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FIVE-COLOUR PHOTOMETRY OF 12 CEPHEIDS IN THE SMALL MAGELLANIC CLOUD

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A discussion is presented of photo-electric five-colour observations of 12 SMC Cepheids made in 1966. The periods of these variables range from 8 to 88 days. Their colour-curves, loops and intrinsic colours have been compared with those of galactic Cepheids. The characteristics of their colour-curves differ in many respects from those for the galactic Cepheids, and their intrinsic colours are on the average bluer by 0.06 in $V-B$, 0.13 in $B-L$ and 0.03 in $B-U$ (all in log intensity). A metal deficiency of the SMC Cepheids could be the explanation.

1. Introduction

The comparative photometry of classical Cepheids in the Galaxy and the Magellanic Clouds, which has been made during the last years by different authors, often resulted in contradictions, some of which are most likely due to systematic errors in the standard sequences (VAN GENDEREN, 1969a, 1969b; hereafter called Papers I and II).

WALRAVEN *et al.* (1964) have made five-colour observations of 24 galactic Cepheids. The need was felt to observe also Cepheids in both Clouds with the same five-colour photometer, to increase our knowledge of the intrinsic differences by means of more colours. The available time did not allow us to observe more than 12 Cepheids in the central part of the SMC. Two-colour observations of these stars have already been discussed in Paper I. Their periods range from 8 to 88 days.

2. The observations and reductions

The observations have been made with the simultaneous five-channel photometer of Walraven, attached to the 90-cm light-collector of the Leiden Southern Station in South-Africa. The 12 Cepheids and the six comparison stars selected for observation are listed in table 1. Coordinates, which have been read off from the telescope, are given with an accuracy of roughly 6^s in α and $0'.5$ in δ. The usual diaphragm size was $16''$. The observing routine for one Cepheid was generally: comparison star-sky-Cepheid-sky-comparison star-sky. The integration time for every star and sky

TABLE 1

Cepheids and comparison stars

Cepheid	P (days)	log P	α (1966)	δ (1966)	Number of obs.	Comp. star	α (1966)	δ (1966)
HV 829	88.51	1.947	$0^h49^m15^s$	−72°55′.0	24	2	$0^h48^m50^s$	−72°55′.0
LV 60	86.6	1.938	0 54 40	−73 28.0	28	1	0 54 08	−73 24.0
HV 824	65.80	1.818	0 45 47	−72 52.6	24	3	0 45 55	−72 51.0
HV 10357	32.012175	1.505	0 49 05	−73 17.0	20	4	0 49 05	−73 16.7
HV 1430	23.97284	1.380	0 45 55	−73 07.5	7	4	0 49 05	−73 16.7
HV 1579	14.573011	1.163	0 52 15	−73 16.6	18	5	0 53 55	−73 14.4
HV 1387	14.428973	1.159	0 42 40	−73 29.6	11	6	0 42 26	−73 29.8
HV 1682	12.149930	1.085	0 55 14	−73 33.0	17	1	0 54 08	−73 24.0
HV 1630	11.401209	1.057	0 53 55	−73 13.7	23	5	0 53 55	−73 14.4
HV 1377	10.528089	1.022	0 42 08	−73 30.0	10	6	0 42 26	−73 29.8
HV 1484	9.025906	0.956	0 48 44	−73 11.8	19	4	0 49 05	−73 16.7
HV 1437	8.376213	0.923	0 46 45	−73 06.3	13	4	0 49 05	−73 16.7

TABLE 2

Brightness and colours of comparison stars

Comp. star	V	$V-B$	$B-U$ (log intensity)	$U-W$	$B-L$	V_J (mag)	$(B-V)_J$	Notes*
1	−2.233	+0.016	+0.235	+0.127	+0.022	12.45	+0.02	
2	−2.148	+0.224	+0.333	+0.173	+0.194	12.20	+0.53	
3	−1.853	+0.556	+0.754	+0.568	+0.636	11.40	+1.24	
4	−3.034	0.000	+0.011	−0.001	−0.015	14.46	−0.02	a
5	−2.366	+0.186	+0.504	+0.327	+0.194	12.76	+0.45	b
6	−2.568	+0.760	+0.754	(+0.005)	+0.516	13.15	+1.64	c

*a. Sequence star 781 in table 3, Paper I, $V_J = 14.24$, $(B-V)_J = +0.09$.
b. Check star 3 in table 8, Paper I, $V_J = 12.72$.
c. $U-W$ very unreliable.

observation was 2, 2½ or 3 minutes. With the aid of plate 2 in Paper I, the sky measurements were chosen close to the star and with about the same background light as that around the star. Sometimes when comparison star and Cepheid were close to each other, the same sky measurement has been used.

The brightness and colours of the comparison stars in table 2, in the system of Walraven, followed from a comparison with three to five standard stars at widely different sec z, measured each night before and after the programme stars. The mean error varies from 0.004 in V to 0.015 in $U-W$. The brightness and colours of the Cepheids were then obtained from a comparison with the comparison stars. Brightness and colours are expressed throughout in the logarithm of the intensity, but for the comparison stars the Johnson magnitudes and colours have been added. The magnitude V_J is computed with the formula

$$V_J = 6.88 - 2.5\,[V - 0.08\,(V-B)]$$

(Walraven, private communication), and $V-B$ has been transformed into $(B-V)_J$ with the aid of table 7 given by WALRAVEN *et al.* (1964). Corrections for differential extinction have been applied if necessary, but often they were negligible. Individual observations of the Cepheids relative to the comparison stars are given in table 3.

3. The periods

The periods have been taken from PAYNE-GAPOSCHKIN and GAPOSCHKIN (1966), except that of LV 60 which is one of the new variables given in Paper I and whose period will be discussed in section 4. The phases φ of all variables have been computed with the formula

$$\varphi = (\text{J.D.} - 2439000) \times P^{-1}.$$

Julian Days and phases in three decimals are listed in table 3.

TABLE 3

Brightness and colours of the Cepheids relative to their comparison stars

Cepheid	J.D. −2439000	Phase	ΔV	$\Delta(V-B)$	$\Delta(B-U)$ (log intensity)	$\Delta(U-W)$	$\Delta(B-L)$
HV 829	324.608	.349	+0.257	+0.118	+0.168		+0.124
	325.594	.361	+0.221	+0.134	+0.191	+0.218	+0.089
	327.623	.383	+0.206	+0.084	+0.212	+0.186	+0.079
	333.607	.451	+0.199	+0.127	+0.226	+0.212	+0.117
	334.633	.463	+0.195	+0.133	+0.240	+0.145	+0.119
	339.578	.519	+0.162	+0.136	+0.287	+0.190	+0.138
	340.561	.530	+0.172	+0.132	+0.208	+0.212	+0.137
	342.603	.553	+0.151	+0.148	+0.242	+0.215	+0.148
	355.583	.699	+0.104	+0.207	+0.220	+0.159	+0.141
	360.601	.756	+0.044	+0.218	+0.242	+0.367	+0.228
	367.576	.835	−0.035	+0.231	+0.110	−0.109	+0.164
	378.517	.958	−0.053	+0.257	+0.213		+0.173
	380.597	.982	−0.072	+0.212	+0.228	+0.083	+0.183
	389.415	.082	+0.056	+0.128	+0.214	+0.266	+0.109

