

FIVE-COLOUR OBSERVATIONS OF 24 CLASSICAL CEPHEIDS

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This paper presents light-curves and colour-curves for 24 Cepheids, mostly of type I. The periods vary from 5^d to 79^d, but are mainly concentrated around 9^d.

The observations were made with the simultaneous five-channel photometer attached to the 36-inch "light-collector" of the Leiden Southern Station on the Departmental Grounds near Hartebeespoortdam, Transvaal, Republic of South Africa. The reduction took place at the Mount Stromlo Observatory of the Australian National University, Canberra A.C.T., Australia. The number of observations per Cepheid varies from 20 to 95. Each observation was accompanied by an observation of a nearby comparison star, while often standard stars were observed also.

1. Introduction

While studying the results of simultaneous five-colour observations of early-type stars, it was noticed that appreciable effects of spectral class and luminosity can also be observed for supergiants of a somewhat later type. Consequently the need was felt for a more detailed and complete knowledge of the colours of the various types of supergiants in the five-colour system. For this purpose numerous supergiants, both in the Magellanic Clouds and in the Galaxy, were observed. This led to the study of a number of classical Cepheids, which provide another extension to the system of supergiants. The Cepheids are especially valuable for this purpose, since the observations of one variable during its cycle of variation are equivalent to the study of a sequence of stars of different spectral types, but otherwise under constant conditions such as distance and reddening and, it may be assumed, with nearly constant luminosity.

Our interest was directed mainly towards the more luminous Cepheids. These may form a continuation of the supergiants of classes Ia and Ib, which we had already observed. Since the most luminous Cepheids with the longest periods are rare, most of the programme stars have periods around 9 days. Since we

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Table 8 gives the variations of brightness and colours of the Cepheids relative to those of the comparison stars. Table 3 gives the brightness and colours of the comparison stars in the natural photometric system of the telescope. A conversion to the *UBV* system is given for *V* and *V - B* only.

The properties of the light and colour variations of the Cepheids are discussed briefly in section 5. A discussion of the stability of the comparison stars and standard stars, using the observations of the previous years, will be found in section 4. Of the 28 comparison stars, chosen at random near the Cepheids, four were identified by us as supergiants of type F or G.

considered an investigation of the homogeneity of the colours as more important, we restricted ourselves to stars of this group, rather than studying a wide variety of periods and various types of population. Another reason for concentrating on the 9-day period group was that the sharp change of shape in the light-curve takes place at about this period. It may well be that the detailed study of these shapes will lead us to a better definition of the luminosity class, which, in view of the use of Cepheids as distance indicators, is highly important.

2. Programme

The stars selected for detailed observation are listed in table 1. The periods and epochs have all been taken from the second General Catalogue of Variable Stars (KUKARKIN *et al.*, 1958).

The two longer-period variables KN Cen and QT CrA were included in the programme at a later stage and have not been observed intensively. Likewise some variables of other types were included in the programme originally, but were abandoned soon after the observations were started, when it became apparent that no time would be available for these stars in a regular programme. The results of these observations are not discussed in this paper and these stars are not included in table 1. Only one star of a different type, i.e. Kappa Pav, was kept on the list.

TABLE 1
Cepheids and comparison stars

CEPHEID	P	J.D. 2 400 000 +	R.A. 1960	DEC. 1960	N	HD	R.A. 1960	DEC. 1960	N	REMARKS
V381 Cen	5.07878	34932.29	13 ^h 48 ^m 02 ^s	-57° 23.0'	69	120 459	13 48 25	-57 16.6	34	
V636 Sco	6.79663	34906.47	17 19 50	-45 34.8	81	156 623	17 17 54	-45 22.8	41	
R Mus	7.50990	34847.38	12 39 35	-69 11.3	84	110 080 110 716	12 38 03 12 42 33	-70 19.6 -68 36.7	28 16	
IT Car	7.5356	24214.92	11 10 27	-60 32.3	57	97 670	11 11 46	-59 24.1	43	
W Sgr	7.594710	34587.26	18 02 28	-29 35.2	69	164 972 165 118	18 02 30 18 03 07	-25 36.6 -29 16.9	32 30	
ER Car	7.717806	26777.62	11 07 58	-58 37.2	56	97 670 97 093 97 000	11 11 46 11 08 02 11 07 28	-59 24.1 -58 29.0 -58 30.0	43 12 12	1
IQ Nor	8.2317	34234.3	15 09 49	-54 36.5	95	134 600	15 10 02 15 09 04	-54 36.3 -54 36.3	34 34	
S Sge	8.38216	33131.80	19 54 13	+16 31.6	27	189 090	19 55 55	+16 40.8	15	
V500 Sco	9.31665	34925.64	17 46 04	-30 28.0	55	161 665	17 45 40	-32 39.5	26	
SX Vel	9.54993	21015.95	8 43 32	-46 11.8	75	74 868 75 026	8 43 28 8 44 31	-44 23.9 -46 08.8	28 19	
YZ Sgr	9.55345	34931.42	13 47 10	-16 46.3	48	174 467	18 49 00	-17 12.2	26	
S Mus	9.65869	34580.62	12 10 35	-69 55.7	82	105 119	12 04 03	-68 54.2	40	
S Nor	9.75418	34586.39	16 15 31	-57 48.4	81	145 782	16 12 31	-57 48.8	40	2
AQ Car	9.77014	23967.41	10 20 01	-60 52.2	47	90 454	10 23 32	-58 22.4	49	
XX Cen	10.956130	19846.821	13 37 39	-57 24.8	82	119 020	13 39 38	-58 25.1	43	
UU Mus	11.63641	34835.12	11 50 18	-65 10.8	66	103 338	11 51 45	-65 04.0	32	
XY Car	12.43519	23074.034	11 00 40	-64 02.8	46	95 752	11 00 14	-64 05.3	56	
SV Vel	14.09707	34869.92	10 43 20	-56 04.7	66	93 563 93 319	10 45 20 10 43 42	-56 32.8 -56 12.9	28 11	
XX Car	15.71624	34917.03	10 55 37	-64 55.2	51	95 752	11 00 14	-64 05.3	56	3
XZ Car	16.6499	20304.64	11 02 34	-60 45.8	41	96 829	11 06 25	-60 36.5	21	
YZ Car	18.1631	34907.04	10 26 49	-59 08.7	44	90 454	10 23 32	-58 22.4	49	4
WZ Sgr	21.849708	24625.350	18 14 47	-19 05.5	34	167 499	18 14 04	-16 49.0	16	
KN Cen	34.019	35247.63	13 33 58	-64 22.0	20	118 294	13 35 17	-66 02.0	8	
QT CrA	79.145	26550.	18 06 35	-40 12.6	24	166 618	18 10 43	-41 24.0	11	
Kappa Pav	9.0696	34693.11	18 52 51	-67 17.4	31	174 787	18 53 15	-66 23.1	17	5

- 1. Cf. IT Car
- 2. In cluster NGC 6087
- 3. Cf. XY Car
- 4. Cf. AQ Car
- 5. Population II cepheid

The criteria used to select the comparison stars were proximity to the variable, matching brightness, and sufficient ultraviolet intensity. The latter consideration meant that stars of type K and M were excluded. The comparison stars are also listed in table 1. The programme included occasional observations of main standards for calibration purposes.

Only the first half of the night was available for the Cepheid programme, the other half being devoted to observations of the Magellanic Clouds. As a rule no observations were made in the week around full Moon; although at the time this was considered a welcome rest, the lack of these observations was regretted later.

No attempt was made to determine in advance the phase of the variable, but the observations were made at random times.

