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Space motions of galactic G- and K-type stars

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Summary. Spectra of 912 G- and K-type stars in six galactic directions ($l^{II} = 90°$, $b^{II} = \pm 20°$; $l^{II} = 180°$, $b^{II} = \pm 20°$; $l^{II} = 90°$, $b^{II} = +45°$; $b^{II} = +90°$) have been secured. The relevant space motions of the stars, subdivided into distance groups have been derived and these show no significant departures from the mean motion of nearby stars. The velocity dispersions, in general, indicate that these (mainly giant) stars are moderately old. The dispersion in u, however, is lower than that for nearby stars and the significance of this result is discussed.

1 Introduction

Some years ago when the Royal Greenwich Observatory (RGO) was conducting joint radial velocity programmes with the Helwan Observatory of the United Arab Republic, interest was expressed in the question whether the solar velocity relative to the nearby stars was the same as the velocity relative to stars some hundreds of parsecs distant and a number of velocities of K-type stars were measured to test this. In each case the spectral type of the star on the MK system was determined as well as the radial velocity, in order to determine its distance.

As the results from these studies were somewhat inconclusive, it was decided to supplement the data by conducting a similar series of observations, this time on G stars using the 36- and 98-in reflector telescopes at the RGO.

2 Selection and observation

The G and K stars were selected from the Henry Draper catalogue such that they lay in six

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Table 1. The selected areas.

l^{II}	b^{II}	RA range (h)	dec range	Area name
90	+45	15–17	50–70	A
90	+20	18–20	55–65	B
90	−20	21–00	28–38	C
	+90	12–14	23–33	D
180	+20	06–08	33–45	E
180	−20	03–05	12–22	F

areas corresponding to six directions of galactic longitude and latitude. The areas are defined in Table 1.

Details of the spectroscopic observations and reduction to radial velocity and spectral types are shortly to be published in *Royal Observatory Annals* so that only a brief account of the observations will be given here. Table 2 lists the proportion of stars observed on each telescope together with the relevant spectrographic dispersions used and the typical standard error in radial velocity.

Table 2. Summary of observations.

No. stars	Sp. type	Telescope (in)	Dispersion (A/mm)	Mean s.e. (km/s)
538	K	74 (Helwan)	66	5
262	G	98 (RGO)	60	4
59	G	98 (RGO)	180	10
53	G	36 (RGO)	80	6

The spectral types were determined by comparing the spectra with those of a range of MK standard stars (at different densities of exposure) taken with the same equipment.

Most of the stars were observed at least twice and it became clear that before a final solution could be made, some of the stars would have to be removed from the initial sample. Those rejected were:

(a) stars with apparently variable velocity (10 per cent of the total),
(b) stars which exhibited peculiar spectra, composite etc. (3 per cent),
(c) stars whose spectral type did not lie in the range F8–K3 (5 per cent),
(d) stars which were, or suspected to be, members of the Hyades group (4 per cent). (This concerned area F only.)

The identification of Hyades members made from the lists of van Bueren (1952) and Wayman, Symms & Blackwell (1965) and a total of 33 probable and eight possible Hyades stars were excluded.

Finally, the sample was sorted into distance groups for each area (except A and D) as shown in Table 3. Also shown in this Table are the corresponding distance ranges above and below the galactic plane (Z).

3 Reddening, magnitudes and spectral types

In order to examine the effect of velocity with distance for these stars we need to know the apparent and absolute magnitudes and the interstellar reddening. The apparent magnitudes

Table 3. The distance groups for each area.

$m-M$ range (mag)	Distance range (pc)	Z range (pc)	Group name
0–5	1–100	1–50	1
5–7	100–250	50–100	2
7–8	250–400	100–200	3
>8	>400	>200	4

were taken entirely from the HD catalogue; however, as an independent check on these magnitudes and to some extent, the derived spectral types (which in turn leads to a value of the reddening) photoelectric (*UBV*) photometry was obtained for a sample of the stars (in area C) using the 12-in reflector at Sierra Nevada, Spain. Table 4 lists the derived spectral types, HD magnitudes, the Spanish magnitudes, the colours and the reddening determined from these types and the unreddened values according to FitzGerald (1970). If the derived types are reliable then, for this area, the reddening is negligible for all distance groups. An attempt to determine the reddening with distance in the remaining five areas from stars listed in the *Bright star catalogue,* Hoffleit (1964) showed that, in general, the reddening was small. As a result it has been treated as zero in the final solutions.

