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DIFFUSE INTERSTELLAR BAND 6202 Å AS AN INDICATOR OF ORGANIC MATTER IN COSMOS: CEPHEID SPECTRA

S. M. Andrievsky[1], A. Shereta[1], S. V. Khrapaty[2], S. A. Korotin[3],
V. V. Kovtyukh[1], V. I. Kashuba[1]

[1] Astronomical Observatory, Odesa National University,
Odesa, Ukraine, *andrievskii@ukr.net*,
[2] Department of Biophysics and Medical Informatics,
National Taras Shevchenko University of Kyiv,
[3] Crimean Astrophysical Observatory, Nauchny 298409, Crimea

ABSTRACT. We have described the method of investigation of the diffuse interstellar band (DIB) at 6202 Å. This DIB is seen in the spectra of cepheid stars, and it is blended with two stellar lines of Ce II (6201.773 Å) and Ni I (6204.6 Å). After removal of the blending lines of ionized cerium and neutral nickel, we can determine the equivalent widths (EW) of the DIB. This procedure can be applied for the sample of cepheids (with well known distances), which enables one to construct the map of the organic matter distribution in the Galactic disc and use these values to investigate the E(B–V)–DIB EW relation. The relation found from Cepheids matches that found in B stars. This relation can help to find the reddening for newly discovered Cepheids without extensive photometric data, and thus determine their distances. The relation between E(B–V) and the DIB EW does not yield precise reddening values. It is not a substitute for better photometric or spectroscopic methods. At best, it is indicative, but it provides some information that may not be otherwise available.

Keywords: Classical cepheids; ISM lines and bands, ISM molecules, ISM structure

АНОТАЦІЯ. Відомо, що досить значна частина речовини Галактики (приблизно 20% за масою) входить до складу міжзоряного середовища (газопилова компонента). Міжзоряне середовище – основа внутрішнього взаємозв'язку систем кожної галактики. Саме в ньому відбуваються процеси зореутворення, обміну речовиною і енергією між туманностями (що є невід'ємною частиною та проявом міжзоряного середовища), системами нових зір та протозорями, чорними дірами. Тому дослідження фізики та визначення хімічного складу міжзоряного середовища протягом багатьох років займає важливе місце в теоретичній астрофізиці та космології. Особливий інтерес представляє, зокрема в рамках сучасної космохімії, дослідження міжзоряного середовища на молекулярному рівні. Ототожнення міжзоряних молекул може відповісти на багато питань космогонії і теорії зореутворення. Одна з особливостей міжзоряного середовища полягає в значній неоднорідності речовини. Ми описуємо метод дослідження дифузної міжзоряної смуги (ДМС) на довжині хвилі 6202 Å. Ця ДМС спостерігається в спектрах класичних цефеїд, і вона блендується з двома зоряними лініями – Ce II (6201.773 Å) і Ni I (6204.6 Å). Були застосовані розрахунки синтетичного спектру зорі у межах ДМС з наступним вилученням цих зоряних ліній з профілю смуги. Ця методика дає можливість знайти істинні профілі ДМС та визначити їхні еквівалентні ширини (EW). Цю процедуру можна застосувати для цефеїд (для яких відстані добре відомі), побудувати карту розповсюдження органічної речовини в галактичному диску та використати ці значення для дослідження відношення E(B–V) EW(DIB). Це відношення може допомогти знайти почервоніння для нещодавно відкритих цефеїди, для яких ще немає достатніх фотометричних даних. Після отримання високоточних індивідуальних значень надлишків кольору для усіх програмних зір буде встановлено радіальну та довготну залежність екстинкції міжзоряного газу у площині Галактики та отримати інформацію про існування локальних неоднорідностей густини міжзоряного газу. Тут мова йде про неперервне поглинання пиловою компонентою, яка входить до складу міжзоряних газових хмар.

