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Local Kinematics and the Local Standard of Rest with *Gaia* Radial Velocity Survey

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ABSTRACT

Two main questions will be asked and answered in this manuscript using data of the *Gaia* DR2 (Gaia Collaboration et al. 2016, 2018,b). 1: What is the mean motion of stars in the solar neighbourhood, and do the velocities depend on temperature (section 3) ? 2: Is there an easy way to determine the Local Standard of Rest (LSR) that gives similar results compared to other methods (section 4) ? The results that were found are that the velocities of the stars are constant for temperatures below 5800K, but with significant changes in the high temperature area. We found a very simple method to determine the LSR. The calculated velocities are $(U, V, W)_\odot = (11.92 \pm 1.17, 11.87 \pm 0.72, 6.44 \pm 0.46)$ km s^{-1}, which is in agreement to literature.

Keywords: Galaxy: fundamental parameters, kinematics and dynamics, solar neighborhood — stars: fundamental parameters — ISM: kinematics and dynamics

1. INTRODUCTION

The amount of data provided by the *Gaia* mission is significantly larger than previous data sets. Therefore it makes sense to study stellar motions based on much more values with better statistics. In the first part of this chapter, we want to find out something about the motion of stars close to our Sun. Because of the gravitational potential of all objects in the Milky Way, stars cross the disk vertically in an oscillating motion as well as they do in radial direction, towards and away from the galactic centre. Because all stars are assumed to follow such motions, this should result in a statistically steady state. In particular we want to find out if these motions depend on temperature.
In the second part, we want to determine the local standard of rest, the mean motion of the disk material in the solar neighbourhood.

2. DATA SELECTION & DATA TRANSFORMATION

The starting point is the part of the *Gaia* DR2 containing information about radial velocities. Since we are interested in the solar neighborhood, only objects closer than 100pc are considered. Furthermore, all stars with either $\frac{\sigma_{\alpha^*}}{\alpha^*}, \frac{\sigma_\delta}{\delta}$ or $\frac{\sigma_{\bar{\omega}}}{\bar{\omega}}$ larger than 0.1, $\sigma_{v_{rad}} \leq |5|$ km s^{-1} as well as the ones with temperatures above 7000K are neglected.
To obtain the velocities from the data, μ_{α^*}, μ_δ and v_{rad} are transformed to Cartesian coordinates using

$$\vec{v}_{Equat} = \begin{pmatrix} v_x \\ v_y \\ v_z \end{pmatrix} = \begin{pmatrix} rv\cos(\alpha)\cos(\delta) - dk\mu_{\alpha*}\cos(\alpha)\sin(\delta) - dk\mu_\delta\sin(\alpha) \\ rv\sin(\alpha)\cos(\delta) - dk\mu_\delta\sin(\alpha)\sin(\delta) + dk\mu_{\alpha*}\cos(\alpha) \\ rv\sin(\delta) + dk\mu_\delta\cos(\delta) \end{pmatrix}, \tag{1}$$

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in km s^{-1} where d is the distance (parallax^{-1}), and k was introduced to transform au yr^{-1} to km s^{-1}. These velocities in Equatorial coordinates are then transformed to Galactic coordinates, as shown in the documentation of the *Gaia* DR2 documentation (DR2 Documentation 2018) using

$$\begin{pmatrix} U \\ V \\ W \end{pmatrix}_{\odot} = A'_G \cdot \vec{v}_{Equat}. \tag{2}$$

A'_G is a transformation matrix,

$$\begin{aligned} A'_G &= R_z(-l_\Omega)R_x(90^\circ - \delta_G)R_z(\alpha_G + 90^\circ) \\ &= \begin{pmatrix} -0.0548755604162154 & -0.8734370902348850 & -0.4838350155487132 \\ 0.4941094278755837 & -0.4448296299600112 & 0.7469822444972189 \\ -0.8676661490190047 & -0.1980763734312015 & 0.4559837761750669 \end{pmatrix}, \end{aligned} \tag{3}$$

where $\alpha_G = 192^\circ.85948$ and $\delta_G = 27^\circ.12825$ define the north galactic pole and $l_\Omega = 32^\circ.93192$ is the node of the galactic plane on the equator as described in (Perryman, ESA, 1997).

