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LIGHT CURVE VARIATIONS OF AR LACERTAE[1]

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ABSTRACT

Sixteen unitary Light curves of AR Lac in B and V are made at Yonsei University Observatory in the period of 1980-1988 Some overview findings of light variations are made.

(1) The light variations outside eclipse follow none of the wave migration patterns reported by previous investigators.

(2) Complicated shapes outside eclipse are apparently much reduced in the light curves of 1983-1984. This suggests that, in the future, AR Lac has a chance to attain a normal state with no complicated interactions.

(3) The depths of the primary and the secondary mid-eclipses are changing year-to-year.

(4) The K0 star, the larger component, has brightened by $0.^m14$ in V, while the G2 star has shown a fluctuation of about $0.^m05$ in V.

(5) The B-V values at primary mid-eclipse have no correlation with the depth variations.

(6) Independently of the increase of maximum brightness, the B-V colors in the non-eclipsed phases changed slightly over the years.

I. INTRODUCTION

Because its peculiar light variations are not caused by eclipses, the brightest eclipsing RS CVn star AR Lac has been observed and studied most intensively recently by many photometric investigators (*e. g.*, Chambliss 1976, Srivastava 1981, Kurutac *et al.* 1981, Nha and Kang 1982, Lee *et al.* 1986, Kang and Wilson 1989).

After the two year-break following our first observations in 1976-1977 at Yonsei University Observatory (YUO), observations of AR Lac resumed in 1980 and continued without interruption until January 1988. A total of sixteen unitary light curves, two each year in the V and B bandpasses, has been made.

Three other observatories joined the observational effort in the first two years, 1980 and 1981, and the combined results were published elsewhere (Nha *et al.* 1985). The V and B light curves made in the third year, 1982, were analyzed and reported by Lee *et al.* (1986). But the remaining ten light curves made afterwards for five years, 1983-1988, has been left untouched because the light curves in these seasons demonstrate a shape of light curve significantly different from those of perviously known. The new observations lead one to look at AR Lac in many possible ways.

This is a part of series of reports preceeded by the three previous works, and in this paper an overview of the light curve variations of AR Lac is given. The detailed analyses of the light curves will be left unattempted until more clues for a clarity of the nature of light

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variations be apparent in a future monitoring. But, in the meantime, it is hoped that the present observations become useful to interested investigators for their study.

II. OBSERVATIONS

Before we proceed to our investigation of the sixteen light curves mentioned in the Introduction, we want to list in Table I a summary of the observations of AR Lac and the check star (HR 8422, BD+44°4041) made over eight years at YUO alone. Each observation was calculated from about one minute of *dc* amplification of the multiplied photocurrent traced onto strip recorder chart. The instruments used throughout this eight year period remained essentially the same as given already by Nha and Kang. The observational technique and reduction procedure are given by Nha *et al.* (1985).

The importance of the check star in connection with the long-term monitoring of a peculiar object such as AR Lac must be emphasized . The check star makes it possible to check light levels which are systematically changing due to minor instrumental repairs and unknown causes as may occur during the observing period. Fortunately, the constancy of light of the comparison star (HR 8429, BD+44°4044) used for the observations of AR Lac was demonstrated by Srivastava during the 1975-1976 season with average standard deviations of $\pm0\overset{m}{.}022$ in U, $\pm0\overset{m}{.}015$ in B, and $\pm0\overset{m}{.}016$ in V. This was confirmed by us (Nha and Kang 1982) in two seasons, 1976 and 1977, for which the internal probable errors for a single observation calculated from the Δm (ch. star - comp. star) are $\pm0\overset{m}{.}02$, and again by Nha *et al.* (1985) in the course of the 1980-1982 seasons.

Table I. Journals of observations of AR Lac and check star (HR8422). AR_V, AR_B, and AR_U are numbser of obsevations of AR Lac Ch_V, Ch_B, and Ch_U are numbser of obsevations of HR8422. n_D is numbser of nights.

