BULLETIN OF THE ASTRONOMICAL INSTITUTES
OF THE NETHERLANDS

1952 JUNE 20 VOLUME XI NUMBER 433

COMMUNICATIONS FROM THE OBSERVATORY AT LEIDEN

# THE AGE AND EVOLUTION OF THE ζ PERSEI GROUP OF O- AND B-TYPE STARS

BY A. BLAAUW

The age of the stars of the group, 1.3 million years, is derived from the expansion of the group as revealed by the proper motions (Figures 2 and 3). The mean velocity of the stars with respect to the centre of the group is 12 km/sec. The presence of high-luminosity stars, ζ and ξ Persei, also indicates that the group is very young. The relation with interstellar matter is discussed, particularly the connection with conspicuous dark clouds in the region of the group. An interesting feature of the group is the presence of a very small open cluster of faint stars south of o Persei (Figure 5); photographically determined proper motions for this cluster are given in Table 3.

## 1. *Internal motions and the age of the group.*

The moving cluster of early-type stars which includes, among others, the bright stars ζ Per, ξ Per and o Per, has been described in *B.A.N.* No. 363, page 29 (1944). In the following this article will be referred to as paper I, and the moving cluster will be called the ζ Persei group after its brightest member. Further study of this group, especially of the internal motions as revealed by the proper motions and the radial velocities, leads to interesting conclusions with relation to its evolution, and to an estimate of the age of its members.

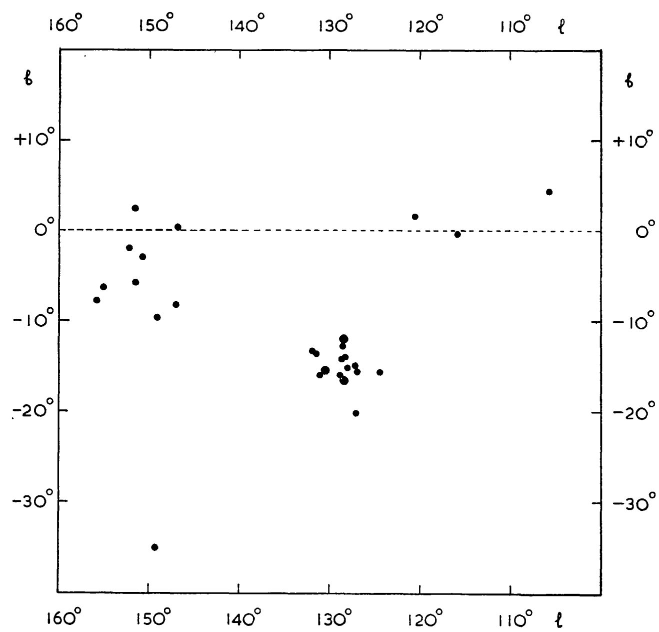
The study of the group was resumed as part of a general discussion of the motions and distribution of the O- and B-type stars in connection with the calibration of the Yerkes luminosity classifications. Figure 1 shows the distribution of the O to B3 stars in Perseus and the adjacent region between galactic longitudes 100° and 160° and between latitudes + 20° and − 40°. It contains all members of these types of the ζ Persei group, which is at the centre of the diagram, and in addition the stars in the Yerkes list (which is nearly complete) for which the distance modulus $m_0 - M$ is between 7.0 and 8.0 (distances 250 to 400 parsecs). The distance modulus of the ζ Persei group is 7.4.

The principal observational data concerning the stars of the group are in Table 1. $M_v$ is the visual absolute magnitude. The colour excesses $E$ are in the scale of *Mt Wilson Cont.* No. 621, with a slightly corrected zeropoint.

In paper I an estimate was made of the dispersion of the internal motions in the group. A value of ± 4.5 km/sec for the root mean square residual velocity in one component was derived from the radial velocities, while an even larger value was indicated by the proper motions. In order to check the large relative proper motions as well as to increase their precision, the proper motions given in paper I, which were taken from the GC, have been supplemented with new determinations. These were based on recent meridian observations, not included in the construction of the GC. The following catalogues were used:

*Second Greenwich Catalogue* (for 1925.0);
*Publ. U.S. Naval Observatory,* Second Series XIV, Pt

FIGURE 1




Distribution on the sky of the O to B3 stars with distance moduli between 7 and 8. The ζ Persei group is at the centre of the diagram.

