RAA 2015 Vol. **15** No. **4**, 501–516 doi: 10.1088/1674–4527/15/4/004
http://www.raa-journal.org *http://www.iop.org/journals/raa*

***R**esearch in*
***A**stronomy and*
***A**strophysics*

Modern comprehensive study of the W UMa system TY Boo

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Received 2014 February 12; accepted 2014 June 21

Abstract New three color light curves of TY Boo were acquired during five nights from February to May 2006 in the BVR bandpass using a 50-cm F/8.4 Ritchey-Chrétien telescope (Ba50) at the Baja Astronomical Observatory (Hungary), with a 512×512 Apogee AP-7 CCD camera. A photometric solution of these light curves was obtained by means of the Wilson-Devinney code. The results showed that the less massive component is hotter than the more massive one, and the temperature difference between the components is $\Delta T \sim 249$ K. Long term investigation of the system based on all available data shows two stages of increase and a similar trend for decrease, which appears to be periodic behavior. A set of new light elements yields a new period ($P = 0.3171506^{\rm d}$) and shows a periodic decrease with the rate $dP/dE = 5.858 \times 10^{-12}$ d cycle^{-1}, 6.742×10^{-9} d yr^{-1} or 0.058 s century^{-1}. The evolutionary status of the system is discussed.

Key words: binaries: eclipsing — stars: evolution

1 INTRODUCTION

The eclipsing binary system TY Boo was discovered to be a variable star and classified as a W UMa type by Guthnick & Prager (1926), with a period of $0.31730^{\rm d}$. A cyclic period variation of about 400 orbital revolutions (127 days) was found by Szafraniec (1953). Carr (1972) suggested that the system was an A-type system consisting of two main sequence components (G3 and G7). The published data by Carr (1972) were re-analyzed by Niarchos (1978) using frequency domain techniques. The results suggested that the system is a W UMa system with a mass ratio of 0.22. A new BV light curve was published by Samec & Bookmyer (1987); they concluded that the system has become redder since Carr's observations were acquired, but the amplitude of the eclipse curves did not show any apparent changes. Their study of the period shows no indication of the cyclic period variation, which was suggested by Szafraniec (1953).

The first spectroscopic observations of the system TY Boo were carried out by Rainger et al. (1990). They used their spectroscopic observations together with B light curves published by Samec & Bookmyer (1987) to yield a combined orbital solution, which gave the masses and absolute dimensions for the components. Their results show that the system is a normal W UMa type contact binary, with a main sequence primary star and a secondary component larger than expected by ~ 1.4 considering its zero age main sequence (ZAMS) mass. They confirmed the orbital period change of the system, and calculated the first radial velocities for the system.

Photometric and spectroscopic observations were carried out for the system TY Boo by Milone et al. (1991) in three observing sessions. They calculated the mass ratio of the system ($q = M_{\rm h}/M_{\rm c} = 0.465$), which is consistent with the value derived using light curve analysis ($q = 0.481$). Christopoulou et al. (2012) observed the system in a four color bandpass and derived a long term light curve solution.

In this work we present a new CCD light curve in the BVR band for the system TY Boo which was analyzed using an advanced version of the Wilson-Devinney (W-D) code. Long term stability for both the period and observed light curve is investigated by considering a possible connection between.

The structure of the paper is as follows: Section 2 describes the observations. Section 3 deals with the orbital period analysis. Light curve stability is outlined in Section 4. In Section 5, we perform the light curve modeling. Section 6 presents the evolutionary status of the system. Finally, the discussion is outlined in Section 7.

2 OBSERVATIONS

The present CCD observations of TY Boo were acquired on five nights from February to May 2006 in the BVR bandpass using a 50-cm F/8.4 Ritchey-Chrétien telescope (Ba50) at the Baja Astronomical Observatory (Hungary), and a 512×512 Apogee AP-7 CCD camera. The observed frames were processed by the photometry software AIP4WIN (Berry & Burnell 2000) which applied aperture photometry, including bias and dark subtraction and flat field correction. Star GSC 02568–00997 ($V = 11.59$ mag, $B - V = 0.37$) was used as a comparison star, while GSC 02568–00991 ($V = 11.67$ mag) was used as a check. The original data are listed in Table 1. A total of 962 individual observations were obtained in the BVR bandpass (240 in B, 293 in V and 429 in R). The BVR light curves displayed in Figure 1 show the difference in magnitude (DM, the variable minus the comparison star) versus the phase in the BVR bands. The orbital phases were computed according to the following ephemeris by Kreiner et al. (2001)

$$\rm Min\,I = 2447612.6035 + 0.3171490\,. \qquad (1)$$

Figure 1 indicates that the light curve variation of the system TY Boo is typical of W UMa type and the data collected on all days can be joined smoothly. New values for 19 times of minima were derived (12 primary and 7 secondary), which were estimated by means of the Minima V2.3 package

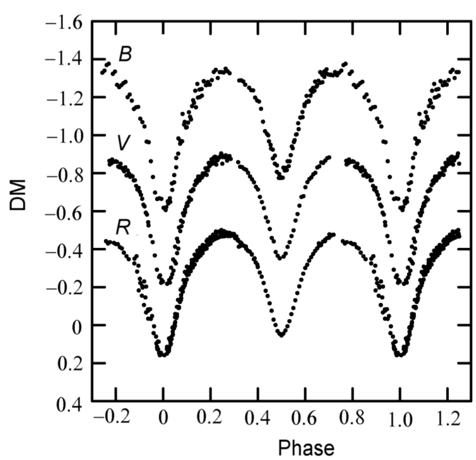

Fig. 1 BVR light curves of TY Boo.

(Nelson 2006) based on the Kwee & Van Woerden (1956) fitting method. The new times of light minima appear in Table 2 and values are given in Table 3 for visual (vis), photometric (pe) and CCD (ccd) observations.

Table 1 The Magnitude Differences in the BVR Bands of TY Boo Together with the Heliocentric Julian Dates and Phases

