Astron. Astrophys. 154, 308–312 (1986)

ASTRONOMY AND ASTROPHYSICS

VBLUW photometry of two hypergiants HD 80077 (B2Ia$^+$) and HD 74180 (F2Ia$^+$) and of the open cluster Pismis 11

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Received July 4, accepted August 20, 1985

Summary. We present and discuss *VBLUW*-photometry of HD 80077 and HD 74180, two galactic hypergiants, and in addition also of the young open cluster Pismis 11, of which HD 80077 presumably is a member. Both hypergiants were observed for several months during two consecutive years, and appear to show small, irregular variations in brightness and colours. The results of our observations concerning distances and reddening do not contradict other studies of these stars.

Key words: supergiants – variables – photometry – open cluster

1. Introduction

In an article by Moffat and FitzGerald (1977) about supergiants associated with groups of luminous OB stars, special attention was drawn to the stars HD 80077 (B2Ia$^+$) and HD 74180 (F2Ia$^+$), which appeared to be superluminous. Later Knoechel and Moffat (1982) published an extended investigation of HD 80077, involving spectroscopy, polarimetry and wide-band photometry. We present *VBLUW* photometry (Walraven-system) of HD 80077 and HD 74180, and of Pismis 11, a small open cluster, associated with HD 80077, with the aim to find new values for the stars' parameters and to compare these with previous values. The observations of the hypergiants are spread over a long time in order to detect a possible variability, as found for numerous other supergiants.

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2. Observations and reductions

The observations were made with the *VBLUW*-photometer of Walraven, attached to the 90-cm lightcollector of the former Leiden Southern Station at the SAAO annex in South-Africa; the hypergiants in February-May 1977 and January-June 1978, the cluster Pismis 11 in three nights in February 1977. A description of the photometer and the photometric system has been given by Walraven and Walraven (1960), Rijf et al. (1969) and Lub and Pel (1977).

We measured all cluster stars numbered on the identification chart of Moffat and FitzGerald (1977), with respect to a large number of standard stars. Each night the observations of the hypergiants HD 80077 and HD 74180 were done a few times alter-

Table 1. The photometric parameters of the stars of Pismis 11 in the *VBLUW* photometric system of 1970/1978 (in log intensity scale) and in the *UBV* system (with subscript *J*)

Star	V	$V-B$	$B-U$	$B-L$	V_J	$(B-V)_J$	n	Member
3	− 2.140	0.317	0.400	0.380	12.18	0.78	3	
4	− 2.317	0.388	0.263	0.166	12.60	0.98	2	*
5	− 2.375	0.401	0.233	0.137	12.75	1.01	3	*
6	− 2.432	0.381	0.253	0.152	12.89	0.96	2	*
7	− 2.328	0.241	0.293	0.251	12.66	0.60	3	
8	− 2.664	0.901	0.787	0.453	13.39	2.30	1	
9	− 2.609	0.351	0.272	0.158	13.34	0.89	2	*
10	− 2.617	0.434	0.357	0.206	13.35	1.10	3	*
11	− 2.356	0.368	0.681	0.320	12.71	0.94	2	
12	− 1.923	0.777	0.843	0.525	11.55	1.99	1	
13	− 2.095	0.343	0.186	0.121	12.06	0.86	3	*
14	− 2.130	0.189	0.322	0.193	12.17	0.47	2	
15	− 2.094	0.208	0.338	0.237	12.08	0.52	2	
16	− 2.027	0.250	0.328	0.273	11.90	0.62	2	
17	− 1.303	0.472	0.617	0.540	10.06	1.13	2	
SLS 1267	− 1.704	0.396	0.202	0.131	11.07	1.00	3	*

Table 2. The differences of magnitude V_J and colours $(B-V)_J$ between those based on this work and on those of Moffat and FitzGerald (1977)

ΔV_J	-0.005
σ	± 0.051
$\sigma/\sqrt{n}$	± 0.013
$\Delta(B-V)_J$	$+0.02$
σ	± 0.08
$\sigma/\sqrt{n}$	± 0.02

nated by the comparison stars HD 88015 (B3III) and HD 93030 (O9.5 *V*). Since they are standard stars of the Walraven-system, the brightness and colours on the natural *VBLUW*-system could be easily found. As is the normal practice in this photometric system, brightness and colours are expressed in terms of the logarithm of the intensity. The *V*-magnitude and the $B-V$ colour of the *UBV*-system (subscript *J*) were found with the aid of formulae provided by Pel (1982) and Thé et al. (1980), respectively. These transformations are best applicable to unreddened stars.