TABLE 3 *(continued)*

Cepheid	J.D. −2439000	Phase	ΔV	$\Delta(V-B)$	$\Delta(B-U)$ (log intensity)	$\Delta(U-W)$	$\Delta(B-L)$
HV 829	391.471	.105	+0.097	+0.102	+0.162	+0.116	+0.089
(cont.)	395.505	.150	+0.142	+0.056	+0.138	+0.081	+0.072
	399.485	.195	+0.192	+0.045	+0.176	+0.184	+0.057
	403.314	.239	+0.216	+0.060	+0.156	+0.331	+0.063
	408.535	.298	+0.243	+0.072	+0.202	+0.146	+0.056
	415.535	.377	+0.206	+0.117	+0.193	+0.326	+0.065
	420.306	.431	+0.187	+0.120	+0.280	+0.043	+0.115
	423.441	.466	+0.201	+0.142	+0.230	−0.130	+0.134
	425.374	.488	+0.169	+0.130	+0.200	+0.073	+0.148
	440.337	.657	+0.124	+0.211	+0.169	+0.474	+0.146
LV 60	324.567	.633	+0.229	+0.609	+0.518		+0.248
	325.563	.645	+0.197	+0.570	+0.530		+0.402
	327.594	.668	+0.164	+0.565	+0.558		+0.335
	333.587	.738	+0.099	+0.550	+0.605		+0.368
	334.644	.750	+0.090	+0.575	+0.561		+0.362
	339.563	.806	+0.049	+0.496	+0.375		+0.458
	340.547	.818	+0.032	+0.536	+0.422	−0.102	+0.501
	342.588	.841	−0.023	+0.472	+0.586		+0.350
	355.567	.991	−0.012	+0.514	+0.465		
	359.628	.038	−0.007	+0.492	+0.530		+0.349
	361.628	.061	−0.029	+0.513	+0.533	−0.012	+0.338
	367.538	.129	+0.100	+0.500	+0.366	+0.573	+0.452
	371.613	.177	+0.143	+0.511	+0.557	+0.153	+0.372
	378.484	.256	+0.222	+0.558	+0.495		+0.372
	380.500	.279	+0.221	+0.547	+0.533	+0.686	+0.400
	389.393	.382	+0.248	+0.558	+0.482	+0.328	+0.433
	391.447	.405	+0.238	+0.534	+0.547	+0.376	+0.414
	395.435	.452	+0.258	+0.568			+0.392
	399.465	.498	+0.253	+0.525	+0.392	+0.777	+0.346
	402.283	.531	+0.270	+0.567	+0.541	+0.291	+0.402
	408.449	.602	+0.245	+0.580	+0.549	−0.071	+0.430
	415.324	.681	+0.172	+0.559	+0.550	+1.470	+0.394
	420.289	.738	+0.102	+0.506	+0.448		+0.363
	422.410	.763	+0.064	+0.532			+0.348
	432.297	.877	−0.005	+0.536			+0.215
	432.325	.877	−0.030	+0.534		−0.128	+0.218
	433.341	.889	−0.064	+0.488	+0.418	+1.350	+0.241
	440.316	.970	−0.025	+0.492	+0.450		+0.328
HV 824	325:621	.731	−0.530	−0.068	−0.229		−0.237
	327.640	.761	−0.549	−0.065	−0.196	−0.251	−0.199
	333.624	.852	−0.570	−0.108	−0.196		−0.234
	334.644	.868	−0.543	−0.101	−0.148	−0.242	−0.274
	339.592	.943	−0.390	−0.244	−0.137	−0.257	−0.384
	340.574	.958	−0.347	−0.260	−0.348		−0.333
	342.615	.989	−0.290	−0.318	−0.230		−0.345
	355.595	.186	−0.235	−0.289	−0.193	−0.144	−0.359
	360.601	.262	−0.257	−0.241	−0.188	−0.330	−0.371
	367.590	.369	−0.298	−0.181	−0.338	−0.061	−0.357
	378.531	.535	−0.394	−0.133	−0.138	−0.140	−0.245
	380.608	.566	−0.427	−0.136	−0.074		−0.227
	389.426	.700	−0.496	−0.076	−0.128	−0.068	−0.198
	391.594	.733	−0.550	−0.068	−0.224	−0.273	−0.220
	395.515	.793	−0.576	−0.031	−0.369	+0.031	−0.302
	399.490	.853	−0.576	−0.106			−0.247
	403.324	.912	−0.494	−0.172	−0.201	−0.038	−0.337

TABLE 3 *(continued)*

Cepheid	J.D. −2439000	Phase	ΔV	$\Delta(V-B)$	$\Delta(B-U)$ (log intensity)	$\Delta(U-W)$	$\Delta(B-L)$
HV 824	408.541	.991	−0.302	−0.301	−0.264	+0.179	−0.369
(cont.)	408.564	.991	−0.295	−0.305	−0.232		−0.376
	415.552	.098	(−0.285)	−0.302	−0.263	−0.077	−0.351
	419.596	.159	−0.223	−0.276	−0.203	−0.066	−0.329
	422.435	.202	−0.236	−0.285	−0.104	+0.212	−0.382
	425.359	.247	−0.264	−0.257	−0.223	+0.059	−0.352
	440.340	.474	−0.352	−0.147	−0.176	+0.041	−0.285
HV 10357	361.580	.437	+0.120	+0.357	+0.341	+0.582	+0.351
	362.565	.468	+0.139	+0.419		−0.301	+0.317
	368.470	.652	+0.033	+0.420	−0.039	−0.094	+0.141
	378.549	.967	+0.376	+0.219	+0.476	+0.496	+0.220
	380.456	.027	+0.375	+0.235	+0.515	+0.838	+0.214
	389.435	.307	+0.224	+0.401	+0.453		+0.344
	390.519	.341	+0.229	+0.402	+0.487		+0.250
	391.513	.372	+0.136	+0.427	+0.381	+0.260	+0.314
	395.476	.496	+0.126	+0.506	+0.322	−0.051	+0.103
	401.464	.683	+0.061	+0.520	+0.216		+0.026
	402.244	.707	+0.035	+0.427			+0.259
	403.335	.741	+0.026	+0.366	+0.659	−0.367	+0.136
	408.472	.902	+0.091	+0.366	+0.272	+0.417	+0.363
	415.400	.118	+0.275	+0.263	+0.566		+0.220
	419.481	.246	+0.243	+0.367	+0.367	+0.389	+0.361
	421.279	.302	+0.193	+0.309	+0.450		+0.345
	422.333	.335	+0.250	+0.389	+0.308		+0.348
	423.369	.367	+0.195	+0.469	+0.643		+0.410
	433.271	.677	+0.027	+0.462	+0.285	−0.094	+0.225
	440.278	.895	−0.007	+0.341	+0.230	+0.070	+0.186
HV 1430	408.553	.468	+0.168	+0.170	+0.494	+0.162	+0.219
	415.423	.755	+0.072	+0.427	+0.907		+0.274
	419.496	.925	−0.086	+0.328	+1.060		+0.459
	422.347	.044	−0.124	+0.406	+0.415		
	423.417	.088	−0.148	+0.499		−1.510	
	433.289	.500	+0.214	+0.228	+0.579	+0.450	+0.172
	440.299	.793	+0.027	+0.428	+0.876		+0.316
HV 1579	389.517	.308	−0.668	−0.022	−0.264	+0.235	−0.029
	390.484	.375	−0.616	+0.072	−0.261	−0.451	−0.074
	391.582	.450	−0.624	+0.080	−0.221	−0.354	−0.103
	395.463	.717	−0.808	+0.229		+0.563	−0.012
	401.233	.113	−0.469	−0.002	−0.064	−0.443	+0.001
	402.314	.187	−0.562	−0.028	−0.106	−0.181	+0.018
	408.524	.613	−0.805	+0.012	−0.273	−0.313	+0.051
	415.448	.088	−0.549	−0.144	−0.069	−0.282	−0.045
	415.448	.088	−0.491	−0.033	−0.103	−0.526	−0.079
	419.563	.370	−0.662	+0.049	−0.318	−0.216	−0.046
	421.251	.486	−0.766	−0.013	−0.089		+0.110
	422.306	.559	−0.653	+0.128	−0.470	−0.102	−0.048
	423.344	.630	−0.685	+0.191	−0.381	−0.545	
	426.374	.838	−0.827	−0.013	+0.050		−0.074
	426.374	.838	−0.920	−0.060	+0.178		−0.035
	432.273	.243	−0.483	+0.046	−0.026	−0.367	−0.037
	433.308	.314	−0.538	+0.119	−0.222	−0.477	−0.072
	440.262	.791	−0.761	+0.079	−0.213	−0.429	+0.079
HV 1387	389.537	.742	−0.781	−0.315	−0.192		−0.278

