YOUNG STARS: IRREGULARITIES OF THE VELOCITY FIELD

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ABSTRACT

We present here a first review of the structure and kinematics of the local system of young stars. Hipparcos astrometric data for a large sample of O and B stars have been complemented with a careful compilation of available radial velocities and Strömgren photometry thus providing reliable distance, spatial velocity and age for each star in the sample. The fundamental parameters characterizing the structure of the Gould Belt, inclination, size and age are determined. The velocity field is studied by means of the classical first order approach. Oort's constants A, B, C, K are determined for several subsamples selected by age and the results explained by the presence of the Gould Belt.

Key words: galactic kinematics; young stars; Gould Belt.

2. THE CATALOGUE

Our initial sample contains 6922 O-B type stars (Hipparcos Internal proposal, INCA060), of which 5846 belong to the Hipparcos Survey. The sources of radial velocities have been the Barbier-Bressat (1997) and the Duflot et al. (1995) compilations. Priority has been given to the first one, and only stars with quality A, B or C in the last compilation have been considered (Grenier 1997). Using these sources, only 3182 stars of our total sample have known radial velocity, this parameter being, at present, the most important limitation to undertake the study of the velocity field in the solar neighbourhood.

Strömgren photometry has been used to compute photometric distances and ages. 3031 stars from our sample have complete photometry in the Hauck & Mermilliod (1996) catalogue. From these, we have rejected the stars being double or multiple from Hipparcos \((\rho < 10 \text{ arcsec} \text{ and } \Delta m < 3 \text{ mag})\), the variable stars \((\Delta m > 0.6 \text{ mag})\) and the stars showing peculiarities in the spectral type or in the photometric indices (Masana 1994). Crawford (1978) calibration has been used to derive photometric distances which are compared to the Hipparcos distances – computed as the inverse of the parallax – in Figure 1. Although no systematic trend seems to be present, an expected large scattering is observed for stars at distances higher than 200 pc. Other photometric cal-
Photometric distances computed from Crawford (1978) calibrations.

Individual ages have been computed from the evolutionary models of Bressan et al. (1993) for solar composition following Asiain et al. (1997) interpolation algorithm, which considers, as input parameters, the $T_{\text{eff}}$ and $\log g$ derived from the photometric indices (Moon et al. 1985, grids). The stars showing a relative error on age larger than 100 per cent have been rejected (these are stars near or below the ZAMS for which the obtained age is not reliable). The histograms of the age distribution and the computed individual errors are presented in Figure 2 and Figure 3 respectively.

According to the physical information available we have defined two working samples:

- **Sample 1**: 2139 stars with good ($\Delta \tau / \tau \leq 100$ per cent) ages and photometric distances. Useful to determine the fundamental parameters of the Gould Belt.
- **Sample 2**: 1539 stars, a subsample of Sample 1, containing the stars with known radial velocities having $v_r \leq 7$ km/s, well suited for the analysis of the systematic velocity field.

### 3. FUNDAMENTAL PARAMETERS OF THE GOULD BELT

We can see in Figure 4 where $(X, Y, Z)$ are the galactic heliocentric coordinates with $X$ directed towards the galactic center, $Y$ in the direction of the galactic rotation and $Z$ directed towards the north galactic pole, the well known spatial distribution of young stars clearly showing the galactic belt and the inclined and asymmetric structure of the Gould Belt.

We have not tried to individually separate the stars belonging to the Gould Belt from the ones in the galactic plane; otherwise we will follow the method developed by Comeron et al. (1994), well suited for large samples, which allows a statistical determination of the parameters characterizing the geometry of both belts. We assume that the density distribution of the sample in the celestial sphere can be written as:

$$\sigma(l, b) = \sigma_G(l, b) + \sigma_g(l, b)$$  \hspace{1cm} (1)

where $\sigma_G$ and $\sigma_g$ are the density distributions around the Gould Belt and the galactic equator respectively.

