بسم الله الرحمن الرحيم

دانشگاه فردوسی مشهد

دانشکده علوم

پایان نامه کارشناسی ارشد فیزیک

عنوان

مشاهده و حل منحنی نوری ستاره دوتایی گرفتی
ER VULPECULAE

استاد راهنما

دکتر محمد تقی عدالتی

نگارش و پژوهش

فاطمه زینلی

خرداد ۱۳۷۵

تشکر و قدردانی

ای عـقل مـرا کـفایت از تـو   جستن زمـن و هـدایت از تـو

هــم تــو بــه عــنایت الهــی   آنجا قدمم رسان که خـواهـی

سپاس خدای راکه بی دیدن چشم شناخته می شود و آفریدگاری که بی‌اندیشه و امعان نظر هستی را بیافرید ، ذات بیچونی که جاودانه قائم دائم است . از آن هنگام که آسمان ستاره نشان بود ، نه حجابهایی دارای درهای عظیم ، نه شب مظلم نه دریای آرام ، نه کوهستان با دره های عمیق نه راههای فراخ و کج ، نه زمین گسترده ، نـه آفریده‌ای دارای قصد و اراده . آفرینندهٔ مخلوق است و بعد از همه برقرار و باقی .

بعد از حمد و ثناء پروردگار بر خود لازم می دانم که از تمامی اساتید معظمی که در دوران کارشناسی و کارشناسی ارشد ، در خدمتشان بوده و از دریای بیکران علم و معرفتشان بهره جسته‌ام تشکر و قدردانی کنم .

از جناب آقای دکتر محمد تقی عدالتی که سرپرستی این پایان نامه را به عهده داشته و در مراحل مختلف مرا راهنمایی کرده‌اند ، صمیمانه تشکر می‌نمایم .

از هیئت محترم داوران آقایان دکتر نعمت الله ریاضی ، دکتر جمشید قنبری و دکتر بهرام خالصه به خاطر پیشنهادات و نظریات ارزندهٔ ایشان قدردانی می‌کنم .

از آقایان محمد تقی میرترابی و صادق غفوری که در امر رصد یاریم کـردند ، سپاسگزارم.

فاطمه زینلی

مشهد - خرداد ۱۳۷۵

COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS
Number 4190

Konkoly Observatory
Budapest
8 May 1995

HU ISSN 0374 – 0676

PHOTOELECTRIC OBSERVATIONS OF THE ECLIPSING VARIABLE ER VULPECULAE

The eclipsing binary system ER Vul with the period of 0.6980960 days (Northcott and Bakos, 1967) was observed during four nights, 29 July-1 August, 1994, with the 51 centimeter Cassegrain telescope of Birouni Observatory (Iran, Shiraz, latitude=29°36' N, longitude=52°31'48" E) using a photoelectric photometer equipped with an unrefrigerated RCA 4509 photomultiplier tube. The observations were made through UBV filters which are approximately in the standard system. The probable errors of a single observation were estimated to be about ±0.01 in the three colours, i.e., corresponding to a measure of the observational scatter at a particular phase. The variable was observed differentially with respect to the comparison star HD 200270. The star HD 200425 was observed as check star.

Figures 1,2 and 3 show the UBV light curves for ER Vul, respectively.

The following light elements given by Ibanoglu et al. (1985) were used in computing the phases of the individual observations:

$$\text{Min. I=J.D. Hel. } 2440182.2621+0^{d}_{.}69809409\times E.$$

Table 1 indicates the photoelectric minimum times of ER Vul, in the three different filters.

Table 1

J.D. Hel. 2449000+	Filter	Min.
563.26074	U	I
563.25953	B	I
563.24449	V	I
564.29480	U	II
564.31173	B	II
564.28007	V	II

Table 2

Date	Phase
29 July 1994	0.9448-0.1319
30 July 1994	0.3403-0.5707
31 July 1994	0.7729-0.9826
1 August 1994	0.2146-0.4309

