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Hβ photometry of southern CP2 stars: is the $uvby\beta$ luminosity calibration also valid for peculiar stars?*

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Abstract. We present Hβ photometry of 233 southern CP2 stars (covering the magnetic Ap stars according to the definition by Preston 1974) brighter than V $<$ 8.5 mag from the list of Bidelman & MacConnell (1973).

Absolute magnitudes derived from this photometry together with already existing $uvby$ photometry is confronted with Hipparcos results available for a common subset of 152 stars.

In order to compare peculiar with normal stars, we identified a sample of 1147 normal B to F-type stars using their published $uvby\beta$ and Hipparcos data.

For our analysis we divide both samples into three temperature as well as two Hipparcos parallax accuracy groups. The error distribution of both samples proved to be statistically comparable.

As a result the absolute magnitudes for the B-type CP2 stars show up to be significantly too bright by an average of 0.5 mag using the actual photometric calibration. On the other hand, the photometric absolute magnitudes for cool A to F-type CP2 stars are up to three magnitudes fainter as compared to Hipparcos.

Key words: stars: chemically peculiar – stars: early-type

1. Introduction

One of the basic tools in modern astrophysics is the calibration of stellar absolute magnitudes which enables conclusions on luminosity, age, distance and evolution of stars. More than 40 years ago, Crawford (1958) introduced a powerful method for this purpose: the photoelectric measurement of the Hβ absorption line in two interference filters (a narrow and a broad one, both centered at Hβ) which allows to determine absolute magnitudes of stars of early and intermediate spectral types (B - F). However, it took more than two decades until Crawford (1975, 1978, 1979) and Hilditch et al. (1983) have published a reliable $M_{\rm V}$-$uvby\beta$ calibration for normal main sequence, in the above mentioned spectral type range. On the other hand, the question whether this calibration is also valid for peculiar stars remains to a large extent open till now.

25 years ago Bidelman & MacConnell (1973) published a list of nearly 800 southern Ap-stars which they had identified on objective prism plates collected at the Cerro Tololo Interamerican Observatory as kind of a precursor work for the huge Michigan project of two-dimensional spectral classification.

This list has been used as basis for three different photometric projects carried out at ESO-La Silla with a limiting magnitude V = 8.5 mag:

1. $uvby$ photometry of 341 Ap stars by Vogt & Faúndez (1979);
2. Δa-photometry of 338 Ap stars by Maitzen & Vogt (1983) in the system of Maitzen (1976) demonstrating the very high agreement of photometric Ap-detections with the spectroscopic results of Bidelman & MacConnell (1973);
3. Hβ photometry of 233 objects which were observed at the Danish 50cm telescope on La Silla in 1982 (this paper).

The latter work was intended not only to formally complete Strömgren-Crawford data for a significantly large set of chemically peculiar stars (excluding Am and HgMn objects) but also to yield their galactic locations. Publishing these data has been delayed for some years because we wanted to have an independent data set to compare with in order to check how far the application of a normal star calibration to our Ap-sample deviates from reality. Such an independent set has become available by the meanwhile published Hipparcos catalogue (Perryman et al. 1997) which, fortunately, contains high precision parallaxes for two thirds of our sample.

After a brief description of observing and reduction procedures, we give the results of our Hβ photometry (Sect. 2) and compare the photometric absolute magnitude calibrations with those based on trigonometric parallaxes of Hipparcos (Sect. 3). We discuss these results for different spectral types as well as for two different domains of the accuracy of trigonometric parallaxes (Sect. 4).

