Luminosity–colour relations for thin-disc main-sequence stars

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ABSTRACT
In this study we present the absolute magnitude calibrations of thin-disc main-sequence stars in the optical (\(M_V\)), and in the near-infrared (\(M_J\)). Thin-disc stars are identified by means of Padova isochrones, and absolute magnitudes for the sample are evaluated via the newly reduced Hipparcos data. The obtained calibrations cover a large range of spectral types: from A0 to M4 in the optical and from A0 to M0 in the near-infrared. Also, we discuss the effects of binary stars and evolved stars on the absolute magnitude calibrations. The usage of these calibrations can be extended to the estimation of galactic model parameters for the thin disc individually, in order to compare these parameters with the corresponding ones estimated by \(\chi^2\) statistics (which provides galactic model parameters for thin and thick discs and halo simultaneously) to test any degeneracy between them. The calibrations can also be used in other astrophysical researches where distance plays an important role in that study.

Key words: stars: distances – Galaxy: disc – solar neighbourhood.

1 INTRODUCTION
The distance of an astronomical object plays an important role in deriving intrinsic luminosities of stars, in calculating accurate masses for binary system components and in answering questions about galactic structure. Particularly, the distributions of three populations (i.e. thin and thick discs and halo) in the Galaxy can be determined using the distances of the concerning stars. For nearby stars, the most appropriate procedure for distance determination is the trigonometric parallax. However, this procedure fails for distant stars due to large errors in their trigonometric parallaxes. In this case, photometric parallax replaces the trigonometric one. This alternative requires absolute magnitude determination which needs a lot of work, though not as much as the former one.

The photometric parallax can be evaluated in different ways. Many astronomers prefer an absolute magnitude–colour diagram for a star category. For example, Phleps et al. (2000) separated their star sample into two subsamples, disc and halo, according to their \((r-i)\) colours and they used two absolute magnitude diagrams to evaluate their absolute magnitudes. Karaali et al. (2003) and Karaali, Bilir & Hamzaoğlu (2004) and Bilir, Karaali & Gilmore (2006b) separated their star samples into three populations, i.e. thin and thick discs and halo, and they used the absolute magnitude–colour diagrams of three globular clusters with the same metallicity of the corresponding population. Bilir, Karaali & Tuncel (2005) calibrated the \(M_V\) absolute magnitudes of late-type disc dwarfs with \((g-r)\) and \((r-i)\) colours in Sloan Digital Sky Survey (SDSS) system. The works of Siegel et al. (2002) and Jurić et al. (2008) are examples for distance estimation based on photometric parallax. Another procedure for absolute magnitude determination is based on the use of colours and individual UV-excesses of stars relative to a standard absolute magnitude–colour diagram, such as Hyades (Laird, Carney & Latham 1988; Karaali et al. 2003; Karaali, Bilir & Tuncel 2005). In this procedure, one does not need to separate the stars into different population types. Additionally, individual UV-excess for each star results in more precise absolute magnitudes relative to the procedure where a single colour magnitude diagram is used for all stars in a population.

Despite the extensive applications of the aforementioned procedures in the previous paragraph, additional constraints can be considered for obtaining a more reliable one. We applied three limitations, i.e. age, metallicity and surface gravity, to a star sample and calibrate the absolute magnitude of thin-disc stars as a function of two colours. All these data were provided from Padova data base of stellar evolutionary tracks and isochrones (Marigo et al. 2008) by using a web interface.1 For the thin-disc stars we adopted a range of age of \(0 \leq t \leq 10\) Gyr, and the metal abundance is assumed to be \(0.01 \leq z \leq 0.03\) (solar metal abundance \(z_\odot = 0.019\)), corresponding to the metallicity interval \(-0.30 \leq [M/H] \leq 0.20\) dex. Finally, evolved stars were excluded from the sample by imposing a third

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1 http://stev.oapd.inaf.it/~lgiurardi/cgi-bin/cmd.
constraint, i.e. surface gravity $\log g > 4$. Thus, we should supply a homogeneous thin-disc main-sequence sample by eliminating all thick disc and halo stars, as well as evolved (white dwarfs, subgiants and giants) thin-disc stars.

