SYSTEMATIC EFFECTS ON PHOTOMETRIC PARALLAXES FOR FGK DWARFS AND SUBDWARFS

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ABSTRACT

Hipparcos trigonometric parallaxes were used to establish a preliminary absolute magnitude calibration in terms of effective temperature, metallicity and evolutionary stage indicators for FGK dwarfs and subdwarfs. Photometric determinations of metallicity, needed to establish the calibration, were evaluated by the comparison with known spectroscopic metallicities. The new calibration removes systematic trends present in the calibrations available today and it decreases the rms of the residuals.

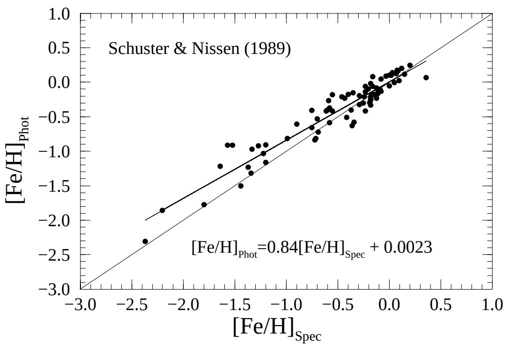
Key words: Subdwarfs; main-sequence; absolute magnitude; metallicity.

1. INTRODUCTION

The methods used to derive the absolute magnitude of FGK dwarfs and subdwarfs stars are based on the definition of a standard relation on a colour–magnitude diagram, which fits the sequence of stars with standard metallicity (the Hyades metallicity). A term (ΔM_v) is then added to account for different metallicities; this is computed from the position of the star in a colour-colour diagram (Wildey et al. 1962, Luri 1991) or directly through the parameter $\delta(U-B)_{0.6}$ (Laird et al. 1988). In the case of the Schuster & Nissen (1989) calibration, based on the Strömgren-Crawford photometric system, a polynomial expression is fitted as a function of $(b-y)$, c_1 and m_1 colours.

These methods, based on broad and intermediate band photometric systems, show discrepancies of up to $\Delta M_v = 1$ mag for stars with $\delta(U-B)_{0.6} \simeq 0.2$. These differences may be caused by the corrections applied for blanketing effects and the lack of available trigonometric parallaxes.

To cope with this problem all the Hipparcos FGK dwarfs and subdwarfs with $UBVRI$ photometry available at the time of internal proposals were selected. Among them, our sample contains the stars with $4 \leq V \leq 12$, $0.3 \leq (B-V) \leq 1.1$, $0 \leq \delta(U-B)_{0.6} \leq 0.30$ and Hipparcos parallaxes better than 20 per cent (i.e. 350 stars). Strömgren-Crawford and JHK photometric data, available for 75 per cent and 50 per cent of the stars, respectively, were compiled from the literature and own observations (Masana 1997). About 75 per cent of the stars in the sample have known radial velocities. Spectroscopic determinations of the metallicities are available only for 25 per cent of the stars.



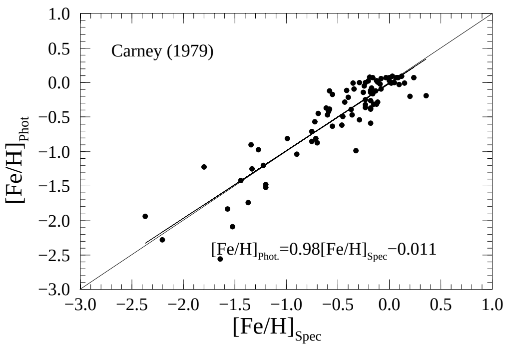


Figure 1. Photometric versus spectroscopic (Cayrel de Strobel et al. 1992) determination of metallicity. 78 stars for Schuster & Nissen's calibration (Strömgren system) and 82 for Carney's calibration (Johnson system).

