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Revisiting the Local Kinematics of the Milky Way using the New Hipparcos Data *

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Abstract With the new Hipparcos data recently released, we reexamine the kinematics in the solar neighborhood. Two different populations of objects, namely the thin-disk O-B5 stars and the thick-disk K-M giants, are selected for tracing the kinematical parameters of the Galaxy. Using a 3-D kinematical model, the components of the solar motion and the Oort constants are derived. The solutions and the kinematics inferred from both types of stars are analyzed. The results obtained with the new data are compared with those from the old Hipparcos data. We conclude that the present solution provides a more reliable estimation of the Oort constants, thanks to the new reduction of the Hipparcos data that provides even more accurate astrometric measurements of stars.

Key words: astrometry — Galaxy: disk — Galaxy: solar neighborhood — Galaxy: kinematics and dynamics

1 INTRODUCTION

Since the early part of last century, the kinematics in the solar neighborhood has been known to provide crucial information to both the structure and the evolution of the Galaxy. In 1908, Schwarzschild interpreted the distribution of random velocities as forming a triaxial velocity ellipsoid (Schwarzschild 1908). Lindblad (1927) and Oort (1927) developed an axisymmetric model of rotation, and introduced the two Oort constants, A and B, for describing the differential rotation of the Milky Way. In the early 1950's, Parenago (1950), Roman (1950, 1952) and others pointed out that stellar kinematics varies systematically with the stellar type, because groups of stars that are on average younger have smaller velocity dispersions and larger mean Galactic rotation velocities than older stellar groups do. From then on, analyses of the Galactic structure and kinematics have been carried out based on various kinds of observational data. After considering the results obtained so far, the IAU recommended a set of Galactic constants in 1985 (Kerr & Lynden-Bell 1986). The Hipparcos Catalogue (ESA 1997) has now provided an important opportunity to reexamine the fundamental data in the solar neighborhood.

The proper-motion data observed by the Hipparcos satellite supply unprecedented accurate transverse velocities of stars for an examination of the solar neighborhood kinematics. However, since the publication of the Hipparcos Catalogue, there have been suggestions of the presence of systematic errors in the catalogue (e.g. Narayanan & Gould 1999; Soderblom et al. 2005). Now, because some of the problems suggested by Makarov (2002) and identified in detail by van Leeuwen (2005) as due to inaccuracies in the along-scan attitude reconstruction were found to be curable, the new reduction of data recently published (van Leeuwen 2007) became a feasible option. Since the new reduction data are more accurate and credible than the old one (the formal errors in the astrometric parameters for the bright stars have been decreased by a factor of 2 to 4), it is necessary to reconsider the solar neighborhood kinematics with the new data and to compare it with the results generated from the old one.

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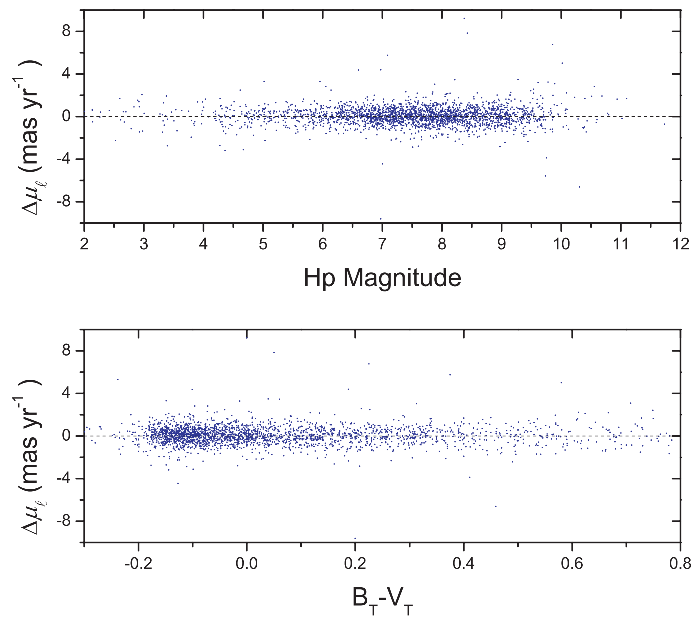

Fig. 1 Difference in the galactic longitude proper motion of the O-B5 stars between the new and old data (new - old) as function of the parallax (upper) and the color (lower). No clear systematic variation has been detected.

The present paper is based on the new reduction of Hipparcos data and reexamines the kinematics of the solar neighborhood. Since the O-B5 stars and K-M giants belong respectively to the thin and thick Galactic disks, and their kinematics have been studied in detail before, we will concentrate on an in-depth analysis of the O-B5 stars and K-M giants using the new data, and a comparison between the new and old results.

