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THE PROPERTIES OF RED GIANT STARS IN THE SOLAR VICINITY. I. DETERMINATION OF COLOUR EXCESSES

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An application of the Q-method for determining the interstellar reddening of field and cluster red giants is discussed on the basis of data in UBV and Vilnius photometric systems. The equations connecting the intrinsic colours and Q-parameters of these systems are constructed where the luminosity and metallicity differences are taken into account. The reddenings of some open cluster red giants are determined.

KEY WORDS Red giants, colour excesses

1 INTRODUCTION

Red giants are very suitable objects for investigating the properties of galactic disk in solar vicinity. A high luminosity of these stars allows one to perform precise photometric and spectroscopic observations providing absolute stellar magnitudes, radial velocities and chemical abundances of objects. The same we can say about proper motions which give the opportunity to evaluate space motions. Red giants are numerous enough to be used in the investigations of large samples causing trustworthy estimates of various values we are interested in. To investigate the properties of the galactic disk, it would be convenient that red giants of solar vicinity be a mixture of the objects of various ages, which give a possibility of evaluating the age dependencies of galactic disk parameters.

A decade ago the author investigated the kinematical properties of red giants in the volume of diameter of 100 pc (Loktin, 1983) around the Sun. After the publication, a great amount of observations become accessible which allow one to extend samples for new investigation.

This work is devoted to the discussion of methods of reddening determination for red giants on the basis of data of three photometric systems – UBV, DDO and Vilnius. The necessity of this discussion is forced by the demand of reddening determinations of open clusters red giants, especially old ones, where usually few luminous stars are measured in U-band of UBV system. On the other hand, there are some difficulties in the determination of colour excesses of field giants. The position of dereddened main sequence (DMS) on two-colour diagram is a function of the absolute stellar magnitude and chemical abundance of a star, that is why the reddening estimation must be performed for each star separately with special DMS. In Loktin (1993) an attempt to determine the DMS position of red giants of various luminosities and abundances was made for UBV and WBV systems. But afterwards we decided to use the Q-method, where the diagram Q-colour index is employed for reddening determination. The advantages of this method will be discussed below.

2 SAMPLE

To determine the DMS position on Q-colour diagram and its dependence on the star luminosity and abundance, one must construct the corresponding data sample. During last decade the author gathered photometric, kinematical and spectroscopic data on bright field red giants in a card catalogue, containing now information on more than 5000 objects. As a red giant here we regard the star of IV-I luminosity class with colour index $(B-V)_0 > 0\overset{m}{.}80$. For this work near 1200 stars from the card catalogue are selected, which is sufficient to estimate their absolute magnitudes and chemical abundances. For evaluating the absolute magnitudes two methods are used. The first method uses a dependence of the intensity of the emission component of ionized calcium lines on luminosity (Wilson–Bappu effect), with the data being mainly taken from Wilson (1976) and McWilliam (1990). The second method estimates the luminosity from the data of Vilnius and DDO-photometry. This method will be discussed in the following paper of the series. To take into account the abundance differences, estimates of the values of [Fe/H] are selected from the catalogues of Cairel de Strobel *et al.* (1992) and McWilliam (1990) supplemented by the values calculated from DDO photometry data. Finally the sample contains 867 stars, and most of them are bright ones with $V < 7\overset{m}{.}0$ close to the Sun. The known binary stars are eliminated from the sample. Unfortunately there is no any supergiants in our sample, and the number of bright giants is low, that is why the discussion below relates to stars of the types G8–M2 with absolute magnitudes from $+3\overset{m}{.}0$ to $-3\overset{m}{.}0$.

3 COLOUR EXCESSES

3.1 *UBV System*

An estimation of red giants colour excesses is proposed to be performed using the values of the parameter $Q_{UBV} = (B-V) - a \cdot (U-B)$, (further denoted as Q) where the value of $a = E(B-V)/E(U-B)$ slightly depends on the star temperature and

