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ИЗВЕСТИЯ АКАДЕМИИ НАУК ЭСТОНСКОЙ ССР. ТОМ 19
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# THE PECULIAR STAR CH CYGNI IN 1968

Irregular light variations with a very short period and peculiar spectrum have recommended CH Cygni as a favourable object for spectroscopic and photoelectric research. Some interesting papers have been published by Swings and Swings [1], Faraggiana [2], Wallerstein [3] and Cester [4]. From their results one may briefly sum up that CH Cygni is variable in light with short irregular variations, the amplitudes of which rise from red to ultraviolet. The spectrum of CH Cygni is gM6 with relatively strong additional hot continuum and emission lines of H, HeI, FeII and [FeII]. In the present paper we give an account of our photoelectric and spectral observations in 1968 and make an attempt to explain the nature of CH Cygni.

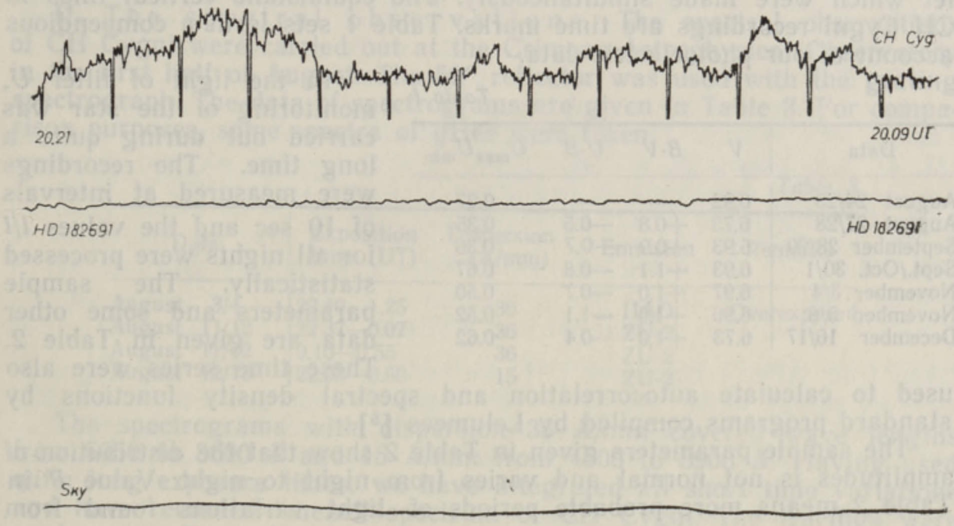

Fig. 1.

I. The photoelectric observations. Two 20″ reflectors with direct current amplifying photometers were used for the photoelectric observations at W. Struve Tartu Astrophysical Observatory. Almost all observations were made using one telescope for monitoring the sky clearness and the other for observing CH Cygni in the system that nearly corresponds to the *UBV* system. The comparison star used was HD 182691. It is so near to CH Cygni that the greater part of observations needed no correction from differential extinction. At all observation nights CH Cygni was found to vary rapidly in ultraviolet. In Fig. 1 we