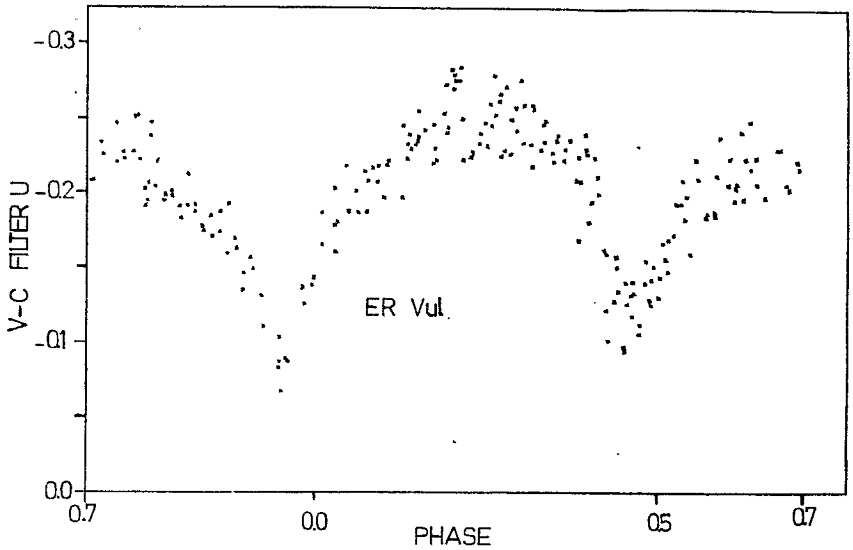

Figure 1

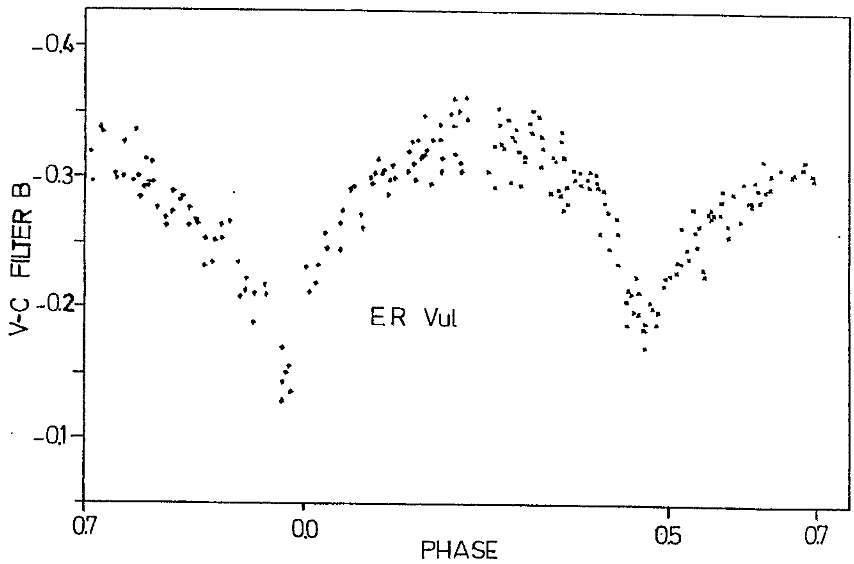

Figure 2

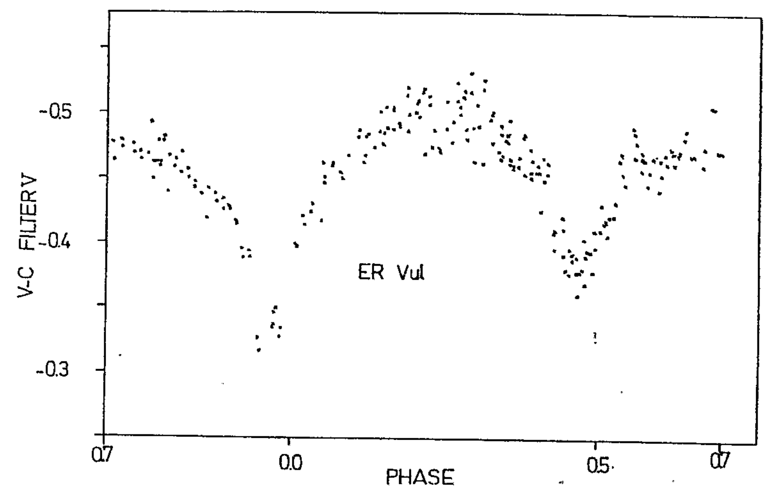

Figure 3

Our observations indicate the existence of asymmetry, especially in the beginning of the ascending part of the secondary minimum. These phenomena can be explained as a result of the presence of a gaseous stream flowing from the secondary to the primary component, starting off roughly in the inner Lagrangian point and falling behind the primary as that star moves round on its orbit (Struve, 1947). Also we see in our observations a shift for primary and secondary minima from phases zero and 0.5.

Table 2 lists the dates of observations and phases covered. The data has been folded so that both primary and secondary minima are clearly visible. These observations do indicate proximity effects, wave-like distortions, mutual eclipses and short-term light fluctuations (see Northcott and Bakos (1967)).