Year	AR_V	AR_B	AR_U	Ch_V	Ch_B	Ch_U	n_D	Intervals obseverd
1980*	240	221	-	96	94	-	18	1980 Oct -1981 Jan
1981*	270	257	-	47	51	-	18	1981 Oct -1982 Jan
1982**	579	579	-	133	123	-	34	1982 Sep -1983 Jan
1983	666	672	-	62	38	-	36	1983 Aug-1983 Dec
1984	730	730	10	89	88	2	42	1984 Aug-1985 Jan
1985	537	543	25	58	53	3	38	1985 Jul -1986 Jan
1986	1012	1012	1	75	45	13	53	1986 Aug-1987 Jan
1987	945	902	-	70	6	-	49	1987 Sep -1988 Jan
Total	4979	4916	36	630	498	18	288	

* Nha *et al.* (1985), ** Lee *et al.* (1986)

A total of 9,931 *UBV* observations of AR Lacertae with an additional 1,146 observations of HR 8422 in *UBV* was made at YUO alone in eaght years, 1980 OCT-1988 JAN. Observations of Δm were corrected differentially by the extinction determined each night from the observations of the comparison star. The characteristics of these three stars are given in

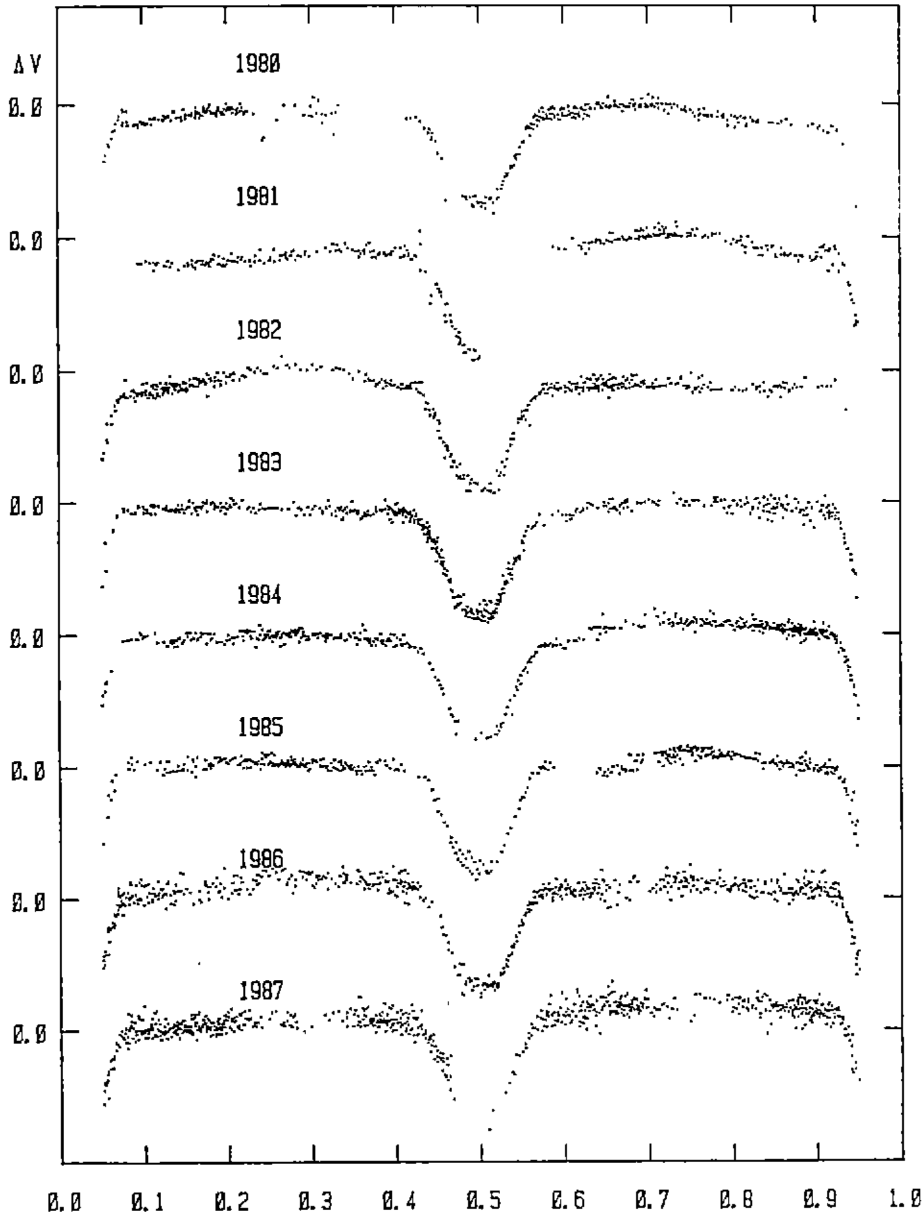

Figure 1. Partial yellow light curves of AR Lac Lacertae. Ordinates are the instrumental magnitudes in the sense of ΔV (AR Lac - comp. star) with a scale of $0\overset{m}{.}4$ for each tick mark