TABLE 1

| Des | GC | HD | α 1950 | δ 1950 | l | b | m | Sp | $M_v$ | E | ρ km/sec | p.e. | $\mu_\alpha \cos\delta$ | p.e. | $\mu_\delta$ | p.e. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | h m | ° ′ | ° | ° | | | | m | | ± | unit ″/a.001 | ± | | ± |
| | 4131 | 21483 | 3 25.7 | + 30 12 | 127.0 | − 20.2 | 7.08 | B2 | − 2.8 | + .35 | − 6.0 | 0.5 | − 8 | 5 | − 10 | 3.4 |
| | 4222 | 21856 | 29.5 | 35 18 | 124.3 | − 15.7 | 5.80 | B2 | − 2.3 | + .10 | + 24.9 | 2.6 | − 5 | 2.1 | − 2 | 2.0 |
| 40 Per | 4420 | 22951 | 39.2 | 33 48 | 126.9 | − 15.6 | 5.04 | B1 | − 3.4 | + .15 | + 19 | var. | − 2 | 2.3 | − 11 | 1.7 |
| | | 23060 | 40.2 | 33 57 | 127.0 | − 15.4 | 7.9 | B3: | | | + 19 | 3 | + 6 | 8 | − 9 | 8 |
| o Per | 4461 | 23180 | 41.2 | 32 8 | 128.4 | − 16.6 | 3.94 | B1 | − 4.6 | + .17 | + 18.5 | *) | + 9 | 1.0 | − 11 | 1.1 |
| | 4465 | + 31°643 | 41.4 | 32 0 | 128.4 | − 16.7 | 8.4 | B5 | − 2.4: | + .49: | + 32 | var. | + 1 | 7 | − 9 | 5 |
| | 4516 | 23478 | 43.5 | 32 8 | 128.7 | − 16.2 | 6.51 | B3 | − 2.4 | + .21 | + 15 | var. | + 1 | 3.4 | − 23 | 5 |
| | 4548 | 23625 | 44.7 | 33 27 | 128.0 | − 15.1 | 6.36 | B2 | − 2.6 | + .22 | + 35 | var. | − 4 | 5 | − 5 | 2.6 |
| | 4649 | 24131 | 48.7 | 34 13 | 128.2 | − 14.0 | 5.73 | B1 | − 2.9 | + .17 | + 17.8 | 0.4 | + 5 | 3.9 | − 3 | 3.3 |
| | | 24190 | 49.2 | 34 3 | 128.4 | − 14.1 | 7.49 | B3 | − 1.1 | + .17 | + 18 | var. | + 6 | 8 | − 8 | 8 |
| ζ Per | 4688 | 24398 | 51.0 | 31 44 | 130.3 | − 15.5 | 2.91 | B1 | − 6.0 | + .21 | + 21.4 | 0.3 | + 8 | 0.7 | − 12 | 0.8 |
| X Per | 4720 | 24534 | 52.3 | 30 54 | 131.0 | − 15.9 | 6.5 † | Bop | − 3.0: | + .30:: | + 17.2 | 1.4 | − 9 | 3.4 | − 3 | 3.4 |
| | 4734 | 24640 | 53.2 | 34 56 | 128.4 | − 12.8 | 5.48† | B2 | − 2.8 | + .12 | + 17.3 | 2.8 | + 8 | 3.3 | − 1 | 2.6 |
| ξ Per | 4779 | 24912 | 55.7 | 35 39 | 128.3 | − 12.0 | 4.05 | O7 | − 4.3 | + .13 | + 67.6 | 2.1 | + 7 | 1.0 | 0 | 1.2 |
| | 4891 | 25539 | 4 1.5 | 32 26 | 131.4 | − 13.5 | 6.70 | B3 | − 1.9 | + .17 | + 29.9 | 1.0 | + 16 | 8 | − 6 | 6 |
| | 4933 | 25799 | 3.5 | 32 15 | 131.9 | − 13.3 | 6.87† | B3 | − 1.6 | + .15 | + 24 | var. | − 4 | 8 | − 4 | 6 |
| AG Per | 4943 | 25833 | 3.7 | 33 19 | 131.2 | − 12.5 | 6.61† | B5 | − 1.6 | + .12 | + 15.8 | *) | + 16 | 6 | − 2 | 4 |

† Brightness variable *) The radial velocity is the γ velocity of the spectroscopic orbit.

III, "Declinations of 2094 Standard Stars (1925.0)"; XV, Pt V, "Catalogue of 5446 Stars (1940.0)"; XVI, Pt I, "Catalogue of 2383 Stars (1925.0)" and "Catalogue of 1536 Stars (1950.0)";

*Annals Tokyo Astr. Obs.*, Second Series II, No. 3 (1950.0; right ascensions only).

The improved proper motions were reduced to the mean of the systems of FK3 and N30 and precessional corrections were applied. The corrected components in α and δ and their probable errors are in the last columns of Table 1. Particularly interesting are the large differences between the accurately determined proper motions of the stars ζ, ξ, and o Per and GC 4222, for which many modern observations are available. Table 2 shows, for these stars, the values of the components according to the GC, and those derived from recent positions in combination with the position at the mean epoch of the GC, both reduced to the system mentioned above. The two sets of data are entirely independent. The large differences between the GC proper motions are confirmed by the new values.

Such large relative motions must cause rapid changes in the dimensions of the group. The diameter of the group is about 6°, corresponding to 30 parsecs. The mean density within the group as far as the contribution due to its members is concerned, is of the order of 0.01 solar mass per $ps^3$. This is only one tenth of the minimum density required for stable systems, which is about 0.1 solar mass per $ps^3$ [1]). The mutual

TABLE 2

Comparison of GC proper motions with determinations from recent positions (unit of proper motions is ″/a.001).

| | $\mu_\alpha \cos\delta$ | | $\mu_\delta$ | |
|---|---|---|---|---|
| | GC | New | GC | New |
| GC 4222 | − 6 ± 3.0 | − 5 ± 3.0 | + 2 ± 2.8 | − 2 ± 3.0 |
| o Per | + 9 1.3 | + 8 1.5 | − 11 1.3 | − 7 1.9 |
| ζ Per | + 8 1.0 | + 6 1.8 | − 10 1.0 | − 10 1.2 |
| ξ Per | + 7 1.2 | + 4 1.5 | 0 1.3 | + 4 2.0 |

attractive forces between the members of the group are negligible; their motions are governed mainly by the general galactic field of force.

Relative motions in stellar systems where the mutual attractions are negligible must ultimately lead to an expansion of the group as a whole. The hypothesis of the occurrence of such expansive motions has been recently introduced by AMBARZUMIAN in order to explain the presence of the large but sparsely populated groups of early-type stars, called "O-associations" by this author [1]).

In so far as the papers by AMBARZUMIAN and his collaborators are available in this country, we have found no reference to the nearest of these groups of

[1]) B.J. BOK, *Harvard Circular* No. 384 (1934); H. MINEUR, *Annales d'Astrophysique*, Tome 2, No. 1 (1939).