2 DATA AND REDUCTIONS

$BVI$ photometric data and $\pi$ parallaxes with relative errors ($\sigma_\pi/\pi$) $\leq 0.05$ for 11 644 stars were taken from the newly reduced Hipparcos data (van Leeuwen 2007), whereas the Two Micron All Sky Survey (2MASS) near-infrared photometric data for the same stars were extracted of the point-source catalogue and atlas (Cutri et al. 2003). The 2MASS photometric system comprises Johnson’s $J$ (1.25 $\mu$m) and $H$ (1.65 $\mu$m) bands with the addition of $K_s$ (2.17 $\mu$m) band, which is bluer than Johnson’s $K$ band (Skrutskie et al. 2006). The $E(B - V)$ colour excesses were individually evaluated for each sample star making use of 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). The $E(B - V)$ iso-colour excess contours within 100 pc of solar neighbourhood are given in Fig. 1. The distribution of $E(B - V)$ for the star sample for two distance intervals, $0 < d \leq 40$ and $40 < d \leq 70$ pc, have a peak at $E(B - V) = 0.0041$ and 0.0098 mag (Fig. 2) which are rather close to the ones of Holmberg, Nordström & Andersen (2007). Holmberg et al. (2007) evaluated the colour excesses, $E(B - V) = 0.0034$ and $E(B - V) = 0.0065$ mag, for the same distance intervals by using Strömgren photometry, respectively. The transformation of $E(b - y)$ reddening to the $E(B - V)$ one is carried out by the equation $E(B - V) = 1.35 E(b - y)$. The excellent agreement between both sets of reddening data confirms the reduction equations of Bahcall & Soneira (1980) and the accuracy of the colour excesses used in our paper.

Thus, colours and magnitudes from the sample stars are dereddened by using the following two sets of equations, one for the $BVI$

data (equation 1) and one for the 2MASS (equation 2) photometry:

\begin{align}
V_0 & = V - 3.1E(B - V), \\
(B - V)_0 & = (B - V) - E(B - V), \\
(V - I)_0 & = (V - I) - 1.25E(B - V); \\
J_0 & = J - 0.887E(B - V), \\
(J - H)_0 & = (J - H) - 0.322E(B - V), \\
(H - K_s)_0 & = (H - K_s) - 0.182E(B - V)
\end{align}

(1)

(2)

(see also Bilir, Güver & Aslan 2006a; Ak et al. 2007).

The absolute magnitude of each star is evaluated by the combination of its reddenning apparent magnitude and its distance estimated using its trigonometric parallax. The corresponding propagated errors were calculated as $\sigma M = 2.17(\sigma_\pi/\pi) + \sigma m$, where $(\sigma_\pi/\pi)$ and $\sigma m$ are the relative parallax error and the error of the apparent magnitude in the relevant photometric system, respectively.

3 THE PROCEDURE AND ABSOLUTE MAGNITUDE CALIBRATION

The procedure consists of the calibration of the absolute magnitudes for thin-disc main-sequence stars with two colours: one sensitive to early-type (hot) and another sensitive to late-type (cool) stars, providing a large range of absolute magnitudes for the thin-disc population. We calibrated $M_V$ absolute magnitudes with $(B - V)_0$ and $(V - I)_0$, for the 2MASS photometry and $M_J$ absolute magnitudes with $(J - H)_0$ and $(H - K_s)_0$ for the 2MASS data. As it was stated in Section 1, we limited the metallicity, the age and the surface gravity with the following constraints: $-0.30 \leq [M/H] \leq 0.20$ dex, $0 \leq t \leq 10$ Gyr and $\log g > 4$. By doing this we avoid any contamination due to thick disc and halo stars, as well as from evolved thin-disc stars. Hence, our calibrations should provide precise absolute magnitudes for thin-disc main-sequence stars.

