1940ApJ....91..546S

SPECTROGRAPHIC OBSERVATIONS OF PECULIAR STARS*

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ABSTRACT

1. The spectra of several absorption O-type stars showing vestiges of Wolf-Rayet emission have been investigated from λ 3300 to λ 6700. The absorption spectrum consists mainly of *H*, *He* II, *He* I, *O* III, *O* IV, *N* III, *N* IV, and *Si* IV. The emission lines show a P Cygni character and are confined to *H*, *He* I, and a few transitions of *He* II, *N* III, *N* IV, *N* V, *C* III, and *Si* IV. The location of the expanding shell giving rise to the emission and absorption lines is estimated.

2. The visual spectrum of P Cygni reveals strong *Fe* III lines originating from metastable levels (dilution effect). Lines of other elements show a peculiar selectivity of the emission lines.

The spectra of three other P Cygni type stars (Z Canis Majoris, BD+47°3487, and BD+11°4673) are described, especially in connection with the phenomena arising in expanding shells.

RY Scuti shows a strong system of forbidden [*Fe* III] lines, and the variations in the spectrum of this star are discussed.

3. The ultraviolet region of the spectrum of ζ Tauri shows several sets of absorption lines (*H*, *He*, and ionized metals) arising from the reversing layer and from various layers in the surrounding shell. The $a^5D - 4p^5P^0$ multiplet of *Fe* III was the most conspicuous feature in the visual region of γ Cassiopeiae in March, 1940. New data are given for the spectra of several other stars with extended shells (MtW 143, HD 218393, HD 160529, and HD 190073). A group of stars showing forbidden [*Fe* II] lines is discussed (WY Geminorum, W Cephei, B 1985, B 5481, and HD 45677); and new [*Fe* II] multiplets are found in the ultraviolet region of these objects.

4. The spectra of four binary systems showing simultaneously an M-type spectrum and forbidden lines of high excitation are described in detail. The spectroscopic phenomena accompanying the recent outburst of Z Andromedae are discussed; the continuous absorption in the shell plays an important role in the relative intensities of the emission and absorption components of the P Cygni type lines. The two stars AX Persei and CI Cygni have very similar bright-line spectra, of which the nebular part shows a very high excitation; besides *H*, *He* I, and *He* II, the strongest lines are due to [*Fe* VII] and [*Ne* V], and there is good evidence in favor of [*Fe* X]. The temperature of the nucleus exciting these nebular lines must be of the order of 150,000°, or more. Another multiple object of lower excitation is R Aquarii, and new spectroscopic data show the occultation effect of the nebula by the *TiO* atmosphere of the late-type component. There is good reason to believe that the binary nature of a star stimulates the process of shell formation.

The new quartz spectrograph of the McDonald Observatory is well suited for observations in the region between λ 3200 and λ 3900, where heretofore few peculiar stars have been observed. The purpose of the present investigation is to gather new material in this region, toward the study of extended stellar atmospheres. The stars

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* *Contributions from the McDonald Observatory, University of Texas*, No. 22.

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which we have observed and the data of the observations are given in Table 1. All the stars have been observed previously in the ordinary photographic region. In two cases, namely those of P Cygni and γ Cassiopeiae, we have observed the visual region with a special grating spectrograph. In all other cases the prism spectrograph was used, for which the dispersion in the visual region is relatively insufficient. The photographic region, although observed previously by Merrill, H. H. Plaskett, and others, has been measured in most cases, partly to record changes which have taken place since the former observations were made and partly to study the lines of especially interesting atoms, such as [*Fe* III], [*Fe* VII], etc.

Our observations cover a short interval of time and are, therefore, not in themselves suitable for a study of the changes which take place in these interesting spectra. But in conjunction with the work of others and with additional observations, which we hope to secure in the future, they should be helpful in elucidating such remarkable phenomena as the outburst of Z Andromedae or the periodic changes of BD+11°4673.

Although the new material contains a wealth of information on various types of departures from thermodynamic equilibrium, on fluorescence processes, on the origin of the forbidden lines, and on the relative intensities of the forbidden lines, we have in most cases presented only the results of the observations and have in only a few instances attempted to interpret the results. The complete theoretical evaluation of the observations must wait until more material is available.

The material is presented in five sections: Section I deals with several absorption O stars which show vestiges of Wolf-Rayet character; Section II deals with P Cygni type stars; Section III is devoted to a number of interesting Be stars; Section IV discusses the spectra of several stars which combine features of very high and of very low excitation; and Section V contains some of our conclusions.

In the wave-length tables the individual wave lengths of the emission lines were adjusted to correspond with the laboratory values. Except in those cases in which radial velocity results are specifically mentioned, these wave lengths should not be used to determine the radial velocities of emission lines. The wave lengths of the absorption

TABLE 1

LIST OF OBSERVATIONS

HD	BD	Name	α 1900	δ 1900	Sp.	Mag.	Plate	Date	Mid. Exp. U.T.	Exp.	Dispersion at λ 3933
				Section I							
188001....	+18°4276	9 Sagittae	$19^h47^m.9$	+18°25′	O7	6.3	CQ 223	1939, Sept. 10	6^h11^m	3^h30^m	40 A/mm
							251	16	5 00	0 28	40
							260	23	3 53	1 00	40
190429....	+35 3930 N.	....	19 59.8	+35 45	O5	7.2	213	9	6 43	1 00	40
							261	23	5 43	2 00	40
34656....	+37 1146	....	5 14.0	+37 20	O6	6.7	228	10	10 07	0 30	40
190864....	+35 3949	....	20 1.9	+35 19	O6	8.0	259	22	5 56	2 06	40
	+21 1609	Nucleus of NGC 2392	7 23.3	+21 07	O	10.0	F/2q492	Oct. 6	10 18	1 04	100
							F/2g629	Dec. 16	12 24	0 16	50
							F/2q750	1940, Feb. 2	9 56	0 30	100
				Section II							
193237....	+37°3871	P Cygni	$20^h14^m.1$	+37°43′	B1p	4.7	G 6	1939, Sept. 20	3^h23^m	2^h00^m	26 A/mm
							G 7	20	5 56	3 00	26
53179....	−11 1760	Z Canis Majoris	6 59.0	−11 24	Beq	8.4–11.5	F/2q493	Oct. 6	11 29	0 50	100
							F/2g594	Dec. 5	10 35	2 00	50
							F/2g668	Dec. 21	8 53	2 45	50
							F/2q749	1940, Feb. 2	6 39	1 12	100
	+47 3487	MWC 374	21 32.2	+47 25	B3eq	9.1	F/2g356	1939, Sept. 13	9 8	2 15	50
							F/2q386	25	5 24	1 36	100
							F/2q387	25	6 34	0 30	100
							F/2g409	29	4 08	0 30	50

TABLE 1—*Continued*

HD	BD	Name	α 1900	δ 1900	Sp.	Mag.	Plate	Date	Mid. Exp. U.T.	Exp.	Dispersion at λ 3933
				Section II—*Continued*							
207757....	+11°4673	AG Pegasi	$21^{h}46^{m}2$	+12°09′	Bep	6.3–7.9	F/2g410	1939, Sept. 29	$4^{h}33^{m}$	$0^{h}05^{m}$	50 A/mm
							F/2g411	29	4 44	0 10	50
							F/2q456	Oct. 4	6 29	0 10	100
							F/2q457	4	6 41	0 05	100
							CQ 279	Nov. 14	2 10	2 40	40
							281	31	3 05	2 40	40
169515....	−12 5045	RY Scuti	18 19.9	−12 45	Pec.	9.6–10.4	F/2q354	1939, Sept. 9	2 59	1 47	100
							F/2g358	14	3 52	3 00	50
							CQ 258	22	3 08	3 00	40
							F/2g377	23	2 19	1 10	50
							F/2g383	24	1 37	0 20	50
							F/2g405	29	1 43	0 50	50
							F/2q462	Oct. 5	1 40	1 00	100
				Section III							
37202....	+21°908	ζ Tauri	$5^{h}31^{m}.7$	+21°05′	B3e	3.0	CQ 216	1939, Sept. 9	$10^{h}02^{m}$	$0^{h}15^{m}$	40 A/mm
							267	24	9 26	0 05	40
10516....	+49 444	φ Persei	1 37.4	+50 11	Bone	4.2	215	9	9 26	0 30	40
							264	24	8 01	0 10	40
5394....	+60 144	γ Cassiopeiae	0 50.7	+60 11	Bop	2.2	G 22	1940, Mar. 17	2 24	0 21	26
							G 23	17	3 01	0 33	26

TABLE 1—*Continued*

HD	BD	Name	α 1900	δ 1900	Sp.	Mag.	Plate	Date	Mid. Exp. U.T.	Exp.	Dispersion at λ 3933
				Section III—*Continued*							
190073....	+ 5°4393	....	$19^h58^m.1$	+ 5°28′	Aoep	7.9	CQ 238	1939, Sept. 11	7^h59^m	1^h23^m	40 A/mm
							270	25	2 50	2 00	40
186568....	+33 3572	....	19 40.1	+33 55	Ao	6.0	222	10	4 00	0 30	40
							234	11	4 52	0 30	40
160529....	−33 12361	....	17 35.3	−33 27	A4se	6.7	221	10	3 00	1 00	40
							233	11	2 10	0 30	40
....	....	MtW 143	4 11.6	+55 46	Bep	11.5	F/2g361	14	11 12	1 24	50
							F/2q491	Oct. 6	9 03	1 00	100
218393....	+49 4045	MWC 397	23 2.6	+49 40	Ave	6.8	CQ 214	Sept. 9	8 18	1 13	40
42474....	+23 1243	WY Geminorum	6 5.8	+23 14	M3ep	7.4–7.9	F/2q366	21	11 15	1 00	100
							F/2q367	21	11 54	0 10	100
							CQ 269	24	11 02	1 45	40
							F/2g423	30	10 03	0 40	50
							F/2g424	30	10 31	0 05	50
							CQ 282	Dec. 1	7 50	4 00	40
							285	3	6 28	4 03	40
							289	4	5 59	4 03	40
214369....	+57 2568	W Cephei	22 32.6	+57 54	K5e	8.6–9.3	F/2g412	Sept. 29	5 11	0 20	50
							F/2g413	29	5 28	0 05	50
							F/2g431	Oct. 1	6 23	0 01½	50
							F/2g432	1	6 34	0 02½	50
							F/2q458	4	6 55	0 10	100
							F/2q472	5	5 51	1 00	100
							F/2q589	Dec. 4	2 35	2 08	100

TABLE 1—*Continued*

HD	BD	Name	α 1900	δ 1900	Sp.	Mag.	Plate	Date	Mid. Exp. U.T.	Exp.	Dispersion at λ 3933
				Section III—*Continued*							
60414 60415 ...	$-14^\circ 1971$	Boss 1985	$7^h29^m.2$	$-14^\circ 18'$	M2ep	5.2	F/2g426	1939, Sept. 30	11^h03^m	$0^h01\frac{1}{2}^m$	50 A/mm
							F/2q494	Oct. 6	12 05	0 05	100
							CQ 280	Nov. 14	11 20	2 00	40
							286	Dec. 3	9 38	2 00	40
203338 203339 ...	+58 2249	Boss 5481	21 16.5	+58 13	K0+ A0	5.6	F/2g407	Sept. 29	3 36	0 05	50
							F/2g408	Sept. 29	3 42	0 01	50
							F/2q454	Oct. 4	6 04	0 05	100
							F/2q455	Oct. 4	6 12	0 01	100
45677....	−12 1500	....	6 23.7	−13 00	B2e	7.2	CQ 275	Nov. 7	12 12	3 45	40
							CQ 283	Dec. 2	10 01	3 33	40
				Section IV							
221650....	$+48^\circ 4093$	Z Andromedae	$23^h28^m.8$	$+48^\circ 16'$	......	8.3–11.4	F/2g360	1939, Sept. 14	9^h18^m	1^h35^m	50 A/mm
							CQ 252	16	8 15	5 30	40
							F/2q471	Oct. 5	4 59	0 30	100
							F/2q489	6	7 54	0 11	100
							F/2q490	6	8 13	0 20	100
							F/2q501	12	7 50	0 08	100
							F/2q502	12	8 01	0 03	100
							CQ 271	18	4 33	3 15	40
							CQ 290	Dec. 5	3 00	2 00	40

TABLE 1—*Continued*

HD	BD	Name	α 1900	δ 1900	Sp.	Mag.	Plate	Date	Mid. Exp. U.T.	Exp.	Dispersion at λ 3933
					Section IV—*Continued*						
....	....	AX Persei	$1^h30^m.0$	$+53^\circ45'$	......	11.0	F/2q363	1939, Sept. 18	11^h00^m	1^h46^m	100 A/mm
							F/2q365	21	9 00	3 00	100
							F/2g415	29	6 58	1 02	50
							F/2q757	1940, Feb. 5	3 12	1 04	100
....	....	CI Cygni	19 46.5	+35 26	......	11.0	F/2g429	1939, Oct. 1	5 06	1 30	50
							F/2q453	4	5 03	1 30	100
222800....	$-15^\circ6352$	R Aquarii	23 38.6	−15 50	Md	5.8–10.8	F/2g359	Sept. 14	6 59	2 31	50
							CQ 257	18	5 59	2 32	40
							F/2q362	18	8 30	2 00	100
							F/2g414	29	5 55	0 30	50
							F/2g433	Oct. 1	6 57	0 10	50
							F/2g595	Dec. 6	1 06	0 12	50

lines of the P Cygni type stars were not corrected for the velocity of expansion, except in Table 15, where they were also adjusted to correspond with the laboratory values.

I. ABSORPTION O STARS WITH EMISSION LINES

These stars are intermediate between Wolf-Rayet stars and P Cygni stars. The purpose of our work was to investigate the ultraviolet region of the spectrum, which has not formerly been described, and to discuss the spectral features of the photographic and the visual regions in the light of recent work on the spectra of highly ionized light atoms.

Former investigations by W. H. Wright[1] and by H. H. Plaskett[2] were largely devoted to the O stars: 9 Sagittae, BD+35°3930 N., 29 Canis Majoris, and the nucleus of the planetary nebula NGC 2392. Besides the bright *He* II line at λ 4686, these authors mention two bright *N* III lines at λ 4634 and λ 4640. The occurrence in emission of these particular *N* III lines seems at first very strange;[3] in early B stars and in pure absorption O stars, the lines λ 4097 and λ 4103 are always much stronger than λ 4634 and λ 4640; but in the four stars just mentioned, only the lines λ 4634 and λ 4640 appear in emission, whereas λ 4097 and λ 4103 are strong absorption lines.

C. H. Payne[4] examined the spectra of several southern stars of class O, taken with an objective prism and covering the photographic region. Among these objects, nine may be considered as essentially absorption O stars. All of them show *He* II 4686 and *N* III 4634 and 4640 in emission. In one case (HD 152408) these bright lines show an absorption companion on the violet side; in the same star $H\beta$, $H\gamma$, $H\delta$, *Si* IV 4116, *He* I 4471, and *Mg* II 4481 show both absorption and emission.

We shall discuss the spectra of 9 Sagittae, of BD+35°3930 N., and of the nucleus of NGC 2392, using spectrograms obtained at the Cassegrain focus of the 82-inch McDonald reflector. The spectrograms extend from λ 3327 to λ 6678. For comparison we have also

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[1] *Pub. Lick Obs.*, **13**, 206, 1918.

[2] *Pub. Dom. Ap. Obs., Victoria*, **1**, 325, 1922.

[3] Dr. W. H. Wright has called our attention to this peculiar behavior of *N* III.

[4] *Harvard Bull.*, Nos. 842, 843, 844, 1927.

examined two other O stars, HD 34656 and HD 190864, which at certain times have been observed to possess *N* III emission at λ 4634 and λ 4640. However, on our plates, taken on September 10 and September 12, 1939, there is no trace of emission. The fact that the *N* III emission is not permanent is of interest.

1. 9 SAGITTAE

This star is often considered as an absorption O-type star showing vestiges of Wolf-Rayet character. It was classified as O7w by C. H. Payne.[5] Three spectrograms have been measured, one on a Process plate and two others on Agfa Superpan Press film. The list of wave lengths and their identifications are given in Table 2. The scale of stellar intensities ranges from 0 (trace) to 10. The letter "s" designates a sharp line; "n," a nebulous line. The strong interstellar *Ti* II line λ 3384 was not included. Plaskett's list[2] contained the twenty-six strongest lines between *Ca* II K and $H\beta$.

Hydrogen.—The Balmer series may be followed to H_{24}. $H\alpha$ appears as a line of the P Cygni type.[6] $H\beta$ is an undisplaced absorption line; the weak emission on the violet wing is probably not due to $H\beta$.

He I.—The triplets are much stronger than the singlets, as compared with the laboratory intensities. The series $2p^1P^0 - nd^1D$ appears only for $n \leqslant 7$; whereas $2p^3P^0 - nd^3D$ is still present for $n = 14$. All these lines appear in the star itself; there seems to be some slight departure from thermodynamic equilibrium in the stellar reversing layer, but this matter will not be discussed here, since the much more extreme case of P Cygni has been investigated recently by Struve and Roach.[7] The line $2p^3P^0 - 3d^3D$ at λ 5875.62 is displaced toward the violet and shows possibly a weak emission at the normal wave length. This absorption line would thus originate in an expanding shell of the P Cygni type. The line $2p^1P^0 - 3d^1D$ at λ 6678 seems to have a similar structure.

The two absorption lines λ 3613.64 ($2s^1S - 5p^1P^0$) and λ 3888.65 ($2s^3S - 3p^3P^0$), whose lower levels are metastable, seem to be accom-

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[5] *Stars of High Luminosity*, p. 67 (*Harvard Obs. Mono.*, No. 3, 1930).

[6] Merrill records (*Lick Obs. Bull.*, **8**, 24, 1913) that in 1913 $H\alpha$ was not present in emission.

[7] *Ap. J.*, **90**, 727, 1939.

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TABLE 2

LINES IN 9 SAGITTAE

λ	Int.	Identification			Note
		Elem.	λ	Int.	
3327.2	0	......	....	.....	
3340.89	4	*O* III	3340.74	6	
3348.2	0	*O* IV *O* IV *O* III	3348.08 3349.11 3348.05	2 3 2	
3354.56	3	*N* III *N* III *O* III *O* IV *He* I	3354.29 3353.78 3355.92 3353.70 3354.52	7 6 3 2 1	
3360.54	2s	......	....	.....	
3367.58	3	*N* III *Ca* III	3367.36 3367.81	7 5	
3373.95	2	*N* III *Ca* III	3374.06 3372.68	6 8	
3384.66	1	*O* III *O* III	3384.95 3383.85	4 2	
3386.2	1	*O* IV	3385.55	6	
3390.0	1	*O* II	3390.25	8	
3390.9	1	......	....	.....	
3397.41	2n	......	....	.....	
3401.53	1s	......	....	.....	
3411.42	1	*O* IV	3411.76	4	
3430.47	1	*O* III	3430.60	4	
3433.13	1	......	....	.....	
3440.50	1	*O* III	3440.39	4	
3444.20	1	*O* III	3444.10	5	
3447.71	1	*He* I	3447.59	2	
3463.9	0	*N* IV	3463.4	1	
3468.0	0	......	....	.....	
3471.88	2	*He* I	3471.78	.....	1
3478.66	5	*N* IV	3478.69	7	
3480.42	0	......	....	.....	2
3482.50	2	*N* IV	3482.98	5	
3487.8	0	*He* I	3487.72	.....	
3498.62	1	*He* I	3498.63	1	
3530.48	1	*He* I	3530.50	1	
3554.67	2n	*He* I	3554.5	1	
3563.8	0n	*O* IV	3563.36	2	
3567.2	0n	......	....	.....	
3583.80	1s	......	....	.....	
3587.0	2n	*He* I	3587.4	1	
3600.41	1	(*Fe* III	3600.93	10)	
3604.03	1	(*Fe* III	3603.88	9)	
3609.79	1s	*C* III	3609.40	5	
3611.36	1s	*He* I	3613.64	3	3
3613.62	2	*He* I	3613.64	3	
3623.68	1s	......	....	.....	
3634.35	5	*He* I	3634.3	2	
3638.77	0	*O* III	3638.70	3	
3643.41	2	......	....	.....	
3653.36	1	......	....	.....	
3663.82	0	*Ne* II	3664.09	9	
3672.23	1n	H_{24} H_{23}	3671.48 3673.76	....	
3676.4	1	H_{22}	3676.36	.....	
3679.4	1	H_{21}	3679.35	.....	
3682.46	1	H_{20}	3682.81	.....	
3686.58	1	H_{19}	3686.83	.....	
3691.89	1	H_{18}	3691.56	.....	
3694.43	2s	*Ne* II (*O* III	3694.22 3695.37	10 4)	
3696.83	1	H_{17}	3697.15	.....	
3699.05	2	*O* III	3698.70	5	
3704.45	4n	H_{16} *He* I *O* III *O* III *O* III	3703.85 3705.00 3702.75 3703.37 3704.73	..... 3 5 5 3	
3707.50	1	*O* III	3707.24	6	
3709.66	1	*Ne* II (*O* III	3709.64 3709.52	7 2)	
3711.90	3	H_{15}	3711.97	.....	
3715.03	3	*O* III	3715.08	6	
3721.77	4	H_{14}	3721.94	.....	
3725.6	0	*O* III *O* IV	3725.30 3725.81	3 2	
3727.8	0	*Ne* II *O* II	3727.08 3727.33	9 8	
3730.8	0	......	....	.....	
3734.43	4	H_{13}	3734.37	.....	
3738.92	1	......	....	.....	
3744.2	0	*O* IV?	3744.73	.....	
3748.23	1	*N* III *N* IV *S* III	3747.66 3747.7 3747.90	..... 0 5	
3750.40	4	H_{12}	3750.15	.....	
3753.03	1	......	....	.....	
3754.70	2	*O* III *N* III	3754.67 3754.62	7 6	
3757.17	3	*O* III *O* IV	3757.21 3756.9	5	
3759.85	5	*O* III	3759.87	9	
3761.89	1	*Ca* III *O* II *Si* IV	3761.62 3762.63 3762.41	6 5 4	
3769.7	1	*He* II	3769.3	.....	
3770.60	5	H_{11} *N* III	3770.63 3771.08	 7	
3774.47	1	*O* III	3774.00	6	
3777.0	0n	*Ne* II	3777.16	8	
3781.74	1	*He* II	3781.71	.....	
3787.5	0	......	....	.....	
3791.16	4	*O* III	3791.26	6	
3794.1	0	(*S* III	3794.69	6)	
3796.8	2	*He* II	3796.36	.....	
3798.05	6	H_{10}	3797.90	.....	
3803.30	1	(*O* II	3803.14	6)	
3808.0	1	......	....	.....	
3810.59	1	*O* III	3810.96	2	
3813.54	2	*He* II	3813.53	.....	
3819.51	5	*He* I	3819.61	4	
3824.23	0	*N* IV	3824	.....	
3834.49	2	*He* II	3833.83	.....	
3835.58	6	H_{9}	3835.39	.....	
3847.79	1	......	....	.....	
3858.30	2	*He* II	3858.10	.....	
3862.5	0	......	....	.....	
3867.18	1	*He* I	3867.46	2	
3882.13	1	*O* II	3882.19	7	
3886.33	1s	*He* I	3888.65	10	3
3887.70	2	*He* II	3887.47	.....	
3889.17	6	H_{8} *He* I	3889.05 3888.65	 10	
3896.74	1	......	....	.....	
3900.33	1	(*A* II (*Al* II	3900.63 3900.68	5) 10)	
3905.59	1	......	....	.....	
3909.55	1	......	....	.....	
3919.50	1	*O* II	3919.28	6	
3923.76	3	*He* II	3923.51	.....	
3927.96	1	......	....	.....	
3929.8	1	......	....	.....	
3961.96	3	*O* III	3961.59	8	
3964.52	2	*He* I	3964.73	4	
3968.20	7	*Ca* II *He* II	3968.49 3968.47	....	4
3970.20	7	$H\epsilon$	3970.08	.....	
3998.15	1	*N* III	3998.69	3	
4003.87	1	*N* III	4003.64	4	

TABLE 2—*Continued*

λ	Int.	Identification			Note
		Elem.	λ	Int.	
4005.4	0	......	....	.....	
4009.8	1	(*He* I	4009.27	1)	
4020.22	1	......	....	.....	
4026.09	7	*He* I	4026.19	5	
		He II	4025.64	.....	
4030.93	1	......	....	.....	
4051.1	0	......	....	.....	
4057.74	2	*N* IV	4057.80	2	
4062.64	1	......	....	.....	
4067.3	1	*C* III	4067.87	6	
4068.9	1	*C* III	4068.94	7	
4070.5	1	*C* III	4070.43	8	
4081.3	0	*O* III	4081.10	1	
		Ca III	4081.74	5	
4088.89	6	*Si* IV	4088.86	10	
4092.11	2	......	....	.....	
4094.28	2	......	....	.....	
4097.14	6	*N* III	4097.31	10	
4100.5	2	*He* II	4100.08	2	
4101.7	7	*H*δ	4101.74	.....	
4103.7	6	*N* III	4103.37	9	
4108.11	1	......	....	.....	
4116.34	3	*Si* IV	4116.10	8	
4120.87	2	*He* I	4120.81	3	
4143.64	2	*He* I	4143.77	2	
4156.21	2	......	....	.....	
4168.84	0	*He* I	4168.97	1	
4186.30	1	*C* III	4187.05	10	
		O II	4185.45	8	
4195.56	2	*N* III	4195.70	5	
4199.93	5	*N* III	4200.02	6	
		He II	4199.87	2	
4207.4	0	*Ca* III	4207.26	10	
		Ti III	4207.54	3	
4212.77	1	*Si* IV	4212.44	3	
		Ca III	4213.15	5	
4215.67	1	*N* III	4215.69	3	
		Ti III	4215.55	5	
4234.65	1	......	....	.....	
4267.5	1	*C* II	4267.27	20	
		C II	4267.02	19	
4325.15	1	*C* III	4325.70	8	
4338.29	2	*He* II	4338.71	3	
4340.43	10	*H*γ	4340.47	.....	
4350.1	0	......	....	.....	
4356.8	0	......	....	.....	
4368.8	1	......	....	.....	
4379.15	2	*N* III	4379.09	10	
4387.87	2	*He* I	4387.93	3	
4403.8	0	(*Ti* IV	4403.54	2)	
4420.1	0	(*Fe* III	4419.61	10)	
4448.0:	0	......	....	.....	
4463.17	2	......	....	.....	
4471.43	8	*He* I	4471.48	6	
4476.1	0	......	....	.....	
4479.9	2	(*N* IV	4479	...)	
4482.8	3	......	....	.....	5
4485.43	2E	......	....	.....	5
4489.74	3	......	....	.....	
4494.13	2	(*N* IV	4495	...)	
4500.3	3	......	....	.....	3
(4504.0	2E)	......	....	.....	3
4510.4	2	*N* III	4510.92	6	
4515.1	2	*N* III	4514.89	7	
4524.12	2	*N* III	4523.60	4	6
4534.94	2	*N* III	4534.57	3	
		N III	4535.11	2	6
4541.57	8	*He* II	4541.63	5	
4630.97	4	*N* III	4634.16	9	7
4634.13	5E				
4638.42	5	*N* III	4640.64	10	7
4641.22	6E	*N* III	4641.90	3	
4647.53	2	*C* III	4647.40	10	
		C IV	4646.5	.....	
		Ti IV	4647	3	
4654.3	1	*Si* IV	4654.14	4n	
4675.8	2	......	....	.....	5, 10
4679.3	2E	......	....	.....	5, 10
4682.8	2	*He* II	4685.81	300	8
4685.9	2E				8
4705.0	2	......	....	.....	9, 10
4708.6	2E	......	....	.....	9, 10
4713.3	2	*He* I	4713.14	3	
4736.1	0	*A* II	4735.93	15	
4848.6	2	......	....	....	10
4853.2	2	......	....	....	
4855.9	3E	......	....	....	
4859.2	3	*He* II	4859.36	7	
4861.0	7	*H*β	4861.34	.....	
4921.7	2	*He* I	4921.93	4	
5015.8	3	*He* I	5015.67	6	
5136.1	2	......	....	.....	
5411.5	7	*He* II	5411.57	50	
5426.9	0	......	....	.....	
5592.4	2	*O* III	5592.37	6	
5695.8	3E	*C* III	5696.0	5	8
5872.2	4	*He* I	5875.62	10	11
5893.0	3	......	....	.....	12
6077.5	2	......	....	.....	
6280.6	0n	......	....	.....	13
6555.6	3	*H*α	6562.82	.....	8
6563.0	5E	*He* II	6560.16	.....	8
6678	2	*He* I	6678.15	6	

NOTES TO TABLE 2

The unblended interstellar lines of *Ca* II and *Ti* II are not included in the table.

