Photoelectric photometry of eclipsing contact binaries: U Peg, YY CrB, OU Ser and EQ Tau

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Abstract. New photoelectric *UBV* observations of the eclipsing contact binary systems U Peg, YY CrB, OU Ser and EQ Tau obtained from August 2000 to October 2001 are presented and analyzed. The (O-C) diagram of U Peg indicates a decrease of the orbital period combined with a quasi-periodic variation. In the case of EQ Tau the long-term period changes can be interpreted by the presence of a third body on a 50 year orbit. The present ephemerides for the studied systems were determined. The primary minimum of OU Ser, according to the Hipparcos photometry, is found to be the shallower one and hence the system belongs to the W subgroup. The photometric elements determined from our light curves combined with published spectroscopic elements yielded the absolute parameters of the systems.

Key words: contact binaries - photometry - orbital period - photometric elements

1. Introduction

The present paper is a continuation of a series analyzing the photoelectric observations of contact binaries at the Stará Lesná Observatory. The relevant data regarding the four studied systems are given in Table 1. U Peg, YY CrB and OU Ser were included in the Hipparcos astrometric mission providing their $(B-V)$ colour indices, maximum and minimum visual brightness, parallaxes and proper motions. The photometric and astrometric data for EQ Tau (except $V_{\rm min}$ and $V_{\rm max}$ taken from GCVS5) were taken from the Tycho 2 Catalogue (Hog et al., 2000). The spectroscopic elements for U Peg were adopted from Zhai et al. (1988), for YY CrB and OU Ser from Rucinski et al. (2000) and for EQ Tau from Rucinski et al. (2001). The space velocities $V_{\rm space}$ were computed from the systemic velocity V_0, proper motions $\mu_\alpha \cos\delta$, μ_δ and parallax π as follows:

$$V_{\rm space} = \sqrt{V_0^2 + \left(\frac{4.74}{\pi}\right)^2 [(\mu_\alpha \cos\delta)^2 + \mu_\delta^2]} \qquad (1)$$

The visual absorption A_V was computed from the E_{B-V} excess using the following relation (Cox, 2000):

Table 1. Characteristics of the observed systems.

	U Peg(W)	**YY CrB(A)**	**OU Ser(W)**	**EQ Tau(A)**
GSC	01722-00533	03054-00795	01487-00733	01260-00909
HIP	118149	77598	75269	–
$\mu_\alpha \cos\delta$ [mas.y^{-1}]	-46.5(11)	-74.1(8)	-387.5(9)	+68.4(14)
μ_δ [mas.y^{-1}]	-53.9(8)	10.9(9)	2.8(8)	-29.6(15)
$V_{\rm space}$ [km.s^{-1}]	55.6(64)	31.6(22)	124.0(47)	–
π [mas]	7.18(1.43)	11.36(0.85)	17.31(0.95)	–
$d = 1/\pi$ [pc]	139^{+35}_{-23}	88^{+7}_{-6}	57^{+3}_{-3}	–
P [days]	0.374777	0.376565	0.296764	0.341348
$V_{\rm max} - V_{\rm min}$	9.60-10.13	8.64-9.13	8.23-8.42	10.50-11.03
$(B-V)$	0.648(33)	0.620(22)	0.635 (11)	0.98(23)
V_0 [km s^{-1}]	-29.8(5)	-4.6(10)	-64.1(4)	72.0(12)
K_1 [km s^{-1}]	82.5(2)	68.1(15)	40.6(6)	112.4(14)
K_2 [km s^{-1}]	249.3(8)	279.9(16)	234.2(7)	254.4(24)
$(m_1+m_2)\sin^3 i$ [$M_\odot$]	1.418(10)	1.647(44)	0.640(9)	1.749(55)
m_2/m_1	0.331(1)	0.243(23)	0.173(17)	0.442(7)
sp. type	G2V	F8V	F9/G0V	G2V
E_{B-V}	0.018	0.100	0.070	0.350:
A_V	0.062	0.345	0.242	1.222:
$M_V^{\rm max}$	3.82(40)	3.57(16)	4.18(12)	–

$$\frac{A_V}{E_{B-V}} = 3.30 + 0.28(B-V)_0 + 0.04E_{B-V}, \qquad (2)$$

where intrinsic $(B-V)_0$ colour index was taken according to the spectral type.

The variability of **U Peg** was discovered in 1894 by Chandler (1895). Later observations revealed that U Peg is a short-period eclipsing binary of the W UMa type with partial eclipses. The more massive component is the cooler one so the system is of the W subtype. Frequent photoelectric photometry (for references see Zhai et al., 1988 and Djuraševic et al., 2001) shows significant asymmetries of its light curve (hereafter LC). These changes can be relatively well interpreted by the development and migration of spotted regions on the cooler (and more massive) component. Lu (1985) analyzed 66 high-dispersion spectra of the system obtained at the Dominion Astrophysical Observatory and determined the first reliable spectroscopic elements and G2V spectral type. Zhai et al. (1988) determined the absolute parameters of the system by simultaneous solution of the published radial velocity and LC assuming the Roche model. The period changes in the system were studied by Borkovits & Hegedüs (1996), who interpreted the long-term period change as a light-time effect (hereafter LITE) caused as a third body on a 136 year orbit.

The variability of **YY CrB** was found as a by-product of the Hipparcos satellite mission (ESA, 1997). According to the Hipparcos photometry and spectroscopic solution of Rucinski et al. (2000), YY CrB is an A-subtype contact binary. The first photoelectric LCs were obtained by Sipahi et al. (2000). The

Table 2. The journal of photoelectric observations of U Peg, YY CrB, OU Ser and EQ Tau obtained at the Stará Lesná Observatory. The phase intervals were computed according to ephemerides (5) - (8). The number of observations in one filter (N) and estimated standard deviation of individual observation in the V passband (σ_V) are given in the last two columns.

System	Date	HJD_{mean} 2 400 000+	Phases	Filters	N	σ_V
U Peg	Aug 21, 2000	51778.530	0.428 – 0.724	*BV*	152	0.010
	Sep 03, 2000	51791.394	0.854 – 0.956	*BV*	60	0.009
	Sep 06, 2000	51794.477	0.968 – 1.312	*BV*	212	0.007
	Aug 01, 2001	52123.461	0.920 – 0.982	*BV*	22	0.014
	Aug 12, 2001	52134.517	0.282 – 0.623	*BV*	155	0.010
	Aug 30, 2001	52152.486	0.105 – 0.711	*UBV*	168	0.012
	Oct 09, 2001	52192.355	0.658 – 0.896	*BV*	86	0.010
	Oct 14, 2001	52197.278	0.847 – 1.070	*BV*	110	0.012
YY CrB	Mar 06, 2001	51975.610	0.914 – 1.124	*BV*	59	0.007
	Apr 29, 2001	52029.439	0.615 – 1.310	*UBV*	171	0.007
	May 01, 2001	52031.516	0.324 – 0.620	*UBV*	56	0.007
OU Ser	Apr 01, 2001	52001.523	0.297 – 0.874	*BV*	152	0.007
	Apr 30, 2001	52030.382	0.694 – 0.922	*BV*	50	0.009
	May 22, 2001	52052.420	0.827 – 1.235	*BV*	100	0.009
EQ Tau	Dec 17, 2000	51896.290	0.888 – 1.112	*BV*	83	0.016
	Jan 01, 2001	51911.282	0.727 – 1.117	*BV*	87	0.008
	Jan 20, 2001	51930.289	0.313 – 0.873	*BV*	124	0.023
	Feb 17, 2001	51958.264	0.423 – 0.680	*BV*	62	0.014
	Oct 02, 2001	52185.552	0.171 – 0.644	*BV*	127	0.027

authors obtained three primary and one secondary minimum (see Tab. 5). Later photometry of Erdem et al. (2001) indicates that its LC is variable: maximum II (phase 0.75) was found to be fainter than maximum I (phase 0.25). The photometric elements of the systems have not been published yet.

