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A PHOTOMETRIC STUDY OF THE W UMA TYPE ECLIPSING BINARY V376 AND

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RESUMEN

Hemos analizado las nuevas curvas de luz UBV y BV para V376 And obtenidas en los observatorios de la Universidad de Ankara y de Rozhen y Bucarest, respectivamente, con el objeto de determinar los parámetros físicos del sistema y de estudiar su posible actividad. Las soluciones obtenidas por el método del problema inverso de Djuraševic, analizando simultáneamente las dos curvas de luz para la estación, describen al sistema V 376 And como una configuración en alto sobrecontacto ($f_{\rm over} \sim 36\%$ - 2004 y $f_{\rm over} \sim 55\%$ - 2003) con una diferencia de temperaturas relativamente grande entre las componentes ($\Delta T = T_{\rm h} - T_{\rm c} \sim 880 - 840$ K), la cual es característica de los sistemas tipo A en contacto. La asimetría de la curva de luz puede explicarse suponiendo una mancha fría (de tipo solar) en la componente menos masiva y más fría.

ABSTRACT

The new UBV photoelectric light curves of V376 And acquired at Ankara University Observatory in 2004 by the present authors and its BV light curves collected at Rozhen and Bucharest Observatories in 2003 (Dumitrescu et al. 2004) have been analysed and reanalysed, respectively, with the aim to derive physical parameters and to study the possible activity of the system. The solutions made by using Djuraševic's inverse-problem method in the simultaneous analysis of both seasonal light curves describe the V376 And system as a high overcontact configuration ($f_{\rm over} \sim 36\%$ - 2004 and $f_{\rm over} \sim 55\%$ - 2003) with relatively large temperature difference between components ($\Delta T = T_{\rm h} - T_{\rm c} \sim 880 - 840$ K) which is characteristic for an A-type contact system. The light curve asymmetry can be explained by introducing the cool (solar type) spot region on the less massive, cooler, component.

Key Words: binaries: close — binaries: eclipsing — stars: fundamental parameters — stars: individual (V376 And)

1. INTRODUCTION

V376 And (HD 15922, SAO 38140, BD +49° 701, HIP 12039) is one of the W UMa-type eclipsing binary system discovered by the HIPPARCOS mission (ESA 1997). The spectral type of this contact binary was estimated as A4 V in the radial velocity study of close binary systems by Rucinski et al. (2001). This estimation of spectral type was different from that given in the HIP Catalogue and in SIMBAD, which list it as A0. Other photometric and spectroscopic characteristics of V376 And are summarized in Table 1. The times of minima for V376 And since 2000 are published (see Keskin, Yaşarsoy, & Sipahi 2000; Tanriverdi et al. 2003; Porowski 2005; Drózdz & Ogloza 2005; Albayrak et al. 2005; Hübscher, Paschke, & Walter 2005). The light curves in BV colours together with six times of minima were given by Dumitrescu, Iliev, & Tudose (2004).

In this study we present the light curve analysis of the new UBV photometric observations of V376 And, obtained by the authors in 2004 at the Ankara University Observatory, together with the reanalysis of the BV light curves collected at Rozhen and Bucharest observatories during the last quarter of 2003 (Dumitrescu et al. 2004). These seasonal light curves have been analyzed by using the inverse-problem method of Djurašević's code (1992a).

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TABLE 1

CHARACTERISTICS OF V376 AND

Parameter	Value	References
α_{2000}	$02^h 35^m 11^s.63$	ESA (1997)
δ_{2000}	$+49^\circ\ 51'\ 37"$	‘’
Parallax [mas]	5.07 ± 0.89	‘’
$P_{\rm orb.}$	$0^{\rm d}.798669$	Rucinski et al. (2001)
Sp. Type	A4 V	‘’
$q_{\rm sp}=m_{\rm c}/m_{\rm h}$	0.305	‘’
$M_{\rm V}$	$0^{\rm m}.85 \pm 0.40$	‘’
Hp max. mag.	$7^{\rm m}.70$	ESA (1997)
Hp min. mag.	$7^{\rm m}.96$	‘’
$B-V$	$0^{\rm m}.256$	‘’
$V-I$	$0^{\rm m}.29$	‘’

2. THE OBSERVATIONAL DATA AND LIGHT CURVES

The new UBV observations of V376 And were carried out at the Ankara University Observatory on three nights (October 2, November 4 and November 5, 2004) by using a SSP-5A photometer head which consists of a Hamamatsu R1414 photomultiplier tube attached to a 30 cm Maksutov telescope. The log of observations and the probable error of a single observation point for every night of observation are given in Table 2. During the observations, BD +49° 699 and BD +49° 703 were used as comparison and check star, respectively. The nightly extinction coefficients for each colour were determined by observing the comparison star.

The light levels were estimated by averaging data around the maxima and minima (by taking a phase interval of ± 0.02) and their differences are listed in Table 2. The magnitude differences between the two maxima exhibit the socalled O'Connell effect that amounts to Δm = Max I − Max II of 0.059, 0.065 and 0.036 for U, B and V bands, respectively. Light curve asymmetries of this kind are generally attributed to inhomogeneities in the surface brightness distribution (cool or hot spots) of the component stars in late-type binaries.

The differential U, B and V magnitudes, in the sense variable minus comparison, corrected for atmospheric extinction, are given in Table 3. The photometric phases of the light and colour curves are calculated with the following ephemeris obtained in this study:

$$\begin{aligned} HJD\ \mathrm{Min}\ I &= 2448500.7431(\pm 0.0041) + \\ &+ 0^{\rm d}.7986715(\pm 0.0000009) \times E. \end{aligned}$$

There are only 21 minimum times, consisting of 11 minima of Min I and 10 minima of Min II, obtained between Sept. 1, 1991 (corresponding to HJD = 2448500.7420, see ESA 1997) and Oct. 10, 2006 (corresponding to HJD = 2454018.3694, see Csizmadia et al. 2006) and published so far. The O-C diagram of V376 And constituted by using all these minima did not show any considerable period variation in this time interval. Therefore, an O-C analysis to establish period variation could not be made.

