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A REVISED SPECTRAL CLASSIFICATION SYSTEM AND A NEW CATALOGUE FOR GALACTIC WOLF-RAYET STARS

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Summary

A revised classification system for Wolf–Rayet (WR) stars is presented. Spectrograms of 41 southern stars are reproduced.

A search of 436 square degrees along the southern part of the galactic plane yields 13 WR stars not included in Roberts's catalogue. 15 stars in Roberts's catalogue have been found not to be WR stars. The total number known now stands at 127. A new catalogue is given including reliable spectral classification on the new system for 107 stars and photoelectric v-magnitudes, on a system similar to that defined by Westerlund, for 106 stars.

1. *Introduction.* In 1962 Roberts catalogued the 124 WR stars known or suspected at that time. It was immediately obvious that consistent spectral classification and photoelectric photometry of these stars was urgently needed, together with a further search for these rare objects.

The classification system for WR stars adopted by the IAU (Beals 1938) now appears inadequate. The problem arises mainly from the importance, in the Beals system, of the ratio He I λ 5875/He II λ 5412. As pointed out by H. J. Smith (1955, henceforward referred to as HJS) the strengths of the He I lines may differ greatly in otherwise identical spectra. This is illustrated by a comparison of the spectra of HD 92740 and HD 93131 (Plate 1); these are identical except that, in the latter, He I λ 5875 is hardly visible.

A revised classification system is defined by Hiltner & Schild (1966). A somewhat different system is suggested here (Section 2). The differences between the two new systems are discussed in Section 2.6. Spectra in Hiltner & Schild's atlas have been reclassified on the present system so that we now have consistent classification of all the brighter WR stars in both hemispheres.

Since the publication of Roberts's catalogue, two of the stars listed have been found not to be WR stars (Bond & Bidelman 1966), seven new WR stars have been identified (Pik Sin Thé 1963, 1965, Stephenson 1966), and one star, reported by Iriarte & Chavira (1956) has been confirmed (Stephenson, *loc. cit.*). In the present programme, we have deleted fifteen stars from Roberts's catalogue (see Section 3.2) and added thirteen (see Section 3.1). Of the latter stars, twelve were not previously known, and one, reported previously by Cannon & May (1938), has been confirmed. Due to faintness of the spectra and crowding of the fields, three of the newly found WR stars are only tentative. The final catalogue is given in Section 3.3.

Narrow-band photometry of northern WR stars has been performed by Westerlund (1966). The author has carried out photometry of southern WR stars with a similar filter system. Details will be published in a forthcoming paper, but v-magnitudes are included in the catalogue.

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2. *The spectra and the classification system*

2.1 *The observations.* The spectra used for classification of the WR stars were obtained with either of two spectrographs—the Zeiss two-prism spectrograph at the Cassegrain focus of the 50-inch reflector, or the Nebular spectrograph at the Newtonian focus of the 74-inch reflector—both at Mount Stromlo Observatory. The Zeiss spectrograph has been fully described by Gollnow (1963); it was used with the NA arrangement yielding a dispersion of 94 Å/mm at Hγ. The Nebular spectrograph is similar to the prime focus spectrograph of the 200-inch reflector at Mount Palomar (Bowen 1952); it has been used with the F/1·2 camera and the 400 line grating, yielding dispersion of 280 Å/mm in the first order visual, and of 140 Å/mm in the second order blue. Eastman Kodak IIa-O and IIa-D emulsions were used throughout. Spectra of a few stars were obtained with all combinations to assure uniformity of the classification. Plates 1 to 4 show spectra of 41 different stars.

2.2 *Classification of WN spectra.* We use a classification of WN spectra based on a judgement of which ionisation state of nitrogen predominates in the spectrum. Only for differentiation between the classes WN7 and WN8 is a criterion dependent on helium employed. Since it is often the case that only blue spectra are available, lines with wavelengths below λ 5000 are preferred. The lines used to represent each ion are:

N III λ 4634–λ 4641 (blend), λ 5314
N IV λ 3479–λ 3484 (blend), λ 4058
N V λ 4603, λ 4619, λ 4933–λ 4944 (blend).

These are the only strong lines which do not suffer serious blending with helium lines. The N V lines, λ 4603 and λ 4619, are affected by blending with N III λ 4634–41 and by violet absorption edges; however, they are the most prominent lines of N V which occur in the spectra and, together with λ 4940, provide the best representation of this ion.

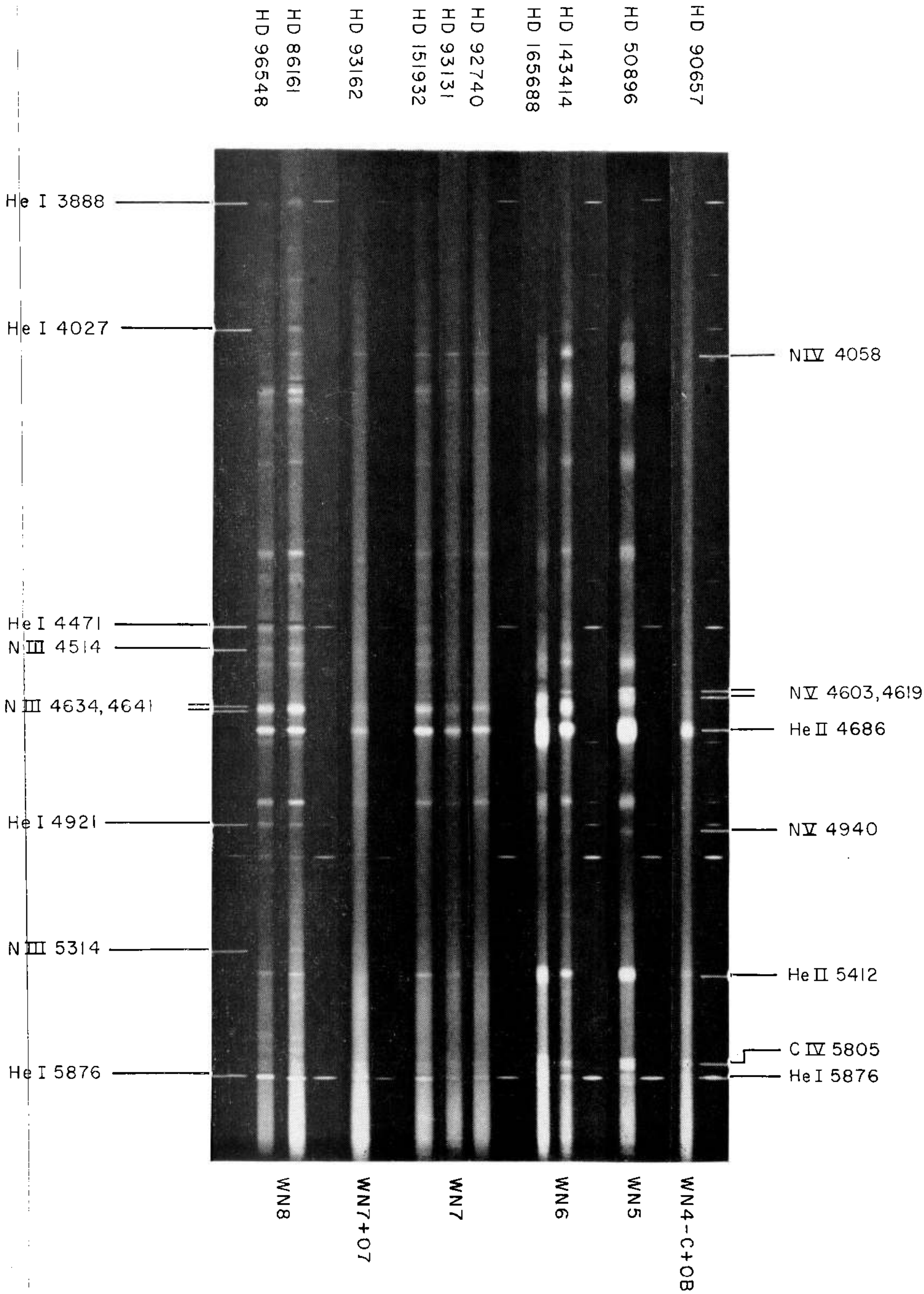
The criteria are summarized in Table I. The classes have been defined in order to obtain the best possible agreement with the classifications assigned to the spectra of southern stars by HJS. However, HJS included the strength and width of the lines amongst the characteristics of the class WN5; this has the consequence that he may have classified a spectrum as WN5 which, by relative line strengths alone, is classified as WN6 here.

