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SPECTROSCOPIC STUDY OF PULSATION-TYPE QUASI-PERIODIC MOTIONS IN EARLY SUPERGIANT ATMOSPHERES. II. HD 21291. RADIAL VELOCITY VARIATIONS

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ABTRACT. *The harmonic analysis of radial velocities from long-time series of spectral observations from 1976 to 1988 indicates that the velocity variations of the supergiant HD 21291 lines are due to complex pulsations. The lines show radial velocity variations with a period much greater than the value of the fundamental period, which can be identified as non-radial pulsations, with non-radial mode oscillations superimposed.*

The period, amplitude and average values of radial velocity of the layer are stable for a long time interval from 1976 to 1988, but they are different for different layers. The period and amplitude of pulsations increase from lower layers, where HeI lines are formed toward upper layers, where H_β *and* H_α *lines are formed.*

The average radial velocity of the lower and intermediate layers, where ion lines and higher Balmer lines up to H_γ *are formed, does not differ from the stellar centre of mass velocity. They demonstrate the most "pure" oscillations. The upper layers are expanded, and the rate of the expansion increases to the most upper layers where the absorption of* H_α *is formed.*

1. INTRODUCTION

Rzaev et al. (1991b, hereafter Paper 1) reported on observations of the white supergiants HD 21291 and HD 21389 which were carried out on the coude-spectrograph of the Shamakha Astrophysical Observatory Azerbaijan AS since 1983. Data have been accumulated to check the assumption on the existence of periodic and quasi-periodic pulsation-type motions in the atmospheres of these objects. The Paper 1 presented investigations of HD 21389. The present paper consideres HD 21291.

Paper 1 reported on the obtained data, techniques of measurement and reduction of spectrograms and the positional accuracy. A part of the data used here was obtained earlier (1976-1983) on the Main Stellar Spectrograph of the 6 m telescope of SAO RAS and 2 m telescope of Shamakha (Zvereva et al., 1984; Rzaev et al., 1989). Heliocentric radial velocities of individual lines and their homogeneous groups are listed in Table 1. The rms measurement errors for the groups are also presented there, numbers of lines in the groups are given in brackets.

2. HD 21291. INVESTIGATIONS

In spite of the fact that HD 21291 is a sufficiently bright star ($m_v = 4\overset{m}{.}3$) its spectroscopic and photometric investigations are very scarce.

Small-amplitude radial velocity variations have been suggested by Plaskett et al. (1921). This can be supported by the data from the catalogues of Frost et al. (1926) and Campell and Moor (1928).

Mohler (1940) has noted anomalous weakness of the absorption H_α.

Crawford (1963) has revealed photometrically variability of H_β, possibly, previously suspected by Williams (1936).

From two spectrograms Rosendal (1973) has found variable emission in H_α (inverse P Cyg profile and asymmetric absorption with a trace of weak emission in the red wing) and established variability of the absorption HeI λ6678 Å. A differential shift between the H_α absorption and HeI and SiII lines has been noted. Whereas Kontisas and Kontisas (1980), using one coude-spectrogram of 1970, have found no essential differential shift between the groups of ion lines, HeI and hydrogen Balmer series. All these data suggest only non-stationarity of the HD 21291 atmosphere and do not allow to specify the picture of differential shifts of lines and reveal its kinematic nature.

The line differential shifts for HD 21291 for a wide interval of optical depths and their variations with time were investigated for the first time by Zvereva et al. (1984). Similar study was performed by Denisman and Huck (1988). Information on the velocity field in the atmosphere of HD 21291 and its variation both with depth in the atmosphere and with time was obtained. Denisman and Huck (1988) noted that the radial velocity variations were accompanied also by variations of line profiles. However, as it was noted in Paper 1, the obtained results, especially short time radial velocity variations, should be treated with care.

Further spectroscopic investigation of this star was based on the homogeneous high-dispersion good-quality coude-spectrograms taken on the 2 m telescope of Shamakha observatory from 1983 to 1988 (Paper 1). Addition of new spectrograms to already available extended essentially the information on the velocity field and on its time variations. It was established that the non-stationarity of the HD 21291 atmosphere is, apparently, caused by pulsation-type quasiperiodic motions of layers (Rzaev et al., 1989; 1991a). The different atmospheric layers: lower, intermediate and upper, where HeI lines, ions and the highest members of the Balmer series, and the first Balmer series members (H_α, H_β, and H_γ) are formed, respectively, oscillate independent of each other. Evidently, the values of the period, amplitude and the mean radial velocity value for these layers are different. The amplitude increases towards the upper layers. The upper layers expand and the expansion rate increases towards the uppermost layers, where the absorption H_α is formed (Rzaev and Chentsov, 1992). Short-time radial velocity variations ($<1^d$) are also observed. They are characteristic of the upper layers, where H_γ, H_β and H_α lines are produced, and not accompanied by the line profile variations (Rzaev et al., 1991a). Now consider possible periodicity in the variations of radial velocities and line profiles.

3. SEARCH FOR PERIODS

In the search for periodicity the method of harmonic analysis was used. For each frequency the radial velocity values were convoluted with the period corresponding to this frequency. Using the least-squares method the obtained phase dependence was compared with a theoretical sinusoid relative to which the sum of squares of Z deviations was computed. From the graphical dependence of Z value on the frequency (periodogram) minima of these deviations were defined. Then, reducing the step in frequency, similar procedure was repeated to find the most significant period. The final step in frequency for all the data available (from 1976 to 1988) was $0.000001^{d^{-1}}$ (i.e. $0^d.000004$).

The search was done for the frequencies from 0.5 to $0.0005^{d^{-1}}$ (i.e. from 2 to 2000^d) with the intervals 0.5 - 0.1, 0.1 - 0.01 and 0.01 - $0.0005^{d^{-1}}$. In each frequency interval from different lines or line groups were revealed from 2 to 4 more significant (from minimum of Z values) periods. For all these periods graphs of phase dependence of the radial velocity $V_r(\varphi)$ were plotted and compared. Usually the best of the graphs corresponded to the most significant period. The periods P, amplitudes ΔV_r and mean values of radial velocities $\bar{v}_r$ thus selected are presented in Table 2, the graphs are shown in Figs. 3-7. Both in Table 2 and in the figures numbers of observational moments are given in brackets. The vertical line in the figures marks the values of the mean error found from all the data available for each line or group of lines. In Figs. 3-7 they are presented only for the basic (long-period components) period values. For other values of the period (P_1, P_2 and P_3) these errors become consecutively smaller, on the average, 1.5-2 times. The accuracy of period determination, for example, is listed for the basic period values and for H_β lines in Table 2.

