1953MNRAS.113..211T

IDENTIFICATIONS IN THE SPECTRA OF ETA CARINAE AND RR TELESCOPII

A. D. Thackeray

(Received 1952 November 5)

Summary

Wave-lengths and intensity estimates of lines in the spectra of Eta Carinae and RR Telescopii between 3700 and 8900 A are presented. Both spectra are characterized by strong Fe II emission, forbidden and permitted, and by weak continua. Representations of individual elements in the two stars are discussed in Section 4 (Eta Carinae) and in Section 8 (RR Tel). Doubly ionized elements (especially O, Ne, S, A and Fe) are better represented in RR Tel which shows in 1952 a transition between the " Eta Carinae " and " nebular " stages of a slow nova. Oxygen lines, permitted and forbidden, are so much stronger in RR Tel that a deficiency of O in Eta Carinae is rather strongly indicated.

A few unidentified lines are listed in Table VI. The strongest (in Eta Carinae) is in the infra-red at about 8493 A.

The relative intensities of [Fe II] lines agree generally with the order of prominence suggested in the *Revised Multiplet Table*, but a few exceptions are noted (Section 6).

The strongest lines in Eta Carinae have structures characteristic of Type III in Beals's classification of P Cygni profiles (Section 5). They are accompanied by diffuse absorptions with velocities about −450 km/s. These absorptions are found accompanying 12 strong [Fe II] lines. The double emission peaks are best marked for H and [Fe III]. Similar displaced absorptions are found in a few He lines in RR Tel with velocities −685 (1951) and −865 km/s (1952).

1. The purpose of this paper is to present wave-lengths and identifications of lines (almost entirely emission) measured in the spectra of Eta Carinae and RR Telescopii with the 2-prism Cassegrain spectrograph attached to the 74-inch Radcliffe reflector.

For the past half-century Eta Carinae has shown a spectrum consisting mostly of emission lines with hydrogen and forbidden ionized iron predominating.* The continuum is very weak, and, unlike many [Fe II] variables, there is no sign of a late-type companion; hence there is an unusual opportunity to study the spectrum of [Fe II] and other ions in the red and infra-red. The star is the best known source in Nature for such a study.

RR Telescopii, listed as a semi-regular variable, $12^{m}{\cdot}5$ to $>14^{m}$, brightened to the 7th magnitude in 1945 and since then has suffered a slow decline. In 1949 July–September there was a rather abrupt transition from cF absorption to a pure emission spectrum† and in 1951, when Cassegrain spectra could first be obtained at the Radcliffe Observatory, the spectrum of the star had come to bear a strong resemblance to that of Eta Carinae, although the state of ionization

---

* See P. W. Merrill, *Ap. J.*, **67,** 391, 1928 for references to early work, and H. Spencer Jones, *M.N.*, **91,** 794, 1931.

† A. D. Thackeray, *M.N.*, **110,** 45, 1950; K. G. Henize and D. B. McLaughlin, *Ap. J.*, **114,** 163, 1951. For light-curve see M. W. Mayall, *H.B.*, No. 919.

was clearly somewhat higher. The value of the results on Eta Carinae is considerably enhanced by having another spectrum so generally similar for comparison; for instance, in the case of an unidentified line in common to the two stars, the relative intensity in Eta Carinae and RR Telescopii offers some clue to the probable nature of the carrier.

2. Table I presents the journal of observations of the two stars. The prefix to the plate number shows which of the four cameras of the Cassegrain spectrograph was used; the dispersions at Hγ of the corresponding spectra are as follows: (a) 22·5, (b) 30, (c) 48 A/mm. The prisms are set permanently for minimum deviation at 4200 A and the limit of the plate with the *a* camera is about 5300 A. However, with the *b* camera, Hα appears near the edge of the plate and the remarkable fact has been found that spectra with good definition can be obtained simultaneously through the blue to the red. With the *c* camera, it is even possible to extend the study into the infra-red with a small adjustment of the camera focus. The accuracy of the measures naturally diminishes rapidly towards the red and infra-red; the dispersion varies from 10 A/mm in the ultra-violet to about 400 A/mm in the infra-red.

TABLE I

Observations of Eta Carinae (nucleus)

Plate (and dispersion)	Date	Emulsion	Exposure (min.)	Region Measured
a 9	1951 Apr. 12	Kod. 103J	20	4068–5334
c 40(*b*)	1951 Apr. 29	Kod. 103aF	2½	4889–6809
c 40(*a*)	1951 Apr. 29	,,	6	5276–6874
c 63(*b*)	1951 May 8	,,	2 :	5169–6678
c 121(*b*)	1951 June 5	Kod. II N	12	7065–8863
c 122(*a*)	1951 June 5	,,	30	7065–8863
c 135	1951 June 11	Kod. 103aO	10	3704–4076
a 142(*a*)	1951 June 14	,,	45	3677–4021 4947–5197
a 142(*c*)	1951 June 14	,,	15	3900–4973
b 204(*b*)	1951 July 7	Kod. 103aF	30	4811–6810
b 208(*a*)	1951 July 10	,,	70	4774–7065
a 896(*a*)	1952 June 26	Kod. 103aO	34	3748–5169

Observations of RR Telescopii

Plate	Date	Emulsion	Exposure (min.)	Region Measured
a 144	1951 June 14	Kod. 103aO	30	3835–5018
c 270	1951 Aug. 21	Kod. II N	60	7065–8748
b 794	1952 May 21	Kod. 103aF	120	3750–6678
c 912	1952 July 2	Kod. 103aO	100	3697–5056
c 1133	1952 Sept. 30	Kod. 103aF	90	4889–6678
c 1134	1952 Sept. 30	Kod. I N	120	Hα–8446

3. Table II presents the results of measurements in the spectra of Eta Carinae. Explanatory details are as follows:

First column: The mean wave-length after reduction to the Sun and correcting for a stellar velocity of +25·0 km/s as found by the Lick observers. A colon indicates uncertainty in the measures.

Second column: Mean visually estimated intensity. It was possible to combine estimates from different exposures by means of empirical calibration of lines estimated in duplicate. Estimates near the long wave-length limit of sensitivity of blue plates were not used, and the estimated intensity on the panchromatic 103aF plates were used as a basis for the whole range 3670–6800 Through this method of calibration it occurs that the faintest lines observed in the red have adjusted intensity 4, while those in the blue have adjusted intensities less than 1. It was not possible to push the limiting intensity lower in the red with the available dispersion, on account of interference from the continuum. *n*, *N* and *NN* indicate increasing diffuseness in the lines; *s* indicates unusual sharpness; ***a***, preceding the estimate of intensity, indicates an absorption line; *d* indicates a suspected double.

Third column: Number of exposures used in the mean wave-length and intensity.

Fourth column: Suggested identifications giving the responsible ion followed by the multiplet number in the *Revised Multiplet Table* and wave-length* (also from the *R.M.T.*). Forbidden lines are distinguished by *F* following the multiplet number. In the case of blends the probable major contributor is given first. The identifications were arrived at in the usual manner by systematic searches for the strongest lines of each ion in the *Revised Multiplet Table.* Two completely independent searches were made at different times separated by a considerable interval.

A final asterisk denotes a special remark on the line at the end of the table.

TABLE II

Eta Carinae

Mean wave-lengths and intensities of emission and absorption lines

Wave-length	Int.	Number of Measures	Identification Main Contributor Element	*R.M.T.*		Minor Contributors Element	*R.M.T.*	
3677·87	1*N*	1	Cr II	12	77·93 77·69 77·86			
3685·42	0·5	1	Ti II	14	85·19	H		86·83
3704·1:	1*n*	1	H		03·85			
05·9:	2*n*	1	Ti II	73	06·22	He	25	05·00
12·1	0·5*n*	1	Fe II	10*F*	12·26	H		11·97
12·93	1·5	2	Cr II	12	12·97 13·04			
15·24	1*n*	2	Cr II	20	15·19	V II	15	15·48
22·16	1·5*N*	2	H		21·94			
27·18	1*n*	2	V II	21	27·35	Cr II	117	27·37
34·26	2·5*N*	2	H		34·37			
38·5	0·5	1	Cr II	20	38·38			
41·6	0·5	1	Ti II	72	41·63			
48·17	2	3	Fe II	154	48·49			
49·7	?0·3	1						
50·60	2	3	H		50·15	V II	21	50·88
54·8	?0·3	1	Cr II	20	54·59			
59·58	1	1	Ti II	13	59·29	Fe II	154	59·46
61·73	1	1	Ti II	13	61·32			
64·22	1·5	3	?Fe II	29	64·09			
3769·53	3	3	Ni II	4	69·46			

---

* For the forbidden lines of Ni II the wave-lengths are given in italics to show that they have been taken from the latest laboratory data by Shenstone, and not from the *R.M.T.*; the writer is deeply indebted to Mrs Moore-Sitterly for communicating this information (*Atomic Energy Levels*) in proof-stage.

