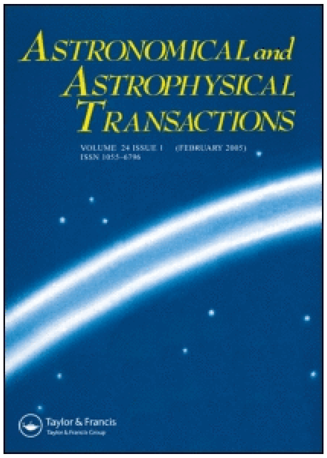

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A SEARCH FOR EVOLUTIONARY CHANGES IN THE PERIODS OF CEPHEIDS USING ARCHIVAL DATA FROM THE HARVARD OBSERVATORY PLATE COLLECTION I: VY, WZ AND GH CARINAE

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2052 magnitude estimates for the Cepheids VY Car, WZ Car and GH Car were made using plates from the Harvard College Observatory photographic plate collection. The data complemented 2398 photoelectric measurements in the B and V filters of the Johnson system, essentially extending the time baselines of O−C data for the stars, which now span more than one century. Evolutionary changes in pulsation period were established for WZ Car and GH Car and were improved for VY Car.

Keywords: Stars; Cepheids; Period changes of stars; Evolution

1 INTRODUCTION

Since Cepheids are primary distance indicators, any information related to their intrinsic luminosities is very important. In particular, if we knew the number of times that each Cepheid has crossed the instability strip, it would be possible to define a period–luminosity relation for each crossing separately, which might allow us to calculate the distances to individual Cepheids more precisely.

Analyses of Cepheid period changes using O−C diagrams have allowed us to establish the direction of evolution for individual stars across the Hertzsprung–Russell diagram as well as to estimate the rates of such changes. A comparison of the same data with predictions based upon computational models of evolving stars provides a possibility for defining the number of crossing modes of the instability strip.

Obviously, the longer the time baseline for O−C data, the more reliable are the results that are obtained. There are two possibilities for extending the time interval under consideration: one is by going forward in time and another is by going back. The first way is unlimited but too slow; to extend the baseline for 100 years we must wait as long as 100 years. The second

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way is much faster but is limited; we can obtain magnitude estimates on old photographic plates spanning 100 years in the course of 1 week's effort, but we cannot go back earlier than the 1880s.

Fortunately, our experience (Berdnikov *et al.*, 1997; Berdnikov and Ignatova, 2000; Turner *et al.*, 2001; Turner and Berdnikov, 2003) shows that a baseline of 100 years is large enough to detect evolutionary changes in the periods of some Cepheids, even if they are very small; so we began a new long-term project to search for such changes in all Cepheids. For that we intend to perform new photoelectric observations of the Cepheids as well as to make magnitude estimates for them using old plates of different photographic plate collections.

In this first paper we present the results obtained for three Cepheids in Carina using data both from patrol plates of the Harvard College Observatory photographic plate collection and our Cepheid database (Berdnikov, 1995), which contains all existing photoelectric observations of Cepheids.

2 OBSERVATIONAL DATA AND METHOD OF ANALYSIS

Three Cepheids, VY Car, WZ Car and GH Car, have been included in our program 'Annual photoelectric monitoring of Cepheids', which allows us to update the O−C data for the stars almost every year. Magnitudes for the same Cepheids were also estimated from patrol plates of the field contained in the Harvard College Observatory Photographic Plate Collection. Table I gives an account of the number of observations obtained, while the observations themselves are represented graphically in Figure 1.

To study period changes in Cepheids, we applied the generally used technique of the analysis of O−C diagrams, including the test to establish the degree of regularity of the pulsations in these stars (Eddington and Plakidis, 1929). We calculated the O−C residuals by the Hertzsprung method, for which a computer version was previously developed and described by one of us (Berdnikov, 1992). In the case of photoelectric observations, we reduced the measurements both in the yellow (the V band of Johnson's photometric system or measurements in yellow bands of various systems transformed to V) and in the blue (the B band of Johnson's broad-band system or measurements in blue bands of various systems transformed to B). For the photographic measurements, the Harvard photometric system is generally close to the B system; so we reduced them in the same manner as blue photoelectric measurements.

3 RESULTS

The results of reductions using Hertzsprung's method are summarized in Table II. The first and second columns give the times of light maximum (maximum heliocentric Julian date

TABLE I Numbers of photographic (PG) and photoelectric B and V observations of Cepheids used in this paper.

	Number of observations		
Cepheid	*PG*	*B*	*V*
VY Car	750	281	622
WZ Car	703	270	517
GH Car	599	213	495

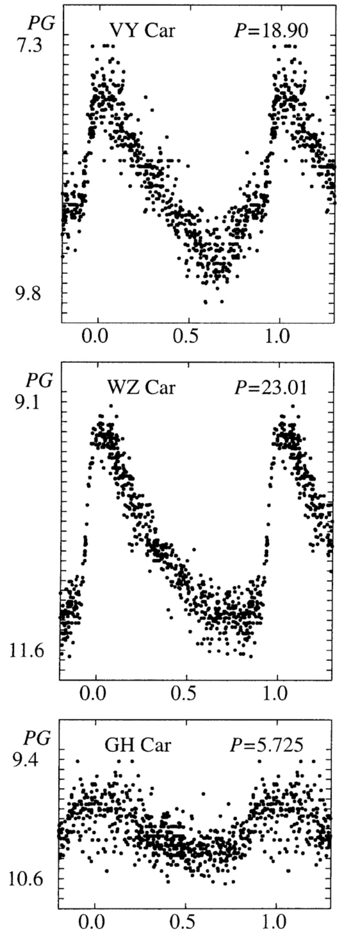

FIGURE 1 Photographic light curves of three Cepheids (the abscissae give the phases).