3. Observations

As described in an earlier publication (TH. and J. H. WALRAVEN, 1960), the five-colour photometer yields simultaneous measurements in five wavelength regions with an integration time of one minute. This integration time could not be varied and the variations in light intensity were taken up mostly by changing the attenuation in the recording devices (10 steps of 0^m.5) or by changing the integrating capacitors (1 step of 2^m.5). A neutral optical attenuator could be switched in for the brighter stars, reducing the light by nearly three magnitudes.

The greatest loss of observing time was due to the necessity to connect each of the five channels in turn to the recording potentiometer. Since this is done manu-

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ally, it takes about one minute, as much as the integration time itself. During the minute of integration, the coordinates of the star under observation were noted down and the controls of the telescope preset to the coordinates of the star to be observed next.

As a rule a Cepheid was observed twice, once before and once after the comparison star. Now and again during the night, main standards were observed in the usual way, i.e. three or four stars at widely different hour angles, observed one after the other, so that the extinction coefficient could be determined. At a later period this standard procedure was neglected somewhat and we made supplementary determinations of the extinction from the many observations of the comparison stars.

4. Reduction

For normal programmes the reduction of the observations consists of the following steps:

- a) Reading the deflections on the Brown recorder chart.
- b) Multiplication by the attenuation factor.
- c) Subtraction of the sky background.
- d) Determination of the logarithms of intensity.
- e) Determination of the difference between the logarithms of intensities in the different wavelength bands.
- f) Determination of the extinction coefficients for brightness and colours by comparison of standard stars at large and small zenith distances.
- g) Reduction of the brightness and colours to zenith.
- h) Plotting, for each night, the deviations from the standard values for the known standard stars against time. These deviations are produced by so far unknown instrumental effects.
- i) Drawing smooth curves (the "instrumental curves") through these plots.
- j) Correction of the observations of other stars with the values read off these "instrumental curves".

Due to the enormous observing capacity of the telescope, these reductions are very time-consuming. In the case of the Cepheids we therefore applied a shortened procedure. The determinations of the extinction were omitted and constant average values were used. These values are given in the table below.

These average values are based on the results of other programmes, which proceeded in the normal way de-

Extinction coefficient
(logarithm of intensity)

V	$V - B$	$B - U$	$U - W$	$B - L$
0.100	0.065	0.110	0.175	0.065

scribed above. The brightness and colours of the Cepheids were determined relative to the comparison stars, so that the correction mentioned above under g) could be omitted.

The brightness and colours of the comparison stars were determined by the normal method described above, except that the constant average values of the extinction coefficients were used. This method can be applied only to those nights where a sufficient number of main standard stars with known brightness and colours were observed. The number of such determinations of the brightness and colours of the comparison stars varies between nine and zero.

Using the mean preliminary values of the comparison stars in addition to those of the standard stars, we constructed for every observing night new instrumental curves, now with more comprehensive data. Using these, we obtained new values of brightness and colours, now for all observations. These values were plotted against the data for all comparison stars and standards in order to detect signs of possible variability.

The diagrams show remarkable conformity. In all cases the scatter in the brightness is considerably larger than that in the colours. Moreover the scatter is consistently the same for all the stars, increasing only when the signals become fainter. No indication of variability could be found amongst the comparison stars. Obviously the atmospheric disturbances and instrumental effects produce most of the scatter, while for the faint stars the random fluctuations in the photocurrent become more important.

Table 2 lists the mean value of the deviation for one

TABLE 2
Mean absolute deviation for some standard stars

ID	V	V-B	B-U	U-W	B-L
74 575	.0034	.0017	.0016	.0019	.0014
104 337	.0064	.0020	.0019	.0020	.0017
135 382	.0061	.0018	.0029	.0025	.0017
144 470	.0055	.0020	.0018	.0021	.0018
164 402	.0045	.0016	.0014	.0016	.0011
178 175	.0103	.0020	.0046	.0023	.0027

observation, for some standard stars. It should be noted that the mean deviation shown in the table is still larger than necessary, because a constant value of extinction has been assumed and also because iteration of the procedure starting from h) with the new mean values would certainly have reduced the scatter. However, it seems superfluous to repeat the procedure when we consider the difference between the preliminary values and the new values which we derived. The mean absolute value of this difference for all 28 comparison stars, expressed in logarithm of intensity, is shown in the table below.

<i>V</i>	<i>V - B</i>	<i>B - U</i>	<i>U - W</i>	<i>B - L</i>
0.0038	0.0008	0.0009	0.0020	0.0008

These figures represent primarily the errors of the

preliminary values of the brightness and colours, since they are larger than one would expect from the data in table 2. The large value for *U - W* is due to the fact that the comparison stars of the Cepheids are on the average of a later spectral type than the standards and therefore have a very low intensity in the ultraviolet. On the whole, however, the differences between the preliminary and new values are sufficiently small and we decided not to repeat the procedure, but to consider the new values as definite. They are given in table 3 and are discussed at the end of this paper.

In table 4 we give the brightness and the colours of the standard stars, determined in the same way as those of the comparison stars of the Cepheids. In this table are also given the preliminary values used, which are based on the reductions of observations of preceding years and have much more significance. These

TABLE 3
Brightness and colours of comparison stars

HD	<i>V_J</i>	(<i>B-V</i>) _J	SP	<i>V</i>	<i>V-B</i>	<i>B-U</i>	<i>U-W</i>	<i>B-L</i>	N
74 868	6.54	.555	G3 IV	0.121	.2323	.3456	.1999	.2674	28
75 026	8.00	.194	B3	-0.456	.0808	.2569	.1185	.0720	19
90 454	5.91	.320	F0	0.377	.1318	.4353	.1863	.2116	49
93 563	5.13	-.074	B8	0.698	-.0226	.2637	.0728	.0569	28
93 319	8.40	.986	K0	-0.632	.4300	.5232	.3208	.4613	11
95 752	6.93	.476	F0	-0.034	.1984	.6150	.3613	.1870	56
96 829	7.31	.253	B8	-0.181	.1047	.0635	.0582	.0280	21
97 670	5.73	-.090	B3	0.458	-.0273	.0532	.0110	.0006	43
97 093	8.69	.020	A2	-0.729	.0112	.4211	.1050	.1386	12
97 000	7.93	.080	A2	-0.426	.0348	.4628	.1592	.1432	12
103 338	7.48	.158	B5	-0.248	.0663	.1077	.0561	.0309	32
105 119	7.16	.569	G0	-0.128	.2386	.3411	.1996	.2529	40
110 080	7.39	.252	A0	-0.214	.1045	.4835	.1601	.2151	28
110 716	6.15	.687	G0	0.273	.2909	.3259	.3259	.2866	16
118 294	8.51	.345	A3	-0.662	.1418	.4644	.1859	.2114	8
119 020	7.90	.229	F0	-0.418	.0948	.4355	.1622	.2016	43
120 459	7.95	.204	A2	-0.437	.0847	.5068	.1766	.1890	34
134 600	10.26	.060	A0	-1.356	.0268	.3790	.0857	.1399	34
*	10.43	.562	-	-1.435	.2357	.3697	.1992	.2383	34
145 782	5.61	.137	A2	0.502	.0580	.4852	.1495	.1883	40
156 623	7.23	.086	A0	-0.146	.0373	.4276	.1021	.1950	41
161 756	6.37	.151	B3	0.198	.0634	.1730	.0642	.0640	4
161 665	7.33	.138	A2	-0.188	.0581	.4326	.1299	.2078	26
164 972	7.17	.508	F0	-0.132	.2123	.5450	.2977	.2422	32
165 118	7.27	.087	A2	-0.162	.0377	.4417	.1177	.1942	30
166 618	9.31	.186	A3	-0.982	.0776	.4844	.1637	.2006	11
166 162	9.67	.556	F5	-1.132	.2331	.4066	.2200	.2297	44
165 244	7.32	.275	A5	-0.188	.1140	.4458	.1604	.2225	45
167 499	9.02	.174	A0	-0.865	.0727	.4578	.1375	.1738	16
174 467	6.83	.304	A0	0.009	.1254	.5666	.2794	.1512	26
174 787	7.61	.332	F0	-0.302	.1371	.3535	.1520	.1846	17
177 171	5.17	.533	G0	0.671	.2272	.3316	.2037	.2232	73
189 090	5.55	-.048	B9	0.528	-.0136	.3592	.0845	.1137	15

