ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES

MARCH II **2000**, PAGE 389

Astron. Astrophys. Suppl. Ser. **142**, 389–398 (2000)

Spectral classification of O–M stars on the basis of UBV photometry

V.I. Kuznetsov[1], G.Z. Boutenko[1], G.A. Lazorenko[2], and P.F. Lazorenko[2]

[1] International Centre for Astronomical, Medical and Ecological Investigations, National Academy of Sciencies of the Ukraine, Golosiiv, 252680 Kyiv-127, Ukraine
e-mail: kouznets@mao.kiev.ua
[2] Main Astronomical Observatory, National Academy of Sciencies of the Ukraine, Golosiiv, 252680 Kyiv-127, Ukraine
e-mail: gallaz@mao.kiev.ua

Received May 28; accepted November 29, 1999

Abstract. A new technique allowing the Q-method to be used surely for both the spectral classification of young O–A0 stars and older spectral subclasses A1–M5 is described. Characteristics of interstellar light absorption dependence on distance in the given direction of the sky is used as a main criterion for excluding possible multiplicity of star spectral estimates at some constant values of Q_{UBV}. Information on open cluster membership probabilities is also useful as additional criterion of the spectral classification. The method was tested on stars up to $V = 14$ mag in directions of young open clusters NGC 2244 and NGC 2264. The spectral study based on UBV photometry was extended to faint stars of NGC 2264 in the V magnitude range $17 - 22$ mag.

Key words: methods: numerical — stars: fundamental parameters — ISM: dust, extinction — Galaxy: open clusters and associations: individual: NGC 2244; NGC 2264

1. Introduction

Solutions to various problems of modern astrophysics and stellar astronomy necessitate knowing spectral characteristics of faint stars. In light of this, the use of multicolour photometric systems seems to be rather appropriate. One of the most informative systems is the Vilnius seven-colour system (Strayzis 1977) which permits us to carry out two-dimensional classification in a wide spectral range from O to M stars.

The problem of the present research consists of finding an efficient approach to spectral classification of O–M stars yet not leaving the framework of the standard three-colour UBV system. A simple opportunity to extend spectral studies to faintest stars is possible in this case and a large amount of information on UBV values of stars already stored in photometric databases can be used. Also important is the fact that observations in UBV system do not present particular difficulties.

Unfortunately the opportunities for application of the Q-method (Johnson 1958; Johnson & Morgan 1953), used for O–A0 star spectral classification on the basis of UBV photometry, are rather limited because of the ambiguity of this method. For this reason classification errors on temperature parameters can reach 2–3 classes (Kuznetsov 1986; Kuznetsov & Lazorenko 1992) whereas errors in the MK system (Johnson & Morgan 1953) or Abastumany system of spectral criteria (Kharadze & Bartaya 1960) are usually one order lower and do not exceed 1–2 subclasses.

Dependence of Q_{UBV} values on the intrinsic colour $(B-V)_0$ or spectrum of a star Sp has been studied by Strayzis (1977). It was shown that knowledge of the Q_{UBV} value does not allow us to determine the spectral class of a star or its luminosity. Thus some additional information is required in order to obtain a single-valued treatment of the star spectral characteristics.

In the present study as a main criterion which permits us to avoid multiplicity in the estimates of stellar spectral characteristics at the fixed value Q_{UBV}, we suggest using information on the character of absorbing dust matter distribution versus distance from the Sun. In practice it is more convenient to use dependence of colour excesses $E(B-V)$ on the intrinsic distance module $V_0 - M_V$ in some direction of the sky. It is easy to construct such dependence in any section of the Galaxy, in particular, in directions of young open clusters. At present extensive information on distribution of interstellar

---

Send offprint requests to: V.I. Kuznetsov absorbing matter in the Galaxy is available, see for example Voroshylov & Khalandadze (1983).

2. Technique of the spectral classification

The process of spectral classification of O–M stars on the basis of UBV data is carried out as follows. First of all it is necessary to construct a reliable dependence of colour excesses of stars on intrinsic distance modulus along a given direction. The practice of research of interstellar light absorption (e.g. Urasin et al. 1989) proves that for construction of such a dependence towards the Galactic periphery it is enough to know magnitudes and spectra of stars up to $V = 15$ mag only. Of course this absorption curve like the one shown in Fig. 1 can be successfully used not only for spectral classification of stars brighter than V=15 mag, but also for fainter stars. The present technique is based on the Q-method which is equally applicable for classifying both bright and faint stars with a difference caused by the different level of photometric measurements errors.

Thus, using absorption curves derived from photometric values and spectra of one or two hundred stars brighter than $14 - 15$ mag, it is possible to extend spectral classification on many hundreds and even thousands of stars taking advantage of a sharp increase of star numbers with a growth of star magnitudes. For the determination of bright star spectra it is possible to use either photometric (e.g. Strayzis 1977; Urasin 1973; Urasin et al. 1989) or spectrographic methods (e.g. Voroshylov et al. 1985; Kuznetsov 1978; Kharadze & Bartaya 1960; Johnson & Morgan 1953; Walker 1956; Young 1978). The most simple is a photometric method whose features are described by Urasin (1973), Urasin et al. (1989). In this case the spectra of O–B6 stars to be used later for absorption curve construction are determined unequivocally by the Q-method. This gave an opportunity to investigate interstellar absorption in the Milky Way in an interval of galactic longitudes $7 - 222^0$ and distances up to 10 kpc from the Sun using UBV photometry data alone (Urasin et al. 1989).

In some rare cases, construction of absorption curves towards the periphery of the Galaxy meets certain difficulties and can appear inconvenient. The origins of these difficulties should be studied and used for elaboration of criteria useful for spectral classification. For example, according to the data by Williams & Cremin (1969), a dense dust cloud is located just beyond the open cluster NGC 2264 along a line of sight, shielding light of background stars. At shorter distances stars are practically not subject to absorption. Average colour excess $E(B-V)$ of these stars is 0.08 mag (Arshutkin et al. 1990). At the same time, according to Arshutkin et al. (1990), Khalandadze et al. (1986), Cohen & Kuhl (1979), on distances between the cluster and the cloud there exist stars with large colour excesses which are one order higher than $E(B-V)$. The method of the spectral classification described in the present study allows us to take advantage of such features in distribution of absorbing matter thus excluding multiplicity in spectral estimates of stars at fixed Q_{UBV} value.

For construction of reliable absorption curves the open cluster members should be excluded from the analyzed sample of stars because random errors of determination distances to the cluster members can exceed a linear size of the cluster by one or two orders. As a consequence $E(B-V)$ and $(V_0 - M_V)$ values for members instead of being concentrated in practically one point on absorption curves are found to be rather heavily scattered along the axis of the intrinsic distance module (Kuznetsov 1978). This circumstance markedly biases behaviour of the absorption curve which is the principal element of the present method of spectral classification based on UBV photometry. Due to the influence of cluster members on the character of the absorption curve plot, the latter can go almost horizontally for some distance. This so called effect of the "horizontal bar" was earlier explaining only by the influence of observational selection (Voroshylov & Khalandadze 1983).

