Photoelectric and CCD photometry of eclipsing contact binaries: UV Lyn, FU Dra and AH Aur

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Abstract. New photoelectric BV and CCD BVR observations of the eclipsing contact binary systems UV Lyn, FU Dra and AH Aur obtained from January 2000 to April 2001 are presented and analyzed. Photometric elements determined from our light curves combined with published spectroscopic elements yielded the absolute parameters of the systems. Analysis of the (O-C) diagram of AH Aur revealed fast period changes. The correct ephemeris for the primary minimum was determined. The evolutionary status of all three systems is discussed.

Key words: contact binaries - photometry - orbital period

1. Introduction

Contact binary stars consisting of solar-type components (so called W UMa - type binary stars) are very important for stellar evolution research. Most of them have orbital periods within $0.25 < P < 1$ day. They apparently do not exist below orbital periods of 0.22 day and they are rare at orbital periods longer than one day and spectral types earlier than about F0 to F2. The orbital periods of contact binaries are often variable. Their changes are caused by a strong interaction of the components or/and the presence of a third body. A common convective envelope surrounds both components, leading to a large-scale energy transfer from the larger, more massive component to the less massive one, roughly equalizing surface temperatures over the entire system. The exact

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Table 1. Characteristics of the observed systems. The paralaxes, distances, maximum and minimum visual magnitudes and average colour indices were taken from the Hipparcos Catalogue (ESA, 1997). The spectroscopic parameters were taken from papers Lu & Rucinski (1999), Rucinski et al. (2000), Lu & Rucinski (1999). The E_{B-V} reddenings, visual absorptions A_V and absolute visual magnitudes were computed from observed spectral types, Hipparcos maximum visual magnitudes and $(B-V)$ colours

	UV Lyn(W)	FU Dra(W)	AH Aur(A)
GSC	02983-01870	04181-00673	01887-00926
HIP	44455	76272	30618
π [mas]	8.16±1.62	6.25±1.09	6.18±2.05
d [pc]	122^{+31}_{-20}	160^{+34}_{-24}	162^{+80}_{-41}
P [days]	0.414985	0.306717	0.494108
$V^{max} - V^{min}$	9.60 - 10.00	10.55 - 11.10	10.25 - 10.65
$(B-V)$	0.636±0.036	0.592±0.065	0.550±0.081
V_0 [km s^{-1}]	-0.3±1.3	-11.4±1.1	31.9±1.4
K_1 [km s^{-1}]	86.5±1.5	280.8±2.1	47.2±1.2
K_2 [km s^{-1}]	235.7±1.9	70.4±1.8	279.6±2.8
$(m_1+m_2)\sin^3 i$ [$M_\odot$]	1.440±0.020	1.379±0.046	1.787±0.050
m_2/m_1	0.367±0.007	0.251±0.002	0.169±0.006
sp. type	F6V	F8V	F7V
E_{B-V}	0.17	0.05	0.05
A_V	0.58	0.17	0.17
M_V^{max}	4.16±0.33	4.53±0.31	4.20±0.48

nature of the energy transfer process is still not understood and contact systems almost certainly cannot exist in static equilibrium (Lucy, 1976).

Many bright (V <12 mag) contact systems have unknown photometric and absolute elements. This fact was the main motivation for investigation of these objects. The present paper is the second in a series analyzing the photoelectric observations obtained at the Stará Lesná (SL) and Skalnaté Pleso (SP) Observatories. This paper also presents CCD photometry obtained at the Sobaeksan Observatory (SO), Korea. The main aim is the analysis of the light curves (hereafter LCs), period changes and evolution of neglected or newly discovered contact binaries.

UV Lyn was discovered to be a variable by Kippenhahn (Geyer et al., 1955). Although Kuklin (1961) and Strohmeier et al. (1964) found 1.2 day periodicity, Strohmeier (1968, see Bossen, 1973) suspected an orbital period 0.4 day. Bossen (1973) classified UV Lyn as a W UMa type binary with a period 0.415 day and maxima of unequal brightness. He also determined the distance to the system $d = 176$ pc. Markworth & Michaels (1982) analyzed photoelectric UBV LCs of UV Lyn taken in 1981 and found that it is a contact binary with an inclination $i = 67.7°\pm0.9°$ and a mass ratio $q = 0.526\pm0.05$.

Zhang et al. (1995) published photoelectric BV observations of UV Lyn taken in 1994. The LC was asymmetric with Max I brighter than Max II by about 0.03 mag in V and 0.05 mag in B. They found a slow increase of the orbital period and explained it by a mass transfer from the secondary to the primary component. The asymmetry of the LC could be caused by a gaseous stream between the components.

The first spectroscopic orbit of UV Lyn was determined by Lu & Rucinski (1999) (see Table 1).

Contact binary **FU Dra** was discovered by Hipparcos. Although the system is relatively faint (V_{max} = 10.55), it was observed spectroscopically by Rucinski & Lu (2000). On the assumption of the Hipparcos determination of the primary eclipse the authors concluded that the object belongs to the W-type subgroup. The system is known to have large proper motion (see Rucinski et al., 2000). Combining radial velocity of the mass center V_0 = -11 km s^{-1} and the Hipparcos proper motions in the right ascension and declination one gets the spatial velocity 195 km s^{-1}.

The system was observed at the Baja Observatory in June 2000 as a part of a diploma thesis (Heiner, 2000). The CCD observations yielded two times of the secondary minima and approximate geometric elements: inclination $i = 80.8°$ and fill-out $f = 0.05$ assuming the spectroscopic mass ratio $q = 0.25$.

Contact binary **AH Aur** was discovered by Prager & Guthnick (1929). Photographic LC obtained by Bodokia (1938) shows clear asymmetry of the minima. The system has been neglected since its discovery. The photoelectric observations of AH Aur were published only by Hinderer (1960).

The first spectroscopy of the system was performed by Rucinski & Lu (1999) yielding the spectroscopic elements given in Table 1. The slight asymmetry of the radial velocity curve is caused by the fact that the authors accepted the period from the ephemeris published in GCVS 4:

$$\mathrm{Min\ I} = 2\,436\,495.571 + 0.4942624 \times E \tag{1}$$

We have recomputed their radial velocities using the correct ephemeris but the difference between their and our set of the spectroscopic elements is not significant.

2. New photometric data

2.1. Photoelectric photometry

The present photoelectric BV observations of UV Lyn, FU Dra and AH Aur were performed from December 2000 to April 2001 at the Stará Lesná and Skalnaté Pleso Observatories of the Astronomical Institute of the Slovak Academy of Sciences. BD+38°1990, BD+28°1109 and GSC 4181-1726 were used as the comparison stars for UV Lyn, FU Dra and AH Aur, respectively. Since BD+28° 1109 was chosen as the comparison star for FU Dra rather arbitrarily, we also observed a check star HD140023. The mean V magnitude of this star with respect to the comparison was stable within 0.005 mag. The journal of the photoelectric observations is given in Table 2.