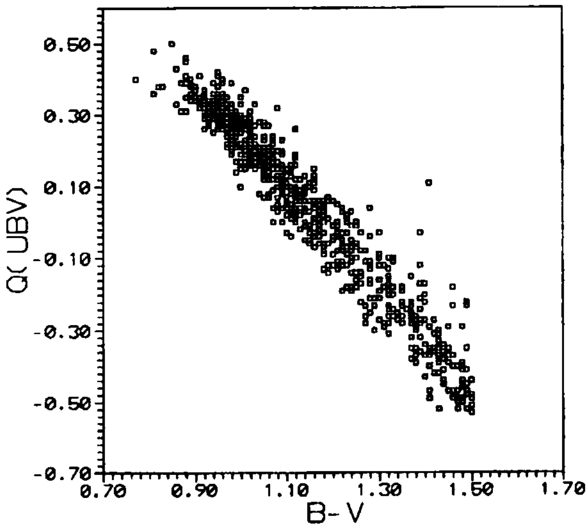

Figure 1 Connection between the values of $Q_{\rm UBV}$ and $B-V$ for all stars of the sample discussed.

luminosity due to the effect of a finite passband width of the UBV system (see Stayzis, 1977). The Q-method has one advantage: the reddening lines pass parallel to the colour axes on the Q-colour diagram, which simplifies calculations.

Let us try to find an expression connecting the values of Q and intrinsic colour indices $(B-V)_0$ accounting for the effects of luminosity and metallicity differences. For all stars of sample the values of Q are calculated, with a being calculated using the expression

$$a = 0.67 + 0.28 \cdot (B-V)_0, \tag{1}$$

which we obtained by smoothing the values taken from Table 8 of Strayzs (1977) for the stars under discussion. As the first approximation to $(B-V)_0$ the observed values $(B-V)$ are used to calculate a. Our sample includes stars more distant than those used in Loktin (1983), and now it is insufficient to suppose that most of stars are nonreddened. That is why we have decided to use several approximations to DMS using at every step a new dependence $Q-(B-V)_0$ to remove stars with the maximum reddening from the sample. The discordant stars, which are stars with great photometric errors or doubles or peculiar ones are removed by this procedure too. Stars with $(B-V)_0 > 1\overset{m}{.}5$ are eliminated from the sample to avoid the duality of the dependence Q-colour for most red stars. This value of $(B-V)_0$ fixes the red boundary of applicability of the expression below.

After three approximations for 768 stars of the remaining sample the use of a stepwise regression procedure gives the expression for DMS

$$(B-V)_0 = 1.163 - 0.67Q - 0.135Q^2 - 0.028M_V + 0.005M_V^2 - 0.142[\mathrm{Fe/H}], \tag{2}$$

where the dispersion of deviations is equal to $\sigma = 0\overset{m}{.}029$ whose value can be regarded as satisfactory due to inhomogeneity of the UBV data. The values of root mean square errors of the coefficients of the expression are equal to 0.002, 0.005, 0.018, 0.002, 0.001 and 0.006, respectively.

The dependence of Q on observed colour indeics $(B-V)$ for all stars of the sample is shown on Figure 1. As seen from the figure, most of our stars are situated along one nearly straight line with small dispersion around it. This fact allow us to conclude that the reddening of stars of our sample is low enough to provide a high reliability of expression (2).

3.2 DDO Photometry

Independent estimates of red giants colour excesses can be obtained from DDO-photometry data. The independence of UBV and DDO data allows one to use mean values of colour excesses and to control the systematic bias. The necessity of such control is revealed in determining the parameters of open clusters from DDO data (Loktin, 1996) where it is shown that in spite of high inner quality (small errors of the mean reddening estimations for clusters and the value of $0^m_.02$ for random error of reddening per one star) the mean values of cluster colour excesses obtained from DDO-photometry often deviate appreciably from the reliable estimates of UBV-photometry.

To extend the sample for determining the red giants parameters from DDO-data we, following Janes (1975), decided to use the data of Koppenhavn photometric system (see Stayzis, 1977). To calculate DDO-colour indices from the values of indices g, n, k, m, f, u of Koppenhavn system, the expressions were established by a stepwise regression procedure for 253 common stars in our sample:

$$C_{45-48} = 0.982 + 0.027n - 0.377m + 0.42f \tag{3}$$

with the values of rms errors of coefficients 0.003, 0.006, 0.011 and 0.005 respectively and rms deviation $\sigma = 0^m_.007$,

$$C_{42-45} = 0.148 + 0.261g - 0.196n + 0.452m + 0.286f \tag{4}$$

with the values of rms errors of coefficients 0.048, 0.084, 0.017, 0.035 and 0.016 respectively and rms deviation $\sigma = 0^m_.012$, and

$$C_{41-42} = -0.230 + 0.082g - 0.818n + 0.021k \tag{5}$$

with the values of rms errors of coefficients 0.029, 0.020, 0.009 and 0.012 respectively and rms deviation $\sigma = 0^m_.011$.