Ключові слова: Класичні цефеїди, міжзоряні лінії та смуги, міжзоряні молекули, структура міжзоряного середовища

1. Introduction

Diffuse interstellar bands (DIBs) are quite broad absorptions which can be found in the spectra of the different astronomical objects. In visual and near IR region there are about 500 DIBs.These bands are observed when the light of the star is absorbed when it crosses translucent clouds. The origin of the DIBs (i.e. their carriers) is still a mystery. There have been a number of theories advanced regarding the nature of interstellar absorbing material resulting in the phenomenon of DIBs in stellar spectra. No exact nidentification of the central wavelengths of DIBs are available at present, but there are strong belief that they are caused by complex molecular absorption. At present the widely accepted hyphotesis about DIBs carriers supposes that polycyclic aromatic hydrocarbons can produce observed absorptions in the stellar spectra. Nevertheless, Cox (2011) and Salama et al. (2014) doubted this hyphotesis. Another way to explain the appearance of DIBs may be to consider the absorption capacity of and/or bucky ball carbon structures.

Many works were devoted to a comprehensive observational study of DIB, their fine structure, in particular. In particular, it was found that The equivalent widths of the DIBs vary within a wide range, and in some cases correlate with the reddening along the line-of-sight. The wavelength of a DIB in the photospheric rest frame of the background source varies due to the system velocity of the background source.

As a rule, DIBs were studied in the spectra of hot O–B stars because their visual region is less crowded with spectral lines and the continuum is smooth. High resolution spectra of such stars afford an excellent possibility to study the fine structure of DIBs. Unfortunately, the distances of O–B stars can be determined with low accuracy. Therefore, if we are interested in study the spatial distribution of the DIBs absorption in our Galaxy, then we must understand that such spatial distribution can be burdened with distance inaccuracy. It would be a good opportunity to use for this purpose spectra of the stars whose distances are know with a high precision, the cepheid spectra, for instance. Cepheids are the stars of F–G spectral class, and their visual region is full of the stellar spectral lines. With a high probability any DIB profile in their spectra is spoiled with stellar lines. This is a problem that prevents the direct determination the DIB characteristics, like its equivalent width, in particular. Kashuba et al. (2015) and Kashuba et al. (2016) described a method that allows to clean 6613 Å DIB blended profile. In this paper we describe similar procedure which allows to refine 6202 Å DIB profile.

2. Method

The diffuse interstellar band at the wavelength 6202 Å was selected as an object of the study. In the cepheid spectra, in most cases this DIB is superimposed on two stellar absorption lines, namely ionised cerium(6201.773 Å) and neutral nickel (6204.6 Å) lines. In contrast to weak line of cerium, the neutral nickel line is quite strong. A correct measurement of the equivalent width of the DIB at 6202 Å is not feasible unless the blending lines of stellar origin are removed. As it was stated in Introduction Kashuba et al. (2016) developed a method that enables performing such a procedure. Similar to that method our approach concerning the DIB 6202 Å consists the following steps.

1. We checked accuracy of the oscillator strengths of two blending lines: Ce II (6201.773 Å) and Ni I (6204.6 Å). This is necessary in order to calculate synthetic spectrum of the background star in vicinity of 6202 Å DIB. Preliminary values of $\log gf$ for the lines were taken from the Vienna Atomic Line Database (VALD) (http://vald.astro.uu.se/). Initial values of the oscillator strengths for the considered lines were −1.949 and –1.079 respectively. Then the oscillator strengths for these two lines were updated using the solar spectrum of Kurucz et al (1984) and the cerium and nickel abundances in the Sun from Grevesse et al. (1996). The resulting values are $\log gf = -1.550$ for the cerium line and $\log gf = -1.155$ for the nickel line. The best fits for profiles of these lines in the solar spectrum are shown in Fig. 1.

2. The synthetic spectrum for a particular star is generated using its atmosphere model, which is calculated using previously known such parameters as effective temperature, surface gravity, microturbulent velocity and metallicity.

3. Then the observed spectrum is divided into synthetic spectrum, and this procedure gives us a DIB profile free of stellar spectral lines.

