ON THE STRUCTURE OF THE ENVELOPE OF NOVA DELPHINI 1967 IN THE NEBULAR STAGE

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Abstract. The analysis of line profiles in the spectrum of Nova Del 1967 in the nebular stage shows that the polar axis of the envelope is longer than the equatorial one. The polar caps are probably cooler and thinner than the equatorial rings.

1. Introduction

The aim of this paper is to show how variations of physical conditions between particular regions of the Nova Del 1967 envelope in the nebular stage can explain the observed profiles of emission lines, and to estimate the magnitude of these variations. The following lines are treated: $H\beta$ (or $H\gamma$), [O III] $\lambda\lambda$4363, 4959, 5007 Å, [Ne III] λ3869 Å and [Ne V] λ3426 Å.

Observations were made by Dr A. Woszczyk at McDonald Observatory from May to August, 1969. The spectra were taken at dispersions of 17 Å mm^{-1} and 3 Å mm^{-1}. The detailed description of the observational material and the preliminary interpretation will be published elsewhere (Tylenda and Woszczyk, 1975).

Each unblended line in the spectrum of Nova Del consists of six components, which have been marked with numbers from 1 to 6 towards longer wavelengths in Figure 1. Relative intensities of particular maxima are different for different lines.

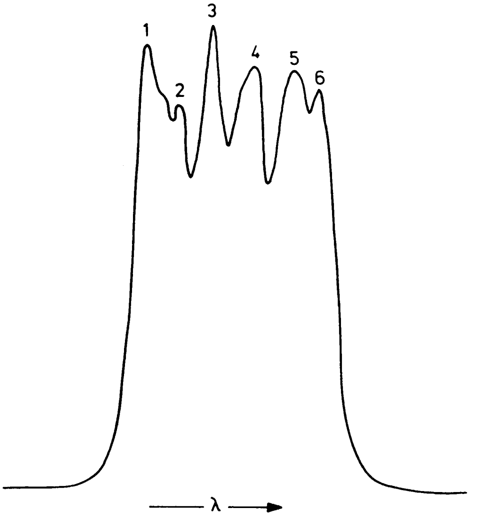

Fig. 1. Line profile for $H\beta$ emission line.

Sherwood and Plaut (eds.), Variable Stars and Stellar Evolution, 339–344.

Roughly speaking, the higher the ionization potential of a particular element, the smaller are the intensities of maxima 3 and 4 relative to the remaining ones. In this paper, the measurements of intensities of components 2, 3, 4, 5, and 6 are relative to the intensity of the first one for the above-mentioned lines.

It is assumed that each maximum is produced by one condensation in the nova envelope and that these regions are homogeneous; physical conditions are constant in each condensation.

2. Evaluation of Formulae

Let us consider an *i*th region of the nova envelope at a distance R_i from the central star (Figure 2) and let θ_i be the angle between the line of sight and the radius of the region. A thickness ΔR of the envelope is assumed to be constant throughout the envelope. After simple considerations, one obtains

$$I_i \, \Delta\lambda_i \cong j_i V_i, \tag{1}$$

where I_i is the intensity of the spectral line from the *i*th region, j_i is the emissivity per unit volume, and V_i is the volume of the *i*th region. Because of the high expansion

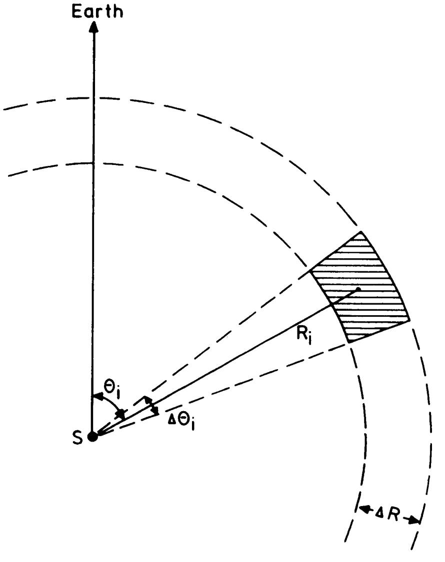

Fig. 2. Evaluation of formulae in Section 2.

velocity ($\sim 580 \text{ km s}^{-1}$) of the envelope, V_i is a volume of a region contained between two cones with angles $\theta_i - \Delta\theta_i$ and $\theta_i + \Delta\theta_i$. Thus

$$V_i = 2\pi R_i \sin\theta_i R_i \, \Delta\theta_i \, \Delta R. \tag{2}$$

It is assumed that the whole envelope was ejected in one moment. This is consistent with Malakpur's (1974) recent investigations.

