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PHOTOELECTRIC PHOTOMETRY AT THE HVAR OBSERVATORY

III. The Ap Star CQ UMa

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Фотоэлектрическая фотометрия в обсерватории Хвар

III. Ар-звезда CQ UMa

Фотоэлектрическая *UBV* фотометрия пекулярной А-звезды CQ UMa, проведенная в обсерватории Хвар в 1973 и 1975 годах, комбинируется со всеми доступными фотоэлектрическими данными, чтобы получить улучшенное значение периода $P = (2{,}449967 \pm 0{,}000004)$ дней. Фотометрия из Хвара позволяет определить и абсолютные *UBV* значения для CQ UMa. В работе рассматривается также положение переменной в диаграмме цвет — зв. величина.

The *UBV* observations of the Ap star CQ UMa, obtained at the Hvar Observatory in 1973 and 1975, are combined with all other available photometric data to get an improved value of the period $P = (2{\cdot}449967 \pm \pm\ 0{\cdot}000025)$ days. The Hvar photometry also enabled the absolute *UBV* values for CQ UMa to be derived and the position of the variable in the colour diagram to be discussed.

1. Introduction

CQ UMa (HD 119213, HR 5153) is an A1p star with sharp and strong Sr lines. Presently, it is classified as a SrCrEu star (Cowley et al., 1969). The light variability of the object was discovered by Burke and Howard (1972), who published 28 *UBV* observations of the star obtained in May–June, 1970 and in June–July, 1971. They used the F5 star HD 119992 as the primary comparison star. They inferred that the light of CQ UMa varied with the period of 1·706 days and the amplitudes of $0{\cdot}052^m$ in U and of $0{\cdot}056^m$ in B, the V magnitude being apparently constant. One can note (see Fig. 1 in their paper) that the scatter of the measurements plotted with the 1·7-day period is rather large ($0{\cdot}05^m$), indicating thus the relatively low quality of the data and/or incorrect period. Winzer (1974) obtained other 18 *UBV* observations of CQ UMa in June and July, 1971 using the A0p star 81 UMa (HD 118214) as the comparison star. He published an improved ephemeris of the light variation

$$\mathrm{JD}(U_{\max}) = 2\,441\,450{\cdot}70 + 1{\cdot}6980^d E$$

and announced slight variability of the star in V in antiphase to the B and U light curves; the V amplitude

Bull. Astron. Inst. Czechosl. **29** (1978), 44–49.

being 0.005^m. Wolff and Morrison (1975) published 25 *ubvy* observations of the star obtained at the Mauna Kea Observatory during February – May, 1973. They found two possible periods, 1·68 and 2·45 days, respectively, and showed that the former period was spurious. They obtained a substantially better phase diagram using the ephemeris

$$\mathrm{JD}_{\mathrm{hel}}(v_{\max}) = 2\,441\,450{\cdot}74^{\mathrm{d}} + 2{\cdot}451^{\mathrm{d}}\,\mathrm{E}\,.$$

They also pointed out that the light maximum of CQ UMa coincides with the maximum in the strengths of the Cr lines as described by Bonsack (1974).

On request of one of the authors (Z. M.) ten-colour photometry of the star was obtained by a group of astronomers from the Zentralinstitut für Astrophysik (G.D.R.) at the Shemakha Observatory (U.S.S.R.). These data were published in preliminary form by Schöneich et al. (1976). They suggest period of 2·433 days. The measurements in longer wavelengths clearly confirmed the antiphase behaviour of the light variations.

Mikulášek (1975), combining all the above-mentioned data, derived an improved value of the period $P = (2{\cdot}45002 \pm 0{\cdot}00018)$ days. Finally, Mikulášek (1976) pointed out that the real photometric period of CQ UMa may be twice as large (i.e. 4·90 days) – like for some other Ap variables.

