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The Eclipse of 16 Lacertae Revisited

by

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ABSTRACT

The old and new observations of this well-known β Cephei star and eclipsing variable are used in order to separate the light variations due to pulsations from those caused by the eclipse. An up-to-date set of photometric elements is then derived. In addition, the evolutionary state of the components of the system is examined. Finally, the primary component's pulsation constants are briefly discussed.

1. Introduction

16 (EN) Lac is a single-line spectroscopic binary system (Lee 1910, Struve and Bobrovnikoff 1925). The system's primary is a β Cephei-type variable. It shows short-period light and radial-velocity variations, consisting of three sinusoidal components. The amplitudes of the components vary on a time scale of years (Fitch 1969, Jarzębowski *et al.* 1979). The star is also an eclipsing variable (Jerzykiewicz *et al.* 1978). However, the eclipse covers only three percent of the total orbital period of $12^{d}.097$. The first analysis of the eclipse light-curve (Jerzykiewicz 1980) showed that the eclipse is a partial transit, and yielded the following elements:

(1) ratio of the radii, $k = r_2/r_1 = 0.22$,

(2) inclination, $i = 83^{\circ}.9$,

(3) radius of the primary in terms of the radius of the relative orbit, $r_1 = 0.117$.

Using additional observations, obtained in 1980 and 1981, Garrido *et al.* (1983) derived slightly different values of these parameters, viz., $k = 0.236$,

$i = 84\overset{\circ}{.}5$, and $r_1 = 0.106$. Both Jerzykiewicz (1980) and Garrido *et al.* (1983) estimated the mass of the primary to be equal to 10 $M_{\odot}$.

Since the analysis of Garrido *et al.* (1983), additional photometric data became available. The data include photoelectric observations obtained in 1979 by Jerzykiewicz *et al.* (1984), and in 1980 by Sato and Hayasaka (1986) and Jerzykiewicz (this paper, Appendix B). In the present paper, we add these data to the ones used previously by Jerzykiewicz (1980) and Garrido *et al.* (1983), and derive up-to-date photometric elements of 16 Lac. In addition, we make use of the spectroscopic elements of the system and the available estimates of the effective temperature of the primary in order to examine the evolutionary state of the components. Finally, we discuss the primary component's pulsation constants.

2. The eclipse

As we have already mentioned in the Introduction, the light variation of 16 Lac is caused by two different phenomena: the β Cephei-type pulsations and the eclipse. Therefore, in order to derive the eclipse light-curve, one must free the observations from the contribution due to pulsations. The latter can be derived from observations obtained outside the eclipse. In practice, the trygonometric polynomial

$$A_0 + \sum_{i=1}^{3} A_i \sin\left[2\pi f_i (t - T_0) + \varphi_i\right] \qquad (1)$$

is fitted to the out-of-eclipse data by the method of least squares, and then used to calculate the pulsation contribution to be subtracted from observations made during eclipse. Since, however, the pulsation amplitudes, A_i, vary on a time scale of years, a number of nights outside the eclipse are needed in each observing season when eclipses were observed. Fortunately, the pulsation frequencies, f_i, are constant, so that their mean values, derived from observations obtained over several years, could be used in the analysis. The values we adopted were the following: $f_1 = 5.9112$, $f_2 = 5.8551$, and $f_3 = 5.5033$ c/d (Jerzykiewicz *et al.* 1984).

All nights on which at least one observation falls between the first and the last contact according to the solution of Jerzykiewicz (1980) are listed in Table 1. The columns should be self-explanatory. The out-of-eclipse data are presented and analyzed in Appendix A. Finally, the observations obtained on the nights listed in Table 1, freed from the pulsational contribution, are plotted in Figs. 1 and 2 as a function of orbital phase, computed according to the following equation:

$$\text{Min. light} = \text{JD}_{\odot}\, 2439054.568 + 12\overset{d}{.}09684\; E, \qquad (2)$$

Table 1
The list of nights with observations taken during eclipse

JD-2400000	Observing season	Filters	N*	References
34239	1952	B	37	Walker (1954)
38993	1965	UBV	9	Jerzykiewicz, unpublished
39042		BV	6	
39054		UBV	28	
43421	1977	B	10	Jarzębowski et al. (1980)
43433	1977	b and B	22	Jarzębowski et al. (1979)
44147	1979	b	27	Jerzykiewicz et al. (1984)
44159			33	
44171			22	
44510	1980	b	16	This paper, Appendix B
44522	1980	UB	7	Garrido et al. (1983)
44909	1981	4 and 5**	49	Garrido et al. (1983)

*) The number of observations falling between the first and the last contact.

