

DELTA LIBRAE*

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ABSTRACT

A new spectrographic investigation of δ Librae has yielded the following orbital elements: $\gamma = -36.4$ km/sec; $K = 78.3$ km/sec; $e = 0.048$; $\omega = 153^\circ.4$; $T_0 = 1.754$ days; $a_1 \sin i = 2.5 \times 10^6$ km; $f(M) = 0.115 \odot$; and has eliminated the possibility of a third body in the system. δ Librae appears to be another case where the star that has evolved faster has the smaller mass. The analysis of the available radial velocities suggests an improved value of 2.3273537 days for the period.

I. INTRODUCTION

δ Librae [$\alpha = 14^{\text{h}}55^{\text{m}}37^{\text{s}}$; $\delta = -8^\circ 07'.3$ (1900.0). 19 Librae = BD-7°3938 = HD 132742 (A0) = GC 20195] is an eclipsing variable, discovered as such by Schmidt (1865), with no constant phase at maximum light (cf. Stebbins 1928). The photographic magnitude at maximum is 4.79, and the amplitudes of the primary and of the secondary minima are 1.14 and 0.07 mag., respectively, as quoted in the 1958 *General Catalogue of Variable Stars*.

The first photoelectric light-curve was observed by Stebbins (1928), yielding, for $x = 0.4$ (Plaut 1950),

$$\begin{aligned} k &= 0.97 \pm 0.04, & a_2 &= 0.303 \pm 0.009, \\ L_1 &= 0.900 \pm 0.008, & i &= 80^\circ.0 \pm 0^\circ.6. \\ a_1 &= 0.313 \pm 0.005, \end{aligned}$$

A more recent three-color photoelectric light-curve by Koch (1962) has led to the following approximate orbital elements

$$\begin{aligned} k &= 0.975, & a_g &= 0.308, \\ a_s &= 0.300, & b_g &= 0.302, \\ b_s &= 0.294, \end{aligned}$$

where s and g stand for smaller and larger (greater) star, respectively.

The spectrum is a single-lined one and corresponds to the star which is eclipsed at primary minimum. Our plates suggest that the brighter component of the system is an A0 V object, in the MK system, in agreement with Miss Roman's (1956) classification and Koch's (1962) expectations. The 1958 *General Catalogue of Variable Stars* quotes δ Librae as being of spectral type A1s. No emission features are present, not even at H α , on any of our spectrograms.

It has not been possible to obtain any spectrogram clearly showing the spectrum of the secondary component of the system; however, lines of a late-type object are suspected on one of our spectrograms taken during eclipse. The photometric elements suggest

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that this late-type component is an sg F8 star (Plaut 1953) or a G(1-2) IV (Koch 1962) and, therefore, that δ Librae belongs to group 3 in Sahade's (1960) scheme of classification of binary systems. Because of this fact and because the two existing spectrographic orbits by Schlesinger (1910; Luyten 1936) and by McLaughlin (1934) differ in the γ velocity, it was decided to secure a new series of spectrograms covering the photographic as well as the $H\alpha$ regions. This was done in April, May, and June, 1960, at the Mount Wilson Observatory with the X spectrograph attached to the 60-inch reflecting telescope, by using the arrangement that gives a dispersion of about 20 Å/mm in the photographic

TABLE 1
STELLAR LINES

H	Si II	Ca II	Mg II
3770 63	3853 66	3933.66	4481 23
3797 90	3856 02		
3835 39	3862 59		
3889 05	4128 05		
4101 74	4130 88		
4340 47			
6562 82			

