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The Complex Structure of the Ca II (H and K) Lines in the Spectrum of the AOep Star with Infrared Excess HD 190073

I. Line Profiles and Variations during three Decades (1943–1974)

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Summary. Radial velocities and profiles of the components of the H- and K-lines in the spectrum of HD 190073 are analyzed on a 24-spectrum sample covering the period 1943–1974. A 2 to 1 ratio in the radial velocities of some components is shown not to be significant on a spectrum to spectrum basis, contrary to suggestions by Merrill (1951) and Scargle (1973). The details of the H- and K-complex structure are correlated with the profiles of the Balmer lines, especially H_ε. The same correlation is found in a series of emission-line stars with infrared excess.

Key words: Ca II H and K-complex profiles — variable profiles — emission-line stars — infrared excess

A. Introduction

The spectrum of the AOep star HD 190073[1]) is remarkable for the presence of a complex structure for Ca II H and K absorption lines. During the last three decades the general aspect of the complex pattern has remained the following: one stationary component and at least two strong components displaced to the violet by 180 and 320 km s^{-1}. The dramatic variations (long as well as short term) observed within that pattern are described and analyzed in the present paper, where they are also shown to be correlated with variations in the profiles of the Balmer lines.

Besides the remarkable Ca II lines, the spectrum of HD 190073 is characterized by emission components in the Balmer lines (complex P Cygni type structure), in the D_1- and D_2-lines of sodium and in metallic lines. For the latter, no correlation is found between the separation of the emission wings and the excitation potential of the line. A detailed description of the spectrum of HD 190073 from the near ultraviolet to the near infrared is in preparation and will soon be submitted for publication (Surdej and Swings, 1976a).

It should also be mentioned that emission lines due to the Ca II triplet at $\lambda\lambda$ 8498-8542-8662 Å (indicative of an extended atmosphere around HD 190073) have recently been observed by Andrillat and Swings (1976).

Scargle (1973) has proposed a pure scattering model in order to explain the ejection of Ca^+ ions from the atmosphere of the star: he attempts to explain the 2:1 ratio between the radial velcities of some components of the H- and K-lines. Such a ratio, however, does not appear to be significant if one considers the 24 spectrum sample for which we measured the radial velocities of the different Ca II components. On the contrary, we find a correlation between the aspect of the structure of the H- and K-lines and the complex profile of the Balmer lines, especially H_ε. In the present paper, we describe the evolution of the structure of the H- and K-lines and the measurements of the radial velocities of their components for 24 spectra covering the period 1943–1974. In paper II (Surdej and Swings, 1976b), we shall interpret the observations in terms of a model based on the selective effect of radiative forces.

[1]) HD 190073 = BD + 5°4393 = MWC 325; $m_v \sim 7.9$; $\alpha(1950) = 20^h00^m.6$; $\delta(1950) = +5°35'.8$.

B. The Ca II H- and K-lines in the Spectrum of HD 190073

A typical profile of the H- and K-lines in the spectrum of HD 190073 is illustrated in Fig. 1 where one readily sees the variations occurring between two spectra, the upper one from 1970, the lower from 1974. The three main absorption components in H and K are called H_1, H_2, H_3 and K_1, K_2, K_3 respectively, H_1 and K_1 corresponding to the rest velocity wavelengths; additional components between H_2 and H_3, K_2 and K_3 are visible on the 1974 spectrum.

The first description of the H- and K-profiles, essentially of K since H is perturbed by the Balmer line H_ε, was

