

## TWO-DIMENSIONAL SPECTRAL CLASSIFICATIONS FOR O STARS IN THE SOUTHERN MILKY WAY

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### ABSTRACT

Spectral classifications in the two-dimensional system are given for 53 additional O stars in the southern hemisphere. A number of these stars are members of the interesting clusters NGC 3324, Trumpler 14/16, NGC 3603, and NGC 6334, which are discussed in particular. A 4-m H $\alpha$  photograph of the remarkable nebulosities associated with NGC 6334 is reproduced.

### I. INTRODUCTION AND OBSERVATIONS

A two-dimensional spectral classification system for the O stars was introduced by Walborn (1971), and lists of classifications in the new system for stars in both hemispheres were given by Walborn (1972, 1973a). The classification criteria and standard stars that define the system were discussed in those papers. This paper presents classifications for an additional 53 stars in the southern hemisphere, observed during 1974–1980 at the Cerro Tololo Inter-American Observatory\*, bringing to 327 the number of galactic O stars classified by the author in the two-dimensional system.

All but two of the new spectrograms were obtained with the CTIO 1.5-m Cassegrain spectrograph mounted at either the 1.5- or the 4-m telescope. The dispersion is 78 Å mm<sup>-1</sup> and the widening is 1.2 mm; the IIA-O plates were developed in D-76. The spectrograms of Herschel 36 and Feinstein 97 were obtained with a similar dispersion and the direct photographic camera of the 4-m Cassegrain spectrograph.

The new spectral classifications are listed in Table I, along with remarks and references regarding cluster membership, spectral peculiarities, and variability. A superscript "a" in the remarks column denotes a more extended note below.

### II. CLUSTER MEMBERS

#### a) NGC 3324

This small cluster, studied photometrically by Clariá (1977), is located inside a partial ring of structured nebulosity immediately northwest of the giant Carina Nebula (NGC 3372). The spectrum of HD 92206 C (No. 1695 of Stephenson and Sanduleak 1971) is interesting because of the very strong, broad hydrogen lines, possibly similar to those in the Orion Trapezium cluster and indicative of extreme youth. This star may be considered a candidate for a bona fide O-type zero-age-main-sequence object. However, it should be noted that the assumption of normal absolute visual magnitudes (Wal-

born 1973a) for both HD 92206 A and C leads to distance moduli (12.16 and 12.07 mag, respectively, for  $A_V/E_{B-V} = 3.0$ ) consistent with each other and with those of the clusters Trumpler 16/Collinder 228 in the Carina Nebula. The characteristics of the HD 92206 stellar system as well as the surrounding nebulosity are strikingly similar to those of the HDE 319703 system in NGC 6334 discussed below.

#### b) Trumpler 14

Here it is assumed that this compact cluster is located in the Carina Nebula (NGC 3372) at the adopted distance of Trumpler 16/Collinder 228 (see Sec. II c; Walborn 1973b, 1982a). A consequence of this assumption is that the Tr 14 O main-sequence stars are subluminal, possibly on or very near the zero-age main sequence. In particular, CPD - 58°2611 and - 58°2620 have derived absolute visual magnitudes of - 4.4 and - 4.5, respectively, compared with a calibration value of - 5.3 for their spectral types (Walborn 1973a). (The adoption of a value of  $A_V/E_{B-V}$  greater than 3.0 does not affect this result significantly because the average reddening in Tr 14 is only 0.08 mag greater than that in Tr 16.) The unique importance of Trumpler 14 for understanding the early evolution of the most massive stars is emphasized anew. It contains the O3 If\* star HD 93129 A, which is very strongly related to the WN-A objects (Walborn 1973b, 1974; Conti, Niemela, and Walborn 1979). It contains two O3 V((f)) stars which are 1.5 mag fainter than the O3 If\* object, and two O6 V((f)) stars that are 0.6 mag fainter than the O3 V((f))'s.

#### c) Trumpler 16

The addition of the five Tr 16 O stars in Table I to the Tr 16/Cr 228 stars discussed by Walborn (1973b) leads to a combined true distance modulus of 12.26 mag, or 2800 pc, on the assumption of  $A_V/E_{B-V} = 3.0$ . Eta Carinae is a member of Tr 16 (Walborn and Liller 1977; Allen 1979).