TABLE I

Classification of WN spectra

Class		Criteria
WN8	N III ≫ N IV	He I strong with violet absorption edges N III λ 4640 ≈ He II λ 4686, N III λ 5314 present
WN7	N III ≫ N IV	He I weak N III λ 4640 < He II λ 4686
WN6	N III ≈ N IV	N V present but weak N III λλ 4634–41 band present
WN5	N III ≈ N IV ≈ N V	N III λλ 4634–41 band present
WN4·5	N IV > N V	N III very weak or absent
WN4	N IV ≈ N V	N III very weak or absent
WN3	N IV ≪ N V	N III absent

PLATE I



Spectra of some southern WN stars, obtained with the Zeiss two-prism spectrograph. The comparison spectrum is helium.

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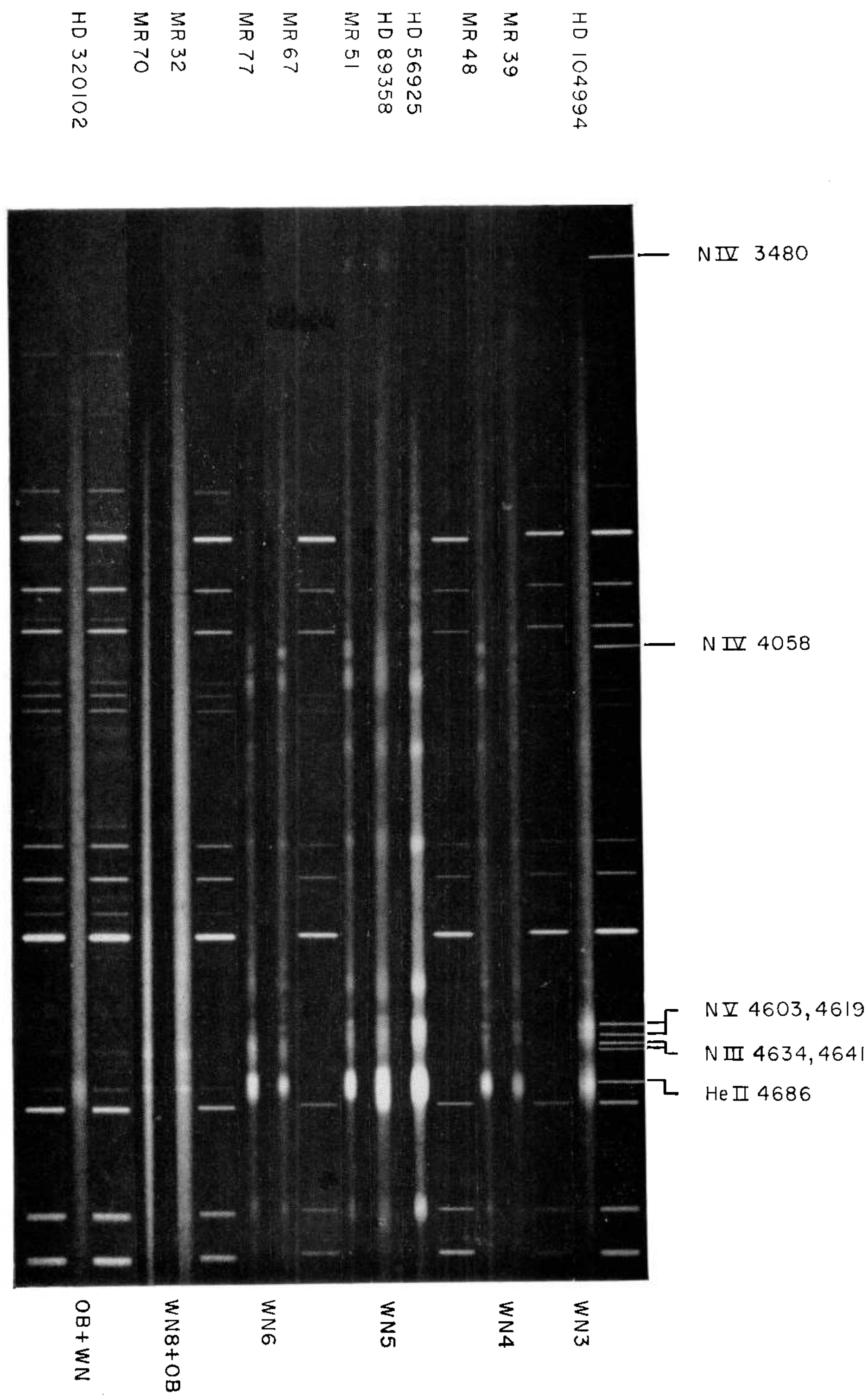
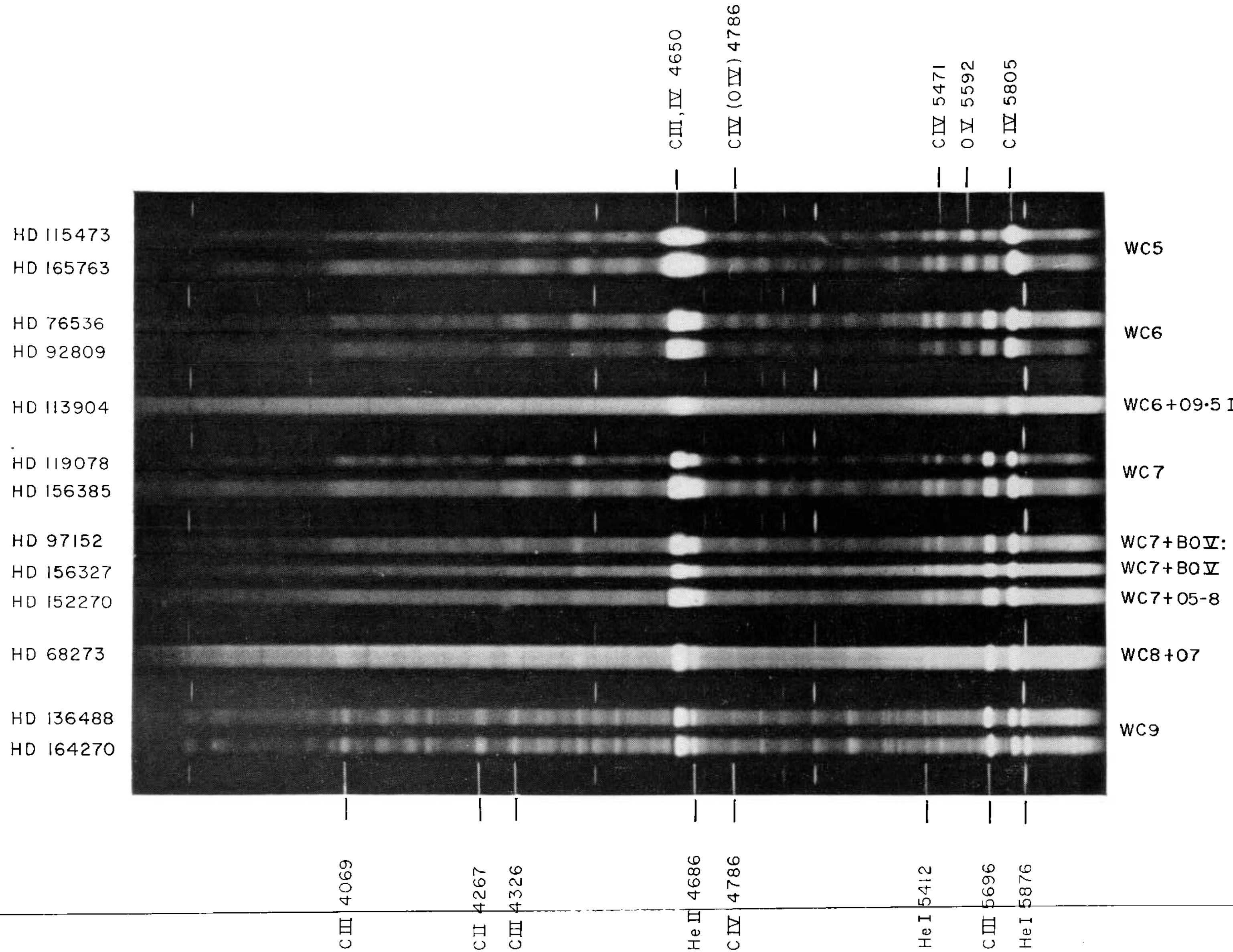
PLATE 2