* COORDINATES 1960: R.A. 15^h 09^m 40^s, DEC. -54° 36.3'

TABLE 4

Brightness and colours of standard stars: adopted standard values (1961) and results of Cepheid programme (1962)

HD	YEAR	V	V-B	B-U	U-W	B-L	N
74 575	1962	+1.288	-.0536	-.0140	-.0168	-.0234	45
	1961	+1.287	-.0539	-.0151	-.0182	-.0219	-
93 030	1962	+1.661	-.0717	-.0706	-.0437	-.0451	8
	1961	+1.661	-.0717	-.0731	-.0433	-.0463	-
104 337	1962	+0.650	-.0637	-.0056	-.0177	-.0164	95
	1961	+0.649	-.0646	-.0044	-.0178	-.0155	-
122 980	1962	+1.016	-.0643	+0.0310	-.0166	+0.0035	9
	1961	+1.010	-.0694	+0.0330	-.0181	+0.0048	-
135 382	1962	+1.598	+0.0125	+0.4516	+0.1329	+0.1287	32
	1961	+1.594	+0.0126	+0.4537	+0.1305	+0.1292	-
144 470	1962	+1.174	+0.0025	+0.0004	+0.0010	+0.0020	63
	1961	+1.172	+0.0020	+0.0002	+0.0008	+0.0011	-
164 402	1962	+0.458	+0.0072	-.0348	-.0001	-.0155	24
	1961	+0.453	+0.0078	-.0358	-.0012	-.0161	-
61 068 *	1962	+0.498	-.0548	-.0117	-.0286	-.0166	8
	1961	+0.476	-.0566	-.0128	-.0204	-.0167	-
178 175 **	1962	+0.524	-.0149	+0.0782	+0.0143	+0.0176	28
	1961	+0.560	-.0129	+0.0698	+0.0190	+0.0134	-

* SEC Z > 2.00
 ** VARIABLE

values form the link by which the colours of the Cepheids are finally connected with those of the supergiants of another programme. They have been obtained by a process of repeated approximation which included the closing of a belt of such standards around the sky. The final results for these standards can be obtained only by a discussion of all the observations, which is not given in this paper.

In table 5 we show the differences between the adop-

TABLE 5

Differences (1962-1961) of brightness and colours of standard stars

HD	V	V-B	B-U	U-W	B-L	N
61 068	.0005	.0000	.0025	-.0004	.0012	8
74 575	.0011	.0003	.0011	.0014	-.0015	45
104 337	.0011	.0009	-.0012	.0001	-.0009	95
122 980	.0063	.0021	-.0020	.0015	-.0013	9
135 382	.0041	-.0001	-.0021	.0024	-.0005	32
144 470	.0021	.0005	.0002	.0002	.0009	63
164 402	.0054	-.0006	.0010	.0011	.0006	24
WEIGHTED MEAN	.0022	.0005	-.0003	.0007	-.0004	

ted values (1961) and the values derived from the Cepheid programme (1962) in the sense 1962 minus 1961. The differences are similar to those for the Cepheid comparison stars, but reveal a systematic component, which is shown in the last line of table 5. Since the reduction procedure used is such that we should find back the values that were originally used, there must be some external cause for this systematic deviation. It seems probable that variability of one of the standard stars, HD 178 175, is responsible for it, because for this star the discrepancy between 1962 and 1961 is appreciable (see table 4).

This is illustrated more clearly in table 6, where the differences 1962 - 1961 have been corrected with the systematic value of table 5. The table shows, that HD 178 175 has decreased in brightness, has become bluer in the $V-B$ and $U-W$, and redder in the $B-U$ and $B-L$. The most strongly varying colour is $B-U$. A similar effect has been found also for other stars in the B star programme, in each case the colour $B-U$ varying most, $V-B$ somewhat less, but in opposite sense, while the changes in colour are accompanied by relatively

small changes in brightness. In one case, HD 20 340, the variation in $B - U$ amounts to $0^m.07$, but in many other cases the variations are only of the order of $0^m.01$ and their reality could only be suspected. It is an important result of the present discussion that a variation in the colour $B - U$ of only $0^m.02$ is established with certainty. We have the impression that the variation is always in the same sense as for HD 178 175. So far the effect has only been noted for B stars.

Apart from these cases of colour variability, the colours of the stars are in general surprisingly stable, as is shown by the values in table 6.

TABLE 6

Final differences (1962 - 1961) of brightness and colours of standard stars

HD	V	V-B	B-U	U-W	B-L	N
61 068	-.0017	-.0005	.0028	-.0011	.0016	8
74 575	-.0011	-.0002	.0014	.0007	-.0011	45
104 337	-.0011	.0004	-.0009	-.0006	-.0005	95
122 980	.0041	.0016	-.0017	.0008	-.0009	9
135 382	.0019	-.0006	-.0018	.0017	-.0001	32
144 470	-.0001	.0000	.0005	-.0005	.0013	63
164 402	.0032	-.0011	.0013	.0004	.0010	24
178 175	-.0384	-.0025	.0087	-.0054	.0046	28

The unweighted means, without regard to sign, of the residuals shown in table 6, excluding HD 178 175, are:

	V	V-B	B-U	U-W	B-L
Log intensity	0.0019	0.0006	0.0015	0.0008	0.0009
Magnitudes	$0^m.0047$	$0^m.0015$	$0^m.0038$	$0^m.0020$	$0^m.0022$

These values are larger than would be expected from the mean error of observation, as shown in table 2. Rather than being due to instrumental errors, they seem to reflect the intrinsic changes in brightness and colours of the stars over a period of a year. This is supported by the fact that the character of the fluctuations is different in the two cases; the instrumental errors are smallest for the colour $B - L$, while the intrinsic variations are smallest for $V - B$.

Independent of whether the deviations are due to an intrinsic or an instrumental cause, it may be concluded that the colours of stars in general do not vary by more than a few thousandths of a magnitude.

So far we have discussed the brightness and colours

of the comparison and standard stars only as they are determined from the observations, i.e. the natural values for the instrument. The reason for this is that it turned out to be rather difficult to transform our colours to those of standard photometric systems such as the UBV system. Such transformations are non-linear and multivalued. For $B - L$ and $U - W$ no comparison exists, while for $U - B$ the transformation is very complicated. The comparison of $V - B$ with $(B - V)_j$ of the UBV system is the only one worth while, although even here the relation is strongly non-linear and multivalued. The cause of this complication is that the spectral regions used in the UBV system are too wide. For the band U, which contains the Balmer discontinuity, this is obvious, but for the band B, which includes the region containing the higher members of the Balmer series, the undesirable effects are perceptible too.

Instead of forcing our colours into an unsatisfactory transformation, we decided to discuss the results in terms of natural colours. In order to make the confusion with colours of other systems less likely, we give the results not in magnitudes, but as logarithms of intensity. However, to make possible at least a rough comparison of our results with those obtained by other types of photometry, we give the two transformations which have reasonable accuracy.