TABLE 3 *(continued)*

Cepheid	J.D. −2439000	Phase	ΔV	$\Delta(V-B)$	$\Delta(B-U)$ (log intensity)	$\Delta(U-W)$	$\Delta(B-L)$
HV 1387	390.551	.812	−0.848	−0.424	−0.031	+0.146	−0.340
(cont.)	391.547	.881	−0.712	−0.354			+0.063
	408.413	.050	−0.769	−0.385	−0.255	−0.338	+0.037
	408.413	.050	−0.758	−0.432			−0.109
	415.356	.531	−0.626	−0.383	+0.077		−0.156
	419.458	.816	−0.677	−0.341	+0.280		−0.184
	420.274	.872	−0.792	−0.211	−0.555	+0.268	−0.362
	422.284	.011	−0.602	−0.300	−0.873		−0.085
	433.324	.777	−0.779	−0.299	−0.578	−0.967	−0.003
	440.356	.264	−0.577	−0.508	−0.271		−0.298
HV 1682	378.501	.898	−1.007	+0.276	+0.436		+0.165
	379.451	.976	−0.978	+0.367			+0.306
	380.508	.063	−1.092	+0.312	+0.500	−0.457	
	389.402	.795	−0.933	+0.255	+0.030		+0.206
	390.499	.885	−0.996	+0.288			+0.209
	390.499	.885	−0.992	+0.272			+0.334
	391.457	.964	−0.925	+0.314	+0.366		+0.332
	395.444	.292	−0.874	+0.294			+0.156
	402.292	.856	−0.996	+0.251	+0.247	+0.841	
	408.458	.363	−0.924	+0.197	+0.317		+0.160
	415.340	.930	−0.899	+0.321	+0.552	−0.748	+0.310
	415.340	.930	−1.008	+0.358			+0.366
	419.581	.279	−0.964	+0.305	−0.053	−0.267	+0.163
	420.294	.337	−0.922	+0.088	−0.060	+0.205	+0.014
	422.416	.512	−0.705	+0.134	+0.053	−0.385	+0.115
	433.403	.416		+0.066	+0.449		−0.008
	440.326	.986	−1.100	+0.323			+0.410
HV 1630	361.604	.106	−0.946	+0.090	−0.069	−0.542	−0.003
	362.578	.192	−0.983	+0.016	−0.279		
	367.606	.633	−0.845	−0.083	−0.498	−0.474	+0.200
	368.483	.710			−0.354	−0.135	−0.164
	369.574	.805	−0.625	+0.026			
	378.596	.597	−0.964	+0.062			
	379.420	.669	−0.816	+0.070	−0.276	+0.006	−0.066
	380.487	.763	−0.846	+0.125	−0.101	+0.104	−0.114
	389.510	.554	−1.006	+0.111	−0.407	−0.287	+0.031
	390.478	.639	−0.904	+0.028	−0.164		+0.089
	391.571	.735	−0.887	+0.020	−0.426	+0.129	−0.027
	391.571	.735	−0.912	+0.018	−0.056		−0.009
	395.456	.075	−0.948	−0.034	+0.038	−0.723	+0.091
	401.226	.582	−0.888	+0.095			−0.213
	402.307	.676	−0.890	+0.015	−0.427	+0.063	−0.137
	408.528	.222	−0.902	+0.188	+0.017	−0.915	+0.242
	415.433	.828	−0.724	+0.008	−0.193	+0.733	−0.027
	419.552	.189	−0.870	+0.160	−0.379		+0.090
	421.261	.339	−1.104	+0.261			
	422.312	.431	−1.018	+0.222			+0.169
	423.356	.523	−0.945	+0.171			−0.128
	433.306	.395	−1.042	+0.152	−0.273	−0.678	+0.017
	440.258	.005	−0.778	+0.092	−0.132		+0.203
HV 1377	389.547	.857	−0.660	−0.480	−0.472		−0.349
	390.558	.953	−0.764	−0.678	−0.187	+0.043	−0.361
	391.554	.047	−0.639	−0.514	−0.487	−0.256	−0.578
	408.425	.650	−0.846	−0.459	−0.185		−0.394

TABLE 3 *(continued)*

Cepheid	J.D. −2 439 000	Phase	ΔV	$\Delta(V-B)$	$\Delta(B-U)$ (log intensity)	$\Delta(U-W)$	$\Delta(B-L)$
HV 1377	415.371	.310	−0.936	−0.500			−0.641
(cont.)	419.466	.699	−0.885	−0.615	−0.487		−0.298
	420.276	.775	−0.750	−0.556	+0.215		−0.236
	422.288	.967	−0.756	−0.724	−0.266		−0.245
	433.328	.015	−0.765	−0.614	−0.170	−0.828	−0.269
	440.360	.683	−0.815	−0.526	−0.534		−0.408
HV 1484	378.578	.071	+0.047	+0.337	+0.720		+0.315
	379.434	.166	+0.032	+0.343	+0.636	+0.176	+0.170
	380.463	.280	−0.038	+0.291	+0.515		+0.371
	389.442	.275	+0.051	+0.360	+0.588	−0.366	+0.269
	390.526	.395	−0.043	+0.473	+0.620	−0.497	+0.388
	391.521	.505	−0.168	+0.385	+0.512	+1.081	+0.412
	395.482	.944	−0.033		+0.192	+0.217	+0.281
	401.472	.608	−0.032	+0.530			+0.546
	402.255	.695	−0.128	+0.413	+0.375		+0.158
	402.255	.695	−0.048	+0.458	+0.527	−0.855	+0.272
	408.482	.385	−0.046	+0.414	+0.651	−0.429	+0.192
	415.408	.152	+0.054	+0.404		+0.346	+0.265
	419.511	.606	−0.140	+0.440			+0.454
	419.535	.609	−0.010	+0.504	+1.083	−0.696	+0.333
	421.289	.803	+0.118	+0.404	+0.504		+0.144
	422.358	.922	+0.131	+0.447	+0.840	−0.462	+0.286
	423.372	.034	+0.088	+0.462	+0.285	+0.122	
	433.274	.131	+0.055	+0.374	+0.753	−0.661	+0.083
	440.281	.908	+0.046	+0.377	+0.558	+0.351	+0.265
HV 1437	389.463	.970	−0.252	+0.197	+0.357		+0.190
	390.537	.099	−0.447	+0.077	+0.650		
	391.532	.217	−0.399	+0.175	+0.478	−0.049	+0.383
	395.492	.690		+0.062			+0.029
	402.270	.499	−0.648	+0.298			+0.261
	403.342	.627	−0.339	+0.192	−0.074	+0.793	+0.142
	408.504	.244	−0.429	+0.220	+0.073		+0.134
	415.412	.068	−0.370	+0.214	+0.270	+1.841	+0.183
	419.490	.555	−0.453	+0.382			+0.295
	421.279	.769	−0.331	+0.069		−1.946	+0.019
	422.340	.895	−0.361	+0.116	+0.427	+0.355	
	433.283	.202	−0.464	+0.185			
	440.293	.039	−0.323	+0.198	+0.478	+0.513	+0.213

4. The variable period and light-curve of LV 60

This variable has changed its period appreciably from $71^{d}.6 \pm 1^{d}.0$ in the years 1955 and 1956 (Paper I) to $86^{d}.6 \pm 1^{d}.7$ in 1966 (figure 2). Also the light-curve has undergone important alterations. To investigate these variations in more detail, LV 60 has been measured on 115 blue plates of the SMC with the Sartorius iris-diaphragm photometer of the Leiden Observatory. The plates were taken with the Rockefeller twin-telescope of the Leiden Southern Station in the years 1939, 1940, 1942 to 1946, and 1959 to 1962 by W. C. Martin, H. van Gent, J. Wolterbeek Muller, J. Ponsen and J. Tinbergen. The exposure times varied generally between 10 and 70 minutes.