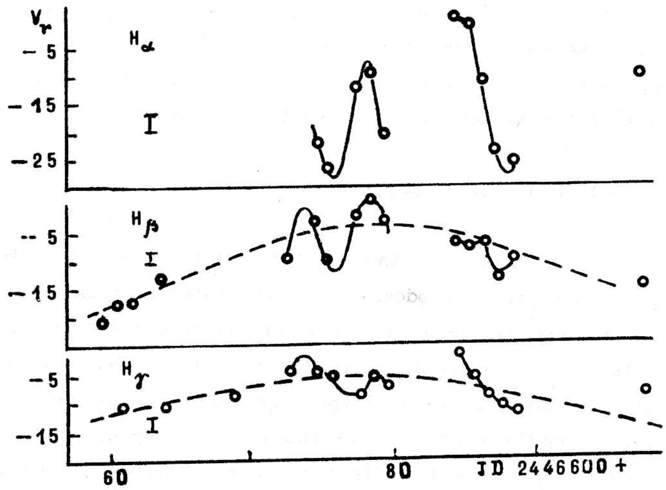

Fig. 1a. *Line radial velocities of the first members of the Balmer series versus Julian date. The solid line connects contiguous dates of observations; the dotted line is for discrete series.*

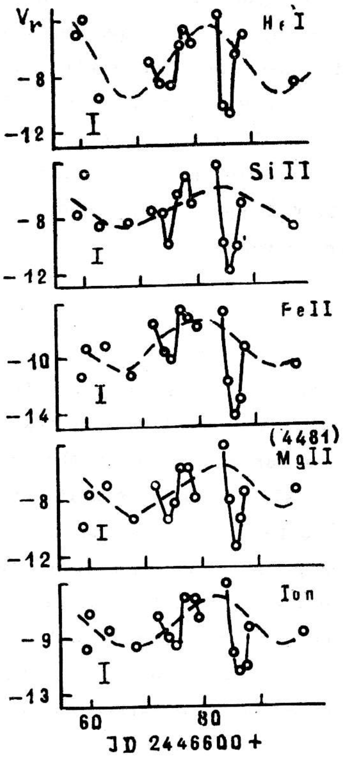

Fig. 2. *The same as in Fig. 1a for HeI lines and ions.*

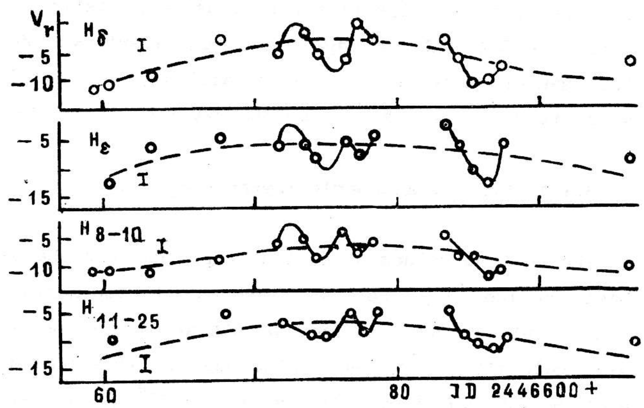

Fig. 1b. *The same as in Fig. 1a for higher members of the Balmer series.*

For both HD 21389 (Paper 1) and HD 21291 the search for possible periods was performed separately for each selected line or group of lines. The data on line radial velocities from 28 spectrograms (16 in the blue and 12 in the red region of the spectrum, total of 16 observational points) obtained during 37 days in 1986 (see

Table 1) were used in the first turn. They were added successively with the data and, at last, for 1976-1983. The found P, ΔV_r and $\bar{v}_r$ values both for the longer and continuous season (1986) and from all the data available differed very little. This suggests that these parameters of oscillation are stable for each atmospheric layer for a long time interval, although they are different for different layers.

3.1. Hydrogen Balmer series

For all hydrogen lines (but for H_α) two sets of significant periods were distinguished on the periodograms: in the interval from 30 to 60 and from 5 to 6 days. Fig. 1a, b shows the dependences of radial velocities of the Balmer series lines on Julian date for the observing run of 1986. It is seen that for these data (as well as for all the data) a trend of the long-period radial velocity component is observed, upon which short-period oscillations are superimposed. After definition of the most significant period in the first interval a phase dependence $V_r(\varphi)$ for this period was constructed. The corresponding value of the theoretical curve was then subtracted from each radial velocity value. New radial velocity were analyzed again. For this time new sets of significant periods were distinguished from the periodogram in the intervals 5-6 and 2-4 days. All significant periods in each interval were found in this manner. Note that in determination of periods for all hydrogen lines the radial velocity data obtained during one day (for 1987-1988) were averaged.

3.1.1. Upper atmospheric layers - H_β line

The derived values of period, amplitude and the mean radial velocity value for the basic period (i.e. for the long-period component) are much different for hydrogen lines. Only 29 observational points are available for H_β. After averaging of the radial velocities obtained during one day they numbered 26. All in all 4 significant periods were obtained. The period $P = 42\overset{d}{.}3209$ turned out to be the most significant. The phase dependence of the radial velocity with this period and initial epoch $2446668\overset{d}{.}5$ is marked in Fig.3 as H_β (26). After the subtraction of this (basic) period by the way mentioned above, $P_1 = 5\overset{d}{.}6993$ turned out to be the most significant. In Fig.3 it is marked as B1 = H_β- 42.3. Further, the same procedure was used to find the periods $P_2 = 3\overset{d}{.}8327$ and $P_3 = 2\overset{d}{.}8656$. In Fig. 3 their phase curves are marked as B1 - 5.69 and B2 - 3.83, respectively.