Table II (*cont.*)

			Identification						
			Main Contributor			Minor Contributors			
Wave-length	Int.	Number of Measures	Element	*R.M.T.*		Element	*R.M.T.*		
3770·9	?0·5*n*	1	H		70·63	V II	21	70·97	
79·7	?0·5*n*	1	?Fe II		79·58				
81·4	?0·3	1	?Fe II	130	81·51				
83·38	2	2	Fe II	14	83·35				
3798·27	3*N*	2	H		97·90				
3800·25	1	1							
06·27	1·5	2	Cu II	2*F*	06·34				
17·4	0·5	1							
19·32	1	3				He	22	19·6	
21·84	?0·3*n*	1	Fe II	14	21·92				
24·95	4	3	Fe II	29	24·91				
30·61	*a*6*N*	2							
35·68	5*N*	3	H		35·39				
38·34	3*n*	3	?Mg I	3	38·29				*
40·4	?*a*1	1							
41·0	?0·3	1							
49·66	1	3	Ni II	11	49·58				*
54·5	1	1	(Si II	1	53·66)				
56·01	1	3	Si II	1	56·02				
58·5	0·5	1							
63·71	0·5*n*?*d*	1	Fe II	127	63·95	Si II	1	62·59	
65·72	0·5*n*	1	?Cr II	167	65·59				
68·61	4	3	Ne III	1*F*	68·74				
72·88	2	2	Fe II	29	72·76				
78·4	1	2	?V II	33	78·72				
79·8	*a*4*N*	1							
83·35	*a*6*N*	3							
85·9	?3	1							
87·94	10*N*	3	H		89·05				*
88·76	*a*3*s*	1	He		88·65				*
89·58	15*N*	3	H		89·05				*
94·1	0·5	1							
96·13	0·5	1	V II	10	96·15				
97·8	0·5	1							
3898·94	0·5	1	?V II	33	99·14				
3900·52	2*n*	3	Ti II	34	00·55				
03·13	1*n*	3	V II	11	03·27				
05·94	1*n*	4	Fe II	173	06·04	?Fe II	8*F*	05·62	
13·5	?1	1	Ti II	34	13·46				
14·44	3	4	Fe II	3	14·48	V II	33	14·33	
16·2	?0	1	V II	10	16·42				
23·61	?*a*0	1							
27·44	*a*10	3	Ca II	1	33·66				*
29·04	?*a*3	1							*
30·31	3	4	Fe II	3	30·31				
31·24	?*a*2	2							
32·09	1	3							
33·83	*a*6*s*	3	Ca II	1	33·66				
34·48	1	1							
36·03	1	4	?Fe II	173	35·94				
38·30	8	4	Fe II	3	38·30				
45·18	3	3	Fe II	3	45·21				
51·86	1	1	V II	10	51·97				
3953·3	?2*n*	1							

TABLE II (*cont.*)

Wave-length	Int.	Number of Measures	Identification Main Contributor Element	*R.M.T.*		Minor Contributors Element	*R.M.T.*		
3959·91	?*a1N*	1							
62·17	*a8s*	3	Ca II	1	68·47				*
64·65	*a5*	1							
65·87	?3*n*	1							
66·98	2·5*N*	2	Ne III	1*F*	67·51	Fe II	3	66·43	
68·57	*a3s*	4	Ca II	1	68·47				
69·36	7	3	?H		70·07	Fe II	3	69·40	
69·87	?*a2s*	1							
70·61	10*n*	4	H		70·07				
72·5	?1·5	1							
74·16	4	4	Fe II	29	74·16				
77·65	0·5	1	V II	10	77·73				
79·62	1	2	Fe II	9*F*	79·78	?Cr II	183	79·51	
81·75	0·5	3	Fe II	3	81·61				
89·60	?0·5	2							
93·08	6	4	Ni II	4*F*	*93·15*				
95·1	?0·3	1							
3996·96	0·5	2	V II	9	97·13				
4000·41	0·5	1							
02·36	3	4	Fe II	29	02·07	?Fe II	190	02·55	*
03·3	1	1	?Cr II	194	03·33				
05·52	1	3	V II	32	05·71				
08·8	?1	1							
11·7	?1	1							
12·35	2	4	Fe II	126	12·47	Cr II	183	12·50	
15·55	1	3	Ni II	12	15·50				
21·27	*a5N*	3	He	18	26·2				
24·72	3*n*	1	Fe II	127	24·55				
26·10	5*n*	2	He	18	26·2				
28·42	1·5	2	Ti II	87	28·33				
32·95	2	2	Fe II	126	32·95	Ni II	4*F*	*33·06*	
35·34	0·5	2	V II	32	35·63				
37·9	?0	1	?Cr II	194	38·03				
45·0	?2*n*	2							
49·1	?1	1	?Cr II	193	49·14				
53·74	2*n*	3				Ti II	87	53·81	
64·53	2·5	2							
67·23	5	1	Ni II	11	67·05				
68·63	12	4	S II	1*F*	68·62				
76·37	4	3	S II	1*F*	76·22				
97·42	3*s*	2	N III	1	97·31				
4099·74	9	2							
4100·4 :	15	2							
02·29	30	3	H		01·74	N III	1	03·37	
10·83	1	2	Fe II	9*F*	10·91	Cr II	18	11·01	
14·49	7	3	?Fe II	23*F*	14·48				*
20·03	1·5*n*?*d*	2				He	16	20·8	
22·61	6	3	Fe II	28	22·64				
24·73	1	2	Fe II	22	24·79				
28·28	5*n*	3	Fe II	27	28·73	(Si II	3	28·0)	
43·88	6	3	He		43·76	?Fe III		43·87	
46·53	?2*n*	1	Fe II	21*F*	46·65				
52·45	4	2	?Co II	*F*	52·59				*
4163·61	2·5	2	Ti II	105	63·64				

TABLE II (*cont.*)

Wave-length	Int.	Number of Measures	Identification				
			Main Contributor Element	*R.M.T.*	Minor Contributors Element	*R.M.T.*	
4171·82	1	1	Ti II	105 71·89			
73·48	12	3	Fe II	27 73·45			
77·33	10	3	Fe II	21*F* 77·21			
78·80	15	3	Fe II	28 78·85	Fe II	23*F* 78·95	
4187·80	0·5	2					*
4201·18	7	3	Ni II	3*F* *01·19*			
10·93	3	3	?Fe III	10·87			
14·14	1	1					
24·99	1	2	Cr II	162 24·85			
29·29	3	2					*
33·19	20	3	Fe II	27 33·17	(Fe II	21*F* 31·56)	
37·73	*a6n*	2					
44·08	45*N*	3	Fe II	21*F* 43·98	Fe II	21*F* 44·81	
					Cr II	31 43·38	
46·8 :	6 :	2	?Sc II	7 46·83			*
48·90	6*n*	2	Fe II	36*F* 49·07	Ni II	4*F* *48·90*	
52·94	1	1			Cr II	31 52·62	
54·65	1	1					
58·23	4	2	Fe II	28 58·16			
61·96	4	2	Cr II	31 61·92			
73·23	7	3	Fe II	27 73·32			
76·68	20	3	Fe II	21*F* 76·83	(Cr II	31 75·57)	
80·80	*a6n*	2					
83·55	10	3	?Fe II	7*F*	(Cr II	31 84·21)	*
87·39	50*N*	3	Fe II	7*F* 87·40			
90·02	?6*n*	1	Ti II	41 90·22			
93·34	3*n*	2	(Ni II	4*F* *94·11*)?	(Ti II	20 94·10)?	
95·16	?*a4s*	2					
96·61	8	3	Fe II	28 96·57			
97·9	?*a2s*	2					
4299·55	2*n*	2	———	———	Ti II	41 00·05	*
4303·24	10	3	Fe II	27 03·17			
05·93	8	3	Fe II	21*F* 05·90			
08·00	1·5	2	Ti II	41 07·90			
12·87	1	2	Ti II	41 12·86			
14·51	2·5	2	Fe II	32 14·29	Ti II	41 14·98	
19·64	15	3	Fe II	21*F* 19·62			
26·04	6	3	Ni II	3*F* *26·28*			
34·3	?*a6*	1					*
38·50	25	3			Ti II	20 37·92	*
41·30	75*N*	3	H	40·47			*
46·82	8	3	Fe II	21*F* 46·85	Fe II	36*F* 47·35	
51·98	20	3	Fe II	27 51·76	Fe II	21*F* 52·78	
55·28 :	?10	3	?Fe II	7*F*	Fe II	22*F* 56·14	
59·08	60	3	Fe II	7*F* 59·34	Fe II	21*F* 58·37	
61·92 :	6	1	Ni II	9 62·10			
64·8	3	1					
66·63	*a4s*	2					
69·34	3	2	Fe II	28 69·40			
72·40	9	3	Fe II	21*F* 72·43			
74·90	2	2			Ti II	93 74·83	
					?Sc II	14 74·45	
82·68 :	4	3	Fe II	6*F* 82·75			
4385·23	12	3	Fe II	27 85·38			

TABLE II (*cont.*)

Wave-length	Int.	Number of Measures	Identification: Main Contributor Element	*R.M.T.*		Minor Contributors Element	*R.M.T.*	
4387·63	I	I				?He	51	87·93
94·07	2	I	Ti II	51	94·06			
95·24	2	I	Ti II	19	95·03			
4399·63	4	2	Ti II	51	99·77			
4405·83	*a*4	I						
07·44	*a*4	I						
09·92	6	2	Fe II	22*F*	09·86	?Fe II	7*F*	
13·70	50*N*	3	Fe II	7*F*	13·78	(Fe II	32	13·60)
16·25	50*N*	3	Fe II	6*F*	16·27	Fe II	27	16·82
19·0 :	?6	I				?Fe III	4	19·59
22·08	?2	2	?Ti II	93	21·95			
32·33	4	2	Fe II	6*F*	32·45			
40·43	*a*I*s*	I						
43·87	?I·5*n*	2	Ti II	19	43·80			
45·65	*a*6*N*	2						
47·93	?4	3	?Fe II	7*F*				
52·02	20	3	Fe II	7*F*	52·11			
54·7	?3	I						
57·85	18	3	Fe II	6*F*	57·95			
61·43	2·5*n*	2	Fe II	26	61·43			
64·11	2	2				?Ti II	40	64·46
65·83	*a*6	2						
67·84	?2	I				Ti II	31	68·49
71·40	15*N*	3	He	14	71·5	(Fe II	6*F*	70·29)
						Fe II	37	72·92
74·83	12	3	Fe II	7*F*	74·91			
81·08	I	2	Mg II	4	81·26			
85·00	2·5	2	Ni II	3*F*	*85·22*			
88·98	15	3	Fe II	6*F*	88·75	Fe II	37	89·18
4491·56	15	3	Fe II	37	91·40	(Fe II	6*F*	92·64)
4501·08 :	2*n*	2	Ti II	31	01·27			
02·55	*a*3	2						
08·32	15	3	Fe II	38	08·28	Fe II	6*F*	09·61
15·29	16	3	Fe II	37	15·34	Fe II	6*F*	14·90
20·20	15	3	Fe II	37	20·22			
22·58	15	3	Fe II	38	22·63			
28·44	3	3	Fe II	6*F*	28·39	(V II	56	28·51)
33·2 :	?2	I	Fe II	6*F*	33·00			
34·08	7	3	Fe II	37	34·17	Ti II	50	33·97
41·60	6	3	Fe II	38	41·52			
43·18	*a*4*s*	2						
45·3 :	I	I						
49·42	18	3	Fe II	38	49·47	Ti II	82	49·62
55·81	18	3	Fe II	37	55·89	(Cr II	44	55·02)
58·78	7	3	Cr II	44	58·66			
63·74	4	3	Ti II	50	63·76			
71·28	6	3	Mg I	I	71·10	Ti II	82	71·97 *
76·40	10	3	Fe II	38	76·33			
80·09	7	3	Fe II	26	80·05	(?Cr II	3*F*	81·2)
83·67	25	3	Fe II	38	83·83	Fe II	37	82·84
88·20	9	3	Cr II	44	88·22			
92·26	2·5	2	Cr II	44	92·09			
4596·08	I·5	2				Fe II	38	95·68
4616·74	2	2	Cr II	44	16·64			

