CHAPTER 6

Moving Groups of Stars

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§ 1. INTRODUCTION

THERE is little evidence for believing that the formation of a star is an isolated event in either space or time. On the contrary, there is evidence, e.g., the existence of clusters and multiple star systems, indicating that many stars were formed in batches. Furthermore, the forces often suggested as capable of breaking up these stellar batches once they are formed can not always be effective because of the great ages now assigned to many of the clusters and multiple systems. If the majority of the stars were produced in a few batches, and if the disrupting forces are not greatly effective, might not the individual stars of a batch still be identifiable by their motion? If so, the space motions of the stars near the sun should be distributed in a non-random way. It is usual in applying the various statistical procedures used in the study of stellar motions to assume that these motions are randomly distributed with, at most, only minor variations. If in fact the observed motions are dominated by those of a relatively few stellar groups, then many of these procedures may be invalid. Furthermore, if the now widely spread members of an original batch of stars can be identified by their motion, a large sample of coeval stars could be examined for chemical constitution and distribution in the color-luminosity array and the possibility of catching stars in such interesting, rapid stages of their evolution as the Hertzsprung gap would be greatly increased.

Proctor (1869) was probably the first to note that community of proper motion seemed to exist for stars located in several regions of the sky. For example, he mentioned stars spread over a 15° area centered on the Hyades cluster and also remarked that five of the "Dipper" stars in Ursa Major were moving together. While compiling the *Preliminary General Catalogue*, Lewis Boss (1908) developed the now well known convergent-point method for discussing

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such widely spread groups of stars. Applying this method to the Hyades, using the proper motions of 40 stars and the radial velocities of only three, he derived a distance and space motion that have been little changed in the intervening half century. In 1909 Hertzsprung applied the same technique to the five "Dipper" stars, comprising what is now known as the Ursa Major cluster, with equal success. Hertzsprung went even further and demonstrated that (*a*) several widely separated bright stars, including Sirius, also shared the motion of the Dipper stars, and (*b*) a half-dozen widely scattered objects shared the space motion of Boss's Hyades cluster.

The success of the convergent-point method depends upon the assumption that the motions of the individual stars in these moving clusters are precisely the same. If we separate the space motion of an individual star, relative to the the sun, into components U directed away from the galactic center, V in the direction of galactic rotation, and W toward the north galactic pole, then, if the convergent-point method is to be successful, these components for all of the group stars must be precisely the same.

TABLE 1

STARS ORIGINALLY ASSIGNED TO THE "61 CYGNI CLUSTER"

GC	V_E	$B-V$	Sp.	$m-M$	U	V	W
92	$5\overset{\mathrm{m}}{.}59$	$+0\overset{\mathrm{m}}{.}52$	G1 V	$3\overset{\mathrm{m}}{.}00$	+90	−55	−18
588	6.21	0.84	K0 IV	4.10	+91	−51	−16
7161	5.64	0.60	G3 IV	1.50	+92	−51	0
9523	5.14	1.24	gK4	4.70	+92	−52	+ 6
16149	4.90	0.64	G5 V	0.70	+94	−49	+ 4
29509	5.19	1.19	K5 V	−2.43	+91	−53	− 8
32342	7.59	+0.56	F9 V	2.90	+90	−56	−12

Subsequent to Boss's and Hertzsprung's success in applying the convergent-point method, several investigations were made of other possible moving groups; the Vela moving cluster (Kapteyn 1914), the Perseus moving cluster (now called the α Persei association, Eddington 1910), the Corona Borealis moving cluster (Rasmuson 1921), the Scorpio-Centaurus moving cluster (Plummer 1913), and the 61 Cygni cluster (Boss 1911, Russell 1912). Aside from the α Persei and Scorpio-Centaurus associations, both of which may only be segments of a large local association of B-type stars (Eggen 1961), all of these moving clusters have subsequently been regarded as non-existent. For example, Rasmuson (1921) and Chaudhuri (1940) concluded that cluster motion was not present in the stars assigned by Boss and Russell to the 61 Cygni cluster; by this conclusion they meant that the stars did not meet the test of common convergent point and appropriate radial velocity for parallel motion. It is of interest to examine the (U, V, W) vectors for some of the stars originally assigned to this 61 Cygni cluster. Seven of these objects are listed in Table 1, where the distances have been adjusted to yield values of (U, V) that best match the well-determined values for 61 Cygni (*GC* 29509) with the resulting moduli, $m - M$. The array formed by these stars in the $(B - V, M_V)$ plane is very similar to that for M67 (Eggen 1962). The first three, and possibly the last, star in the table would appear to have common motion, even by the convergent-point test, but their values of W differ enough from that for 61 Cygni, and from those for the rest of the stars in the table, to give a quite different convergent point, and for this reason the stars would not appear to form a group moving with 61 Cygni when the convergent-point test was applied.

Attempts to find members of Hertzsprung's extended Hyades and Ursa Major moving clusters met with better success. The extensive literature of these "streams" has been summarized by Roman (1949: UMa) and by Wilson and Raymond (1932: Hyades). There has been a tendency in many investigations of the extended clusters to give larger and larger tolerances to the required accuracy with which a star has to meet the convergent-point test before being accepted as a cluster member. These extended tolerances admitted more members but, of course, at the same time greatly increased the probability that spurious members would be accepted. In the case of the 61 Cygni group members in Table 1, if the requirements on the convergent test had been loosened to the point where the observed value for a star only had to fall within 20° of that for 61 Cygni, most of the stars would have been regarded as members. However, loosening the tolerances on the convergent point not only admits stars whose W motion alone differs from the group mean, but it also admits those, probably non-members, whose U or V motions deviate by an equal amount.