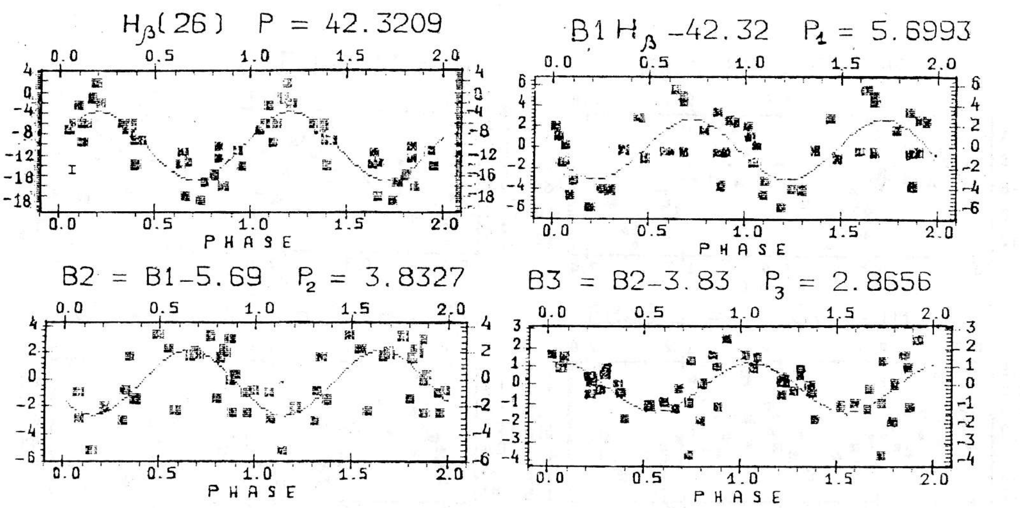

Fig.3. *Phase dependences of the radial velocity for* H_β *line (upper layers) convoluted with the periods presented on the graphs and initial epoch* $2446668^{d}.5$*. The number of points for a particular group is shown in brackets. See the text for a detailed description.*

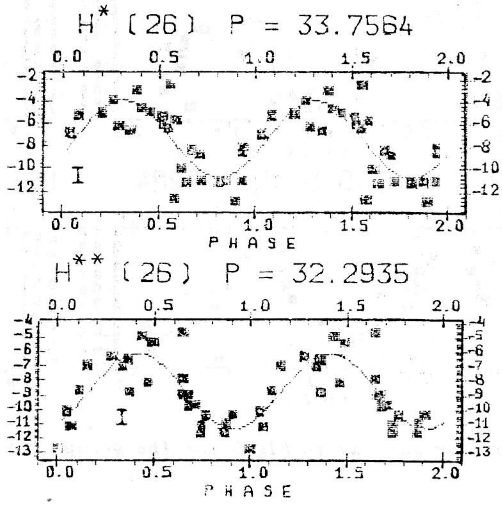

Fig.4. *The same as in Fig.3 for the groups of* H^{*} *and* H^{**} *lines.*

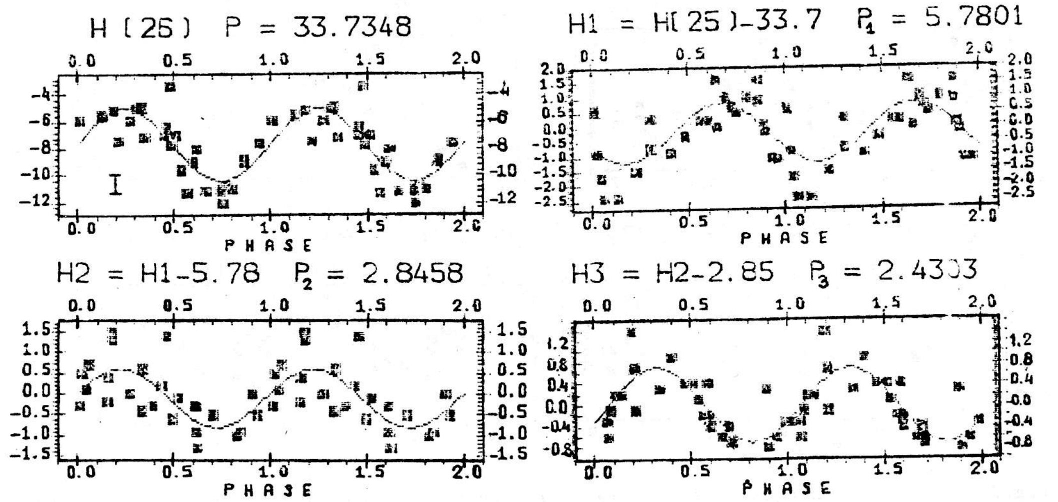

Fig.5. *The same as in Fig. 3 for the group of H lines (intermediate atmospheric layers).*