2 DATA

According to "Astrophysical Quantities", 3155 O-B5 stars (luminosity class I∼V) and 27693 K-M giants (luminosity class III) are identified. For both groups, we first rejected suspected non-single systems for accuracy. Secondly, we retained only the data whose relative errors in parallax are not too large ($\sigma_\pi/\pi < 1.0$), again for the sake of precision of the results. For the O-B5 stars, we also rejected stars which belong to the Gould Belt, since Gould Belt stars have their own peculiar distribution and kinematics (Westin 1985). Then, we carefully investigated the overall system of the stars selected, and compared the new Hipparcos proper motions and parallaxes with the old values. As an example, we show in Figure 1 the difference between the two systems of proper motion of the O-B5 stars as functions of the magnitude and the color. We found that there is no evident magnitude or color equations for both the O-B5 stars and the K-M giants. It means that the new Hipparcos system is well consistent with the old system.

The distribution of the proper motions along the Galactic longitude is shown in Figure 2. It is well known that the O-B5 stars belong to the thin-disk population of objects with a typical scale height of around 0.1 kpc (Kong & Zhu 2008). According to the simple Oort-Lindblad model of circular rotation, the mean longitude proper motion of stars is given by

$$\kappa\mu_\ell \cos b = S_1 \sin\ell/r - S_2 \cos\ell/r + (A\cos 2\ell + B)\cos b, \quad (1)$$

where κ is a numerical constant ($\kappa = 4.74047$) and r is the heliocentric distance of a star. S_1 and S_2 are the two components of the solar motion in the direction pointing to the Galactic center and to the direction of Galactic rotation, respectively. In principle, we can simply fit the proper motion data using Equation (1) to obtain the kinematical parameters. However, difficulties arise concerning the nearby stars: they normally have large proper motions, and will be given over-large weights when determining the Oort constants using

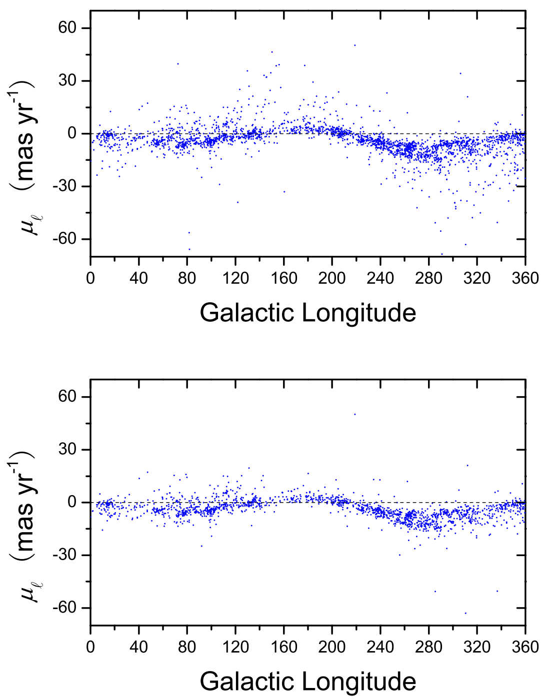

Fig. 2 Distribution of observed proper motions of O-B5 stars along the Galactic longitude. The top panel refers to all 3155 O-B5 stars, and the bottom panel, only to those with heliocentric distances larger than 0.3 kpc.

a simple least squares fit. This feature is evident if we compare the two panels of Figure 2, which refer respectively to all the O-B5 stars and only those with heliocentric distances larger than 0.3 kpc: we see that the proper motions of nearby stars are always distributed away from the average curve. Now, the transverse velocity dispersion is statistically proportional to the reciprocal of the heliocentric distance of stars (Zhu 2006), so the inclusion of the nearby stars may introduce a ruinous effect when evaluating the Oort constants A and B.

Most of the selected stars are favorably located within 1 kpc from the Sun. More than 80% of the O-B5 stars lie within 1 kpc, and only about 10% are located beyond 1.5 kpc. For the K-M giants, 90% are situated within 0.8 kpc from the Sun. Therefore, the first order kinematical model may be sufficient for the description of the velocity field.

3 ANALYSIS

To analyze the kinematics of the Milky Way, we used the classical process given by Miyamoto & Sôma (1993) and Zhu (2000a), involving the matrix $\mathbf{M}$,

$$\begin{pmatrix} \mu_\alpha \cos\delta \\ \mu_\delta \end{pmatrix} = \mathbf{MX}, \tag{2}$$

With proper motion data only, the vector $\mathbf{X}$ refers to $(S_1, S_2, S_3, D^-_{32}, D^-_{13}, D^-_{21}, D^+_{12}, D^+_{31}, D^+_{32})$ where (S_1, S_2, S_3) are the three components of the solar motion, $(D^-_{32}, D^-_{13}, D^-_{21})$ are the three components of vorticity, and $(D^+_{12}, D^+_{31}, D^+_{32})$, the three components of strain velocity.