TABLE II (*cont.*)

Wave-length	Int.	Number of Measures	Identification					
			Main Contributor Element	*R.M.T.*		Minor Contributors Element	*R.M.T.*	
4618·80	2	2				Cr II	44	18·83
20·43	4	3	Fe II	38	20·51			
21·8 :	?*a*1	1						
23·05	1	2						
29·30	25	3	Fe II	37	29·34	Ni II	3*F*	*28·08*
34·18	4	1	Cr II	44	34·11	N III	2	34·16
35·58	4	1	?Fe II	186	35·33			
39·58	15	3	Fe II	4*F*	39·68	N III	2	40·64
53·40 :	6	2	?Fe III	3*F*				
57·74	10	3	Fe III	3*F*	58·1	Fe II	43	56·97
64·18	6	3	Fe II	4*F*	64·45	(Fe II	44	63·70)
66·88	9	3	Fe II	37	66·75	Fe III	3*F*	67·0
70·17	4	3	Fe II	25	70·17			
85·6 :	0	1	?He II		85·68			
4696·95	2*n*?*d*	2	?Fe III	3*F*				
4701·41	5*n*	2	Fe III	3*F*	01·5			
12·92	4*n*	2	He	12	13·2			
21·2 :	?*a*3	1						
24·3	?4*n*	1						
28·01	20	3	Fe II	4*F*	28·07			
31·37	7	3	Fe II	43	31·44			
34·22	1·5	2	Fe III	3*F*	33·9			
46·84	?2	2	(Fe II	20*F*	45·49)			
54·79	3*n*	1	Fe III	3*F*	54·7			
64·66	2	1	?Ti II	48	64·54			
72·14	?2	1	Fe II	4*F*	72·07			
74·74	10	4	Fe II	20*F*	74·74			
4798·25	5	3	Fe II	4*F*	98·28	Fe II	4*F*	99·31
4802·37	0	3						
07·4	*a*3*s*	2						
10·8 :	?5	2	?Fe II	20*F*				
14·42	25	6	Fe II	20*F*	14·55			
24·34	5	5	Cr II	30	24·13			
29·16	?1	1						
33·15	2	1				?Fe II	30	33·21
36·46	1	1	Cr II	30	36·22			
48·38	4	5	Cr II	30	48·24			
50·3	?*a*2	1						
52·6	2	1	Fe II	20*F*	52·73			
59·1	75	2 }						
62·62	150	6 }	H		61·33			
74·55	10	6	Fe II	20*F*	74·49			
82·8	?*a*4	2						
85·48	3	2	?Fe II	4*F*				
89·56	20	6	Fe II	4*F*	89·63			
4898·66	3	3						*
4905·34	15	6	Fe II	20*F*	05·35			
15·5	?*a*8*N*	2						
19·7	?3	2	?Fe II	42				
23·93	45	6	Fe II	42	23·92	He	48	21·93
30·00	?3	3						
47·42	7	6	Fe II	20*F*	47·38			
50·71	10	6	Fe II	20*F*	50·74			
73·40	10	6	Fe II	20*F*	73·39			
4993·59	1*n*	3	Fe II	36	93·36			

TABLE II (*cont.*)

			Identification				
Wave-length	Int.	Number of Measures	Main Contributor Element	*R.M.T.*	Minor Contributors Element	*R.M.T.*	
5001·62	1·5	2			Fe II	36 00·73	
06·18	10	4	Fe II	20*F* 05·52	Fe II	4*F* 06·65	
10·5	*a*5	2					
18·79	70	4	Fe II	42 18·43	Fe II	20*F* 20·24	
43·32	8 :	4	Fe II	20*F* 43·53			
48·4	6 :	3	Fe II	*F* 48·2	Fe II	20*F* 49·3	*
56·3	4 :	3	Si II	5 56·0	Si II	5 56·3	
60·3	7 :	4			?Fe III	1*F* 60·3	
5072·6	5	3	Fe II	19*F* 72·4			
5107·8	11	5	Fe II	18*F* 07·9			
11·5	13	5	Fe II	19*F* 11·6			
32·8 :	5	3	?Fe II	35 32·7			
45·8	5	1	Fe II	35 46·1			
54·6	5	2	Fe II	35 54·4	Cr II	24 53·5	
58·6	45	4	Fe II	18*F* 58·0	Fe II	19*F* 58·8	
64·0	10	3	Fe II	35*F* 63·9			
69·0	50	6	Fe II	42 69·0			
81·9	11	4	Fe II	18*F* 82·0			
84·7 :	?4*n*	1	Fe II	19*F* 84·8			
5197·8	18	6	Fe II	49 97·6	Fe II	35*F* 99·2	
5220·1	10	5	Fe II	19*F* 20·1			
34·6	16	5	Fe II	49 34·6	(Cr II	43 37·3)	
55·6 :	8	1	Fe II	41 56·9	Fe II	49 54·9	
61·4	20	5	Fe II	19*F* 61·6			
68·7	15	4	Fe II	18*F* 68·9	(Fe III	1*F* 70·4)	
74·3	60	6	Fe II	18*F* 73·4	Fe II	49 76·0	
84·1	10	5	Fe II	41 84·1			
5296·7	9	5	Fe II	17*F* 95·7	Fe II	19*F* 96·8	
5316·2	40	6	Fe II	49 16·6	Fe II	48 16·8	
27·1	?4	1	Fe II	49 25·6			
33·8	25	6	Fe II	19*F* 33·6			
47·7	6	3	Fe II	18*F* 47·7	Fe II	49 46·6	
63·3	10	5	Fe II	17*F* 62·1	Fe II	48 62·9	
68·3	*a*4	1					
5376·2	25	5	Fe II	19*F* 76·5			
5408·5 :	?5*n*	1	Cr II	23 07·6			
12·9	15	5	Fe II	17*F* 12·6	Fe II	16*F* 13·3	
25·6	8	3	Fe II	49 25·3			
33·0	18	5	Fe II	18*F* 33·1			
55·0 :	?6*n*	1					
77·7	10	4	Fe II	34*F* 77·2	Fe II	49 77·7	
91·7	4	1					
5496·0	8*N*	4	Fe II	17*F* 95·8			
5511·2	4	1	?Cr II	23 10·7			
19·1 :	?*a*3	1					
23·6 :	?6	1	?Fe II	35*F* 23·3			
27·9	25	5	Fe II	17*F* 27·3	(Sc II ?(Fe II	31 26·8) 34*F* 27·6)	
34·8	15	4	Fe II	55 34·9			
51·4	6	1	Fe II	39*F* 51·3			
57·1 :	?4*n*	1	Fe II	18*F* 56·3			
80·7	4*N*	1	Fe II	39*F* 80·8			
5587·0	6*N*	1	Fe II	*F* 87·5	?Fe II	39*F* 88·1	*
5601·1	?4*N*	1	Fe II	33*F* 00·7			

TABLE II (*cont.*)

Wave-length	Int.	Number of Measures	Identification				
			Main Contributor		Minor Contributors		
			Element	*R.M.T.*	Element	*R.M.T.*	
5614·4	6*N*	1					
28·0	?8*N*	1	Fe II	*F* 27·3	?Fe II	57 27·5	*
42·8 :	?4*N*	1	Fe II	18*F* 44·0	Fe II	39*F* 43·4	
50·3	6*N*	2	?Fe II	2*F* 50·4	Fe II	39*F* 50·9	
57·1	6*N*	2	?Fe II	57 57·9	?Sc II	29 57·9	
73·4	8	3	Fe II	*F* 73·2			*
5695·2	4	1	?Fe I	2*F* 96·4			
5719·5 :	?4	2			Fe II	33*F* 21·3	
26·4 :	?4	1	Fe II	39*F* 25·9	Fe II	57 26·0	
39·0	?*a*2	1					
48·2	20	3	Fe II	34*F* 47·0	?Fe II	17*F* 45·7	
5754·6	30	3	N II	3*F* 54·8	?Fe II	17*F* 53·8	
5824·7	?*a*1	1					
35·6	8	5	?Fe II	*F* 35·6	Fe II	57 34·9	*
75·4	45	5	He	11 75·6			
82·8	*a*6	2					*
86·6	4*n*	2					*
94·1	18	5	Na I		?Zn II	1 94·35	*
96·2	*a*1*s*	1					*
5899·8	9	2			?Fe II	34*F* 01·3	
5914·2	6	1			?Cr II	13·9	
57·1 :	10*NN*	1	Si II	4 57·6			
67·6	?*a*4*N*	1					
79·4 :	8*NN*	2	Si II	4 79·0			
5991·6	10	4	Fe II	46 91·4			
6044·2	10*N*	3	?Fe II	46 44·5			
6084·2	6*n*	2	Fe II	46 84·1			
6130·5 :	?4	1	?Fe II	46 29·7			
41 :	*a*3	2					
48·8	12	5	Fe II	74 47·7	Fe II	46 50·1	
					Fe II	74 49·2	
6188·4	7	3	Fe II	44*F* 88·5			
6229·4	?4	1	?Fe II	34 29·3			
39·3	12	4	Fe II	74 38·4	Fe II	34 39·4	
47·6	18	4	Fe II	74 47·6			
6291 :	?6*N*	2					*
6305	?6	1	?Fe II	200 05·3			
12·5	10	2	S III	3*F* 10·2			*
18·1	12	2	Fe II	18·0			*
47·7	10	5	(Si II	2 47·1)			
52 :	?8	1					
64·0	8	1					*
68·9	12	1	Fe II	40 69·4	Si II	2 71·4	
6383·7	10	4	Fe II	83·7			
6416·8	10	4	Fe II	74 16·9			
32·6	10	5	Fe II	40 32·7			
41·5	6	2	?Fe II	15*F* 40·4			
56·3	20	4	Fe II	74 56·4			
84·5 :	10	3					
6491·4	8	4	Fe II	91·3	Fe II	93·0	
6515·8	10	5	Fe II	40 16·0			
27·2	?4	1	N II	1*F* 27·4			
48	?	1	N II	1*F* 48·1			*
6562·9	1000 :	5	H	62·8			

