A New Absolute Magnitude Calibration for Red Clump Stars

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Abstract

We present an \( M_V \) absolute magnitude calibration including the \( B-V \) colour and \([Fe/H]\) metallicity for the red clump stars in the globular and open clusters with a wide range of metallicities: \( M_V = 0.627(\pm0.104) (B-V)_0 + 0.046(\pm0.043) [Fe/H] + 0.262(\pm0.111) \). The calibration equation is valid in the ranges \( 0.42 < (B-V)_0 < 1.20 \) mag, \(-1.55 < [Fe/H] < +0.40 \) dex and \( 0.43 < M_V < 1.03 \) mag. We found that the consistencies in the comparisons of the distances estimated from the calibration equation in this study both with the distances obtained from trigonometric parallaxes and spectrophotometric analysis demonstrate that reliable precise absolute magnitudes for the clump giants can be estimated from the calibration formula.

Key words: 97.10.Vm Distances, parallaxes, 97.20.Li Giant and subgiant stars, 98.20.Di Open clusters in the Milky Way, 98.20.Gm Globular clusters in the Milky Way

1 Introduction

Clumping of the core-helium-burning stars to the red end of the metal-rich counterpart to the horizontal branch is one of the outstanding features in the colour-magnitude diagrams of globular and open clusters (Girardi, Mermilliod & Carraro, 2000). Hence, these giant stars are called the red clump (RC) stars or clump

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giants. Moreover, the RC stars occupy a very small region in the colour-magnitude diagram of the stars in the solar neighbourhood. Absolute magnitudes of the RC stars lie between $M_V = +0.7$ and $M_V = +1$ mag for the stars of spectral types G8 III to K2 III, respectively (Keenan & Barnbaum, 1999). These features of the RC stars make them suitable standard candles for distance estimation of stellar clusters and nearby galaxies for which the RC stars are resolved (Pietrzyski, Gieren & Udalski, 2003). Moreover, the RC stars are one of the most reliable distance indicators due to the fact that their absolute magnitude calibrations are precisely tied to the Hipparcos distance scale (Alves, 2000; Percival & Salaris, 2003; Groenewegen, 2008; Laney et al., 2012; Bilir et al., 2013).

van Helshoecht & Groenewegen (2007) used the Two Micron All Sky Survey (2MASS; Skrutskie et al., 2006) near-infrared data for a sample of 24 open clusters in order to investigate how the $K_s$-band absolute magnitude of the RC stars depends on age and metallicity. They showed that a constant value of $M_{K_s} = -1.57 \pm 0.05$ mag is a reasonable assumption to use in distance determinations of clusters with metallicities of $-0.5 \leq [Fe/H] \leq 0.4$ dex and ages of $0.31 \leq t \leq 7.94$ Gyr. This absolute magnitude value was also confirmed by Groenewegen (2008) who found $M_{K_s} = -1.54 \pm 0.04$ mag using the newly reduced Hipparcos trigonometric data (van Leeuwen, 2007). On the other hand, Bilir et al (2013) showed that the absolute magnitudes of RC stars depend on two-colour indices defined in the Johnson-Cousins ($BVI$), 2MASS ($JHK_s$) and Sloan Digital Sky Survey (SDSS; $gri$) photometries.

Although it is possible to define mean colours and absolute magnitudes for the RC stars in different photometric bands and the mean values have been suggested in some studies (e.g. Alves, 2000; Groenewegen, 2008; Laney et al., 2012; Bilir et al., 2013), it is well known that the RC stars occupy certain ranges of colours and absolute magnitudes in the colour-magnitude diagrams. Thus, absolute magnitudes of the RC stars depend on the metallicity and colours especially in optical bands, although it is found that the metallicity dependence is weak (Bilir et al., 2013).