In a Galactocentric cylindrical coordinate system (R, θ, z), the above kinematical parameters can be expressed as follows:

$$D^+_{12} = \frac{1}{2}\left(\frac{\partial V_\theta}{\partial R} - \frac{V_\theta}{R} + \frac{1}{R}\frac{\partial V_R}{\partial \theta}\right)_{R=R_0}, \tag{3}$$

$$D_{21}^{-} = \frac{1}{2}\left(\frac{\partial V_\theta}{\partial R} + \frac{V_\theta}{R} - \frac{1}{R}\frac{\partial V_R}{\partial \theta}\right)_{R=R_0}, \tag{4}$$

$$D_{13}^{+} = -\frac{1}{2}\left(\frac{\partial V_R}{\partial z} + \frac{\partial V_z}{\partial R}\right)_{R=R_0}, \tag{5}$$

$$D_{31}^{-} = -\frac{1}{2}\left(\frac{\partial V_R}{\partial z} - \frac{\partial V_z}{\partial R}\right)_{R=R_0}, \tag{6}$$

$$D_{32}^{+} = -\frac{1}{2}\left(\frac{1}{R}\frac{\partial V_z}{\partial \theta} + \frac{\partial V_\theta}{\partial z}\right)_{R=R_0}, \tag{7}$$

$$D_{32}^{-} = -\frac{1}{2}\left(\frac{1}{R}\frac{\partial V_z}{\partial \theta} - \frac{\partial V_\theta}{\partial z}\right)_{R=R_0}. \tag{8}$$

Note that in the Oort-Lindblad model, the coefficients D_{12}^{+} and D_{21}^{-} are identical to the Oort constants A and B. The detailed description and explanation of Equations (2) $\sim$ (8) have been given by Miyamoto & Sôma (1993) and Zhu (2000a).

The sampling is based on the following considerations. First, O-B5 stars are the youngest stars belonging to the thin disk which have a typical scale height of about 0.1 kpc, while K-M giants belong to the thick-disk population with a scale height of about 1 kpc. Secondly, the limiting magnitude of the Hipparcos Catalogue means that the most of the O-B5 stars are within 3 kpc from the Sun and the K-M giants are located closer, essentially all within 1 kpc. Thirdly, the velocity dispersion of stars is unstable within small heliocentric distances. To avoid such disturbances, we set different distance groups of nearby stars.

As an initial step, we set the sampling domains $|z| < 0.35$ kpc for the O-B5 stars and $|z| < 0.50$ kpc for the K-M giants, as was done in Zhu (2000b, 2006). The detailed sampling domain will be explained in Section 4.

For a few stars the observed proper motions and parallaxes still have outstanding errors, and the velocity dispersion contributes additional noise for all stars. It is known that there are various streams in the solar vicinity which affect the local velocity field, especially for the young O-B5 stars. Some of these streams can be identified from Figure 2, a majority of them are embedded especially along the direction of the local spiral arm ($l \sim 90^\circ$ and $l \sim 270^\circ$). In order to exclude stars with extremely wild transverse velocities as well as extremely large random motions, we set a maximum value of the residual velocity: stars with residual velocities larger than this value will be automatically eliminated from our analysis. Considering both the measurement errors and random velocities given by Binney & Merrifield (1998), this maximum value of residual velocity was set at $50\,\mathrm{km\,s^{-1}}$ for the O-B5 stars, and at $90\,\mathrm{km\,s^{-1}}$ for the K-M giants, roughly the 2.6σ level of the mean noise.

4 SOLUTION

We define several distance groups to explore the variations of the parameters with distance. The results derived from each group are presented in Tables 1–3. As an example we refer to the first column of Table 1. The sampling of this column refers to the distance range $0\,\mathrm{kpc} < r < 3\,\mathrm{kpc}$. The number 1709 is the total number of stars used at the initial step (after rejecting multi-system stars and, for the O-B5 stars, the Gould Belt stars). The number in the bracket 1657 refers to the stars that remained in the final solution, after we apply the least-squares algorithm. Note that all the solutions were given by an iterative calculation. It shows that the upper limit value of the residual velocity we accepted can properly eliminate stars with extremely wild proper-motion data and provide a stable final solution.

It is noticed that for the thin-disk population of O-B5 stars, the two pairs of parameters are actually equivalent, namely $D_{13}^{+} = -D_{31}^{-}$ and $D_{32}^{+} = D_{32}^{-}$, so there are seven independent parameters to be solved for the O-B5 stars.

