Photometry of variable stars with periods near 1 day

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Mon. Not. R. astr. Soc. (1988) **235,** 1059–1072

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Accepted 1988 May 6. Received 1988 April 29; in original form 1988 January 25

Summary. We have obtained accurate, well-sampled light curves for seven stars which were candidates for short period type II Cepheids. One of the stars, CM UMa, was found to have an erroneous period. The correct period is 0.589 day and the star is an RRab star. The Fourier decomposition coefficients for the light curve of KP Cyg (period=0.86 day) combined with its high metallicity are consistent with its being either a type II Cepheid or an RR Lyrae star. The result for V486 Her (period=0.8 day) is inconclusive; it is probably an RRab star. The Fourier coefficients showed that CE Her (period=1.21 day) and XX Vir (period=1.35 day) are type II Cepheids as suspected. Both stars show excess scatter and rapid variations during declining light which we suggest deserve further attention. BB Gem has Fourier coefficients which are appropriate to a short period classical Cepheid, making it the shortest period fundamental pulsator of that class known in the Galaxy.

1 Introduction

A period of 1 day is commonly assumed as the boundary between the RRab stars and the type II Cepheids. The latter stars in the short-period range are a heterogeneous group with metallicities ranging from very low to at least solar (Harris 1981), kinematics appropriate to a range of populations (Harris & Wallerstein 1984) and a variety of light curve shapes. Diethelm (1983) sorted the light curves into several categories and subsequently (Diethelm 1986) used photometric abundances to show that at least one of the groups, his RRd stars, was physically distinct.

Petersen & Diethelm (1986) carried out Fourier decomposition of the light curves of 35 type II Cepheids and concluded that their pulsational properties were similar to those of the classical Cepheids. However, Simon (1986) rediscussed the Fourier coefficients in connection with pulsation models and reached somewhat different conclusions. In particular, he suggested that there

may be mass differences between some of Diethelm's groups. We are led to conclude that among pulsating stars with periods near 1 day there are several different types of object.

Although these studies have provided new insights, it is clear that more observations are needed. An examination of the light curves (see Diethelm 1983 for plots) shows that the data, drawn from a number of sources, often contain excessive scatter, exceeding 0.1 mag in some cases. For some stars there are gaps in the phase coverage which can introduce difficulties for Fourier decomposition. Furthermore, the sample of usable light curves is rather small. Peterson & Diethelm considered only five of the 35 light curves they decomposed to be of high quality.

To improve this situation we have started a program of photometric observations of variable stars with periods from about 0.75 day to 1 week. While the long-period limit is consistent with the usual division between BL Her and W Vir stars, we have extended the sample to somewhat shorter periods since, as Wallerstein & Cox (1984) pointed out, terminating the type II Cepheid regime at 1 day is an essentially arbitrary choice.

This paper presents results for the seven stars listed in Table 1. The first column gives the star name while columns two and three give the period and type of variability from the *General Catalogue of Variable Stars* (4th edn). As discussed below we have determined new epochs of maximum for all except one of them. These are given in column four while column five indicates the type of variability inferred from our data.

Table 1. The variable stars.

Star	Period	Type (GCVS)	Epoch of Maximum *	Type (revised)
CM UMa	0.589	Cep:	6057.92 6442.03 7196.69	RRab
FK Vul	0.4340529	RRab	6593.88	RRab
V486 Her	0.8059317	RRab	6624.83	RRab?
KP Cyg	0.855936	RRab	6699.62	Type II Cepheid or RR Lyrae
CE Her	1.2094357	CWB	6583.77	Type II Cepheid, S-XX
XX Vir	1.3482051	CWB	6203.67	Type II Cepheid, S-XX
BB Gem	2.308207	DCep	6056.78	Classical Cepheid

* Determined from present data, Heliocentric Julian Date - 2,440,000. For CM UMa, the period determined with the present data was not accurate enough to carry the phasing from one season to the next. For that reason, we give a date of maximum for each year it was observed.

2 The observations

We made most of the observations with the automatic filter photometer (Taylor 1980) on the Behlen Observatory 0.76-m telescope. An RCA 31034C photomultiplier was used with broad-band *V*- and *R*-filters matched to the Cousins system. Both the telescope and the photometer were under computer control. This allowed rapid switching between the star and sky apertures and between the variable and its comparison star. It was thus possible to obtain accurate differential magnitudes under somewhat adverse conditions.

Measurements of the variable through both the *V*- and *R*-filter were alternated with observations of the comparison star. A sequence consisted of at least four observations of the variable and continued until the internal errors of the differentials were judged to be satisfactory. The only exception to this practice occurred when rapid changes in the variable were noted. In that case, the sequence was continued as long as possible.

On photometric quality nights we observed standard stars from Landolt's (1983) list and

determined transformations to the system of Cousins. The nights were grouped into intervals no longer than a month and mean colour terms calculated. These were then used for all the nights in the interval. When a night was regarded as photometric, zero points were also derived and the magnitudes were reduced to the standard system. For nights which were not of photometric quality, only differential magnitudes were derived but they are still on the standard system in the sense of having been corrected for colour terms. It was found that the mean colour terms for our filters and photocell changed by less than 0.02 mag over periods of months. Since this is smaller than the error in determining nightly transformations, the use of mean coefficients is justified and will reduce the internal scatter in the final results.

Once the observations had been placed on the standard system for the photometric nights or corrected for colour terms on the non-photometric nights, differential magnitudes were formed for the variables relative to the comparison stars. The observational sequence was generally

Table 2. Photometric data for CM UMa (period: 0.589, epochs of maximum: 2 446 057.92 and 2 446 442.03).

