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A PHOTOMETRIC STUDY OF THE CLOSE BINARY DELTA ORIONIS A

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ABSTRACT

Green and blue photoelectric light curves show the historical intrinsic variability of the δ Ori A close binary superposed on the interaction and eclipse effects. There is a considerable measure of agreement between spectrographic and photometric determinations of the rate of apsidal advance. The determinacy of orbital eccentricity, however, is confused because few minima of indifferent precision exist to check the spectrographic value. No physical mechanism can be found to account for a possible diminution of orbital eccentricity, and this is probably best attributed to unrecognized complications of at least one of the existing light curves. After numerous trials, a less-than-perfect theoretical representation of the light curve was achieved and shows the system to be detached. The absolute stellar parameters make clear that both components have evolved substantially. A mean stellar structure constant k_2 is derived but cannot be compared usefully to existing theoretical values. The importance of the recently discovered visual companion, hz 42, is emphasized.

Subject headings: stars: eclipsing binaries — stars: individual

I. INTRODUCTION

The hot close binary δ Ori A (34 Ori, HR 1852, BD −0°983, HD 36486, ADS 4134 A) continues to be an important object for studying O-star atmosphere and envelope processes, bulk stellar parameters, and stellar evolution. This accounts for its appearance, for instance, in the studies by Snow and Morton (1976), Hutchings (1975), and Stothers (1972). At the same time, the binary has shown many manifestations of intrinsic variability in its light curve (Stebbins 1915; Worley 1955), radial velocity curve (Luyten, Struve, and Morgan 1939), and line profiles (Snow and Hayes 1978). In fact, the only observational characteristic thought to be constant is the visible-band polarization (Snow and Hayes), which is ascribed entirely to interstellar scattering. Many other historical references are not cited here.

II. OBSERVATIONS AND LIGHT CURVES

Because δ Ori A (hereafter, δ Ori) has not been systematically observed for more than 25 years, we placed it on the 1978 observing program at Flower and Cook Observatory. Over two observing seasons it was measured with the simultaneous two-source, pulse counting Pierce-Blitzstein photometer coupled to the 38 cm refractor. The comparison star, BD −0°1000 (HD 36840), was checked against BD −0°1005 (HD 36898) and showed no evidence of variability. The instantaneous differential extinction, though small, was always calculated and removed. All these stars are so bright that it was necessary to use neutral density filters to attenuate the fluxes so as to avoid large pulse coincidence corrections. The counting time was typically 0.0005 days. Green and blue filters were used with spectrally matched RCA 4509 multiplier photocells, which are similar to commercially available RCA 8645 detectors. For each bandpass, about 350 observations were accumulated over 46 nights. These observations are not published here but have been compiled into the phase-averaged points listed in Table 1. Since the average standard deviation for the means of Table 1 is ±0.003 mag, the noise of the light curves shown in Figure 1 must be intrinsic to the variable. Since the observations of a given night span only a brief time interval, it is impossible to test if the intrinsic variability is periodic. This variability, whether within a night or on a night-to-night comparison, is about at the level previously found by Stebbins (1915), Storer (1930), Worley (1955), Johnson *et al.* (1966), and probably also by Cousins (1963). It must be considered an enduring characteristic of at least one of the stars of the system.

III. LIGHT EPHEMERIS

The ephemeris used to compute the phases of Table 1 is:

$$\text{Heliocentric Primary Minimum} = 2419068.20 + 5.732476\,E, \quad (1)$$

the epoch being due to Stebbins and the period being slightly different from his value. Although there remains confusion concerning the results of Hnatek (1920) and Miczaika (1951), the comprehensive studies by Natarajan and Rajamohan (1971) and Monet (1980)

