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A photometric survey of the bright southern Be stars

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Summary. Repeated *UBV* photometric measurements were made of the 86 bright Be stars south of declination −20°, and a network of comparison stars was set up. From a statistical study of the differential photometry it was found that short- or intermediate-term variability seems to be occurring in about half of the Be stars, and to be more evident in the stars of earlier spectral type. It was also possible to identify 11 individual short- or intermediate-term variables. Four of these (all of early B spectral type) appear to exhibit significant variability on a time-scale of a day or less. More intensive observations of one of these stars, 28 ω CMa, indicate short-term variations consistent with the published spectroscopic period of 1.37 day.

1 Introduction

It has been known for some time (e.g. Feinstein 1968, 1970, 1975; Ferrer & Jaschek 1971), that long-term photometric variability on a time-scale of years to decades was occurring in at least half of the Be stars. Small-amplitude variability on a time-scale of half a day to a day is also known to occur among these objects (e.g. Walker 1953; Lynds 1959a, b, 1960; Schmidt 1959; Hill 1967; Percy 1972). Indeed, it has been suggested that the occurrence of short-term variability is widespread (e.g. Harmanec 1984b). It was therefore decided to undertake a comprehensive photometric survey of Be stars to investigate short-term variability. All the bright classical Be stars brighter than about magnitude 6.5 and south of declination −20° were included. [In contrast, the Be stars included in the photometric survey of Waelkens & Rufener (1983, 1985) appear to have been selected on the basis of possible variability, and do not constitute a magnitude-limited sample.] Only four or five measurements of each star were planned, making it difficult to identify individual variables, but making statistical studies possible. It was felt especially worthwhile to determine how prevalent short-term variability is, and whether it has any dependence on spectral type. It has been suggested that short-term Be variables may be non-radial pulsators, and B stars in which non-radial pulsation is known to occur (the β Cephei and 53 Per stars) are of early B spectral type (e.g. Lesh 1982; Smith 1980).

A second aim of the photometric survey was to set up a network of carefully measured *UBV* standard stars for future observers. Such a network has already been set up for the northern Be stars brighter than magnitude 6.5 by Drs P. Harmanec, J. Horn, and P. Koubsky at Ondrejov Observatory in Czechoslovakia as part of their Bright Be Stars observing Programme (Harmanec 1980; Harmanec *et al.* 1980a; Harmanec, Horn & Koubsky 1980b, 1982). The extension of the Programme beyond its present southern limit was particularly timely, since important studies are now being carried out on southern hemisphere objects (e.g. Balona & Engelbrecht 1985a, b; Baade 1982a, 1984a, b).

2 The observations

The survey was carried out at Cerro Las Campanas in Chile in 1983 March–April and 1984 February. Additional observations were also made on three nights in 1984 September by Mr B. Slawson. All the data were obtained on the 0.6-m University of Toronto telescope, using an S-25 refrigerated photomultiplier tube in pulse-counting mode. Count rates through each of the *U, B,* and *V* filters were corrected for coincidence effects by the formula of Fernie (1976). Since the bright Be star α Eri was observed through a neutral density filter, it was necessary to correct the count rates for that star by dividing by the filter transmission in each band.

The stars were divided into 44 groups, with each group having at least two comparison or check stars and one red standard within 3°. Each group was observed at least four times. Where possible, two sets of observations were made on one night, and two sets on the next night. (Sometimes a fifth set of observations was also made.) When this could not be done, it was nearly always possible to observe each group twice on at least one night, to check for short-term photometric variations.

3 Reduction procedure

For the 1983 observations, the magnitudes and colours of comparison, check, and red standard stars were taken from the 'prime standards' list of Johnson *et al.* (1966). [Most of these stars were in fact observed by Cousins & Stoy (1963) and then corrected to the Johnson *UBV* system.] Measurements of these 'prime standards' were used to determine the reduction coefficients according to the method of Harris, Fitzgerald & Reed (1981). Extra coefficients were included to correct for linear trends with declination, V, V^2, and (on one night only) hour angle. Flexure in the photometer and non-linearities in the photomultiplier or counter may account for the need for these extra terms.

The use of the 'prime standards' list ensured that the 1983 observations were indeed on the 'Johnson' system. Since a number of comparison, check, and red standard stars did not have Johnson magnitudes and colours, however, four additional sources were used for the 1984 observations:

(i) 'Prime standards' (Johnson *et al.* 1966).

(ii) Supplementary Cape photometry (Johnson *et al.*, 1966), corrected to the Johnson system. (This was used for two stars in the 'prime standards' list which appeared to have incorrect *U–B* values.)

(iii) Cousins photometry (Cousins 1970, 1972a, b; Cousins & Stoy 1963, 1970), corrected to the Johnson system, using the procedure of Johnson *et al.* (1966).

(iv) E-region standards (Menzies & Laing 1980), corrected to the Johnson system. In appropriate cases, these values replaced the measurements in the 'prime standards' list.

(v) Standards from the 1983 photometry.

Later data from (iii) and (iv) had a −0.005 mag correction applied to V to bring the data to the same system as used in Cousins & Stoy (1963). Data from (iv) were given weight 4, and data from (v) were given weight 2 if the standard deviation was less than 0.01 mag. All other data were given weight 1.

In the final reduction procedure, only prime standard stars with no outliers in the residual plots were used. The average standard error in the observed magnitudes or colours of the standard stars is about 0.006 mag in V, 0.004 mag in $B–V$, and 0.005 mag in $U–B$. The reduced magnitudes of all stars observed in 1983 and 1984, together with the times of observation, have been submitted to the IAU Commission 27 Archive of Unpublished Photoelectric Photometry. The average values of V, $B–V$, and $U–B$ are recorded in Table 1 together with the standard deviations.

4 Evidence for long-term variability from all sky photometry

Once magnitudes and colours had been determined for the programme stars, it was possible to compare them with earlier determinations, to look for long-term variations. In the histogram plots in Fig. 1 the (Stagg–Johnson) magnitudes and colours for comparison/check stars are compared with those for Be stars. Few of the comparison and check stars have observed magnitudes differing by more than 0.02 mag from the 'Johnson' magnitudes, and in many cases the observed magnitude and the Johnson magnitude are the same (to the nearest 0.01 mag). Many Be stars differ by more than 0.02 mag from the Johnson magnitude, however, and very few have the same magnitude.

To determine whether this variability was due to the influence of short-term, small-amplitude variations, numerical simulations were performed. A sine curve was sampled at five random phases to obtain a theoretical 'Johnson magnitude', and at an additional five phases to give a theoretical 'Stagg magnitude'. The standard deviation in the second sample was taken to correspond to the observed standard deviation $\bar{\sigma}(V)$ in Stagg magnitude (discussed in Section 5). (The amplitude of the sine curve was chosen to make the two distributions correspond as closely as possible.) This procedure was repeated 100 times to represent a hypothetical sample of 100 Be stars. With the exception of a few outliers, the observed distribution of $\bar{\sigma}(V)$ for Be stars (Fig. 3) is quite similar to the theoretical distribution. However, the observed distribution of ΔV (Stagg–Johnson) is quite different from the theoretical one. There are to many differences of over 0.02 mag between Stagg and Johnson magnitudes to be explained by random sampling of short-term variability. Indeed, the data suggest that many, if not most, Be stars are undergoing long-term brightness variations of 0.01 mag or more. This result agrees with earlier studies by Feinstein (1968, 1970, 1975) and Ferrer & Jaschek (1971) which reveal long-term variability on a time-scale of years to decades in half or more of the Be stars studied.

In analysing the long-term variability of the programme objects, it was important to see whether the absolute differences between Johnson and Stagg V, $B–V$, and $U–B$ values had any dependence on spectral type of $v \sin i$. Student's t-test showed that there was a significant trend with spectral type of $|\Delta(B–V)|$ (at the 99 per cent level) and $|\Delta V|$ (at the 97 per cent level). The t-test also showed that there was a significant difference between the mean values of $|\Delta(B–V)|$ calculated for early B stars (B0 to B5.9) and late B stars (B6 to B9.9), at the 99 per cent level. It was also noted that $|\Delta V|$ and $|\Delta(B–V)|$ tended to be larger in the stars with $v \sin i$ between 100 and 200 km s^{-1} [although this result was only significant at the 83 per cent level for $|\Delta V|$ and at the 87 per cent level for $|\Delta(B–V)|$]. This may be an effect of the dependence on spectral type, however, since all but three of the stars in the 100 to 200 km s^{-1} group are of early spectral type. The data, binned into intervals of two spectral subclasses or 100 km s^{-1}, have been plotted against spectral class and $v \sin i$ in Fig. 2.

It may also be noted that three of the six Be stars which were measured at least twice in both

Table 1. Stagg and 'Johnson' magnitudes and colours for the programme stars. Each of the 44 groups has at least one Be, one comparison ('Co'), one check ('Ch'), and one red standard ('RS') star. Column 'N' gives the number of measurements used in determining Stagg magnitudes and colours. Where three sets of Stagg values are given, the first set is for 1983 observations, the second for 1984 observations, and the third for both years combined. The standard deviation in each Stagg value is given under '+/−'. Unless noted, 'Johnson' magnitudes are from the Johnson *et al.* (1966) 'prime list'. Column 'R' refers to remarks following the Table.

HR	STAGG							JOHNSON			TYPE	
NO	V	+/−	B−V	+/−	U−B	+/−	N	V	B−V	U−B		R
420	5.916	0.007	1.535	0.003	1.909	0.021	2	5.93	1.56	1.91	RS	
472	0.455	0.013	−0.110	0.013	−0.557	0.013	3	0.47	−0.15		Be	
520	5.043	0.032	0.027	0.003	0.059	0.005	3	5.04	0.04		Ch	
591	2.881	0.005	0.259	0.001	0.133	0.030	3	2.87	0.28	0.14	Co	

1766	6.337	0.023	0.334	0.013	0.093	0.015	4	6.34	0.33		Ch	
1772	6.057	0.055	−0.170	0.018	−0.727	0.015	4	6.11	−0.19		Be	1
1835	5.571	0.015	0.010	0.006	0.030	0.009	4	5.57	0.02		Co	
1862	3.852	0.027	1.167	0.018	1.096	0.007	4	3.87	1.14	1.08	RS	
1956	2.651	0.025	−0.136	0.017	−0.429	0.008	4	2.64	−0.12	−0.46	Be	1
1973	5.308	0.033	−0.047	0.021	−0.079	0.018	4				Co	

2160	5.798	0.009	0.017	0.011	0.034	0.011	5	5.80	0.02		Co	
2170	5.797	0.011	−0.109	0.008	−0.632	0.005	5				Be	
2282	3.022	0.014	−0.199	0.010	−0.658	0.015	4					
2282	3.029	0.011	−0.223	0.008	−0.670	0.004	5					
2282	3.026	0.012	−0.212	0.015	−0.665	0.011	9	3.02	−0.18	−0.72	Ch	
2288	5.567	0.028	−0.184	0.005	−0.849	0.007	4	5.52	−0.19		Be	
2296	3.845	0.015	0.887	0.004	0.515	0.009	4					
2296	3.836	0.014	0.879	0.011	0.515	0.003	5					
2296	3.840	0.014	0.883	0.009	0.515	0.006	9	3.85	0.88	0.52	RS	
2361	4.478	0.021	−0.163	0.007	−0.608	0.005	4					
2361	4.452	0.010	−0.154	0.009	−0.603	0.005	5					
2361	4.464	0.020	−0.158	0.009	−0.605	0.005	9	4.48	−0.17	−0.61	Co	
2364	5.729	0.033	−0.164	0.007	−0.692	0.003	4				Be	1
2492	5.164	0.013	−0.098	0.006	−0.882	0.049	4				Be	
2538	3.567	0.032	−0.100	0.008	−0.972	0.005	4	3.95	−0.23	−0.93	Be	
2545	5.754	0.021	0.139	0.016	−0.489	0.010	4				Be	

2507	6.593	0.006	−0.117	0.003	−0.518	0.005	5	6.62	−0.12		Be	
2518	5.253	0.008	−0.079	0.005	−0.237	0.007	5	5.26	−0.08		Co	
HD49850	7.387	0.007	0.166	0.006	0.144	0.005	5	7.420	0.156	0.137	Ch	9
2612	6.234	0.009	0.443	0.004	−0.060	0.005	5	6.23	0.46	−0.04	RS	11

2628	6.509	0.019	−0.149	0.011	−0.804	0.013	4	6.52	−0.16		Be	
2640	5.640	0.004	−0.169	0.009	−0.670	0.011	3	5.63	−0.17		Ch	
2690	5.842	0.009	−0.128	0.004	−0.868	0.006	4				Be	
2733	6.355	0.011	−0.173	0.008	−0.811	0.008	4					
2733	6.360	0.009	−0.174	0.004	−0.820	0.007	35					
2733	6.359	0.009	−0.174	0.005	−0.819	0.007	39	6.27	−0.13		Co	1,6
2745	4.639	0.008	−0.174	0.006	−0.813	0.017	4	4.65	−0.20	−0.69	Be	
2749	3.921	0.025	−0.143	0.011	−0.707	0.010	4					
2749	3.789	0.018	−0.155	0.009	−0.700	0.010	35					
2749	3.803	0.044	−0.154	0.010	−0.701	0.010	39	3.82	−0.18	−0.73	Be	
2755	6.326	0.022	−0.002	0.019	−0.042	0.029	4				Ch	
2774	6.429	0.017	−0.136	0.013	−0.597	0.011	4					
2774	6.431	0.009	−0.139	0.006	−0.599	0.006	35					
2774	6.431	0.010	−0.138	0.007	−0.599	0.007	39	6.43	−0.14	−0.60	Ch	
2786	5.296	0.003	0.965	0.004	0.646	0.003	4					
2786	5.297	0.009	0.972	0.005	0.658	0.007	35					
2786	5.297	0.008	0.972	0.005	0.657	0.008	39	5.28	0.96	0.65	RS	
2802	5.852	0.010	1.584	0.008	1.906	0.025	3				RS	
2855	5.649	0.009	−0.091	0.009	−0.972	0.010	4				Be	