The question of the reality of the Hyades group was re-examined in 1957 (Eggen 1958, 1959). The convergent-point method, with suitable modification to allow for errors in both the observed proper motions and in the convergent point itself, was used. That is, the same severe requirements of closely parallel motion that this method places on cluster members were also applied to the widely scattered members of the group. The results left little doubt that far more stars showed the space motion of the Hyades than would be expected from chance alone. Delhaye (1948) using a different procedure, had arrived earlier at a similar conclusion concerning the Ursa Major stream. However, because of (1) the relatively low space motions of the Hyades, and especially, the Ursa Major stream, (2) the very large number of low velocity stars, and (3) the large systematic and accidental errors occurring in much of the available motion data, spurious group members are difficult to eliminate from a consideration of the observed motions alone.

There are at least two objections to the use of the convergent-point method in isolating group members; (1) the W-motions may be uncoupled from those in (U, V), which would limit the group members found by this method to those that happened to have W values near that of the defining stars, and (2) by working with the observed equatorial components of the motions, instead of components that have some galactic significance, the physical situation is obscured. Both of these objections are overcome if we work directly with the (U, V, W) components of the space motion. The dependence of the values of (U, V, W) on the assumed distance of the star is a linear one so that (U, V) loci generated by varying the assumed distances are straight lines in the (U, V) plane. Therefore, for members of a cluster the location of the intersection point of these loci is a two-dimensional equivalent of finding the convergent point of the observed proper motions. Furthermore, because some estimate of the luminosity exists for nearly all stars for which accurate observed motions are available, probable limits to the lengths of the (U, V) loci can be pre-assigned and obviously spurious group members eliminated from consideration. This method has been applied to the Hyades group (Eggen 1960*b*), and approximately 200 stars and binary systems, in addition to the known members of the Hyades and Praesepe clusters, were selected as members. A similar procedure applied to the Ursa Major group (renamed the Sirius group) isolated 100 members (Eggen 1960*c*).

§ 2. YOUNG GROUPS

To assist in the search for moving groups among the brighter stars a catalogue containing the objects for which the presently available motion data are of the highest accuracy has been formed (Eggen 1962). The basis of this catalogue was a list of all stars for which radial velocities of quality *a* or *b* in the *GCRV* were available and (*a*) of spectral type later than B8, (*b*) are in the *GC*, and (*c*) have a probable luminosity fainter than -1^{m}; the limitation on the luminosity was dropped for the K- and M-type stars. A mean position, on the system of the *GC*, was then formed for all of these stars also occurring in at least two post-1925 position catalogues, and a post-1900 proper motion determined by comparison with the *GC* position, which has a mean epoch near 1900. These new proper motions were then compared with the pre-1900 values given in the *GC*, and the catalogue was formed of those stars for which the pre- and post-1900 values agree well enough to insure that, if the available luminosity estimates are nearly correct, the combined values of the proper motions will lead to space velocities with an accidental error of only about 5 km/sec. The catalogue contains all of the information necessary to construct the (U, V) loci for the some 4000 stars comprising it, i.e., the values of (U, V, W) based on the "best" luminosity derived from all available estimates, and the changes in these velocity components (dU, dV, dW) per 1000 parsec change in the distance.

One method of detecting the presence of moving groups is to examine the distribution of a large number of stars in the (U, V) plane. To do this requires a homogeneously accurate set of luminosity estimates, preferably for members of a relatively pure population sample. Such a sample is represented by the A-type stars which are most probably less than some 5×10^8 years old and populate a restricted region in the $(M_V, B - V)$ plane. The lower envelope of the Pleiades main sequence, obtained by fitting the F- and G-type cluster stars to the main sequence of the Hyades stars, is shown in Figure 1. Also, the luminosities of the metallic line (Am) and the peculiar (Ap) A-type stars in galactic clusters (Table 2) or in wide double and multiple systems (Eggen 1963*b*) are shown in Figure 1 as filled and open circles, respectively. The luminosities of the Ap and Am stars show little dispersion about a mean relation, $M_V = 0.35 + 7.8\ (B - V)$. The few A-type stars with known luminosity of MK luminosity class V fall in the region of Figure 1 that is enclosed by the Pleiades main sequence and the Ap and Am stars. Accurate (U, B, V) photometry is available for most of the A-type stars brighter than visual magnitude 5.5 (Eggen 1963*c*).

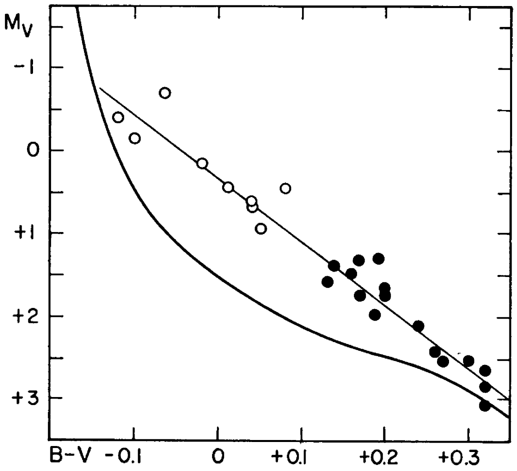

FIG. 1.—The Ap (*open circles*) and Am (*filled circles*) stars in clusters or wide binary systems. The mean $(M_V, B - V)$ relation is $M_V = 0^{\mathrm{m}}35 + 7.8(B - V)$. The Pleiades main sequence is also shown.

The (U, V) diagram for the Ap-, Am-, and A-type stars with known luminosity class V, omitting a dozen known members of the Hyades *cluster*, is shown in Figure 2.

