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DISCUSSION OF PHOTO-ELECTRIC FIVE-COLOUR OBSERVATIONS OF DIFFERENT TYPES OF PULSATING VARIABLES

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In this paper a discussion is presented of the photo-electric five-colour measures of different types of pulsating variables published by Ponsen and Oosterhoff (1966). Some unpublished observations from the years 1959 and 1960 of the short-period variables BS Aqr, RS Gru and EH Lib are given in the tables 3, 4 and 6.
In section 2 the discussion of the observations is based on the light-curves and the colour-curves. For seven variables these curves are shown in figure 1. In section 3 we discuss the spectral energy distribution relative to that for RU Scl at the phase of minimum. The results for the maximum and the minimum of the light-curves are shown in figure 2. In section 4 we have studied the loops in the different two-colour diagrams. These diagrams are shown in the figures 3, 4, 5, 6 and 7. Although the corrections for reddening are uncertain for the RR Lyrae and short-period variables, we notice a remarkable dependence of the shape of the loops on the period for the RR Lyrae stars. Furthermore the observations indicate that the short-period variables with periods smaller than 0.20 days should not be considered as an extension or continuation of the sequence of RR_{ab}- and RR_c-type variables.
In the last section we discuss the variables in the globular clusters ω Cen and M 4, using mean values of all observations for each variable. After correction for reddening we find a pronounced correlation between the colours $(V-B)$ and $(B-U)$ and the period, the stars with large period being redder in $(V-B)$ and bluer in $(B-U)$ as compared with the variables with short period. In M 4 several non-variable stars were measured. A colour-magnitude diagram for all stars measured in this cluster is shown in figure 9.

1. The observations

We shall here discuss the five-colour observations of different types of pulsating variables, including some variables in the globular clusters ω Centauri and Messier 4, which have been published by Ponsen† and Oosterhoff (1966). In this article we shall refer to this paper by Ponsen and Oosterhoff as paper I. The stars with a sufficient number of observations to be included in the present discussion have been listed in table 1. They have been tabulated according to period. The values of the reciprocal periods actually used in the formula: phase = reciprocal period × (J. D. Hel. – 2430000) are given in the third column. The visual magnitude in the *UBV* system at maximum and minimum is given in the fourth column. They were computed from the observed V and $(V-B)$ values with Walraven's equation, given in paper I. Some of these magnitudes are slightly uncertain because some light-curves are insufficiently covered by the observations. The next column gives the galactic coordinates, and in the last column information is presented concerning the spectral classification. These data were taken from the *General Catalogue of Variable Stars.*

Although the 15 observations of δ Delphini cover a complete cycle, they practically do not reveal any change in magnitude or colour. Considering the variable as of constant brightness we find a mean error of a single observation of $\pm 0^m.010$ for V and of $\pm 0^m.006$ for $(B-V)$. Perry (1957) derived an amplitude in the yellow of $0^m.05$, whereas Eggen (1956b) in his discovery announcement found a similar value, but stated that the light-range is apparently variable.

Some other short-period pulsating variables have been observed with the light-collector of the Leiden southern station by Ponsen and Walraven. However these stars were observed relative to a comparison star. We have reduced these measures to the photometric system of paper I. Most of this material has not yet been published and therefore we present it here in order to include these variables in the discussion. Some data for these variables have been collected in table 2. The two variables AI Velorum and V 703 Scorpii show strong variations in their light-curves. The magnitudes given in table 2 for these stars represent the maximum and minimum of the observed cycle.

The star BS Aqr of table 1 had already been observed

TABLE 1

General data on the variable stars for which observations have been published in *Bull. Astr. Inst. Netherlands Suppl.* **1** 3

Star	Period	P^{-1}	V_J max.	V_J min.	l^{II}	b^{II}	Sp.
W Vir	$17^d.27$	0.05788	$9^m.52$	$10^m.57$	$319^\circ.6$	$+58^\circ.4$	cF2e – G6e
Z Sct	12.90	0.077511	9.06	10.05	26.8	– 0.8	F8 – G5
Y Sct	10.34	0.096698	9.38	10.02	24.0	– 0.8	F7 – G4
X Sct	4.19	0.238205	9.58	10.39	19.0	– 1.6	F5 – G4
SS Sct	3.67	0.272386	7.90	8.42	25.2	– 1.8	F6 – G2
DN Aqr	0.634	1.5757	10.79	11.47	35.7	–69.0	
RV Phe	0.596	1.67669	11.54	12.23	259.5	–38.4	
Z Mic	0.586	1.703769	11.25	11.90	15.7	–43.2	F0 – F5
RU Scl	0.493	2.02705	9.35	10.69	41.5	–78.8	A0
V Ind	0.479	2.08511	9.12	10.48	355.3	–43.1	A0 – F2
RV Cap	0.447	2.23338	10.58	11.44	33.1	–35.5	A8
AM Tuc	0.405	2.46494	11.44	11.87	299.1	–49.0	
AO Tuc	0.332	3.0035	10.90	11.38	313.8	–56.6	
YZ Cap	0.273	3.6569	11.06	11.54	35.4	–39.5	F5
BS Aqr	0.197	5.054947	9.12	9.54	82.0	–65.9	F2
δ Sct	0.193	5.16076	4.64	4.78	23.8	– 2.1	F3 III-IV
δ Del	0.134	7.43439	4.44	4.44	60.1	–16.6	A7 III
CY Aqr	0.061	16.3831	10.42	11.13	69.2	–46.9	B8 – A3
SX Phe	0.054	18.19366	7.12	7.42	341.4	–70.4	sdA2

TABLE 2

General data on the variable stars for which observations have been published in this paper or in *Bull. Astr. Inst. Netherlands Suppl.*

Star	Period	P^{-1}	V_J max.	V_J min.	l^{II}	b^{II}	Sp.
RS Gru	$0^d.147$	6.80219	$7^m.93$	$8^m.49$	$349^\circ.9$	$-48^\circ.0$	A5
ρ Pup	0.140	7.09817	2.75	2.83	243.1	+ 4.4	F6 II
V 703 Sco	0.115	8.67932	7.47:	7.88:	356.6	– 1.3	F0
AI Vel	0.111	8.96266	6.33:	6.74:	260.9	– 5.5	A2p – F2p
EH Lib	0.088	11.31053	9.48	10.00	355.6	+48.4	A5 – F0

in 1960. These unpublished observations, reduced to the system of paper I, are given in table 3. Observations from the year 1959 of RS Gru are given in table 4. The period given in the *General Catalogue of Variable Stars* does not represent the observations anymore. Therefore we derived new elements from epochs by HOFFMEISTER (1956), EGGEN (1956a) and from the present observations. The new elements are

$$\text{maximum} = 2434325.2931 + 0.14701147\,E$$
$$\pm \qquad 26 \text{ (m.e.)}.$$

Numbers of epochs and residuals of this least-squares solution are shown in table 5.

Observations of the year 1960 of EH Lib are given in table 6. The period could be considerably improved by a least-squares solution from old and new epochs. We derived the elements

$$\text{maximum} = 2433438.6090 + 0.088413216\,E$$
$$\pm \qquad 34 \text{ (m.e.)}.$$

Details of this solution are given in table 7. The oldest epoch is from CODE (1951), the next seven epochs from BATYREV (1951), the following eight epochs from FITCH (1957), while the last three were derived from our own observations.

In his article on ρ Puppis, PONSEN (1963b) has given in his table 8 observations covering a full cycle of the three variables: ρ Pup, AI Vel and V 703 Sco. These observations have been reduced to the photometric system of paper I and the resulting values are here given in the tables 8, 9 and 10.

TABLE 3
Observations of BS Aqr from the year 1960

J. D. Hel. −2430000	V	$V-B$	$B-U$	$U-W$	$B-L$	Phase	J. D. Hel. −2430000	V	$V-B$	$B-U$	$U-W$	$B-L$	Phase
7186.4627	3.077	0.105	0.438	0.168	0.202	.188	7186.5363	2.991	0.138	0.420	0.196	0.202	.560
7186.4873	3.101	0.106	0.430	0.162	0.199	.312	7186.5387	2.986	0.141	0.418	0.202	0.205	.572
7186.4906	3.074	0.106	0.449	0.182	0.202	.329	7186.5415	2.986	0.142	0.422	0.192	0.206	.586
7186.4957	3.071	0.116	0.443	0.187	0.197	.355	7186.5439	2.979	0.140	0.416	0.210	0.203	.599
7186.5002	3.056	0.109	0.444	0.182	0.203	.378	7186.5469	2.975	0.143	0.422	0.187	0.201	.614
7186.5031	3.051	0.113	0.442	0.191	0.203	.392	7186.5495	2.976	0.145	0.415	0.200	0.205	.627
7186.5056	3.049	0.116	0.442	0.196	0.199	.405	7186.5524	2.974	0.146	0.418	0.196	0.208	.641
7186.5085	3.047	0.122	0.434	0.200	0.200	.420	7186.5557	2.971	0.145	0.416	0.206	0.210	.658
7186.5109	3.040	0.123	0.434	0.205	0.202	.432	7186.5587	2.969	0.145	0.418	0.191	0.206	.673
7186.5141	3.030	0.124	0.429	0.189	0.205	.448	7186.5616	2.966	0.148	0.409	0.211	0.204	.688
7186.5168	3.027	0.126	0.433	0.195	0.204	.462	7186.5662	2.963	0.150	0.411	0.205	0.205	.711
7186.5196	3.016	0.123	0.424	0.207	0.202	.476	7186.5688	2.958	0.152	0.411	0.196	0.209	.724
7186.5222	3.015	0.129	0.432	0.191	0.202	.489	7186.5719	2.958	0.153	0.416	0.214	0.204	.740
7186.5252	3.009	0.129	0.426	0.178	0.201	.504	7186.5745	2.954	0.154	0.408	0.223	0.205	.753
7186.5276	3.004	0.128	0.425	0.201	0.207	.516	7186.5778	2.946	0.153	0.408	0.193	0.201	.770
7186.5307	2.999	0.136	0.424	0.196	0.199	.532	7186.5807	2.947	0.158	0.402	0.212	0.208	.785
7186.5333	2.996	0.135	0.433	0.185	0.209	.545							