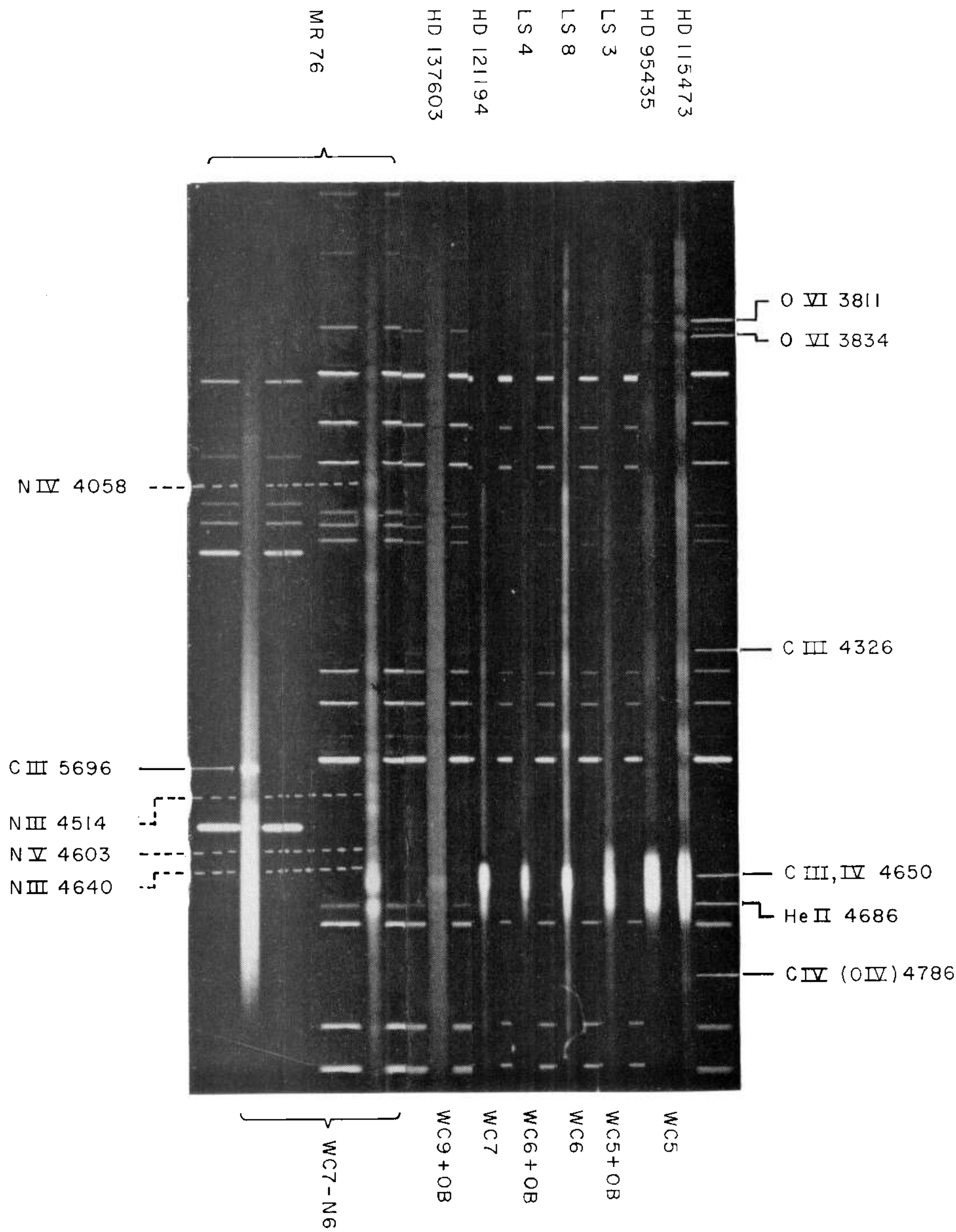


Spectra of some southern WN stars obtained with the Nebular grating spectrograph. The comparison spectrum is helium.

PLATE 3



Spectra of some southern WC stars obtained with the Zeiss two-prism spectrograph. The comparison spectrum is helium.



Spectra of some southern WC stars obtained with the Nebular grating spectrograph. The comparison is helium.

2.3 *Classification of WC spectra.* The classification of WC spectra presents relatively few problems. The three classes defined by Beals are, in general, well marked and easily separated. One refinement has been found necessary. Stars previously classified as WC6 are found to constitute two quite distinct classes which we call WC5 and WC6. They are defined by the Beals criteria for WC6, but with the modified values for the ratios of C III λ 5696/O V λ 5592 and for the line widths given in Table II. Clear distinction between these classes is important because we have found that, of these two classes, only WC5 stars occur in the Large Magellanic Cloud (this will be demonstrated and discussed in a later paper).

To obtain uniformity with the classification system defined by Hiltner & Schild, the class WC8, defined by Beals, is now denoted as WC9, and the spectra intermediate between classes WC7 and WC8 in the Beals system are now denoted as WC8. The spectra in the new class WC8 are mainly characterized by the ratio C III λ 5696/C IV λ 5812 $\approx$ 1·0. These changes are summarized in Table II.