By comparing our observations of about 240, mostly bright, field stars with those made at the Royal Observatory at the Cape (1963), and with some other sources, we found the following preliminary relations.

The relation between the V_j magnitude in the UBV system and our brightness V is

$$V_j = 6.87 - 2.5[V + 0.05(V - B)].$$

The relation between $(B - V)_j$ and $V - B$ is strongly nonlinear, viz. we find both the very blue and the very red stars to be redder than in the UBV system. The deviation reaches $0^m.08$ for the bluest O stars and $0^m.25$ for M-type stars. The transformation is given in table 7.

In this table may be noted the gradual changes from Orion stars to supergiants, due to the decreasing strength of the hydrogen lines included in the band B of the UBV system but not in our band B. The table gives the magnitudes to three decimal places; the actual accuracy is difficult to estimate and varies for the

TABLE 7
Transformation for $V - B$ of the five-colour system to $(B - V)_J$
of the UBV system

V-B		(B-V) _J		
LOG INT	2.5 LOG INT	MAGNITUDES		
		ORION STARS	FIELD STARS	SUPERGIANTS
-0.1000	-0.250	-0.329	-0.329	
-0.0900	-0.225	-0.295	-0.295	
-0.0800	-0.200	-0.262	-0.262	
-0.0700	-0.175	-0.229	-0.229	
-0.0600	-0.150	-0.189	-0.195	
-0.0500	-0.125	-0.148	-0.162	
-0.0400	-0.100	-0.110	-0.130	
-0.0300	-0.075	-0.078	-0.098	
-0.0200	-0.050	-0.050	-0.068	-0.078
-0.0100	-0.025	-0.025	-0.038	-0.051
0.0000	0.000	0.000	-0.010	-0.025
0.0100	0.025		0.017	-0.002
0.0200	0.050		0.042	0.028
0.0300	0.075		0.067	0.054
0.0400	0.100		0.092	0.080
0.0500	0.125		0.117	0.106
0.0600	0.150		0.142	0.132
0.0700	0.175		0.167	0.158
0.0800	0.200		0.192	0.182
0.0900	0.225		0.217	0.208
0.1000	0.250		0.241	0.232
0.1500	0.375		0.365	0.358
0.2000	0.500		0.480	0.478
0.2500	0.625		0.595	0.595
0.3000	0.750		0.708	0.708
0.3500	0.875		0.816	0.816
0.4000	1.000		0.924	0.924
0.4500	1.125		1.029	1.029
0.5000	1.250		1.132	1.132
0.5500	1.375		1.235	1.235
0.6000	1.500		1.334	1.334
0.6500	1.625		1.432	1.432
0.7000	1.750		1.528	1.528
0.7500	1.875			1.625

different parts of the table. In particular the supergiants showed a larger scatter in the comparison, which probably indicates a tendency to instability in these stars.

The transformations were applied to the V and $V - B$ of the Cepheid comparison stars and the results are given in table 3 as V_J and $(B - V)_J$.

5. Discussion

The brightness and colours of the Cepheids are given in table 8 at the end of this paper. The values are given as logarithms of intensity and represent the difference

between the Cepheid and the comparison star. The brightness and colour of the latter in the natural photometric system may be found in table 3. By adding these values to those in table 8, the brightness and colours of the Cepheids may be found, also in the natural photometric system. By means of the transformations given in the previous section, the brightness V and the colour $V - B$ may be translated into the UBV system.

It may be remarked here that the nonlinearity of the transformation has serious consequences for the discussion of the properties of the Cepheids. This should be kept in mind if the results in this paper are compared with the observations of Cepheids in the UBV system. For example a typical unreddened Cepheid may vary in $V - B$ from $+0.2000$ to $+0.4000$, i.e. over a range of 0.50 magnitude. According to table 7 the range in $(B - V)_J$ would be 0.45 magnitude, which is considerably less. If the same star is reddened by 0.5 magnitude, the range in $(B - V)_J$ would decrease to 0.41 magnitude. Here again we see the influence of the wide band of the UBV system. In this case the increasing strength of the metallic lines may be responsible for a considerable displacement of the effective wavelength. The apparent reduction of the amplitude is relative to the five-colour system, where the displacement of effective wavelength is much smaller. However, even in the five-colour system a small effect of the same kind may be present compared to the ideal system. It is difficult to estimate the strength of any such effect, but if present, it will make the discrepancies in the UBV system still larger.

A general discussion of the colours will be included in a forthcoming paper on the intrinsic colours of supergiants in the five-colour system. In the present paper we restrict ourselves to presenting the variations with phase of the brightness and colour, together with a few comments. The light-curves and colour-curves are shown in figures 1 to 23. The curves for KN Cen and QT CrA are not shown, because the limited number of observations did not permit us to study the shape of their curves to the same extent as those of the other stars. Curves of the colour $U - W$ are not shown; except for a few bright stars, the accuracy for this colour is very low, due to the extreme weakness of the far ultraviolet (band W) for later type stars. In those cases where the accuracy is better, it appears that the amplitude variation in colour $U - W$ is rather small. In

figures 1 to 22 we have drawn a smooth line through the dots representing the individual observations. In cases where uncertainty exists, a broken line has been drawn. In the case of S Sge ($P = 8^{\text{d}}.38216$), only a limited number of observations exist and the line drawn in figure 8 was given approximately the same shape as that in figure 7 (IQ Nor, a Cepheid of similar period: $P = 8^{\text{d}}.2317$). For Kappa Pav, an abnormal Cepheid, no such comparison was available and the curves are very uncertain. The vertical lines denote zero phase (maximum brightness) according to the ephemerides given in table 1, which were taken from the second General Catalogue of Variable Stars (KUKARKIN *et al.*, 1958). Clearly some of the ephemerides need revision. A study of figures 1 to 23 leads to the following general remarks:

a) The scatter is not unduly large for any of the Cepheids. In the case of S Nor, a number of observations of previous years were available which fit the curves remarkably well. The deviations do not exceed the scatter of the other points in figure 13. In general the classical Cepheids seem to repeat their variations with high regularity.

b) The changes in character of the curves for $B - V$ relative to those for V (and of $B - L$ relative to $V - B$ and so on) are similar for all stars. The curve for $V - B$ is shifted to an earlier phase relative to V . This is a well known effect of the classical Cepheids and has been interpreted as evidence of variation in the radius of the star. In the curve for $B - U$, which on the whole is rather flat, a hump often shows at the phase of increasing brightness. Consequently the relation between $B - U$ and $V - B$ is not singlevalued. The same effect, to a lesser extent, is seen in the comparison of $B - L$ with $V - B$. It presents itself as a shift in phase, $B - L$ coming earlier, and as a slight bulging upward of the ascending part of the curve for $B - L$.

In the colour-colour diagrams the Cepheids describe a rather elongated loop. Our observations show that this is a general property of the Cepheids.

c) The variation in the colour $B - L$ is remarkably strong, considering that the difference in effective frequency between bands B and L is much smaller than that between V and B. On the other hand, the amplitude of $B - U$ is smaller than would be expected from the change in temperature gradient.

