CCD PHOTOMETRY OF FIVE NEGLECTED ECLIPSING BINARY STARS

Stephen P. Cook
Arkansas Tech University
Physical Sciences Dept.
Russellville, AR 72801

Presented at the 85th AAVSO Annual Meeting, November 2 1996; revised January 6 1997

Abstract

Differential V-magnitude CCD photometric data are presented for five neglected eclipsing binary stars with shallow eclipses. An improved period is derived for SV Equ, past O-C trends are confirmed for AN And and DL Vir, and unexpectedly large O-C values are found for BW Del and CS Lac.

1. Introduction

At the 84th AAVSO Annual Meeting in 1995, I described the capabilities of a CCD wide-angle lens system I had been using since February 1995 for photometry of eclipsing binary (EB) stars (Cook 1995). This system employs an ST6 CCD camera attached to a 2-inch f/3.6 lens fitted with V filter to capture images, and standard SBIG CCDOPS software to reduce them. As I described, this system offers a number of advantages (including semi-automatic operation), but also presents problems which limit the precision of the photometry. While this system has been used to make over 8000 differential V-magnitude estimates of over 300 EB stars, this paper presents data on five such objects—ones previously rather neglected.

In the spring of 1995, with the aid of the *Rocznik Ephemerides* (Kurpinska-Winiarska and Kiewicz-Krosniak 1995), I targeted several neglected EB stars for observation. Objects whose eclipses my system seemed capable of detecting and whose last reported minimum (as listed there) was at least 15 years ago appeared on my list. Over the next 18 months I obtained minima for nine of these stars (date of last reported eclipse is in brackets): AN And [1980], AO Cas [1970], EM Cep [1980], BW Del [1965], SV Equ [1966], AD Her [1965], CS Lac [1961], V Ser [1943], and DL Vir [1979].

Subsequent investigation established that some of these stars could not really be characterized as "neglected EB stars." AAVSO Eclipsing Binary Committee Chairman Marvin Baldwin had seen AD Her at minimum several times in his 17 years of observing it, and had recorded a minimum of V Ser in 1988 (Baldwin 1996). Times of minima deduced from his observations of these stars (and from mine) will be published in a future volume of *Observed Minima Timings of Eclipsing Binaries*, an AAVSO publication. Likewise, despite the Rocznik indication, AO Cas appears to have been well observed, at least up through the 1980s. Also, EM Cep apparently is not an eclipsing binary. This Be star shows periodic variations now best interpreted using pulsation or starspot / rotation models (Balona 1995). These four stars will not be considered here.

Basic information for the remaining stars is presented in Table 1. All of the information there is from the *General Catalogue of Variable Stars* (GCVS) (Kholopov *et al.* 1985), unless indicated. Note that all of these objects have shallow eclipses (<0.4 magnitude amplitude), either difficult or impossible to detect by visual means.

2. Previous work on the neglected EB stars

AN And, also designated HD 219815, is a 6th magnitude spectral type A star. It was

Table 1. Basic information for the neglected EB stars AN And, BW Del, SV Equ, CS Lac, and DL Vir.

EB star	*max. V mag.*	*min. V mag.*	*period (days)*	*type*	*epoch JD 2400000+*
AN And	6.00pg	6.16pg	3.2195665	EB/DM	36095.726
BW Del	11.4pg	11.8pg	2.423114	EA	25795.39
SV Equ	9.25 secondary	9.45 = 9.41	0.881	EW/KE	39382.427
CS Lac	9.3pg	9.7pg	3.797807	EB/DM	27695.478
DL Vir[1]	6.95	7.31	1.315475 1.31548[2]	EA/SD	38796.475 38796.525[2]

[1] data from Schoffel 1977
[2] elements from GCVS (Kholopov *et al.* 1985)

found to be a spectroscopic binary in 1916. Photometry, beginning in 1928, revealed 0.2-magnitude amplitude partial eclipses every 3.2 days. According to a 1978 photometric study (Tremko and Bakos 1978), the period was more or less constant over the next 50 years, but "considerable departures exist from a smooth light curve." To account for these in part, a model of two evolved stars of equal size, with mass transfer from the cooler star, perhaps forming a ring around the hotter, primary star, was proposed. Given Young's (1974) suggestion of the presence of a third body in this system, Tremko and Bakos conclude that it is of low mass and low luminosity. They suggest that transits of it across the disk of one of the other stars cause "occasional small depressions" in the light curve. Despite their fascinating depiction, apparently little (if any?) work has been done on AN And since the early 1980s.