The mean $V$ and $I$ magnitudes of the RC stars can be considerably affected by stellar population differences. Udalski (2000) found a weak dependence of the $I$-band absolute magnitude of the RC stars in the solar neighbourhood on $[Fe/H]$ at the level of $\sim 0.13$ mag dex$^{-1}$ and suggested an absolute magnitude correction of 0.07 mag in the $I$-band for Large Magellanic Cloud. Using the models of Girardi et al (2000), Girardi & Salaris (2001) predicted mean RC absolute magnitudes in $V$ and $I$ bands for a large range of ages and metallicities. Their models clearly showed that the absolute magnitudes of the RC stars in $I$-band depends both on metallicity and age, so that the metallicity dependence must be taken into account in the absolute magnitude calculations of the RC stars (Salaris & Girardi, 2002).
Thus, instead of a general mean for the absolute magnitude, an absolute magnitude calibration including at least one colour and metallicity should be used in the distance estimation of the RC stars. As more and more distant objects are observed in the sky surveys, metallicity-dependent uncertainties in the absolute magnitude determinations of the RC stars increase the error levels in the estimation of distances and physical parameters of the objects including these stars, such as stellar clusters.

Aim of this study is to derive an $M_V$ absolute magnitude calibration including the $B−V$ colour and $[Fe/H]$ metallicity using the RC stars in the globular and open clusters with a wide range of metallicities. In the next section we describe how the data for the RC stars were collected from the literature. In the Section 3, we derive an absolute magnitude calibration for the RC stars and compare the distances of the RC stars derived from our calibration formula with those obtained from the *Hipparcos* trigonometric data and spectrophotometric data. Finally, we conclude and discuss the results in the Section 4.

2 The data

The data in this study were collected from the colour-magnitude diagrams of the globular and open clusters in our Galaxy. The data for globular clusters were taken from Piotto et al. (2002) who analysed *Hubble Space Telescope* observations. Piotto et al. (2002) examined 74 globular clusters in $F439W$ and $F555W$ bands and analysed their colour-magnitude diagrams. They transformed the original magnitudes to $BV$ photometry using calibrations given in their study. It is clearly seen that 25 of these globular clusters show remarkable clumping in the RC region in their colour-magnitude diagrams (see Fig. 4 in Piotto et al. 2002). Borders of the RC regions were determined by eye inspection of the colour-magnitude diagrams of globular clusters. Distance moduli, colour excesses and metallicities of the globular clusters were primarily taken from Piotto et al. (2002). In cases where newer measurements exist, we used the new ones. The Galactic coordinates ($l$, $b$), distance moduli $(m − M)_V$, colour excesses $E(B−V)$ and metallicities $[Fe/H]$ for the globular clusters are listed in Table 1.

$B−V$ colours and $V$ magnitudes of the RC stars were de-reddened and their $M_V$ absolute magnitudes were calculated using distance moduli given in Table 1. Frequency distributions of the de-reddened colours $(B−V)_0$ and absolute magnitudes $M_V$ of the RC stars in each globular cluster were estimated and central positions of the peaks in the distributions obtained for each globular cluster were found by fitting Gaussian functions. $(B−V)_0 − V_0$ colour-magnitude diagrams and frequency distributions of the $(B−V)_0$ colours and $M_V$ absolute magnitudes of the globular clusters listed in Table 1 are shown in
As the aim of this study is to derive a colour \((B - V)\) and metallicity \([Fe/H]\) dependent absolute magnitude \((M_V)\) calibration of the RC stars, metallicity range of the sample must be as large as possible. Metallicity range of the globular clusters in our sample is \(-1.55 < [Fe/H] < -0.30\) dex. In order to extend this metallicity range, the RC stars in the open clusters must be included in our sample. However, in general there are a few RC stars in open clusters. In this study, we selected the open clusters, where the RC stars prominently detectable in their colour-magnitude diagrams, from the studies by Twarog et al. (1997); Grocholski & Sarajedini (2002); Percival & Salaris (2003); van Helshoet & Groenewegen (2007). We listed their colour excesses, distance moduli and metallicities of these open clusters in Table 1. We determined borders of the RC region by eye inspection of the colour-magnitude diagrams of open clusters. As the number of RC stars is small, we simply calculated the average \((B - V)_0\) colour indices and \(M_V\) absolute magnitudes of these stars (see Table 1). By including the selected open clusters in the sample, upper limit of the metallicities were extended to about +0.40 dex. The selected open clusters increased the total number of the clusters in the sample to 31 (Table 1).

