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A Spectrographic Study of Early Class B Stars

By F. HENROTEAU, PH.D., and J. P. HENDERSON, M.A.

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A SPECTROGRAPHIC STUDY OF EARLY CLASS B STARS

BY F. HENROTEAU, Ph.D., AND J. P. HENDERSON, M.A.

The systematic study of early class B stars seems to be very important in modern astrophysical researches. Not only do these stars appear to occupy a prominent place in the scale of stellar evolution, but they seem to be enormous bodies which are altogether unlike our sun or stars of classes F, G, K, and M. There are very puzzling facts about them, their masses are evidently of a higher order (over three times that of the sun), their absolute brightnesses exceedingly great, their densities rather small, the chemical elements of which they are composed usually very simple, the chief elements being hydrogen, helium, oxygen, silicon, nitrogen and magnesium; the presence of helium is the principal characteristic of the type, hence the name Helium stars is often applied to them. As they are simple bodies of low density and also very bright, not only will gravitation play an important part in their dynamics but also radiation pressure and various thermal atomic forces.

Class B stars are usually found in much greater numbers in the Milky Way or especially in regions of space where there is a great profusion of nebulae or nebulous matter. Regions like Orion and like Scorpio abound with them. If we consider the actual spectral classification of stars

$$(P, Q)\ O, B, A, F, G, \begin{cases} K, M \\ R, N \end{cases}$$

P and Q being really spectral classes of nebulae rather than of stars, and O being Wolf Rayet stars (stars with bright lines, usually nuclei of planetary nebulae) it can be shown, as has been done by W. H. Wright and also by Miss Cannon, that the spectra of class B stars are closely connected with nebulae. This added great weight to the probability of these stars being formed in nebular masses (nuclei of condensation) and evolving slowly to become successively stars of the different spectral classes given above.

This natural conception of evolution seems however not to be the right one, and Russell's theory, strongly enhanced by the researches of W. S. Adams at Mount Wilson as to giant and dwarf stars, and by the theoretical investigations of Eddington in England, would perhaps be the proper one to adopt.

The existence of giant and dwarf stars of the same spectral classes is no more to be contested, but do we not have to consider the influence of enormous patches of nebulous matter (in which stars may be embedded) in the evolution of stars, or is it logical to consider all stars as lonely bodies (such as a great many of them no doubt are)? There may be an evolution of lonely bodies perhaps according to Russell's theory, but do we not see the principal stars of the Pleiades, of Orion, and others, submerged completely in nebulae?

The spectrum of a star is mostly the spectrum of its outer atmosphere, and may it not be that B stars show us only the spectra of nebulae that surround them? It would not be impossible for instance that the core of an apparent B star should be a G or a K star hidden by nebulous clouds.

An important factor in our discussion is that B stars are exceedingly far away from us. There are no B stars in our immediate neighbourhood; there are, however, stars of all the other spectral classes; perhaps it is true that the immediate neighbourhood (let us say within a radius of 30 parsecs) is devoid of these enormous gaseous clouds which we see spread all over the Milky Way.

The problem of the role of these gaseous clouds seems to be exceedingly important and, as B stars are found where these clouds are, they ought to attract our careful attention.

As B stars have usually wide and diffuse lines their study is best done with a spectrograph of small dispersion, hence, it is well suited to the equipment of the Dominion Observatory at Ottawa.

The intention was then to photograph the spectra of all the brightest early class B stars (B1 to B5 and Bp), if possible taking spectra of each of them consecutively during the same night. This was specially suggested by the fact that there must be a fairly great number of stars of the β Canis Majoris type.*

Only very few stars of this type are at present known, such as β Canis Majoris, σ Scorpii, β Cephei and 12 Lacertæ, and all are early class B. These stars are considered as spectroscopic binaries, their period being usually very short (from four to six hours); it is possible, however, that these stars are not binaries at all and that the phenomenon that produces the displacement of the spectral rays is analogous to what happens in Cepheid variables; perhaps, as Shapley thinks it, a pulsation phenomenon, or perhaps, as Cepheid variables are also located in the Milky Way, an effect due to the presence of gas clouds in the neighbourhood of the star.

These stars of the β Canis Majoris type seem to open the way to new discoveries of a general character, and to have an important bearing on theories regarding the nature of the gaseous clouds spread in the interstellar space, and to lead to a new experimental celestial dynamics in which forces which are at present generally ignored, such as those of light pressure and atomic and electron emission and other molecular actions, will play an important part in the interior structure of the stars.

R. K. Young thought it probable that the amplitude of the radial velocity curve of 12 Lacertæ varied, (which was lately confirmed by his observations at Victoria). Such a variation of amplitude (most likely irregular) was discovered for β Canis Majoris by Henroteau at the Lick Observatory, as well as a variation in the widths and intensities of its spectral rays. These variations of aspect of the rays were also discovered for σ Scorpii where the variation of amplitude was not confirmed, but replaced by a double period variation of radial velocity, one of about six hours and the other of about 34 days ($0.^d246834$ and $34.^d08$ respectively). The variation of about six hours is the same as that of the variation of the appearance of the spectral rays. σ Scorpii which is a star with *stationary calcium lines* is moreover situated (like β Canis Majoris, β Cephei and 12 Lacertæ) in a magnificent region of the Milky Way where nebulosities and dark currents are abundant.

The purpose of the present investigation is then (1) to give all the data available for the stars investigated, (2) to make a study complete as possible of the early class B stars, (3) to study their line-widths and see if there is a relation between these widths and the

* See *Lick Obs.* Bull., IX, p. 155 and p. 173.

position of the stars far from, in or near nebulosities, dark currents, or the Milky Way in general, (4) discover more stars of the β Canis Majoris type in order to make a more complete study of this type of stars.

It is the intention to publish our investigations in several series, the stars being classified according to their increasing right ascensions. Each star will then be treated separately.

