NON-STATIONARY ATMOSPHERES OF SUPERGIANTS

II. *The Hα Profile Variations in the Spectra of HD 21291 and HD 21389*

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Abstract. On the basis of the spectrograms obtained in the period 1976–1984 the Hα profiles present time variation. There are also variations in the profiles of Hβ, Hγ, Hδ, and of other elements. The profile of the Hα line has been analysed, as well as its relations with possible expansion, contraction, quiet and mixed conditions of the atmosphere of HD 21291 and HD 21389. In our opinion it is possible that there are two cycles of periods in the variation of Hα line profile. These two periods in the variation of the physical conditions of the atmosphere for the studied stars, give us the key for understanding the movement of matter in the different layers and the complex mechanism of pulsation in the stellar atmosphere.

1. Introduction

According to the analysis of the existing observational material by Zvereva *et al.* (1984), Rzaev *et al.* (1989) with a sufficient confidence the profiles of the Hα, line in the spectra of HD 21291 and HD 21389 presented different shapes: pure absorption, normal P Cyg, inverse P Cyg, or emission on both sides of absorption. There is also a variation in the profiles of Hβ, Hγ, Hδ, and other elements.

In this work we will analyse only the profile of the Hα line and its relation with expansion and contraction of the atmosphere of the stars HD 21291 and HD 21389, because Hα line of the hydrogen is the main indicator of this phenomenon. The kinematic properties and variation in the radial velocities has been noted by Zvereva *et al.* (1984), Zeinalov (1984), Denizman and Hack (1988), Rzaev *et al.* (1989). The measurements of the positions of the spectral lines, their selection and division into groups, their errors of measurements and also the values of $\log \tau$ have been discussed by Zeinalov and Rzaev (1988), Rzaev *et al.* (1989), and Sokolov and Chentsov (1984). The values of the assigned optical depth and the radial velocity for each star are given in Tables I and II, respectively.

2. Analysis of HD 21291 and HD 21389

2.1. HD 21291

The profiles of Hα for the HD 21291 are given in Figure 1 in relative intensity for each date, respectively. On the basis of this figure we have suggested:

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The pure absorption of Hα for HD 21291 has been observed on 12 October, 1976. At first it indicates a quiet (stationary) phase ($\Delta_{1/2}$ = 2.6 Å; R_0 = 0.28). The halfwidth ($\Delta_{1/2}$) has its maximum value and the profile is symmetric. Such symmetric lines have been noted by Denizman *et al.* (1988) for Hα and Hβ. The functional relation between $\log \tau$ and V_r for this observation is linear. The atmosphere of the star is stationary. The values of radial velocities are constant at all optical depths from $\log \tau = -1.1$ to 0.0 of the atmosphere ($V_r \approx -10$ km s^{-1}). Similar profiles of Hα have been observed by Zvereva *et al.* (1984) on 4 January, 1977 and 9 September, 1977 for HD 21389.

The Hα profile, which has been observed on 4 December 1976 (see Figure 1), consists of two components. The profile is inverse P Cyg ($\Delta_{1/2}$ = 1.5 Å, R_0 = 0.30) and asymmetric. The halfwidth of the profile is two times less than the quiet phase of the atmosphere. The radial velocities of the lines are variable and the atmosphere shows a contraction phase and is non-stationary.

The profile of the Hα which was observed on 8 May, 1978 (Figure 1) consists of two emission wings and a stronger absorption component. The kinematic properties indicate that the radial velocities of the lines have changed from -15 km s^{-1} to -4 km s^{-1} at $\log \tau = -1.1$, to 0.0, respectively. This is an atmospheric expansion phase and again the atmosphere of the star is non-stationary.

The profile of the Hα line which was observed on 1 August, 1978 (Figure 1), is a normal P Cyg profile and is asymmetric ($\Delta_{1/2}$ = 1.5 Å, R_0 = 0.18). The kinematic properties indicate that the radial velocities of the lines vary from -30 km s^{-1} to -8 km s^{-1} at $\log \tau = -1.1$ to 0.0, respectively. This observational fact suggests that at this phase the star has a maximum activity in the atmosphere and is expanding.