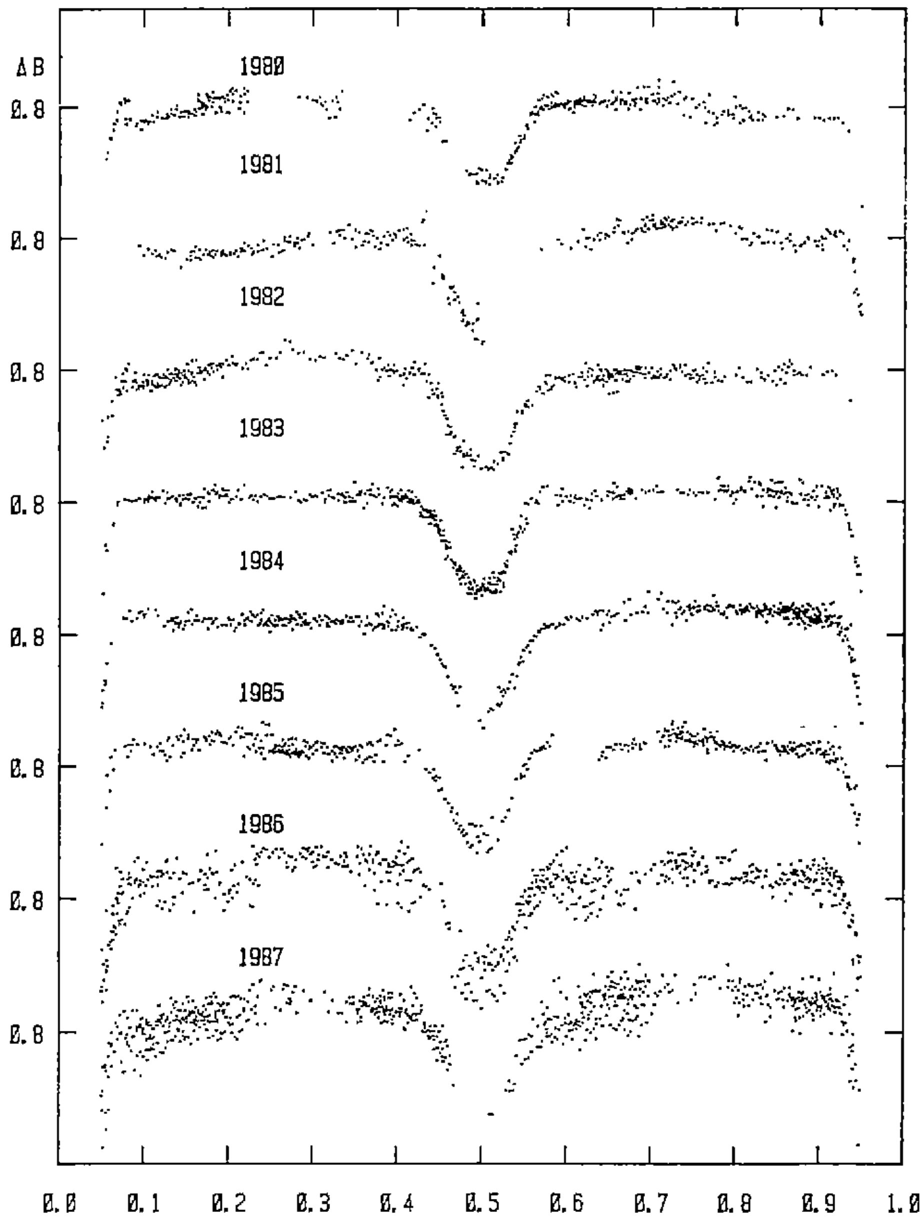

Figure 2. Partial blue light curves of AR Lacertae Ordinates are the same as in Fig. 1.

Table II. In this Table the standardized V and B-V of AR Lac and check star are determined by us using Hoffleit's (1982) values of the comparision star and on the basis on our observations made in the 1983-1984 season alone.

Table II. Characteristics of AR Lac, and the comparison and check stars

Star	HR	Sp*	V	B-V	U-B*
AR Lacertae	8448	G2IV+K0III	6.11-6 77*	+0.72*	+0.26
Max.			6.19**	+0.79**	
Min. I			6.85**	+0.92**	
Min. II			6.52**	+0.75**	
Comp. star	8429	A3V	6.19*	+0.09*	+0.14
Check star	8422	A0V	6.44*	-0.03*	-0.14
			6.51*	-0.03*	

* Hoffleit (1982)
** Based on the observations in 1983-1984 using Hoffleit's values of HR 8429

Except for observations of the first two-year interval already reported elsewhere, phase coverage of the B and V light curves of this difficult star in each year has been guite complete. This makes it possible to investigate the variability of the light curve of AR Lac over a long time span. For these light curves, difficulties arising from limitations such as the single observing location, an orbital period of nearly two days, finite telescope time, *etc.*, were successfully overcome.

III. LIGHT CURVE SCENARIO

The sets of the eight instrumental V and B light curves of AR Lac centered at the secondary eclipse are shown in Figures 1 and 2, respectively. Phases are calculated by the light elements given by Kim (*1991*) for the interval, *1979 - 1986 :*

$$Min.\ I = JD\ Hel.\ 2444114.3431 + 1^d\!.98316736\,E.$$

These light curves of 1980 - 1988 show peculiar light variations, which are known to be one of the most typical characteristics of RS CVn stars. Each of these light curves shows itself dissimilar to any other, but there is no clear evidence of any regular pattern suggested by many previous investigators (*e.g.*, Kurutac *et al.* 1982, Kang 1985). There are, however, other distinct characteristic light variations found among our light curves monitored over the long span.