**) These filters, defined by Sareyan et al. (1976), are similar to Crawford's u and b, respectively.

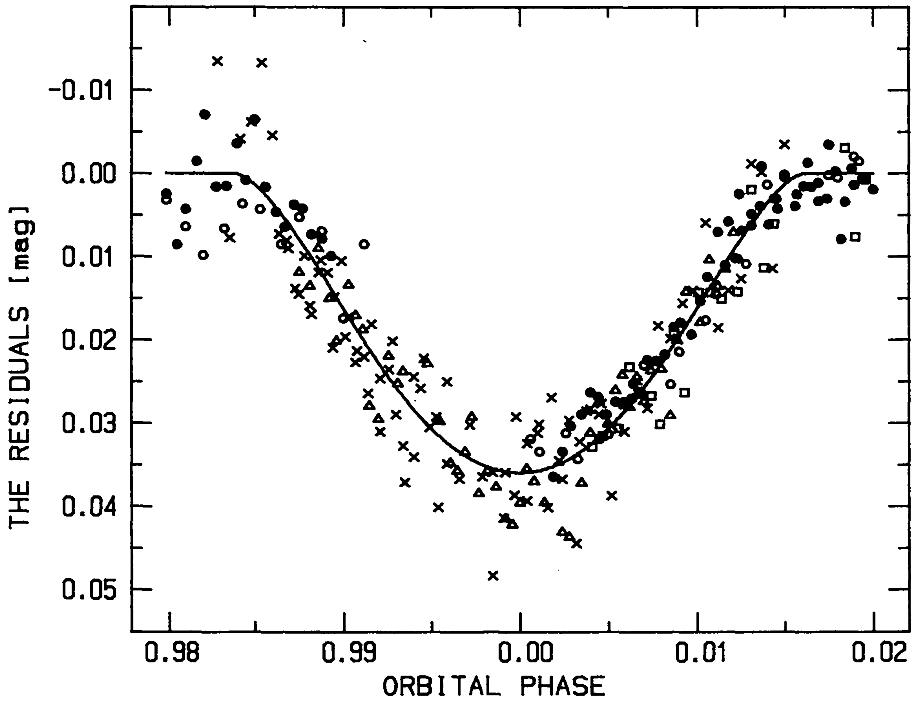

Fig. 1. The blue spectral region observations of 16 Lac, freed from the pulsational contribution, shown plotted as a function of the orbital phase. Observations obtained in 1965 are represented by filled circles; in 1977, by open circles; in 1979, by crosses; in 1980, by squares; and in 1981, by triangles. These data were used in deriving the photometric solution, shown as the solid line.

which is a slightly improved version of Jerzykiewicz's (1980) original ephemeris.

The data shown in Fig. 1 are used in the eclipse solution, discussed in the next chapter. They include all blue spectral region observations referred to in Table 1, except those of Walker (1954), Jarzębowski *et al.* (1980), and the 1980 observations of Garrido *et al.* (1983). Walker's data were not used in the solution for the reasons given in Appendix A, while those of Jarzębowski *et al.* (1980) and Garrido *et al.* (1983) were omitted because of their excessive scatter. They are compared with the computed eclipse light-curve in Fig. 2, together with the 1965 *V* observations of Jerzykiewicz (unpublished) and the 1981 filter No. 4 (ultraviolet) observations of Garrido *et al.* (1983).