	B-band				V-band				R-band		
JD	Phase	ΔB	Error	JD	Phase	ΔV	Error	JD	Phase	ΔR	Error
2453796.4316	0.0132	–0.621	0.025	2453794.4926	0.7794	–0.863	0.035	2453794.5147	0.9810	0.087	0.004
2453796.4342	0.0215	–0.640	0.026	2453794.4942	0.7845	–0.872	0.036	2453794.5163	0.9741	0.114	0.005
2453796.4369	0.0299	–0.649	0.027	2453794.4974	0.7946	–0.860	0.035	2453794.5179	0.9791	0.128	0.005
2453796.4395	0.0383	–0.712	0.029	2453794.4990	0.7997	–0.863	0.035	2453794.5200	0.9857	0.158	0.007
2453796.4422	0.0466	–0.790	0.032	2453794.5006	0.8048	–0.860	0.035	2453794.5216	0.9907	0.146	0.006
2453796.4448	0.0549	–0.831	0.034	2453794.5023	0.8099	–0.835	0.034	2453794.5261	0.0051	0.158	0.007
2453796.4475	0.0633	–0.903	0.037	2453794.5039	0.8149	–0.831	0.034	2453794.5309	0.0203	0.140	0.006
2453796.4501	0.0717	–0.955	0.039	2453794.5055	0.8200	–0.850	0.035	2453794.5325	0.0253	0.120	0.005
2453796.4528	0.0800	–0.968	0.040	2453794.5071	0.8251	–0.828	0.034	2453794.5341	0.0304	0.088	0.004
2453796.4554	0.0883	–1.056	0.043	2453794.5087	0.8302	–0.821	0.034	2453794.5358	0.0355	0.073	0.003
2453796.4581	0.0968	–1.040	0.043	2453794.5103	0.8352	–0.810	0.033	2453794.5374	0.0406	0.052	0.002
2453796.4607	0.1051	–1.066	0.044	2453794.5119	0.8403	–0.831	0.034	2453794.5390	0.0456	0.017	0.001
2453796.4634	0.1134	–1.097	0.045	2453794.5135	0.8453	–0.788	0.032	2453794.5406	0.0507	–0.016	0.001
2453796.4660	0.1218	–1.153	0.047	2453794.5151	0.8504	–0.814	0.033	2453794.5422	0.0558	–0.038	0.002
2453796.4687	0.1302	–1.170	0.048	2453794.5167	0.8555	–0.798	0.033	2453794.5452	0.0654	–0.096	0.004
2453796.4713	0.1385	–1.147	0.047	2453794.5183	0.8606	–0.781	0.032	2453794.5469	0.0705	–0.122	0.005
2453796.4740	0.1469	–1.198	0.049	2453794.5199	0.8656	–0.787	0.032	2453794.5485	0.0756	–0.159	0.007
2453796.4766	0.1552	–1.201	0.049	2453794.5216	0.8707	–0.783	0.032	2453794.5501	0.0807	–0.186	0.008
2453796.4793	0.1635	–1.208	0.049	2453794.5232	0.8758	–0.762	0.031	2453794.5517	0.0857	–0.200	0.008
2453796.4819	0.1719	–1.283	0.052	2453794.5248	0.8808	–0.763	0.031	2453794.5533	0.0908	–0.221	0.009
2453796.4846	0.1803	–1.263	0.052	2453794.5264	0.8859	–0.733	0.03	2453794.5549	0.0958	–0.237	0.010
2453796.4872	0.1886	–1.266	0.052	2453794.5280	0.8910	–0.714	0.029	2453794.5774	0.1668	–0.399	0.016
2453796.4899	0.1970	–1.266	0.052	2453794.5296	0.8961	–0.723	0.03	2453794.5790	0.1719	–0.414	0.017
2453796.4925	0.2054	–1.290	0.053	2453794.5312	0.9012	–0.702	0.029	2453794.5822	0.1820	–0.419	0.017
2453796.4952	0.2137	–1.333	0.054	2453794.5328	0.9062	–0.686	0.028	2453794.5838	0.1871	–0.436	0.018
2453796.4978	0.2220	–1.344	0.055	2453794.5344	0.9113	–0.665	0.027	2453794.5855	0.1922	–0.436	0.018
2453796.5005	0.2304	–1.301	0.053	2453794.5360	0.9164	–0.634	0.026	2453794.5871	0.1973	–0.451	0.018
2453796.5031	0.2388	–1.332	0.054	2453794.5377	0.9215	–0.625	0.026	2453794.5887	0.2023	–0.453	0.019
2453796.5058	0.2472	–1.332	0.054	2453794.5393	0.9265	–0.592	0.024	2453794.5903	0.2074	–0.461	0.019
2453796.5084	0.2555	–1.330	0.054	2453794.5409	0.9315	–0.582	0.024	2453794.5919	0.2125	–0.47	0.019
2453796.5111	0.2639	–1.350	0.055	2453794.5425	0.9366	–0.542	0.022	2453794.5935	0.2176	–0.463	0.019
2453796.5137	0.2722	–1.336	0.055	2453794.5427	0.0625	–0.439	0.018	2453794.5951	0.2227	–0.477	0.020
2453796.5164	0.2806	–1.326	0.054	2453794.5458	0.0721	–0.495	0.02	2453794.6016	0.2430	–0.474	0.019
2453796.5293	0.3213	–1.288	0.053	2453794.5474	0.0772	–0.521	0.021	2453794.6031	0.2480	–0.48	0.020
2453796.5319	0.3297	–1.289	0.053	2453794.5490	0.0822	–0.543	0.022	2453794.6047	0.2530	–0.480	0.020
2453796.5346	0.3381	–1.283	0.052	2453794.5506	0.0873	–0.578	0.024	2453794.6063	0.2581	–0.480	0.020
2453796.5373	0.3464	–1.266	0.052	2453794.5522	0.0924	–0.594	0.024	2453794.6080	0.2632	–0.479	0.020
2453796.5425	0.3630	–1.250	0.051	2453794.5538	0.0974	–0.625	0.026	2453794.6096	0.2682	–0.473	0.019
2453796.5452	0.3714	–1.237	0.051	2453794.5554	0.1025	–0.629	0.026	2453794.6128	0.2784	–0.477	0.020
2453796.5478	0.3798	–1.236	0.051	2453794.5570	0.1076	–0.649	0.027	2453794.6144	0.2835	–0.469	0.019
2453796.5505	0.3881	–1.198	0.049	2453794.5586	0.1126	–0.666	0.027	2453794.6176	0.2937	–0.472	0.019
2453796.5531	0.3965	–1.183	0.048	2453794.5602	0.1177	–0.661	0.027	2453794.6209	0.3039	–0.458	0.019
2453796.5558	0.4048	–1.177	0.048	2453794.5605	0.9937	–0.238	0.01	2453794.6225	0.3089	–0.467	0.019
2453796.5584	0.4132	–1.139	0.047	2453794.5619	0.1228	–0.707	0.029	2453794.6241	0.3140	–0.448	0.018
2453796.5611	0.4215	–1.071	0.044	2453794.5622	0.9988	–0.229	0.009	2453796.4325	0.0160	0.150	0.006
2453796.5637	0.4299	–1.021	0.042	2453794.5635	0.1279	–0.713	0.029	2453796.4351	0.0243	0.133	0.005
2453796.5664	0.4382	–1.007	0.041	2453794.5651	0.1329	–0.738	0.03	2453796.4378	0.0327	0.098	0.004
2453796.5690	0.4466	–0.968	0.040	2453794.5667	0.1380	–0.759	0.031	2453796.4404	0.0410	0.049	0.002
2453796.5717	0.4549	–0.930	0.038	2453794.5683	0.1430	–0.765	0.031	2453796.4431	0.0494	0.005	0.000
2453796.5743	0.4632	–0.878	0.036	2453794.5699	0.1481	–0.783	0.032	2453796.4457	0.0577	–0.046	0.002
2453796.5770	0.4716	–0.850	0.035	2453794.5715	0.1532	–0.762	0.031	2453796.4484	0.0661	–0.090	0.004
2453796.5796	0.4800	–0.807	0.033	2453794.5715	0.0283	–0.224	0.009	2453796.4510	0.0744	–0.132	0.005
2453796.5823	0.4883	–0.775	0.032	2453794.5731	0.1582	–0.782	0.032	2453796.4537	0.0828	–0.176	0.007