For each one of these distributions we assume that:
\[ \sigma(\theta) \propto \exp\left(-\frac{\sin^2 \theta}{2 \sin^2(\xi/2)}\right) \] (2)

\( \theta \) being the angular distance to the equator of the corresponding distribution and \( \xi \) its halfwidth. The geometric parameters: inclination, \( i \), longitude of the ascending node, \( \Omega \), halfwidths of both belts \( \xi_G, \xi_g \) as well as the fraction of the stars, \( q \), belonging to the Gould Belt which enters in the proportionality constant in Equation 2 are determined by an iterative maximum likelihood method.

The method has the advantage that the heliocentric distance of the stars are only used to define the limit of the subsamples considered. The method will produce accurate results only if the sample is complete enough. As can be seen in Figure 5, if we want to use individual ages, to be complete, our sample is limited to stars brighter than 6.5 mag.

In Table 1 we show the results obtained for several subsamples of sample 1 selected by age and photometric distance. Assuming \( q > 0 \) as an indicator of the presence of the Gould Belt, we see that it is defined by \( i = 17^\circ - 20^\circ \) and \( \Omega = 278^\circ - 290^\circ \), in good agreement with previous results. We found the highest \( q \) value, 0.94, for stars younger than 30 million years and distances between 400 and 600 pc; some older stars up to 60 million years establish the limits of the Gould Belt at 400 pc, and very few, if any, stars older than 60 million years indicate also a limit of 400 pc. Tsioumis & Frice (1979) considered the extent to be 450-600 pc, and Westin (1985) considered 250-500 pc depending on the galactic longitude. In Figure 4 we can see the relationship between age and structure in the X, Z plane. We want to remark that when the method is applied to the complete sample of OB Survey stars with \( V < 7.9 \) (see Figure 5) the same conclusions are reached, although in this case only spectral types are available as indicators of evolution.

4. SYSTEMATIC MOTION OF YOUNG STARS

4.1. Distribution of Residual Velocities

The sample of 1539 O-B type stars used to derive the systematic motion of young stars in the solar neighbourhood shows (see Figure 6) an irregular distribution in the (U,V) plane, (U,V,W) being the components of the velocity in the system defined in Section 3. The sample is reduced to 1417 stars when those with residual velocity exceeding 65 km s\(^{-1}\) are eliminated. Mean velocity and dispersions of the working sample are:

\[
(U_o, V_o, W_o) = (-12.7, -14.6, -8.1) \text{ km s}^{-1}
\]

\[
(\sigma_U, \sigma_V, \sigma_W) = (16.0, 11.5, 8.0) \text{ km s}^{-1}
\]

The values obtained for the solar motion when age groups are considered (see Table 2) are affected.
by the presence of moving groups as described by Figueras et al. (1997).

Thanks to the good quality of the Hipparcos astrometric data and the accurate compilation of radial velocities, the mean errors are \( (e_u, e_v, e_W) = (3.8, 3.8, 3.0) \) km s\(^{-1}\), between 1 and 2 km s\(^{-1}\) better than previous studies.

### 4.2. Derivation of the Oort’s Constants

The Oort’s constants have been derived using a first-order approximation of the systematic velocity field (Ogorodnikov 1965):

\[
V_r = A r \sin b \cos l \cos b + C r \cos 2l \cos 2b + K r \cos b - U_\odot \cos l \cos b - V_\odot \sin l \cos b - W_\odot \sin b \tag{3}
\]

\[
rk \mu_r \cos b = A r \cos 2l \cos b + B r \cos b - C r \sin 2l \sin b + U_\odot \sin l - V_\odot \cos l \tag{4}
\]

\[
rk \mu_b = -A r \sin 2l \cos b \cos b - C r \cos 2l \sin b \cos b + K r \sin b \cos b + U_\odot \cos l \sin b + V_\odot \sin l \sin b - W_\odot \cos b \tag{5}
\]

