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COMMON PROPER MOTION STARS IN A SOUTHERN ZONE CATALOGUE

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In the recent Yale Zone Catalogues star charts have been included showing 20,000 year changes in star positions indicated by the proper motions of the catalogued stars. An inspection of such charts (e.g. Figure 1) reveals some widely scattered stars which seem to share large proper motions. In the Zone Catalogue for -40° to -50°, just published as Vol. 30 of the Transactions of the Yale University Observatory, we have indicated some fifty pairs or groups of stars appearing to have closely the same proper motions exceeding 0."100. The numbers of stars represented in each group range from two to fifty. In general, the largest groups correspond to the smallest motions, where the uncertainties are also the greatest. The average number of stars per group decreases from eleven for proper motions between 0."100 and 0."200, to three between 0."300 to 0."500, to two for proper motions exceeding 0."500.

Figure 2 is a polar chart with the south equatorial pole at the center, showing all of the suggested groups listed in Vol. 30 as though they were all centered at exactly -45° declination. Sizes of the dots represent the number of individual stars represented in each group, and the arrows the size and direction of the proper motion, on an arbitrary scale. Also indicated are the approximate positions of the Milky Way, the pole of the Milky Way, the solar apex and the coordinates of the two vertices of star streaming. Just off the chart to the left, on the Milky Way, is the position of the galactic center. Although a two-dimensional diagram representing the better part of a hemisphere distorts the picture, the diagram does confirm the well known expected situation that many of the groups converge toward the solar apex and Drift I vertex, while comparatively few appear to belong to Drift II.

Stars of high apparent space velocity generally belong to Population II. Stars of high proper motion, on the other hand, may be expected to be either high velocity Population II stars or comparatively nearby stars of either population. Pairs of stars close enough together to be considered simply as double stars might well belong to either population. Of greater interest here are the widely separated pairs or loosely distributed groups. Groups of CPM stars would ordinarily be considered as open or moving clusters, and therefore Population I members partaking of galactic rotation. Population II stars taken over the sky as a whole would show individual motions in almost any direction. However, if these stars move in cometary-

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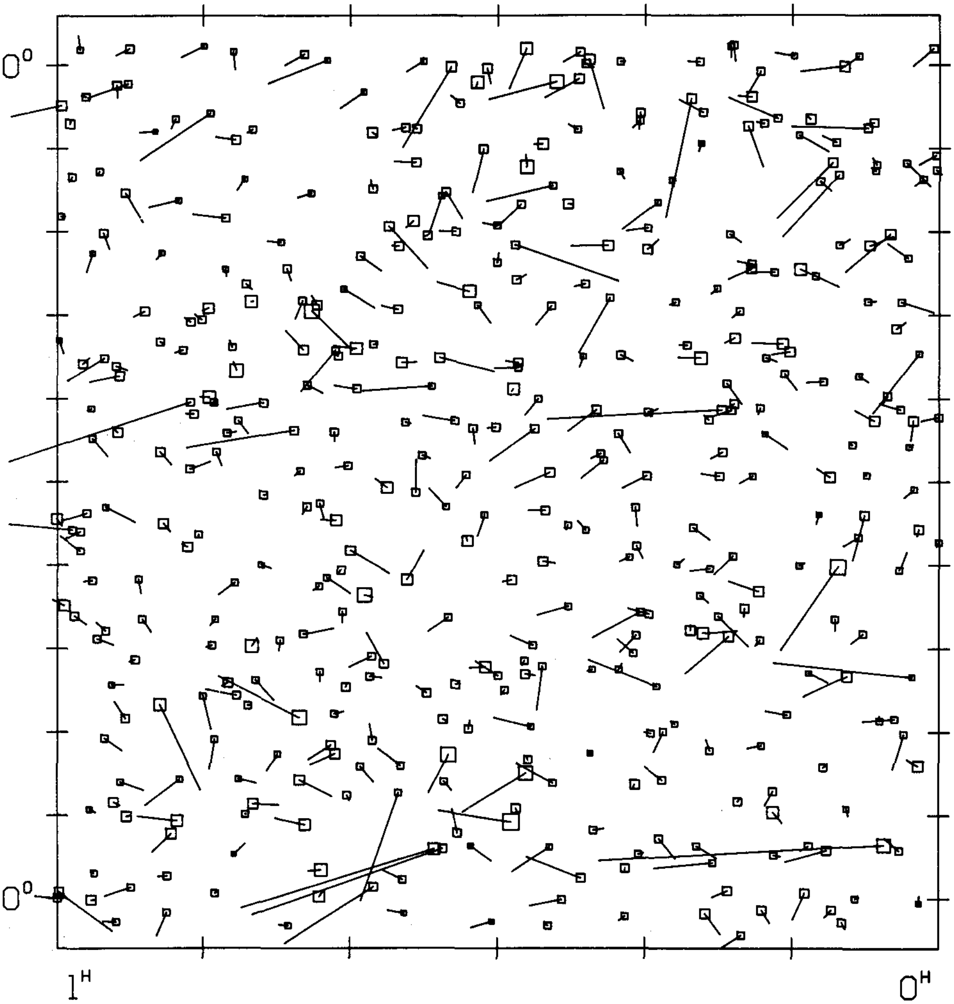

