THE ASTROPHYSICAL JOURNAL, 199: 535–543, 1975 July 15


# COMPLEX INTERSTELLAR CALCIUM LINE STRUCTURE IN THE CARINA NEBULA

NOLAN R. WALBORN AND JAMES E. HESSER
Cerro Tololo Inter-American Observatory*
*Received 1974 December 16; revised 1975 January 24*

## ABSTRACT

Exceedingly complex structure has been found in the interstellar Ca II lines on 9 Å $mm^{-1}$ coudé spectrograms of stars in the Carina Nebula. As many as six components have been observed in a single spectrum; moreover, the profiles show large variations over small angular distances, and a total velocity range of 330 km $s^{-1}$ has been measured. Stars in the outer part of the nebula have single calcium lines, which suggests that the additional components in the inner region are formed there. Measurements of the interstellar Ti II lines, which are double in a few cases, are also presented. These results probably represent a new kind of interstellar-line velocity structure, and some possible causes are summarized.

The double nebular emission lines have been measured on a long-exposure spectrogram of HD 93204. There is good agreement with the previous interferometric results of Bohuski and Smith. In addition, the spectrograms of all stars in bright nebulosity show a *single* He I λ3889 nebular absorption line. Its velocity agrees with the negative component of the emission pairs, which suggests that the positive-velocity ionized material lies beyond the stars.

A search for similar interstellar calcium-line structure at the center of the 30 Doradus Nebula in the Large Magellanic Cloud is briefly discussed.

*Subject headings:* interstellar matter — nebulae, individual

## I. INTRODUCTION

In general terms, velocity structure in the interstellar absorption lines is known to arise from three distinct causes: (1) galactic structure and dynamics (Münch 1965), (2) individual clouds along the line of sight (Beals 1936; Adams 1949; Hobbs 1969; Marschall and Hobbs 1972), and (3) expanding supernova remnants (Wallerstein and Silk 1971). On the average, of course, the total strength of the interstellar lines increases with distance. Recently, however, an anomalous variation of the interstellar calcium line strengths was observed on low-dispersion spectrograms of stars in the η Carinae complex, associated with the Carina Nebula (NGC 3372) (Walborn 1971*b*). This variation was found to be quite systematic, in the sense that stars in the inner part of the nebula have strong interstellar lines, while those in the outer parts have weaker lines. It was suggested that an additional interstellar line component associated with the nebula might produce such an effect, and the present study was undertaken to investigate that possibility. The rather surprising results are described below; it is believed that they represent a fourth kind of interstellar-line velocity structure, namely, structure within or associated with a giant H II region.

The emission lines throughout a part of the Carina Nebula have been known to be double since the hydrogen recombination-line observations of Gardner *et al.* (1970). Similar structure in the optical emission lines has been extensively mapped interferometrically by Bohuski and Smith (1975) and Smith and Gull (1974), who find complex profiles to large distances from the center of the nebula. Double emission lines have been measured on one spectrogram of the present investigation; and measurements of the metastable He I λ3889 nebular absorption line on several spectrograms provide a useful new constraint on interpretations of the nebular-line puzzle. The relationship, if any, between the interstellar and nebular line phenomena is unclear at the present time, however.

## II. OBSERVATIONS AND REDUCTIONS

Spectrograms of 16 stars distributed throughout the field of the Carina Nebula were obtained during 1974 March and April, with the No. 2 coudé camera of the Cerro Tololo 1.5-m reflector. The dispersion is 9 Å $mm^{-1}$, the widening 0.6 mm, and the projected slit width was 20 μ, on nitrogen-baked IIa-O plates which were developed in D-76. The plates were calibrated by means of a spot sensitometer.

Radial velocities were measured with the CTIO Grant comparator-microphotometer, by linear interpolation with respect to nearby comparison lines. The accuracy of the velocities is difficult to determine, since it undoubtedly depends upon the strength and severity of blending of a given component; and only one spectrogram per star is available. However, an estimate of the internal error can be obtained by comparing the difference between the measured velocities for the Ca II H (λ3968) and K (λ3933) lines of the same velocity component on a given plate. The average

* Operated by the Association of Universities for Research in Astronomy, Inc. under contract with the National Science Foundation.

difference of 33 pairs is 1.8 ± 0.2 (m.e.) km s$^{-1}$. That the plate-to-plate error is not much larger for relatively unblended components may be seen by intercomparing the −90 km s$^{-1}$ features in HD 93204 and 93205, for which the average difference is 2.9 km s$^{-1}$. There is, however, a systematic difference between the measured Ca II velocities and those of the ultraviolet interstellar Ti II lines at λλ3242 and 3384; the average difference of corresponding components in a given spectrum, from 17 comparisons, is 4.8 ± 0.8 (m.e.) km s$^{-1}$ in the sense Ca-Ti, which is significantly larger than the average difference between H and K. This effect may be due to the generally lower photographic densities at the wavelengths of the Ti lines (typical continuum densities on these plates are 0.5 at the Ca II lines, 0.4 at λ3384, and 0.3 at λ3242), or to differential refraction effects over the wavelength interval between the Ca and Ti lines.

Intensity tracings were also made with the Grant machine, by means of a computerized density-to-intensity conversion of the photomultiplier output before the chart recorder, developed by Dr. P. S. Osmer. Equivalent widths were measured on the tracings with a planimeter, after blended profiles had been resolved by graphical equalization of areas. The accuracy of the equivalent widths is again very difficult to estimate, for reasons similar to those hindering the velocity error determination. Cases in which the blending was severe will be denoted as uncertain; and the reality of three calcium components for which the measured equivalent widths are less than 20 mÅ requires confirmation by further observations, since the largest grain fluctuations in the continuum near the Ca II lines have "equivalent widths" in the range 10–15 mÅ.