Table 1–*continued*

HR		STAGG							JOHNSON		TYPE	
NO	V	+/-	B-V	+/-	U-B	+/-	N	V	B-V	U-B		R
2787	4.746	0.019	-0.130	0.006	-0.794	0.010	4	4.67	-0.10	-0.79	Be	
2790	5.120	0.025	-0.167	0.008	-0.674	0.006	4	5.11	-0.16	-0.66	Be	
2911	5.389	0.023	-0.100	0.017	-0.743	0.010	4	5.56	-0.06		Be	
2937	4.527	0.015	-0.078	0.011	-0.318	0.004	4	4.53	-0.09	-0.31	Co	
2961	4.843	0.016	-0.179	0.008	-0.661	0.012	4	4.85	-0.19	-0.65	Ch	
2968	6.024	0.025	-0.034	0.012	-0.460	0.009	4	6.00	-0.04	-0.46	Be	
3002	5.132	0.019	1.105	0.008	1.038	0.008	4	5.17	1.10		RS	

2794	6.312	0.026	1.312	0.023	1.456	0.041	4				RS	
2819	5.401	0.008	-0.162	0.005	-0.702	0.016	4	5.43	-0.14		Be	
2827	2.469	0.016	-0.092	0.006	-0.735	0.007	4	2.44	-0.09	-0.71	Co	
2873	5.779	0.014	-0.192	0.004	-0.725	0.010	4	5.77	-0.19		Ch	
2881	4.640	0.006	0.924	0.005	0.614	0.004	4	4.65	0.93	0.64	RS	
2922	4.637	0.010	-0.118	0.004	-0.400	0.007	4					
2922	4.628	0.008	-0.110	0.010	-0.404	0.014	5					
2922	4.632	0.010	-0.114	0.008	-0.402	0.011	9	4.61	-0.12	-0.43	Ch	

2922	4.637	0.010	-0.118	0.004	-0.400	0.007	4					
2922	4.628	0.008	-0.110	0.010	-0.404	0.014	5					
2922	4.632	0.010	-0.114	0.008	-0.402	0.011	9	4.61	-0.12	-0.43	Ch	
2996	3.968	0.005	0.186	0.009	-0.133	0.016	5	3.95	0.18	-0.14	Co	4
3034	4.470	0.003	-0.052	0.005	-1.008	0.005	5	4.52	-0.05	-1.02	Be	2
3043	5.329	0.018	0.746	0.012	0.361	0.015	5	5.33	0.76		RS	
3045	3.331	0.019	1.245	0.006	1.107	0.008	5	3.35	1.25	1.13	RS	4

3036	6.391	.....	0.953	.....	0.659	.....	1					
3036	6.393	0.006	0.938	0.007	0.680	0.010	5					
3036	6.392	0.007	0.941	0.009	0.676	0.012	6	6.38	0.95	0.65	RS	
3081	5.785	.....	-0.036	.....	-0.174	.....	1					
3081	5.783	0.008	-0.039	0.006	-0.159	0.006	5					
3081	5.784	0.007	-0.039	0.006	-0.161	0.008	6	5.79	-0.04	-0.16	Ch	
3147	5.811	.....	-0.075	.....	-0.769	.....	1					
3147	5.842	0.009	-0.078	0.006	-0.732	0.004	5					
3147	5.837	0.015	-0.078	0.005	-0.738	0.015	6	5.81	-0.10		Be	
3159	4.810	0.008	-0.154	0.004	-0.630	0.009	5	4.82	-0.17	-0.62	Co	
3217	6.322	0.009	-0.053	0.004	-0.370	0.007	5	6.28	-0.06		Be	
3165	2.303	0.014	-0.303	0.012	-1.100	0.006	4	2.25	-0.27	-1.09	Co	
3195	6.296	0.013	-0.015	0.007	-0.549	0.005	4	6.41	-0.05		Be	
3233	6.415	0.006	0.108	0.006	0.152	0.003	4	6.43	0.10		Ch	
3237	4.893	0.010	-0.145	0.005	-0.963	0.006	4	4.77	-0.11	-0.98	Be	
3241	6.120	0.006	-0.166	0.002	-0.702	0.007	4	6.11	-0.18	-0.71	Ch	
3243	4.431	0.010	1.174	0.004	1.082	0.007	4	4.44	1.17	1.09	RS	

3330	5.195	0.004	-0.175	0.002	-0.673	0.004	2				Be	
3330	5.179	0.012	-0.171	0.010	-0.680	0.006	5				Be	
3330	5.184	0.013	-0.172	0.008	-0.678	0.006	7				Be	2
HD72754	6.913	0.005	0.221	0.004	-0.704	0.004	2				Be	
HD72754	6.823	0.058	0.197	0.013	-0.732	0.009	5				Be	
HD72754	6.849	0.064	0.204	0.016	-0.724	0.016	7				Be	
3407	5.001	0.006	1.343	0.001	1.349	0.002	2					
3407	4.988	0.017	1.353	0.008	1.350	0.017	5					
3407	4.992	0.016	1.350	0.008	1.350	0.014	7	5.01	1.33	1.38	RS	
3452	4.779	0.004	0.131	0.003	0.109	0.013	2					
3452	4.776	0.015	0.130	0.011	0.112	0.009	5					
3452	4.777	0.013	0.130	0.009	0.111	0.009	7	4.77	0.12	0.12	Ch	
HD74234	6.944	0.001	-0.118	0.002	-0.775	0.003	2				Co	
HD74234	6.940	0.012	-0.137	0.009	-0.798	0.009	5				Co	
HD74234	6.941	0.010	-0.132	0.012	-0.792	0.014	7				Co	

3356	5.825	0.010	-0.156	0.004	-0.736	0.009	5				Be	
3426	4.141	0.009	0.110	0.003	0.126	0.009	5	4.14	0.10	0.13	Co	
3477	4.061	0.012	0.877	0.006	0.505	0.008	5	4.07	0.87	0.52	RS	
3487	3.892	0.011	0.009	0.006	-0.030	0.012	5	3.91	0.00	-0.05	Ch	

1987MNRAS.227..213S

Table 1–*continued*

HR NO	STAGG V	+/-	B-V	+/-	U-B	+/-	N	JOHNSON V	B-V	U-B	TYPE	R
3498	4.426	0.015	-0.134	0.007	-0.775	0.008	5				Be	
3570	5.729	0.016	0.472	0.001	-0.023	0.008	5	5.71	0.48	0.00	RS	
3571	3.836	0.012	-0.099	0.007	-0.433	0.008	5	3.84	-0.10	-0.45	Co	2
3574	4.680	0.015	-0.115	0.004	-0.484	0.005	5	4.69	-0.12	-0.47	Ch	1

3527	5.089	0.011	-0.212	0.011	-0.973	0.013	4	5.10	-0.21	-0.98	Ch	1
3593	6.054	0.006	-0.162	0.007	-0.792	0.006	4	6.09	-0.17		Be	
3614	3.745	0.017	1.205	0.006	1.233	0.008	4	3.75	1.20	1.22	RS	
3661	5.577	0.020	-0.117	0.009	-0.481	0.003	4	5.57	-0.11	-0.49	Ch	3,7
3670	5.921	0.016	-0.055	0.014	-0.117	0.008	4	5.92	-0.05	-0.10	Be	
3680	6.257	0.017	-0.065	0.006	-0.288	0.004	5	6.25	-0.06	-0.27	Co	7

3544	6.127	0.009	0.204	0.004	0.186	0.004	5	6.11	0.20	0.17	Co	
3610	5.888	0.008	1.609	0.006	1.965	0.013	5	5.88	1.63	1.96	RS	
3615	4.012	0.007	0.148	0.004	0.159	0.002	5	4.01	0.14	0.13	Ch	
3642	4.741	0.013	-0.142	0.004	-0.787	0.002	5	4.71	-0.15	-0.80	Be	

3710	6.386	0.008	-0.093	0.004	-0.351	0.010	5	6.39	-0.10		Ch	
3715	6.789	0.007	0.010	0.006	-0.015	0.018	5	6.82	0.00		Ch	1
3745	6.110	0.017	-0.096	0.006	-0.544	0.008	5	6.10	-0.10	-0.55	Be	
3770	5.494	0.010	1.346	0.003	1.473	0.014	5	5.48	1.36		RS	2
3878	6.431	0.010	-0.101	0.008	-0.949	0.006	5	6.45	-0.13	-0.94	Co	
3858	4.740	0.005	-0.125	0.004	-0.613	0.003	2					
3858	4.717	0.004	-0.120	0.006	-0.615	0.007	5					
3858	4.724	0.012	-0.121	0.006	-0.614	0.006	7	4.78	-0.12	-0.58	Be	
3919	4.886	0.006	1.221	0.002	1.306	0.009	2					
3919	4.866	0.003	1.226	0.005	1.288	0.013	5					
3919	4.872	0.010	1.224	0.005	1.293	0.014	7	4.88	1.23	1.30	RS	
3931	6.278	0.000	0.214	0.008	0.112	0.006	2					
3931	6.264	0.003	0.201	0.005	0.109	0.006	5					
3931	6.268	0.007	0.204	0.008	0.110	0.006	7	6.28	0.22	0.11	Co	1
3946	6.230	0.004	-0.109	0.000	-0.624	0.001	2					
3946	6.191	0.004	-0.107	0.004	-0.660	0.009	5					
3946	6.202	0.019	-0.108	0.003	-0.649	0.019	7	6.21	-0.10	-0.68	Be	
3962	6.716	0.007	0.023	0.004	0.012	0.002	2					
3962	6.699	0.003	0.005	0.004	-0.005	0.008	5					
3962	6.704	0.009	0.010	0.010	0.000	0.011	7				Ch	2

3971	6.146	0.008	-0.024	0.004	-0.471	0.004	5				Be	1
4009	5.680	0.016	-0.059	0.004	-0.871	0.010	5	5.70	-0.08		Be	
4018	6.090	0.012	-0.064	0.006	-0.534	0.011	5	6.10	-0.08		Be	
4074	4.492	0.007	-0.118	0.005	-0.593	0.015	5	4.50	-0.12	-0.58	Be	1
4140	3.324	0.010	-0.089	0.007	-0.710	0.007	5				Be	
4173	5.902	0.009	-0.124	0.003	-0.627	0.012	6					
4173	5.890	0.007	-0.122	0.003	-0.619	0.006	8					
4173	5.895	0.010	-0.123	0.003	-0.622	0.010	14	5.91	-0.14		Co	
4179	5.951	0.008	1.626	0.004	1.991	0.017	5	5.87	1.44		RS	1,6
4180	4.279	0.009	1.043	0.006	0.758	0.014	5					
4180	4.278	0.008	1.039	0.006	0.758	0.008	8					
4180	4.278	0.008	1.040	0.006	0.758	0.010	13	4.28	1.04	0.75	RS	
4217	6.258	0.008	0.037	0.007	0.043	0.012	5	6.25	0.04		Ch	1
4221	5.272	0.033	-0.059	0.013	-0.374	0.030	5					
4221	5.237	0.004	-0.057	0.005	-0.345	0.007	8					
4221	5.250	0.026	-0.058	0.008	-0.356	0.023	13	5.26	-0.08		Be	
4222	4.836	0.006	-0.149	0.004	-0.653	0.006	5	4.85	-0.15	-0.64	Co	
4239	5.856	0.008	-0.003	0.008	-0.073	0.018	5					
4239	5.858	0.008	-0.002	0.004	-0.057	0.007	8					
4239	5.857	0.008	-0.002	0.006	-0.063	0.014	13	5.85	0.01		Ch	1
HD94910	6.865	0.017	0.640	0.006	-0.613	0.017	5				Be	

1987MNRAS.227..213S

Table 1–*continued*

HR NO	STAGG V	+/-	B-V	+/-	U-B	+/-	N	JOHNSON V	B-V	U-B	TYPE	R
3995	5.281	0.012	0.971	0.005	0.753	0.007	5	5.28	0.98	0.75	RS	
4002	5.806	0.011	0.007	0.004	-0.015	0.006	5	5.81	0.02	-0.02	Ch	
4037	3.304	0.010	-0.101	0.018	-0.301	0.003	5	3.32	-0.08	-0.33	Be	
4089	4.966	0.010	-0.126	0.009	-0.533	0.004	5	4.99	-0.13	-0.51	Co	
4206	5.974	0.013	-0.054	0.009	-0.511	0.011	5	5.97	-0.07	-0.51	Be	
4231	5.477	0.018	0.952	0.007	0.768	0.014	5	5.47	0.95	0.74	RS	
4234	4.436	0.015	-0.181	0.010	-0.690	0.014	5	4.45	-0.19	-0.70	Co	
4304	6.708	0.020	0.529	0.005	0.034	0.010	5	6.71	0.55	0.04	Ch	
4312	6.200	0.025	0.096	0.009	0.117	0.015	5	6.19	0.11	0.12	Ch	

4537	4.326	0.011	-0.143	0.003	-0.605	0.011	5	4.32	-0.15	-0.62	Be	
4549	4.897	0.011	-0.118	0.004	-0.554	0.005	5	4.90	-0.11	-0.53	Ch	1
4599	4.332	0.015	0.274	0.004	0.051	0.005	5	4.33	0.27	0.04	Co	1
4729	4.845	0.016	-0.133	0.008	-0.597	0.005	5	4.86	-0.12	-0.59	Ch	
4747	6.237	0.014	1.247	0.003	1.310	0.016	5	6.22	1.26	1.31	RS	5

4390	3.891	0.021	-0.151	0.004	-0.589	0.005	4	3.89	-0.15	-0.59	Co	
4460	4.637	0.023	-0.074	0.005	-0.214	0.003	4	4.62	-0.08	-0.21	Be	
4546	4.473	0.021	1.306	0.006	1.453	0.011	8					
4546	4.467	0.005	1.311	0.004	1.456	0.013	6					
4546	4.471	0.016	1.308	0.005	1.454	0.011	14	4.469	1.301	1.453	RS	9
4592	6.160	0.010	-0.022	0.007	-0.028	0.007	6	6.16	0.00		Ch	
4618	4.458	0.012	-0.161	0.011	-0.679	0.003	4	4.47	-0.15	-0.67	Be	
4620	5.354	0.017	-0.018	0.007	-0.064	0.006	4					
4620	5.345	0.005	-0.022	0.004	-0.051	0.010	6					
4620	5.349	0.011	-0.020	0.005	-0.056	0.010	10	5.339	-0.015	-0.033	Ch	9
4621	2.613	0.006	-0.147	0.015	-0.887	0.008	4	2.65	-0.09		Be	
4638	3.944	0.026	-0.156	0.006	-0.602	0.004	4					
4638	3.953	0.007	-0.163	0.011	-0.589	0.011	6					
4638	3.949	0.017	-0.160	0.010	-0.594	0.011	10	3.96	-0.15	-0.61	Co	