TABLE 1

AVERAGE OBSERVATIONS OF δ ORIONIS

(JD-2440000.)	Phase	$(V-C)_g$	(JD-2440000.)	Phase	$(V-C)_b$
3865.6875	0.7900	-4.404			
3870.7290	0.6695	4.421	3870.7386	0.6711	-5.135
3871.6342	0.8274	4.414	3871.6288	0.8264	5.150
3872.5874	0.9936	4.345	3872.5922	0.9945	5.045
3878.6299	0.0477	4.388	3878.6368	0.0489	5.116
3883.7275	0.9370	4.384	3883.7348	0.9382	5.115
3892.6133	0.4871	4.351	3892.6073	0.4860	5.093
3914.5631	0.3161	4.416	3914.5583	0.3152	5.152
3915.6014	0.4972	4.398	3915.5969	0.4964	5.132
3915.6200	0.5004	4.392	3915.6170	0.4999	5.123
3940.5760	0.8539	4.400	3940.5708	0.8530	5.147
3945.5609	0.7235	4.439	3945.5567	0.7227	5.174
3948.5162	0.2390	4.426	3948.5216	0.2399	5.130
3949.5346	0.4167	4.382	3949.5394	0.4175	5.096
3952.5467	0.9421	4.367	3952.5511	0.9429	5.099
3953.5445	0.1162	4.410	3953.5399	0.1154	5.154
3955.5395	0.4642	4.288	3955.5351	0.4634	4.995
3958.5341	0.9866	4.327	3958.5389	0.9874	5.036
4162.8473	0.6280	4.392	4162.8543	0.6292	5.142
4169.7876	0.8387	4.394	4169.7822	0.8377	5.138
4176.7789	0.0583	4.356	4176.7733	0.0573	5.105
4177.8671	0.2481	4.413	4177.8569	0.2463	5.146
4181.7800	0.9307	4.384	4181.7854	0.9316	5.124
4182.7667	0.1028	4.394	4182.7629	0.1021	5.117
4182.7846	0.1059	4.380	4182.7798	0.1051	5.113
4183.8313	0.2885	4.405	4183.8275	0.2878	5.144
4192.7506	0.8445	4.406	4192.7529	0.8449	5.143
4196.7288	0.5384	4.401	4196.7313	0.5389	5.117
4201.7937	0.4219	4.373	4201.7964	0.4224	5.092
4204.7173	0.9320	4.384	4204.7192	0.9323	5.118
4205.7387	0.1102	4.414	4205.7411	0.1106	5.128
4207.6717	0.4474	4.376	4207.6747	0.4479	5.102
4207.6868	0.4500	4.351	4207.6892	0.4504	5.066
4207.8600	0.4802	4.348	4207.8576	0.4798	5.083
4208.7383	0.6334	4.386	4208.7401	0.6337	5.137
4210.6716	0.9707	4.321	4210.6741	0.9711	5.049
4210.6829	0.9726	4.324	4210.6859	0.9732	5.047
4210.8590	0.0034	4.310	4210.8584	0.0033	5.034
4213.6834	0.4961	4.352	4213.6864	0.4966	5.076
4213.6956	0.4982	4.350	4213.6982	0.4987	5.074
4213.8455	0.5243	4.369	4213.8479	0.5248	5.093
4218.6350	0.3599	4.417	4218.6357	0.3600	5.138
4218.6903	0.3695	4.396			
4225.6037	0.5755	4.403	4225.6064	0.5760	5.166
4225.6174	0.5779	4.398	4225.6192	0.5782	5.124
4225.7488	0.6008	4.383	4225.7512	0.6012	5.109

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TABLE 1—*Continued*

(JD-2440000.)	Phase	$(V-C)_g$	(JD-2440000.)	Phase	$(V-C)_b$
4236.5737	0.4892	4.342	4236.5761	0.4896	5.078
4236.5847	0.4911	4.338	4236.5871	0.4915	5.069
4236.7718	0.5237	4.367	4236.7744	0.5242	5.096
4239.6379	0.0237	4.348	4239.6403	0.0241	5.078
4239.7155	0.0372	4.372	4239.7173	0.0375	5.108
4239.7259	0.0390	4.373	4239.7277	0.0394	5.106
4254.7319	0.6568	4.391	4254.7343	0.6572	5.121
4260.5578	0.6730	4.413	4260.5608	0.6736	5.150
4260.7098	0.6996	4.406	4260.7130	0.7001	5.146
4267.5323	0.8897	4.407	4267.5349	0.8902	5.120
4267.5809	0.8982	4.412	4267.5833	0.8986	5.107
4272.5151	0.7589	4.421	4272.5162	0.7593	5.147
4272.6744	0.7867	4.420	4272.6766	0.7871	5.152
4274.6548	0.1322	4.401	4274.6594	0.1330	5.143
4296.5262	0.9475	4.365	4296.5295	0.9481	5.104
4302.5305	0.9950	4.327	4302.5338	0.9955	5.068
4314.5243	0.0872	4.394	4314.5270	0.0877	5.114
4326.5268	0.1810	-4.412	4326.5307	0.1816	-5.135