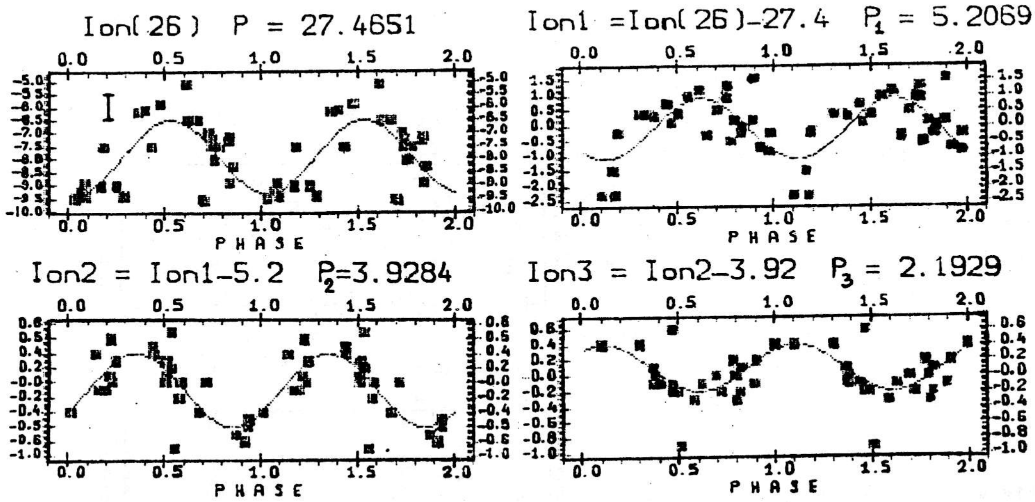

Fig.6. *The same as in Fig.3 for the group of ion lines (intermediate layers).*

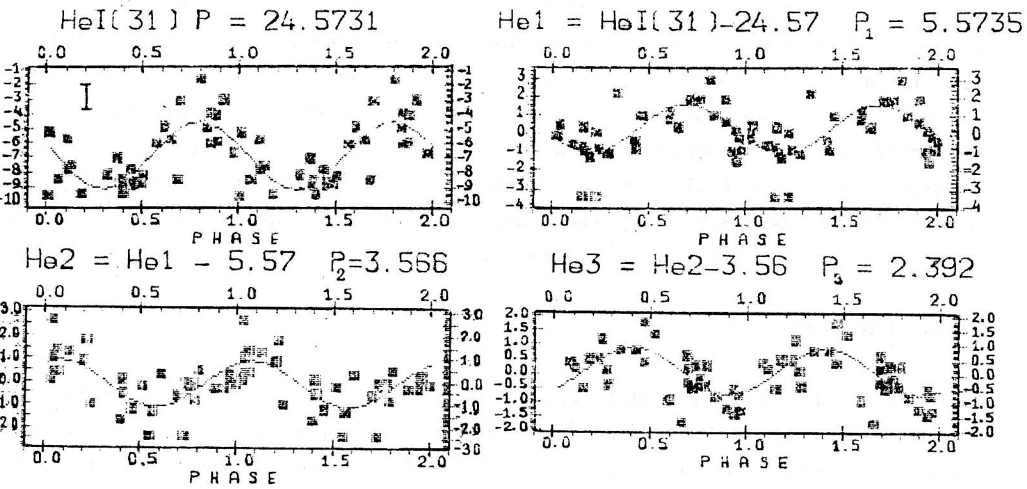

Fig.7. *The same as in Fig.3 for the group of HeI lines (lower layers).*

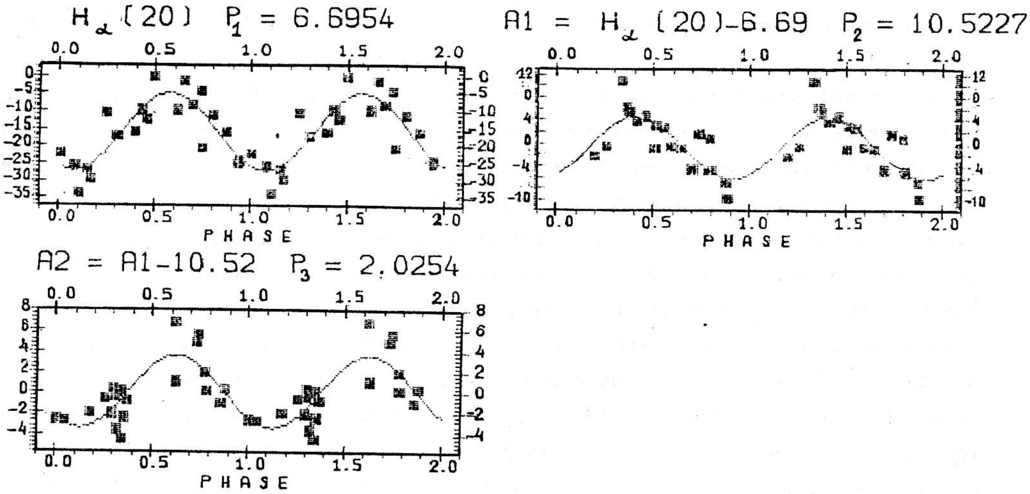

Fig.8. *The same as in Fig.3 for the group of H_α lines (uppermost layers).*

3.1.2. Intermediate layers

a) H_γ, H_δ, H_ε and higher members of the Balmer series

The derived values of P, ΔV_r and $\bar{v}_r$ for each line H_γ, H_δ, H_ε and for the groups of lines H_{8-10}, H_{11-25} hardly differ from each other and we have jointed them in two groups. In Tables 1 and 2 the H^* group is the mean over H_γ, H_δ, and H_ε, and H^{**} group - the mean over H_{8-10} and H_{11-25}. Note that when averaging the number of lines in the groups H_{8-10} and H_{11-25} was not taken into account. The values of P, ΔV_r and $\bar{v}_r$ for the H^* and H^{**} groups (for the main period value) are given at the bottom of Table 2, and the corresponding graphs are shown in Fig.4. Despite the fact that the parameters of the radial velocity variations for these groups are different (which will be discussed in the **CONCLUSION**), we jointed them in one group H(26). For this group 4 significant periods were also found. The values of P, ΔV_r and $\bar{v}_r$ are listed in Table 2 and the corresponding graphs are shown in Fig.5.

b) Ion lines

Fe II, Si II and Mg II (4481) lines belong to this group. As in the previous case the derived values of P, ΔV_r and $\bar{v}_r$ for these lines differ a little from one another and were jointed in one group Ion. The number of lines in the groups Fe II and Si II was also left out of account at averaging. The one-day data for the group were averaged. They do not give essential scatter on the $V_r(\varphi)$ graphs. In this group SiII line has a maximum number of points, 37, and Fe II and Mg II have 29 each. The search for periods was made in both Ion(37) and Ion(29). The results turned out to be the same.

Unlike hydrogen lines, for the group Ion only one set of significant periods in the interval from 5 to 6 days has been noticed on the periodograms. The following circumstances point on the existence of the long-period component. First, in spite of the fact that the measurement accuracy of ion lines is better than for hydrogen lines, Z values found for more significant periods in the specified interval for the group Ion exceeded Z value for the main period of the group H(26). This is caused by the fact that on $V_r(\varphi)$ graph the V_r values of the group Ion show for some dates clear systematic deviations from the curve (sinusoid), which is the reason of Z increase. On the other hand, as can be seen from Fig.2, if one does not take into account V_r values for the dates JD 6685 - 6687, then a trend of the long-period component of the radial velocity oscillations is observed. We have assumed that for the above mentioned dates an abrupt systematic expansion (for some reason) is observed in the layers where ion lines are formed. This may be a characteristic feature of the lower atmospheric layers of a supergiant, which may recur at times (regularly or irregularly). Note that such systematic expansions were also observed in the supergiant HD21389 (Paper 1) and HD 188209 (Musaev and Chentsov, 1989). Ascribing all values $V_r \leq -10$ km/s to such systematic expansions (for ion lines they turned out to number 11) which as if "prevent" from distinguishing of the long-period component, we made a search for possible periods for the rest of the data (26 points). The period $P = 27^{d}.4651$ proved to be the most significant. After subtraction of this period we found P_1 =

$5^{d}_{.}2069$, etc. As for the hydrogen lines, we found 4 significant periods. The values of P, ΔV_r and $\bar{v}_r$ are given in Table 2, the graphs are displayed in Fig.6.