F. ZEINALI
M.T. EDALATI
Physics Dept.,
School of Sciences
University of Ferdowsi,
Mashad, Iran

M.T. MIRTORABI
Birouni Observatory
University of Shiraz,
Shiraz, Iran

References:

Ibanoglu, C., Akan, M. C., Evren, S., and Tunca, Z., 1985, *Inf. Bull. Var. Stars*, No. 2782
Northcott, R. J. and Bakos, G. A., 1967, *Astronomical J.*, **72**, 89
Struve, O., 1947, *Astrophys. J.*, **106**, 255

THE PHOTOMETRIC OBSERVATIONS OF ER VULPECULAE: PHOTOMETRIC ANALYSIS WITH THE W-D CODE

M.T. EDALATI and F. ZEINALI
Physics Department, School of Sciences, University of Ferdowsi, Mashhad, Iran

(Received 19 May, 1995; accepted 19 September 1995)

Abstract. The photometric observations of ER Vul were obtained in UBV light in 1994, at Birouni Observatory, University of Shiraz, Iran. The three light curves, which are almost complete, have been analyzed separately by means of Wilson and Devinney method (1971). The light curves include proximity effects, wave-like distortions, mutual eclipses, and short term light fluctuations. The appropriate value of the mass ratio of this system was found after extensive searches. ER Vul has a detached configuration where the two components are very nearly fill their Roche lobe. ER Vul has the characteristic of a RS CVn type system. The absolute dimensions for the primary and secondary of this system were calculated from its spectral types and by combining the photometric solution with inferred component radial velocities (Northcott and Bakos, 1967).

1. Introduction

The variability of ER Vul (HD 200391, BD+27° 3952, $\propto_{1950} = 21^h00^m16^s.4$, $\delta_{1950} = 27°36'33''.4$) was discovered to be an eclipsing binary by Northcott and Bakos (1967). They derived it from the spectral types of components to be G0V and G5V, and also its eclipsing behaviour with a period of 0.698096 msd that was determined from the combined spectroscopic and photometric epochs of minima.

They found it to be a double-lined spectroscopic binary in 1946 at David Dunlap observatory. The first light curve of ER Vul was obtained photoelectrically in 1963 (Abrami and Cester), while the first spectroscopic orbital elements spectrogramly were made in 1949 to 1951 (Northcott and Bakos, 1956). The system was observed, and analyzed using different methods by many investigators; Hrivnak (1980) with the Wilson–Devinney code, Al–Naimiy (1981) with the Kopal's Fourier method and Ibanoglu *et al.* (1993) by means of WINK-10 code.

The light variability of ER Vul exhibit various peculiarities such as CaII H and K emission lines indicating the existence of active chromospheres and also coronal X-rays emission, include the eclipsing binary was found to be a member of short period RS CVn group.

Most of the light curves show asymmetries both inside and outside of eclipses, that provides on evidence for the presence of a gaseous cloud between the components at the inner lagrangian point. This phenomena described by Al-Naimiy with starspots hypothesis and later Mclean (1982) attributed it to the circumstellar material.

Astrophysics and Space Science **234:** 271–280, 1995.

In the present paper, light curves of the system ER Vul are presented and analyzed by Wilson-Devinney code. The Wilson and Devinney approach is based on the theory that the stellar surfaces are confined to the Roche geometry. In Section 2 are descriptions of data, and in Section 3, we introduce our assumptions on this system, while in Section 4, 5 and 6 we give the photometric solutions, calculations of absolute dimensions for the primary and secondary components, and concluding remarks.

2. Data

The eclipsing system ER Vul was observed during four nights 29 July–1 August, 1994, with the 51 cm Cassegrain reflector in Birouni Observatory (Iran, Shiraz, Latitude 29°, 36′ N, Longitude 52°, 31′, 48″ E) using a photoelectronic photometer equipped with an unrefrigerated RCA4509 photomultiplier tube, standard B, U and V filters of the Johnson's wide band photometric system were used. The comparison and check stars in the neighbourhood of variable were HD 200270 (BD+27° 3940) and HD 200425 (BD+27° 4442), respectively. These stars were most frequently used by many investigators and, therefore, they could provide a comparison of the light curves plotted as differential magnitudes versus orbital phase with those obtained by the others. The observing sequence was sky-comparison-variable-comparison-sky, that each observation consisted of measuring during 20 seconds the number of pulses of the variable and comparison stars through UBV filters. The differential magnitudes in three colours were taken as variable minus comparison. These magnitudes were corrected for atmospheric extinction using the conventional method. The following light elements given by Ibanoglu *et al.* (1985) were used in computing the phases of the individual observations:

MinI = J.D.Hel. 2440182.2621+0^d.69809409E.