TABLE II (*cont.*)

Wave-length	Int.	Number of Measures	Identification Main Contributor Element	 *R.M.T.*	 Minor Contributors Element	 *R.M.T.*	
6587 :	40 :	1	N II	1*F* 83·6	?Fe II	86·7	*
6666	18	4	Ni II	2*F* *66·8*			
6677	25	4	He	46 78·1			
6728	8	3	Fe II	31*F* 29·8			
6746	8	1					
6809·6	10	4	Fe II	31*F* 09·2			
35	10	1					
57	?8*N*	2					
74	?6	2	Fe II	43*F* 73·9	Fe II	31*F* 72·2	
6880	?6	1					
6944	8	1	Fe II	43*F* 44·9			
7065	6	3	He	10 65·2			
7156	8	2	Fe II	14*F* 55·1			
7171	2	1	Fe II	14*F* 72·0			
7310	?1	1	?Ni II	7*F* 07·8	Fe II	73 08·0	
7379	15	2	Ni II	2*F* *77·9*	Fe II	76·5	
7413	5	2	Ni II	2*F* *11·6*			
7453	4	2	Fe II	14*F* 52·5			
7512	2	1					
7691	?1	1	?Fe II	14*F* 86·2	?Ni II	7*F* 94·8	
7712	4	2	Fe II	73 11·7			
7867	2	2	P II	3*F* 69·5			
7915	?1	1					
7973	1·5	2	?Cr II	11*F* 74·3	?Fe II	*F* 75·3	
8000	3	2	Cr II	1*F* 00·1			
8114	5*N*	2			(Cr II	1*F* 25·5)	*
8155	?1	1					
8222	5*N*	2			(Cr II	1*F* 29·8)	*
8285	3	2					
8305	3	2	Ni II	2*F* *01·0*	(Cr II	1*F* 08·7)	
8356	4	2	Cr II	1*F* 57·8			
8417	2	2			H	13·3	
8446	6	2	?O I	4 46·5			*
8467	2	2	H	67·3			
8494	25	2			H	02·5	*
8544	4	2	H	45·4			
8598	5	2	H	98·4			
8619	10	2	Fe II	13*F* 17·0			
8664	6	2	H	65·0			
8681	4	2					
8714	6	2	Fe II	42*F* 15·8			
8750	5	2	H	50·5			
8832	?1	2					
8863	2	2	H	62·8			

NOTES TO TABLE II

3838·34 Mg I seems to be indicated despite the non-appearance of the weaker lines 3829, 3832, which may be masked by displaced H absorption. See remark under 4571·28.

3849·66 Measured as double with 0·4 A separation on one plate.

3877–3889 Complex structure, mainly due to hydrogen (double?) and helium (single?) (see Table III).

3927·44 Wave-length of sharp absorption edge depends on one plate only which also shows faint minimum in absorption band at 3939·04 and 3931·2. Centre of wide absorption measured on two other plates at 3928·30.

1953MNRAS.113..211T

3962·17 Wave-length of sharp absorption edge depends on one plate only. Centre of wide absorption measured on two other plates at 3962·89.

4002·36 Noted as possibly double on one plate.

4114·49 This line appears surprisingly strong for Fe II 23*F*, but the wave-length agreement is good. It is probably identical with the line observed by Swings and Struve in WY Gem (*Ap. J.*, **93**, 457).

4152·45 This line, which appears relatively stronger in RR Tel, is attributed to [Co II], $a^3F_4-b^3P_2$ (not in *R.M.T.*). The predicted wave-length from "Atomic Energy Levels", *N.B.S. Circular*, No. 467, Vol. II is 4152·59. It furnishes the only evidence for the presence of cobalt, other lines being weaker or in unfavourable regions of the spectrum.

4187·80 Merrill records an unidentified line in XX Oph at 4187·81 (*Ap. J.*, **114**, 40, 1951).

4229·29 Fe V 1*F* possible contributor, the stronger lines of this multiplet being liable to masking, 3970 by emission, 4136 by displaced He absorption (see Dufay and Bloch, *Ann. d'Ap.*, **3**, 3, 1940). No line appears here in RR Tel and this tells against the ascription to [Fe V], despite the lower limiting intensity recorded in Eta Carinae. The line might be a displaced component of Fe II 4233.

4246·8 Component (with uncertain wave-length and intensity) in wing of very strong line may be due to Sc II 7.

4283·55 Probably a violet component of Fe II 7*F* 4287 similar to the doubled H lines.

4299·55 Measured as double with 0·81 A separation on one plate.

4334, 4338 Absorption and emission components in complex H structure.

4571·28 Measured as double with 1·1 A separation on one plate. The resolution of this double, together with the observation of 3838 seems to establish the presence of Mg I. See also under RR Telescopii.

4898·66 This unidentified line is also present in RR Tel, relatively stronger than in Eta Carinae. A doubly or trebly ionized element seems to be indicated.

5048·4 Although Fe II 20*F* 5049·3 may contribute, the line is too strong, and the wave-length is discrepant ; it is here attributed chiefly to the forbidden transition $a^2P_{1\frac{1}{2}}-c^2D_{2\frac{1}{2}}$, 5048·2 (not listed in *R.M.T.*). The upper state has E.P. 4·71, only 0·04 volts below the lowest odd state of Fe II. A line at this wave-length is also observed in RR Tel.

5587·0 A diffuse line, attributed here chiefly to [Fe II] $a^2P_{1\frac{1}{2}}-b^2D_{2\frac{1}{2}}$, 5587·45 (not listed in *R.M.T.*).

5628·0 Another diffuse line, attributed chiefly to [Fe II] $a^2P_{1\frac{1}{2}}-b^2D_{1\frac{1}{2}}$, 5627·25.

5673·4 A moderately strong line, attributed to [Fe II] $a^2G_{4\frac{1}{2}}-c^2G_{4\frac{1}{2}}$, 5673·22 (not in *R.M.T.*).

5835·6 Attributed chiefly to [Fe II] $a^2G_{3\frac{1}{2}}-c^2G_{3\frac{1}{2}}$, 5835·44.

5882–5896 Complex structure apparently due to Na I emission accompanied by displaced absorption, the absorption due to D_1, being displaced by a shift capable of obliterating most of the D_2 emission. Sharp absorption at 5896·2 is presumably interstellar, the D_2 component is lost in the complex structure. Zn II may contribute to the emission at 5894.

6291 Merrill finds an unidentified line at 6291·8 in XX Oph (*Ap.J.*, **114**, 42, 1951).

6312·5 Attributed to S III 3*F* despite the discrepancy of 2·3 A in wave-length which is far too great for observational error. The same wave-length is found for a stronger line in RR Tel. Since [S II] appears in both stars and a higher state of ionization appears in RR Tel, this line is practically certainly due to [S III]. No expected line should appear as a blend to the red of 6310·2.

6318 Leading member of multiplet Fe II, $z^4D^0-c^4D$ (Edlén, private communication).

6364 This line, measured faintly on one plate, might be due to O I 1*F*, but no trace of 6300 or 5577 can be found.

6548, 6584 This [N II] pair was measured on one plate of short exposure specially taken for the purpose. On all normal exposures the wings of Hα obliterate the neighbouring lines.

8114, 8222 Two very diffuse emissions, apparent width about 30 A, probably representing unresolved blends.

8446 This may be due to O I excited by Ly β through a fluorescent cycle. If so it represents the only evidence of oxygen in Eta Carinae in any stage of ionization. This line is much stronger in RR Tel.

8494 This, by far the strongest line in the infra-red, is unidentified. H is only a minor contributor. The same line appears to be weakly present in RR Tel.

4. *Representation of elements in Eta Carinae.*

H	Hα is easily the strongest line in the spectrum and is responsible for the red colour of the star to the eye. The gradient of intensity in the Balmer series (observed to 3703) is fairly rapid. Lines of the Paschen series are observed in the infra-red, but no continuum at the limit. The strongest lines have complex structures (see Tables III, IV).
He I	Well represented, 5876, 6678 and 4471 being the strongest lines. For displaced absorption see Table IV.
He II	An exceedingly weak line, measured on only one plate, may be He II 4686.
C	No lines due to carbon have been found.
N II	No lines found.
[N II]	The lines 6584, 6548 and 5755 are strong, but the former pair is usually lost in the wings of Hα.
N III	Doubtfully present, the most certain evidence being from the line 4097, but the upper E.P. of 30 volts is exceptional for Eta Carinae.
O I	A moderately strong line at 8446 may be excited by Lyman β through a fluorescent mechanism (Bowen, *P.A.S.P.*, **59**, 196). The weaker line 6726 which might appear in this mechanism is blended with Fe II.
[O I], [O II], [O III].	No lines found despite the regions of the well-known lines being covered by the investigation. A weak line at 6364·0, once measured, might be due to [O I], but the stronger line at 6300 was not found.
[F II]	Not found.
[Ne III]	3868 and 3968 are present, moderately weak.
Na I	Diffuse emission at 5894 probably due to D_1; displaced D_1 absorption may mask D_2 emission. Displaced D_2 absorption is measured (see Table IV). Higher dispersion is required for studying this complex structure.
Mg I	Probably represented by 4571 and 3838. The lines 3829, 3832 may be lost in displaced absorption by H.
Mg II	Probably represented by a weak line at 4481·1.
Al	Not represented.
Si II	A few lines are weakly present.
[P II]	The strongest line*, with measured wave-length 7867, appears. There is no other reasonable explanation.
[S II]	The pair 4068, 4076 are quite strong.
[S III]	The line 6312·5 is almost certainly due to this ion despite its lying 2·3 A from the predicted wave-length (see RR Telescopii).
[Cl II]	The line 6153 (wave-length uncertain), which might well appear, may be masked by Fe II 6147, 6149.
Ca II	Not found in emission; highly complex absorption due to *H* and *K* displaced to the violet by 475 km/s is found (see Table IV).
Sc II	4246 probably present, blended with [Fe II]. Other weaker lines also probably contribute to blends.
[Sc III]	The pair 3914, 3945 coincide with Fe II lines, and a possible contribution from this ion cannot be estimated with the available dispersion.

---

* See S. Pasternack, *Ap. J.*, **92**, 129, 1940. The writer is indebted to Dr P. Swings for this reference.

