THE ASTROPHYSICAL JOURNAL, 254:L15–L17, 1982 March 1


# THE O3 STARS

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*Received 1981 September 8; accepted 1981 October 30*

## ABSTRACT

A brief review of the 10 known objects in this earliest spectral class is presented. Two new members are included: HD 64568 in NGC 2467 (Puppis OB2), which provides the first example of an O3 V ((f*)) spectrum; and Sk −67°22 in the Large Magellanic Cloud, which is intermediate between types O3 If* and WN6-A. In addition, the spectrum of HDE 269810 in the LMC is reclassified as the first of type O3 III (f*). The absolute visual magnitudes of these stars are rediscussed.

*Subject headings:* stars: early-type — stars: O-type — stars: Wolf-Rayet

## I. INTRODUCTION

Since the original definition of spectral type O3 to describe four stars in the $\eta$ Carinae association (Walborn 1971), several additional members of the class have been found, and subsequent investigations have tended to confirm the extreme nature of these stars. Two further O3 spectra were discovered in the Carina Nebula (Walborn 1973*a*), and one each in the VI Cygni (Cygnus OB2) association (Walborn 1973*b*) and in the Large Magellanic Cloud (Walborn 1977). An additional two objects will be described here, bringing to ten the number of O3 spectra currently known.

Conti and Burnichon (1975), with observations given by Conti and Frost (1977), placed the Carina Nebula O3 stars in a theoretical H-R diagram, suggesting masses as high as 120 $M_\odot$ and the possibility that the O3 If* object HD 93129A is the most luminous and massive star known in the Galaxy. The Carina Nebula O3 V object HD 93205 is a double-line spectroscopic binary, but an unfavorable inclination allows only a lower limit of 39 $M_\odot$ for the primary to be determined (Conti and Walborn 1976); HD 93129A is an apparently single star (Conti, Niemela, and Walborn 1979). Kudritzki (1980) and Thé *et al.* (1980) studied the line spectrum and energy distribution, respectively, of the Carina Nebula O3 V ((f)) star HD 93250; the detection of He I λ4471 on fine-grain, high-dispersion spectrograms permitted the derivation of an effective temperature of 52,500 K and a mass of, again, 120 $M_\odot$. Ultraviolet spectroscopy with the *International Ultraviolet Explorer* of HD 93129A by Hutchings and von Rudloff (1980), and of HD 93250 by Conti and Garmany (1980) and Black *et al.* (1980), has shown the largest C IV λλ1548, 1551 terminal velocities (3300–4100 km s$^{-1}$) in their respective samples. Very recently, Hutchings (1981) has found a C IV edge velocity of 4000–5000 km s$^{-1}$ in the LMC O3 star HDE 269810 (= Radcliffe 122).

The principal defining characteristic of an O3 spectrum is that He I λ4471 absorption is not present above the noise level on 60 Å mm$^{-1}$ classification spectrograms. The notation f* means that N IV λ4058 emission is stronger than N III λλ4634–4640–4642. The designation ((f)) describes spectra in which He II λ4686 is strongly in absorption while weak emission is present in the aforementioned N III lines; (f) denotes He II λ4686 weakly in absorption or absent with N III emission of intermediate strength; and f is reserved for spectra with both these He II and N III features strongly in emission. These are selective emission effects: that is, they occur while other transitions from the same ions remain in absorption; they correlate with the morphology of the absorption-line spectra; and they are functions of temperature and luminosity among the normal majority of O stars.

## II. OBSERVATIONS

The observations discussed here are blue-violet classification spectrograms with a dispersion of 78 Å mm$^{-1}$ and a widening of 1.2 mm, obtained with the CTIO 1.5 m Cassegrain spectrograph mounted at either the 1.5 m or the 4 m telescope. The emulsion is IIa-O, and development was in D-76.

## III. DISCUSSION

Table 1 lists the 10 known O3 stars, along with their detailed spectral classifications, locations, group distance moduli, observed magnitudes and colors, and derived absolute visual magnitudes. Throughout, $(B-V)_0 = -0.32$ and $A_V/E_{B-V} = 3.0$ have been assumed.

[1]Supported by the National Science Foundation under contract AST 78-27879.

TABLE 1

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| Star | Spectral Type | Location | $V_0 - M_V$ | $V$ | $B - V$ | $M_V$ |
|---|---|---|---|---|---|---|
| HD 93128..... | O3 V((f)) | Tr 14/Carina Nebula | 12.26 | 8.77 | +0.24 | −5.2 |
| HD 93129A .... | O3 If* | Tr 14/Carina Nebula | 12.26 | 7.3 | +0.22 | −6.6 |
| HD 93129B .... | O3 V((f)) | Tr 14/Carina Nebula | 12.26 | 8.9 | +0.22 | −5.0 |
| HD 93205..... | O3 V | Tr 16/Carina Nebula | 12.26 | 7.75 | +0.05 | −5.6 |
| HD 93250..... | O3 V((f)) | Tr 16/Carina Nebula | 12.26 | 7.38 | +0.15 | −6.3 |
| HDE 303308 ... | O3 V((f)) | Tr 16/Carina Nebula | 12.26 | 8.17 | +0.13 | −5.4 |
| VI Cyg No. 7 ... | O3 If* | VI Cygni/Cygnus OB2 | 11.3 | 10.50 | +1.44 | −6.1 |
| HD 64568..... | O3 V((f*)) | NGC 2467/Puppis OB2 | 13.18[a] | 9.39 | +0.11 | −5.1 |
| HDE 269810 ... | O3 III(f*) | Large Magellanic Cloud | 18.6 | 12.28 | −0.23 | −6.6 |
| Sk −67°22..... | O3 If*/WN6-A | Large Magellanic Cloud | 18.6 | 13.50 | −0.22 | −5.4 |