FIRST SERIES

H. R.	Star	R. A. (1900)	Decl. (1900)	Visual Mag.	Spect.
		h m	° ′		
39	γ Pegasi	0 8·1	+14 38	2·87	B2
123	λ Cassiopeiæ	0 26·2	+53 59	4·88	B5
130	κ Cassiopeiæ	0 27·3	+62 23	4·24	B
144	H. R. 144	0 30·5	+53 38	5·14	B5
153	ζ Cassiopeiæ	0 31·4	+53 21	3·72	B2
179	ξ Cassiopeiæ	0 36·5	+49 58	4·85	B3
779	δ Ceti	2 34·4	− 0 6	4·04	B2
1203	ζ Persei	3 47·8	+31 35	2·91	B1
1679	λ Eridani	5 4·4	− 8 53	4·34	B2
1897	θ^2 Orionis	5 30·5	− 5 29	5·17	B1
2135	χ^2 Orionis	5 58·0	+20 8	4·71	B2

In the measures of the radial velocities of these stars a great many spectral lines have been identified; the following table gives their wave-lengths together with a description of their general appearances. Most of these lines may be found in the majority of the early class B stars.

TABLE OF WAVE-LENGTHS OF THE PRINCIPAL ABSORPTION LINES OCCURRING IN THE SPECTRA OF EARLY CLASS B STARS

Element	λ	Character of the line
$H\iota$	3770·78	strong
$H\theta$	3798·05	strong
He	3819·75	usually strong
$H\eta$	3835·509	strong
Si	3853·82	not very strong }
Si	3856·19	not very strong } stronger in late class B
Si	3862·80	not very strong }
?	3871·95	only present in later class B
$H\zeta$	3889·15	very strong
N	3919·24	medium strength or rather weak
C	3920·8	weak, stronger in late class B
?	3926·68	weak, stronger in late class B
$Ca(K)$	3933·825	very wide and strong in late class B, narrow and sharp or non-existent in earliest types; very often does not belong to the elements of the star itself, but probably to a cloud situated in front of it
?	3936·06	very weak
O	3945·25	weak

TABLE OF WAVE-LENGTHS OF THE PRINCIPAL ABSORPTION LINES OCCURRING IN THE SPECTRA OF EARLY CLASS B STARS—*Continued.*

Element	λ	Character of the line
O	3954·55	weak
He	3964·875	rather strong
Ca(H)	3968·625	very wide and strong in late class B, same remarks as for *Ca* 3933, very often blended with *Hε*
Hε	3970·177	very strong
O	3973·44	weak
O	3982·9	very weak
N	3995·26	sometimes fairly strong
He	4009·417	strong
He	4026·352	strong to very strong
N	4035·07	fairly weak
N	4041·48	weak
?	4070·05	weak
O	4072·4	weak, vanishing in late class B
O	4076·08	weak, vanishing in late class B
O	4079·11	weak
O	4085·36	weak
Si	4089·09	strong, weaker in late class B
O	4093·15	weak
N	4097·43	rather strong
Hδ	4101·890	very strong
Si	4116·51	strong in early class B, vanishing in late
He	4121·016	fairly strong
Si	4128·211	very weak, but strong in late class B
Si	4131·047	very weak, but strong in late class B
N	4133·85	very weak
He	4143·928	rather strong
O	4153·85	fairly weak
S	4163·3	weak and present only in a few stars especially of late class B
He	4169·183	fairly weak
O	4185·72	fairly weak
O	4190·06	weak
H	4200·5	weak to fairly strong; does not belong to the Balmer series of hydrogen lines
N	4236·93	very weak
N	4241·94	very weak
S	4253·77	sometimes fairly strong in early class B
C	4267·301	rather strong
?	4276·2	weak
S	4285·13	fairly weak, non-existent in late class B
?	4304·2	weak
O	4317·272	weak, vanishing in late class B
O	4319·762	weak, vanishing in late class B
O	4327·61	very weak
N	4332·62	very weak
Hγ	4340·634	very strong
O	4345·677	weak
O	4347·58	very weak
N	4348·134	rather weak
O	4349·541	sometimes fairly strong
O	4351·495	weak
Mg	4352·083	sometimes fairly strong
O	4367·012	fairly weak
N	4379·75	fairly weak
He	4388·100	strong

TABLE OF WAVE-LENGTHS OF THE PRINCIPAL ABSORPTION LINES OCCURRING IN THE SPECTRA OF EARLY CLASS B STARS—*Concluded.*

Element	λ	Character of the line
O	4396·14	fairly weak
O	4415·076	fairly weak
O	4417·121	fairly weak
N	4432·9	very weak
N	4447·163	weak and only in early class B
O	4465·54	very weak
He	4471·676	strong to very strong
?	4477·5	very weak
Mg	4481·397	very strong in late class B; still existing but much weaker in early class B
N	4507·78	very weak
N	4530·08	weak
H	4542·4	rather strong in early class B, does not belong to Balmer series of hydrogen, non-existent in late class B
Si	4552·636	sometimes rather strong
Si	4567·897	sometimes rather strong
Si	4574·791	sometimes fairly strong
O	4591·066	weak
O	4596·291	weak
N	4601·632	weak
N	4607·305	weak
O	4609·7	very weak
N	4614·033	very weak
N	4621·548	weak
N	4630·703	weak to fairly strong
O	4638·937	weak
O	4641·886	weak to fairly strong
N	4643·244	weak
C	4647·53	moderately strong, especially in early class B
O	4649·25	weak
C	4650·925	strong, especially in early class B
O	4661·728	weak to fairly strong
O	4676·34	weak
H	4685·97	rather strong in early class B, vanishing in late class. Does not belong to Balmer series of hydrogen
O	4699·39	weak
O	4705·56	weak
He	4713·308	strong
Hβ	4861·527	very strong
He	4922·10	strong

In addition to the above lines we may add a great many weak metallic lines which are found in the spectra of the late class B stars and which gradually become stronger in the spectra of class A and class F stars.

The oxygen, nitrogen and hydrogen lines which do not belong to the Balmer series are not found in the late class B spectra.

Let us now proceed to the individual study of the stars mentioned above.

γ PEGASI

This star has a great many wide and diffuse lines rather hard to measure. It was first investigated by Frost and Adams at the Yerkes Observatory, and the results obtained for the radial velocity are given in their article, "Radial Velocities of Twenty Stars having Spectra of the Orion Type."