Table 1 Results from the new reduction data of O-B5 stars. The heliocentric distance ranges of the columns are, respectively, (0, 3) kpc, (0.1, 3) kpc, (0.2, 3) kpc, (0.3, 3) kpc, (0.4, 3) kpc. S denotes the total solar motion, and ($l_\odot$, $b_\odot$) the apex.

Lower Limit	0.0 kpc 1709(1657)	0.1 kpc 1686(1637)	0.2 kpc 1575(1526)	0.3 kpc 1396(1350)	0.4 kpc 1111(1067)
S_1(km s^{-1})	7.38 ± 0.40	9.35 ± 0.38	9.17 ± 0.40	9.19 ± 0.43	9.09 ± 0.51
S_2(km s^{-1})	8.13 ± 0.39	10.41 ± 0.36	8.66 ± 0.38	7.47 ± 0.42	8.02 ± 0.51
S_3(km s^{-1})	4.35 ± 0.36	5.51 ± 0.33	5.83 ± 0.34	5.73 ± 0.38	5.71 ± 0.46
D_{32}^-(km s^{-1} kpc^{-1})	1.61 ± 0.66	1.40 ± 0.52	1.22 ± 0.44	1.15 ± 0.40	0.96 ± 0.40
D_{13}^-(km s^{-1} kpc^{-1})	-0.30 ± 0.81	-0.47 ± 0.64	-0.27 ± 0.55	-0.07 ± 0.52	-0.18 ± 0.53
D_{21}^-(km s^{-1} kpc^{-1})	-17.34 ± 1.05	-15.85 ± 0.83	-15.12 ± 0.71	-15.09 ± 0.67	-15.10 ± 0.68
D_{12}^+(km s^{-1} kpc^{-1})	15.84 ± 1.40	16.16 ± 1.10	15.33 ± 0.94	15.34 ± 0.89	15.37 ± 0.90
S(km s^{-1})	11.81 ± 0.39	15.04 ± 0.36	13.90 ± 0.38	13.16 ± 0.42	13.40 ± 0.50
$l_\odot$(°)	47.77 ± 2.06	48.07 ± 1.52	43.36 ± 1.77	39.11 ± 2.05	41.42 ± 2.41
$b_\odot$(°)	21.61 ± 2.41	21.50 ± 1.76	24.81 ± 1.94	25.82 ± 2.24	25.22 ± 2.65
$A + B$(km s^{-1} kpc^{-1})	-1.50 ± 1.75	0.31 ± 1.38	0.21 ± 1.18	0.25 ± 1.11	0.27 ± 1.13
$A - B$(km s^{-1} kpc^{-1})	33.18 ± 1.75	32.01 ± 1.38	30.45 ± 1.18	30.43 ± 1.11	30.47 ± 1.13

Table 2 Results derived from the O-B5 stars of the new data. The minimum of the Galactic distance range is fixed at 0.2 kpc, the maximum takes the values 1 kpc, 1.5 kpc and 2 kpc, respectively.

Upper Limit	1.0 kpc 1355(1333)	1.5 kpc 1534(1495)	2.0 kpc 1567(1521)
S_1(km s^{-1})	9.41 ± 0.42	9.15 ± 0.40	9.16 ± 0.40
S_2(km s^{-1})	8.46 ± 0.40	8.65 ± 0.38	8.66 ± 0.38
S_3(km s^{-1})	5.80 ± 0.37	5.83 ± 0.35	5.83 ± 0.35
D_{32}^-(km s^{-1} kpc^{-1})	1.38 ± 0.50	1.25 ± 0.45	1.23 ± 0.44
D_{13}^-(km s^{-1} kpc^{-1})	-0.33 ± 0.61	-0.28 ± 0.56	-0.26 ± 0.55
D_{21}^-(km s^{-1} kpc^{-1})	-15.36 ± 0.79	-15.16 ± 0.73	-15.12 ± 0.71
D_{12}^+(km s^{-1} kpc^{-1})	15.18 ± 1.06	15.33 ± 0.96	15.33 ± 0.95
S(km s^{-1})	13.86 ± 0.40	13.88 ± 0.38	13.89 ± 0.38
$l_\odot$(°)	43.46 ± 1.86	43.39 ± 1.77	43.40 ± 1.77
$b_\odot$(°)	24.73 ± 2.08	24.85 ± 1.97	24.82 ± 1.96
$A + B$(km s^{-1} kpc^{-1})	-0.18 ± 1.32	0.17 ± 1.20	0.21 ± 1.19
$A - B$(km s^{-1} kpc^{-1})	30.54 ± 1.32	30.49 ± 1.21	30.45 ± 1.19

4.1 O-B5 Stars

In Table 1, the maximum heliocentric distance is fixed at 3 kpc. The minimum of distance is variously taken from 0 to 0.4 kpc when examining the nearby stars. As Table 1 shows, the results for the ranges (0.2, 3) kpc and (0.3, 3) kpc have the least errors, so we shall consider these results as more reliable than others.