HJD − 2,440,000	PHASE	V	s.d.	R	s.d.	HJD − 2,440,000	PHASE	V	s.d.	R	s.d.
6056.995	0.430	2.701	3	2.761	7	6078.705	0.288	2.512	7	2.607	13
6057.796	0.790	2.855	6	2.934	16	6078.768	0.395	2.622	11	2.709	8
6057.851	0.883	2.705		2.775		6110.612	0.459	2.700	8	2.737	13
6057.853	0.887	2.686		2.755		6110.671	0.560	2.773	8	2.804	7
6057.856	0.892	2.599		2.703		6113.601	0.534	2.763	7	2.801	17
6057.859	0.897	2.599		2.661		6113.703	0.707	2.790	11	2.836	14
6057.862	0.902	2.483		2.610		6441.941	0.848	2.838		2.935	
6057.864	0.905	2.428		2.547		6441.945	0.855	2.868		2.956	
6057.867	0.911	2.378		2.496		6441.954	0.870	2.746		2.883	
6057.870	0.916	2.319		2.455		6441.957	0.875	2.622		2.758	
6057.873	0.921	2.281		2.461		6441.960	0.880	2.681		2.855	
6057.881	0.934	2.250		2.434		6441.963	0.886	2.675		2.763	
6057.884	0.939	2.199		2.372		6441.968	0.894	2.613		2.711	
6057.886	0.943	2.206		2.358		6441.971	0.899	2.483		2.600	
6057.889	0.948	2.155		2.343		6441.974	0.904	2.533		2.588	
6057.892	0.953	2.118		2.310		6441.976	0.908	2.472		2.599	
6057.894	0.956	2.101		2.278		6441.983	0.920	2.407		2.533	
6057.897	0.961	2.061		2.283		6441.985	0.923	2.332		2.518	
6057.899	0.965	2.079		2.266		6441.988	0.928	2.375		2.557	
6057.902	0.970	2.040		2.229		6441.992	0.935	2.314		2.472	
6057.904	0.973	2.039		2.243		6441.995	0.940	2.219		2.420	
6057.907	0.978	2.049		2.256		6441.997	0.943	2.184		2.411	
6057.909	0.982	2.059		2.266		6442.000	0.948	2.203		2.413	
6057.912	0.987	2.056		2.272		6463.889	0.111	2.377		2.500	
6057.914	0.990	2.040		2.238		6463.890	0.115	2.385		2.530	
6057.917	0.995	2.048		2.273		6463.894	0.120	2.398		2.526	
6057.925	0.009	2.095		2.259		6463.896	0.125	2.404		2.519	
6057.928	0.014	2.091		2.265		6463.899	0.130	2.410		2.534	
6057.930	0.017	2.096		2.314		6493.788	0.875	2.710		2.832	
6057.933	0.023	2.108		2.270		6493.791	0.880	2.698		2.801	
6057.936	0.028	2.120		2.347		6493.794	0.885	2.662		2.765	
6057.966	0.079	2.234	3	2.382	14	6493.797	0.890	2.635		2.756	
6057.998	0.133	2.326	8	2.445	7	6493.800	0.895	2.601		2.729	
6058.016	0.163	2.372	8	2.525	11	6493.803	0.901	2.619		2.708	
6067.952	0.032	2.257	4	2.408	6	6493.806	0.906	2.597		2.680	
6068.003	0.119	2.387	14	2.496	21	6493.809	0.911	2.538		2.641	
6068.963	0.749	2.781	10	2.853	7	6493.812	0.916	2.503		2.609	
6068.988	0.791	2.831	6	2.887	27	6493.816	0.923	2.507		2.602	
6069.005	0.820	2.770		2.806		6493.818	0.926	2.491		2.590	
6069.007	0.824	2.749		2.835		6493.820	0.929	2.460		2.590	
6069.010	0.829	2.747		2.829		6493.861	0.999	2.232		2.418	
6069.012	0.832	2.734		2.842		6493.863	0.002	2.219		2.383	
6069.015	0.837	2.719		2.810		6493.865	0.006	2.226		2.383	
6069.020	0.846	2.734		2.826		6493.869	0.013	2.212		2.382	
6069.022	0.849	2.685		2.751		6493.889	0.047	2.219		2.349	
6069.024	0.852	2.667		2.740		6493.890	0.048	2.254		2.370	
6069.026	0.856	2.650		2.748		6493.892	0.052	2.246		2.409	
6069.029	0.861	2.634		2.722		6493.895	0.057	2.240		2.427	

started and terminated with an observation of the variable, so usual practice was to form a differential magnitude for the mean of pairs of variable measurements and the intervening comparison star magnitude. The differential magnitudes were then averaged for the sequence and the root mean square of the deviations from the mean calculated. This rms value was then increased by the square root of two since there are only $n/2$ statistically independent data points in n differential magnitudes.

The differential magnitudes of the seven variable stars and their internal standard deviations are listed in Tables 2–8 and are plotted in Figs 1–7. The phases were calculated from the GCVS periods (column 2 of Table 1) and the epochs of maximum determined from our data (column 4).

In instances when the variable changed significantly between successive observations, differential magnitudes from single observations are given in Tables 2–8. Such cases can be recognized because they lack an entry in the standard deviation column. Observations of this type were only retained when they defined parts of the light curve not otherwise available and when the sky conditions were judged to be stable from the comparison star observations.

In order to verify the constancy of the comparison stars, a check star was selected for each (with

Table 3. Photometric data for FK Vul (period: 0.4340529, epoch of maximum: 2 446 593.88).

HJD – 2,440,000	PHASE	V	s.d.	R	s.d.
6262.846	0.342	2.401	25	2.395	30
6263.835	0.620	2.529	8	2.520	8
6272.771	0.208	2.206	10	2.339	11
6272.839	0.365	2.410	14	2.399	6
6272.885	0.471	2.508	7	2.477	4
6273.840	0.671	2.617	7	2.585	10
6315.697	0.104	2.048	10	2.136	20
6315.702	0.116	2.075	3	2.148	4
6315.709	0.132	2.112	16	2.191	13
6315.798	0.337	2.406	6	2.413	11
6315.809	0.362	2.468	10	2.425	1
6315.861	0.482	2.556	10	2.505	11
6316.638	0.272	2.339	8	2.340	6
6316.644	0.286	2.363	4	2.359	14
6316.692	0.396	2.474	6	2.468	3
6316.764	0.562	2.545	10	2.513	1
6316.806	0.659	2.579	6	2.563	18
6316.858	0.779	2.706	14	2.686	23
6343.785	0.814	2.749	18	2.723	23
6551.870	0.215	2.240	11	2.269	7
6551.920	0.330	2.378	8	2.378	20
6564.826	0.063	1.819		1.967	
6564.828	0.068	1.825		1.973	
6564.830	0.073	1.832		1.970	
6564.833	0.080	1.871		1.977	
6564.835	0.084	1.897		1.990	
6564.837	0.089	1.920		2.011	
6564.895	0.222	2.169	4	2.208	8
6590.837	0.989	1.817	7	1.985	4
6593.799	0.814	2.717	4	2.669	10
6593.833	0.892	2.431		2.463	
6593.835	0.897	2.372		2.388	
6593.837	0.901	2.307		2.366	
6593.840	0.908	2.266		2.324	
6593.842	0.913	2.247		2.288	
6593.844	0.917	2.231		2.264	
6593.846	0.922	2.168		2.280	
6593.849	0.929	2.109		2.215	
6593.851	0.933	2.066		2.184	
6593.853	0.938	2.031		2.154	
6593.856	0.945	1.992		2.140	
6593.858	0.950	1.940		2.092	
6593.861	0.956	1.933		2.073	
6593.874	0.986	1.839		1.982	
6593.877	0.993	1.835		1.990	
6593.879	0.998	1.816		1.992	
6593.881	0.003	1.817		1.976	
6593.883	0.007	1.836		1.999	
6593.886	0.014	1.856		1.977	
6593.888	0.019	1.865		1.983	
6593.890	0.023	1.856		1.977	
6593.893	0.030	1.865		2.006	
6613.784	0.857	2.654	6	2.626	13
6613.801	0.896	2.454	17	2.489	3
6613.807	0.910	2.400		2.447	
6613.809	0.915	2.347		2.438	
6613.811	0.919	2.341		2.344	
6613.814	0.926	2.282		2.349	
6613.816	0.931	2.222		2.311	
6613.819	0.938	2.197		2.277	
6613.821	0.942	2.127		2.218	
6613.823	0.947	2.082		2.178	
6613.826	0.954	2.047		2.172	
6613.828	0.958	2.003		2.105	
6613.831	0.965	1.928		2.084	
6613.833	0.970	1.919		2.050	
6613.836	0.977	1.874		2.004	
6613.851	0.011	1.786	4	1.974	10
6613.854	0.018	1.774		1.950	
6613.857	0.025	1.808		1.975	
6613.859	0.030	1.837		2.001	
6650.679	0.856	2.652		2.612	
6650.684	0.868	2.550		2.575	
6650.689	0.879	2.461		2.487	
6650.694	0.891	2.410		2.450	
6650.717	0.944	1.946		2.044	
6650.719	0.949	1.922		2.069	
6650.721	0.953	1.891		2.055	
6650.723	0.958	1.876		2.004	
6650.726	0.965	1.830		2.976	
6650.728	0.969	1.810		1.948	
6650.730	0.974	1.798		1.983	
6650.732	0.979	1.804		1.953	
6650.735	0.985	1.809		1.974	
6669.706	0.694	2.644	7	2.588	6
6699.665	0.713	2.599	14	2.568	4
6699.699	0.794	2.709	8	2.694	10

Table 4. Photometric data for V486 Her (period: 0.8059317, epoch of maximum: 2 446 624.83).