2. Our Photometric Data

We observed CQ UMa during 9 nights in May 1973 and in July 1975 at the Hvar Observatory, Yugoslavia, in the *UBV* system. The data were reduced in a standard way described by Harmanec et al. (1977). We used HD 120 874 as our primary comparison star because it is the only non-peculiar and reasonably bright A star in the vicinity of CQ UMa. Three other Ap stars, HD 118 214[= 81 UMa used by Winzer (1974)], HD 120 198 and HD 121 409, were used as check stars. Simultaneous measurements of several (usually 8 – 12) properly chosen standard stars allowed us not only to define extinction coefficients, but also to derive absolute international *UBV* magnitude of the comparison star HD 120 874:

$$\begin{aligned} V &= (\ \ 6{\cdot}458 \pm 0{\cdot}009)^{\mathrm{m}} \\ B &= (\ \ 6{\cdot}544 \pm 0{\cdot}008)^{\mathrm{m}} \\ U &= (\ \ 6{\cdot}620 \pm 0{\cdot}012)^{\mathrm{m}} \\ B - V &= (+0{\cdot}086 \pm 0{\cdot}005)^{\mathrm{m}} \\ U - B &= (+0{\cdot}076 + 0{\cdot}007)^{\mathrm{m}}\,. \end{aligned}$$

The international *UBV* magnitudes of our check stars were then derived differentially (relatively to HD 120 874) using the above values for the comparison star. They are as follows:

HD	*V*	*B*	*U*	*B – V*	*U – B*
118 214	5·597 ± 0·011	5·562 ± 0·012	5·510 ± 0·013	–0·035	–0·052
120 198	5·695 ± 0·009	5·638 ± 0·011	5·501 ± 0·013	–0·057	–0·137
121 409	5·712 ± 0·010	5·676 ± 0·012	5·604 ± 0·016	–0·036	–0·072

It may be useful to mention that simple relations exist between the alternatively suggested periods – a fact which has not been pointed out explicitly so far. Firstly, according to Tanner's (1948) well-known relation for spurious periodicity existing in any astronomical data when observing in one geographic longitude only,

$$1{\cdot}0027379 - 1/2{\cdot}45^{\mathrm{d}} = 1/1{\cdot}68^{\mathrm{d}}\,,$$

where $1{\cdot}0027379 = 366{\cdot}2422/365{\cdot}2422$ is the ratio of the sidereal to the mean solar year. Secondly

$2{\cdot}43^{\mathrm{d}} = 365{\cdot}2422^{\mathrm{d}}/(365{\cdot}2422^{\mathrm{d}}/2{\cdot}45^{\mathrm{d}} + 1)$, i.e. these two periods differ for one period per year. This ambiguity arose from the fact that most of the original observations were obtained during the May – July period only.

To enable direct comparison of the *UBV* data, published by several authors, we derived absolute *UBV* values of all measurements of CQ UMa, based on the above-mentioned values of our comparison star HD 120 874, by comparing mean values of our measurements to the mean values of Burke and Howard (1972) and Winzer (1974), respectively. We thus arrived at the following values for their comparison stars:

HD	*V*	*B*	*U*	*B – V*	*U – B*
119 992	6·476	6·956	6·914	+0·480	–0·042
118 214	5·608	5·589	5·531	–0·019	–0·058

Table 1

Absolute *UBV* Photometry of CQ UMa

JD 2 400 000^d +	Cycle and phase	V	B	U	MEAN
Burke and Howard (1972)					
40 749·764	0·875	6·294	6·372	6·407	64
40 753·713	2·487	6·284	6·427	6·434	−91
40 755·695	3·296	6·290	6·396	6·423	−4
40 756·707	3·709	6·293	6·383	6·399	58
40 758·731	4·535	6·298	6·435	6·453	−113
40 760·736	5·354	6·304	6·435	6·455	−100
40 761·690	5·743	6·293	6·379	6·399	66
40 762·693	6·152	6·299	6·412	6·418	−7
40 763·696	6·562	6·293	6·438	6·462	−97
40 767·718	8·203	6·288	6·380	6·409	40
41 102·720	144·941	6·288	6·369	6·393	81
41 103·688	145·336	6·294	6·422	6·435	−56
41 105·716	146·164	6·290	6·376	6·410	47
41 106·707	146·568	6·284	6·422	6·441	−81
41 108·707	147·384	6·285	6·437	6·441	−102
41 109·705	147·792	6·298	6·394	6·413	27
41 112·716	149·021	6·293	6·388	—	35
41 116·707	150·650	6·298	6·428	—	−57
41 117·749	151·075	6·293	6·379	—	59
41 118·713	151·469	6·283	6·419	—	−73
41 121·712	152·693	6·302	6·419	6·430	−49
41 122·694	153·093	6·283	6·366	6·395	94
41 123·720	153·512	6·287	6·433	6·441	−93
41 125·708	154·324	6·301	6·429	6·423	−54
41 127·698	155·136	6·293	6·423	6·436	−61
41 134·688	157·989	6·302	6·382	6·396	66
41 135·692	158·399	6·286	6·444	6·446	−119
41 136·721	158·819	6·291	6·382	6·399	56
Winzer (1974)					
41 103·709	145·344	6·289	6·421	6·438	−67
41 106·750	146·586	6·288	6·427	6·441	−82
41 108·736	147·396	6·283	6·436	6·441	−95
41 110·696	148·196	6·294	6·389	6·417	22
41 111·748	148·626	6·294	6·417	6·439	−54
41 114·716	149·837	6·290	6·379	6·400	58
41 120·686	152·274	6·287	6·412	6·431	−45
41 121·675	152·678	6·291	6·398	6·416	6
41 122·685	153·090	6·297	6·390	6·414	30
41 444·728	284·538	6·290	6·430	6·440	−82
41 445·718	284·942	6·299	6·373	6·410	66
41 447·715	285·757	6·299	6·395	6·415	24
41 450·739	286·991	6·294	6·373	6·394	82
41 452·707	287·795	6·296	6·391	6·410	33
41 453·781	288·233	6·290	6·393	6·411	19
41 457·756	289·855	6·294	6·385	6·405	47
41 459·699	290·648	6·295	6·415	6·429	−34
41 461·688	291·460	6·290	6·438	6·443	−99

