STELLAR GROUPS. II. THE ζ HERCULIS, ε INDI AND 61 CYGNI GROUPS OF HIGH-VELOCITY STARS

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Summary

A catalogue of 700 high-velocity stars has been searched for objects that share the well-determined space motions of ζ Herculis (22 stars), ε Indi (14 stars) and 61 Cygni (15 stars). The space motions of these groups can be summarized as follows (the Hyades and Sirius Groups of Paper I have been added for comparison):

Group	A		D	V_t	U	V	W
	h	m	°			km/sec	
Sirius	20	44	−42·7	18·4	−14	0	−12
Hyades	6	18	+ 7·5	44·0	+40	−18	− 2
ζ Her	5	48	−16·5	74·5	+54	−45	−26
ε Ind	6	44	+ 6·7	88·5	+79	−39	+ 6
61 Cyg	6	28	+ 0·3	108·0	+92	−53	− 6

where the values of (A, D) represent the convergent points of the apparent motions and V_t is the total space velocity of each group with respect to the Sun (the vector space velocities are in the direction $l=148°$, $b=0°$; $l=58°$, $b=0°$; and $b=+90°$ for U, V, and W respectively). A search through the same catalogue for stars that might be "members" of synthetic groups with convergent point at $\delta=-90°$ and $V_t=74·5$, 88·5, and 108 km/sec indicated that only 2 or 3 chance members are expected to be included in each group.

The colour–luminosity array for the stars in all three high-velocity groups is very similar to that for the galactic cluster M 67.

In 1911 Benjamin Boss (1912*a*) announced the discovery that a dozen stars or so of large proper motion formed a moving cluster with 61 Cygni. Further investigations by Boss (1912*b*) and by Russell (1912) appeared to establish the reality of the cluster but several years later when Rasmuson (1921) re-examined the evidence with the new material then available, he concluded that "there are great reasons to exclude from the list of moving clusters the 61 Cygni-stream . . .". Still later, Chaudhuri (1940) came to the same conclusion.

The purpose of the present investigation is not to re-hash the available data for the stars originally assigned to the 61 Cygni cluster but rather to search for stars sharing the well-determined space motions of selected high-velocity stars, including 61 Cygni. The stars chosen, for the accuracy of their proper motions, radial velocities and parallaxes, are as follows:

Star	π_t	ρ_0 (km/sec)	μ	U	V	W
	″		″			
β Hyi	0·153	+22·9	2·255	+53	−43	−28
ζ Her	0·101	−69·9	0·608	+54	−47	−24
61 Cyg	0·296	−64·0	5·205	+92	−53	− 6
ε Ind	0·285	−40·4	4·692	+79	−39	+ 6

where the vector space velocities (galactic), U, V and W, are directed toward $l=148°$, $b=0°$; $l=58°$, $b=0°$; and $b=+90°$, respectively. The catalogue searched consisted of 700 high-velocity stars, mainly from the lists published by Miczaika (1940) and by Roman (1955) but with a few additional stars obtained from recently published lists of radial velocities.

Since most of the trigonometric parallaxes for the high-velocity stars are much less accurately determined than those for the stars listed above, the method used for selecting group members was that described in a previous paper (Eggen 1958; Paper I). Stars were admitted to candidacy for membership in a group if the observed position angle of the proper motion, θ_0, agreed with that computed from the group motion to the extent that $\Delta\theta \sin\lambda < 10°$, where λ is the angular distance of the star from the convergent point (A, D) of the group motion. The candidates were then admitted to group membership only if the difference, $\rho_0 - \rho_c$, between the observed radial velocity, ρ_0, and that computed from the group motion, ρ_c, was less than, or equal to, 5, 6, or 7 km/sec, respectively, for radial velocities of quality a, b or c, as defined by R. E. Wilson (1953).

The first two stars listed above, β Hydi and ζ Herculis, obviously have a common space motion and the convergent point of what will be called the ζ Herculis Group was obtained from the mutual convergent point of the proper motions of these two stars. The values of (A, D) for what will be called the 61 Cygni and ϵ Indi Groups are merely the apices of the motion of the defining stars, computed from the radial velocities, proper motions and parallaxes listed above. The three convergent points and total space velocities with respect to the Sun, V_t, are as follows (those for the Hyades and Sirius Groups, discussed in Paper I, are added for comparison):

Group	A		D	V_t
	h	m	°	km/sec
Sirius	20	44	−42·7	18·4
Hyades	6	18	+ 7·5	44·0
ζ Her	5	48	−16·5	74·5
ϵ Ind	6	44	+ 6·7	88·5
61 Cyg	6	28	+ 0·3	108·0