## III. RESULTS

The results for the interstellar Ca II lines are presented in Table 1, and graphically in Figure 1. In the table, following the star and line identifications, successive pairs of columns give the heliocentric radial velocity and equivalent width for each component measured in a given spectrum. The stars have been somewhat arbitrarily divided into four groups, based upon their relative positions on the sky and some roughly corresponding characteristics of their calcium line profiles. Group A contains stars just northwest of η Car (see Fig. 1), which have the most heavily blended profiles. Group B consists of the stars nearest η on the sky, which in general have the most numerous, although somewhat weaker, high-velocity components. Group C contains two stars southwest of η with the highest-velocity components of all (although its reality in the case of HD 93206 requires confirmation). Finally, group D contains stars located around the outer boundaries of the nebula; with one minor exception, these stars all have a single, low-velocity interstellar calcium line.

The arrangement of the columns in Table 1 is also arbitrary and does not *necessarily* imply that all components in a given column are to be identified with the same line-forming region. It is very likely that this *is* in fact true in certain cases, however. (1) The strong low-velocity feature in the fourth component column-pair, which is present in all the stars, is undoubtedly the "normal" interstellar line formed across the distance between the Sun and the Carina Nebula; it will hereafter be called the "line-of-sight component." The scatter in its measured velocities is probably due mostly to different blending effects, often with the −30 km s$^{-1}$ feature, and perhaps with weaker, unresolved features in some cases. (2) The −30 km s$^{-1}$ feature in the third component column-pair, which appears in all stars of groups A and B (probably including HD 93250, in which it is unresolved), is particularly interesting in connection with the nebular line phenomena, to be discussed below in § V. If one assumes that a common region produces the feature in all cases (i.e., the measured velocity scatter is again due to blending, primarily with the line-of-sight component), the average velocity is −30.1 ± 0.8 (m.e.) km s$^{-1}$. (3) The correspondence between certain high-velocity features occurring in pairs of stars very close to each other on the sky is clear, especially in the pairs HD 93204/93205, η Car/HDE 303308, and perhaps HD 93130/93206.

Despite the correspondences just noted, the most striking feature of these interstellar calcium profiles is their marked diversity; no two among groups A, B, and C are identical, despite the small angular separations involved. The most dramatic example is provided by HD 93204 and 93205, which are just 20″ apart on the sky. The large number of components observed and the very high velocities of some of them are also surprising. Six components spanning a velocity range of 196.4 km s$^{-1}$ are resolved in HDE 303308, which is just 1′ north of η Car; moreover, the appearance of some components in this profile suggests that even more may be seen with higher resolution. The largest positive velocity observed is +137.9 km s$^{-1}$ in HD 93204, and the most negative (average of H and K), −193.6 km s$^{-1}$ in HD 93130, which may be the largest velocity known for a galactic interstellar line; thus the total velocity range observed is 331.5 km s$^{-1}$.

In Table 2 are presented the heliocentric radial velocities and equivalent widths measured for the interstellar ionized titanium lines at λλ3242 and 3384. No correction has been made for the systematic velocity effect noted in § II. Clearly it is primarily the line-of-sight component which is being measured here. In a few cases, however, additional components were measurable, and their velocities correspond fairly well with a calcium component in each case, after allowance for the systematic effect.

## IV. DISCUSSION

### *a) The Distances of the Stars*

In order to interpret the interstellar line phenomena just described, it is important to know the distances, or at least the relative distances, of the stars observed. Most of them are members of the clusters Trumpler 16 and Collinder 228, which apparently excite the Carina

