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DISCUSSION OF FIVE-COLOUR OBSERVATIONS OF STARS OF HIGH VELOCITY

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A discussion is presented of the five-colour measures of stars of high velocity published by PONSEN and OOSTERHOFF (1965). The accidental errors and night errors are analysed. The final magnitudes and colours with their mean errors are given in table 3. Most of the stars observed show an excess in the *L*, *U* and *W* intensities. A two-colour diagram is shown in figure 1. A strong correlation is found to exist between the ultraviolet excess and the spacial motion. This correlation is shown in figure 2.

The individual photo-electric measures in five colours of stars of high velocity and of several pulsating variables made with the light-collector of the Leiden southern station in South Africa are published by PONSEN and OOSTERHOFF (1965). In the present article we shall refer to this publication as Paper I.

The stars of high velocity were selected from the finding list by BUSCOMBE and MORRIS (1958). The number of stars from this list which have been measured is 53. Most of these stars were observed more than once in the same night. From the differences between such observations we have derived the accidental mean errors of a single observation. The stars were first divided into three groups according to brightness, i.e. according to their value of V. The resulting mean errors are given in table 1. The numbers in brackets indicate the number of differences used. V_J is the visual magnitude in the *UBV* system, computed with the formula of Paper I. Brightness and colours as well as the mean errors are expressed in the logarithm of the intensities. Within each brigthness group the colour $(V-B)$ has the highest accuracy. The colours $(B-L)$ and $(B-U)$ are about of equal accuracy and are only slightly less accurate than the colour $(V-B)$. However, the mean error of the $(U-W)$ colour is about two and a half times as large as that for the colours $(B-L)$ and $(B-U)$. For the stars in this programme the intensity in the W-band is very much smaller than in any of the other bands and furthermore the extinction coefficient is considerably larger than for the other bands. These two effects no doubt explain the larger mean errors.

Studying the observations in the main table of Paper I we found that the differences between the observations of the same star made in different nights are larger than would be expected from the accidental errors derived above. Not all the nights were photometrically perfect. In some the extinction coefficients showed considerable variaticns. The value of these coefficients, which we used, were interpolated in time and assumed to be the same all over the sky. Therefore it is not sur-

TABLE 1

Accidental errors

Group		Mean error	
$2 < V < 3$	V	± 0.0047	(53)
$9.35 < V_J < 11.85$	$V-B$	± 0.0029	(53)
	$B-U$	± 0.0044	(53)
	$U-W$	± 0.0102	(52)
	$B-L$	± 0.0043	(53)
$3 < V < 4$	V	± 0.0029	(53)
$6.85 < V_J < 9.35$	$V-B$	± 0.0014	(53)
	$B-U$	± 0.0021	(53)
	$U-W$	± 0.0056	(53)
	$B-L$	± 0.0024	(53)
$4 < V$	V	± 0.0035	(35)
$V_J < 6.85$	$V-B$	± 0.0012	(35)
	$B-U$	± 0.0012	(35)
	$U-W$	± 0.0036	(35)
	$B-L$	± 0.0014	(35)

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TABLE 2
Night errors

	Mean error	
V	$\pm$ 0.0056	(44)
$V-B$	$\pm$ 0.0021	(44)
$B-U$	$\pm$ 0.0031	(44)
$U-W$	$\pm$ 0.0059	(43)
$B-L$	$\pm$ 0.0011	(44)

prising that the true errors are larger than the accidental errors of table 1. From the differences between observations made in different nights we have computed night errors taking due account of the accidental errors already derived. The resulting mean night errors are shown in table 2. In this case we made no distinction between bright and faint stars.

The final results for the 53 stars measured are presented in table 3. The stars are indicated by their number from Buscombe's finding list (further identifications at the end of the paper). The final results for V and for the four colours are weighted mean values. The mean errors have been computed from the accidental and night errors given in the tables 2 and 3. In the last two columns of this table we have added the visual magnitude in the *UBV* system as computed with the formula from Paper I, and the spectral type as given in the finding list.

