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Four-colour photometry of hydrogen-deficient stars and related objects

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Summary. Strömgren *uvby* photometry of hydrogen deficient and helium-weak stars suggests that the 'extreme helium' (= 'hydrogen deficient') stars which have been well observed are all variable, probably in a complex way. Previously observed short-term variability of HD 160641 and long-term variability of HD 168476 are confirmed. There is no evidence for variability in the intermediate helium stars or the helium-weak stars.

1 Introduction

In a recent review paper, Hunger (1975) has described the various groups of hot stars with helium abundance peculiarities. For some of these objects, Hill (1969) and Landolt (1968, 1973, 1975) have found evidence of small-scale magnitude variations. In particular, the extreme helium star, BD $+13°3224$, has a reasonably well-defined period of 0.1 day with an amplitude of 0.1 mag in V (Landolt 1975).

We have made four-colour (*uvby*) observations on several nights to search for variability in three extreme helium stars (HD 124448, 160641, 168476), three intermediate helium stars (HD 133518, 168785, CPD $-69°2698$), one helium-rich subdwarf (HD 127493) and two helium-weak stars (HD 5737, 202671). The star HD 120640 was originally thought to be an intermediate helium star and was included in our programme. However, a fine-abundance analysis by Detz (1977) has shown it to be a normal B star; Houk (1978) classifies it B2 III.

2 Four-colour photometry

Photoelectric observations were made in 1976 July, 1977 and 1978 June with a 'Peoples' photometer on the 0.5-m telescope of the South African Astronomical Observatory (SAAO). The 1978 data were obtained with a pulse-counting system and the remainder by d.c. integration. No significant systematic differences were detected between data obtained with the two modes of operation. Standard stars were taken from Crawford & Barnes (1970) with some secondary 'standards' from Crawford, Barnes & Golson (1970). On a given night, up to 20 standards were observed, including one or two over a good range of air mass to check extinction coefficients. For the programme stars, the observing sequences C, V, C or

C_1, V, C_2, V, C_1 were generally used. In the early series of observations, single measurements (comparison followed by suspected variable) were made occasionally during a given night.

With the d.c. system, a 30-s integration time was used in each stage of the sequence *ybvuuvby* (star), *uvby* (sky). In 1978, the pulse-counting observations were mostly made with the 'b' filter alone to improve time resolution. In this case, a set of six 20-s integrations were made on each object (comparison or suspected variable).

3 Results

The mean four-colour data are listed in Table 1 which gives star name, V, $(b-y)$, m_1 and c_1, together with standard deviations in each quantity in units of 0.001 mag and the total number

Table 1. Four-colour photometry.

Star		V	σ	(b-y)	σ	m_1	σ	c_1	σ	n	He	Comp
HD	5737	4.313	9	−0.067	10	0.101	12	0.482	11	10	weak	
HD	6178	5.505	9	0.040	5	0.188	8	1.052	8	11		A2V
HD	120640	5.777	6	−0.067	7	0.095	9	0.186	11	21	B2III	
HD	121483	6.964	8	−0.049	8	0.088	11	0.267	12	28		B2/3 IV
HD	124286	9.950	16	0.188	14	0.192	17	0.848	17	10		A9 V
HD	124448	9.993	27	−0.005	14	0.055	17	0.123	17	12	extr.	
HD	127493	10.045	8	−0.111	9	0.046	13	−0.206	10	7	sdO	
HD	132101	6.791	6	0.007	7	0.088	10	0.469	12	22		B5 V
HD	133518	6.397	7	−0.024	6	0.090	7	0.173	10	14	int.	
HD	143699	4.899	5	−0.061	3	0.102	4	0.360	9	3	weak	
HD	144334	5.919	4	−0.012	2	0.102	3	0.337	4	2	weak	
HD	144472	5.866	4	0.036	4	0.111	6	0.585	7	3		A3
HD	144661	6.328	3	0.007	2	0.094	4	0.381	4	2	weak	
BD	$-9^\circ 4395$	10.52		0.141		0.001		−0.147		1	extr.	
BD	$+13^\circ 3224$	10.59		−0.074		0.074		−0.064		1	extr. (var)	
HD	154198	8.375	5	0.254	9	0.130	10	0.995	8	7		FO III
CPD	$-69^\circ 2698$	9.359	8	−0.041	6	0.069	10	0.050	9	7	int.	
BD	$-17^\circ 4880$	9.411	9	0.115	7	0.093	9	1.019	12	8		B
HD	160641	9.838	22	0.200	10	−0.053	13	−0.125	13	10	extr.	
BD	$-1^\circ 3438$	10.29		0.381		0.039		0.276		1	extr.	
CPD	$-56^\circ 8745$	10.251	6	0.174	8	0.171	11	0.944	20	5		A
HD	167918	7.803	7	−0.003	6	0.079	8	0.504	8	24		B5 III
HD	168476	9.297	19	0.043	10	0.061	15	0.188	15	63	extr.	
HD	168785	8.506	6	0.074	6	0.045	7	0.075	6	6	int.	
HD	168910	9.879	20	0.142	11	0.213	16	0.961	34	39		A8 V
HD	202671	5.404	9	−0.044	4	0.098	7	0.535	16	15	weak	
HD	202723	7.605	14	0.208	6	0.191	8	0.733	11	17		A5