Eight per cent, or 54, of the 700 stars examined were found to be members of the three high-velocity groups as follows: ζ Herculis, 23 members; ϵ Indi, 15 members; and 61 Cygni, 16 members. The members of the ζ Herculis, ϵ Indi and 61 Cygni Groups are listed in Tables I, II and III, respectively, together with the observed position angle of the proper motion, θ_0, and the normalized residual from the computed value, $\Delta\theta \sin\lambda$; the observed radial velocity, ρ_0, and its residual, $\Delta\rho$, and quality Q; the total annual proper motion μ; the group parallax π_g, computed from $4{\cdot}738\mu/V_t \sin\lambda$; the observed magnitude and colour V_E and $(P-V)_E$; and the spectral type and visual absolute magnitude, M_v. The proper motions are mainly uncorrected values from the *General Catalogue* (Boss 1937) except for a few stars from the Yale zones or unpublished Greenwich determinations. The radial velocities and their quality have been taken from Wilson's (1953) catalogue. The magnitudes and colours were observed on the $(P, V)_E$ system or reduced to that system from observations by Roman (1955) or by Stoy and his collaborators (cf. Evans, Menzies and Stoy 1957). The spectral types are mainly by Roman (1955).

As a test of the possibility that the group members might be so classified by chance coincidences of θ_0 and ρ_0 with θ_c and ρ_c, the same catalogue of 700 stars was examined for "members" of a synthetic group with convergent point $\delta = -90°$. The galactic coordinates of this convergent, $l = 270°$ and $b = -28°$, place it near the centre of that hemisphere of the sky toward which the velocity vectors of the high-velocity stars show a strong preference (Oort 1926). Eleven per cent, or 76 of the 700 stars examined for membership in the synthetic group gave values of $\Delta\theta \sin\lambda < 10°$. When the criterion that $\Delta\rho \leqslant 5$, 6, or 7 km/sec for stars of quality a, b, and c, respectively, was applied, the following "members" were obtained for three values of V_t:

V_t (km/sec) =	74·5	88·5	108
No. =	3	(1)	3

The one "member" for $V_t = 88{\cdot}5$ km/sec, shown in parentheses, is a star with a small radial velocity of quality c that also satisfies the requirements for the group with $V_t = 74{\cdot}5$ km/sec. Apparently, we might expect two or three accidental members to the groups in Tables I–III but it does not seem possible to dismiss all the members as spurious.

Because of the proximity of the apparent convergent points of the three high-velocity groups, there is some ambiguity in assigning four stars to a particular group. These stars, together with the appropriate values of $\Delta\theta \sin\lambda$, $\Delta\rho$ (in km/sec) and π_g, are as follows:

	ζ Herculis			61 Cygni			ε Indi		
	$\Delta\theta \sin\lambda$	$\Delta\rho$	π_g	$\Delta\theta \sin\lambda$	$\Delta\rho$	π_g	$\Delta\theta \sin\lambda$	$\Delta\rho$	π_g
η Ret	−2°	−3	0″·016	−8°	+5	0″·009			
HD 66171				0	+6	0·023	+3	+2	0·030
HD102365				+7	0	0·070	0	+4	0·0855
HD104988				+6	+2	0·023	−1	−1	0·028

The assignment of these stars to the groups in Tables I–III has been guided by the trigonometric values of the parallaxes.

Also, there are two high-velocity white dwarfs that may belong to either the 61 Cygni or ε Indi Groups, but because of (1) the uncertainty in the observed radial velocities of these faint stars with poor spectral lines and (2) the possibility that the observed line-shifts do not represent the true radial velocity, it is not possible to assign them definitely to either group. These stars are as follows:

			61 Cygni			ε Indi		
	π_t	(p.e.)	$\Delta\theta \sin\lambda$	$\Delta\rho$	π_g	$\Delta\theta \sin\lambda$	$\Delta\rho$	π_g
−32°5613	0″·108	0″·007	+8	(−18)	0″·104	+1	(−1)	0″·122
L1534–1	0·059	0·005	+3	(− 6)	0·068	+6	(+4)	0·100

The mean trigonometric parallaxes, π_t, indicate that both stars may belong to the 61 Cygni Group.