4546	4.473	0.021	1.306	0.006	1.453	0.011	8					
4546	4.467	0.005	1.311	0.004	1.456	0.013	6					
4546	4.471	0.016	1.308	0.005	1.454	0.011	14	4.469	1.301	1.453	RS	9
4625	5.556	0.019	-0.092	0.002	-0.642	0.019	4	5.48	-0.07		Be	
HD107422	6.818	0.010	0.062	0.006	0.025	0.015	4	6.829	0.045	0.041	Co	1,9
4836	6.447	0.010	0.249	0.004	0.073	0.010	4	6.44	0.25		Ch	

4565	5.935	0.007	1.477	0.004	1.905	0.020	4	5.93	1.50		RS	
4579	6.428	0.010	0.026	0.004	0.029	0.003	4	6.43	0.03		Ch	
4623	4.016	0.009	0.338	0.010	-0.030	0.010	4	4.02	0.32	-0.02	Co	
4635	5.464	0.013	0.043	0.007	0.058	0.012	4	5.46	0.06		Ch	
4696	5.220	0.009	-0.100	0.007	-0.338	0.006	4	5.21	-0.10		Be	2

4823	4.953	0.023	-0.019	0.008	-0.455	0.003	4				Be	
4830	5.279	0.025	0.264	0.015	-0.825	0.010	4				Be	
4842	4.702	0.039	1.046	0.009	0.974	0.005	4					
4842	4.709	0.010	1.049	0.006	0.978	0.004	5					
4842	4.706	0.025	1.048	0.007	0.976	0.005	9	4.69	1.05	0.93	RS	2
4848	4.619	0.031	-0.159	0.008	-0.640	0.003	4					
4848	4.629	0.009	-0.153	0.007	-0.629	0.005	5					
4848	4.625	0.021	-0.156	0.008	-0.634	0.007	9	4.65	-0.16	-0.63	Co	
4897	4.626	0.045	-0.147	0.007	-0.604	0.005	4	4.62	-0.15	-0.60	Be	
4899	5.151	0.038	-0.114	0.013	-0.533	0.005	3					
4899	5.161	0.011	-0.109	0.007	-0.525	0.007	5					
4899	5.157	0.023	-0.111	0.009	-0.528	0.007	8	5.19	-0.11	-0.50	Be	
4944	6.000	0.037	0.472	0.010	0.099	0.008	4					
4944	6.013	0.011	0.463	0.007	0.105	0.008	5					
4944	6.007	0.025	0.467	0.009	0.102	0.008	9	5.99	0.48		Ch	

Table 1–*continued*

HR NO	STAGG V	+/-	B-V	+/-	U-B	+/-	N	JOHNSON V	B-V	U-B	TYPE	R
4773	3.852	0.009	−0.156	0.003	−0.593	0.001	2					
4773	3.858	0.010	−0.151	0.008	−0.580	0.005	5					
4773	3.857	0.010	−0.152	0.007	−0.584	0.008	7	3.87	−0.15	−0.61	Co	
4804	6.515	0.021	0.092	0.004	−0.238	0.014	2					
4804	6.515	0.011	0.091	0.009	−0.244	0.011	5					
4804	6.515	0.013	0.092	0.007	−0.242	0.011	7	6.49	0.08	−0.24	Be	1
4862	5.578	0.015	1.160	0.001	0.960	0.006	2					
4862	5.577	0.009	1.167	0.006	0.945	0.008	5					
4862	5.577	0.010	1.165	0.006	0.950	0.010	7	5.55	1.17	0.95	RS	
4930	5.977	0.034	0.055	0.009	−0.837	0.012	2					
4930	5.982	0.010	0.065	0.003	−0.847	0.002	5					
4930	5.981	0.016	0.062	0.007	−0.844	0.007	7	6.03	0.05	−0.86	Be	
5030	6.097	0.009	0.078	0.009	−0.325	0.014	2					
5030	6.088	0.013	0.078	0.007	−0.335	0.002	5					
5030	6.090	0.012	0.078	0.007	−0.332	0.008	7	6.05	0.09	−0.34	Ch	

5157	5.974	0.001	−0.075	0.002	−0.340	0.002	2					
5157	5.984	0.014	−0.070	0.006	−0.341	0.006	5					
5157	5.981	0.012	−0.072	0.006	−0.341	0.005	7	5.97	−0.07		Ch	8
5193	3.462	0.001	−0.209	0.003	−0.770	0.019	2					
5193	3.463	0.012	−0.219	0.008	−0.802	0.011	5					
5193	3.463	0.010	−0.216	0.008	−0.793	0.020	7	2.94	−0.16		Be	
5206	5.774	0.003	−0.153	0.002	−0.729	0.005	2					
5206	5.781	0.015	−0.148	0.005	−0.740	0.009	5					
5206	5.779	0.013	−0.149	0.005	−0.737	0.009	7				Ch	
5223	6.271	0.003	−0.120	0.001	−0.801	0.005	2					
5223	6.259	0.022	−0.116	0.005	−0.815	0.006	5					
5223	6.262	0.019	−0.117	0.004	−0.811	0.009	7				Be	2
5249	3.860	0.005	−0.205	0.017	−0.776	0.006	2					
5249	3.867	0.013	−0.209	0.005	−0.784	0.006	5					
5249	3.865	0.012	−0.208	0.008	−0.781	0.007	7	3.87	−0.20	−0.80	Co	
5260	4.338	0.002	0.610	0.003	0.260	0.004	2					
5260	4.359	0.011	0.605	0.004	0.261	0.005	5					
5260	4.353	0.014	0.607	0.005	0.261	0.004	7	4.34	0.60	0.27	RS	

5292	6.348	.....	0.052	.....	−0.489	.....	1					
5292	6.344	0.013	0.048	0.010	−0.495	0.006	5					
5292	6.345	0.012	0.049	0.009	−0.494	0.006	6	6.34	0.05	−0.50	Ch	10
5297	4.752	.....	0.938	.....	0.708	.....	1					
5297	4.741	0.010	0.935	0.006	0.701	0.004	5					
5297	4.743	0.010	0.936	0.006	0.702	0.005	6	4.75	0.94	0.72	RS	2
5316	4.996	.....	−0.039	.....	−0.603	.....	1					
5316	4.973	0.011	−0.034	0.003	−0.621	0.002	5					
5316	4.977	0.013	−0.035	0.003	−0.618	0.008	6	5.07	−0.08		Be	
5358	4.347	.....	0.121	.....	−0.450	.....	1					
5358	4.340	0.013	0.118	0.013	−0.448	0.016	5					
5358	4.341	0.011	0.118	0.011	−0.448	0.014	6	4.33	0.12	−0.44	Co	7

5240	6.122	0.028	0.023	0.004	−0.160	0.007	4	6.09	0.03	−0.17	Ch	
5306	6.489	0.014	1.383	0.009	1.348	0.016	4	6.49	1.42	1.42	RS	7
5327	6.432	0.014	0.040	0.007	−0.321	0.005	4	6.42	0.02	−0.33	Be	
5336	5.080	0.010	−0.106	0.009	−0.572	0.012	4	5.06	−0.10	−0.56	Co	

5396	4.360	0.025	0.420	0.015	0.179	0.007	3					
5396	4.362	0.011	0.419	0.005	0.188	0.010	5					
5396	4.361	0.016	0.419	0.009	0.184	0.009	8	4.360	0.417	0.229	RS	9
5439	5.892	0.012	−0.089	0.008	−0.403	0.010	5	5.88	−0.08		Ch	8
5440	2.419	0.051	−0.225	0.024	−0.848	0.020	4					
5440	2.510	0.027	−0.281	0.016	−0.807	0.011	5					
5440	2.469	0.060	−0.256	0.035	−0.825	0.026	9	2.31	−0.19	−0.82	Be	

Table 1–*continued*

HR NO	STAGG V	+/−	B−V	+/−	U−B	+/−	N	JOHNSON V	B−V	U−B	TYPE	R
5471	3.975	0.018	−0.168	0.009	−0.691	0.015	4					
5471	3.999	0.008	−0.173	0.009	−0.687	0.009	5					
5471	3.989	0.018	−0.171	0.009	−0.689	0.012	9	4.00	−0.17	−0.69	Co	
5528	4.303	0.010	−0.152	0.012	−0.612	0.002	3					
5528	4.326	0.010	−0.154	0.002	−0.606	0.008	5					
5528	4.317	0.015	−0.153	0.007	−0.608	0.007	8	4.325	−0.152	−0.630	Ch	9

5482	5.374	0.004	0.284	0.005	0.061	0.005	4	5.36	0.29		Ch	
5500	5.931	0.030	−0.095	0.006	−0.688	0.014	4	5.91	−0.07	−0.70	Be	
5539	6.086	0.023	−0.053	0.008	−0.590	0.007	4					
5539	6.093	0.005	−0.064	0.007	−0.586	0.015	4					
5539	6.089	0.016	−0.059	0.009	−0.588	0.011	8	6.09	−0.06	−0.60	Co	
5551	5.505	0.023	−0.067	0.004	−0.531	0.018	4				Be	
5632	6.304	0.011	0.614	0.005	0.149	0.002	4					
5632	6.307	0.006	0.604	0.008	0.148	0.017	4					
5632	6.305	0.009	0.609	0.009	0.148	0.011	8	6.30	0.63		RS	5
5661	5.737	0.014	−0.061	0.008	−0.877	0.002	4	5.73	−0.08	−0.87	Be	1
5684	6.283	0.013	−0.086	0.007	−0.594	0.008	4					
5684	6.278	0.005	−0.089	0.006	−0.599	0.006	4					
5684	6.281	0.009	−0.087	0.006	−0.597	0.007	8	6.28	−0.09	−0.60	Ch	

5559	5.636	0.009	−0.037	0.005	−0.264	0.008	4	5.63	−0.03	−0.26	Ch	1,7
5646	3.836	0.011	−0.049	0.007	−0.101	0.004	4	3.87	−0.05	−0.14	Be	2
5647	5.693	0.009	0.142	0.004	0.108	0.008	4	5.69	0.14	0.09	Co	2
5683	4.251	0.013	−0.105	0.007	−0.358	0.004	4	4.27	−0.09	−0.37	Be	1
5699	5.656	0.009	0.638	0.002	0.084	0.009	4	5.65	0.65		RS	

5730	5.401	0.017	−0.134	0.008	−0.829	0.007	5	5.49	−0.12	−0.76	Be	2
5757	6.192	0.018	1.202	0.006	1.363	0.015	5	6.18	1.21	1.36	RS	
5782	5.654	0.016	−0.045	0.003	−0.359	0.008	5	5.65	−0.04	−0.38	Co	2
5786	5.949	0.017	−0.042	0.009	−0.146	0.005	5	5.95	−0.04	−0.16	Ch	

5806	5.850	0.007	1.061	0.007	0.943	0.013	4				RS	
5824	4.964	0.044	1.323	0.006	1.502	0.021	4					
5824	5.005	0.011	1.326	0.003	1.536	0.018	4					
5824	4.985	0.037	1.324	0.005	1.519	0.025	8	4.96	1.33	1.51	RS	
5856	6.530	0.003	0.324	0.007	0.044	0.011	4	6.51	0.32		RS	
5885	4.633	0.028	−0.053	0.016	−0.732	0.005	4					
5885	4.686	0.013	−0.054	0.006	−0.710	0.010	4					
5885	4.659	0.035	−0.054	0.011	−0.721	0.014	8	4.68	−0.06	−0.73	Ch	
5904	4.591	0.024	−0.069	0.002	−0.649	0.008	4	4.59	−0.06	−0.67	Co	1
5907	5.414	0.019	−0.022	0.005	−0.605	0.009	4	5.43	−0.04		Be	

6151	5.502	0.020	0.941	0.002	0.693	0.009	3	5.52	0.93	0.73	RS	
6172	5.885	0.034	−0.076	0.007	−0.409	0.005	5	5.91	−0.08	−0.42	Be	
6182	6.010	0.030	0.025	0.008	0.037	0.008	5	6.03	0.02	0.02	Co	
6233	6.115	0.029	−0.016	0.009	−0.281	0.005	5	6.13	−0.02	−0.28	Ch	

6188	5.665	0.018	−0.010	0.011	−0.868	0.010	4	5.66	−0.03		Co	
6274	6.283	0.019	0.034	0.010	−0.676	0.007	4	6.33	−0.02		Be	
6331	6.276	0.018	0.071	0.009	0.093	0.005	4				Ch	
6374	5.836	0.019	1.759	0.008	1.783	0.005	4				RS	
6416	5.486	0.018	0.785	0.003	0.345	0.007	4	5.48	0.81	0.35	RS	1,7
6451	5.263	0.021	−0.109	0.006	−0.822	0.012	4	5.25	−0.11	−0.81	Be	
HD157832	6.656	0.029	0.041	0.001	−0.852	0.011	4				Be	
6510	2.855	0.025	−0.146	0.013	−0.764	0.008	4	2.95	−0.17	−0.69	Be	
6537	4.568	0.011	−0.029	0.002	−0.097	0.005	4	4.58	−0.02	−0.07	Co	7

6304	6.178	0.050	−0.068	0.011	−0.917	0.009	6	6.11	−0.03		Be	
6320	5.745	0.009	−0.104	0.011	−0.545	0.007	5				Co	
6438	5.858	0.008	1.078	0.008	0.856	0.013	9	5.88	1.07		RS	1
6462	3.321	0.009	−0.126	0.012	−0.934	0.020	6	3.34	−0.13	−0.95	Be	2
6500	3.588	0.010	−0.101	0.008	−0.294	0.006	5	3.62	−0.10	−0.31	Ch	