[a]Havlen 1972, 1976.

Figure 1 (Plate L4) reproduces classification spectrograms of HD 64568, Sanduleak (Sk) −67°22, and HDE 269810, to be discussed below, and of HD 93129A (O3 If*) and HD 93162 (WN6-A) in the $\eta$ Car association for comparison.

### *a) Spectroscopic Characteristics*

#### i) *HD 64568*

The absorption-line spectrum of this star, located in NGC 2467 (Puppis OB2; Havlen 1972, 1976), indicates an extremely early type. In addition, there is a weak but definite emission line from N IV λ4058 and a trace of the N V absorption lines. On the other hand, no N III emission is visible. These properties, together with the strong He II λ4686 absorption, suggest the designation ((f*)), a logical development from the earlier definitions summarized in § I. This star may be hotter (and possibly more massive) than the Carina Nebula O3 V stars.

#### ii) *Sk −67°22*

This star was observed because of the classification "Of" given by Sanduleak (1970) in his objective-prism survey of the Large Magellanic Cloud; to the writer's knowledge no further spectroscopic information about the star has been published. At first glance the broad He II λ4686 emission suggests a W-R type, but several characteristics indicate strong relationships to the O3 If* objects as well. In the first place, all of the emission features are very weak; it should be emphasized that HD 93162 is already a weak-line WN star, which has been discussed as intermediate between HD 93129A and HD 93131 (Walborn 1974). The very weak emission in Sk −67°22 is no doubt the reason it has not appeared in the W-R surveys of the LMC, now believed to be essentially complete (Breysacher 1981). Moreover, the width of λ4686 in Sk −67°22 is not much greater than the full extent of the corresponding feature in HD 93129A, which has a quasi-P-Cygni profile. Finally, the He II absorption lines are very strong in Sk −67°22, much more similar to those in HD 93129A than in HD 93162.

#### iii) *HDE 269810*

The spectrum of this star was classified O3 If* by Walborn (1977), partly on the basis of an apparent weak quasi-P-Cygni profile at He II λ4686. However, the present spectrogram, which is of higher quality, shows clearly that λ4686 is dominated by absorption. Furthermore, the N IV emission and N V absorption are intermediate in strength between those in HD 64568 and HD 93129A. These characteristics lead to the (f*) designation and the intermediate luminosity class given in Table 1 and Figure 1.

### *b) Absolute Visual Magnitudes*

The interpretation of Trumpler 14 implied by Table 1 differs from that adopted by Walborn (1973*a*), where the same average absolute magnitudes were assumed for the Tr 14 and Tr 16 O main-sequence stars, leading to a larger distance for the former cluster and $M_V = -7.0$ for HD 93129A. The alternative possibility, also pointed out, that the O dwarfs in the very compact Tr 14 are somewhat less luminous (i.e., less evolved from the zero-age main sequence) than those in Tr 16, and that both clusters are located in the $\eta$ Car association, now appears preferable. The latter interpretation leads to the absolute magnitudes given in Table 1. Similarly, the assumption of $M_V = -7.0$ for VI Cyg No. 7 led to a discordantly large distance modulus (Walborn 1973*b*); adoption of the group modulus derived from the later O-type members leads to the absolute magnitude for No. 7 given in Table 1.

The derived absolute magnitudes show a good separation between the O3 V stars, on the one hand, and the O3 III–I stars, on the other, with two notable exceptions: HD 93250 in the former case and Sk −67°22 in the latter. The average values are −5.4 ± 0.2 (standard