TABLE II

Classification of WC spectra

New notation	C III λ 5696 / Q V λ 5592	C III λ 5696 / C IV λ 5805	Width of C III, IV λ 4650	Beals notation
WC5	< 1·0	0·3	85 Å	WC6
WC6	> 1·0	0·3	45 Å	WC6
WC7	8·0	0·7	35 Å	WC7
WC8		1·0		WC7–8
WC9		3·0	10 Å	WC8

2.4 *Classification of binaries.* A spectrum is classified as composite, WR+OB, when an absorption spectrum is present together with the WR emission spectrum. In such cases, the strengths of the emission lines with respect to the continuum are always significantly less than for other stars of the same WR type. This is consistent with the hypothesis (Wilson 1940) that the composite spectrum is due to the presence of a binary system. It is found that, for some stars, the strengths of the emission lines are lower than normal, despite the fact that no absorption spectrum is observed. It is assumed here that these stars are also binaries, and that the absorption spectrum of the companion is masked by the emission features of the WR spectrum.

When a strong continuum is present with only weak lines of He II λ 4686 and possibly λ 4512 visible in emission, the spectrum is denoted as OB+WN, indicating that the OB spectrum is dominant and that it has not been possible to decide the subclass of the WN spectrum. That is, it is supposed that nitrogen lines are present but, being weaker than the helium lines, are not detectable against the strong continuum. The spectrum of HD 97950 is typical of this class; this object (Sher 1964) is a very compact cluster, of which the WR star is a member. The observed spectrum is integrated over the cluster; the contribution of the WR star to the total brightness is small and only the strongest emission lines remain visible.

The spectrum of the star HD 6327, illustrated by Hiltner & Schild, appears to be unique. The line He II λ 4686 stands strongly above the continuum as does He II λ 6560, and weaker lines of the Pickering series, λ 5412, λ 4859, λ 4542, λ 4339 and λ 4200, are also discernible; hence, the absence of nitrogen lines may not be explained by lack of contrast with a strong continuum as in the case of the OB + WN spectra discussed above.

2.5 *Intermediate classes.* It is clear from the spectra reproduced in Plates 1 to 4 that it is still difficult to classify some stars uniquely. For this reason, as many spectra as possible have been reproduced here so that future investigators may form their own opinion.

There are two stars illustrated which are intermediate between the two sequences—MR 76 (Plate 4) which has all the strong lines of class WN6 and of class WC7, and HD 90657 (Plate 1) which is described by HJS and which shows C IV λ 4650 in comparable intensity to N V λ 4603, λ 4619.

We also note that the stars MR 32 and MR 70 (Plate 2), classified as WN8 + OB, may be Of stars.

2.6 *Comparison with the classification system of Hiltner & Schild.* Classifying the spectra given by Hiltner & Schild (1966) on the present system yields the relationship between the subclasses of the WN sequence shown in Table III. The transformation from one system to the other is unique except that within the Hiltner–Schild classes WN5, 5·5, 7 and 8 of the A series the author considers some stars to be binaries and some to be single.

TABLE III

Comparison between the present and the Hiltner–Schild classifications of WN spectra

Present	Hiltner–Schild Sequence A	Hiltner–Schild Sequence B
WN3	WN4–A	
WN4 [+OB]	WN5–A	
WN4·5 [+OB]	WN5·5–A	
WN5		WN5–B
WN5 + OB	WN6–A	
WN6		WN6–B
WN6 + OB	WN6·5–A	
WN7 [+OB]	WN7–A	
WN8 [+OB]	WN8–A	
WN6–C7		WN7–B

The Hiltner–Schild class WN5·5–A has only one known representative in the south (HD 65865) and, prior to that publication, was not recognized as a separate class; it has been incorporated into the present system and called WN4·5.

The differences between the two systems originate from the attitudes adopted towards the spectra of binary stars. The Hiltner-Schild system divides the WN spectra into two sequences, A and B, according to the strengths and width of the emission lines with only an implicit recognition that this is sometimes due to the presence of binary systems. In the present study we have made a basic distinction between spectra of stars believed to be binary and those of stars believed to be single. The spectra of binaries are given the classification WR + OB, explicitly indicating their binary nature, and the WR spectrum is classified according to the relative strengths of the emission lines, as for the spectrum of a single star. Amongst stars of the carbon sequence, the spectra of the binaries differ from those of the single stars only in the level of the continuum. However, in some subclasses of the nitrogen sequence (e.g. WN5), the spectra of the binary stars Hiltner–Schild class WN6–A) show consistently narrower lines than do those of the single stars (Hiltner–Schild class WN5–B), indicating that the WR stars in the binary systems may differ somewhat from single stars assigned to the same WR class.

The Hiltner–Schild class WN7–B contains only the star HD 62910 which, in this study, is classified as WN6–C7. The latter classification depends on the strength and redward extension of the line at λ 4640, and the strength of the line at λ 5805; these features are attributed to contributions from C IV λ 4650 and from C IV λ 5801 and λ 5812, respectively.

Subclasses WC7, WC8 and WC9 are the same in the two systems. The division of WC5 and WC6 spectra seems, in principle, to be the same. However, of the three spectra given by Hiltner & Schild as examples of class WC5, one is under-exposed and the other two are probably of binary systems. (HD 63099 is definitely a binary (HJS), and the spectrum of HD 195177 shows low contrast between the emission lines and the continuum, implying that it is also a binary.) Thus, the appearance of the three spectra is dominated by the absence of weak emission lines either because of under-exposure or because the lines are drowned in the continuum. From the spectra given by Hiltner & Schild, the author classifies HD 195177 as WC5+OB, HD 63099 as WC6+O7 : 1 (the classification of the companion is from HJS), and Stephenson No. 5 (1966) ($21^h 46^m.5$, $+50° 14'$, 1900) as WC6.

The star HD 193793, classified as WC6 pec by Hiltner & Schild, is called WC7 pec+OB by the author.

2.7 *Photometric classification.* In a later paper, it will be shown that WR stars may be effectively classified by means of photometric criteria that depend essentially on measured strengths of selected emission lines. Classifications derived in this way are included in the catalogue and enclosed in brackets. Classifications