It is interesting to compare this behaviour with that

shown by variables with very short periods (J. PONSEN, 1961, 1963) e.g. V 703 Sco, RS Grus, EH Lib, BS Aqr, AI Vel (unpublished). The curve for $B - U$ for these stars resembles the curve for $V - B$, inverted, while $B - L$ shows hardly any variation. These differences in behaviour are to be expected, if one notes that in the colour-colour diagram the narrow closed loop described by the variable lies along a line of constant luminosity.

d) Figures 1 to 22 strongly suggest that the humps on the light-curves are a normal aspect of the classical Cepheids. Except that they tend to weaken when the amplitude is smaller than normal for the period, they are strongly pronounced in all light-curves for periods around 9 days. Their position and amplitude show a pronounced systematic relation with the period. The Cepheids V 500 Sco ($P = 9^{\text{d}}.31665$) and YZ Sgr ($P = 9^{\text{d}}.55345$) show, within the errors of observation, identical curves for V , and for $B - L$, $V - B$ and $B - U$. Likewise the behaviour of S Nor is practically identical with that of AQ Car in all respects.

All this gives the impression of regularity, so that there is no reason to classify the Cepheids in groups according to the character of the humps. In fact only S Mus ($P = 9^{\text{d}}.65869$) stands out clearly from the general pattern. This star is abnormal in the following respects (figure 12):

a) The amplitude is small, while the humps are clearly pronounced.

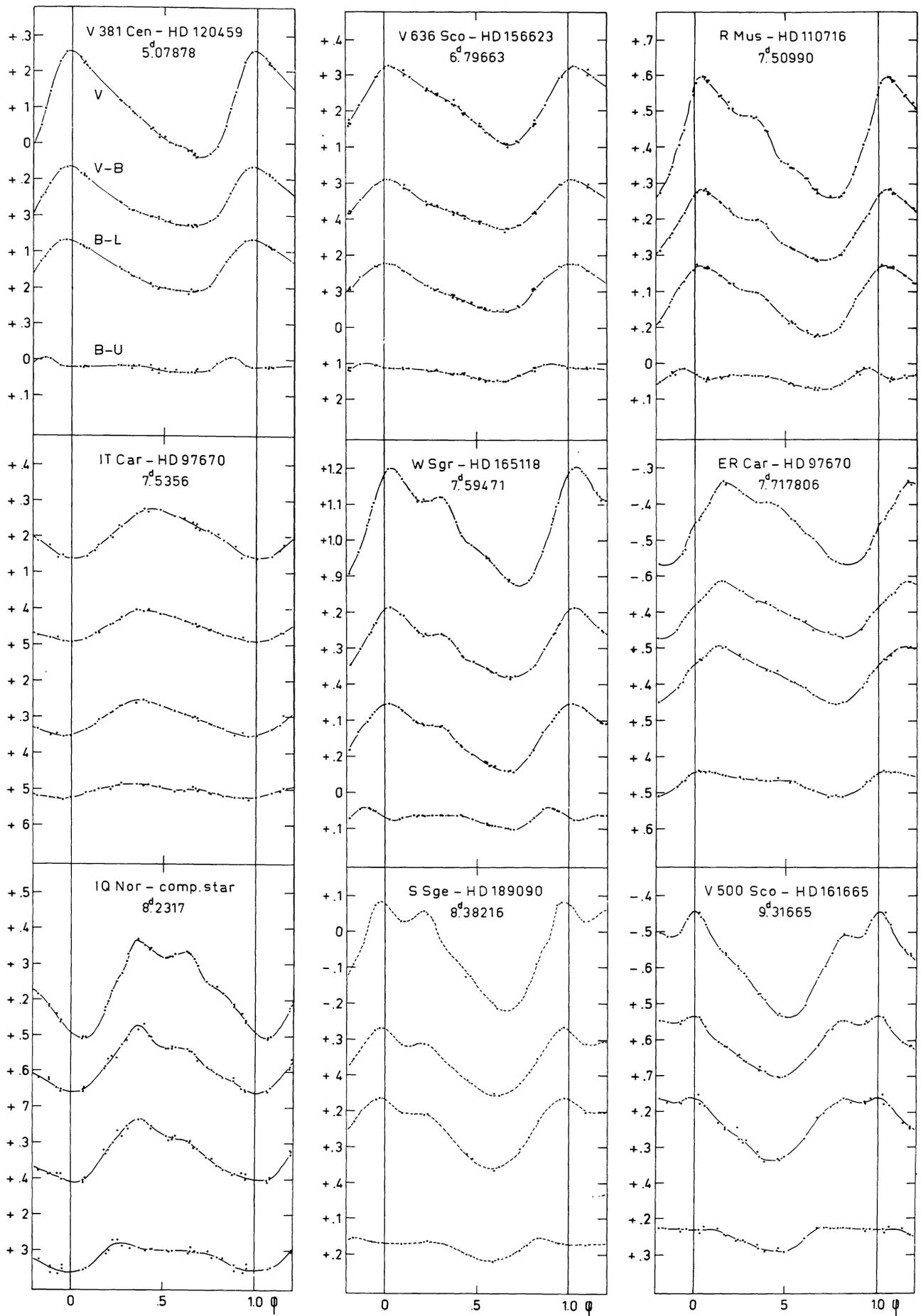
b) The colour-curve $B - U$ is unlike that of other stars of the same period.

c) The intrinsic colours are abnormal as regards position in the colour-colour diagrams.

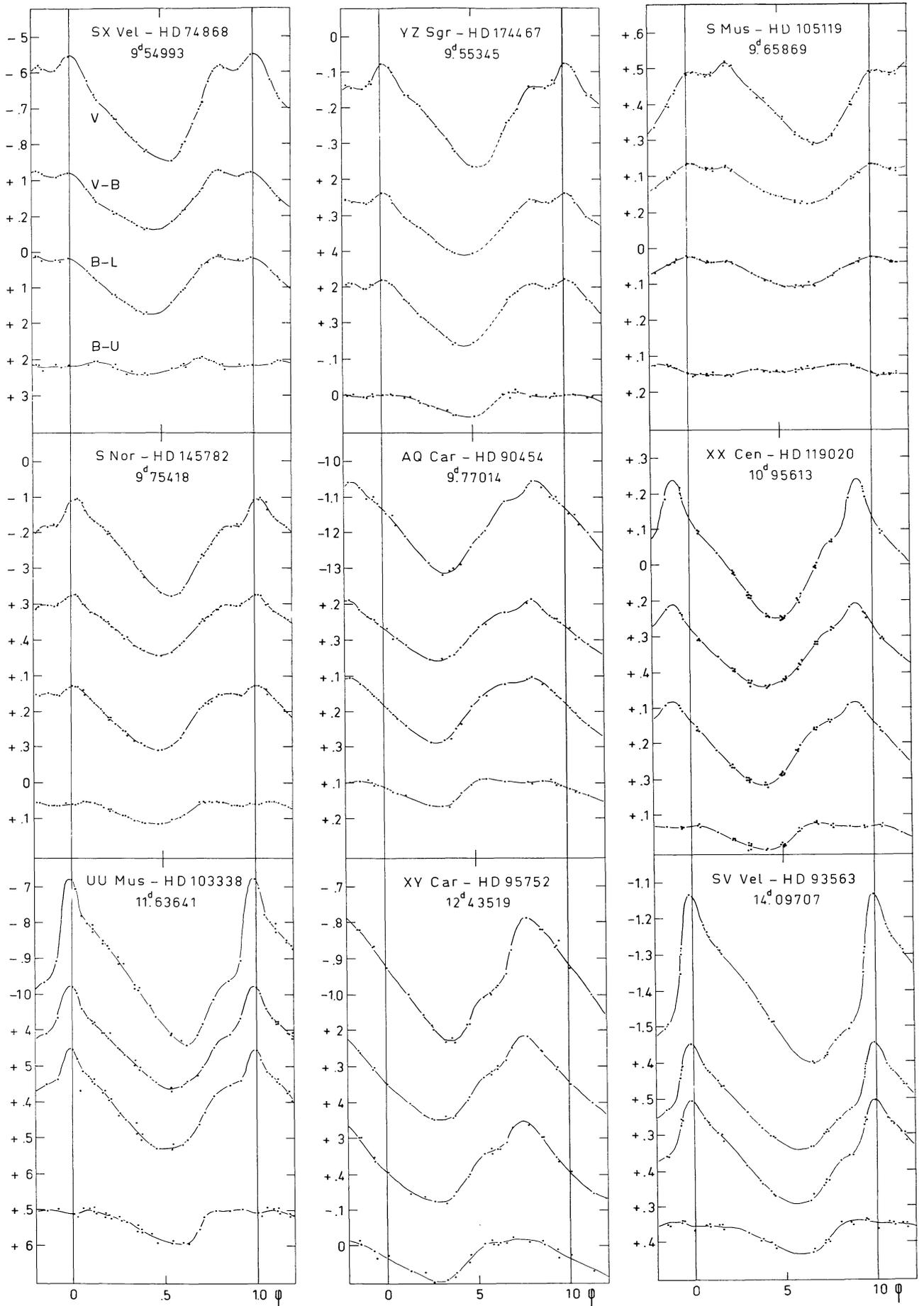
d) The intrinsic colours are abnormal as regards the tilt of the loops in the colour-colour diagrams.