Three of our stars occur also in the catalogue of high-velocity stars by ROMAN (1955). These stars are

Buscombe 128	A5	=	Roman 62	sdF4
Buscombe 821	F5	=	Roman 373	sdF5
Buscombe 1258	sd F8	=	Roman 551	sdF8.

For star 128 our measures confirm the spectral type given by Miss Roman. For the two stars 1247 and 1248, for which Buscombe and Morris give spectral type K0, our measures indicate a spectral type in the F-class.

The numbers 83, 127 and 1258 of our list are identical with the numbers 5, 10 and 49 in the article by PRZYBYLSKI and MORRIS KENNEDY (1965). Furthermore 22 stars of our list also occur in the list of photoelectric magnitudes and colours of southern stars by COUSINS and STOY (1963).

We have compared the values of V_J in the last column but one of our table 3 with the V values in the *UBV* system as given by the authors mentioned above. The agreement is very close. For the 22 stars of the Cape list the zero-point difference was found to be 0.002 mag and the mean error of one difference $\pm$0.018 mag. According to the mean errors given in table 3 we expect a mean error of $\pm$ 0.012 mag for the V_J values, which would leave an error of $\pm$ 0.013 mag for the Cape magnitudes.

Walraven has made a thorough study of the relations between the colours in his five-colour photometry and the colours given by Cousins and Stoy in the publication mentioned above. His comparisons are based on a much larger number of stars and on a wider spectral range than we have at our disposal. As Walraven intends to publish the results of his investigation in *Bull. Astr. Inst. Netherlands*, it is sufficient to state here that our results in comparing our colours with the Cape colours are in close agreement with the relations derived by Walraven.

Dr. Walraven informed me that among the bright stars which he measured there is one star of high velocity, namely HD 132475 = Buscombe 776. His measures for this star are

$$V = 3.322 \qquad V-B = +0.2282$$
$$V_J = 8.536 \qquad B-U = +0.2557$$
$$\mathrm{Sp} = \mathrm{F8} \qquad U-W = +0.2371$$
$$B-L = +0.1738.$$

In figure 1 we have plotted the observations in the two-colour diagram of $(V-B)$ against $(B-U)$. The curve for the main-sequence stars was taken from Walraven. From type O to A0 the curve is accurately determined. For the subtypes A, F and G its determination is less accurate and for the K- and M-type stars the curve is very uncertain.

Many of the points in figure 1 fall well above the main-sequence curve, indicating the existence of an ultraviolet excess. In this respect our diagram is very similar to the two-colour diagrams in the *UBV* system given by BECKER (1963) for the stars of Miss Roman's list and by SANDAGE and EGGEN (1959) for a number of subdwarfs.

In figure 1 we first notice one star with an exceptional ultraviolet excess. It is Buscombe 981, a peculiar B-type star at low galactic latitude in the direction of the galactic centre. Consequently it may be strongly reddened and probably does not intrinsically belong

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TABLE 3

Final magnitude and colours, expressed in the logarithm of the intensity, of stars of high velocity. The star numbers are from the catalogue by Buscombe and Morris. The visual magnitude in the *UBV* system is given in the column headed V_J