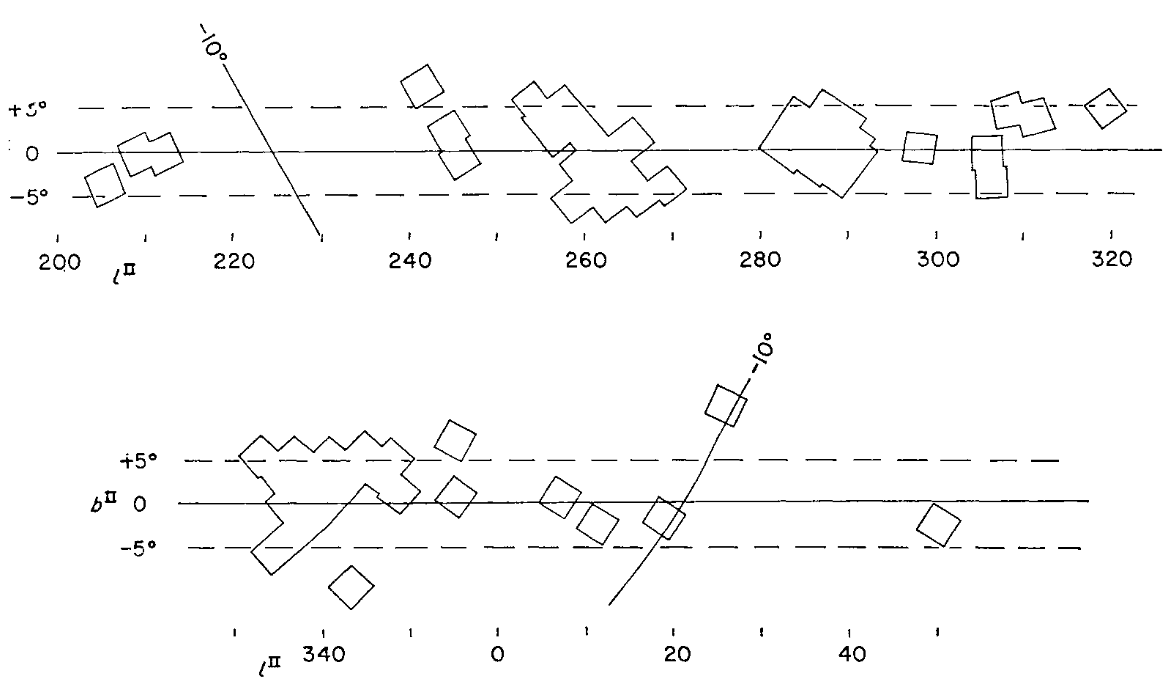


FIG. 1. *The area searched for Wolf–Rayet stars.*

made by Westerlund (1966) on the basis of photometric criteria are also enclosed in brackets.

3. *The search for southern Wolf–Rayet stars; the Catalogue*

3.1 *The observations.* The material used in this programme consists of objective prism plates taken with the 20/26-inch Schmidt telescope of the Uppsala Southern Station. The dispersion is 480 Å/mm at Hγ. All plates were taken on Eastman Kodak IIa-O emulsion with no filter.

39 plates taken by the Uppsala observers, Drs C. Roslund and G. Lynga for the Uppsala Observatory were kindly made available by Dr Roslund. In addition, Dr Roslund obtained 33 plates at the special request of the author. These were centred on positions of WR stars which were included in Roberts' catalogue but

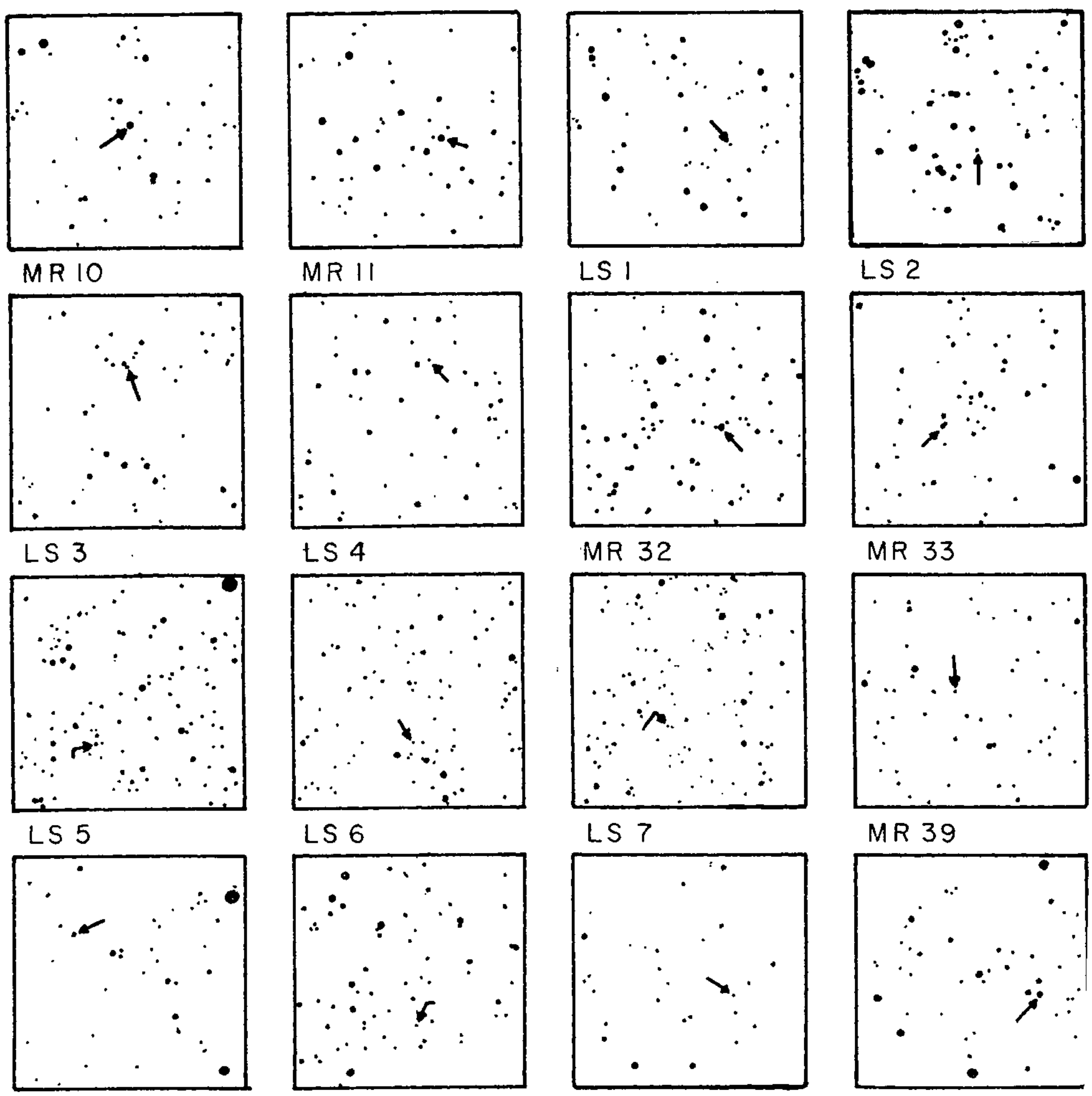


FIG. 2. *Finding charts for some galactic Wolf–Rayet stars. North is at the top, east is to the left. The squares are* 10 *min. arc on a side. The charts are made from* 103a–D *plates exposed behind a Schott GG* 14 *filter. The stars are identified by their MR, LS or ST numbers, as given in the catalogue, Table V.*

which were not adequately identified in the literature. Most plates were exposed for 20 min. with the spectra widened 0·2 mm. Five plates were exposed for 30 min. with the spectra widened to only 0·15 mm. Each plate covers a field of $3^\circ{\cdot}7 \times 3^\circ{\cdot}7$. The area observed is shown in Fig. 1 and covers 436 square degrees, representing 25 per cent of the area that is within the limits $|b^{\mathrm{II}}| \leqslant 5^\circ$ and $\delta \leqslant -10^\circ$.

Experience has shown that, on a 20 min. plate, emission lines can be detected for a WR star as faint as $v = 15$ mag. All WR stars brighter than $v = 14$ mag have probably been found in the area searched. O and B stars on the same plates can be identified to only about 12th magnitude. The five 30-min. plates should reach all WR stars brighter than $v = 14{\cdot}7$ mag.

Fig. 2 gives finding charts for the twelve stars found in this programme and for some others for which adequate charts have not been previously published.

3.2 *Stars deleted from the Catalogue.* If a star listed by Roberts was not detected on an objective prism plate of the area, it was deleted from the catalogue. The only exception was Roberts No. 45, which was reported by Lindsay (1954) to have spectral type WC7 and $m_{\mathrm{pg}} = 14{\cdot}7$ mag. This star is confirmed by Pik Sin Thé (1962) from observation of emission on red objective prism plates; he gives $m_v = 14{\cdot}2$ mag. However, no emission appears on our 30 min. blue objective prism plate. The WR nature of this object is considered suspect.

