The velocity field of young stars in the solar neighbourhood

J. Torra, D. Fernández and F. Figueras
Departament d’Astronomia i Meteorologia, Universitat de Barcelona, Av. Diagonal 647, E-08028 Barcelona, Spain

F. Comerón
European Southern Observatory, Karl-Schwarzschild-Strasse 2, D-85748 Garching bei München, Germany

Abstract. A sample of O- and B-type stars with Hipparcos astrometric data, ages computed from Strömgren photometry and radial velocities, has been used to characterize the structure, age and kinematics of the Gould Belt system. The local spiral structure of our galaxy is determined from this sample, and also from a sample of Hipparcos Cepheid stars.

The Gould Belt, with an orientation with respect to the galactic plane of \(i_G = 16-22^\circ\) and \(\Omega_G = 275-295^\circ\), extends up to a distance of 600 pc from the Sun. Roughly the 60-65\% of the O and B stars younger than 60 Myr in the solar neighbourhood belong to this structure. Our results indicate that the kinematical behaviour of this system is complex, with an expansion motion in the solar neighbourhood (\(R < 300\) pc).

In the frame of the Lin’s theory, and analysing the O and B stars further than 600 pc and the Cepheids, we found a galactic spiral structure characterized by a 4-arm spiral pattern with the Sun located at \(\psi_\odot = 350-355 \pm 30^\circ\) – near the Sagittarius-Carina arm – and outside the corotation circle. The angular rotation speed of the spiral pattern was found to be \(\Omega_p = 31-32 \pm 4 \text{ km s}^{-1} \text{ kpc}^{-1}\).

Keywords: Galaxy: kinematics and dynamics – Galaxy: solar neighbourhood – Galaxy: structure – Stars: early-type – Stars: kinematics – Stars: variables: Cepheids

1. The working samples

1.1. Sample of O and B stars

Our initial sample contains 6922 O and B stars. The astrometric data come from Hipparcos Catalogue (ESA, 1997), radial velocities from the compilation of Grenier (1997) and Strömgren photometry from Hauck & Mermilliod (1998) catalogue (see details in Fernández, 1998). Photometric distances were computed from Crawford (1978) calibration. Close binaries, high amplitude variables and peculiar stars were rejected. Once the trigonometric and photometric distances were known, that with small relative error was chosen. Individual ages were com-
puted from the models of Bressan et al. (1993) following the interpolation algorithm described in Asiain et al. (1997).

The sample with distances, proper motions and ages contains 2468 stars, whereas the subsample with available radial velocities contains 1789 stars.

1.2. Sample of Cepheid stars

The initial sample contains all the Hipparcos classical Cepheids, whereas overtone Cepheids were eliminated. Astrometric data were taken from the Hipparcos Catalogue (ESA, 1997) and radial velocities from the Hipparcos Input Catalogue (ESA, 1992). Using Hipparcos data, Luri et al. (1998) derived individual estimates of luminosities and distances for these stars through the LM method (Luri et al., 1996).

The sample with known distances and proper motions contains 207 stars. The subsample with known radial velocities contains 99 stars.

2. Characterizing the Gould Belt

2.1. Structure parameters and age

Our model assumes that both the Gould and galactic belts trace two great circles in the celestial sphere. The decrease of star density with the angular distance to each belt was assumed to follow a gaussian law, the standard deviation being the angular halfwidth of the belt. The resolution procedure was based on the maximum likelihood method. An iterative procedure was implemented to minimize the dependence of the final results on the initial values (see details in Comerón, 1992, and Torra et al., 1999).

The Gould Belt structure is clearly present in the subsamples of young stars with \( R \leq 600 \) pc. The orientation parameters were found to be \( i_C = 16-22^\circ \) and \( \Omega_C = 275-295^\circ \), depending on the age and the distance interval considered. For stars with \( \tau \leq 60 \) Myr and \( R \leq 600 \) pc, the fraction of them belonging to the Gould Belt was found to be 60-66%. This percentage decreased to 42-44% when stars with \( 60 < \tau \leq 90 \) Myr were considered. We estimate an age of the Gould Belt inside the interval 60-90 Myr. The angular halfwidth of the belts were found to be 6-8\(^\circ\) and 23-26\(^\circ\) for the Gould and galactic belts, respectively.