HJD – 2,440,000	PHASE	V	s.d.	R	s.d.	HJD – 2,440,000	PHASE	V	s.d.	R	s.d.
6210.879	0.369	5.494	7	5.321	7	6582.833	0.890	5.324		5.228	
6238.824	0.043	5.203	13	5.119	13	6582.835	0.892	5.328		5.210	
6238.858	0.086	5.243	10	5.166	17	6582.838	0.896	5.289		5.209	
6238.899	0.136	5.301	20	5.184	11	6582.841	0.900	5.309		5.286	
6239.811	0.268	5.387	8	5.245	7	6582.844	0.903	5.310		5.251	
6239.845	0.310	5.436	11	5.291	8	6582.846	0.906	5.361		5.211	
6239.855	0.323	5.529	13	5.378	20	6582.849	0.910	5.308		5.233	
6239.861	0.330	5.416	4			6582.854	0.916	5.301		5.210	
6239.890	0.366	5.468	11	5.288	31	6582.869	0.934	5.307		5.202	
6239.897	0.375	5.432	7	5.320	30	6582.876	0.943	5.268	4	5.211	18
6261.826	0.585	5.610	8	5.435	14	6582.886	0.956	5.244	16	5.166	8
6272.703	0.080	5.219	8	5.122	10	6583.682	0.943	5.282	14	5.196	25
6272.790	0.188	5.311	8	5.204	20	6583.720	0.990	5.209	16	5.106	3
6273.733	0.358	5.482	7	5.328	13	6589.699	0.409	5.482	7	5.325	8
6273.803	0.445	5.517	7	5.351	14	6590.725	0.682	5.666	7	5.495	10
6316.609	0.560	5.587	4	5.401	14	6590.787	0.759	5.708	10	5.521	11
6316.676	0.643	5.630	4	5.473	20	6593.701	0.375	5.480	4	5.314	4
6316.725	0.704	5.667	10	5.516	17	6593.757	0.444	5.505	3	5.328	20
6493.903	0.545	5.568	7	5.378	11	6613.655	0.135	5.277	13	5.162	11
6530.870	0.414	5.514	6	5.325	10	6613.709	0.200	5.321	6	5.204	0
6530.916	0.472	5.518	4	5.360	17	6624.682	0.817	5.651	13	5.503	11
6551.731	0.299	5.419	13	5.257	11	6624.695	0.833	5.644	7	5.471	23
6551.796	0.379	5.469	11	5.303	16	6624.760	0.913	5.327	11	5.223	4
6551.893	0.500	5.551	7	5.367	11	6624.772	0.928	5.304	11	5.214	20
6582.739	0.773	5.728	10	5.498	18	6624.786	0.946	5.278	3	5.190	8
6582.782	0.826	5.683		5.531		6624.804	0.968	5.230	7	5.140	13
6582.784	0.829	5.731		5.554		6624.818	0.985	5.180	11	5.114	14
6582.787	0.833	5.668		5.473		6650.625	0.007	5.185	7	5.092	6
6582.789	0.835	5.681		5.467		6650.654	0.042	5.210	6	5.106	7
6582.792	0.839	5.576		5.466		6650.704	0.104	5.252	6	5.143	13
6582.794	0.841	5.655		5.506		6669.640	0.600	5.609	10	5.429	3
6582.797	0.845	5.585		5.465		6699.568	0.735	5.665		5.540	
6582.799	0.848	5.590		5.460		6699.569	0.736	5.682		5.571	
6582.802	0.851	5.586		5.420		6699.572	0.740	5.717		5.507	
6582.805	0.855	5.536		5.402		6699.574	0.742	5.763		5.555	
6582.807	0.857	5.516		5.398		6698.999	0.029	5.665		5.534	
6582.810	0.861	5.542		5.354		6699.579	0.749	5.676		5.528	
6582.830	0.886	5.338		5.227		6699.580	0.750	5.681		5.517	

Table 5. Photometric data for KP Cyg (period: 0.855936, epoch of maximum: 2 446 699.62).

HJD – 2,440,000	PHASE	V	s.d.	R	s.d.	HJD – 2,440,000	PHASE	V	s.d.	R	s.d.
6272.736	0.266	3.350	17	3.438	16	6699.593	0.969	3.137		3.295	
6272.814	0.357	3.472	8	3.519	6	6699.595	0.971	3.109		3.310	
6272.865	0.417	3.541	3	3.569	4	6699.597	0.973	3.115		3.257	
6272.902	0.460	3.592	7	3.623	8	6699.599	0.976	3.105		3.269	
6273.872	0.594	3.791	8	3.769	7	6699.602	0.979	3.072		3.256	
6302.744	0.325	3.420	10	3.484	10	6699.604	0.982	3.081		3.243	
6302.756	0.339	3.457	8	3.513	8	6699.606	0.984	3.050		3.213	
6316.622	0.539	3.701	6	3.703	20	6699.609	0.987	3.027		3.217	
6316.706	0.637	3.841	6	3.823	16	6699.612	0.991	3.004		3.201	
6316.752	0.690	3.890	7	3.873	20	6699.614	0.993	3.018		3.214	
6316.832	0.784	3.948	18	3.921	8	6699.616	0.996	3.001		3.173	
6343.688	0.160	3.204	16	3.335	6	6699.618	0.998	2.982		3.169	
6343.752	0.235	3.314	7	3.412	10	6699.621	0.001	3.010		3.196	
6551.841	0.349	3.470	8	3.502	8	6699.622	0.003	3.007		3.194	
6590.819	0.887	3.757	6	3.784	13	6710.698	0.942	3.363		3.496	
6590.894	0.975	3.081				6710.700	0.945	3.350		3.494	
6590.896	0.977	3.068		3.245		6710.702	0.947	3.326		3.458	
6590.898	0.979	3.042		3.245		6710.704	0.949	3.323		3.436	
6590.900	0.982	3.045		3.213		6710.707	0.953	3.307		3.407	
6590.903	0.985	3.034		2.205		6710.709	0.955	3.275		3.393	
6596.814	0.890	3.697	6	3.743	13	6710.712	0.959	3.231		3.391	
6699.589	0.964	3.182		3.343		6710.715	0.962	3.174		3.345	
6699.590	0.965	3.180		3.335		6710.718	0.966	3.161		3.278	

Table 6. Photometric data for CE Her (period: 1.2094357, epoch of maximum: 2 446 583.77).