of observations in the mean. The final two columns give spectral-type comments: 'weak', 'intermediate' or 'extreme' for the anomalous helium abundance stars and, for the comparison stars, spectral types from Hoffleit (1964), Houk & Cowley (1975), Houk (1978) or the HD catalogue when no other type could be found in the literature. Pedersen & Thomsen (1977) suspect HD 144334 to have variable helium line strength and Hoffleit (1964) notes HD 144661 as a velocity variable.

Four stars in Table 1 are common to the Lindemann & Hauck (1973) compilation of four-colour photometry, and from these we obtain the following mean residuals:

$\Delta(b-y) = +0.003 \pm 0.010$
$\Delta m_1 = +0.001 \pm 0.005$
$\Delta c_1 = -0.010 \pm 0.013$

the sense being this paper *minus* Lindemann & Hauck.

Figs 1 and 2 are the $(b-y) - m_1$ and $(b-y) - c_1$ diagrams for the stars listed in Table 1. Intrinsic colour lines are taken from Slettebak, Wright & Graham (1968) and Crawford (1970, 1975, 1978). The helium stars do not appear to occupy an unusual position in the colour–colour index diagrams although they have higher c_1 indices than expected for their temperatures. This is due to the absence of hydrogen (in the case of the 'extreme' stars) and consequently of a Balmer discontinuity. In these stars, the c_1-index is primarily a measure of the helium discontinuities at 3725 and 3450 Å.

We can obtain a rough colour–temperature correlation for the extreme helium stars analogous to that derived by Philip & Newell (1975) for 'normal' B stars. These authors calibrate the reddening-free parameter

$$[u-b] = (u-b) - 1.61(b-y)$$

against θ_e for Population I and II blue stars. In Fig. 3 we show the Philip & Newell (1975) calibration together with data for the extreme helium stars. The $[u-b]$ values are derived from Table 1 photometry; θ_e results are from Aller (1954), Schönberner & Wolf (1974),