The other set of BV photometric observations of V376 And analysed in this paper has been collected at Rozhen and Bucharest observatories in 2003 (Dumitrescu et al. 2004). Unfortunately, within that set different comparison and check stars have been used (HD 16184 and HD 15583, respectively), making the direct comparison of ours and their light curve much harder. Also, Dumitrescu et al. (2005) have noted other problems in the data acquisition process. We think that the selection of HD 16184 as a comparison star is quite problematic, because SIMBAD data (`http://simbad.u-strasbg.fr`) presents this star as a double or multiple star system. This fact can affect the quality and reliability of the data obtained in the differential photometry of V376 And. A possible variability of the comparison star might be the main cause of the problems noted in Dumitrescu et al. (2005). In order to directly compare the analysed seasonal light curves, in Figure 1 we present BV light curves and B-V colour curves of the Ankara (2004) set (left) and the Rozhen-Bucharest (2003) set (right) together. From this figure it is evident that the maxima of the light curve levels, as well as the light curve amplitudes, asymmetries and B-V colour curves are different in these two sets of photometric observations. In our opinion the main origin of these changes is the intrinsic system activity (including the presence of spot activity), but we cannot exclude the influence of the possible comparison star variability in the Rozhen-Bucharest Dumitrescu et al. (2004) observations.

3. THE LIGHT-CURVE ANALYSIS

In order to model the two light curve sets of this binary systems we used the code by Djurašević (1992b) modified for the overcontact configuration by Djurašević et al. (1998). The code is based on the Roche model and the principles given in the paper by Wilson & Devinney (1971). The light-curve analyses were made by applying the inverse-problem method by Djurašević (1992a), based on the modified Marquardt (1963) algorithm. More details about the code and the method of light-curve analysis can be found in e.g. Djurašević et al. (2004a).

TABLE 2

LOG OF OBSERVATIONS OF V376 AND. PROBABLE ERRORS, LIGHT CURVE LEVELS AND THEIR DIFFERENCES [MAG]

Date of Obs.	Number of points	σ_U	σ_B	σ_V
Oct. 02, 2004	143	± 0.051	± 0.091	± 0.028
Nov. 04, 2004	137	± 0.022	± 0.060	± 0.062
Nov. 05, 2004	150	± 0.004	± 0.011	± 0.006

	ΔU	ΔB	ΔV
Max. light at $\phi = 0.25$	−1.624±0.013	−1.562±0.009	−1.498±0.015
Max. light at $\phi = 0.75$	−1.565±0.013	−1.497±0.014	−1.462±0.013
Δ max ($m_{0.75} - m_{0.25}$)	0.059	0.065	0.036
Depth of Min I	0.300	0.306	0.299
Depth of Min II	0.243	0.249	0.248

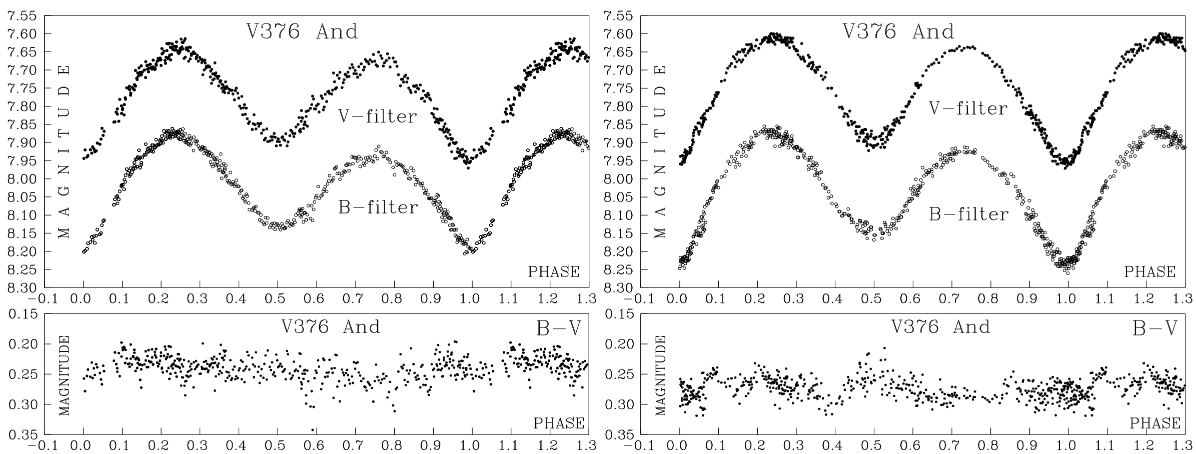

Fig. 1. *BV* light curves and *B-V* colour curves of V376 And (left - Ankara observations obtained 2004, and right - Rozhen-Bucharest observations collected 2003).

A non-linear limb-darkening law has been used in this study to avoid the possible negative influence of the wrong evaluation of limb-darkening coefficients on other parameters in the inverse problem. The tables of Claret (2000) were used in the light-curve analysis together with the new approximation described in the paper by Djurašević et al. (2004b).

The present light-curve analyses were carried out by the simultaneous solution of the Ankara (2004) *UBV* light curves and Rozhen-Bucharest (2003) *BV* light curves. In these analysis, the mass ratio of the components was fixed at the value $q_{\rm sp} = m_{\rm c}/m_{\rm h} = 0.305 \pm 0.005$, estimated by Rucinski et al. (2001) from the radial velocity curve solution. Based on the range of spectral type estimates between of A0 (given in SIMBAD) and of A4 V (Rucinski et al. 2001) used in this paper, the temperature of the hotter and more massive component, $T_{\rm h}$, following Lang (1992) was adopted as 8460 K.

Following Lucy (1967), Rucinski (1969) and Rafert & Twigg (1980), the gravity-darkening exponent, $\beta_{\rm c}$, and the albedo, $A_{\rm c}$, of the components, were set at the values of 0.08 and 0.5, respectively, appropriate to the stars with convective envelopes.

An application of a quite dense coordinate grid, having $72 \times 144 = 10368$ elementary cells per star, was made for the reliable estimates of the model parameters in the light-curve analysis programme. The intensity and the angular distribution of radiation of elementary cells are determined by the stellar effective temperature, limb-darkening, gravity-darkening and by the reflection effect in the system.