HJD − 2,440,000	PHASE	V	s.d.	R	s.d.
5935.728	0.178	1.034	7	1.007	10
5938.681	0.620	1.680	8	1.531	11
5938.728	0.658	1.717	11	1.554	10
5939.676	0.442	1.495	3	1.355	6
5939.722	0.480	1.545	10	1.403	10
6203.853	0.873	1.831	17	1.657	18
6203.910	0.920	1.791	6	1.648	10
6206.790	0.301	1.287	8	1.199	14
6206.904	0.395	1.423	6	1.289	13
6210.739	0.566	1.633	8	1.486	7
6210.790	0.608	1.691	6	1.529	11
6210.846	0.655	1.691	8	1.548	10
6210.909	0.707	1.705	11	1.550	7
6234.771	0.436	1.489	14	1.372	10
6234.810	0.468	1.551	10	1.412	17
6234.873	0.521	1.655	7	1.503	18
6234.889	0.534	1.608	6	1.477	11
6236.746	0.069	0.705	7	0.755	20
6236.804	0.117	0.859	8	0.872	3
6236.833	0.141	0.923	13	0.925	16
6236.862	0.165	0.997	6	0.976	4
6236.889	0.187	1.053	6	1.030	8
6238.757	0.732	1.718	11	1.577	11
6238.798	0.766	1.730	8	1.595	8
6238.841	0.801	1.703	10	1.551	16
6238.888	0.840	1.760	11	1.620	16
6239.673	0.489	1.562	10	1.434	10
6239.704	0.515	1.586	8	1.423	8
6239.742	0.546	1.621	7	1.478	4
6239.789	0.585	1.664	11	1.504	7
6239.832	0.621	1.673	10	1.518	6
6239.877	0.658	1.672	4	1.526	17
6261.798	0.783	1.738	8	1.586	3
6261.864	0.838	1.771	16	1.632	8
6315.639	0.301	1.293	10	1.216	14
6316.599	0.094	0.775	6	0.808	8
6493.919	0.708	1.709	10	1.579	8
6509.951	0.964	1.155		1.126	
6509.954	0.967	1.148		1.133	
6509.959	0.971	1.129		1.118	
6509.961	0.973	1.054		1.037	
6509.964	0.975	0.929		0.944	
6509.966	0.977	0.918		0.934	
6509.969	0.979	0.875		0.909	
6509.971	0.981	0.849		0.892	
6511.857	0.540	1.653	17	1.491	4
6526.822	0.913	1.852		1.712	
6526.826	0.917	1.779		1.646	
6526.829	0.919	1.745		1.580	
6526.862	0.946	1.494		1.390	
6526.865	0.949	1.466		1.353	
6526.867	0.951	1.363		1.267	
6526.869	0.952	1.359		1.276	
6526.872	0.955	1.318		1.273	
6526.874	0.956	1.321		1.234	
6526.879	0.960	1.227		1.183	
6526.882	0.963	1.198		1.171	
6526.884	0.965	1.121		1.129	
6526.887	0.967	1.111		1.123	
6526.889	0.969	1.067		1.083	
6526.892	0.971	1.067		1.061	
6526.894	0.973	1.024		1.020	
6526.897	0.975	0.955		0.977	
6526.900	0.978	0.894		0.920	
6552.750	0.352	1.312	24	1.237	18
6564.725	0.253	1.182	6	1.108	6
6564.916	0.411	1.420	6	1.303	16
6582.673	0.093	0.778	10	0.822	8
6582.713	0.126	0.876	6	0.892	8
6583.736	0.971	1.012		1.007	
6583.741	0.976	0.958		0.953	
6583.742	0.977	0.879		0.918	
6583.747	0.981	0.770		0.810	
6583.758	0.990	0.661		0.723	
6583.760	0.992	0.636		0.684	
6583.764	0.995	0.563		0.645	
6583.769	0.999	0.568		0.626	
6583.770	0.000	0.495		0.591	
6583.774	0.003	0.537		0.630	
6589.675	0.882	1.809	6	1.653	7
6589.722	0.921	1.780	4	1.621	14
6589.730	0.928	1.742	4	1.618	23
6589.734	0.931	1.691		1.560	
6589.736	0.933	1.713		1.553	
6589.739	0.935	1.670		1.561	
6589.741	0.937	1.680		1.492	
6589.746	0.941	1.613		1.514	
6589.748	0.942	1.576		1.445	
6589.750	0.944	1.542		1.411	
6589.752	0.946	1.506		1.413	
6589.754	0.947	1.464		1.387	
6589.757	0.950	1.402		1.295	
6589.759	0.952	1.386		1.278	
6589.761	0.953	1.338		1.224	
6589.763	0.955	1.271		1.200	
6589.765	0.957	1.275		1.238	
6589.768	0.959	1.263		1.201	
6589.776	0.966	1.125		1.128	
6589.778	0.967	1.099		1.111	
6589.789	0.976	0.880		0.897	
6589.791	0.978	0.884		0.889	
6589.793	0.980	0.847		0.882	
6589.795	0.981	0.784		0.816	
6589.797	0.983	0.738		0.792	
6589.799	0.985	0.716		0.769	
6589.802	0.987	0.685		0.744	
6589.804	0.989	0.622		0.648	
6589.806	0.990	0.629		0.683	
6589.808	0.992	0.637		0.719	
6589.811	0.995	0.627		0.684	
6589.813	0.996	0.590		0.657	
6589.815	0.998	0.569		0.630	
6589.817	1.000	0.552		0.652	
6589.818	0.000	0.543		0.624	
6589.836	0.015	0.538	6	0.616	4
6589.856	0.032	0.569	7	0.638	7
6589.886	0.057	0.638	10	0.700	8
6590.757	0.777	1.753	10	1.607	16
6593.683	0.196	1.072	10	1.039	13
6593.728	0.233	1.150	4	1.100	8
6593.816	0.306	1.293	7	1.202	4
6596.704	0.694	1.688	10	1.545	7
6596.715	0.703	1.724	6	1.543	4
6596.766	0.745	1.715	6	1.565	13
6596.829	0.797	1.708	6	1.565	14
6596.884	0.843	1.767	10	1.628	10
6624.654	0.804	1.719	10	1.584	11

Figure 1. Light curves for CM UMa. The two upper panels present the data from the photoelectric photometry while the lower panel contains the data from the CCD photometry. All are phased with a period of 0.589 and the epoch from Table 1 which is appropriate to each observation. Here and in subsequent figures open circles denote points based on a single differential or points with standard errors larger than 0.01 mag. When a number of open circles are closely crowded, they are plotted as a single larger circle.

Table 7. Photometric data for XX Vir (period: 1.3482051, epoch of maximum: 2 446 203.67).