3.1 Absolute magnitude calibration for $BVI$ photometry

We applied a series of limitations in the absolute magnitude calibration for $BVI$ photometry. First of all, we limited our star sample with absolute magnitudes $0 < M_V < 12$. This limitation reduced the original star sample from 11 644 to 10 654. Then, we applied the procedure described in Section 2 to the Padova isochrones with metallicity and age limitations mentioned above (Marigo et al. 2008) which separates the thin-disc stars with different luminosity classes.
Figure 3. $M_V/(B−V)_0$ colour–absolute magnitude diagram for the original sample. The upper and lower envelopes (the dashed lines) show the final sample, i.e. thin-disc main-sequence stars. The thin curves correspond to Padova isochrones.

(dwarf and evolved stars) from the sample of 10 654 stars. At the third step, we applied the constraint for being a main-sequence star, i.e. log $g > 4$. Thus, the sample reduced to 6117 stars. Fig. 3 shows the colour–absolute magnitude diagram for the original sample (11 644 stars) and the upper and lower envelopes of the final sample, i.e. thin-disc main-sequence stars. Then we adopted the $M_V$ calibration as follows and evaluated the coefficients by the least-squares method, for the final sample:

$$M_V = a_1(B−V)_0 + b_1(V−I)_0 + c_1(B−V)_0(V−I)_0 + d_1(B−V)_0 + e_1(V−I)_0 + f_1.$$  \hspace{1cm} (3)

The numerical values of the coefficients and their errors, as well as the corresponding standard deviations and the squared correlation coefficients are all given in Table 1. The calibration described by equation (3) covers a large range of thin-disc main-sequence stars, i.e. $−0.15 < (B−V)_0 < 1.60$, $−0.15 < (V−I)_0 < 2.90$ and $0 < M_V < 12$, which corresponds to the spectral types A0–M4.

3.2 Absolute magnitude calibration for 2MASS photometry

The procedure described in Section 2 and the limitations applied in Section 3.1 produced 4449 main-sequence stars with 2MASS photometric data, 93 per cent of the best quality following the survey criteria (labelled in the catalogue as A△A). Here, the star sample is limited with absolute magnitude $0 < M_J < 6$. The $M_J/(J−H)_0$ colour–magnitude diagram for all stars taken from newly reduced Hipparcos catalogue (11 644 stars) and the upper and lower envelopes for the final sample, i.e. thin-disc main-sequence stars, are given in Fig. 4. We adopted an absolute magnitude calibration for the 2MASS data similar to the $BVI$ ones as follows:

$$M_J = a_2(J−H)_0 + b_2(H−K)_0 + c_2(J−H)_0(H−K)_0 + d_2(J−H)_0 + e_2(H−K)_0 + f_2.$$  \hspace{1cm} (4)

The numerical values of the coefficients and their errors, the corresponding standard deviations, and the squared correlation coefficients are given in Table 1. The calibration given in equation (4) covers a large range of thin-disc main-sequence stars, as the one in equation (3), i.e. $−0.16 < (J−H)_0 < 0.70$, $−0.07 < (H−K)_0 < 0.26$ and $0 < M_J < 6$ corresponding to the spectral types A0–M0.

We plotted the errors of the observed colours against the intrinsic colours in Fig. 5 in order to test the accuracy of the observed colours. The lower uncertainties belong to $(B−V)_0$ and $(V−I)_0$ colours, whereas those for $(J−H)_0$ and $(H−K)_0$ colours are larger. The mean observational errors are about $0.01 (\sigma = \pm 0.02)$ and $0.04 (\sigma = \pm 0.04)$ mag in the optical and near-infrared colours, respectively. This is not surprising, because 2MASS magnitudes were obtained from single-epoch observations, whereas optical magnitudes have been observed more than once. The mean errors introduce typically $\pm 0.12$ and $\pm 0.14$ mag uncertainties in $M_V$ and $M_J$, respectively.