OU Ser is another Hipparcos discovery. The system has a quite large proper motion (see Table 1). Rucinski et al. (2000) obtained spectroscopic observations and determined the radial velocities of both components providing reliable spectroscopic elements. Using the Hipparcos notation of the primary minimum the authors classified OU Ser as an A-subtype contact binary. No ground-based photometry of the system has been published.

EQ Tau was discovered and observed by Tsesevitch (1954). Since then the system has been neglected and monitored only occasionally by amateur observers. New photometric observations were obtained by Benbow & Mutel (1995) and Buckner et al. (1998). Modern photometric solution of the LC is not available. Rucinski et al. (2001) presented spectroscopic observations yielding the first reliable spectroscopic elements of the system (Table 1).

2. New observations

The present BV photoelectric observations of OU Ser, EQ Tau and UBV observations of U Peg, YY CrB were carried out from August 2000 to October 2001 at the Stará Lesná Observatory of the Astronomical Institute of the Slovak Academy of Sciences. BD+15°4916, GSC 3054-0640, GSC 1487-1219 and GSC 1260-0575 were used as the comparison stars for U Peg, YY CrB, OU Ser and EQ Tau, respectively. The check stars GSC 3054-1473, GSC 1487-0814 and GSC 1260-0575 were used for YY CrB, OU Ser and EQ Tau, respectively. The check stars were measured on most nights. In the case of OU Ser and EQ Tau the comparison stars were found to be stable within the errors of the observations. The comparison star for YY CrB, i.e., GSC 3054-0640 seems to be a low-amplitude variable. The relative magnitudes of this comparison star with respect to the check star in the B passband on March 6, April 29 and May 1, 2001 were -0.326(3), -0.351(3) and -0.354(2), respectively. The change in the brightness caused a shift in the depth of the primary minimum. The data for March 6 were therefore appropriately shifted in magnitudes.

The journal of our observations is given in Table 2. The standard errors were determined by fitting appropriate high-degree polynomials to the data in the V passband. Due to relatively short orbital periods and late spectral types all studied systems show spot activity and probably also flare activity on their surfaces. This is manifested mainly by the LC asymmetries and variability. The LC extrema of all studied systems, determined by the parabola fitting to the adjoining phase intervals ±0.05, and O'Connell effect (Δmag = mag$_{0.75}$ - mag$_{0.25}$) are given in Table 3.

Table 3. The light curve extrema and O'Connell effect Δmag = mag$_{0.75}$ - mag$_{0.25}$ in the light curves of the studied systems. The standard errors are given in parentheses.

System	Filter	Phase 0.00	0.25	0.50	0.75	Δmag
U Peg (2000)	B	0.698(10)	0.120(9)	0.638(4)	0.155(8):	0.025
	V	1.050(10)	0.504(4)	1.008(7)	0.523(12):	0.019
U Peg (2001)	B	0.700(14)	0.079(10)	0.617(10)	0.095(13)	0.016
	V	1.060(14)	0.472(10)	0.983(9)	0.492(7)	0.020
YY CrB	U	0.090(10)	-0.433(7)	0.048(12)	-0.454(8)	-0.021
	B	0.017(5)	-0.487(5)	-0.027(7)	-0.503(4)	-0.016
	V	-0.140(9)	-0.616(50	-0.164(10)	-0.625(7)	-0.009
OU Ser	B	-2.211(5)	-2.407(7)	-2.229(7)	-2.386(11)	-0.018
	V	-1.727(5)	-1.907(6)	-1.743(7)	-1.901(10)	-0.016
EQ Tau	B	2.279(11)	1.525(17)	2.165(27)	1.540(12)	0.015:
	V	2.304(17)	1.626(26)	2.230(26)	1.609(12)	-0.017:

For all observations a 0.6m Cassegrain telescope equipped with a single-channel photoelectric photometer was used. A detailed description of the observational technique and reduction of the data to the international photometric

Table 4. New times of the primary (I) and secondary (II) minima of U Peg, YY CrB, OU Ser and EQ Tau obtained at the Stará Lesná Observatory. The standard errors of the minima are given in parentheses. The (O-C) residuals are given with respect to ephemerides (5) - (8).

JD_{hel} 2 400 000+	Filter	(O-C) [days]	type	JD_{hel} 2 400 000+	Filter	(O-C) [days]	type
U Peg				52031.5247(1)	V	-0.0003	II
52134.5343(1)	V	0.0003	II	52031.5247(4)	U	-0.0003	II
52134.5345(1)	B	0.0005	II	**OU Ser**			
52152.5247(1)	U	0.0014	II	52001.5054(2)	B	0.0000	II
52152.5248(4)	V	0.0015	II	52001.5059(2)	V	0.0005	II
52152.5250(1)	B	0.0017	II	52052.4003(3)	V	-0.0001	I
52197.3083(1)	BV	-0.0009	I	52052.4004(4)	B	-0.0002	I
YY CrB				**EQ Tau**			
52029.4538(3)	U	-0.0001	I	51958.2453(2)	B	-0.0016	II
52029.4543(3)	B	0.0004	I	51958.2457(1)	V	-0.0012	II
52029.4546(2)	V	0.0004	I	52185.5859(1)	B	0.0019	II
52031.5244(1)	B	-0.0006	II	52185.5845(2):	V	0.0005	II

system is given in Paper I (Pribulla et al., 2001a). The resulting photoelectric LCs are depicted in Fig. 1 and Fig. 2.

Our observations enabled us to determine 6 times of minima of U Peg, 3 times of minima of YY CrB, 2 times of minima of OU Ser and 5 times of minima of EQ Tau. Part of the minima has already been published (Pribulla et al., 2001b) the rest is given in Table 4. The times of minima were determined separately for all employed filters using the Kwee & Van Woerden method, the parabola fit, the sliding integration method, the tracing paper and the "center of mass" method described in detail by Ghedini (1982). We always used the average of the above methods. The computer code was kindly provided by Komžík (2001).