3.2. HeI lines - lower atmospheric layers

In spite of the fact that at some moments of observations (e.g. JD 6675 - 6697) the HeI lines and ions show the same run of radial velocity variation with time, these variations are not alike in general. Therefore, HeI lines were considered separately. The one-day values of radial velocities for them were not averaged either.

In the search for periods we encountered with a situation similar to that for ion lines and behaved in the same manner as was described above. As distinct from ion lines, for HeI $V_r \leq -10$ km/s for continuous season of 1986 turned out to be 3 in number, and over the entire data there were 6 in all. The derived periods, amplitudes and $\bar{v}_r$ for HeI (31) are also listed in Table 2, the graphs for $V_r(\varphi)$ are in Fig.7.

3.3. H_α line - uppermost atmospheric layer

There are 20 spectrograms for H_α line, 11 of them were taken during 23 days in 1986. As can be seen from Fig.1a, even if the radial velocity behaviour of H_α, H_β, and H_γ are the same at some phases the scales of their variations are different.

The data for H_α(20) did not allow to find long-period component of radial velocity variation. On the periodograms a set of significant periods in the interval from 5 to 7 days stood out most evidently. $P_1 = 6^{d}_{.}6954$ is the most significant among them. After subtraction of this period there appeared several sets of significant periods of about 172, 90, 72, 27, 25 and 10^d on the periodogram. The periods of about 172, 90 and 10 days turned out to be the most significant among them. As was said above, the final version of the period was chosen according to the shape of the graph for $V_r(\varphi)$. In Fig.8 the graph is displayed for $P_2 = 10^{d}_{.}5227$, since for the first two values of the period the points on the curve $V_r(\varphi)$ cover a very narrow phase interval. The appearance of secondary periods of high significance (after subtraction of P_1) and also the larger Z value for P_1, P_2 and P_3 as compared to Z values for P_1, P_2 and P_3 in other groups (see Table 2) evidence for the existence of the long-period component of the radial velocity.

4. DISCUSSION OF RESULTS

Existence of periodicity poses a question on the nature of its origin: is this associated with possible second companion and/or stellar rotation? Since the derived periods for different layers are different, the question on the binarity is eliminated. If one assumes for HD 21291 that vsini ≈ 29 km/s (Lamers, 1981) and $R \approx 83 R_\odot$

(the mean according to Underhill (1980), and Lamers (1981) is 80 $R_\odot$ and 85.7 $R_\odot$, respectively), then we find the period associated with the star's rotation to be ≈ 145 days. As can be seen from Table 2, this quantity differs greatly from the period values we found.

If one takes $M_{bol} = -7^m.1$ (Underhill, 1980) and $T_{eff} \approx 10150$ K (the mean according to Underhill (1980) and Lamers (1981) 10310 K and 10000 K, respectively), then from Lovy et al. (1984) for theoretical value of the period of the fundamental mode of pulsations we obtain $P_0 \approx 7^d.5$, for the pulsation constant $Q \approx 0^d.037$, and $P_1/P_0 \approx 0.8$ and $P_2/P_0 \approx 0.64$ for the first and second overtones of radial pulsations, respectively. The standard model yields for these ratios the following values: $P_1/P_0 \approx 0.74$, $P_2/P_0 \approx 0.57$,, $P_3/P_0 \approx 0.46$, etc. Comparing the theoretical values with the data of Table 2, one can say that the periodical radial velocity variations we found are caused by pulsation-type motions. The long-period components of radial velocity variations may be ascribed to non-radial pulsations, since the former are several times larger than P_0 (see Maeder, 1986), other periods - to the first three overtones of radial pulsations.

As is seen from Table 2, the parameters of pulsations vary markedly with depth in the atmosphere, however, they are constant for the specified layer for a long time interval.

For the lower layers, in which HeI lines are formed, the period is $P = 24^d.5731$. It increases toward the intermediate layers, wherein ion lines and higher members of the Balmer series up to H_γ are formed, $27^d.4651$ and $33^d.7348$, respectively. And it increases considerably toward the upper layers, $P = 42^d.3209$, where H_β line is formed.

The amplitude of variations for the lower layers (HeI) is about $\Delta V_r = 4.6$ km/s. For the layers, where ion lines are formed it shows its minimum value $\Delta V_r = 2.8$ km/s and again reaches $\Delta V_r = 5.4$ km/s for the layers where higher members of Balmer series up to H_γ are formed. Further, in the uppermost layers, the amplitude increases to 13 and 22 km/s for H_γ and H_α, respectively.

Comparison of the mean radial velocities of individual layers with the radial velocity of the star's mass center ($V_* = -7.0$ km/s from Humphress, 1978) shows that the lower and intermediate layers are on the average motionless with respect to it. They demonstrate the most "pure" oscillations. For the upper layers, where H_β is formed $\bar{v}_r \approx -10$ km/s, i.e these layers show systematic expansion. The rate of expansion increases toward the uppermost layers, where the H_α absorption is formed, $\bar{v}_r \approx -16$ km/s.

As it can be seen from Table 2, Z values for H_α, H_β and HeI lines is larger than for the groups Ion(26) and H(26). This indicates that for these lines, as it has been noted by Rzaev ét al. (1991a), the short-period variations ($<1^d$) of radial velocities exist there besides the periods found (see Table 2).

For HeI and ion lines from 6 and 11 points (when systematic expansion in these layers is observed) we found that the regularity of these expansions is approximately 18^d.

5. CONCLUSION

So, the harmonic analysis of the long series of observations from 1976 to 1988 has shown that the variability of line radial velocities of the star HD 21291 is caused by the complex pulsation. Long-period variations are observed, that may be identified as non-radial pulsations upon which radial-mode oscillations are superimposed.

The period, amplitude and mean radial velocity are constant for a specified layers for a long time interval from 1976 to 1988, however, they are different for different layers.

