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An Alternate Light Curve Solution of AR Lacertae*

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Abstract

Photoelectric UBV light curves of AR Lacertae made in one season during 1981-82 are presented. Although the shape of the light curves in the outside eclipses shows a strong distortion, the scatter of observations as well as phase coverage are better than those previously available. Fourier coefficients are derived from the *V*-light curve and the observed curve successfully rectified to the Russell model. Light curve solutions are computed and the geometrical and physical parameters of AR Lac are derived as $a_s = 0.182$, $a_g = 0.341$, $j = 86^\circ 3$, $L_s = 0.372$, $L_g = 0.628$, $k = 0.53$, $X_s = 0.85$, $X_g = 0.4$.

I. INTRODUCTION

The light variability of AR Lac was discovered by Miss Leavitt in 1903 and confirmed by Wendel in 1907. However the nature of variation was not recognized until 1929. This delay of more than 20 years was due to the fact that the period of AR Lac is nearly two day of intega and makes it difficult to obtain a full light curve at one site in one observing season. A series of observations by Jacchia and Loreta in 1929 made it possible to make a conclusion that it is an eclipsing binary system with a flat bottomed primary and shallow secondary minimum light.

Photometric investigations of AR Lac have been continued by many observers after Jacchia (who made a visual light curve). Rugemer (1931) and Schneller and Plaut (1932) published photographic light curve and Gainullin (1943) derived photometric element from that two color photographic light curve. In 1938-39 Wood (1946) obtained photoelectric light curve in blue and published photometric solution for the photometric element and his observation was used by

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Kopal and Shapley (1956) to get the new photometric elements even though his comparison was identified (known) scholax to propose as an intrinsic variable by Blanco and Catalano (1970).

Mean time, Kron performed a series of photoelectric observation during 1938-47 and proposed firstly the star spot model to explain irregular light variation superimposed on outside of eclipse. His observations were used in deriving of a set of new orbital elements 30 years later by Theokas (1976) who adopted the frequency domain concept proposed by Kopal.

AR Lac, whose photoelectric light curves have shown it to be an intrinsically variable system, belongs to a detached eclipsing binary system and was classified as RS CVn type stars. Both components of AR Lac were regarded as subgiants, spectral type of G2lV and KOIV. It became one of typical RS CVn system as the existance of CaII H & K emission lines, wave-like distortion, radio emission (Gibson and Hiellming, 1974). The exclusive analysis by Chambliss (1976) was followed by many investigator, Srivastava (1980), Kurutac (1980), Nha and Kang (1982) and Hoffmann (1980). But all of them used partially completed light curves.