The stars that have been deleted are listed in Table IV, which gives in successive columns:

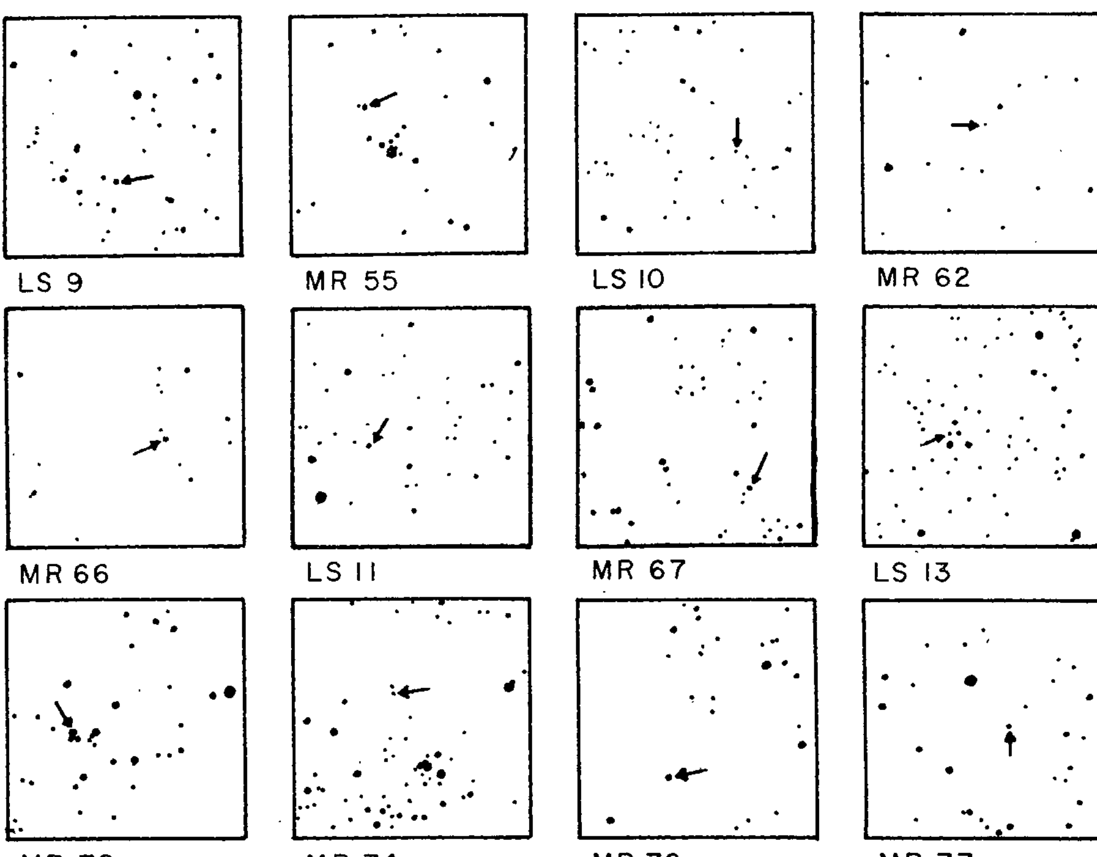


FIG. 2 (*continued*)

1. Number of the star in Roberts's catalogue, referred to below as the MR number;
2. HD number;

3, 4. Equatorial co-ordinates for equinox 1900;

5. Photographic magnitude, m_{pg};
6. Spectral type from the present data;
7. Reference to the discovery (numbers) and spectral class (letters).

Photographic magnitudes and references to the discovery are those quoted by Roberts.

TABLE IV

Stars deleted from Roberts' Catalogue of WR stars

MR	HD	R.A.	(1900)		Dec	m_{pg}	Sp	Ref.
8		07	39·2	−29	04		Be?	(1), (d)
14		08	45·4	−45	43		Be??	(1), (e)
18		09	50·0	−54	24		B9e?	(1), (b)
22		10	18·0	−57	36		Be??	(1), (e)
24	91421	10	28·2	−57	43	9·1	09	(2), (a)
27	93128	10	40·1	−59	02	8·5	05f var	(3), (6), (a)
35		11	04·4	−60	11		Be?	(1), (d)
37		11	10·3	−60	46		Be?	(1), (d)
41		12	06·0	−61	56		Be?	(1), (d)
59		16	13·3	−36	24		Be?	(1), (d)
61		16	19·5	−51	12		B9e?	(1), (c)
63		16	45·1	−25	49		Neb	(4), (b)
78	163758	17	52·7	−36	00	7·1	07f	(5), (a)
81		17	56·7	−18	05		Be??	(1), (e)
92		19	12·8	−11	16		Neb	(7), (c)

References

(1) Henize, K. G., 1961, Private communication to Roberts.
(2) Hoffleit, D., 1956. *Astrophys. J.*, **124**, 61.
(3) Payne, C. H., 1927. *Harv. Black Rock Forest Bull.*, **846**, 10.
(4) Mayall, M. W., 1951. *Harv. Black Rock Forest Bull.*, **920**, 32.
(5) Fleming, W. P., 1912. *Harv. Ann.*, **56**, 165.
(6) Fleming, W. P., 1898. *Harv. Circ.*, 32.
(7) Merrill, P. W. & Burwell, C. G., 1950. *Astrophys. J.*, **112**, 72.
(a) Classified from Zeiss spectrograms.
(b) Classified from a spectrum obtained with the Nebular Spectrograph.
(c) Classified from a blue objective prism spectrum.
(d) Only a faint continuous spectrum on our blue objective prism plate.
(e) No spectrum visible on our blue objective prism plate.

Of the 15 stars in this Table, one is an O9 star, two are Of stars, and two are nebulae. The remaining ten were tentatively classified as WR stars by Henize on the grounds of perceptibly widened Hα emission. Dr Henize has kindly allowed the use of his charts. From these, the stars responsible for the Hα emission have been re-identified and studied on the blue objective prism plates. No emission spectra have been found at the positions of these stars. Since Henize's plates reach an 11th magnitude AO star, they would probably show the emission lines of a WR star as faint as 14th magnitude. Unless such a star is very reddened, its emission lines should also appear on our objective prism plates. Thus, it seems that none of these stars has strong emission in the blue; they are probably all of type Be.

3.3 *The Catalogue.* The catalogue of galactic WR stars is given in Table V, which gives in successive columns:

1. MR or Stephenson (ST) number. When the star has no previous number a running number has been assigned with the prefix LS. An asterisk (*) indicates a comment at the end of the catalogue;
2. HD, CD or BD number;

3, 4. Equatorial co-ordinates for equinox 1900;

5, 6. Galactic co-ordinates in the new system;

7. Spectral type as defined in Section 2. Classifications derived from photometric criteria are given in brackets;
8. v-magnitude determined by Westerlund (1966) or by the author (to be presented in a later paper). The two systems differ slightly in the zero point of the v-magnitude scale; accordingly, 0·07 mag has been added to each of the magnitudes given by Westerlund. When a v-magnitude is not available, this column contains m_v, as given by Roberts, in round brackets, ( ), m_{pg}, as given by Roberts or by Stephenson (1966), in square brackets, [ ], or an eye estimate of the magnitude, made from a visual photographic plate, in curly brackets, { };
9. References to the source of the spectral classification (numbers) and to the discovery (letters). For binaries, the classification of the companion is that quoted by Roberts, HJS or Westerlund (1966), and the numbers in the reference column refer to those papers. References to the discovery of WR stars in Roberts' catalogue are given by him and are not repeated here. References are given to the original papers only for stars discovered since 1961.

