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EXTINCTION ESTIMATION FROM THE COLOUR-MAGNITUDE DIAGRAMS OF RESOLVED DWARF GALAXIES

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Abstract. Differential color functions are established for revealing the apparent color indexes of the sequences of OB stars, blue He burning stars and red He burning stars as raw extinction estimators. The standard error of the extinction estimation seems to be 0.2 mag and this method may be useful for galaxies observed through the Milky Way. Examples of the estimation of the total extinction of the resolved stellar populations of the galaxies NGC 3109, NGC 2366, NGC 4449 and Ho IX are shown.

1. INTRODUCTION

The color-magnitude diagram (CMD) of the resolved stars in a late type galaxy contains a mix of stellar populations. Usually the top part of the CMD consists of blue and red plume stars (BPS, RPS), containing the brightest blue and red supergiants (BBS, BRS). These stars, with absolute magnitudes from –7 to –9 and –6 to –8, respectively, are used as distance indicators so far. However, usually the apparent BBS are not single stars and the apparent BRS may be Milky Way dwarfs, which could cause misleading results in the distance estimations. Moreover, the number of the used BBS and BRS is usually only 3 and the mean color indexes of these stars are poorly defined.

More information about extinction, metallicity and star formation may be obtained from statistical study of the bright blue and red stars, e.g. by means of the color and luminosity functions of the blue and red plume of the CMD, blue-to-red supergiant ratio, etc. This approach seems to be efficient in the case of dwarf starforming galaxies rather than of giant ones. The reason for this is that the dwarf irregular galaxies usually have young stellar population with uniform metallicity, which is a result of one episode of global star formation.

In principle, the majority of the BPS and RPS belong to the nearby part of the studied galaxy and therefore they are weakly influenced by the internal extinction. The mean color indexes of BPS are practically metallicity independent and they may be used as raw extinction indicator. The color indexes of the RPS are metallicity dependent - when the metallicity grows the color indexes become more red. So, if the extinction is already estimated, the RPS may be used as metallicity indicator. In principle, if the metallicity is known, the RPS may be used as extinction indicator, too. However, the mean color indexes of the BPS and RPS are poorly defined.

There are three interesting sequences of stars with absolute magnitudes from –4 to –6 on the CMD: (i) the main sequence OB stars (OBS), (ii) the blue He burning stars (BHS, blue loop stars) and (iii) the red He burning stars (RHS, red loop stars). The brightest parts of the first two of these sequences have blue colors. Such colors are rare for the foreground Milky Way stars and the contamination from the Milky Way may be considered negligible.

The OBS and BHS have almost vertical displacement on the CMDs, with narrow intervals of color indexes ($\sim$ 0.2) and they may be used for extinction estimation. The color indexes of the RHS are intermediate, worse defined and metallicity dependent. These color indexes correspond to the most typical Milky Way stars - red dwarfs. In principle, when the Milky Way contamination may be concidered negligible, RHS may be used, too. Moreover, when the Milky Way extinction is high (e.g. > 1 mag), the color indexes of the RHS become more red. Then the apparent RHS occur in the zone of the very red dwarfs, which are more rare objects and the bump of the RHS seems to be detectable.

The spike of the red giant stars (RGS, red giant branch stars) is another important formation on the CMD, which is used more efficiently as distance and metallicity indicator in the last ten years. However, the absolute magnitudes of the RGS are < – 2.5 mag (<–4 mag in I band) and their use needs significantly deeper observations.

In the present paper we discuss the mean colors and the revealing of the reddening of the OBS, BHS and RHS on the CMDs for their use as extinction indicators.

2. THE MEAN COLOR INDEXES OF THE CHOSEN STELLAR SEQUENCES

The main sequence of the OBS forms a well pronounced vertical strip with higher concentrations of stars on the blue part of the CMD. Comparing data from many sources (Schmidt-Kaler 1965; Flower 1977; Humphryes 1978; Straizys 1977, 1987; Drilling and Landolt 2000) we adopt the mean true color index for these stars to be $(B-V)_0 = (V-I)_0 = -0.3$, within estimated uncertainty of 0.05.