(Max JDhel) with their estimated uncertainties; the third column indicates the types of observation: PG for photographic, and *B* and *V* for photoelectric observations with *B* and *V* filters respectively. The fourth and fifth columns contain the epoch numbers *E* and the O−C residuals respectively; the sixth and seventh columns present the numbers of observations reduced and the references for the sources of data, respectively.

It should be noted that all our results refer to particular standard curves. Therefore, we present them in Table III to make them available to other researchers either for use in their future studies or for finding relationships with our data when different standard curves are used. Table III contains *B* and *V* magnitudes of the three Cepheids for phases from 0 to 0.995, sampled at intervals of 0.005. These standard curves are plotted in Figure 2.

When plotting and analysing O−C graphs, we took into account that the moments of maximum brightness of Cepheids in the *B* filter occur earlier than those in the *V* filter. The corrections to maxima in *B* filter are presented in Table IV. The data in Table IV were also used to improve the Cepheid light elements (Tab. V) that refer to the *V* system. Those elements were used to plot the photographic light curves in Figure 1, whereas their linear parts were used to calculate the O−C residuals in the fifth column of Table II; the O−C residuals are plotted in Figures 3–5 as open circles with vertical bars showing the uncertainty limits. The uncertainties

TABLE II Epochs of the maximum light of Cepheids.

Max JD hel 2 400 000+	*Error*	*Filter*	*E*	*O–C*	*Number of observations*	*Reference*
VY CAR						
2 415 495.706 9	0.1253	PG	−979	−21.1229	30	This paper
2 416 368.831 2	0.1254	PG	−933	−19.0778	41	This paper
2 417 203.850 9	0.1413	PG	−889	−17.2644	39	This paper
2 418 285.233 6	0.0894	PG	−832	−15.2626	71	This paper
2 419 214.978 6	0.0882	PG	−783	−13.4064	47	This paper
2 420 258.222 7	0.0705	PG	−728	−11.6701	48	This paper
2 421 130.585 1	0.1216	PG	−682	−10.3870	47	This paper
2 421 965.346 3	0.1302	PG	−638	−8.8320	24	This paper
2 423 842.495 2	0.1702	PG	−539	−6.3972	25	This paper
2 425 055.476 8	0.3669	PG	−475	−5.3520	12	This paper
2 427 519.803 2	0.2682	PG	−345	−2.7714	12	This paper
2 428 865.348 5	0.0681	PG	−274	−1.7181	135	This paper
2 429 528.668 0	0.1059	PG	−239	−1.1763	64	This paper
2 430 362.313 2	0.1090	PG	−195	−0.7373	36	This paper
2 431 461.062 2	0.1329	PG	−137	−0.3057	35	This paper
2 432 332.345 5	0.0857	PG	−91	−0.1017	41	This paper
2 432 976.464 4	0.1506	PG	−57	0.1760	26	This paper
2 433 657.978 0	0.6490	PG	−21	−0.0246	17	This paper
2 434 207.045 8	0.0437	*V*	8	−0.2158	9	Eggen *et al.* (1957)
2 434 244.851 8	0.0213	*B*	10	−0.1825	8	Eggen *et al.* (1957)
2 434 661.653 8	0.0318	*B*	32	0.0164	8	Walraven *et al.* (1958)
2 434 661.779 7	0.0371	*V*	32	0.0419	8	Walraven *et al.* (1958)
2 434 850.684 4	0.0582	*B*	42	−0.3181	5	Eggen *et al.* (1957)
2 434 851.118 0	0.0639	*V*	42	0.0152	7	Eggen *et al.* (1957)
2 435 210.639 8	0.0270	*B*	61	−0.1563	12	Irwin (1961)
2 435 210.695 4	0.0461	*V*	61	−0.2011	12	Irwin (1961)
2 441 040.066 1	0.0108	*B*	369	−3.1739	34	Pel (1976)
2 441 040.178 0	0.0124	*V*	369	−3.1623	34	Pel (1976)
2 441 739.961 2	0.0300	*B*	406	−3.9295	13	Madore (1975)
2 441 740.007 2	0.0790	*V*	406	−3.9838	12	Madore (1975)
2 441 778.387 9	0.1838	*B*	408	−3.3758	6	Grayzeck (1978)
2 441 778.594 4	0.2623	*V*	408	−3.2696	6	Grayzeck (1978)
2 442 856.129 3	0.0663	*B*	465	−5.0153	10	Dean (1977)
2 442 856.270 9	0.0391	*V*	465	−4.9739	10	Dean (1977)
2 443 348.050 7	0.1565	*B*	491	−5.4430	9	Dean (1981)
2 443 348.161 9	0.0842	*V*	491	−5.4321	9	Dean (1981)
2 443 877.800 2	0.1284	*V*	519	−6.0160	8	Harris (1980)
2 443 953.282 1	0.0535	*V*	523	−6.2801	21	Eggen (1980)
2 443 953.345 6	0.0379	*B*	523	−6.1163	21	Eggen (1980)
2 444 009.955 7	0.0634	*B*	526	−6.3158	9	Coulson and Caldwell (1985)
2 444 010.037 0	0.0558	*V*	526	−6.3347	9	Coulson and Caldwell (1985)
2 444 766.247 0	0.0258	*B*	566	−7.4847	13	Coulson and Caldwell (1985)
2 444 766.364 2	0.0234	*V*	566	−7.4677	15	Coulson and Caldwell (1985)
2 448 056.042 0	0.0177	*V*	740	−12.7420	43	European Space Agency (1997)
2 448 415.119 9	0.0122	*V*	759	−13.4577	45	European Space Agency (1997)
2 448 774.195 4	0.0156	*V*	778	−14.1758	42	European Space Agency (1997)
2 450 115.971 9	0.0134	*B*	849	−16.7910	11	Bersier (2002)
2 450 116.107 9	0.0091	*V*	849	−16.7552	11	Bersier (2002)

