THE DISTRIBUTION OF NEARBY STARS IN PHASE SPACE MAPPED BY HIPPARCOS 2-WAVELET ANALYSIS OF 3D-DENSITY AND 2D-VELOCITY DISTRIBUTIONS

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ABSTRACT

A volume limited and absolute magnitude limited sample of A-type dwarfs within 125 parsecs of the Sun is searched for inhomogeneities in the density-velocity space, expecting some signatures of the cluster melting, phase mixing and possibly of the disc heating mechanisms. This sample has been wavelet analysed to find a-periodic structures in both 3-d position and 2-d velocity distributions. In the 3-d space of positions, known open clusters (Hyades, Coma and Cr285), concentration of association stars (Lupus-Centaurus) and two new significant concentrations are identified at (l,b)=$(97°,+56°)$ and (l,b)=$(56°,-35°)$. The sample is relatively well-mixed in the position space since no more than 7 per cent of the stars belong to structures with coherent kinematics. Only two components of the velocity vectors are provided by Hipparcos measurements. However the missing component can be obtained for stars in streams by a convergent point method. The multi-scale analysis exhibits the strong structuring of the reconstructed (U,V) velocity distributions. Four major groups (among them Hyades, Pleiades and Sirius superclusters) are found to be sub-structured in a cascade of tiny velocity clumps.

Key words: galactic physics; solar neighbourhood; open clusters and associations.

1. INTRODUCTION

Density and velocity inhomogeneities are searched for in the phase space distributions of the solar neighbourhood to address problems of the disc heating and the phase mixing mechanisms.

The velocity dispersion of stars grows with age. The disc formed by old stars is hotter and thicker than the one of young stars. There is no satisfactory explanation for this heating. Close encounters between stars are scarce, the gas of stars is essentially collisionless and has zero viscosity. Various mechanisms have been suggested to explain the heating including massive black holes (Lacey & Ostriker 1985), large molecular clouds (Spitzer & Schwarzschild 1951, 1953), ephemeral spiral waves (Barbanis & Woltjer 1967) or transient dynamical instabilities. All are hypothetical ways to force gravitational potential inhomogeneities with basically unknown scales and amplitudes, to convert part of the orbital momentum of stars into velocity dispersion. It is of interest to know if small scales inhomogeneities (between few parsecs and tens of parsecs) may play a role in this process.

While clumpy at star formation time, the phase space distributions of the stars reach quite rapidly, in a very few crossing times, a quasi steady state in which they do not change any more: it is the dynamical phase mixing mechanism (Lynden-Bell 1962, Hénon 1964). However streams and association of stars loosely bound by internal gravitation are observed (Eggen 1991, 1992a, 1992b, 1992c) well beyond this time scale (a few 10^8 yr). A precise knowledge of the amount of stars involved in inhomogeneities of the phase space distributions according to their age will help clarifying this paradox.

Hipparcos data provide for the first time, with a precision never reached the opportunity of studying the phase space of volume limited and absolute magnitude limited samples and to observe these mechanisms in action. Density and velocity distributions are analysed with discrete wavelet analysis implemented by the 'à trou' algorithm, a method already applied in the study of large scale distribution of galaxies (Lega et al. 1996, Bijaoui et al. 1996). The first sample analysis is presented here. It is made of dwarf A-type stars, complete for $M_v \leq 2.5$ and up to the limiting distance 125 pc. Results in terms of clustering in 3-d spatial distributions (X,Y,Z) and 2-d projections of reconstructed velocity distributions (U,V) and (U,W) are given.