Unfortunately, random errors, presumably symmetric on the measured parallaxes, do not provide symmetric uncertainties on the computed distances. Therefore, a measured trigonometric parallax is very likely to be larger than the true parallax. The problem has already been noticed and studied by Lutz & Kelker (1973). Assuming a uniform space distribution of stars and a Gaussian distribution of observed parallaxes about a true parallax, Lutz & Kelker (1973)
revealed that there is a systematic error in the computed distances which depends only upon the ratio \((\sigma_\pi/\pi)\), where \(\pi\) is the observed parallax. Jerzykiewicz (2001) showed that only the studies which are careful enough to use parallaxes with \((\sigma_\pi/\pi) < 0.1\) could be excused as the bias would be negligible. This is the case in our paper, where \((\sigma_\pi/\pi) \leq 0.05\). Actually, the Lutz–Kelker correction in absolute magnitude, taken from Lutz & Kelker (1973), is less than 0.03 mag. Hence, we omitted the mentioned bias in our study. Although no absolute magnitude calibration based on trigonometric parallaxes is present for the \(M_\lambda\) absolute magnitude in SDSS system, one can use our recent transformation equations (Bilir et al. 2008).

3.3 Comparison of the estimated absolute magnitudes with the trigonometric parallaxes and synthetic photometry

We compared the absolute magnitudes estimated in this paper with two sets of absolute magnitudes, one evaluated by means of the trigonometric parallaxes taken from the newly reduced Hipparcos catalogue (van Leeuwen 2007) and one taken from the stellar spectral flux library of Pickles (1998). Figs 6 and 7 show the one-to-one correspondence of the absolute magnitudes \(M_V\) and \(M_\lambda\), respectively, estimated in this paper and the corresponding ones evaluated from the newly reduced Hipparcos data, i.e. \(M_{V_{Hip}}\) and \(M_{\lambda_{Hip}}\).

Pickles (1998) offers the synthetic colours, \(M_{bol}\) bolometric absolute magnitudes and BC bolometric corrections for 131 stars with a large range of spectral type, O5–M6, and different luminosity classes. The optical data are on the same scale of \(UBVRI\) photometry. Hence, it was easy to evaluate the \(M_V\) absolute magnitudes, by placing \((B-V)_0\) and \((V-I)_0\) colours into equation (3). However, the infrared colours and magnitudes scale differently than the 2MASS data. Hence, we used the normalized equations of Carpenter (2001) to reduce Pickles’ (1998) infrared data to 2MASS colours and magnitudes. Then, we evaluated the \(M_\lambda\) absolute magnitudes by placing the reduced \((J-H)_0\) and \((H-K_0)\) colours into equation (4). The original data of Pickles (1998) and the reduced ones according to normalized equations of Carpenter (2001) are given in Tables 2 and 3, respectively. Finally, we evaluated the \(M_{V_{Hip}}\) and \(M_{\lambda_{Hip}}\) absolute magnitudes from the data in Table 3 and we compared them with the \(M_{V}\) and \(M_\lambda\) absolute magnitudes, respectively (Figs 8 and 9). There is a one-to-one correspondence in these figures as well. The slight declination at the faint end of absolute magnitudes in Fig. 9 is probably due to the different scales between the Pickles (1998) and 2MASS. We should add that the mentioned comparison has been carried out only for stars of solar metallicity.

4 DISCUSSION

We present two equations (equations 3 and 4) derived from newly reduced Hipparcos data (van Leeuwen 2007) with the aim of applying these formulae to relatively distant stars whose distances are either newly reduced not accurately known or not known at all. To do this, one needs to obtain a sample of thin-disc stars and replace the \((B-V)_0\) and \((V-I)_0\) colours with equation (3) or \((J-H)_0\) and \((H-K_0\) colours with equation (4), depending on the preferred photometry. This procedure can supply the following contributions to the estimation of galactic model parameters.