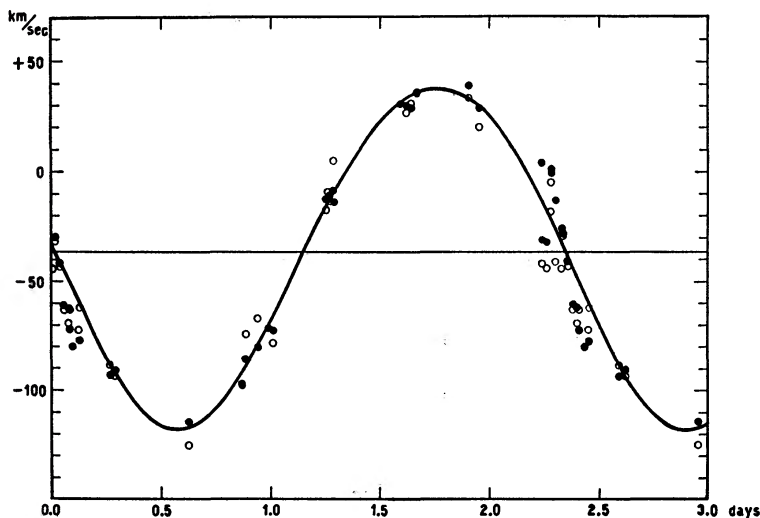


FIG. 1—Radial velocities and velocity-curve of δ Librae. The filled circles are the mean velocities from all lines, $H\alpha$ excluded, which were used for the determination of the orbital elements, as explained in the text. The empty circles are the velocities from $H\alpha$.

region (second order of the grating). The $H\alpha$ region was exposed concurrently in the first order, and 35 spectrograms in total were secured.

Table 1 lists the lines used in the determination of the radial velocities, while Table 2 gives the values obtained. The radial velocities in the third column of Table 2 are plotted in Figure 1. This plot shows the presence of a rotational disturbance of an amount in agreement with that previously found by McLaughlin (1934). The phases were computed by using Stebbins' (1928) elements, namely,

$$\text{Pr. Min.} = \text{JD}2422852.3536 + 2^{\text{d}}32734906E.$$

If we disregard the velocities in the phase interval where the rotational disturbance is present, namely, the phase interval covering principal eclipse ($D \sim 0.54$ day), one is left with 19 values upon which the determination of the orbital elements was based. These were computed with the Mercury electronic computer of the Instituto de Cálculo of the National University of Buenos Aires, making use of the equations of condition formulated by Huang (Sahade, Huang, Struve, and Zebergs 1959) in an investigation of the system of β Lyrae. Table 3 lists the derived orbital elements, together with those that were yielded by the same electronic computer when fed with Schlesinger's and with McLaughlin's velocities, leaving aside the values in the phase interval of the rotational disturbance. The velocity-curve drawn in Figure 1 corresponds to our elements. The $H\alpha$ velocities, which are also plotted in Figure 1 as empty circles, seem to suggest a lower maximum of the curve, but no definite conclusion can be drawn from the present material.

TABLE 2
RADICAL VELOCITIES

JD 2437000+	PHASE* (days)	RADIAL VELOCITIES (km/sec) FROM	
		All Lines ($H\alpha$ Excluded)	$H\alpha$
39 835	2 289	+ 2	- 5
886	0 013	- 28	- 29
962	0 089	- 72	- 63
40 007	0 133	- 77	- 62
742	0 868	- 97	- 97
765	0 892	- 85	- 74
821	0 948	- 80	- 67
41 785	1 912	+ 39	+ 44
824	1 950	+ 29	+ 20
42 835	0 635	-114	-125
67 717	2 242	+ 4	
760	2 285	+ 1	
68 800	0 998	- 71	..
819	1 018	- 72	- 78
71 810	1 681	+ 36	+ 36
87 671	1 250	- 12	- 17
693	1 273	- 11	- 13
718	1 298	- 13	.
88 665	2 245	- 31	- 42
687	2 266	- 32	- 44
708	2 288	0	- 18
730	0 095	- 13	- 41
756	0 008	- 23	- 44
784	0 036	- 41	- 43
810	0 062	- 61	- 63
831	0 083	- 62	- 69
853	0 105	- 80	- 49
92 676	1 601	+ 31	..
700	1 625	+ 30	+ 27
723	1 648	+ 29	+ 31
93 675	0 273	- 93	- 88
701	0 299	- 91	- 93
94 669	1 267	- 17	- 9
694	1 292	- 8	+ 5

*The phases were computed with Stebbins' (1928) elements, namely,
Pr. Min = JD2422852 3536 + 2432734906E.