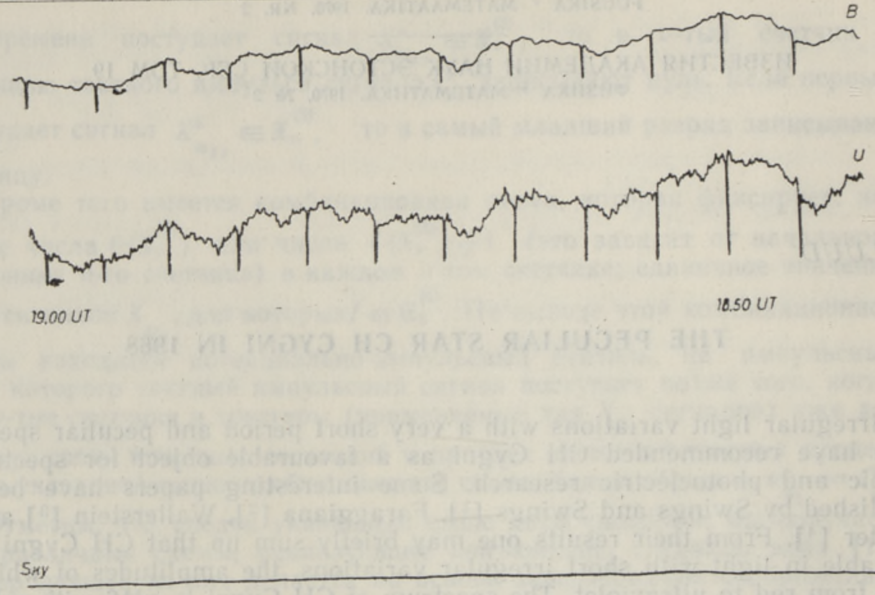

Fig. 2.

represent as an example the recordings of CH Cygni and HD 182691 in ultraviolet and in Fig. 2 the recordings of CH Cygni in blue and ultraviolet which were made simultaneously. The equidistant vertical lines in CH Cygni recordings are time marks. Table 1 sets forth a compendious account of our photoelectric data.

*Table 1*

| Data | $V$ | $B$-$V$ | $U$-$B$ | $U_{\max}U_{\min}$ |
|---|---|---|---|---|
| August 24/25 | 6.92 | — | — | 0.27 |
| August 27/28 | 6.73 | +0.8 | −0.5 | 0.35 |
| September 28/29 | 6.93 | +0.9 | −0.7 | 0.36 |
| Sept./Oct. 30/1 | 6.93 | +1.1 | −0.8 | 0.67 |
| November 3/4 | 6.97 | +1.0 | −0.7 | 0.50 |
| November 5/6 | 6.96 | +1.0 | −1.1 | 0.52 |
| December 16/17 | 6.73 | +1.0 | −0.4 | 0.62 |

In the light of filter $U$, monitoring of the star was carried out during quite a long time. The recordings were measured at intervals of 10 sec and the values $l/\bar{l}$ for all nights were processed statistically. The sample parameters and some other data are given in Table 2. These time series were also used to calculate autocorrelation and spectral density functions by standard programs compiled by Lelumees [5].

The sample parameters given in Table 2 show that the distribution of amplitudes is not normal and varies from night to night. Value $P$ in Table 2 means more probable periods of light variations found from

*Table 2*

| Data | $N$ | $\sigma$ | $\sigma^2$ | $\Delta\sigma^2$ | $A$ | $E$ | $P$ |
|---|---|---|---|---|---|---|---|
| August 24/25 | 361 | 0.050 | 0.0025 | 0.0002 | 0.117 | −0.843 | 13 |
| August 27/28 | 495 | 0.084 | 0.0070 | 0.0005 | 0.435 | 0.569 | 9.5 |
| September 28/29 | 269 | 0.063 | 0.0040 | 0.0003 | 0.125 | −0.603 | 6 |
| Sept. /Oct. 30/1 | 663 | 0.051 | 0.0026 | 0.0002 | −0.106 | 0.130 | 10.5 |
| November 3/4 | | | | | | | |
| Sample A | 643 | 0.102 | 0.0105 | 0.0005 | 0.546 | −0.650 | (31) |
| Sample B | 337 | 0.049 | 0.0024 | 0.0002 | 0.483 | 0.408 | 8.25 |
| November 5/6 | 608 | 0.099 | 0.0098 | 0.0006 | 0.616 | 0.247 | 9.75 |
| December 16/17 | 1254 | 0.113 | 0.0128 | 0.0004 | 0.312 | −0.572 | 21 |

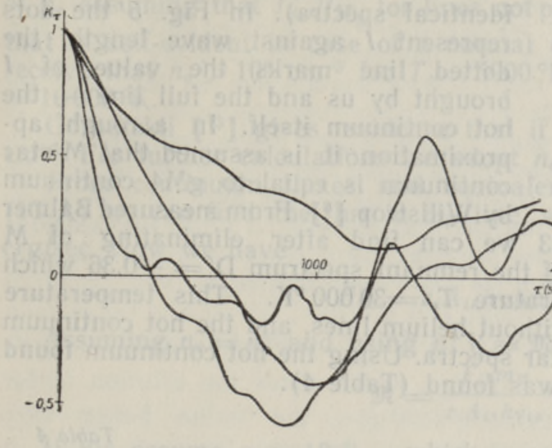

Fig. 3.

