spectral class from B3 to B1 as the period increases from $0^d.16$ to $0^d.25$. This would produce a decrease in the international color index of about $0^m.04$. The ordinary spectral classification quoted in Table 1 is too coarse to establish any deviation of the observed period-temperature relation from that predicted.

The cepheid variables also show a period-luminosity relation, as first pointed out by Miss LEAVITT [1]). Mrs PAYNE-GAPOSCHKIN and GAPOSCHKIN [2]) tabulate the bolometric magnitude-period relation (old zero point) from which we obtain

$$\Delta M = -1.0 - 2.7 \log P.$$

For KRAMERS' opacity law this is equivalent to $\alpha = -5$, while for electron scattering $\alpha = -6$. Both are unreasonable. This failure should not be surprising, since these cepheids are known to be rather far from the main sequence in a region of the H-R diagram where deviations from homology are believed to be important.

We hope this result may stimulate an attempt to obtain observationally a more accurate period-luminosity correlation. Any substantial advance must depend upon discovery of these stars in other associations or in some suitable object like the Magellanic clouds. As all but one of the β Canis Majoris stars known at present are located within 500 parsecs from the sun and these objects should be easily recognizable up to twice this distance, there is a fair chance that their number will be soon doubled. It is hoped that model calculations will substantiate the predicted period-luminosity law and that these results will provide a useful incentive to investigate pulsation models for these stars.

1) *Harv. Circular* No. 173, 1912.

2) *Proc. Am. Phil. Soc.* **86**, 329, 1943; *Harvard Reprint*, Series II, No. 2.

NEW PROPER MOTIONS IN THE ζ PERSEI ASSOCIATION,

BY J. DELHAYE *) AND A. BLAAUW

Recent meridian observations at the Paris Observatory are used for the derivation of new proper motions in the ζ Persei association. Total proper motions relative to the average of the association are shown in Figure 1. The coefficient of expansion is found to be $0''/^a.00236$ per degree $\pm\ 0''/^a.00025$ (p.e.), which leads to a probable age of the association of 1.5 million years. Attention is drawn to the deviating proper motion of the star o Persei and of a few other possible cases. It is suggested that these deviations must be interpreted as relative motions around a common centre of mass in multiple systems of which one, massive, component is still in the prestellar non-luminous state.

Meridian observations of the stars in the ζ Persei association have been made recently with the 19-cm meridian circle of the Paris Observatory. The observations were made in order to improve the proper motions studied in *B.A.N.* No. 433, especially those of the apparently faintest stars, for the further study of the expansion of the association and its internal motions.

The meridian observations.

The observed positions at mean epoch, reduced to 1950.0 with NEWCOMB's precession, and in the system of the FK3 are listed in Table 1. They are based on 4 to 11 observations per star and were made with reference to the following FK3 stars:

ζ Ari	11 Tau	48 Per
τ Ari	ζ Per	μ Per
α Per	ξ Per	54 Per
BD + 34°674,		

except for the four stars with mean epoch before 1952.0. These were observed in the regular programme of reference stars in the zone +33° to +36° for the *Carte du Ciel*, and therefore the definition of the fundamental system for these four stars is based on a more extensive list of reference stars and of a more smoothed character. The remaining stars were observed during the winter of 1952/1953. For particulars about the observing methods and the reductions we refer to the introduction to the zone catalogue which will be published in the near future by the Paris Observatory. The provisional discussion of the accuracy of the observations of the zone catalogue gives for the internal probable errors of one observation: $\pm 0^s.013$ in right ascension and $\pm 0''.21$ in declination. The three observations for GC 4465 were not considered sufficient for the derivation of a reliable position.

The proper motions.

New proper motions were computed in two steps.

First, the new observations were used together with the positions at mean epoch in the GC and the positions from the following catalogues, which were not incorporated in the GC:

The Second Armagh Catalogue for 1875 (1886);
Second Greenwich Catalogue for 1925 (1935);
Publications U.S. Naval Observatory, Second Series: Vol. XIV, Part III, "Catalogue of Declinations of 2094 Standard Stars" (1938); Vol. XV, Part V, "Catalogue of 5446 Stars" (1948); Vol. XVI,

*) Paris Observatory.