# TABLE 1

## Interstellar Calcium II Components in the Eta Carinae Complex. Radial Velocities and Equivalent Widths

| HD Number | Line | R.V. (km s⁻¹) | W (mÅ) | R.V. (km s⁻¹) | W (mÅ) | R.V. (km s⁻¹) | W (mÅ) | R.V. (km s⁻¹) | W (mÅ) | R.V. (km s⁻¹) | W (mÅ) | R.V. (km s⁻¹) | W (mÅ) | R.V. (km s⁻¹) | W (mÅ) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | A. Northwest of η Car | | | | | | | |
| 93129........ | K | ... | ... | ... | ... | −26.6 | 332: | +3.8 | 448: | ... | ... | ... | ... | ... | ... |
| | H | ... | ... | ... | ... | −27.0 | 225: | +3.2 | 320: | ... | ... | ... | ... | ... | ... |
| 93160........ | K | −83.8 | 153: | −49.8 | 370: | −31.8 | 420: | −7.6 | 382: | ... | ... | ... | ... | ... | ... |
| | H | −82.0 | 114: | −51.5 | 288: | −31.4 | 337: | −4.2 | 323: | ... | ... | ... | ... | ... | ... |
| 93250........ | K | ... | ... | ... | ... | ... | ... | −2.2 | 825b | +58.8 | 53 | ... | ... | ... | ... |
| | H | ... | ... | ... | ... | ... | ... | −3.0 | 680b | +60.2 | 36 | ... | ... | ... | ... |
| | | | | | | | | B. Adjacent to η Car | | | | | | | |
| 93162........ | K | ... | ... | −58.5 | 423b? | −30.2 | 353 | +0.4 | 380 | ... | ... | ... | ... | ... | ... |
| | H | ... | ... | −57.5 | 170 | −30.4 | 261 | +3.9 | 260 | ... | ... | ... | ... | ... | ... |
| 93204........ | K | −92.2 | 87 | ... | ... | −27.1 | 99 | +0.6 | 434 | ... | ... | +102.8 | 48 | +137.9 | 43 |
| | H | −94.0 | 37 | ... | ... | −28.6 | 74 | +4.0 | 266 | ... | ... | ... | ... | ... | ... |
| 93205........ | K | −89.8 | 175 | ... | ... | −31.8 | 119 | −0.2 | 415 | ... | ... | +100.4 | 18 | ... | ... |
| | H | −90.5 | 126 | ... | ... | −34.2 | 59 | +1.6 | 274 | ... | ... | +103.4 | 9.5 | ... | ... |
| η Car........ | K | ... | ... | −74.7 | 174 | −35.3 | 311 | +2.8 | 440 | ... | ... | +93.6 | 165 | ... | ... |
| | H | ... | ... | ... | ... | ... | ... | +2.8 | 428 | ... | ... | +87.2 | 199 | ... | ... |
| 303308....... | K | −109.1 | 87 | −73.6 | 52 | −29.4 | 445b | +0.2 | 368 | +70.9 | 70 | +88.3 | 48 | ... | ... |
| | H | −107.0 | 32 | −85.8: | ... | −27.6 | 306b | +2.0 | 305 | +68.2 | 29 | ... | ... | ... | ... |
| | | | | | | | | C. Southwest of η Car | | | | | | | |
| 93130........ | K | −196.0 | 94 | ... | ... | ... | ... | 0.0 | 574b? | ... | ... | ... | ... | ... | ... |
| | H | −191.1 | 67 | ... | ... | ... | ... | +1.0 | 332b? | ... | ... | ... | ... | ... | ... |
| 93206........ | K | −183.8: | 14 | −60.0: | 14 | ... | ... | +1.7 | 475 | ... | ... | ... | ... | ... | ... |
| | H | ... | ... | ... | ... | ... | ... | −0.4 | 270 | ... | ... | ... | ... | ... | ... |
| | | | | | | | | D. Outer Boundary | | | | | | | |
| 92740........ | K | ... | ... | ... | ... | ... | ... | +5.4 | 449 | ... | ... | ... | ... | ... | ... |
| | H | ... | ... | ... | ... | ... | ... | +7.0 | 345 | ... | ... | ... | ... | ... | ... |
| 92741........ | K | ... | ... | ... | ... | ... | ... | 0.0 | 414 | ... | ... | ... | ... | ... | ... |
| | H | ... | ... | ... | ... | ... | ... | +1.2 | 196 | ... | ... | ... | ... | ... | ... |
| 92964........ | K | ... | ... | ... | ... | −40.3 | 132 | +6.0 | 565 | ... | ... | ... | ... | ... | ... |
| | H | ... | ... | ... | ... | ... | ... | +7.0 | 450: | ... | ... | ... | ... | ... | ... |
| 93131........ | K | ... | ... | ... | ... | ... | ... | +3.0 | 492 | ... | ... | ... | ... | ... | ... |
| | H | ... | ... | ... | ... | ... | ... | +1.9 | 317 | ... | ... | ... | ... | ... | ... |
| 93403........ | K | ... | ... | ... | ... | ... | ... | −0.6 | 493 | ... | ... | ... | ... | ... | ... |
| | H | ... | ... | ... | ... | ... | ... | +1.6 | 265 | ... | ... | ... | ... | ... | ... |
| 93843........ | K | ... | ... | ... | ... | ... | ... | −3.4 | 399 | ... | ... | ... | ... | ... | ... |
| | H | ... | ... | ... | ... | ... | ... | −2.2 | 205 | ... | ... | ... | ... | ... | ... |

NOTES.—Colon indicates severely blended component (equivalent width) or uncertain velocity measure. (b), blended feature measured as a whole.