TABLE 4
Observations of RS Gru from the year 1959

J. D. Hel. −2430000	V	$V-B$	$B-U$	$U-W$	$B-L$	Phase	J. D. Hel. −2430000	V	$V-B$	$B-U$	$U-W$	$B-L$	Phase
6756.4406	3.524	0.090	0.455	0.159	0.201	.593	6760.4768	3.367	0.139	0.401	0.166	0.197	.048
6756.4476	3.496	0.096	0.443	0.171	0.194	.640	6760.4817	3.359	0.140	0.402	0.170	0.195	.081
6756.4545	3.479	0.103	0.436	0.162	0.192	.687	6760.4865	3.352	0.144	0.398	0.162	0.187	.114
6756.4594	3.465	0.105	0.432	0.171	0.193	.721	6760.4921	3.346	0.141	0.406	0.168	0.197	.152
6756.4697	3.438	0.115	0.427	0.170	0.194	.791	6760.4956	3.346	0.143	0.395	0.167	0.193	.176
6756.4760	3.423	0.116	0.422	0.178	0.195	.833	6760.5032	3.354	0.137	0.398	0.161	0.191	.227
6756.4824	3.398	0.123	0.416	0.175	0.198	.877	6760.5067	3.366	0.135	0.398	0.166	0.188	.251
6756.4906	3.395	0.128	0.411	0.177	0.196	.933	6760.5095	3.379	0.130	0.399	0.162	0.190	.270
6756.4976	3.377	0.136	0.408	0.174	0.192	.980	6760.5129	3.394	0.138	0.400	0.161	0.188	.293
6756.5038	3.372	0.134	0.408	0.171	0.200	.023	6760.5164	3.418	0.119	0.402	0.153	0.187	.317
6756.5108	3.362	0.137	0.407	0.182	0.201	.070	6760.5192	3.441	0.113	0.408	0.155	0.183	.336
6756.5149	3.353	0.141	0.401	0.162	0.200	.098	6760.5227	3.471	0.101	0.427	0.149	0.191	.360
6756.5233	3.350	0.140	0.399	0.165	0.198	.155	6760.5261	3.507	0.089	0.431	0.148	0.191	.383
6756.5295	3.353	0.142	0.397	0.171	0.194	.197	6760.5289	3.542	0.089	0.448	0.136	0.180	.402
6756.5351	3.358	0.134	0.400	0.178	0.196	.235	6760.5324	3.566	0.073	0.448	0.153	0.186	.426
6756.5413	3.376	0.131	0.396	0.169	0.186	.278	6760.5365	3.576	0.067	0.459	0.156	0.189	.454
6756.5469	3.408	0.124	0.403	0.161	0.193	.316	6760.5400	3.572	0.070	0.457	0.156	0.185	.478
6756.5524	3.448	0.108	0.411	0.160	0.198	.353	6760.5435	3.562	0.072	0.457	0.158	0.198	.501
6756.5580	3.513	0.087	0.429	0.151	0.186	.391	6760.5463	3.552	0.074	0.458	0.157	0.189	.520
6756.5614	3.538	0.079	0.443	0.153	0.188	.414	6760.5504	3.541	0.082	0.452	0.152	0.191	.548
6756.5649	3.560	0.067	0.455	0.147	0.189	.438	6760.5539	3.523	0.086	0.457	0.161	0.193	.572
6756.5712	3.567	0.070	0.454	0.146	0.185	.481	6760.5560	3.517	0.087	0.447	0.164	0.189	.586
6756.5746	3.562	0.076	0.454	0.146	0.186	.504	6760.5615	3.505	0.091	0.445	0.164	0.185	.624
6756.5781	3.548	0.076	0.455	0.157	0.188	.528	6760.5643	3.493	0.098	0.443	0.167	0.191	.643
6756.5816	3.537	0.082	0.455	0.158	0.193	.552	6760.5678	3.486	0.097	0.443	0.165	0.194	.667
6756.5858	3.525	0.083	0.452	0.162	0.189	.580	6760.5713	3.473	0.104	0.434	0.164	0.193	.690
6756.5906	3.506	0.083	0.444	0.159	0.190	.613	6760.5747	3.466	0.107	0.431	0.169	0.193	.714
							6760.5782	3.457	0.113	0.423	0.173	0.196	.737
6760.4490	3.406	0.124	0.420	0.175	0.189	.859	6760.5810	3.451	0.113	0.427	0.170	0.198	.756
6760.4546	3.393	0.130	0.404	0.174	0.197	.897	6760.5852	3.442	0.119	0.418	0.164	0.191	.785
6760.4608	3.383	0.130	0.409	0.174	0.189	.939	6760.5893	3.430	0.120	0.422	0.175	0.191	.813
6760.4643	3.377	0.133	0.408	0.169	0.198	.963	6760.5921	3.419	0.123	0.418	0.179	0.195	.832
6760.4720	3.373	0.141	0.398	0.175	0.193	.015							

TABLE 5
Least-squares solution of the period of RS Gru

Epoch max. J. D. Hel. −2430000	Author	E	$O-C$
4325.294	Hoffmeister	0	$+0^{d}.001$
4573.451	Hoffmeister	1688	+0.003
5399.059	Eggen	7304	−0.006
6756.571	this paper	16538	+0.002
6760.538	this paper	16565	0.000

The material which we have now at our disposal consists of

1 population II Cepheid,
4 classical Cepheids,
6 RR Lyrae stars of subclass ab,
3 RR Lyrae stars of subclass c,
10 stars with periods shorter than 0.2 days.

It may be repeated that brightness and colour are ex-

TABLE 6
Observations of EH Lib from the year 1960

J. D. Hel. −2430000	V	$V-B$	$B-U$	$U-W$	$B-L$	Phase
7114.2445	2.801	0.124	0.407	0.172	0.203	.876
7114.2473	2.791	0.124	0.411	0.189	0.208	.908
7114.2503	2.784	0.132	0.409	0.193	0.201	.941
7114.2534	2.775	0.132	0.408	0.179	0.200	.977
7114.2560	2.762	0.132	0.400	0.173	0.198	.006
7114.2591	2.759	0.133	0.400	0.184	0.195	.041
7114.2617	2.755	0.134	0.396	0.177	0.206	.070
7114.2647	2.748	0.138	0.395	0.192	0.207	.104
7114.2671	2.743	0.138	0.394	0.174	0.205	.131
7114.2702	2.743	0.141	0.390	0.181	0.194	.167
7114.2727	2.747	0.142	0.393	0.168	0.194	.195
7114.2760	2.740	0.136	0.390	0.178	0.199	.232
7114.2786	2.743	0.138	0.395	0.162	0.197	.262
7114.2817	2.753	0.134	0.386	0.158	0.198	.297
7114.2839	2.762	0.127	0.394	0.156	0.193	.321
7114.2865	2.777	0.125	0.400	0.158	0.200	.351
7114.2893	2.810	0.114	0.395	0.177	0.201	.383
7114.2909	2.831	0.109	0.404	0.177	0.198	.401
7114.2924	2.862	0.104	0.419	0.158	0.200	.418
7114.2952	2.911	0.088	0.428	0.161	0.202	.449
7114.2964	2.931	0.082	0.440	0.148	0.199	.463
7114.2980	2.945	0.075	0.448	0.178	0.197	.481
7114.3011	2.953	0.074	0.446	0.132	0.194	.516
7114.3025	2.943	0.070	0.450	0.142	0.199	.532
7114.3048	2.939	0.079	0.452	0.148	0.202	.558
7114.3077	2.922	0.083	0.458	0.150	0.206	.591
7114.3101	2.910	0.090	0.446	0.154	0.202	.618
7114.3133	2.889	0.096	0.440	0.149	0.201	.654
7114.3157	2.874	0.102	0.441	0.158	0.194	.681
7114.3188	2.855	0.102	0.433	0.157	0.194	.716
7114.3213	2.849	0.106	0.421	0.160	0.198	.744
7114.3242	2.831	0.113	0.421	0.178	0.202	.777
7114.3268	2.829	0.119	0.416	0.174	0.200	.807
7114.3304	2.808	0.122	0.413	0.154	0.197	.847
7114.3332	2.792	0.121	0.413	0.154	0.204	.879
7114.3365	2.786	0.124	0.400	0.182	0.205	.916
7114.3393	2.779	0.126	0.399	0.168	0.195	.948
7114.3426	2.770	0.133	0.402	0.176	0.193	.985
7114.3452	2.764	0.130	0.406	0.178	0.203	.015
7116.2247	2.737	0.130	0.401	0.168	0.202	.273
7116.2279	2.749	0.131	0.395	0.181	0.201	.309
7116.2313	2.779	0.127	0.396	0.166	0.200	.348
7116.2339	2.803	0.120	0.397	0.144	0.196	.377
7116.2369	2.847	0.105	0.412	0.148	0.200	.411
7116.2383	2.872	0.098	0.417	0.149	0.208	.427
7116.2407	2.916	0.086	0.436	0.156	0.204	.454
7116.2438	2.953	0.079	0.447	0.146	0.198	.489
7116.2450	2.954	0.076	0.446	0.156	0.200	.503
7116.2475	2.948	0.076	0.451	0.150	0.200	.531
7116.2506	2.935	0.080	0.449	0.160	0.202	.566
7116.2520	2.925	0.082	0.452	0.159	0.203	.582
7116.2544	2.906	0.084	0.450	0.176	0.205	.609
7116.2576	2.889	0.089	0.436	0.172	0.208	.645
7116.2588	2.881	0.093	0.442	0.165	0.197	.659
7116.2612	2.867	0.094	0.436	0.173	0.205	.686
7116.2641	2.854	0.103	0.431	0.159	0.201	.719
7116.2667	2.844	0.110	0.426	0.161	0.200	.748
7116.2695	2.831	0.112	0.420	0.167	0.202	.780
7116.2721	2.823	0.117	0.418	0.164	0.200	.809
7116.2751	2.810	0.120	0.416	0.174	0.199	.843
7116.2779	2.802	0.123	0.411	0.172	0.197	.875
7116.2813	2.787	0.124	0.409	0.176	0.196	.913
7116.2838	2.778	0.124	0.408	0.170	0.199	.941
7116.2867	2.770	0.129	0.407	0.160	0.195	.974
7116.2897	2.768	0.136	0.402	0.177	0.198	.008
7116.2928	2.760	0.138	0.395	0.170	0.200	.043
7116.2952	2.747	0.134	0.392	0.191	0.202	.070
7116.2966	2.750	0.139	0.396	0.154	0.204	.086
7116.2980	2.746	0.140	0.394	0.155	0.198	.102
7116.3015	2.739	0.139	0.392	0.149	0.206	.142
7116.3041	2.739	0.137	0.394	0.168	0.200	.171
7116.3072	2.739	0.139	0.391	0.150	0.198	.206
7116.3100	2.743	0.142	0.396	0.162	0.198	.238
7116.3131	2.743	0.137	0.394	0.166	0.190	.273
7116.3155	2.749	0.134	0.390	0.146	0.198	.300
7116.3185	2.764	0.126	0.393	0.147	0.193	.334
7116.3209	2.785	0.122	0.390	0.174	0.195	.361
7116.3239	2.819	0.110	0.402	0.158	0.192	.395
7116.3251	2.843	0.112	0.405	0.147	0.199	.409
7116.3275	2.884	0.098	0.423	0.148	0.197	.436
7116.3303	2.934	0.083	0.439	0.141	0.200	.467
7116.3320	2.944	0.077	0.449	0.130	0.199	.487
7116.3343	2.951	0.074	0.452	0.142	0.202	.513
7116.3374	2.943	0.078	0.452	0.148	0.204	.548
7116.3398	2.927	0.079	0.457	0.148	0.206	.575