On 2 October, 1983 (Figure 1) an asymmetric P Cyg profile was observed for Hα. The radial velocities of the lines have changed from -24 km s^{-1} to -6 km s^{-1} ($\Delta_{1/2}$ = 1.6 Å, R_0 = 0.30). The atmosphere is expanding but the velocity of expansion is slow.

On 15 December, 1976 the Hα profile is only in asymmetric absorption ($\Delta_{1/2}$ = 1.5 Å), two times less than on 12 October, 1976, R_0 = 0.26) (Figure 1). The radial velocities of the lines vary from -10.4 to -14 km s^{-1} and the atmosphere is in a quiet phase.

The variations in the profile of Hα and kinematic properties suggest that there is an evidence of a definite cyclic variation of the atmosphere of the star. But owing to the absence of continuous observations we cannot specify the period of the variations. However, such a massive and extended ($\mathscr{R}_* = 10^8$ km) star cannot have only one variation period but several.

Lastly the profiles of Hα which are observed at interval of one night are given in Figure 1. From these profiles we can see that:

(a) On 27 September, 1984 the profile, consists only of absorption and is asymmetric. After the symmetric Hα and Hβ observations, similar asymmetric profiles has been observed by Denizman and Hack (1988). The radial velocity values changed from -15 km s^{-1} to -1.5 km s^{-1}. The atmosphere of the star is in the expansion phase. The velocity of the expansion is two times less than the one on date 8 January, 1978. Next, the Hα profile confirms that the atmosphere is not in a quiet phase.

