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COMMUNICATIONS FROM THE OBSERVATORY AT LEIDEN

ON THE LUMINOSITIES OF THE NEAREST CEPHEIDS

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The zero-point of the period-luminosity relation for Cepheids (periods > 1.5 days) is derived from newly determined proper motions of 18 stars. A correction of − 1.4 magnitudes ± 0.3 (p.e.) is found from the parallactic motions and confirmed by analysis of the τ-components. The uncertainty in the result is mainly due to the limited number of stars with accurate proper motions and to the lack of data on interstellar reddening.

Since SHAPLEY's publication of the period-luminosity law in his monograph *Star Clusters*, chapter X, 1930, the zero-point used by this author has been usually adopted in statistical investigations. It had been the subject of discussions previous to 1930—for an account of which we refer to the monograph—but the zero-point adopted by SHAPLEY was essentially the same as that originally derived by HERTZSPRUNG in 1913 [1]) from the proper motions of 13 Cepheids in B. Boss' *Preliminary General Catalogue*. In later years, discussions of the zero-point were published, a.o. by R. E. WILSON [2]) and by H. MINEUR [3]) and his associate H. BERTHOD-ZABOROWSKI [4]). WILSON, in 1938, concluded that no correction was needed; the French authors, in 1944 and 1946, derived a correction of − 0.73 magnitudes. WILSON's result was based on the mean parallaxes derived from proper motions of 85 Cepheids. MINEUR and Mrs BERTHOD used a method based on the mean parallaxes of Cepheids and RR Lyrae variables, and on the assumption that the mean distance of the Cepheids from the galactic plane is independent of the distance from the sun, a principle applied earlier by BOTTLINGER and SCHNELLER [5]) in an investigation of interstellar absorption. Neither WILSON, nor MINEUR and Mrs BERTHOD realized the fundamental importance of distinguishing between the Cepheids with periods longer than 1.5 days and the RR Lyrae variables. (MINEUR's investigation, when carried through separately for the Cepheids, gives a correction of − 1.3 magnitudes.) The necessity of this discrimination has been pointed out most convincingly by BAADE's research on the Andromeda nebula [6]), leading to a correction of about − 1.4 magnitudes for the Cepheids. It was strongly supported by research on the Magellanic Clouds, particularly by THACKERAY and WESSELINK's work on the cluster-type variables in globular clusters connected with the Clouds [7]).

Mean parallaxes from υ-components.

A new determination of the zero-point of the period-luminosity curve for the Cepheids in the neighbourhood of the sun is described below. It is based on newly determined proper motions of 18 stars for which the proper motions can be most accurately computed at present; it results in the same correction to the zero-point as proposed by BAADE. The basis for the selection of the 18 stars was the list of 54 Cepheids brighter than visual magnitude 8.0 in maximum, for which all meridian observations available at present were collected and used to improve the GC proper motions. Most of these stars lack recent observations; it is mainly for

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1) *A. N.* **196**, 201, 1913.

2) *Ap. J.* **89**, 218, 1939; *Mt Wilson Contr.* No 604.

3) *Ann. d'Astroph.* **7**, 160, 1944.

4) *Ann. d'Astroph.* **9**, 123, 1946.

5) *Zs. f. Ap.* **1**, 339, 1930.

6) Communicated at the meeting of commission 28 of the I.A.U. at Rome, 1952.

7) *Nature* **171**, 693, 1953, and also reported at the Rome meeting.

CONTENTS

the brightest ones that places are found in the modern catalogues. Consequently, the probable errors of the proper motions increase with the apparent magnitudes of the stars and, hence, also with the distances.