3. Analysis and reduction

For U Peg and EQ Tau we used comprehensive lists of minima provided by Prof. Kreiner (see also Kreiner et al., 2001). For YY CrB, OU Ser and EQ Tau we also included the instants of the spectroscopic conjunction calculated from radial velocities. We weighted the minima according to their precision: photoelectric and CCD $w = 6$, photographic $w = 2$, the spectroscopically determined times and Hipparcos JD_0 $w = 3$. For minima determined in several filters separately we used weighted averages. All available photoelectric, photographic, CCD and spectroscopic times of minima for U Peg, YY CrB and EQ Tau are given in Table 5. In our analysis of the LITE we assumed that the minima times follow a quadratic ephemeris and are deviated due to the LITE by a third body, so they can be computed as follows:

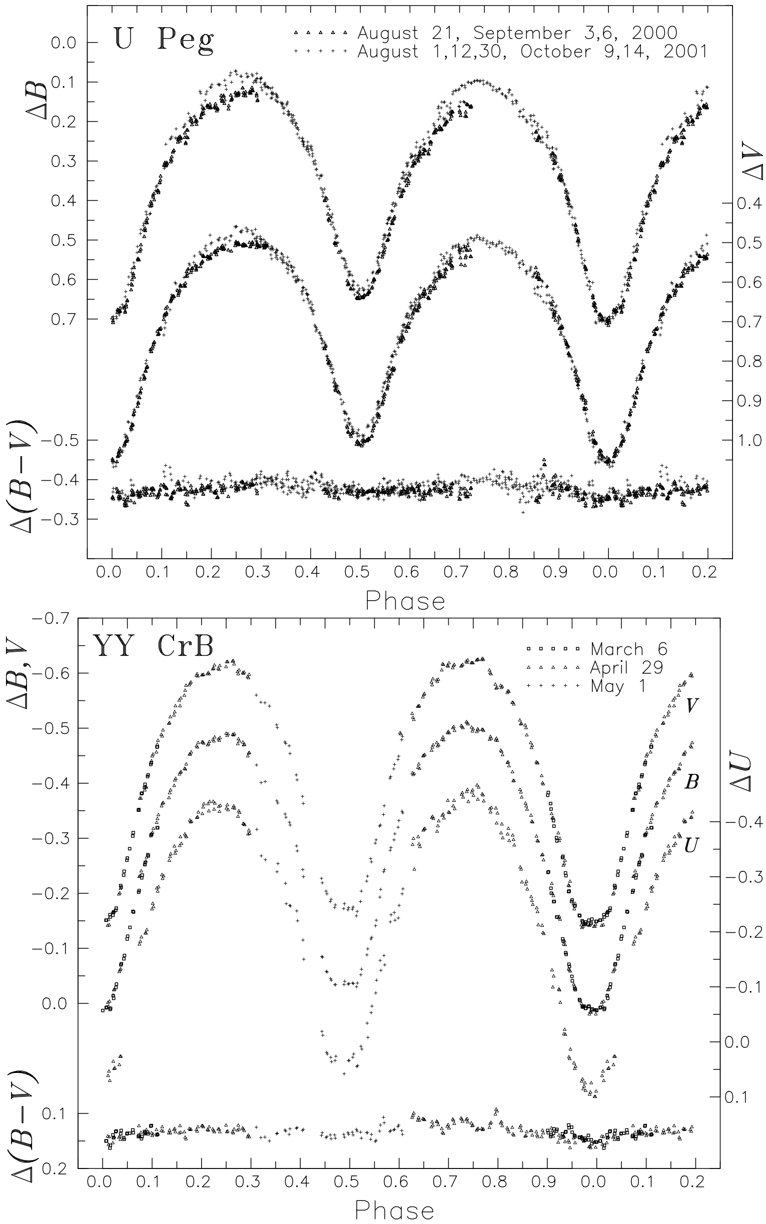

Figure 1. The photoelectric *BV* light curves and $(B-V)$ colour index of U Peg (top) and *UBV* light curves and $(B-V)$ colour index of YY CrB with respect to the comparison star.

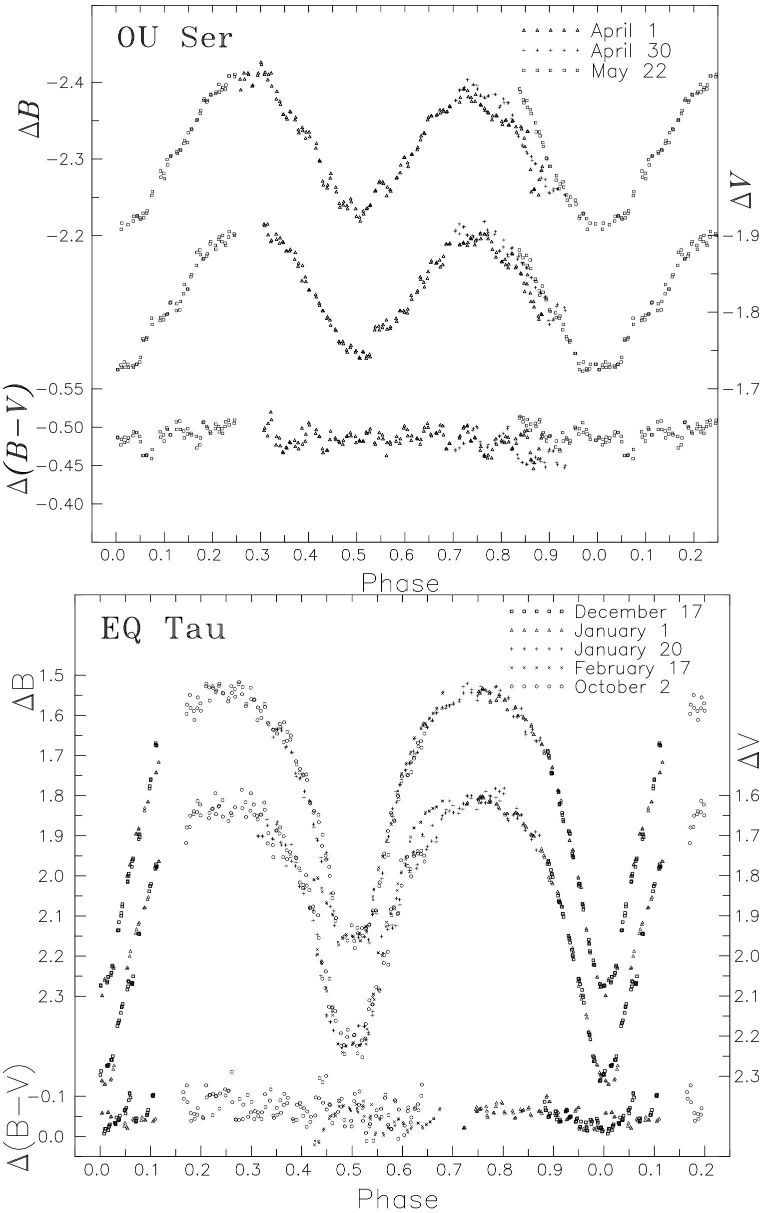

Figure 2. The photoelectric BV light curves and $(B-V)$ indices of OU Ser (top) and EQ Tau with respect to the comparison star.

$$Min\ I = JD_0 + PE + QE^2 + \frac{a_{12} \sin i}{c} \left[\frac{1-e^2}{1+e\cos\nu} \sin(\nu+\omega) + e \sin\omega \right] \quad (3)$$

where $a_{12} \sin i$ is the projected semi-major axis, e is the eccentricity, ω is the longitude of the periastron of the binary orbit around the centre of mass of the triple system. $JD_0 + PE + QE^2$ is the quadratic ephemeris of the minima of the eclipsing pair. To obtain the optimal elements we used the damped differential corrections method.

