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Calibrating the P-Factor in the IR Baade-Wesselink Method for Classical and Dwarf Cepheids

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Abstract. The Baade-Wesselink method using VJK photometry was shown by Laney and Stobie (1995) to yield apparently precise results, free of obvious systematics with phase, surface gravity and microturbulence. Here we extend the empirical calibration of the p-factor [1] to a maximal sample of galactic classical Cepheids. HADS or 'dwarf Cepheids' have been shown to follow the same PL relation (at least for high-metallicity objects), and a HADS sample is therefore added in order to extend the period range and examine the variation of the p-factor with period. The derived pulsation parallaxes give a slope of 0.07±0.02, in good agreement with the calculations of Nardetto et al. [2]. Applying this period vs. p-factor relation to 68 galactic pulsation parallaxes gives a slope for the galactic PL relation in good agreement with the LMC PL relation.

Keywords: stars, distances, parallaxes, radii
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INTRODUCTION AND METHOD

It has always been much easier to estimate the internal errors in Baade-Wesselink radii and pulsation parallaxes than to get a grip on the systematic errors. Laney and Stobie (1995) demonstrated that phase-dependent residuals and the effects of surface gravity and microturbulence appeared to be negligible if BW radii were calculated using the K magnitude and either the V-K or J-K color, using the maximum likelihood method of Balona (1977). This IR BW method is the one used in this paper.

But it has remained true that 'the projection factor . . . is the most important bias of the IBW method for Cepheid distance determination.' (Nardetto et al. 2006). Sharply different approaches have been taken by different authors with respect to assumed zero point and variation with period, usually based on theoretical model atmospheres.

With the availability of higher-quality parallaxes, notably from the HST, it is possible for the first time to derive empirical values for the projection factors used in calculating BW pulsation parallaxes. For the present poster we have used HST FGS parallaxes [5] for 8 of the 10 classical Cepheids for which such parallaxes are available (omitting FF Aql and RT Aur, which lack complete IR photometry of adequate quality). For SU Cas, the Hipparcos parallax given in [6] was corrected to the HST system by using the parallaxes of Cepheids in common. This turned out to be almost exactly the same as the original (1997) Hipparcos parallax for that star. A discussion of systematic effects in Hipparcos Cepheid parallaxes will appear in a later paper.

For RS Pup, the K-band PLC relation in [6] was used to calculate a geometrically calibrated parallax (superscript vL in Table 1). Also tabulated there (superscript K) is the result if we accept the geometric parallax from the results of Kervella et al. [7].

For the dwarf Cepheids (HADS), the PL-[Fe/H] relation of McNamara et al. [8] was used to calculate geometrically calibrated parallaxes.

The radii were calculated using an initial assumed p-factor of 1.27 for classical Cepheids and 1.36 for HADS, and the pulsation parallax was derived using the mean of the (K,V-K) and (K,J-K) radii, converted to an absolute magnitude using the K-band surface brightnesses in Hindsley and Bell [9] for classical Cepheids, and the Kurucz JHK color grids [10] for HADS. These give equivalent results, as might be expected given the weak dependence of K surface brightness on any factors likely to be considered. The ratio of the pulsation parallax to the geometrical or geometrically calibrated parallax then yielded a projection factor (p) for each star (Figure and Table 1).

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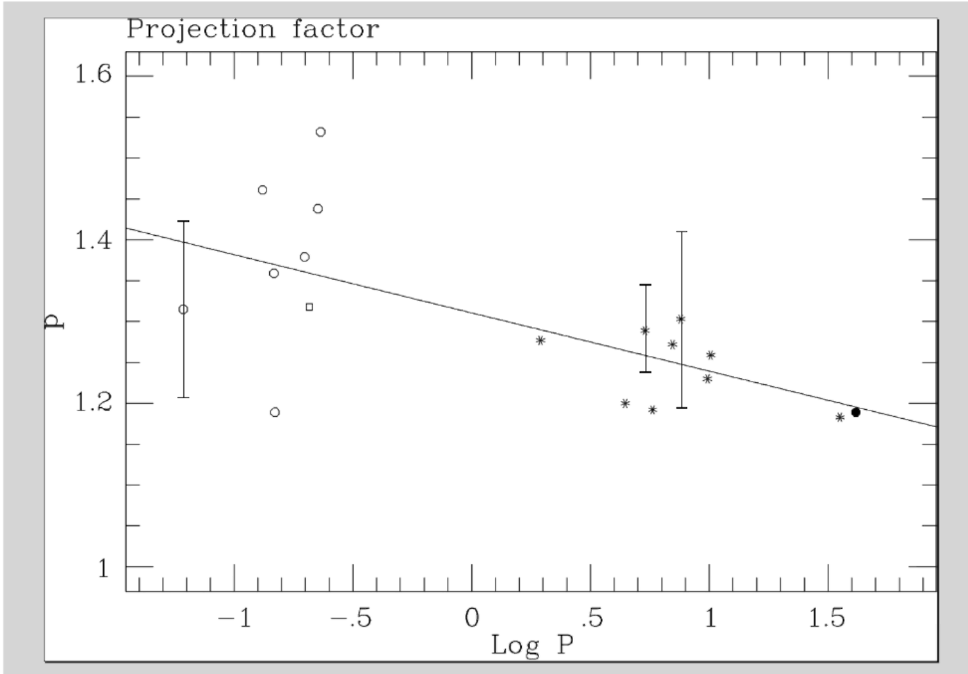