Table 1–*continued*

HR NO	STAGG V	+/-	B-V	+/-	U-B	+/-	N	JOHNSON V	B-V	U-B	TYPE	R
6366	5.919	0.013	0.275	0.009	0.152	0.004	4					
6366	5.949	0.012	0.267	0.013	0.149	0.005	7					
6366	5.938	0.019	0.270	0.012	0.150	0.005	11	5.97	0.25		Ch	
6422	6.342	0.031	0.177	0.010	-0.396	0.006	4					
6422	6.386	0.009	0.138	0.010	-0.384	0.012	7					
6422	6.370	0.028	0.152	0.022	-0.389	0.011	11	6.36	0.15		Be	2
6470	6.135	0.008	0.037	0.005	0.029	0.006	4					
6470	6.143	0.009	0.017	0.013	0.016	0.009	7					
6470	6.140	0.010	0.024	0.015	0.021	0.010	11	6.17	0.02	0.04	Ch	
6508	2.697	0.011	-0.238	0.003	-0.820	0.004	4	2.68	-0.23	-0.81	Co	
HD160202	6.731	0.011	0.031	0.008	-0.446	0.010	4				Be	
6587	6.401	0.011	1.737	0.008	1.990	0.019	4					
6587	6.434	0.014	1.739	0.008	2.072	0.022	7					
6587	6.422	0.021	1.738	0.008	2.042	0.046	11	6.42	1.73	2.00	RS	

6519	4.784	0.009	0.011	0.013	-0.071	0.006	4	4.81	0.00	-0.06	Be	
6520	6.041	0.006	-0.058	0.008	-0.374	0.007	4					
6520	6.059	0.015	-0.079	0.007	-0.378	0.011	6					
6520	6.052	0.015	-0.071	0.013	-0.377	0.009	10	6.06	-0.07	-0.38	Ch	
6595	4.852	0.009	0.461	0.007	-0.052	0.004	4					
6595	4.890	0.011	0.472	0.008	-0.043	0.007	6					
6595	4.875	0.022	0.468	0.010	-0.046	0.007	10	4.87	0.47	-0.04	RS	
6621	6.319	0.053	0.142	0.004	-0.443	0.006	4					
6621	6.312	0.040	0.122	0.009	-0.440	0.006	6					
6621	6.315	0.043	0.130	0.013	-0.441	0.006	10	6.35	0.12		Be	
6700	4.727	0.015	-0.032	0.009	-0.060	0.006	4					
6700	4.733	0.007	-0.040	0.010	-0.052	0.009	6					
6700	4.730	0.010	-0.036	0.010	-0.055	0.009	10	4.75	-0.05	-0.04	Co	

6438	5.858	0.008	1.078	0.008	0.856	0.013	9	5.88	1.07		RS	1
6549	5.249	0.007	0.194	0.010	0.086	0.007	4	5.25	0.20		Co	
6743	3.670	0.009	-0.086	0.014	-0.857	0.012	4	3.66	-0.08	-0.84	Ch	
6819	5.338	0.009	-0.038	0.006	-0.701	0.006	4				Be	

6913	2.832	0.020	1.055	0.011	0.922	0.010	4	2.81	1.04	0.90	RS	
6929	6.570	0.018	0.081	0.020	-0.739	0.014	4				Be	
7039	3.158	0.006	-0.113	0.008	-0.363	0.006	4	3.16	-0.11	-0.36	Co	
7121	2.187	0.015	-0.281	0.012	-0.754	0.013	4	2.03	-0.22	-0.75	Ch	

7004	5.789	0.038	0.953	0.014	0.757	0.008	4	5.78	0.96	0.77	RS	
7012	4.789	0.016	0.195	0.003	0.084	0.002	4	4.79	0.20	0.08	Ch	
7036	5.731	0.020	0.249	0.004	0.095	0.003	4	5.73	0.24	0.11	Co	
7074	4.224	0.015	-0.149	0.005	-0.848	0.009	4	4.23	-0.14		Be	
8305	4.341	0.012	-0.061	0.023	-0.098	0.009	2	4.34	-0.05	-0.11	Ch	2
8386	5.431	0.019	-0.105	0.018	-0.358	0.009	4	5.42	-0.10		Be	
8405	6.488	0.003	1.602	0.004	1.922	0.029	2	6.47	1.63	1.93	RS	
8408	5.967	0.030	-0.173	0.015	-0.650	0.009	4	5.96	-0.14		Be	
8478	5.448	0.015	-0.131	0.015	-0.391	0.014	4	5.43	-0.16	-0.55	Co	6
8576	4.291	0.026	-0.002	0.031	0.037	0.005	2	4.29	0.01	0.02	Co	1
8628	4.172	0.024	-0.125	0.018	-0.365	0.014	4	4.16	-0.12	-0.34	Be	

8502	2.850	0.019	1.399	0.016	1.543	0.012	7	2.86	1.39	1.54	RS	
8527	5.774	0.013	0.387	0.013	0.034	0.009	7	5.78	0.38	0.03	Ch	
8540	4.454	0.010	-0.037	0.017	-0.056	0.015	7	4.47	-0.03	-0.07	Be	
8547	5.564	0.019	0.190	0.018	0.081	0.009	7	5.55	0.20	0.08	Co	

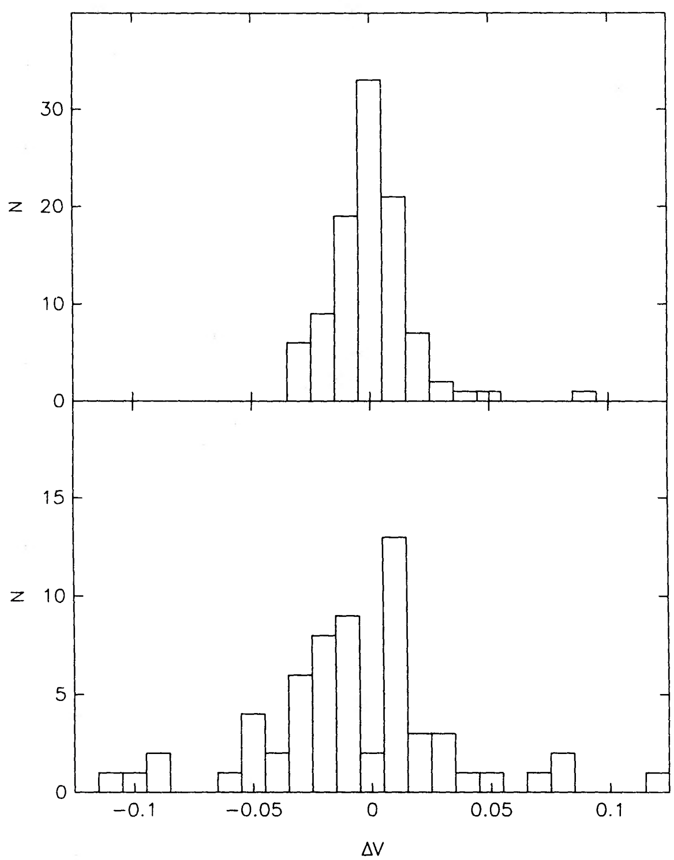
Remarks:

1. Combined magnitude and colours of components A and B.
2. Magnitude and colours of A component only.
3. Combined magnitude and colours of components A, B, and C.

Table 1–*continued*

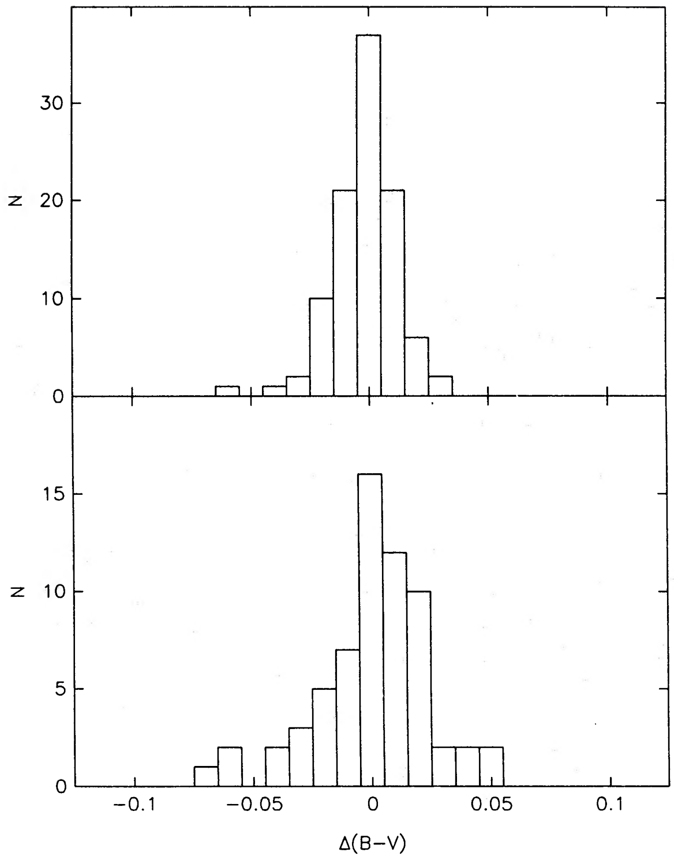
4. 'Johnson' U-B colour from Johnson et al. (1966) 'supplementary Cape list'.
5. Corrected 'Johnson' U-B colour from Cousins 1972b.
6. Stagg magnitudes and colours are for component A only.
7. Corrected 'Johnson' magnitude and colours from Cousins & Stoy 1963.
8. Corrected 'Johnson' magnitude and colours from Cousins & Stoy 1970.
9. Corrected 'Johnson' magnitude and colours from Menzies & Laing 1980.
10. Corrected 'Johnson' magnitude and colours from Cousins 1970.
11. Corrected 'Johnson' magnitude and colours from Cousins 1972a.

1983 and 1984 showed a difference of over 0.03 mag between their 1983 and 1984 V magnitudes. All three stars (HR 5440, 6422, and 2749) are of early B spectral type. Earlier data from Feinstein (1968, 1970, 1975) and van Hoof (1975) confirm the variability of HR 2749 (Fig. 5). These results all tend to confirm that *many Be stars, especially of earlier B spectral type, tend to show long-term, small-amplitude variations.* This is significant because Jaschek, Hubert-Delplace & Jaschek (1980) have noted that emission features are more variable in early Be stars, and Hubert-Delplace *et al.* (1982) find greater long-term spectroscopic variability in these objects as well.

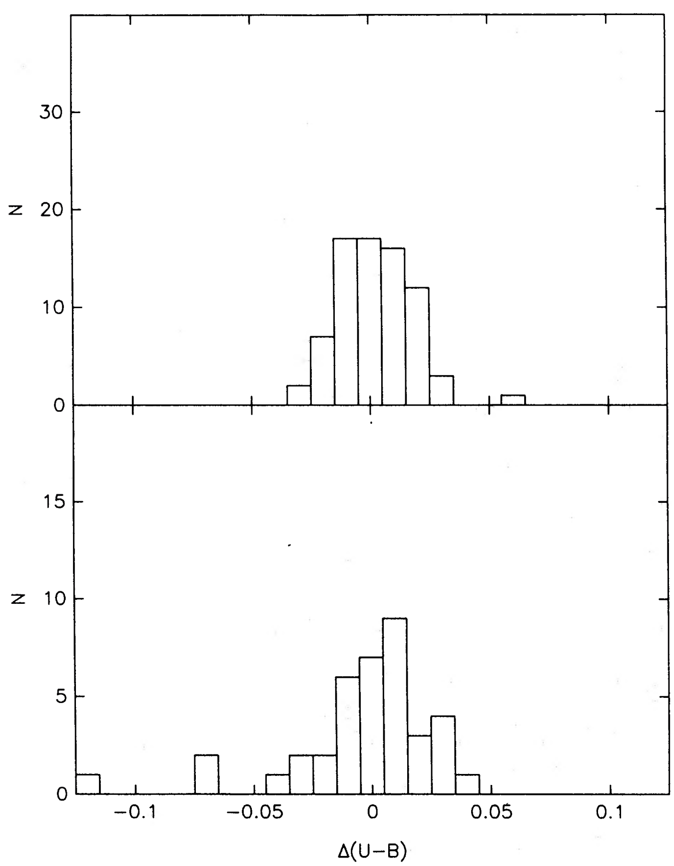


(a)

Figure 1. Histograms of (Stagg–Johnson) magnitudes and colours for Be and comparison/check stars. (a) V data, (b) $B–V$ data, (c) $U–B$ data.



(b)



(c)

Figure 1–*continued*

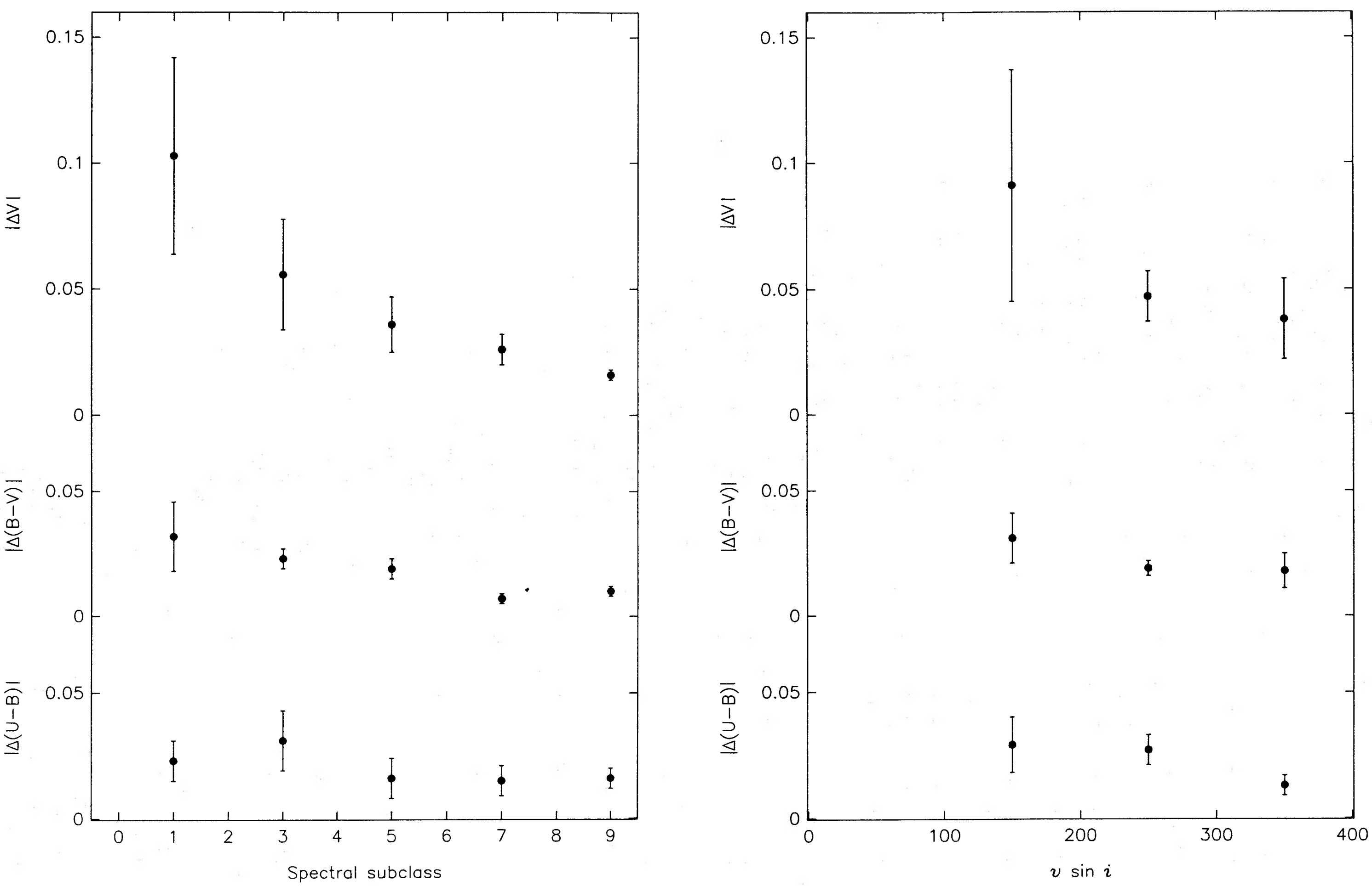


Figure 2. Plots of $|\Delta V|$, $|\Delta(B-V)|$, and $|\Delta(U-B)|$ versus (a) spectral type, and (b) projected rotation velocity, for Be stars. Data have been binned into intervals of two spectral subclasses or $100\,\mathrm{km\,s^{-1}}$. Spectral types and values of $v \sin i$ are from Hoffleit & Jaschek (1982).