TABLE 7
Least-squares solution of the period of EH Lib from epochs of maxima

J. D. Hel. −2430000	E	$O-C$
3438.608	0	$-0^{d}.001$
3756.546	3596	+0.003
3770.511	3754	−0.001
3782.357	3888	−0.003
3819.321	4306	+0.005
3822.320	4340	−0.002
3824.359	4363	+0.003
3865.289	4826	−0.002
5223.760	20191	0.000
5223.848	20192	−0.001
5223.937	20193	0.000
5225.793	20214	−0.001
5243.741	20417	−0.001
5243.830	20418	0.000
5622.680	24703	−0.001
5622.769	24704	0.000
7114.301	41574	+0.001
7116.245	41596	0.000
7116.334	41597	0.000

TABLE 8
Observations of ρ Pup from the year 1961

J. D. Hel. −2430000	V	$V-B$	$B-U$	$U-W$	$B-L$	Phase
7415.2035	5.631	0.172	0.422	0.202	0.236	.375
7415.2164	5.632	0.168	0.422	0.201	0.235	.467
7415.2296	5.639	0.165	0.425	0.203	0.234	.560
7415.2438	5.639	0.167	0.426	0.202	0.234	.661
7415.2570	5.632	0.169	0.426	0.203	0.237	.755
7415.2688	5.625	0.173	0.425	0.202	0.238	.839
7415.2898	5.612	0.177	0.421	0.205	0.240	.988
7415.3092	5.606	0.179	0.419	0.203	0.240	.125
7415.3275	5.609	0.175	0.420	0.202	0.237	.255
7415.3479	5.627	0.168	0.418	0.198	0.232	.400

TABLE 9
Observations of AI Vel from the year 1961

J. D. Hel. −2430000	V	$V-B$	$B-U$	$U-W$	$B-L$	Phase
7415.2097	4.188	0.090	0.428	0.155	0.190	.003
7415.2235	4.129	0.109	0.410	0.160	0.192	.127
7415.2374	4.083	0.122	0.398	0.170	0.190	.252
7415.2509	4.046	0.136	0.388	0.172	0.188	.373
7415.2634	4.043	0.133	0.380	0.175	0.186	.485
7415.2756	4.117	0.111	0.387	0.156	0.188	.594
7415.2841	4.185	0.087	0.417	0.149	0.191	.670
7415.2941	4.212	0.079	0.435	0.152	0.192	.760
7415.3019	4.193	0.085	0.433	0.154	0.192	.830
7415.3165	4.140	0.100	0.415	0.150	0.188	.961
7415.3195	4.130	0.105	0.411	0.154	0.188	.987
7415.3365	4.089	0.120	0.397	0.165	0.184	.140
7415.3394	4.095	0.121	0.397	0.162	0.185	.166

TABLE 10
Observations of V 703 Sco from the year 1960

J. D. Hel. −2430000	V	$V-B$	$B-U$	$U-W$	$B-L$	Phase
7069.4975	3.585	0.216	0.397	0.206	0.208	.031
7069.5098	3.625	0.195	0.398	0.193	0.201	.137
7069.5190	3.670	0.169	0.408	0.183	0.202	.218
7069.5274	3.721	0.141	0.428	0.176	0.200	.290
7069.5346	3.754	0.125	0.446	0.176	0.202	.352
7069.5420	3.743	0.130	0.451	0.175	0.200	.418
7069.5499	3.714	0.140	0.446	0.179	0.201	.486
7069.5598	3.686	0.158	0.434	0.186	0.202	.572
7069.5706	3.667	0.172	0.424	0.189	0.205	.665
7069.5842	3.643	0.188	0.414	0.190	0.203	.784
7069.6004	3.606	0.206	0.404	0.202	0.206	.924

pressed throughout in the logarithm of the intensity, unless we have used the symbol V_J for the visual magnitude in the *UBV* system.

2. The light-curves and the colour-curves

It is possible to analyse the present material, consisting of magnitudes and colours as a function of time, in several ways. As the shape and the range of the light-curves and colour-curves are practically independent from interstellar absorption and reddening, we shall first study the main characteristics of these light- and colour-curves. We present these curves for seven variables in figure 1. There are no Cepheids among the variables of figure 1 because the number of observations is small for these stars and because excellent light-curves and colour-curves have been published by WALRAVEN, TINBERGEN and WALRAVEN (1964). Their photometric system is the same as ours with the exception that their V- and colour values have zero-points relative to a different comparison star for each Cepheid. The variables have been arranged according to period in figure 1. Z Mic and V Ind are RR_{ab} stars, AO Tuc is an RR_c star. BS Aqr is a δ Scuti-type variable, while RS Gru has a somewhat shorter period. CY Aqr and SX Phe are very-short-period variables. All these stars have stable light-curves. Under the light-curve in V have been plotted the colour-curves in $(V-B)$, $(B-U)$, $(B-L)$ and $(U-W)$. For some variables the last colour-curve is lacking, the W-intensity being too weak.

The authors of the article on Cepheids, quoted above, have noticed the following main characteristics of the light- and colour-curves of classical or population I Cepheids.

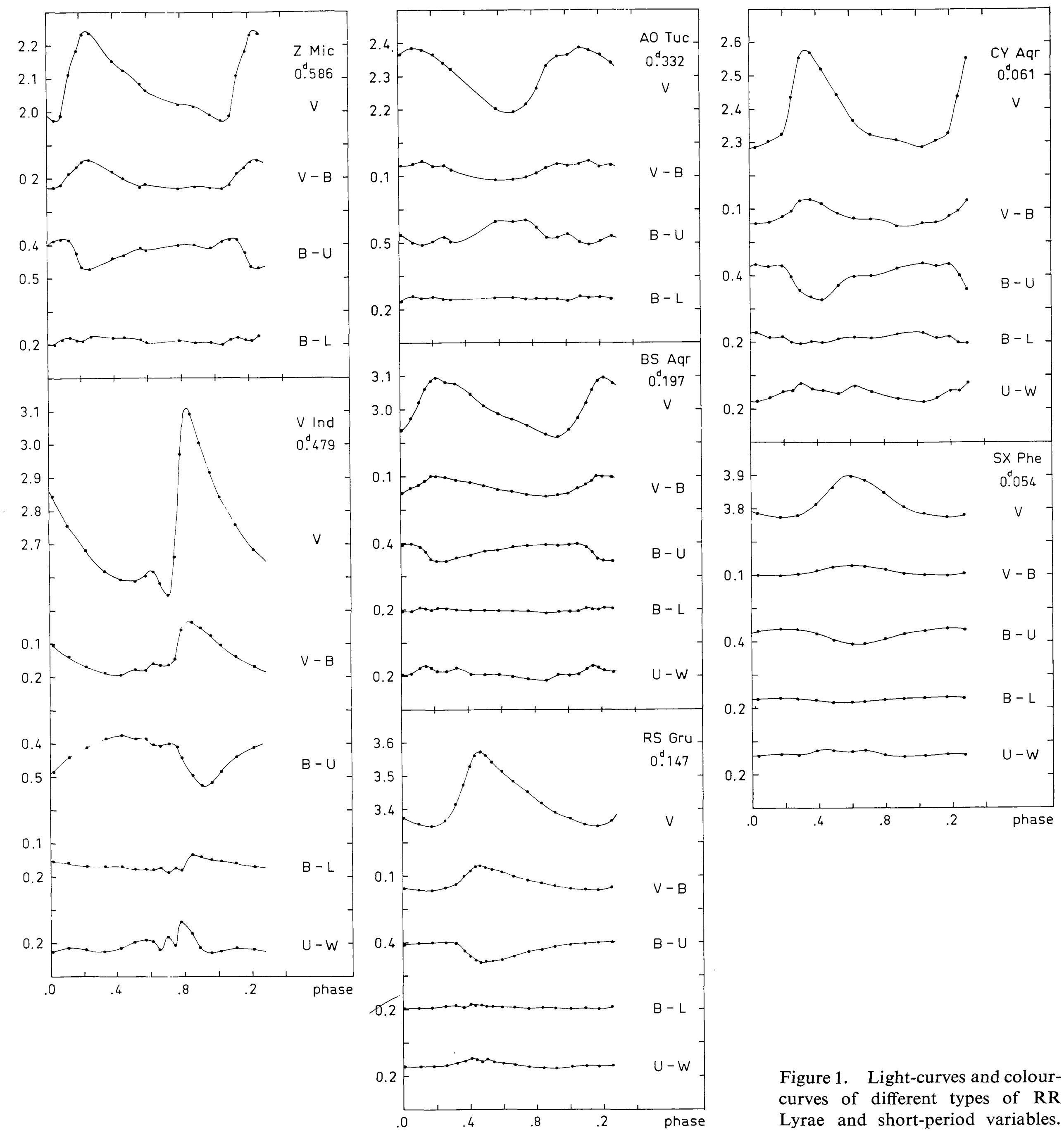

Figure 1. Light-curves and colour-curves of different types of RR Lyrae and short-period variables.