2. IMPLEMENTATION OF THE WAVELET ANALYSIS

The discrete approach of the wavelet transform can be implemented with the 'à trou' algorithm (Holschneider et al. 1989, Starck 1993). The binned data $C_0(i,j,k)$ are the scalar products of the initial parent distribution $F(x,y,z)$ with a scaling function $\Phi(x,y,z)$ which corresponds to a low pass filter. Here $\Phi(x,y,z)$ is a separable function built with a one dimensional B_3 spline function. This function ensures

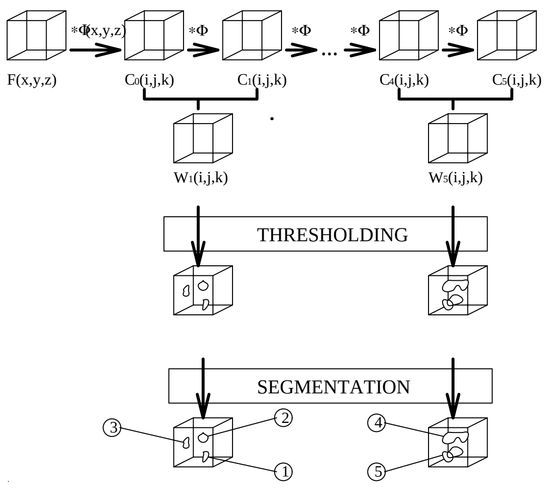

Figure 1. Implementation of the wavelet analysis.

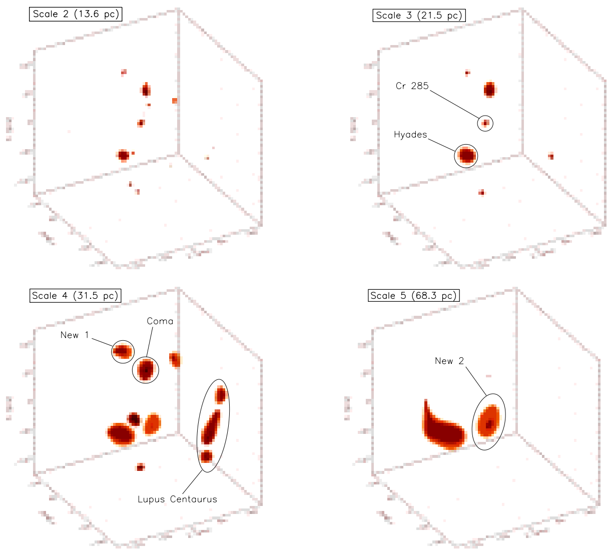

Figure 2. Results in wavelet coefficient space after thresholding for spatial distributions.

a quasi-isotropic wavelet transform.

The distance between two bins increases by a factor 2 from scale $s-1$ to scale s. The signal difference $C_{s-1}(i,j,k) - C_s(i,j,k)$ contains the information between these two scales and is the discrete set of wavelet coefficients $W_s(i,j,k)$ associated with the wavelet transform corresponding to $\Phi(x,y,z)$ (Figure 1).

At each scale s the set of wavelet coefficients $\mathrm{W}_s(i,j,k)$ is thresholded above a significance level λ_s to get rid of noise generated coefficients. λ_s are defined so that the probability of false detection is $P(W_s^{\mathrm{unif.}} > \lambda_s) = 10^{-4}$; it is the probability that one coefficient at scale s exceeds this limit if the parent distribution studied is uniform. Levels are estimated through numerical experiments.

A segmentation procedure is applied on thresholded coefficients to precisely localize significant over-densities. All adjacent remaining coefficients are considered to sign one structure. All structures are labelled and their characteristics are obtained.

3. 3D DENSITY ANALYSIS

This sample of 2977 A-type stars is complete for stars more luminous than 2.5 and up to a limiting distance of 125 pc. (X,Y,Z) distributions are binned in a Sun centered orthonormal frame ranging from -125 pc to 125 pc, X-axis towards the galactic center, Y-axis in the rotation direction and Z-axis towards the north galactic pole. The discrete wavelet analysis is performed on five scales: 9.7, 13.6, 21.5, 37.1 and 68.3 pc. Over-densities are identified at each scale (Figure 2) by the segmentation procedure and their members are selected. An iterative 2.5 sigma clipping procedure is done on tangential velocity distributions of each group to select kinematically coherent structures (Table 1 and Figure 3).