As it is noted by Ibanoglu *et al.* (1987) the light curves of the system undergo variations in short time intervals. Therefore, the observations obtained in short time intervals as well as possible had been combined together to construct the light curve. In Figure 1 the observations obtained in three filters in July and August, 1994, were plotted and are shown.

3. Assumptions

Initially expecting ER Vul to be a detached configuration, it is assumed that this binary system has zero or negligible ellipticity ($e = 0.0$), and that its rotational and orbital spins are synchronous. Also black-body models are employed, and the luminosity of the cool star, $L_c = L_2$, is computed by the Wilson and Devinney program. We assume there is no third light ($l_3 = 0.0$).

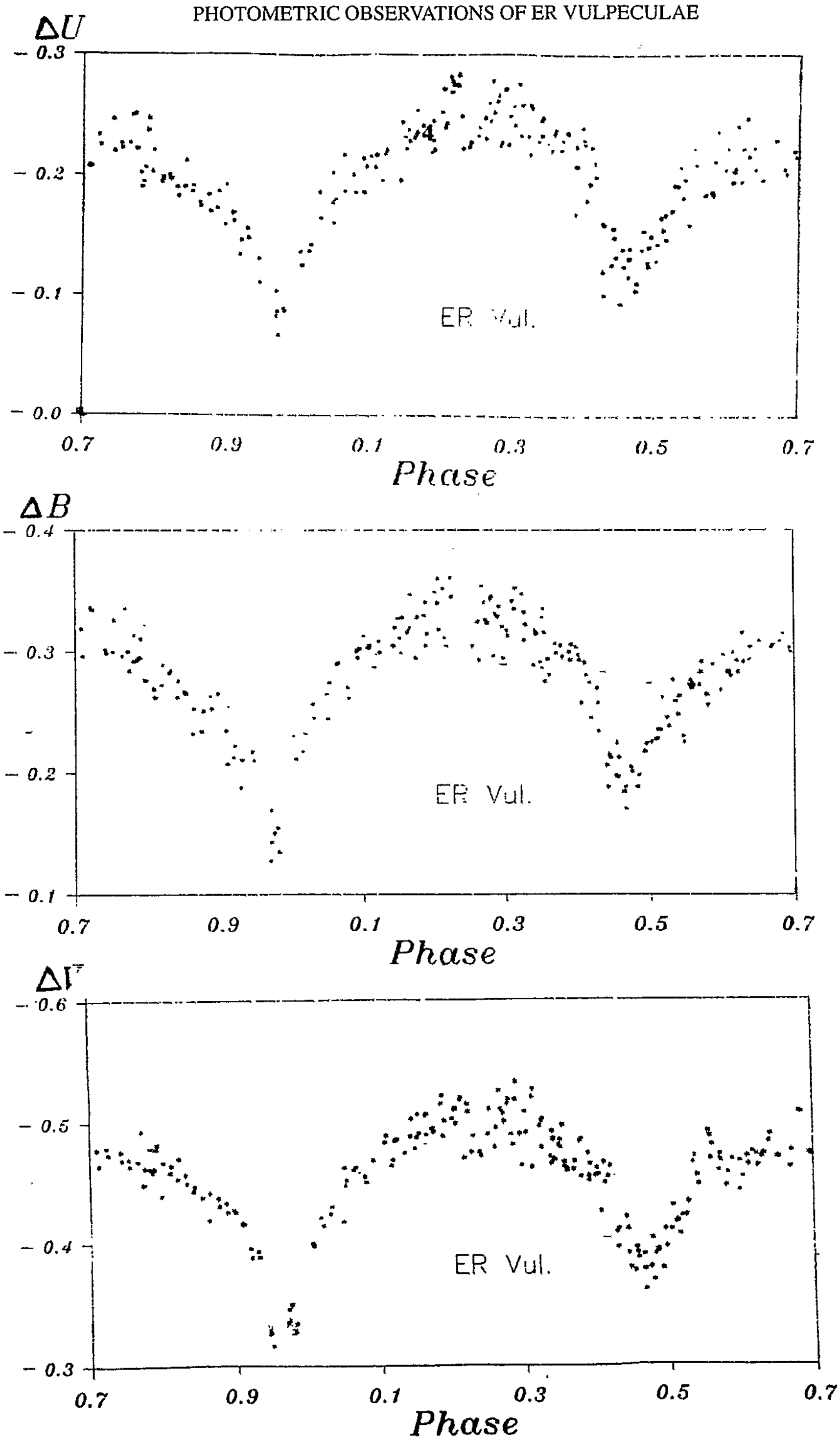

Fig. 1. The light curves of ER Vul obtained in July and August 1994.