Rather strong influences on absorption curve plot are caused by existing distinctions in scales of absolute magnitudes of main sequence (MS) and zero-age-main-sequence (ZAMS) stars. In practically all previous studies on research of the Galaxy structure in directions of young open clusters, star-forming regions, and OB-associations, the absolute magnitudes of these stellar group members were determined the same way as for field stars, that is using the MS scale.

In Table 1 absolute magnitudes M_V(ZAMS) were determined on the ZAMS scale and these values for members of young stellar groups are compared with those given in the MS scale available for field stars. For the spectral interval O–A0 we used Schmidt-Kaler (1982) data. One can see that the differences of absolute magnitudes $\Delta M_V = M_V(\mathrm{ZAMS}) - M_V(\mathrm{MS})$ are positive and vary from +0.5 to +1.0 mag. In the plot of the absorption curve the $(V_0 - M_V)$ values of young stellar group members will be systematically shifted on $0.5-1.0$ mag larger distances, which substantially increases the scale of distances in the Galaxy. Using the Schmidt-Kaler (1982) tables of intrinsic distance module transformation to linear distances it is easy to calculate systematic errors in distances r (Table 2). Calculations show that a maximum "stretching" of the scale of distances up to 60% is expected at $M_V = +0.5$ and $M_V = +1.0$ mag.

Thus, presently developed observational knowledge on absorbing medium and star distribution in space can essentially differ from a real picture of the Galaxy structure. This short analysis substantiates a conclusion that for the increase in accuracy of interstellar dust and star distribution studies in the Galaxy cluster, members are to be preliminary excluded before the analysis started. The member selection can be carried out with one of the

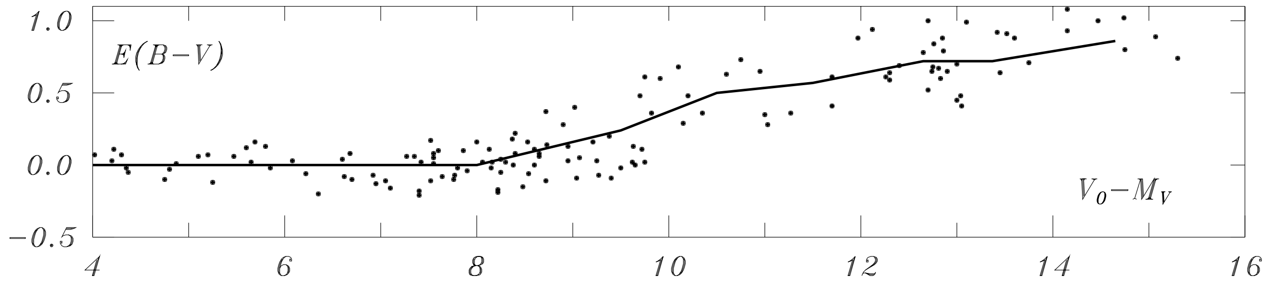

Fig. 1. Individual (dots) and smoothed (solid line) colour excesses $E(B-V)$ versus intrinsic distance module $V_0 - M_V$ for stars brighter than $V = 14$ mag in a direction of NGC 2244

Table 1. Differences $\Delta M_V = M_V(\text{ZAMS}) - M_V(\text{MS})$ of absolute magnitudes $M_V(\text{ZAMS})$ and $M_V(\text{MS})$ related to the ZAMS and MS distance scales correspondingly, for O-A0 stars

Sp	M_V(ZAMS)	M_V(MS)	ΔM_V
O4	−5.2	−5.9	+0.7
O9,5	−3.6	−4.25	+0.65
B0	−3.25	−4.0	+0.75
B0,5	−2.6	−3.6	+1.0
B1,5	−2.1	−2.8	+0.7
B2,5	−1.5	−2.0	+0.5
B3	−1.1	−1.6	+0.5
B6	−0.2	−0.9	+0.7
B8	+0.6	−0.25	+0.85
B9,5	+1.1	+0.4	+0.7
A0,5	+1.5	+0.8	+0.7

Table 2. Systematic errors Δr_1 and Δr_2 of distance r determination caused by $\Delta M_V = +0.5$ and $\Delta M_V = +1.0$ errors of the absolute magnitudes scale correspondingly

$V_0 - M_V$	r,pc	Δr_1,pc	Δr_2,pc
8.0	400	100	200
9.0	630	160	370
10.0	1000	250	500
11.0	1600	400	900
12.0	2500	700	1500
13.0	4000	1000	2300
14.0	6300	1600	3700

commonly used methods, or with those presently developed by authors (Kuznetsov 1988; Kuznetsov et al. 1989; Kuznetsov et al. 1993) for various initial sets of observational data on kinematic, photometric and spectral characteristics of stars. Certainly, this discussion concerns also a case of researching interstellar light absorption and spatial star distribution in directions of more extended stellar groups (star-forming regions and OB-associations).

In Fig. 1 the observed dependence $E(B-V)$ versus $(V_0 - M_V)$ for NGC 2244 is shown, derived here in a way described.

Once a reliable dependence $E(B-V)$ versus (V_0-M_V) in a given direction is found, it is possible to proceed directly to realization of the spectral classification. First of all it is necessary to calculate Q_{UBV} values for each star under the commonly used formula given e.g. by Strayzis (1977), Holopov (1981), and Johnson (1958):

$$Q_{UBV} = (U-B) - [E(U-B)/E(B-V)](B-V). \quad (1)$$

At $E(B-V) < 1$ a relation $E(U-B)/E(B-V) = X + SE(B-V)$ with factors X and S depending on the spectral class of a star takes place. Because for the Cepheus-Perseus-Monoceros law the $E(U-B)/E(B-V)$ value varies mainly in the limits $0.70-1.00$ (Strayzis 1977; Sudjus 1974), its average value 0.85 may be used as a good initial approximation for computing Q_{UBV}. Knowing the dependence of Q_{UBV} on spectra Sp (Strayzis 1977), it is easy to determine a set of N possible spectral classes $Sp_1, Sp_2, \ldots Sp_N$ of any star at fixed Q_{UBV}. Then, using the Schmidt-Kaler (1982) tables, these spectra are transformed to normal colour parameters $(B-V)_0$ and absolute magnitudes M_V. Supplementing this information with observed BV values of stars, we find colour excesses, light absorption $A_V = 3.2\ E(B-V)$, and intrinsic distance module $(V_0 - M_V)$. The last values should be computed two ways, using the ZAMS scale for open cluster members, and the MS scale for field stars.