The period increases from the lower layers, where HeI lines are formed ($24\overset{d}{.}5731$), to the upper layers, where H_β line is formed, ($42\overset{d}{.}3209$). For the intermediate layers, where ion lines and higher members of the Balmer series up to H_γ are formed, it is $27\overset{d}{.}4651$ and $33\overset{d}{.}7348$, respectively.

The amplitude of pulsations for the lower layers is 4.6 km/s. Taking the minimum value 2.8 km/s for the layers, where ion lines are formed, it increases toward the upper layers, where H_β and H_α lines are formed, reaching 13 and 22 km/s, respectively.

The lower and intermediate layers do not reveal systematic contraction or expansion, but show "pure" oscillations. The upper layers expand and the expansion rate increases toward the uppermost layers -10 and -16 km/s for H_β and H_α, respectively.

It should be noted that for the lower layers (HeI) and intermediate layers, where ion lines are formed, besides the found periodical variations there are observed semi-regular systematic expansions which hamper the search for possible periods. Apparently, they are characteristic of early supergiants, and in the investigation of the velocity field in the atmospheres of some supergiants these phenomena should be taken into account. For H_α, H_β, H_γ and HeI lines short-time variations also exist ($<1^d$). However, our data do not allow to find such short-time variations. Although the higher members of the Balmer series are jointed into one group H(26), the periods for the groups of H^* lines (the sum over H_γ, H_δ and H_ε) and H^{**} (H_{8-10} and H_{11-25}) are different.

All the features show that investigation of non-stationarity of the atmospheres of supergiants needs detailed analysis of the velocity field in their atmospheres, including account for the stratification effects, involving the zero-point of radial velocities, and allowance for certain observed peculiarities of the spectra of these stars.

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Table 1. The line radial velocities in HD 21291 spectra

Group of lines	lg τ_λ	No	JD 2440000 + 3016.5	3063.542	3117.385	3127.5	3490.344
H_α	-1.1	1	-	- 8.1±0.1	- 4.3±2.0	-10.4±2.0	-
H_β	-1.02	2	-19.8±3.0	-	-	-	-18.0±2.0
H_γ	-0.98	3	-13.2±2.0	-	-	-	-
H_δ	-0.92	4	-12.4±1.5	-	-	-	-11.0±2.0
H_ε	-0.88	5	-	-	-	-	-
H_{8-10}	-0.8	6	-11.1±1.5	-	-	-	-11.0±2.0
H_{11-25}	-0.64	7	-	-	-	-	-
H^*	-	8	-12.8±0.4(2)	-	-	-	-11.0±2.0
H^{**}	-	9	-11.1±1.5(1)	-	-	-	-11.0±2.0
H	-	10	-12.1±0.9(3)	-	-	-	-11.0± 0 (2)
MgII(4481)	-0.4	11	- 8.1±2.0	-	-	-	-13.0±2.0
SiII	-0.18	12	- 9.5±1.5	- 7.5±1.6	- 7.5±1.0	-14.3±1.2	-10.9±2.0
FeII	-0.15	13	-10.0±2.0	-	-	-	-12.2±2.0
Ion	-	14	- 9.2±0.8(3)	-	-	-	-12.0±0.6(3)
HeI	0.0	15	-13.0±2.0	- 8.2±0.2	- 3.1±2.0	- 5.7±2.0	-12.0±2.5
м/з		16	- 9.0±1.5	- 9.6±0.6	- 9.0±1.5	- 9.0±1.8	-
Date			26.08.76	12.10.76	04.12.76	15.12.76	12.12.77

Table 1 (continued)

No	JD 2440000 + 3637.344	3722.458	5364.25	5436.26	5586.625	5609.424
1	-15.9±2.0	-33.7±2.0	-	-	-	-24.8±1.0
2	-	-	- 5.9±0.3	-10.3±0.6	- 9.1±1.5	-11.0±2.0
3	-	-	- 4.6±0.4	-11.9±1.5	- 6.7±1.5	-
4	-	-	- 5.3±0.9	-11.4±0.4	- 6.9±1.0	- 7.9±1.5
5	-	-	- 4.8±1.5	-14.4±2.0	-	- 9.4±2.0
6	-	-	- 9.5±1.6(3)	-10.7±1.0(3)	- 7.9±2.0(3)	- 6.5±2.0(1)
7	-	-	-11.4±2.0(10)	-	- 9.8±3.0(8)	-
8	-	-	- 4.9±0.3(3)	-12.6±1.4(3)	- 5.4±2.0(3)	- 8.7±0.8(2)
9	-	-	-10.5±1.0(2)	-10.7 (1)	- 8.9±1.0(2)	- 6.5 (1)
10	-	-	- 7.1±2.8(5)	-12.1±1.1(4)	- 7.6±1.2(4)	- 8.0±1.2(3)
11	-	-	-10.0±0.8	- 9.1±1.3	-11.0±2.0	- 4.5±2.0
12	- 6.5±0.5	-10.5±1.0	-10.6±1.5(5)	- 8.9±3.0(5)	-11.9±3.0(5)	- 6.5±1.2(7)
13	-	-	-10.4±2.0(21)	- 8.9±2.0(17)	-11.4±2.0(14)	- 6.8±2.0(16)
14	-	-	-10.3±0.3(3)	- 9.0±0.1(3)	-11.4±0.4(3)	- 5.9±1.0(3)
15	- 6.0±2.0	- 8.1±1.5	- 7.5±2.5(11)	- 5.0±2.0(7)	- 8.5±1.4(6)	- 7.8±2.0(9)
16	- 7.4±0.3	- 8.8±1.0	- 9.6±1.0(2)	-10.5±0.5(2)	- 9.5±0.5(2)	- 7.6±0.5(4)
	08.05.78	01.08.78	29.01.83	11.04.83	09.09.83	02.10.83

Table 1. (continued)

