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HYPERGIANT 6 CAS AND ASSOCIATION CAS OB5

R.A.BARTAYA[1], K.B.CHARGEISHVILI[1],
E.L.CHENTSOV[2], Z.U.SHKHAGOSHEVA[2]
[1]Abastumani Astrophysical Observatory of the Georgian AS,
Abastumani, mt. Kanobili 383762, Georgia
[2]Special Astrophysical Observatory of the Russian AS,
Nizhnij Arkhyz 357147, Russia

ABSTRACT. *On the basis of the spectrograms obtained with the main stellar spectrograph of the 6 m telescope quantitative spectral classification is performed, distances are specified, and radial velocities for 21 stars in the region of the association Cas OB5 are found. The mean velocity of the members of the association (-44.5 km/s) falls within the interval of time velocity variations of the lowest atmospheric layers of the white hypergiant 6 Cas (-41 to -50 km/s). The oscillating character of the motion at the base of the stellar wind of 6 Cas is thus established. Pulsation of the atmosphere of the supergiant HD 223960 is revealed, a new Wolf-Rayet type star is found, and two stars are suspected to be spectral binaries.*

INTRODUCTION

The purpose of the study is to estimate the mass centre radial velocity of the hypergiant 6 Cas A2.5Ia$^+$ (which belongs to the association Cas OB5), on the basis of stars composing this association. We have already attempted to do this from the visual satellite of 6 Cas (Barsukova, Chentsov, 1990). The satellite more accurately represents the motion of the primary object (6 Cas A), but is only 1.6″ distant from it, and is less bright by the order of $2\overset{m}{.}5$. The task was also complicated by the fact that 6 Cas B turned out to be a binary. However, let us note that the high surface temperature of 6 Cas B (spectral class O9.8) supports hopes of detecting, in time, weak forbidden emissions from the envelope formed by the wind 6 Cas A.

The association Cas OB5 is located on the inner edge of the Perseus arm. A number of investigations (Ampel, 1969; Haug, 1970; Martin, 1972 and others) revealed in its direction condensations of stars at distances 1.7, 2.5 and 3.4 kpc. We will display interest in the second of them, Cas Va by Ampel (1969), containing 6 Cas. The association falls within the zone of the known kinematic anomaly (Humphreys, 1976; Gerasimenko, 1983), and is close in both location and age to the recently discovered epicentre of the explosion which resulted in a gigantic expanding envelope (Verschuur, 1992). All this supports the conclusion that for our purpose the stars closest both spatially and kinematically to 6 Cas are most suitable.

SELECTION OF OBJECTS

The first, surplus list of the main sequence stars through B3 and supergiants no later than A5 with $V \leqslant 11^{m}.5$, $112^{\circ}.5 < L < 119^{\circ}.5$ and $-2^{\circ} < b < +1^{\circ}.5$, removed from the Sun by more than 1 kpc, was made up on the basis of the electrophotometry by Haug (1970) and spectral classification by Ampel (1969). To specify the distances, in particular for the reliable separation of the foreground, two-dimensional classification was performed. It covered 243 stars in a circular field of $4^{\circ}.5$ in diameter with the centre in 6 Cas. The 70-cm meniscus telescope of the Abastumani Astrophysical Observatory, with an 8° objective prism (dispersion 160 Å/mm in H_{γ}) and Kodak IIaO and IIIaJ plates, was used for the purpose. The spectra were broadened to 0.4 mm.

The location of stars in the plane of the sky is displayed in Fig. 1a. Absorption in the region of association is large, especially in the western part, which overlaps with a dust nebula raising the value of Av to 4^{m}-5^{m}, even at the distance of 1 kpc. The upper limits of this quantity in and outside the nebula are outlined in Fig. 1b with the solid and dashed lines, respectively. As is shown in Fig. 1c the greater part of bright hot stars are located in the interval between galactic longitudes 113° and 117°. The distribution of these stars with depth is presented in Fig. 8. Its main maximum corresponds to 2.3 - 2.5 kpc.

Since the choice of objects for spectroscopic study in the centre of the association is strongly limited by interstellar absorption several stars were also taken from its eastern part. The total number of selected stars was 21. They are shown with circles in Fig. 1a. The first three columns of Table 1 contain their HD or BD numbers, galactic coordinates and B magnitudes.

OBSERVATIONAL DATA AND PROCESSING

Spectrograms obtained with the help of the Main Stellar Spectrograph of the 6 m telescope on Kodak IIaO and 103aF plates were accumlated for seven years (as can be seen in column 7 of Table 1). During this time only the type of gas which filled the hollow cathode lamps was changed (Ne, Ar, or their mixture with Xe). All the observing procedures remained unchanged and did not differ from those used for the spectroscopy of 6 Cas (Sokolov, Chentsov, 1987). In particular the positional instability of the spectrograph was controlled and corrected by obtaining of 2 or 3 of the comparison spectrum during the exposure. Reciprocal linear dispersions of 9, 14 and 28 Å/mm were used (column 8 of Table 1). The latter, with the broadening of the spectra up to 0.6 mm, allowed us to include stars up $B=10^m$ in the program.

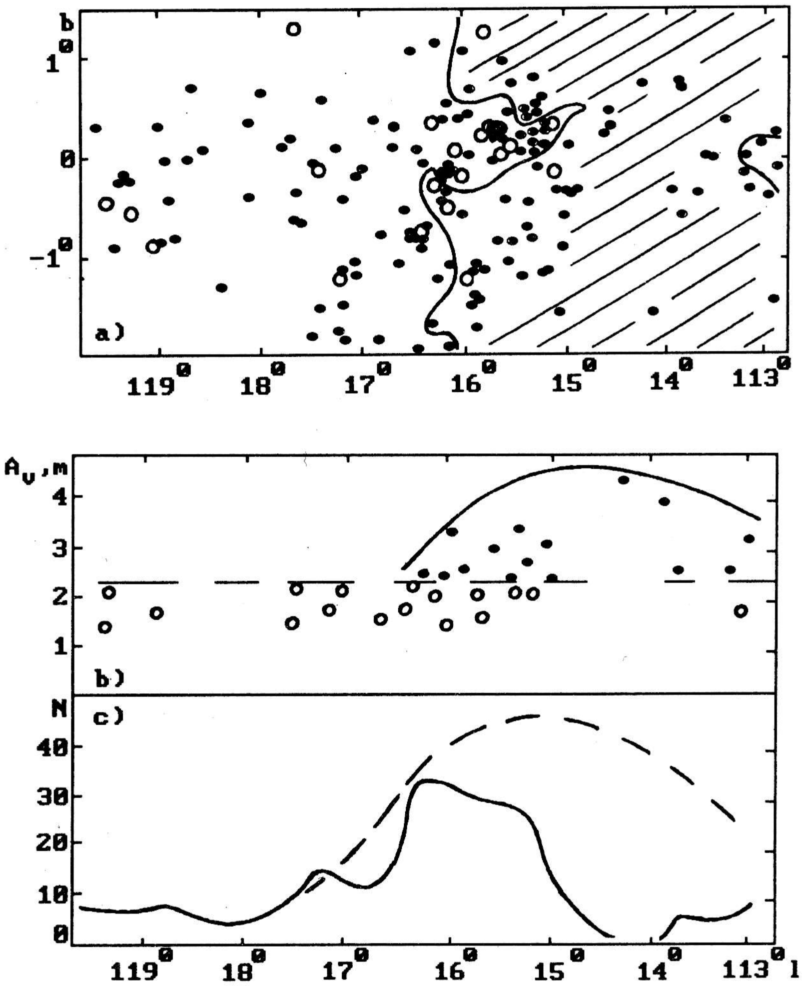


Fig.1.a) *Distribution of early spectral class stars at a distance of more than 1 kpc in the region of the association Cas OB 5. The dust nebula is separated. The dots are the stars from the preliminary list, lacking in the final list, open circles are the objects of spectroscopic study, filled circle is 6 Cas.* b) *Absorption within the boundaries of the nebula (dots) and outside of them (circles).* c) *Galactic longitude distribution of the number of stars for every 0°.5. The dashed line is the supposed profile of Cas OB 5.*

