RevMexAA (Serie de Conferencias), **34**, 64–67 (2008)

STELLAR KINEMATICS IN THE LOCAL DISK

R. Teixeira,[1] R. E. De Souza,[1] and S. Dos Anjos[1]

RESUMEN

A partir de las distancias y movimientos propios para unas 22000 estrellas del Hipparcos, describimos la distribución de velocidades residuales mediante la superposición de dos Gaussianas, en vez de una sola, como es costumbre. La muestra se seleccionó de acuerdo con la magnitud, color, posición galáctica y distancia, y se separó en seis grupos según el tipo espectral, tres de ellos de tipo temprano y tres tardíos. Verificamos que para las estrellas tempranas nuestra representación no ofrece ventajas. Sin embargo, para las tardías, la representación mediante dos Gaussianas describe mejor la distribución de velocidades. Nuestros resultados señalan claramente la existencia de dos poblaciones cinemáticas distintas entre los tres grupos tardíos: una de ellas con dispersión de velocidades grande, la otra con dispersión pequeña. Las dos poblaciones se encuentran presentes en ambos grupos; sólo difieren sus proporciones.

ABSTRACT

From Hipparcos distances and proper motions for approximately 22000 stars we described the residual velocity distribution by the superposition of two Gaussians instead one as traditionally used. The sample of stars was selected by magnitude, color, Galactic position and distance and ranged in 6 spectral-type groups, 3 of early-type and 3 of late-type stars. We verified that for the early-type stars no gain is attained with our representation but for the late-type stars it is clear that the superposition of two Gaussians better describe the velocity distribution. Our results clearly point to the existence of two different kinematic populations very well characterized in the three late-type star groups: one population with high velocity dispersion and another with low velocity dispersion. It is still more interesting since the high and the low velocity dispersion population is the same in all the three groups. The core of this work was published in De Souza & Teixeira 2007.

Key Words: stars: kinematics — Galaxy: kinematics and dynamics

1. INTRODUCTION

The kinematic description of the local disk stars is fundamental to the understanding of the structure, formation and evolution of the Milky Way. The statistics of velocities in the solar neighborhood provides a database to describe the dependence of the disk kinematics on age, metallicity and spectral group (Stromgren 1987; Soubiran & Girard 2005).

The velocity field in the neighbourhood of the Sun is traditionally described by a single Gaussian in each component of the spatial motion as proposed by Schwarzschild (1907). It is not difficult to see that this one-Gaussian model is not the best fit for the data. Many groups of stars can present a large spread of age and this model does not take this fact into account. On the other hand, most work on this theme was faced with the difficulty of obtaining the components of the spatial motion from the available data; more specifically, radial velocities and/or distances are often missing. In our work we deal with two basic questions that arise naturally: How can we best describe the velocity distribution? How can we do that with the available data?

Using the trigonometric parallaxes and proper motions from the Hipparcos catalog (ESA 1997) for approximately 22000 stars we attempted to answer these two questions. To better represent the velocity distribution and consequently to better take into account the change of the velocity dispersion with age, we fitted to the data two Gaussians instead of one. To overcome the difficulty due to the lack of radial velocity for most of the considered stars we developed a strategy that allows us to obtain the velocity ellipsoid only from the tangential components, v_l and v_b, of the spatial velocity (De Souza & Teixeira 2007).

2. DATA SELECTION

Our work is based on a sample of 22392 Hipparcos stars (ESA 1997) selected basically with the same criteria adopted by Mignard (2000) in his work about stellar kinematic: only single stars, stars lying in the distance interval of 0.1–2.0 kpc, with com-

[1] Instituto de Astronomia, Geofísica e Ciências Atmosféricas, USP, Rua do Matão, 1226, Cidade Universitária, 05508-090, São Paulo, Brazil (teixeira@astro.iag.usp.br).