TABLE 1

Results of meridian observations at the Paris Observatory

GC or *HD*	BD	R.A. 1950.0	Decl. 1950.0	No. of Obs.	Epoch 1900 +
	+	h m s	° ′ ″		
4131	29°566	3 25 42.248	30 12 11.76	7	53.1
4222	34 674	29 28.529	35 17 36.06	7	53.1
4420	33 698	39 12.052	33 48 22.26	8	51.9
23060	33 704	40 13.089	33 57 30.39	4	53.1
4461	31 642	41 10.619	32 7 52.42	5	53.1
4465	31 643			3	53.1
4516	31 649	43 32.108	32 8 8.43	4	53.1
4548	33 717	44 41.969	33 26 47.60	7	53.1
4649	33 728	48 41.511	34 12 35.63	8	50.7
24190	33 730	49 6.901	34 4 23.99	9	53.1
4688	31 666	50 58.969	31 44 12.69	10, 11	53.1
4720	30 591	52 15.178	30 54 0.75	8	53.1
4734	34 768	53 14.943	34 56 11.16	8	50.4
4779	35 775	55 42.842	35 38 56.40	11	53.1
4891	32 714	4 1 32.166	32 26 7.55	11	53.1
4933	31 703	3 28.237	32 15 4.46	11	53.1
4943	33 785	3 43.449	33 18 46.25	8	50.0 ; 50.1

Part I, "Catalogue of 2383 Stars" and "Catalogue of 1536 Stars" (1949);

"Katalog der Anhaltsterne" (AGK2A), *Veröff. Coppernicus Inst. Berlin-Dahlem* (1943);

First Cape Catalogue for 1950 (1953).

For two stars not in GC, HD 23060 and HD 24190, the proper motions were derived from the Leiden A.G. zone catalogue (*Ann. Sternwarte Leiden*, Vol. **8**, 1902), the *Second Greenwich Catalogue* mentioned above, and the new Paris observations.

The catalogue positions were reduced to the system of GC with the systematic corrections as given in Vol. I of the GC and in GYLLENBERG's tables, *Meddel. Lund*, Ser. II, No. 122, 1948, and next to the FK3 system with the corrections published by KOPFF in *Mitt. Coppernicus Inst.*, Bnd. 5, No. 5, 1940 (*Abh. Preuss. Ak. Wiss.* 1939, Math. Naturw. Klasse, No. 18). Thus, the proper motions were derived directly in the system of the FK3. The system of weights as given in Vol. I of the GC and in GYLLENBERG's tables was adopted with the exception of catalogue positions with weights in excess of 2.5, the weights of which were somewhat reduced in order not to overemphasize the significance of such catalogues. The probable errors of the proper motions were derived from the weights of the catalogue positions and not from the residuals, as the latter method when applied to a small number of epochs may give spuriously large or small values for some of the stars.

The new proper motions thus obtained were combined with those given in the GC, also reduced to the FK3 system. The two sets of proper motions can be considered to be practically independent. As for the present purpose we are mainly interested in the relative motions of the stars of the association, we have not considered a possible further reduction to the N30 system.

Table 2 shows the two sets of proper motions, both with precessional corrections applied according to the most recent values of the correction terms [1]). The weighted mean proper motions are given in the next columns, and also the galactic components.

Comparison of the newly derived proper motions with those of the GC shows how valuable the new meridian observations were for the determination of the proper motions, especially for the faint stars. For those fainter than magnitude 6.0 the weight of the final, combined, proper motions is four times larger than that according to the GC.

Expansion and internal motions.

The mean galactic components of proper motion are

$$\overline{\mu_l \cos b} = +0''.0098, \qquad \overline{\mu_b} = -0''.0035.$$

Figure 1 shows the proper motions relative to this mean. The scale is indicated in the lower left-hand corner, and the directions of increasing right ascension and declination in the upper right one. The greater accuracy of the proper motions compared to

[1]) H. R. MORGAN and J. H. OORT, *B.A.N.* No. 431, 1951.

TABLE 2

GC proper motions, newly derived proper motions and average values, all with precessional corrections applied and in the system of FK3. Unit of p.m. is 0".0001 per year.