The comparison of colour excesses taken from DDO-data with those obtained from other photometric systems for stars of our sample is meaningless because for most stars the values of excess are lower than those of photometric errors. Such a comparison is performed for open star clusters in next section of this paper and in Loktin (1996).

3.3 Colour Excesses of Open Clusters Giants

To check the efficiency of the proposed method of colour excess estimations of red giants we evaluated the mean excess of red giants of 39 open clusters, every of which contains more than 4 probable red giant members. The results of calculations are shown in Table 1, where the following information is given accordingly in columns: cluster name, number of stars used, colour excess from red giants photometry (this paper method), colour excess from UBV-photometry of main sequence stars taken from the second version of the catalogue Loktin and Matkin (1994), colour excess from DDO-photometry taken from Loktin (1996), the values of distance moduli assumed for estimating M_V and taken from Loktin and Matkin (1994), assumed values of [Fe/H] taken from the list of Pilskaya (1996) where data were collected from publications. For clusters with yet unknown metallicity the value [Fe/H] = 0.0 is used. The last column of the table contains references on the sources of UBV-photometry used. For some clusters (e.g., M67 = NGC2682) several sources are used.

Table 1. The estimation of mean values of colour excesses of red giants in open clusters

Cluster	*N*	$E_{(B-V),RG}$	σ	$E_{(B-V),MS}$	$E_{(B-V),DDO}$	*DM*	*[Fe/H]*	*Ref.*
NGC188	8	0.14	0.01	0.09	0.06	11.1	-0.06	Eggen, 1969
NGC752	9	0.07	0.02	0.05	0.02	7.8	-0.18	Eggen, 1963
	13	0.05	0.01	0.05	0.01	7.8	-0.18	Johnson, 1953
NGC1245	13	0.28	0.02	0.31	-	12.1	0.00	Chincarini, 1963
	12	0.30	0.02	0.31	-	12.1	0.00	Hoag, 1961
NGC1342	4	0.28	0.04	0.26	-	8.6	-0.38	Hoag, 1961
NGC1817	20	0.20	0.01	0.30	-	11.6	-0.04	Harris, 1977
	14	0.23	0.02	0.30	-	11.6	-0.04	Purgath., 1964
NGC2099	13	0.38	0.02	0.28	0.29	10.7	-0.09	West, 1967
NGC2286	8	0.46	0.01	0.03	-	11.7	0.00	Chincarini, 1963
NGC2324	3	0.02	0.03	0.04	-	13.2	-0.06	Hoag, 1961
NGC2354	7	0.09	0.02	0.17	-	11.6	0.00	Durbeck, 1960
NGC2360	10	0.08	0.01	0.09	-	11.1	-0.15	Eggen, 1968
NGC2420	11	0.01	0.01	0.00	0.04	12.0	-0.60	McClure, 1974
NGC2423	5	0.03	0.04	0.04	0.11	9.5	0.06	Hassan, 1976
	9	0.07	0.02	0.04	0.11	0.5	0.06	Smith, 1962
NGC2477	20	0.23	0.01	0.33	0.28	11.3	0.00	Hartwick, 1972
NGC2506	5	0.10	0.05	0.13	0.09	12.5	-0.46	Purgath., 1964
	11	0.04	0.02	0.13	-	12.5	-0.46	McClure, 1981
NGC2682	13	0.06	0.02	0.07	0.04	9.5	-0.06	Gilliland, 1991
	16	0.09	0.01	0.07	0.04	9.5	-0.06	Montgom., 1993
	26	0.07	0.01	0.07	-	0.5	-0.06	Eggen, 1964
NGC2818	16	0.20	0.02	0.18	-	13.0	-0.30	Tifft, 1972
NGC3496	6	0.48	0.02	0.47	-	9.7	-0.70	Sher, 1965
NGC3680	16	0.09	0.01	0.08	0.08	9.3	-0.03	Eggen, 1969
NGC4349	9	0.27	0.04	0.39	0.35	11.8	0.00	Lohmann, 1961
NGC4815	7	0.64	0.04	0.78	-	12.1	0.00	Kjeldsen, 1991
NGC5822	8	0.07	0.02	0.15	0.15	10.0	-0.05	Bruck, 1968
	9	0.11	0.03	0.15	0.13	10.0	-0.10	Bozkurt, 1974
NGC6134	8	0.33	0.03	0.38	0.35	10.0	0.15	Lindoff, 1972
NGC6208	11	0.24	0.02	0.15	-	10.5	0.00	Lindoff, 1972

