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Research Note

Local kinematic properties of Population I (B5–F5)-type stars and galactic disk evolution

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Abstract. Using a sample of (B5-F5) V type stars, located up to 250 pc, the basic parameters of the velocity ellipsoid have been derived. The observed distribution function of the peculiar velocities for different subsamples have been decomposed into a sum of three-dimensional gaussians using the SEM algorithm (Celeux and Diebolt, 1985, 1986). Assuming that the stars are formed in bursts, the observed velocity distribution is explained as the sum of several independent (approximately spherical) distributions, each one corresponding to one generation of stars.

Key words: kinematics of (B5-F5) V type stars – velocity ellipsoid – solar velocity – velocity dispersion increase with age – galactic disk evolution

1. Introduction

Absolute magnitude calibrations of (B5-F5) type stars, dwarfs and giants, were derived by Grenier et al. (1985, Paper I) using large and homogeneous samples of stars, carefully selected and treated statistically in the same way. The purpose of our work is a kinematical study of the solar neighbourhood based on a large sample – 1000 stars – from Paper I.

The sample used is the apparent-magnitude limited sample of dwarf stars of Paper I, restricted to the region nearer than 250 pc. The sources for the different spectroscopic and photometric data are given in Paper I. We have used the absolute magnitude calibrations obtained in Paper I to derive the heliocentric distance of each star. Our sample does not contain high velocity stars nor known cluster members.

2. The peculiar velocities distribution function

In Table 1 we present the results concerning the first and second order moments of the distribution functions of the residual velocity components for the different subsets (we call subset any of the subdivisions of our sample). The components of the space velocity with respect to the centroid were calculated for each star, after correcting for galactic rotation. They are expressed in the conventional directions, namely: U, in the direction of the galactic center; V, in the direction of the galactic rotation; W, in the direction perpendicular to the galactic plane. In the Table 1, U_0, V_0, W_0 are the components of the solar velocity with respect to the group centroid expressed in km s^{-1}. Similarly σ_U, σ_V, and σ_W are the semi-major axes of the velocity ellipsoid in the U, V, and W directions, also expressed in km s^{-1}. The vertex deviation ϕ is given in degrees; it is omitted when $\sigma_U \cong \sigma_V$, since then ϕ is almost undetermined. The last column finally provides the logarithm of the average age of each group. The average age ($\bar{t}$) in years was derived using the isochrones of Maeder and Mermilliod (1981), taking into account the dispersion on the absolute magnitude obtained in Paper I.

The obtained results are as expected. Nevertheless, the large spread in the values of U_0 in Table 1 deserves attention. Figure 1 gives the distribution of the U components for each subset. For the sake of comparison we have also indicated (vertical bars) the positions of the open cluster velocity components, but including only clusters nearer than 250 pc (the distance limit of our sample). The average cluster velocity components are given in Table 2, where the clusters are ordered according to their ages. The latter are taken from Mermilliod (1981a). The age dispersion within a group amounts to 0.05 in log t for the younger clusters and to 0.02 for the older. The age given by Mermilliod (1981b) are in good agreement with those given by Palouš et al. (1977), except for IC 2602 for which Palouš et al. quote $(10 \pm 0.5)\ 10^7$ yr.

With the exception of the earliest (and youngest) stars, Fig. 1 suggests a possible mixture of velocity distributions. Moreover, the position of the maximum for the youngest stars agrees well with those of open clusters with ages $< 8\ 10^7$ yr. For the subset A0-A2 there are two observed maxima, one coincides with that of the earliest stars and the other agrees with that of the UMa moving cluster. The latter has an age intermediate between the youngest clusters and the Coma Ber cluster. For A3 and later subsets contributions from several distributions seem present. In particular, the "gap" which appears in the A2 subset is filled up in the A3-A4 subset and coincides very well with the position of Coma