As the metallicities were collected from the literature that includes continually changing average of parameters, the metallicity scale used in our study should be carefully taken into account. One of the most important metallicity scales was given by Zinn & West (ZW, 1984). They used photometric indices of clusters calibrated primarily by Cohen’s (1983) spectroscopic data. As the distance moduli, colour excesses and metallicities for 18 of 25 globular clusters in Table 1 were taken from Piotto et al. (2002) and the 2010 version of the Harris catalog (Harris, 1996) whose metallicity scales fit to ZW metallicity scale, we conclude that the metallicities in our globular cluster data fit to this scale, in general. We also checked for the metallicity scale of the remaining seven globular clusters in Table 1 that were not taken from the Harris catalog (Harris, 1996) and found that these metallicities are in a good agreement with the ZW scale.

Dependence of the mean \(M_V\) absolute magnitude of the RC stars in the sample clusters both on \([Fe/H]\) metallicity and \((B - V)_0\) colour are presented in Fig. 2a-b. It is clearly seen that the RC stars in our study comprise a considerably wide range of \((B - V)_0\) colours, \(0.4 \leq (B - V)_0 \leq 1.2\) mag. Metallicity of the clusters covers a wide range as well, \(-1.55 < [Fe/H] < +0.40\) dex. \(M_V\) absolute magnitudes of the RC stars in our sample range from 0.43 to 1.03 mag. Metal-poor halo clusters are found in the bluer \((B - V)_0\) colours in Fig. 2 while metal-rich bulge clusters are redder \((0.6 \leq (B - V)_0 \leq 0.9\) mag). In
Table 1
The Galactic coordinates \((l, b)\), \((m-M)_V\) distance moduli, \(E(B-V)\) colour excesses and \([Fe/H]\) metallicities collected from the literature for the clusters in this study. Central positions of the Gaussian fits applied to the distributions of the de-reddened \((B-V)_0\) colours and \(M_V\) absolute magnitudes of the RC stars in the globular clusters are given. The \((B-V)_0\) colours and \(M_V\) absolute magnitudes of the RC stars in the open clusters are also indicated. Number of the RC stars for each cluster are given in the last column.

| ID | Cluster | \(l\) | \(b\) | \((m-M)_V\) | \([Fe/H]\) | \((B-V)_0\) | \(M_V\) | N |
|----|---------|------|------|------------|-------|-----------|-------|---|
| 1  | NGC 6723| 0.07 | -17.30| 0.05       | 14.87 | -1.12     | 1     | 58 |
| 2  | NGC 6569| 0.48 | -6.68 | 0.53      | 16.83 | -0.76     | 2     | 155|
| 3  | NGC 6652| 1.53 | -11.38| 0.09      | 15.28 | -0.81     | 2     | 51 |
| 4  | NGC 6637| 1.72 | -10.27| 0.18      | 15.28 | -0.64     | 2     | 121|
| 5  | NGC 6624| 2.79 | -7.91 | 0.28      | 15.36 | -0.44     | 2     | 114|
| 6  | NGC 6171| 3.37 | 23.01 | 0.33      | 15.05 | -1.02     | 2     | 26 |
| 7  | NGC 6356| 6.72 | 10.22 | 0.28      | 16.77 | -0.50     | 1     | 328|
| 8  | NGC 6440| 7.73 | 3.80  | 1.07      | 17.95 | -0.34     | 1     | 466|
| 9  | NGC 6638| 7.90 | -7.15 | 0.43      | 16.40 | -1.00     | 3     | 63 |
| 10 | NGC 6864| 20.30| -25.75| 0.16      | 17.09 | -1.29     | 2     | 182|
| 11 | NGC 6539| 22.30| 6.78  | 0.97      | 17.63 | -0.66     | 1     | 123|
| 12 | NGC 6712| 25.35| -4.32 | 0.45      | 15.60 | -1.01     | 1     | 46 |
| 13 | NGC 6934| 52.10| -18.89| 0.09      | 16.48 | -1.54     | 1     | 41 |
| 14 | NGC 1851| 71.45| -31.05| 0.02      | 15.58 | -1.31     | 4.5   | 126|
| 15 | NGC 1261| 270.54| -52.12| 0.01      | 16.10 | -1.27     | 5     | 57 |
| 16 | NGC 2808| 282.19| -11.25| 0.18      | 15.61 | -0.93     | 6     | 340|
| 17 | NGC 362 | 301.53| -46.25| 0.04      | 14.94 | -1.16     | 7     | 157|
| 18 | NGC 104 | 305.90| -44.89| 0.04      | 13.37 | -0.76     | 1     | 283|
| 19 | NGC 6362| 325.55| -17.57| 0.09      | 14.68 | -0.99     | 2     | 24 |
| 20 | NGC 5927| 326.60| 4.86  | 0.45      | 15.82 | -0.49     | 2     | 179|
| 21 | NGC 6584| 342.14| -16.41| 0.10      | 15.95 | -1.49     | 1     | 39 |
| 22 | NGC 6388| 345.56| -6.74 | 0.40      | 16.54 | -0.60     | 1     | 1038|
| 23 | NGC 6441| 353.53| -5.01 | 0.51      | 17.04 | -0.53     | 8     | 1197|
| 24 | NGC 6304| 355.83| 5.38  | 0.52      | 15.54 | -0.59     | 1     | 87 |
| 25 | NGC 6316| 357.18| 5.76  | 0.51      | 17.08 | -0.55     | 9     | 177|