HJD – 2,440,000	PHASE	V	s.d.	R	s.d.	HJD – 2,440,000	PHASE	V	s.d.	R	s.d.
6141.872	0.162	2.164	15	2.105	0	6552.791	0.952	1.975		1.972	
6171.749	0.323	2.396	8	2.286	10	6552.822	0.975	1.749	10	1.785	10
6171.806	0.365	2.463	10	2.335	14	6556.659	0.821	2.874	14	2.680	7
6203.673	0.002	1.729	4	1.781	10	6556.668	0.828	2.848	11	2.674	17
6203.724	0.040	1.846	8	1.864	10	6556.698	0.850	2.883	11	2.708	11
6203.768	0.073	1.945	3	1.944	6	6556.745	0.885	2.840	8	2.680	13
6203.819	0.111	2.035	10	2.012	8	6556.754	0.892	2.812		2.685	
6210.658	0.183	2.184	6	2.102	11	6556.778	0.909	2.595		2.490	
6210.711	0.222	2.255	10	2.172	4	6556.780	0.911	2.571		2.422	
6210.774	0.269	2.342	6	2.233	13	6556.782	0.912	2.555		2.437	
6210.812	0.297	2.362	4	2.260	7	6556.785	0.915	2.437		2.321	
6171.886	0.425	2.498	4	2.336	28	6556.787	0.916	2.380		2.275	
6236.720	0.514	2.650	20	2.487	7	6556.790	0.918	2.428		2.329	
6239.685	0.713	2.734	6	2.578	16	6556.792	0.920	2.367		2.234	
6239.719	0.739	2.749	8	2.607	11	6556.795	0.922	2.382		2.266	
6493.837	0.224	2.262	10	2.190	10	6556.798	0.924	2.389		2.314	
6493.876	0.253	2.324	3	2.210	6	6556.800	0.926	2.365		2.293	
6493.940	0.301	2.384	8	2.275	3	6556.803	0.928	2.368		2.266	
6493.961	0.316	2.410	3	2.296	8	6556.805	0.929	2.337		2.255	
6493.990	0.338	2.442	8	2.315	7	6556.824	0.944	2.183		2.107	
6509.825	0.083	1.993	10	1.985	8	6556.826	0.945	2.117		2.093	
6509.865	0.113	2.045	17	2.019	21	6556.828	0.947	2.094		2.055	
6509.922	0.155	2.168	11	2.122	14	6556.831	0.949	2.054		2.059	
6511.796	0.545	2.644	7	2.479	14	6556.833	0.950	2.030		2.058	
6511.827	0.568	2.676	7	2.519	8	6556.835	0.952	2.048		2.038	
6530.785	0.630	2.680	11	2.524	13	6556.838	0.954	1.941		1.994	
6530.935	0.741	2.733	10	2.586	8	6564.653	0.750	2.776	7	2.604	11
6536.703	0.019	1.803	4	1.833	13	6564.676	0.767	2.771	10	2.603	10
6552.716	0.897	2.788	7	2.626	10	6564.753	0.825	2.876	8	2.704	7
6552.768	0.935	2.311		2.249		6564.786	0.850	2.920	7	2.719	8
6552.772	0.938	2.258		2.207		6564.802	0.861	2.884	4	2.710	14
6552.774	0.940	2.210		2.186		6582.645	0.096	1.991	11	1.972	10
6552.776	0.941	2.198		2.149		6590.675	0.052	1.891	7	1.888	23
6552.779	0.943	2.155		2.121		6594.701	0.038	1.841	4	1.884	10
6552.781	0.945	2.153		2.119		6596.676	0.503	2.626	10	2.455	10
6552.784	0.947	2.119		2.090		6596.738	0.549	2.671	6	2.514	17
6552.786	0.948	2.078		2.060		6613.687	0.121	2.060	11	2.024	10
6552.789	0.951	1.951		1.950		6624.665	0.264	2.343	6	2.231	10

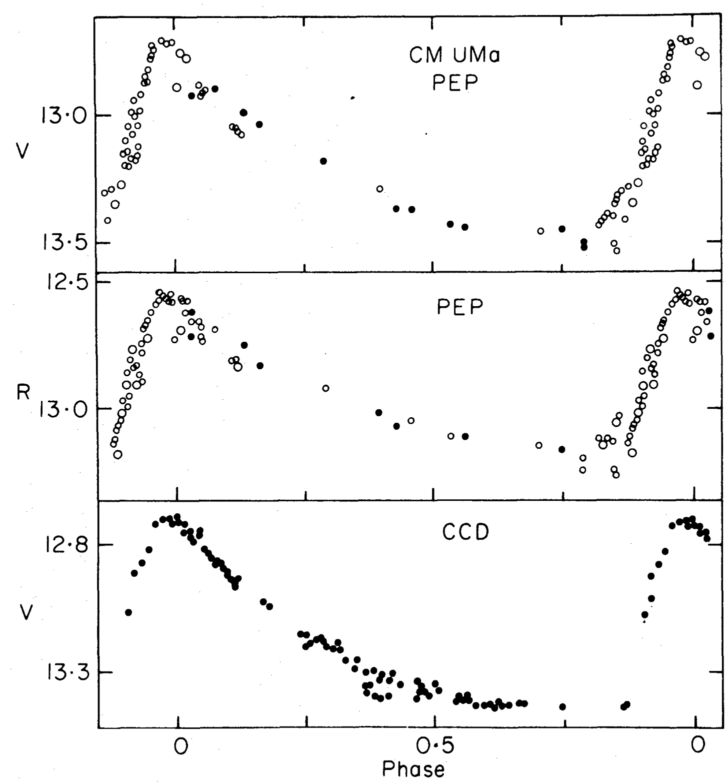

Figure 1.

Table 8. Photometric data for BB Gem (period: 2.308207, epoch of maximum: 2 446 056.78).

HJD - 2,440,000	PHASE	V	s.d.	R	s.d.	HJD - 2,440,000	PHASE	V	s.d.	R	s.d.
6056.795	0.006	1.173	1	1.316	4	6439.776	0.928	1.776		1.809	
6056.879	0.043	1.204	6	1.331	4	6439.780	0.929	1.719		1.740	
6056.937	0.068	1.261	6	1.385	3	6439.782	0.931	1.705		1.721	
6057.662	0.382	1.903	3	1.862	4	6439.785	0.932	1.718		1.739	
6057.758	0.424	1.950	6	1.911	4	6439.789	0.933	1.734		1.775	
6057.831	0.455	1.975	7	1.929	7	6439.791	0.935	1.681		1.720	
6057.949	0.506	2.036	1	1.970	6	6439.797	0.937	1.615		1.679	
6067.923	0.827	2.168	6	2.099	6	6439.801	0.939	1.595		1.660	
6077.633	0.034	1.202	13	1.334	13	6439.806	0.941	1.562		1.643	
6078.625	0.464	1.990	8	1.931	7	6439.811	0.943	1.544		1.607	
6078.682	0.489	2.020	7	1.959	4	6439.813	0.944	1.525		1.594	
6078.732	0.511	2.035	3	1.981	6	6439.817	0.945	1.490		1.571	
6110.573	0.305	1.786	4	1.772	4	6439.819	0.947	1.448		1.552	
6110.637	0.333	1.839	1	1.801	6	6439.822	0.948	1.495		1.576	
6113.580	0.608	2.112	3	2.037	4	6439.824	0.949	1.465		1.562	
6113.616	0.623	2.117	4	2.043	3	6439.827	0.950	1.451		1.538	
6113.675	0.649	2.135	4	2.061	3	6441.808	0.808	2.199	7	2.124	8
6113.738	0.676	2.144	10	2.069	7	6444.632	0.032	1.190	6	1.332	7
6140.601	0.314	1.778	11	1.770	8	6444.711	0.066	1.263	4	1.388	4
6140.622	0.324	1.823	6	1.796	4	6444.765	0.090	1.331	7	1.433	8
6141.590	0.743	2.190	6	2.103	3	6444.827	0.116	1.401	7	1.489	7
6141.651	0.769	2.220	7	2.142	7	6444.879	0.139	1.451	4	1.515	7
6146.588	0.908	1.884	7	1.884	7	6463.762	0.319	1.810	4	1.787	4
6146.618	0.921	1.804	4	1.823	10	6483.689	0.953	1.427		1.509	
6146.634	0.928	1.747	13	1.774	4	6483.691	0.954	1.395		1.503	
6148.593	0.777	2.207	10	2.131	7	6483.694	0.955	1.397		1.483	
6148.656	0.804	2.207	10	2.128	10	6483.696	0.956	1.389		1.481	
6153.584	0.939	1.600	16	1.648	16	6483.699	0.957	1.381		1.462	
6153.592	0.943	1.567	21	1.627	21	6483.704	0.959	1.365		1.457	
6153.598	0.945	1.553	21	1.589	21	6483.707	0.961	1.334		1.448	
6153.602	0.947	1.491	21	1.572	21	6483.709	0.961	1.347		1.476	
6153.609	0.950	1.440	31	1.549	31	6483.711	0.962	1.356		1.485	
6164.597	0.710	2.207	14	2.110	21	6483.714	0.964	1.321		1.439	
6164.633	0.726	2.191	17	2.111	14	6483.718	0.965	1.302		1.435	
6171.607	0.747	2.197	8	2.109	10	6483.720	0.966	1.321		1.432	
6343.917	0.398	1.967	8	1.934	13	6483.723	0.967	1.307		1.421	
6412.682	0.190	1.574	7	1.613	10	6483.743	0.976	1.234	16	1.372	14
6412.748	0.219	1.655	4	1.670	10	6488.636	0.096	1.344	17	1.454	13
6412.791	0.237	1.670	6	1.680	4	6488.723	0.133	1.440	8	1.512	8
6413.846	0.694	2.170	3	2.093	4	6490.639	0.964	1.317	7	1.431	8
6413.870	0.705	2.187	11	2.103	11	6490.695	0.988	1.194	7	1.337	7
6413.968	0.747	2.202	3	2.121	3	6490.740	0.007	1.163	13	1.314	11
6439.695	0.893	2.022		1.979		6497.631	0.993	1.169	4	1.313	4
6439.698	0.894	1.990		1.967		6497.668	0.009	1.174	1	1.316	3
6439.704	0.897	1.924		1.885		6517.609	0.648	2.152	7	2.072	8
6439.706	0.898	1.953		1.923		6530.682	0.312	1.803	10	1.774	11

