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DETERMINATION OF THE TEMPERATURES OF THE CENTRAL STARS OF SELECTED PLANETARY NEBULAE

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ABSTRACT. In this work, for planetary nebulae İC 1295, İC 4191, Zanstra temperatures were calculated using the H_β line of the central stars. Respectively, the temperatures 64252 K and 47663 K were determined. The flux in the H_β radiative line used in the calculations, has been determined from the spectra retrieved from the archive of the European Southern Observatory. Our results have been compared with results of the other authors.

Keywords: planetary nebulae, central stars, temperature.

АНОТАЦІЯ. В даній роботі ми дослідили дві планетарні туманості IC 1295 і IC 4191б та визначили температури середовища за допомогою метода Занстра. Лінія Hbeta, яка належить центральним зорям цих туманостей, була використана для цієї цілі. Метод Занстра може бути застосований тільки у разі, коли середовище туманості є оптично товстим в лайманівському континуумі. Всі атоми Гідрогену вважаються такими, що перебувають в незбудженому стані. Температура зорі може бути визначена шляхом порівняння числа квантів до числа квантів, що випромінюютьс у видимій частині спектра. Ми визначили ефективні температури центральних зір туманстей, як 64252 К та 47663 К.

Ключові слова: планетарні туманності, центральні зорі, температура.

1. Introduction

Planetary nebulae (PN) are an advanced stage of the stellar evolution of the low and intermediate mass stars. Central stars of PN (CSPN) are difficult to study because of their faintness in the visible spectral region and contamination of their spectra by the nebular emission. CSPN undergo considerable changes in temperature over their short lifetimes. Therefore, the temperatures of the central stars of planetary nebulae are considered an important quantity that directly characterizes their evolution. The Zanstra method is the most widely used method of the temperature determination methods. The Zanstra method can be applied for determining the temperature of CSPN if two quantities are known: first, the flux in the stellar continuum (or the stellar magnitudes); second, the amount of ionizing photons ($\lambda < 912$Å), as deduced from the total nebular flux at H_β. The ratio of the stellar to nebula fluxes at H_β is equivalent to the temperature of a blackbody between the UV and the visual range, if the nebula is optically thick regarding to the hydrogen ionizing radiations. Considering these two points, in this work for planetary nebulae IC 1295 and IC 4191 the H_β flux was used to determine temperatures of the central stars. For this we used Zanstra method. We discuss our results and compare our values to the temperatures obtained by other authors (Montez et al., 2015; Phillips, 2003) using different methods.

2. Determination of the Zanstra temperature

The Zanstra method can only be applied to nebulae that are optically thick in L_c. At this time, it is assumed that the star radiates as a black body. All neutral hydrogen atoms are assumed to be in unexcited condition (Kostyakova, 1982). Thus, each L_c quantum emitted by the nucleus in the Lyman series limit of hydrogen being swallowed up in the nebula, produces one L_α quantum and one Balmer series quantum. In optically thick nebulae all L_c quanta radiated by the star absorbed by the nebula. In a unit time interval, the number of Balmer quanta emitted by the nebula determines the number of quanta emitted by the star in the ultraviolet region. The temperature of the star can be determined by comparing the number of quanta with number of quanta emitted in the visible region of the spectrum (Pottasch, 1987). If we assume that a star with radius R_s and temperature T radiates as a black body, one can define the luminosity within frequency interval:

$$L_\nu = 4\pi^2 R_S^2 B_\nu(T) \ . \tag{1}$$

Here, B_ν is the Planck function. Thus,

$$L = \int_0^\infty L_\nu d\nu = \frac{8\pi^6 k^4}{15 h^3 c^2} R_S^2 T^4. \tag{2}$$

$\nu \geq \nu_I$, the number of stellar quanta will be:

Table 1:

PN	W (Å)	F(H_c) $\times 10^{-13}$	F(H_β) $\times 10^{-11}$	F(H_β) $/F_\lambda$	V	E(B-V)	F(H_β) $\times 10^{-11}$	Referens
İC 1295	474	0.166	0.39	6586	16.82	0.32		5,8,9
IC 4191	500	3.3	16.5	2471	11.61	0.48	1.02	5,6,8,9

H_β in units $erg \cdot cm^{-2} s^{-1}$.