1. *He* I is only a weak contributor.
2. Unidentified line, present in the B-type stars; see O. Struve, *Ap. J.*, **90**, 699, 1939.
3. Line presumably due to the expanding shell; somewhat uncertain.
4. Interstellar.
5. Unidentified lines of P Cygni character, originating in the shell.
6. Another contributor probable.
7. These *N* III lines of the P Cygni type are due to the shell.
8. Lines originating in the shell.
9. Lines originating in the shell, but bright component uncertain.
10. Very difficult region; measures uncertain.
11. Possibly weak emission on red side of the absorption line. This absorption is due to both the star and the shell.
12. Probably interstellar (D lines of *Na*).
13. Possibly interstellar.

panied by very weak absorption lines measured at λ 3611.36 and λ 3886.33. These two companions are sharper; if they are real, they are probably due to absorption in the expanding shell.[8]

He II.—H. H. Plaskett's work has shown that *He* II is strong in 9 Sagittae. He observed the series $4f^2F^o - ng^2G$ from $n = 9$ (λ 4541.63) to $n = 12$ (λ 4100.08, close to $H\delta$). On our plates this series may be observed from $n = 7$ (λ 5411.57, intensity 7) as far as $n = 22$. The even values of n give lines close to the Balmer lines, and these have been separated on our Process plate as far as H_{11}.

The series $3d^2D - nf^2F^o$ is especially interesting. The line λ 4685.81 ($n = 4$), which is the strongest *He* II line in the laboratory and in ordinary stellar spectra, appears as a very weak emission line with a weak absorption companion displaced toward the violet. On the other hand, Dr. A. B. Wyse[9] has called our attention to the fact that the line λ 3203 ($n = 5$), which is outside the wave-length range covered by our plates, is a strong absorption line. It is obvious that the "stellar" absorption line at λ 4686 must also be strong and that it has been covered by emission produced in the outer shell, whereas the stellar line λ 3203 has not been filled up by emission in the shell. A tentative interpretation of this different behavior of $3d^2D - 4f^2F^o$ and $3d^2D - 5f^2F^o$ may be found in the fairly close agreement of the line L_α (λ 1215.66) and of the *He* II line at λ 1215.13, which is the transition between the quantum levels $n = 2$ and $n = 4$. Since the $2s^2S$ level of *He* II is metastable, atoms of the shell which are in that level may absorb the Lyman α radiation emitted by the whole shell. That Lyman α is an emission line seems extremely probable, because $H\alpha$ is bright. By absorption of L_α from $2s^2S$, the *He* II atoms are brought to quantum number 4, whence they can fall down to $n = 3$, emitting λ 4686. The difference in wave lengths is compensated by the widths of the emission and absorption lines. There is no such process for λ 3203, which can, therefore, appear only as an absorption line. Lyman β (λ 1025.72) is close to the *He* II line λ 1025.27, connecting the quantum levels $n = 2$ and $n = 6$. But it is probable that the effect of L_β must be small compared with that of L_α. The

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[8] The line λ 3965 ($2s^1S - 4p^1P^o$) yields no information on this point, because a fairly strong *O* III line falls at λ 3961.59.

[9] Private communication.

effect should be largest for the $4f^2F^o - 6g^2G$ transition at λ 6560.16, but this is blended with *Hα*. These circumstances are illustrated in Figure 1. A similar behavior was observed in Nova Aquilae by Wyse.

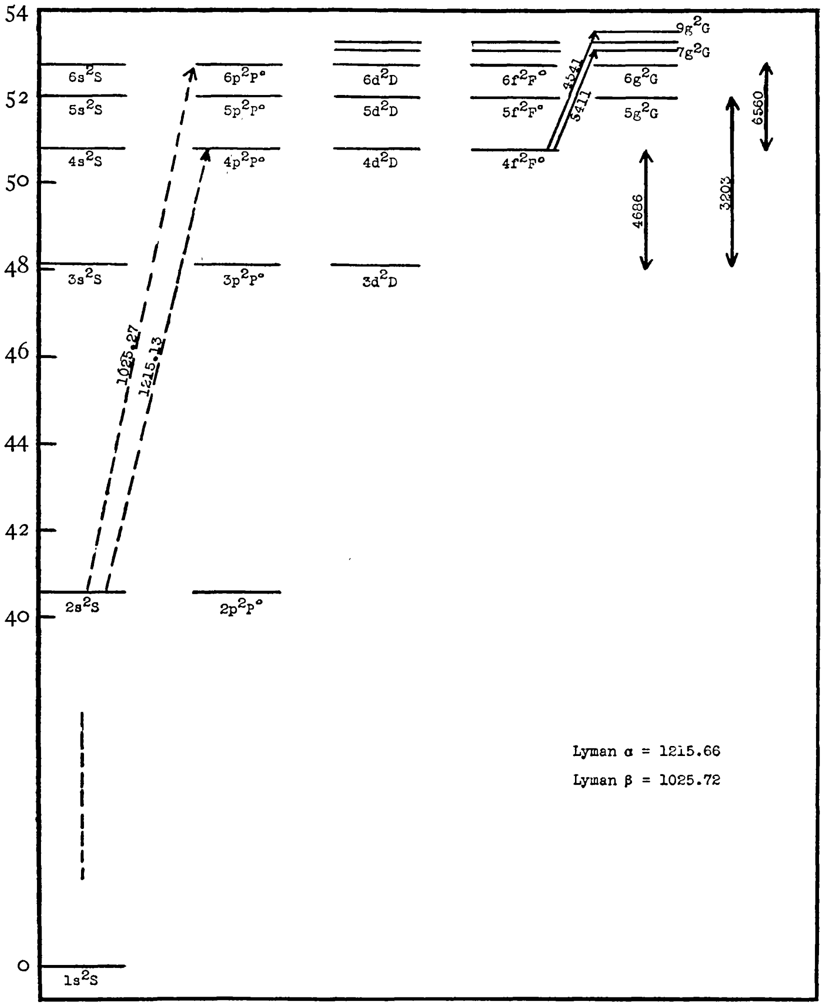

FIG. 1.—*He* II lines in 9 Sagittae

O II.—Extremely weak, no line being stronger than intensity 1 on our scale.

O III.—Strongly represented: twenty-four lines were measured, thirteen of them being free from blends. The strongest multiplets[10] are shown in Table 3.

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[10] Dr. Wyse (private communication) has observed several strong absorption lines of *O* III in the ultraviolet region, below our limit, λ 3327.

The fact that *O III* appears only in absorption and with normal intensities is of importance. For example, the presence of λ 3759.87 as a strong absorption line shows that Bowen's mechanism of excitation of the *O* III atoms by *He* II 304 does not play a role here.

TABLE 3

STRONGEST ABSORPTION LINES OF *O* III IN 9 SAGITTAE

TRANSITION		λ LAB.	INTENSITY	
			Star	Lab.
$3s^3P^o-3p^3D$...........	1–2	3754.67	2	7
(Excitation potential,	0–1	3757.21	3bl	5
33.0–36.3 v.)	2–3	3759.87	5	9
	1–1	3774.00	1	6
	2–2	3791.26	4	6
	2–1	3810.96	1	2
$3s^3P^o-3p^3S_1$...........	2–1	3340.74	4	6
(33.0–36.7 v.)				
$3p^3P-3d^3D^o$...........	0–1	3702.75	bl	5
(37.1–40.4 v.)	1–2	3707.24	1	6
	2–3	3715.08	3	6
	2–2	3725.30	0	3
$3s^1P^o-3p^1S$...........	1–0	3961.59	2	8
(33.7–36.8 v.)				
$3s^1P^o-3p^1D$...........	1–2	5592.37	2	6
(33.7–35.9 v.)				

TABLE 4

STRONGEST UNBLENDED LINES OF *N* IV IN 9 SAGITTAE

TRANSITION		λ LAB.	INTENSITY	
			Star	Lab.
$3s^3S-3p^3P^o$.........	1–2	3478.69	5	7
(46.5–50.1 v.)	1–1	3482.98	2	5
$3p^1P^o-3d^1D$.........	1–2	4057.80	2	2
(49.9–53.0 v.)				
$3s'^3P^o-3p'^3S$	0–1	4479	2	Predicted
(57.4–60.1 v.)	1–1	4495	2	Predicted

O IV.—The presence of *O* IV may be considered as certain, one of its lines, λ 3385.55 (lab. int. 6), being of intensity 3. The other line, λ 3411.76 (lab. int. 4), is also present in 9 Sagittae (int. 1).

TABLE 5

LINES OF *N* III IN 9 SAGITTAE

TRANSITION		λ LAB.	INTENSITY	
			Star	Lab.
	Doublets			
$4d^2D-5f^2F^o$ .... (39.2–42.3 v.)	1½–2½	3998.69	1	3
	2½–3½	4003.64	1	4
$3s^2S-3p^2P^o$ .... (27.3–30.3 v.)	½–1½	4097.31	6	10
	½–½	4103.37	6	9
$4p^2P^o-5s^2S$ .... (38.5–41.4 v.)	½–½	4195.70	2	5
	1½–½	4200.02	5 bl	6
$3s'^2P-3p'^2D^o$ .... (36.7–39.6 v.)	1½–1½	4215.69	1 bl	3
$4f^2F^o-5g^2G$ .... (39.7–42.4 v.)	3½–4½	4379.09	2	10
$3p^2P^o-3d^2D$ .... (30.3–33.0 v.)	½–1½	4634.16	4A–4E	9
	1½–2½	4640.64	5A–5E	10
	1½–1½	4641.90		3
	Quartets*			
$3s^4P^o-3p^4P$ .... (35.5–39.1 v.)	½–1½	3353.78	3 bl	6
	1½–2½	3354.29		7
	2½–2½	3367.36	3	7
	2½–1½	3374.06	2	6
$3s^4P^o-3p^4D$ .... (35.5–38.2 v.)	1½–2½	4510.92	2	6
	2½–3½	4514.89	2	7
	1½–1½	4523.60	2	4
	2½–2½	4534.57	2	3
$3p^4S-3d^4P^o$ .... (38.7–41.5 v.)	½–1½	4535.11		2

* The multiplet $3s^4P^o-3p^4P$ has also been observed by Dr. Wyse (private communication).

Nitrogen.—*N* II is extremely weak or absent. *N* IV shows several lines, the strongest of which are listed in Table 4. The best criteria for *N* IV are $3s^3S - 3p^3P^0$ and $3p^1P^0 - 3d^1D$. *N* V is possibly present as an extremely weak line at λ 4603. *N* III is very abundant, as is shown in Table 5.

The reproduction in Plate X shows that the *N* III lines at λ 4634 and λ 4641 have a P Cygni character, which has not been mentioned, as far as we know, by previous investigators.

TABLE 6

P CYGNI CHARACTER OF *N* III 4634–4641

Int.	Mean λ	Edges	Widths	
			In Angstroms	In Kilometers per Second
4A.......	4630.97	4630.10–4631.71	1.61	104
5E.......	4634.13	4632.18–4636.42	4.24	275
5A.......	4638.42	4637.71–4639.12	1.41	91
6E.......	4641.22	4639.67–4645.49	5.82	376

The best values for the widths are: for the absorption component, 1.61 A, or 104 km/sec; for the emission line, 5.82 A, or 376 km/sec.

The velocity of ejection in the shell giving rise to the absorption and emission line[11] is of the order of 200 km/sec. The computed values are slightly different, depending upon whether we assume that the broadening of the P Cygni absorption line is due to mechanical causes. If not, we should take the distance between the centers of the emission and absorption lines as: for 4634:

$$\Delta\lambda = 3.16 \text{ A or } V = 205 \text{ km/sec} ,$$

and for 4641:

$$\Delta\lambda = 2.80 \text{ A or } V = 181 \text{ km/sec} .$$

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[11] It is reasonable to assume that the absorption and emission components of P Cyg type lines originate at the same distance from the star.

The most reliable value is 205 km/sec. If, on the other hand, we assume that the width of the absorption line is mainly due to the angular range in ejection velocity, we shall obtain the correct value of that velocity by taking the distance between the center of the bright line and the violet edge of the absorption line:

$$\Delta\lambda = 4.03 \text{ A} \qquad \text{or} \qquad V = 261 \text{ km/sec} .$$

All the lines of Table 5, except λ 4634 and λ 4641, originate essentially in the star itself. The absorptions and emissions at λ 4634 and λ 4641 are due to the shell surrounding the central star. This is illustrated in Figure 2, where the heavy lines correspond to the shell and the lighter lines to the central star. In HD 34656, HD 190864, and 10 Lacertae—all pure absorption O stars—the absorption lines λ 4097 and λ 4103 are much stronger than λ 4634 and λ 4641, and the higher-level line λ 4379 is approximately of the same intensity

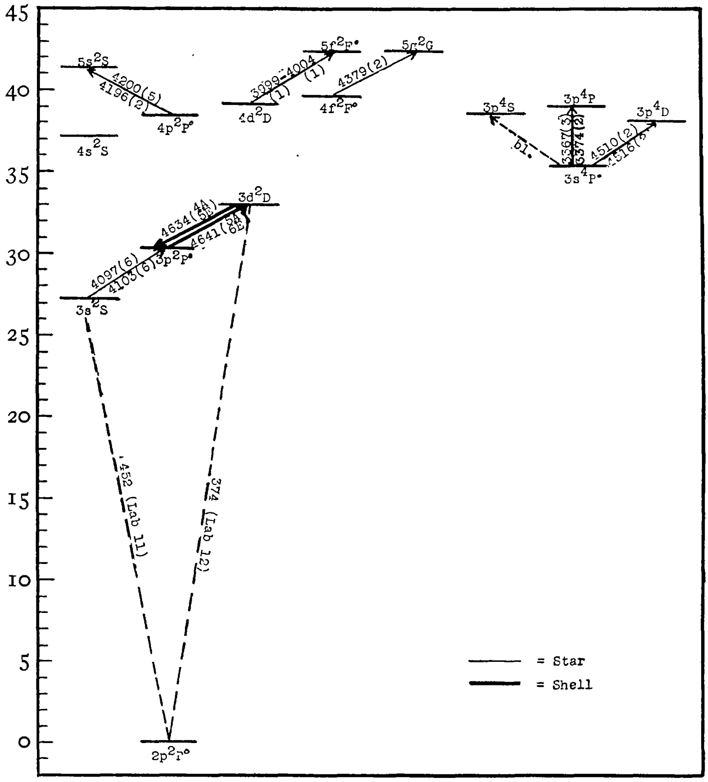

FIG. 2.—*N* III lines in 9 Sagittae

as λ 4604. In 9 Sagittae the relative intensities of λ 4379 and of λλ 4097 – 4103 are quite normal, in contrast to the appearance of λλ 4634 – 4641.

The following conclusions may be drawn from the observations:

a) We are certainly not dealing with a pure recombination spectrum, because λ 4379 and also λ 4097 and λ 4103 are in absorption.

b) The *N* III lines are not excited by the fluorescence mechanism which prevails in the nebulae. The absence of bright *O* III lines shows that this process does not play a role. In the nebulae the groups λ 4097 and λ 4103, and λ 4634 and λ 4641, have normal intensities.

TABLE 7

C III LINES IN 9 SAGITTAE

TRANSITION		λ LAB.	INTENSITY	
			Star	Lab.
4f^{3}F$^\circ$–5g^{3}G.........	2–3	4067.87	1	6
(39.7–42.8 v.)	3–4	4068.94	1	7
	4–5	4070.43	1	8
4f^{1}F$^\circ$–5g^{1}G......... (39.8–42.8 v.)	3–4	4187.05	1 bl	10
3s$'^1$P$^\circ$–3p$'^1$D........ (38.3–41.1 v.)	1–2	4325.70	1	8
3s^{3}S–3p^{3}P$^\circ$......... (29.4–32.1 v.)	1–2	4647.40	2	20
3p^{1}P$^\circ$–3d^{1}D........ (32.0–34.1 v.)	1–2	5696.0	3E	5

c) No high-level line appears in emission.

Carbon.—*C* II is extremely weak, the strongest transition 3d^{2}D – 4f^{2}F$^\circ$ at λ 4267 being only of intensity 1. *C* IV is absent. *C* III is weak.

The behavior of *C* III is illustrated in Figure 3 and is somewhat similar to that of *N* III. In the singlets the transition 3s^{1}S – 3p^{1}P$^\circ$ is in the unobservable infrared. In the triplets the transition

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$3p^3P^o - 3d^3D$ is in the unobservable ultraviolet. We note the following:

a) The notations of the emission and absorption lines are similar in *C* III and *N* III.

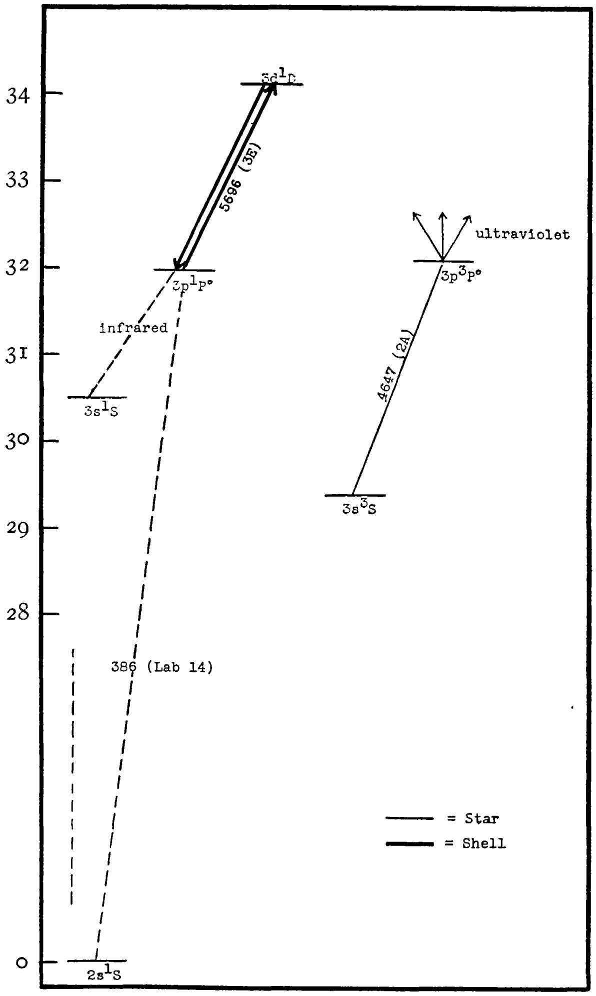

FIG. 3.—*C* III lines in 9 Sagittae

b) Contrary to the case of *N* III, the $3d^1D$ level requires two absorption processes from the ground level.

c) Again, as in *N* III, the highest levels do not give emission lines.

The carbon lines are weak, compared with the nitrogen lines. The star 9 Sagittae is apparently more closely related to the Wolf-

Rayet nitrogen sequence than to the carbon sequence, but carbon is not completely absent, and even *C* III shows an emission line.

The analysis of the spectrum of P Cygni[12] has shown that this star is also related to the nitrogen sequence, as the carbon lines are abnormally weak, compared with the nitrogen lines. The two stars HD 190864 and HD 34656, which at times have shown *N* III in emission, are also extremely poor in carbon lines. We have found no trace of *C* II and *C* IV and have only suspected a weak trace of *C* III. In the laboratory, λ 4647.4 is by far the strongest *C* III line in the astronomical region. The same is true in the carbon Wolf-Rayet stars.

TABLE 8

Si IV LINES IN 9 SAGITTAE

TRANSITION		λ LAB.	INTENSITY	
			Star	Lab.
$4s^2S-4p^2P^0$	$\frac{1}{2}-1\frac{1}{2}$	4088.86	6	10
(24.0–27.0 v.)	$\frac{1}{2}-\frac{1}{2}$	4116.34	3	8
$5g^2G-6h^2H^0$	$4\frac{1}{2}-5\frac{1}{2}$	4654.14	1	4n
(36.3–38.9 v.)				

Other atoms.—*Ca* III may be present but gives only very weak lines. The identifications of *Ne* II and *Ar* II are tentative and give only very weak lines. *Fe* III and *Ti* III may also be present as very weak lines.

Si II and *Si* III are absent. But *Si* IV is fairly strong, the unblended lines being given in Table 8.

Several bright lines are still unidentified, the two strongest being λ 4485.4 (2) and λ 4855.9 (3).

The expanding shell of 9 Sagittae.—The widths of the displaced *N* III absorptions at λ 4634 and λ 4641 are 1.61 A, corresponding to $\Delta V = 104$ km/sec. The widths of ten stellar absorption lines have been measured, and the mean width is $\Delta V_{\text{st}} = 200$ km/sec, which corresponds roughly to a stellar axial rotation of the order of 100 km/sec. At the mean position of the P Cygni layer, the velocity of

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[12] Struve, *Ap. J.*, **81**, 66, 1935.

ejection is either 205 km/sec (3.16 A) or 261 km/sec (4.03 A). These values are in fair agreement with the width of the emission line at λ 4641, which is 5.82 A, or 376 km/sec.

The wave lengths of the centers of the emission lines, after correction for the stellar radial velocity, are in agreement with the laboratory values.[13] Hence, there is no strong occultation effect, and the emitting layer cannot be very close to the surface of the star. Let us suppose that the broadening of the displaced *N* III lines is due to one of the following mechanical causes: (*a*) the range in ejection velocity within the thickness of the P Cygni layer; (*b*) the range in the component of the ejection along the line of sight, inside the star's cylinder of sight; (*c*) the range in the component of axial rotation along the line of sight. We are unable to estimate the factor (*a*), but we may assume that the shell is rather thin and neglect this factor. A minimum value of *r* will be obtained with this procedure.

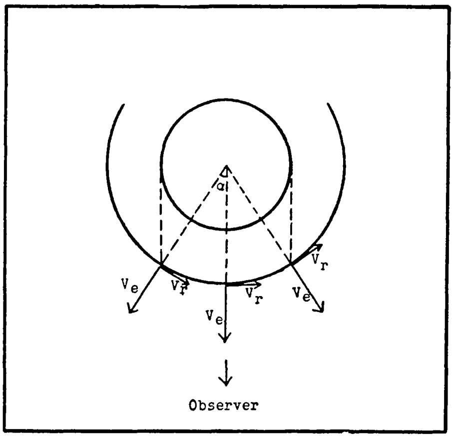

FIG. 4

Let us use the following terms: V_e, for the velocity of ejection at distance r (shell); V_r, for the velocity of axial rotation at distance r; V_R, for the velocity of axial rotation at the surface of the star; and α, for the angle shown in Figure 4.

The width of the absorption line is

$$\Delta V = V_e(1 - \cos \alpha) + 2V_r \sin \alpha \, .$$

As a working hypothesis, we shall assume that V_r is inversely proportional to r. We then obtain

$$\Delta V = V_e\left(1 - \sqrt{1 - \frac{R^2}{r^2}}\right) + 2V_r\left(\frac{R}{r}\right)^2 .$$

---

[13] The peculiar displacement of emission lines which is present in the spectroscopic binary 29 Can Maj (Luyten and Ebbighausen; Struve) is not observed in 9 Sag.

If we adopt $V_e = 205$ km/sec, we find $R^2/r^2 \sim 0.31$ or $R/r \sim 0.56$; this corresponds to a dilution factor of $W \sim 0.08$. In other words, the distance of the P Cygni layer from the star would be at least equal to the stellar radius. If we assume $V_e \sim 260$ km/sec, we find $R/r = 0.4$, or $r = 2.5R$. The P Cygni layer would then be at a distance of $1.5R$ from the stellar reversing layer.

2. BD + 35° 3930 N.

This star is the northern component of Σ 2624 (separation 2″). It was classified as O5w by C. H. Payne.[5] The absorption spectrum shows a stage of ionization much higher than that of 9 Sagittae. *N* IV is much stronger; *N* III shows λ 4634 and λ 4641 strongly in emission, whereas λ 4097 and λ 4103 have practically disappeared. *He* I is much weaker, and D_3 shows the P Cygni character. *He* II is of about the same intensity in both stars, but now λ 4686 is extremely strong in emission and is very broad (about 14 A). This may be due to the fact that *H* is now weaker. *Hα* again is a bright line, and *Hβ* has the P Cygni character (with $\Delta\lambda = 5.17$ A or $\Delta V = 319$ km/sec). *O* III is weaker. *C* II, *C* III, and *C* IV are absent. It is probable that BD+35°3930 N. is also related to the WN stars.

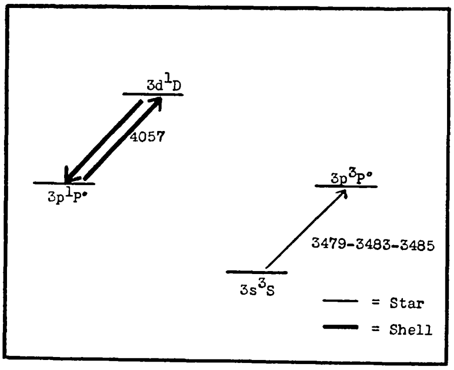

FIG. 5.—*N* IV lines in BD+35°3930 N.

The most interesting features in this star are the emission lines of *N* III, *N* IV, *N* V, and *Si* IV. Except for *N* III, these lines had not been previously observed.

N III.—The only difference from 9 Sagittae is that the absorption lines λ 4097 and λ 4103 have practically disappeared; there may even be faint emissions in their places.

N IV.—The multiplet $3s^3S - 3p^3P^0$ is very strong in absorption; in fact, λ 3478.7 (1–2) and λ 3483.0 (1–1) to λ 3484.90 (1–0) are the strongest ultraviolet lines below λ 3800. On the other hand, λ 4057.80 ($3p^1P^0 - 3d^1D$) appears in emission (int. 2E) with a displaced absorption component (int. 1A; $\Delta\lambda = 2.46$ A, or 182 km/sec). The level diagram (Fig. 5) is quite similar to that of the isoelectronic ion *C* III. The laboratory intensity of λ 4057.80 (2) is much lower than those of λλ 3478.7 (7), 3483.0 (5), and 3484.90 (3).

N V.—The multiplet $3s^2S - 3p^2P^\circ$ appears in emission:

$3s^2S_{\frac{1}{2}} - 3p^2P^\circ_{1\frac{1}{2}}$ 4603.2 (1A–1E) ,
$^2S_{\frac{1}{2}} -\ ^2P^\circ_{\frac{1}{2}}$ 4619.4 (0A–0E) .

Here we encounter a type of transition (Fig. 6) with notations quite different from the cases of *N* III, *N* IV, and *C* III. The transitions between $3p^2P^\circ$ and $3d^2D$ are in the unobservable infrared region. The observed lines are the strongest to be expected in the observable region. They have been predicted by Edlén from his laboratory investigations. The ejection velocity of *N* V is $\Delta\lambda = 2.59$ A, or $\Delta V = 169$ km/sec.

