The Impact of Large-Scale Surveys on Pulsating Star Research
ASP Conference Series, Vol. 2??, 2000
L.Zsabados & D.W. Kurtz, eds.

Numerical simulations of the Cepheid population in the HIPPARCOS catalogue

M.A.T. Groenewegen

Max-Planck Institut für Astrophysik, Karl-Schwarzschild-Straße 1, D-85740 Garching, Germany

Abstract. The population of Cepheids in the HIPPARCOS catlog is retrieved. Some observational properties of the sample are modelled using a Monte Carlo code. This code is then used to verify that the bias introduced by the method of "reduced parallax" in deriving the zero point of the PL-relation is of order 0.01 mag, confirming earlier results. This bias is likely due to Malmquist bias.

1. Introduction

Cepheids are important standard candles in determining the extra-galactic distance scale. The results of the HIPPARCOS mission allow, in principle, a calibration of the period-luminosity relation based on the available parallaxes. Feast & Catchpole (1997; hereafter FC) did that for the $M_{\rm V} - \log P$-relation based on pre-released HIPPARCOS data of 223 Cepheids available to them at that time. Now that the full catalogue has become available it is timely to analyse the final sample of Cepheids in it.

2. Sample selection

The number and some properties of the Cepheid population in the HIPPARCOS catalogue were discussed by Groenewegen (1999; hereafter G99). To summarise: by cross-correlating the general HIPPARCOS database, the HIPPARCOS "resolved variable catalogue" and the electronic database of Fernie et al. (1995), a total of 280 Cepheids was identified. Then, 9 Type II Cepheids, 1 factual RR Lyrae variable, 1 CH-like carbon-rich Cepheid, 10 double-mode Cepheids, 7 Cepheids with an unreliable HIPPARCOS solution and 4 Cepheids with no or unreliable optical photometry were excluded. Furthermore, 12 stars are excluded where the photometry may be contaminated by a binary companion. This leaves 236 stars, of which 32 are classified as overtone pulsators in the literature. For this sample, G99 calculated intensity-mean (and some magnitude-mean) I and $V-I$ magnitudes for 191 stars, and provided JHK intensity-mean magnitudes on the Carter system for 63 stars.

3. Properties of the HIPPARCOS Cepheids, and numerical simulations

The observed distributions of the fundamental period, the V magnitude, reddening free $(B-V)_0$, colour excess, and absolute distance to the Galactic plane are plotted in Fig. 1 for the 236 Cepheids (the dotted lines). For the overtones, the fundamental period was calculated following FC. $(B-V)_0$ follows from a Period-Colour-relation (Laney & Stobie 1994, the one also used by FC), and $E(B-V)$ from the observed value of $(B-V)$ minus $(B-V)_0$. The absolute distance to the Galactic plane is calculated from the galactic latitude combined with the reddening free V-magnitude and a photometric distance based on a $M_{\rm V} - \log P$-relation with slope -2.81 and zero point $\rho = -1.43$.

A numerical code was devised to simulate the distributions described above. The input period distribution is assumed ad hoc to be Gaussian in $\log P$ with mean $X_{\rm P}$, and spread $X_{\sigma \rm P}$. Based on the observed properties of the sample only $\log P$ values between 0.43 and 1.66 are allowed. The values of $X_{\rm P}$ and $X_{\sigma \rm P}$ directly influence the resulting distribution and so are easily determined. It is found that values of $X_{\rm P}$ between 0.65 and 0.75 and of $X_{\sigma \rm P}$ between 0.2 and 0.25 give acceptable fits. The galactic distribution of Cepheids is assumed to be an exponential disk with a scale height H. The value of H is directly determined by the distribution of the number of stars as a function of z, and is found to be between 60 and 80 pc. This is consistent with the scale height of a relative massive population of stars, as the Cepheids are.

The value of $M_{\rm V}$ and $(B-V)_0$ are correlated in the sense that brighter Cepheids are also bluer for a given period. Contrary to other studies we do not assume a Gaussian spread around the (assumed) $M_{\rm V} - \log P$ and $(B-V)_0 - \log P$ relations, but instead a 'box' like distribution which is more physical because of the finite width of the instability strip. The full width of the instability strip in $M_{\rm V}$ is taken to be 0.84 magnitude, and that of the $(B-V)_0$ relation to be 0.3 mag. (Gieren, Fouqué, & Gómez 1998; Tanvir 1999; Laney & Stobie 1994). The reddening is calculated from: $A_{\rm V} = 0.09 \, \frac{1-\exp(-0.0111 \; d \; \sin b)}{\sin b}$ where b is the absolute value of the galactic latitude, and d the distance in pc.

The simulated 'observed' visual magnitude is calculated from $V = M_{\rm V} + 5 \; \log d - 5 + A_{\rm V}$. Then a term is added simulating the uncertainty in the observed V, which is described by a Gaussian distribution with a dispersion of 0.005 mag. HIPPARCOS was complete only down to about $V = 7$ and a 'observing probability function' was used to determine if a star was 'observed' or not.

The simulation is continued until 25 sets of 236 stars fulfill all criteria. A similar procedure was followed in I and K. The simulated distributions (in V) are depicted in Fig. 1 using the solid lines (normalised to the observed number of 236 stars). Typical parameters $X_{\rm P} = 0.70$, $X_{\sigma \rm P} = 0.25$, and $H = 70$ pc have been used. The overall fit is good.

