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Five-colour Photometry of 12 Magnetic Variable Stars

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A discussion is presented of photo-electric five-colour observations of 12 magnetic variable stars made in 1966. The periods of these variables range from $0\overset{d}{.}58$ to 314^d. From four stars no photometric observations have been reported as yet, viz. HD 15144, HD 188041, HD 190073 and HD 221760. The light- and colour-curves are given and their ranges are schematically represented in three colour-colour diagrams. Most of the colour changes are more or less parallel to the main sequence, but only for a small number of stars is this parallelity present in all three colour-colour diagrams.

Key words: magnetic variable stars-photometry

1. Observations and Reductions

Photo-electric observations of 12 magnetic variable stars have been made in 1966 with the Walraven five-colour photometer, attached to the 90-cm light-collector of the Leiden Southern Station in South Africa. The effective wavelengths are roughly 5590, 4260, 3900, 3620 and 3220 Å for the V, B, L, U and W passbands respectively (Walraven and Walraven, 1960; Rijf *et al.*, 1969).

A complete observation usually consisted of a set of: comparison star-sky-variable star-sky-comparison star-sky. Such sets were repeated on the average ten times consecutively. One such a series delivered one normal point. The integration time for each star and sky observation was 30 seconds. Corrections for differential extinction have been applied, using the extinction coefficients derived from three to five standard stars at widely different sec z which were measured several times during each night. The brightness and the colours of the comparison stars in the system of Walraven were also derived from comparison with these standards. These values given in Table 1, are generally the means of ten nights. The mean error in these values is seldom larger than 0.003 in V and 0.002 in the colours. Brightness and colour are expressed throughout in the logarithm of the intensity, but sometimes the Johnson magnitude and

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Table 1. *Magnitudes colour indices of comparison stars*

Variable (HD and name)	Comp. star (HD)	HD Sp.	V_J (mag)	$(B-V)_J$ (mag)	V	$V-B$	$B-U$ (log intensity)	$U-W$	$B-L$
10783	10262	F2	6.34	+0.382	+0.205	+0.156	+0.323	+0.163	+0.199
11503 = γAri	11636	A5	2.65	+0.116	+1.687	+0.050	+0.443	+0.134	+0.203
15144	15798	F5	4.73	+0.431	+0.846	+0.179	+0.328	+0.173	+0.199
118022 = 78 Vir	117698	F5	8.62	+0.475	−0.712	+0.197	+0.315	+0.180	+0.218
140160 = χSer	141187	A0	5.74	+0.069	+0.454	+0.031	+0.431	+0.122	+0.192
153882	154228	A0	5.95	−0.010	+0.373	0.000	+0.400	+0.101	+0.162
173650	174933	B9	5.43	−0.106	+0.584	−0.032	+0.216	+0.048	+0.074
188041	189359	A2	6.60	+0.043	+0.069	+0.021	+0.434	+0.109	+0.187
190073	189851	F0	8.51	+0.474	−0.666	+0.198	+0.426	+0.199	+0.240
201601 = γEqu	201616	A2	6.06	+0.015	+0.326	+0.010	+0.440	+0.115	+0.168
220825 = $\varkappa$Psc.	221318	F5	7.16	+0.411	−0.125	+0.170	+0.322	+0.167	+0.212
	220858	K0	6.4 (var)						
221760 = ιPhe	221736	A2	6.67	+0.210	+0.078	+0.084	+0.419	+0.139	+0.194

Table 2. *Brightness and colours of the magnetic stars relative to their comparison stars*
(For numbers in italics see the text)

Star	J.D. −2439000	Phase	*n*	*Δ V*	*Δ*(*V*—*B*)	*Δ*(*B*—*U*) (log intensity)	*Δ*(*U*—*W*)	*Δ*(*B*—*L*)
HD 10783	315.670	0.99	10	−0.0728	−0.1786	+0.0146	−0.0746	−0.0845
	320.705	0.21	9	−0.0803	−0.1818	+0.0157	−0.0798	−0.0827
	333.538	0.31	11	−0.0808	−0.1786	+0.0227	−0.0815	−0.0805
	334.563	0.56	9	−0.0803	−0.1799	+0.0205	−0.0846	−0.0804
	338.567	0.53	4	(−0.0794)	(−0.1772)	(+0.0213)	(−0.0851)	(−0.0836)
	340.518	0.00	5	−0.0736	−0.1817	+0.0179	−0.0818	−0.0823
	340.592	0.02	10	−0.0734	−0.1834	+0.0153	−0.0792	−0.0817
	355.617	0.66	10	−0.0811	−0.1776	+0.0194	−0.0826	−0.0807
	359.606	0.62	11	−0.0801	−0.1779	+0.0206	−0.0851	−0.0795
	360.583	0.86	10	−0.0756	−0.1789	+0.0164	−0.0853	−0.0803
	361.542	0.09	11	−0.0736	−0.1814	+0.0154	−0.0822	−0.0823
	368.516	0.78	10	−0.0812	−0.1770	+0.0179	−0.0820	−0.0800
	369.508	0.02	15	−0.0733	−0.1823	+0.0165	−0.0820	−0.0826
	371.527	0.51	10	−0.0783	−0.1777	+0.0215	−0.0854	−0.0813
	378.626	0.22	10	−0.0788	−0.1795	+0.0159	−0.0734	−0.0842
	380.542	0.69	10	−0.0813	−0.1751	+0.0169	−0.0807	−0.0827
	381.470	0.91	11	−0.0801	−0.1831	+0.0123	−0.0769	−0.0841
	389.589	0.88	8	−0.0784	−0.1790	+0.0127	−0.0798	−0.0840
	395.532	0.31	8	−0.0788	−0.1780	+0.0188	−0.0805	−0.0828
	401.497	0.76	12	−0.0794	−0.1759	+0.0164	−0.0797	−0.0830
	423.315	0.04	12	−0.0736	−0.1803	+0.0114	−0.0757	−0.0847
	425.317	0.52	11	−0.0797	−0.1750	+0.0187	−0.0793	−0.0840
	426.417	0.79	5	−0.0799	−0.1765	+0.0151	−0.0802	−0.0832
	429.411	0.51	9	−0.0800	−0.1763	+0.0167	−0.0772	−0.0846
HD 11503	368.553	0.80	4	(−0.4934)	(−0.0671)	(−0.0780)	(−0.0485)	(−0.0688)
	369.551	0.19	8	−0.4838	−0.0620	−0.0913	−0.0501	−0.0694
	371.592	0.97	8	−0.4836	−0.0628	−0.0869	−0.0509	−0.0695
	380.566	0.41	10	−0.4896	−0.0675	−0.0852	−0.0493	−0.0725
	381.499	0.77	13	−0.4923	−0.0714	−0.0802	−0.0455	−0.0700
	389.569	0.86	8	−0.4877	−0.0695	−0.0831	−0.0479	−0.0729
	390.462	0.21	8	−0.4879	−0.0614	−0.0926	−0.0455	−0.0707
	391.486	0.60	6	−0.4881	−0.0688	−0.0819	−0.0508	−0.0724
	295.553	0.16	7	−0.4846	−0.0589	−0.0933	−0.0510	−0.0698
	399.532	0.68	6	−0.4889	−0.0685	−0.0845	−0.0494	−0.0729
	401.524	0.45	6	−0.4884	−0.0666	−0.0888	−0.0480	−0.0736
	425.392	0.60	7	−0.4886	−0.0679	−0.0823	−0.0489	−0.0732
HD 15144	395.585	0.60	5	−0.4455	−0.1312	+0.1080	−0.0489	+0.0093
	399.549	0.92	6	−0.4461	−0.1292	+0.1066	−0.0474	+0.0102
	401.543	0.58	6	−0.4465	−0.1307	+0.1087	−0.0493	+0.0092
	408.575	0.93	4	−0.4426	−0.1286	+0.1062	−0.0482	+0.0094
	422.454	0.56	5	−0.4466	−0.1315		*−0.3736*	+0.0110
	423.400	0.88	5	−0.4431	−0.1275	+0.1071	−0.0476	+0.0103
	429.433	0.89	9	−0.4442	−0.1284	+0.1081	−0.0484	+0.0092
	433.383	0.21	7	−0.4463	−0.1267	+0.1079	−0.0481	+0.0093
HD 118022	291.355	0.15	5	(+1.4908)	(−0.1874)	(+0.0848)	(−0.0721)	(−0.0490)
	306.272	0.16	8	+1.4907	−0.1846	+0.0824	−0.0666	−0.0516
	307.259	0.42	10	+1.4960	−0.1825	+0.0805	−0.0681	−0.0486
	308.265	0.70	11	+1.4933	−0.1847	+0.0791	−0.0646	−0.0527
	309.269	0.96	10	+1.4939	−0.1817	+0.0813	−0.0686	−0.0545
	313.240	0.03	11	+1.4902	−0.1828	+0.0809	−0.0633	−0.0580
	314.261	0.31	10	+1.4934	−0.1826	+0.0813	−0.0641	−0.0511
	316.248	0.84	10	+1.4928	−0.1811	+0.0820	−0.0639	−0.0544
	317.247	0.11	11	+1.4892	−0.1841	+0.0803	−0.0636	−0.0547
	320.283	0.92	12	+1.4902	−0.1842	+0.0795	−0.0629	−0.0580

Table 2 (continued)