Table 1 — *Continued*

JD	Phase	ΔB	Error	JD	Phase	ΔV	Error	JD	Phase	ΔR	Error
2453796.5849	0.4966	–0.775	0.032	2453794.5731	0.0334	–0.250	0.01	2453796.4563	0.0911	–0.209	0.009
2453796.5876	0.5050	–0.776	0.032	2453794.5747	0.1633	–0.777	0.032	2453796.4590	0.0995	–0.240	0.010
2453796.5902	0.5134	–0.814	0.033	2453794.5748	0.0384	–0.268	0.011	2453796.4616	0.1079	–0.267	0.011
2453796.5929	0.5217	–0.816	0.033	2453794.5763	0.1685	–0.788	0.032	2453796.4643	0.1162	–0.284	0.012
2453796.5955	0.5300	–0.837	0.034	2453794.5764	0.0435	–0.287	0.012	2453796.4669	0.1246	–0.303	0.012
2453796.5982	0.5384	–0.895	0.037	2453794.5780	0.1735	–0.794	0.032	2453796.4696	0.1330	–0.319	0.013
2453796.6008	0.5468	–0.931	0.038	2453794.5780	0.0486	–0.336	0.014	2453796.4722	0.1413	–0.342	0.014
2453796.6035	0.5551	–0.974	0.040	2453794.5796	0.1786	–0.826	0.034	2453796.4748	0.1496	–0.358	0.015
2453796.6061	0.5635	–1.005	0.041	2453794.5796	0.0537	–0.325	0.013	2453796.4775	0.1580	–0.367	0.015
2453796.6088	0.5719	–1.032	0.042	2453794.5812	0.1837	–0.791	0.032	2453796.4802	0.1663	–0.379	0.016
2453796.6114	0.5802	–1.092	0.045	2453794.5812	0.0588	–0.379	0.016	2453796.4828	0.1747	–0.399	0.016
2453796.6141	0.5885	–1.095	0.045	2453794.5828	0.1888	–0.815	0.033	2453796.5275	0.3158	–0.445	0.018
2453796.6167	0.5969	–1.163	0.048	2453794.5828	0.0638	–0.403	0.017	2453796.5302	0.3241	–0.437	0.018
2453796.6194	0.6053	–1.207	0.049	2453794.5844	0.1938	–0.835	0.034	2453796.5328	0.3324	–0.427	0.017
2453796.6220	0.6136	–1.180	0.048	2453794.5860	0.1989	–0.843	0.034	2453796.5355	0.3408	–0.417	0.017
2453796.6247	0.6220	–1.208	0.049	2453794.5876	0.2040	–0.873	0.036	2453796.5381	0.3492	–0.414	0.017
2453796.6273	0.6303	–1.227	0.050	2453794.5892	0.2090	–0.863	0.035	2453796.5408	0.3575	–0.392	0.016
2453796.6300	0.6387	–1.234	0.050	2453794.5908	0.2141	–0.883	0.036	2453796.5434	0.3658	–0.387	0.016
2453796.6326	0.6470	–1.256	0.051	2453794.5924	0.2192	–0.887	0.036	2453796.5461	0.3742	–0.372	0.015
2453796.6353	0.6554	–1.287	0.053	2453794.5940	0.2242	–0.845	0.035	2453796.5487	0.3826	–0.347	0.014
2453796.6379	0.6638	–1.276	0.052	2453794.6005	0.2445	–0.904	0.037	2453796.5514	0.3909	–0.330	0.014
2453796.6406	0.6721	–1.279	0.052	2453794.6069	0.2648	–0.894	0.037	2453796.5540	0.3992	–0.306	0.013
2453796.6432	0.6804	–1.307	0.053	2453794.6117	0.2801	–0.890	0.036	2453796.5567	0.4076	–0.277	0.011
2453796.6459	0.6888	–1.326	0.054	2453794.6133	0.2851	–0.875	0.036	2453796.5593	0.4160	–0.255	0.010
2453796.6485	0.6972	–1.320	0.054	2453796.4334	0.0168	–0.218	0.009	2453796.5620	0.4243	–0.222	0.009
2453796.6512	0.7055	–1.317	0.054	2453796.4360	0.0252	–0.237	0.01	2453796.5646	0.4327	–0.181	0.007
2453796.6597	0.7326	–1.327	0.054	2453796.4387	0.0335	–0.303	0.012	2453796.5673	0.4410	–0.154	0.006
2453911.3761	0.4437	–0.999	0.041	2453796.4413	0.0419	–0.346	0.014	2453796.5699	0.4494	–0.115	0.005
2453911.3793	0.4538	–0.949	0.039	2453796.4439	0.0502	–0.413	0.017	2453796.5726	0.4577	–0.076	0.003
2453911.3821	0.4627	–0.924	0.038	2453796.4466	0.0585	–0.455	0.019	2453796.5752	0.4660	–0.029	0.001
2453911.3849	0.4716	–0.892	0.036	2453796.4492	0.0669	–0.514	0.021	2453796.5778	0.4744	–0.001	0.000
2453911.3878	0.4805	–0.841	0.034	2453796.4519	0.0752	–0.550	0.023	2453796.5805	0.4828	0.031	0.001
2453911.3906	0.4894	–0.796	0.033	2453796.4545	0.0836	–0.589	0.024	2453796.5831	0.4911	0.045	0.002
2453911.3934	0.4984	–0.778	0.032	2453796.4572	0.0920	–0.608	0.025	2453796.5858	0.4994	0.054	0.002
2453911.3963	0.5073	–0.829	0.034	2453796.4598	0.1003	–0.641	0.026	2453796.5884	0.5077	0.044	0.002
2453911.3991	0.5162	–0.828	0.034	2453796.4625	0.1087	–0.673	0.028	2453796.5911	0.5161	0.028	0.001
2453911.4019	0.5252	–0.863	0.035	2453796.4652	0.1170	–0.705	0.029	2453796.5937	0.5245	0.006	0.000
2453911.4048	0.5341	–0.863	0.035	2453796.4678	0.1254	–0.715	0.029	2453796.5964	0.5328	–0.021	0.001
2453911.4076	0.5430	–0.941	0.038	2453796.4704	0.1337	–0.737	0.03	2453796.5990	0.5412	–0.058	0.002
2453911.4104	0.5519	–0.964	0.039	2453796.4731	0.1421	–0.749	0.031	2453796.6017	0.5496	–0.090	0.004
2453911.4133	0.5609	–1.003	0.041	2453796.4757	0.1504	–0.762	0.031	2453796.6043	0.5579	–0.131	0.005
2453911.4161	0.5698	–1.063	0.043	2453796.4784	0.1588	–0.783	0.032	2453796.6070	0.5663	–0.169	0.007
2453911.4189	0.5788	–1.093	0.045	2453796.4810	0.1671	–0.799	0.033	2453796.6097	0.5747	–0.204	0.008
2453911.4218	0.5878	–1.122	0.046	2453796.4837	0.1754	–0.800	0.033	2453796.6123	0.5830	–0.239	0.010
2453911.4246	0.5967	–1.153	0.047	2453796.4863	0.1838	–0.819	0.033	2453796.6149	0.5914	–0.271	0.011
2453911.4275	0.6057	–1.174	0.048	2453796.4890	0.1922	–0.854	0.035	2453796.6176	0.5997	–0.301	0.012
2453911.4303	0.6145	–1.177	0.048	2453796.4916	0.2005	–0.855	0.035	2453796.6203	0.6081	–0.318	0.013
2453911.4331	0.6235	–1.236	0.051	2453796.4943	0.2089	–0.850	0.035	2453796.6229	0.6165	–0.340	0.014
2453911.4360	0.6325	–1.249	0.051	2453796.4969	0.2173	–0.854	0.035	2453796.6255	0.6248	–0.358	0.015
2453911.4388	0.6414	–1.282	0.052	2453796.4996	0.2257	–0.868	0.035	2453796.6282	0.6331	–0.375	0.015
2453911.4416	0.6504	–1.264	0.052	2453796.5023	0.2340	–0.880	0.036	2453796.6309	0.6415	–0.391	0.016
2453911.4456	0.6629	–1.332	0.054	2453796.5049	0.2424	–0.890	0.036	2453796.6335	0.6499	–0.404	0.017
2453911.4484	0.6718	–1.318	0.054	2453796.5076	0.2507	–0.885	0.036	2453796.6362	0.6582	–0.418	0.017
2453911.4513	0.6807	–1.336	0.055	2453796.5102	0.2591	–0.885	0.036	2453796.6388	0.6666	–0.421	0.017
2453911.4541	0.6896	–1.347	0.055	2453796.5129	0.2675	–0.888	0.036	2453796.6415	0.6749	–0.440	0.018
2453911.4569	0.6985	–1.319	0.054	2453796.5155	0.2758	–0.882	0.036	2453796.6441	0.6832	–0.442	0.018
2453911.4598	0.7075	–1.319	0.054	2453796.5284	0.3165	–0.858	0.035	2453796.6467	0.6916	–0.458	0.019
2453911.4626	0.7164	–1.315	0.054	2453796.5311	0.3249	–0.834	0.034	2453796.6494	0.7000	–0.460	0.019
2453911.4654	0.7254	–1.332	0.054	2453796.5337	0.3332	–0.832	0.034	2453796.6521	0.7084	–0.471	0.019
2453911.4682	0.7343	–1.315	0.054	2453796.5364	0.3416	–0.823	0.034	2453835.3908	0.8453	–0.363	0.015