Several features usually found in a discussion of the motions of A-type stars are apparent in Figure 2. The (U, V) distribution is roughly elliptical with the major axis of the ellipse showing a definite tilt from the direction toward the galactic center (the deviation of the vertex). The median values for the 240 stars are $(U, V) = (+9, -9)$. From a discussion of nearly 700 A0–A9 stars Vyssotsky and Janssen (1951) found median values of $(U, V) = (+10, -9)$, which they use to define the "basic" solar motion. However, another obvious feature of Figure 2 is the clumpiness in the distribution of (U, V) values. If each of these clumps represents a kinematically related group of stars, the median values of U, and especially of V, upon which the "basic" solar motion is based, is determined from a statistically inadequate sample of only a half-dozen independent vectors. The bulk of the A-type stars in Figure 2 can be assigned to a half-dozen groups: the Hyades group (Eggen 1960*b*), the Sirius group (Eggen 1960*c*), the Coma Berenices group (Eggen 1963*c*), and two anonymous groups near $(U, V) = (+18, -18)$ and $(-5, +5)$ (Eggen 1963*c*). The Hyades, Pleiades, and the Sirius groups are the easiest to recognize because they lie near the extremities of the (U, V) distribution of the A-type stars.

From evolutionary consideration the age of the stars in Figure 2 can be esti-

TABLE 2

THE Ap AND Am STARS IN SOME GALACTIC CLUSTERS

Name	M_V	$B-V$	$U-B$	Sp.
	Coma Berenices ($m-M=4^{m}53$)			
16 Com	$+0^{m}47$	$+0^{m}08$	$+0^{m}13$	Ap
17 Com	+0.76	− .05	− .12	Ap
21 Com	+0.93	+ .05	+ .10	Ap
22 Com	+1.76	+ .11	+ .10	Am
8 Com	+1.74	+ .17	+ .15	Am
HD 107276	+2.14	+ .18	+ .09	Am
HR 4751	+2.13	+ .21	+ .09	Am
HD 108486	+2.23	+ .16	+ .10	Am
HD 107935	+2.24	+ .24	+ .05	Am
HD 107513	+2.89	+ .28	+ .03	Am
	Hyades			
16 Ori	+2.13	+ .24	+ .14	Am
81 Tau	+2.42	+ .26	+ .10	Am
60 Tau	+2.88	+ .32	+ .10	Am
63 Tau	+2.54	+ .30	+ .14	Am
HD 28226	+2.55	+ .27	+ .10	Am
	Praesepe ($m-M=6^{m}04$)			
HD 73618	+1.28	+ .19	+ .14	Am
HD 73711	+1.50	+ .16	+ .13	Am
HD 73709	+1.66	+ .20	+ .15	Am
HD 73730	+1.98	+ .19	+ .13	Am
HD 73818	+2.67	+ .32	+ .11	Am
	M39 ($m-M=7^{m}20$)			
E5	+0.65	+ .04	− .01	Ap
HD 205117	+0.45	+ .01	+ .03	Ap
+47°3452	+1.68	+ .17	+ .14	Am
E45	+1.87	+0.22	+0.10	Am

mated as probably not more than about 5 × 10^8 years. It may be possible to further subdivide this sample by considering the Ap (Morgan 1933) stars only. Figure 3 shows, as filled circles, the (U, V) distribution for the bluest (and therefore, presumably the youngest) Ap stars, with $B - V < -0^m10$. All of these objects have spectral peculiarities characterized by "Si-λ 4200" or "Mn." The redder Ap stars, which are of the "Eu-Cr" or "Eu-Cr-Sr" types, are indicated in the figure by open circles. Also, four galactic clusters with relatively well-determined space velocities are shown as crosses. The Ap stars in Figure 3 show the same general distribution as all of the A stars in Figure 2, but a sharp demarcation appears in Figure 3 between the bluest (Si-λ 4200, Mn) stars and the Eu-Cr-Sr stars. The color-luminosity arrays for the clusters Ursa Major, Coma Berenices, and M39, which are distributed in Figure 3 like the Eu-Cr-Sr stars, are shown in Figure 4. All three clusters are apparently of similar age, and each contains Ap stars of the Eu-Cr-Sr variety which are indicated in Figure 4 by arrows. Furthermore, the F- and G-type main-sequence stars in the Ursa Majoris and Coma Berenices clusters show an ultraviolet excess of about $+0^m05$ with respect to those in the Hyades cluster (Sandage and Eggen 1959); no certain cluster member of type later than about F0 is known in M39. The Hyades and Pleiades clusters, on the other hand, which have the same intrinsic ($U - B$, $B - V$) relation and therefore, presumably, the same abundance of heavy elements, fall in Figure 3 among the bluest Ap stars. Neither of these clusters contain Ap stars, but the clusters NGC 2516 and IC 2602, which have motions

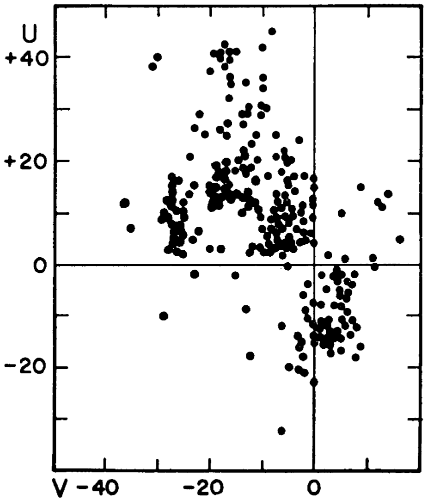

FIG. 2.—The (U, V) diagram for the A-type stars brighter than visual magnitude 5^m5 and of luminosity class V.

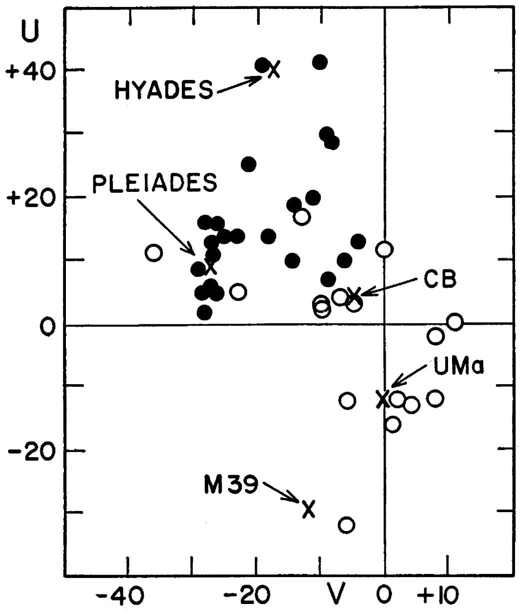

FIG. 3.—The (U, V) diagram for Ap stars bluer (*filled circles*) and redder (*open circles*) than $B - V = -0^m.10$.