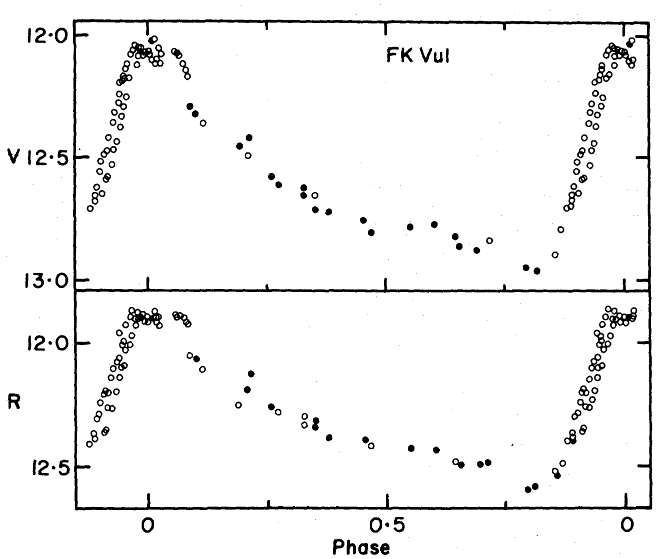

Figure 2. Light curve for FK Vul plotted with a period of 0.4340529 and epoch of maximum of 2446593.88.

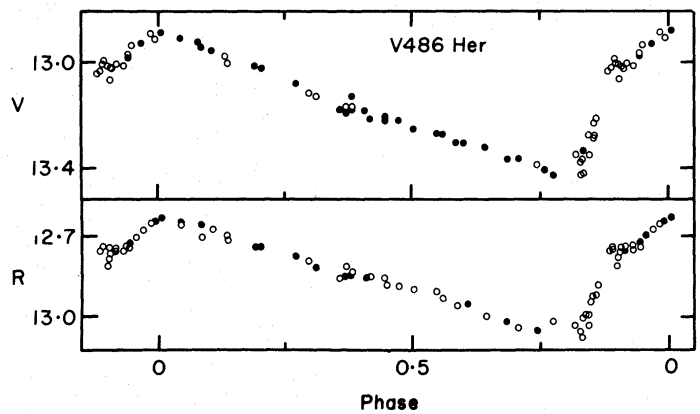

Figure 3. Light curve for V486 Her plotted with a period of 0.8059317 and epoch of maximum of 2446624.83.

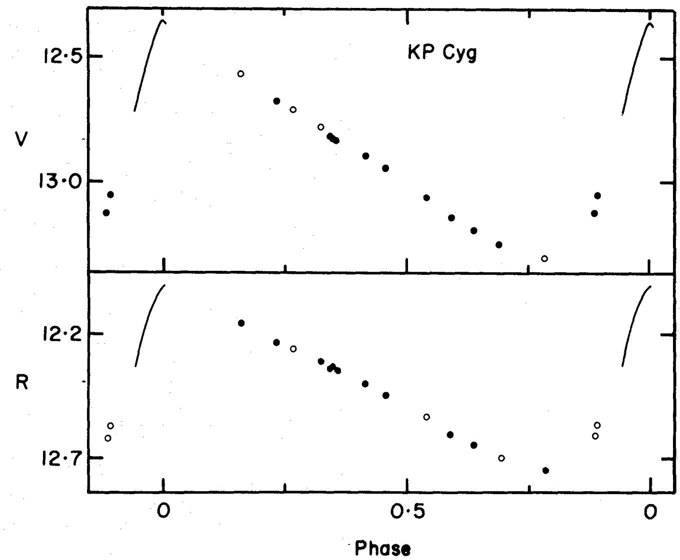

Figure 4. Light curve for KP Cyg plotted with a period of 0.855936 and epoch of maximum of 2446699.62. In this figure and subsequent figures, the points during rising light are very numerous and too crowded to be plotted individually. The solid curve shows their locus.

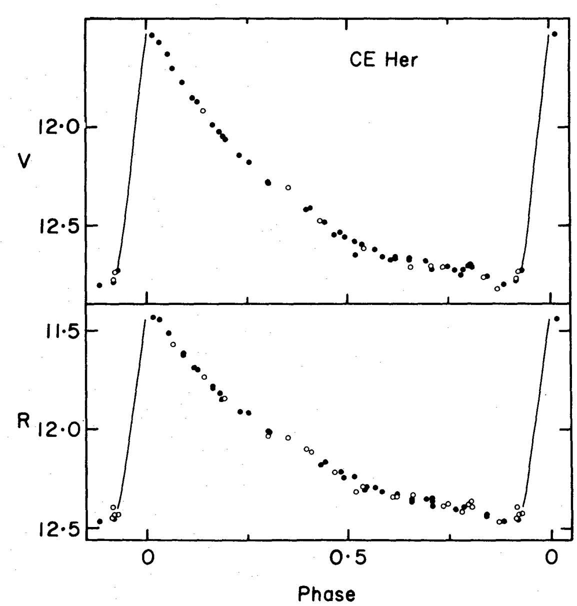

Figure 5. Light curve for CE Her plotted with a period of 1.2094357 and epoch of maximum of 2446583.77.