The blue magnitudes of LV 60 were derived with the aid of the photo-electric sequence discussed in Paper I. Figure 1 shows the brightness change as a function of time. It appears that the brightness variation is of an irregular nature. In 1960 to 1962 the star did not show much variation. In other years, such as 1942/1943, 1955/1956 (Paper I) and 1966 (figure 2), the blue amplitude is nearly 1 mag. The light-curve seems to repeat itself in the next one or two cycles, at least for

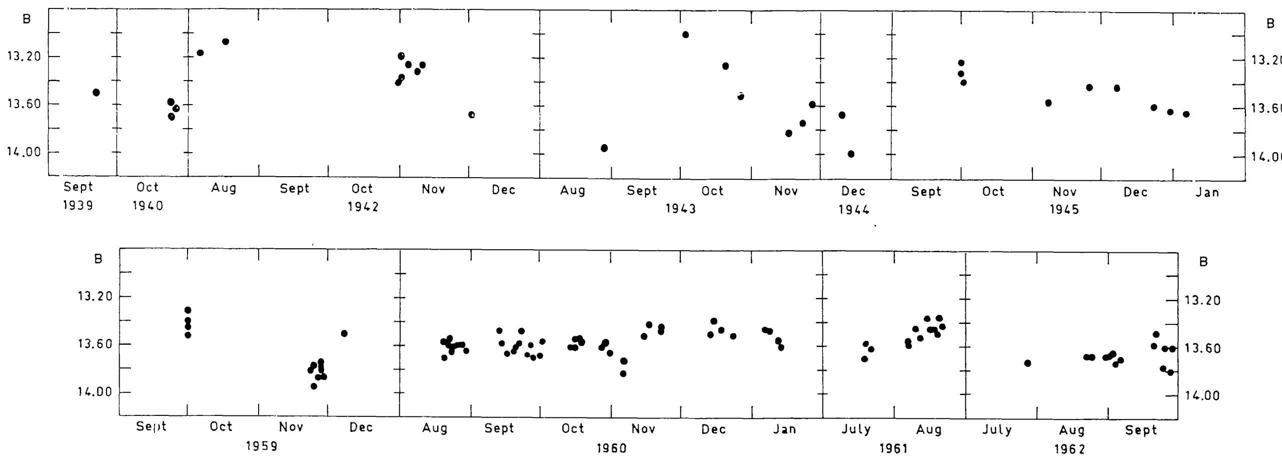


Figure 1. Brightness change of LV 60 during several years.

the last two intervals, The colour-curves are also abnormal, as will be shown in section 7.

5. The light- and colour-curves

Figure 2 shows the light- and colour-curves of the 12 Cepheids in order of decreasing period. The dispersion strongly depends on the brightness of the stars, which have mean visual magnitudes between 12 and 15. Because of the weakness in the W band, the $U-W$ curves are not shown. Often the W intensity of the fainter Cepheids is too faint to be measured. Also when other colours like $B-L$ and $B-U$ show a very large dispersion, the curve has been omitted, although we shall sometimes use its average value.

The curves in figure 2 are to some extent rather arbitrary. For the V curves we have been guided by the light-curves from Paper I. Long unobserved parts in the curves have been dashed.

6. The loops in the two-colour diagrams

Figure 3 and 4 show the idealized loops in the $V-B/B-L$ diagram. For Cepheids with a large dispersion in the $B-L$ curve, the average position is represented by a filled circle. The positions of the maximum and minimum brightness are marked with the symbols M and m respectively. The arrows indicate the direction in which the Cepheids pass through the diagram. To make the comparison of $V-B$ with $(B-V)_J$ more easy, $(B-V)_J$ is also indicated on the horizontal axis. The relations for main-sequence stars and Ia and Ib supergiants are also shown, together with the reddening line for O- and B-type stars. The unreddened locus for galactic Cepheids as derived by WALRAVEN (1966) is indicated by the broken line. For sake of comparison with the long-period Cepheids HV 829 (88^d) and HV 824 (66^d), we also show the loop for the galactic Cepheid QT CrA (79^d), observed by Walraven et al.

The same description holds for figure 5, where the observed loops are shown in the $V-B/B-U$ diagram.

7. Discussion

Before we discuss the observations in detail, it is necessary to repeat at first the main characteristics of the galactic Cepheids in Walraven's photometric bands. The characteristics show a great regularity in the following respects.

1. The $V-B$ and $B-L$ curves closely resemble each other.
2. The $B-U$ curves are rather flat, and generally increase in amplitude with increasing range of visual light-curve.
3. The maxima of the $V-B$ and $B-L$ curves are only slightly shifted to an earlier phase relative to V. The $B-U$ curves often show a hump on the rising branch.

The 12 SMC Cepheids deviate in many respects from the three rules mentioned above. We mention here:

1. The colour-curves of LV 60 (87^d) are opposite to the V light-curve. Therefore at maximum brightness the colour is reddest. In Paper I we discussed the high intrinsic luminosity in V and in section 4 the variations in period and light-curve.
2. For HV 10357 (32^d) the $B-L$ and $B-U$ curves are opposite to the $V-B$ one. The latter begins to

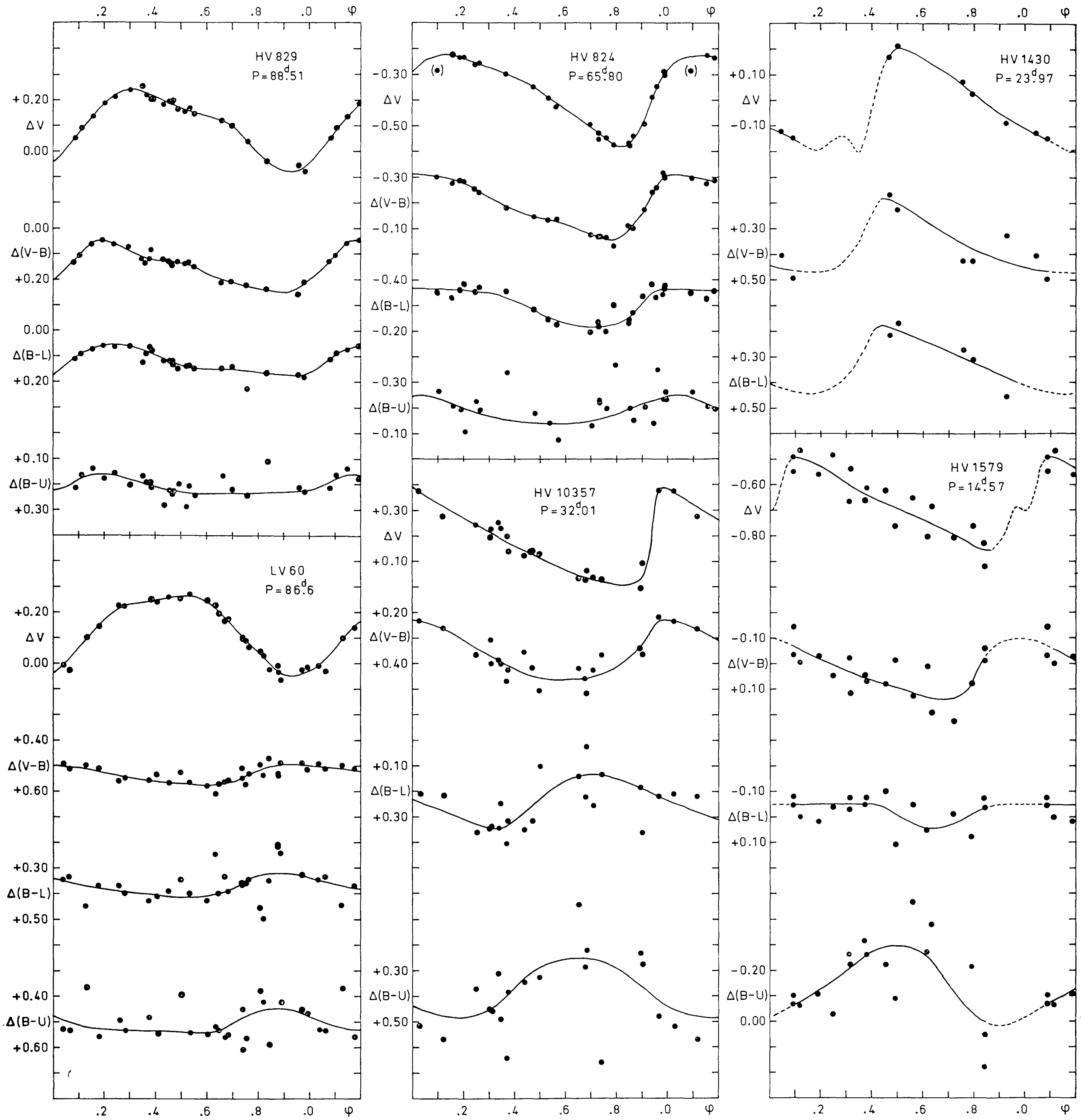
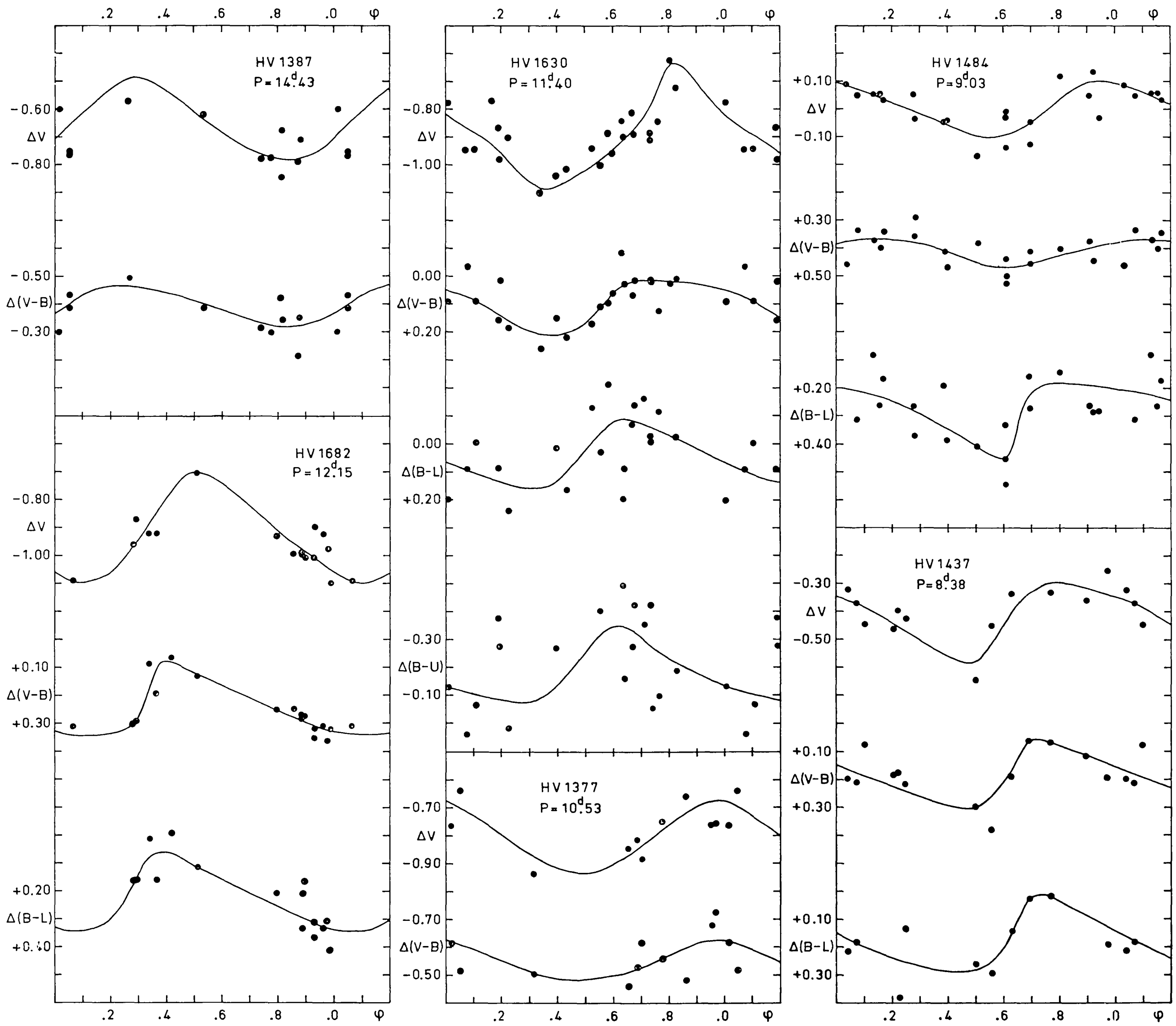