(*continued*)

TABLE II Continued.

Max JD hel 2 400 000+	*Error*	*Filter*	*E*	*O–C*	*Number of observations*	*Reference*
2 450 380.628 6	0.0344	V	863	−17.3456	26	Berdnikov and Turner (1998b)
2 450 493.956 5	0.0199	B	869	−17.5366	14	Bersier (2002)
2 450 494.092 6	0.0137	V	869	−17.5006	14	Bersier (2002)
2 450 569.702 4	0.0170	V	873	−17.6368	16	Berdnikov and Turner (1998a)
2 450 890.910 6	0.0120	V	890	−18.3492	47	Berdnikov and Turner (2000a)
2 451 249.802 8	0.0060	B	909	−19.1505	45	Berdnikov and Turner (2001b)
2 451 249.911 1	0.0070	V	909	−19.1423	46	Berdnikov and Turner (2001b)
2 451 646.727 0	0.0130	V	930	−19.9931	42	Berdnikov and Caldwell (2001)
2 451 948.914 5	0.0258	B	946	−20.6895	22	Berdnikov and Turner (2001a)
2 451 949.001 4	0.0236	V	946	−20.7028	22	Berdnikov and Turner (2001a)
2 452 345.597 8	0.0115	B	967	−21.6729	41	Berdnikov and Turner (2003a)
2 452 345.689 2	0.0152	V	967	−21.6816	41	Berdnikov and Turner (2003a)
2 452 647.974 7	0.0146	V	983	−22.3802	34	Berdnikov and Turner (2003b)
				WZ CAR		
2 415 518.198 8	0.0643	PG	−807	3.4407	25	This paper
2 416 369.049 0	0.0978	PG	−770	2.8044	35	This paper
2 417 197.266 8	0.1319	PG	−734	2.5489	39	This paper
2 418 347.507 0	0.0754	PG	−684	2.1318	74	This paper
2 419 544.128 4	0.0589	PG	−632	2.0696	37	This paper
2 420 694.455 5	0.0899	PG	−582	1.7393	59	This paper
2 421 637.980 7	0.1068	PG	−541	1.7255	39	This paper
2 423 409.104 7	0.1994	PG	−464	0.8372	15	This paper
2 424 767.156 6	0.2068	PG	−405	1.1134	20	This paper
2 427 919.192 9	0.2463	PG	−268	0.3486	22	This paper
2 428 931.283 6	0.1679	PG	−224	−0.1392	123	This paper
2 429 529.984 9	0.0833	PG	−198	0.2203	64	This paper
2 430 381.398 2	0.0840	PG	−161	0.1472	37	This paper
2 431 462.929 8	0.0518	PG	−114	0.0609	34	This paper
2 432 337.062 0	0.1619	PG	−76	−0.3065	41	This paper
2 433 211.874 0	0.1070	PG	−38	0.0059	42	This paper
2 434 799.811 2	0.0315	B	31	0.0360	16	Walraven *et al.* (1958)
2 434 845.908 5	0.0255	V	33	0.0357	14	Walraven *et al.* (1958)
2 435 213.975 1	0.0354	B	49	−0.0368	5	Irwin (1961)
2 435 214.019 7	0.0565	V	49	−0.0635	5	Irwin (1961)
2 441 059.364 3	0.0163	B	303	0.0131	40	Pel (1976)
2 441 059.443 6	0.0167	V	303	0.0211	40	Pel (1976)
2 441 749.876 8	0.0108	B	333	0.1312	13	Madore (1975)
2 441 749.977 9	0.0196	V	333	0.1610	13	Madore (1975)
2 444 028.698 1	0.0159	B	432	0.6510	12	Coulson and Caldwell (1985)
2 444 028.771 8	0.0152	V	432	0.6533	12	Coulson and Caldwell (1985)
2 444 028.858 4	0.0784	V	432	0.7399	6	Harris (1980)
2 444 396.944 4	0.0231	B	448	0.6869	12	Eggen (1983)
2 444 420.018 5	0.0268	V	449	0.6765	13	Eggen (1983)
2 444 765.176 8	0.0096	B	464	0.7090	26	Coulson and Caldwell (1985)
2 444 765.229 7	0.0102	V	464	0.6905	27	Coulson and Caldwell (1985)
2 448 171.573 2	0.0159	V	612	1.0883	52	European Space Agency (1997)
2 448 654.797 2	0.0166	V	633	1.0362	53	European Space Agency (1997)
2 449 529.263 1	0.0189	B	671	1.0739	13	Berdnikov and Turner (1995a)
2 449 529.313 3	0.0773	V	671	1.0527	15	Berdnikov and Turner (1995a)

(*continued*)

TABLE II Continued.