The following table gives the spectral lines with their widths (mean of the two plates) measured in angstroms, and the radial velocities as found by us on the two plates, 8755 and 8757. The weights are on scale 10, 10 being the very best line.

CHARACTERISTICS OF LINES IN SPECTRUM OF γ PEGASI

Element	λ	Width	8755		8757	
			Vel.	Wt.	Vel.	Wt.
Hδ	4101·890	very diffuse	−11·2	1	.....	.....
He	4143·928	2·4, diffuse	−26·2	1	− 1·9	3
S	4253·770	diffuse	.....	.....	−32·9	1
C	4267·301	2·2, diffuse	+24·6	2	−46·0	1
O	4317·272	very diffuse	−30·0	1	.....	.....
Hγ	4340·634	5·2, wide	+ 7·9	3	−42·9	2
He	4388·100	3·0, diffuse	− 1·2	8	.....	.....
N	4447·163	very diffuse	−68·3	2	−48·7	5
He	4471·676	4·0, diffuse	−57·0	4	− 6·2	4
Mg	4481·397	very diffuse	−81·3	1	.....	.....

As may be seen from this table the spectrum is very poor and not susceptible of great accuracy in the measures. It should also be noted that the velocities given by the wide and diffuse lines are highly negative and greatly different from those given by the better defined lines. It is very likely that most of these lines are greatly unsymmetrical and therefore give values which do not represent the true radial velocity at all.

Many radial velocities have been obtained previously for this star; the following is a list which includes also the reduced velocities obtained from the above plates.

Place	Date	Velocity
Yerkes*	1901, Sept. 5·895	+ 3·7
"	" 6·713	+ 5·1
"	" 18·618	+ 2·6
"	" 26·586	+ 4·2
"	Oct. 16·532	+ 7·6
"	Nov. 27·508	+ 6·4
"	1902, Aug. 22·861	+ 6·3
"	Oct. 9·745	+ 6·8
Lick†	1899, Aug. 21·900	+ 7·7
"	Oct. 23·714	+ 2·8
"	1900, Aug. 7·003	+ 1·6
"	1901, Aug. 13·937	+ 1·7
"	Nov. 5·698	+ 1·6
"	1903, Aug. 5·987	+ 0·1
"	1904, Aug. 16·998	+13·4
"	Sept. 12·897	+ 4·4
"	Dec. 25·647	+10·0
"	1906, July. 30·946	+ 7·5
"	Aug. 13·972	+ 8·2
"	Sept. 13·907	+ 4·6
"	1910, July, 23·022	+10·1
"	Dec. 21·592	+ 3·2
"	Dec. 21·633	+ 8·6
"	" 25·647	+ 7·3
"	1911, Feb. 8·608	+ 7·1
Ottawa	1913, Sept. 30·646	+ 5·3
Ottawa	1919, Oct. 6·510	−22·4 ± 7·3
"	" 6·616	−30·5 ± 5·5

From the above Lick measures the star was announced to be a spectroscopic binary, differences in radial velocity were, however, not real on account of the fact that some measures depended largely on the helium lines which were found to be unsymmetrical, causing them to give results which vary with the density of the spectrum. No probable errors were given except as indicated above.

λ CASSIOPEIÆ

No velocity has been published for this star; its spectrum is very poor, the lines are very wide and diffuse and only a very few can be seen. However, an attempt was made to measure their widths as well as the velocities they yield, the widths being given in the following table.

Element	λ	Width in angstroms	Element	λ	Width in angstroms
$H\epsilon$	3970·177	8·6	$H\gamma$	4340·634	6·8
$H\delta$	4101·890	6·1	$H\beta$	4861·527	11·6

The velocities that were obtained are so unreliable that we did not deem them worth mentioning.

κ CASSIOPEIÆ

This star contains a fairly large number of lines for an early class B star; some of them are fairly narrow although diffuse. The widths of the lines (average of all the measures) together with the individual velocities and weights, are given in the following table.

Yerkes Publications, Vol. II, p. 145
† *L. O. B.* 199, p. 141

LINES, THEIR WIDTHS AND VELOCITIES, IN SPECTRUM OF κ CASSIOPEIÆ

Element	λ	Width in A.	8775		8776		8777		8778		8779		8780	
			Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
N	3995·26	2·2	.....	....	−19·4	1	.....	....	.....	....	.....	....	.....	....
He	4026·352	2·2	.....	....	−17·3	3	.....	....	−18·2	3	−15·6	1	+31·2	1
N	4041·48	2·2	.....	....	.....	....	.....	....	−28·2	2	.....	....	.....	....
Si	4089·09	2·1	.....	....	+24·4	4	.....	....	−19·3	4	+22·0	2	.....	....
Hδ	4101·890	2·6	.....	....	−12·1	3	+10·2	1	.....	....	.....	....	+ 1·9	1
He	4121·016	wide	.....	....	−41·9	1	.....	....	.....	....	.....	....	.....	....
He	4143·928	2·3	.....	....	− 9·6	1	− 4·8	3	−17·3	1	−59·6	1	− 9·6	1
S	4253·77	2·4	+ 8·4	5	.....	....	+24·3	1	+ 4·2	6	− 1·1	3	.....	....
C	4267·301	wide	.....	....	.....	....	.....	....	.....	....	.....	....	+ 1·0	1
O	4317·272	wide	.....	....	−69·7	1	.....	....	.....	....	+48·6	1	.....	....
Hγ	4340·634	3·9	−56·4	3	.....	....	−32·7	4	−45·0	2	−72·0	6	−27·0	4
O	4367·012	2·8	.....	....	.....	....	−29·8	3	.....	....	−14·9	6	.....	....
He	4388·100	2·8	.....	....	+ 7·0	1	−15·3	2	0·0	5	−14·0	6	.....	....
O	4415·076	3·8	+34·4	2	.....	....	.....	....	+35·7	3	.....	....	− 6·0	1
He	4471·676	3·0	.....	....	+ 5·0	1	− 2·5	4	+ 2·5	4	−26·1	6	+ 1·2	6
Si	4552·636	3·2	.....	....	+ 1·3	3	+28·8	2	+18·3	1	− 9·2	7	+34·0	4
Si	4567·897	4·1	.....	....	−25·2	2	.....	....	+ 5·3	2	−47·6	4	.....	....
Si	4574·791	3·6	.....	....	.....	....	.....	....	−18·6	4	+17·5	1	.....	....
O	4591·066	fuzzy	.....	....	.....	....	.....	....	.....	....	.....	....	.....	....
N	4630·703	wide	+87·2	1	.....	....	.....	....	.....	....	.....	....	.....	....
O	4638·937	4·4	−59·6	1	−27·7	2	− 8·3	2	.....	....	−45·8	1	−43·0	1
O	4649·25	4·6	+37·6	2	−29·3	3	+ 5·6	5	+20·9	6	+ 7·0	6	+ 9·7	3
O	4661·728	fuzzy	+28·2	1	− 9·8	1	−42·2	2	.....	....	−53·4	2	.....	....
O	4676·34	fuzzy	.....	....	.....	....	.....	....	.....	....	−72·3	2	.....	....
Hβ	4861·527	5·7	.....	....	.....	....	.....	....	.....	....	−66·6	4	.....	....