The present light-curve analysis of V376 And was carried out by using the black-body approxima-

TABLE 3

OBSERVATIONAL DATA FOR V376 AND

HJD 2400000+	ΔU	ΔB	ΔV	HJD 2400000+	ΔU	ΔB	ΔV	HJD 2400000+	ΔU	ΔB	ΔV
53281.2367	−1.389	−1.353	−1.309	53281.5074	−1.467	−1.386	−1.358	53314.4732	−1.587	−1.517	−1.445
53281.2391	−1.393	−1.339	−1.276	53281.5093	−1.455	−1.387	−1.321	53314.4755	−1.592	−1.526	−1.456
53281.2411	−1.399	−1.335	−1.299	53281.5123	−1.444	−1.375	−1.318	53314.4775	−1.592	−1.517	−1.447
53281.2429	−1.396	−1.342	−1.309	53281.5142	−1.456	−1.369	−1.310	53314.4794	−1.600	−1.521	−1.444
53281.2451	−1.407	−1.321	−1.279	53281.5184	−1.465	−1.389	−1.298	53314.4814	−1.596	−1.533	−1.467
53281.2469	−1.389	−1.347	−1.297	53281.5205	−1.469	−1.496	−1.332	53314.4855	−1.607	−1.526	−1.444
53281.2492	−1.414	−1.327	−1.326	53281.5224	−1.449	−1.393	−1.295	53314.4877	−1.607	−1.530	−1.453
53281.2537	−1.419	−1.341	−1.312	53281.5243	−1.443	−1.377	−1.303	53314.4896	−1.621	−1.533	−1.464
53281.2556	−1.437	−1.366	−1.328	53281.5265	−1.451	−1.373	−1.306	53314.4916	−1.606	−1.535	−1.472
53281.2602	−1.439	−1.331	−1.334	53281.5284	−1.455	−1.358	−1.301	53314.4935	−1.609	−1.534	−1.467
53281.2627	−1.445	−1.366	−1.345	53281.5302	−1.459	−1.334	−1.275	53314.4955	−1.617	−1.545	−1.473
53281.2646	−1.455	−1.326	−1.368	53281.5322	−1.425	−1.323	−1.277	53314.4975	−1.587	−1.538	−1.453
53281.2668	−1.437	−1.356	−1.360	53281.5342	−1.403	−1.346	−1.269	53314.4995	−1.618	−1.545	−1.485
53281.2686	−1.412	−1.376	−1.333	53281.5364	−1.406	−1.333	−1.270	53314.5013	−1.631	−1.539	−1.486
53281.2709	−1.425	−1.388	−1.332	53281.5382	−1.389	−1.322	−1.257	53314.5057	−1.602	−1.562	−1.466
53281.2727	−1.481	−1.394	−1.342	53281.5401	−1.404	−1.342	−1.278	53314.5078	−1.606	−1.550	−1.475
53281.2759	−1.487	−1.419	−1.346	53281.5423	−1.423	−1.338	−1.251	53314.5097	−1.626	−1.567	−1.513
53281.2777	−1.469	−1.386	−1.324	53281.5445	−1.425	−1.331	−1.233	53314.5129	−1.634	−1.572	−1.512
53281.2823	−1.478	−1.394	−1.369	53281.5464	−1.396	−1.312	−1.237	53314.5147	−1.620	−1.556	−1.514
53281.2846	−1.482	−1.396	−1.362	53281.5483	−1.404	−1.299	−1.252	53314.5169	−1.624	−1.553	−1.502
53281.2864	−1.536	−1.406	−1.330	53281.5503	−1.374	−1.300	−1.215	53314.5188	−1.628	−1.566	−1.502
53281.2885	−1.508	−1.411	−1.338	53281.5534	−1.387	−1.312	−1.240	53314.5207	−1.640	−1.578	−1.512
53281.2904	−1.503	−1.418	−1.373	53281.5552	−1.342	−1.299	−1.238	53314.5225	−1.609	−1.562	−1.496
53281.2934	−1.495	−1.405	−1.353	53281.5573	−1.345	−1.285	−1.237	53314.5270	−1.628	−1.557	−1.505
53281.2955	−1.511	−1.426	−1.380	53281.5593	−1.326	−1.281	−1.240	53314.5292	−1.630	−1.568	−1.505
53281.2977	−1.536	−1.435	−1.382	53281.5613	−1.324	−1.265	−1.215	53314.5323	−1.611	−1.571	−1.488
53281.2995	−1.530	−1.449	−1.375	53281.5633	−1.319	−1.275	−1.212	53314.5342	−1.619	−1.568	−1.486
53281.3038	−1.537	−1.433	−1.374	53281.5652	−1.346	−1.278	−1.212	53314.5361	−1.597	−1.549	−1.489
53281.3058	−1.507	−1.437	−1.385	53281.5671	−1.298	−1.271	−1.210	53314.5381	−1.605	−1.549	−1.495
53281.3076	−1.515	−1.442	−1.432	53281.5721	−1.298	−1.263	−1.221	53314.5403	−1.601	−1.570	−1.504
53281.3097	−1.511	−1.468	−1.407	53281.5741	−1.314	−1.264	−1.204	53314.5427	−1.612	−1.560	−1.498
53281.3115	−1.506	−1.470	−1.388	53281.5760	−1.340	−1.268	−1.189	53314.5447	−1.606	−1.545	−1.472
53281.3135	−1.503	−1.473	−1.391	53281.5781	−1.342	−1.262	−1.216	53314.5473	−1.627	−1.541	−1.475
53281.3154	−1.523	−1.455	−1.425	53281.5802	−1.294	−1.261	−1.201	53314.5498	−1.614	−1.543	−1.496
53281.3190	−1.558	−1.455	−1.417	53281.5822	−1.307	−1.273	−1.195	53314.5522	−1.624	−1.549	−1.496
