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ON THE LUMINOSITIES, MOTIONS, AND SPACE DISTRIBUTION OF THE NEARER NORTHERN O–B5 STARS

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ABSTRACT

The luminosities, motions, and space distribution of the O–B5 stars within 600 pc and north of declination −20° have been studied, with emphasis on the problem of the calibration of the MK luminosity classifications for the subclasses B1 V, B2 IV, B2 V, and B3 V. Analysis of the apparent distribution of the stars in different distance groups and of their proper motions reveals the existence of a loose group of stars in the constellations Cassiopeia to Taurus, with very small internal velocity dispersion and probably of related origin. This Cassiopeia-Taurus group is identical with the extended Perseus stream recognized by earlier investigators but subjected to doubt more recently. Solutions for the elements of the motions of these stars with respect to the sun are discussed in detail. The conventional procedure of applying corrections for differential galactic rotation does not appear to be justified in the present case, since the principal feature of the relative motions within the group is that of a general expansion and not of differential motions according to different circular galactic orbits. A solution based on the assumption of approximately linear expansion leads to satisfactory elements of motion and an "expansion age" of at least 50 million years. This seems compatible with the H-R diagram of the group, which contains no stars of types earlier than B0 and no absolute magnitudes brighter than −4.7. The average peculiar motions are found to be 2 km/sec in the τ components and 3 km/sec in the radial components. Individual parallaxes and absolute magnitudes are derived for the members of this group.

Other information on absolute magnitudes used for the calibration is derived from the field stars in the region between galactic longitudes 340° and 50°, where the motions are random except for a common solar motion and where they are undisturbed by local streamings or associations. The data thus derived on the luminosities of the northern stars are supplemented with absolute magnitudes in the Scorpio-Centaurus association borrowed from a recent investigation by Bertiau, particulars of which will be published separately. We thus arrive at the following mean visual absolute magnitudes in the $U-B-V$ system: −3.8 for B1 V, −2.7 for B2 IV, −2.4 for B2 V, and −1.5 for B3 V. These apply to stars selected per volume of space and not per apparent magnitude, as were the preliminary values tabulated by Morgan and Keenan. The average deviations from these means are ±0.6 mag. for the three subclasses V and ±0.3 for B2 IV.

The moving cluster around α Persei is shown to belong to the Cassiopeia-Taurus group, which leads to a determination of its distance (127 pc) and of the absolute magnitudes of its members. Mean values for luminosity class V are −0.5 for B3–B5 and +1.6 for B9–A1, suggesting that the main sequence around B3 in the extended group lies somewhat higher than in the cluster.

A few stars of very high space velocity occur in the region of space studied. Of particular interest are 53 Arietis (B2 V) and 68 Cygni (O8). 53 Arietis appears to have originated in the Orion association about 4.8 million years ago and is moving away from it with a speed of 73 km/sec. It is thus the third star known to move with very high velocity from this origin. 68 Cygni very probably originated in the association I Cephei 5.1 million years ago and has a space velocity of 45 km/sec.

I. INTRODUCTION

The present paper describes a study of the space distribution, the motions, and the luminosities of the nearer northern early B-type stars. It is based on the extensive material of spectral and luminosity classifications made by W. W. Morgan on the MK system, and special attention is given to the problem of the calibration of these luminosity classifications. The investigation is limited to the stars within about 600 pc and north of −20° declination. The absolute magnitudes are derived exclusively from the proper motions. Only a few stars of high luminosity occur within the region studied, and the results for the calibration therefore refer mainly to the low-luminosity classes, particularly for B2 and B3. Additional information on the absolute magnitudes of the low-luminosity classes, included in the present discussion, is borrowed from a recent investigation of the Scorpio-Centaurus cluster by Bertiau. The detailed results of Bertiau's work will soon be published separately.

The results of the present paper represent a fundamental step in the process of the calibration of the MK classifications, inasmuch as they determine the zero point of the scale of the absolute magnitudes. They will later be supplemented by the information derived from the associations of early B stars; these will add data particularly on the relative luminosities of the high- and low-luminosity classes. No distances will be derived from the effect of differential galactic rotation, so that this, and particularly the value of the constant A, can later be investigated independently.

Numerous investigations of the motions of the bright B stars have been published during the last twenty-five years. A summary of these has been given by Torondjadze (1953), and we will therefore only occasionally refer to earlier work. It appeared desirable to reinvestigate the kinematical properties of the nearer B-type stars in order to arrive at the most reliable use of the proper motions as a measure of distance. As a result, the data on the calibration obtained in the present paper are based mainly on the following stars:

1. The nearer stars in the region from Cassiopeia to Taurus. These stars seem to form a loose association. The small internal velocities in this group allow an estimate of the individual absolute magnitudes.
2. The stars in the region between galactic longitudes 340° and 50°. Here the proper motions can be interpreted on the basis of solar motion and random peculiar motions without complications by associations.

The region occupied by the stars studied in this paper contains several associations—Orion, Lacerta, II (ζ) Persei—the α Persei cluster, the loose group just mentioned, and a fairly uniformly distributed population of "field" stars in the lower longitude section. It may well be considered as a representative sample of a spiral-arm population of early-type stars.

II. BASIC OBSERVATIONAL DATA

Morgan's observations have covered most of the *Henry Draper* O to B3 stars north of declination $-20°$ and many south of this limit. The *HD* B5 stars were completely observed to apparent magnitude 6.5, whereas the fainter ones are as yet very incompletely observed.

Accordingly the basic list of stars in the present investigation was chosen as follows: (*a*) all the stars north of declination $-20°$ and brighter than visual magnitude 8.5, classified by W. W. Morgan as O–B5 in the MK system; and (*b*) the remaining *HD* O–B3 stars within the same limits of declination and magnitudes. These stars were included in the first stage of the investigation in order to obtain an estimate of the completeness of the data for O–B3 in the various distance groups discussed later.

The basic list may thus be assumed to be fairly complete for the MK types O–B3 (classified *plus* still unclassified), but it contains only the brightest of the MK B5 stars. Some aspects of the completeness of the basic list will be considered in the next section.

In correcting the visual magnitudes for interstellar absorption, we have used the observed colors by Stebbins, Huffer, and Whitford (1940) and the intrinsic colors and the relation $A_{\text{vis}} = 6.1E_1$ as given by Morgan, Harris, and Johnson (1953). For a small number of stars, $B - V$ colors and V magnitudes have been used (see Sec. V, *d*).

The proper motions were taken from the Albany *General Catalogue* (Boss 1937) and combined with new values derived by Dr. H. R. Morgan from recent meridian observations. Part of these have been published in the "N30" catalogue (H. R. Morgan 1952). For the fundamental system we adopted the average of FK3 and N30. The difference between the two systems is generally small for the region of the sky with which we are concerned here. Precessional corrections were applied as recommended by Morgan and Oort (1951). The radial velocities were taken from Wilson's (1953) catalogue.

III. DISTANCE GROUPS; COMPLETENESS

The stars in the basic list were first divided into distance groups according to provisional distance moduli, computed with the provisional mean visual absolute magnitudes for stars of a given apparent magnitude, tabulated by Keenan and Morgan (1951). For the main-sequence subclasses these values were based partly on a preliminary analysis by the author (Blaauw 1952*a*). Only the stars in three distance groups within 600 pc were retained for the present discussion. Particulars about these three groups are given in Table 1. The distribution on the sky for the stars between galactic latitudes −50° and +40° in these three modulus groups is shown in Figures 1*a* and 1*b*, 2*a* and 2*b*, and 3*a* and 3*b*. Stars of MK types O–B3 are represented by dots; types B5 by open circles.

The stars in the three associations within 600 pc were all plotted in the modulus group corresponding to the distance of the association, although a good many of them would have been assigned to other modulus groups on the basis of individual values of $m_0 - M$. In the case of the Orion association with $m_0 - M = 8.5$ (Sharpless 1952), all stars within the region R.A. = 5^h12^m to 5^h44^m, Decl. = +5° to −8° were assigned to modulus group C. All stars in the II (ζ) Persei association, for which $m_0 - M = 7.4$ (Blaauw 1952*b*), were placed in group B, and those in the Lacerta association, with $m_0 - M = 8.3$ (Blaauw and Morgan 1953), in group C.

TABLE 1

DISTANCE GROUPS AND NUMBERS OF STARS

	Group A	Group B	Group C
Provisional distance moduli	<6.6	6.6–7.9	8.0–8.9
Provisional distances (pc)	0–200	200–400	400–600
No. MK O–B3 stars outside associations and clusters in basic list	24	83	128
No. MK B5 stars outside associations and clusters in basic list	19	31	7

To those stars in the basic list which have no MK classification (*HD* types B3 and earlier) but for which the color is known, we have tentatively assigned a distance modulus according to the *HD* spectral type and luminosity class V. None of these stars then falls into group A or B and 10 into group C. For 35 stars no color or MK type is available. All these are fainter than visual magnitude 7.5, three are of *HD* type B2 and the remainder of type B3. These 35 stars and the 10 mentioned before are plotted as plus signs in Figures 3*a* and 3*b*. Very likely a considerable fraction of these will eventually prove to be beyond the distance limit of 600 pc of group C, and few or none in group A or B. Further, there are 10 stars in the region studied without MK classification and classified as B without subclass in the *Henry Draper Catalogue*. All these are fainter than visual magnitude 8.0. Judging by the MK classifications of other stars in this category, we can safely assume that they will all turn out to be OB stars beyond 600 pc. We conclude that within the distance of 600 pc we have MK classifications for nearly all the stars classified as B3 or earlier in the *Henry Draper Catalogue*.

Part of the stars belonging to MK types B2 and B3 occur as later-type B stars in the *Henry Draper Catalogue*. Therefore, the incompleteness of the observations of the *HD* B5 stars fainter than magnitude 6.5 also causes incompleteness in the MK types B3 and earlier. The same holds for the *HD* types B8 and later, but these will contribute less to the MK types B3 and earlier. The numbers of stars of MK types B3 and earlier which would be added by a complete classification of the *HD* type B5 and later are hard to estimate, as the relation between the two systems of classification appears to vary over

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the sky and the MK classifications for the fainter *HD* stars are not yet numerous enough. A rough estimate indicates that probably very few stars of MK types B3 and earlier are lacking from the modulus groups A and B but that some 20 or 30 B2 and B3 main-sequence stars are still missing in modulus group C.

IV. PROPER MOTIONS AND APPARENT DISTRIBUTION ON THE SKY

The proper motions are quite accurate for the brightest and nearest stars. For the stars in modulus group C they are generally poor. With increasing distance of the stars, the sizes of the proper motions diminish, whereas their probable errors increase, the stars becoming fainter and having less meridian observations; hence the proportions between the errors and the sizes of the proper motions increase rapidly from modulus group A to group C. For our present purpose proper motions with probable errors in excess of $\pm 0\overset{''}{.}006$ are of little use, and only the more accurate ones have been plotted in Figures 1–3; those with probable errors below $\pm 0\overset{''}{.}004$ as full lines, the remaining ones as dashed lines. The scale is indicated in the lower-left-hand corner of Figures 1*a*, 2*a*, and 3*a*. No individual proper motions are plotted for the stars in the three associations (II [ζ] Persei, Orion, and Lacerta) and in the α Persei moving cluster. For the Perseus and Lacerta associations and the α Persei cluster the mean values are plotted at their centers. Stars for which no proper motions were plotted are represented by somewhat smaller symbols.

The six diagrams reveal some interesting properties of the space distribution and motions:

1. In modulus group A, Figures 1*a* and 1*b* (stars within 200 pc), the stars are somewhat more numerous between longitudes 80° and 200° than between 340° and 80°, even if we do not count those in the α Persei cluster, which is located at $l = 115°$, $b = -5°$. Nearly all stars in Figure 1*a* are at negative galactic latitudes, whereas those in Figure 1*b* are distributed symmetrically with respect to the galactic circle. The Gould belt is very clearly marked by the location of these nearest stars.

The proper motions in Figure 1*a* are remarkably parallel and generally of the same size. Those in Figure 1*b* are smaller. This does not seem to be due only to the fact that these latter stars are located around the solar apex, the standard co-ordinates of which are $l = 24°$, $b = +22°$, for we notice that the large motions in Figure 1*a* persist up to about 30° from the standard antapex ($l = 204°$, $b = -22°$). Figures 1*a* and 1*b* suggest strongly that between longitudes 80° and 170° there is a group of stars within 200 pc from the sun whose relative velocities are very small compared to their systematic motion with respect to the sun. We shall call this group the "Cassiopeia-Taurus group."

2. The distribution of the stars in Figure 2*a* (modulus group B, 200–400 pc) lends support to the assumption that the nearest Cassiopeia-Taurus stars form a more or less isolated group, for there are very few more distant stars in modulus group B between galactic longitudes 90° and 140°. Near the center of this region is the II Persei association, and the region immediately around it is remarkably devoid of stars. It is unlikely that this is due to interstellar absorption, which might have eliminated these stars from our basic list, for the heavy absorption takes place mainly in the Taurus clouds and in the immediate vicinity of the II Persei association. The Taurus clouds are represented by the shaded area around $l = 140°$, $b = -10°$ in Figure 1*a;* the contour lines correspond to photographic absorptions of 1, 2, and 3 mag., according to McCuskey's (1941) analysis of star counts. The distance of the Taurus clouds is estimated at about 145 pc (see, e.g., Greenstein 1937).