[1]) *A. J. U.S.S.R.* **26**, 3 (1949); *Izv. Ak. Nauk, U.S.S.R.* Phys. Ser. XIV, 15 (1950). See also the references to papers by AMBARZUMIAN and his collaborators in *Abh. Deutsche Ak. Wiss., Klasse Naturw.* 1950 No. 2 and V. KOURGANOFF's summary in "Quelques Documents sur la Structure de la Galaxie", 2ème partie (1951).

early-type stars, such as the Scorpio-Centaurus group and the $\zeta$ Persei cluster. Still, these near-by groups present striking examples of the "O-associations", and allow detailed studies of the properties of the extended aggregates of early-type stars. It appears that the large internal motions observed in the $\zeta$ Persei group have indeed the character of an expansion. This expansion reveals itself by an increase of the components $\mu_\alpha \cos\delta$ as a function of $\alpha$, and by a similar increase of $\mu_\delta$ with $\delta$. In Figures 2a and 2b the two components are plotted against the corresponding co-ordinates. The length of the vertical lines is twice the probable error of the proper motions. The general trend is the same in the two diagrams; both show an increase of the component of proper motion with increasing value of the co-ordinate.

In order to show more clearly the peculiar character of the internal motions, total proper motions are shown in Figure 3. These are reckoned with respect to the mean proper motion of the group, which is given by

$$\overline{\mu_\alpha \cos\delta} = +0''/^a.0030 \qquad \overline{\mu_\delta} = -0''/^a.0070$$

or (1)

$$\overline{\mu_l \cos b} = +0''/^a.0069 \qquad \overline{\mu_b} = -0''/^a.0033.$$

The figure represents all O to B5 stars of the group and the remaining stars of these types with GC proper motions in the region between galactic longitudes 117° and 140° and between latitudes −6° and −22°. The four stars above latitude −10° do not belong to the group. They are situated at smaller distances than the group. The star at $l = 125°.2$, $b = -9°.0$ is $\varepsilon$ Persei, a probable member of EDDINGTON's moving cluster in Perseus [1]). The arrows represent the relative proper motions for individual stars or weighted means for subgroups of two or three stars close together on the sky. The tails of the arrows are in the centres of these groups. The radii of the dashed circles represent the probable errors of the proper motions. The scale is indicated in the lower left-hand corner. Stars brighter than visual absolute magnitude −4 are represented by large dots. The directions of the arrows show clearly the expansion of the group, especially if we consider the stars at the greatest angular distance from its centre.

The rate of expansion has been derived from the data represented in Figures 2a and 2b. A linear relation is adopted between the component of proper motion and the co-ordinate of the star, and the slope of this relation is taken as a measure of the apparent expansion.

Such a relation should exist under the following circumstances:

1) The present dimensions of the group are large compared to the dimensions at the time when the stars began their independent motions.

2) These motions started at the same time and have since been uniform.

It can be easily shown that the linear relation is then independent of the distribution of the sizes and of the directions of the velocities.

In the case of the components in $\alpha$, the only observation which is incompatible with a linear relation is the accurately determined proper motion of o Persei. Therefore, two solutions were made, with and without

[1]) Cf. W. W. MORGAN and N. G. ROMAN, *Ap. J.* **111**, 431 (1950).

FIGURE 2a

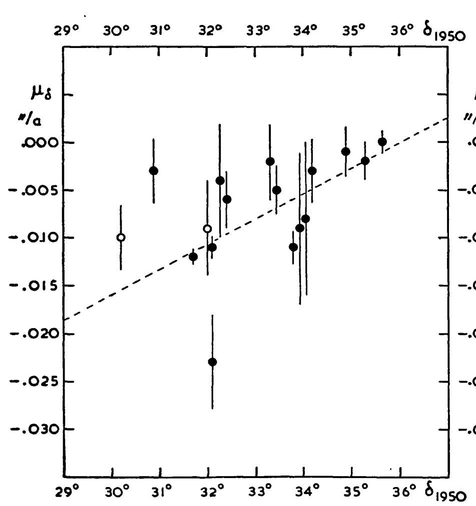
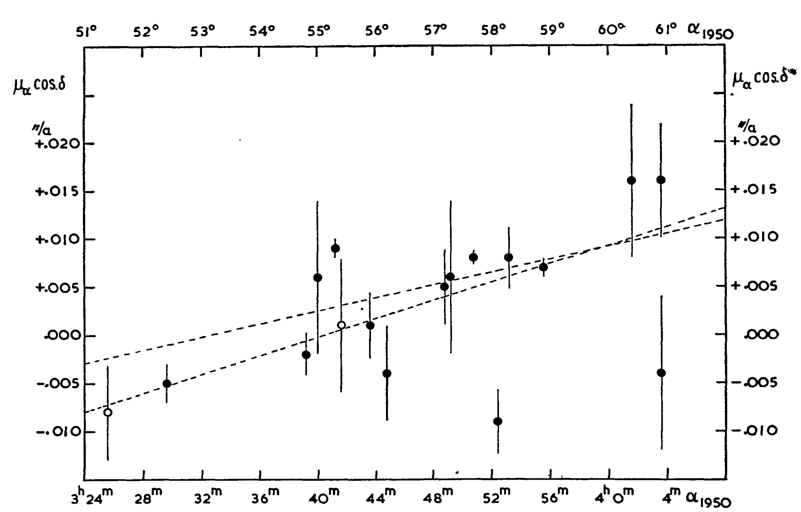



FIGURE 2b




Components of proper motion in $\alpha$ and $\delta$ for the stars in Table 1, plotted against the co-ordinates $\alpha$ and $\delta$, respectively. The dotted lines represent the linear relations. In the case of the $\alpha$ components, both solutions (with and without o Persei) are shown. Circles represent stars not used in the determination of these relations.

this star. The proper motions were weighted according to their probable errors, but the weights of the few very accurately determined proper motions were slightly reduced in order that they should not have preponderating influence on the results.

