ABSOLUTE MAGNITUDE CALIBRATION OF GENEVA PHOTOMETRY BASED ON HIPPARCOS PARALLAXES: THE B-TYPE STARS

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ABSTRACT

The Hipparcos data give us access, for the first time, to trigonometric parallaxes of B-type stars. This allows us to refine and re-adjust extant empirical absolute magnitude calibrations of the Geneva X and Y reddening-free photometric parameters on the basis of the parallaxes that are presently available. The new calibration presented here, which is totally independent of other data, is compared with results that were derived with earlier versions. Its validity regarding a selection of Ap stars is tested on the basis of their Hipparcos parallaxes. The calibration must, however, not be considered to be optimal until the whole Hipparcos and Tycho data are distributed and enable a definitive study to be undertaken.

Key words: space astrometry; photometry; B-type stars.

1. INTRODUCTION

The absence of B-type stars in the immediate solar neighbourhood has up to now restricted the evaluation of their absolute magnitudes to indirect methods, such as cluster sequence fitting or, in very rare cases, to the application of the moving cluster method (e.g. the Scorpio – Centaurus association). The results of the Hipparcos mission provide us, however, with an important sample of primary parallaxes extending, with reasonable precision, up to early B-types. Reddening-free photometric indices that are able to separate $T_{\rm eff}$ and gravity for B stars are not very sensitive to variations of composition in that temperature domain, and may be calibrated in a straightforward manner in terms of absolute magnitude. This is true for the Geneva X and Y parameters (Cramer & Maeder, 1979) which were designed to optimise the separation of those physical quantities. A variety of calibrations have been established for B-stars in this system to estimate intrinsic colours, $T_{\rm eff}$, log g, M_v, and to correlate Geneva photometry with Johnson indices, the Strömgren β index and the MK spectral classification (see references in Cramer, 1993, 1994). A recent revision of the absolute magnitude calibration was undertaken on the basis of the apparent distance moduli of 18 clusters derived by Meynet, Mermilliod and Maeder (1993), and is published in the context of a study of NGC 6231 by Raboud, Cramer & Bernasconi (1997). The present work re-visits the M_v(X,Y) calibration, but in the *totally independent* context provided by the Hipparcos parallaxes.

2. THE CALIBRATION

The basic calibration sample consists of 6044 B- to A-type field stars (Internal Proposal 70), and 134 members of the Scorpio-Centaurus association (Proposal 164). A large portion of the field stars are, however, at the range limit of Hipparcos, having poor, insignificant or negative parallaxes. A first selection was therefore made by restricting the sample to stars with $\pi/\sigma(\pi) \geq 5$, thus effectively reducing its range to within about 300 pc and also limiting the incidence of statistical bias. Except for a few discrepancies, the whole Sco-Cen sample was retained at this stage. Then, all known spectroscopic binaries and binaries not separated by photometry were deleted, as well as measurements having $Y < -0.06$, and which would lie outside the field where the X,Y parameters are related to $T_{\rm eff}$ and log g without overlapping. The selection finally contains 1580 stars of classes V to III with Geneva photometry. The corresponding absolute magnitudes were then computed with the aid of the parallaxes and the de-reddened Geneva visual magnitudes (procedure defined by Cramer, 1982). No statistical correction was, however, attempted here for the individual M_v derived in this manner. Following earlier experience with the properties of the X,Y diagram, we have chosen to construct our model by smoothing the data with a polynomial expression. The most realistic description, that is not excessively susceptible to diverge by extrapolation, is rendered by a relation that is of the fourth degree in X (temperature) and quadratic in Y (luminosity). The regression gives the M_v(X,Y) polynomial function, with its corresponding coefficients listed in Table 1 and mapped with its calibration stars into the X,Y plane of Figure 1.

The residuals of the fitting show no significant colour-related bias over the validity range. Their standard deviation is equal to the rather high value of 0.52 mag. The average one over the parallax determinations is, however, equal to 0.27 mag, and accounts for a good part of the total dispersion. This is well illustrated by Figure 2, where the residuals

Table 1. Coefficients of the $M_v(X,Y)$ calibration.

Const	Y	Y^2	X	XY	XY^2
-3.7528	-21.0189	-161.4130	5.2076	-2.5839	138.1530
X^2	X^2Y	X^2Y^2	X^3	X^3Y	X^4
-2.8463	13.2480	-29.8913	2.9363	-4.0510	-1.2997

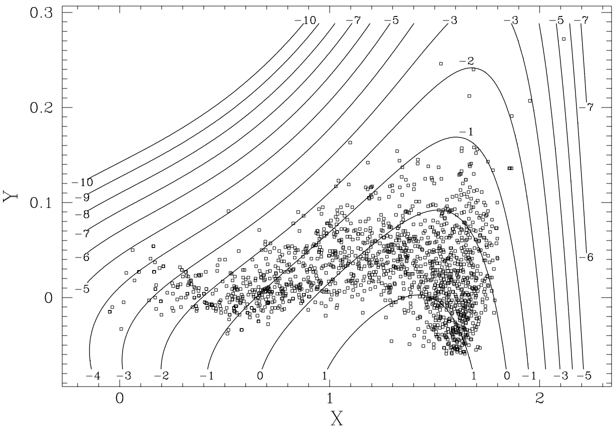

Figure 1. The $M_v(X,Y)$ calibration with the calibration stars.