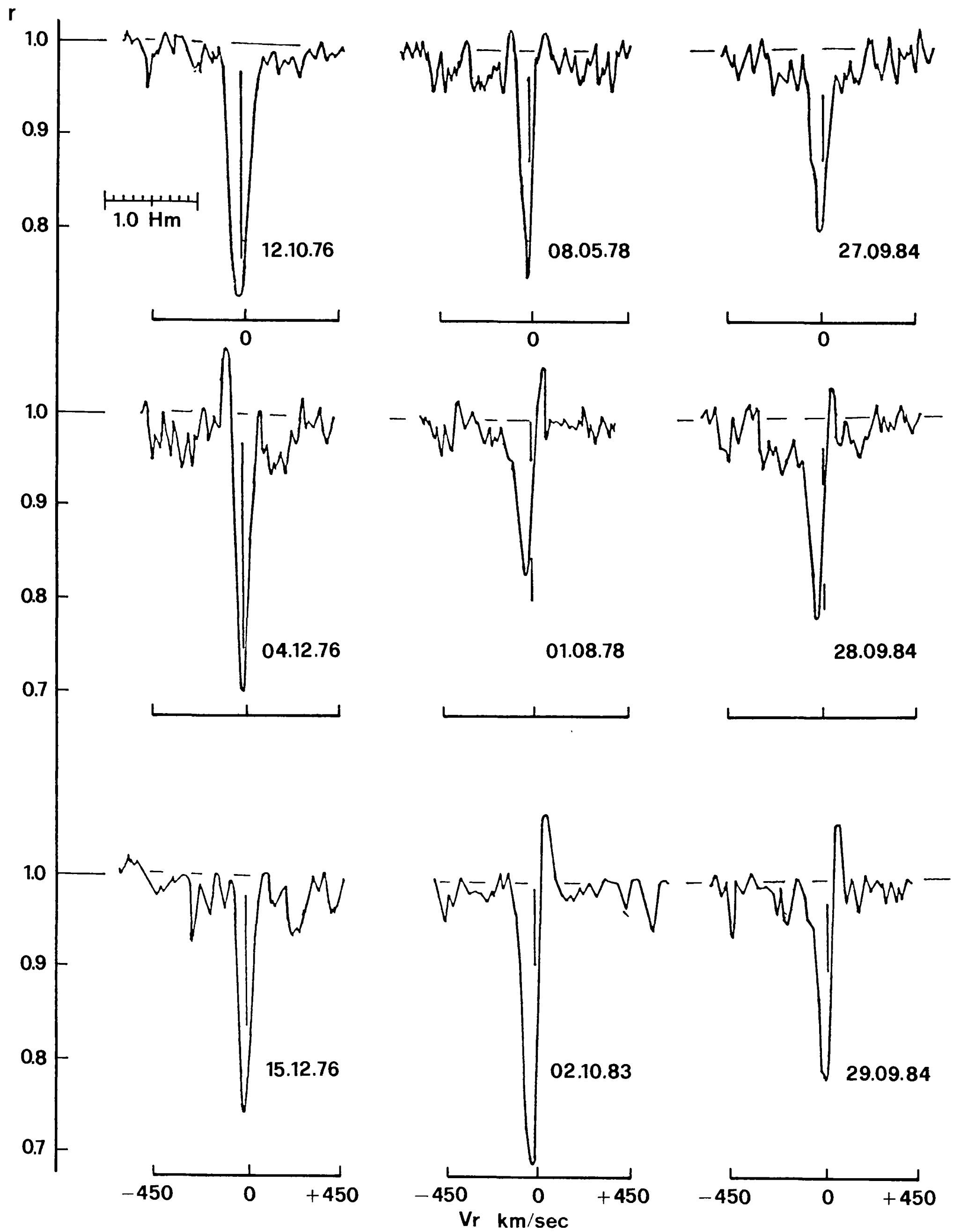

Fig. 1. Hα profiles of HD 21291. The X-axis gives the relative radial velocity with heliocentric correction in km s^{-1} and Y-axis gives the relative residual intensity in continuum units.

(b) On the following night (28 September, 1984) (Figure 1), the profile of Hα has changed to normal P Cyg with an asymmetric absorption component. The radial velocities varied from -29 km s^{-1} to -5.6 km s^{-1} and the expansion velocity is two times larger than the night before.

(c) The profile of the Hα observed on the night of 29 September, 1984 is also a normal P Cyg, but with a stronger emission component than the night before. The radial velocities varied from -16 km s^{-1} to -3 km s^{-1} this night. Also during this night the

TABLE I

Assigned optical depths for line or line groups taken from Zeinalov and Rzaev (1988) and Rzaev *et al.* (1989) for HD 21291

Line groups	log τ	V_r (km s^{-1})								
		12 Oct., 1976	4 Dec., 1976	15 Dec., 1976	8 May, 1976	1 Aug., 1978	2 Oct., 1983	27 Sept., 1984	28 Sept., 1984	29 Sept., 1984
Hα	−1.1	−8.0 ± 0.1	−4.3 ± 2.0	−10.4 ± 2.0	−15.9 ± 2.0	−33.7 ± 2.0	−24.8 ± 1.0	−15.7 ± 2.0	−29.6 ± 2.0	−16.7 ± 2.0
Hβ	−1.0						−11.0 ± 2.0			
Hγ	−0.98									
Hδ	−0.92						−7.9 ± 1.0			
H_{8-10}	−0.80						−6.0:			
H_{11-20}	−0.64									
Mg II	−0.40						−4.5 ± 2.0			
Fe_1 II	−0.40						−6.7 ± 1.0			
Si II	−0.18	−7.5 ± 1.0	−7.5 ± 1.0	−14.3 ± 1.0	−6.5 ± 0.0	−10.5 ± 1.0	−6.5 ± 1.0	−6.5 ± 1.0	−9.5 ± 1.0	−7.0 ± 1.0
Fe_2 II	−0.15						−6.9 ± 2.0			−3.0 ± 2.0
He I	−0.0	−8.2 ± 0.0	−3.1 ± 2.0	−5.7 ± 2.0	−6.0 ± 2.0	−8.1 ± 1.0	−6.0 ± 2.0	−1.5 ± 2.0	−5.8 ± 3.0	
Interstellar		−9.6 ± 0.0	−9.0 ± 1.0	−9.0 ± 1.0	−7.4 ± 0.0	−8.8 ± 1.0	−7.6 ± 0.0	−8.2 ± 1.0	−9.7 ± 0.0	−8.1 ± 0.0