We find from the $\alpha$ components:

$$\frac{d(\mu_\alpha \cos\delta)''^{/a}}{d(\alpha\cos\delta)^\circ} = +0''^{/a}.00167 \text{ per degree (incl. of o Per)} \\ \pm \quad 47 \text{ (p.e.)}$$

and

$$\frac{d(\mu_\alpha \cos\delta)''^{/a}}{d(\alpha\cos\delta)^\circ} = +0''^{/a}.00234 \text{ per degree (without o Per)}. \\ \pm \quad 47 \text{ (p.e.)}$$

In the case of the $\mu_\delta$'s no such incompatible deviations occur; we find

$$\frac{d\mu_\delta''^{/a}}{d\delta^\circ} = +0''^{/a}.00269 \text{ per degree.} \\ \pm \quad 33 \text{ (p.e.)}$$

The solutions were based only on the stars occurring in Table 1 of paper I. Thus, HD 21483 and BD + 31°643, which have been added in the new list on page 406, were not used. See also the remark below on HD 21483.

We adopt the weighted mean of the results from the two components, using the average of the two solutions for $\alpha$. We thus arrive at the coefficient of the apparent expansion:

$$+0''^{/a}.00246 \text{ per degree.} \\ \pm \quad 27 \text{ (p.e.)} \qquad (2)$$

Before the observed coefficient of expansion (2) can be interpreted in terms of a real expansion of the group, it must be corrected for an apparent contraction due to the motion of the group in the direction of the line of sight. The motion of the group with respect to the sun can be resolved into a radial and a tangential component. The latter does not contribute to the apparent expansion. The radial component gives rise to an apparent contraction, the amount of which is

$$\frac{\pi}{180} \cdot \frac{V_r}{4.74} p \text{ seconds of arc per year per degree,}$$

where $V_r$ is the mean radial velocity of the group expressed in km/sec and $p$ is the mean parallax.

$V_r$, corrected for a red-shift $K$-term of +1.3 km/sec, is +18.6 km/sec. For $p$ we adopt 0".0033 (see page 411). Hence this apparent contraction amounts to

$$0''^{/a}.00022 \text{ per degree} \qquad (3)$$

and the real expansion is given by the sum of (2) and (3):

$$+0''^{/a}.00268 \text{ per degree.} \\ \pm \quad 27 \text{ (p.e.)} \qquad (4)$$

If we assume the simple picture of the evolution of the group as described by the assumptions 1) and 2), the quantity (4) permits directly to evaluate the time $T$ which has elapsed since the beginning of the uniform motions. $T$ is the reciprocal of the coefficient of expansion (4); we find

$$T = 1.3 \text{ million years.} \qquad (5)$$

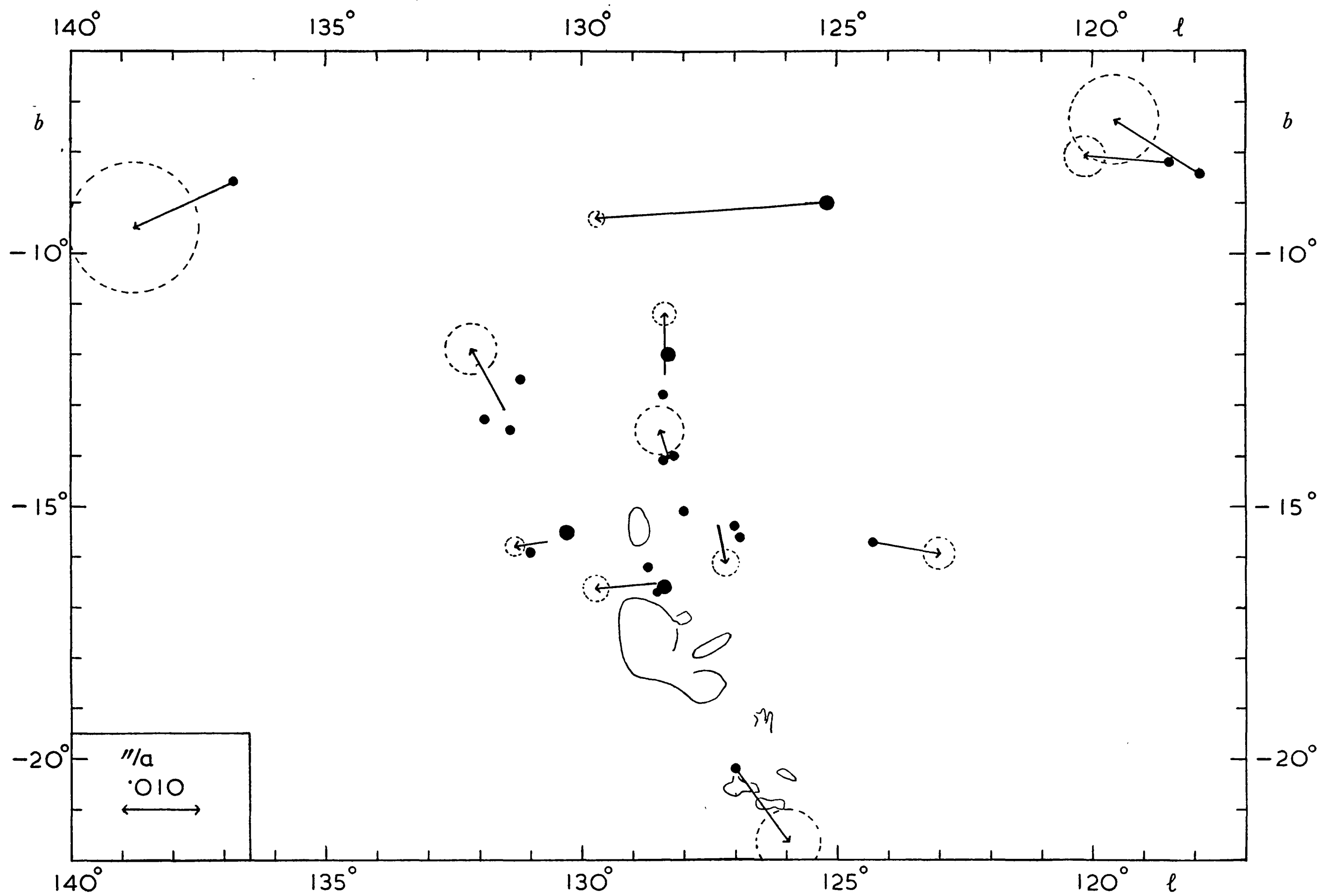
This time probably is also the age of the stars in the group, if we count these ages from the epoch at which the stars began their motions as independent units. The true ages of the stars will be different from the time (5), if the motions have not been uniform since the stars left the cloud in which they were formed or if the stars have spent an appreciable time in this cloud with random motions, before they finally escaped. It can be shown that deviations from uniform motion due to the mutual attraction since the stars left the region of formation are practically negligible.