TABLE 1

SELECTED DATA GROUPED BY SPECTRAL-TYPE

B–V	Spec. type	$N_{\rm star}$
0.00–0.15	A0–A5	4202
0.15–0.30	A5–F0	3185
0.30–0.45	F0–F5	2837
0.85–1.15	K0–K5	6533
1.15–1.40	K5–M0	3350
1.40–1.60	M0–M5	2285

pleteness greater than 70% based on the Tycho catalogue (ESA 1997) as function of Galactic latitude, magnitude and color. Mignard (2000) also imposed a limit of 60-90 km s^{-1} depending on the spectral type for the residual velocity. Here we work with a limit of 100 km s^{-1} that corresponds approximately to 3 times the velocity dispersion in the disk. These stars were grouped into spectral types: 3 groups of early-type and 3 of late-type, as show in Table 1. The criterion of distance and the observational magnitude limit of the Hipparcos satellite compells us, for the late type stars, to work only with the giant and sub-giant stars. Thus, the main-sequence late type stars were not considered here. In turn, the stars with B–V between 0.45–0.85 were not selected due to the mixed characteristics of this sample.

3. DATA TREATMENT STRATEGY

The components, u (Galactic center direction), v (direction of increasing Galactic longitude) and w (direction to North Galactic Pole) of the spatial velocity are obtained from the observational quantities distance and proper motion, from which we determine the tangential components, v_l and v_b, and the radial velocity, as indicated in the following equations:

$$\begin{aligned}
\mathrm{u} &= \mathrm{v_r}\ \cos l\ \cos b\ - \mathrm{v_b}\ \cos l\ \sin b\ - \mathrm{v}_l\ \sin l\,, \\
\mathrm{v} &= \mathrm{v_r}\ \sin l\ \cos b\ - \mathrm{v_b}\ \sin l\ \sin b\ + \mathrm{v}_l\ \cos l\,, \\
\mathrm{w} &= \mathrm{v_r}\ \sin b\ + \mathrm{v_b}\ \cos b\,.
\end{aligned} \tag{1}$$

From these components we can describe the velocity distribution in each direction. In general, as said, this is done by the fit of a single Gaussian to the data. Of course, in this way, we are able to perform a kinematic study only for the stars for which we know all the observational data, that is, the distances, proper motions and radial velocities.

3.1. *Ellipsoid velocity determination*

As a consequence of the lack of distance and/or radial velocity measurements many works on this theme, as we can see in the literature, are limited to a small number of stars. However, even if we cannot obtain the individual velocity for each object, we can obtain the statistic quantities σ_u, σ_v and σ_w that describe the velocity ellipsoid, from only the tangential components of the spatial motion v_l and v_b. In other words, we are working with the projected distribution in the radial direction.

In the present case, we have no radial velocities for the most of the stars. So, we construct the velocity distribution for the tangential components v_l and v_b:

$$\begin{aligned}
s(\mathrm{v}_l) &= \frac{1}{\sqrt{2\pi\sigma_v l}}\ \exp\left(-\frac{\mathrm{v}_l^2}{2\sigma_v l^2}\right)\,, \\
t(\mathrm{v}_b) &= \frac{1}{\sqrt{2\pi\sigma_v b}}\ \exp\left(-\frac{\mathrm{v}_b^2}{2\sigma_v b^2}\right)\,.
\end{aligned} \tag{2}$$

These distributions provide the velocity dispersions σ_{v_l} and σ_{v_b} from which we obtain the velociy dispersions σ_u, σ_v and σ_w (equation 3). For a detailed development of this formalism see De Souza & Teixeira (2007).

$$\begin{aligned}
\sigma_{v_l}^2 &= \left(\frac{\cos^2 l}{\Gamma_{\mathrm{v}}^2} + \sin^2 l\right)\sigma_{\mathrm{u}}^2\,, \\
\sigma_{v_b}^2 &= \left(\cos^2 l \sin^2 b + \frac{\sin^2 l \sin^2 b}{\Gamma_v^2} + \frac{\cos^2 b}{\Gamma_w^2}\right)\sigma_u^2\,,
\end{aligned} \tag{3}$$

where $\Gamma_{\mathrm{v}} = \sigma_{\mathrm{u}}/\sigma_{\mathrm{v}}$ and $\Gamma_{\mathrm{w}} = \sigma_{\mathrm{u}}/\sigma_{\mathrm{w}}$ are the anisotropy parameters that describe the dispersion of the velocity ellipsoid in terms of the dispersion in the Galactic center direction.

To develop this strategy we need to make some hypotesis to compensate for the fact that v_l and v_b are not in a fixed direction. To overcome this obstacle we work in equal area sectors of the celestial sphere imposing on each sector the hipothesis that the directions of sectors v_l and v_b are fixed, corresponding to the direction of the center of the sector. This is the same as saying that the velocity dispersions σ_{v_l} and σ_{v_b} are constant in each sector. Here, we divided the celestial sphere in 72 equal area sectors having in each sector about 300 stars. The ideal was to work with smaller sectors, but in this case, we would have had only a few stars per sector.