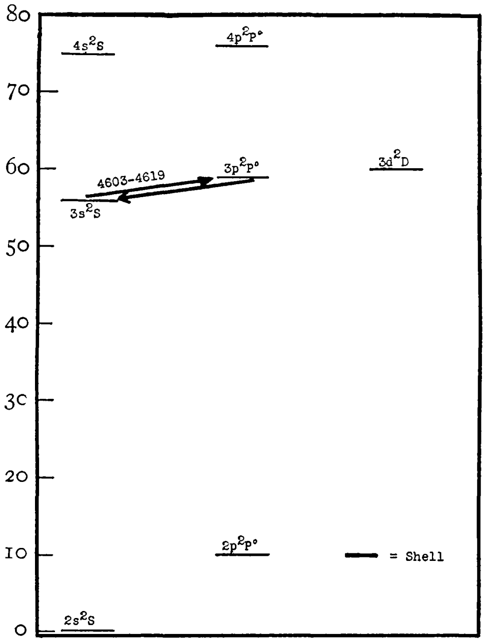

FIG. 6.—*N* V lines in BD+35°3930 N.

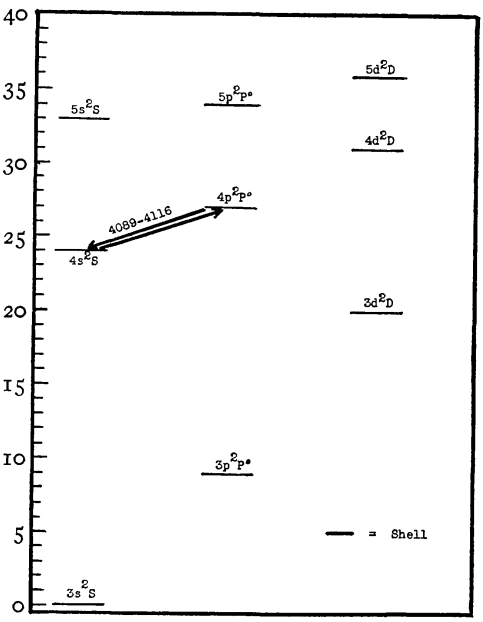

FIG. 7.—*Si* IV lines in BD+35°3930 N.

Si IV.—The multiplet $4s^2S - 4p^2P^\circ$ appears in emission, λ 4088.9 and λ 4116.1 having the intensities 1A and 2E, and 1A and 3E, respectively. The ejection velocity is $\Delta V = 161$ km/sec, corresponding to $\Delta\lambda = 2.20$ A. The type of transition is similar to that of *N* V (Fig. 7).

Unidentified lines of P Cygni character.—Three unidentified lines appear in the red region, the bright centers being near λλ 6215 (2), 6289 (2), and 6387 (2). All three show absorption on the violet side; the ejection velocity is of the order of 400 km/sec. The line λ 6387 is near $3s^1S - 3p^1P^o$ of *N* IV (λ 6383).

3. NUCLEUS OF NGC 2392

The region λ 3930 to λ 4860 of this spectrum has been investigated by W. H. Wright,[14] who has shown that the nucleus of this planetary nebula is a typical O star, with *He* II 4686 and *N* III 4634 and 4641 in emission. We have obtained spectrograms of this object extending from λ 3400 to λ 6700. The absorption spectrum is typical of the early O stars. $H\gamma$ is present only in absorption, whereas $H\beta$ presents the P Cygni character.

Besides the bright lines observed by Wright, our spectrograms reveal also the strongest *N* V emission line at λ 4603. There is no trace of the *C* III line observed in emission in 9 Sagittae. The presence of a bright *N* IV line at λ 4057 is not conclusive.

This star is quite similar to BD+35°3930 N. Incidentally, it should be noted that the spectrum of the surrounding nebula (double-ring planetary in Gemini) contains the forbidden [*N* II] lines at λ 6548 and λ 6584;[15] these lines are very weak in comparison with $H\alpha$.

4. SUMMARY OF P CYGNI TYPE LINES IN 9 SAGITTAE AND IN BD+35°3930 N.

Table 9 lists the P Cygni type lines in 9 Sagittae and BD+35°3930 N. Even aside from *H* and *He*, there is a wide range in excitation potential. This is especially true for BD+35°3930 N., which shows in emission both *Si* IV (exc. pot. 24.0–27.0 v.) and *N* V (exc. pot. 56.3–59.0 v.). This, combined with the absence of emission corresponding to transitions between the highest states, excludes the pure process of recombination of ions and electrons. Any kind of "superexcitation" or "underexcitation" favoring either the higher or the lower levels is also excluded. On the other hand, these elements have no metastable levels. Hence, no dilution effect of the ordinary type

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[14] *Lick Obs. Pub.*, **13**, 204, 1918.

[15] This region was not covered by Wright's spectrograms.

is to be expected. But it is not impossible that dilution influences different excited levels in different ways.

A similar effect has been observed by Struve and Roach in the *Si* III lines of P Cygni. The lines $4s^{1,3}S - 4p^{1,3}P^0$ appear in absorption, whereas $4p^{1,3}P^0 - 4d^{1,3}D$ are emission lines. In this case, the excitation potentials are

$4s^1S$, 19.6 v.; $4s^3S$, 18.9 v.,
$4p^1P^0$, 21.8 v.; $4p^3P^0$, 21.6 v.,
$4d^1D$, 25.2 v.; $4d^3D$, 24.9 v.

Struve and Roach have pointed out that the lowest triplet level of *Si* III can be reached from state $^3P^0$ only in two steps. The same is true for *N* III, but not for *C* III.

TABLE 9

EMISSION LINES OF P CYGNI TYPE

Element	Wave Lengths	Notations	Excitation Potentials (Volts)
N III.........	4634.2–4640.6	$3p^2P^0 - 3d^2D$	30.3–33.0
N IV.........	4057.8	$3p^1P^0 - 3d^1D$	49.9–53.0
N V.........	4603–4619 (predicted)	$3s^2S - 3p^2P^0$	56.3–59.0
C III.........	5696	$3p^1P^0 - 3d^1D$	32.0–34.1
Si IV.........	4089–4116	$4s^2S - 4p^2P^0$	24.0–27.0
Hα, *Hβ*......	6563–4861	$2p^2P^0 - 3, 4d^2D$	10.2–12.0 10.2–12.7
He I.........	5876	$2p^3P^0 - 3d^3D$	20.9–23.0
He II........	4686	$3d^2D - 4f^2F^0$	48.2–50.8

We have already shown that Bowen's fluorescence mechanism does not produce the excitation of the *N* III lines, but we have not found other plausible cases of fluorescence excitation.

According to Table 9, the emission lines are either of the type pP – dD, in which case the absorption lines are sS – pP, or they are of the type sS – pP, in which case the nature of pP – dD is unobservable. Hence, even the spectral notation of the transition is not conclusive. There is as yet no satisfactory explanation for the strong selection shown by the emission lines.

The emitting shells of HD 34656 and HD 190864 are not permanent features. This may also be true for 9 Sagittae and BD+35°3930 N. In the case of BD+35°3930 N., H. H. Plaskett observed only absorption lines at λ 4603, while we find a fairly strong emission line of *N* v. No emission lines of *N* iv (λ 4058) and *Si* iv (λ 4089 and λ 4116) are mentioned by Plaskett, although it is impossible to miss them on our spectrograms. *Hα* was absent in 9 Sagittae in 1913, according to Merrill. Perhaps we should refrain from applying to such stars our usual ideas based upon permanent or equilibrium conditions.

Both stars are related to the WN sequence. Although 9 Sagittae is not free of carbon, we observe the continuous ejection of nitrogen. This reminds us of Campbell's hydrogen-envelope star.[16] The strong red character of the envelope which was thought to be due to *Hα* is largely produced by the forbidden doublet $2p^2\ {}^3P_{1,2} - 2p^2\ {}^1D$ of [*N* ii] at λ 6548.4 and λ 6583.9; these two lines are roughly of the same intensity as *Hα*.[17] On the other hand, the nucleus is a typical carbon Wolf-Rayet star, classified as WC8 by Beals. We do not know whether carbon is absent from the nebular envelope, because the carbon ions have no forbidden lines; but at least we do know that nitrogen is not abundant in the nucleus. It is tempting to think that the entire supply of nitrogen of the atmosphere of the nucleus has been ejected in a manner similar to that which we actually observe in 9 Sagittae.

II. STARS OF THE P CYGNI TYPE

1. The Visual Spectrum of P Cygni

The ultraviolet and the photographic regions of P Cygni have been investigated by Struve and Roach,[18] by Struve,[19] and by Beals.[20] The region of wave lengths above *Hβ* has been considered only in a preliminary manner by Beals,[20] Kharadze,[21] and Struve.[19] We have obtained several good spectrograms of P Cygni in the visible region, using a normal incidence grating spectrograph at the Cassegrain

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[16] BD+30°3639 = HD 184738; α 19^h31^m, δ +30°18′.

[17] P. W. Merrill, *Pub. A.S.P.*, **44**, 123, 1932.

[18] *Ap. J.*, **90**, 727, 1939.

[19] *Ap. J.*, **81**, 66, 1935.

[20] *M.N.*, **95**, 581, 1935.

[21] *Zs. f. Ap.*, **11**, 304, 1935.

focus of the 82-inch reflector. The measured lines are listed in Table 10.[22]

Fe III.—The multiplet $a^5D - z^5P^o$ is very strong, although it is not especially outstanding in laboratory sources; this is due to the metastable character of a^5D. The dilution effect is shown in Table 11. In the comparison star, γ Pegasi, the *Fe* III absorption lines have normal intensities. The great strength in P Cygni of *Fe* III lines originating from metastable levels confirms the results by Struve and Roach.[18]

N II.—Has no metastable levels involved in the production of permitted lines in the observable region. Figures 8 and 9 summarize the observed results for the singlets and for the triplets. There is some selection in the emission lines similar to that observed in the shells of O-type stars. Struve's observation[19] that the low levels are privileged is confirmed. For example, all the transitions $3s^1P^o - 3p^1S$, ^1P, ^1D and $3s^3P^o - 3p^3S$, ^3P, ^3D are very strong; high-level lines which have similar intensities in the laboratory are much weaker; the strong laboratory line λ 4447 is relatively weak in P Cygni. Among the singlets, the absence or extreme weakness of the low-level line λ 4895 ($2p'\,^1D^o - 3p^1P$; lab. int. 4) is puzzling, but the spectral notation of this line is somewhat doubtful.

Carbon.—Struve[19] has noticed the surprising faintness of the *C* II and *C* III lines. Effects similar to those observed in *N* II appear also in *C* II. The low-level doublet λ 6578 and λ 6583, $3s^2S - 3p^2P^o$ (lab. int. 10 and 8; exc. pot. 14.4–16.3 v.), appears in emission, but the line λ 4267.20, $3d^2D - 4f^2F$ (exc. pot. 18.0–20.9 v.), which is much stronger in the laboratory, appears as a weak absorption and emission. It would be interesting to observe the behavior of the $3p^2P^o - 3d^2D$ transition (λλ 7231–7236; lab. int. 6 and 8) which connects the

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[22] The following corrections and additions should be made in the paper by Struve and Roach (*Ap. J.*, **90**, 727, 1939):

a) In the list of lines, p. 735, the *Fe* III lines, λ 3329.89 and λ 3396.71, are $b^3G_3 - z^3H^o_4$ and $b^3G_5 - z^3H^o_6$. The line $b^3G_4 - z^3H^o_5$ at λ 3347.7 is also present in emission.

b) λ 3324.85 attributed to *S* III on p. 751 is blended with *Fe* III.

c) λ 3919 of *N* II is present.

d) λ 3437 of *N* II has a weak absorption component.

e) λ 3856 of *Si* II is present in emission.

1940ApJ....91..546S

TABLE 10

LINES IN P CYGNI

(Region *H*β–λ 6678)

λ	Int.	Identification			Note
		Elem.	λ	Int.	
4858.04..	10A	*H*β	4861.34	....	
4861.04..	20E				
4919.61..	6A	*He* I	4921.93	4	1
4921.72..	3E				
5006.40..	1E	*N* II	5005.14 5007.32	10 7	2
5013.20..	8A	*He* I	5015.67	6	1, 3
5015.76..	8E				
5040.65..	1E	*Si* II	5041.13	8	4
5043.09..	2A	*N* II	5045.10	8	
5047.15..	0E	*He* I	5047.74	2	3, 4
5055.65..	1E	*Si* II	5056.17	10	1, 3, 5
5071.69..	1A	*Fe* III	5073.78	3	3, 6
5077.32..	1A	*Fe* III?	5078.93	4	
5084.55..	1A	*Fe* III	5086.69	3	3, 6
5095.18..	1A	....	....	....	3
5125.37..	6A	*Fe* III	5127.32	6	3
5127.89..	3E				
5154.09..	6A	*Fe* III	5155.97	4	3
5156.12..	2E				
5191.84..	1A	*Fe* III	5193.89	4	
5193.92..	1E		5194.43	4	
5235.37..	0E	*Fe* III	5235.30	5	
5243.38..	1E	*Fe* III	5243.26	10	
5552.58..	0A	....	....	....	
5568.20..	1A	....	....	....	
5571.21..	1A	*Fe* III?	5573.3	4	
5664.22..	6A	*N* II	5666.64	8	1, 4
5666.32..	4E				
5671.73..	1E	....	....	....	
5673.56..	3A	*N* II	5676.02	6	
5675.57..	2E				
5677.47..	7A	*N* II	5679.56	10	1, 4
5679.17..	5E				
5684.34..	2A	*N* II	5686.21	6	1
5686.12..	2E				
5694.83..	0A	*C* III	5695.8	5	1
5696.17..	0E	*Al* III	5696.47	8	
5708.71..	2A	*N* II	5710.76	6	1, 4
5710.54..	2E				
5720.97..	1A	*Al* III	5722.65	6	
5737.85..	3A	*Si* III	5739.76	8	1, 4
5739.8...	0E				
5744.96..	0A	*N* II	5747.29	4	6
5749.35..	1A	....	....	....	6
5762.51..	1A	....	....	....	
5765.52..	1A	*N* II?	5767.43	3	
5833.46..	0E	*Fe* III	5834.0	10	7
5872.07..	10A	*He* I	5875.62	10	1, 4
5875.45..	20E				
5886.49..	1A	*C* II	5889.97	5	
5889.94..	10	*Na* I	5889.95	....	8
5895.90..	8	*Na* I	5895.92	....	8
5920.15..	1En	*Fe* III	5919.3	7	
5928.34..	1E	*Fe* III	5929.5	5	9, 10
5931.22..	1E	*N* II?	5931.79	7	4, 12
5952.93..	1E	*Fe* III	5953.6	6	5
5978.49..	3E	*Fe* III *Si* II	5978.1 5978.97	5 7	5 1
5998.73..	3E	*Fe* III	5999.4	5	5
6031.90..	3E	*Fe* III	6031.1	7	5
6172.47..	1E	....	....	....	
6220.54..	1E	*Fe* III?	6220.6	3	
6241.37..	1E	*N* II	6242.52	5	
6244.15..	1E	*Al* II?	6243.35	10	
6277.74..	2A	....	....	....	
6283.46..	1A	*N* II	6284.30	3	
6306.60..	1A	....	....	....	
6340.08..	1E	*N* II?	6340.67	4	
6344.14..	1E	....	....	....	
6346.63..	3E	*Si* II	6347.10	10	1
6355.62..	1E	....	....	....	
6361.40..	1E	....	....	....	
6369.88..	2E	*Si* II?	6371.36	8	1, 11, 13
6374.74..	2E	....	....	....	
6377.80..	1A	*N* II	6379.63	5	4
6379.67..	1E				
6480.24..	4A	*N* II	6482.07	8	1, 4
6482.04..	3E				
6497.05..	1A	....	....	....	
6499.99..	1A	....	....	....	
6534.59..	1A	....	....	....	
6558.10..	20A	*H*α	6562.82	....	1, 4, 14
6562.83..	100E				
6570.75..	1E	*Fe* III?	6570.4	1	
6572.92..	0E	....	....	....	
6577.76..	2E	*C* II	6578.03	10	
6582.37..	1E	*C* II	6582.85	8	
6611.02..	2E	*N* II	6610.58	6	
6674.82..	8An	*He* I	6678.15	6	1, 4
6677.98..	5E				

NOTES TO TABLE 10

1. Identified also by Beals, *M.N.*, **95**, 580, 1935.
2. The emission character is somewhat uncertain; may be two absorption lines.
3. Observed also by Struve, *Ap. J.*, **81**, 66, 1935.
4. Identified also by Kharadze, *Zs.f. Ap.*, **11**, 304, 1936.
5. Has extremely weak absorption on violet edge.
6. Very weak emission perhaps present.
7. Observed by King in strong spark in air.
8. Interstellar.
9. Separation from λ 5931.22 difficult.
10. Attributed to *N* II by Kharadze.
11. Separation from λ 6374.74 difficult.
12. Absence of λ 5941.7 (8) of same multiplet makes identification doubtful.
13. Double?
14. Emission extends from λ 6559.02 to λ 6567.29. The width measured by Beals is 8.8 A.

upper level of λ 6578 and λ 6583 (16.3 v.) and the lower level of λ 4267. Another transition similar to λ 7231 and λ 7236 is $3p^2P^\circ - 4s^2S$ (exc. pot. 16.3–19.4 v. λ 3918.98 and λ 3920.68); this seems to be absent in P Cygni.[23]

C III behaves as it does in 9 Sagittae. The $3p^1P^\circ - 3d^1D$ line at λ 5695.8 appears both in absorption and emission,[24] while the $3s^3S - 3p^3P^\circ$ group λλ 4651, 4650, and 4647, which is much stronger in the laboratory, is extremely weak in absorption.

Silicon.—The *Si* II lines λ 4128 and λ 4131, $3d^2D - 4f^2F^\circ$ (lab. int. 8–10; exc. pot. 9.79–12.78 v.) are absent, whereas λ 5041 and λ 5056, $4p^2P^\circ - 4d^2D$ (lab. int. 8–10; exc. pot. 10.02–12.47 v.) are present. This puzzling behavior was first noticed by Beals.[20] It is typical for P Cygni type stars. In the red region we observe the low-level lines λ 6347 and λ 6371, $4s^2S - 4p^2P^\circ$. The ultraviolet line λ 3856 is definitely present.

TABLE 11

COMPARISON OF THE TWO TYPES OF *Fe* III LINES IN LABORATORY SOURCES, P CYGNI AND γ PEGASI

λ	TRANSITION	LAB. INT.	INTENSITY IN P CYGNI		INTENSITY IN γ PEGASI
			Abs.	Em.	
5127	$a^5D - z^5P^\circ$	6	6	3	Absent
5156	$a^5D - z^5P^\circ$	4	6	2	Absent
5243	$4d^7D_5 - 5p^7P^0_4$	10	....	1	1
5834	$5s^7S_3 - 5p^7P^0_4$	10	....	1	1

Si III has already been discussed by Struve and Roach.[18] In the visual region, λ 5739 is present almost entirely in absorption. Hence, the *Si* III triplets show exactly the same behavior as the singlets: the $sS - pP^\circ$ transitions appear in absorption and the $pP - dD$ transitions in emission. This is the same phenomenon which we recorded for *N* III in 9 Sagittae.

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[23] The very weak line near λ 3919 is presumably *N* II 3919; it does not show duplicity.

[24] The blending by *Al* III will not affect the emission line, because the other component of the *Al* III doublet, λ 5722.65, appears only in absorption.

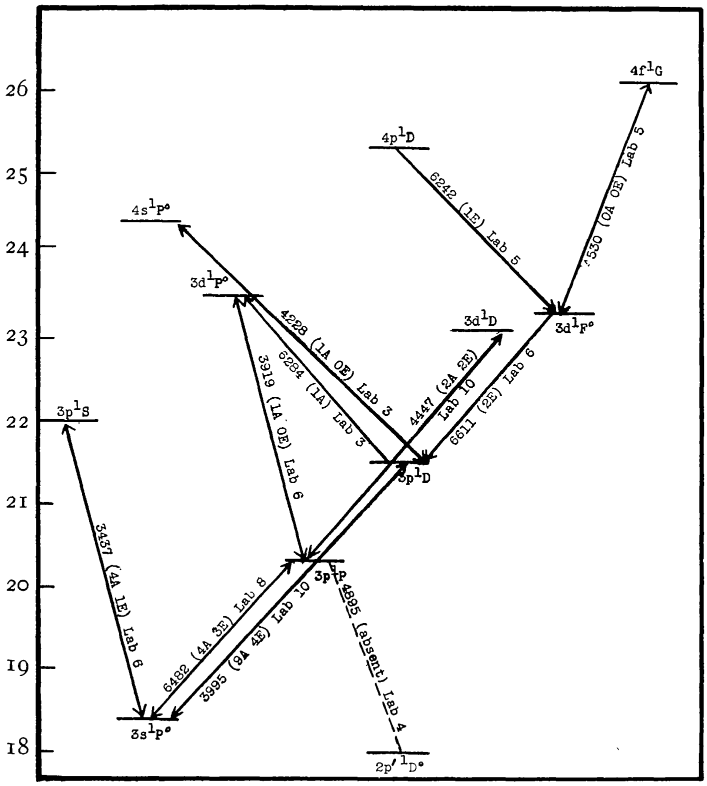

FIG. 8.—*N* II singlet transitions observed in P Cygni

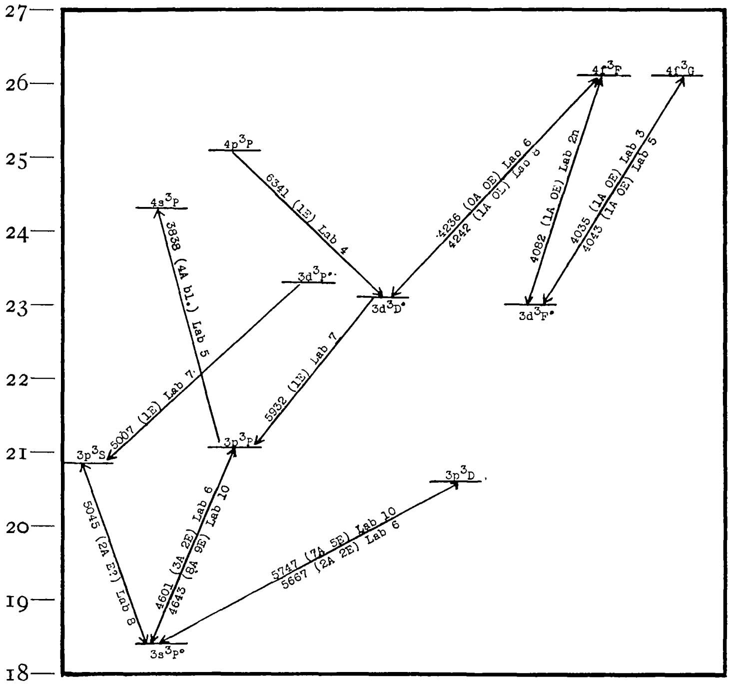

FIG. 9.—*N* II triplet transitions observed in P Cygni

The peculiar selectivity of the emission lines is the most outstanding unsolved problem of P Cygni. It is incorrect to assume, as some investigators have done, that the lines have normal intensities. The usual effect of dilution does not explain these observations, although its presence has been demonstrated by Struve and Roach's discussion of the *He* I and *Fe* III lines.

2. Z CANIS MAJORIS

This is a variable star listed by C. Payne-Gaposchkin and S. Gaposchkin among the objects of the R Coronae type[25] ($m = 8.4$–11.5). Merrill has described the spectrum near maximum brightness ($m \sim 9$).[26] It was of the P Cygni type, the main features of the spectrum being bright *H* and *Fe* II lines with broad dark components on their violet sides. A spectrogram taken by Merrill at about the same magnitude, but 15 months later, showed conspicuous differences in the relative intensities of the absorption and emission lines of *Fe* II and *Ti* II. According to Merrill, the behavior of the spectrum in a measure resembles that of the "iron star" XX Ophiuchi.

Four spectrograms were taken near minimum brightness ($m \sim 11.5$) with the McDonald quartz and glass spectrographs and the F/2 Schmidt camera. The spectrum resembles that observed by Merrill. *H* is very strong in absorption, except in the case of $H\alpha$, which is seen on our plates only as a strong emission line. The emission components of $H\beta$, $H\gamma$, and $H\delta$ are relatively weak. *Ca* II shows a strong emission line and a very strong absorption line. *Na* I (D_1 and D_2 blended) is present as a very strong absorption line, without emission. The strongest lines of *Fe* II are present in emission and, rather faintly, in absorption. There is a suspicion[27] of forbidden [*Fe* II] 4359 and 4287. A fairly strong emission line, without absorption, at λ 6296 may be identical with [*O* I] 6300.

The radial velocities measured on December 21, 1939, are given

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[25] *Variable Stars*, p. 290 (*Harvard Obs. Mono.*, No. 5, 1938).

[26] *Ap. J.*, **65**, 291, 1927.

[27] Merrill listed no forbidden [*Fe* II]. The Gaposchkins (their Table XI, II, p. 311) state that [*Fe* II] is present but attribute this to Vorontsov-Velyaminov (*New Stars and Galactic Nebulae*, p. 271, Moscow, 1935). This is probably based upon a misunderstanding. Vorontsov-Velyaminov does not actually state that [*Fe* II] is present, and he remarks that his data are essentially those of Merrill.

in Table 12. The violet displacements of the *H* absorption lines are somewhat larger than those recorded by Merrill. The blended line of *Na* I shows a large violet displacement; the measured wave length is 5885.6.

TABLE 12

RADIAL VELOCITIES OF Z CANIS MAJORIS

Line	Absorption	Emission	Line	Absorption	Emission
	km/sec	km/sec		km/sec	km/sec
Ca II K	−122	+95	*Fe* II 4549	....	+ 36
$H\delta$	−424	+48	*Fe* II 4556	....	+108
$H\gamma$	−451	+58	*Fe* II 4584	....	+ 46
$H\beta$	−438	+36	*Fe* II 4924	....	+130
Fe II 4233	....	+56	*Fe* II 5018	−256	+130
Fe II 4352	−170	+55	*Fe* II 5169	−297	+ 90
Fe II 4523	....	+31			

3. BD+47°3487

This star was announced by Merrill[28] as belonging to the class of P Cygni. Its spectral type is B3eq.[29] No other description of the spectrum is known to us. The *H* lines show the P Cygni character conspicuously. Emission is present as far as $H\epsilon$. The higher members of the Balmer lines are sharp absorption lines and can be traced on low-dispersion plates to H_{20}. There are several moderately strong P Cygni lines of *Fe* II, especially the conspicuous multiplet $a^6S - z^6P^o$ (λλ 4924, 5018, and 5169). On the other hand, the *Fe* II multiplet $b^4P - z^4D^o$, which includes λ 4233 and λ 4352, is weak. This may not be abnormal. *Ca* II K is a strong absorption line, without emission, which is displaced toward the violet and, therefore, originates in the expanding shell. There are a number of weak, diffuse *He* I lines, having normal intensities and small displacements. These lines probably originate in a stationary reversing layer. The *H* lines also show traces of broad wings, of the Stark-effect type, on the red sides of the emission lines. Thus, the spectrum of the star itself is B3, with considerable rotation and Stark effect, while the shell with *Fe* II and *Ca* II is characteristic of much lower ionization. This differ-

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[28] *Ap. J.*, **76**, 182, 1932 (Star No. 212).