Figure 2. The light- and colour-curves of 12 SMC Cepheids.

rise about 0.2 in phase before the brightness starts increasing.

3. For HV 1579 (15^d) the $B-L$ curve is nearly flat, while $B-U$ is opposite to $V-B$ and has a maximum half-way the descending branch of V. The $V-B$ curve reaches its maximum about half-way the rising branch of V.
4. For HV 1682 (12^d) and HV 1630 (11^d) the $V-B$ and $B-L$ curves show pronounced maxima half-way the rising branch in V; for HV 1484 (9^d) only $B-L$

Figure 2 *(continued)*



shows this feature, while $V-B$ has an abnormal low amplitude of 0.1. Also this variable has a high intrinsic brightness in V according to Paper I.

5. There is a tendency for the amplitudes of the $B-U$ curves to decrease with increasing periods. For the galactic variable QT CrA the amplitude is 0.3, while for the Cloud variables HV 824 and 829 this amplitude is smaller than 0.1.

Though the dispersion in our curves is rather large, the abnormal characteristics are definitely real. We can show the abnormal behaviour of the Cloud Cepheids also by determining the amplitudes of the light-variation in the four wavelength-bands V, B, L and U.

For HV 10357 these amplitudes are 0.4, 0.55, 0.5 and 0.4. The L curve of this Cepheid is rather flat near minimum brightness, the minimum covering nearly half the period.

For HV 1579 the amplitudes are found to be 0.35, 0.4, 0.5 and 0.35.

For the galactic Cepheids these amplitudes always increase with decreasing wavelength. In other words these Cloud variables seem to have a strong ultraviolet excess near minimum brightness. It is clear that for these two Cepheids the shape of the loops in the

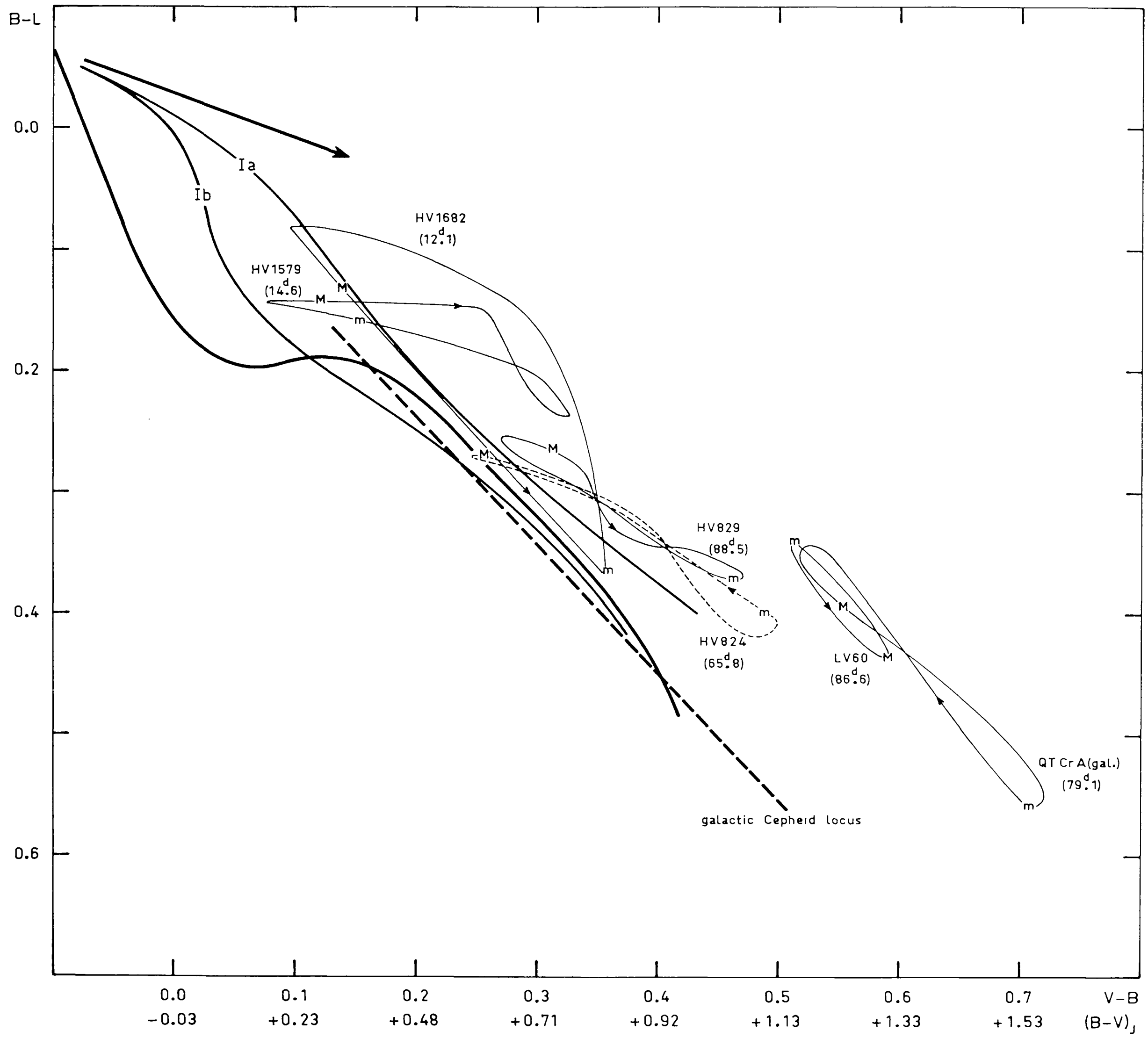


Figure 3. The loops in the $V-B/B-L$ diagram.

figures 3, 4 and 5 should also deviate considerably from those of the galactic Cepheids, which usually follow a path of constant luminosity (WALRAVEN, 1966; OOSTERHOFF and WALRAVEN, 1966).

