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THE MASSIVE MULTIPLE SYSTEM HD 93206 (QZ CARINAE) IN THE GREAT CARINA NEBULA

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ABSTRACT

From photographic coudé spectrograms and published photoelectric light curves, it is found that HD 93206 (QZ Carinae) consists of at least four stars: a B0 Ib star which orbits an unseen star of deduced spectral type O9 V in 5.9983 days and an O9.7 Iab star with an unseen companion in a 20.72 day orbit. Both pairs probably revolve around a common barycenter in less than 25 years with maximum angular separation of about 0".012. The combined magnitudes of the four stars make HD 93206 the brightest object in the young Carina cluster Collinder 228, although it does not contain the brightest individual star.

Spectroscopic and photometric solutions are obtained for the short-period pair. This system is semi-detached (the primary eclipse is total), consisting of a contact component, the 16.7 $M_\odot$ B0 Ib star, and a detached component, the 28 $M_\odot$ O9 V star. Assuming QZ Car to be a member of Cr 228, the detached component is not found to be under-luminous for its mass. It is conjectured that this subsystem has undergone case-B mass transfer.

Subject headings: nebulae: individual — stars: binaries — stars: early-type — stars: eclipsing binaries — stars: individual

I. INTRODUCTION

At 6th magnitude, HD 93206 ($\alpha_{2000} = 10^{h}44^{m}.4$, $\delta_{2000} = -60°00'$) is the brightest star seen in the direction of the young Carina star cluster Collinder 228. The second-brightest star is HD 93131, a probably single Wolf-Rayet star of the luminous type WN7 (Moffat and Seggewiss 1978). HD 93206 is listed as QZ Carinae in the *General Catalogue of Variable Stars* as a result of the variable light curve obtained by Walker and Marino (1972). Their data indicate that HD 93206 is an eclipsing binary, with a period of 6.000 ± 0.007 days and a light curve possibly of the β Lyrae type. In a study of some of the luminous, hot stars in the Carina Nebula, Walborn (1973) assigned a spectral type of O9.7 Ib:(n), while Conti, Leep, and Lorre (1977) gave O9 Ib(f) for HD 93206. Thus, according to Herbst (1976), who gives the most comprehensive list of spectral types for stars in the Carina Nebula, it is one of three O9–B2 supergiants whose colors fit as a member of Cr 228. However, treated as a single star, HD 93206 would appear to be in the foreground. The earliest spectral type of stars in Cr 228, O5 V (Herbst 1976) makes Cr 228 somewhat older than the adjacent η Carina clusters, Trumpler 14 and 16, which contain extremely young O3 V stars. The distance of Cr 228 has been obtained by Feinstein, Marraco, and Forte (1976) from a comprehensive photoelectric study in *UBV*. They obtained a distance modulus of 12.0 ± 0.2 compared to 12.2 given by Walborn (1973) from spectroscopic parallaxes of three stars. We adopt a modulus of 12.2 ± 0.2 for Cr 228 (and therefore also for HD 93206) which leads to a distance of 2.8 kpc.

With out-of-eclipse visual magnitude $V = 6.23$ (Walker and Marino 1972), $E_{B-V} = 0.40$ (Herbst 1976), and $A_V/E_{B-V} = 3$, HD 93206 has an absolute magnitude $M_V = -7.2 \pm 0.2$ as a member of Cr 228. A single star of type O9.7 Ib would have $M_V = -5.9 \pm 0.2$ (Crampton and Georgelin 1975); the difference of 1.3 ± 0.3 mag therefore deviates significantly from zero and, as a nearly central member of the cluster, strongly implies the presence of light from another (other) star(s) at least as bright as the O9.7 Ib component. Since a second star has not previously been explicitly noted in the spectrum, we initiated a high-dispersion spectroscopic investigation of HD 93206 to look for a velocity orbit of at least two stars and to derive their masses.

II. LIGHT CURVE AND PERIOD

Before attempting a spectral analysis we first need a precise estimate of the period. This can be best obtained from two fairly complete sets of published

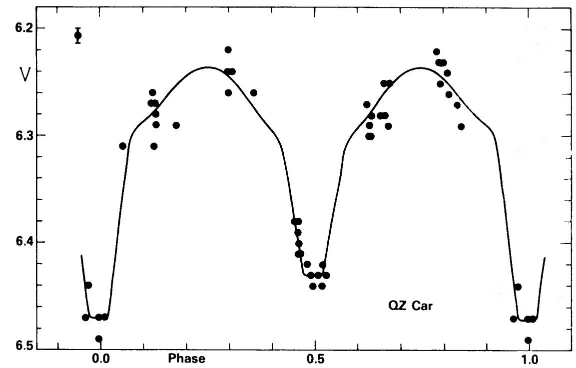

FIG. 1.—V observations of Walker and Marino (1972) phased according to the improved ephemeris in the text. The theoretical light curve based on the parameters in Table 3 is drawn in.