Space distributions turn out essentially smooth at all scales, only 7 per cent of the stars are in clusters or groups, most well known: Hyades, Coma, Ursa Major (Cr285) and Lupus-Centaurus association which shows three well limited over-densities with an elongated shape crossing the galatic disc. Two new structures are found: New1 at a mean distance of 105 pc with 5 stars centered on $(l,b) = (97.^\circ64, +56.^\circ68)$ and New2 which appears to be composed of two different kinematical groups of 10 and 8 stars at mean distances of respectively 97 and 89 pc and centered on $(l,b) = (60.^\circ77, -32.^\circ57)$ and $(l,b) = (54.^\circ20, -31.^\circ33)$.

4. 2D VELOCITY ANALYSIS

Velocities U, V and W are reconstructed by a convergent point method for stars which may belong to streams. All pairs of stars are examined. Each pair gives a possible convergent point (assuming the stars move exactly parallel) and the hypothetic third component is inferred for both stars. Then total reconstructed velocities, V_1 and V_2 of the two stars are kept if $\mid \mathrm{V}_1 - \mathrm{V}_2 \mid$ do not exceed a fixed threshold. Here this threshold is 0.5 km s^{-1}. By this way a large number of plausible velocities are obtained which distributions are wavelet analysed. Streams are signed by over-density clumps and their scale of detection is related to the dispersion velocity.

(U,V) and (U,W) distributions are binned in a 128 pixel edge square and wavelet analysed. The decomposition is performed on five scales: 3.2, 5.5, 8.6, 14.9 and 27.3 km s^{-1}.

The velocities in the (U,V) plane turn out highly structured. Four large dispersion velocity structures appear at scale 3 (Figure 4). Three of them have mean U and V velocities matching these of Hyades, Pleiades and Sirius superclusters. At higher resolution (Figure 5) they are found to be substructured in a cascade of tiny velocity clumps. The Pleiades moving group includes Pleiades and α Persei open clusters and seems to be connected with the Lupus-Centaurus concentration. Eggen's supercluster IC 2391 is found to have smaller dispersion velocities (Figure 5) than the three other moving

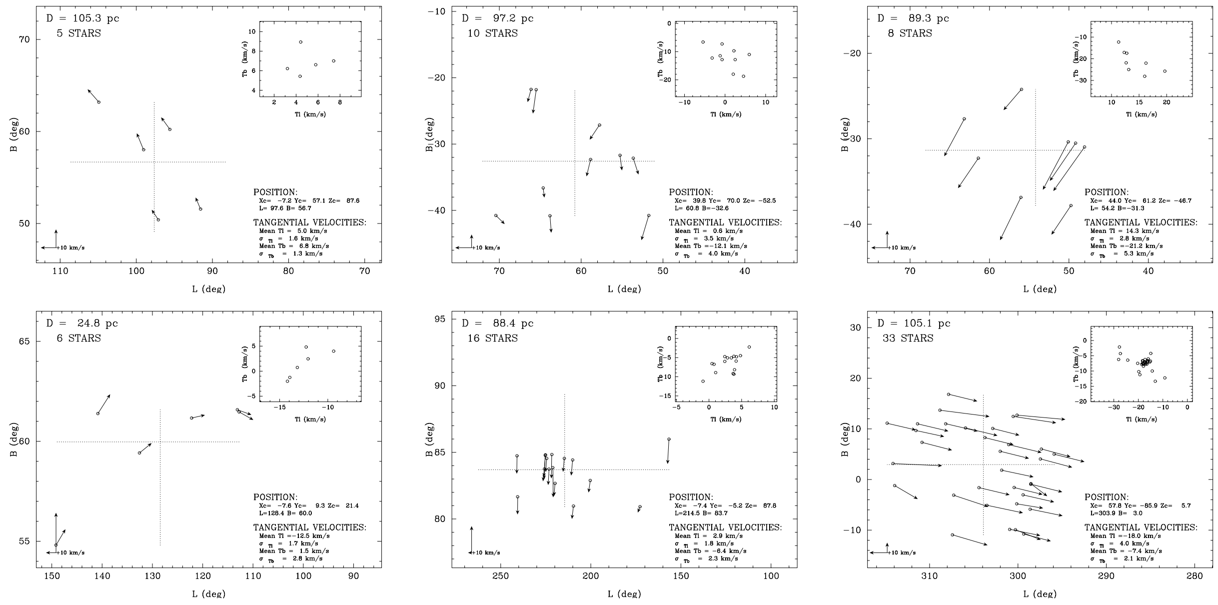

Figure 3. New 1 (upper left) and the two groups of New 2 (upper middle and right), the Ursa Major (Cr285) (lower left), Coma Ber (lower middle) open clusters and the concentration of Lupus-Centaurus (lower right) after selection on tangential velocities.