#### d) NGC 3603

The luminous, compact multiple system HD 97950 at

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TABLE I. New spectral classifications.

HD/HDE/BD/CPD	Spectrum	Remarks
57236	O8 V((f))	
64315	O6 Vn	NGC 2467
64568	O3 V((f*))	NGC 2467; 1
— 26°2716	O6.5 Ib(f)	
— 47°2963	O4 III(f)	
298429	O8 III((f))	
92206 AB	O6.5 V(n)	NGC 3324; <sup>a</sup>
92206 C	O8.5 Vp	NGC 3324; <sup>a</sup>
93343	O7 V(n)	Trumpler 16; 2?
303311	O5 V	Trumpler 16
303492	O9 Ia	
305532	O6 V((f))	3
305539	O7p	3, <sup>a</sup>
305619	O9.7 Ib	
— 58°2611	O6 V((f))	Trumpler 14; 4
— 59°2628	B0:	Trumpler 16; 2, <sup>a</sup>
— 59°2635	O7 Vnn	Trumpler 16
— 59°2636	O8 V	Trumpler 16
— 59°2641	O5 V	Trumpler 16; 2?
Feinstein 97	O5 Vn	3, 5
95589	O7.5 III(n)((f))	
97848	O8 V	
97950 EF	O4–5 V	NGC 3603; 6
100213	O8.5 Vn	7
102415	O8.5 Vn(p?)	<sup>a</sup>
104565	OC9.7 Ia	8
116282	O8 III(n)((f))	
117490	O9 Vn	
117797	O8 Ib(f)	
123008	ON9.7 Iab	8
— 59°5634	O9.7 Ib	
130298	O6.5 III(n)(f)	
Muzzio 116	O9.5 IV	9
149452	O8 Vn((f))	
150574	ON9 III(n)	8
322417	O6 III(f)	10
155756	O9.5 Iab	
156738	O6.5 III(f)	NGC 6334
319699	O5 V((f))	NGC 6334
319702	O8 III((f))	NGC 6334
319703 A	O7.5 III((f))	NGC 6334
319703 B	O6.5 V((f))	NGC 6334
164019	O9.5 III	
313846	O7: Iafpe	11
Herschel 36	O7.5 V(n)	NGC 6530
— 11°4586	O8 Ib(f)	
168075	O6 V((f))	NGC 6611; <sup>a</sup>
— 13°4927	O7 Ib(f)	NGC 6611?
168941	O9.5 II–III	
169515	O9.7 Ibpe var	12, <sup>a</sup>
172175	O6 I(n)f	<sup>a</sup>
173010	O9.7 Ia	
173783	O9.5 Iab	

Remarks to Table I

1. Walborn (1982a).
2. Secondary spectrum present.
3. In Collinder 228 field but probably more distant.
4. Walborn (1973b).
5. Feinstein, Marraco, and Forte (1976).
6. Walborn (1973c).
7. TU Muscae; Andersen and Grønbech (1975).
8. Walborn (1976).
9. Muzzio and McCarthy (1973) suggested a spectral type of O5 from *UBV* photometry. Their stars 94 and 120, for which the same sug-

gestion was made, are early B stars.  
 10. At northeastern edge of Scorpius OB1 but probably more distant.  
 11. Walborn (1982b).  
 12. RY Scuti; Cowley and Hutchings (1976). Note below.