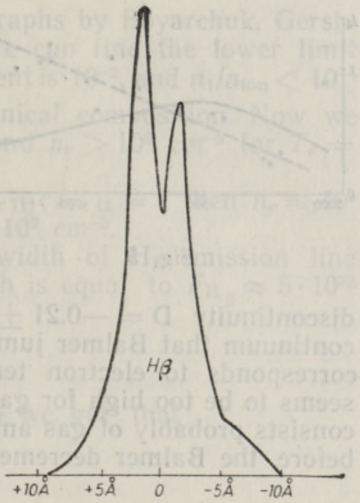

Fig. 4.

spectral density functions. Fig. 3 demonstrates the autocorrelation functions for several nights — it may be concluded that they are of nonstationary type, hence they are not only functions of intervals between observations, but also the time functions. For references to methods of statistical investigations see [6,7].

II. The spectral observations. The spectral observations of CH Cygni were carried out at the Crimean Astrophysical Observatory in the first half of August. The 50″ reflector was used with the grating spectrograph. The data of spectrograms are given in Table 3. For comparison purposes, some spectra of gHer were taken.

*Table 3*

| Data | Exposition time (UT) | Dispersion (Å/mm) | Emulsion | Remarks |
|---|---|---|---|---|
| August 3/4 | 22.40—1.25 | 36 | IIAO | Overexposed |
| August 11/12 | 22.37—0.07 | 36 | ZU-2 | |
| August 11/12 | 0.10—0.55 | 36 | ZU-2 | |
| August 12/13 | 22.05—0.50 | 15 | ZU-2 | |

The spectrograms with dispersion 36 Å/mm covered wave lengths from 5050 to 3600 Å and 15 Å/mm from 4500 to 3900 Å. Having used quite long exposure times, we have integrated all short time variations and have recorded "mean" spectrum of CH Cygni. The tracings were made on the Tartu direct intensity microphotometer, and in Fig. 4 the $H_\beta$ line contour is given.

The Balmer lines of hydrogen are in emission, and the last line detectable is $H_{18}$. No certain features of helium are present. The FeI spectrum is in absorption. FeII is present with emissions in λλ 4233, 4351, 4303 (multiplet 27); λλ 4178, 4296 (28); λλ 4629, 4555, 4515 (37); λλ 4583, 4549, 4522, 4508 (38). The forbidden lines of [FeII] λλ 4244, 4287 and 4359 are present and have the intensities well comparable to the permitted line intensities. CaII resonance lines are of an ordinary P Cyg type.

The line and TiO band head depths compared with gHer ones enable us to determine the intensity of overlapping continuum in the units of

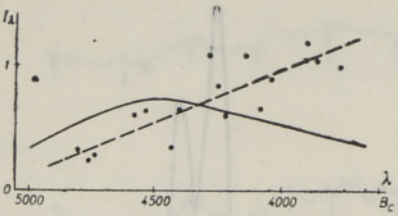

Fig. 5.

red giant continuum (assuming the M star in CH Cygni and gHer to have identical spectra). In Fig. 5 the dots represent $I$ against wave length, the dotted line marks the value of $I$ brought by us and the full line — the hot continuum itself. In a rough approximation it is assumed that M-star continuum is equal to gM4 continuum by Willstrop [8]. From measured Balmer discontinuity $D = -0.21 \pm 0.03$ we can find after eliminating of M continuum that Balmer jump of the remnant spectrum $D' = -0.36$ which corresponds to electron temperature $T_e = 30\,000\,°K$. This temperature seems to be too high for gas without helium lines, and the hot continuum consists probably of gas and star spectra. Using the hot continuum found before, the Balmer decrement was found (Table 4).