53281.3207	−1.583	−1.438	−1.434	53281.5840	−1.306	−1.253	−1.170	53314.5543	−1.594	−1.535	−1.464
53281.3249	−1.533	−1.449	−1.392	53314.2598	−1.448	−1.380	−1.334	53314.5575	−1.599	−1.533	−1.471
53281.3273	−1.566	−1.458	−1.405	53314.2621	−1.448	−1.380	−1.296	53314.5597	−1.607	−1.552	−1.485
53281.3292	−1.558	−1.461	−1.413	53314.2647	−1.443	−1.371	−1.305	53314.5650	−1.600	−1.555	−1.485
53281.3313	−1.575	−1.459	−1.428	53314.2669	−1.426	−1.360	−1.303	53314.5674	−1.600	−1.544	−1.486
53281.3332	−1.564	−1.478	−1.426	53314.2694	−1.418	−1.351	−1.294	53314.5696	−1.590	−1.543	−1.471
53281.3352	−1.559	−1.478	−1.421	53314.2714	−1.434	−1.363	−1.277	53314.5719	−1.588	−1.544	−1.480
53281.3370	−1.536	−1.482	−1.434	53314.2765	−1.409	−1.348	−1.302	53314.5742	−1.581	−1.530	−1.464
53281.3393	−1.573	−1.463	−1.422	53314.2797	−1.378	−1.342	−1.284	53314.5768	−1.593	−1.525	−1.474
53281.3411	−1.519	−1.479	−1.445	53314.2821	−1.419	−1.355	−1.292	53314.5791	−1.591	−1.520	−1.469
53281.3455	−1.559	−1.501	−1.455	53314.2851	−1.406	−1.345	−1.276	53314.5818	−1.589	−1.528	−1.469
53281.3475	−1.605	−1.482	−1.447	53314.2878	−1.410	−1.348	−1.269	53314.5840	−1.562	−1.524	−1.465
53281.3493	−1.553	−1.500	−1.430	53314.2902	−1.384	−1.334	−1.274	53314.5874	−1.587	−1.526	−1.467
53281.3520	−1.575	−1.498	−1.439	53314.2923	−1.375	−1.332	−1.262	53314.5900	−1.581	−1.517	−1.445
53281.3543	−1.570	−1.498	−1.429	53314.2951	−1.366	−1.331	−1.248	53314.5925	−1.590	−1.515	−1.448
53281.3571	−1.593	−1.489	−1.420	53314.2971	−1.368	−1.315	−1.250	53314.5951	−1.574	−1.507	−1.451
53281.3594	−1.536	−1.502	−1.449	53314.3020	−1.364	−1.300	−1.196	53314.5975	−1.571	−1.511	−1.449
53281.3623	−1.538	−1.474	−1.427	53314.3054	−1.351	−1.300	−1.197	53314.5994	−1.570	−1.503	−1.437
53281.3644	−1.534	−1.495	−1.457	53314.3083	−1.319	−1.272	−1.223	53314.6017	−1.593	−1.510	−1.442
53281.3689	−1.554	−1.483	−1.440	53314.3112	−1.320	−1.273	−1.203	53314.6037	−1.570	−1.504	−1.429
53281.3711	−1.566	−1.478	−1.448	53314.3133	−1.327	−1.284	−1.219	53314.6067	−1.558	−1.494	−1.415
53281.3731	−1.571	−1.497	−1.469	53314.3158	−1.323	−1.276	−1.204	53314.6087	−1.571	−1.494	−1.426
53281.3755	−1.576	−1.487	−1.464	53314.3179	−1.351	−1.272	−1.200	53314.6132	−1.555	−1.487	−1.422
53281.3780	−1.558	−1.499	−1.462	53314.3203	−1.348	−1.260	−1.207	53314.6163	−1.566	−1.472	−1.423
53281.3802	−1.562	−1.491	−1.457	53314.3227	−1.324	−1.234	−1.186	53314.6183	−1.543	−1.490	−1.407
53281.3826	−1.547	−1.500	−1.468	53314.3254	−1.341	−1.239	−1.182	53314.6204	−1.537	−1.508	−1.410
53281.2866	−1.565	−1.490	−1.463	53314.3274	−1.318	−1.237	−1.188	53314.6223	−1.537	−1.441	−1.390
53281.3894	−1.559	−1.487	−1.483	53314.3322	−1.332	−1.249	−1.184	53314.6246	−1.513	−1.458	−1.380
53281.3923	−1.554	−1.503	−1.464	53314.3345	−1.326	−1.247	−1.188	53314.6263	−1.556	−1.482	−1.393
53281.3950	−1.598	−1.520	−1.454	53314.3365	−1.342	−1.247	−1.198	53314.6285	−1.532	−1.469	−1.389
53281.3977	−1.563	−1.496	−1.450	53314.3392	−1.340	−1.239	−1.196	53314.6303	−1.564	−1.477	−1.389
53281.4003	−1.566	−1.529	−1.489	53314.3416	−1.319	−1.242	−1.220	53315.2066	−1.515	−1.372	−1.318
53281.4046	−1.549	−1.515	−1.479	53314.3455	−1.320	−1.247	−1.200	53315.2094	−1.509	−1.383	−1.299
53281.4069	−1.582	−1.513	−1.472	53314.3475	−1.329	−1.262	−1.204	53315.2153	−1.478	−1.422	−1.320
53281.4097	−1.604	−1.501	−1.451	53314.3525	−1.346	−1.266	−1.220	53315.2176	−1.500	−1.423	−1.334
53281.4119	−1.567	−1.503	−1.460	53314.3555	−1.346	−1.280	−1.211	53315.2203	−1.517	−1.411	−1.316
53281.4161	−1.568	−1.513	−1.466	53314.3573	−1.339	−1.272	−1.228	53315.2225	−1.512	−1.432	−1.363