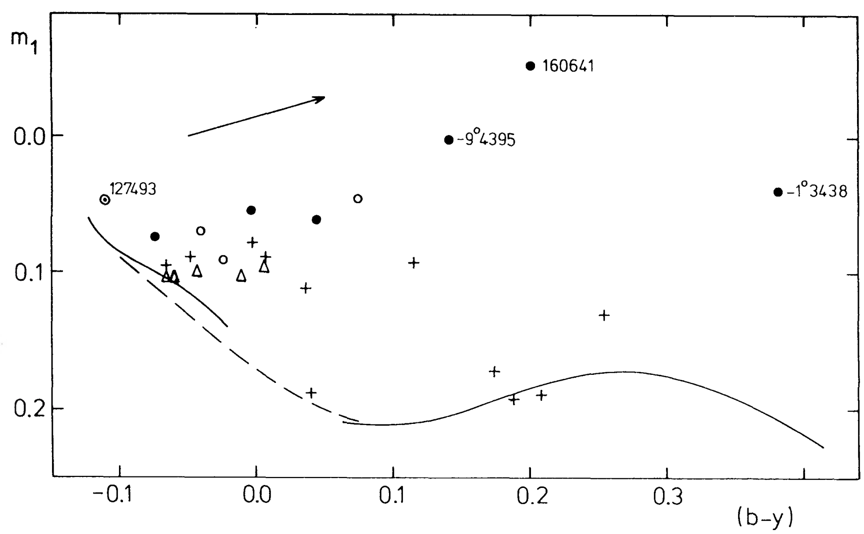

Figure 1. $m_1 - (b-y)$ diagram for Table 1 stars. Intrinsic colour lines are from Slettebak *et al.* (1968) (broken line) and Crawford (1970, 1975, 1978). The arrow indicates the effect of interstellar reddening. Symbols are as follows: •, 'extreme helium' stars; ○, 'intermediate helium'; △, 'helium-weak'; +, comparison stars. HD 127493 is a helium-rich sdO star.

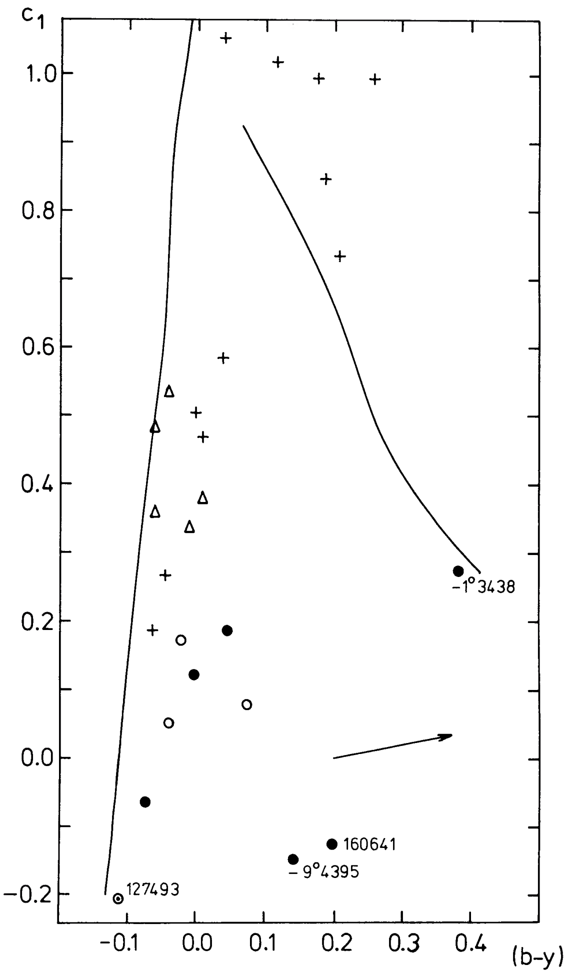

Figure 2. $c_1 - (b-y)$ diagram for Table 1 stars. Comments are as for Fig. 1.

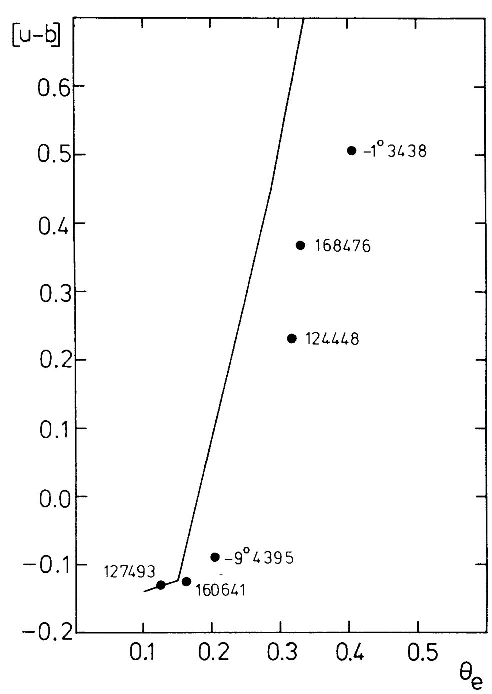

Figure 3. $[u-b]$ versus θ_e calibration for B stars from Philip & Newell (1975), together with derived data for the extreme helium stars and HD 127493.

Kaufmann & Schönberner (1977) and Schönberner (1978). The extreme helium stars are clearly cooler than B stars with the same [u–b].

4 Variability

The standard deviations of the mean V magnitudes in Table 1 suggest that most of these stars are not variable. Exceptions are the three helium stars, HD 124448, 160641 and 168476, and one star, HD 168910, originally used as a comparison for HD 168476.