[29] *Ibid.*, **78**, 99, 1933 (Star MWC 374).

ence in the spectra of reversing layer and shell is typical for most stars of the P Cygni type in which the reversing layer can be seen through the shell. BD+47°3487 is in this latter respect similar to such stars as 17 Leporis and HD 190073, which show the spectrum of the reversing layer conspicuously, and it differs materially from P Cygni itself, which shows only the spectrum of the expanding shell. One plate shows a sharp line at λ 3959.0. This may be *He* I 3965, which arises from the metastable level 2^1S, and may therefore occur in the shell. But the violet displacement is excessive. The radial velocities are given in Table 13. The normal velocity of the *He* I lines and the large velocity of expansion of the shell are conspicuous. The star should be useful for the study of dilution effects in the shell.

TABLE 13

RADIAL VELOCITIES OF BD+47°3487

Line	Absorption	Emission	Line	Absorption	Emission
	km/sec	km/sec		km/sec	km/sec
Ca II K	−110	....	*Fe* II 4924	−124	+52
$H\epsilon$	−159	+21	*Fe* II 5018	−272	+19
$H\delta$	−175	+11	*Fe* II 5169	−237	+11
$H\gamma$	−164	−26	*He* I 4026	− 22	....
$H\beta$	....	+24	*He* I 4144	− 24	....
Fe II 4233	−181	−20	*He* I 4388	(+ 92)	....
Fe II 4352	....	+41			

4. BD+11°4673

This remarkable spectrum has been investigated by Merrill in the photographic and visual regions.[30] Our results (Table 14) extend the list of lines into the ultraviolet region. Since the spectrum has somewhat changed from that described by Merrill, we have extended the measurements to cover the entire photographic region. The forbidden lines of [*Fe* II] are very weak on our plate, and it is probable that the permitted lines of *Fe* II are also weaker than on Merrill's plates. *N* III is strong on our plate, both in absorption and in emission. It was absent on Merrill's plates. *He* II 4686 was present in emission in 1939, although it was absent on Merrill's plates. *Si* III 4567 was an emission line in 1939, as was also *Si* III 4552, although

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[30] *Ibid.*, **69**, 330, 1929; **75**, 413, 1932.

TABLE 14

LINES IN BD+11°4673

λ	INT.	IDENTIFICATION			NOTE
		Elem.	λ	Int.	
3368.4....	0E	*Ca* III? *Cr* II? *N* III	3367.81 3368.05 3367.36	5 150 7	
3379.6....	1E	*Cr* II	3379.82	60	
3392.0.... 3392.74...	1A 1E	*Cr* II?	3393.00	25	
3439.7.... 3440.38...	1A 1E	*Fe* I?	3440.63 3441.02	150 75	
3486.78... 3487.6....	1A 0E	*Si* III	3486.93	6	
3529.41... 3530.24...	2A 1E	*He* I *V* II?	3530.50 3530.76	1 500	
3553.24... 3554.18...	2A 1E	*He* I	3554.57	1	
3570.52...	1E	*Fe* I?	3570.14	100	
3586.2.... 3587.22...	1A 1E	*He* I *Al* II	3587.28 3586.55 3587.06 3587.44	2 9 8 7	
3589.99...	2E	*Si* III *V* II?	3590.46 3589.74	8 1000	
3599.70... 3601.28...	0A 3E	*Al* III *Fe* III?	3601.62 3600.93	6 10	
3611.52...	1E	*Al* III	3612.35	4	
3613.32...	1E	*He* I *Sc* II?	3613.64 3613.84	3 100	
3633.09... 3634.32...	4A 2E	*He* I	3634.24	2	
3654.50...	0E	*Al* II	3655.00	8	
3660.62...	1E	......	....	.....	
3666.08...	0E	H_{27}	3666.10	.....	
3667.86...	0E	H_{26}	3667.68	.....	
3669.35...	1E	H_{25}	3669.47	.....	
3671.32...	1E	H_{24}	3671.48	.....	
3673.66...	2E	H_{23}	3673.76	.....	
3676.31....	2E	H_{22}	3676.36	.....	
3679.70...	2E	H_{21}	3679.35	.....	
3682.85...	2E	H_{20}	3682.81	.....	
3686.65...	2E	H_{19}	3686.83	.....	
3691.44...	3E	H_{18}	3691.56	.....	
3692.35	1E	......	....	.....	
3694.33...	1E	*Ne* II	3694.23	10	
3697.97...	3E	H_{17}	3697.15	.....	1
3703.99...	3E	H_{16}	3703.85	.....	
3705.44...	3E	*He* I	3705.1	.....	
3707.31...	0E	......	....	.....	
3708.92...	0E	*Ne* II? *Fe* I?	3709.64 3709.26	7 75	
3712.02...	3E	H_{15}	3711.97	.....	
3713.15...	2E	*O* II *Ne* II	3712.75 3713.09	7 10	
3719.78...	1E	*Fe* I?	3719.95	250	
3721.98...	4E	H_{14}	3721.94	.....	
3727.32...	1E	*O* II *Ne* II *V* II?	3727.33 3727.08 3727.35	8 9 1000	2
3734.48...	5E	H_{13}	3734.37	.....	
3737.18...	1E	*Fe* I?	3737.14	150	
3750.27...	5E	H_{12} *O* II	3750.15 3749.49	 9	
3754 79...	0E	*N* III	3754.62	6	
3757.71...	0E	*Fe* I?	3758.25	150	
3770.65...	5E	H_{11} *N* III	3770.63 3771.08	 7	
3797.70...	6E	H_{10}	3797.90	.....	
3798.52...	0E	......	....	.....	
3805.74... 3806.60...	2E 2E	*He* I *Si* III	3805.75 3806.56	1 5	3
3818.19... 3819.56...	4A 3E	*He* I	3819.61	4	
3823.35... 3824.22...	0A 0E	....	....	....	
3829.09...	1E	*Mg* I	3829.37	40	
3832.06...	1E	*Mg* I	3832.31	80	
3834.15... 3835.33...	1A 6E	H_9	3835.39	.....	
3838.06...	2E	*He* I *N* II *Mg* I	3838.09 3838.39 3838.30	1 5 100	
3840.72...	0E	*Fe* I?	3840.45 3841.06	80 80	
3855.55...	2E	*Si* II	3856.03	8	
3862.32...	1E	*Si* II	3862.59	6	
3872.36...	1E	*He* I *Fe* I?	3871.80 3872.51	1 60	
3878.04...	0E	*He* I *Fe* I?	3878.18 3878.58	1 100	
3886.87... 3888.42...	3A 8E	*He* I	3888.65	10	
3888.96...	6E	H_8	3889.05	.....	
3900.41...	0E	*Al* II	3900.66	10	
3905.45...	2E	*Si* I	3905.53	10	
3910.55...	0E	......	....	.....	
3914.41...	0E	*V* II?	3914.33	250	
3918.56...	1En	*N* II	3919.00	6	
3926.62...	0E	*He* I	3926.53	1	
3933.78...	2Es	*Ca* II	3933.66	40	
3937.96...	2Es	*N* III?	3938.52	4	
3963.00... 3964.89...	4A 3E	*He* I	3964.73	4	
3967.95...	1Es	*Ca* II	3968.49	35	
3969.89...	7E	$H\epsilon$	3970.08	....	
3994.91...	3E	*N* II	3994.99	10	
4007.60... 4009.27...	1A 2E	*He* I	4009.27	1	
4024.48... 4026.25...	3A 4E	*He* I	4026.19	5	
4087.76... 4089.26...	2A 1E	*Si* IV	4088.86	10	
4096.17... 4097.67...	3A 2E	*N* III	4097.31	10	
4101.85...	10E	$H\delta$	4101.74	.....	
4114.81... 4115.92...	1A 1E	*Si* IV	4116.10	8	
4119.84... 4121.85...	1A 2E	*He* I	4120.81	3	
4141.89... 4143.84...	1A 3E	*He* I	4143.77	2	
4163.12...	0En	......	....	.. ..	
4173.12...	1E	*Fe* II	4173.48	8	
4175.94...	0E	[*Fe* II]?	4177.22	.....	
4178.97...	2E	*Fe* II	4178.87	8	
4197.80... 4199.99...	1A 0E	*N* III *He* II	4200.02 4199.87	6	
4226.61...	0E	*Ca* I	4226.74	500	
4230.51... 4233.21...	1A 3E	*Fe* II	4233.16	11	
4258.37...	1E	*Fe* II	4258.16	3	
4290.87...	1E	*Ti* II	4290.23	50	
4296.75...	1E	*Fe* II	4296.56	6	
4302.33...	1E	*Ti* II	4301.93	15	

TABLE 14—*Continued*

λ	Int.	Identification			Note	λ	Int.	Identification			Note
		Elem.	λ	Int.				Elem.	λ	Int.	
4313.66...	0E	*Sc* II?	4314.08	30		4548.42...	1E	*Fe* II	4549.48	10	
4340.43...	20E	$H\gamma$	4340.47	.....		4554.19...	1E	*Fe* II	4555.90	8	
4351.13...	2E	*Fe* II	4351.77	9		4567.63...	2E	*Si* III	4567.87	7	
4379.39...	1E	*N* III	4379.09	10		4576.02...	2E	*Fe* II	4576.31	4	
4384.82...	1E	*Fe* II	4385.39	7		4583.53...	3E	*Fe* II	4583.84	11	
4388.19...	5E	*He* I	4387.93	3		4590.61...	1E	....	....	.....	
4416.06...	2nn	[*Fe* II]	4416.28	.....		4601.78...	1E	*N* II	4601.49	8	
4427.84...	1E	*N* II?	4427.21	2		4607.55...	1E	*N* II	4607.17	7	
4431.92...	1E	*N* II	4432.71	.....		4610.68...	1E	*N* II?	4609.60	0	
4442.99...	0E	*Ti* II	4443.80	50		4620.29...	0En	*N* II?	4621.40	7	
4447.16...	3E	*N* II	4447.04	10		4629.29...	3E	*Fe* II	4629.33	7	
4459.27...	0E	[*Fe* II]?	4457.96	.....		4634.15...	3E	*N* III	4634.16	8	
4469.41...	1A }	*He* I	4471.48	6		4640.51...	4E	*N* III	4640.64	10	
4471.78...	1E }					4658.39...	0E	[*Fe* III]	4658.18	.....	
4507.68...	1E	*Fe* II	4508.29	8		4665.06...	0E	*Fe* II?	4666.75	2	
4515.43...	1E	*Fe* II	4515.34	7		4685.06...	4E	*He* II	4685.81	.....	
4520.69...	1E	*Fe* II	4520.24	7		4700.12...	1E	[*Fe* III]	4701.54	.....	
4527.69...	0E	....	....	.....		4713.60...	3E	*He* I	4713.14	3	
4534.96...	0En	*Fe* II	4534.17	2							

NOTES TO TABLE 14

1. Double?
2. Possibly with 0A.
3. Separation from λ 3806.60 difficult.

the latter was blended with two *Fe* II lines. *Si* III 4575, although not measured, is almost certainly present as a very weak emission line.

In the ultraviolet region the Balmer emission lines can be followed to H_{27}. The Balmer emission continuum is fairly strong. *N* II is fairly strong. *C* II is very weak or absent. Silicon is present in four consecutive stages of ionization: *Si* I, II, III, and IV. *Si* II shows the same behavior as in P Cygni: the lines λ 4128 and λ 4131 ($3d^2D - 4f^2F^0$; lab. int. 8–10), which are strong in A and B stars, are absent, whereas λ 5055 ($4p^2P^0 - 4d^2D$) and λ 5958 and λ 5979 ($4p^2P^0 - 5s^2S$) are present. The presence of *Mg* I and *Ca* I is fairly certain. *Fe* I is doubtful. *O* II and *O* III are uncertain.

The unusually large range of ionization represented in the spectrum of BD+11°4673 is very interesting. It suggests that there is considerable stratification in the emitting shell.

The radial velocities of the emission lines give, in the mean, −1.6 km/sec. The absorption lines of *He* I, *N* III, and *Si* IV give −123 km/sec.

5. RY Scuti

This object occupies a special place among the P Cygni stars. Merrill[31] has shown that RY Scuti has $H\beta$, $H\gamma$, and *He* I 4472 in emission, $H\gamma$ and λ 4472 being accompanied by weak absorptions on the violet side. Besides these three lines, Merrill observed a group of fairly strong bright lines at λλ 4658 (int. 4), 4701 (2), 4734(1^+), 4755 (1), and 4770 (1). The strongest lines of this group had also been found in other objects—for example, in Nova Serpentis, where they are very intense, in Z Andromedae, BD+11°4673, etc. Their identification with the forbidden transitions of *Fe* III, $3d^6\,{}^5D - 3d^6\,{}^3F$, has recently been announced by Edlén and Swings.[32] On a spectrogram taken on May 11, 1938, in the visual region, P. W. Merrill[33] has also found the forbidden lines of [*N* II] at λλ 5755, 6548, and 6584, together with *He* I 5876 and $H\alpha$. There is some absorption on the violet side of D_3, and D_1 and D_2 of *Na* appear as stationary lines.

RY Scuti may be considered as representing a definite stage in the evolution of certain novae. These objects often pass through the η Carinae stage characterized by strong [*Fe* II] lines; the next stage may well be characterized by [*Fe* III]. This is one of the reasons why RY Scuti deserves careful attention. Our present knowledge concerning the spectral type was summarized by C. and S. Gaposchkin[34] as follows: "As there are almost no absorption lines in the spectrum, its spectral classification is difficult; it may be described as a bright-line spectrum of high excitation."

Seven spectrograms were obtained at the McDonald Observatory, on September 9, 14, 22, 23, 24, 29, and October 5, 1939; two of them were taken with the quartz prisms and the F/2 Schmidt camera, one with the quartz prisms and the 500-mm camera, and four with the glass prisms and the F/2 Schmidt camera. The star is greatly reddened; hence, different exposures are required for the different spectral regions. The results of the measures are collected in Tables 15 and 16.

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[31] *Ibid.*, **67**, 179, 1928.

[32] *Observatory*, **62**, 234, 1939.

[33] Private communication.

[34] *Variable Stars*, p. 91 (*Harvard Obs. Mono.*, No. 5, 1938).

TABLE 15

ABSORPTION LINES IN RY SCUTI

λ	Int.	Identification			Note
		Elem.	λ	Int.	
3341	1	*O* III	3340.74	6	
3407.8	0	*O* II	3407.38	7	
3428.6	1	*O* III?	3428.67	3	
3473.6	1	*He* I	3471.78	.....	
3531.5	0	*He* I	3530.50	.....	
3555.5	1	*He* I	3554.50	1	
3569.3	0	....	....	.....	
3574.1	0	....	....	.....	
3587.3	1	*He* I	3587.33	2	
3606.6	0	....	....	.....	
3636.2	0	*He* I	3634.28	2	
3652.6	0	*He* I	3652.06	1	
3661.7	0	*S* III	3662.0	5	
3674.2	0	H_{23}	3673.76	.....	
3679.8	0	H_{21}	3679.36	.....	
3686.4	0	H_{19}	3686.83	.....	
3694.6	0	*O* III *Ne* II	3695.37 3694.22	4 10	
3704.6	0	H_{16} *He* I	3703.86 3705.07	 3	1
3712.2	0	H_{15} *O* II	3711.97 3712.75	 7	
3721.0	0	H_{14} *O* III	3721.94 3720.86	 3	2
3725.0	0	*O* II?	3727.3	8	
3734.6	1	H_{13}	3734.37	.....	
3743.2	0	*O* IV?	3744.73	.....	
3749.4	1	H_{12} *O* II	3750.15 3749.49	 9	
3758.5	0	*O* III	3759.87	9	
3770.3	1	H_{11}	3770.63	.....	
3782.9	0	....	....	.....	
3797.6	1	H_{10}	3796.22	.....	3
3800.0	1	....	....	.....	
3820.2	2	*He* I	3819.61	4	
3835.9	3	H_9	3835.39	.....	
3870.8	1	*He* I	3871.82	1	
3888.6	4	*He* I H_8	3888.64 3889.05	10	
3902.5	1	*S* III?	3901.55	7	
3911.5	0	*O* II	3911.95	10	
3925.1	0	*Si* III *He* I	3924.44 3926.53	4 1	
3933.9	3	*Ca* II	3933.68	.....	4
3942.9	1	....	....	.....	
3964.9	1	*He* I	3964.73	4	
3969.8	4	*Ca* II $H\epsilon$	3968.49 3970.08	.....	4
3996.3	1	*N* II	3995.00	10	
4010.3	1	*He* I	4009.27	1	
4017.5	1	....	....	.....	
4025.5	2	*He* I	4026.19	5	
4028.8	1	*S* II	4028.74	7	
4070.4	1	*O* II *C* III *C* III	4069.90 4068.94 4070.43	7 10 8	5
4090.3	2	*Si* IV *O* II	4088.86 4089.29	10 7	
4097.0	1	*N* III	4097.31	10	
4101.4	3	$H\delta$	4101.74	.....	
4104.3	2	*N* III	4103.37	9	
4115.3	1n	*Si* IV	4116.10	8	
4144.4	2	*He* I *S* II *S* II	4143.82 4142.24 4145.05	2 8 8	
4162.0	1	*C* III *S* II	4162.80 4162.64	4 10	5
4187.0	1	*C* III	4187.05	10	
4190.6	0	*O* II	4189.79	8	5
4211.0	0	*Si* IV?	4212.44	4	
4267	0	*C* II	4267.02 4267.27	19 20	5
4340.4	3	$H\gamma$	4340.48	.....	
4354.9	1n	....	....	.....	
4366.9	1n	*O* II? *C* III?	4366 90 4368.14	5 4	5
4387.8	4	*He* I	4387.93	3	
4416.5	0	*O* II	4414.89 4416.97	10 8	
4430	.....	....	....	.....	6
4471.7	3	*He* I	4471.48	6	
4480.0	1	*Mg* II *Al* III	4481.2 4479.97	100 4	5
4504.2	1	....	....	.....	
4513	1	*N* III	4514.89	7	
4552	1	*Si* III?	4552.61	9	5, 7
4857	0	*N* III? *N* III?	4858.74 4858.88	2 3	
4922.0	4	*He* I	4921.93	4	
5446	1	....	....	.....	
5664	1	....	....	.....	
6202	2n	....	....	.....	8
6287	3n	....	....	.....	9
6395	2n	....	....	.....	
6459	1n	*N* III?	6453.95	3	

NOTES TO TABLE 15

1. Double?
2. Separation from λ 3725.0 difficult.
3. Separation from λ 3800.0 difficult.
4. Interstellar.
5. Line uncertain.
6. Broad interstellar band from λ 4415 to λ 4445.
7. There may be some emission at λ 4557.6.
8. Interstellar (Merrill λ 6203.0).
9. Interstellar (Merrill λ 6284).

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General discussion.—The absorption spectrum is fairly rich in the ultraviolet region and is typical of an early type—say, late O or B0. The elements represented are *H*, *He* I, *N* III and *N* II, *O* III and *O* II, weak C III and *C* II; probably also *S* III and *S* II, *Si* IV and *Si* III, and *Mg* II. The stationary lines H, K, and $D_{1,2}$, and the interstellar bands λλ 4415–4445, 6284, and 6203 are strong.

TABLE 16

EMISSION LINES IN RY SCUTI

λ	INT.	*N**	IDENTIFICATION		NOTE	λ	INT.	*N**	IDENTIFICATION		NOTE
			Elem.	λ					Elem.	λ	
4340.5...	3	4	*Hγ*	4340.48		5007.6...	1	3	[*O* III]	5007.6	
4471.5...	2	3	*He* I	4471.48		5010.5...	1	3	[*Fe* III]	5010.86	
4574.7...	0	2	[*Fe* III]	4573.29	1	5032.2...	0	1	[*Fe* III]	5032.93	1
4606.4...	0	1	[*Fe* III]	4607.01		5040.1...	1	2	....	....	2
4623.....	1	3	....	....		5058.....	0	1	[*Fe* III]	5060.06	1
4635.4...	0	4	*N* III	4634.16		5117.2...	1	1	[*Fe* III]?	5116.4	1
4641.5...	0	1	*N* III	4640.64		5136.....	1	2	[*Fe* III]?	5135.2	1
4658.2...	5	4	[*Fe* III]	4658.18		5270.2...	5	3	[*Fe* III]	5270.30	
4670.....	0	2	[*Fe* III]	4667.10		5698.....	1	1	*C* III	5695.8	
4686.4...	2n	4	*He* II	4685.81		5713.....	1	1	[*Cr* III]?	5712.7	
4701.5...	3	4	[*Fe* III]	4701.54		5732.....	2	1	....	....	
4733.8...	1	4	[*Fe* III]	4733.82		5755.....	3	2	[*N* II]	5755.0	
4756.3...	1	1	[*Fe* III]	4754.87		5787.5...	1	2	....	....	
4769.3...	1	3	[*Fe* III]	4769.34		5834.....	1	2	....	....	
4777.6...	1	2	[*Fe* III]	4777.71	1	5853.....	1	1	....	....	
4861.5...	10	4	*Hβ*	4861.34		5876.....	6	2	*He* I	5875.6	
4895.4...	1	1	....	....		5904.....	2	1	....	....	
4958.....	0	1	[*O* III]	4958.9		6548.....	3	2	[*N* II]	6548.4	
4985.6...	1	2	[*Fe* III]	4985.99		6563.....	10	2	*Hα*	6562.8	
			[*Fe* III]	4985.99		6584.....	6	2	[*N* II]	6583.9	

* *N* designates the number of spectrograms on which the lines were measured.

NOTES TO TABLE 16

1. Line uncertain.
2. Present in NGC 7027 (int. 5), NGC 6572 (int. 1), and AX Persei. May be [*Fe* IV].

The emission spectrum shows *Hγ*, *Hβ*, *Hα*, *He* I 4471 and 5876, *He* II 4686, [*N* II], [*O* III], and *N* III 4634 and 4641. All the other strong emission lines are due to [*Fe* III]. This should be compared with the case of P Cygni, where the permitted *Fe* III lines are so outstanding. There is no trace of permitted *Fe* II or *Fe* III, or of forbidden [*Fe* II], in RY Scuti.

The only bright *He* I lines are λ 4472 ($2p^3P^o - 4d^3D$) and λ 5876 ($2p^3P^o - 3d^3D$), whereas the very strong transition $2s^3S - 3p^3P^o$ at λ 3888 does not appear in emission. The lines λ 4635.4 and λ 4641.5 are the *N* III lines which appear so characteristically in emission in 9 Sagittae and similar stars (Sec. I). The line at λ 5698 may be *C* III 5696.

The bright-line spectrum is due to an ejected nebulosity surrounding the star and is very rich in forbidden [*Fe* III].

Forbidden lines of [*Fe III*].—According to the analysis of the *Fe* III spectrum by Edlén and Swings,[35] the ground level is $3d^6\ {}^5D$, and

TABLE 17

FORBIDDEN LINES OF [*Fe* III] IN RY SCUTI

Transition	λ Predicted	λ and Intensity in RY Scuti
${}^5D-{}^3F$ 4–4	4658.18	4658.2 (5)
4–3	4607.01	4606.4 (0)
4–2	4573.29	4574.7 (0)*
3–4	4754.87	4756.3 (1)
3–3	4701.54	4701.5 (3)
3–2	4667.10	4670. (0)
2–3	4769.34	4769.3 (1)
2–2	4733.82	4733.8 (1)
1–2	4777.71	4777.6 (0)*
${}^5D-{}^3P$ 3–2	5270.30	5270.2 (5)
2–1	5010.86	5010.5 (1)
1–1	5060.06	5058. (0)*
${}^5D-{}^3H$ 4–6	4985.99	4985.6 (1)
3–5	5032.93	5032.2 (0)

* Line somewhat uncertain.

several metastable terms are based on the configurations $3d^6$ and $3d^5 4s$. The final term values are somewhat different from the ones used in the preliminary note.[32] The forbidden multiplet ${}^5D-{}^3F$ forms a prominent group of lines, the leading line being ${}^5D_4-{}^3F_4$ at λ 4658.18; besides the five components observed by Merrill, four others have now been found.

The forbidden multiplet ${}^5D-{}^3P$ may also be expected, and three components have been found in RY Scuti, the leading line being ${}^5D_3-{}^3P_2$ at λ 5270; this line is as strong as λ 4658. Hence, the two principal lines upon which an identification of forbidden [*Fe* III]

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[35] Unpublished.

should be based are ${}^{5}D_{4}-{}^{3}F_{4}$ at λ 4658.18 and ${}^{5}D_{3}-{}^{3}P_{2}$ at λ 5270.30; next come ${}^{5}D_{3}-{}^{3}F_{3}$ at λ 4701.54 and ${}^{5}D_{2}-{}^{3}P_{1}$ at λ 5010.86.

The multiplet ${}^{5}D-{}^{3}H$ also appears in RY Scuti, with ${}^{5}D_{4}-{}^{3}H_{6}$ (λ 4985.99) and ${}^{5}D_{3}-{}^{3}H_{5}$ (λ 5032.93).

Several other very weak emission lines are present and may belong to other forbidden multiplets, but a complete discussion of these very weak lines would require additional material. The observed lines are listed in Table 17.

Summarizing, we may say that [*Fe* III] shows only two very privileged transitions. ${}^{5}D_{4}-{}^{3}F_{4}$ at λ 4658.18 and ${}^{5}D_{3}-{}^{3}P_{2}$ at λ 5270.30. This is fortunate, because it permits [*Fe* III] to appear fairly easily when the excitation conditions are fulfilled, because the excitation energy is distributed among a small number of lines.

It is quite certain that [*Fe* III] must be present in many novae at a certain stage; but its detection may be difficult when the bright bands are wide, because of blending:

[*Fe* III]	Neighboring Lines
4658.18......	*N* III 4634–4641; *C* III 4650; *C* IV 4659; *O* II 4649
4701.54......	*O* II 4699
4733.82......	[*Fe* II] 4728; [*A* IV] 4740
5010.86......	[*O* III] 5007; *He* I 5016; *Fe* II 5018
5270.30	[*Fe* II] 5273; *Fe* II 5276; [*Fe* VII] 5276

Remark concerning the forbidden lines of [*Fe* IV].—The spectrum of *Fe* IV has not yet been classified. But the analysis of *Fe* III makes it possible to locate approximately the centers of gravity of the metastable states of *Fe* IV:[36]

Fe III		*Fe* IV	
$3d^5$ (^6S) 4s	0 cm^{-1}	$3d^5$ (^6S)	0 cm^{-1}
(^4G) 4s	31,548	(^4G)	~32,000
(^4P) 4s	34,605	(^4P)	~35,100
(^4D) 4s	37,861	(^4D)	~38,500
(^4F) 4s	51,313	(^4F)	~52,100

The only transition in the observable region is ${}^{4}G-{}^{4}F$, requiring an excitation energy greater than 6 v.; it seems, therefore, that [*Fe* IV] should be weak. Several very weak emission lines appear in the

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[36] See Edlén's report to the Paris meeting of 1939.

region around λ 5000; λ 5040.1 is also observed in AX Persei (see Sec. IV) and in NGC 7027, and may possibly be due to [*Fe* IV].

Variations in the spectrum.—In the Mount Wilson series, taken between 1921 and 1927, no appreciable changes[31] occurred in the spectrum. S. Gaposchkin[37] considers RY Scuti an eclipsing variable resembling β Lyrae. The radial velocities determined by Merrill from the emission lines show little variation. But this is no proof against the binary nature of this star.