Star	V		V-B		B-U		U-W		B-L		V_J	Sp
83	2.6952	±46	0.2141	±20	0.2445	±31	0.1666	±66	0.1743	±23	10.105	F1
88	3.4112	60	0.2369	23	0.2669	34	0.1964	71	0.1912	20	8.312	F8
95	4.1926	43	0.2102	16	0.2948	23	0.1736	46	0.2118	11	6.362	F5
127	2.5568	46	0.1820	20	0.2542	31	0.1603	66	0.1555	23	10.455	dF1
128	2.8351	46	0.1801	20	0.2410	31	0.1493	66	0.1503	23	9.760	A5
161	2.2558	46	0.1744	20	0.2288	31	0.1584	66	0.1471	23	11.209	sdA8
451	2.8754	38	0.1956	17	0.2330	25	0.1562	54	0.1624	19	9.657	sdF3
456	3.8422	34	0.2069	13	0.3047	20	0.1800	41	0.2108	12	7.239	F8
460	3.8244	42	0.2636	16	0.3029	24	0.2219	50	0.2541	14	7.276	G0
461	3.5480	42	0.2434	16	0.3275	24	0.2180	50	0.2492	14	7.970	F8
462	2.9766	58	0.0640	23	0.4574	35	0.1337	69	0.2084	19	9.420	A0
465	4.3976	43	0.4636	16	0.5642	23	0.3634	46	0.5038	11	5.818	K0
484	3.9538	42	0.2468	16	0.3102	24	0.1988	50	0.2437	14	6.955	G0
493	2.9638	46	0.3025	20	0.3259	31	0.2138	66	0.3041	23	9.423	G5
502	5.2868	66	0.4382	24	0.5961	33	0.3269	69	0.5325	18	3.598	K0
522	4.4609	43	0.2208	16	0.3015	23	0.1978	45	0.2187	10	5.690	F8
531	3.9308	60	0.1706	23	0.3404	34	0.1732	71	0.2061	20	7.022	F2
532	5.4791	66	0.5580	24	0.7214	33	0.4389	69	0.6285	18	3.102	K0
556	4.3087	61	0.0816	22	0.4287	32	0.1508	64	0.2338	15	6.088	F0
565	4.7120	61	0.1820	22	0.3394	32	0.1870	64	0.2018	15	5.067	F2
821	3.8543	60	0.2073	23	0.2414	34	0.1754	71	0.1431	20	7.208	F5
928	3.2478	42	0.1911	16	0.2507	24	0.1580	50	0.1497	14	8.727	F5
934	2.4894	65	0.2554	29	0.2709	44	0.1954	93	0.1785	32	10.615	sdF8
954	3.6950	42	0.2772	16	0.3168	24	0.2114	50	0.2610	14	7.598	G0
975	5.1715	43	0.6016	16	0.8078	23	0.4648	45	0.6906	10	3.866	K0
981	3.6794	63	0.2199	25	0.1357	37	0.1243	81	0.0833	27	7.644	Bp
1057	4.3884	43	0.2467	16	0.3223	23	0.1895	45	0.2519	10	5.868	F8
1067	3.2052	42	0.2728	16	0.3261	24	0.2203	50	0.2732	14	8.823	G0
1080	4.2261	43	0.2336	16	0.3082	23	0.1890	46	0.2204	11	6.276	F8
1085	3.2750	42	0.2302	16	0.2477	24	0.1792	49	0.1898	13	8.654	sdG0
1090	4.6777	43	0.2279	16	0.3109	23	0.1873	45	0.2070	10	5.147	F8
1131	3.7070	42	0.2334	16	0.2938	24	0.1936	50	0.2179	14	7.573	G0
1150	3.6085	42	0.2436	16	0.3386	24	0.2031	50	0.2605	14	7.818	G0
1159	3.1242	42	0.2798	16	0.3306	24	0.2020	50	0.2832	14	9.025	G5
1163	2.5220	46	0.1686	20	0.2274	31	0.1388	66	0.1359	23	10.544	sdF
1168	3.2837	42	0.3704	16	0.4730	24	0.2407	50	0.4403	14	8.614	G5
1177	2.4870	46	0.6088	20	0.6896	31	0.4595	93	0.5645	23	10.576	K4
1186	3.8879	42	0.2429	16	0.3064	24	0.1981	49	0.2332	13	7.120	F8
1197	4.2484	43	0.2763	16	0.3421	23	0.2135	45	0.2860	10	6.214	G0
1204	4.6281	43	0.2901	16	0.2805	23	0.2336	45	0.1991	10	5.263	G0
1209	3.5935	42	0.2604	16	0.3195	24	0.2136	50	0.2554	14	7.854	G0
1220	3.5846	42	0.2738	16	0.3127	24	0.2056	50	0.2670	14	7.874	G0
1237	3.6154	42	0.2515	16	0.3100	24	0.2106	50	0.2442	14	7.800	G0
1246	4.4086	43	0.1941	16	0.3174	23	0.1760	46	0.2071	11	5.824	F8
1247	2.0567	45	0.2163	20	0.3106	30	0.1811	62	0.2316	21	11.701	K0
1248	2.1047	46	0.2186	20	0.3263	31	0.1838	66	0.2120	23	11.581	K0
1258	3.4752	42	0.1982	16	0.2332	24	0.1612	50	0.1602	14	8.157	sdF8
1266	3.1327	42	0.2420	16	0.3120	24	0.1962	49	0.2437	13	9.008	F8
1276	3.0490	60	0.3500	23	0.4601	34	0.2311	71	0.4130	20	9.204	G5
1279	3.8838	42	0.4314	16	0.5698	24	0.3274	49	0.5274	13	7.107	K0
1283	2.6940	65	0.2824	29	0.3222	44	0.1990	93	0.2763	32	10.100	G0
1284	4.2854	61	0.4249	22	0.5328	32	0.3310	64	0.4685	15	6.103	G5
1311	3.1627	42	0.1297	16	0.3117	24	0.1409	50	0.1658	14	8.947	A2