photometric data: Walker and Marino's (1972) V observations (see Fig. 1) give an ephemeris of primary minimum

$$\text{JD } 2{,}441{,}033.06(\pm 0.20) + 6.000(\pm 0.007)E\,.$$

Note that the principal epoch published by these authors is wrong by 3.00 days, judging from their given civil dates and their journal of observations. Moffat's (1977) observations through a filter centered at 5170 Å with half-intensity width 190 Å yield the ephemeris

$$\text{JD } 2{,}442{,}472.64(\pm 0.10) + 5.98(\pm 0.10)E\,.$$

Combining these (5 years time base) we obtain an improved period and the finally adopted ephemeris is

$$\text{JD } 2{,}442{,}472.64(\pm 0.10) + 5.9983(\pm 0.0009)E\,.$$

It should be noted that the light curve is only half complete; international cooperation is probably needed to complete it since the period is very close to 6.000 days. The depths of primary and secondary minima are 0.24 and 0.20 mag, respectively. We leave the interpretation of the light curve until after analysis of the radial-velocity orbit.

III. SPECTROSCOPY

We have a total of 16 spectra at 12 Å mm^{-1} taken on N_2-baked IIa-O plates at the coudé focus of the ESO 1.5 m telescope. Three plates were taken on three consecutive nights in 1977 (exposure time ~5–10 min) and 13 plates on seven consecutive nights in 1978 (~15 min). A journal of observations is presented in Table 1.

Log intensity tracings of the Hδ/Si IV and He I 4471 Å regions of the three 1977 plates are depicted in Figure 2. These are typical and show that, using the above ephemeris, the lines near phase zero are deep and sharp while at phases 0.87 and 0.24 they separate into two components of nearly equal spectral type. Inspection of other lines and other spectrograms at phases of good line separation, and reference to the Kitt Peak Spectral Atlas (Abt *et al.* 1968) yield the spectral types given in Table 4 (stars 1 and 2). By definition, component 1 is taken to be the O-type supergiant with the deeper lines, while component 2 is the B0 supergiant. There is no evidence in our spectra of even weak emission at He II 4686 Å as found by Conti *et al.* (1977); possibly this feature is variable on a long time scale. The spectral types are compatible with the relative line strengths. The He I and Si IV lines (well separated at quadrature) are 1.5–2.0 times

TABLE 1

JOURNAL OF SPECTROSCOPIC OBSERVATIONS WITH MEAN PLATE VELOCITIES (km s^{-1}) OF RELATIVELY SHARP LINES OF He I (λλ4472, 4026, 3820) AND Si IV (λ4089) AND OF BALMER LINES (Hγ, H8–H11)

Plate No.	JD (2,443,000+)	Phase	Component 1 He I/Si IV	n	Component 1 H	n	Component 2 He I/Si IV	n	Component 2 H	n
G 8278.......	209.646	0.869	+42 ± 10	4	+24 ± 13	5	−219 ± 5	4	−197 ± 53	5
G 8293.......	210.633	0.033	+36 ± 16	4	+28 ± 20	5	−55 ± 51	3	−57	1
G 8312.......	211.861	0.238	+27 ± 12	4	+14 ± 24	5	+212 ± 35	3	+191	1
Mean 1977..............................			+35 ± 8	3	+22 ± 7	3				
G 9069.......	528.767	0.071	−16 ± 10	4	−12 ± 12	5	+66	1	+92	1
G 9075.......	529.706	0.228	−25 ± 10	4	−26 ± 12	4	+237 ± 16	3	+236 ± 39	5
G 9079.......	529.751	0.235	−18 ± 4	4	−23 ± 19	5	+222 ± 22	3	+254 ± 81	5
G 9091.......	530.780	0.407	−1 ± 10	4	−1 ± 7	5	+110 ± 21	3	+118 ± 30	5
G 9101.......	531.773	0.572	−9 ± 12	4	−24 ± 17	5	−172 ± 20	4	−180 ± 38	5
G 9106.......	531.835	0.583	−16 ± 13	4	−40 ± 24	5	−202 ± 8	4	−194 ± 12	5
G 9107.......	531.847	0.585	−13 ± 8	4	−27 ± 9	5	−202 ± 13	4	−207 ± 54	5
G 9111.......	532.708	0.728	−8 ± 16	4	−4 ± 12	4	−266 ± 46	4	−230 ± 33	4
G 9115.......	532.875	0.756	+2 ± 4	4	−8 ± 12	5	−301 ± 22	4	−276 ± 40	5
G 9119.......	533.728	0.898	+11 ± 12	4	+4 ± 11	5	−194 ± 21	4	−174 ± 20	5
G 9122.......	533.890	0.925	+3 ± 13	4	−22 ± 13	5	−137 ± 36	4	−142 ± 14	4
G 9128.......	534.745	0.068	+21 ± 4	4	+13 ± 10	5	+73	1	−48	1
G 9131.......	534.877	0.090	+22 ± 7	4	+23 ± 8	5	+91	1	+104 ± 33	2
Mean 1978..............................			−4 ± 15	13	−11 ± 18	13				

NOTE.—All errors are standard deviations. The phases were calculated using the ephemeris in the text. Overall mean interstellar line velocities are as follows: Interstellar Ca II (H, K) = +0.6 ± 2.6, n = 16; interstellar He I (λ3889) = −10.9 ± 3.9, n = 16.