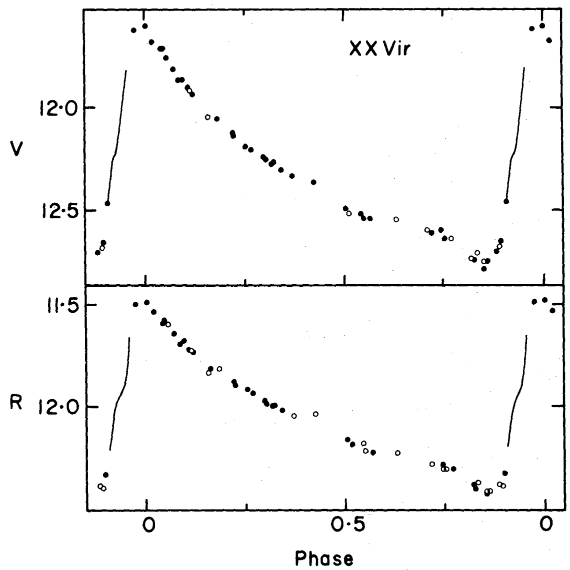

Figure 6. Light curve for XX Vir plotted with a period of 1.3482051 and epoch of maximum of 2446203.67.

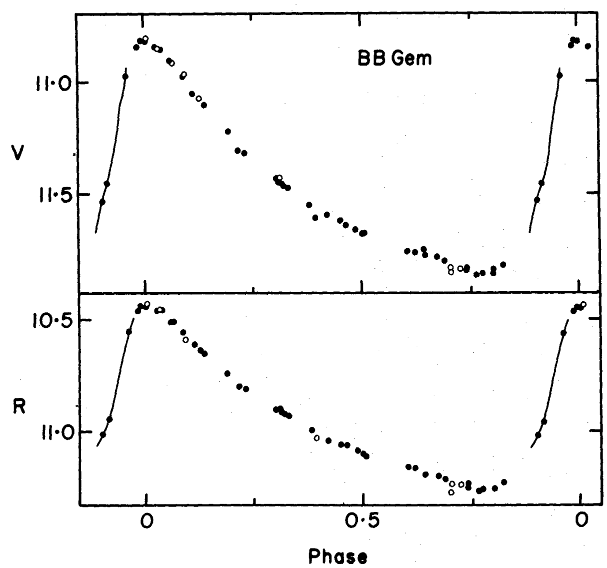

Figure 7. Light curve for BB Gem plotted with a period of 2.308207 and epoch of maximum of 2446056.78.

the exception of KP Cyg). Differential measurements were made between the check stars and the comparison stars at random times. While it is common practice to observe the check stars every night, the present procedure is less time consuming and serves to alert us to any potential variability in our comparison stars. Additionally, the constancy of the magnitudes of the comparison stars on photometric nights was found to be consistent with the usual photometric errors. There is thus little likelihood that any variation as great as 0.01 mag would have escaped our notice.

In Table 9 we list the comparison and check stars for each variable. They are identified by the variable name in column one. Co indicates a comparison star and Ch a check star. Columns 2 and 3 give the coordinates of the check and comparison stars. The mean magnitudes, colours and their standard errors, calculated from the nights which were judged to be photometric, are listed in columns 4–9. The last column gives the number of nights included in the means.

Table 9. Comparison and check stars.

Star*	RA (1950)	Dec	V	se	R	se	V-R	se	n
CM UMa Co	9:40:16	49:44:59	10.667	7	10.310	8	0.358	3	5
CM UMa Ch	9:40:08	49:44:57	10.438	8	10.153	10	0.285	4	3
FK Vul Co	20:50:18	22:26:20	10.245	6	9.916	7	0.329	2	7
FK Vul Ch	20:50:27	22:23:57	11.202	7	10.883	9	0.319	4	6
V486 Her Co	17:24:32	27:15:31	7.691	5	7.530	5	0.158	3	9
V486 Her Ch	17:24:59	27:14:37	10.748	6	10.233	6	0.515	5	5
KP Cyg Co	20:04:49	41:02:39	9.356	10	8.833	9	0.522	6	5
CE Her Co	17:37:47	15:19:38	10.997	5	10.812	6	0.186	2	11
CE Her Ch	17:40:00	15:09:44	11.312	5	10.987	6	0.325	3	5
XX Vir Co	14:13:06	-5:53:06	9.870	9	9.710	9	0.152	2	9
XX Vir Ch	14:13:04	-6:10:20	10.143	10	9.747	10	0.396	3	4
BB Gem Co	6:31:39	13:03:42	9.648	5	9.128	5	0.521	1	6
BB Gem Ch	6:31:43	13:04:52	10.321	6	10.102	6	0.219	3	6

* V486 Her Co is SAO 049185
KP Cyg Co is SAO 085093

Owing to difficulties in determining the period of CM UMa as discussed in the next section, further observations of that star were undertaken on six nights during 1988 January and February with the newly commissioned CCD camera at Behlen Observatory. This instrument and data reduction procedures are described by Schmidt (1988). The instrument was new at that time and its performance was not fully optimized. Consequently, the data quality is not completely consistent among the various nights used and the photometry was not reduced accurately to the standard system. For these reasons, we do not tabulate the data here. However, they are fully adequate for the purpose of resolving the period of CM UMa and it will be seen that the light curve from the CCD is in very good agreement with that from the photoelectric data.

3 Discussion of individual stars

3.1 CM UMa

When it became obvious that the period listed in the GCVS for this star (1.44 day) was grossly in error, we tried to employ the phase dispersion minimization technique (Stellingwerf 1978) to search for a new period in our data. However, we could not definitively establish the period owing to the relatively long intervals between the observations which made the cycle count ambiguous.

When the star again became available in 1988 January we obtained further data with the CCD camera. An effort was made to obtain data on successive nights and over as long an interval on a given night as possible. Two consecutive nights with 6 and 9 hr of coverage eliminated any period shorter than half a day. The fit of all the CCD data then yielded a period of 0.589 days. It should be noted that the cycle count between successive years of data is still ambiguous so we can not refine this period by combining all the data. We give a date of maximum for each year in Table 1.

The light curves for CM UMa are plotted in Fig. 1. The upper panels contain the V and R data from the photoelectric photometer (which is listed in Table 2) while the CCD data are plotted in the lower panel. It can be seen that the light curve is typical for a type ab RR Lyrae star. A comparison of the photoelectric and the CCD light curves in Fig. 1 shows excellent agreement in the overall shape and the actual magnitude levels. The scatter during rising light and after maximum is likely to be due to the Blazhko effect.

Owing to the short time over which the CCD observations were obtained (31 days) compared to the interval for the photoelectric observations (438 days), the Blazhko effect is less evident in the former. However, there is excess scatter in the light curve around phase 0.4. Since the

CCD camera was new, we might wonder whether this is an instrumental effect or is due to the star itself. We prefer the latter interpretation for several reasons. In the first place, this region of the light curve was observed with the CCD on three different nights. In each case the data agree well before and after this region but the star follows a different curve (but a curve with little scatter) through this region on each of the three nights. Secondly, photometry for other stars of comparable brightness observed with the CCD on the same nights shows scatter much too small to explain the scatter in this part of the light curve of CM UMa. Finally, other RR Lyrae stars of similar period show similar scatter in their light curves (see, e.g. Lub 1977).