The W&D (Wilson & Devinney, 1971) code was employed to determine the photometric elements of the systems. We used the Mode 3 appropriate for the contact configuration. All our $(U)BV$ observations were used to compute about 150 normal points for each passband. For weighting of the individual observations we employed the mean standard deviation of the observations during night (see Table 2). The standard deviations (σ) used for weighting of the LC in each passband were evaluated as described by Wilson (1979). For the computation of monochromatic luminosities, the approximate stellar-atmosphere model option of the W&D program was used. Since all studied systems have late-type spectra we assumed coefficients of gravity darkening and bolometric albedo appropriate for convective envelopes ($T_{\rm eff}$ <7500 K). Hence we adopted $g_1 = g_2 = 0.32$ (Lucy, 1967) and $A_1 = A_2 = 0.5$ (e.g., Rucinski, 1969). The linear limb darkening coefficients were interpolated from Table 1 of Al-Naimiy (1978). The mean temperatures of the primary components were fixed according to their spectral types (Table 1) using spectral-type $T_{\rm eff}$ calibration of Popper (1980). The mass ratios for all three systems were adopted from spectroscopy [1].

The resulting photometric elements for the studied systems together with their standard errors and minimum inclination for the total eclipses to occur (for particular fill-out and mass ratio) are given in Table 6. Corresponding best fits to the normal points are presented in Figs. 5 and 6. For U Peg and YY CrB we improved the fits by introducing a cool spot on the primary component. In the description of the spot coordinates we used the W&D notation[2].

3.1. U Peg

The orbital period of the system decreased over the whole time interval of the observations (1894 - 2001). The rate of the decrease is, however, variable. The total period shortening since the beginning of the observations is about $\Delta P/P$ = -2.05±0.16 10^{-5}. This period decrease can be explained by the conservative mass transfer from the more to the less massive component. If we neglect the

[1]Mass ratios throughout this paper are always $q = m_2/m_1 \leq 1$, the primary component is the more massive component.
[2]The spot longitude is measured counter-clockwise (as viewed from above) from the line of star centres.

Table 5. Photographic (pg), photoelectric (pe), CCD (cc) and spectroscopic (sp) times of the primary (I) and secondary (II) minima of U Peg, YY CrB and EQ Tau.

JD_{hel} 2 400 000+	Type		Ref.	JD_{hel} 2 400 000+	Type		Ref.	JD_{hel} 2 400 000+	Type		Ref.
U Peg											
13094.823	I	pg	1	36511.6688	I	pe	5	44490.3789	I	pe	20
13514.6157	I	pg	2	36515.6057	II	pe	5	44500.4922	I	pe	21
15021.237	I	pg	3	37173.5306	I	pe	5	44501.4295	II	pe	21
15400.141	I	pg	4	37192.4568	II	pe	5	44502.5554	II	pe	21
16880.171	I	pg	4	37636.0099	I	pe	7	44503.4923	I	pe	21
20050.100	I	pg	4	38691.7693	I	pe	8	44504.6165	I	pe	21
20756.751	II	pg	5	38692.7072	II	pe	8	44886.324	II	pe	22
21130.0598	II	pg	5	38703.388	I	pe	9	46383.3906	I	pe	23
22050.313	I	pg	4	40096.4534	I	pe	10	46704.3833	II	pe	24
23735.3396	I	pg	5	40205.320	II	pe	10	47070.3528	I	pe	25
24250.290	I	pg	4	40511.338	I	pe	11	47826.287	I	pe	26
26300.351	I	pg	4	40826.9010	I	pe	12	47833.7754	I	pe	27
28858.636	I	pg	6	40827.8396	II	pe	12	47834.7121	II	pe	27
29522.736	I	pg	4	40831.4001	I	pe	13	47849.3285	II	pe	28
29870.158	I	pg	4	40831.7729	I	pe	12	47849.3285	II	pe	28
30260.679	I	pg	4	40832.7122	II	pe	12	48107.548	II	pe	29
30260.866	II	pg	4	40835.3337	II	pe	11	48233.2922	I	pe	30
33182.8561	I	pe	5	40837.7692	I	pe	12	49677.3079	I	pe	31
33190.7262	I	pe	5	40843.3929	I	pe	13	49979.5649	II	pe	32
33190.9132	II	pe	5	40867.3784	I	pe	11	50002.4319	II	pe	33
33202.7181	I	pe	5	40888.7399	I	pe	12	50006.3630	I	pe	33
33230.6408	II	pe	5	40891.7381	I	pe	12	50008.4239	II	pe	34
33244.5075	II	pe	5	40892.6763	II	pe	12	50033.3456	I	pe	35
33255.5630	I	pe	5	40893.8008	II	pe	12	50034.2816	II	pe	36
33558.7624	I	pe	5	41185.3804	II	pe	13	50368.3978	I	pe	37
33561.7529	I	pe	5	41198.311	I	pe	13	50378.1407	I	pe	38
33924.5497	I	pe	5	42291.543	I	pe	14	50383.0313	I	pe	38
33998.9448	II	pe	5	42347.3879	I	pe	15	50383.2010	II	pe	38
34303.4545	I	pe	5	42714.309	I	pg	16	50383.9480	II	pe	38
34334.9383	I	pe	5	42741.2810	I	pe	15	50384.1370	I	pe	38
34387.9733	II	pe	5	43012.445	II	pg	16	50402.3150	II	pe	37
34635.5126	I	pe	5	43015.435	II	pg	16	50712.4420	I	pe	39
34685.3586	I	pe	5	43021.6134	I	pe	17	50728.3701	II	pe	40
34707.2857	II	pe	5	43785.0431	I	pe	18	50728.5567	I	pe	40
34988.5578	I	pe	5	43785.2312	II	pe	18	50750.2953	I	pe	40
36481.6864	I	pe	5	43789.535	II	pe	19	50766.408	I	pe	41
36483.7490	II	pe	5	44185.3093	I	pe	14	50789.272	I	pe	41
36484.6839	I	pe	5	44469.3855	I	pe	20	51146.2454	II	pe	42
36508.4851	II	pe	5	44469.3859	I	pe	20	51860.3855	I	pe	43
36508.6702	I	pe	5	44490.3782	I	pe	20				
YY CrB											
48500.2960	I	cc	44	51372.3485	I	cc	46	51692.4305	I	pe	66
50955.8711	I	sp	45	51668.3306	I	pe	66	51975.6055	I	pe	43
51318.4992	I	pe	66	51669.4588	I	pe	66	52045.4574	I	pe	66
51361.4268	I	cc	46	51670.3971	II	pe	66	52060.3331	I	pe	66
51368.3958	II	cc	46	51673.4147	II	pe	65				
51370.4653	I	cc	46	51674.3583	I	pe	65				