Computed pairs of $E(B-V)$ and $(V_0 - M_V)$ values of the studied star are then put in the diagram of colour excess dependence versus intrinsic distance modulus, for example in a diagram shown in Fig. 1. Of all possible sets of $E(B-V)$ and $(V_0 - M_V)$ values the most real is that pair which is in best agreement with the absorption curve in view of errors of observations. Normally deviations of colour excesses and the distance module from the mean absorption curve should not exceed $3\sigma\{E(B-V)\}$ and $3\sigma\{(V_0 - M_V)\}$ accordingly. All spectra which do not satisfy the above-stated criterion are discarded and as a result a preliminary spectrum $\overline{Sp}$ of a star is determined. According to Kuznetsov (1978) the errors of $E(B-V)$ and (V_0-M_V) determination are $\sigma\{E(B-V)\} = 0.10$ mag and $\sigma\{(V_0 - M_V)\} = 0.60 - 0.80$ mag accordingly. Therefore scattering of the data points in the plot of colour excess versus intrinsic distance modulus within areas where absorption is constant, should not exceed 0.20 − 0.25 mag (Voroshylov et al. 1972). In directions of NGC 2244 and NGC 2264 it does not exceed $3\sigma\{E(B-V)\} = 0.30$ mag (Fig. 1; Arshutkin et al. 1990; Khalandadze et al. 1986; Kuznetsov 1978).

Once the star spectrum $\overline{Sp}$ is determined, more accurate $E(U-B)/E(B-V)$ and Q'_{UBV} values are recomputed and a final spectral type Sp_{UBV} of the star is determined with the help of transition tables by Strayzis (1977). In the cases to be discussed below, when two spectral estimates $\overline{Sp}$ are equally possible for a star, it is necessary to use auxiliary data, for example, the probability of the star to be a cluster member.

3. Spectral classification of stars up to $V = 13 - 14$ mag in the directions of open clusters NGC 2244 and NGC 2264

The reliability of the present technique was checked on stars in the area of two young open clusters NGC 2244 and NGC 2264. In the case of NGC 2244 only those stars which have spectral estimates in either MK system (Ogura & Ishida 1981), Abastumany classification system (Voroshylov et al. 1985), or were classified via processing of unwidened low-dispersion spectrograms (Kuznetsov 1986) have been involved to the study. Photometric values and colour parameters of stars were taken from the paper by Ogura & Ishida (1981), and proper motions from the paper by Marschall et al. (1982).

Tables 3-6 give particular examples of the spectral classification on the basis of UBV photometry for open cluster NGC 2244 stars Nos. 127, 158, 239 and 278 (numbering is given here as by Ogura & Ishida 1981) with different spectral types. These examples show which way the use of average colour excess dependence on intrinsic distance modulus (Fig. 1) allows us to select a single correct spectral type among some possible ones.

For example, the star No. 127 at fixed value $Q_{UBV} = 0.11$ have a set of seven possible spectra: A2 V, K5 V, A2 III, K3 III, M3 III, F2 I and K5 I. It is not difficult to see that only two spectral estimates (A2 V and A2 III) have such $E(B-V)$ and $(V_0 - M_V)$ values which deviate not more then $3\sigma\{E(B-V)\}$ and $3\sigma\{V_0 - M_V\}$ from the mean curve shown in Fig. 1. All other alternative estimates of spectra are surely discarded as wrong and a preliminary spectrum of a star is thus determined as $\overline{Sp}$ =A2. Then using $\overline{Sp}$ a new value of $E(U-B)/E(B-V)$ is recomputed giving a final spectral class Sp_{UBV} =A2. Similar reasoning allows us to determine spectra of stars Nos. 158, 239 and 278 (Tables 4-6).

The offered technique however does not permit us to classify stars on their luminosities. At the same time there is a good agreement of received results with other available estimates of spectra in the MK system on the temperature parameter.

In the process of spectral classification, about 60% of analyzed stars have been assigned to a single or two rather close estimates of spectra. In the last case an average value was adopted. Another 40% of stars have obtained two substantially different estimates of spectra. Double results of the classifying process based on UBV data originates as a rule in equal probability of some stars to be classified as young B or late F–G stars. In order to determine correct spectral type we applied the next criterion. In general, it may be modified, depending on the peculiarities of the character of the absorbing medium and star distribution in the space, and on interval of star magnitudes where spectral classification is carried out.

According to Kuznetsov (1988), on the distance of the open cluster NGC 2244, one may observe only young O–A5 stars as far as a limiting magnitude in the catalogue used is $V_{\rm lim} = 14.0$ mag. It is clear therefore that if the star with an uncertain spectral estimate is a cluster member or belongs to a far background population it can not be of a late spectral type F–G to be observable. In this case from two possibilities (B or F–G) the spectral type of such a star is determined unequivocally as B. And on the contrary, if the star is not a member of an open cluster, and belongs to the foreground, then with a high degree of probability it should be of a late spectral type. Thus a solution of this particular problem is reduced to the problem of membership study, or to separation of cluster members from field stars. This was carried out with the use of an earlier developed method (Kuznetsov et al. 1993) of membership study which takes advantage of star distribution in multidimensional data space formed by all available observational data. Normally, coordinate axes of the space correspond to proper motions, angular astrometric positions, $E(B-V)$, $(B-V)_0$, and the intrinsic distance module. In some particular cases, when a few faint stars have no derived proper motions, computing procedure for these stars was carried out in a data subspace of lower dimension. A star was identified as a cluster member when calculated membership probability P exceeded 50%.

Observational data and results of the spectral classification of 125 stars brighter than $V = 14.0$ mag around NGC 2244 are presented in Table 7. In the first three columns of the table, serial numbers, magnitudes V, and spectral classes $Sp_{\rm MK}$ of stars in MK system, according to the catalogue by Ogura & Ishida (1981) are given. The next columns contain: estimates $Sp_{\rm Ab}$ of spectra in Abastumany system of spectral classification (Voroshylov et al. 1985); spectral types $Sp_{\rm K}$ derived by Kuznetsov (1986) from unwidened low-dispersion spectrograms; spectra Sp_{UBV} received on the basis of UBV photometry with the present technique of spectral classification; probabilities of membership P in percent (see comments above; P are given only for the cluster members, field stars are marked with “f”).

Comparison of the present spectral classification results (Col. 6 in the Table 7) with Ogura & Ishida (1981)

Table 3. A set of possible photometric and spectral characteristics of the star No. 127 at a fixed Q_{UBV} value

Measured values: $V = 8.77$, $B - V = 0.09$, $U - B = 0.19$

N	Sp	$(B - V_0)$	$E(B - V)$	A_V	V_0	M_V (MS)	M_V (ZAMS)	$V_0 - M_V$ (MS)	$V_0 - M_V$ (ZAMS)	$\overline{Sp}$
1	A2 V	0.05	0.04	0.13	8.64	1.3	1.7	7.34	6.94	A2 V
2	K5 V	1.15	−1.06	0.00	8.77	7.35	7.3	1.42	1.47	-
3	A2 III	0.05	0.04	0.13	8.64	0.3	-	8.34	-	A2 III
4	K3 III	1.27	−1.18	0.00	8.77	0.3	-	8.44	-	-
5	M3 III	1.61	−1.52	0.00	8.77	−0.6	-	9.37	-	-
6	F2 I	0.23	−0.14	0.00	8.77	−6.6	-	15.37	-	-
7	K5 I	1.60	−1.51	0.00	8.77	−5.8	-	14.57	-	-

$Q_{UBV} = 0.11$, $\overline{Sp} =$ A2, $Q'_{UBV} = 0.12$, $Sp_{UBV} =$ A2, $Sp_{\mathrm{MK}} =$ A2 V