3.2 FK Vul

This star was included in our programme because the period given in the third edition of the GCVS, 0.77 day, fell within the range of interest. The fourth edition has corrected this period to 0.4340529 day. From the phase dispersion minimization analysis of our data we obtained a period of 0.43404 day, in good agreement. Subjecting the observations to Fourier decomposition yielded the coefficients listed in Table 10. The quantities are as defined by Simon & Lee (1981). The amplitude ratio, $R(21)$, and phase differences, $\phi(21)$ and $\phi(31)$, for FK Vul place it among the RRab stars (Simon & Teays 1982), a classification which is also consistent with its period and amplitude. The scatter (in excess of observational error) apparent in Fig. 2 is likely due to the Blazhko effect which is common in RR Lyrae stars with periods like that of FK Vul.

Table 10. Fourier coefficients of the light curves.

Star	Order of fit	Std. Dev. (mag)	Ampl. (mag)	R(21)	ϕ(21)	R(31)	ϕ(31)	ϕ(41)
FK Vul	5	0.056	0.975	0.565	3.92	0.299	2.01	6.09
V486 Her	5	0.035	0.551	0.459	4.54	0.206	3.11	----
KP Cyg	5	0.022	0.966	0.442	4.52	0.224	2.47	6.77
CE Her	8	0.037	1.36	0.480	4.06	0.375	1.96	6.20
XX Vir	8	0.037	1.19	0.535	4.21	0.369	2.22	6.73
BB Gem	7	0.262	1.06	0.471	4.08	0.240	2.10	6.11

3.3 V486 Her

The light curve for this star is plotted in Fig. 3. The long period (compared with most RR Lyrae stars) and low amplitude of this star make it comparable to XZ Cet (Simon & Teays 1982) which is best modelled as an anomalous Cepheid (Teays & Simon 1985) similar to the cluster variable NGC 5466–V19 (Zinn & Dahn 1976). Indeed, the values of $\phi(21)$ and $\phi(31)$ displayed in Table 10 place V486 Her between the RRab stars and XZ Cet on the corresponding Fourier diagrams. However, the amplitude ratio $R(21)$ for V486 Her agrees with the RR Lyr stars. This is in sharp contrast to both XZ Cet and NGC 5466–V19 whose small values of $R(21)$ set them apart from the RRab stars of similar period. Although this may indicate that V486 Her is an RRab star, the unusual still-stand and sudden change in slope about three-quarters of the way up the rising branch of the light curve raise doubts. The star needs further study.

3.4 KP Cyg

The light curve for this star is presented in Fig. 4. While the phase coverage is not fully adequate for Fourier decomposition, the lower order coefficients seem stable enough for inclusion in Table 10. The coefficients are consistent with the Fourier diagrams for both field RR Lyr stars (Simon & Teays 1982) and type II Cepheids (Simon 1986).

A solar metallicity ($\Delta S=0$) was found by Preston (1959) for KP Cyg. This, too, is consistent with either type. We are therefore unable to assign this star to a class on the basis of present information.

If KP Cyg turns out to be a type II Cepheid, it will have the shortest period among this class. This would extend the domain of these objects well below 1 day. For this reason, further study of KP Cyg and similar stars is needed.

3.5 CE Her and XX Vir

Our light curves for these stars are plotted in Figs 5 and 6. Both of these stars were assigned by Diethelm (1983) to the class he designated RRd. A light curve for XX Vir was analysed by Simon (1986) who classified it as a type II Cepheid of subclass S-XX. The Fourier parameters from our light curve (Table 10) agree with his. Those for CE Her also place it in the S-XX subclass.

In both CE Her and XX Vir there is excessive scatter before minimum. Fig. 8 shows the last part of declining light for both stars on an expanded scale with error bars. The observations were made during a number of cycles as indicated by different symbols. At phases 0.52–0.55 and 0.66 in CE Her and phases 0.54 and 0.82 in XX Vir, the scatter between different cycles is large compared with the error bars. We note that at this magnitude level and fainter our internal errors for other stars realistically represent the scatter in the light curves.

There are also bumps and dips in the light curves which seem to repeat from cycle to cycle. For example, there is a local maximum at phase 0.8 in CE Her which is established by three

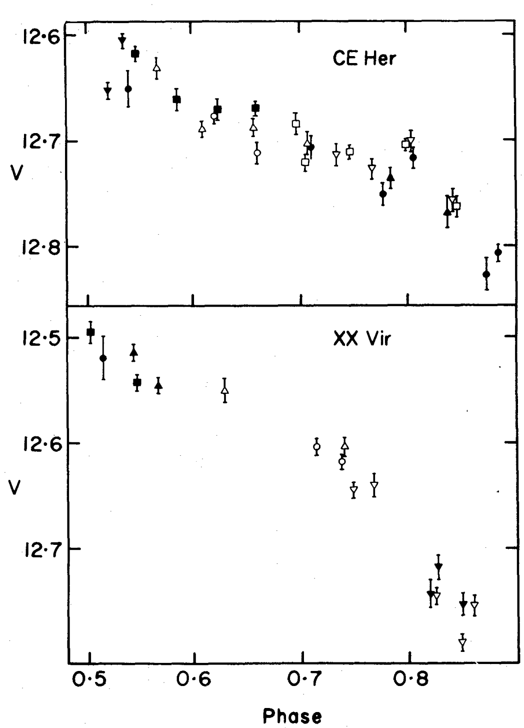

Figure 8. Expanded plots of the last part of declining light in CE Her and XX Vir. When only one point is present for a particular night, it is plotted as a filled circle. Otherwise, each night is represented by a different symbol.

concordant data points which are also well determined. The dip near phase 0.6 is also significant. Looking at the expanded light curve for XX Vir we see that the behaviour is not so well delineated but is consistent with what we see in CE Her.

This behaviour is complex and can be interpreted in various ways. It is possible to draw several straight lines through the variation of CE Her with breaks near phases 0.54, 0.63 and 0.79. On the other hand, we might consider the bumps, dips and intervals of excessive scatter to be small, relatively rapid fluctuations about a smooth overall decline. In any event, we suggest that this behaviour is indicative of the pulsational properties of these stars and should be pursued further.

3.6 BB Gem

Based on its location, Diethelm (1983) considers this star to be a classical Cepheid. Fourier coefficients derived from our light curve (Fig. 7) are listed in Table 10. Plotting these in the Fourier diagrams for both the type II (Simon 1986) and classical (Simon & Moffett 1985) Cepheids we find the phases $\phi(21)$, $\phi(31)$ and $\phi(41)$ to be discrepant with type II stars of similar period such as UX Nor and V465 Oph. On the other hand, the Fourier parameters for BB Gem fit extremely well with the sequence of classical Cepheids. Thus, the Fourier decomposition strongly supports Diethelm's classification. Since the well studied classical Cepheid SU Cas ($P=1.95$ day) is almost certainly an overtone pulsator (Gieren 1982; Aikawa, Antonello & Simon 1987), BB Gem becomes the shortest period fundamental mode pulsator known among the classical Cepheids in the Galaxy.

Acknowledgements

Three of the stars were taken from a list of pulsating variables with periods near 0.8 day compiled by T. J. Teays. This proved very useful in setting up our program and we are grateful to him for providing it. The phase dispersion minimization program used in this project was kindly supplied by R. F. Stellingwerf.

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