There was a suspicion from the individual measures of the widths of the lines on the different plates, that on one of them the lines were narrower and better defined than on the others. It would not seem impossible that the star should show such a variation, but the quality of the spectrum, the small dispersion and other factors prevent any such positive conclusion. The star was announced to be a spectroscopic binary from the Lick measures by Merrill.

The radial velocities found at various observatories are given below, including the reduced velocities obtained from the above measures.

RADIAL VELOCITIES OF κ CASSIOPEIÆ

Place	Plate	Date	Velocity	
Yerkes*	.....	1908, Sept. 7·683	− 3	
"	.....	" 8·632	− 8	
"	.....	Oct. 5·630	+ 2	
"	.....	1910, Aug. 8·777	−16	
"	.....	" 12·824	−10	
Vienna†	.....	1913, Oct. 13·335	−11·3	
"	.....	" 25·434	− 9·7	
"	.....	" 27·378	−18·2	
"	.....	Nov. 19·401	−11·8	
Lick‡	.....	1902, Nov. 4·825	+ 6	
"	.....	1903, Oct. 13·907	− 6	
"	.....	1906, Aug. 20·026	+ 3	
"	.....	1908, Aug. 9·011	− 5·4	
"	.....	1910, Nov. 16·774	+13·4	
"	.....	1911, Jan. 8·592	−11·7	
Ottawa**	8775	1919, Oct. 20·516	+ 7·5	±11·6
"	8776	" " 20·562	− 9·2	± 4·1
"	8777	" " 20·600	− 6·3	± 4·3
"	8778	" " 20·683	+ 0·8	± 4·2
"	8779	" " 20·756	−23·1	± 5·1
"	8780	" " 20·792	+ 4·1	± 4·9

These measures are much poorer than expected and show rather large probable errors. It might be remarked that the hydrogen line $H\gamma$ always gives a highly negative velocity, much different from the others. It seems the same for $H\beta$, but this was measured on one plate only. It might be better to eliminate the hydrogen lines and other lines of small weight in finding the mean velocity because of their widths and unsymmetrical character, but even so, the results obtained would still be indefinite. Nevertheless, the observations indicate that the star is possibly a short period binary and therefore worth investigating as such.

H. R. 144

We have only one published radial velocity for this star, doubtless the mean of several measures, as no date is given. It is to be found in Adams' list of radial velocities of 500 stars (*Ap. J.* 42, p. 175, 1915), and is given as +2·8 km. per second. The lines in the spectrum are few and fuzzy although not as ill-defined as in some class B spectra.

* Lee, *Ap. J.*, XXXIX, p. 43
† Hnatek, *A. N.* 193, p. 185
‡ Merrill, *L. O. B.* 199
** See also Pub. Dom. Obs., Vol. IV, No. 21

Their widths and measured velocities are given in the following table.

CHARACTERISTICS OF LINES IN THE SPECTRUM OF H. R. 144

Element	λ	Width in A.	8784		8786		8787	
			Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
Hδ	4101·890	7·1	.....	.....	+ 4·6	2	.....	.....
Hγ	4340·634	8·1	−25·9	7	−11·3	7	−13·4	7
He	4471·676	4·2	−11·1	5	− 5·0	8	0·0	10
Mg	4481·397	5·2	+26·2	5	−22·4	8	− 8·7	10

The plates have evidently slightly different qualities as can be noticed from the more or less good definition of the lines. The reduced velocities they yield are given below; they seem to be fairly good for this type of spectrum.

Plate	Date	Velocity	
8784	1919, Oct. 23·740.....	− 5·7	±10·4
8786	" 24·611.....	−10·9	± 3·3
8787	" 24·712.....	− 6·2	± 2·6

These three velocities do not seem to indicate any short period variation. The mean (−7·6 km.) seems to diverge slightly from Adams' measure, +2.8 km.

ζ CASSIOPEIÆ

This is one of the twenty stars whose velocities have been determined by Frost and Adams at the Yerkes Observatory (see Radial Velocities of Twenty Stars having Spectra of the Orion Type; *Publ. of the Yerkes Obs.*, Vol. II, p. 184).

The spectra we have obtained for this star are very poor; the measures of their lines which are not of the best cannot be satisfactory. Nevertheless, they are given in the following table.

LINES, THEIR WIDTHS AND VELOCITIES, IN SPECTRUM OF ζ CASSIOPEIÆ

Element	λ	Width	8756		8758		8759		8774	
			Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
Hε	3970·177	.....	.....	....	.....	....	.....	....	+33·3	1
He	4009·417	1·6	−56·4	2	.....	....	.....	....	+ 6·3	5
He	4026·352	.....	.....	....	.....	....	.....	....	−14·3	9
He	4121·016	3·3	−38·7	10	−63·0	1	.....	....	+ 2·7	9
He	4143·928	4·2	.....	....	.....	....	.....	....	−12·5	9
C	4267·301	3·3	−53·2	10	.....	....	.....	....	−13·9	9
Hγ	4340·634	7·3	+30·4	5	+19·1	3	+19·2	2	+27·1	5
He	4388·100	2·1	−57·2	10	+16·3	1	−19·8	9	−18·3	9
He	4471·676	2·3	−32·2	10	−89·2	9	.....	....	−11·6	9
Hβ	4861·527	11·9	+82·5	5	−34·9	5	+26·2	9	+ 3·6	9

The hydrogen lines are very poor and from the measures appear to be unsymmetrical, because they give velocities altogether different from the others. They have been omitted from the means given below. The following is a summary of the reduced velocities found for this star.