Table 1. Main characteristics of detected spatial structures after iterative 2.5 sigma clipping procedure on tangential velocities: galactic coordinates (l,b), distance D, mean tangential velocities ($\overline{T_l}$,$\overline{T_b}$), their dispersions (σ_{T_l},σ_{T_b}) and the number of stars N. Other parameters are given: scales of detection, the volume v occupied by the total over-density, the number of stars $N_{exp.}$ expected in this volume according to the mean density, the total number of stars observed $N_{obs.}$, the probability P_1 of finding one such concentration with a Poissonian distribution in this v volume and the probability P_2 to find this volume v with this concentration in the whole volume.

Structure	l (deg)	b (deg)	D (pc)	$\overline{T_l}$	σ_{T_l} (km/s)	$\overline{T_b}$	σ_{T_b}	N	Scale	v (pc^3)	$N_{exp.}$	$N_{obs.}$	P_1	P_2
1	227.65	-6.14	116.8	Possible double system				2	2	831	0.302	2	.037	.999
2	58.52	+35.89	54.0	-4.9	0.6	10.1	6.8	2	2	20	0.007	2	$2\ 10^{-5}$	.999
3	83.96	-42.34	81.5	Possible double system				2	2	5	0.002	2	$1\ 10^{-6}$	.933
4	40.71	-0.60	121.0	6.0	3.3	-5.5	5.4	4	2	696	0.253	4	$1\ 10^{-4}$	.807
5	231.58	-20.34	100.9	Possible double system				2	2	77	0.02	2	$3\ 10^{-4}$	≃1.
6 Cr 285	128.44	+59.97	24.7	-12.5	1.7	1.5	2.8	6	2-3	1191	0.43	6	$6\ 10^{-6}$	.042
7 Lup-Cen (1)	303.91	+2.95	105.1	-17.9	3.9	-7.4	2.1	33	2-4	52229	19.0	36	$3\ 10^{-4}$	.050
8	228.98	+28.84	110.4	-7.6	11.4	-17.0	8.3	8	4	16093	5.8	8	.236	≃1.
9 Lup-Cen (2)	325.40	-34.41	110.9	-20.9	13.9	-8.1	8.5	6	4	11718	4.2	6	.257	≃1.
10 Lup-Cen (3)	335.27	+17.30	116.8	-17.7	10.5	-5.2	10.5	9	4	33028	12.0	12	.540	≃1.
11 Coma	214.50	+83.6	88.4	2.9	1.8	-6.4	2.3	16	2-4	10968	3.9	21	$8\ 10^{-10}$	$6\ 10^{-7}$
12 Hyades	180.26	-21.38	47.5	19.4	2.8	14.2	2.1	22	2-4	63986	23.3	45	$4\ 10^{-5}$	.005
13	34.39	+33.89	107.7	-9.5	7.6	-0.5	14.3	7	4	18316	6.6	7	.499	≃1.
14 New 1	97.64	+56.68	105.2	5.0	1.6	6.8	1.3	5	2-4	12574	5.9	13	$9\ 10^{-4}$	.455
15 New 2 (1)	60.77	-32.57	97.2	0.6	3.5	-12.0	3.9	10	4-5	71687	26.0	35	.054	0.998
New 2 (2)	54.20	-31.33	89.2	14.2	2.8	-21.2	5.2	8	4-5	”	”	”	”	”
16	80.44	+32.61	108.9	4.7	16.3	0.3	3.7	8	4	17651	6.4	8	.316	.999
17 Hyades' tail	163.56	-8.34	67.4	20.8	8.5	-2.6	4.4	39	5	246202	89.5	90	.496	≃1.

groups and NGC 1901 supercluster is not present in our sample velocity field. Sirius is shown to be sub-structured with Ursa Major (Cr285) and two other velocity clumps. The fourth large dispersion velocity structure is made of Coma Ber open cluster, Lupus-Centaurus concentration and another unknown group. Large dispersion velocity structures in the (U,V) distributions involve 60 per cent of the stars while 40 per cent are concerned by their sub-structuring.