where \( l, b \) are the galactic coordinates, \( r \) the distance, \( V_r \) the radial velocity, \( \mu_r \) and \( \mu_b \) the proper motions, \( U_\odot, V_\odot \) and \( W_\odot \) are the components of the peculiar motion of the Sun in km s\(^{-1}\) respect to the circular velocity and \( A, B, C \) and \( K \) are the Oort’s constants, linear combinations of the gradients of the systematic velocity:

\[
A = \frac{1}{2} \left( \frac{\partial U}{\partial y} + \frac{\partial V}{\partial x} \right)
\]

\[
B = -\frac{1}{2} \left( \frac{\partial U}{\partial y} - \frac{\partial V}{\partial x} \right)
\]

\[
C = \frac{1}{2} \left( \frac{\partial U}{\partial x} - \frac{\partial V}{\partial y} \right)
\]

\[
K = \frac{1}{2} \left( \frac{\partial U}{\partial x} + \frac{\partial V}{\partial y} \right)
\]

where no systematic motion perpendicular to the plane is considered other than that arising from the solar peculiar motion. The conversion factor \( k = 4.74 \) if velocities are expressed in km/s, proper motions in arcsec/yr, and distances in parsecs.

The three equations – radial velocity and proper motion in longitude and latitude – have been simultaneously solved using an unweighted least square fit. In Table 2 we show the results obtained when different subsamples selected in distance and age are considered. The results for stars with distances \( 70 < r < 400 \) pc are summarized in Figure 7 where we can appreciate the monotonic behaviour of the \( A \) and \( B \) Oort’s constants against age. The classical values of \( A \sim 15 \) and \( B \sim -12 \) km s\(^{-1}\) are obtained for the oldest sample, while values as low as \( A = 0 \) km s\(^{-1}\) and \( B = -26 \) km s\(^{-1}\) are found for the youngest stars. The \( K \) term shows, as expected, a strong decrease with increasing age and disappears for ages between 40 and 60 million years, thus confirming its relationship with the expanding motion of the Gould Belt. On the contrary, the \( C \) constant shows a rather erratic and not explained behaviour that could be related to the spiral arms. The same trends appear in Figure 8 where we have plotted, for broad age groups, the values of the Oort’s constants against the distance. We see that for the youngest age group \( A \) and \( B \) take low values for the nearest region associated with the Gould Belt, reaching the classical values for distant stars, whereas for the oldest group quite stable classical values are found. The \( K \) constant reaches the zero values at a distance of about 500 pc which could indicate the extend of the Belt in agreement with the determination we did in the previous paragraph. Now again the \( C \) constant behaves rather different being the intermediate group (30–60 Myr) the one showing the maximum variation.

### Table 1. Geometrical parameters of the Gould Belt as a function of distance and age: inclination \( (i_c) \), longitude of the ascending node \( (\Omega_c) \), fraction of stars belonging to the Gould Belt \( (q) \), angular width of the Gould Belt \( (\xi_d) \) and the galactic belt \( (\xi_g) \), and number of stars \( (N) \).