Table 2. Journal of photoelectric observations of UV Lyn, FU Dra and AH Aur obtained at the Stará Lesná (SL) and Skalnaté Pleso (SP) Observatory and CCD photometry obtained at the Sobaeksan Observatory (SO). Intervals of orbital phases were calculated from the ephemerides (3),(4),(5). The number of observations in one filter (N) and estimated standard deviation of an individual observation in V filter (σ) are given in the last two columns

Date	HJD$_{mean}$ 2 400 000+	Phases	Filters	Obs.	N	σ
UV Lyn						
Dec 19, 2000	51898.509	0.939 – 1.172	BV	SL	160	0.004
Jan 18, 2001	51928.441	0.018 – 0.367	BV	SL	174	0.006
Jan 19, 2001	51929.505	0.378 – 1.111	BV	SL	468	0.011
Feb 14, 2001	51955.524	0.347 – 0.432	BV	SP	36	0.011
Feb 17, 2001	51958.439	0.232 – 0.698	BV	SL	216	0.008
Mar 30, 2001	51999.326	0.850 – 0.120	BV	SL	110	0.008
FU Dra						
Jan 15, 2001	51925.645	0.657 – 1.088	BV	SL	74	0.015
Jan 17, 2001	51927.616	0.984 – 1.609	BV	SL	160	0.013
Feb 11, 2001	51952.580	0.318 – 1.053	BV	SL	266	0.012
Mar 30, 2001	51999.442	0.322 – 0.644	BV	SL	108	0.008
AH Aur						
Jan 25, 2000	51569.041	0.346 – 0.882	BVR	SO	47	0.008
Jan 26, 2000	51570.161	0.625 – 1.115	BVR	SO	46	0.006
Feb 09, 2000	51584.080	0.721 – 1.346	BVR	SO	67	0.004
Feb 10, 2000	51584.981	0.754 – 0.955	BVR	SO	18	0.005
Feb 17, 2000	51591.993	0.904 – 1.207	BVR	SO	34	0.007
Mar 24, 2000	51628.046	0.865 – 1.150	BVR	SO	19	0.018
Mar 25, 2000	51629.039	0.879 – 1.181	BVR	SO	31	0.008
Mar 26, 2000	51630.025	0.862 – 1.186	BVR	SO	35	0.006
Dec 21, 2000	51900.499	0.107 – 0.698	BV	SL	182	0.007
Jan 15, 2001	51925.431	0.611 – 1.147	BV	SL	248	0.007
Jan 17, 2001	51927.476	0.965 – 1.072	BV	SL	46	0.003
Jan 30, 2001	51940.013	0.192 – 0.604	BVR	SO	45	0.010
Feb 11, 2001	51952.406	0.371 – 0.571	BV	SL	116	0.023
Feb 25, 2001	51966.303	0.466 – 0.720	BV	SL	146	0.010
Apr 03, 2001	52003.310	0.411 – 0.593	V	SL	86	0.028

At the SP and SL Observatories 0.6m Cassegrain telescopes equipped with single-channel pulse-counting photoelectric photometers were used. Detailed description of the observational technique and reduction of the data to the international photometric system is given in Paper I (Pribulla et al., 2001). The resulting photoelectric light curves (LCs) are depicted in Fig. 1 and Fig. 2 (top).

Our observations enabled us to determine 5 times of minima of UV Lyn, 5 times of minima of FU Dra and 4 times of minima of AH Aur (see Table 3). The times of minima were determined separately for all three filters using the Kwee and Van Woerden (K&W) method, the parabola fit, the sliding integration method, the tracing paper and the "center of mass" method described in detail by Ghedini (1982). The computer code was kindly provided by Komžík (2001).

Table 3. New times of primary (I) and secondary (II) minima of UV Lyn, FU Dra and AH Aur obtained at the Stará Lesná (SL) Observatory, Sobaeksan Observatory (SO) and Hlohovec Observatory (HO). The standard errors of the minima are given in parentheses. For example, entry 51628.0388(21) should be interpreted 51628.0388±0.0021

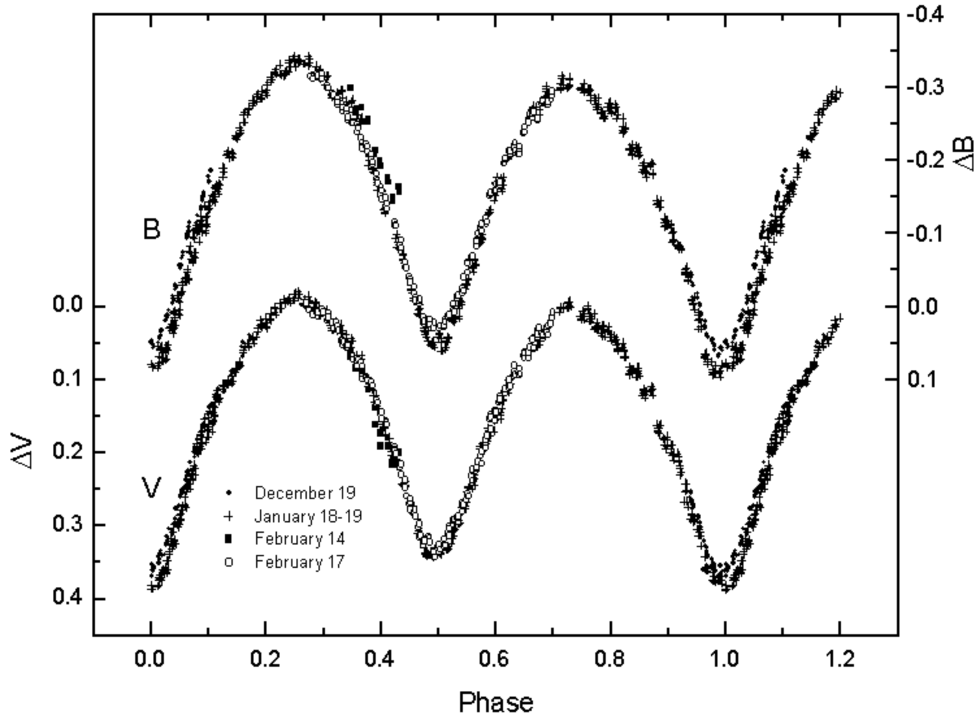
JD$_{hel}$ 2 400 000+	Fil.	type	Obs.	JD$_{hel}$ 2 400 000+	Fil.	type	Obs.
UV Lyn				51570.2216(5)	*B*	I	SO
51898.4814(1)	*B*	I	SL	51570.2225(2)	*V*	I	SO
51898.4821(2)	*V*	I	SL	51570.2215(2)	*R*	I	SO
51929.4004(2)	*B*	II	SL	51584.0562(3)	*B*	I	SO
51929.3997(1)	*V*	II	SL	51584.0566(3)	*V*	I	SO
51929.6068(2)	*B*	I	SL	51584.0566(2)	*R*	I	SO
51929.6066(1)	*V*	I	SL	51591.9650(6)	*B*	I	SO
51958.4496(5)	*B*	II	SL	51591.9644(3)	*V*	I	SO
51958.4490(2)	*V*	II	SL	51591.9643(2)	*R*	I	SO
51999.3234(2)	*B*	I	SL	51628.0388(21)	*B*	I	SO
51999.3231(1)	*V*	I	SL	51628.0367(5)	*V*	I	SO
FU Dra				51628.0363(4)	*R*	I	SO
51925.6761(5)	*B*	I	SL	51629.0251(19)	*B*	I	SO
51925.6756(1)	*V*	I	SL	51629.0226(3)	*V*	I	SO
51927.6710(1)	*B*	II	SL	51629.0254(6)	*R*	I	SO
51927.6701(4)	*V*	II	SL	51630.0118(6)	*B*	I	SO
51952.5140(1)	*B*	II	SL	51630.0121(3)	*V*	I	SO
51952.5134(3)	*V*	II	SL	51630.0113(3)	*R*	I	SO
51952.6665(2)	*B*	I	SL	51900.5351(3)	*B*	II	SL
51952.6679(1)	*V*	I	SL	51900.5353(2)	*V*	II	SL
51999.4407(2)	*B*	II	SL	51925.4891(3)	*B*	I	SL
51999.4402(1)	*V*	II	SL	51925.4880(1)	*V*	I	SL
52085.4777(4)	*V*	I	HO	51940.0611(6)	*B*	II	SO
52086.3984(4)	*V*	I	HO	51940.0604(3)	*V*	II	SO
52088.3913(3)	*V*	II	HO	51940.0604(2)	*R*	II	SO
AH Aur				51952.4119(1)	*B*	II	SL
51568.9857(5)	*B*	II	SO	51952.4154(4)	*V*	II	SL
51568.9657(6)	*V*	II	SO	52003.3084(5)	*V*	II	SL
51568.9862(4)	*R*	II	SO				