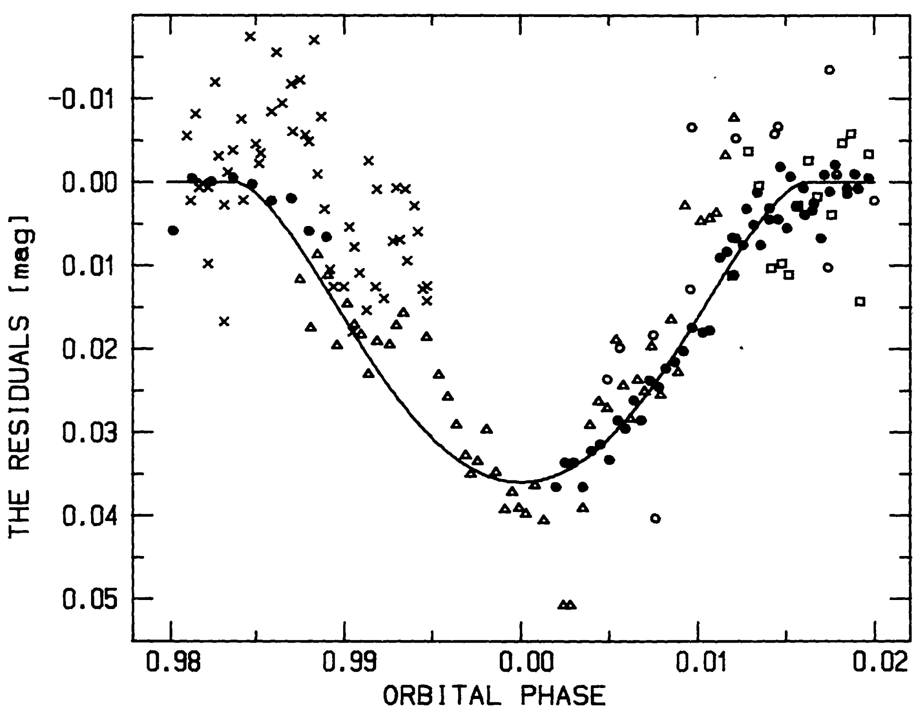

Fig. 2. The same as Fig. 2, but for observations not taken into account in the eclipse solution. The 1952 observations of Walker (1954) are represented by crosses; the *V* observations obtained in 1965, by filled circles; the 1977 Zacatecas *B* observations, by open circles; the 1980 Mojon del Trigo *B* data of Garrido *et al.* (1983), by squares; and the 1981 filter 4 observations of Garrido *et al.* (1983), by triangles.

3. Determination of the elements

3.1. The method.

We used the method of differential corrections, described in detail by Irwin (1947) and Kopal (1959). In Irwin's (1947) notation, the light of the system during transit is equal to

$$l^{tr} = 1 - {}^{x}f^{tr} L_1, \tag{3}$$

where L_1 is the out-of-eclipse light of the primary star, and ${}^xf^{tr}$, its fractional loss of light. For a circular orbit — which can safely be assumed in the case of 16 Lac because the system's orbital eccentricity amounts to an almost insignificant value of 0.047 ± 0.019 (Le Contel *et al.* 1983) — ${}^xf^{tr}$ is a function of six variables: $r_1, r_2, \cos^2 i, x_1, P, T_0$, where r_1 and r_2 are the radii of the primary and secondary star, respectively, i is the inclination of the orbit, x_1 — the primary's limb-darkening coefficient, P — the orbital period, and T_0 — the epoch of the principal conjunction. Differentiating Eq. (3) with respect to all six variables leads to the following equation:

$$\Delta l_{(o-c)} = -{}^xf^{tr}\Delta L_1 - L_1\left\{\frac{\partial\,{}^xf^{tr}}{\partial r_1}\Delta r_1 + \frac{\partial\,{}^xf^{tr}}{\partial r_2}\Delta r_2 + \frac{\partial\,{}^xf^{tr}}{\partial(\cos^2 i)}\Delta(\cos^2 i) + \right.$$

$$\left. + \frac{\partial\,{}^xf^{tr}}{\partial x_1}\Delta x_1 + \frac{\partial\,{}^xf^{tr}}{\partial P}\Delta P + \frac{\partial\,{}^xf^{tr}}{\partial T_0}\Delta T_0\right\}, \tag{4}$$

where $\Delta l_{(o-c)}$ is the difference between the observed light of the system and a value computed from approximate r_1, r_2, $\cos^2 i$, x_1, P and T_0. Each observation, taken during eclipse, yields one such equation of condition, so that the differential corrections to the approximate elements, Δr_1, Δr_2, $\Delta(\cos^2 i)$, Δx_1, ΔP and ΔT_0, can be derived by means of the method of least squares.

In the present case Eq. (4) can be considerably reduced. In the first place, the secondary component's brightness is negligible, so that $L_1 \equiv 1$. Moreover, ΔP and ΔT_0 can be put equal to zero, provided that P and T_0 are taken from Eq. (2). Finally, retaining the limb darkening coefficient as an unknown cannot, of course, lead to a significant improvement of the solution. Therefore, we adopted a value of $x_1 = 0.39$, given by Grygar (1965) for the blue region of the spectrum of a B2 star. Thus, the equation to be solved is

$$\Delta l_{(o-c)} = -\left\{\frac{\partial\,{}^xf^{tr}}{\partial r_1}\Delta r_1 + \frac{\partial\,{}^xf^{tr}}{\partial r_2}\Delta r_2 + \frac{\partial\,{}^xf^{tr}}{\partial(\cos^2 i)}\Delta(\cos^2 i)\right\}. \tag{5}$$

3.2. The results.

To begin with, we took the elements of Garrido *et al.* (1983) as the first approximation. After four iterations we obtained the following results:

$$k = r_2/r_1 = 0.19 \pm 0.04,$$
$$i = 83\overset{\circ}{.}3 \pm 0\overset{\circ}{.}8,$$
$$r_1 = 0.128 \pm 0.006.$$

Since they did not differ significantly from the results of the third iteration, we adopted them as final. The number of observations used in the solution was equal to 219. All observations were given the same weight.