In Table 2, the minimum heliocentric distance in each group is fixed at 0.2 kpc, and the maximum is varied from 1 kpc to 2 kpc in order to examine the effect of the more distant stars. The results show that the effect is rather small (the results are very stable). Thus, the model of the first order expansion of the velocity field is satisfactory to characterize the kinematics of stars with the present sampling domain.

4.2 K-M Giants

For the thick-disk population of K-M giants, there are nine parameters to be estimated in our model. From a trial solution we found that there were no significant radial and warping motions beside the circular rotation. Thus, we need only to determine five kinematical parameters, namely, the solar motion and the two Oort constants for the circular rotation. This fact is easy to understand because the population of the old K-M giants is well relaxed. The reduction is quite similar to the O-B5 stars. Due to the small number of stars further than 0.4 kpc (actually, only 6279 stars have heliocentric distances larger than 0.4 kpc), we have not given the results for the group of stars with further than 0.3 kpc.

Since the observed K-M giants are very concentrated in the solar vicinity, i.e., there are very few stars (about 1%) with distances greater than 1 kpc, the upper limit of the sampling ranges can be fixed at 1 kpc.

Table 3 Results from the new reduction data of K-M giants. The heliocentric distance ranges of the columns are (0.0, 1.0) kpc, (0.1, 1.0) kpc, (0.2, 1.0) kpc and (0.3, 1.0) kpc, respectively.

Lower Limit	0.0 kpc 23598(22096)	0.1 kpc 22239(20767)	0.2 kpc 17830(16429)	0.3 kpc 11364(10089)
$S_1(\mathrm{kms}^{-1})$	9.27 ± 0.28	8.62 ± 0.29	8.46 ± 0.32	8.78 ± 0.43
$S_2(\mathrm{kms}^{-1})$	19.40 ± 0.28	18.80 ± 0.29	17.70 ± 0.32	19.03 ± 0.44
$S_3(\mathrm{kms}^{-1})$	7.66 ± 0.29	6.61 ± 0.29	6.32 ± 0.32	6.97 ± 0.43
$D_{21}^{-}(\mathrm{kms}^{-1}\mathrm{kpc}^{-1})$	-12.12 ± 2.02	-12.39 ± 1.19	-14.57 ± 1.01	-14.68 ± 1.04
$D_{12}^{+}(\mathrm{kms}^{-1}\mathrm{kpc}^{-1})$	17.22 ± 2.59	16.20 ± 1.54	15.86 ± 1.30	16.91 ± 1.35
$S(\mathrm{kms}^{-1})$	22.83 ± 0.28	21.72 ± 0.29	20.61 ± 0.32	22.09 ± 0.44
$l_{\odot}(^{\circ})$	64.47 ± 0.75	65.38 ± 0.79	64.46 ± 0.92	65.25 ± 1.18
$b_{\odot}(^{\circ})$	19.61 ± 0.96	17.72 ± 1.02	17.87 ± 1.19	18.39 ± 1.51
$A + B(\mathrm{kms}^{-1}\mathrm{kpc}^{-1})$	5.10 ± 3.29	3.82 ± 1.95	1.29 ± 1.65	2.23 ± 1.71
$A - B(\mathrm{kms}^{-1}\mathrm{kpc}^{-1})$	29.33 ± 3.29	28.59 ± 1.95	30.44 ± 1.65	31.59 ± 1.71

5 DISCUSSION AND CONCLUSIONS

Considering the results for the O-B5 stars and K-M giants in Tables 1 and 3, we find that samples with the lower limit fixed at 0.2 kpc or 0.3 kpc give more reliable estimates of the parameters of Galactic rotation, even though they give less accurate determinations of the solar motion than the star groups with a smaller lower distance limit. This fact can be easily explained: the solar motion should be defined by the nearest objects of a given group of stars, while the velocity dispersion in the proper motion of the nearest stars contribute large disturbances in the determination of the parameters of Galactic rotation. This fact can be also understood from Equation (1). Note that the first solution in Table 1 for O-B5 stars in the range of $(0.0,\ 3.0)$ kpc may be an exception, the possible reason for this could be the effect of local streaming of the nearest young objects. In the present investigation, we concentrate on the kinematical parameters of the Galactic rotation. Thus, we prefer to accept the solution with the lower limit fixed at 0.2 kpc. For the investigation of the solar motion, a detailed study will be given separately using the MS stars from the new Hipparcos Catalogue.