TABLE 18

OBSERVATIONS OF RY SCUTI

Date 1939	Phase in Days	Velocity of λ 4472 in Kilometers per Second		Description of Spectrum
		Abs.	Em.	
Sept. 9.12.....	1.04	−162	....	Absorptions very strong. No emission at *He* I 4472
Sept. 23.10.....	3.89	−170	− 1	Absorptions moderately faint. Emission at *He* 4472 strong
Oct. 5.07.....	4.74	−183	....	Absorptions faint
Sept. 24.07.....	4.86	−100	+39	Absorptions faint. Emission at *He* I 4472 present
Sept. 14.16.....	6.08	−128	....	Absorptions strong. Emission at *He* I 4472 absent
Sept. 29.07.....	9.86	−135	+22	Absorptions faint, but λ 4472 is sharp. Emission at *He* I 4472 present

Our spectrograms show rather marked changes in the intensities and profiles of the lines. The material is not sufficient to prove conclusively that these changes follow Gaposchkin's period, $P =$ 11.124939 days, but they certainly take place within intervals of a few days. Using the last published minimum confirmed by the observations of J. G. Baker,[37] min. = JD 2428413.21, we compute the phases in days (Table 18).

Since only one line was measured, the scatter is no larger than may be attributed to errors of measurement. The mean of the three emission-line velocities is +21 km/sec, which compares reasonably well with Merrill's result, +30 km/sec. The absorption lines show P Cygni character throughout the period of 11 days. It is perhaps sig-

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[37] *Harvard Ann.*, 105, 511, 1937.

nificant that these absorption lines are strongest immediately following the primary minimum determined by Gaposchkin. It will be recalled that in β Lyrae the B5 component is also strongest soon after primary minimum. This component is essentially a P Cygni line.[38] On the other hand, it is certain that RY Scuti has no such large range in velocity as that observed in β Lyrae, for which $2K = 367$ km/sec.

III. OBSERVATIONS OF Be STARS

1. ζ Tauri

Attention has recently been drawn toward early-type stars surrounded by extended shells;[39] a typical example is ζ Tauri, which shows at times conspicuously sharp *He* lines at λλ 3965[39] ($2s^1S - 4p^1P^0$), 5016[40] ($2s^1S - 3p^1P^0$), and 3889[40] ($2s^3S - 3p^3P^0$), whereas all the other observed *He* lines are greatly broadened. Struve and Wurm have shown that this is due to the metastability of the $2s^1S$ and $2s^3S$ levels and to the resulting much higher populations of these levels in the case of dilution of radiation. The lines of ionized metals also arise from the shell and are not constant in intensity.

Ultraviolet spectra of ζ Tauri have recently been secured with the McDonald reflector. The series $2p^3P^0 - ns^3S$ (to $n = 9$), $2p^1P^0 - ns^1S$ (to $n = 9$), $2p^1P^0 - nd^1D$ (to $n = 14$), and $2p^3P^0 - nd^3D$ (to $n = 10$) are represented by very broad lines of relatively high intensity. The broadening of both the $2pP^0 - nsS$ and $2pP^0 - nd\,D$ series is obviously in agreement with the hypothesis of rotational broadening of these stellar lines.

On the contrary, *He* I 3613.64 ($2s^1S - 5p^1P^0$) appears as a rather sharp line, which is in agreement with the metastability of the $2s^1S$ level.

Our Process plates do not show the double Balmer continuum observed by Barbier and Chalonge,[41] beginning around λ 3720 and λ 3660, respectively, which they attribute to the stellar reversing layer and to the shell. This presumably indicates that the continuous

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[38] Struve, *Observatory*, **57**, 265, 1934.

[39] Struve and Wurm, *Ap. J.*, **88**, 84, 1938.

[40] Biermann and Hachenberg, *Zs. f. Ap.*, **18**, 89, 1939; Davis, *Pub. A.S.P.*, **52**, 147, 1940.

[41] *Ap. J.*, **90**, 627, 1939.

hydrogen absorption is also variable. Incidentally, it should be noticed that the presence of strong, broad absorption lines of *He* I may distort the continuous background.

The sharp Balmer series due to the shell is easily followed to H_{30}; the Balmer continuum is rather strong and weakens several stellar *He* I lines.

TABLE 19

METALLIC LINES OBSERVED IN THE ULTRAVIOLET SPECTRUM OF ζ TAURI

λ	INT.	IDENTIFICATION			INTENSITY IN α CYGNI*	λ	INT.	IDENTIFICATION			INTENSITY IN α CYGNI*
		Elem.	λ	Int.				Elem	λ	Int.	
3243 8...	1	*Fe* II	3243.72	8	3	3434.3...	2	*Cr* II?	3433.70	75	8
3247.3...	2	*Fe* II	3247.17	9	5	3442.7...	2	*Mn* II	3441.98	30	8
3255.7...	1	*Fe* II	3255.88	8	4	3454.6...	1	*Ni* II?	3454.17	5	2
3259.1...	2	*Fe* II	3258.77	10	6	3460.3...	1	*Mn* II	3460.33	20	6
		Fe II	3259.05	10		3468.8...	1	*Fe* II	3468.68	8	4
3276.1...	1	*V* II	3276.12	1500	3 bl	3474.2...	1	*Mn* II	3474.06	8	6
3281.2...	1	*Fe* II	3281.29	7	4			*Mn* II	3474.15	8	
3289.2 ..	1	*Fe* II	3289.35	7	3	3482.9...	0	*Mn* II	3482.91	12	6
3295.4...	1	*Cr* II	3295.42	30	10	3488.3...	0	*Mn* II	3488.68	10	5
		Fe II	3295.81	6		3493.2 ..	2	*Fe* II	3493.47	10	8
3306.9...	1	*Cr* II	3307.04	30	3	3510.9...	1	*Ti* II	3510.85	60	4
3329.5...	2	*Ti* II	3329.48	70	5	3513.9...	1	*Ni* II	3513.94	8	5
3335.9...	2	*Cr* II?	3335.28	30	6 bl	3556.9...	1	*V* II	3556.80	1500	3
3341.6...	1	*Ti* II	3341.84	100	5	3585.7 ..	2	*Cr* II	3585.31	60	10
3342.5...	1	*Cr* II	3342.51	50	5			*Cr* II	3585.54	40	
3349.7...	1	*Ti* II	3349.42	125	10	3596.1...	1	*Ti* II	3596.05	60	3
3358.7...	1	*Cr* II	3358.50	75	5	3621.4...	1	*Fe* II	3621.27	6	5
3367.6...	1	*Cr* II	3368.05	150	7	3624.9...	1	*Ti* II	3624.84	70	4
3372.6...	1	*Ti* II	3372.82	100	7	3631.0...	1	*Cr* II?	3631.49	50	8
3373.7...	1	*Ni* II?	3373.98	4	3	3640.6...	1	*Ti* II?	3641.34	100	4
3380.5...	1	*Cr* II	3379.82	60	6 bl	3715.4...	1	*Cr* II	3715.19	20	5
3383.8†..	2	*Ti* II	3383.77	125	6			*Cr* II	3715.45	18	
3387.7...	1	*Ti* II	3387.85	50	5	3759.6...	2	*Ti* II	3759.30	200	6
3394.1...	1	*Cr* II	3393.86	30	6			*Fe* II	3759.46	6	
		Cr II	3394.32	30		3762.4...	1	*Ti* II?	3761.32	200	6
3403.4...	1	*Cr* II	3403.32	100	6	3845.3...	2	....	....	.....	3
3407.3...	1	*Ni* II	3407.32	8	4	3853.3...	1	*Si* II	3853.67	3	3
3409.4...	1	*Cr* II	3408.77	150	6	3856.2...	2	*Si* II	3856.03	8	5
3421.5...	1	*Cr* II	3421.20	75	7	3862.9...	2	*Si* II	3862.59	6	6
3422.7...	2	*Cr* II	3422.74	125	7	3935.9...	1	*Fe* II	3935.94	6	3

* O. Struve, *Ap. J.*, **90**, 699, 1939.

† May be partly interstellar.

The new Process plates reveal many metallic lines in the ultraviolet region which are much sharper than the *He* I lines and thus arise in the outer shell. Most of these lines are at the limit of visibility. The identified lines have been collected in Table 19. There is good evidence for the presence of *Si* II, *Fe* II, *Ni* II, *Cr* II, and *Mn* II; *Ti* II is probably present and the two strongest lines of *V* II are suspected. The unidentified line λ 3845 observed by Struve in the A-type stars[42] is also present. The *Si* II lines are appreciably broadened,

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[42] *Ap. J.*, **90**, 699, 1939.

compared with the cores of the Balmer lines. The other metallic lines are sharp, although not as sharp as the Balmer cores. All the observed absorption lines, except the sp^2 ^{2}D − 4p^{2}P^0 transition of *Si* II, arise from a lower metastable level, in good agreement with the theory.[43]

2. THE VISUAL REGION OF γ CASSIOPEIAE IN MARCH, 1940

Struve and Elvey[44] have recently found that the absorption lines of *Fe* III were strong and sharp in γ Cassiopeiae during the first part of 1940. We obtained two grating spectrograms on March 16, 1940, extending from *H*β to *He* I 6678. Besides strong *H*β (central absorption with emission borders at distances of 1.98 A), *H*α, *He* I [4713 (3A), 4922 (4A), 5016 (6A), 5048 (1A), 5876 (6A, 3E), 6678 (5A)], weak *Si* II [6347 (1A, 1E), 6371 (1A, 1E)], and very weak *N* II and *O* II (?), the spectrum shows only the a^{5}D − 4p^{5}P^0 multiplet of *Fe* III. All the components of this multiplet are present (Table 20). The lower level a^{5}D is metastable. The situation is similar to the case of P Cygni, where a^{5}D − 4p^{5}P^0 is also outstanding in the visual region, five components having been observed; but since the intensity

TABLE 20

Fe III LINES IN THE VISUAL REGION OF γ CASSIOPEIAE

γ CASSIOPEIAE		LABORATORY		
λ	Int.	λ	Int.	Transition
5063.7	1	5063.4	2	0–1
5074.1	1	5073.8	3	1–1
5086.7	1	5086.7	3	2–1
5114.4	0	....	Predicted	1–2
5127.7	4	5127.3	6	{3–2 {2–2
5156.1	4	5156.0	4	4–3
5194.0	2	5193.9	4	{3–3 {2–3

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[43] The ultraviolet region of φ Per also shows the sharp *He* I line λ 3613.64. The three *Si* II lines are present, as well as the unidentified line λ 3845.3. Sharp lines of *Ti* II and *Cr* II may be present, but the measurements are uncertain.

[44] *Pub. A.S.P.*, **52,** 140, 1940.

gradient in γ Cassiopeiae is not as steep as in P Cygni, the multiplet is more fully represented.

The observed *Fe* III multiplet is the only one classified in the visual region which starts from a metastable level. Because of the strong dilution effect, the lines starting from metastable levels are greatly enhanced; for example, λ 5243.26 ($4d^7D_5 - 5p^7P_4^\circ$; lab. int. 10) and 5833.65 ($5s^7S_3 - 5p^7P_4^\circ$; lab. int. 10), which start from ordinary excited levels, are both absent. There is no other *Fe* III line which may be identified with certainty in the visual region of γ Cassiopeiae.

3. MtW 143

This spectrum has not appreciably changed since Merrill's observations[45] in 1931 and 1932. In the visual region, $H\alpha$ and *He* I D_3 are very strong emissions. In the ultraviolet region $H\zeta$ is extraordinarily strong—doubtless because it is blended with *He* I. The last Balmer line seen in emission is H_9. Beyond this line there is only a suspicion of bright *He* I 3820. The continuous spectrum on the violet side of λ 3820 shows no absorptions or emissions. The permitted lines of *Fe* II are fairly strong, but there are no forbidden lines. *Fe* III is absent. No absorption lines could be seen with certainty. The radial velocities from the best plate are summarized in Table 21. The agreement with Merrill's mean velocity of −46 km/sec is satisfactory. The absence of *Mg* II 4481 in emission is conspicuous, in view of the great strength of *He* I and *Fe* II.

TABLE 21

RADIAL VELOCITIES OF MTW 143

Element	No. of Lines	Velocity
		km/sec
H	4	−46
He I	6	40
Fe II	9	−52

4. HD 218393

This is a remarkable representative of the small group of stars having extended atmospheres in which dilution of radiation sup-

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[45] *Ap. J.*, 77, 49, 1933.

presses lines which do not originate from metastable levels or from the ground levels. The spectrum has been described[46] by Merrill and by Harper. $H\alpha$ is a strong emission line; $H\beta$ is a fairly strong, double, emission line with weak absorption borders. The other Balmer lines, up to H_{24}, are sharp and deep absorption lines. $H\gamma$, $H\delta$, and $H\epsilon$ show traces of the double emission lines, and all Balmer lines give evidence of very weak Stark-effect wings. These wings are much weaker and narrower than in 17 Leporis and HD 190073—in keeping with the earlier spectral type of the reversing layer. The *He* I lines are very broad, and rather faint. *Mg* II 4481 and *Si* II are weak and intermediate in width. Several lines of *Fe* II are very sharp and resemble the cores of the *H* lines. The whole spectrum bears a decided resemblance to that of ζ Tauri, but *Ca* II is very strong in the shell of HD 218393, while it is weak in ζ Tauri, and the former shows no sharp lines of *He* I arising from metastable levels. The shell of HD 218393 corresponds to a lower degree of excitation than that of ζ Tauri. The progression of line widths from *H* to *He* is, however, similar and suggests in both cases stratification of the extended atmosphere.

The variability of the sharp α Cygni lines has already been commented upon by Merrill. Our plate shows them faintly. Merrill assigns to HD 218393 spectral type Ave; Harper proposes B9p; and the *Henry Draper Catalogue* gives A5p. The discrepancies in these data are due to the variability of the spectrum, on one hand, and to the intrinsic peculiarity of the spectrum, on the other. Evidently the reversing layer is of type B3 or B5. The large variations recorded by Harper and Merrill in the velocities of the *He* I lines suggest that the star is a binary—perhaps like φ Persei[47] or ζ Tauri. The outer shell corresponds to a later type, but because of the effect of dilution it is futile to assign it to a definite class. The radial velocities from our plate are summarized in Table 22. The large negative value derived from *He* I agrees with Harper's result in 1931 and 1932. Merrill obtained positive velocities in 1923. The available material is insufficient to trace the variations in velocity.

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[46] Merrill, *Ap. J.*, **72**, 109, 1930; **78**, 109, 1933 (Star MWC 397); Harper, *Pub. Victoria*, **7**, 94, 1937.

[47] Hynek, unpublished.

5. HD 186568

This is not a Be star. *Hα* is a strong absorption line, and there are no other emission lines. The star was placed on the observing program because Harper[48] had called attention to the fact that, while *He* I 4472 is broad and fuzzy, *He* I 4026 is sharp. Our plate shows that *Mg* II 4481, *Ca* II K, and *He* I 4009 are extremely sharp. The *Si* II lines are fairly sharp. *He* I 4472 is diffuse, and *He* I 3820 is very diffuse. On our plate, *He* I 4026 also looks slightly diffuse but perhaps less so than does *He* I 4472. The *H* lines are very strong and show large broadening by Stark effect. It is surprising that *He* I 4009 should be sharp, while *He* I 4388 does not show. The lines of *He* I which become strengthened when the radiation is diluted are not present. Hence, there is no reason to suspect the existence of an extended atmosphere. The ultraviolet region of the spectrum is normal and shows weak indications of the strongest *Mn* II lines. There is no similarity to HD 218393 or ζ Tauri. The radial velocity from our plate is −18 km/sec. The mean from Harper's three plates is −12 km/sec.

TABLE 22

RADIAL VELOCITIES OF HD 218393 ON SEPTEMBER 9, 1939

Element	No. of Lines	Velocity
		km/sec
Sharp *H* cores	19	−26.1
Diffuse *He* I	4	−99
Sharp *Fe* II	4	−44.6
Slightly diffuse *Si* II	5	− 8.1
Slightly diffuse *Mg* II	1	−59.4
Sharp *Ca* II	2	− 8.3

6. HD 160529

This star, classified as Oe5 in the *Henry Draper Catalogue*, was found by Merrill, Humason, and Burwell[49] to possess a bright line at *Hα*, while "the dark *Hβ* line is weak as if partly neutralized by emission." The rest of the spectrum was similar to that of α Cygni. Our observation confirms the similarity to α Cygni, but *Hβ* is an

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[48] *Pub. Victoria*, **7**, 79, 1937.

[49] *Ap. J.*, **76**, 159, 1932.

emission line of the P Cygni type. Several strong *Fe* II lines, especially the strongest members of the multiplet $a^6S - z^6P^o$, λλ 4924, 5018, and 5169, show weak emission lines with violet absorptions. The star is clearly a P Cygni type object and resembles 17 Leporis.[50] The latter has a strong emission line at $H\alpha$[51] and occasionally a very weak P Cygni type emission line at $H\beta$. The *Fe* II lines have often been suspected of having faint emission borders on their red sides, but this has not been proved.

In HD 160529 the strongest absorption lines are H and K of *Ca* II. They are broad and deep, suggesting a large amount of turbulence. The mean radial velocity derived from these two lines is −91 km/sec. There can be little doubt that they originate in an expanding shell. The *H* lines are remarkably weak. Were it not for the P Cygni character of $H\beta$ we should be inclined to attribute this to low hydrogen content, as in υ Sagittarii.[52] Our plate does not extend to the limit of the Balmer series, and we have no record of the drop in the continuous spectrum. The velocities derived from the *H* lines show a considerable range. The strongest lines give:

$H\delta$..........	− 62.5 km/sec
$H\gamma$..........	− 90.3
$H\beta$..........	−120.9

This apparent increase in the velocity of expansion as we pass from the weaker lines near the Balmer limit to the stronger lines showing P Cygni structure is common in the spectra of expanding shells. A similar effect is present in *Fe* II, the mean from all thirty absorption lines being −67 km/sec, while the members of multiplet $a^6S - z^6P^o$ give

λ 4924.......	−109.1 km/sec
5018.......	−133.9
5169.......	−136.7

Table 23 gives a summary of the radial velocities. *Mg* II 4481 is a fairly strong and sharp line. Since we know that dilution of the radiation tends to weaken this line, it is reasonable to suppose that it belongs to the reversing layer, not to the outer shell. The radial veloci-

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[50] Struve, *Ap. J.*, **76**, 85, 1932.

[51] *Ap. J.*, **90**, 727, 1939.

[52] Struve and Sherman, *Ap. J.*, **91**, 428, 1940; Greenstein, *Ap. J.*, **91**, 438, 1940.

ty of the reversing layer would then be −33 km/sec; and the maximum velocity of expansion, with respect to the reversing layer, would be of the order of −100 km/sec.

TABLE 23

RADIAL VELOCITIES OF HD 160529 ON SEPTEMBER 11, 1939

Element	No. of Lines	Velocity	Element	No. of Lines	Velocity
		km/sec			km/sec
H (absorption).......	9	−49.2	*V* II (absorption)....	2	−36.5
H (emission)..........	1	+39.0	*Cr* II (absorption)....	15	−30.4
Fe II (absorption).....	30	−67.1	*Ca* II (absorption)...	2	−91.4
Fe II (emission)......	4	+32.3	*Sc* II (absorption)....	2	−19.5
Fe I (absorption).....	9	−33.6	*Ni* II (absorption)...	1	−45.2
Si II (absorption).....	3	−37.2	*Mg* II (absorption)...	1	−32.9
Ti II (absorption).....	24	−42.3			

The *H* lines show no wings produced by Stark effect, and if our interpretation of *Mg* II 4481 is correct, the reversing layer is that of a supergiant, like α Cygni.

7. HD 190073

The remarkable structure of the *Ca* II lines and the presence of bright *Na* I $D_{1,2}$ was announced by Merrill.[53] The *H* lines were described by him and by Beals.[54] The spectrum has not changed much since 1928. The emission lines of *Ti* II and *Fe* II—all permitted—are fairly conspicuous on our plate. The strong *Fe* II lines λλ 4924, 5018, and 5169 show P Cygni structure, but the violet absorptions are weak, while the emissions are strong. Several other strong *Fe* II lines also suggest P Cygni structure. The emission lines of *H* are conspicuous as far as $H\delta$; they are quite broad and, in the case of $H\delta$ and $H\gamma$, may be centrally reversed. Otherwise, the *H* lines agree with Beals's description. $H\epsilon$ is complicated by *Ca* II H, but $H\zeta$ seems to show an exceedingly weak double emission line. The higher members of the Balmer series are in absorption only. These lines are unusually strong and give indication of large Stark effect. The wings of the higher members blend so that the background of the continuous spectrum rapidly declines toward the vio-

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[53] *Ap. J.*, 77, 51, 1933.

[54] *Pub. A.S.P.*, 51, 219, 1939.

let. The continuous spectrum on the violet side of λ 3647 is very weak. This feature permits several emission lines to stand out conspicuously against the faint continuous background. The emission lines, measured in the ultraviolet region and between the Balmer lines, are given in Table 24. These emission lines are fairly broad, suggesting a considerable dispersion in the motion of the shell.

In addition to the absorption lines described by Merrill, there are a number of faint but sharp absorption lines of *Si* II (λλ 3854, 3856, 3863, 4128, and 4132), of *Fe* II (violet borders of emission lines), and a few others, some of which have not been satisfactorily identified.

TABLE 24

EMISSION LINES IN HD 190073

Line	Intensity	Line	Intensity
Ti II 3535.41	1	*Cr* II 3677.86	1
Fe I 3581.21	0	*Ti* II 3685.20	10
Cr II 3585.31	1	*Ti* II 3706.22	1
Ti II 3596.06	2	*Ti* II 3741.65	1
Fe I 3608.87	0	*Ti* II 3759.30	12
Cr II 3613.21	1	*Ti* II 3761.32	12
Cr II 3631.49	3	*Fe* I 3859.92	2
Ti II 3641.34	0	*Ti* II 3900.54	2
Fe I 3647.85	0		

For example, a line at λ 3814 can hardly be the faint *Fe* II line 3814.12 or the *Ti* II line 3814.60.

The structure of the *Ca* II lines agrees with Merrill's description. The only difference is in the position of the faint narrow emission within the broad violet absorption component. On Merrill's plates this emission was unsymmetrically displaced toward the red from the middle of the absorption line.[55] On our plate the emission is clearly displaced toward the violet side of the middle of the absorption line. The radial velocities agree well with those published by Merrill.

The most significant fact about HD 190073 is the existence of an undisplaced reversing layer of high density in which the Stark wings of the *H* lines originate. Superposed over this spectrum is the P Cyg-

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[55] See Merrill's Fig. 1, *Ap. J.*, 77, 53, 1933.

ni type structure produced in the expanding shell. The similarity of this phenomenon to that observed in 17 Leporis has been discussed elsewhere.[56]

8. Stars with Forbidden [*Fe* ii] Lines

Fe ii has a large number of metastable levels of multiplicities 6, 4, and 2 based on the configurations $3d^64s$, $3d^7$, and $3d^54s^2$. In Dobbie's table,[57] all the 24 levels up to 38,215 cm^{-1} are metastable.

It is well known that Merrill[58] has identified several [*Fe* ii] multiplets in η Carinae, and these lines have subsequently been found in many other stars. Heretofore, only the following transitions have been observed:[59]

$$\begin{array}{rr} a^6D-a^6S & a^4F-b^4F \\ -b^4P & -a^4G \\ -b^4F & -b^4P \\ & -a^4H \end{array}$$

The two lowest metastable levels are a^6D and a^4F, the next one being a^4D. It is safe to expect the two multiplets $a^6D - b^4D$ and $a^4F - b^4D$. These groups of lines are in the observable ultraviolet region. We should also expect other transitions, such as $a^4D - b^2D$, which arrive in the higher level, a^4D. No transitions involving doublet terms have been found thus far, and several such multiplets may be expected.

In order to search for these lines, we selected a number of stars having strong [*Fe* ii] lines. Our program included WY Geminorum, W Cephei, Boss 1985, Boss 5481, BD+11°4673, HD 45677, etc. Among these stars, WY Geminorum and Boss 1985 proved to be best suited for our purpose.

WY Geminorum (HD 42474, mag 7.4–7.9) varies irregularly and rather slowly. It was classified at Harvard as ordinary K5 and at Mount Wilson[60] as M3ep. It is most certainly a multiple object, the ultraviolet region being perfectly free from the late-type spectrum and showing broad Balmer lines, down to H_{23}, with sharp centers.

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[56] Struve, *Proc. Nat. Acad.*, **26**, 117, 1940.

[57] *Ann. Solar Phys. Obs., Cambridge*, **5**, Part I, 1938.

[58] *Ap. J.*, **67**, 391, 1928.

[59] I. S. Bowen, *Rev. Mod. Phys.*, **8**, 80, 1936.

[60] Adams and collaborators, *Ap. J.*, **81**, 220, 1935.

There is a sharp and narrow line of *Ca* II K. A strong line at λ 3820 must be due to *He* I. The earlier component is of type B3. Redman[61] observed the photographic region of the spectrum with a dispersion of 92 A/mm at $H\gamma$ and found six emission lines, five of which had been identified as [*Fe* II]; the sixth line is λ 4068.8, which Redman believes is also due to [*Fe* II].

The star W Cephei is similar to WY Geminorum. It was classified as Kp at Harvard and as Mep at Mount Wilson, and it also shows [*Fe* II] lines, though they are weaker than in WY Geminorum. The continuous spectrum extends far into the ultraviolet, and there is a strong, but sharp, line at *Ca* II K. The Balmer lines are not clearly seen in the ultraviolet region, but there are several other absorption lines which we have not yet fully identified. The strongest is at λ 3708. This is probably not *Fe* I 3710, because the stronger laboratory line *Fe* I 3720 is not pronounced in the star. The spectrum is mostly continuous, but some of the weaker features may be due to *Fe* I. It is possible that the spectrum of a bright late-type star is combined with that of a relatively faint star of very early type—so early, in fact, that the Balmer absorption lines are no longer visible with the small dispersion which we have used for the ultraviolet region.

Boss 1985 (HD 60414–60415), classified as K5 + Be at Harvard and as M2ep at Mount Wilson, is also a double object, consisting of an M star and a Be star. It is known to possess [*Fe* II] lines. The structure of the H lines is remarkable. A bright line of appreciable width is flanked on the red side by a narrow, deep absorption line; and this structure is superposed over a broader line, having Stark-effect wings, especially on the violet side of the emission line. The emission line is strong in $H\epsilon$, $H\zeta$, and H_9. It can still be detected in H_{10}. The higher members of the Balmer lines are well visible, and their strength, as well as the intensity of *He* I 3820, suggest that the type of the earlier component is B3e. The blending with the late-type star renders it difficult to identify the absorption lines even in this region.

Boss 5481 (HD 203338-9) is a visual binary (K0 + A0 at Harvard; K5p at Mount Wilson); the [*Fe* II] lines are present but are

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[61] *M.N.*, **92**, 118, 1932; *Pub. Victoria*, **6**, 34, 1931.

much weaker than in Boss 1985. On our plates the earlier component is clearly of type B2: the *He* I lines are strong, and there are lines of *O* II. This spectrum predominates on the violet side of $H\gamma$; but even $H\beta$, belonging to it, is still clearly visible. The forbidden [*Fe* II] lines are very weak, and it is probable that they originate in the outer atmosphere of the K star. The binary is listed by Aitken as No. 14864. The components have magnitudes 5.6 and 9.9; their separation is about 5″ in position angle 45°. It is doubtful that the light of the fainter visual component has entered the slit of the spectrograph. The brighter component must itself be composite, and the excitation of the gases in the K star by the B star is doubtless responsible for [*Fe* II] lines. The relatively great intensity of the B star is disadvantageous to the emission lines, and it is possible that they are intrinsically as strong as in other stars of this group.

BD+11°4673, already considered in Section II, and Z Andromedae, which will be discussed in Section IV, were poor in [*Fe* II] at the time of our observations.