Table 1 lists brightness and colours in *VBLUW*- and *UBV*-system of the measured stars of Pismis 11. The colour index $U-W$ has been omitted because the flux in the *W* passband ($\lambda_{\text{eff}} \sim 3250$ Å) was very low. The number of observations per star is given in the column with the heading "n", and the membership is indicated by an asterisk in the last column (see Sect. 3). The average differences between our values for V_J and $(B-V)_J$ and those of Moffat and FitzGerald (1977) (results of this work minus those of Moffat and FitzGerald) are listed in Table 2 together with standard deviations and mean errors. The agreement is satisfactory.

Table 3 lists brightnesses and colours of HD 80077 and HD 74180. The average standard deviation in brightness and colours is estimated to amount to ± 0.006 and ± 0.003 in log intensity respectively, except for JD 2443220.38, 2443539.47, 2443576.45 and 2443651.22; for these nights the errors could be somewhat larger (in Figs. 2 and 3 indicated by circles). The colour-index $U-W$ is omitted because of a low *W*-flux, resulting

Table 4. Average photometric parameters of the two hypergiants. Bracketed values are from Moffat and FitzGerald (1977)

	HD.80077	HD 74180
$\langle V \rangle$	-0.320	1.207
$\langle V-B \rangle$	0.548	0.293
$\langle B-U \rangle$	0.319	0.553
$\langle U-W \rangle$		0.419
$\langle B-L \rangle$	0.198	0.200
$\langle V_J \rangle$	7.59 (7.58)	3.81 (3.80)
$\langle (B-V)_J \rangle$	1.40 (1.37)	0.74 (0.72)

Table 3. Brightnesses and colour-indices of the two hypergiants

$JD-2440000$	V	$V-B$	$B-U$	$B-L$	V_J	$(B-V)_J$
HD 80077						
3186.47	-0.299	0.544	0.317	0.199	7.53	1.27
3189.46	-0.306	0.547	0.318	0.197	7.55	1.28
3198.45	-0.324	0.545	0.313	0.197	7.60	1.27
3220.38	-0.313	0.551	0.310	0.188	7.57	1.29
3248.32	-0.325	0.552	0.315	0.195	7.60	1.29
3265.23	-0.326	0.553	0.313	0.199	7.60	1.29
3275.25	-0.316	0.550	0.319	0.197	7.58	1.29
3289.26	-0.321	0.554	0.310	0.192	7.59	1.29
3535.36	-0.314	0.552	0.316	0.207	7.57	1.29
3539.47	-0.331	0.546	0.340	0.199	7.61	1.28
3576.45	-0.318	0.547	0.330	0.206	7.58	1.28
3592.31	-0.325	0.545	0.318	0.203	7.60	1.27
3672.27	-0.329	0.545	0.322	0.188	7.61	1.27
HD 74180						
3186.47	1.229	0.286	0.544	0.193	3.76	0.70
3189.46	1.215	0.290	0.547	0.196	3.79	0.71
3198.45	1.207	0.293	0.548	0.198	3.81	0.72
3220.38	1.168	0.279	0.556	0.205	3.91	0.69
3248.32	1.195	0.299	0.556	0.203	3.84	0.73
3265.23	1.205	0.294	0.550	0.198	3.82	0.72
3275.25	1.206	0.294	0.553	0.198	3.81	0.72
3289.26	1.201	0.295	0.548	0.196	3.83	0.72
3535.36	1.209	0.290	0.560	0.205	3.81	0.71
3539.47	1.204	0.295	0.559	0.202	3.82	0.72
3576.45	1.203	0.298	0.561	0.206	3.82	0.73
3582.41	1.198	0.300	0.559	0.206	3.83	0.73
3592.31	1.203	0.294	0.558	0.202	3.82	0.72
3651.22	1.200	0.304	0.577	0.210	3.83	0.74
3672.27	1.217	0.283	0.550	0.196	3.79	0.70

in a large scatter in $U-W$. Only the average $U-W$ of HD 74180 is accurate enough to be used.