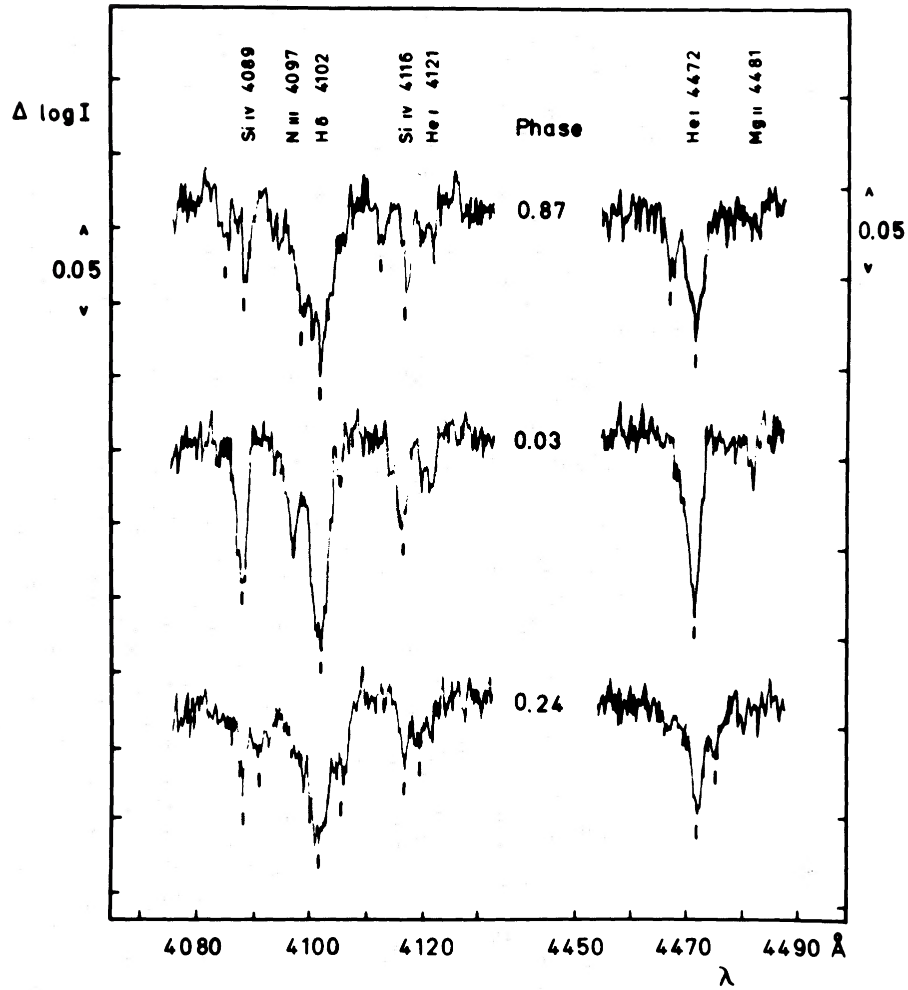

FIG. 2.—Log intensity tracings of the 1977 coudé spectrograms of HD 93206 for the regions around Hδ and He I 4472

stronger in component 1 than in 2, implying a difference in absolute magnitude $M_{V2} - M_{V1} = 0.60 \pm 0.15$. The spectral types give a similar difference of 0.5 ± 0.3 based on the calibration of Crampton and Georgelin (1975). More definitive values of the absolute magnitudes will be estimated in § VII.

Radial velocities (see Table 1) were measured using the ARCTURUS oscilloscope measuring machine at the Dominion Astrophysical Observatory. The relatively sharp lines of He I and Si IV give the most reliable velocities for both components while the intrinsically wider Balmer lines, although measured, were not used to derive orbital parameters. In any case, all lines measured for a given star on a given plate yield the same mean velocity. The interstellar H and K lines of Ca II give a mean velocity which is ~ 4 km s^{-1} larger in 1977 than in 1978. In view of the small number of plates in 1977, no correction is made for this small difference.

Radial velocities of components 1 and 2 are plotted in a phase diagram in Figure 3 using the above 6-day ephemeris. While component 2 shows a large amplitude orbit, component 1 does not appear to participate in such an orbit. In fact, it appears to exhibit smaller velocity variations on a slower time scale. From independent spectroscopic data, Morrison and Conti (1979) find that component 1, the O9.7 Iab star, oscillates in velocity with a period of 20.72 ± 0.01 days. It therefore appears that HD 93206 is composed of four stars, only two of which are bright enough to be seen in the composite photographic spectrum. We now discuss each pair in turn.