(i) One can evaluate the space densities in the solar neighbourhood \((r < 400 \text{ pc} – \text{we assume all these stars belong to the thin disc})\) by using the 2MASS data where the SDSS magnitudes are saturated; and combine them with space densities at larger distances evaluated by SDSS data. Thus, we obtain a continuous space density function from the Sun to large distances. This approach provides accurate
galactic model parameters for the galactic components (thin and thick discs and halo).

(ii) This procedure provides individually estimated galactic model parameters for the thin disc. Hence, one can compare these parameters with the ones estimated by $\chi^2_{\text{min}}$ statistics which provide galactic model parameters simultaneously for thin and thick discs and halo; and we can test any possible degeneracy between different galactic model parameters. We should emphasize that the mentioned degeneracy is a serious problem for the galactic model parameters. Thus, we hope to contribute a little to this problem which is suffered by the galactic model researchers.

The absolute magnitude calibrations for the thin-disc main-sequence stars with two colours, one sensitive to early-type (hot) and another sensitive to late-type (cool) stars, can also be used in

Table 2. Original photometric data of Pickles (1998).

| Spectral type | $(B - V)$ | $(V - I)$ | $(R - I)$ | $(J - H)$ | $(H - K)$ | $M_{V,\text{Pic}}$ | $M_{K,\text{Pic}}$ |
|---------------|-----------|-----------|-----------|-----------|-----------|----------------|----------------|
| A0V           | 0.015     | 0.011     | 0.023     | 0.000     | 0.000     | 0.48           | 0.49           |
| A2V           | 0.029     | 0.049     | 0.043     | 0.010     | 0.010     | 1.18           | 1.32           |
| A3V           | 0.089     | 0.102     | 0.065     | 0.030     | 0.020     | 1.33           | 1.45           |
| A5V           | 0.153     | 0.156     | 0.103     | 0.060     | 0.020     | 1.69           | 1.33           |
| A7V           | 0.202     | 0.241     | 0.131     | 0.090     | 0.030     | 2.09           | 1.62           |
| F0V           | 0.303     | 0.378     | 0.203     | 0.130     | 0.030     | 2.98           | 2.30           |
| F2V           | 0.395     | 0.457     | 0.246     | 0.170     | 0.040     | 3.27           | 2.63           |
| F5V           | 0.458     | 0.496     | 0.255     | 0.230     | 0.040     | 3.50           | 2.44           |
| F6V           | 0.469     | 0.562     | 0.292     | 0.260     | 0.050     | 3.83           | 2.70           |
| F8V           | 0.542     | 0.615     | 0.312     | 0.300     | 0.040     | 4.04           | 2.79           |
| G0V           | 0.571     | 0.671     | 0.351     | 0.350     | 0.050     | 4.24           | 2.94           |
| G5V           | 0.686     | 0.735     | 0.372     | 0.340     | 0.070     | 4.78           | 3.27           |
| K2V           | 0.924     | 0.968     | 0.448     | 0.500     | 0.090     | 6.19           | 3.96           |
| K3V           | 0.930     | 1.109     | 0.513     | 0.540     | 0.100     | 6.80           | 4.40           |
| K4V           | 1.085     | 1.232     | 0.570     | 0.580     | 0.110     | 7.21           | 4.56           |
| K5V           | 1.205     | 1.361     | 0.610     | 0.610     | 0.110     | 7.64           | 4.77           |
| K7V           | 1.368     | 1.578     | 0.750     | 0.660     | 0.150     | 8.21           | 5.11           |
| M0V           | 1.321     | 1.709     | 0.847     | 0.670     | 0.170     | 8.62           | 4.94           |
| M1V           | 1.375     | 1.874     | 0.993     | 0.660     | 0.280     | 9.05           | 5.16           |
| M2V           | 1.436     | 2.020     | 1.061     | 0.660     | 0.200     | 9.58           | 5.44           |
| M3V           | 1.515     | 2.436     | 1.362     | 0.640     | 0.230     | 10.63          | 5.96           |
| M4V           | 1.594     | 2.781     | 1.565     | 0.620     | 0.270     | 11.54          | 6.24           |
Figure 8. Absolute magnitudes, estimated by equation (3), versus optical absolute magnitudes calculated from Pickles’ data (upper panel) and variation of the differences between two sets of absolute magnitudes (lower panel).