TABLE 3 (CONTINUED)

HJD 2400000+	ΔU	ΔB	ΔV	HJD 2400000+	ΔU	ΔB	ΔV	HJD 2400000+	ΔU	ΔB	ΔV
53281.4185	−1.597	−1.496	−1.485	53314.3597	−1.344	−1.282	−1.222	53315.2317	−1.551	−1.448	−1.386
53281.4215	−1.585	−1.493	−1.473	53314.3616	−1.326	−1.263	−1.215	53315.2339	−1.550	−1.452	−1.377
53281.4237	−1.543	−1.485	−1.448	53314.3645	−1.339	−1.283	−1.217	53315.2367	−1.507	−1.458	−1.392
53281.4229	−1.536	−1.471	−1.473	53314.3666	−1.372	−1.300	−1.239	53315.2389	−1.533	−1.469	−1.389
53281.4329	−1.526	−1.451	−1.462	53314.3721	−1.355	−1.287	−1.235	53315.2415	−1.521	−1.475	−1.385
53281.4354	−1.553	−1.487	−1.462	53314.3743	−1.361	−1.290	−1.249	53315.2439	−1.528	−1.494	−1.439
53281.4379	−1.552	−1.478	−1.450	53314.3763	−1.378	−1.312	−1.279	53315.2463	−1.537	−1.494	−1.417
53281.4407	−1.553	−1.481	−1.427	53314.3787	−1.390	−1.324	−1.260	53315.2483	−1.527	−1.500	−1.432
53281.4452	−1.582	−1.479	−1.396	53314.3806	−1.392	−1.326	−1.271	53315.2510	−1.581	−1.519	−1.446
53281.4473	−1.551	−1.476	−1.414	53314.4008	−1.446	−1.368	−1.296	53315.2534	−1.550	−1.499	−1.433
53281.4494	−1.530	−1.474	−1.415	53314.4029	−1.434	−1.383	−1.297	53315.2557	−1.542	−1.484	−1.426
53281.4515	−1.535	−1.472	−1.407	53314.4055	−1.446	−1.390	−1.324	53315.2649	−1.583	−1.536	−1.463
53281.4534	−1.536	−1.462	−1.422	53314.4078	−1.456	−1.393	−1.333	53315.2685	−1.567	−1.522	−1.443
53281.4558	−1.525	−1.458	−1.426	53314.4128	−1.463	−1.405	−1.359	53315.2707	−1.551	−1.525	−1.435
53281.4580	−1.553	−1.463	−1.407	53314.4163	−1.470	−1.420	−1.341	53315.2778	−1.572	−1.533	−1.442
53281.4601	−1.554	−1.454	−1.417	53314.4185	−1.460	−1.424	−1.331	53315.2799	−1.582	−1.515	−1.449
53281.4621	−1.529	−1.441	−1.390	53314.4224	−1.457	−1.438	−1.345	53315.2837	−1.588	−1.528	−1.441
53281.4649	−1.538	−1.440	−1.384	53314.4247	−1.501	−1.450	−1.360	53315.2860	−1.604	−1.548	−1.456
53281.4668	−1.539	−1.470	−1.378	53314.4271	−1.505	−1.467	−1.391	53315.2958	−1.584	−1.548	−1.468
53281.4718	−1.533	−1.463	−1.396	53314.4300	−1.524	−1.457	−1.390	53315.2981	−1.602	−1.558	−1.499
53281.4740	−1.532	−1.446	−1.394	53314.4325	−1.525	−1.462	−1.395	53315.3023	−1.582	−1.572	−1.492
53281.4762	−1.504	−1.424	−1.380	53314.4352	−1.499	−1.469	−1.371	53315.3056	−1.613	−1.549	−1.459
53281.4780	−1.513	−1.438	−1.397	53314.4407	−1.542	−1.467	−1.388	53315.3082	−1.636	−1.571	−1.494
53281.4802	−1.517	−1.437	−1.390	53314.4429	−1.545	−1.485	−1.399	53315.3103	−1.604	−1.554	−1.471
53281.4824	−1.496	−1.430	−1.388	53314.4453	−1.546	−1.470	−1.396	53315.3122	−1.627	−1.572	−1.475
53281.4856	−1.472	−1.427	−1.398	53314.4485	−1.547	−1.474	−1.414	53315.3139	−1.624	−1.559	−1.481
53281.4878	−1.480	−1.423	−1.361	53314.4508	−1.563	−1.499	−1.423	53315.3159	−1.612	−1.563	−1.468
53281.4903	−1.475	−1.428	−1.362	53314.4529	−1.540	−1.495	−1.430	53315.3177	−1.642	−1.563	−1.483
53281.4922	−1.516	−1.414	−1.382	53314.4548	−1.565	−1.471	−1.430	53315.3204	−1.634	−1.556	−1.497
53281.4947	−1.495	−1.401	−1.353	53314.4569	−1.560	−1.479	−1.452	53315.3223	−1.636	−1.572	−1.505
53281.4966	−1.512	−1.403	−1.371	53314.4588	−1.562	−1.499	−1.434	53315.3244	−1.633	−1.567	−1.495
53281.4986	−1.493	−1.408	−1.366	53314.4635	−1.572	−1.506	−1.440	53315.3263	−1.639	−1.560	−1.496
53281.5012	−1.463	−1.397	−1.376	53314.4659	−1.566	−1.507	−1.419	53315.3283	−1.631	−1.563	−1.518
53281.5033	−1.457	−1.386	−1.371	53314.4684	−1.572	−1.514	−1.452	53315.3302	−1.619	−1.568	−1.493
53281.5050	−1.467	−1.386	−1.362	53314.4712	−1.572	−1.515	−1.453	53315.3322	−1.638	−1.552	−1.490
53315.3339	−1.637	−1.565	−1.493	53315.4309	−1.551	−1.449	−1.395	53315.5108	−1.413	−1.333	−1.252
53315.3358	−1.637	−1.575	−1.500	53315.4327	−1.510	−1.434	−1.391	53315.5134	−1.409	−1.318	−1.277
53315.3375	−1.627	−1.556	−1.525	53315.4349	−1.499	−1.430	−1.377	53315.5153	−1.395	−1.332	−1.243
53315.3395	−1.627	−1.561	−1.516	53315.4366	−1.497	−1.434	−1.387	53315.5194	−1.362	−1.306	−1.244
53315.3413	−1.633	−1.578	−1.515	53315.4386	−1.526	−1.458	−1.385	53315.5220	−1.359	−1.313	−1.256
53315.3442	−1.633	−1.552	−1.521	53315.4404	−1.494	−1.424	−1.384	53315.5243	−1.376	−1.317	−1.247
53315.3460	−1.627	−1.564	−1.526	53315.4422	−1.477	−1.427	−1.384	53315.5263	−1.384	−1.305	−1.256
53315.3480	−1.622	−1.539	−1.501	53315.4439	−1.497	−1.431	−1.374	53315.5286	−1.400	−1.318	−1.265
53315.3502	−1.607	−1.548	−1.502	53315.4471	−1.505	−1.420	−1.358	53315.5307	−1.389	−1.301	−1.254
53315.3525	−1.597	−1.537	−1.492	53315.4489	−1.466	−1.425	−1.383	53315.5328	−1.368	−1.313	−1.231
53315.3545	−1.605	−1.559	−1.503	53315.4508	−1.497	−1.436	−1.390	53315.5349	−1.374	−1.316	−1.243
53315.3568	−1.623	−1.549	−1.502	53315.4538	−1.459	−1.420	−1.376	53315.5369	−1.373	−1.312	−1.251
53315.3586	−1.602	−1.538	−1.480	53315.4559	−1.473	−1.419	−1.363	53315.5393	−1.367	−1.306	−1.243
53315.3629	−1.590	−1.518	−1.490	53315.4576	−1.464	−1.400	−1.340	53315.5414	−1.362	−1.300	−1.233
53315.3688	−1.615	−1.536	−1.475	53315.4603	−1.461	−1.407	−1.334	53315.5444	−1.388	−1.316	−1.254
53315.3798	−1.609	−1.522	−1.460	53315.4620	−1.456	−1.409	−1.367	53315.5462	−1.385	−1.310	−1.256
53315.3820	−1.612	−1.528	−1.427	53315.4639	−1.447	−1.387	−1.317	53315.5485	−1.398	−1.303	−1.248
53315.3847	−1.570	−1.510	−1.440	53315.4657	−1.466	−1.392	−1.336	53315.5505	−1.371	−1.304	−1.246
53315.3870	−1.583	−1.518	−1.459	53315.4676	−1.456	−1.381	−1.345	53315.5524	−1.363	−1.306	−1.265
53315.3896	−1.567	−1.509	−1.450	53315.4694	−1.445	−1.377	−1.318	53315.5550	−1.382	−1.319	−1.231
53315.3927	−1.562	−1.505	−1.451	53315.4714	−1.439	−1.397	−1.335	53315.5569	−1.384	−1.324	−1.242
53315.3958	−1.566	−1.513	−1.448	53315.4732	−1.449	−1.393	−1.306	53315.5607	−1.403	−1.310	−1.259
53315.3977	−1.572	−1.486	−1.421	53315.4759	−1.452	−1.373	−1.292	53315.5628	−1.408	−1.316	−1.274
53315.4000	−1.537	−1.479	−1.403	53315.4777	−1.431	−1.355	−1.297	53315.5647	−1.374	−1.315	−1.271
53315.4026	−1.567	−1.474	−1.413	53315.4835	−1.403	−1.353	−1.276	53315.5669	−1.402	−1.313	−1.265
53315.4051	−1.549	−1.497	−1.429	53315.4855	−1.400	−1.358	−1.292	53315.5690	−1.369	−1.327	−1.257
53315.4069	−1.578	−1.482	−1.459	53315.4872	−1.430	−1.361	−1.316	53315.5709	−1.381	−1.320	−1.265
53315.4089	−1.565	−1.478	−1.432	53315.4891	−1.426	−1.352	−1.289	53315.5733	−1.409	−1.340	−1.283
53315.4107	−1.548	−1.498	−1.422	53315.4910	−1.429	−1.363	−1.277	53315.5775	−1.429	−1.345	−1.290
53315.4126	−1.516	−1.478	−1.417	53315.4950	−1.404	−1.346	−1.293	53315.5805	−1.412	−1.356	−1.272
53315.4146	−1.519	−1.464	−1.396	53315.4971	−1.412	−1.347	−1.285	53315.5827	−1.411	−1.353	−1.269
53315.4175	−1.528	−1.465	−1.410	53315.4989	−1.428	−1.327	−1.292	53315.5845	−1.421	−1.354	−1.328
53315.4213	−1.532	−1.478	−1.401	53315.5011	−1.408	−1.340	−1.293	53315.5867	−1.417	−1.358	−1.307
53315.4233	−1.523	−1.460	−1.398	53315.5028	−1.397	−1.324	−1.266	53315.5887	−1.410	−1.346	−1.290
53315.4251	−1.548	−1.457	−1.383	53315.5065	−1.393	−1.318	−1.275	53315.5916	−1.417	−1.346	−1.290
53315.4270	−1.549	−1.465	−1.378	53315.5084	−1.391	−1.314	−1.247	53315.5943	−1.420	−1.327	−1.285
53315.4289	−1.541	−1.446	−1.407								