4. Finally, the equivalent width of the cleaned DIB profile is determined by direct integration.

3. Atmospheric parameters and synthetic spectra

The atmospheric parameters (effective temperature $T_{\rm eff}$, surface gravity $\log g$, microturbulent velocity $V_{\rm t}$ and [Fe/H]) of the program stars were used to calculate the fragments of synthetic spectra of cepheids containing the 6202 Å DIB. We used stellar atmosphere models first applied for analysis in Kashuba et al. (2016). In synthetic spectrum calculations in the 6202 Å DIB vicinity we used cerium abundance derived from Ce II line 6043.37 Å , and nickel abundance derived from Ni I 6176.81 Å line. Both lines are situated close to the DIB region, they are not blended with

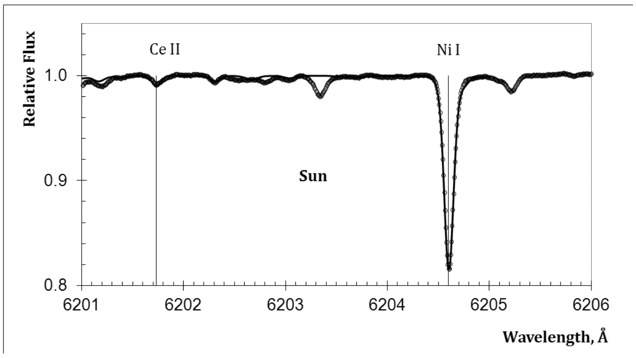

Figure 1: Observed (circles) and synthetic (thin line) spectra of the Sun in vicinity of the 6202 Å DIB.

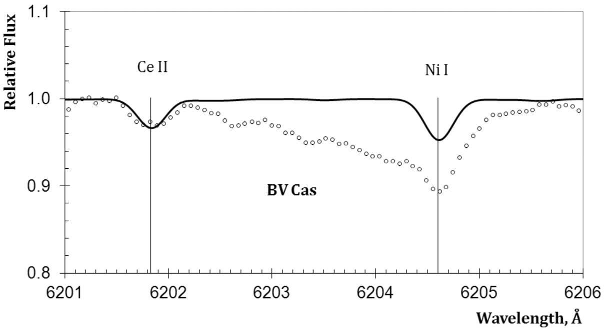

Figure 2: Observed (circles) and synthetic (thin line) spectra of BV Cas in vicinity of the 6202 Å DIB (wide absorption).

other species, and produce reliable abundances of the corresponding elements (their oscillator strengths were calibrated using the solar spectrum). In Fig. 2 we show observed and synthetic spectra in the 6202 Å DIB region for one program star: BV Cas (T_{eff} = 5551 K, log $g = 1.99$, $V_t = 3.29$ km s^{-1}, [Fe/H] = +0.02).

The result of applying step 3 (see previous section) is shown for BV Cas in Fig. 3.

Measured equivalent width of the 6202 Å DIB in BV Cas is 0.1006 Å.

Conclusion

We described method which enables one to clean the 6202 Å diffuse interstellar band from the stellar blending lines of ionezed cerium (6201.773 Å) and neutral nickel (6204.6 Å). This procedure gives a possibility to measure pure DIB equivalent width. In turn, this characteristic can be traced as a function of interstellar reddening caused by the absorption of light by dust particles. We plan to apply described procedure for the sample of cepheid spectra previously analyzed by Kashuba et al. (2016) with the aim of the 6613 Å DIB study.

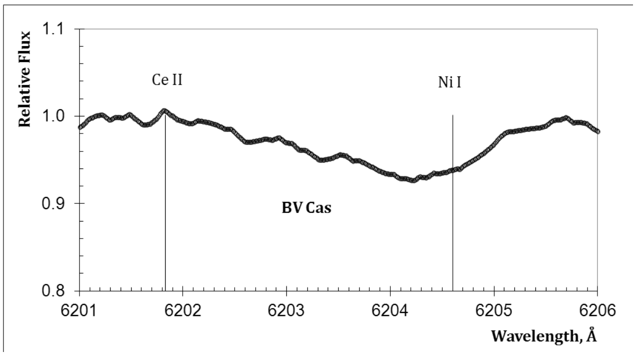

Figure 3: Normalized fragment of the spectrum of BV Cas.

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