Since the observed parallaxes of the stars, except 61 Cygni, ε Indi, and the four stars mentioned above, were not used in assigning the members to the groups, a comparison between these and the group parallaxes offers an additional test of the reality of the groups. The parallaxes are listed in Table IV, where the absolute trigonometric values, π_t, were taken from the Yale *Parallax Catalogue*

TABLE I

Members of the ζ Herculis Group

Star	θ_0	$\Delta\theta \sin\lambda$	ρ_0	$\Delta\rho$	Q	μ	π_g	V_E	$(P-V)_E$	Sp.	M_v
	°	°	(km/sec)			″	″	m	m		m
TV Psc	80	+3	+ 6	+1	b	0·115	0·0075	4·6v	+1·6:	M3 III	−1·0:
β Hyi	82	−3	+23	0	a	2·255	0·1510	2·75	+0·52	G1 IV	+3·64
HD9166	117	−2	−14	−6	b	0·115	0·0075	6·76	+1·15	K3 III	+1·14
ρ Per	129	−6	+28	0	b	0·172	0·0120	3·4v	+1·53	M4 III	−1·2
η Ret	26	−2	+45	−3	a	0·189	0·0160	5·26	+0·85	K0	+1·28
HD30455	153	+3	+55	−3	a	0·435	0·0445	6·97	+0·51	G2 V	+5·22
HD43899	536	+5	+70	+1	d	0·090	0·0155	5·6:	–	K0	+1·6:
HD68788	212	−6	− ·3	+1	b	0·567	0·0360	8·38	+0·74	K1 V	+6·16
HD71377	257	−1	+65	+6	c	0·094	0·0095	5·54	+1·11	K2 III	+0·42
HD89668	254	+1	+35	+7	c	0·670	0·0465	9·41	+1·02	K3 V	+7·75
HD90250	237	−7	+11	+3	b	0·129	0·0085	6·49	+1·01	K1 III	+1·14
HD98824	259	+7	+ 5	+3	b	0·119	0·0075	7·04	+0·96	K1 III	+1·42
HD100733	262	0	+18	0	a	0·088	0·0055	5·4v	+1·60	M3 III	−0·9:
HD106364	262	+3	−10	+6	b	0·113	0·0075	6·87	+1·05	K2 III	+1·25
								8·77	+0·49	F9 V	+3·15
HD119425	255	+2	−42	−6	b	0·127	0·0085	6·26	+1·22	K3 III	+0·90
φ′ Lup	224	+3	−29	+4	a	0·134	0·0095	3·52	+1·48	gM0	−1·60
HD150275	240	0	−32	+3	b	0·289	0·0210	6·34	+0·91	sg K0	+2·95
ζ Her	309	0	−70	−1	a	0·608	0·0990	2·80	+0·54	G0 IV	+2·78
ε Oct	118	+2	+12	−4	a	0·084	0·0055	4·8:	+1·6:	gM6	−1·5:
HD209134	82	−9	−18	+6	b	2·092	0·1410	5·56	+0·92	K3 V	+6·51
HD219829*	103	−3	−14	−2	b	0·484	0·0310	8·00	+0·72	K0 V	+5·46
HD221354	84	−9	−25	−4	b	1·085	0·0720	6·75	+0·74	K0 V	+6·04

*ADS 16645, Δm = 1^{m}, P = 108 yrs: not plotted in Fig. 1. The dynamical parallax is 0″·033.

TABLE II

Members of the ε Indi Group

Star	θ_0	$\Delta\theta \sin\lambda$	ρ_0	$\Delta\rho$	Q	μ	π_g	V_E	$(P-V)_E$	Sp.	M_v
	°	°	(km/sec)			″	″	m	m		m
+66°34	97	0	+10	−6	c	1·76	0·096	10·34	+1·30	dM3	+10·25
λ Aur	141	−1	+66	−3	a	0·845	0·0720	4·68	+0·50	G0 V	+ 3·97
HD39853	58	+9	+87	+6	b	0·076	0·0100	5·66	+1·46	K5 III	+ 0·66
HD40409	14	+1	+25	−4	a	0·557	0·0315	4·59	+0·98	sg K3	+ 2·09
HD72324	231	−4	+75	−1	b	0·085	0·0090	6·36	+0·93	G9 III	+ 1·13
HD99196	263	−9	+38	+6	b	0·107	0·0060	5·79	+1·30	K4 III	− 0·32
HD102365	274	0	+15	+4	a	1·585	0·0855	4·87	+0·54	G5 V	+ 4·53
HD104988	276	−1	+14	−1	b	0·521	0·0285	8·19	+0·66	G8 V	+ 5·47
HD112758	283	+7	− 4	+2	b	0·839	0·0450	7·54	+0·70	dK1	+ 5·81
HD115539	272	−7	− 8	−1	b	0·096	0·0050	7·21	+0·87	G8 III–IV	+ 0·70
HD135101	296	+4	−39	+6	b	0·656	0·0410	6·68	+0·58	G5 V	+ 4·74
								7·53	+0·63	dG6	+ 5·59
HD137704	294	−6	−48	−6	b	0·118	0·0070	5·46	+1·33	K4 III	− 0·30
HD142574	295	−2	−61	−4	b	0·091	0·0065	5·44	+1·52	K4 III	− 0·50
HD148704	231	−1	−59	+4	b	0·532	0·0405	7·28	+0·65	G5	+ 5·32
ε Ind	123	0	−40	0	a	4·692	0·2850	4·72	+0·95	K5 V	+ 6·96