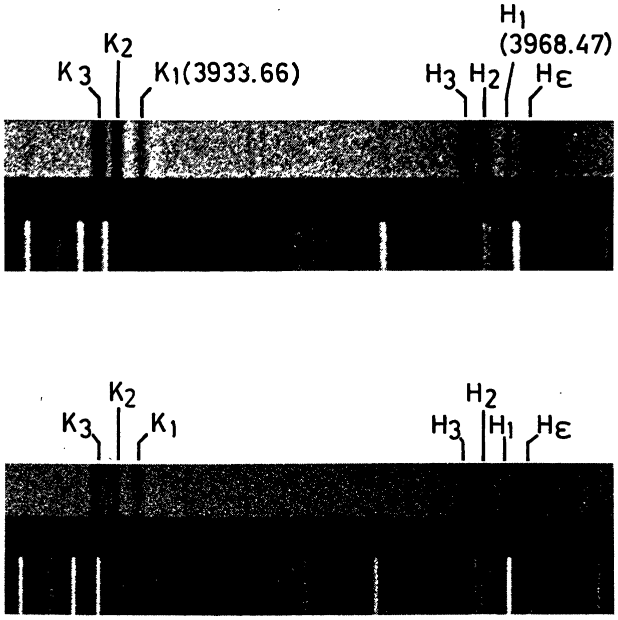

Fig. 1. The complex profile of the H- and K-lines in the spectrum of HD 190073 exhibits variations with time. The upper is from July 23, 1970 (20 Å/mm) and the lower from Sept. 30, 1974 (10 Å/mm). Both plates were obtained at the coudé focus of the Observatoire de Haute Provence 193 cm telescope

given by Merrill (1933) on the basis of fairly low dispersion plates (23 Å/mm): "The ionized calcium lines H and K are very abnormal. K consists chiefly of two absorption components, one a narrow line of moderate intensity in its normal position, the other a much stronger line 3 Å wide, displaced 3.2 Å toward shorter wavelengths.. The edges of both components are sharply defined... Between the two absorption components is a maximum whose effective center lies 1.1 Å toward shorter wavelengths from the normal position of K. Within the broad displaced component is a very narrow weak maximum 2.9 Å toward shorter wavelengths from the normal position of K". As can be seen from Fig. 1 this "emission" actually represents a separation between absorption components K2 and K3.

Variations in the H- and K-profiles were established a few years later (Swings and Struve, 1940; Struve, 1942). Merrill's "emission" seemed to oscillate from one spectrum to the other. The H- and K-profile variations are studied in greater detail in the next chapter.

C. The H- and K-profiles during the Period 1943—1974

An illustration of the variations in the H- and K-line profile is given in Fig. 2: the spectrograms were obtained by several observers at the coudé foci of the Mount Wilson 100-inch (1943–1952: by the late P. W. Merrill; 1949: H. W. Babcock; 1959: P. Swings; 1971: J. P. Swings) and of the Haute Provence 193- and 152-cm telescopes (1970–1973: J. P. Swings; 1974: J. Surdej and J. P. Swings) at dispersions ranging from 4.5 to 20 Å/mm.

1. Radial Velocities of the Components

For 24 spectra covering a period of 30 years we measured the radial velocities of the various components appearing in the H- and K-lines. The accuracy of the measurements is $\pm 5\,\mathrm{km\,s^{-1}}$ and $\pm 10\,\mathrm{km\,s^{-1}}$ for plates having a dispersion of respectively 10 or 20 Å/mm. Figures 3 and 4 show typical profiles on which radial velocity measurements were performed. Table 1 collects the data (in $\mathrm{km\,s^{-1}}$) for the various components of H and K: E^+, A and E^- refer respectively to the red emission wing, the central absorption and the violet emission wing of the "undisplaced" H- and K-lines. For the other components the velocities are grouped under headings ranging from -110 to $-400\,\mathrm{km\,s^{-1}}$ in order to readily see which blueshifted components