BW Del, also designated AN 131.1935, is an 11½-magnitude F star. Every 2.4 days it undergoes a primary eclipse lasting 8 hours. Apparently no secondary eclipse has been detected. After noting Kordylewski's last minimum of this object in 1965, Wood *et al.* (1980) suggest "probably var P."

SV Equ, also designated HD 199465, is a 9th magnitude A0 star. It was discovered to be an EB in 1966 during photoelectric photometry of the nearby EB star S Equ. Its discoverers soon provided both B and V light curves (Catalano and Rodono 1966) and elements (the GCVS elements). While their photometry was good enough to distinguish clearly between 0.20-magnitude amplitude primary and 0.16-magnitude amplitude secondary eclipses, its short baseline left the period poorly determined (to but three decimal places).

CS Lac, also designated BD +41°4339, is a 9th magnitude B5 object. It was identified as an EB in 1936. Its 0.4-magnitude amplitude primary eclipses last around 14½ hours; secondary eclipses have a mere 0.1-magnitude amplitude. Apparently, the last person to work on this system was Vyskuporitis (1961).

DL Vir, previously designated BV 443, is a 7th magnitude object exhibiting 4.4-hour long eclipses every 1.3 days. It consists of three components: a 2.18-solar mass A3-A5V star and a 1.06-solar mass K0-K2 star, which form a semi-detached system, and a distant, larger (in diameter) 1.86-solar mass G8III star (Schoffel 1977). As such, it provides a rare opportunity to find the mass and age of the single G8III star. This star orbits the common center of mass with period = 2280 days and introduces a periodic light time effect in the times of minima. Thus, points (based on decades of photographic minima) plotted in an O-C diagram (Figure 1 in Schoffel 1977), exhibit an oscillation with period 2280 days (the amplitude is about 0.075 day). Independent of this oscillation is a slow period increase, which Schoffel fits with a parabola. Using the linear ephemeris

$$T_{min} = \mathrm{JD}\ 2438796.475 + 1.315475\ E, \qquad (1)$$

he computes O-C, plots points, and fits a parabola through the center of their distribution according to

$$O\text{-}C = 0.148\ \mathrm{day}\ -\ 1.30 \times 10^{-5}\ T\ +\ 2.74 \times 10^{-10}\ T^2, \qquad (2)$$

where T = the number of days since JD 2400000.

With the secondary K star steadily losing mass to its A companion, to conserve angular momentum, the period increases. While both the O-C diagram and evolutionary history of this system are interesting, unfortunately, the last reported minimum of DL Vir was apparently in 1979!

3. Observations and results

The light curves in Figures 1–6 are derived from my photometric data. All of the points shown there are normal points, based on averages of two to four CCD images. As reported previously (see Table 1, Cook 1995), associated with these points are standard deviations in the range of 0.02 to 0.04 magnitude (with smaller values associated with brighter stars). All of the dates shown in the figures are in 1996, unless noted. The larger-than-expected scatter in Figure 3 for mid-July observations of SV Equ may be due to moisture in the CCD's desiccant. Scatter in Figure 6 for DL Vir is attributed to thin clouds.

Table 2 numerically summarizes the observations. Included here are deduced heliocentric times of minima and O-C results. Minima times were determined using either the tracing paper (tp) method or a computer program based on the Kwee algorithm (Kwee and van Woerden 1956). With the Kwee determinations, mean errors in the times of minima are given. While similar values were not estimated in tp reductions, they should be similar to those provided (again, with smaller values associated with brighter stars). O-C computations were based on the elements of Table 1, except as noted for SV Equ, for which new elements were determined.

These new elements were determined by entering four times of primary eclipse minima for SV Equ, the three listed in Table 2 and the epoch listed in Table 1, in a linear least-squares period search program based on E. Belserene's methods (Belserene 1988). The period listed in Table 1, 0.881 day, was entered as the initial guess. In this way the new period of 0.88097307 day, with mean error = 0.00000047, was obtained. Combining this with the best determined minimum of Table 2 leads to the following new elements for this object:

$$T_{min} = 2450357.593 + 0.88097307\ E. \qquad (3)$$

4. Discussion and conclusions

Based on GCVS elements, an O-C of +0.005 day is associated with the primary eclipse of AN And documented in Figure 1. The rather small value indicates that these

Table 2. Observed minima of the neglected EB stars AN And, BW Del, SV Equ, CS Lac, and DL Vir.