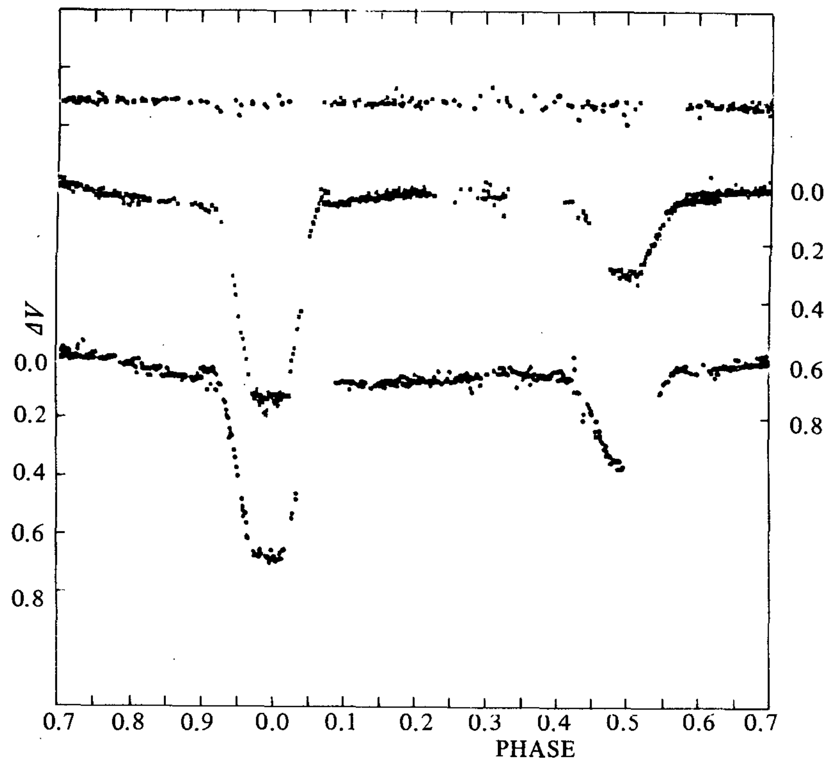


Fig. 1. The yellow light curves of AR Lac and the check star, BD+44°4041, made in 1980-81 and 1981-82. X represents 1980-81 observations and the open rectangle represents 1981-82 observations.

For an confident and intensive investigation to make a completed light curve, an international campaign was proceeded by I.S. Nha at Yonsei University and F. B. Wood at University of Florida during 1980-1982. As one of the series of international campaign this study was aimed to get the analysis of the light curves using the data made at Yonsei University and Konju National Teacher's College during the 1981-82 season.

II. OBSERVATION AND INSTRUMENTATION

AR Lac was observed for (during) 16 nights from September to December 1981 at YUO (Yonsei University observatory) with 16" Casscgrain reflector and 8 nights from December 1981 to January 1982 at KNTC (Kongju National Teacher's College) observatory with 16" Cassegrain reflector. A total of 506 in B and V at YUO and 300 in UBV at KNTC were made Unrefrigerated Hamamatsu 1P21 and the standard UBV filters of Johnson system used fat both observatories. Fig. 1 shows the wavelength characteristic curves of KNTC filters measured with the spectrophotometer of Perkin Elmer.

The comparison star used for all observations was BD+44° 4044 A whose constancy of light has been proved by previous observers, Kang (1977), Srivastava (1981), and Nha and Kang (1982). BD+44 4041 (A0 was observed as a check star. The constancy of check star's light was regularly checked by Kang (1977) and Nha and Kang (1982).

Light curves in Fig. 1 are constructed by Δ m (AR Lac – comparision star), or Δ m (check star – comparison star), and phases which are calculated with the ephemeris of Nha and Kang (1982) as

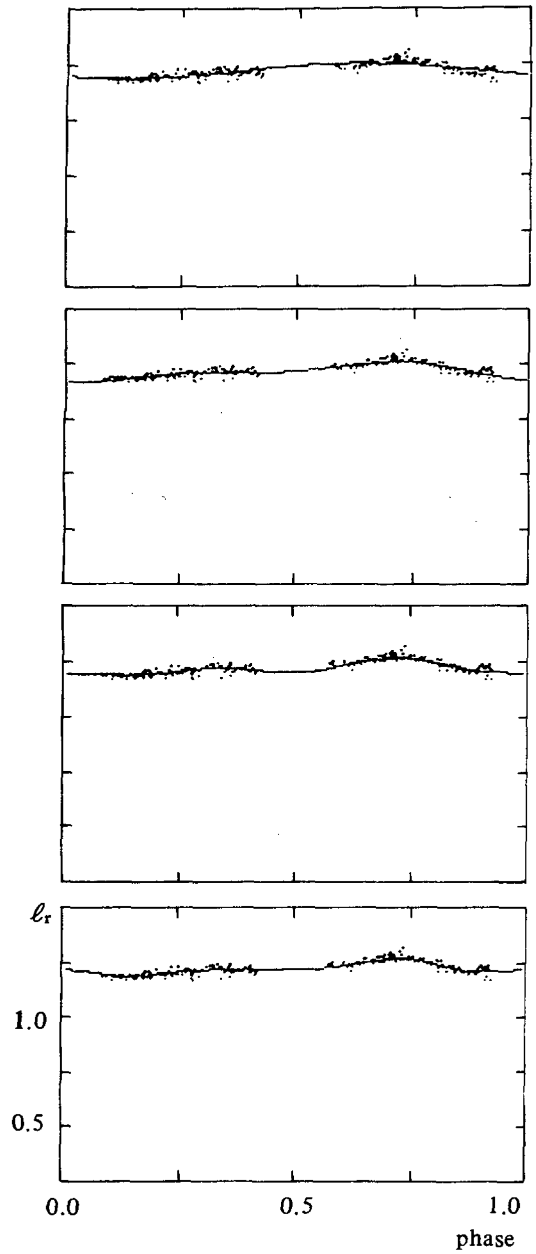
$$\text{Hel Min I} = \text{JD}2440933.3081 + 1.9831917\text{E}.$$