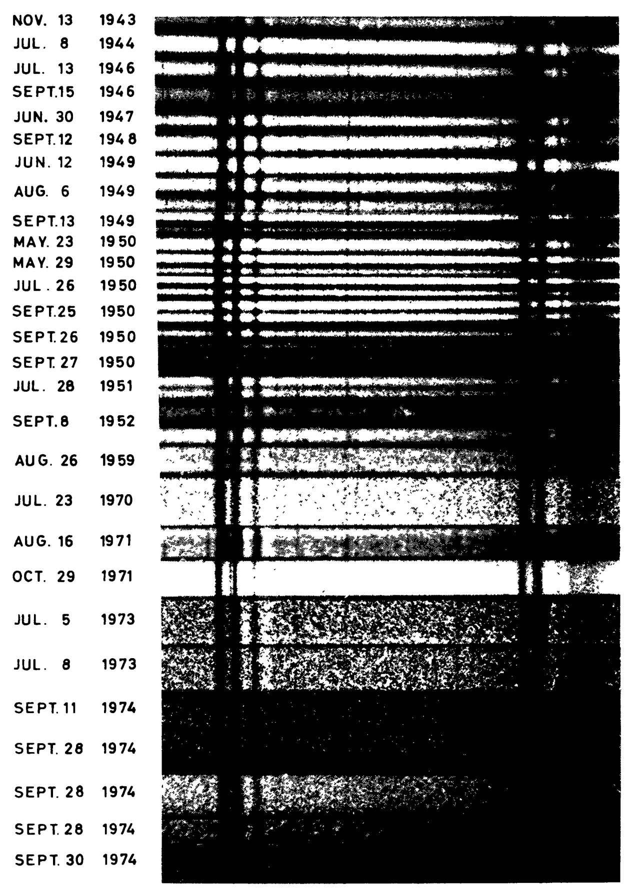

Fig. 2. The H- and K-lines in the spectrum of HD 190073 between 1943 and 1974. Details about observers and telescopes are given in the text

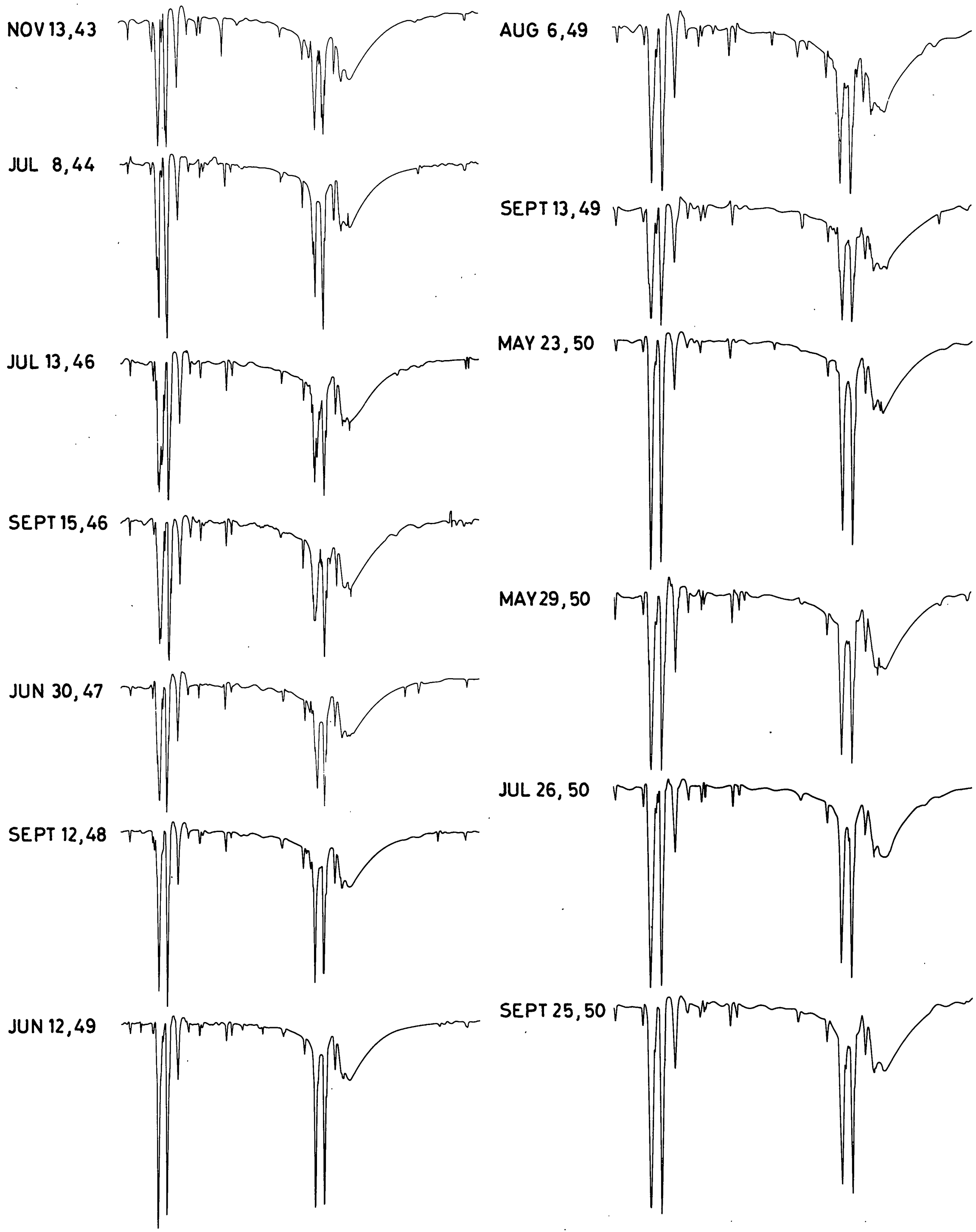

Fig. 3. Density tracings (normalized with respect to the depth of H_ε) of the first 13 plates of Fig. 2 showing variations in the H- and K-line structure

appear most often. The date at which the spectrogram was obtained, as well as its dispersion, are given in column 1.