Table 1 — *Continued*

JD	Phase	ΔB	Error	JD	Phase	ΔV	Error	JD	Phase	ΔR	Error
2453911.4711	0.7432	–1.329	0.054	2453796.5390	0.3500	–0.818	0.0334	2453835.3938	0.8546	–0.347	0.014
2453911.4711	0.7432	–1.329	0.054	2453796.5417	0.3583	–0.802	0.033	2453835.3975	0.8782	–0.325	0.013
2453911.4739	0.7522	–1.340	0.055	2453796.5443	0.3667	–0.783	0.032	2453835.4012	0.8899	–0.282	0.012
2453911.4739	0.7522	–1.340	0.055	2453796.5470	0.3750	–0.768	0.031	2453835.4049	0.9015	–0.244	0.010
2453911.4768	0.7611	–1.369	0.056	2453796.5496	0.3833	–0.752	0.031	2453835.4086	0.9132	–0.198	0.008
2453911.4796	0.7700	–1.376	0.056	2453796.5523	0.3917	–0.728	0.03	2453835.4123	0.9248	–0.146	0.006
2453911.4851	0.7873	–1.323	0.054	2453796.5549	0.4000	–0.714	0.029	2453835.4159	0.9361	–0.083	0.003
2453911.4879	0.7963	–1.335	0.055	2453796.5575	0.4083	–0.675	0.028	2453835.4196	0.9479	–0.033	0.001
2453911.4908	0.8052	–1.265	0.052	2453796.5602	0.4168	–0.648	0.027	2453835.4233	0.9595	0.042	0.002
2453911.4936	0.8141	–1.253	0.051	2453796.5629	0.4251	–0.616	0.025	2453835.4270	0.9712	0.096	0.004
2453911.4964	0.8230	–1.263	0.052	2453796.5655	0.4334	–0.567	0.023	2453835.5332	0.3040	–0.464	0.019
2453911.4992	0.8319	–1.274	0.052	2453796.5682	0.4418	–0.545	0.022	2453835.5369	0.3157	–0.450	0.018
2453911.5021	0.8409	–1.281	0.052	2453796.5708	0.4501	–0.506	0.021	2453835.5406	0.3274	–0.435	0.018
2453911.5049	0.8498	–1.200	0.049	2453796.5734	0.4585	–0.459	0.019	2453835.5443	0.3390	–0.418	0.017
2453911.5077	0.8587	–1.214	0.050	2453796.5761	0.4668	–0.441	0.018	2453835.5480	0.3507	–0.402	0.016
2453911.5105	0.8676	–1.182	0.048	2453796.5787	0.4751	–0.385	0.016	2453835.5516	0.3623	–0.389	0.016
2453911.5133	0.8764	–1.138	0.047	2453796.5814	0.4835	–0.365	0.015	2453835.5554	0.3740	–0.374	0.015
2453911.5162	0.8854	–1.147	0.047	2453796.5840	0.4919	–0.352	0.014	2453835.5591	0.3857	–0.352	0.014
2453911.5190	0.8943	–1.149	0.047	2453796.5893	0.5085	–0.361	0.015	2453835.5627	0.3973	–0.319	0.013
2453911.5219	0.9033	–1.087	0.044	2453796.5920	0.5169	–0.377	0.015	2453850.5833	0.7585	–0.442	0.018
2453911.5247	0.9122	–1.069	0.044	2453796.5946	0.5253	–0.412	0.017	2453850.5860	0.7669	–0.43	0.018
2453911.5275	0.9211	–1.046	0.043	2453796.5973	0.5337	–0.437	0.018	2453850.5886	0.7753	–0.437	0.018
2453911.5303	0.9301	–0.966	0.039	2453796.5999	0.5420	–0.469	0.019	2453850.5939	0.7920	–0.433	0.018
2453911.5332	0.9390	–0.963	0.039	2453796.6026	0.5504	–0.499	0.02	2453850.5966	0.8004	–0.427	0.017
2453911.5360	0.9479	–0.863	0.035	2453796.6052	0.5587	–0.551	0.023	2453850.5993	0.8088	–0.426	0.017
2453911.5388	0.9568	–0.780	0.032	2453796.6079	0.5671	–0.585	0.024	2453850.6019	0.8172	–0.410	0.017
2453911.5417	0.9658	–0.698	0.029	2453796.6105	0.5755	–0.629	0.026	2453850.6046	0.8256	–0.404	0.017
2453911.5445	0.9747	–0.664	0.027	2453796.6132	0.5838	–0.675	0.028	2453850.6072	0.8340	–0.382	0.016
2453911.5474	0.9837	–0.668	0.027	2453796.6158	0.5922	–0.679	0.028	2453878.5321	0.8956	–0.313	0.013
2453911.5502	0.9926	–0.665	0.027	2453796.6185	0.6005	–0.726	0.03	2453878.5344	0.9030	–0.222	0.009
2453911.5530	0.0015	–0.618	0.025	2453796.6211	0.6088	–0.753	0.031	2453878.5371	0.9113	–0.206	0.008
2453911.5559	0.0105	–0.606	0.025	2453796.6238	0.6172	–0.769	0.031	2453878.5397	0.9197	–0.230	0.009
2453911.5587	0.0194	–0.652	0.027	2453796.6264	0.6256	–0.778	0.032	2453878.5530	0.9614	0.006	0.000
2453911.5615	0.0283	–0.668	0.027	2453796.6291	0.6339	–0.794	0.032	2453878.5556	0.9698	0.060	0.003
2453911.5643	0.0372	–0.746	0.031	2453796.6317	0.6422	–0.802	0.033	2453878.5583	0.9782	0.086	0.004
2453911.5672	0.0461	–0.752	0.031	2453796.6344	0.6507	–0.830	0.034	2453878.5609	0.9745	0.124	0.005
2453911.5700	0.0551	–0.880	0.036	2453796.6370	0.6590	–0.836	0.034	2453878.5636	0.9829	0.147	0.006
2453911.5728	0.0640	–0.983	0.040	2453796.6397	0.6673	–0.857	0.035	2453878.5662	0.9912	0.155	0.006
2453911.5756	0.0729	–0.970	0.040	2453796.6423	0.6757	–0.854	0.035	2453911.3733	0.8968	–0.183	0.008
2453911.5785	0.0818	–1.112	0.045	2453796.6450	0.6841	–0.866	0.035	2453911.3774	0.9099	–0.155	0.006
2453911.5813	0.0908	–1.070	0.044	2453796.6476	0.6924	–0.879	0.036	2453911.3803	0.9188	–0.106	0.004
2453911.5841	0.0997	–1.042	0.043	2453796.6503	0.7007	–0.883	0.036	2453911.3831	0.9278	–0.067	0.003
2453911.5870	0.1086	–1.121	0.046	2453796.6589	0.7728	–0.865	0.035	2453911.3859	0.9367	–0.034	0.001
2453911.5898	0.1175	–1.083	0.044	2453796.6615	0.7811	–0.852	0.035	2453911.4437	0.6570	–0.431	0.018
2453911.5926	0.1265	–1.184	0.048	2453911.5264	0.9378	–0.525	0.021	2453911.4466	0.6660	–0.425	0.017
2453911.5955	0.1354	–1.234	0.050	2453911.5293	0.9467	–0.469	0.019	2453911.4522	0.6838	–0.450	0.018
2453911.5983	0.1444	–1.270	0.052	2453911.5321	0.9556	–0.437	0.018	2453911.4579	0.7016	–0.478	0.020
2453911.6012	0.1533	–1.240	0.051	2453911.5349	0.9646	–0.367	0.015	2453911.4607	0.7106	–0.475	0.019
2453911.6040	0.1622	–1.243	0.051	2453911.5378	0.9735	–0.292	0.012	2453911.4636	0.7195	–0.476	0.019
2453911.6068	0.1711	–1.285	0.053	2453911.5406	0.9825	–0.253	0.01	2453911.5455	0.9778	0.129	0.005

3 ORBITAL PERIOD ANALYSIS

Issues related to stability of the orbital period for the system TY Boo were first recognized by Szafraniec (1953), who found a cyclic period variation of about 127 d. A cubic equation for the ephemeris was obtained by Wood & Forbes (1963) with a rate of period increase of $dP/dE = +7.79 \times 10^{-10}$ d cycle^{-1} ($dP/dt = +1.79 \times 10^{-6}$ d yr^{-1}). Their study was based on only 22 times

Table 2 Newly Observed Times of Light Minima for TY Boo in the BVR Bands

HJD	Error	Min	Filter
2453794.47770	0.0003	I	B
2453794.48280	0.0006	I	V
2453794.49470	0.0002	I	R
2453796.55590	0.0005	II	B
2453796.55630	0.0002	II	V
2453796.55640	0.0001	II	R
2453835.39900	0.0013	I	B
2453835.39902	0.0001	I	V
2453835.39903	0.0002	I	R
2453850.46370	0.0005	I	V
2453850.46670	0.0015	II	B
2453850.47210	0.0003	II	V
2453850.62220	0.0004	II	R
2453878.53750	0.0005	I	V
2453878.53780	0.0011	I	R
2453911.36400	0.0004	I	B
2453911.52300	0.0006	I	V
2453911.52360	0.0004	I	R
2453911.52370	0.0010	II	B

of light of minima. Carr (1972) confirmed the period ($P = 0.317146^{\rm d}$) given by Wood & Forbes (1963).

A study of the period by Samec & Bookmyer (1987) gives no indication of the cyclic period variation which was suggested by Szafraniec. A noncontinuous period variation was reported by Milone et al. (1991). They recorded a rapidly developing Ca II flare in the system. Li et al. (2005) found two periodic variations (31.5 and 11.76 yr) superimposed on a continuous increase ($dP/dt = +6.28 \times 10^{-8}$ d yr^{-1}). They indicate there is a continuous increase in the mass transfer from the secondary to the primary, rather than an expansion of the primary due to its dynamical instability. Yang et al. (2007) concluded there was a secular period decrease superimposed on a cyclic variation. They attributed this decrease to the mass transfer from the more massive component to the less massive component, which appears as a shrinking of the inner and outer critical Roche lobes, which caused the degree of contact to increase. A study of the period based on published minima up to 2011 by Christopoulou et al. (2012) showed a long term period decrease.

In the present work, we used the list collected by Christopoulou et al. which covers the interval from 1926 to 2011 together with our new 19 minima, all published from 2011 to 2014. In addition, we added published minima before 2011 that were not included in the Christopoulou et al. list. An additional 76 minima were added in our study, which results in a total of 454 light minima timings, spanning over 88 years ($\sim 101\,277$ revolutions). These data were used to follow and update the long term orbital behavior of the system TY Boo by means of an observed minus calculated $(O-C)$ diagram. $(O-C)$ for the eclipse timings have been calculated using a linear ephemeris (Kreiner et al. 2001 eq. (1)) and are listed in Table 3.