Let us consider the case that the original dimensions of the cloud were nine times smaller than the present ones, i.e. about 0°.7 diameter, corresponding to 3.7 parsecs (this is about the size of BARNARD's dark cloud $B5$ observed in the direction of the centre of the group; see the next section). If we assign a mass of 300 solar masses to this original cloud, which is somewhat more than the total of 230 solar masses of the members of the group in Table 1 and which corresponds to a mean density of 12 solar masses per cubic parsec, then the velocity of escape at the edge of the cloud is 1.2 km/sec. For stars with velocities of 10 km/sec at the edge, the total retardation until they have reached nine times the original distance from the centre amounts to less than 0.1 km/sec. The observed mean velocity of expansion is about 12 km/sec (see page 410): hence we may conclude that the original velocities have not changed since the stars left the cloud. Important changes in the motions of the members of the group can have taken place only if the original dimensions of the group were of the order of one percent of the present ones. But even then, the retardations will have occurred only during an interval of time which is short compared with the 1.3 million years derived above.

That the stars could have spent an appreciable time in the cloud before they escaped seems also very improbable. In that case we should expect them to have acquired their large velocities by encounters with other stars which should have remained in the cloud with smaller energies. We do not, however, observe a concentration of O and B stars in the centre of the group.

We have noticed already that the proper motion of o Persei deviates markedly from the linear relation in Figure 2b. This may serve as an indication that the original volume where the stars were formed was

FIGURE 3




Proper motions of the stars of the ζ Persei group and of surrounding O to B5 stars, relative to the mean proper motion of the ζ Persei group. The radii of the dotted circles represent the probable errors of the proper motions. BARNARD's dark regions are indicated.

rather large, or that they were formed in more or less separated groups, or that o Persei is of a more recent formation than the other stars. Our present knowledge of the proper motions is too inaccurate to trace the paths of the stars in the past and to estimate the original dimensions of the group. However, important information might already be obtained if for the stars of Table 1 proper motions were available with the same degree of precision as the present determination for ζ Persei. It should be noticed that the problem is simplified by the circumstance that we need relative motions and not absolute ones, so that the uncertainty of the fundamental system plays a minor rôle.

An age of 1.3 million years as found from the rate of expansion is surprisingly short when compared with the period of revolution of the stars in the solar neighbourhood around the galactic centre (220 million years), or with current estimates of the age of the sun. Still, the evidence in favour of a recent formation is rather strong. The precision of the proper motions does not leave room for serious doubt with respect to the reality of the expansion, and from what has been said above, it appears difficult to reconcile the expansion with an appreciably higher age.

One possibility, which allows for a somewhat higher age, is that the condensation of the interstellar material into stars took place already during the process of contraction of the original cloud. But even then it would seem rather improbable that the true age exceeds the 1.3 million years derived above by more than a few hundreds of thousand years.

Besides, the presence of high-luminosity stars like ζ Persei and ξ Persei also points to a small maximum age. We can estimate this maximum age in the same way as it has been done, for instance, by UNSÖLD [1]), i.e. on the assumptions that a) the star has during the past radiated energy at the same rate as at present, b) the source of this energy is the transformation of H into He, c) the amount of helium present in the star is the same as that observed in the atmospheres of the O to B3 stars in general, particularly in τ Scorpii,

[1]) *Z. f. Astroph.* **24**, 278 (1944).

and d) all helium present in the star has been formed by transformation of hydrogen. We find maximum ages of 7.9 and 7.4 million years for ζ and ξ Persei, respectively. But the true ages may be considerably shorter; assumptions a), c), and d) are, of course, very uncertain.

The mean linear velocity of expansion has been derived from the radial velocities and the proper motions. Column ρ of Table 1 gives the radial velocities. The data in MOORE's catalogue have been combined with more recent measures. I am much indebted to Dr O. NEUBAUER of Lick Observatory and to Miss S. L. LIPPINCOTT for observing and measuring the velocities of HD 23060 and BD $+31°643$. The results for these stars, given in Table 1, are based on ten plates each. From these revised values we find the mean residual radial velocity from 16 stars:

$$\eta_{rad} = \pm 6 \text{ km/sec}$$

(ξ Persei was excluded; see below).

The corresponding quantities derived from the residual proper motions in α and δ, assuming the mean parallax (6) are:

$$\eta_{\alpha} = \pm 9 \text{ km/sec}, \qquad \eta_{\delta} = \pm 6 \text{ km/sec}.$$

The agreement between the value of $\eta_{rad}$ and those of $\eta_{\alpha}$ and $\eta_{\delta}$ shows that the velocity of expansion is about the same in the direction of the line of sight as in the tangential directions.