Table 1. Continued

Cluster	*N*	$E_{(B-V),RG}$	σ	$E_{(B-V),MS}$	$E_{(B-V),DDO}$	*DM*	*[Fe/H]*	*Ref.*
NGC6633	9	0.15	0.01	0.16	–	7.9	–0.20	Hiltner, 1958
NGC6705	23	0.32	0.02	0.42	–	11.3	0.00	Johnson, 1956
	7	0.34	0.04	0.42	–	11.3	0.00	Kjeldsen, 1991
NGC6802	5	0.92	0.13	0.85	–	9.6	–0.60	Hoag, 1961
NGC6811	5	0.09	0.03	0.13	–	10.6	0.00	Lindoff, 1972
	9	0.13	0.03	0.13	–	10.6	0.00	Barkhat., 1978
NGC6819	48	0.19	0.01	0.21	–	11.1	–0.10	Auner, 1974
	29	0.21	0.02	0.21	–	11.1	–0.10	Lindoff, 1972b
	18	0.21	0.02	0.21	–	11.1	–0.10	Purgath., 1966
NGC6940	14	0.16	0.01	0.23	–	10.1	–0.10	Walker, 1958
	6	0.20	0.04	0.23	–	10.1	–0.10	Hoag, 1961
NGC7062	8	0.48	0.03	0.41	–	11.5	0.00	Hassan, 1973
NGC7142	10	0.36	0.03	0.40	–	10.0	–0.10	vdBergh, 1970
	7	0.38	0.03	0.40	–	10.0	–0.10	Hoag, 1961
NGC7226	8	0.42	0.02	0.47	–	12.1	0.00	Karaali, 1971
NGC7789	5	0.19	0.04	–	0.23	12.1	–0.30	Bubidge, 1958
IC1369	6	0.75	0.02	0.60	–	10.0	0.00	Hassan, 1973
IC4651	14	0.15	0.01	0.13	0.13	9.5	0.00	Eggen, 1971
	8	0.14	0.02	0.13	–	9.5	0.00	Lindoff, 1972c
IC4756	14	0.12	0.02	0.20	–	8.4	–0.06	Alcaino, 1965
	9	0.20	0.02	0.20	–	8.4	–0.06	Herzog, 1975
Mel66	4	0.11	0.03	–	0.12	13.2	–0.60	Eggen, 1962
Mel71	4	0.01	0.01	0.00	–	12.5	–0.35	Hassan, 1976
Praesepe	4	0.01	0.01	0.01	0.01	6.3	0.04	Loktin, 1986

To estimate open cluster red giants reddening the following method is used. For each star the preliminary value of Q_{UBV} and intrinsic colour from (2) and reddening are estimated, with the value of a in (1) being estimated using observed values of the colour index, and the absolute stellar magnitudes necessary for estimating $(B-V)_0$ from (2) are calculated by the cluster distance modulus value taken from the catalogue of Loktin and Matkin (1994). The preliminary value of $E(B-V)$ is used for estimating a and Q, which are used for improvement of $(B-V)_0$ and colour excess and so on. In all cases 5 approximations are performed, but in most cases 2–3 approximations were enough for values not to alter in third digit. There were no cases where approximations diverge. The problem of convergence of the approximations to true values of reddening at any case remains until more data for giants of old and strongly reddened clusters appear.

Rms error of reddening determination for one star appears to be equal to $0^m.06$, this value may be regarded as the upper estimate of real dispersion bacause we do not select cluster members carefully. Certain part of the dispersion may be caused by differential reddening and duplicity of some stars too.