With regard to our observations, each point is given equal weight in the Wilson and Devinney scheme of analysis and begin nothing the scatter of the individual points. We assume that determining the gravity-darkening coefficients (g_1 and $g_2$0) and the albedos (A_1 and A_2) of the hot star and the cool star of ER Vul is difficult, if not impossible. Hence, it is initially assumed that $g_1 = g_2 = 1.0$ and $A_1 = A_2 = 0.8$, and these are treated as fixed parameters. The limb-darkening coefficient of the cool star ($X_2 = 0.9$) and hot star ($X_1 = 0.8$) are also assumed to be fixed parameters (they are functions of temperature).

In summary, the following physical parameters are fixed while implementing the Wilson and Devinney differential corrections program: T_1, L_2, g_1, g_2, A_1, A_2, and L_1.

One must keep in mind that if L_2 becomes greater than L_1, we must put T_2 instead of T_1 in differential corrections program as fixed parameter and leave T_1 as a variable parameter.

4. Photometric Solutions

Initially, the light curve program (LC) was implemented in mode 2 (detached configuration, Leung and Wilson, 1977) for 78 normal points in units of intensity in B and U and 75 normal points in V filters, with both stars having temperatures $T_1 =$ 5990 K and T_2 =5800 K for U, $T_1 = 6000$ K and $T_2 = 5700$ for B, $T_1 = 6000$ K and $T_2 = 5990$ for V, according to the spectral types of ER Vul (Northcott and Bakos, 1956), equal masses ($q = 1$), and equal dimension: less potentials ($\Omega_1 = \Omega_2$, but slightly greater than Ω_{in}, i.e. detached but nearly contact configuration).

By means of X2 486 computer, and the Wilson-Devinney program (Wilson and Devinney, 1971; Wilson, 1972) was used in the analysis of the system; in this way, an initial guess for the inclination, i, could be obtained by reducing q and T_2, without restricting the model to detached configuration. It must be mentioned that the observations of three filters have been treated separately. After a few program runs of the LC program an initial set of values was employed as input parameters for the Differential–Corrections Program (DC).

Following a couple of DC runs and adjusting the parameters i, T_2, q, Ω_1, Ω_2, and L_1 as recommended by the results of the calculations, no change to mode 2 was made because $\Omega_1 > \Omega_{\text{in}}$ and $\Omega_2 > \Omega_{\text{out}}$. Several runs later, a converging solution was obtained (i.e., the recommended corrections were smaller than the probable errors) $q = 0.975$, $q = 0.957$ and $q = 0.903$ for the filters U, B, V, respectively. According to the Wilson and Devinney light-curve analysis, ER Vul is a nearly contact binary system. In order to ensure that our converging solution is unique, the following tests were performed. We try to obtain converging solution for seven different q values. Figure 2 (solid dot) is a plot of these q values and the sum of the weighted square deviations, Σ. All solutions indicate that ER Vul has a nearly contact configuration.