Table 5. (continued)

JD_{hel} 2 400 000+	Type		Ref.	JD_{hel} 2 400 000+	Type		Ref.	JD_{hel} 2 400 000+	Type		Ref.
EQ Tau											
30647.217	II	pg	64	40511.516	II	pe	47	49028.293	I	pg	57
36646.568	I	pg	47	40512.540	II	pe	47	49687.607	II	pe	58
36905.653	I	pg	47	44986.398	I	pg	48	49725.6672	I	cc	59
36910.602	II	pg	47	45011.292	I	pg	48	50396.9250	II	cc	60
36946.616	I	pg	47	45289.496	I	pg	49	51166.3224	II	cc	61
37257.584	I	pg	47	45991.544	II	pg	48	51166.4931	I	cc	61
37267.658	II	pg	47	46102.280	I	pg	48	51183.9030	I	sp	62
37295.651	II	pg	47	46109.445	I	pg	48	51184.2423	I	cc	61
37355.554	I	pg	47	46358.628	I	pg	50	51822.9035	I	cc	63
37357.607	I	pg	47	47138.428	II	pg	51	51896.2932	I	pe	43
37367.676	II	pg	47	47153.450	II	pg	51	51911.3128	I	pe	43
37371.596	I	pg	47	47436.597	I	pg	52	51930.2564	II	pe	43
37706.633	II	pg	47	47469.366	I	pg	52	52185.4141	I	cc	61
40212.492	II	pe	47	47470.390	I	pg	52	52185.5855	II	cc	61
40213.346	I	pe	47	47530.3021	II	pe	53	52193.4327	II	cc	61
40229.218	II	pe	47	47880.3453	I	pe	54	52195.4835	II	cc	61
40504.518	I	pe	47	47880.3459	I	pe	54	52198.5537	II	cc	61
40508.444	II	pe	47	48176.639	I	pg	55	52219.5491	I	cc	61
40509.468	II	pe	47	48312.323	II	pg	55				
40510.492	II	pe	47	48558.6008	I	pe	56				

References: (1) - Chandler (1895), (2) - Cannon (1903), (3) - Jordan (1930), (4) - Recillas & Woodward (1946), (5) - Purgathofer & Prochazka, (6) - Gaposhkin (1953), (7) - Saito (1971), (8) - Gordon (1975), (9) - Pohl & Kizilirmak (1966), (10) - Pohl & Kizilirmak (1970), (11) - Kizilirmak & Pohl (1971), (12) - Rovithis et al. (1982), (13) - Dumitrescu (1971), (14) - Patkós (1980), (15) - Patkós (1976), (16) - Ahnert (1977), (17) - Mallama et al. (1977), (18) - Lafta & Grainger (1986), (19) - Pohl & Gulmen (1981), (20) - Aslan et al. (1981), (21) - Rovithis & Rovithis (1981), (22) - BBSAG 57, (23) - BAA VSS 68, 30, (24) - BAVM 46, (25) - Keskin & Pohl (1989), (26) - BBSAG 93, (27) - Maupome et al. (1991), (28) - BAVM 56, (29) - BBSAG 29, (30) - BBSAG 97, (31) - BBSAG 108, (32) - Hegedüs et al. (1996), (33) - Šafář & Zejda (2000) (34) - BBSAG 110, (35) - BBSAG 111, (36) - Agerer & Huebscher (1996), (37) - Agerer & Huebscher (1998a), (38) - Lee et al. (1998), (39) - Agerer & Huebscher (1998b), (40) - Kiss et al. (1999), (41) - BBSAG 118, (42) - Agerer & Huebscher (1999), (43) - Pribulla et al. (2001b), (44) - ESA (1997), (45) - Rucinski et al. (2000), (46) - Keskin et al. (2000), (47) - Whitney (1972), (48) - BAVM 39, (49) - BAVM 36, (50) - BAVM 43, (51) - BAVM 50, (52) - BAVM 52, (53) - BBSAG 90, (54) - BAVM 56, (55) - BAVM 59, (56) - BAVM 60, (57) - BAVM 68, (58) - Benbow & Mutel (1995), (59) - Baldwin & Samolyk (1996), (60) - Buckner et al. (1998), (61) - *http://sirrah.troja.mff.cuni.cz/ mira/variables/lightcurves/*, (62) - Rucinski et al. (2001), (63) - Nelson (2001), (64) - Tsesevich (1954), (65) - Erdem (2001), 66 - Dumitrescu (2001)

spin angular moments of components and take their masses from Table 7, for the total amount of the transferred mass we have:

$$\Delta m = \frac{mq}{3(1-q^2)}\frac{\Delta P}{P} = 3.9 \pm 0.3\ 10^{-6} M_\odot \qquad (4)$$

The last, approximately linear, part of the minima (since 1991) was used to determine the following ephemeris appropriate to phase our observations:

$$\text{Min I} = 2\,450\,000.3658 \underset{\pm 6}{} + 0.37477710 \underset{\pm 21}{} \times E. \tag{5}$$

The general trend of the minima in the (O-C) diagram (Fig. 3) can be represented well by a 4th degree polynomial. This long-term period change was explained by Borkovits & Hegedüs (1996) as a part of the LITE caused by a third body. The derived period of such a component (136 years) is longer than the interval of observations. The residuals from the best 4th degree polynomial approximation still show some low-amplitude short-period variations. The Fourier period analysis of the residuals shows only one significant period $P_{\rm var} = 18.8 \pm 3.9$ years in the period interval 100 - 10000 days. This periodicity, already detected by Zhai et al. (1984), clearly seen in the minima between 1950 - 1980 can be interpreted either as a LITE caused by the presence of another body to the eclipsing pair, Applegate's (1992) mechanism or cyclic variability of the spot regions. Recent minima, however, do not show such a variation. The detailed analysis of possible mechanisms, including the influence of the LC asymmetries on the minima times, is out of the scope of the present study.

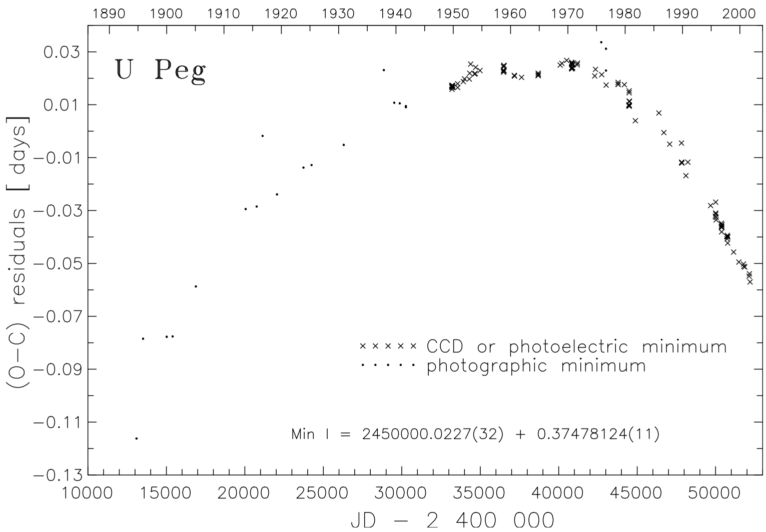

Figure 3. (O-C) diagram of all photographic, CCD and photoelectric minima of U Peg with respect to the mean linear unweighted ephemeris (indicated in the figure).