Star	J.D. −2439000	Phase	n	ΔV	$\Delta (V-B)$	$\Delta (B-U)$ (log intensity)	$\Delta (U-W)$	$\Delta (B-L)$
HD 118022	326.255	0.53	4	(+1.4963)	(−0.1832)	(+0.0750)		(−0.0501)
	327.240	0.47	11	+1.4914	−0.1840	+0.0810	−0.0634	−0.0510
	329.215	0.32	9	+1.4918	−0.1844	+0.0843	−0.0660	−0.0487
	330.244	0.60	10	+1.4900	−0.1878	+0.0771	−0.0614	−0.0520
	331.225	0.86	10	+1.4888	−0.1854	+0.0819	−0.0658	−0.0561
	333.227	0.40	11	+1.4940	−0.1851	+0.0843	−0.0657	−0.0454
	334.219	0 67	10	+1.4923	−0.1845	+0.0772	−0.0632	−0.0498
	335.233	0 94	8	+1.4857	−0.1864	+0.0828	−0.0675	−0.0546
	336.220	0 21	7	+1.4875	−0.1864	+0.0813	−0.0663	−0.0528
	338.259	0.75	8	+1.4923	−0.1848	+0.0815	−0.0659	−0.0523
	339.240	0.02	10	+1.4879	−0.1841	+0.0782	−0.0626	−0.0560
	340.227	0.28	10	+1.4904	−0.1826	+0.0820	−0.0629	−0.0520
	342.231	0.82	12	+1.4897	−0.1844	+0.0816	−0.0636	−0.0531
	359.215	0.38	8	+1.4915	−0.1838	+0.0803	−0.0681	−0.0504
	361.229	0.92	8	+1.4896	−0.1829	+0.0820	−0.0543	−0.0565
	362.225	0.19	9	+1.4882	−0.1818	+0.0806	−0.0705	−0.0575
HD 140160	292.351	0.33	7	+0.1501	−0.0232	+0.0086	−0.0035	−0.0124
	306.312	0.08	11	+0.1576	−0.0219	+0.0093	−0.0037	−0.0121
	307.301	0.70	10	+0.1598	−0.0262	+0.0117	−0.0068	−0.0117
	308.306	0.33	10	+0.1516	−0.0222	+0.0110	−0.0030	−0.0108
	309.304	0.96	8	+0.1565	−0.0232	+0.0088	−0.0042	−0.0130
	313.292	0.46	10	+0.1516	−0.0204	+0.0076	−0.0041	−0.0143
	317.289	0.96	11	+0.1588	−0.0233	+0.0087	−0.0032	−0.0139
	320.337	0.87	10	+0.1588	−0.0232	+0.0088	−0.0066	−0.0141
	330.305	0.12	11	+0.1583	−0.0217	+0.0072	−0.0023	−0.0135
	331.321	0.75	12	+0.1607	−0.0245	+0.0104	−0.0049	−0.0118
	333.319	0.01	11	+0.1597	−0.0211	+0.0072	−0.0014	−0.0130
	334.323	0.64	10	+0.1573	−0.0235	+0.0085	−0.0048	−0.0113
	335.324	0.26	8	+0.1510	−0.0208	+0.0096	+0.0003	−0.0127
	336.356	0.91	11	+0.1588	−0.0223	+0.0080	−0.0028	−0.0125
	338.276	0.11	11	+0.1592	−0.0212	+0.0095	−0.0032	−0.0123
	339.281	0.74	6	+0.1577	−0.0241	+0.0105	−0.0046	−0.0122
	340.259	0.36	9	+0.1504	−0.0216	+0.0102	−0.0065	−0.0133
	342.264	0.61	8	+0.1585	−0.0230	+0.0085	−0.0069	−0.0121
	359.258	0.26	10	+0.1551	−0.0208	+0.0095	−0.0011	−0.0126
	360.251	0.88	10	+0.1579	−0.0229	+0.0085	−0.0076	−0.0129
	361.248	0.51	10	+0.1538	−0.0220	+0.0075	−0.0058	−0.0119
	364.240	0.38	9	+0.1519	−0.0220	+0.0101	−0.0063	−0.0124
	368.247	0.89	10	+0.1589	−0.0225	+0.0077	−0.0043	−0.0124
HD 153882	292.491	0.28	4	(−0.1486)	(+0.0113)	(+0.0267)	(+0.0260)	(−0.0028)
	306.432	0.60	8	−0.1491	+0.0114	+0.0218	+0.0310	−0.0107
	307.340	0.75	10	−0.1498	+0.0106	+0.0226	+0.0321	−0.0099
	308.339	0.92	10	−0.1541	+0.0132	+0.0298	+0.0288	−0.0084
	313.342	0.75	11	−0.1481	+0.0102	+0.0214	+0.0317	−0.0079
	314.361	0.92	10	−0.1537	+0.0137	+0.0292	+0.0303	−0.0070
	315.367	0.09	9	−0.1521	+0.0129	+0.0324	+0.0246	−0.0064
	316.403	0.26	10	−0.1474	+0.0155	+0.0287	+0.0266	−0.0052
	317.368	0.42	10	−0.1543	+0.0146	+0.0250	+0.0269	−0.0082
	321.341	0.08	10	−0.1494	+0.0145	+0.0335	+0.0266	−0.0056
	324.422	0.60	11	−0.1526	+0.0103	+0.0193	+0.0298	−0.0090
	327.426	0.10	9	−0.1495	+0.0133	+0.0308	+0.0268	−0.0063
	330.372	0.59	11	−0.1483	+0.0132	+0.0195	+0.0281	−0.0084
	334.372	0.25	10	−0.1491	+0.0148	+0.0275	+0.0245	−0.0068
	336.381	0.59	10	−0.1501	+0.0135	+0.0209	+0.0313	−0.0082
	338.294	0.90	8	−0.1524	+0.0127	+0.0270	+0.0292	−0.0082
	339.326	0.08	8	−0.1500	+0.0146	+0.0299	+0.0289	−0.0075

Table 2 (continued)

Star	J.D. −2439000	Phase	n	ΔV	$\Delta\,(V-B)$	$\Delta\,(B-U)$ (log intensity)	$\Delta\,(U-V)$	$\Delta\,(B-L)$
HD 153882	361.289	0.73	10	−0.1502	+0.0104	+0.0200	+0.0344	−0.0090
	363.265	0.06	6	−0.1504	+0.0147	+0.0301	+0.0289	−0.0059
	368.266	0.89	8	−0.1538	+0.0135	+0.0275	+0.0284	−0.0086
	371.263	0.39	8	−0.1538	+0.0138	+0.0226	+0.0318	−0.0085
HD 173650	292.531	0.65	5	−0.4390	+0.0397	+0.1289	+0.0756	+0.0378
	306.502	0.05	9	−0.4552	+0.0371	+0.1571	+0.0697	+0.0390
	307.408	0.15	13	−0.4557	+0.0359	+0.1603	+0.0673	+0.0405
	308.402	0.24	10	−0.4537	+0.0381	+0.1588	+0.0714	+0.0393
	309.374	0.34	12	−0.4555	+0.0384	+0.1557	+0.0695	+0.0381
	310.485	0.45	9	−0.4423	+0.0408	+0.1400	+0.0728	+0.0368
	313.389	0.74	10	−0.4453	+0.0392	+0.1379	+0.0701	+0.0347
	314.388	0.84	10	−0.4508	+0.0370	+0.1465	+0.0723	+0.0368
	315.393	0.95	10	−0.4548	+0.0376	+0.1541	+0.0706	+0.0377
	316.476	0.05	11	(−0.4610)	+0.0373	+0.1591	+0.0702	+0.0399
	317.415	0.15	10	−0.4571	+0.0351	+0.1616	+0.0682	+0.0409
	320.441	0.45	10	−0.4477	+0.0377	+0.1410	+0.0731	+0.0372
	321.394	0.55	10	−0.4388	+0.0441	+0.1287	+0.0730	+0.0352
	323.392	0.75	13	−0.4463	+0.0388	+0.1354	+0.0765	+0.0346
	325.410	0.95	10	−0.4544	+0.0402	+0.1534	+0.0688	+0.0383
	331.373	0.55	11	−0.4407	+0.0432	+0.1289	+0.0733	+0.0360
	333.402	0.75	10	−0.4444	+0.0396	+0.1356	+0.0733	+0.0344
	334.403	0.85	9	−0.4516	+0.0384	+0.1451	+0.0754	+0.0351
	336.405	0.05	9	−0.4561	+0.0373	+0.1543	+0.0722	+0.0371
	338.356	0.25	13	−0.4547	+0.0371	+0.1566	+0.0703	+0.0375
	339.346	0.35	8	−0.4533	+0.0379	+0.1517	+0.0714	+0.0365
	340.313	0.44	8	−0.4467	+0.0396	+0.1399	+0.0712	+0.0361
	342.335	0.65	9	−0.4395	+0.0418	+0.1265	+0.0741	+0.0342
	356.379	0.05	10	−0.4556	+0.0383	+0.1544	+0.0724	+0.0387
	359.330	0.35	10	−0.4510	+0.0389	+0.1512	+0.0697	+0.0371
	360.309	0.45	10	−0.4458	+0.0400	+0.1381	+0.0724	+0.0357
	363.278	0.75	6	−0.4450	+0.0393	+0.1343	+0.0734	+0.0350
	395.241	0.95	7	−0.4540	+0.0384	+0.1490	+0.0724	+0.0359
	400.258	0.45	6	−0.4435	+0.0415	+0.1369	+0.0707	+0.0330
HD 188041	291.552	0.58	5	+0.4274	+0.0420	−0.0242	+0.0004	+0.0164
	306.535	0.65	9	+0.4259	+0.0439	−0.0272	+0.0051	+0.0160
	307.473	0.66	10	+0.4249	+0.0446	−0.0268	+0.0038	+0.0165
	313.447	0.68	10	+0.4263	+0.0451	−0.0269	+0.0063	+0.0186
	317.458	0.70	5	(+0.4304)	(+0.0448)	(−0.0276)	(+0.0067)	(+0.0189)
	333.449	0.77	7	+0.4267	+0.0508	−0.0307	+0.0103	+0.0233
	360.331	0.89	8	+0.4274	+0.0611	−0.0410	+0.0108	+0.0284
	371.285	0.93	7	+0.4256	+0.0634	−0.0422	+0.0081	+0.0298
	389.317	0.01	8	+0.4274	+0.0654	−0.0432	+0.0078	+0.0316
	415.288	0.13	7	+0.4278	+0.0581	−0.0390	+0.0059	+0.0279
	433.242	0.21	7	+0.4258	+0.0491	−0.0304	+0.0021	+0.0257
HD 190073	291.592		5	+0.2702	−0.1660	+0.0007	−0.1052	−0.0947
	306.573		7	+0.2715	−0.1644	−0.0064	−0.1174	−0.1033
	307.509		10	+0.2746	−0.1650	−0.0061	−0.1233	−0.1034
	308.451		10	+0.2726	−0.1656	−0.0088	−0.1238	−0.1033
	311.477		8	+0.2761	−0.1636	−0.0144	−0.1169	−0.1051
	313.477		10	+0.2757	−0.1657	−0.0192	−0.1104	−0.1081
	314.441		10	+0.2761	−0.1669	−0.0178	−0.1166	−0.1076
	315.466		14	+0.2782	−0.1643	−0.0188	−0.1183	−0.1073
	317.488		10	+0.2699	−0.1662	−0.0141	−0.1178	−0.1053
	320.496		11	+0.2739	−0.1660	−0.0131	−0.1262	−0.1067
	321.465		10	+0.2757	−0.1657	−0.0128	−0.1228	−0.1058

Table 2 (continued)