From these values we find the mean space velocity with respect to the centre of the group:

$$\eta = \pm 12 \text{ km/sec}.$$

As has been said above already, the accidental errors of the proper motions are too large to allow a discussion of the individual motions of the members. A few remarks may be made:

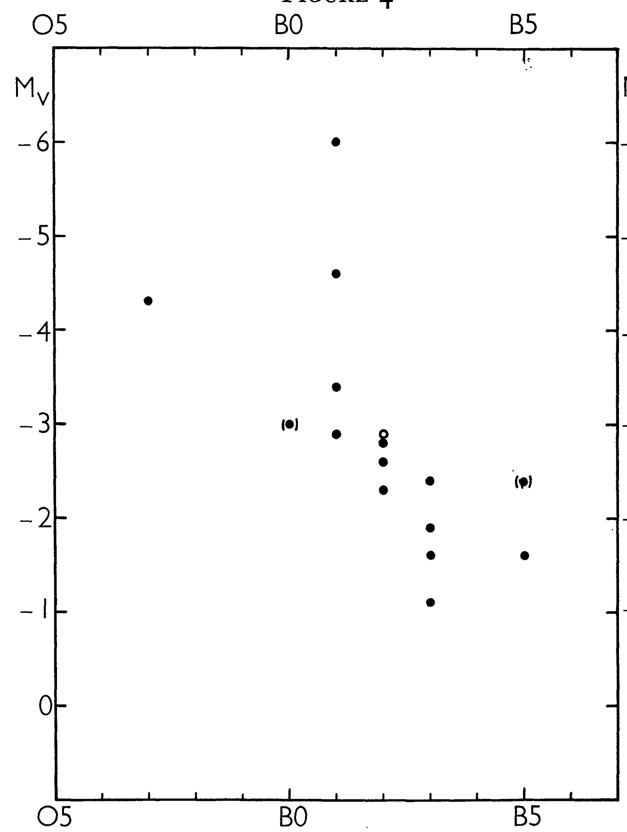
*HD 21483 = GC 4131.* The radial velocity of this star differs by 25 km/sec from the mean for the group given in paper I. For that reason the star was not considered as a member in that paper. However, the proper motion fits remarkably well in the picture of the expansion, and the position of this star in the HR diagram (represented by a circle in Figure 4) indicates that the star must be at about the same distance as the remaining stars. It is immersed in the nebulosity which seems to be associated with a large part of the group (see the next section). The proper motion corresponds to a velocity with respect to the centre of the group of about 16 km/sec. If we consider so large a residual proper motion possible for stars belonging to the group, there is no obvious reason to exclude a difference of 25 km/sec in the direction of the line of sight. Accordingly the star will be considered as a member.

The negative radial velocity with respect to the group must have brought the star nearer to the sun than the rest of the group. From the residual radial velocity $-25$ km/sec and the time 1.3 million years we find that the distance of the star from the sun must be 8/9 of that of the centre of the group. The true absolute magnitude is then 0.3 fainter than that given in Table 1 and in Figure 4. The star was not used in the solution of the coefficient of expansion (1), this solution being confined to the stars considered as members of the group in paper I.

*ξ Persei.* The high residual radial velocity of $+48$ km/sec gives rise to doubt about its membership of the group. In paper I reasons have been given why we think that the radial velocity of this star may not represent the star's true motion. The high value obtained by PEARCE [1]) was confirmed by WILSON and JOY [2]).

If real, the positive residual velocity will have brought the star at 6/5 of the distance of the group from the sun, and the true absolute magnitude must be $0^m.4$ brighter than that given in Table 1 and Figure 4.

FIGURE 4




The spectrum-luminosity diagram of the ζ Persei group. The star HD 23060, for which no colour is known, is not represented. Positions of the stars in parentheses are very uncertain.

1) *Publ. Dominion Obs. Victoria* **5**, 23 (1931).
2) *Ap. J.* **111**, 221 (1950).

The absolute magnitudes $M_v$ and the spectral classes of Table 1 are plotted in Figure 4, except for one star, HD 23060, for which no colour has yet been determined. For two stars the absolute magnitudes are quite uncertain and the positions in the HR diagram are given in parentheses. One of them is the spectrum variable X Persei for which the intrinsic colour and hence the colour excess is not well known. The other one is BD + 31°643; this star is one of the most reddened B stars known at present. A provisional measurement, kindly made by Dr W. A. HILTNER of Yerkes Observatory in 1948, gave an excess of +0.49 in STEBBINS and WHITFORD's scale, corresponding to an absorption in photographic light of about 4 magnitudes. For further particulars about the individual members of the group we refer to paper I.

The distance of the group and the individual absolute magnitudes have been determined on the assumption that the mean absolute magnitudes for stars of types B2 V and B3 V are −2.7 and −1.8, respectively. We thus find the distance modulus corrected for interstellar absorption

$$m_0 - M = -7.4 \qquad (6)$$

and the parallax of the group: 0".0033.

The mean velocity of the group with respect to the sun is 21.6 km/sec in the direction $l = 159°$, $b = -25°$. After elimination of the normal solar motion (20 km/sec towards $\alpha = 270°$, $\delta = +30°$) the velocity of the group is 14.5 km/sec in the direction $l = 95°$, $b = -7°$.

**2.** *Relation with interstellar matter.*

The ζ Persei group is situated in a region of the sky rich in nebulosity and dark matter. The evidence of recent origin of the group makes a study of its relation with the interstellar matter particularly interesting.

The region of the ζ Persei group is represented by plate 16 of BARNARD's collection of photographs in *Lick Publ.* XI (1913). This photograph is centred on ξ Persei and shows the emission nebula NGC 1499 north of this star as well as the dark nebulae in the region around o Persei. Photographs of NGC 1499 (the "California Nebula") in different colours are shown by BAKER in *Harvard Observatory Monographs* No. 7 (Centennial Symposia), p. 50. This nebula appears to be associated with the dark cloud north of the ζ Persei group.