VARIATIONS IN THE OUTSUDE ECLIPSE INTERVALS

The shapes of the light curves are asymmetric over both non-eclipse phase intervals as usual, but the complicated features common to all previous light curves mentioned by Nha *et al.* (1985) are reduced significantly, particularly in the two seasons 1983 and 1984. The light curves of these seasons are representative of those of some normal Algol binaries, but these apparently do not indicate the common state of the system. Complications, however, resume in 1985 particularly for the shape of the light curves between $0^p_.62$ and $0^p_.80$.

INCREASING TOTAL BRIGHTNESS

The brightness of AR Lac outside eclipse with respect to the brightness of the comparison star HR 8429 has never remained the same, but has increased steadily during our monitoring years. Due to the irregular levels in the light curves, homogeneous comparison directly between one curve and another is not possible, but it is possible to see the tendency of the increasing brightness of AR Lac.

Table III lists the maximum light levels in blue and yellow for each observing season with the deduced colors as well. Tabulated entries are differential instrumental magnitudes in the sense of (AR Lac - HR8429). In the last column of this table the values given are the phase ranges from which the mean maximum brightnesses were read. The phase intervals over which maximum brightness appears are different every year, but they are rather closely clustered over two major intervals with different frequencies: two years around $0^p_.3$ and six around $0^p_.7$

Table III. Maximum total brightness, color, and the phase range of AR Lac Values are instrumental Δmag (AR Lac - HR8429).