IV. ORBIT ANALYSIS OF COMPONENT 2 (B0 Ib)

Due to the possible long-term mutual orbital motion of each close pair's barycenter about a common mass center, we derive the orbital elements of component 2 from the more complete 1978 spectroscopic observations (of He I and Si IV) only. Combining 1977 and 1978 data could lead to systematic deviations of one epoch from the other. An initial solution of the orbit

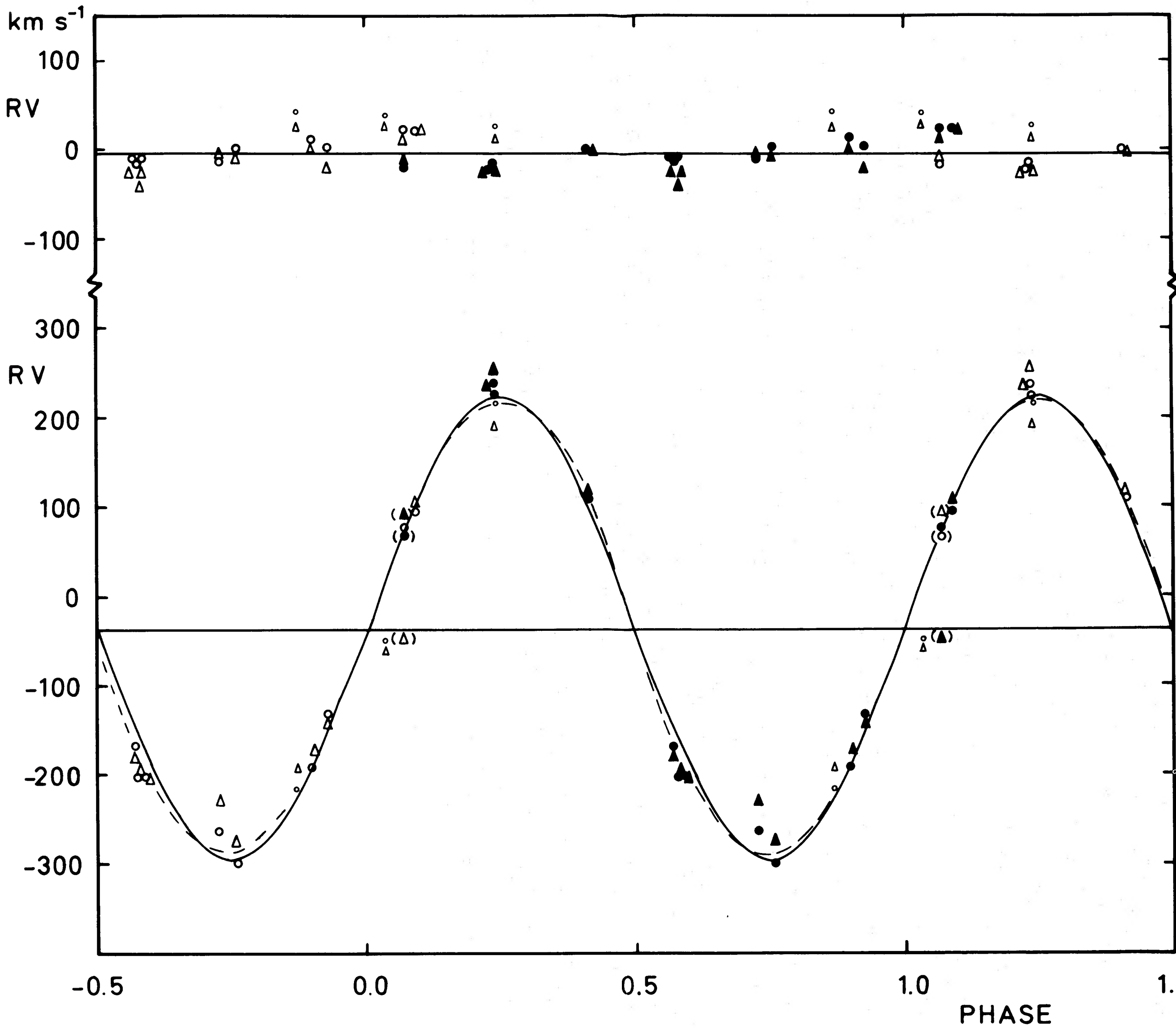

FIG. 3.—Radial velocity curve of HD 93206 (QZ Car) phased with the 6 day ephemeris in the text: *upper*, component 1; lower, component 2. The solid curve is a sine wave according to the velocity elements in the text; the dashed curve allows for the additional effects due to Rossiter effect and distortion. Large symbols refer to 1978 observations, small symbols to 1977. Closed symbols are actual observations, open symbols are phase shifted. Circles refer to mean velocity from the lines of He I (4471, 4026, and 3820 Å); triangles to the Balmer lines of Hγ, 8, 9, 10, and 11.

yields the eccentricity $e = 0.04 \pm 0.03$. Since this does not differ significantly from zero, we assume $e = 0.00$ and find the remaining parameters:

$$\text{velocity semiamplitude } K_2 = 260 \pm 10 \text{ km s}^{-1} ,$$

$$\text{systemic velocity } \gamma_2(1978) = -36 \pm 11 \text{ km s}^{-1} ,$$

$$\text{rms deviation (O} - \text{C) } \sigma_2 = 20 \text{ km s}^{-1} .$$

The Balmer lines yield $K_2 = 237 \pm 19, \gamma_2 = -4 \pm 23$, $\sigma_2 = 39$, values which overlap with those above but which are of lower precision. We therefore adopt the former. The time of ascending of star 2 through its γ-velocity is JD 2,443,528.28 $\pm$ 0.07, which is smaller than phase zero predicted by the light curve ephemeris by 0.06 $\pm$ 0.20 days. This is insignificantly different from zero. Thus component 2 passes in front of a less luminous star at phase zero. We refer to this unseen companion as component 3.