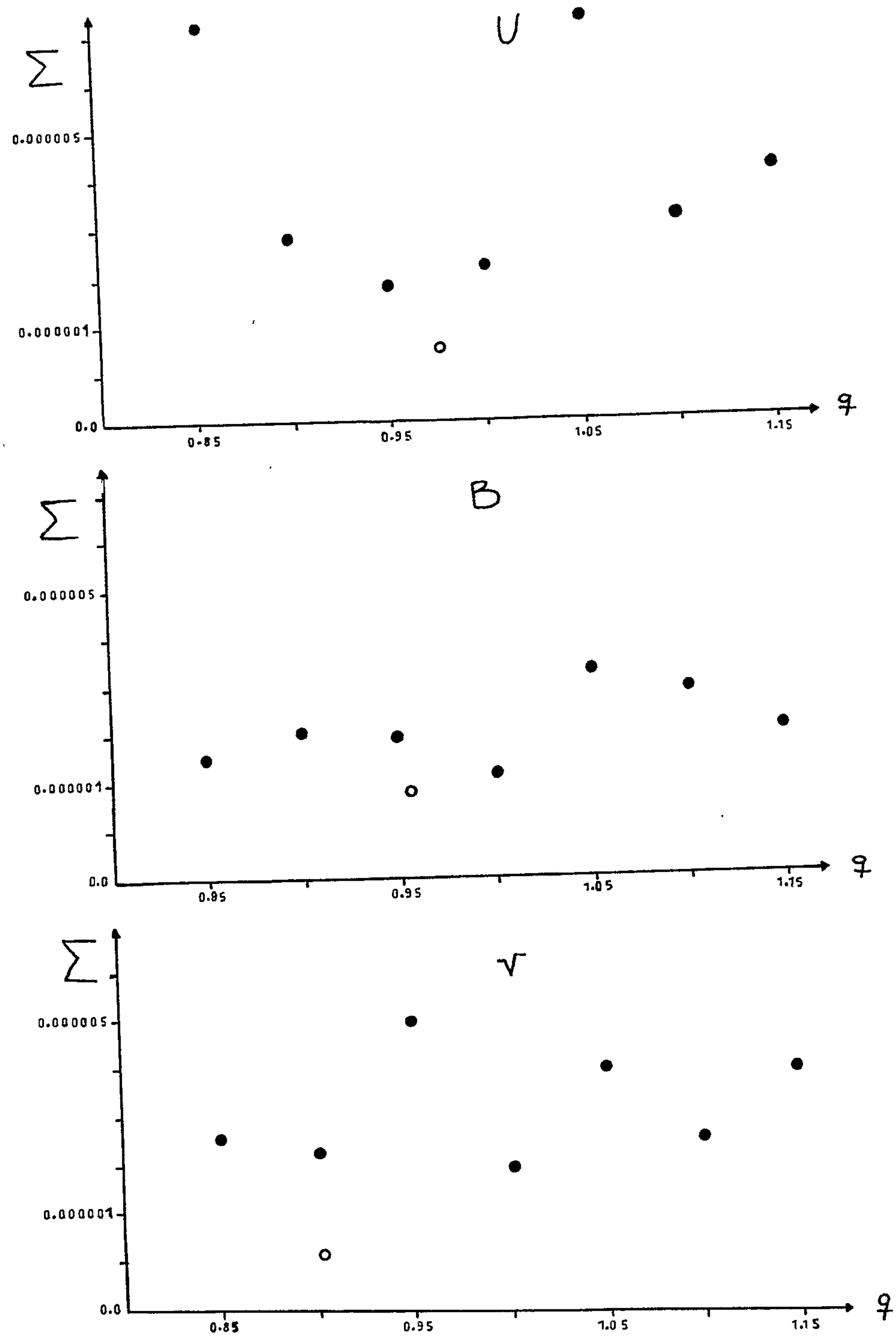

Fig. 2. Behaviour of Σ (sum of weighted squares of the deviations) of ER Vul as a function of mass ratio q. Open circle shows the best solution.

TABLE I

Photometric parameters of ER Vul*

	U	B	V
i(degrees)	68.190 ± 0.518	66.725 ± 0.542	67.667 ± 0.433
$q = M_c/M_h$	0.975 ± 0.006	0.957 ± 0.026	0.903 ± 0.061
Ω_h	5.343 ± 0.161	5.007 ± 0.113	5.011 ± 0.053
Ω_c	4.654 ± 0.174	4.378 ± 0.084	4.314 ± 0.019
T_c(K)	5714 ± 0.007	5552 ± 0.005	5311 ± 0.005
$L_h/(L_h + L_c)$	0.529	0.559	0.593
$L_c/(L_h + L_c)$	0.471	0.441	0.407
r_h(pole)	0.228 ± 0.051	0.245 ± 0.059	0.242 ± 0.058
r_h(point)	0.236 ± 0.059	0.256 ± 0.072	0.252 ± 0.068
r_h(side)	0.230 ± 0.054	0.249 ± 0.063	0.245 ± 0.061
r_h(back)	0.234 ± 0.057	0.254 ± 0.068	0.249 ± 0.065
r_c(pole)	0.265 ± 0.071	0.282 ± 0.081	0.273 ± 0.081
r_c(point)	0.282 ± 0.093	0.305 ± 0.116	0.294 ± 0.113
r_c(side)	0.271 ± 0.077	0.289 ± 0.089	0.279 ± 0.088
r_c(back)	0.278 ± 0.086	0.299 ± 0.103	0.289 ± 0.101
Ω_{in}	3.709	3.679	3.591
Ω_{out}	3.177	3.156	3.092

*All errors cited are probable errors.
Adopted values:
$T_h = 5990$ K for U, $T_h = 6000$ K for B and V.
$g_1 = g_2 = 1.0$
$A_1 = A_2 = 0.8$
$x_1 = 0.8$
$x_2 = 0.9$
$l_3 = 0.0$

Finally, it should be noted that the restrictions on g_1, g_2, A_1, A_2, x_1, and x_2 were then released, but these variables do not converge.