Thus, using equation (3) we obtain by the least squares method, the values of σ_u, σ_v and σ_w in each sector.

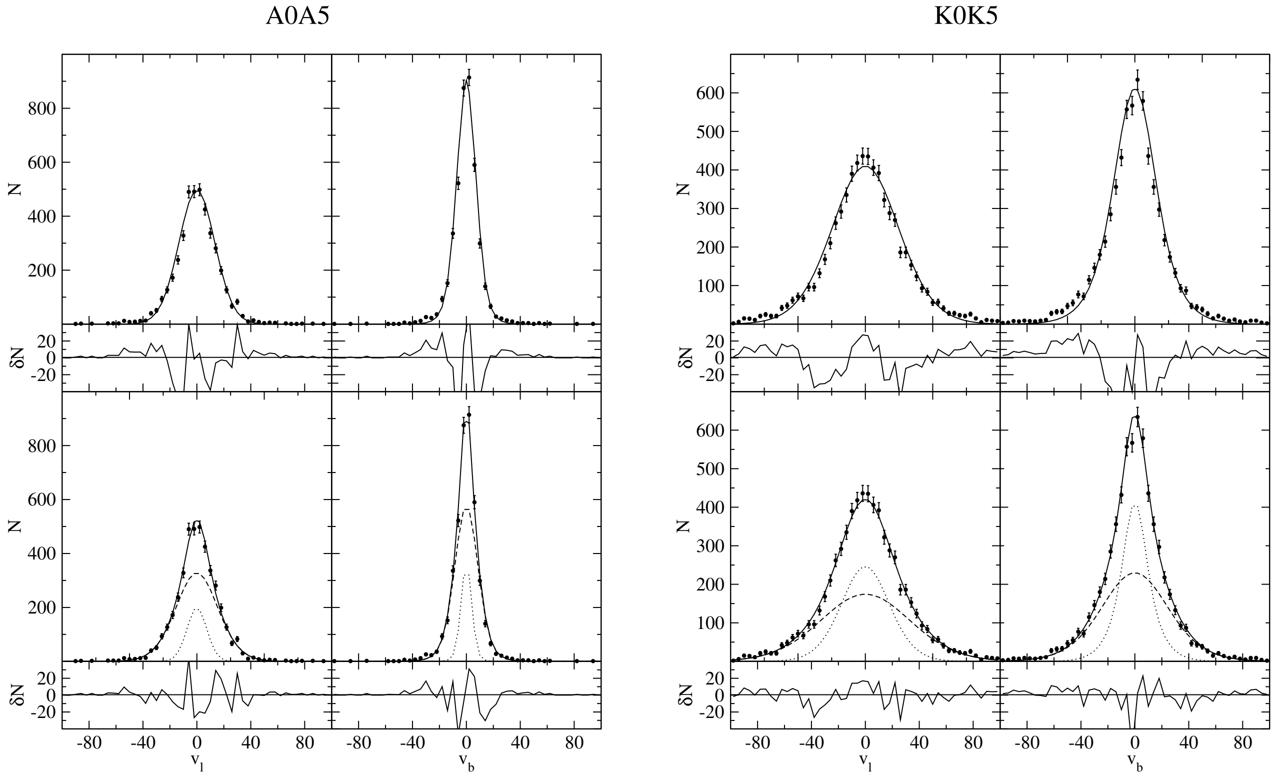

Fig. 1. Marginal velocity distributions (v_l and v_b). (*left*) Early-type stars A0A5 group. (*right*) Late-type stars K0K5 group.

3.2. *Velocity distribution by the superposition of two Gaussians*

Since the radial velocities are not available we work as described with the marginal distribution of v_l and v_b in each sector, but here, differently than has been done in most cases, instead a single Gaussian $s(\mathrm{v}_l)$ and $t(\mathrm{v}_b)$ we represent the velocity distribution by the superposition of two Gaussians:

$$\begin{aligned} s(\mathrm{v}_l) &= \alpha s_1(\mathrm{v}_l) + (1-\alpha) s_2(\mathrm{v}_l)\,, \\ t(\mathrm{v}_b) &= \alpha t_1(\mathrm{v}_b) + (1-\alpha) t_2(\mathrm{v}_b)\,, \end{aligned} \qquad (4)$$

where α is a proportionality coefficient.