FU Dra was observed also during tests of the photoelectric photometer attached to the 0.6 Cassegrain of the Hlohovec Observatory (HO), Slovak republic. Three times of minima were determined from the observations in the V passband (Petrík, 2001).

Important data regarding all three variables compiled from the Hipparcos Catalogue (ESA, 1997) and spectroscopic studies (Lu & Rucinski, 1999, Rucinski & Lu, 1999, Rucinski et al., 2000) are given in Table 1.

2.2. CCD observations

AH Aur was observed on eight nights between January and March, 2000 and one night in January 2001 with a 61-cm reflector at the Sobaeksan Optical As-



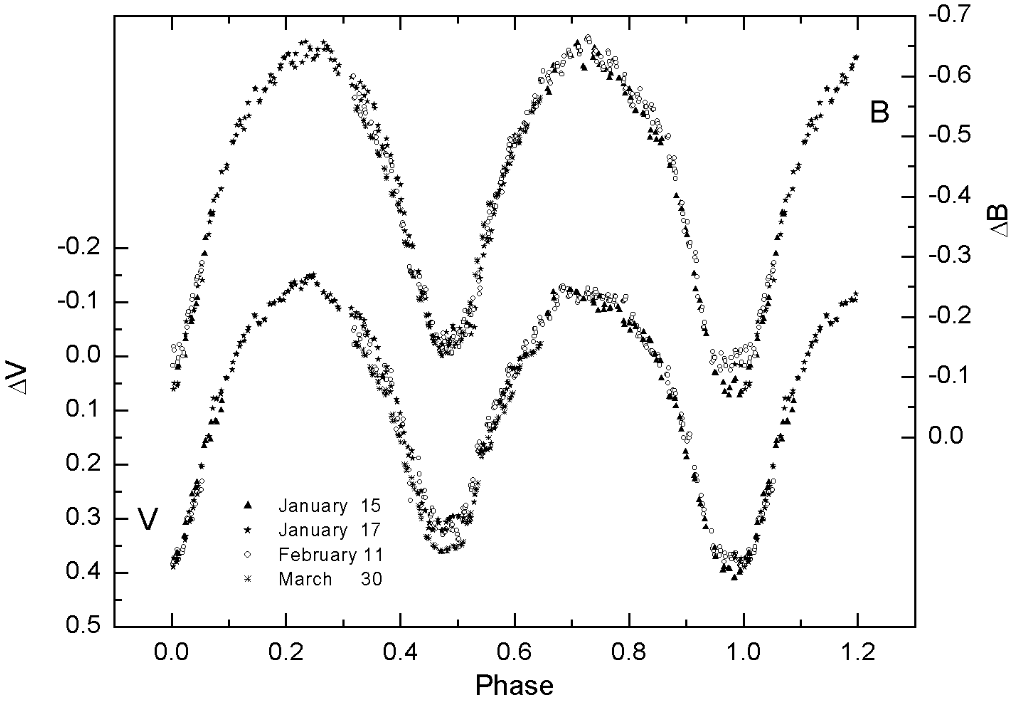
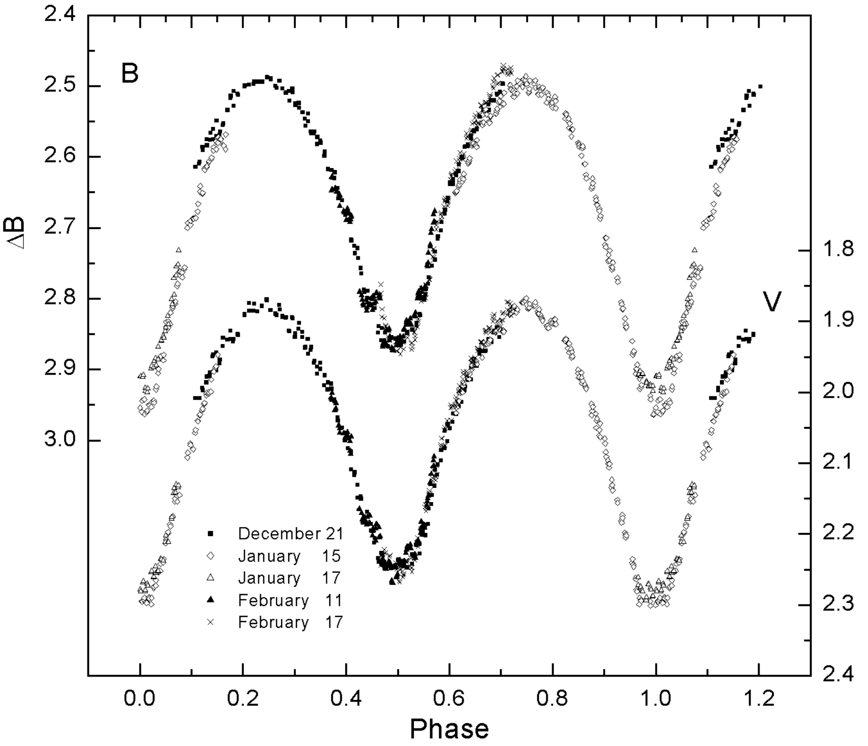


Figure 1. The photoelectric *BV* LCs of UV Lyn (top) and FU Dra (bottom) obtained at the SL and SP Observatories in 2000-1 and 2001, respectively