The adopted solutions for ER Vul are summarized in Table I. The computed light curves according to the parameters in Table I are shown as smooth curves in Figure 3. The agreement between the observed and the theoretical light curves is fairly good.

5. Absolute Dimensions

We have used the spectroscopic elements that have been obtained by Hill *et al.* (1990) for determination of the absolute parameters. Therefore, we are able to determine the absolute dimensions for the primary and secondary of this system from its spectral types and by combining the photometric solution with inferred

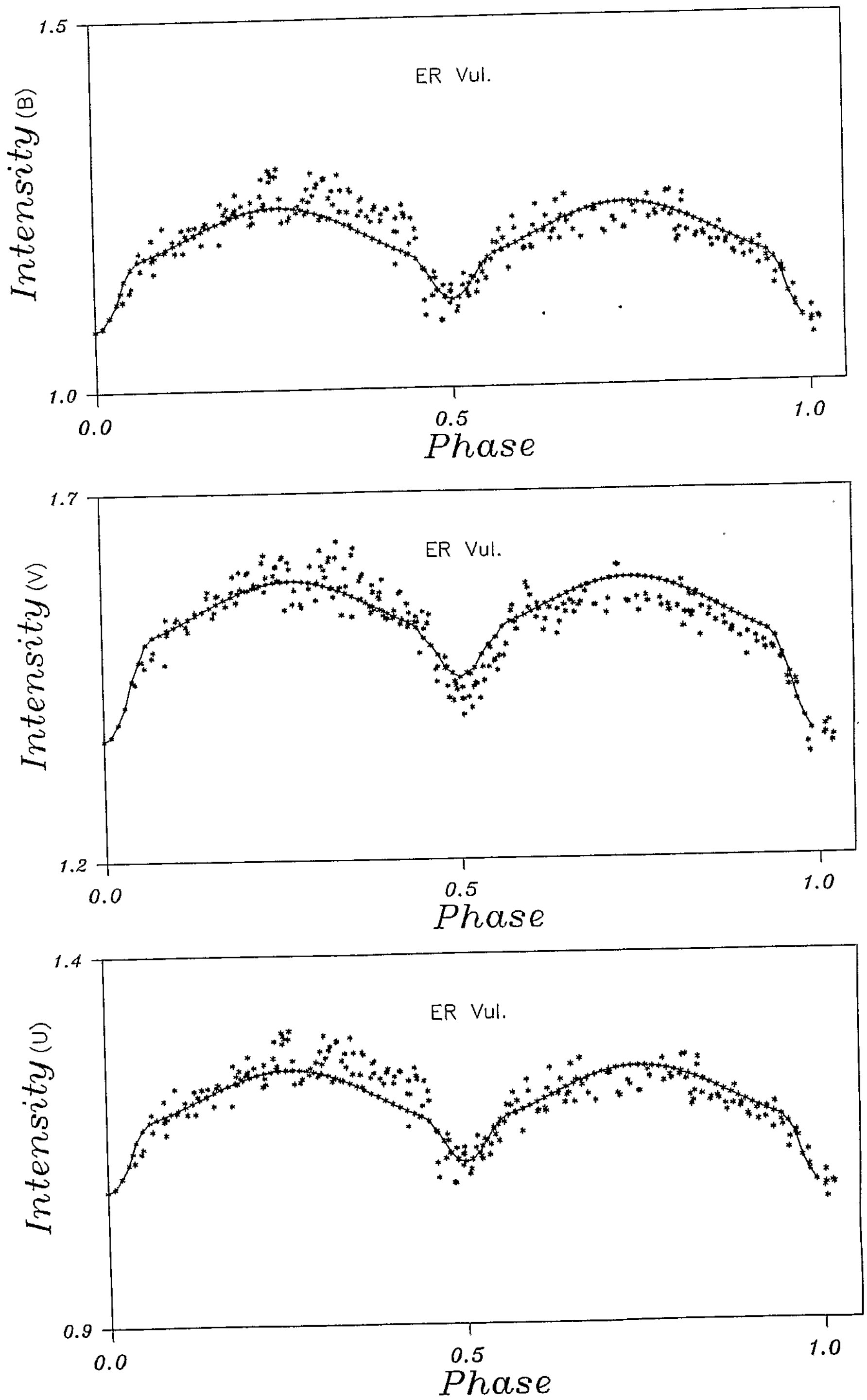

Fig. 3. Light curves of ER Vul. Points represent the individual observations. Solid lines are theoretical light curves based on the parameters in Table I.