The comparison between the mean values of cluster red giants colour excesses and the data from the catalogue of Loktin and Matkin (1994) is shown on Figure 2, and with those from DDO-photometry data on Figure 3. One can see from these figures that for most clusters the coincidence is good although some cases of large

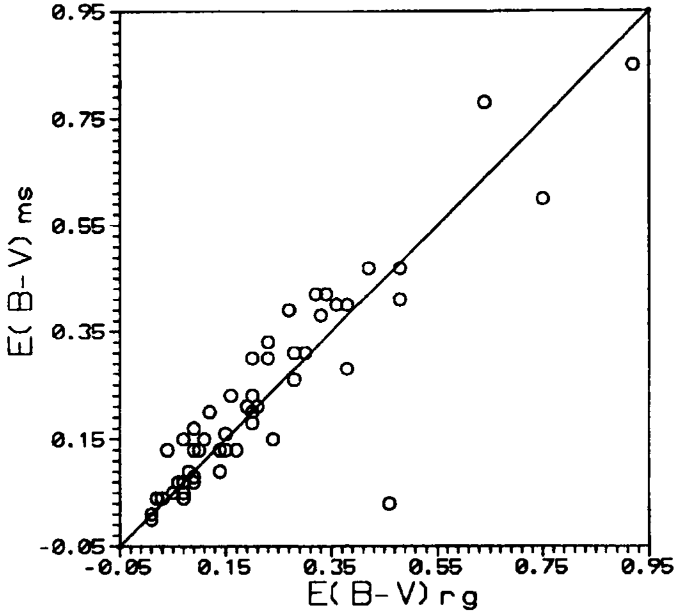

Figure 2 The comparison of open cluster mean colour excesses evaluated from main sequence fitting $E(B-V)_{ms}$ and equations of this paper $E(B-V)_{rg}$

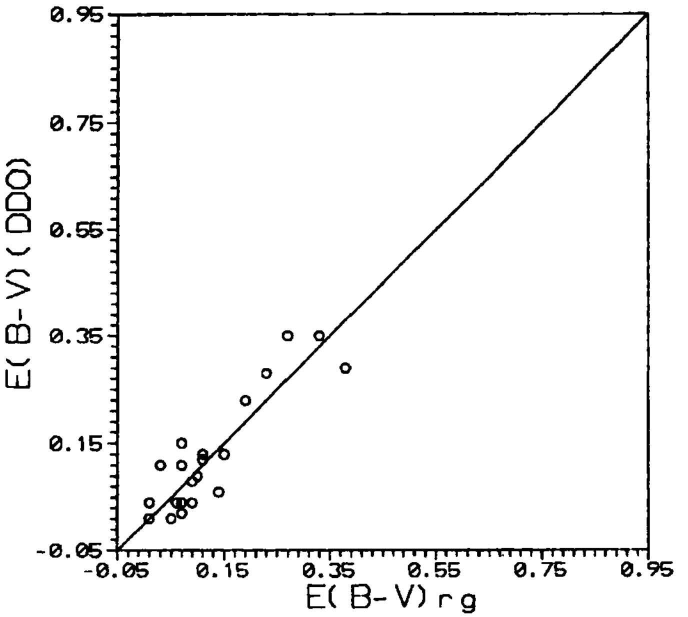

Figure 3 The comparison of cluster mean colour excesses from DDO-photometry and equations of this paper $E(B-V)_{rg}$.

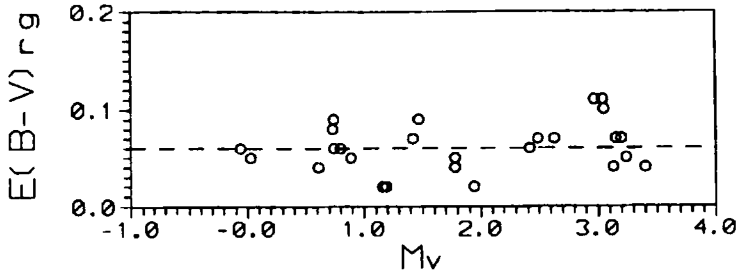

Figure 4 The dependence of the estimates of colour excess on absolute stellar magnitudes for M67 red giants.

deviations exist. The latter can be explained by the influence of background stars in this region of the HR-diagram.