The $(V-B)$ curve closely resembles the V light-curve, although its range is smaller. It is slightly shifted to an earlier phase relative to V.

The $(B-L)$ colour varies strongly and its range is about equal to the range of the $(V-B)$ curve, although the difference in effective frequency between bands B and L is much smaller than that between the V- and B-bands. It shows a slight phase shift relative to the $(V-B)$ curve, which presents itself as a slight bulging upward of the ascending branch of this colour-curve.

The amplitude of the $(B-U)$ curve is smaller than would be expected from the change in temperature

TABLE 11

Spectral energy distribution relative to that of RU Scl at the phase of minimum brightness

Star		V	B	L	U	W
Z Sct	max.	0.000	−0.085	−0.197	−0.236	−0.376
	min.	0.000	−0.343	−0.725	−0.614	−0.773
RU Scl	max.	0.000	+0.140	+0.165	+0.051	+0.099
	min.	0.000	0.000	0.000	0.000	0.000
RV Cap	max.	0.000	+0.106	+0.121	−0.016	+0.009
	min.	0.000	−0.008	−0.005	−0.005	−0.009
AO Tuc	max.	0.000	+0.101	+0.101	+0.015	+0.080
	min.	0.000	+0.060	+0.071	+0.011	+0.069
BS Aqr	max.	0.000	+0.070	+0.048	+0.005	+0.037
	min.	0.000	+0.014	−0.016	−0.005	+0.015
RS Gru	max.	0.000	+0.102	+0.090	+0.033	+0.093
	min.	0.000	+0.028	+0.007	+0.018	+0.064
ρ Pup	max.	0.000	+0.004	−0.055	−0.033	−0.019
EH Lib	max.	0.000	+0.094	+0.071	+0.035	+0.107
	min.	0.000	+0.032	+0.009	+0.027	+0.076
CY Aqr	max.	0.000	+0.099	+0.073	+0.025	+0.101
	min.	0.000	+0.026	+0.028	+0.049	+0.086
SX Phe	max.	0.000	+0.098	+0.092	+0.079	+0.167
	min.	0.000	+0.068	+0.075	+0.095	+0.174

gradient. On the whole the $(B-U)$ curves are rather flat and they often show a hump at the phase of increasing brightness.

If we pass on now to the curves of figure 1, we notice the following characteristics.

The $(V-B)$ curves closely resemble the V light-curves, although with a smaller range.

The $(B-U)$ curves seem to have a slightly larger range than the $(V-B)$ curves and are very much the mirror image of the latter, although for V Ind and for CY Aqr the minimum of the $(B-U)$ curve occurs clearly later than the maximum of the $(V-B)$ curve.

The range of the $(B-L)$ curves is very small. For the first five variables with periods from 0.58 to 0.14 days the maximum of the $(B-L)$ curve has about the same phase as the maximum of the light-curve. However, for the two stars with very short periods the $(B-L)$ curves show a minimum when the light-curves show a maximum.

The $(U-W)$ curves are not very accurate. They have a small range and their maximum occurs at a somewhat earlier phase than the maximum of the light-curve.

3. The relative spectral energy distribution

A different manner to present and analyse our data consists of the computation of relative spectral energy gradients. Such an analysis has been provisionally published by the first author (OOSTERHOFF, 1965). For a number of variables, typical for their class, we have computed the differences of the log I-values for the B, L, U and W-bands with that for the V-band. We have limited this computation to the phases of maximum and of minimum of the V light-curve. We intended to compare these differences with those derived for a standard star, preferably for a main-sequence F-type star. As such a star had not been observed, we have used as standard the variable RU Scl at its minimum phase. This variable is an RR_{ab}-type star with a period of nearly half a day. Its spectral type at minimum has not been determined, but we may assume that it is about

F5. The differences computed for our programme stars minus those computed for this standard star are given in table 11, and these values have been plotted against the reciprocal wavelengths of the five photometric bands in figure 2.

The wavelengths of the five bands were taken from table 1 of the article by WALRAVEN and WALRAVEN (1960). The second author of the present paper has determined more accurate values since, and according to him the best values, for unreddened O-type stars, are

	λ^{-1}
V	1.850
B	2.337
L	2.615
U	2.756
W	3.085

The upper lines in figure 2 represent the phase of maximum, the lower lines the phase of minimum of the V light-curves. For ρ Pup the range of the V light-curve is so small, that we have only given the curve for phase of maximum. These diagrams and the data in table 11 are affected by interstellar reddening. For most of the stars the effect of reddening will be very small, as they are situated at high galactic latitudes. But for the Cepheid Z Sct and for the short-period variable ρ Pup this is not the case. For Z Sct we have corrected our measures for reddening in a way to which we shall return below. Nothing is known about the reddening of ρ Pup, but it is such a bright star that the reddening probably is very slight.

We can immediately read the range of the different colour-curves from the diagrams in figure 2. For the

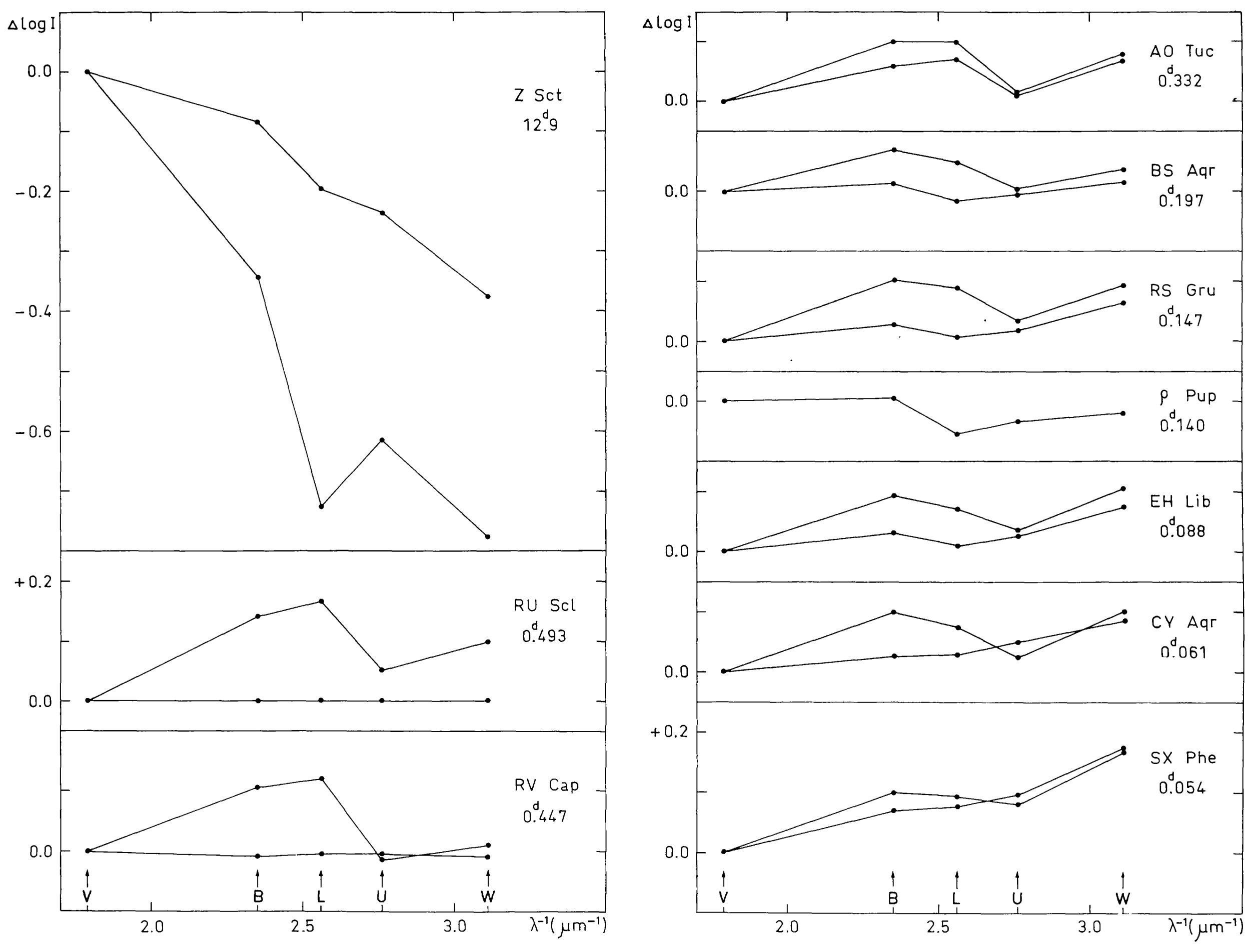

Figure 2. Relative spectral energy distribution for different types of pulsating variables at maximum and at minimum of the light-curves. All stars have been compared with RU Scl at minimum phase.