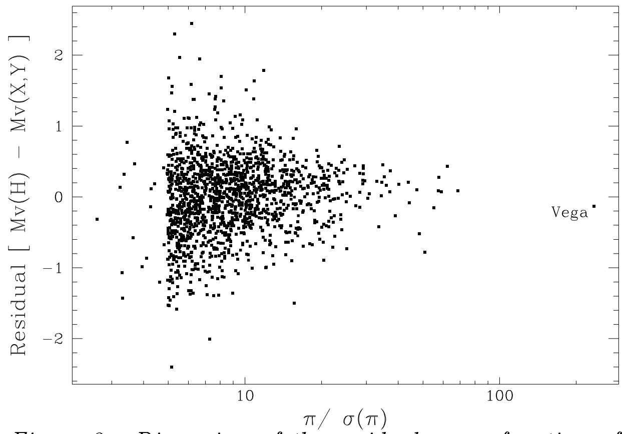

Figure 2. Dispersion of the residuals as a function of astrometric accuracy.

are plotted as a function of the accuracy of the parallax determination, i.e. the ratio $\pi/\sigma(\pi)$, implying that the photometric calibration effectively averages out most of the dispersion of the trigonometric data. The overall standard deviation for the photometric M_v estimate, which accumulates the photometric as well as the various astrophysical causes of dispersion (undetected binarity, rotation, etc.) would then be about 0.44 mag, which is comparable to those of earlier calibrations based on this method.

3. SOME APPLICATIONS AND TESTS

It is interesting to confront the latest of the 'classically derived' absolute magnitude calibrations (Raboud et al., 1997) with the present one that is based exclusively on trigonometric parallaxes. The application of the latter to the same sample of stars that was chosen to define the former is presented in Table 2, and shows that the distance estimate via the cluster main sequence fitting procedure used by Meynet et al (1993) is consistent with the Hipparcos parallaxes, as far as the upper main sequence is concerned. The distances estimated by the present calibration have a standard error of about 11pc. The validity of the present calibration is likewise restricted to stars of classes V to III. It tends, however, to slightly brighten the latest B- and earliest A-types.

The question of the validity of standard colour-defined absolute magnitude calibrations regarding Ap stars can now finally be discussed in an objective context. The application of the present calibration to 95 'photometrically detected' Ap stars (77 of which are also spectroscopically identified as Ap) is shown in Figure 3. These stars (Proposal 172) were taken from the list of photometrically peculiar stars selected by means of the Z parameter (orthogonal to X and Y) published by Cramer & Maeder (1980). The figure shows that the absolute magnitudes of the cooler Ap stars are correctly estimated *on the average*, though rather dispersed, and suggests that standard photometric criteria may be validly applied for their study. For temperatures higher than about 14 000 K (i.e. the hotter Si stars), however, the calibration tends to significantly overestimate luminosity. 60 per cent of the latter sample are also spectroscopically classified as Bp.

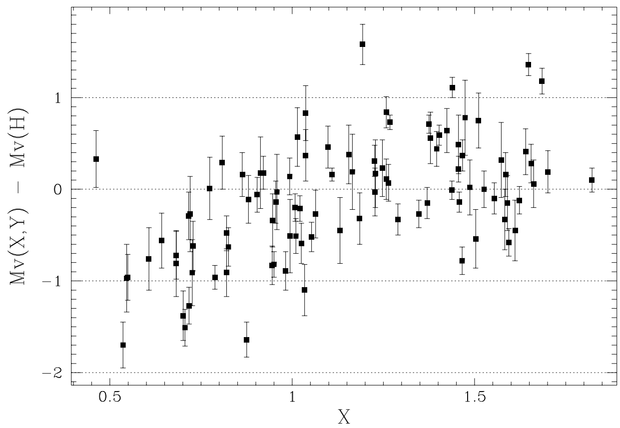

Figure 3. Comparison of the photometric M_v estimate with the Hipparcos determination, for Ap stars. The error bars are for the Hipparcos magnitudes.

A calibration of the X,Y plane in terms of MK types (Cramer, 1994) can be directly linked with the present M_v calibration. The results are given in Table 3. The locations of the MK types were derived by averaging over both reddening-free parameters with a sample of about 3600 well classified stars containing no known binaries. The low sensitivity of photomet-

Table 2. Comparison with earlier results. Column 1: Cluster name, 2: Mean Geneva colour excess (E_{B-V} Gen = 1.188E_{B-V} John, and Av = 2.75E_{B-V} Gen), 3: Modulus (Meynet et al), 4: Mean modulus (this calibration), 5: Distance (Meynet et al), 6: Distance (this calibration).