Table 4. Comparison of the Spanish and HD magnitudes.

HD	Sp. type	m (ptm)	m (ptg)	V	$B-V$	$U-B$	Date (1970)	$E(B-V)$	Dist. group
202989	F8 V	8.6	9.2	8.67	0.50	−0.04	6 Nov	−0.03	1
203014	F6 III	8.5	9.1	8.84	0.47	−0.02	6 Nov	+0.01	3
203047	F7 IV	9.1	9.7	8.71	0.48	0.02	6 Nov	−0.02	3
203204	F6 IV	9.1	9.7	8.85	0.46	0.02	6 Nov	0.00	3
203233	G8 III–IV	9.4	10.2	8.92	0.88	0.44	6 Nov	−0.01	4
206331	F6 V	8.7	9.3	8.82	0.49	0.03	6 Nov	+0.01	2
208222	F8 V	9.1	9.9	9.07	0.52	−0.03	6 Nov	−0.01	2
208237	F6 V	8.8	9.6	9.01	0.46	0.00	6 Nov	−0.02	2
209707	F6 IV–V	8.8	9.6	8.85	0.50	0.10	2/3/4 Nov	+0.02	1
213856		8.72	9.50	8.64	0.46	0.00	2/3/4 Nov		
214458	K0 III	7.38	8.38	7.30	1.23	1.35	25 Oct	+0.22	3
214980		9.2	10.0	10.05	0.42	−0.06	6 Nov		
218354	G3 III–IV	8.17	8.95	8.20	0.65	0.23	26 Oct–2 Nov	−0.11	2
219236	F5 V	8.6	9.2	8.88	0.44	0.02	25 Oct–3 Nov	−0.01	2
219856	F6 IV–V	8.8	9.4	8.70	0.39	0.02	26 Oct–2/3 Nov	−0.07	2
224721	G8 III	6.58	7.36	6.53	0.95	0.69	26 Oct–1/2 Nov	0.00	2
110	G8 III	6.71	7.49	6.63	0.90	0.54	27 Oct	−0.05	2
863	G7 III	7.90	8.68	7.71	0.95	0.66	26 Oct–1/2 Nov	+0.01	3
1315	G8 III	7.9	8.7	7.57	0.95	0.67	26 Oct–2/3 Nov	0.00	3

It should be emphasized that in a statistical study of an adequately large sample of stars, such as this, the reddening, providing it is reasonably uniform, does not affect the general result. This is so since we are investigating the possible changes of velocity ratios with distance rather than the precise distances to which our mean values refer. It is also true that the apparent magnitudes need to be consistent rather than strictly accurate.

A comparison of the derived spectral types with those appearing in other lists namely Jaschek, Conde & de Sierra (1964) and Kennedy & Buscombe (1974) is made in Table 5. With a few exceptions the agreement is good. As the total sample is sufficiently large a few poorly determined types will not be of statistical importance.

Table 5. Comparison of spectral types.

HD	Type (HD)	Type (this paper)	Type (others)
691	G5	G9 V	K0 V
1605	G0	G8 IV	K1 IV
23825	G0	G3 IV	G3 IV
25391	G0	G0 V	G0 V
26749	G0	G2 V	G2 V
27029	G5	G8 III	K1 III
28085	G5	G8 II–III	G8 V, G8 II
28124	K0	K3 III	K5 V
29117	G5	G9 III	K0 III
180161	K0	K0 IV	G8 V
186815	G5	G8 III	K2 III
189251	K0	G7 III	G8 II
189843	K0	K1 III	G8 III–IV
190913	K0	K2 III	K0 III
191009	K0	G9 IV	G9 III
204921	K0	K1 III	K2 III
206978	G	G0 V	G0 IV
213177	K0	K0 II–III	K0 II
213857	K0	K0 III	K0 III
214202	K0	G9 III	G8 III
214332	G5	G9 III	G8 III
215274	G5	G3 V	G5 V
218633	G5	G5 IV	G2 V
218880	K0	K0 III	G8 III
222033	G0	G0 IV	G0 V
225239	G0	F9 V	G2 V