2.2. The Gould Belt kinematics

The Oort constants \( A, B, C \) and \( K \) were derived using the first-order development of the galactic velocity field. A combined solution
The velocity field of young stars in the solar neighbourhood was applied, solving simultaneously radial velocity and proper motion equations, and rejecting high residual stars.

In the region with $R > 600$ pc, the stellar kinematics is dominated by the differential galactic rotation, since the Oort constants were found to be $A = 13.0 \pm 0.5 \text{ km s}^{-1} \text{kpc}^{-1}$, $B = -12.2 \pm 0.5 \text{ km s}^{-1} \text{kpc}^{-1}$, $C = 0.2 \pm 0.5 \text{ km s}^{-1} \text{kpc}^{-1}$ and $K = -2.0 \pm 0.5 \text{ km s}^{-1} \text{kpc}^{-1}$. Contrary to that, in the region with $R \leq 600$ pc, the Gould Belt defines the kinematics of the youngest stars ($\tau \leq 60-90$ Myr), producing a decrease of the $A$ and $B$ Oort constants ($A \approx 6-8 \text{ km s}^{-1} \text{kpc}^{-1}$, $B \approx -(22-14) \text{ km s}^{-1} \text{kpc}^{-1}$) and an increase of $C$ and $K$ ($C \approx 6-9 \text{ km s}^{-1} \text{kpc}^{-1}$, $K \approx 4-7 \text{ km s}^{-1} \text{kpc}^{-1}$). This peculiar kinematics was also found when those stars belonging to the Sco-Cen and Ori OB1 complexes were eliminated. Therefore, these associations are not the only responsible for these peculiarities. Through the analysis of the variation of the Oort constants with the age, a kinematic age of the Gould Belt inside the interval 60-90 Myr was inferred, in good agreement with previous estimations from the spatial distribution of stars.

The study of the residual velocity field of the youngest stars shows that it cannot be explained as an expansion from a point (Olano, 1982) or a line (Comerón et al., 1994). Moreover, the expansion motion classically attributed to the Gould Belt seems to be due to the nearest stars ($R \leq 300$ pc). In the region $300 < R \leq 600$ pc, only Per OB2 has a clear residual motion away from the Sun.

### 3. Galactic spiral structure

The spiral structure of the Galaxy was studied developing the galactic velocity field projected on the galactic disk, taking into account the contributions of the solar motion, differential galactic rotation (up to second-order approximation) and spiral arm kinematics (modelled in the frame of Lin’s theory). See details of the model in Fernández et al. (1999).

Coherent results for O-B stars ($R > 600$ pc) and Cepheids ($R < 4000$ pc) are obtained when adopting a 4-arm spiral pattern with a pitch angle of $-14^\circ$ (Amaral & Lépine, 1997), with the Sun placed at 7.1 kpc from the galactic center and the circular velocity being equal to 184 km s$^{-1}$ (Olling & Merrifield, 1998). Other values of these parameters have been also discussed in Fernández et al. (1999). From a least squares fit we derived that the Sun is located in an arm, between its center and the outer edge ($\psi_\odot = 350-355 \pm 30^\circ$), near the Sagittarius-Carina arm and outside the corotation circle, placed at $\varpi_{\text{cor}} = 5.9-6.1 \pm 0.7$ kpc. The angular rotation velocity of the spiral structure was found to be
\[ \Omega_p = 31.32 \pm 4 \text{ km s}^{-1} \text{ kpc}^{-1} \]. Following Lindblad (1980), we checked that the obtained spiral structure pattern can justify the difference found in the Oort constants (except in the case of \( B \)) between solutions using nearby O-B stars not belonging to the Gould Belt (\( R \leq 600 \text{ pc} \) and \( \tau > 90 \text{ Myr} \)) and O-B stars at \( R > 600 \text{ pc} \) (see Torra et al., 1999).

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Address for Offprints:
J. Torra
e-mail: jordi@am.ub.es