In contrast there are no such structures to be observed along the W component whose distribution is essentially smooth. This is likely to be related to the confinment of the interstellar medium by the potential well along Z-axis.

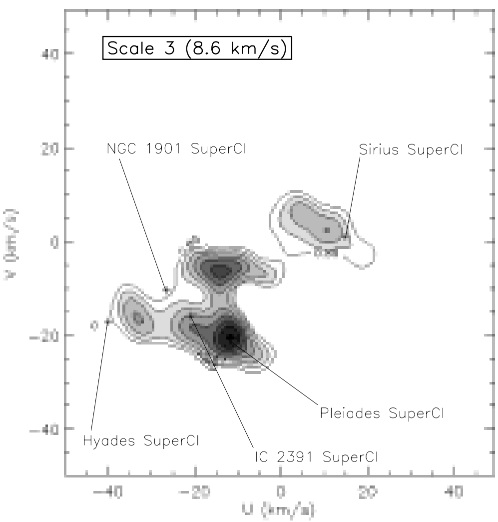

Figure 4. Results in wavelet coefficient space at scale 3 (typical size 8.6 km/s) for (U,V) distributions. Cross-identification is made with Eggen's superclusters.

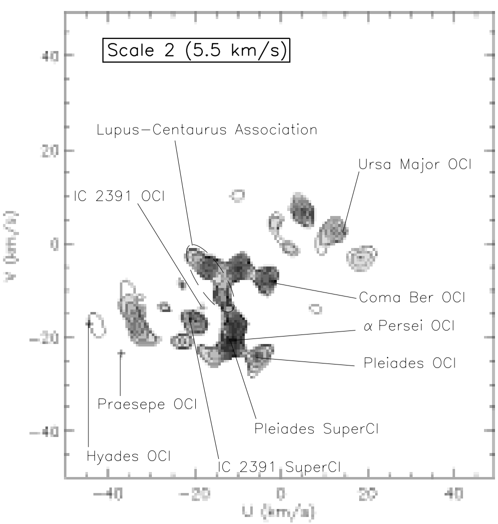

Figure 5. Results in wavelet coefficient space at scale 2 (typical size 5.5 km s^{-1}) for (U,V) distributions. Cross-identification is made with known open clusters and associations.

5. CONCLUSION

Density and velocity distributions of an A-type dwarf volume and absolute magnitude limited sample has been investigated using wavelet analysis to detect local inhomogeneities at different scales.

In position space not only well known structures are found (Hyades, Coma Ber, Ursa Major open clusters and Lupus-Centaurus association) but two new groups are brought to the fore. The sample is spatially relatively well-mixed since no more than 7 per cent of stars are in structures with coherent tangential velocities.

Four large dispersion velocity structures (an 8.6 km s^{-1} typical size corresponds roughly to a velocity dispersion of 2.9 km s^{-1}) appear in the (U,V) distribution and three of them are clearly cross-identified with Eggen's superclusters (Hyades, Pleiades and Sirius). At higher resolution they are sub-structured with tinier velocity clumps ($\sigma \sim$ 1.8 km s^{-1}). The Sirius moving group appears to be made of the Ursa Major open cluster and two other groups. The Pleiades moving group is clearly connected along V-velocity to the Lupus-Centaurus association. Sixty per cent of the stars have (U,V) velocities belonging to large dispersion velocity structures while fourty per cent are in tiny clumps. This sub-structuring traced exhaustively for the first time is a remnant of the state of motion in the interstellar medium at star formation time.

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