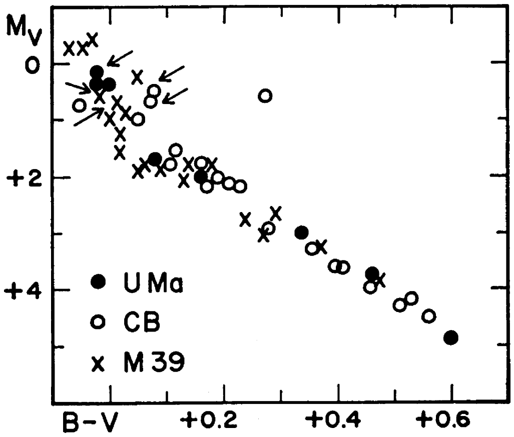

FIG. 4.—$(M_V, B - V)$ diagram for three clusters with Ap stars (*arrows*) of the "Eu-Cr-Sr" type.

similar to that of the Pleiades, do contain at least one Ap star each of the Si type. The (U, V, W) vectors of these clusters, based on the distance moduli and reddening values shown in the figure, are given in Figure 5, which also contains the color-luminosity arrays; the Ap stars in NGC 2516 and IC 2602 and the peculiar shell star Pleione in the Pleiades are indicated by arrows.

Figure 3 indicates that most of the clumpings in the (U, V) distribution of Figure 2 are associated with clusters. This distribution may be affected by further parameters involving the chemical composition of the stars. Unfortunately, the ultraviolet excess, as an indicator of the abundance of heavy elements, is not very effective for the A-type stars. There are available, however, many wide binary and multiple systems containing an early-type component and one or more F- or G-type main-sequence stars. If the components of these systems are coeval, the ultraviolet excess, and therefore the abundance of heavy elements, can be obtained from members of late type which also serve to give a photometric parallax for the system. The necessary photometric observations have been made for several of these systems (Eggen 1963*b* and unpublished), and the results for those containing one component bluer than $B - V = +0\overset{\mathrm{m}}{.}40$ are shown in Figure 6. The systems in which the fainter components show an ultraviolet excess of $+0\overset{\mathrm{m}}{.}04$ or more are indicated by crosses and those with smaller excess by filled circles. When the difficulty involved in the photometry of relatively faint stars in the vicinity of brighter and bluer objects, and the uncertainty of the reddening corrections for some systems, is taken into account, it can be concluded from Figure 6 that probably all of the systems showing little or no ultraviolet excess with respect to the Hyades cluster main-sequence stars have positive values of U and have a distribution in the (U, V) plane that is similar to that of the Ap (Si-λ 4200, Mn) stars in Figure 3. The systems with an excess of $+0\overset{\mathrm{m}}{.}04$ or more have a distribution in Figure 6 that shows the same concentration near $U = -10$ as the Ap (Eu-Cr-Sr) stars in Figure 3, but there are also conspicuous groupings near (U, V) = (+19, −19)

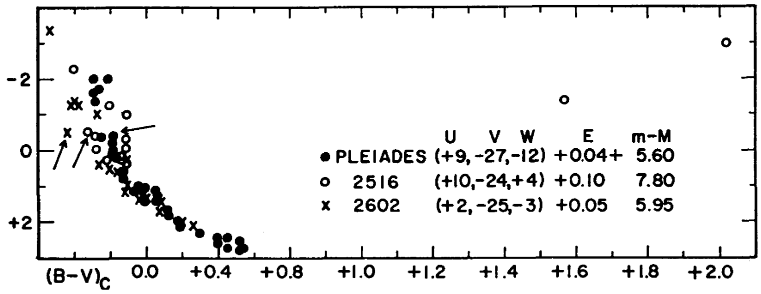

FIG. 5.—Clusters probably belonging to the Pleiades group and containing Ap stars (*arrows*) of the "Si" type.

and (+14, −7). In addition to the evidence from Figures 3 and 6 that there is a correlation between the abundance of heavy elements and the galactic orbits of the A-type stars, there is also some indication that the ratio of hydrogen to helium may be similarly correlated with the kinematic properties. Stars showing no ultraviolet excess with respect to the Hyades cluster main sequence populate one ("Hyades-Pleiades") mass-luminosity relation, whereas those showing an excess populate another ("Sun-Sirius") relation and the differences between the two relations can be understood if the Hyades-Pleiades stars have a He/H ratio twice that of the Sun-Sirius stars (Eggen 1963*a*).

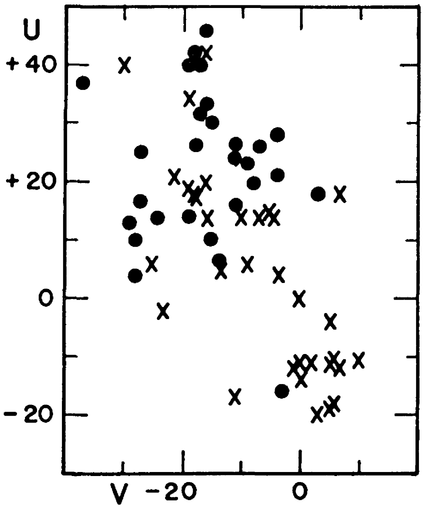

FIG. 6.—(U, V) diagram for wide binaries with the brighter component bluer than $B - V = +0^{m}4$. The filled circles and crosses represent systems with an ultraviolet excess smaller or larger, respectively, than $+0^{m}03$.