Open Clusters

| ID | Cluster | \(l\) | \(b\) | \((m-M)_V\) | \([Fe/H]\) | \((B-V)_0\) | \(M_V\) |
|----|---------|------|------|------------|-------|-----------|-------|
| 26 | NGC 6791| 69.96| 10.90| 0.16       | 13.56 | 0.37      | 10, 11 |
| 27 | NGC 7789| 115.53| -5.38| 0.29      | 12.12 | -0.13     | 12, 13 |
| 28 | NGC 188 | 122.86| 22.38| 0.09      | 11.45 | -0.03     | 12, 14 |
| 29 | NGC 39  | 223.46| 10.09| 0.11      | 13.31 | -0.15     | 12, 15 |
| 30 | NGC 2477| 253.56| -5.84| 0.23      | 11.45 | 0.00      | 12, 15 |
| 31 | Mel 66  | 259.56| -14.24| 0.14     | 13.65 | -0.38     | 12, 16 |

1) Piotto et al. (2002), 2) Harris (2010), 3) Valenti, Ferraro & Origlia (2007), 4) Walker (1998), 5) Gratton et al. (2010), 6) Milone et al. (2012), 7) Szekely et al. (2007), 8) Matsumaga et al. (2009), 9) Lavlen et al. (2003), 10) Sandage, Lubin & Vandenberg (2003), 11) Stetson, Bruntt & Grundahl (2003), 12) Percival & Salaris (2003), 13) Girardi, Mermilliod & Carraro (2001), 14) Saraiedini et al. (1999), 15) Kassis et al. (1997), 16) Twarog, Twarog & Hawarden (1995).
our sample, $B - V$ colours of open clusters in the thin disc are larger than 0.9 mag.

There is a linear relation with a slope of 2.97 dex mag$^{-1}$ between the [Fe/H] metallicity and $M_V$ absolute magnitude of the RC stars in Fig. 2a. The scatter in this relation ($\sim 0.1$ mag) is larger than the scatter ($\sim 0.04$ mag) in the relation between the $M_V$ absolute magnitude and $(B - V)_0$ colour of the RC stars. Fig. 2c shows the linear relation between the $(B - V)_0$ colour indices and [Fe/H] metallicities for the clusters in our sample. Slope of the relation is 2.44 dex mag$^{-1}$. Fig. 2a-c demonstrate that the population effects on the absolute magnitudes and colour indices of the RC stars can not be negligible in the Galactic scales.