Table 3 Times of Light Minima for TY Boo (2011–2014)

HJD	Method	E	$O-C$	$(O-C)$p	References
2432688.5390	vis	–47057	0.0160	0.0038	Szafraniec (1948)
2432688.5390	vis	–47057	0.0160	0.0038	Szafraniec (1948)
2433082.4350	vis	–45815	0.0129	0.0009	Szafraniec (1948)
2433362.4660	vis	–44932	0.0014	–0.0102	Szafraniec (1948)
2443587.8020	vis	–12690.5	–0.0221	–0.0057	Samolyk (1992)
2444334.7090	vis	–10335.5	–0.0010	0.0132	Samolyk (1992)

Table 3 — *Continued*

HJD	Method	E	$O-C$	$(O-C)$p	References
2444402.7250	vis	–10121	–0.0135	0.0005	Samolyk (1992)
2445173.7150	vis	–7690	–0.0127	–0.0016	Samolyk (1992)
2445492.7770	vis	–6684	–0.0026	0.0072	Samolyk (1992)
2446210.7980	vis	–4420	–0.0069	–0.0005	Samolyk (1992)
2446210.8000	vis	–4420	–0.0049	0.0015	Samolyk (1992)
2446226.8110	pe	–4369.5	–0.0100	–0.0036	Milone et al. (1991)
2446227.7629	pe	–4366.5	–0.0095	–0.0031	Milone et al. (1991)
2446231.7266	pe	–4354	–0.0102	–0.0038	Milone et al. (1991)
2446600.7230	vis	–3190.5	–0.0166	–0.0121	Samolyk (1992)
2446606.7660	vis	–3171.5	0.0006	0.0051	Samolyk (1992)
2446678.6020	vis	–2945	0.0023	0.0065	Samolyk (1992)
2446875.7160	vis	–2323.5	0.0082	0.0114	Samolyk (1992)
2446951.6690	vis	–2084	0.0040	0.0069	Samolyk (1992)
2447010.6550	vis	–1898	0.0003	0.0028	Samolyk (1992)
2447219.8060	vis	–1238.5	–0.0085	–0.0070	Samolyk (1992)
2447263.5774	vis	–1100.5	–0.0036	–0.0024	Agerer (1988)
2447263.5781	vis	–1100.5	–0.0029	–0.0017	Agerer (1988)
2447299.7430	vis	–986.5	0.0070	0.0081	Samolyk (1992)
2447316.7060	vis	–933	0.0025	0.0035	Samolyk (1992)
2447612.6025	vis	0	–0.0010	–0.0015	Hubscher et al. (1989)
2447612.6032	vis	0	–0.0003	–0.0008	Hubscher et al. (1989)
2447681.7510	vis	218	0.0090	0.0082	Samolyk (1992)
2448161.5940	vis	1731	0.0056	0.0023	Samolyk (1992)
2448330.6410	vis	2264	0.0122	0.0081	Samolyk (1992)
2448331.7410	vis	2267.5	0.0021	–0.0020	Samolyk (1992)
2448661.8970	vis	3308.5	0.0060	0.0004	Samolyk (1992)
2448690.5994	vis	3399	0.0065	0.0006	Hubscher et al. (1989)
2448717.7150	vis	3484.5	0.0058	–0.0001	Samolyk (1992)
2448724.8440	vis	3507	–0.0010	–0.0070	Samolyk (1992)
2448770.6700	vis	3651.5	–0.0031	–0.0093	Samolyk (1992)
2453794.4777	ccd	19492	0.0059	–0.0096	This paper
2453794.4828	ccd	19492	0.0110	–0.0045	This paper
2453794.4947	ccd	19492	0.0229	0.0074	This paper
2453796.5559	ccd	19498.5	0.0226	0.0071	This paper
2453796.5563	ccd	19498.5	0.0230	0.0075	This paper
2453796.5564	ccd	19498.5	0.0231	0.0076	This paper
2453835.3990	ccd	19621	0.0150	–0.0004	This paper
2453835.3990	ccd	19621	0.0150	–0.0004	This paper
2453835.3990	ccd	19621	0.0150	–0.0004	This paper
2453850.4637	ccd	19668.5	0.0151	–0.0003	This paper
2453850.4667	ccd	19668.5	0.0181	0.0027	This paper
2453850.4721	ccd	19668.5	0.0235	0.0081	This paper
2453850.6222	ccd	19669	0.0150	–0.0003	This paper
2453878.5375	ccd	19757	0.0212	0.0059	This paper
2453878.5378	ccd	19757	0.0215	0.0062	This paper
2453911.3640	ccd	19860.5	0.0228	0.0076	This paper
2453911.5230	ccd	19861	0.0232	0.0080	This paper
2453911.5236	ccd	19861	0.0238	0.0086	This paper
2453911.5237	ccd	19861	0.0239	0.0087	This paper
2454958.7319	vis	23163	0.0061	–0.0051	Bialozynski (2009)
2454958.7420	vis	23163	0.0162	0.0050	Bialozynski (2009)
2455232.9082	vis	24027.5	0.0071	–0.0026	Menzies (2010)
2455642.3477	vis	25318.5	0.0072	0.0000	Hubscher (2011)
2455642.5067	vis	25319	0.0077	0.0004	Hubscher (2011)
2455648.3732	ccd	25337.5	0.0069	–0.0003	Hubscher et al. (2012)
2455664.0717	ccd	25387	0.0065	–0.0006	Shiokawa (2011)
2455664.2305	ccd	25387.5	0.0068	–0.0003	Shiokawa (2011)
2455681.5158	vis	25442	0.0074	0.0005	Parimucha et al. (2013)
2455992.6392	ccd	26423	0.0077	0.0029	Honkova (2012)
2455992.6395	ccd	26423	0.0080	0.0032	Honkova (2012)

Table 3 — *Continued*

HJD	Method	E	$O-C$	$(O-C)$p	References
2456023.8779	vis	26521.5	0.0072	0.0027	Diethelm (2012)
2456062.7300	vis	26644	0.0085	0.0043	Sabo (2012)
2456069.3859	vis	26665	0.0043	0.0001	Hubscher & Lehmann (2013)
2456069.5470	vis	26665.5	0.0068	0.0026	Hubscher & Lehmann (2013)
2456078.4252	vis	26693.5	0.0049	0.0007	Parimucha et al. (2013)
2456085.7218	vis	26716.5	0.0070	0.0030	Diethelm (2012)
2456382.7220	vis	27653	–0.0028	–0.0045	Menzies (2010)
2456399.6891	ccd	27706.5	–0.0032	–0.0048	Poklar (2013)
2456408.4154	vis	27734	0.0015	0.0002	Hubscher (2013)
2456408.5742	vis	27734.5	0.0018	0.0003	Hubscher (2013)

For a more accurate result, we discarded some uncertain minima times that were collected (i.e. the first visual minimum taken in 1926) which do not agree with the others in the $(O-C)$ diagram. Scattering of the minima in the $(O-C)$ diagram may result from cycle to cycle variation in the observed light curves, which leads to asymmetry and also uncertainty in times of minima calculations. The $(O-C)$ values are presented in Figure 2 versus the integer cycle E; no distinctions have been made between primary and secondary minima. It is clear that the behavior of the $(O-C)$ points in Figure 2 cannot adequately represent any light elements derived by a linear fit. In order to follow the periodic behavior of the system TY Boo through the 88 years since its discovery, we divided the $(O-C)$ variation into four intervals, $E_i - E_{i-1}, i = 1, 2, 3, 4$.