Additional evidence of the kind described above is needed, but that already available strongly suggests that at least two kinds of objects make up the young stars near the sun:

Kind	$\delta(U-B)$	He/H	Z/H	U	V
Hyades-Pleiades . . .	$\leq +0^{m}03$	(3/2):	(1.5−2⊙):	+ 5 to +40	− 5 to −30
Sun-Sirius	$> +0.03$	2/3	⊙	+20 to −20	+10 to −20

The values of Z/H, which are here equated to Fe/H as measured in the spectra, depend upon the spectroscopic and photometric comparisons between the sun and the Hyades and are subject to considerable uncertainty. It seems clear that, because of the presence of groups and an imperfect understanding of the relation between the chemical constitution and the kinematics of the stars, the sun's galactic orbit cannot now be obtained from the solar motion with respect to the A stars as a whole.

Most of the groups have a considerably larger dispersion in U than in V, which may result from an effect described by Woolley (1961). If a batch of stars with a common origin in time, and in place within a kiloparsec or so, is overtaken by the sun sometime later, we would see only a selection of the original batch because of the dispersive effect of whatever velocity dispersion the stars had at origin. This selection yields those stars with a V velocity that would place them at the time and place of rendezvous with the sun. The sharpness of the V selection would depend upon both the volume surveyed and on the age of the stars, and could range from the total, original dispersion in V, if the batch is overtaken near the time of its origin, to well within 1 km/sec, if the stars had made 4 or more complete orbits about the galactic center. The U velocities of the group stars, on the other hand, may indicate the original dispersion in U, unless the dispersions in U and V are correlated for some reason. The youngest stars in the Pleiades group are probably near 5×10^7 years old, so we might expect 4 or 5 km/sec dispersion in the V velocity, whereas the older Hyades group may represent more highly selected members of the original batch with a range of perhaps only 2 km/sec in V.

It is difficult, even in the case of the relatively high-velocity groups like the Pleiades and Hyades to be certain of the membership of some individual stars; the groups of lowest velocity, such as the Coma Berenices group, are only detected when highly accurate data such as that used in constructing Figure 2 is available. However, additional tests of the group hypothesis are to be had in the consistency of the resulting color-luminosity arrays. A full discussion of this point, as well as of the new information the groups may provide for refining the theories of stellar evolution, would be out of place here. Discussions of this type are given in the references cited above for the individual groups.

§ 3. OLDER GROUPS

It would appear that the tendency of young stars to occur in groups is well established. Because of the limitations of the available observational data it cannot now be determined how strong this tendency is among the older stars. The effect of the V selection discussed above becomes sharper with time but of course the number of stars meeting the stricter tolerance on V will be smaller, so that the remnants of an old group in the solar neighborhood at any moment will decrease as the age of the group increases.

Also, it is more difficult to isolate a pure sample of old stars. As we move down the main sequence from the A stars to the F and G dwarfs we will find older stars but always mixed with young objects, so that the total age spread of our sample will increase with increasing spectral type. The subgiants, of type later than about G5, probably represent a relatively pure sample of stars older than some 5×10^9 years. The available data have been collected (Eggen 1960*a*), but it is difficult to obtain accurate space motions because of the lack of accurate luminosities. Several of these objects occur in wide binaries together with a main-sequence component, but not enough photometric and spectroscopic data are yet available to make a useful analysis of the space motions.

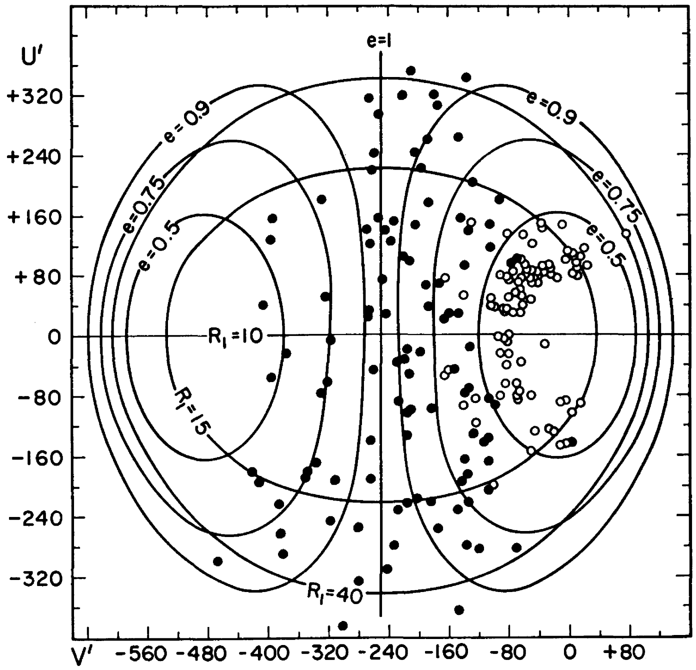

FIG. 7.—Bottlinger diagram for stars with total space velocity over 100 km/sec. The filled circles indicate objects with an ultraviolet excess greater than $+0^{\mathrm{m}}15$ and the open circles those with smaller excess. Curves of equal eccentricity, e, and apogalactic distance, R_1, have been computed from a galactic model by Lynden-Bell.

The total space motion and the abundance of heavy elements may be useful indicators of stellar age. The lowest abundances of heavy elements (the largest ultraviolet excesses) are associated with the oldest stars, such as those occurring in globular clusters, and these stars also have the largest space motions in galactic orbits characterized by large eccentricities (Eggen, Lynden-Bell, and Sandage 1962). A catalogue has been formed of stars whose space motions referred to the sun probably exceed 100 km/sec (Eggen 1964). Velocity components $U' = U - 10$ and $V' = V + 15$, corrected to the local standard of rest, for the some 200 of these objects that are probably dwarfs, are shown in Figure 7, where the open and filled circles represent those with ultraviolet excesses smaller and larger, respectively, than $+0\overset{\mathrm{m}}{.}15$. The loci of equal eccentricity, $e = (R_1 - R_2)/(R_1 + R_2)$, and equal apogalactic distance, R_1, shown in the figure are valid for the model galaxy contributed by Lynden-Bell (Eggen *et al.* 1962).