tion for the stellar atmosphere. To explain the light curve asymmetry we included a cool spot on the less-massive component. In our code this active region is approximated by a circular spot characterised by the temperature contrast between the spot and the surrounding photosphere ($A_{\rm cs} = T_{\rm cs}/T_{\rm c}$), by the angular dimension (radius) of the spot ($\theta_{\rm cs}$) and by the longitude ($\lambda_{\rm cs}$) and latitude ($\varphi_{\rm cs}$) of the spot centre.

Optimum model parameters are obtained through the minimization of $\Sigma(O-C)^2$, where $O-C$ is the residual between the observed (LCO) and synthetic (LCC) light curves for a given orbital phase. The minimization of $\Sigma(O-C)^2$ is done in an iterative cycle of corrections of the model parameters by using the modified Marquardt (1963) algorithm. In this way, the inverse-problem method provides estimates of the system and spot parameters and their standard errors arising from the nonlinear least-squares method, on which the inverse-problem method is based.

The optimum fit of each passband observed light curves (LCO) to the synthetic ones (LCC) are shown in Figure 2. The final $O-C$ residuals between the observed (LCO) and optimum synthetic (LCC) light curves are also given. Finally, the bottom panel in these figures shows the view of the Roche model of the system, obtained with the optimum parameters, estimated by simultaneous analysis of the seasonal Ankara UBV (2004-left) and Rozhen-Bucharest BV (2003-right) light curves. Using such plots, one can see how the model would appear at a certain orbital phase, chosen so that the spot region on the corresponding component is visible.

4. RESULTS AND DISCUSSION

The inverse problem of the optimisation of system parameters together with cool spot located on the secondary component provides good fit for both sets of seasonal light curves. At the same time the obtained solutions show satisfactory mutual consistency in the fitting of the individual seasonal passband light curves. These solutions are given in Table 4, and the results are presented graphically in Figure 2.

Some important absolute parameters of the system, given in Table 4, are derived by combining our photometric solutions with the spectroscopic elements given by Rucinski et al. (2001).

Our estimate of the accuracy in the determination of these parameters is based on the influence of formal errors arising from the nonlinear least-squares method on which the inverse-problem method of the light-curve analysis is based. Keeping in mind the errors of the input parameters of the model, which are treated as fixed in the inverse - problem method, the real errors will be approximately 2–3 times larger. The main contribution comes from the error in effective temperature of the primary fixed on the basis of its spectral type, which means with a relatively high uncertainty. Thus, the estimated error of the temperature of the secondary component is significantly larger than the tabular value obtained under the assumption that the temperature of the primary is accurate. The errors in the estimates of the stellar radii are included (through the filling factors), while the errors in the masses are not formally used (the mass ratio is treated as fixed), but they certainly contribute to the real accuracy of the system parameter estimation. Because of these considerations, the real errors will be larger than the values given in Table 4.