## Notes to Table I

- 92206 AB. Both stars on slit. However, according to Clariá (1977), the blue magnitude difference is 1 mag, so that B should not affect the spectrogram significantly. He II  $\lambda$  4541 is broader than He I  $\lambda$  4471, in contrast with HD 168075.
- 92206 C. The hydrogen lines are unusually strong and broad, perhaps similar to  $\theta^1$  Orionis C (Morgan and Keenan 1973). This undoubtedly accounts for the classification OB<sup>-</sup> by Stephenson and Sanduleak (1971).
305539. A very strong C III  $\lambda$  4650 absorption feature at this early type gives the spectrum an unusual appearance. Si IV  $\lambda$  4089 absorption is also quite strong. Alternative hypothetical interpretations in terms of known categories could be OC7 V–III, or a composite O5–6 V + O9–B0 III. In any event this spectrum warrants further investigation.
- 59°2628. No He II lines are visible. All He I lines appear double with a separation  $\sim 10$  Å and the redward components slightly stronger. The hydrogen lines also appear stronger redward of the nebular emissions. A less likely alternative interpretation could be a single, very broad-lined spectrum with superimposed nebular He I emissions.
102415. From the appearance of  $\lambda\lambda$  4511–15 and 4640–50, this spectrum may well be of type ON and similar to HD 150574, but the line quality is too poor to allow certainty.
168075. He II  $\lambda$  4541 is sharper than He I  $\lambda$  4471.
169515. The unique [Fe III] emission lines are strong. The classification is based upon a spectrogram obtained 1976 April 10–11, on which the spectrum has a normal appearance below 4200 Å except for a sharp He I  $\lambda$  3889 absorption. However, on a second plate obtained two nights later, the line ratios and profiles are very different, and the overall appearance is highly peculiar: He I  $\lambda$  4026 is very broad and the spectrum appears hydrogen deficient and possibly nitrogen enhanced. Interstellar  $\lambda$  4430 is extremely intense on both plates.
172175. Very similar to  $\lambda$  Cephei; possibly (n)fp (Walborn 1973a).

the center of this distant cluster and supergiant H II region was discussed and illustrated by Walborn (1973c), where the seven components A–G are identified. The integrated spectral type is O5-6(n)? + WN6-A(B), where the interrogative refers to the question of whether or not the absorption lines arise in the WN object, and the WN line-width categories are defined by Walborn (1974). The spectrogram classified in Table I was obtained with the 1.5-m spectrograph at the 4-m RC focus, where the scale allowed isolation of components EF. Due to seeing effects, there is still mild contamination by the WN emission features from the brighter ABCD components (which of these is the WN object has not yet been established), but the He II absorption lines in EF, including strong  $\lambda$  4686, are far more pronounced relative to the continuum than in the integrated spectrum of the entire object. Hence the presence of an early O main sequence star in the system is established. This system is of considerable significance because of its probable similarity to the (unresolved) 30 Doradus central object in the Large Magellanic Cloud.

## e) NGC 6334

A 4-m photograph of this remarkable grouping of bright and dark nebulosities is reproduced in Fig. 1, with the five O stars in Table I identified. The individual and average distance moduli of the latter are computed