Table 2. Standard deviations in differential magnitudes for Be stars and comparison/check stars. 'Sp' refers to spectral subclass. Spectral types and values of $v \sin i$ for Be stars are from Hoffleit & Jaschek (1982).

Be stars.

HR number	Mean std deviation V	B	U	Sp	v sin i
472	0.017	0.019	0.024	3.0	251
1772	0.044	0.040	0.056	5.0	
1956	0.015	0.010	0.016	7.0	176
2170	0.006	0.005	0.006	4.0	
2288	0.018	0.020	0.023	1.5	211
2364	0.020	0.025	0.033	4.0	
2492	0.013	0.018	0.045	2.0	
2507	0.004	0.004	0.007	6.0	
2538	0.021	0.014	0.022	1.5	199
2545	0.026	0.008	0.018	6.0	270
2628	0.019	0.020	0.030	2.0	
2690	0.022	0.010	0.022	2.0	290
2745	0.020	0.010	0.014	3.0	139
2749	0.023	0.021	0.024	2.0	120
2787	0.008	0.012	0.011	2.0	277
2790	0.011	0.013	0.012	2.0	124
2819	0.017	0.018	0.016	5.0	
2855	0.015	0.010	0.016	0.0	244
2911	0.012	0.009	0.011	3.0	297
2968	0.011	0.008	0.007	6.0	
3034	0.007	0.006	0.011	0.0	368
3147	0.006	0.009	0.007	2.0	250
3195	0.012	0.010	0.006	4.0	
3217	0.006	0.006	0.010	6.0	
3237	0.009	0.007	0.005	1.5	156
3330	0.012	0.006	0.009	2.0	158
3356	0.006	0.008	0.013	2.0	
HD72754	0.055	0.062	0.060		50
3498	0.006	0.009	0.013	3.0	332
3593	0.019	0.021	0.016	2.5	
3642	0.008	0.005	0.004	2.0	140
3670	0.012	0.018	0.012	9.0	
3745	0.016	0.020	0.022	6.0	
3858	0.004	0.005	0.007	6.0	332
3946	0.004	0.003	0.010	4.0	220
3971	0.008	0.011	0.021	7.0	
4009	0.018	0.022	0.040	2.0	360
4018	0.015	0.011	0.019	4.0	
4037	0.006	0.009	0.009	8.0	225
4074	0.008	0.012	0.021	3.0	81
4140	0.012	0.011	0.016	4.0	303
4206	0.009	0.013	0.011	4.0	
4221	0.020	0.017	0.015	8-9	218
HD94910	0.016	0.014	0.024	2.0	
4460	0.021	0.015	0.017	9.0	159
4537	0.008	0.009	0.007	3.0	268
4618	0.021	0.018	0.019	6.0	127
4621	0.021	0.019	0.017	2.0	181
4625	0.017	0.015	0.020	3.0	204
4696	0.009	0.006	0.011	8.0	
4804	0.004	0.004	0.013	8.0	
4823	0.019	0.019	0.020	6.0	185
4830	0.015	0.010	0.010	2.0	275
4897	0.017	0.025	0.027	4.0	317
4899	0.007	0.008	0.007	5.0	201
4930	0.006	0.011	0.008	1.5	
5193	0.013	0.009	0.020	2.0	175
5223	0.012	0.011	0.013	2.0	
5316	0.007	0.008	0.007	4.0	242
5327	0.015	0.017	0.012	8.0	
5440	0.038	0.031	0.041	1.5	333
5500	0.026	0.023	0.031	2.5	
5551	0.020	0.024	0.034	4.0	199
5646	0.006	0.005	0.004	9.5	202
5661	0.017	0.017	0.016	0.5	196
5683	0.006	0.005	0.004	8.0	308
5730	0.015	0.013	0.021	1.0	
5907	0.015	0.012	0.021	2.5	349
6172	0.008	0.009	0.006	7.0	
6274	0.016	0.018	0.015	3.0	
6304	0.055	0.050	0.047	2.0	201
6422	0.019	0.021	0.018	2.0	
6451	0.015	0.018	0.017	2.0	369
6462	0.009	0.012	0.016	1.0	281
HD157832	0.026	0.032	0.040	5.0	400
6510	0.014	0.010	0.009	2.0	298
6519	0.011	0.008	0.006	9.5	
HD160202	0.009	0.005	0.009	7.0	
6621	0.050	0.048	0.052	4.0	
6819	0.008	0.009	0.013	3.0	
6929	0.027	0.013	0.009	2.0	
7074	0.008	0.006	0.012	2.0	189
8386	0.006	0.008	0.007	8.0	
8408	0.018	0.016	0.015	4.0	300
8540	0.011	0.020	0.010	9.5	245
8628	0.010	0.012	0.002	8.0	290

Comparison/check stars.

520	0.033	0.030	0.018
591	0.033	0.030	0.018
1766	0.017	0.009	0.012
1835	0.024	0.010	0.015
1973	0.020	0.008	0.014
2160	0.009	0.009	0.007
2282	0.009	0.011	0.018
2361	0.009	0.011	0.018
2518	0.004	0.007	0.006
HD49850	0.004	0.007	0.006
2640	0.011	0.006	0.015
2733	0.009	0.006	0.011
2755	0.012	0.006	0.020
2774	0.007	0.006	0.010
2827	0.009	0.006	0.006
2873	0.007	0.008	0.007
2922	0.011	0.008	0.009
2937	0.005	0.010	0.006
2961	0.005	0.010	0.006
2996	0.013	0.005	0.012
3081	0.005	0.006	0.011
3159	0.005	0.006	0.011
3165	0.015	0.010	0.006
3233	0.011	0.008	0.008
3241	0.011	0.008	0.007
3426	0.007	0.008	0.009
HD74234	0.012	0.008	0.013
3452	0.012	0.008	0.013
3487	0.007	0.008	0.009
3527	0.023	0.016	0.016

Table 2–*continued*

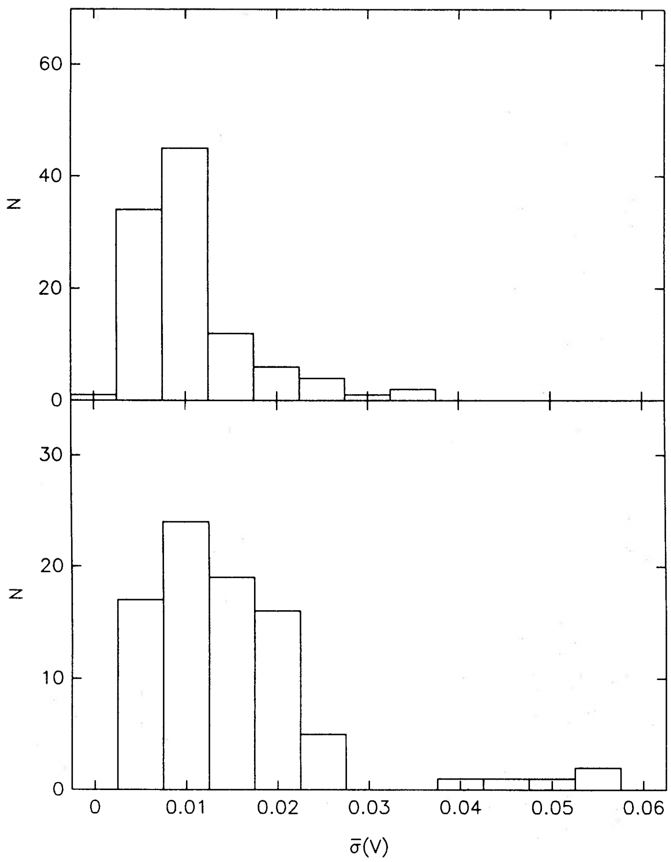
HR number	Mean std deviation V	B	U	Sp	v sin i
3544	0.005	0.005	0.006		
3571	0.005	0.003	0.010		
3574	0.005	0.003	0.010		
3615	0.005	0.005	0.006		
3661	0.020	0.017	0.021		
3680	0.017	0.017	0.016		
3710	0.006	0.007	0.009		
3715	0.006	0.011	0.010		
3878	0.005	0.009	0.008		
3931	0.005	0.003	0.005		
3962	0.005	0.003	0.005		
4002	0.006	0.008	0.006		
4089	0.006	0.008	0.006		
4173	0.010	0.011	0.018		
4217	0.009	0.011	0.018		
4222	0.011	0.014	0.022		
4234	0.012	0.012	0.011		
4239	0.008	0.012	0.018		
4304	0.008	0.008	0.009		
4312	0.012	0.010	0.012		
4390	0.030	0.025	0.028		
4549	0.010	0.008	0.009		
4579	0.010	0.005	0.012		
4592	0.009	0.019	0.011		
4599	0.009	0.008	0.009		
4620	0.015	0.017	0.016		
4623	0.012	0.004	0.008		
4635	0.016	0.005	0.010		
4638	0.022	0.025	0.026		
HD107422	0.012	0.012	0.012		
4729	0.008	0.007	0.010		
4773	0.005	0.007	0.004		
4836	0.012	0.012	0.012		
4848	0.007	0.009	0.011		
4944	0.007	0.009	0.011		
5030	0.005	0.007	0.004		
5157	0.006	0.007	0.007		
5206	0.006	0.006	0.004		
5240	0.024	0.025	0.011		
5249	0.007	0.006	0.005		
5292	0.009	0.011	0.008		
5336	0.024	0.025	0.011		
5358	0.009	0.011	0.008		
5439	0.010	0.016	0.015		
5471	0.010	0.019	0.016		
5482	0.002	0.010	0.008		
5528	0.013	0.021	0.018		
5539	0.017	0.022	0.019		
5559	0.004	0.007	0.006		
5647	0.004	0.007	0.006		
5684	0.018	0.021	0.020		
5782	0.008	0.013	0.006		
5786	0.008	0.013	0.006		
5885	0.012	0.009	0.012		
5904	0.012	0.009	0.012		
6182	0.011	0.008	0.010		
6188	0.008	0.013	0.014		
6233	0.011	0.008	0.010		
6320	0.006	0.011	0.016		
6331	0.007	0.009	0.013		
6366	0.008	0.010	0.009		
6470	0.007	0.009	0.010		
6500	0.006	0.011	0.016		
6508	0.012	0.008	0.007		
6520	0.016	0.015	0.015		
6537	0.008	0.014	0.013		
6549	0.011	0.006	0.021		
6700	0.016	0.015	0.015		
6743	0.011	0.006	0.021		
7012	0.010	0.011	0.010		
7036	0.010	0.011	0.010		
7039	0.013	0.007	0.007		
7121	0.013	0.007	0.007		
8527	0.019	0.027	0.018		
8547	0.019	0.027	0.018		

Such variability is associated with the circumstellar envelope. Indeed, Harmanec (1983b) and others have suggested that the long-term photometric variability may also be caused by changes in the circumstellar material, rather than in the star itself.

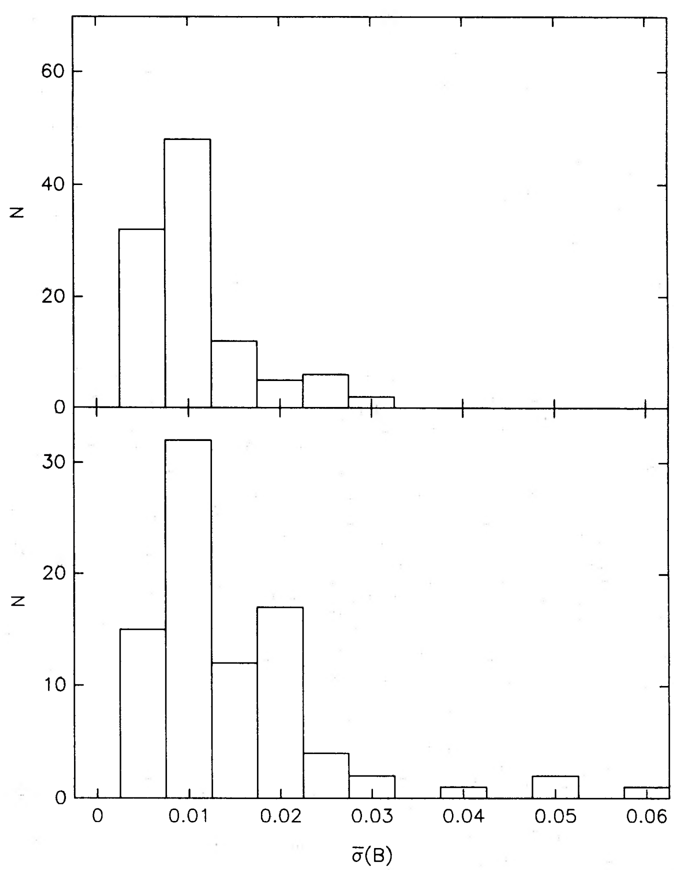
It has also been suggested (e.g. Roxburgh 1970; Bolton 1982; Vogt & Penrod 1983) that there is a link between short-term variability and the presence of emission lines. If short-term variability results in changes in the circumstellar material, one might expect to see long-term photometric variability in the same sorts of stars in which one sees short-term photometric variability. As will be seen in Section 5 the earlier Be stars seem to show greater photometric variability on short time-scales as well.