Cepheids, for example, we find the range for the $(B-L)$ curve to be equal to the difference in ordinate between maximum and minimum at the L-band minus this difference at the B-band. The range of the $(V-B)$ curve is given by the difference in ordinate at the B-band. From the diagram it is clear that the range in the $(B-L)$ curve is about as large as the range in the $(V-B)$ curve. We also see that this effect is due to a strong deficiency in the intensity of the L-band at the phase of minimum light of the V light-curve. This deficiency is probably due to strong blanketing in this particular region of the spectrum partly by the H and K lines of Ca^+ and especially by other strong absorption features around 3850 A which are also conspicuous in the solar spectrum. The dip at the L-band is very conspicuous at minimum, about 0.6 magnitude, but is also present at the phase of maximum.

In a similar way, the diagrams make it clear why for the RR Lyrae and short-period variables the $(B-U)$ curve is reversed as compared with the $(V-B)$ colour-curve. Concerning the RR Lyrae and short-period variables in our diagram we notice the following phenomena. Leaving ρ Pup apart for the moment, we see that at phase of maximum all variables have a relative energy distribution corresponding with A-type spectra. For the two RR_{ab}-type variables we find a small deficiency in the L-intensity, probably due to the Balmer lines in this spectral region, and a strong Balmer jump between the B and U-intensities. For these stars the U,W gradient seems to be slightly less steep than the V,B gradient. Following the diagrams in figure 2 to shorter periods we conclude that the Balmer discontinuity, or the difference between the B and U-intensities, decreases although the V,B gradients remain unchanged. Greenstein (1959) has remarked that the stars of the horizontal branch in the H-R diagram are characterized by strong sharp hydrogen lines and a large Balmer jump.

For the stars with very short periods the U,W gradients are steeper than the V,B gradients. With respect to the curves at the phase of maximum brightness we notice another interesting feature, namely that for all the short-period variables, which we usually do not classify as RR Lyrae-type variables, the intensity in the L-band relative to that in the B-band is systematically lower than for the ordinary RR Lyrae variables. A broadening of the hydrogen lines in these denser stars could cause such an effect.

The energy curves for the phase of minimum light give rise to the following remarks. For the RR_{ab} stars this curve is flat, because we used the energy distribution of RU Scl at minumum as standard. The RR_c star AO Tuc shows an A-type distribution. However, the two variables with the shortest period show practically the same gradient relative to the standard star throughout the spectrum. The Balmer discontinuity has nearly disappeared. Comparing the minimum of SX Phe with the maximum of BS Aqr or with the minimum of AO Tuc, we find that the V, B gradient is about the same in the three cases, but that the distribution in the far blue and ultraviolet is very peculiar for SX Phe. At minimum this variable has a strong ultraviolet excess as compared with the other two stars. The spectrum of SX Phe has been classified as that of a subdwarf and F-type subdwarfs are characterized by an ultraviolet excess, but SX Phe as well as CY Aqr have early A-type spectra, even in the phase of minimum, and it is surprising that the Balmer discontinuity is practically absent.

Finally we may say a few words about ρ Pup. The energy distribution in the V,B region is the same as that for our standard and it is in full accord with its spectral type F6. However, there is a considerable deficiency in L and a smaller one in U and W as compared with our standard. This may be connected with the luminosity class II which has been assigned to this variable. Among the ten variables in tables 1 and 2 with periods between 0.20 and 0.05 days we find one subdwarf, SX Phe, while luminosity classes II, III and III to IV have been assigned to the stars ρ Pup, δ Del and δ Sct respectively. Although it seems to be a heterogeneous group of variables, there exist some pronounced correlations. In the first place the spectral type varies with period. If we use, according to Ponsen (1963a), a fundamental period of 0.15 days for V 703 Sco and if we omit ρ Pup, we find a change of spectral type from A1 for a period of 0.05 days to F2 for a period of 0.20 days with a mean deviation of two tenths of a spectral type for an individual variable. Woltjer (1956) has analysed the proper motions and radial velocities of eight of the stars of our list. His results indicate that the two variables with the shortest periods, CY Aqr and SX Phe, are considerably fainter absolutely, by two magnitudes or more, than the variables with periods near 0.20 days. In his paper on the mean parallaxes of RR Lyrae variables, VAN HERK (1965) confirms that the stars with periods shorter than 0.10 days are about 4.5 magnitudes fainter than normal RR Lyrae stars. On the other hand, his grouping number 4 with 16 stars with periods between 0.10 and 0.20 days yields an absolute photographic magnitude of -1.6, a luminosity which is considerably higher than for any other grouping of RR Lyrae stars. All seven stars of our list within this range of period occur in Van Herk's group 4. He considers the high luminosity mentioned above as an accidental deviation. However, the question arises whether these short-period pulsating variables are really more or less directly related to the normal RR Lyrae variables. Such a relation is suggested by PLAUT (1965) when he states that the sequence of the short-period variables in the H-R diagram fades into the region of the RR Lyrae variables at a period of 0.20 days.

On the other hand we do not find short-period variables in globular clusters, with the exception of variable number 65 in ω Centauri with a period of 0.062 days. This variable probably is a foreground star. According to WOLTJER (1956) the space density of the short-period variables is about a hundred times the space density of the RR Lyrae variables in the solar neighbourhood. Furthermore we notice that the frequency curve of the periods of short-period and RR Lyrae stars shows a pronounced minimum for periods between 0.20 and 0.24 days. We therefore should keep in mind the possibility that the short-period variables could have reached their position in the H-R diagram along evolutionary tracks which are essentially different from the tracks of the ordinary RR Lyrae stars. We have already drawn attention to the fact that luminosity classes II and III have been assigned to some of the variables of our list. Among the 16 stars of Van Herk's grouping number 4 we find two more variables with luminosity classes III and IV, namely VZ Cnc and CC And respectively.

A comparative study of the spectra of short-period variables like VZ Cnc, A7–F2 III, and δ Sct, F3 III, IV, with the spectra of ordinary RR Lyrae stars with similar spectral types could probably help to solve some of the problems which we have discussed.

4. The two-colour diagrams

Finally we can study our observations by means of the two-colour diagrams and the properties of the loops in these diagrams.

We shall first discuss the Cepheids from our list. The four galactic Cepheids in the constellation Scutum are no doubt affected by interstellar reddening. We have determined the reddening with the aid of the $(V-B)$ and $(B-L)$ two-colour diagram as has been explained at the Saltsjöbaden symposium in 1964 by the second author (WALRAVEN, 1966). We have adopted the following ratios between the different colour excesses:

$$E_{(B-L)} = 0.36\, E_{(V-B)},$$
$$E_{(B-U)} = 0.63\, E_{(V-B)},$$
$$E_{(U-W)} = 0.44\, E_{(V-B)}.$$

We found the following colour excesses in $(V-B)$ for these four Cepheids:

Z	Sct	+0.203,
Y	Sct	+0.333,
X	Sct	+0.277,
SS	Sct	+0.148.

The reddening of the population II Cepheid W Vir remains unknown, but its high galactic latitude makes it unlikely that the reddening is considerable. In the upper part of figure 3 we have plotted the observations, corrected for reddening, in the $(V-B)$ and $(B-U)$ colour diagram. The direction of reddening and the main sequence have been indicated in the diagram, together with the locus of unreddened supergiants of absolute visual magnitudes of -5 and -4. These data were taken from earlier work by the second author. A similar diagram for the $(V-B)$ and $(U-W)$ plane is shown in the lower part of this figure. Only two of our five Cepheids have sufficiently reliable W-measures to be shown in this diagram. The locus of the main-sequence stars and of the supergiants of classes Ia and Ib are also shown. The situation of the loops of the galactic Cepheids in these two diagrams is in full agreement with the results derived by the second author in his article mentioned above. The loop of W Vir differs strongly in shape from those of the galactic Cepheids, being much more open. In the upper diagram the stars move along the loop in an anti-clockwise direction.

Next we shall study the nine RR Lyrae variables of

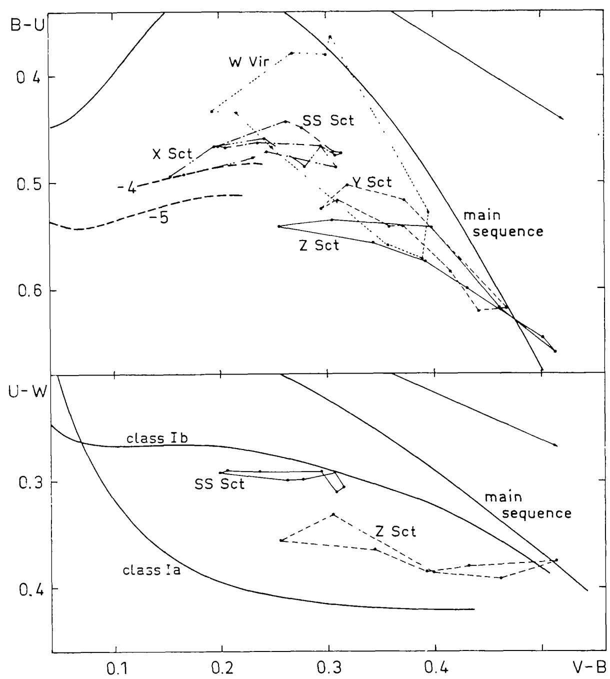

Figure 3. Loops of Cepheids in the $(V-B)$ and $(B-U)$ and in the $(V-B)$ and $(U-W)$ two-colour diagrams, corrected for reddening.

our list. All these stars have galactic latitudes south of $-35°$ and consequently we shall not meet heavy reddening. In drawing the loops in the $(V-B)$ and $(B-U)$ plane we found that some of the variables are reddened relative to the others. Reddening is conspicuous for Z Mic and for YZ Cap. We also noticed that that part of the loop, which corresponds with the descending branch of the light-curve, runs practically parallel to the rising part of the main-sequence curve in this diagram. We have therefore determined provisional values for the reddening by shifting the loops in the direction of the reddening line so as to make the parallel parts of the loops coincide with the loop which is closest to the main-sequence curve. In this way we derived the following colour excesses in $(V-B)$:

DN Aqr $+0.013$, RU Scl $+0.013$, AM Tuc $+0.000$, RV Phe $+0.014$, V Ind $+0.021$, AO Tuc $+0.004$, Z Mic $+0.060$, RV Cap $+0.018$, YZ Cap $+0.024$.