The loops of most of the other Cepheids in the $V-B/B-L$ diagram tend to show more or less the same trend as galactic Cepheids, but they are bluer in both colours. The variables LV 60 and HV 1484 lie further to the right than can be explained by interstellar absorption. This supports the abnormal high intrinsic brightness in V found in Paper I.

Not much weight can be assigned to the shape of the sometimes wide open loops of the faintest Cepheids in figure 5. The observational dispersion in $B-U$ is therefore too large. This is not the case for the two brightest Cepheids HV 829 (88^d) and HV 824 (66^d), the colour-curves and thus also the loops of which are rather well defined. In figure 3 as well as in figure 5, their loops are clearly parallel to the sequence of Ia supergiants, contrary to QT CrA (79^d) which seems to behave like a Ib supergiant. If this feature implies that the long-period SMC Cepheids belong to a higher luminosity class than their galactic counterparts, it supports the suggestion from Paper II, that at least the

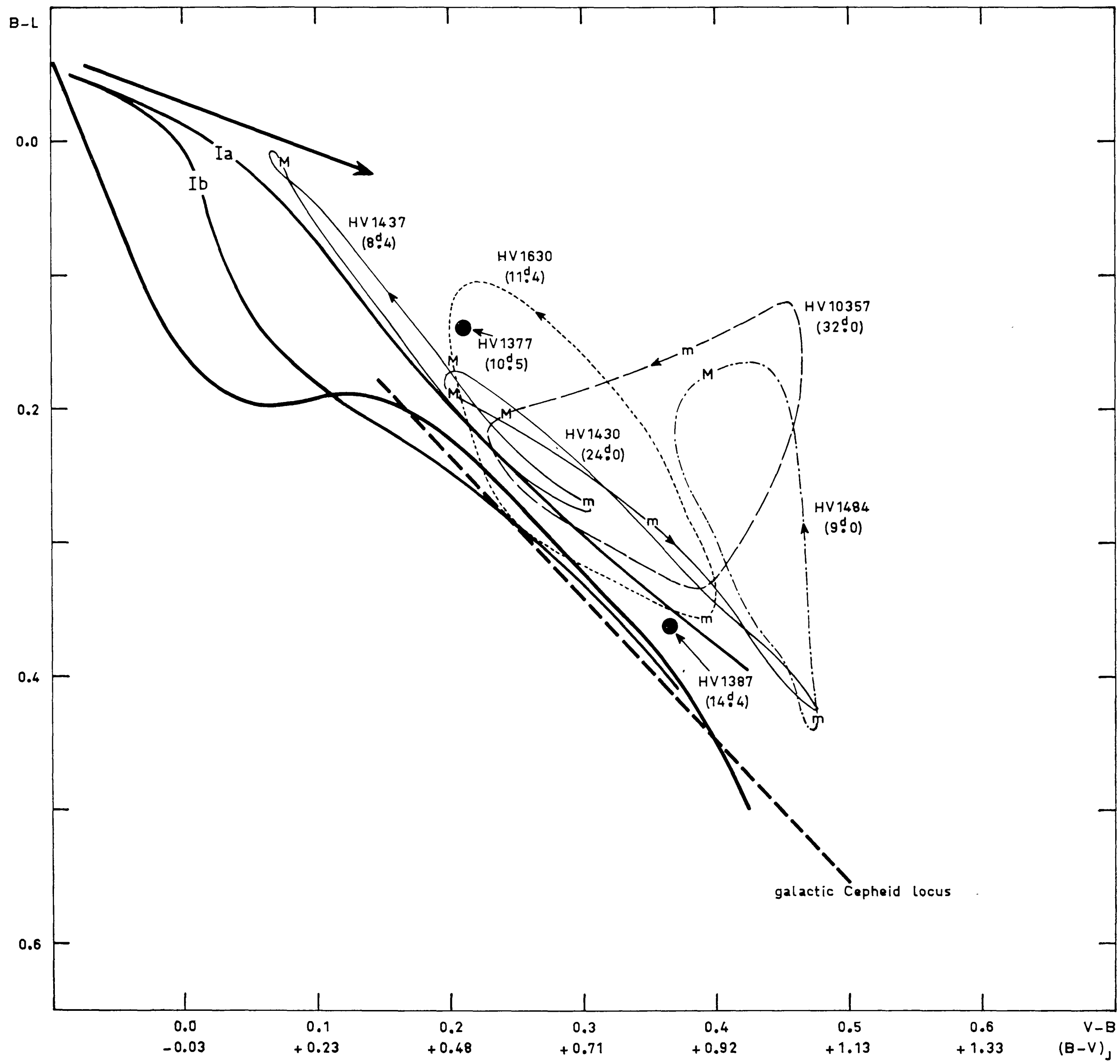


Figure 4. Loops in the $V-B/B-L$ diagram.

long-period Cepheids in the Clouds are absolutely brighter by some tenths of a magnitude.

With a distance modulus of the SMC of 19.0 (Paper I), M_V for HV 829 and HV 824 is -7.1 and -6.7 respectively, while using the standard $P-L$ relations of Paper II for galactic Cepheids, M_V of QT CrA is at most -6.6. However, also for these two long-period Cepheids the slope of the loops may have been affected by the U excess at minimum mentioned above.

Finally we notice that the slope of the loops in the $V/V-B$ diagram varies between 1.1 and 1.8. Only for HV 1579 and LV 60 it amounts to 0.3 and -3.8, respectively.

To study the intrinsic colours of the SMC Cepheids, we have plotted in figure 6, as open circles, the median values of the colour-curves, or in the case that the colour-curves show a too large dispersion, the average