The proper motions in Figure 2*a* are generally smaller than those in Figure 1*a*, as one would expect from the difference in the mean distances, but a number of them have the same size and direction as those in modulus group A. They may actually be stars at the smaller distances of group A, but with lower-than-average luminosities, which place

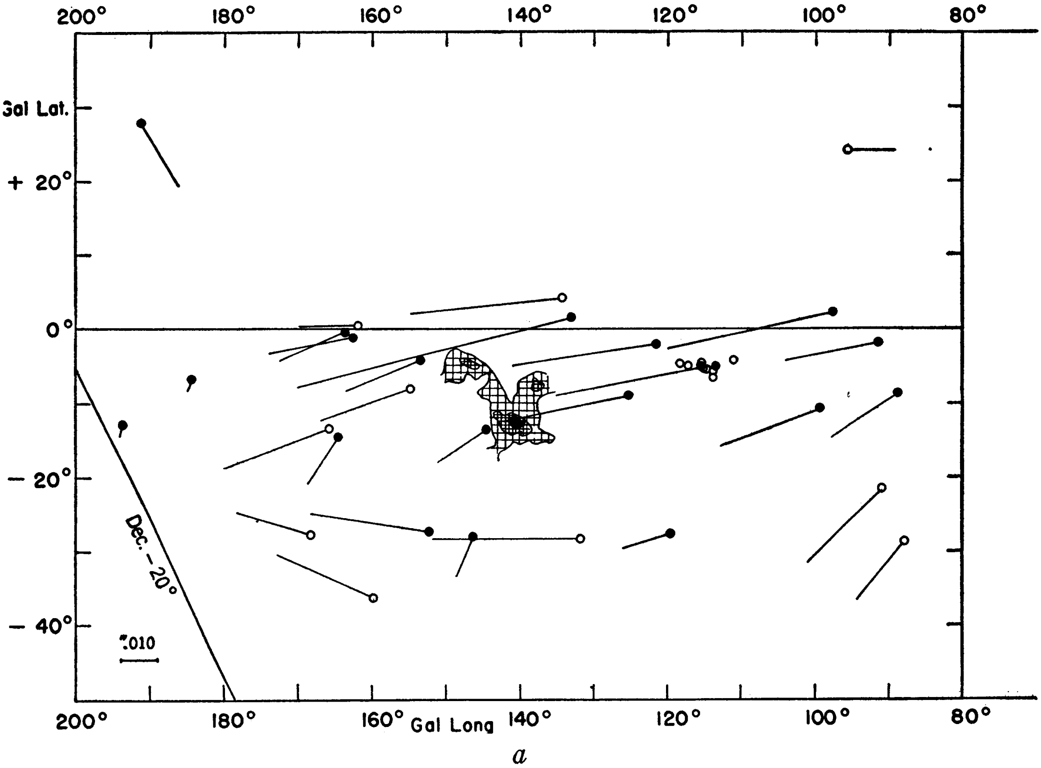

FIG. 1, *a* and *b*.—Apparent distribution and proper motions of the stars in modulus group A (corresponding to distances within 200 pc). *Dots:* MK types B3 and earlier. *Open circles:* MK type B5. Lines drawn from the dots and circles represent proper motions with probable errors below ″.0040; dashed lines represent those with probable errors between ″.0040 and ″.0060 The scale of the proper motions is given in the lower left corner. The hatched region represents the Taurus dark cloud complex. At $l = 115°$, $b = -4°$ is the α Persei cluster.

them in modulus group B. There is a striking difference in the character of the proper motions of the stars above and below galactic longitude 160°. This longitude appears to mark the boundary of the Cassiopeia-Taurus group. On the whole, the space distribution of the stars in group B at longitudes higher than 90° is rather spotty, and it clearly follows the Gould belt.

In Figure 2*b* we find almost ten times as many B3 and earlier-type stars as in Figure 1*b*, whereas, on the basis of the distance limits, one would expect only three or four times as many (we do not count the B5 stars which are already incomplete in modulus group B). The distribution of the stars is fairly uniform, with a majority of them north of the galactic plane. There is a chain of stars at high negative latitudes around longitude 45°. This region is not known to contain heavily obscuring near-by clouds (Bok 1937), but it is of some interest to notice that it shows large deficiencies in Hubble's (1934) counts of extragalactic nebulae. These high-latitude stars may perhaps be associated with a cloud complex at a great distance from the galactic plane. The Lacerta association (at $l = 65°$, $b = -15°$ in Fig. 3*b*) may also be associated with this "flare" of interstellar gas. From Figures 2*b* and 1*b*, it looks as if a uniformly distributed population of early B stars sets in at a distance of about 200 pc. The peculiar motions of these stars are appreciably larger than those in the Cassiopeia-Taurus group (see also Sec. VII).

3. In Figure 3*a* (modulus group C, 400–600 pc) the small number of stars between longitudes 100° and 150° indicates that the emptiness at these longitudes, noted in Figure 2*a*, extends to at least 600 pc. The scarcity of early B-type stars in these directions has

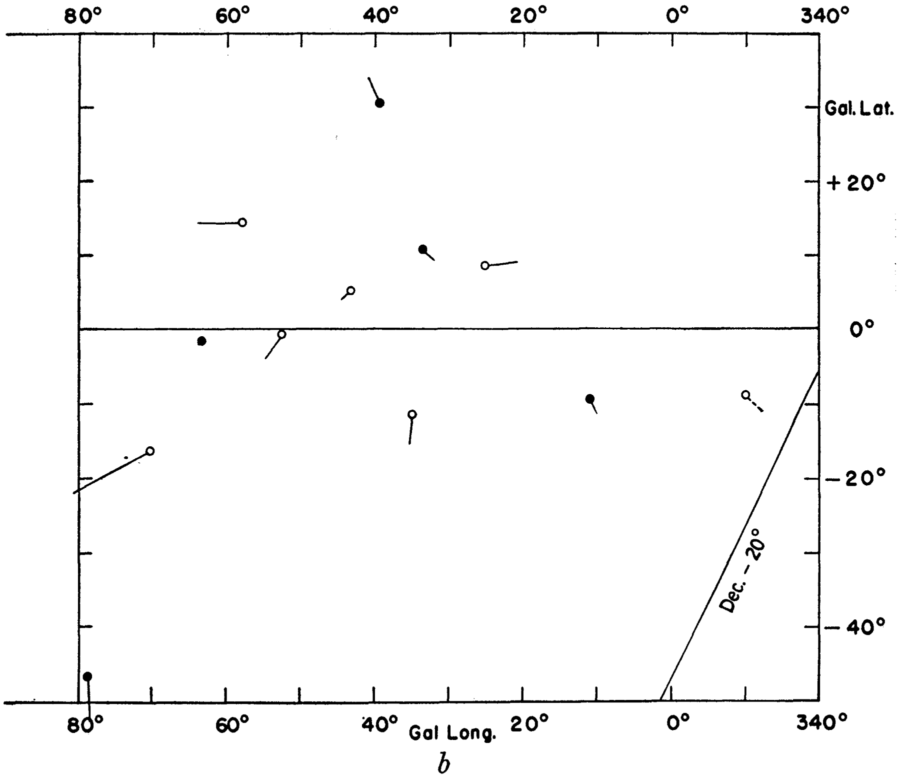

FIG. 1*b*.—See legend under Figure 1*a*

been pointed out earlier by Weaver (1953) on the basis of a study of the space distribution of the OB stars. The local arm, according to Weaver, shows a break in the directions *l* = 110°–145°. The population according to Figure 3*a* is dense at higher longitudes, where the Orion association is located. At longitudes below 90° the population is more or less uniform, as in group B, but in addition it contains the Lacerta association. The Orion association still lies in Gould's belt, which is, however, no longer perceptible below longitudes 150°. Only a few stars in modulus group C have accurate proper motions. Some of them, according to the size and direction of the proper motion, seem to belong to the near group of Figure 1*a*.

In Figure 3*b* the motions are rather irregular. Between longitudes 50° and 80° they are complicated by the fact that part of the stars may be associated with the association I Cephei, around *l* = 69°, *b* = +4°, which is located at a distance of 720 pc just beyond group C (Morgan, Whitford, and Code 1953). There appears to be considerable internal motion and probably expansion in this association (see also Markarian 1953; Artiukhina 1954), and some stars outside the association may be connected with it. An example is the O8 star HD 203064 (68 Cygni) at *l* = 55°.4, *b* = −4°.4 (see also Sec. X for more particulars about this star). A few stars may be associated with the Lacerta association, like those at *l* = 44°.4, *b* = −5°.5 (HD 197419) and at *l* = 52°.5, *b* = −5°.4 (HD 201910) (see also Blaauw and Morgan 1953).

For the calibration of the luminosity classifications it is important that those stars be used for which the interpretation of the proper motions in terms of distances is most reliable. We have, therefore, decided to confine the further analysis to two selections: the Cassiopeia-Taurus group, with its small internal velocities, and the region around the solar apex, where the proper motions can be interpreted on the basis of a common

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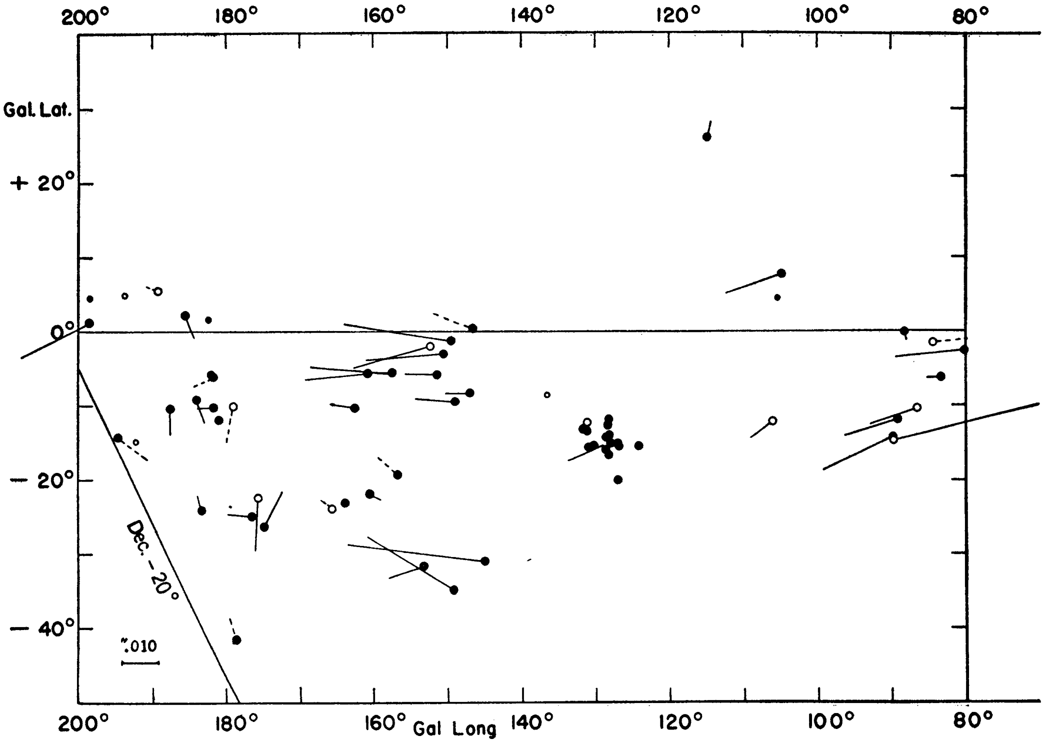


FIG. 2, *a* and *b*.—Apparent distribution and proper motions for modulus group B (200 to 400 pc). The meaning of the symbols is the same as in Fig. 1. At $l = 128°$, $b = -15°$ is the II (ζ) Persei association.

solar motion combined with random peculiar motions. For the latter, we chose the region between galactic longitudes 340° and 50°, thus avoiding the complicated motions between $l = 50°$ and $l = 80°$.

V. THE CASSIOPEIA-TAURUS GROUP

a) *Solutions for Convergent Point and Stream Velocity*

The speed and direction of the motion of this group with respect to the sun have been determined from the directions of the proper motions and from the radial velocities. The sizes of the proper motions were not used. This could have been done, with an assumption concerning the relative distances of the stars based on their provisional distance moduli. The method would have remained somewhat uncertain, however, because of the fairly large range in absolute magnitudes within the principal luminosity classes (see Secs. V, *f*, and VIII). Since the directions alone gave a sufficiently accurate convergent point for our present purpose, the sizes of the proper motions were used only in the determination of the distances.

Usually, in the determination of the elements of the solar motion from stars distributed over a large region of space, one applies corrections for differential galactic rotation to the observed proper motions and radial velocities. This is done on the assumption that different parts of the assembly of stars studied have relative motions which are approximately the same as the relative motions in circular orbits around the galactic center. By applying corrections for differential galactic rotation, one eliminates these relative motions. What is left, then, are the motions of the stars with respect to the local circular velocities plus a common solar motion.

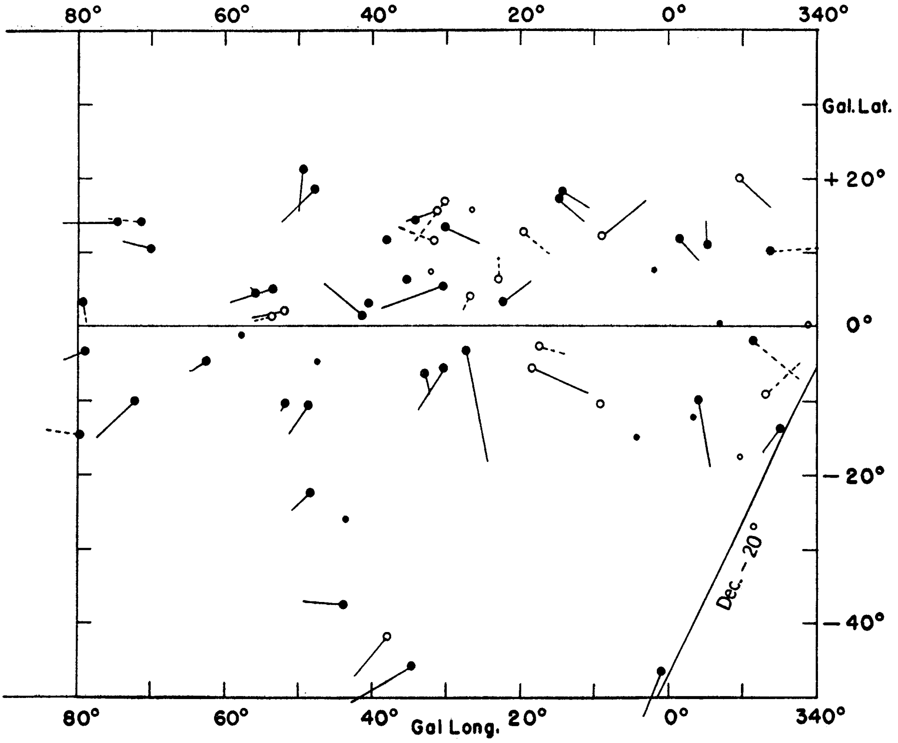


FIG. 2*b*.—See legend under Figure 2*a*

It is questionable whether this procedure should be applied to the Cassiopeia-Taurus group. Both the observation that the group is confined within a region of a few hundred parsecs and the fact that the internal velocity dispersion is small suggest that we are dealing with stars of related origin. If that is the case, the relative motions in different parts may be entirely different from those corresponding to circular motions around the galactic center. We might, for instance, suppose that the stars originated more or less simultaneously in a small volume of space; the question then is whether, after a reasonable lapse of time, the relative motions still display as a principal feature the motions away from this origin or whether they approximate the differential galactic rotation just described.