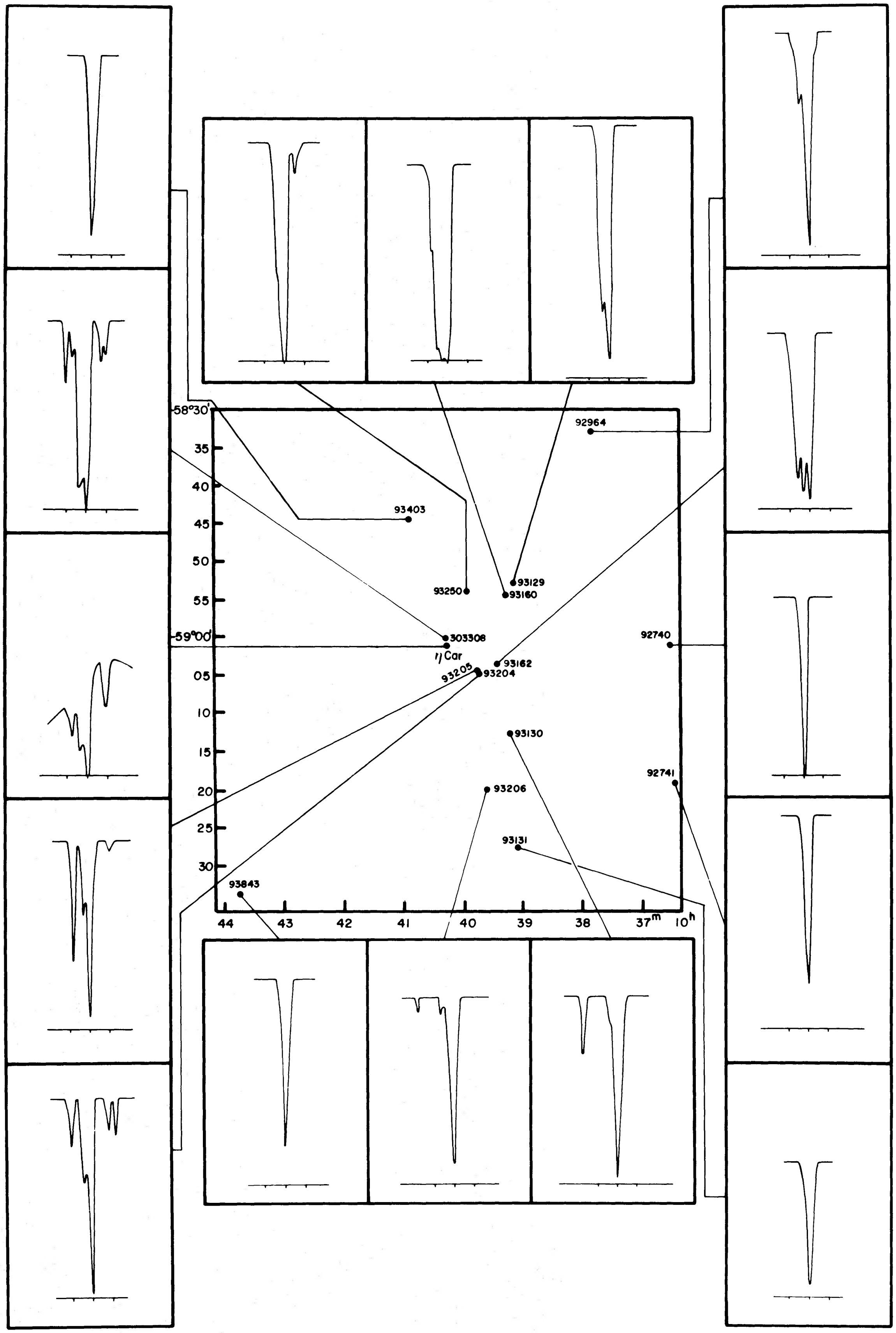


FIG. 1.—The central part of the figure gives the distribution on the sky of the stars observed. They are (except for $\eta$ Car) identified by their HD or HDE numbers; the coordinates are for the 1875 epoch of the *Cape Photographic Durchmusterung*. Surrounding the map are the individual intensity profiles of the interstellar Ca II K-line for each star, as indicated by the connecting lines. The horizontal line below each profile indicates zero intensity (clear plate), and the vertical marks denote 0 and $\pm 100$ km s$^{-1}$ (heliocentric). The continua are somewhat underexposed on the spectrograms of $\eta$ Car and HD 92740, and consequently the K-line profiles actually may not quite reach zero intensity in those two cases.

TABLE 2

INTERSTELLAR TITANIUM II LINES IN THE ETA CARINAE COMPLEX

| HD Number | λ3242 R.V. (km s⁻¹) | λ3242 W (mÅ) | λ3384 R.V. (km s⁻¹) | λ3384 W (mÅ) |
|---|---|---|---|---|
| Group A | | | | |
| 93129 | −3.5 | 142 | −0.5 | 129 |
| 93160 | −16.0* | 92 | −14.6* | 174 |
| 93250 | −8.8 | 51 | −7.8 | 149 |
| Group B | | | | |
| 93162 | −0.8* | 68 | −5.8 | 69 |
| | | | −36.9 | 66 |
| 93204 | +5.4: | 90 | +3.6 | 91 |
| 93205 | −4.1 | 64 | −7.3 | 72 |
| 303308 | −6.7* | 79 | −0.2 | 98 |
| | | | −36.0 | 31 |
| Group C | | | | |
| 93130 | ... | ... | −1.5 | 95 |
| 93206 | ... | ... | −0.7 | 159 |
| | | | −64.8† | 34 |
| Group D | | | | |
| 92741 | ... | ... | −8.3 | 109 |
| 92964 | ... | ... | +1.6 | 78 |
| 93131 | +0.4 | 47 | +0.6 | 124 |
| 93403 | ... | ... | −2.6 | 89 |
| 93843 | ... | ... | −10.0: | 79 |

* Broad, possibly multiple.

† Possibly spurious.

Nebula, and for which a common distance of 2600 pc was found by Walborn (1973*a*). Several individual cases requiring additional consideration are discussed in the Appendix. To summarize the discussion there, it is concluded that all the stars observed are at a common distance and are associated with the Carina Nebula, except for HD 93129 and 93843, which *could* be somewhat more distant; and HD 92741 and 92964, which are probably foreground objects. Perhaps most importantly, it is considered definite that the group D stars HD 92740 and 93131, of type WN, are members of the $\eta$ Car complex.

### *b*) *The Location of the High-Velocity Interstellar Line-forming Regions*

In view of the above considerations of the stellar distances, the distribution of the interstellar calcium profiles on the sky (Fig. 1) becomes highly significant and leads to the principal conclusion of this investigation: since stars associated with the outer parts of the nebula show only the line-of-sight calcium component it follows that *the additional high-velocity components in the inner region are very probably formed there, or in its immediate foreground*. That is, the high-velocity interstellar material is associated with the Carina Nebula. It may be noted that this conclusion is supported by the very small angular scale of the profile variations within the inner region.

Some of these profile differences are undoubtedly related to a spread in depth of the stars within the complex, of the order of a few parsecs or perhaps a few tens of parsecs. For instance, it seems likely that HD 93204 is somewhat behind HD 93205, and that most of the very high-positive-velocity material is between the two stars. On the other hand, the $-90$ km s$^{-1}$ feature is stronger in HD 93205, indicating that there must be significant structure in the high-velocity material on the scale of the projected linear separation of the two stars, which is 0.25 pc.