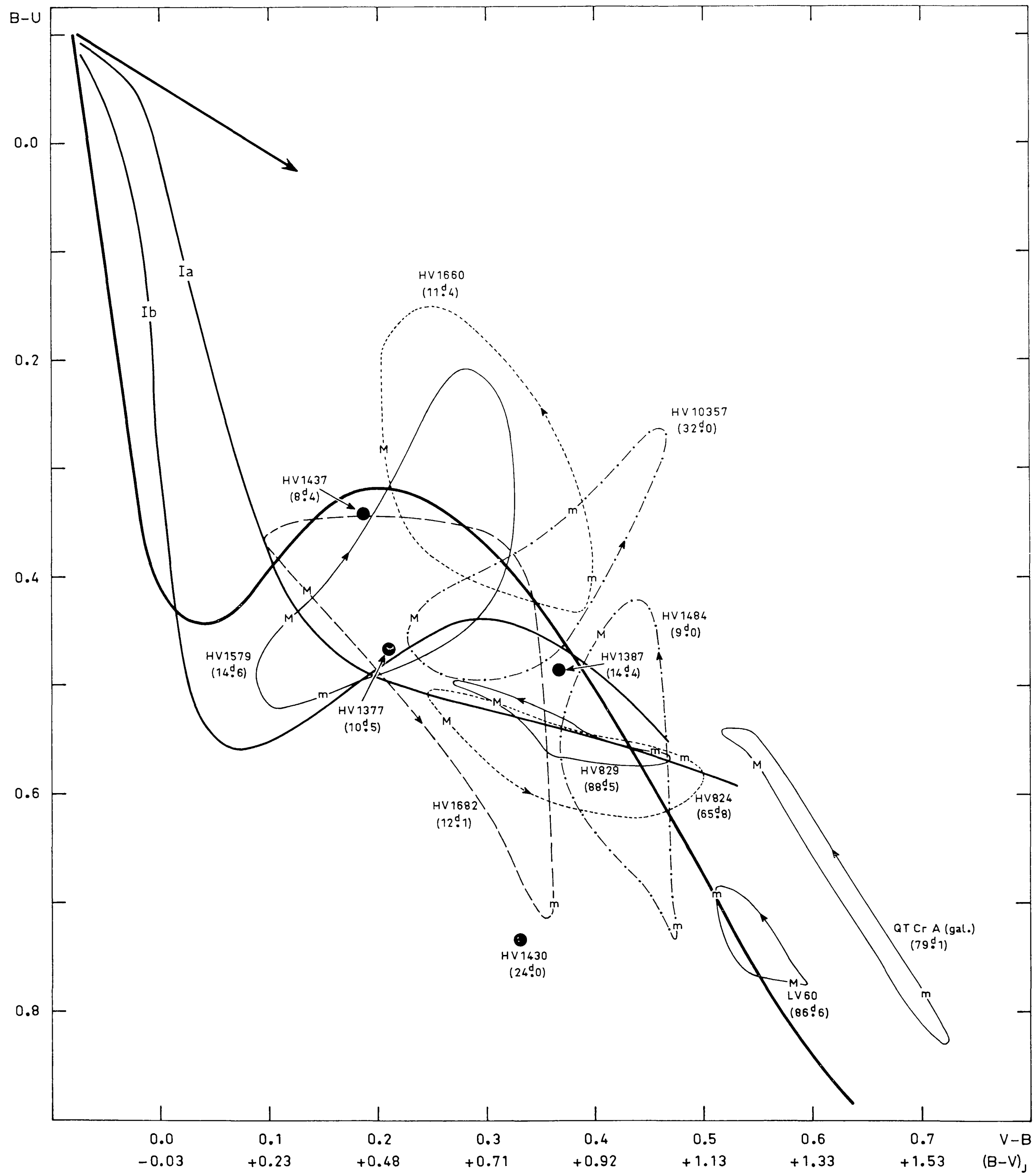


Figure 5. The loops in the $V-B/B-U$ diagram.

colour. These colours have been corrected for galactic absorption in the direction of the SMC, by 0.02 in $V-B$ (Walraven, private communication) and by corresponding values in $B-L$ and $B-U$ (OOSTERHOFF and WALRAVEN, 1966). The crosses indicate the same SMC Cepheids after correction for reddening within the

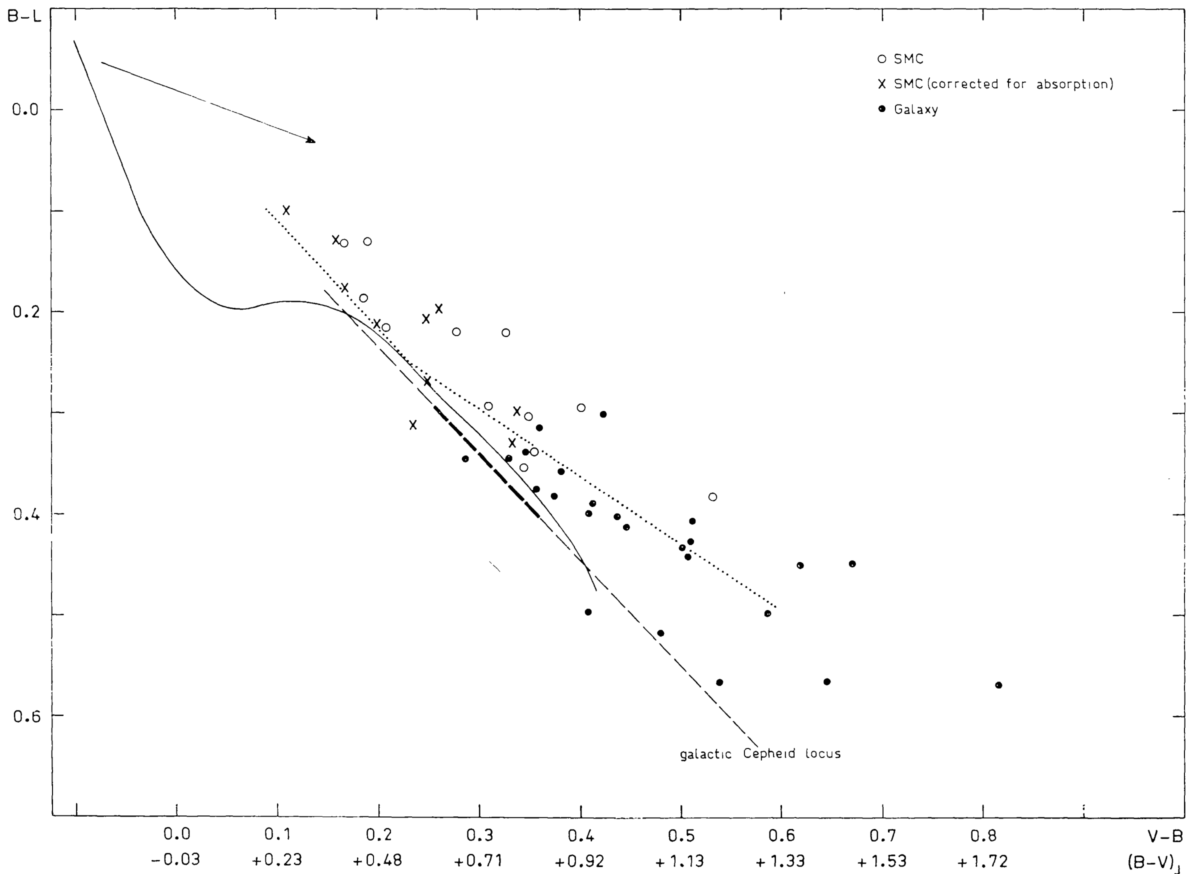


Figure 6. The median colours of galactic and SMC Cepheids.

Cloud. The absorption values which we used for this purpose are given in Paper I. Further we know that $E_{(B-V)_J} = 2.5\ E_{V-B}$. Only for HV 1484 and LV 60 no absorption could be derived.

For the galactic Cepheids we derived the median values roughly from the light-curves published by Walraven et al. (filled circles). The thick dashed part of the galactic Cepheid locus represents the place where the majority of them occur after shifting the galactic Cepheids in the direction opposite to the reddening line. It appears that the SMC Cepheids are on the average much bluer in $B-L$ and also, but less pronounced, in $V-B$.

The dotted line represents more or less the enveloping line of the unreddened left-hand parts of the SMC loops. As the galactic Cepheids have straight narrow loops, their locus can also roughly be considered as the left-hand border of their loops. At the blue side of $V-B = 0.25$ the difference is of minor importance, but at the red side the two enveloping lines diverge considerably.

In figure 7 we have plotted the unreddened median colours only. Symbols between brackets are unreliable. Relations for different luminosity classes, as determined by Walraven (1966), are shown. Several names of galactic Cepheids deviating from the majority have been added to the symbol, together with a very schematic representation of the slope of their loops. In general the loops lie parallel to the lines of constant luminosity. Kappa Pav is probably a Population II Cepheid.

Also in $B-U$ the SMC Cepheids appear to have on the average an ultraviolet excess, although not as pronounced as in $B-L$. Five galactic Cepheids also show a considerable excess in U.

The two long-period Cloud Cepheids HV 824 and 829, and the galactic Cepheid QT CrA, with similar period, do not show any excess, the galactic Cepheid