2. Observations and data reduction

The Hβ data have been obtained during two observing runs at the Danish 50 cm telescope located at ESO-La Silla (Chile): 1982, April 20 - May 2 (12 nights, observer NV) and 1982, July

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* Based on observations at ESO-La Silla and with the Hipparcos satellite

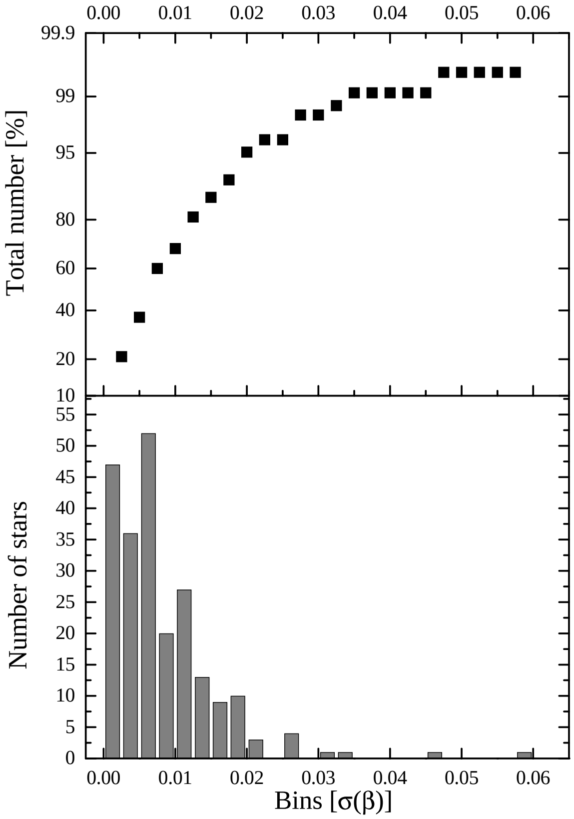

Fig. 1. The error distribution of all measured Hβ indices.

11 - 31 (20 nights, observer WWW), using the two-channel Hβ photometer described by Grönbech & Olsen (1977). A beam splitter in front of the field lens in the direct beam reflected 20% of the light via a spherical mirror through a second field lens. The two photomultipliers of type EMI 6256SA were operated at ambient temperature. The filters were placed immediately in front of the cathodes, the narrow filter in the direct beam and the wide filter in the reflected beam. Thus, the fluxes falling on the cathodes were approximately equal. The dead-time of the photoelectron counting system was 70 nanoseconds. In order to avoid large dead-time corrections we limited our observations to stars V $>$ 3 mag.

The standard stars were taken from Tables 3 and 7 in Grönbech & Olsen (1977) which are based on the system defined by Crawford & Mander (1966). In order to control possible sensitivity changes in the photomultipliers we measured about 5 - 10 standard stars at the beginning and at the end of each night, and 1 - 2 standards every 2 hours during the night. Some individual standard stars were observed 2 - 3 times during the same night at different air masses, but no significant effects on atmospheric extinction and/or telescope position were found.

As program stars we selected all Ap stars with V $<$ 8.5 mag in Table IV of Bidelman & McConnell (1973) within the right ascension range accessible during our observing runs (approx. 0h 30 min $< \alpha <$ 4 h and 8 h $< \alpha <$ 23 h). The main goal of our observations was to obtain precise β values of each program star in at least two different observing nights. In order to reach an accuracy of 0.3% per measurement a total net count rate of about 300000 in each channel was necessary. For practical reasons, the integration time unit was fixed to 20 seconds for standard stars and to 100 seconds for program stars. The integration was repeated as often as necessary to reach the desired total of 300000 counts per channel.

The reduction procedure was rather simple and straightforward: first, we determined the mean instrumental value $\overline{\beta}$ of each standard star, as an average from all observing nights within one run (April/May or July resp.). Subsequently, the individual deviations $\Delta\beta = \beta - \overline{\beta}$ of all standard stars versus time were considered for determining drifts and zero point corrections of each observing night. Applying these corrections, all measurements (standard and program stars) were converted into a uniform instrumental β system. Finally, the transformation into the standard system was performed by means of a simple linear least squares fit

$$\beta(\mathrm{standard}) \;=\; a_0 \;+\; a_1 \cdot \beta(\mathrm{instrumental}),$$

based on the mean values of the standard stars. While the classical procedure (Crawford & Mander 1966) divides the stars into two groups (B-type and late type stars) yielding separate β-transformations for them, our data could be reduced for both groups together, since no increase of the scatter around the regression line was found compared to the analysis of the individual groups.