Magnitude Scale: □ 4.0, □ 6.0, □ 8.0, □ 10.0, ▫ 12.0

Figure 1. A sample chart from the Zone Catalogue showing effect of 20,000 years of proper motion.

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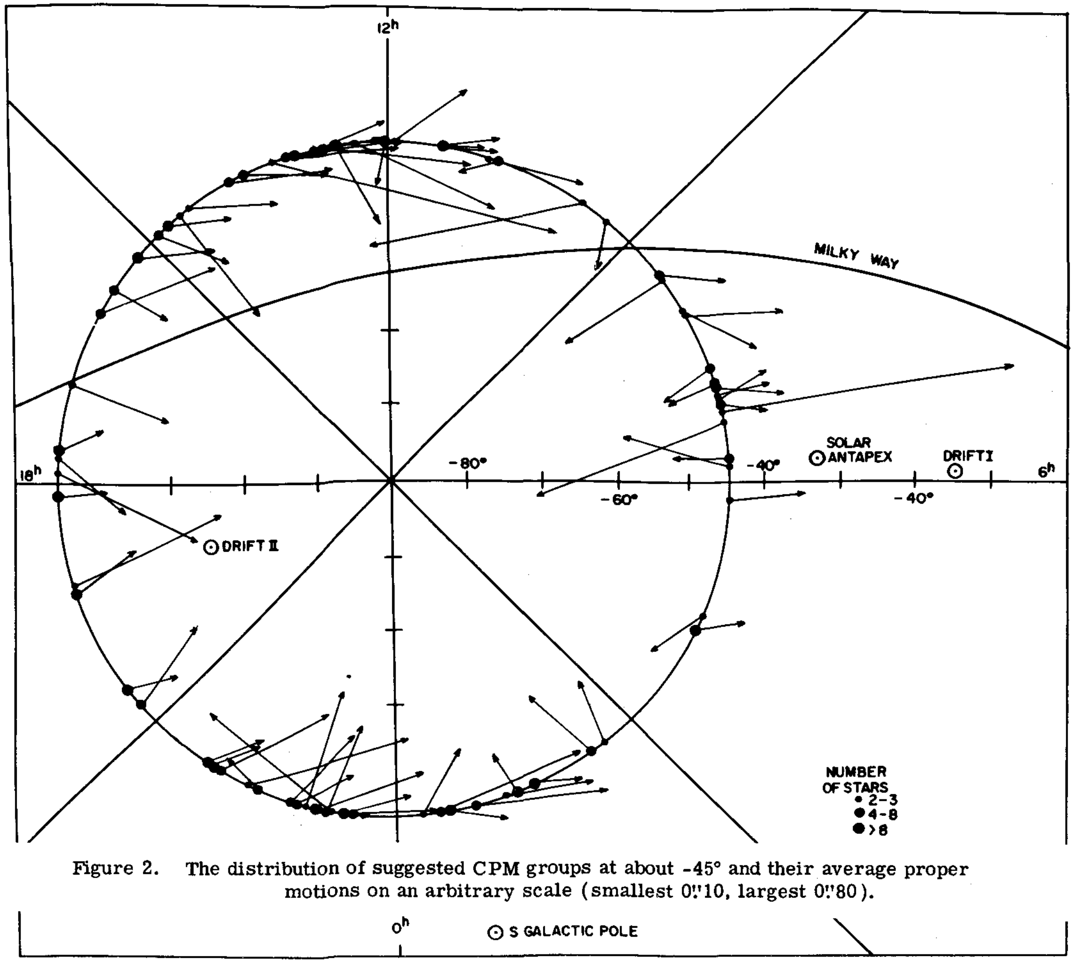

Figure 2. The distribution of suggested CPM groups at about -45° and their average proper motions on an arbitrary scale (smallest 0"10, largest 0"80).

shaped orbits around the galactic center, then in a limited area of the sky they would reveal a preponderance of directions toward or away from the galactic center. In a complete narrow zone of declination one should expect the mean observed position angles to show a progression dependent on right ascension.