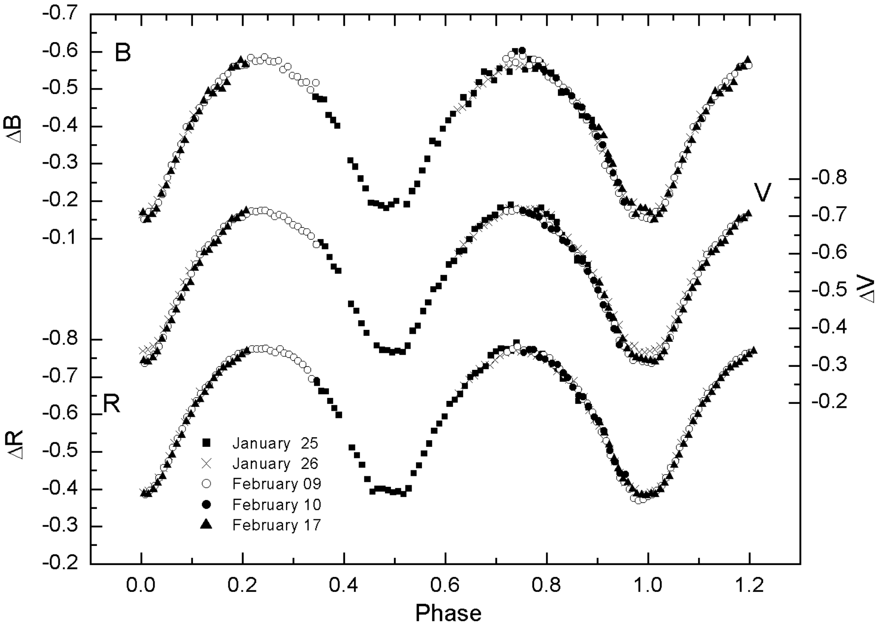


Figure 2. The photoelectric *BV* LCs of AH Aur obtained at the SL Observatory in 2000-1 (top) and the CCD *BVR* LCs of AH Aur obtained at the SO in 2000 (bottom)

tronomy Observatory in Korea. A PM512 CCD imaging System of Photometric Instruments cooled with liquid nitrogen and a standard BVR filters set was used. HD 257287 was used as the comparison star for all our measurements. Our CCD observations were pre-processed according to the method given by Park (1993). Nightly extinction coefficients were computed from the comparison-star measurements and the differential magnitudes in each colour in terms of Δmag (variable-comparison, check-comparison) were reduced in the instrumental system. The January-February 2000 LC of AH Aur is presented in Fig. 2 (bottom). Observations from March 2000 and January 2001 cover only minima.

From our CCD photometry we determined 8 times of minima. They were calculated separately for all three filters using the K&W method. The minima are given in Table 3.

3. Analysis and reduction

We have collected the available times of minima of all three systems (see Table 4). For UV Lyn the photographic, photoelectric and CCD times of minima were kindly provided by Kreiner (2000). For FU Dra only three photoelectric times of minima were published. Minima denoted by asterisk $*$ (see Table 4) were calculated from radial velocities. We have assigned three times larger weights for the photoelectric and CCD minima than for the photographic ones.

The W&D (Wilson & Devinney, 1971) code was employed to determine the photometric elements of the systems. We have used the Mode 3 appropriate for the contact configuration. All our $BV(R)$ observations were used to compute about 150 normal points for each passband. The normal points were determined by running averages of phased observations calculated using ephemerides (3), (4) and (5). 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 atmospheric model option of the W&D program was used. Since all three systems have late F type spectra we have assumed coefficients of gravity darkening and bolometric albedo appropriate for convective envelopes (T_{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 limb darkening 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_{eff} callibration of Popper (1980).

The initial parameters of UV Lyn and FU Dra were taken from Maceroni & van't Veer (1996) and Heiner (2000), respectively. Both systems are W-type contact binaries, i.e., the smaller and hotter component is eclipsed during the primary minimum. Thus using the W&D code we have interchanged them shifting the orbital phases by 0.5. Throughout the article we adopted the following notation: the primary component is always the more massive one - mass ratios $q = m_2/m_1 \leq 1$. No reliable photometric elements were published for AH Aur.

Table 4. Photographic (p), visual (v), CCD and photoelectric primary (I) and secondary (II) times of minima of UV Lyn, FU Dra and AH Aur. Minima derived from the spectroscopic observations are denoted by an asterisk

UV Lyn								
JD$_{hel}$ 2 400 000+	type	Ref.	JD$_{hel}$ 2 400 000+	type	Ref.	JD$_{hel}$ 2 400 000+	type	Ref.
15021.906 p	II	1	27758.858 p	II	1	40314.4562	II	3
15023.786 p	I	1	27901.350 p	I	2	40318.4053	I	3
15674.892 p	I	1	27901.364 p	I	1	40319.4341	II	3
15892.580 p	II	1	27901.372 p	I	2	40320.4693	I	3
16153.726 p	I	1	27901.388 p	I	2	40357.4022	I	3
16625.580 p	I	1	28193.543 p	I	1	40377.3230	I	3
16932.655 p	I	1	28219.481 p	II	1	40586.6804	II	3
18335.707 p	I	1	28248.403 p	I	2	40657.4351	I	3
18679.932 p	II	1	28607.415 p	II	2	40693.7449	II	3
19036.813 p	II	1	28607.438 p	II	2	40694.7842	I	3
19336.709 p	I	1	28626.388 p	I	1	40696.6503	II	3
20439.915 p	II	1	28635.484 p	I	1	45055.397	I	4
20547.713 p	II	1	28950.415 p	I	2	45381.363 p	II	5
20959.632 p	I	1	28954.450 p	II	2	45382.399 p	I	5
21532.860 p	II	1	28962.475 p	I	2	45387.378 p	I	5
22079.619 p	I	1	28962.477 p	I	1	45388.626 p	I	5
22601.895 p	II	1	28977.400 p	I	2	45389.453 p	I	5
23450.726 p	I	1	29231.487 p	I	2	45404.400 p	I	5
24259.561 p	I	1	29315.642 p	I	1	45406.4816	I	5
24528.858 p	I	1	29317.500 p	II	1	45407.3134	I	5
24532.783 p	II	1	29341.379 p	I	1	45781.413 p	II	6
25221.907 p	I	1	29369.381 p	II	1	45782.454 p	I	6
25728.560 p	I	1	29722.485 p	II	1	46500.3732	I	7
25942.899 p	II	1	30031.686 p	II	1	47206.6560	I	8
26024.639 p	II	1	30731.563 p	I	1	47553.3700	II	9
26335.872 p	II	1	31028.663 p	I	1	47554.4261	I	10
26767.435 p	II	2	32118.856 p	I	1	47849.4776	I	11
26767.457 p	II	2	33354.269 p	I	2	47849.4786	I	11
26767.478 p	II	2	33377.229 p	II	2	47929.5706	I	11
26770.354 p	II	1	33392.179 p	II	1	47929.5706	I	11
26798.361 p	I	2	33392.199 p	II	2	47969.3930	I	12
26798.381 p	I	2	33608.647 p	I	1	48272.3457	I	13
26798.404 p	I	2	33656.538 p	II	2	48272.3460	I	13
26825.394 p	I	2	34445.214 p	I	1	48432.530	I	14
27050.706 p	I	2	34501.379 p	II	2	48438.964	II	14
27064.818 p	I	1	36247.231 p	II	1	48700.4016	II	15
27075.793 p	II	1	37375.362 p	I	1	49055.4230	I	16
27102.410 p	II	2	40165.6815	I	3	49055.4248	I	16
27126.442 p	II	1	40187.4654	II	3	49075.3443	I	17
27130.525 p	II	2	40199.7095	I	3	49699.2752	II	18
27133.362 p	I	2	40203.6531	II	3	49700.3010	I	19
27365.656 p	I	2	40205.7238	II	3	49700.3088	I	18
27482.681 p	I	1	40265.4835	II	3	49807.3758	I	20
27538.344 p	I	2	40271.5051	I	3	50189.3691	II	21
27568.381 p	II	1	40303.4562	I	3			
FU Dra								
48500.2630	I	22	50866.2777*	I	23	51722.4762	II	24
51723.3979	II	24						