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Table 1. Velocity ellipsoid

Type	N	U_0 (km s^{-1})	V_0 (km s^{-1})	W_0 (km s^{-1})	σ_U (km s^{-1})	σ_V (km s^{-1})	σ_W (km s^{-1})	ϕ (deg)	$\log \bar{t}$
B5-B7 V	53	11.6 ± 1.5	17.0 ± 1.5	7.8 ± 0.9	10.5 ± 1.0	10.6 ± 1.0	6.8 ± 0.7		7.8
B8 V	45	11.8 ± 1.4	14.8 ± 2.2	7.1 ± 1.4	9.2 ± 1.0	14.6 ± 1.5	9.2 ± 1.0		8.2
B9 V	55	11.9 ± 1.4	15.1 ± 1.5	7.9 ± 1.4	10.1 ± 1.0	11.1 ± 1.1	10.2 ± 1.0		8.3
B9.5 V	32	14.1 ± 2.4	10.7 ± 1.8	8.1 ± 1.4	13.5 ± 1.7	10.2 ± 1.3	7.7 ± 1.0		8.45
A0 V	84	13.2 ± 1.9	13.6 ± 1.3	7.6 ± 1.0	17.5 ± 1.4	11.8 ± 0.9	8.8 ± 0.7	19	8.5
A1 V	101	8.9 ± 1.7	12.2 ± 1.2	8.3 ± 0.8	16.8 ± 1.2	11.9 ± 0.8	7.7 ± 0.5	27	8.6
A2 V	96	9.3 ± 2.0	8.6 ± 1.2	7.0 ± 0.7	19.3 ± 1.4	11.8 ± 0.8	8.2 ± 0.6	24	8.65
A3-A4 V	121	6.9 ± 1.7	7.3 ± 1.1	6.8 ± 0.7	18.5 ± 1.2	11.6 ± 0.8	7.9 ± 0.5	25	8.7
A5-A6 V	43	9.3 ± 2.4	9.2 ± 1.9	6.7 ± 1.4	16.0 ± 1.7	12.7 ± 1.4	9.0 ± 1.0	30	8.85
A7 V	37	13.6 ± 3.0	11.6 ± 2.3	8.3 ± 1.4	18.3 ± 2.1	13.8 ± 1.6	8.7 ± 1.0	29	8.9
A8-A9 V	29	14.6 ± 3.4	11.2 ± 2.6	5.8 ± 1.2	18.3 ± 2.4	13.9 ± 1.8	6.5 ± 0.9	32	9.0
F0 V	53	12.3 ± 2.8	9.7 ± 1.7	5.3 ± 1.8	20.5 ± 2.0	12.4 ± 1.2	12.9 ± 1.3	22	9.1
F1-F2 V	67	11.6 ± 2.8	8.1 ± 1.4	5.9 ± 1.0	22.4 ± 1.9	11.3 ± 1.0	8.0 ± 0.7	10	9.15
F3 V	33	11.7 ± 3.8	6.4 ± 2.3	9.8 ± 1.9	21.4 ± 2.6	13.3 ± 1.6	11.0 ± 1.4	21	9.25
F4 V	37	10.4 ± 3.8	12.7 ± 2.2	6.5 ± 1.8	22.5 ± 2.6	13.3 ± 1.5	10.9 ± 1.3	11	9.3
F5 V	103	7.9 ± 2.5	10.7 ± 1.5	5.7 ± 1.2	25.3 ± 1.8	14.9 ± 1.0	12.1 ± 0.8	12	9.3

Notes: N: number of stars. U_0, V_0, W_0: solar velocity components and their corresponding rms errors. σ_U, σ_V, σ_W: residual velocity dispersions and their corresponding rms errors. ϕ: vertex deviation angle. $\bar{t}$: average age in years.