5.1 Solar Motion

For the O-B5 stars, the components of the solar motion are (9.17 ± 0.40, 8.66 ± 0.38 and 5.83 ± 0.34) in $\mathrm{km\,s}^{-1}$, corresponding to a total solar motion of $S = 13.90 \pm 0.38\,\mathrm{km\,s}^{-1}$. For the K-M giants, we have **S**=($8.46 \pm 0.32, 17.70 \pm 0.32$ and $6.32 \pm 0.32\ \mathrm{km\,s}^{-1}$) and $S = 20.61 \pm 0.32\ \mathrm{km\,s}^{-1}$. Tables 4 and 5 give a comparison between our results and the others'. Based on a kinematically unbiased sample of MS stars from the old Hipparcos catalogue, Dehnen & Binney (1998) determined the solar motion with respect to the LSR to be $(10.00 \pm 0.36, 5.25 \pm 0.62$ and $7.17 \pm 0.38)\,\mathrm{km\,s}^{-1}$. The two components, S_1 and S_3, are in good agreement with ours. Note that the component S_2 given by Dehnen & Binney (1998) is obtained indirectly from an extrapolation from the MS stars to a dynamically cold limit. The difference between our results and that given by Piskunov et al. (2006) using open clusters and given by Zhu (2000b) can be due to the difference of distance scale used. For the K-M giants, the smaller value of our results compared to that of Famaey et al. (2005) can be partly due to the difference of sample selection. However, this factor apart, our results are also noticeably smaller than that of Zhu (2000b), who used the old Hipparcos proper-motion data of the same O-B5 stars and K-M giants, and the heliocentric distances taken from the Skymap Catalogue (spectroscopic distances). It is noticed that the Skymap distance scale is about 10% higher than that given by the old Hipparcos parallaxes. In fact, the determined solar motion is proportional to the distance scale adopted (see Eq. (1)). On the other hand, the new Hipparcos parallaxes are more accurate than the old, and should give a more reliable solution for the solar motion. We also carefully compared the new and old Hipparcos parallaxes, but have not found any systematic differences between the two.

Note that solutions for solar motion derived from the O-B5 and K-M giants are obviously different, especially for the component in the direction of Galactic motion. This can be explained as follows: The solar motion depends on the definition of LSR. With different LSR, we will obtain different solar motion. The solar motion is strongly correlated with the velocity dispersion (asymmetric drift). The larger the velocity dispersion of a group of stars, the larger is the Solar velocity, and the slower is the rotation velocity.

Table 4 Comparison of Determinations of Solar Motion: O-B5

Results	S_1 (km s^{-1})	S_2 (km s^{-1})	S_3 (km s^{-1})
Our Results	9.17 ± 0.40	8.66 ± 0.38	5.83 ± 0.34
Dehnen & Binney (1998)	10.00 ± 0.36	5.25 ± 0.62	7.17 ± 0.38
Piskunov et al. (2006)	9.44 ± 1.14	11.90 ± 0.72	7.20 ± 0.42
Zhu 2000b	11.59 ± 0.49	13.39 ± 0.48	7.12 ± 0.44

Table 5 Comparison of Determinations of Solar Motion: K-M giants

Results	S_1 (km s^{-1})	S_2 (km s^{-1})	S_3 (km s^{-1})
Our Results	8.46 ± 0.32	17.70 ± 0.32	6.32 ± 0.32
Famaey et al. (2005)	10.24 ± 0.66	20.51 ± 0.43	7.77 ± 0.34
Zhu (2000b)	9.66 ± 0.31	21.45 ± 0.32	7.95 ± 0.26

Therefore, for the faster rotating and smaller dispersion O-B5 stars, the derived solar motion is remarkably smaller than the slower rotating and higher dispersion K-M giants, especially in the direction of Galactic rotation.

5.2 Rotation Velocity

The Oort constants A and B are the fundamental quantities of the Milky Way's structure that give the observational local constraints on the Galactic dynamics and its evolution. The combinations of the Oort constants, $(A - B)$ and $(A + B)$, provide the angular velocity of the Galactic rotation and the shape of the rotation curve at the Sun. For a circular rotation, the coefficients D^+_{12} and D^-_{21} in our model are identical to the Oort constants A and B. The rotation velocity at the Sun therefore is $V_0 = 243.6 \pm 9.4\,\mathrm{km\,s^{-1}}$ for the O-B5 stars, and $V_0 = 243.5 \pm 13.0\,\mathrm{km\,s^{-1}}$ for the K-M giants. Here, we take the Galactocentric distance of the Sun, $R_0 = 8.0\,\mathrm{kpc}$, proposed by Reid (1993).