Table 4 lists the average brightnesses and colours of both hypergiants, which will be used to derive some properties of these stars. Also listed are V_J and $(B-V)_J$ as found by Moffat and FitzGerald (1977).

3. The cluster stars of Pismis 11

By comparing the positions of the stars in the field of Pismis 11 in the $V-B/B-U$, $V-B/B-L$ and $[B-U]/[B-L]$ diagrams, where $[B-U]$ and $[B-L]$ are extinction-independent parameters, defined by:

$$[B-U] = (B-U) - 0.63\,(V-B)$$

$$[B-L] = (B-L) - 0.44\,(V-B)\ ,$$

with respect to the (unreddened) main sequence, we conclude that the stars 4, 5, 6, 9, 10, 13 and SLS 1267 are members of Pismis 11, whereas the others do not belong to this cluster. The average reddening amounts to $\langle E(V-B)\rangle = 0.486 \pm 0.030$ (*s.d.*), or with $E(B-V)_J = 2.57\,E(V-B)$ (Lub, 1980; Pel, 1981), valid for OB-type stars: $\langle E(B-V)_J\rangle = 1.25 \pm 0.08$ (*s.d.*). This compares very well with the value of Moffat and FitzGerald (1977): $\langle E(B-V)_J\rangle = 1.26 \pm 0.06$ (*s.d.*). With the aid of the relation $A_V = 3.43\,E(V-B)$ (Pel, 1981), and the individual reddenings of these 7 stars, a corrected CM-diagram can be made resulting into the distance of the cluster by fitting it to the main sequence of Thé et al. (1980): $r = 2.8 \pm 0.4$ kpc. This compares very well with the 3.2 kpc found by Moffat and FitzGerald (1977). As an average we shall take $r = 3.0$ kpc. Figure 1 shows the $M_{V_J}/(B-V)_{J_0}$ diagram for the members of Pismis 11 and the hypergiant HD 80077 (Sect. 4), together with a few empirical isochronous curves of Mermilliod (1981). The age is presumably comparable to that of the NGC 2362 group. For this group no age is explicitly given, but it is certainly less than $2.2\,10^7$ yr. Indeed, the age of HD 80077 is much lower than this value (see Sect. 4).

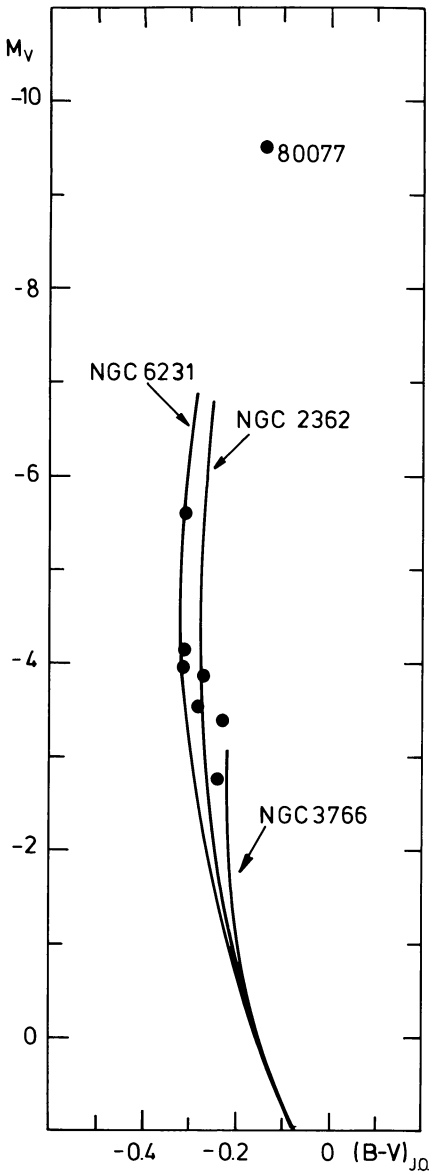

Fig. 1. The HR diagram (in the *UBV* system) of the open cluster Pismis 11. The empirical isochronous curves of a few young open star cluster groups according to Mermilliod (1981) are shown