TABLE III

Members of the 61 Cygni Group

Star	θ_0	$\Delta\theta \sin\lambda$	ρ_0 (km/sec)	$\Delta\rho$	Q	μ	π_g	V_E	$(P-V)_E$	Sp.	M_v
	°	°				″	″	m	m		m
HD10145	109	+3	+16	+3	b	0·734	0·0325	7·66	+0·58	G5V	+5·22
HD18702	106	+9	+66	+1	b	0·677	0·0375	8·12	+0·76	K0V	+6·00
HD23183	115	+3	+78	+2	c	0·130	0·0080	6·14	+0·92	K0 III	+0·66
HD32023	76:	+6	+106	+6	c	0·068	0·0080	9·10	+0·47	F8V	+3·62
HD35783	165	0	+19	−3	b	0·278	0·0125	7·69	+0·35	F6V	+3·17
HD39091	15	+3	+12	−5	b	1·110	0·0495	5·63	+0·46	G0	+4·10
β Col	7	−6	+89	+3	a	0·402	0·0290	3·06	+1·10	gK1	+0·37
HD40460	183	+9	+96	+1	c	0·078	0·0075	6·59	+0·93	K1 III	+0·97
HD53501	351	0	+39	−1	b	0·239	0·0115	4·8:	+1·5:	M0	+0·1:
HD55526	352	+5	+64	−5	a	0·204	0·0115	5·15	+1·14	K4	+0·45
HD66171	204	0	+37	+6	b	0·503	0·0230	8·20	+0·51	G2V	+5·01
HD108076	272	+2	−1	−4	b	0·579	0·0260	8·02	+0·46	G0 V	+5·10
HD112943	271	+1	−12	+2	b	0·768	0·0340	9·79	+1·06	dM0	+7·45
HD120467	254	−8	−35	−1	b	1·814	0·0840	8·3:	—	dK6	+7·9:
HD182572	49	0	−100	−3	a	0·960	0·0890	5·14	+0·68	G8 IV	+4·89
61 Cyg	52	0	−64	0	a	5·205	0·2960	5·19	+1·08	K5V	+7·55
								6·02	+1·24	K7V	+8·38

TABLE IV

Comparison of the trigonometric and group parallaxes for the stars in Tables I–III
(Unit = 0″·001)

Star	π_g	π_t	Star	π_g	π
TV Psc	8	13A	HD102365	86	94Y, 89C
β Hyi	151	143Y, 166C	HD104988	28	−10M, 15C
+66° 34	96	102M, 80Yh, 94G	HD108076	26	17M
409166	8	−3G	HD112758	45	79M, 35C
HD10145	32	32M, 45G	HD112943	34	26M, 59Y, 41V, 71C
HD18702	38	38M, 23Y, −10S, 41D	HD119425	22	8A, −5Y, −12W
ρ Per	12	2A, 30M	HD120467	84	83Y, 56C
η Ret	16	7Y	HD129245	8	12G
HD30455	44	7M, 15V	HD135101	41	28A, 7M
λ Aur	72	65A, 65M, 68S	ϕ' Lup	10	6Y
HD35783	12	12G	HD142574	6	27M, 38W
HD39091	50	38C	HD148704	40	54Y, 75C
β Col	29	5Y, 45C	HD150275	21	19A, 9G
HD40409	32	60Y, 8C	ζ Her	99	95A, 108M, 104Yk, 124S
HD53501	12	15Y, 46C	HD182572	89	51A, 75M, 101Yk
HD55526	12	−1Y, 52C	61 Cyg	296	296 mean
HD66171	23	18M, 13G	ϵ Ind	285	285 mean
HD68788	36	10M, 14G, 22D	HD219134	141	140A, 159M, 181S
HD72324	9	23W	HD219829	31	6M, 44Y, −17k, 8S, 52D
HD89668	46	40M, 42Y, −10V, −4C	HD221354	72	22M

(Jenkins 1952) and the group parallaxes, π_g, from Tables I–III; the abbreviations used to designate the source of the individual trigonometric values are those given by Jenkins. Because of the large scatter in the trigonometric values, there is probably no star in Table IV that could be eliminated as a group member on the basis of this comparison. It is noteworthy that of the 600 stars within 20 parsecs of the Sun for which radial velocities have been determined (Gliese 1957) eight per cent belong to the Hyades, ζ Herculis, ε Indi or 61 Cygni Groups.