<table>
<thead>
<tr>
<th>( r ) (pc)</th>
<th>( i_c ) (°)</th>
<th>( \Omega_c ) (°)</th>
<th>( q )</th>
<th>( \xi_d ) (°)</th>
<th>( \xi_g ) (°)</th>
<th>( N )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( r &lt; 400 )</td>
<td>19.9±8.2</td>
<td>278.8±11.9</td>
<td>0.8±0.08</td>
<td>14.17</td>
<td>10.91</td>
<td>103</td>
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<tr>
<td>( 400 \leq r \leq 600 )</td>
<td>17.6±15.2</td>
<td>287.8±62.4</td>
<td>0.94±0.03</td>
<td>10.06</td>
<td>11.70</td>
<td>96</td>
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<tr>
<td>( 600 \leq r \leq 800 )</td>
<td>13.5±4.0</td>
<td>301.4±138.8</td>
<td>0.50±0.00</td>
<td>15.37</td>
<td>9.19</td>
<td>31</td>
</tr>
<tr>
<td>( 800 \leq r \leq 2000 )</td>
<td>13.9±4.8</td>
<td>322.0±21.9</td>
<td>0.91</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( &gt; 60 ) ( 10^3 ) years</td>
<td></td>
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</tr>
<tr>
<td>( r &lt; 400 )</td>
<td>20.8±10.3</td>
<td>200.4±25.2</td>
<td>0.65±0.03</td>
<td>8.35</td>
<td>23.39</td>
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<td>9.5±2.1</td>
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<td>( 600 \leq r \leq 800 )</td>
<td>13.7±5.4</td>
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<td>( 600 \leq r \leq 2000 )</td>
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<td>0.46±0.00</td>
<td>28.32</td>
<td>6.25</td>
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<td>( &gt; 60 ) ( 10^3 ) years</td>
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Table 2. Oort’s constants and residual solar motion as a function of distance and age. Units: \(A, B, C, K\) in \(\text{km s}^{-1}\) \(\text{kpc}^{-1}\); \(V_\odot, V_\odot, W_\odot\) in \(\text{km s}^{-1}\).

<table>
<thead>
<tr>
<th>Age ((10^7 \text{ yr}))</th>
<th>(A)</th>
<th>(B)</th>
<th>(C)</th>
<th>(K)</th>
<th>(U_\odot)</th>
<th>(V_\odot)</th>
<th>(W_\odot)</th>
<th>(N)</th>
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<tr>
<td>(&lt;2)</td>
<td>-.4±.6</td>
<td>-.6±.4</td>
<td>3.1±.6</td>
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<td>17.9±.1</td>
<td>7.6±.1</td>
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<tr>
<td>(2\leq E \leq 4)</td>
<td>7.5±.8</td>
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<td>(4\leq E \leq 6)</td>
<td>7.1±.3</td>
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<td>6.8±.3</td>
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<td>13.4±.7</td>
<td>15.3±.7</td>
<td>7.7±.7</td>
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<tr>
<td>(6\leq E \leq 8)</td>
<td>12.0±.4</td>
<td>-.1±.4</td>
<td>7.5±.4</td>
<td>-.1±.4</td>
<td>12.6±.8</td>
<td>15.7±.8</td>
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<td>107</td>
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<td>-.2±.0</td>
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<th>(A)</th>
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<th>(C)</th>
<th>(K)</th>
<th>(U_\odot)</th>
<th>(V_\odot)</th>
<th>(W_\odot)</th>
<th>(N)</th>
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<th>(K)</th>
<th>(U_\odot)</th>
<th>(V_\odot)</th>
<th>(W_\odot)</th>
<th>(N)</th>
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<td>-.1±.6</td>
<td>9.4±.2</td>
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<td>10.7±.8</td>
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**REFERENCES**


Barbier-Brossat, M. 1997, private communication


Elmegreen, G.B. 1982, in The formation of giant cloud complexes, Cambridge Univ. Press
Figuera, F., Asín, R., Chen, B., Comerón, F., Gómez, A.E., Grenier, S., Lebreton, Y., Moreno, M., Sabas, V. 1997, this volume
Grenier, S. 1997, private communication
Hauck, B., Mermilliod, J.C. 1996, private communication
Jakobsen, A.M. 1985, PhD Thesis, University of Aarhus, Denmark
Lindblad, P.O., Palouš, J., Lodén, K., Lindegren, L. 1997, this volume
Masana, E. 1994, Degree of Physics, Universitat de Barcelona, Spain
Palouš, J. 1995, Structure and Evolution of Stellar Systems, Ed. V.V. Orlov, in press
Tsioumis, A., Fricke, W. 1979, A&A 75, 1