Since the publication of the old Hipparcos Catalogue, many attempts have been made to improve the measurements of the Oort constants by using accurate absolute proper-motion data observed by different techniques. From the old Hipparcos proper motions of the Galactic Cepheids, Feast & Whitelock (1997) found a low angular speed ($A = 14.8 \pm 0.8$, $B = -12.4 \pm 0.6$ in $\mathrm{km\,s^{-1}\,kpc^{-1}}$) that best approaches the IAU recommended value of 1985 for the Oort constants (Kerr & Lynden-Bell 1986). However, the majority of measurements in recent years have shown a more or less enhanced angular rotation speed. Using the old Hipparcos proper motions of the O-B5 stars, Miyamoto & Zhu (1998) obtained $A = 16.1 \pm 1.1$, $B = -15.6 \pm 0.8$ in $\mathrm{km\,s^{-1}\,kpc^{-1}}$, and $A - B = 29.7 \pm 1.2\,\mathrm{km\,s^{-1}\,kpc^{-1}}$ for the K-M giants (Zhu 2000b). According to the precise absolute proper-motion measurements of the massive compact radio source SgrA^* at the Galactic center by VLBA, Reid & Brunthaler (2004) obtained $A - B = 29.58 \pm 0.14\,\mathrm{km\,s^{-1}\,kpc^{-1}}$, on assuming $R_0 = 8.0\,\mathrm{kpc}$. This determination is in excellent agreement with our present results. Some other determinations of the angular speed are also within the range of our current determinations, e.g., the determination from the photographic absolute proper motions of the Southern Proper Motion Program (SPM) shown by Méndez et al. (2000), and the measurement from the ACT/Tycho-2 proper motions of the old red giants by Olling & Dehnen (2003).

Comparing the current values of the Oort constants with our previous one (Zhu 2000b), we find there are some differences, even though we have used the same O-B5 stars and K-M giants. However, these differences are not large. The most probable cause of this difference could be the accuracy of the Hipparcos parallaxes. Figure 3 shows the error distribution in the heliocentric distances of the O-B5 stars, derived directly from the Hipparcos parallax measurements. The measuring error of distance is quite pronounced for the old Hipparcos system, especially for stars at large distances, even if no overall systematic differences in the distance are found between the new and old Hipparcos parallaxes. Thus, the choice of the parallaxes of stars (with $\sigma_\pi/\pi < 1.0$) may not be a good way for constraining the stellar sample, for it may introduce a systematic bias for the kinematical analysis. However, at the present level of the measurement accuracy, we have no other choice to obtain distances of stars with sufficient accuracy. On the other hand, the new parallaxes give more reliable distances of stars, especially for stars of faint magnitudes. It is shown in

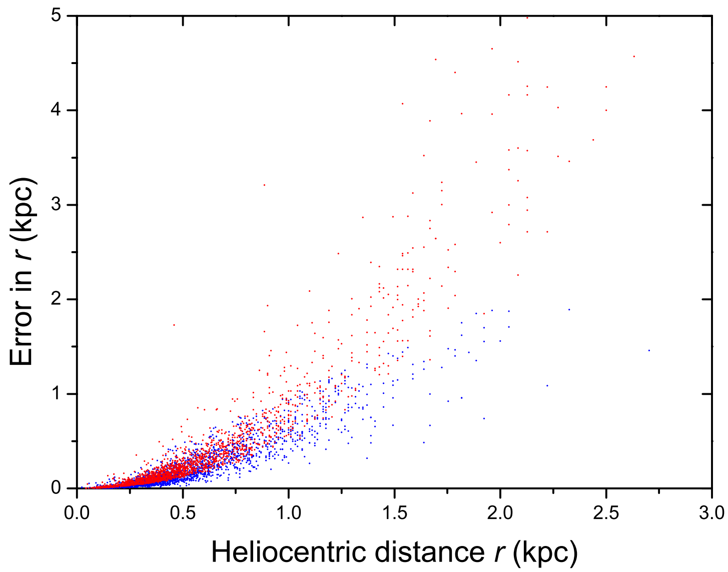

Fig. 3 Distance error distribution for the O-B5 stars. The heliocentric distances and their errors are obtained from the measurements of Hipparcos parallaxes. The blue dots denote stars with relative parallax errors less than 1 ($\sigma_\pi/\pi < 1$) in the new Hipparcos system, and the red dots mark the same stars in the old Hipparcos system.

Figure 3 that the new parallaxes give a relative error in distance, on average, of about 0.5 for stars at $r = 1\,\mathrm{kpc}$, while it reaches 1.0 for the old Hipparcos data. Therefore, the current distance scale associated with the more accurate proper-motion data should provide a more reliable estimation of the kinematical parameters of the Galaxy.