HD 45677 was richer in [*Fe* II] and confirmed the results obtained from the other stars. The spectrum has not changed appreciably since the time of Merrill's observations.[62] This star is not composite in the sense that a late-type spectrum is superposed over that of an early type. The spectrum of the reversing layer shows fairly broad lines of *He* I and sharper lines of *O* II, *C* II, *N* II, and *Mg* II, together with very broad Stark-effect wings of *H;* it is of type B2. The shell is responsible for the emission lines of *Fe* II, [*Fe* II], [*O* I] 6300, etc., for the emission lines of $H\alpha$, $H\beta$, $H\gamma$, and $H\delta$ and for the exceedingly sharp central absorption lines of *H* which are followed to H_{29} or H_{30}. The radial velocities from the lines of the shell agree with those from the reversing layer. It is significant that the sharp component of $H\zeta$ is not greatly strengthened, and that *He* I 3965 is not visible as a strong, sharp line. Evidently *He* I is not excited in the shell; otherwise we should see those lines which arise from metastable levels. The *Ca* II K line is sharp and fairly strong. Its velocity agrees with that of the other lines.

Our investigation is based mainly on WY Geminorum and Boss 1985, and we decided to confine the present discussion to the region of wave lengths shorter than λ 4000, which is practically free from

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[62] *Ap. J.*, 67, 405, 1928.

the spectrum of the late-type component. The permitted lines of *Fe* II are weak compared with the forbidden transitions. Our results for the newly observed forbidden multiplets are collected in Table 25.

TABLE 25

NEW FORBIDDEN TRANSITIONS OF [*Fe* II]

Transition	λ Predicted	λ Observed in WY Geminorum	λ Observed in B 1985
	Lower Level a^6D		
$a^6D_{\frac{1}{2}}-b^4D_{\frac{1}{2}}$	3289.5	3290 (2)	3289.4 (2)
$D_{\frac{1}{2}}$ $D_{1\frac{1}{2}}$	3289.9		
	Lower Level a^4F		
$a^4F_{4\frac{1}{2}}-b^4D_{3\frac{1}{2}}$	3376.2	3376.6 (2)	3376.2 (3)
$F_{4\frac{1}{2}}$ $D_{2\frac{1}{2}}$	3387.1	3387.8 (1)	3386.9 (1)
$F_{3\frac{1}{2}}$ $D_{3\frac{1}{2}}$	3441.0	3441.0 (1)	....
$F_{3\frac{1}{2}}$ $D_{2\frac{1}{2}}$	3452.3	3452.2 (2)	3452.0 (1)
$F_{3\frac{1}{2}}$ $D_{1\frac{1}{2}}$	3455.1	3455.3 (1)	....
$F_{2\frac{1}{2}}$ $D_{2\frac{1}{2}}$	3501.6	3502.1 (2 bl)	3501.5 (2 bl)
$F_{2\frac{1}{2}}$ $D_{1\frac{1}{2}}$	3504.5	3504.4 (4)	3504.2 (4)
$F_{2\frac{1}{2}}$ $D_{\frac{1}{2}}$	3504.0		
$F_{1\frac{1}{2}}$ $D_{3\frac{1}{2}}$	3524.4	3524.4 (0)	....
$F_{1\frac{1}{2}}$ $D_{2\frac{1}{2}}$	3536.2	3536.2 (0)	....
$F_{1\frac{1}{2}}$ $D_{1\frac{1}{2}}$	3537.2	3539.1 (3)	3538.8 (3)
$F_{1\frac{1}{2}}$ $D_{\frac{1}{2}}$	3538.7		
	Lower Level a^4D		
$a^4D_{1\frac{1}{2}}-a^2S_{\frac{1}{2}}$	3502.0	3502.1 (2 bl)	3501.5 (2 bl)
$D_{1\frac{1}{2}}-b^2D_{2\frac{1}{2}}$	3625.8	3626.5 (4)	3626.5 (5)
$D_{\frac{1}{2}}$ $D_{1\frac{1}{2}}$	3664.7	3665.7 (2)	....
$D_{1\frac{1}{2}}-c^2D_{1\frac{1}{2}}$	3385.0	3385.0 (1)	3385.8 (1)
$D_{1\frac{1}{2}}$ $D_{2\frac{1}{2}}$	3390.7	3390.7 (0)	....

The following conclusions have been derived:

1. The excitation potential reached is 4.72 v. instead of 3.2 v.
2. No [*Fe* II] transition has been observed between doublets and sextets. On the other hand, several forbidden lines connect metastable doublets and quartets.
3. In the $a^6D - b^4D$ multiplet, the spectral region observable

with our instrument permitted only the observation of the $\frac{1}{2}$–$\frac{1}{2}$ transition at λ 3289.5.

4. Forbidden lines arriving at the a^4D level are observed. Several new forbidden multiplets which should appear above λ 4000 may be expected, since the [*Fe* II] spectrum is so strong in these stars. But, owing to the presence of the late-type component, our present material is not sufficient for a systematic discussion of these multiplets, although it does show several new forbidden lines.[63]

5. In the $a^4F - b^4D$ multiplet the observations are roughly in agreement with the relative intensities computed from the formulae by A. Rubinowicz.[64]

TABLE 26

FORBIDDEN TRANSITIONS a^6S-b^4D OF [*Cr* II]

Transition	λ Predicted	λ Observed
$2\frac{1}{2}-3\frac{1}{2}$	3993.2	3993.2 (3)
$2\frac{1}{2}-\frac{1}{2}$	3992.9	
$2\frac{1}{2}-1\frac{1}{2}$	3991.8	
$2\frac{1}{2}-2\frac{1}{2}$	3991.1	

6. The spectra of WY Geminorum and Boss 1985 are so rich in [*Fe* II] that it is interesting to search for forbidden transitions of other singly ionized metals. A fairly strong line measured at λ 3993.2 agrees with the forbidden transitions $a^6S - b^4D$ of [*Cr* II], a^6S being the ground level of *Cr* II (Table 26).

7. Two strong unidentified lines appear at λ 3439.0 and λ 3559.6 (see Pl. V); they are also present in HD 45677.

IV. PECULIAR SYSTEMS SHOWING SIMULTANEOUSLY SPECTRAL FEATURES DUE TO VERY HIGH AND VERY LOW EXCITATION

Several recent discoveries have shown that systems consisting of a late-type giant and a hot companion are not infrequent.[65] This sec-

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[63] New observations are planned in this connection. It would be interesting to find a pure Be star showing [*Fe* II] with the same degree of sharpness and completeness. The spectrum of HD 45677 shows that the presence of a late-type binary component is not necessary for the production of [*Fe* II].

[64] Rubinowicz and Blaton, *Erg. Ex. Naturwissenschaften*, **11**, 176, 1932.

[65] In Section III we have considered such objects as WY Gem and W Cep, which consist of a late-type star and of an early B star. Other examples are VV Cep, ζ Aur, ε Aur, etc.

tion is devoted to the discussion of several objects of this type, showing simultaneously an M-type spectrum and forbidden lines of high excitation.

1. Z ANDROMEDAE

The spectrum of Z Andromedae has been described by H. H. Plaskett.[66] During the entire period of his observations, 1923–1926, it showed only emission lines. Hogg[67] found *TiO* bands in absorption, which increased in intensity while the star was fading in light. The recent outburst in the total light of the star[68]—was accompanied by a remarkable change in spectrum.[69] The star is now of the P Cygni type. The permitted emission lines of lower excitation (*Fe* II, *Ti* II, etc.) are present, and are fairly conspicuous. The forbidden lines of [*Fe* II] are much weaker than on Plaskett's plates. The strong emission lines attributed by Plaskett to the nebular part of Z Andromedae have disappeared.

It has been suggested[70] that the *TiO* spectrum comes from an M-type companion, while the emission lines of Plaskett's "nebula" are excited in a tenuous shell surrounding a very hot, small star. The emission lines of the "star" (*Fe* II, etc.) could perhaps come from

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[66] *Pub. Victoria*, **4**, 119, 1928.

[67] *Pub. A.S.P.*, **44**, 328, 1932; *Pub. A.A.S.*, **8**, 14, 1934.

[68] L. Campbell, *Pop. Astr.*, **47**, 571, 1939; K. Himpel, *Die Sterne*, **19**, 210, 1939, and **20**, 14, 1940.

[69] Struve and Elvey, *Pub. A.S.P.*, **51**, 297, 1939. [*Note added in proof:* According to L. Campbell, the visual magnitude of Z And was 8.2 when our first plate was taken—September 14, 1939. The star remained bright until December 5, 1939, when the last spectrogram of this series was obtained. Two spectrograms were secured after the star became again observable in the east—on May 12 and 15, 1940. The entire aspect of the spectrum has changed. It again resembles that described by Plaskett, but the "nebular" spectrum is more pronounced on our plates than on Plaskett's. The visual apparent magnitude was estimated to be 9.3. The spectrum shows almost only emission lines. The forbidden lines of [*O* III] are strong, with the auroral transition relatively strong—as in novae. There is some indication of the fluorescence lines of *O* III, but λ 3760 is weak or absent. [*Ne* III] and [*Ne* V] are very strong; *He* I is strong; *He* II 4686 is very strong. *N* III 4634–4640 is fairly strong. The *H* lines are visible in emission as far as H_{10}. The higher members are not clearly seen, but there is a suspicion of several P Cygni type lines at λλ 3687, 3693, etc. The continuous spectrum shows a marked drop near λ 3647, showing that the continuous Balmer absorption is not completely filled in by emission. Several permitted emission lines of *Fe* II are present, but the forbidden lines of [*Fe* II] have not with certainty been identified. The development of Z And bears strong resemblance to that of a nova.]

[70] Hogg, *Pub. A.A.S.*, **8**, 14, 1934.

the outer layers of the M star, excited by the radiation of the hot star.

The recent outburst permits us to clarify this picture. The spectrum of *TiO* has disappeared, together with the emission lines of *He* II, *N* III, *O* III, etc. The permitted emission lines of *H*, *Fe* II, *Ti* II, etc., have remained, but they now have violet absorption borders. The forbidden lines are weak. There can be little doubt that the outburst occurred in the hot star and that the light of the M star is lost in the increased brilliance of that object. The presence of emission *Fe* II, etc., suggests that these lines are produced in the shell which surrounds the hot star. The weakening of [*Fe* II] may well be caused by the decrease in dilution of radiation occasioned by the expansion of the photosphere. The disappearance of emission lines of *He* II, etc., may be due to the fact that the exciting radiation in the extreme ultraviolet has changed, or it may point to the possibility that these lines originate in the atmosphere of the M star and have been obliterated by the outburst. The latter hypothesis would require a strengthening of the emission lines because of the increased radiation of the hot star. But theoretical considerations suggest that there may be a lag of months or even years before the ionization of the extremely tenuous gas of the M star adjusts itself to the changes in radiation of the hot star. Whether the presence of emission lines of *He* II, etc., after the outburst[71] should be considered as evidence that their light was not suppressed is not certain at the present time.

The succession of events in Z Andromedae resembles those in T Coronae Borealis. This nova of 1866 was observed at several places during its recent rise in brightness.[72] Hachenberg and Wellmann have established the binary nature of this object.

Table 27 shows the intensities of the lines measured on our first and out last plates of Z Andromedae. In general, the absorption lines became more prominent and the emission lines slightly fainter. But the change was not conspicuous. The dilution of the exciting radiation could not have been very pronounced, because *Mg* II 4481 and several *Ti* II lines were present in absorption. This is interest-

[71] *Die Sterne*, **19**, 210, 1939.

[72] Hachenberg and Wellmann, *Zs. f. Ap.*, **17**, 246, 1939; Wellmann, *Zs. f. Ap.*, **19**, 16, 1939; Joy, *Pub. A.S.P.*, **50**, 300, 1938; Minkowski, *Pub. A.S.P.*, **51**, 54, 1939.

TABLE 27

INTENSITIES OF LINES IN Z ANDROMEDAE

λ	ABSORPTION 1939		EMISSION 1939	
	Sept. 16	Dec. 5	Sept. 16	Dec. 5
Ti II				
3372.8	3	.....	0	.....
3383.8	3	.....	0	.....
3387.8	2	.....	0	.....
3394.4	.....	2	.....	0
3444.3	1	.....	0	.....
3456.4	.....	2	.....	0
3465.7	1	1	0	0
3477.2	1	2	0	0
3491.1	.....	1	.....	0
3504.9	1n	3	0	0
3510.9	1	1	0	0
3520.3	1	.....	0	.....
3535.4	.....	1	.....	1
3596.1	0	2	0	0
3624.8	.....	2n	.....	0
3641.3	0	1	0	0
3659.8	0	3	0	0
3662.2	1	1	0	0
3685.2	3	4	0	0
3741.7	1	5	0	0
3757.7	.....	1	.....	0
3759.3	4	4	1	0
3761.3	3	4	2	0
3776.1	.....	1	.....	0
3900.5	1	2	1	1
3913.5	1	4	3	2
4012.4	1	0	4	1
4028.4	1	.....	2	.....
4053.8	0	0	1	1
4161.5	1	1	2	1
4163.7	0	2	3	1
4171.9	1	.....	1	.....
4290.2	0	1	2	1
4294.1	0	2	0	0
4300.1	.....	3	.....	0
4312.9	1n	1nn	1n	0
4337.9	0	.....	1	.....
4374.8	0	0	2n	1
4395.0	1n	0	3	1
4399.8	0	.....	2	.....
4443.8	0	2	2	1
4468.5	1	2	1	0
4488.3	0	.....	1	.....
4501.3	1	.....	1	.....
4534.0	0	.....	1	.....
4563.8	0	2	1	0
Ti II—*Cont.*				
4572.0	0	1	1	0
5336.8	0	0	2	1
Fe II				
3468.5	0	1	0	0
3493.5	1	1	0	0
3499.9	1n	.....	0	.....
3507.4	1	1	0	0
3564.5	1n	.....	0	.....
3621.3	2	1	1	0
3634.9	.....	1	.....	0
3764.1	.....	2	.....	0
3814.1	1nn	.....	3nn	.....
3824.9	.....	1	.....	0
3906.0	.....	0	.....	0
3935.9	1	2	1	0
3938.7	2	1	2	1
3945.2	.....	0	.....	2
3981.6	1nn	.....	1	.....
4002.1	.....	0	.....	0
4122.7	1	0	0	2
4173.5	0	0	3	3
4178.9	0	0	5	3
4233.2	2	3	6	5
4258.2	.....	0	.....	1
[4287.4]	0	.....	1	.....
4296.6	2	1	0	1
4303.2	0	0	1	0
4351.8	0	0	3	4
[4359.4]	0	0	1	1
4379.4	.....	0	.....	1
4384.3	0	.....	3n	.....
4385.4	.....	0	.....	1
4416.8	0	0	3	1
4455.3	.....	1	.....	0
4489.2	.....	0	.....	1
4491.4	0	0	2	1
4508.3	.....	1	.....	1
4515.3	0	1	2	2
4520.2	0	.....	0	.....
4522.6	0	0	1	1
4534.2	.....	1	.....	1
4541.5	0	0	1	1
4549.5	1	3	3	3
4555.9	0	1	2	1
4576.3	.....	1	.....	1

TABLE 27—*Continued*

λ	ABSORPTION 1939		EMISSION 1939	
	Sept. 16	Dec. 5	Sept. 16	Dec. 5
Fe II—*Cont.*				
4583.8	0	1	5	5
4629.3	0	0	4	2
4666.8	0	.....	1nn	.....
4731.5	0	0	1n	1
4923.9	3	1	3	4
5018.5	7	1	4	4
5169.1	2	2	4	3
5197.6	1	1	2	1
5234.6	1	1	1	1
5276.0	2	.....	1	.....
5284.1	0	.....	2	.....
5316.6	1	0	5	3
5362.9	1	1	3	2
5534.9	.....	0	.....	1
6149.3	.....	0	.....	3
Cr II				
3391.4	1	.....	0	.....
3394.4	.....	2	.....	0
3403.3	2	.....	0	.....
3408.8	3	2	0	0
3421.2	2	1	0	0
3422.7	2	2	0	0
3433.3	2	3	1	0
3585.3	3n	3	0	1
3603.8	1	2	1	0
3608.7	1	1	0	0
3613.2	1n	.....	0	.....
3631.5	2	3	3	1
3644.7	1	.....	0	.....
3677.8	2	3	0	0
3715.3	2	3	2	1
3727.4	2	2n	1	0
3754.6	.....	1	.....	0
3765.6	.....	1	.....	0
3905.6	1	.....	2	.....
3979.5	.....	1n	.....	0
4242.4	1	1	0	1
4261.9	1	.....	0	.....
4634.1	.....	1	.....	0
4848.3	.....	0	.....	1
H				
H_{28}	1	.....	0	.....
H_{27}	1	.....	0	.....
H_{26}	2	1	0	0
H_{25}	2	2	0	0
H—*Cont.*				
H_{24}	3	3	0	0
H_{23}	4	4	0	0
H_{22}	4	4	0	0
H_{21}	4	4	0	0
H_{20}	5	5	0	0
H_{19}	4	4	0	0
H_{18}	6	6	0	0
H_{17}	6	6	0	1
H_{16}	7	7	0	1
H_{15}	7	9	1	4
H_{14}	8	6	1	1
H_{13}	8	7	0	1
H_{12}	8	7	2	6
H_{11}	6	7	0	4
H_{10}	10	8	1	3
H_{9}	9	10	2	3
H_{8}	10	8	2	4
$H\epsilon$	9	8	4	7
$H\delta$	10	7	5	8
$H\gamma$	9	4	7	12
$H\beta$	6	0	10	10
Fe I				
3719.9	.....	0	.....	0
3737.0	1	1	3	1
3748.3	1	3	0	0
3763.8	2	.....	1	.....
3767.2	1n	1	0	0
3820.4	.....	1nn	.....	0
3827.8	.....	1	.....	0
3850.0	0	1	0	0
3860.0	.....	0	.....	1
3872.5	.....	0	.....	1
4005.3	0	.....	1	.....
4045.8	0	.....	0	.....
4143.9	0nn	.....	0	.....
4202.0	0	.....	1	.....
Mn II				
3439.0	0	.....	2	.....
3442.0	3	3	3	2
3460.3	2	1	1	0
3474.1	2	2	1	0
3482.9	1n	1n	0	0
3488.7	1	.....	0	.....
3495.8	1	.....	0	.....
3497.5	1	.....	0	.....

TABLE 27—*Continued*

λ	ABSORPTION 1939		EMISSION 1939		λ	ABSORPTION 1939		EMISSION 1939	
	Sept. 16	Dec. 5	Sept. 16	Dec. 5		Sept. 16	Dec. 5	Sept. 16	Dec. 5
V II					*Ca* II				
3517.3	2n	1n	0	0	3706.4	3	1	3	0
3556.8	1	.....	0	.....	3737.0	1	1	3	1
3589.7	2	1	0	0	3933.7	9	8	4	3
3592.0	.....	1	.....	0	3968.5	10	8	0	0
3593.3	.....	1	.....	1					
3727.4	2	2n	1	0	*Mg* I				
3745.8	1	1	0	0	3829.4	1	.....	0	.....
3847.3	.....	1	.....	0	3832.3	1	3	0	1
3896.2	.....	1nn	.....	1	3838.0	2	3	1	1
3903.3	.....	0	.....	0					
3973.6	.....	1	.....	0	*Mg* II				
3997.1	0	.....	0n	.....	4481.3	1	1	0	0
4005.7	.....	0	.....	0					
4035.6	0	.....	0	.....	*Si* II				
					3856.0	1	1	1	1
Ni II					3862.6	1n	1	0	0
3471.4	2n	1	0	0	4128.1	1	1	0	2
3513.9	4	3	1	1	4130.9	2	1	0	0
3576.8	2	3	2	1					
3769.5	3	5	0	0	*He* I				
4067.0	3	0	0	0	4471.5	1	.....	0	.....
4362.1	0	0	0	0					
Sc II									
3572.5	1	1	0	0					
3580.9	.....	1n	.....	0					
3613.8	.....	1nn	.....	0					
3642.8	1	.....	0	.....					
4325.0	0n	.....	0	.....					

ing, in view of the presence of weak forbidden [*Fe* II] lines. But it is possible that the forbidden lines originate in a distant shell which has not yet been engulfed by the expanding photosphere.

A very remarkable astrophysical phenomenon becomes apparent from an inspection of Table 27. The metallic lines (notably *Ti* II) tend to show pure absorption lines on the violet side of the Balmer limit (λ 3647) and emission lines on the red side. This phenomenon is the exact opposite of what we had described in HD 190073. We are not aware of other stars showing the same conspicuous discontinuity in the appearance of the metallic lines.

Figure 10 shows the transitions of *Ti* II. The effect is not connected with the excitation potentials of the levels involved; nor is it in any way correlated with the spectroscopic notations of the various

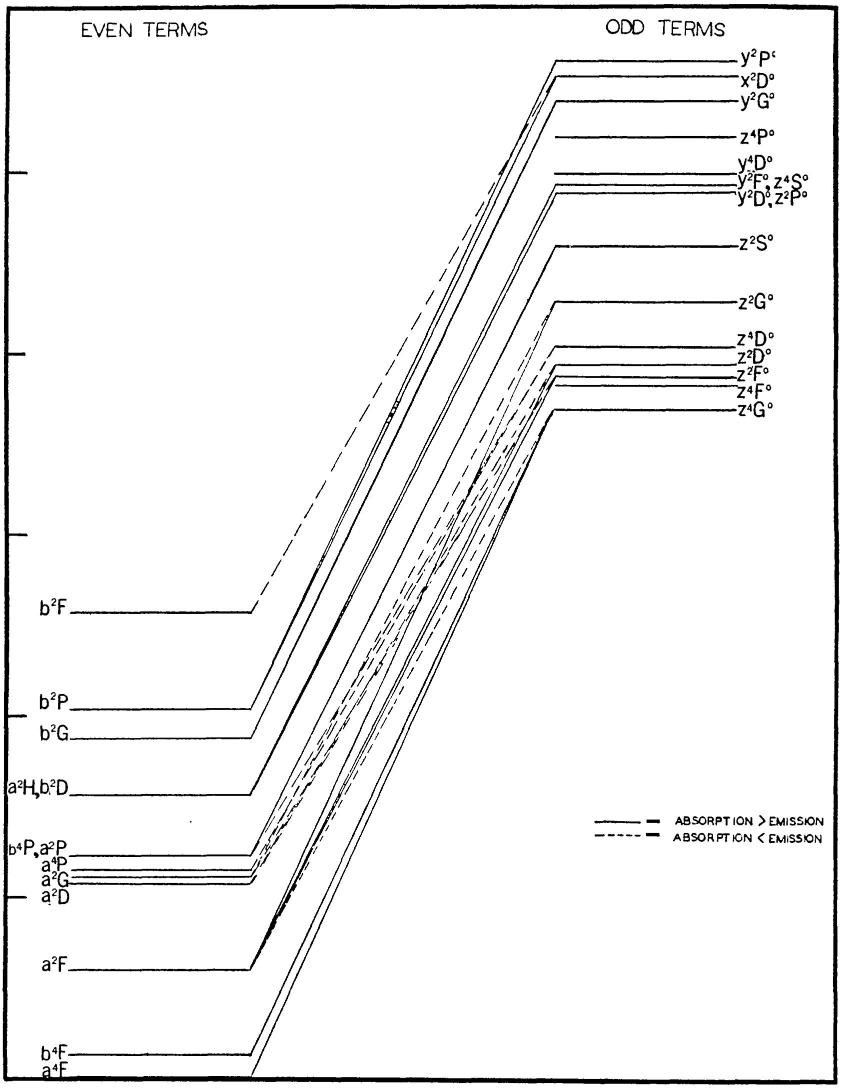

FIG. 10.—*Ti* II lines in Z Andromedae

terms. Moreover, other metals show the same discontinuity near λ 3647.

The following explanation suggests itself. The *H* absorption lines are strong, and they extend to H_{28}. The continuous spectrum shows a marked step at λ 3647, and all evidence points toward a large continuous absorption coefficient, due to H, in the expanding shell.[73] At the Balmer limit the continuous absorption coefficient κ_ν experiences a sudden change. This produces a weakening of the absorption lines on the violet side of λ 3647 by a factor of $\gamma = \kappa_\nu''/\kappa_\nu'$.[74] The existence of this effect has been so abundantly proved in ordinary stars and even in shells[74] that we safely assume that it holds for Z Andromedae.

The emission lines originate in a tenuous ring formed by the outer layers of the shell. In reality, there must be a gradual transition from continuous spectrum to line emission as we pass from the center of the apparent disk of the star to the edge. But if we adopt Milne's picture of a hazy atmosphere for the expanding shell, we may well extend this picture and assume that line emission comes from those parts of the shell for which the total optical thickness $\tau < \tau_1$, where τ_1 is the level of the fictitious photosphere according to Milne (approximately $\tau_1 = 1/3$). If we assume, for simplicity, that the outer parts of the shell have a constant κ_ν, then τ_1 is proportional to the length of the chord, x, which separates the region of line emission from the region of continuous emission. The volume of the shell which gives rise to line emission is $V = \frac{1}{6}\pi x^3$. But $x \propto \kappa_\nu$. Accordingly, the intensities of the emission lines should vary as γ^3, and the ratio of emission intensity to equivalent breadth in absorption should vary as γ^2. A density gradient in the shell would only increase the effect. In ordinary A stars γ is of the order of 10. Hence, the ratio of emission to absorption should vary greatly when we pass from the violet side of the Balmer limit to the red side.

Table 28 gives the radial velocities measured for Z Andromedae on three plates.

2. AX Persei and CI Cygni

The spectra of these two stars have been investigated by Merrill[75] from spectrograms taken in 1931 and 1932. They showed bright lines of H, He I, He II, N III, [O III], and [Ne III], superimposed on an M-type spectrum. The variable character of the two stars has

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[73] Struve, *Proc. Nat. Acad.*, **26**, 117, 1940.

[74] Struve and Sherman, *Ap. J.*, **91**, 428, 1940; Roach and Blitzer, *Ap. J.*, in press.

[75] *Ap. J.*, **77**, 44, 1933.

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been discussed extensively. C. and S. Gaposchkin[76] state that "CI Cygni is another double (or triple) object: a red star, a blue star, and a nebula (which may possibly be the outer envelope of the red star)." In both cases the light curve shows similarity to Z Andromedae.

Several spectrograms of AX Persei and CI Cygni were obtained in the wave-length region λλ 3300–6700.

At first sight the spectrum of AX Persei appears to have changed greatly since 1931–1932. At the present time AX Persei and CI Cygni are so similar that we combine their description in the same section.[77] In Table 29 we have collected the emission lines and their probable identifications.

TABLE 28

RADIAL VELOCITIES OF Z ANDROMEDAE

ELEM.	ABSORPTION 1939			EMISSION 1939		
	Sept. 16	Oct. 18	Dec. 5	Sept. 16	Oct. 18	Dec. 5
Ti II	−118.5	−65.4	−58.3	− 8.2	+28.1	+50.4
Fe II	−140.0	−62.9	−72.4	+ 3.1	+35.0	+42.4
H	− 80.9	−72.5	−54.7	+23.2	+60.5	+58.6
Cr II	− 88.3	−44.4	−58.6	+ 8.8	+13.5	+43.2
Fe I	−112.6	−63.6	−82.1	+ 0.9	....	+22.6
Mn II	− 89.0	....	−50.5	+14.4	....	+46.5
Ni II	− 87.9	....	−65.5	−10.2	....	+25.4
V II	−105.0	....	−61.4	− 8.2	+13.5	+49.6
Sc II	−126.7	....	−39.0	+ 5.6	....	....
Ca II	− 68.5	−67.2	−41.2	− 3.2	+36.3	+28.1
Ca I	....	....	....	−11.5	....	+22.6
Mg I	− 70.6	−58.8	−46.9	− 4.1	....	+41.6
Mg II	− 92.6	−20.0	−53.2	....	....	....
Si II	− 82.5	−87.2	−42.9	+ 7.6	....	+62.3
He I	−106.4	....	....	....	....	....