The HD identifications, the mean β values and the total number N of observations obtained are listed in Table 1. The resulting internal mean errors of the April/May run are rather small (0.003 mag) while those of the July run are larger (about 0.005 mag in average), probably due to worse weather condition which prevented, in some cases, to reach the above mentioned accuracy requirements. On the other hand, in the July run we obtained more individual observations (up to 6 per star). Therefore, the accuracy in the final mean values in each observing run should be comparable. Fig. 1 shows the error distribution of the observed Hβ values. About 95 % of our program stars have a $\sigma(\beta) \leq$ 0.02 mag.

3. Absolute magnitudes of our program stars

Using the observed Hβ values, we have applied the standard calibrations in the $uvby\beta$ system to derive absolute magnitudes of our program stars as well as of a sample of apparent "normal" type stars in the relevant spectral range. These values were compared to absolute magnitudes derived by the parallaxes measured with the Hipparcos satellite.

3.1. Calibration in the $uvby\beta$ system

The program stars were divided in three groups (early, intermediate and late) as suggested by Crawford (1975, 1978, 1979) before applying the relevant calibrations. The $uvby$ photometry was taken from Vogt & Faúndez (1979).

The absolute magnitudes were then derived using the calibrations given in Crawford (1975, 1978, 1979) and Hilditch et

Table 1. Mean Hβ indices for 233 Ap stars.