Table 1 (cont.)

JD 2 400 000^d +	Cycle and phase	V	B	U	MEAN
this paper					
41 828·402	441·141	6·297	6·370	6·388	101
41 829·420	441·557	6·290	6·429	6·455	−104
41 830·409	441·961	6·294	6·372	6·392	87
41 831·404	442·367	6·291	6·427	6·444	−82
42 602·404	757·065	6·297	6·374	6·398	79
42 607·413	759·109	6·294	6·385	6·383	46
42 608·396	759·511	6·292	6·436	6·459	−118
42 609·372	759·909	6·293	6·376	6·399	69
42 610·411	760·333	6·293	6·431	6·428	−61

The agreement of these values for HD 118 214 with the values obtained directly from our Hvar data is reasonable, bearing in mind that we only secured a few measurements of HD 118 214. All the *UBV* measurements of CQ UMa reduced to our absolute *UBV* values for HD 120 874 are given in Tab. 1.

3. Re-Determination of the Period

Using a program for determining periods we first analyzed separately the U, B and V values of Tab. 1, searching in the interval from 0·7 to 5 days. We arrived at the following results:

Data	Possible Periods			
U	2·4500^d	4·9005^d	2·4337^d	4·8673^d
B	2·4498^d	4·9009^d	2·4336^d	4·8670^d
V	2·4498^d		2·4340^d	

The 2·45-day period is apparently the best. One can note that the possible periods $1·6818^d = 1/[1·0027379 - 1/2·4501^d]$ and $0·7088^d = 1/[1·0027379 + 1/2·4501^d]$ are definitely ruled out. To be able to search for a more precise value of the period using all (not only the *UBV*) data, we proceeded in the following way: We assumed that the shapes of the light curves in different colours are similar, i.e. that the light variations in one colour $[m_1(t)]$ are related to the variations in another colour $[m_2(t)]$ by means of a linear transformation

$$m_1(t) = a_{12} \cdot m_2(t) + b_{12} \qquad (1)$$

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for any time t. (Some experiments with the data have shown that such an assumption is quite justified — at least within the precision of the available data). We could then define a "mean" light curve $[m(t)]$ of a multicolour photometry $m_i(t)$, $i = 1, 2, \ldots, N$ (where N is the number of colours measured and t the time of the measurement) by the relation

$$m(t) = \sum_{i=1}^{N} \delta_i \, m_i(t) , \tag{2}$$

where $\delta_i = +1$ if the particular colour exhibits the antiphase behaviour and $\delta_i = -1$ otherwise.