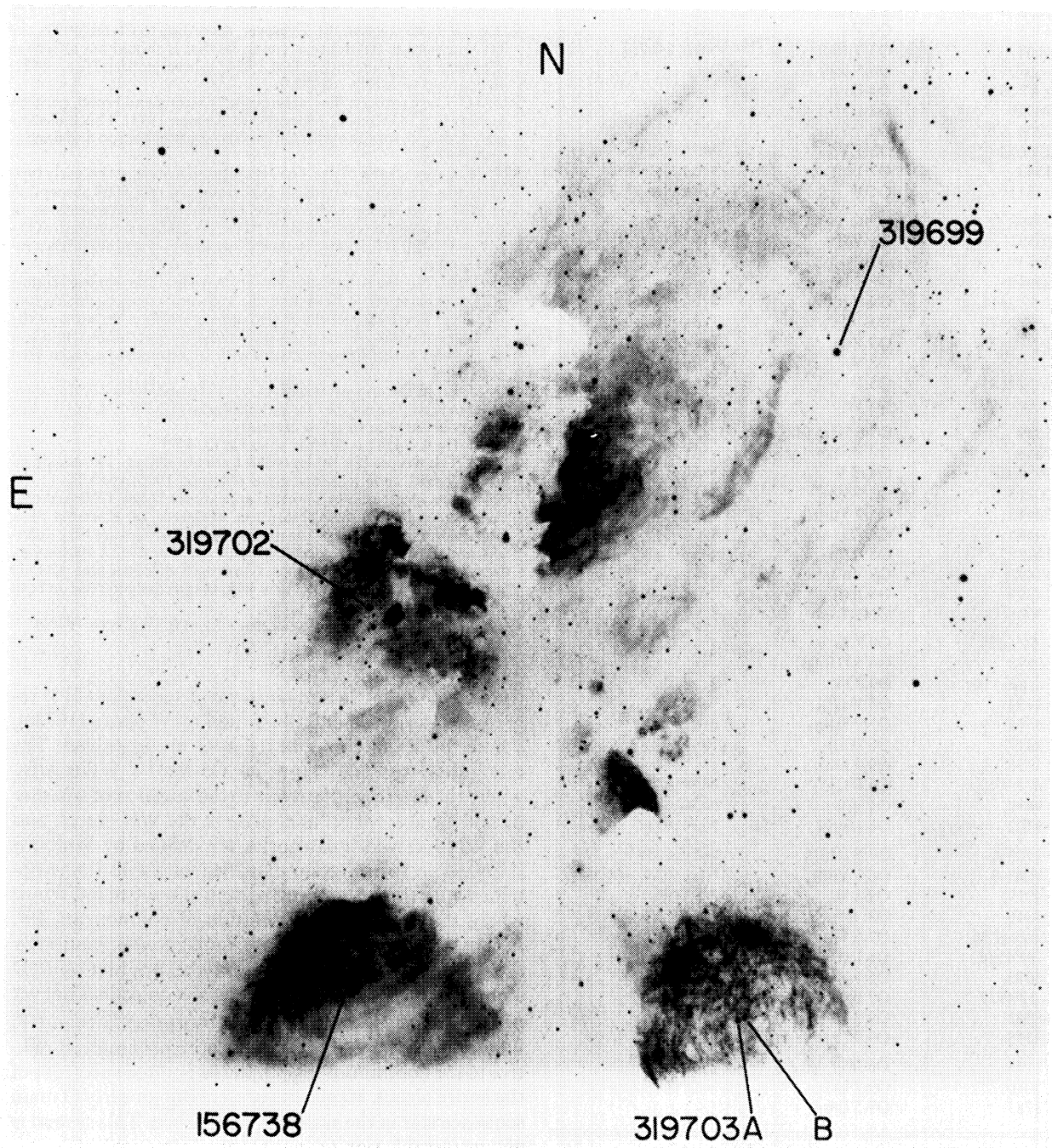


FIG. 1. Direct photograph of NGC 6334, obtained through a  $100 \text{ \AA}$   $H\alpha$  interference filter at the CTIO 4-m prime focus by Dr. A. E. Rydgren. Emulsion 127-04, exposure time 30 min. For scale, HD 156738 and HDE 319702 are separated by 12.6 arcmin in declination.

TABLE II. Distance moduli of O stars in NGC 6334.

HD/HDE	$V$	$B - V$	$E_{B - V}$	$V_0$	$M_V$	$V_0 - M_V$
156738	9.37	+ 0.86	1.18	5.83	- 5.6	11.43
319699	9.63	+ 0.77	1.09	6.36	- 5.5	11.86
319702	10.13	+ 0.90	1.21	6.50	- 5.6	12.10
319703A	10.71	+ 1.14	1.46	6.33	- 5.6	11.93
319703B	11.2	+ 1.25	1.57	6.49	- 5.3	11.79
Average						$11.82 \pm 0.11$

in Table II, on the assumption of  $A_V/E_{B-V} = 3.0$ . A value of 3.8 for this ratio was derived by Neckel and Chini (1981), but their analysis included some stars of the HD 156154 group (Walborn 1973a) whose association with the stars in the NGC 6334 nebulosities is not obvious. (This remark does not necessarily invalidate their determination, but suggests further evaluation of

the problem.) The intricate filamentary structure of the partial nebular ring surrounding the HDE 319703 system, in contrast to the amorphous HD 156738 nebulosity, is particularly noteworthy (see also Roslund 1966 and references therein). The average true modulus of 11.82 mag corresponds to a distance of 2300 pc.

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