Table 4. (continued)

AH Aur								
JD$_{hel}$ 2 400 000+	type	Ref.	JD$_{hel}$ 2 400 000+	type	Ref.	JD$_{hel}$ 2 400 000+	type	Ref.
24907.396 p	I	25	35186.4372	II	30	48290.3334	II	39
24946.428 p	I	25	35191.3788	II	30	48307.3807	I	39
24975.344 p	II	25	35761.595 v	II	31	48445.980	II	40
25271.344 p	II	25	36462.460 v	I	32	48463.272	II	40
25275.550 p	I	25	36495.571 v	I	31	48463.2723	II	40
25298.546 p	II	25	44253.300 v	I	33	48463.5167	I	40
25300.510 p	II	25	44303.473 v	II	34	48525.2777	I	40
25301.482 p	II	25	45346.420 p	II	35	48525.278	I	40
25302.515 p	II	25	45671.564 p	II	36	48539.114	I	40
25319.307 p	II	25	45684.649 p	I	36	48561.5989	II	41
25320.514 p	I	25	47595.3648	I	37	48667.0910	II	40
25556.434 p	II	25	47787.5793	I	38	48745.665	II	40
25647.401 p	II	25	47804.6246	II	38	48983.3234	I	42
25271.358 p	I	26	47849.5868	II	38	49399.3707	I	43
26068.431 v	I	27	47862.4356	II	38	49739.3193	I	44
28519.476 p	II	28	47862.6796	I	38	50469.8591*	I	45
28542.671 v	II	29	47885.6588	II	38	51906.9592	I	46
28542.913 v	I	29	48251.2970	II	39			

References: (1) - Bossen (1973), (2) - Strohmeier et al. (1964), (3) - Zhang et al. (1995), (4) - BBSAG 59 (1983), (5) - BAV-M 36 (1983), (6) - BAV-M 38 (1984), (7) - BBSAG 79 (1986), (8) - BBSAG 87 (1988), (9) - BSAG 91 (1989), (10) - BAA VSS Circ. 73 (1992), (11) - BAV-M 56 (1990), (12) - BBSAG 94 (1990), (13) - BAV-M 51 (1991), (14) - unpublished, (15) - BBSAG 100 (1992), (16) - BAV-M 62 (1993), (17) - BBSAG 103 (1993), (18) - Zhang et al. (1995), (19) - Zhang (1998), (20) - BBSAG 108 (1995), (21) - BBSAG 112 (1996), (22) - Hipparcos Catalogue, (23) - Rucinski et al. (2000), (24) - Heiner (2000) (25) - Prager & Guthnick (1929), (26) - Guthnick & Prager (1928), (27) - Tsesevitch (1954), (28) - Bodokia (1938), (29) - Glownia (1985), (30) - Kämper (Lichtenknecker, 1986), (31) - Tsesevitch (1956), (32) - Kordylewski (1960), (33) - BBSAG Bull. 46, (34) - BBSAG Bull. 47, (35) - BAV Mitt. 68, (36) - BAV Mitt. 38, (37) - BAV Mitt. 52, (38) - BAV Mitt. 56, (39) - BAV Mitt. 59, (40) - Hipparchos (Kreiner, 2000), (41) - BAV Mitt. 60, (42) - BAV Mitt. 62, (43) - BAV Mitt. 68, (44) - Agerer & Huebscher (1996), (45) - Rucinski & Lu (1999), (46) - Nelson (2001)

3.1. UV Lyn

We have collected more than 140 times of minima of UV Lyn. Only photovisual minima with a very large scatter (about 0.05 day) were available until 1968. More recent photoelectric and CCD times of minima clearly show the increase of the orbital period. The (O-C) diagram of all available times of minima from the mean linear ephemeris is shown in Fig. 3. The quadratic fit to the CCD and photoelectric times of minima gives:

$$\begin{array}{llll} \mathrm{Min\ I} & = 2\,447\,000.4223 & + \, 0.41498200 & \times E \; + 1.15 \; 10^{-10} \times E^2. \\ & \quad\ \pm 12 & \quad\ \pm 15 & \quad\ \pm 11 \end{array} \tag{2}$$

The period increase $\Delta P/P = (4.88 \pm 0.47)\ 10^{-7}$ year^{-1} can be interpreted by the mass transfer from the less to more massive component. Using the masses of the components given in Table 6 we need the mass transfer rate $\Delta m/\Delta t = (1.28\pm0.12)\ 10^{-7} M_\odot$ year^{-1} to explain the observed period increase. Since the broadening function of the system does not show a third component, an explanation of the observed period change by a light-time effect is questionable.

The recent photoelectric and CCD times of minima were used to determine the linear ephemeris:

$$\begin{array}{rcl} \text{Min I} & = 2\,447\,000.4197 & + 0.41498460 \times E. \\ & \pm 10 & \quad \pm 15 \end{array} \tag{3}$$

This ephemeris was used for phasing our new photometry and it is suitable for future minima times forecast.

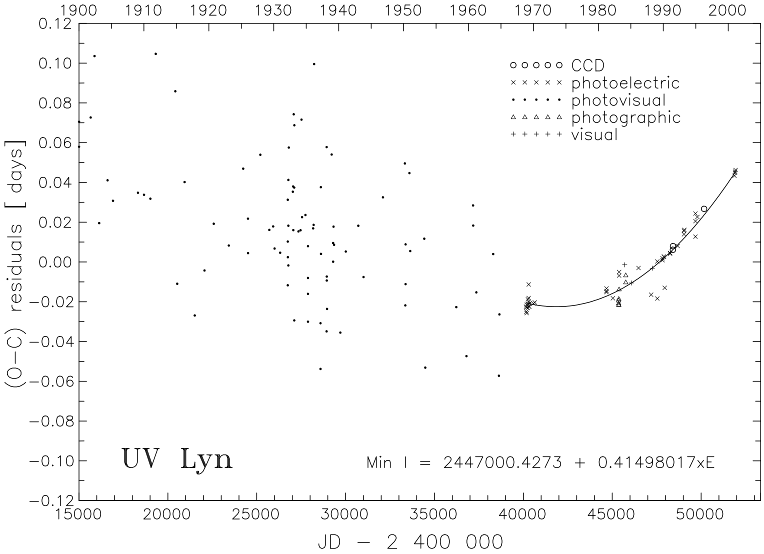


Figure 3. The (O-C) diagram of UV Lyn corresponding to the mean linear ephemeris given at the bottom of the figure. The best quadratic fit to photoelectric times of minima is represented by a solid curve

UV Lyn is a W-type contact binary (Lu & Rucinski, 1999). During our observations, the *BV* LCs were clearly asymmetric - maximum I (phase 0.25) was brighter than maximum II (phase 0.75) about 0.02 mag in the V and 0.03 mag in the B passband. The depression of the observed LCs was largest around the phase 0.85. The colour index was $\Delta(B-V) = -0.345\pm0.005$ and $\Delta(B-V) = -0.324$ at the phases 0.25 and 0.85, respectively. Hence we can interpret the depression by a cool spot positioned on either of the components facing the observer at the phase 0.85.

