

# A Comparison of ground-based Cepheid P-L Relations with HIPPARCOS Parallaxes

H. Baumgardt, C. Dettbarn, B. Fuchs, J. Rockmann, R. Wielen

*Astronomisches Rechen-Institut Heidelberg, Mönchhofstr. 12-14,  
D-69120 Heidelberg, Germany*

**Abstract.** The statistical test described by Wielen et al. (1994) is used to derive new zero-points of ground-based Cepheid period-luminosity (PL) and period-luminosity-colour (PLC) relations. Eleven relations are compared with the Hipparcos data. Our results argue for a typical increase of the adopted distance scale by about  $8\% \pm 8\%$ . Our zero-point for the PL relation of Caldwell & Laney (1991) is in agreement with that of Feast & Catchpole (1997).

## 1. Method

Most Hipparcos parallaxes of Cepheids are individually not very accurate and do not allow to determine their distances with high confidence. They can nevertheless be useful if the whole sample is used in a statistical way. For our test, photometric distances  $r_{phot}$  of all Hipparcos Cepheids are calculated according to several recent period-luminosity and period-luminosity-colour relations. These distances  $r_{phot}$  are converted into photometric parallaxes  $\pi_{Phot}$ . Figure 1 shows the differences between Hipparcos and photometric parallaxes  $\pi_{Hipp} - \pi_{Phot}$  plotted against the photometric parallaxes. A linear fit of these differences according to

$$\Delta\pi = \pi_{Hipp} - \pi_{Phot} = \pi_{0,f} + (f - 1) \pi_{Phot}$$

provides one with a correction  $\pi_{0,f}$  of the zero-points of the Hipparcos parallaxes, as well as with corrections  $f$  of the photometric distances, where  $f$  is defined as

$$r_{phot,true} = (1/f) r_{phot,used} .$$

Our method does not require to calculate individual distances from the Hipparcos parallaxes, thereby minimizing bias of the Lutz-Kelker (1972) type. In addition, we can utilize all stars, including those which have negative parallaxes in the Hipparcos Catalogue. We finally note that our method avoids to take weights according to the ratio of  $\pi^2/\sigma_\pi^2$  (as in Madore & Freedman 1998), which would introduce bias.

Caldwell & Laney (1991) determined the spread of LMC Cepheid absolute magnitudes around the center line of PL/PLC relations. They obtained a spread of  $\sigma = 0.21$  for a PL relation and  $\sigma = 0.13$  for a PLC relation. We therefore assume uncertainties of 10% (5%) for the photometric distances derived from PL (PLC) relations. This uncertainty is transformed into an error of the photometric

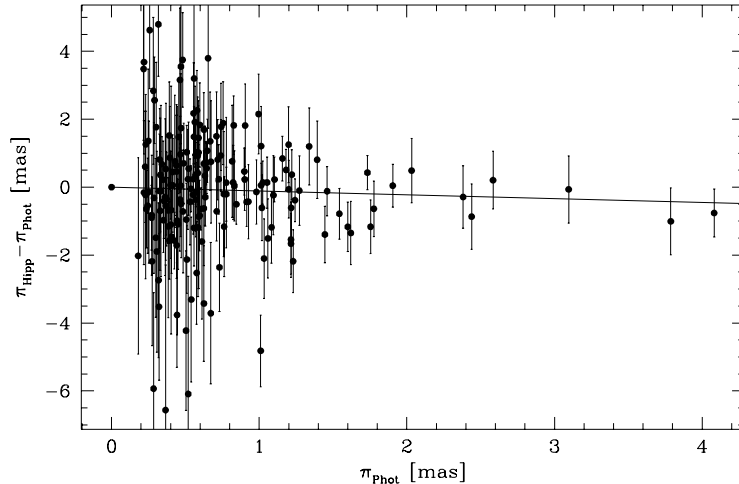


Figure 1. Comparison of photometric parallaxes  $\pi_{Phot}$  of Cepheids (based on LS94) with Hipparcos parallaxes  $\pi_{Hipp}$ . Note that the error bars represent the Hipparcos and the photometric errors (see text).

parallax and we add the square of this error to the square of the error in the Hipparcos parallax. Weights are taken according to the inverse of this sum.