4 The solutions

Following Woolley *et al.* (1965) a star's radial velocity may be resolved into three components of galactic motion and we can write

$$\rho = ul_3 + vm_3 + wn_3 + K$$

where ρ is the radial velocity.

u, v, w are the orthogonal components of the stellar velocity,

l_3, m_3, n_3 are the appropriate direction cosines,

K is the expansion term which previous analyses have shown can be ignored.

A least-squares solution for a group of stars well distributed about the sky gives mean values of the galactic motion (u_0, v_0, w_0) for those stars. However, if for example we examine a group of stars in the direction of galactic rotation where values of l_3 and n_3 are near zero and $m_3 \sim 1$, then an analysis of the velocities is a good measure of the v_0 component of velocity only if mean values of u_0 and w_0 from a more complete sample are fed into the equations.

In this case we have

$$\rho^1 = \rho - u_0 l_3 - w_0 n_3 = vm_3$$

from which we get the normal equation

$$\Sigma m_3 \rho^1 = v_0 \Sigma m_3^2.$$

Similarly u_0 and w_0 may be obtained from observations of stars away from the Galactic Centre and towards the North Galactic Pole.

In this way values of u_0, v_0 or w_0 were calculated for different distance groups of stars in the areas A–F of Table 1. Mean values of $u_0 = -7.6$ km/s, $v_0 = -17.3$ km/s and $w_0 = -5.5$ km/s were adopted. These were derived from 800 nearby evolved G and K stars from Wilson's (1953) catalogue.

As the galactic longitudes lie near 90° and 180° the effect of neglecting a galactic rotation term amounts, at most, to 2 km/s and has been ignored.

5 Results

The velocity solutions are given in Table 6 as follows:

Columns 1, 2: The area and distance groups as defined in Tables 1 and 3. The galactic longitude and latitude are given below the area name.

Columns 3, 4: The median distances from the Sun above and below the galactic plane ($\bar{Z} = \bar{R} \sin b^{\mathrm{II}} + 10$ pc).

Columns 5, 6: The number of stars in each distance group divided into dwarfs (class V) and giants (classes II, III and IV).

Columns 7, 8, 9: The velocity solutions which consist of: the differences of the derived velocities from the mean motions (i.e. $-7.6 - u$, $-17.3 - v$, $-5.5 - w$), the associated standard errors and velocity dispersions (where $\sigma = \sqrt{N} \times$ standard error and N is the number of stars). The dispersions for area A have components in both v and w and are referred to as σ_v/σ_w.

6 Discussion

The results of this investigation are embodied in Table 6 and show no departure from the mean motion of the nearby stars greater than can nearly be accounted for in terms of their standard errors, and no greater significance can be claimed for them. The velocity dispersions themselves indicate that the stars have an age not inconsistent with a moderately old (disc) population of stars, but the dispersions in u show consistently low values (as set out in Tables 7 and 8) while the other two dispersions σ_v and σ_w are normal, that is to say, very similar to those shown by the nearby stars in general.

The results shown in Table 6 have a great deal of weight, in the sense of the number of stars contributing to them. A possible explanation for the lower values of σ_u is that the sample examined in the survey in this paper consists predominantly of giant stars whereas the surveys of nearby stars shown in Table 7 are dominated by dwarfs, and for this reason Table 8 was drawn up which shows the nearby giants counted separately; with a reduction in σ_u from 37 km/s for 760 mixed stars to 34 km/s for 103 nearby giants. This is still not as low as the 31 km/s found from a larger number of giants in the regions surveyed in this paper, but the associated standard errors in σ_u make this difference barely significant.