Before considering the radial velocities of the absorption components, a word should be said concerning the H- and K-emission wings. From the data collected in Table 1 it appears that the separation between the emission wings in the K-line is greater than that in the H-line, i.e. 184 km s^{-1} compared to 86 km s^{-1}. Such a discrepancy is due to the effect of the underlying profile of the Balmer line H_ε which perturbs the H-line of Ca II: an emission in H_ε acts dramatically on H in filling in the undisplaced H_1 component, therefore reducing the separation between the emission wings.

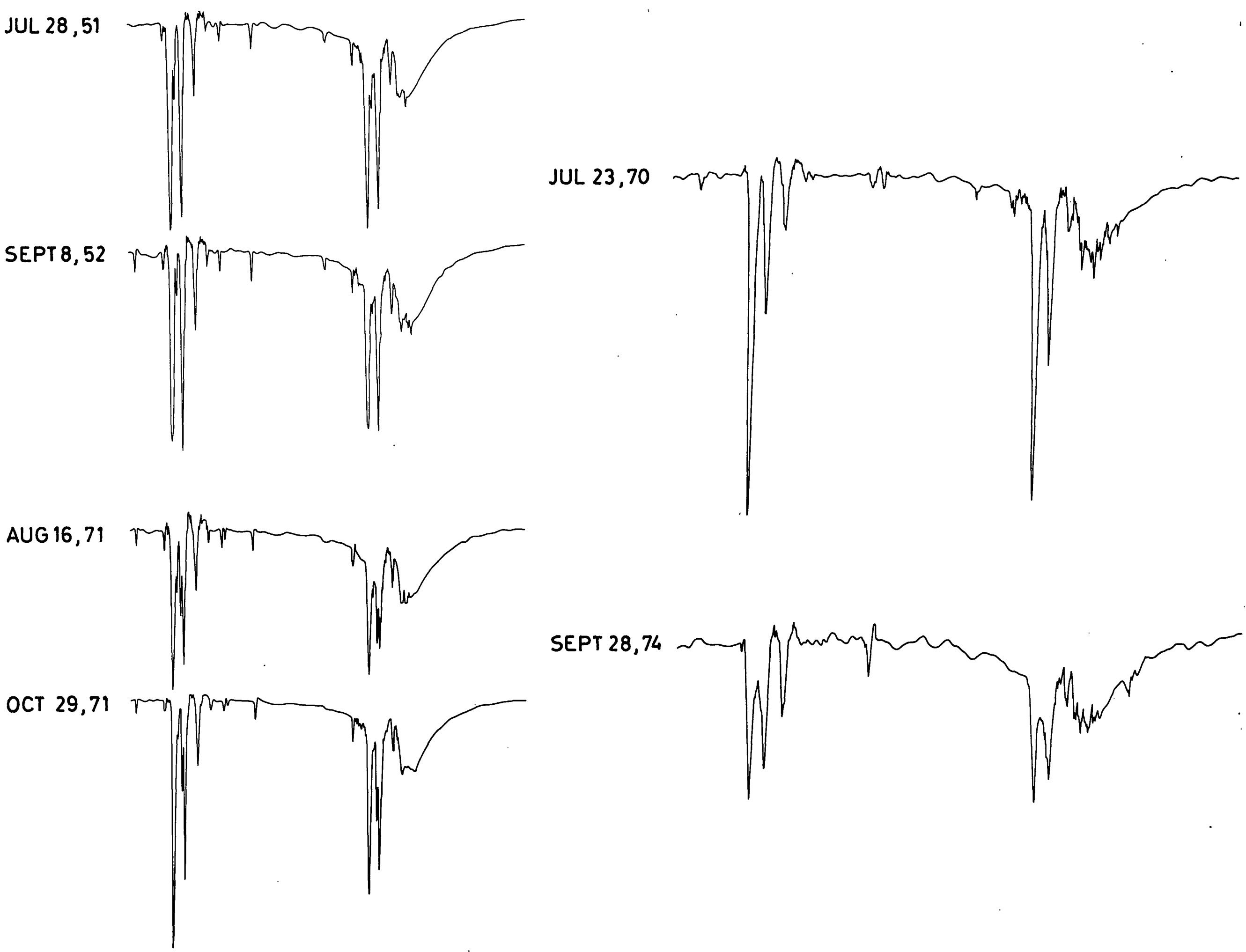

Fig. 4. Density tracings of a heterogeneous sample of plates of Fig. 2 showing dramatic variations in the profiles and intensities of the components of the H- and K-lines