In the analysis of these light curves, the inclination of the orbit was estimated to be $i \sim 61^\circ.6 - 62^\circ.0$, which suggests partial eclipses in both of the light curve minima. During the deeper (primary) minimum, the cooler - less massive and smaller component partially eclipses the hotter - more massive and larger one. The filling coefficient for the critical Roche lobe $F_{\rm h}$ indicates a distinct overcontact configuration with a variable high degree of overcontact ($f_{\rm over} \sim 36\%$ - 2004 and $f_{\rm over} \sim 55\%$ - 2003).

One can see that the main differences between the solutions for Ankara UBV (2004) and Rozhen-Bucharest BV (2003) are in the degree of overcontact and in the spot position and size on the smaller and cooler component. Also, there are smaller differences in the estimates of the temperature for the secondary, and of the orbital inclination. The variation in the orbital inclination could be within the interval of probable errors.

If the observed variability of the light curves can be attributed to the system activity with certainty, then this implies that the degree of overcontact has decreased in the interval 2003 (Rozhen-Bucharest)-2004 (Ankara). At the same time the spot size has decreased, and its temperature contrast to the surrounding photosphere has increased. The temperature of the secondary has increased also ($\Delta T \sim 40$ K). There are some changes in the location of the spot centre at the secondary which suggest that the spot is moving toward lower longitudes and latitudes. However, the estimates of the spot latitudes are less reliable in general. But, here we have to point out that we are not quite convinced that these changes are real. Our scepticism is founded on the above mentioned problematic choice of the com-

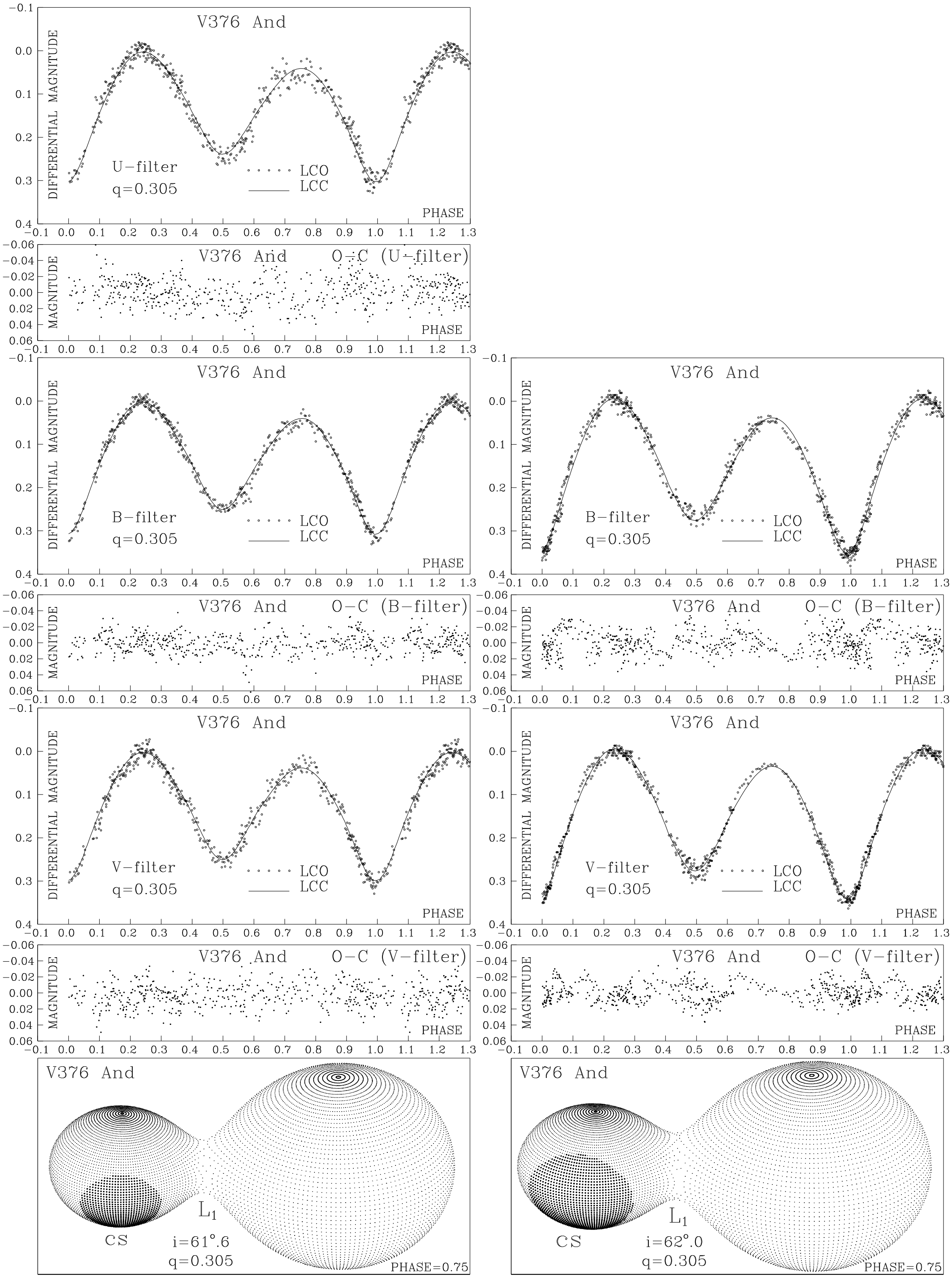

Fig. 2. Observed (LCO) and final synthetic (LCC) light curves of the V376 And with final $O - C$ residuals obtained by analysing photometric observations and the view of the system at orbital phase 0.75, obtained with parameters estimated by analysing the Ankara UBV (left) and the Rozhen-Bucharest BV (right) observations.