In Table 9 we compare the ratio of the velocity dispersions with other groups of stars of different ages.

The high value of σ_v/σ_u found for giants is not unique as it has been found before, notably by Feast (1963) and Feast *et al.* (1972) in surveys of late-type variables. A puzzling feature of the giants is the lack of any great disturbance from the circular velocity, which the late-type variables do show. No doubt a solution to this peculiar problem in terms of the age of the giant stars concerned will be sought but the present authors do not offer one. The facts concerning the dispersions which have been brought to light appear to us, however, to merit further study.

Table 6. The velocity solutions.

Area	Dist. group	$\bar{R}$ (pc)	$\bar{Z}$ (pc)	No. Dw	Stars Gi	Velocity difference (km/s)	s.e. (km/s)	Disp. (km/s)
A						$V-V_c$		σ_v/σ_w
90		230	160	0	19	+1.2	5.7	24.8
+45		530	370	0	21	+15.7	7.2	33.0
		700	490	0	19	+20.6	9.0	39.2
B						$V-V_c$		σ_v
90	1	70	35	26	19	+2.6	4.1	27.5
+20	2	160	65	6	32	−3.8	3.3	20.3
	3	320	120	0	42	−2.9	3.4	21.9
	4	460	170	0	13	−1.3	3.8	13.7
C						$V-V_c$		σ_v
90	1	60	10	54	10	+0.5	3.1	24.8
−20	2	165	45	9	63	0.0	2.3	19.5
	3	320	100	0	74	+0.3	3.0	25.8
	4	460	150	0	37	+2.8	5.0	30.4
D						$W-W_c$		σ_w
90	1	58	68	4	7	0.0	5.2	17.2
	2	182	192	0	28	−1.7	4.2	22.2
	3	331	341	0	28	+1.9	5.4	28.6
	4	479	489	0	25	+3.6	3.6	18.0
E						$U-U_c$		σ_u
180	1	50	28	29	9	+3.7	5.2	30.6
+20	2	200	80	5	68	+13.6	3.7	31.0
	3	300	110	0	65	−2.5	3.8	30.8
	4	480	175	0	49	+6.5	4.4	30.9
F						$U-U_c$		σ_u
180	1	50	8	21	7	+1.9	5.8	30.7
−20	2	190	55	5	44	+5.0	4.6	32.5
	3	320	100	0	45	−12.1	5.3	30.4
	4	525	170	0	29	−2.9	6.1	33.0

Table 7. Comparison of velocities and dispersions (giants and dwarfs).

Source	No. stars	u	s.e.	v	s.e. (km/s)	w	s.e.	σ_u	σ_v	σ_w
(a)	410	14		18		8		36	21	16
(b)	760	10	1.3	21	1.2	8	0.8	37	23	18
(c)	376 (u), 385 (v), 92 (w)	9	4.8	17	3.5	7	4.6	31	23	22

(a) From Woolley (1965). (b) Computed from data from Woolley *et al.* (1970). (c) This paper.

Table 8. Comparison of velocities and dispersions (giants only).

Source	No. stars	u	S.e.	v	S.e.	σ_u	σ_v
(b)	103	12	3.3	21	2.3	34 ± 2.4	24 ± 1.7
(c)	271 (u), 317 (v)	9	4.5	14	3.5	31 ± 1.3	22 ± 0.9

Table 9. Comparison of dispersion ratios.

Group	σ_v/σ_u	Reference
SR (red) variables	1.0 ± 0.2	Feast, Woolley & Yilmaz (1972)
Me variables	0.87 ± 0.11	Feast (1963)
G, K giants	0.71 ± 0.04	This paper – Table VIII(c)
G, K giants	0.71 ± 0.10	This paper – Table VIII(b)
High-eccentricity stars	0.67	Woolley (1958)
(Mainly) G, K, dwarfs	0.62 ± 0.03	This paper – Table VII(b)
Extreme Population I objects	0.56 ± 0.06	Feast (1963)
Low and moderate eccentricity stars	0.56	Woolley (1958)
Faint low-latitude stars	0.49	Hins & Blaauw (1948)

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