Table 4. Same as Table 3 for the star No. 158

Measured values: $V = 10.25$, $B - V = 0.66$, $U - B = 0.04$

N	Sp	$(B - V_0)$	$E(B - V)$	A_V	V_0	M_V (MS)	M_V (ZAMS)	$V_0 - M_V$ (MS)	$V_0 - M_V$ (ZAMS)	$\overline{Sp}$
1	B3 V	−0.20	0.86	2.75	7.50	−1.6	−1.1	9.10	8.60	-
2	G2 V	0.63	0.03	0.10	10.15	4.7	4.7	5.45	5.45	G2 V
3	M5 V	1.64	−0.98	0.00	10.25	12.3	12.3	−3.05	−3.05	-
4	B5 III	−0.20	0.86	2.37	7.88	−2.2	-	10.08	-	-
5	G0 III	0.65	0.01	0.03	10.22	1.0	-	9.22	-	G0 III

$Q_{UBV} = -0.52$, $\overline{Sp} =$ G1, $Q'_{UBV} = -0.55$, $Sp_{UBV} =$ G1, $Sp_{\mathrm{MK}} =$ G0 IV

Table 5. Same as Table 3 for the star No. 239

Measured values: $V = 11.06$, $B - V = 0.29$, $U - B = -0.21$

N	Sp	$(B - V_0)$	$E(B - V)$	A_V	V_0	M_V (MS)	M_V (ZAMS)	$V_0 - M_V$ (MS)	$V_0 - M_V$ (ZAMS)	$\overline{Sp}$
1	B5 V	−0.17	0.46	1.47	9.59	−1.2	−0.5	10.79	10.09	B5 V
2	G2 V	0.63	−0.34	0.00	11.06	4.7	4.86	6.36	6.20	-
3	G6 V	0.70	−0.41	0.00	11.06	5.2	5.2	5.86	5.86	-
4	B5 III	−0.17	0.46	1.47	9.59	−2.2	-	11.79	-	B5 III
5	G0 III	0.65	−0.36	0.00	11.06	1.0	-	10.06	-	-
6	B9 I	−0.02	0.31	0.93	10.13	−6.9	-	17.03	-	-

$Q_{UBV} = -0.45$, $\overline{Sp} =$ B5, $Q'_{UBV} = -0.41$, $Sp_{UBV} =$ B6, $Sp_{\mathrm{MK}} =$ B7 V

spectral estimates in MK system (Col. 3) is shown in Fig. 2 by triangles. One can notice a fair agreement of compared results. Also good results give a comparison with spectra derived by Kuznetsov (1986) from unwidened low-dispersion spectrograms (cf. Cols. 5 and 6).

In Fig. 2 the number of NGC 2244 stars later than O8–A3 was found to be insufficient for comparison purposes. Therefore, in order to check reliability of the present spectral classification for these spectral classes, a similar study of stars in the area around NGC 2264 has been carried out. Due to the cluster being a relatively short distance from the Sun (Arshutkin et al. 1990; Walker 1956), the O–K3 spectral range where spectral classification in MK system had already been fulfilled by Voroshylov et al. (1985), Walker (1956), and Young (1978) is much wider.

To bypass multiplicity of NGC 2264 stellar spectral estimates at a certain fixed Q_{UBV} value, data on interstellar light absorption dependence versus distance (Arshutkin et al. 1990; Cohen & Kuhl 1979; Walker 1956; Williams & Cremin 1969) were used as the main criterion to be fitted. In the case with double largely diverging spectral estimates (B or F–G) we also took into account probabilities of membership derived by Arshutkin et al. (1990). Table 8 presents results of spectral classification for 75 NGC 2264 stars. In the first three columns of the table serial numbers, magnitudes V, and spectral classes Sp_{MK} of stars in MK system according to Walker (1956) catalogue are given. The next three columns contain estimates of spectra Sp_{Y} found by Young (1978), Voroshylov et al. (1985) Sp_{V}, and spectra Sp_{UBV} obtained on the basis of the present technique of spectral classification.

A comparison of obtained spectra with estimates in the standard MK system (Walker 1956; Young 1978) for NGC 2264 is shown in Fig. 2 by crosses. In the same figure

Table 6. Same as Table 3 for the star No. 278

Measured values: $V = 10.21$, $B - V = 1.04$, $U - B = 0.69$

N	Sp	$(B - V_0)$	$E(B - V)$	A_V	V_0	M_V (MS)	M_V (ZAMS)	$V_0 - M_V$ (MS)	$V_0 - M_V$ (ZAMS)	$\overline{Sp}$
1	B9 V	−0.07	1.11	3.55	6.66	0.2	0.9	6.46	5.76	-
2	F0 V	0.30	0.74	2.37	7.84	2.7	2.8	5.14	5.04	-
3	K2 V	0.91	0.13	0.42	9.79	6.4	6.3	3.39	3.49	K2 V
4	M0 V	1.40	−0.36	0.00	10.21	8.8	8.8	1.61	1.61	-
5	B9 III	−0.07	1.11	3.55	6.66	0.2	-	6.46	-	-
6	F2 III	0.35	0.69	2.21	8.00	1.7	-	6.3	-	-
7	G8 III	0.94	0.10	0.32	9.89	0.8	-	9.09	-	G8 III
8	M6 III	1.52	−0.48	0.00	10.21	−0.3	-	10.51	-	-
9	A3 I	0.02	1.02	3.26	6.95	−7.2	-	14.15	-	-
10	G0 I	0.76	−0.28	0.00	10.21	−6.4	-	16.61	-	-
11	G8 I	1.14	−0.08	0.00	10.21	−6.2	-	16.41	-	-
12	M2 I	1.71	−0.68	0.00	10.21	−5.6	-	15.81	-	-

$Q_{UBV} = -0.19$, $\overline{Sp} =$ K0, $Q'_{UBV} = -0.03$, $Sp_{UBV} =$ K5, $Sp_{\mathrm{MK}} =$ K3 III

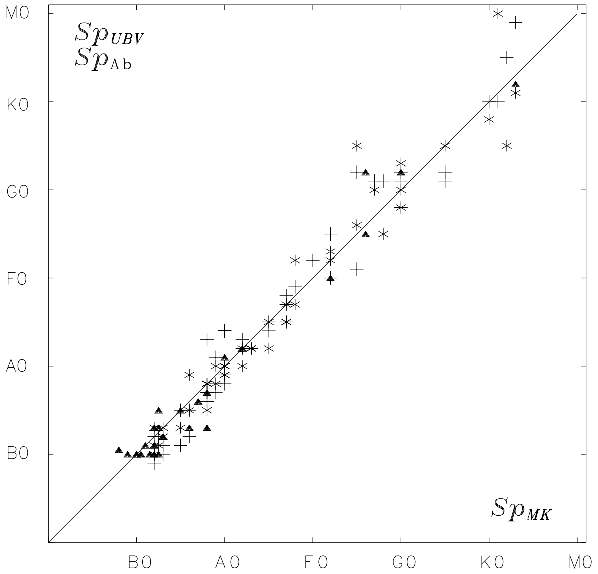

Fig. 2. Comparison of the spectral classification results obtained with different methods (vertical axis) with those in MK system (horizontal axis). Triangles - present results versus MK estimates by Ogura & Ishida (1981); direction of NGC 2244. Crosses - present results versus MK spectra by Walker (1956) and Young (1978); direction of NGC 2264. Asterisks - spectra in Abastumany system (Voroshylov et al. 1985) versus estimates by Walker (1956) and Young (1978); direction of NGC 2264

we give (by asterisks) a comparison of the spectral classification results in the Abastumany system (Voroshylov et al. 1985) with those in MK system (Walker 1956; Young 1978). Approximately equal scattering of points in both cases testify that on its accuracy the present technique matches that of the Abastumany system of criteria (Kharadze & Bartaya 1960).