Max JD hel 2 400 000+	*Error*	*Filter*	*E*	*O–C*	*Number of observations*	*Reference*
2 449 805.371 8	0.0136	*B*	683	1.0248	26	Berdnikov and Turner (1995b)
2 449 805.443 0	0.0161	*V*	683	1.0247	26	Berdnikov and Turner (1995b)
2 450 035.474 3	0.0209	*B*	693	0.9959	8	Bersier (2002)
2 450 058.595 4	0.0192	*V*	694	1.0325	9	Bersier (2002)
2 450 518.779 5	0.0120	*B*	714	1.0250	16	Bersier (2002)
2 450 518.938 3	0.0106	*V*	714	1.1124	16	Bersier (2002)
2 450 564.743 7	0.1463	*V*	716	0.8915	23	Berdnikov and Turner (1998a)
2 450 887.202 5	0.0137	*V*	730	1.1663	46	Berdnikov and Turner (2000a)
2 451 255.295 7	0.0061	*B*	746	1.1205	46	Berdnikov and Turner (2001b)
2 451 255.378 3	0.0082	*V*	746	1.1317	47	Berdnikov and Turner (2001b)
2 451 646.688 6	0.0068	*V*	763	1.2185	40	Berdnikov and Caldwell (2001)
2 451 945.833 9	0.1447	*B*	776	1.2643	22	Berdnikov and Turner (2001a)
2 451 945.922 1	0.1518	*V*	776	1.2811	22	Berdnikov and Turner (2001a)
2 452 336.985 3	0.0091	*B*	793	1.1922	42	Berdnikov and Turner (2003a)
2 452 337.048 7	0.0122	*V*	793	1.1842	42	Berdnikov and Turner (2003a)
2 452 636.237 7	0.0063	*V*	806	1.2023	37	Berdnikov and Turner (2003b)
GH CAR						
2 416 135.044 7	0.0947	PG	−3188	−0.0393	61	This paper
2 417 617.758 5	0.1222	PG	−2929	−0.2506	56	This paper
2 418 877.486 2	0.1162	PG	−2709	−0.1504	43	This paper
2 421 225.169 6	0.1182	PG	−2299	0.0454	57	This paper
2 424 099.389 6	0.1164	PG	−1797	0.0245	30	This paper
2 424 219.593 3	0.2286	PG	−1776	−0.0090	30	This paper
2 428 244.534 8	0.1489	PG	−1073	−0.1499	41	This paper
2 428 983.334 1	0.1221	PG	−944	0.0496	99	This paper
2 429 578.798 4	0.1253	PG	−840	0.0536	62	This paper
2 430 878.017 3	0.1134	PG	−613	−0.4340	53	This paper
2 432 263.895 2	0.1188	PG	−371	−0.1464	39	This paper
2 433 225.962 5	0.1234	PG	−203	0.0236	38	This paper
2 435 178.386 0	0.0364	*V*	138	−0.0168	13	Walraven *et al.* (1958)
2 435 207.052 8	0.0332	*B*	143	0.0633	12	Walraven *et al.* (1958)
2 435 235.574 4	0.0431	*B*	148	−0.0429	10	Irwin (1961)
2 435 235.646 2	0.0421	*V*	148	−0.0124	10	Irwin (1961)
2 440 755.083 2	0.0119	*B*	1112	0.0072	30	Pel (1976)
2 440 755.116 2	0.0148	*V*	1112	−0.0011	30	Pel (1976)
2 444 127.249 6	0.0340	*B*	1701	−0.1928	7	Caldwell *et al.* (2001)
2 444 150.194 8	0.0389	*V*	1705	−0.1911	8	Caldwell *et al.* (2001)
2 448 095.267 5	0.0172	*V*	2394	−0.0427	57	European Space Agency (1997)
2 448 621.977 3	0.0182	*V*	2486	−0.0863	57	European Space Agency (1997)
2 449 538.107 2	0.0523	*V*	2646	−0.0491	15	Berdnikov and Turner (1995a)
2 449 538.131 7	0.0533	*B*	2646	0.0166	15	Berdnikov and Turner (1995a)
2 449 818.594 9	0.0120	*B*	2695	−0.0736	27	Berdnikov and Turner (1995b)
2 449 818.615 6	0.0182	*V*	2695	−0.0941	28	Berdnikov and Turner (1995b)
2 450 385.340 7	0.0484	*V*	2794	−0.2014	12	Berdnikov and Turner (1995b)
2 450 580.083 3	0.0116	*V*	2828	−0.1285	21	Berdnikov and Turner (1998a)
2 450 814.843 6	0.0663	*V*	2869	−0.1169	13	Berdnikov and Turner (2000b)
2 450 906.449 6	0.0214	*V*	2885	−0.1202	45	Berdnikov and Turner (2000a)
2 451 267.133 7	0.0074	*B*	2948	−0.1064	49	Berdnikov and Turner (2001b)
2 451 267.178 0	0.0092	*V*	2948	−0.1033	49	Berdnikov and Turner (2001b)

(*continued*)

TABLE II Continued.