*Table 4*

| Line | $H_\beta$ | $H_\gamma$ | $H_\delta$ | $H_\varepsilon$ | $H_8$ | $H_9$ | $H_{10}$ | $H_{11}$ | $H_{12}$ | $H_{13}$ | $H_{14}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $100\frac{I_{H\,n}}{I_{H\,\beta}}$ | 100 | 18.8 | 17.6 | — | 14.8 | 14.4 | 11.6 | 8.0 | 7.6 | 7.6 | 7.6 |

The Balmer lines have central absorptions that are due by $\sim 10^{15}$ absorbing atoms, at it turns out from the wellknown Unsöld's procedure.

III. Determination of some emitting gas parameters. The absolute magnitude of gM6 stars is approximately $M_v \approx 0$. Taking into account the interstellar reddening according to Parenago [9], we found that the distance to CH Cygni $r \approx 230$ pc, and therefore the interstellar reddening is negligible in rough estimations of physical properties. Having used the following formulae

$$\log f(pv) = -0.4 m_{pv} - 8.40$$

and

$$\log f(pg) = -0.4 m_{pg} - 8.20$$

taken from Allen's handbook [10], we receive fluxes from CH Cygni in absolute energy units $F_{5400} \simeq 4.5 \cdot 10^{31}$ erg/Åsec and $F_{4300} \simeq 2.6 \div 4.0 \cdot 10^{31}$ erg/Åsec. Having light rise velocities $\partial U/\partial t \approx 0.^{m}3\ \mathrm{min}^{-1}$ and $\partial U/\partial t \approx$ $\approx 0.^{m}1\ \mathrm{min}^{-1}$, we are able to evaluate the energy of these rises, which equals in Balmer and Pashen continua to $10^{34} - 10^{35}$ ergs.

According to Sobolev [11] one can write that

$$n_e \approx \sum_{i=2}^{\infty} C_i / t_*,$$

where $t_*$ is the time of gas out-emitting in seconds. From our recordings we can find this time to be in order of 100 sec (from time series analysis $t_* \approx 600$ sec), and hence $n_e \approx 10^9 \div 10^{10}\ \mathrm{cm}^{-3}$.

The second way to determine the electron density is with the help of forbidden line intensities and formula

$$\frac{I_{\mathrm{ion}}}{I_{H\,\beta}} = \frac{n_1}{n_{\mathrm{ion}}} \cdot \Theta_{\mathrm{ion}}^{-1}(n_e, T_e),$$

where $\Theta(n_eT_e)$ is the function presented on graphs by Boyarchuk, Gershberg and Pronik [12]. In the present case we can find the lower limit of $n_e$ assuming that $I_{\text{ion}}/I_{\text{H}_\beta}$ for lines not present is $10^{-2}$, and $n_1/n_{\text{ion}} < 10^{-4}$ that is self-evident in case of a normal chemical composition. Now we receive that $n_e > 10^8$ cm$^{-3}$ for $T_e = 5000$ °K and $n_e > 10^9$ cm$^{-3}$ for $T_e = 10\,000$ °K.

Gorbatskii [13] gives evidence that if $I_{[\text{Fe II}]} : I_{\text{Fe II}} \approx 1$ then $n_e \approx 10^8$ cm$^{-3}$. For further calculations we adopt $n_e = 10^9$ cm$^{-3}$.

From continuum fluxes and equivalent width of $\text{H}_\beta$ emission line (13 Å) we can find the flux in $\text{H}_\beta$ line, which is equal to $F_{\text{H}_\beta} \approx 5 \cdot 10^{32}$ erg/sec. Now we have

$$F_{ik} = z_i A_{ik} h\nu_{ik} n_e^2 V\,.$$

Assuming $n_e = n^+$ and using $n^+ V \approx \mathfrak{M}/m_{\text{H}}$ we get that

$$\mathfrak{M} = \frac{F_{ik} m_{\text{H}}}{z_i A_{ik} h\nu_{ik}} n_e^{-1}\,.$$

If we assume $z_i \approx 10^{-21}$, which is valid within factor 2—3, we have $\mathfrak{M}_{\text{gas}} \approx 10^{-10}\,\mathfrak{M}_\odot$.