For all of the zone stars having proper motions $\geq 0''.200$, irrespective of CPM, we have computed the position angles relative to the galactic pole, rather than the equatorial pole as usual. The galactic position angle is defined as the angle at a star between the direction of the north galactic pole and the direction of the proper motion. The effects of solar motion have not been eliminated; but for stars of such large motion the effects are comparatively small. (For an individual bright star the change in position angle might be as large as 15° but for the average in any of the groups it would be under 5°.) Motions primarily indicative of galactic rotation should have galactic position angles close to -90°. Stars moving in highly eccentric comet-like orbits headed close to or away from the galactic nucleus are expected to have galactic position angles clustering around 0° in R.A. $0 - 1^h$ and $12 - 13^h$, and 90° in $6 - 7^h$ and $18 - 19^h$, the sign depending on whether the star is approaching or receding from the galactic center.

Galactic position angles have been plotted against R. A. in Figure 3 for all of the zone stars with proper motions $\geq 0''.200$. A wide scattering is noted around two apparent correlation lines, one nearly horizontal in position angle 270° representing motions nearly in the galactic plane: therefore Population I stars. The other line is the diagonal which indicated the preferred direction of motion of Population II stars in this zone. In Figure 4 the diagram is repeated for only those stars that appear to belong to CPM groups or pairs. (In these two diagrams no differentiation has been made between the stars of highest and lower proper motion, as no dependence on size of proper motion appeared to be indicated.) Nearly sixty percent of all of the high proper motion stars in this zone appear to share the motion of one or more widely separated stars. From Figures 3 and 4 there is evidently little difference between the CPM stars and the single stars. The scattering is a little less pronounced in Figure 4. In Figure 5 the average position angle is shown for each of the suggested groups, the different symbols representing the relative numbers of stars in each group. Data on the individual groups are given in Table I, where the designations in the first column have been taken from Table 12 (Possible Group Motions) of Vol. 30 of the Yale Transactions. ΔRA gives the extent of the group in one coordinate. The mean total proper motions and their dispersion, ordinary position angles and the galactic position angles follow. The population designations have been assigned on the basis of which correlation in Figure 5 best fits the group. Under D the table gives the number of stars in the group which are contained in catalogues of double stars. Finally the number for which trigonometric parallaxes have been determined are given together with the dispersion of the individual parallaxes from their mean. For true CPM stars one would expect the parallaxes also to be alike within the

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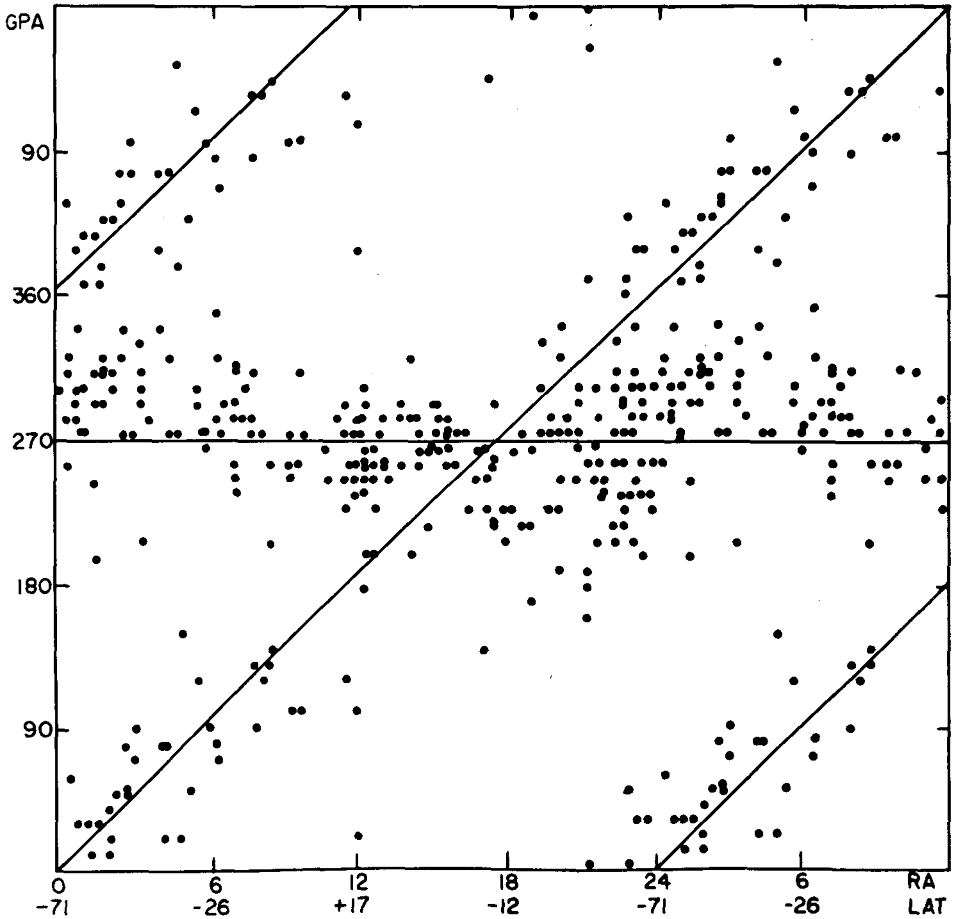