2. METALLICITY, TEMPERATURE AND EVOLUTIONARY STAGE INDICATORS

2.1. Determination of the Metallicity

Due to the lack of spectroscopic determinations of metallicity for most of the stars in our sample, it is

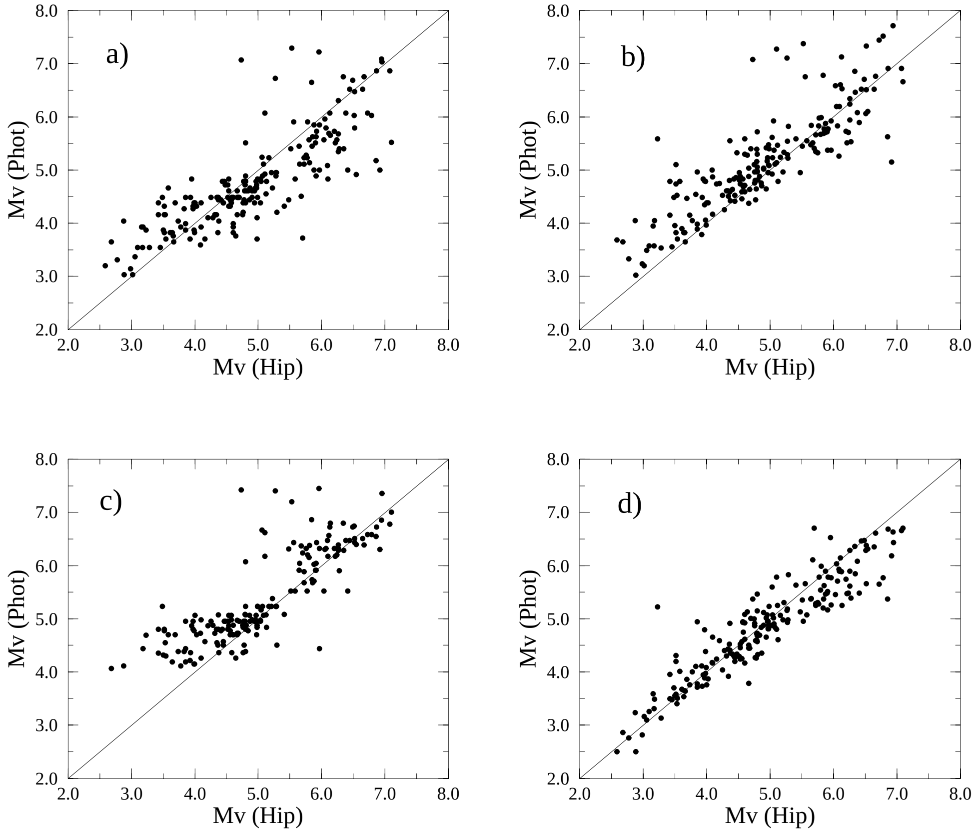


Figure 2. Photometric versus Hipparcos determination of absolute magnitude for 196 stars with parallaxes better than 20 per cent. M_v(Phot) computed from: (a) Wildey et al. (1962) and Sandage & Kowal (1986), (b) Laird et al. (1988), (c) Luri (1991), (d) Crawford (1975) and Olsen (1984).

necessary to resort to photometric calibrations. We considered two photometric calibrations: the Schuster & Nissen (1989) calibration using Strömgren indices, and Carney's (1979) calibration based on the Johnson parameter $\delta(U-B)_{0.6}$. In order to analyse the accuracy of these calibrations, spectroscopic determinations of metallicities quoted in the *Catalogue of [Fe/H] determinations* (Cayrel de Strobel et al., 1992) were compared with both photometric values (Figure 1). The regression lines show that a slight correction should be applied to the Schuster & Nissen (1989) calibration. The obtained correction is in agreement with the one proposed by Alonso (1994), and, since his sample is larger than ours, his correction was adopted in this work.