With its abnormal behaviour S Mus stands out from all the other Cepheids observed by us (except of course Kappa Pav). The most probable explanation for this abnormality is the assumption that this star has an invisible companion.

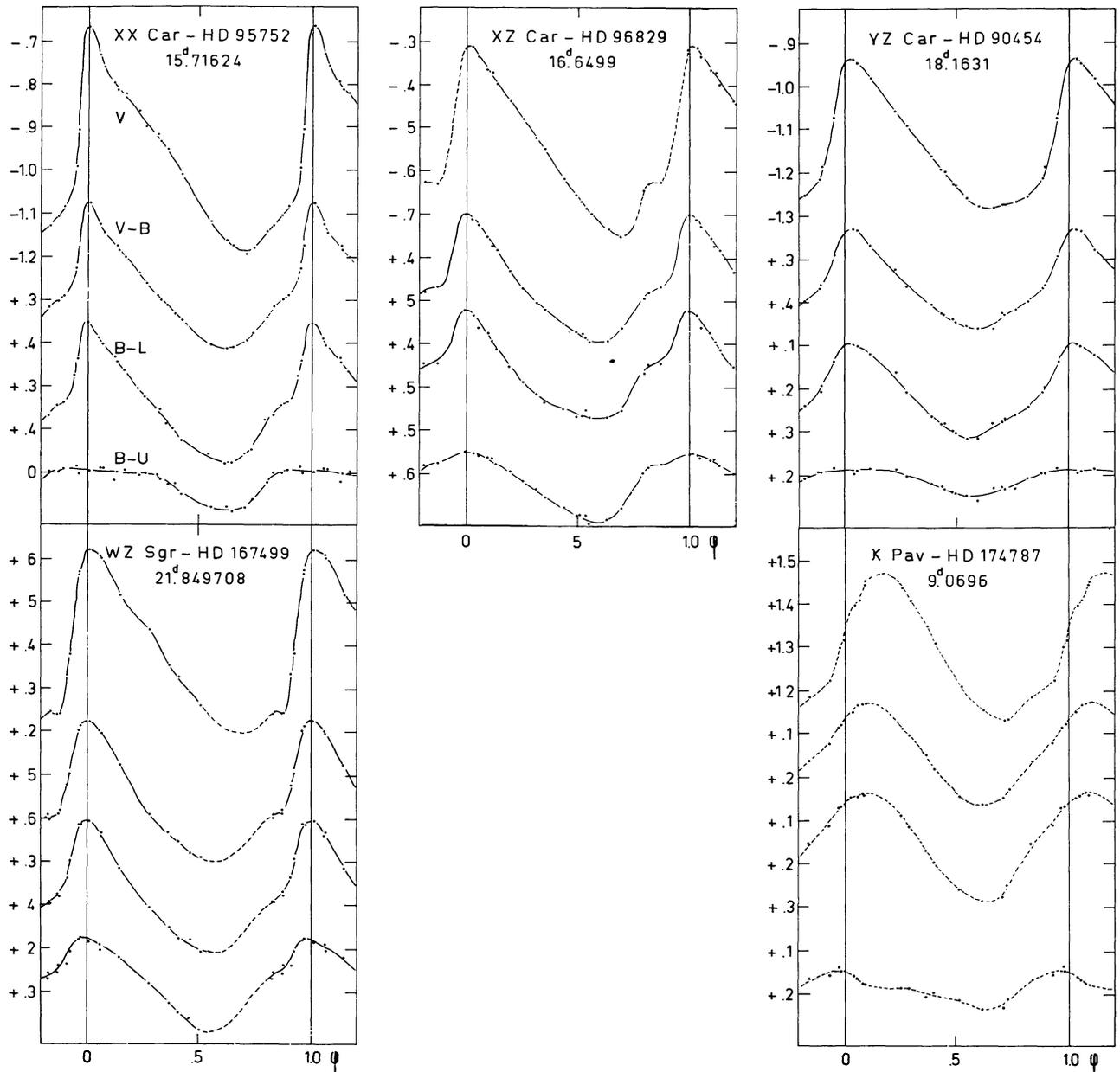
A remark could be made about some of the comparison stars. As described in the previous section, these stars were chosen at random, in the vicinity of the Cepheids. Four of the 28 comparison stars are F or G-type supergiants. This fraction is somewhat larger than one would expect. It might be interesting to in-



Figures 1-9. Light-curves and colour-curves of Cepheids. V , $V - B$, $B - L$ and $B - U$ are expressed in logarithms of intensity.



Figures 10–18. Light-curves and colour-curves of Cepheids. V , $V - B$, $B - L$ and $B - U$ are expressed in logarithms of intensity.



Figures 19-23. Light-curves and colour-curves of Cepheids. V , $V - B$, $B - L$ and $B - U$ are expressed in logarithms of intensity.

investigate whether the numbers of supergiants are normally under-estimated, either in general or perhaps in the vicinity of Cepheids. The four stars, whose supergiant character is established beyond any doubt from the colours $U - W$ and $B - L$, are

HD 95752	GC 15166	6 ^m .96	F0	(near XX and XY Car)
HD 110716	GC 17325	6.34	G0	(near R Mus)
HD 164972	GC 24603	7.25	F0	(near W Sgr)
HD 174467	GC 25852	6.70	A0	(near YZ Sgr).