The residual velocities v_l and v_b were calculated after subtraction of the solar motion and the Galactic rotation, for which we used the parameters determined in Mignard (2000).

4. RESULTS AND DISCUSSION

In Figure 1 we can see the marginal velocity distributions obtained using the two models, one Gaussian (upper panels) and two Gaussians (lower panels), for one group of the early-type stars (A0A5) and another of the late-type stars (K0K5) as examples. This figure, where δN corresponds to the residual of the fit, shows that for the A0A5 group, as well as for the other two early-type star groups, we have no significant gain using two Gaussians instead of one; both results are very similar. However, for the K0K5 group, as well as for the other two late-type star groups, the scenario is quite different and we can easily note the better representation of the velocity distribution by the two-Gaussian model.

Apart from the gain in the representation other interesting results concerning the late-type star groups are shown in Table 2.

In this table we clearly see the presence of two well-defined kinematic populations in each late-type star group: one of high velocity dispersion ($\sigma_u \approx$ 40 km s^{-1}) and another of low velocity dispersion ($\sigma_u \approx 20$ km s^{-1}). We can also see that the two populations are the same in the three groups; only the proportions given by the parameter α change. Curiously, we note that the late-type low velocity dispersion population having mean $\sigma_u \approx 20.6$ km s^{-1}, $\sigma_v \approx 13.0$ km s^{-1} and $\sigma_w \approx 5.4$ km s^{-1} presents the same values obtained here ($\sigma_u \approx 19.3$ km s^{-1}, $\sigma_v \approx 13.0$ km s^{-1} and $\sigma_w \approx 7.0$ km s^{-1}) and elsewhere as for example in Bienaymé (1999) ($\sigma_u \approx$

TABLE 2

VELOCITY ELLIPSOID FROM TWO GAUSSIAN MODEL

group	N_{stars}	α(%)	σ_u (km s^{-1})	σ_v (km s^{-1})	σ_w (km s^{-1})
K0K5	6533	57	40.66 ± 4.48	27.29 ± 3.02	19.64 ± 2.18
			23.11 ± 2.31	13.59 ± 1.38	5.78 ± 0.64
K5M0	3350	65	41.25 ± 5.19	26.79 ± 3.38	19.93 ± 2.52
			20.02 ± 3.33	16.28 ± 2.73	5.27 ± 1.02
M0M5	2285	74	41.28 ± 5.20	31.27 ± 3.95	17.42 ± 2.21
			18.54 ± 4.34	9.09 ± 2.24	5.05 ± 1.34

21.3 km s^{-1}, $\sigma_v \approx 11.3$ km s^{-1} and $\sigma_w \approx 9.0$ km s^{-1}) and Mignard (2000) ($\sigma_u \approx 19.8$ km s^{-1}, $\sigma_v \approx 13.3$ km s^{-1} and $\sigma_w \approx 8.4$ km s^{-1}) for the early-type stars using the single Gaussian model.

Since our stars are concentrated at a distance from the Galactic plane of less than 600 pc it is clear that the two kinematic populations detected here belong to the thin disk, with a negligible contamination of the thick disk.

5. CONCLUSION

Our results show that the two-Gaussian model better represents the velocity distribution for the late-type stars. We interpret this better fit to the data as a consequence of the fact that our approach takes into account the spread of age inside each group. On the other hand, the very remarkable fact that the same populations are clearly present in each group of late-type stars in a well defined way gives rise to the following question: can the two populations we found the late-type groups be explained simply by the spread of age, or we are seeing two different moments of star formation?

REFERENCES

Bienaymé, O. 1999, A&A, 341, 86
De Souza, R. E., & Teixeira, R. 2007, A&A, 471, 475
ESA 1997, The Hipparcos and Tycho Catalogues, ESA SP-1200 (Noordwijik: ESA)
Mignard, F. 2000, A&A, 354, 522
Schwarzschild, K. 1907, Gottingen Nachr., 614
Soubiran, C., & Girard, P. 2005, A&A, 438, 139
Stromgen, B. 1987, in NATO ASI, ed. G. Gilmore & R. Carswell (Dordrecht: Reidel), 229