5 Evidence for short- and intermediate-term variability from differential photometry

Although all sky photometry provides much useful information, a careful analysis for small-amplitude variability requires differential magnitudes and colours. In the present study magnitudes were obtained from *all-sky* photometry, and *differential* magnitudes were derived by taking

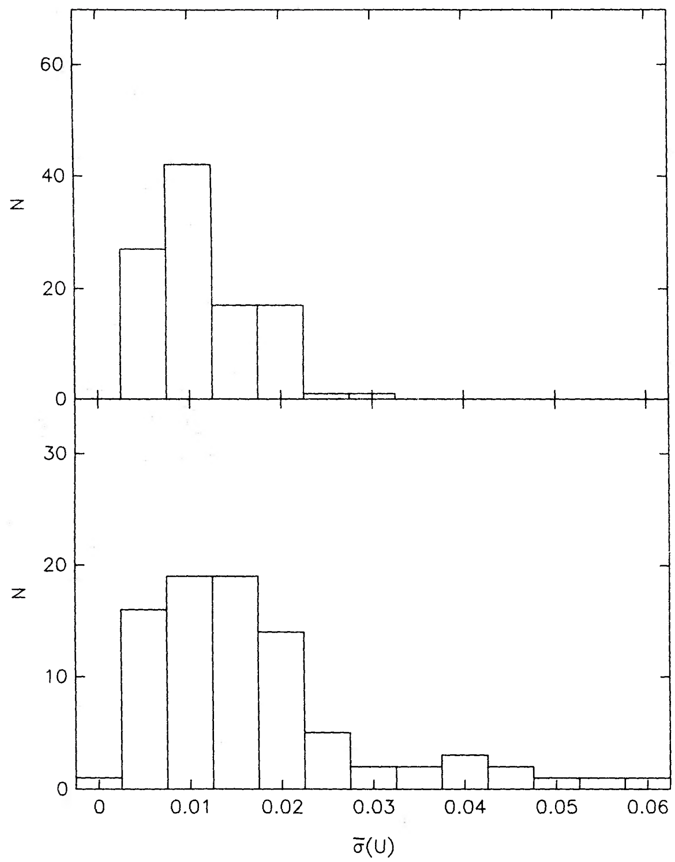


(a)



(b)

Figure 3. Histograms of (a) $\bar{\sigma}(V)$, (b) $\bar{\sigma}(B)$, and (c) $\bar{\sigma}(U)$ for comparison/check stars (top) and Be stars (bottom).



(c)

Figure 3–*continued*

differences between these values. For a Be star, the differential magnitude was obtained of each Be star relative to the comparison and check stars in its group. Then the standard deviations for all sets of these magnitudes were averaged to give a *mean standard deviation.* For a Be star observed more than twice in both 1983 and 1984, the mean of the two years was adopted.

In a similar way mean standard deviations were obtained for comparison and check stars with respect to other comparison and check stars in their group.

These mean standard deviations have been tabulated in Table 2 and recorded in histograms (Fig. 3). For very few of the comparison and check stars was the mean standard deviation greater than 0.01 mag. But about half the Be stars had $\bar{\sigma}>0.01$ mag, indicating that *about half of all Be stars may exhibit short- and intermediate-term photometric variation at a low level.* To prove significant variability (at the 99 per cent level) in *individual* cases typically requires $\bar{\sigma}>0.03$ mag, however.

To see whether $\bar{\sigma}$ had any dependence on spectral type or $v \sin i$, regression lines were constructed. Student's *t*-test showed that there was a trend of $\bar{\sigma}(U)$ with spectral type (although only at the 97 per cent significance level). There did not appear to be any clear correlation between $\bar{\sigma}$ and $v \sin i$. The *t*-test also showed that there was a significant difference (at the 99 per cent level) between the mean value of $\bar{\sigma}(U)$ calculated for early B stars (B0 to B5) and late B stars (B6 to B9). And $\bar{\sigma}(B)$ and $\bar{\sigma}(V)$ also appeared to be larger for stars of earlier spectral type (although the difference was again only significant at the 97 per cent level). The data, binned into intervals of two spectral subclasses or 100 km s^{-1}, have been plotted against spectral class and $v \sin i$ in Fig. 4.

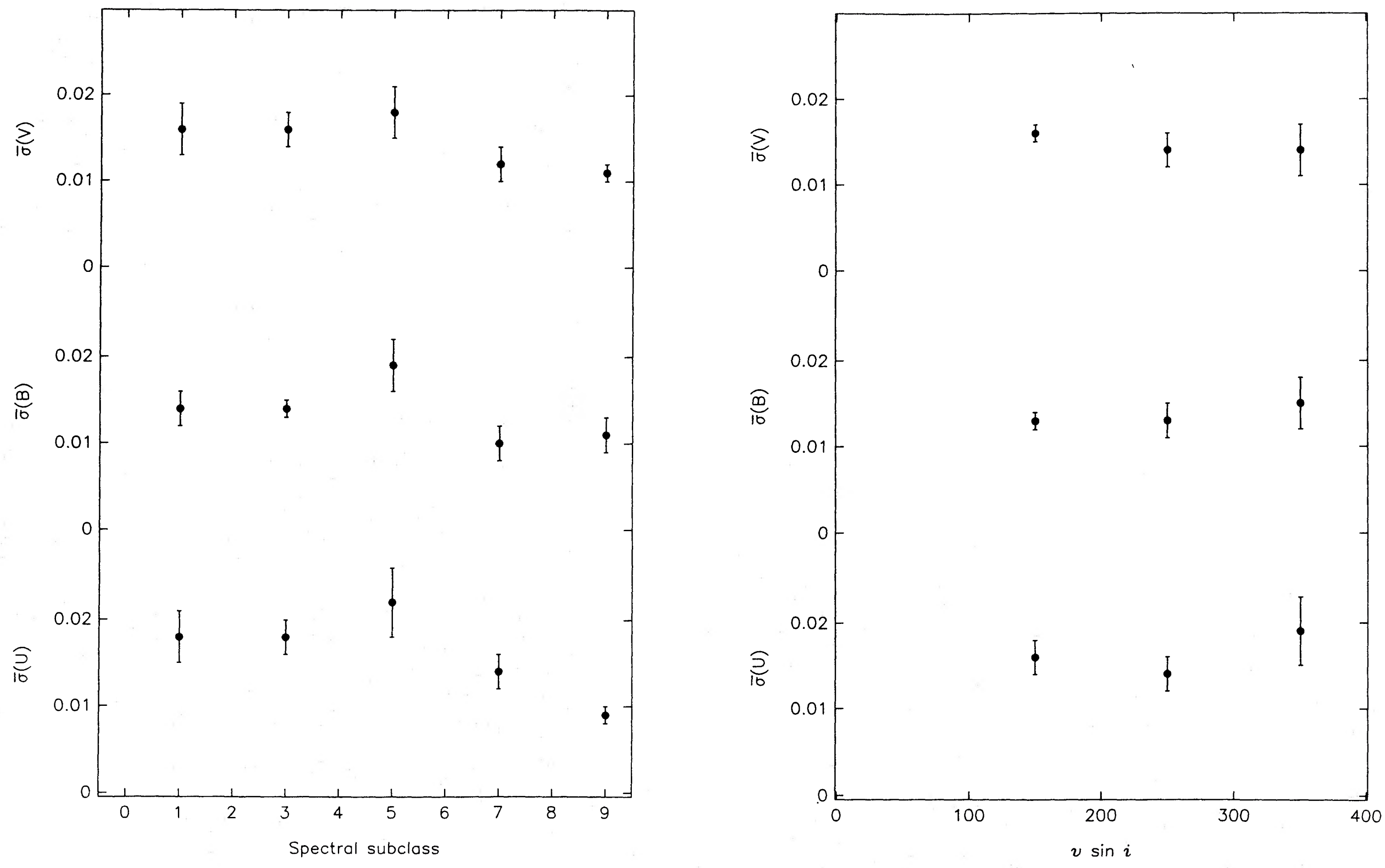


Figure 4. Plots of $\bar{\sigma}(V)$, $\bar{\sigma}(B)$, and $\bar{\sigma}(U)$ versus (a) spectral type, and (b) projected rotation velocity, for Be stars. Data have been binned into intervals of two spectral subclasses or $100\,km\,s^{-1}$. Spectral types and values of v sin i are from Hoffleit & Jaschek (1982).

It should also be noted that the four suspected short-term variables identified in Section 6 are all of spectral type B4 or earlier. These are important results because B stars in which non-radial pulsation is known to occur (the β Cephei and 53 Per stars) are of early B spectral type (e.g. Lesh 1982; Smith 1980), whilst B stars in which rotational modulation of the brightness occurs (the Bp stars) are of late B spectral type (e.g. Preston 1974; Baschek 1975). None the less, rotational modulation of brightness is also observed to occur in stars such as the helium strong stars (e.g. Bolton 1983), which tend to be of earlier spectral type. The greater variability at earlier spectral type is therefore consistent with both rotational and pulsational models.

6 Identification of individual short- and intermediate-term variables

In order to identify individual short- and intermediate-term variables amongst the Be stars it was first necessary to test each comparison or check star for constancy. To do this, each star was selected in turn as a *test* star, and the other comparison and check stars in its group were considered as *reference* stars. (If only one reference star was available, a red standard was used as a second reference.) The differential magnitude of the test star relative to the ith reference star could be represented by m_{0i}, and its variance by $\sigma^2(m_{0i})$. The value of $\sigma^2(m_{0i})$ could then be compared with the value σ_c^2 which one would expect for a test star with no intrinsic variation. Since the standard deviations in the differential magnitudes of comparison and check stars vary widely from group to group, σ_c^2 was calculated for each group, from the reference stars themselves. The differential magnitude of the jth reference star relative to the ith reference star has mean value m_{ji} and variance $\sigma^2(m_{ji})$. The value of σ_c^2 may be obtained by combining the values of $\sigma^2(m_{ji})$ over all $(M-1)$ remaining reference stars into a *pooled variance*:

$$\sigma_c^2 = \sum_{j=1,\, j\neq i}^{M} \sigma^2(m_{ji})/(M-1).$$

Fisher's F-test was used to compare $\sigma^2(m_{0i})$ and σ_c^2. If the average value of $(1-p)$ over all reference stars was greater than 99 per cent in any of U, B, or V, the test star was then considered to be a 'suspected variable', and was investigated further. (Stars with a large range in their magnitudes were also investigated further.) A few of the comparison and check stars could not be tested, either because of too few observations or (in the case of HR 520, 591, and 8478), a lack of suitably measured reference stars. (The method was used only where at least three observations had been made of the test and reference stars.)

The next step was to test each red standard for constancy, using the comparison and check stars as references, together with the other red standard in each group, if there was one. And finally, the Be stars were tested for variability, using the comparison and check stars in each group as references. Because of a lack of other suitable reference stars, the Be star HR 8386 was used as a reference star in two cases. This procedure could be justified on the basis of the small standard deviation in the differential magnitudes for HR 8386–8478 (0.006 mag in V, 0.008 mag in B, 0.007 mag in U).

For each suspected variable, differential magnitudes were obtained relative to two or more reference stars. The values listed in Table 3(a) are averages of these differential magnitudes. The *approximate errors* recorded in this table were taken to be the average of the standard deviations in the differential magnitudes of all pairs of reference stars. The data on suspected variable stars have been summarized in Table 3(b). As noted in the next section, none of the 'suspected variable' comparison or check stars appears in fact to be a short- or intermediate-term variable star. The two red standards identified as 'possible variables' are also unlikely to be undergoing intrinsic variability.

Table 3. (a) Magnitudes of suspected variables. For each set of entries, the first star listed is the suspected variable, and the stars in parentheses are the comparison stars. Differential magnitudes were obtained relative to the comparison stars and then averaged to give the results in the table. An asterisk denotes 1984 observations.

Comparison/check stars.

HR 4638 – (HR 4390, HR 4620)

JD 2 440 000+	V	B	U
5427.590	-0.658	-0.729	-1.004
5428.675	-0.733	-0.803	-1.081
5428.808	-0.664	-0.736	-1.005
5429.575	-0.661	-0.735	-1.014
approx error	0.016	0.010	0.013

*HR 4638 – (HR 4620, HR 4592)

JD 2 440 000+	V	B	U
5756.702	-1.795	-1.947	-2.497
5756.755	-1.807	-1.962	-2.502
5757.547	-1.793	-1.924	-2.464
5757.586	-1.805	-1.923	-2.490
5757.629	-1.797	-1.942	-2.491
5757.662	-1.801	-1.948	-2.497
approx error	0.009	0.015	0.006

HR 5539 – (HR 5684, HR 5632)

JD 2 440 000+	V	B	U
5429.646	-0.194	-0.522	-0.897
5431.638	-0.253	-0.562	-0.930
5433.685	-0.193	-0.506	-0.875
5433.785	-0.191	-0.510	-0.868
approx error	0.008	0.013	0.007

*HR 5539 – (HR 5684, HR 5482)

JD 2 440 000+	V	B	U
5756.720	0.268	0.117	-0.216
5756.770	0.269	0.107	-0.203
5757.701	0.264	0.106	-0.217
5757.736	0.266	0.090	-0.210
approx error	0.003	0.008	0.010

Red standard stars.