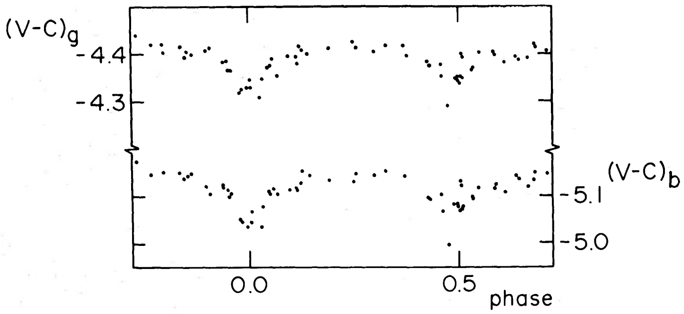

FIG. 1.—Green (*above*) and blue (*below*) average points for δ Ori phased according to equation (1) of the text. The scatter within the light curve is due to intrinsic variability of the star and not to observational noise.

make it certain that the orbit is eccentric and the apse is rotating. Thus, the period of (1) cannot be the anomalistic one.

Not many timings of minimum light exist for this binary, and we have redetermined from the published or unpublished data those which are given in Table 2. A search was made through the 19th century Harvard photometry and even through the purported minima observed by Auwers (1859) in order to see if more timings could be uncovered. Unless one accepts the hypothesis that the light curve, despite large photometric errors, had a drastically altered appearance in the last century, no such minima can be validated. Thus, Table 2 and Figure 2 derived from it contain all the dynamical photometric history of this binary. The calibration of the apsidal advance by Natarajan and Rajamohan agrees well with the variation of $(O-C)$ with E. Specifically, $E=+90$ occurred between Worley's and the present photometry, and it is most satisfying to see that the sense of and the difference of $O-C$ at a given E has changed sign. Further, during Stebbin's photometry $E\approx 0$, and therefore $O-C$ should have attained a maximum amplitude at that time. The axis of symmetry of the run of $O-C$ with E is obviously not horizontal, and this permits an evaluation of the anomalistic period as 5.732403 days. This procedure ignores any $\dot{P}$ which may be due to the mass loss rate of $\sim 10^{-6}\ M_\odot\ \mathrm{yr}^{-1}$, summarized by Barlow and Cohen (1977).

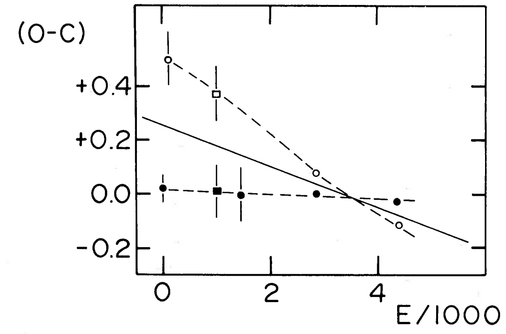

FIG. 2

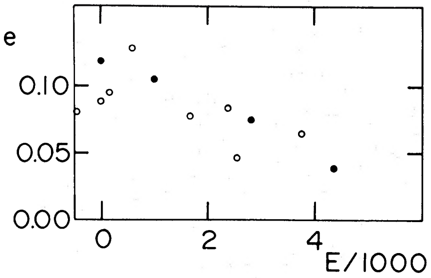

FIG. 3

FIG. 2.—The ($O-C$)-diagram from δ Ori based upon equation (1) of the text. Filled circles refer to the primary and open circles to the secondary eclipses. The squares derive from a light curve by Storer published only in figure form by Worley and have been fitted to smooth runs through the filled and open circles. The error bars are estimates. The broken arcs are freehand ones, and the unbroken line is described in the text.