All the data obtained through international campaign at four observatories including the data used in this study were reported elsewhere (Nha et al. 1984).

DC amplifier systems which are consisted with 2F4539, a FET OP-amp and circuit of 100% negative current feedback were employed by YUO and KNTC. The amplifier of YUO was aligned by J. H. Chung and KNTC's one was designed and adjusted by H. S. Park to guarantee the temperature variation smaller than $0.^{m}001$ by testing temperature coefficient of resistors which were used in fine and coarse gain steps.

III. FOURIER ANALYSIS AND RECTIFICATION

When we perform Fourier transformation to the light curve of RS CVn type stars to get a set of photometric elements, it should be noted on the effect of wave-like distortion which might alter the coefficients of reflection and ellipsoid to rectify into Russell model. Among the coefficients, cos θ and cos 2θ are meaningful to impress reflection and ellipsoid but the other coefficients could not bear any physical interpretation (Binnendijk 1970, Russell and Merrill 1952).



a. *V* – 1981-82 .... ITERMS

COEFFICIENTS		PROBABLE ERRORS
A_0	0.9664	0.0006
A_1	−0.0222	0.0012
B_1	−0.0260	0.0007

S2 = 2.82368877 E - 04

b. V–1981-82 .... 2 TERMS

A_0	0.9585	0.0007
A_1	−0.0220	0.0010
B_1	−0.0260	0.0006
A_2	−0.0187	0.0011
B_2	−0.0004	0.0007

S2 = 1.9896786 E – 04

c. *V*–1981-82 .... 3 TERMS

A0	0.9589	0.0006
A_1	−0.0104	0.0016
B_1	−0.0235	0.0006
A_2	−0.0177	0.0010
B_2	0.0000	0.0007
A_3	0.0091	0.0011
B_3	0.0064	0.0007

S2 = 1.71180313 E – 04

d. *V*–1981-82 .... 4 TERMS

A_0	0.9636	0.0011
A_1	−0.0104	0.0015
B_1	−0.0233	0.0006
A_2	−0.0093	0.0019
B_2	0.0005	0.0008
A_3	0.0090	0.0011
B_3	0.0067	0.0007
A_4	0.0070	0.0013
B_4	0.0001	0.0008

S2 = 1.64562038 E – 04

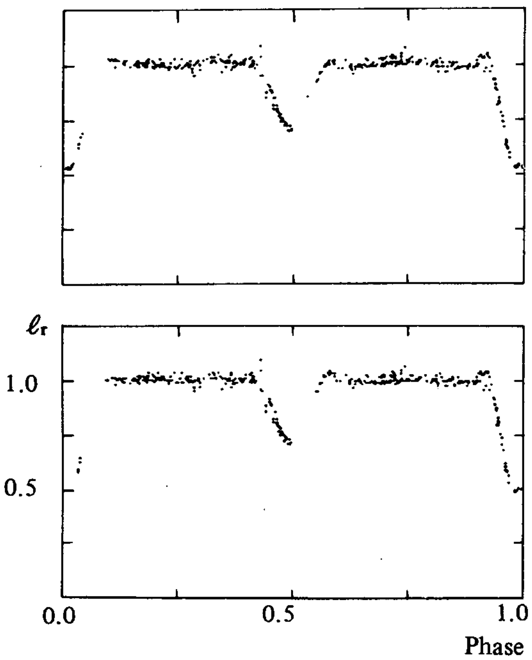
Fig. 2. Curves of Fouries transformation and coefficients of 1981-82. A is coefficient of cosine and B is coefficient of sine, second column is coefficient and third column is probable error.