EB star		observed minima JD 2400000+	mean error	min. det. method	cycle E	O-C (days)	# images	# normal points
AN And	pri	50419.583	0.002	kwee	+4449	+0.005	65	21
BW Del	pri	50283.624		tp	+10106	+0.241	71	18
SV Equ	sec	50278.737		tp	-88	-0.008[1,2]	102	37
	pri	50281.820	0.003	kwee	-86	0.009[2]	12	6
	pri	50282.708	0.002	kwee	-85	-0.002[2]	19	8
	pri	50357.593	0.001	kwee	0	0.000[2]	37	16
CS Lac	pri	50275.865	0.004	kwee	+5972	-0.117	54	19
DL Vir	pri	50184.752		tp	+8657	+0.210[3]	60	24

[1] assumes secondary min at fractional phase = 0.500
[2] based on elements in equation (3)
[3] based on elements from Schoffel 1977

elements continue to predict adequately its primary eclipse minima times. Using these elements to calculate O-C residuals for all known times of primary minima, Tremko and Bakos (1978) noted that "the residuals appear to lie on a straight line" (see their Figure 2). Instead of using this pattern to improve the period, they felt that additional times of minima were needed to confirm the trend. If the minimum presented in Table 2 is inserted on an extended version of their plot, it lies exactly on their straight line (surprising, given its 0.002-day mean error)! If future observations continue to confirm this trend, a period refinement will be appropriate.

Primary eclipses of BW Del (Figure 2) are occurring nearly 6 hours later than predicted by the GCVS elements. This object is near the faint limit of stars that can be worked with the CCD / 2-inch lens system, and its time of minimum was not as precisely determined as the others shown in Table 2. Now that when to look has been established, obtaining additional times of minima is in order. Once that is done, such minima can be combined with times of previous minima and a new period derived.

SV Equ now has a much more precisely determined period. The GCVS elements (in Table 1), which could no longer be used to predict upcoming eclipses of this object, have been replaced by the new elements of equation (3). How did this come about? A challenging first step was sorting out (from Figures 3 and 4) the primary and secondary eclipses, whose amplitudes differ by a mere 0.04 magnitude. After the primary minima in mid-July were obtained, observing another primary minimum two-and-a-half months later provided the baseline necessary to extend the period from three to five significant figures. Using the original 1966 epoch extended it to eight figures! However, since the period is based on supplementing the limited 1966 data with times of only three additional primary minima, even with the observations of secondary minima, admittedly this period may not be unique. Clearly, SV Equ needs more work.

CS Lac has primary eclipses (see Figure 5) coming nearly three hours earlier than predicted by the GCVS elements.

Based on Schoffel's equation (1) elements, an O-C = +0.210 day is associated with the primary eclipse of DL Vir (Figure 6). Using equation (2), the parabolic fit corresponding to a linearly increasing period, an O-C (with respect to equation (1) elements) of +0.186 day was expected at the time of this primary minimum. Factoring in the (varying and somewhat uncertain) light time effect due to the third component of this system, we expect O-C to be +0.186 day plus or minus 0.075 day, or +0.111 < O-C < +0.261 day. Since the +0.210-day value is comfortably within this range, the period of this star appears to be steadily lengthening, more or less as predicted by Schoffel.

5. Acknowledgements

I wish to thank Arkansas Tech University undergraduate computer science student Md. Mahabubur Rahman for helping with data reduction, especially for SV Equ. I also wish to thank John Percy and Jeff Robertson for aiding my literature search.