Star	J.D −2439000	Phase	n	ΔV	$\Delta (B-V)$	$\Delta (B-U)$ (log intensity)	$\Delta (U-W)$	$\Delta (B-L)$
HD 190073	324.473		10	+0.2749	−0.1668	−0.0186	−0.1190	−0.1072
	325.461		10	+0.2774	−0.1650	−0.0117	−0.1262	−0.1045
	327.483		12	+0.2773	−0.1655	−0.0106	−0.1287	−0.1032
	330.445		11	+0.2790	−0.1684	−0.0173	−0.1253	−0.1071
	333.467		9	+0.2797	−0.1658	−0.0149	−0.1272	−0.1022
	334.442		7	+0.2763	−0.1669	−0.0141	−0.1218	−0.1051
	335.421		8	+0.2768	−0.1669	−0.0128	−0.1182	−0.1032
	336.485		10	+0.2762	−0.1683	−0.0122	−0.1216	−0.1030
	340.411		10	+0.2750	−0.1661	−0.0080	−0.1159	−0.1034
	342.358		5	+0.2811	−0.1670	−0.0141	−0.1111	−0.1016
	368.391		8	+0.2770	−0.1639	−0.0036	−0.1104	−0.1014
	390.344		6	+0.2746	−0.1610	−0.0022	−0.1091	−0.1037
	399.327		10	+0.2726	−0.1654	−0.0034	−0.1109	−0.1012
HD 201601	306.610	0.708	10	+0.5394	+0.0861	−0.0243	+0.0152	+0.0602
	307.557	0.711	10	+0.5412	+0.0866	−0.0249	+0.0162	+0.0598
	308.483	0.714	10	+0.5409	+0.0866	−0.0250	+0.0166	+0.0601
	311.532	0.723	10	+0.5400	+0.0858	−0.0237	+0.0123	+0.0604
	313.528	0.730	10	+0.5404	+0.0867	−0.0241	+0.0118	+0.0597
	314.521	0.733	10	+0.5410	+0.0860	−0.0245	+0.0152	+0.0599
	315.515	0.736	10	+0.5404	+0.0871	−0.0248	+0.0167	+0.0603
	316.508	0.739	10	+0.5391	+0.0862	+0.0241	+0.0157	+0.0593
	317.522	0.743	10	+0.5392	+0.0869	+0.0242	+0.0122	+0.0596
	320.531	0.752	11	+0.5429	+0.0886	−0.0257	+0.0148	+0.0592
	321.521	0.755	10	+0.5400	+0.0877	−0.0255	+0.0141	+0.0589
	324.503	0.765	12	+0.5393	+0.0875	−0.0255	+0.0157	+0.0565
	325.491	0.768	11	+0.5413	+0.0894	−0.0250		
	327.507	0.774	9	+0.5414	+0.0897	−0.0247	+0.0153	+0.0582
	333.490	0.793	10	+0.5415	+0.0896	−0.0247	+0.0136	+0.0590
	334.472	0.796	6	+0.5423	+0.0894	−0.0254	+0.0183	+0.0599
	336.512	0.803	8	+0.5416	+0.0892	−0.0246	+0.0151	+0.0601
	340.434	0.815	6	+0.5407	+0.0892	−0.0265	+0.0162	+0.0581
	355.424	0.863	9	+0.5418	+0.0889	−0.0240	+0.0151	+0.0600
	360.430	0.879	6	+0.5406	+0.0888	+0.0253	+0.0165	+0.0582
	371.307	0.914	7	+0.5428			+0.0174	
	391.327	0.977	6	+0.5419	+0.0878	−0.0234	+0.0142	+0.0611
	403.299	0.015	8	+0.5413	+0.0876	−0.0220	+0.0143	+0.0615
	425.269	0.085	7	+0.5422	+0.0870	−0.0208	+0.0133	+0.0616
HD 220825	371.378	0.40	12	+0.9026	−0.1557	+0.0660	−0.0650	−0.0455
	371.412	0.45	13	+0.9023	−0.1573	+0.0653	−0.0678	−0.0443
	371.451	0.52	10	+0.9017	−0.1573	+0.0647	−0.0676	−0.0458
	371.499	0.60	10	+0.9058	−0.1552	+0.0651	−0.0707	−0.0438
	371.556	0.72	12	+0.9064	−0.1555	+0.0618	−0.0668	−0.0455
	399.374	0.23	4	(+0.9030)		(+*0.9921*)	(+*1.0491*)	(+*1.1056*)
	399.420	0.40	11	+0.9033		+*0.9933*	−0.0618	+*1.1046*
	399.510	0.46	10	+0.9020	−0.1566	+0.0653	−0.0585	−0.0479
	401.355	0.61	6	+0.9037		+*1.0035*	(−0.0594)	+*1.1086*
	401.406	0.70	9	+0.9027		+*1.0037*	(−0.0645)	+*1.1086*
	415.302	0.44	5	+0.9000	−0.1575	+0.0636	−0.0618	−0.0463
	422.381	0.53	8	+0.9025	−0.1571	+0.0649	−0.0620	−0.0449
	425.288	0.50	7	+0.9021	−0.1567	+0.0625	−0.0645	−0.0475
	426.332	0.28	7	+0.9014	−0.1563	+0.0662	−0.0636	−0.0457
	429.390	0.51	9	+0.8988	−0.1577	+0.0639	−0.0597	−0.0468
HD 221760	334.590	0.77	7	+0.7860	−0.0500	+0.0386	−0.0110	−0.0190
	335.442	0.84	5	(+0.7866)	(−0.0522)	(+0.0363)	(−0.0150)	(−0.0199)
	340.485	0.24	8	+0.7841	−0.0508	+0.0383	−0.0122	−0.0189

Table 2 (continued)

Star	J.D. −2439000	Phase	n	ΔV	$\Delta(V-B)$	$\Delta(B-U)$ (log intensity)	$\Delta(U-W)$	$\Delta(B-L)$
HD 221760	342.567	0.41	8	+0.7850	−0.0495	+0.0388	−0.0123	−0.0184
	360.546	0.84	10	+0.7840	−0.0500	+0.0387	−0.0109	−0.0189
	361.521	0.92	7	+0.7844	−0.0504	+0.0384	−0.0131	−0.0190
	362.526	0.00	10	+0.7854	−0.0498	+0.0369	−0.0105	−0.0187
	363.519	0.08	10	+0.7855		+*0.7969*	−0.0118	+*0.8532*
	364.506	0.16	5	(+0.7860)	(−0.0510)	(+0.0382)	(−0.0113)	(−0.0199)
	367.517	0.40	8	+0.7856	−0.0508	+0.0378	−0.0100	−0.0183
	368.425	0.47	7	+0.7864	−0.0514	+0.0399	−0.0125	−0.0176
	369.458	0.56	10	+0.7865	−0.0515	+0.0395	−0.0118	−0.0193
	371.475	0.72	8	+0.7841	−0.0499	+0.0377	−0.0128	−0.0190
	380.431	0.43	10	+0.7874		+*0.8011*	−0.0090	+*0.8583*
	381.449	0.52	8	+0.7863	−0.0505	+0.0378	−0.0113	−0.0206
	389.497	0.16	8	+0.7860	−0.0507	+0.0399	−0.0108	−0.0198
	390.443	0.24	7	+0.7856	−0.0506	+0.0385	−0.0120	−0.0204
	391.426	0.31	6	+0.7838	−0.0504	+0.0389	−0.0112	−0.0199
	393.322	0.47	6	+0.7878	−0.0510	+0.0401	−0.0111	−0.0217
	395.422	0.63	6	+0.7865	−0.0500	+0.0392	−0.0109	−0.0205
	399.452	0.96	6	+0.7835		+*0.7959*	−0.0126	+*0.8547*
	400.374	0.03	6	+0.7846		+*0.7971*	−0.0094	+*0.8561*
	401.441	0.12	5	+0.7840		+*0.7963*	−0.0117	+*0.8555*
	403.360	0.27	3		(−0.0505)	(+0.0386)	(−0.0133)	(−0.0192)
	423.289	0.86	13	+0.7860	−0.0508	+0.0387	−0.0107	−0.0206
	425.304	0.02	6	+0.7846	−0.0508	+0.0396	−0.0106	−0.0212
	426 347	0.11	6	+0.7872	−0.0503	+0.0403	−0.0112	−0.0201

colour (V_J and $(B-V)_J$) has been added for comparison. V_J was computed from 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 in Walraven *et al.* (1964).

The brightnesses and colours of the normal points for the variable star–comparison star differences are given in Table 2. The number of observations n are also listed.

Sometimes it happened that because of still unexplained electronic disturbances, the intensity in one or more channels was wrong, so that it was useless to give the colour in which this intensity was used. We then only give in italics the other intensity which was not disturbed as follows: in the columns of $\Delta(V-B)$, $\Delta(B-U)$, $\Delta(U-W)$ and $\Delta(B-L)$ the values of ΔB, ΔU, ΔW and ΔL respectively.

Figures 1 to 14 show the light- and colour-curves, firstly the brightnesses relative to the comparison star in order of decreasing wavelength and then the colours.

An important part of the reduction concerning the calculation of logarithms, colour differences, sec z and differential extinction was made by means of a computer program written by J. Tinbergen and L. Maitimo.

2. Description of Individual Stars

We mainly confine ourselves to reporting the latest literature, in which other references can be found. The data of the respective comparison stars is given in Table 1.

HD 10783. The phases in Fig. 1 have been computed with the new elements given by Preston and Stępień (1969):

$$\varphi = (\text{J.D.} - 2439757.91) \times 4.1327^{-1}\,.$$

The observations made by the author in 1965 (van Genderen, 1967), which were not used by the two authors mentioned above for deriving the new elements, also fitted satisfactorily.