## 2. Sample selection

261 stars classified as classical Cepheids were found in the Hipparcos Catalogue. From this list all known overtone and beat Cepheids were removed. We also removed stars included in the Double and Multiple Systems Annex of the Hipparcos Catalogue (C,G,V,O or X entries in field H59), since the astrometric solution derived by Hipparcos may be affected by the binary nature of these stars.

We were left with a sample of 179 Cepheids. These are considerably fewer stars than used by Feast & Catchpole (1997), resulting in larger zero-point errors. This drawback is however compensated for by the fact that our results are based on a more reliable sample of Hipparcos stars. For our stars Rockmann (1995) has compiled the necessary information from the literature to calculate their photometric distances.

## 3. Results

Table 1 lists the photometric calibrations that were compared with the Hipparcos measurements. We first allowed for a global zero-point error  $\pi_{0,f}$  in the Hipparcos parallaxes. However, our test did not reveal significant zero-point errors (we typically obtained  $\pi_{0,f} = 0.2 \pm 0.14$  for the different PL relations).

We therefore set  $\pi_{0,f}$  equal to zero. We have listed the new zero-points of the PL/PLC relations, obtained with  $\pi_{0,f} = 0$ , in column 4 of Table 1.

Author(s)	Type	Old Zero-Point	New Zero-Point	1/f
FW87	PLC	-2.27	$-2.58 \pm 0.16$	$1.15 \pm 0.08$
GBM93	PL	-1.32	$-1.30 \pm 0.17$	$0.99 \pm 0.08$
GF93	PL	-1.30	$-1.43 \pm 0.17$	$1.06 \pm 0.08$
LS94	PL	-1.197	$-1.45 \pm 0.17$	$1.13 \pm 0.08$
IT75	PLC	-2.77	$-2.67 \pm 0.16$	$0.95 \pm 0.08$
CL91A	PLC	-2.01	$-2.33 \pm 0.16$	$1.16 \pm 0.08$
HB89	PL	-1.542	$-1.26 \pm 0.17$	$0.88 \pm 0.08$
MF91	PL	-1.39	$-1.54 \pm 0.17$	$1.07 \pm 0.08$
B87	PL	-1.24	$-1.52 \pm 0.17$	$1.14 \pm 0.08$
CL91B	PL	-1.31	$-1.50 \pm 0.17$	$1.09 \pm 0.08$
GFG98	PL	-1.294	$-1.54 \pm 0.17$	$1.12 \pm 0.08$

Table1: Photometric calibrations compared with the Hipparcos parallaxes. The new zero-points and their errors can be found in column 4. The abbreviations in column 1 have the following meaning: FW87: Feast & Walker (1987); GBM93: Gieren, Barnes & Moffet (1993); GF93: Gieren & Fouqué (1993); LS94: Laney & Stobie (1994); IT75: Iben & Tuggle (1975); CL91A: Caldwell & Laney (1991); HB89: Hindsley & Bell (1989); MF91: Madore & Freedman (1991); B87: Berdnikov (1987); CL91B: Caldwell & Laney (1991); GFG98: Gieren, Fouqué & Gómez (1998)

The Hipparcos parallaxes indicate that the zero-points of most Cepheid PL/PLC relations have to be shifted by 0.0 - 0.3 mag to brighter magnitudes, indicating that the previous distance scales were too short by about 10 %. For most relations, the shifts are however of the same order as the errors.