We have observed two LCs of U Peg. LC1 is composed of three nights: August 21, September 3 and September 6, 2000. LC2 from five nights: August 1, August 12, August 30, October 9 and October 14, 2001. The second LC was constructed over quite a long interval compared to the time scale of the LC variations. The intrinsic change between August and October, 2001 is visible before the maximum II (see Fig. 1).

For the determination of the geometric parameters we assumed the presence of *dark* spots on either of the components. Hence we excluded depressed parts of the LC and used only phases 0.0 - 0.5. The mass ratio $q = 3.019$ has been adopted from Zhai et al. (1988). The resulting fits to both LCs are shown in Fig. 5 and corresponding photometric elements are given in Table 6. It is interesting to note that the orbital inclination is almost equal in both solutions, while the fill-out is much larger in the second LC.

For both LCs we tried to improve the fits by introducing dark spots on the primary component. Since the spot(s) affect the LC outside the eclipses we did not try to determine the spot latitude and positioned the spots on the equator. The observed LCs were satisfactorily explained by one spot. The resulting spot parameters for the 2000 LC are temperature factor $k = T_{\rm spot}/T_1 = 0.882(9)$, longitude $l_{\rm spot} = 258.1{\pm}2.3°$ and radius $R_{\rm spot} = 13{\pm}4°$. For the 2001 LC we obtained $k = 0.881(7)$, $l_{\rm spot} = 281.6{\pm}1.9°$ and $R_{\rm spot} = 13{\pm}3°$. Although the latitute information is unavailable it is clear that the spot moved 23° in the course of one year in the direction of the orbital motion.

3.2. YY CrB

The total number of available minima in the time interval 1991-2001 is only 15. Therefore we also used the JD_0 determined from the Hipparcos photometry (ESA, 1997) and the instant of the spectroscopic conjunction (Rucinski et al., 2001). Due to lower precision, these two minima were assigned two times lower weights. The resulting weighted linear ephemeris is:

$$\begin{array}{rl} \text{Min I} = 2\,450\,000.1496 & + 0.37656416 \times E. \\ \pm 13 & \qquad \pm 29 \end{array} \tag{6}$$

The (O-C) residuals do not exceed 0.006 day. Hence the period of the system seems to be stable since its discovery. The ephemeris (3) was used to phase our photometry.

The observed LC of the system shows a slight O'Connell effect: ΔB = -0.016(5) and ΔV = -0.009(7) magnitudes (the maximum II brighter than maximum I). The same sense of the maxima asymmetry was detected by Erdem et al. (2001) ΔB = -0.048, ΔV = -0.052 found in LCs observed in May 2000 and by Sipahi et al. (2000) ΔB = -0.014, ΔV = -0.022 found from July 1999 LCs. The asymmetry was quite stable over two years. Our LC seems to be depressed by the presence of a dark spot on either of the components visible between the phases 0.1 - 0.3. These phases were excluded from the geometric elements determination (see Table 6 and Fig. 5). The system is partially eclipsing although the eclipses are close to total.

Since the observed LC of the system is quite asymmetric we tried to improve the fits introducing a dark spot on the primary component. Similarly as in the case of U Peg we positioned the spot on the equator. The resulting spot parameters are $k = 0.975(9)$, $l_{\rm spot} = 278.5{\pm}2.2°$ and $R_{\rm spot} = 25{\pm}3°$.

3.3. OU Ser

In our paper we present the first ground-based photometry of the system. We had at our disposal only our 2 photoelectric times of minima (w=2), the Hipparcos JD_0 (w=1) and spectroscopic time of the conjunction (w=1) determined by Rucinski et al. (2001). According to our LC, the minimum corresponding to the Hipparcos JD_0 is the deeper one. This cannot be caused by the period change or unsure number of elapsed cycles, since our minima are predicted using the Hipparcos ephemeris with a shift of only about 0.001 days. Therefore we interchanged the notation of the minima.

The weighted least squares fit to all available minima and spectroscopic conjunction led to the following ephemeris:

$$\begin{array}{llll} \text{Min I} & = 2\,450\,000.2739 & + 0.29676451 & \times E. \\ & \pm 15 & \pm 23 & \end{array} \tag{7}$$

used to phase our observations. The period of the system seems to be constant. The observed LC of the system shows slow variability: the height of the maximum II (observed on all three nights) is slowly getting brighter but is always fainter than the other maximum. The O'Connell effect is visible in the B passband (in average $\Delta B = 0.027(11)$), in the V passband the LC is rather symmetric.

The major complication of the system is its low mass ratio and low orbital inclination causing the amplitude of the LC to be as low as 0.18 mag in the V passband and 0.19 mag in the B passband. This together with three deviating Hipparcos observations probably caused the erroneous assignment of the primary minimum. In fact, the secondary minimum (according to the Hipparcos ephemeris) is the deeper one and the system is in spite of its low mass ratio, of the W subtype ! This is also supported by our LC solution.

The V passband LC is virtually free of asymmetries but maximum I of the B LC is somewhat brighter than maximum II. Hence for the determination of the geometric elements we used only the first half of the LC (phases 0.0 - 0.5). The resulting photometric elements are given in Table 6 and corresponding best fits are shown in Fig. 5. Due to low amplitude of the LC we did not try to improve the photometric solution by spots.

An interesting property of OU Ser is its large proper motion and radial velocity corresponding to its space velocity $V_{\rm space} = 124.0 \pm 4.4$ km.s^{-1} (see Table 1).

3.4. EQ Tau

Although the system lacks a modern photometric solution, there is quite a lot of available minima. Published times of minima were augmented by the minima obtained from unpublished CCD photometry performed at the Observatory &

Planetarium, Hradec Králové and the MEDUZA group, Czech Republic[3]. The (O-C) diagram with respect to the mean linear ephemeris is shown in Fig. 4. The period of the systems seems to slowly vary. The continuous period change can be explained by the LITE caused by another body to the eclipsing pair. A damped differential corrections solution leads to the approximate orbit of the eclipsing pair around the common mass centre: P_3 = 50.2±1.8 years, e = 0.37(12), ω = 0.76(26) rad, T_0 = 2 440 800±900, $a_{12} \sin\ i$ = 3.93(35) AU and the optimal linear ephemeris Min I = HJD 2 450 000.1248(21) + 0.34134803(4). Using the mass function $f(m_3) = 0.024(7)$ M$_\odot$ and the mass of the eclipsing pair we obtain the minimum mass (i_3 = 90°) of the possible third component as m_3 = 0.19 M$_\odot$. Using an estimated distance to the system d = 163 pc (see below) and the total mass of the eclipsing pair $m_1 + m_2$ = 1.754 M$_\odot$ (Table 7) the approximate angular distance of the visual pair is about 0.25". Assuming that all components of the system are main-sequence objects, the third component should be a red dwarf of a M6 spectral type as much as 8 mag fainter than the contact binary. In fact, no third component in the broadening functions of EQ Tau has been detected. Another possible interpretation of the observed period changes is the intermittent mass transfer between the components in both directions.