The photometric processing of spectrograms was executed with the automatic microdensitometer AMD-1: the results are presented graphically as $r(\lambda)$. In Fig. 2 the graphs for 8 giants and supergiants of spectral classes from O8 to B3 are collected. For the measurement, reduction and radial velocity determination we also used the traditional oscilloscopic comparator, the breaking up of spectra into several working portions, and the systems of effective wavelengths which allowed for blends, dispersion but preserved kinematic differential shifts of lines (Aab & Chentsov, 1989; Dobrichev et al., 1986).

Table 1. Spectral classes, absolute values, distances and radial velocities.

1 star	2 l (1950)	b (1950)	3 m_B	4 Sp	5 M_v	6 r, kpc	7 Date	8 D, Å/mm	9 V_r, km/s st.	10 V_r, km/s IS
60°2615*	115°.1	-0°.1	9^m.7	B0.2±0.3	-6^m.0±0^m.2	3.0±0.3	4.02.83	28	-57±3	-24
61°2509*	115.2	0.3	8.9	B0.2±0.2	-5.2±0.2	1.8±0.3	30.11.82	9	-45±3	-45:,-1
							15.09.83	28	-89±4	-22.
							18.09.83	9	-40±3	-47:,-2
61°2526	115.5	0.1	9.1	B1.5±0.1	-4.6±0.2	1.9±0.2	3.02.83	28		
									-47±2	-37±2
							15.10.87	28		
61°2529	115.6	0.0	9.2	B1.1±0.2	-6.0±0.2	2.6±0.3	3.02.83	28		
									-46±3	-27±2
							30.11.87	28		
61°2531*	115.7	0.3	9.8	B1.2±0.2	-4.9±0.3	2.7±0.3	3.02.83	28	-61:	-29
6 Cas A*	115.7	0.3	6.1	A2.5	-8.5	2.3				-23
6 Cas B*	115.7	0.2	8.3	O9.8	-5.8	2.3			-45:	
62°2296A*	115.8	1.2	9.7	B3.2±0.2	-7.0±0.2	2.2±0.3	4.02.83	28		
									-53±2	-45±3
							14.10.87	28		
62°2296B*	115.8	1.2	11:	WN4			14.10.87	28		
223501*	115.8	0.2	7.8	B2.3ne	-3.5:	1.2	15.09.82	9		
									-30:	-8±2
							3.02.83	28		
223960*	116.0	1.2	7.6	A0.1±0.2	-7.3±0.2	2.5±0.3	12.07.82	9	-55±1	
							14.09.82	9,14	-54.5±1	-28±0.5
							1.12.82	9	-54±1.5	
							14.01.84	9,14	-52.5±1	-33±2
							2.12.87	9	-56.5±1.5	
223767*	116.0	-0.2	7.9	A3.9±0.3	-5.4±0.2	1.3±0.2	16.11.80	9		
							17.01.81	9	-39.5±0.7	
							19.10.81	9		
61°2550	116.1	0.0	9.6	B0.7±0.4	-4.8±0.2	2.7±0.2	3.02.83	28		
									-49±2	-31±2
							1.12.87	28		
223987*	116.2	-0.5	8.1	B1.3±0.1	-5.9±0.2	1.8±0.2	3.09.80	28		-32
									-44.5±1.5	
							20.01.81	9		-53:,-9
61°2559	116.3	0.3	10.0	O9.3±0.2	-4.9±0.2	3.3±0.3	4.02.83	28	-59±3	-24
224055	116.3	-0.3	7.9	B2.9±0.2	-6.9±0.2	1.8±0.2	12.07.82	9	-44.1±0.7	-48:,-1
60°2644*	116.4	-0.8	9.9	B1.8±0.4	-3.8±0.3	2.2±0.3	19.09.83	28	-59±3	-31
225146	117.2	-1.2	9.0	O9.8±0.3	-5.7±0.3	2.7±0.3	2.02.83	9	-43±1.5	-16±2
225160	117.4	-0.1	8.5	O7.9±0.2	-6.1±0.3	3.0±0.3	30.11.82	9	-44-2	-16
							1.12.87	28		-26
225094*	117°.6	1°.3	6.5	B2.9-0.1	-6.8-0.2	2.2-0.2	2.06.83	9	-25±2	-13
							19.09.83	9	-48±1.5	-16
1383*	119.0	-0.9	7.9	B0.9±0.5	-5.3±0.1	2.3±0.2	2.06.83	9		-37:,-12.5
									-42±2	
							19.09.83	9		-35:,-1
1544	119.3	-0.6	8.3	B0.3±0.2	-5.2±0.2	2.4±0.3	14.09.83	9	-56	-50:,-1
1743*	119.5	-0.5	8.5	B0.2±0.2	-4.7±0.2	2.1±0.2	15.09.83	28	-38±3	-20
							17.09.83	9	-106±2	-60:,-1