4. Spectral classification of $V = 17.0 - 22.0$ mag stars in the area of NGC 2264

For extension of the present spectral classification to faint stars it is desirable to know not only their *UBV* values but, for comparison purposes, also have any reliable spectral estimates for some of these stars. The last requirement however involves a fair number of difficulties considering the magnitude range 17.0 – 22.0 discussed. This problem can be tentatively solved in the case when interstellar light absorption in a direction towards an open cluster is negligibly small. In this case the observed colours of stars will coincide with their intrinsic colours, whence it is easy to yield spectral estimates by means of Schmidt-Kaler (1982) transition tables and then use these stars as spectral standards.

The open cluster NGC 2264 in a direction of which there is practically no dust matter (Arshutkin et al. 1990) was chosen as a test object of research. *UBV* values of NGC 2264 stars in the V magnitude range 17.0 – 22.0 were derived by Adams et al. (1983) with the U.S.A. Kitt Pick National observatory 4 m telescope, and used here for spectral classification. These data are given in the first four columns in Table 9 (the star numbers, V values and colour indexes). The fifth column contains spectra Sp_{UBV} obtained with use of the present spectral classification technique. In sixth column "standard" spectra Sp calculated at $E(B - V)$, assumed to be equal to 0.08 for each star and used later for comparison with results of the spectral classification, are given. The seventh column contains intrinsic colour excesses of stars $E(B - V)_{UBV}$ calculated on the basis of Schmidt-Kaler (1982) transition tables via spectra Sp_{UBV} that are given in Col. 5.

When computing intrinsic colours of open cluster members and foreground stars

$$(B - V)_0 = (B - V) - E(B - V) \quad (2)$$

Table 7. Photometric and spectral characteristics of stars brighter than $V = 14.0$ mag in the direction of open cluster NGC 2244

N	V	$Sp_{\rm MK}$	$Sp_{\rm Ab}$	$Sp_{\rm K}$	Sp_{UBV}	P,%
11	12.37	-	-	G6	G6	f
14	12.66	-	-	K2:	K3	f
16	10.99	-	-	F8	G3	f
20	12.50	-	-	F6	F3	f
30	12.72	-	-	G0	F2	f
35	12.90	-	A3:	A2	A2	f
36	13.21	-	-	B5	B9	f
39	12.09	-	-	F3	F0	f
45	10.40	-	A1 V	A2	A3	f
53	10.63	-	-	G3	G2	f
56	12.91	-	A0-A2:	F2	A3	f
59	12.16	-	A2 V	B9	B5	f
61	13.86	-	-	B5	B9	f
62	12.76	-	-	B2	B3	f
65	12.66	-	F5-F8:	G0	F3	f
67	12.99:	-	-	K0	K0	f
69	12.87	-	-	A0	A2	f
72	12.42	-	-	F6	F4	f
74	12.39	-	-	B7	B7	93
79	10.62	B2 V	B0	-	B3	99
80	9.29	B0,5 V	B0 V	-	B0	99
84	8.19	O8 V	O8 V	-	B0,5	89
85	13.16	-	F5-F6:	F6	A9	f
95	13.80	-	-	B7	A2	f
100	12.45	-	-	F5	F2	f
106	11.82	-	-	G8	G2	f
108	11.40	B8 III	B8 V	B8	B7	83
109	13.71	A0 III	A0:	A0	A1	62
110	10.72	-	-	K5	K6	f
111	12.07	-	-	K3	K2	f
115	7.90	B0 V	B1 III	-	B0	89
116	12.73	-	B	B8	B8	100
118	12.35	-	-	K7	K5	f
127	8.77	A2 V	A2 V	-	A2	f
128	9.36	B1,5 V	B2 V	-	B0	100
130	11.60	B2,5 V	B5	B3	B3	100
133	11.69	-	A2 V	A1	B9	98
135	11.65	-	-	G2	G0	f
136	13.45	-	-	G8	G2	f
137	13.43:	-	A0 V	A0	B9	f
140	13.84	-	-	A3	A2	61
141	13.91	-	-	F3	F3	f
142	10.09:	F6 IV	-	F8	F5	f
145	12.75	-	-	F5	F4	f
153	12.55	-	A2 V	A5	A2	f
156	10.69	F6 V	-	F5	G2	f
158	10.25	G0 IV	-	F8	G2	f
160	12.68	-	A0 V	B8	B8	91
163	13.02	-	-	K3	K5	f
164	13.21	-	-	B8	B5	f
167	10.73	B2 V	B2 V	B2	B0	100
169	12.46	-	-	F8	G2	f
171	12.81	-	-	G8	G2	f
172	11.18	B2,5 V	B2 V	B2	B0	100
173	10.28	-	-	K3	K1	f
180	8.17	O9 V	O9 III	-	B0	100
183	11.33	-	A2 V	A3	A7	f
188	11.71	-	-	K2	K4	f
189	11.15:	-	-	A0	A0	f
190	11.24:	B2,5 V	-	-	B5	100
192	12.40	-	B3 V	-	B7	78
193	10.31	B2 V	B0 V	-	B1	100
194	11.95	B6 V	A5 V	A3	B3	100
197	12.57	-	-	A0:	B7	100
198	12.64	-	A	B8	B8	99
200	8.54	B0 V	B1 V	-	B0	100
201	9.71	B1 V	B1 V	-	B1	100
207	11.43	-	-	G8	G2	f
210	11.50:	-	-	K7	K5	f
213	11.51:	F2	A2p	A3	F0	f
215	13.40	-	-	F5:	F2	f
217	12.86	-	-	F6	F0	f
219	11.33	-	-	F5	F0	f
223	13.16	-	-	F3	F0	f
225	12.09	-	-	K5	K5	f
227	13.66	-	-	K0:	K1	f
229	13.42:	-	-	G3	G2	f
231	12.56	B5	-	B5	B5	97
233	12.85	-	-	G0:	G2	f
236	13.60	-	-	G0	G2	f
239	11.06	B0 V	B9 V	B7	B6	98
241	11.07	B8 V	A2 V	B5	B3	99
245	12.53:	-	B8 V	A0	A2	96
253	10.76	B3 V	B5 V	B5	B2	100
263	12.35	-	-	K7	K7	f
264	13.50	-	-	G3:	G2	f
267	12.84:	-	-	B7	B6	100
268	12.75	-	-	A5	A2	97
274	11.31	-	B5-B7	B5	B2	99
276	12.41	-	A0 V	A0	A1	f
278	10.21	K3 III	-	K3	K2	f
282	11.60:	-	-	K2	K0	f
283	10.00:	-	-	K7	K5	f
289	13.39:	-	-	G0	G2	f
290	11.73	-	A0 V	A0	A2	f
292	11.89	-	A2 V	A3	A2	f
299	13.70	-	-	G8	G1	f
301	12.55:	-	-	A2	B9	95
305	12.10	-	B8 V	B9	B8	95
308	13.67	-	-	A0	A2	85
312	12.51	-	A1 V	A1	B8	73
315	11.17	-	-	G0	G2	f
319	12.78	-	-	A3	A0	98
323	12.56	-	A0 V	A0	B9	97
327	13.56	-	A0 V	A1	B9	68
328	14.01	-	-	B5:	B2	f
330	10.64	-	-	K7	K5	f
331	12.68	-	A0 V	B9	B7	98
332	13.56	-	A0:	A0	A0	90
334	12.88	-	-	B7	B3	99
336	12.60	-	A2:III	A5	A0	f
337	12.61	-	A0:	B8	B8	98
340	13.03	-	-	G8	G2	f
342	12.78	-	F2-F6:	G5	G2	f
343	13.11:	-	A2 V	A2	A2	f
345	12.85:	-	B5:	B5	B2	93
348	9.08:	-	B8 III	-	B4	86
349	12.02	-	B5:	B5	A9	98
356	13.70	-	-	B9	A1	62
358	10.12	-	B9 V	-	A0	f
359	13.62	-	-	G2:	G2	f
361	13.82:	-	-	F5	G0	f
362	12.47	-	-	G3	G2	f
363	13.02	-	-	G5	K2	f
365	11.86	-	-	G5	G2	f