The rms of the residuals is 0.18 dex for Schuster & Nissen's calibration (after correction) and 0.26 dex for Carney's. So, in this work we derived photometric metallicity from the former. This calibration covers the metallicity range of $-3.5 <$ [Fe/H] < 0.2 for F-type stars and $-2.6 <$ [Fe/H] < 0.4 for G-type stars. We restricted our sample to these limits.

2.2. The Effective Temperature Parameter

A good effective temperature indicator must be insensitive to metallicity and luminosity effects. Traditionally, the colours used as temperature indicators have been $(b-y)$ and β for the Strömgren-Crawford photometric system and $(B-V)$ and $(V-K)$ in the case of Johnson photometry.

Alonso (1994) showed that while $(b-y)$ is only slightly sensitive to metallicity, the β index is clearly affected by blanketing. Concerning the Johnson system, he showed that $(V-K)$ is a better indicator than $(B-V)$, because the former is practically insensitive to the blanketing and the surface gravity. We used $(V-K)$ as effective temperature parameter, although this index is available only for about 50 per cent of the stars in our sample.

2.3. The Evolutionary Parameter

Strömgren's δc_0 parameter is, for late type stars, a good evolutionary indicator (Crawford 1975). It is defined as:

$$\delta c_0 = c_0(\mathrm{obs}) - c_0(ZAMS)$$

$(b-y)$ is used to derive $c_0(ZAMS)$ in Crawford's calibration.

We used this parameter to take into account the evolutionary stage in our absolute magnitude calibration.

3. THE ABSOLUTE MAGNITUDE CALIBRATION

3.1. The Existing Calibrations

Four calibrations that take the effect of the metallicity into account were considered:

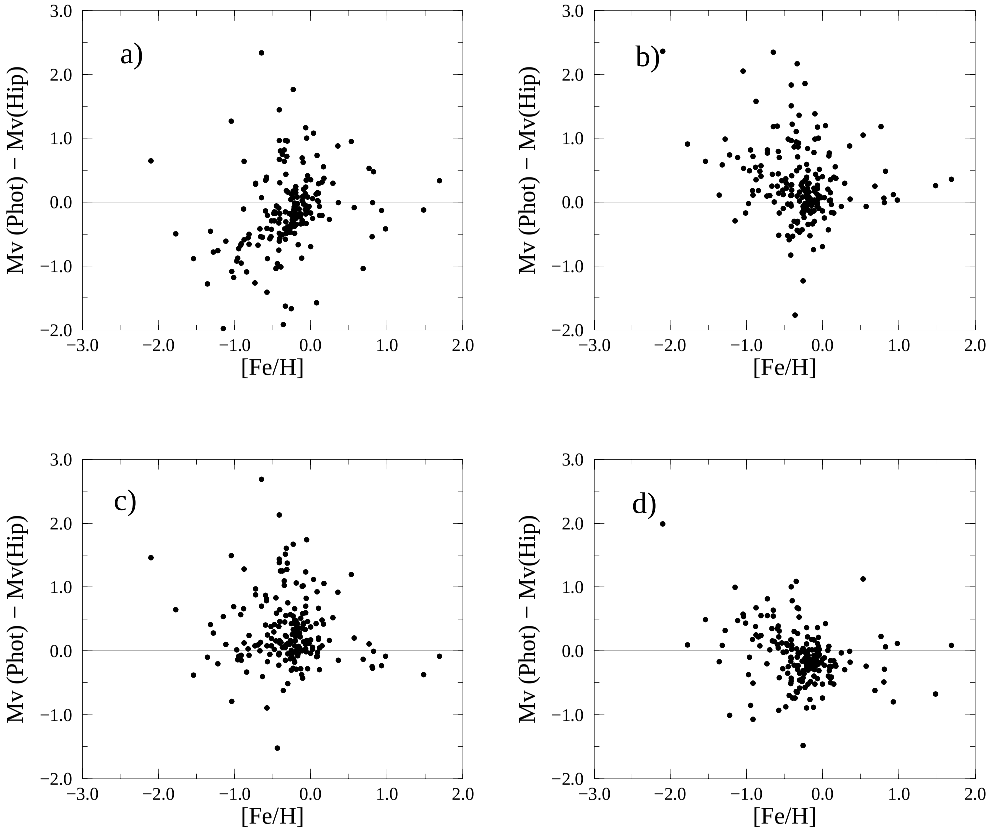


Figure 3. Residuals versus metallicity for the four considered calibrations: (a) Wildey et al. (1962) and Sandage & Kowal (1986), (b) Laird et al. (1988), (c) Luri (1991), (d) Crawford (1975) and Olsen (1984). The same sample as in Figure 2.

- the Wildey et al. (1962) method extrapolated by Sandage and Kowal (1986) up to $(B-V)=1.2$. V and $(B-V)$ are corrected for the blanketing effects;
- the empirical relation derived by Laird et al. (1988), based on a few stars with known trigonometric parallaxes. This calibration uses the colour $(B-V)$ and the $\delta(U-B)_{0.6}$ parameter;
- the use of the near-infrared $(R-I)$ index, assuming it is only slightly affected by metallicity effects, Luri (1991), and
- the calibrations by Crawford (1975) and Olsen (1984) using Strömgren's indices.

The four photometric M_v determinations are plotted versus the M_v from Hipparcos data (Figure 2). The stars were previously dereddened using Strömgren-Crawford photometry. The rms of the residuals are 0.61, 0.57, 0.55 and 0.41 mag, respectively. The three Johnson calibrations overestimate the M_v for the brightest stars, and a slight correlation of the residuals with the temperature was also found. Moreover, the first Johnson calibration and the Strömgren ones show a tendency of the residuals with the metallicity (Figure 3).

3.2. The Hipparcos Data

After selecting stars with Strömgren-Crawford photometry and $(V-K)$ colour available and removing the stars placed far above the main sequence, our sample was reduced to 122 stars. Figure 4 shows the colour–Hipparcos magnitude diagram for these stars. We also plotted the $M_{v\ \mathrm{ZAMS}}((V-K)$,[Fe/H]) relation for different metallicities computed from the zero age isochrone of the models of Padova's group (Bressan et al. 1993, Fagotto et al. 1994a, 1994b). The synthetic colours and bolometric corrections by Alonso et al. (1995), based on models of stellar atmospheres by Kurucz (1991), were used to transform T_{eff} and luminosity from evolutionary models to $(V-K)$ and M_v, for each metallicity. The dispersion observed in the diagram is unlikely to be due to binarity, since only four stars are quoted as multiple by Hipparcos. This should be considered as a true dispersion due to metallicity and evolutionary effects.

3.3. The Preliminary Calibration

To remove the systematic effects observed in the nowadays available calibrations, we propose a new calibration, in terms of temperature, metallicity and evolutionary stage, of the form:

$$M_v = M_{v\ \mathrm{ZAMS}}((V-K), [\mathrm{Fe/H}]) + \Delta M_v$$

ΔM_v is assumed to be a function of temperature, metallicity and evolutionary stage, of the form:

$$\Delta M_v = a_1 + (a_2 + a_3(V-K))[\mathrm{Fe/H}] + (a_4 + a_5[\mathrm{Fe/H}] + a_6(V-K) + a_7[\mathrm{Fe/H}](V-K))\delta c_0$$

The first three coefficients take into account possible differences between the theoretical and the observational ZAMS or inaccuracies of the relations used to