TABLE II
Absolute dimension for ER Vul

spectral type	periods(days)		$A(R_\odot)$	$M_1(M_\odot)$	$M_2(M_\odot)$	$R_1(R_\odot)$	$R_2(R_\odot)$	$L_1(L_\odot)$
G0V and G5V	0.69809409	U	4.144	0.959	1.002	0.836	0.999	0.915
		B	4.161	0.972	1.015	0.906	1.067	1.009
		V	4.057	0.901	0.941	1.031	0.995	1.401

component radial velocities. According to the orbital parameters and mass functions that have been derived by the above mentioned authors, we determine new masses and absolute dimensions by using the following formula:

$$M_h/M_\odot = f(m)(1+q)^2/\mathrm{Sin}^3 i$$

$$f(m)_k = 1.0385 \times 10^{-7}(1-e^2)^{3/2}K^3P(\mathrm{days})$$

$$M_c/M_\odot = q(M_h/M_\odot)$$

$$R/R_\odot = 4.207(M/M_\odot(1+q)P^3)^{1/3}\ r(\mathrm{side})$$

$$L/L_\odot = (R/R_\odot)^2\ (T/T_\odot)^4$$

$$P^2 = 0.013433 \times A^3/(M_c + M_h)$$

$$A = [(1+q)/q]a_1, \quad A = (1+q)a_2.$$

The values of the absolute dimensions of ER Vul are listed in Table II.

ER Vul turns out to be a nearly detached system with the more massive and hotter component (star 1) and low massive and cooler component (star 2) do not fill their Roche lobe. The configuration of ER Vul is shown in Figure 4. The configuration indicates that both components are very close to their Roche lobe.

The near contact nature of ER Vul has important implications for the evolutionary state of the system.

6. Concluding Remarks

The light curves of ER Vul obtained in successive four nights clearly show that its shape suffers to change in short time-intervals. The depths of the eclipses are too shallow and, therefore, they are fairly affected from the distorting effects. On the

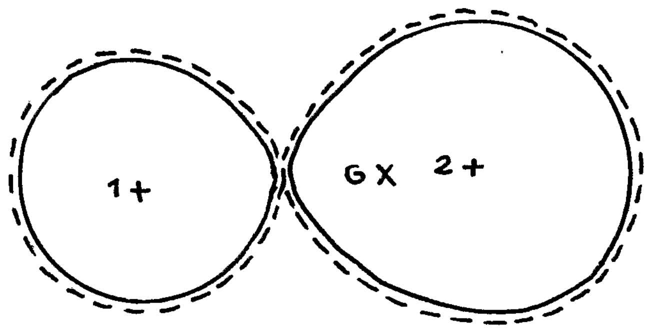

Fig. 4. Configuration of the components of ER Vul in the orbital plane.

other hand, the appearance of the distortion in both eclipses at the same direction in a light curve urges us strong by to suggest that there may be spotted areas on the surfaces of both components.

The double-lined spectroscopic and eclipsing binary ER Vul has received more attention following its classification by Hall (1976) as a short period RS CVn-type binary.

Despite of any spectroscopic and photometric evidence, most recently Botsula (1985) suggested the existence of the gaseous matter between the components. These phenomena are clearly seen in three – colour light curves of ER Vul system. The variations in the shapes of distorting effect in short time-intervals can be taken as a good indication of intense chromospheric activity over both components of ER Vul. According to the high-resolution IUE spectrograms for ER Vul, there are remarkable doubling of the MgII H and K emission (Ibanoglu *et al.*, 1987). Therefore, the light changes occuring in short time – intervals cannot be interpreted with the star spot hypothesis alone.

According to the absolute dimensions of the short-period system ER Vul (summarized in Table II) the radii of components are bigger than zero-age radii for the corresponding masses. This suggested that short-period system is an evolved system. There is agreement fairly good between the photometric mass ratio has been obtained by us ($q = 0.957$ for B filter) and spectroscopic mass ratio ($q = 0.9333$ for B colour) obtained by Northcott and Bakos (1967).

Based on the facts that: 1) the light curve of ER Vul indicated that the short-period eclipsing system has unequal minima; 2) that we found this system to be nearly contact, we conclude that ER Vul is not a late-type contact W UMa system.

References

Abrami, A. and Cester, B.: 1963, Oss, *Astron. Thrieste*, No. 320.
Al-Naimiy, H.M.K.: 1981, *Astron. Astrophys. Suppl.* **43**, 85.