In order to see how much the corrections for differential galactic rotation affect the solution, we have analyzed the proper motions and radial velocities with and without these corrections. The corrections were based on the values of the constants A and B of rotation as recommended by Morgan and Oort (1950). We shall distinguish between solution I, without corrections, and solution II, with corrections applied. After the convergent point had been determined from the proper motions, the stream velocity toward this convergent and a K term were derived from the radial velocities. The procedure was formally the same in both solutions. Their interpretations are, however, quite different. They will be discussed in the next subsections.

We have used the following stars in determining the convergent point:

1. Those in Figure 1*a*, below galactic longitude 180° and between the latitudes of −40° and +10° but excluding the α Persei cluster, which will be discussed separately in Section IX, and the star λ Tauri at $l = 146°$, $b = -28°$. The exclusion of the latter is somewhat arbitrary. The deviation of its motion from the general pattern is well estab-

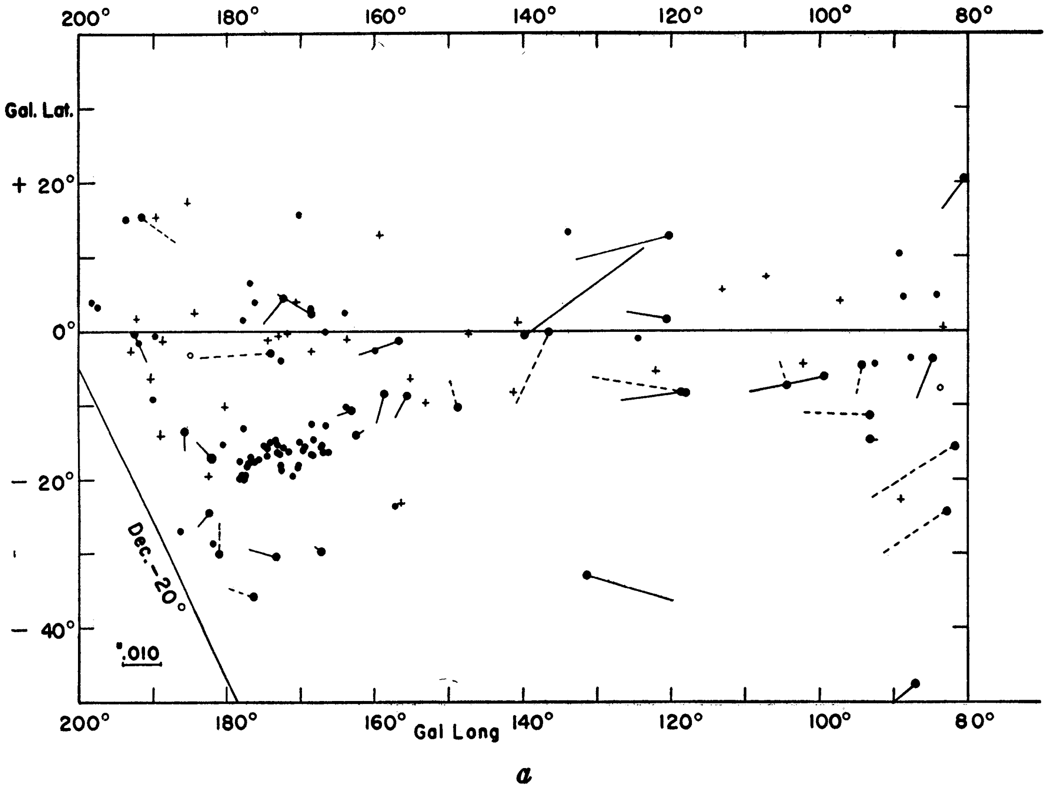


FIG. 3, *a* and *b*.—Apparent distribution and proper motions for modulus group C (400 to 600 pc). Plus signs represent stars without MK classification which may lie in the modulus group. The meaning of the other symbols is the same as in Fig. 1. At $l = 170°$, $b = -17°$ is the Orion association and at $l = 67°$, $b = -16°$ the Lacerta association.

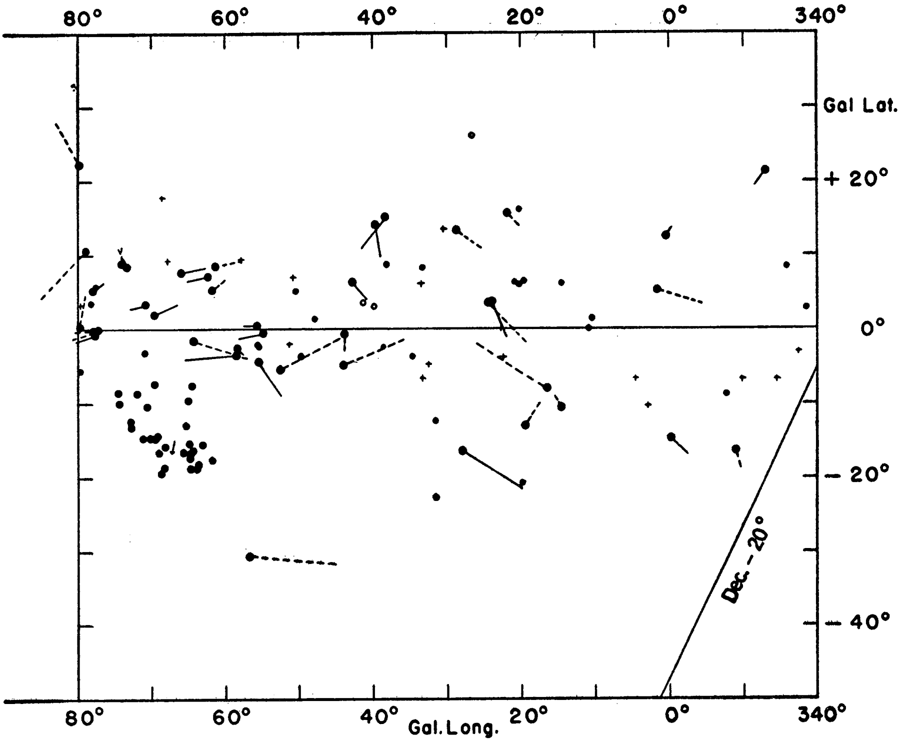
lished; on the other hand, the other stars also show certain, though smaller, mutua differences in motion.

2. Of the stars in Figure 2*a*, the group around $l = 150°$, $b = -5°$; the three stars around $l = 150°$, $b = -30°$; the four with proper motions of about 0″.015 around $l = 85°$, $b = -10°$; and the star at $l = 105°$, $b = +8°$.

The star at $l = -70°$, $b = -16°$ in Figure 1*b* was also included in the first steps but does not contribute to the final determination (see below).

The stars were divided into subgroups according to their position in the sky. Table 2 gives their mean co-ordinates, the numbers of stars, the mean proper motions in galactic longitude and latitude, and the mean radial velocities, all without corrections for differential galactic rotation. The mean proper motions and the numbers of the subgroups are also shown in Figure 4. Almost all the stars used occur in Table 5, where the number in the fourth column refers to the subgroup in which the star was used.

Some explanation is required for the treatment of the stars around $l = 150°$, $b = -5°$. One notices in Figures 1*a* and 2*a* a curious difference between the direction of the motions in that part of the sky for the two modulus groups. Those in group B (Fig. 2*a*) are approximately parallel to the galactic equator, whereas those in group A (Fig. 1*a*) are directed away from it. At first sight, the stars in the two groups seem to have a relative motion perpendicular to the galactic plane. There are, however, reasons to doubt whether this is real. There is probably considerable overlap in the true distances of the stars in the two groups. This follows both from the fact that the range of the true absolute magnitudes within the subclasses B2 V and B3 V, to which most of these stars



b

FIG. 3*b*.—See legend under Figure 3*a*

belong, is considerable, so that the true distance moduli of groups A and B are not sharply separated, and from the fact that the sizes of the proper motions in the two modulus groups overlap. We would then be dealing with two kinematically different, but intermingled, groups, and it is hard to see how our division into modulus groups could so nicely have separated them. No quite satisfactory explanation can be offered, and only a suggestion will be made. The differences in the proper motions in latitude are approximately differences in the motions in right ascension. The stars in modulus group

TABLE 2

SUBGROUPS IN THE CASSIOPEIA-TAURUS REGION

(Observed Quantities Not Corrected for Differential Galactic Rotation)

No. of Subgroup	No. of Stars	Mean Co-ordinates		Mean Proper Motion (0″.0001)		Mean Radial Velocity ± p.e. (km/sec)	Residuals in Radial Velocity (km/sec)	
		l	*b*	$\mu_l \cos b$	μ_b		Solution I	Solution II
1	3	83°.0	−22°.2	+180	−157	− 9.7±10	. .	. . .
2	9	92.0	− 5.6	+207	− 57	− 3.4± 2.3	+1.4	+0.7
3	2	125.7	−28.2	+265	− 20	+16.5± 2.2	+6.6	+6.6
4	4	128.4	− 1.3	+470	− 90	+ 4.0± 1.3	−5.2	−5.2
5	6	154.7	−31.6	+245	+ 67	+14.9± 1.3	−3.6	−4.1
6	8	155.8	− 4.9	+245	− 41	+20.5± 0.9	+2.2	+1.6
7	9	154.4	− 6.4	+122	− 29	+21.3± 1.4	+1.8	+1.2

A have apparent magnitudes 1.7–5.3; those in group B from 4.9 to 6.1 (the mean magnitudes are 4.0 and 5.4, respectively). A magnitude error in the proper motions in right ascension of $0''.007$ ($0^{s}.0005$) would account for the difference. So large an error for bright stars seems unlikely, but, on the other hand, regional magnitude errors amounting to as much as $0^{s}.0010$ have been shown to exist for stars fainter than magnitude 6.0 (Delhaye 1955). We have assumed that the difference in the latitude motion is not real and,

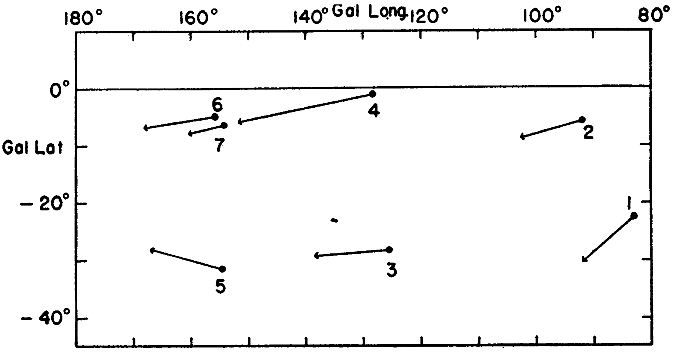


FIG. 4.—Mean positions and mean proper motions of the subgroups in the Cassiopeia-Taurus region. Numbers refer to the numbering of the subgroups.

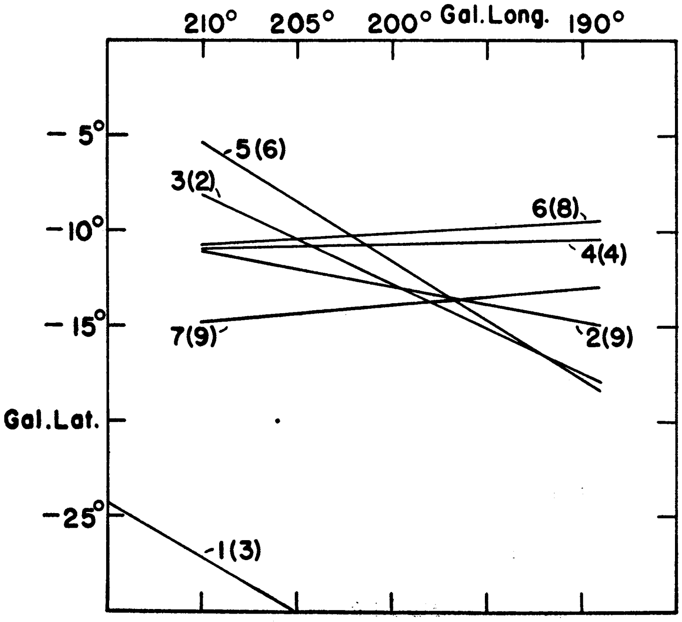


FIG. 5.—Sections of the great circles defined by the mean proper motions, determining the convergent point of the Cassiopeia-Taurus group. Numbers of stars in the various subgroups are in parentheses.

for further analysis, have subdivided the stars in this region into one subgroup (No. 6) with large and one (No. 7) with small proper motions. This selection avoids most of the possible magnitude effect.

Figure 5 shows, for solution I (no corrections for differential galactic rotation), the sections of the great circles defined by the directions of the mean proper motions in the vicinity of the convergent point. The numbers refer to the numbers of the subgroup with the numbers of stars in parentheses. Except for subgroup 1, the great circles define the

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convergent point reasonably well. The three stars in subgroup 1, all of type B5, deviate systematically. They are excluded from further discussion. The position of the convergent point was determined by computing the latitudes at which the circles intersect the galactic meridian circles between $l = 195°$ and $l = 205°$ and by defining the longitude of the convergent point, L_0, as the value for which the scatter in these latitudes is a minimum. The mean latitude at this point was taken as the latitude of the convergent point, B_0. The various subgroups were weighted according to the numbers of stars. The results for solutions I and II are in the first lines of Table 3. The difference between the two solutions is small.