FIG. 3.—The orbital eccentricity (*filled circles* if photometric, *open circles* if spectrographic) as a function of E and thus of time.

It appears, however, that Figure 2 may be complex. For instance, since the periastron argument, ω, is known spectrographically for each determination of $O-C$, the orbital eccentricity, e, may be evaluated from:

$$e\cos\omega=\frac{\pi(D-0.5)}{1+\csc^2 i}, \tag{2}$$

where (D—0.5) measures the shift of secondary minimum from the half-period point and i is the orbital inclination. For $i=65°$, the assorted values of e are given in Table 2 and are plotted in Figure 3 along with the spectrographic values. The photometric values are, of course, of low precision, but it is an interesting result that early values of e are relatively large whether based on absorption line centroids or on continuum photometric measures and are small at later times irrespective of the method of derivation. This result may be expressed in another way: the freehand broken curves drawn among the values of $O-C$ in Figure 2 are not arcs of sinusoids.

Two possible causes of a diminution of e may be tested. First, it may be imagined that there exists a thick systemic disk in δ Ori so that the orbit would decay and circularize as do satellites in Earth's atmosphere. The constant term in Danby's (1962) equation (11.7.7) may be calibrated by a change of $\Delta e \approx -0.01$ over 1000 Keplerian cycles, as may be noted from Figure 3. If it is assumed that the gas density in the supposed disk is independent of orbital longitude, ($a^{-1}\Delta a$) can be calculated from Danby's equation (11.7.6). This calculated value is far greater than the extreme values of $a_1 \sin i$ shown by all the radial velocity investigations. Second, it may be conjectured that tidal effects, as presented by Zahn (1977) or Alexander (1973), are circularizing the orbit. It is possible to show that by this mechanism a decreases more slowly than does e for small values of eccentricity, but it is also possible to show that ~100 years is a time scale too short for a detectable change in e for hot stars such as those of δ Ori.

There remains the possibility that the decay of e is spurious. By appropriately choosing the error bars for Stebbin's ($O-C$)-values, e may be diminished to about 0.08 for his light curve. Storer's observations apparently no longer exist, so it is impossible to treat his data

TABLE 2

OBSERVED MINIMA OF δ ORIONIS A

(JD−2400000.)	E	($O-C$)	Reference	e
19016.63	−9.	+0.02	Stebbins	0.12
19478.6	+71.5	+0.5	Stebbins	...
27133.8	+1407.	0.0	Skoberla 1935	...
27156.8	+1411.	+0.1	Skoberla 1935	...
35170.73	+2809.	0.00	Worley	0.08
35173.67	+2809.5	+0.08	Worley	...
43872.589	+4327.	−0.035	Koch, Hrivnak	0.04
44207.860	+4385.5	−0.114	Koch, Hrivnak	...

NOTE.—Storer's light curve for $E \approx +1014$ permits $(O-C)_{\rm pr}-(O-C)_{\rm sc} \approx +0.37$ and leads to $e=0.11$.

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decisively, but one can show (from Worley's presentation of Storer's light curve) that a phase shift of $-0.02P$ (in the appropriately selected sense) will also give $e \approx 0.08$. It appears impossible, however, to double the phase shift in the present light curves as would be required for $e \approx 0.08$. Thus, it is necessary to postulate some unknown distortion afflicting the light curves in such a way which will continue to permit the detection both of eclipses and of the ellipticity due to the tidal distortion. It is true, of course, that some understanding of the two most recent and small spectrographic evaluations of e must be achieved. Monet indicates these two determinations to fail his criterion of significance and gives $e = 0.089 \pm 0.001$. His investigation, however, leaves unexplained the different values of the systemic velocity. In this paper, the point of view is taken that enough new visible-band and UV spectroscopic details are known so that the plates themselves and not the journal of observations should be reexamined. In sum, our opinion is that the orbital eccentricity is probably constant but it cannot be properly evaluated from the present light curves.