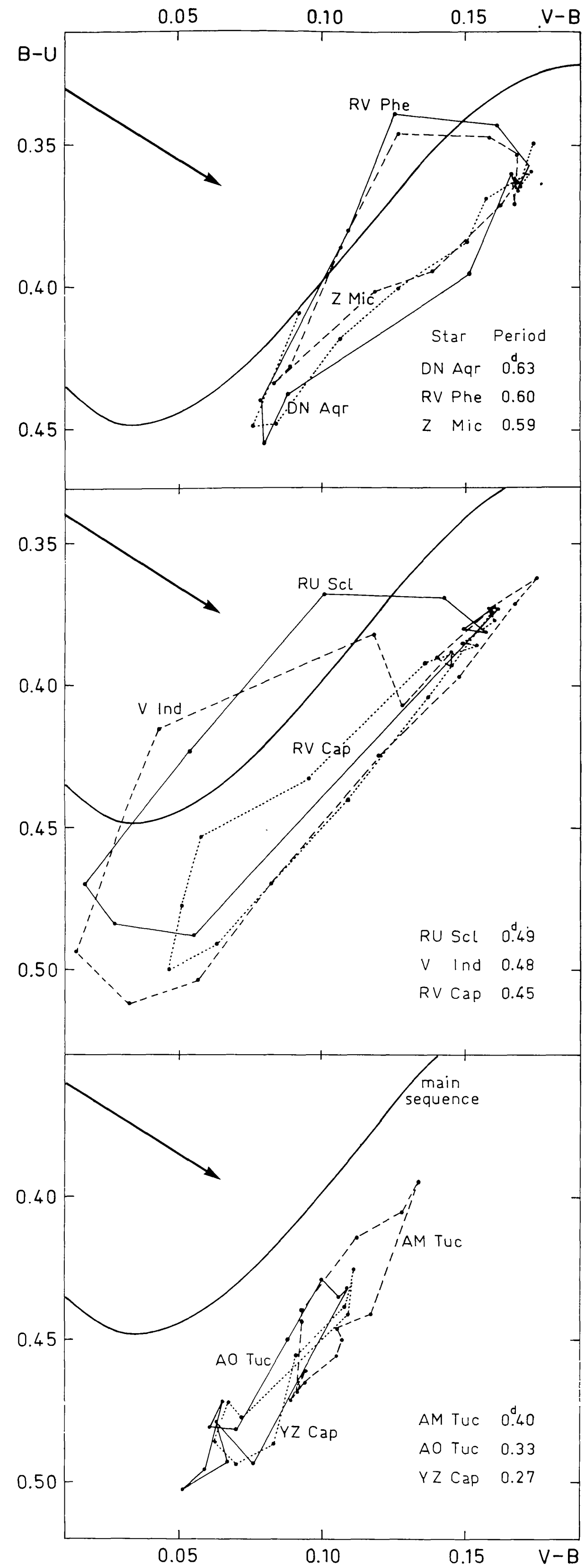

Figure 4. Loops of RR Lyrae stars, corrected for reddening, in the $(V-B)$ and $(B-U)$ two-colour diagram for long- and short-period subclass-ab stars and for subclass-c stars.

We then corrected all colours for reddening applying the same factors as for the Cepheids.

The observations, corrected for reddening, have been plotted in the $(V-B)$ and $(B-U)$ plane in figure 4. This figure is divided in three diagrams. The upper one shows the loops for the variables of subclass ab with periods larger than half a day. In the middle diagram we collected the remaining three stars of this subclass, but they have periods smaller than half a day. In the lowest diagram the loops are shown for the three variables of subclass c. The variables follow the loops in an anti-clockwise direction. Although we missed a considerable part of the rising branch of the light-curve of DN Aqr, we may conclude that the loops for the three stars with long period are nearly identical. They are narrow and sharp towards the lower left, when the light-curve shows its maximum, and wide open towards the upper right, when the variable is on the lower part of the rising branch of the light-curve.

The loops in the second diagram for the ab-type stars with shorter periods are rather different in character. They are wide and open towards the lower left, while the variable is near maximum brightness. There are considerable differences in the shape of the loops in the upper right. It is interesting to notice that the upper part of the loop of RU Scl, which has the longest period of the three variables in the diagram, resembles the loops for the variables with long periods in the upper diagram. On the other hand, RV Cap with the shortest period has a loop which is very sharp and narrow towards the upper right, when the variable is near minimum.

In the third diagram we present the loops for three variables of subclass c. The loops of AO Tuc and YZ Cap coincide, but that of AM Tuc is shifted to the upper right. From the direction of the reddening line it is clear that reddening cannot be the cause of this shift. AM Tuc has the longest period of the three variables and the shift could indicate that the shorter periods are correlated with earlier spectral types.

All nine variables from figure 4 are in the southern hemisphere and we have no information about their ΔS-values. An interpretation of the different loop shapes should be based on a thorough spectro-analysis or on theoretical models.

In figure 5 the loops in the $(V-B)$ and $(B-L)$ plane are shown. The same division into three diagrams has been made as for figure 4. In the diagrams of figure 5 the variables run along the loops in a clockwise direction. All loops are situated above the locus for the main-sequence stars. There is very little difference in the mean $(B-L)$ values for the different stars, although there seems to be a tendency for the short-period variables to be slightly redder in $(B-L)$ than those with longer periods. It may be that this could be explained by a decrease in the metal deficiency with decreasing period.

Most of the W-measures for these stars are not very accurate. In figure 6 we have drawn the loop in the

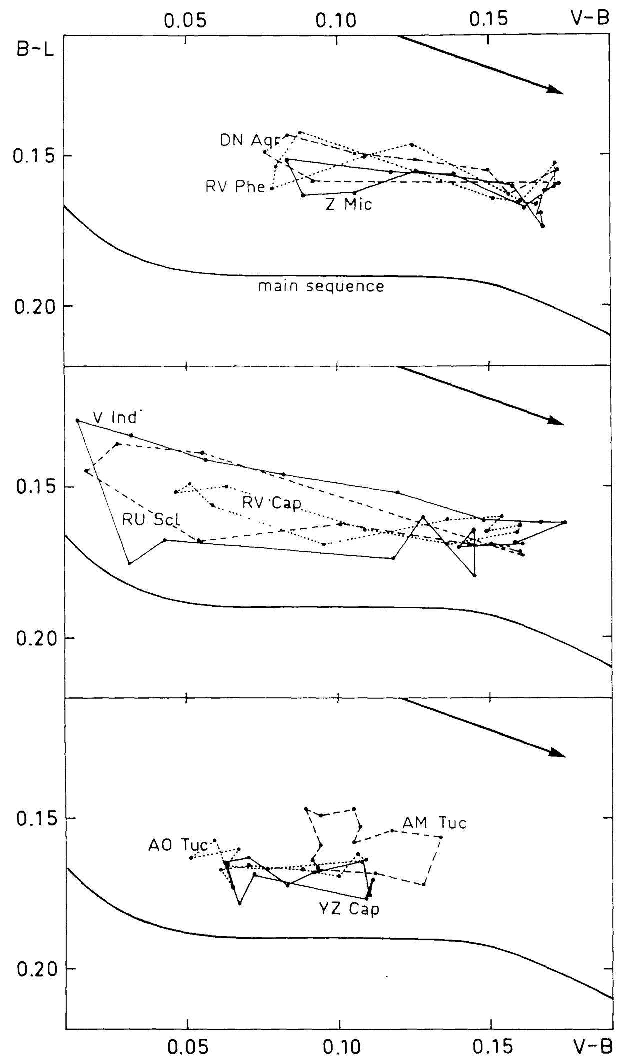

Figure 5. Loops of RR Lyrae stars, corrected for reddening, in the $(V-B)$ and $(B-L)$ two-colour diagram for subclass-ab stars of long and short period and for subclass c-variables.

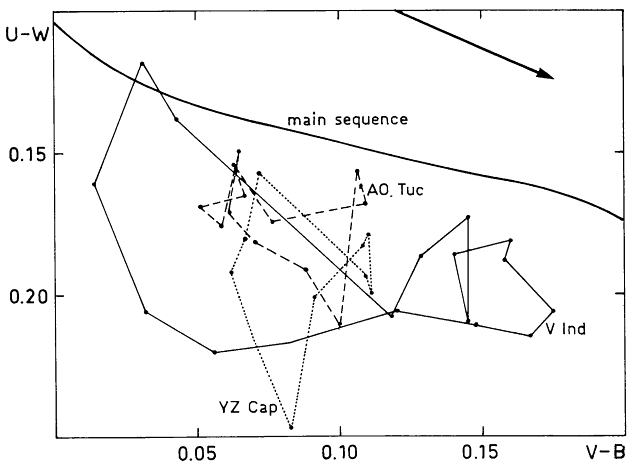

Figure 6. Loops of three RR Lyrae stars in the $(V-B)$ and $(U-W)$ two-colour diagram after correction for reddening.