To obtain the "clean" elements (without the spot disturbances) we have used only observations between the phases −0.05 - 0.65. The resulting photometric elements are presented in Table 5 and corresponding fits in Fig. 4 (solid line).

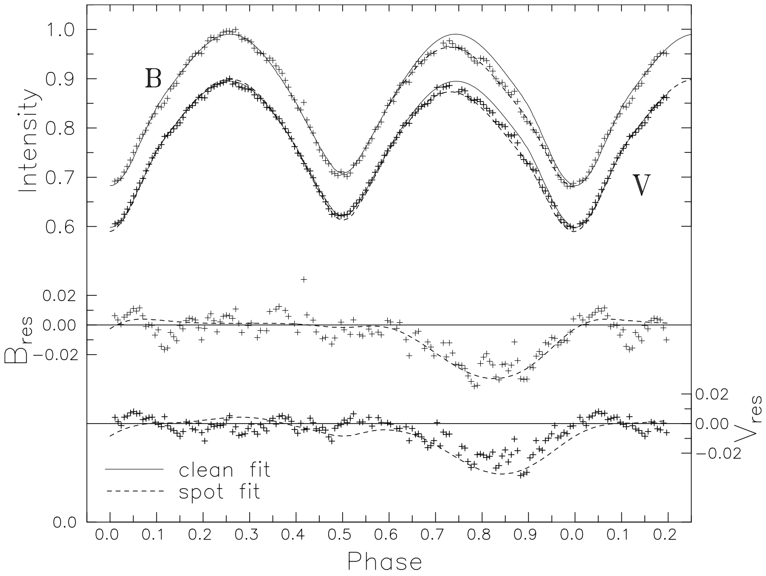


Figure 4. The normal points, their best fits and the fit residuals for UV Lyn. The solid lines give clean fits to phases −0.05 - 0.65. The dashed lines represent the spot fits

Although the LC of UV Lyn exhibits large variations, the resulting geometric elements are within the error of the parameters obtained by Markworth & Michaels (1982). Thereafter, the geometric elements were fixed and all normal points were used to fit a cool spot facing the observer around the phase 0.85. Since the spot is not eclipsed, there is little information on its latitude. Therefore we put the spot on the equator. The spot can be located either on the primary or secondary component. The location and parameters of the spot are in the first case: longitude $l = 237.5^\circ \pm 1.7^\circ$, temperature factor $k = 0.843 \pm 0.006$, $\chi^2 = 0.001362$; and in the second case: $l = 48.6^\circ \pm 4.0^\circ$, $k = 0.913 \pm 0.004$, $\chi^2 = 0.001336$. For both possibilities we have obtained quite good fits. The difference between the fits is negligible. The resulting spot fit for the spot positioned on the primary components is given in Fig. 4 (dashed line).

3.2. FU Dra

The linear fit to the available 12 times of minima provides the following ephemeris:

$$\begin{array}{rll} \text{Min I} = 2\,450\,866.2770 & + \, 0.30671686 & \times E. \\ \pm 3 & \pm 9 & \end{array} \qquad (4)$$

The (O-C) residuals do not exceed 0.003 day. Hence the period of the system seems to have been stable since its discovery. The ephemeris (4) was used to phase our photometry. Maximum I of the LC is about 0.02 mag brighter than maximum II. We detected small perturbations of the LC during the primary minimum. The small interval of constant brightness during the primary eclipse suggests that the system is totally eclipsing (subtype W).

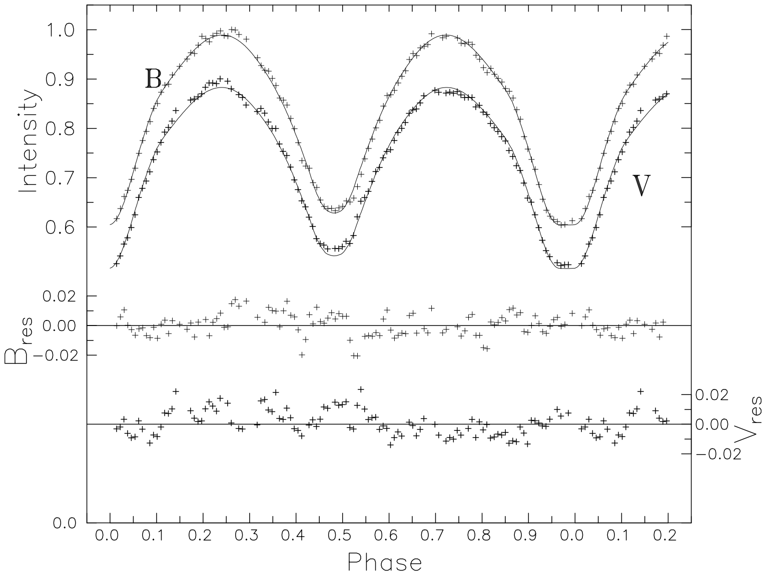


Figure 5. The normal points, their best fits and the fit residuals for FU Dra

Since the LC of the system is quite symmetric we have used all observations to obtain the photometric elements. The normal points and the resulting fits are shown in Fig. 5.

3.3. AH Aur

The major complication of the system are pronounced period changes which make published ephemerides unusable, e.g., the forecasts of the present times of minima with ephemeris (4) give a shift of about 4.83 days! The discrepancy has already been noted by Lichtenknecker (1986). This is the reason why AH Aur is observed only seldomly. The list of presently available minima (Table 4) consists mainly of the minima published in BAV Mitteilungen (Huebscher et al., 1989, 1990, 1991), minima determined from the Hipparcos photometry (Kreiner, 2000) and our observations. The photoelectric and CCD times of minima are rather numerous after about JD 2 445 000. The weighted linear regression gives:

$$\begin{array}{llll}\text{Min I} & = 2\,448\,500.3296 & + 0.49410834 & \times E. \\ & \quad\pm 8 & \quad\pm 21 & \end{array} \tag{5}$$

The (O-C) diagram for all available minima corresponding to the ephemeris (5) is presented in Fig. 6. The period behaviour before 2 445 000 was very unusual. The minima in the interval JD 2 426 000 - 2 445 000 occurred about one quarter of the period later than predicted by the ephemeris (5). The shift is so large that the primary and seconadry minimum could be interchanged. The fact that it is almost impossible to determine the type of the minimum in older observations mean that the (O-C) diagram is ambiguous. The LC of Hinderer (1960) in the B passband suggests that the minima HJD 2 435 186.4372 and 2 435 191.3788 determined from the Hinderer's photometry by Lichtenknecker (1986) are secondary. Two visual minima just prior to JD 2 443 000 and three photographic minima after HJD 2 445 000 give orbital period $P = 0.494074(8)$. After HJD 2 445 000 the period increases by about $\Delta P/P = 6.9\ 10^{-5}$! Since Rucinski & Lu (1999) did not detect the third component in the broadening functions the LITE explanation is questionable. Also the LC analysis does not indicate a third light. It is possible that the hypothetical third body is not a main-sequence object.