Max JD hel 2 400 000+	*Error*	*Filter*	*E*	*O–C*	*Number of observations*	*Reference*
2 451 650.795 4	0.0163	*V*	3015	−0.0997	41	Berdnikov and Caldwell (2001)
2 451 959.906 4	0.0172	*B*	3069	−0.1288	17	Berdnikov and Turner (2001a)
2 451 959.949 1	0.0188	*V*	3069	−0.1273	17	Berdnikov and Turner (2001a)
2 452 354.958 8	0.0094	*B*	3138	−0.1414	68	Berdnikov and Turner (2003a)
2 452 360.728 7	0.0106	*V*	3139	−0.1383	69	Berdnikov and Turner (2003a)
2 452 652.780 6	0.0121	*V*	3190	−0.0910	33	Berdnikov and Turner (2003b)

TABLE III *B* and *V* filter standard light curves of cepheids: brightness for curve phases from 0 to 0.995 sampled at intervals of 0.005.

Brightness									
VY CAR B									
7.743	7.745	7.751	7.760	7.771	7.782	7.794	7.806	7.818	7.830
7.842	7.854	7.867	7.881	7.895	7.910	7.926	7.943	7.961	7.979
7.997	8.021	8.039	8.056	8.073	8.089	8.105	8.121	8.137	8.153
8.169	8.186	8.203	8.221	8.238	8.256	8.274	8.292	8.309	8.326
8.343	8.360	8.376	8.391	8.407	8.422	8.438	8.453	8.469	8.485
8.500	8.516	8.531	8.546	8.561	8.576	8.590	8.604	8.618	8.631
8.646	8.660	8.673	8.687	8.701	8.716	8.730	8.744	8.759	8.773
8.787	8.801	8.815	8.828	8.841	8.853	8.865	8.877	8.889	8.901
8.913	8.926	8.939	8.952	8.966	8.980	8.994	9.008	9.022	9.037
9.050	9.064	9.077	9.090	9.103	9.115	9.127	9.139	9.152	9.164
9.177	9.189	9.202	9.216	9.229	9.242	9.255	9.268	9.280	9.292
9.303	9.314	9.325	9.335	9.345	9.354	9.363	9.372	9.380	9.389
9.397	9.404	9.411	9.418	9.424	9.430	9.435	9.439	9.443	9.446
9.447	9.448	9.449	9.448	9.447	9.445	9.442	9.439	9.434	9.429
9.424	9.417	9.409	9.400	9.389	9.378	9.365	9.351	9.336	9.320
9.302	9.283	9.265	9.246	9.226	9.206	9.185	9.162	9.139	9.115
9.089	9.065	9.039	9.012	8.987	8.963	8.941	8.923	8.909	8.900
8.896	8.897	8.903	8.912	8.923	8.935	8.944	8.949	8.948	8.938
8.908	8.873	8.826	8.768	8.699	8.620	8.533	8.441	8.350	8.259
8.171	8.088	8.012	7.945	7.887	7.839	7.802	7.774	7.756	7.746
VY CAR V									
6.890	6.891	6.895	6.901	6.908	6.914	6.921	6.929	6.937	6.945
6.952	6.960	6.967	6.975	6.984	6.992	7.001	7.010	7.019	7.027
7.036	7.045	7.054	7.063	7.072	7.081	7.090	7.100	7.109	7.118
7.127	7.136	7.145	7.154	7.163	7.172	7.181	7.189	7.198	7.207
7.216	7.225	7.233	7.242	7.251	7.260	7.268	7.277	7.285	7.294
7.302	7.311	7.319	7.328	7.336	7.345	7.353	7.362	7.370	7.379
7.387	7.396	7.404	7.413	7.422	7.430	7.439	7.447	7.456	7.465
7.473	7.482	7.490	7.499	7.508	7.517	7.526	7.534	7.543	7.552
7.561	7.570	7.580	7.589	7.598	7.607	7.616	7.626	7.635	7.644
7.654	7.663	7.673	7.682	7.692	7.701	7.711	7.720	7.730	7.739
7.749	7.758	7.767	7.777	7.786	7.795	7.804	7.813	7.822	7.831
7.840	7.848	7.857	7.865	7.873	7.881	7.889	7.896	7.903	7.910
7.917	7.923	7.929	7.934	7.940	7.945	7.949	7.953	7.957	7.960
7.963	7.965	7.967	7.968	7.969	7.969	7.968	7.967	7.966	7.963

(*continued*)

TABLE III Continued.