Perhaps more closely connected with the medium in which the stars of the group originated are the dark and the faintly luminous clouds in the central and the south-western regions of the group. These regions contain some very dark objects which are well represented on Plate 3 of BARNARD's *Atlas of Selected Regions of the Milky Way*, Part I, and described by this author in *Ap. J.* **41**, 253. The most conspicuous objects were marked by BARNARD and numbered *B*1 to *B*5 and *B*202 tot *B*205. They are indicated in Chart 3 of Part II of the *Atlas* and described in the catalogue of dark objects in the introduction to the atlas. Their outlines according to BARNARD are reproduced in Figure 3 of the present paper. The most northern object *B*5 is about at the centre of the group. The other objects are distributed approximately along a radius in the south-western direction reaching beyond the star HD 21483, which is immersed in these clouds and strongly reddened (see Table 1, column *E*). The dark regions are also well marked on Ross' photograph reproduced in *Ap. J.* **67**, page 292.

Judging from BARNARD's photographs the heaviest obscuration seems to occur in *B*5 and *B*4. Projected on the sky between these two objects are o Persei, which is only slightly reddened, and BD +31°643, the strongly reddened star to which we have already referred. The angular distance between these two stars is only 8′. Unless the dark cloud enveloping BD + 31°643 is very sharply edged, this proves that the cloud is behind o Persei, and hence it must be at the distance of the group. This, together with the distribution of the dark objects which suggests a motion from the centre of the group outward like that observed among the stars, renders a genetic relation with the group very probable.

Analyses of starcounts in these regions have been made by SHAJN [1]), REIMER [2]) and HEESCHEN [3]). An average absorption of $2^m$ is indicated by these investigations. More detailed studies of the individual dark clouds, especially of their absorbing power, would be very valuable.

**3.** *The small cluster south of* o *Persei.*

Another interesting feature of the group is the presence of a very small cluster of faint stars immediately south of o Persei. A chart of this group is shown in Figure 5, it was made after an exposure reaching the $12^{th}$ photographic magnitude. The reddened star BD + 31°643 is at its north-eastern border and the other stars, except nos 3 and 7, are also strongly reddened[4]). The diameter of the cluster is about one half parsec, much smaller than the dimensions of ordinary open clusters, which usually are about ten times larger. HUBBLE [5]) and GREENSTEIN [6]) have studied this clus-

1) *Pulkovo Circular* No. 11 (1934).
2) *Mitt. Wiener Sternw.* I, 237 (1936).
3) *Ap. J.* **114**, 132 (1951).
4) See C. H. GINGRICH, *Ap. J.* **56**, 139; *Mt Wilson Contr.* No. 239 (1922).
5) *Ap. J.* **56**, 181, and 404, *Mt Wilson Contr.* Nos 241 (1922) and 250 (1922).
6) *Ap. J.* **107**, 376; *McDonald Contr.* No. 148 (1948).

ter in connection with its relation to the interstellar matter in which it is immersed. Proper motions have been published by KOVALENKO [1]) and by VYSSOTSKY and WILLIAMS [2]).

As important information about the nature of the cluster might be derived from the proper motions, the data by KOVALENKO and by VYSSOTSKY and WILLIAMS have been supplemented with new determinations. The region of the cluster occurs in the *Astrographic Catalogues* of Oxford (Vol. I, plate 2113, 1903 Febr. 18) and of Potsdam (Band IV, plate 25, 1899 Febr. 19). The old positions according to these catalogues have been compared with modern ones, measured on plates taken with the Leiden 33-cm photographic refractor (Plates No. 8632 of 1951 Oct. 2 and No. 8306 of 1951 Febr. 2). The observations, the measurements and the reductions were all made by Mr G. PELS. The results are in Table 3. The numbers in the first column, given also in Figure 4, are those according to GINGRICH, who was the first to study this region astrometrically. In the second column are the photovisual magnitudes according to VYSSOTSKY and WILLIAMS. The next columns give the spectral classes according to VYSSOTSKY and WILLIAMS, HUBBLE (communicated by GINGRICH) and GREENSTEIN. The last columns give the relative proper motions. These are the means of the two Leiden series, and of those of KOVALENKO and of VYSSOTSKY and WILLIAMS. The probable error is $\pm$ 0″/a.0021 for the components in $\alpha$ and $\pm$ 0″/a.0015 for those in $\delta$. The proper motions could be reduced to the fundamental system of Table 1 by means of the relative proper motion of o Persei measured by KOVALENKO and by VYSSOTSKY and WILLIAMS. The reductions are + 0″/a.010 in $\alpha$ and − 0″/a.011 in $\delta$.

Subtracting from these absolute motions the mean values (1) we get the proper motions relative to the mean of the $\zeta$ Persei group. These relative proper motions, which are directly comparable to those in Figure 3, are shown in Figure 5, where the scale of the proper motions has been chosen the same as in Figure 3. It should be noticed that the accuracy of the reduction to absolute is less than that of the individual relative proper motions, as it depends only on the SPROUL and McCORMICK measurements; its probable error is about $\pm$ 0″/a.004 in either co-ordinate. The directions of increasing $\alpha$ and $\delta$ and galactic longitude $l$ and latitude $b$ are indicated in the lower right-hand corner of the diagram.