Year	ΔB	ΔV	$\Delta (B-V)$	Phase range
1980-81	0 77	0.00	0.77	0.65-0.75
1981-82	0.75	-0.01	0.76	0.68-0.75
1982-83	0.75	-0.02	0.77	0.24-0.35
1983-84	0.76	0.00	0.76	0.66-0.85
1984-85	0 72	-0 04	0 76	0.65-0 83
1985-86	0.70	-0.05	0 75	0.69-0.76
1986-87	0.67	-0.07	0 74	0.22-0.35
1987-88	0 66	-0.08	0.74	0.62-0.82

Except for 1983 all entries in Table III increase steadily with time in both the yellow and blue as shown in Figure 3. In our eight year monitoring these increases of the brightness in magnitude are $0^m_.08$ and $0^m_.11$ for the yellow and blue, respectively. The color also has a tendency to change accordingly, in a decreasing sense which may be an indication of increasing temperature or of the existence of unknown activity in the system.

DEPTH VARIATIONS AT THE MID-ECLIPSES

The brightening of the system mentioned above and shown in Table III and in Figure 3 has been investigated to see if this light variation originated in either or both of the component stars in the AR Lac system. It is easy to check which component responded more to the total light of the system, because the light curves show that the primary eclipse is a total occultation. The depths of the primary and secondary eclipses were read from the light curves. These are illustrated in Figure 4 for the primary and secondary eclipses in V and B.

Except for 1980, a significant increase has occurred in V but the increase in B is much smaller. This seemingly result contradicts that for the maximum brightness outside eclipses (shown in Figure 3), wherein the increase in B is greater than that in V.

The color indices at the mid-eclipses change with a tendency of increasing (*i.e.*, more reddening) as time goes on. This also seems to contradict the results for the maximum brightness outside eclipses. The increases of the individual component stars cannot, therefore, be the major contribution to the total brightness of the system.

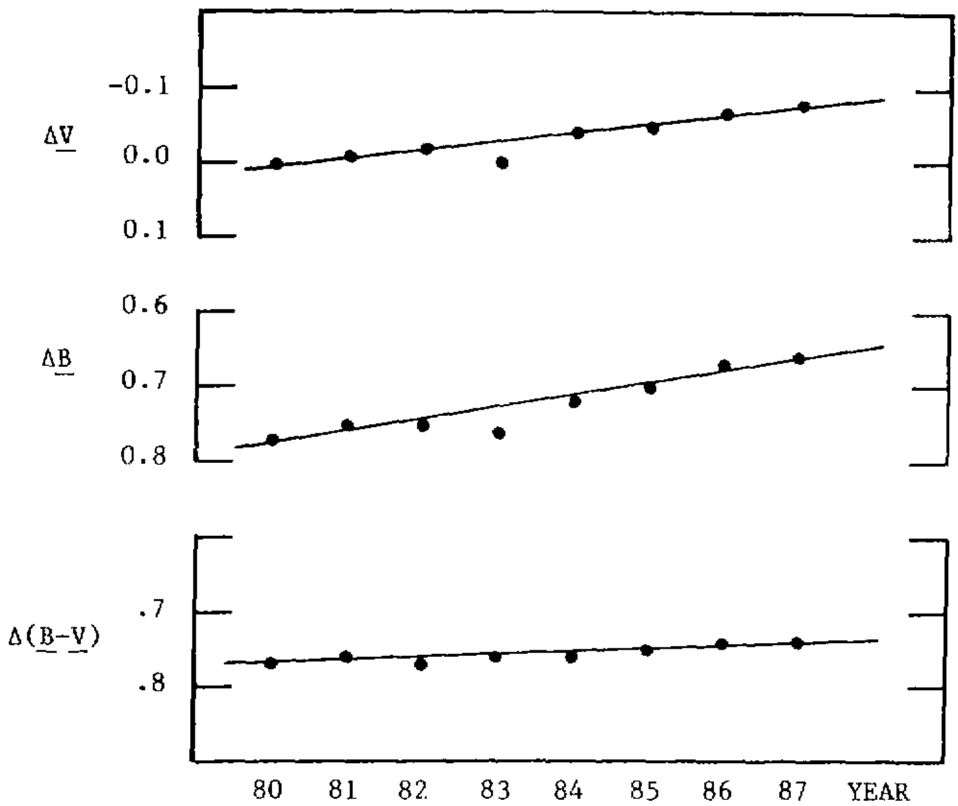

Figure 3. Increasing brightness of AR Lac at its extreme-brightness phase.