Table 4 summarizes the intervals and the best fit data with standard deviations SD, correlation coefficients r and residual sum of squares. The time interval ΔE and the corresponding changes in the period ΔP for each interval according to the best fit of the $(O-C)$ residuals are also listed in Table 4. It is clear from the table that the period of the system TY Boo shows two stages of increase and a similar trend of decrease, which looks like periodic behavior. The $(O-C)$ residuals in Figure 2 show two peaks, representing the turning points from the phase of period increase to decrease. The first peak is at HJD $\sim$ 24329961949 (1949) while the second one is at HJD $\sim$ 2452362 (2002), with an interval of about 53 yr between them. The general trend of the $(O-C)$ diagram can be represented by a sixth degree polynomial with a residual sum of squares $= 0.0094$ and correlation coefficient $= 0.89$ as follows

$$\begin{aligned} \mathrm{Min\,I} \;=\; & 2447612.6040 + 0.3171506 \cdot E - 2.929 \times 10^{-12} \cdot E^2 - 2.051 \times 10^{-15} \cdot E^3 \\ & -7.491 \times 10^{-21} \cdot E^4 + 4.049 \times 10^{-25} \cdot E^5 - 9.218 \times 10^{31} \cdot E^6. \end{aligned} \tag{2}$$

The new light elements in Equation (2) can be used to estimate minimum times in the next few years. The equation yields a new period (P= 0.3171506^{d}). The period shows a decrease with the rate $dP/dE = 5.858 \times 10^{-12}$ d cycle^{-1}, 6.742×10^{-9} d yr^{-1} or 0.058 s century^{-1}. The $(O-C)$p residuals calculated using polynomial ephemeris (Eq. (2)) are listed in Table 3 and displayed in Figure 3.

4 LIGHT CURVE STABILITY

The light curve variation of the system TY Boo was noted through the historical survey of published light curves since its discovery in 1926. Observations by Carr (1972) in 1969 were brighter than those of Samec & Bookmyer (1987). Li et al. (2005) suggested that the more massive component was brighter in 1969 than in 1986, which might be caused by star spot(s) or as a result of the stellar activity. Large scatter was clearly seen in the light curves reported by Samec & Bookmyer (1987) and Milone et al. (1991), and a rapid light variation occurring night by night was observed near the two maxima and two minima. This phenomenon has been observed in many contact binaries (i.e. KN Per Goderya et al. (1997), CN And Keskin (1989), and AQ Tuc Hilditch & King (1986)),

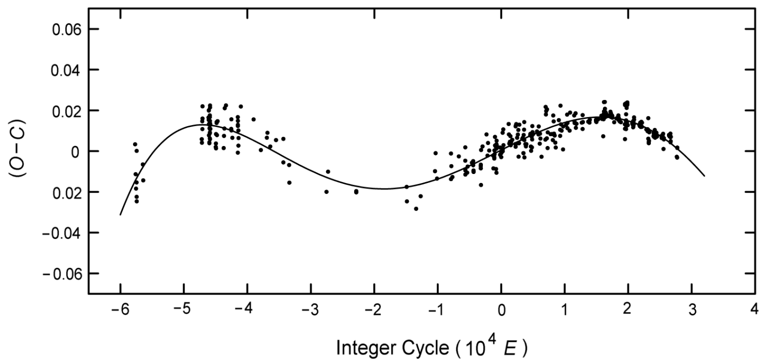

Fig. 2 Periodic behavior of TY Boo.

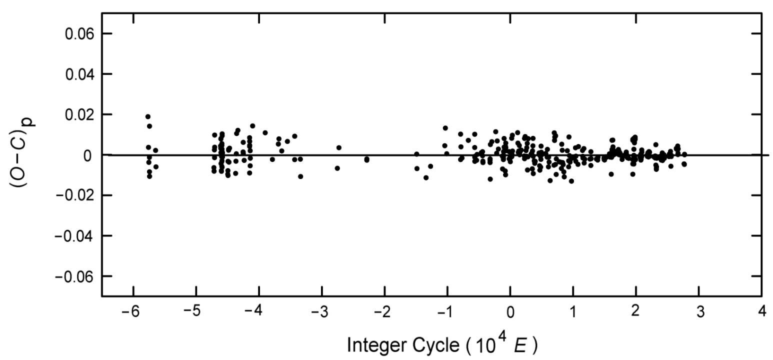

Fig. 3 Calculated residuals from the quadratic ephemeris.

which might be caused by the pulsation of a common envelope due to mass transfer between two components (Li et al. 2002). Studying the light curve variation together with the orbital period of W UMa systems is very important in understanding the evolution of structure in these systems. Applegate (1992) predicts a relation between the orbital period changes and light variations during the same cycle. We studied the possibility of applying the prediction by Applegate to the system

Table 4 Comprehensive Periodic Behavior for the System TY Boo

	Intervals (2400000+)			
Parameters	E_0 to E_1 29348–32996	E_1 to E_2 32996–40370	E_2 to E_3 40370–52452	E_3 to E_4 52452–56408
ΔE(d)	3648	7374	12082	3956
P (d)	0.3171519	0.3171476	0.3171502	0.3171477
ΔP(d)	2.858×10^{-6}	-1.3949×10^{-6}	1.1849×10^{-6}	-1.2620×10^{-6}
$\Delta P/P$	9.012×10^{-6}	-4.398×10^{-6}	3.7360×10^{-6}	-3.9790×10^{-6}
$\Delta P/\Delta E$ (d/cycle)	2.485×10^{-10}	-5.999×10^{-11}	3.1103×10^{-10}	-1.0120×10^{-10}
Epoch (2400000+)	47612.7507	47612.5531	47612.6040	47612.5643
SD	0.00559	0.00624	0.00503	0.00303
r	0.94300	0.85700	0.84700	0.82620
Residual sum of squares	0.00041	0.00261	0.01134	0.00172
R^2	0.88980	0.73450	0.71720	0.68260

Table 5 Light Curve Parameters for TY Boo

HJD	Date	$D_{\max}$ (mag)	$D_{\min}$ (mag)	$A_{\rm p}$ (mag)	$A_{\rm s}$ (mag)	References
2441351	1972	0.009 ± 0.001	-0.119 ± 0.006	0.357 ± 0.018	0.476 ± 0.024	Carr (1972)
2446830	1987	-0.006 ± 0.001	0.146 ± 0.007	0.674 ± 0.028	0.398 ± 0.020	Samec & Bookmyer (1987)
2447561	1989	0.005 ± 0.001	-0.070 ± 0.004	0.455 ± 0.023	0.385 ± 0.019	Samec et al. (1989)
2447926	1990	0.200 ± 0.010	0.160 ± 0.008	0.180 ± 0.009	0.340 ± 0.017	Rainger et al. (1990)
2448291	1991	0.030 ± 0.002	0.075 ± 0.004	0.460 ± 0.023	0.385 ± 0.019	Milone et al. (1991)
2453770	2006	0.010 ± 0.001	0.135 ± 0.006	0545 ± 0.065	0.680 ± 0.028	This paper
2454866	2009	–	0.089 ± 0.005	–	–	Bialozynski (2009)
2455596	2011	0.050 ± 0.002	0.211 ± 0.010	0.768 ± 0.031	0557 ± 0.023	Christopoulou et al. (2012)
2456326	2013	–	0.049 ± 0.003	–	–	Menzies (2013)

TY Boo. Using the historical published light curves together with our observations in the V band, the light levels (Max I, Min I, Max II and Min II) were evaluated from the curves. The differences in magnitude between both maxima (O'Connell) $D_{\max}$ (Max I – Max II) and minima $D_{\min}$ (Min I – Min II) and amplitude of the primary $A_{\rm p}$ (Min I – Max I) and secondary $A_{\rm s}$ (Min II – Max I) have been calculated for each light curve and are listed in Table 5 with their corresponding observers and observational date in years.

Figure 4 displays the variation in magnitude differences $D_{\max}$ and $D_{\min}$, and the amplitude of the primary eclipse $A_{\rm p}$ and secondary one $A_{\rm s}$, for TY Boo in the V band. From Figure 4(a), (c) and (d), we can note that the amplitude of the primary and secondary eclipses, $A_{\rm p}$, and $A_{\rm s}$ respectively, showed the same trend of variation, but with an opposite trend than what was shown by $D_{\max}$.

The tabulated results lead to a conclusion that the calculated parameters $D_{\max}$, $D_{\min}$, $A_{\rm p}$ and $A_{\rm s}$ show an oscillatory variation and wave-like behavior like a periodic function, which can be interpreted as periodic action by some physical mechanism. Synchronous periodic variation of both orbital period and light curve parameters ($D_{\max}$, $D_{\min}$, $A_{\rm p}$ and $A_{\rm s}$) for the system TY Boo may be interpreted as the presence of magnetic activity cycles and/or a mass transfer mechanism.

5 LIGHT CURVE MODELING

Light curve solutions for the W UMa system TY Boo estimated by many authors (i.e. Rainger et al. 1990; Milone et al. 1991; Christopoulou et al. 2012) have shown that the less massive, but hotter, star is eclipsed at the primary minimum. Although the light curve solution by Carr (1972) has limited accuracy, it suggested that the system TY Boo can be classified as an A-type W UMa system which consists of two main-sequence components with spectral types G3 and G7 and a mass ratio of 0.88. Niarchos (1978) re-analyzed Carr's (1972) observations using frequency domain techniques, and suggested that TY Boo was a W UMa system with a small mass ratio of 0.22 and indicated that the smaller component is the hotter one (Rainger et al. 1990).