In order to check the influence of the limb darkening coefficient on the solution, we repeated the calculations with $x_1 = 0.34$, a value for the blue spectral region and the effective temperature of 16 Lac from the tables of Al-Naimiy (1978). The results turned out to be the same as before.

The synthetic light-curve, computed with the above-mentioned final values of the photometric elements, is compared with observations in Figs. 1 and 2.

4. Discussion

4.1. The evolutionary state of the components.

Because 16 Lac is a single-line spectroscopic binary, a direct determination of the masses and radii of the components is not possible. However, if the primary component's mass were known, the mass of the secondary and the radii of both components could be obtained by using the photometric solution and the spectroscopic orbital elements. The effective temperatures of the components would then yield the luminosities. In other words, assuming an effective temperature for either component leads to a mass-luminosity relation for this component.

Recent estimates of the effective temperature of the primary component of 16 Lac range from 21 530 K (Shobbrook 1985) to 22 750 K (Jerzykiewicz and Sterken 1980). The mass-luminosity relations for these two values of T_{eff}, which we derived from the photometric solution, obtained in the preceding

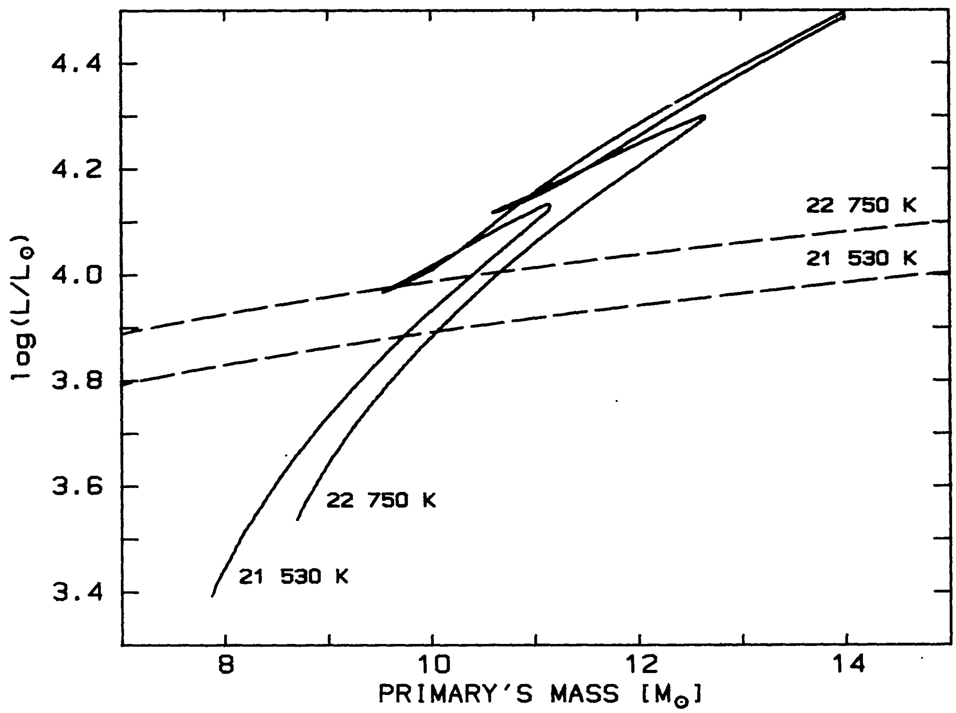

Fig. 3. The mass-luminosity relations for the primary component, derived for the indicated values of the effective temperature from the photometric and spectroscopic elements (dashed lines), and from the evolutionary tracks of models of Population I stars (solid lines). The latter range from the ZAMS to early phases of shell hydrogen burning.

chapter, and the recent spectroscopic elements of Le Contel *et al.* (1983), are shown in Fig. 3. Also shown in Fig. 3 are the mass-luminosity relations obtained from models of massive Population I stars for the same two values of T_{eff}. In order to derive the latter we used models computed by de Loore and De Greve (1978) with a modified Paczyński's stellar evolution program, Cox-Steward opacity tables, and initial chemical composition $X = 0.70$ and $Z = 0.03$.