Figure 9. Absolute magnitudes, estimated by equation (4), versus near-infrared absolute magnitudes calculated from Pickles’ data (upper panel) and variation of the differences between two sets of absolute magnitudes (lower panel).

Table 4. Scatter in absolute magnitude, $\Delta M_V$ and $\Delta M_J$, as a function of binary fraction $f$.

| $f$ | $\Delta M_V$ | $\Delta M_J$ |
|-----|-------------|-------------|
| 0.0 | 0.000       | 0.000       |
| 0.1 | 0.057       | 0.044       |
| 0.2 | 0.102       | 0.077       |
| 0.3 | 0.136       | 0.101       |
| 0.4 | 0.172       | 0.124       |
| 0.5 | 0.208       | 0.148       |
| 0.6 | 0.248       | 0.171       |
| 0.7 | 0.294       | 0.196       |
| 0.8 | 0.348       | 0.226       |

Figure 10. Lines indicating the fraction of binary stars in the $M_V/(B-V)_0$ colour–magnitude diagram.

other astrophysical researches, apart from the galactic model parameters estimation. The absolute magnitude supplies the distance of a star that plays an important role in the investigation of many properties of that star.

However, there are two significant issues which need to be considered on this subject, i.e. binary stars and evolved stars.

### 4.1 Binary stars

A high fraction of stars are in fact binary systems and being a binary system makes stars appear brighter and redder than they normally are. Different fractional values (defined as $f$) can be found in the literature. For example, using the data in the Gliese catalogue of nearby stars, Brosche (1964) found a value of $f = 0.4$ for his simple model for the resolution criterion. On considering the local (within a distance of 10 pc) binary fraction, Reid (1991) concluded that the proportion of binaries among ‘stars’ is consistent with a value ranging from 30 to 50 per cent. When all systems in question are binary stars, i.e. $f = 1$, Kroupa, Gilmore & Tout (1991) found that a single mass function provides the best representation of a single luminosity function. However, a smaller value cannot be discarded with high confidence. Halbwachs (1986) used all available data on binary systems and concluded that the proportion of single stars among all stellar systems is at most 23 per cent when spectroscopic binaries are taken into account. An extensive long-term radial velocity study of the Hyades cluster reveals that at least 30 per cent of the cluster stars are spectroscopic binaries and that essentially all stars brighter than the Hyades main-sequence stars are in fact binary systems (Griffin et al. 1988).

The effect of binary stars were discussed in Kroupa, Tout & Gilmore (1990, 1993, hereafter KTG90 and KTG93, respectively)
extensively as well as other effects such as metallicity, age, distance, etc. KTG93 adopt the binary fraction \( f \sim 0.6 - 0.7 \) as a reasonable value. They give the mentioned combined effects as ‘cosmic scatter’ as a function of \((V − I)\) colour in the range \(0.5 < (V − I) < 4.5\). These authors estimate the scatter belonging to binaries alone as \( \sigma = 0.27 \) mag, if a fraction \( f = 0.8 \) of all stars are unresolved binary systems. We adopted a simple but reasonable procedure, explained in the following paragraphs, to reveal the binarism effect in our paper and to compare with the ones appeared in the studies cited above.