Brightness									
7.961	7.957	7.952	7.948	7.942	7.936	7.929	7.922	7.914	7.905
7.897	7.887	7.877	7.866	7.854	7.842	7.829	7.814	7.800	7.785
7.771	7.754	7.739	7.725	7.712	7.701	7.692	7.686	7.682	7.681
7.683	7.687	7.694	7.702	7.710	7.717	7.721	7.722	7.717	7.705
7.685	7.656	7.618	7.572	7.518	7.458	7.396	7.332	7.268	7.207
7.150	7.097	7.051	7.011	6.978	6.950	6.926	6.909	6.898	6.892
WZ CAR B									
9.401	9.404	9.413	9.426	9.441	9.457	9.473	9.487	9.500	9.514
9.528	9.543	9.559	9.576	9.594	9.613	9.634	9.655	9.677	9.698
9.720	9.741	9.762	9.782	9.801	9.820	9.839	9.858	9.877	9.895
9.913	9.931	9.949	9.967	9.984	10.001	10.018	10.035	10.051	10.068
10.085	10.102	10.119	10.136	10.153	10.170	10.187	10.204	10.219	10.235
10.250	10.264	10.279	10.293	10.307	10.322	10.336	10.351	10.367	10.382
10.397	10.413	10.428	10.443	10.457	10.470	10.484	10.497	10.509	10.522
10.536	10.549	10.564	10.579	10.595	10.611	10.627	10.644	10.660	10.676
10.692	10.706	10.720	10.734	10.746	10.758	10.770	10.782	10.794	10.807
10.819	10.833	10.846	10.860	10.874	10.889	10.904	10.918	10.933	10.948
10.962	10.976	10.991	11.005	11.018	11.031	11.044	11.056	11.068	11.079
11.089	11.099	11.108	11.117	11.126	11.135	11.144	11.153	11.163	11.174
11.184	11.195	11.205	11.215	11.225	11.233	11.241	11.247	11.252	11.256
11.259	11.261	11.262	11.264	11.265	11.266	11.267	11.268	11.270	11.271
11.273	11.274	11.275	11.275	11.275	11.274	11.273	11.272	11.271	11.270
11.269	11.270	11.272	11.275	11.280	11.285	11.292	11.299	11.306	11.312
11.317	11.320	11.321	11.319	11.315	11.309	11.300	11.291	11.281	11.271
11.262	11.255	11.249	11.245	11.242	11.239	11.236	11.236	11.227	11.210
11.181	11.137	11.077	11.001	10.907	10.792	10.664	10.526	10.383	10.239
10.099	9.965	9.842	9.733	9.639	9.561	9.500	9.455	9.425	9.408
WZ CAR V									
8.634	8.635	8.640	8.647	8.655	8.663	8.671	8.680	8.688	8.695
8.704	8.712	8.721	8.732	8.742	8.753	8.763	8.774	8.785	8.796
8.806	8.815	8.824	8.833	8.842	8.851	8.860	8.869	8.878	8.887
8.895	8.904	8.913	8.921	8.930	8.938	8.946	8.955	8.963	8.971
8.979	8.987	8.994	9.003	9.011	9.019	9.027	9.035	9.042	9.049
9.056	9.063	9.071	9.078	9.086	9.094	9.102	9.110	9.119	9.127
9.135	9.144	9.152	9.160	9.167	9.175	9.182	9.190	9.198	9.206
9.215	9.223	9.232	9.241	9.250	9.259	9.268	9.277	9.286	9.295
9.304	9.313	9.323	9.332	9.341	9.351	9.361	9.370	9.380	9.390
9.399	9.409	9.418	9.427	9.436	9.445	9.454	9.463	9.472	9.482
9.493	9.503	9.514	9.524	9.535	9.545	9.555	9.565	9.574	9.581
9.589	9.597	9.605	9.613	9.621	9.629	9.637	9.646	9.654	9.662
9.670	9.678	9.685	9.692	9.699	9.705	9.711	9.717	9.722	9.728
9.733	9.738	9.742	9.747	9.751	9.756	9.760	9.763	9.766	9.769
9.772	9.775	9.777	9.780	9.783	9.785	9.788	9.791	9.795	9.798
9.802	9.806	9.811	9.815	9.820	9.825	9.830	9.835	9.840	9.846
9.846	9.847	9.852	9.856	9.860	9.864	9.868	9.871	9.874	9.877
9.878	9.879	9.879	9.877	9.874	9.869	9.865	9.856	9.838	9.829
9.810	9.781	9.740	9.686	9.621	9.546	9.460	9.362	9.258	9.152
9.056	9.969	8.891	8.823	8.766	8.721	8.686	8.661	8.645	8.636

(*continued*)

TABLE III Continued.