Finally, it may be noted that the WN star HD 93162 is located just behind the edge of a dense obscuring lane which crosses the nebula (Graham 1965; Walborn 1973*a*). It may be that the $-60$ km s$^{-1}$ feature in its rather unique interstellar profile is caused by material associated with this lane.

### *c*) *The Doublet Ratios*

The doublet ratio method (Strömgren 1948) permits estimates of the velocity dispersion and total number of absorbers to be made from observations of the equivalent widths of the interstellar calcium lines. The application of the method has been hampered in the present investigation, however, by saturation in the case of the stronger components; and by a tendency for the measured K/H ratios to exceed the limiting value of 2.0 in the case of many weaker, high-velocity components. This latter problem was also encountered by Routly and Spitzer (1952). In any event, the usefulness of the method for deriving quantitative column densities appears to be limited in view of the recent results of Nachman and Hobbs (1973). Therefore, application of the method here will be restricted to the qualitative remark that the value of the ratio for the $-90\ \mathrm{km\ s^{-1}}$ feature in HD 93204 (2.35), relative to the corresponding ratio in HD 93205 (1.39), indicates a smaller number of absorbers at that velocity in front of the former star, consistent with the weaker feature observed in its spectrum.

#### *d*) *Hypotheses Concerning the Origin of the Phenomenon*

The complex, high-velocity interstellar line profiles discovered in the Carina Nebula likely represent a new kind of such structure. Three possible hypotheses about its cause, together with some observations which may help decide which, if any, is correct, will now be discussed.

##### i) *Eta Carinae*

The remarkable history of this eruptive object has been discussed many times. Several authors have pointed out that the amount of energy involved is comparable to that of a supernova (Thackeray 1956; Ostriker and Gunn 1971). It seems reasonable to suggest that the violent gas motions indicated by the interstellar-line observations in its vicinity may be related to one or more outbursts by $\eta$ Car, presumably prior to the one being observed at the present time. In support of this possibility, it may be noted that the stars with the most numerous calcium components are those nearest $\eta$ on the sky. Further information relevant to this hypothesis may be gained from high-dispersion observations of a number of additional, fainter stars in the region immediately adjacent to $\eta$.

##### ii) *The O3 Stars*

The group of stars under consideration is hardly an ordinary one, in that it contains four stars of spectral type O3 (which probably include the most massive main-sequence stars and one of the highest excitation supergiants known) and three high-luminosity WN stars (Walborn 1971*a*, 1973*a*, 1974). The compact cluster Tr 14 contains two additional O3 V stars not observed in the present study. The energy input to the surrounding gas by these stars, in the form of both ultraviolet radiation and stellar winds, may be expected to be considerable. Both mechanisms have been considered as sources of mass motions in H II regions (Pikel'ner 1968, 1973; Dyson 1973 and references therein). It may be noted that if the energy source is provided by the stars, then it would appear to be the O3 rather than the WN stars which are most important, since no interstellar calcium structure is seen in the vicinity of the group D WN stars HD 92740 and 93131. All of the O3 stars observed, on the other hand, have complex interstellar line profiles.

Unfortunately, little quantitative information about the relevant physical characteristics of the O3 stars is available at the present time. The determination of their temperatures is hampered by the absence of He I lines from their spectra, even at coudé dispersions (present study and Conti 1974), which allows only a lower limit of 50,000–55,000 K to be estimated. Perhaps far-ultraviolet spectroscopic observations (which will also be crucial to the determination of mass-loss rates) may enable improved temperature estimates to be made. Similarly, no direct information is yet available about the masses of the O3 stars, although very large values have been suggested by Conti and Burnichon (1975). However, one of them, HD 93205, has been discovered to be a double-line binary with a large velocity range (Walborn 1971*a*, 1973*a*) and is currently the object of radial-velocity study by N. R. W. and Dr. P. S. Conti.

##### iii) *The Ring and Carina II*

Perhaps the most intriguing hypothesis about the origin of the high-velocity gas motions concerns the remarkable ring structure of the brightest optical nebulosity, which contains a radio continuum maximum (Car II) at its center (Gardner *et al.* 1970; Smith 1972; Walborn 1973*a*). It is located in the midst of the observed interstellar-line activity. If it were a uniformly expanding structure, its age would be $10^4$ years (Gardner *et al.* 1970). Its nature is unclear at the present time; however, the available information suggests that some energetic event has occurred or is occurring there. Two obvious speculative possibilities are a supernova (a new nonthermal source possibly in the vicinity of $\eta$ Car has recently been reported by Jones 1973), or activity associated with a massive protostar or -stars. The latter has recently been discussed as a possible source of high velocities in H II regions by Dopita (1974). Clearly, further optical, infrared, and radio observations are called for in order to determine the nature of the ring and Car II, and their possible relationship to the interstellar-line phenomenon.

It will be important to investigate the interstellar sodium D lines in the Carina Nebula with a resolution comparable to that applied to the calcium lines here. In particular, it will be of interest to determine whether the newly found high-velocity features show the well-known anomalously low Na/Ca ratios characteristic of high-velocity interstellar lines in general. It has recently been suggested that this anomaly is due to the association of all such lines with supernova remnants (Siluk and Silk 1974). On the other hand, one may also recall the remark by Routly and Spitzer (1952), that the anomaly might be explained *if* it could be shown that the high-velocity components selectively are formed nearer to the OB stars in whose spectra they are observed; such certainly appears to be the case here.