As can be seen from Fig. 3, both pairs of the mass-luminosity relations intersect in the region of core hydrogen burning. We thus find that the primary component of 16 Lac is a main sequence object, in agreement with Sterken and Jerzykiewicz (1980), who reached the same conclusion from the star's position in the H-R diagram. The lower effective temperature relations indicate an age of 1.3×10^7 years since the ignition of hydrogen in the core of the primary component, whereas the higher temperature ones yield an age of 1.0×10^7 years. These values, along with other parameters corresponding to the points of intersection of the mass-luminosity relations in Fig. 3, are listed in the first two columns of Table 2. The last column contains mean errors which result from the mean errors of the photometric and spectroscopic elements used in the analysis, if M_1 is assumed to be error-free.

Table 2

Parameters of the components of 16 Lac that correspond to the points of intersection of the mass-luminosity relations in Fig. 3. Last column contains mean errors, resulting from the mean errors of the photometric and spectroscopic elements used in the analysis.

T_{eff} [K]	21530	22750	--
age* [years]	1.3×10^7	1.0×10^7	--
$M_1/M_\odot$	9.7	10.7	--
$R_1/R_\odot$	6.3	6.5	± 0.3
$\log(L_1/L_\odot)$	3.88	4.01	± 0.04
$M_2/M_\odot$	1.25	1.33	± 0.03
$R_2/R_\odot$	1.2	1.2	± 0.3

*) since the core hydrogen ignition.

The results presented in Table 2 agree, on the whole, with the earlier results of Jerzykiewicz (1980) and Garrido *et al.* (1983). The greatest difference between the new and old values occurs for the primary component's radius, for which Jerzykiewicz (1980) obtained 5.8 $R_\odot$, and Garrido *et al.* (1983), 5.3 $R_\odot$.

The secondary component's radius, $R_2 = 1.2 \pm 0.3\ R_\odot$, is very close to the theoretical ZAMS value for a 1.3 $M_\odot$, which is equal to 1.15 $R_\odot$. However, the primary contraction phase of a 1.3 $M_\odot$ star lasts about 2.7×10^7 years. If, therefore, the two components began their contraction onto the main sequence at the same time, the secondary would now be some 1.5×10^7 years short of reaching the ZAMS. As the pre-main sequence evolutionary tracks of Iben (1965) predict, its radius would then be equal to about 1.4 $R_\odot$. Since this value also agrees with the observed R_2 to within one standard deviation, the possibility that the secondary component of 16 Lac is still in the pre-main sequence phase cannot be excluded.

4.2. The pulsation constants.

The photometric and spectroscopic elements of 16 Lac were used in the preceding paragraph to derive the mass-luminosity relations for a given effective temperature. In the first place, however, they lead to a mass-radius relation:

$$M_1 \sim (R_1)^{3+x}, \tag{6}$$

where $x \approx 0.1$ for $7 < M_1/M_\odot < 15$. Consequently, in this range of M_1, the pulsation constant, $Q = P\langle\varrho\rangle^{1/2}$, where P is the pulsation period, is virtually independent of M_1. In other words, in the case of 16 Lac, Q is independent of the photometric calibrations of the luminosity and effective temperature scales.

The pulsation constants of 16 Lac, corresponding to the three pulsation frequencies mentioned in Chapter 2, amount to $Q_1 = 0^{\rm d}.0335 \pm 0^{\rm d}.0023$, $Q_2 = 0^{\rm d}.0339 \pm 0^{\rm d}.0023$, and $Q_3 = 0^{\rm d}.0360 \pm 0^{\rm d}.0024$. The latter value indicates that the f_3 component should probably be identified as the radial fundamental mode. The other components would then represent nonradial modes, perhaps having the same harmonic order l. This simple possibility is supported by the proximity of f_1 and f_2, suggesting first order rotational splitting of a single l mode, and by the fact that the pulsation amplitudes, A_1 and A_2, show a similar long-term variation.

APPENDIX A

Analysis of the out-of-eclipse observations

In what follows, we describe how the pulsation contributions to the light variation of 16 Lac, mentioned in Chapter 2, were derived from the out-of-eclipse data. The results are then summarized in Table A1. Note that instead of the initial phases, φ_i, we list the corresponding epochs of maximum light, Max_i, which are independent of the initial epoch, T_0.

Walker's (1954) out-of-eclipse observations consist of nine nights of blue-magnitude differences, 16 Lac *minus* 14 Lac, obtained in August 1952 at the Lick Observatory. Unfortunately, the original lists of Walker's photoelectric measures are not available. The data we used are numbers read from

Table A1
The parameters of Eq. (1) derived from the out-of-eclipse data.