HD 11503 = γ *Ari*. This star has a close companion (8″) of nearly the same brightness and spectrum, so that the variable could not be observed separately. The light amplitudes are therefore reduced by roughly 50%. The phases in Fig. 2 have been computed from the formula:

$$\varphi = (\text{J.D.} - 2437207.85) \times 2.607^{-1}\,,$$

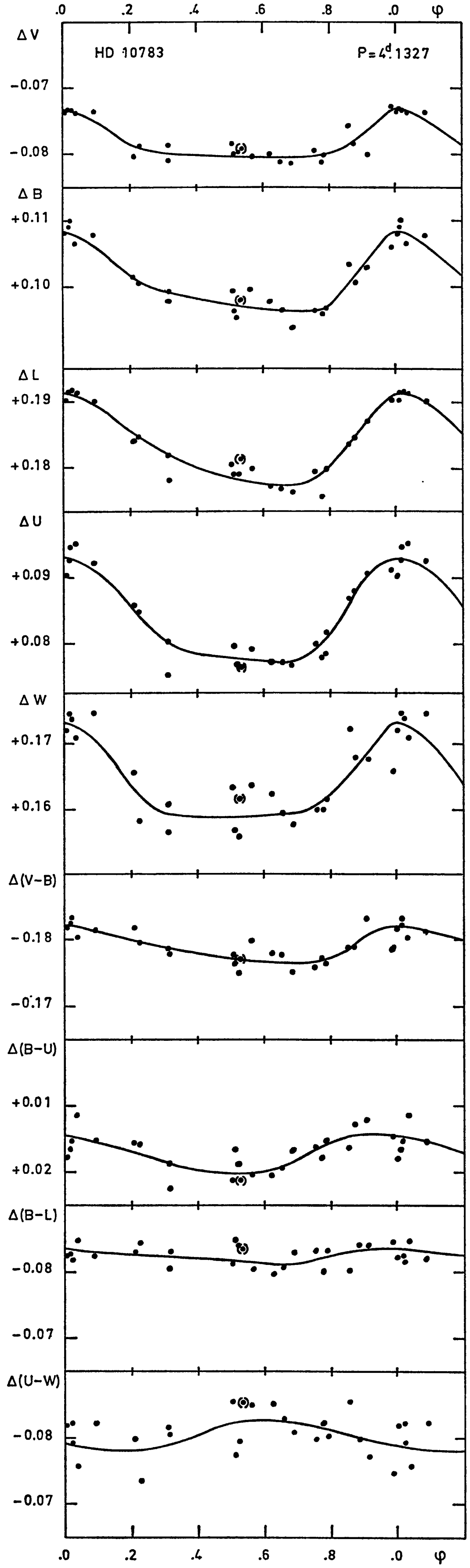


Fig. 1. The light- and colour-curves of HD 10783

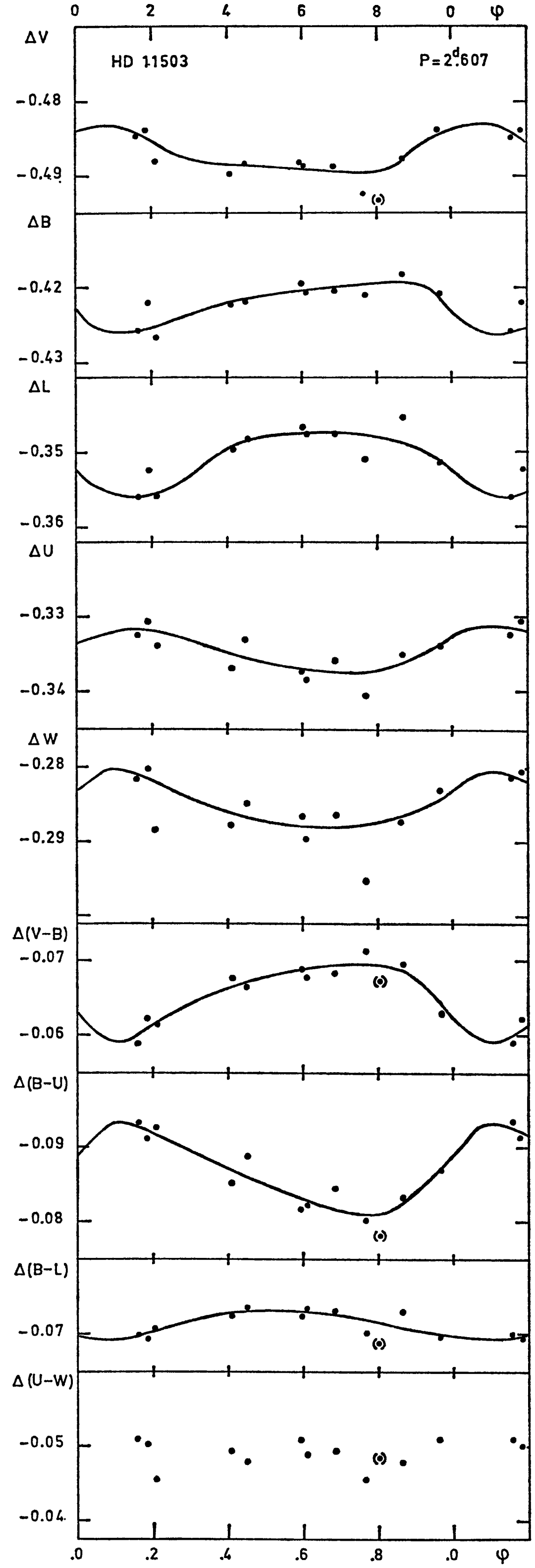


Fig. 2. The light- and colour-curves of HD 11503. The light amplitudes are reduced by roughly 50%, as a consequence of the presence of a close companion of nearly the same brigthness and colour as the magnetic star