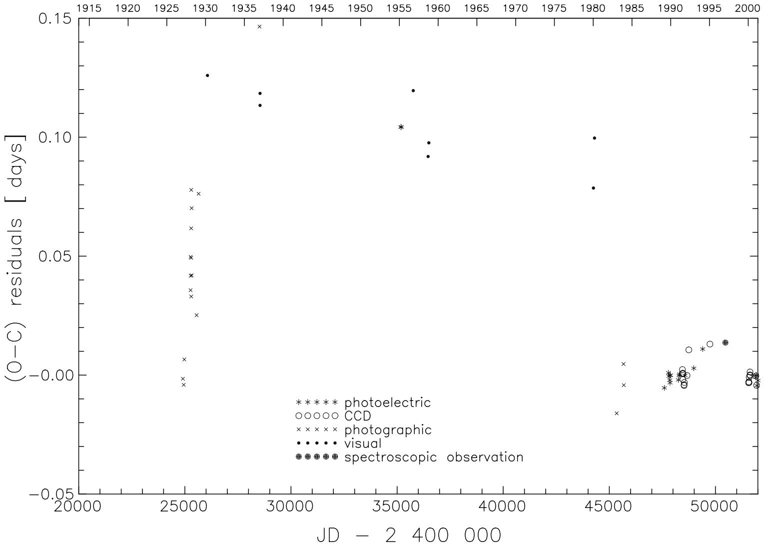
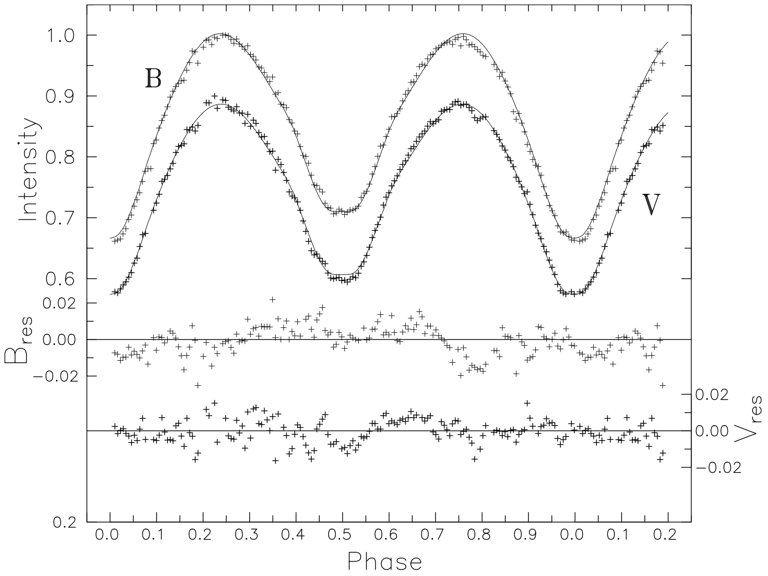


Figure 6. The (O-C) diagram of AH Aur corresponding to the mean linear ephemeris (5)

The reliable study of the period changes of AH Aur is affected by the long intervals without any data and the unreliability of the minima type determination prior to JD 2 445 000. Due to the fast period changes, the system requires more regular observations.

Unlike the orbital period, the LC of the system seems to be rather stable. There are only slight variations in the minima depth - the secondary minima are relatively deeper during the 2000 CCD photometry. The short interval of constant light during the secondary minimum indicates that the system is just totally eclipsing.



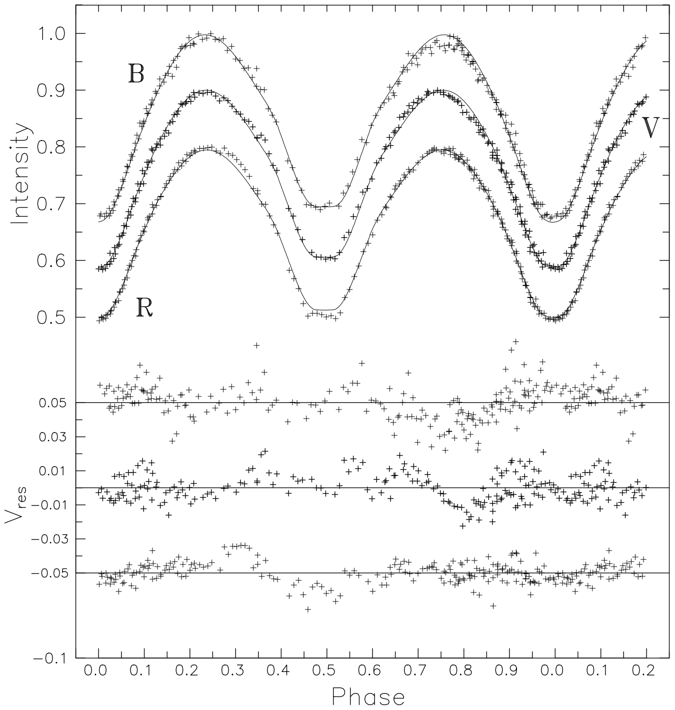


Figure 7. The normal points, their best fits and the fit residuals for AH Aur. The photoelectric BV LCs obtained at the SL (top) and the CCD BVR LCs from the SO (bottom)

For the determination of the photometric elements we have used the photoelectric BV observations obtained in December 2000 - February 2001 and the CCD BVR observations obtained in January - February 2000. The photoelectric BV and the CCD BVR LCs were solved separately. In both cases we have accepted the spectroscopically determined mass ratio $q = 0.169$. Broadening functions (Rucinski & Lu, 1999) did not indicate the presence of the third component to the eclipsing binary, therefore we have fixed the third light as zero for both datasets. Since the mass ratio was also fixed, the differential corrections converged quickly. The computed photometric elements for both data sets are given in Table 5. The resulting fits are presented in Fig. 7.

It is interesting to note that while the geometric elements (fill-out and inclination) are consistent for both CCD and photoelectric LCs, the temperature of the secondary component differs by as much as 131 K. It is possible that the secondary minimum (according to ephemeris (5)) is sometimes deeper than the primary and the system changes between W and A types (like e.g., TZ Boo, Hoffmann, 1978). This probably causes the problems with the minima type identification (Lichtenknecker, 1986).