This is easily seen when one considers an intensity tracing of the $H+H_\varepsilon$ blend (see Fig. 1 of paper II).

From Figs. 1 and 2, and from Table 1, it appears that during the entire period of three decades 1943–1974 three distinct groups of absorption components exist for the H- and K-lines, i.e. H_1, K_1; H_2, K_2; H_3, K_3. Furthermore an examination of Table 1 reveals that these groups may be split into subgroups for which there exists a common radial velocity. For H_1 and K_1 there are the emission wings referred to as E^+ and E^- in Table 1; for H_2, K_2 and H_3, K_3 there exist inflexions in the wings of the strong absorptions.

In the rest of this chapter we consider the following subgroups: a_1 for H_1, K_1, i.e. the core of the undisplaced Ca II absorption; a_2, b_2, c_2 for H_2, K_2; a_3, b_3, c_3, d_3 for H_3, K_3. These subgroups are listed and characterized in Table 2, in which the different columns indicate for each subgroup (for either H or K) the mean radial velocity and standard deviation (in km s^{-1}) determined from Table 1; the last two columns give the number of spectra on which each subgroup is present and the number of spectra for which the radial velocity is measured.

On the basis of a 12 spectrum sample Merrill (1951a) reported that the absorption components of the H- and K-lines were distinctly grouped into a lower-velocity (-150, -200 km s^{-1}) and a higher-velocity (-300, -400 km s^{-1}) system. As stated by Scargle (1973): "Merrill noted the remarkable fact that the velocities in the higher-velocity system are, within the measurement uncertainties, precisely twice those in the lower-velocity system. He felt that this result was significant, but was unable to find a satifactory explanation". Scargle's (1973) interest in HD 190073 came mainly from the fact that: "A number of stars, Seyfert galaxies and quasi-stellar objects are ejecting gas at discrete velocities which, in some cases, form arithmetic sequences. This mass loss is probably driven by radiation pressure; the discreteness and ordered velocity structure can be understood as the result of the presence of opacity in closely spaced pairs of lines. The value of the "quantum" of velocity in a number of specific cases predicted by the theory (pure

TABLE I

Radial Velocities of the Blue Shifted Components of the H and K Lines (km s^{-1})
observed in the Spectrum of HD 190073 from 1943 to 1974

Spectrum		E^+	A	E^-	110	140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	290
Nov 13, 43	H	33	-2	45			151			176		200									
(10)	K	97	+1	105			P			177		202						262			
Jul 8, 44	H	34	-1	57			147		174			P									
(10)	K	71	-1	106			P			181		198						261			
Jul 13,46	H	39	-2	44			145			179								258			
(10)	K	109	-2	107			150			184								261			
Sept 15,46	H	39	+4	52		144				181											
(10)	K	141	+2	102			147			185								260			
June 30,47	H	42	+2	45			147			180							246				
(10)	K	79	+3	89			148			181						239		258			
Sept 12,48	H	35	+5	43		141			175												
(10)	K	98	+2	77			147			180											
June 12,49	H	31	+2	55			149			178							252			287	287
(10)	K	86	+2	95			148			177								259		291	291
Aug 6, 49	H	32	+1	> 35			147			180							250				
(10)	K	92	+1	91			155			181								258			
Sept 13,49	H	44	+4	57			145			176				224							
(10)	K	100	-1	83			147			178							255	255			
May 23, 50	H	48	+1	53			146			177											
(10)		90	-2	93			P			183								262			
May 29, 50	H	> 33	+2	48			147			175						238					
(10)	K	106?	0	< 102			147			184								262			
Jul 26,50	H	45	+2	-45		144			175						227						
(10)	K	99	+7	<107		143			173						233		254				
Sept 25,50	H	>33	-3	51			151			182					234				274		
(10)	K	87	-6	>68			151				185									277	
Sept 26,50	H	40	0	43			150			179·					237				274		
(10)	K	93	-2	>69				161			188				236						
Jul 28, 51	H	44	1	36			147			176					230				267		
(10)	K	<104	2	90			149			175									271		
Sept 8, 52	H	33	-2	42			149			178								260			
(10)	K	<109	+5	77			P			178								256			
Jul 23, 70	H	43	-8	67					173												
(20)	K	95	-4	96					171												
Aug 16, 71	H	35	+4	38		146		162				205						255			
(10)	K	100	0	91		P			173				212						265		
Oct 29, 71	H	39	+6	42					169			203						258			
(10)	K	108	+2	75					170				206					255			
Jul 5, 73	H	42	-3	65					169			P									
(20)	K	89	+2	91					175			P									
Jul 8, 73	H	37	≤-14	<35					169	178			207				249		267	281	
(20)	K	<111	<-15	<59					168	180			207			243			P	P	
Sept 28,74	H	44	≤-12	29	110			159		183			207			235					
— (20)	K	86	∿-4	86						177			207								
Sept 28,74	H	∿40	-4	53				160				204				242					
(20)	K	106	-1	88						177		203						258			
Sept 30,74	H	32	1	37		140		P	174					215	233		252				
(20)	K	103	0	69		143		157	173				212				252				