In Fourier transformation it is important to decide the number of terms of the series as many as possible to fit the observed light curve, but it should be controlled to take several terms because of the problems of calculation and the reciprocal correlation between the number of terms and the value of coefficients (Merrill 1970).

Fig. 2 contains the observed points and the curves according to Fourier transformation and the coefficients. The coefficients were calculated by using a least square method which was programmed by Choi (1983) in Basic Language.

For the rectification, the Fig. 2 of Princeton Contribution No. 26 (Russell and Merrill 1952) was used in assuming the reflection coefficients instead of using the depth relation because of the effects of the wavelike distortion on outside eclipse.

The rectified points are plotted in Fig. 3 respectively along the number of terms and assumed limb darkening coefficient as X=0.6.



c. Light curve rectified with 2-term expansion coefficients.

Al = .9585 Al = -.022 A2=-.0187 A3 = 0
B1 = -.026 B2 = -0.0004 B3 = 0
C0 = .0666 C1 = .022 C2 = .0221
Nz = .175

d. Light curve rectifeed with 3-term expansion coefficients

A0 = .9589 Al=-.0104 A2=-0.177 A3 = 0.0091
B1 = -.0235 B2=0 B3=0.0064
C0 = .0315 C1=.0104 C2=.0105
Nz = .118

Fig. 3. Rectified light curves of 1981-82. A and B are Fourier coefficients. The index of a, b, c is same as α. C. N and Nz are constants for rectification.

IV. LIGHT CURVE SOLUTION

The observations around primary and secondary minimum are appeared insufficient to use depth relation in obtaining k, the ratio of stellar radius because only descending branch of primary minimum were observed. By choosing θ_s and α_s from the descending branch of the rectified curve, the table of Russell and Merrill (1952) give us the corresponding ks and their mean value was 0.53.

Table 1. Photometric Elements of AR Lac (Solution of *V*-light curve.)

	Chambliss (1976)	Srivastava (1981)	this paper
x_s	0.5	0.8	0.85
x_g	0.9	0.8	0.4
k	0.55	0.50	0.53
a_s	0.169	r_s = 0.176	0.182
a_g	0.307	r_g = 0.351	0.341
b_s	0.165		0.176
b_g	0.300		0.329
Po	−1.41		−1.53
j	86°1	i = 75.6	86°3
ϵ	0.020		0.034
θe	27°.6	30°.8	30°.6
θi	8°.0	5°.2	8°.5
α_0^{oc}	1.00	1.0	1.00
α_0^{tr}	1.11	1.16	1.13
L_s	0.411	0.555	0.372
L_g	0.589	0.445	0.628
J_s/J_g	2.30	5.00	2.08