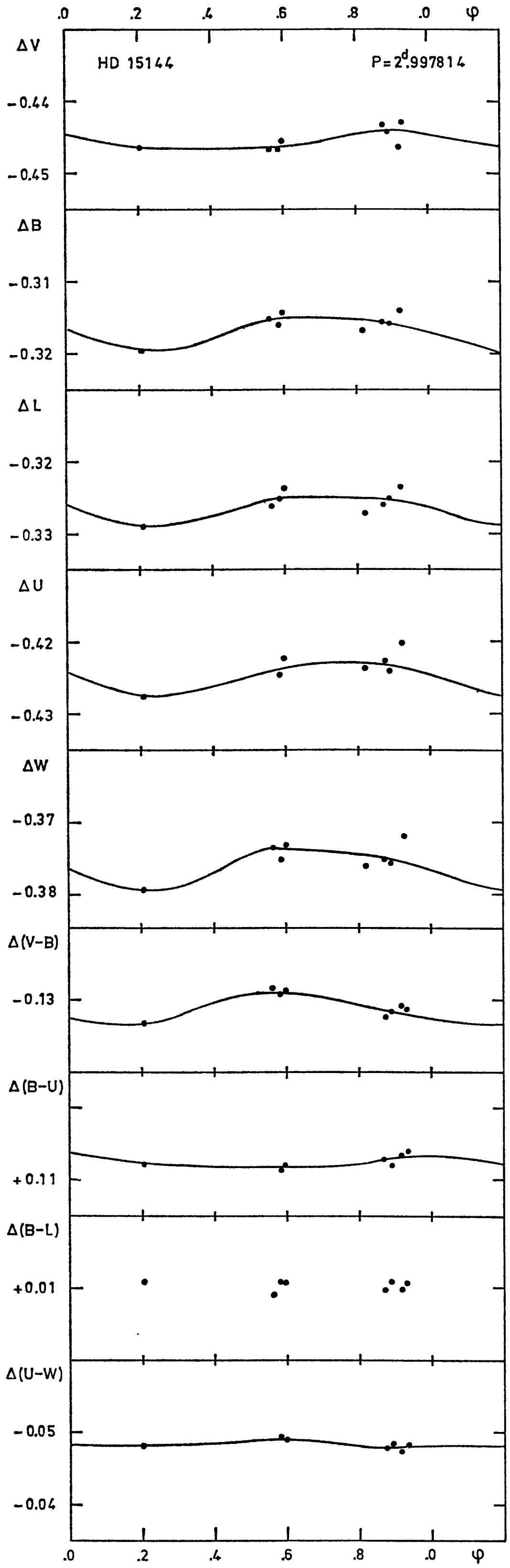


Fig. 3. The light- and colour-curves of HD 15144

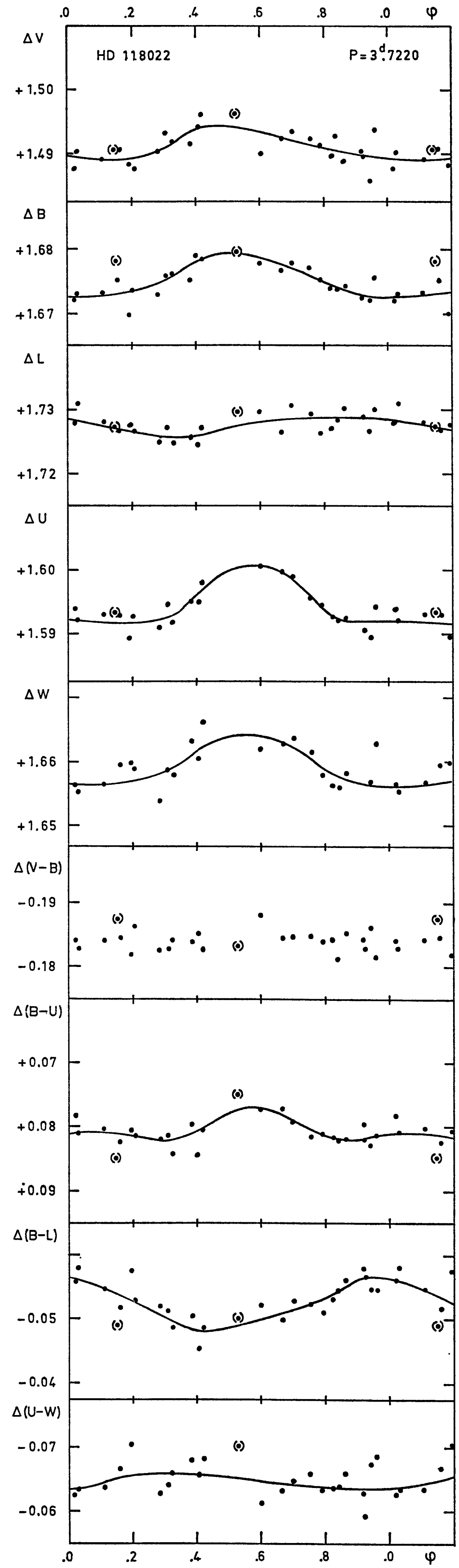


Fig. 4. The light- and colour-curves of HD 118022

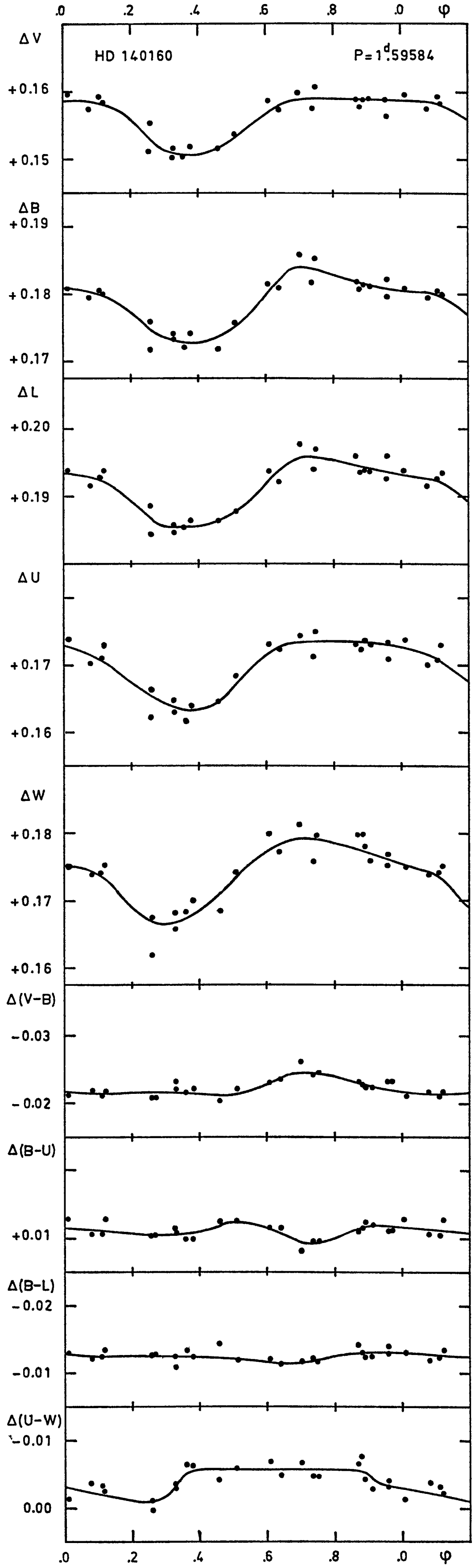


Fig. 5. The light- and colour-curves of HD 140160

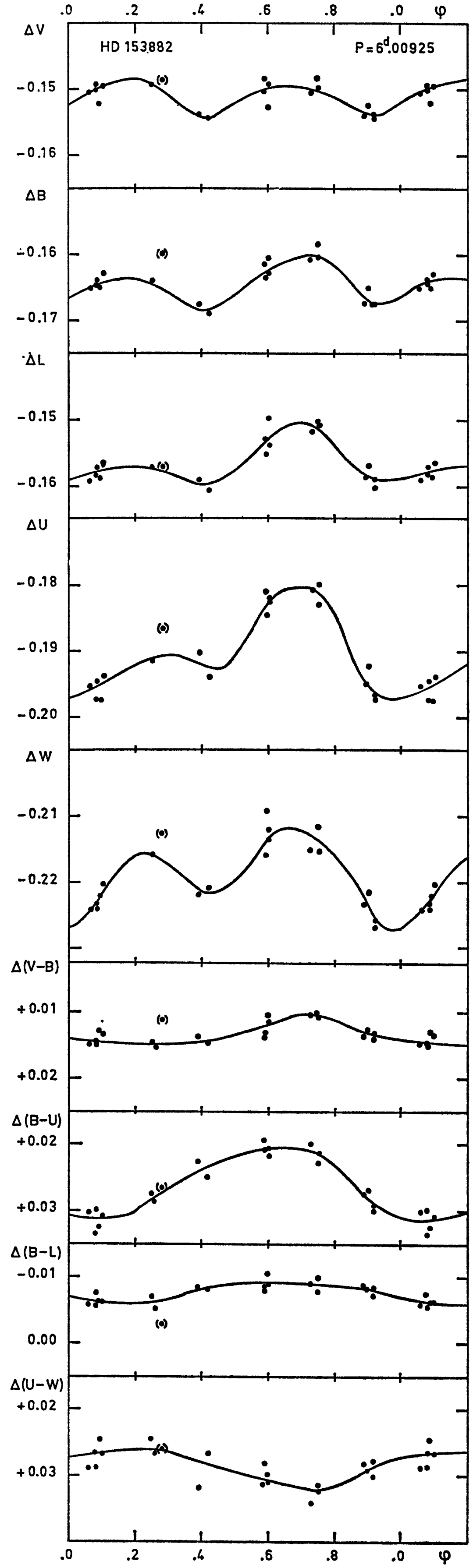


Fig. 6. The light- and colour-curves of HD 153882

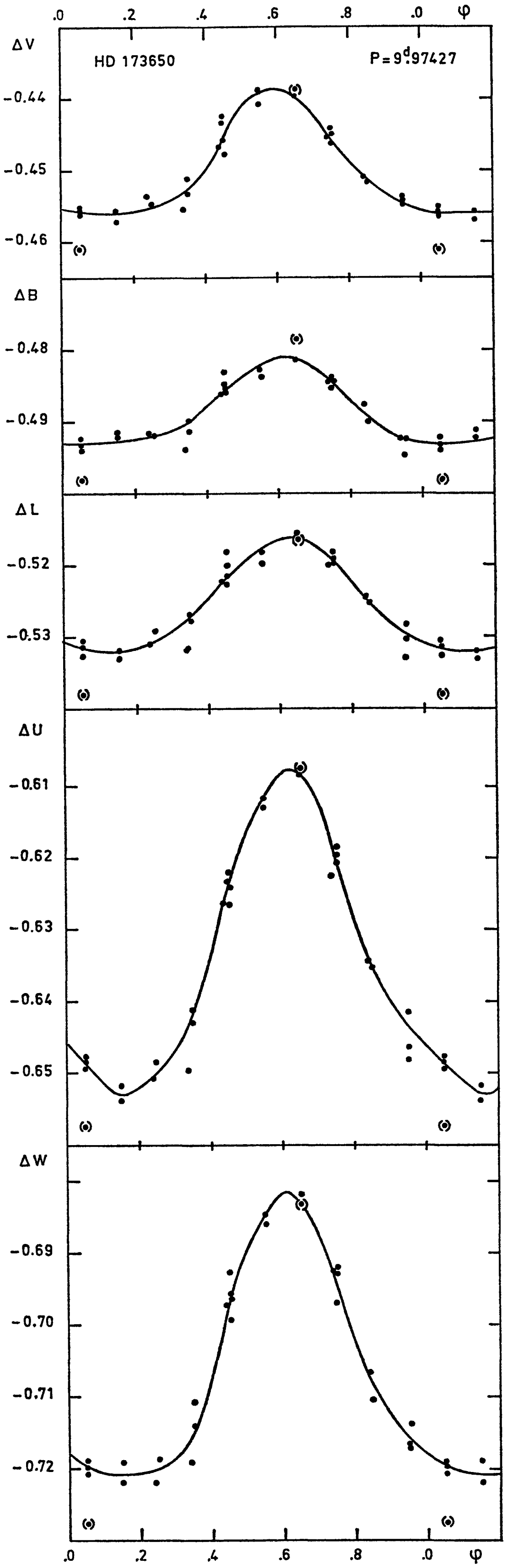


Fig. 7a. The light-curves of HD 173650

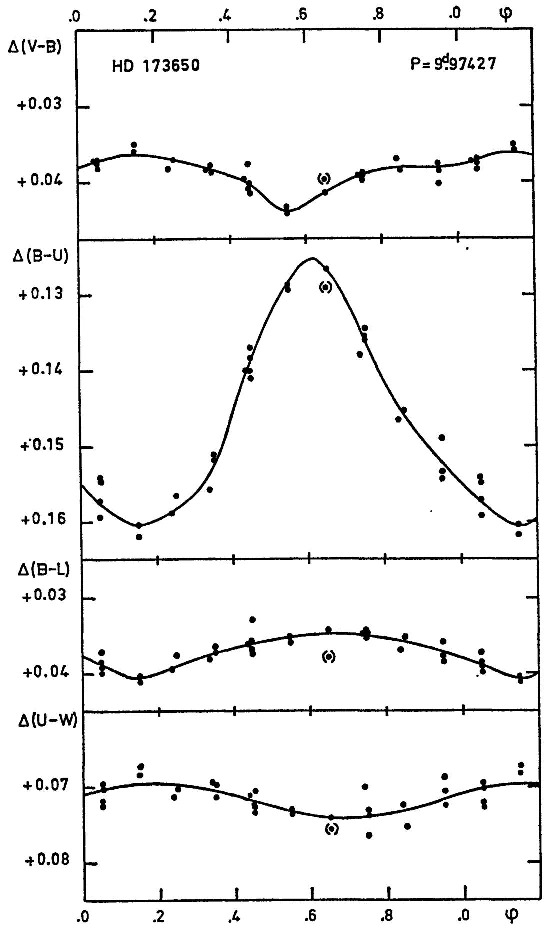


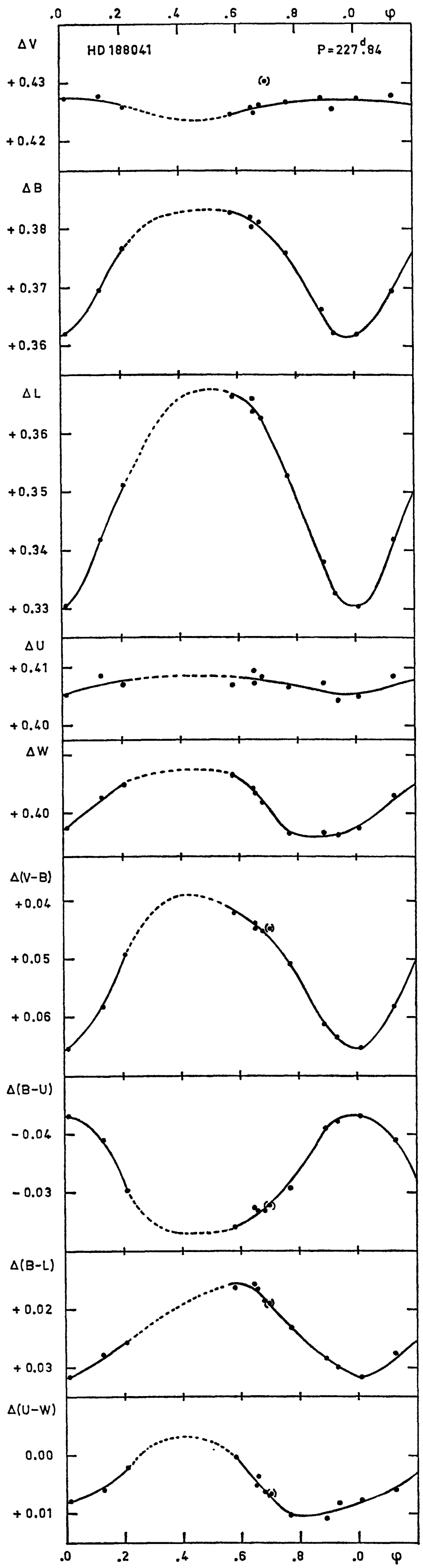
Fig. 7b. The colour-curves of HD 173650

which was also used by Rakos (1963) for his B and V photometry. The period, taken from Deutsch (1947) according to his measurements of the Ca II and Cr II lines, seems to be correct. Because of too few observations by Rakos and the present author, a refinement of the elements was not yet possible. Rakos' blue and yellow light-curves appeared to be in phase, which is opposite to the B and V curves presented here. This is probably due to a difference in passband, especially for the B. No short-time variations amounting to about 0.02 mag as reported by Rakos are seen.