$$Q_i = \int_{\nu_i}^{\infty} (L_\nu / h\nu)\, d\nu = \frac{8\pi^2 R_s^2}{c^2} \left(\frac{kT}{h}\right)^3 G_i(T) \quad (3)$$

Here,

$$G_i(T) = \int_{h\nu_i/kT}^{\infty} x^2 (e^x - 1)^{-1}\, dx \quad . \quad (4)$$

$$\int_{x_0}^{\infty} \frac{x^2 dx}{e^{x_i} - 1} = \sum_{n=0}^{\infty} \int_{x_0}^{\infty} e^{-(n+1)x} x^2 dx$$

By subtracting R_s from formulas (2) and (3) we obtain:

$$Q_i = \frac{15 G_i(T) L}{\pi^4 kT} \quad (5)$$

When the nebula is optically thick in the Layman's continuum, the star's hydrogen-ionizing quanta will be absorbed by the nebula. The observed $F(H_\beta)$ radiation flux of the nebula will be as follows:

$$4\pi d^2 F(H_\beta) = h\nu(H_\beta) \int n_e\, n(H^+) \alpha(H_\beta) dv \;\; [erg/s] \quad (6)$$

Here, the frequency of the $\nu(H_\beta)$- H_β line is the effective recombination coefficient related to the generation of $\alpha(H_\beta)$- H_β quanta. Considering the $(L_\nu = 4\pi d^2 F_\nu)$, (5) and (6) in L/L_0 expression (L_0 is the luminosity of the Sun) of luminosity in terms of the star's radiation flux F_ν, we get the following expression:

$$\frac{F(H_\beta)}{F_\nu} = \frac{15 h\nu(H_\beta)}{4\pi^6 k} \frac{L_0 \alpha(H_\beta) T^3 G_1(T)}{R_0^2 T_0^4 \alpha_B B_\nu} \quad (7)$$

It is convenient to use the visual region of the spectrum to solve this equation. It can be neglected because the ratio very weakly depends on T_e-, and for calculation one can use $T_e = 10^4 K$. Instead of $F_\nu [erg \cdot cm^{-2} s^{-1} Hz^{-1}]$ it is useful to express $F(H_\beta)$ is $[erg \cdot cm^{-2} s^{-1}]$, $F_{\lambda(vis)}$– m_v, the radiation flux in the visible region of the spectrum is determined by the size of the visible star:

$$F_\lambda = 3.68 \cdot 10^{-9} \cdot 10^{-m_v/2{,}5} \quad [erg/(cm^2 \cdot s \cdot Å)]. \quad (8)$$

After taking this into account, an expression (7) takes the following form:

$$\frac{F(H_\beta)}{F_\lambda} = 3.95 \cdot 10^{-11} T^3 G_i(T) \;\; \left[e^{26650/T} - 1\right] [Å]. \quad (9)$$

Temperatures along the HI line of the central stars of planetary nebulae İC 1295 and İC 4191 were calculated from the last equation. In calculations $F_{\lambda(vis)}$ vs $F(H_\beta)$, an absorption in the interstellar medium was taken into account. İC 1295 and İC 4191 spectra of planetary nebulae gained in 2016, were retrieved from the European Southern Observatory's archive and processed using the DECH30 program (Galazutdinov, 1992). Obtained results are given in the Table 1. In the 3rd column of the Table1, the flux in the continuum is given, and in the 8th column the flux obtained by other authors is shown.

In the 2nd column of the Table 2, Zanstra temperature calculated by us using the line HI is given, while in the 3d column of the Table 2 Zanstra temperature calculated using the line HeII by other authors is given.

Table 2:

PN	T_z(HI)	T_z(HeII)	Reference
İC 1295	64252	98000	1
IC 4191	47663	107200	2

3. Conclusion

Obtained results on $F(H_\beta)/F_\lambda$ ratio as a function of the star's effective temperature exactly coincides with the known graphic dependence from literature. It is also consistent with the results obtained from the atmosphere model provided by Hammer and Mihalas (He/H=0.16) (Phillips, 2003). This shows the accuracy of the spectrum processing results. Since Zanstra method assumes that the nebula is optically thick in the Lyman continuum, and since PN change from optically thick to optically thin in H and He at different times, this can lead to the different estimates of the central star temperature by using either H or He lines. The fact that stellar atmosphere are not well approximated by the blackbody can also contribute to an errors in the Zanstra temperatures (Kwok, 2000).

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