Cluster	$< E_{B-V} >$	$(m_0 - M)$	$(m_0 - M)^*$	$d[pc]$	$d^*[pc]$
α Per	0.13	6.00	6.13	158	169
χ Per	0.69	11.78	11.51	2249	2003
h Per	0.66	11.83	11.61	2320	2103
Orion	0.08	8.14	8.11	424	418
Pleiades	0.08	5.38	5.57	119	130
NGC 457	0.59	11.99	12.01	2499	2524
NGC 581	0.53	11.80	12.00	2294	2509
NGC 1039	0.11	8.34	8.26	466	449
NGC 2287	0.07	8.96	9.10	618	660
NGC 2516	0.16	7.90	8.02	381	403
NGC 2682	0.11	9.31	9.82	728	922
NGC 3532	0.08	8.12	8.20	420	437
NGC 4755	0.49	11.21	11.27	1749	1791
NGC 5460	0.16	9.07	8.99	650	627
NGC 6025	0.23	9.30	9.42	726	766
NGC 6231	0.58	10.90	10.85	1513	1477
NGC 6281	0.22	8.39	8.67	476	541
NGC 6475	0.11	6.77	6.91	226	241

Table 3. The MK - Type versus $M_v(X,Y)$ correlation for B-stars of classes V to III.

Type	Class V	Class IV	Class III
O9	(-3.9)	(-4.0)	(-4.0)
O9.5	-3.8	-3.7	-3.9
B0	-3.7	-3.6	-3.9
B0.5	-3.3	-3.4	-3.7
B1	-2.9	-2.9	-3.3
B1.5	-2.5	-2.7	-2.9
B2	-1.7	-2.4	-2.7
B2.5	-1.4	-1.7	—
B3	-1.2	-1.3	-1.6
B4	-0.9	-1.2	-1.2
B5	-0.7	-1.1	-0.9
B6	-0.4	-0.8	-0.8
B7	-0.3	-0.7	-0.8
B8	0.0	-0.5	-0.7
B8.5	0.1	—	—
B9	0.5	0.1	-0.5
B9.5	0.7	0.5	-0.3
A0	0.8	0.6	0.0
A1	0.9	0.9	0.3
A2	1.1	1.2	0.8

ric indices regarding O to B0 stars does not, however, allow us to extend the M_v calibration with confidence into that domain. The average luminosities proposed in Table 3 do not differ significantly from those of our earlier work regarding the B stars, but tend to be brighter by 0.1 to 0.2 mag for the earliest A-types.

4. CONCLUSIONS

The Hipparcos parallaxes have allowed the hitherto most objective absolute magnitude calibration of the Geneva X and Y reddening-free parameters to be undertaken for B-type stars. As with former calibrations involving these parameters, the relation is purposely biased against duplicity, as far as that could be identified in the initial data. The intrinsic luminosity of multiple stars is underestimated by multicolour photometry. Their inclusion in a calibration tends to lower the brightness of its estimate. Rotation, which is the next most important source of scatter in photometric classification, was not considered in the selection process because of its ubiquitous nature midst early-type stars. The uncertainties over the parallaxes tend to average out (Figure 2) thanks to the size of the calibration sample consisting of 1580 stars. No attempt was made here to introduce a statistical correction of bias to the individual M_v derived from the parallaxes (such a correction would be expected to slightly brightened the calibration). The new relation compares favourably with earlier calibrations: when applied to the early type stars of 18 clusters studied by Meynet et al. (1993), the moduli derived by the authors are well reproduced, and no drastic systematic difference is apparent (Table 2) *even for the Pleiades cluster*, whose Hipparcos parallaxes did not contribute to this calibration. The absolute magnitudes corresponding to the mean locations of MK types of classes V to III (the range of validity of this calibration) are largely identical to those of an earlier estimate (Cramer, 1994), except for the earliest A-type stars which are made a bit brighter. Finally, an objective test of the validity of colour versus absolute magnitude relations regarding Ap stars is now possible and shows that, in the present case, their M_v are estimated correctly in the *photometric* temperature range 10 000 K to 14 000 K, but that for higher temperatures (the hotter Si stars) photometry systematically overestimates luminosity (Figure 3). The present calibration must not be regarded as definitive because of the limited release of Hipparcos satellite results at this date. It does, however, demonstrate the value of the parallaxes thus acquired even for stars of the extreme upper main sequence. The availability of the whole Hipparcos and Tycho data will allow a more optimal study to be undertaken with an assessment of the incidence of statistical bias regarding the M_v derived from the parallaxes. It should also be accompanied by a discussion of the various astrophysical effects that influence the absolute magnitude estimate.

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