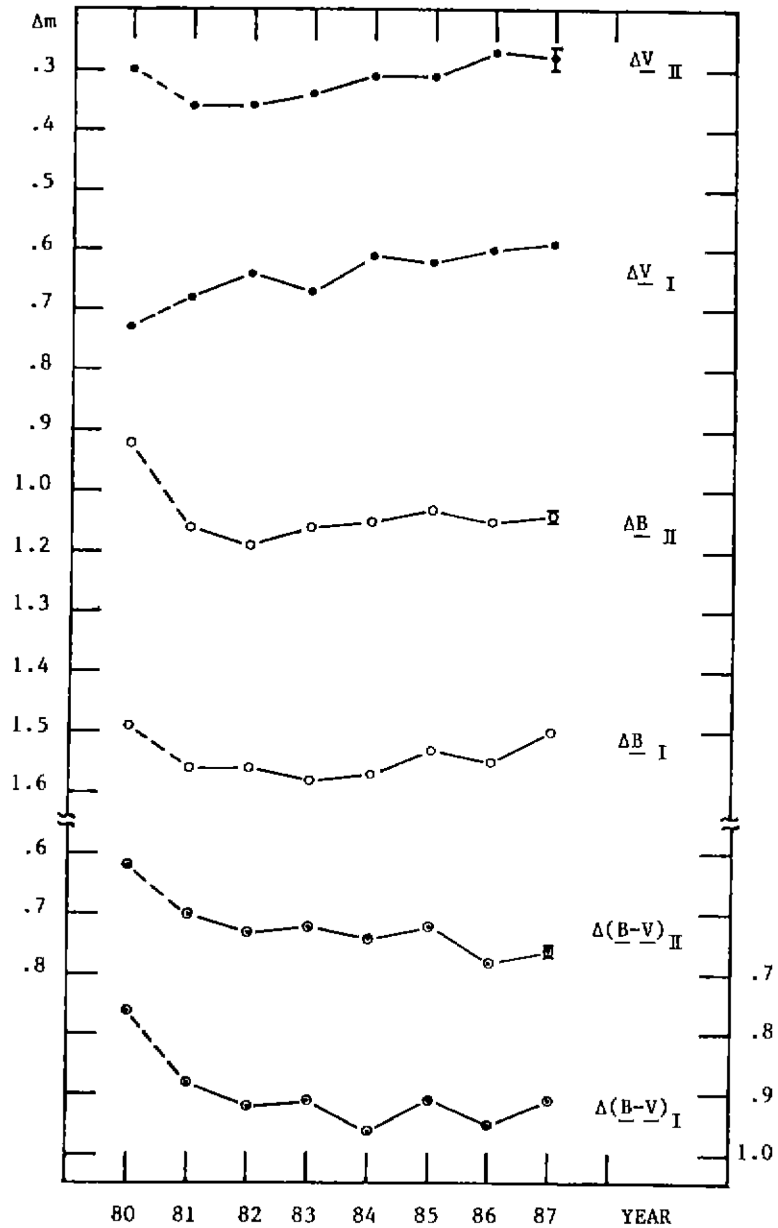

Figure 4. Depth and color variations of the primary and secondary eclipses of AR Lac. Subscripts I and II represent, respectively, the primary and secondary eclipses.

THE DURATIONS OF THE TOTAL ECLIPSES

Since the primary eclipse is a total occultation we see only the cool, larger K0 star during the orbital phases between the second and third contacts. This duration can be found as a flat bottom in the light curves of AR Lac.