TABLE 3

SOLUTIONS FOR SOLAR MOTION AND K TERM

	Solution I (No Corrections for Differential Galactic Rotation)	Solution II (Differential Galactic Rotation Eliminated)
Longitude of convergent point (L_0)	201° ± 3° (p e.)	198° ± 3° (p e.)
Latitude of convergent point (B_0)	−12°.0 ± 0°.5	−11°.9 ± 0°.5
R.A. of convergent point	99°	97°
Decl. of convergent point	−24°	−21°
Stream velocity, S (km/sec)	24.1 ± 2.1	19.8 ± 2.2
K term (km/sec)	+2.2 ± 1.0	+5.1 ± 1.1

The radial velocities were analyzed with the formula

$$\rho = S \cos \lambda + K \;, \tag{1}$$

where ρ is the observed radial velocity of a star and λ its angular distance from the convergent point. S and K will provisionally be called the "stream velocity" and the "K term," but we shall see later that their interpretation is different for solutions I and II. The results are in Table 3. We notice that solution II, with corrections for differential galactic rotation applied, differs from solution I by a larger K term and smaller stream velocity. Residuals O − C for the two solutions are in the last two columns of Table 2. They are similar.

b) *Interpretation of Solutions I and II*

Let us first consider a group of stars in a state of strictly linear expansion, i.e., with velocities directed outward from the center and proportional to the distance from it. The rate of expansion is k km/sec/pc. The motions of these stars are observed from the sun, which has a certain velocity with respect to the center of the group. How are this velocity and the expansion effect shown in the proper motions and radial velocities?

The rate of expansion of the group is the same, irrespective of the star in the group from which it is observed. Hence the state of motion of the members of the group with respect to the sun can be described by the motion of any of its members and an expansion at the rate k with respect to this star. Consider an imaginary star N, belonging to the group and at the time of observation coinciding with the sun, but with a relative velocity S' with respect to the sun. As seen from the sun, all the stars will have the velocity S' and, superimposed on this, the linear expansion k with respect to the sun. From this the following conclusions may be drawn:

1. The proper motions cannot reveal the expansion of the group, as this is observable only in the line of sight; they all converge toward one convergent point just as in the case of parallel motions of the members. However, the direction of the convergent is the

direction of the motion of star N with respect to the sun, not the direction of the motion of the group's center with respect to the sun.

2. The radial velocities will contain two terms: one is due to the motion S' and equal to $S' \cos \lambda$; the other is rk, where r is the distance of the star from the sun:

$$\rho = S' \cos \lambda + r k \; . \tag{2}$$

If the distance of the center of the group from the sun is r_0, then the motion of this center with respect to the sun is the vector sum of S' and $r_0 k$.

Before discussing the applicability of relations (1) and (2), let us now investigate how far we are justified in assuming that an association in a state of disintegration resembles the case of strictly linear expansion, as described previously. The evolution of expanding associations has been considered in an earlier paper, with special application to the Scorpio-Centaurus association (Blaauw 1952*c*). As an illustration, we reproduce here in somewhat modified form the case in which the initial velocities of expansion from the origin are 1 km/sec or less and the age of the association 70×10^6 years. The initial velocities are supposed to be in the galactic plane and isotropic. Figure 6 shows the configuration in the galactic plane after 70×10^6 years. The outer ellipse corresponds to the stars with initial velocities $s_0 = 1$ km/sec. The shape of this configuration depends only on the time elapsed since the beginning of the expansion; its dimensions depend on s_0. Stars with velocities s_0 smaller than 1 km/sec will be located on a configuration of the same shape as that for $s_0 = 1$ but of proportionally smaller dimensions. A few of the stars with $s_0 < 1$ km/sec are shown in the drawing.

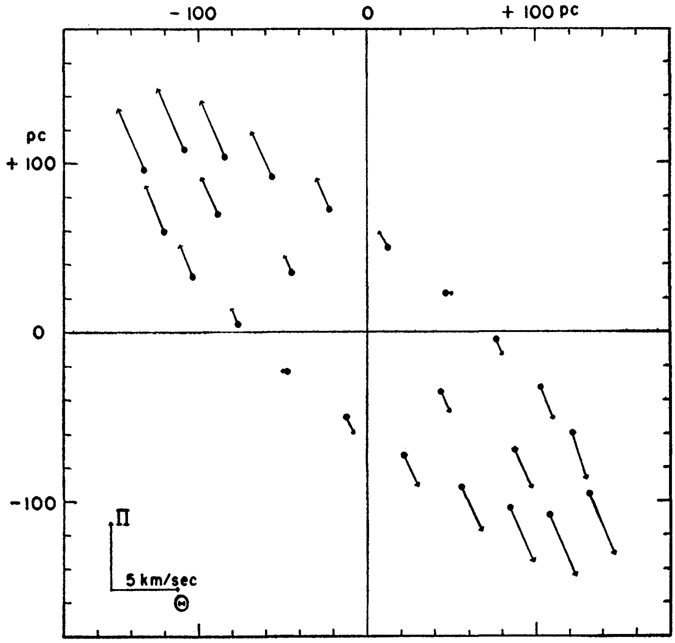

FIG. 6.—Pattern of velocities parallel to the galactic plane for the stars in an expanding association in the neighborhood of the sun at an age of 70 million years and with initial velocities of 1 km/sec or less. Direction of components Π (toward anticenter) and Θ (of galactic rotation) are indicated in the lower-left-hand corner, showing also the scale of velocities.

The arrows represent the velocities of the stars with respect to the origin of the group. The components Θ are in the direction of galactic rotation, the components Π in the direction of the anticenter of the Galaxy. The pattern of velocities is slightly different from that given in Figure 5*b* of the earlier paper, as the motions there were counted in the specially selected rotating co-ordinate system ξ, η. For the comparison with actually observed quantities it is better to consider them in the Π, Θ system. The scale of velocities is given in the lower-left-hand corner of Figure 6.

We compare this velocity pattern with the patterns for differential galactic rotation and for linear expansion. The latter can easily be visualized. The pattern for differential galactic rotation is rather complicated; its radial components with respect to the origin are inward in the upper-right and lower-left quadrants of Figure 6 and outward in the other two. The tangential component shows the well-known double sine wave in galactic latitude combined with the constant term connected with the constant B.

If a detailed comparison is made with these two cases, it is found that the pattern of Figure 6, although it is definitely different from both, shows more resemblance to the case of linear expansion than to that of differential galactic rotation. The quality of the observational data does not justify a more refined consideration of the velocity pattern of a dispersing group. We shall therefore assume that the case of linear expansion is a suitable approximation of its state of motion and shall ask whether the motions in the Cassiopeia-Taurus group are better represented by this or by the differential galactic rotation exhibited by a sample of field stars.

Solution II applies to the latter case. Since corrections for differential galactic rotation were applied to the observational quantities, we would expect to find an approximately normal solar motion, but no K term. The solar motion has indeed its usual value, but the K term, even after subtraction of a gravitational red shift of +1 km/sec, is much higher than can be accounted for by observational errors in the radial velocities. We conclude that the motions in the Cassiopeia-Taurus group are distinctly different from those in a sample of field stars.

In the case of linear expansion, no corrections should be applied for differential galactic rotation. Solution I is therefore applicable to this case, except that the solution should have been made with equation (2) instead of equation (1). We may, however, with sufficient approximation put $\langle r \rangle k = K$, where $\langle r \rangle$ is the mean distance of the stars in the Cassiopeia-Taurus group, because the mean provisional distances in the six subgroups 2–7 are approximately the same. They are all between 170 (for subgroup 5) and 200 pc (for the mean of subgroups 6 and 7) except for group 4, 110 pc; but this group has only four stars. It would, therefore, have made little difference if a solution had been made with equation (2) and the provisional individual distances r instead of equation (1). Using the mean provisional distance, 180 pc, we have $180k = K$. We subtract from K a gravitational red shift of +1.0 km/sec and hence have $180k = +1.2$ km/sec $\pm$ 1.0 (p.e.), and $k = 0.007 \pm 0.006$ km/sec/pc.

Apparently the rate of expansion may have any value between 0 and 2 km/sec per 100 pc. On the assumption of linear expansion, this corresponds to an age of more than 50×10^6 years. It can easily be shown that this age, derived for the case of strictly linear expansion, also applies if we have only the approximate linear expansion shown in Figure 6, which is a result of the galactic orbits of the stars with respect to their origin. The mean outward velocity along the major axis of the elliptical configuration in Figure 6 increases linearly and amounts to 2.4 km/sec at a distance of 170 pc from the center. This corresponds to an expansion rate of 0.014 km/sec/pc. The linear expansion derived from the assumed initial velocity $s_0 = 1$ km/sec and the age of 70×10^6 years would give a rate of expansion of 1 km/sec per 70 pc or 0.015 km/sec/pc. Hence we see that the expansion age derived from the observed state of motion on the assumption of strictly linear expansion is a good approximation of the true age. An age of 50×10^6 years or more seems quite reasonable for the Cassiopeia-Taurus group, in view of the fact that the group contains no stars of absolute magnitudes brighter than -4.7 and no types earlier than B0.

The foregoing considerations are, of course, of a very simplified nature in several respects. No attention has been paid to the motions in the direction perpendicular to the galactic plane. If the initial velocities were less than 1 km/sec on the average, the velocities perpendicular to the galactic plane probably would not have significantly changed the thickness of the group in this direction, which is compatible with the fact that it is still confined within the Gould belt.

We conclude that solution I leads to a plausible interpretation, whereas solution II does not. Solution I will, therefore, be preferred for the further treatment in this paper. It seems quite natural to assume the stars of the Cassiopeia-Taurus group to have a more or less related origin. On the other hand, the foregoing considerations should not be taken as an attempt to demonstrate that these stars have really been formed simultaneously in one association. We would prefer the more general statement that they may have originated within a much smaller volume than that occupied by the group at present and that their average age is of the order of 50 million years or more.

The elements of the solar motion with respect to the center of the group can now be found, adopting for S' the value of S in Table 3, solution I, and combining this, as previously described, with the velocity $r_0 k$, where $r_0 = 150$ pc, taken from Table 4 (see also Sec. V, *g*). The galactic longitude of the center of the group is 124°. We thus find the elements of motion in Table 4.

TABLE 4

MEAN POSITION AND MOTION OF CASSIOPEIA-TAURUS GROUP

Mean position:
$l=124°$, $b=-11°$, distance, $r_0=150$ pc

Mean motion with respect to the sun:	
Component X (toward $l=0°$, $b=0°$)	−22.6 km/sec
Component Y (toward $l=90°$, $b=0°$)	− 7.6 km/sec
Component Z (toward $b=90°$)	− 5.0 km/sec
Mean motion corrected for standard solar motion:	
Component X	− 5 6 km/sec
Component Y	− 0 2 km/sec
Component Z	+ 2 3 km/sec

Total velocity, 6.1 km/sec toward $l=182°$, $b=+22°$

The latitude of the convergent point is lower than that found from the bright stars of later types for which an average value of −20° might be taken (Delhaye 1951), whereas somewhat better agreement exists with the results derived from tenth- and eleventh-magnitude A–K stars (Vyssotsky and Williams 1948). The Cassiopeia-Taurus group appears to have a motion perpendicular to the galactic plane with respect to the A–K stars in the vicinity of the sun of about +3 km/sec.

A different interpretation of the large positive K term which results from solutions similar to solution II has recently been proposed by Torondjadze (1953). This author considers the state of motion which would have existed for the B-type stars if these had originated simultaneously in expanding associations arranged along a spiral arm. It appears that the motions observed at present from the location of the sun should then show a K term which might well be of the order of that observed for the bright B stars. In this manner, Torondjadze relates the observed dynamical properties of these stars—which are in several respects different from those of later types—to their young age and their initial velocities in the association.

Although this theory has some attractive features, it is doubtful whether it is really applicable to the bright B stars. The Cassiopeia-Taurus group and the Scorpio-Centaurus association are together almost fully responsible for the large K term in the classical radial-velocity solutions, but the limited dimensions and the very small internal velocity dispersion of both the Cassiopeia-Taurus group (see the next paragraph) and the Scorpio-Centaurus association (Blaauw 1946; Bertiau, unpublished) indicate strongly that these groups consist of stars of common origin and are not assemblies of stars at present occupying the same region in space but having originated in different associations. Furthermore, as was shown by Markowitz (1948) in a study of the clustering and the K term of the bright B stars, the stars outside the clusterings give a negligible K term. One would expect Torondjadze's theory to be especially applicable to these stars.

c) Peculiar Motions

With the elements derived from solution I we have computed υ components in the direction of the convergent point and τ components perpendicular to it for all stars in the Cassiopeia-Taurus group. The peculiar motions can be studied by means of the τ components and the radial velocities.

For the analysis of the τ components we have selected the stars which, according to Table 5 (explained in Sec. V, *e*), have individual parallaxes larger than $p = 0\overset{''}{.}0025$ and probable errors of the proper motions below $0\overset{''}{.}0030$. These include not only stars used in the preceding calculations but also some more which may belong to the Cassiopeia-Taurus group according to Section V, *e*. We consider separately the stars with parallaxes larger than $0\overset{''}{.}0050$ (24 stars) and those with smaller ones (14 stars). After correcting the mean absolute values of the τ components for the influence of accidental errors in the proper motions, we get $\langle|\tau|\rangle = 0\overset{''}{.}0029$ and $0\overset{''}{.}0022$, respectively. Converting these values into linear velocities by means of the parallaxes of Table 5, we find 1.8 and 2.8 km/sec, respectively. The latter value is less reliable, because in that group the true τ components are of the order of the accidental errors in the proper motions. We conclude that

$$t = \pm 2.0 \text{ km/sec}$$

is the most probable value of the mean peculiar velocity in the τ direction.