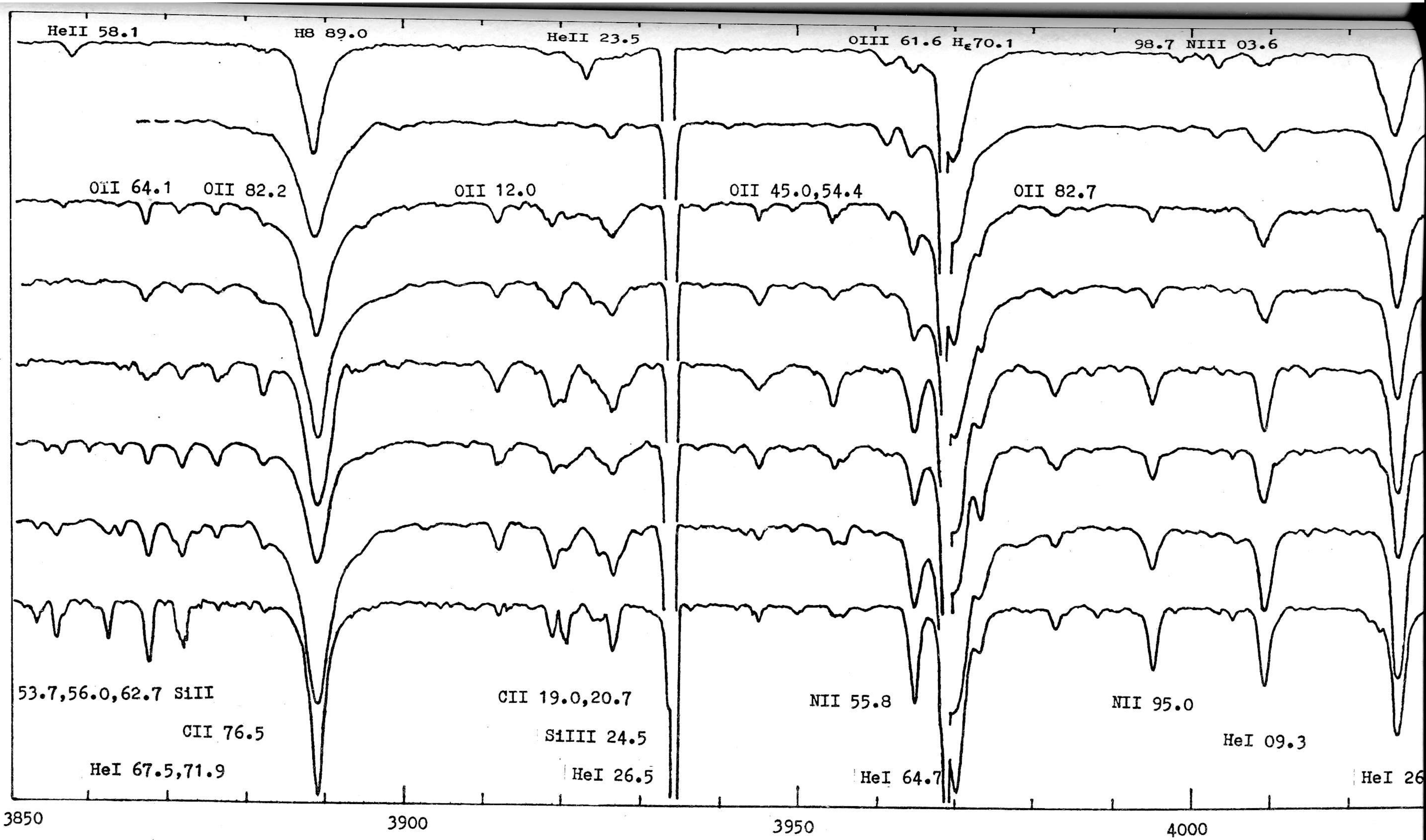
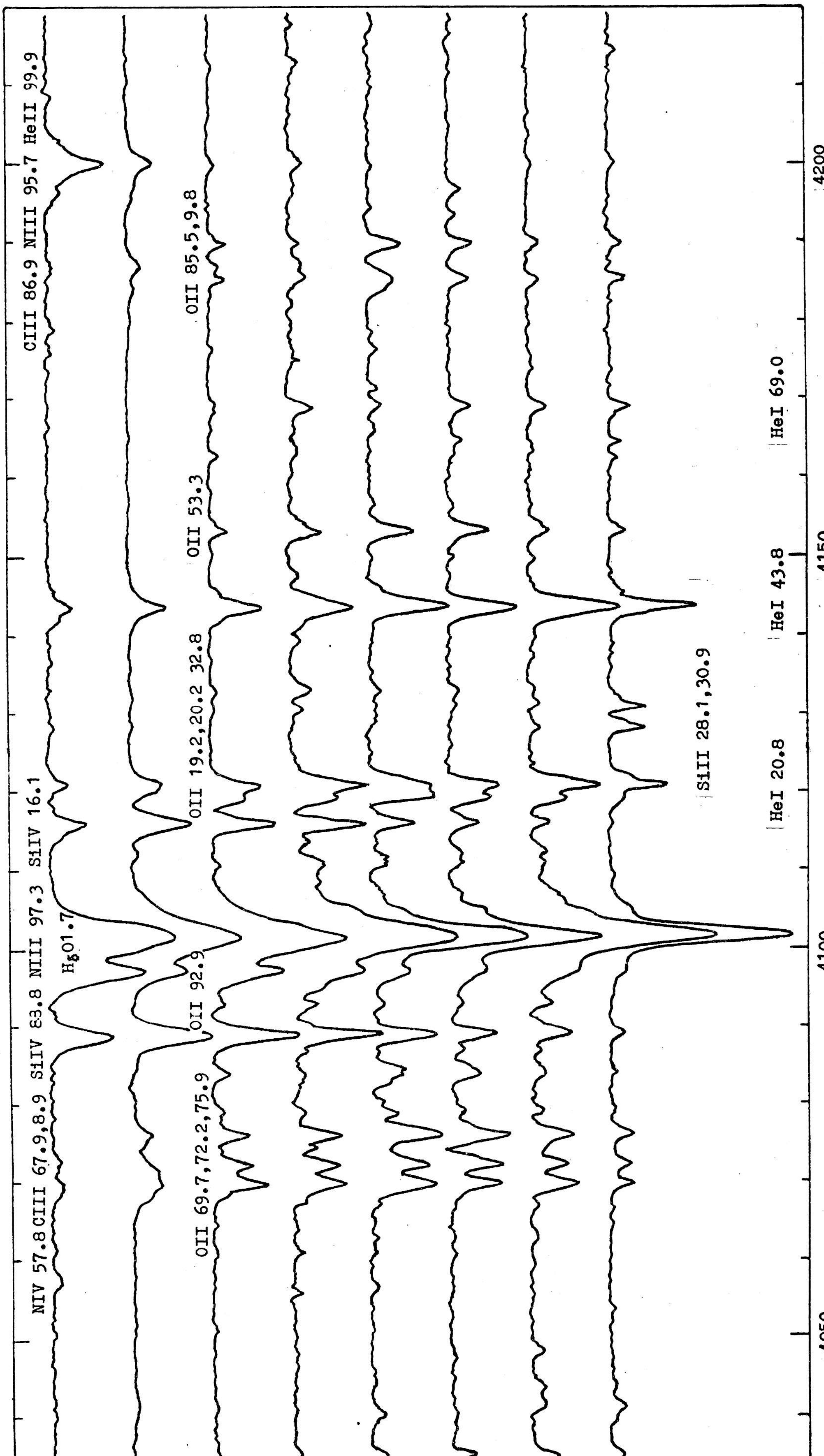


Fig. 2. *Dependences r(λ) for some stars of Cas OB 5 from O8 to B3 from top to bottom: HD 225160 O7.9 Ib, 6 Cas B09.8 II, 61°2509 B0.2 II, HD 1743 B0.2 III, 61°2529 B1.1 Ib, HD 223987 B1.3 Ib, 61°2526 B1.5 II, HD 225094 B2.9 Iab. The spectra are shifted along the r-axis by 0.2. The dots mark OII lines.*


NIV 57.8 CIII 67.9,8.9 SiIV 83.8 NIII 97.3 SiIV 16.1
CIII 86.9 NIII 95.7 HeII 99.9
Hδ 01.7
OII 69.7,72.2,75.9
OII 92.9
OII 19.2,20.2 32.8
OII 53.3
OII 85.5,9.8
SiII 28.1,30.9
HeI 20.8
HeI 43.8
HeI 69.0
4050
4100
4150
4200