Figure 3. The distributions by R. A. of galactic position angles for all of the zone stars with proper motions > 0".200. Galactic latitude corresponding to R. A. and -45° Dec. are given at bottom.

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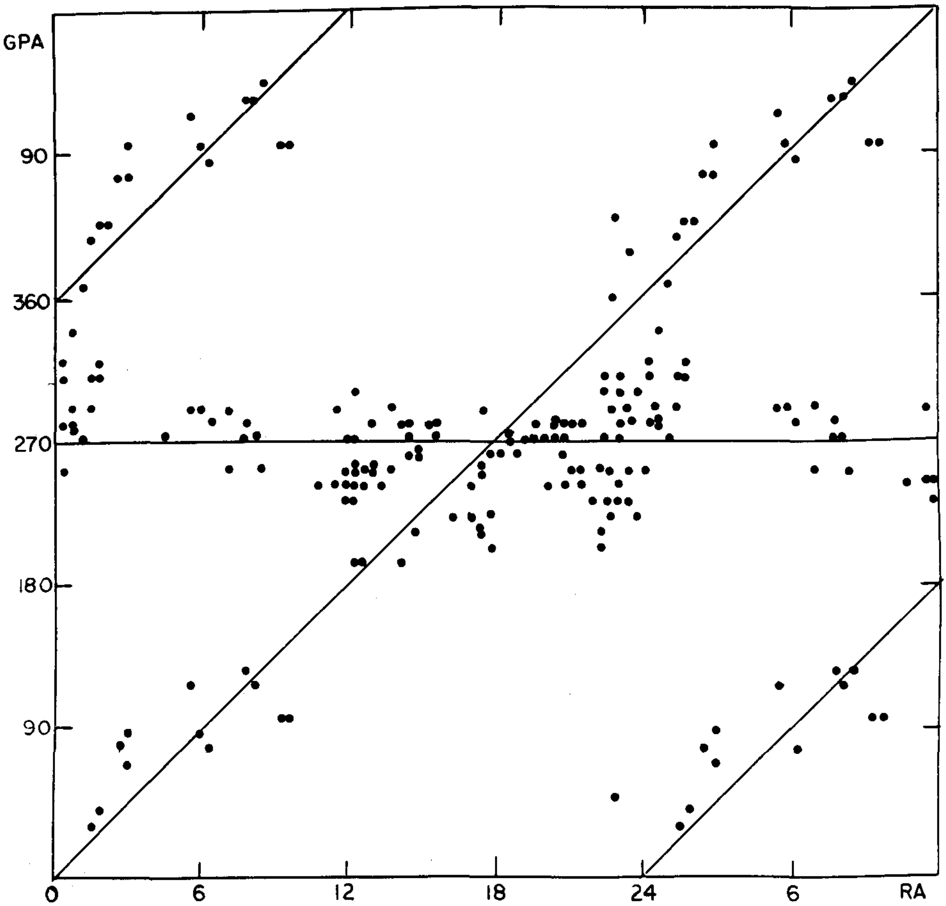

Figure 4. The distributions of the galactic position angles only for the stars that are suggested members of CPM groups.