To render these "mean" curves of different authors comparable, we reduced their arithmetic mean values to zero and their amplitudes to 184 (a value chosen arbitrarily) by means of the linear transformation

$$\mathrm{MEAN}\,(t) = \frac{184[m(t) - \sum_{i=1}^{N} \delta_i \bar{m}_i]}{\sum_{i=1}^{N} A_i} , \tag{3}$$

where $\bar{m}_i$ and A_i denote the arithmetic mean values of the i-th magnitude over the range of variations observed and its amplitude, respectively. The values of the quantity MEAN, computed by means of (2) and (3) are tabulated in the last column of Tab. 1 for the *UBV* data and in Tab. 2 for other photometric data of CQ UMa. In addition to the data already published, we also used the ten-colour photometry by Musielok (1976) obtained at the Shemakha Observatory, USSR, in June—August 1974 and February to July 1975.

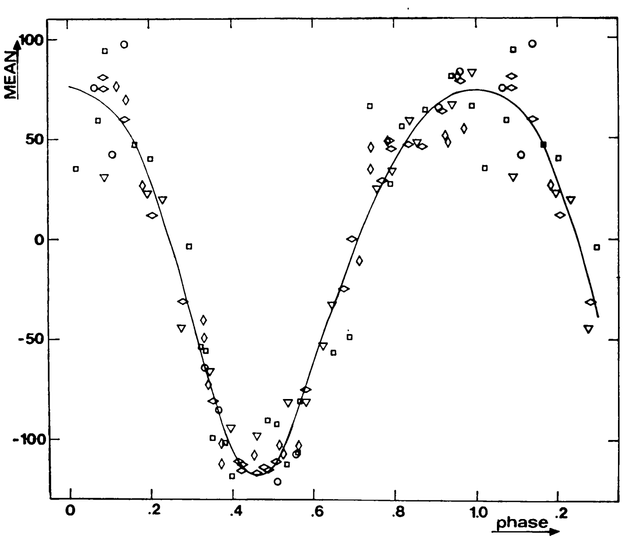

Fig. 1. The "MEAN" light curve of CQ UMa plotted with the 2·4499669-day period. Symbols used: □ — Burke and Howard (1972), ▽ — Winzer (1974), ○ — Hvar observations, ◆ — Wolff and Morrison (1975), ♦ — Musielok (1976).

Table 2

MEAN Magnitudes of CQ UMa (non — *UBV* photometries only)

JD 2 400 000^d +	Cycle and phase	MEAN	O—C
Wolff and Morrison (1975)			
41 731·090	401·422	−113	− 2
41 732·100	401·834	50	− 4
41 767·930	416·459	−114	3
41 775·020	419·353	− 78	− 5
41 776·040	419·769	32	1
41 776·950	420·140	63	6
41 780·990	421·789	52	13
41 782·930	422·581	− 72	− 1
41 784·970	423·414	−108	0
41 785·900	423·793	48	8
41 786·910	424·206	15	−14
41 789·900	425·426	−110	2
41 790·980	425·867	49	−13
41 793·970	427·087	84	13
41 796·890	428·279	− 28	−10
41 797·860	428·675	− 22	− 7
41 798·870	429·087	78	7
41 799·850	429·487	−112	2
41 821·880	438·479	−111	4
41 824·860	439·696	3	7
41 826·850	440·508	−108	0
41 827·850	440·916	67	− 5
41 828·840	441·320	− 61	− 12
41 832·860	442·961	82	5
Musielok (1976)			
42 229·320	604·784	56	15
42 230·300	605·184	34	−10
42 238·310	608·453	−101	11
42 250·260	613·331	− 42	11
42 251·270	613·743	42	18
42 254·240	614·955	88	7
42 275·210	623·515	− 96	5
42 276·210	623·923	59	−18
42 277·210	624·331	− 33	20
42 279·200	625·143	77	17
42 458·610	698·373	−105	−22
42 594·270	753·745	53	28
42 597·270	754·969	62	−20
42 598·260	755·373	− 95	−12
42 616·250	762·716	− 4	−15
42 617·240	763·120	84	17
42 618·230	763·525	−100	− 3
42 619·230	763·933	55	−24
42 620·230	764·341	− 66	− 5
42 623·220	765·561	− 96	−18