Besides the weak continuous spectrum with M-type absorptions, our spectrograms show only emission lines.

Hydrogen.—The Balmer lines are observed from $H\alpha$ to H_{21}, and there is also a strong Balmer continuum in emission as far as λ 3470. This spectrum may be attributed essentially to the "nebular com-

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[76] *Variable Stars*, pp. 315–316, 1938.

[77] Dr. G. P. Kuiper has found from low-dispersion spectrograms (340 A/mm at $H\gamma$) that the spectral type of AX Per is gM3e and that of CI Cyg, gM4e.

TABLE 29

EMISSION LINES IN AX PERSEI AND CI CYGNI

AX PERSEI		CI CYGNI		IDENTIFICATION		EXCITATION POTENTIAL OF HIGHER LEVEL (VOLTS)	NOTES
λ	Int.	λ	Int.	Elem.	Lab. λ		
3340.7	1	3340.7	1	*O* III	3340.74	36.7	1
3346	4	3346	4	[*Ne* V]	3345.8	3.8	
3426	8	3425.6	8	[*Ne* V]	3425.8	3.8	
3443.8	4	3444.0	3	*O* III	3444.1	40.7	1
3586.4	3	3586.7	4	[*Fe* VII]	3587.2	3.6	
3678.5	1	......	......	H_{21}	3679.3	13.51	
3682.5	2	3682.0	1	H_{20}	3682.81	13.51	
3686.4	2	3685.9	1	H_{19}	3686.8	13.50	
3691.2	2	3691.4	1	H_{18}	3691.6	13.50	
3696.7	2	3697.0	1	H_{17}	3697.2	13.49	
3703.7	3	3703.6	1	H_{16}	3703.9	13.49	2
3705.0	1	......	......	......	......	......	
3712.1	3	3712.0	1	H_{15}	3712.0	13.48	
3714.8	1	......	......	......	......	......	
3721.8	3	3722.3	1	H_{14}	3721.9	13.47	
3727.8	on	3727	on	[*O* II]	3726.1 3728.6	3.3	
3734.5	4	3734.7	2	H_{13}	3734.4	13.46	3
3750.0	4	3750.7	2	H_{12}	3750.2	13.45	
3754.7	1	......	......	[*Fe* V]	3755.5	3.3	
3759.3	6n	3759.1	5	*O* III [*Fe* VII]	3759.9 3759.9	36.3 3.6	1, 4
3770.8	4	3770.6	2	H_{11}	3770.6	13.43	
3798.4	4	3798.1	2	H_{10}	3797.9	13.40	
3820.4	1	3820.0	1	[*Fe* V]	3820.2	3.3	
3826.9	on	......	......	......	......	......	
3835.5	5	3835.5	3	H_9	3835.4	13.37	
3840.8	0	3840	0	[*Fe* V]	3838.9	3.3	
3869.5	4	3869.3	1	[*Ne* III] [*Fe* XI]?	3868.7 3871.9	3.2 4.7	
3889.3	7	3888.8	3	H_8	3889.1	13.33	
3904.9	1	3905.4	0	*Si* I	3905.5	5.06	5
......	......	3923.4	0	*He* II [*Ti* IX]	3923.51 3923	53.9 3.2	
3933.6	3	3933.9	1	*Ca* II	3933.7	3.1	
......	......	3938.0	1	......	......	......	6
3964.8	1	3964.9	1	*He* I	3964.7	23.64	
3969.5	7n	3970.0	4n	[*Ne* III] $H\epsilon$	3967.5 3970.1	3.2 13.26	
......	......	4010.6	1	*He* I	4009.3	24.2	
4026.4	2	4026.5	2	*He* I	4026.2	23.9	7
4071.1	0	4071	0	[*Fe* V]	4071.5	3.1	
4097.4	2	4097.4	2	*N* III	4097.3	30.3	1
4102.4	8	4101.9	5	$H\delta$ *N* III	4101.7 4103.4	13.16 30.3	 1
......	......	4122.0	0	*He* I [*K* V]	4120.8 4120±	23.9 3.0	

TABLE 29—*Continued*

AX PERSEI		CI CYGNI		IDENTIFICATION		EXCITATION POTENTIAL OF HIGHER LEVEL (VOLTS)	NOTES
λ	Int.	λ	Int.	Elem.	Lab. λ		
4144.6	1	4143.6	1	*He* I	4143.8	24.1	
....	......	4161.7	1	[*K* V]	4160±	3.0	
....	......	4173.4	0	*Fe* II	4173.4	5.53	
4178.6	on	4179.7	1	*Fe* II [*Fe* V]	4178.9 4181.4	5.52 3.0	
4233.7	1	4233.1	0	*Fe* II	4233.2	5.49	
....	......	4244.4	1	[*Fe* II]	4244.8	3.21	
4277.2	0	4277.5	0	....	....	....	8
4286.2	0	4286.8	0	[*Fe* II]	4287.4	2.88	8
4296.4	0	4297.0	0	*Fe* II	4296.6	5.56	8
4303.6	0	4303.9	0	*Fe* II	4303.2	5.56	8
4316.3	0	....	......	....	....	....	8
4340.2	10	4340.3	8	*H*γ	4340.5	13.00	
4352.1	1	4351.6	1	*Fe* II	4351.8	5.53	
4359.3	1	....	......	[*Fe* II]	4359.3	2.88	
4364.1	5	4363.3	2	[*O* III]	4363.2	5.3	
4371.5	0	....	......	[*Fe* II]	4372.5	3.21	
4378.5	1	....	......	....	....	....	
4387.9	1	4387.0	1	*He* I	4387.9	23.9	
....	......	4409.7	0	[*Cr* IX]	4408	3.8	
4472.4	2	4471.5	3	*He* I	4471.5	23.6	
....	......	4481.6	0	*Mg* II	4481.2	11.6	9
4491.7	1	4489.9	1	*Fe* II *Fe* II [*Fe* II] [*Fe* II]	4489.2 4491.4 4488.8 4492.6	5.56 5.59 2.83 2.79	
....	......	4516.2	1	*Fe* II	4515.3	5.56	
....	......	4523.6	0	*Fe* II	4522.6	5.56	
4541.5	0	4541.2	1	*He* II	4541.6	53.5	
4550	0	4549.8	1	*Fe* II *Ti* II	4549.5 4549.6	5.53 4.3	
4557.8	0	4555.3	1	*Fe* II	4555.9	5.52	
4571.7	0	4571.7	2	*Mg* I	4571.1	2.7	5
....	......	4576.6	1	*Fe* II	4576.3	5.53	
4584.0	1	4582.4	2	*Fe* II	4583.8	5.49	
....	......	4629.2	1	*Fe* II	4629.3	5.46	
4634.0	0	4633.0	1	*N* III	4634.2	33.0	1
4640.7	1	4640.2	1	*N* III	4640.6	33.0	1
....	......	4658.6	0	[*Fe* III]	4658.2	2.7	9
4684.6	8	4685.8	6	*He* II	4685.8	50.8	
4704.9	0	....	......	[*Ti* IX]? [*Fe* III]?	4700± 4701.5	2.7 2.7	
4713.4	3	....	......	*He* I [*A* IV]?	4713.1 4711.4	23.6 2.6	
4861.5	15	4861.3	10	*H*β	4861.3	12.69	
4923.2	1	4922.5	1	*He* I *Fe* II	4921.9 4923.92	23.64 5.38	
4944.7	1	4940.5 4949.5	1 1	[*Ca* VII] [*Fe* VII]	4941 4942.3±	2.7 2.5	 10

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TABLE 29—*Continued*

AX PERSEI		CI CYGNI		IDENTIFICATION		EXCITATION POTENTIAL OF HIGHER LEVEL (VOLTS)	NOTES
λ	Int.	λ	Int.	Elem.	Lab. λ		
5007.7	1	5008	0	[*O* III]	5007.6	2.5	
5016.6	0	....	......	*He* I *Fe* II	5015.7 5018.4	23.0 5.34	
5041.3	1	....	......	....	....	....	11
5160.8	3	5156.0	3	[*Fe* VII]	5158.3±	2.6	
5274.0	1	5274.1	2	[*Fe* VII] [*Fe* III]	5276.1± 5270.5	2.6 2.6	
5309.2	1	....	......	[*Ca* V]	5308.9	2.3	
5337.5	1	....	......	[*Fe* VI]?	5336.4	2.5	12
5408.4	3n	....	......	*He* II	5411.6	53.1	
5581	0	....	......	[*O* I]?	5577.3	....	9
....	......	5618.2	1	[*Ca* VII]	5619	2.7	
5719.9	2	5721.5	4s	[*Fe* VII]	5720.9	2.2	
....	......	5739.5	1	*Si* III?	5739.8	21.8	
5752	1	5752	1	[*N* II]	5755	4.0	9
5875.5	9	5876.8	5	*He* I	5875.6	23.0	
6090.0	8	6089.8	7	[*Fe* VII] [*Ca* V]	6085.5 6085.9	2.2 2.3	
6349.7	1	....	......	[*K* V]	6349.5	4.9	
6371.0	1	6370.3	1	[*Fe* X]	6372±	1.9	
$H\alpha$	25	$H\alpha$	15	$H\alpha$	6562.8	12.04	

NOTES TO TABLE 29

1. These are the *O* III and *N* III lines excited by Bowen's fluorescence mechanism.
2. In AX Persei, H_{16} is abnormally broad and strong.
3. In AX Persei, H_{13} is broader than the other Balmer lines.
4. Both contributors are certainly present.
5. Characteristic lines of the long-period variables.
6. Also present in BD+11°4673.
7. There are possibly two weak emission lines in AX Persei between λ 4030 and λ 4070.
8. The measurement of this group of lines was very difficult.
9. Uncertain.
10. The line is possibly double in AX Persei.
11. Also present in NGC 7027, NGC 6572, and RY Scuti. May be [*Fe* IV].
12. Identification doubtful.

ponent" of the system, its intensity being too high for the "late-type component." There is no anomaly in the intensities of $H\epsilon$, $H\beta$, etc., like those present in late-type variables.

He I.—Many lines belong to the series $2p^3P^0 - nd^3D$, $2p^1P^0 - nd^1D$, $2p^3P^0 - ns^3S$, and $2s^1S - np^1P^0$. The line λ 4713 seems to be abnormally strong, but this may be due to blending with [*A* IV] 4711.4.

He II.—Many lines are blended; but, aside from the strong line λ 4686, the following are unblended: λ 4541 ($4f^2F^\circ - 9g^2G$) and λ 5411 ($4f^2F^\circ - 7g^2G$).

O II.—The forbidden [*O* II] doublet at λ 3727 is extremely weak.

O III.—The lines excited by λ 303.780 of *He* II ($1s^2S - 2p^2P^\circ$) are very conspicuous (λλ 3341, 3444, and 3760). The forbidden lines have relative intensities similar to those found in planetaries of type Pd, such as IC 4997: the auroral transition λ 4363.2 ($2p^2\,{}^1D - 2p^2\,{}^1S$) is much stronger than the nebular transition N_1, λ 5007.6 ($2p^2\,{}^3P_2 - 2p^2\,{}^1D$). Such relative intensities are rare among galactic nebulae but have been observed also in Z Andromedae, RW Hydrae, and R Aquarii,[78] which are closely related to the present stars. This would seem to indicate a rather high electron pressure in those regions where [*O* III] 4363 originates.

N II.—The auroral line λ 5752 is faintly present.

N III.—The two doublets λλ 4097–4103 and λλ 4634–4640, excited by *O* III 374 (itself excited by *He* II, according to Bowen's mechanism), are present.

Ne III.—The nebular-type lines are present; the auroral transition at λ 3342.8 is absent.

Ne V.—The forbidden nebular lines λ 3346 and λ 3426 are very strong.

Ca II.—K λ 3933.7 is present.

Ca V.—There is some evidence of the presence of [*Ca* V]: the first component $3p^4\,{}^3P_2 - 3p^4\,{}^1D$ at λ 5309 is present in AX Persei, and the second is blended with [*Fe* VII] at λ 6088.

Ca VII.—Its presence is fairly certain in CI Cygni; λ 5618.2 ($3p^2\,{}^3P_2 - 3p^2\,{}^1D$) and λ 4941 (${}^3P_1 - {}^1D$) are both present.

Mg I.—λ 4571, which is typical of the long-period variables, is present.

Mg II.—The evidence for λ 4481 is inconclusive.

Si I.—λ 3905 is usually present in long-period variables.

Fe II.—Many permitted lines are observed, all of them coming from z^4D° and z^4F° (both 5.5 v.). The presence of [*Fe* II] is still uncertain.

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[78] See end of this section.

Fe III.—The strongest forbidden line of [*Fe* III] at λ 4658 is faintly present in CI Cygni.

Fe IV.—We refer here to the discussion of the spectrum of RY Scuti in Section II. It is possible that λ 5041.3 is a forbidden [*Fe* IV] line.

Fe V.—Bowen has located the metastable levels of *Fe* V. Several forbidden lines have been tentatively identified by various investigators, in nebulae or novae; but all of these identifications were based only upon rough wave-length agreements. The results for [*Fe* III] in RY Scuti (see Sec. II) may bring some light, as *Fe* III and *Fe* V have complementary electronic configurations $3d^6$ and $3d^4$ with regard to the half-closed shell $3d^5$. We may, thus, assume for [*Fe* V] that the identification criteria are also

$$\left\{\begin{matrix} {}^5D_4-{}^3F_4\ (\lambda\ 3891) \\ {}^5D_3-{}^3F_3\ (\lambda\ 3839) \end{matrix}\right\} \quad \text{and} \quad \left\{\begin{matrix} {}^5D_3-{}^3P_2\ (\lambda\ 3896) \\ {}^5D_2-{}^3P_1\ (\lambda\ 4072) \end{matrix}\right\}.$$

The line ${}^5D_4 - {}^3F_4$ will usually be blended with the Balmer line *H*8, but ${}^5D_3 - {}^3F_3$ was actually observed in AX Persei and CI Cygni; the ${}^5D_3 - {}^3F_4$ component appears also at λ 3820.2. The line ${}^5D_2 - {}^3P_1$ was found at λ 4071 in both stars.

Fe VI.—There is no certain identification of [*Fe* VI], the only coincidence being λ 5337 (${}^4F_{\frac{3}{2}} - {}^4P_{\frac{1}{2}}$).

Fe VII.—The analysis of this spectrum by Bowen and Edlén permitted them to identify [*Fe* VII] in Nova Pictoris, where it produces the strongest lines. We have found the [*Fe* VII] transitions to be a prominent feature in AX Persei and CI Cygni. The measured wave lengths are given in Table 30, and these are probably better than the predicted values or than the wave lengths measured in Nova Pictoris, because the lines of AX Persei and CI Cygni are fairly sharp.

The prominence of [*Fe* VII] shows that AX Persei and CI Cygni are especially suitable for investigations of forbidden lines of highly ionized atoms.

Fe X.[79]—The ground level $3p^5\ {}^2P^0$ has become so widely separated that the forbidden transition between the two components falls near λ 6372, according to Edlén's analysis. We have observed an emission line at λ 6370.7 in AX Persei and CI Cygni, with no other

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[79] The *Fe* VIII and *Fe* IX ions have no forbidden lines of low excitation potential.

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good identification available.[80] The identification with [*Fe* x] seems plausible for the following reasons:

a) AX Persei and CI Cygni show high ionization.

b) This transition is the only forbidden line of *Fe* x which is possible for a low electronic excitation, and the intensity would, therefore, be concentrated in one line.

c) The ionization potential of *Fe* IX, which is somewhere around 230 v., is not much higher than that of *Fe* VI (around 150 v.?), and we know that *Fe* VII is very abundant in AX Persei.

The line λ 6372 is a transition between the two components of the ground level $^2P^\circ$: $3p^5\,{}^2P^\circ_{1\frac{1}{2}} - 3p^5\,{}^2P^\circ_{\frac{1}{2}}$ (exc. pot. 1.9 v.). The transition probability of magnetic dipole radiation is[81] in this case 70 sec^{-1}, which is a normal value for a forbidden transition.

TABLE 30

[*Fe* VII] LINES OBSERVED IN AX PERSEI AND CI CYGNI

λ	TRANSITION	INTENSITY		REMARKS
		AX Persei	CI Cygni	
3586.6	$^3F_3-{}^1G_4$	3	4	
3759.2	$^3F_4-{}^1G_4$	6	5	Blended with fluorescence line of *O* III
4945	$^3F_3-{}^3P_2$	1	1	Separation from [*Ca* VII] difficult
5158.0	$^3F_3-{}^3P_1$	3	3	
5274.1	$^3F_4-{}^3P_2$	1	2	
5721.5	$^3F_2-{}^1D_2$	2	4	
6089.9	$^3F_3-{}^1D_2$	8	7	Weakly blended by [*Ca* V]

K V.—The predicted wave lengths of the $^4S - {}^2D$ forbidden transitions of [*K* v] are very uncertain. The following identifications are possible.

4161.7 : $3p^3\,{}^4S - 3p^3\,{}^2D_{1\frac{1}{2}}$
4122.0 : $3p^3\,{}^4S - 3p^3\,{}^2D_{2\frac{1}{2}}$ (blended with *He* I)
6349.7 : $3p^3\,{}^2D_{1\frac{1}{2}} - 3p^3\,{}^2P_{\frac{1}{2}}$

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[80] *Si* II 6371.4 is excluded because all the transitions in other regions are absent. The effect of the superposed late-type spectrum has been considered.

[81] From Brinkman's formula, kindly communicated by Dr. G. Breit.

Cr IX.—All the intensity due to low electronic excitation would be concentrated in two lines: λ 3273.5 and λ 4407.9. A weak line measured at λ 4409 has no other identification.

Mn IV.—One of the two strongest expected lines of [*Mn* IV][82] is $^5D_3 - {}^3P_2$, near λ 4591; a weak line is present at λ 4594.8, but $^5D_4 - {}^3F_4$ being absent, this is probably not the correct identification.

Ti IX.—This ion has two forbidden lines around λ 3923 and λ 4700 ($^3P_{1,2} - {}^1D_2$). The first is blended with *He* II; but the observed line appears abnormally strong because the stronger line, $4f^2F^\circ - 11g^2G$ (λ 4199.9) of the same series, is absent. The second [*Ti* IX] line may be the line observed at λ 4704.9.

The spectrum of CI Cygni does not seem to have suffered important modifications since the time of Merrill's observations. But the matter is quite different in the case of AX Persei. It is evident at once that *He* I is now weaker, compared with *He* II, that [*Ne* III] has also decreased in intensity, and that [*O* III] 4363 is weaker than in 1932, although it is still fairly conspicuous. It is clear that the ionization has increased in the regions giving rise to forbidden lines.

Even if we compare spectrograms taken at such a short interval as from September 20, 1939, to February 4, 1940, we find a change in the direction of increased ionization. Compared with [*Fe* VII], *H* and *He* I decreased in intensity; *Ca* II has practically disappeared; *N* III has increased, which is due to an increase of *He* II causing the *N* III fluorescence. *Fe* II has not changed appreciably.

The complex character of AX Persei and CI Cygni is obvious. The late-type component is presumably a variable itself, the bright lines of *Si* I (λ 3905) and *Mg* I (λ 4571) being characteristic of late-type variables. There is also a nebula of very high excitation ([*Ne* V] and [*Fe* VII] being strong) and of density similar to that of the planetaries of type Pd (provided that [*O* III] 4363 originates in the nebula itself); we observe in the nebula the fluorescence of *O* III and *N* III excited by the *He* II line at λ 303.78. In this nebulosity the excitation increases, which means that the corresponding nucleus becomes hotter. Now the similarity with Nova Pictoris, which also shows strong [*Fe* VII] lines, suggests that this nucleus is a post-nova, the surrounding

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[82] Derived from a comparison with [*Fe* V] and [*Fe* III].

nebulosity being the matter ejected at the time of the outbursts.[83] The present effective temperature of the nucleus must be very high, of the order of 150,000° or more, in order to produce six and probably nine ionizations of the iron atom. Accordingly, its maximum radiation is near λ 200, and the quantity of continuous radiation emitted in the observable range is an extremely small fraction of the total radiated energy. There is no difficulty in understanding why the spectrum of the nucleus has not been observed.

The *Fe* II lines appear much too strong to be attributed solely to the regular emission of a late-type variable. The spectrum shows strong [*Fe* VII], weak intermediate ionizations, including [*Fe* III], and then again fairly strong *Fe* II.[84] It is possible that the *Fe* II lines are excited in the outer part of the M star by the diluted radiation of the hot nucleus, which is itself surrounded by the [*Fe* VII] nebula.[85]

Besides the M spectrum, Merrill had observed in AX Persei an absorption spectrum of a type earlier than M3—say Kop. This does not appear now, but the change may perhaps be due to a change in the excitation of a certain region of the M star by the hot companion.

3. R AQUARII

The complex case of the spectrum of R Aquarii has been investigated by Merrill,[86] using Mount Wilson spectrograms extending over 15 years. In this section we present some additional spectroscopic data based on McDonald spectrograms taken between September 13 and December 12, 1939. Besides the nebular lines tabulated by Merrill, our spectrograms show the [*O* II] doublet fairly strongly; λ 4363 (auroral transition of [*O* III]) is now weak.[87] The relative intensities of N_1 and N_2 are quite irregular, N_2 being too weak when we consider its theoretical transition probability. Photometric measurements

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[83] The velocity of expansion is very small at the present time, because the bright lines are sharp.

[84] Individually the *Fe* II lines are not strong; but the energy is distributed among many lines.

[85] But in Z And this hypothesis is not tenable.

[86] *Ap. J.*, **81**, 312, 1935.

[87] Relative to the nebular transitions, the auroral transition λ 4363 is much weaker in R Aqr than in AX Per and CI Cyg.

show that N_2 is 6.9 times weaker than N_1; whereas the theoretical ratio is 3. This behavior is presumably due to an occultation effect of the nebula by the *TiO* atmosphere of the late-type component, since N_2 falls very close to a strong *TiO* band head. N_1 also falls in a *TiO* band, but much farther from the head, and is consequently less reabsorbed. Such an occultation effect was discussed by Wright[88] in order to explain the absence of the [*Ne* III] line at λ 3968. The other component, λ 3869, of the nebular pair had been observed by J. H. Moore;[89] in this case the blanketing was due to the *Ca* II line H. This appears also on our spectrograms. The absorption of the nebular light by the *TiO* layer is much weaker than the absorption of the hydrogen lines and of the other bright lines. This appears from a comparison of plates taken in September and in December, 1939. $H\gamma$ falls in a region practically free from *TiO* absorption. The strength of the *TiO* bands at the wave length of $H\beta$ is appreciable, but it is still more at N_1 and much more at N_2. Between September and December, 1939, $H\gamma$ increased considerably in intensity; it was much weaker than N_1 in September and much stronger in December. But $H\beta$ remained weaker than N_1. An examination of the spectrograms shows that N_1 is not reduced by *TiO* to the same extent as $H\beta$, although the absorption band appears stronger at N_1 than at $H\beta$. This shows that [*O* III] does not originate in the same region as the Balmer lines.

At certain phases, the spectrum of R Aquarii is very rich in [*Fe* II] lines, and it is then very similar to WY Geminorum.

Merrill has observed at certain phases the forbidden transitions of [*Fe* III]; but these, as well as the permitted *Fe* III lines, were absent during our period of observation.

We shall not consider here the outer lenticular nebulosity discovered by C. O. Lampland,[90] although it is puzzling that no marked change has ever been noticed in its brightness. But continuous observations of this nebulosity are lacking, and there may be a consid-

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[88] *Pub. A.S.P.*, **31**, 309, 1919.

[89] *Ibid.*

[90] *Pop. Astr.*, **30**, 619, 1922.

erable lag of time between the variation in excitation and the variation in nebular brightness.

The character of the long-period variable seems to be quite regular. In the light of Z Andromedae, AX Persei, and CI Cygni it seems most promising to try to explain the spectroscopic data by assuming the presence of two stars: one regular long-period variable and one of early type surrounded by nebular matter. This hypothesis, which has been considered on several occasions,[91] gains weight from the observations discussed in this section.

V. CONCLUSIONS

Two advances have recently been made in the interpretation of emission-line stars of early spectral type. The dilution of the exciting radiation from the hot star, caused by the distance between the source of continuous radiation and the gases responsible for the shell, produces marked changes in the spectrum and permits us to evaluate, under favorable conditions, the ratio, R/r, of the radius of the star to the radius of the shell. This, in most cases, is not excessively small, and we may estimate that in nearly all cases $0.1 < R/r < 1$. This is one important result, as it gives us the order of size of the nebulous shell.

The second advance consists in our recognition of the importance of the continuous absorption in the shell. The optical thickness of the shell may be very small (α Cygni) or very large (P Cygni). In those cases in which the optical thickness is small, we are able to see the spectrum of a deeper layer. In most cases the transition from the deep reversing layer to the shell is discontinuous, or, at least, very sudden; but in a few stars there are definite indications of stratification in the shell (P Cygni, ζ Tauri, and HD 218393). When the shell expands, the reversing layer usually has a small radial velocity. In a few cases (17 Leporis) it is certain that the shell covers the entire apparent disk presented by the reversing layer, and the phenomenon is not one of prominence action, with normal regions between expanding prominences.

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[91] Merrill, *Ap. J.*, **81**, 331, 1935; C. and S. Gaposchkin, *Variable Stars*, p. 315, 1938.

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The study of P Cygni type stars shows that expanding shells may be associated with reversing layers of the supergiant class (HD 160529, α Cygni, and β Orionis) or with reversing layers of main-sequence characteristics (HD 190073, 17 Leporis, and BD+47°3487). Rapid axial rotation of the reversing layer is not a necessary condition, even in the main-sequence reversing layers (17 Leporis and HD 190073), although in some stars the rotation does seem to be large (BD+47°3487).

It will be recalled here that in ordinary Be stars axial rotation plays an important role.[92] There can be no doubt that this is not the case in P Cygni type stars. It is almost certain that axial rotation acts as a trigger mechanism in the production of shells of Be stars. There is no evidence that these stars are, as a rule, binaries. But there is some evidence that Be stars are, on the average, more luminous than main-sequence stars without emission lines. They are definitely less luminous than the supergiants, but the latter do not, as a rule, have large rotational velocities.