IV. ANALYSIS

Ephemeris (1) does not locate primary minimum exactly at 0.000 phase, and a small zero point correction was applied to all phases in order to achieve this. To impose $e = 0.08$ on the present light curve is to create the impossibility that the true anomalies for the eclipses are not separated by 180°. Accordingly, analysis was pursued for $e = 0.04$, $\omega_h = 120°$ (later refined to 118°), and the phases given in Table 1 were converted to true anomalies. The intrinsic variability, small eccentricity, and low inclination all prevent any recognition of a difference in the widths of the two eclipses. Furthermore, the small asymmetries in maximum light are of opposite algebraic signs in green and blue, so there is no possibility of searching for a periastron effect such as Guinan and McCook (1979) have described. Consequently, it was decided that further study of the light curve would assume a circular orbit with a radius equal to the radius vector at primary minimum. This creates an error at all other phases, but the very small corrections through the rest of primary eclipse were ignored. However, it is easily shown that this assumption means secondary eclipse is too shallow. Numerous theoretical light curves, presently to be described, indicated suitably small ranges of the orbital inclination and stellar radii so that an approximation to the corrections to the light levels within secondary eclipse could be developed from the tabulated parameters of Merrill (1950). At secondary minimum itself the correction deepens the light levels by 0.02 mag. The additional light curve representations show this value to be imprecise by no more than 0.005 mag. The corrections to the other observations within secondary eclipse were scaled appropriately.

Beyond the difficulties imposed by the dubious choice of e, it is both important and discouraging that Heintz (1980) has recently detected a visual companion (hz 42, not ADS 4134B or C) which is not sensibly different in brightness from the eclipsing pair. This object, presently at an angular separation of only $0\rlap{.}''15$, must contribute ~100% "third" light to the phase-locked light variation and possibly is the seat of the intrinsic variability. The orbital inclination is therefore likely to be higher than inspection of Figure 1 suggests, and correction for the "third" light level inevitably scales up the scatter of the light curve by 100%. Despite this limitation, a correction of $L_3 = 1.00$ was made to the observations, and all analysis was pursued on this newly scaled light curve.

With scatter so large and the amplitude of light variation still modest, solution of the light curve in the conventional sense is not likely. Our approach was to establish values of parameters from the Wilson and Devinney (1971) code which would remain fixed thereafter because there was little or no hope of improving the initial values. These assumptions appear in the first column of Table 3. The values for the gravity and albedo parameters are the conventional ones for hot stars; the limb darkening coefficient was taken from Al-Naimiy (1978); and a temperature appropriate for an O9.5 II classification was chosen from Underhill *et al.* (1979). The meager observational weight was then exploited to search out best values for the parameters of column (3) of Table 3. Initializing of these parameters proceeded as follows. The relative depths of the eclipses, corrected for the orbital eccentricity, shows T_c only slightly smaller than T_h. A relative light balance for

TABLE 3

LIGHT CURVE PARAMETERS FOR δ ORIONIS A

$L_3 = 1.00$	$25{,}000\ \mathrm{K} \le T_c \le 29{,}200\ \mathrm{K}$	$T_c = 25{,}000$ K (1,000 K)	$r_{h,\mathrm{point}} = 0.43$ (2)
$g_h = g_c = 1.00$	$0.60 \le L_h \le 0.82$	$L_h = 0.79$ (2)	$r_{h,\mathrm{side}} = 0.40$ (2)
$A_h = A_c = 1.00$	$0.40 \ge L_c \ge 0.18$	$L_c = 0.21$ (2)	$r_{h,\mathrm{back}} = 0.41$ (2)
$x_h = x_c = 0.27$	$0.33 \le q \le 0.50$	$q = 0.40$ (7)	$r_{h,\mathrm{pole}} = 0.38$ (2)
$T_h = 31{,}100$ K	$2.00 \le \Omega_h \le 3.93$	$\Omega_h = 2.98$ (7)	$r_{c,\mathrm{point}} = 0.25$ (4)
	$2.40 \le \Omega_e \le 4.67$	$\Omega_c = 3.00$ (15)	$r_{c,\mathrm{side}} = 0.24$ (4)
	$63° \le i \le 75°$	$i = 68°$ (1°)	$r_{c,\mathrm{back}} = 0.25$ (4)
			$r_{c,\mathrm{pole}} = 0.23$ (4)