Season	1952	1965	1965	1977	1979	1980	1981	1981
Sp. region	blue	B	V	b&B	b	blue	4	5
N. of obs.	399	1074	966	426	548	221	421	464
N. of nights	9	30	30	15	19	10	7	9
S.D. [mag]	0.0086	0.0037	0.0037	0.0044	0.0049	0.0055	0.0054	0.0042
A_0 [mag]	0.0002 4	5.4537 1	5.5957 1	-0.0000* 2	0.4072 2	-0.0002** 4	-0.3629 3	0.4056 2
A_1 [mag]	0.0257 7	0.0200 2	0.0179 2	0.0083 3	0.0073 3	0.0069 6	0.0123 5	0.0071 4
A_2 [mag]	0.0145 7	0.0102 2	0.0098 2	0.0049 3	0.0031 3	0.0035 6	0.0063 5	0.0053 4
A_3 [mag]	0.0144 6	0.0111 2	0.0104 2	0.0068 3	0.0063 3	0.0121 6	0.0156 5	0.0108 3
Times of maxima	2424230.+	2438972.+	2438972.+	2443400.+	2444101.+	2444502.+	2444908.+	2444908.+
Max_1	0.1247 8	0.0604 2	0.0600 3	0.0322 10	0.0657 12	0.1650 23	0.1641 11	0.1647 14
Max_2	0.1671 14	0.1499 5	0.1493 5	0.0356 18	0.0778 28	0.0658 48	0.0004 21	0.0044 19
Max_3	0.1753 13	0.1456 4	0.1451 4	0.0900 14	0.0419 14	0.0818 14	0.0932 8	0.0942 9

*) <Δm> = 0.4107 for Białków, 0.4069 for San Pedro Martir, 0.2978 for Mt.Chiran and 0.2340 for Zacatecas.
**) <Δm> = 0.2732 for Akita, 0.2527 for Mojon del Trigo, 0.4036 for San Pedro Martir and 0.4097 for Białków.

photographic enlargements of the published light curves. They were kindly communicated to us by Dr. W. S. Fitch.

Eq. (1) fits the data with a standard deviation (SD) equal to $0\overset{m}{.}018$. This value is much too large to be accounted for by observational errors alone. In fact, about half of it is due to a night-to-night variation of the magnitude differences, attributable to 14 Lac (Fitch 1969). After applying night corrections, equal to the nightly mean residuals from the least-squares solution, one gets a fit with SD $= 0\overset{m}{.}0086$, and the pulsation amplitudes and epochs of maximum light listed in Table A1. Since, however, the mean magnitude difference for the night of the eclipse, JD 2434239, is not known, Walker's observations could not be used in the eclipse solution. The residuals shown in Fig. 2 were derived assuming the overal out-of-eclipse mean value, $A_0 = -0\overset{m}{.}560$.

The 1965 observations of Jerzykiewicz (unpublished) were obtained with a conventional *UBV* photometer, mounted at the Cassegrain focus of the Lowell Observatory 21-inch reflecting telescope. HR 8766 = 2 And was used as the comparison star. The data consist of 264, 1110, and 1002 *U*, *B*, and *V* observations, respectively. The *U* data were not used in the present analysis. In the *B* and *V* least-squares solutions, which yielded parameters listed in Table A1, we omitted the observations obtained on JD 2439054, but included the ones obtained on JD 2438993 and JD 2439042, because the few points falling between the first and last contact on these two nights (see Table 1) were scarcely affected by the eclipse.

The 1977 parameters in Table A1 are based on the blue-magnitude observations of Jarzębowski *et al.* (1979). The four mean magnitude differences, $\langle \Delta m \rangle$, given in the footnote to the table, correspond to the four different filter-cell combinations used by these workers. They were subtracted from the data, and then Eq. (1) was fitted to the residuals by the method of least squares.

The 1979 solution in Table A1 is identical with that given in Table 7 of Jerzykiewicz *et al.* (1984), except that φ_i have been replaced by Max_i.