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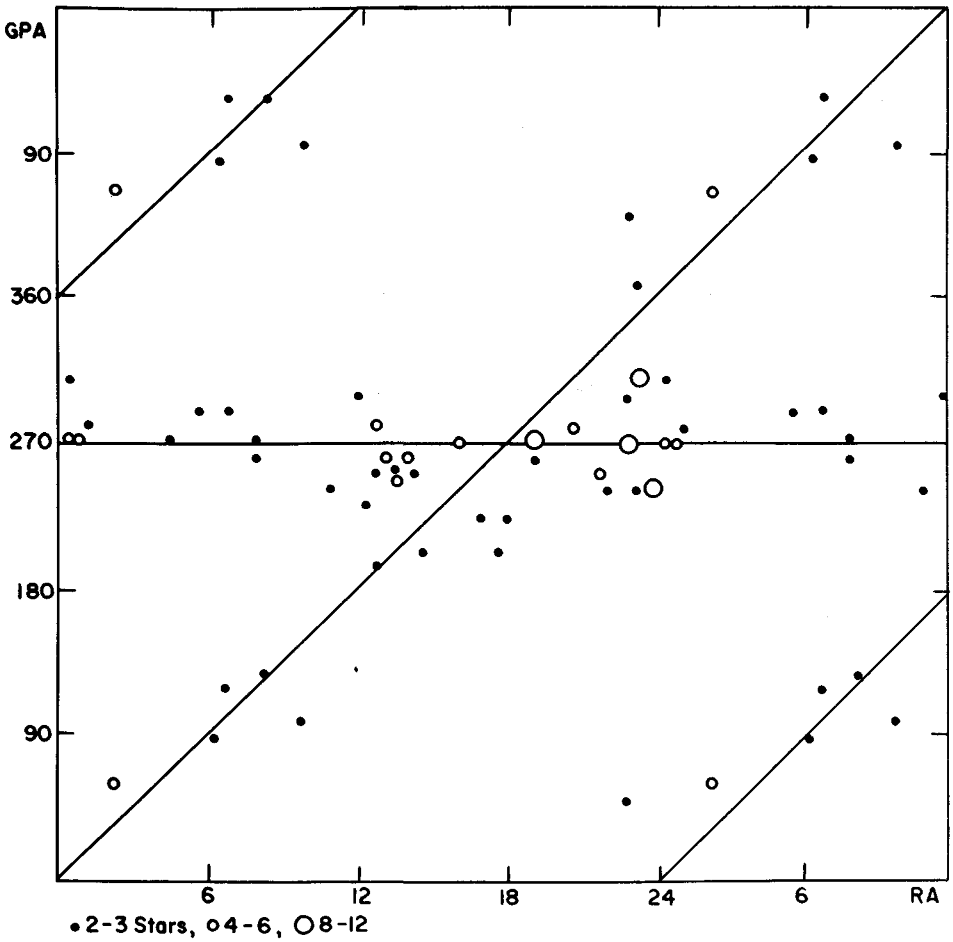

Figure 5. Average galactic position angles for each group. Symbols indicate number of stars in each group.

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Table I. Apparent CPM Groups

	N	RA	ΔRA*	μ ± σ		PA ± σ		GPA	Pop	D	N_π	π	± σ
3a	8	22 48	48°	″.234 ±	6	155 ±	1	276	I	0	6	.017	± 3
3b	8	23 12	19	.235	7	170	1	309	I	1	3	.006	15
6	8	23 29	35	.240	5	102	3	241	I	1	6	.031	4
8	4	00 54	25	.351	13	84	2	266	I	1	4	.024	7
9	4	00 33	6	.405	9	105	3	275	I	1	4	.038	13
10a	2	00 20	4	.213	4	146	0	304	I	0	1	.059	—
11	2	01 17	5	.228	12	80	3	280	I	0	0	—	—
12	(5)	02 23	19	.227	13	189	2	62	II	0	2	.028	31
16	2	06 39	22	.534	37	191	3	120	II	1	2	.038	12
17	2	05 46	1	.206	9	9	3	289	I	0	2	.010	0
18	2	06 11	1	.284	9	162	4	86	II	0	2	.024	15
19	2	06 47	6	.798	24	356	2	286	I	0	2	.028	4
21a	3	08 01	16	.229	9	316	5	257	I	0	3	.019	6
21b	2	11 58	8	.252	4	309	2	297	I	0	2	.018	9
23	3	07 57	1	.261	3	333	1	274	I	0	3	.019	1
24	2	08 26	6	.319	25	178	2	124	II	0	2	.028	13
(26)	2	09 39	3	.590	52	137	1	96	II	0	2	.057	37
27e	4	12 49	17	.199	3	278	1	278	I	0	0	—	—
29b	4	13 07	30	.274	13	261	1	265	I	0	3	.017	9
29c	5	13 50	38	.270	13	250	2	263	I	0	4	.032	7
31	2	13 19	30	.795	19	245	5	252	I	0	2	.025	0
32a	6	13 38	39	.209	3	245	2	256	I	0	3	.004	2
32c	10	15 09	30	.191	4	225	2	256	I	2	5	.018	6
33	3	14 24	14	.235	4	234	1	255	I	0	2	.014	8
34a	2	12 36	10	.357	18	253	4	250	I	1	2	.038	6
34b	3	12 22	3	.412	28	240	3	234	I	0	3	.015	4
35a	2	12 35	1	.231	3	200	1	196	II	1	1	.015	—
36	2	14 31	8	.330	3	180	3	203	II	1	2	.029	15
39	4	15 58	25	.333	16	229	3	270	I	3	3	.030	13
40	2	16 49	7	.275	15	175	3	225	II	0	2	.033	22
41a	12	19 14	45	.198	3	195	2	269	I	4	7	.017	6
41b	6	20 42	35	.258	7	193	2	282	I	1	4	.011	9
42	3	17 41	2	.226	7	148	2	207	II	0	2	.029	9
43	2	17 52	5	.416	15	158	4	218	II	0	2	.055	15
44	3	19 11	33	.442	15	188	2	261	I	1	3	.013	4
45	5	21 47	28	.336	6	148	1	252	I	1	5	.036	10
47	2	22 14	4	.466	3	130	5	240	I	0	2	.034	15
48	(3)	22 57	8	.320	10	177	2	298	I	1	3	.016	24
49	2	23 16	11	.437	9	242	1	9	II	0	2	.028	10
50	2	23 05	1	.297	16	121	1	245	I	0	2	.008	3
51+	3	07 02	0	.405	4	347	1	278	I	3	2	.047	3
52#	2	22 52	0	.236	1	284	1	47	II	2	1	.016	—