The space motions of the stars represented in Figure 7 are based on photometric parallaxes obtained from a force-fit to the Hyades main sequence after the observed colors were corrected for line-blanketing effects. These stars are probably all quite old and in various stages of evolution, so that considerable error can be introduced into photometric parallaxes obtained in this way, and the presence of stellar groups could be obscured in the figure. Also, the estimated distances of many of these stars are such that the cosecant law of interstellar reddening would predict values of $E(B - V) = +0\overset{\mathrm{m}}{.}02$ or $+0\overset{\mathrm{m}}{.}03$, which, if allowed for, would increase the estimated distances and, therefore, also the space motions.

Examination on a larger scale, of the space-motion vectors of the stars represented in Figure 7 by open circles, reveals several clumpings in their distribution. Some of these clumpings, which include stars with well-determined parallaxes such as ζ Herculis, 61 Cygni, and η Cephei, are discussed elsewhere (e.g., Eggen 1964). Probable members of one of these groups, the 61 Cygni group, are listed in Table 3. If the space motions are correct, all of these stars are moving in isoperiodic galactic orbits with a spread of ±10 km/sec about the value of $U = +91$ km/sec for 61 Cygni. The color-luminosity array is shown in Figure 8. The Hyades main sequence (Sandage and Eggen 1959) and the subgiant sequence of M67 (Sandage 1962) are also shown. The color-luminosity array of the 61 Cygni group is very similar to that for M67. The mean value of $\delta(U - B)$ for the main-sequence stars with $B - V$ between $+0\overset{\mathrm{m}}{.}6$ and $+0\overset{\mathrm{m}}{.}8$ is $+0\overset{\mathrm{m}}{.}07$. The main sequence shows a small displacement from that of the Hyades which, for the fainter stars, cannot be entirely explained as an evolutionary effect. Because the few binaries in this group populate the "Sun-Sirius" mass-luminosity relation mentioned in Section 2, one explanation of this displacement is that it results from the different He/H ratio in the Hyades and in the 61 Cygni group.

The stars in Figure 8 were selected on the basis of their motion, and it is desirable to have some independent test of the resulting group parallaxes. Figure 9 contains the correlation between the absolute magnitudes obtained from the group parallaxes, $M_V(G)$, and those obtained from spectroscopic luminosity criteria (filled circles) and trigonometric parallaxes larger than $0\overset{\prime\prime}{.}035$ (open circles). It appears from this correlation that the luminosities obtained from the group parallaxes agree well with the spectroscopic and trigonometric luminosities. However, it must be stressed that the small displacement of main sequences in Figure 8 cannot be confirmed by these data.

Groombridge 1830 (HD 103095) and Kapteyn's star (HD 33793) are the only extremely high-velocity stars for which space motions are known with high

TABLE 3

PROBABLE MEMBERS OF THE 61 CYGNI GROUP

HD/BD	V_E	$B-V$	$U-B$*	E†	$\delta(U-B)$	$m-M$	U	V	W	Sp.
61 Cyg A	$5^{\mathrm{m}}19$	$1^{\mathrm{m}}19$	$1^{\mathrm{m}}10$	....	....	$-2^{\mathrm{m}}43$	+ 91	−53	− 8	K5 V
B	6.02	1.38	1.23	....	....					K7 V
142	5.69	+0.52	(1.65)	....	$+0^{\mathrm{m}}02$	2.90	+ 88	−53	−18	G1 IV
2589	6.21	0.84	+0.55	$+0^{\mathrm{m}}02$	(− .05)	4.00	+ 94	−53	−17	K0 IV
Wolf 1056	11.02	1.53	+1.08	....	....	1.05	+103	−53	− 9	dM4
3443 AB	5.56	0.71	(1.79)	....	+ .06	0.95	+ 88	−53	−22	G5 V
4550	6.89	1.08	+0.94	+ .02	(+ .02)	6.75	+ 91	−53	+11	K0 III
10145	7.66	0.69	+0.19	....	+ .05	2.50	+ 97	−53	−17	G5 V
13530	5.32	0.93	+0.62	....	(+ .08)	3.70	+ 88	−53	−18	K0 III
14680	8.81	0.93	(2.03)	....	(.00)	2.40	+ 88	−53	−22	K3 V
22254	8.32	0.58	+0.16	+ .03	(− .06)	4.70	+ 85	−53	+ 6	gF8
23183	6.14	1.01	+0.74	+ .03	(+ .08)	5.30	+ 90	−53	−15	K0 III
30604	8.85	0.57	+0.03	+ .02	+ .06	4.45	+100	−53	− 3	G0 V
+ 0°873	10.10	0.52	0.00	+ .03	+ .04	5.60	+103	−53	− 1	dF8
+31°769	9.06	0.49	−0.03	+ .04	+ .06	5.80	+ 94	−53	−13	dF6
+31°846	9.22	0.61	+0.04	+ .04	+ .09					dG0
35783	7.69	0.46	−0.02	+ .02	+ .03	4.45	+ 88	−53	− 9	G6 V
39091	5.64	0.60	(1.66)	....	+ .09	1.60	+ 96	−53	+ 1	G3 IV
39425	3.12	1.18	(2.26)	....	....	2.35	+ 88	−54	−22	gK1
55526	5.14	1.24	....	+ .03	....	5.30	+ 90	−53	+ 5	gK4
95272	4.09	1.10	+0.99	....	(.00)	3.30	+100	−53	+ 6	K0 III
100030	6.42	0.88	+0.51	+ .02	(+ .06)	4.45	+ 80	−53	+19	G8 IV
106849	4.2 var.	1.56	....	+ .03	....	4.90	+ 85	−53	−24	gM6
110313	7.87	0.61	+0.06	....	+ .08	3.45	+ 90	−53	−13	dG1
120467	8.14	1.27	(2.35)	....	....	0.40	+ 82	−53	−21	dK6
+34°2451	9.61	1.25	+1.17	....	....	1.95	+ 87	−53	− 1	dM0
130992	7.82	1.02	(2.15)	....	(− .03)	1.25	+ 92	−53	−24	dK4
132142	7.76	0.79	+0.32	....	+ .08	1.75	+100	−53	+18	K1 V
149324	4.26	1.07	+0.94	....	(+ .02)	3.50	+ 95	−53	+12	K0 III
162756 AB	7.63	0.61	+0.06	....	+ .08	2.55	+101	−53	−25	G0 IV–V
207692	6.90	0.48	−0.03	....	+ .05	3.95	+ 99	−53	−32	dF5
210905	6.30	1.12	+1.05	+ .05	(− .05)	5.85	+ 97	−53	− 2	K0
+57°2480	9.74	0.58	−0.02	+0.05	+ .12					G0
216777	8.00	0.64	+0.09	....	+ .09	3.35	+ 99	−53	−33	G6 V
219175 A	7.59	0.56	−0.02	....	+ .12	2.70	+ 83	−53	− 7	F9 V
219175 B	8.22	+0.68	+0.11	....	+0.12					G3 V