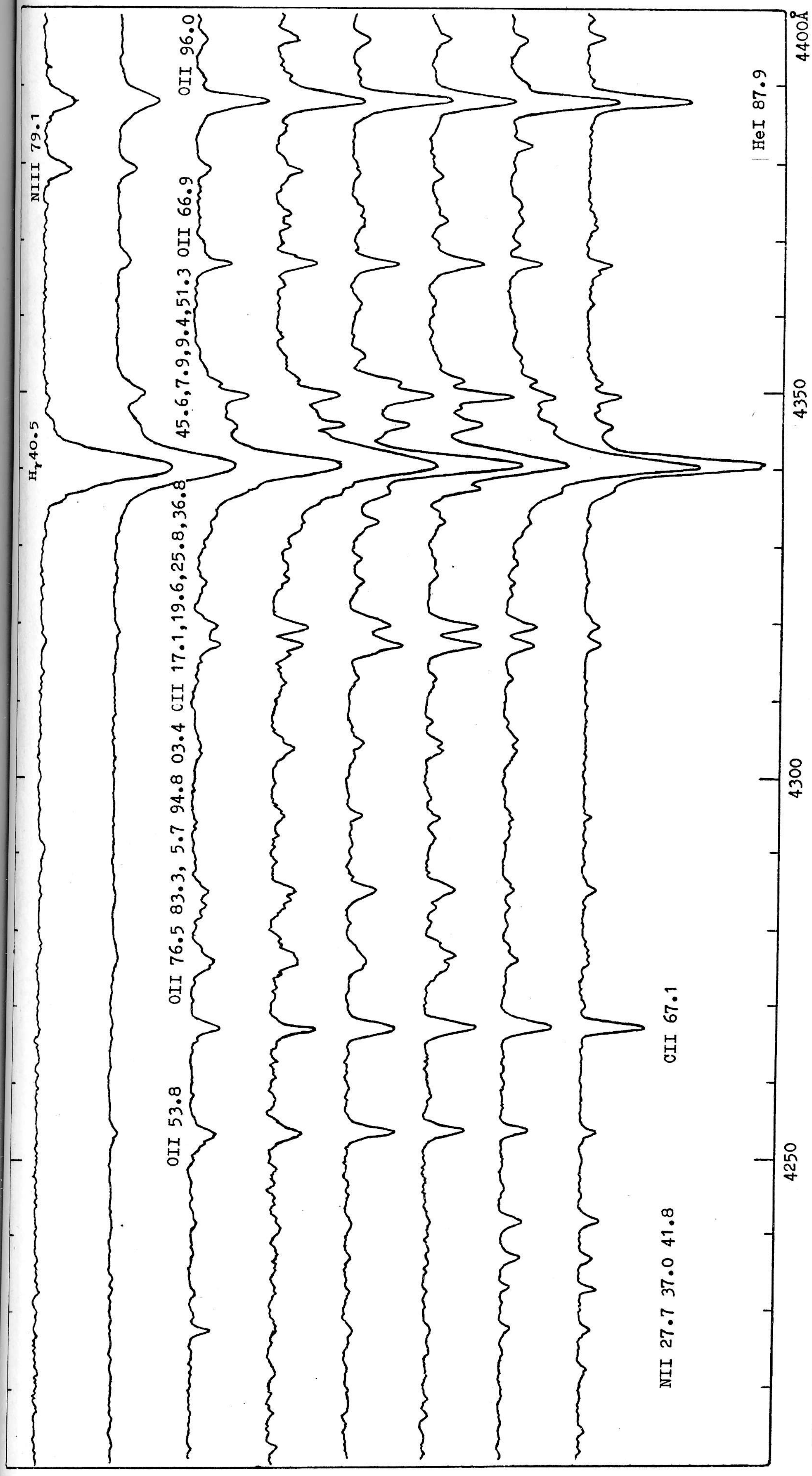
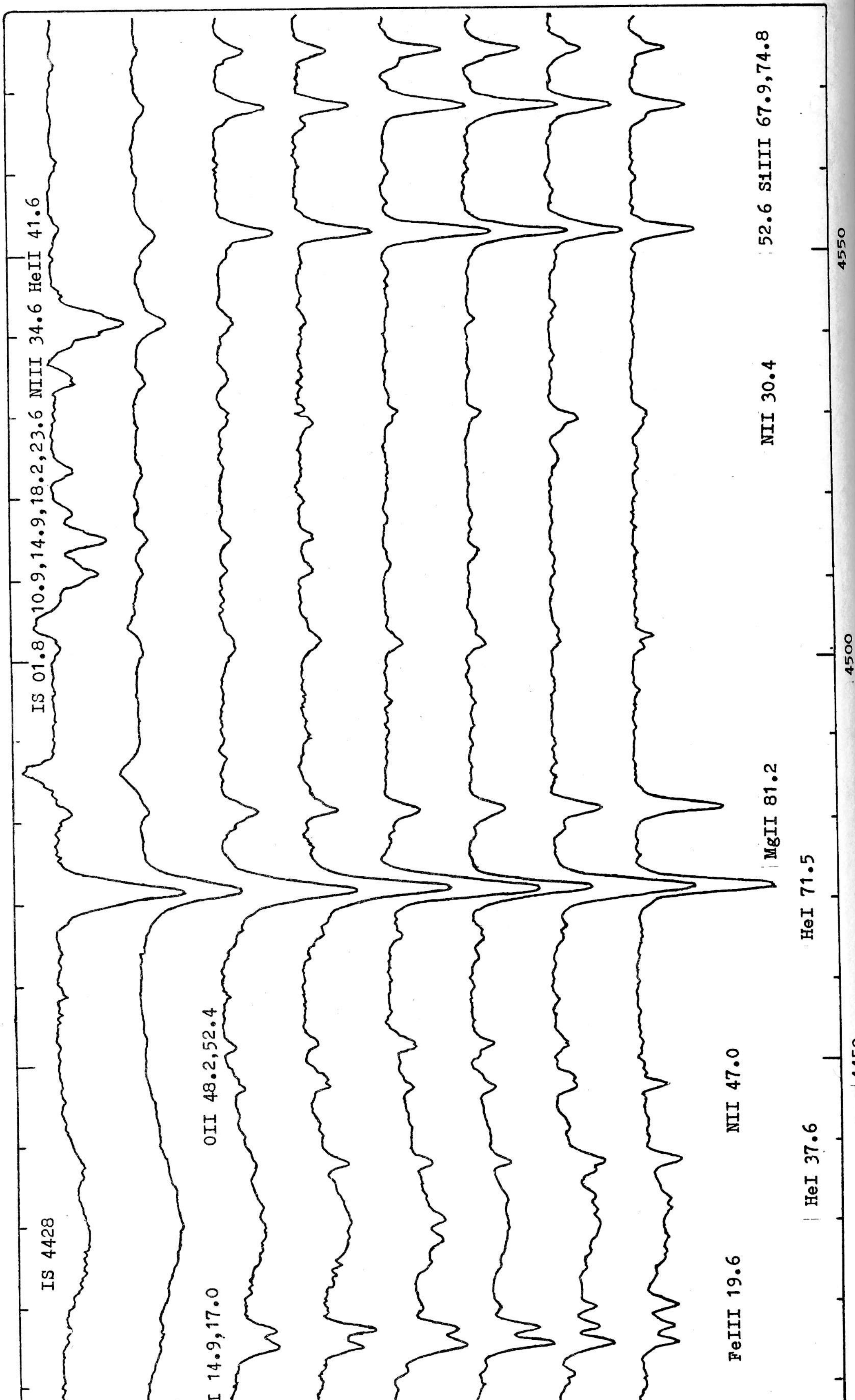

NII 27.7 37.0 41.8
OII 53.8
CII 67.1
OII 76.5 83.3, 5.7 94.8 03.4 CII 17.1,19.6,25.8,36.8
Hγ 40.5
45.6,7.9,9.4,51.3 OII 66.9
NIII 79.1
HeI 87.9
OII 96.0
4250
4300
4350
4400Å

Fig. 2.