4. HD 80077

HD 80077 is located in the field of Pismis 11. This star has a spectral type B2Ia$^+$e (Garrison, 1976, quoted by Moffat and FitzGerald, 1977) and can therefore be called a hypergiant (= super-supergiant: luminosity class Ia^+). Figure 2 shows the brightness and colours versus Julian Date. The error bar refers to twice the standard deviation and is shown in the top left hand corner. Obviously the star shows light variations of the order of 0.03 in V (or $\sim 0^m.07$) on a long time-scale. A quasi- or characteristic period $\bar{P}$ cannot be determined. In the colour indices the variations amount to 0.01 in $V-B$ to 0.03 in $B-U$. Similar to other high luminous stars, the variations in the latter colour index are largest (the U band contains the Balmer jump), indicating that temperature and/or density variations occur on these stars (van Genderen et al., 1985). Knoechel and Moffat (1982) also detected a light variation, during a time interval of $\sim 25^d$, of which the total amplitude is $\sim 0^m.03$.

Now let us focus our attention to the averages of the photometric parameters of this star. If the star is corrected with the average cluster reddening, its reddening should obviously be higher in view of its position with respect to the grid of theoretical colours. This grid is based on model atmospheres of Kurucz (1979) and computed by Lub and Pel (1977). By adopting a $T_{\rm eff} \sim 19000$ K which is valid for B2 supergiants, the reddening turns out to be $E(V-B) = 0.598$ (compare with the average cluster reddening of 0.486) and the gravity $\log g \sim 2.2$. The latter value is in good accordance with the values listed by de Jager (1984) for two other B-type hypergiants. Then the intrinsic photometric parameters are:

$$V_0 = 1.589$$

$$(V-B)_0 = -0.050$$

$$(B-U)_0 = -0.058$$

$$(B-L)_0 = -0.065\ .$$

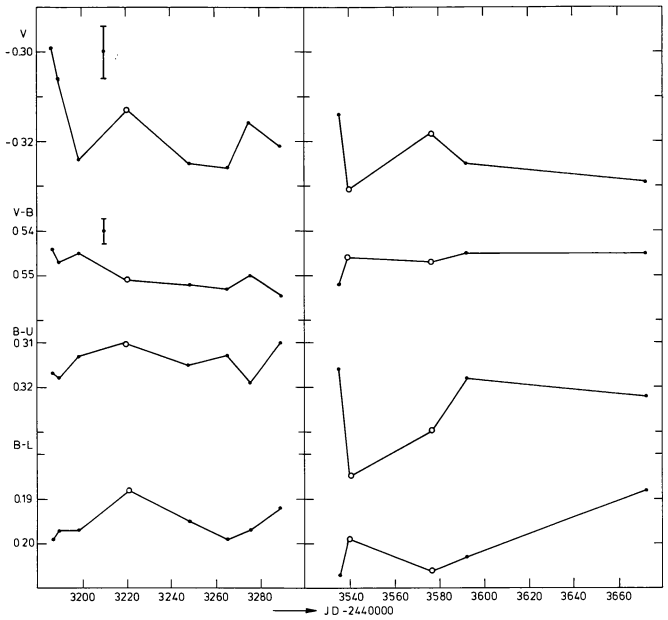

Fig. 2. The light- and colour curves (in log intensity scale) of HD 80077 as a function of the Julian Date. The error bars refer to twice the standard deviation. Circles are less accurate than dots

The reddening and the equivalent parameters in the *UBV*-system are:

$E(B-V)_J = 1.54$ (average cluster reddening: 1.26)

$V_{J_0} = 2.31$

$(B-V)_{J_0} = -0.14$.

Moffat and FitzGerald (1977) found $E(B-V)_J = 1.46$, $(B-V)_{J_0} = -0.09$, and according to Knoechel and Moffat (1982) $E(B-V)_J = 1.53$, assuming $(B-V)_{J_0} = -0.16$.