We separated the \((B − V)_0\) and \((J − H)_0\) colours into small bins and omitted a fraction of bright stars, each time, in these intervals. Then, we recalibrated the absolute magnitudes \( M_V \) and \( M_J \) as a function of colours for the remaining stars. The fractions of binaries range from 0 to 80 per cent in steps of 10 per cent. Each time the locus of the stars on the colour–magnitude diagram moved to fainter absolute magnitudes. The mean of the differences between the absolute magnitudes estimated by the calibration in Section 3 and by these loci is adopted as the scatter due to the binaries in question (Table 4 and Fig. 10). Our procedure is based on the fact that binarism makes stars too bright and too red. We calibrated the absolute magnitude scatter in \( f \)–absolute magnitude diagram, \( \Delta M_V \) and \( \Delta M_J \), linearly (Fig. 11) as follows:

\[ \Delta M_V = 0.411f + 0.009, \]  
\[ \Delta M_J = 0.266f + 0.014. \]

The last two equations can be used to reduce the estimated absolute magnitudes by an amount of scatter corresponding to the adopted fraction of binary stars. The scatter \( \sigma = 0.35 \) mag in Table 4 is close to the one of KTG93, i.e. \( \sigma = 0.27 \) mag, for the fraction \( f = 0.8 \) of binary stars, confirming our simple but reasonable procedure used to reveal the fraction of binary stars and the linear regressions in equations (5) and (6).

4.2 Evolved stars

A sample of field stars intrinsically brighter than an old star with the same or similar spectral type–passed its turn-off is consisted of evolved stars, and they will be brighter and redder than a younger sample. In our case, the contamination of the evolved stars seems to be at a minimum due to the restrictions applied to the Padova isochrones in our paper, i.e. the sample of the field stars are limited with metallicity \(-0.30 \leq [M/H] \leq 0.20\) dex, age \(0 \leq t \leq 10\) Gyr and surface gravity \(\log g > 4\). However, we applied the calibrations in equations (3) and (4) to the stars of young cluster Hyades and compared the resulting absolute magnitudes with the ones estimated by the photometric parallaxes of the cluster stars. After a comprehensive study Perryman et al. (1998) stated that the Hyades cluster has 282 member stars. However, to increase the probability of the membership, we restricted the sample to 141 stars within 10 pc distance from the cluster centre. It turned out that 81 of them were binary stars or variable stars (Mason et al. 1993; Patience et al. 1998, SIMBAD data centre). Hence, the 60 Hyades stars used in our paper are single and non-variable stars within 10 pc from the centre of Hyades cluster.

The absolute magnitudes of the Hyades sample estimated by equations (3) and (4) are plotted against the ones calculated from their trigonometric parallaxes, taken from the newly reduced Hipparcos reduction.

\[ \text{Figure 11. Scatter in absolute magnitude versus fraction of binary stars. (a) } \Delta M_V \text{ versus } f \text{ and (b) } \Delta M_J \text{ versus } f. \]

\[ \text{Figure 12. Absolute magnitudes, estimated via the calibrations presented in our paper versus the ones evaluated by the parallaxes in the improved Hipparcos reduction. (a) } M_{V_C} \text{ versus } M_{V_{Hip}} \text{ and (b) } M_{J_C} \text{ versus } M_{J_{Hip}}. \]
Hipparcos data (Fig. 12). There is an agreement between two sets of data, indicating that the field sample is not contaminated seriously by the evolved stars. The slight declination of the points towards the bright absolute magnitudes is due to single epoch observations of the 2MASS data (Fig. 12b).

We should add that both binarism and evolution effects make the star brighter and redder, which means they both make the star move towards the same direction on the colour–magnitude diagram. Hence, the scatter in $M_V$ and $M_J$ absolute magnitudes cited in equations (5) and (6) can be assumed as the combined effect of binarism and evolution. In this case, it is not surprising that the scatter $\sigma = 0.35$ mag cited for the binary fraction $f = 0.8$ is a bit larger than the one of KTG93, i.e. $\sigma = 0.27$ mag, which corresponds to the binarism effect alone.

We wish to add that studying the effect of the evolved stars in the Hyades cluster revealed an unexpected issue for the cluster. Using the newly reduced Hipparcos data we derived a new distance modulus for the cluster: 3.33 $\pm$ 0.02 mag. This value is slightly larger than the 3.30 $\pm$ 0.04 mag of Perryman et al. (1998).

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