IS 01.8 10.9,14.9,18.2,23.6 NIII 34.6 HeII 41.6
IS 4428
OII 48.2,52.4
OII 14.9,17.0
96.0
FeIII 19.6
NII 47.0
HeI 37.6
HeI 71.5
MgII 81.2
NII 30.4
52.6 SiIII 67.9,74.8
4400
4450
4500
4550

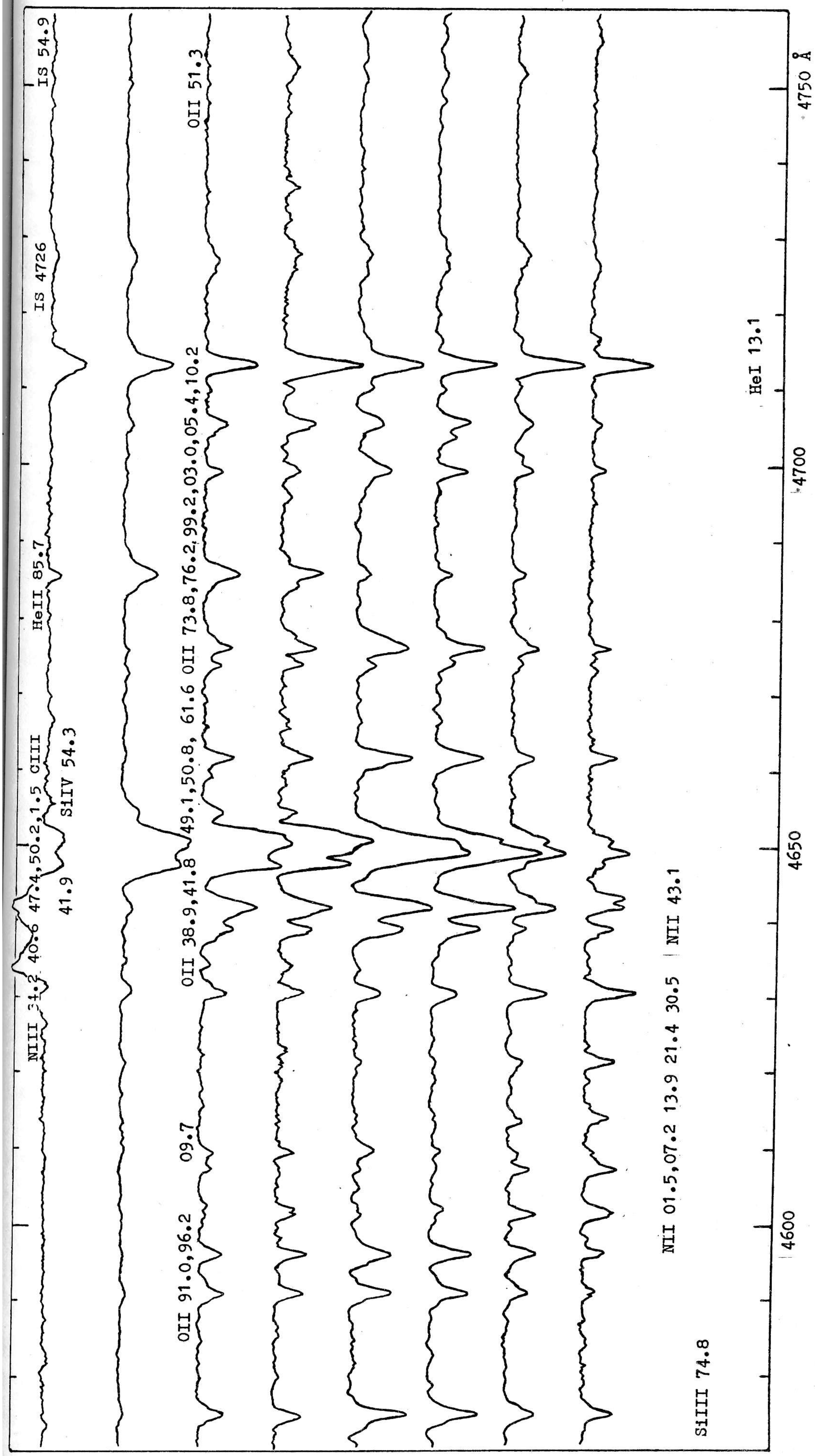
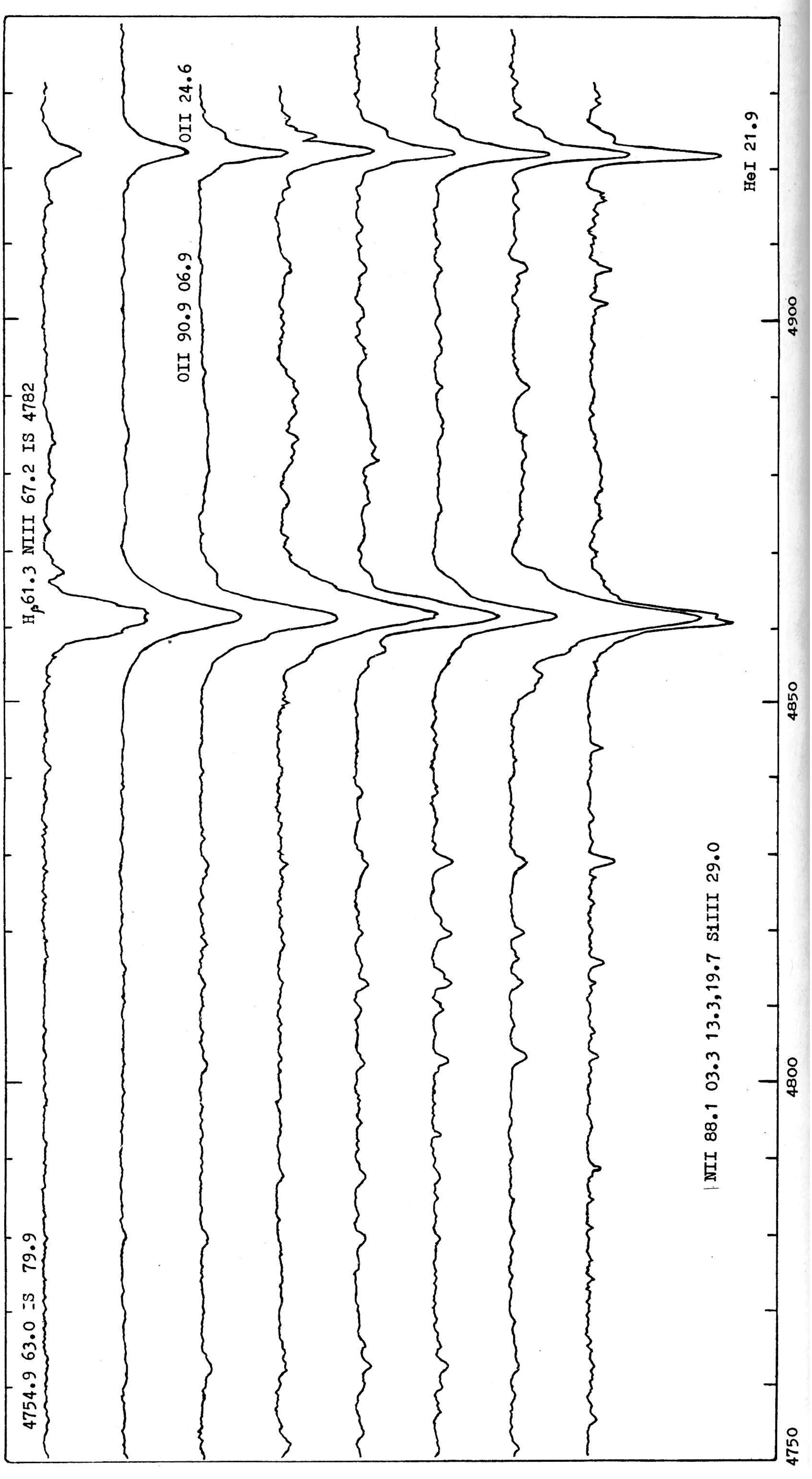