Spectrum		300	310	320	330	340	350	360	370	380	390	400
Nov 13, 43	H			318								
(10)	K		314	325								
Jul 8, 44	H			316		344						
(10)	K			316			348					
Jul 13,46	H	302				338		356			388	
(10)	K	302			335			355			389	
Sept 15,46	H	301		320	332	342		363				
(10)	K			319	334	342		383				
June 30,47	H	303					349					
(10)	K		306				351					
Sept 12,48	H			322				361				399
(10)	K				326			361				400
June 12,49	H				329			362				
(10)	K				329			361				
Aug 6, 49	H	298			326							400
(10)	K	298			329							
Sept 13,49	H			320				362				
(10)	K			321				363				
May 23, 50	H			321								
(10)					329							
May 29, 50	H			322				P				
(10)	K			322				358				
Jul 26,50	H	301		322			348					
(10)	K	P		322			354					
Sept 25,50	H				329							400
(10)	K				335							
Sept 26,50	H	300		321		342		355				
(10)	K	297		325			350					
Jul 28, 51	H				325							
(10)	K				332							
Sept 8, 52	H			320	330							
(10)	K			324		337						
Jul 23, 70	H		307									
(20)	K		312									
Aug 16, 71	H		305									
(10)	K			321								396
Oct 29, 71	H	304						357				
(10)	K	305		316								
Jul 5, 73	H		309									
(20)	K			316								
Jul 8, 73	H		305									
(20)	K		315									
Sept 28,74	H	301										
— (20)	K		315									
Sept 28,74	H		310									
(20)	K		310									
Sept 30,74	H	304				336						
(20)	K		307									

Notes to Table I :

P : the component is present, but not measured.

? : implies caution due to probable uncertainty in the measurement.

The component at −259 km s^{-1} in the K line is actually due to the Fe I line λ 3930.29.

Table 2. Groups and subgroups to which belong the different absorption components of the H and K lines in the spectrum of HD 190073

Group	Line	Subgroup	$\bar{v}$(km s^{-1})	Δv(km s^{-1}) (r.m.s.)	Present	Measured
1	H	a_1	1	4	24	22
1	K	a_1	0	3	24	22
2	H	b_2	146	3	18	18
2	K	b_2	148	4	18	12
2	H	a_2	176	4	23	23
2	K	a_2	178	5	23	23
2	H	c_2	204	2	6	6
2	K	c_2	206	5	6	6
3	H	b_3	303	3	12	12
3	K	b_3	307	6	12	10
3	H	a_3	322	4	14	14
3	K	a_3	323	5	14	14
3	H	c_3	359	4	8	7
3	K	c_3	359	4	8	8
3	H	d_3	397	6	4	4
3	K	d_3	395	8	2	2

Notes: a_1, a_2, a_3 correspond to the core of the three strong absorptions in H and K;
b_2, b_3 correspond to inflexions in the long wavelength wing of a_2 and a_3;
c_2, c_3 / d_2, d_3 } correspond to inflexions in the blue wing of a_2 and a_3.

scattering) is in good agreement with the observations". One can easily see from Table 2 that there indeed seems to exist a 2:1 ratio between the mean radial velocities ($\bar{v}$) of some subgroups, such as

$-b_2$ and b_3;

$-a_2$ and c_3;

$-c_2$ and d_3.

this last ratio being however of very little significance. In our opinion the 2:1 ratio is to be considered only as a statistical result. Indeed the appearance of such a ratio in any one spectrum (see Table 1) is not significant: it appears either occasionally or only for a very limited number of components (see e.g. column 6 of Table 2).