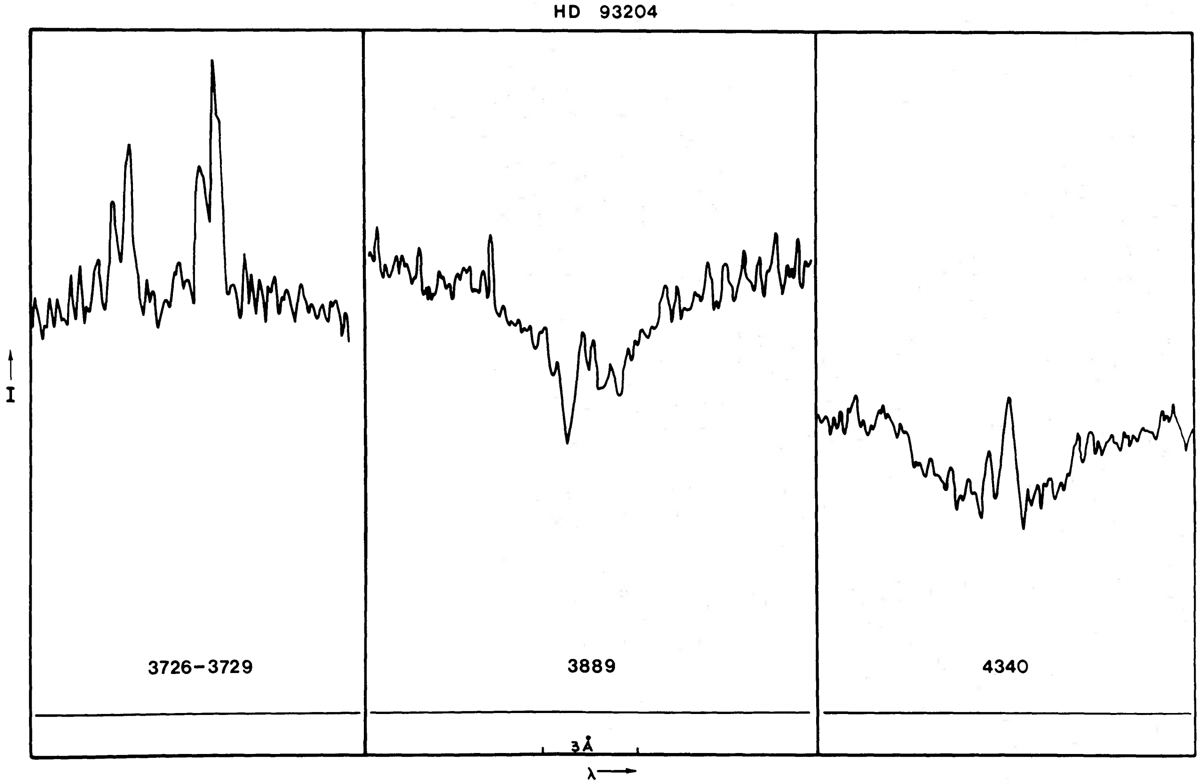


FIG. 2.—Intensity profiles of the nebular lines [O II] λλ3726, 3729; He I λ3889; and Hγ (λ4340) in the spectrum of HD 93204. The horizontal line below each profile indicates zero intensity (clear plate).

## V. THE NEBULAR LINES

Peculiar, double H 109α profiles were found in the vicinity of Car II by Gardner *et al.* (1970), which led to their suggestion of an expanding structure. However, the difficulties with a simple interpretation, which they also pointed out, have been emphasized by the recent optical interferometric results of Bohuski and Smith (1975) and Smith and Gull (1974), who have found double and broad [N II], [O III], and Hα emission line profiles to distances as large as 2°.5 from the center of the Carina Nebula. Part of the explanation may be that two expansions are being observed, one from Car II with a time scale of $10^4$ years, and the other involving the whole nebula with a time scale of $10^6$ years (Dickel 1974).

While nebular emission lines are not usually prominent on stellar coudé spectrograms, the nebulosity was sufficiently bright and the exposure sufficiently long (4 hours) in the case of HD 93204 to record them quite strongly. The observed intensity profiles of [O II] λλ3726, 3729 and Hγ are illustrated in Figure 2, and the measured heliocentric radial velocities and intensity ratios (including Hδ as well) are given in Table 3. As can be seen, the agreement with the interferometric measurements of [O III] λ5007 by Bohuski and Smith at the position of HD 93204, also given in Table 3, is excellent.

The most interesting result of the present nebular line observations concerns the metastable He I λ3889 absorption feature, first discovered in the Orion Nebula by Wilson *et al.* (1959). It has been observed here in

TABLE 3

DOUBLE NEBULAR EMISSION LINES IN HD 93204

| | λ | Velocities (km s$^{-1}$) | | Separation (km s$^{-1}$) | Intensity Ratio (red/blue) |
|---|---|---|---|---|---|
| [O II] | 3726 | −33.0 | +5.1 | 38.1 | 1.58 |
| [O II] | 3729 | −31.0 | +3.6 | 34.6 | 1.90 |
| Hδ | 4101 | −29.9 | +1.9 | 31.8 | 1.59 |
| Hγ | 4340 | −35.0 | +6.0 | 41.0 | 2.00 |
| Average | | −32.2 | +4.2 | 36.4 | 1.77 |
| Bohuski and Smith: | | | | | |
| [O III] | 5007 | −30.2 | +4.0 | 34.2 | 1.76 |