Ti II	Well represented by weak lines (up to 5·5 volts, upper E.P.); the lines due to Ti II seem to have faded slightly since 1919 relative to Fe II.
[Ti II]	No evidence; the best lines lie too far in the infra-red.
V II	Represented by weak lines up to 5·0 volts, upper E.P.
[V II]	Same remark as for [Ti II].
Cr II	Many moderately weak lines present, up to 9·5 volts, upper E.P. Like Ti II, Cr II, may have faded slightly since 1919.
[Cr II]	Represented by 1*F*. 8125, 8230 are lost in very diffuse emission, 8308 is blended with [Ni II]; 8357 appears to be too strong and may be blended with another line (see under [Fe I]). No evidence found for other multiplets in the photographic region.
Mn II	No evidence.
Fe I	No evidence.
[Fe I]	The expected strongest line 8347 might contribute to the observed line 8356, attributed partially to [Cr II]. A weak line at 5695·2 measured only once, might be due to the leading member of 2*F*.
Fe II	Responsible for numerous prominent lines permitted and forbidden. The permitted lines are observed up to 8·15 volts, upper E.P. For structure of strongest lines see Tables III, IV.
[Fe II]	Numerous lines present from multiplets 2*F*? up to 44*F*. A few multiplets not listed in the *R.M.T.* also are apparently represented. The highest upper E.P. is that of $c^2D_{2\frac{1}{2}}$, only 0·04 volts below the lowest odd state.
Fe III	4419 appears to be present in the wing of the strong line 4416.
[Fe III]	4658 and other weaker lines are present; for double emission see Table III.
Co II	No evidence.
[Co II]	Represented by the one line 4152·45 (*q.v.* in Notes to Table II).
Ni II	Lines up to 7·1 volts upper E.P. found.
[Ni II]	Lines present in strength, especially multiplet 2*F* in the infra-red (predicted by Swings, *P.A.S.P.*, **56**, 242, 1944). The laboratory wave-lengths in Table II are revised in accordance with the latest laboratory data.
Cu II	No evidence.
[Cu II]	The line 3806 is present.
Zn II	Doubtfully contributes to 5894.

Other elements: not found.

5. *Complex structure of strongest lines.*—Generally speaking, the analysis of the spectrum of Eta Carinae is much simplified, compared with most novae, because the lines are relatively sharp and yield practically the same velocities.*

The only examples of complex structure analogous to the spectra of novae occur in the very strongest lines, particularly those of hydrogen. Here not only do the emission lines appear doubled (as first noted by the Lick observers) with the red component considerably stronger, but there is also a diffuse absorption component shifted to the violet by some 450 km/s.

---

* There is some evidence that [Fe II] lines are slightly shifted to the red compared with permitted Fe II, but the difference amounts to about 2 km/s and is only slightly in excess of the probable error.

Emission lines which are attributed to components of doubles are listed in Table III. It will be seen that for hydrogen the ratio of intensity is about two to one, and the separation decreases steadily from 3·5 A for Hβ to about one-third this value for the higher members of the Balmer series. Note also that the stronger component lies to the red of the normal wave-length by an amount which is greatest for the strongest lines. For [Fe II] the separation of emission components is larger—about 4 A, and the ratio of intensity is about five to one. There is only one instance recorded for permitted Fe II (4923) and here the intensity ratio is still greater (15 : 1), this displacement being 4·2 A.

It is of interest to note that the two strongest lines of [Fe III], 4658 and 4701, appear to have violet-displaced emission components which have no other satisfactory identification. The displacements of 4·34 and 4·46 A are slightly larger than those for [Fe II] and the intensity ratio is of the order 2 : 1.

Thus judging by the relative intensities of the two components the secondary component is most prominent for H and [Fe III] (2 : 1), next for [Fe II] (5 : 1) and next Fe II (15 : 1).

TABLE III

Double emission components

Elt.	λ_1	λ_2	$\Delta\lambda$	I_1	I_2
H	4862·62	4859·1	3·5	150	75
H	4341·30	4338·5	2·8	75	25
H	4102·29	4100·4	1·9	30	15
H	3970·61	3969·36 :	1·25 :	10*n*	7 :
H	3889·58	3887·94	1·64	15*N*	10*N*
[Fe II]	4889·65	4885·48	4·18	20	3
[Fe II]	4814·42	4810·8	3·6	25	?5
[Fe II]	4452·02	4447·93	4·09	20	?4
[Fe II]	4413·70	4409·92	3·88	50*N*	6
[Fe II]	4359·08	4355·28 :	3·80	60	?10
[Fe II]	4287·39	4283·55	3·84	50*N*	10
Fe II	4923·93	4919·7	4·2	45	?3
[Fe III]	4657·74	4653·40 :	4·34	10	6
[Fe III]	4701·41	4696·95	4·46	5*n*	2*n*?*d*

The absorption components only appear weakly on dense exposures and their reality might be doubted were it not for the fact that the displacements agree rather well with one another (considering their diffuseness), and in particular with the strong and incontrovertible absorption due to Ca II *H* and *K*.

The measured displacements of these absorptions are listed in Table IV.

It is to be noted that, as with the emission components, the displacements of the absorption components interpreted as velocities (Δv in Table IV) are larger for the stronger members of the Balmer series; Δv also appears to be correlated with the intensity of the undisplaced emission, in the same sense, for Fe II and [Fe II]. For instance, among [Fe II] absorptions the largest displacement is found for 4416 (50*N*), the smallest for 4372 (9), 4889 (20) and 5746 (20).

It is not the purpose of this paper to analyse the physical meaning of these interesting structures of the strongest lines in Eta Carinae. The calcium absorptions, in particular, show subsidiary structure which should be studied with higher dispersion. But there can be no doubt that the main absorption component represented by Ca II, H, [Fe II] and Fe II is to be attributed, as

TABLE IV

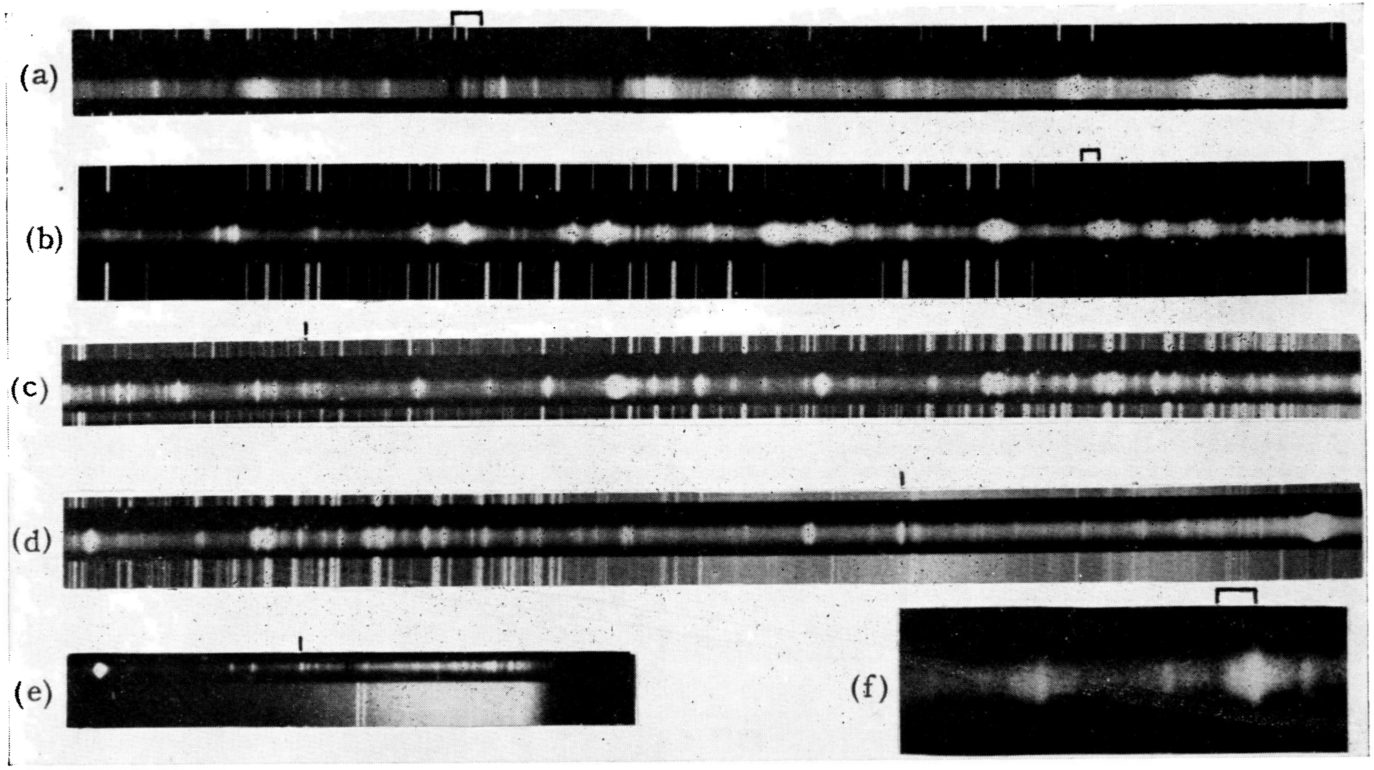
Absorption measured in Eta Carinae

Elt.	λ	Emission Intensity	Δλ	Δv (km/s)
H	3830·61	5*N*	− 4·78	−374
	4334·3 :	75*N*	− 6·2	−430 :
	4850·3	150	−11·0	−680 :
			Mean H	−465 :
He	4021·27	5*n*	− 4·9	−365
	4465·83	15*N*	− 5·7	−383
			Mean He	−376
Na I	5882·8	...	− 7·2	−370
Ca II	3927·44	abs.	− 6·22	−475
	3962·17	abs.	− 6·30	−476
			Mean Ca II	−475
Fe II	*4295·16 }	10	− 8 }	
	97·9 }		− 5·3 }	
	4502·55	15	− 5·73	−380
	4543·18	18	− 6·29	−415
	4621·8 :	25	− 7·54 :	−490 :
	4915·5 :	45	− 8·4 :	−512 :
			Mean Fe II	−432
[Fe II]	4237·73	45*N*	− 6·35	−450
	4280·80	50*N*	− 6·59	−460
	4366·63	9	− 5·77	−395
	4405·83	50*N*	− 7·87	−535
	4407·44	50*N*	− 8·81	−600
	4445·65	20	− 8·17	−550
	4721·2 :	20	− 6·9 :	−440 :
	4807·4	25	− 7·15	−445
	4882·8	20	− 6·83	−420
	5368·3	25	− 8·2	−460
	5519·1 :	25	− 8·2 :	−445 :
	5739·0	20	− 8·0	−420
			Mean [Fe II]	−471

* The emission line 4296·57 (Fe II 28), int. 8, is flanked by two sharp absorptions. Absorption of 4303·17 (Fe II 27) displaced by −475 km/s would have wave-length 4296·36. It is suggested that emission of 4296·57 (Fe II 28) takes place primarily *above* layer of absorption. Laboratory and stellar intensities of Fe II 28 are as below :

	Lab.	Stellar
4178	8	15 (−)
4296	6	8
4369	2	3
4122	4	6
4258	3	4
4087	pred.	...