Brightness									
GH CAR B									
9.890	9.890	9.891	9.891	9.892	9.894	9.895	9.897	9.899	9.901
9.903	9.906	9.909	9.911	9.914	9.917	9.920	9.923	9.927	9.930
9.934	9.937	9.941	9.945	9.949	9.953	9.957	9.961	9.965	9.969
9.974	9.978	9.983	9.987	9.992	9.997	10.001	10.006	10.011	10.016
10.021	10.026	10.032	10.037	10.042	10.047	10.052	10.058	10.063	10.068
10.074	10.079	10.084	10.090	10.095	10.100	10.106	10.111	10.116	10.121
10.127	10.132	10.137	10.142	10.147	10.152	10.158	10.163	10.168	10.173
10.178	10.183	10.188	10.193	10.197	10.202	10.207	10.212	10.217	10.221
10.226	10.230	10.235	10.239	10.244	10.248	10.252	10.256	10.261	10.265
10.268	10.272	10.276	10.280	10.283	10.287	10.290	10.293	10.296	10.299
10.302	10.305	10.308	10.310	10.313	10.315	10.317	10.319	10.321	10.323
10.325	10.327	10.328	10.330	10.331	10.332	10.333	10.334	10.335	10.335
10.336	10.337	10.337	10.337	10.337	10.337	10.337	10.337	10.337	10.336
10.335	10.335	10.334	10.332	10.331	10.330	10.328	10.326	10.324	10.321
10.318	10.315	10.312	10.308	10.305	10.300	10.296	10.291	10.285	10.280
10.274	10.267	10.260	10.253	10.245	10.237	10.229	10.220	10.211	10.201
10.191	10.181	10.171	10.160	10.149	10.138	10.127	10.116	10.105	10.093
10.082	10.071	10.059	10.048	10.037	10.027	10.016	10.006	9.996	9.986
9.977	9.968	9.960	9.952	9.945	9.938	9.931	9.925	9.919	9.914
9.910	9.906	9.902	9.899	9.897	9.895	9.893	9.891	9.891	9.890
GH CAR V									
9.012	9.012	9.012	9.012	9.013	9.014	9.015	9.016	9.017	9.019
9.020	9.022	9.024	9.025	9.027	9.029	9.031	9.033	9.035	9.037
9.040	9.042	9.044	9.046	9.048	9.051	9.053	9.055	9.058	9.060
9.063	9.065	9.068	9.070	9.073	9.075	9.078	9.081	9.083	9.086
9.089	9.092	9.094	9.097	9.100	9.103	9.106	9.109	9.112	9.116
9.119	9.122	9.125	9.128	9.132	9.135	9.138	9.142	9.145	9.148
9.152	9.155	9.158	9.162	9.165	9.169	9.172	9.175	9.179	9.182
9.185	9.189	9.192	9.195	9.199	9.202	9.205	9.208	9.212	9.215
9.218	9.221	9.224	9.227	9.230	9.233	9.235	9.238	9.241	9.243
9.246	9.248	9.251	9.253	9.256	9.258	9.260	9.262	9.264	9.266
9.268	9.270	9.272	9.274	9.275	9.277	9.279	9.280	9.282	9.283
9.284	9.286	9.287	9.288	9.289	9.290	9.291	9.292	9.293	9.294
9.295	9.296	9.297	9.297	9.298	9.298	9.299	9.299	9.299	9.299
9.299	9.299	9.299	9.298	9.297	9.297	9.296	9.294	9.293	9.291
9.290	9.288	9.285	9.283	9.280	9.277	9.273	9.270	9.266	9.262
9.258	9.253	9.248	9.243	9.238	9.232	9.226	9.220	9.214	9.207
9.201	9.194	9.187	9.180	9.173	9.166	9.159	9.152	9.144	9.137
9.130	9.123	9.116	9.109	9.102	9.096	9.089	9.083	9.077	9.071
9.065	9.060	9.055	9.050	9.045	9.041	9.037	9.033	9.030	9.027
9.024	9.022	9.019	9.017	9.016	9.014	9.013	9.013	9.012	9.012

in the photoelectric observations are so small that the vertical error bars are frequently within the circles. For convenience, we express the O−C residuals in fractions of the period.

The curves in the O−C diagrams are graphs of polynomials of third order for VY Car and WZ Car, and of a parabola for GH Car. Table V gives the coefficients M, P, q and Q of the light elements in the form

$$\text{Max JDhel} = M + PE + qE^2 + QE^3. \quad (1)$$

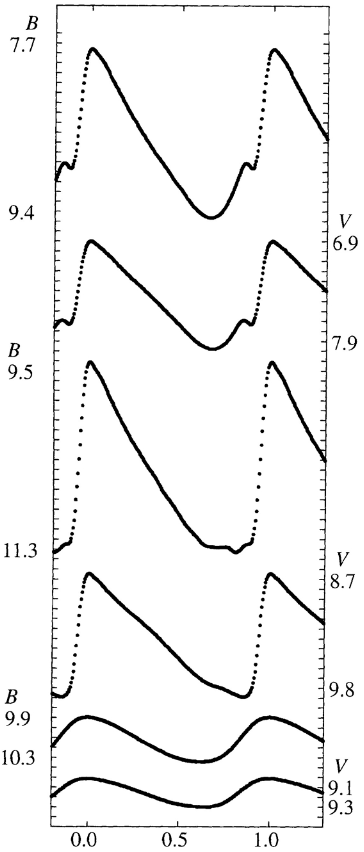

FIGURE 2 *B* and *V* filter standard light curves of VY Car (two upper curves), WZ Car (two middle curves) and GH Car (two lower curves). The abscissae give the phases.

TABLE IV Lags *D* of *B* filter epochs of maximum light compared with *V* filter epochs.

Cepheid	*D (days)*
VY Car	0.100
WZ Car	0.071
GH Car	0.041

TABLE V Light elements of cepheids of Form (1): M/σ, initial epoch and its error; P/σ, period and its error; q/σ, quadratic term and its error; Q/σ, cubic term and its error; $\mathrm{d}P/\mathrm{d}E$, period changes.