TABLE 4

NEBULAR He I λ3889 IN THE ETA CARINAE COMPLEX

| HD Number | R.V. (km s$^{-1}$) | $W$ (mÅ) |
|---|---|---|
| | Group A | |
| 93129........... | −23.4 | 198 |
| 93160........... | −30.4 | 98 |
| 93250........... | −26.0 | 87 |
| | Group B | |
| 93162........... | −32.9 | 121 |
| 93204........... | −33.7 | 95 |
| 93205........... | −36.5 | 58 |
| 303308........... | −34.2 | 75 |
| | Group C | |
| 93130........... | −25.0 | ... |
| 93206........... | −10.0: | 116 |
| | Group D | |
| 93131........... | −27.0 | 49 |

the spectra of all the stars in the brighter regions of the Carina Nebula; its intensity profile in HD 93204 (superposed on that of the stellar H$\zeta$ line) is also shown in Figure 2, and its heliocentric radial velocity in each spectrum is listed in Table 4. The line is *single* in all cases; and the average velocity for the groups A and B stars is $-31.0 \pm 1.8$ (m.e) km s$^{-1}$, in excellent agreement with the negative component of the emission pairs in HD 93204. The absence of the positive-velocity feature in the He I line is unlikely to be due to a detection problem, since that feature is the stronger of the emission pairs; and the identical intensity ratios of the [O II] and [O III] pairs indicates that the excitation is similar in the two regions, at least along the line of sight to HD 93204. The most likely conclusion is that *the positive-velocity ionized material lies predominantly beyond the stars*, and thus cannot give rise to an absorption feature in their spectra.

It is not clear whether there is a relationship between the nebular line phenomena and that observed in the interstellar calcium lines. As noted in § III above, there is a persistent calcium feature in the stars of groups A and B with average velocity $-30.1$ km s$^{-1}$, in good accord with the negative-velocity nebular emission component (and the He I nebular absorption line); this correspondence could be a mere coincidence or it could be the result of a physical connection. No connection is expected between the positive-velocity nebular emission and the calcium lines, since (*a*) the line-of-sight calcium component dominates at that velocity; and (*b*) it was concluded above from the He I λ3889 results that the material responsible for the positive-velocity emission lies behind the stars. It should be noted that, on the one hand, the complex nebular line profiles appear from the interferometric results to extend to much larger distances from the center of the nebula than do the complex calcium profiles; and, on the other hand, there is at present no evidence in the nebular line observations for the higher-velocity components found in the interstellar calcium lines.

## VI. A COMPARATIVE OBSERVATION OF THE 30 DORADUS NEBULA

In order to investigate the structure of the interstellar calcium lines at the center of the supergiant H II region 30 Dor (NGC 2070) in the Large Magellanic Cloud, a spectrogram of the central object (HD 38268 = Radcliffe 136) was obtained with the No. 1 coudé camera of the 1.5-m reflector on 1974 December 30, with an exposure time of 4 hours. The dispersion is 18.6 Å mm$^{-1}$ and the widening 0.4 mm; all other observational and reduction procedures were identical to those for the Carina spectrograms. Structure such as that found in the calcium lines in HD 93129 and 93250 (Fig. 1) would not be clearly seen at this dispersion, while profiles such as those in HD 93204 and 93205 would be quite obvious.

The following components are observed in the interstellar Ca II K (λ3933) line in the spectrum of HD 38268: (1) a well-marked component with velocity $+20.8$ km s$^{-1}$ and equivalent width 153 mÅ; (2) a strongly blended component at $+249.2$ km s$^{-1}$ with intensity 73 mÅ, which is probably real but requires confirmation; and (3) a principal component with velocity $+295.8$ km s$^{-1}$ and equivalent width 325 mÅ. This last velocity is in perfect agreement with that given by Feast, Thackeray, and Wesselink (1960) and Feast (1961). Also, the velocities of components 2 and 3 are in excellent accord with the two peaks in the [O III] λ5007 nebular emission line observed at the center of the nebula by Smith and Weedman (1972), through their smallest diaphragm.

The calcium component at $+20.8$ km s$^{-1}$ most likely arises within the Galaxy. The velocity is similar to those of several lines measured by Feast *et al.* (1960) in LMC stars near 30 Dor but outside the nebula, and ascribed a galactic origin by them. Strictly speaking, however, it is not possible to distinguish easily between a galactic component and a very highly blueshifted component formed in the nebula.

It is noteworthy that at the position of 30 Dor, the LMC rotation curve (Smith and Weedman 1972), the optical emission line averages (Smith and Weedman 1972), the radio recombination lines (Mezger *et al.* 1970), the 21-cm profile maximum (McGee and Milton 1966), and the stellar average (Feast 1961) all yield radial velocities within a few km s$^{-1}$ of $+270$ km s$^{-1}$. Moreover, it is curious that while the $+250$ km s$^{-1}$ emission-line peak observed at the center of the nebula by Smith and Weedman is stronger than the one at $+290$ km s$^{-1}$, the opposite is the case by far in the interstellar calcium profile. If a connection between the nebular emission and interstellar absorption lines is assumed (an interpretation favored by the close agreement of the velocities), the foregoing results could imply that the more positive-velocity material is in front of the central object, while most of the more negative-velocity material lies behind; that is, the gas would be flowing in toward the central object rather than away from it. An alternative possibility is that the calcium lines are not associated with the nebula at all, but rather with the larger-scale "spiral arm" features discussed by McGee and Milton, although in that case their conclusion that their $+300\ \mathrm{km\ s^{-1}}$ feature lies behind 30 Dor may require revision.

In summary, it is interesting that the central region of the far more massive 30 Doradus Nebula may lack structure in the interstellar calcium lines as extreme as that found in the Carina Nebula, although higher-resolution observations of the interstellar lines in the 30 Dor central object and other members of the complex may prove to be of considerable interest.