NIII 34.2 40.6 47.4,50.2,1.5 CIII
41.9 SiIV 54.3
HeII 85.7
IS 4726
IS 54.9
OII 91.0,96.2 09.7
OII 38.9,41.8 49.1,50.8, 61.6 OII 73.8,76.2,99.2,03.0,05.4,10.2
OII 51.3
SiIII 74.8
NII 01.5,07.2 13.9 21.4 30.5
NII 43.1
HeI 13.1
4600
4650
4700
4750 Å

Fig.2.


4754.9 63.0 IS 79.9
H_β 61.3 NIII 67.2 IS 4782
OII 90.9 06.9
OII 24.6
HeI 21.9
NII 88.1 03.3 13.3,19.7 SiIII 29.0
4750
4800
4850
4900

SPECTRAL CLASSIFICATION

Spectral classes and absolute magnitudes with their determination errors are tabulated in Table 1, columns 4 and 5, respectively. Appropriate equivalent widths were averaged over several graphs r(λ) for one star, and also over several lines of one element at a specific stage of ionization. The errors of photometric calibration were reduced by the use of equivalent width ratios. The basic system of equivalent widths was made available by I.M. Kopylov. The empirical classification criteria were also close to those developed by Kopylov et al.(1989). For the control and evaluation of errors the data of Conti and Alschuler (1971), and Didelon (1982), were drawn.

The distances found on the basis of our classification are listed in column 6 of Table 1. When estimating them the intrinsic colours by Straizis and Kuriliene (1981) were used. The colours of stars were also taken into account when calculating the transition coefficient from absorption to total. The latter were found by Straizis (1977) and were, on average, close to 3.3.

RADIAL VELOCITIES

The values of Vr presented in column 9 of Table 1 have been obtained from stellar lines, in column 10 from interstellar lines. For one star 15 to 40 lines were involved, among them the lines of the Balmer series from H_β through H_δ at a dispersion of 9 Å/mm, and through H_{14} at a dispersion of 28 Å/mm. For OB stars the lines of HeI, II; NII, III; OII; SiIII, IV, and for A stars SiII, MgII, FeII etc., were also used. In the cases where differential shifts were observed the velocities of the deepest atmospheric layers were included in the table. All the observed radial velocity variations with time can also be found in the table. If two or more spectrograms obtained on different nights gave differences in V_r close to measurement errors, their mean values were then included in the table.

The interstellar lines in the region under investigation are peculiar due to their rather complex structure. They have two main components: a long-wave component belonging to the local spiral arm and a short wave component formed in the Perseus arm (Munch, 1957). Their intensities depend on the localization of a star, especially so for the short-wave component. Therefore the radial velocities found mainly from CaII lines and listed in column 10 of Table 1 are more sensitive to dispersion, as compared to "stellar", and, unfortunately, unsuitable as an additional distance indicator. They can be used for controlling the spectrograph's stability, but only in the case where a series of spectrograms for one star obtained at one dispersion is available.

61°2509. Illustration of the role of dispersion in the variation of V_r (I S): the components, resolvable at 9 Å/mm, blend at 28 Å/mm, and the line position is determined by the stronger long-wave component. For 9 dates Abt et al. (1972) obtained $-56<V_r<-33$ km/s at the mean value of -44.8 ± 1.4 km/s. From our data one can suspect that the star is a spectral binary.

6 Cas A. V_r(IS) - from the unresolvable lines of NaI (CaII lines have stellar components).

6 Cas B. A spectral binary. Data are as yet insufficient for plotting the curve of V_r (φ). The result of formal averaging of the radial velocities over 9 dates is presented.