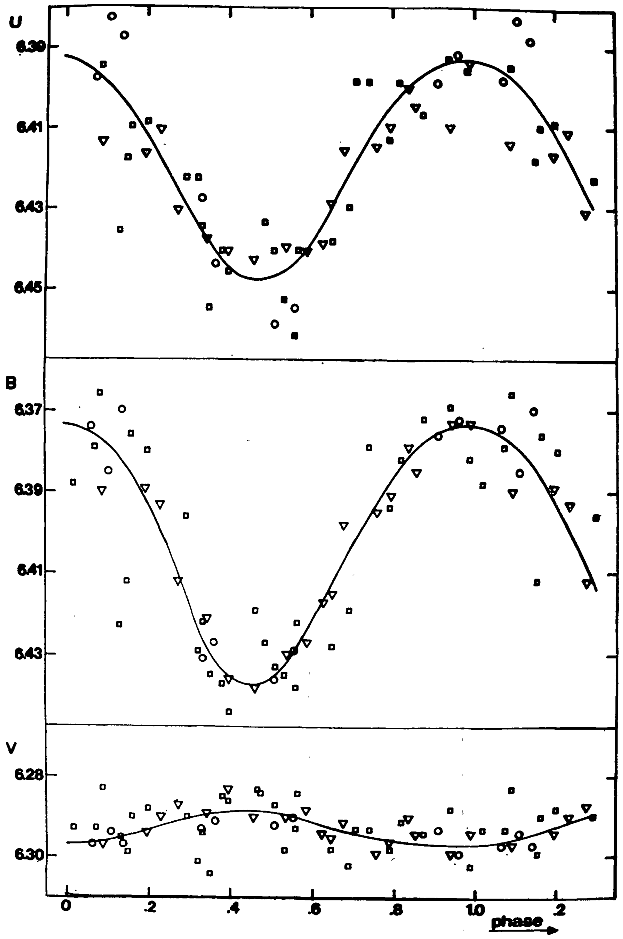

Fig. 2. The U, B and V light curves of CQ UMa plotted with the 2·4499669-day period. Symbols used: □ — Burke and Howard (1972), ▽ — Winzer (1977), ○ — Hvar observations

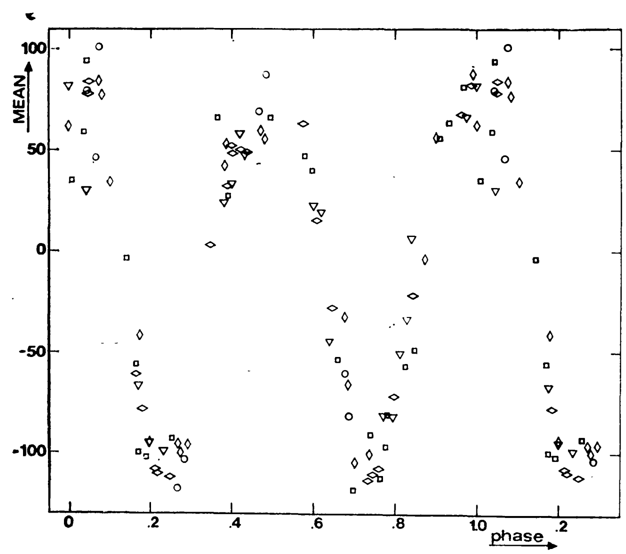

Fig. 3. The "MEAN" light curve of CQ UMa plotted with the 4·8999338-day period. Symbols used: □ — Burke and Howard (1972), ▽ — Winzer (1977), ○ — Hvar observations, ◆ — Wolff and Morrison (1975), ♦ — Musielok (1976).

Analysing all the MEAN values by means of a program for determining periods, we found

P = 2·4499 days (and its double value 4·8998 days) as the only possible periods. The agreement with the periods, obtained from the UBV data only, is remarkably good.

The last step of our period analysis was taking advantage of the fact that the light curve of CQ UMa resembles formally (by its shape) a radial-velocity curve of a binary moving in an elliptical orbit. Using the SPEL program for computing orbital elements of a spectroscopic binary (kindly provided by Dr. J. Horn), we computed the period, epochs of maximum light, amplitudes and shapes of the light curves of CQ UMa by the least-squares technique. It confirmed geometrical "similarity" of the individual curves, the formal "eccentricity" being always around 0·18.