Nearly all of these 18 stars are within 600 ps in the new distance scale. Little would have been gained by the addition of more objects. If, for instance, we take the group of 20 stars next in accuracy of proper motions among the list of 54 objects referred to above, we find these to have a mean parallax about half as large as that for the 18 stars. The probable errors of the proper motions are on the average 2.5 times larger than in the first group, and have become much larger than the peculiar motions. As a result, only one fourth of the weight of the determination of the secular parallax would be added by inclusion of these 20 stars. This advantage is, moreover, compensated by the increased uncertainty of the interstellar absorption and by the somewhat larger influence of possible errors in the fundamental system of proper motions. Only continued meridian observations of all Cepheids brighter than, say, 8th visual magnitude in maximum, resulting in proper motions with probable errors of $\pm''.002$ or less, combined with accurate colour measures, will provide the much wanted extension of the observational basis for the determination of the zero-point.

The new proper motions of the 18 stars are given in Table 1. They are in the system of N30 with precessional corrections applied [1]). The average probable error is $\pm 0''.0020$.

υ- and τ-components, in the direction to the antapex and perpendicular to it, were computed after differential galactic rotation had been eliminated. For the co-ordinates of the apex we adopted the standard elements R.A. 270°, Decl. +30°. These values are somewhat lower, especially in declination, than those derived by E. RAIMOND in the following article in this *Bulletin*, but it is doubtful whether the apex for the Cepheids really differs much from that for early B stars and interstellar matter. These objects show much similarity with the Cepheids with regard to distribution in space and average motions, and the standard elements are supposed to be a sufficient approximation of the average results for the three kinds of objects. The υ- and τ-components are shown in the table.

TABLE 1

Proper motions of δ Cephei variables. Unit is 0″.0001 per year.

Name	GC	median m_{pg}	Period	$\mu_\alpha \cos\delta$	p.e.	μ_δ	p.e.	υ	τ
α UMi	2243	2.6	3.97	+595 ±	4	− 74 ±	5	+557	−102
SU Cas	3403	6.5	1.95	+ 49	16	− 68	16	+ 99	+ 14
SZ Tau	5621	7.3	3.15	− 36	38	− 64	36	+ 23	+ 67
β Dor	6944	4.9	9.84	+ 41	36	+ 56	24	+ 17	+ 36
RT Aur	8371	6.0	3.73	+ 37	19	−126	18	+104	− 35
W Gem	8560	7.7	7.91	+ 96	43	− 65	41	+ 39	− 98
ζ Gem	9313	4.7	10.15	− 64	6	− 21	6	+ 23	+ 63
l Car	13462	5.0	35.53	− 83	26	+ 81	23	+ 55	+ 35
X Sgr	24135	5.4	7.01	+ 13	11	− 87	12	+105	− 14
W Sgr	24605	5.5	7.59	+104	19	0	17	+ 17	− 85
Y Sgr	25038	6.5	5.77	+ 91	24	−133	24	+155	− 73
U Sgr	25287	7.8	6.74	− 9	24	−104	24	+116	+ 28
FF Aql	26052	6.0	4.47	− 33	22	− 79	22	+ 26	+ 54
η Aql	27517	5.0	7.18	+106	9	− 87	9	+133	− 50
S Sge	27601	6.3	8.38	+ 23	18	− 57	16	+ 53	+ 1
T Vul	29089	6.3	4.44	+ 12	25	+ 5	23	+ 38	+ 32
DT Cyg	29502	6.5	2.50	− 40	24	+ 13	24	− 9	− 49
δ Cep	31421	4.7	5.37	+122	7	− 4	7	+167	− 8

The present data on proper motions are too limited to allow more than a check on the zero-point of the period-luminosity curve; for its shape one has to rely on the information from the Magellanic Clouds, as given in SHAPLEY's monograph, or on some analytical expression representing this curve. JOY [2]) has published distances for the Cepheids, computed with a photographic absorption of 0.85 magnitudes per

[1]) H. R. MORGAN and J. H. OORT, *B.A.N.* No 431, 1951.
[2]) *Ap. J.* **89**, 356, 1939; *Mt Wilson Contr.* No 607.