HR 2794 – (HR 2827, HR 2873, HR 2922, HR 2881)

JD 2 440 000+	V	B	U
5423.672	2.173	3.613	5.837
5429.637	2.183	3.622	5.828
5430.634	2.225	3.710	5.837
5434.544	2.169	3.621	5.806
approx error	0.010	0.008	0.008

HR 5824 – (HR 5885, HR 5904)

JD 2 440 000+	V	B	U
5425.806	0.338	1.726	3.931
5425.878	0.403	1.777	3.939
5426.712	0.328	1.717	3.913
5426.790	0.341	1.727	3.934
approx error	0.012	0.009	0.012

*HR 5824 – (HR 5806, HR 5856)

JD 2 440 000+	V	B	U
5756.739	-1.179	-0.553	0.497
5756.788	-1.194	-0.554	0.468
5757.718	-1.183	-0.548	0.499
5757.751	-1.184	-0.550	0.499
approx error	0.004	0.007	0.013

HR 6587 – (HR 6508, HR 6366, HR 6470)

JD 2 440 000+	V	B	U
5433.837	1.475	3.189	5.386
5434.732	1.490	3.208	5.414
5434.855	1.481	3.181	5.364
5435.733	1.490	3.207	5.433
approx error	0.010	0.006	0.008

*HR 6587 – (HR 6366, HR 6470)

JD 2 440 000+	V	B	U
5955.098	0.390	1.975	3.976
5955.141	0.380	1.983	3.966
5956.033	0.401	1.988	3.985
5956.072	0.391	1.996	4.025
5964.036	0.393	1.973	3.948
5964.070	0.389	1.987	3.941
5964.124	0.370	1.988	3.977
approx error	0.006	0.013	0.010

Be stars.

HR 1772 – (HR 1766, HR 1973)

JD 2 440 000+	V	B	U
5419.509	0.212	-0.101	-0.848
5420.515	0.208	-0.107	-0.853
5420.616	0.227	-0.084	-0.818
5424.613	0.291	-0.024	-0.734
approx error	0.012	0.007	0.010

HR 2628 – (HR 2733, HR 2774)

JD 2 440 000+	V	B	U
5419.565	0.102	0.105	-0.007
5420.537	0.109	0.113	0.015
5420.665	0.113	0.122	0.023
5424.629	0.144	0.151	0.058
approx error	0.010	0.005	0.007

HR 2749 – (HR 2733, HR 2774)

JD 2 440 000+	V	B	U
5419.585	-2.465	-2.457	-2.457
5420.548	-2.467	-2.455	-2.459
5420.685	-2.449	-2.435	-2.439
5424.648	-2.503	-2.492	-2.495
approx error	0.010	0.005	0.007

*HR 2749 (see Table 4)

*HD72754 – (HD74234, HR 3452)

JD 2 440 000+	V	B	U
5749.765	0.952	1.148	0.756
5749.831	0.948	1.159	0.760
5750.766	0.941	1.124	0.743
5750.840	0.925	1.127	0.746
5755.770	1.062	1.273	0.884
approx error	0.012	0.008	0.013

Table 3 (a) – *continued*

HR 4221 – (HR 4222, HR 4173, HR 4239, HR 4217)

JD 2 440 000+	V	B	U
5427.574	−0.109	−0.040	0.270
5428.902	−0.126	−0.035	0.203
5429.563	−0.039	0.019	0.262
5429.815	−0.098	−0.006	0.268
5430.565	−0.114	−0.034	0.237
approx error	0.010	0.014	0.022

*HR 4221 – (HR 4173, HR 4239)

JD 2 440 000+	V	B	U
5756.553	−0.640	−0.630	−0.644
5756.586	−0.628	−0.628	−0.635
5756.616	−0.631	−0.623	−0.644
5756.646	−0.641	−0.632	−0.644
5757.531	−0.640	−0.634	−0.639
5757.563	−0.633	−0.627	−0.625
5757.612	−0.643	−0.635	−0.634
5757.645	−0.643	−0.645	−0.649
approx error	0.007	0.009	0.011

*HR 5193 – (HR 5249, HR 5206, HR 5157)

JD 2 440 000+	V	B	U
5750.710	−1.769	−1.831	−2.024
5750.781	−1.743	−1.831	−2.029
5752.732	−1.739	−1.812	−1.987
5752.797	−1.746	−1.826	−1.995
5755.709	−1.742	−1.821	−1.990
approx error	0.006	0.006	0.005

HR 5440 – (HR 5471, HR 5528)

JD 2 440 000+	V	B	U
5423.800	−1.731	−1.805	−2.004
5424.741	−1.656	−1.731	−1.911
5425.723	−1.752	−1.791	−2.003
approx error	0.011	0.025	0.019

*HR 5440 – (HR 5471, HR 5528, HR 5439)

JD 2 440 000+	V	B	U
5746.719	−2.231	−2.363	−2.593
5747.713	−2.257	−2.399	−2.655
5749.711	−2.247	−2.377	−2.615
5749.779	−2.199	−2.344	−2.587
5754.818	−2.212	−2.372	−2.613
approx error	0.011	0.015	0.015

HR 6304 – (HR 6320, HR 6500)

JD 2 440 000+	V	B	U
5420.876	1.575	1.598	1.086
5434.677	1.535	1.575	1.083
5434.808	1.525	1.551	1.059
5435.743	1.457	1.489	1.002
5435.833	1.444	1.489	0.987
approx error	0.006	0.011	0.016

HR 6422 – (HR 6508, HR 6366, HR 6470)

JD 2 440 000+	V	B	U
5433.817	1.389	1.550	1.363
5434.714	1.449	1.602	1.415
5434.835	1.412	1.556	1.384
5435.715	1.452	1.603	1.416
approx error	0.010	0.006	0.008

*HR 6422 – (HR 6470, HR 6366)

JD 2 440 000+	V	B	U
5955.078	0.344	0.333	−0.124
5955.129	0.330	0.340	−0.132
5956.019	0.339	0.340	−0.134
5956.060	0.338	0.334	−0.145
5964.024	0.337	0.316	−0.138
5964.057	0.346	0.335	−0.126
5964.108	0.344	0.352	−0.117
approx error	0.006	0.013	0.010

HD157832– (HR 6537, HR 6188, HR 6331)

JD 2 440 000+	V	B	U
5427.705	1.182	1.217	0.668
5428.744	1.162	1.200	0.643
5429.758	1.120	1.144	0.580
5429.881	1.148	1.174	0.601
approx error	0.007	0.012	0.013

HR 6621 – (HR 6700, HR 6520)

JD 2 440 000+	V	B	U
5433.761	0.950	1.136	0.920
5433.883	1.011	1.193	0.976
5434.747	0.876	1.067	0.829
5434.872	0.904	1.092	0.862
approx error	0.014	0.009	0.009

*HR 6621 – (HR 6700, HR 6520)

JD 2 440 000+	V	B	U
5955.104	0.869	1.063	0.838
5956.040	0.961	1.142	0.913
5956.102	0.949	1.132	0.912
5964.042	0.939	1.121	0.888
5964.092	0.878	1.052	0.834
5964.128	0.903	1.074	0.852
approx error	0.017	0.020	0.021

Of the Be stars studied, 10 show significant variability at the 99 per cent level. In most cases the time-scale of variability appears to be longer than the time-span of the observations. In only three stars (HR 6422, 6621, and 2749) is there an indication of short-term variability. (For HR 6422 and 6621, although the 1983 observations indicate variability on a time-scale of a day or less, this could not be confirmed in 1984.) In addition, the star HR 5440 shows significant variability at only the

Table 3. (b) Summary of information on possible variables. An asterisk denotes a 1984 observation. Spectral types and values of $v \sin i$ are from Hoffleit & Jaschek (1982).

NAME	NO OF OBS'NS	TIME-SPAN	APPROX RANGE V	B	U	APPROX ERROR V	B	U	SP TYPE	v sin i
Comparison/check stars.										
HR 4638	4	2d	0.08	0.07	0.08	0.016	0.010	0.013	B3V	
*HR 4638	6	1.0d	0.01	0.04	0.04	0.009	0.022	0.016		
HR 5539	4	4d	0.06	0.06	0.06	0.008	0.013	0.007	B3Vn	
*HR 5539	4	1.0d	0.01	0.03	0.01	0.005	0.008	0.010		
Red standard stars.										
HR 2794	4	11d	0.06	0.10	0.03	0.010	0.008	0.008	K2-3III	
HR 5824	4	1.0d	0.08	0.06	0.03	0.012	0.009	0.012	K3IIICN	
*HR 5824	4	1.0d	0.02	0.01	0.03	0.005	0.007	0.013		
HR 6587	4	2d	0.02	0.02	0.07	0.010	0.006	0.008	M1III	
*HR 6587	7	3d	0.02	0.02	0.08	0.006	0.013	0.010		
Be stars.										
HR 1772	4	5d	0.08	0.08	0.12	0.012	0.007	0.010	B5IVnpe	
HR 2628	4	5d	0.04	0.05	0.07	0.010	0.005	0.007	B2IV-Vne	
HR 2749	4	5d	0.05	0.06	0.06	0.010	0.005	0.007	B2IV-Ve	120
*HR 2749	35	7d	0.06	0.07	0.09	0.005	0.006	0.007		
*HD72754	5	6d	0.12	0.15	0.14	0.012	0.008	0.013	Be	50
HR 4221	5	3d	0.09	0.06	0.07	0.010	0.014	0.022	B8-9IIIe	218
*HR 4221	8	1.1d	0.02	0.02	0.02	0.007	0.009	0.011		
*HR 5193	4	2d	0.03	0.02	0.04	0.006	0.006	0.005	B2IV-Ve	175
HR 5440	3	2d	0.10	0.07	0.09	0.011	0.025	0.019	B1.5Vne	333
*HR 5440	5	8d	0.06	0.06	0.07	0.011	0.015	0.015		
HR 6304	4	1.2d	0.09	0.09	0.10	0.006	0.011	0.016	B2IVne	201
HR 6422	4	2d	0.06	0.06	0.05	0.010	0.006	0.008	B2Vne	
*HR 6422	7	3d	0.02	0.04	0.03	0.006	0.013	0.010		
HD157832	4	2d	0.06	0.07	0.09	0.007	0.012	0.013	B5Vnne	400
HR 6621	4	1.1d	0.14	0.13	0.15	0.014	0.009	0.009	B4IVe	
*HR 6621	6	3d	0.09	0.09	0.08	0.017	0.021	0.020		

95 per cent level in both the 1983 and 1984 observations, but it has a large range. Since the 1984 observations indicate short-term variability, this star should also be regarded as a possible short-term variable.

7 Comments on suspected short- or intermediate-term variables

7.1 COMPARISON AND CHECK STARS

HR 4638 (1983): the variation is significant only at the 95 per cent level. The large range is attributable to a single, possibly bad, set of observations. However, the variation, if real, represents an increase in magnitude of 0.07 mag in B and V, 0.08 mag in U over 3.2 hr, followed by a decrease over a day or less.

HR 4638 (1984): there is no significant variation at the 95 per cent level.

HR 5539 (1983): the variation is significant only at the 95 per cent level. The large range is attributable to a single, possibly bad, set of observations. However, the variation, if real, represents an increase in magnitude of 0.06 mag in U, B, and V over two days, followed by a decrease over two days or less.

HR 5539 (1984): there is no significant variation at the 95 per cent level.

7.2 RED STANDARDS

HR 2794: the star is probably not variable. A single discrepant set of observations was made just before widespread cirrus was noted in the sky.

HR 5824 (1983): the variation is significant only at the 95 per cent level. The large range is attributable to a single, possibly bad, set of observations. However, the variation, if real, represents an increase in magnitude of 0.06 mag in V, 0.05 mag in B, 0.01 mag in U over 1.7 hr, followed by a decrease over a day or less.

HR 5824 (1984): there is no significant variation at the 95 per cent level.

HR 6587: the star is probably not variable. Fluctuations in the U-band are almost certainly a result of low count rates rather than intrinsic variability.

7.3 BE STARS

HR 1772 and *HR 2628:* a steady increase in magnitude is observed.

HR 2749 (1983): there is a steady decrease in magnitude over six nights of 0.04 mag in U, B, and V. There is also a possible increase in magnitude over 3 hr of 0.02 mag in U, B, and V.

HR 2749 (1984): see Section 8.

HD 72754: [this star is not in fact a classical Be star, but rather a peculiar interacting binary extensively studied by Thackeray (1971)]. A decrease in magnitude is followed by an increase.

HR 4221 (1983): an increase in magnitude is followed by a decrease.

HR 4221 (1984): no significant variation at the 95 per cent level is observed.

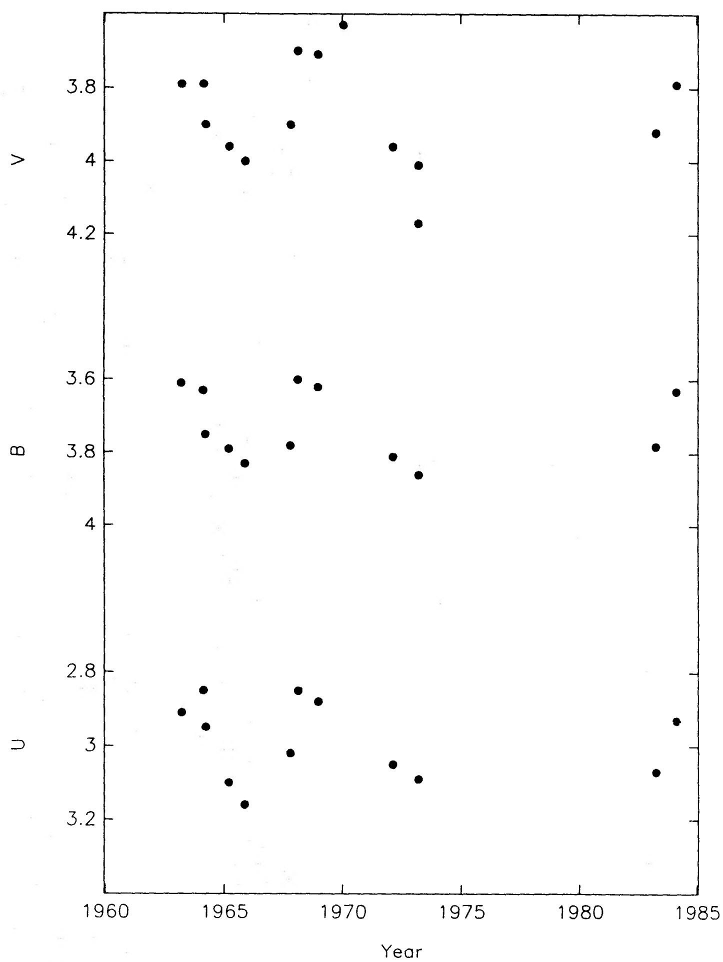


Figure 5. Long-term variations in the mean magnitude of 28 ω CMa. Data are from Feinstein (1968, 1975), van Hoof (1975), and this work.

