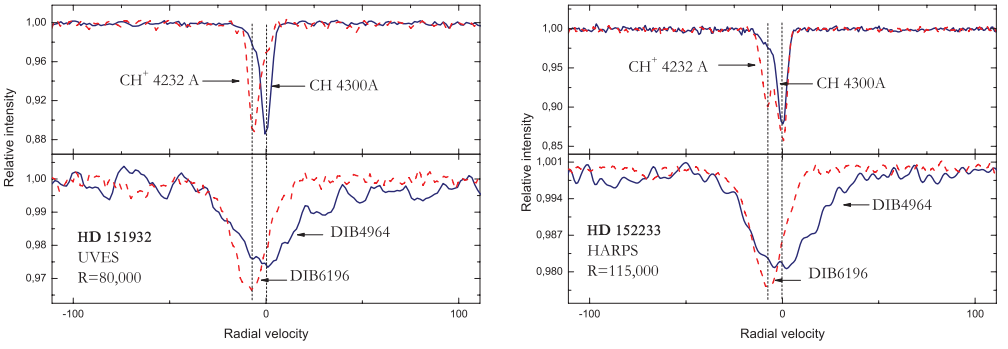

Figure 1. In spectrum of HD 151932 the 6196 DIB shares the velocity of the second component of CH^+, while 4964 DIB remains at the position of CH. The depth of the 6196 DIB is scaled down by a factor of 2 (left). At right we present the same but in the case of HD 152233 observed with another instrument. The depths of 4300 Å CH line and of 6196 DIB are scaled down by a factor of 2.

• UVES spectrograph at Paranal in Chile. For more information see: http://www.eso.org/sci/facilities/ paranal/instruments/uves; R = 80.000

All the spectra were reduced using MIDAS and IRAF, as well as our own DECH code (Galazutdinov 1992), which provides all the standard procedures of image and spectra processing. The DECH code was used during final data analysis.

3. Results

For this project we selected a sample of 106 reddened OB stars, which have both CH and CH^+ features in their spectra. In Figure 1 we present spectra of HD 151932 and HD 152233 in the vicinity of CH and CH^+ at 4300 and 4232 Å in the radial velocity scale. At the bottom of this figure we also present spectral region of 4964 and 6196 DIBs in the same scale. Intrinsic DIB wavelengths were determined using the rest wavelength velocity frame based on K I (7698.974 Å) line. This method allows us to measure radial velocities of profiles and in the case of narrow interstellar features gives very low uncertainty, smaller than 0.3 km s^{-1}. It is evident that in spectra of HD 151932 and HD 152233 the 6196 DIB shares the radial velocity with the CH cation component while the 4964 DIB shares the radial velocity of CH.

Given the usually very small velocity shifts between CH and CH^+ spectral features the only possibility of investigating the spacial relationships between DIB carriers and simple

https://doi.org/10.1017/S1743921313015731 Published online by Cambridge University Press

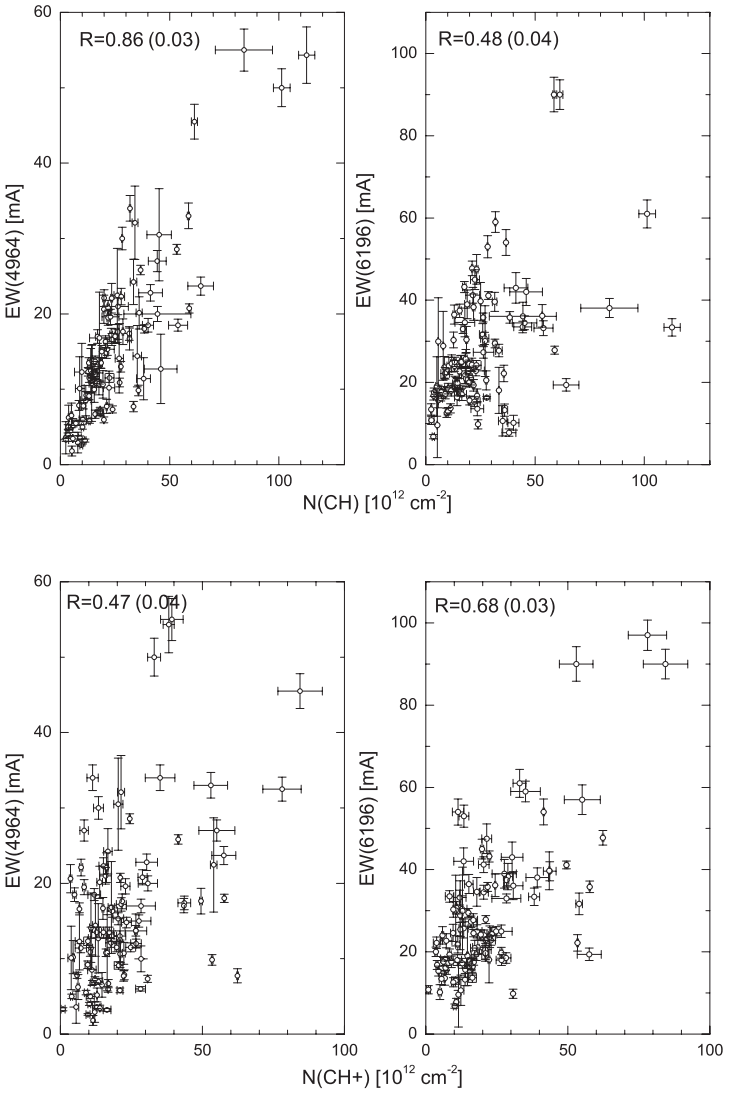

Figure 2. Equivalent widths of 4964 and 6196 DIBs plotted vs. the column density of CH (correlation coefficients equal 0.86 and 0.48, respectively) – top panel. Poor correlation of both DIBs with the column density of CH^+ with correlation coefficients equal 0.47 and 0.68 (bottom panel).

molecules is to correlate DIB strengths with molecular column densities derived from an extensive sample of objects from our database. To obtain column densities we used the relation of Herbig (1968) which gives proper column densities when the observed lines are unsaturated:

$$N = 1.13 \times 10^{20} W_\lambda / (\lambda^2 f), \tag{3.1}$$

where W_λ and λ are in Å and column density in cm^{-2}. To obtain column density we adopted f-values listed in Table 1.

Figure 2 shows relations between column densities of CH and CH^+ molecules and equivalent widths of 4964 and 6196 DIBs. It is evident that the 4964 DIB is correlated more tightly with the column density of CH while the 6196 DIB – with that of CH^+.

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4. Conclusions

The above considerations led us to infer following conclusions:

• The 4964 DIB carrier is spatially correlated with neutral methylidyne; this is confirmed by both the analysis of Doppler velocities and by the correlation of N(CH) vs. EW(4964).

• The 6196 DIB, which seemed related to CH^+ based on Doppler shifts, correlates only marginally with this species, in terms of $N(CH^+)$ vs. EW(6196).

Acknowledgements

JK and TW acknowledge the financial support of the Polish National Center for Science during the period 2011 - 2014 (project Nr 5820/B/H03/2011/40).

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