TABLE V

Catalogue of galactic WR stars

MR	HD	R.A. (1900)		Dec.		l^{II}	b^{II}	Sp type	v	Ref.
1	4004	00	37·5	+64	14	122·1	+1·9	WN5	10·54	(2)
2	6327	00	59·2	+59	53	124·6	−2·4	W(He)	11·43	(2)
3	9974	01	32·4	+57	39	129·2	−4·1	WN3	10·79	(2)
4	16523	02	33·9	+56	18	137·6	−3·0	WC6	10·61	(2)
5	17638	02	44·8	+56	31	138·9	−2·2	WC6	11·12	(2)
6	50896	06	50·0	−23	48	234·8	−10·1	WN5	6·94	(1), (2), (3)
7	56925	07	13·9	−13	03	227·8	−0·1	WN5	11·74	(1), (2)
9	62910	07	41·1	−31	41	247·1	−3·8	WN6–C7	10·56	(2), (3)
10	63099	07	42·0	−34	05	249·3	−4·8	WC6+07 : I	11·04	(2), (3)
11	65865	07	55·7	−28	28	246·0	+0·6	WN4·5	11·08	(2), (3)
12	68273	08	06·5	−47	03	262·8	−7·7	WC8+07	1·74	(1), (2), (3)
13	CD−45° 4482	08	41·4	−45	37	265·2	−2·0	(WN6)	11·06	
15		08	46·4	−44	48	265·1	−0·8	WC6 : (+OB)	13·83	(8), (13)
16	76536	08	51·6	−47	13	267·6	−1·6	WC6	9·42	(1), (3)
17	79573	09	09·8	−49	42	271·4	−1·1	WC6	11·73	(3)
19	86161	09	51·6	−57	15	281·1	−2·6	WN8	8·43	(1), (3)
LS1		09	59·2	−61	26	284·4	−5·4	WN	{15}	(8), (a)
LS2		10	00·8	−60	13	283·8	−4·2	WN	{13·5}	(8), (a)
20	88500	10	07·2	−60	09	284·4	−3·7	WC7(+OB)	11·11	(3)
21	89358	10	13·5	−57	25	283·6	−1·0	WN5	11·20	(1)

TABLE V (*continued*)

MR	HD	R.A. (1900)		Dec.		l^{II}	b^{II}	Sp type	v	Ref.
LS3		10	14·7	−57	46	283·9	−1·2	WC5+OB	13·85	(1), (a)
23	90657	10	22·9	−58	08	285·0	−0·9	WN4–C+OB	9·80	(1), (3)
25	92740	10	37·4	−59	09	287·2	−0·8	WN7	6·44	(1), (3)
26	92809	10	37·8	−58	15	286·8	0·0	WC6	9·71	(1), (3)
28	93131	10	40·1	−59	36	287·7	+1·1	WN7	6·49	(1), (3)
29	93162	10	40·3	−59	12	287·5	−0·7	WN7+07	8·17	(1), (3)
LS4		10	40·9	−58	17	287·2	+0·1	WC6+OB	14·73	(1), (a)
30	94305	10	47·9	−61	46	289·5	−2·6	WC6+OB	12·73	(1)
31	94546	10	49·7	−58	59	288·5	0·0	WN4+BOn ::	10·69	(1), (3), (
32		10	54·7	−60	39	289·8	−1·2	WN8+OB	10·88	(1)
33	95435	10	55·8	−57	17	288·5	+1·9	WC5	12·34	(1)
LS5		10	56·3	−60	54	290·1	−1·4	WR :	{14}	(8), (a)
LS6		10	58·5	−58	54	289·5	+0·5	WR	{13·5}	(8), (a)
34	96548	11	02·3	−64	58	292·3	−4·8	WN8	7·85	(1), (3)
*LS7		11	03·9	−60	55	290·9	−1·0	WC6 : +OB :	14	(8), (a)
36	97152	11	05·8	−60	26	290·9	−0·5	WC7+BOV ::	8·25	(1), (3)
38	97950	11	10·8	−60	43	291·6	−0·5	OB+WN	(8·8)	(8), (3)
39		11	12·5	−58	53	291·2	+1·3	WN4	12·96	(1)
40	104994	12	00·2	−61	29	297·6	+0·4	WN3	10·96	(1), (3)
42		12	37·9	−62	32	302·1	−0·2	WN6	11·09	(1)
43	113904	13	01·7	−64	46	304·7	−2·5	WC6+09·5I	5·69	(1), (3)
44		13	11·5	−61	54	306·0	+0·3	(WC6)	12·49	(15)
45		13	11·9	−61	57	306·0	+0·2	WC7 :	[> 14·7]	(15)
46	115473	13	12·2	−57	37	306·5	+4·5	WC5	9·98	(1), (3)
47	117297	13	24·2	−61	34	307·5	+0·4	WC7	11·06	(3)
48		13	25·8	−64	30	307·3	−2·5	WN4	12·99	(1)
LS8		13	26·8	−63	36	307·5	−1·6	WC6	13·97	(1), (a)
49	117688	13	26·8	−61	48	307·8	+0·2	WN6–C	10·87	(3)
50	119078	13	35·9	−66	54	307·9	−5·0	WC7	10·11	(1), (3)
51		13	41·8	−65	12	308·8	−3·5	WN5	13·08	(1)
52	121194	13	48·8	−60	40	310·6	+0·8	WC7	13·25	(1)
LS9		13	58·3	−64	07	310·8	−2·9	(WC9 :)	13·68	(a)
53		14	05·3	−64	58	311·3	−3·9	WN6	12·56	(1)
54	134877	15	07·1	−59	28	320·1	−1·8	WN8	11·71	(1)
55		15	07·7	−58	40	320·6	−1·2	WN6	12·21	(1)
56	136488	15	15·8	−62	19	319·5	−4·8	WC9	9·43	(1), (3)
57	137603	15	21·8	−58	14	322·3	−1·8	WC9+OB	10·15	(1), (3)
LS10		15	22·1	−61	57	320·3	−4·9	WR :	14·57	(8), (a)
58	143414	15	55·0	−62	24	323·1	−7·6	WN6	10·22	(1), (3)
60	147419	16	16·8	−51	18	332·8	−1·5	WN6	11·42	(3)
*62		16	33·9	−47	49	337·3	−1·1	WC9+OB	13·16	(1)
64	151932	16	45·3	−41	41	343·2	+1·4	WN7	6·61	(1), (2),
65	152270	16	47·3	−41	40	343·5	+1·2	WC7+05–8	6·95	(1), (2),
66		16	55·3	−45	50	341·1	−2·6	(WC9)	12·75	
LS11		16	56·8	−45	05	341·9	−2·4	WN7	12·42	(1), (a)
67		17	03·6	−46	28	341·5	−4·1	(WN6)	12·79	
LS12		17	04·4	−39	45	347·1	−0·2	WN6	13·55	(1), (b)
LS13		17	10·2	−45	25	343·0	−4·4	(WC9) :	15·1	(a)
68	156327	17	11·8	−34	18	352·2	+1·8	WC7+BOV	9·73	(1), (2)
69	156385	17	12·1	−45	32	343·2	−4·8	WC7	7·45	(1), (2)