HR 5193: there is an increase in magnitude over three nights. A fifth observation of HR 5193 made three nights later does not reveal any further increase in magnitude. The total range over five days is 0.03 mag in *V*, 0.02 mag in *B*, 0.04 mag in *U*.

HR 5440 (1983): despite the large range, the variation is significant only at the 95 per cent level. An apparent decrease in magnitude is followed by an increase.

HR 5440 (1984): despite the large range, the variation is significant only at the 95 per cent level. An apparent increase in magnitude is followed by a decrease. The range over 1.7 hr is 0.05 mag in *V*, 0.03 mag in *B* and *U*. One observation five days later shows a slight increase in magnitude.

HR 6304: a steady decrease in magnitude is observed. A fifth observation of HR 6304 was made about two weeks earlier, and confirms the steady decrease in magnitude. The total range over 15 days is 0.13 mag in *V,* 0.11 mag in *B*, 0.10 mag in *U*.

HR 6422 (1983): there is variation on a time-scale of a day or less. The decrease in magnitude over 3 hr is 0.04 mag in *V*, 0.05 mag in *B*, 0.10 mag in *U*.

HR 6422 (1984): no significant variation at the 95 per cent level is observed.

HD 157832: a decrease in magnitude is followed by an increase.

HR 6621 (1983): there is an increase in magnitude over 3 hr during the first night of 0.06 mag in *U, B,* and *V*. The increase over the same time interval during the second night is 0.03 mag in *U, B,*

Table 4. *UBV* photometry of 28 ω CMa, HR 2733, and 2774. Dates are heliocentric Julian dates.

28 CMa − HR 2733

JD 2445 000+	V	B	U
749.5391	−2.582	−2.557	−2.429
749.5764	−2.590	−2.563	−2.451
749.6137	−2.595	−2.570	−2.446
749.6421	−2.583	−2.582	−2.443
749.6742	−2.580	−2.565	−2.435
750.5342	−2.578	−2.561	−2.449
750.5725	−2.580	−2.552	−2.443
750.6162	−2.564	−2.548	−2.435
750.6507	−2.578	−2.546	−2.441
750.6850	−2.580	−2.549	−2.436
752.5390	−2.574	−2.553	−2.424
752.5870	−2.570	−2.552	−2.444
752.6144	−2.580	−2.565	−2.434
752.6487	−2.594	−2.563	−2.437
752.6731	−2.582	−2.561	−2.432
753.5326	−2.584	−2.561	−2.441
753.5616	−2.594	−2.569	−2.452
753.5924	−2.591	−2.578	−2.460
753.6229	−2.591	−2.574	−2.460
753.6487	−2.596	−2.580	−2.481
754.5317	−2.538	−2.513	−2.391
754.6004	−2.539	−2.512	−2.402
754.6320	−2.544	−2.530	−2.398
754.6595	−2.545	−2.530	−2.408
754.6880	−2.548	−2.530	−2.400
755.5291	−2.556	−2.524	−2.407
755.5736	−2.560	−2.540	−2.432
755.6055	−2.561	−2.537	−2.432
755.6387	−2.547	−2.539	−2.420
755.6688	−2.563	−2.545	−2.428
756.5340	−2.559	−2.542	−2.406
756.5715	−2.555	−2.543	−2.423
756.6041	−2.553	−2.549	−2.431
756.6338	−2.552	−2.550	−2.421
756.6633	−2.571	−2.556	−2.427

HR 2733 − HR 2774

JD 2445 000+	V	B	U
749.5452	−0.065	−0.115	−0.330
749.5806	−0.078	−0.126	−0.318
749.6167	−0.057	−0.104	−0.325
749.6452	−0.079	−0.113	−0.327
749.6771	−0.075	−0.107	−0.337
750.5403	−0.081	−0.109	−0.326
750.5763	−0.075	−0.119	−0.328
750.6196	−0.068	−0.105	−0.315
750.6539	−0.070	−0.113	−0.333
750.6878	−0.066	−0.097	−0.315
752.5451	−0.070	−0.106	−0.333
752.5904	−0.067	−0.108	−0.333
752.6206	−0.073	−0.109	−0.332
752.6522	−0.074	−0.106	−0.333
752.6763	−0.072	−0.108	−0.334
753.5356	−0.067	−0.102	−0.330
753.5650	−0.072	−0.105	−0.337
753.5957	−0.073	−0.108	−0.331
753.6262	−0.072	−0.107	−0.321
753.6517	−0.065	−0.097	−0.328
754.5354	−0.075	−0.115	−0.331
754.6036	−0.072	−0.114	−0.326
754.6349	−0.074	−0.114	−0.334
754.6625	−0.068	−0.101	−0.316
754.6909	−0.071	−0.097	−0.335
755.5330	−0.066	−0.105	−0.339
755.5771	−0.071	−0.099	−0.326
755.6086	−0.069	−0.098	−0.318
755.6421	−0.077	−0.107	−0.316
755.6718	−0.070	−0.105	−0.321
756.5374	−0.071	−0.100	−0.330
756.5749	−0.078	−0.112	−0.326
756.6071	−0.073	−0.104	−0.327
756.6366	−0.068	−0.108	−0.332
756.6663	−0.074	−0.106	−0.330

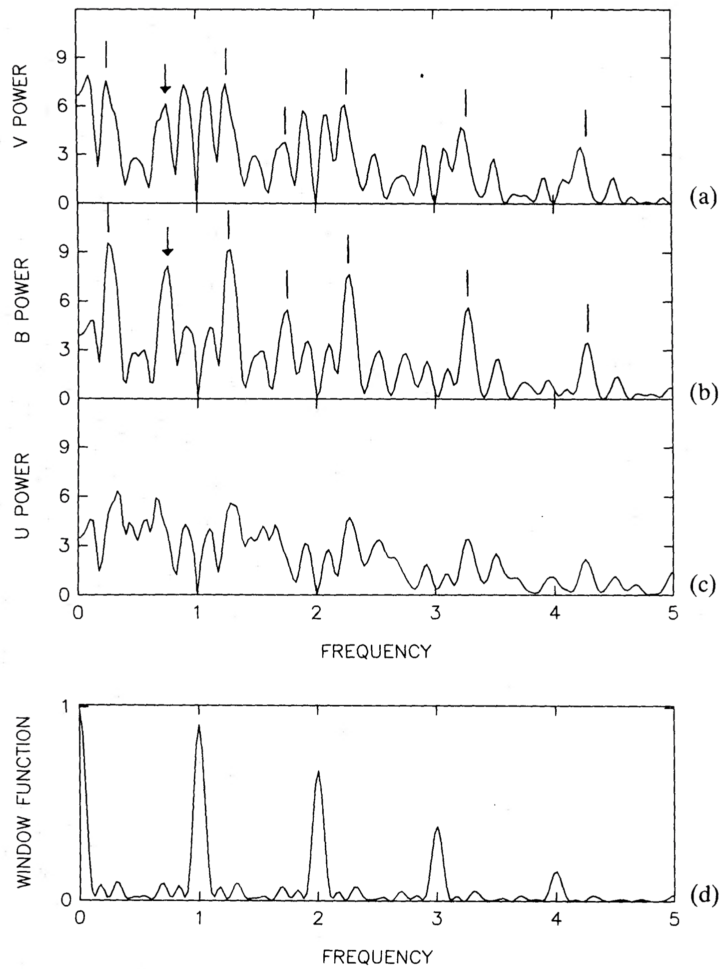


Figure 6. Power spectra for 28 ω CMa photometric data. The power level for detection of a signal at the 99 per cent confidence level was determined by numerical experiments to be 8.1. Peaks corresponding to the spectroscopic period are marked by arrows, and peaks corresponding to aliases by straight lines. (a). *V* power, (b) *B* power, (c) *U* power, (d) window function.

and *V*. The mean magnitude on the second night is less by 0.09 mag in *V*, 0.08 mag in *B*, 0.10 mag in *U*.

HR 6621 (1984): the variation is significant only at the 95 per cent level. There is a decrease in magnitude over the first two nights. The total range over 1.0 day is 0.08 mag in *V*, 0.07 mag in *B* and *U*. A sharp increase in magnitude over 1.2 hr during the last night of 0.06 mag in *V*, 0.07 mag in *B*, 0.05 mag in *U*, is followed by a decrease.

8 Photometric observations of the Be star 28 ω Canis Majoris

In 1982, Baade (1982a, c) observed line-profile and radial velocity variations with a period of 1.36673 day in the Be star HR 2749 (28 ω CMa). He also detected small-amplitude photometric variations with a probable period of 0.435 day and *b* amplitude of 0.006 mag (Baade 1982b). No variations at the spectroscopic period were detected. Both the spectroscopic and photometric variations were interpreted in terms of a non-radial pulsator model (Baade 1982a, b).

From the 1983 observations, 28 ω CMa had been identified as a 'possible variable' (Table 3), and it was decided to make more detailed observations. In 1984, a series of 35 *V*, *B*, and *U*

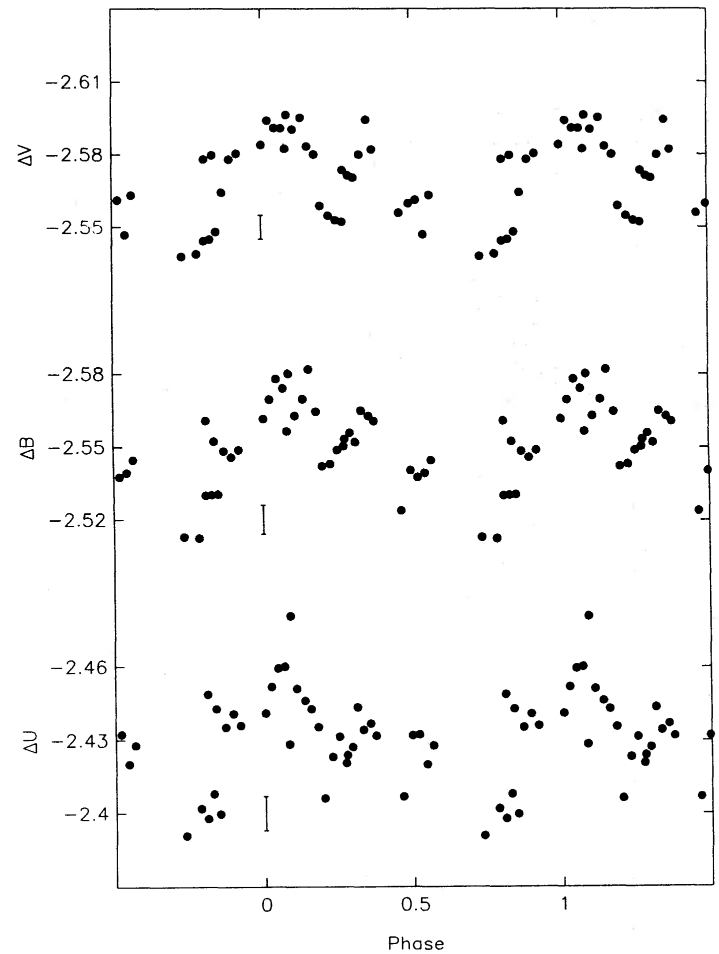


Figure 7. *V, B,* and *U* magnitudes of 28 ω CMa, plotted for a period of 1.36673 day. Error bars indicate the standard deviations in comparison minus check star magnitudes. Phase 0.5 corresponds to JD 2445 500.

measurements was made over seven nights. The observed magnitudes for 28 ω CMa minus HR 2733 are recorded in Table 4. The data for the comparison star (HR 2733) minus the check star (HR 2774) have also been recorded.

Power spectra were then obtained by the method of Scargle (1982). Numerical simulations were performed following Horne & Baliunas (1986) to determine the power level for 99 per cent significance. The *V* and *B* power spectra (Fig. 6) both show a series of peaks at 0.73 cycles day^{-1} and its aliases, but only the peaks at frequencies of 0.73, 0.27, and 1.27 cycles day^{-1} in the *B* power spectrum were found to be statistically significant. These correspond to the spectroscopic period of 1.37 day, and periods of 3.73 and 0.79 day, respectively. In his analysis of the *B* data using the method of Stellingwerf (1978), Harmanec (1985, private communication) finds a broad minimum in the θ statistic, again near the spectroscopic period. Since there is an *a priori* reason for preferring the spectroscopic period, and the 0.79 and 3.73 day periods give only a slightly better fit to the data (at the 73 and 66 per cent level, respectively), the light and colour curves have been plotted with the 1.36673 day spectroscopic period in Fig. 7.

There is also a series of peaks in the *V* power spectrum at frequencies of 0.11 cycles day^{-1} and its aliases. The presence of peaks in the low-frequency end of the power spectrum may be evidence for irregular light variations, probably due to the circumstellar envelope.

9 Conclusions

From all sky photometry it was clear that there were much larger differences between Stagg and Johnson magnitudes and colours for the bright southern Be stars than there were for the comparison and check stars. Whilst some of this variability was undoubtedly due to the influence of short-term, small-amplitude variability, the large number of differences of over 0.02 mag were difficult to explain in this way. Indeed, the data supported earlier conclusions by Feinstein (1968, 1970, 1975) and Ferrer & Jaschek (1971), that long-term photometric variability on a time-scale of years to decades was occurring in at least half of the Be stars. This variability appeared to be greater for stars of earlier spectral type. Of six Be stars measured more than twice in both 1983 and 1984, three, all of early B spectral type, changed by more than 0.03 mag in observed V-magnitude.

The differential magnitudes of Be stars (relative to comparison and check stars), were compared with the differential magnitudes of comparison and check stars (relative to other comparison and check stars). The excessive number of Be stars with a mean standard deviation in the differential magnitudes of over 0.01 mag indicates that about half of the Be stars may be undergoing short- or intermediate-term variability. There is no clear correlation between this variability and $v \sin i$, but there does appear to be greater variability for stars of earlier spectral type. This greater variability is consistent with both magnetic oblique rotator and non-radial pulsator models.

Eleven stars were identified as possible short- or intermediate-term variables. The four of these that appeared to exhibit short-term variability were all of spectral type B4 or earlier. More intensive observations were made of the Be star 28 ω CMa. The observations were consistent with the previously observed spectroscopic period of 1.37 day.

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