References

Baldwin, M. 1996, private communication.
Balona, L. 1995, *Mon. Not. Royal Astron. Soc.*, **277**, 1547.
Belserene, E. 1988, *J. Amer. Assoc. Var. Star Obs.*, **17**, 123.
Catalano, S., and Rodono, M. 1966, *Mem. Soc. Astron. Italy*, **37**, 809.
Cook, S. 1995, *J. Amer. Assoc. Var. Star Obs.*, **24**, 122.
Kholopov, P. N. *et al.* 1985, *General Catalogue of Variable Stars*, 4th ed., Moscow.
Kwee, K., and van Woerden, H. 1956, *Bull. Astron. Inst. Netherlands*, **12**, 327.
Kurpinska-Winiarska, M., and Kiewicz-Krosniak, E. D. 1995, *Rocznik Astronomiczny Obserwatorium Krakowskiego Ephemerides*, Krakow.
Schoffel, E. 1977, *Astron. Astrophys.*, **61**, 107.
Tremko, J., and Bakos, G. 1978, *J. Royal Astron. Soc. Canada*, **72**, No. 5, 263.
Vyskuporitis, V. 1961, *Bull. Astron. Obs. Vilnius*, **3**, 25.
Wood, F., Oliver, J. P., Florkowski, D. R., and Koch, R. H. 1980, *A Finding List for Observers of Interacting Binary Stars*, Univ. Pennsylvania Press, Philadelphia.
Young, A. 1974, *Publ. Astron. Soc. Pacific*, **86**, 63.

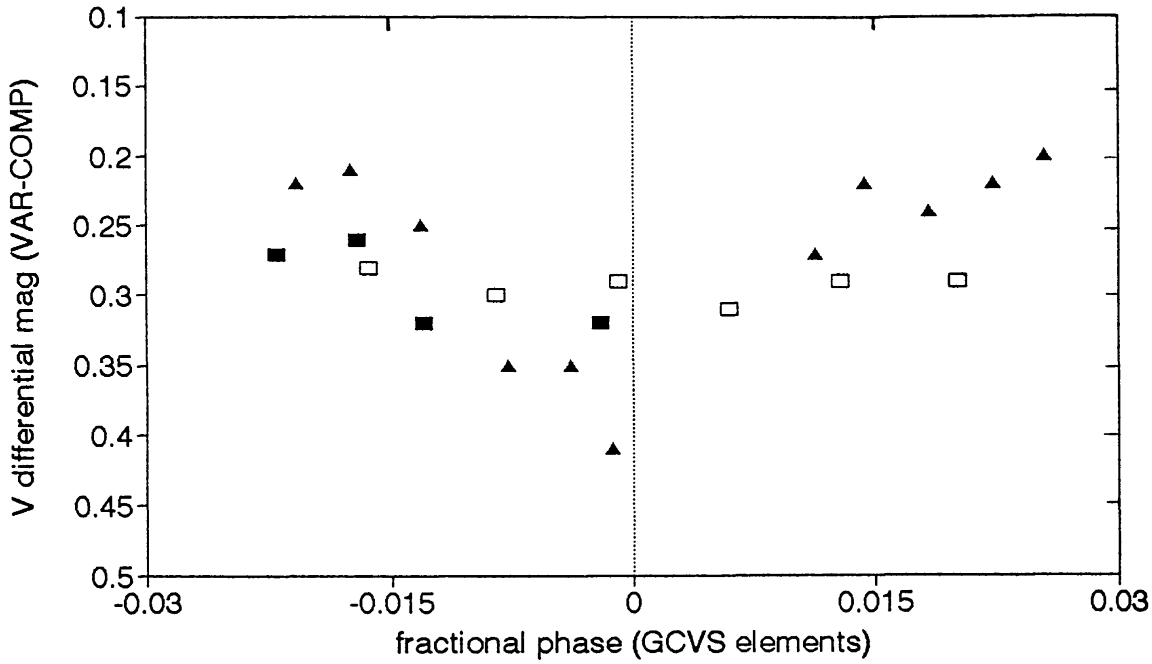

Figure 1. Primary minimum of AN And (using COMP = 10 And = SAO 52914). Based on author's 1995–1996 CCD photometry with 2-inch f/3.6 lens. V differential magnitude is plotted vs. (heliocentric) fractional phase. (■ = Aug. 7–8, 1996; □ = Sept. 4–5, 1995; ▲ = Dec. 1–2, 1996.)