Free-hand curves which represent the observations each year were made and the phases of the second and third contacts were determined by eye estimation except for the B light curves in 1981. The durations between these contacts in terms of phase range (ΔP) and in hours are shown in Figure 5 to see if there is any systematic variation related to a possible pulsation of the cool, large star on a long-term basis. Such a variation would offer a hope of some correlation with the depth and color variations of the eclipses in Figure 4.

A significant increase of the duration of primary totality is clear in B between 1983 and 1987. This interval lasted about 2.00 hours in 1983 and about 2.62 hours in 1987. Over eight years a general trend of expansion of the K0 star is clear in both V and B as shown in Figure 5. Except those of 1983 and 1984, the intervals determined by the B curves are longer than those by the V curves. Minor year-to-year fluctuations do exist, but it is important to note the direct correlation between the mean brightnesses of the K0 star and the durations of totality of the primary eclipse.

IV.DISCUSSIONS AND RESULTS

Reliable light curves of AR Lac in B and V passbands are now available as a result of the continuous monitoring at YUO since 1980. Altogether sixteen light curves, eight each in $B$and V, served as the primary material for the study of the light variations of AR Lac.

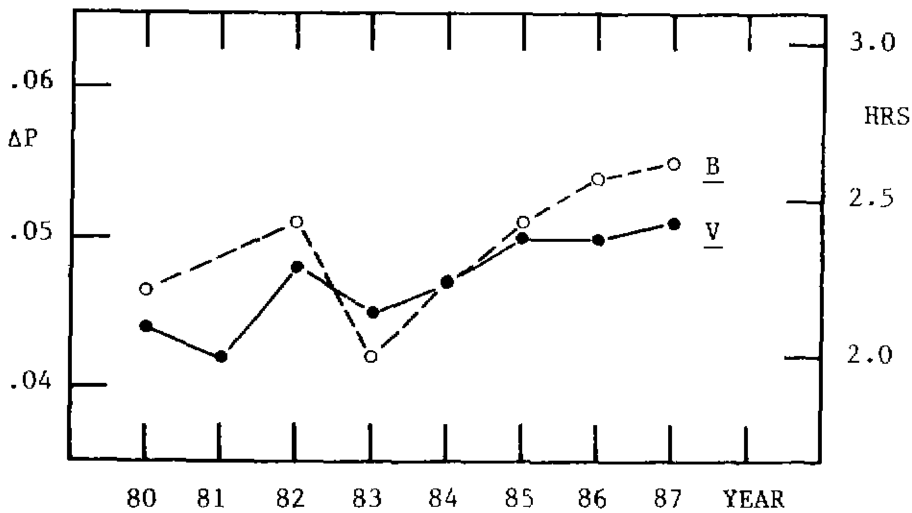

Figure 5. The durations of totality of the primary eclipses. Closed and open circles indicate V B, respectively. The left ordinate shows the length with the orbital period as unit and the right ordinate gives duration in hours

Unpredictable variations both in the overall shape and in the levels of maximum brightness outside eclipse and of the totality of the primary eclipse are apparent. This suggests that the migration of the distorted wave common to most light curves of RS CVn stars seens unlikely in the case of AR Lac. Kang and Wilson (1989) deduced migration periods of 10.6 years and 9.0 years for a two-spot model, and these periods are short enough to check with our eight-tear monitoring.

The increasing total brightness of AR Lac over the eight years may not be the result of the pulsation of one or both components of the AR Lac system. As were shown in Figure 3, the brightness in V and B at the extreme-brightness phase around either $0\overset{P}{.}3$ or $0\overset{P}{.}7$ are increasing with time, but with on sign of cyclic variation. The possibility of the pulsation of shorter period in the range of hours to days, on the other hand, cannot be ruled out, but it is almost impossible to find any observational clue to prove it. The uneven appearance of the maximum brightness outside eclipse between the two different phases, around $0\overset{P}{.}3$ for two years and $0\overset{P}{.}7$ for six years, implies that the surface of one hemisphere is brighter more often than that of other side.

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