Thus λ 4296 does not seem to be weakened by any overlying absorption.

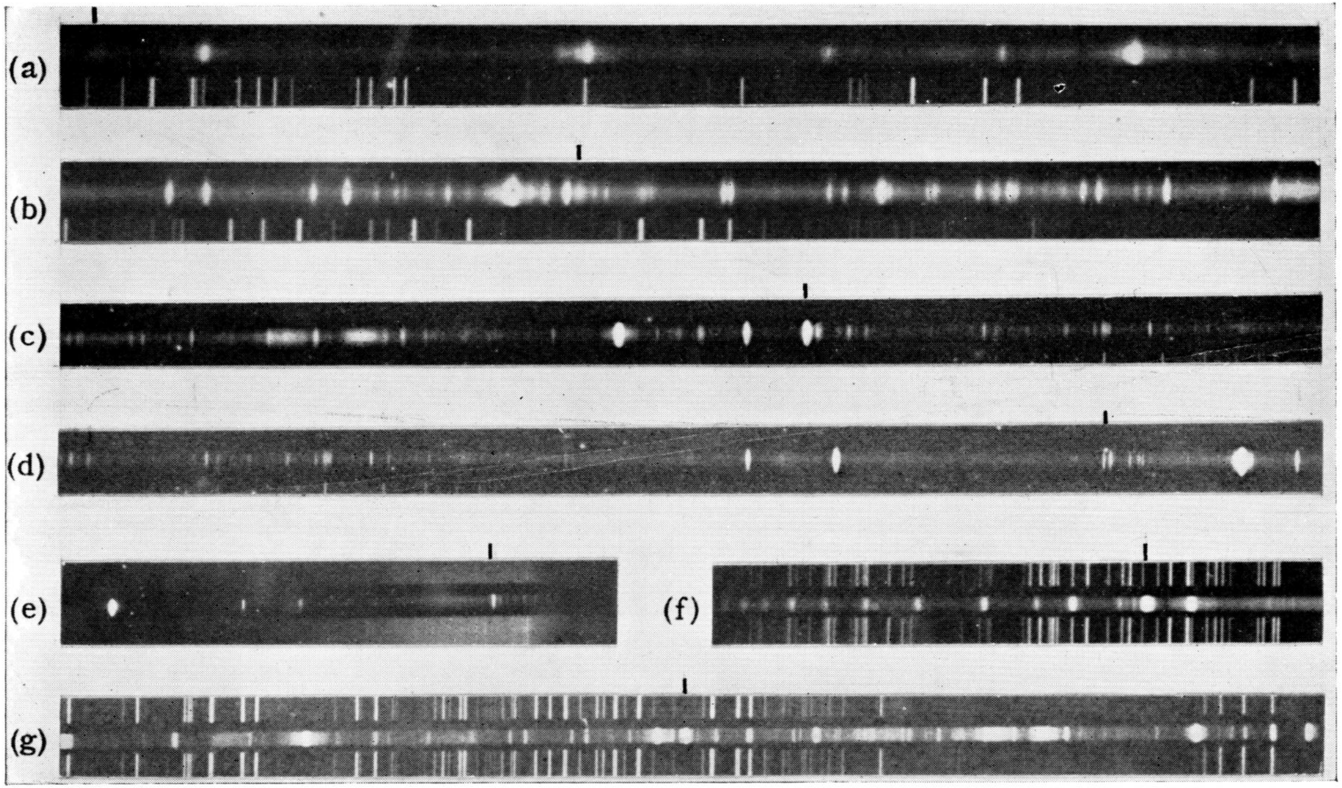


Spectra of Eta Carinae

	Region	*Marked line*
(a)	3860–4120	Ca II 3933; *interstellar and displaced absorption.*
(b)	4135–4540	[Fe II] 4452; *emission and absorption.*
(c)	4520–5530	[Fe III] 4658
(d)	5000–6600	He 5876
(e)	6560–8860	[Ni II] 7378
(f)	4750–4830	[Fe II] 4814; *emission and absorption.*

A. D. Thackeray, Identifications in the spectra of Eta Carinae and RR Telescopii

1953MNRAS.113..211T



Spectra of RR Telescopii

	Date	*Region*	*Marked line*
(a)	1951	3865–4145	[Ne III] 3868
(b)	1951	4200–4650	[O III] 4363
(c)	1952	4490–5600	[O III] 5007
(d)	1952	5100–6700	[O I] 6300
(e)	1951	6560–8800	O I 8446
(f)	1952	3700–3950	[Ne III] 3868
(g)	1952	3968–5007	[O III] 4363

A. D. Thackeray, Identifications in the spectra of Eta Carinae and RR Telescopii with P Cygni stars, to a shell surrounding the star and expanding with a velocity of about 475 km/s. And if this shell is identified with the directly observed halo, then, as mentioned in a previous note*, an estimate of the distance of Eta Carinae can be made (as for novae) by assuming that this velocity has been maintained since the star suffered its main outburst. The result is 1200 parsecs, in agreement with Bok's estimate for the diffuse nebula NGC 3372 in the region of Eta Carinae. This supports the idea that the star is actually embedded in the nebula.

Rottenberg† has recently calculated profiles of lines produced by a model of an expanding shell in which scattering and recombination processes are active. And the varying prominence of secondary emission and displaced absorption components observed in Eta Carinae for various atoms and ions could undoubtedly be reproduced by varying the parameters in Rottenberg's profiles. His Fig. 6*a* in particular shows close correspondence to the hydrogen profiles in Eta Carinae. Rottenberg's analysis presupposes that light from the star plus shell is received, unresolved, by the slit of the spectrograph. The above derivation of the distance attributes the displaced absorption to absorption in the visible shell which is fully resolved from the star at the slit. It may be that the observed absorption represents recent, or even continuous, ejection of matter much closer to the star than the visible shell. In this connection it is of interest to note that the star has appreciably brightened in recent years.‡

All the spectra discussed here relate to the "nucleus" which has a star-like appearance. The character of the spectrum, with bright lines predominating over a very weak continuum, suggests a low-excitation corona; the dimensions might well be of the order of several hundred astronomical units without presenting a detectable disk.

One spectrum so far has been obtained of a portion of the surrounding shell, 3″ of arc from the nucleus, including Gaviola's § condensation *c′*. This spectrum is quite different from the nucleus. There are very broad nova-like bands bordered on the violet by absorption in a relatively prominent continuum. Fe II bands, permitted and forbidden, are still strong. Discussion of this spectrum must be postponed until other portions of the shell have been studied.

6. *Relative intensities of* [Fe II] *lines.*—The metastable states of Fe II giving rise to the strongest forbidden lines have configurations $3d^6 4s$, $3d^7$ and $3d^5 4s^2$. In these complicated conditions little is known about theoretical transition probabilities, especially for intercombination systems; and our knowledge of the transitions must therefore have largely an empirical basis on observations of Eta Carinae.

In general, it can be stated that within forbidden multiplets of Fe II, the strongest lines in Eta Carinae are usually those which are listed first in the *Revised Multiplet Table*; the order in the *R.M.T.* seems to have the following basis:

(*a*) Between terms of the same multiplicity, $\Delta J = \Delta L$ gives the strongest lines (examples, multiplets 13*F*, 18*F*, 19*F*, 20*F*, 21*F*, 31*F*).

(*b*) For multiplicity $6-4$ or $4-2$, $\Delta J = \Delta L - 1$ gives the strongest lines (examples, 6*F*, 14*F*, 23*F*).

---

* A. D. Thackeray, *The Observatory*, **71**, 167, 1951.

† J. A. Rottenberg, *M.N.*, **112**, 125, 1952.

‡ G. de Vaucouleurs and O. J. Eggen, ***P.A.S.P.*, 64**, 155, 1952. But see following paper, p. 237.

§ E. Gaviola, *Ap. J.*, **111**, 408, 1950.

No exception to rule (*a*) has been found, but there are two clear-cut exceptions to rule (*b*). These are as follows:

(i) Multiplet 4*F* (a^6D-b^4P); here $\Delta L=-1$, according to rule (*b*) $J=4\frac{1}{2}-2\frac{1}{2}$ (λ4799) should be the strongest line. A blended line is observed, intensity 5, but the strongest line of the multiplet in Eta Carinae is undoubtedly λ4889 (intensity 20), for which $J=3\frac{1}{2}-2\frac{1}{2}$. This result is not so clear from the Lick intensities because of the falling-off in sensitivity of the 1913 plates near 4900 A; it is consistent with Spencer Jones's intensities from a panchromatic plate.

By analogy, the strongest line in the infra-red multiplet 1*F* should be 7637 rather than 7419, but neither line has been observed.

(ii) Multiplet 17*F* (a^4F-a^2D); here $\Delta L=-1$, and again the *R.M.T.* lists $J=4\frac{1}{2}-2\frac{1}{2}$ (λ5362) as the strongest line. This line has intensity 10 (blended with Fe II 48), much weaker than λ5527 (25) and λ5412 (15) for which $\Delta J=-1$.

In addition to the question of relative intensities within multiplets, there is the matter of relative intensities of multiplets considered as a whole. In general, of course, transitions between terms of the same multiplicity give the strongest multiplets (e.g. 7*F*, 18*F*, 19*F*, etc.), and secondly strong multiplets are not associated with $\Delta L>1$. It is of interest to note that transitions between doublet terms have been observed for the first time in this paper (e.g. 42*F*, 43*F*, 44*F*), and that several observed lines which are not listed in the *R.M.T.* apparently represent such transitions (e.g. 5587, 5628, 5673, 5835; see Notes to Table II).