Place	Plate	Date	Velocity
Yerkes	.....	1901, Oct.. 31·577	+ 2·4
"	.....	1901, Nov. 7·613	+ 5·1
"	.....	1901, Nov. 27·700	+ 4·8
"	.....	1902, July. 22·799	+ 5·0
Ottawa	8756	1919, Oct. 6·569	−38·7
"	8758	1919, Oct. 6·635	−70·2
"	8759	1919, Oct. 6·688	−12·8
"	8774	1919, Oct. 19·924	− 7·7

The velocities given by plates 8758 and 8759: are unreliable as they depend on the measure of practically a single line on each. On the other hand, the velocities given by plates 8756 and 8774 seem to be very good, as is shown by the agreement between the different velocities for the different lines. Therefore, the star is apparently a spectroscopic binary of rather short period, but more plates would be required to establish this.

ξ CASSIOPEIÆ

This star was announced to be a spectroscopic binary by Frost and Adams (see *Ap. J.*, 18, 1903, p. 384) on the basis of three velocities. Its spectrum is exceedingly poor; the lines being very diffuse, their widths are not given here. The following table only gives the velocities.

RADIAL VELOCITIES GIVEN BY LINES IN THE SPECTRUM OF ξ CASSIOPEIÆ

Element	λ	8760		8761		8762		8763		8764		8765		8766	
		Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
Hδ	4101·890	.....	....	−17·7	1	.....	....	.....	....	.....	....	.....	....	.....	....
Hγ	4340·634	+ 6·8	1	+20·3	1	−12·4	1	−38·4	1	−32·8	1	−31·6	1	+39·6	1
He	4388·100	.....	....	+51·5	3	.....	....	.....	....	−19·9	2	−35·1	4	−35·1	1
He	4471·676	+13·6	1	.....	....	.....	....	.....	....	−17·4	5	.....	....	.....	....

In addition, some other lines were also found, but it has not been possible to identify them with lines of known elements. A few of their wave-lengths coincide with the wave-lengths of Xenon lines. The existence of Xenon in an early class B star is doubtful however, and owing to the poor quality of the spectrum and indefiniteness of the lines in general, it was impossible to reach any definite conclusion.

The radial velocities for this star are given below, which includes the values reduced from the above measures.

Place	Plate	Date	Velocity	
Yerkes ..	.....	1903, Oct. 10	−14	
" ..	.....	" 24	−35	
" ..	.....	Nov. 7	− 5	
Ottawa	8760	1919, Oct. 7·545.....	+16·9	± 2·4
"	8761	..... " 7·692.....	+37·9	± 8·2
"	8762	..... " 7·738.....	− 6·0	
"	8763	..... " 7·776.....	−32·1	
"	8764	..... " 7·814.....	−13·6	± 2·4
"	8765	..... " 7·853.....	−28·2	± 0·9
"	8766	..... " 7·892.....	+10·7	±25·6

The plates of this star are among the poorest we have taken; however, even if the two plates, on which only one line was measured and hence for which no probable error could be determined, are omitted, it would seem probable that the star is a very short period binary.

δ CETI

The spectrum of δ Ceti seems to be good for a star of early class B; the lines are fairly narrow and give good results when measured. The star was announced to be a spectroscopic binary by Frost and Adams (*Ap. J.* 17, 1903, p. 150) and according to them the range of variation in velocity is not large, from + 6 to +16 km. per second, but they cannot question its reality.

The following table gives the means of the widths of the lines measured on the various plates and the radial velocities they furnish.

CHARACTERISTICS OF LINES IN THE SPECTRUM OF δ CETI

Element	λ	Width in A.	8790		8791		8792		8793		8794		8795	
			Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
Hζ	3889·15	diffuse	−33·6	1	.....	....	.....	....	+28·3	1	.....	....	.....	....
K	3933·825	0·8	− 6·4	5	.....	....	.....	....	.....	....	.....	....	.....	....
He	3964·875	0·6	+12·3	10	.....	....	+ 9·9	5	+36·2	7	+25·5	5	+ 4·3	2
H	3968·625	2·2	.....	....	.....	....	.....	....	.....	....	.....	....	−33·1	3
Hε	3970·177	2·5	+63·6	2	.....	....	+13·2	5	+23·1	7	+53·7	2	.....	....
N	3995·26	0·6	.....	....	.....	....	0	7	+10·3	3	+30·5	3	− 1·7	5
He	4009·417	1·0	+26·6	8	− 4·3	2	+17·2	8	+34·3	9	+28·3	5	+12·9	5
He	4026·352	1·2	− 7·2	10	+ 2·6	6	+16·6	8	+22·7	7	+32·1	8	− 4·4	7
Hδ	4101·890	2·1	+ 3·7	8	−71·0	2	+10·2	5	+35·4	8	+22·4	5	− 2·7	8
He	4121·016	0·9	+10·4	10	− 3·8	5	− 5·6	9	+11·4	10	+36·0	8	− 8·6	8
He	4143·928	0·7	+ 8·7	12	−12·6	7	+ 6·8	7	+10·6	9	+32·9	8	+ 1·0	10
He	4169·183	0·5	.....	....	.....	....	.....	....	.....	....	.....	....	+ 4·9	8
C	4267·301	0·6	.....	....	.....	....	.....	....	+15·9	7	+38·4	1	− 6·4	8
Hγ	4340·634	1·7	+14·7	8	+ 2·3	7	+18·1	7	+28·3	10	+40·7	10	+14·7	10
He	4388·100	1·5	+ 2·8	10	+18·8	10	+ 2·3	7	+12·8	10	+41·1	10	− 4·7	10
He	4471·676	1·7	+16·4	10	− 3·7	10	+13·7	10	+27·3	10	+54·7	10	+ 9·9	9
He	4713·308	.....	.....	....	+21·8	8	.....	....	.....	....	.....	....	.....	....
Hβ	4861·527	2·9	+15·9	10	+65·4	3	+35·0	10	+57·3	10	+49·4	8	+17·5	10
He	4922·10	1·8	.....	....	.....	....	.....	....	.....	....	.....	....	.....	....