a value of average colour excess for open cluster $E(B-V) = 0.08$ was used. According to Strayzis (1977), the value of parameter Q_{UBV} for O–M stars of I–V luminosity classes varies in the limits from -0.91 to $+0.17$:

$$-0.91 \pm \sigma\{Q_{UBV}\} < Q_{UBV} < +0.17 \pm \sigma\{Q_{UBV}\}. \qquad (3)$$

Here $\sigma\{Q_{UBV}\}$ is this value error caused by errors of colour photometry $\sigma\{U-B\}$, $\sigma\{B-V\}$ and of X value approximation $\sigma\{X\}$:

$$\sigma^2\{Q_{UBV}\} = \sigma^2\{U-B\} + \sigma^2\{B-V\}X^2 + \sigma^2\{X\}(B-V)^2. \qquad (4)$$

Because the value of X for the majority of stars according to Strayzis (1977) is very close to one, the third member in the formula (4) may be safely omitted. Thus the value $\sigma\{Q_{UBV}\}$ practically depends only on errors of colour parameters $(U-B)$ and $(B-V)$ measurement, which are given in Cols. 6 and 10 of Tables 13-18 presented

Table 8. Photometric and spectral characteristics of stars brighter than $V = 13.0$ mag in direction of open cluster NGC 2264

N	V	$Sp_{\rm MK}$	$Sp_{\rm Y}$	$Sp_{\rm V}$	Sp_{UBV}
2	9.68	A7 III-IV	A7 V	A7 V	A7
6	8.17	-	-	F3 V	F0
7	7.74	-	B3 V	B3 V	B1
17	12.87	-	-	A0:	A0
20	10.27	F2 III	F0 V	F3 V	F2
25	7.80	-	-	F3 V	F4
26	11.78	-	-	F8 V	G2
28	12.29	-	-	F8 V	G2
30	10.75	-	A0 V	A0 V	A4
33	11.67	-	K1 V	M	K0
35	10.35	-	-	A1 V	A7
36	10.88	-	B9 V	A0 V	A1
39	11.32	-	-	A2 V	A3
43	10.50	A7 III	A7 V	A5 V	A5
46	9.19	A5 III	A3 V	A2 III	A5
50	8.11	B3 V	B3 V	B2 III	B0
65	11.71	-	-	F5 V	G2
67	10.80	B2 V	B2 V	B0	B0
68	11.72	G0 IV-V	F4 V	G0:	G2
69	8.26	K3 II-III	-	K1 III	K9
70	11.08	-	-	G3 V	G3
73	9.32	G5 III	-	G5 V	G1
83	7.93	-	B2 V	B1 III	O9
87	10.74	-	A0 V	-	A4
88	9.02	B5 V	B5 V	B3 III	B1
92	11.69	K0 IV	-	G8	K0
99	10.80	-	-	F5 V	F2
100	9.98	A2 IV	B8 V	A0 V	A3
104	11.36	A5 IV	-	A5	A4
107	8.81	-	B6 V	B9 III	B5
108	11.87	G0 III-IV	F7 V	F8:	F8
109	9.08	B6 V	B3 V	B5 V	B2
112	10.77	A0 V	A0 V	B9 V	B8
114	11.54	-	-	F8 V	G1
116	11.58	F5 III-IV	F7 V	F6 V	G2
125	12.29	F6-G0III-V	F9 V	F5	G1
132	10.23	-	B8 V	B8 V	B7
134	12.38	-	G5 V	-	G2
137	9.88	-	B5 V	-	B5
145	10.64	A0 V	A0 V	A0 V	A4
151	12.53	-	-	G3	G2
152	9.10	-	-	B8 IV	B5
157	10.06	-	B8 V	B5 III	B7
158	10.36	A7-F0IV-V	F0 V	A7 5	A9
159	10.97	A0 V	A0 V	A0 V	A4
172	10.04	-	B8 V	B8 V	B6
177	9.20	-	-	G5 III	G1
179	9.95	-	B9 V	-	B8
180	12.86	-	-	G5:	G5
181	10.03	B9-A0IV-V	B9 V	B8 V	B7
182	10.31	A2 V	-	A2 V	A2
187	9.21	-	B8 V	B8 V	B7
189	11.20	-	-	G0:	G2
190	12.26	-	G0 V	-	G1
193	9.77	A7 IIIp	-	A5 V	A8
196	11.46	F6-F8 IV	-	G0 V	G1
202	8.98	B2 V	-	B3 V	B2
203	12.90	-	-	F8	G1
205	10.60:	-	A8 V	F2 V	F3
206	8.70:	-	B8 V	B8 V	B7
209	11.29	-	F2 V	F2 V	F5
212	7.47	B2,5 V	B3 V	B1 III	B2
215	9.29	A0 IV-V	A0 V	B9 III	B9
216	11.69	-	-	G5:	G2
220	9.69	-	-	F6 V	G2
221	12.12	-	-	F3	F4
222	9.88	A3 IV	A2 V	A2 III	A2
223	10.86	-	-	F0 V	F3
224	11.49	-	F5 V	G5 V	F1
226	9.59	A3 III	-	A2 III	A2
227	11.77	-	-	G2:	G1
228	11.07	-	F0 V	-	F2
231	8.96	-	B5 V	-	B1
233	9.54	G0 V	-	G3 V	G1
237	9.44	K2 III	K2II-III	G5 III	K5