We thank Sres. Victor Pérez and Mancho Rojas for preparing the illustrations, and Sra. Elisa Bauer for typing the manuscript.

## APPENDIX

## STELLAR DISTANCE CONSIDERATIONS

1) *HD 93129.*—This star is the brightest of the very compact cluster Trumpler 14, for which a distance greater than that of Tr 16 was derived by Walborn (1973*a*). However, as was also pointed out, if Tr 14 were significantly younger than Tr 16, its early O main sequence members could be relatively subluminous and the distance difference would be reduced or eliminated. In view of the strong spectroscopic relationships of HD 93129 with the WN stars HD 92740, 93131, and 93162 (Walborn 1974), which are all at the 2600 pc distance, this latter possibility does not appear unlikely.

2) *Eta Carinae.*—The distance of this peculiar object is difficult to determine. However, it should be noted that the presence of high-velocity interstellar calcium components in its spectrum, which correspond with some of those in HDE 303308, definitely establishes that it is not a foreground object (in view of the conclusion reached in § IV*b*). The association of $\eta$ Car with Tr 16 and the Carina Nebula will be assumed here.

3) *HD 93206.*—As noted by Walborn (1973*a*), a straightforward evaluation of the distance modulus of this somewhat peculiar variable star would suggest a foreground object. However, the light curve shows two eclipses (Walker and Marino 1972), indicating that the absolute magnitude should be significantly brighter. Moreover, the discovery of He I $\lambda$3889 nebular absorption in its spectrum in the present study (§ V) establishes that it is at least as distant as the nebula.

4) *HD 92741 and 92964.*—These two stars are probably foreground objects, and their spectral types (B1 II and B2.5 Ia, respectively) do not suggest association with the very young O-type clusters within the nebula. If one assumes absolute magnitudes of $-5.0$ and $-7.0$ (Walborn 1972), respectively, the corresponding distances are 2100 and 1700 pc.

5) *HD 93843.*—The distance to this star is uncertain due to variability in its spectrum; however, it is *at least* as distant as the nebula (Walborn 1973*b*).

## REFERENCES


Adams, W. S. 1949, *Ap. J.*, **109**, 354.
Beals, C. S. 1936, *M.N.R.A.S.*, **96**, 661.
Bohuski, T. J., and Smith, M. G. 1975, in preparation.
Conti, P. S. 1974, private communication.
Conti, P. S., and Burnichon, M. L. 1975, *Astr. and Ap.*, in press.
Dickel, H. R. 1974, *Astr. and Ap.*, **31**, 11.
Dopita, M. A. 1974, *Nature*, **250**, 397.
Dyson, J. E. 1973, *Astr. and Ap.*, **23**, 381.
Feast, M. W. 1961, *M.N.R.A.S.*, **122**, 1.
Feast, M. W., Thackeray, A. D., and Wesselink, A. J. 1960, *M.N.R.A.S.*, **121**, 337.
Gardner, F. F., Milne, D. K., Mezger, P. G., and Wilson, T. L. 1970, *Astr. and Ap.*, **7**, 349.
Graham, J. A. 1965, *Observatory*, **85**, 196.
Hobbs, L. M. 1969, *Ap. J.*, **157**, 135.
Jones, B. B. 1973, *Australian J. Phys.*, **26**, 545.
Marschall, L. A., and Hobbs, L. M. 1972, *Ap. J.*, **173**, 43.
McGee, R. X., and Milton, J. A. 1966, *Australian J. Phys.*, **19**, 343.
Mezger, P. G., Wilson, T. L., Gardner, F. F., and Milne, D. K. 1970, *Ap. Letters*, **5**, 117.
Münch, G. 1965, in *Galactic Structure*, ed. A. Blaauw and M. Schmidt (Chicago: University of Chicago Press), p. 203.
Nachman, P., and Hobbs, L. M. 1973, *Ap. J.*, **182**, 481.
Ostriker, J. P., and Gunn, J. E. 1971, *Ap. J.* (*Letters*), **164**, L95.
Pikel'ner, S. B. 1968, *Ap. Letters*, **2**, 97.
———. 1973, *Comments Ap. and Space Phys.*, **5**, 151.
Routly, P. M., and Spitzer, L. 1952, *Ap. J.*, **115**, 227.
Siluk, R. S., and Silk, J. 1974, *Ap. J.*, **192**, 51.
Smith, M. G. 1972, *Astr. and Ap.*, **16**, 482.
Smith, M. G., and Gull, T. R. 1974, private communication.
Smith, M. G., and Weedman, D. W. 1972, *Ap. J.*, **172**, 307.
Strömgren, B. 1948, *Ap. J.*, **108**, 242.
Thackeray, A. D. 1956, *Observatory*, **76**, 103.
Walborn, N. R. 1971*a*, *Ap. J.* (*Letters*), **167**, L31.
———. 1971*b*, *Pub. A.S.P.*, **83**, 811.
———. 1972, *A.J.*, **77**, 312.
———. 1973*a*, *Ap. J.*, **179**, 517.
———. 1973*b*, *A.J.*, **78**, 1067.
———. 1974, *Ap. J.*, **189**, 269.
Walker, W. S. G., and Marino, B. F. 1972, *IAU Inform. Bull. Var. Stars*, No. 681.
Wallerstein, G., and Silk, J. 1971, *Ap. J.*, **170**, 289.
Wilson, O. C., Münch, G., Flather, E. M., and Coffeen, M. F. 1959, *Ap. J. Suppl.*, **4**, 199.


JAMES E. HESSER and NOLAN R. WALBORN: Cerro Tololo Inter-American Observatory, Casilla 63-D, La Serena, Chile