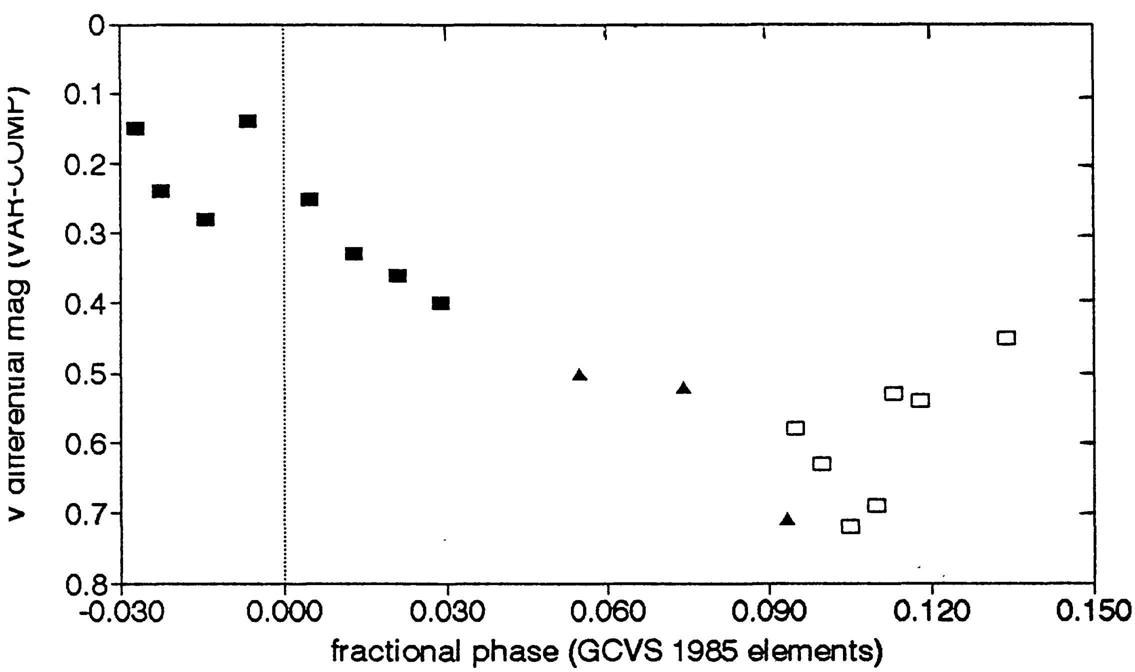

Figure 2. Primary minimum of BW Del (using COMP = GSC reg 1635 star 1181). Based on the author's 1996 CCD photometry with 2-inch f/3.6 lens. V differential magnitude is plotted vs. (heliocentric) fractional phase. (■ = July 7–8; ▲ = July 13–14; □ = July 18–19.)

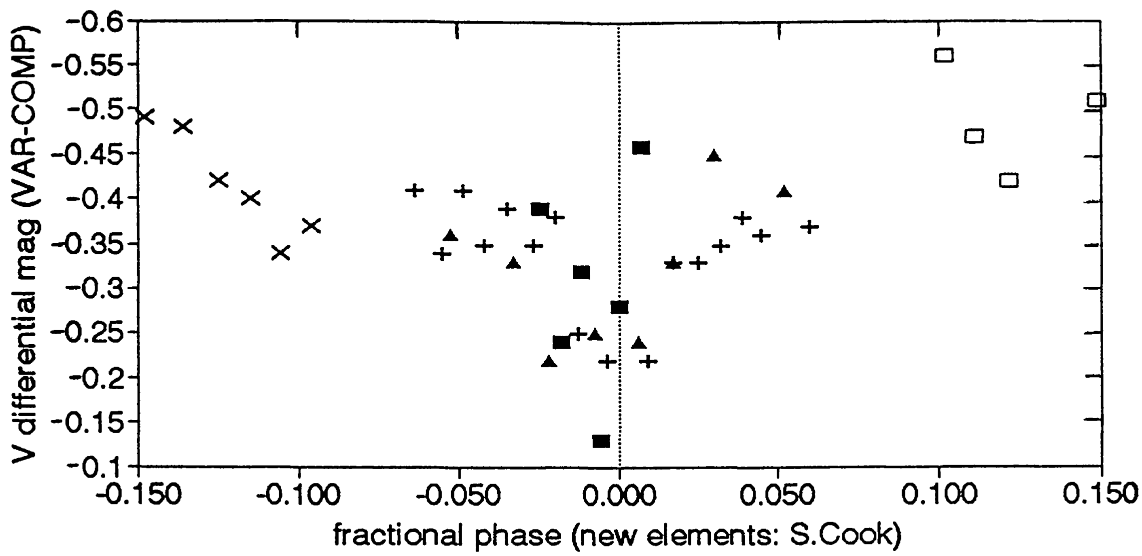

Figure 3. Primary minimum of SV Equ (using COMP = BD +05° 4654 = GSC reg 0525 star 1019). Based on the author's 1996 CCD photometry with 2-inch f/3.6 lens. V differential magnitude is plotted vs. (heliocentric) fractional phase. (■ = July 16–17; ▲ = July 17–18; □ = July 18–19; × = Aug. 8–9; + = Sept. 30–Oct. 1.)

