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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 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 definite dependences of the luminosity on physical stellar 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 enough.

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 the evolution, while the zero point was directly or indirectly fixed through the few trigonometric parallaxes precise enough available at the epoch. 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.

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 roughly by about 4%.

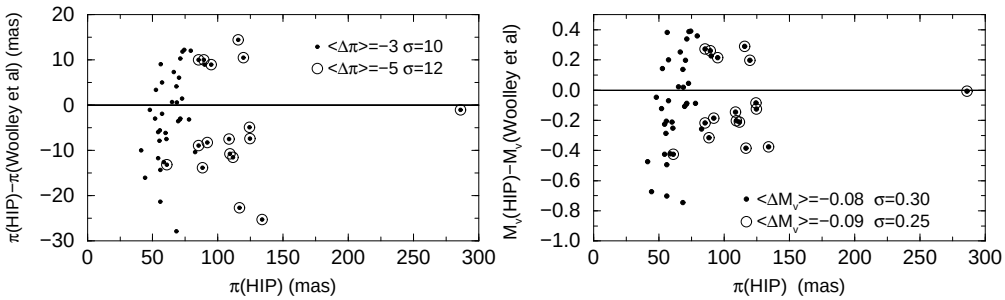

Figure 1. *Left*: Comparison of Woolley et al. (1970) and HIPPARCOS parallaxes for the stars used to establish the luminosity calibration of F-type stars (circled points represent those stars used to fix the zero point). *Right*: Differences of M_v obtained using HIPPARCOS and Woolley et al. trigonometric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

2. HIPPARCOS based luminosity calibrations

HIPPARCOS did not only improve the existent trigonometric parallaxes. It considerably enlarged the sample of stars with precise parallaxes, provided accurate proper motions and new data on duplicity and variability. All this information yields larger and cleaner samples than before. However, a big amount of precise data is not enough. To exploit the HIPPARCOS data to its full extent, a careful evaluation of the sample observational selection effects is needed, as well as taking into account the involved observational errors. Furthermore, statistically robust treatments accounting for these items are necessary.

We describe in the following sections the calibrations done in this direction.

2.1. F-type stars

A sample of unreddened stars with $2.59 < \beta < 2.72$ ($\approx$ F0-G2) was built from the HIPPARCOS catalogue and Hauck & Mermilliod (1998, HM) photometric data. The sample was cleaned of luminosity classes I & II, peculiar, variable, binaries 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 $\sigma_\pi/\pi < 15\%$ (about two orders of magnitude more stars than those available to 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 on metallicity is observed when working with the

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

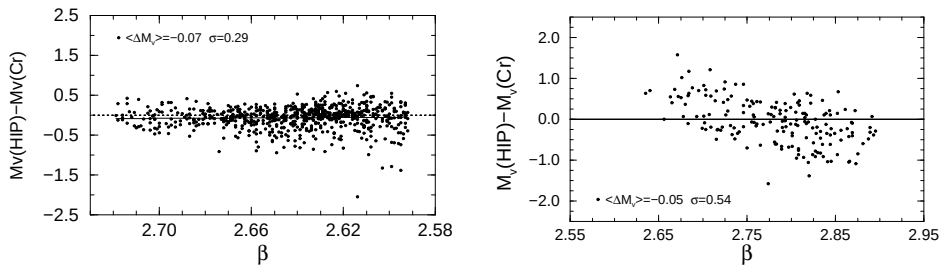

Figure 2. Differences of M_v in the sense HIPPARCOS−Crawford (1975) as a function of effective temperature for the F-type stars with $\sigma_\pi/\pi < 5\%$ (*left*) and HIPPARCOS−Crawford (1978) as a function of luminosity for the B-type stars with $\sigma_\pi/\pi < 10\%$ (*right*)

Biases due to the observational selection effects and errors were tested using MonteCarlo 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 square fit. The results point out to $\sim 30\Delta\beta$ more likely than the $20\Delta\beta$ adopted by Crawford (1975) as evolutionary term, to a small correction for metallicity ($\sim 0.2[Fe/H]$) and to a slightly different M_v(ZAMS) relation (< 0.2 mag) . The dispersion of the residuals is of 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, unsolved binarity, differences in helium composition, cromospheric activity and so on. The continuity with the A-type stars (see next subsection) has not been tested yet. A more conclusive 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 (1979) calibration is better than Guthrie (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 and working with a sample of stars closer than 100 pc (including individual Lutz & Kelker correction). The precision of their calibration is of 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

As for the F-type stars, a sample of B-type stars was built with similar selection criteria. It contains ∼1500 stars (∼ 20 stars with $\sigma_\pi/\pi < 5\%$ and ∼200 stars with $\sigma_\pi/\pi < 10\%$). Photometric and HIPPARCOS based absolute magnitudes are compared in Fig. 2 (right) for Crawford (1978) calibration. Similar simulations that for the F-type stars were performed and we obtained 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 (1984) calibration, a similar trend also appears, although less pronounced.

Due to the scarcity of early B-type stars in the near vicinity of the Sun, the calibration should be approached by using open clusters or by using a statistical method capable of dealing with the whole sample, accounting for its biases and 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 considered an evolutionary term when $c_o > 0.9$ and this could be the cause of the large discrepancy at the B8-B9 range in Fig. 2 right). Dependences on projected rotational velocity are not clear at this stage of the calibration. Again, a more definite calibration using LM and its comparison with the classical approach is the subject of our future work, although we are limited by the small number of projected rotational velocities available.

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