The radial velocities have been used for the 26 stars in the quality classes *a* and *b* in Wilson's (1953) catalogue. These have probable errors below 2.0 km/sec. Residuals were computed by means of formula (1) and solution I of Table 3. We get, after a correction for the influence of accidental errors, ±3.4 km/sec for the mean residual in the radial velocity. This is an upper limit rather than the most probable value of the peculiar motions in the radial direction, since the true probable errors may be somewhat larger than the adopted values and the distance dependence, as expressed by formula (2), has not been taken into account. However, the difference is probably not more than 0.5 km/sec, and we adopt, for the mean residual radial velocity,

$$u = \pm 3.0 \text{ km/sec.}$$

The star HD 21448 appeared to have a well-determined large residual (−18 km/sec) and will therefore not be regarded as belonging to the group.

Most of the τ components are directed approximately perpendicular to the galactic plane, whereas those in the line of sight are mostly in this plane. The difference between the values of t and u may well represent a true difference between the peculiar motions in these two directions. One would indeed expect such a difference if the expansion hypothesis is correct.

d) Individual Parallaxes and Absolute Magnitudes

The small amount of the peculiar motions as compared with the solar motion allows the determination of fairly accurate individual parallaxes from the υ components. Such parallaxes were computed with the elements of the solar motion as given in Table 3,

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solution I. From the interpretation of this solution given in Section V, *b*, it is clear that one can derive individual parallaxes according to the usual formula,

$$p=\frac{4.74v}{S\sin\lambda}, \tag{3}$$

where p is the parallax, and the v component is computed without the application of corrections for differential galactic rotation.

The sources of accidental errors in the determination of these individual parallaxes are the observational errors of the proper motions and the peculiar motions. Denoting the corresponding probable errors by ϵ_0'' and ϵ_c km/sec, respectively, we have

$$f=\frac{\text{p.e. of parallax}}{\text{parallax}}=\sqrt{\left[\left(\frac{\epsilon_0}{v}\right)^2+\left(\frac{\epsilon_c}{S\sin\lambda}\right)^2\right]}\,.$$

For ϵ_c we adopted $0.85u = 2.5$ km/sec. The individual parallaxes, p, and the values of f are given in Table 5. The table also gives the corresponding visual absolute magnitudes, M_v, derived by means of these parallaxes. These are either in the system of the *Revised Harvard Photometry* or in the $U-B-V$ system when B and V measures were available. Most of the latter were kindly provided by Dr. W. A. Hiltner in advance of publication. Absolute magnitudes in the V system are printed in italics. For the stars considered, it was found that there is no systematic difference between the absolute magnitudes in the two systems. The probable errors of the absolute magnitudes given in Table 5 were derived from the probable errors of the parallaxes.

e) Stars Listed in Table 5

Apart from the stars used in subgroups 2–7 discussed before, the following, with their individual parallaxes and visual absolute magnitudes derived from the v components, are listed in Table 5.

1. Stars in modulus group C and probably belonging to the Cassiopeia-Taurus group. We noticed in Section IV that a number of the stars in Figure 3*a* show proper motions similar to those in Figures 1*a* and 2*a*. They were included in the discussion after it had become apparent that there is appreciable scatter in the absolute magnitudes within the luminosity classes B2 V and B3 V. These stars in modulus group C might be the ones with lower-than-average luminosities, and their omission might, therefore, systematically affect the determination of the mean luminosities.

It is hard to decide which of these stars really belong to the Cassiopeia-Taurus group. The nine stars marked "C" in the fourth column of Table 5 are probably members; their proper motions fit the convergent point somewhat better than the standard antapex. It is somewhat doubtful whether they represent all members in modulus group C, and there are dubious cases, like HD 829 at $l = 82.^\circ9$, $b = -24.^\circ4$, which may be related to the Lacerta association. The star HD 21448 at $l = 117.^\circ9$, $b = -8.^\circ4$ has already been excluded because of its strongly deviating radial velocity. The radial velocities of the remaining stars agree very well with those predicted by means of formula (1) and solution I.

2. The two high-latitude stars, δ Ceti (HD 16582) and η Ursa Majoris (HD 120315). In both cases there is little doubt that the star belongs to the Cassiopeia-Taurus group. The directions of the proper motions are in agreement with this hypothesis. δ Ceti is in the general region near subgroup 5. η Ursa Majoris is at lower longitude than the other members of the group, but its position in space, close to the sun, is certainly within the boundaries of the group. For none of the other stars outside the latitudes of Figures 1–3 does membership of the Cassiopeia-Taurus group seem likely.

3. The star α Arae (HD 158427). No systematic search for members of the Cassiopeia-

Taurus group south of declination −20° has been made, and so far only a few of the brighter stars, with large proper motions, have been investigated. In the case of α Arae, the proper motion as well as the radial velocity indicate membership. This star is probably also the nearest of the bright southern stars considered.

f) *Distribution and Mean Values of Absolute Magnitudes*

The Cassiopeia-Taurus group, according to Table 5, contains only two stars of types earlier than B2, namely, γ Cas (B0 IV: e) and ϵ Per (B0.5 V), and, except for ζ Tau (B2 III: p), all stars are of luminosity classes IV or V. Most numerous are the subclasses B2 V (12 stars) and B3 V (15 stars). In the H-R diagram in Figure 7, absolute magnitudes with p.e. < 0.55 mag. are represented by dots, the more uncertain ones by open circles.

The large range in absolute magnitudes within the two subclasses, B2 V and B3 V, is partly real and partly due to the accidental errors of M_v. For the determination of the mean absolute magnitudes and of the true value of the scatter in the absolute magnitudes we shall rely mainly on the most accurately determined parallaxes. For this purpose it is useful first to consider Table 6. This shows the distribution of the parallaxes for the different classes of accuracy given in the heading of the second to fourth columns. The stars in the fourth column are the ones with p.e. of $M_v > 0.55$ mag.; they are represented by open circles in Figure 7. One notices that the large values of (p.e. of p)/p, in the last column, occur at the small values of p. This is due to two causes:

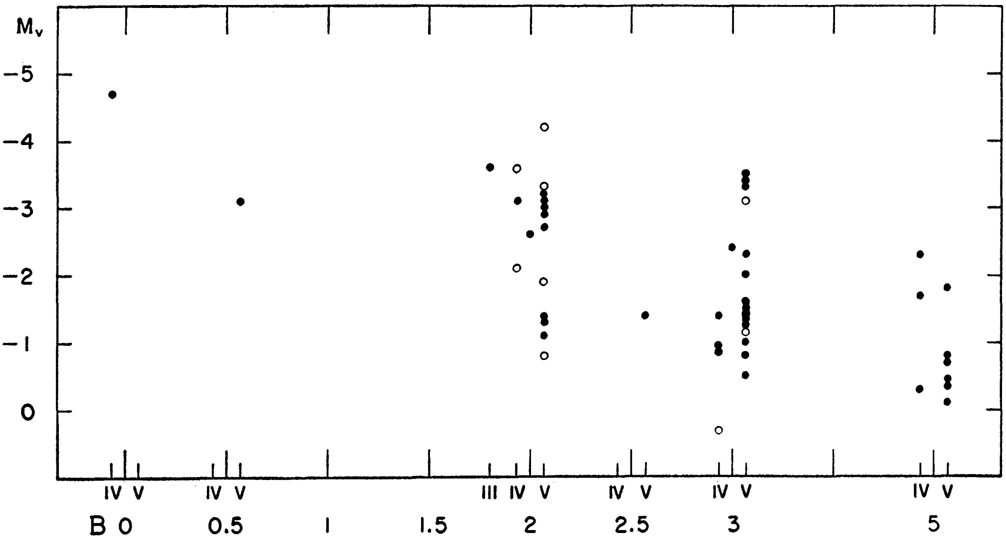

FIG. 7.—Luminosity–spectral-type diagram for stars in the Cassiopeia-Taurus group. *Circles:* stars for which (p.e. of p)/p is larger than 0 25; *abscissae:* MK subclasses; *ordinates:* visual absolute magnitudes.

1. The smaller parallaxes are those of the apparently fainter stars with the less accurate proper motions. The mean apparent magnitudes for the three classes of (p.e. of p)/p in the table are 3.7, 5.0, and 6.0, respectively.

2. If the accidental error of the proper motion happens to decrease the v component, it will cause p to be smaller than the true parallax and increase the ratio (p.e. of p)/p. Thus we must expect the parallaxes in the last category in Table 6 to be systematically too small.

The latter effect also influences the absolute magnitudes derived from the parallaxes. It works in the sense that the stars in the last category will come out too bright, whereas those in the first category will be too faint. However, as the ratios (p.e. of p)/p are so

TABLE 5

STARS IN THE CASSIOPEIA-TAURUS GROUP

Name	HD No.	GC No.	g*	l	b	m	v†	τ†	p.e.† ±	p†	f‡ ±	Rad. Vel. (km/sec)	q§	A_v (0.01 mag.)	MK	M_v	p.e. ±
AR Cas.	221253	32683	2	80°2	− 2°6	4.9	178	+ 29	12	40	0.17	−15.9	a	24	B3 V:	−2.3	0.4
	224559	33252	C	81.7	−15.4	6.46	256	− 53	40	55	.21	− 1.1	b	24	B3 IV	−0.9	.5
	829	228	C	82.9	−24.4	6.57	200	− 33	50	42	.29	− 9.0	b	48	B2 V	−0.8	.6
	1976	476	2	86.7	−10.4	5.36	136	0	25	29	.23	−12	c	15	B5 IV	*−2.3*	.5
ζ 17 Cas.	3360	727	2	88.7	− 8.6	3.72	206	− 65	9	43	.15	+ 2.1	a	8	B2 V	*−3.2*	.3
ξ 19 Cas. . . .	3901	828	2	89.4	−12.0	4.85	146	+ 3	20	30	.24	− 8	c	32	B2 V	*−3.1*	.5
ο 22 Cas. . . .	4180	882	2	89.9	−14.3	4.70	208	− 29	10	43	.15	− 8	c	52	B2 V	*−2.7*	.3
γ 27 Cas.	5394	1117	2	91.3	− 1.8	2.25	255	+ 10	7	53	.14	− 6.8	a	90:	B0 IV:e	*−4.7*	.3
	6300	1293	C	93.1	−11.4	6.50	170	+ 59	40	35	.27	− 5.4	b	36	B3 V	−1.2	.6
φ Per........	10516	2102	2	99.3	−10.8	4.19	287	− 31	9	57	.13	+ 0.8	a	60	B2 pe	−2.6	.3
1 Per..... ..	11241	2241	C	99.4	− 6.2	5.49	203	+ 7	20	41	.16	− 3	c	00	B2 V	−1.4	.4
ε 45 Cas.... ..	11415	2289	2	97.5	+ 2.2	3.44	383	− 22	7	77	.13	− 8.1	a	16	B3 p	*−2.4*	.3
δ 82 Cet.... ..	16582	3192	.	139.4	−50.9	4.04	183	+ 25	7	40	.16	+13.0	a	12	B2 IV	*−3.1*	.4
35 Ari..... ..	16908	3273	3	119.6	−27.9	4.58	134	− 25	11	27	.15	+19	c	17	B3 V	*−3.3*	.3
	20336	3947	2	105.0	+ 7.7	4.76	157	− 20	17	31	.17	+20	c	18	B2 Ve	−2.9	.4
τ 61 Ari..	20756	4007	3	131.9	−28.4	5.17	400	+ 8	9	86	.14	+14	c	32	B5 Vp:	*−0.4*	.3
	21803	4217	C	118.5	− 8.2	6.33	161	+ 11	35	32	.26	+ 3.7	b	90	B2 IV	−2.1	.6
29 Tau. .	23466	4505	5	149.3	−35.0	5.36	257	+ 95	17	64	.17	+13	c	36	B3 V	−1.0	.4
30 Tau.......	23793	4568	5	145.2	−31.2	5.03	363	+ 4	19	87	.17	+18.9	b	27	B3 V	*−0.5*	.4
ε 45 Per... . .	24760	4759	4	125.2	− 9.0	2.96	347	− 10	8	71	.13	− 1	c	29	B0.5V	*−3.1*	.3
35 Eri..... ..	25340	4828	5	159.7	−36.3	5.25	286	+ 11	15	81	.20	+16	c	18	B5 V	−0.4	.4
40 Tau.......	25558	4876	5	153.3	−31.9	5.33	90	− 52	21	24	.29	+12.1	b	38	B3 V	*−3.1*	.6
48 Per..... ..	25940	4967	4	121.4	− 2.0	4.03	394	+ 21	8	79	.13	+ 3.0	b	52	B3 Vp	*−2.0*	.3
μ 49 Tau..... .	26912	5134	5	152.1	−27.4	4.32	323	+ 4	13	85	.17	+18.2	b	46	B3 V	*−1.4*	.4
	27192	5207	C	120.5	+ 1.6	5.54	103	+ 44	30	20	0.32	−18	d	66	B2 IV	−3.6	0.7

* g = number of subgroup. † unit (0″0001). ‡ f = (p.e. of p)/p. § q = quality of radial-velocity determination.