On the other hand we can write according to Gorbatskii and Minin [14] that

$$t_* N_{\text{Ba}} = N^+,$$

where $N_{\text{Ba}}$ is the amount of the emitted Balmer quanta, and $N^+$ is the amount of out-emitting hydrogen atoms. The amount of Balmer quanta is given by

$$N_{\text{Ba}} = \frac{\sum\limits_{i=2}^{\infty} C_i}{z_i A_{ik}} \cdot \frac{\Delta F_{i2}}{h\nu_{i2}}$$

and from these formulae we found that $\mathfrak{M}_{\text{out-emitting}} \overset{\sim}{<} 10^{-10}\,\mathfrak{M}_\odot$ if $\text{H}_\beta$ intensity varies as $U$. It means that nearly all emitting gas takes part in variations. In case of the spherical gas, one can receive the radius of the emitting volume $R_{\text{gas}} \approx 1000\,R_\odot$. The maximum radius for gas varying within the period of 10 minutes is the distance that light passes during this time. We get $\sim 250\,R_\odot$, and for further discussions we have $10^2 - 10^3\,R_\odot$. If we assume that it is the Strömgrens radius, we receive $U(S_p) \approx 10$ and the spectral class of the exciting star is nearly B1.

Now we turn to the Balmer decrement. The most striking feature of the decrement is the very slow intensity decrease, which begins from $\text{H}_\gamma$ line. It is likely caused by two or more zones in emitting gas, where in one zone the electron impacts are important. This question needs further investigations. The hydrogen emission lines give us an opportunity to find the effective temperature of the exciting star by means of the method first developed by Zanstra. Having taken that $I_{\text{H}\alpha} : I_{\text{H}\beta} \approx 3$ we receive $T^* = 22\,500$ °K if hydrogen lines are not weakened by self-absorption. If we take the self-absorption into account, using weakening factors by formulae

and
$$y = \frac{\tau}{1 - e^{-\tau}}$$

$$\tau = \frac{\sqrt{\pi} e^2 \lambda f}{mvc} N_2 H,$$

we get $T^* = 44\,000$ °K, but this value is probably overestimated. The most probable value is 30 000 — 35 000 °K, which corresponds to the spectral class slightly earlier than B0.

IV. The possible models of CH Cygni. Normal gM6 star has $B-V=1.77$ [15]. In the wavelengths of $V$ the additional hot spectrum has the intensity, which approximately equals to 0.2 of the red star continuum intensity and therefore, if we assume in the absolute scale that $V_{\text{red}} \approx 0$, $V_{\text{hot}} \approx 1.75$ also in the absolute scale. If $V_{\text{red}}$ is underestimated here and we really have $V_{\text{red}} \approx -0.5$ and $V_{\text{hot}} \approx 1.2$; even then the hot star seems to be under mean sequence. From our observations $(B-V)_{\Sigma} \approx 1.0$, hence $B_{\Sigma} \approx 1.0$, $B_{\text{hot}} \approx 1.52$ and $(B-V)_{\text{hot}} \approx$ $\approx -0.27$, which corresponds to the spectral class B2. Taking into account the Zanstra temperature and the spectral class from spectral function, we may adopt that the hot star is an underluminous star with a temperature of nearly 30 000 °K.

From formula $M_v = 29\,500\,T^{-1} - 5 \log R/R_{\odot} - 0.08$ given in Martynov's textbook [16] we get that $R_{\text{hot}} \approx 1.5\,R_{\odot}$, which gives the dilution factor $W \approx 10^{-6}$. For a cold star $R_{\text{red}} \approx 2800\,R_{\odot}$, the value being very approximate (determined from energy-poor spectral interval). Now it seems to be quite a good picture if we read that the emitting gas is the outer atmosphere of M giant. According to Deutsch, these areas have the lumpy structure with the packing coefficient more than $10^2$ [17] and the real dilution factor may be smaller, nearly $10^{-8}-10^{-9}$ seems to be the real value.