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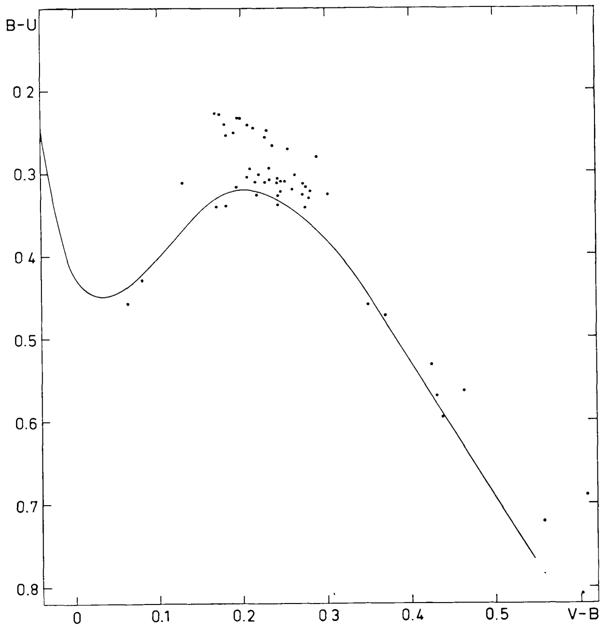

Figure 1. The high-velocity stars in the two-colour diagram. $(V-B)$ and $(B-U)$ expressed in logarithm of the intensity.

to that part of the diagram where it is found. Next we notice a group of stars with large ultraviolet excess, the excess in U being about 0.075. Quite separate from this group we find another group of stars with an excess in U of about 0.030. And finally there are some stars which fall just above or below the main-sequence curve.

We refer here also to the interesting two-colour diagrams for dwarfs and subdwarfs by DIXON (1965), who used them for a study of the past rates of star formation. As our colours deviate from those in the *UBV* system a direct comparison of the diagrams cannot be made.

We have computed approximate values of the excesses in the logarithm of the intensities for the L-, U- and W-bands separately, by comparing each programme star with a star on the main sequence with identical value of $(V-B)$. The photometric data for these main-sequence stars were read from Walraven's curves in the two-colour diagrams presented at the symposium on Spectral Classification and Multicolour Photometry, held at Saltsjöbaden in 1964. As the red part of the main sequence is very poorly determined, we have not made this computation for the programme stars with values of $(V-B)$ larger than $+ 0.4$. The results are presented in table 4. In this table the stars have been arranged in three groups, with large ultraviolet excess, with moderate excess and without noticeable excess. Within each group the stars have been placed in the order of increasing $(V-B)$ values. In the fourth column we have added the spectral type, taken from the catalogue by Buscombe and Morris. The data within brackets were taken from Miss Roman's catalogue. In the last column we have given the space motions in km/sec relative to the local standard of rest, or the observed radial velocities. The latter are given in brackets. These data also were taken from the catalogue by Buscombe and Morris.