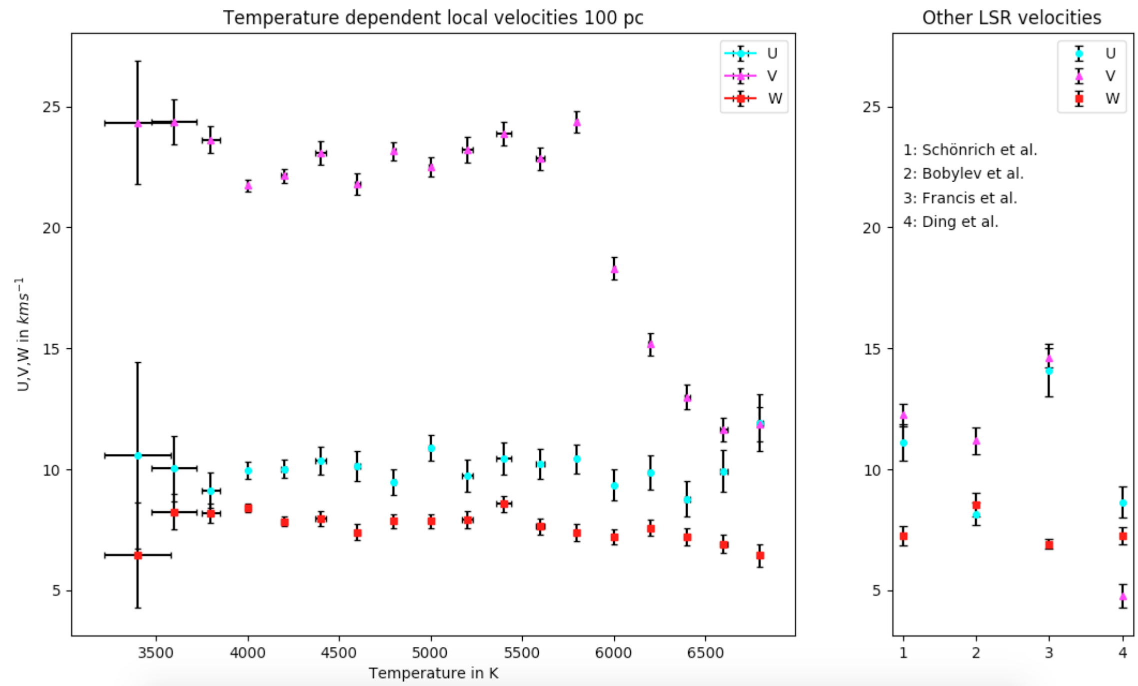
3. LOCAL KINEMATICS

Stars similar to our Sun are confined to a thin disk, orbiting the center of the Galaxy (Keel 2007). At the moment, our solar system is located very close to this galactic plane. But it is not at rest, because of the gravitational potential of all objects in the Milky Way. Stars cross the disk in an oscillating motion as well as they do in radial direction. Because all stars are assumed to follow such motions, this should result in a statistically steady state (Tayler 1993). Only stars with a temperature between 3400K and 7600K were examined because there is not enough data outside this range. The stars were grouped by temperature $T_i = (3400 + i \cdot 200)$K, where each group contained all objects that satisfy $T_i - 100\mathrm{K} < \mathrm{T_{star}} < \mathrm{T_i} + 100\mathrm{K}$. Then, the mean values for each component of (U, V, W) were calculated for each temperature-bin. The result can be found in figure 3. As one can see, U and W are approximately constant over almost the entire temperature scale. We also note a significant decrease of V at 5800K, and that its values are less constant for temperatures below. However, the differences are less than 3km s^{-1}. It is interesting to see that the motions of the stars seem to have a temperature-independent behavior over 2400K. It would be interesting to see if the stars keep to change their velocities as they tend to for the highest temperatures. But we have no information in this area, more data is needed.