TABLE V (*continued*)

IR	HD	R.A. (1900)		Dec.		l^{II}	b^{II}	Sp type	v	Ref.
70		17	12·2	−38	57	352·6	+2·0	WN8+OB	11·64	(1)
71	157451	17	18·2	−43	24	345·5	−4·4	WC9	10·60	(3)
72	157504	17	18·5	−34	06	353·2	+0·8	WC6(+OB)	11·46	(3)
*73	158860	17	26·5	−33	33	354·6	−0·2	(WN6)	12·27	(3)
74		17	29·7	−33	22	355·1	−0·7	(WN5) ::	14·10	
75	320102	17	30·3	−33	58	354·7	−1·1	OB+WN	11·15	(1)
76		17	30·6	−33	24	355·2	−0·9	WC7–N6	12·51	(1)
77		17	35·6	−32	30	356·5	−1·3	WN6	13·44	(1)
79	164270	17	55·2	−32	43	358·5	−4·9	WC9	9·01	(1), (2), (3)
80		17	56·0	−23	38	6·4	−0·5	(WC9)	13·54	(13)
82		17	58·9	−21	12	8·9	+0·1	WC9	12·36	(7)
LS14		17	59·4	−23	09	7·3	−1·0	OB+WN	10·16	(8), (c)
83	165688	18	02·1	−19	25	10·8	+0·4	WN6	10·23	(1), (2), (3)
84	165763	18	02·5	−21	16	9·2	−0·6	WC5	8·25	(1), (2), (3)
85	168206	18	13·5	−11	40	18·9	+1·8	WC8+BO :	9·43	(2), (17)
86	169010	18	17·5	−13	46	17·5	−0·1	WC5	12·92	(7)
87		18	19·8	−14	42	17·0	−1·0	WN6	12·26	(1), (4)
ST1		18	21·5	−12	26	19·2	−0·3	WN	[14·1]	(e)
88		18	25·7	−06	41	24·7	+1·5	WC7	(13·34)	(4)
LS15		18	33·7	−10	12	22·5	−1·9	WC9	12·5	(2), (d)
89		18	36·0	−04	33	27·8	+0·2	WN7	(11·94)	(2)
90		18	39·2	−03	54	28·7	−0·2	WC9	(11·94)	(2)
91	177230	18	58·7	−04	28	30·5	−4·8	WN8	(11·1)	(2)
93		19	24·0	+19	23	54·5	+1·0	WC5	13·48	(4)
ST2		19	35·9	+26	20	61·9	+2·6	WC :	[14·0]	(e)
94	186943	19	42·2	+28	01	64·0	+1·7	WN4+B	10·36	(2), (16)
95	187282	19	44·1	+17	57	55·6	−3·8	WN4	10·56	(2), (17)
96		19	44·3	+30	12	66·2	+2·4	WC :	[13·4]	(12)
LS16		19	55·2	+31	11	68·2	+1·0	WN8 :	[13·7]	(e), (f)
97		19	56·4	+32	59	69·9	+1·7	WN7	12·30	(4)
98	190002	19	57·8	+32	18	69·5	+1·1	WC7	11·55	(4)
99	190918	20	02·2	+35	31	72·7	+2·1	WN4·5+ O9·5Ia	7·48	(2), (16)
100	191765	20	06·5	+35	53	73·4	+1·6	WN6	8·31	(2)
101	192103	20	08·1	+35	54	73·6	+1·3	WC8(+OB)	8·51	(2), (16)
102	192163	20	08·4	+38	03	75·5	+2·4	WN6	7·73	(2)
103	192641	20	10·8	+36	21	74·3	+1·1	WC7+Be	8·18	(2), (16)
104	193077	20	13·3	+37	07	75·2	+1·1	WN5(+OB)	8·21	(2), (16)
105	228766	20	13·8	+37	00	75·2	+1·0	WN7+O	9·33	(11)
106	193576	20	15·8	+38	25	76·6	+1·4	WN5+O6	8·27	(2), (16)
107	193793	20	17·1	+43	32	80·9	+4·2	WC7p+O5	7·19	(2), (16)
108	193928	20	17·8	+36	36	75·3	+0·1	WN6+OB	10·15	(2), (18)
ST3		20	17·9	+37	04	75·8	+0·1	WC	[15·2]	(e)
109	195177	20	24·7	+38	17	77·5	0·0	WC5(+OB)	12·32	(2), (16)
110		20	28·5	+40	55	80·0	+0·9	WC5	[15·5]	(6)
111		20	28·5	+40	28	79·7	+0·7	WN7 :	[14·0]	(6)
112	BD+40° 4243	20	32·3	+41	00	80·6	+0·4	WC5	[15·5]	(6)
113	197406	20	38·4	+52	14	90·1	+6·5	WN7	10·50	(2)
ST4		21	03·9	+48	01	89·5	+0·6	WN	[15·1]	(e)
ST5		21	46·5	+50	14	96·1	−2·5	WC6 :	[13·5]	(2), (e)
114		22	06·1	+57	13	102·6	+1·4	WN5+OB	12·40:	(5)

TABLE V (*continued*)

MR	HD	R.A. (1900)		Dec.		l^{II}	b^{II}	Sp type	v	Ref.
115	211564	22	12·9	+55	07	102·2	−0·9	WN3	11·62:	(2)
116	211853	22	15·0	+55	37	102·8	−0·6	WN6+BO : I :	9·20	(2), (17)
117	213049	22	23·7	+55	46	103·9	−1·2	WC5 :	11·69	(14)
118	214419	22	32·9	+56	23	105·3	−1·3	WN7+07	8·94	(2), (17)
119		22	56·1	+60	24	109·8	+0·9	WN8	11·18	(2)
120	219460	23	10·8	+59	55	111·3	−0·2	WN4·5+BO	10·03	(2), (16)
122		23	38·7	+61	23	115·0	+0·1	WR	11·49	(10)

Notes to the Catalogue

LS7. SF member of a close pair—not resolved on the finding chart (Fig. 2).
MR62. A close pair—not resolved on the finding chart (Fig. 2).
MR73. SF member of a close pair.
LS14. SF member of a pair.
LS15. New position determination by Pik Sin Thé (private communication).

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3.4 *Completeness of the Catalogue.* In the area studied in this programme ($\delta < -10°$) the catalogue appears to be complete to $v = 12$ mag.

If we assume that we have found all of the WR stars in the area searched (25 per cent of the area south of $\delta = -10°$ with $|b^{II}| < 5°$) to a limiting magnitude of $v = 14$ mag, we estimate that the catalogue is now 73 per cent complete in the interval 12–13 mag and 40 per cent complete in the interval 13–14 mag. Fainter than $v = 14$ mag, the present search is very incomplete and so also is the catalogue.

WR stars are potentially powerful spiral tracers. It would be of considerable value to improve the completeness of the catalogue to fainter magnitude limits. Particularly in the south, continuation of the search along the rest of the galactic plane should yield many more stars. In the northern hemisphere, Stephenson (1966) finds a high degree of completeness to 15th magnitude within 2° of the galactic plane. It is probably worth while to extend the limits of the search to

$b^{II} = \pm 5°$ since, of the 11 new WR stars fainter than $v = 13$ mag found in the present search, 5 are between $|b^{II}| = 2°$ and $5°$.

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