Weak transitions between sextet and doublet terms are possibly represented by the lines 5650 (2*F*), 3979 (9*F*) and 3712 (10*F*).

7. Table V presents the lines measured in RR Telescopii in the same manner as Table II for Eta Carinae. In the column of identifications, however, the laboratory wave-length is only given if the same identification has not already appeared in Table II. Moreover, while the wave-lengths from the 1951 and 1952 plates have been combined to form a mean, the intensities for the two years

TABLE V

RR Telescopii

Mean wave-lengths and intensities of emission and absorption lines

Wave-length	Int.		Incr.	Identification			
	1951	1952	1952				
3697·13	...	0·2		H		97·15	
3704·07	...	0·3		H		03·85	
11·74	...	0·2		H		11·97	
34·25	...	0·5		H			
50·18	...	1		H			
70·56	...	2		H			
3798·02	...	3		H			
3819·64	...	1		He I	22		
35·60	2*N*	6		H			
55·88	0·5*n*	1		Si II	1		
59·1	...	0·2					
62·42	...	0·5		Si II	1		
68·61	1*N*	30	++	Ne III	1*F*		
77·09	...	*a*6		He I			
79·90	?*a*2			He I			
87·73	...	3		H			He I
88·30		*a*4*s*					
3889·27	5*N*	12		H			He I
3926·45	...	1		He I	58	26·53	

TABLE V (*cont.*)

Wave-length	Int. 1951	Int. 1952	Incr. 1952	Identification		
3933·6	...	0·5		?Ca II	1	33·66
36·2	...	0·5		He I	57	35·91
38·30	0·3	1		Fe II	3	
64·85	1*N*	1		He I	5	64·73
68·07 :	1	35	++	Ne III	1*F*	
70·55	6	15		H		
93·2	0·3	1		Ni II	4*F*	
3995·2	...	1		N II	12	95·00
4009·2	...	1·5*n*		He I	55	09·27
14·9	...	*a*3		He I	18	
17·3	*a*1			He I	18	
26·16	2*N*	8	+	He I	18	
55	Bd.	15*NN*		?N IV	3	57·80
68·57	2	3		S II	1*F*	
72·1	...	0·5				
75·96	0·5	1		S II	1*F*	
87·2	...	1				
4089·0		?0·3				
4100·14	?2					
01·74	20	30		H		
14·40	...	?1		Fe II	23*F*	
20·65	...	2		He I	16	
43·90	1*n*	6	+	He I	53	
52·80	0·5	1·5*n*		?Co II	*F*	
69·1	...	0·5		He I	52	68·97
73·56	1	1		Fe II	27	
77·44	0·5	1		Fe II	21*F*	
4178·80	4	3		Fe II	28	
4201·08	0·5	0·5		Ni II	3*F*	
07·4	...	2·5*N*				
33·12	8	6		Fe II	27	
44·12	6	7		Fe II	21*F*	
57·98	0·3	0·3		Fe II	28	
61·5 :	0·5	...				
67·1	...	?0·3		?C II	6	67·1
73·4	?0·3	...		Fe II	27	
76·63	3	5		Fe II	21*F*	
87·28	9	9		Fe II	7*F*	
4296·58	1	1		Fe II	28	
4300·0 :	0·3	0·5		?Ti II	41	
03·17	1	1		Fe II	27	
05·90	0·5	1		Fe II	21*F*	
14·17	0·5*N*	0·5				
19·63	2	3		Fe II	21*F*	
26·24	1*N*	1		Ni II	3*F*	
40·40	30	40		H		
46·70	1	1·5		Fe II	21*F*	
51·89	4*d*	4		Fe II	27	
58·88	6	6		Fe II	7*F*, 21*F*	
63·28	2*N*	35	++	O III	1*F*	63·21
68·31	1	?1				
72·36	1	1·3		Fe II	21*F*	
83·3 :	0·3	0·5				
85·0	1·5*N*	...		Fe II	27	
4388·04	2	3		He I	51	

TABLE V (*cont.*)

Wave-length	Int.		Incr.	Identification		
	1951	1952	1952			
4413·81	9	6		Fe II	7*F*	
16·34	9	6		Fe II	6*F*, 27	
32·57	0·3	0·5		Fe II	6*F*	
37·6	...	0·5		He I		37·55
52·11	3	3		Fe II	7*F*	
57·86	2	2		Fe II	6*F*	
60·84	*a*6			He I	14	
71·58	12	15		He I	14	
75·0	1	...		Fe II	7*F*	
80·4	...	0·5*n*		?Mg II	4	
88·96	2	2		Fe II	6*F*, 37	
4491·76	2	2		Fe II	37	
4508·33	3	2		Fe II	38, 6*F*	
15·25	4	3		Fe II	37, 6*F*	
20·10	4	2·5		Fe II	37	
22·63	2·5	2·5		Fe II	38	
34·2	0·5	...		Fe II	37	
39·7	...	ft. Bd.				
41·89	1*N*	0·5		Fe II	38	
				He II		41·59
49·51	5	3		Fe II	38	
55·89	6	3		Fe II	37	
71·16	1·5	2		?Mg I	1	
76·53	1	1		Fe II	38	
83·80	10	6		Fe II	38	
91·3	...	1				
4596·46	...	1				
4600·99	...	1		?N II	5	01·5
07·08	0·5*N*			?N II	5	07·2
29·36	5	8		Fe II	37, N II 5	30·5
39·9	2	15*NN*	++	N III	2	40·6, 34·2, 41·9
49·4	0·5*N*	4*n*	+	C III	1	47·4, 50·2, 51·3
58·28	6	8		Fe III	3*F*	
66·96	1	1		Fe III	3*F*	67·0, Fe II 37
4685·8	3*NN*	20*NN*	+	He II		85·68
4701·68	2*n*	4		Fe III	3*F*	
13·34	1·5	8	+	He I	12	
27·98	2	2·5		Fe II	4*F*	
33·5	0·5	1		Fe III	3*F*	
40·8	...	1				
54·94	1*n*	2		Fe III	3*F*	
69·90 :	0·5	1		Fe III	3*F*	69·4
4775·09	0·5	1		Fe II	20*F*	
4814·53	2	3		Fe II	20*F*	
51·0 :	...	?1				
61·75	60	60		H		
74·70	0·5	1		Fe II	20*F*	
89·62	3	3		Fe II	4*F*	
4899·28 :	0·5	0·5				
4905·7	1	3		Fe II	20*F*	
21·8	0·2	4	+	He	48	
23·4	4	4		Fe II	42	
59·1	0·5	25	++	O III	1*F*	58·9
4973·8	...	0·5		Fe II	20*F*	
5006·8	1	50	++	O III	1*F*	06·8

TABLE V (*cont.*)

Wave-length	Int. 1951	Int. 1952	Incr. 1952	Identification		
5016·1	0·5	6	+	He	4	15·7
18·6	2	3		Fe II	42	
32·8	...	1·5		?Fe III	2*F*	
41·4	...	6		——, Si II	5	41·1
48·2	...	1		——, Fe II	—*F*	
5056·0		3		Si II	5	
5111·5		1		Fe II	19*F*	
58·7		5		Fe II	18*F*, 19*F*	
68·9		1·5		Fe II	42	
5197·9		1·5		Fe II	49, 35*F*	
5234·4		4		Fe II	49	
61·8		4		Fe II	19*F*	
70·7		6		Fe III	1*F*	70·4, Fe II 18*F*
76·2		3		Fe II	49, 18*F*	
5297·5		1		Fe II	17*F*, 19*F*	
5316·8		5		Fe II	49	
33·8		2		Fe II	19*F*	
63·0		1		Fe II	17*F*, 48	
5376·6		2		Fe II	19*F*	
5411·9		4*N*		He II	2	11·5
				Fe II	17*F*	
5432·7		1		Fe II	18*F*	
5527·0		2·5		Fe II	17*F*	
5535·4:		0·5		Fe II	55	
5679·9		1·5*N*		N II	3	79·6
5754·6		12		N II	3*F*	
5799·8		2*N*				
5876·0		30		He I	11	
5958·0		1		Si II	4	
6300·8		7		O I	1*F*	00·2
12·5		9		S III	3*F*	
47·2		3		Si II	2	
63·7		3		O I	1*F*	63·9
71·6		3		Si II	2	
6384·6		1·5		Fe II		
6415·3:		2*N*		Fe II	74	
6456·3		1·5		Fe II	74	
6516·4		1		Fe II	40	
49		?4		N II	1*F*	
63·0		100		H		
6582·4:		6		N II	1*F*	
6678·1		12		He	46	
7065	8	8		He	10	
7121		?0		N IV	4	23·1
7135	?0	1	+	A III	1*F*	35·8
7319	4			O II	2*F*	19·4, 18·6
7329	2			O II	2*F*	29·9, 30·7
8095	?cont.					
8445	15	2	...	?O I	4	
8492	2			...		
8544	1			H		
8601	1			H		
8667	2*n*			H		
8748	2			H		

have been listed separately, and a separate column is given to draw attention to those lines which were somewhat stronger (+) or very much stronger (+ +) in 1952.

Since RR Telescopii was considerably fainter than Eta Carinae at the time of observation, the limiting intensity of the lines is set by exposure time rather than by a faint continuum.