BM	HD	β	m.e.	N	BM	HD	β	m.e.	N	BM	HD	β	m.e.	N
1	2957	2.887	0.005	3	522	85892	2.717	0.004	2	687	120059	2.762	0.008	2
2	3580	2.716	0.007	3	529	86976	2.899	0.006	2	691	121661	2.877	0.006	2
4	3980	2.871	0.013	3	537	88385	2.857	0.002	2	693	122208	2.896	0.006	2
6	5601	2.792	0.002	3	544	89103	2.771	0.004	2	700	123627	2.895	0.001	2
8	6783	2.754	0.019	3	545	89192	2.902	0.008	2	703	124051	2.806	0.002	2
10	8783	2.882	0.003	4	546	89217	2.729	0.001	2	707	125532	2.717	0.010	2
15	15144	2.900	0.016	3	547	89385	2.886	0.003	2	709	125630	2.808	0.009	2
16	16145	2.883	0.010	3	548	89393	2.841	0.008	2	712	126198	2.669	0.001	2
19	18610	2.831	0.013	3	549	89519	2.792	0.001	2	714	126515	2.934	0.002	2
20	19712	2.860	0.006	2	550	89680	2.888	0.004	2	716	126876	2.682	0.006	2
23	20880	2.878	0.016	2	556	90612	2.744	0.001	2	719	127453	2.717	0.007	2
24	21201	2.830	0.018	2	560	91087	2.705	0.011	2	720	127575	2.749	0.006	2
28	23207	2.881	0.011	2	561	91089	2.751	0.001	2	730	128898	2.829	0.001	3
350	64988	2.829		1	562	91134	2.866	0.002	2	735	129899	2.752	0.003	3
366	66605	2.745		1	571	92385	2.812	0.002	2	736	130335	2.728	0.004	3
367	66698	2.782	0.001	2	572	92379	2.747	0.005	2	740	131505	2.739	0.002	2
378	67835	2.719	0.005	2	575	92664	2.706	0.011	2	747	132322	2.905	0.003	4
386	68292	2.701	0.006	2	579	93500	2.837	0.009	2	756	133281	2.760	0.001	3
404	70325	2.746	0.003	2	582	93821	2.752	0.001	2	760	133757	2.723	0.007	5
407	70507	2.771		1	587	94455	2.886	0.001	2	762	133880	2.764	0.003	2
409	70749	2.764		1	588	94873	2.731	0.004	2	765		2.775	0.001	2
417	72055	2.718		1	589	95198	2.776	0.003	2	769	135297	2.848	0.016	4
422	72295	2.863		1	590	95413	2.823	0.001	2	770	135396	2.733	0.011	5
427	72611	2.810	0.008	2	591	95442	2.912	0.002	2	771	135415	2.709	0.007	5
428	72634	2.888	0.006	2	592	95569	2.759	0.003	2	776	135728	2.852	0.009	4
431	72881	2.761	0.006	2	593	95699	2.891	0.001	2	781	136347	2.784	0.002	5
433	72976	2.713	0.007	2	597	96910	2.801	0.005	2	784	137160	2.862	0.010	4
436	73340	2.701	0.003	2	599	97394	2.881	0.004	2	785	137193	2.784	0.019	4
440	73737	2.816		1	600	97986	2.754	0.002	2	787	137509	2.717	0.012	5
442	74169	2.866	0.001	2	604	98340	2.826	0.002	2	792	137949	2.820	0.006	4
450	74888	2.742	0.002	2	605	98457	2.756	0.047	2	798	138519	2.679	0.008	4
455	75445	2.804	0.002	2	606	98486	2.732	0.004	2	801	138758	2.816	0.006	4
456	76104	2.813	0.009	2	614	101600	2.745	0.007	2	802	138773	2.746	0.014	4
464	76439	2.723		2	615	101724	2.710	0.002	2	814	141461	2.752	0.010	4
466	76650	2.736	0.004	2	617	102354	2.700	0.005	2	816	141641	2.697	0.010	4
467	76897	2.762	0.006	3	619	103302	2.893	0.018	3	822	142884	2.708	0.003	4
471	77609	2.809	0.002	2	621	103457	2.776	0.001	3	825	143473	2.737	0.005	5
472	77689	2.721	0.014	3	626	104810	2.709	0.006	3	827	143592	2.797	0.017	4
476	78201	2.822	0.005	2	627	105379	2.930	0.001	2	828	143658	2.709	0.007	5
477	78568	2.740	0.005	3	629	105457	2.758	0.005	2	832	144231	2.706	0.008	4
482	79606	2.732	0.004	2	630	105770	2.740	0.002	2	834	144748	2.882	0.014	5
485	79976	2.859	0.003	2	631	106204	2.746	0.003	3	841	146971	2.898	0.011	4
486	80282	2.739	0.001	2	640	109809	2.737	0.008	3	847	147890	2.748	0.027	5
488	80316	2.883	0.007	2	644	110446	2.724	0.002	3	854	148848	2.780	0.033	5
492	81141	2.782	0.001	2	650	112381	2.867	0.003	3	862	149764	2.735	0.009	4
493	81289	2.797	0.002	2	651	112528	2.853	0.001	2	863	149831	2.734	0.007	4
494	81588	2.884	0.002	2	659		2.872	0.006	2	865	149911	2.891	0.005	4
495	81847	2.752	0.005	2	663	115440	2.757	0.005	2	867	150035	2.871	0.018	4
498	80293	2.880	0.011	2	665	115599	2.744	0.001	2	868	150040	2.847	0.016	4
499	82154	2.760	0.004	2	667	116114	2.832	0.025	2	872	150323	2.735	0.025	3
501	82567	2.746	0.003	2	669	116423	2.795	0.011	2	873	150486	2.731	0.016	4
507	83266	2.890	0.003	2	674	117057	2.716	0.006	2	874	150500	2.690	0.006	4
508	83368	2.842	0.003	3	678	118242	2.776	0.002	2	876	150714	2.826	0.007	4
510	83625	2.767	0.002	3	679	118816	2.738	0.004	2	879	151363	2.714	0.005	2
514	84451	2.772	0.012	2	680	118913	2.868	0.002	2	881	151742	2.735	0.005	4
516	84907	2.870	0.001	2	682	119308	2.886	0.003	2	882	151860	2.755	0.014	4