No	JD 2440000 +					
	5970.524	5972.521	5973.431	6659.438	6660.479	6663.52
1	-15.7±2.0	-29.6±2.0	-16.7±2	- .	-	-
2	-	-	-	-20.7±1.3	-17.3±0.7	-12.6±0.9
3	-	-	-	-	-10.5±0.5	-10.3±0.6
4	-	-	-	-11.2±1.5	-10.1±0.8	- 8.7±0.8
5	-	-	-	-	-12.4±0.7	- 6.1±0.9
6	-	-	-	-10.9±2.8(2)	-10.8±1.1(3)	-11.1±3.2(3)
7	-	-	-	-	- 9.7±2.0(1)	-14.2±3.1(7)
8	-	-	-	-11.2 (1)	-11.0±1.0(3)	- 8.4±1.7(3)
9	-	-	-	-10.9 (1)	-10.3±0.6(2)	-12.7±1.6(2)
10	-	-	-	-11.1±0.2(2)	-10.7±0.9(5)	- 9.1±1.9(5)
11	-	-	-	- 9.9±0.5	- 7.6±0.5	- 7.1±0.4
12	- 6.5±1.5	- 9.5±1.0	- 7.0±1.0	- 7.6±2.0(7)	- 4.9±1.2(5)	- 8.6±1.6(5)
13	-	-	-	-11.3±1.8(20)	- 9.1±1.0(15)	- 9.1±1.7(20)
14	-	-	-	- 9.6±1.2(3)	- 7.2±1.7(3)	- 8.3±0.9(3)
15	- 1.5±2.0	- 5.8±3.0	- 3.0±2.0	- 5.0±0.6(6)	- 4.0±1.8(4)	- 9.6±0.7(6)
16	- 8.2±1.6	- 9.7±0.5	- 8.1±0.5	- 9.0±1.0(4)	- 7.4±0.4(2)	- 7.9±1.1(2)
	27.09.81	28.09.84	29.09.84	16.08.86	17.08.86	21.08.86

Table 1. (continued)

No	JD 2440000 +				
	6668.417	6672.5	6674.375	6675.375	6677.396
1	-	-	-22.2±0.8	-26.7±1.5	-12.3±0.2
2	-14.1±1.8	- 7.0±1.5	- 2.6±0.6	- 9.4±1.0	- 1.2±0.3
3	- 8.2±2.0	- 4.1±1.5	- 4.4±0.9	- 5.2±1.2	- 8.2±1.9
4	- 2.6±1.5	- 5.1±1.5	- 1.8±0.7	- 5.4±1.5	- 6.0±1.4
5	- 4.7±1.6	- 5.8±1.5	- 5.5±0.5	- 8.0±1.0	- 5.3±1.8
6	- 8.6±5.6(3)	- 5.8±1.2(3)	- 5.2±0.6(3)	- 8.4±1.0(3)	- 4.1±1.4(3)
7	- 5.2±5.4(3)	- 6.8±1.6(8)	- 8.8±3.3(7)	- 9.1±2.0(9)	- 5.1±1.1(7)
8	- 5.2±2.3(3)	- 5.0±0.7(3)	- 3.9±1.6(3)	- 6.2±0.9(3)	- 6.5±1.2(3)
9	- 6.9±1.7(2)	- 6.3±0.5(2)	- 7.0±1.8(2)	- 8.8±0.4(2)	- 4.6±0.5(2)
10	- 5.9±2.3(5)	- 5.5±0.9(5)	- 5.1±2.2(5)	- 7.4±1.6(5)	- 5.9±1.4(5)
11	- 9.3±1.0	- 7.2±1.0	- 9.6±0.6	- 7.3±0.8	- 5.8±0.6
12	- 8.2±0.7(4)	- 7.5±1.4(5)	- 7.6±1.1(7)	- 9.8±0.8(7)	- 6.4±0.9(7)
13	-11.1±2.1(20)	- 7.7±2.6(23)	- 9.8±2.2(19)	-11.1±1.9(17)	- 6.5±1.7(22)
14	- 9.6±1.2(3)	- 7.5±0.2(3)	- 9.0±1.0(3)	- 9.4±1.6(3)	- 6.2±0.3(3)
15	-11.8±1.8(7)	- 7.0±1.8(8)	- 8.6±1.6(11)	- 8.7±1.9(10)	- 6.0±2.0(9)
16	- 8.1±0.4(2)	- 8.1±0.4(2)	- 8.3±0.3(4)	- 7.8±0.3(4)	- 7.0±1.0(4)
	25.08.86	30.08.86	31.08.86	01.09.86	03.09.86

Table 1. (continued)

No	JD 2440000 +				
	6678.458	6679.325	6684.375	6685.438	6686.396
1	- 9.7±1.5	-20.4±2.0	- 0.0±0.8	- 1.3±1.0	-11.1±0.3
2	1.8±1.5	- 2.1±2.0	- 6.1±0.7	- 7.0±0.5	- 6.2±1.9
3	- 3.5±1.7	- 6.8±2.0	- 1.3±0.3	- 5.2±0.4	- 8.3±0.7
4	0.2±1.7	- 3.1±2.0	- 3.2±0.8	- 5.8±0.7	-10.7±0.3
5	- 5.4±2.2	- 3.9±2.0	- 2.6±1.2	- 5.8±1.0	-10.6±1.3
6	- 8.2±0.5(2)	- 5.8±0.2(2)	- 4.8±0.1(2)	- 8.2±0.7(2)	- 8.7±0.7(2)
7	- 8.1±1.8(6)	- 4.8±0.7(5)	- 4.3±1.8(4)	- 9.7±1.8(3)	-10.4±2.2(9)
8	- 2.9±2.3(3)	- 4.6±1.9(3)	- 2.4±0.8(3)	- 5.6±0.3(3)	- 9.9±1.1(3)
9	- 8.2±0.1(2)	- 5.3±0.5(2)	- 4.6±0.3(2)	- 9.0±0.8(2)	- 9.6±0.9(2)
10	- 5.0±3.1(5)	- 4.9±1.3(5)	- 3.3±1.2(5)	- 7.0±1.7(5)	- 9.6±1.0(5)
11	- 5.9±1.0	- 8.0±0.6	- 4.3±0.8	- 8.1±0.4	-11.5±0.6
12	- 5.2±1.9(7)	- 7.0±0.8(6)	- 4.3±1.2(7)	- 9.9±2.5(7)	-11.8±1.1(6)
13	- 7.2±1.9(17)	- 7.4±1.6(16)	- 6.8±1.5(20)	-11.9±2.4(17)	-14.1±2.7(16)
14	- 6.1±0.8(3)	- 7.5±0.4(3)	- 5.1±1.2(3)	-10.0±1.5(3)	-12.5±1.2(3)
15	- 4.8±2.7(8)	- 5.7±1.0(7)	- 3.9±0.8(10)	-10.5±0.8(9)	-10.7±0.7(7)
16	- 8.2±0.4(4)	- 7.7±1.0(4)	- 8.3±1.1(4)	- 8.7±0.2(3)	- 8.2±0.6(4)
	04.09.86	05.09.86	10.09.86	11.09.86	12.09.86