HD 160641

In Table 2 we list differential 'b' magnitudes from the 1978 data for three stars. Inspection of the standard deviations suggests that HD 160641 varies on a time-scale of less than 1 day. Inspection of Δb values, standard deviations and comparison star 'b' magnitudes suggests that the other two stars are not variable on time-scales of several hours or a few days.

Landolt (1975) estimates that HD 160641 may have a period of about 0.6 day. Application of the period-finding program by Morbey (1973) to our differential 'b' magnitudes results in a 'best-fit' around 0.71 day. The Δb data and 'b' magnitudes for the comparison star are phased accordingly in Fig. 4. Because these data only cover four days and the derived period is a large fraction of a day, we have only about one-half of the light-curve displayed and so the period must remain rather uncertain. In fact, attempts to fit a few earlier four-colour observations to the above period were unsuccessful and this must cast some doubt on existence of a simple period. In this context, Fig. 1 of Landolt (1973) shows small variations, on a time-scale of ~2 hr, superimposed on a secular brightening over about 7 hr.

Table 2. 'b' magnitudes from 1978 data.

Star (Var – Comp)	Hel. J.D. (2440000+)	Δb	σ	n	Comp 'b'	σ	n
HD 127493	3662	2.819	5	18	7.108	2	18
minus	3663	2.817	5	15	7.116	7	14
HD 127208	3665	2.802	2	9	7.126	1	8
HD 160641	3662	−0.732	8	16	10.729	11	15
minus	3663	−0.727	22	20	10.722	7	20
BD −17°4880	3665	−0.713	26	23	10.726	11	24
HD 168476	3659	1.551	3	12	7.774	5	12
minus	3660	1.555	3	15	7.789	2	15
HD 167918	3662	1.561	1	14	7.783	2	13
	3663	1.554	2	11	7.790	4	12
	3665	1.559	3	15	7.788	4	14

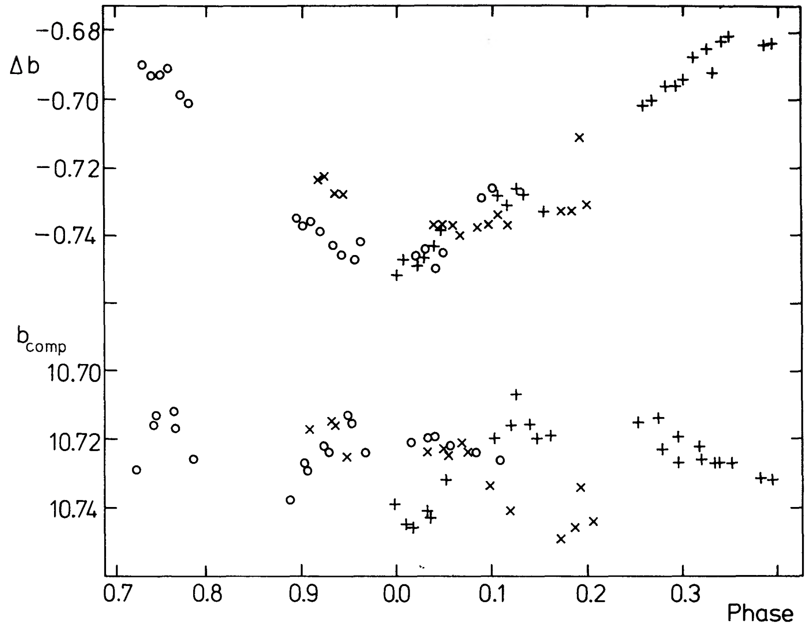

Figure 4. Differential '*b*' magnitudes. Δ*b*, for HD 160641 *minus* BD −17°4880 and '*b*' magnitudes for the comparison BD −17°4880. Each symbol represents observation on a given night.

HD 168476

In Table 3 are listed the mean four-colour observations of HD 168476 for individual nights. The standard deviations in *V* on a given night suggest that there is no variation of the star on a time-scale of hours (see also Table 2). Analysis of the Table 3 observations using Bartlett's statistic indicates that, if the data for each night can be regarded as random samples from normal populations, the variances are not significantly different. On that basis, the hypothesis of equality of the mean of the populations for each night is strongly rejected at a significance level of 0.1 per cent. The conclusion is therefore that HD 168476 is a light variable on a time-scale of about one year or less.