FIGURE 1. Projection factor (p) vs. log period. AD CMi is represented by an open square (second overtone pulsation), while the other HADS are represented by open circles. RS Pup is represented by a filled circle, while the other classical Cepheids are represented by asterisks. The RS Pup distance of Kervella et al. [7] gives p=1.35 (not shown), which would be rather discrepant. A few sample error bars are shown (for Delta Cep, W Sgr and CY Aqr). A simple least squares fit to the points is represented by the solid line.

RESULTS

A simple least squares fit to the data in Table 1 gives:

$$p = 1.311 \pm 0.019 - 0.071 \pm 0.020 \cdot \text{Log } P \quad (1)$$
$$\sigma = 0.079$$

in good agreement with the theoretical value of Nardetto et al. [1]:

$$p = 1.366 \pm 0.037 - 0.075 \pm 0.031 \cdot \text{Log } P$$

For 60 galactic Cepheids and 8 HADS with available radii and pulsation parallaxes calculated as in this paper, using the p-factor in equation (1) yields a PL relation with a slope of 2.80±0.04. This is a shallower slope than previously found by Laney et al. [11] using a constant value of p.

For comparison, we calculated the slope of the LMC Cepheid PL relation using a combination of the LMC data sample of Caldwell and Laney [12] with data from OGLE so as to have reasonably comprehensive samples at both long and short periods. Allowing for a slight zero point shift between the two samples, mostly due to larger reddenings in the OGLE sample, we derive an LMC PL slope for classical Cepheids of 2.76±0.03 – there is no statistically significant difference in PL slope between the Milky Way and LMC samples, and we find no break in slope at a period of 10 days.

As an aside, we note that the RS Pup distance of Feast [13] is in better agreement with our p-factor relation than the distance derived by Kervella et al. [7].

TABLE 1. Classical Cepheid Results

Star	Period	Pulsation parallax	Geometric parallax	p-factor
Delta Cep	5.366	3.72±0.09	3.66±0.15	1.289±0.061
Beta Dor	9.843	3.04±0.07	3.14±0.16	1.230±0.069
X Sgr	7.013	3.00±0.09	3.00±0.18	1.272±0.086
Zeta Gem	10.150	2.76±0.07	2.78±0.18	1.259±0.088
W Sgr	7.595	2.34±0.06	2.28±0.20	1.303±0.119
SU Cas	1.949	2.31±0.16	2.30±0.34	1.277±0.208
Y Sgr	5.773	2.00±0.06	2.13±0.29	1.192±.166
l Car	35.543	1.87±0.04	2.01±0.20	1.183±0.120
T Vul	4.435	1.80±0.05	1.90±0.23	1.200±0.150
RS Pup^{vL}	41.404	0.53±0.01	0.57±0.03	1.189±0.065
RS Pup^{K}	41.404	0.53±0.01	0.50±0.01	1.351±0.033
HADS results				
Star	**Log P**	**Pulsation parallax**	**Geometric parallax**	**p-factor**
VZ Cnc	-0.749	4.23±0.10	4.37±0.35	1.32±0.11
RS Gru	-0.833	4.09±0.13	4.09±0.33	1.36±0.12
V4425 Sgr	-0.880	2.32±0.08	2.16±0.17	1.46±0.15
RY Lep	-0.648	3.16±0.27	2.99±0.24	1.44±0.17
CY Aqr	-1.214	2.25±0.11	2.33±0.19	1.32±0.12
BS Aqr	-0.704	1.89±0.02	1.86±0.15	1.38±0.11
AD CMi^{++}	-0.684	1.82±0.05	1.88±0.15	1.32±0.11
DY Her	-0.828	1.30±0.08	1.49±0.12	1.19±.12

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