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* The values in parentheses are on the Cape $(U-B)c$ system (Cousins, Eggen, and Stoy 1961).

† Computed from $E(B-V) = 0^{\mathrm{m}}057 \csc b\ [1 - \exp(-r \sin b/187)]$.

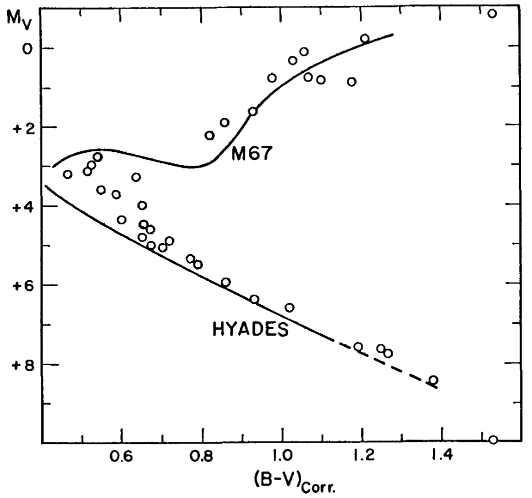

FIG. 8.—(M_V, $B - V$) relation for the 61 Cygni group stars in Table 3. The Hyades main sequence and the M67 subgiant sequence are also shown.

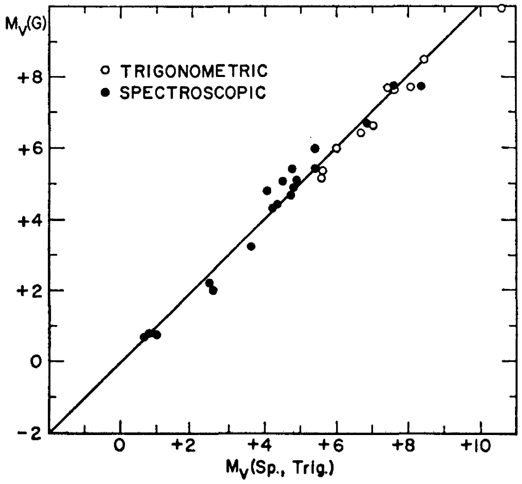

FIG. 9.—Correlation between the luminosities of the 61 Cygni group stars obtained from the group motion with the luminosities from spectroscopic (*filled circles*) or trigonometric (*open circles*) parallaxes.

accuracy, because of the large trigonometric parallaxes. A few of the stars that may share the motions of these subdwarfs are listed in Tables 4 and 5. Members of a third, possible group are listed in Table 6 but, in this case, no defining star of large parallax is available. Tables 4, 5, and 6 contain the photometric (U, B, V) and astrometric (μ_α, μ_δ) data, the radial velocity, ρ, the assigned modulus, $m - M$, values of (U, V, W), and their change (dU, dV, dW) per 100 parsec *increase* in the assumed distance. For the variables, the periods and values of ΔS, which measures the difference in spectral type between that estimated from the hydrogen lines and from the metal lines, are listed in the last columns of the

TABLE 4

GROOMBRIDGE 1830 GROUP

Name/Sp	V_E/ $B-V$	$U-B/\delta$	μ_α/μ_δ	$\rho/m-M$	U/dU	V/dV	W/dW	Remarks
+72°94......	$9^{\mathrm{m}}.94$	$-0^{\mathrm{m}}.20$	$-0^{\mathrm{s}}.0492$	−268.0	− 258	− 143	+ 8	$E=+0^{\mathrm{m}}.03$
sdF2.........	+0.41	+ .22	$+0''.164$	$5^{\mathrm{m}}.20$	− 98	+ 61	+ 54	....
Gmb 1830....	6.49	+ .15	−0.3386	− 98.3	− 267	− 150	− 17	$\pi_t=0''.115$
G8 Vp.......	+0.75	+ .19	−5.798	− 0.30	+2754	−1664	+888	....
ADS10938....	9.62	− .06	−0.0322	+191.0	− 240	− 161	+ 34	$\pi_t=0''.020$
sdF8.........	+0.61	+ .20	−0.695	3.70	− 101	− 383	+ 29	$m=0.5$
RR Lyr*.....	7.81	+0.05	−0.0110	− 72.4	− 253	− 145	+ 2	$E=+0^{\mathrm{m}}.07$
A–F.........	+0.38	....	−0.205	7.00	− 108	− 108	+ 7	$\Delta S=6$

* Photometric data are median values.