From the radial velocity orbit of component 2, we derive the following mass function:

$$f_3(m) \equiv \frac{(m_3 \sin i)^3}{(m_2 + m_3)^2} = 10.9 \pm 1.2 \, M_\odot .$$

The errors quoted in §§ IV and V are standard deviations.

V. ORBIT ANALYSIS OF COMPONENT 1 (O9.7 Iab)

The present observations were obtained with the aim of determining an orbit corresponding to the observed 6 day light curve and therefore do not give sufficient phase coverage to fix an orbit for the brighter star (component 1) and its unseen companion (component 4). We therefore adopt the preliminary elements for component 1 derived from several years of 18 Å mm^{-1} coudé data by Morrison and Conti (1979). They obtained $P_1 = 20.72 \pm 0.01$ days, $e_1 = 0.34 \pm 0.04$, $\omega_1 = 126 \pm 11°$, $K_1 = 48$ km s^{-1}, and $\gamma_1 = -8$ km s^{-1}. Adopting their values of P, e, ω, and K and forcing the orbit through the present data (1977 and 1978; see Fig. 4) yield $\gamma_1 = +4$ km s^{-1} and the ephemeris of phase zero when star 1 increases through its γ velocity:

$$\text{JD } 2{,}443{,}532.72 + 20.72\,E\,.$$

Morrison and Conti (1979) found a mass function of

$$f_4(m) \equiv \frac{(m_4 \sin i)^3}{(m_1 + m_4)^2} = 0.198 \pm 0.026\,.$$

Taking a nominal value of 40 $M_{\odot}$ (§ VII) for the mass of component 1 and a most likely orbital inclination of 60° yields a rough mass $m_4 \approx 9\ M_{\odot}$. The inclination need not be identical for both subsystems (see Batten 1973). The fact that the γ-values differ may be a result of the slow motion of a wide orbit.

VI. PHOTOMETRIC SOLUTION

The fact that the period of the eclipsing system (i.e., components 2 and 3) is very close to 6 days makes it extremely difficult to obtain good coverage of the light curve. The observations by Moffat (1977) were acquired using a very different photometric system than that of Walker and Marino (1972), and unfortunately also covered nearly the same phase intervals. In our analysis, we adopt the approach of Wilson and Devinney (1971). The general procedure to arrive at a photometric solution is described in the article by Schneider, Darland, and Leung (1979). The adjustable parameters employed are: inclination, i; temperature of component 3, T_3; surface potential of component 3, Ω_3; mass ratio, m_2/m_3; luminosity of component 2, L_2; and the "third light," $l_{(1+4)}$. The unadjusted and assumed parameters are listed in Table 3. As is to be expected from such poor coverage of the light curve (Fig. 1), multiple solutions were found. (For problems related to multiple solutions, see Leung and Schneider 1978*a*, *b*).

TABLE 2

SELECTED PARAMETERS FROM SOLUTIONS OF QZ CARINAE (HD 93206)

	Fraction of Total Light				
Solution	comp. 1*	comp. 2	comp. 3	m_2/m_3	i
A........	0.25	0.44	0.31	0.76	71°
B........	0.50	0.28	0.22	1.56	75°
C........	0.50	0.29	0.21	0.76	79°
D........	0.49	0.38	0.13	0.60	86°

* Representing the combined light of components 1 and 4. It is also assumed that the latter is negligibly faint.

TABLE 3

PHOTOMETRIC PARAMETERS (Solution D) FOR QZ CARINAE (HD 93206)

i	85°9 ± 2°7
$(L_1 + L_4)/(L_1 + L_2 + L_3 + L_4)$	0.484 ± 0.060
$L_2/(L_1 + L_2 + L_3 + L_4)$	0.380 ± 0.022
$L_3/(L_1 + L_2 + L_3 + L_4)$	0.131 ± 0.012
X_2	0.24*
X_3	0.23*
$\Omega_2 = \Omega_{\rm inner}$	3.056
Ω_3	6.12 + 0.84
$g_2 = g_3$	1†
$A_2 = A_3$	1†
T_2 (K)	30,000‡
T_3 (K)	32,463 ± 178
m_2/m_3	0.60 ± 0.11
r_2 (pole)	0.314 ± 0.012
r_2 (side)	0.327 ± 0.012
r_2 (back)	0.360 ± 0.013
r_2 (point)	0.428 ± 0.016
r_3 (pole)	0.181 ± 0.027
r_3 (side)	0.182 ± 0.028
r_3 (back)	0.183 ± 0.028
r_3 (point)	0.183 ± 0.029
Period (days)	5.9983 ± 0.0009

* Linear limb-darkening coefficients derived from the grid model atmosphere of Carbon and Gingerich 1969.

† Assumed value.

‡ Assumed temperature from spectral type and Morton's 1969 temperature calibration.