* $15\Delta\alpha\cos\delta$

\+ Group 51 is the triple system consisting of Cape Zone Nos. 4147, 4149, and 4150.

\# Group 52 is Cape Nos. 20183 and 20184 both of which are close doubles.

( ) doubtful entries

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accidental uncertainties. In most of the suggested groups this is indeed the case. Group 12, however, is in a dubious category. On the basis of proper motions alone, it appears to have possibly five members and to belong to Population II. It is the only group on the diagonal sequence in Figure 5 with ostensibly more than three members. One of the five stars is γ Phe, $5^{m}.4$ K5II, with a parallax determination of -0".003; another is Cat. No. 1342, $8^{m}.5$ G0, parallax 0".58. Here it is more probable that the similarity in proper motion is coincidental rather than that the two stars are related. The other three components are $9^{m}.5$ G5, $9^{m}.6$ G0 and $10^{m}.0$ without indication of spectral or color class. Their motions agree with one another more closely than with No. 1342. It is probable that this group should be reduced from five to at most three members. It would be of interest to obtain parallaxes for the three stars.

The largest parallax discordance in Table I is for the pair, group 26. This consists of a $9^{m}.1$ K0 star with parallax 0".020, and an $8^{m}.3$ K5 with parallax 0".094. Although the percentage difference in the high proper motions for these two stars (0".539 and 0".642) is no greater than for some other suggested pairs, the actual difference is sufficient to discredit this as a real pair. Group 48 should also, on the basis of the parallaxes be reduced in membership. The suggested constituents are a binary, $6^{m}.3$ G1, $7^{m}.8$ M1, parallax 0".060; and two other stars: $10^{m}.9$ F8, parallax -0".018; and $10^{m}.0$ K0, parallax 0".007. The binary is probably not associated with the other two.

From the data compiled in Table I the differences and similarities between pairs and groups assigned to each of the two Populations are summarized in Table II.

Table II. Intercomparison of CPM Group Characteristics

	Pop. I	Pop. II
No. of pairs or groups	30	11
Average no. of stars per group	4.2	2.2
Average spread in R. A.	19°	8°
Average separation of pairs only	8°	7°
Percent known double stars	16	18
Max. frequency HD spectral class	G5	G5
Average photographic magnitude	8.9 ± 0.9	8.1 ± 1.0
Average parallax	0".025	0".031
Average group proper motion	0".33	0".37 ± 0.10
Galactic Position Angle	270°	0° - 360° trend

As expected, the average number of stars per group is greater for Population I; high CPM "groups" in Population II appear to be represented by at most three stars each, as compared with an average of more than four in

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Population I. The percentage of real double stars among the CPM groups is about the same, sixteen and eighteen percent, and is negligibly different from the percentage of doubles (fourteen percent) among all of the zone stars with proper motion ⩾ 0."200. The parallaxes also are closely the same, as are the total proper motions. On the basis of the astrometric data alone, only the position angles differentiate the Population II stars from Population I. At longitudes close to the galactic center or anti-center, however, this criterion also becomes ambiguous. High multiplicity in CPM groups is a strong indicator of Population I only.