$\Delta m = 1.3$ and $q = 0.33$ are consistent with the apparent detection of absorption features from the cool star by Luyten *et al.* It was assumed that the hot star rotates synchronously with its orbital angular velocity. Conti and Ebbets's (1977) $V_{\rm rot} \sin i = 109$ km s^{-1} then gives a projected radius, $R_h \sin i = 12.3\ R_\odot$. For $q = 0.33$, $a_h \sin i = 3.2 \times 10^7$ km so that $r_h = 0.28$ was taken as an initial value. The modified potential, Ω_h, was computed for (r_h, q), and Ω_c was calculated so that $r_h > r_c$ as seems to be required by the near equality of temperatures but the great difficulty of detecting the spectrum of the cool star. An inclination of 67° was chosen because it falls midway between the extreme values given by Stebbins.

It is hardly surprising that these initialized parameters lead to a light curve which fails to represent the observations satisfactorily. As a consequence, the parameters of column (3), Table 3, were varied over the ranges shown in column (2) of the same table in the course of computing 26 light curves with modes 0 or 2 of the Wilson-Devinney code. These calculations consistently showed that a semidetached configuration required more curvature outside eclipse than the observations permit. The best evaluations are those of column (3), and to these are attached the parenthesized estimated uncertainties of the last given figure. The eclipses are partial. The radii of the stars are shown in the last column of the table. This representation is of a detached binary. Because the green and blue light curves are so similar in shape, amplitude, and distortion, both are shown to the same scale in Figure 4 with the theoretical light curve from Table 3. It can be seen that the observed primary eclipse appears to be narrower than the theoretical light curve. It is not known if this deviation is due to shell/wind effects associated with the hot star alone. Ever since eclipse-width differences were first recognized in V444 Cyg, this possibility has been a reality. Alternatively, it could be that the deviations in primary eclipse really express the possibility that at least one star is smaller than Table 3 indicates. Against this interpretation, it is possible to say that light curves computed with smaller stars consistently gave a smaller outside-eclipse curvature than the observations appear to require. Because of the great uncertainty of L_3 and the intrinsic variability of the δ Ori system, no least squares differential correction was attempted.

Only Stebbins has attempted to solve the light curve previously. The present representation, imperfect as it is, bears a resemblance to the second of his solutions and is consistent with the latter in requiring a larger value of i to compensate for a nonzero value of L_3.

V. DISCUSSION AND SUMMARY

The radii of Table 3 are in units of the orbital radius vector for primary minimum. A correction of +4% scales these radii to the orbital semimajor axis. Batten, Fletcher, and Mann (1978) give $a_1 \sin i = 7.92 \times 10^6$ km so that $a = 2.99 \times 10^7$ km from the values of q and i in Table 3. This result and the evaluations of Table 3 give the absolute parameters in columns (2) and (3) of Table 4. The precision of the stellar masses and radii is low (~±2 solar units), but the accuracies of these values are unknown. Other authors, quoted earlier in this paper, give the ranges of values in the last two columns of the table. The bolometric corrections have been taken from Allen (1973). Johnson *et al.* give $V = +2.20$, $(B-V) = -0.22$ for maximum light. It has been assumed that hz 42 is equal in brightness to the eclipsing pair, so that $V = +2.95$ for that pair alone. It was further assumed that hz 42 does not differ significantly in temperature from the hot, eclipsing star. Since $(B-V_0) \approx -0.31$, $E(B-V) = +0.09$ and $V_0 = +2.68$ at maximum light for $A(V) = 3.0E(B-V)$. The light balance from Table 3 then yields the values of V_0 in Table 4. The distance to the binary is very close to 500 pc whereas the distance to the Orion cluster is typically given as 400–450 pc. This discrepancy translates into only 0.5 mag, and the errors accumulating from the light