Fortunately, there are several constraints imposed by the spectroscopic observations, by the extremely small color variations (Walker and Marino 1972), and by the small difference in the eclipse depths of the photoelectric light curves. The constraints are: (1) component 1, the O9.7 Iab star, is brighter than component 2, the B0 Ib star, by several tenths of a magnitude; (2) component 3 (the unseen companion of component 2) must be fainter than the B0 Ib star by at least 0.8 mag in order not to be seen in the spectrum; (3) component 3, which is eclipsed at primary minimum, is slightly hotter or earlier in spectral type than B0. These indicate component 3 to be a hotter but much smaller star than component 2.

In our analysis, we found four sets of parameters (or solutions) which equally satisfy the observations better than any other set. They all suggest semidetached configurations in which component 2 fills its Roche lobe. The relevant photometric parameters are collected in Table 2. Solution A requires that the B0 Ib star (component 2) be appreciably brighter than the O9.7 Iab star (component 1). Both solutions B and C require that the unseen component have a luminosity similar to the B0 Ib star. Only solution D is astrophysically meaningful with respect to the constraints outlined above. The inclination for this solution indicates that the primary eclipse is total. This agrees with Walker and Marino's (1972) comment that the eclipses at the minima are of relatively long duration.

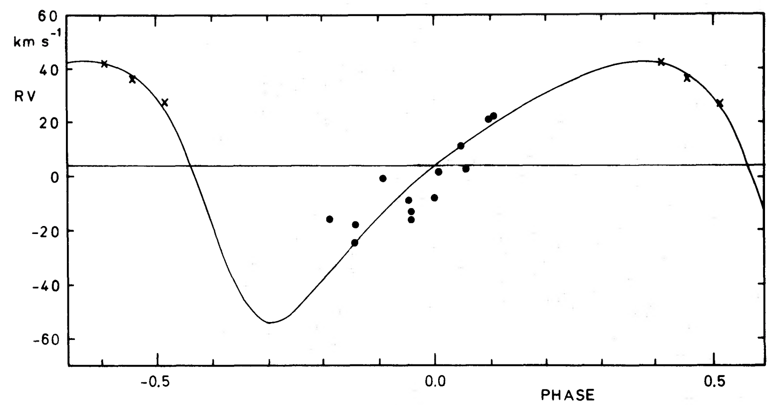

FIG. 4.—Radial-velocity curve of the O9.7 Iab star, component 1, phased according to Morrison and Conti's (1979) orbital elements (P = 20.72 days, e = 0.34, ω = 126°, K = 48 km s^{-1}). The zero points of both axes were force-fitted to the present data (*dots*, 1978; *crosses*, 1977).

Thus, solution D is adopted for this study, the photometric parameters of which are listed in Table 3, along with their internal probable errors. The semidetached configuration of QZ Car (components 2 and 3) at phase 0.25 is shown in Figure 5. There is considerable tidal distortion for the B0 Ib component. The theoretical light curve according to the parameters in Table 3 is shown as a smooth line in Figure 1. In view of the very limited coverage and the appreciable scatter, the agreement between the computed and observed light curves is good. It is suggested that a further improvement of the period may be necessary and/or the system may have an unstable light curve. Obviously, new observations are needed to improve on the photometric solution of this interesting system.

As mentioned earlier, there is considerable tidal distortion in the B0 Ib star (Fig. 5). This will affect the measured radial velocities of this component as follows: When the effects of tidal distortion, reflection, and eclipses are taken into account, the radial-velocity curve will not be sinusoidal in shape even if the eccentricity of the orbit is zero (see Wilson and Sofia 1976, for details of the computation technique). The computed radial-velocity curve for QZ Car with these effects included is shown as a broken line in Figure 3. This curve gives a slightly better fit to the observations.

VII. ABSOLUTE DIMENSIONS

With the radial velocity semiamplitude of component 2, K_2, and the photometric parameters from Table 3, we calculate the radii and masses of the eclipsing subsystem of QZ Car. The results, with their associated internal probable errors, are listed in Table 4. Since the quadruple system is a likely member of Cr 228 (§ I), the absolute visual magnitude of the combined light is known ($M_v = -7.2$). Combining this with the light fractions in Table 3, we derive the individual absolute visual magnitudes of the three components (assuming the fourth component to be insignificantly faint). The resulting M_v's are listed in Table 4. The effective surface temperatures of components 1 and 2 (Table 4) are adopted from Morton's (1969) temperature calibration. The temperature of component 3 was obtained from the photometric solution. The spectral type estimated for this unseen star is O9 according to Morton's calibration. The mass and radius of this star (Table 4) are essentially that of a zero-age main-sequence star (Stothers 1972). Therefore, a spectral-luminosity class of O9 V is suggested for component 3. From the adopted temperatures, the derived M_v's, and the appropriate bolometric corrections (Morton 1969), we calculate the bolometric magnitudes of the stars. The results are listed in Table 4. The radius of the O9.7 Iab star is determinated from its temperature and bolometric magnitude. Unfortunately, a direct determination of its mass is not possible. However, its location in the H-R diagram compared to the evolutionary models of Stothers (1972) suggests a mass of roughly 40 $M_\odot$. Direct information on absolute dimensions for its companion (component 4) is totally lacking, although a rough idea of its mass can be obtained from the mass function (§ V).