We arrived at the following values, which we accept as final:

$$\text{(4)} \qquad \mathrm{JD}_{\mathrm{Hel}}(\mathrm{MEAN}_{\max}) = \begin{pmatrix} 2\,440\,747{\cdot}620 \\ \pm{\cdot}002 \end{pmatrix}^{\mathrm{d}} + \left(\begin{matrix} 2{\cdot}449967^{\mathrm{d}} \\ \pm 0{\cdot}000025^{\mathrm{d}} \end{matrix} \right) E\,,$$

the amplitudes of the light curves being $0{\cdot}055^{\mathrm{m}}$, $0{\cdot}064^{\mathrm{m}}$ and $0{\cdot}009^{\mathrm{m}}$ in U, B and V, respectively. Within the estimated errors, our ephemeris can be considered as "final" for rather a long time (on the assumption of constant period, of course). We chose JD 2 440 747·620 [the time of the light maximum immediately preceding the first observation of CQ UMa by Burke and Howard (1972)] as the reference epoch. This enabled us to compute unambiguously the number of all cycles, covered by the observations.

The "MEAN" light curve and the UBV light curves plotted with the final period (4) are shown in Fig. 1 and 2, respectively.

It is necessary to stress that the double period (4·9 days) can be neither be excluded, nor confirmed from the available data, though there is some suspicion that odd and even light maxima differ slightly (see Fig. 3). Measurements of possible variations of the intensity of the magnetic field could be decisive in this respect.

4. The Nature of the Light Changes

It is immediately seen that the light curves have a rather flat maxima and narrower minima (the opposite is true for curves exhibiting the antiphase effect). The curves are also slightly asymmetric. According to current ideas about the nature of Ap stars, their light changes are connected with the rotation and surface inhomogeneities of these objects. A more quantitative discussion of the nature of photometric changes of CQ UMa will be presented elsewhere (Mikulášek, to be publ.).

5. Colour Changes and Position of CQ UMa in the Colour Diagram

Our *UBV* photometry allows us to discuss, for the first time, the position of CQ UMa in the colour diagram with a precision of a few hundredths of magnitude (given essentially by the precision of the comparison star HD 120 874). Clearly, CQ UMa exhibits remarkable colour changes which manifest themselves in the colour diagram as an abscissa with an asymmetrically placed mean value (see Fig. 4). This abscissa lies definitely above the main sequence in the $(U - B)$, $(B - V)$ diagram. This fact can hardly be explained by interstellar reddening. Firstly, CQ UMa lies far from the galactic plane ($b = 58°41'$) and at the distance of 130 pc only ($M_v = +0{\cdot}7^m$). Secondly, our study of the position of all A stars within 25° around CQ UMa in the sky in the colour diagram, for which *UBV* photometry is available in the photometric catalogue by Blanco et. al 1968, does not indicate any detectable reddening larger than $0{\cdot}03^m$ (for CQ UMa).

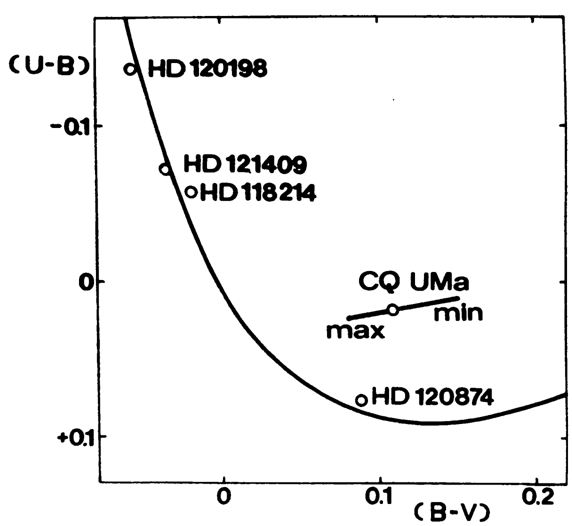

Fig. 4. The $(U - B)$ versus $(B - V)$ diagram for CQ UMa, comparison and check stars. Full line depicts the unreddened main sequence.

In turn, this means that the position of CQ UMa in the colour diagram indicates an anomalous energy distribution, a fact which is independently confirmed by multicolour photometry of the star. At maximum brightness, the energy distribution is close to the energy distribution of normal stars.

Finally, it is worthwhile mentioning that the position of the comparison star HD 120 874 in the colour diagram gives some confidence to our absolute *UBV* photometry for this star. It is necessary to stress, however, that our photometry indicates the spectral class A 2 or A 3 rather than the spectral type A0, given in the HD catalogue. Also the positions of the check stars (whose *UBV* values were derived relative to HD 120 874) are very satisfactory.

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