Table 1. (continued)

No	JD 2440000 +				
	6687.333	6688.333	6697.333	7054.5	7459.396
1	-24.0±0.7	-25.4±1.4	- 9.7±0.5	-	-
2	-13.9±1.1	- 9.2±1.2	-13.7±2.5	- 6.1±1.5	-13.4±1.8
3	-10.3±1.1	-11.4±1.0	- 8.7±0.8	- 5.9±0.2	- 6.7±0.7
4	-10.2±0.6	- 7.2±0.8	- 6.7±0.8	- 5.1±0.7	- 5.6±3.2
5	-13.1±0.5	- 5.9±0.5	- 8.4±0.5	- 7.1±2.5	- 2.4±1.3
6	-11.8±0.7(3)	-10.8±0.5(3)	-10.1±1.9(3)	- 7.1±0.3(3)	- 4.4±2.2(3)
7	-11.3±0.3(4)	- 9.9±2.1(4)	-10.1±2.0(5)	-10.1±0.5(1)	- 5.0±0.7(4)
8	-11.2±1.3(3)	- 8.2±2.4(3)	- 7.9±0.9(3)	- 6.0±0.8(3)	
9	- 8.2±0.1(2)	- 5.3±0.5(2)	- 4.6±0.3(2)	- 8.6±1.5(2)	
10	-11.3±1.1(5)	- 9.0±2.1(5)	- 8.8±1.3(5)	- 7.0±1.7(5)	
11	-10.5±0.4	- 8.0±0.6	- 7.5±0.4	-10.3±0.1	- 7.1±0.5
12	-10.1±1.7(5)	- 6.9±1.9(5)	- 8.7±0.8(6)	- 9.2±0.9(5)	- 6.3±0.8(5)
13	-13.1±2.0(23)	- 9.3±2.3(16)	-10.6±1.7(23)	- 8.6±1.3(13)	- 8.6±1.9(16)
14	-11.2±1.3(3)	- 8.0±1.0(3)	- 8.9±1.3(3)	- 9.4±0.7(3)	- 7.3±1.0(3)
15	- 6.6±2.5(11)	- 5.2±0.6(6)	- 8.7±3.0(12)	-10.4±2.3(5)	- 8.5±1.3(3)
16	- 9.4±0.5(4)	- 7.3±0.4(4)	- 8.6±1.2(4)	- 8.3±0.8(2)	- 7.7±0 (2)
	13.09.86	14.09.86	23.09.86	16.09.87	24.10.88

Table 1. (continued)

No	JD 2440000 +				
	7459.5	7459.583	7460.5	7460.563	7466.5
1	-	-	-	-	-
2	- 8.9±1.2	-12.0±2.0	-11.3±0.8	-15.1±0.8	-15.8±0.2
3	-10.4±1.2	- 7.9±0.3	- 6.3±1.2	- 8.4±0.5	-10.4±1.7
4	- 3.2±1.6	- 5.0±1.0	- 5.9±1.5	- 6.4±1.5	-11.4±0.8
5	- 6.6±0.3	- 1.8±0.5	- 2.6±2.0	- 8.1±0.5	-11.2±1.2
6	- 7.9±2.2(3)	- 7.2±0.9(3)	- 8.7±1.9(3)	- 9.9±1.2(3)	-14.3±1.8(3)
7	- 6.4±1.1(10)	-12.5±2.3(4)	-10.3±1.8(8)	-10.2±2.1(1)	-11.6±2.9(6)
8	-5.5±2.0(3)		-6.3±0.8(3)		-11.0±0.4(2)
9	-7.8±0.2(2)		-9.8±0.5(2)		-13.0±1.3(2)
10	-6.4±1.9(5)		-7.7±1.8(5)		-11.2±1.4(5)
11	- 7.3±0.1	- 9.5±0.8	-11.6±0.1	-11.3±0.4	-12.2±0.6
12	- 6.6±0.7(4)	- 8.7±1.4(5)	-10.8±1.4(5)	-11.0±1.5(5)	-10.4±0.6(5)
13	- 7.3±1.8(14)	- 8.5±1.3(15)	-12.6±1.5(14)	-13.4±1.7(10)	-13.2±1.5(11)
14	- 7.1±0.9(3)	- 8.9±0.4(3)	-11.7±0.7(3)	-11.8±1.1(3)	-11.9±1.2(3)
15	- 8.8±1.1(4)	- 9.4±0.9(3)	- 8.9±1.9(10)	- 8.0±3.0(4)	- 8.5±1.3(4)
16	- 7.8±0.1(2)	- 7.3±1.5(2)	- 7.6±0.2(2)	- 8.8±2.2(2)	- 8.3±0.5(2)
	25.10.88	25.10.88	26.10.88	26.10.88	01.11.88

Table 2. Oscillation parameters of different layers in the atmosphere of HD 21291

Line or group of lines	Z	Period (P^d)	Amplitude ΔV_r, km/s	Mean radial velocity value $\bar{v}_r$, km/s
H_α(20)	4.99	6.6954	22.2	-15.9
	3.00	10.5227	10.8	-0.8
	1.91	2.0254	7.0	-
H_β(26)	3.06	42.3209±0.01	13.0	-10.3
	2.32	5.6993	5.8	-
	1.73	3.8327±0.0001	4.8	-
	1.08	2.8656	2.6	-
H(26)	1.40	33.7348±0.005	5.4	-7.7
	.99	5.7801	2.8	-
	.56	2.8458	1.4	-
	.38	2.4303	1.4	-
Ion(26)	1.00	27.4651±0.004	2.8	-7.9
	.71	5.2069	2.0	-
	.29	3.9284	1.0	-
	.24	2.1929	0.6	-
He(31)	1.44	24.5731±0.003	4.6	-6.8
	1.11	5.5735	2.6	-
	.85	3.5660	2.0	-
	.65	2.3920	1.6	-
H^*(26)	1.96	33.7564	6.8	-7.3
H^{**}(26)	1.35	32.2935	5.2	-8.7