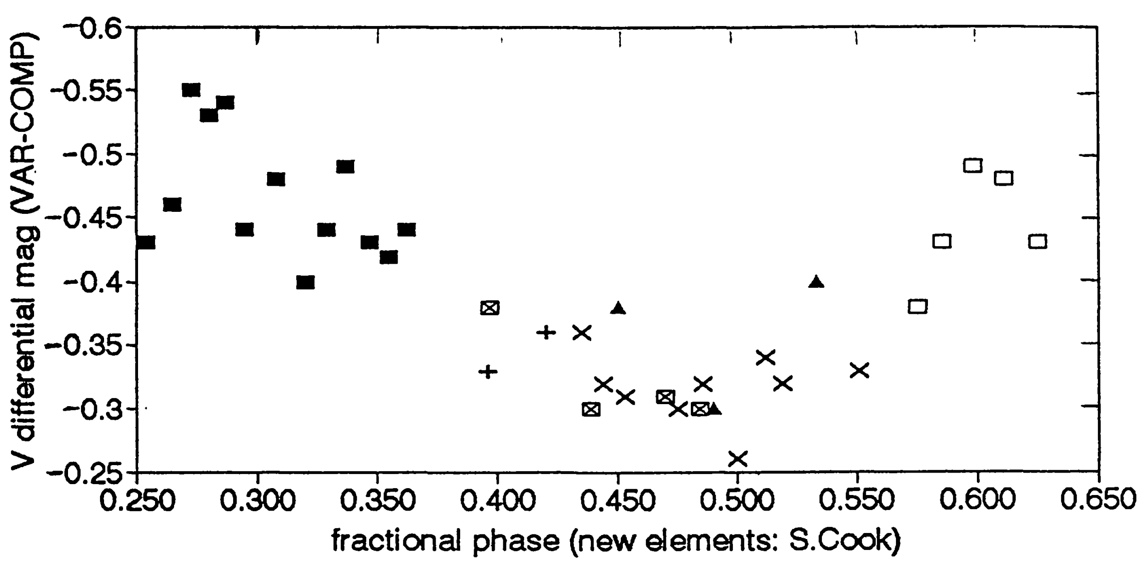

Figure 4. Secondary minimum of SV Equ (using COMP = BD +05° 4654 = GSC reg 0525 star 1019). Based on the author's 1996 CCD photometry with 2-inch f/3.6 lens. V differential magnitude is plotted vs. (heliocentric) fractional phase. (■ = June 27–28; ▲ = July 6–7; □ = July 7–8; × = July 13–15; + = Aug. 4–5; ⊠ = Aug. 12–13.)