$(V-B)$ and $(U-W)$ plane for the brightest variable V Indi. Here again the variable runs along the loop in an anti-clockwise direction. The loop is wide open when the variable is near the maximum of its light-curve. The fluctuations near minimum are probably due to errors of observation. The loop is situated below the locus of the main-sequence stars. In the same figure we have drawn the loops for two c-type variables, AO Tuc and YZ Cap. Although the W-measures are rather poor, they confirm the position of the loops in this two-colour diagram.

The variables run along the loops in the three two-colour diagrams in such a way that they reach that part of the loop, which is closest to the locus of the main-sequence stars, at the moment when they are high on the ascending branch of the light-curve, but have not yet reached maximum brightness. Shortly after maximum they reach that part of the loop which is furthest away from the locus of main-sequence stars. Therefore it is likely that these phenomena are closely related with the rapid change in the effective gravity near the phase of the maximum of the light-curve, which has been discussed for RR Lyrae itself by OKE and BONSACK (1960). No doubt emission features on the rising branch would affect the shape of the loops, but from the present material we cannot decide whether emission is present or not.

The loops in the three two-colour planes for the short-period variables are shown in figure 7. In the diagrams on the left the variables have been collected with periods between 0.12 and 0.20 days. In these diagrams we included V 703 Sco, as its fundamental period is probably 0.149 days. The stars with periods shorter than 0.12 days are shown in the diagrams on the right. The stars have been plotted as observed and no corrections for reddening were applied, as the amount of reddening is unknown. The galactic latitudes of the variables RS Gru, BS Aqr, EH Lib, CY Aqr and SX Phe are larger than 40 degrees and for this reason we cannot expect much reddening. For ρ Pup we do not expect much reddening on account of its large apparent brightness. The same is true for δ Del with a latitude of $-17°$. The only stars for which we can expect some reddening are: δ Sct, AI Vel and V 703 Sco. It is clear from the diagrams that a correction for reddening of about 0.04 in $(V-B)$ would bring V 703 Sco more in line with the other variables.

From the two upper diagrams in the $(V-B)$ and $(B-U)$ plane it is clear that most variables occupy the same region as the RR Lyrae stars of subclasses ab and c. There are however three exceptions, δ Sct and ρ Pup which lie below and to the right of the RR Lyrae locus, and SX Phe which even lies above the locus of the main sequence stars. In all three two-colour planes the first two stars could be made to coincide with the other variables by assuming a suitable amount of reddening. On the other hand, the spectral type of δ Del is given as A7 and that of δ Sct as F3 and therefore one would not expect their loops to coincide.

In the two lowest diagrams of the $(V-B)$ and $(U-W)$ plane the short-period variables again lie about in the same region as the RR Lyrae stars. The variables with very short period in the diagram on the right seem to be situated closer to the locus of the main-sequence stars than the RR Lyrae variables. The loop of CY Aqr lies practically on this locus, while SX Phe falls above it.

The two diagrams in the middle of figure 7 of the $(V-B)$ and $(B-L)$ plane are different from that for the RR Lyrae stars. While the latter variables all lie above the main-sequence locus, the short-period variables show loops below this locus. Only SX Phe falls above the main-sequence stars, while stars like RS Gru, δ Del and AI Vel have loops which practically coincide with the locus of the main-sequence stars. One gets the impression that in this two-colour plane there does not exist a gradual transition from RR Lyrae stars to short-period variables.

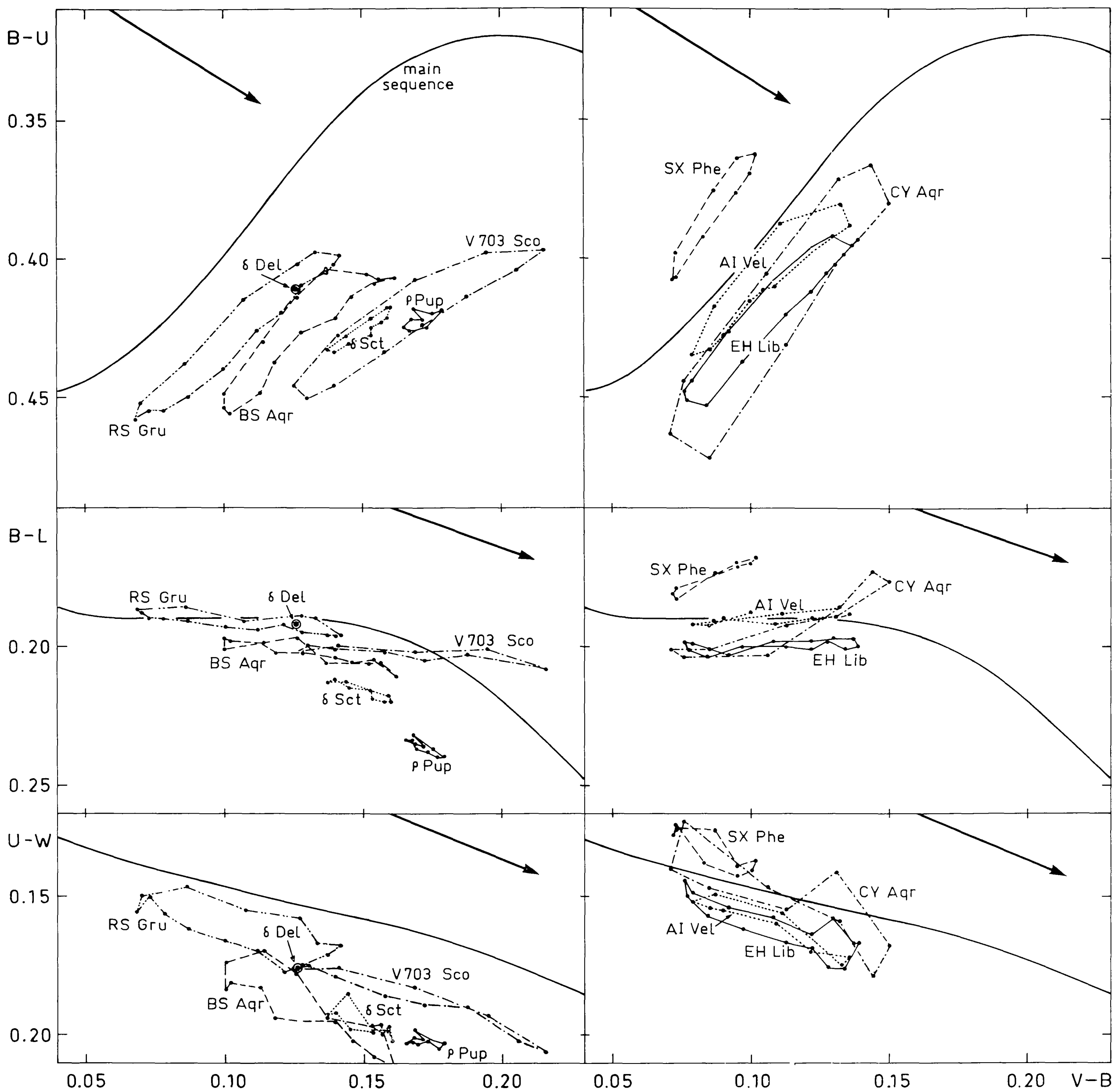

Figure 7. Loops of short-period variables in three two-colour diagrams. Periods between 0.12 and 0.20 days in the left part, periods between 0.05 and 0.12 days in the right part.

5. Stars in the globular clusters *ω* Cen and M 4

The measures of stars and variables in these two globular clusters are of poor quality, not only on account of the faintness of these stars, but probably also because the sky measures show considerable dispersion. In these clusters the *W*-band has not been used, and for some stars or for some variables at certain phases the *U*-intensity was too small to be read. In paper I we have given the identification of the variables and the other stars which were measured in both clusters.

From the non-variable stars in M 4 we can derive the mean error of a single observation. We find

	V	$(V-B)$	$(B-U)$	$(B-L)$
$V > 1.500$	± 0.005	± 0.016	± 0.021	± 0.010
$1.000 < V < 1.500$	± 0.013	± 0.025	± 0.030	± 0.034
$1.000 > V$	± 0.043	± 0.038		

As the number of measures per star is rather small, we have simply computed mean values for each star for V and the colours. The results are given in table 12. The small figures in brackets indicate the number of measures from which the mean value was computed. Star 13 in M 4 was used as local standard and has been measured many times. In figure 8 we have plotted the variables in the $(V-B)$ and $(B-U)$ plane. The variables in M 4 are considerably more reddened than those in ω Cen. In this diagram the periods of the individual variables have been indicated. In both clusters the variables are arranged according to a line which is approximately parallel to the rising part of the locus of the main-sequence stars. We have determined the reddening by shifting the points in figure 8 in the direction opposite to the reddening line until they reach the average position of the RR Lyrae stars in figure 4. We then find the following values of reddening in the three colours.