Table 9. Photometric and spectral characteristics of $V = 17 - 22$ mag stars in direction of open cluster NGC 2264

N	V	$U-B$	$B-V$	Sp_{UBV}	Sp	$E(B-V)_{UBV}$
302	20.00	1.18	1.33	K7	K6	0.18
303	20.37	1.54	1.81	K6	M6	0.57
306	20.87	1.63	1.52	K5	M1	0.37
321	17.49	1.05	1.30	K6	K6	0.15
355	17.51	1.39	1.53	K5	M1	0.38
404	20.66	1.36	1.62	K6	M4	0.38
407	20.08	1.95	1.98	K5	M8	0.83
409	20.52	1.37	1.58	K5	M2	0.43
410	20.39	0.72	1.57	M5	M2	0.00
413	21.71	1.49	1.64	K5	M4	0.49
415	20.93	1.08	1.62	M5	M4	0.00
416	20.82	1.28	1.51	K6	M0	0.27
417	19.68	1.18	1.43	K6	K7	0.19
419	20.68	1.56	1.81	K5	M6	0.51
424	20.56	1.47	1.50	K5	M0	0.35
426	20.71	1.74	1.94	K8	M7	0.58
429	21.08	1.25	1.61	K5	M4	0.45
431	21.76	0.98	1.70	M5	M5	0.06
433	18.14	1.13	1.88	M5	M7	0.17
438	21.38	1.08	2.07	M5	M8	0.43
440	20.87	1.20	2.17	M5	M8	0.53
451	20.96	1.27	1.59	K6	M3	0.25
456	20.97	0.95	1.31	K2	K6	0.40
465	22.35	1.33	2.01	K5	M8	0.37
466	22.09	0.78	1.34	K4	K6	0.29
471	18.51	1.08	1.60	M5	M3	0.00
509	19.32	0.67	0.98	K2	K0	0.07
518	20.77	0.85	1.67	M5	M5	0.03
525	20.38	0.88	1.62	M5	M5	0.00
526	17.47	1.57	1.36	K5	M6	0.21
531	21.66	0.43	1.30	K4	K6	0.25
532	17.56	1.44	1.44	K5	K7	0.29
533	19.98	0.85	1.47	K5	M0	0.32
536	20.29	1.57	1.50	K5	M0	0.35
545	17.17	1.47	1.57	K5	M2	0.42
551	20.63	1.59	1.50	K5	M0	0.35
553	18.90	0.57	1.39	K4	K7	0.24
562	21.70	0.92	1.36	K4	K7	0.31
564	17.48	0.73	0.98	K6	K2	0.00
588	19.66	0.74	1.27	K4	K5	0.22
603	18.19	0.72	1.37	K4	K7	0.32
607	18.32	0.70	1.40	K4	K7	0.35
612	22.37	1.00	1.58	K4	M3	0.53
619	19.57	1.35	1.51	K5	M1	0.36
639	17.25	1.64	1.52	K5	M4	0.37
644	21.83	0.63	1.03	K4	K3	0.00
723	18.05	0.70	1.47	K4	M0	0.42
724	20.86	1.19	1.48	K5	M0	0.33
728	18.93	0.96	1.19	K6	K5	0.00
742	21.03	1.27	1.83	K4	M6	0.78
749	20.84	1.00	1.50	K4	M0	0.45
819	18.30	1.09	1.56	K4	M2	0.51
821	17.98	1.06	1.38	K5	K6	0.23
838	19.13	1.57	1.60	K5	M3	0.45
839	17.68	0.98	1.33	K6	K6	0.09
841	17.59	1.84	1.82	K5	M6	0.67
849	19.06	0.69	1.18	K0	K4	0.37
858	17.25	1.31	1.12	K5	K5	0.00
859	19.88	0.99	1.25	K5	K5	0.10
865	18.22	0.74	1.24	K4	K5	0.19

by Adams et al. (1983). These tables contain data on approximately 200 stars which have both $(U-B)$ and $(B-V)$ values. About a half of these stars which satisfy the condition (3) have been involved to the spectral classification by the present technique. Other stars with $Q_{UBV} \gg 0.17 \pm \sigma\{Q_{UBV}\}$, which according to Adams et al. (1983) is caused by strong ultraviolet colour excess of stars, were not considered in this study.

As an example, we shall carry out spectral classification of the first star in Table 9 of the present study. It has a visual magnitude of $V = 20.0$ and colour parameters $(U - B) = 1.18$, $(B - V) = 1.33$ (Adams et al. 1983). Via the formula (1) with average $E(U - B)/E(B - V) = 0.85$ we derive $Q_{UBV} = 0.05$ as the first approximation. The value identified of Q_{UBV} corresponds to the following set of spectral estimates: Sp_1 = K5 V, Sp_2 = A2 V, Sp_3 = A2 III, Sp_4 = M4 III, Sp_5 = F2 I, and Sp_6 = K5 I. Spectra Sp_4, Sp_5, and Sp_6 should be excluded from consideration in as far as they lead to such estimates of distances which move a star out the Galaxy. Other estimates Sp_1 = K5 V, Sp_2 = A2 V and Sp_3 = A2 III correspond to distances 2.6 kpc, 8.3 kpc, and 12.6 kpc. The assumption of the star spectral type being A2 V or A2 III moves it almost to the limits of the Galaxy (distances 8.3 kpc and 12.6 kpc respectively). And if, in view of errors of distance determination towards a star $\pm 3\sigma\{V_0 - M_V\}$, it does remain inward of the Galaxy, simple calculations show that it has undoubtedly moved far beyond the open cluster NGC 2264 and T Tau stellar grouping. This, however, contradicts observational evidence (Arshutkin et al. 1990; Adams et al. 1983) according to which the star number 302 as well as all other stars in Table 9 belong to the open cluster NGC 2264 or T Tau star grouping, located at distances about 1 kpc from the Sun.

On the other hand, Williams & Cremin (1969) specify existence of the dark dust nebula which completely cut off the light of background stars located beyond the open cluster. An opportunity for observation of stars, in particular on distances 8.3 kpc and 12.5 kpc computed for spectra Sp_2 = A2 V and Sp_3 = A2 III, is thus excluded. As an exception a few O–B2 high luminosity stars of extragalactic origin have been discovered in the process of the spectral classification, which is discussed later in brief.

So, spectral estimates $Sp_2 \ldots Sp_6$ should be excluded from the considered set of probable spectra $Sp_1 \ldots Sp_6$. As a result there remains only one acceptable spectrum Sp_1 = K5 V. Then, using an exact value of $E(U - B)/E(B - V)$ (Strayzis 1977) for Sp_1 = K5 V, we yield a more accurate value $Q_{UBV} = -0.10$. With this value, via the table given by Strayzis (1977), two corresponding estimates of spectra K3 V and K7 V are obtained. Simple averaging gives K5 as a final spectrum of the star Sp_{UBV} and a new value of colour excess $E(B - V)_{UBV} = 0.18$ mag. Allowing for $\pm 3\sigma\{E(B-V)\}$ random error, the last value of $E(B-V)$, unlike other alternative values $E_2(B - V) \ldots E_6(B - V)$ corresponding to spectra $Sp_2 \ldots Sp_6$, fits the absorption curve (Arshutkin et al. 1990; Cohen & Kuhl 1979; Walker 1956; Williams & Cremin 1969) fairly well.