We suggest that some mechanism other than axial rotation is responsible for P Cygni type emission. It is probable that high luminosity favors this process: a surprisingly large percentage of supergiants show weak P Cygni emission at $H\alpha$ when they are examined with sufficient dispersion. But there are also normal main sequence stars with strong P Cygni characteristics. We must infer that luminosity is not alone to blame. Some of these stars (Z Andromedae, RY Scuti, and β Lyrae) are known binaries. It is at least probable that the binary nature of a star favors the origin of a shell. This hypothesis is supported by the peculiar class of composite spectra which we have discussed in Sections III and IV. Some of these objects have B-type spectra which are perfectly normal in all respects and which have no excessive rotation and no supergiant characteristics. Yet, when these normal stars are associated with an M star, as a binary, they give rise to strong emission spectra of [*Fe* II] (WY Geminorum, W Cephei, and Z Andromedae) or to emission spectra of higher excitation and ionization (AX Persei and CI Cygni). The

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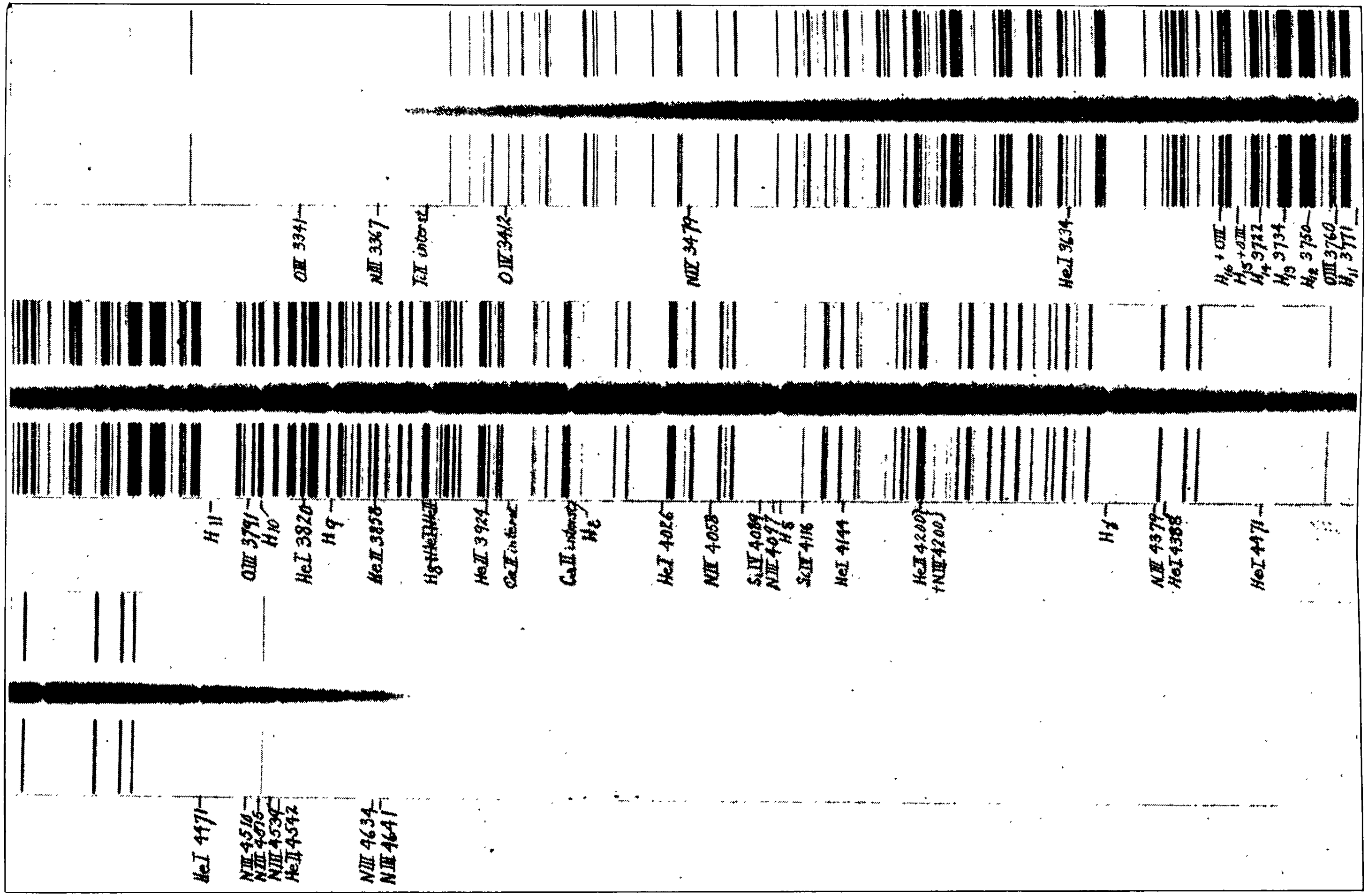
[92] Struve, *Ap. J.*, **73**, 94, 1931; *J. Appl. Phys.*, **10**, 802, 1939; Struve and Swings *Ap. J.*, **75**, 161, 1932; Merrill, *Pub. A.S.P.*, **45**, 49, 1933.

fact that a few related stars (HD 45677) are apparently not composite does not mean that they are not binaries. Z Andromedae in its present stage would also be interpreted as a single star. However, we know from the work of Hogg that an M-type spectrum was present when the brightness of the hot star was low.

There is all reason to believe that the binary nature of a star stimulates the process of shell formation. But there are many close spectroscopic binaries which show no tendency toward emission.

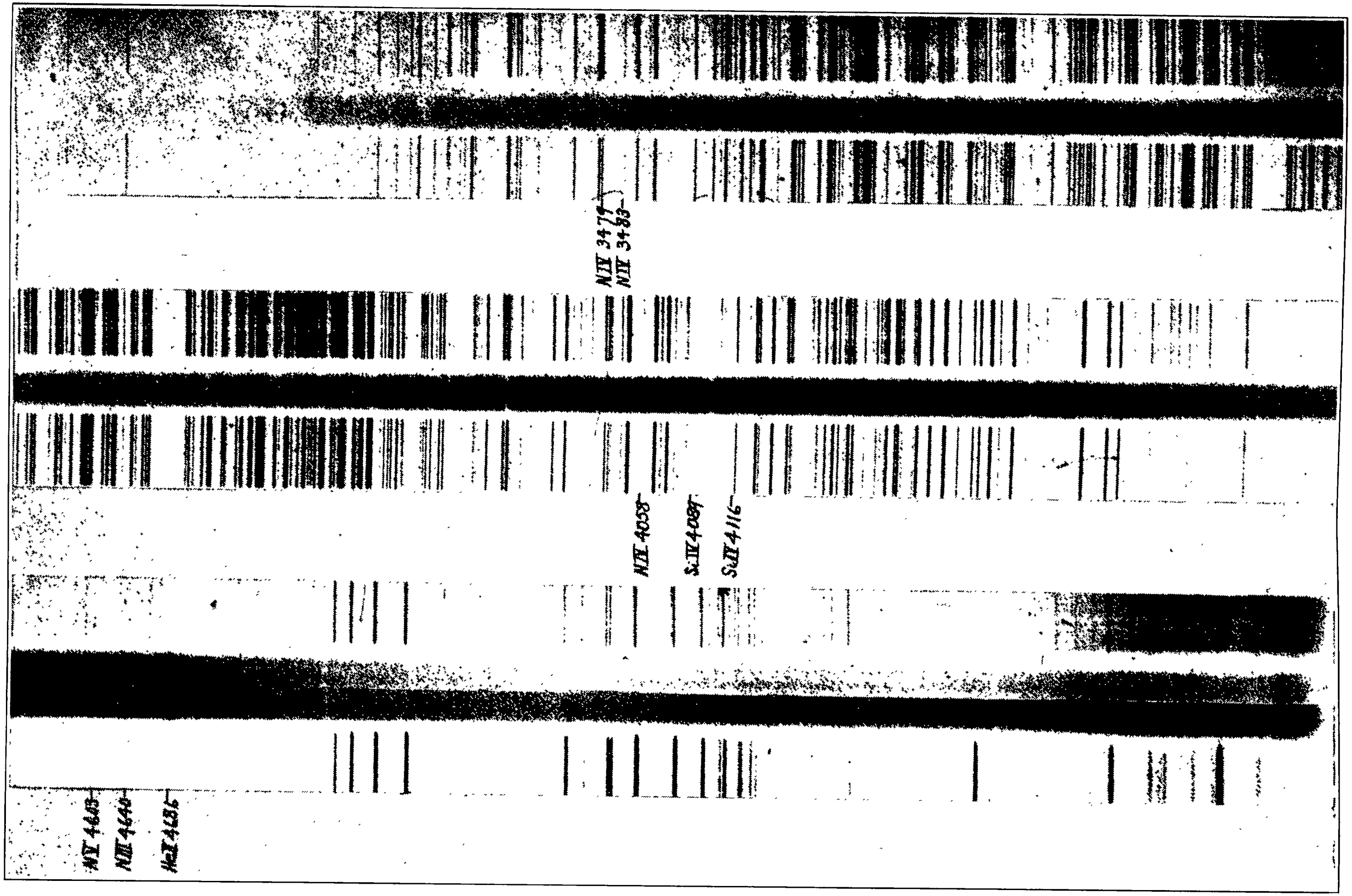
YERKES OBSERVATORY
AND
McDONALD OBSERVATORY
March 1940

PLATE X



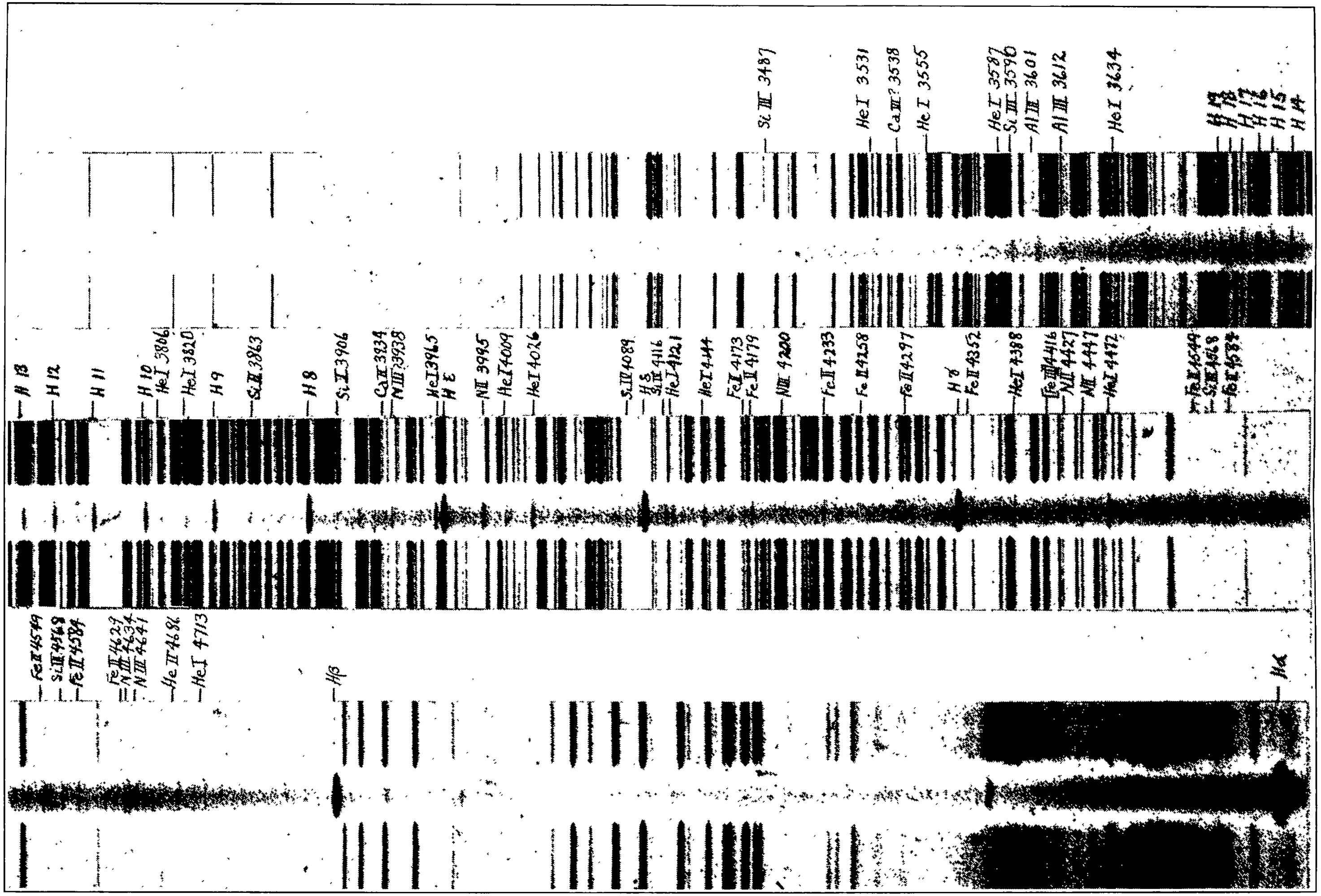
The Spectrum of 9 Sagittae

PLATE XI



The Spectrum of BD+35°3930 N.

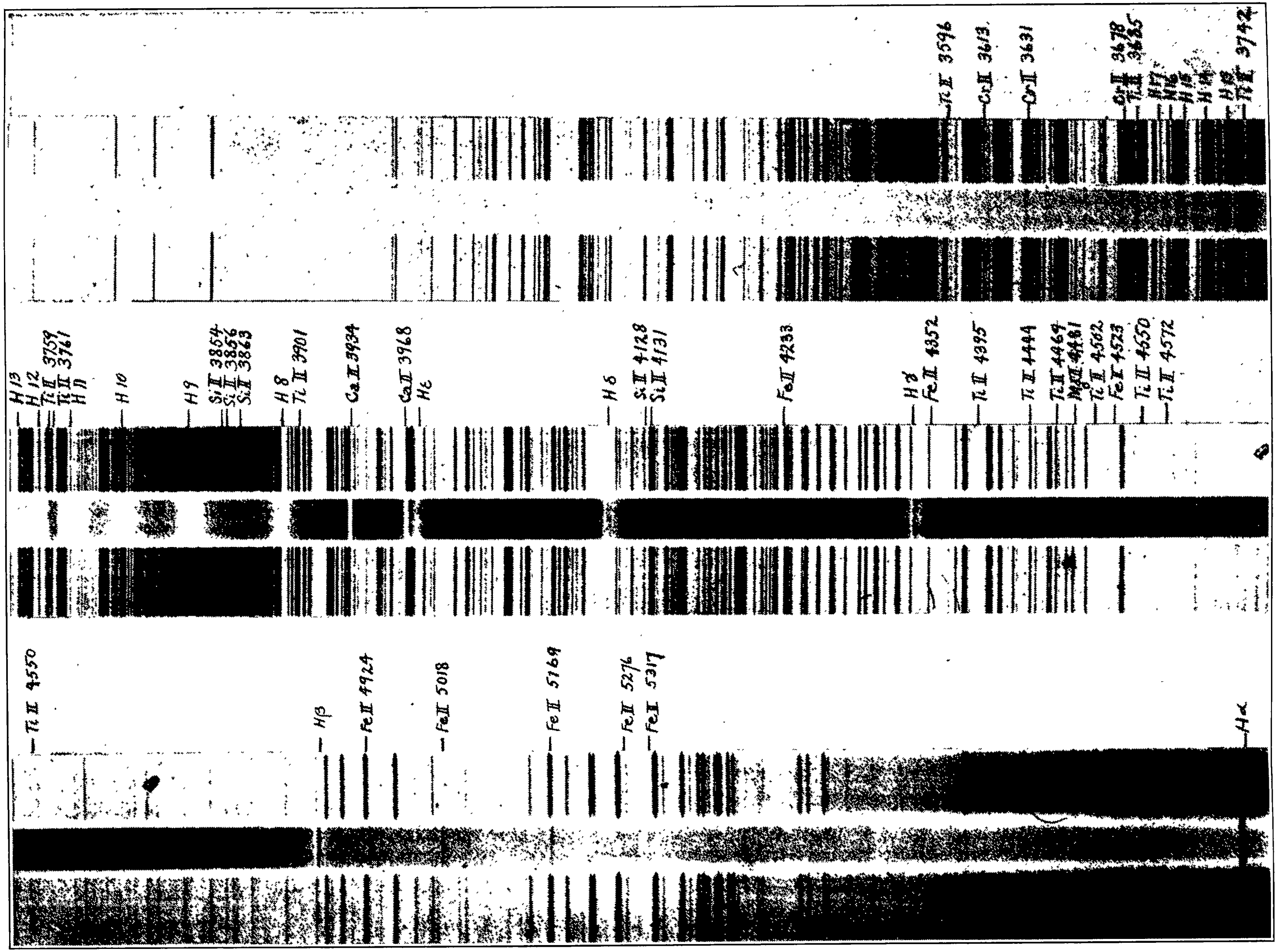
PLATE XII



The Spectrum of BD+11°4673

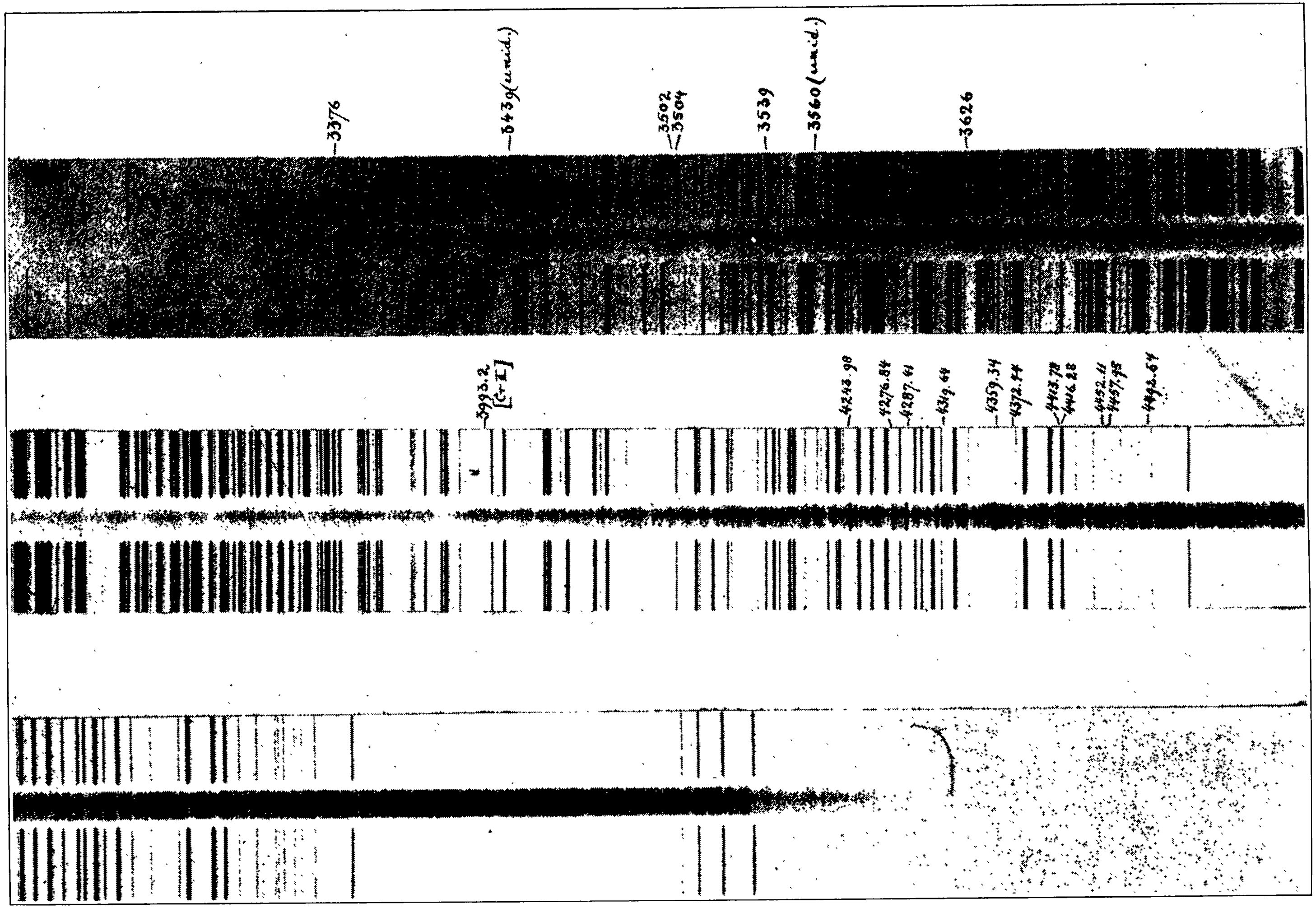
(The line λ 4416 belongs to *Fe* II], not to [*Fe* III])

PLATE XIII



The Spectrum of HD 190073

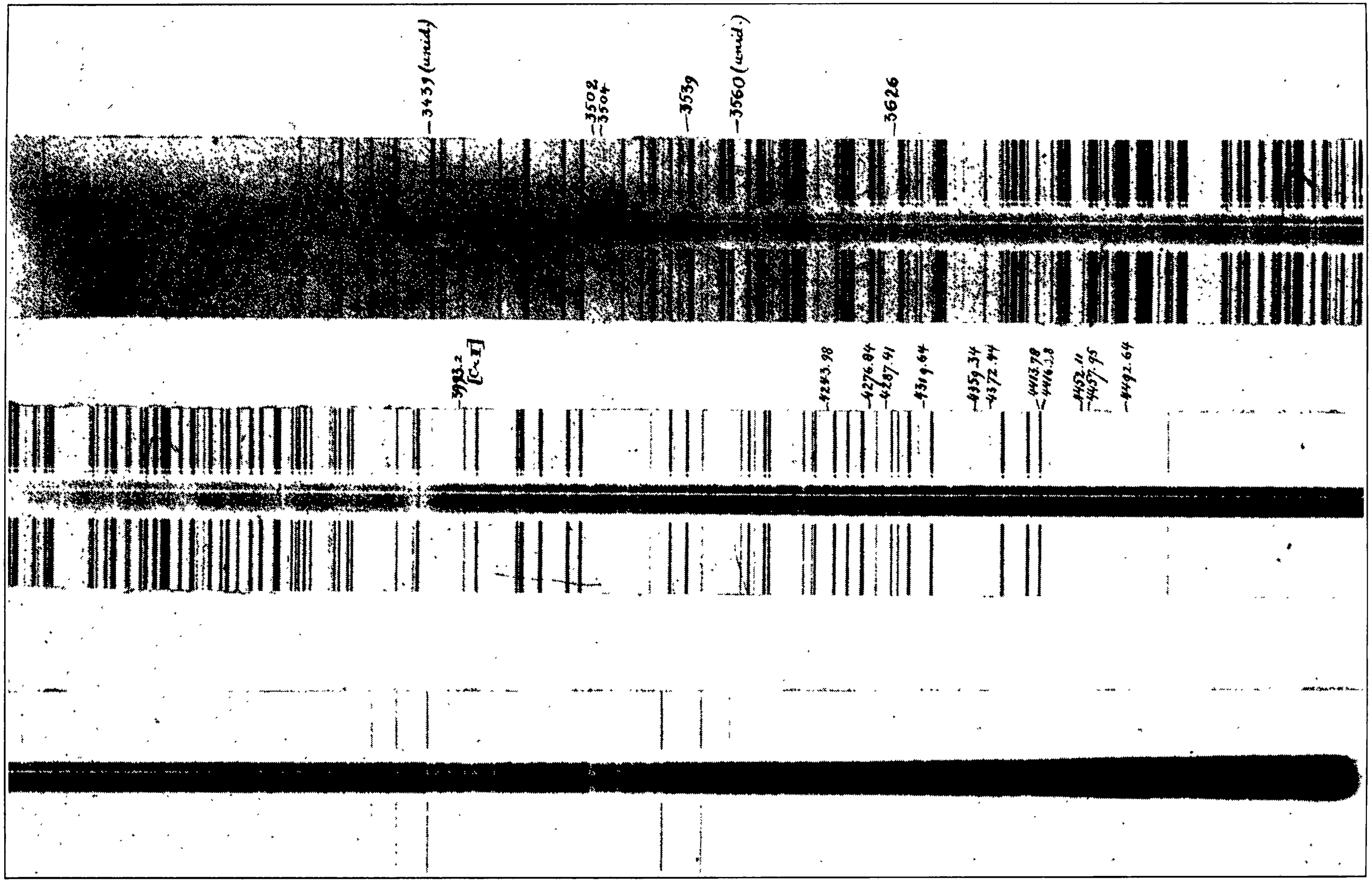
PLATE XIV



THE SPECTRUM OF WY GEMINORUM

Except for the unidentified lines λ 3439 and λ 3560 and the [*Cr* II] line χ 3992, only lines of [*Fe* II] have been indicated

PLATE XV



The Spectrum of Boss 1985

Except for the unidentified lines λ 3439 and λ 3626 only lines of [*Fe* II] have been indicated

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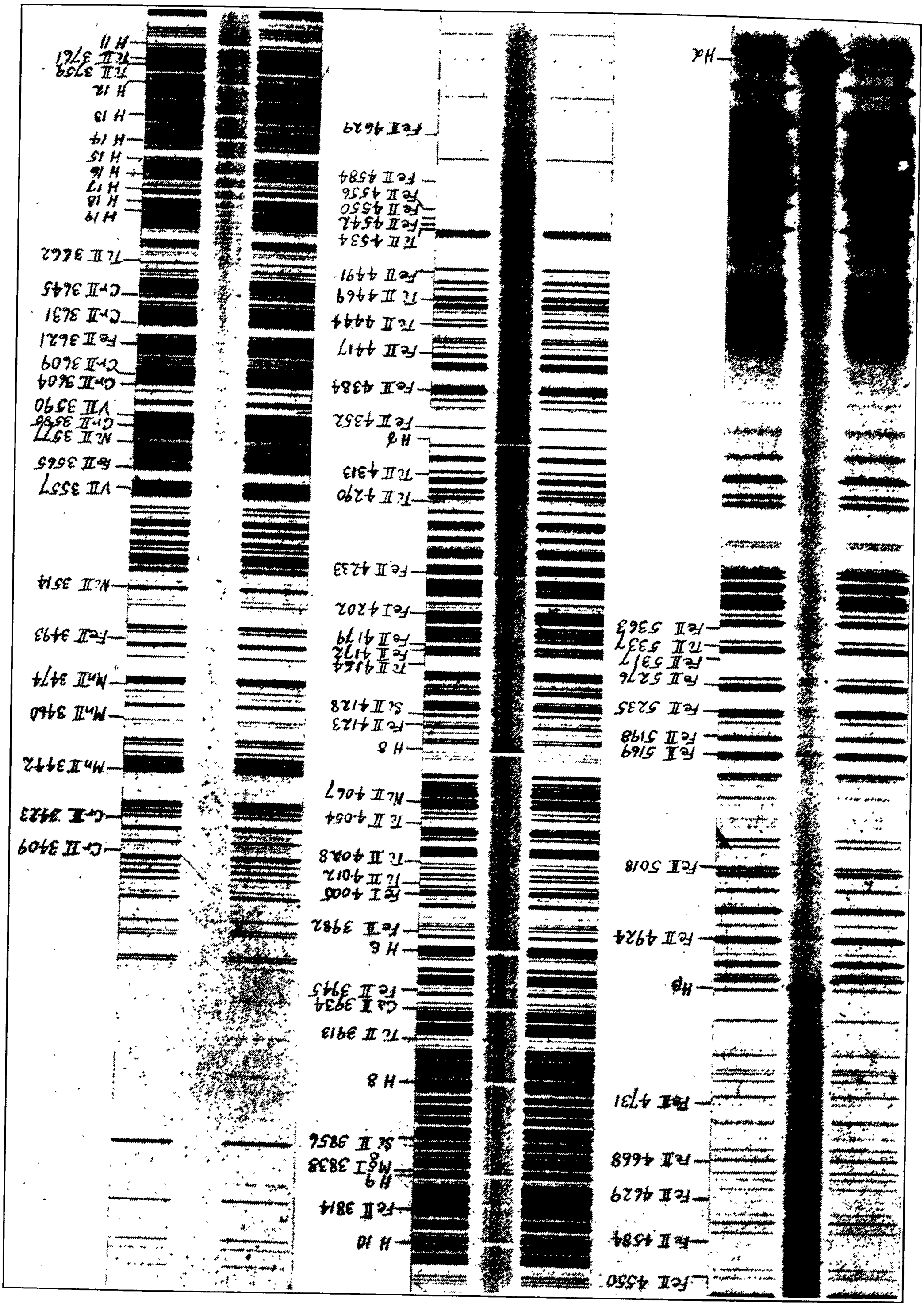
PLATE XVI



THE SPECTRUM OF Z ANDROMEDAE