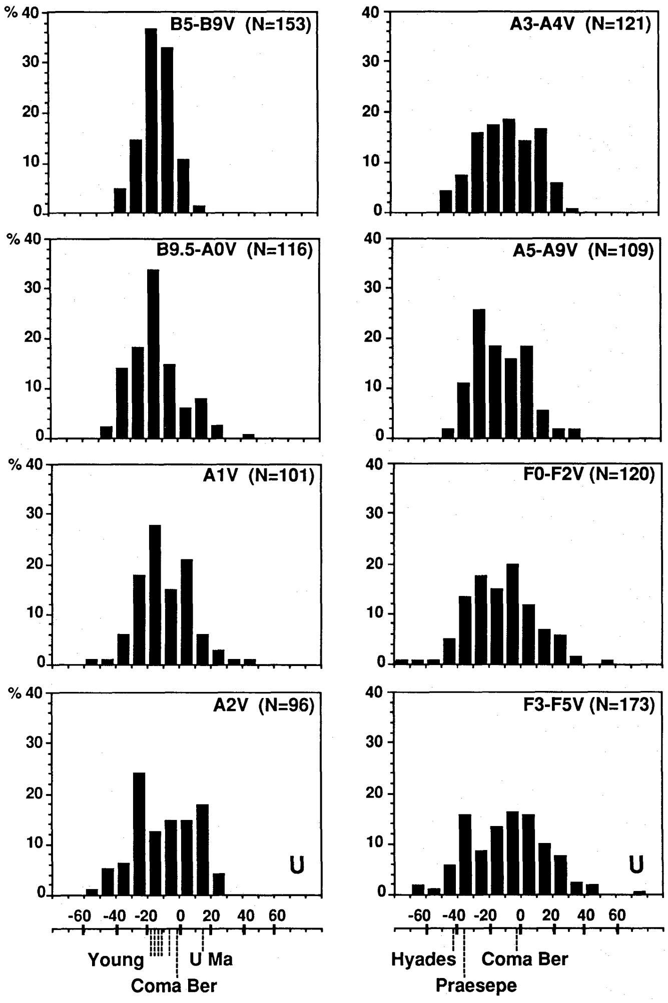

Fig. 1. Histogram of the distribution of the U components (in km s^{-1}). The vertical bars correspond to the open clusters values from Table 2

Ber. Finally for the F3-F5 subset there appears a new contribution, which coincides with the position of the old clusters Hyades and Praesepe.

We intend to interpret the histograms of Fig. 1 assuming that stars are formed in "bursts", i.e. in a discontinuous fashion. If we observe a long time after the "bursts", the velocity histogram is a sum of the distributions corresponding to the different bursts, plus an addition of stars which migrated into the solar vicinity from outside. The contamination as well as the "spreading" of the old star bursts (mainly due to stochastic acceleration processes) will become progressively more effective as time passes, so that after a "long time" any trace of the individual burst will be lost.

In order to isolate possible bursts of star formation and to assert that the "bumps" observed in Fig. 1 are physical associations (and not the result of the human eye image-processing), we have decomposed each sample (B9.5-A4 and F3-F5) into a sum of three-dimensional Gaussians. To do so we have used the SEM (Stochastic, Expectation, Maximization) algorithm developed by Celeux and Diebolt (1985, 1986). The aim of the SEM algorithm is to resolve the finite mixture density estimation problem under the maximum likelihood approach, using a probabilistic teacher step. Full details can be found in the above mentioned papers. Through SEM one can obtain the number of components of the Gaussian mixture (without any assumption on this number), its mean values and dispersions and the percentage of each component with respect to the whole sample. SEM also gives an estimation of the parameters standard-deviations, which allow to measure the degree of overlap of the mixture components. Different statistical procedures and tests were applied in order to verify the results obtained with SEM; EM algorithm with Bootstrap, the Wilks test (Soubiran, 1988; Soubiran et al., 1989) and multivariate data analysis (Bougeard et al., 1989; Bougeard and Arenou, 1989). Finally, the errors in the data used to calculate the velocity components (radial velocity, proper motions and distance) were taken into account (Diebolt and Celeux, 1989). The errors were assumed to be distributed randomly, with null expectation and mean square error obtained from the sources of the corresponding data. For the distances, a 20% relative error was adopted. The results are given in Table 3. We can isolate four possible bursts of star formation, each one defined by its $\bar{U}$, $\bar{V}$, and $\bar{W}$, which are indicated in the "remarks" column. As for the dispersions σ_U, σ_V, and σ_W we notice that all of them are $\leqq 14\,\mathrm{km\,s^{-1}}$ and of similar magnitude. The obtained distribution functions are approximately spherical, the corresponding mean dispersions $\bar{\sigma}$ are smaller than $11\,\mathrm{km\,s^{-1}}$, which suggest that the bursts kinematically share the same characteristics of the gas in the solar neighbourhood.