Table 1. (continued)

BM	HD	β	m.e.	N	BM	HD	β	m.e.	N	BM	HD	β	m.e.	N
883	151965	2.706	0.009	4	942	161349	2.724	0.006	4	1021	174779	2.750	0.007	3
886	152366	2.730	0.009	4	945	161841	2.701	0.004	5	1027	176555	2.772	0.005	4
890	153707	2.761	0.017	5	950	162651	2.785	0.014	4	1043	181550	2.749	0.017	5
896	154253	2.875	0.030	5	951	162725	2.772	0.012	5	1048	184020	2.843	0.013	4
897	154308	2.890	0.011	4	952	163555	2.671	0.005	5	1055	185280	2.925	0.018	4
899	154458	2.711	0.014	4	959	164224	2.867	0.019	4	1057	187473	2.782	0.004	3
904	155127	2.868	0.002	3	960	164258	2.908	0.011	4	1062	189502	2.779	0.012	5
908	155778	2.733	0.007	4	968	166053	2.684	0.014	4	1066	191439	2.909	0.059	6
909	156300	2.784	0.007	3	970	166469	2.801	0.009	5	1068	191796	2.856	0.009	6
912	156853	2.717	0.012	4	971	166473	2.812	0.009	3	1076	197417	2.891	0.020	6
913	156869	2.854	0.011	4	972	166596	2.572	0.004	7	1077	199728	2.728	0.002	6
915	157678	2.725	0.010	4	975	166921	2.746	0.018	5	1078	200623	2.873	0.025	7
917	157751	2.870	0.005	4	976	166968	2.725	0.012	4	1080	203932	2.800	0.022	5
920	158128	2.783	0.003	4	988	168856	2.726	0.004	4	1082	206653	2.740	0.019	7
922	158175	2.733	0.004	4	989	169021	2.716	0.017	4	1083	207188	2.739	0.012	7
927	158450	2.887	0.002	4	994	170397	2.830	0.014	4	1085	208217	2.840	0.007	6
928	158596	2.798	0.003	3	997	171279	2.903	0.009	5	1088	212385	2.905	0.018	7
931	159376	2.714	0.003	3	1002	172032	2.744	0.005	4	1090	212432	2.733	0.010	6
932	159545	2.738	0.008	4	1009	172690	2.761	0.014	4	1092	215966	2.845	0.005	7
933	159846	2.734	0.008	4	1011	173406	2.733	0.011	4	1094	217522	2.707	0.007	7
936	160127	2.885	0.020	5	1012	173562	2.904	0.012	4	1096	218994	2.815	0.005	6
941	161277	2.767	0.014	6	1020	174646	2.749	0.011	5					

BM .... Number according to Bidelman & McConnell (1973)
HD .... HD number
β .... Derived Hβ index
m.e. ...... Mean error of the derived Hβ index
N .... Number of measurements in different nights

al. (1983). We have considered the individual reddening (mainly based on the Hβ index) of the stars. For most of the stars the reddening can be neglected because of their neighborhood to the Sun. For the remaining objects, the derived reddening was compared with that of the Johnson UBV system (taking the UBV colors from Mermilliod et al. 1997 and the calibration given by Schmidt-Kaler 1982).

In order to avoid effects by selecting the wrong calibration (e.g. stars which are just on the edge of the validity for a selected group), “critical” stars were also calibrated within the adjacent group. Since none of the program stars exhibit a large deviation within this procedure we are confident to believe that a wrongly selected group does not affect the derived absolute magnitudes significantly.