In 1980, 16 Lac was observed by Garrido *et al.* (1983 and file 104 in the I.A.U. Archives of Unpublished Observations of Variable Stars), Sato and Hayasaka (1986), and Jerzykiewicz (this paper, Appendix B). In all cases, 2 And was used as the comparison star. The out-of-eclipse data of Garrido *et al.* consist of three sets: five nights of U and B observations obtained with the 30-cm reflecting telescope of the Mojon del Trigo Observatory, four nights of filter No. 40 (Johnson and Mitchell 1975) photometry with the San Pedro Martir Observatory 152-cm telescope, and one night with the same telescope and filter No. 5 of Sareyan *et al.* (1976). The data of Sato and Hayasaka (1986) include three nights of UBV photometry, carried out at the Akita University Observatory with a 25-cm reflecting telescope. Finally, Jerzykiewicz's out-of-eclipse data consist of a single night of b observations, obtained with a 60-cm telescope of the Białków station of the Wrocław University Observatory.

Out of all these data, we used only the blue-magnitude observations. However, filter No. 5 photometry of Garrido *et al.* showed an excessive amount of scatter, and was therefore rejected. In addition, we rejected all nights on which observations covered less than $0\overset{d}{.}1$. There were two such nights in Garrido *et al.*, and one in Sato and Hayasaka (1986). Thus, the data were reduced to four sets, each obtained with a different filter-cell combination, and therefore having different $\langle \Delta m \rangle$ values. Fortunately, in 1980 the f_3 component's amplitude was so much greater than the amplitudes of the remaining two components that we could derive $\langle \Delta m \rangle$ by fitting the f_3 component alone to each of the four data sets separately. The four $\langle \Delta m \rangle$ values, given in the footnote to Table A1, were derived in this way. After these values were subtracted from the data, Eq. (1) could be fitted to the residuals by the method of least-squares. Before doing this, however, we averaged each two successive observations of Sato and Hayasaka (1986) in order to make the number of points per full observing night about the same in each data set.

The 1981 parameters in Table A1 are based on the data of Garrido *et al.* (1983 and file 104 in the I.A.U. Archives of Unpublished Observations of Variable Stars), obtained with the Geneva type photometer, attached to the automated 62-cm telescope of the Pico de la Veleta Observatory. The data consist of 13 nights of two-colour observations with filters 4 and 5 (ultraviolet and blue) of Sareyan *et al.* (1976). However, not all these data were used in the least-squares analysis. Along with JD 2444909, that is, the night on which the eclipse took place, we also rejected JD 2444883, JD 2444910, and JD 2444919 from both the ultraviolet and blue data, and, in addition, JD 2444881 and JD 2444934 from the ultraviolet data, because observations on these nights deviated from the least-squares solutions in a manner indicating that gross errors must have been introduced somewhere on the way between the telescope and the I.A.U. Archives. Finally, we note that night JD 2444907, mentioned in Garrido *et al.* (1983), does not appear in the I.A.U. file 104.

APPENDIX B

The 1980 Białków observations of 16 Lac

The observations were carried out by M. J. on two nights in September 1980, using the same equipment and observing procedures as those described in Jerzykiewicz *et al.* (1984). The *b* magnitude-differences, Δm = "16 Lac *minus* 2 And", corrected for the effect of the differential atmospheric extinction, are listed in Table B1, and plotted in Figs. B1 and B2.

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Table B1
The *b* filter differential photometry of 16 Lac in 1980.

$JD_{\odot}$ 2444500+	Δm	$JD_{\odot}$ 2444500+	Δm
$10^{d}.2932$	$0^{m}.429$	$11^{d}.2791$	$0^{m}.413$
10.2992	0.432	11.2872	0.410
10.3102	0.439	11.2952	0.408
10.3175	0.437	11.3025	0.398
10.3243	0.445	11.3121	0.395
10.3318	0.450	11.3213	0.398
10.3390	0.457	11.3285	0.397
10.3475	0.449		
10.3558	0.457	11.3361	0.400
10.3648	0.444	11.3446	0.399
		11.3518	0.406
10.3735	0.441	11.3592	0.404
10.3809	0.438	11.3664	0.410
10.3915	0.430	11.3773	0.416
10.4017	0.410	11.3850	0.416
10.4102	0.413	11.3923	0.417
10.4172	0.403	11.3997	0.420
10.4658	0.391	11.4420	0.415
10.4729	0.406		
10.4798	0.404	11.4492	0.408
10.4868	0.419	11.4568	0.406
		11.4645	0.400
10.4937	0.414	11.4722	0.403
10.5005	0.433	11.4800	0.396
10.5083	0.431	11.4887	0.405
10.5157	0.431	11.4971	0.395
10.5228	0.433	11.5060	0.395
10.5304	0.437	11.5141	0.401
10.5379	0.432	11.5227	0.409
11.2564	0.422	11.5314	0.402
11.2637	0.417	11.5394	0.411
11.2710	0.411	11.5470	0.407