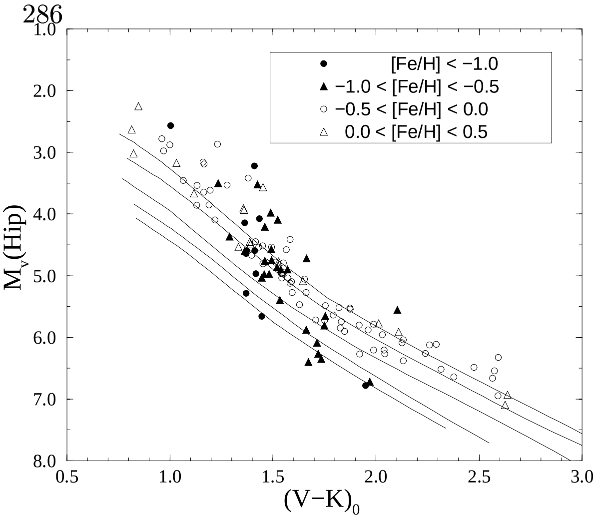


Figure 4. $M_v - (V-K)_0$ *diagram for the 122 stars of the working sample. Solid lines represent, from bottom to top, the ZAMS for [Fe/H]* $= -1.5, -1.0, -0.5, 0.0$ *and 0.5 (Bressan et al. 1993, Fagotto et al. 1994a, 1994b).*

transform $T_{\rm eff}$ to $(V-K)$ and the bolometric correction, and they should be studied in more detail with a large sample of stars.

The sample was divided into two subsamples:

- 38 stars with [Fe/H] < -0.5;
- 84 stars with [Fe/H] > -0.5.

and least square fits were performed to both. The rms is 0.32 mag for the first subsample and 0.26 mag for the second. No systematic tendency of the residuals is observed either with $M_v(Hip)$ or with [Fe/H] (Figure 5).

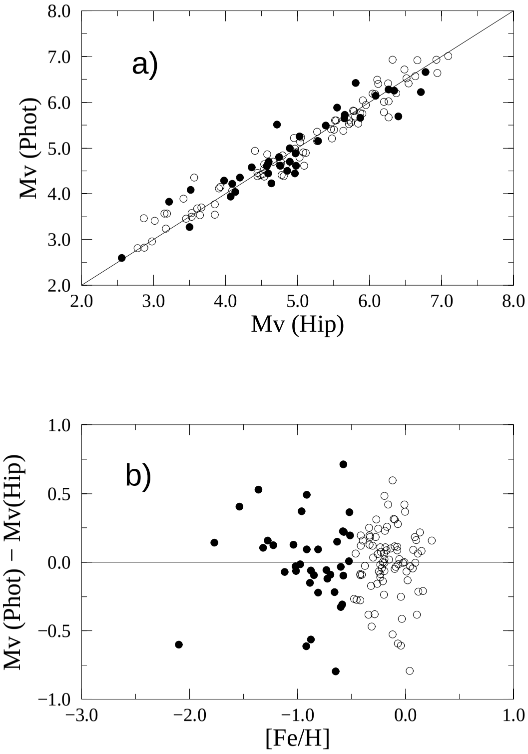


Figure 5. The new calibration of absolute magnitude. Full circles are stars with [Fe/H] < -0.5*, and open circles stars with [Fe/H]* > -0.5*. (a) Photometric versus Hipparcos determination. (b) Residuals versus metallicity. No systematics tendency is observed.*

4. CONCLUSIONS

Using Hipparcos parallaxes with $\Delta\pi/\pi < 20$ per cent a preliminary calibration of M_v in terms of effective temperature, metallicity and evolutionary stage is presented. $(V-K)$ was chosen as temperature parameter because it is almost insensitive to the blanketing effect. The metallicity was computed from Strömgren indices, using the Schuster & Nissen (1989) calibration, corrected following Alonso (1994). The evolutionary stage was represented by the δc_0 parameter.

Our calibration removes the systematic trend in metallicity present in the available calibrations, and it decreases the rms of the residuals (0.32 mag and 0.26 mag for [Fe/H] < -0.5 and [Fe/H] > -0.5, respectively) by a factor of about two.

With the whole Hipparcos Catalogue available and new photometric observations, the present working sample will be enlarged and redefined, allowing a more accurate M_v calibration. Special care will be taken to evaluate the biases of the sample as well as the observationals errors involved.

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