2. *Variations of the Profiles of the* H- *and* K-*Lines.*

Density tracings were obtained for the spectra of Fig. 2. A few of them (normalized with respect to the depth of H_ε) are reproduced in Figs. 3 and 4; they clearly show that the H- and K-profiles vary on time scales going from years (e.g. Jul. 8, 44; Jul. 13, 46; Jul. 23, 70; Sept. 28, 74) to months (e.g. Sept. 13, 49; May 23, 50), days (May 23, 50; May 29, 50) and even hours (several 20 Å/mm plates of Sept. 28, 74 of which only one is given in Fig. 4).

The emission wings and the absorption of the first component (H_1, K_1) vary as well as the other components. This indicates that the extended atmosphere surrounding HD 190073 in which the emission lines are taking place suffers strong variations. The latter, which are observed not only in H and K, but also in the Balmer lines, are important in explaining the profiles of the components H_2, K_2 and H_3, K_3 of the Ca II lines, as will be demonstrated in Paper II.

A qualitative study of the profiles of the Balmer lines H_γ and H_δ was performed for all the spectra on which the Ca II H- and K-lines were analyzed. Figure 5 reproduces portions of the spectra around H_γ, aligned with respect to the Fe II emission line with central absorption λ 4351.76 Å. It shows that the complex structure of H_γ consists essentially of a broad (up to

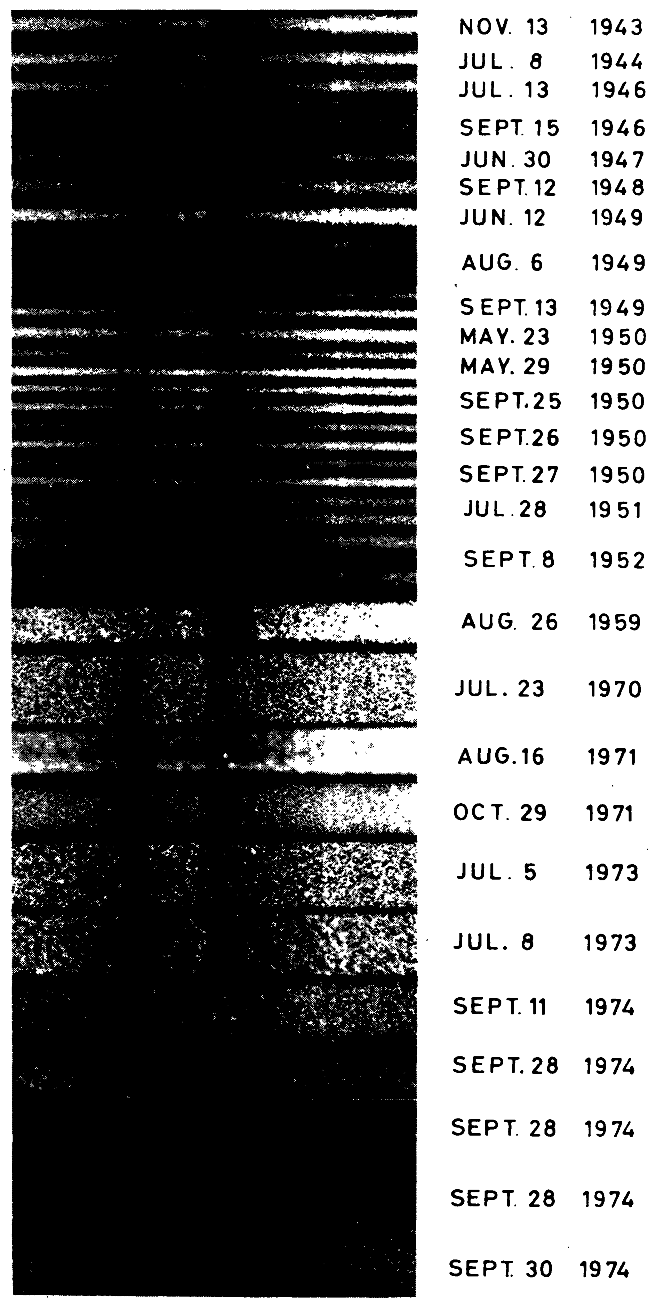

Fig. 5. H_γ in the spectrum of HD 190073 between 1943 and 1974. Same plates as for Fig. 2