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After simple evaluations, one obtains the relation

$$\frac{I_i}{I_1} = \frac{j_i R_i}{j_1 R_1}. \tag{3}$$

Let us assume an electron temperature T_e and an electron density N_e in the ith region. The emissivity from the unit of volume in a Balmer line arising from mth excitation level is equal to

$$j_m = \text{const}\, N_e^2 \frac{b_m(T_e)}{T_e^{3/2}} \exp\left(\frac{h\nu_m}{kT_e}\right). \tag{4}$$

Using relations (3) and (4), one obtains

$$n_i^2 = \frac{H_{m,i} t_i^{3/2}}{\varrho_i} \frac{\exp\left(\dfrac{h\nu_m}{kT^1}\right)}{\exp\left(\dfrac{h\nu_m}{kt_i T^1}\right)} \frac{b_m(T^1)}{b_m(t_i T^1)}, \tag{5}$$

where

$$\left.\begin{aligned} n_i &\equiv \frac{N_{e,i}}{N_{e,1}}, \\ t_i &\equiv \frac{T_{e,i}}{T_{e,1}}, \\ \varrho_i &\equiv \frac{R_i}{R_1}, \\ T^1 &\equiv T_{e,1}, \qquad N^1 \equiv N_{e,1}, \end{aligned}\right\} \tag{6}$$

$$H_{m,i} \equiv \frac{I_{m,i}}{I_{m,1}} \tag{7}$$

($I_{m,i}$ is the intensity of the ith maximum of a Balmer line arising from the mth excitation level.)

The ratio of the sum of intensities of the lines of [O III] $\lambda\lambda$4959 and 5007 Å, to the intensity of [O III] λ4363 Å is a function of the electron temperature and density:

$$\frac{I_{5007} + I_{4959}}{I_{4363}} = E(T_e, N_e) = \text{const}\frac{f_2(T_e, N_e)}{f_3(T_e, N_e)}. \tag{8}$$

Let us introduce an observational value

$$R_i \equiv \left(\frac{I_{5007} + I_{4959}}{I_{4363}}\right)_i \bigg/ \left(\frac{I_{5007} + I_{4959}}{I_{4363}}\right)_1 = \frac{2.93 r_{5007,i} + r_{4959,i}}{3.93 r_{4363,i}}, \tag{9}$$

where $r_{\lambda,i} \equiv I_{\lambda,i}/I_{\lambda,1}$. In the last expression the theoretical value of the ratio $I_{5007}/I_{4959} = 2.93$ is used (observations of Nova Del give the value 2.8–3.0).

Using (8) one obtains

$$R_i = \frac{E(t_i T^1, n_i N^1)}{E(T^1, N^1)}. \tag{10}$$

The emissivity in the line [N_e III] λ3869 Å may be expressed by the following formula:

$$j_{3869} = \text{const}\, N_{\text{Ne III}} \frac{f_{2,\text{Ne III}}(T_e, N_e)}{f_{\text{Ne III}}(T_e, N_e)}. \tag{11}$$

A similar expression may be written for the line [Ne V] λ3426 Å. We now introduce the observed value

$$A_i \equiv \frac{I_{3426,i}}{I_{3426,1}} \frac{I_{3869,1}}{I_{3869,i}} = \frac{N^i_{\text{Ne V}} N^1_{\text{Ne III}}}{N^1_{\text{Ne V}} N^i_{\text{Ne III}}} \frac{f^i_{2,\text{Ne V}} f^1_{\text{Ne V}} f^i_{\text{Ne III}} f^1_{2,\text{Ne III}}}{f^i_{\text{Ne V}} f^1_{2,\text{Ne V}} f^i_{2,\text{Ne III}} f^1_{\text{Ne III}}}. \tag{12}$$

The equation of ionization equilibrium for Ne III in the ith region of the envelope has the form

$$4\pi N^i_{\text{Ne III}} \int_{\nu_1}^{\infty} \frac{L_\nu}{16\pi^2 R_i^2} \exp(-\tau_{\nu,i})\, a_\nu \, d\nu = N^i_e N^i_{\text{Ne IV}} \alpha^i_{\text{Ne III}}. \tag{13}$$

One can write a similar equation for the ionization of Ne IV. Assuming $\tau_{\nu,i}$ to be the same for all regions and neglecting a dependence of the recombination coefficient α on the electron temperature, we get the relation

$$\frac{N^i_{\text{Ne V}} N^1_{\text{Ne III}}}{N^1_{\text{Ne V}} N^i_{\text{Ne III}}} = \frac{1}{\varrho_i^4 n_i^2}, \tag{14}$$

which together with (12) gives the formula

$$\varrho_i^4 = \frac{1}{A_i n_i^2} \frac{f^i_{2,\text{Ne V}} f^1_{\text{Ne V}} f^i_{\text{Ne III}} f^1_{2,\text{Ne III}}}{f^i_{\text{Ne V}} f^1_{2,\text{Ne V}} f^i_{2,\text{Ne III}} f^1_{\text{Ne III}}}. \tag{15}$$

3. Results

The observational values are presented in Table I. H_i quantities have been evaluated from Hβ and Hγ. It should be mentioned that, in the line [Ne V] λ3426 Å, maxima 2 and 6 have been blended by maxima 1 and 5 respectively. The values A_2 and A_6 have been determined assuming $I_{3426,2} = I_{3426,1}$ and $I_{3426,6} = I_{3426,5}$. Therefore, the results obtained for regions 2 and 6 should be taken as less certain than those for the other ones.