TABLE II

Same as previous table but for HD 21389

Line groups	log τ	V_r (km s^{-1})					
		25 Sept., 1984	26 Sept., 1984	28 Sept., 1984	29 Sept., 1984	29 Sept., 1984	30 Sept., 1984
Hα	−1.1	−0.0 ± 0.5	−6.2 ± 0.7	−9.2 ± 0.8	−14.0 ± 1.0	−3.6 ± 0.8	−6.5 ± 1.0
Si II	−0.18	−2.7 ± 0.8	−4.6 ± 1.7	−8.0 ± 0.08	−8.6 ± 0.7	−9.0 ± 0.2	−7.1 ± 0.4
He I	0.0	+6.1 ± 1.1	+7.1 ± 1.0	− −7.6 ± 1.5	−2.6 ± 1.0	−7.5 ± 1.2	−2.8
Inter-stellar		−9.4 ± 0.8	−8.1 ± 0.2	−10.0 ± 1.0	−9.0 ± 0.9	−9.7 ± 0.5	−8.4 ± 0.6

atmosphere of the star is in expansion, but, however, the expansion velocity is less than the night before.

Because of the lack of the data we cannot determine the period of the Hα profile variation from absorption to normal P Cyg profile and the development of the non-stationary condition of the atmosphere. On the basis of this research we can suggest that there are at least two different cycles of variations of the atmosphere of HD 21291. Apparently after each period (cycle) the phase of the atmosphere develops differently. If in the first cycle, after a pure Hα absorption profile is observed, it later develops to a normal P Cyg but in the second cycle transforms to an inverse P Cyg. This observational fact suggests that these cycles cannot have just one period and there is a need of further continuous observations.

2.2. HD 21389

This star was observed continuously for six nights from 25 September, 1984 to 30 September, 1984 by Rzaev *et al.* (1989). The changes in the radial velocities and the sign of radial velocity curves of H Balmer progression, He I, Mg II, Si II, and other kinematic properties of this star have been studied by Zvereva *et al.* (1984), Zeinalov and Rzaev (1988), Denizman and Hack (1988), Rzaev *et al.* (1989).

In this work we have analysed only the Hα line profiles of hydrogen which are presented in Figure 2 (also see Table II).

The Hα profile observed on the night of 25 September, 1984 consists of two absorption components: the red component has a relative residual intensity of 0.26 continuum units and the shortward shifted component is weaker ($R_0 = 0.11$). Moreover, there are two weak emission wings. The whole profile is asymmetric. The measured radial velocities varied from 0 km s^{-1} to 6 km s^{-1} (see Table I). The atmosphere of the star is in the contraction phase.

On 26 September, 1984, the structure of the Hα is changed. The emission wings disappeared, and the radial velocities varied between −6.2 km s^{-1} to 7 km s^{-1}. This indicates that the upper layers are expanding and the lower layers are contracting. The upper layers changed the direction of movement but lower layers continued to contract, and the physical conditions of the atmosphere is non-stationary.