The colour–luminosity array for the stars in Tables I–III is shown in Fig. 1, where the ζ Herculis, ε Indi and 61 Cygni Group members are indicated by crosses, open circles and filled circles, respectively. The standard main sequence (Eggen 1955) is shown with a half-width of $0^{m}{\cdot}2$. This colour–luminosity array

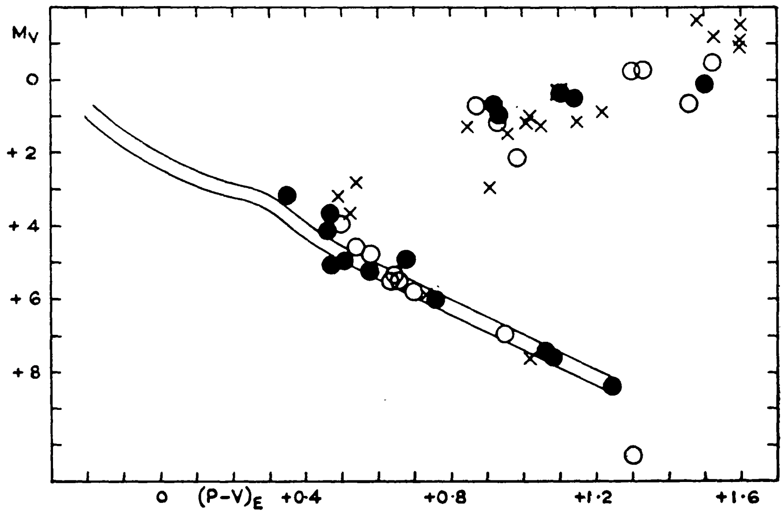

FIG. 1.—*Colour–luminosity array for stars in the ζ Herculis (crosses), ε Indi (open circles), and 61 Cygni (filled circles) Groups.*

is almost identical with that obtained from the members of the cluster M 67 (Johnson and Sandage 1955) and, indeed, nearly every group star in Fig. 1 can be matched in colour and in luminosity by a member of the M 67 cluster except for the five bright stars near $M_v \sim -1^{m}$ and $(P-V)_E \sim +1^{m}{\cdot}5$ to $+1^{m}{\cdot}6$, which occur in the groups but not in the cluster. These M-type giants, members of the ζ Herculis Group, are mainly known (irregular) or suspected light variables.

In the notation of a previous paper (Woolley and Eggen 1958) the galactic orbits of the members of these high-velocity groups are of class D, that is, the pericentric distances of the stars are between two-thirds and one-half of their present distances from the galactic centre.

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References

Boss, B., 1912 *a*, *A.J.*, **27**, 33.
Boss, B., 1912 *b*, *A.J.*, **27**, 67.
Chaudhuri, P., 1940, *M.N.*, **100**, 574.
Eggen, O. J., 1955, *A.J.*, **60**, 407; *Lick Obs. Bull.* No. 539.
Eggen, O. J., 1958, *M.N.*, **118**, 65.
Evans, D. S., Menzies, A. and Stoy, R. H., 1957, *M.N.*, **117**, 534.
Gliese, W., 1957, *Astr. Rechen-Inst. in Heidelberg*, Mitt. Ser. A, No. 8.

Jenkins, L., 1952, *General Catalogue of Trigonometric Parallaxes*, Yale University Observatory.

Johnson, H. and Sandage, A., 1955, *Ap. J.*, **121**, 616.

Miczaika, G., 1940, *A.N.*, **270**, 249.

Oort, J., 1926, *Groningen Pub.* No. 40.

Rasmuson, N., 1921, *Medd. Lund*, Series II, No. 26.

Roman, N. G., 1955, *Ap.J. Supplement Series* **2**, No. 18.

Russell, H. N., 1912, *A.J.*, **27**, 96.

Wilson, R. E., 1953, *General Catalogue of Stellar Radial Velocities*, Carnegie Institution of Washington, Pub. No. 601.

Woolley, R. v. d. R. and Eggen, O. J., 1958, *M.N.*, **118**, 57.