### 3 The absolute magnitude calibration

From the considerations above, it is clear that the $M_V$ absolute magnitude of the RC stars is well correlated both with the [Fe/H] metallicity and $(B - V)_0$ colour. Thus, a regression analysis based on 31 clusters in Table 1 gives the following relation:

$$M_V = 0.627(\pm 0.104) (B - V)_0 + 0.046(\pm 0.043) [Fe/H] + 0.262(\pm 0.111).$$

Numbers in parenthesis are standard errors of the coefficients. The correlation coefficient and standard deviation of the calibration are $R = 0.971$ and $s = 0.036$ mag, respectively. T-scores of the variables $(B - V)_0$, [Fe/H] and the constant in Eq. 1 are 6.01 ($p = 0.00$), 1.06 ($p = 0.30$) and 2.35 ($p = 0.03$), respectively, with a degree of freedom of 29. This equation is reliable and valid in the ranges $0.42 < (B - V)_0 < 1.20$ mag, $-1.55 < [Fe/H] < +0.40$ dex and $0.43 < M_V < 1.03$ mag.

A comparison of the absolute magnitudes calculated from the calibration with the original absolute magnitudes in Table 1 is shown in Fig. 3. This figure demonstrates that 22 of the clusters ($\sim 71\%$) are within $1\sigma$ deviation. There is no any systematical tendency in the lower panel of Fig. 3 that shows residuals from the calibration equation.

T-score analysis shows that metallicity dependence of the calibration is relatively weak, while the dependence on the colour $(B - V)_0$ is strong. If the metallicity is not taken into account, the absolute magnitude changes $\sim 0.1$ mag for the stars with lowest and highest metallicities. It should be also noted that the absolute magnitude decreases with decreasing metallicity (see Fig. 2). That is why we emphasize that the metallicity, if it is known, should be taken into account in the absolute magnitude calibrations of the RC stars.
Although the metallicity dependence of the Eq. 1 is found weak, we suggest that absolute magnitude estimation errors related with the metallicity will be more important for the distant RC stars.

3.1 The application

Using the absolute magnitude calibration in this study, $M_V$ absolute magnitudes were estimated for the RC stars collected from two studies, i.e. Laney et al. (2012) and Saguner et al. (2011). The RC stars with $[Fe/H]$ metallicities are listed in Laney et al. (2012) who collected metallicities from Liu et al. (2007) and McWilliam (1990). They observed 226 RC stars in the near-infrared JHK-bands in the Solar neighbourhood and calculated mean absolute magnitudes of the RC stars using Hipparcos parallaxes (van Leeuwen, 2007). In our study, $B - V$ colours were taken from newly reduced Hipparcos catalogue (van Leeuwen, 2007), parallaxes and $[Fe/H]$ metallicities from Laney et al. (2012) who collected $[Fe/H]$ metallicities of only 101 RC stars from Liu et al. (2007) and McWilliam (1990). $[Fe/H]$ metallicities of these stars are between -0.6 and 0.4 dex. As Laney et al. (2012) scaled the metallicities taken from McWilliam (1990) according to the ones from Liu et al. (2007), it can be concluded that the metallicities in Laney’s study are in the same scale and self-consistent.

We first de-reddened the B-V colour indices using the $E(B-V)$ colour-excesses evaluated for the 101 program stars using the maps of Schlegel, Finkbeiner & Davis (1998), and this was reduced to a value corresponding to the distance of the star by means of the equations of Bahcall & Soneira (1980). For a detailed explanation of the de-reddening procedure, see Bilir et al. (2013). The reduced $E(B-V)$ colour-excesses of the program stars are between 0.001 and 0.081 mag with a median value of 0.010 mag. We calculated $M_V$ absolute magnitudes of these 101 RC stars using the absolute magnitude calibration derived in this study.