II. DISCUSSION

The difference in γ between Schlesinger's and McLaughlin's elements was tentatively interpreted as indicating the presence of a third body in the system, and one alternative in Koch's (1962) discussion points in the same direction. The least-squares solutions we performed with the electronic computer give

$$\begin{aligned}\gamma_S &= -43.4 \pm 1.13 \text{ km/sec} && \text{(from Schlesinger's velocities),} \\ \gamma_{McL} &= -31.4 \pm 2.34 \text{ km/sec} && \text{(from McLaughlin's velocities),} \\ \gamma_{MtW} &= -36.4 \pm 1.16 \text{ km/sec} && \text{(from our velocities).}\end{aligned}$$

TABLE 3
ORBITAL ELEMENTS (AND MEAN ERRORS) OF δ LIBRAE

	Schlesinger (1910)	McLaughlin (1934)	Present Work
γ	$-43.4 \pm 1.13 \text{ km/sec}$	$-31.4 \pm 2.34 \text{ km/sec}$	$-36.4 \pm 1.16 \text{ km/sec}$
K	$75.2 \pm 1.23 \text{ km/sec}$	$77.3 \pm 2.16 \text{ km/sec}$	$78.3 \pm 1.66 \text{ km/sec}$
e	0.020 ± 0.0062	0.053 ± 0.0089	0.048 ± 0.0058
ω	$84^\circ.4 \pm 2^\circ.72$	$191^\circ.6 \pm 5^\circ.12$	$153^\circ.4 \pm 4^\circ.49$
T_0	$1.712 \pm 0.0094 \text{ days}$	$1.761 \pm 0.0201 \text{ days}$	$1.754 \pm 0.0096 \text{ days}$
$a \sin i$	$2.404 \times 10^6 \text{ km}$	$2.469 \times 10^6 \text{ km}$	$2.501 \times 10^6 \text{ km}$
$f(\mathcal{M})$	$0.103 \odot$	$0.111 \odot$	$0.115 \odot$
Error per plate	$\pm 6.3 \text{ km/sec}$	$\pm 7.8 \text{ km/sec}$	$\pm 3.8 \text{ km/sec}$
No of plates	51	22	19

The difference between γ_S and the other two values looks significant, considering the mean errors involved. However, it can be traced to the laboratory wavelengths used by Schlesinger for the four lines he measured. These differences are

$$\begin{aligned}-0.16 \text{ \AA} & \text{ for Ca II-K,} \\ -0.18 & \text{ for H}\delta, \\ -0.16 & \text{ for H}\gamma, \\ -0.17 & \text{ for Mg II } \lambda 4481,\end{aligned}$$

the $\Delta\lambda$'s being taken in the sense of wavelengths used in this work minus wavelengths used by Schlesinger. The $\Delta\lambda$'s imply a mean systematic shift of Schlesinger's radial velocities by -12 km/sec ; this implies that the actual γ_S is of the order of -31 km/sec .

A similar, although smaller, difference in the γ 's of λ Tauri (cf. McLaughlin 1934) disappeared when the Allegheny plates were remeasured and reduced with modern wavelength values (Ebbighausen and Struve 1956). Although McLaughlin's wavelengths were not published, the results from several systems, including λ Tauri, suggest that his wavelength system does not differ greatly from, for instance, the one we have been using.

The available spectrographic information, therefore, does not lend support to the suggestion of a third body in the system and, as a consequence, the explanation of the photometric complications pointed out by Koch will have to drop such an alternative, at least for the time being.

If we correct Schlesinger's velocities in order that his γ may coincide with ours, the phase-velocity relationship from both his and our velocities, derived by using Stebbins'

elements, suggests that Stebbins' value of the period could be improved to 2.3273537 days (the last figure is not significant), if we interpret the relative shift of the two velocity-curves as due to incorrectness of the period. Our value is to be compared with the one quoted by Koch (1962), namely, 2.32735297 days, as satisfying the photoelectric minima.

Koch (1962) has made a study of the available times of primary minimum of δ Librae, and his plot of the residuals seems to suggest the possibility of the period beginning to increase early this century.