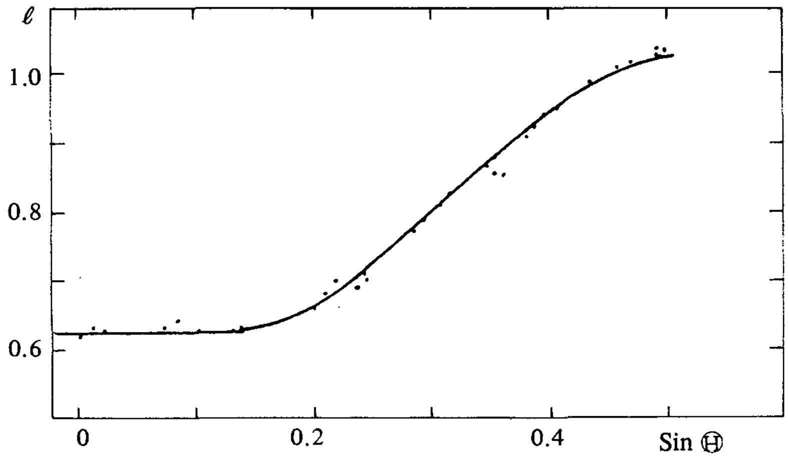


Fig. 4. Rectified points and theoretical curve at primary minimum. X=0.85 and Θ is rectified phase and *l* is rectified luminosity.

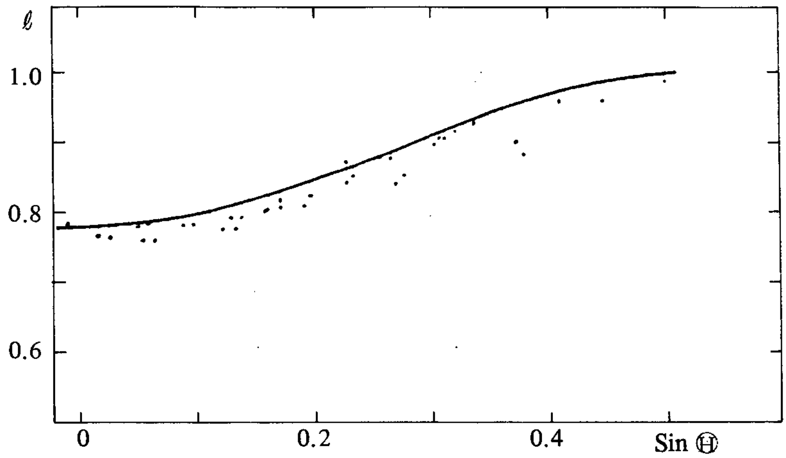


Fig. 5. Rectified points and theoretical curve at secondary minimum. X=0.4 and Θ is rectified phase and ℓ is rectified luminosity.

With keeping k=0.53,we changed limb darkening coefficients from 0 to 1 by step of 0.1 and can obtained most reasonable value as Xs=0.85 which is much different from 0.5, the value of Chambliss (1976). The light curve of secondary minimum not only deviated too much from the theoretically calculated curves but also the brightness of primary minimum became too much higher than unrectified light curve as a result of high reflection coefflicient.

We compared these calculations with the values of other investigators in TableI and presented rectified points and theoretical curves around primary and secondary minimum is Fig. 4 and Fig. 5 respectively.

V. RESULTS

On the basis of computer program by Choi (1984) we calculated the photometric elements according to the method of Russell and Merrill and the results are listed in Table I. The calculations identified most of our results with the elements of Chambliss (1976) except the limb darkening coefficient. Our results of Xs = 0.85 and Xg = 0.4 is a reversed situation compared to the values of Chambliss and general values of normal stars. It might be a cause that we had used only the descending branch.

The inclination of Srivastava (1981) which is smaller than ours might have come from the distortion around the second contact of primary minimum whose descending slope is so slow as to make the small internal tangency.

Absolute dimensions of AR Lac are computed with the adoption of spectroscopic elements of Sanford (1951) as

$a_1 \sin i = 3.167 \times 10^6$ km
$a_2 \sin i = 3.151 \times 10^6$ km
$M_1 \sin^3 i = 1.29$ M⊙
$M_2 \sin^3 i = 1.30$ M⊙

The results of calculation compared with those of Chambliss (1976) shows nearly identical. We did not compare with those of Srivastava (1981) because of his mistake. His value of a=6.51 R⊙ should be 6.51×10^6Km.

We presented the model of AR Lac system and Roche lobe calculated from the table of Plavec and Kratochvil (1964) and confirmed that both components of AR Lac did not fill the Roche lobe.

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