For more definite consideration of the errors let us discuss the determination of colour excesses of stars from the well studied cluster NGC2682(M67). This cluster contains a lot of red giants of various luminosities and is situated far from the galactic plain which minimize the problems from background stars. On Figure 4 one can see the values of determined here reddening of cluster stars versus their absolute stellar magnitude. The data of UBV-photometry are taken from Eggen and Sandage (1964). Here we can see clearly that for the interval of magnitudes from 0^m to $+3\overset{m}{.}5$ there is no dependence of reddening on luminosity, and that random errors are not very large.

The main problem of reddening determination of cluster red giants is the problem of membership. For example on Figure 5 we show the diagram $E(B-V)_0 - M_V$ for cluster NGC3496. One can see that the scatter of values of reddening is very large, all stars may be divided in three groups and only the middle group gives the mean value of reddening close to that determined for main sequence stars.

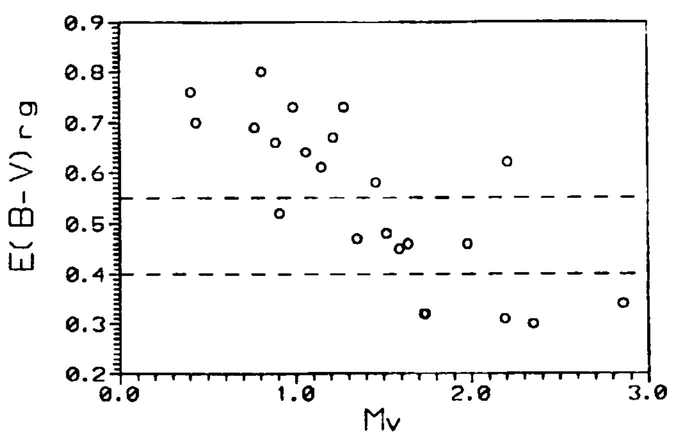

Figure 5 The values of colour excesses for NGC3496 cluster red giants.

3.4 *Vilnius Photometry*

It is well known (Strayzis, 1977) that Vilnius photometric system allows one to carry out two-dimensional spectral classification of reddened stars of various spectral types. We have decided to choose this system photometry in order to enlarge red giants sample for future investigation of galactic disk properties and to increase the reliability of estimates of star parameters by using one more source of data. The same idea is used for reddening estimation in the case of Vilnius system is used for UBV-photometry. This is an evaluation of the expression for the Q-intrinsic colour dependence, but in the case of Vilnius photometry several parameters Q can be used. This allows one to obtain several reddening estimates independent in the sense of random errors and to minimize the error of calibration.

The search for published Vilnius photometry of red giants provides the data for 331 stars of our sample mainly taken from compilation of data from 1983 version catalogue of Data Center of Institute of Astronomy of the RAS. This list is supplemented by search in latest publications.

In order to build the most suitable expression connecting the values of Q with colour indices 56 diagrams are examined, where the dependencies of Q against colour indices are marked. The Q-values regarded are $Q_{\rm UPY}$, $Q_{\rm PYV}$, $Q_{\rm XYV}$, $Q_{\rm XYZ}$, $Q_{\rm XZS}$, $Q_{\rm UXY}$, $Q_{\rm UYV}$ and $Q_{\rm PUZ}$ for which the ratios of colour excesses are published in the book of Straizis (1977) and the mean values for stars G8–M2 are used for the calculation of Q. For the later discussion we choose diagrams with minor dispersion of points, because we hope in this case for the minimum effect of luminosity and chemical composition on the reddening calculations. Using a stepwise variable selection we search the expression $CI = CI(Q, M_V, [{\rm Fe/H}])$ where CI denotes one of the Vilnius photometry colour indices, and as well as in the case of UBV-photometry after the first determination of expressions, some deviating stars (reddened of peculiar) are rejected. Finally to estimate dereddened colour indices, we choose the expressions

$$(P-X)_0 = 0.118 + 0.644 \cdot Q_{\rm PYV} - 0.012 \cdot Q^3_{\rm PYV} - 0.026 \cdot [Fe/H] \qquad (6)$$

with the rms errors of the coefficients equal to 0.027, 0.025, 0.003 and 0.008, respectively and rms deviation of equations of condition $0\overset{\rm m}{.}024$,

$$(X-Y)_0 = 0.256 + 1.383 \cdot Q_{\rm XYV} - 0.016 \cdot Q_{\rm XYV} \cdot M_V - 0.080 \cdot Q_{\rm XYV} \cdot [Fe/H] \quad (7)$$

with the errors of coefficients 0.007, 0.008, 0.002 and 0.009, and dispersion of deviations $0\overset{\rm m}{.}024$, and

$$(P-X)_0 = -0.048 + 0.661 \cdot Q_{\rm UYV} - 0.013 \cdot Q^3_{\rm UYV} + 0.003 \cdot M_V \qquad (8)$$

with the errors of coefficients 0.036, 0.028, 0.002 and 0.002, and dispersion of deviations $0\overset{\rm m}{.}029$.