We estimated distances putting our calibration results into the Pogson equation. Fig. 4 shows the comparison of distances from our calibration with those taken from Laney et al. (2012). We note that Laney et al. (2012) selected the distances of the RC stars in their study from Hipparcos catalogue (van Leeuwen, 2007). The distances calculated from our calibration are in very well agreement with those taken from Hipparcos catalogue (Laney et al., 2012). The mean and standard deviation of the residuals are only -3.5 and 6.2 pc, respectively. A considerable part of the sample is in 1σ limits in Fig. 4. This comparison demonstrates that the distances based on the $M_V$ absolute magnitude calibration of the RC stars in the stellar clusters are as precise as comparable to the distances derived from Hipparcos parallaxes of the RC stars.
within 150 pc.

We also compared the distances estimated via our calibration with those obtained by a spectrophotometric method. Saguner et al. (2011) calculated spectrophotometric distances of 305 faint and high Galactic latitude RC stars by deriving their atmospheric parameters from high signal-to-noise middle resolution spectra. We removed 54 of 305 stars from the sample as they are out of the validity limits of the absolute magnitude calibration in this study, reducing the number of stars to 251. While the $[Fe/H]$ metallicities and $A_V$ total absorptions were taken from Saguner et al. (2011), $V$ apparent magnitudes and $B − V$ colours from Hipparcos catalogue (van Leeuwen, 2007). The $[Fe/H]$ metallicities are between -0.54 and 0.42 dex. Since the metallicities were found by Saguner et al. (2011), we conclude that the metallicities in this study are in the same scale and self-consistent.

After apparent magnitudes and colours were de-reddened, absolute magnitudes and distances of 251 RC stars listed in Saguner et al. (2011) were estimated using the absolute magnitude calibration derived in this study. In Fig. 5, we compared the distances of the RC stars estimated using our absolute magnitude calibration with the spectrophotometric distances taken from Saguner et al. (2011) in which the RC stars lie between 200 and 500 pc from the Sun. Note that the distances taken from Laney et al. (2012) are smaller than 150 pc. Fig. 5 demonstrates that the distances obtained from two different methods are very well correlated with a scatter of $s = 11$ pc. As the mean distance difference is only $< \Delta d >= -0.4$ pc (see Fig. 5b), we conclude that there is no any systematic difference between these distances.

4 Conclusions

We derived an $M_V$ absolute magnitude calibration in terms of the $B − V$ colour and $[Fe/H]$ metallicity using the RC stars in the globular and open clusters with a wide range of metallicities. The comparisons of the distances estimated from the calibration equation in this study both with the distances obtained from trigonometric parallaxes and spectrophotometric analysis indicate that the calibration formula gives very reliable absolute magnitudes for the estimation of distances for the RC stars up to 500 pc. We conclude in this study that, instead of using a unique absolute magnitude for all the RC stars, an absolute magnitude calibration in the optical bands based on at least one colour and metallicity should be used in the precise distance estimates.

Taking into account the metallicity in the calculation of absolute magnitudes of the RC stars can be important in the shallow/deep photometric and spectroscopic surveys, such as the RAdial Velocity Experiment (RAVE) and SDSS,
and in the distance calculations of the stellar clusters or field RC stars. With the help of the absolute magnitude calibration derived in this study, and with the uncertainties in the metallicity dependence of the Cepheid period-luminosity relation [Percival & Salaris, 2003; Majaess et al., 2012], the RC stars can serve as standard candles for the distance calculations of nearby Galaxies, as well. This powerful calibration can be also used in the derivation of the Galactic model parameters in the optical bands.