HD 15144. No photometric investigation of this star has been reported as yet. The star was observed too late in the season, resulting in eight normal points only. The phases in Fig. 3 have been computed using the elements of Babcock (1958) derived from the radial velocity variations:

$$\varphi = (\text{J.D.} - 2433227.29) \times 2.997814^{-1}.$$

The zero point is near radial velocity zero (increasing).



HD 118022 = 78 Vir. The phases in Fig. 4 have been computed from the formula:

$$\varphi = (\text{J.D.} - 2434816.9) \times 3.7220^{-1}\,.$$

The period was found by Preston (1969), using the variation in the magnetic field strength, Henry's K-line index, the radial velocity, the UBV observations of Stępień (1968) etc.

HD 140160 = χ Ser. The phases in Fig. 5 have been computed from the formula:

$$\varphi = (\text{J.D.} - 2434134.06) \times 1.59584^{-1}\,.$$

The elements derived by Deutsch (1952) with the aid of Sr II line variation were also used by Provin (1953) for his B and V photometry. The observations of the latter however, are too few in number, especially in the minimum, to refine the period. The Sr II line minimum coincides with the minimum of the light-variation.

HD 153882. The phases in Fig. 6 have been computed from the formula:

$$\varphi = (\text{J.D.} - 2432752.73) \times 6.00925^{-1}\,.$$

The elements taken from Preston and Pyper (1965) were also used by Stępień (1968) for his UBV observations. Our observations show a clear secondary maximum in the light-curves, which is also slightly-recognizable in those of Stępień.

HD 173650. Wehlau (1962) has observed this star in blue and yellow light and derived a period of $10^{\mathrm{d}}.1$. Renson (1969) after a detailed discussion on the magnetic behaviour, suggested a period of $10^{\mathrm{d}}.09$ as the best possibility. But only with the periods $9^{\mathrm{d}}.97427$ and $9^{\mathrm{d}}.92970$ do the light-curves of Wehlau and the author coincide, without making the scatter in the light-curves too large. We have chosen the first one as being the best, but are not very certain of it, because of the obscurity of the number of epochs elapsed between the two series. The phases in Fig. 7a and b have been computed from the formula

$$\varphi = (\text{J.D.} - 2437121.6) \times 9.97427^{-1}$$

in which the zero-point is taken from Wehlau. However, this formula did not fit the magnetic observations.

With periods of near one day we also obtained a good fit for Wehlau's and our observations viz. $0^{\mathrm{d}}.906490$, $0^{\mathrm{d}}.906861$, $0^{\mathrm{d}}.907231$ and $0^{\mathrm{d}}.907602$. Because the dates of Babcock's (1957) observations are given without much precision we could not check these short periods.

Fig. 8. The light- and colour-curves of HD 188041

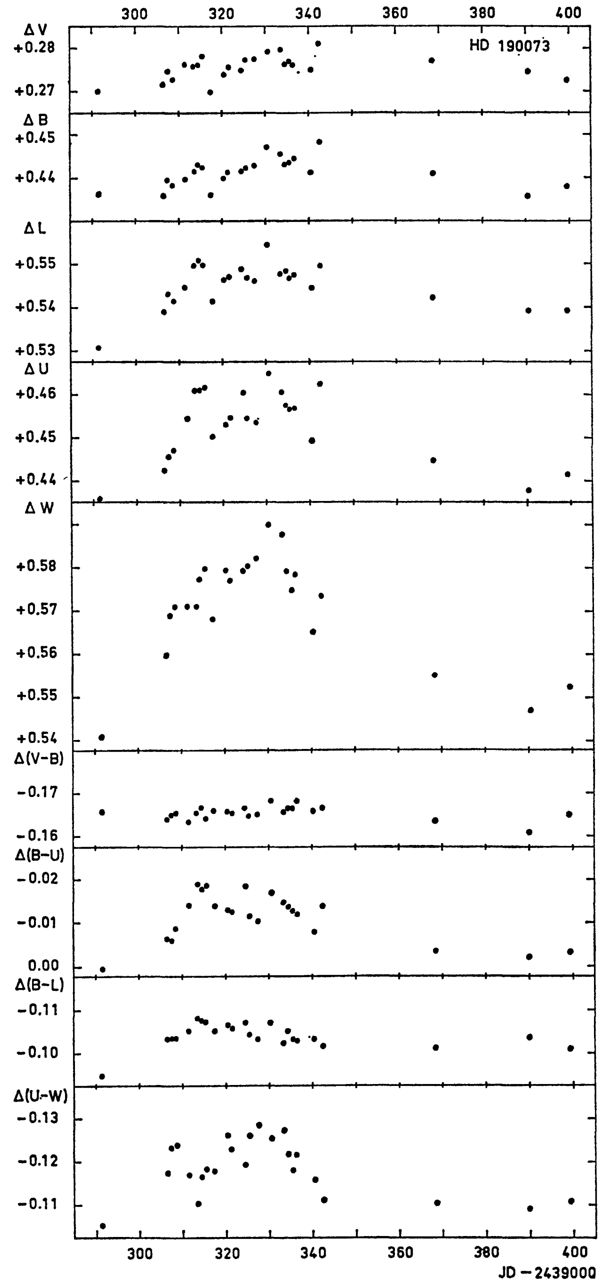


Fig. 9. The light- and colour-curves of HD 190073 plotted against the date

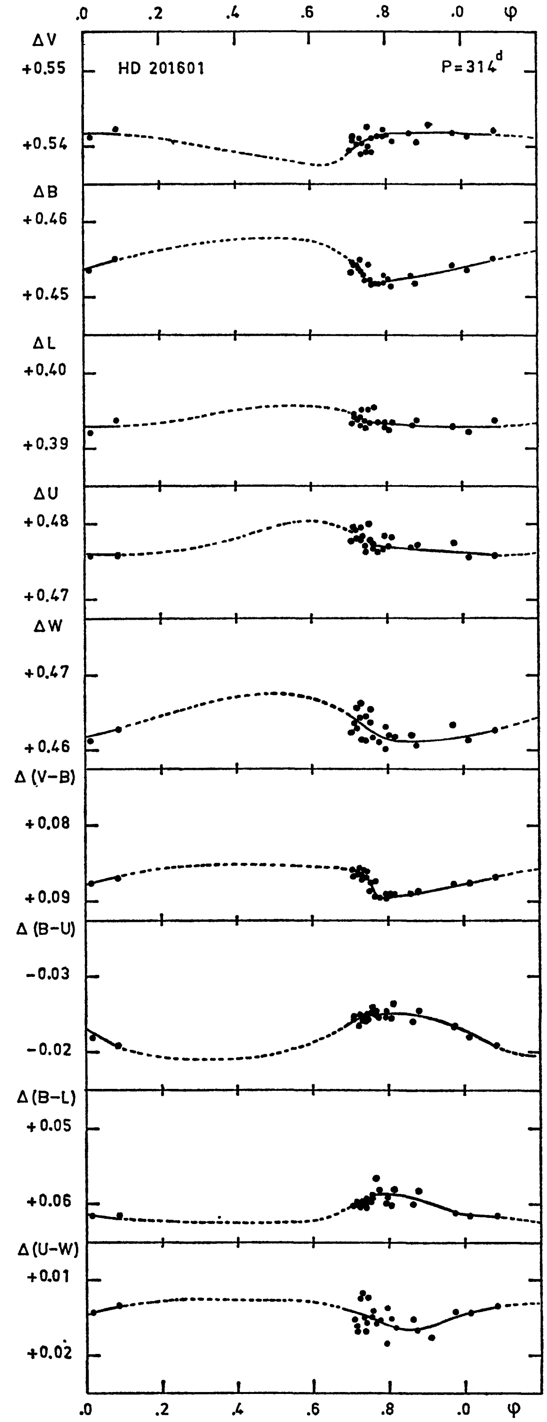


Fig. 10. The light- and colour-curves of HD 201601

HD 188041. No photometric investigation of this magnetic variable has been reported as yet. Babcock (1960) derived from the magnetic field variation a period of 226^d, with the minimum at phase 0. Our observations plotted with this period showed that the minimum of the V light-curve was near phase 0.7 and the maximum near phase 0.2. As there seems to be no preference for antiphase or in-phase relationships between visual light-curves and magnetic-curves (Stępień, 1968), it is not possible to derive with

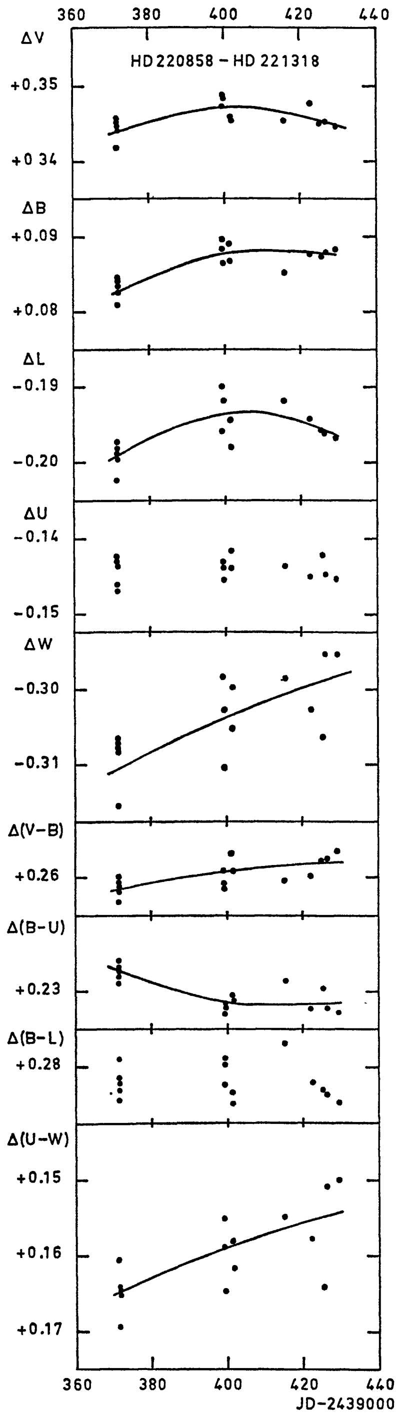


Fig. 11. The light and colour difference HD 220858 – HD 221318, the two comparison stars of HD 220825, plotted against the date