Des.	HD	m	l	b	GC reduced to FK3				New				Combined				$\mu_l \cos b$	μ_b
					$\mu_\alpha \cos\delta$	p.e.	μ_δ	p.e.	$\mu_\alpha \cos\delta$	p.e.	μ_δ	p.e.	$\mu_\alpha \cos\delta$	p.e.	μ_δ	p.e.		
			°	°		±		±		±		±		±		±		
	21483	7.08	127.0	−20.2	−185	67	− 63	48	+ 61	40	−201	46	− 3	34	−135	33	+ 82	−108
	21856	5.80	124.3	−15.7	− 59	30	+ 7	28	−110	36	+ 10	41	− 80	23	+ 6	23	− 67	− 45
40 Per	22951	5.04	126.9	−15.6	− 38	25	−101	19	+141	33	−104	35	+ 27	20	−102	17	+ 87	− 61
	23060	7.9	127.0	−15.4					+ 72	35	−128	43	+ 72	35	−128	43	+137	− 52
o Per	23180	3.94	128.4	−16.6	+103	13	−121	13	+ 90	25	−188	29	+100	12	−132	12	+163	− 34
		8.4	128.4	−16.7	+ 13	71	− 91	49					+ 13	70	− 91	49	+ 70	− 60
	23478	6.51	128.7	−16.2	− 77	63	−251	55	+110	42	−191	49	+ 53	35	−217	37	+182	−129
	23625	6.36	128.0	−15.1	− 48	50	− 31	34	+ 55	35	− 95	33	+ 21	29	− 64	24	+ 58	− 34
	24131	5.73	128.2	−14.0	+ 52	39	− 70	35	+ 28	45	− 62	51	+ 42	29	− 67	29	+ 75	− 22
	24190	7.49	128.4	−14.1					+ 68	33	−147	41	+ 68	33	−147	41	+147	− 64
ζ Per	24398	2.91	130.3	−15.5	+ 93	10	−110	10	+ 45	20	− 90	24	+ 83	9	−107	9	+134	− 21
X Per	24534	6.5	131.0	−15.9	−106	46	− 70	43	+ 46	37	− 43	40	− 14	29	− 55	29	+ 28	− 50
	24640	5.48	128.4	−12.8	+ 70	33	− 9	26	+ 63	42	− 60	51	+ 67	26	− 19	23	+ 62	+ 32
ξ Per	24912	4.05	128.3	−12.0	+ 60	12	− 9	13	+ 39	22	− 17	28	+ 55	10	− 10	12	+ 47	+ 31
	25539	6.70	131.4	−13.5	+182	80	−168	80	+140	43	−123	51	+150	38	−136	43	+203	+ 6
	25799	6.87	131.9	−13.3	− 48	80	− 18	78	+136	41	−115	48	+ 97	36	− 89	41	+132	+ 6
AG Per	25833	6.61	131.2	−12.5	+142	58	− 58	52	+ 82	39	− 87	41	+101	32	− 76	32	+126	+ 15

those given in the previous paper on the association (*B.A.N.* No. 433, 1952), justifies the representation of the individual proper motions instead of means for groups, as shown in Figure 3 of that paper. BARNARD's most conspicuous dark nebulae are again indicated by their outlines. The names of the brightest stars are also given.

The expansion of the association is clearly shown by the stars in the outer parts. It can also be demonstrated by plotting the proper-motion components in right ascension and declination against these co-ordinates, respectively, as was done in the previous paper. From the components in right ascension we find the coefficient of expansion, uncorrected for radial motion,

$$E_\alpha = +0''.00199 \text{ per degree,} \quad \pm 32 \text{ (p.e.)}$$

and from the components in declination

$$E_\delta = +0''.00238 \text{ per degree.} \quad \pm 40 \text{ (p.e.)}$$

o Persei was excluded from the determination of E_α, for the reason explained below. That the probable errors, as compared to the determination in the previous paper, have not decreased as might be expected from the increased weight, is due partly to a somewhat different system of weighting the proper motions and partly to probably real deviations from the linear relation between the components and the corresponding co-ordinates. Weights were given inversely proportional to the squares of the probable errors with a maximum corresponding to the p.e. ± 0".0020.

For the average coefficient of expansion we adopt

$$E_{\alpha,\delta} = +0''.00214 \text{ per degree.} \quad \pm 25 \text{ (p.e.)}$$

Applying the correction of + 0".00022 per degree for perspective contraction due to radial motion (see *B.A.N.* No. 433, page 408) we get the final value