This numerical code for the quoted parameters provides a tool with which synthetic samples of Cepheids can be generated that obey the observed distributions. It now will be discussed if the zero point Period-Luminosity (PL)-relation derived from the method of "reduced parallax" is subject to bias or not. This method was used by FC, and basically entails calculation of the weighted mean of $10^{0.2\rho} = \pi \times 0.01 \; 10^{0.2(<V_0> - \delta \; \log \; P)}$, with the error in this quantity following from the propagation of errors (see FC for details). Recently, Koen & Laney

(1998) argued on analytical grounds that this method is not subject to Lutz-Kelker type bias (Lutz & Kelker 1973).

To this end a description is used to simulate the error in the parallax and calculate the 'observed' parallax (details will be given in a forthcoming paper, Groenewegen & Oudmaijer, in preparation). The simulation is continued until 100 sets of 236, 191, or 63 stars fulfill all criteria, depending whether the simulation relates to V, I or K. This was done with the parameter set that best described the observed distributions, as discussed above, that is with $X_{\rm P} = 0.70$, $X_{\sigma {\rm P}} = 0.25$, and $H = 70$ pc.

For every set of 236, 191, or 63 stars we apply the "reduced parallax" method outlined in FC, and derive the zero point of the PL-relation. From the distribution of the zero points of the 100 sets, we determine the mean, and the dispersion. The results are given in Tab. 1, where we list the zero point assumed in the numerical simulation, the zero point retrieved, and to which solution the simulation refers to (in the K-band no meaningfull volume complete sample could be constructed). The results indicate that the zero point of the volume complete sample is dimmer than for the whole sample, as expected from Malmquist bias. In any case, the biases are very small, of order 0.01 mag, or less, similar to the results found by Lanoix, Paturel, & Garnier (1999) and Pont (1999). Second, we confirm the result by Pont (1999) that the errors derived are larger compared to the outcome of the "reduced parallax" method (± 0.10 mag. quoted in FC).

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Table 1. Zero points from numerical simulations

Input	Result	Band	Remarks
-1.43	-1.429 ± 0.124	V	all stars
-1.43	-1.420 ± 0.140	V	volume complete sample
-1.90	-1.914 ± 0.143	I	all stars
-1.90	-1.906 ± 0.205	I	volume complete sample
-2.60	-2.610 ± 0.261	K	all stars

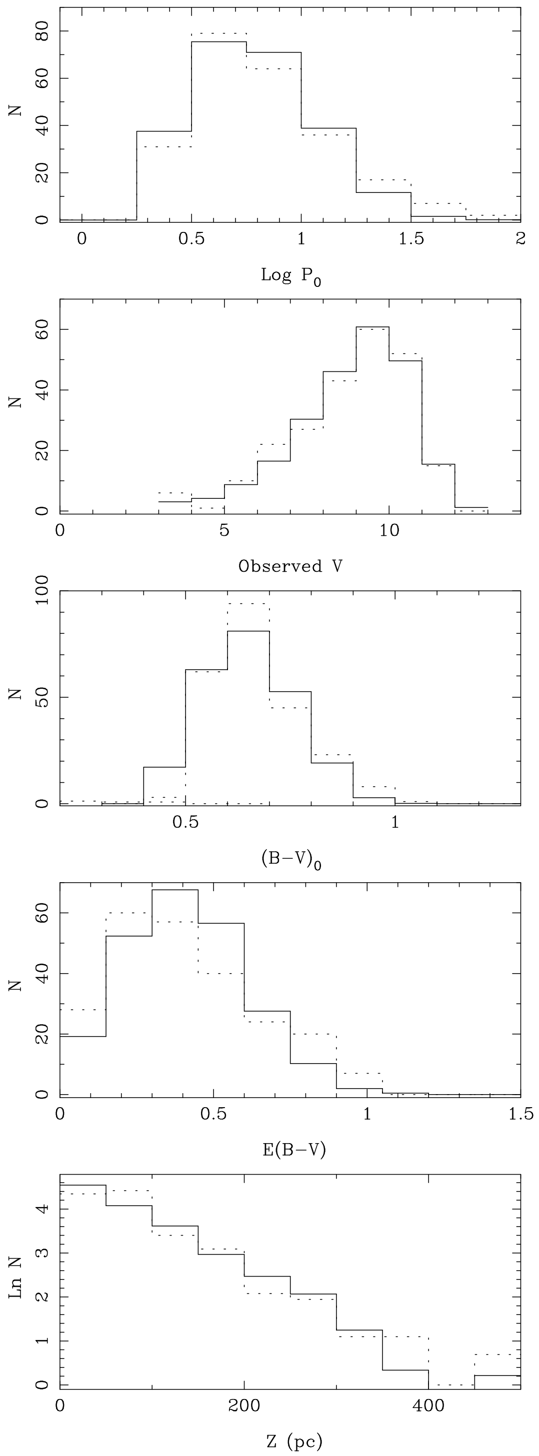

Figure 1. Observed (dotted line) and numerical simulation (solid line) of the 236 Cepheids in HIPPARCOS. Harmonic periods have been converted to the fundamental period.