The data also suggest a light variation on a much longer time-scale; Landolt (1973) has noted an apparent secular brightening between 1960 and 1973. Fig. 5 shows all published *V*-magnitude data (Hill 1960; Landolt 1973 and this paper) which indicate a brightening of

Table 3. HD 168476: Mean four-colour observations from individual nights.

Hel. J.D. (2440000 +)	V	σ	(b-y)	σ	(v-b)	σ	(u-b)	σ	n
2972	9.298	5	0.048	7	0.116	8	0.398	13	8
2974	9.301	6	0.050	8	0.102	7	0.392	6	12
2979	9.324	10	0.033	12	0.114	5	0.398	11	7
2980	9.324	4	0.034	9	0.118	6	0.384	6	5
3299	9.275	7	0.040	7	0.092	6	0.399	4	12
3379	9.284	7	0.043	7	0.101	5	0.403	9	5
3662	9.304	7	0.047	1	0.108	7	0.393	5	3

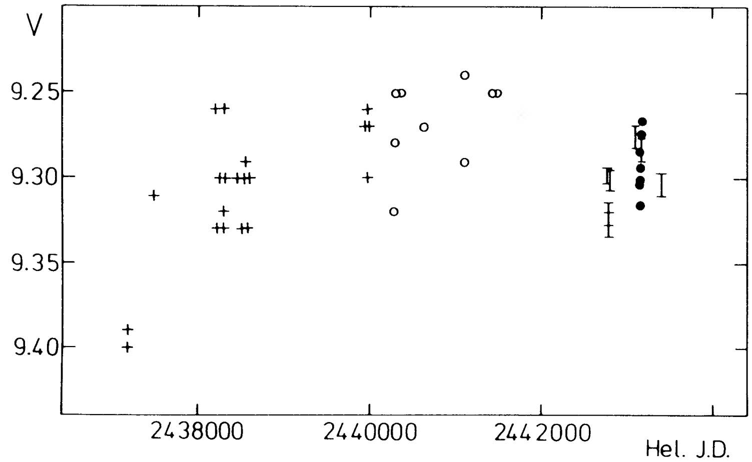

Figure 5. Published magnitudes of HD 168476. Symbols for single observations are: + (Hill 1969), ○ (Landolt 1973), • (this paper). The error bars are for several observations on a given night (see Table 3).

the star from 9.40 mag in 1960 to 9.25 mag in 1972, followed by a fading to about 9.30 mag in the most recent observations (1978). The long- and short-term variations reinforce our conclusion for HD 160641, that any variability is probably complex.

HD 124448

Hill (1969) thought this star was constant in magnitude, although Landolt (1973) suggested it to be variable. We have been unable to detect any periodic or systematic variation in our few observations but the standard deviation in V is almost twice that for the comparison star which is of similar magnitude. Standard deviations of colour indices are identical for the two stars. It therefore seems likely that HD 124448 is also a small amplitude variable.

5 Discussion

Of the six extreme helium stars in Table 1, the three which have significant numbers of observations are proven or probable light variables. Of the remaining three, BD $+13°3224$ is a known small-amplitude (light) variable and BD $-9°4395$ is suspected to have variable C II λ4267 and He II λ4686 (Kaufman & Schönberner). Dr Landolt (private communication) has indicated that his broadband photometry shows BD $-9°4395$ and $-1°3438$ to be variable and he agrees with our general conclusion that all observed extreme helium (= hydrogen deficient) stars vary in brightness.

The nature of the variations involved are not yet clear but, since we have evidence for possible 'periods' from 0.1 day (BD $+13°3224$) to many years (HD 168476), it may be that the nature of the variation is a property of individual objects rather than a group characteristic. In addition, it seems highly probable that variation in the extreme helium stars is rather complex.

Schönberner (1977) has shown that the rate of change of magnitude due to fast evolution through the helium-star phase is very small in observational terms, around 0.001 mag/yr, so that the observed variations are probably not a direct consequence of such fast evolution. Because the helium stars are related to the RCrB stars (Schönberner 1977) it may be that variability is a residue of that experienced in the RCrB stage. In any case, determination of the exact nature of the helium star variations is clearly of importance to the understanding of their nature and evolutionary status.

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