In the first group of stars with large ultraviolet excess we find the three stars common with Miss Roman's list and further all the stars of which the subdwarf character has been established spectroscopically. It is clear that the ultraviolet excess affects all three bands L, U and W. If we form mean values for the 14 stars in this group, we find for L + 0.065, for U +0.081 and for W +0.086. Therefore the effect is smallest for L and largest for W. However the figures in table 4 for this first group indicate a systematic change with colour, or with the value of $(V-B)$, in the ratio between the excess for the three bands. For the blue stars the excess in L is definitely smaller than the excess in U or W, but for the reddest stars the excess in L is larger than that of the other two bands.

There probably are two causes for this systematic shift in the values of these ratios. In computing the excesses we have assumed that the B-band is not affected by the difference in strength of the metal lines between subdwarfs and normal dwarfs. It is not unlikely that the errors in the computed excesses, introduced by this assumption, depend on the spectral type. Another cause for the systematic shift mentioned above could be errors in the shape of the curves, representing the main-sequence stars, in the various two-colour diagrams. According to Walraven the shape of the curves for the main sequence in the F and G spectral region is not very well determined.

There is little to say about the stars with moderate ultraviolet excess or about the stars near the main sequence. It is clear, however, that the space motions and radial velocities of the stars in these two groups are systematically smaller than those of the stars with large excess.

To study the correlation between ultraviolet excess

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TABLE 4

The excess in L, U en W, expressed in the logarithm of the intensity. The last column shows the space motion in km/sec relative to the local standard of rest and in brackets the radial velocity relative to the Sun

Star	$V-B$	Excess in L	Excess in U	Excess in W	Spectrum	Velocity (km/sec)
			Stars with large ultraviolet excess			
1311	0.1297	+ 0.026	+ 0.055	+ 0.069	A2	
1163	0.1686	+ 0.068	+ 0.104	+ 0.126	sdF	(+103)
161	0.1744	+ 0.058	+ 0.099	+ 0.102	sdA8	(+154)
128	0.1801	+ 0.057	+ 0.085	+ 0.097	A5 (sdF4)	(+ 63)
127	0.1820	+ 0.054	+ 0.071	+ 0.084	dF1	(+234)
928	0.1911	+ 0.064	+ 0.071	+ 0.077	F5	
451	0.1956	+ 0.055	+ 0.097	+ 0.098	sdF3	178
1258	0.1982	+ 0.059	+ 0.087	+ 0.094	sdF8	252
821	0.2073	+ 0.081	+ 0.079	+ 0.075	(sd)F5	231
83	0.2141	+ 0.056	+ 0.088	+ 0.096	F1	
1085	0.2302	+ 0.056	+ 0.079	+ 0.085	sdG0	218
88	0.2369	+ 0.064	+ 0.063	+ 0.056	F8	
934	0.2554	+ 0.096	+ 0.072	+ 0.071	sdF8	182
1204	0.2901	+ 0.111	+ 0.090	+ 0.073	dG0	213
			Stars with moderate ultraviolet excess			
456	0.2069	+ 0.014	+ 0.016	+ 0.007	F8	
95	0.2102	+ 0.016	+ 0.026	+ 0.024	F5	69
522	0.2208	+ 0.018	+ 0.023	+ 0.003	F8	86
1090	0.2279	+ 0.037	+ 0.015	+ 0.011	F8	65
1131	0.2334	+ 0.033	+ 0.035	+ 0.027	G0	
1080	0.2336	+ 0.030	+ 0.020	+ 0.017	F8	
1266	0.2420	+ 0.016	+ 0.021	+ 0.016	F8	
1186	0.2429	+ 0.029	+ 0.028	+ 0.020	F8	
484	0.2468	+ 0.024	+ 0.026	+ 0.019	G0	
1237	0.2515	+ 0.026	+ 0.020	+ 0.012	G0	
1209	0.2604	+ 0.025	+ 0.027	+ 0.011	G0	
460	0.2636	+ 0.029	+ 0.044	+ 0.033	G0	85
1067	0.2728	+ 0.019	+ 0.030	+ 0.014	G0	
1220	0.2738	+ 0.026	+ 0.044	+ 0.044	G0	154
954	0.2772	+ 0.035	+ 0.042	+ 0.038	G0	
1159	0.2798	+ 0.017	+ 0.032	+ 0.039	G5	
1283	0.2824	+ 0.025	+ 0.041	+ 0.051	G0	(− 98)
493	0.3025	+ 0.020	+ 0.056	+ 0.065	G5	
			Stars near the main sequence			
462	0.0640	− 0.020	− 0.021	− 0.017	A0 SB	
556	0.0816	− 0.046	− 0.007	− 0.017	F0 SB	
531	0.1706	− 0.003	− 0.010	− 0.022	F2	
565	0.1820	+ 0.006	− 0.014	− 0.039	F2	75
1246	0.1941	+ 0.008	0.000	− 0.011	F8	
1247	0.2163	+ 0.001	+ 0.011	+ 0.007	K0	
1248	0.2186	+ 0.023	− 0.003	− 0.010	K0	
461	0.2434	+ 0.013	+ 0.006	− 0.021	F8	(+ 71)
1150	0.2436	+ 0.002	− 0.005	− 0.017	G0	
1057	0.2467	+ 0.015	+ 0.014	+ 0.016	F8	67
1197	0.2763	+ 0.010	+ 0.016	+ 0.010	G0	97
1276	0.3500	− 0.035	− 0.013	+ 0.009	G5	
1168	0.3704	− 0.035	+ 0.009	+ 0.031	G5	90