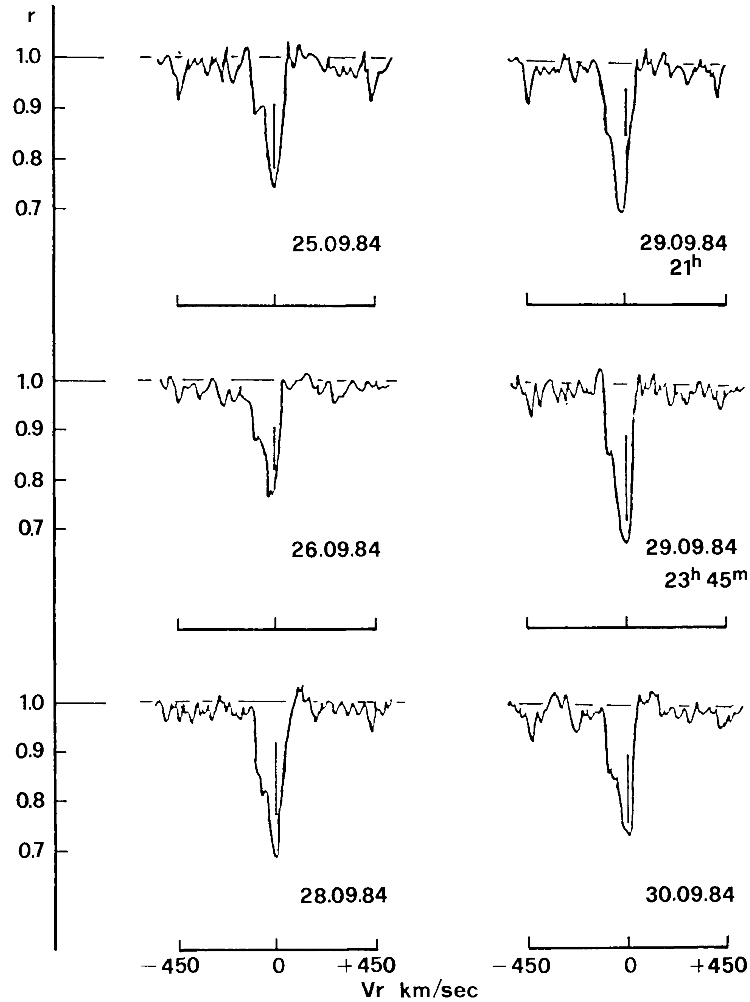

Fig. 2. Hα profiles of HD 21389. Same as previous figure.

The Hα profile which is observed 28 September, 1984 revealed that the profile is changed considerably to a normal P Cyg profile. There are two absorption components (R_0 = 0.32, and a weaker one with R_0 = 0.19). The values of the radial velocities has changed from − 9.2 km s^{-1} to − 7.2 km s^{-1}. The structure of the Hα line and the kinematic properties show that the atmosphere is expanding.

On 29 September two Hα profiles have been secured (Figure 2). The first profile consists of two absorption components (R_0 = 0.30 and R_0 = 0.14, respectively). The radial velocities varied between − 14.0 km s^{-1} to − 2.6 km s^{-1} and the atmosphere is still in the expansion phase. But it seems that the emission component of the P Cyg profile is diminished.

On the same night the Hα profile which is obtained two hours later from the previous one presents an inverse P Cyg profile with an absorption component splitted into two components. The radial velocity distribution is between − 3.6 km s^{-1} to − 7.5 km s^{-1}. It is clear that the velocity of the expansion has slowed down (especially for the upper layers). This state of the star is similar to that of 25 September, 1984. It seems that the weak emission on the red side of the absorption is still present.

One night later, on 30 September, 1984, we observed a normal P Cyg for Hα and for this observation we have a full spectrum from Hα to H_{25}. The kinematic properties are variable and include the atmosphere of the star at all optical depths. The radial velocities has changed from -5.8 km s^{-1} to -2.8 km s^{-1}. This indicates that the upper and lower layers are expanding but also between these two layers there are transition layers which are revealed with a linear behavior of the V_r versus $\log \tau$ curve (see also Rzaev *et al.*, 1989).

3. Conclusion

Summing up the data described previously we may suggest the following conclusions:

(1) The Hα profile of the hydrogen presented a complicated structure and a time variation for both HD 21291 and HD 21389.

(2) It is possible that there are at least two cycles or periods in the profile variation of the Hα line. For example, the profiles analysed in this work present the following cycles: (a) A pure absorption profile transforms to a normal P Cyg and this changes to an inverse P Cyg and finally again a pure absorption. (b) In the second cycle a pure absorption profile transforms to an inverse P Cyg and then to a normal P Cyg and again to a pure absorption profile.

(3) The repetition of the normal P Cyg profile and inverse P Cyg apparently takes place during three hours (even perhaps less than one hour).

(4) The repetition of the normal and inverse P Cyg profiles is mainly accompanied by expansion and contraction of the atmosphere of both stars. The emission and absorption components inversely oscillates along the Hα laboratory wavelength (around the normal position $\lambda_{\mathrm{lav}} = 6562.8$ Å).

(5) The hydrogen lines are splitted for HD 21389 (see also Zeinalov, 1984; 1987). The absorption component of Hα presents always a double-peak absorption for HD 21389. And the relative intensities of these components varied substantially. The weaker absorption component is -80 km s^{-1} shortward shifted and is stationary. This observational fact suggests that there is a shell around the HD 21389 where this shortward shifted weak absorption component of Hα is effectively formed. Denizman and Hack (1988) have noted that in the UV spectra there are shortward shifted lines for also other elements.

(6) The observational data accumulated need a theoretical model analysis.

(7) The suggestion of two cycles or periods of variation in the physical conditions of the atmosphere for HD 21291 and HD 21389 give us the key for understanding the movement of mass in the stellar atmosphere.

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