PLATE L4

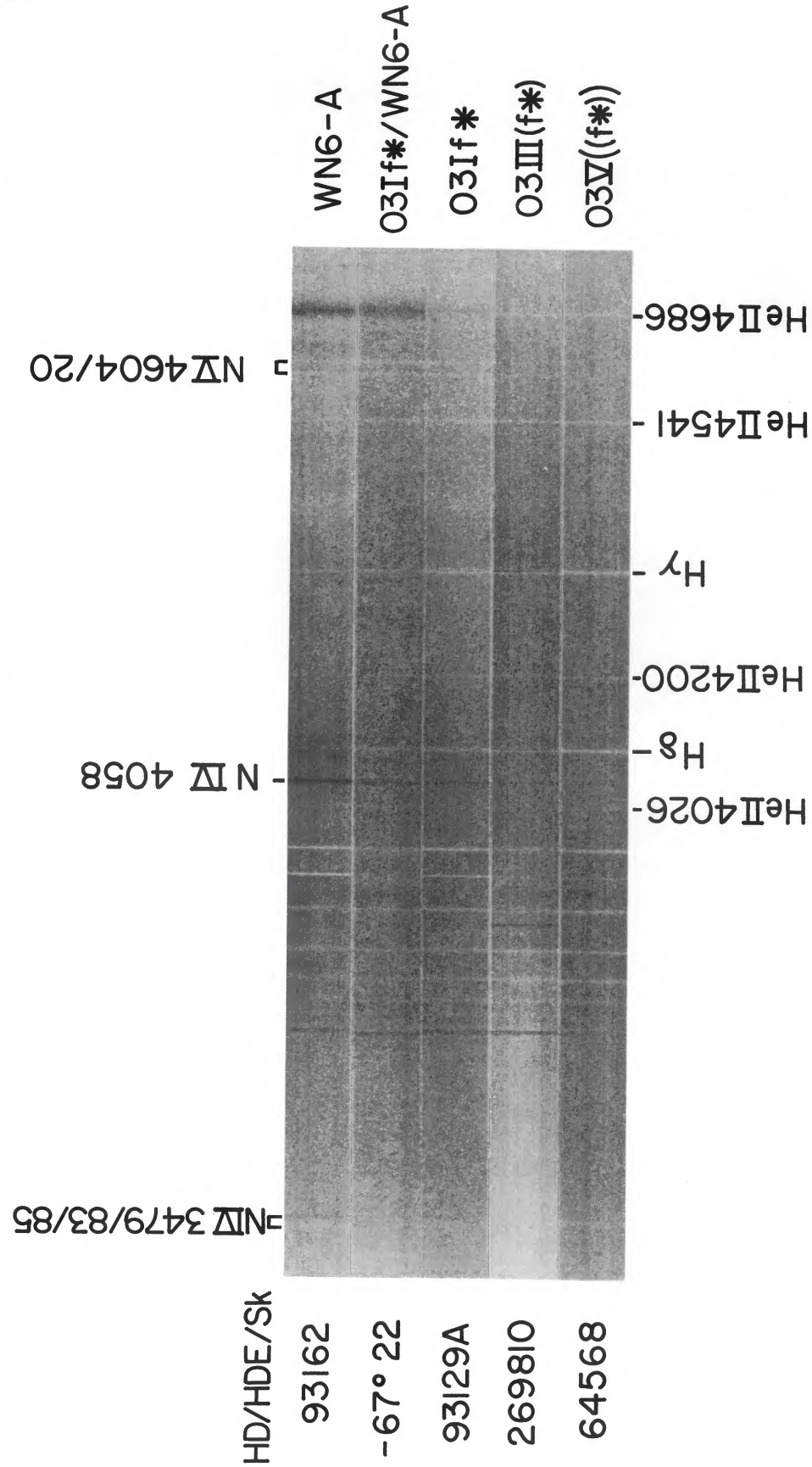


FIG. 1.—Blue-violet classification spectrograms of five O3 and WN6-A stars of original dispersion 78 Å $mm^{-1}$. In addition to the identified stellar features, [O II] λλ3726, 3729 nebular emission is prominent on the upper four spectrograms, and, on that of HDE 269810, [Ne III] λ3869 and Hγ nebular emissions are strong as well. The spectrogram of Sk −67°22 shows some moonlight contamination.

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deviation of the mean) for O3 V, or $-5.3 \pm 0.1$ with HD 93250 omitted; and $-6.2 \pm 0.3$ for O3 III–I, or $-6.4 \pm 0.2$ with Sk $-67°22$ omitted. Evidently the spectroscopic distinction between O3 I and O3 III does not correspond to a luminosity difference. These results are consistent with the calibration of Walborn (1973*c*) for type O3 V, but the (uncertain) earlier value of $-7.0$: for type O3 I should be revised to $-6.4$.

Two possible explanations of the discrepancy in the case of HD 93250 can be suggested: either it is not a single star, or it is in fact more luminous (more evolved?) than the other O3 V stars, but the spectroscopic effects are too subtle to indicate the distinction clearly with the present observational parameters. The faint absolute magnitude of Sk $-67°22$ is rather more perplexing. Not only is it anomalous for an O3 If* spectrum; it is also uncharacteristic of a narrow-line WN star. For instance, with the present distance modulus the Carina Nebula WN6-A stars HD 93131 and HD 93162 have $M_V = -6.2$ and $-6.0$, respectively, while HD 38282, WN6-A(B), in the 30 Doradus association has $M_V = -7.7$ (Walborn 1977). Hence, one has a well-determined absolute-magnitude range of 2.3 mag at the same WN subtype, providing another illustration of the diversity of the objects producing W-R envelopes with similar physical conditions (Massey 1981).

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