It seemed from the width measurements of the individual plates that there might be a variation in the widths of the lines; this, however, could only be satisfactorily established by means of very good three-prism spectrograms.

A few velocities were obtained for this star at the Lick Observatory; a mean of these and of the Yerkes velocities was taken by W. W. Campbell to introduce in his study of the motions of the brighter class B stars, (*L. O. B.*, 195). This mean is given as +10 km. per second. A summary of the various radial velocities found for this star is given in the following table.

RADIAL VELOCITIES OF δ CETI

Place	Plate	Date	Velocity	
Yerkes*	.....	1901, Nov. 1	+ 8	
"	.....	..... Nov. 13	+12	
"	.....	..... Dec. 19	+16	
"	.....	1902, Jan. 4	+ 6	
"	.....	..... Aug. 7	+13	
"	.....	..... " 11	+ 6	
"	.....	..... " 27	+ 9	
"	.....	..... Sept. 3	+12	
"	.....	..... " 6	+12	
"	.....	..... " 7	+ 6	
"	.....	..... Oct. 29	+ 9	
Ottawa	8790	1919, Nov. 2·561.....	+ 7·9	± 2·7
"	8791	..... " 2·617.....	+ 3·0	± 6·2
"	8792	..... " 9·567.....	+ 6·4	± 2·3
"	8793	..... " 9·621.....	+20·1	± 2·6
"	8794	..... " 9·664.....	+32·3	± 1·8
"	8795	..... " 9·711.....	− 3·6	± 1·7

A plot of the radial velocities obtained for Nov. 9th shows that δ Ceti is a spectroscopic binary of very short period, approximately a quarter of a day. It is thus a star of the β Canis Majoris type, and a careful study of its variation would be of considerable value.

ζ PERSEI

This is one of the twenty stars studied by Frost and Adams at the Yerkes Observatory, (*Publ. of the Yerkes Obs.*, Vol. II, p. 191). According to them, the lines in its spectrum though numerous are extremely broad and ill-defined, making accurate measurement difficult.

The widths of the lines were measured on two of the plates, the means being given in the following table, along with the individual velocities given by each line. The lines are in general more or less diffuse, and are not likely to give as reliable velocities as in the spectrograms of δ Ceti. It was suspected that one or two lines might be double, but on a re-examination of the plates the only line that seemed likely to be made up of several components was the line λ 4349.541; this was to be expected, since we know that the following other lines are situated in the same region; *O*, 4345.677; *O*, 4347.580; *N*, 4348.134; *O*, 4349.541; *O*, 4351.495; *Mg*, 4352.006.

Ap.. J. XVII, p. 150.

CHARACTERISTICS OF LINES IN THE SPECTRUM OF ζ PERSEI

Element	λ	Width in angst.	8809 (1)		8810 (1)		8810 (2)		8811 (1)		8811 (2)	
			Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
He	3819·75	.....	.....	....	.....	....	.....	....	−12·1	2	.....	....
Hη	3835·509	.....	.....	....	.....	....	.....	....	+14·5	2	.....	....
Hζ	3889·15	4·0	.....	....	+ 5·6	4	− 1·5	2	+23·2	5	.....	....
(*Ca*) *K*	3933·825	.....	.....	....	.....	....	.....	....	− 2·6	5	.....	....
He	3964·875	0·6	.....	....	+ 6·5	2	.....	....	+ 4·8	5	.....	....
(*Ca*) *H*	3968·628	0·4	.....	....	+ 1·8	3	.....	....	.....	....	.....	....
Hε	3970·177	1·1	+ 8·4	8	+24·2	4	− 5·3	7	+10·6	10	.....	....
O	3973·44	.....	.....	....	.....	....	.....	....	−11·3	5	.....	....
He	4026·352	1·2	+ 1·9	7	+ 6·1	5	+15·8	10	+10·7	10	+ 8·5	8
O	4072·4	1·0	.....	....	+10·6	2	.....	....	.....	....	.....	....
O	4076·08	0·7	.....	....	+15·3	2	.....	....	− 2·4	5	.....	....
Si	4089·09	0·4	.....	....	+14·8	3	.....	....	+ 4·6	8	.....	....
Hδ	4101·890	1·6	+10·9	5	+18·5	4	+ 4·0	10	+21·2	10	+ 5·3	8
He	4121·016	0·6	− 1·5	7	+10·4	4	.....	....	−30·2	5	+10·2	2
He	4143·928	0·7	.....	....	+ 3·4	2	.....	....	−12·4	5	+ 4·5	5
C	4267·301	1·0	− 2·6	8	.....	....	.....	....	.....	....	.....	....
Hγ	4340·634	2·4	+15·5	10	+19·5	4	+12·8	10	+ 3·4	10	+20·2	10
O	4349·541	0·8	.....	....	+13·2	3	.....	....	.....	....	.....	....
O	4367·012	1·5	.....	....	+11·2	3	.....	....	.....	....	+36·6	8
He	4388·100	1·3	+20·7	10	+16·6	4	− 4·0	8	+25·3	5	+ 5·3	5
He	4471·676	1·6	+22·8	10	+15·4	10	+11·6	10	+31·7	5	+16·5	10
Mg	4481·397	.....	.....	....	.....	....	0·0	8	.....	....	.....	....
Hβ	4861·527	2·2	+22·3	10	+ 7·0	5	− 4·6	10	+ 7·3	10	+19·4	10
He	4922·10	2·4	.....	....	.....	....	.....	....	.....	....	.....	....
Si	4552·636	.....	.....	....	.....	....	+15·8	2	.....	....	+32·8	5
N	3995·26	.....	.....	....	.....	....	.....	....	− 7·2	5	.....	....
He	4009·417	.....	.....	....	.....	....	.....	....	− 0·1	5	.....	....