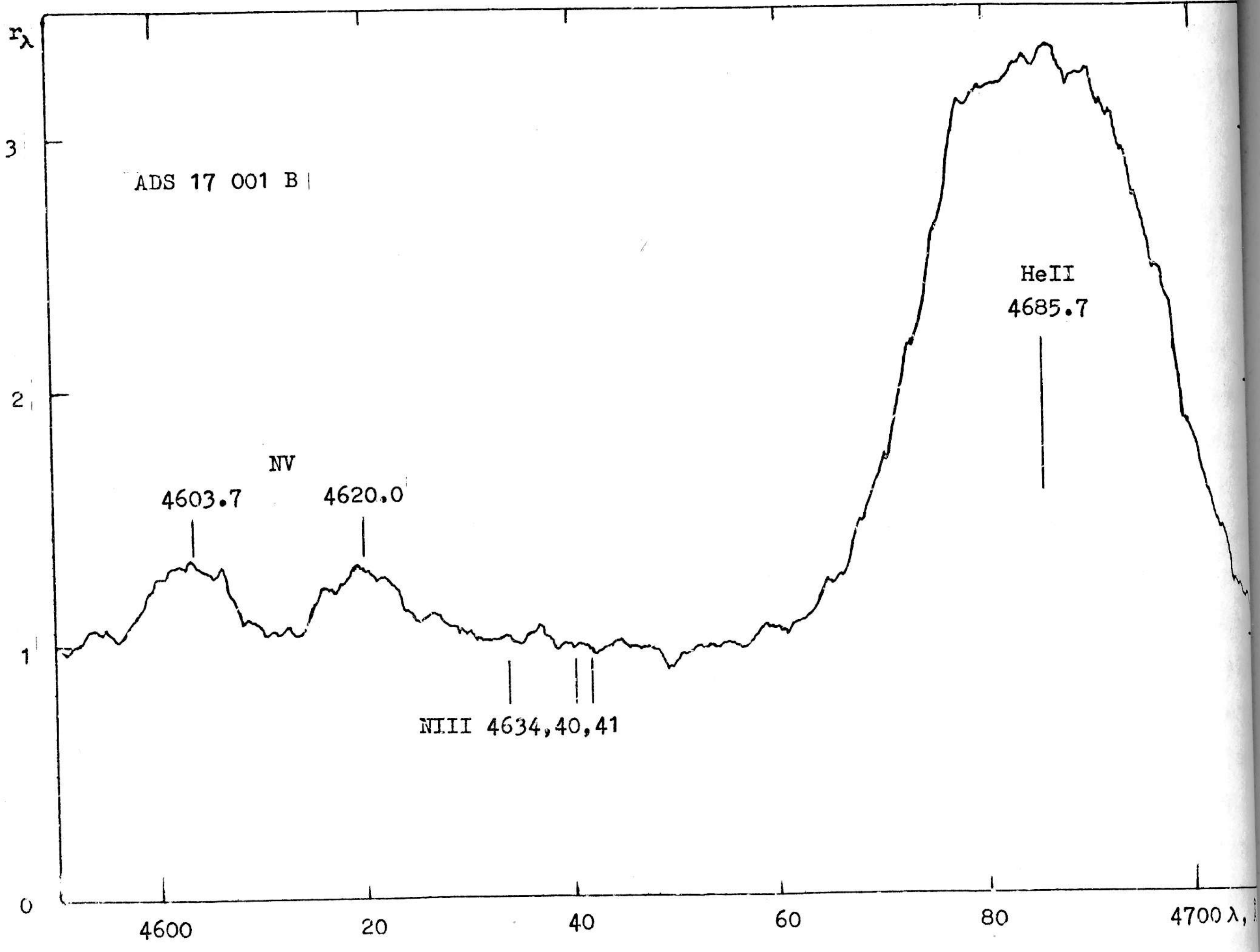


Fig. 3. *A fragment of spectrum of nitrogen Wolf-Rayet star 62°2296B=ADS17001B.*

62°2296 A. Expansion of the atmosphere is evident: the Balmer progress, negative shifts of H_β, HeI 4471 and MgII 4481 are about 10 km/s. Abt et al. (1972) found V_r to vary from -50 to -68 km/s.

62°2296 B. Together with 62°2296 A is a member of the multiple system ADS 17001;

it is fainter by 2^m than the A component and is 1.7″ apart from it. The fragment of graph r(λ) presented in Fig.3 is free from the 40% contribution of the A component. Also present in the spectra are weak emissions of NIV 4058 and HeII 4511. The relation between the emission intensities points to the early subtype of the nitrogen branch of Wolf-Rayet stars. The fact that it belongs to the type WN was established firstly from the slitless prism spectra.

HD 223501. It is the only case when V_r(IS) does not depend on dispersion: blue-shifted component is absent and the star belongs to the local arm.

HD 223960. As for 6 Cas A, V_r (IS) have been measured from the lines of NaI. Additional values are given by dust bands: -13±1 km/s. The mean V_r=-54±0.7 km/s. Fig. 4a shows the kinematic sections of atmospheric layers accessible to observations. The optical depths have been taken from the paper by Zvereva et al.(1984) which was devoted to supergiants of a close spectral class. The character of oscillating motions also turned out similar: their amplitude increases outward, and the Balmer progress is replaced by the regress. Fig. 4b shows how the H_α and H_β profile shapes changes with it.

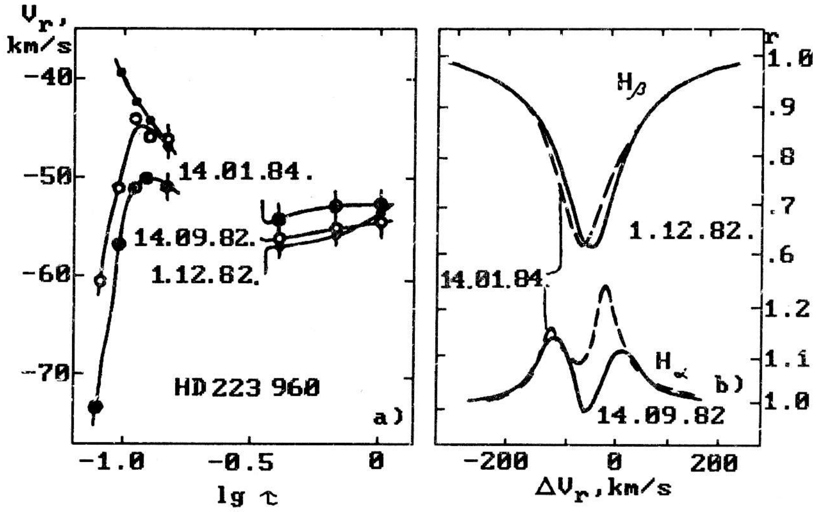


Fig. 4. *Kinematic sections through the atmosphere of HD 223960 A0.1a* **(a)** *and profile variations corresponding to them* **(b)**.

HD 223767. The latest star of our program. By the velocity, distance estimate and position on the spectrum-magnitude diagram it is positioned both outside the association and closer to us.

HD 223987. A nitrogen-defficient star (Fig. 5).

60°2644. No.1 star in the cluster NGC 7788 (Becker, 1965). The distance to the cluster, according to the colour-magnitude diagram, is 2.4 kpc.

HD 225094. Despite varying radial velocity from date to date spectral binarity is doubtful. As can be seen from Fig. 6b the increase of V_r (02.06.83) in comparison with V_r (12.09.83) is due to the displacement of the red wings of the absorptions, possibly even with a slight splitting of the latter. The blue wings remain undisplaced. From the blue minima V_r (02.06.83)≈-42 km/s.

HD 1383. A double-spectrum spectral-binary by Hill and Fisher (1986). The equivalent widths of the components of the splitted lines (therefore the spectral classes and luminosities of stars) coincide within the errors. From our data the intensities of the components are markedly different (Fig.6a) which increases the uncertainty about the main spectral class estimate. The distance is corrected for its binarity. For V_r(st) we present the γ-velocity in our velocity system.

HD 1743. The spectral binarity suspected by Sanford and Merrill (1938) is corroborated.

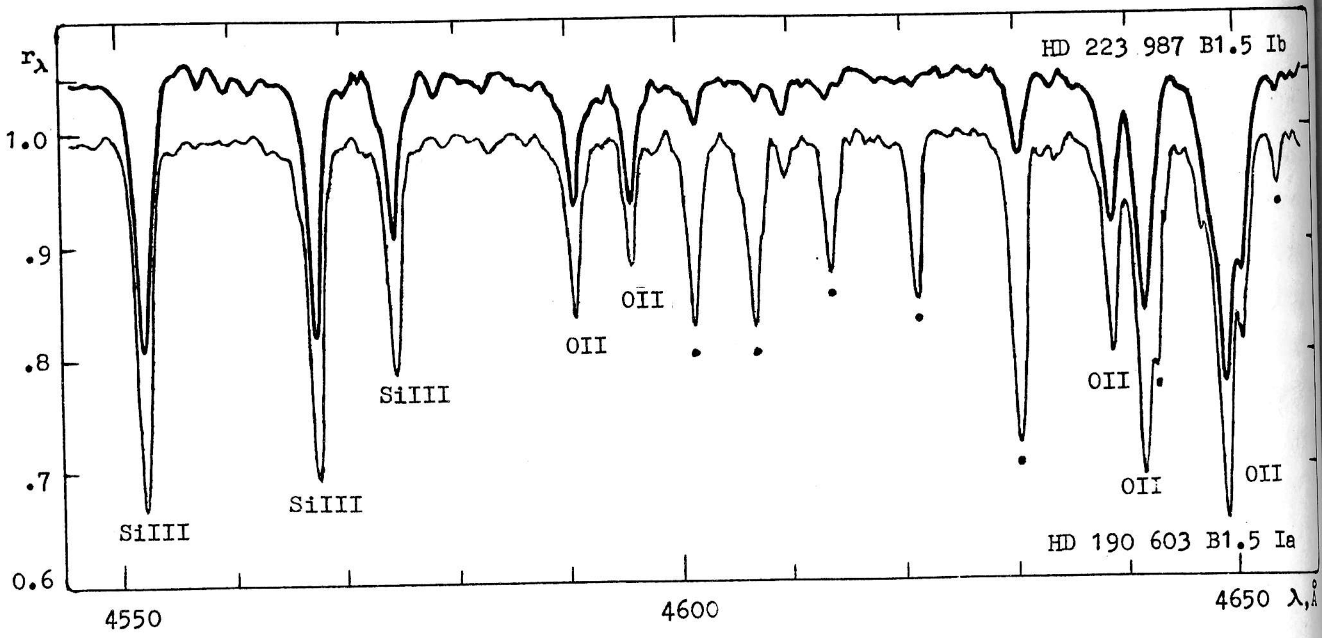
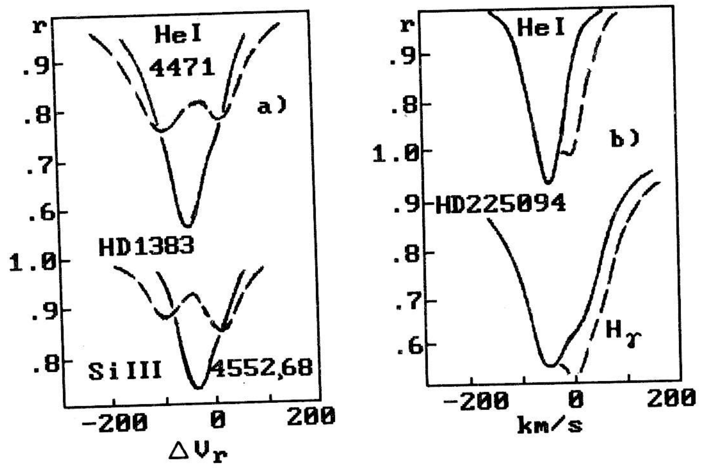