TABLE 8

Brightness and colours of 24 Cepheids relative to their comparison stars

J. D.: Julian Day + 2 437 000

PHASE: Phase, computed from KUKARKIN *et al.*, 1958

V, V - B, B - U, U - W and B - L are expressed in logarithms of intensity

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J. PONSEN, 1961, *B.A.N.* 15 325 (No. 508)

J. PONSEN, 1963, *B.A.N.* 17 29

TH. WALRAVEN and J. H. WALRAVEN, 1960, *B.A.N.* 15 67 (No. 496)

V 381 Cen - HD 120 459							
J.D.	PHASE	V	V-B	B-U	U-W	B-L	
798.38	564.326	.0905	.2842	.0229	.1876	.1670	
803.36	565.307	.1023	.2827	.0182	.1500	.1578	
804.35	565.502	.0206	.3178	.0244	.2076	.1978	
807.35	566.093	.2076	.2008	.0199	.1529	.0912	
812.36	567.079	.2181	.1953	.0189	.1517	.0901	
814.35	567.471	.0291	.3113	.0257	.1874	.1981	
815.37	567.672	-.0374	.3284	.0290	.1904	.2093	
817.36	568.064	.2222	.1902	.0197	.1555	.0870	
818.35	568.259	.1216	.2638	.0142	.1773	.1422	
820.37	568.656	-.0301	.3320	.0345	.1804	.2094	
821.38	568.855	.0985	.2395	-.0057	.1408	.1133	
822.35	569.046	.2394	.1834	.0202	.1483	.0799	
825.38	569.643	-.0148	.3284	.0329	.1638	.2012	
826.34	569.832	.0516	.2611	-.0016	.1448	.1270	
829.35	570.424	.0415	.3026	.0126	.1791	.1838	
840.32	572.584	-.0063	.3276	.0359	.1566	.2069	
841.33	572.783	-.0081	.3015	.0101	.1687	.1615	
842.28	572.970	.2528	.1685	.0205	.1385	.0682	
844.28	573.364	.0724	.2930	.0174	.1728	.1724	
845.28	573.561	-.0019	.3256	.0278	.1803	.2064	
851.28	574.742	-.0266	.3168	.0300	.1580	.1946	
852.27	574.937	.2280	.1752	.0154	.1388	.0703	
854.28	575.333	.0852	.2869	.0150	.1678	.1694	
855.27	575.528	.0071	.3150	.0332	.1598	.2024	
871.26	578.676	-.0337	.3295	.0270	.1827	.2082	
872.30	578.881	.1458	.2139	-.0036	.1366	.0948	
873.23	579.064	.2240	.1884	.0214	.1498	.0846	
874.26	579.267	.1186	.2640	.0166	.1532	.1488	
875.28	579.468	.0204	.3038	.0443	.1803	.2025	
876.28	579.665	-.0251	.3254	.0384	.1573	.2098	
885.27	581.435	.0466	.3033	.0304	.1735	.1966	
886.25	581.628	-.0192	.3258	.0358	.1810	.2162	

V 636 Sco - HD 156 623							
J.D.	PHASE	V	V-B	B-U	U-W	B-L	
799.44	425.648	.1109	.4370	.1508	.2571	.2494	
803.38	426.227	.2641	.3596	.1187	.2444	.1835	
804.38	426.375	.2308	.3856	.1306	.2553	.2098	
807.36	426.813	.1769	.3814	.1224	.2464	.1922	
812.36	427.549	.1408	.4169	.1521	.2594	.2520	
815.39	427.994	.3170	.2954	.1136	.2392	.1240	
817.38	428.287	.2491	.3664	.1198	.2573	.1974	
818.36	428.431	.1930	.3982	.1290	.2600	.2266	
820.41	428.733	.1174	.4158	.1363	.2634	.2420	
822.38	429.023	.3254	.2930	.1132	.2382	.1254	
825.42	429.470	.1774	.4040	.1412	.2559	.2292	
826.38	429.611	.1185	.4266	.1484	.2661	.2553	
829.38	430.053	.3178	.2983	.1158	.2372	.1276	
839.36	431.521	.1566	.4073	.1464	.2567	.2464	
840.35	431.667	.1000	.4263	.1494	.2610	.2554	
841.36	431.815	.1641	.3716	.1128	.2480	.1947	
842.30	431.954	.2895	.3066	.1082	.2347	.1322	
844.31	432.250	.2506	.3578	.1229	.2409	.1910	
845.31	432.397	.2109	.3807	.1308	.2560	.2222	
850.33	433.135	.2924	.3230	.1168	.2450	.1536	
851.32	433.281	.2412	.3638	.1192	.2574	.1968	
852.33	433.430	.1881	.3933	.1318	.2598	.2274	
853.28	433.569	.1357	.4192	.1486	.2598	.2499	
854.32	433.722	.1127	.4176	.1356	.2454	.2403	
855.30	433.867	.2135	.3504	.1043	.2392	.1616	
871.30	436.221	.2552	.3504	.1251	.2484	.1844	
872.34	436.374	.2164	.3826	.1315	.2528	.2109	
873.29	436.513	.1634	.4110	.1407	.2630	.2450	
874.29	436.661	.1101	.4252	.1506	.2588	.2546	
875.31	436.811	.1631	.3824	.1138	.2564	.1932	
876.31	436.958	.2916	.3040	.1081	.2351	.1314	
877.28	437.100	.2984	.3158	.1136	.2474	.1434	
885.29	438.279	.2444	.3635	.1210	.2438	.1980	
886.28	438.425	.1940	.3912	.1297	.2564	.2278	
899.25	440.333	.2280	.3728	.1275	.2590	.2075	
906.29	441.369	.2189	.3794	.1306	.2525	.2184	
907.30	441.517	.1567	.4079	.1464	.2585	.2463	
909.24	441.803	.1594	.3846	.1208	.2540	.1990	
911.27	442.101	.3126	.3072	.1162	.2328	.1431	

1964BAN...17...520W

TABLE 8 (continued)