TABLE 5

KAPTEYN'S STAR GROUP

Name/Sp	V_E/ $B-V$	$U-B/\delta$	μ_α/μ_δ	$\rho/m-M$	U/dU	V/dV	W/dW	Remarks
Kapt.*.....	$8^{\mathrm{m}}.81$	$+1^{\mathrm{m}}.20$:	$+0^{\mathrm{s}}.6190$	+244.0	− 22	− 289	− 50	$\pi_t=0''.250$
M0 V......	+ 1.59	....	$-5''.722$	− $2^{\mathrm{m}}.00$	−2201	−2594	+2342	....
LTT12271..	10.97	−0.12	0:	− 5.0	− 10	− 281	− 38	$E=+0^{\mathrm{m}}.03$
sdF8.......	+ 0.58	+0.22	−0.430	5.70	− 4	− 201	− 24	....
SU Dra*...	9.70	....	−0.0062	−161.0	− 19	− 282	− 22	$E=+0^{\mathrm{m}}.07$
A–F.......	+ 0.33	....	−0.074	8.90	+ 9	− 34	+ 16	$\Delta S=6$
ST Leo*....	11.3	....	−0.0010	+150.0	− 19	− 285	+ 45	$\Delta S=7$
A–F.......	....	....	−0.041	10.50	− 3	− 19	− 8	....
HD106038..	10.18	−0.18	−0.0128	+ 96.0	− 28	− 284	+ 18	$E=+0^{\mathrm{m}}.03$
F6 IV–V...	+ 0.48	+0.20	−0.434	5.40	− 25	− 213	− 63	....
−13°3834..	10.68	−0.10	−0.0239	+123.5	− 33	− 286	+ 3	$E=+0^{\mathrm{m}}.02$
sdF7.......	+ 0.60	+0.22	−0.440	5.00	+ 44	− 248	− 85	....

* Photometric data are median values.

TABLE 6

GROUP WITH (U, V) NEAR (−160, −320)

Name/Sp	$V_E/B-V$	$U-B/\delta$	μ_α/μ_δ	$\rho/m-M$	U/dU	V/dV	W/dW	Remarks
HD74000.....	$9^{m}65$	$-0^{m}20$	$+0^{s}0205$	+206.0	−166	− 317	+ 62	$E=+0^{m}03$
sdF1.........	+ 0.41	+0.22	$-0''482$	$5^{m}10$	−250	− 137	+ 8	....
+29°2091....	10.24	−0.20	+0.0141	+ 74.0	−156	− 326	+ 88	$\pi_t=0''021$
sdF5.........	+ 0.49	+0.22	−0.790	4.90	−197	− 329	+ 24	$E=+0^{m}02$
Ross 451.....	12.23	+1.16	+0.0595	−118.0	−152	− 335	+152	LFT834
sdM0........	+ 1.45	....	−3.180	2.00	−393	−1107	+956	....
Ross 453.....	11.08	−0.20	−0.0027	+ 98.0	−156	− 332	− 81	LTT13387
sdF2.........	+ 0.43	+0.22	−0.415	6.30	− 80	− 156	− 91	$E=+0^{m}03$
HD108177....	9.68	−0.23	−0.0018	+158.5	−170	− 332	− 8	$\pi_t=0''031$
sdF4.........	+ 0.43	+0.25	−0.476	5.00	− 99	− 177	−100	$E=+0^{m}02$
−35°14849...	10.52	−0.22	−0.0076	+110.0	−163	− 332	− 49	$E=+0^{m}03$
sdF..........	+ 0.40	+0.25	−0.475	5.95	− 58	− 222	+ 20	....

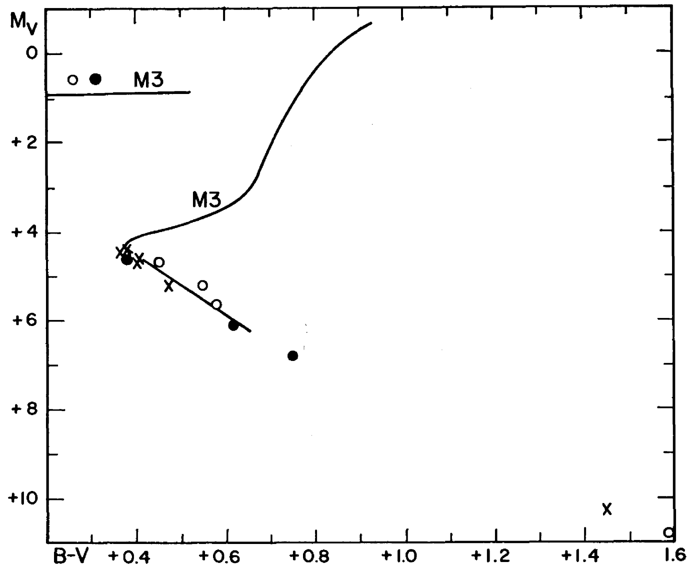

FIG. 10.—The (M_V, $B-V$) diagram for the high-velocity stars in Tables 4 (*filled circles*), 5 (*open circles*), and 6 (*crosses*). The sequences shown schematically are for M3 with $E=+0^{m}04$ and $m-M$, corrected, of $14^{m}50$.

tables; this column also contains the trigonometric parallaxes for a few stars and the values of the reddening, $E(B-V)$, obtained from the cosecant law.

The colors, corrected only for reddening, and the luminosities of the group stars are shown in Figure 10, with filled circles, open circles, and crosses representing those in Tables 4, 5, and 6, respectively. Accurate photometric data are not available for ST Leonis, but the median value of M_V is near $+0\overset{m}{.}6$. The mean color-luminosity array for M3 (Sandage 1962) with $E(B-V) = +0\overset{m}{.}04$ and corrected $(m - M) = 14\overset{m}{.}50$ is also shown in the figure. From the ultraviolet excess and the size of the space motions, we can identify these stars with those in globular clusters. The ratio of three cluster variables to only 13 subdwarfs appears high compared to an estimate of approximately 1 variable per 10^5 stars in a globular cluster. However, recent surveys indicate that the 100 or so field subdwarfs now known represent only a small fraction of those near the sun, whereas the census of RR Lyrae variables to, say, magnitude 10 is probably nearly complete.

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