Detailed CMDs from HST and model investigations show that in the case when continuous star formation process had taken place from 10–15 Gyr ago, the stellar content is prominent also by well-pronounced blue loop, containing BHS. We analyzed the CMDs given in numerous papers, mainly based on HST observations, e.g. Dohm-Palmer et al. (1997) for Sextans A, Gallagher et al. (1998) for Pegasus, Dohm-Palmer et al. (1998) for GR 8, Lynds et al. (1998) for UGC 6456, Tolstoy et al. (1998) for Leo A, etc., as well as the simulated CMDs of Aparicio et al. (1997) and Tolstoy et al. (1998). For the brightest of the BHS we adopt all mean color indexes to be $(B-V)_0 = (V-I)_0 = 0.0$ with estimated uncertainty of 0.05.

In the mentioned papers we see also prominent branches of the RHS, consisting of G5–K5 supergiants, with absolute magnitudes up to about –6 mag. The RHS form on the CMDs a vertical column, like the columns of the BHS. The color indexes of these stars are metallicity dependent and thay may be used for extinction estimation if the metallicity is known. Here we adopt raw mean color indexes for the RHS, in the case of low metallicity, to be $(B-V)_0 = 1$ and $(V-I)_0 = 1.2$, within estimated

Table 1: Adopted mean color indexes for the discussed supergiant stars

Stars	$(B-V)_0$	$(V-R)_0$	$(B-R)_0$	$(V-I)_0$	uncert-ainty
Main sequence OB stars	-0.3	-0.1	-0.4	-0.3	0.05
Blue He burning stars	0	0	0	0	0.05
Red He burning stars	1.0	0.5	1.5	1.2	0.1
Plume of BSS	-0.1	-0.05	-0.15	-0.1	0.1
Plume of RSS	1.5	0.7	2.2	1.7	0.2

uncertainty about 0.1. After respective callibration, the RHS may be raw metallicity indicators.

The color indexes of OBS stars and BHS are similar and they could hardly be distinguished from ground observations, when they merge together. The same problem appears in the HST observations of more distant galaxies. For such cases we must adopt also mean color indexes for the BPS for very raw extinction estimations. This is a more complicated task. Let us compare the luminosities of the components of the BPP. In galaxies with continuous long star forming process the BHS stars may be more than the OBS. We must account also for the possible presence of rare BBS. These stars are observed more frequently in cases of star formation of massive stars. The concentrations of the different components in the BSP are previously not known and we can not recognize them. So, we may adopt an arbitrary mean value for the color index. Here we adopt mean values for OBS and BHS stars, giving to the BHS twice greater weight. Then the mean color indexes for the brightest part of the BPS, containing the BSB, are $(B-V)_0 = (V-I)_0 = -0.1$, within estimated uncertainty of about 0.1.

In rare cases, if the population of the BRSs is sufficiently rich, the CMD shows prominant RPS. The mean color indexes of these stars are the most poorly defined among the considered types of stars and they are metallicity dependent. Looking at the CMDs in the mentioned papers, we can see some BRS, but they do not form significant concentration. These rare stars are situated arbitrarily above and to the right from the spike of the RGS. For the cases of well-pronounced RPS, in conditions of low metallicity, we adopt the main color indexes $(B-V)_0 = 1.5$ and $(V-I)_0 = 1.7$, within possible uncertainty of about 0.2. Probably, the brightest RPS may be used also as very raw metallicity indicator.

The adopted mean color indexes for the discussed bright stars, useful for reddening estimations, are given in Table 1.

For calculating the extinctions and the color excesses in different bands of the $BVRI$ system we use relations, adopted from the paper of Fitzpatrick (1999):

$$A_V = 0.76A_B, \quad A_R = 0.57A_B, \quad A_I = 0.38A_B,$$
$$E_{B-V} = 0.24A_B, \quad E_{V-R} = 0.19A_B,$$
$$E_{B-R} = 0.43A_B, \quad E_{V-I} = 0.38A_B.$$

Using the estimated uncertainities of the mean color indexes in Table 1, we may estimate the errors of the extinction derivations. In the case of excess error of 0.05