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References

Alves, D.R., 2000. ApJ 539, 732
Bahcall, J.N., Soneira, R.M., 1980. ApJS 44, 73
Bilir, S., Önal, Ö, Karaali, S., Cabrera-Lavers, A., Çakmak, H., 2013. Ap&SS 344, 417
Cohen, J.G., 1983. ApJ 270, 654
Girardi, L., Mermilliod, J.-C., Carraro, G., 2000. A&A 354, 892
Girardi, L., Bressan, A., Bertelli, G., Chiosi, C., 2000. A&AS 141, 371
Girardi, L., Salaris, M., 2001. MNRAS 323, 109
Gratton, R. G., Carretta, E., Bragaglia, A., Lucatello, S., D’Orazi, V., 2010. A&A 517, A81
Grocholski, A.J., Sarajedini, A., 2002, AJ 123, 1603
Groenewegen, M.A.T., 2008. A&A 488, 25
Harris, W.E., 1996. AJ 112, 1487
Harris, W.E., 2010. arXiv, arXiv:1012.3224
Kassis, M., Janes, K. A., Friel, E. D., Phelps, R. L., 1997. AJ 113, 1723
Keenan, P.C., Barnbaum, C., 1999. ApJ 518, 859
Laney, C.D., Joner, M.D., Pietrzyński, G., 2012. MNRAS 419, 1637
Layden, A. C., Bowes, B. T., Welch, D. L., Webb, T. M. A., 2003. AJ 126, 255
Liu, Y.J., Zhao, G., Shi, J.R., Pietrzynski, G., Gieren, W., 2007. MNRAS 382, 553
Majaess, D.J., Turner, D.G., Gieren, W.P., Berdnikov, L.N., Lane, D.J., 2012. Ap&SS 344, 381
Matsunaga, N., Feast, M. W., Menzies, J. W., 2009. MNRAS 397, 933
McWilliam, A., 1990. ApJS 74, 1075
Milone, A. P., et al., 2012. ApJ 754, L34
Percival, S. M., Salaris, M., 2003. MNRAS 343, 539
Pietrzyński, G., Gieren, W., Udalski, A., 2003. AJ 125, 2494
Piotto, G., et al., 2002. A&A 391, 945
Piotto, G., et al., 2002. A&A 391, 945
Saguner, T., Munari, U., Fiorucci, M., Vallenari, A., 2011. A&A 527, 40
Salaris, M., Girardi, L., 2002, MNRAS, 337, 332
Sandage, A., Lubin L. M., VandenBerg D. A., 2003. PASP 115, 1187
Sarajedini, A., von Hippel, T., Kozhurina-Platais, V., Demarque, P., 1999. AJ 118, 2894
Schlegel, D.J., Finkbeiner, D.P., Davis, M., 1998. ApJ 500, 525
Skrutskie, M.F., et al., 2006. AJ 131, 1163
Stetson, P. B., Bruntt, H., Grundahl, F., 2003. PASP 115, 413S
Székely, P., Kiss, L. L., Jackson, R., Derekas, A., Csák, B., Szatmáry, K., 2007. A&A 463, 589
Twarog, B. A., Twarog, B. J. A., Hawarden, T. G., 1995. PASP 107, 1215
Twarog, B.A., Ashman, K.M., Anthony-Twarog, B.J., 1997. AJ 114, 2556
Udalski, A., 2000. ApJ 531, L25
Valenti, E., Ferraro, F. R., Origlia, L., 2007. AJ 133, 1287
van Helshoecht, V., Groenewegen, M.A.T., 2007. A&A 463, 559
van Leeuwen, F., 2007. A&A 474, 653
Walker, A. R., 1998. AJ 116, 220
Zinn, R., West, M.J., 1984. ApJSS 55, 45
Fig. 1. Colour-magnitude diagrams and distributions of the \((B-V)_0\) colours and \(M_V\) absolute magnitudes of the globular clusters listed in Table 1.
Fig. 1 — continued.
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Fig. 2. Dependence of the mean absolute magnitude of the RC stars in the sample clusters on \([Fe/H]\) metallicity (a) and \((B-V)_0\) colour (b). Relation between the \((B-V)_0\) colours and \([Fe/H]\) metallicities of the RC stars is shown in the panel c. Filled and open circles denote the data from globular and open clusters, respectively. The data are taken from Table 1.
Fig. 3. Comparison of the mean absolute magnitudes of the RC stars in Table 1 with those calculated from the calibration formula in this study.
Fig. 4. The comparison of distances estimated using our calibration with those taken from Laney et al. (2012).
Fig. 5. The comparison of distances estimated using our calibration with those taken from Saguner et al. (2011).