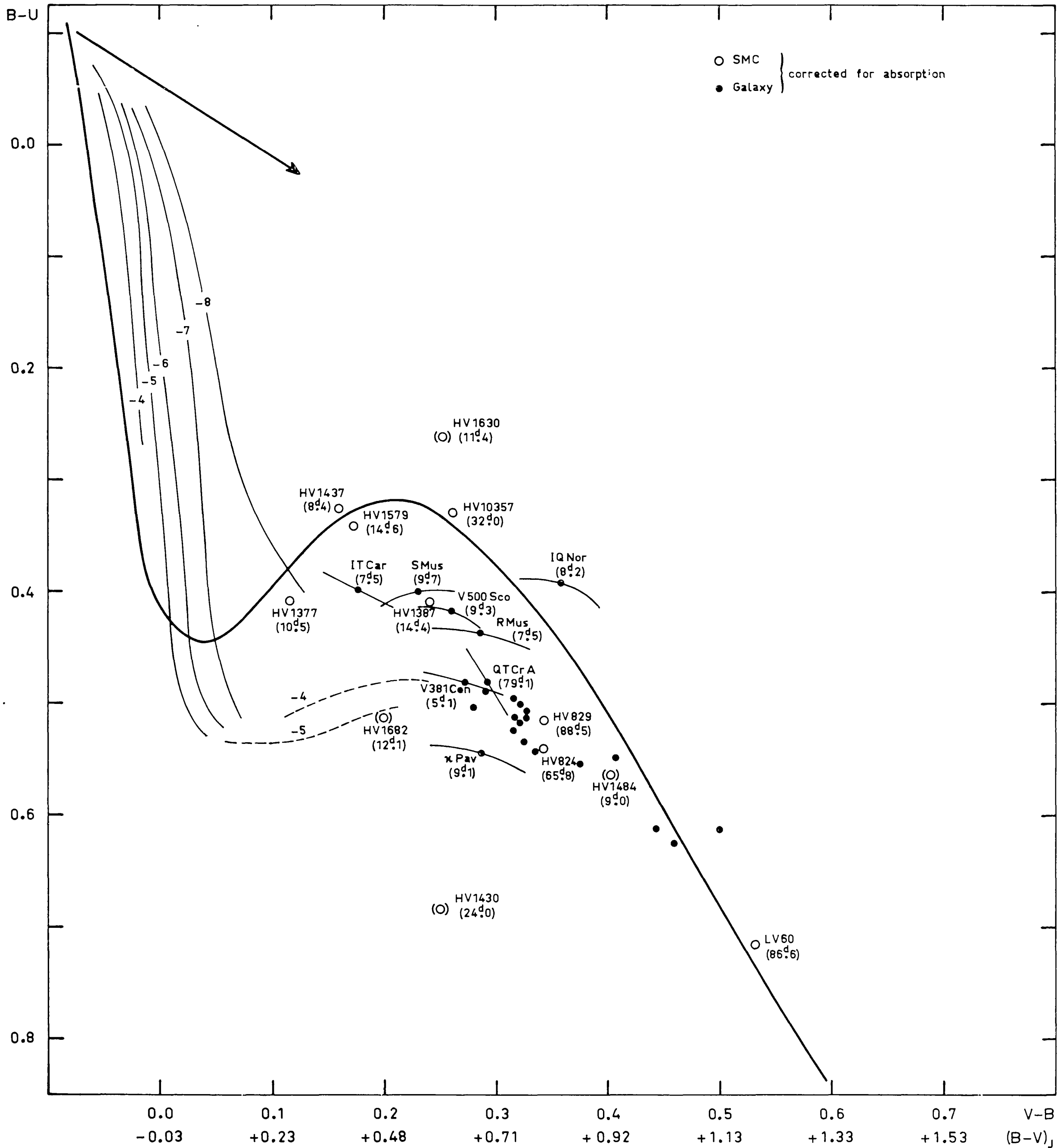


Figure 7. The median colours of galactic and SMC Cepheids after correction for reddening has been applied.

being even slightly bluer in both colours than the two Cloud Cepheids.

If we compare the average colours of galactic and SMC Cepheids, we find that those of the SMC are bluer by 0.06 in $V-B$, 0.13 in $B-L$ and 0.03 in $B-U$. That is to say, compared to the galactic Cepheids they are brighter by 0.15 mag in the B band, 0.5 mag in the L band and 0.2 mag in the U band relative to the intensity in the V band. The blueness in $V-B$ is about of the same order as was found by GASCOIGNE and

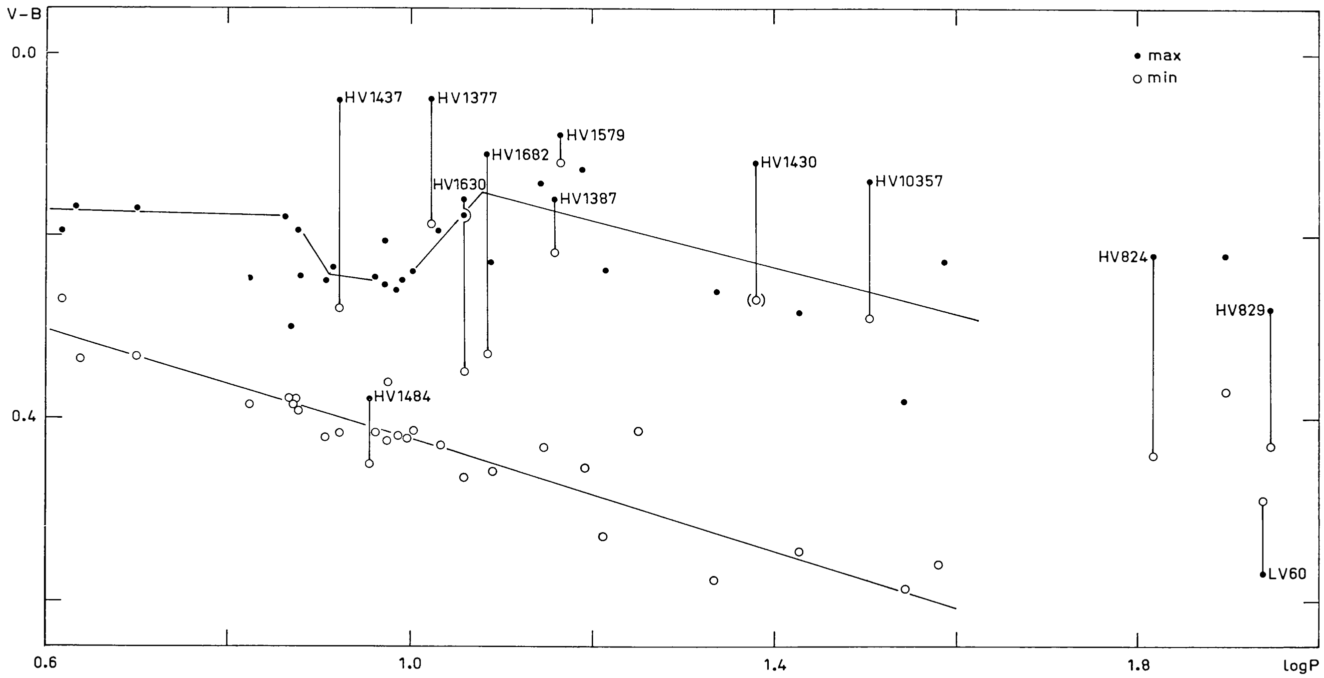


Figure 8. The colour $V-B$, corrected for reddening, at maximum and minimum brightness for galactic and SMC Cepheids as a function of log P. A vertical line connects the symbols of the SMC Cepheids.

KRON (1965) and the author in Paper I. But the ultraviolet excess was up to now unknown.

The most obvious explanation is metal deficiency, because the number of metal absorption lines in galactic Cepheids strongly increases in the blue and ultraviolet region. The large excess in L might be caused by a strong weakening of the very intense H and K absorption lines of Ca II. These lines are situated nearly in the middle of the L band.

As the intensity of the metal lines appreciably increases during minimum brightness of the galactic Cepheids (LEDOUX and WALRAVEN, 1958), we expect the SMC Cepheids to show the strongest excess during minimum. This appears to be clearly the case for HV 10357 and HV 1579 of which the minima of the ultraviolet light-curves are appreciably brighter than for galactic Cepheids. We can illustrate this also by plotting the colour $V-B$ (corrected for reddening) at maximum and minimum brightness as a function of log P. Figure 8 shows this diagram as given by WALRAVEN (1966), in which we added the SMC Cepheids (and QT CrA). This diagram confirms our supposition of metal deficiency for nearly all Cloud Cepheids, with the exception of the stars LV 60 and HV 1484.

For these two viariables especially the maxima are quite abnormal. Both Cepheids lie near the red boundary of the instability strip, close to the region of the non-variable red giants (Paper I, figure 23). Their V magnitudes are much too bright when compared to variables of the same period: roughly 0.5 mag. They may be well on the way to become non-variable red giants, for which the evolutionary track turns upwards after the passage through the instability strip. A red companion near both Cepheids cannot offer an explanation, because the amplitude of the $V-B$ curves should then be larger than normal, which is clearly not the case.

8. Conclusion

The analysis of these observations seems to confirm the presumable intrinsic differences between galactic and SMC Cepheids. A metal deficiency of the SMC Cepheids could explain the ultraviolet excess. Confirmation by spectral analysis is clearly required.

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Note added in proof

In Petit's catalogue (*Ann. Ap.* 1960, **23** 681), QT CrA is classified as a Population II Cepheid. Therefore, one must be cautious about the parts of our discussion pertaining to this star.