Table 2: Data on the galaxies and extinction estimations

Galaxy	A_B(PGC)	V-intervals	R- or I-intervals	A_B(T)	$\sigma_{A_B(\mathrm{T})}$	N
NGC 3109	0.41	17.7 - 20.0 - 21.5	19.6 - 21.0 - 22.0	0.83	0.11	3
NGC 2366	0.41	18.2 - 21.0 - 23.0	19.6 - 21.0 - 22.0	0.95	0.25	4
NGC 4449	0.26	17.0 - 20.4 - 23.0	17.0 - 20.6 - 22.5	0.48	0.10	4
Ho IX	0.32	19.0 - 21.8 - 23.4	19.6 - 21.4 - 22.8	0.55	0.32	3

and 0.1 mag the extinction errors belong to the intervals from 0.12 mag (for $B-R$) up to 0.26 mag (for $V-R$) as well as from 0.23 (for $B-R$) up to 0.52 mag (for $V-R$). We consider the mean estimated error of the method as 0.2.

3. RESULTS

The OBS, HBS and RBS sequences appear as vertical strips of higher concentrations stars on the CMDs. Therefore, they may be recognized as local maximums in the differential distributions of the stars along the color index range. We call such kind of stellar distributions color functions (CFs). Our experience shows that two magnitude intervals, including the brightest resolved objects and the interemediate ones, are enough for revealing the local maximums of the CFs, which may be used as detectors of the mean colors of OB, HBC and RBC stars.

We set up smoothed CFs using published CMDs from ground based observations for four star forming dwarf galaxies: NGC 3109 (Greggio et al. 1993), NGC 2366 (Aparicio et al. 1995), NGC 449 (Karachentsev & Drozdovski 1998) and Ho IX (Georgiev & Bomans 2002). The data for three of these galaxies are obtained in the BVR system and in the case of NGC 4449 the system is BVI. The CFs are presented in Fig.1. Interpreting the local maximums of the CFs as regions of higher concentration of OBS, BHS or RHS, we derive the extinction estimations and their errors from 3–5 individual estimations of the color excesses, using the color data for OB, BH and (sometimes) RHS.

The data are listed in Table 2, where A_B(PGC) is the estimation of the Milky Way extinction in the B band, adopted from the catalog PGC. The magnitude intervals of two CFs (plotted in Fig.1) are given in V and R (or I) bands by means of three magnitudes: the top limit of the first interval, the intermediate magnitude (that is bottom limit of the first interval and the top limit of the second interval) and the bottom limit of the second interval. Further A_B(T), $\sigma_{A_B(\mathrm{T})}$ and N are the estimations of the mean total extinctions (foreground and internal) toward the resolved stellar population, its standard error and the number of the individual estimations.

Table 2 shows that our total extinction estimations are significantly higher than the foreground extinction, given in the PGC. The reason for this is that the galaxies in our sample have high amount of gass and dust. Ho IX is the smallest galaxy in the sample with a shortage of bright stars. For this reason its color functions are too complicated and the total extinction to Ho IX appears worse defined.