Light curve analysis by Samec et al. (1989) shows that the system has a spectral type ranging between G4 and G8. Rainger et al. (1990) combined their spectroscopic observations together with photometric observations by Samec & Bookmyer (1987) to compute the masses and absolute dimensions of the components. Their solution shows that the system TY Boo has components with spectral types G2 and F8. Milone et al. (1991) was the first to suggest a spotted solution with both hot and cold spots on a cooler component, and showed that the published light curves by Carr (1972) and Samec & Bookmyer (1987) have minimal asymmetry and can be fitted without spots.

Christopoulou et al. (2012) confirmed the spotted model solution suggested by Milone et al. (1991) and produced a model that included a spot on both stellar components. They suggested that the spots were caused by cyclic magnetic activity rather than by an unseen companion. They compared the light curve parameters obtained from 1926 to 2011, and demonstrated that the system

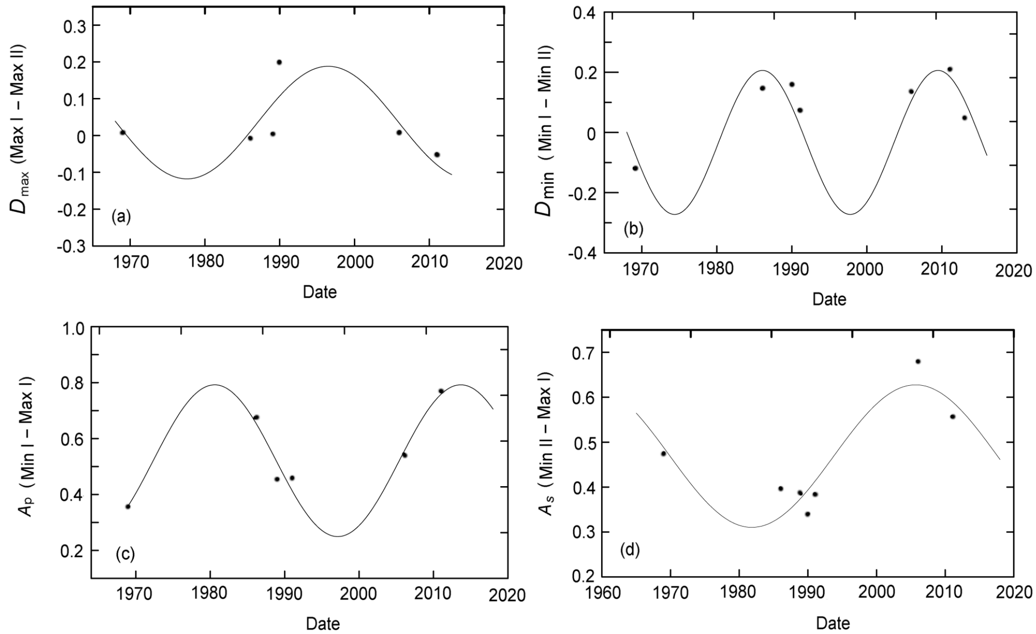

Fig. 4 Variation of the magnitude differences $D_{\max}$ and $D_{\min}$, and the amplitude of the primary $A_{\rm p}$ and secondary $A_{\rm s}$ for TY Boo in the V band.

TY Boo has been a difficult system to analyze because it yields widely divergent results in terms of mass ratio and size.

Our observations cover three bandpasses (BVR) and have high accuracy compared to the previously published photometric data. In our modeling we use Mode 3 (overcontact) of the WDint56a Package (Nelson 2009), which is based on the W-D code. The surface temperature of the primary (less massive and hotter) star was fixed at 5732 K, which is compatible with its spectral classification of G3 (Cox 2000).

The individual observations were analyzed instead of complete light curves, which do not reveal a real light variation in the system. The bolometric limb darkening coefficients ($x_b(h) = x_b(c)$ and $y_b(h) = y_b(c)$) were adopted and interpolated using the square-root law from van Hamme (1993). Tabulated values and a model atmosphere were applied. Gravity darkening and bolometric albedo were assumed according to the exponents appropriate for convective envelopes ($T_{\rm eff} < 7500$ K) in a late spectral type. We adopted $g_{\rm h} = g_{\rm c} = 0.32$ (Lucy 1967) and the albedo value $A_{\rm h} = A_{\rm c} = 0.5$ (Ruciński 1969). Mode 3 (overcontact) was applied with a synchronous rotation and a circular orbit was assumed. Some parameters were kept fixed (i.e. $T_{\rm h}$, g, A, X), and the adjustable parameters were the temperature of the cool star $T_{\rm c}$ for star 2, the monochromatic luminosity L1 for star 1 (the luminosity of star 2 was calculated by the stellar atmosphere model), the surface potential $\Omega_{\rm h} = \Omega_{\rm c}$, and the mass ratio $q = (M_{\rm c}/M_{\rm h})$. The model solution without a spot (not shown here) does not fit the observed light curves well. The parameters of the accepted model are listed in Table 6 with the presence of a dark spot on the cooler component and a hot one on the hotter component, which confirms the spotted solution suggested by Christopoulou et al. (2012) and gives a credible uniform description for the TY boo system. The estimated parameters show that the less massive component is hotter than the more massive one, which verifies the results of Milone et al. (1991) and Christopoulou et al. (2012). The temperature difference between the components is $\Delta T \sim 249$ K, and the theoretical BVR light curves for the system TY Boo are displayed in Figure 5. The absolute

Table 6 Photometric Solution for TY Boo

Parameter	BVR
$i(^\circ)$	78.76 ± 0.16
gh = gc	Fixed
$A_\mathrm{h} = A_\mathrm{c}$	Fixed
$q = (M_\mathrm{c}/M_\mathrm{h})$	2.2592 ± 0.005
$\Omega_\mathrm{h} = \Omega_\mathrm{c}$	5.5935 ± 0.010
Ω_in	5.6174
Ω_out	4.5571
T_h (K)	5732 Fixed
T_c (K)	5483 ± 2
$L_\mathrm{h}/(L_\mathrm{h} + L_\mathrm{c})$	Fixed
$L_\mathrm{c}/(L_\mathrm{h} + L_\mathrm{c})$	Fixed
r_h (pole)	0.2920 ± 0.0006
r_h (side)	0.3048 ± 0.0007
r_h (back)	0.3385 ± 0.0013
r_c (pole)	0.4260 ± 0.0002
r_c (side)	0.4540 ± 0.0003
r_c (back)	0.4819 ± 0.0006
Spot parameters for hot star	
Co-latitude	120 Fixed
Longitude	350 Fixed
Spot radius	16 Fixed
Temp. factor	1.1076 Fixed
Spot parameters for cool star	
Co-latitude	140 Fixed
Longitude	155 Fixed
Spot radius	21 Fixed
Temp. factor	0.7 Fixed
$\sum(O-C)^2$	0.08447

Table 7 Absolute Physical Parameters for the System TY Boo

M_h ($M_\odot$)	M_c ($M_\odot$)	R_h ($R_\odot$)	R_c ($R_\odot$)	M_h (bol)	M_c (bol)	L_h ($L_\odot$)	L_c ($L_\odot$)	T_h ($T_\odot$)	T_c ($T_\odot$)	Ref.
0.40±0.01	0.93±0.02	0.69±0.01	1.00±0.01	5.28±0.14	4.75±0.15	0.62±0.03	1.02±0.04	1.07±0.04	1.00±0.04	[1]
0.53±0.02	1.14±0.05	0.75±0.03	1.05±0.04	5.29±0.22	4.82±0.02	0.58±0.02	0.89±0.04	1.01±0.04	0.94±0.04	[2]
0.57±0.05	1.21±0.06	0.75±0.01	1.07±0.01	5.34±0.22	4.88±0.02	0.54±0.01	0.87±0.02	0.99±0.04	0.88±0.04	[3]
0.53±0.02	1.19±0.05	0.73±0.03	1.06±0.04	5.47±0.22	4.85±0.20	0.52±0.02	0.92±0.04	0.99±0.04	0.95±0.04	[4]

Notes: Subscript ‘h’ and ‘c’ means hot and cool component respectively. Reference: [1] Rainger et al. (1990); [2] Milone et al. (1991); [3] Christopoulou et al. (2012); [4] This Paper.

physical parameters of the system TY Boo were calculated based on the results of the radial velocity data from Milone et al. (1991) and our new photometric solution. The calculated parameters together with those calculated by previous light curve solutions are listed in Table 7. A three dimensional geometrical structure for the system TY Boo was constructued using the software Package Binary Maker 3.03 (Bradstreet and Steelman, 2004) based on the calculated parameters resulting from our model and is displayed in Figure 6. It is clear from our results that the system TY Boo shows a rapid transformation in physical properties, which can have many interpretations, i.e. Milone et al. (1991) suggested that the system is chromospherically active and a rapidly developing Ca II flare was recorded in the system’s spectrum. A shrinking of the inner and outer critical Roche lobes caused an increase in the degree of contact which results from the decrease in orbital period.