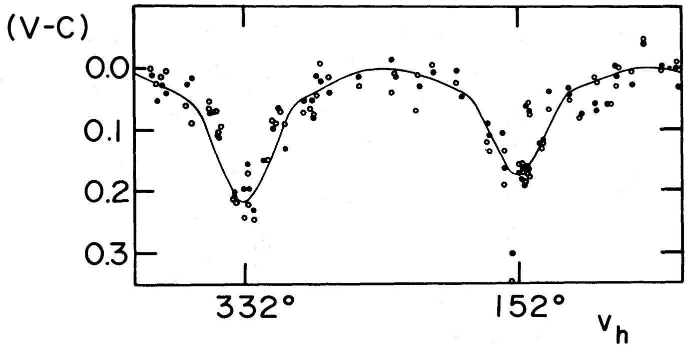

FIG. 4.—The observations (*filled circles*, green; *open circles*, blue) corrected for 100% "third" light and with the observations of secondary eclipse scaled as described in the text. Zero point corrections of 4.420 and 5.150 have been added to green and blue observations, respectively, in order to bring maximum light to 0.00. The abscissa scale is the true anomaly for the hot star. The smooth curve is calculated from the parameters of Table 3.

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TABLE 4

Absolute Parameters for Components of δ Orionis

Parameter	Hot Star	Cool Star	Hot Star	Cool Star
Mass ($M_\odot$)	23	9	28–37	10
Radius ($R_\odot$)	17	10	(16–23)	9
Mean density	$0.0046_\odot$	$0.0085_\odot$	...	...
$M_{\rm bol}$	−8.7	−6.6	−(8.5–9.2)	−5.5
Bolometric correction	−3.0	−2.5	...	...
M_V	−5.5	−4.1	−(5.8–6.3)	...
V_0	+2.9	+4.4	...	...

curve representation and the correction for hz 42 may well add up to such a value. Because the radii of the eclipsing stars are larger than those of main sequence objects, both components deviate in the expected senses from the mass-radius and mass-luminosity relations for unevolved stars. For the hot star $V_{\rm rot} \approx 120$ (± 12) km s^{-1} while $V_{\rm syn} \approx 150$ km s^{-1}. An error of ± 18 km s^{-1} can be ascribed to the latter value from the precision of ± 2 $R_\odot$ claimed for the radius of the hot star. Most likely the seeming slower-than-synchronous rotation is not significant. If it were, it would presumably be a consequence of post–main-sequence evolution or of braking by the stellar wind. It may be noted that, according to the precept of Snow and Morton, a stellar wind should flow from each star, a detail which may eventually be checked with high-dispersion UV spectra. The cool star should be of luminosity classes IV or III. Lastly, from the conventional equation and an apsidal period of 210 yr, $k_2 = 0.00068$ for $0.04 \leq e \leq 0.08$, with the hot star contributing twice the weight of the cool star to this mean. A literature search uncovered only the theoretical values of k_2 by Petty (1973) for massive stars as evolved as is the hot component of δ Ori, but Petty's values (extrapolated to 23 $M_\odot$) are much larger than the coefficient for δ Ori. Use of more modern evolved models with more realistic opacities is probably necessary for a sensitive test of the value derived above.

The visual object, hz 42, commands interest also. If the variation of the γ-velocities and the visual detection or lack of detection of this star are correlated with each other, an orbital period of 100–150 yr may be suggested. Since the star is so bright, and almost surely very hot, it too should drive a stellar wind. The star may or may not be variable, and it is not inconceivable that it too is a close binary as are a large fraction of hot, massive stars. Both rocket and spacecraft spectra now exist for δ Ori, and Doppler separation of the lines of hz 42 from those of the close pair should improve as the visual system continues to open.

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