Another important issue is the error estimation. There are two main sources which have to be considered: 1) the error propagation of the observational uncertainties; 2) the intrinsic error of the calibration itself. The latter is always given as ±0.3 mag. This value takes into account the apparent width of the main sequence (due to rotation and evolutionary effects) as well as the observational errors from $uvby\beta$ data of galactic clusters used for the calibration. Since we are not able to independently test the intrinsic validity of the calibration, we have to assume the correctness of the given error. The estimation of the error propagation of the observational uncertainties on the absolute magnitude is not straightforward. But we are able to make the following assumption: taking the changes of $M_{\rm V}$ with β from Crawford (1975, 1978, 1979) we find that an error of 0.02 mag in β results in an error of 0.15 mag in $M_{\rm V}$. Fig. 1 shows that about 95 % of our program stars fall below $\sigma(\beta) = 0.02$ mag. We therefore have adopted an *overall* error of the photometrically calibrated absolute magnitudes of ±0.4 mag taking into account the most deviant Hβ measurements.

3.2. Calibration in the Hipparcos system

The Hipparcos database (Perryman et al. 1997) was searched for entries of our program stars. In total, 152 stars with a measured parallax were found. The V magnitudes from Vogt & Faúndez (1979) as well as the reddening values from the $uvby\beta$ photometry were used to calculate absolute magnitudes. We have not applied the Lutz-Kelker correction (Koen 1992). This seems justified because the relative error of the parallaxes (Fig. 2) is very small for almost all stars implying that these objects are in the vicinity of the Sun.

We have to emphasize that there is an unknown error introduced by not correcting for apparent variability (e.g. rotational light variations or binarity). The amplitudes are typically a few hundredth magnitudes but can go up to one magnitude (Paunzen & Maitzen 1998). This might effect individual stars but will not change the conclusions drawn in the next section.

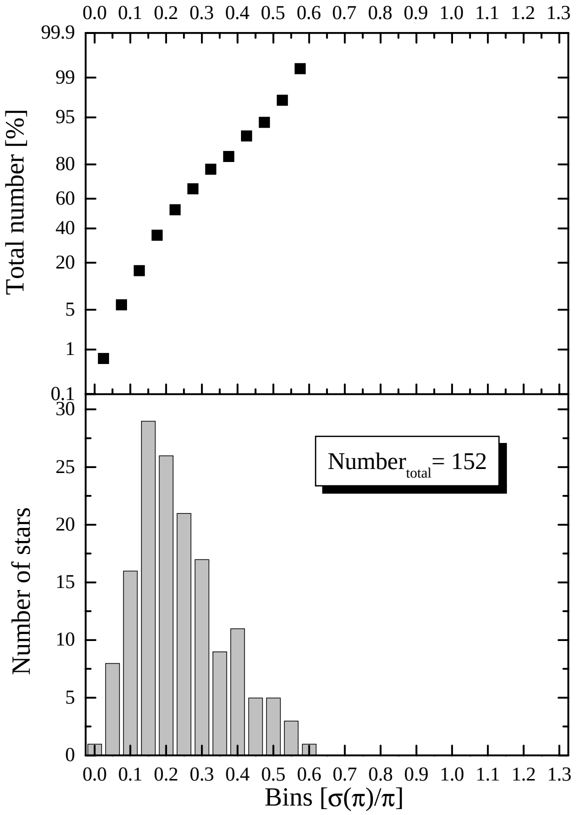

Fig. 2. The error distribution of the relative parallax errors for 152 program CP2 stars.

4. Results

Before we are able to judge whether the $uvby\beta$ and Hipparcos absolute magnitudes are consistent, a sample of apparent "normal" type stars has to be selected. There are two recent spectral surveys in the relevant domain (B - F): 1) the papers of Gray & Garrison (1987, 1989a, 1989b) and Garrison & Gray (1994) dealing with B6 to F4 type stars; 2) the extensive classification of 1700 A-type stars by Abt & Morrell (1995). From these sources we have extracted all "normal" type stars (exluding all kinds of peculiarities) with measured $uvby\beta$ colors (taken from Mermilliod et al. 1997) and Hipparcos parallaxes. In total, 1147 stars were selected. The absolute magnitudes were derived as described in Sects. 3.1 and 3.2.