Cepheid	M/σ	P/σ	q/σ	Q/σ	dP/dE *(s year^{-1})*
VY Car	34 055.769	18.936 505 88	$-0.225\,714 \times 10^{-4}$	$-0.677\,123 \times 10^{-9}$	−75.23
	0.031	0.000 090 70	$0.647\,490 \times 10^{-7}$	$0.128\,615 \times 10^{-9}$	0.21
WZ Car	34 086.439	23.013 146 89	$0.356\,957 \times 10^{-5}$	$-0.197\,816 \times 10^{-8}$	9.79
	0.039	0.000 132 00	$0.110\,888 \times 10^{-6}$	$0.270\,653 \times 10^{-9}$	0.30
GH Car	34 388.272	5.725 579 55	$-0.124\,630 \times 10^{-7}$	—	−0.137
	0.019	0.000 005 87	$0.330\,800 \times 10^{-8}$	—	0.036

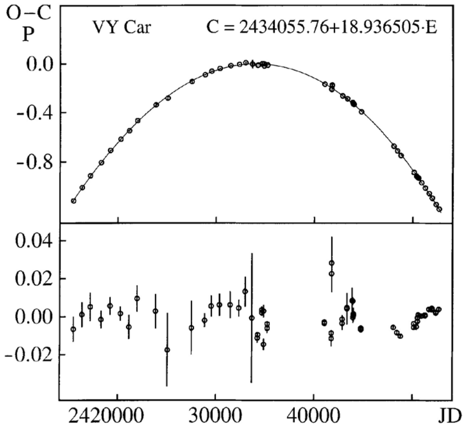

FIGURE 3 O−C data for VY Car plotted (a) as a function of the observed heliocentric Julian date of the light maximum and (b) corrected for the gradual decrease in pulsation period.

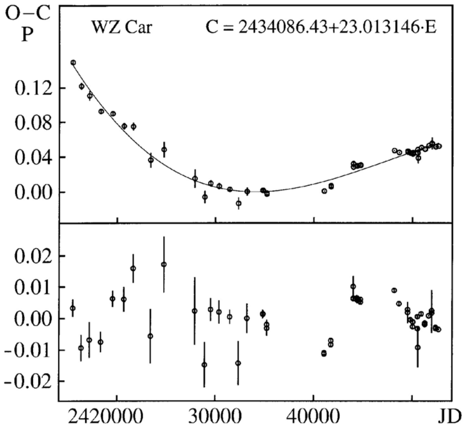

FIGURE 4 O−C data for WZ Car plotted (a) as a function of the observed heliocentric Julian date of the light maximum and (b) corrected for the gradual increase in pulsation period.

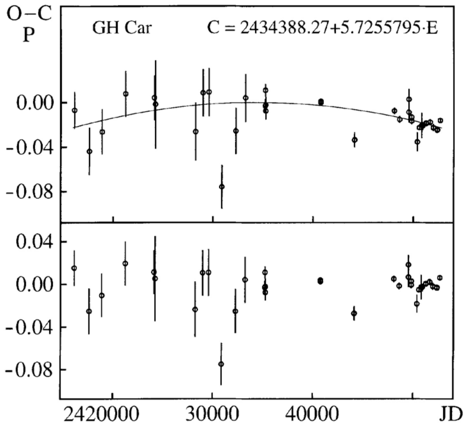

FIGURE 5 O−C data for GH Car plotted (a) as a function of the observed heliocentric Julian date of the light maximum and (b) corrected for the gradual decrease in pulsation period.

4 DISCUSSION

According to stellar evolutionary models, the evolutionary tracks of Cepheids crossing the instability strip do not run parallel to lines of constant period, which should result in progressive changes in their pulsation periods; so data points on an O−C diagram (according to the linear elements) should group themselves along a curve of the third (or greater) order (Fernie, 1990). The O−C diagrams in Figures 3(a), 4(a) and 5(a) suggest the existence of progressive changes in period for all three Cepheids. For VY Car and WZ Car the changes are large, and it is possible to approximate their O−C diagrams with a polynomial of third order, but in the case of GH Car we observe only a small period change and, because of the large scatter in the data points, it is not worth representing the O−C data by a polynomial of order larger than two. Therefore, the improved ephemeris for the times of light maxima (Tab. V) include four terms for VY Car and WZ Car, but only three terms for GH Car; the corresponding curves are plotted in Figures 3–5. Because of their large period changes, the light elements for VY Car and WZ Car are reliable and unlikely to be refined in the near future; for GH Car, its small period changes and low-quality O−C data (because of its small amplitude and the sine-like shape of light curve) do not allow us to obtain a good ephemeris, and its light elements will certainly improve in the future as new data are obtained.

The period P_E is the time derivative of the O−C approximating curve (1):

$$P_E = P + 2qE + 3QE^2, \tag{2}$$

and the rate of period change is the time derivative of P_E:

$$\frac{dP}{dE} = 2q + 6QE. \tag{3}$$

Calculated changes in the periods of our three Cepheids are given in the last column of Table V. The data refer to the middle of the time interval under consideration, that is M in Table V. In this case, $E = 0$ and

$$\frac{dP}{dE} = 2q. \tag{4}$$

Deviations from the curves presented in Figures 3(a), 4(a) and 5(a) are plotted in Figures 3(b), 4(b) and 5(b); cyclical waves are distinctly seen for VY Car and WZ Car, with cycle lengths of about 11 000 and 24 000 days respectively. Such waves are typical features in the O−C diagrams of many Cepheids (Berdnikov, 1994; Berdnikov and Pastukhova, 1994a, b, 1995; Berdnikov *et al.*, 1997, 2002).

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