8. *Representation of elements in RR Telescopii*

H	The Balmer series is recorded from Hα to 3697 (one line further than in Eta Carinae) and the gradient is considerably slower than in Eta Carinae. Four Paschen lines are recorded, and there is some evidence of a faint continuum at the Paschen limit.
He I	Well represented, the lines being relatively stronger than in Eta Carinae, and subject to considerable increase in 1952.
He II	4686 is a very broad band, much stronger in 1952. 5412 is also recorded.
C II	4267 appears to be weakly present in 1952.
C III	The 4650 band is present, strengthened in 1952.
N II	Represented weakly by lines from multiplets 3, 5, 12.
[N II]	5755 is apparently stronger than the pair 6584, 6548.
N III	The 4640 band is present greatly strengthened in 1952.
N IV	A broad band, with measured centre at 4055, is probably due to N IV. A line glimpsed on a weak infra-red plate in 1952 is probably due to the leading member of multiplet 4 (52 volts upper E.P.).
O I	8446 is the strongest line in the infra-red in 1951, but it was much weaker than He 7065 in 1952.
[O I]	6300, 6363 were present in moderate strength in 1952; 5577 is not found.
[O II]	Although 3727 was not recorded in the ultra-violet, the infra-red pair 7319, 7329 was found (in 1951) with roughly the same relative intensity as that recorded by Merrill in nebulae (*P.A.S.P.*, **39**, 254, 1928). The non-detection on the weak 1952 plate does not necessarily mean that the lines had weakened.
[O III]	5007, 4959 and 4363, weakly present in 1951, all increased enormously in 1952.
[Ne III]	3868, 3968 behaved just like the [O III] lines.
Mg I	The line 4571 appears to be present, as in Eta Carinae.
Mg II	A very weak line, measured in 1952 only, may be due to Mg II.
Si II	Multiplets 1, 5 are represented. 5041 is too strong to be entirely due to Si II; a line at this wave-length, which has been observed in several objects is suspected by Swings* to be due to [Fe IV].
[S II]	4068, 4076 are present.
[S III]	The line 6312·5, attributed to this ion, is much stronger in RR Tel than in Eta Carinae.
[A III]	The line 7135 is present, exceedingly weak in 1951, but definitely appears on the weak 1952 plate. This apparent increase is consistent with the higher ionization observed in 1952.

---

* P. Swings, *J.O.S.A.*, **41**, 153, 1951.

Ca II	A very weak line, measured in 1952, may represent Ca II *K*.
Ti II	The only line which may represent Ti II is a very weak one at 4300 A. Others may be lost in blends.
V II	No evidence; the lines recorded in Eta Carinae are too weak to be expected on the plates of RR Tel.
Cr II, [Cr II]	Same remark as for V II.
Fe II	Represented by multiplets 3, 27, 28, 37, 38, 40, 42, 49, 55, 74.
[Fe II]	Represented by multiplets 4, 6, 7, 17, 18, 19, 20, 21, 23 (35). The increase of forbidden relative to permitted Fe II which has occurred ever since the transition to a bright-line spectrum was maintained from 1951 to 1952.
[Fe III]	Better represented in RR Tel than in Eta Carinae. 1*F* is represented by 5270. 2*F* is doubtfully represented by 5032. Six lines of 3*F* appear.
[Fe IV]	Possibly represented by 5041. See Si II.
[Fe V], [Fe VI]	Not found, but their appearance within the next few years may be expected.
[Co II]	Represented by the one line 4152, as in Eta Carinae.
Ni II	Same remark as for V II.
[Ni II]	3993, 4201 and 4326 alone are recorded. Exposures in the red and infra-red are too weak to record 2*F*.

9. *Absorptions in RR Telescopii.*—Absorptions displaced to the violet were measured accompanying a few lines of He I in RR Telescopii, similar to those in Eta Carinae. More might have been found had it been practicable to secure the appropriate density on higher dispersion. The mean velocity in km/s found for these absorptions relative to the emission lines is as follows:

Lines	1951	1952
3888, 4026, 4471	−685	−865

At 3888·30 a peculiar absorption was measured, very sharp on its longward side. This might be partly due to a doubling of the emission component (H + He) as found for the strongest emissions in Eta Carinae; alternatively there might be another absorption system with small velocity. But it is strange that a similar feature does not show in the other strong lines.

10. *Velocity of RR Telescopii from emission lines.*—The wave-lengths in Table V were obtained by assuming a stellar velocity relative to the Sun of −62·3 km/s (as found in 1951); combined with the 1952 material a mean velocity of −61·8 km/s is found.

There appears to be a systematic difference in velocity between permitted and forbidden Fe II lines as follows:

	[Fe II] − Fe II
1951	+4·4 km/s
1952	3·2 km/s

It should be remembered that the excitation potentials are on the whole smaller for the lines of [Fe II] than for Fe II, and this fact may have some bearing on these systematic differences. The difference is in the same sense as the much smaller, and questionable, difference between [Fe II] and Fe II velocities previously found in Eta Carinae.

11. *Unidentified lines in Eta Carinae and RR Telescopii.*—On the whole it is possible to suggest reasonable identifications for the great majority of lines in the two stars. Owing to the relatively low dispersion in yellow and red, a number of the identifications in this region may have to be modified later. The accompanying table lists some of the best established cases of lines for which no reasonable identification can be offered. This table omits those lines in Eta Carinae which are attributed to components of strong emission lines already listed in Table III.

Table VI

Strongest unidentified lines

Eta Carinae		RR Telescopii		
Wave-length	Int.	Wave-length	Int.	
			1951	1952
4064·53	2·5			
		4207·4	...	2·5*N*
4364·8	3			
		4368·31	1	?1
4596·08	1·5	4596·46	...	1
4898·66	3	4899·28:	0·5	0·5
		5041·4	...	6
		5799·8	...	2*N*
5899·8	9			
7512	2			
8114	5*N*			
8222	5*N*			
8285	3			
8494	25	8492	2	
8681	4			

4596, 4898, in common to the two stars, appear with longer wave-lengths in RR Telescopii than in Eta Carinae, despite the fact that the measures should be good to 0·1 A. It is probable that the wave-lengths for Eta Carinae are the more reliable. It has already been noted that in RR Tel [Fe II] lines give a different velocity from Fe II; and there is some indication that [Fe III] in RR Tel is still further shifted to the red. Both lines appear relatively *stronger* in RR Tel, after allowance for intensity scales. Thus a doubly or trebly ionized element seems to be indicated. Perhaps the most likely origin is [Ni III] or [Fe IV]. 5041 in RR Tel, as already noted, is only partly due to Si II.

4207 (RR Tel) was observed in Nova Pictoris in the "nebular" stage.

5900 (Eta Carinae) may possibly be connected with the very complex structure around the Na *D* lines.

8114, 8222 (Eta Carinae) are very broad bands which might be resolved into separate lines with higher dispersion.

8494 is by far the strongest line in the infra-red in Eta Carinae. H 8502 can only be a very minor contributor. It is relatively weak in RR Tel. There seems to be no possibility that Ca II 8498 contributes. One rather unlikely explanation is in terms of the member of the forbidden molecular transition of H_2, observed in absorption by Herzberg.*

---

* G. Herzberg, *Ap. J.*, **115**, 337, 1952.

12. *A summarized comparison.*—A comparison of the intensities of lines in Eta Carinae and RR Telescopii (1951–52) indicates that while the two spectra are in general strikingly similar, the following differences are apparent:

(1) The state of ionization and excitation is higher in RR Telescopii. This is indicated by the relative intensity Fe III/Fe II, the strength of other doubly ionized elements C III, N III, O III, S III and A III in RR Tel, and the presence of lines of high E.P. due to He I, He II, N III and N IV. RR Tel has begun to show a transition from the "Eta Carinae" to the "nebular" stage of a slow nova.

(2) The intensity gradient along the hydrogen series is considerably slower in RR Tel than in Eta Carinae, and moreover there is some evidence for a continuum at the head of the Paschen series. Thus the electron temperature may be considered to be higher in RR Tel.

(3) The most outstanding difference between the two stars undoubtedly concerns the oxygen lines. In Eta Carinae no forbidden lines due to oxygen have certainly been detected and the only evidence for its presence lies in the detection of O I 8446. In RR Tel neutral, ionized and doubly ionized oxygen are all well represented, and in 1951 the permitted line 8446 was the strongest line in the infra-red.

Taken by itself, the strength of O I 8446 is a very poor indication of oxygen abundance because it depends not only on the density of O I atoms in the ground state but also on the intensity of the exciting Ly β and on any Doppler shift between Ly β and the absorbing oxygen atoms. The strength of the [O I] lines similarly depends not only on the density of O I atoms in the ground state, but also on the frequency of electron impact raising the O I atoms to the ^{1}D state.

TABLE VII

					Observed intensity		
					Eta Carinae	RR Telescopii	
Ion	I.P.	λ	e	m		1951	1952
[O I]	13·6	6300	$6{\cdot}3\times10^{-6}$	·0026	...		7
[O II]	35·0	7319	0·23	·0088	...	4	
[O III]	54·7	4363	2·8	...	...	2*N*	35
[O III]	54·7	5007	$5{\cdot}7\times10^{-5}$	·016	...	1	50
[N II]	29·5	5755	2·2	...	30		12
[N II]	29·5	6584	$1{\cdot}4\times10^{-5}$	·0022	40 :		6 :
[Ne III]	63·3	3868	$4{\cdot}8\times10^{-4}$	·21	4	1*N*	30
[S II]	23·3	4068	$3{\cdot}9\times10^{-6}$	·32	12	2	3
[S III]	34·9	6312	5·6	...	10		9

Taken together, the dual argument of the observed strength in RR Tel of O I 8446 (despite the higher state of ionization) and of the forbidden lines due to [O I], [O II] and [O III], gives very strong support to the idea that oxygen abundance must be considerably higher in RR Tel than in Eta Carinae. The mechanism for the production of 8446 depends on radiative processes, that for the forbidden lines on collision processes. The two stars are strikingly similar in the appearance of their forbidden lines, such as [N II], [S II] and [Fe II]. Oxygen alone stands out as a glaring exception and there seems to be little escape from the conclusion that a difference in relative abundance offers the most reasonable explanation of the differences in intensity.

It may further be pointed out that in the short-lived "Eta Carinae" stage of Nova Herculis in 1935 April, [O I] 6300 was exceedingly prominent and [O III] also began to appear.* In the similar stage of development of Nova Pictoris, [O III] was also prominent.†

In Table VII the magnetic dipole (*m*) and electric quadrupole (*e*) probabilities as calculated by Pasternack‡ are compared with the observed intensities of various forbidden lines due to O, N, Ne and S in the two stars. In this comparison it should be remembered that the limiting intensity recorded is lower for Eta Carinae that for RR Tel. This table emphasizes the extraordinary absence of forbidden oxygen lines in Eta Carinae.

Radcliffe Observatory,
Pretoria :
1952 *October* 30.

---

* F. J. M. Stratton, *M.N.*, **96,** 373, 1936. D. B. McLaughlin, *Publ. Mich. Obs.*, **6,** 196–198, 1937.

† H. Spencer Jones, *Cape Annals*, **10,** Pt. 9, p. 127, Table XLII, 1931.

‡ S. Pasternack, *Ap. J.*, **29,** 129, 1940.