Our values for $\log g$ and $(B-V)_{J_0}$ are also consistent with the spectrum B2I according to Allen (1973) and Flower (1977). If we further assume that HD 80077 is a member of Pismis 11, its distance is 3.0 kpc, then $M_{V_J} = -9.5 \pm 0.5$. Moffat and FitzGerald (1977) found $M_{V_J} = -9.5$ and Knoechel and Moffat (1982) gave a few estimates ranging from -8.8 to -9.5. With the bolometric correction according to Flower (1977): $M_{bol} = -11.1$ and so $\log L/L_\odot = 6.35$. From a comparison with the evolutionary tracks with mass loss (case B) of Maeder (1983) the mass $M \sim 50\,M_\odot$ and the age $t \sim 3\,10^6$ yr and with the empirical PLC-relation of Maeder (1980): quasiperiod $\bar{P} \sim 30-50$ days.

The results of Knoechel and Moffat (1982) are generally the same, with that difference that they found a 21.2 days-period from the polarimetry, which is ascribed to a companion. We are not able to confirm this period, nor the longer one according to the empirical PLC relation. The reason is, of course, that our observations are too far apart in time and too little in number. Besides, it is quite well possible that these variations are caused by the intrinsic variations (partly quasi periodic, partly stochastic) to which all supergiants are apparently subject to (e.g. van Genderen, 1985).

5. HD 74180

This star has a spectrum F2Ia (Garrison, 1976, quoted by Moffat and FitzGerald, 1977) or even F2Ia$^+$ (FitzGerald et al., 1979). The IUE spectrum is sF2 (IUE Low-Dispersion Spectra 1984) and the MK spectral classification is F3Ia (Buscombe, 1977).

Figure 3 shows the diagram of brightness and colours versus Julian Date. The star is clearly variable by ~ 0.06 in V (or $\sim 0^m.15$). A rough time-scale for the variations in the first set of observations is ~ 90 days. The variations in the colours amount to ~ 0.02.

Since we have no information on the interstellar reddening, we assume that the intrinsic colour index is $(B-V)_{J_0} = 0.22$ (Schmidt-Kaler, 1982). From the relation between the colour indices $(B-V)_J$ and $V-B$ we then find $(V-B)_0 = 0.089$, thus $E(V-B) = 0.204$, which is of the same size as the reddening in the *UBV* system as given by Moffat and FitzGerald (1977): $E(B-V)_J = 0.47$. (For F-type stars the ratio between both reddenings amounts to 2.32). Then the intrinsic photometric parameters are:

$V_0 = 1.858$

$(V-B)_0 = 0.089$

$(B-U)_0 = 0.424$

$(U-W)_0 = 0.327$

$(B-L)_0 = 0.110$.

It appears that with these parameters the values for $\log g$ and T_{eff}, which can be read off in the three theoretical two-colour diagrams, do not agree with each other. The disagreements are larger than can be explained by the estimated errors in the colour-indices. E.g. in the $V-B/U-W$ diagram $\log g \sim 1.1$, which is in agreement with the value given by de Jager (1984) for ε Aur (F0Ia), whereas in the $V-B/B-U$ diagram $\log g \sim 3.5$. The latter value is obviously much too high for such a type of star. This suggests that the star's atmosphere is quite different from Kurucz' model atmosphere, from which the grids were calculated. A possible explanation can be that the star is enveloped by an extended atmosphere, causing an excess in the Balmer lines and Balmer continuum. Such an excess should be noticeable especially