TABLE 4

RESULTS OF THE SIMULTANEOUS ANALYSIS OF ANKARA (2004) UBV (LEFT) AND BUCHAREST-ROZHEN (2003) BV (RIGHT) OBSERVATIONS OF THE V376 AND

Quantity	UBV (2004)		BV (2003)
n	1290		997
$\Sigma(\mathrm{O-C})^2$	0.3097		0.1745
σ	0.0155		0.0132
$q = m_{\rm c}/m_{\rm h}$	0.305		0.305
$T_{\rm h}$	8460		8460
$A_{\rm h,c}$	0.5		0.5
$\beta_{\rm h,c}$	0.08		0.08
$f_{\rm h} = f_{\rm c}$	1.0		1.0
$A_{\rm cs}$=$T_{\rm cs}/T_{\rm c}$	0.77 $\pm$ 0.03		0.86 $\pm$ 0.03
$\theta_{\rm cs}$	38.4 $\pm$ 0.8		48.8 $\pm$ 0.8
$\lambda_{\rm cs}$	271.0 $\pm$ 4.3		285.0 $\pm$ 3.7
$\varphi_{\rm cs}$	-18.3 $\pm$ 3.4		-11.2 $\pm$ 3.6
$T_{\rm c}$	7620 $\pm$ 31		7583 $\pm$ 37
$F_{\rm h}$	1.031 $\pm$ 0.002		1.049 $\pm$ 0.002
i [°]	61.6 $\pm$ 0.3		62.0 $\pm$ 0.4
$\Omega_{\rm h,c}$	2.4096		2.3723
$\Omega_{\rm in}$	2.4773		2.4773
$\Omega_{\rm out}$	2.2873		2.2873
$f_{\rm over}[\%]$	35.6		55.2
$R_{\rm h}[D=1]$	0.469		0.477
$R_{\rm c}[D=1]$	0.278		0.287
$L_{\rm h}/(L_{\rm h}+\mathrm{L_c})$	0.833(U); 0.827(B); 0.822(V)		0.817(B); 0.811(V)
$\mathcal{M}_{\rm h}[\mathcal{M}_\odot]$		2.50 $\pm$ 0.04	
$\mathcal{M}_{\rm c}[\mathcal{M}_\odot]$		0.76 $\pm$ 0.03	
$\mathcal{R}_{\rm h}[\mathcal{R}_\odot]$		2.75 $\pm$ 0.03	
$\mathcal{R}_{\rm c}[\mathcal{R}_\odot]$		1.68 $\pm$ 0.03	
log $g_{\rm h}$		3.96 $\pm$ 0.03	
log $g_{\rm c}$		3.88 $\pm$ 0.03	
$M_{\rm bol}^{\rm h}$		0.94 $\pm$ 0.03	
$M_{\rm bol}^{\rm c}$		2.49 $\pm$ 0.05	
$a_{\rm orb}[R_\odot]$		5.37 $\pm$ 0.02	

Notes: Black-body approximation of stellar atmosphere.

n - total number of Ankara (2004) UBV (left) and Rozhen-Bucharest (2003) BV (right) observations, $\Sigma(O-C)^2$ - final sum of squares of residuals between observed (LCO) and synthetic (LCC) light-curves, σ - standard deviation of the observations, $q = m_{\rm c}/m_{\rm h}$ - mass ratio of the components, $T_{\rm h,c}$ - temperature of the hotter primary and of the cooler secondary, $\beta_{\rm h,c}$, $A_{\rm h,c}$, $f_{\rm h,c}$ - gravity-darkening exponents, albedos and nonsynchronous rotation coefficients of the components respectively, $A_{\rm cs}$, $\theta_{\rm cs}$, $\lambda_{\rm cs}$ and $\varphi_{\rm cs}$ - cool spot temperature coefficient, angular dimension, longitude and latitude (in arc degrees), $F_{\rm h}$ - filling factor for the critical Roche lobe of the hotter primary, i [°] - orbit inclination (in arc degrees), $\Omega_{\rm h,c}$, $\Omega_{\rm in}$, $\Omega_{\rm out}$ - dimensionless surface potentials of the components and of the inner and outer contact surfaces respectively, $f_{\rm over}[\%]$ - degree of overcontact, $R_{\rm h,c}$ - polar radii of the components in units of the distance between the component centres, $L_{\rm h}/(L_{\rm h}+L_{\rm c})$ - luminosity (U;B;V) of the more massive hotter star (including cool spot on the secondary), $\mathcal{M}_{\rm h,c}$ $[\mathcal{M}_\odot]$, $\mathcal{R}_{\rm h,c}$ $[\mathcal{R}_\odot]$, - stellar masses and mean radii of stars in solar units, log $g_{\rm h,c}$ - logarithm (base 10) of the system components effective gravity, $M_{\rm bol}^{\rm h,c}$ - absolute bolometric magnitudes of V376 And components and $a_{\rm orb}$ $[R_\odot]$ - orbital major semiaxis in units of solar radius.

parison star for Rozhen-Bucharest BV observations (Dumitrescu et al. 2004). Such a choice of comparison star might affect the reliability of the differential photometry of V376 And and also of the obtained solutions.

5. CONCLUSIONS

The results describe the active V376 And system as a high overcontact configuration with relatively large temperature differences between the components ($\Delta T = T_{\rm h} - T_{\rm c} \sim 880 - 840$ K). Therefore, the light curve analysis shows that V376 And is an A-type W UMa contact binary system with the more massive, hotter star eclipsed at Min I.

It was seen from the magnitude differences of the maxima of the light curves that V376 And has an O'Connell effect present at both sets of the analysed seasonal light curves, being slightly more conspicuous in the Rozhen-Bucharest BV photometric observations. In the latter the amplitude of the light curve variability is also larger. To explain this light curve asymmetry we include an active spot region on the less massive cooler component of V376 And.

A summary of the results, given in Table 4, proves that a Roche model with a cool spot on the less massive component can successfully simulate the observed seasonal light curves. The change of the spot radius, temperature contrast and location together with the change of the degree of overcontact and a somewhat smaller change in the temperature of the secondary can explain the changed shape and amplitude of the seasonal light curves acquired in the last months of 2003 (Rozhen-Bucharest) and 2004 (Ankara).

Synthetic light curves, obtained by solving the inverse problem, fit the observations very well, and we have quite a good agreement between the solutions obtained for different seasons. This suggests the suitability of Roche model with the spot on the cooler secondary in simulating the real observations.

Further photometric monitoring of V376 And system is necessary in order to exclude any suspicion about the system activity. This might also solve the dilemma about the quality of the Rozhen-Bucharest photometric observations (Dumitrescu et al. 2004).

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