To phase our data we have used only minima from the last approximately linear part of the diagram (since 1989). The weighted least squares solution resulted in the following linear ephemeris:

$$\begin{array}{lll} \text{Min I} = 2\,450\,000.1104 & + 0.34134691 & \times E. \\ \pm 13 & \pm 23 & \end{array} \quad (8)$$

The large scatter of the photoelectric and CCD minima in the last part of the (O-C) diagram is probably caused by spot activity on the contact pair.

EQ Tau is quite faint and was not included into the Hipparcos astrometric mission. In the TYCHO 2 catalogue it appears with V = 11.28 and $B - V$ = 0.98(22) and large proper motion $\mu_\alpha \cos\delta$ = +68.4±1.4 mas/year and μ_δ = -29.6±1.5 mas/year. Rucinski et al. (2001) discuss its possible membership in the Pleiades cluster. According to Robichon et al. (1999) the mean proper motion and parallax of Pleiades is $\mu_\alpha \cos\delta$ = +19.15±0.23 mas/year, μ_δ = -45.72±0.18 mas/year and $\pi = 118.2^{+3.2}_{-3.0}$ pc. Hence EQ Tau is not a member of Pleiades, but its light is, very probably, reddened by Pleiades dust and gas.

We can estimate the absolute magnitude of EQ Tau using the calibration of Rucinski & Duerbeck (1997):

$$M_\mathrm{v}^\mathrm{cal} = -4.44 \log P + 3.02(B - V)_0 + 0.12. \quad (9)$$

For EQ Tau we get M_v = 4.10. Using $A_\mathrm{v} \approx 1.222$ and V_max = 10.50 (Table 1) we get the distance to the system d = 108 pc. Using V_0 = 72 km.s^{-1} and the observed proper motion, for the space velocity of the system we get V_space = 82 km.s^{-1}.

[3]http://sirrah.troja.mff.cuni.cz/ mira/variables/lightcurves/

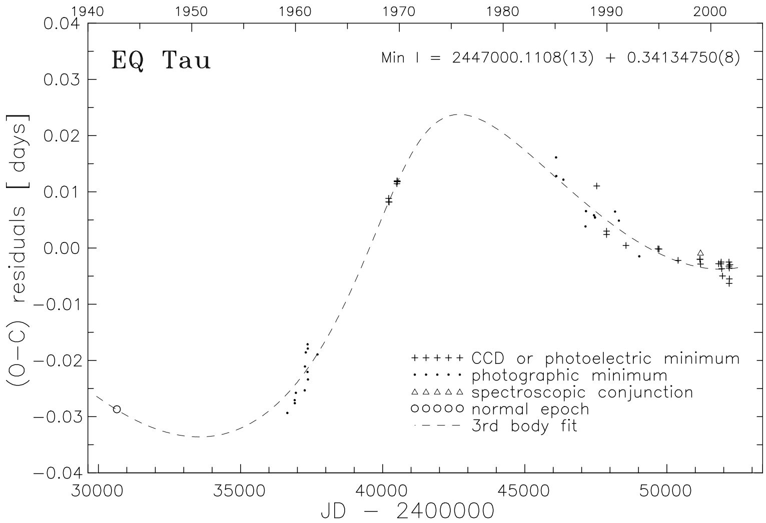

Figure 4. (O-C) diagram of all photographic, CCD and photoelectric minima as well as normal epoch (from Tsesevitch, 1954) of EQ Tau with respect to the mean linear weighted ephemeris (indicated in the figure). LITE fit is plotted with the dashed line.

The determination of the geometric elements of EQ Tau is complicated by the asymmetry of the B passband LC (maximum I being slightly fainter) and insufficient coverage of the maximum I. Hence we have analyzed only observations in the phase interval 0.47 - 1.00. The resulting elements are given in Table 6 and corresponding fits in Fig. 6. The system is totally eclipsing with the duration of the constant phase about 20 minutes (0.041 in phases). Due to the low quality and coverage of the maximum I we did not try to better the solution introducing cool spot(s) on either of the components.

4. Discussion and conclusion

The orbital-period changes could be studied for two systems U Peg and EQ Tau. For YY CrB and OU Ser there are only few available minima. The observed period of U Peg is probably the result of the secular variable mass exchange between the components and cyclic variation interpreted either by the Applegate's mechanism or LITE ($P_3 \approx 19$ years) caused by a low massive body in the system. The former mechanism is not supported by the the mean brightness changes of the system (see Zhai et al., 1984). For EQ Tau the third body orbit ($P_3 = 50.2$ years) is well defined. Unfortunately, its whole orbital cycle is not covered uniformly by precise times of minima. In both cases the possible third body is of low mass and luminosity. Therefore the expected third light is negligible and spectroscopic detection improbable. Conclusive confirmation of

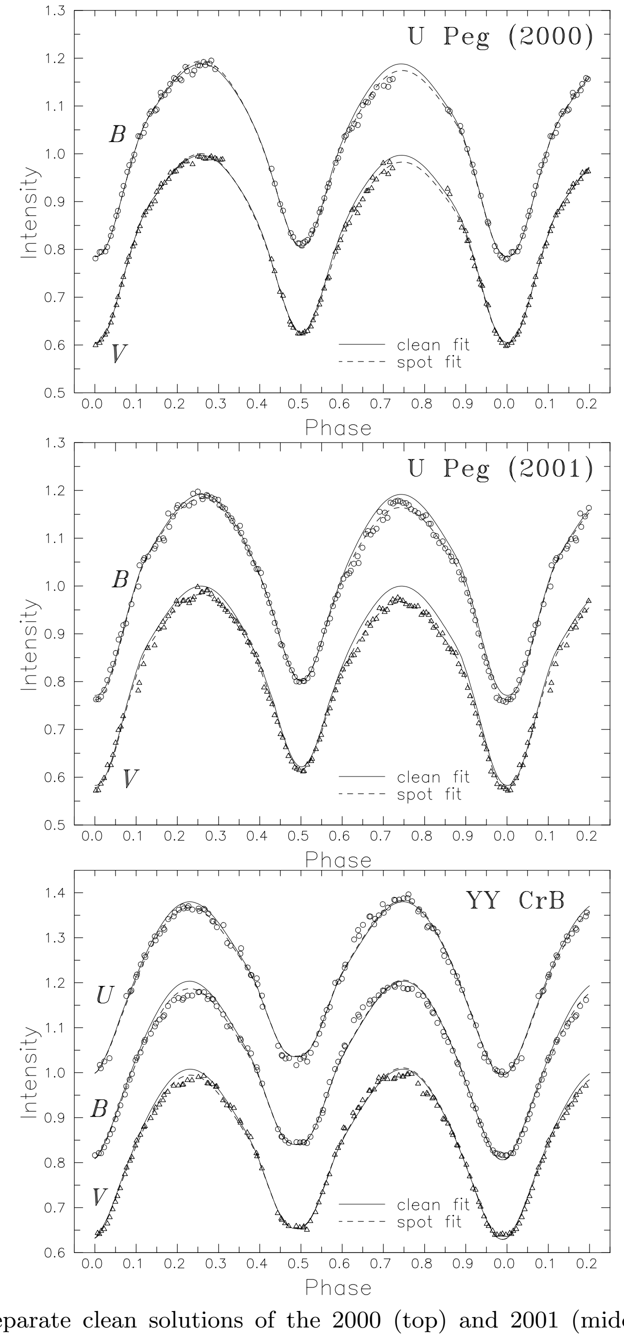

Figure 5. Separate clean solutions of the 2000 (top) and 2001 (middle) *BV* light curves of U Peg and *UBV* light curve of YY CrB.