Fig. 5. *HD 223 937 B1.3 Ib with the faint NII lines (dots). A corresponding fragment of HD 190 603 81.5 Ia spectrum is given for comparison.*

Fig. 6. *Profile variations in HD 1383 (solid line, 2.06.83, dashed line, 19.09.83) and HD 225 094 (solid line, 19.09.83, dashed line, 2.06.83).*



DISCUSSION OF RESULTS

As Fig.7, the spectral type-magnitude diagram shown for all the stars of Table 1, shows we could not avoid including in the observational programme several stars from outside the association Cas OB5. HD 223501 and HD 223767 are located closer than the association, possibly in the interarm space or even in the local arm. On the other hand, HD 225160 (61-121), 61°5959 (62-46) and HD 223960, judging from their positions on the diagram and distance estimates, are located at a greater distance than the association. If these five stars are rejected then the rest of them (filled circles in Fig.7) give the distance from 1.7 to 3.0 kpc. The distance distribution maximum (bold one-humped curve in Fig.8) falls on 2.3 kpc. Our result is close to the value obtained by Ampel (1964) for Cas Va.

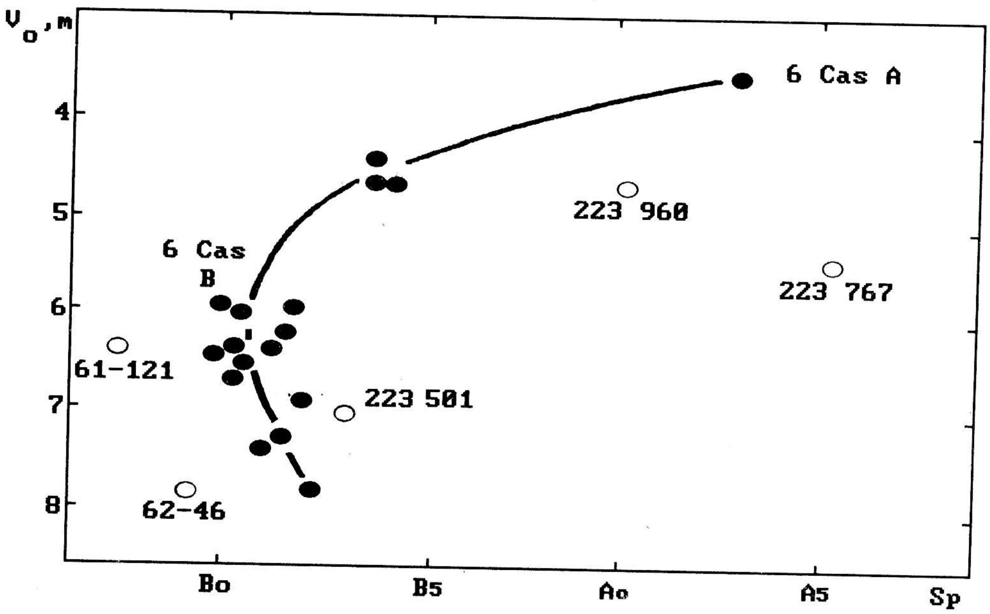


Fig. 7. Spectral type - magnitude diagram for the supposed members of the association Cas OB 5 (filled circles) and for the remaining program stars.

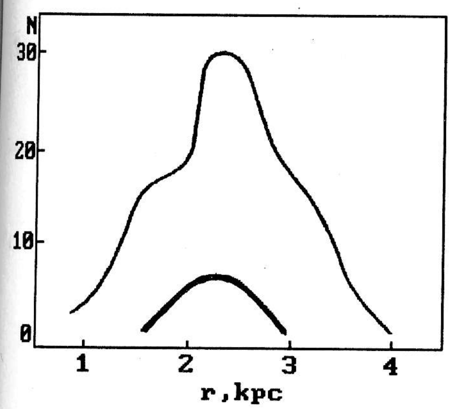


Fig. 8. Distribution of the stars from the preliminary list and finally selected Cas OB 5 members (bold line) with distance.

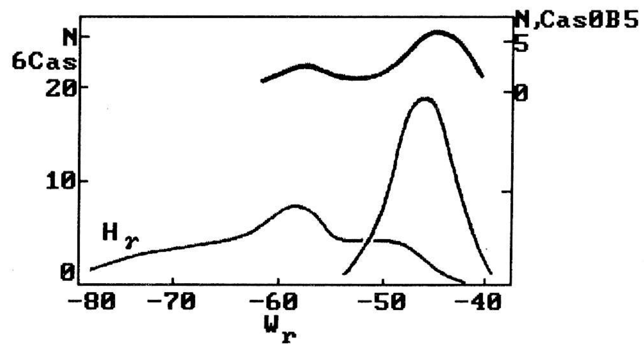


Fig. 9. *Comparison of the curve of velocity distribution of Cas OB 5 stars (bold line at the top) with radial velocity distribution for the inner and intermediate layers of the 6 Cas atmosphere.*

The curve of distribution of scarce stars versus radial velocities has two maxima: main at -44.5 km/s and secondary at -58 km/s. In Fig. 9 this curve is compared with the velocity distribution curves, which corresponds to the layers in the atmosphere of 6 Cas where the cores of H_γ and FeII lines and those of other ions are formed. The latter were plotted over 32 observation dates from 1976 to 1988. Bearing in mind that the systematic errors for individual dates can hardly exceed ±2 km/s, and attaching to the mass centre of the star V_r=-44.5 km/s, we conclude that the internal atmosphere layers of 6 Cas at least part of the time oscillate relative to the star's mass centre. The layer corresponding to H_γ is the one most likely to expand at a larger or smaller velocity. Moreover this refers to the layers of formation of H_β and H_α showing radial velocities up to -150 km/s.

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