Figure 2 pictures the model of δ Librae and the first critical equipotential surface. The stellar dimensions are based on the photometric elements, and the mass ratio was derived

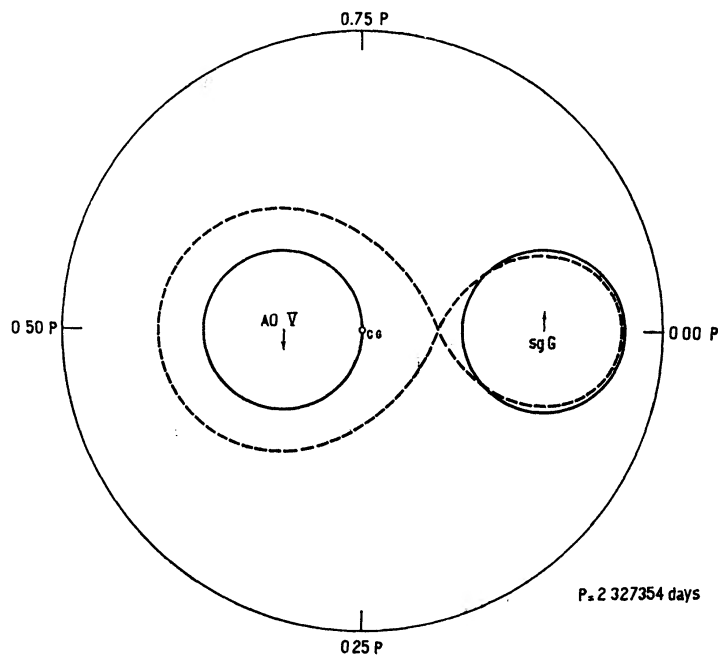


FIG. 2.—Schematic model of δ Librae

from the mass function by assuming for the A0 V star a mass of about $3\odot$, which led to $1.3\odot$ for the mass of the subgiant secondary. It seems reasonable to assign a mass of $3\odot$ for the A0 V component, in view of the fact that its spectrum looks that of a normal A0 main-sequence star. On this assumption, the secondary fills its lobe of the inner contact surface, and, as a consequence, one would expect loss of mass from the star to take place. In a configuration such as the one in Figure 2, the mass lost by the secondary would conceivably produce a gaseous ring around the primary, which would give rise to emission features detectable at least in $H\alpha$ and at least during primary minimum. As we have already mentioned, no emission features were found on our plates, nor is any distortion in the velocity-curve of the primary present. However, the possibility of a lengthening of the period could be the result of mass loss, and, in this connection, it is interesting to note that Koch (1962) finds a violet excess in the light of the system that could be due to the existence of an extended atmosphere.

One could still wonder whether the secondary could not actually be appreciably smaller than the corresponding lobe of the first critical equipotential surface. This would require a mass ratio smaller than 2 and a mass for the primary not larger than about one-half the mass of a normal A0 V object; therefore, it seems hard at the present time to ac-

cept a model for δ Librae very much different from the one we have schematized in Figure 2.

Table 4 lists a set of possible values of \mathcal{M}_1 and \mathcal{M}_2 for different mass ratios. It is certainly true that, at any rate, $\mathcal{M}_1/\mathcal{M}_2$ should be greater than 1 for any reasonable values of \mathcal{M}_1 . Hence, as is the case in practically all the systems with periods not longer than, say, 10 days that belong in Sahade's (1960) group 3, we also have here the mass of the subgiant secondary smaller than that of the main-sequence primary.

Further investigation of δ Librae some years from now will certainly add greatly to our understanding of this system.

The trigonometric parallax of δ Librae, quoted in the Yale *General Catalogue of Trigonometric Stellar Parallaxes*, is $+0''.021 \pm 0''.013$ (m.e.), suggesting a visual absolute mag-

TABLE 4
SET OF POSSIBLE VALUES OF \mathcal{M}_1 AND \mathcal{M}_2 FOR
DIFFERENT MASS RATIOS
AND $f(\mathcal{M}) = 0.115\odot$

$\mathcal{M}_1/\mathcal{M}_2$	\mathcal{M}_1	\mathcal{M}_2
0.4	0.09 \odot	0.24 \odot
0.6	0.18	0.31
0.8	0.31	0.39
1.0	0.48	0.48
1.2	0.70	0.58
1.4	0.88	0.69
1.6	1.30	0.81
1.8	1.69	0.94
2.0	2.16	1.08
2.3	3.01	1.31

nitude of $+1.7 \pm 0.7$ (m.e.) for the primary component of δ Librae. Unfortunately, the available parallax value does not add any information against or for the A0 component being a normal main-sequence star.

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