Component 2 (B0 Ib) appears to rotate nearly synchronously with its 6 day orbital motion: From the narrowest measurable lines (He I 4471 Å, Si IV 4089 Å) at or near quadrature, their half-width where they

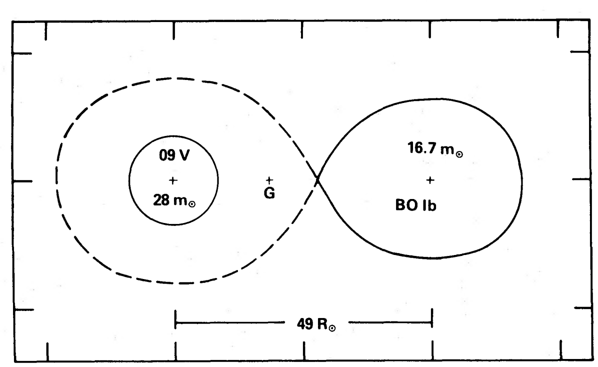

FIG. 5.—Configuration of QZ Car (HD 93206), components 2 and 3, at 0.25 phase. The broken lines represent the inner surface potential. The center of the components as well as the center of gravity are denoted by plus signs.

TABLE 4

ABSOLUTE DIMENSIONS OF QZ CARINAE (HD 93206)

Component	Sp	Teff (K)	Radius ($R_\odot$)	Mass ($M_\odot$)	M_v	M_{bol}
1............	O9.7 Iab	32,000	22.5 ± 2.6	(40)	-6.4 ± 0.3*	-9.4 ± 0.3*
2............	BO Ib	30,000	16.1 ± 2.4	16.7 ± 5.4	-6.2 ± 0.3	-9.1 ± 0.3
3............	O9 V	32,463	8.9 ± 2.4	28.0 ± 7.2	-5.0 ± 0.3	-8.1 ± 0.3
4†..........	(B2 V)	...	...	(9)	(-2.3)	...

NOTE.—Separation of components 2 and 3: $49.2 \pm 5.4\ R_\odot$.

* Assuming its companion, component 4, is relatively faint.

† Assuming an orbital inclination of 60° and a main-sequence star.

intersect the continuum is $\Delta\lambda/\lambda \sim (3.0 \pm 0.5) \times 10^{-4}$. With $i = 85.^\circ9$, the observed equatorial rotational velocity is thus $v_{\rm rot}({\rm obs}) = 90 \pm 15$ km s^{-1}. With a radius of $R_2 = 16.1 \pm 2.4\ R_\odot$, the synchronous rotational velocity would be $v_{\rm rot}({\rm synch}) = 2\pi R_2/P = 137 \pm 20$ km s^{-1}. In view of the uncertainties involved, agreement is satisfactory. The eclipse (Rossiter) effect in Figure 3 supports the synchronous rotation for the system.

VIII. THE WIDE ORBIT OF THE TWO PAIRS

The fact that the systemic γ-velocities of component 1 in the 1,4 pair and component 2 in the 2,3 pair are not identical implies that these two systems are revolving around a common center of mass. Letting Γ represent the overall center of mass velocity of the whole system, assumed to be composed of these four stars only, we find

$$\Gamma = \frac{(m_2 + m_3)\gamma_2 + (m_1 + m_4)\gamma_1}{m_2 + m_3 + m_1 + m_4} = -15 \text{ km s}^{-1} ,$$

after substitution for the masses from Table 4 and $\gamma_1 = +4$ km s^{-1}, $\gamma_2 = -36$ km s^{-1} from the 1977/1978 data. This velocity is similar to the radial velocities of other O and B stars which belong to the same part of the Carina nebula complex (see Moffat and Seggewiss 1978).

Further constraints can be obtained by assuming a circular orbit of period P, radius a, inclination $i = 60°$, and values of velocity semiamplitude

$$K_{14} \gtrsim |\gamma_1 - \Gamma|_{1977/78} = 19 \text{ km s}^{-1} .$$

Thus

$$P = \frac{(m_2 + m_3)^3 \sin^3 i}{(m_1 + m_4 + m_2 + m_3)^2 1.038 \times 10^{-7} K_{14}{}^3} \lesssim 25.4 \text{ years} ,$$

and

$$a \sin i = 13{,}751(K_{14} + K_{23})P \lesssim 5.1 \times 10^9 \text{ km} .$$

Therefore, the mean angular separation is $a \sin i/d(=2800 \text{ pc}) \lesssim 0.''012$ which necessitates the use of interferometric techniques to observe it.