It should be noted that expressions (6)–(8) are efficient for the whole interval of colour indices of our sample stars: $0.70 < (P-X)_0 < 1.55$ or $0.85 < (X-Y)_0 < 2.25$, which is approximately equal to the interval of spectral classes from G8 to M2.

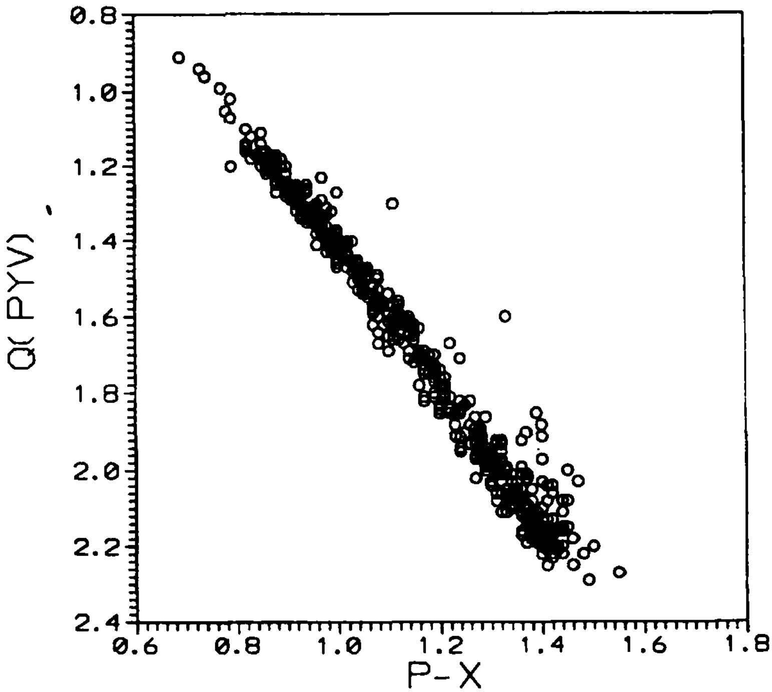

Figure 6 Connection between the values of Q_{PYV} and $P - X$ for all stars of the sample discussed.

We do not include S-type stars and stars redder than type M2, the applicability of our expressions to such stars must be checked separately.

Figure 6 examplifies a dependence of parameter Q_{PYV} on observed colour index $P - X$ for stars of our sample.

The values of colour excess $E(B-V)$ may be calculated by estimates of intrinsic colours using the expressions

$$E(B-V) = [(P-X) - (P-X)_0]/0.281, \tag{9}$$

and

$$E(B-V) = [(X-Y) - (X-Y)_0]/0.553, \tag{10}$$

where $(X-Y)$ and $(P-X)$ are observed values of colour indices and the values of excess ratios are taken from Strayzis (1977).

4 DISCUSSION

In this paper the methods of reddening determination for field red giants on the basis of collected values of star parameters are discussed. Figure 2 shows that Q-method for UBV-photometry with expression (1) results in the absence of a systematic error though random deviations may be appreciable. The latter may be caused by the difficulties of the determination of U-value for red stars. It should be noted that for our work we tried to use Vilnius photometry colour indices to check values of $U-B$ and $B-V$ of our sample stars and found that the values of $B-V$ are calculated from Vilnius data perfectly (with rms deviation $0^{m}.016$. but we could calculate the values of $U-B$ with very low accuracy. In spite of all the rms errors of determination of colour excess is equal to $0^{m}.026$, in the interval of colours considered the reddening determination turns to be unambiguous.

Difficulties with membership complicate reddening determination of star clusters from red giants photometry. But if differential reddening in known to be low and the mean colour excess of main sequence stars is determined one can evaluate individual colour excesses of cluster red giants using the expressions above.

Next paper of the series will be devoted to a discussion of the absolute magnitude determination for field red giants.

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