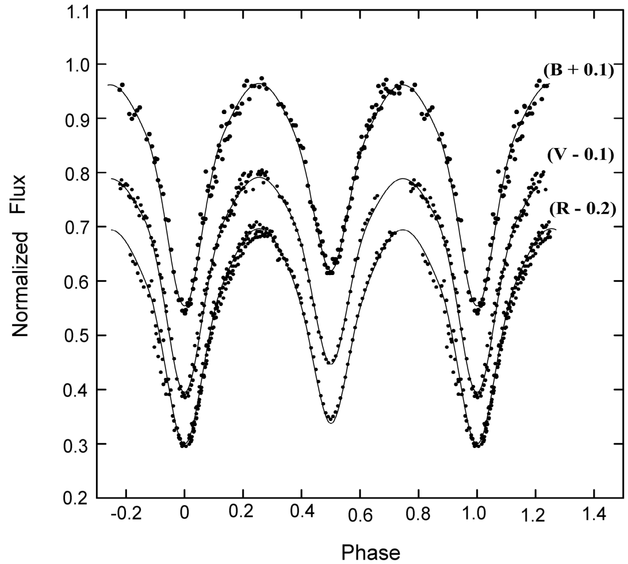

Fig. 5 Observed light curves. Observed light curves (*filled circles*) and fitted light curves (*solid lines*).

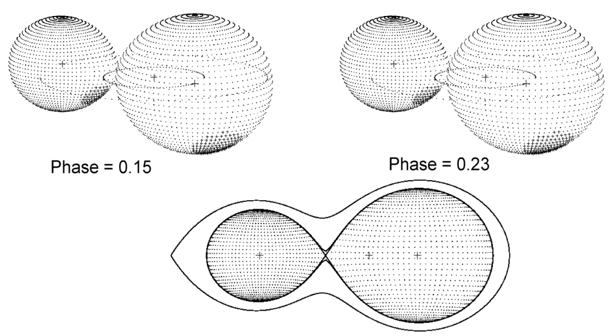

Fig. 6 Geometric structure of the binary system TY Boo.

6 EVOLUTIONARY STATUS

In order to investigate the current evolutionary status of the system, we used the physical parameters listed in Table 7. We used the evolutionary tracks computed by Girardi et al. (2000) for both ZAMS stars and terminal age main sequence (TAMS) stars with metallicity $z = 0.019$. The components of TY Boo are plotted on mass-luminosity ($M - L$) and mass-radius ($M - R$) relations in Figures 7 and 8 respectively. As is clear from these figures, the primary component of the system is located above the TAMS for the $M - L$ relation but it is located on the TAMS for the $M - R$ relation. The secondary component is close to the ZAMS track for both the $M - L$ and $M - R$ relations. In the figures, we also plot the physical parameters computed by other authors listed in Table 7. The locations of both primary and secondary components have more or less the same behavior as in our solution. The same trend is obtained by Christopoulou et al. (2012) for a sample of W-type systems.

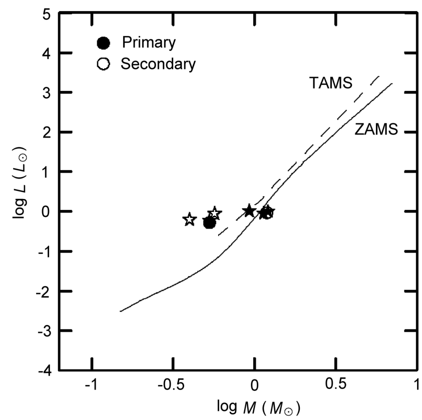

Fig. 7 The position of the components of TY Boo on the mass-luminosity diagram. The filled circle denotes the primary and the open circle represents the secondary. Filled and open star symbols represent the masses and luminosities of the other solutions presented in Table 7.

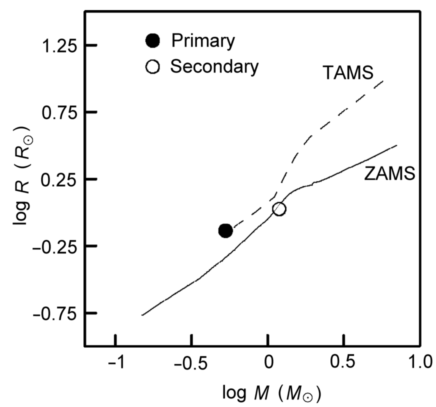

Fig. 8 The position of the components of TY Boo on the mass-radius diagram. The filled circle denotes the primary and the open circle represents the secondary.

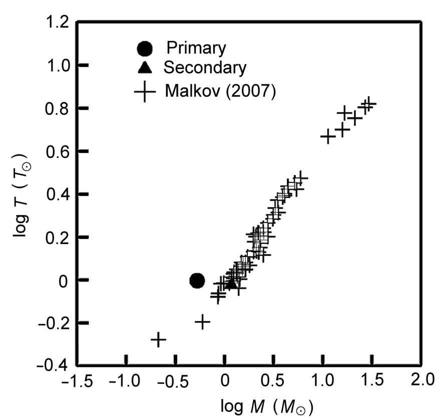

Fig. 9 Position of the components of TY Boo on the empirical mass-$T_{\rm eff}$ relation for low-intermediate mass stars by Malkov (2007).

The location of our physical parameters on the mass-effective temperature ($M - T_{\rm eff}$) relation is displayed in Figure 9. This shows the relation for intermediate and low mass stars based on data from detached double-lined eclipsing binaries (Malkov 2007). The location of our mass and radius on the diagram indicates there is a good fit for the secondary component but a poor fit for the primary one.

Some open questions have arisen related to the evolutionary status of the TY Boo system, including the mass transfer from the secondary to the primary and its relation with the period change of the system. As the system has a low degree of contact, many authors (i.e. Christopoulou et al. 2012) do not consider the mass transfer to be a possible reason for a period change.

Another open question is what influence does the magnetic activity have on the period change. Our investigation shows that the period change may be attributed to magnetic activity. However, as shown by Stępień et al. (2001), the X-ray flux (for the time interval 1990-1991) is weaker than that of single stars, so Christopoulou et al. (2012) excluded magnetic activity as the cause of period change.

7 DISCUSSION

New light curves of TY Boo were acquired with a CCD over five nights in the BVR bandpass and 19 new times of light minima were calculated. The parameters calculated by a photometric solution of these light curves by means of the W-D code showed that the less massive component is hotter than the more massive one. The temperature difference between the components is $\Delta T \sim 249$ K. The periodic behavior of the system and the new light elements yield a new period ($P = 0.3171506^{\rm d}$) and show a period decrease with the rate $dP/dE = 5.858 \times 10^{-12}$ d cycle^{-1}, 6.742×10^{-9} d yr^{-1} or 0.1 s century^{-1}. The conclusion reached may be drawn from the following points.

(1) Light curve modeling is performed using the complete light curve from the BVR bandpass. The curves were analyzed by means of the W-D code and the accepted solution confirms the presence of a hot spot on the hotter component and a dark spot on the cooler one. The absolute physical parameters were calculated and compared with those estimated by the previous light curve solutions for the system. The comparison showed that the physical properties of the system transform rapidly, which can be interpreted in terms of chromospheric activity and a rapidly developing Ca II flare recorded in the system's spectrum (Milone et al. 1991).
(2) We performed the first study of long term stability exhibited by this system's light curves and the possible connection with its periodic behavior, by using all published light curves. Long term stability in the system's light curves shows a periodic variation in the magnitude differences $D_{\rm max}$ and $D_{\rm min}$ and the amplitude of the primary $A_{\rm p}$ and secondary $A_{\rm s}$.
(3) Synchronous periodic variations of both orbital period and light curve parameters ($D_{\rm max}$, $D_{\rm min}$, $A_{\rm p}$ and $A_{\rm s}$) for the system TY Boo may be correlated with the presence of magnetic activity cycles and/or a mass transfer mechanism. Future observations, particularly high resolution spectroscopic and photometric measurements, are needed to verify this behavior.
(4) We have investigated the evolutionary status of the system using stellar models. The primary component is near or on the TAMS track, but the secondary component is still on the ZAMS track.

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