Spectral classification of other faint stars was carried out in a similar way and results are given in Table 9. Colour excesses of the stars vary from 0.00 to 0.80 mag, and their spectra are all in the interval K0–M5. This agrees well with results of previous studies (Arshutkin et al. 1990; Cohen & Kuhl 1979), taking into consideration photometric and spectral classification errors.

The comparison of the present classification results Sp_{UBV} (Col. 5) with "standard" spectra Sp (Col. 6) shows a good agreement. The differences for more than half of the stars do not exceed three subclasses. It should be noted that the accuracy of photometric observations of $17.0 - 22.0$ mag stars is much worse than that for stars brighter than 14.0 mag, the spectral classification of which was discussed in Sect. 3. To some extent, deviations which exceed three subclasses are possibly explained by this circumstance. The deviations, however, have systematic character and may be caused by the initially accepted assumption that $E(B - V) = 0.08$ for each star, which may be incorrect. Actually, the real colour excesses of stars often exceed this value, and according to Cohen & Kuhl (1979) reach 0.70 mag, which agrees well with results of the present work (Col. 7 of Table 9).

Arshutkin et al. (1990), and Walker (1956) have shown that inside the open cluster NGC 2264 and at shorter distances there is practically no dust substance, and the average colour excess is here 0.08. Thus, stars with colour excesses $E(B-V) \gg 0.08$ are located a little further than the open cluster, which confirms the conclusion made by Arshutkin et al. (1990) about the existence of T Tau star grouping on 1 kpc distance from the Sun.

A study on spectral classification of NGC 2244 and NGC 2264 faint stars with the use of UBV photometric data allowed us to draw a very important conclusion. It was found that extension of spectral studies into the region of faint stars leads to the increase of percentage of unambiguous estimates of spectra. For the $V = 17 - 22$ mag stars spectral classification in a direction of NGC 2264 there is practically no necessity to employ any additional astrometric criteria. Otherwise, the difficulties in obtaining reliable observational material would make up a serious problem in proper motions determination of faint stars.

The list of stars in Table 9 could be supplemented with a few of O–B2 objects whose spectra are unequivocally determined with the Q- method. Estimates of distances show that these objects are far out the Galaxy. They are observable due to their high luminosity and existence of transparency windows (Arshutkin et al. 1990). It is quite obvious that they were listed by Adams et al. (1983) as NGC 2264 members as a consequence of selection criteria used by him. These criteria probably give equivalent results when being applied both to NGC 2264 stars, T Tau star grouping, and to objects of extragalactic origin. Many of O–B2 objects have large colour excesses $E(B-V) > 2.0$, which exceed the threshold value of the Q-method applicability (Johnson 1958; Johnson & Morgan 1953). Because these objects do not belong to NGC 2264 or to T Tau star grouping, we did not include them in Table 9.

5. Conclusion

The principal opportunity and expediency of use of the present technique for spectral classification of O–M stars up to $V = 22$ mag was shown in the example of two young open clusters NGC 2244 and NGC 2264. It was proved also by results of comparison of spectral estimates obtained on the basis of UBV photometry with other independent estimates of spectra available in MK system (Fig. 2, Tables 3-9).

The developed technique can be used for spectral classification of stars not only in directions of young open clusters, but also in directions of more extended stellar groups (star-forming regions, OB - associations). The present technique, comparing to Q-method which is applicable only to young O–A0 stars, is more universal as far as it permits us to carry out spectral classification in much more useful O–M spectral intervals.

The main advantage of the present technique in relation to other multicolour photometric methods of spectral classification consists of allowing us to carry out extensive spectral classification programs of O–M stars up to $V = 22.0$ mag using for this purpose only three-colour UBV photometric data. An important conclusion made was that for faint star spectral classification there is practically no necessity to use additional data, in particular on proper motions. In this case spectral classification can be carried out with the use of one main criterion which characterizes distribution of dust substance in a given direction.

References

Adams M.T., Strom K.M., Strom S.E., 1983, ApJS 4, 893

Arshutkin L.N., et al., 1990, The structure and evolution of star-forming regions. Naukova dumka, Kyiv

Cohen M., Kuhi L.V., 1979, ApJS 4, 743

Holopov N.P., 1981, Open star clusters. Science, Moscow

Johnson H.L., 1958, Lowell. Observ. Bull. 4, 37

Johnson H.L., Morgan W.W., 1953, ApJ 3, 313

Khalandadze N.B., Kuznetsov V.I., Voroshylov V.I., 1986, Kinematics Phys. Celest. Bodies 2, 27

Kharadze E.K., Bartaya R.A., 1960, Bull. Abastumany Astrophys. Obs. 25, 139

Kuznetsov V.I., 1978, Astrometriya i Astrofizika 34, 30

Kuznetsov V.I., 1986, Kinematics Phys. Celest. Bodies 2, 45

Kuznetsov V.I., 1988, Kinematics Phys. Celest. Bodies 4, 80

Kuznetsov V.I., Lazorenko G.A., 1992, Kinematics Phys. Celest. Bodies 4, 76

Kuznetsov V.I., Lazorenko G.A., Lazorenko P.F., 1989, Kinematics Phys. Celest. Bodies 3, 7

Kouznetsov V.I., Lazorenko G.A., Lazorenko P.F., 1993, A&A 278, 43

Marschall L.A., van Altena W.F., Chiu L.-T.G., 1982, AJ 11, 1497

Mermilliod I.C., 1976, A&AS 24, 159

Ogura K., Ishida K., 1981, PASJ 33, 149

Strayzis V., 1977, Multicolour photometry of stars. Photometric systems and methods. Mokslas, Vilnius

Sudjus I., 1974, Bull. Vilnius Astron. Obs. 39, 18

Schmidt-Kaler Th., 1982, Physical parameters of the star. Landolt-Bornstein Numerical data and functional relationship in science and technology. Springer Verlag, Berlin

Urasin L.A., 1973, News Kazan Astron. Obs. 40, 98

Urasin L.A., Tohtasiev S.S, Dubjago I.A., Fomin S.K., 1989, News Kazan Astron. Obs. 54, 3

Voroshylov V.I., Guseva N.G., Khalandadze, et al., 1985, The catalogue of B, V values and spectral classes of 6000 stars. Naukova dumka, Kyiv

Voroshylov V.I., Khalandadze N.B., 1983, Astrometriya i Astrofizika 50, 35

Voroshylov V.I., Khalandadze N.B., Kuznetsov V.I., 1972, Bull. Abastumany Astrophys. Obs. 43, 55

Walker M.F., 1956, ApJS 2, 365

Williams I.R., Cremin A.N., 1969, MNRAS 1, 359

Young A., 1978, PASP 534, 144