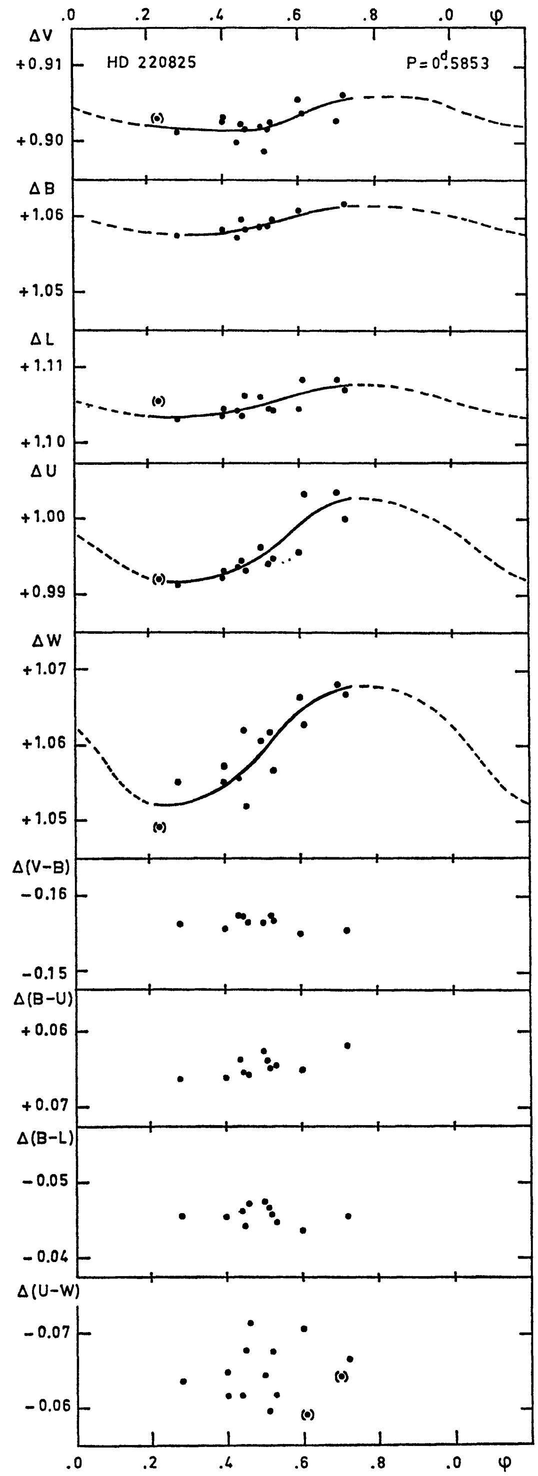


Fig. 12. The light- and colour-curves of HD 220825

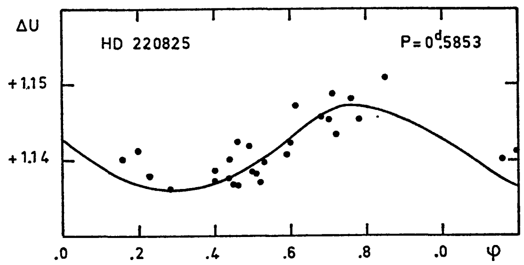


Fig. 13. The light variation of HD 220825 in the U band relative to C1 = HD 220858

certainty the correction for Babcock's period. When we assume that the maximum of the V curve should coincide the minimum of the magnetic-curve, the correction is smallest, viz. 0.25 in phase. We then obtain a period of 227^{d}84. The phases in Fig. 8 have been computed from the formula:

$$\varphi = (\text{J.D.} - 2432323) \times 227.84^{-1}$$

in which the zero-point is taken from Babcock. With these elements our observations begin just after the remarkable hump in the maximum of the magnetic-curve.

HD 190073. No photometric investigation of this magnetic star [which is designated as A0ep in Babcock's (1958) catalogue] has been reported as yet. No smooth periodic curves could be seen in our observations, which are plotted against the date in Fig. 9. If this star varies periodically, the period may be near 100^d. This is the only magnetic star in our sample which sometimes shows clear and definite established brightness fluctuations in the course of a few days, amounting to about 0.01 mag or more. This is probably related to the outstanding peculiarity in the spectrum (Merrill, 1951; Babcock, 1958).

HD 201601 = γ Equ. Wehlau (1962) has made the first photo-electric observations of this star and found no real variation either in yellow or in blue light. The observations presented here, show a clear but small change in brightness with a period of 314^d. This period with an uncertainty of $\pm 3^d$ was found by Renson (1969) with the aid of Babcock's (1958) magnetic field strengths. The phases in Fig. 10 have been computed from the formula:

$$\varphi = (\text{J.D.} - 2435624.9) \times 314^{-1}$$

in which the Julian Date of the origin of the phases is represented by a minimum of the magnetic curve, chosen arbitrary by Renson, but increased by 0^{d}4 to obtain roughly the true Julian Date for California.

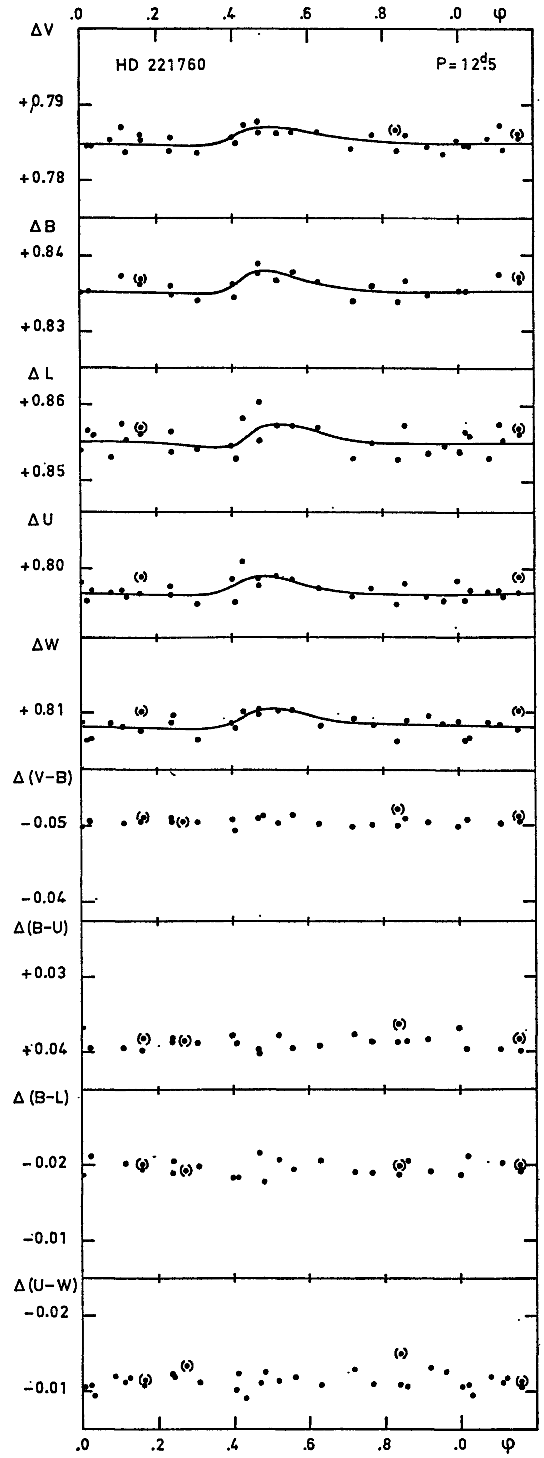


Fig. 14. The light- and colour-curves of HD 221760

Table 3. *The brightness and colour difference* HD 220858(K0) – HD 221318(F5) (The two comparison stars of HD 220825)

J.D. −2439000	ΔV	$\Delta (V-B)$	$\Delta (B-U)$ (log intensity)	$\Delta (U-W)$	$\Delta (B-L)$
371.378	+0.3419	+0.2611	+0.2270	+0.1693	+0.2790
371.412	+0.3447	+0.2600	+0.2272	+0.1652	+0.2818
371.451	+0.3442	+0.2611	+0.2260	+0.1648	+0.2820
371.499	+0.3456	+0.2631	+0.2290	+0.1606	+0.2845
371.556	+0.3455	+0.2615	+0.2272	+0.1648	+0.2831
399.374	+0.3474	+0.2608	+0.2323	+0.1648	+0.2826
399.420	+0.3487	+0.2609	+0.2318	+0.1588	+0.2796
399.510	+0.3486	+0.2590	+0.2329	+0.1550	+0.2794
401.355	+0.3459	+0.2590	+0.2306	+0.1616	+0.2849
401.406	+0.3459	+0.2567	+0.2309	+0.1582	+0.2834
415.302	+0.3455	+0.2604	+0.2288	+0.1550	+0.2769
422.381	+0.3476	+0.2599	+0.2328	+0.1577	+0.2820
425.288	+0.3451	+0.2577	+0.2296	+0.1642	+0.2831
426.332	+0.3453	+0.2575	+0.2324	+0.1507	+0.2839
429.390	+0.3447	+0.2564	+0.2338	+0.1500	+0.2849

The minimum of the V curve coincides with the minimum of the magnetic-curve.

HD 220825 = $\varkappa$ Psc. Rakos (1962) has observed this star photo-electrically in blue and yellow light and reported a period of $0^d.5805$. Our observations have been made with the same comparison star as that of Rakos viz. HD 220858 (= C1) of spectral type K0. Later on we also used a second one viz. HD 221318 (= C2) of spectral type F5. A comparison between C1 and C2 and of each of them with the magnetic variable star, showed that C1 must also be variable. The difference C1–C2 is shown in Fig. 11 and listed in Table 3. Rakos' observations and a part of our observations which were only measured relative to C1 are therefore unreliable. The latter observations are then also omitted in Table 2. In Fig. 12 we only plotted our observations of the magnetic star relative to C2. As can be seen our period of $0^d.5853$ differs from that of Rakos. Phases have been computed with the formula:

$$\varphi = (\text{J.D.} - 2437198.48) \times 0.5853^{-1}$$

Table 2 shows that we have obtained two or more series of observations within several nights. The shortness of the period seems to be confirmed by them.

From Fig. 11 it can be concluded that C1 did not show much variation in the U band. Assuming that this trend can be extrapolated, we obtained Fig. 13 in which we have plotted the magnetic star minus C1 difference for this particular passband. The new period also appeared to fit satisfactorily the observations in the longer time interval.

HD 221760 = ι Phe. No photometric investigation of this magnetic star has been reported as yet. Babcock (1958) obtained evidence for a weak field of positive polarity. The period for the photometric variability, which shows an amplitude of about 0.006 mag, could be $12^d.5$, but needs further confirmation. The phases in Fig. 14 have been computed using the formula:

$$\varphi = (\text{J.D.} - 2439000) \times 12.5^{-1} .$$

3. Discussion

In Table 4 a summary is given of some photometric properties. The quantitive brightness and colours in the system of Walraven are median values of the curves displayed in Figs. 1 to 14 (except Fig. 11). The amplitudes are given in log intensity, but a column with the V amplitudes in magnitudes is added. The signs associated with them, show the phase relationship: a plus sign means that the appropriate curve is in phase with the V curve and a minus sign means that it is in antiphase. Brackets indicate uncertain quantities. For HD 153882, which shows two maxima, we have only listed the amplitudes of the maximum near phase 0.7, because the other one is not visible in the colour-curves.