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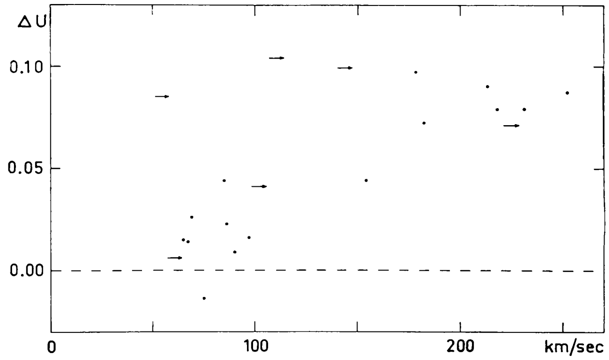

Figure 2. The excess in *U*, expressed in the logarithm of the intensity, plotted against the spacial motion relative to the local standard of rest. Arrows indicate stars for which only radial velocities are known.

and space velocity we have plotted in figure 2 the excess in the *U*-band, from table 4, against the space motions from the same table. For stars with unknown spacial motion, but with given radial velocity we have reduced the latter to the local standard of rest. These radial velocities have been indicated in figure 2 by arrows. The coefficient of correlation between the excess and the space motion is +0.90. We derived the following relation

$$\text{space motion} = \underset{\pm 8}{59} + \underset{230}{1730} \cdot (\text{excess in } U) \quad \text{(m.e.)}.$$

The dispersion of the space velocities relative to this formula is ±31 km/sec. All the stars plotted in figure 2, which have a spacial motion larger than 80 km/sec, show an ultraviolet excess. We conclude that for F-type and early G-type stars high-velocity and ultraviolet excess are strongly correlated.

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Identification of Buscombe numbers with Henry Draper or Durchmusterung numbers

Busc.	HD or DM	Busc.	HD or DM	Busc.	HD or DM	Busc.	HD or DM
83	−61°282	502	88 284	1067	190 649	1209	212 231
88	10 607	522	91 889	1080	193 307	1220	214 385
95	11 262	531	93 751	1085	193 901	1237	217 276
127	−17°484	532	93 813	1090	196 378	1246	218 630
128	16 031	556	98 088	1131	201 099	1247	218 693
161	Ross 570	565	98 991	1150	203 448	1248	218 750
451	−3°2525	821	140 283	1159	204 670	1258	219 617
456	77 462	928	160 617	1163	−35°148 49	1266	220 536
460	78 558	934	−8°4501	1168	205 855	1276	222 013
461	78 670	954	165 896	1177	−41°146 56	1279	222 237
462	78 753	975	171 443	1186	208 998	1283	222 766
465	80 050	981	172 488	1197	210 918	1284	222 803
484	83 529	1057	189 340	1204	211 998	1311	224 927
493	−13°2948						

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