The combination of Oort constants, $(A + B)$, denotes the inclination of the rotation curve measured at the Sun. In our definition in Equations (3)$\sim$ (8), a plus value of $(A + B)$ means a flattening of the curve. The present determination indicates a flat rotation curve at the Sun, because no reliable measurements of $(A + B)$ have been obtained from both the O-B5 stars and K-M giants.

The parameter D_{32}^{-} for the O-B5 stars implies a clear warping motion or a systematic rotation of the O-B5 stars about the axis pointing to the Galactic center in the sense of increasing the inclination of the HI warp. Based on the old proper motions of the Hipparcos O-B5 stars, Miyamoto & Zhu (1998) found a velocity gradient $\partial V_z/\partial\theta = -30 \pm 8\ \mathrm{km\,s^{-1}}$ at the Sun, suggesting $R_0 = 8\,\mathrm{kpc}$. Our new determination gives a very stable solution for the parameter D_{32}^{-} (see Tables 1 and 2), and suggests $\partial V_z/\partial\theta = -20 \pm 7\ \mathrm{km\,s^{-1}}$. Taking the measuring errors into account, these two estimates are in good mutual agreement.

Based on the study of the new Hipparcos proper motions for the O-B5 stars and K-M giants, we come to the conclusion that the Oort constants,

$$A = 15.9 \pm 0.9\,\mathrm{km\,s^{-1}\,kpc^{-1}}, B = -15.1 \pm 0.7\,\mathrm{km\,s^{-1}\,kpc^{-1}},$$

yielded from the O-B5 stars. The corresponding rotational speed of the O-B5 stars is $243 \pm 9\,\mathrm{kms}^{-1}$, suggesting $R_0 = 8.0\,\mathrm{kpc}$. For the K-M giants, we have

$$A = 15.9 \pm 1.3\,\mathrm{km\,s^{-1}\,kpc^{-1}}, B = -14.6 \pm 1.0\,\mathrm{km\,s^{-1}\,kpc^{-1}}.$$

The present determination gives more reliable Oort constants because of the high quality data of the new reduction of the Hipparcos Catalogue.

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References

Binney J. J., Merrifield M., 1998, Galactic Astronomy, Princeton: Princeton University Press
Caldwell J. A. R., Coulson I. M., 1987, AJ, 93, 1090
Dehnen W., Binney J. J., 1998, MNRAS, 298, 387
Famaey B., Jorissen A., Luri X., Mayor M., Udry S., Dejonghe H., Turon C., 2005, A&A, 430, 165
Feast M., Catchpole R. M., 1998, MNRAS, 286, L1
Feast M. W., Whitelock P., 1997, MNRAS, 291, 683
Kerr F. J., Lynden-Bell D., 1986, MNRAS, 221, 1023
Kong D. L., Zhu Z., 2008, AcASn, 49 (in print)
Makarov V., 2002, AJ, 124, 3299
Mayor M., 1974, A&A, 32, 321
Méndez R. A., Platais I., Girard T. M. et al., 1999, ApJ, 524, L39
Méndez R. A., Platais I., Girard T. M. et al., 2000, AJ, 119, 813
Mihalas D., Binney J. J., 1981, Galactic Astronomy (2nd ed.), San Fransisco: Freeman
Miyamoto M., Sôma M., 1993, AJ, 105, 691
Miyamoto M., 1998, AJ, 115, 1483
Narayanan V. K., Gould A., 1999, ApJ, 523, 328
Olling R. P., Dehnen W., 2003, ApJ, 599, 275
Parenago P. P., 1950, AZh, 27, 150
Piskunov A. E., Kharchenko N. V., Röser S., Schilbach E., Scholz R.-D., A&A, 445, 545
Reid M. J., 1993, ARA&A, 31, 345
Reid M. J., Brunthaler A., 2004, ApJ, 616, 872
Roman N. G., 1950, ApJ, 112, 554
Roman N. G., 1952, ApJ, 116, 122
Schwarzschild K., 1908, Nachr. Kgl. Ges. der Wissenschaften, Göttingen, 191
Soderblom D. R., Nelan E., Benedict G. F. et al., 2005, AJ, 129, 1616
Spitzer L., Schwarzschild M., 1953, ApJ, 118, 106
van Leeuwen F., 2005, A&A, 439, 791
van Leeuwen F., 2007, A&A, 474, 653
Wielen R., 1977, A&A, 60, 263
Westin T. N. G., 1985, A&AS, 60, 99
Zhu Z., 2000a, Ap&SS, 271, 353
Zhu Z., 2000b, PASJ, 52, 1133
Zhu Z., 2006, Chin. J. Astron. Astrophys. (ChJAA), 6, 363