The inclination $i = 75.5^\circ \pm 0.5^\circ$ indicates that the system is totally eclipsing, but the intervals of the constant light are short. It is interesting that both components have nearly equal temperatures. The less massive component is even slightly (40 K) hotter.

4. Discussion and conclusions

Unlike in Paper I, all three systems have reliable spectroscopic elements. This enabled us to determine the absolute parameters (see Table 6) using the inclinations determined from our data and published spectroscopic semi-major axes. The errors of the masses are mainly determined by the errors of $(m_1+m_2)\sin^3 i$. The contribution of the error of the inclination was less than 20% for all three systems.

It is interesting to note that $(B-V)$ colour indices determined from the Hipparcos photometry are rather redder than expected from the spectroscopic classification (see Table 1). The discrepancy is the largest for UV Lyn, where $(B-V) = 0.636$ corresponds to a G2 spectral type (Popper, 1980).

The absolute maximum visual magnitudes of all three system were determined from the temperatures of the components (Table 5) and absolute radii (Table 6) using Popper's (1980) radiative calibration for the main-sequence stars:

$$M_V = -\log R - 10F_V + C_1, \tag{6}$$

where R is the stellar radius in solar units, $F_V = F_V(T_{eff})$ are fluxes and $C_1 = 42.255$. Since the components of a contact binary do not radiate like spherical stars we have compared their absolute visual magnitudes with the

Table 5. Photometric elements and their standard errors (σ) - i - inclination; $q = m_2/m_1$ - mass ratio; Ω - surface potential; r_1, r_2 - volume mean fractional radii; T_1, T_2 - polar temperatures. $\sum w(O-C)^2$ is the weighted sum of squares of residuals for all light curves. Parameters not adjusted in the solution are denoted by a superscript "a"

Parameter	**UV Lyn**	**FU Dra**	**AH Aur** LC1(SL)	**AH Aur** LC2(SO)
i [°]	66.80(12)	78.64(24)	75.46(26)	75.60(22)
q	0.367^a	0.251^a	0.169^a	0.169^a
Ω	2.5590(19)	2.3180(16)	2.0805(19)	2.0858(13)
Fill-out	0.455	0.235(10)	0.674(18)	0.625(12)
r_1	0.4821	0.5143(5)	0.5647(7)	0.5626(5)
r_2	0.3091	0.2788(6)	0.2737(11)	0.2705(8)
T_1 [K]	6045^a	5800^a	6215^a	6215^a
T_2 [K]	6262(12)	6133(8)	6141(8)	6272(9)
$L_1^B/(L_1^B + L_2^B)$	0.6769(8)	0.7216(5)	0.8270(2)	0.8130(3)
$L_1^V/(L_1^V + L_2^V)$	0.6769(7)	0.7290(4)	0.8260(2)	0.8138(2)
$L_1^R/(L_1^R + L_2^R)$	–	–	–	0.8152(2)
$\sum(O-C)^2$	0.00073	0.00534	–	0.00534

Table 6. Absolute parameters and the distance to the the observed systems. The masses of the components are derived from spectroscopic elements (Table 1) and new inclination angles (Table 5). The errors of the parameter are given in the parentheses

	UV Lyn(W)	FU Dra(W)	AH Aur(A)
M_1 [$M_\odot$]	1.356(19)	1.169(39)	1.683(47)
M_2 [$M_\odot$]	0.498(8)	0.293(10)	0.284(8)
A [$R_\odot$]	2.875(13)	2.172(24)	3.294(31)
R_1 [$R_\odot$]	1.386(6)	1.117(12)	1.853(17)
R_2 [$R_\odot$]	0.889(4)	0.605(6)	0.891(8)
$\log g_1$ [cm s^{-2}]	4.29	4.41	4.12
$\log g_2$ [cm s^{-2}]	4.24	4.34	3.99
M_V	3.386	4.160	2.831
d [pc]	134	175	282
$\overline{\rho_1}$	0.717	1.181	0.372
$\overline{\rho_2}$	0.998	1.863	0.401

output from the W&D code. The absolute magnitudes from the W&D code were systematically fainter by about 0.1 mag. The distances were computed using the Hipparcos maximum visual magnitudes assuming interstellar and/or circumstellar extinction determined from the observed E_{B-V} (Table 1).

The resulting distances to UV Lyn and FU Dra are within the errors of the Hipparcos astrometric values. The distance to AH Aur is, however, much larger than the astrometric value. It is interesting to note the very large relative error of the astrometric parallax (33%). The discrepancy and large error of the astrometric parallax can be explained by a presence of a third component in the system. The pronounced variations of the orbital period also support the third body hypothesis, although the small number of times of minima does not allow us to calculate its orbital elements. On the other hand, the broadening functions (Rucinski & Lu, 1999) show only two components.

The evolutionary status of the components of all three systems can be inferred using the mean densities. Since the absolute parameters for all three systems are known, the densities were directly computed from the mean radii and masses of the components (see Table 6). The resulting mean densities for the primary and secondary components together with the ZAMS densities are shown in Fig. 8.

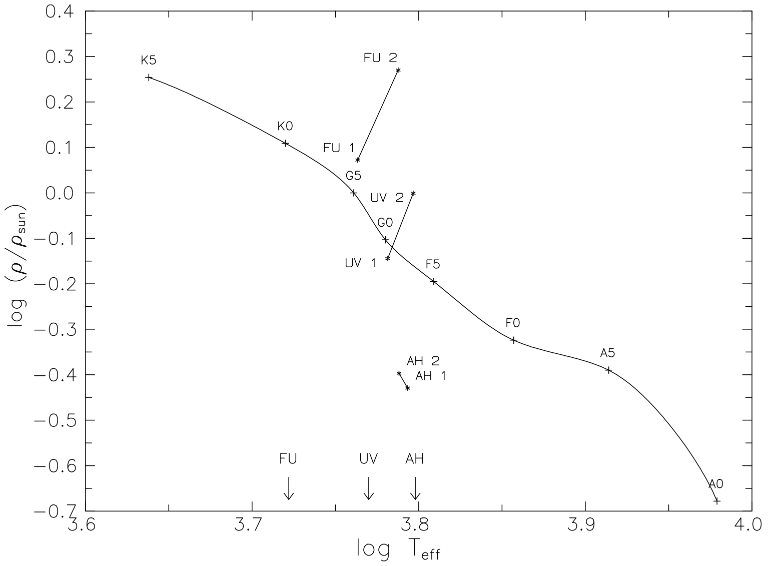


Figure 8. The ZAMS mean densities (Lang, 1992) and the mean densities of the primary(1) and the secondary(2) components of UV Lyn, FU Dra and AH Aur. The logarithms of the effective temperatures expected from the period-colour relation (Wang, 1994) are indicated by arrows

The mean effective temperatures expected from the colour-period relation $(B - V)_0 = 0.062 - 1.31 \log P$ (Wang, 1994) are indicated by the arrows. From the figure it is clearly visible that the period-colour relation is not obeyed well by all three systems. Their spectral types range from F6 to F8 while their orbital periods range from 0.3067 to 0.4941 day. The spectral type of FU Dra (F8) is too early for its period. According to the period-colour relation it should be of G8 spectral type.

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