4. LOCAL STANDARD OF REST

In this section we want to determine the LSR. It is defined to follow the mean motion of the disk material in the solar neighbourhood (Shu 1982). Because disk material is not only the stars, but also gas, and dust, we cannot just take all the values found for the local kinematics. As already mentioned, our aim is to find a trivial way to determine the LSR. The idea is the following: Hotter stars have a shorter lifetime than colder ones. Therefore, we assume that they are in average younger than colder stars. Because stars are created in gas clouds, which can also be found in galactic disks, and the assumption that these stars are young, their mean velocities should be close to the one of the gas contained in the disk. Therefore, we look at the velocities of high temperature stars. As can be seen in table 1, the highest temperature with sufficient data is 6800K with $(U, V, W)_\odot = (11.92 \pm 1.17, 11.87 \pm 0.72, 6.44 \pm 0.46)$ km s^{-1}.

There are many ways of determining the LSR, we will now compare our results with some that were determined in the past.
$(U, V, W)_\odot = (11.1^{+0.69}_{-0.75}, 12.24^{+0.47}_{-0.47}, 7.25^{+0.37}_{-0.36})$km s^{-1} (Schönrich et al. 2009),
$(U, V, W)_\odot = (8.16 \pm 0.48, 11.19 \pm 0.56, 8.55 \pm 0.48)$km s^{-1} (Bobylev & Bajkova 2018),
$(U, V, W)_\odot = (14.1 \pm 1.1, 14.6 \pm 0.4, 6.9 \pm 0.1)$km s^{-1} (Francis & Anderson 2018),
$(U, V, W)_\odot = (8.63 \pm 0.64, 4.76 \pm 0.49, 7.26 \pm 0.36)$km s^{-1} (Ding et al. 2018).
One can see that our values are within uncertainties when we compare them with *Schönrich et al.* which probably enjoys the highest acceptance. However, these values are by far the oldest ones listed here. The other publications listed are based on much more recent data which are probably more accurate. As one can see, there is not really a



consensus in these results. All values for $W_\odot$ are within 2km s^{-1}, but it is not clear how the results for $U_\odot$ and $V_\odot$ should be interpreted.

Table 1. Temperature dependent velocities

Temperature K	# of stars	U km s^{-1}	V km s^{-1}	W km s^{-1}
3400	114	10.59 ± 3.85	24.34 ± 2.55	6.46 ± 2.18
3600	857	10.04 ± 1.35	24.38 ± 0.93	8.24 ± 0.73
3800	2769	9.13 ± 0.73	23.63 ± 0.55	8.19 ± 0.4
4000	11519	9.97 ± 0.35	21.73 ± 0.25	8.39 ± 0.19
4200	10711	10.02 ± 0.37	22.12 ± 0.27	7.84 ± 0.19
4400	3992	10.35 ± 0.58	23.07 ± 0.48	7.95 ± 0.32
4600	3576	10.14 ± 0.62	21.8 ± 0.45	7.4 ± 0.33
4800	5271	9.46 ± 0.52	23.14 ± 0.38	7.86 ± 0.28
5000	5356	10.9 ± 0.53	22.5 ± 0.41	7.86 ± 0.28
5200	3191	9.72 ± 0.66	23.2 ± 0.53	7.91 ± 0.35
5400	3769	10.44 ± 0.66	23.88 ± 0.5	8.57 ± 0.34
5600	3777	10.22 ± 0.62	22.84 ± 0.46	7.63 ± 0.33
5800	4208	10.43 ± 0.61	24.36 ± 0.45	7.39 ± 0.34
6000	2822	9.35 ± 0.65	18.3 ± 0.46	7.21 ± 0.33
6200	2198	9.86 ± 0.71	15.17 ± 0.45	7.57 ± 0.33
6400	1461	8.77 ± 0.73	12.99 ± 0.5	7.21 ± 0.34
6600	886	9.93 ± 0.88	11.64 ± 0.5	6.91 ± 0.38
6800	375	11.92 ± 1.17	11.87 ± 0.72	6.44 ± 0.46
7000	21	5.63 ± 3.11	7.81 ± 2.71	11.0 ± 2.4

5. CONCLUSION

It was shown that the motion of stars near our solar system is nearly independent of temperature for stars with T$\leq$ 5800K. At this temperature, $V_\odot$ drops significantly. Since there are not enough data on the high-temperature area, it is not possible to make predictions how velocities change there.
As shown in section 4, recent results of the LSR are not consistent. Therefore, it is not clear if we really have found a simple but robust way to determine the LSR. If it turns out that the results from *Schönrich et al.* are still valid, it would be interesting to test our method again, once there is more data accessible for stars with temperatures above 6800K.

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