As a next step we have taken into account a possible influence of the relative Hipparcos parallax errors on the absolute magnitudes. For this purpose a statistical analysis of $(\frac{\sigma(\pi)}{\pi})$ was performed. The results are shown in Figs. 2 and 3. We have divided each sample in two parts according to a 50% limit in the total number distribution of $(\frac{\sigma(\pi)}{\pi})$. The exact values are $(\frac{\sigma(\pi)}{\pi})_{50\%} = 0.22$ and $(\frac{\sigma(\pi)}{\pi})_{50\%} = 0.14$ for the CP2 and normal type stars, respectively. Both samples are very similar (beside an error tail of the latter) allowing one-to-one comparison.

Fig. 4 shows the overall result for both samples divided into three subgroups (early, intermediate and late) and two accuracies of the relative Hipparcos parallax errors.

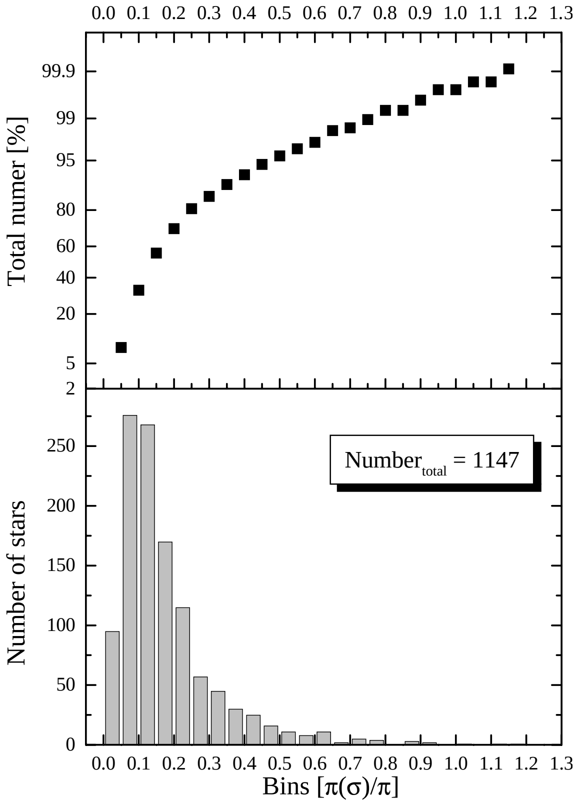

Fig. 3. The same as Fig. 2 for 1147 "normal" type stars.

It is immediately evident that the agreement for the "normal" type stars is acceptable although the scatter for the hottest stars is very large. This scatter might be introduced by the intrinsic band width of the main sequence itself (Paunzen 1999). No influence of the relative parallax errors on the derived absolute magnitudes can be detected.

The result for the peculiar stars is rather surprising. For the early type group we find that 85 % of all stars fall *above* the linear relation, on the average at a level of 0.5 magnitudes. This means that either the $M_{\rm V}$(Hip) magnitudes are too faint (= the absolute parallaxes are too small) or the $M_{\rm V}(uvby\beta)$ magnitudes are too bright. Adopting the photometric calibration we would therefore obtain distances which are 25 % too large. This situation is *not* influenced by the error of the parallaxes. It would be desirable to calibrate the absolute magnitude difference versus a suitable astrophysical parameter in order to derive correct distances for these stars.

This trend reverses as we go to the intermediate and late type groups. The most extreme deviant cases for the late type group even reach three magnitudes. While it is interesting to obtain a physical explanation for these remarkable differences, they do not bear on any substantial influence for investigations concerning the galactic distribution.