1000 ps in a uniform stratum of 400 ps thickness, using the period-luminosity curve given by SHAPLEY. PARENAGO [1]) has given distances based mainly on FLORYA's estimates of the absorption as a function of distance and direction [2]); the adopted absorptions are considerably higher than those assumed by JOY; on the average for these 18 stars they correspond to 3.0 magnitudes per 1000 ps, photographic. PARENAGO used the analytical form of the period-luminosity relation given by KUKARKIN [3]); apart from a slightly different shape of this curve, there is a systematic difference in these absolute magnitudes as compared to those used by JOY. For the 18 stars, PARENAGO's values are on the average -0.18 magnitudes brighter. The two sets of distances given by JOY and by PARENAGO may well be considered as extremes as regards the assumed absorption, and the truth probably lies in between. For the 18 Cepheids studied here the average distance according to PARENAGO's list is 0.88 times that according to JOY's.

The correction to be applied to the zero-point of the absolute magnitudes changes all these distances with a certain factor, and involves only small changes in the proportion of the distances. We have, therefore, first adopted the scale of the parallaxes, p, as given by each of the two authors mentioned, and reduced with the aid of this all υ-components in the proportion to the mean parallax $\bar{p}/p$ ($\bar{p}$ also in the 'old' system). These reduced υ-components were used for the determination of the secular parallax $V\bar{p}_{new}$, V being the solar motion in a.u. per year with respect to the Cepheids and $\bar{p}_{new}$ the true mean parallax. The ratio between $\bar{p}$ and $\bar{p}_{new}$ is the factor by which the original distances have to be multiplied. Weights were assigned proportional to $\sin^2\lambda$, λ being the angular distance from the apex. The reduction of the probable errors of the proper motions as a consequence of the reduction to the mean parallax is relatively unimportant in determining the weights, as the deviations from exact solar motion reflex are mainly due to the peculiar motions of the stars.

The results of these computations are in Table 2.

TABLE 2

	Distance scale taken from:	
	JOY (zero-point SHAPLEY)	PARENAGO (zero-point KUKARKIN)
'Old' mean parallax, $\bar{p}$	0″.00468	0″.00495
Newly derived secular parallax	0″.0136 ± 16 (p.e.)	0″.0120 ± 14 (p.e.)
'New' mean parallax, $\bar{p}_{new}$	0″.00307	0″.00272
$5 \log (\bar{p}_{new}/\bar{p})$	$-$ 0^m.91 ± .24	$-$ 1^m.30 ± 26
Mean absorption adopted in derivation of 'old' distances	0^m.25	0^m.74
Correction to zero-point with extrapolated absorptions	$-$ 1^m.04	$-$ 1^m.91
Correction to zero-point with adopted absorption of 0.7 magn.	$-$ 1^m.35	$-$ 1^m.26

For V we take 4.43 a.u. per year (21.0 km/sec). This is an average of the velocities found for the Cepheids, the O and B stars, and the interstellar calcium (see Table 1 of E. RAIMOND's paper). A change of -1.0 km/sec corresponds with a change of $+0.1$ magnitude in the zero-point correction. It seems improbable that the adopted velocity is in error by more than 2 km/sec. The corrections to the zero-point which correspond to the ratio between the new distances and those in the lists of JOY or PARENAGO are given in the 4th line of the table. This is not, of course, the final correction, as the absorption to be used should fit the new distances. The average photographic absorption which has actually been adopted for the 18 stars by JOY and by PARENAGO is given in the 5th line. An increase of these values in the same ratio as the distances would lead to total absorptions of 0.38 and 1.35 magnitudes, respectively, and to the corrections

[1]) *Publ. Sternberg State Astr. Inst.* XVI, 71, 1949.
[2]) *Publ. Sternberg State Astr. Inst.* XVI, 4, 1949.
[3]) *A. J. U.S.S.R.* **14**, 125, 1937.

to the adopted zero-points given in the 6th line. In comparing these values it should be noticed that the value −1.91 in the case of PARENAGO's distances becomes −2.09 when referred to SHAPLEY's zero-point adopted by JOY.