We may now ask if these bursts are physically real, or if they are pure random coincidences. We would expect that stars born in the same burst have the same or similar ages. Since we cannot determine individual ages, we can circumvent the difficulty by assuming that each burst also produced a few open clusters; both the kinematics and the ages of these clusters must then be compatible with those of the star bursts.

We have remarked already that Fig. 1 shows a good agreement between the position of the bursts and the open clusters in the U component diagram. We find then that burst I corresponds to young stars with ages less than or equal to $8\ 10^7$ yr, burst II to the stars of the UMA cluster generation, burst III to those of the Coma Ber generation and IV to those of the Hyades generation.

If we consider that these bursts are real (i.e. not chance associations) we must show that:

1. the distribution functions (of all three velocity components) of the bursts coincide well with those of the clusters associated with the bursts;
2. the ages of the stars of each burst and the ages of the clusters coincide.

With regard to the first point, Table 4 provides the data for the bursts and the clusters, the latter being taken from Table 2. In Table 4, we have also included the subset of (B5-B9) V stars which, according to our considerations, are associated to burst I.

Table 2. Velocity components for clusters within 250 pc

Age (years)	Cluster	U ($\mathrm{km\,s^{-1}}$)	V ($\mathrm{km\,s^{-1}}$)	W ($\mathrm{km\,s^{-1}}$)	Ref.
$3.6\ 10^7$	NGC 2451	-15.1 ± 2.1	-19.7 ± 1.2	-16.5 ± 2.7	M
	IC 2391	-18.3 ± 2.1	-13.5 ± 0.8	-5.9 ± 2.1	P
	IC 2602	-0.7 ± 1.8	-25.7 ± 1.1	-1.4 ± 1.8	P
$5.1\ 10^7$	α Per	-10.8 ± 1.4	-20.5 ± 2.0	-0.7 ± 2.2	P
	BL 1	-17.0 ± 2.8	-11.3 ± 2.1	-9.2 ± 1.1	M
$7.8\ 10^7$	Pleiades	-5.8 ± 1.3	-24.0 ± 2.0	-12.4 ± 2.0	P
$3.0\ 10^8$	U Ma	$+14.5\pm0.8$	$+2.5\pm0.6$	-8.5 ± 0.9	E
$4.0\ 10^8$	Coma Ber	-1.8 ± 1.1	-8.2 ± 1.1	-0.7 ± 0.6	P
$6.6\ 10^8$	Hyades	-44.4 ± 0.8	-17.0 ± 1.0	-5.0 ± 1.3	P
	Praesepe	-37.1 ± 1.6	-23.5 ± 2.4	-7.0 ± 1.7	P

References: E: Eggen (1973), M: Mermilliod (1986), P: Palouš et al. (1977).