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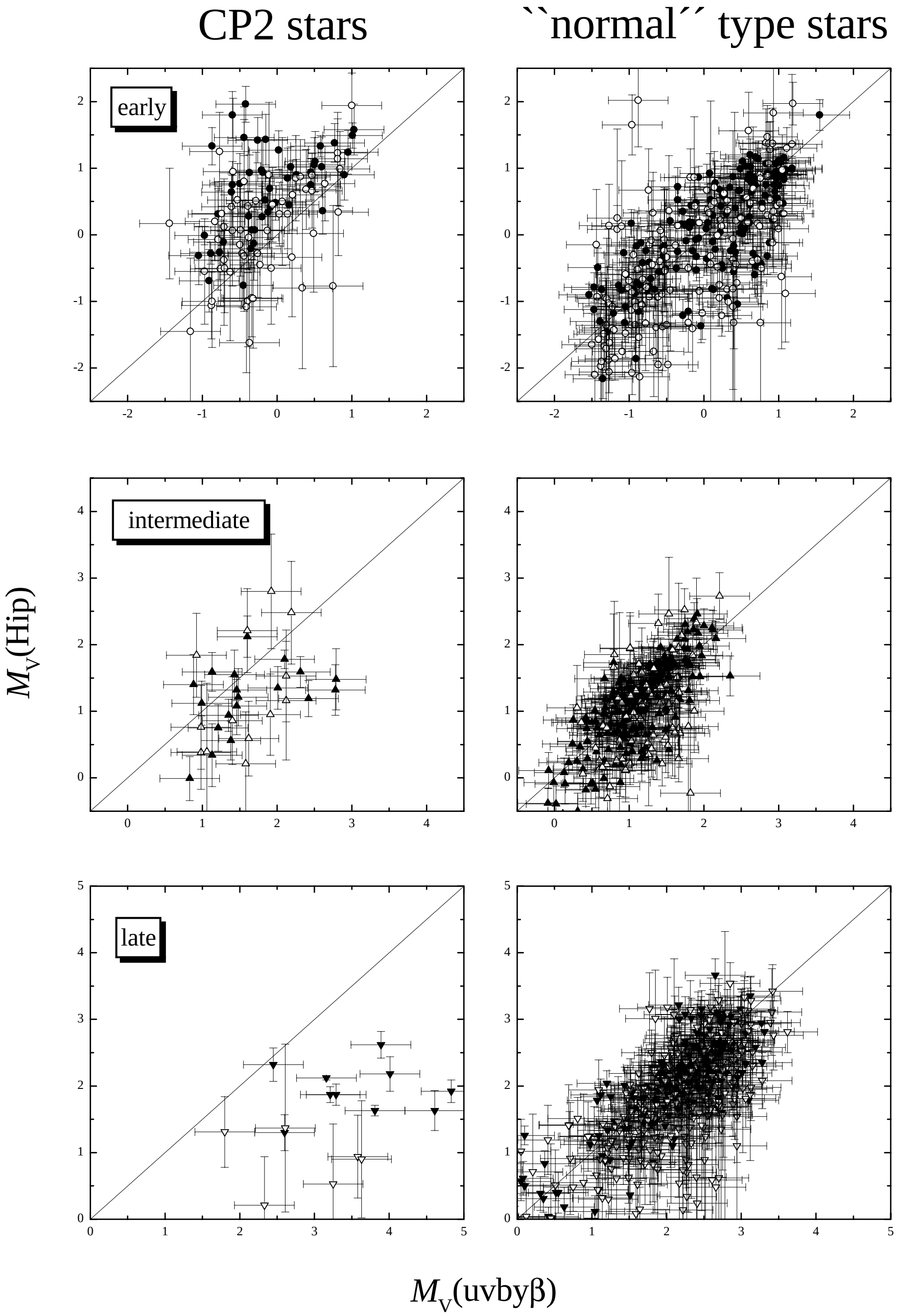

Fig. 4. M_V(Hip) versus $M_V(uvby\beta)$ for our program (left panels) and "normal" type stars (right panels) divided into three subgroups (early, intermediate and late) and two accuracies of the relative Hipparcos parallax errors (filled (small error) and open (large error) symbols).

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