	$(V-B)$	$(B-U)$	$(B-L)$
ω Cen	0.057	0.036	0.021
M 4	0.149	0.094	0.054

We have not used variable number 65 in ω Cen, as this is most likely a foreground star. Neither did we use

TABLE 12

Mean values of brightness and colours of variable stars in ω Centauri and Messier 4 and of non-variable stars in Messier 4

Star	V	$V-B$	$B-U$	$B-L$	V_J
ω Cen Var. 14	1.008 (16)	0.183 (16)	0.484 (16)	0.192 (16)	14.33
33	1.052 (4)	0.182 (4)	0.432 (4)	0.222 (4)	14.22
45	1.024 (23)	0.238 (23)	0.414 (18)	0.215 (23)	14.28
50	0.996 (2)	0.140 (2)	0.481 (2)	0.182 (2)	14.36
63	0.897 (15)	0.225 (15)	0.404 (11)	0.186 (15)	14.60
64	0.884 (20)	0.130 (20)	0.443 (15)	0.170 (20)	14.64
65	1.082 (6)	0.096 (6)	0.449 (6)	0.187 (6)	14.15
69	0.864 (19)	0.231 (19)	0.431 (11)	0.190 (19)	14.68
95	1.029 (23)	0.193 (23)	0.430 (20)	0.187 (23)	14.27
127	0.886 (19)	0.122 (19)	0.492 (17)	0.187 (19)	14.64
M 4 Var. 6	1.282 (15)	0.270 (15)	0.524 (15)	0.229 (15)	13.63
7	1.429 (2)	0.286 (2)	0.533 (2)	0.252 (2)	13.26
13	2.358 (9)	0.783 (9)	0.879 (9)	0.652 (9)	10.88
19	1.372 (22)	0.287 (22)	0.497 (22)	0.218 (22)	13.40
27	1.405 (23)	0.313 (23)	0.465 (23)	0.217 (23)	13.32
30	1.383 (18)	0.223 (18)	0.547 (18)	0.217 (18)	13.38
31	1.465 (20)	0.248 (20)	0.515 (20)	0.229 (20)	13.18
M 4 Star 2	1.499 (3)	0.560 (3)	0.493 (2)	0.461 (3)	13.05
3	1.326 (3)	0.415 (3)	0.449 (3)	0.300 (3)	13.50
4	1.355 (3)	0.393 (3)	0.413 (3)	0.286 (3)	13.43
6	0.910 (3)	0.460 (3)			14.54
7	1.493 (4)	0.550 (4)	0.593 (3)	0.459 (4)	13.07
8	1.402 (1)	0.443 (1)		0.293 (1)	13.31
10	0.721 (4)	0.437 (4)			15.01
12	1.212 (2)	0.342 (2)	0.382 (2)	0.250 (2)	13.80
13	2.153	0.339	0.399	0.293	11.45
14	1.251 (2)	0.546 (2)		0.511 (2)	13.67
15	0.730 (2)	0.412 (2)			14.99
16	1.387 (1)	0.414 (1)	0.404 (1)	0.261 (1)	13.35
17	0.958 (2)	0.473 (2)		0.401 (2)	14.42
18	1.192 (2)	0.512 (2)			13.83
19	1.408 (4)	0.392 (4)	0.432 (4)	0.264 (4)	13.30
20	1.346 (4)	0.483 (4)	0.456 (4)	0.370 (4)	13.44
22	1.622 (2)	0.608 (2)		0.472 (2)	12.74
23	2.196 (2)	0.672 (2)	0.748 (2)	0.582 (2)	11.30

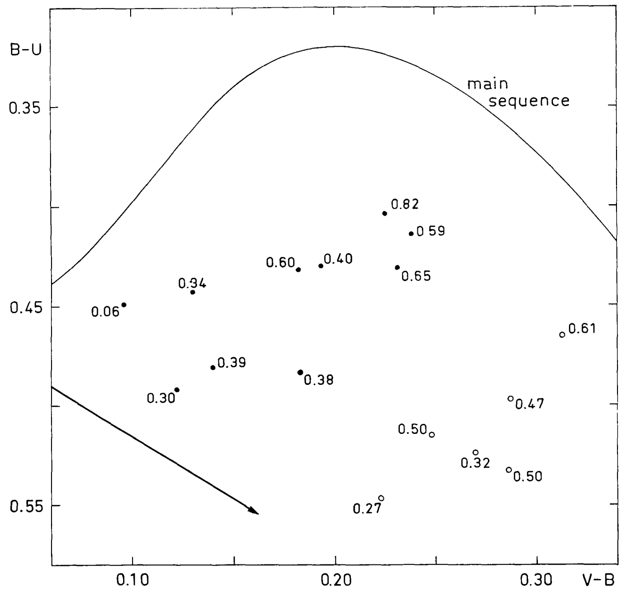

Figure 8. The variables of ω Cen (dots) and of M 4 (circles) in the $(V-B)$ and $(B-U)$ two-colour diagram.

variable 13 in M 4, which is a giant on top of the giant branch in the H-R diagram. Taking the mean value of the three colours, corrected for reddening, for all variables within each cluster, we find

	$(V-B)$	$(B-U)$	$(B-L)$
ω Cen	0.126	0.410	0.171
M 4	0.122	0.420	0.173

In the $(V-B)$ and $(B-L)$ plane these two mean points lie well above the locus of the main-sequence stars in the same position as the RR Lyrae variables in figure 5.

In both clusters the variables with short period are systematically situated to the lower left of those with long periods. After corrections for reddening, we find from the variables of both clusters combined the following relations between colour and period.

$$V-B = +0.030+0.197\,P$$
$$\pm 21 \quad \pm 42 \text{ (m.e.)}$$
$$B-U = +0.487-0.155\,P$$
$$\pm 17 \quad \pm 33 \text{ (m.e.)}$$
$$B-L = +0.158+0.030\,P$$
$$\pm 13 \quad \pm 25 \text{ (m.e.)}$$

These relations are not very accurate due to the uncertainty in the corrections for reddening and on account of the fact that with so few observations per variable the mean values of brightness and colours can have considerable errors.

In the last column of table 12 we have given the V_J-values which should be about the same as the V-magnitudes from the *UBV* system. We used the formula given in paper I.

For the mean value of V_J for the cluster variables in ω Cen and in M 4 we find respectively

	V_J
ω Cen	14.45
M 4	13.36

These values are uncorrected for interstellar absorption.

Finally we have plotted our measures of stars in M 4, uncorrected for absorption and reddening in a magnitude-colour diagram. In figure 9 values of V_J have been plotted against 2.5 $(V-B)$. Although the number of stars is small, the horizontal branch with six cluster variables and the giant branch with a red variable at the top are clearly defined. The only star which certainly is not a physical member of the cluster is star 13, which was used as secondary standard star.

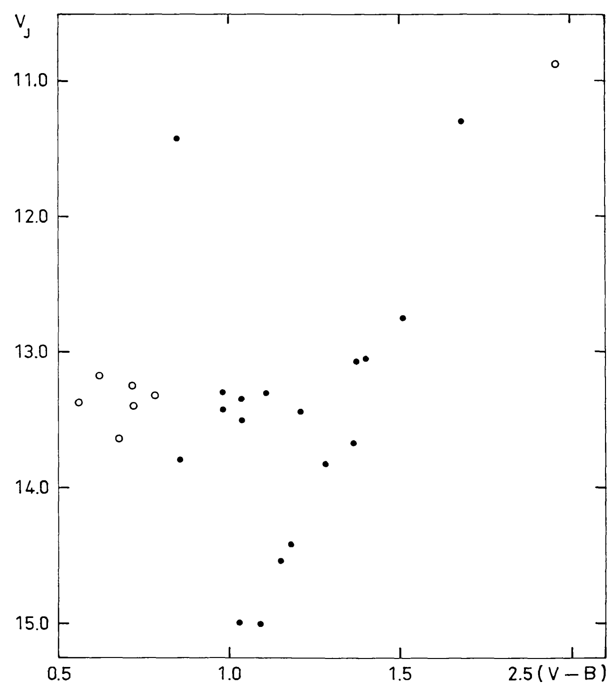

Figure 9. The colour-magnitude diagram for stars in M 4. Variable stars have been indicated by circles.

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Communication from the Netherlands Foundation for Radio Astronomy, the Kapteyn Astronomical Laboratory at Groningen, and the Observatory at Leiden

INTERMEDIATE AND HIGH VELOCITIES IN THE NEUTRAL HYDROGEN AT HIGH GALACTIC LATITUDES

Received 25 February 1966

The following is a series of associated papers, based on 21-cm line observations at galactic latitudes above $\pm 10°$ made with the Dwingeloo radio telescope. These papers report preliminary results of a joint Groningen-Leiden program, in which the Groningen domain of investigation consisted of the hydrogen with velocities between about ± 70 km/sec, and Leiden concentrated on velocities outside these limits.

One of the earlier searches for neutral hydrogen at high galactic latitudes had been undertaken by Leiden in 1954 with the 7.5-m Würzburg aerial at Kootwijk (WESTERHOUT, 1957). There was a suggestion in these initial profiles of long wings extending mostly to negative velocities, but the equipment was not sufficiently sensitive for firm conclusions to be drawn. In 1957 tentative line profiles were derived for several high-latitude fields from observations made with the, then, new 25-m telescope at Dwingeloo (VAN DE HULST, 1958), but the high-velocity wings found in these profiles were not confirmed after an improvement in the receiver in 1958. In the fall of 1959, Raimond made a special search for hydrogen with velocities between ± 50 and ± 250 km/sec using the Dwingeloo telescope and a bandwidth of about 40 km/sec; again, the results were negative.

In 1961, Oort suggested a new attempt to detect hydrogen clouds in the halo with moderate velocity dispersions. At the same time, results of the intermediate-latitude survey being carried out in Groningen (VAN WOERDEN, TAKAKUBO and BRAES, 1962) indicated that an extension to higher latitudes would be desirable, both to test the derived cloud parameters and to investigate an apparent streaming in the near-by gas noted in the profiles by BLAAUW (1962). It was decided to combine the Groningen and Leiden programs into a joint survey which was begun in 1962.

A few high-velocity clouds ($V < -100$ km/sec) were detected in the first half of 1962 (MULLER, OORT and RAIMOND, 1963), and in 1963, when a parametric amplifier came into operation, the survey was repeated and extended with the more sensitive equipment. This material was reported at the Hamburg meeting of the I.A.U. by OORT (1965, 1966) and circulated in preprint form by BLAAUW *et al.* (1964). The results are presented in detail in the next three papers; the observations and reductions will be described elsewhere.

The observations were greatly extended in 1964 and 1965 and some of the new results have been incorporated in the articles by Hulsbosch and Raimond and by Oort.

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