IX. DISCUSSIONS

The semidetached configuration of the subsystem 2–3 of QZ Car (Fig. 5) suggests that it is evolved. The evolved B0 Ib star (less massive than the relatively unevolved O9 V star) was originally the more massive component. A considerable portion of its mass must have been lost to its companion through Roche-lobe overflow. It is believed that the rapid phase of mass transfer (i.e., mass ratio reversal phase) has been accomplished; the system is presently in its slow phase of mass loss. The locations of components 2 and 3 in the mass-radius diagram are shown in Figure 6. [The zero-age main sequence (ZAMS) and terminal-age main sequence (TAMS) are taken from Stothers 1972, for initial composition of $X_e = 0.739$ and $Z_e = 0.044$.] Similar systems having well-determined absolute dimensions (i.e., through the more realistic Roche-model approach) are also shown in the same diagram. Due to the uncertainties associated with the photometric solution (as a direct result of poor coverage of the observed light curve), the error bars for QZ Car are appreciably larger than the other systems: BF Aur, μ^1 Sco, and V Pup (Schneider, Darland, and Leung 1979); SX Aur (Chambliss and Leung 1979). The detached, massive O9 V component of QZ Car is very similar to the corresponding components of μ^1 Sco and V Pup in the sense that they closely follow the ZAMS mass-radius relation. This suggests that the mass-gaining components have sufficient time to absorb the additional mass and settle down as normal main-sequence stars. The luminosity of the detached component (3) of QZ Car, derived from cluster membership of Cr 228, indicates that it is normal for its mass. Stothers and Lucy (1972) and Stothers (1973) found that mass-accreting components tend to be under-luminous for their masses owing to fast differential rotation induced by mass transfer. Wilson and Caldwell (1978) and Schneider, Darland, and Leung (1979) suggested that the appearance of under-luminosity may be caused by systematic misclassification of spectral type (due to the cooler companion), since the luminosity is calculated from the spectral temperature.

The facts that the contact (B0 Ib) component of QZ Car lies above the TAMS line (Fig. 6) and that the orbital period is fairly long (6 days), make the system a likely candidate for case-B mass transfer. Observational evidence for case B is sparse in the literature: for semidetached systems, one has β Lyr (see Wilson 1974), V356 Sgr (Wilson and Caldwell 1978), and BF Aur (Schneider, Darland, and Leung 1979, for the case of mass ratio equal to 1.20); for contact systems, one

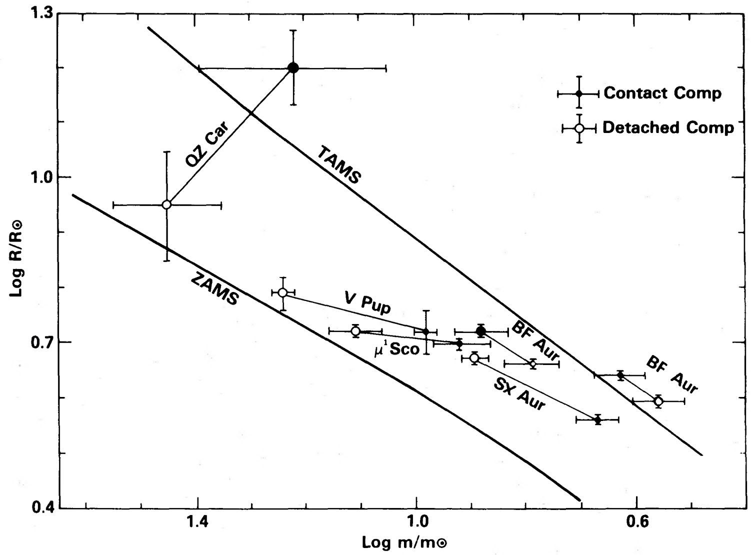

FIG. 6.—Mass-radius diagram depicting the location of components 2 and 3 of QZ Car with respect to the zero-age main sequence (ZAMS) and the terminal-age main sequence (TAMS). The locations of similar early-type systems are also shown. The filled circles represent Roche-lobe–filled components.

has V729 Cyg (Leung and Schneider 1979). With spectral types B0 Ib + O9 V, this subsystem of QZ Car is the earliest among the known semidetached systems. On the contrary, from an evolutionary lifetime point of view, this system could be a case-A mass transfer.

X. CONCLUSION

HD 93206 (QZ Car) consists of two close binaries, each with a total mass of about 45 $M_\odot$. By virtue of its combined light, HD 93206 is the most luminous object in the very young open cluster Cr 228 near η Carina. However, the most luminous individual star in Cr 228 appears to be the single WN7 star HD 93131, whose progenitor mass must have been greater than 35–40 $M_\odot$ (Moffat and Seggewiss 1978). The individual spectral types of the four stars in HD 93206 are similar to other stars in CR 228 (see Herbst 1976). It is also interesting to note that component 1 is identical in spectral type with the 5.600 day single-line binary HD 226868 (O9.7 Iab) associated with the X-ray source Cyg X-1.

The eclipsing pair (components 2 and 3), which has a semidetached configuration, consists of a B0 Ib star (contact component) and an unseen O9 V star. Absolute dimensions were determined by combining the photometric and spectroscopic results. The mass-gaining component is a normal main-sequence star and has not been found to be under-luminous for its mass. It is suggested that the system has undergone case-B mass transfer. The primary (O9.7 Iab) of the other spectroscopic binary may be a normal evolved early-type supergiant with a mass of about 40 $M_\odot$. It is also suggested that the period of revolution of each system about a common barycenter may be as much as 25 years.

Due to the poor coverage of the light curve of the eclipsing binary, the photometric solution should not be taken to be definitive. It is strongly recommended that an international observational program be scheduled for this interesting and important system. In view of the very large inclination of 86° (total eclipse), accurate parameters could be deduced from it.

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