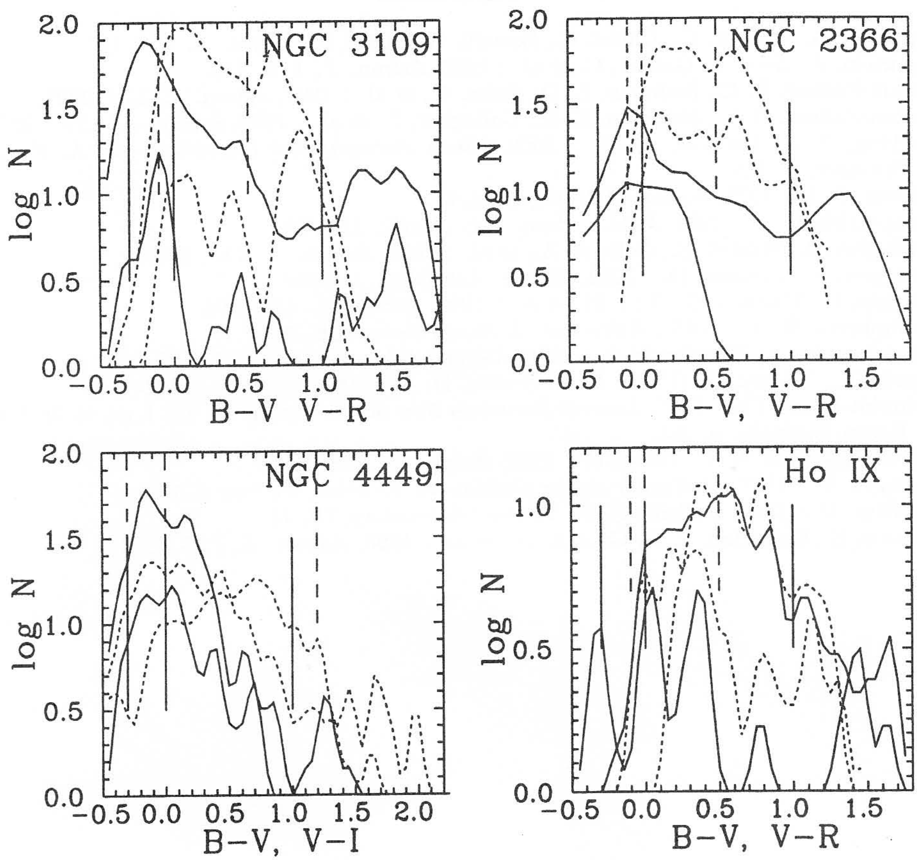

Fig. 1: Differential distributions of the stellar colors (color functions, CFs) on the CMDs, established with color index step 0.05 in two magnitude intervals for each color system. The intervals are given in Table 2. The solid curves correspond to the V band and the dashed - to the R band (for NGC 4449 – to the I band). The vertical lines (solid and dashed, respectively) show the adopted true mean color indexes of the unreddened sequences of OB stars, blue He burning and red He burning stars in V and R (or I) bands, given in Table 1. The well pronounced local maximums of the CFs are interpreted as counterparts to the corresponding sequences of bright stars and their shifts to the right are used for extinction estimations.

4. CONCLUSIONS

In this paper we check the possibility to estimate the total extinction to the resolved stellar population of dwarf galaxies using the sequences of OBS, BHS and (uncertainly) RHS. This approach may be useful in the cases of large foreground extinction, as in the case of the galaxies belonging to IC 342/Maffei complex. The accuracy of the presented method for extinction estimation is ~ 0.2 mag. For small galaxies, like Ho IX, the accuaracy of the method is lower.

References

Aparicio, A., Gallart, C., Choisi, C., Bertelli, G. : 1996, *Astrophys. J.*, **469**, L97.
Aparicio, A., Sera, J., Gallart, C. et al. : 1995, *Astron. J.*, **110**, 212.
Dohm-Palmer, R. C., Skillman, E. D., Saha, A., et al. : 1997, *Astron. J.*, **114**, 2527.
Dohm-Palmer, R. C., Skillman, E. D., Gallagher, J., et al. : 1998, *Astron. J.*, **116**, 1227.
Drilling, J. S., Landolt, A. U. : 2000, *Allen's Astrophysical Quantities*, ed. A. N. Cox, Springer, p. 388.
Flower, P. J. : 1977, *Astron. Astrophys.*, **54**, 31.
Fitzpatrick, E. L. : 1999, *Publ. Astron. Soc. Pacific*, **111**, 63.
Gallagher, J., Tolstoy, E., Colo, A. A., et al. : 1998, *Astron. J.*, **115**, 1869.
Georgiev, T., Bomans, D. : 2002, *Astron. Astrophys.*, in print.
Griggio, L., Marconi, G., Tosi, M. et al. : 1993, *Astron. J.*, **105**, 894.
Humphreys, R. M. : 1978, *Astrophys. J. Suppl. Series*, **38**, 309.
Karachentsev, I., Drozdovski, I. : 1998, *Astron. Astrophys. Suppl.*, **131**, 1.
Lynds, R., Tolstoy, E., O'Neil, E. J., Hunter, D. A. : 1998, *Astron. J.*, **116**, 146.
Schmidt-Kaler, Th. : 1965, *Landolt-Bornstein New Series*, Group VI, vol. I, ed. H. H. Voigt, Berlin, Springer, p. 284.
Schulte-Ladbeck, R. E., Hopp, U. : 1998, *Astron. J.*, **116**, 2886.
Straizys, V. : 1977, *Multicolor stellar photometry*, Mokslas, Vilnius, p. 100.
Straizys, V. : 1987, *Bulletin of the Vilnius Observatory*, **78**, 43.
Tolstoy, E., Gallagher, J. S., Cole, A. A., et al. : 1998, *Astron. J.*, **116**, 1244.