TABLE 5—*Continued*

Name	HD No.	GC No.	g^*	l	b	m	ν†	τ†	p.e.† ±	p†	f‡ ±	Rad. Vel. (km/sec)	q§	A_v (0.01 mag.)	MK	M_v	p.e. ±
τ 94 Tau. .	29763	5716	7	144°5	−13°7	4.33	137	− 78	6	33	0.16	+14.6	b	36	B3 V	−3.4	0.4
μ 57 Eri. .	30211	5796	5	168.2	−27.9	4.18	209	− 15	8	72	.23	+ 7	d	6	B5 IV·	*−1.7*	0.5
η 10 Aur .	32630	6226	4	133.0	+ 1.5	3.28	765	− 9	8	162	.14	+ 7.4	b	10	B3 V	*−0.8*	0.3
103 Tau. .	32990	6267	7	147.0	− 8.2	5.50	69	+ 11	15	17	.27	+16.2	a	90	B2 V	−4.2	0.6
105 Tau. .	32991	6263	7	149.1	− 9.7	5.95	108	+ 24	17	27	.23	+25	c	114	B2 Vp	−3.0	0.5
15 Cam. . . .	34233	6478	C	120.2	+12.8	6.23	257	+ 2	25	51	.16	− 3	c	60	B3 IV	−0.9	0.4
ρ 20 Aur .	34759	6556	4	134.2	+ 4.2	5.12	407	+ 65	23	86	.15	+ 5	c	7	B5 V	*−0.1*	0.3
115 Tau. .	35671	6714	6	154.8	− 8.0	5.31	251	− 52	13	70	.19	+19	c	30	B5 V	−0.8	0.4
114 Tau. . .	35708	6723	7	151.5	− 5.8	4.83	89	+ 17	15	23	.24	+14.4	b	18	B3 V	−3.5	0.5
32 Ori. .	36267	6813	6	165.7	−13.5	4.32	361	−102	29	126	.24	+21	c	12	B5 IV	−0.3	0.5
121 Tau. . .	36819	6916	6	150.7	− 3.1	5.28	207	+ 38	20	53	.20	+22.6	b	36	B3 V	*−1.4*	0.4
ζ 123 Tau. .	37202	6985	6	153.4	− 4.2	3.00	212	− 34	7	56	.17	+24.3	b	33:	B2 III:p	*−3.6*:	0.4
	37367	7026	7	146.8	+ 0.4	6.00	96	+ 67	40	23	.45	+30	d	108	B2 V	−3.3	1.1
125 Tau. .	37438	7047	6	149.6	− 1.3	5.00	267	+121	17	67	.18	+14.8	a	18	B2 V	−1.1	0.4
126 Tau. .	37711	7094	6	157.8	− 5.8	4.87	213	+ 53	20	62	.21	+21	c	24	B3 IV	*−1.4*	0.5
	37967	7148	6	152.3	− 2.0	6.06	218	− 7	30	56	.22	+19.1	b	42	B5 Vp	−0.7	0.5
133 Tau. .	38622	7249	7	160.9	− 5.9	5.20	169	+ 24	17	52	.22	+28.3	b	12	B2 V	−1.3	0.5
57 Ori. .	39698	7436	C	156.7	− 1.4	5.89	114	+ 1	20	32	.25	+ 7.2	b	30	B2 V	−1.9	0.5
ν 67 Ori. . .	41753	7772	6	162.5	− 1.2	4.40	231	+ 31	7	71	.20	+22.1	a	11	B3 V	*−1.4*	0.4
69 Ori. . . .	42545	7891	7	161.8	+ 0.3	4.92	152	+ 51	20	46	.24	+22	c	8	B5 V	*−1.8*	0.5
ξ 70 Ori. . .	42560	7889	7	163.5	− 0.6	4.35	196	− 19	16	62	.22	+24	d	11	B3 V	*−1.6*	0.5
	44700	8227	C	174.0	− 3.0	6.25	182	+ 57	40	76	.36	+29	c	30	B3 IV	+0.3	0.8
η 85 UMa. . . .	120315	18643	. .	65.2	+65.0	1.91	1196	+ 35	5	269	.15	−10.9	b	00	B3 V	*−1.4*	0.3
α Ara.	158427	23708		308.3	−10.0	2.97	714	− 81	18	145	0.13	− 2	c	12	B2.5V	−1.4	0.3

much smaller in the first one, this effect is much weaker in the first category than in the third.

Therefore, we have decided to determine the mean absolute magnitudes and the scatter with respect to these means exclusively from the stars with (p.e. of p)/p < 0.25. The probable errors of M_v for these stars range from 0.28 to 0.53 mag., and the average p.e. is ± 0.40 mag. The mean value of M_v for B3 V has been corrected by $+0.2$, to account for incompleteness at the low luminosities, as will be explained later. The final values and their probable errors are in the second column of Table 8. The probable errors of the mean absolute magnitudes represent the uncertainty due to three causes:

1. The uncertainty due to the scatter in the individual absolute magnitudes within each subclass. This amounts to a p.e. of ± 0.26 mag. for class B2 V and of ± 0.20 mag. for class B3 V.

2. The common error due to errors in the stream elements of solution I. The principal source of uncertainty is in the stream velocity S. Its p.e. amounts to 9 per cent of S itself, which corresponds to a probable error of ± 0.19 mag. in the zero point of all absolute magnitudes in Table 5 and Figure 7.

TABLE 6

DISTRIBUTION OF PARALLAXES AND THEIR PROBABLE ERRORS

p (0″0001)	(P.E. OF p)/p			p (0″0001)	(P.E. OF p)/p		
	≤0.15	0.16–0.24	≥0.25		≤0.15	0.16–0.24	≥0.25
15–19	.	...	1	55–59	1	3	.
20–24	.	1	3	60–64		3	
25–29	1	2	..	65–69	...	1	.
30–34	.	3	2	70–74	1	3	..
35–39	..	.	1	75–79	2	..	1
40–44	2	3	1	80–84	.	1	
45–49	.	1	..	85–89	2	2	.
50–54	1	3	...	90	3	1	.

3. The correction for the possible omission of the intrinsically faintest stars in the compilation of Table 5. We have estimated its effect as follows: We assume that the group does not extend beyond about 330 pc. This is based on the remarks in Section IV and is not incompatible with the distribution of parallaxes in Table 6. The few values of p below 0″0030 in that table can be explained by the accidental errors in the parallaxes. A distance of 330 pc corresponds to $m_0 - M = 7.6$. Stars with $M_v = -1$ at this distance limit have $m_0 = 6.6$ and, with the generally small visual absorption, $m = 7$. Our data are probably not quite complete between $m = 6$ and $m = 7$, and this incompleteness will affect especially the subclass B3 V. Assuming that two or three stars are missing in the interval between $M_v = 0$ and $M_v = -1$, we estimate the correction to the mean value for B3 V derived from Table 5 to be $+0.2$ mag. The uncertainty of this estimate is represented by an additional probable error of ± 0.1 mag.

Thus we arrive at the total probable error of about ± 0.3 mag. of the mean values for both B2 V and B3 V. These mean absolute magnitudes apply to the stars selected per volume of space. In general, mean absolute magnitudes can be defined, either in this way or per apparent magnitude. The latter are brighter because they include the intrinsically luminous stars within a larger volume of space than the faint ones. We present mean values per volume of space, as these have more fundamental significance and because they are more naturally determined from the Cassiopeia-Taurus group and from the Scorpio-Centaurus association.

The mean deviations of the individual absolute magnitudes from the average values for B2 V and B3 V have been determined from the same stars as those used for the mean absolute magnitudes. Corrections for the accidental errors of M_v were applied. The results are also in Table 8. The mean deviations, 0.6 mag. for both B2 V and B3 V, are somewhat larger than might have been expected. They are, however, confirmed by the study of the Scorpio-Centaurus association reported in Section VI.

Part of the scatter of the absolute magnitudes must be due to the fact that we have not corrected them for the duplicity of some of the stars. Such corrections would have reduced somewhat the average deviations and also changed the mean absolute magnitudes in Table 8 by about +0.1 mag. However, in the present paper we are primarily interested in obtaining the information on the distribution of absolute magnitudes which can later serve for the distance determinations of faint associations. For these, no information on the duplicity of the main-sequence stars will be available. The duplicity and multiplicity properties of the stars in the Cassiopeia-Taurus group and their relation to the kinematical properties will be discussed in a later paper.

We have made a provisional investigation of the possibility of improving the estimation of individual absolute magnitudes by means of $H\gamma$-line intensity measurements. These were available for part of the stars in Table 5, mostly from unpublished measurements kindly communicated by Dr. R. M. Petrie and by Dr. J. Stock. We find that the data for most stars fit a mean relation with an average deviation of about ±0.5 in the absolute magnitude. There are, however, some striking deviations: namely, the stars HD 16908 and HD 29763, both of type B3 V and about 2 mag. too bright, and some stars in the α Persei cluster discussed in Section IX, which are of lower than expected luminosity. A more complete discussion of the relation between Hγ intensities and absolute magnitudes is postponed until the calibration of the high-luminosity classes is completed.

g) Space Distribution of Members of Group and of Field Stars

The space distribution of the stars in Table 5 projected on the galactic plane is shown by the dots in Figure 8. The distances plotted were based on the individual parallaxes of Table 5 and on values derived from the mean absolute magnitudes per subclass given in Table 9. These latter are not quite independent of the first, as the mean absolute magnitudes were based partly on the data of Table 5, but the photometric data can in this way contribute to the determination of relative distances within the group. Weighted means of the two distances were used. Dots in parentheses represent the stars with (p.e. of $p)/p \geq 0.25$; their distances are more uncertain than those of the other members of the group and may be systematically too large. The mean position of the Cassiopeia-Taurus group, derived from the more reliable distances, is given in the upper part of Table 4.

The diagram covers the region within a distance of 400 pc and between galactic longitudes 340° and 200°. Field stars are represented by plus signs if they are at positive galactic latitude and by minus signs if at negative latitude. Their distances are based on the mean absolute magnitudes per subclass, with allowance for the fact that these stars were selected on the basis of apparent magnitude. The distribution shown here is probably only a rough approximation of the true distribution and is intended only to give some idea of the relative population of field stars around the Cassiopeia-Taurus group. We notice that this group, as well as the II Persei association, lies in a region which is almost unpopulated by the field stars, a feature which we had already observed in Section IV. It seems that in the section of our spiral arm between galactic longitudes 90° and 160° formation of the early-type stars started at a more recent date than in the adjacent regions. It is interesting to notice that the population of these field stars contains no star of type B0 or earlier and no star of luminosity class I or II. The percentages of stars in the various subclasses are as follows: B1 II–III, 1; B1 IV, 0; B1 V, 7; B2 III, 4; B2 IV,

5; B2 V, 24; B3 III, 1; B3 IV, 7; B3 V, 46; B2–B3, no subclass, 4. O-type stars and stars of luminosity classes I and II occur only in the associations.

The positions of the three associations within 600 pc in the northern sky and of the Scorpio-Centaurus association are also shown. The distances for the first three were taken from the sources referred to in Section III, although these may have to be revised when the calibration for all MK luminosity classes has been completed. The location of the Scorpio-Centaurus association was copied from earlier work by the author (Blaauw 1946).

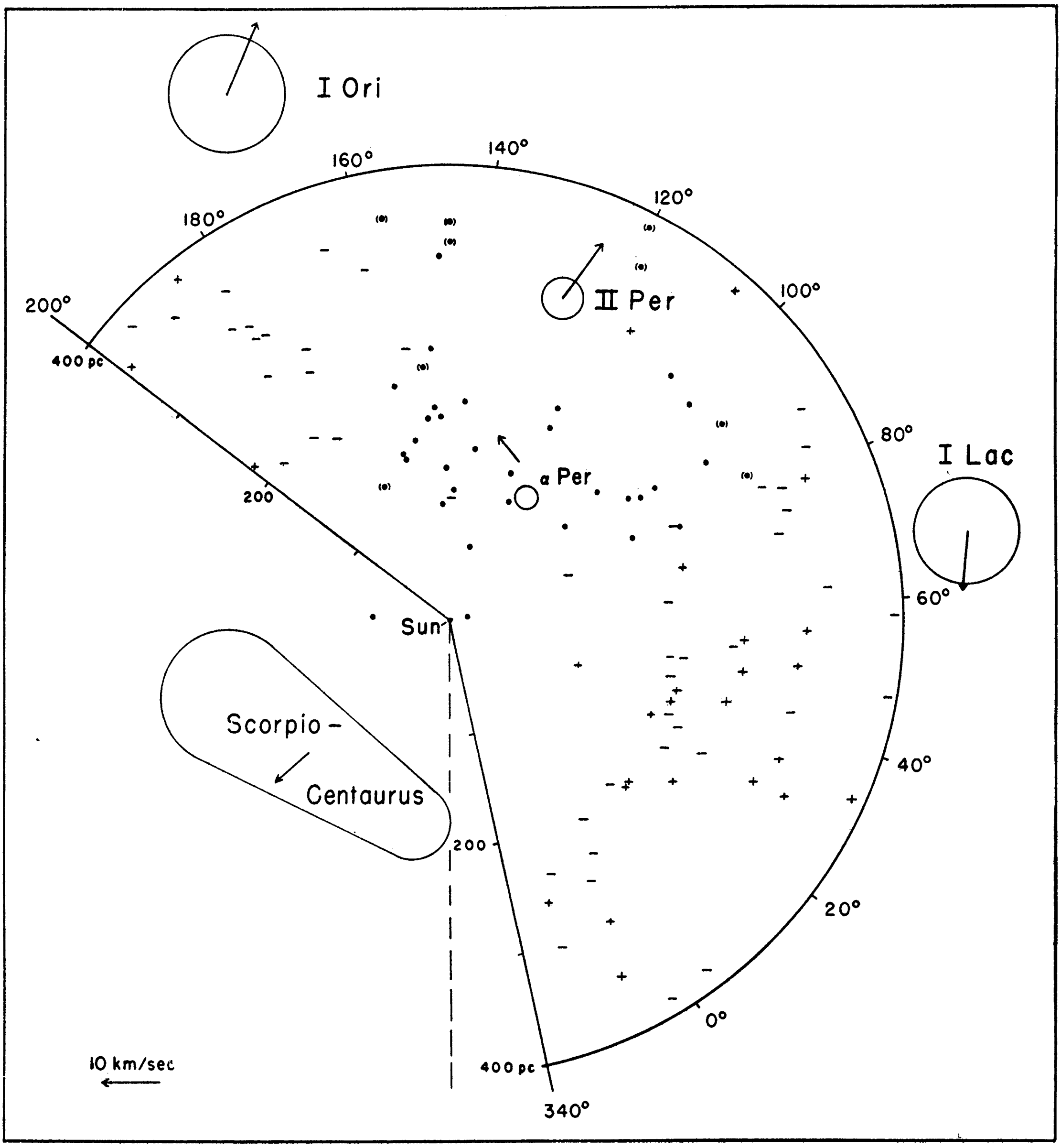

FIG. 8.—Distribution of stars B3 and earlier within 400 pc and between galactic longitudes 340° and 200°, projected on the galactic plane. *Dots:* stars in the Cassiopeia-Taurus group (dots in parentheses have the most uncertain distances from the sun); *plus signs:* field stars at positive galactic latitudes; *minus signs:* field stars at negative latitudes. "α Per" marks the position of the α Persei cluster. The locations of the nearest associations are represented by the large circles. The dashed line is in the direction toward the galactic center.

