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The Luminosity Calibration of the $uvby - \beta$ Photometry

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Abstract. The ESA HIPPARCOS satellite has provided astrometry of unprecedented accuracy, allowing us to reassess, improve and refine the pre-Hipparcos luminosity calibrations. We review the "classical" absolute magnitude calibrations with the Strömgren-Crawford intermediate-band photometric system. A small zero point correction of about 2-4% seems necessary, as well as to refine the dependences on metallicity and projected rotational velocity. The need of a rigorous statistical treatment of the extremely precise Hipparcos data to derive definitive dependences of the luminosity on physical parameters is emphasized.

1. The pre-Hipparcos luminosity calibrations

The $uvby - \beta$ photometric system is well suited to derive stellar physical parameters and in particular the luminosity, through calibrations accounting for the dependence on $T_{\rm eff}$ and evolution. Further dependences on metallicity and projected rotational velocity were considered by several authors but the results were not conclusive.

The most widely used calibrations are fully empirical (Crawford 1975, 1978, 1979; Strömgren 1966; Olsen 1984 and Balona & Shobbrook 1984 among others). Open clusters and young stellar associations were used to derive the shape of the ZAMS and the dependence on evolution, while the zero point was directly or indirectly fixed through the few available trigonometric parallaxes which were precise enough. A different approach was taken by Nissen & Schuster (1991), who included theoretical stellar evolutionary models to derive metallicity dependences of the ZAMS. The unavoidable need to transform from theoretical to observed stellar quantities adds a source of uncertainty, however.

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Figure 1 shows how the ground-based parallaxes used to fix the zero point of the luminosity (17 F-type stars closer than 11 pc, $\sigma_\pi/\pi < 10.5\%$) compare with the Hipparcos parallaxes ($\sigma_\pi < 1$ mas). Hipparcos parallaxes are smaller by 5 ± 3 mas, i.e. the stars are 0.09 ± 0.06 mag brighter than previously considered. Thus, the photometric distances derived with the pre-Hipparcos calibrations are underestimated by about 4%.

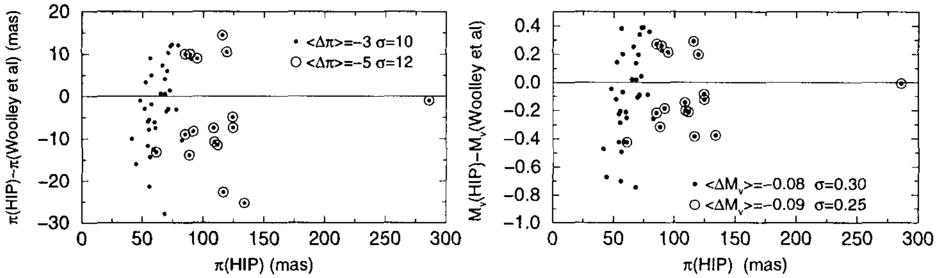

Figure 1. *Left*: Comparison of Woolley et al. (1970) and Hipparcos parallaxes for the stars used to establish the luminosity calibration of F-type stars (circled points represent those stars used to fix the zero point). *Right*: Differences of M_v obtained using Hipparcos and Woolley et al. trigonometric parallaxes

2. Hipparcos based luminosity calibrations

Hipparcos did not only improve the existing trigonometric parallaxes. It considerably enlarged the sample of stars with precise parallaxes and provided accurate proper motions and new data on duplicity and variability. All this information yields larger and cleaner samples than before. However, a large amount of precise data is not enough. To exploit the Hipparcos data to its full extent, a careful evaluation of the selection effects is needed and the observational errors must be taken into account. Furthermore, a statistically robust treatment which accounts for these factors is necessary. The following sections describe the first steps in this direction.

2.1. F-type stars

A sample of unreddened stars with $2.59 < \beta < 2.72$ ($\approx$ F0-G2) was obtained from the Hipparcos catalogue and the photometric data of Hauck & Mermilliod (1998, HM). The sample was cleaned of luminosity classes I & II, peculiar, variable, binary and emission stars according to the Hipparcos flags, SP information, "type object" in SIMBAD and flags in HM. The sample contains ~700 stars with $\sigma_\pi/\pi < 5\%$ and ~2500 stars with $\sigma_\pi/\pi < 15\%$. This is about two orders of magnitude more stars than were available for pre-Hipparcos calibrations.

Figure 2 (left) compares the photometric absolute magnitude with the Hipparcos data for the first subsample. Crawford's calibration shows a small zero point difference, as expected from the parallax differences of the zero point stars (see Fig. 1). A slight trend with metallicity is observed in the subsample with

$\sigma_\pi/\pi < 15\%$. A similar comparison using Nissen & Schuster's (1991) calibration reveals that it is more appropriate for the metal poor stars than Crawford's one, which performs better for metal rich stars.