W. W. Campbell in his study of the motions of the brighter class B stars uses the velocity +20.4 km. per sec. If we consider the above measures, we see that a certain number of lines of smaller weight give smaller velocities than the better lines, probably on account of poor estimation of the centres of these lines, (they being very diffuse).

If we should take account of this, we might be able to say that the mean obtained would certainly be very near the velocity used by W. W. Campbell. It seems then that the star has a constant velocity. A summary of the reduced velocities are given below.

RADIAL VELOCITIES OF ζ PERSEI

Place	Plate	Date	Velocity
Yerkes*	.....	1901, Sept. 12·753	+24·4
"	.....	" 18·768	+25·1
"	.....	Nov. 8·689	+24·0
"	.....	" 14·839	+22·5
"	.....	1902, Oct. 15·696	+24·3
Ottawa	8809 (1)	1919, Nov. 14·672	+16·9
"	8810 (1)	" 14·739	+15·2
"	8810 (2)	" 14·751	+ 9·2
"	8811 (1)	" 14·808	+10·1
"	8811 (2)	" 14·818	+21·3

λ ERIDANI

The lines in the spectrum of this star are exceedingly wide and diffuse, and their measurement for radial velocity is very inaccurate. A few lines of hydrogen, helium, oxygen, nitrogen and carbon can be distinguished in the spectrum. The widths of only three lines have been measured and are:

Element	λ	Width in angstroms
$H\gamma$	4340·634	13·4
He	4471·676	9·5
$H\beta$	4861·527	4·5

It is one of the poorest spectra of class B stars encountered to date, and we have no previous recorded radial velocity. The following velocities were obtained for three plates taken the same night, but they must be considered as far from reliable, on account of the very poor quality of the spectrum.

Plate	Date	Velocity
8872	1919, Dec. 18·568	+13
8873	..... " 18·618	+16
8874	..... " 18·645	−36

* *Yerkes Publications* II, p. 191
Ap. J. XXXI, p. 430

θ^2 ORIONIS

The star θ^2 Orionis or 43 Orionis (Bond 685) is situated in the very midst of the Orion nebula. It was found by Professor Frost to be a spectroscopic binary with a range of about 140 km., the Yerkes velocities being the following:

Date	Velocity
1903, Dec. 21·610	+70
1904, Jan. 2·593	+80
..... " 23·534	+24
..... " 29·551	−37

The velocities obtained at Ottawa were the following ones:

Date	Velocity
1909, Oct. 12·748	+76
..... " 19·790	+74

According to E. B. Frost and W. S. Adams, (*Ap. J.* XIX, 1904, p. 153) the star is of class B1, the hydrogen and helium lines being broad and diffuse and hard to set upon, though not complicated by nebular lines.

On all the plates taken by us in the course of our regular programme on early class B spectra, it was found that the broad hydrogen absorption lines were divided by *sharp and well-defined emission lines*. These emission lines were found also in the centre of some other absorption lines. The existence of the emission lines on our plates, and the fact that Frost and Adams did not find them on their plates, led us to consider the possibility of variation in intensity, the emission lines being sometimes so weak that they cannot be seen on the spectrograms. To determine whether this variation of intensity was real, a comparison of our recent plates with the older plates taken at the Dominion Observatory was made, but as these older plates are rather poor in definition, no positive conclusion could be reached, for in some cases we thought we saw weak emission lines, but in some others they failed to appear. In all, ten plates taken in Dec. 1909 and Jan. and Feb. 1910 were examined.

The detailed velocity measures as given by the recent plates are given in the following table.

LINES AND MEASURES OF θ^2 ORIONIS

Element	λ	8846		8848		8849		8850		8885		8891	
		Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
Emission $H\delta$.....	4101·890	+28·8	2	+ 7·4	2	.....	....	.....	....	.....	....	.....	....
Emission $H\gamma$.....	4340·634	+14·7	8	+ 7·9	8	+59·9	8	− 1·1	8	.....	....	+46·3	9
Absorption C.....	4650·925	+39·2	4	.....	....	.....	....	.....	....	.....	....	.....	....
Emission $H\beta$.....	4861·527	+20·7	8	+23·9	8	+30·2	4	−10·1	4	+14·3	4	+42·9	5

LINES AND MEASURES OF θ^2 ORIONIS—*Continued*

Element	λ	8892		8893		8894		8895		8898		8899	
		Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
Emission $H\gamma$.....	4340·634	+45·2	6	+39·6	8	+22·6	6	+33·9	8	+24·9	9	+36·2	9
Emission $H\beta$.....	4861·527	+41·3	8	+44·5	7	+36·6	7	+33·4	8	+31·8	8	+30·2	5

As a rule the absorption lines are very broad and diffuse, and it is to be expected that these lines alone would not give us very reliable velocities. The emission lines on the contrary are as sharp as the finest of the lines of the comparison spectrum of iron-vanadium, their measuring is easy and the results obtained are undoubtedly of the greatest accuracy. From measures of these emission lines (which always divide the absorption lines into two equal parts) and occasionally an absorption line without any emission, the above results were obtained. The reduced velocities as given by the various plates are summarized below.

Plate	Date	Velocity	
8846	1919, Dec. 14·683.....	+22·1	±3·5
8848	" 15·651.....	+14·1	±3·8
8849	" 15·729.....	+48·9	±9·5
8850	" 15·808.....	− 5·4	±2·8
8885	1920, Jan. 9·755.....	+ 1·9	only one line
8891	" 14·609.....	+30·9	±1·0
8892	" 14·674.....	+28·6	±0·5
8893	" 14·740.....	+27·5	±0·7
8894	" 15·628.....	+15·5	±1·8
8895	" 15·694.....	+19·0	±0·1
8898	" 18·628.....	+12·3	±0·9
8899	" 18·694.....	+18·3	±0·9

The large velocity indicated by plate 8849 has to be discarded, however, on account of the great change of temperature of the prism box, a sudden change of temperature having occurred during the exposure.

Our velocities indicate without any doubt that the star is a spectroscopic binary, having probably a rather short period (a few days), if there is a period. The range we find is about 36 km.