The arrows represent the projected mean space velocities for the stars in the four associations and in the Cassiopeia-Taurus group, corrected for the standard solar motion (20 km/sec toward R.A. = 270°, Decl. = +30°), but not for differential galactic rotation. For all five objects the velocity perpendicular to the galactic plane is smaller than 4 km/sec. The scale of velocities is shown in the lower-left-hand corner of the diagram.

VI. THE SCORPIO-CENTAURUS ASSOCIATION

The principal data derived from Bertiau's study are in Table 8. Full particulars about this study will soon be published. The study is based on better proper motions, radial velocities, and photometry than were available at the time of a previous investigation by the author (Blaauw 1946). It is the most precise one of the contributions to the calibration of the MK luminosity classifications discussed in the present paper. The small internal motions in this association, its short distance from the sun, and the high accuracy of the proper motions allow a very accurate determination of the distances and absolute magnitudes.

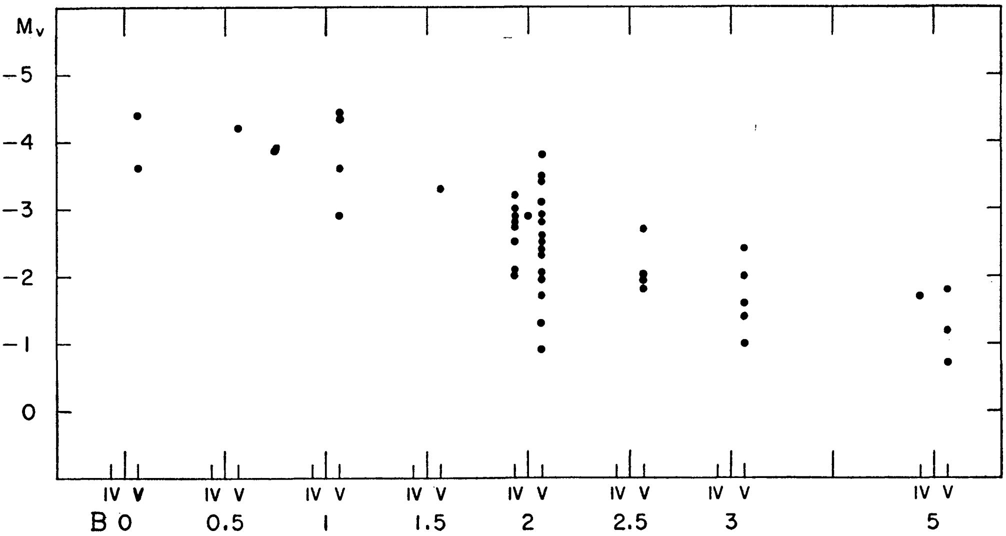

FIG. 9.—Luminosity–spectral-type diagram for the Scorpio-Centaurus association according to Bertiau.

The H-R diagram is shown in Figure 9. This is probably complete for types B2 and earlier but somewhat incomplete for B3 and very incomplete for B5. The third column of Table 8 gives the mean visual absolute magnitudes in the $U - B - V$ system and the average deviations from the means for B1 V, B2 IV, B2 V, and B3 V. The probable errors of the mean absolute magnitudes include the uncertainty in the zero point due to the possible errors in the elements of the stream motion; the probable error in the zero point is ±0.10 mag.

VII. THE REGION BETWEEN LONGITUDES 340° AND 50°

The fairly uniform distribution of the stars and the absence of local stream motions in this region justify the assumption that the proper motions can be interpreted as due to random peculiar motions superimposed on a common motion with respect to the sun. Mean parallaxes have been derived from the υ and from the τ components and, from these, the mean luminosities for the subclasses B2 IV and V and B3 IV and V. The stars used are those with probable errors of the proper motions smaller than 0".005 and with provisional distance moduli smaller than 8.4.

It was assumed that in the present case the mean motions of the stars show the effect of differential galactic rotation, and this was therefore eliminated from the proper motions and radial velocities, using the provisional distance moduli and the values of the constants A and B referred to in Section V, *a*. For the apex of the solar motion, we used the standard co-ordinates $l = 24°$, $b = +22°$ after we had checked these by means of mean proper motions for ten small subdivisions of the whole area. These mean proper motions gave $l = 20°$, $b = +22°$ for the apex, with an uncertainty of about $\pm 4°$. This checking on the apex was based on 62 stars, including some B5 stars and some earlier than B2.

TABLE 7

RESULTS FOR REGION BETWEEN LONGITUDES 340° AND 50°
(Numbers of Stars in Parentheses)

	PROVISIONAL m_0-M					
	≤ 7.2		7.3–8.4		All $\leq$ 8.4	
From radial velocities:						
Solar motion, S (km/sec)	$20\ 7\pm 1\ 0$ (p.e.)	(29)	$24\ 7\pm 1\ 3$ (p.e.)	(37)	$22\ 3\ \pm 0\ 8$ (p.e.)	(66)
Mean residual $\langle \lvert\Delta\rho\rvert \rangle$	$5\ 5\pm 0\ 5$		$6\ 4\pm 0\ 5$		$6\ 3\ \pm 0\ 4$	
From v components:						
$\langle p\rangle S/4\ 74$ (0″.0001)	186 ± 23	(18)	87 ± 26	(15)		
$\langle p\rangle$(0″.0001)	43 ± 5		$17\pm\ 5$			
Mean m_0-M_v	$6\ 85\pm 0\ 25$		$8\ 9\pm 0\ 65$			
Mean M_v per apparent magnitude	$-2\ 44\pm 0\ 25$					
From τ components:						
$\langle \lvert\tau\rvert \rangle$ (0″.0001)					52 ± 5	(33)
$\langle p\rangle$ (0″.0001)					39 ± 4	
Mean m_0-M_v					$7\ 0\pm 0\ 25$	
Mean M_v per apparent magnitude					$-2\ 10\pm 0\ 25$	
Means from τ and v components:						
Mean M_v for B2 and B3, IV and V					$-2\ 27\pm 0\ 18$	(33)
Mean M_v for B2, IV, V					$-2\ 82\pm 0\ 30$	(13)
Mean M_v for B3, IV, V					$-1\ 92\pm 0.25$	(20)

The results obtained in this section are summarized in Table 7. For the analysis of the v components, we first subdivided the stars into the modulus groups $m_0 - M \leq 7.2$ and 7.3–8.4. The solar velocity, S, was determined separately for these two groups and for the two combined. Stars with inaccurate proper motions but good radial velocities were also used in this determination. The radial velocities had been corrected for a gravitational red shift of 1.0 km/sec. No K term was introduced into the solution; this would have been indeterminate, as the region considered lies around the apex. The results for S are in the first division of Table 7, where also is given the mean residual radial velocity $\langle \lvert\Delta\rho\rvert \rangle$ for the three solutions.

The next division gives, first, the quantity $\langle p\rangle S/4.74$ derived from the v components by means of the formula

$$\frac{\langle p\rangle S}{4.74}=\frac{\langle v \sin \lambda\rangle}{\langle \sin^2 \lambda\rangle},$$

and next the mean parallax $\langle p\rangle$ derived with the value of S for the corresponding distance group and the mean distance modulus.

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The result for the second modulus group is quite uncertain. The probable error of the mean distance modulus is large, and, moreover, this value can easily be affected by a systematic error in the proper motions, as the mean v component is only 0″.004. Therefore, we have discarded this modulus group as far as the v components are concerned. The mean visual absolute magnitude for the first modulus group is in the fourth line of this division of Table 7.

For the τ components, there is no reason to reject the second modulus group, as the mean value of $|\tau|$ will not be much affected by a systematic error in the proper motions. The two modulus groups were combined, and the results are in the third section of Table 7. With the observed value of $\langle|\tau|\rangle$ and $\langle|\Delta\rho|\rangle = 6.3$ km/sec, one finds the mean parallax according to $\langle p\rangle = 4.74\langle|\tau|\rangle/\langle|\Delta\rho|\rangle$ and the mean distance modulus and mean absolute magnitude in the fourth line of this section of the table.

TABLE 8

MEAN VISUAL ABSOLUTE MAGNITUDES PER VOLUME OF SPACE FROM THREE INDEPENDENT SOURCES

(Numbers of Stars in Parenthesis)

	Cassiopeia-Taurus Group	Scorpio-Centaurus Association	Stars between $l=340°$ and $l=50°$
Mean visual absolute magnitudes:			
B1 V	. . . .	−3.8 ±0.29 (p.e.) (4)	. . . . .
B2 IV	−3.1 ±0.4 (p.e.) (1)	−2.73±0.14 (7)	−2.30±0.30 (p.e.) (1)
B2 V	−2.34±0.31 (8)	−2.48±0.17 (15)	(12)
B3 V	−1.65±0.29 (16*)	−1.40±0.25 (6†)	−1.40±0.25 (20‡)
Average deviations:			
B1 V	. . . . . .	0.6 ±0.17 (4)	
B2 IV	. . . .	0.31±0.06 (7)	
B2 V	0.6 ±0.11 (8)	0.65±0.09 (15)	
B3 V	0.6 ±0.08 (16*)	0.6 ±0.15 (6†)	

* Includes three hypothetical stars with $M_v = -0.5$.

† Includes two hypothetical stars with $M_v = -0.5$.

‡ Includes four stars of type B3 IV.

The mean absolute magnitudes obtained from the two components are averaged in the first line of the bottom section of the table. This average applies, altogether, to sixteen B3 V; four B3 IV; twelve B3 V; and one B2 IV stars. Only part of these were used in the treatment of the v components, but the subclasses occur in about the same proportions for the v and the τ components. We have derived from this average one mean value for B3 IV and V and one for B2 IV and V, assuming the difference between these two to be 0.9 mag., as suggested by the second and third columns of Table 8. This leads to the mean values for B2 IV and V and B3 IV and V in the last lines of Table 7.

The mean absolute magnitudes thus obtained apply to stars selected according to a certain apparent magnitude and not per volume of space. The latter are fainter by an amount of

$$\Delta M = \frac{\sigma^2}{0.434}\,\frac{d \log A(m)}{dm}, \tag{4}$$

where σ is the dispersion of the absolute magnitudes and $A(m)$ is the number of stars per unit area as a function of the apparent magnitude (Malmquist 1920). We have adopted $\Delta M = +0.52$ mag., using the value of 0.6 mag. for the average deviation in M_v, as suggested by the data on the Cassiopeia-Taurus and the Scorpio-Centaurus associations in Table 8, and $d \log A(m)/dm = 0.4$. The latter value corresponds to an increase in the number of stars with the square of the distance, as seems most plausible in view of the strong galactic concentration of the stars considered here. We thus obtain the mean absolute magnitudes per volume of space in the last column of Table 8.

VIII. ADOPTED MEAN ABSOLUTE MAGNITUDES PER VOLUME OF SPACE

Weighted means of the visual absolute magnitudes derived in the preceding sections for B1 V, B2 IV, B2 V, and B3 V, together with their probable errors, are given in the second column of Table 9. The few data which the Cassiopeia-Taurus group and the Scorpio-Centaurus association provide for the other subclasses will be incorporated later in more extensive discussions of these classes. The third column gives the average deviations from the mean absolute magnitudes per subclass, together with their probable errors.

The next columns give the provisional standard absolute magnitudes of Keenan and Morgan (1951) and the differences between these and our adopted values. Our new results apply to the stars per volume of space, whereas the tabulation by Keenan and Morgan refers to the stars selected per apparent magnitude. The difference, ΔM, between the two kinds of mean absolute magnitudes depends on the dispersion of the absolute magnitudes within the subclass and on the space distribution of the stars as described in Section VII (eq. [4]). In the case of the general population of field stars discussed in Section VII, we estimated ΔM to be about +0.5 mag. for B2 V and B3 V. For most applications the differences will be between this value and zero. The latter value holds, for instance, if we are dealing with an isolated group of stars in which the observations cover the complete range in luminosities for the subclass.

TABLE 9

ADOPTED MEAN ABSOLUTE MAGNITUDES PER VOLUME OF SPACE

Subclass	Adopted Mean Visual Absolute Magnitude per Volume of Space $\langle M_v \rangle$	Average Deviation from $\langle M_v \rangle$	Provisional Standard Absolute Magnitudes	Adopted $\langle M_v \rangle$ *minus* Standard Values
B1 V..	−3.8±0 29 (p.e.)	0 6±0.2 (p.e.)	−3 2	−0 6
B2 IV	−2.7± .13	3± .06	−3 3	+ 6
B2 V..	−2.4± 13	.6± .08	−2 6	+ 2
B3 V..	−1.5+0.15	0.6±0 07	−2 0	+0 5

The differences for B2 V and B3 V in the last column of Table 9 are thus of the order of magnitude to be expected and show that the provisional standard absolute magnitudes per apparent magnitude were approximately correct. For B2 IV our results indicate a smaller difference with respect to B2 V than that in the Keenan-Morgan table. The value for this subclass is based mainly on the contribution from the Scorpio-Centaurus group; it suggests that subclass B2 IV is a well-defined group with a narrow range in absolute magnitude, which may make it particularly useful for distance determinations.

The mean absolute magnitude for B1 V is considerably brighter than that in the Keenan-Morgan table but also much more uncertain than that for the other three subclasses. It is based entirely on the Scorpio-Centaurus association and requires further confirmation.

Although there is good agreement between the three sources from which the mean absolute magnitudes have been obtained, these should be adopted with some reservation. In all three classes we were dealing with assemblies of stars which are not of recent formation, judging from the absence of O-type stars and of stars of high luminosity, as well as from the kinematics and space distribution. We must expect that for these stars evolutionary changes have already caused the main-sequence absolute magnitudes to be somewhat different from those for stars of more recent origin. For the latter we would expect the luminosities to be lower, especially for the earliest types. See, for instance, Tayler's (1954) computation of the evolutionary path of a star of 10 solar masses (original type around B2) in the course of 50 million years, which shows that a differential effect of at least several tenths of a magnitude must be expected.