Table 3. Decomposition of the velocity distribution in gaussian components

Type	N	$\bar{U}$ ($\mathrm{km\,s^{-1}}$)	σ_U ($\mathrm{km\,s^{-1}}$)	$\bar{V}$ ($\mathrm{km\,s^{-1}}$)	σ_V ($\mathrm{km\,s^{-1}}$)	$\bar{W}$ ($\mathrm{km\,s^{-1}}$)	σ_W ($\mathrm{km\,s^{-1}}$)	%	Remark
(B9.5-A0) V	94	−19	11	−16	11	−8	7	81	Burst (I)
$N=116$	22	11	13	− 2	4	−5	7	19	Burst (II)
A1 V	74	−16	13.5	−17	9.5	−8	7	73	Burst (I)
$N=101$	27	10	7	2	4	−9	6	27	Burst (II)
A2 V	61	−21	13	−14	10	−7	9	64	Burst (I)
$N=96$	35	12	6	2	5	−7	6	36	Burst (II)
(A3-A4) V	34	−20	11	−19	9	−7	9	28	Burst (I)
$N=121$	36	13	9	1	7	−6	7	30	Burst (II)
	51	−11	14	− 7	7	−8	6	42	Burst (III)
(F3-F5) V	45	−36	13.5	−16	14	−7	12	26	Burst (IV)
$N=173$									

Notes: N: number of stars. $\bar{U}$, $\bar{V}$, $\bar{W}$: mean velocity components. σ_U, σ_V, σ_W: residual velocity dispersions. SEM standard deviations lie between 1 and $5\,\mathrm{km\,s^{-1}}$ for mean velocities, 1 and $3\,\mathrm{km\,s^{-1}}$ for dispersions, 5 and 10% for percentages of stars belonging to each burst.

Table 4. Velocity distribution function of stars in the detected star formation bursts

Burst	Object	N	$\bar{U}$ (km s^{-1})	$\bar{V}$ (km s^{-1})	$\bar{W}$ (km s^{-1})	$\bar{\sigma}$ (km s^{-1})
I	(B5-A4) V	416	−16	−16	−8	10
	Clusters	6	−12	−19	−8	
II	(B9.5-A4) V	120	12	1	−7	7
	Cluster	1	15	3	−9	
III	(A3-A4) V	51	−11	− 7	−8	10
	Cluster	1	− 2	− 8	−1	
IV	(F3-F5) V	45	−36	−16	−7	13
	Clusters	2	−41	−20	−6	

Notes: N: number of objects. $\bar{U}$, $\bar{V}$, $\bar{W}$: Mean velocity components[a]. $\bar{\sigma}$: Mean residual velocity dispersion[a].

[a] Averaged rms errors lie between 1 and 3 km s^{-1}.

Concerning the second point, we may reason as follows. Group II is not present in the subset (B5-B9) V; this implies that stars of this burst must be older than the age of a B9V star, i.e. 2.7 10^8 yr. For group III a similar reasoning implies a minimum age of 4 10^8 yr (corresponding to an A0 star which left the dwarf stage), and for group IV, 6 10^8 yr (age of an A4 star which left the main sequence stage). If we compare these minimum ages with the ages of the open clusters which we considered to be characteristic for each group, we find (see Table 2) respectively 3 10^8, 4 10^8, and 6.6 10^8 yr – in each case the agreement is excellent.

Scalo (1987) studying the present-day mass function (PDMF) of the solar neighbourhood main sequence stars, observed two peaks, one at spectral type F2-F5 and the other around A0, and a dip between types F0 and A5. He interpreted each "knee" in the PDMF as representing the effect of one past burst of star formation, one burst may consist of more than one burst, since the resolution in mass of the PDMF is poor. The bursts found here are in good agreement with those suggested by the Scalo's results.

3. Concluding remarks

We may conclude that the observed distribution of residual velocities is the sum of several independent (spherical) distributions, each one corresponding to one generation ("burst") of stars. This can be seen easily for early A-type stars; it becomes less visible for F-type stars.

Our results show that the kinematic characteristics of the bursts are still observable after about 2 to 3 10^9 yr, suggesting that the galactic disk is neither well mixed nor relaxed in 10 galactic years.

In particular, the determination of the solar velocity with respect to the circular velocity via the Strömberg relation (see Delhaye, 1965) needs the use of well mixed samples and, in the light of the present work, this implies ages larger than 2 to 3 10^9 yr.

Finally, the estimation of the distribution function of residual velocities is expected to depend on the investigated space volume, since larger volumes should include new bursts.

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