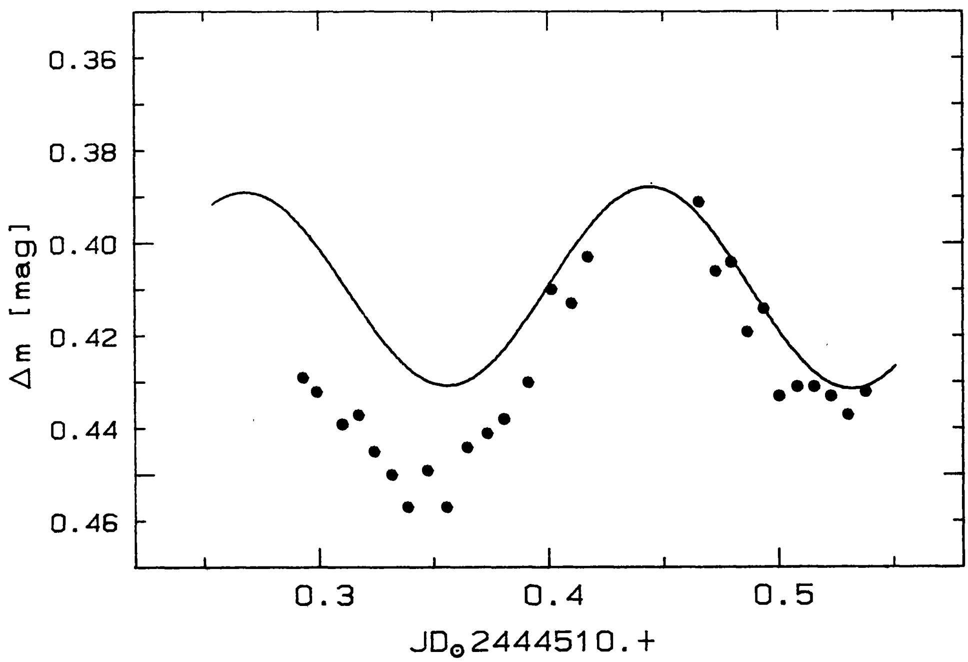

Fig. B1. The *b* magnitude differences "16 Lac *minus* 2 And", obtained on JD 2444510, plotted as a function of heliocentric Julian day. The 1980 pulsational contribution to the light variation is shown by means of a solid line. The deviations during the first half of the night are due to the eclipse.

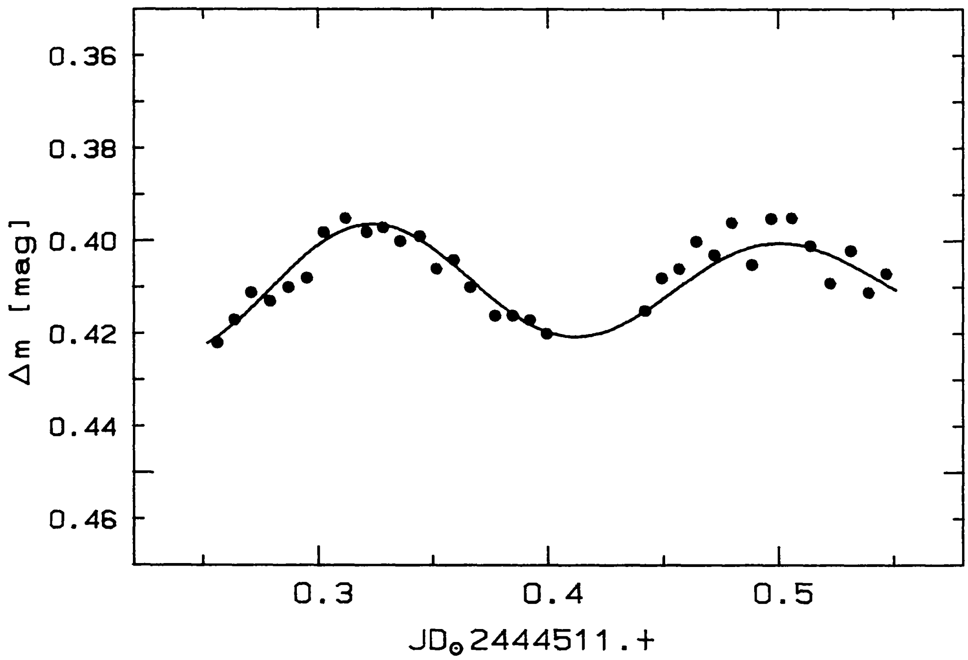

Fig. B2. The *b* magnitude differences "16 Lac *minus* 2 And", obtained on JD 2444511.

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