A quick search of the literature on groups and associations reveals that a number of stars in this zone had previously been identified as group members. The stars of such groups are frequently so widely dispersed in the sky that they could not be recognized as related in a simple search for common proper motions. Table III lists a few stars in this zone that had been noted in the Bright Star Catalogue (BS) as members of the association given in the first column. The fourth column indicates the CPM groups to which these stars had been assigned in Yale Transactions, Vol. 30. The assortment of CPM groups to which, for example, the Hyades group members belong, suggests that some 110 additional zone stars belong to the Hyades group; and consequently that several Yale CPM groups must have a common dynamical origin.

Table III. Zone Members of Known Widely Dispersed Associations

Association	Zone Cat. No.	BS	Vol. 30 Group	N	R. A. h	P. M. α	P. M. δ	GPA
61 Cygni Group	10	6	—	D	0.1	$+0^s.058$	$-0''.035$	240°
	4269	2719	15b	6	7.2	-0.024	+0.184	250
Pleiades Group	38	25	10a	2	0.1	+0.117	-0.179	295
Hyades Group	226	125	7b	27	0.5	+0.149	-0.025	250
	4157	2672	15a	10	7.0	-0.064	+0.131	265
	9319	4453	27b	15	11.2	-0.105	+0.030	265
	10617	4831	27c	34	12.7	-0.132	-0.044	250
	20068	8636	2b	31	22.7	-0.130	-0.005	210

There are other associations that are more compact; but they may have such small proper motions that one cannot ascertain solely from the proper motions that the stars do form a CPM system. A case in point is the Association in Ara (16^h27^m to 16^h46^m). This association has been studied by J. R. Whiteoak (M. N. 125: 105, 1962) who identified 127 stars as probable members. Of these fifty-three are in the -40° to -50° Zone Catalogue. Their proper motions range from 0."005 to 0."044, with mean values of $+0^s.0002$ in R. A. and -0."016 in Dec. (This corresponds very nearly to the standard

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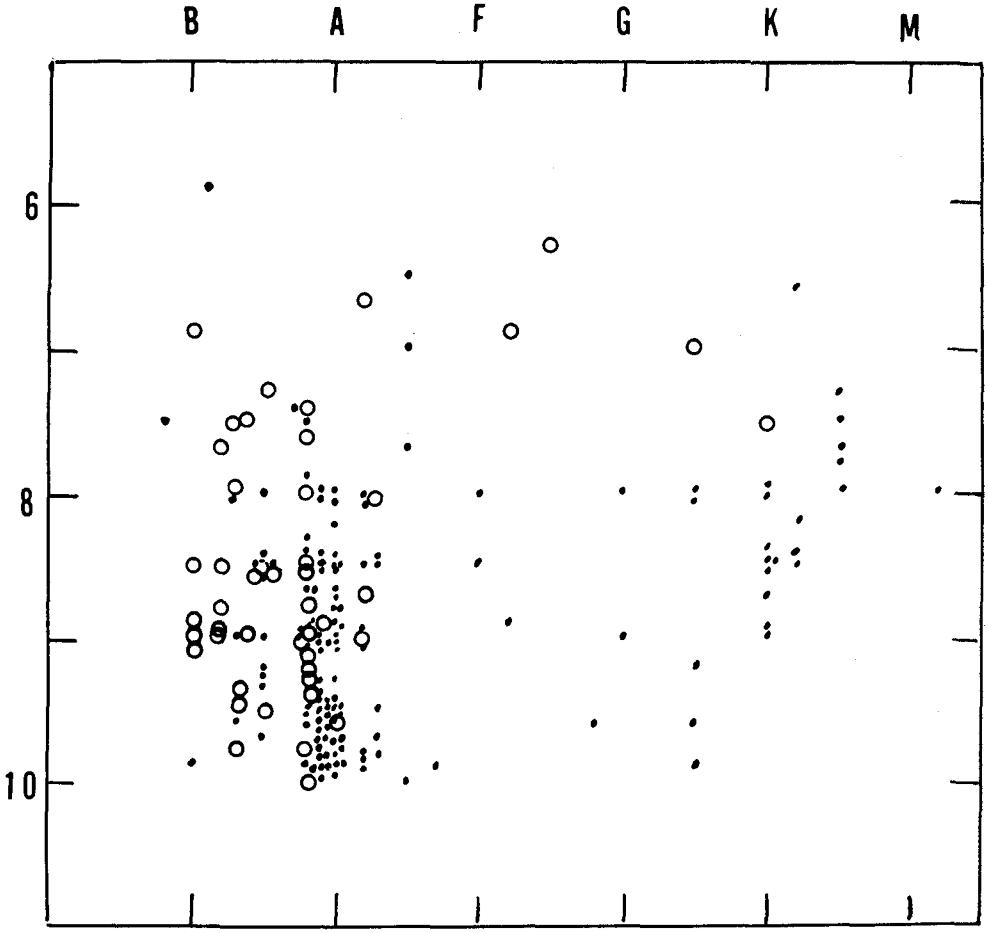

Figure 6. Apparent visual magnitude — HD spectral class distribution for stars in the field of the Ara Association. Circles, known association-members; dots, field stars having the same array of small proper motions.