χ^2 ORIONIS

This star was found to be a spectroscopic binary by Merrill at the Lick Observatory. The spectrum is fairly good for an early class B star; however, among the great number of lines it has, there are many that are very diffuse and that cannot furnish any reliable radial velocities. The lines found in its spectrum together with their widths and the velocities they yield are given in the following table.

CHARACTERISTICS OF LINES IN THE SPECTRUM OF χ^2 ORIONIS

Element	λ	Width in A.	8875		8877		8878		8879	
			Vel.	Wt.	Vel	Wt.	Vel.	Wt.	Vel.	Wt.
(Ca)K	3933·825	2·0	.....	.....	.....	.....	.....	.....	.....	.....
Hε	3970·177	2·6	.....	.....	.....	.....	.....	.....	.....	.....
N	3995·26	diffuse	.....	.....	.....	.....	.....	.....	.....	.....
He	4009·417	2·2	.....	.....	.....	.....	.....	.....	.....	.....
He	4026·352	2·1	+13·0	3	.....	.....	.....	.....	.....	.....
Hδ	4101·890	2·6	− 5·6	5	+ 4·7	4	−14·0	4	.....	.....
He	4121·016	1·8	+ 3·8	3	.....	.....	.....	.....	.....	.....
He	4143·928	1·8	+17·5	5	− 6·8	3	+13·5	5	.....	.....
H	4200·5	1·8	+ 9·1	4	.....	.....	.....	.....	.....	.....
S	4253·77	diffuse	.....	.....	.....	.....	.....	.....	.....	.....
C	4267·301	diffuse	.....	.....	.....	.....	−10·7	4	.....	.....
O	4317·272	diffuse	.....	.....	.....	.....	.....	.....	.....	.....
Hγ	4340·634	2·2	−20·3	6	− 3·4	9	− 6·8	7	−14·7	9
O	4349·541	1·1	.....	.....	− 4·5	7	.....	.....	.....	.....
O	4367·012	diffuse	.....	.....	.....	.....	.....	.....	.....	.....
He	4388·100	1·9	+ 5·9	6	− 4·7	3	− 7·0	5	+10·5	8
?	4415·293	diffuse	.....	.....	.....	.....	.....	.....	.....	.....
He	4471·676	2·7	− 1·2	9	+16·1	8	+ 2·5	9	+ 8·7	3
N	4530·08	diffuse	.....	.....	+45·2	4	.....	.....	.....	.....
Si	4552·636	2·0	+23·6	5	+32·8	3	+15·7	6	+27·5	2
Si	4567·897	2·4	+ 5·3	5	+34·6	3	+ 9·3	6	+16·0	2
Si	4574·791	1·8	+37·2	5	.....	.....	+34·6	6	− 2·6	1
O	4596·291	diffuse	.....	.....	.....	.....	.....	.....	.....	.....
N	4601·632	2·3	.....	.....	.....	.....	.....	.....	+10·9	1
N	4607·305	3·7	+27·2	3	.....	.....	.....	.....	+13·6	1
N	4621·548	2·2	.....	.....	.....	.....	.....	.....	.....	.....
N	4630·703	2·8	.....	.....	.....	.....	.....	.....	.....	.....
N	4643·244	2·3	.....	.....	.....	.....	.....	.....	.....	.....
C	4650·925	3·2	.....	.....	.....	.....	.....	.....	.....	.....
N	4661·728	2·3	.....	.....	.....	.....	.....	.....	.....	.....
Hβ	4861·527	4·3	−23·9	1	− 6·4	2	.....	.....	−19·1	3

A summary of the various velocities, including the reduced results obtained from the above measures, is given in the following table.

Place	Plate	Date	Velocity
Lick*	.....	1908, Oct. 27·065	+19·1
"	.....	1909, Oct. 14·996	+27·1
"	.....	..... Dec. 27·814	+26·0
"	.....	1910, Mar. 3·661	+27·9
"	.....	..... Oct. 31·948	+14·4
Ottawa	8875	1919, Dec. 18·682	+14·1
"	8877	..... " 18·783	+15·7
"	8878	..... " 18·819	+10·2
"	8879	..... " 18·861	+12·2

In these velocities we did not take account of the velocities given by the hydrogen lines of the Balmer series, which usually gave negative velocities. The fact that the hydrogen lines give velocities different from the other lines is true in a certain number of stars; we have found it in the case of κ Cassiopeiæ and ζ Cassiopeiæ. The results obtained above do not seem to indicate any very short period variation in the star's radial velocity.

* *L. O. B.* 199

RELATION OF THE LINE WIDTHS TO THE POSITION OF THE STAR FAR FROM, OR NEAR, NEBULOUS CLOUDS

If we consider the approximate line-widths of two important lines $H\gamma$ 4340 and *He* 4471 for the stars studied above we have the following table:

Star	Width in ang. units		Physical appearance of region where star is located
	$H\gamma$ 4340	*He* 4471	
γ Pegasi	5·2	4·0	
λ Cassiopeiæ	6·8	.....	
κ Cassiopeiæ	3·9	3·0	Rather dense region of the Milky Way, but apparently no nebulosity nor dark current (Barnard photograph).
H. R. 144	8·1	4·2	
ζ Cassiopeiæ	7·3	2·3	
ξ Cassiopeiæ	diffuse	diffuse	
δ Ceti	1·7	1·7	Not in Milky Way nor very dense region of stars.
ζ Persei	2·4	1·6	Does not seem to be very dense region (Barnard photograph).
λ Eridani	13·4	9·5	Dense region of stars (Bonner Durchmusterung).
θ^2 Orionis	wide +emission	wide	In the very midst of the Orion nebula.
χ^2Orionis	2·2	2·7	Not near nebulosity nor very dense region of stars.

The data we have about the relation of the above stars to nebulous regions of the sky is very scant. Outside of the photographs of Barnard (*Publications of the Lick Observatory*, Vol. XI) and the photographs of Isaac Roberts, no large atlas showing in sufficient detail all the nebulous and close starry regions of the sky seems to have been published. However, there seem to be indications that the widths of the lines in spectra of class B stars are functions of the depths or densities of nebulous clouds in which they are located.

Dominion Observatory
Ottawa,
March 6, 1920.