IX. THE *α* PERSEI MOVING CLUSTER

The *α* Persei cluster is represented in Figure 1*a* by two B3 and eight B5 stars around the mean position $l = 115°$, $b = -5°$. It also contains later-type stars, one of which is *α* Persei of type F5 I*b*, the brightest of its members, after which we shall name it. The cluster has sometimes also been named after Boss, Eddington, or Kapteyn, who detected it independently.

The mean proper motion derived from the ten stars with probable errors of the proper motions smaller than 0″.0040 is shown in Figure 1*a*. Its equatorial and galactic components are

$$\mu_\alpha \cos\delta = +0''.0286\ , \qquad \mu_\delta = -0''.0280\ ,$$

$$\mu_l \cos b = +0''.0394\ , \qquad \mu_b = -0''.0069\ ,$$

with a probable error of ±0″.0009 as determined from the scatter of the individual values around the mean.

The cluster was not included in the discussion of the Cassiopeia-Taurus group in Section V, but there are strong reasons to believe that it belongs to this group. Earlier studies like, for instance, the one by Rasmuson (1921), have revealed the probable existence of an extended stream of stars around the cluster, sharing its motion. The evidence for such an extended stream was criticized by Smart and Ali (1940) mainly on the basis of the large internal motions. The existence of extended streams with large internal velocities and in a state of disintegration is, however, quite compatible with modern ideas on stellar evolution, and the significance of the stream around the Perseus moving cluster as described by Rasmuson cannot be doubted. In fact, his Figure VI, displaying the proper motions of the bright stars of the extended stream, bears close resemblance to our Figure 1*a*. The cluster deserves special attention because the assumption of its membership in the Cassiopeia-Taurus group leads to a geometrical determination of the luminosities of its members, and these luminosities are found to be considerably fainter than the values for the field stars of the corresponding MK spectral types.

The mean proper motion is almost exactly in the direction of the convergent point given in Table 3. This is apparent from Figure 1*a*, where its direction agrees very well with that of the proper motions of the surrounding stars. It is shown more precisely by the values of the υ and τ components computed with the elements of solution I, for which we have

$$\upsilon = 0''.0400\ , \qquad \tau = +0''.0012\ , \qquad \text{p.e.} = \pm 0''.0009\ .$$

The direction of the mean proper motion differs by only 1°.7 from that toward the convergent, which is well within the observational uncertainties, whereas it differs about 10° from the direction toward the standard solar antapex.

The radial velocity also fits the elements of solution I quite well. The predicted value is +2.8 km/sec, which includes the term $rk = +0.8$ km/sec based on the distance of 127 pc derived below. The mean observed value for eight B3 and B5 stars, corrected for gravitational red shift, is +3.2 km/sec, whereas for *α* Persei it is −2.4 km/sec. These

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results leave little doubt that the cluster does indeed belong to the Cassiopeia-Taurus group. Computing the parallax from the v component and solution I, we get $p = 0''.0079 \pm 0''.0007$ (p.e.) with the corresponding distance and distance modulus: $r = 127$ pc $\pm$ 11 (p.e.); $m_0 - M = 5.5 \pm 0.2$ (p.e.). The uncertainty in these values is due mainly to that in the stream velocity, S. The elements of the space motion of the cluster with respect to the sun can, for all practical purposes, be taken to be the same as those for the Cassiopeia-Taurus group given in Table 4.

With the foregoing distance modulus we have computed the visual absolute magnitudes for the ten B3 and B5 stars, for α Persei, and for the remaining stars of types A2 and earlier which were considered to be members by Roman and Morgan (1950). These authors' corrections for interstellar absorption for the stars for which no direct observations are available were slightly reduced in accordance with the somewhat smaller ratio between total absorption and color excess used for the B-type stars in the present paper.

For α Persei we find $M_v = -4.1$. Most of the other stars belong to luminosity class V, and, for these, Table 10 gives the mean absolute magnitudes per spectral subclass. The table also gives, in the last column, the amount by which these mean absolute magnitudes are fainter than the standard values tabulated by Keenan and Morgan (1951). The mean difference is $+1.06 \pm 0.20$ (p.e.) mag. The probable error consists mainly of the zero-point error, which is common to all values of M_v in Table 10.

TABLE 10

VISUAL ABSOLUTE MAGNITUDES FOR LUMINOSITY CLASS V IN α PERSEI CLUSTER

Spectral Class	No. of Stars	Mean M_v	Mean M_v *minus* Prov. Standard	Spectral Class	No. of Stars	Mean M_v	Mean M_v *minus* Prov. Standard
B3 V .	2	−1.0	+1.0	B9 V	4	+1.2	+1.2
B5 V... .	3	−0.2	+1.1	A0 V	4	+1.7	+1.2
B6 V .	1	−0.4	+0.7	A1 V ...	3	+1.8	+0.9
B8 V .	2	+0.8	+1.3	A2 V.	1	+1.5	+0.3

We do not conclude that this mean difference represents a correction to be applied to the provisional standard absolute magnitudes of Keenan and Morgan. A small but uncertain fraction of it is due to the fact that the Keenan-Morgan values apply to stars selected per apparent magnitudes, whereas the proper comparison would be with values per volume of space. The remaining difference is similar to that between the A-type stars in the Pleiades and the near-by stars, noticed by Johnson and Knuckles (1951) and interpreted by these authors as an age effect, the near-by stars in general being older and more luminous than those in the Pleiades.

We further notice that, around spectral class B3 V, Tables 8 and 9 indicate a smaller difference in the sense Cassiopeia-Taurus group *minus* standard values than the difference α Persei cluster *minus* standard values just described. This suggests a small difference between the Cassiopeia-Taurus group and the α Persei cluster, the class V stars of the group being a few tenths of a magnitude brighter than the main sequence of the cluster. Since the zero point of the luminosities of the group and of the cluster are affected in the same way by a possible error in the stream velocity S, the probable error of this difference in the luminosities is only between 0.1 and 0.2 mag.

If this difference between group and cluster is also interpreted in terms of a different age, it means that the α Persei cluster is of more recent origin than the Cassiopeia-Taurus group as a whole. For the latter we found a minimum age of 50×10^6 years. An indication of expansion of the cluster derived from the proper motions of fainter stars and corresponding to an expansion age of 8 ± 3 (p.e.) million years has been announced by

Dieckvoss (1953). An accurate study of the color-magnitude diagram, including the faint cluster stars found by Dieckvoss, Heckmann, and Kox (1954) and additional measures of the proper motions, will be of great interest.

X. STARS WITH HIGH SPACE VELOCITIES; MOTIONS AND ORIGINS

The region l = 340°–200° contains several stars whose motions deviate considerably from the general pattern. Some of these stars have high space velocities. We shall consider the most conspicuous cases, beginning with those in which the origin and age of the star can be determined. A more complete study of the space motions and physical properties of these stars, will be published later.

1. HD 34078 = AE Aurigae, l = 139°.8, b = 0°.9, O9.5 V (see Fig. 3*a*). This star and HD 38666 (μ Columbae), which lies just outside the region considered, are known to have originated in the Orion association (Blaauw and Morgan 1954*a*, *b*).

2. HD 19374 = 53 Arietis, l = 131°.3, b = −33°.0, B2 V (see Fig. 3*a*). The direction of the proper motion suggests that this star also originated in the Orion association, and this is confirmed by closer study. Some data on the star are assembled in Table 11. The proper motion was first corrected for the standard solar motion. This correction depends on the star's distance and is given for three assumed values of the absolute magnitude: −2.5, −2.9, and −3.5.

TABLE 11

OBSERVED AND DERIVED QUANTITIES FOR 53 ARIETIS (HD 19374, GC 3728)*

Adopted visual absolute magnitude	− 2 5	− 2 9	− 3 5
Parallax (0″.0001)	26 3	21 9	16 6
Distance (pc)	380	456	603
$\mu_\alpha \cos\delta$ } corrected for standard solar motion (0″.0001)	−304	−292	−278
μ_δ } corrected for standard solar motion (0″.0001)	+156	+144	+133
Declination of intersection with R.A. 5^h30^m	− 4°.9	− 3°.4	− 2°4
Tangential velocity (km/sec)	61 6	70 6	
Predicted radial velocity if origin in Orion association (solar motion not included) (km/sec)	+1 8	+ 18 1	
Observed radial velocity corrected for standard solar motion and red shift	+18 0±3 4 (p e)		
Total space velocity (km/sec)	73		
Age (years)	4 8×10⁶		

* R.A. = $3^h1^m.8$; Decl = +17°30′ (1900); l = 131°.3, b = −33°.3; Sp MK B2 V $\mu_\alpha \cos\delta$ = −0″.0233; μ_δ = +0″.0085; p e = ±0″.0020; Rad Vel = +27 8 km/sec±3 4 (p e)

In order to show how well the direction of the corrected proper motion fits the hypothesis that the star originated in the Orion association, we give in Table 11 the declination of the point of intersection of the great circle defined by this proper motion with the meridian at R.A. 5^h30^m. This is the R.A. of the Trapezium stars, whose declination is −5°.5. For each of the three cases the coincidence with this declination is quite close, and the great circle always passes through the Orion Nebula. The probable error of the declination of intersection corresponding to the probable error in the proper motion is about 2°.5.

We next test how well the radial velocity fits the hypothesis of the star's origin in the region of the Orion Nebula. The radial velocity can be predicted from the geometry of the triangle Orion-star-sun and from the tangential velocity. The latter was derived from the proper motion for the different values of M_v. The distance of the Orion Nebula was assumed to be 500 pc, as in the work on AE Aurigae and μ Columbae, although this may have to be revised when the calibration is complete. The table shows that exact agreement of observed and predicted radial velocity is obtained for $M_v = -2.9$. This is within the range of possible values for B2 V, according to Table 9.

The evidence that the star originated in the Orion association thus appears quite strong, and we have computed the space velocity and the age, assuming $M_v = -2.9$. We find 73 km/sec and 4.8×10^6 years, respectively. For AE Aurigae and μ Columbae we found an age of 2.6×10^6 years. The difference between these two ages being considerably larger than its probable error, we conclude that star formation in the central region of the Orion association took place over a period of at least 2 million years.

The fact that AE Aurigae and μ Columbae form the remarkable pair, with equal and opposite velocities with respect to the region around the Trapezium stars, was reason to look for the same phenomenon in connection with 53 Arietis. There are a few stars which may match 53 Arietis in this respect, the most likely candidate being HD 54224 ($m = 6.38$, *HD* spectral class B3). However, the proper motions of these stars are poor, no radial velocities are known, and the stars have not yet been classified in the MK system. A satisfactory answer to this question also requires a careful study of the motions of the early-type stars in the Canis Major region in general.

TABLE 12

PRINCIPAL DATA ON 68 CYGNI (HD 203064)

Observed proper motion	$\mu_l \cos b = -0''.006$, $\mu_b = -0''.009$
Corrected for standard solar motion	$\mu_l \cos b = -0''.0085$, $\mu_b = -0''.0065$
Total corrected proper motion	$\mu = 0''.011 \pm 0''.002$ (p.e.)
Observed radial velocity	+1 km/sec
Best-fitting distance	780 pc
Visual absolute magnitude	−5 1
Space velocity	45 km/sec
Age	$5\ 1 \times 10^6$ years

TABLE 13

STARS WITH WELL-ESTABLISHED STRONGLY DEVIATING MOTIONS

	HD 4142	HD 26356	HD 214930
Adopted visual absolute magnitude	−0.7	−0.7	−1.5
Distance (pc)	170	140	440
Observed quantities:			
$\mu_l \cos b$ and p.e. ($0''.0001$)	−360±34	−141±16	−230±50
μ_b and p e ($0''0001$)	+100±34	− 5±16	− 20±50
Radial velocity (km/sec) and quality class	− 60 (*c*)	− 7 (*c*)	− 53 (*b*)
Space-velocity components corrected for standard solar motion:			
X (toward $l=0°$, $b=0°$) (km/sec)	+ 46	+ 27	+ 31
Y (toward $l=90°$, $b=0°$) (km/sec)	− 49	+ 2	− 58
Z (toward $b=90°$) (km/sec)	+ 31	+ 4	+ 31
Total space velocity (km/sec)	74	28	73

3. HD 203064 = 68 Cygni, $l = 55^\circ.4$, $b = -4^\circ.4$, O8 (see Fig. 3*b*). When the proper motion of this star is corrected for the standard solar motion, we find it to point exactly away from the center of the association I Cephei. This is located around $l = 69°$, $b = +4°$, at a distance of about 720 pc (Morgan, Whitford, and Code 1953; Markarian 1953). We can, as in the case of 53 Arietis, specify the absolute magnitude for which the photometric distance of the star is such that its radial velocity and proper motion fit the same

value of the space velocity away from the association. Table 12 summarizes the observational data and the results. The probable error of the last two quantities is of the order of 20 per cent. The age found, 5.1×10^6 years, agrees well with that of 4.5×10^6 years found by Markarian for the association I Cephei as a whole.

4. HD 197419, $l = 44^{\circ}.4$, $b = -5^{\circ}.5$, B2 Ve; and HD 201910, $l = 52^{\circ}.5$, $b = -5^{\circ}.4$, B5 V. These two stars may be moving from the Lacerta association. The proper motions are rather uncertain. They lead to an average estimated space velocity of 35 km/sec and an age of 5×10^6 years for the two stars, with an uncertainty of about 25 per cent.

5. HD 4142, $l = 89^{\circ}.8$, $b = -14^{\circ}.7$, B5 V; HD 26356, $l = 95^{\circ}.5$, $b = +23^{\circ}.9$, B5 V; and HD 214930, $l = 56^{\circ}.8$, $b = -30^{\circ}.7$, B3 V. For these three stars we have computed the space-velocity components corrected for the normal solar motions, using the visual absolute magnitude given in Table 13. This table summarizes the observed quantities and the resulting space velocities. We have checked whether HD 4142 may have originated from the II (ζ) Persei association, but this seems to be out of the question.

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