We have three stars in common with Stępień (1968) viz. HD 10783, HD 118022 and HD 153882. A comparison with his values for V_J and $(B-V)_J$ showed that our magnitudes are fainter by about 0.01 mag and the colours bluer by about 0.01 to

Table 4. *Photometric parameters of the magnetic stars*

Variable (HD and name)	P (days)	V_J	$(B-V)_J$ (mag)	$(B-V)_{J0}$	V	$V-B$	$B-U$ (log intensity)	$U-W$	$B-L$
10783	4.1327	6.57	−0.075		+0.127	−0.023	+0.340	+0.082	+0.117
11503[a] = γAri	2.607	3.88	−0.05		+1.201	−0.014	+0.356	+0.085	+0.132
15144	2.997814	5.87	+0.115		+0.401	+0.050	+0.435	+0.124	+0.208
118022 = 78 Vir	3.7220	4.93	+0.02		+0.778	+0.013	+0.396	+0.115	+0.166
140160 = χSer	1.59584	5.36	+0.015		+0.609	+0.009	+0.440	+0.118	+0.180
153882[b]	6.00925	6.32	+0.025		+0.222	+0.013	+0.426	+0.129	+0.154
173650	9.97427	6.54	+0.01	−0.045	+0.136	+0.007	+0.363	+0.119	+0.111
188041	227.84	5.63	+0.18		+0.495	+0.074	+0.402	+0.114	+0.211
190073	100 (?)	7.85	+0.07	−0.065	−0.391	+0.032	+0.415	+0.080	+0.135
201601 = γEqu	314	4.69	+0.235		+0.867	+0.098	+0.418	+0.130	+0.229
220825 = $\varkappa$Psc	0.5853	4.93	+0.025		+0.778	+0.014	+0.384	+0.103	+0.166
221760 = ιPhe	12.5	4.72	+0.075		+0.863	+0.034	+0.458	+0.128	+0.174

[a]) This star has been measured together with its visual companion.
[b]) Only the amplitude for the maximum near phase 0.7 has been listed.

Amplitudes in: V (mag)	V	B	L (log intensity)	U	W	$V-B$	$B-U$ (log intensity)	$B-L$	$U-W$
0.018	0.0070	+0.0125	+0.0140	+0.0160	+0.0140	+0.0055	+0.0060	+0.0025	−0.0045
0.016	0.0065	−0.0065	−0.0085	+0.0060	+0.0075	−0.0105	+0.0120	−0.0040	0
0.006	0.0025	+0.0045	+0.0045	+0.0045	+0.0055	−0.0045	+0.0020	0	−0.0010
0.014	0.0055	+0.0065	−0.0035	+0.0090	+0.0075	0	+0.0050	−0.0085	+0.0025
0.020	0.0080	+0.0110	+0.0105	+0.0100	+0.0125	+0.0035	(−0.0035)	−0.0015	+0.0050
0.012	0.0050	+0.0085	+0.0095	+0.0165	+0.0150	+0.0045	+0.0110	+0.0030	−0.0065
0.044	0.0175	+0.0120	+0.0155	+0.0450	+0.0390	−0.0075	+0.0355	+0.0060	−0.0045
0.010	0.0040	−0.0220	−0.0370	−0.0035	−0.0115	−0.0265	+0.0200	−0.0160	−0.0135
(0.020)	(0.0080)	(+0.0100)	(+0.0200)	(+0.0250(	(+0.0500)	(+0.0060)	(+0.0150)	(+0.0100)	(+0.0200)
(0.011)	(0.0045)	(−0.0060)	(−0.0025)	(−0.0045)	(−0.0060)	(−0.0040)	(+0.0060)	(+0.0040)	(−0.0040)
0.011	0.0045	+0.0040	+0.0045	+0.0115	+0.0160	−	+	(−)	
0.006	0.0025	+0.0030	+0.0030	+0.0025	+0.0030	0	0	0	0

0.02 mag. This difference also exists between our $(B-V)_J$ values and those listed by Ledoux and Renson (1966). The cause of this discrepancy is not known.

Because of the rather small scatter displayed in nearly all curves, we can confirm Stępień's (1968) conclusion on the constancy of periods and shape of the light-curves.

The amplitude of the light-variations generally increases towards the shorter wavelengths, a phenomenon already recognized by other authors. Nine stars of Stępień's and our sample are red near minimum light and thirteen are blue.

In Fig. 15 we show the three colour-colour diagrams in the system of Walraven. To make the comparison of $V-B$ with $(B-V)_J$ easier, $(B-V)_J$ is also indicated on the horizontal axis. The range of the colour-variation is schematically indicated. Just as in the case of Stępień's sample, most of the colour changes are more or less parallel to the main sequence. Stępień suggested a classification of magnetic stars in several groups of which the first group consisted of stars whose V_J, $(B-V)_J$ and $(U-B)_J$ curves are in phase and of which the variation was more or less parallel to the main sequence in the colour-colour diagram. However, the last characteristic means that the $B-U$ (or $(U-B)_J$) curve can be just as well as in antiphase with V and $V-B$ (or V_J and $(B-V)_J$), depending on whether the star has a high or low $V-B$ index, see for example HD 188041 and HD 201601 in Fig. 15. Furthermore, there are only a few stars which show the parallelity in all our three colour-colour diagrams, viz. (in order of increasing $V-B$): HD 190073, HD 15144 and perhaps also

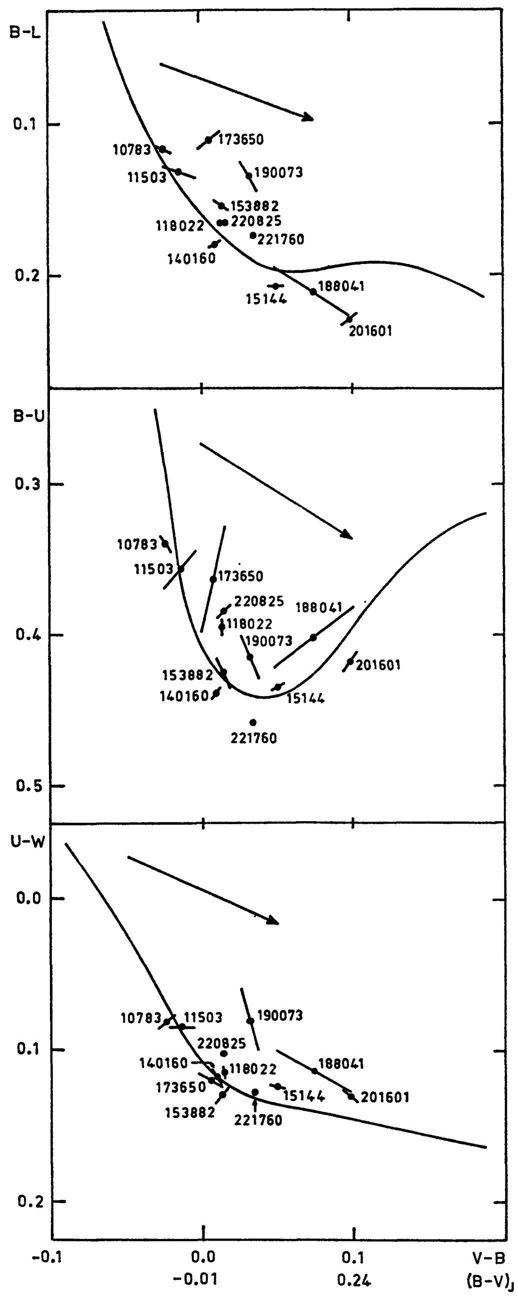


Fig. 15. The colour-colour diagrams in which the observed range during one cycle is schematically indicated by the length of the line. The solid curves and the arrows show the main sequences and reddening paths, respectively (according to Walraven, 1966)

HD 188041 and HD 201601, so that the question arises whether such a classification has much sense.

Figure 16 shows Stępień's diagram in which the dependence of the V variation on the unreddened

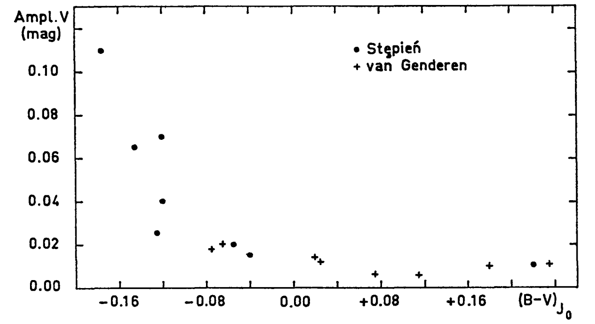


Fig. 16. The dependence of the amplitude in yellow light on $(B-V)_{J0}$ for stars in Stępień's first group

$(B-V)_J$ is displayed for stars of his first group. We plotted all stars, also Stępień's star HD 176232, of which the variations are more or less parallel to the main sequence in the diagrams $V-B/B-U$ and $(B-V)_J/(U-B)_J$. The star HD 190073, also belonging to this group, has been corrected for interstellar reddening. The star HD 173650 has been also corrected for reddening. By shifting them to the main sequence in the three colour-colour diagrams we obtained an average reddening. The $(B-V)_{J0}$ values so obtained are also listed in Table 4. For $(B-V)_{J0}$ redder than 0.00 one can no longer speak of a relationship between effective temperature and V variation. Using amplitudes in other passbands, the scatter even becomes considerable. Figure 16 seems to confirm Peterson's (1970) explanation for the light-variation in magnetic stars, which predicts rather small variations in V for the cooler objects. Furthermore, a certain parallelity of the colour variation with the main sequence can also be explained by that theory, which is based on the blanketing effect of silicon.

The fact that the three long-period variables also show rather large light-variations, does not support the explanation that these variations could be caused by a companion, producing disturbances of different kinds on the magnetic star: the larger the distance between both stars and consequently the larger the period of revolution, the smaller the light-variation should be (Ledoux and Renson, 1966; Renson, 1969 p. 73).

Note added in proof. Since this work has been completed and submitted, a referee drew attention to a paper concerning HD 173650 by Burke *et al.* (1969), which escaped the author's attention. From BV photometry these authors derived a period of

$9\overset{d}{.}9748 \pm 0\overset{d}{.}002$, which is close to the period used in section 2. It strengthens the supposition, that this one may be indeed the best.

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