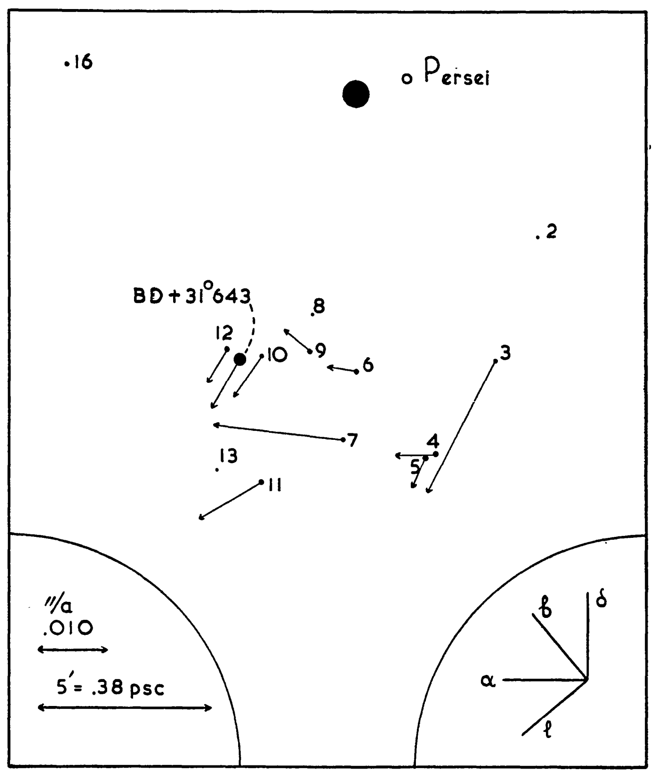
The mean residual proper motion according to Table 3 is $\pm$ 0″/a.0039 in $\alpha$ and $\pm$ 0″/a.0044 in $\delta$, or, when corrected for accidental errors, $\pm$ 0″/a.0034 for the average of the two components. This corresponds to $\pm$ 4.9 km/sec when the parallax (6) is adopted. However, this high value is due mainly to the strongly deviating motions of stars nos 3 and 7. It is quite possible, and even probable, that these are foreground stars. If they are omitted, the remaining dispersion of the proper motions can be explained entirely as due to

TABLE 3

Proper motions in the cluster near o Persei

| No. GINGRICH | $m_{pv}$ | Spectral class VW | H | Gr. | Relative p.m. $\mu_\alpha \cos\delta$ (unit ″/a.001) | $\mu_\delta$ |
|---|---|---|---|---|---|---|
| 3 | 11.1 | F 8 | | | + 3 | − 15 |
| 4 | 9.7 | A 0 | B 8 | | − 1 | + 4 |
| 5 | 9.7 | A 0 | B 8 | | − 5 | 0 |
| 6 | 11.5 | | A 2 | A 7 | − 3 | + 5 |
| 7 | 11.3 | F 8 | F 2 | | + 12 | + 6 |
| 9 | 11.3 | F 8 | A 1 | A 8 | − 3 | + 7 |
| 10 | 11.4 | | B 9 | A 2: | − 3 | − 2 |
| 11 | 10.4 | B 8 | B 9 | A 3: | + 2 | − 1 |
| + 31°643 | 8.3 | B 5 | B 6 | B 5 | − 3 | − 3 |
| 12 | 9.9 | | B 9 | B 9 | − 4 | − 1 |

FIGURE 5




The small cluster of faint stars south of o Persei. The numbering is according to GINGRICH. Proper motions are reckoned with respect to the mean proper motion of the $\zeta$ Persei group. For stars 2, 8 and 13 no proper motions are available.

[1]) *A. J.* **42**, 92 (1932).
[2]) *Publ. Leander McCormick Obs.* X (1948); region No. 404.

the errors of the measures. Stars 4 and 5 form the visual double ADS 2723, whereas BD + 31°643 and no 12 form the multiple system ADS 2730.

AMBARZUMIAN and MARKARIAN [1]) have pointed out that the occurrence of open clusters is a characteristic property of the O-associations in general. It appears doubtful whether open clusters occur in all O-associations; there seems to be no ordinary open cluster definitely associated with the Scorpio-Centaurus group, and we may also refer to VORONTSOV-VELYAMINOV's criticism of AMBARZUMIAN and MARKARIAN's work [2]). Nevertheless, it is quite interesting that the small cluster in the ζ Persei group reminds of this phenomenon in connection with the O-associations in general; and in particular also of a small cluster of faint stars in the Orion group [3]). According to MARKARIAN the clusters which are "nuclei" of the O-associations should always contain O- or B-type giants. In this respect the small cluster near o Persei is exceptional, unless we consider o Persei as belonging to it.

The relation of the cluster with the dark clouds surrounding o Persei and with the ζ Persei group should be more firmly established by more extensive measures of the colours of all the stars in the cluster and by measures of their radial velocities. Further study of the cluster will also be important for the problem of the co-existence of main-sequence stars of intermediate luminosity in groups of early-type stars of high luminosity. A search for similar small clusters in the other regions of the ζ Persei group is now under way at this observatory.

[1]) See the references on page 406.
[2]) *A. J. U.S.S.R.* **27**, 211 (1950).
[3]) R. J. TRUMPLER, *P.A.S.P.* **43**, 255 (1931). W. BAADE and R. MINKOWSKI, *Ap. J.* **86**, 119; *Mt Wilson Cont.* No. 571 (1937).

### 4. *Applications of the hypothesis of initial expansions.*

The observation of expanding motions in the ζ Persei group lends considerable support to AMBARZUMIAN's hypothesis of the occurrence of such motions as an explanation of the phenomenon of the O-associations. AMBARZUMIAN estimated that the initial velocities of expansion should be between 1 and 10 km/sec in order to account for the shapes of the approximately spherical associations, where the influence of these inherent expanding motions apparently predominates the effect of differential galactic rotation. The observed velocities of expansion in the ζ Persei group are undoubtedly unusually large. This follows from the simple consideration that the average residual motions observed among the early-type stars in general are smaller than those observed in the ζ Persei group.

In a following paper we shall show that the principle of the inherent expanding motions in the formation of the O-associations may have an even wider application. It appears to lead to a satisfactory theory of the shape, orientation and dimensions of the Scorpio-Centaurus group of early-type stars, and to an age of 70 million years for this group. It also may be the basis for an understanding of certain characteristic features in the outer parts of the spiral structure of late-type extragalactic nebulae.

I am indebted to Mr G. PELS for his valuable assistance in the investigation described in the third section.