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solar reflex motion for 9 - 10 magnitude stars at the given position.) For such small apparent motions an investigation of position angles would be of no avail. At least 155 other stars in the zone catalogue within the same limits of R. A. and Dec. have the same array of proper motions - taken between $+0^{s}.0015$ and $-0^{s}.0015$ in R. A. and between $+0''.015$ and $-0''.015$ in Dec. The percentage of double stars among the stars on Whiteoak's list is thirteen percent; among the other stars of the same proper motions, twelve percent, closely the same.

As the group members in this instance are distributed over only a small area of the sky and can be assumed to be at effectively the same distance, an apparent magnitude - HD spectral class diagram should closely represent a true HR diagram, except for zero point and the effects of highly spotty interstellar absorption. A comparison of such diagrams for the Whiteoak stars and the others sharing their proper motions might then reveal possible additional group members. Figure 6 shows such a diagram with different symbols for the two categories of stars. This does strongly suggest that a great many more of the zone stars, especially B, A, and late-type giant stars are probably Ara Association members. For definitive identifications accurate magnitudes, spectral and luminosity classes and color indices are clearly needed. As Whiteoak has shown, the color excesses in this region for the stars he studied, range from $+0^{m}.11$ to $+1^{m}.24$, indicating a variation of some three magnitudes in extinction! Clearly, the common proper motions, even though small, should prove an asset in sorting out association members from field stars.

In summary, the search for CPM stars has revealed nothing basically new. We have re-discovered star streaming and the existence of Populations I and II; demonstrated the usefulness of zone catalogues for extending the known membership of stellar groups and associations; noted that several CPM groups together belong to the widely dispersed Hyades group. More elaborate search of the literature might well reveal similar relations between more of our groups. Pairs or triplets of CPM stars belong to either Population I or II whereas larger groups are Population I. Otherwise the proper motions of groups and pairs seem to have nothing to differentiate them from the "run of the mill" single stars of the same population.

DISCUSSION

Stoy: Miss Hoffleit kindly attributed this catalogue to the Cape of my generation, actually it is the best catalogue the Cape ever produced, and it was produced by Hough. It is based on the astrographic plates with an epoch of 1900, and Hough was one of the first users of the overlap method. This catalogue, which incidentally is ignored in the GC, is an extremely strong catalogue for 1900. And so I think that the proper motions that Miss Hoffleit has derived by comparison with her recent plates with this must be amongst the strongest group of proper motions that you will get from any of her

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catalogues. We have always regarded this as a Cape zone, the Cape astrographic zone, and it is a very interesting zone in that it goes from very high galactic latitudes right through the galactic equator twice. She remarked on the number of parallaxes available. That is because Dr. Jackson made a particular point of taking stars from these catalogues for the Cape parallax program; hence of all the Southern zones this will be the one with the most parallaxes in. Unfortunately, as it was not in the CPC 50, it has not yet been done for photographic photo-visual magnitudes and colors. That program is underway. But we did do a whole lot of photoelectric magnitudes and colors, and these are available for calibrating whatever magnitude systems you have there.

Hughes: Do you have on hand the range of the magnitudes you have in this catalogue?

Hoffleit: The faintest stars are of the order of eleventh magnitude. I believe a few are as bright as seven. But mostly they are between eighth and ninth magnitude.

Stoy: This catalogue is actually composed of two. The first catalogue is for 20,000 stars down to CPD 9.0; the second catalogue has another 20,000 (CPD 9.0 to 9.5). Did you do stars from both catalogues or only the first one?

Hoffleit: We used only the brighter catalogue, for this particular zone. Provided we can get financial support, we are hoping to repeat part of the work we have done for this catalogue and go down to the fainter stars, to make use of the recent plates taken at El Leoncito.

Murray: Can you say anything about the distribution over the sky of your Hyades and suspected Hyades members? Were they scattered all around in right ascension?

Hoffleit: Those in the -40 to -50 degree zone are distributed pretty much all around in right ascension.

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