Observational data have been put into expressions (5), (10), and (15) and values for n_i, t_i, and ϱ_i have been computed. Seaton's (1959) values of $b_m(T_e)$ have been used. Functions f, f_2, and f_3 occurring in (8) and (15) were evaluated by Gorbatzky and

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TABLE I
Observational data

i	$H_i(\mathrm{H}\beta)$	$H_i(\mathrm{H}\gamma)$
1	1.00	1.00
2	0.82±0.1	0.86±.02
3	1.12±.01	1.07±.01
4	0.96±.01	0.97±.01
5	0.96±.02	1.00±.02
6	0.89±.02	0.95±.02

i	R_i	A_i
1	1.00	1.00
2	0.99±.05	(1.12±.03)
3	1.30±.04	0.66±.02
4	1.26±.05	0.70±.03
5	0.92±.05	1.13±.06
6	0.86±.04	(1.26±.09)

Minin (1963). Transition probabilities and collision strengths for forbidden lines have been taken from Garstang (1968) and Czyzak *et al.* (1968), respectively. In all above expressions N^1 and T^1 are free parameters. Computations have been performed using $N^1 = 4.5 \times 10^6\ \mathrm{cm}^{-3}$ and $T^1 = 1.15 \times 10^4$ K (Malakpur, 1973). The values of these parameters are not important because the results are almost independent of variations of $N1$ and $T1$.

Table II contains the results of the computations together with their errors resulting from observational errors in H_i, R_i and A_i (Table I). The agreement of results

TABLE II
Results of computations
($N^1 = 4.5 \times 10^6\ \mathrm{cm}^{-3}$, $T^1 = 1.15 \times 10^4$ K)

i	n_i	t_i	Q_i
H_i derived from Hβ			
1	1.00	1.00	1.00
2	0.91±.01	1.04±.02	1.02±.01
3	0.97±.01	0.92±.02	1.12±.01
4	0.89±.01	0.95±.02	1.15±.02
5	1.01±.02	1.03±.03	0.97±.02
6	0.99±.02	1.07±.03	0.96±.03
H_i derived from Hγ			
1	1.00	1.00	1.00
2	0.93±.01	1.03±.02	1.01±.01
3	0.94±.01	0.92±.01	1.13±.02
4	0.90±.01	0.95±.02	1.14±.02
5	1.03±.01	1.02±.03	0.96±.02
6	1.03±.01	1.06±.03	0.94±.03

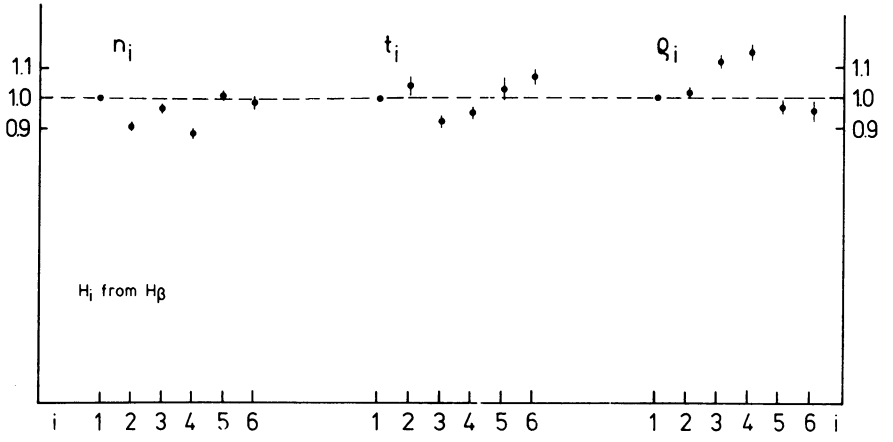

Fig. 3. Results of computations; see Table II.

obtained using $H\beta$ and $H\gamma$ observations is very good. Some of the values from Table II are presented in Figure 3.

The above results show that maxima 3 and 4 are produced by regions of the nova envelope which are about 7% thinner, 7% cooler and 13% more distant from the central star than the others. Adopting Malakpur's (1973) geometrical model of the Nova Del envelope, we conclude that the polar axis of the envelope is longer than the equatorial one. This is consistent with results obtained for other novae by Mustel and Boyarchuk (1970).

In future the author intends to extend the investigations by including the influence of the geometry of the nova envelope on line profiles, and a helium ionization structure which determines the optical thickness of the envelope in a wavelength range in which Ne III and Ne IV are ionized.

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