Now we are able to sum up, in Table 5, the most important parameters of CH Cygni. The masses of stars are taken in accordance to the mass-luminosity relation.

*Table 5*

| | Cold star | Hot star | Gas |
|---|---|---|---|
| Spectrum | gM6 | underluminous B0 | |
| $T_{\text{eff}}$ °K | 2600 | 30 000 | |
| $\mathfrak{M}$ | $\sim 4\mathfrak{M}_{\odot}$ | $\sim 1.2\mathfrak{M}_{\odot}$ | $10^{-10}\mathfrak{M}_{\odot}$ |
| $R$ | $\sim 1000\ R_{\odot}$ | $\sim 1.5 R_{\odot}$ | $10^2-10^3\ R_{\odot}$ |
| $W$ | | | $<10^{-6}$ |
| $n_e$ | | | $10^9$ cm$^{-3}$ |

This model is the framework in terms of which we must explain very short-time irregular light variations. For this purpose we may treat the following mechanisms:

A) Light variations of the exciting star;
B) irregular outflow from the hot star;
C) exciting of gM6 star atmosphere with irregularities caused by the lumpy structure of the atmosphere in which the exciting star moves.

The two last cases are possible if the amount of atoms in the excited area changes at least 10% within some minutes. If we have the excited area with a radius of $10^2-10^3\ R_{\odot}$, then the exciting star or the outflowing matter must pass within some minutes 10—100 $R_{\odot}$ and have a velocity of $10^4-10^5$ km/sec. We see that the cases B and C must be turned down, and if our model embraces only the radiative excitation, then the luminosity of the hot star must have very rapid light variations.

Taking into account the dilution factor and M-star radius we may suppose that the excited gas is the outer part of M-giant atmosphere (Fig. 6).

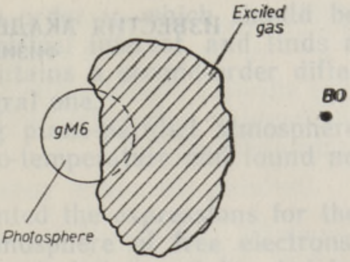

Fig. 6.

V. Conclusions. The components of CH Cygni are quite normal for a symbiotic star. The light variations are the nonstationary random variations possibly caused by the short-time light variations of the hot exciting star, but not by geometrical changing of the emitting matter.

The author is greatly indebted to the Crimean Astrophysical Observatory for putting the 50″ telescope into his possession and to the Institute of Cybernetics of the Academy of Sciences of the Estonian SSR for the opportunity to use the computer "Минск-22".

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## PEKULIAARNE MUUTLIK TÄHT CH CYGNI 1968. AASTAL

CH Cygni fotoelektrilised ja spektroskoopilised vaatlused näitasid, et ultraviolettkiirguse heleduse muutlikkus on mittenormaalne mittestatsionaarne juhuslik funktsioon ajast. Hinnati CH Cygni mitmesuguseid füüsikalisi karakteristikuid ja näidatakse, et nende iseärasused on tõenäoliselt põhjustatud punase hiiu välise atmosfääri ergutamisest kuuma muutliku kaaslase poolt.

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*Л. ЛУУД*

## ПЕКУЛЯРНАЯ ПЕРЕМЕННАЯ ЗВЕЗДА СН ЛЕБЕДЯ в 1968 г.

Проведены фотоэлектрические и спектроскопические наблюдения СН Лебедя. Показано, что изменение блеска в ультрафиолетовых лучах есть ненормальная нестационарная случайная функция от времени. Оценены разные физические характеристики СН Лебедя и показано, что особенности, вероятно, появляются вследствие возбуждения верхней атмосферы красного гиганта переменным горячим спутником.