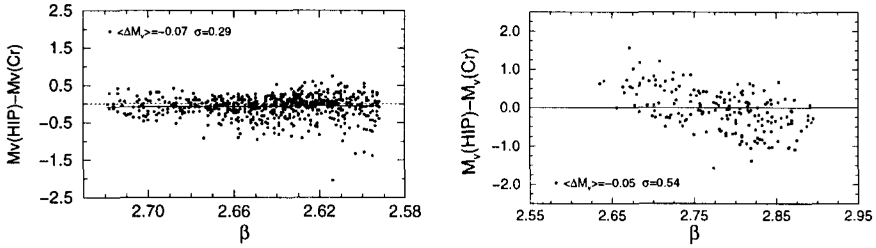

Figure 2. Differences of M_v in the sense Hipparcos−Crawford (1975) as a function of effective temperature for the F-type stars with $\sigma_\pi/\pi <$ 5% (*left*) and Hipparcos−Crawford (1978) as a function of luminosity for the B-type stars with $\sigma_\pi/\pi < 10\%$ (*right*)

Biases due to the observational selection effects and errors were tested using Monte Carlo simulations. A sample of stars of a given $\overline{M_v}$ with spatial distribution typical of the disc (assuming $\sigma_{M_v} = 0.3$ mag, typical Hipparcos errors for parallax and appropriate limits on apparent magnitude) was generated. When the M_v is derived by just using $\pi_{\rm obs}$ and the sample is limited to contain stars with $\sigma_\pi/\pi < 5\%$, we found that $\overline{M_v(\rm true) - M_v(\pi_{\rm obs})} = -0.01$ if $\overline{M_v} = 2.7$ mag ($\sim$ F0) and $\overline{M_v(\rm true) - M_v(\pi_{\rm obs})} = +0.06$ if $\overline{M_v} = 4.7$ mag($\sim$ G2).

With those biases in mind, we attempted to derive a new calibration by a simple least squares fit. The results indicate that an evolutionary term of $\sim 30\Delta\beta$ is more likely than the $20\Delta\beta$ adopted by Crawford (1975) and that there is a small correction for metallicity (~ 0.2[Fe/H]) and a slightly different M_v(ZAMS) relation (< 0.2 mag) . The dispersion of the residuals is 0.25 mag, only slightly better than the 0.29 mag (Fig. 2, left) of Crawford's calibration and larger than expected from the σ_π/π value, reflecting the contribution of the photometric errors, undetected binarity, differences in helium composition and chromospheric activity and so on. The continuity with the A-type stars (see next subsection) has not been tested yet. A more definitive calibration including the observational errors will be the subject of a forthcoming paper.

2.2. Late A-type stars

Domingo & Figueras (1999) compared photometric and Hipparcos parallaxes for a sample of normal and metallic A-type stars and they concluded that Crawford's (1979) calibration is better than Guthrie's (1987) calibration for normal A-type stars, while Guthrie's calibration is better than Crawford's one for Am stars. In both cases, according to Hipparcos, the stars are brighter than predicted by the old calibrations, as for the F-type stars.

A new calibration (including normal and Am stars) was derived by these authors using the weighted least square and the BCES methods; they used a sample of stars closer than 100 pc (including individual Lutz & Kelker (1973) corrections). The precision of their calibration is 0.23 mag. The dependences on evolution, blanketing and rotational velocity are smaller than the ones derived in the pre-Hipparcos calibrations.

2.3. B-type stars

A sample of B-type stars was selected with the same criteria used for the F-type stars. It contains ~1500 stars (~ 20 stars with $\sigma_\pi/\pi < 5\%$ and ~200 stars with $\sigma_\pi/\pi < 10\%$). Hipparcos based absolute magnitudes are compared in Fig. 2 (right) with those obtained from Crawford's (1978) photometric calibration. Simulations like that for the F-type stars were performed and we found that $\overline{M_v(\mathrm{true}) - M_v(\pi_{\mathrm{obs}})} = -0.10$ mag at $\beta = 2.65$ and $\overline{M_v(\mathrm{true}) - M_v(\pi_{\mathrm{obs}})} = -0.05$ mag at $\beta = 2.90$ for a sample limited to $\sigma_\pi/\pi < 10\%$. Thus, the biases are smaller than the actual differences. When the comparison is performed with Balona & Shobbrook's (1984) calibration, a similar trend appears, although it is less pronounced.

Due to the scarcity of early B-type stars in the near vicinity of the Sun, the calibration should be derived by using open clusters or by using a statistical method capable of dealing with the whole sample, accounting for its biases as well as the observational errors. The maximum likelihood method (LM) by Luri et al. (1996) was adapted to this case. We parameterized the absolute magnitude as a function of the β and $[u-b]$ colours and the results are quite promising, although the influence of the adopted interstellar absorption model must be checked. Luminosity seems to depend only on β for the B0-B3 subsample, while an additional dependence on $[u-b]$ exists in the B4-B9 subsample. (Crawford (1978) did not consider an evolutionary term when $c_o > 0.9$ and this could be the cause of the large discrepancy in the B8-B9 range in Fig. 2 right). Dependences on projected rotational velocity are not clear at this stage of the calibration.

References

Balona, L.A., & Shobbrook, R.R. 1984, MNRAS, 211, 375

Crawford, D.L. 1975, AJ, 80, 955

Crawford, D.L. 1978, AJ, 83, 48

Crawford, D.L. 1979, AJ, 84, 1858

Domingo, A., & Figueras, F. 1999, A&A, 343, 446

Guthrie, B.N.G. 1987, MNRAS, 226, 361

Hauck, B., & Mermilliod, J.-C. 1998, A&A, 129, 431

Luri, L., Mennessier, M.O., Torra, J., & Figueras, F. 1996, A&A, 117, 405

Lutz, T. E., & Kelker, D. H. 1973, PASP, 85, 573

Nissen, P.E., & Schuster, W.J. 1991, A&A, 251, 457

Olsen, E.H. 1984, A&AS, 57, 443

Strömgren, B. 1966, ARA&A, 4, 433

Woolley, R.vd.R., Epps, E.A., Penston, M.J., & Pocock, S.B. 1970, Royal Obs. Ann., 5