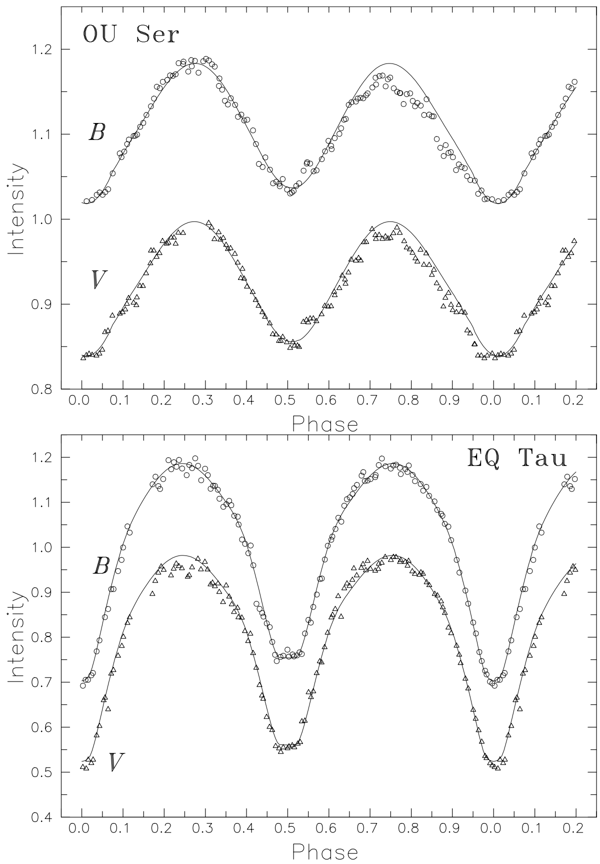

Figure 6. Clean solutions of the *BV* light curves of OU Ser (top) and EQ Tau (bottom).

the invisible components will require further times of minima over a long time interval.

The photometric fits explain the observed LCs quite well. The determination of the "clean" geometric parameters is, however, complicated by the LC asymmetries present in all four systems. The most probable explanation is the presence of spotted regions on either of the components. For U Peg and YY CrB the solutions were improved introducing a dark spot on the more massive component. The "clean" photometric elements were combined with the published spectroscopic parameters (Table 1) to provide the absolute parameters of the systems (Table 7). In the case of U Peg we chose the geometric parameters provided by the 2000 LC due to its lower asymmetry.

Two of the studied systems (EQ Tau and OU Ser) are high velocity stars. The analysis of the proper motion of EQ Tau conclusively proves that the system

Table 6. Photometric elements and their standard errors (σ) - i - inclination; $i_{\rm min}$ - minimum inclination for the eclipses to be total; $q = m_2/m_1$ - mass ratio; Ω - surface potential; r_1, r_2 - volume mean fractional radii; T_1, T_2 - polar temperatures. $\sum w({\rm O-C})^2$ is the weighted sum of squares of residuals for all light curves. Parameters not adjusted in the solution are denoted by a superscript "f".

Parameter	**U Peg** LC1	**U Peg** LC2	**YY CrB**	**OU Ser**	**EQ Tau**
i [°]	77.51(15)	77.54(16)	77.00(23)	54.23(41)	86.59(69)
$i_{\rm min}$ [°]	79.82	79.84	77.33	74.29	82.41
q	$0.331^{\rm f}$	$0.331^{\rm f}$	$0.243^{\rm f}$	$0.173^{\rm f}$	$0.442^{\rm f}$
Ω	2.5031(21)	2.4837(33)	2.2392(26)	2.1300(30)	2.7303(29)
Fill-out	0.150(10)	0.244(16)	0.634(7)	0.307(27)	0.120(13)
r_1	0.4864(6)	0.4918(10)	0.5374(9)	0.5477(11)	0.4595(8)
r_2	0.2956(6)	0.3017(10)	0.3027(13)	0.2542(14)	0.3174(9)
T_1 [K]	$5860^{\rm f}$	$5860^{\rm f}$	$6135^{\rm f}$	$5960^{\rm f}$	$5860^{\rm f}$
T_2 [K]	5785(7)	5841(10)	6142(9)	6380(42)	5851(8)
$L_1^U/(L_1^U+L_2^U)$	–	–	0.7682(4)	–	–
$L_1^B/(L_1^B+L_2^B)$	0.6962(5)	0.6833(7)	0.7670(4)	0.7707(17)	0.6784(1)
$L_1^V/(L_1^V+L_2^V)$	0.7015(4)	0.6902(6)	0.7672(4)	0.7778(14)	0.6782(2)
$\sum w({\rm O-C})^2$	0.0431	0.0587	0.4149	0.0409	0.0558

Table 7. The absolute parameters of the studied systems

Parameter	U Peg	YY CrB	OU Ser	EQ Tau
$A/A_\odot$	2.516(6)	2.657(17)	1.986(12)	2.478(19)
$R_1/R_\odot$	1.224(3)	1.428(9)	1.088(7)	1.139(9)
$R_2/R_\odot$	0.744(2)	0.804(5)	0.505(2)	0.786(6)
$m_1/M_\odot$	1.149(9)	1.429(25)	1.018(14)	1.217(29)
$m_2/M_\odot$	0.379(2)	0.348(11)	0.176(4)	0.537(13)
$\rho_1/\rho_\odot$	0.626	0.491	0.790	0.824
$\rho_2/\rho_\odot$	0.920	0.670	1.366	1.106
$\log g_1$ [cm.s^{-2}]	4.32	4.28	4.37	4.41
$\log g_1$ [cm.s^{-2}]	4.27	4.17	4.28	4.38
M_V	3.94	3.38	4.13	4.00
M_V^{cal}	3.91	3.63	4.21	4.10
d [pc]	132	96	59	114

is not a member of the Pleiades cluster. Its distance is virtually unknown.

The absolute maximum visual magnitudes of all three system were determined from the temperatures of the components (Table 6) and absolute radii (Table 7) using Popper's (1980) radiative calibration for the main-sequence stars:

$$M_V = -\log R - 10F_V + C_1, \tag{10}$$

where R is the stellar radius in solar units, $F_V = F_V(T_{\rm eff})$ are fluxes and $C_1 = 42.255$.

Comparison of the absolute visual magnitudes computed from absolute parameters of the components and those determined from relation (9) shows good accord except for YY CrB, which is 0.25 mag brighter than expected.

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