Table 3. Stars with infrared excess whose spectrum reveals P Cygni profiles of the Balmer lines and complex structure of the Ca II lines

Star	Sp. Type	Vis. mag.	I.R. excess $1.6\mu - 2.2\mu$	Ca II lines	Notes and reference
AB Aur	B9q	7.0	0.90(1)	Variable	
HD 31648	A2q	7.7	0.66(1)	2 comp. on Sept. 28, 1974 variable	
HD 45677	B2 IV ep	8.5	1.87(1)	variable	(2)
U Mon	F8 – K0	8.5 – 6.8	4.0(3)	2 comp. in Jan. 1963 1 comp. in Oct. 1971	(4)
HD 87643	Bep	8.5	1.17(1)	2 comp.	
GG Car	Bep	8.8	1.03(1)	2 comp.	
CD-52°9243	Be	9.3	1.29(1)	2 diff. comp.	
XX Oph	Symb	~10	0.46(5)	variable	see Paper II
HD 190073	A0 ep	7.9	0.79(1)	several comp. variable	
V 1057 Cyg	var	$\leqq 10$, var	0.44(1)	{ several comp. variable	
HD 200775	Be	$\simeq$ 7	0.86(1)	2 comp. in Sept. 1974	

(1) Allen, D. A. 1973, *Monthly Notices Roy. Astron. Soc.* **161**, 145
(2) see Swings, J. P. 1973, *Astron. & Astrophys.* **26**, 443
(3) color index: $L(3.5\,\mu) - O(11.0\,\mu) = 4.0$ from Gehrz, R. D., Woolf, N. J. 1970, *Astrophys. J. Letters* **161**, L 213
(4) Preston, G. W. 1972, *Astrophys. J. Letters* **172**, L 105
(5) Swings, J. P., Allen, D. A. 1972, *Publ. Astron. Soc. Pacific* **84**, 523

60 Å) shallow absorption on which are superimposed emission and absorption components (sometimes multipe and complex), the former located mainly near rest wavelength whereas the latter is blue shifted. A comparative examination of the profiles of H_γ and H_δ and of the Ca II H- and K-lines leads to the following correlations:

(i) A fusion between K_2 and K_3 tends to appear when the blue shifted absorption component in H_γ and H_δ is strong and wide (see e.g. spectra of Sept. 28, 1974 in Figs. 4 and 5).

(ii) $K_3(H_3)$ is stronger than $K_2(H_2)$ when a distinct blueshifted emission is present in the hydrogen lines H_γ and H_δ (see e.g. spectra of June 12, 1949 in Figs. 4 and 5).

These correlations are explained by the mechanism proposed in Paper II.

D. Stars Exhibiting Similarities to HD 190073

A non exhaustive list of stars whose spectra reveal P Cygni profiles of the Balmer lines and a complex and/or variable structure of Ca II H- and K-lines, as well as an excess of continuous radiation beyond 1 micron is given in Table 3. To that list should be added the two symbiotic stars AG Pegasi and Z Andromedae for which the profile of the He I line λ 3888 is variable as is the underlying Balmer line H_8.

Contrary to the stars of Table 3, Be stars without infrared excess, without apparent P Cygni profile of H_ε do not have discrete absorption components of the Ca II H- and K-lines. This was checked on the basis of 10 Å/mm plates obtained at Mt Wilson in 1971–72 of the following Be stars: HD 83953, HD 85860, HD 86612, HD 89884, HD 91120.

It appears from Table 3 that the profile of the Balmer lines modulates that of other lines of about the same wavelengths (Ca II (H) and H_ε; He I 3888 and H_8...). This will be explained as in the case of HD 190073 by selective radiative forces acting on the atoms considered. There further seems to exist a correlation between the presence of an infrared excess and the fact that atoms are ejected from the central star; such ejections of atoms can naturally lead to the formation of circumstellar envelopes in which dust grains form.

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