R Mus - HD 110 080							W Sgr - HD 165 022						
J.D.	PHASE	V	V-B	B-U	U-W	B-L	J.D.	PHASE	V	V-B	B-U	U-W	B-L
798.33	392.941	.4494	.1893	.0165	.1532	.0744	839.39	428.210	1.0995	.2588	.0668	.2112	.1161
799.34	393.076	.5769	.1363	.0430	.1589	.0403	840.38	428.340	1.0998	.2699	.0659	.2133	.1289
801.34	393.342	.4837	.2065	.0342	.1697	.1065	841.38	428.472	0.9822	.3356	.0749	.2293	.1932
803.33	393.607	.3144	.3074	.0676	.1848	.2113	842.32	428.596	0.9277	.3667	.0920	.2352	.2274
804.32	393.739	.2590	.3148	.0713	.1888	.2188	844.32	428.859	0.9635	.3004	.0484	.2088	.1332
807.34	394.141	.5450	.1604	.0420	.1707	.0595	850.35	429.653	0.8930	.3771	.0982	.2340	.2396
812.34	394.807	.2752	.2903	.0504	.1710	.1848	851.35	429.785	0.8844	.3541	.0808	.2213	.1994
814.32	395.071	.5854	.1330	.0416	.1494	.0351	852.36	429.918	1.0545	.2542	.0482	.1930	.0970
815.36	395.209	.5054	.1926	.0309	.1534	.0816	854.34	430.178	1.1025	.2538	.0664	.2115	.1093
817.34	395.472	.3624	.2708	.0433	.1916	.1712	855.35	430.311	1.1133	.2624	.0656	.2058	.1170
818.33	395.605	.3150	.2079	.0666	.1948	.2164	871.33	432.415	1.1013	.3228	.0672	.2180	.1729
820.35	395.873	.3468	.2428	.0240	.1744	.1244	872.36	432.551	0.9466	.3573	.0903	.2213	.2160
821.35	396.007	.5794	.1309	.0318	.1466	.0293	873.30	432.675	0.8818	.3778	.1024	.2390	.2402
822.33	396.137	.5408	.1574	.0370	.1544	.0584	874.31	432.808	0.9044	.3437	.0711	.2196	.1828
825.35	396.539	.3435	.2885	.0621	.1873	.1914	875.33	432.942	1.0986	.2290	.0517	.1928	.0792
826.32	396.668	.2733	.3199	.0696	.2007	.2255	876.33	433.074	1.1840	.2038	.0753	.1934	.0660
829.33	397.069	.5805	.1339	.0426	.1553	.0366	877.30	433.202	1.1018	.2648	.0638	.2110	.1099
839.32	398.399	.4473	.2304	.0368	.1746	.1277	885.31	434.256	1.1056	.2608	.0630	.2120	.1174
840.30	398.530	.3443	.2882	.0569	.1858	.1895	886.30	434.387	1.0462	.2988	.0654	.2148	.1602
841.31	398.664	.2826	.3183	.0720	.1958	.2218	895.31	435.573	0.9398	.3633	.0919	.2280	.2268
842.27	398.792	.2672	.3032	.0566	.1790	.1932	899.27	436.094	1.1630	.2088	.0702	.2002	.0739
844.27	399.059	.5929	.1204	.0500	.1408	.0389	906.31	437.021	1.1914	.1858	.0770	.1882	.0546
845.27	399.192	.5075	.1840	.0330	.1707	.0802	907.32	437.154	1.1258	.2424	.0630	.2086	.1004
846.29	399.328	.4812	.2082	.0341	.1686	.1043	909.26	437.410	1.0141	.3200	.0623	.2198	.1704
850.29	399.860	.3249	.2540	.0362	.1657	.1440	910.32	437.549	0.9505	.3548	.0856	.2234	.2153
851.26	399.989	.5426	.1398	.0316	.1442	.0430	911.29	437.677	0.8856	.3826	.1012	.2263	.2408
853.23	400.252	.4876	.1996	.0340	.1681	.0997	913.26	437.936	1.0884	.2331	.0506	.2019	.0872
854.26	400.389	.4483	.2182	.0376	.1737	.1256	928.23	439.908	1.0378	.2604	.0448	.1950	.1049
855.25	400.521	.3464	.2856	.0538	.1676	.1838	930.23	440.171	1.1136	.2501	.0684	.2020	.1072
871.24	402.650	.2844	.3145	.0700	.1955	.2258	931.22	440.301	1.1174	.2598	.0640	.2055	.1202
872.26	402.786	.2616	.3036	.0596	.1820	.2014	933.23	440.566	0.9485	.3612	.0924	.2306	.2279
873.22	402.913	.4081	.2114	.0145	.1590	.0926	934.24	440.699	0.8747	.3754	.1045	.2381	.2433
874.23	403.048	.5930	.1252	.0418	.1566	.0380							
875.25	403.184	.5256	.1745	.0360	.1486	.0798							
876.25	403.317	.4838	.2083	.0345	.1686	.1044							
885.24	404.514	.3537	.2814	.0585	.1858	.1914							
886.23	404.646	.2877	.3125	.0765	.1929	.2282							
IT Car - HD 97 670							ER Car - HD 97 670						
J.D.	PHASE	V	V-B	B-U	U-W	B-L	J.D.	PHASE	V	V-B	B-U	U-W	B-L
798.30	1802.561	-0.9202	.4262	.5088	.3454	.3881	798.27	1427.951	-.5237	.4152	.4647	.3269	.3783
799.29	1802.693	-0.9572	.4498	.5050	.3234	.4126	799.28	1428.082	-.3994	.3470	.4412	.3184	.3101
801.30	1802.959	-1.0294	.4915	.5319	.3674	.4574	801.27	1428.340	-.3966	.3728	.4605	.3346	.3478
803.30	1803.225	-0.9887	.4440	.4953	.3972	.3890	803.29	1428.602	-.4809	.4286	.4846	.3458	.4111
804.30	1803.357	-0.9124	.4062	.4904	.3340	.3631	804.28	1428.730	-.5470	.4580	.5088	.3740	.4530
807.29	1803.754	-0.9654	.4596	.5166	.3295	.4240	807.28	1429.117	-.3672	.3264	.4440	.3110	.2986
808.29	1803.887	-1.0014	.4776	.5253	.3656	.4530	808.28	1429.248	-.3634	.3416	.4572	.3226	.3204
812.31	1804.420	-0.9076	.4046	.4903	.3546	.3636	812.30	1429.769	-.5592	.4641	.5050	.3508	.4566
814.28	1804.682	-0.9416	.4484	.5077	.3542	.4070	814.27	1430.024	-.4432	.3735	.4378	.3216	.3337
815.33	1804.821	-0.9859	.4724	.5212	.3655	.4368	815.30	1430.158	-.3373	.3180	.4504	.3156	.3007
817.31	1805.084	-1.0302	.4798	.5132	.3623	.4379	817.30	1430.417	-.3985	.3834	.4657	.3294	.3650
818.30	1805.215	-0.9755	.4458	.5021	.3389	.3921	818.29	1430.545	-.4480	.4188	.4689	.3344	.3972
820.31	1805.481	-0.9027	.4180	.4969	.3533	.3711	820.30	1430.806	-.5665	.4736	.5097	.3516	.4512
821.31	1805.615	-0.9252	.4318	.5066	.3550	.3959	821.29	1430.934	-.5353	.4259	.4694	.3518	.3956
822.30	1805.746	-0.9616	.4574	.5126	.3649	.4210	822.29	1431.063	-.4114	.3544	.4426	.3135	.3249
825.33	1806.148	-0.9990	.4660	.5008	.3284	.3989	825.32	1431.456	-.4048	.3968	.4590	.3302	.3650
826.29	1806.276	-0.9486	.4225	.4857	.3529	.3732	826.27	1431.579	-.4645	.4220	.4761	.3374	.4081
829.30	1806.675	-0.9526	.4418	.5006	.3372	.4035	829.29	1431.970	-.4901	.4036	.4519	.3313	.3650
839.30	1808.002	-1.0340	.4900	.5274	.3667	.4552	839.29	1433.266	-.3714	.3449	.4615	.3157	.3318
840.27	1808.131	-1.0152	.4662	.5090	.3468	.4256	840.27	1433.393	-.3967	.3728	.4684	.3266	.3642
841.28	1808.265	-0.9446	.4300	.4924	.3443	.3737	841.27	1433.523	-.4430	.4114	.4704	.3328	.3938
842.25	1808.394	-0.8998	.4050	.4935	.3298	.3567	842.24	1433.648	-.4954	.4437	.4918	.3478	.4312
844.25	1808.659	-0.9349	.4406	.4967	.3638	.4038	844.24	1433.908	-.5513	.4438	.4817	.3390	.4100
845.25	1808.792	-0.9692	.4664	.5160	.3596	.3292	845.25	1434.038	-.4333	.3633	.4409	.3190	.3348
846.26	1808.926	-1.0337	.4835	.5272	.3694	.4469	846.25	1434.168	-.3530	.3188	.4524	.3198	.2988

ERRATA

In *B.A.N.* 17, 311, 1964 (“The formation of molecular lines in the solar spectrum” by A. SCHADEE) on p. 322, eq. (III, 26) should read as follows:

$$\psi(\alpha\beta) \equiv \psi'(\alpha\beta)/kT.$$

On p. 323 in eq. (III, 30):

$$\text{for } \frac{N(\xi^{++})}{N(\xi)} \text{ read } \frac{N(\xi^{++})}{N(\xi^+)}.$$

In eq. (III, 36):

$$\text{for } \frac{\pi\varepsilon^2}{m_e c^2} \text{ read } \frac{\pi\varepsilon^2}{m_H m_e c^2}.$$

On p. 325 the left-hand side of eq. (III, 50) should read:

$$\varphi(\text{H}) p_g \left[1 + \frac{p(\text{H}_2)}{p_g} \right].$$

In *B.A.N.* 17, 381, 1964 (“The neutral hydrogen in the central region of the Galactic System” by G. W. ROUGOOR) on p. 382, right column, line 3:

for section 5.7
read section 4.7.

On p. 387, table 2, column 8:

for 1 of 8 channels
read 1 or 8 channels.

On p. 424, left column, line 2:

for at ($\lambda = 3$ cm)
read (at $\lambda = 3$ cm).