We obtain a new zero-point of  $\rho = -1.50 \pm 0.17$  for the PL relation of Caldwell & Laney (1991B). This agrees very well with the value  $\rho = -1.43 \pm 0.10$ , that Feast & Catchpole (1997) determined as the new zero-point of this PL relation. Values between  $\rho = -1.52 \pm 0.13$  and  $\rho = -1.45 \pm 0.13$ , depending on the adopted reddening, were also derived by Feast et al. (1998). If we compare our zero-point with the apparent zero-point of the LMC Cepheids from Caldwell & Laney (1991) ( $\rho = 17.23$ ), and add a metallicity-correction of +0.042 (Laney & Stobie 1994) to the difference, we obtain a distance modulus of  $18.77 \pm 0.17$  to the LMC.

The PL relation of Madore & Freedman (1991) is of particular interest since the HST Key Project on the Extragalactic Distance Scale uses this relation to determine the distances to other galaxies containing Cepheids. For their relation, we derive a distance scale correction of  $1/f = 1.07 \pm 0.08$ , i.e. an increase of all distances and a corresponding decrease of the Hubble Constant by  $7\% \pm 8\%$ .

Monte-Carlo simulations were performed in order to check the influence of Malmquist bias on our results. We assumed a uniform spatial distribution of the Cepheids and a spread of their absolute magnitudes of 0.2 mag around the

center line. The distribution of the Cepheids over periods and the completeness function of our sample were varied. The resulting bias in our zero-point was in most cases below 0.01 mag and never exceeded 0.015 mag. We therefore conclude that Malmquist bias plays only a minor rôle and have neglected it in our zero-point determination.

We finally note that our results do not change significantly if the nearby Cepheids are omitted from our analysis. For example, restricting our analysis to Cepheids with photometric distances above 500 pc would change the zero-point of the PL relation of Laney & Stobie (1994) by only 0.04 mag to  $-1.41 \pm 0.21$ . Shifts of the same order are also obtained for the other PL/PLC relations. We conclude that our changes for the zero-points are not due to a few nearby (and perhaps peculiar) Cepheids.

**Acknowledgments.** We are grateful to Frédéric Arenou for useful discussions. HB is supported by the Sonderforschungsbereich 328 Entwicklung von Galaxien.

## References

- Berdnikov, L.N. 1987, *Perem. Zvezdy* 22(4), 505 (B87)
- Caldwell, J.A.R., Laney, C.D. 1991, in: *IAU Symp. 148, The Magellanic Clouds*, eds. R. Haynes, D. Milne, Kluwer, Dordrecht, p. 249 (CL91AB)
- Feast, M.W., Catchpole, R.M. 1997, *MNRAS*, 286, L1
- Feast, M.W., Pont, F., Whitelock, P. 1998, *MNRAS*, 298, L43
- Feast, M.W., Walker, A.R. 1987, *ARA&A*, 25, 345 (FW87)
- Gieren, W.P., Barnes, T.G., Moffet, T.J. 1993, *ApJ*, 418,135 (GBM93)
- Gieren, W.P., Fouqué, P. 1993, *AJ*, 106, 734 (GF93)
- Gieren, W.P., Fouqué, P., Gómez, M. 1998, *ApJ*, 496, 17 (GFG98)
- Hindsley, R.B., Bell R.A. 1989, *ApJ*, 341, 1004 (HB89)
- Iben, I., Tuggle, R.S. 1975, *ApJ*, 197, 39 (IT75)
- Laney, C.D., Stobie, R.S. 1994, *MNRAS*, 266, 441 (LS94)
- Lutz, T.E., Kelker, D.H. 1973, *PASP*, 85, 573
- Madore, B.F., Freedman, W.L. 1991, *PASP*, 103, 933 (MF91)
- Madore, B.F., Freedman, W.L. 1998, *ApJ*, 492, 110
- Rockmann, J. 1995, *Photometric Distances of Cepheids and RR Lyrae-Stars*, Diploma Thesis, Fac. of Physics and Astronomy, Univ. of Heidelberg
- Wielen, R., Bernstein, H.-H., Dettbarn, C., Hering, R., Jährling, R., Lenhardt, H., Walter, H.G. 1994, in: *Galactic and Solar System Optical Astrometry*, eds. L.V. Morrison, G.F. Gilmore, Cambridge University Press, p. 74