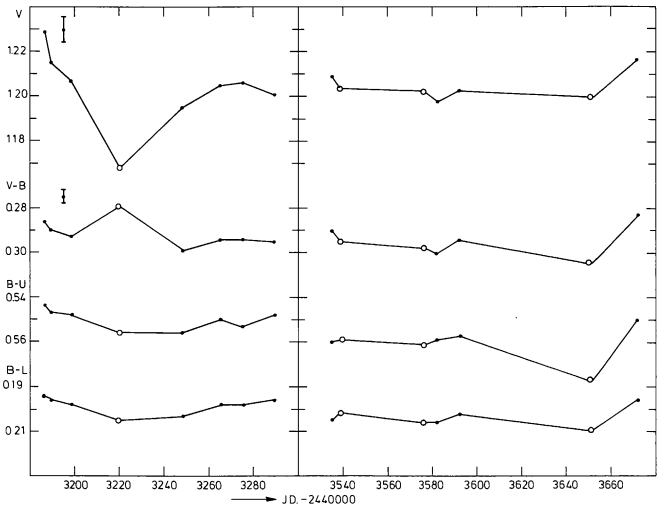

Fig. 3. Similar to Fig. 2, but for HD 74180

in the $B-L$ and $B-U$ colour indices. Therefore we should expect the indices $V-B$ and $U-W$ to be relatively unaffected, whereas $B-L$ and $B-U$ will be too small with respect to a "normal" atmosphere. Following this line of reasoning, we assume that the position of the star in the $V-B/U-W$ diagram can be more trusted, and thus we find $\log g \sim 1.1$, $T_{\rm eff} \sim 7000$ K. As stated above, this value for $\log g$ compares very well with de Jager's (1984) result for ε Aur, but the temperature we find is somewhat too low. One would rather expect $T_{\rm eff} \sim 7300$ K (e.g. Flower, 1977). Indeed, the $B-U$ and $B-L$ colour indices of a normal atmosphere with $\log g \sim 1.1$ and $T_{\rm eff} \sim 7300$ K should be redder than the observed values. Although one has to be careful with such manipulations, we have two other hints that the star has an extended atmosphere. Firstly, with the $\log L/L_{\odot}$ determined below, the star's position in the HR-diagram is very close to the stability limit of de Jager (1984), which suggests a high mass-loss-rate indeed. Secondly, the UV-flux as measured by the IUE-satellite proved to be higher than normal in all bands except at 2740 Å. This conclusion is based on the following study. We took the fluxes for HD 74180 from the IUE-Low-Dispersion Spectra Reference Atlas and corrected them for interstellar extinction with the aid of the interstellar extinction curves of Nandy et al. (1976) and Code et al. (1976), computed the "colour-indices" $(m(\lambda) - V)_0$, and compared these with the intrinsic parameters given by Wu et al. (1980) and Parsons (1981).

If we assume the star to be at a distance of 1.7 kpc (FitzGerald et al., 1979), then (with $V_{J_0} = 2.22$) $M_{V_J} = -8.9$, compare with Moffat and FitzGerald (1977): $M_{V_J} = -9.4$ and FitzGerald et al. (1979): $M_{V_J} = -8.9$. With B.C. = 0.14 (Flower, 1977) $M_{\rm bol} = -8.8$ and $\log L/L_{\odot} = 5.43$. Similar to the procedures as used for the previous star, we estimate that the mass $M \sim 20 M_{\odot}$, the age $t \sim 7\,10^6$ yr and the quasi period $\bar{P} \sim 100$ days. This age is twice as large as the age estimated by FitzGerald et al. (1979). The time scale $\bar{P}$ compares very well with our first set of observations (Fig. 3).

6. Conclusions

The parameters for the cluster Pismis 11, based on the *VBLUW* photometry agree very well with other studies. The two hypergiants HD 80077 (B2Ia$^+$) and HD 74180 (F2Ia$^+$) are micro variables with maximum light amplitudes of $\sim 0\overset{m}{.}07$ and $\sim 0\overset{m}{.}15$, respectively. The colour variations are largest in the $B-U$. The number of observations is too low to determine proper characteristic or quasi-periods ($\bar{P}$).

The photometric parameters of HD 80077 and HD 74180 are also in agreement with those of other studies. Photometric considerations lead to low gravities for both stars: $\log g \sim 2.2$ and ~ 1.1, respectively.

The age of HD 80077 is estimated to amount to $\sim 3\,10^6$ yr, that for Pismis 11, to which it presumably belongs, may be of the same order.

There are indications that HD 74180 has an ultraviolet excess caused by an extended gaseous envelope.

Acknowledgements. We are much indebted to Dr. J. Tinbergen and Mr. J.J. Schafgans, who made the computer programs for the photometric reduction and to Prof. C. de Jager for reading the manuscript.

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