As was mentioned above, the amounts of absorption adopted by JOY and by PARENAGO are extremes, and therefore the true correction to the zero-point probably lies between these results. The true amount of absorption can be obtained only from accurate measures of the interstellar reddening. For 9 of the 18 stars such measures have been published by EGGEN [1]). From his Table 11 we find the average photographic absorption for these stars to be 0.62 magnitudes. As the normal colours used by EGGEN may be somewhat too red (EGGEN finds zero reddening for about a quarter of the stars in his list, notwithstanding the considerable distances involved), we shall use the round value of 0.7 magnitudes. The values adopted by JOY and by PARENAGO for these 9 stars are on the average the same as those for the 18 stars considered above, so that the amount of 0.7 magnitude according to EGGEN can immediately be compared with the extrapolated values of 0.38 and 1.35 magnitudes in the scales of JOY and PARENAGO. As was to be expected, it lies near the average of the two.

We shall, for the further discussion, adopt the value of 0.7 magnitudes total photographic absorption for the 18 stars, although it may well be in error by 0.3 magnitudes. We then get the corrections to the zero-point −1.35 ('JOY') and −1.26 ('PARENAGO'). Taking into account the reduction of the latter to SHAPLEY's zero-point we get −1.44. The two results agree well enough, and we shall adopt as the final correction to the zero-point used by SHAPLEY:

$$-1.4 \text{ magnitudes} \pm 0.3 \text{ (p.e.)}.$$

The probable error is estimated as follows: due to peculiar motions ±0.2; due to uncertainty in the adopted absorption ±0.2; due to uncertainty in the solar motion ±0.1 magnitude.

τ-Components.

Confirmation of the mean parallaxes derived from the υ-components is found from the τ-components and the peculiar radial velocities. The τ-components are reduced to the same mean parallaxes as the υ-components and the corresponding average linear velocity in km/sec, t, is found from the formula $t = 4.74\, \overline{|\tau'|}/\bar{p}_{new}$; τ′ being the reduced τ-component. Correcting for the observational errors of the proper motions we get $\overline{|\tau'|} = 0''.00559$ and $\overline{|\tau'|} = 0''.00507$ for the two distance scales of JOY and PARENAGO used above, and, with the respective values of $\bar{p}_{new}$ in Table 2, $t = \pm 8.6$ and ± 8.8 km/sec.

The same value, ±8.6 km/sec, is found from the radial velocities of the 18 stars, corrected for solar motion and for differential galactic rotation, whereas E. RAIMOND, in the following article, from the radial velocities of 70 stars within 1700 parsec, finds ±10.0 km/sec. The values derived from the radial velocities and from the τ-components agree very well. This confirms the mean parallax derived from the υ-components.

Influence of various systematic corrections.

As the proper motions of the 18 Cepheids, which are the basis of the above determination of the zero-point, are very small, the results are very sensitive to systematic corrections applied to the proper motions. The table below illustrates this for the various steps if we go from the system of the *Preliminary General Catalogue*, without corrections to NEWCOMB's precession — which was used by HERTZSPRUNG 40 years ago — to the N30 system with precessional corrections and elimination of differential galactic rotation, as used in the present discussion.

TABLE 3

Corrections to the zero-point derived from the 18 stars, corresponding to various systematic corrections to the proper motions.

	m
Transfer from PGC to N30	−0.50
Application of precessional corrections	+0.21
Elimination of differential galactic rotation	−0.05

The large difference between the use of GC (or PGC) and the N30 system — which we now know to be much more reliable — explains part of the difference between earlier results and the present one. Transfer from N30 to FK3 makes no difference at all.

[1]) *Ap. J.* **113**, 401; *Lick Obs. Contr.* Ser. II, No 32, 1951.