$$E = +0''.00236 \text{ per degree,} \quad \pm 25 \text{ (p.e.)}$$

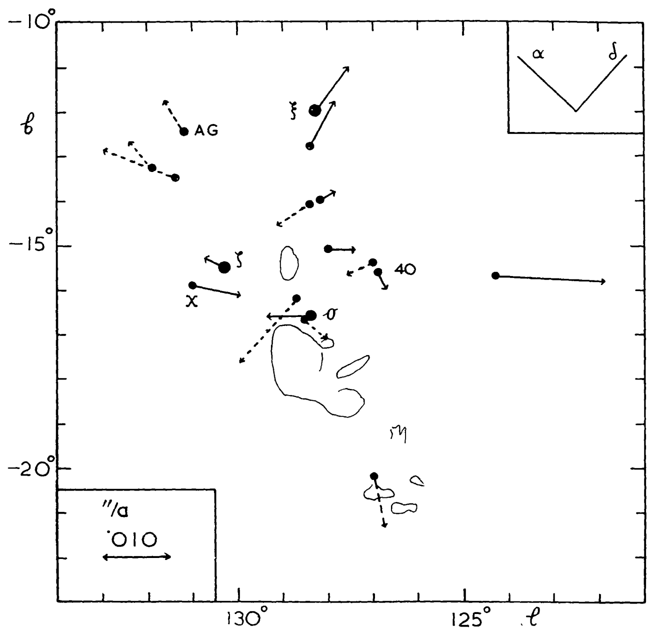
which corresponds with the "expansion-age"

$$T = 1.5 \times 10^6 \text{ years.}$$

This is slightly higher than the value previously found (1.3×10^6 years).

As was noticed in the previous paper, the proper motion in right ascension for o Persei deviates considerably from what would be expected from the simple picture of an expansion proportional to the distance from the centre. The deviation is confirmed by the new meridian observations and amounts to about seven times the probable error of the proper motion. If the star had its present motion with respect to the centre of the association during the past 1.5 million years, it must have been located originally at a distance of 3.3 degrees (17 parsecs) from this centre. The phenomenon of expansion being so pronounced in this association, it seems unacceptable that for one star belonging to the group the initial motion can have been so totally different. On the other hand, it seems improbable that o Persei is a field star which originally had nothing to do with the association, as its distance, radial velocity as well as reddening all indicate membership.

FIGURE 1



Relative proper motions with respect to the mean motion of all the stars in the association. Drawn arrows represent proper motions with probable errors below $\pm$ 0″.0030, dotted arrows those with probable errors between this value and $\pm$ 0″.0041, except BD + 31°643, for which it amounts to $\pm$ 0″.0060. The brightest stars are indicated by the largest dots and by their names. BARNARD's dark nebulae are shown by their contours.

We are, therefore, rather inclined to explain the deviating motion in right ascension as a temporary phenomenon, due to orbital motion around an invisible massive object close to o Persei. This object may be either a dark mass in the prestellar state, between globule and luminous star, forming a double star with o Persei (or rather a multiple system as o Persei itself is a spectroscopic binary) – or a more distant massive cloud causing o Persei to deviate from its original path. The presence of massive dark clouds in the immediate neighbourhood of o Persei seems quite plausible in view of the presence of the heavily absorbing clouds noticed already by BARNARD and indicated in Figure 1. On the other hand, we know that multiple systems are the rule rather than the exception among the stars of earliest types, and it might well be that in this extremely young group of stars we observe a multiple system of which one of the components has not yet reached the observable luminous stage whereas the other one has already.

The deviation of the proper motion corresponds to a linear velocity of approximately 10 km/sec. Interpreting this as circular motion around a common centre of mass, and supposing the mass of o Persei to be 25 solar masses, we find that the non-luminous companion may have, for instance, a mass of 62 solar masses if we assume the period of the system to be 1000 years; the corresponding distance of the two objects would then be 446 a.u. For a period of 10 000 years we find a mass of 370 solar masses and a distance of 3200 a.u. Motion around a heavy cloud complex at a distance of 10^6 a.u. (which is the order of the distances from the dark clouds near o Persei shown in Figure 1) would require a mass for these complexes of about 100 000 solar masses. The first-mentioned case of a companion of between two and three times the mass of o Persei is certainly in the range of masses and distances observed for early-type multiple systems.

If the period of the system indeed is of the order of 1000 years, changes in the proper motion of o Persei should be observable in the course of a century. Comparison of the proper motion during the next decades with the motion found from the observations in the past will therefore be of the utmost interest.

Whether or not the same phenomenon occurs also among the other members of the group may also be decided by continued meridian observations. The cases of X Persei and HD 23478, for which the deviations from the general expansion are also conspicuous, deserve special attention. It should be noticed, however, that in these cases there are discrepancies between the GC proper motions in right ascension and the modern values, which may be due to unreliable old catalogue positions.

It is a pleasure to thank Dr A. DANJON, Director of the Paris Observatory, for permission to use and publish the meridian observations in the present paper, and Dr J. LEVY for making them available to us.