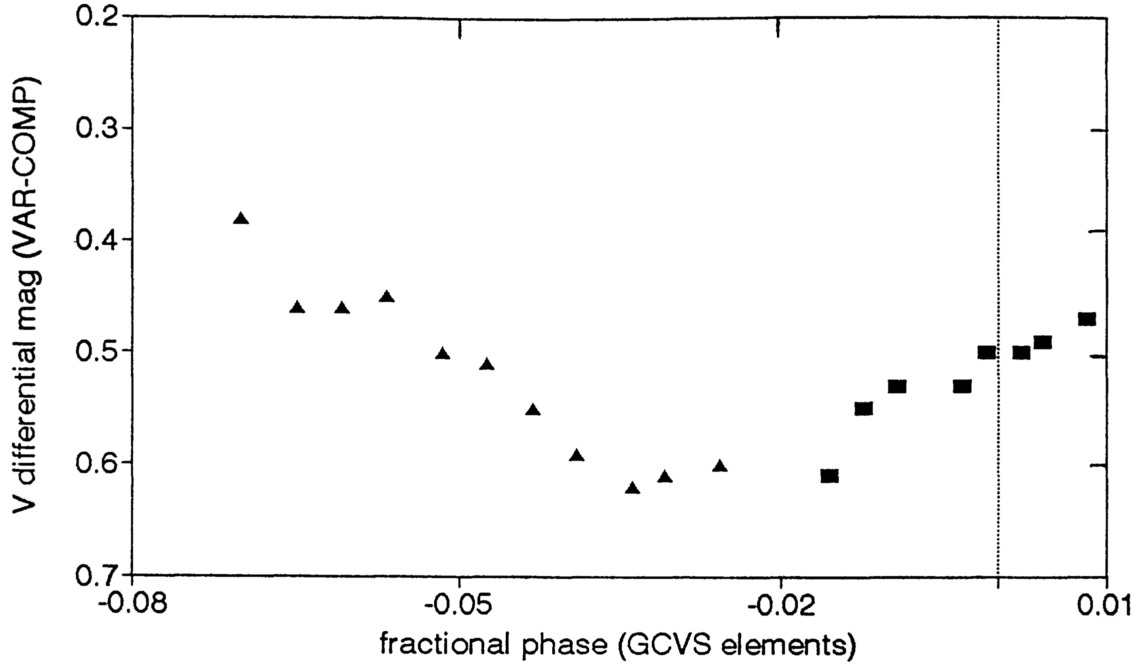

Figure 5. Primary minimum of CS Lac (using COMP = SAO 51520 = GSC reg 3193 star 0995). Based on the author's 1996 CCD photometry with 2-inch f/3.6 lens. V differential magnitude is plotted vs. (heliocentric) fractional phase. (■ = Oct. 7–8; ▲ = Oct. 18–19.)

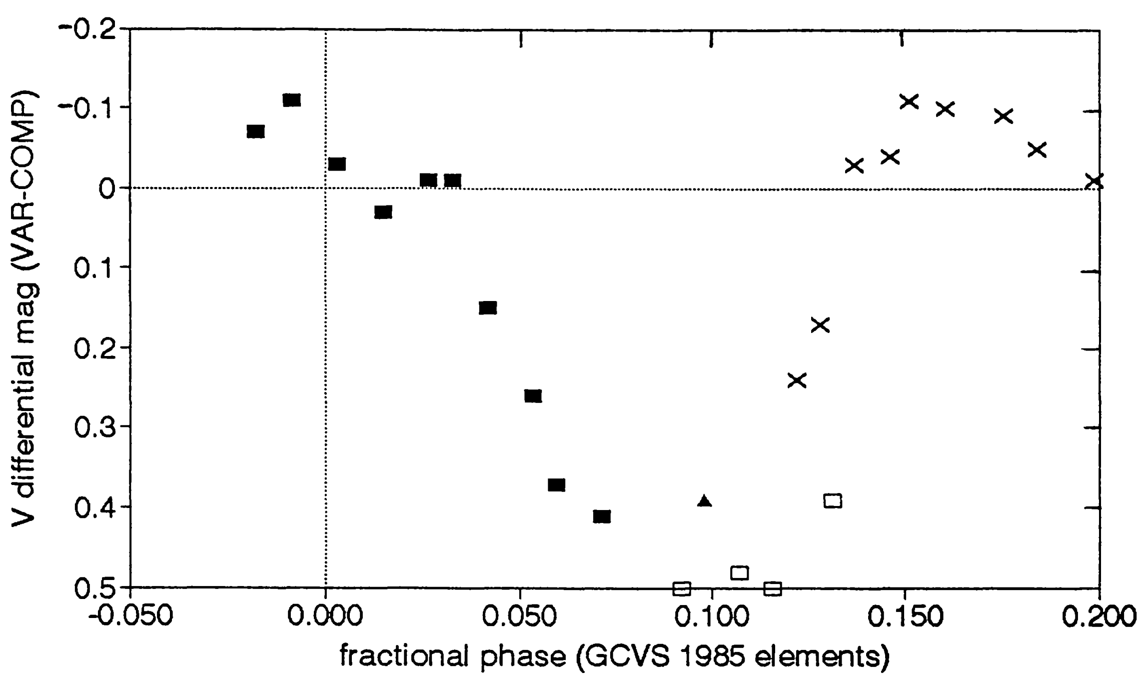

Figure 6. Primary minimum of DL Vir (using COMP = SAO 158229 = GSC reg 6144 star 0390). Based on the author's 1996 CCD photometry with 2-inch f/3.6 lens. V differential magnitude is plotted vs. (heliocentric) fractional phase. (■ = Apr. 10–11; ▲ = Apr. 14–15; □ = Apr. 18–19; × = Apr. 26–27.)